ELSEVIER

Journal of
Environmental Radioactivity 47 (2000) 183–188

JOURNAL OF
ENVIRONMENTAL
RADIOACTIVITY

www.elsevier.com/locate/jenvrad

The effects of covering materials on indoor Rn concentrations in offices in Hong Kong

K.N. Yu*, T. Cheung, E.C.M. Young, W.N. Mui, K.K. Tang

Department of Physics and Materials Science, City University of Hong Kong, Tat Chee Avenue, Kowloon Tong, Kowloon, Hong Kong

Received 27 July 1998; accepted 1 March 1999

Abstract

The variation of Rn concentrations in 134 offices with different covering materials cladded on internal building surfaces, including walls, ceilings and floors, were measured. The three commonest combinations (87 sites) of covering materials for the walls, ceilings and floors in Hong Kong are (A): wall paper, fibre board, carpet; (B): paint, paint and plastic tile and (C): paint, fibre board, plastic tile. The average Rn concentrations for combinations (A) and (B) were about the same, while that for combination (C) was significantly lower than those for (A) and (B). A person working in an office with combination (C) can receive an average annual tracheobronchial equivalent dose smaller than one working in an office with combinations (A) and (B) by an amount as large as 0.8 mSv. © 1999 Elsevier Science Ltd. All rights reserved.

Keywords: Radon; Buildings; Coverings; Offices; Hong Kong

1. Introduction

Comprehensive studies on the sources and the health effects of environmental Rn have been carried out following the linking of Rn and lung cancer. Surveys on the level of environmental Rn in Hong Kong showed that the levels here are significant (Yu, Young, Stokes, Luo & Zhang, 1992; Yu, Young & Li, 1996b; Yu, Young, Stokes, Guan & Cho, 1997; Yu, Young, Stokes & Tang, 1998). Extensive efforts were made to identify efficient mitigation methods to remedy the situation, which included applying ion generators, employing air conditioning, providing smoke-free working environments and using lightweight concrete in the building industry (Yu, Guan, Liu, Young,

* Corresponding author. Tel.: +852-2788-7831; fax: +852-2788-7830.
E-mail address: peter.yu@cityu.edu.hk (K.N. Yu)

PII: S0265-931X(99)00030-2

Stokes & Cheung, 1995a,b; Yu, Young, Guan & Liu, 1996a; Yu, Young, Stokes & Lo, 1996d; Yu, Young, Stokes & Tang, 1996e). In a previous investigation (Yu, 1993), the effects of typical covering materials used in Hong Kong on the Rn exhalation rate from concrete surfaces were studied in the laboratory. These covering materials were wall paper, plaster, ceramic mosaics and glazed ceramic. It was found that some covering materials could satisfactorily inhibit the Rn exhalation and reduce the corresponding indoor Rn concentration. Nevertheless, it was remarked that care should be taken in transferring the results to real buildings, and we should not be over-optimistic that the results would be as good as expected when such covering materials are actually applied to internal surfaces of real buildings.

In the present work, Rn concentration and the total potential α energy concentration of Rn progeny (PAEC) for 134 offices with typical covering materials on internal building surfaces, including walls, ceilings and floors, were surveyed, in order to identify realistic effects of covering materials on the indoor Rn properties. There were three objectives. First, the major combinations of covering materials for the walls, ceilings and floors in Hong Kong were identified. Second, the differences in the average indoor Rn concentrations for sites with different combinations of covering materials for the walls, ceilings and floors were found. Third, the average annual tracheobronchial equivalent dose were calculated using different contemporary dosimetric lung models.

While it was believed that only the Rn concentrations (or the Rn exhalation rate from building surfaces) would be affected by different covering materials, the PAEC was used together with the Rn concentration to calculate the equilibrium factor *F*, which cross-checked whether the variation in the Rn concentrations could be solely attributed to the different covering materials (see discussions below).

2. Materials and methods

The experiments were carried out in the summer and autumn months (July–December) in 1995 and 1996. A total of 134 offices were surveyed on a random basis. The air sampling points were chosen to be as stagnant as possible; i.e., they were away from windows, doors and air-conditioning units, since the concentrations of Rn and its progeny would be greatly influenced by air flow. The three-count filter method or the modified Tsivoglou method (Thomas, 1972) was employed using the Thompson–Nielson TN-WL-MS filter with a diameter of 22 mm. The time for collection was 30 min. An air flow rate of 8 l min^{-1} and thus a screen face velocity of 35 cm s^{-1} were employed. The counting periods of 2–5, 6–20 and 21–30 min were employed after the end of sampling, giving counts $N_{2,5}$, $N_{6,20}$ and $N_{21,30}$, respectively. The PAEC is then calculated by

$$\mathrm{PAEC} = \frac{1}{v\varepsilon\eta}(0.0490N_{2,5} - 0.0196N_{6,20} + 0.0374N_{21,30}), \qquad (1)$$

where v is the air flow rate (l min^{-1}), ε is the efficiency of the filter paper and η is the instrumental detection efficiency of α particles. The filter was counted by the Canada

RDA-200 Rn/Rn progeny detector. The Rn concentration was also measured by the RDA-200 detector, with the sampled air being drawn through the filter into the ZnS scintillation cell with a volume of 160 ml, and counted for 30 min after a waiting time of 30 min to allow equilibrium. At each site, the Rn concentration and PAEC were simultaneously measured.

3. Results

Within the 134 surveyed offices, 11 sites were either on the ground floor or with natural ventilation. Since the sites on the ground floor have larger indoor Rn concentrations due to the additional Rn source in the soil under the building, and the sites with natural ventilation have smaller indoor Rn concentrations due to higher air exchange with outdoor air (Yu, Young & Li, 1996c; Yu, Young, Stokes & Tang, 1998), these sites were excluded in our analysis. It is a common practice in Hong Kong that the air-conditioned offices have all their windows closed all the time, even after office hours when the air-conditioning is switched off.

The majority (87) of the remaining 123 sites had one of the three combinations of covering materials described below. The commonest combination (62) of covering materials for the walls, ceilings and floors was (wall paper, fibre board, and carpet, respectively). The second (13) and third (12) common combinations were (paint, paint and plastic tile) and (paint, fibre board and plastic tile), respectively. These are hereafter referred to as combinations (A), (B) and (C). Other combinations included (paint, fibre board, carpet) with 7 sites, (paint, paint, ceramic tiles) with 4 sites, (paint, paint, carpet) with 4 sites, etc. In the present paper, wall paper refers to plastic-lined wall paper.

Only the 87 sites for combinations (A), (B) and (C) were considered because the sample sizes of the other combinations were not large enough to give good statistics. The experimental data of the Rn concentration and the PAEC obtained from direct indoor measurements for these 87 sites are shown in Table 1, from which the equilibrium factor F has also been calculated. Simple observations reveal that the equilibrium factors for the three combinations are commensurate with each other. This is in fact an expected and desired result, because the covering materials should only affect the Rn exhalation and thus the indoor Rn concentration and PAEC, but not F. Significantly different F values show that there are factors other than the

Table 1
The radon concentration (RC), PAEC and equilibrium factor F for offices with different covering materials for walls, ceilings and floors

Combination	Wall	Ceiling	Floor	Sites	RC ($Bq\ m^{-3}$)	PAEC (mWL)	F
(A)	Wall paper	Fibre board	Carpet	62	50.30 ± 30.66	5.25 ± 5.45	0.41 ± 0.28
(B)	Paint	Fibre board	Plastic tile	12	52.09 ± 29.11	5.66 ± 4.00	0.39 ± 0.11
(C)	Paint	Paint	Plastic tile	13	32.69 ± 11.23	3.29 ± 1.54	0.37 ± 0.08

Table 2
The significance level (%) for difference in Rn concentrations for offices with different combinations of covering materials

Comparisons between	Significance level (%)
(A) and (B)	15.1
(A) and (C)	99.9
(B) and (C)	95.2

covering materials which are affecting the Rn properties, such as meteorological conditions (Yu et al., 1996c, 1997).

On the other hand, a clear picture of the difference among the Rn concentrations of the three combinations can only be made by performing *t*-tests on the data. The results of the *t*-tests are shown in Table 2. Here the significance level (%) for difference in Rn concentrations for offices with different combinations of wall covering materials are shown. From Table 2, it can be observed that the average Rn concentrations for combinations (A) and (B) are about the same, while that for combination (C) is significantly lower than those for (A) and (B).

4. Annual tracheobronchial equivalent dose

The annual tracheobronchial equivalent doses (mSv y^{-1}) from Rn for people working in offices with different combinations (A)–(C) of covering materials were calculated for different common lung dose models, including the Jacobi–Eisfeld (J–E) model (Jacobi & Eisfeld, 1980), the James–Birchall (J–B) model (James, Greenhalgh & Birchall, 1980), the James model (James, 1988) and the model of the National Research Council (1991) (NRC model).

For the J–B and J–E models, the formulae for the conversion factors were taken from the Nuclear Energy Agency (1983), i.e., $(5.0 + 62f_p)$ and $(5.3 + 15f_p)$ mGy WLM^{-1}. For the James model, the formula was given by James (1988) as

$$T_{T-B} = f_p D_u + (1 - f_p) D_a \quad (mGyWLM^{-1}), \tag{4}$$

where D_u and D_a were the dose conversion factors for unattached and attached progeny, which were 150 and 7 mGy WLM^{-1}, respectively, for Rn progeny. For the NRC model, Eq. (4) was still valid. The dose conversion factors for Rn progeny for an adult male under light exercise were adopted for comparison. In particular, factors corresponding to the nasal deposition according to Cheng, Swift, Su and Yeh (1989) and corresponding to an AMD of 0.15 μm for attached progeny were used. Under such conditions, D_u and D_a were 80.9 and 7.86 mGy WLM^{-1}, respectively.

The average unattached fraction of 0.13 (Yu et al., 1998) was employed in all the calculations. The annual tracheobronchial equivalent doses calculated for these lung dose models are shown in Table 3. It can be seen that the values vary to a great extent, and the more recent models give greater values. A person working in an office with combination (C) receives an average annual tracheobronchial equivalent dose smaller

Table 3
Annual tracheobronchial equivalent doses (mSv y^{-1}) calculated for offices with different combinations of covering materials

Combination	NRC	James	J–B	J–E
(A)	1.28	1.89	0.97	0.39
(B)	1.38	2.04	1.04	0.42
(C)	0.80	1.19	0.61	0.24

than one working in an office with combinations (A) and (B) by an amount as large as 0.8 mSv when using the James model, which is a significant value.

5. Conclusions

(1) The three commonest combinations of covering materials for the walls, ceilings and floors in Hong Kong were (A) wall paper, fibre board and carpet; (B) paint, paint and plastic tile and (C) paint, fibre board and plastic tile.

(2) The average Rn concentrations for combinations (A) and (B) were about the same, while that for combination (C) was significantly lower than those for (A) and (B).

(3) The annual tracheobronchial equivalent doses from Rn for people working in offices were calculated using different common lung dose models. It was found that a person working in an office with combination (C) could receive an average annual tracheobronchial equivalent dose smaller than one working in an office with combinations (A) and (B), by an amount as large as 0.8 mSv when using the James model.

Acknowledgements

This research is supported in part by the research grants 7000270 and 7000640 from the City University of Hong Kong.

References

Cheng, A. Y. S., Swift, D. L., Su, Y. F., & Yeh, H. C. (1989). Deposition of radon progeny in human head airways. *Proceedings of the DOE Technical Exchange Meeting on Assessing Indoor Radon Health Risk*, September 18–19, 1989, Grand Junction, CO. Department of Energy CONF 8909190. National Technical Information Service, Springfield, VA.

Jacobi, W., & Eisfeld, K. (1980). *Dose to tissue and effective dose equivalent by inhalation of Radon-222, Radon-220 and their short-lived daughters*. GSF Report S-626.

James, A. C. (1988). Lung dosimetry. In W. W. Nazaroff, & A. V. Nero, *Radon and its decay products in indoor air* (pp. 259–309). New York: Wiley.

James, A. C., Greenhalgh, J. R., & Birchall, A. (1980). A dosimetric model for tissues of the human respiratory tract at risk from inhaled radon and thoron daughters. In *Radiation protection, a systematic approach to safety* (Vol. 2, pp. 1045–1048). Oxford: Pergamon.

National Research Council (1991). *Comparative dosimetry of radon in mines and homes*. Washington, DC: National Academic Press.

Nuclear Energy Agency (1983). *Dosimetry aspects of exposure to radon and thoron daughters*. Paris: OECD.

Thomas, J. W. (1972). Measurement of radon daughters in air. *Health Physics*, *23*, 783–789.

Yu, K. N., Young, E. C. M., Stokes, M. J., Luo, D. L., & Zhang, C. X. (1992). Indoor radon and environmental gamma radiation in Hong Kong. *Radiation Protection Dosimetry*, *40*, 259–263.

Yu, K. N. (1993). The effects of typical covering materials on the radon exhalation rate from concrete surfaces. *Radiation Protection Dosimetry*, *48*, 367–370.

Yu, K. N., Guan, Z. J., Liu, X. W., Young, E. C. M., Stokes, M. J., & Cheung, T. (1995a). The effects of positive and negative ions on the lung dose from environmental radon. *Radiation Protection Dosimetry*, *58*, 65–68.

Yu, K. N., Guan, Z. J., Liu, X. W., Young, E. C. M., Stokes, M. J., & Cheung, T. (1995b). Mitigation of indoor radon hazard by air conditioning. *Journal of Radiological Protection*, *15*(1), 67–71.

Yu, K. N., Young, E. C. M., Guan, Z. J., & Liu, X. W. (1996a). The reduction of radon hazard in smoke free working environments. *Radiation Protection Dosimetry*, *63*(2), 147–149.

Yu, K. N., Young, E. C. M., & Li, K. C. (1996b). A survey of radon properties for dwellings for Hong Kong. *Radiation Protection Dosimetry*, *63*(1), 55–62.

Yu, K. N., Young, E. C. M., & Li, K. C. (1996c). A study of factors affecting the indoor radon properties. *Health Physics*, *71*(2), 179–184.

Yu, K. N., Young, E. C. M., Stokes, M. J., & Lo, T. Y. (1996d). The reduction of indoor radon dose by using light weight concrete in the building industry. *Radiation Protection Dosimetry*, *67*, 143–146.

Yu, K. N., Young, E. C. M., Stokes, M. J., & Tang, K. K. (1996e). Reduction of radon hazard in smoke-free offices. *Radiation Protection Dosimetry*, *67*(4), 287–298.

Yu, K. N., Young, E. C. M., Stokes, M. J., Guan, Z. J., & Cho, K. W. (1997). A survey of radon and thoron daughters for dwellings in Hong Kong. *Health Physics*, *73*, 373–377.

Yu, K. N., Young, E. C. M., Stokes, M. J., & Tang, K. K. (1998). Radon properties in offices. *Health Physics*, *75*, 159–164.