INDOOR RADON MEASUREMENT IN SOME VILLAGES OF WEST KHASI HILLS DISTRICT OF MEGHALAYA, INDIA

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***Abstract*:** Indoor radon measurement using LR-115 films (in bare mode) was carried out in four different seasons for a period of one year in 99 houses of four villages *viz*. Nongkasen & Markasa (N&M), Rambrai, Nongkhlaw and Nongstoin under West Khasi Hills District of Meghalaya, India. Seasonal variations are noted and discussed as well as the variations between different house types. The measured indoor radon concentration in N&M (119.56±5.55 Bq.m^{-3}) and Nongstoin (102.74±5.10 Bq.m^{-3}) villages are found to be higher than the lower limit set by the ICRP (100 Bq.m^{-3}).

Keywords: Radon; LR-115 type 2 films, Annual effective dose (AED)

I. Introduction

Natural radioactivity has always been a part of our living environment in varying quantities in geological formations such as soil and rocks and in building materials [1]; their ubiquitous presence has led to continuous exposure of human beings to ionizing radiation which resulting from the decay of these radionuclides. It has been estimated that 90% of human radiation exposure arises from natural sources such as cosmic and terrestrial radiation; out of which radon from terrestrial radiation alone is responsible for nearly half of the dose received by man from natural sources [2]. Radon is a decay product of primordial radionuclide uranium and is an inert gas with an estimated half-life of about ~3.823 days. Radon has been recognized as one of the most significant indoor pollutant in the last century and a second leading cause of lung cancer after smoking [3,4]. Outdoor radon has been found to have lesser impact on human health as atmospheric mixing quickly dilutes it to insignificant levels. However, in enclosed areas such as homes and workplaces, radon can migrate from soils, rocks, and building materials and build-up to significantly higher concentrations which can be hazardous to the general population [3,5]. Inhalation of radon has been related to an increase in the risk of lung cancer and other respiratory diseases [6,7]. The International Agency for Research on Cancer (IARC) in 1988 declared radon as a carcinogenic gas [8]. The importance of indoor radon study has also been noted by various reputed health and environmental organizations such as United States Environmental Protection Agency (US-EPA), World Health Organization (WHO), United Nations Scientific Committee on the Effects of Atomic Radiation (UNSCEAR), National Council on Radiation Protection and Measurements (NCRP), International Commission on Radiological Protection (ICRP) to name a few.

In this paper we are reporting indoor radon concentration and annual effective dose estimation in West Khasi Hills District of Meghalaya. The present work reports indoor radon measured in 4 villages with a total of 99 households located in current study area. This region is especially important for radon study due to its close proximity to the reportedly uranium rich areas in Kylleng Pyndengsohiong Mawthabah (KPM) and Wahkyn region, which are located in the West Khasi Hills District at about ~25 to 57 km from the study area. Indoor radon concentration has been reported to show variations in different seasons of the year and in different types of buildings [9–14].This is mainly reasoned to be due to the change in meteorological parameters like temperature, pressure etc. in different seasons of the year [15–17]. For this survey, we have used solid state nuclear tracks detectors which are one of the most reliable technique for integrated and long term radon concentration measurements [18,19].

We have categorized the houses into three types according to the most commonly found house types in the area which are:

- Wooden house: flooring and walls are completely wooden and ceilings are constructed with the combination of wood and tin sheets.
- Semi-Concrete house: either floor/walls are made of concrete/bricks/woods or both are wooden/concrete and their ceilings are made with the combination of wood and tin-sheets.
- Concrete house: flooring, walls and ceilings are completely made of concrete or bricks.

II. About the study area

The villages under study are located in West Khasi Hills District which lies between latitude 25°10'N and 25°51' N and longitude 90°44'E and 91°49' E with a total geographical area of about 5,247 sq. km in Meghalaya which is a state situated in the north-eastern part of India, shown in figure 1. The total population in this district is about 3, 85,601 [20]. The four seasons namely spring, monsoon (rainy), autumn and winter are prevalent in the district. The spring season is characterized by relatively higher temperature (15 to 25 ºC), occasional rainfall and thunderstorm with high wind velocities. Winter season is the coldest time of the year with a sharp decline in the temperature. The district receives a high rainfall (1200 mm to 3000 mm per annum) throughout the year [21]. To derive seasonal value and annual concentration, the measurements are carried out in the four seasons viz. winter (from December to February), spring (from March to May), rainy (from June to August) and autumn (from September to November).

III. Experimental method

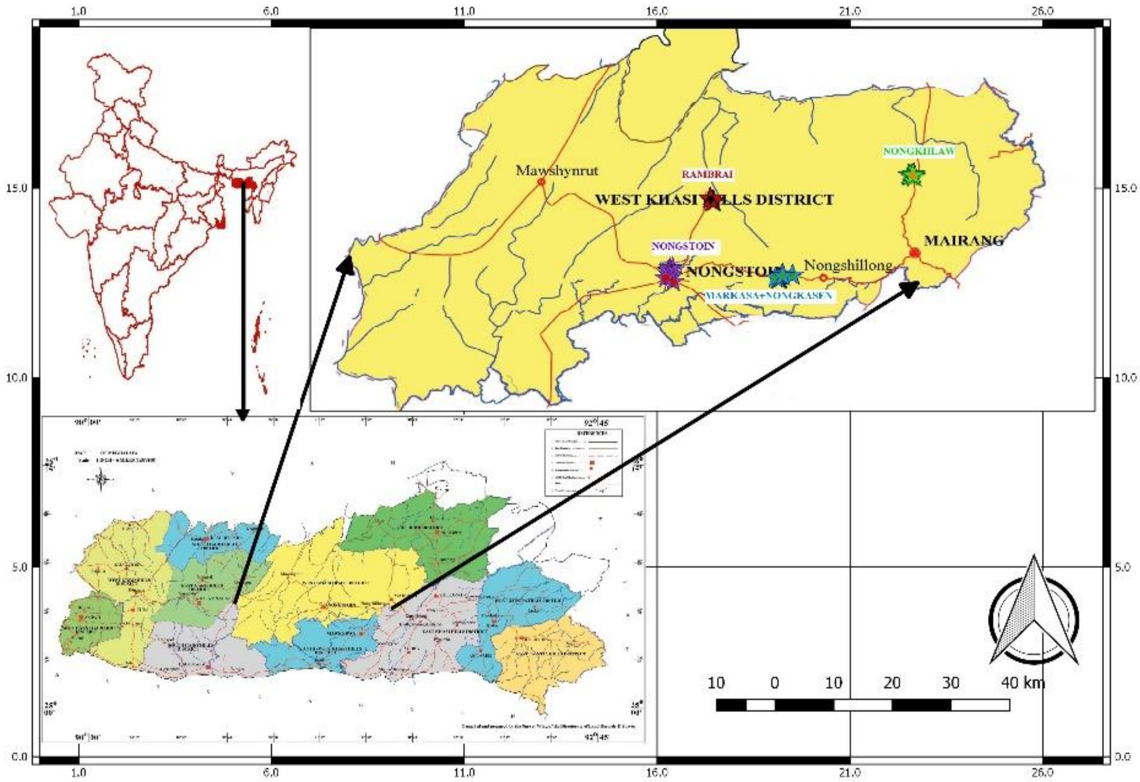

Figure 1. Map depicting the study area with locations (denoted by stars).

Solid State Nuclear Track Detectors, commercially available under the name of LR-115 Type 2 films are used for our study. The films are cut in approximate 2.5 × 2.5 cm^2 area and pasted onto a cardboard of dimension 6 × 9 cm^2 with the sensitive part of the film exposed. The detector films are then

hung at the centre of the selected rooms in the houses and placed at a distance of not less than 10 cm from the roof and about 2 meters from the ground. The detectors are retrieved after a period of exposure of about three months (~90 days) which comprises a season; these retrieved films are then chemically etched in 2.5N NaOH solution at 60ºC for 120 minutes. The perforated holes or tracks appear as bright spots (~ 4μm in diameter) in the reddish background, which are then manually counted using a microscope at 150x magnification.

The track density obtained are then converted into radon activity concentration using the following equation,

$$C_{Rn} = \frac{\rho}{kT} \quad (1)$$

where ρ is the density of tracks (number of tracks counted per unit area of the film), k is the calibration factor taken as 0.02 tracks.cm-2 d^{-1} $(Bq.m^{-3})^{-1}$ [22] and T is the duration (in days) for which the detectors have been exposed.

The annual effective dose (AED) and lifetime fatality risk have been estimated based on UNSCEAR reports of year 1993 and year 2000; assuming a 7000 hours per year indoors (with an occupancy factor of 80%), equilibrium factor of 0.4 and dose conversion factor of 9 nSv per (Bq. h m^{-3}).

$$AED = C_{Rn} \times 0.4 \times 7000h \times 9nSv(Bq.h.m^{-3}) \quad (2)$$

IV. Results

The indoor radon activity concentration measured in the four seasons with the minimum, maximum, geometric mean and annual radon activity concentration values for the villages are given in table 1.

Since the spatial as well as temporal spread of indoor radon values are considered log-normally distributed [23,24] also corroborated by the positive skewness values shown in figure 2, we have used the geometric mean (G.M) instead of the arithmetic mean to represent the mean value of our data and the errors represent the inaccuracy in counting.

The seasonal values for the entire study area are found to vary between 9.63 and 555.46 $Bq.m^{-3}$ with G.M value of 67.04±8.34 $Bq.m^{-3}$ during spring season, 5.23 and 490.07 $Bq.m^{-3}$ with G.M of 76.63±3.85 $Bq.m^{-3}$ during rainy season, 18.72 and 490.07 $Bq.m^{-3}$ with G.M value of 122.83±4.87 $Bq.m^{-3}$ during autumn season and between 6.62 and 570.06 $Bq.m^{-3}$ with G.M value of 165.19±7.21 $Bq.m^{-3}$ while the annual values vary between 18.56 and 365.73 $Bq.m^{-3}$ with G.M value of 101.04±5.8 $Bq.m^{-3}$ in the study area.

Figure 2 shows the box-whisker plot of radon activity concentration measured in the four seasons. From the plot, it is evident that the radon concentration measured is maximum in winter season (with G.M value of 165.20±8.34 $Bq.m^{-3}$) and minimum in the spring season (with G.M value of 67.04±3.85 $Bq.m^{-3}$).

Table 2 shows the range of annual effective dose and lifetime fatality risk calculated from the measured annual radon concentration. The average annual effective dose (AED) value in the study area is found to vary between 0.47 and 9.22 $mSv.y^{-1}$ with G.M value of 2.55±1.78 $mSv.y^{-1}$ and the average lifetime fatality risk value is found to vary between 0.05 and 1.02 × 10^{-4} with G.M value of 0.29±1.78 × 10^{-4}. Table 3 gives the measured average radon activity concentration (in the three categorized types of houses viz. Wooden, Semi-concrete and Concrete) with their minimum and maximum values. The radon concentration measured in the three types of houses are shown in figure 3 and it shows that the median indoor radon activity concentration in wooden house is minimum and maximum in concrete house types.

Figure 4 shows the measurement values in the form of box-whisker plot of annual radon concentration (G.M) measured from the four villages. Figure 5 shows the pie chart distribution of annual radon data in comparison to the international standards given by US-EPA, WHO and ICRP. As seen from the figure 28% of the annual radon concentration measured in different houses under the study are above 100 $Bq.m^{-3}$ and 46% are below 100 $Bq.m^{-3}$ which is the ICRP lower limit [25], 23 % are above than the US-EPA limit of 148 $Bq.m^{-3}$ [26] and only 3% are above than the ICRP upper limit of 300 $Bq.m^{-3}$ which is also the limit set by WHO [25,26].

Table 1: Consolidated data giving the indoor radon concentration measured in the four villages in the four seasons and the annual radon concentration.

Name of the village	No. of houses	Spring			Rainy			Autumn			Winter			Annual Radon Conc. in $Bq.m^{-3}$
		Min	Max	G.M	Min	Max	G.M	Min	Max	Mean	Min	Max	G.M	
N&M	35	9.63	417.6	104.41 ±6.72	5.2	332.1	73.13 ±5.33	23.6	524.8	134.23 ±11.57	73.8	570.1	199.37± 9.99	119.56 ± 3.24
Rambrai	21	19.1	555.5	86.8 ± 5.2	12.5	218.2	42.6 ± 3.6	19.1	552.5	94.3 ± 6.4	6.6	246.5	103.2 ± 4.9	77.4 ± 4.9
Nongkhlaw	21	10.2	139.2	41.3 ± 2.8	8.6	490.1	112.1 ± 6.2	18.7	511.9	122.1 ± 6.5	48.7	512.3	162.2 ± 8.6	97.9 ± 5.5
Nongstoin	22	11.1	389.7	41.1 ± 1.9	12.6	375.1	100.5 ± 5.1	47.5	390.1	138.1 ± 7.6	88.9	488.9	195.4 ± 9.2	102.7±5.1

Table 2: Consolidated data of annual radon concentration measured in houses located in four villages with their estimated annual effective dose and life-time fatality risk.

Name of the village	Total no. of houses	Annual radon concentration in $Bq.m^{-3}$			AED in $mSv.y^{-1}$			Lifetime Fatality Risk x 10^{-4}		
		Min.	Max.	G.M	Min.	Max.	G.M	Min.	Max.	G.M
N&M	35	42.2	303.02	119.56 ± 3.24	1.06	7.65	3.01±1.82	0.12	0.9	0.35±1.83
Rambrai	21	24.89	211.09	77.44±4.93	0.63	5.32	1.95±1.64	0.07	0.64	0.23±1.66
Nongkhlaw	21	18.56	365.73	97.87±5.45	0.47	9.22	2.46±2.01	0.05	1.02	0.27±2.02
Nongstoin	22	53.04	257.35	102.74±5.10	1.34	6.49	2.59±1.42	0.14	0.7	0.28±1.42

Table 3. Consolidated data of mean radon activity concentration measured in the three types of houses with their minimum and maximum values for the four villages.

Name of the village	Wooden			Semi- concrete			Concrete		
	Min.	Max.	G.M ($Bq.m^{-3}$)	Min.	Max.	G.M ($Bq.m^{-3}$)	Min.	Max.	G.M ($Bq.m^{-3}$)
N&M	42.2	175	68.41±3.59	84.07	300	165.44±3.31	58.7	303.01	155.59±2.81
Rambrai	24.89	211.09	73.81 ± 1.74	49.24	92.2	71.96 ± 1.26	78.24	211.09	128.52±2.96
Nongkhlaw	20.71	168.05	75.38 ± 2.06	80.93	135.33	104.58 ± 1.23	56.06	407.99	160 ± 1.76
Nongstoin	65.46	113.07	86.7 ± 1.27	53.04	257.35	106.39 ± 1.66	82.43	154.47	109.14 ± 1.21

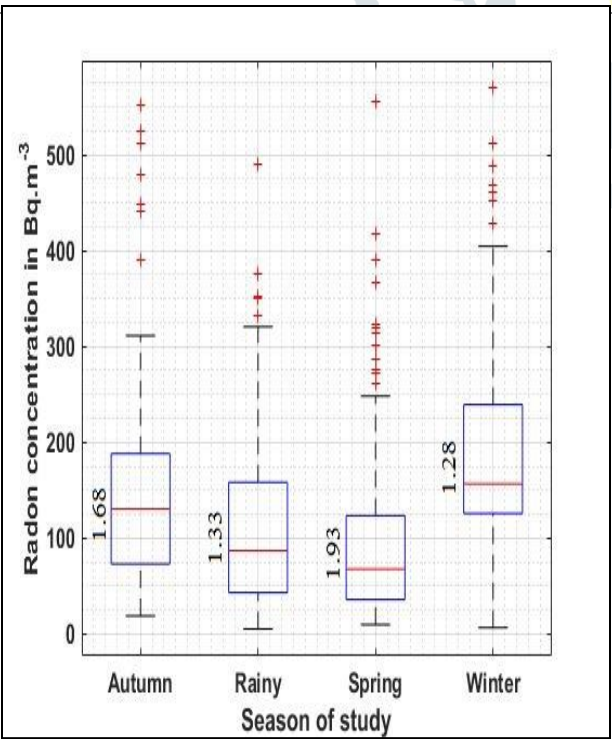

Figure 2. Box plot of indoor radon activity concentration measured in the four seasons. The numbers on the side give skewness values of the data.

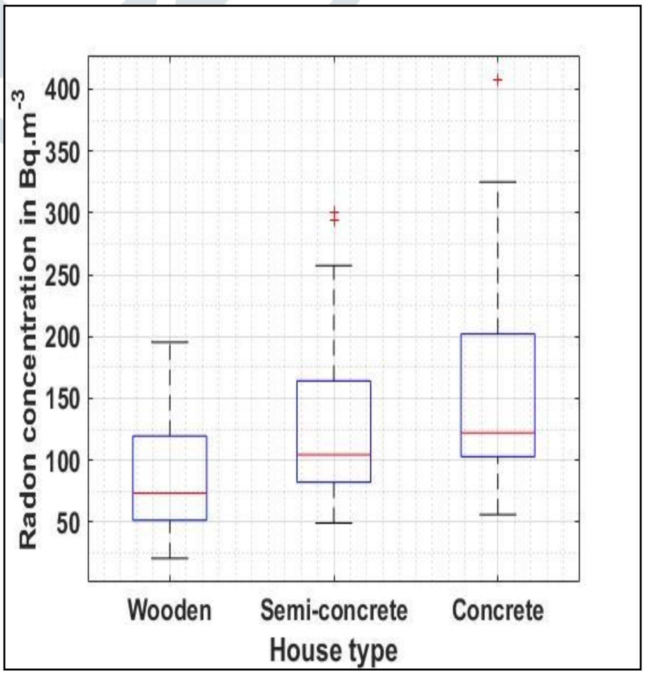

Figure 3: Box plot of radon concentration measured in the three different house types.

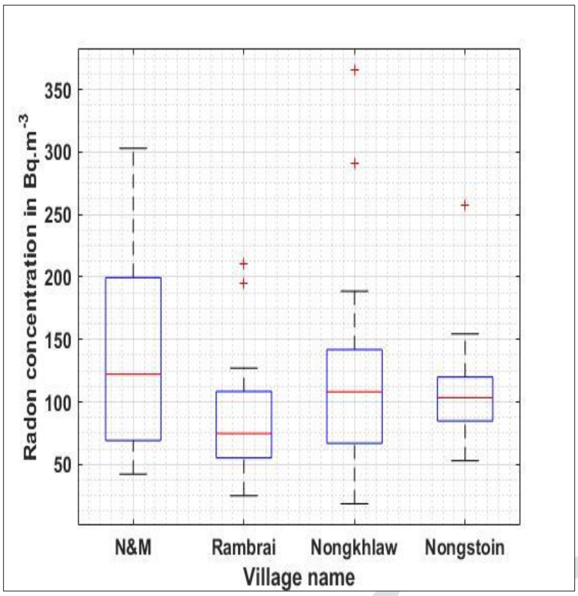

Figure 4: Box plot of annual radon concentration measured in the four villages.

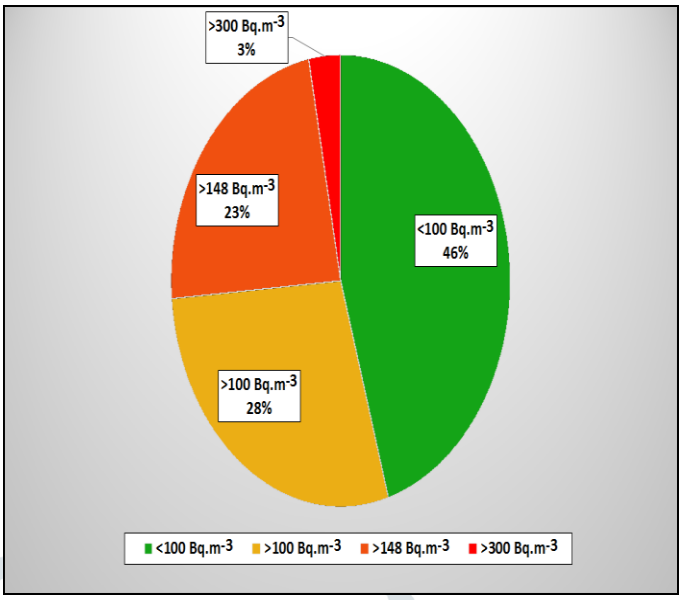

Figure 5: Pie chart of measured annual radon data distributed according to the proportion that fall within the international standards of ICRP lower limit (100 Bq.m^{-3}), US-EPA limit (148 Bq.m^{-3}) and WHO and ICRP upper limit (300 Bq.m^{-3}).

V. Discussion

From the table 1 we can see that in the two villages viz. N&M (Nongkasen & Markasa) and Nongstoin, the annual radon concentration measured is found to be higher than the lower limit set by the ICRP (100 Bq.m^{-3}) [25], while Nongkhlaw only narrowly misses the limit. This shows that in majority of the places the people are at risk from radon as can also be seen from figure 5. However, in terms of the radiation dose received by residents calculated as AED, all the villages have values well within the limit of 10 mSv.y^{-1} as set by the World Health Organization (table 2). Since, broad assumptions have been made in the calculation of AED and lifetime fatality risk, the recommendations in terms of actual radon concentrations may be more applicable.

Radon activity concentration measured in the four seasons are found to vary in the following ascending trend: spring < rainy < autumn < winter. Similar trend in the seasonal variation of the radon concentration have been reported by various authors [27–29] and usually attributed to ventilation and temperature difference between indoor and outdoor environments. Particularly, in winter, the indoor temperature is generally higher by about 10^{o}C or more in comparison to outdoors, therefore the convective forces come into effect which leads to drawing of more air from the ground, walls through cracks and pores which ultimately leads to higher indoor concentration to accumulate in the houses. However, in spring season when the outdoor temperature is as high as or higher than the indoor temperature, the convective movements of the indoor air are negligible [3].

Out of the total 99 houses studied, 43 are wooden houses, 23 are semi-concrete houses and 33 are concrete houses. Concrete materials being derived from raw material found in the earth's crust are expected to have more radium, which over time can emanate radon; woods products are generally not of any concern in this respect. Also, concrete houses have lower air exchange rates in comparison to wooden houses which can lead to higher radon accumulation inside the house [30–35]. As expected, in the current study, higher radon concentration is observed in concrete houses followed by semi-concrete and wooden house (figure 3) respectively. Thus, the contribution of building materials to enhanced radon in indoor environments cannot be overlooked.

VI. Conclusion

From the measurements of the indoor radon carried out for a year-long duration in 99 houses in four villages of West Khasi Hills Districts of Meghalaya, India, the geometric mean value of indoor radon concentration is found to be 98.23±5.28 Bq.m^{-3}, which is just lower than the lowest recommended value above which action needs to be taken. When we take the upper limit set by ICRP and the Action level set by WHO (which is 300 Bq.m^{-3}) into consideration then the annual radon concentration measured in all the four villages under the present study are well within the acceptable limits. The indoor radon concentrations show significant dependence on seasons of the year and on the nature of construction of houses. Consistent with previous studies [30–38], we found that radon concentration is maximum in winter season and minimum in the spring season. Again, as expected, higher radon concentration is observed in concrete houses in comparison to wooden houses.

VII. Acknowledgements

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