ENVIRONMENTAL RADON, ITS EXHALATION RATES AND ACTIVITY CONCENTRATION OF ^{226}Ra, ^{232}Th, AND ^{40}K IN NORTHERN INDIA

by

Rupinderjeet KAUR [1], Deep SHIKHA [2*], Supreet Pal SINGH [1], and Vimal MEHTA [2]

[1] Department of Physics, Punjabi University, Patiala, India
[2] Department of Physics, Sri Guru Teg Bahadur Khalsa College, Sri Anandpur Sahib, India

Review paper
https://doi.org/10.2298/NTRP2003268K

Human beings are constantly exposed to radioactivity in the environment. As they are major sources of harmful radiation, radionuclides found in the atmosphere might result in a substantial potential risk to living beings. On the Earth's surface, the radioactive elements uranium and radium are naturally present, contributing to radon and thoron gases in the indoor as well as outdoor climate, soil and water. Radon is one of the most important toxins that, after cigarette smoking, is the second most common cause of generating lung cancer. Due to these health-related concerns, a lot of work has been undertaken by numerous research organizations to determine their levels at different locations throughout the world. This paper is an attempt to comprehensively report with different techniques all those studies being carried out in this part of India so that a current assessment of the indoor radon levels should be available for further work in this field. Six northern Indian states, viz. Punjab, Haryana, Himachal Pradesh, Rajasthan , Uttar Pradesh and Uttarakhand are considered for this examination. This study also provides data on exhalation rates and activity concentration of natural radionuclides (^{226}Ra, ^{232}Th, and ^{40}K) present in these states.

Key words: indoor radon, thoron, exhalation rate, annual dose, activity concentration

INTRODUCTION

In 1899, Robert Bowie Owens and Ernest Rutherford first discovered radon (^{222}Rn). Radon is a gaseous radioactive gas that is colourless, monatomic, odourless, tasteless and single. However, it is particularly carcinogenic and radiotoxic when inhaled [1]. After the discovery of uranium, thorium, radium and polonium [2], Friedrich Ernst Dorn discovered radon as the fifth radioactive element on Earth. The primary cause of lung cancer, second only to smoking cigarettes, is ^{222}Rn [3]. Radon parent radionuclide radium is responsible for nasal and cranial tumors [4]. According to the International Commission on Radiological Protection, radon constitutes about 53 % of human health exposure to natural radiation [5]. Further, radon has no stable isotopes. Out of 36 known isotopes (all radioactive), only three ^{222}Rn, ^{220}Rn, ^{219}Rn, are supported by decay of primordial radionuclides.

Both radon and thoron are itself decay by emission of alpha particles and produces radon or thoron progenies (daughter products), tabs. 1 and 2.

These decay isotopes are heavy metals. Inhalation of ^{222}Rn and its progeny is associated with a substantial risk of pulmonary cancer as it causes bronchial epithelial damage [7]. The ^{218}Po and ^{214}Po are the key sources of health risk for all decay materials, as they

* Corresponding author; e-mail: deep_shikha79@yahoo.co.in

Table 1. Radon decay products [6]

Radionuclide	Half life	Energy [MeV]	Product
^{222}Rn	3.8235 d	5.4895	^{218}Po
^{218}Po	3.10 min	6.0024	^{214}Pb
^{214}Pb	27 min	–	^{214}Bi
^{214}Bi	19.9 min	–	^{214}Po
^{214}Po	164.3 μs	7.6869	^{210}Pb
^{210}Pb	22.3 years	–	^{210}Bi
^{210}Bi	5.01 d	–	^{210}Po
^{210}Po	138.38 d	5.3044	^{206}Pb

Table 2. Thoron decay products [6]

Radionuclide	Half life	Energy [MeV]	Product
^{222}Rn	55.6 s	6.2882	^{216}Po
^{216}Po	0.145 s	6.7785	^{212}Pb
^{212}Pb	10.64 h	–	^{212}Bi
^{212}Bi	1.009 h	6.34, 6.30	^{212}Po
^{212}Po	45 s	11.65	^{208}Pb
^{208}Tl	3.053 min	–	–
^{208}Pb	Stable	–	–

contain very energetic alpha particles [8-10]. The DNA damage is caused by the interaction of these progenies with biological tissue in the lungs [11]. The progenies can attach to aerosols or not attach to them. Both attached and unattached radon progenies, if inhaled, can cause lung tissue irradiation by damaging them as they emit a small burst of energy called alpha particles. The risk of radioactive material in an unattached state is much higher than that of radioactive material in the attached state [12].

Lung cancer is primarily caused by bronchial stem cells and by secretion cells [13]. Research studies have shown that exposure to indoor ^{222}Rn could lead to an increased risk of lung cancer [14-22]. Scientists at the National Academy of Science estimate that exposure to an elevated level of ^{222}Rn gas may cause 15000-22000 lung cancer deaths per year. Some studies have also indicated that exposure to indoor ^{222}Rn can lead to other types of cancer [23-26]. The ICRP measured the risk of cancer to various organs of the body at about 2 % of the risk of lung cancer [27].

Thus, keeping in mind the numerous health hazards caused by ^{222}Rn and its descendants, the monitoring of radon and its decay products is important for identifying human health hazards. Wide scale ^{222}Rn surveys have been conducted in a range of countries [28-33]. In Indian homes, one of the systematic surveys of indoor radon levels in 15 different cities was performed using Solid State Nuclear Track Detectors (SSNTD) [34]. This research was further expanded by carrying out additional surveys from 24 cities in the north-eastern region of India [35]. This paper is intended to provide an overview of the analysis carried out by a variety of research groups in the Punjab, Himachal Pradesh, Haryana, Rajasthan, Uttar Pradesh, and Uttarakhand states of India.

Study Area Climate:

The state of Punjab, with an area of 50362 km^2, lies between 29.30° and 32.32° north latitude and 73.55° and 76.50° east latitude [36]. Punjab has much fertile plain land [37]. The climate of Punjab is primarily affected by the Himalayas (because as the distance from the Himalayas increases, so the rainfall decreases) and the Thar Desert in the north and south, respectively. The sum of rainfall in Punjab ranges from 240 to 1000 mm [38]. Himachal Pradesh occupies a land area of 55673 km^2. It is located in the western Himalayas between 30.22° and 33.12° north and 75.45° to 79.04° east [39]. The state touches Punjab in the west, Jammu and Kashmir in the north, Uttarakhand in the south-east, Haryana in the south, and China in the east [40]. Altitude changes climate across the state [41]. The state receives annual rainfall of the order 2909 to 3800 mm [42]. Haryana (16th largest state), lies between 27.47° and 30.30° north latitude and 74.29° to 77.22° east longitudes. It is bordered by Punjab in the north-west, Himachal Pradesh in north, Uttarakhand in north-east, Uttar Pradesh in the east [43]. Temperature in summer is very hot up to a high of 47° C and in winters is very cold up to 5 °C [44]. Rajasthan (largest state of India) lies between north 23.30° and 30.11° latitude and east 69.29° and 78.17° longitude. The state is bordered by Punjab in the north, Pakistan in the west, Haryana and Uttar Pradesh oin the north-east and Gujarat in the south-west respectively [45]. The state has a maximum temperature of 50.6 °C [46]. Uttar Pradesh (4th largest state) covers a 243290 km^2 area which lies 26.85° north and 80.91° east. The state borders Haryana in the west, Madhya Pradesh in the south, Bihar in the east, Uttarakhand in the north, Rajasthan, Haryana, Himachal Pradesh and Delhi to the west [47].

The climate varies according to altitude [48]. The mean annual rainfall of the state is 946 mm [49]. Uttarakhand (18th biggest state) covers a total 53566 km^2 area and lies between 28.43° and 31.27° north latitude and 77.34° to 81.02° east longitude. The state borders Himachal Pradesh in the west, Nepal in the east, Uttar Pradesh in the south and China in the north. Annual temperature ranges from 0 to 40 °C. The climate in the northern part of Uttarakhand is typically Himalayan.

MATERIALS AND METHODS

Indoor radon survey

Various indoor radon measurement experiments have been performed using active and passive techniques. Active radon monitoring techniques include electrical power and an assessment of ^{222}Rn leakage through the chamber, whereas passive radon monitoring techniques do not include electrical power and do not include an assessment of ^{222}Rn leakage through the chamber. Some of these methods are:

The RAD7 is one of the active methods used to assess the concentration of radon in air, soil and water. The RAD7 will calculate the concentration of radon from 0.4 to 750000 Bqm^{-3} [50]. The RAD7 is a continuous radon control based on the alpha spectrometry technique. It is one of the fast measurements of indoor radon activity levels at sites built to detect alpha particles only [51]. The RAD7 is attached to the drystik accessory in a closed loop configuration that allows indoor radon measurement [52]. It uses an internal sample cell hemisphere of 0.7 liters of RAD7 at the centre of which silicon is positioned to help produce an electrical signal from the conversion of alpha radiation [53]. The RAD7 uses ^{218}Po for determination of the radon concentration and ^{216}Po for determination of the thoron concentration. However, according to EPA all continuous radon monitoring must be calibrated at least every six months.

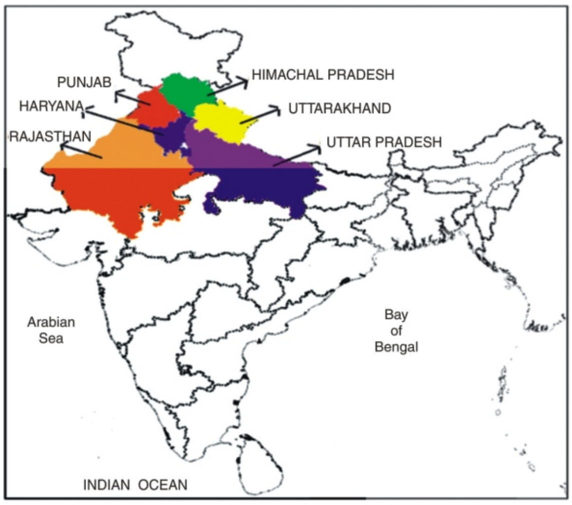

Figure 1. Map of the study are

Nuclear track detectors have been commonly used for the study of the concentration of radon in passive techniques due to their high durability. The LR-115 (SSNTD) is essentially a thin cellulose nitrate film, while CR-39 (SSNTD) is an allyl diglycol carbonate polymer [32]. Passive techniques include both the bare mode and dosimeter (twin cup dosimeter and pin hole dosimeter) techniques. In the bare mode, SSNTD films fixed to the glass slide are hung in the room at a height of 2 m from the floor [54]. After the exposure time, the detectors are removed and etched in a 2.5N NaOH solution at 60 °C for 90 minutes. The registered tracks are then counted using a spark counter or an optical microscope.

In dosimetric mode, both the twin cup dosimeter (double input dosimeter, consisting of bare mode and two chambers, *i. e*. filter and membrane mode chamber) and the pin hole dosimeter (single input dosimeter, comprising two identical cylindrical chambers) are used by SSNTD connected to each chamber to detect the radon concentration [44, 55]. Dosimeters are suspended in the same way as for the bare mode. These detectors are recovered after a three month exposure. The CR-39 etching can be completed with 6N NaOH at 70 °C for approximately 5-6 hours [37]. The detectors are then washed properly to remove chemical and dry matter. After washing the tracks produced by the alphas they are counted with a spark counter or optical microscope and are then converted in the Bqm^{-3} by using an appropriate calibration factor [56].

Radon survey in soil gas

Many techniques are in use for monitoring the radon concentration and its exhalation rates from soil samples. Some of them are:

The *RAD7* radon monitoring apparatus used by many groups applies an air pump and a detector consisting of a silicone material (semiconductor) which helps to obtain an electrical signal by converting alpha radiation [57-59]. With the aid of a stainless steel probe, soil-gas samples from each area were obtained. The probe is immersed in the soil at some depth and is attached to the RAD7 detector. In order to examine the soil perfectly, it should be uniform and usually free from rocks. Until counting, the hole was adequately sealed to prevent soil-gas from interacting with air from the atmosphere. The sampling of soil gas was achieved with the aid of the grab mode. The soil was sucked through a measuring instrument in a 5-minute pumping process. This loop is repeated four times. The RAD7 will include a description of the average concentration of radon in soil gas after half an hour. This method uses a very limited amount of soil and gives a fast reading [59].

The *Canister Procedure* used by several groups has also been adapted to assess the concentration of soil radon gas [60-63]. The soil samples to be analyzed from different regions were collected and then dried in an oven at 110 °C for a period of 24 hours to extract moisture and some fine soil powder was stored in different canisters. SSNTD was attached to the bottom of the lid and can finally be locked. After three months of exposure, SSNTD was removed from the lid and etched in a 2.5N NaOH solution at 60 °C for 90 minutes. The engraved detectors are carefully cleaned, dried and used for alpha counting by means of a spark counter or optical microscope [60].

Activity concentration of radium, ^{226}Ra, thorium, ^{232}Th, and potassium, ^{40}K

The soil is collected at a depth of 0.75 m from the ground level to determine the activity concentration of natural nuclides. This is provided for the selection of natural soils. The samples are then transformed into a known quantity of fine powder and dried in an oven. Every sample is packed and sealed in an airtight container to prevent moisture. After the exposure time (~30 days) the sample activity is measured using the HPGe/NaI(Tl) detector. Samples were counted for a duration of 72000 seconds for the HPGe detector and 10800 s for the NaI(Tl) detector [64, 65]. The activity concentrations of ^{226}Ra, ^{232}Th, and ^{40}K were then determined from the photo peaks of ^{226}Ra, ^{232}Th, and ^{40}K respectively in the Multi Channel Analyzer.

RESULTS AND DISCUSSION

Tables 3-8 show the details of the district wide annual indoor radon concentration in six states Punjab, Himachal Pradesh, Haryana, Rajasthan, Uttar Pradesh, and Uttarakhand, respectively. These data include mainly the indoor radon concentration and annual effective dose to the residents obtained from active (RAD7) and passive (Bare Mode, Twin Cup, and

Table 3. The average annual value of indoor radon recorded in dwellings of Punjab

Sight number	District	Bare mode		Twin cup		Pin hole		RAD7	
		Concentration [Bqm^{-3}]	Dose [mSv]	Concentration [Bqm^{-3}]	Dose [mSv]	Concentration [Bqm^{-3}]	Dose [mSv]	Concentration [Bqm^{-3}]	Dose [mSv]
1	Hoshiarpur	(50)108 16	2 [37]	–	–	–	–	–	–
2	Jalandhar-I	(10)125 39	2 [37]	–	–	(11)36 5	1.27 [71]	(11)43 9	1.28 [67]
	Jalandhar-II	–	–	–	–	(10)35 5	1.38 [72]	–	–
	Jalandhar-III	–	–	–	–	(130)18 3	0.66 [96]	–	–
	Jalandhar-IV	–	–	–	–	(45)40 14	– [75]	–	–
3.	Amritsar	(70)122 48	– [37]	–	–	(36)52 5	1.5 [102]	(19)19	0.11 [68]
4.	Bathinda-I	(111)154 31	3 [37]	–	–	(60)68 6	1.7 [102]	(9)24	0.08 [68]
	Bathinda-II	–	–	–	–	–	–	(17)32	0.80 [148]
5.	Faridkot	(25)76 7	1.00 [37]	–	–	(60)63 5	1.7 [102]	–	–
6.	Ferozepur	(40)107 23	1.83 [37]	–	–	–	–	–	–
7.	Gurdaspur	(20)157	3.97 [69]	–	–	–	–	(25)20	0.11 [68]
8.	Ludhiana	(25)91 21	1.50 [37]	–	–	(45)28 7	– [70]	–	–
9.	Kapurthala-I	–	–	–	–	(4)48 6	1.54 [66]	(4)29 8	1.04 [66]
	Kapurthala-II	–	–	–	–	(8)42 5	1.69 [67]	–	–
	Kapurthala-III	–	–	–	–	(45)19 19	– [70]	–	–
10.	Mansa	(25)107 38	1.80 [37]	–	–	(18)54 5	–[71]	–	–
11.	Moga	(25)82 5	1.20 [37]	–	–	–	–	–	–
12.	Mohali	–	–	(10)34 2	– [72]	(13)27	1.61[149]		–
13.	Ropar	(40)89 19	1.51 [37]	(11)15	0.69 [147]	(5)20	1.29[147]	–	–
14.	Sangrur	(45)63 8	1.00 [37]	–	–	–	–	–	–
15.	Patiala	(25)93 9	1.80 [37]	–	–	–	–	–	–
16.	Mukatsar	(65)102 18	1.74 [37]	–	–	(14)56 5	–[71]	–	–
17.	Patnankot	(5)138	3.47 [69]	–	–	–	–	–	–
18.	Tarn taran	–	–	–	–	(40)58 5	1.8 [97]	–	–
19.	Fazilka	–	–	–	–	(100)119	4.58 [98]	–	–
20.	Chandigarh	(5)139 7	2.37 [37]	(15)23.2	0.8 [146]	(10)40 2	1.9 [102]		

Table 4. The average annual value of indoor radon recorded in dwellings of Himachal Pradesh*

Sight number	District	Bare mode		Pin hole		RAD7	
		Concentration [Bqm^{-3}]	Dose [mSv]	Concentration [Bqm^{-3}]	Dose [mSv]	Concentration [Bqm^{-3}]	Dose [mSv]
1.	Hamirpur	(68)464 123	7.92 [37]	(80)85 34	2.13 [80]	(14)189	4.77 [81]
2.	Kangra	(70)253 70	4.30 [37]	–	–	(37)17 9	–[57]
3.	Kullu	(108)296 118	5.07 [37]	–	–	–	–
4.	Una	(90)315 158	5.37 [37]	–	–	(10)99 2	2.48 [58]
5.	Mandi	(64)94	1.61 [82]	–	–	–	–
6.	Shimla	(5)194	4.88 [69]	–	–	–	–

*Twin cup data is not available for this district.

Pin Hole) techniques. A superscript added in the indoor radon values shows the number of dwellings used in the survey.

SOIL SURVEY

Tables 9-14 show a soil survey which presents the radon concentration, surface exhalation, mass exhalation and radium concentration in six states reported by various researchers. The superscript added to the concentration shows the number of dwellings. To carry out the exhalation study various researchers used different techniques like the canister technique, RAD7 monitor, smart radon monitor *etc*, tabs. 15-17.

ACTIVITY CONCENTRATION

Tables 18 and 19 show the activity concentration of natural radionuclides in Punjab, Himachal Pradesh, Haryana, Rajasthan, and Uttarakhand, respectively. These data mainly include concentration of natural radionuclides ^{226}Ra, ^{232}Th, and ^{40}K with their respective doses. It also shows the annual effective dose due to these radionuclides. The superscript added to the

Table 5. The annual average indoor radon values recorded in the dwellings of Haryana*

Sight number	Distric	Bare mode		Twin cup		Pin hole	
		Concentration [Bqm^{-3}]	Dose [mSv]	Concentration [Bqm^{-3}]	Dose [mSv]	Concentration [Bqm^{-3}]	Dose [mSv]
1.	Ambala-I	(15)138 45	2.36 [37]	(14)94 8	4.0 [13]	(4)29 6	– [88]
	Ambala-II	–	–	(15)13 1	0.68 [44]	–	–
2.	Bhiwani-I	(6)107 11	1.85 [37]	–	–	(91)50 22	1.11[89]
	Bhiwani-II	(157)306 194	– [37]	–	–	–	–
3.	Faridabad	(6)134 11	2.31 [37]	–	–	–	–
4.	Fatehbad	(25)147 13	2.50 [37]	–	–	(10)19	– [90]
5.	Gurgaon	(5)70 7	1.15 [37]	–	–	–	–
6.	Hisar	(25)144 17	2.46 [37]	–	–	(10)46	– [90]
7.	Jhajjar	(4)51±7	0.87 [37]	–	–	–	–
8.	Jind	(6)61 11	1.05 [37]	–	–	–	–
9.	Kaithal	(7)66 7	1.14 [37]	(10)81 12	3.3 [13]	–	–
10.	Karnal	(8)71 11	1.21 [37]	–	–	(3)23 6	– [88]
11.	Kurukshetra	(8)40 7	0.69 [37]	(30)79 7	3.1 [13]	(5)21 5	– [88]
12.	Mahendragar	(5)99 11	1.71 [37]	–	–	–	–
13.	Panchkula	(40)108 27	1.84 [37]	(8)104 12	4.3 [13]	(2)24 5	[88]
14.	Panipat	(5)134 13	2.30 [37]	–	–	–	–
15.	Rewari	(6)115 11	1.98 [37]	–	–	–	–
16.	Rohtak	(4)70 7	1.20 [37]	–	–	–	–
17.	Sirsa	(50)91 19	1.56 [37]	–	–	(10)13.8	– [101]
18.	Sonipat	(5)84 11	1.44 [37]	–	–	–	–
19.	Yamunanagar	(7)118 11	2.03 [37]	(18)85 8	3.4 [13]	(4)36 6	– [88]

*RAD7 data is not available for this district.

Table 6. The annual average indoor radon values recorded in the dwellings of Rajasthan*

Sight number	District	Bare mode		Twin cup		RAD7	
		Concentration [Bqm^{-3}]	Dose [mSv]	Concentration [Bqm^{-3}]	Dose [mSv]	Concentration [Bqm^{-3}]	Dose [mSv]
1.	Jaipur-I	–	–	(18) 59 6	1.70 [104]	–	–
	Jaipur-II			40	0.64 [107]		
2.	Jodhpur	–	–	75	0.96 [107]	(10)30	0.75 [53]
3.	Nagaur	–	–	–	–	(10)34	0.85 [53]
4.	Hanumangarh-I	–	–	–	–	(9)25	– [51]
	Hanumangarh-II	–	–	–	–	(50)124 11	2.12 [109]
5.	Sri Ganganagar	(50)143 21	2.45 [105]	–	–	(9)35	– [51]
6.	Churu	(10)135 18	2.31 [106]	–	–	(3)26	– [51]
7.	Sikar	(10)153 28	2.62 [106]	–	–	(9)39	– [51]
8.	Pali	–	–	37	0.60 [107]	–	–
9.	Sirohi	–	–	110	1.75 [107]	–	–
10.	Jalore	–	–	66	1.54 [107]	–	–
11.	Jaiselmer	–	–	88	1.36 [107]	–	–
12.	Udaipur	–	–	94	1.06 [107]	–	–
13.	Barmer	–	–	60	1.54 [107]	–	–
14.	Bikaner	–	–	59	0.94 [107]	–	–

*Pin Hole data is not available for this district.

concentration shows the number of dwellings. However, the data for the activity concentration of radionuclides is not available for the Uttar Pradesh district.

DISCUSSION

In the state of Punjab, tab. 3, indoor radon values are between 100-300 Bqm^{-3} which are well within the reference level. However, if we compare the tech-

Table 7. The annual average indoor radon values recorded in the dwellings of Uttar Pradesh*

Sight number	District	Bare mode		Twin cup	
		Concentration [Bqm^{-3}]	Dose [mSv]	Concentration [Bqm^{-3}]	Dose [mSv]
1.	Bareilly	–	–	(20)87 48	1.56 [113]
2.	Faizabad	–	–	(19)61 28	2.21 [114]
3.	Shahjahanpur	–	–	(23)28	– [115]
4.	Farrukhabad	–	–	(19)67 15	– [116]
5.	Etah	(51)256 7	4.8 [117]	–	–
6.	Firozabad	(14)90 32	1.08 [118]	–	–
7.	Kanshiram nagar	–	–	(13)29 19	– [119]
8.	Moradabad	–	–	(22)19	– [120]

*Pin Hole and RAD7 data is not available for this district.

Table 8. The annual average indoor radon values recorded in the dwellings of Uttarakhand

Sight number	District	Bare mode		Twin cup		Pin hole		Rad7	
		Concentration [Bqm^{-3}]	Dose [mSv]	Concentration [Bqm^{-3}]	Dose [mSv]	Concentration [Bqm^{-3}]	Dose [mSv]	Concentration [Bqm^{-3}]	Dose [mSv]
1.	Almora	–	–	–	–	(52)100	–[127]	–	–
2.	Tehri Garhwal-I	(82)110 42	– [128]	–	–	–	–	–	–
	Tehri Garhwal-II	(99)114	– [54]						
3.	Dehradoon	(11)393	– [129]	(32)44	[130]	(25)89 13	[125]	(15)85 36	[126]
4.	Bhilangna valley	(7)147	[131]	–	–	–	–	–	–
5.	Uttarkashi	(8)101	[56]	–	–	(78)38 40	– [132]	–	–
6.	Pauri Garhwal	(8)76	[56]	–	–	(35)84	– [133]	–	–
7.	Garhwal Himalaya	–	–	(100)64	– [142]	(122)41 44	– [134]	–	–
	Garhwal Himalaya-II	–	–	71	– [144]	–	–	–	–
8.	Kumaun	–	–	36	[144]	–	–	–	–

Table 9. Radon concentration, surface exhalation, mass exhalation and radium concentration from soil samples in Punjab

Sight number	District	Radon concentration [Bqm^{-3}]	Surface exhalation [mBqm^{-2}h^{-1}]	Mass exhalation [mBqkg^{-1}h^{-1}]	Radium concentration [Bqkg^{-1}]	Reference
1.	Mohali-I	(10)35 7	(10) 28 5	(10)1 6	–	[72]
	Mohali-II	–	–	(4)3 1	–	[149]
2.	Ropar-I	(5)33 11	(5)27 9	(5)1 1	–	[60]
	Ropar-II	(10)30 2	(10)24 2	(10)1	–	[147]
3.	Sangrur	–	(45)725	(45)21	(45)14	[73]
4.	Faridkot	–	(25)702	(25)20	(25)15	[73]
5.	Mansa	–	(25)652	(25)19	(25)14	[73]
6.	Patiala	–	(25)520	(25)15	(25)11	[73]
7.	Ludhiana	–	(25)452	(25)13	(25)10	[73]
8.	Moga	–	(25)386	(25)11	(25)9	[73]
9.	Gurdaspur	(9)9 0.09	–	–	–	[74]
10.	Hoshiarpur	(6)12 0.26	–	–	–	[74]
11.	Amritsar	(11)13 0.11	–	–	–	[74]
12.	Kapurthala	(6)4 0.10	–	–	–	[74]
13.	Tarn taran	(7)9 0.07	–	–	–	[74]
14.	Fazilka	–	(20)32 2	–	–	[98]
15.	Chandigarh	–	–	(8)5 1	–	[102]

niques, then the values using the bare mode technique are greater as compared to the pin hole twin cup, and RAD7 technique. In the state of Himachal Pradesh tab. 4, the Hamirpur District has higher values of indoor radon using the bare mode which exceed the action level. These high values of indoor radon may be due to the presence of mineralization of uranium in the area. Nonetheless by using the pinhole technique this concentration is far less than the earlier reported concentration. These studies were done in the mineralized

Table 10. Radon concentration, surface exhalation, mass exhalation and radium concentration from soil samples in Himachal Pradesh

Sight number	District	Radon concentration [Bqm^{-3}]	Surface exhalation [mBqm^{-2}h^{-1}]	Mass exhalation [mBqkg^{-1}h^{-1}]	Radium concentration [Bqkg^{-1}]	Reference
1.	Hamirpur	463	–	–	–	[81]
2.	Una-I	$^{(10)}$117	–	–	–	[58]
	Una-II	–	507	15	–	[83]
3.	Dharamshala	$^{(37)}$ 44 1	–	–	$^{(37)}$40 2	[84]
4.	Chamba	$^{(35)}$15 1	–	–	$^{(35)}$39 2	[84]
5.	Kangra-I	–	$^{(18)}$806	$^{(18)}$24	$^{(18)}$19	[85]
	Kangra-II	$^{(71)}$12	–	–	–	[86]

Table 11. Radon concentration, surface exhalation, mass exhalation and radium concentration from soil samples in Hareyana*

Sight number	District	Radon concentration [Bqm–3]	Surface exhalation [mBqm^{-2}h^{-1}]	Mass exhalation [mBqkg^{-1}h^{-1}]	Reference
1.	Kurukshetra	–	–	$^{(5)}$55 3	[88]
2.	Yamunanagar	–	–	$^{(5)}$52 6	[88]
3.	Ambala-I	–	–	$^{(4)}$46 6	[88]
	Ambala-II	$^{(5)}$49 9	$^{(5)}$40 8	$^{(5)}$2	[145]
4.	Panchkula	–	–	$^{(4)}$56 7	[88]
5.	Karnal	–	–	$^{(4)}$63 6	[88]
6.	Sirsa	–	$^{(20)}$499	$^{(20)}$27	[101]
7.	Bhiwani-I	–	$^{(9)}$256	$^{(9)}$8	[91]
	Bhiwani-II	–	$^{(22)}$465	$^{(22)}$25	[101]
	Bhiwani-III	–	–	$^{(14)}$12 1	[103]
8.	Fatehbad	–	–	$^{(23)}$32	[90]
9.	Hisar	–			

*The radium equivalent concentration is not available for this district.

Table 12. Radon concentration, surface exhalation, mass exhalation and radium concentration from soil samples in Rajasthan

Sight number	District	Radon concentration [Bqm^{-3}]	Surface exhalation [mBqm^{-2}h^{-1}]	Mass exhalation [mBqkg^{-1}h^{-1}]	Radium concentration [Bqkg^{-1}]
1.	Bikaner	$^{(10)}$4870 146 [108]	–	–	–
2.	Jhunjhunu	$^{(10)}$4248 184 [108]	–	–	–
3.	Hanumangarh-I	$^{(52)}$4308 447 [109]	–	–	–
	Hanumangarh-II	–	$^{(10)}$508 [110]	$^{(10)}$15 [110]	$^{(10)}$13 [110]
4.	Sri Ganganagar-I	$^{(10)}$2881 299 [59]	–	–	–
	Sri Ganganagar-II	–	$^{(10)}$433 [110]	$^{(10)}$13 [110]	$^{(10)}$11 [110]
5.	Churu	–	$^{(10)}$407 [110]	$^{(10)}$12 [110]	$^{(10)}$10 [110]
6.	Sikar	–	$^{(10)}$632 [110]	$^{(10)}$19 [110]	$^{(10)}$16 [110]

Table 13. Radon concentration, surface exhalation, mass exhalation and radium concentration from soil samples in Uttar Pradesh*

Sight number	District	Surface exhalation [mBqm^{-2}h^{-1}]	Mass exhalation [mBqkg^{-1}h^{-1}]	Radium concentration [Bqkg^{-1}]	Reference
1.	Bulandshahr	$^{(22)}$601 110	$^{(22)}$23 4	$^{(22)}$14 3	[121]
2.	Etah	$^{(12)}$700 1	$^{(12)}$3	$^{(12)}$35 6	[122]
3.	Farrukhabad	–	$^{(25)}$1 1	$^{(25)}$17 7	[123]
4.	Aligarh	–	$^{(4)}$8	$^{(4)}$56	[124]
5.	Mathura	–	$^{(2)}$4	$^{(2)}$31	[124]

*The radon concentration in soil is not available for this district.

Table 14. Radon concentration, surface exhalation, mass exhalation and radium concentration from soil samples in Uttarakhand*

Sight number	District	Radon concentration [Bqm^{-3}]	Surface exhalation [mBqm^{-2}h^{-1}]	Mass exhalation [mBqkg^{-1}h^{-1}]	Reference
1.	Almora	–	–	(24)30 10	[135]
2.	Bhilangna valley	29 1	–	–	[136]
3.	Doon valley	7	–	–	[129]
4.	Garhwal himalaya	6	–	–	[137]
5.	Tehri	–	(25)279	(25)187	[138]
6.	Rajpur	(15)6 3	–	–	[126]

*The radium equivalent concentration is not available for this district.

Table 15. Values of ^{226}Ra, ^{232}Th, and ^{40}K concentration and dose in Punjab

Sight number	District	Radium (^{226}Ra)		Thorium (^{232}Th)		Potassium (^{40}K)		Annual effective dose [mSv]	Reference
		Concentration [Bqkg^{-1}]	Dose [mSv]	Concentration [Bqkg^{-1}]	Dose [mSv]	Concentration [Bqkg^{-1}]	Dose [mSv]		
1.	Bathinda-I	$^{(6)}$56	25.7	$^{(6)}$93	56.0	$^{(6)}$377	15.7	0.12	[64]
	Bathinda-II	21	–	39.0	–	75	–	–	[68]
	Bathinda-III	–	–	52 7		418 20		0.3	[99]
2.	Amritsar-I	$^{(6)}$55	25.2	$^{(6)}$78	47.3	$^{(6)}$302	12.6	0.10	[64]
	Amritsar-II	69	–	89	–	157	–	–	[68]
	Amritsar-III			61 7		535 19		0.3	[99]
	Amritsar-IV	65 2	29.88	95 2	59.37	155 1	6.44	11.7	[77]
3.	Pathankot-I	$^{(6)}$43	19.7	$^{(6)}$10	41.9	$^{(6)}$331	13.8	0.09	[64]
	Pathankot-II	64 2	29.50	93 2	57.73	124 1	5.15	11.3	[77]
4.	Sangrur-I	$^{(9)}$25 1	11.6	$^{(9)}$69 5	42.8	$^{(9)}$249 9	10.2	0.29	[75]
	Sangrur-II	$^{(15)}$37	17.2	$^{(15)}$39 7	24.2	$^{(15)}$471 46	19.53	0.29	[100]
5.	Mukatsar	$^{(13)}$37 1	17.1	$^{(13)}$74 5	46.3	$^{(13)}$359 7	12.8	0.38	[75]
6.	Ferojpur	$^{(8)}$43 1	19.7	$^{(8)}$102 5	63.6	$^{(8)}$325 7	13.5	0.47	[75]
7.	Hoshiarpur-I	–	–	$^{(10)}$221	137.3	$^{(10)}$920	38.02	0.90	[76]
	Hoshiarpur-II			47 6		339 16		0.2	[99]
8.	Batala	36 1	16.59	50 1	30.86	80 1	3.33	0.06	[77]
9.	Gurdaspur-I	62 2	28.91	78 2	48.82	165 2	6.84	0.10	[77]
	Gurdaspur-II	54	–	80	–	145	–	–	[68]
10.	Ludhiana	–	–	$^{(10)}$51	31.74	$^{(10)}$570	23.58	0.33	[78]
11.	Mansa	$^{(5)}$25	11.56	$^{(5)}$124	77.34	$^{(5)}$332	82.66	0.50	[89]
12.	Tarn tarn	–	–	59 7	–	419 18	–	0.3	[99]
13.	Faridkot	$^{(5)}$29	13.50	$^{(5)}$66	41.29	$^{(5)}$293	12.14	0.33	[79]
14.	Barnala	$^{(10)}$36 7	16.6	$^{(10)}$41 7	25.3	$^{(10)}$422 40	17.4	0.28	[100]

Table 16. Values of ^{226}Ra, ^{232}Th, and ^{40}K concentration and dose in Himachal Pradesh

Sight number	District	Radium(^{226}Ra)		Thorium(^{232}Th)		Potassium(^{40}K)		Annual effective dose [mSv]	Reference
		Concentration [Bqkg^{-1}]	Dose [mSv]	Concentration [Bqkg^{-1}]	Dose [mSv]	Concentration [Bqkg^{-1}]	Dose [mSv]		
1.	Kangra	56.74	26.11	87.42	57.97	143.04	6.245	0.10	[77]
2.	Una	45.68	21.10	17.11	10.33	1444.04	63.96	0.3	[87]
3.	Chamba	63.8	29.51	91.56	55.31	340.78	14.21	0.12	[64]
4.	Hamirpur	44.21	–	93.10	–	174.48	–	–	[95]

zone of the Hamirpur area. In the rest of the areas in Himachal Pradesh the concentration using the bar mode technique is more similar to the one in the other techniques. In the state of Haryana, tab. 5 the Bhiwani district has higher values of radon concentration because the study was completed in the Tusham Ring Complex, where a higher content of natural radionuclides exists. This study was completed using the bare mode. The rest of the areas have a radon concentration well within the limits. The studied areas of Rajasthan, tab. 6, and Uttar Pradesh, tab. 7, also have radon values well within the recommended limits. In

Table 17. Values of ^{226}Ra, ^{232}Th, and ^{40}K concentration and dose in Haryana

Sight number	District	Radium (^{226}Ra)		Thorium (^{232}Th)		Potassium (^{40}K)		Annual effective dose [mSv]	Reference
		Concentration [Bqkg^{-1}]	Dose [mSv]	Concentration [Bqkg^{-1}]	Dose [mSv]	Concentration [Bqkg^{-1}]	Dose [mSv]		
1.	Sirsa	$^{(10)}$27.93	11.99	$^{(10)}$72.55	45.2	$^{(10)}$286.73	12.03	0.34	[92]
2.	Hisar	$^{(10)}$ 17.79	8.20	$^{(10)}$45.45	28.31	$^{(10)}$359.96	14.90	0.25	[93]
3.	Fatehbad	$^{(8)}$19.918	9.18	$^{(8)}$39.97	31.45	$^{(8)}$346.04	14.32	0.27	[94]
4.	Sirsa	$^{(2)}$105.82	48.78	$^{(2)}$58.99	36.7	$^{(2)}$1008.5	41.7	0.625	[94]
5.	Kurukshetra	$^{(1)}$76.35	55.9	$^{(1)}$89.7	31.14	$^{(1)}$752.2	31.14	0.6	[94]
6.	Bhiwani-I	$^{(7)}$54.10	24.94	$^{(7)}$80.46	50.12	$^{(7)}$717.78	29.71	0.513	[94]
	Bhiwani-II	$^{(14)}$12.00	–	$^{(14)}$46.70	–	$^{(14)}$309.07	–	0.23	[103]
7.	Jhajjar	$^{(1)}$92.56	42.67	$^{(1)}$58.78	36.62	$^{(1)}$776.83	32.16	0.55	[94]
8.	Rohtak	$^{(1)}$16.43	7.57	$^{(1)}$45.65	28.44	$^{(1)}$398.23	16.49	0.26	[94]

Table 18. Values of ^{226}Ra, ^{232}Th, and ^{40}K concentration and dose in Rajasthan

Sight number	District	Radium (^{226}Ra)		Thorium (^{232}Th)		Potassium (^{40}K)		Annual effective dose [mSv]	Reference
		Concentration [Bqkg^{-1}]	Dose [mSv]	Concentration [Bqkg^{-1}]	Dose [mSv]	Concentration [Bqkg^{-1}]	Dose [mSv]		
1.	Jodhpur	$^{(10)}$24 9	11.1	$^{(10)}$52 10	32.5	$^{(10)}$627 146	26	–	[111]
2.	Nagaur	$^{(10)}$24 9	11.2	$^{(10)}$57 11	35.7	$^{(10)}$471 135	19.7	–	[111]
3.	Sri Ganganagar	$^{(10)}$55 10	25.3	$^{(10)}$22 8	13.2	$^{(10)}$1620 224	67.4	0.65	[112]
4.	Hanumangarh	$^{(10)}$56 11	26.1	$^{(10)}$24 8	14.3	$^{(10)}$1577 23	65.7	0.65	[112]
5.	Churu	$^{(10)}$50 10	23.1	$^{(10)}$15 8	9.1	$^{(10)}$1683 229	70	0.62	[112]
6.	Sikar	$^{(10)}$48 10	22.1	$^{(10)}$15 8	9.3	$^{(10)}$1630 225	67.8	0.60	[112]

Table 19. Values of ^{226}Ra, ^{232}Th, and ^{40}K concentration and dose in Uttarakhand

Sight number	District	Radium (^{226}Ra)		Thorium (^{232}Th)		Potassium (^{40}K)		Annual effective dose [mSv]	Reference
		Concentration [Bqkg^{-1}]	Dose [mSv]	Concentration [Bqkg^{-1}]	Dose [mSv]	Concentration [Bqkg^{-1}]	Dose [mSv]		
1.	Kumaun Himalaya	67 7	–	79 6	–	887 73	–	0.6	[139]
2.	Uttarkashi	$^{(18)}$31	–	$^{(18)}$30	–	$^{(18)}$583	–	0.26	[140]
3.	Garhwal Himalaya	$^{(25)}$20	–	$^{(25)}$26	–	$^{(25)}$329	–	0.18	[141]
4.	Almora	$^{(24)}$48 9	–	$^{(24)}$45 8	–	$^{(24)}$2059 260	–	–	[135]
5.	Ukhimath (Garhwal)	$^{(18)}$81	–	$^{(18)}$119	–	$^{(18)}$341	–	–	[143]

Uttarakhand, tab. 8, the Doon valley of Dehradoon has a high concentration of radon which is due to adsorbed uranium in the carbonaceous shales. The radon escape is rapid through weak planes connected in depthdeep with the main boundary thrust and thus this results in a high concentration of radon. The rest of the areas has have a radon concentration well within the limits. The rate of increase of concentration of radon also depends on the rate of exchange between indoor and outdoor air, which depends on the construction of the house, ventilation conditions and the air tightness of the buildings.

Tables 9-14 shows a soil survey of six states which is done with various techniques: Canister, Smart Radon Monitor, RAD7, Alpha Guard, and soil gas probe. The recorded values of radon concentration, exhalation rates in Punjab, Haryana, Rajasthan, Uttar Pradesh and Uttarakhand are lower than the worldwide average values. In the Hamirpur area of Himachal Pradesh the recorded value of radon in soil is higher which may be due to the presence of mineralization of uranium in this area. The concentration of radon in soil also depends on the amount of uranium in the underlying rocks and soil. Rocks and stones contain veins of radioactive materials that decay into radon. When radon released from rocks outside dissipates in the outdoor air, the radon in rocks directly goes through small cracks into the home. Thus, radon from rocks affects indoor air which ultimately affects the inhabitants of the home.

Tables 15-19 show the activity concentration of natural radionuclides in Punjab, Himachal Pradesh, Haryana, Rajasthan, and Uttarakhand, respectively. In Punjab, (tab. 15), the higher concentration of ^{232}Th was observed in Bathinda, Amritsar, Sangrur, Hoshiarpur, Ludhiana, and Mansa which might be due to the mineralization and high content of thorium in soil. In some districts, higher content of radium and potassium is observed which might be due to the use of potassium rich fertilizers for agriculture. In the Una district of the state of Himachal Pradesh (tab. 16), the potassium content is on the higher side which may be due to the mineralization and use of construction material. The Sirsa district of Haryana has a higher value of radionuclides. In the state of Rajasthan, the content of potassium is on the higher side which may be due to the use of fertilizers in agriculture. A higher content of radionuclides was also observed in some of the areas of Uttarakhand.

CONCLUSIONS

In the present study, the results of indoor radon concentration, exhalation rates, activity concentration of natural radionuclides (^{226}Ra, ^{232}Th, and ^{40}K) in six states of northern India Punjab, Haryana, Himachal Pradesh, Rajasthan, Uttar Pradesh and Uttarakhand are shown. From tabs. 3-18 it has been concluded that:

Indoor radon values lie well within the recommended limits in all states except the Hamirpur district of Himachal Pradesh, Bhiwani district of Haryana and Doon valley of the state of Uttarakhand. This may be due to the mineralization of uranium, higher content of uranium and absorbed uranium in the carbonaceous shales.

Radon levels in homes can be reduced by:

– Increasing the under floor ventilation,
– Improving the sealing of floors and walls, and
– Avoiding the passage of radon from basements into living rooms

Improving the ventilation of a house:

Values of radon concentration in soil, exhalation rates in Punjab, Haryana, Rajasthan, Uttar Pradesh and Uttarakhand are recorded lower than the worldwide average values except in the Hamirpur district of Himachal Pradesh. This may be due to the presence of mineralization of uranium in this area. This may also be due to the increased amount of uranium in rocks and soil.

Recorded values of the activity concentration in Punjab, Haryana, Rajasthan, Uttar Pradesh and Uttarakhand are also discussed. In some districts of Punjab, the higher concentration of ^{232}Th was observed which might be due to the mineralization and high content of thorium in soil. In some districts of Haryana, Rajasthan and Uttarakhand, higher content of radium and potassium is observed which might be due to the use of potassium rich fertilizers for agriculture, mineralization and use of construction material. By lowering fertilizer use and mineralization, the higher values of radionuclides can be reduced.

ACKNOWLEDGEMENT

The authors, Dr. Deep Shikha and Dr. Vimal Mehta would like to thank the DBT Star College Scheme (No. BT/HRD/11/020/2018) & UGC-CPE Scheme (F.No.10-96/2016(NS/PE)) for supporting this work. The authors also acknowledge the Principal, SGTB Khalsa College, Sri Anandpur Sahib, for the facilities provided for the completion of this work.

AUTHORS' CONTRIBUTIONS

The idea for this study was put forward by V. Mehta and S. P. Singh. Rupinderjeet Kaur and D. Shikha carried out the scanning of the whole data available in literature. V. Mehta and D. Shikha 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] Phillips, P. S., *et al*., Radon: A Human Carcinogen, National center for Biotechnology Information, *U.S. National Library of Medicine, 80* (1997), pp. 317-36
[2] Dorn, F. E., The Emanation Emitted by Radioactive Substances, *Abhandlungen der Naturforschenden Gesellschaft zu Halle, 23* (1900), pp. 1-15
[3] Vukotić, P., *et al*., Radon Concentration in Multi-Story Building in Montenegro, *Nucl Technol Radiat, 34* (2019), 2, pp. 165-174
[4] Kamenova-Totzeva, R. M., *et al*., Radium Content in Bulgarian Mineral Waters, *Nucl Technol Radiat, 33* (2018), 1, pp. 133-138
[5] ***, International Commission on Radiological Protection, Protection Against Radon-222 at Home and work, (1993), Publication 65
[6] ***, Knolls Atomic Power Laboratory, Chart of the Nuclides, 16th Edition, Lockheed Martin Distribution Services, 2002, Available from www.ChartOfThe Nuclides.com
[7] Brookins, D., The Indoor Radon Problem, New York: Columbia University, 1990
[8] Cohen, B. L., Radon, a Homeowner's Guide to Detection and Control, New York: Consumers Union, 1987
[9] Momčilović, L., *et al*., Seasonality of ^{214}Bi Activity in the Human Body and of ^{222}Rn Concentration in Home Ambient Air, *Health Phys, 92* (2007), 5, pp. 484-487
[10] BEIR IV, Health Risks of Radon and Other Internally Deposited Alpha-Emitters, Washington DC: National Academy, 1988
[11] Abdalla, A. M., El-Gamal, S., Measurement of Indoor Radon Concentration in Different Dwellings in Arar, Saudi Arabia, *Nucl Technol Radiat, 33* (2018), 3, pp. 293-300
[12] ***, IAEA, Radiation Protection Against Radon in Workplaces Other than Mines, Safety Reports Series 33, 2003
[13] Chauhan, R. P., Monitoring of Radon, Thoron and their Progeny in Dwellings of Haryana, *Indian Journal of Pure and Applied Physics, 48* (2010), July, pp. 470-472

[14] Gilbert, E. S., Cross FT and Dagle GE, Analysis of Lung Tumor Risks in Rats Exposed to Radon, *Radiation Research, 145* (1996), 3, pp. 350-360
[15] Field, R.W., *et al*., Residential Radon Gas Exposure and Lung Cancer, *Am. J. Epidemiology, 151* (2000) 11, pp. 1091-1102
[16] Green, B. M. R., *et al*., Radon in Dwellings in England, London, England: *National Radiological Protection Board,* (1992) NRPB-R254, HMSO
[17] Smith, B. J., *et al*., Correlating Point-Referenced Radon and Areal Uranium Data Arising from a Common Spatial Process, *J Royal Soc Series C Appl Stat, 56* (2007), 3, pp. 313-326
[18] Luthi, J. C., *et al*., Residential Radon and Lung Cancer: results form an Ecologic Study in the Swiss Alps, *Epidemiology, 170* (2006), 6, p. 313
[19] Catelinois, O., Lung Cancer Risk Assessment Attributable to Indoor Radon in France, *Epidemiology 17* (2007), 6, p. 67
[20] Samet, J. M., *et al*., Lung Cancer in Never Smokers: Clinical Epidemiology and Environmental Risk Factors, *Clin Cancer Res, 15* (2009), pp. 5626-5645
[21] Edling, C., *et al*., Radon in Homes – A Possible Cause of Lung Cancer, *Scand j Work Environ Health, 10* (1984), Feb., pp. 25-34
[22] Darby, S., Radon in Homes and Risk of Lung Cancer, *Epidemiology, 17* (2006), 6, p. 67
[23] Bochicchio, F., *et al.*, Residential Radon Exposure, Diet and Lung Cancer, A Case-Control Study in a Mediterranean Region, *Int J Cancer, 114* (2005), 6, pp. 983-991
[24] Riesenfeld, E. P., *et al*., Radon Awareness and Mitigation in Vermont, *Health Phys, 92* (2007), 5, pp. 425-431
[25] Ojo, T. J., *et al*., A Review on Environmental Radon and Its Potential Health Risk on Humans, IOSR Journal of Environmental Science, Toxicology And Food Technology (IOSR-JESTFT),8:1(2014), pp. 01-08
[26] Henshaw, D. L., *et al*., Radon as a Causative Factor in Induction of Myeloid Leukemia and Other Cancers, *Lancet, 335* (1990), 1008-1012
[27] Jasimuddin, U. Ahmed., Radon in Human Environment:Assessing the Pictures, *IAEA Bulletin, 2* (1994)
[28] Edling, C., *et al*., Quantification of the Lung Cancer Risk from Radon Daughter Exposure in Dwellings-An Epidemiological Approach, *Environmental International, 12* (1986), pp. 55-60
[29] Srivastava, A., An Overview of an Indoor Radon Study Carried Out in Dwellings in India and Bangladesh During the Last Decade Using Solid State Nuclear Track Detectors, *Journal of Environmental Radioactivity, 78* (2005), pp. 113-121
[30] Petersell, V., *et al*., Radon in the Soil Air of Estonia, *Journal of Environmental Radioactivity, 166* (2017), 235-241
[31] Cucos (Dinu) A., *et al*., Residential, Soil and Water Radon Surveys in North-Western Part of Romania *Journal of Environmental Radioactivity, 166* (2017), pp. 412-416
[32] Poffijn, A., *et al*., The Radon Problem in Schools and Public Buildings in Belgium, *Radiat. Prot. Dosim., 45* (1992), pp. 499-501
[33] Sohrabi, M., *et al*., Determination of the ^{222}Rn Levels in Houses, Schools and Hotels of Ramsar by Atomic Energy Organization of Iran with Passive Radon Diffusion Dosimeters, High Levels of Natural Radiation, IAEA, 1993, Vienna
[34] Subba Ramu, M. C., *et al.*, Indoor Radon Levels of Radon Daughters in Some High Background Areas in India, *Radiation Protection Dosimetry, 30* (1990), pp. 41-44
[35] Srivastava, A., Measurement of Potential Alpha Energy Exposure (PAEE) of Radon and Its Progenies in Dwellings in North Eastern Region of India, *Radiation Measurement, 26* (1996), pp. 291-295
[36] Jindal, M., Sadda, P., MM Writings Publishing House, (2016-17), 4th Revised Edition
[37] Mehta, V., *et al*., Environmental Radon: Health Aspects and Present Status in Northern India, *Indoor and Built Environment, 24* (2015), 1, pp. 52-62
[38] Climate and Seasons of Punjab, https://www.webindia123.com/punjab/land/climate.htm
[39] Geology and Mineral Resources of Himachal Pradesh (pdf), Miscellaneous Publication Number 30:part XVII (pdf)
[40] Dr. Syed, Himachal Pradesh General Knowledge, (2015), Ramesh Publishing House
[41] ***, NIDM, Himachal Pradesh, National Disaster Risk Reduction Portal (pdf)
[42] ***, Climate of Himachal Pradesh-Maps of India, https://www.mapsofindia.com/himachal-pradesh/geography/climate.html (accessed on 28 May 2018)
[43] Geology and Mineral Resources of Haryana, Miscellaneous Publication no. 30: part-XVIII (pdf)
[44] 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
[45] Khanna, C. L., Rajasthan General Knowledge-at a Glance, 2012, Upkar Prakashan
[46] Rajasthan State Action Plan on Climate Change, Government of Rajasthan (pdf)
[47] Uttar Pradesh the State Profile-PHD Research Bureau, PHD Chamber of Commerce and Industry (pdf)
[48] Climate in Uttar Pradesh, https://www.indianholiday.com/uttar-pradesh/climate-in-uttar-pradesh.html (accessed on 29 May, 2018)
[49] ***, Uttar Pradesh State Action Plan on Climate Change' Department of Environment, Government of Uttar Pradesh, pdf
[50] Mehra, R., *et al*., ^{222}Rn and ^{220}Rn Levels of Mansa and Muktsar District of Punjab, India, *Frontier in Environmental Science, 3* (2015), 37, pp.1-7
[51] Duggal, V., *et al*., Indoor Radon Level Measurement in the Dwellings of Northern Rajasthan, India, *Advances in Applies Research Science, 3* (2012), 6, pp. 3956-3960
[52] ***, RAD7 Electronic Radon Detector, User Manual, Durridge Radon Capture and Analytics, 2018
[53] Rani, A., *et al*., Variation of Annual Effective Dose Due to Radon Level in Indoor Air in Marwar Region of Rajasthan, India, AIP Conference Proceedings (2015), 1675:030098, DOI: 10.1063/1.4929314
[54] Ramola, R. C., *et al*., A Study of Seasonal Variations of Radon Levels in Different Types of Houses, *J. Environ. Radioactivity, 39* (1998), 1, pp. 1-7
[55] 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
[56] Ramola, R. C., *et al*., Indoor Radon Levels Around Uttar Kashi and Pauri Garhwal Areas Using Nuclear Track Detectors Techniques, *Radiation Protection Environment, 20* (1997), 4, pp. 198-200
[57] Kumar, A., *et al*., Soil ^{222}Rn Concentration, CO_2 and CH_4 Flux Measurements Around the Jwalamukhi Area of North-West Himalayas, India, *Radiation Protection Dosimetry, 171* (2016), 2, pp. 262-266
[58] Mehra, R., *et al*., Estimation of Annual Effective Dose from Indoor Radon/Thoron Concentrations and Measurement of Radon Concentrations in Soil, *Radiation Protection Dosimetry, 158* (2014), 1, pp. 111-114

[59] Duggal, V., *et al*., Measurement of Soil-Gas Radon in Some Areas of Northern Rajasthan, India, *J. Earth Syst. Sci., 123* (2014), 6, pp. 1241-1247
[60] Mehta, V., *et al*., Radon Exhalation Rates from Some Soil Samples of Nangal, Punjab, *IJITKM Special Issue* (2014), May, pp. 225-227
[61] Khan, M. S., *et al*., Radium and Radon Exhalation Studies of Soil, *Iran*, *J. Radiat. Res., 8* (2011), 4, pp. 207-210
[62] Sharma, H. K., Radon Activity and Radon Exhalation Rates from Some Soil Samples by Using SSNTD, International Journal of Advanced Research in Electrical, *Electronics and Instrumentation Engineering, 2* (2013), 10, pp. 5024-5029
[63] Chauhan, R. P., *et al*., Estimation of Dose Contribution from Ra, Th, and K Radon Exhalation Rates in Soil Samples from Shivalik Foot Hills in India, *Radiation Protection Dosimetry, 158* (2014), 1, pp. 79-86
[64] Mehra, R., *et al*., Measurement of Radioactivity of ^{238}U, ^{226}Ra, ^{232}Th, and ^{40}K in Soil of Different Geological Origins in Northern India, *Journal of Environmental Protection, 2* (2011), Sept., pp. 960-966
[65] Sonkawad, R. G., *et al*., Natural Radioactivity in Common Building Construction and Radiation Shielding Materials, *Atmospheric Environment, 42* (2008), 9, pp. 2254-2259
[66] Mehra, R., *et al*., Assessment of Inhalation Dose from the Indoor ^{222}Rn and ^{220}Rn Using Rad7 and Pinhole Cup Dosimeters, *Radiation Protection Dosimetry, 171* (2016), 2, pp. 208-211
[67] Mehra, R., *et al*., Assessment of Lung Dose from Indoor ^{222}Rn and ^{220}Rn Exposure in the Jalandhar and Kapurthala districts of Punjab, India, *Indoor and Built Environment, 26* (2015), 9, pp. 1305-1310
[68] Sharma, N., *et al*., Environmental Radioactivity: A Case Study of Punjab, India, *Advances in Applied Science Research, 2* (2011), 3, pp. 186-190
[69] Rani, A., *et al*., Indoor Radon Measurements in the Dwellings of Punjab and Himachal Pradesh, *Radiation Protection Dosimetry, 156* (2013), 1, pp. 118-124
[70] Mehra, R., *et al*., Study of Variation of ^{222}Rn/^{220}Rn and Their Progeny Concentration in Dwellings Using Single Entry Pin Hole-Based Diffusion Chambers, *Indoor and Built Environment, 25* (2016), 2, pp. 390-396
[71] Bangotra, P., *et al*., Estimation of EEC, Unattached Fraction and Equilibrium Factor for the Assessment of Radiological Dose Using Pin Hole Cup Dosimeters and Deposition Based Progeny Sensors, *Journal of Environmental Radioactivity, 148* (2015), Oct., pp. 67-73
[72] Mehta, V., *et al*., Study of Indoor Radon, Thoron, Their Progeny Concentration and Radon Exhalation Rate in the Environs of Mohali, Punjab, Northern India, *Aerosol and Air Quality Research, 15* (2015), 4, pp. 1380-1389
[73] 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 and Built Environment, 15* (2006), Oct., pp. 499-505
[74] Singh, B., *et al*., Soil Gas Radon Analysis in Some Areas of Northern Punjab, India, *Environment Monitoring Assessment, 174* (2011), pp. 209-217
[75] Mehra, R., *et al*., ^{226}Ra, ^{232}Th, and ^{40}K Analysis in Soil Samples from Some Areas of Malwa Region, Punjab, India Using Gamma Ray Spectrometry, *Environment Monitoring Assessment, 134* (2007), Mar., pp. 333-342
[76] Mehra, R., *et al*., Analysis of Terrestrial Natural Radionuclides in Soil Samples and Assessment of Average Effective Dose, *Indian Journal of Pure and Applied Physics, 48* (2010), Nov., pp. 805-808
[77] Singh, S., *et al*., ^{226}Ra, ^{232}Th, and ^{40}K Analysis in Soil Samples from Some Areas of Punjab and Himachal Pradesh, India Using Gamma Ray Spectrometry, *Radiation Measurements, 39* (2005), Aug., pp. 431-439
[78] Badhan, K., *et al*., Primordial Radioactivity (^{238}U, ^{232}Th, and ^{40}K) Measurements for Soils of Ludhiana District of Punjab, India, *Radiation Protection Dosimetry, 152* (2012), 1-3, pp. 29-32
[79] Mehra, R., *et al*., Analysis of ^{226}Ra, ^{232}Th, and ^{40}K in Soil Samples for the Assessment of the Average Effective Dose, *Indian J. Phys., 83* (2009), 7, pp. 1031-1037
[80] Bajwa, B. S., *et al*., A Follow-Up Study on Indoor ^{222}Rn, ^{220}Rn and Their Decay Product Concentrations in a Mineralised Zone of Himachal Pradesh, India, *Radiation Protection Dosimetry, 168* (2016), 4, pp. 553-560
[81] Mehra, R., *et al*., Estimation of Annual Effective Dose Due to Radon Level in Indoor Air and Soil Gas in Hamirpur District of Himachal Pradesh, *Journal of Geochemical Exploration, 142* (2014), July, pp. 16-20
[82] Kumar, G., et al., Indoor Radon Monitoring in the Mandi District of Himachal Pradesh, India, for Health Hazard Assessment', *Radioprotection, 51* (2016), 1, pp. 47-50
[83] Kumar, A., *et al*., Radon Exhalation Studies in Building Material Using Solid State Nuclear Track Detector, *PRAMANA Journal of Physics, 62* (2004), 1, pp. 143-146
[84] Kumar, A., *et al*., Study of Soil Gas Radon Variations in the Tectonically Active Dharamshala and Chamba regions, Himachal Pradesh, India, *Environ Earth Sci, 72* (2014), 8, pp. 2837-2847
[85] Singh, S., *et al*., Uranium, Radium and Radon Measurements in the Environs of Nurpur Area, Himachal Himalayas, India, *Environment Monitoring Assessment, 128* (2007), pp. 301-309
[86] Sharma, D. K., *et al*., Geological Significance of Radon Gas in Soil and Underground Water: A Case Study of Nurpur Area, District Kangra, Himachal Pradesh, India, *Radiation Protection and Environment, 36* (2013), 1, pp. 3-9
[87] Bala, P., *et al*., Distribution of Natural Radioactivity in Soil Samples and Radiological Hazards in Building Material of Una, Himachal Pradesh, *Journal of Geochemical Exploration, 142* (2014), July, pp. 11-15
[88] Chauhan, R. P., *et al*., Ventilation Effect on Indoor Radon-Thoron Levels in Dwellings and Correlation with Soil Exhalation Rates, *Indoor and Built Environment, 25* (2016), 1, pp. 203-212
[89] 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), Apr., pp. 226-233
[90] Mann, N., *et al*., Measurement of Indoor Radon-Thoron in Air and Exhalation from Soil in the Environment of Western Haryana, India, *Radiation Protection Dosimetry, 171* (2016), 2, pp. 248-253
[91] Singh, H., *et al*., Regional Variations Pattern of Indoor Radon Levels in Some Areas of Punjab and Haryana, *Radiation Protection Dosimetry, 130* (2008), 2, pp. 257-263
[92] Mehra, R., *et al*., Analysis of Terrestrial Naturally Occurring Radionuclides in Soil Samples from Some Areas of Sirsa District of Haryana, India Using Gamma Ray Spectrometry, *Environment Earth Sciences, 59* (2010), pp. 1159-1164
[93] Kansal, S., *et al*., Analysis and Assessment of Radiological Risk in Soil Samples of Hisar District of

Haryana, India, *Indian Journal of Pure and Applied Physics, 48* (2010), July, pp. 512-515
[94] Kansal, S., *et al*., Evaluation and Analysis of ^{226}Ra, ^{232}Th, and ^{40}K and Radon Exhalation Rate in the Soil Samples for Health Risk Assessment, *International Journal of Low Radiation, 10* (2015), 1, pp. 1-1
[95] Singh, S *et al*., Natural Radioactivity Measurements in Soil Samples from Hamirpur District, Himachal Pradesh, India, *Radiation Measurements, 36* (2003), 1-6, pp. 547-549
[96] Kumar, M., *et al*., Radon/Thoron and Progeny Levels in Dwellings: Regional Variations and Effect of Dwelling Characteristics – A Case Study in Jalandhar district of Punjab, India, *Indoor and Built environment, 27* (2017), 5, pp. 707-714
[97] Saini, K., *et al*., Estimation of Indoor Radon, Thoron and their Decay Products Concentrations Along with Annual Inhalation Dose in Dwellings of Punjab, India, *Indoor and Built Environment, 27* (2016), 3, pp. 380-389
[98] Narang, S., *et al*., A Study of Indoor Radon, Thoron and their Exhalation Rates in the Environment of Fazilka District, Punjab, India, Acta Geophysica (2018), https://doi.org/10.1007/s11600-018-0114-5
[99] Saini, K., *et al*., Mapping Natural Radioactivity of Soil Samples in Different Regions of Punjab, India, *Applied Radiation and Isotopes, 127* (2017), Sept., pp. 73-81
[100] Bangotra, P., *et al*., Estimation of ^{222}Rn Exhalation Rate and Assessment of Radiological Risk from Activity Concentration of ^{226}Ra, ^{232}Th, and ^{40}K, *Journal of Geochemical Exploration, 18*4 (2018), Part B, Jan., pp. 304-310
[101] 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
[102] Deep, S., *et al*., Measurement of Variation of Radon-Thoron and their Progeny Concentrations in Dwellings Using Pin Hole Based Dosimeters, *Aerosol and Air Quality Research, 18* (2018), 3, pp. 811-819
[103] Singh, P., *et al*., Radionuclide Measurements Along with Exhalation Study in Subsoil of Southeast Haryana, India, *Environ Earth Sci., 76* (2017), 1-10, p. 332
[104] Sharma, J., *et al*., Measurement of Indoor Radon, thoron and Annual Effective Doses in the Some Dwellings of Jaipur City, Rajasthan, India, *Int. J. Curr. Res. Aca. Rev., 2* (2014), 8, pp. 112-117
[105] Duggal, V., *et al*., Study of Seasonal Variations of Radon Levels in Different Types of Dwellings in Sri Ganganagar District, Rajasthan, *Journal of Radiation Research and Applied Sciences,7* (2014), 2, pp. 201-206
[106] Duggal, V., *et al*., Measurement of Indoor Radon Concentration and Assessment of Doses in Different Districts of Northern Rajasthan, India, *Indoor and Built Environment, 23* (2013), 8, pp. 1142-1150
[107] Kumar, S., *et al*., Estimation of Indoor Radon Levels in Cities of Rajasthan by SSNTD, *Radiation Protection Dosimetry, 37* (1991), 2, pp. 127-131
[108] Mittal, S., *et al*., Estimation of Radon Concentration in Soil and Groundwater Samples of Northern Rajasthan, India, *Journal of Radiation Research and Applied Sciences, 9* (2016), 2, pp. 125-130
[109] Duggal, V., *et al*., An Investigation of Factors Influencing Indoor Radon Concentrations in Dwellings of Northern Rajasthan, India, *Journal of Geological Society of India, 86* (2015), Aug., pp. 173-180
[110] Duggal, V., *et al*., Study of Radium and Radon Exhalation Rate in Soil Samples from Areas of Northern Rajasthan, *Journal of Geological Society of India, 86* (2015), Sept., pp. 331-336
[111] Rani, A., *et al*., Assessment Of Natural Radionuclides In The Soil Samples From Marwar Region of Rajasthan, India, *Applied Radiation And Isotopes, 101* (2015), July, pp. 122-126
[112] Duggal, V., *et al*., Assessment of Natural Radioactivity Levels and Associated Dose Rates Inin Soil Samples from Northern Rajasthan, India, *Radiation Protection Dosimetry, 158* (2014), 2, pp. 235-240
[113] Verma, D., *et al*., Assessment 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
[114] Verma, D., *et al*., Measurement of Indoor Radon and Thoron in Dwellings of Faizabad City Using Plastic Track Detectors, Indian, *J. of Pure and Applied Physics, 51* (2013), Apr., pp. 219-222
[115] Kumar, A., *et al*., Measurement of Indoor Radon and Thoron Concentration in Environment of Shahjahanpur District of Uttar Pradesh, *International Journal of Science and Research, 3* (2014), 6, pp. 1195-1198
[116] Verma, D., *et al*., Radon and its Progeny Measurement in Dwellings of Farrukabad City of Uttar Pradesh in Northern India, *Indian J. of Pure and Applied Physics, 50* (2012), June, pp. 355-357
[117] Khan, M. S., *et al*., Study of Indoor Radon and its Progeny Levels in Rural Areas of North India Using LR-115 Plastic Track Detectors, *Radiation Measurements, 43* (2008), Suppl. 1, pp. S385-S388
[118] Zubair, M., *et al*., Assessment of Indoor Radon, Thoron and their Decay Products in the Surrounding Areas of Firozabad, Uttar Pradesh, India, *Archives of Applied Science Research, 3* (2011), 1, pp. 77-82
[119] Khan, M. S., *et al*., Measurements of Indoor Radon, Thoron, and Their Progeny Using Twin Cup Dosimeters in Rural Areas of Northern India, *Environ Earth Sci, 71* (2014), 3, pp. 1319-1325
[120] Singha, I., *et al*., Study of Radon and Thoron Concentration in Environment of Moradabad District of Uttar Pradesh, India, *Green Chemistry & Technology Letters, 2* (2016), 4, pp. 171-176
[121] Zubair, M., *et al*., Measurement of Radium Concentration and Radon Exhalation Rates of Soil Samples Collected from Some Areas of Bulandshahr District, Uttar Pradesh, India Using Plastic Track Detectors, *Iran. J. Radiat. Res, 10* (2012), 2, pp. 83-87
[122] Khan, M. S., *et al*., Radium and Radon Exhalation Studies of Soil, *Iran. J. Radiat. Res., 8* (2011), 4, pp. 207-210
[123] Verma, D., *et al*., Assessment of Effective Radium Content and Radon Exhalation Rates in Soil Samples, *Radioanal Nucl Chem, 294* (2012), 2, pp. 267-270
[124] Khan, M. S., *et al*., Study of Radium Content and Radon Exhalation Rates in Soil Samples of Northern India, *Environ Earth Sci., 67* (2012), 5, pp. 1363-1371
[125] Kandari, T., *et al.*, Study of Radiation Exposure Due to Radon, Thoron and Their Progeny in the indoor Environment of Rajpur region of Uttarakhand Himalaya, *Radiation Protection Dosimetry, 171* (2016), 2, pp. 204-207
[126] Kandari, T., *et al*., Estimation of Annual Effective Dose from Radon Concentration Along Main Boundary Thrust (MBT) in Garhwal Himalaya, *Journal of Radiation Research and Applied Sciences, 9* (2016), 3, pp. 228-233
[127] Singh, K., *et al*., Measurement of Radon Thoron and their Progeny in Different Types of Dwellings in Almora District of Kumaun Himalayan Region, *Radiation Protection Dosimetry, 171* (2016), 2, pp. 223-228
[128] Ramola, R. C., *et al*., Variation of Radon and Thoron Levels in Garhwal Homes, Conference Paper, May 2000

[129] Choubey, V. M., *et al*., Soil Gas and Indoor Radon Gas Studies in Doon Valley, India, *Nucl. Geophys, 8* (1994), 1, pp. 49-54
[130] Choubey, V. M., *et al.*, Measurement of Radon and Thoron Concentrations in the Indoor Atmosphere and Drinking Water of Eastern Doon Valley, India, *Indoor Built Environ, 12* (2003), June, pp. 191-196
[131] Choubey, V. M., *et al*., Correlation Between Geology and Radon Levels in Groundwater, Soil and Indoor Air in Bhilangana Valley, Garhwal Himalaya, India, *Environmental Geology, 32* (1997), 4, pp. 258-262
[132] Prasad, M., *et al*., Study of Radiation Exposure due to Radon, Thoron and Progeny in the Indoor Environment of Yamuna and Tons Valleys of Garhwal Himalaya, *Radiation Protection Dosimetry, 171* (2016), 2, pp. 187-191
[133] Joshi ,V., *et al*., Measurement of Radon, Thoron and Their Progeny Concentrations in the Dwellings of Pauri Garhwal, India, *Radiation Protection Dosimetry, 171* (2016), 2, pp. 234-237
[134] Ramola, R. C., *et al*., Dose Estimation Derived from the Exposure to Radon, Thoron and their Progeny in the Indoor Environment, Scientific Reports, 2016, 6:31061. DOI: 10.1038/srep31061
[135] Semwal, P., *et al*., Measurement of ^{222}Rn and ^{220}Rn Exhalation Rate from Soil Samples of Kumaun Hills, India. Acta Geophysica (2018), https://doi.org/10.1007/s11600-018-0124-3
[136] Choubey, V. M., *et al.*, Radon Variations in Soil and Groundwater of Bhilagana Valley, Garhwal Himalaya, India, *Jpn. J. Health Phys., 45* (2010), 3, pp. 278-283
[137] Ramola, R. C., *et al*., Measurement of Radon Exhalation Rate from Soil Samples of Garhwal Himalaya, India, *Journal of Radioanalytical and Nuclear Chemistry, 256* (2003), 2, pp. 219-223
[138] Bourai, A. A., *et al*., Study of Radon Flux From Soil In Budhakedar Region Using SRM, *Radiation Protection Dosimetry, 171* (2016), 2, pp. 267-270
[139] Ramola, R. C., *et al.*, Radionuclide Analysis in the Soil of Kumaun Himalaya, India, Using Gamma Ray Spectrometry, Current Science, 100 (2011), 6, pp. 906-914
[140] Yadav, M., *et al*., Analysis of Natural Radionuclides in Soil Samples of Purola Area of Garhwal Himalaya, India, *Radiation Protection Dosimetry, 167* (2015), 1-3, pp. 215-218
[141] Yadav, M., *et al*., Levels and Effects of Natural Radionuclides in Soil Samples of Garhwal Himalaya, *J Radioanal Nucl Chem, 302* (2014), 2, pp. 869-873
[142] Bisht, R. K., *et al*., Measurements of Radon, Thoron and their Daughter Products in Garhwal Homes, *Proc XIth Symp, SSNTD* (1998), pp. 256-258
[143] Rautela, B. S., *et al*., Study of Natural Radionuclide and Absorbed Gamma Dose in Ukhimath Area of Garhwal Himalaya India, *Radiation Protection Dosimetry, 15*2 (2012), 1-3, pp. 58-61
[144] Ramola, R. C., Survey of Radon and Thoron in homes of Indian Himalaya, *Radiation Protection Dosimetry, 146* (2011), 1-3, pp. 11-13
[145] Mehta, V., *et al*., Measurement of Radon Exhalation Rates from Soil Samples of Some Villages of Ambala, Haryana, *Sch. J. Phys. Math. Stat., 3* (2016), 2, pp. 66-68
[146] 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 and Built Environment, 24* (2014), 6, pp. 833-842
[147] 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), May, pp. 4145-4155
[148] Mehra, R., *et al*., Annual Effective Dose of Radon Due to Exposure in Indoor Air and Groundwater in Bathinda District of Punjab, *Indoor and Built Environment, 25* (2015), 5, pp. 848-856
[149] Mehta, V., *et al*., Measurement of Radon, Thoron and their Progeny in Indoor Environment of Mohali, Punjab, Northern India, Using Pin Hole Dosimeters, *Nucl Technol Radiat, 31* (2016), 3, pp. 299-305

Received on April 15, 2020
Accepted on October 13, 2020

Рупиндерџит КАУР, Дип ШИКА, Суприт Пал СИНГ, Вимал МЕХТА

РАДОН У ОКРУЖЕЊУ, ЈАЧИНА ЕКСХАЛАЦИЈЕ И КОНЦЕНТРАЦИЈА АКТИВНОСТИ ^{236}Ra, ^{232}Th, И ^{40}K У СЕВЕРНОЈ ИНДИЈИ

Људска бића изложена су стално радиоактивности у окружењу. Будући да су главни извори штетног зрачења радионуклиди који се налазе у атмосфери, могу резултирати значајним потенцијалним ризиком за жива бића. На земљиној површини, радиоактивни елементи уранијум и радијум природно су присутни, доприносећи гасовима радона и торона у затвореном простору, као и спољашњој средини, земљи и води. Радон је један од најважнијих загађивача који је, после пушења цигарета, други најчешће узрок стварања рака плућа. Услед забринутости за здравље, многобројне истраживачке организације предузеле су бројне послове како би откриле нивое загађивача на различитим локацијама у свету. Овај рад је покушај да се свеобухватно извести о свим овим студијама са различитим техникама које се спроводе у Северној Индији, тако да би скорија процена нивоа радона у затвореном могла да буде меродавна за даљи рад на овом пољу. Шест северноиндијских држава, то јест, Панџаб, Харјана, Химахал Прадеш, Раџастан, Утар Прадеш и Утаракaнд, узете су на испит. Ова студија такође пружа податке о јачинама ексхалације и концентрације активности природних радионуклида (^{226}Ra, ^{232}Th, и ^{40}K) присутних у овим државама.

Кључне речи: радон у затвореној средини, торон, јачина ексхалације, годишња доза, концентрација активности