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House-Type Analysis of ^{222}Rn, ^{220}Rn, and their Progeny in some Dwellings in Budgam Karewas of the Kashmir Valley

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The average radiation dose received by humans each year as natural background radiation is 2.4 mSv and long-term exposure to such harmful radiation can be severely hazardous. According to the BEIR-VI report, radon (^{222}Rn) alone accounts for higher than 50% of all ambient radiation from natural sources. Thus, its quantification is essential to evaluate any risk imposed by radiation dose to human health. Newly created LR-115 films embedded in the pinhole detectors have been used for passive time-integrated assessment of the radon (^{222}Rn), thoron (^{220}Rn), and their progeny levels in permanent, semi-permanent, and temporary house types. The annual average radon levels in these three house types were 31.7 Bqm^{-3}, 37.2 Bqm$^{-3,}$ and 55.2 Bqm^{-3}, respectively. The annual average value of radon of permanent and semi-permanent houses was found to lie below, while that of temporary houses exceeded the worldwide average of 40 Bqm^{-3}. Meanwhile, permanent houses have annual mean thoron concentrations of 31.3 Bqm^{-3}, semi-permanent houses have 40.9 Bqm^{-3}, and temporary houses have 41.58 Bqm^{-3}. All three house types outperformed the annual global average of thoron.

Keywords: Radon; Thoron; SSNTDs; Progeny levels; Types of dwellings; Radiation dose

1 Introduction

The earth's crust contains naturally occurring radioactive materials like uranium (U^{238}) and thorium (Th^{232}) practically everywhere. These materials (U^{238} and Th^{232}) undergo radioactive decay which leads to the production of radon (^{222}Rn) and thoron (^{220}Rn), respectively[1,2]. Radon gas is colourless, odourless, tasteless, radioactive inert gas and thus is undetected by our sensory organs. The half-life of ^{222}Rn is 3.82 days, and that of thoron (^{220}Rn) is 55 seconds. Previously, Thoron was thought not to add to the overall annual inhalation dose due to its short half-life. Nevertheless, recent research refuted earlier assertions[3]. It was discovered that the indoor thoron concentration was occasionally much higher than that of radon, making it eligible to be considered a significant contribution to the overall dosage[4–8]. The study of radon is highly valued because it is radiologically toxic, contributing to about 55% of the total radiation dose that the general public was exposed to and thus posing an immense health risk to the local population. Radon (^{222}Rn) decays into polonium-218 and polonium-214, and thoron (^{220}Rn) decays into polonium-216 and polonium-212, commonly known as their progenies. These short-lived daughter nuclei of radon and thoron frequently combine or cluster along with aerosols or tiny particles in the environment to form attached and unattached proportions[7,9–11]. The unattached progeny are decay products with AMD (activity median diameter) lower than 10 nm[12] whereas attached progeny are those with AMD in the range of 10-1000 nm[13]. Being gas, radon is easily exhaled out of the respiratory tract, but the progeny of radon affixed to aerosol particles suspended in the atmosphere is readily inhaled through the lungs, and accumulates in the alveoli, from where it enters the bloodstream and may lead to biological damage[14]. The rate of exhalation of radon varies for different places depending on the geological formation of rock and its level of radioactivity[15]. Radon tends to build up in confined spaces, such as indoor environments of homes, workplaces, and underground mines. Inadequate ventilation indoors contrary to the outside environment is responsible for this accumulation. Factors that have a significant impact on the activity levels of radon, thoron, and their progeny are residential construction, ventilation, wind velocity, building materials, topography, temperature, humidity, pressure, and even the way of living of the

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*Corresponding author: (E-mail: ssimnani@gmail.com) occupants in the house[16]. Researchers worldwide have conducted extensive epidemiological investigations and examinations of high radon inhalation doses in residential buildings because radon, thoron, and their decay products have accumulated in homes, imposing a significant radiation dosage on the inhabitants[17–19]. After smoking, radon is the second most important factor for lung carcinoma and is a proven carcinogen. In the USA, radon inhalation causes over 16,000-24,000 annual lung cancer deaths[20–28]. Numerous agencies have suggested the action limit for indoor radon concentration due to the risks of radon exposure to the general population. Significantly, WHO (World Health Organization) has recommended the maximum permissible limit of 100 Bqm^{-3}, the US-EPA (United States Environmental Protection Agency) recommended 150 Bqm^{-3}, and the ICRP (International Commission on Radiological Protection) has recommended an acceptable maximum limit of 200-300 Bqm^{-3} for indoor radon concentrations[29,30]. Nazir *et al*. have done radon analysis in the Budgam district to determine the seasonal variation of radon, thoron, and their progeny in the indoor air of the research region, as well as the radon concentration in groundwater and yearly average activity concentration[31]. However, the current study focuses on the house-wise analysis of radon (^{222}Rn, ^{220}Rn, and progeny) activity concentration in three kinds ofhouses: temporary, permanent, and semi-permanent. A similar type of measurement was done by Nazir *et al*. in the Srinagar district, where they found higher radon and thoron levels in the semi-permanent houses[32].

2 Measurement and methodology

2.1 Study Area

District Budgam is mountainous to the northeast and southwest with a wide intermountain valley[31]. The hill has an elevation that can reach 3700 mASL. The area is underlain by geological strata that range from the Cambrian to the Quaternary. Geological stratigraphies present in the region include alluvium, Upper and Lower Karewa, and Panjal Traps[31]. Panjal traps (Permo-Carboniferous age) create the region's mountainous landscape with solid igneous and metamorphic rock formations[33]. Most of the valley area is covered by the Karewa (Plio-Pleistocene age) formation, Upper Karewa consists of bed layers like grey clay and greenish sand with calcareous Laminae and then a layer fluvio-glacial boulder bed. Lower Karewa is made up of a fluvio-glacial boulder bed as the first layer, followed by a layer of blue-grey clay and conglomerates, with coarse to fine greenish sand alternating with clays (grey sandy). Alluvium (recent age) comprises bands of sand, silt, and clay[31,33]. The geological map of the district Budgam is shown in Fig. 1 and the red solid triangles in the map indicate sample locations of the study region.

2.2 Methodology

The present investigation aims to compare the indoor ^{222}Rn, ^{220}Rn, and their progeny concentrations in different house types. The houses were categorized into permanent, semi-permanent, and temporary, on the bases of materials used for construction. The residential houses built with reinforced concrete, metal sheets, stone, and burned bricks were

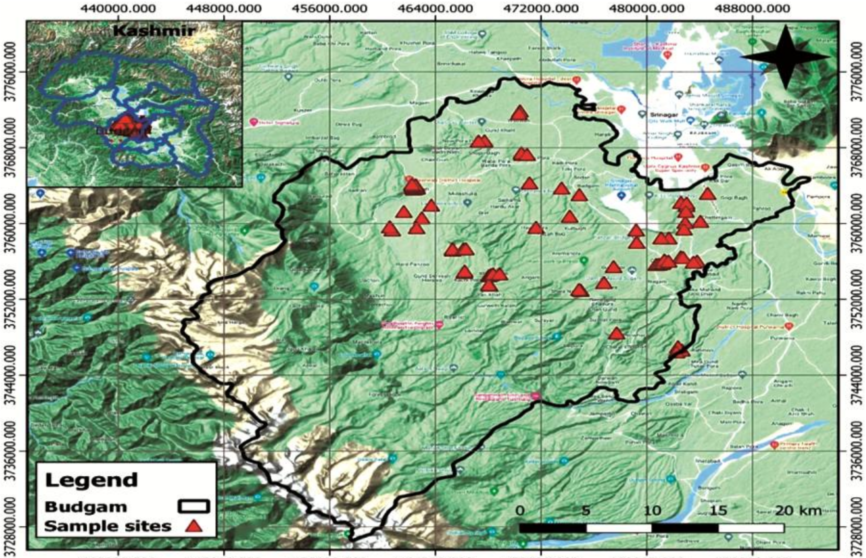

Fig. 1 — A geological map with sample sites of the study area

considered permanent houses while the houses constructed with burnt bricks, clay, and lumber, without any reinforced concrete, were known as semi-permanent houses. The houses made of wooden logs, unburned bricks, straw, and clay were termed temporary houses. A total of 75 dosimeters were installed in the study area, with 25 detectors in each house type. For the assessment of ^{222}Rn, ^{220}Rn, and their progeny activity levels in the indoor air, one-entry pin-hole dosimeters with financially affordable LR-115 Type-II solid state nuclear track detectors (SSNTDs) have been used[34–36]. Fig. 2(a) shows the schematic of the pin-hole dosimeter along with inserted LR-115 films. The pin-hole dosimeter is a cylindrical-shaped passive device with two compartments, a radon-thoron chamber and a radon chamber, divided by a central disc with four pin-holes, each pin-hole is 2mm long and has a diameter of 1mm. A 0.56µm glass-fibre filter paper at the single entry of the dosimeter separates out the decay products and pinholes prevent transmission of thoron (^{220}Rn) from the radon-thoron chamber and permit only radon (^{222}Rn) to enter the radon chamber. The pin-hole dosimeters with LR-115 films were dangled upright to the ceiling with the end from where gas enters the dosimeter facing downward in an area with little air disturbance in the room. The DRPS (direct radon progeny sensors) and DTPS (direct thoron progeny sensors) were used for the calculation of activity concentrations of radon and thoron progeny, a schematic is shown in Figs 2(b), and 2(c).

The DRPS and DTPS were attached to the chains that wereused to connect the dosimeters to the ceiling. The imprints of alpha radiations released during the decay of radon (^{222}Rn), thoron (^{220}Rn), and their progenies were registered on the LR-115 film embedded in dosimeters and progeny sensors. Chemical etching was performed on the LR-115 films with alpha tracks using a 2.5N sodium hydroxide (NaOH) solution at 60 ºC steady temperature for one and a half hours continuously. Following etching, the alpha imprints were easily distinguished from background scratches and were counted in the spark counter. The equations used to measure radon concentration (C_R) and thoron concentration (C_T) from obtained track densities are given below[34]:

$$C_R(\mathrm{Bqm^{-3}}) = \frac{\mathrm{Tracks}_{\ Rn} - \mathrm{Tracks}_{\ BG}}{\mathrm{t}\times \mathrm{K}_{\mathrm{R}_{\mathrm{R}}}}$$

$$C_T\,(\mathrm{Bqm^{-3}}) = \frac{(\mathrm{Tracks}_{\ Rn+Tn} - \mathrm{Tracks}_{\ BG}) - \mathrm{Tracks}_{\ Rn}}{\mathrm{t}\times \mathrm{K}_{\mathrm{T}_{\mathrm{RT}}}}$$

where, $Tracks_{Rn}$ is the track density registered in radoncompartment,$Tracks_{Rn+Tn}$ represents the track densityobserved in radon + thoron compartment, and $Tracks_{BG}$ (= 4 tracks cm^{-2}) represents the background track density[32]. K_{R_R}(= 0.0170Trcm^{-2}(Bqm^{-3}d)$^{-1}$) is the calibration factorsfor ^{222}Rn in radon compartment[32] and $K_{T_{RT}}$(= 0.010Trcm^{-2}(Bqm^{-3}d)$^{-1}$) is the calibration factorsfor ^{220}Rn in radon + thoron compartment[32].

2.3 Annual inhalation dose

The total annual inhalation dose of radon, thoron, and their progeny in each of the three housing types, D_{inh}(mSvy^{-1}), was obtained by using the relation:

$$D_{\mathrm{inh}}(\mathrm{mSvy^{-1}}) = \{(\mathrm{DCF_{Rn}} + \mathrm{DCF}_{\alpha}\times F_{\mathrm{Rn}}) \times C_{\mathrm{Rn}} + (\mathrm{DCF_{Tn}} + \mathrm{DCF}_{\beta}\times F_{\mathrm{Tn}}) \times C_{\mathrm{Tn}}\} \times F_{\mathrm{occ}} \times T$$

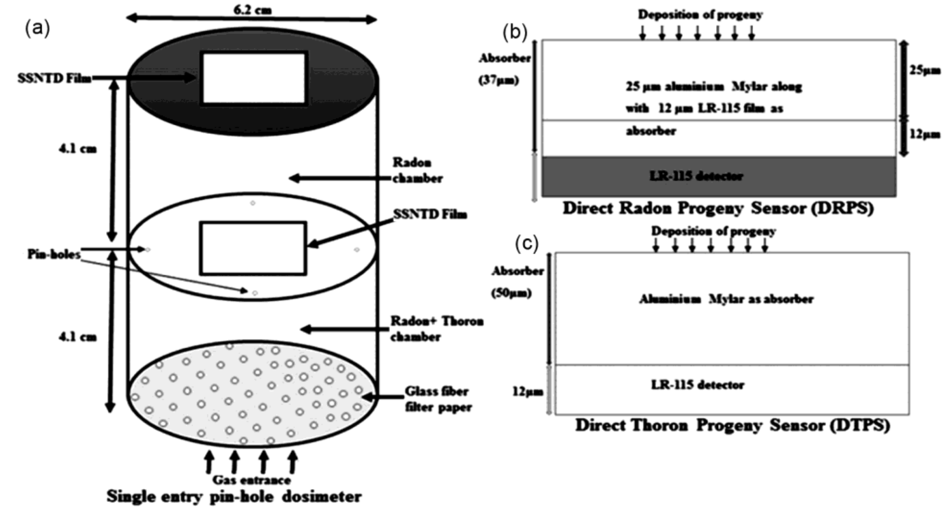

Fig. 2 — A diagram of (a) Pin-hole dosimeter (b) Direct Radon Progeny Sensor (c) Direct Thoron Progeny Sensor

Where DCF_{Rn} having a value 0.17 nSv (Bq h m^{-3})$^{-1}$ depicts the radon dosage conversion factor and DCF_{α} [=9 nSv (Bq h m^{-3})$^{-1}$] is the radon progeny dose conversion factor. DCF_{Tn} [=0.11 nSv (Bq h m^{-3})$^{-1}$] indicates the thoron dose conversion factor while DCF_{β}[=40 nSv (Bq h m^{-3})$^{-1}$] is the dose conversion factor of thoron progeny. C_{Rn} and C_{Tn} represent theradon and thoron concentrations, respectively. F_{Rn} is the equilibrium factor for radon and F_{Tn} is the equilibrium factor for thoron. Worldwide approved values for F_{Rn} = 0.4 and F_{Tn} = 0.02 have been used in this study[37]. F_{occ} is the occupancy factor for the study area[32] and T represents the year in hours.

3 Results and discussions

The statistical information in Table 1 shows radon, thoron, and their progeny concentrations in the indoor air of the three different types of houses in the research area. The result of the house-type analysis revealed that the radon levels of permanent houses, semi-permanent houses, and temporary houses varied from 15.2 to 48.61 Bqm^{-3} with an average value of 31.7 Bqm^{-3}, 15.2 to 70.5 Bqm^{-3} with the mean value of 37.2 Bqm^{-3} and 31.5 to 116.8 Bqm^{-3} with the mean value of 55.2 Bqm^{-3} respectively. The average concentrations of radon in permanent and semi-permanent houses were found to lie below the worldwide average of 40 Bqm^{-3} while that of temporary houses exceeded this limit. However, with a mean value of 31.3 Bqm^{-3},the thoron concentration of permanent houses ranged from 14.9 to 54.6 Bqm^{-3}, thoron levels in semi-permanent varied from 15.7 to 81.9 Bqm^{-3} with an average of 40.9 Bqm^{-3}, and in temporary houses varied from 19.89 to 63.96 Bqm^{-3} with a mean value of 41.58 Bqm^{-3}. All three dwelling types had average thoron values that were higher than the globally accepted average of 10 Bq m^{-3}.

Fig. 3 displays the frequency distribution of radon and thoron concentrations in temporary, semi-permanent, and permanent homes. The radon concentration of the majority of temporary houses (~52%) lies between 40 and 60 Bqm^{-3}, 24% of houses lie between 20 and 40 Bqm^{-3}, 12% of houses lie between 100 and 120 Bqm^{-3}, 8% of houses lie between 80 and 100 Bqm^{-3}, and 4% houses lie between 60 and 80 Bqm^{-3}. The thoron concentration of the majority of temporary houses (~32%) lies in the

Table 1 — Radon, thoron, and progeny concentrations in three house types along with annual inhalation dose

Temporary Houses

Statistical Parameters	Concentration of Radon (Bqm^{-3})	Concentration of Radon progeny (Bqm^{-3})	Concentration of Thoron (Bqm^{-3})	Concentration of Thoron progeny (Bqm^{-3})	Inhalation dose due to radon (mSvy^{-1})	Inhalation dose due to thoron (mSvy^{-1})	Total Inhalation dose (mSvy^{-1})
Minimum	31.5	8.34	19.89	0.16	0.57	0.07	0.68
Maximum	116.8	23.39	63.96	1.82	1.58	0.56	2.09
Average	55.2	15.02	41.58	0.82	1.01	0.26	1.27
Median	44.2	13.30	40.34	0.78	0.88	0.26	1.00
Standard deviation	25.166	5.80	11.53	0.54	0.34	0.15	0.47

Semi-permanent Houses

Statistical Parameters	Concentration of Radon(Bqm^{-3})	Concentration of Radon progeny (Bqm^{-3})	Concentration of Thoron (Bqm^{-3})	Concentration of Thoron progeny (Bqm^{-3})	Inhalation dose due to radon (mSvy^{-1})	Inhalation dose due to thoron (mSvy^{-1})	Total Inhalation dose (mSvy^{-1})
Minimum	15.2	3.3	15.7	0.2	0.2	0.1	0.3
Maximum	70.5	20.0	81.9	1.1	1.3	0.3	1.6
Average	37.2	10.6	40.9	0.6	0.7	0.2	0.9
Median	38.4	11.2	41.2	0.5	0.7	0.2	0.9
Standard deviation	11.84	3.65	16.02	0.28	0.24	0.08	0.29

Permanent Houses

Statistical Parameters	Concentration of Radon (Bqm^{-3})	Concentration of Radon progeny (Bqm^{-3})	Concentration of Thoron (Bqm^{-3})	Concentration of Thoron progeny (Bqm^{-3})	Inhalation dose due to radon (mSvy^{-1})	Inhalation dose due to thoron (mSvy^{-1})	Total Inhalation dose (mSvy^{-1})
Minimum	15.2	1.8	14.9	0.1	0.1	0.0	0.2
Maximum	48.6	12.4	54.6	0.9	0.8	0.3	1.1
Average	31.7	6.3	31.3	0.4	0.4	0.1	0.6
Median	34.6	5.2	28.0	0.2	0.4	0.1	0.4
Standard deviation	10.577	3.912	12.129	0.268	0.254	0.0754	0.3170

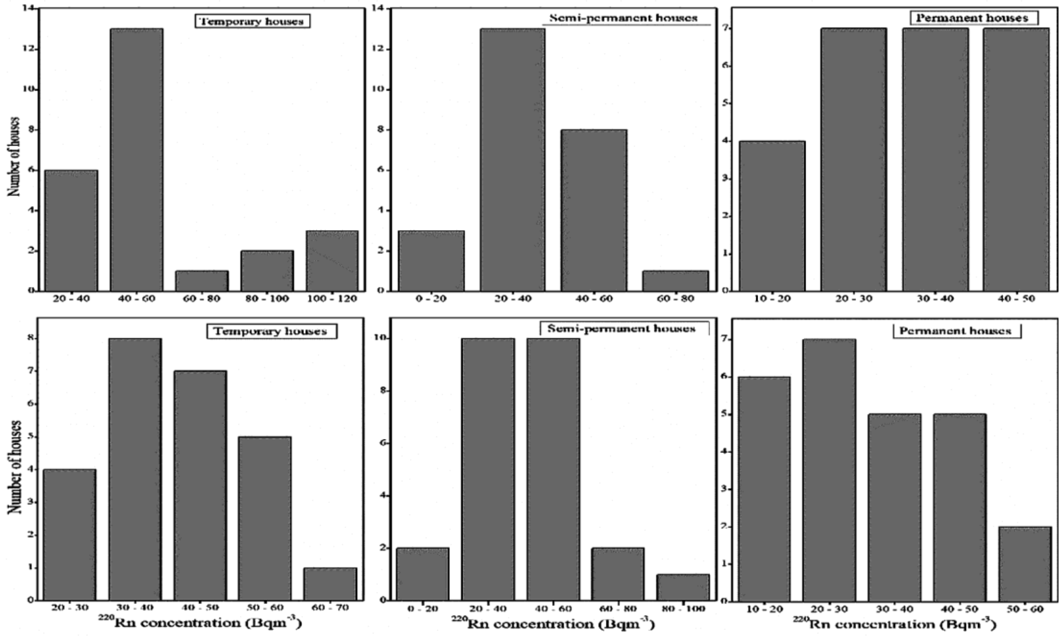

Fig. 3 — A frequency distribution of radon and thoron in three house types

range of 30 to 40 Bqm^{-3}, 28% of houses lie in the range of 40 to 50 Bqm^{-3}, 20% of houses lie in the range of 50 to 60 Bqm^{-3}, 16% houses lie in the range of 20 to 30 Bqm^{-3}, and other 4% houses lie in the range of 60 to 70 Bqm^{-3}. For semi-permanent houses, the radon concentration of 52% of houses was found to vary from 20 – 40 Bqm^{-3}, 32% of houses was found to vary from 40 – 60 Bqm^{-3}, 12% of houses was found to vary from 0 – 20 Bqm^{-3}, and 4% houses was found to vary from 60 – 70 Bqm^{-3}. The thoron concentration of 40% of semi-permanent houses lies between 20 – 30 Bqm^{-3}, the other 40% of houses lie between 40 – 50 Bqm^{-3}, 8% of houses lie between 0 – 20 Bqm^{-3}, and 60 – 80 Bqm^{-3}and remaining 4% houses have thoron concentration of 80 – 100 Bqm^{-3}. Additionally, the radon concentration of 28% of permanent houses lies in the range of 20 – 30 Bqm^{-3}, the next 28% of houses lies in the range of 30 – 40 Bqm^{-3}, other 28% of houses lies in the range of 40 – 50 Bqm^{-3}, and remaining 16% of houses have radon concentration in the range of 10 – 20 Bqm^{-3}. The thoron concentration in 28% of the permanent houses lie between 20 – 30 Bqm^{-3}, 24% of houses lie between 10 – 20 Bqm^{-3}, 20% of houses lies between 30 – 40 Bqm^{-3}. The remaining 20% and 8% of the houses lie between 40 – 50 Bqm^{-3} and between 50 – 60 Bqm^{-3}, respectively.

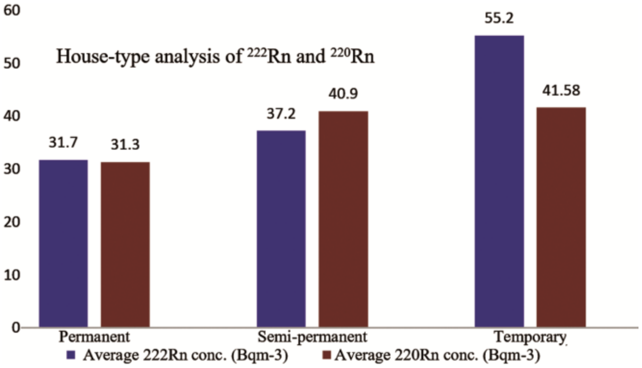

Fig. 4 — The comparison of average radon and thoron concentrations in three different house types

The comparison of average radon and thoron concentrations in all three house types is shown in Fig. 4 and the average concentration of radon and thoron in temporary houses was found higher than that in semi-permanent and permanent houses. Since, temporary houses were made of wooden logs, unburned bricks, straw, and clay, these materials are more porous resulting in radon and thoron penetration more easily in the indoor air. The semi-permanent houses and permanent houses, on the contrary, are built more airtightly, which minimises the amount of radon that can enter the home from the soil. Additionally, radon and thoron concentrations were found more in the indoor of semi-permanent houses as compared to permanent houses because, semi-permanent houses were made of burnt bricks, clay, and lumber without any reinforced concrete, these materials are more porous than reinforced concrete, metal sheets, stone, and burned bricks, which were used to construct permanent homes.

Furthermore, the indoor radon and thoron progeny concentrations were also calculated (Table 1). For permanent, semi-permanent, and temporary houses the mean radon progeny concentration was 6.3 Bqm^{-3}, 10. 6 Bqm^{-3}, and 15.02 Bqm^{-3} respectively, while the mean thoron progeny concentration was 0.4 Bqm^{-3}, 0.6 Bqm^{-3}, and 0.82 Bqm^{-3} respectively, which lie under the permissible limit recommended by ICRP, 1993.

3.1 Annual Inhalation dose

The statistical summary of annual radon and thoron inhalation doses in temporary, semi-permanent, and permanent houses are provided in Table 1. The average indoor radon inhalation dose found was 1.01 mSvy^{-1}, 0.7 mSvy^{-1}, and 0.4 mSvy^{-1} in temporary, semi-permanent, and permanent houses, respectively.

Additionally, the average indoor thoron inhalation dose in temporary, semi-permanent, and permanent houses found was 0.26 mSvy^{-1} (contributing to 20.47% of the total dose), 0.2 mSvy^{-1} (contributing to 22.22% of the total dose) and 0.1 mSvy^{-1} (contributing to 20% of the total dose), respectively. Thus, thoron contributes a remarkable amount to the overall radiation dose and cannot be neglected.

4 Conclusions

1 The annual average radon concentration of permanent and semi-permanent houses lies below the global average while that of temporary houses exceeds the global average of 40 Bqm^{-3}, as recommended by UNSCEAR 2000. However, thoron's annual mean value in all house types exceeds the global average value of 10 Bqm^{-3}, as recommended by UNSCEAR 2000.

2 The annual average radon and thoron concentration of temporary houses was found more than that of permanent and semi-permanent houses in the study area. Annual averages of ^{222}Rn and ^{220}Rn levels of most temporary houses were found slightly higher than thoron levels.

3 The radon concentration of the majority of temporary, semi-permanent, and permanent houses lies in the range of 40 to 60 Bqm^{-3}, 20 to 40 Bqm^{-3}, and 20 to 50 Bqm^{-3}, respectively. The thoron concentration of the majority of temporary, semi-permanent, and permanent houses lies in the range of 30 to 40 Bqm^{-3}, 20 to 60 Bqm^{-3}, and 20 to 30 Bqm^{-3}, respectively.

4 The overall annual effective inhalation dose due to ^{222}Rn, ^{220}Rn, and progenies observed in all three house types was less than the recommended ICRP 2009. Additionally, the study reveals that thoron contributes around 20 - 22 % of the total dose. Hence its contribution cannot be neglected.

5 This data is significant to the health professionals in the study area, who are researching the incidences of lung cancer. The administrative bodies should take certain majors, including public awareness, remediation allowance, and organizing a panel to investigate the risk of radon exposure.

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