note technique

Spatial variation of radon concentration in a room

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RÉSUMÉ **On a mesuré la concentration en radon en différents endroits à l'intérieur d'une habitation à l'aide de détecteurs CSR solides de traces avec ou sans electret. Les mesures montrent que les concentrations en radon varient à l'intérieur d'une même pièce ; au centre de la pièce, elles diminuent à mesure que s'élève la hauteur au-dessus du plancher. A une hauteur de 0,88 m (c'est-à-dire la zone de respiration du dormeur), elle est d'environ 1,3-1,5 fois celle mesurée sous le plafond. Elle est la plus élevée à la tête d'un lit situé contre le mur (là où se trouve, généralement, la tête du dormeur), soit 1,6-1,8 fois celle trouvée à 0,5 m sous le plafond. Pour obtenir une évaluation plus réaliste de la dose délivrée aux occupants, estimée selon la concentration moyenne en radon mesurée à 0,5 m sous le plafond, il conviendrait donc de la multiplier par un facteur de correction d'environ 1,5.**

ABSTRACT **Radon concentrations were measured at different locations in a house using CSR solid track detectors with and without electret. The results show that radon concentrations differ even in the same room; in the middle of the room, they decrease with increasing height from the floor. Radon concentrations at the height of 0.88 m (*i.e.* about the breathing height when the resident is sleeping) are about 1.3-1.5 times that at 0.5 m below the ceiling. They are the highest at the head of a bed close to the wall where the sleeper's head usually lies, viz. 1.6-1.8 times that at 0.5 m below the ceiling. The radiation dose to the inhabitants, estimated in accordance with the average radon concentration measured at the 0.5 m location below the ceiling, should therefore be multiplied by a correction factor of about 1.5 to obtain the realistic dose.**

1. Introduction

It has been reported that the radiation dose resulting from inhalation of radon daughters accounts for more than 50 % of the total dose from natural radiation [1]. Consequently, radon and its progeny have attracted great attention. In addition to radon exposure of uranium miners, large-scale investigations of indoor radon have been undertaken by many countries. Similar investigations have also been undertaken in China.

In the investigation on radon in coal-cinder brick houses, the detectors are usually placed 0.5 m below the ceiling (hung on a thin wire in the middle of the room for convenience of fixation and safety). However, this is not the

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normal position of the occupants of a house. In order to estimate the realistic dose to occupants resulting from radon and its progeny, investigations of spatial variations of radon at different locations within a house are needed.

2. Investigations

2.1 Measurement procedures

The main factors affecting indoor distribution of radon are radon sources, building structures, ventilation, etc. In our measurements, the following procedure was adopted.

1) Three kinds of measurements were carried out:

a) exposure for 24 h with both the door and window closed,
b) exposure for 24 h with both the door and window open,
c) exposure for 3 months and then for 1 year under every-day living conditions.

2) Detectors were placed at 5 representatives locations (fig. 1):

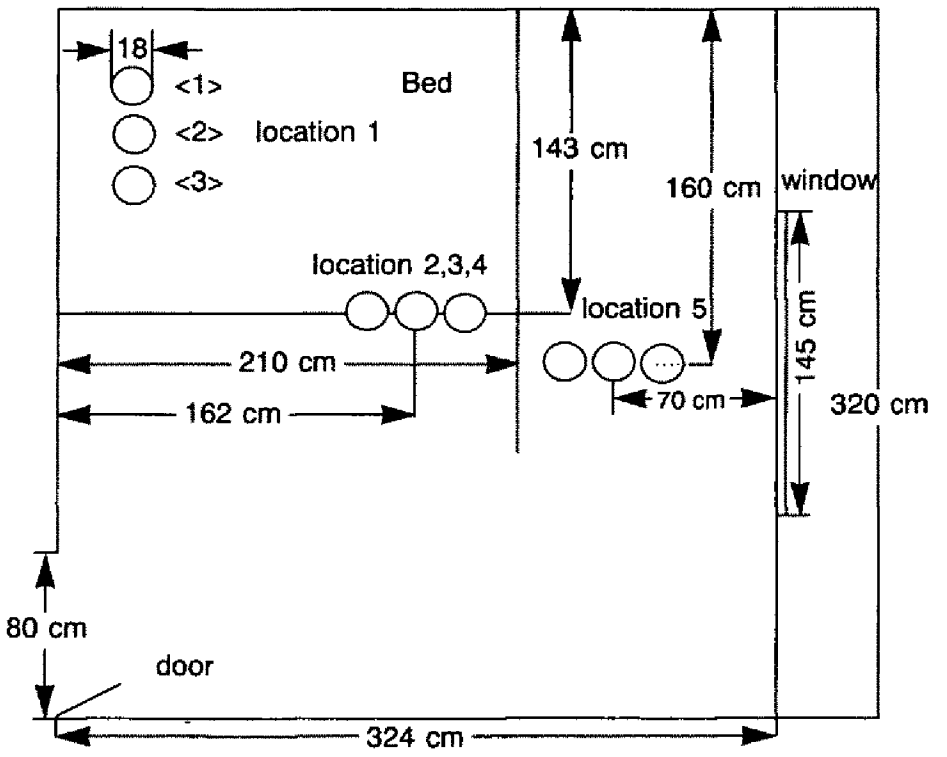
Location 1: head of the bed, where the sleeper's head usually lies; the detector is placed 0.88 m above the floor and 0.2 m from the wall (dosemeters 1, 2, 3);
Location 2: in the middle of the room, 0.88 m above the floor (dosemeters 4, 5, 6);
Location 3: in the middle of the room, 1.55 m above the floor (dosemeters 7, 8, 9);
Location 4: in the middle of the room, 2.4 m above the floor, *i.e.* 0.5 m below the ceiling (dosemeters 10, 11, 12);
Location 5: 0.70 m from the window and 1.55 m above the floor (dosemeters 13, 14, 15).

The bedroom of a coal-cinder brick house is 3.24 m long, 3.2 m wide and 2.97 high. The window is 1.45 m wide and 1.85 high. The door is 0.80 m wide and 1.95 high. As shown in figure 1, the bed (1.43 m wide, 2.1 m long and 0.8 m high) is in the corner of the room.

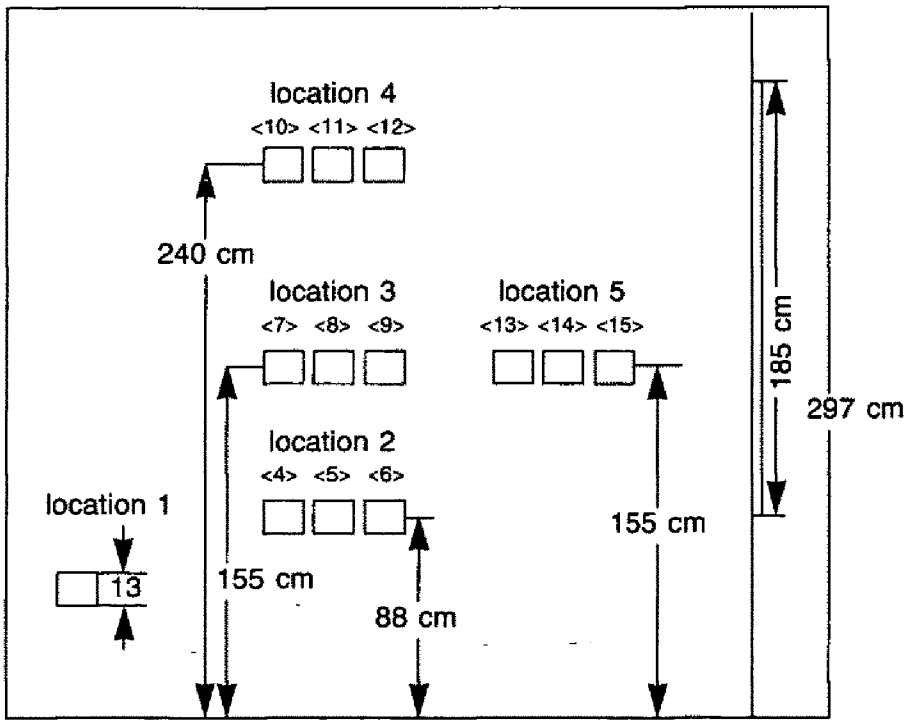
2.2 Measurement method

The 3-month and 1-year cumulative exposures were estimated using CSR solid track detectors [2]. The detector was a new CR-39 (DPA) material–sensitive, uniform and stable with low background noise. A detector sheet (1.75 x 1.75 x 0.22 mm) was placed on the bottom of a diffusion canister (inner diameter: 38 mm and height: 17 mm). The canister was then sealed with a filter. The lower detectable limit was 2.2 Bq · m^{-3} when the sampling time was 6 months.

The radon concentration was measured with electret [3] exposed for 24 h. The electret was used to establish a static electrical field to increase collection of radon daughters and, therefore, to improve the detector sensitivity. The sampling chamber had a volume of 3.8 l (diameter: 0.18 m, height: 0.13 m). The lower detectable limit was 0.13 Bqm^{-3} when the sampling time was 2 days.



(a) Top view



(b) Front view

Fig. 1. – Distribution of the monitor detectors in the rom
Répartition des détecteurs : a) coupe horizontale ; b) coupe verticale

3. Results

3.1 Cumulated exposure for 24 h

• Radon concentrations were measured in the bedroom of a coal-cinder brick house from February 5 to 7, 1991. The results are shown in table I, where:

$$k_i = \frac{\text{average radon concentration at location 1}}{\text{average radon concentration at location 4}}$$

Table I shows that:

a) the average radon concentration at location 4 was 228 Bq · m^{-3} when both the door and window were closed, and 41 Bq · m^{-3} when they were open;

b) in both cases, radon concentrations varied with the locations, for instance k_i was highest, 1.61 and 1.83 respectively with door and window closed or open;

c) measurements at locations 2, 3 and 4 indicated that radon concentrations decreased with increasing height from the floor; radon concentrations at location 2 was 30 % higher than at location 4 when both the door and window were closed, and 46 % higher when they were open.

• The results of measurements carried out on August 17-18, 1991 on the second floor of a red brick laboratory are also given in table I. The results showed that when the door and window were closed, k_2 = 1.27 and k_3 = 1.22, *i.e.* much the same as in the bedroom of the coal-cinder brick house.

TABLE I

k_i values for a 24 h exposure
Valeurs de k_i pour une exposition de 24 h

Location	Door and window closed				Door and window open	
	Red brick laboratory		Coal-cinder brick bedroom		Coal-cinder brick bedroom	
	mean	SD	mean	SD	mean	SD
1			1.61	0.55	1.83	0.72
2	1.27	0.04	1.30	0.34	1.46	0.64
3	1.22	0.02	1.13	0.50	1.34	0.93
4	1.0**	0.01	1.0	0.25	1.0*	0.39
5			1.57	0.63	0.35	0.14
average			1.32 (N = 5)	0.27	1.20	0.57

* average radon concentration at location 4, when the door and window are closed = 228 ± 56.8 Bq m^{-3}, and 41 ± 16.1 Bq m^{-3} when the door and window are open.

** average radon concentration at location 4, when the door and window are closed = 9.6 ± 0.1 Bq m^{-3}.

3.2 Cumulated exposure for 86 days and 1 year

Radon concentrations at representative locations in a bedroom of a red brick five-story building were measured from February 24 to May 20, 1991 and from May 20, 1991 to May 20, 1992 using a CSR solid track detector without electret. The results are given in table II. It can be seen that k_i values in the red brick building are similar to values in the coal-cinder brick house.

TABLE II

k_i values for exposure over 86 days and 1 year
Valeurs de k_i pour une exposition de 86 jours et 1 an

Location	Exposure for 86 days		Exposure for 1 year	
	mean	SD	mean	SD
1	1.72	1.23	1.53	0.10
2			1.38	0.09
3	1.0*	0.37	1.0**	0.05

* average radon concentration = 25 ± 9.2 Bq m^{-3}
** average radon concentration = 15 ± 4.3 Bq m^{-3}

3.3 Estimation of the dose-concentration correction factor k_c

1) It is clear from our investigation that indoor radon concentrations differ with locations. As the detectors were usually placed at location 4, a correction factor k_{c1} should be used to obtain the average radon concentration. The average concentration of radon is C_a, therefore k_{c1} is equal to C_a divided by C_4, *i.e.* the average radon concentration at location 4:

$$k_{c1} = k_{ic}t_c + k_{io}t_o \ldots \quad [1]$$

where k_{ic} and k_{io} are the average values of k_i over 5 locations when the door and window were closed and open respectively; for coal-cinder brick house, $k_{ic} = 1.32$, $k_{io} = 1.20$;

t_c and t_o are the daily average times with closed and open doors and windows; according to [4], $t_c = 11/24$, $t_o = 13/24$, so $k_{c1} = 1.3$.

2) When in bed, the occupant's head is at location 1 where the radon concentration is shown to be highest. If the dose to occupants is estimated according to the concentration at location 4, then a correction factor k_c should be used to obtain the realistic dose. Assuming an indoor occupancy factor of 0.8 [1], an average sleeping time of 8.6 h per day [5], the occupant's exposure to the average radon concentration when staying indoors – except when sleeping:

$$k_c = (k_{1c}t_c + k_{1o}t_o) \times 8.6 / (24 \times 0.8) + k_{c1} [1 - 8.6 / (24 \times 0.8)] \quad [2]$$

where k_{1c} is the k_1 value when door and window are closed
k_{1o} is the k_1 value when door and window are open

Based on our investigation, $k_{1c} = 1.61$ and $k_{1o} = 1.83$, then $k_c = 1.5$.

4. Conclusion

The investigation demonstrated that radon concentrations at different indoor locations were different ; they decreased with increasing height, and were the highest at the head of the bed (where the occupant's head usually lies when in bed), *i.e.* 1.6-1.8 times that at 0.5 m below the ceiling. This may be due to the specific gravity of radon (greater than that of air) and to radon exhalation from the wall surface. It can be seen from above that exposure from radon can be lowered if the sleeper's head is kept as far from the wall as possible during sleep.

The distribution of radon concentrations is dependent on many factors such as room structure, time distribution of open/shut doors and windows, meteorological parameters, resulting in different k_i values. This preliminary investigation will be further developed. ■

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