MEASURMENT OF RADON, THORON AND THEIR PROGENY IN INDOOR ENVIRONMENT OF MOHALI, PUNJAB, NORTHERN INDIA, USING PINHOLE DOSIMETERS

by

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The health hazards of radon and its decay products above certain levels are well known. However, for any preventive measures to be taken, we have to be aware of radon levels of that particular area. Measurement of radon and its decay products in indoor environments is an important aspect of assessing indoor air quality and health conditions associated with it. Keeping this in mind, measurements of radon, thoron and their progeny concentrations were carried out in Mohali, Northern India, using pinhole-based twin cup dosimeters. Radon exhalation rates of soil samples in the dwellings/areas were measured via an active technique of a continuous radon monitor. The indoor radon concentration in Mohali varied from 15.03 0.61 Bq/m^3 to 39.21 1.46 Bq/m^3 with an average of 26.95 Bq/m^3 ,while thoron concentration in the same dwellings varied from 9.62 0.54 Bq/m^3 to 52.84 2.77 Bq/m^3 with an average of 31.09 Bq/m^3. Radon progeny levels in dwellings under study varied from 1.63 to 4.24 mWL, with an average of 2.94 mWL, while thoron progeny levels varied from 0.26 to 1.43 mWL , with an average of 0.84 mWL. The annual dose received by the inhabitants of dwellings under study varied from 0.78 to 2.36 mSv, with an average of 1.61 mSv. The *in situ* gamma dose rate varied from 0.12 to 0.32 Sv/h.

Key words: radon, thoron, progeny, solid-state nuclear track detector, dwelling, annual effective dose, ventilation

INTRODUCTION

Due to lack of awareness, environmental radioactivity poses a serious potential risk to all living things. The world is naturally radioactive and around 90 % of human radiation exposure arises from natural sources [1]. The naturally occurring radionuclides of interest are uranium, thorium, actinium series elements ^{40}K and ^{14}C. The said radionuclides are of main concern due to their relatively long half-lives and the fact that they are the principal source of exposure to natural radiation. Since they are not uniformly distributed, the knowledge of radionuclide distribution and radiation levels in the environment is important for assessing the effects of human exposure to radiation. As most people spend 90 % of their time indoors, indoor air quality is of great importance to those responsible for protection against adverse health effects caused by inhaled radionuclides.

Uranium, a naturally occurring radioactive element, is present in trace amounts throughout the Earth's crust. The decay of uranium leads to radium which decays to radon [2] in indoor and outdoor environment, soil, ground water, and oil and gas deposits. There are three major isotopes of radon – actinon (^{219}Rn) with a half-life of 3.96 seconds, thoron (^{220}Rn) with a half-life of 55.6 seconds, and radon (^{222}Rn) with a half-life of 3.824 days [3]. These three radon isotopes emit alpha particles of 6.82 MeV, 6.28 MeV, and 5.48 MeV, respectively.

Radon appears mainly by diffusion processes from the point of origin, following – decay of radium (^{226}Ra) in underground soil and building materials used in the construction of floors, walls, and ceilings. It is found in natural sources only because of its continuous replenishment from the radioactive decay of its longer-lived precursors in minerals containing uranium or thorium. Radon can enter the buildings through cracks and other openings caused by the aging of the structures or due to inherent design and construction problems [4]. Depending on various geological and geophysical aspects and features of building materials, radon can migrate into indoor air, which can lead to an increase in concentrations [5].

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A link between exposure to radon and its decay products in mining environments and an increased risk of lung cancer has been reported in [6]. These reports have prompted the International Commission on Radiological Protection (ICRP, 1993) to approve recommendations on how to control radon exposure in dwellings and work places [7]. Many researchers have reported on the values of indoor radon [8-10] in various parts of the world and India, as well [11-13]. However, our earlier paper has shown that there are still many places for which no data of indoor radon levels are available [14]. Not much has previously been reported on indoor radon levels of the area under study in this paper.

The study reported here is useful for the assessment of the radiation dose received by the inhabitants and for mapping a database of radon levels in the country. Keeping these important points in mind, an environmental monitoring of radon, thoron and their progeny in some dwellings in Mohali, Northern India, has been carried out using pinhole dosimeters, as this technique does not suffer the limitations of twin cup dosimeters of thoron interface and wind turbulence. The newly designed single entry pinhole dosimeter is one of the more accurate techniques which overcomes the limitations of previous techniques *i. e*., those of the bare and twin cup dosimetry systems.

GEOLOGY OF STUDY AREA

The state of Punjab is surrounded by Pakistan on the west, Indian states Haryana and Rajasthan to its south, Jammu and Kashmir to the north, Himachal Pradesh to its northeast. It covers a geographical area of 50.362 km^2 and is located between 29°30'N to 32°32'N latitude and 73°55' E to 76°50'E longitude, with an average elevation of 300 m above the sea level. Punjab is a region of fertile plains with some portions at its southeast edge accommodating semiarid and desert landscapes.

Figure 1 shows the Mohali district (also called Sahibzada Ajit Singh Nagar (S. A. S. Nagar), located between 30°21'N and 30°56'N latitude and 76°30'E and 76°55'E longitude.

The district is bounded by the Rupnagar district in the northwest, Patiala and Fatehgrah Sahib districts in the southwest, Ambala district of Haryana state in the south, Union Territory Chandigarh in the east. This research is also important because most of the districts mentioned here are in the Shivalik foothill range (*i. e*., Rupnagar, Mohali, Ambala, and U. T. Chandigarh), hardly previously included into any studies. The climate of the Mohali district can be classified as monsoon subtropical. The southwest monsoon contributes by about 80 % of annual rainfall. The major soil type of the district is arid, weakly solonized brown soil [15].

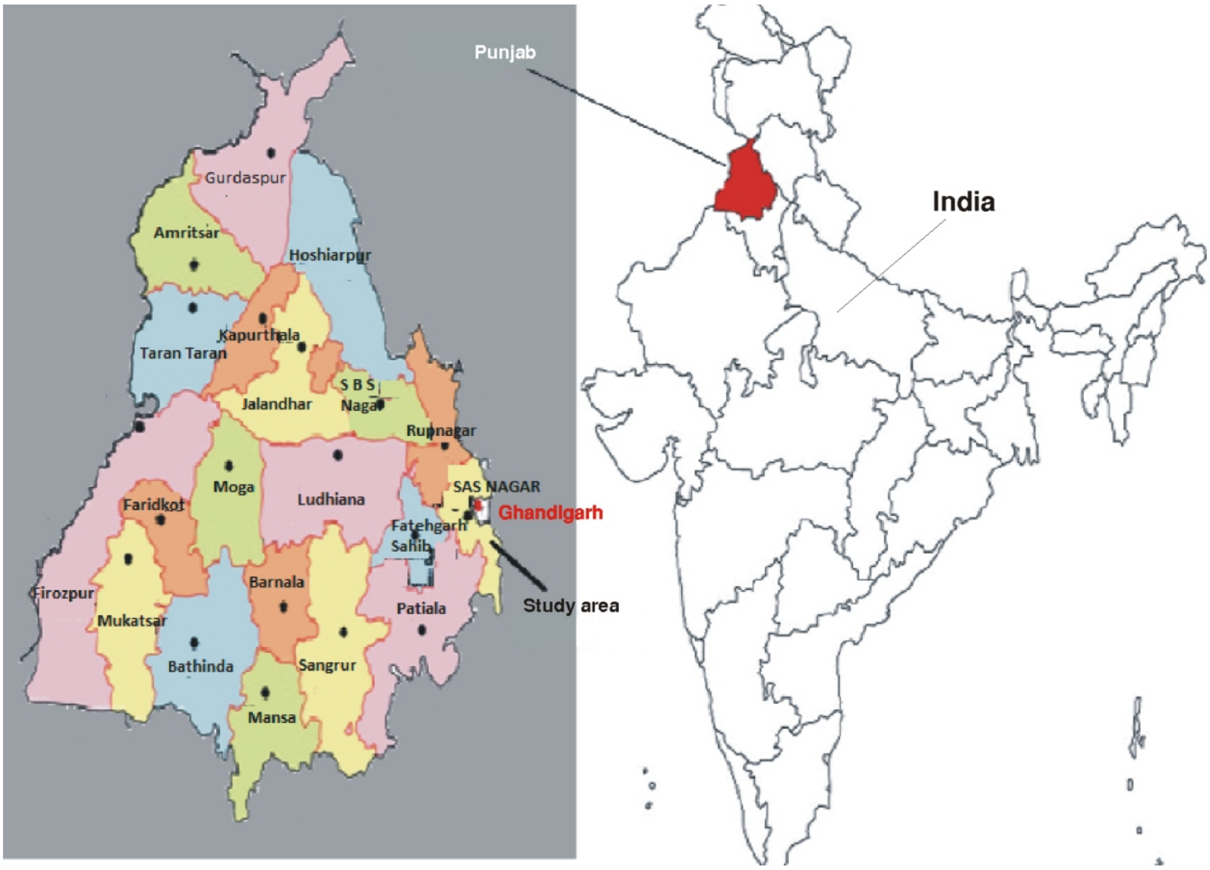

Figure 1. Location of the study area

MATERIALS AND METHODS

Several methods are in use for measuring radon and its daughter elements in buildings but, in this study, the measurement of radon, thoron and their progeny levels was done using single entry pinhole-based twin cup radon dosimeters *i. e*., passive radon, thoron meters (PRTM). The details of a twin pinhole radon-thoron dosimeter and its calibration are described elsewhere [16]. Pinhole radon-thoron dosimeters (PRTM) consist of two compartments, each cylindrical in shape, with a length of 4.1 cm and radius of 3.1 cm, internally coated with metallic powders so as to result in a zero electric field inside the compartment volume in order to ensure the deposition of progenies formed from the gases in an uniform manner throughout the volume. The two compartments are separated by a central pinhole disc, acting as a ^{220}Rn discriminator. The disc has four pinholes, each 2 mm in length and of a 1 mm diameter. There is a single entry for the gas in the dosimeter cups. The gas enters into the first, namely "radon and thoron" compartment, through a glass fiber filter paper (pore size 0.7 m) and diffuses to the second one, namely "radon" compartment, through pinholes cutting off the entry of ^{220}Rn into it. The schematic of the pinhole dosimeter is shown in fig. 2. Solid-state nuclear track detector (SSNTD), particularly CR-39 and LR-115, are used to measure ^{222}Rn and its progeny [11, 17, 18]. However, we have used LR-115 type II, a strippable plastic track detector film (2 cm 2 cm), as we have studied its etching characteristics in detail [19]. Pristine LR-115 (cellulose nitrate, type-II, strippable, procured from DOSIRAD, France) is an alpha sensitive plastic track detector. It is a 12 m thick film, red-dyed cellulose nitrate emulsion coated with an inert polyester base 100 m thick. The films were fixed at opposite ends of the entry face in each compartment. The detector of the "radon and thoron" compartment measures the tracks produced by the alphas emitted from both radon and thoron, while the detector of the second one measures the tracks due to radon only.

The single entry of air in a pinhole-based radon-thoron dosimeter has advantages over the conventional double entrance twin cup dosimeter [16]. There is a common entrance for radon so that the concentration of the gas is always the same in both chambers. Since the entrance port is at the bottom, when installed, the effect of turbulence from horizontal wind velocity is minimal. The metallic coating on the inner side of the cup provides a net zero electric field which gives a uniform deposition of radon and thoron progeny inside the cup.

Inside the room, the dosimeters were suspended at a height of more than two meters above ground level and approximately a meter from the ceiling. The distance of the dosimeters from the walls was kept at two meters. In still air, the diffusion length of thoron is 2-3 cm, so the contribution of thoron to track formation on the dosimeter is negligible; but, in the presence of convective thoron transport due to natural intermixing of air, the thoron emitted from the walls is distributed throughout the room. The monitored dwellings were all built from similar materials, with cemented walls and floorings, located at different areas within the Mohali district for the purpose of uniform distribution.

The annual effective dose received by the inhabitants was looked into in the light of guidelines given by the International Commission on Radiological Protection, 2009 [20].

The detectors were left exposed for a period of three months. At the end of exposure time, the detectors were removed and subjected to chemical etching in a 2.5 N NaOH solution, at 60 °C for 90 minutes and, upon this, to alpha track counting using a spark counter (Polltech Inst., Mumbai), the details of which have been provided earlier in [11].

The counted track density is converted into radon-thoron concentration according to following relations

$$C_{\mathrm{T}} \quad \frac{T_2 \quad dC_{\mathrm{R}} K_{\mathrm{R}}}{dK_{\mathrm{T}}} \tag{1}$$

$$C_{\mathrm{R}} \quad \frac{T_1}{dK_{\mathrm{R}}} \tag{2}$$

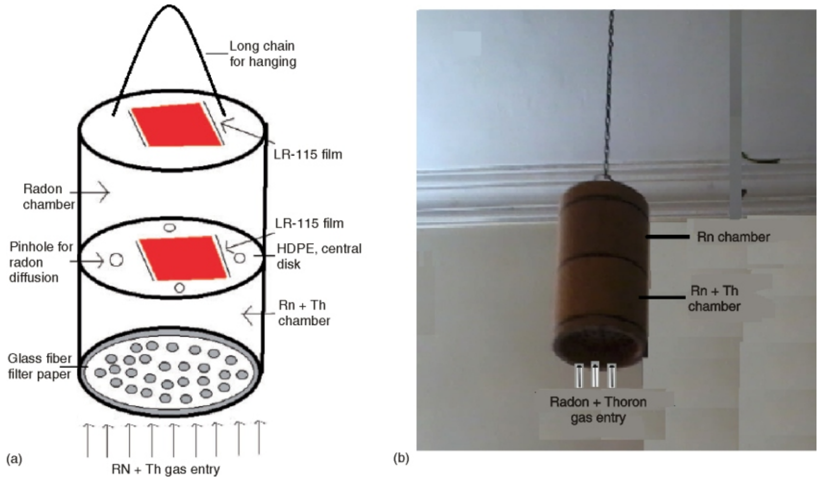

Figure 2. Schematic diagram (a), actual single entry radon-thoron dosimeter cup (b)

where C_R and C_T are the radon and thoron concentration, while T_1 is the track density observed in the "radon" compartment. K_R – the calibration factor of radon in the "radon" compartment (0.0170   0.002 tr. cm^{-2} per $Bqdm^{-3}$), d – the number of exposure days. T_2 – the track density observed in the "radon and thoron" compartment, K_R (0.0172   0.002 tr. cm^{-2} per $Bqdm^{-3}$) and K_T (0.010 ± 0.001 tracks per cm^2 per $Bqdm^{-3}$) calibration factors of radon and thoron in the "radon and thoron" compartment [16]. The inhalation dose due to radon and thoron was calculated by the conversion coefficient of 9 and 40 $nSvh^{-1}$ per Bqm^{-3} with equilibrium factors F_R = 0.4 and F_T = 0.1 for radon and thoron, respectively [21, 22]. The dose coefficients for radon and thoron are calculated using the conversion coefficient 0.17 nSv for radon and that of 0.11 nSv for thoron. Finally, an estimation of the annual inhalation dose in mSv may be provided [23-25]

$$D \quad [(0.17 \quad 9F_R)C_R + (0.11 + 40F_T)C_T] \; 7000 \; 10^{\;6} \tag{3}$$

Measurement of radon exhalation rates from soil samples using an active technique

Measurements of the radon exhalation rate were carried out by an active measurement technique for detecting radon growth in a sealed accumulator [26]. The samples were dried and sealed in a leakproof exhalation chamber. The growth of radon in the accumulator was measured by the scintillation radon monitor (SRM) connected to the chamber. The measurement of radon growth was continued to the saturation point of radon concentration. Growth data was then fitted to eq. (4) for estimating the radon mass exhalation rate (J_m)

$$C \quad \frac{J_m M}{V\lambda_e}(1 \quad e^{\;\lambda_e t}) \quad C_0 e^{\;\lambda_e t} \tag{4}$$

where J_m represents radon mass exhalation rates in $Bqkg^{-1}h^{-1}$, M and V represent the mass of the soil sample and effective volume of the chamber, including the volume of the scintillation cell. λ_e represents the effective decay constant which is the sum of the radon decay constant, radon back diffusion constant, and chamber leakage rates if any and C_0 is the initial radon concentration in the chamber.

In situ measurement of gamma dose

Beta-gamma radiation survey meter (RM707), manufactured by Nucleonix Systems, Hyderabad, was used for the *in situ* measurement of the gamma dose in the dwellings of the study area. This instrument is a lightweight, battery operated portable radiation survey meter. It has a miniature halogen quenched GM detector with an energy compensation filter.

RESULTS AND DISCUSSION

The measurement of indoor radon and thoron concentrations in some dwellings of Mohali were carried out using pinhole dosimeters. The results for the summer season are listed in tab. 1.

Table 1 shows the indoor levels of radon, thoron and their progeny and the value of the *in-situ* gamma dose rate received by the inhabitants over the summer season. These values are calculated using eqs. (1) and (2). It also has the value of the annual effective dose received by the inhabitants, calculated using eq. (3).

The indoor radon concentration in Mohali varied from 15.03   0.61 Bqm^{-3} to 39.21   1.46 Bqm^{-3}, with an average of 26.95 Bqm^{-3}, while the concentration of thoron

Table 1. Radon, thoron and their progeny levels in some dwellings of Mohali over summer season, using PRTM

Location	Ventilation condition	*In situ* gamma dose rate [Svh^{-1}]	Radon concentration C_R [Bqm^{-3}]	Thoron concentration C_T [Bqm^{-3}]	Progeny levels of radon C_R [mWL]	Progeny levels of thoron C_T [mWL]	Annual dose [mSv]
D-1	Good	0.18	15.03 0.61	20.81 1.10	1.63	0.56	1.00
D-2	Average	0.17	28.76 1.01	31.65 1.52	3.11	0.86	1.67
D-3	Poor	0.32	24.84 0.82	52.84 2.77	2.69	1.43	2.18
D-4	Average	0.19	23.53 0.72	31.75 1.58	2.54	0.86	1.53
D-5	Poor	0.28	31.37 1.21	48.26 2.54	3.39	1.31	2.21
D-6	Average	0.20	35.95 1.37	31.50 1.55	3.89	0.85	1.86
D-7	Good	0.12	18.31 0.61	17.41 0.91	1.98	0.47	0.98
D-8	Poor	0.30	33.34 1.28	51.56 2.57	3.61	1.39	2.36
D-9	Average	0.18	35.95 1.37	17.06 0.90	3.88	0.46	1.44
D-10	Average	0.23	24.18 0.85	29.52 1.32	2.61	0.81	1.49
D-11	Poor	0.26	39.21 1.46	38.11 1.79	4.24	1.03	2.13
D-12	Good	0.16	18.95 0.65	9.62 0.54	2.05	0.26	0.78
D-13	Good	0.19	20.92 0.71	24.03 1.23	2.26	0.65	1.24

in the same dwellings varied from 9.62 0.54 Bqm^{-3} to 52.84 2.77 Bqm^{-3} with an average of 31.09 Bqm^{-3}.

Radon progeny levels in dwellings under study varied from 1.63 to 4.24 mWL* with an average of 2.94 mWL, while thoron progeny levels varied from 0.26 to 1.43 mWL with an average of 0.84 mWL. The annual dose received by the inhabitants of the dwellings under study varied from 0.78 to 2.36 mSv, with an average of 1.61 mSv.

The measurement of radon exhalation rates of some soil samples collected from the Mohali was also carried out using the active technique and the results of these measurements are listed in tab. 2. Radon exhalation rates from the soil samples varied from 2.17 to 4.76 mBqkg^{-1}h^{-1}, with an average of 3.43 0.54 mBqkg^{-1}h^{-1}. Radon exhalation rates of Mohali soil measured by the active technique were found to be lower than the worldwide average.

The value of the *in situ* gamma dose rate was found to vary from 0.12 to 0.32 μSvh^{-1}, with an average of 0.21 μSvh^{-1}. The values of indoor radon levels found were below the lower limits of the reference level recommended by the ICRP, 2009 [20].

Figure 3 shows the amount of the annual dose received by occupants according to the ventilation conditions of the dwellings. It clearly shows that the dose received by the inhabitants of the poorly ventilated homes is higher in comparison to that of the average and well ventilated residences. This demonstrates that, by improving ventilation, the risk from radon can be reduced. High values of indoor radon in dwellings with poor ventilation were also reported recently [11].

Table 2. Radon exhalation rates from Mohali soil samples using a scintillation radon monitor

No.	Location	Mass exhalation rate [mBqkg^{-1}h^{-1}]
1	S-1	3.69
2	S-2	3.12
3	S-3	4.76
4	S-4	2.17

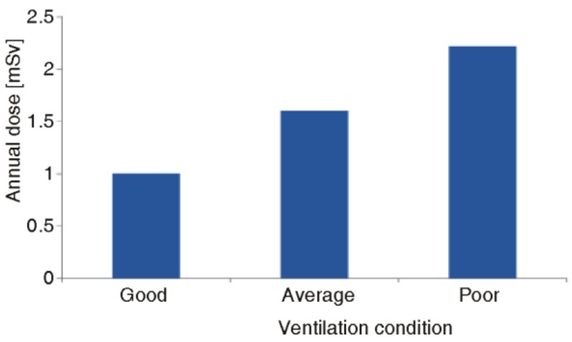

Figure 3. Dependence of annual dose received by inhabitants on ventilation conditions

Table 3. Comparison of indoor radon levels, Mohali, Punjab, along with different parts of Northern India and some other countries

No.	Region	Annual average indoor radon value [Bqm^{-3}]	Reference
1	Chandigarh (India)	23.3	[27]
2	Sirsa (India)	13.8	[28]
3	Kurukshetra (India)	40.33	[29]
4	Yamunanagar (India)	118.03	[29]
5	Panchkula (India)	51.8	[29]
6	Bathinda (India)	153.6	[12]
7	Ambala (India)	13.0	[11]
8	Mansa (India)	106.6	[30]
9	Ludhiana (India)	90.6	[30]
10	Moga (India)	82.0	[30]
11	Rupnagar (India)	14.6	[31]
12	Yemen	42	[32]
13	Egypt	65.97	[33]
14	Romania	112, 105	[34, 10]
15	Belgium	48	[35]
16	Spain	86	[24]
17	Saudi Arabia	18.4	[36]
18	Austria	97	[37]
19	Italy	70	[38]
20	Mohali (India)	26.95	Present study

Table 3 shows the values of radon concentration from different parts of Northern India.

CONCLUSIONS

Using newly developed single entry radon-thoron dosimeters, in the study presented here we have measured the indoor values of radon, thoron and their progeny levels in some dwellings of the Mohali district in Northern India for which no data previously existed in literature. The annual effective dose for the occupants of these dwellings was calculated, as well. Radon exhalation rates from some soil samples of the study area were measured using a scintillation radon monitor. The *in situ* measurement of the gamma dose was carried out via a beta-gamma radiation survey meter. The conclusions of our study are:

- The overall average value of radon is found to be 26.9 Bqm^{-3}, lower than the global average value of 40 Bqm^{-3} [39] for indoor radon levels. The recorded indoor radon values are below the reference level recommended by ICRP. It is also clear from tab. 3 that radon levels in the dwellings of the Mohali district are close to indoor radon levels of nearby areas in Northern India, as measured by other researchers.
- The maximum value of the radon progeny level is found to be 4.24 mWL, below the action limit of 21.50 mWL for Indian dwellings [40, 41].
- The values of the annual effective dose in dwellings under study are found to be lower than the

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* WL stands for working level – the radiation level releasing 130 000 MeV energy per 1 liter of air in 1 hour. In SI units, 1 WL = 20.8

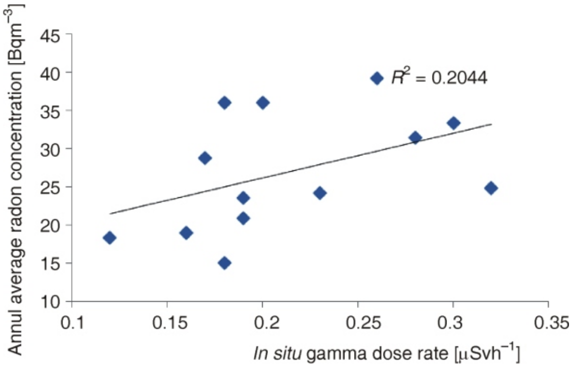

Figure 4. Average radon concentration *vs.* *in situ* gamma dose rate of the dwellings in Mohali

worldwide average radiation dose of 2.4 mSv per year. The effective annual dose received by the residents in the study area is below 3-10 mSv, as recommended by ICRP.

– Radon concentration values are found to be higher in dwellings with poor ventilation.
– The measurement of radon exhalation rates of some soil samples collected from the Mohali was also carried out by the active technique using a scintillation radon monitor.
– Our study shows radon exhalation rates values to be lower than the worldwide average of 57 mBqKg^{-1}h^{-1} [37].
– A weak positive correlation ($R^2 = 0.2$) was found between the average indoor radon and the gamma ray dose rate of these dwellings, as shown in fig. 4.

AUTHORS' CONTRIBUTIONS

The idea for this study was put forward by R. P. Chauhan and G. S. Mudahar. V. Mehta and D. Shikha carried out the laboratory processing of detectors and samples. S. P. Singh helped in the writing of this paper. All authors contributed to the analysis and interpretation of data and the preparation of the manuscript.

REFERENCES

[1] El-Taher, A., Makhul, S., Natural Radioactivity Levels in Phosphate Fertilizer and Its Environmental Implications in Assuit Governorate, Upper Egypt, *Indian J. Pure and Appl. Phys., 48* (2010), 10, pp. 697-702

[2] Simion, F., *et al*., Modeling the ^{222}Rn and ^{220}Rn Progeny Concentrations in Atmosphere Using Multiple Linear Regression with Meteorological Variables as Predictors, *Rom. Rep. Phys., 65* (2013), 2, pp. 524-544

[3] Milic, G., *et al*., Indoor Radon Mapping: A Survey of Residential Houses of Kosovo and Metohija, *Rom. Journ. Phys., 58* (2013), Suppl., pp. S180-S188

[4] ***., Building a New Home, Have you Considered Radon?, United State Environmental Protection Agency, https://www.epa.gov/radon/building-new-home-have-you-considered-radon#entry (accessed 25 August 2016)

[5] Armencea (Mutoiu), E. S., *et al*., Indoor Radon Measurements in Bacau County, *Rom. Journ. Phys., 58* (2013), Suppl., pp. S189-S195

[6] Thomas, D. C., *et al*., Estimates of Lifetime Lung Cancer Risks Resulting from Rn Progeny Exposure, *Health Physics, 45* (1985), 5, pp. 825-846

[7] ***, ICRP Protection Against ^{222}Rn at Home and at Work, International Commission on Radiological Protection Publication 65, Ann. ICRP 23 (2), Pergamon Press, Oxford, UK, 1993

[8] Anssi, A., *et al*., Indoor Radon Exposure and Risk of Lung Cancer: A Nested Case-Control Study in Finland, *JNCI J Natl. Cancer Inst., 88* (1996), 14, pp. 966-972

[9] Doi, M., *et al*., A Passive Measurement Technique for Characterization of High-Risk Houses in Japan Due to Enhanced Levels of Indoor Radon and Thoron Concentrations, *Radiat. Prot. Dosim., 45* (1992), 1-4, pp. 425-430

[10] Muntean, L. E., *et al*., Assessment of Annual and Seasonal Variation of Indoor Radon Levels in Dwelling Houses from Alba County, Romania, *Rom. Journ. Phys., 59* (2014), 1-2, pp. 163-171

[11] Mehta, V., *et al*., Measurement of Indoor Radon, Thoron and Their Progeny Levels in Dwellings of Ambala District, Haryana, Northern India, Using Solid State Nuclear Track Detectors, *Rom. Journ. Phys., 59* (2014), 7-8, pp. 834-845

[12] Singh, S., *et al*., The Study of Indoor Radon in Dwellings of Bathinda District, Punjab, India and its Correlation with Uranium and Radon Exhalation Rate in Soil, *Radiat. Meas., 39* (2005), 5, pp. 535-542

[13] Verma, D., Khan, M. S., Assessement of Indoor Radon, Thoron and Their Progeny in Dwellings of Bareilly City of Northern India Using Track Etch Detectors, *Rom. Journ. Phys., 59* (2014), 1-2, pp. 172-182

[14] Mehta, V., *et al*., Environmental Radon: Health Aspects and Present Status in Northern India, *Indoor Built Environ., 24* (2015), 1, pp. 52-62

[15] Rani, V. R., Ground Water Information Booklet S. A. S. Nagar District Punjab, Central Ground Water Board, Ministry of Water Resources, Government of India, Publication, 2007, pp. 1-26

[16] Sahoo, B. K., *et al*., A New Pin-Hole Discriminated ^{222}Rn/^{220}Rn Passive Measurement Device with Single Entry Face, *Radiat. Meas., 58* (2013), Nov., pp. 52-60

[17] Ghita, I. A., Vasilescu, A., Radon Assessment with Solid-State Nuclear Track Detectors in Bucharest and Its Surrounding Region, *Rom. Rep. Phys., 63* (2011), 4, pp. 940-947

[18] Robu, E., *et al*., Influence of Exposure Geometry on the Response of CR-39 SSNTD Radon Detectors, *Rom. Rep. Phys., 63* (2011), 2, pp. 376-382

[19] Mehta, V., *et al*., Surface Chemical Etching Behavior of LR-115 Type II Solid State Nuclear Track Detector, *Rom. Rep. Phys., 67* (2015), 3, pp. 865-871

[20] ***, International Commission on Radiological Protection (2009), Statement on Radon, ICRP Ref 00/902/09, Available on: www.icrp.org/consultation_page.asp.

[21] Chen J., *et al*., An Update on Thoron Exposure in Canada with Simultaneous ^{222}Rn and ^{220}Rn Measurements in Fredericton and Halifax, *Radiat. Prot. Dosim., 147* (2011), 4, pp. 541-547

[22] ***, Sources and Effects of Ionizing Radiation. UNSCEAR Report to the General Assembly with Scientific Annexes, United Nations, 2006

[23] ***, Sources and Effects of Ionizing Radiation, UNSCEAR, United Nation Scientific Committee on the Effects of Atomic Radiation, United Nations: New York, 1993

[24] Mayya, Y. S., *et al*., Methodology for Mixed Field Inhalation Dosimetry in Monazite Areas Using a Twin-Cup Dosimeter with Three Track Detectors, *Radiat. Prot. Dosim., 77* (1998), 3, pp. 177-184

[25] Sannappa, J., *et al*., Study of Background Radiation Dose in Mysore City, Karnataka State, India, *Radiat. Meas., 37* (2003), Feb., pp. 55-65

[26] Petropoulos, N. P., *et al*., Building Materials Radon Exhalation Rate: ERRICCA Intercomparison Exercise Results, *Sci. Total Environ., 272* (2001), 1, pp. 109-118

[27] Mehta, V., *et al*., Measurement of Indoor Radon, Thoron and Their Progeny Levels in Dwellings of Union Territory Chandigarh, India: Correlation with Radon Exhalation Rates, *Indoor Built Environ., 24* (2015), 6, pp. 833-842

[28] Mann, N., *et al*., Radon-Thoron Measurements in Air and Soil from Some Districts of Northern Part of India, *Nucl Technol Radiat, 30* (2015), 4, pp. 294-300

[29] Kant, K., Chakarvarti, S. K., Radiological Impact of Airborne Radon and Its Progeny in Dwellings, *Indian J. Pure Appl. Phys., 42* (2004), 1, pp. 157-161

[30] Mehra, R., *et al*., A Study of Uranium, Radium, Radon Exhalation Rate and Indoor Radon in the Environs of Some Areas of the Malwa Region, Punjab, *Indoor Built Environ., 15* (2006), 5, pp. 499-505

[31] Mehta, V., *et al*., Monitoring of Radon, Thoron, Their Progeny Concentration in Dwellings and Radon Exhalation Rates of Soil/Sand of Rupnagar District, Punjab, India, *Environ. Earth Sci., 74* (2015), 5, pp. 4145-4155

[32] Khayrat, A. H., *et al*., Indoor Radon Survey in Dwellings of Some Regions in Yemen, *Radiat. Meas., 36* (2003), 1-6, pp. 449-451

[33] Abdel Ghany, H. A., Variability of Radon Levels in Different Rooms of Egyptian Dwellings, *Indoor Built Environ., 15* (2006), 2, pp. 193-196

[34] Szacsvai K., *et al*., Indoor Radon Exposure in Cluj-Napoca City Romania, *Rom. J. Phys., 58* (2013), Suppl., pp. S273-S279

[35] Zhu, H. C., *et al*., Radon Risk Mapping in Southern Belgium, *Sci. Total Environ., 272* (2001), 1-3, pp. 203-210

[36] Al-Saleh, F. S., Measurements of Indoor Gamma Radiation and Radon Concentrations in Dwellings of Riyadh City, Saudi Arabia, *App. Rad. Isotop., 65* (2007), 7, pp. 843-848

[37] Friedmann, H., *et al*., The Austrian Radon Project, *Sci. Total Environ, 272* (2001), 1-3, pp. 211-212

[38] Bochicchio, F., *et al*., Results of the Representative Italian National Survey on Radon Indoors, *Health Physics, 71* (1996), 5, pp. 743-750

[39] ***, Effects and Risks of Ionizing Radiation. UNSCEAR United Nation Scientific Committee on the Effects of Atomic Radiation, United Nations: New York, 2000

[40] Ramachandran, T. V., Indoor Radon Levels in India: Current Status of the Coordinated Nationwide Study Using Passive Detector Technique, *Proceedings*, 11th National Symposium on SSNTD Amritsar, 50, 1998

[41] Ramachandran, T. V., *et al*., Measurement of Radon Permeability through Some Membranes, *Nucl. Tracks Radiat. Meas., 13* (1987), 1, pp. 81-84

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МЕРЕЊА РАДОНА, ТОРОНА И ЊИХОВИХ ПОТОМАКА У ЗАТВОРЕНИМ СРЕДИНАМА УПОТРЕБОМ ПИНХОЛ ДОЗИМЕТАРА У МОХАЛИ, ПАНЏАБ, СЕВЕРНА ИНДИЈА

Здравствени ризик од радона и његових потомака изнад одређених нивоа добро је познат, међутим, да би се превентивне мере спровеле потребно је одредити нивое радона у датој области. Мерење радона и производа његовог распада у затвореним срединама значајно је ради оцене квалитета ваздуха и здравствених услова повезаних са тим. Мерење концентрације радона, торона и њихових потомака из узорака земљишта у области Мохали, Северна Индија, спроведено је активном методом континуалног мониторинга радона. Концентрације радона у затвореним срединама у Мохали су у интервалу од 15.03 0.61 Bq/m^3 до 39.21 1.46 Bq/m^3, са средњом вредношћу од 26.95 Bq/m^3, док је концентрација торона у истим објектима била у опсегу од 9.62 0.54 Bq/m^3 до 52.84 2.77 Bq/m^3, са средњом вредношћу од 31.09 Bq/m^3. Нивои потомака радона у објектима варирали су од 1.63 mWL до 4.24 mWL, са средњом вредношћу од 2.94 mWL, а нивои потомака торона износили су од 0.26 mWL до 1.43 mWL, са средњом вредношћу од 0.84 mWL. Годишња ефективна доза коју прими становништво у објектима укљученим у истраживање износи од 0.78 mSv до 2.36 mSv, са средњом вредношћу од 1.61 mSv. *In situ* вредност јачине дозе гама зрачења варира од 0.12 μSv/h до 0.32 μSv/h.

Кључне речи: радон, торон, потомак, нуклеарни траг детектор, насељени објект, годишња ефективна доза, вентилација