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Indoor radon/thoron survey report from Hamirpur and Una districts, Himachal Pradesh, India

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Abstract

A survey of indoor radon and thoron levels has been carried out in a number of villages in the vicinity of uranium bearing sites in the Hamirpur and Una districts of Himachal Pradesh (H.P.), India. Levels were analysed with reference to the nature of building material, soil type and different seasons of the year. The one year average for radon concentration was found to vary from a minimum of 19.7 to a maximum of 146.3 Bq/m^3 while the minimum and maximum thoron concentrations were 9.1 and 70.7 Bq/m^3, respectively. The dose rate varied from 0.1 to 8.67 μSv/h. These are discussed in the light of ICRP recommendations. © 2000 Elsevier Science Ltd. All rights reserved.

Keywords: Radon; Thoron; Alpha tracks; Dosimeter cups; Inhalation dose

1. Introduction

The presence of ^{222}Rn and ^{220}Rn in indoor environment constitutes a major health hazard for man. The short-lived daughters of radon (^{222}Rn) and thoron (^{220}Rn) are well established as causative agents of lung cancer (Rajewsky, 1940; Sevc et al., 1976; Edling et al., 1986; Jacobi, 1991). These are mostly radioactive isotopes of Po, Pb and Bi which when produced in the air attach to the aerosol particles that are present. These radioactive aerosols when inhaled give rise to radiation dose to the lungs. For these reasons, it is very important to assess the indoor environment for exposure from radon, thoron and their daughters particularly in areas known to have high radioactive contents of soil.

As the daughters are responsible for the inhaled dose, the equilibrium factor between parent gas and daughters must be known in order to measure the dose accurately. It is known that the equilibrium factor varies from house to house, depending on the ventilation of the house and aerosol concentration. The equilibrium factor is reported to vary from 0.2 to 0.95 for India (Ramachandran et al., 1994). As such, use of a single average value for the equilibrium factor will not provide an accurate assessment of the inhaled dose.

Some areas of Himachal Pradesh, India, particularly the Hamirpur and Una districts, are well known for uranium mineralisation (Narayan Das et al., 1979). Some earlier studies have reported very high values of soil-gas radon in Himachal Pradesh (Ramola et al., 1989; Virk et al., 1998a,b). We have selected some villages near the radioactive mineral bearing sites for measurement of indoor levels of radon and thoron using the plastic track detector material LR-115, and twin chamber dosimeter cups.

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2. Experimental technique

Experimental techniques for radon measurement are based on alpha counting of radon and thoron daughters. The track-etch technique, using plastic detectors, is considered to be one of the best techniques available for passive long-term integrated measurements (Frank and Benton, 1977). In this survey, we have utilised this technique using 12-μm thick cellulose nitrate film, commonly known as LR-115 Type II, as our detector. Details of this technique are available elsewhere (Prasad, 1994; Virk et al., 1998a,b).

We have used twin chamber dosimeter cups to measure the concentration of radon and thoron separately. The detectors were exposed in these cups, the latter being obtained from Environment Assessment Division, BARC, Trombay. Each cup has two chambers, each with a height of 4.5 cm and a diameter of 6.2 cm. The detectors were fixed at the bottom of each chamber, the mouth of one chamber being covered with glass fibre filter paper and the other with a semi-permeable membrane (NWSUR, 1994). These cups also have provision for exposing the detector in bare mode on the outer side of the cup. The detector that is placed in the chamber covered by a membrane records alpha tracks due to radon (^{222}Rn), the membrane only allowing radon to pass through it, suppressing the thoron to less than 1%. The other detector, covered with filter paper, records tracks due to alpha particles from radon and thoron. The bare detector records the tracks due to alpha particles from radon, thoron and their progeny and is used to determine radon and thoron concentration in mWL. From this data the inhalation dose due to radon, thoron and their progeny can be calculated. These cups were exposed in 29 dwellings at a height of about 2.5 m from the ground. The total exposure period of 1 yr was obtained as two, three-month surveys, and one six-month survey. The exposed detectors were etched under standard conditions (2.5 N NaOH solution at 60°C for 80 min.) and track density measurements were made using a spark-counter. Then, using the calibration factors and the software developed at the Bhabha Atomic Research Centre (BARC), Trombay, the track densities were converted to radon and thoron concentrations. Other parameters, such as dose, equilibrium factors and progeny concentrations were also calculated.

3. Theoretical formulation

The methodology proposed by Mayya et al. (1998) for mixed field situations has been used to calculate the dose rate as well as equilibrium factors. Here we let T_1, T_2, T_3 be the track densities for the membrane chamber film, filter paper chamber film and bare film, respectively. S_1 and S_1' are the calibration factors for the radon in the membrane and filter compartments, respectively, S_2 is the calibration factor for thoron in the filter compartment, and d is the exposure period in days.

Thus, radon concentration is given by

$$C_R = T_1/(d \cdot S_1), \tag{1}$$

and thoron concentration by

$$C_T = (T_2 - d \cdot C_R \cdot S_1')/(d \cdot S_2). \tag{2}$$

The activity fractions of the progeny are controlled by their wall loss rates for the fine fractions (λ_W^F), coarse fractions (λ_W^C) and ventilation rate (λ_V), through use of the following formulae:

For radon progeny:

$$F_{R\text{-}A} = \lambda_{R\text{-}A}/[\lambda_{R\text{-}A} + f_A\lambda_W^f + (1 - f_A)\lambda_W^C + \lambda_v], \tag{3}$$

$$F_{R\text{-}B} = F_{R\text{-}A}\lambda_{R\text{-}B}/[\lambda_{R\text{-}B} + f_B\lambda_W^f + (1 - f_B)\lambda_W^C + \lambda_v], \tag{4}$$

$$F_{R\text{-}C} = F_{R\text{-}B}\lambda_{R\text{-}C}/[\lambda_{R\text{-}C} + f_C\lambda_W^f + (1 - f_C)\lambda_W^C + \lambda_v], \tag{5}$$

where f_A, f_B, f_C are the unattached fractions for the respective species.

For thoron progeny:

$$F_{T\text{-}B} = \lambda_{T\text{-}B}/(\lambda_{T\text{-}B} + \lambda_W^C + \lambda_v), \tag{6}$$

$$F_{T\text{-}C} = F_{T\text{-}B}\lambda_{T\text{-}C}/(\lambda_{T\text{-}C} + \lambda_W^C + \lambda_v), \tag{7}$$

assuming that thoron progeny unattached fractions are negligible.

The bare track density T_3 is related to the concentration of both the gases and their daughters through Eq. (8):

$$T_3 = S_3 \cdot d\,[\{C_R + C_{R\text{-}A} + C_{R\text{-}C}\} + \{2C_T + C'_{T\text{-}C}\}], \tag{8}$$

where S_3 is the calibration factor for the bare film, $C_{R\text{-}A}$ and $C_{R\text{-}C}$ are the concentrations of the radon daughters ^{218}Po and ^{214}Po, respectively, and $C_{T\text{-}C}'$ is the concentration of the thoron daughter ^{212}Po.

The bare track density is dependent on the ventilation rate through equations for progeny fractions for both the gases. Considering the one-dimensional spatial profile for thoron, the ventilation parameter is worked out using Eq. (8).

The progeny working levels are determined using Eqs. (9) and (10):

Table 1
Indoor radon/thoron levels in some villages of Hamirpur and Una districts, Himachal Pradesh, India

Village (No. of houses)	Value	Radon (Bq/m^3)	Thoron (Bq/m^3)	FR[a]	FT[b]	Dose rate (μSv/h)
Ramera (8)	Min.	38.9	9.4	0.205	0.019	0.67
	Max.	146.3	51.4	0.616	0.219	8.67
	Average	86.3	27.1	0.336	0.082	3.6
Asthota (4)	Min.	40.6	9.1	0.416	0.064	1.54
	Max.	70.8	49.2	0.558	0.122	4.53
	Average	55.0	29.2	0.491	0.086	2.92
Galot (5)	Min.	30.7	14.6	0.165	0.026	1.13
	Max.	70.7	70.7	0.522	0.101	2.43
	Average	46.4	34.7	0.305	0.050	1.86
Samur-Khurd (3)	Min.	23.9	14.4	0.295	0.058	1.54
	Max.	46.3	35.7	0.513	0.100	2.54
	Average	33.3	22.2	0.414	0.074	2.14
Samur-Kala (2)	Min.	29.9	8.8	0.524	0.100	1.53
	Max.	30.9	16.1	0.565	0.157	2.54
	Average	30.4	12.5	0.545	0.129	2.04
Kheri (2)	Min.	47.3	10.8	0.475	0.073	2.51
	Max.	50.2	26.5	0.616	0.211	2.58
	Average	48.8	18.7	0.546	0.142	2.55
Ropa (2)	Min.	20.9	14.0	0.352	0.044	0.98
	Max.	38.7	21.4	0.399	0.049	1.18
	Average	29.8	17.7	0.376	0.046	1.08
Mehre (1)		19.7	14.0	0.143	0.010	0.100
Bangana (1)		40.6	9.1	0.483	0.077	1.00
Jaure-Amb (1)		76.3	44.8	0.325	0.034	1.41
	Mean	55.1	25.5	0.390	0.078	2.42
	S.D.	30.5	15.0	0.149	0.051	1.87
	Median	46.3	25.5	0.416	0.071	2.03

[a] FR: equilibrium factor for radon.
[b] FT: equilibrium factor for thoron.

$$\mathrm{WL_R} = C_\mathrm{R}\cdot F_\mathrm{R}/3700 = C_\mathrm{R}(0.104F_{\mathrm{R\text{-}A}} + 0.518F_{\mathrm{R\text{-}B}} + 0.37F_{\mathrm{R\text{-}C}})/3700, \tag{9}$$

$$\mathrm{WL_T} = C'_\mathrm{T}\cdot F_\mathrm{T}/275 = C'_\mathrm{T}\,(0.908F_{\mathrm{T\text{-}B}} + 0.092F_{\mathrm{T\text{-}C}})/275, \tag{10}$$

where C_T' is the room averaged thoron concentration, calculated taking into account the spatial profile of thoron.

The dose rate is calculated by use of a formula given in UNSCEAR (1993):

$$D\,(\mu Sv/h) = 10^{-3}\,[(0.17 + 9F_\mathrm{R})C_\mathrm{R} + (0.11 + 32F_\mathrm{T})C'_\mathrm{T}]. \tag{11}$$

A computer programme has been developed at BARC to carry out these calculations and we have used the following typical values for the various parameters:

$$f_\mathrm{A} = 0.2,\quad f_\mathrm{B} = 0.025,\quad f_\mathrm{C} = 0.001,$$
$$\lambda_\mathrm{W}^\mathrm{f} = 10\ \mathrm{h}^{-1},\quad \lambda_\mathrm{W}^\mathrm{C} = 0.1\ \mathrm{h}^{-1}.$$

4. Results and discussion

The survey of radon/thoron levels in the dwellings was carried out from August 1997 to September 1998. During this survey, 29 dwellings from ten villages in Hamirpur and Una districts of H.P. were tested for radon and thoron levels. The results of the survey are summarised in Table 1. The maximum value of radon concentration of 146.3 Bq/m^3 was recorded in Ramera village while the minimum value of 19.7 Bq/m^3 was found in Mehre village. The maximum value of 70.7 Bq/m^3 for thoron concentration was recorded in Galot village while the minimum value of 9.1 Bq/m^3 was recorded in the dwellings of Asthota and Bangana vil-

Table 2
Data showing seasonal variation of indoor radon/thoron levels and dose rates (August1997 to September1998)

Season	Radon conc. (Bq/m^3)		Thoron conc.(Bq/m^3)		FR		FT		FT Dose rate (μSv/h)	
	A.M.[a]	S.D.[b]	A.M.	S.D.	A.M.	S.D.	A.M.	S.D.	A.M.	S.D.
Aug.– Nov. 1997	53.4	7.3	29.7	23.0	0.377	0.204	0.073	0.076	1.635	1.281
Dec. 1997–Mar. 1998	81.5	55.6	39.0	26.0	0.499	0.134	0.107	0.072	6.360	6.971
Apr.– Sep. 1998	43.1	26.4	25.5	15.0	0.324	0.213	0.056	0.064	1.013	0.959

[a] A.M.: arithmetic mean.
[b] S.D.: standard deviation.

lages. The equilibrium factor for radon (FR) varied from 0.143 to 0.616, while equilibrium factor for thoron varied from 0.01 to 0.211. The dose rate varies from 0.1 μSv/h in Mehre to 8.67 μSv/h in a dwelling in Ramera village.

Hamirpur and Una districts lie in the middle and lower Siwaliks. The upper part of the lower Siwalik and middle Siwalik formation in Himachal Pradesh is comprised of hard grey to greenish sandstone and interbedded intraformational clay conglomerates which carry an unoxidised greying mudstone, shale and siltstone fragments and carbonaceous and sulphide materials (Udas and Mahadevan, 1974). The sandstones are of sub greywacke type and carry numerous rock fragments. They are feldsparic and micaceous and have a calcite cement. The construction of most of the houses is identical, using local rock and mud for flooring, and wood for roof. Only a few houses have cemented flooring and walls. The ventilation level in houses is comparatively low compared with residential accommodation in plain areas, especially in winter due to the cold climate.

The International Commission on Radiation Protection (ICRP) in its publication No. 65 (ICRP, 1994) has recommended that remedial action against radon is always justified above a continued effective dose of 10 mSv, while an action level within the range 3–10 mSv/yr has been proposed. From the results of the dose rates summarised in Table1, it is evident that considering an average annual occupancy of 7000 h in each dwelling, the effective dose in almost all of the houses is greater than 10 mSv. Although the concentration level of radon is found to be below 200 Bq/m^3, the dose exceeds 10 mSv, values for the equilibrium factor for radon achieving levels as high as 0.616 while values for thoron are as high as 0.219, both being due to low ventilation. Two houses in the village of Ramera gave anomalously high values of dose rate. While this may be due to an overestimation, it nevertheless remains clear that the majority of houses require some form of remedial action.

The seasonal variation of indoor radon/thoron levels and dose rates are shown in Table 2. For the winter season, i.e. December 1997 to March 1998, the mean value of radon concentration is 81.6 Bq/m^3 while the thoron value for this season is 39.0 Bq/m^3. The average values for radon and thoron concentrations for combined summer and rainy seasons (April to September 1998) are 43.1 and 25.5 Bq/m^3, respectively. The average values for autumn season (August to November 1997) for radon and thoron concentrations are 53.4 and 29.7 Bq/m^3, respectively. The maximum observed dose rate for the winter season was 6.36 μSv/h, while the minimum for summer and rainy seasons was 1.01 μSv/h. The dose rate for autumn season was 1.64 μSv/h. It is evident from this analysis that radon/thoron concentrations achieve a maximum which is due to increased exhalation and reduced ventilation during the winter season. Equilibrium factors are also maximum in the winter season, again being due to reduced ventilation, so the dose rates are also maximum for the winter season.

In the construction of almost all of the houses, the building materials used are local sandstone, mud and

Table 3
Distribution of radon/thoron levels in different type of houses

Type of house	No. of houses	1 yr average concentration	
		radon	thoron
I (mud floor)	13	65.4	33.1
II (wooden or concrete floor)	16	46.7	19.3

wood. Some houses have mud flooring, with stone for walls and a wooden roof. Some of the houses have wooden flooring and stone walls. Only a few houses have concrete floor or walls. From the point of view of construction we have divided the houses into two categories. Those with a mud floor as type I and others as type II. The radon and thoron concentration levels in both types of houses are listed in Table 3. The concentrations of both the radon and thoron are higher in type I houses, clearly establishing that subsurface soil is the predominant source of indoor radon and thoron in the dwellings.

We have also surveyed about 90 dwellings, spread over five districts in the neighbouring state of Punjab, in areas that are known to have having non-uranium bearing soil, using the same technique. Annual geometric mean values of radon and thoron concentrations in Punjab dwellings are 15.3 and 5.2 Bq/m^3, respectively, while the integrated dose rate is 0.18 μSv/h. An inter-comparison of indoor radon and thoron levels in Punjab and Himachal dwellings clearly establishes the Hamirpur and Una districts of Himachal Pradesh as radon risk-prone areas, in need of radiation hazard mitigation.

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