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An Investigation of Factors Influencing Indoor Radon Concentrations in Dwellings of Northern Rajasthan, India

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Abstract: An effort has been made to find possible relationships of indoor radon levels with building construction materials, ventilation condition of dwellings and soil gas radon levels. Indoor radon measurements were made using LR-115 type II cellulose nitrate films and the concentrations were estimated by knowing the track density of films through optical microscope. Soil gas radon levels were measured using RAD7, an electronic radon detector manufactured by Durridge Company, USA. This study sheds light on the seasonal indoor radon activities in Rajasthan dwellings. Maximum values of the indoor radon concentration were observed during the winter and minimum during the summer season. Results show that ventilation rate is inversely proportional to radon level. Highest level of indoor radon concentration was found in the mud type dwellings compared with dwellings made of concrete, cement and marble. A positive correlation (R^2 = 0.45) between indoor radon and soil gas radon concentration was observed. A weak positive correlation (R^2 = 0.22) was observed between soil gas radon concentration and radium content in soil. Indoor radon concentration was found to be associated with the presence of radon concentration in local soil, building material used for roof, floor and walls, type of ventilation conditions and presence of cracks on the walls/floor. Positive correlation between indoor and soil gas radon concentration suggest the large contribution of local soil towards indoor radon.

Keywords: Building materials; Indoor radon; LR-115; RAD7 radon detector; Soil, Rajasthan.

INTRODUCTION

^{222}Rn is an alpha emitter that decays with a half-life of 3.8 days into a short-lived series of progeny. A certain fraction of radon progeny may attach to aerosol particles. By inhalation these particles may be deposited in lungs thereby exposing sensitive tissues with alpha radiation. Consequently, it may lead to lung cancer and has been identified to be the second leading cause of lung cancer after tobacco smoking (IARC 1988). In general, residential radon is regulated by a reference level of radon concentration between 200 and 300 Bq m^{-3} based on International Commission on Radiological Protection recommendations (ICRP 2010). About the action level of radon, the World Health Organization has suggested that home owners take actions when radon levels exceed 100 Bq m^{-3}. This is much more conservative figure than the Environmental Protection Agency (EPA) action level of 148 Bq m^{-3} (EPA 1991), which has been the U.S. standard for many years (WHO 2009). The indoor radon concentrations are largely influenced by factors such as topography, type of constructions, building materials, type of soils, temperature, pressure, humidity, ventilation, wind speed and even the lifestyle of the people living in the dwellings (ECA 1995). Henshaw et al. (1990) claimed that indoor radon exposure is associated with the risk of leukaemia and certain other cancers, such as melanoma and cancers of the kidney and prostate (Henshaw et al. 1990). In India, several studies were conducted to measure radon concentration in soil and air (Duggal et al. 2013; Rani et al. 2013; Singh et al. 2005; Kansal et al. 2012; Jayanthi et al. 2011; Prasad et al. 2008). The concentration of indoor radon and its decay products shows large temporal and local fluctuations in the indoor atmosphere due to the variation in topography, house construction type, soil characteristics and weather (Mehra et al. 2006).

Seasonal variations in indoor radon concentrations and some influencing factors have been studied during a one-year period (December 2011 – November 2012) in 50 dwellings made of different building materials in Hanumangarh district of Rajasthan. The annual exposure of occupants, the annual effective dose received by them, and their lifetime fatality risk estimates were assessed in light of guidelines given by International Commission on

Radiological Protection (ICRP 1993). An effort has been made to find possible relationships of indoor radon levels with building construction materials, ventilation condition of dwellings and soil gas radon levels.

GEOLOGY OF HANUMANGARH DISTRICT

The district is situated in the northern most region of the state and forms a part of Indo-Gangatic plain. Figure 1 shows the geographic location of the state of Rajasthan in India, as well as the location of the sampling sites in Hanumangarh district. It has a geographical area of 12,645 km^2. The population of Hanumangarh district is approximately 18 lakh. It is bounded on the north by Punjab state, on the east by Haryana state, on the south by Churu district of Rajasthan, on the west by Sri Ganganagar district of Rajasthan. The climate of the district is marked by the large variation of temperature, extreme dryness and scanty rainfall. Minimum and maximum temperature is 1ºC and 45ºC respectively, whereas the mean temperature remained 23ºC. The normal annual rainfall of the district is 253 mm.

The area is covered by wind blown sands and alluvium excepts for a few patches of recent calcerous and sandy sediments associated with gypsite. The oldest rocks of the area belong to Aravalli Super Groups which includes phyllite, shale and quartz veins, which are overlain by the rocks of the upper Vindhyan which are entirely made up bright to pale red fine and medium grained compact sand stone and siltstone. The only major mineral occurrence of the district is gypsite. The whole district is plain. Its shows a general slope towards north, generally the sand dunes are 4-5 m high except in the south western part, where they are more intensely developed, being sometimes 10-15 m high. No important hill exists in the district. The height of the district varies between 168 and 227 m above the mean sea level. The Ghaggar river is an ephemeral one and has north-east to south-west course near Hanumangarh.

The soil of the Hanumangarh district is yellowish brown in colour, loam to silty loam with massive or blocky structure and are calcareous in nature and stratification is common in these soils. Soils vary in their characteristics along very short distance. At many places they are intermixed with sandy material.

Types of Dwelling and Materials Used for Construction

Most of the houses in the surveyed area are of cement construction and partially ventilated and only a few are mud-type with poor ventilation. Local mud, rocks, cement, sand, bricks, marble and concrete have been used in the construction of these houses. Most of the houses in the surveyed area have single storey, while few of them have a double storey also. In the study area, most dwellings are of 5–30 years old and only a few dwellings are more than 30 years old. In our survey no house was found using mechanical ventilators and fans are used only in a few limited houses. The mud-type earthen-floored houses were built with local mud, unfired bricks and most of them are poorly ventilated having no windows. The sizes of these houses and their rooms are different from area to area and also within the location.

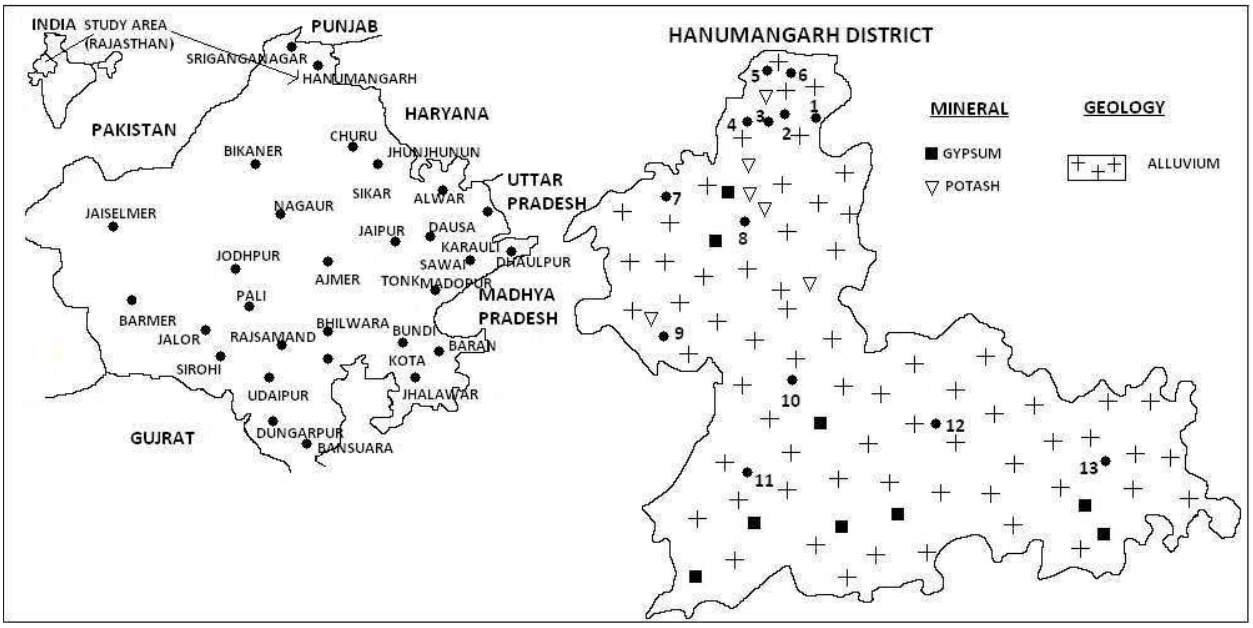

Fig.1. Map of Rajasthan showing the area surveyed during the present investigations

MATERIALS AND METHODS

Soil Radon Study

The radon concentration was measured in 52 soil samples from 13 villages/towns of the Hanumangarh district using RAD7, an electronic radon detector (Durridge Co., USA). From each village/town 4 soil samples were analyzed for radon activity concentration. The RAD7 radon monitor apparatus uses an air pump and a solid state alpha detector which consists of a semiconductor material (generally silicon) that converts alpha radiation directly to an electrical signal. It has desiccant ($CaSo_4$) tubes and inlet filters (pore size 1μm) that blocks fine dust particles and radon daughters from entering the radon test chamber. The RAD7's internal sample cell is a 0.7 litter hemisphere, coated on the inside with an electrical conductor. The centre of the hemisphere is occupied by a silicon alpha detector. One important benefit of solid state devices is ruggedness. Another advantage is the ability to immediately differentiate radon from thoron by the energy of the alpha particle released. The RAD7 has also the ability to tell the difference between the new radon daughters and the old radon daughters left from previous tests. The equipment is portable and battery operated, and the measurement is fast.

The soil-gas samples of each site were collected with the help of the stainless steel probe supplied by DURRIDGE COMPANY (USA), immersed in the soil to a depth of about 1 meter, which was then connected to the RAD7 detector with a special accessory for the purpose. Figure 2 shows the schematic diagram of RAD7 soil-gas setup. The probe was penetrated in the soil with a rotating handle or immersed with gentle strokes of a hammer. The measurements were performed where the soil is uniform and generally free of rocks. Sometimes the depth of the hole was less than 1 meter due to poor development of soil above the parent rock or the pebbly nature of the soil that did not allow the rod to reach 1 meter depth. Taking radon measurement at a depth of about 1 meter, this greatly minimizes errors that arise from shallow depths. Another reason for suggesting depths around 1 meter is that via the process of leaching of the uranium and radium from the top soil, the radon concentration would be more likely to be stable at these depths than at sub-soil levels. The depths of the sampling point is determined by the length of the probe inserted into the ground taking into consideration the location of the sampling points on the probe shaft. Before the counting process started, the hole was properly sealed in order to prevent mixing of soil-gas with air from atmosphere.

For accurate readings, the RAD7 has been dried out thoroughly to reduce the relative humidity below 10% before making each measurement. The sniff protocol and grab mode were used for the soil-gas sampling on the RAD7 detector at each site. The measuring instrument was then attached to the probe for sucking the soil-gas from the deep soil. The soil was sucked through the tube pipe into the measuring instrument for 5 minutes pumping phase. The instrument will wait another five minutes and then count for four five-minute cycles. At the end of the half-hour period, the RAD7 will print out a summary of the measurement, including an average radon concentration in the soil-gas from the four 5-minute cycle measurements. This method gives a quick (half-hour) reading and uses the least amount of soil-gas. The accuracy will depend on the radon concentration, and would typically be better than ±10%. The RAD7 directly gives the radon concentration in the units of Becquerel per meter cube (Bq m^{-3}). All these samples were collected in the month of September to October 2012, during which the temperature remained in the range of 25–40ºC. The average relative humidity of the experimental sites ranges from 22 to 48%. The sampling test should be carried out between 9.00 and 18.00 and not in the rain, in case of rain, should be carried out next day.

Indoor Radon Study

LR-115 type II plastic track detector films and the bare

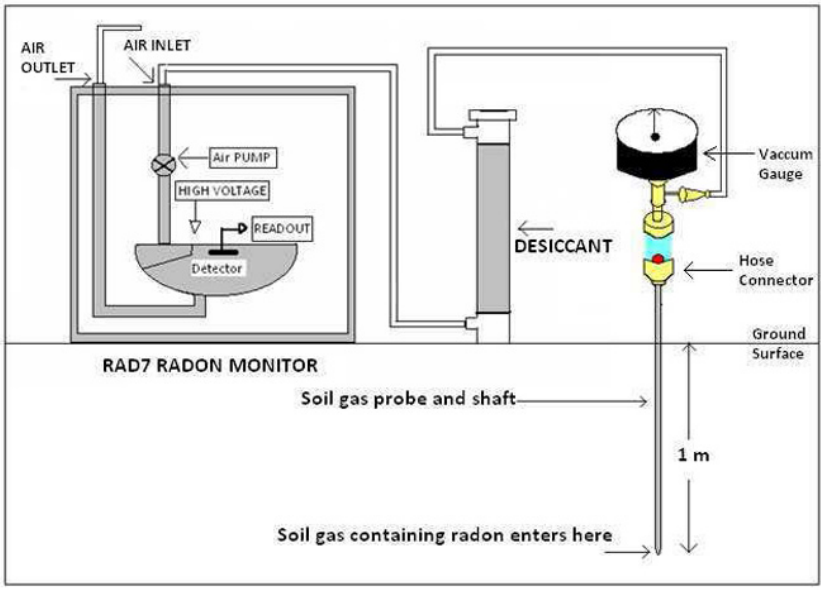

Fig.2. The schematic diagram of the RAD7 soil-gas setup.

mode technique were used to measure the concentration of radon in the indoor environment (Mishra et al. 1997; Ramola et al. 1998; Mehra et al. 2006; Duggal et al. 2013). The houses were chosen in such a manner that the dwellings constructed with different types of building materials and in different localities of the towns/villages were covered. The detectors of size 1.5 cm × 1.5 cm were suspended in the rooms of the dwellings at a height >2 m above the ground level (so that the detectors were not disturbed by the movement of the residents) and about 1 m below the ceiling of the room so that direct alpha particles from the building material of the ceiling did not reach the detectors. The authors assumed that a room with a door and without window would be poorly ventilated, that with one window and a door as partially ventilated and with two or more windows and a door as well ventilated. After exposure the detectors were removed and etched using 2.5N NaOH solutions at 60°C for 90 min. After thorough washing, the detectors were scanned for track density measurements using an optical microscope at a magnification of 400 ×. The track density so obtained was converted into the units of Bq m^{-3} of the radon concentration using the calibration factor of 0.020 ± 0.002 tracks cm^{-2} d^{-1} (Bq $m^{-3})^{-1}$ determined experimentally by Eappen et al. (2001), which satisfies the conditions prevailing in the Indian dwellings. In the bare mode technique there can be some contribution from thoron (^{220}Rn) also. However, the report by UNSCEAR (2000) reveals that the contribution from ^{220}Rn and its progeny in dwellings is in general about 10% of that of ^{222}Rn and its progeny. So this component can be neglected from the point of view of inhalation dose.

RESULTS AND DISCUSSION

The ^{222}Rn concentrations were measured in 52 soil samples from 13 villages of Hanumangarh district, Rajasthan at a depth of about 1 meter using RAD7 detector manufactured by Durridge Company, USA. The measured results are shown in Table 1. The radon concentration in soil vary from 1.46 ± 0.21 in village Sangaryia to 10.50 ± 0.84 kBq m^{-3} in village Rawatsar with an average value of 4.29 ± 2.64 kBq m^{-3}. Figure 3 shows the distribution of soil gas radon concentration (kBq m^{-3}) in 52 sample locations of 13 villages of Hanumangarh district of Rajasthan. The variations in the soil gas radon may be due to the factors that includes the distribution of radium content, the moisture content, the porosity, the density of soil, the underlying bedrocks and meteorological effects. The soil gas radon activity values obtained in the present investigations are comparatively lower than those reported in some areas of Upper Siwaliks (11.5 to 78.47 kBq m^{-3}) by Singh et al. (2010), Northern Punjab (0.3 to 35.8 kBq l^{-1}) by Singh et al. (2011), Kangra district of Himachal Pradesh (1.1 to 82.2 kBq m^{-3}) by Singh et al. (2006) but higher than those reported for soil gas in Hamirpur district of Himachal Pradesh (0.035 to 2.28 kBq m^{-3}) by Mehra et al. (2013).

The results for the annual indoor radon concentrations along with standard deviation of the yearly recorded values in 10 villages of Hanumangarh district of Rajasthan are summarized in Table 2. The radon concentration levels varied from 134 ± 4 to 185 ± 44 Bq m^{-3} in winter, 106 ± 20 to 141 ± 42 Bq m^{-3} in spring, 92 ± 25 to 127 ± 32 Bq m^{-3} in summer and 112 ± 30 to 152 ± 40 Bq m^{-3} in autumn time and the average values were found to be 153 ± 15, 115 ± 10, 102 ± 10 and 125 ± 14 Bq m^{-3}, respectively. The annual average indoor radon concentration varies from 113 ± 14 to 147 ± 26 Bq m^{-3} with a mean value of 124 ± 11 Bq m^{-3}. The minimum value is observed in Hanumangarh city and maximum in Rasuwala village. These values are three to four times more than the world average value 40 Bq m^{-3} reported by United Nations Scientific Committee on the Effects of Atomic Radiation (UNSCEAR 2000). The present results of annual average radon levels are lower than the actual levels recommended by International Commission on Radiological Protection (200 – 300 Bq m^{-3}) (ICRP 2010) and US Environmental Protection Agency (148 Bq m^{-3}) (EPA

Table 1. ^{222}Rn concentration in 52 soil samples at the selected 13 villages/towns of Hanumangarh district.

Sr. No.	Sample Location	Number of samples	Latitude and Longitude	Radon concentration in soil (kBq m^{-3}) Min	Max	Mean	SD	Temp (°C)
1	Sangaryia	4	29.47 N 74.28 E	1.24	1.67	1.46	0.21	27
2	Morjand Sikhan	4	29.80 N 74.39 E	3.95	4.33	4.16	0.16	25
3	Amarpura Jallu Khatt	4	29.79 N 74.33 E	1.62	2.03	1.86	0.17	29
4	Shahpini	4	29.81 N 74.29 E	5.07	5.68	5.41	0.27	26
5	Rasuwala	4	29.90 N 74.32 E	6.18	8.04	6.94	0.70	36
6	Nukera	4	29.88 N 74.37 E	2.47	3.01	2.70	0.25	32
7	Amar Singh wala	4	29.64 N 74.07 E	5.79	6.99	6.30	0.57	33
8	Hanumangarh city	4	29.58 N 74.31 E	5.59	8.82	7.04	1.36	35
9	Pilibanga	4	29.49 N 74.09 E	1.49	2.08	1.78	0.26	40
10	Rawatsar	4	29.28 N 74.38 E	9.67	11.90	10.50	0.84	33
11	Bisarasar	4	28.87 N 74.24 E	2.14	3.38	2.80	0.53	36
12	Nohar	4	29.18 N 74.77 E	2.02	2.60	2.28	0.26	33
13	Bhadra	4	29.12 N 75.17 E	2.27	2.78	2.60	0.23	32

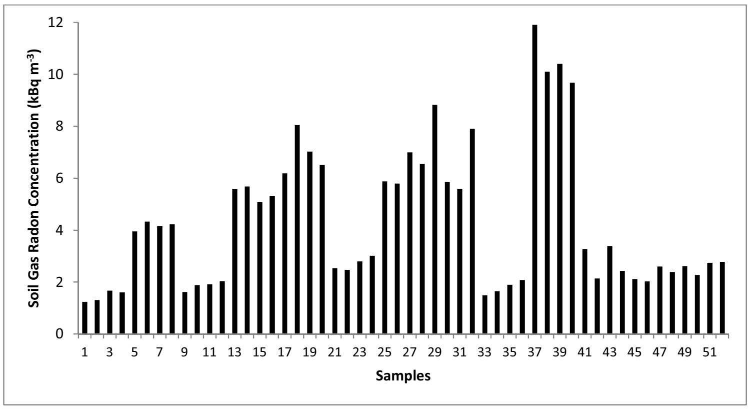

Fig.3. Distribution of soil-gas radon concentration (kBq m^{-3}) in 52 sample locations of 13 villages of Hanumangarh district of Rajasthan, India

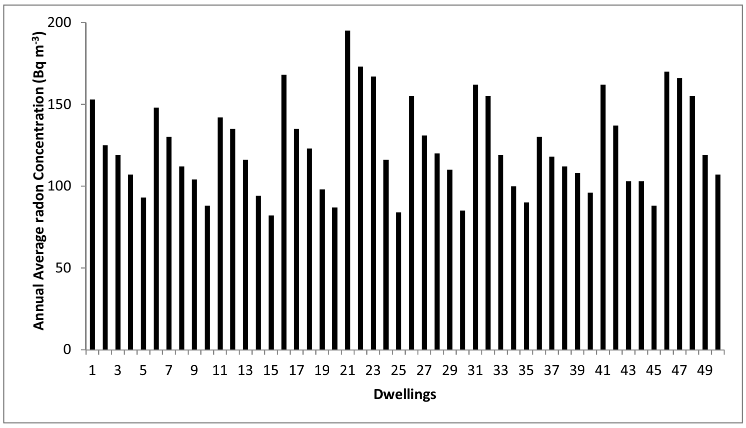

Fig.4. Distribution of annual average radon concentration (Bq m^{-3}) in 50 dwellings of 10 villages of Hanumangarh district of Rajasthan, India

1991). However, these values are higher than the actual level (100 Bq m^{-3}) recommended by World Health Organization (WHO 2009).

The annual exposure to the occupants, the annual effective dose and the lifetime fatality risk for each of the 10 villages were calculated. The calculations were made using the conversion factors given elsewhere (ICRP 1993, Raghavayya 1994) according to which the exposure of an individual to radon progeny of 1 WLM is equivalent to 3.54 mJh m^{-3}. The conversion factor of 3 × 10^{-4} WLM^{-1} and 3.88 WLM^{-1} were used for calculating the lifetime fatality risk and the annual effective dose, respectively. The annual effective dose received by the residents of the study area varies from 1.93 ± 0.24 to 2.51 ± 0.45 mSv y^{-1} with a mean value of 2.12 ± 0.19 mSv y^{-1}, which is less than the lower limit of the actual level (3 – 10 mSv y^{-1}) recommended by International Commission on Radiological Protection (ICRP 1993). The annual exposure to the occupants in the study area varies from 1.76 mJh m^{-3} (0.50 WLM) to 2.29 mJh m^{-3} (0.65 WLM) with a mean value of 1.93 mJh m^{-3} (0.55 WLM). The lifetime fatality risk of the residents of the study area varies from 1.49 × 10^{-4} to 1.94 × 10^{-4} with an average value of 1.64 × 10^{-4}. The average value of the lifetime fatality risk of 1.64 × 10^{-4} (0.02%) is relatively a small fraction (about 4%) of the lifetime risk of lung cancer due to cigarette smoking and chewing of tobacco (Evans et al. 1981). Figure 4 shows the distribution of the annual average radon concentration for all the 50 dwellings of 10 villages studied in Hanumangarh district.

The relationships between indoor radon level, ventilation condition, building material and winter to summer radon ratio are discussed in Table 3. It is evident from Table 3 that the radon level in well-ventilated dwellings is lower compared with that in the poorly ventilated dwellings. This is because in well-ventilated dwellings the radon can easily escape out. Moreover, the results (Table 3) reveal that the seasonal variation of indoor radon shows high values in winter and low values in summer. This is because the doors and windows of the dwellings remained closed most of the times in winter season compared with summer season hence the ventilation is poor in winter. The winter to summer radon ratio ranges from 1.27 to 1.74 with a mean value of 1.52 ± 0.15.

In order to find the distribution of radon levels in the different types of dwellings, we have classified the data according to the building material used for roof, floor and walls in these dwellings. The results are summarized in Table 4. The indoor radon concentration with respect to the type of dwellings of A_1, A_2, A_3 and A_4 ranges from 88 to 173 Bq m^{-3}, 107 to 195 Bq m^{-3}, 82 to 155 Bq m^{-3} and 116 to 167 Bq m^{-3} with overall mean values of 113 ± 25, 152 ± 25, 111 ± 22 and 139 ± 18 Bq m^{-3}, respectively. Figure 5 shows the variation of mean radon concentrations in the dwellings constructed with different types of building materials. Highest level of indoor radon concentration was found in the mud type dwellings (A_2). This may be attributed to the rich content of radium in the local soil used for construction. Relatively higher indoor radon concentration in the mud dwellings (A_2) was due to the little exchange of air in these dwellings. This may be attributed to the age and poor ventilation condition of these dwellings compared to others. Furthermore, the exhalation of radon from the walls, roofs and floors of mud dwellings (A_2) is higher than that of modern dwellings because of cracks and defective joints in their walls, roofs and floors.

Table 2. Seasonal variation in the indoor radon concentration in the dwellings of Hanumangarh district, Rajasthan, the annual effective dose; the annual exposure to occupants and their lifetime fatality risk estimates

Sample Location	Detector No.	Indoor radon activity concentration (Bq m^{-3}) Winter (December – February) Min	Max	Mean±SD	Spring (March – May) Min	Max	Mean±SD	Summer (June – August) Min	Max	Mean±SD	Autumn (September – November) Min	Max	Mean±SD	Annual average radon concentration (Bq m^{-3})	Annual Exposure WLM	mJh m^{-3}	Annual Effective dose (mSv y^{-1})	Lifetime fatality risk × 10^{-4}
Sangaryia	1–5	103	203	155±33	78	139	106±20	85	117	99±12	99	153	118±19	119±22	0.52	1.86	2.03±0.37	1.57
Morjand Sikhan	6–10	110	178	139±24	78	135	108±21	96	131	109±13	60	149	112±30	117±13	0.52	1.82	2.00±0.22	1.55
Amarpura Jallu Khatt	11–15	99	181	141±33	82	131	108±20	50	121	92±25	96	135	115±16	114±18	0.50	1.78	1.95±0.30	1.51
Shahpini	16–20	114	220	156±36	85	149	114±23	57	132	92±27	92	171	127±30	122±23	0.54	1.90	2.09±0.40	1.61
Rasuwala	21–25	107	235	185±44	85	178	141±42	64	163	111±33	82	203	152±40	147±26	0.65	2.29	2.51±0.45	1.94
Nukera	26–30	124	195	151±24	71	149	119±26	68	131	97±20	78	146	114±25	120±20	0.53	1.87	2.05±0.34	1.59
Amar Singh wala	31–35	124	203	159±33	71	142	113±26	71	124	97±22	92	181	133±36	125±23	0.55	1.95	2.14±0.40	1.65
Hanumangarh city	36–40	128	139	134±4	92	131	107±13	68	114	95±15	96	135	115±13	113±14	0.50	1.76	1.93±0.24	1.49
Pilibanga	41–45	99	196	139±40	78	153	111±25	78	131	104±18	96	167	120±26	118±13	0.52	1.84	2.02±0.22	1.56
Rawatsar	46–50	139	206	174±25	89	153	125±28	82	156	127±32	117	167	148±19	143±20	0.63	2.23	2.44±0.57	1.89

Table 3. The building materials, ventilation conditions and winter to summer ratio of the radon concentration for all the dwellings of Hanumangarh district, Rajasthan

Sr. no	Sample Location	Dwelling 1 Type	V.C.	W	S	W/S	Dwelling 2 Type	V.C.	W	S	W/S	Dwelling 3 Type	V.C.	W	S	W/S	Dwelling 4 Type	V.C.	W	S	W/S	Dwelling 5 Type	V.C.	W	S	W/S	Avg. W/S ratio
1	Sangaryia	A_2	I	203	117	1.73	A_4	I	167	107	1.56	A_4	II	163	92	1.77	A_2	II	139	85	1.63	A_1	III	103	92	1.12	1.56
2	Morjand Sikhan	A_4	I	178	131	1.36	A_2	II	153	114	1.34	A_1	III	128	96	1.33	A_4	II	124	99	1.25	A_1	II	110	103	1.07	1.27
3	Amarpura Jallu Khatt	A_3	II	181	121	1.50	A_4	II	167	110	1.52	A_1	I	153	99	1.54	A_1	II	103	78	1.32	A_4	III	99	50	1.98	1.57
4	Shahpini	A_2	I	220	132	1.67	A_3	II	163	110	1.48	A_4	II	146	92	1.59	A_1	II	135	68	1.98	A_4	II	113	57	1.98	1.74
5	Rasuwala	A_2	I	235	163	1.44	A_1	I	213	121	1.76	A_3	I	199	117	1.70	A_3	I	171	89	1.92	A_4	II	107	64	1.67	1.70
6	Nukera	A_4	I	195	131	1.49	A_3	I	153	103	1.48	A_1	I	142	96	1.48	A_1	II	139	89	1.56	A_4	III	124	68	1.82	1.59
7	Amar Singh wala	A_2	I	203	124	1.64	A_3	I	192	121	1.59	A_1	II	146	92	1.59	A_4	II	128	78	1.64	A_4	III	124	71	1.75	1.64
8	Hanumangarh city	A_3	I	139	114	1.22	A_2	II	135	103	1.31	A_1	II	135	99	1.36	A_4	III	131	92	1.42	A_4	III	128	68	1.88	1.44
9	Pilibanga	A_2	II	196	131	1.50	A_4	I	181	114	1.59	A_1	II	114	96	1.19	A_4	II	107	99	1.08	A_1	III	99	78	1.27	1.33
10	Rawatsar	A_1	I	206	156	1.32	A_2	II	195	153	1.27	A_2	II	178	149	1.19	A_4	II	153	96	1.59	A_1	I	139	82	1.69	1.41

V.C.: ventilation condition, **I:** poorly ventilated, **II:** partially ventilated, **III:** well ventilated; **W:** winter, **S:** summer, **W/S:** winter to summer ratio; **A_1:** Floor: cemented, Roof: cement + concrete, Wall: burnt clay bricks, cemented, white wash; **A_2:** Floor: mud, Roof: bricks + mud, Wall: mud, clay wash; **A_3:** Floor: cemented, Roof: bricks + cemented, Wall: burnt clay bricks, cemented, white wash; **A_4:** Floor: marble, Roof: cement + concrete, Wall: burnt clay bricks, cemented, white wash.

Table 4. Indoor ^{222}Rn concentrations in the dwellings constructed with different types of building materials.

Dwelling types	Floor	Roof	Wall	Number of dwellings	Average radon activity concentrations (Bq m^{-3}) Range	Mean
A_1	Cemented	Cement + Concrete	Burnt clay Bricks, Cemented, White wash	15	88–173	113±25
A_2	Mud	Bricks + Mud	Mud, Clay wash	10	107–195	152±25
A_3	Cemented	Bricks + Cemented	Burnt clay Bricks, Cemented, White wash	18	82–155	111±22
A_4	Marble	Cement + Concrete	burnt clay Bricks, Cemented, White wash	7	116–167	139±18

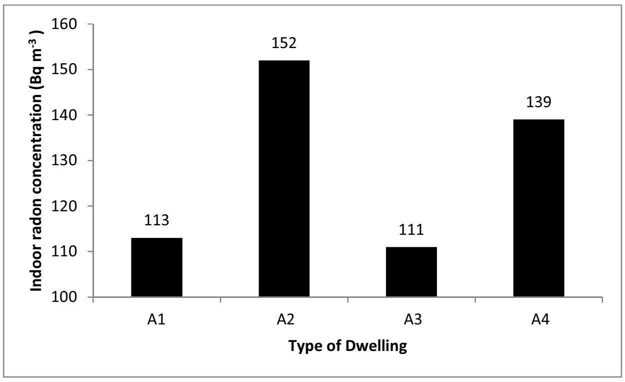

Fig.5. Mean values of radon concentration for the different types of dwellings in Hanumangarh district.

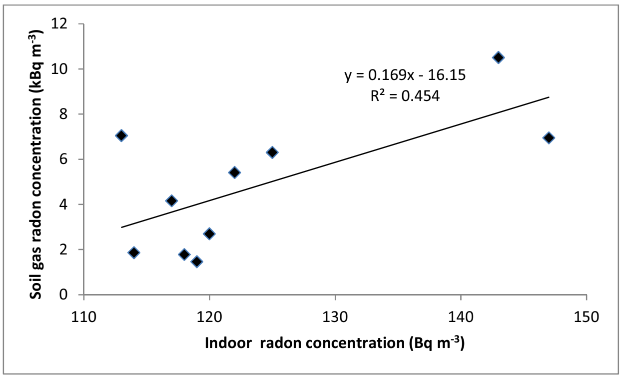

Fig.7. Correlation between indoor radon (Bq m^{-3}) and soil-gas radon levels (kBq m^{-3}).

Earlier our group reported the high concentration of radium in local soil of similar area (Duggal et al. 2013). The radium concentration in local soil obtained was found to vary from 47 ± 11 to 65 ± 11 Bq kg^{-1}. A weak positive correlation (R^2 = 0.22) was observed between soil-gas radon concentration and radium content in soil (Fig.6). Weak positive correlation of soil-gas radon with radium content may be due to the moisture content of the soil. Weak positive correlation of soil-gas radon with radium content show the unstable geological conditions, which lead to disequilibrium and disturb the correlation conditions. Since the most indoor radon comes into the building from the soil or rock beneath it, an effort has been made to find a possible correlation between soil gas radon with the indoor radon levels. A positive correlation (R^2 = 0.45) between indoor radon and soil gas radon concentration suggest the large contribution of local soil towards indoor radon (Fig.7). Our result shows a behavior which agree with the findings of Mehra et al. (2013) for Hamirpur district of Himachal Pradesh, Singh et al (2010). for some areas of upper Siwaliks, India and that of Antoci et al. (2007) for southeast Sicily, Italy.

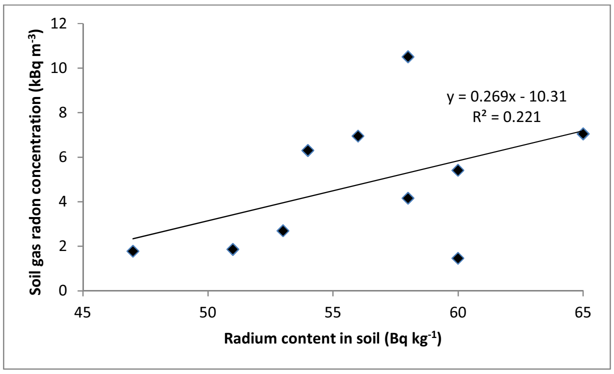

Fig.6. Correlation between soil-gas radon concentration (kBq m^{-3}) and radium content in soil (Bq kg^{-1})

CONCLUSION

1 Seasonal variations in indoor radon concentrations and some influencing factors have been studied during a one-year period in 50 dwellings made of different building materials.
2 The annual average radon concentrations are lower than the actual levels recommended by International Commission on Radiological Protection and US Environmental Protection Agency. However, these values are higher than the levels recommended by World Health Organization.
3 The annual effective dose in the study area is even less than the lower limit of the level recommended by International Commission on Radiological Protection.
4 It has been observed that there is a considerable variation in the indoor radon concentrations with the seasons during a complete year. Maximum values of the indoor radon concentration are observed during the winter and minimum during the summer season.
5 Results show that ventilation rate is inversely proportional to radon level.
6 Highest level of indoor radon concentration was found in the mud type dwellings compared with dwellings made of concrete, cement and marble.
7 The radon values in soil gas in the study area are lower than those reported in neighboring states and thus seem to be safe from the point of view of health hazards.
8 A positive correlation (R^2 = 0.45) between indoor radon concentration and the soil gas radon concentration suggest the large contribution of local soil towards indoor radon.
9 A weak positive correlation (R^2 = 0.22) was observed between soil gas radon concentration and radium content in soil.
10 This preliminary study shows that the radon concentration in dwellings is the effect of several aspects

such as the concentration of radon in the local soil, building construction materials used for roof, floor and walls, type of ventilation conditions and presence of cracks on the walls/floor.

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