STUDY OF THE CONNECTION BETWEEN ROOM SIZE AND RADON/THORON DOSE RATES IN BANGALORE METROPOLITAN AREA

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Abstract. The emanation of gases from the walls, floors, and ceilings is the main source of radon (Rn) and thoron (Tn) in enclosed rooms. The bulk of terrestrial construction materials contain gas in their pores in concentrations 1,000–10,000 times higher than those in the atmosphere. This high concentration results in a considerable radon/thoron concentration difference between the construction materials and ambient air. In this study, indoor radon, thoron, and their progeny concentrations, in Bangalore Metropolitan households, were measured using a significant number of dosimeters.

Key words: Radon (Rn), thoron (Tn), room size, concentrations.

INTRODUCTION

There has been a significant increase interest in the program involving the measurement of ^{222}Rn in the environment ever since studies on uranium (U) miners revealed the existence of a positive risk coefficient for the lung cancer development in miners exposed to elevated levels of ^{222}Rn and its progeny. In numerous countries, the residential ^{222}Rn was recognized as a potential public health concern in the western world as a result of high ^{222}Rn levels in the indoor space. It is expected that large-scale indoor ^{222}Rn (radon) and ^{220}Rn (thoron) surveys would contribute to a quantitative knowledge of the dose effects of Rn exposures in conjunction with epidemiological research [19].

Long-term exposure to high concentrations of ^{222}Rn and its short-lived progeny causes pathological consequences such lung cancer and abnormalities in respiratory function [9]. According to Jacobi [5], the population exposure to natural sources of radiation seems to be mostly caused by inhalation of short-lived ^{222}Rn progeny. One estimates that ^{222}Rn gas, which may be responsible for between 5 and 20 % of all lung cancers, may be the main source of radiation exposure of the general public [3].

Received: April 2023;
in final form May 2023.

ROMANIAN J. BIOPHYS., Vol. 33, No. 1, P. 27–36, BUCHAREST, 2023

The Environmental Protection Agency of the United States recently estimated that ^{222}Rn-inhaled causes annually 20,000 lung cancer fatalities [12]. NRC [10] reviewed the available data on the exposures of general public to radon progeny. The measurement methodologies and the types of measurements were made to assess the health risk due to ^{222}Rn (radon) by dosimeter models [10]. Moreover, a substantial body of epidemiological data on occupational exposure to ^{222}Rn and its progeny has highlighted cancer risk factors that are remarkably constant, down to concentrations encountered in some households. Although ^{222}Rn was discovered at the beginning of the twentieth century, a link between ^{222}Rn exposure and lung cancer in U miners was not discovered until late 1960 [15, 20]. In line with the degree of predicted risk, based on the investigations of underground mines, a new study of published results also demonstrates a marginally elevated risk of lung cancer due to the household ^{222}Rn [6, 20].

Most of the annual radiation received by humans originates from natural sources, and of this portion, around half is brought on by breathing in short-lived descendants of ^{222}Rn [17]. It is now understood that indoor natural radiation sources, particularly ^{222}Rn and its progeny, expose people to significant inhalation danger. Under certain circumstances, the lung dose brought on by inhaling ^{222}Rn progeny can be so great as to increase the risk of developing lung cancer [4].

Depending on the soil qualities and the type of construction, such increased risk may occur in tiny clusters of houses. It is necessary to assess the population exposure in order to determine the incidence of lung cancer linked to ^{222}Rn and to develop effective control strategies. In light of this, efforts have been made for more than a decade to measure the Rn/Tn concentrations in houses throughout the Bangalore metropolitan area.

MATERIALS AND METHODS

The experimental methodology consists in the standard protocol provided by the radon groups of the Environmental Assessment Division, Department of Atomic Energy, Bhabha Atomic Research Center, Government of India, Mumbai. Measurements of radiation levels and of the radionuclide concentrations in the environment are accomplished employing appropriate nuclear instruments. The Rn, Tn, and their progeny concentrations were determined using Solid State Nuclear Track Detectors [7, 11]. The tracks formed in the detector films were counted by Spark Counter by methods discussed elsewhere [1, 16].

RESULTS

On the basis of room size, which ranged from 30 to 350 m^3, all rooms were roughly divided into six groups: 30–40, 45–60, 65–75, 80–100, 110–120, and

200–350 m^3. At least 10 rooms were selected for each group and this is covered for ten different locales. About 10 rooms, in each size (6 groups) lead to 60 rooms in one location, the same procedure is followed in all the 10 different locations, therefore, the total numbers of rooms monitored were 600. These 600 rooms were examined over the course of four seasons, yielding 2,400 measurements. Almost 7,500 films (LR-115 detectors) have been overall exposed throughout the measuring period. In 60 houses, during the course of three years, room size wise fluctuations in ^{222}Rn, ^{220}Rn, their progeny, and dose rates were measured.

Fig. 1b displays the volumetric fluctuations of ^{222}Rn and ^{220}Rn. In comparison to the greater size room, the lower size room showed higher radionuclide concentrations. Fig. 1a depicts the dose rate, the lower dose rate being observed in larger volume rooms and higher dose rate in smaller rooms.

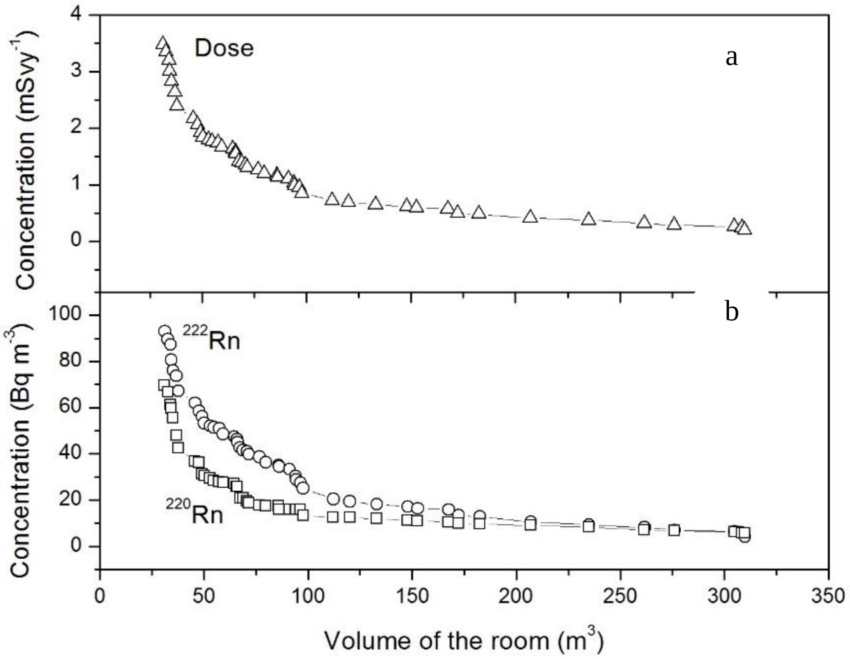


Fig. 1. ^{222}Rn and ^{220}Rn concentration variation with the volume of the room.

A residence with a capacity of 30–350 m^3 has concentrations ranging from 10 to 93 Bq m^{-3}. This finding clearly shows that even though the observations were taken for almost identical types of construction, ventilation, and lifespan of the houses, the concentrations decrease exponentially as room size grows and become nearly beyond the volume of 160 m^3. The concentration exponential drops for ^{222}Rn and ^{220}Rn have regression coefficients of 0.99 and 0.98, respectively. The current study shows that residents of smaller room size will be exposed to greater dose rates, which are 5 times higher than those received in larger room.

Fig. 2 depicts the relationship between Tn, Rn, and their progeny. The correlation between ^{220}Rn, ^{222}Rn, and their progeny, was 0.96 and 0.79, respectively.

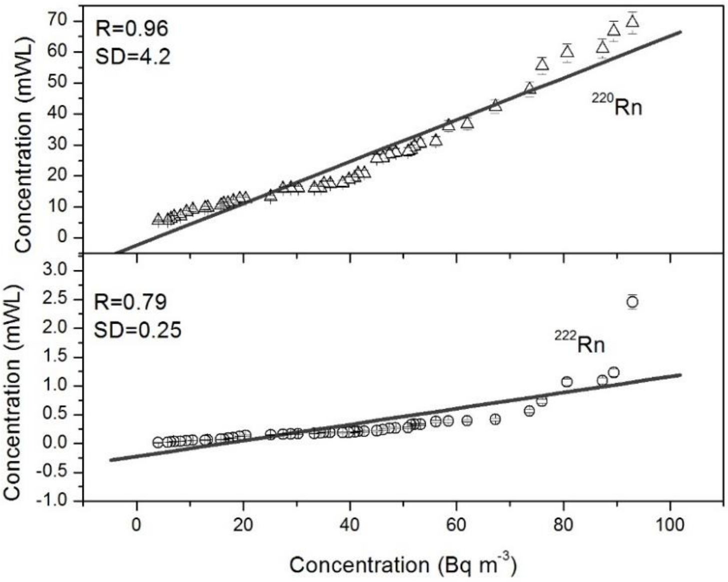


Fig. 2. Relation between Tn/Tn progeny and Rn/Rn progeny concentration.

Fig. 3 shows the frequency distribution of Rn and Tn of the monitored houses with room size varied from 30 to 350 m^3; observed data revealed the higher concentrations in smaller size rooms, whereas lower concentrations are seen in larger size rooms.

According to earlier studies, the natural radioactivity contents of soil samples from the Bangalore region were 15.2, 16.9, and 486.7 Bq kg^{-1} for ^{226}Ra, ^{232}Th, and ^{40}K, respectively [8], and 33.0, 30.5, and 412.3 Bq kg^{-1} for ^{238}U, ^{232}Th, and ^{40}K, respectively, in the building rocks of Karnataka region [13]. Majority of the bricks used for building constructions in Bangalore are from Nelamangala and Magadi (city outskirts), and a smaller amount from Hoskote, Ramanagara, and Channapattana. In the soils of Nelamangala and Magadi, the average activity concentrations of ^{226}Ra, ^{232}Th, and ^{40}K are respectively 31.3 ± 0.6, 52.6 ± 0.9, and 303.1 ± 6.1 Bq kg^{-1} and 16.9 ± 0.6, 57.5 ± 1.1, and 1,073 ± 15.6 Bq kg^{-1} [14].

Figs. 4 and 5 show the occurrence of Rn and Tn concentrations in the monitored houses of the present study of the size of room varied from 30 to 350m^3. Using UNSCEAR [18] dose conversion coefficients, the inhalation dose is calculated. The geometric mean of the inhalation doses, computed from the entire results, was 1.34 mSv y^{-1}, ranging from 0.27 to 4.45 mSv y^{-1} (with Geometric Standard Deviation 2.1).

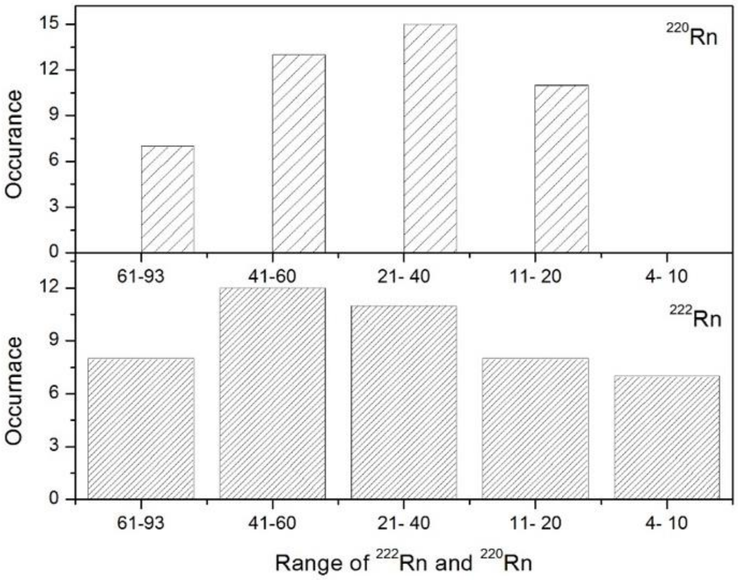


Fig. 3. Occurrence of ^{222}Rn (Bq m^{-3}) and ^{220}Rn concentration (Bq m^{-3})

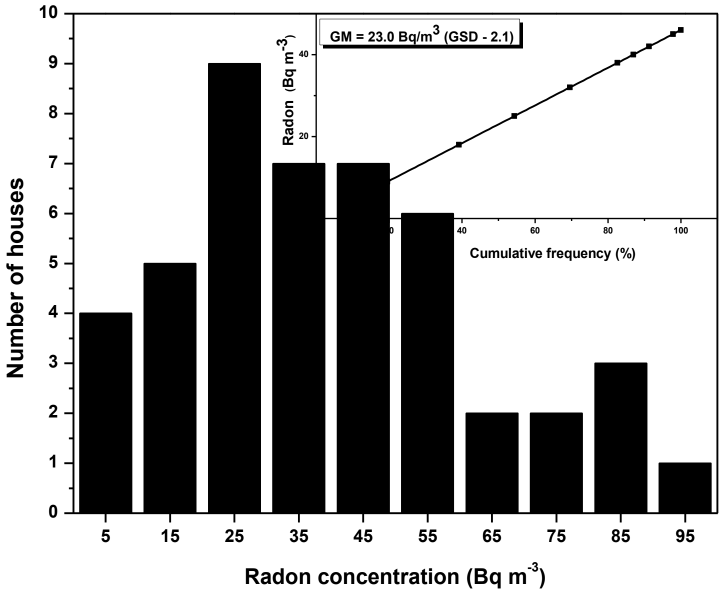


Fig. 4. Occurrence of ^{222}Rn concentration.

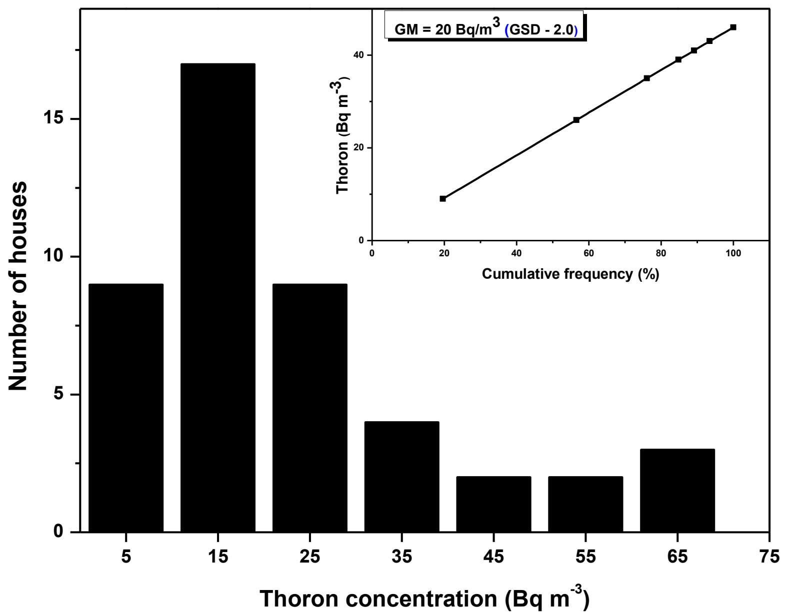
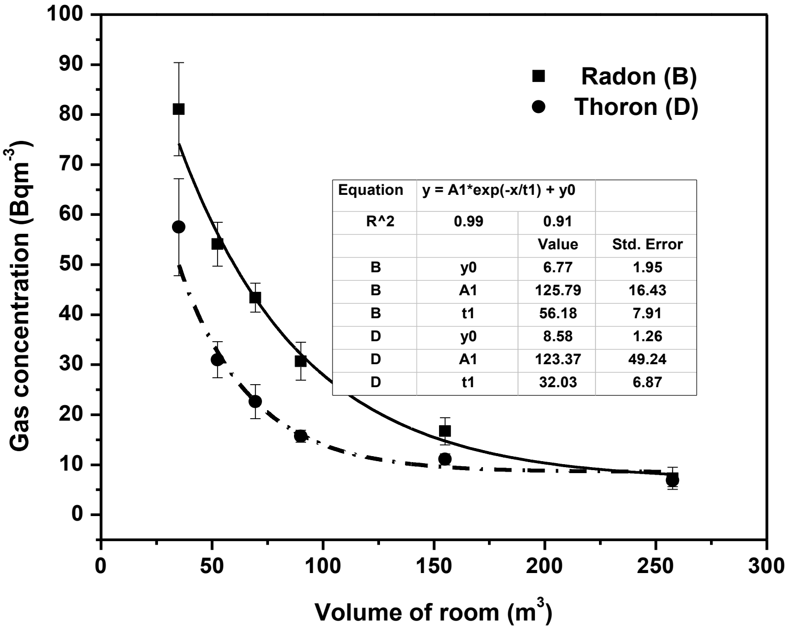


Fig. 5. Occurrence of Tn concentration.



Equation	y = A1*exp(-x/t1) + y0		
R^2	0.99	0.91	
		Value	Std. Error
B	y0	6.77	1.95
B	A1	125.79	16.43
B	t1	56.18	7.91
D	y0	8.58	1.26
D	A1	123.37	49.24
D	t1	32.03	6.87

Fig. 6. Dependence of Rn and Tn gas concentrations on room volume.

Compared to larger volume rooms, lower size rooms showed higher radionuclide concentrations. In Fig. 6, a plot of Rn and Tn concentrations is represented against room size. The figure illustrates that as room sizes expand, concentrations tend to decline. Beyond room size of 160 m^3, the effect in the case of Tn is nearly negligible. If we assume that the building materials used to construct these houses were similar, then the exhalation rates for Rn and Tn from the room surfaces are almost equal. Therefore, it is expected that the gas concentrations will decrease with an increase in room size, since area to volume (*A/V*) ratio decreases with room size increase.

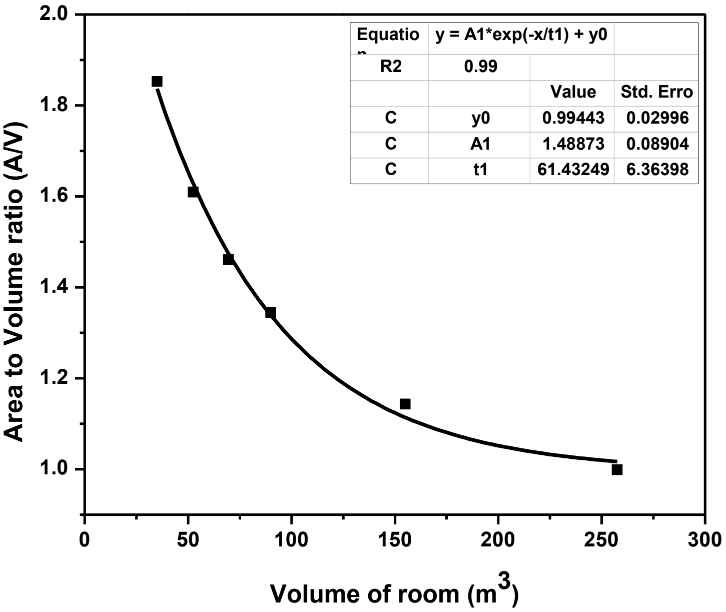


Fig. 7. Correlation between *A/V* ratio and room volume.

Fig. 7 displays a plot of area to volume (*A/V*) ratio versus room volume. One can see from this figure that similarly, *A/V* ratio manifests an exponential fit decreasing with room volume with a correlation coefficient of 0.99. It is interesting to note that radon effective decay value (56.2) in Fig. 6 and the fitting parameter, *t* (61.4) in Fig. 7, are similar. This clearly indicates that the radon concentrations inside houses are predominantly depended on *A/V* ratio. Effect of room ventilation seems negligible when the measurements were carried out for long duration. Thoron, however, produced distinct effects than radon. It can be seen, in the Fig. 6, that the *t* value is almost equal to the *A/V* ratio (32). In this case, it seems to be more phenomena influencing the thoron readings. One can reason that inside the rooms with bigger volumes, the concentration of thoron is greater at surfaces closer to the location of the dosimeter.

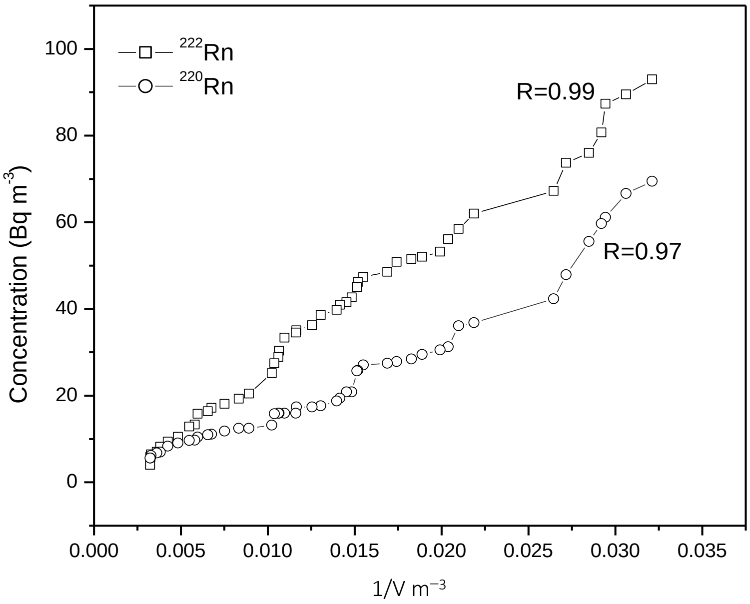


Fig. 8. Rn and Tn concentration as a function of volume reverse (1/*V*).

The fluctuation of concentration with inverse size (*1/V*) of room is depicted in Fig. 8. It is noteworthy that the relationship between concentration fluctuation and room size results in a straight line. In every case, there is a correlation between concentration and size of room that is greater than 90 %, indicating a clear relationship between them. The study found out that the annual effective inhalation dose caused by ^{222}Rn, ^{220}Rn, and their progeny ranged from 0.2 to 4.4 mSv y^{-1}, with an arithmetic mean of 1.7 ± 1.1 mSv y^{-1}. One can write the equation for concentration, *C*, of Rn and Tn as follows [2]:

$$C = \frac{JA}{V(\lambda_0 + \lambda_v)} \tag{1}$$

where J (Bq m^{-2} h^{-1}) is the area averaged emission flux, A (m^2) and V (m^3) are the surface area and room volume, respectively, λ_0 (h^{-1}) is the radioactive decay constant and λ_v (h^{-1}) is the air-exchange rate. When considering the decay of ^{222}Rn, which has air exchange rates of the order of 0.1 to 1 h^{-1}, the decay constant is 0.0076 h^{-1}, leading to $\lambda_v >> \lambda_0$. As a result, J is roughly the same for all the houses in a given area, and different combinations of λ_v, A, and V will lead to various concentrations. However, when the ventilation is disregarded, the decay constant for ^{220}Rn is 45 h^{-1} and the air exchange rates are 0.1–1 h^{-1}. To be more explicit, the above results are the first attempt to analyze the data concerning with regard to the size of room and the fitting parameters.

CONCLUSIONS

In all the observed houses, the concentrations of indoor radon gas are higher in smaller rooms and lower in larger rooms. This clearly shows that, even if the observations have been taken almost for same types of structures and building ages, the concentrations decrease exponentially as room capacity increases and become nearly constant beyond the 200 m^3.

The radionuclides in smaller rooms, of average size 10 m^3, may be more concentrated than in bigger rooms, of average size 20 m^3. There is a direct relationship between radionuclide concentrations and size of rooms with a correlation coefficient over 90 % in every scenario.

Larger spaces with lower radioactive danger include conference halls, classrooms, and other large spaces. In order to decrease the radiation exposure to radon, thoron and their progeny it is advised the lower size rooms to be properly aired.

Based on the paper findings, it can be said that indoor ^{222}Rn and ^{220}Rn levels in Bangalore metropolitan area, are substantially below the UNSCEAR recommended permissible values for the population.

Acknowledgments: The work described here was carried out as a part of a research project supported by the University Grants Commission, New Delhi, India, in recognition of its scientific significance. Author is thankful to the Research Funding Council, University Grants Commission, New Delhi, India for providing the funds to carry out research work. The principals and heads of the departments are acknowledged for allowing us to use the instruments to take the data in the dwellings of Bangalore Metropolitan area during the research period.

REFERENCES

1. DURRANI, S.A., R.K. BULL, *Solid State Nuclear Track Detection, Principles, Methods and Applications*, First Edition, Pergamon Press, Oxford. 1987, pp. 169−173.
2. EATON, R.S., Radon reduction, in: *Radon and its Decay Products in Indoor Air*, Chapter 2, W.W. Nazaroff, A.V. Nero, eds., John Wiley & Sons, New York, 1988, pp. 57–112.
3. HPA, *Radon and Public Health Report of the independent Advisory Group on Ionizing Radiation*, 2009, **RCE-11**, 1−258.
4. ICRP, Radiation protection of workers in mines, *ICRP Publication* 47, **16**(1), 1986.
5. JACOBI, W., The history of the radon problems in mines and homes, *Annals of the ICRP*, 1993, **23**(2), 39−45.
6. LUBIN, J.H., J.D. BOICE Jr, Lung cancer risk from residential ^{222}Rn: Meta-analysis of eight epidemiological studies, *J. of Nat. Canc. Inst.*, 1997, **89**, 49−57.
7. MAYYA, Y.S., K.P. EAPPEN, K.S.V. NAMBI, Methodology for mixed field inhalation dosimetry in monazite areas using a twin cup dosimeter with three track detectors, *Rad. Prot. Dos.*, 1998, **77**, 177−181.
8. MISHRA, U.C., S. SADASIVAN, Natural radioactivity levels in Indian soil, *J. Sci. and Ind. Res.*, 1971, **30**(2), 59−62.
9. NATIONAL ACADEMY OF SCIENCES, The effects on populations of exposure to low levels of ionizing radiation, *Report of the Advisory Committee on the Biological Effects of Ionizing Radiation* (BEIR I) Washington, DC, 1972.

10. NATIONAL RESEARCH COUNCIL (NRC), *Comparative Dosimetry of ^{222}Rn in Mines and Homes*, National Academy Press, Washington, D C, 1991.
11. NIKOLAEVE, V.A., R. ILIC, Etched track radiometers in radon measurements: A Review, *Rad. Meas*., 1999, **30**, 1–13.
12. PUSKIN, J.S., C.B. NELSON, EPA's perspective on risks from residential radon exposure, *J. of Air Poll. Con. assoc*., 1989, **39**(7), 915–920.
13. RAMACHANDRAN, T.V., K.P. EAPPEN, R.N. NAIR, Y.S. MAYYA, S. SADASIVAN, Radon-thoron levels and inhalation dose distribution pattern in Indian dwellings, *BARC Report*, 2003, **26**, 1–63.
14. SHIVA PRASAD, N.G., N. NAGAIAH, G.V. ASHOK, N. KARUNAKARA, Concentrations of ^{226}Ra, ^{232}Th, and ^{40}K in the soil of Bangalore region, India, *Healt. Phys.*, 2008, **94**(3), 264–271.
15. SNIHS, J.O., Swedish radon program, *Rad. Prot. Dos.*, 1992, **42**(3), 177–184.
16. TOMMASINO, L., D.E. CHEROUATI, E. RAPONI, Improvement in the spark-replica counter and the breakdown counter, *Nucl. Trac.*, 1986, **12**, 275–278.
17. UNSCEAR, Genetic and somatic effects of ionizing radiation, *Report to the General Assembly* (a/41/16) and three scientific annexes, E.86.IX.9, 1986.
18. UNSCEAR, Sources, effects and risks of ionizing radiation, *International Atomic Energy Agency*, **1**, 2000, 63–74.
19. UNSCEAR**,** Sources, effects and risks of ionizing radiation**,** *Report to the General Assembly* (A/74/46) and two scientific annexes, 2019.
20. WEBB, J.A., Exposure to ^{222}Rn, *Rad. Prot. Dos.*, 1992, **423**, 191–195.