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STUDY OF INDOOR RADON, THORON AND THEIR PROGENY IN SOUTH WEST KHASI HILLS DISTRICT OF MEGHALAYA, INDIA

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A survey of indoor radon/thoron and their progeny concentrations was carried out in dwellings in the South West Khasi Hills district of Meghalaya, India. The survey was carried out using solid-state nuclear track detectors based on single-entry pinhole dosimeter and direct radon/thoron progeny sensors. The results are subjected to statistical analysis and discussed in the manuscript. The mean value of annual effective dose of the study region is estimated at 1.8 mSv.y $^{-1}$. Seasonal variability and role of different indoor parameters are also discussed.

INTRODUCTION

Radon (^{222}Rn) is a naturally occurring colourless and odourless radioactive gas. It has three natural isotopes, namely, ^{222}Rn (radon), ^{220}Rn (thoron) and ^{219}Rn (actinon) formed from the alpha decay of radium as a part of the decay series of ^{238}U (uranium), ^{232}Th (thorium) and ^{235}U (actinium), respectively. Being radioactive in nature, radon and thoron further decay into their respective progeny, which are chemically active and relatively short-lived. These progenies are particulate in nature and if inhaled may reach the lung and cause internal irradiation as it can interact with soft epithelium tissue, thereby leading to DNA damage. Overtime it may cause cancer.[1–3]

In the context of terrestrial radiation, radon, thoron and their progeny contribute immensely (~52%) to the natural background radiation dose received by humans; the problem was considered so dire from an epidemiological point of view that the World Health Organization (WHO) declared the exposure to radon and its progeny as the second leading cause of lung cancer after smoking.[4–6] Since identification of radon and its progeny as potentially important indoor pollutant, efforts in the form of national survey programmes have been undertaken by different countries to monitor their concentrations in indoor environment.[7–10]

Based on geological and seismic characteristics, the north-eastern region of India is expected to have higher concentration of radon.[11] Thus, it is imperative to assess indoor level of radon, thoron and their progenies to evaluate the dose to the population. The study area is known for having one of the largest sandstone-type uranium deposits of the country,[12] which makes the present study of utmost significance as uranium is the ultimate source of radon in soil and thus may have an effective impact on radon dispersion rate in the atmosphere. The location within India and within Meghalaya of the four villages surveyed in the present study is shown in Figure 1.

EXPERIMENTAL TECHNIQUE

Pinhole-based twin cup dosimeter

A new ‘pinhole based twin cup dosimeter’ with single face entry has been used for the measurement of indoor ^{222}Rn and ^{220}Rn concentration. This dosimeter system has two chambers separated by a central pinhole disc, acting as ^{220}Rn discriminator. Each chamber is cylindrical having a length of 4.1 cm and radius of 3.1 cm. The interior of the chamber is coated with metallic powders to have neutral electric field inside the chamber volume so that the deposition of progenies formed from gases will be uniform throughout the volume. LR-115 detectors are pre-fixed in these chambers, and concentrations are estimated based on tracks registered on these detectors.[13, 14]

Direct radon/thoron progeny sensors

Deposition-based direct radon and thoron progeny sensors (DRPS and DTPS) have been developed by Bhabha Atomic Research Centre (BARC), Mumbai, for estimating the time integrated progeny deposition fluxes in the environment. These are made of passive nuclear track detectors (LR-115) mounted

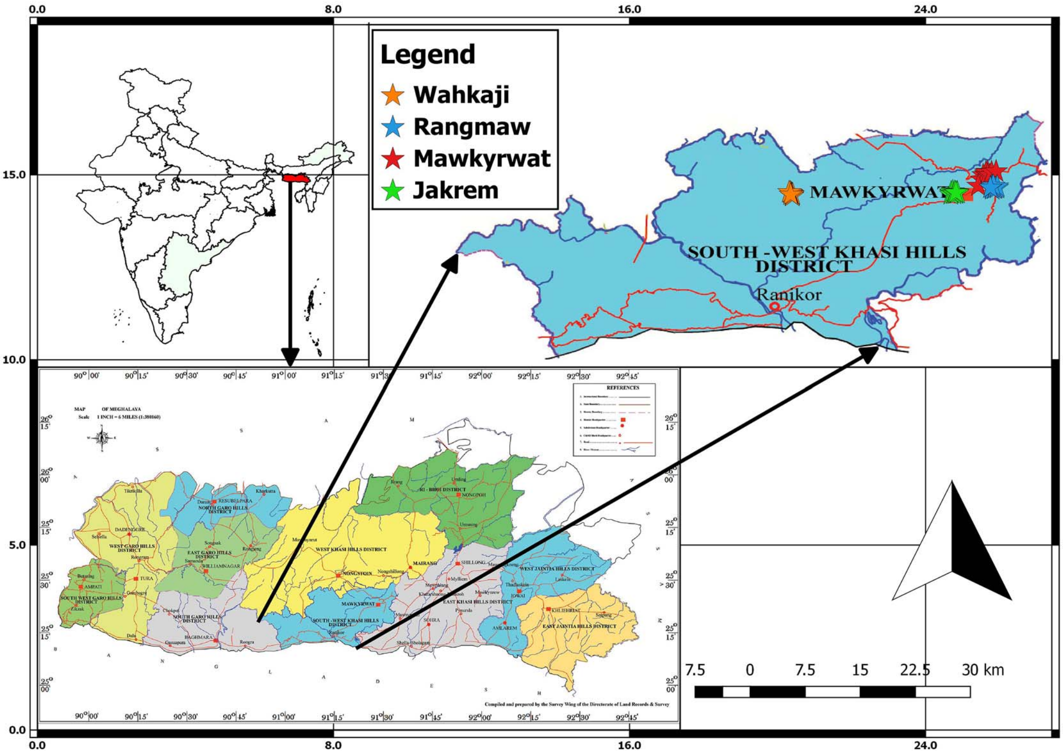

Figure 1. Map showing the location of study area.

with absorbers of appropriate thickness. For ^{220}Rn progeny, the absorber is 50 μm aluminised Mylar, while for ^{222}Rn progeny, the absorber is a combination of aluminised Mylar and cellulose nitrate of effective thickness 37 μm. DTPS element is made up of LR-115 (2.5 x 2.5 cm^2) mounted with 50 μm aluminised Mylar to selectively detect only 8.78 MeV α-particles emitted from ^{212}Po, while the DRPS element is made up of the same dimension LR-115 (2.5 x 2.5 cm^2) mounted with absorber of effective thickness 37 μm to detect mainly 7.67 MeV α-particles emitted from ^{214}Po.[15, 16] The basic principle of operation of these sensors is that the LR-115 detector detects the alpha particles emitted from the deposited progeny atoms.[17]

METHODOLOGY

A pseudorandom sampling methodology was adopted based on the logistics of the study area. Ten houses were chosen from each of the four villages selected for the present study: a total of forty households. A few precautions were taken to make the survey as effective as possible, viz. a minimum distance of 100 m was maintained between surveyed houses; similar type of house structures (concrete) was chosen, and detectors were deployed in rooms of similar dimensions and usage.

For the study of seasonal variation of different indoor parameters, four seasons were identified based on common classification in the region[18, 19], viz. autumn (September–November), winter (December–February), spring (March–May) and rainy (June–August); detectors were then deployed to cover each season completely. After the completion of the exposure period, the detectors were retrieved and then subjected to chemical etching in a solution of 2.5 N NaOH solutions at 60°C for about 90 min. These films are then washed and dried. The alpha tracks formed on the films are counted with the help of a standard spark counter (Model PSI-SC1) at operating voltage of 500 V; prior to pre-sparking voltage of 900 V, simultaneously track densities were obtained.

The obtained track densities in the filter and pinhole compartments of twin cup dosimeter are then converted into radon (C_r) and thoron (C_t) concentrations (in Bq.m^{-3}), using the relations below:

$$C_r = \frac{T_1}{D.k_r} \tag{1}$$

$$C_t = \frac{T_2 - D.C_r k_r}{D.k_t} \quad (2)$$

where T_1 and T_2 represent track densities due to radon and thoron, respectively; D represents the number of days of exposure; and k_r {0.0170 ± 0.002 tr. cm^{-2} d^{-1}(Bq.d.m^{-3})$^{-1}$} and k_t {0.010 ± 0.001 tr. cm^{-2} d^{-1}(Bq.d.m^{-3})$^{-1}$} are the calibration factors of radon and thoron in 'radon + thoron' compartment.[13]

Similarly, the track formed on the LR-115 detector of DTPS and DRPS is converted to radon and thoron equilibrium equivalent concentration (EEC) in the same units as their parent's concentration, using the relations below:

$$EEC_r = \frac{T_{3-B}}{D.S_r} \quad (3)$$

$$EEC_t = \frac{T_{4-B}}{D.S_t} \quad (4)$$

where T_3 and T_4 are the track densities of radon and thoron progeny formed on DRPS and DTPS sensors, respectively. The sensitivity factors used in the present study are $S_r = 0.0900 \pm 0.0036$ tr. cm^{-2} d^{-1}(Bq.d.m^{-3})$^{-1}$ for DRPS and $S_t = 0.940 \pm 0.027$ tr. cm^{-2} d^{-1}(Bq.d.m^{-3})$^{-1}$ for DTPS. Further T_3 value is calculated using the following equation: [(20)]

$$T_3 = T - \frac{\eta_1}{\eta_2} T_4 \quad (5)$$

where T represents the total number of tracks recorded on DRPS. The track registration efficiency of thoron progeny in DRPS is $\eta_1 = 0.0100 \pm 0.0004$ and in DTPS is $\eta_2 = 0.083 \pm 0.004$.[(20)]

In estimating the annual effective dose due to exposure to radon, thoron and their progenies for an indoor occupancy of 7000 h per y (with standard occupancy factor of 0.8)[(21)] the relation below is being followed:

$$\mathrm{D(mSv)} = 0.007\{(0.07\mathrm{C_r} + 9\mathrm{EC_r}) + (0.11\mathrm{C_t} + 40\mathrm{EEC_t})\} \quad (6)$$

where 0.17, 9, 0.11 and 40 {in unit of nSv (Bq.h.m^{-3})$^{-1}$} are the respective dose conversion factors of radon, radon progeny, thoron and thoron progeny.[(3)]

RESULTS AND DISCUSSIONS

The principal results of the survey, which include the average concentration values of radon, thoron, radon progeny and thoron progeny, are given in Table 1; estimates of the annual effective dose are also given. Comparable annual average values of radon and thoron have been observed in three of the four studied villages—the exception being the village of Rangmaw with a lower value of concentration. The observed average values of the four studied indoor parameters in the study area have overturned our expectation of significant influence of proximity to the region of uranium deposits,[(12)] since the observed values are comparable to those reported elsewhere in the state of Meghalaya.[(22)]

The observed annual average concentration of indoor radon in the study region is found to be 55.9 ± 24 Bq.m^{-3}, which is slightly higher than the global average value of 40 Bq.m^{-3}, while the thoron value (60.6 ± 34 Bq.m^{-3}) is found to be almost six times higher than the global average value of 10 Bq.m^{-3}.[(23, 24)] However, the radon and thoron annual averaged concentration values in all the houses lie within the reference level of 300 Bq.m^{-3} [(25)].

With respect to progeny concentrations, radon progeny mean value is 20.9 ± 11 Bq.m^{-3}, which is slightly higher than the global average of 15 Bq.m^{-3}, whereas thoron progeny mean value is 1.4 ± 0.9 Bq.m^{-3}, which also shows a comparatively higher value than the global average of 0.5 Bq.m^{-3} [(23, 24)]. The annual effective dose of the whole study region is 1.8 mSv.y^{-1}, which is slightly higher than the world average value of 1.3 mSv.y^{-1} [(23)]. As may be seen from Table 1, Rangmaw village shows the highest annual effective dose value followed by Mawkyrwat, Wahkaji and Jakrem in descending order of magnitude.

It was observed that 90% of the total houses have radon concentration above the global average value (Figure 2a), while for thoron, all the houses have values above the world average. 87.5% of the total houses were observed to have radon progeny concentration above the global average value, while for thoron progeny, this percentage was 100%. But the overall observed concentration levels in the surveyed houses lie within the recommended action level proposed by WHO as well as those proposed by ICRP.[(5,25)]

A few statistical analyses have been undertaken to draw forth the nature of statistical distribution of the spatial spread of the annual radon, thoron and their progeny concentrations data. Three types of standard statistical distributions have been considered based on our previous experience[(26)], viz. normal, log-normal and gamma. To check how well the data agrees with the fitted distribution we have performed the Anderson–Darling goodness-of-fit test. The threshold considered for rejection of the null hypothesis is 0.05, i.e. at 95% significance. A comparison of the p value shows that radon spatial spread is best described by the normal distribution, while

Table 1. Annual mean value of indoor parameters of four villages together with respective average gamma level and GPS values.

Name of the village (10 dwellings each)	GPS co-ordinates	Average gamma level (μR.h^{-1})	Radon conc. (Bq.m^{-3})	Thoron conc. (Bq.m^{-3})	Radon progeny conc. (Bq.m^{-3})	Thoron progeny conc. (Bq.m^{-3})	Annual effective dose (mSv.y^{-1})
Jakrem	N 25°39′ 02.01″ E 91°50′ 58.08″	34	60 ± 6	67 ± 5	22 ± 2	1.5 ± 0.1	1.4
Wahkaji	N 25°36′ 61.77″ E 91°26′ 14.91″	20	61 ± 6	66 ± 5	19 ± 2	1.07 ± 0.1	1.6
Rangmaw	N 25°37′ 29.62″ E 91°51′ 04.08″	25	42 ± 5	56 ± 5	22 ± 1	1.5 ± 0.1	1.9
Mawkyrwat	N 25°36′ 65.51″ E 91°45′ 76.98″	28	61 ± 6	68 ± 5	20 ± 1	1.5 ± 0.1	1.8

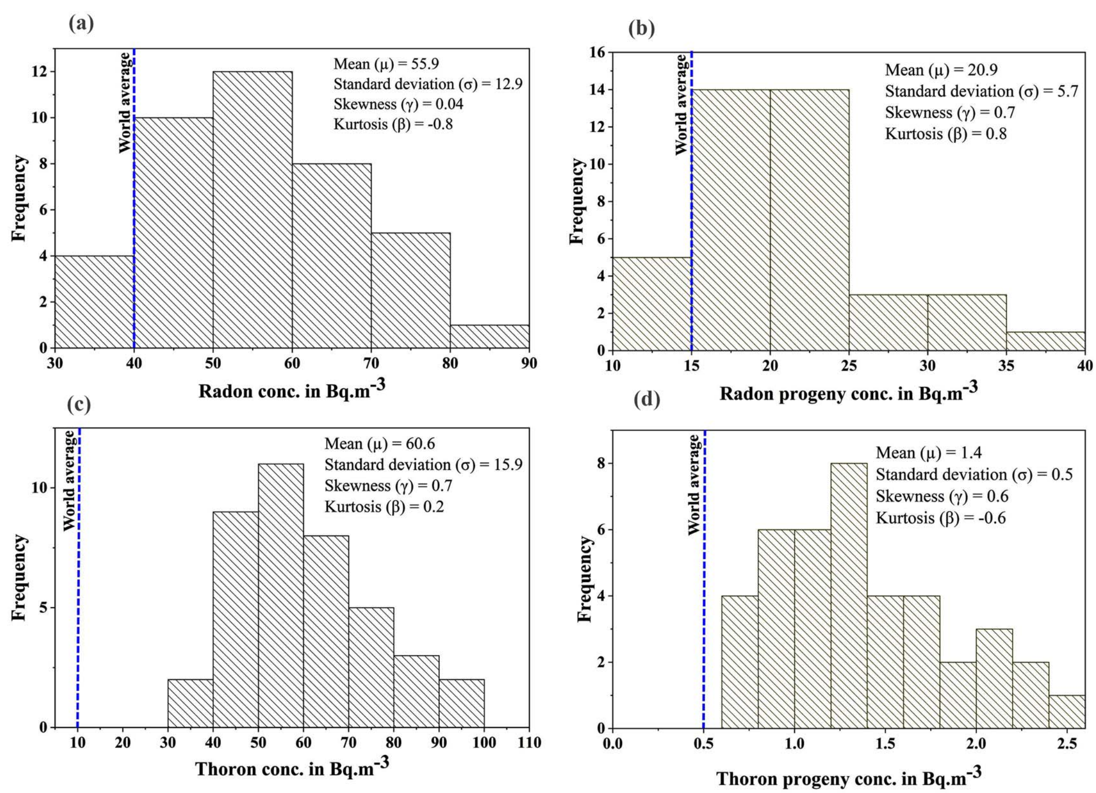

Figure 2. Frequency–distribution plot of (a) radon, (b) radon progeny, (c) thoron and (d) thoron progeny.

the spatial spread of other three indoor parameters follows log-normal distribution.

SEASONAL VARIATIONS

Estimating radon, thoron and their progeny concentration for different seasons of the year is a toilsome task as there are many factors on which their indoor build-up level depends such as ventilation conditions, type of building materials and the radioactivity level of the soil beneath. It is often reported that the winter season witnesses higher value of radon due to poor ventilation and other factors,[27] but interestingly the present study shows a different trend of seasonal

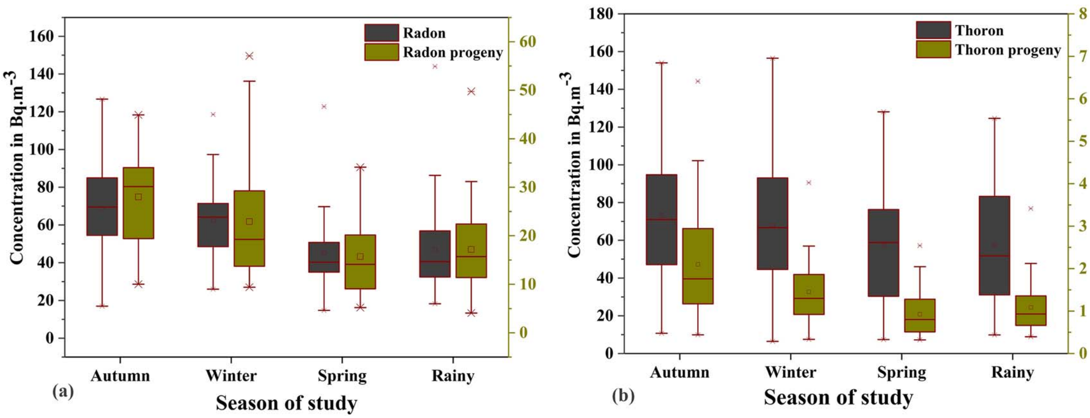

Figure 3. Box plot of seasonal variation of (a) radon and radon progeny and (b) thoron and thoron progeny.

variation, with autumn season showing higher values for all the four indoor parameters.

Figure 3 displays the box–whisker plots of seasonal variation of radon, thoron and their progenies. The radon concentration for autumn not only shows the highest average and median but also the highest variability as seen from the relatively longer interquartile range (IQR). The order, in terms of ascending values of mean radon concentration, is autumn followed by winter, rainy and spring seasons; thoron also shows the same pattern, but the difference in the concentration values for the rainy and spring seasons is negligible.

In terms of the variability of the radionuclide concentration over the different households within a given season also, the autumn shows the highest variability with an IQR of 29.6 Bq.m^{-3} for radon, while for thoron the rainy seasons shows the highest variability with an IQR of 50 Bq.m^{-3}. We also find that the variability of thoron concentration within a given season is much higher than that of radon concentration.

The pattern for the progeny concentration values over different seasons of both radon and thoron are is found to be the same as that of the parent radionuclide. However, the variability within a season of the progeny is different than that of their parent radionuclide with radon progeny showing the highest variability in the winter season with an IQR of 14.8 Bq.m^{-3}, while for thoron progeny, the highest variability is seen for the autumn season with an IQR of 1.8 Bq.m^{-3}. We also find that the variability of radon progeny concentration within a given season is much higher than the variability of thoron concentration—opposite to the observed pattern of the parent nuclides.

CORRELATIONS BETWEEN GAMMA DOSE RATE: RADON, THORON AND THEIR PROGENY

To check for dependency of gamma level on radon, thoron and their progeny concentrations in indoor environment, linear correlation graphs have been plotted (Figure 4a–d), and the Pearson correlation coefficients are calculated between the two groups. It is observed that there exist extremely weak correlations between radon and that of its progeny activity concentrations to gamma radiation levels; this suggests that there are other more prominent factors influencing indoor gamma dose rate. Thoron and its progeny show a more prominent and expected positive correlations with gamma level.

CONCLUSION

The survey on the radon, thoron and their progeny concentrations carried out in the South West Khasi Hills district of Meghalaya, India in the present study leads us to the following conclusions:

(a) Overall, the activity levels of all the measured indoor parameters lie within the safe limit as recommended by the International Commission of Radiation Protection (ICRP).[25] No convincing trends of variation of indoor parameters with respect to distance of the studied villages from the uranium deposit area.

(b) In the entire study region, the annual mean value of radon is found to be slightly higher than the global average value. Thoron shows a much higher mean annual value compared to the world average value; both the radon and thoron progenies

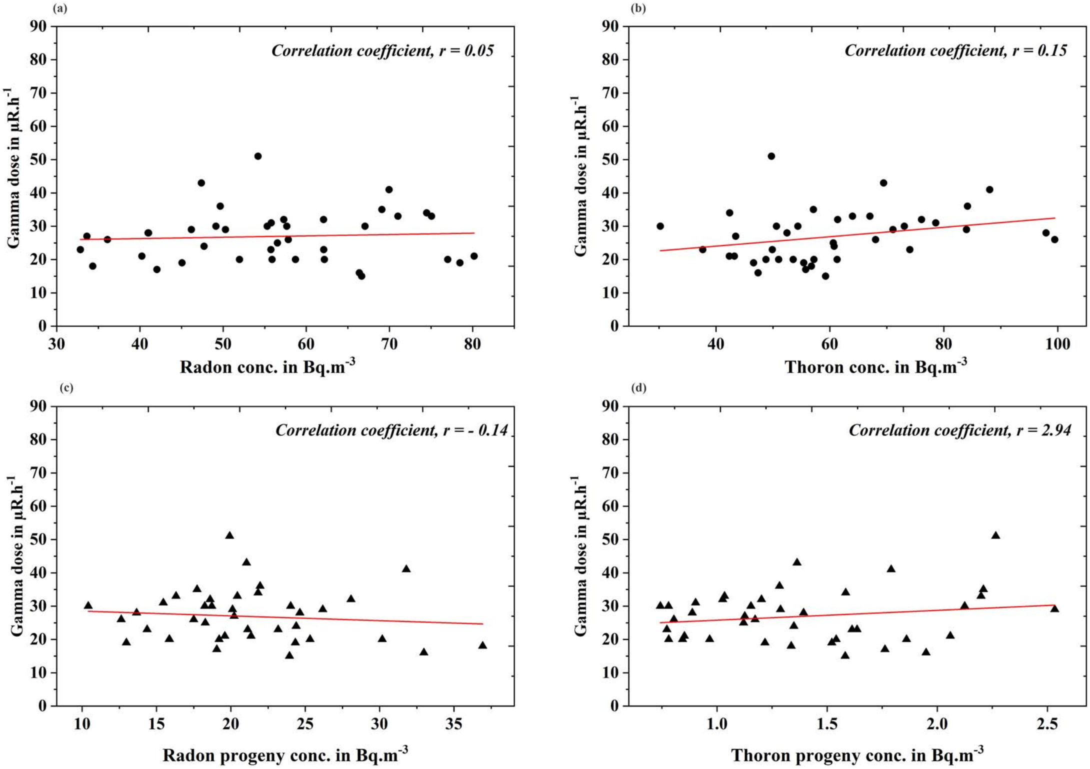

Figure 4. Correlation plots between gamma level and (a) radon, (b) thoron, (c) radon progeny and (d) thoron progeny.

show marginally higher levels than the world average.[23, 24]

(c) Compared to the global average value of annual effective dose, viz.1.25 mSv.y^{-1}, slightly higher value has been observed in the present study but much below the limit given by ICRP, which is 3–10 mSv.y^{-1}.[25]

(d) Seasonal variations of radon, thoron and their progeny concentrations show a consistent pattern of the following descending order of concentration values according to season: autumn, winter and rainy/spring seasons, the difference between rainy and spring seasons being negligible.

(e) Weak positive correlations were observed between gamma dose rate and indoor radon, while negative correlation was seen in the case of radon progeny; more prominent correlations were observed in the case of gamma dose rate versus thoron and its progeny concentrations.

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REFERENCES

1. Nazaroff, William, W. and V. Nero, A. Jr. Radon and its Decay Products in Indoor Air. (New York: Wiley Inter Science Publication) (1988).
2. Durrani, S. A. and Illic, R. Radon Measurement by Etched Track Detectors. (Singapore: World Scientific Publishing Co. Pte. Ltd) (1997).
3. UNSCEAR. United Nations Scientific Committee on the Effects of Atomic Radiation. Sources and Effects Ionizing Radiation, Report to General Assembly with Scientific Annexes, Annex B: Exposure from Natural Sources of Radiation. (New York: United Nations) (2000).
4. National Research Council. Biological Effects of Ionizing Radiation, Health Effect of Radon and Other Internally Deposited Alpha Emitters, (BEIR IV). NRC Report. (Washington DC: National Academic Press) (1998).
5. WHO. Handbook on Indoor Radon: A Public Health Perspective. (Geneva: World Health Organisation) (2009). available from https://apps.who.int/iris/handle/10665/44149.
6. Edling, C., Wingreen, G. and Alexson, O. *Quantification of the lung cancer risk from radon daughter exposure*

in dwellings- an epidemiological approach. Environ. Int. **12**, 55–60 (1986).
7. Cohen, B. I. *A national survey of radon in US homes and correlation factors*. Health Phys. **51**, 175–185 (1986).
8. Abu-Jarad, F. and Al-Jarallah, M. I. *Radon activity in Saudi houses*. Nucl. Tracks Radiat. Meas. **8**, 395–398 (1984).
9. Hughes, J. S., Shaw, K. B. and O'Riordon, M. C. Radiation Exposure of the UK Population. NRPB Rev R77. (London: HMSO) (1989).
10. Lubin, J. H. *et al.* Lung Cancer and Radon: A Joint Analysis of 11 Underground Miners' Studies. National Institutes of Health Publication No. 4-3644. (National Institute of Health: Bethesda, MD) (1994).
11. Dwivedi K. K and Ghosh S. Prospect and potentials of radon monitoring in north-eastern India. In: Proceedings of Second Workshop on Radon Monitoring in Radioprotection Environmental Radioactivity and Earth Sciences, 25th November–6th December (ICTP: Trieste, Italy) (1991).
12. Atomic minerals directorate for exploration and research. Government of India. www.amd.gov.in/ner/shillong.
13. Sahoo, B. K., Sapra, B. K., Kanse, S. D., Gaware, J. J. and Mayya, Y. S. *A new pin hole discriminated $^{222}Rn/^{220}Rn$ passive measurement device with single entry face*. Radiat. Meas. **58**, 52–60 (2013).
14. Eappen, K. P. and Mayya, Y. S. *Calibration factors for LR-115 (type-II) based radon thoron discriminating dosimeter*. Radiat. Meas. **38**, 5–17 (2004).
15. Mishra, R., Mayya, Y. S. and Kushwaha, H. S. *Measurement of 220Rn/222Rn progeny deposition velocities on surfaces and their comparison with theoretical models*. Aero. Sci. **40**, 1–15 (2009).
16. Mishra, R., Prajith, R., Sapra, B. K. and Mayya, Y. S. *Response of direct thoron progeny sensors (DTPS) to various aerosol concentrations and ventilation rates*. Nucl. Instr. Meth. Phys. Res. B **268**, 671–675 (2010).
17. Leung, S. Y. Y., Nikezic, D. and Zu, K. N. *Passive monitoring of the equilibrium factor inside a radon exposure chamber using bare LR-115 SSNTDS*. Nucl. Meas. Met. Phys. Res. A **564**, 319–323 (2006).
18. Kharbani Holdingstone and Hajong Sudhanya Ray. *Seasonal patterns in ant (hymenoptera: Formicidae) activity in a forest habitat of the West Khasi Hills, Meghalaya, India*. Asian Myrmecol. **5**, 103–112 (2013).
19. Kakati, R., Rohit, M. and Bhattacharjee, B. *Seasonal and spatial variation of radon and thoron concentration in the dwellings of Karbi Anglong District of Assam, India using SSNTDs*. Inter. Jour. Appl. Environ. Sci. **2**, 135–171 (2011).
20. Mishra, R., Sapra, B. K. and Mayya, Y. S. *Multiparametric approach towards the assessment of radon and thoron progeny exposure*. Rev. Sci. Instrum. **85**, 1–8 (2014).
21. Mayya, Y. S., Eappen, K. P. and Nambi, K. S. V. *Methodology for mixed field inhalation dosimetry in monazite areas using a twin cup dosimeter with three track detectors*. Radiat. Proct. Dosim. **77**, 177–184 (1998).
22. Mishra, R., Tripathy, S. P., Khathing, D. T. and Dwivedi, K. K. *An extensive indoor $^{222}Rn/^{220}Rn$ monitoring in Shillong, India*. Radiat. Prot. Dosim., 433 **3**, 429 (2004).
23. UNSCEAR. United Nations Scientific Committee on the Effects of Atomic Radiation. Sources and Effects Ionizing Radiation, Report to general assembly with scientific annexes. Vol. **1**. (United Nations: New York) (2008).
24. UNSCEAR. United Nations Scientific Committee on the Effects of Atomic Radiation. Sources and Effect Ionizing Radiation, Report to General Assembly with Scientific Annexes, Annex E, Sources-to-Effects Assessment for Radon in Homes and Work-Places. (New York: United Nations) (2006).
25. ICRP. International Commission on Radiological Protection. Radiological Protection Against Radon Exposure, Publication 126. (Annals of the ICRP) (2014). available from https://www.icrp.org/publication.asp?id=ICRP%20Publication%20126.
26. Maibam, D. Studies on radon activity in soil-air, indoors and in water at selected locations in Meghalaya. Thesis (2014).
27. Ramola, R. C., Prasad, M., Kandari, Pant, T. P., Bossew, P., Mishra, R. and Tokonami, S. Dose Estimation Derived from Exposure to Radon Thoron and Their Progeny in the Indoor Environment. (Scientific Reports) (2016). doi: https://doi.org/10.1038/srep31061.