RADON-THORON MEASUREMENTS IN AIR AND SOIL FROM SOME DISTRICTS OF NORTHERN PART OF INDIA

by

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Scientific paper
DOI: 10.2298/NTRP1504294M

Radon, thoron and their progenies in the indoor environment are considered as one of the health hazards. The alpha emitting nature of these gases made it possible to detect in indoor environment with the help of nuclear track detector techniques. The soil is the main source of indoor radon as it contains varying amounts of uranium and thorium. Thus the exhalation of radon from soil and its environmental activity needs to be studied. In the present study, the measurement of the indoor radon-thoron from the indoor environment and exhalation from soil are carried out using solid state nuclear track detector technique from Sirsa and Bhiwani districts of northern part of India. The canister technique was used to measure the radon exhalation rate from the soil samples collected from the study area and pinhole based radon-thoron dosimeters were used to measure indoor radon and thoron concentration. The results show that indoor radon concentration varied from 9 to 28 Bq/m^3, with an average of 18.9 Bq/m^3 and from 5 to 21 Bq/m^3, with an average of 13.8 Bq/m^3, for Bhiwani and Sirsa, respectively. Similarly, thoron concentration varied from 14 to 48 Bq/m^3, with average of 28.9 Bq/m^3 and 27 to 54 Bq/m^3, with the average of 39.0 Bq/m^3, for Bhiwani and Sirsa, respectively. The mass exhalation rates from soil samples were also measured, to estimate their contribution to indoor radon. A correlation study was carried out between soil exhalation rates and indoor radon concentration.

Key words: radon, thoron, exhalation rate, pinhole dosimeter, soil

INTRODUCTION

Radon and thoron emitted from the uranium and thorium radioactive series are one of the important contributors to radiation dose received by the general public. Radon is the immediate successor of the Ra-226 in the decay series of uranium, having half-life 3.824 days. The inhalation of radon, thoron, and their progenies are among the major causes of lung cancer [1-3]. Hence, the studies involving the measurements of concentrations of radon, thoron and their progenies are very important. Rocks, soils, water, air, building materials, *etc*., are a few sources of radiation exposure [4]. The International Commission on Radiological Protection has recommended a reference level from 200 to 300 Bq/m^3 for residential radon [5]. The indoor radon-thoron concentration shows variations with change in topography, type of construction, soil, and weather conditions [6, 7]. The soil contains varying amount of uranium and radium, which emit radon and thoron. When radium decays into radon by emission of an alpha particle, then, radon is recoiled outside the grain of materials into pore matrix which is called emanation. The transport of radon from pore, by advection and diffusion, out to the environment, is called exhalation. Due to short half-life of thoron, the measurement of thoron exhalation rate is not possible using passive canister technique. The measurement of radon exhalation rate is important for studying the potential of soil contribution to indoor radon concentration, while measurement of indoor radon is important for calculation of radiation dose. A very few investigators have studied the radon exhalation from soil and indoor radon concentrations, thoron levels in dwellings of Western Haryana, using bare mode solid state nuclear track detector (SSNTD) or twin cup dosimeter. Both of these techniques suffer the limitation of thoron interface and wind turbulence, which may sometimes cause negative thoron concentration, as discussed by Sahoo *et al*. [8]. The newly designed single entry pinhole dosimeter is one of the more accurate techniques, that overcomes the limitations of previous dosimeters and which is used in the present study. In the present study, an attempt has been made to correlate the radon exhalation rates from some soil samples and indoor radon-thoron concentrations from the study area, shown in fig. 1.

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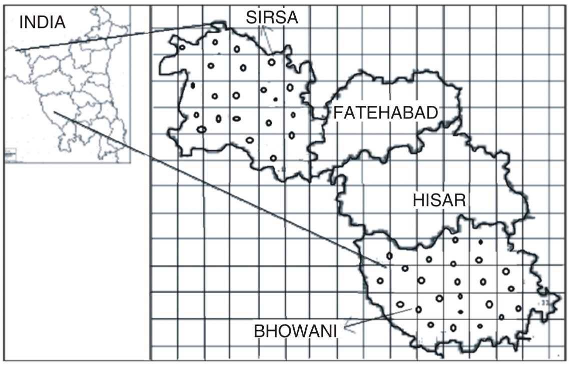

Figure 1. Location map of study area

GEOLOGY OF THE AREA

The area under the study extends from 28º19' to 29º5' N latitude and 75º26' to 76º28' E longitude (Bhiwani district) and 29º14' to 30º N latitude and 74º29' to 75º18' E longitude (Sirsa district), shown in fig. 1. It is located in the ecological zone of western plain hot arid ecosystem. The soil of the study area is sandy loam. The Tosham region in Bhiwani is reported to be rich in acid volcanic and granite solids. Its lithographic structure has attracted researchers to this area. Sirsa, on the other hand, forms the extreme west corner of Haryana with Faridkot and Bathinda (Punjab) in the north, Ganganagar (Rajasthan) to its west and south and Hisar in the east. The terrain of Sirsa is mainly divided into Haryana plain, alluvial plain of Ghaggar and sand dune tracks.

MATERIALS AND METHODS

Measurement of indoor radon and thoron concentrations in dwellings

For the measurement of indoor radon-thoron levels, single entry based pinhole radon-thoron dosimeters were used (fig. 2). The details of the dosimeter used in study are given elsewhere [8]. The LR-115 detectors, with size of 1 cm^2, were deposited into two chambers on the opposite face of air entry. The dosimeters are deployed at 20 locations in the study area, for 100 days in summer, from April to June 2014. The dwellings with cemented floor and walls and non air-conditioned type, were selected. The dosimeters were deployed nearly 1 m away from ventilators, windows, fans, *etc*., and at average human height, to reduce any kind of wind turbulence and air thrust on a dosimeter. After exposure period, the LR-115 detectors were removed from the dosimeter and films were then etched with 2.5 N NaOH solution, for 90 min. The detector tracks, developed in this way, were then counted by an optical microscope of 400 X, which was further used to measure the indoor radon-thoron concentration using the equations

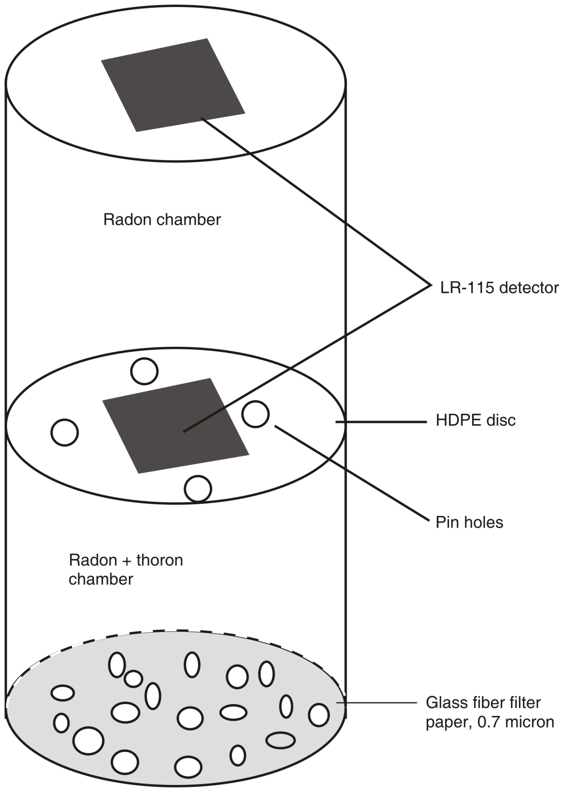

Figure 2. Pinhole based radon-thoron dosimeter used for the study

$$C_T \quad \frac{T_2 \quad dC_R K_R}{dK_T} \qquad (1)$$

$$C_R \quad \frac{T_1}{dK_R} \qquad (2)$$

where C_R and C_T are radon and thoron concentrations, T_1 is the track density observed in "radon" chamber. K_R is the calibration factor of radon in "radon" chamber (0.0170 0.002 tracks per cm^2 per $Bqdm^{-3}$), and d – the number of days of exposure. T_2 is the track density observed in the "radon + thoron" chamber. K'_R (0.0172 0.002 tracks per cm^2 per Bqd m^{-3}), and K_T (0.010 0.001 tracks per cm^2 per Bqd m^{-3}) are the calibration factors of radon and thoron in "radon + thoron" chamber [8].

Measurement of radon exhalation rates from soil samples

The well-known "Canister technique" was used to measure the soil and mass exhalation rates [9]. Passive canister technique, used during the study, is a plastic canister, having thickness more than 3-4 mm, whose radon diffusion coefficient is of the order of 10^{-14}-10^{-15} m^2/s. Thus, the leakage through the wall is negligible. The lid of the canister is tightened and covered with a plastic tape, to avoid any leakage. Secondly, the volume occupied by the samples in the can-

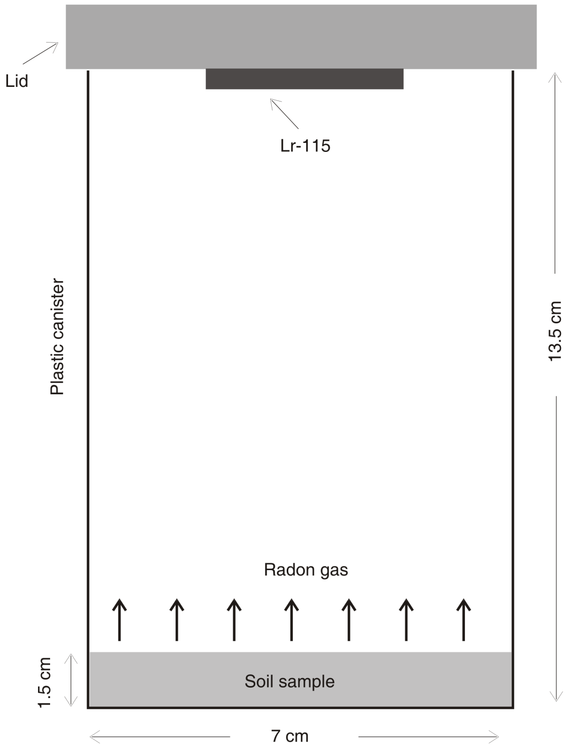

Figure 3. Canister used during the study

ister is approximately 10 % of the total volume and with this, the back diffusion, if any, can be neglected. For this purpose, 200 g of the soil samples was sealed in airtight PVC containers for 100 days with LR-115 detectors, 1 cm^2 in size, fixed on the inner side of the lid, with its curved surface facing the soil sample (fig. 3). The detectors were then etched with standard procedure and alpha track counted with optical microscope. Then, the track density was converted into exhalation rates, using relations

$$E_M = \frac{CV\lambda}{M\left[T + \frac{1}{\lambda}(e^{-\lambda T} - 1)\right]} \qquad (3)$$

$$E_A = \frac{CV\lambda}{A\left[T + \frac{1}{\lambda}(e^{-\lambda T} - 1)\right]} \qquad (4)$$

where E_M and E_A are the mass and surface exhalation rates, C [Bqm^{-3}h^{-1}] – the integrated radon exposure, M [kg] – the mass of a sample, V [m^3]– the volume of air in the canister, T [h] – the exposure time , λ [h^{-1}] – the decay constant for radon, and A [m^2] – the area covered by the canister, or surface area of the sample.

RESULTS AND DISCUSSIONS

Indoor radon and thoron concentrations from the dwellings

Indoor radon and thoron concentrations, measured by pinhole dosimeters, from two districts Bhiwani and Sirsa are listed in tab. 1.

The indoor radon concentration varied from 9 Bq/m^3 (Siwani) to 28 Bq/m^3 (Tosham), with an average of 18.4 Bq/m^3 and from 5 Bq/m^3 (Kalanwali) to 21 Bq/m^3 (Ellanabad), with an average of 13.8 Bq/m^3, for Bhiwani and Sirsa, respectively, while thoron con-

Table 1. Indoor radon and thoron concentrations from the dwellings

Location	Location ID	Latitude and longitude	Radon concentration [Bqm^{-3}]	Thoron concentration [Bqm^{-3}]
Kairu	BD-1	28.69N, 75.87E	12	27
Bhiwani	BD-2	28.79N, 76.13E	18	19
Charkhi Dadri	BD-3	28.59N, 76.26E	21	27
Jui Kalan	BD-4	28.63N, 75.93E	24	25
Siwani	BD-5	28.97N, 75.60E	9	32
Loharu	BD-6	28.42N, 75.80E	21	14
Mundhal	BD-7	29.01N, 76.17E	12	33
Badra	BD-8	28.50N, 75.93E	18	48
Tosham	BD-9	28.86N, 75.91E	28	19
Digawa	BD-10	28.58N, 75.82E	21	43
Sikanderpur	SD-1	29.52N, 75.11E	9	36
Sirsa	SD-2	29.53N, 75.03E	12	32
Sahuwala	SD-3	29.66N, 74.96E	18	32
Odhan	SD-4	29.77N, 74.90E	15	43
Dabbwali	SD-5	29.95N, 74.69E	12	27
Kalanwali	SD-6	29.83N, 74.97E	5	48
Jeevannagar	SD-7	29.53N, 74.73E	9	32
Ellanabad	SD-8	29.44N, 74.66E	21	43
Mallekan	SD-9	29.43N, 74.88E	18	41
Chaupta	SD-10	29.37N, 75.12E	15	54

Abbreviation used: BD and SD stand for Bhiwani and Sirsa districts dwellings, respectively

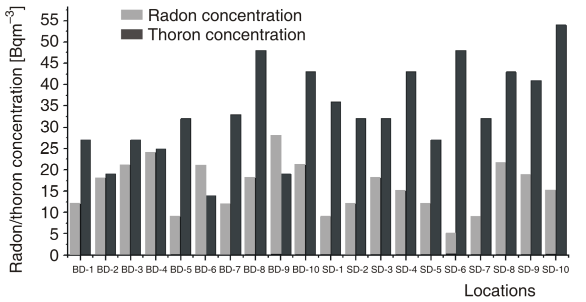

Figure 4. Comparison of indoor radon-thoron concentrations in the dwellings

centration varied from 14 Bq/m^3 (Loharu) to 48 Bq/m^3 (Badra), with an average of 28.9 Bq/m^3 and 27 Bq/m^3 (Dabbwali) to 54 Bq/m^3 (Chaupta), with an average of 39 Bq/m^3, for Bhiwani and Sirsa districts, respectively. All these values of indoor radon and thoron concentrations are much lower than the reference range 200-300 Bq/m^3, given by International Commission on Radiological Protection [5] and 100 Bq/m^3, as recommended by World Health Organization [10]. A comparison of indoor radon and thoron, from the dwellings under study, is shown in fig. 4. From fig. 4, the indoor radon levels for Bhiwani district were found to be more than that of Sirsa, due to its location in high heat producing area, which causes higher emission of indoor radon from soil and rock. The Sirsa and Bhiwani districts are situated near to the Bathinda district, for which higher uranium and radium contents in soil and water was reported by several investigators [11, 12]. The radon and thoron are emitted from the soil and building materials, which contains uranium and thorium. The higher radon and thoron concentration in indoor environment shows the possibility of high radium content in soil and building materials. Higher radon and thoron levels, for area under study and neighbouring area, was reported by many investigators. However, in the present study, the radon and thoron levels are found to be lower than the limit recommended by the ICRP and WHO. This may be due to the fact that the previous studies, by other investigators, for this region, were carried out by bare mode SSNTD and twin cup dosimeters, which suffer some calibration and alignment problems. The advantage of a single entry dosimeter over a twin cup dosimeter and their calibration, is given in details by Sahoo *et al*., [8]. Also, the comparison of a single entry pinhole dosimeter and a twin cup dosimeter, is also well discussed in Sahoo and Sapra [13]. In bare mode SSNTD the thoron and its decay products also interfere the measurement of radon, causing an overestimation, while in twin cup the wind speed and turbulence also cause some uncertainty in the measurement of radon and thoron, as discussed by Sahoo *et al*. [8].

The radon and thoron emitted from soil and building materials are accumulated in indoor environment and act as a radioactive source. The strength of the source can be expressed in terms of radon quantity emitted per unit mass or area, per unit of time, which is known as exhalation rate. The measurement of thoron exhalation rate cannot be determined by passive canister technique due to short half-life, as it does not accumulate and decay within 55 seconds after production. However, the long half-life of radon (3.824 days), allows measurement of its exhalation rate from soil samples using the canister technique. The results from the measurement of radon exhalation rates from 42 samples, collected from the study area, in terms of mass and surface area, are shown in tab. 2.

Table 2 shows that the mass exhalation rates from the soil samples varied from 4.6 mBq/kgh to 46.4 mBq/kgh, with an average of 25.3 mBq/kgh and 11.4 mBq/kgh to 42.7 mBq/kgh, with an average of 27.1 mBq/kgh, for Bhiwani and Sirsa, respectively. The surface exhalation rate varied from 85 mBq/m^{2}h (Sanjarwas) to 853 mBq/m^{2}h (Khanak), with an average of 464.6 mBq/m^{2}h and 210 mBq/m^{2}h (Ellanabad) to 785 mBq/m^{2}h (Mallekan), with an average of 498.9 mBq/m^{2}h, for Bhiwani and Sirsa districts, respectively. The average radon mass exhalation rates from the soil samples were found to be 36.3 8.7 mBq/kgh, which is lower than the worldwide average (56 Bq/kgh), as shown in frequency distribution curve (fig. 5). However, the radon mass exhalation from the study area is found to be higher than that from Northern Haryana, carried out by other investigators [14, 15]. The higher values of radon exhalation rate in Bhiwani and Sirsa may be due to Aravalli-Delhi subgroup, which is rich in radioactivity contents from granite mined in this area [16, 17].

The data given in tabs. 1 and 2 do not show any correlation for radon exhalation rate and indoor concentration. This is because the laboratory processing of the sample is totally different from that practiced *in-situ*. The measurement of mass and surface exhala-

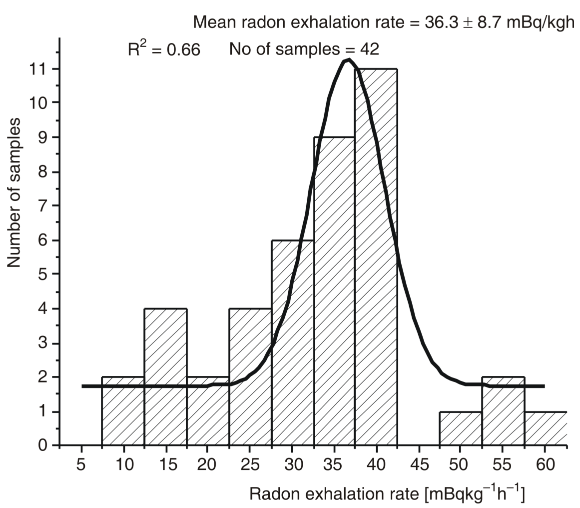

Figure 5. Frequency distribution curve of radon mass exhalation rate

Table 2 Radon mass and surface exhalation rates form the soil samples

Location	Sample ID	Latitude and longitude	Radon mass exhalation [$mBqkg^{-1}h^{-1}$]	Radon surface exhalation [$mBqm^{-2}h^{-1}$]
Siwani	B-1	28.91N, 75.60E	6.8	125
Badwa	B-2	28.97N, 75.60E	29.3	540
Tosham	B-3	28.85N, 75.91E	21.6	398
Khanak	B-4	28.89N, 75.88E	30.9	568
Dullheri	B-5	28.79N, 75.90E	32.4	597
Kairu	B-6	28.68N, 75.88E	17.0	312
Singhani	B-7	28.52N, 75.79E	37.1	682
Dallawas	B-8	28.53N, 75.98E	35.5	654
Pehladgarh	B-9	28.73N, 76.13E	37.1	682
Tigrana	B-10	28.88N, 76.14E	37.1	682
Sanjarwas	B-11	28.72N, 76.31E	5.7	105
Badra	B-12	28.50N, 75.94E	38.6	711
Chakhi Dadri	B-13	28.59N, 76.24E	12.3	227
Digawa	B-14	28.57N, 75.81E	38.6	711
Jui Kalan	B-15	28.63N, 75.93E	12.3	227
Bhiwani	B-16	28.78N, 76.11E	34.9	642
Mandi	B-17	28.54N, 76.02E	16.3	301
Chang	B-18	28.88N,76.24E	38.9	716
Bajina	B-19	28.76N, 75.97E	38.5	709
Dinaud	B-20	28.78N, 76.04E	54.9	1010
Loharu	B-21	28.43N, 75.80E	32.6	600
Mundhal	B-22	29.02N, 76.17E	37.1	682
Sahuwala	S-1	29.66N, 74.96E	34.4	633
Chaupta	S-2	29.36N, 75.12E	10.3	191
Dabbwali	S-3	29.94N, 74.73E	29.6	546
Gauriwala	S-4	29.78N, 74.74E	48.9	901
Kalanwali	S-5	29.83N, 74.96E	32.6	600
Patli Dabar	S-6	29.52N, 75.27E	20.7	382
Pana	S-7	29.91N, 74.81E	25.2	464
Sirsa	S-8	29.58N, 75.02E	40.0	737
Ellanabad	S-9	29.48N, 74.68E	20.7	382
Mahinapur	S-10	29.42N, 74.82E	31.1	573
Jamaal	S-11	29.34N, 75.02E	38.5	709
Gudiyan Khera	S-12	29.39N, 74.99E	34.1	628
Odhan	S-13	29.77N, 74.90E	56.3	1037
Modiyan Khera	S-14	29.43N, 74.96E	54.9	1010
Mallekan	S-15	29.43N, 74.89E	25.2	464
Gajjuwala	S-16	29.72N, 74.73E	34.1	628
Dudiawala	S-17	29.61N, 74.73E	12.7	234
Dhookra	S-18	29.35N, 74.99E	23.7	436
Jeevannagar	S-19	29.53N, 74.73E	29.4	540
Sikanderpur	S-20	29.52N, 75.11E	27.9	515

Abbreviation used: BD and SD stand for Bhiwani and Sirsa districts, raspectively

tion rates was determined after drying the samples in an oven, while in actual dwellings, the moisture present in the sample strongly affects the radon exhalation [18]. In addition, the dwellings under study are concrete houses, other than soil thus, no correlation is expected between the two measured quantities.

CONCLUSIONS\

The measurement of indoor radon and thoron concentrations in the dwellings and radon exhalation rate from the soil samples, collected from the Bhiwani and Sirsa district of Haryana, India, was carried out, to establish a baseline data and a possible correlation between the two. The results show that the indoor radon concentration varied from 9 Bq/m^3 to 28 Bq/m^3, with an average of 18.9 Bq/m^3 and from 5 Bq/m^3 to 21 Bq/m^3, with an average of 13.8 Bq/m^3, for Bhiwani and Sirsa, respectively. Similarly, thoron concentration varied from 14 Bq/m^3 to 48 Bq/m^3, with an average of 28.9 Bq/m^3 and 27 Bq/m^3 to 54 Bq/m^3, with an average of 39 Bq/m^3, for Bhiwani and Sirsa, respectively. The mass exhalation rates from soil samples varied from 4 mBq/kgh to 46 mBq/kgh, with an average of 25.3 mBq/kgh and 11 mBq/kgh to 42 mBq/kgh, with an average of 27.1 mBq/kgh, for Bhiwani and Sirsa, respectively. The average radon mass exhalation rate from the soil samples was found to be 36.3 8.7 mBq/kgh, which is lower than the worldwide average (56 Bq/kgh). From the measurement, it is found that no correlation exists between radon exhalation rate and indoor concentration. This is because the laboratory processing of the sample is totally different from that of *in-situ*. Thus, care should be taken, while extrapolating the radon exhalation rate, for estimation of indoor radon concentration and inhalation dose.

AUTHORS' CONTRIBUTIONS

The idea of this study was put forward by R. P. Chauhan and S. Kumar. N. Mann and A. Kumar carried out deployment and laboratory processing of the detectors and samples. The analysis and interpretation of data and preparation of this manuscript were carried out by all the authors.

REFERENCES

[1] ***, Effects and Risks of Ionizing Radiation, United Nations Scientific Committee on the Effect of Atomic Radiation UNSCEAR Report to the General Assembly, Vol. 1, Annex B, United Nations, 2000
[2] Khan, A. J., A Study of Indoor Radon Levels in Indian Dwellings, Influencing Factors and Lung Cancer Risks, *Radiat Meas., 32* (2000), 2, pp. 87-92
[3] Lubin, J. H., Boice, D., Lung Cancer Risk from Residential Radon: Meta Analysis of Eight Epidemiological Studies, *Journal National Cancer Institute, 89* (1997), 1, pp. 49-57
[4] ***, 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
[5] ***, Lung Cancer Risk from Radon and Progeny and Statement on Radon, International Commission on Radiological Protection ICRP Publication 115, Annals of the ICRP, 40, 1, 2010
[6] Duggal, V., Rani, A., Mehra, R., Measurement of Indoor Radon Concentration and Assessment of Doses in Different Districts of Northern Rajasthan, India, Indoor Built Environ (2013) http://dx.doi.org/101177 //1420326X13500801.
[7] Singh, S., Mehra, R., Singh, K., Seasonal Variation of Indoor Radon Dwellings of Malwa Region, Punjab. *Atm. Environ., 39* (2005), 40, pp. 7761-7767
[8] 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), pp. 52-60
[9] Singh, A. K., *et al*., Calibration of Track Detectors and Measurement of Radon Exhalation Rate from Solid Samples, *Radiation Protection and Environment, 20* (1997), 3, pp. 129-133
[10] ***, WHO Hand Book on Indoor Radon: a Public Health Perspective, 27th edn. World Health Organization, Geneva, 2009
[11] Mehra, R., *et al*., Assessment of Seasonal Indoor Radon Concentration in Dwellings of Western Haryana, *Rad. Meas., 46* (2011), 12, pp. 1803-1806
[12] Mehra, R., Singh, S., Singh, K., A Study of Uranium, Radium, Radon Exhalation Rate in the Environs of Some Areas of the Malwa Region, Punjab, *Indoor Built Environment, 15* (2006), 5, pp. 499-505
[13] Sahoo, B. K., Sapra, B. K., Advances in Measurement of Indoor ^{222}Rn and ^{220}Rn Gas Concentrations using Solid State Nuclear Track Detectors, *Solid State Phenomena, 238* (2015), pp. 116-126
[14] Kumar, A., *et al*., Implications of Variability in Indoor Radon/thoron Levels: a Study of Dwellings in Haryana, India, *Environ Earth Sci., 73* (2014), pp. 4033-4042
[15] Chauhan, R. P., *et al*., Ventilation Effect on Indoor Radon-Thoron Levels in Dwellings and Correlation with Soil Exhalation Rates, 2014, DOI: 10.1177/1420326 X14542887
[16] Singh, P., *et al*., A Study of Indoor Radon, Thoron and their Progeny Measurement in Tosham Region Haryana, India, *Journal of Radiation Research and Applied Sciences, 8* (2015), 2, pp. 226-233
[17] Kochhar, N., High Heat Producing Granites of the Malani Igneous Suite Northern Peninsular, India, *Indian Miner, 45* (1989), pp. 339-346
[18] Tanner, A. B., Radon Migration in the Ground: a Supplementary Review – in the Natural Radiation Environment, Springerfield, Va., USA, National Technical Information Service, 1980, pp. 5-56

Received on September 29, 2015
Accepted on November 12, 2015

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МЕРЕЊА РАДОНА И ТОРОНА У ВАЗДУХУ И ЗЕМЉИШТУ НЕКИХ ОКРУГА НА СЕВЕРУ ИНДИЈЕ

Радон, торон и њихови потомци у затвореном простору сматрају се штетним по здравље. Алфа емисија ових гасова омогућила је њихову детекцију у затвореној средини применом технике нуклеарних траг детектора. Земљиште је главни извор радона у затвореном простору јер садржи променљиве количине уранијума и торијума. Стога се мора проучавати ослобађање радона из земљишта и његова активност у животној средини. У овом раду приказана су обављена мерења радона и торона у затвореној средини и њихово ослобађање из земљишта применом SSNTD технике у окрузима Сирса и Бивани на северу Индије. Примењена је канистер техника за мерење ослобађања радона из узорака земљишта са овог подручја, док су за мерење концентрације радона и торона коришћени пинхол дозиметри за радон и торон. Резултати показују да је концентрација радона у затвореној средини у Бивани округу у опсегу од 9 Bq/m^3 до 28 Bq/m^3, са средњом вредношћу од 18,9 Bq/m^3, а у опсегу од 5 Bq/m^3 до 21 Bq/m^3, са средњом вредношћу од 13,8 Bq/m^3, у Сирса округу. Слично овоме, концентрација торона је у опсегу од 14 Bq/m^3 до 48 Bq/m^3, са средњом вредношћу од 28,9 Bq/m^3 и 27 Bq/m^3 до 54 Bq/m^3, са средњом вредношћу од 39,0 Bq/m^3, за Бивани и Сирсу, респективно. Такође је измерена јачина масене ексхалације из узорака земљишта како би се проценио њихов допринос радону у затвореној средини. Спроведена је и корелациона студија између јачине ексхалације земљишта и концентрације радона у затвореној средини.

Кључне речи: радон, торон, јачина ексхалације, пинхол дозиметар, земљиште