RADON DOSIMETRY USING PLASTIC NUCLEAR TRACK DETECTOR

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SUMMARY: Solid State Nuclear Track Detectors are increasingly being used to obtain the time integrated concentration levels of radon and its daughters. CR-39 plastic detector is very useful in the detection of alpha particles from disintegration of radon and radon daughters. The detector was employed for the measurement of radon concentration and potential alpha energy exposure level in houses in Swaziland. From these values the equilibrium factor (F) between radon and its progeny is estimated for each location. An average F value of 0.71 is obtained. The average effective dose equivalent is found to be $H_E = 1.63\ mSv.y^{-1}$.

Key Words: Nuclear track detector, indoor radon concentration, PAEC, equilibrium factor, effective dose equivalent.

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 concentration of ^{222}Rn and its progeny. The noble gas ^{222}Rn is present in the soil and building materials. Normally, indoor radon concentrations are considerably higher than the outdoor ones. The radiation from radon and its daughters produces a risk of lung cancer by inhalation of air with high radon and radon daughter concentrations over a long period of time (1). The U.S. Environmental Protection Agency (EPA) has suggested that immediate intervention is required if the radon level is above 190 $Bq.m^{-3}$ (2). In order to assess the situation in Swaziland, we have undertaken a project to measure the levels of radon and its daughters in Swazi dwellings. For the estimation of the effective dose equivalent from ^{222}Rn daughters in dwellings, it is necessary to know the potential alpha energy concentration (PAEC) of ^{222}Rn daughters in terms of working level (WL) units. The measured ^{222}Rn values can be converted into WL units if the equilibrium factor, F, is known from the relation (3, 4):

$$F = \frac{WL \times 3700}{C_{Rn}} \qquad \text{...(1)}$$

where C_{Rn} is the ^{222}Rn concentration ($Bq.m^{-3}$).

Solid State Nuclear Track Detectors (SSNTDs) have been widely used for the measurement of time-integrated radon levels in dwellings under different conditions. The effective dose equivalent (H_E) of radon and its daughters for measured track densities of the open (D) and filtered (D_o) SSNT detector can be calculated by means of the following equation (5, 6):

$$H_E = \frac{D_o}{K} \left[d_o + d_e\ a \exp\left(b\ (D_o/D)\right)\right] \text{....................(2)}$$

where the recommended values (5-8) for the effective dose equivalent conversion factors for radon and its

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daughters are d_o = 0.33 μSv.y^{-1} per Bq.m^{-3} and d_e = 80 μSv.y^{-1} per Bq.m^{-3} respectively. The values (5-8) of the two constants a and b are a = 14.958 and b = -7.436. K is the detector sensitivity (tracks cm^{-2} d^{-1} per Bq.m^{-3}) which can be obtained from the calibration experiment. For the calculation of the equilibrium factor in a dwelling, it is necessary to measure both the ^{222}Rn concentration (Bq.m^{-3}) and the ^{222}Rn daughter concentration (WL units). This paper presents the results from a set of measurements carried out in 63 dwellings in different locations of Swaziland in order to estimate an average value of the radon concentration and effective dose equivalent for Swazi dwellings. The F value for each location is also determined.

EXPERIMENTAL PROCEDURE

The detector

The CR-39 (Pershore Moulding, U.K.; 300 μm thick) plastic detector used in the present study is sensitive to alpha particles of energy up to 40 MeV (4). It was used as integrating detector of α-particles from ^{222}Rn and Rn daughter nuclei. When an α-particle penetrates the detector, the particle causes damage along its path. The damage is then made visible by chemical etching. The etching produces a hole in the detector along the path of the particle. The hole can be easily observed in a light transmission microscope with moderate magnification.

The detector film detects α-particles from both ^{222}Rn and its daughters during the time of exposure in the indoor environment of a house. After exposure the detectors were etched chemically in 6 M NaOH solution at 70°C for 12 h. The tracks were counted using an optical microscope having a magnification of 400X. Typical standard deviations for track densities measurements were near 2 tracks cm^{-2} d^{-1}. The background mean value was 0.40 tracks per microscopic field of 0.0113 cm^2.

The dwellings

Measurements were made in 63 detached houses at 7 different locations in Swaziland. In a detached house, there is a single unit dwelling with one family. Some measurements were also taken in multifamily, multistory buildings. The houses selected for the present study were of different styles of construction, falling in a typical range from traditional huts made of mud with un-plastered walls and bare flooring, to mud and thatch houses with floors stamped and polished with smooth stones, to houses made of bricks and cement, to flats made of concrete with plastered and painted walls and carpeted flooring.

The exposure

Detectors of size 2.5x2.5 cm were exposed to the indoor environment of a house for a known period of time of the order of 30-90 days, during which time the alphas originating from ^{222}Rn and its progeny would leave tracks on it. The detectors were exposed in two modes (2-4,9): (i) bare and (ii) cup with a membrane. The exposure in bare mode is done by placing the bare detector (2.5x2.5 cm) film at a height of about 1.5 m from the ground and at least 1 m away from the ceiling and the walls by means of a thread and paper clip. The cup with membrane detector configuration consisted of an open mouthed plastic cup 9.5 cm in height, 6.8 cm in diameter at the open mouth and 5.4 cm in diameter at the bottom, fitted with a CR-39 detector 2.5x2.5 cm at the bottom of the cup. The open mouth of the cup was covered with a semi-permeable membrane (GEC MEM-213). The membrane slows down the normal diffusion of noble gases into the cup and thus discriminates in favor of radon vs. thoron (2-4,10). This configuration is generally used in the exploration to eliminate thoron interference and water condensation. This configuration also prevents the entrance of radon daughters and is a 'radon only' device (3, 4,11).

Normal two detectors were exposed for each mode in each dwelling. Two of these (bare and filtered) were usually exposed in a bedroom while the other two were exposed in the living/dining room. For calculation of track density the average was noted in each mode. The measurements were performed in 63 dwellings at 7 different locations. The ^{222}Rn concentration (Bq.m^{-3}) from cup exposure and the PAEC (mWL) from the bare exposure were obtained directly from the track density using separate calibration curves (9).

The calibration

The calibration experiments were carried out to evaluate the relationship between track density recorded and the radon concentration as well as WL concentrations. Strips of CR-39 detector were exposed in two modes, viz (i) bare mode and (ii) cup with membrane mode (2-4, 9), for calibration. The bare detector configuration is calibrated to estimate the potential alpha energy concentration

(PAEC) in terms of working level (WL). The cup with membrane detector configuration is a 'radon only' device and is used to estimate the radon concentration. These two detector configurations were calibrated in the laboratory and used for radon measurements in dwellings. Both calibrations were performed by exposing the detectors to known quantities of radon and daughters in an exposure chamber. The results were reported elsewhere (9).

The dose equivalent

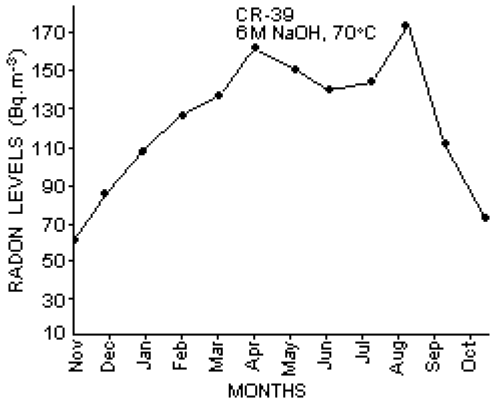
After exposure in the indoor environments the detector samples were etched chemically. The track densities of the bare and filtered detectors were determined microscopically. The radon concentration and PAEC were determined from the calibration curves. The equilibrium factor is calculated from Eq. (1). The effective dose equivalent is then estimated using Eq. (2).

RESULTS AND DISCUSSIONS

The calibration factors obtained from the calibration experiment (9) are 0.20 ± 0.023 tracks cm^{-2} d^{-1} per ($Bq.m^{-3}$) and 1678 ± 318 tracks cm^{-2} d^{-1} per WL. These values are in good agreement with those reported by other investigators (4,12,13). These values are used to estimate the radon concentration and PAEC from the measured track densities.

The first part of the study involved measurements in a single dwelling in Kwaluseni Campus (University of Swaziland) for one year from November 1991 to October 1992. The results are presented in Table 1. The measurements involved 12 exposures of one month each in both the cup and bare modes. Figure 1 gives the typical monthly variation of indoor radon levels for the period from Nov. 1991 to Oct. 1992 of a year for Kwaluseni Campus. It can be seen that during winter season (April-September) Rn concentration in the house is much higher than that in the summer. The average level of radon is 50% higher in winter compared with the summer. The indoor 'thermal stack effect' (14,15) is usually invoked to explain higher radon levels during the winter in colder climates. The winter in Kwaluseni (Manzini District) remains relatively mild and the custom is to use indoor heating only irregularly, or not at all. The 'thermal stack effect' may not be the underlying reason for the higher winter radon levels. Keeping the doors and windows closed during winter period decreases the ventilation rate which allows accumulation of radon

Figure 1: The typical monthly variation of indoor Rn levels for the period from Nov. 1991 to Oct. 1992 of a year for Kwaluseni Campus.



inside houses. Probably this is the reason for the higher radon concentration in winter months. All houses is the study rely on natural ventilation. The radon levels were also estimated for other residences in the campus. The detectors were exposed for 3 months. The results are shown in Table 2. The average effective dose equivalent is found to be H_E=1.29 $mSv.y^{-1}$ for inhabitants of Kwaluseni campus. The effective dose equivalent (H_E) is very close to the yearly average values (Table 1).

Table 1: Radon concentration, equilibrium factor and effective dose equivalent for different months in a house in Kwaluseni Campus (University of Swaziland).

Month		C_{Rn} ($Bq.m^{-3}$)	PAEC (mWL)	F	H_E ($mSv.y^{-1}$)
Nov	1991	60	13	0.80	1.15
Dec		86	16	0.69	0.86
Jan	1992	109	22	0.75	1.48
Feb		126	21	0.62	1.09
Mar		138	25	0.67	1.14
Apr		162	31	0.71	1.73
May		151	28	0.68	1.43
Jun		140	25	0.66	1.08
Jul		145	27	0.76	1.25
Aug		174	32	0.68	1.55
Sep		112	23	0.76	1.64
Oct		72	14	0.72	0.83
		Average: 123		Average : 0.71	Average: 1.27

The second part of the study involved measurements carried out in 63 houses at 7 different locations. The results are presented in Table 3. The average F value is quite close to F value obtained for Kwaluseni Campus (Table 2). The present average value of F is within the range 0.30-0.80 obtained for different countries of the world (3,16). The effective dose equivalent for each location is determined from Eq. (2). These are given in Table 3. The average effective dose equivalent is 1.63 $mSv.y^{-1}$. It does not call for any intervention since EPA has recommended no intervention up to 3.5 $mSv.y^{-1}$. The radon concentration obtained for each location is again less than the intervention level as prescribed by EPA.

Table 2: Radon concentration, equilibrium factor and effective dose equivalent in houses in Kwaluseni Campus .

House	C_{Rn} ($Bq.m^{-3}$)	PAEC (mWL)	F	H_E ($mSv.y^{-1}$)
House no. 1	149	28	0.69	1.47
House no. 2	127	23	0.67	1.05
House no. 3	140	26	0.69	1.30
House no. 4	174	32	0.68	1.55
House no. 5	111	20	0.66	0.89
House no. 6	131	24	0.68	1.14
House no. 7	157	30	0.71	1.67
	Average: 141		Average : 0.68	Average: 1.29

Table 3: Equilibrium factor and dose equivalent for different locations of Swaziland.

Location	No. of obser-varitons	Average C_{Rn} ($Bq.m^{-3}$)	Average PAEC (mWL)	F Average ±SD	H_E ($mSv.y^{-1}$)
UNISWA campus	7	141	26	0.68±0.10	1.27
Kwaluseni	13	146	28	0.71±0.14	1.58
Matsapha	12	166	32	0.71±0.15	1.84
Manzini	9	176	34	0.76±0.17	1.97
Mbabane	6	164	31	0.70±0.13	1.66
Mangweni	8	159	30	0.70±0.12	1.59
Mayiwane	8	154	29	0.69±0.12	1.53
	Average: 158		Average : 0.71±0.15		Average: 1.63

Some measurements were taken in multifamily, multistory buildings. These measurements were made on the ground, first and second floors. The results (Table 4) show that the radon concentration is distinctly greater at ground level. There are decrements in radon concentration of about 50% between successive floors. This trend indicates that the principle source of indoor radon is likely to be soil gas entering the building at ground level. The importance of pressure-driven flow of air through soil and into buildings has been well established by U.S. investigators (15,17,18). Our earlier studies showed that a secondary source of indoor radon is associated with the natural radioactivity of bricks, concrete, cement and gravel used in construction of houses in Swaziland.

Table 4: Levels of radon ($Bq.m^{-3}$) in multi-family apartment buildings.

Room	Ground floor	First floor	Second floor
Living/Dining	162	84	44
Bedroom	159	81	40

CONCLUSION

The equilibrium factor, the indoor radon level and the effective dose equivalent have been estimated in 63 residences (7 locations) in Swaziland using integrating etched track detector. The radon levels are found to be higher during winter months than the summer. The radon concentration and the effective dose equivalent show that no intervention is necessary for the locations under study. Expanded studies are planned to determine the extent and severity of radon problems in other locations of Swaziland.

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