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Survey of the Rn dose conversion factor for offices

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Abstract

The Rn dose conversion factor (DCF), which relates the effective dose to the exposure to the potential α energy concentration (PAEC) of inhaled Rn progeny, was surveyed for 23 occupied and air-conditioned offices in Hong Kong using the bronchial dosimeter for Rn progeny proposed by Yu and Guan in 1998. The mean values of PAEC deposited in the tracheobronchial region ($\mathrm{PAEC_{T\text{–}B}}$), total PAEC in air ($\mathrm{PAEC_T}$) and the concentration of Rn (RC) for the offices were 0.13 ± 0.12 mWL, 3.4 ± 3.3 mWL and 30 ± 12 Bq m^{-3}, respectively. An average bronchial deposition fraction of Rn progeny was obtained as 0.037 (range: 0.033–0.051), which gave a DCF of 9.5 (range: 8.4–13) mSv WLM^{-1}. The annual effective dose (E) was estimated to be 0.38 ± 0.35 mSv yr^{-1} for the offices. © 2000 Elsevier Science Ltd. All rights reserved.

Keywords: Dose conversion factor; Rn; Dose; Dosimeter

1. Introduction

Bronchial deposition of Rn progeny (^{218}Po, ^{214}Pb, ^{214}Bi and ^{214}Po) is believed to cause lung cancers. For the determination of the bronchial dose from Rn progeny, the dose conversion factor (DCF), which relates the effective dose (in mSv) to the exposure

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to the potential α energy concentration (PAEC) of inhaled Rn progeny (in WLM), is required. A current well-known paradox is that the DCFs derived from dosimetric lung model calculations are significantly larger than those derived from epidemiological studies (see e.g. James, 1987). When adopting the lung-model approach, the size distribution of Rn progeny has a strong influence on the DCF. However, the size distributions were seldom determined in large-scale surveys because of the need for sophisticated equipment and tedious procedures.

Hopke et al. (1990) proposed a system consisting of multiple metal wire screens to mimic the deposition properties of Rn progeny in the tracheobronchial (T–B) region, without the requirement to measure the size distribution of Rn progeny. Based on this system, Yu and Guan (1998) proposed a bronchial dosimeter similar to a normal measurement system for Rn progeny or PAEC. It consists of only a single sampler and employs only one 400-mesh wire screen and one filter. In the present work, the above-mentioned bronchial dosimeter was used for the survey of bronchial dose from Rn progeny in offices. The average DCF for offices was then calculated from the measured data.

DCFs were usually determined for residences and mines. However, Yu et al. (1998, 2000) showed that the Rn properties in offices were very different from those in residences. Therefore, it is pertinent to investigate the DCF separately for offices.

2. Experiment

The bronchial dosimeter proposed by Yu and Guan (1998) was employed for the present survey of bronchial dose from Rn progeny in offices. Fig. 1 is the schematic diagram for the sampling set-up. The sampler housed a 400-mesh wire screen (wire velocity factor KVF $= 0.0473\ \mathrm{cm}^2\ \mathrm{s}^{-1}$) and a filter (Thompson–Nielson TN–WL–MS filter with 0.8 μm pore size), both having an effective diameter of 2.128 cm. The sampling face velocity U ($\mathrm{cm\ s}^{-1}$) was calculated from KVF and the wire factor WF, and was determined as $12\ \mathrm{cm\ s}^{-1}$ for our wire screen. The ZnS scintillation cell (volume = 160 ml) was not a requirement for the bronchial dosimeter, but was included for additional information for Rn concentrations.

After sampling, the wire screen and the filter were counted using a Canada RDA-200 Rn/Rn progeny detector. The three-count filter method or the modified Tsivoglou method (Thomas, 1972) was employed to measure the PAEC values recorded by the wire screen and the filter, namely, $\mathrm{PAEC_S}$ and $\mathrm{PAEC_F}$, respectively. Counting periods of 2–5, 6–20 and 21–30 min were employed after sampling of 30 min, giving counts N_1^{F}, N_2^{F} and N_3^{F}, respectively for the filter and counts N_1^{S}, N_2^{S} and N_3^{S}, respectively, for the wire screen, and $\mathrm{PAEC_F}$ and $\mathrm{PAEC_S}$ were calculated by

$$\mathrm{PAEC_F} = \frac{1}{v\eta_1 es}(0.0490N_1^{\mathrm{F}} - 0.0196N_2^{\mathrm{F}} + 0.0374N_3^{\mathrm{F}})\ \mathrm{mWL}, \tag{1}$$

$$\mathrm{PAEC_S} = \frac{(SL)}{v\eta_2(FT)}(0.0490N_1^{\mathrm{S}} - 0.0196N_2^{\mathrm{S}} + 0.0374N_3^{\mathrm{S}})\ \mathrm{mWL} \tag{2}$$

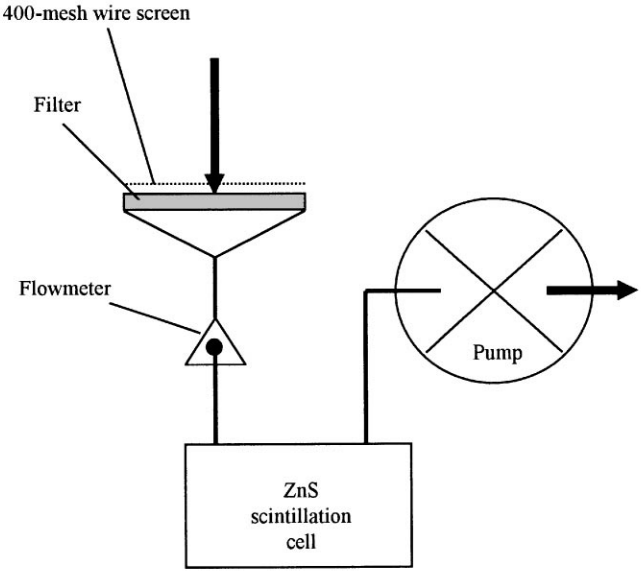

Fig. 1. Schematic diagram of the sampling set-up of the bronchial dosimeter.

where v was the air flow rate ($\mathrm{l\,min^{-1}}$) corresponding to a face velocity of $12\ \mathrm{cm\,s^{-1}}$, e and s were, respectively, the self-absorption coefficient for α particles and the collection efficiency for Rn progeny of the filter paper, η_1 and η_2 were, respectively, the efficiency of the system for detecting α particles from the filter and the wire screen, FT was the front-to-total activity ratio which takes into account that some progenies are attached to the back of the wire screen rather than on the surface, and SL was the screen loss factor (see Ren and Solomon, 1993; Yu and Guan, 1998). For our experiments, $e \times s = 0.8$, $\eta_1 = 0.397$, $\eta_2 = 0.484$, $\mathrm{FT} = 0.67$ and $\mathrm{SL} = 1.19$.

After sampling, the scintillation cell was sealed for 3 h until equilibrium was reached between the Rn and its progeny inside the scintillation cell, and the concentration of Rn (RC, in $\mathrm{Bq\,m^{-3}}$) was then measured also by the Canada RDA-200 Rn/Rn progeny detector.

According to Yu and Guan (1998), the PAEC deposited in the tracheobronchial region ($\mathrm{PAEC_{T\text{-}B}}$) was calculated by

$$\mathrm{PAEC_{T\text{-}B}} = \mathrm{PAEC_T} \times \Gamma\ (\mathrm{mWL}) \tag{3}$$

where

$$\mathrm{PAEC_T} = \mathrm{PAEC_S} + \mathrm{PAEC_F} \tag{4}$$

$$\Gamma = (0.0673 \pm 0.0002)\varepsilon + (0.0316 \pm 0.0000) \tag{5}$$

$$\varepsilon = \mathrm{PAEC_S}/\mathrm{PAEC_T} \tag{6}$$

The formula given by Yu and Guan (1998) for calculating the annual effective dose ($E = 10.5 \times \text{PAEC}_{\text{T-B}}$ mSv yr^{-1}) was derived for residential sites for which the occupancy factor was taken to be 0.8, which corresponded to an annual occupancy of ~ 7000 h. For offices, the nominal annual occupancy should only be 2000 h (see ICRP, 1979), so E should be given by $E = 10.5 \times (2/7) \times \text{PAEC}_{\text{T-B}}$ mSv yr^{-1} or

$$E = 3.0 \times \text{PAEC}_{\text{T-B}}\ (\text{mSv yr}^{-1}). \tag{7}$$

The dose surveys were carried out from August 1998 to January 1999. A total of 23 occupied air-conditioned offices were surveyed. All measurements were made between 9 a.m. and 5 p.m. to ensure uniform experimental conditions. The air sampling points were chosen to be as calm as possible; i.e. they were away from windows, doors and air-conditioning units, since the concentration of Rn and its progeny would be greatly influenced by the air flow.

3. Results and Discussion

The mean values (accompanied by their standard deviations) of $\text{PAEC}_{\text{T-B}}$, PAEC_{T}, RC and E for all the 23 sites were 0.13 ± 0.12 and 3.4 ± 3.3 mWL, 30 ± 12 Bq m^{-3} and 0.38 ± 0.35 mSv yr^{-1}, respectively. An average bronchial deposition fraction of Rn progeny was obtained as 0.037 (range: 0.033–0.051).

The calculated $\text{PAEC}_{\text{T-B}}$ and the total PAEC in air (PAEC_{T}) values are shown in Fig. 2 for the 23 offices, and a linear relationship seemed to be found between the

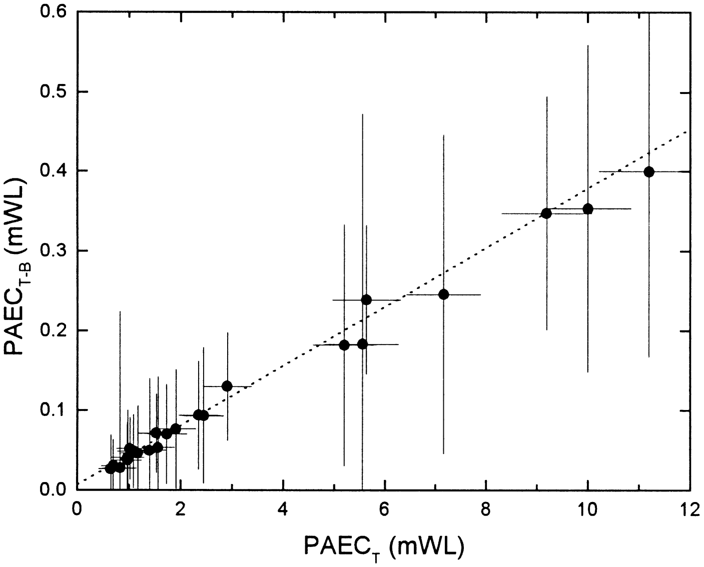

Fig. 2. Measured $\text{PAEC}_{\text{T-B}}$ and PAEC_{T} values for the 23 offices. Dashed line: linear fit to all data (slope = 0.037 ± 0.001, intercept = 0.0066 ± 0.0023, correlation coefficient = 0.99 ± 0.12, ± means 95% confidence intervals).

$PAEC_{T\text{-}B}$ and $PAEC_T$ values reasonably well (slope $= 0.037 \pm 0.001$, intercept $= 0.0066 \pm 0.0023$, correlation coefficient $= 0.99 \pm 0.12$, ± means 95% confidence intervals). The slope was in fact the average deposition fraction Γ, which depended on ε (see Eq. (5)). Since ε increases supra-linearly when $PAEC_T$ decreases below around 1 mWL (see Fig. 3), and Γ increases linearly with ε as shown in Eq. (5), it is expected that Γ (and thus the slope in Fig. 2) will also increase when $PAEC_T$ decreases below around 1 mWL. Nevertheless, in this region of $PAEC_T$, the ε values cluster in the region of 10–20% (see Fig. 3), and the mean value is 12%. For this ε and from Eq. (5), Γ (or the slope in Fig. 2) will be 0.040, which represents a 7% deviation from the nominal value of 0.037. In view of this small relative difference, Γ can be effectively treated as a constant. It can also be inferred that the bronchial deposition fraction of Rn progeny was insensitive to the total potential α energy concentration of Rn progeny ($PAEC_T$).

As described in Yu and Guan (1998), roughly half of the PAEC deposited in the T–B region will be absorbed in the epithelium and the mass of the tissue involved is roughly 15 g (James, 1987). For a breathing rate of $30\,\mathrm{l\,min^{-1}}$, 1 WLM is equivalent to 6.365×10^{-3} J of potential α energy. For quality factor $Q = 20$ for α particles and weighting factor $W_{T\text{-}B} = 0.06$ for the T–B region, we can obtain the DCF as $[0.5 \times \Gamma \times 6.365 \times 10^{-3}] \times [0.06 \times 20]/(15 \times 10^{-3}) = [0.212 \times \Gamma] \times [1.2]\ \mathrm{Sv\,WLM^{-1}}$ or $255 \times \Gamma\ \mathrm{mSv\,WLM^{-1}}$. From $\Gamma = 0.037$ (range: 0.033–0.051), an average DCF of 9.5 (range: 8.4–13) $\mathrm{mSvWLM^{-1}}$ was obtained, which was close to the DCF of $10\ \mathrm{mSv\,WLM^{-1}}$ proposed by James (1987) but higher than the range of $5.7\text{–}6.7\ \mathrm{mSv\,WLM^{-1}}$ for working places reported by Porstendörfer and Reineking

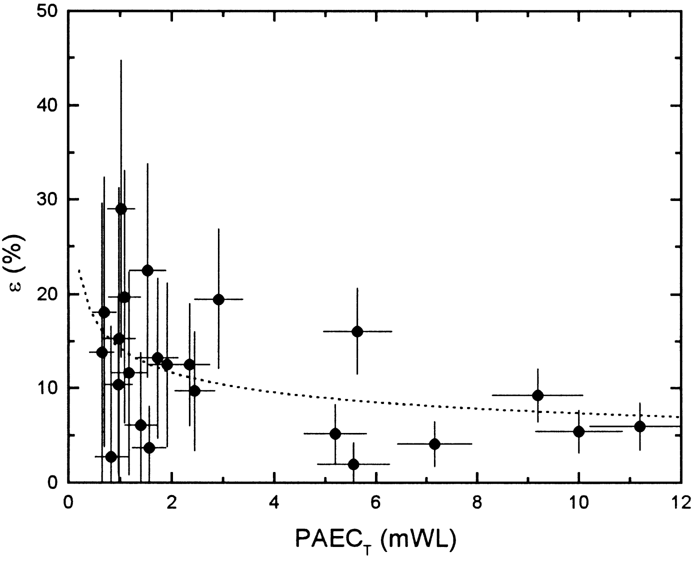

Fig. 3. Measured ε and $PAEC_T$ values for the 23 offices. Dashed line: non-linear fit to all data $\{\varepsilon\ (\%) = (14 \pm 2) \times [PAEC_T\ (\mathrm{mWL})]^{-(0.29 \pm 0.15)}$, ± means 95% confidence intervals$\}$.

(1999) and the value of 7.3 mSv WLM^{-1} obtained by Porstendörfer and Reineking (1999) for dwellings with normal aerosol conditions.

Fig. 3 shows the dependence of ε on $\mathrm{PAEC_T}$. A non-linear fit gave $\varepsilon(\%) = (14 \pm 2) \times [\mathrm{PAEC_T}\ (\mathrm{mWL})]^{-(0.29 \pm 0.15)}$, with ± values as the 95% confidence intervals. In the following, we would like to show that ε surrogates the unattached fraction f_p and $\mathrm{PAEC_T}$ surrogates the number of aerosol particles Z in air. As the nasal deposition fraction of Rn progeny strongly correlates with the unattached fraction f_p (Hopke et al., 1990) and the nasal deposition fraction of Rn progeny can be represented by ε (Yu and Guan, 1998), ε surrogates the unattached fraction f_p. When the number of aerosol particles Z in air increases, the probability of Rn progeny attaching to aerosol particles is enhanced compared to that of attaching to surfaces (i.e., plate-out), so $\mathrm{PAEC_T}$ surrogates the number of aerosol particles Z in air. In this way, the above result that ε decreases with $\mathrm{PAEC_T}$ also indicates that f_p decreases with Z, which agrees with the previous findings (e.g., George and Hinchliffe, 1972; Robkin, 1987; Porstendörfer, 1996; Porstendörfer and Reineking, 1999).

4. Conclusions

1. The Rn dose conversion factor (DCF) was surveyed for 23 occupied and air-conditioned offices in Hong Kong using the bronchial dosimeter for Rn progeny proposed by Yu and Guan (1998).
2. The mean values of potential α-energy concentration (PAEC) deposited in the tracheobronchial region ($\mathrm{PAEC_{T\text{-}B}}$), total PAEC in air ($\mathrm{PAEC_T}$) and the concentration of Rn (RC) for the offices were 0.13 ± 0.12 mWL, 3.4 ± 3.3 mWL and 30 ± 12 Bq m^{-3}, respectively.
3. An average bronchial deposition fraction of Rn progeny was obtained as 0.037 (range: 0.033–0.051), which gave a DCF of 9.5 (range: 8.4–13) mSv WLM^{-1}.
4. The annual effective dose was estimated to be 0.38 ± 0.35 mSv yr^{-1} for the offices in Hong Kong using the obtained DCF value.

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References

George, A. C., & Hinchliffe, L. (1972). Measurements of uncombined radon daughters in uranium mines. *Health Physics*, *23*, 791–803.

Hopke, P. K., Ramamurthi, M., & Knutson, E. O. (1990). A Measurement system for radon decay product lung deposition based on respiratory models. *Health Physics*, *58*, 291–295.

ICRP (1979). ICRP Publications 30 Part 1, Limits for Intakes of Radionuclides by Workers, *A report of Committee 2 of the International Commission on Radiological Protection*. Oxford: Pergamon, p. 9.

James, A. C. (1987). A reconsideration of cells at risk and other key factors in radon daughter dosimetry. In P. K. Hopke, *Radon and Its Decay Products: Occurrence, Properties and Health Effects* (pp. 400–418). Washington, DC: American Chemical Society.

Porstendörfer, J. (1996). Radon: measurements related to dose. *Environment International*, *22*(Suppl.1), S563–S583.

Porstendörfer, J., & Reineking, A. (1999). Radon: characteristics in air and dose conversion factors. *Health Physics*, *76*, 300–305.

Ren, T. S., & Solomon, S. B. (1993). Measurement of counting efficiencies for alpha particles of radon daughters deposited on wire screens. *Radiation Protection*, *13*, 8–15 ((in Chinese)).

Robkin, M. A. (1987). Terminology for describing radon concentration and exposure. In D. Bodansky, M. A. Robkin, & D. R. Stadler, *Indoor radon and its hazards* (pp. 17–29). Washington, DC: University of Washington Press.

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

Yu, K. N., & Guan, Z. J. (1998). A portable bronchial dosimeter for radon progeny. *Health Physics*, *75*, 147–152.

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

Yu, K. N., Cheung, T., Guan, Z. J., Mui, B. W. N., & Ng, Y. T. (2000). ^{222}Rn, ^{220}Rn and their progeny concentrations in offices in Hong Kong. *Journal of Environmental Radioactivity*, *48*, 95–105.