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Estimation of inhalation dose due to exposure to radon, thoron and their progeny in the indoor environment of Shahjahanpur, Uttar Pradesh, India

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Abstract

Radon and thoron is a radioactive gas that emanates from rocks and soils and tends to concentrate in an indoor environment. Soil gas infiltration is identified as the most important source of residential radon. Other sources, including building materials and water extracted from wells, are also important in some circumstances. Radon is one of the major contributors to the ionizing radiation dose received by the general population. The dose due to radon and thoron are mainly delivered by their decay products which tend to get deposited in the respiratory organs of humans during breathing. In this study the measurement of radon, thoron and their daughter products concentration were carried out in the residential houses of Shahjahanpur, Uttar Pradesh, India using solid state nuclear track detector (SSNTD). The measurements were made in residential houses in the indoor environment of Shahjahanpur, using a twin chamber radon dosimeter. In the present study, it is found that the average value of radon and thoron concentration varies from 18.77 Bq/m^3 to 44.95 Bq/m^3 and 10.89 Bq/m^3 to 21.20 Bq/m^3 respectively while the average value of radon progeny and thoron progeny concentration varies from 2.02mWL to 4.85 mWL and .29 mWL to 0.57 mWL respectively. The observed value of radon, thoron and their progeny concentration inside the dwellings were found to be lower than the ICRP value of 200 Bq/m^3 and thus are within safe limits.

Key words: Radon, Thoron, Solid State Nuclear Track Detector – SSNTD, Dosimeter.

Introduction

The behaviors of the radioactive gases have received considerable attention over the past few decades due to the radiological risks to humans in indoor atmosphere. High radon levels were measured in dwellings in a number of countries including United States, Sweden and the United Kingdom[1] and there is a concern that these high levels of radon may lead to an increased risk of lung cancer. These high indoor radon levels can exceed international guidelines[2] and are associated with a number of factors including uranium content of the soil, soil porosity, building materials mode of construction, ventilation, and metrological parameters. These factors account for the large range of the radon levels found and measured in dwellings.

Recent epidemiological evidence also suggests that inhalation of radon decay products in domestic environments could be a cause of lung cancer[3,4,5,6,7,8]. The present study was performed in order to estimate the indoor radon, thoron, and their daughter product concentration levels in the environment of Shahjahanpur district of Uttar Pradesh in India. Measurements were made both in new and traditional houses covering bedrooms as well as drawing rooms. The few traditional mud houses in the rural area are also selected for installation of dosimeters which are old, mostly poor ventilated having small one window or without window and with only one door.

Measurement techniques :

The concentration of radon, thoron and their daughter products were measured by using LR-115 Type II plastic track detector. Three small pieces of detector films (size - 2.5 cm x 2.5cm) were fixed in a twin chamber radon/thoron dosimeter having three different modes.

The bare mode gives the values of radon, thoron and their progeny concentrations while the filter and membrane modes record the values due to radon, thoron, and pure radon gas respectively. The dosimeters were suspended inside the house at a height of about two meters from the ground floor. After an exposure time of about three months, the detector films were removed, etched and scanned for the track density measurements. The recorded track density was then converted in the Bq/m3 by using an appropriate calibration factor[9]. This measurement was repeated on a time integrated four quarterly cycles to cover all the four seasons of a calendar year.

Radon measurement :

The indoor radon concentration in the dwellings of Shahjahanpur was measured using LR-115 type IInd plastic track detectors using twin cup dosimeter. 70 dosimeters were installed, but 62 are included in the study due to losses. Both new and old houses were chosen for installing dosimeters. Some dosimeters are installed in mud houses particularly in rural areas like Kalan and Mirjapur. The dwellings in the area of study are mainly made of bricks using concrete and cement. The dwellings for the purpose of installing dosimeters were selected taking into account the degree of ventilation, number of windows and doors, type of floor, etc. since all of these factors are responsible for variation in indoor radon concentration.

The season wise indoor radon, thoron, and their progeny concentration were obtained after converting measured track densities using spark counter into Bq/m^3 by using appropriate Calibration, given by-

$$3.12 \times 10^{-2} \text{ tracks cm}^{-2} \text{ d}^{-1} = 1 \text{ Bqm}^{-3}$$

The minimum indoor radon concentration (7 Bq/m^3) was recorded in Shahjahanpur city at SPN02 in summer while the highest concentration (75 Bq/m^3) is recorded in Mirjapur at MIJ03 in winter with average value 27.71 Bq/m^3. The minimum value in summer at SPN02 is due to the construction structure of the house. The site SPN02 was greatly ventilated, and the dosimeter is installed in the balcony of a two story building at first floor. Due to high air exchange rate, the concentration is least. Also, earlier studies revel that radon concentration decreases with height from the ground. Also in the summer season, the houses remain open for a long time which contributes to increasing air exchange rate.

The highest concentration (75 Bq/m^3) is recorded in Mirjapur at MIJ03 in winter. This is because the dosimeter is installed in a house inside the room having mud walls and mud floor near the bank of the river the Ramganga having one door and no window. As it was near the bank of the river, moister was high in the environment. The mud walls and mud floor also possible cause in increasing indoor concentration due to exhalation of radon from the soil. Also in winter, the rooms are remaining closed for long hours decreasing air exchange. The experimental results obtained for radon and its progeny are given in the table 1:

Table 1.

Location	No. of Houses	Seasonal variation of radon concentration (Bq/m^3)											
		SUMMER			RAINY			AUTUMN			WINTER		
		Min.	Max.	Ave	Min.	Max.	Ave	Min.	Max.	Ave	Min.	Max.	Ave
SHAHJAHANPUR CITY	4	7	15	10.6	10	27	21	15	34	24.8	29	40	35
KANT	3	9	17	13	15	31	24	10	37	27.3	32	49	38.3
JALALABAD	3	16	21	18	21	31	25.6	18	19	18.5	27	37	31.6
ALLAHAGANJ	3	10	21	14.6	9	24	18.3	25	34	29	32	38	34.3
MIRJAPUR	3	16	27	21.5	28	36	32.6	46	56	50	62	75	68
POWYAN	3	13	27	19.3	24	48	36	29	39	33.3	27	37	36.5
BANDA	3	18	22	20.3	22	38	28.3	21	40	31.3	38	42	40
TILHAR	4	8	15	10.6	12	22	18.2	33	37	32.2	38	52	37.2
KATRA	3	11	32	20	24	31	27	20	32	27	28	39	32
KHUDAGANJ	2	12	19	15.5	37	43	40	30	35	32.5	34	39	36.5
NIGOHI	3	16	23	18.6	21	34	29	31	38	34.5	37	54	43.6
MADNAPUR	3	10	20	15.3	9	22	17.3	10	34	23	17	37	29
ROZA	3	13	16	14.5	23	27	26	18	46	30.6	31	37	33.3
KHUTAR	3	12	15	15	13	33	24.3	33	42	36.6	39	54	44.3
DADRAUL	2	9	12	11	15	38	25	23	37	29	35	52	41
SHARAMAU	3	8	15	11.3	25	27	26	15	34	24.6	15	23	17.6
BANTHRA	3	16	19	17.3	21	37	29.6	24	30	27	19	28	23
KALAN	2	22	23	22.5	32	45	38.5	31	38	34.5	37	40	38.5
HULLAPUR	2	16	17	16.5	21	26	28.5		35	35	46	65	55.5
CHAURASIA	2	9	13	11	15	26	20.5	29	37	33	38	49	43.5

Thoron measurements :

The minimum indoor thron concentration (6 Bq/m^3) was recorded in Khudaganj, Kant, Dadraul, and Kalan in summer while the highest concentration (42 Bq/m^3) is recorded in Mirjapur in winter. The average value of thoron concentration in the study area was found 16.62 Bq/m^3 for the complete year. The results obtained are given in tables. The minimum indoor thron concentration in summer was recorded 6 Bq/m^3 in Khudaganj, Kant, Dadraul, and Kalan while maximum indoor thoron concentration in summer was observed 29 Bq/m^3 in Nigohi with an average of 11.86 Bq/m^3 for the whole study area. The minimum indoor thron concentration in rainy was recorded 7 Bq/m^3 in Khudaganj, Kant and Jalalabad while maximum indoor thoron concentration in rainy was observed 24 Bq/m^3 in Powyan, Banda, Madnapur, and Roza with an average of 16.06 Bq/m^3 for the whole study area. The minimum indoor thron concentration in winter was recorded 9 Bq/m^3 in Khudaganj while maximum indoor thoron concentration in winter was observed 42 Bq/m^3 in Mirjapur with an average of 21.35 Bq/m^3 for the whole study area. The minimum indoor thron concentration in autumn was recorded 8 Bq/m^3 in Shahjahanpur while maximum indoor thoron concentration in autumn was observed 31 Bq/m^3 in Nigohi with an average of 17.74 Bq/m^3 for the whole study area.

There were variations in the values of thoron concentration in study area obtained during the course of study. The concentration was found least in summer while highest in winter which is similar to indoor radon concentration.

In the summer season, the houses remain open for a long time which contributes to increasing air exchange rate while th in winter, the rooms are remaining closed for long hours decreasing air exchange. This is the possible cause for thoron variaton.

In a national radon survey done by BARC, Mumbai and published by Head, Library and information services Division in September 2003, the minimum and maximum concentration of thoron in India were reported 3.5Bq/m^3 and 42.8 Bq/m^3 respectively. The concentration of thoron and in the study area was observed in the above range and below the recommended action level set by various organizations.

Table 2.

Location	No. of Houses	Seasonal variation of thoron concentration (Bq/m^3)											
		SUMMER			RAINY			AUTUMN			WINTER		
		Min.	Max.	Ave	Min.	Max.	Ave	Min.	Max.	Ave	Min.	Max.	Ave
SHAHJAHANPUR CITY	4	7	9	7.8	8	12	10.5	8	18	13.8	17	22	19.6
KANT	3	6	9	7.6	7	21	16.3	8	27	19	16	36	23.3
JALALABAD	3	10	16	13	7	19	12.3	13	15	14	15	23	17.6
ALLAHAGANJ	3	7	11	9	12	15	11.3	13	17	15.3	15	25	20.6
MIRJAPUR	3	13	15	14	15	18	17	12	31	20.3	19	42	28.3
POWYAN	3	7	21	13	16	24	19.3	15	23	18	14	27	20.5
BANDA	3	13	25	18	14	24	18	17	27	23.6	19	21	20
TILHAR	4	7	10	10	7	19	14.6	13	23	16.2	21	27	23.2
KATRA	3	9	15	11.6	18	21	19.3	10	19	14	17	24	20.3
KHUDAGANJ	2	6	12	9	19	23	21	17	21	19	13	26	19.5
NIGOHI	3	10	29	18.6	16	31	23	15	24	19.5	19	43	30
MADNAPUR	3	12	18	14	19	24	22	21	27	24	21	22	20.3
ROZA	3	9	13	10.6	14	24	18.3	17	19	18.3	21	28	24
KHUTAR	3	11	21	15.6	16	19	17.6	13	21	16.3	24	27	25.5
DADRAUL	2	7	9	7.33	11	12	11.5	8	11	11.6	17	22	19
SHARAMAU	3	8	12	10	11	19	14	13	15	14	15	23	17.6
BANTHRA	3	9	10	9.5	13	22	17	16	24	20	19	28	23
KALAN	2	6	9	7.5	13	21	17	16	27	21.5	16	21	18.5
HULLAPUR	2	8	13	10.5	14	21	17.5	17	22	19.5	18	21	19.5
CHAURASIA	2	12	17	14.5	16	19	17.5	22	27	24.5	19		19

Radon daughter products :

The seasonal variation of daughter concentration of radon, thoron in terms of (PAEC) potential alpha energy concentration (mWL) can be calculated. The measured radon/thoron PAEC was converted into radon concentration using the formula-

$$C_R \text{ or } C_T\ (Bq/m^3) = PAEC\ (WL) \times 3700/F$$

Where F is equilibrium factor, and its value is 0.4 for radon and 0.1 for thoron.

The radon progeny concentration in Shahjahanpur district was found least (0.76 mWL) in Shahjahanpur city in summer while highest (5.24mWL) in Mirjapur in winter with mean value 3.02 mWL. The radon progeny concentration in Shahjahanpur district during summer was found least (0.76 mWL) in Shahjahanpur city while highest (2.91 mWL) in Powyan with a mean value of 1.71 mWL. The radon progeny concentration in Shahjahanpur district during the rainy season was found least (0.97 mWL) in Allahaganj and Madnapur while highest (4.64 mWL) in Khudaganj with a mean value of 2.8 mWL. The radon progeny concentration in Shahjahanpur district during autumn was found least (1.08 mWL) in Madnapur while highest (4.97mWL) in Mirjapur with a mean value of 3.3 mWL. The radon progeny concentration in Shahjahanpur district during winter was found least (1.08 mWL) in Shahjahanpur city while highest (8.1 mWL) in Mirjapur with a mean value of 4.25mWL.

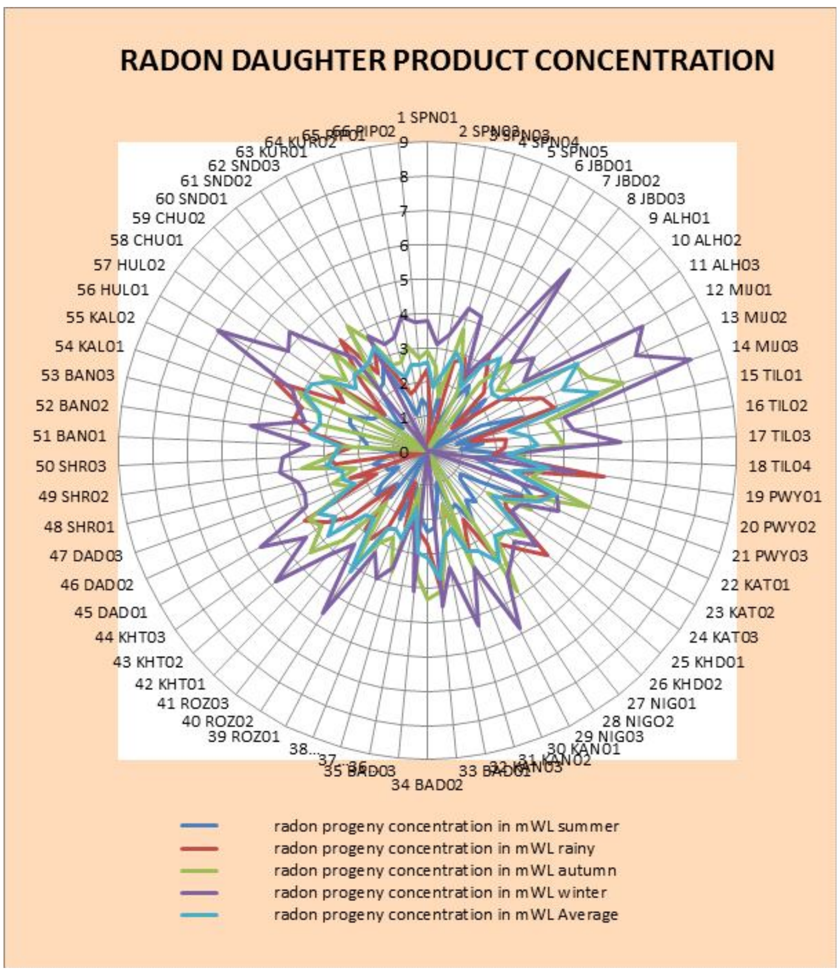


Fig. 1.

Inhalation dose :

The inhalation dose is directly related to the total potential alpha energy concentration (PAEC) of the daughter nuclides and is generally expressed in working level (WL) units. The concept of the working level (WL), a radon progeny concentration unit, developed as a measure of the potential occupational exposure of uranium miners. It has been widely used as a measure of the environmental concentration of radon progeny in indoor air and has been extended to thoron progeny as well[10]. The inhalation dose was calculated for the study area in Shajahanpur district. The concentration of radon and thoron and their progeny in Mirjapur where dosimeter was installed in a mud house was found higher compared to the other sites. The high values of radon and thoron in the mud house may be due to the typical construction of mud house and the construction materials used. The emanation from the ground surface and from the building materials of mud houses results in the high value of radon and thoron inside the room[11,12]. The flow of radon and thoron impedes into the interior of cemented houses due to the coating of ground surface and walls with the layers of cement in the cemented house. As the soil is an important source of indoor radon[13], the emanation of radon is also higher from the ground surface of the house.

The inhalation dose in msvy $^{-1}$ can be estimated by using formula-

$$D = \{(0.17 + 9 F_R) C_R + (0.11 + 32 F_T) C_T\} \times 7000 \times 10^{-6}$$

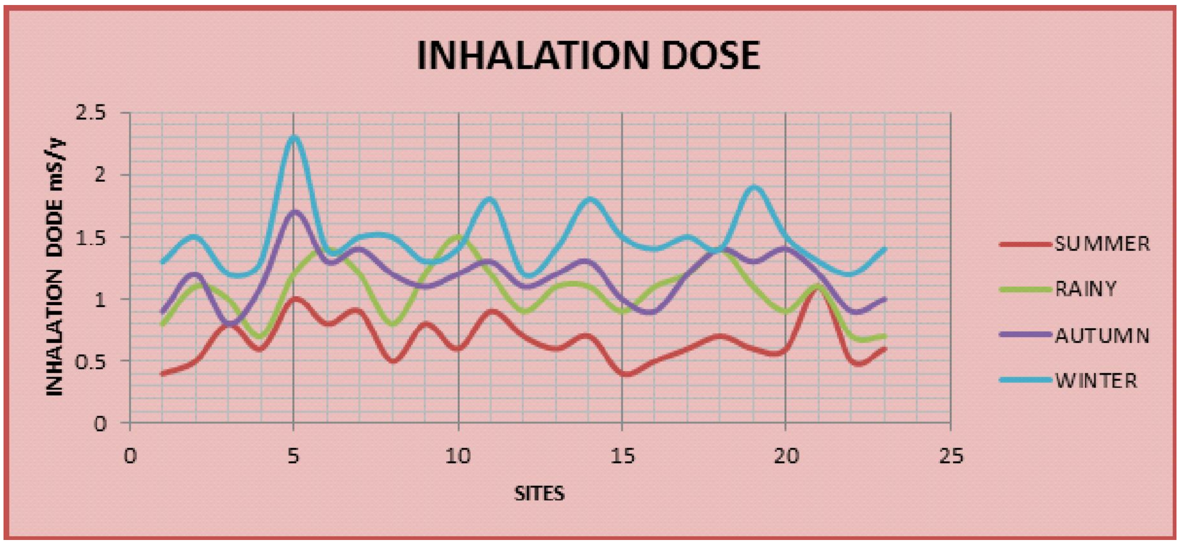
Where F is equilibrium factor, having average values 0.4 and 0.1 for radon and progeny and thoron and progeny, respectively[14,15]. C_R and C_T are radon and thoron concentrations, respectively.

Table 3

LOCATION	INHALATION DOSE (mSvy^{-1})				
	SUMMER	RAINY	AUTUN	WINTER	Avg.
SHAHJAHANPUR CITY	0.4	0.8	0.9	1.3	0.8
KANT	0.5	1.1	1.2	1.5	1.1
JALALABAD	0.8	1	0.8	1.2	1
ALLAHAGANJ	0.6	0.7	1.1	1.3	0.9
MIRJAPUR	1	1.2	1.7	2.3	1.6
POWYAN	0.8	1.4	1.3	1.4	1.2
BANDA	0.9	1.2	1.4	1.5	1.3
TILHAR	0.5	0.8	1.2	1.5	1
KATRA	0.8	1.2	1.1	1.3	1.1
KHUDAGANJ	0.6	1.5	1.2	1.4	1.2
NIGOHI	0.9	1.2	1.3	1.8	1.3
MADNAPUR	0.7	0.9	1.1	1.2	1
ROZA	0.6	1.1	1.2	1.4	1.1
KHUTAR	0.7	1.1	1.3	1.8	1.2
DADRAUL	0.4	0.9	1	1.5	1
SHARAMAU	0.5	1.1	0.9	1.4	1
BANTHRA	0.6	1.2	1.2	1.5	1.1
KALAN	0.7	1.4	1.4	1.4	1.2
HULLAPUR	0.6	1.1	1.3	1.9	1.2
CHAURASIA	0.6	0.9	1.4	1.5	1.1

The inhalation dose rate due to indoor radon in dwellings is shown in Table 3. The inhalation dose rate was found to be highest in winter and lowest in the summer season. Inhalation dose rate in summer found to vary from 0.4 $mSvy^{-1}$ to 1.1 $mSvy^{-1}$ with an average value 0.7 $mSvy^{-1}$, whereas in winter it varies from 1.2 $mSvy^{-1}$ to 2.3 $mSvy^{-1}$ with an average value 1.5 $mSvy^{-1}$. Inhalation dose rate in autumn vary from 0.8 $mSvy^{-1}$ to 1.7 $msvy^{-1}$ with an average value 1.2 $mSvy^{-1}$, while in the rainy season it was found to vary from 0.7 $mSvy^{-1}$ to 1.4 $mSvy^{-1}$ with an average value 1.1 $mSvy^{-1}$. The higher inhalation dose rate in winter is mainly due to poor ventilation conditions of houses during the winter season, which influences the inhalation dose rate inside a house.

In a national radon survey done by BARC, Mumbai and published by Head, Library and information services Division in September 2003, the minimum and maximum inhalation dose due to radon, thoron and its progeny in India were reported 0.27 $mSvy^{-1}$ and 5.14 $mSvy^{-1}$ respectively. The calculated dose is within the safe limit in the study area.



Conclusions and suggestions

The aim of present work was to measure the concentration of radon, thoron and their daughter products in the indoor atmosphere and inhalation dose in Shahjahanpur district. Based on these data, the radiological consequences were to be investigated. Shajahanpur district with geographical area of 4575 Km^2 is a large district having total population 19,87,395 (census 2001). It is a district having three main rivers, the Ganga, the Ramganga and the Garrah and a large fraction of its total population lived near the banks of above said rivers. The radon, thoron, their daughter products concentration and inhalation dose in the dwellings of Shahjahanpur were measured using LR-115 type IInd plastic track detectors based on SSNTD technique using twin cup dosimeter. In rural areas like Mirjapur and Kalan, some dosimeters are installed in mud houses. The seasonal variation of radon, thoron and their daughter products was studied.

The results of the systematic study are obtained by considering the room as a space in which the radon and thoron levels are directly related to the dynamic and static parameters.

The minimum radon concentration (7 Bq/m^3) was recorded in Shahjahanpur city at SPN02 in summer while the highest concentration (75 Bq/m^3) is recorded in Mirjapur at MIJ03 in winter with average value 27.71 Bq/m^3. The least concentration in summer was due to increase in temperature which results in virtual mixing and rising of aerosol and dust particles to a higher altitude, so there will be the reduction in aerosol and dust particles near the earth surface, and hence the radon concentration decreases. The maximum concentration in winter is essentially influenced by the intense temperature inversion, which generally occurs in winter when the wind velocity is low. The maximum concentration in winter is also the result of decreased ventilation because in winter season the houses are closed for a long time and radon accumulated inside the room.

The minimum thoron concentration (6 Bq/m^3) was recorded in Khudaganj, Kant, Dadraul and Kalan and Piprola in summer while the highest concentration (42 Bq/m^3) is recorded in Mirjapur in winter. The average value of thoron concentration in the study area was found 16.62 Bq/m^3 for the complete year. The radon progeny concentration in Shahjahanpur district was found least (0.76 mWL) in Shahjahanpur city in summer while highest (5.24mWL) in Mirjapur in winter with mean value 3.02 mWL.

The inhalation dose rate was found to be highest in winter and lowest in the summer season. Inhalation dose rate in summer found to vary from 0.4 mSvy^{-1} to 1.1 mSvy^{-1} with an average value 0.7 mSvy^{-1}, whereas in winter it varies from 1.2 mSvy^{-1} to 2.3 mSvy^{-1} with an average value 1.5 mSvy^{-1}. Inhalation dose rate in autumn vary from 0.8 mSvy^{-1} to 1.7 mSvy^{-1} with an average value 1.2 mSvy^{-1}, while in the rainy season it was found to vary from 0.7 mSvy^{-1} to 1.4 mSvy^{-1} with an average value 1.1 mSvy^{-1}. Since the results were taken as the average of four seasons of a year, the estimated inhalation dose is expected to be quite accurate.

The concentration of radon and thoron in the study area were observed below the recommended action level set by various organizations. In a national radon survey done by BARC, Mumbai and published by Head, Library and information services Division in September 2003, the minimum and maximum concentration of radon, thoron and inhalation dose in India was reported 4.6 Bq/m^3 and 147.3 Bq/m^3, 3.5 Bq/m^3 to 42.8 Bq/m^3 and 0.27 msvy^{-1} to 5.14 msvy^{-1} respectively.

Based on the result, it was concluded that radon concentration varies with, temperature, humidity and atmospheric pressure As humidity decreases the temperature increases which results in the maximum vertical mixing and rising of dust particles and vice versa. The significant variation of radon concentration was observed for different seasons. It is found that the average radon concentration is maximum during winter season and minimum during the summer season. The radon concentration gradually decreases towards summer and monsoon, the factors that may affect is high temperature and low pressure in summer. During the monsoon with south west winds having strong wind velocity and heavy precipitation, a decrease in radon concentration was found. The decrease of radon in monsoon is due to other factors also, *i.e.*, the soil is saturated with water during monsoon.[16]

The ratio of winter to summer season is slightly more than winter to rainy and winter to autumn. Seasonal variation of radon concentration depends on several parameters that include the type of houses, radon source, living habits of inhabitants, the ventilation system of the houses, outdoor climate and metrological parameters like moisture, pressure, wind speed and temperature differences .This seasonal variation may be attributed to the fact that during hot summer season people lives self ventilated, houses keep open which result in the minimum radon concentration. On the other hand, they normally keep the windows closed in the winter season that results in poor ventilation and hence increased radon levels.

The significant variation in the standard deviation of result suggests that extensive regular survey in this area is needed. Although seasonal variation for one complete year is studied, still diurnal and monthly investigation is suggested in the area.

Geological impacts on the values had minor effect as the entire selected area has almost same soil and rocks. On analyzing the results, it was observed that the radon, thorn and its daughter product concentration higher in mud houses. The possible cause could be the exhalation of radon gas from the soil.

In the area close to industrial area radon concentration is found little higher than the areas in localities. It may be due to the drainage of the harmful chemicals including radioactive elements from industries. Recently thermal power plant was established in Roza, Shahjahanpur. It will be quite interesting to note the change in concentration of radioactive elements in the atmosphere of Shahjahanpur in future. Although the results obtained from site Roza at present indicate no specific significant change in concentration in comparison to other sites, but the recorded concentration will play an important role in all comparative studies proposed in forth coming time and in estimating total radiation dose for habitants of Shahjahanpur.

The present work could be taken as the base model for coming investigations in study area. With atmospheric radon concentration variation, the change will also predict in water radon concentration. These new assumptions will be quite important for further investigations of radon levels in this study area. Theoretical model of radon concentration can also be developed by taking all parameters in consideration.

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References

1. UNSCEAR, Sources, effects and risks of ionizing radiation. United Nations Scientific Committee on Effects of Atomic Radiation. Report to General Assembly with annexes. United Nations sales Publications E. 88.IX.7. United Nations New York (1988).
2. ICRP, Lung Cancer Risk for Indoor Exposure to Radon Daughters. ICRP Publication 50, Pergamon Press, Oxford (1988).
3. ICRP (International Commission on Radiological Protection). “Protection against radon-222 at home and at work”. ICRP Publication 65, Annals of the ICRP 23(2), Pergamon Press, Oxford. (1993).
4. UNSCEAR, Sources and effects of ionizing radiation. United Nations Scientific Committee on Effects of Atomic Radiation. Report to General Assembly with annexes. United Nations sales Publications E.94.IX.2. United Nations New York (1993).
5. Lubin, J. H., Boice, J. D. Jr., Edling, C., Hornung, R. W., Howe, G., Kunz, E., Kuziak, R.A., Morrison, H. T., Radford, E.P., Samet, J.M., Timarche, M., Wood Ward, A., Yao, S.X., Pierce, D.A., Lung Cancer in radon exposed miners and estimation of risk from indoor exposure. J Natl cancer Inst. *87*, 817-827 (1995).
6. NRC, National Research Council. Health Effects of Exposures to Radon. BEIR VI, Washington National Academy Press (1999).
7. World Health Organization, International Radon Project Survey on Radon Guidelines, Programmes and

Activities. WHO, Geneva (2007).

8. World Health Organization, WHO Report on the Global Tobacco Epidemic -The MPOWER package. WHO, Geneva (2008).
9. Ramola, R.C., Rawat, R.B.S., Kandari, M.S., Ramachandran, T.V., Eappen, K.P. and Subba Ramu, M.C., Indoor Built Environ. *5*, 364-366 (1996).
10. Dowell, E.M., Ronald, J.F and Horld, L.G.Jr., Time-averaged Exposures to 220Rn and 222Rn Progeny in Colorado Homes. Health Phys. *58*, 05-713 (1990).
11. Ramola, R.C., Kandari, M.S., Rawat, R.B.S., Ramachandran, T.V. and Choubey, V.M., A study of seasonal variations of radon levels in different types of houses. J. Environ. Radioactivity *39,* 1-7 (1998a).
12. Ramola, R.C., Rawat R.B.S. and Kandari M.S., Estimation of risk from environmental exposure to radon in Tehri Garhwal. Nucl. Geophys. *9*, 383-386 (1995).
13. Schery, S.D., Whittlestone, S., Hart, K.P. and Hill, S.E., the flux of radon and thoron from Australian soils, J. Geophys. Res. *94*, 8567-8576 (1986).
14. UNSCEAR, United Nation Scientific Committee on the Effect of Atomic Radiation. Annex B: Exposures from Natural Radiation Sources. United Nations, p. 104 (2000).
15. R. C. Ramola, Mukesh Prasad, Tushar Kandari, Preeti Pant,Rosaline Mishra & S. Tokonami, Dose estimation derived from the exposure to radon, thoron and their progeny in the indoor environment, nature.com, scientific report, 31061, pp 1-16 (2016).
16. Dr. Mohd. Salim Ahmad Khan, Measurements of Radon Gas (^{222}Rn) Concentration in Ground Water in Shahjahanpur City of Uttar Pradesh by Using Radon Emanometer Technique, American International Journal of Research in Science, Technology, Engineering & Mathematics, *11(2),* June-August, 2015, pp. 167-171.