Defence Science Journal, Vol 42, No 4, October 1992, pp 219-225

Measurements of Indoor Radon Levels in India using Solid-State Nuclear Track Detectors: Need for Standardisation

M.C. Subba Ramu, A.N. Shaikh, T.S. Muraleedharan and T.V. Ramachandran

Environmental Assessment Division, Bhabha Atomic Research Centre Bombay-400 085

ABSTRACT

Solid-state nuclear track detectors are being used to obtain the time integrated concentration levels of indoor radon/thoron and their daughters. This technique is preferred for taking such measurements in dwellings. Such measurements are important as the radiation dose to human beings due to indoor radon constitutes more than 50 per cent of the total dose including that received from the natural sources. Normalisation is necessary to obtain a representative value of the effective dose equivalent to the population. Indoor measurements carried out by several laboratories all over the country show that the indoor radon levels vary from 1.5 to about 2000 Bq m^{-3}, while the normal level is in the range of 10 to 60 Bq m^{-3}. It is rather difficult to compare the levels since the exposure conditions, the period of measurements and the calibration techniques used are not standardised. The present paper discusses the measurements of indoor radon in India by various groups and the important problems associated with the standardisation of these measurements. The standardisation procedure and the calibration set-up developed at this laboratory are also presented.

1. INTRODUCTION

There has been an increasing interest in indoor radioactivity measurements motivated by the concern about the possible consequences of long-term exposure to higher concentrations of radon-222 and radon-220 and their progeny. Measurements of indoor radon are of importance because the radiation dose to human population due to the inhalation of radon and its daughters constitutes more than 50 per cent of the total dose, including that from the natural sources[1]. It has also been well recognised all over the world that inhalation of indoor radon-222 and its short-lived daughters contributes to a major fraction of the total dose to man from all possible sources, both man-made and natural. The available limited data for India has indicated that about 52 per cent of the total radiation dose received by the Indian population is due to inhalation of indoor radon progeny[2].

The main sources of indoor radon are soil, construction material, tap water, and the natural gas used for cooking. It is also significantly influenced by topography, house construction type, soil characteristics, weather, and even the life style of the people. In houses with higher concentrations, the main source of radon is the soil gas of the subjacent ground. Radon in soil gas depends on the radium content of the soil and the soil density. The physical characteristics of soil, viz density of the gas and void fractions influence the transport of radon and the exhalation rate of radon in the atmosphere[3].

Several techniques are in use to measure the radon/thoron levels in air. This includes their collection on a filter paper and subsequent alpha counting. Several personnel dosimeters employing track detectors have also been developed. These techniques have been increasingly used for the measurement of radon or

Received 6 September 1992

thoron in soil gas, uranium exploration, earthquake predictions, and geological and geophysical studies. The nuclear track detector technique is the most reliable method for the integrated and long-term measurement of indoor radon activity[4].

Since the solid-state nuclear track detectors (SSNTD) technique gives time integrated values of the concentrations, it is generally preferred to the grab sampling as the latter is not representative of the conditions prevailing round the clock. Our experience has shown that the SSNTD technique has given a value of 150 per cent for the relative standard deviation for the daughter concentration whereas the corresponding value for the grab sampling is 275 per cent. Thus it is indicated that the assessment of annual population dose from the inhalation of radon daughters present in the dwelling should be preferably based on the time integrated method of radon measurements[5].

The measurements carried out using the SSNTD technique by various laboratories[6-13] all over the country shows that the indoor radon levels vary from 1.5 to about 2000 Bq m^{-3} (Table 1). This data cannot be compared due to several reasons, which include: (a) measurements have been made sporadically without taking into consideration the seasonal, hourly and daily variations exhibited by radon and its progeny level in air, outdoor as well as indoors; (b) the type of houses surveyed for radon concentrations are not outlined; (c) exposure modes are different and assuming the UNSCEAR value for the equilibrium factor, the

Table 1. Measurements of indoor radon levels in India using SSNTD

Location	Exposure mode & calibration	Range of concentration (Bq m^{-3})	Seasonal variation	Average (Bq m^{-3})	Remarks	Reference
Aligarh	Bare-mode (not mentioned)	30-114	Summer & winter	54	Residential	6
		70-650		276		6
				67	Summer	6
				100	Winter	6
Amritsar	Bare-mode (no aerosol used; desicato	52-260		133	30 rooms	7
Himachal Pradesh		1032-2413	Not mentioned		Houses in uranium mineral area	
Jodhpur	Cup with membrane	85-133	9 months in a year		Residential & labs	9
	Radon in a chamber	17-154		43	$F = 0.5$	
Jaduguda		89-254		150	Residential 10 km away from Jaduguda	10
Calcutta	,,	11-36		26	Residential	10
Tamil Nadu	,,	40-55		51	,,	10
Bombay	Bare+cup with membrane; aerosol used 500 l chamber	1.5-32		11.6	Residential	11,12
		0.2-2.0 mWL	Variation observed	0.8		
High background areas in India		8.7-198 .5-22 mWL			Residential Possible U deposits	13
24 states in India used	Bare-mode erosol	10.3 mWL	No variation	3.7	Over two years	13

daughter levels are evaluated; and (d) the concentration of radon and its daughter products shows a large temporal and local fluctuations in the indoor and outdoor atmosphere due to variations of temperature, pressure, building materials, ventilation conditions, and wind speed.

The radon levels depend on the design of the dwellings with respect to windows, doors, and the material used for the construction. The radon levels also vary depending on the geographical location of the houses. Hence the measurement procedures should also take into account the variations occuring in the radon levels as a result of the seasonal changes. Higher levels reported (Table 1) in some locations are found to be much higher than the levels normally encountered in uranium mines, which causes serious concern whether the measurement techniques are proper and the detectors are calibrated properly. Such a serious doubt would not arise if standard techniques are used for the measurements.

2. STANDARDISATION PROCEDURE

To evaluate the concentration in terms of the activity of radon and thoron and their daughters present in air, the detectors are to be calibrated using a known concentration of radon or thoron and their daughter products. The calibration of the detectors has to take into consideration several features: (a) accurately known radon and thoron levels; (b) well characterised parameters with respect to daughter equilibrium factor, aerosol size, and humidity; (c) techniques used for monitoring concentrations of radon and thoron and their daughters; and (d) uniformity of radon and thoron content in the calibration chamber. Figure 1 gives the calibration set-up developed and used in this laboratory. To measure the inhalation dose due to radon daughters, one needs to measure only the radon daughter concentration in terms of working level (WL) concentration by way of exposing the detectors in the bare-mode. It is important to measure WL concentration rather than the radon gas concentration for dose assessment because dose estimation from radon concentration assumes a constant equilibrium factor in dwellings whereas it is observed to vary from 0.1 to 0.95.

In the bare-mode, the detector foil (LR-115 type-II) of a suitable size (say 2.5 × 2.5 cm) is mounted on a rectangular card such that it views a hemisphere of air of radius 6.9 cm, the range of ^{214}Po alpha. No surface

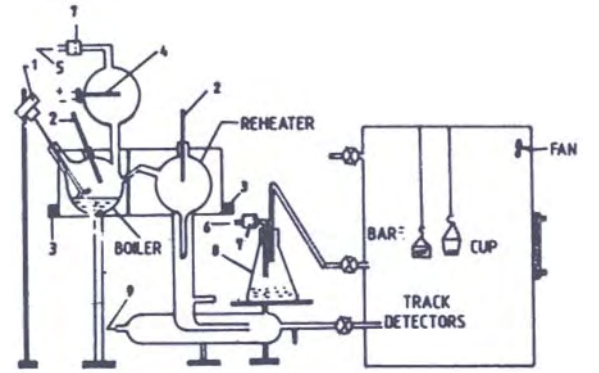

Figure **Schematic diagram of the apparatus used for the calibration of track detectors.**

should be closer than this range as the daughter depositions would then add an indeterminate alpha particle source. An undetermined number of tracks are formed due to the plateout of radon daughters on the surfaces.

Submicron aerosols of size 0.2 μm diameter and concentration (1.5×10^4 cm^{-2}), comparable to the ambient values indoors, are also needed for the attachment of radon daughters to keep them airborne[14]. Otherwise most of the radon daughters will be lost on the walls of the chamber and as a result the calibration factors obained will vary widely. The track-etch reading of a bare detector configuration will be a function not only of radon, but also of the degree of equilibrium of radon with its daughters. The bare detector mode of exposure is therefore a measure of the total potential alpha energy exposure expressed as WL units. Figure 2 gives the calibration curve for WL measurements. The bare detector configuration gives an average calibration factor of 480 tracks cm^{-2} d^{-1} per WL and shows that it is necessary to calibrate the detector over a wide range of radon levels to obtain an accurate sensitivity factor.

Our calibration procedure was validated in an international intercomparison programme conducted by the Australian Radiation Laboratory (ARL) during 1987. It was subsequently revalidated in the international intercomparison exercise carried out by the National Radiation Protection Board (NRPB) of UK, in 1990. The results obtained in this study have given a deviation of -16.2 per cent from the true value

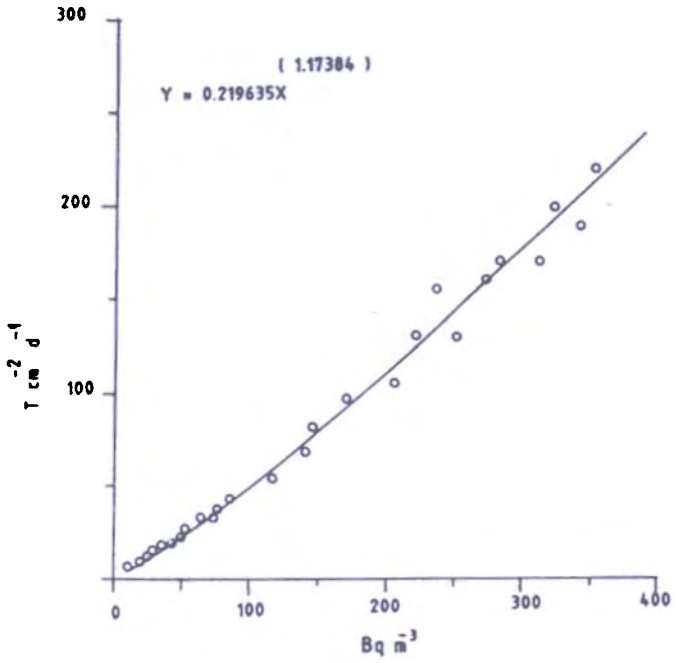

Figure 2. Calibration curve for working level (bare exposure)

for the cup with membrane mode for radon concentration in Bq m^{-3} and a deviation of -7.3 per cent for radon daughters in mWL units for ARL excercise, while it has given a deviation of -13.9 per cent for NRPB excercise[13].

For the measurement of radon concentration, the exposure mode used consists of exposing a small strip of detector material in a plastic cup of suitable

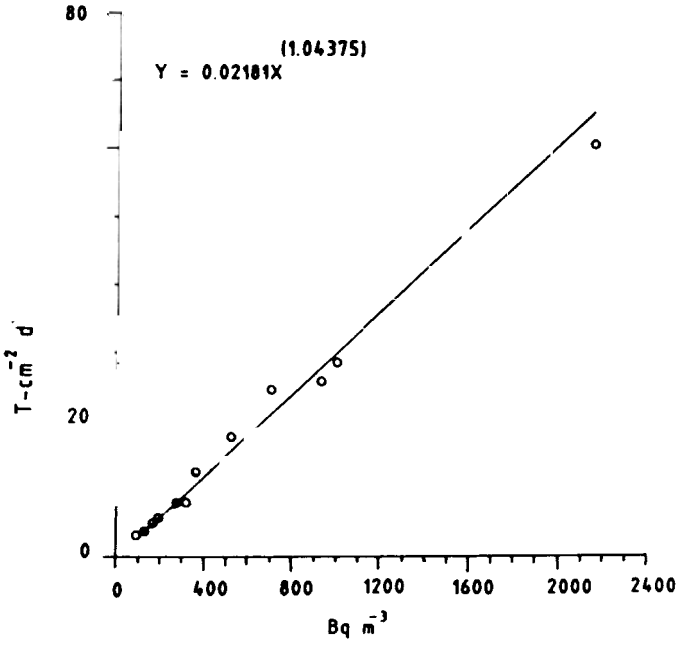

Figure 3. Calibration curve for radon (cup exposure) measurements.

dimension covered with a semipermeable membrane which allows discrimination between radon and thoron, permitting into the cup about 60 to 70 per cent of radon-222 only[15]. The calibration procedures of the two detector configurations are given in detail elsewhere[16]. Figure 3 gives the calibration curve for radon in terms of Bq m^{-3}. The estimated average calibration factor for radon gas is 0.0284 tracks cm^{-2} d^{-1} per Bq m^{-3}. The bare-mode of exposure is generally suspected to suffer from interferences due to dust deposition on the film. It has been reported that on an average about 0.3 mg cm^{-2} of dust load could affect the radon progeny estimates[17] Dust collected over a three-month period of exposure has been typically found to be less than 0.05 mgcm^{-2}. The bare-mode of exposure in the plane vertical to the ground minimises the dust deposition and hence was preferred.

3. RESULTS AND DISCUSSION

The radon and its progeny concentrations in a dwelling exhibit seasonal variations; peak concentrations are observed in winter. From the measurements carried out in this laboratory, it is seen that there is a seasonal variation in the radon as well as its daughter concentrations (Table 2) which have to be taken into consideration while evaluating the dose due to their inhalation in dwellings. For this, the levels

Table 2. Seasonal variations of indoor radon and progeny in a house

Month	Concentration		Equilibrium factor
	(Bq m^{-3})	(mWL)	
January	25.0	3.9	0.58
February	20.0	1.8	0.33
March	16.0	1.0	0.24
April	11.0	1.0	0.33
May	10.0	0.6	0.22
June	8.0	0.5	
July	6.0	0.3	0.18
August	9.0	0.3	0.13
September	4.0	0.4	0.42
October	5.0	0.9	0.62
November	20.0	3.5	0.66
December	37.0	4.2	0.42
Gm	11.7	1.0	0.32
GSD	1.9	2.5	1.6

during the complete year are to be taken into consideration. The minimum to maximum variations can be as high as 9 depending on the month of the calendar year. The radon concentrations can be measured by assuming an equilibrium factor of 0.5 or 0.4 from the radon daughter concentration. It is also seen that one time measurement is not sufficient to calculate the annual effective dose equivalent. It has been observed that the equilibrium factor varies by a factor of 3 or 4 for a given house as shown[13] in Table 3 . It also varies among different houses in various locations at a given period. The variations can be as wide as ± 100 per cent.

Table 3. Equilibrium factor in different locations

Location	Number of data points	Equilibrium factor, *F*		
		Minimum	Maximum	Median
Bombay	83	0.04	0.92	0.25
TTPH,Bombay*	8	0.06	0.69	0.32
Tuwa	18	0.07	0.93	0.36
Godhra	9	0.11	0.89	0.32
Jodhpur	8	0.10	0.72	0.38
Jaduguda	23	0.07	0.93	0.41
Nagpur	13	0.03	0.95	0.37
Median of all data		0.30		
GSD		2.19		

* The rooms are constructed with fly ash-made bricks.

Apart from the soil contribution, the radon is also emanated into the room air by the material or construction material used. Brick houses and houses built on granite rocks have shown higher radon levels. Houses built with bricks made from fly ash also can be expected to have higher radon levels (Table 4). It may be prudent to provide adequate ventilation to avoid building up of the daughter products of radon in such houses. The measurements carried out in the high background areas in this country have shown that the mean potential alpha energy exposure of radon daughters works out[18] to be 9.4 mWL whereas the normal background areas give a mean value of 4.2 mWL. The houses made with rocks and granites and with bricks and stones have shown comparatively higher levels of potential alpha energy concentration than those made of brick, mud, wood and RCC (Table 5).

Table 4. Radon daughter concentration in rooms built with fly ash bricks

Location	Concentration	
	($Bq\,m^{-3}$)	(mWL)
Room No. 1	105	14
Room No. 2	159	13
Room No. 3	74	14
Room No. 4	82	7
Room No. 5	87	9
Room No. 6	129	7

Table 5. Radon progeny levels in mWL in houses made of different construction materials

Material	Range	*Gm*
Brick, mud, wooden floor	1.7–21.5	6.9
RCC structure	1.8–21.5	9.1
Brick, cement	1.5–21.9	9.5
Mud, brick, bare floor	2.8–21.1	11.0
Brick, stone floor	8.2–18.0	12.0
Rock, granite	9.0–21.9	14.9

Therefore, before comparing the levels it is also important to separate the data of radon and thoron measurements on the geological and geographical basis and to take into consideration the material of construction.

4. CONCLUSIONS

Based on the results of the analysis of the data, it can be concluded that there is a need for standardisation of measurement techniques, arising out of the necessity to evaluate a national average and prepare a radon and thoron map of the country. The standardisation of the calibration procedure facilitates in the comparison of levels measured by various laboratories in different parts of the country. Wide variations in the equilibrium factor and the seasonal levels of radon and its daughter have also necessitated the measurement of the concentration for an year covering all the seasons. Otherwise the data collected for a given particular season only should be compared. The materials used for the constructions and the geological and geographical locations of the houses are also to be taken into consideration for intercomparison of the data.

It has been observed that there could be incompatibility among various data if one attempts to normalise them without taking into consideration the seasonal variations occurring in the indoor radon values with the ratio of maximum to minimum being as high as 9 and the supra-linearity of the calibration curve for bare film exposure. If the linearity is assumed by calibrating at higher concentrations, then at lower concentrations, the error is likely to be very high.

REFERENCES

1. UNSCEAR. Report of United Nations Scientific Committee on the Effects of Atomic Radiation. United Nations, New York, 1988. Report No. A/AC 82/R 460.
2. Narayanan, K.K.; Krishnan, D. & Subba Ramu, M.C. Exposure from natural and man-made sources of ionising radiation. Indian Society for Radiation Physics Report, 1991. ISRP(K)-BR-3.
3. Ramachandran, T.V.; Subba Ramu, M.C. & Mishra, U.C. A correlation study of radium content in soil and radon levels in dwellings. *Current Science*, 1990, **59**(20), 979-82.
4. Frank, A.L. & Benton, E.V. Radon dosimetry using plastic nuclear track detectors. *Nuclear Track Detection*, 1979, **1**, 149.
5. Subba Ramu, M.C.; Shaikh, G.N.; Muraleedharan, T.S. & Ramachandran, T.V. A study of seasonal variation in indoor concentration of radon and its progeny. *Bull. of Rad. Prot.*, 1988, **11**(1&2), 887.
6. Khan, A.J.; Varshney, A.K.; Pradesh, Rajendra & Tyagi, R.K. The indoor concentration of radon and its daughters in multistory buildings. *Nucl. Tracks Rad. Meas.*, 1987, **13**(1), 77-80.
7. Ramola, R.C.; Singh, Manwinder; Singh, Surinder & Virk, H.S. Measurement of indoor radon concentration using LR-115 plastic track detectors. *Indian J. of Pure and Applied Physics*, 1987, 25, 127-29.
8. Singh, Jaspal; Singh, Surinder & Virk, H.S. Measurements of radon and daughters in air using solid state nuclear track detectors. *IASTA News Letter*, 1990, **3**(1), 48.
9. Kumar, S.; Gopalani, Deepak; Ramaseshu, P.; Gehlot, G.S. & Nagaratnam, A. Seasonal variation of radon concentration in dwellings: preliminary results for Jodhpur. *Bull. of Rad. Prot.*, 1989, **12**(3), 33-35.
10. Jha, G. & Ragavayya, M. Solid state nuclear track detector technique for the estimation of alpha dose from radon daughter in buildings and dwellings. In Proceedings of the 5th Seminar on Solid State Nuclear Track Detectors in Space Physics, Nuclear Physics and Earth Sciences. Saha Institute of Nuclear Physics, Calcutta, 1987. pp. 171-75.
11. Subba Ramu, M.C.; Shaikh, G.N.; Muraleedharan, T.S. & Ramachandran, T.V. Measurements of indoor radon levels in dwellings using solid state nuclear track detectors. *Bull. of Rad. Prot.*, 1987, **10**(1&2), 49-52.
12. Subba Ramu, M.C.; Muraleedharan, T.S. & Ramachandran, T.V. Calibration of solid state nuclear track detectors for the measurements of radon and its progeny concentrations in dwellings. *Sci. of the Tot. Env.*, 1988, **73**, 245-55.
13. Subba Ramu, M.C.; Ramachandran, T.V.; Muraleedharan, T.S. & Shaikh, A.N. Indoor levels of radon daughters in dwellings in some high background areas in India. *Rad. Prot. Dosim.*, 1990, **30**, 41-44.
14. Muraleedharan, T.S.; Ramachandran, T.V. & Subba Ramu, M.C. A computerised model for the activity to dose conversion factor for radon daughters inhalation in dwellings. BARC, Bombay 1986. Report No. 1317.
15. Ramachandran, T.V.; Lalit, B.Y. & Mishra, U.C. Measurements of radon permeability through some membrane. *Nucl. Tracks. Rad.*, 1987, **13**, 81-84.
16. Ramachandran, T.V.; Muraleedharan, T.S. & Subba Ramu, M.C. Calibration of solid state nuclear track detectors for the measurements of thoron in dwellings. *Indian J. Physics*, 1990, **64**(A 5), 365-74.
17. Orzechowski, W.; Chruscielewski, W. & Domanski, T. Measurements of exposure to radon and its progeny using Kodak LR- 115 type II foil, I: Laboratory investigations of the detector response; II: Proceedings of the Specialists Meeting on the Assessment of Radon and Daughters: Exposure and Related Biological Effects, edited by G.F. Clement, *et al.* University of Utah, 1982, p. 20.

18. Subba Ramu, M.C.; Shaikh, A.N.; Muraleedharan, T.S. & Ramachandran, T.V. Measurements of equilibrium factor for radon-222 daughters in dwellings in India. *Sci. of the Tot. Env.*, 1990, **99**, 49-52.