ELSEVIER

Journal of
Environmental Radioactivity 56 (2001) 327–340

JOURNAL OF
ENVIRONMENTAL
RADIOACTIVITY

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Radon progeny dose conversion coefficients for Chinese males and females

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Received 24 March 2000; received in revised form 6 October 2000; accepted 31 October 2000

Abstract

The airway dimensions for Caucasian males have been scaled by multiplying by factors 0.95 and 0.88 to give those for Chinese males and females, respectively. Employing the most recent data on physical and biological parameters, the radiation doses to the basal and secretory cells due to α particles from ^{218}Po and ^{214}Po, homogeneously distributed in the mucous layer, have been calculated. The emission of α particles has been simulated by a Monte Carlo method. For both basal and secretory cells, the dose conversion coefficients (DCCs) for physical conditions of sleep, rest, light and heavy exercise, have been obtained for Chinese males and females for unattached progeny, and for attached progeny of diameters 0.02, 0.15, 0.25, 0.30 and 0.50 μm. For basal cells, the coefficients lie in the range 0.69–6.82 mGy/(J s/m^3) or 8.7–86 mGy/WLM for unattached progeny and in the range 0.045–1.98 mGy/(J s/m^3) or 0.57–25 mGy/WLM for attached progeny. The corresponding ranges for Caucasian males are 1.27–8.81 mGy/(J s/m^3) or 16–111 mGy/WLM^{-1} and 0.05–2.30 mGy/(J s/m^3) or 0.64–29 mGy/WLM. For secretory cells, the coefficients lie in the range 0.095–16.82 mGy/(J s/m^3) (1.2–212 mGy/WLM) for unattached progeny and in the range 0.095–6.67 mGy/(J s/m^3) (1.2–84 mGy/WLM) for attached progeny. The corresponding ranges for Caucasian males are 0.34–21.51 mGy/(J s/m^3) (4.3–271 mGy/WLM) and 0.1–7.78 mGy/(J s/m^3) (1.3–98 mGy/WLM). The overall DCCs calculated for a typical home environment are 0.59 and 0.52 mSv/(J s/m^3) (7.4 and 6.5 mSv/WLM) for Chinese males and females, respectively,

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PII: S0265-931X(00)00204-6

which are 80 and 70% of the value, 0.73 mSv/(J s/m^3) (9.2 mSv/WLM), for Caucasian males.

Keywords: Lung dosimetry model; Radon; Dose conversion coefficients; Scaling factors; Radon progeny

1. Introduction

Epidemiological studies of underground miners of uranium and other minerals have provided reasonably firm estimates of the risk of lung cancer associated with exposure to radon progeny (Lubin, 1988). More recently, Lubin et al (1994), to provide quantitative information on the risk of radon-induced lung cancer, have carried out a joint analysis of data from 11 studies, in which 2700 lung cancer deaths occurred among 68,000 miners, accumulating nearly 1.2 million person-years. Excess relative risk (ERR) of lung cancer was linearly related to cumulative exposure J s/m^3 (or in WLM = 12.6 J s/m^3) to radon progeny. The dose conversion coefficient (DCC) obtained from miners' epidemiological studies is about 5 mSv/WLM.

Because of the importance, to the public, of the risks of radon exposure in homes (including high-rise apartments), schools and offices, EPA had asked the National Research Council (NRC) to initiate a study of the dosimetric considerations affecting the applications of risk estimates from miners studies, to the general population. The Scientific Panel appointed by the NRC has reviewed the basic information and the modelling procedures needed to extend these data to radon exposure in the home environment. The reviews carried out by the NRC's panel and the ICRP Task Group (Bair, 1991) both concluded that the target tissue at risk are basal and secretory cells in the epithelium.

According to NEA (1983), a DCC of 0.67 mSv/(J s/m^3) (8.5 mSv/WLM) should be used to characterize the lifetime exposure to radon progeny in mines, and 0.44 mSv/(Js/m^3) (5.5 mSv/WLM) in homes. In the opinion of NRC, the latter figure should be 0.95 mSv/(J s/m^3) (12 mSv/WLM). ICRP66 found that it should be 1.19 mSv/(Js/m^3) (15 mSv/WLM) (Birchall & James, 1994). James (1992) also concluded that the effective dose calculated for exposure to radon progeny needs to be substantially modified to allow dosimetric estimates of lung cancer risk to reconcile with values obtained from epidemiological studies.

In view of the considerable discrepancy between the DCCs obtained from dosimetric and epidemiological studies, we have carried out radon progeny dosimetric modelling for Caucasian males and Chinese males and females. It is felt that the latter constitute a significant proportion of the world population, and merit study, which has been undertaken here.

The Report of the Task Group on Reference Man (ICRP, 1975) gives the anatomical dimensions of a Caucasian. The "Reference Man" is defined "as being between 20 and 30 years of age, weighing 70 kg, is 170 cm in height, and lives in a climate with an average temperature from 10 to 20°C. He is a Caucasian and is a Western European or a North American in habitat and custom". In order, therefore, to carry out dosimetric modelling of Chinese males and females, some form of scaling of the respiratory airways is needed. For this purpose, the anatomical data have been taken from respiratory tract dosimetry, proceedings of a Workshop (Roy, Becquemin, & Bouchikin, 1991).

2. Methods and materials

2.1. Scaling of respiratory airways for Chinese males and females from Caucasian males

Lung model: Many authors have used the symmetric Weibel dichotomous model (Weibel, 1963). Yeh and Schum (1980) have made extensive measurements of the airways, which are also currently used. James (1988) has calculated the means of the airway dimensions from the models of Weibel, Yeh, Schum, and Phalen, Oldham, Beaucage, Crocker, and Mortensen (1985), known as the UCI model. The NRC panel has used one version of this model. Recently, Harley, Cohen, and Robbins (1996) used the data of Nikoforov and Schlesinger (1985) on the length and diameters of the airways, but these data are not as extensive as others. It seems to us that the measurements made by Yeh and Schum have a firmer claim to being more realistic; and its scaled version, for Chinese males and females, has been used for the calculation of the DCCs using the most recent parameters.

Calculation of the scaling factors: For the following calculations, the data from Table 1 have been used:

FRC ratio (Chinese males/Caucasian males) = 2950/3300 = 0.894,

$(\text{FRC ratio})^{1/3} = 0.963$,

Weight ratio = 59/70 = 0.8428,

$(\text{Weight ratio})^{1/3} = 0.9446$.

where the functional residual capacity (FRC) is the volume of air remaining in the lung after normal expiration. The NRC panel recommends $(\text{FRC ratio})^{1/3}$ as the basis for scaling, whereas there are others who are in favour of $(\text{weight ratio})^{1/3}$ or (height ratio) — we have used a scaling factor given by the average between $(\text{FRC ratio})^{1/3}$ and $(\text{weight ratio})^{1/3}$, which is 0.95 in this case, i.e. all linear lung dimensions are to be multiplied by 0.95 to obtain those for Chinese males.

Similarly, for Chinese females,

FRC ratio (Chinese females/Chinese males) = 2122/2950 = 0.7193,

$(\text{FRC ratio})^{1/3} = 0.8960$,

Weight ratio = 53/59 = 0.8983,

$(\text{Weight ratio})^{1/3} = 0.9649$.

We have used the scaling factor as 0.93, i.e., all the linear lung dimensions of Chinese males are to be multiplied by 0.93 to obtain those for Chinese females.

In Table 2 are given the diameters and the lengths of tubes in the tracheobronchial (T-B) tree for Chinese males. To get the dimensions of the Chinese female lung, the figures in Table 2 have to be multiplied by the factor 0.93.

Table 1
Anatomical data of Caucasian males and Chinese males and females (after ICRP 66), B.6 and B.8 are the table numbers of the ICRP 66 report

	Caucasian	Chinese (B.8)	
	Males (B.6)	Males	Females
Weight (kg)	73	59	53
Height (cm)	176	168	157
FRC (ml)	3301	2950	2122

Table 2
Dimensions of the Chinese male lung (L: length; D: diameter; both in cm)[a]

Generation	Right lobes						Left lobes			
	Upper		Middle		Lower		Upper		Lower	
	L	D	L	D	L	D	L	D	L	D
0	9.5	1.91	9.5	1.91	9.5	1.91	9.5	1.91	9.5	1.91
1	2.94	1.66	2.94	1.66	2.94	1.66	5.35	1.31	5.35	1.31
2	1.16	0.97	2.87	1.26	2.87	1.26	1.38	0.98	1.35	1.09
3	0.76	0.72 ↑	2.16	0.68	0.84	0.96	1.03	0.79	1.26	0.86 ↑
4	1.21	0.62	1.27	0.59	1.04	0.76 ↑	0.97	0.61	1.07	0.65
5	1.19	0.55	1.55	0.50	1.26	0.62	1.04	0.51	0.85	0.53
6	0.79	0.43	0.99	0.36	1.16	0.55	0.97	0.40	0.97	0.43
7	0.94	0.34	0.99	0.30	0.76	0.45	0.71	0.32	0.79	0.35
8	0.76	0.26	0.66	0.25	0.76	0.35	0.79	0.29	0.74	0.30
9	0.53	0.21	0.50	0.19	0.84	0.33	0.53	0.22	0.73	0.28
10	0.38	0.15	0.37	0.14	0.86	0.30	0.46	0.17	0.58	0.27
11	0.33	0.11	0.25	0.10	0.56	0.24	0.37	0.13	0.52	0.20
12	0.24	0.08	0.21	0.08	0.43	0.17	0.33	0.09	0.41	0.14
13	0.18	0.07	0.16	0.06	0.32	0.13	0.25	0.07	0.29	0.09
14	0.14	0.055	0.11	0.05	0.24	0.096	0.20	0.058	0.21	0.07

[a] ↑ Dichotomous branching starts.

2.2. Yeh–Schum model and calculation of the DCCs

As mentioned before, the Yeh–Schum model is used for our calculation of the DCCs. A flow chart of the used programs is given in Fig. 1. As can be seen from Fig. 1, the calculations of DCCs involved two phases and made use of two separate programs, namely CCOEF and LUNG.

The first computer program CCOEF calculated the absorbed dose per unit surface activity on the inner bronchi wall. In this work, our attention is confined to the calculation of dose to the basal and secretory cells in the epithelium due to 6 MeV α particles from ^{218}Po and 7.69 MeV α particles from ^{214}Po, the ranges of which are

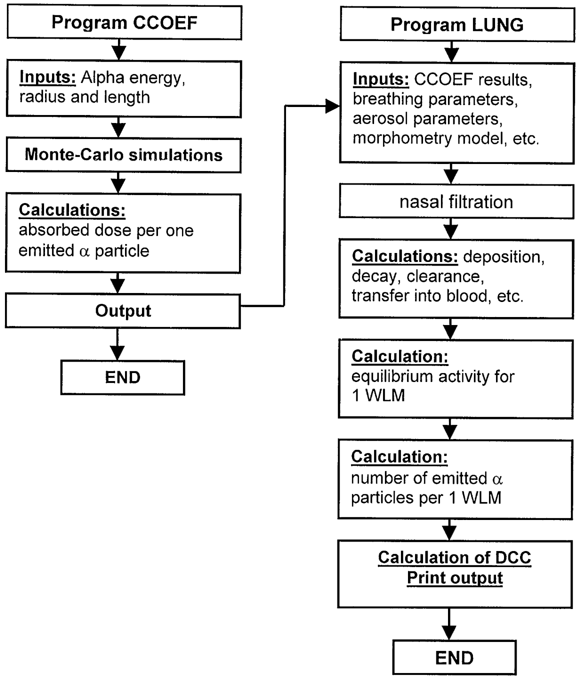

Fig. 1. A flow chart of the programs used to calculate the dose conversion coefficients (DCCs), which involve two phases and two separate programs, namely CCOEF and LUNG.

taken to be 48 and 71 μm, respectively, in tissue (tissue-equivalent liquid). Stopping powers for α particles in striated muscle (ICRU, 1993) have been employed.

In the present work, the idealized picture of the epithelium used is as illustrated by the NRC panel (NRC 1991), i.e. the airway consists of cylindrical tubes. In the bronchial (BB) region (generations 1–8), the tubes have a 5 μm layer of mucous gel, a 6 μm layer of cilia and fluid, and the basal and secretory cells are distributed between 35 and 50 μm, and between 10 and 40 μm, respectively, below the epithelial surface. In the bronchiolar (bb) region (generations after 8), the tubes have a 2 μm layer of mucous gel, a 4 μm layer of cilia and fluid and there are no basal cells; the secretory cells are distributed between 4 and 12 μm below the epithelial surface. As earlier, the calculation takes into account the dose contributed by α particles crossing the airway lumen (the so-called far wall contribution).

Short-lived Rn progeny were taken to be homogeneously distributed in the mucous layer. The emission of the α particle from a point in the mucous layer, i.e. its starting point as well as its direction, have been sampled by a Monte Carlo method. The next step is to calculate the distances the α particle has travelled in tissue from its point of origin to the entrance/exit points in the basal and secretory layers, from which energy loss in the basal or secretory layer has been calculated.

The amount of energy deposited in the target cells depended on the stopping power of the α particles in the tissue. The experimental information about slowing down of α particles in tissue was given in ICRU49 (ICRU, 1993). The data given by ICRU49 were fitted by the seventh-order polynomial in the low-energy region below 2 MeV:

$$-\frac{dE}{dx} = c_1 + c_2E + c_3E^2 + c_4E^3 + c_5E^4 + c_6E^5 + c_7E^6 + c_8E^7, \tag{1}$$

where $c_1 = 332.201$, $c_2 = 11465.805$, $c_3 = -34405.805$, $c_4 = 65160.750$, $c_5 = -74817.644$, $c_6 = 48668.099$, $c_7 = -16413.770$ and $c_8 = -2225.653$ (Nikezic, Yu, Cheung, Haque, & Vucic, 2000). In the higher energy region (above 2 MeV), another sixth-order polynomial fit was used with the parameters as $c_1 = 3467.934$, $c_2 = -1577.94579$, $c_3 = 459.644431$, $c_4 = -81.19981$, $c_5 = 8.44979$, $c_6 = -0.47563$ and $c_7 = 0.01115$ (Nikezic et al., 2000). Therefore, Eq. (1) with two sets of the parameters was employed to determine the absorbed doses per unit exposure to Rn progeny in sensitive cells of the bronchial epithelium.

In this method, the above steps for the Monte Carlo simulation have been repeated 10^4 times. The average absorbed dose in the layers of interest (basal and secretory cells) have then been calculated for one α particle by dividing the average energy by the mass of the basal or secretory layer. This quantity, called the conversion coefficient (CC), was given in units of MeV per α particle. Using the inner surface area of the airway, this figure can then be converted into absorbed dose per unit surface activity. This concludes our first program, CCOEF.

The results obtained in the first phase of calculation were used in the second program, LUNG. In our model each airway tube in generations 1–15 was treated separately. The main objective in the second phase was to obtain the equilibrium activity and the number of emitted α particles N_α of Rn progeny in every airway tube for the exposure of 1 WLM. The equilibrium activity is the activity of some Rn progeny in an airway in generation j, which is established as the balance between the processes which increase its activity (deposition + decay of the parent nuclide in the radioactive chain + activity cleaned and transported by mucus from generations $>j$) and those processes which decrease its activity (decay, transfer to blood, cleaned and transported by mucus into generations $<j$). N_α was found in the present paper as the number of α particles per WLM. The product of $N_\alpha \times$ CC gave the DCF (in mGy/WLM) for the sensitive cells.

As the first step, the nasal filtration of the aerosol particles and the unattached fraction were estimated using the work of Cheng, Swift, Yamada, & Yeh (1988). In order to calculate the DCCs, the breathing rates V_E, for a Caucasian male, were taken from NRC, viz. 0.45, 0.54, 1.5 and 3.0 m^3h^{-1} for conditions of sleep, rest and light and heavy exercise respectively. The respiratory frequencies were 12, 12, 20 and 26/min, respectively, for which the tidal volumes were 625, 750, 1250 and 1923 cm^3.

As regards Chinese males and females, the values of V_E were scaled according to factors (Chinese males/Caucasian males) = 0.81 and (Chinese females/Chinese males) = 0.71. The scaling factors (with respect to the Caucasian male) were obtained as the mean value of the functional residual capacity (FRC) ratio, the total lung capacity (TLC) ratio and the vital capacity (VC). The FRC, TLC and VC ratios for Chinese males are 0.7821, 0.8961 and 0.7371, respectively (Roy et al., 1991), giving a mean value of 0.81. The corresponding ratios for Chinese females are 0.7123, 0.7193 and 0.6868, respectively (Roy et al., 1991), giving a mean value of 0.71. Keeping the respiratory frequencies the same as those for the Caucasian male, the tidal volumes can be readily calculated.

The deposition in the airways has been considered both for inspiration and expiration. The deposition equation of Cohen and Asgharian (1990), applicable in the region 0.04–0.2 μm, has been used together with Gormley and Kennedy's (1949) expressions with Landahl (1963) corrections. For the calculation of diffusion coefficients of aerosol particles, the NRC panel treatment has been, followed. In order to calculate the equilibrium activity, mucous transit times, as given by Cuddihy and Yeh (1988), quoted also by NRC, of 11, 9, 7, 10, 11, 13, 16, 22, 22, 28, 45, 91, 143, 417 and 1667 min., for generations 1–15, respectively, were used. Two main clearance routes were considered: mucus clearance and transfer to blood. The transfer into the blood was characterized by a half-time of $T = 600$ min (NRC, 1991) and the mucous clearance rate throughout the T-B tree was also taken from NRC (1991).

The DCCs were finally obtained by multiplying the number of α particles emitted by ^{218}Po and ^{214}Po for the exposure of 1 WLM by the corresponding conversion coefficients. After obtaining the DCCs in different generations of T-B tree, an average was calculated by weighting them with the surface area in the corresponding generation. This concludes our second program, LUNG.

The dose per WLM or J s/m^3 has been calculated for the unattached fraction of diameter 0.0011 μm, and for aerosol particles of diameters, d_p, 0.02, 0.15, 0.25, 0.30 and 0.5 μm.

3. Results and discussion

Bearing in mind the above parameters, the results of calculation of the DCCs as a function of the size of radon progeny aerosols and the condition of exertion are given in Tables 3–5. For both basal and secretory cells, the DCCs for physical conditions of sleep, rest, light and heavy exercise, have been obtained for Chinese males and females for unattached progeny, diameters 0.0011 μm, and for attached progeny of diameters 0.02, 0.15, 0.25, 0.30 and 0.50 μm.

The DCCs calculated for Chinese males and females have been found to be lower than the corresponding values for Caucasian males. For basal cells, the factors for Chinese males lie in the range 0.87–6.82 mGy/(J s/m^3) (11–86 mGy/WLM) for unattached progeny and in the range 0.045–1.98 mGy/(Js/m^3) (0.57-25 mGy/WLM) for attached progeny. The corresponding ranges for Chinese females are 0.69–5.95 mGy/(Js/m^3) (8.7-75 mGy/WLM) and 0.046–1.9 mGy/(Js/m^3) 0.58–24 mGy/WLM). The corresponding ranges for Caucasian males are 1.27–8.81 mGy/(Js/m^3) (16–111 mGy/WLM) and 0.05–2.3 mGy/(Js/m^3) (0.64–29 mGy/WLM). For secretory cells, the factors for Chinese males lie in the range (0.17–16.82 mGy/(Js/m^3) (2.2–212 mGy/WLM) for unattached progeny and in the range 0.09–6.67 mGy/

Table 3
Dose conversion coefficients for Chinese males

d_p (μm)	Exposure dose conversion coefficient (mGy/WLM)			
	Breathing rate (m^3/h)			
	0.3645	0.4374	1.215	2.43
(a) Basal cells				
0.0011 (unattached)	11.28	14.28	45.30	85.94
0.02	10.12	11.19	18.42	24.86
0.15	1.33	1.42	2.00	2.54
0.25	0.83	0.88	1.23	1.59
0.30	0.72	0.76	1.07	1.41
0.50	0.57	0.60	0.86	1.34
(b) Secretory cells in bronchial (BB) region				
0.0011 (unattached)	32.27	40.03	116.37	212.49
0.02	20.27	22.39	36.81	49.64
0.15	2.67	2.84	4.02	5.10
0.25	1.66	1.77	2.48	3.22
0.30	1.45	1.54	2.16	2.86
0.50	1.15	1.22	1.74	2.76
(c) Secretory cells in bronchiolar (bb) region				
0.0011 (unattached)	2.19	3.47	30.25	95.65
0.02	31.08	34.88	60.98	84.40
0.15	4.52	4.82	6.82	8.59
0.25	2.77	2.94	4.10	5.20
0.30	2.38	2.53	3.51	4.48
0.50	1.80	1.90	2.59	3.54

(Js/m^3) (1.2–84 mGy/WLM) for attached progeny. The corresponding ranges for Chinese females are (0.095–14.76 mGy/(Js/m^3) 1.2-186 mGy/WLM) and 0.095–6.43 mGy/(Js/m^3) (1.2–81 mGy/WLM). The corresponding ranges for Caucasian males are 0.34–21.51 mGy/(Js/m^3) 4.3–271 mGy/WLM) and 0.1–7.78 mGy/(Js/m^3) 1.3–98 mGy/WLM).

It can be observed that the DCCs are largest for Caucasian males, followed by those for Chinese males and then by those for Chinese females. Moreover, the DCCs have the highest values for unattached progeny, and decrease with the particle size for the attached progeny. These are true for both basal cells and secretory cells, and also for Caucasian males, Chinese males and Chinese females. The trend is as expected because diffusion deposition, which is an efficient mechanism for radon progeny deposition in the T-B tree, operates essentially only for small particles. For larger particles, diffusion deposition is less effective and the calculated DCCs are thus smaller. Furthermore, the DCCs increase with the breathing rate, which agrees with previous results (NRC, 1991, p. 231).

Table 4
Dose conversion coefficients for Chinese females

d_p (μm)	Exposure dose conversion coefficient (mGy/WLM)			
	Breathing rate (m^3/h)			
	0.2588	0.3106	0.8627	1.7253
(a) Basal cells				
0.0011 (unattached)	8.75	11.20	37.95	74.75
0.02	9.64	10.69	17.94	24.45
0.15	1.32	1.41	2.00	2.53
0.25	0.83	0.88	1.23	1.58
0.30	0.72	0.77	1.07	1.39
0.50	0.58	0.61	0.84	1.25
(b) Secretory cells in bronchial (BB) region				
0.0011 (unattached)	25.57	32.05	98.52	185.78
0.02	19.19	21.27	35.63	48.51
0.15	2.64	2.82	3.99	5.06
0.25	1.66	1.76	2.46	3.17
0.30	1.44	1.53	2.14	2.79
0.50	1.15	1.21	1.70	2.54
(c) Secretory cells in bronchiolar (bb) region				
0.0011 (unattached)	1.21	1.99	20.33	69.76
0.02	28.67	32.35	58.09	81.46
0.15	4.44	4.75	6.74	8.50
0.25	2.74	2.91	4.06	5.13
0.30	2.36	2.51	3.47	4.41
0.50	1.79	1.89	2.55	3.39

In Table 6, we have listed the DCCs for Chinese males, Chinese females and Caucasian males for the rest condition only, i.e. with breathing rates of 0.4374, 0.3106 and 0.54 m^3/h, respectively. We can still observe that the DCC values decrease rapidly from the unattached fraction to the aerosol particles, but decrease only mildly from larger aerosol particles to smaller aerosol particles. As described in the preceding paragraph, this is due to the characteristics of the diffusion deposition process which is efficient for the unattached fraction but less effective for the aerosol particles.

We can also see the effects of breathing rate on the DCCs. The DCCs for Caucasian males are largest and those for Chinese females are smallest. Similarities between the values for Chinese males and Chinese females were also observed for larger aerosol particles. These are more readily observable from Table 7, which gives the DCCs for Chinese males, Chinese females and Caucasian males for different physical activities at $d_p = 150$ nm. On one hand, a larger breathing rate will draw in more radon progeny for deposition. On the other hand, for higher flow velocities, the nasal filtration through aerodynamic deposition increases while that through thermodynamic deposition decreases. Therefore, the trend of the

Table 5
Dose conversion coefficients for Caucasian males

d_p (μm)	Exposure dose conversion coefficient (mGy/WLM)			
	Breathing rate (m^3/h)			
	0.45	0.54	1.5	3.0
(a) Basal cells				
0.0011 (unattached)	16.38	20.47	60.77	111.20
0.02	12.16	13.39	21.68	29.00
0.15	1.52	1.62	2.29	2.92
0.25	0.94	1.00	1.42	1.88
0.30	0.81	0.87	1.24	1.72
0.50	0.64	0.67	1.04	1.90
(b) Secretory cells in bronchial (BB) region				
0.0011 (unattached)	45.40	55.71	153.04	270.95
0.02	24.23	26.68	43.13	57.67
0.15	3.04	3.24	4.59	5.85
0.25	1.88	2.00	2.84	3.80
0.30	1.63	1.74	2.49	3.48
0.50	1.27	1.35	2.11	3.96
(c) Secretory cells in bronchiolar (bb) region				
0.0011 (unattached)	4.31	6.59	49.36	143.99
0.02	37.78	42.18	72.01	98.41
0.15	5.14	5.48	7.74	9.77
0.25	3.12	3.32	4.66	5.97
0.30	2.68	2.85	3.99	5.20
0.50	1.98	2.10	2.98	4.45

DCCs for larger breathing rates is a result of the competition between a number of factors.

All the parameters employed for the present computations were adopted from original references or authoritative reports such as those of NRC and ICRP, e.g. depths and layer thickness of mucous gel, cilia and fluid, and the basal and secretory cells, breathing rates for a Caucasian male for conditions of sleep, rest and light and heavy exercise, respiratory frequencies, mucous transit time for different generations, transfer half-time into the blood, mucous clearance rate throughout the T-B tree, etc. Sensitivity analysis of these adopted parameters can be found in Birchall & James (1994).

The overall DCCs (in mSv/WLM) have also been calculated for a typical home environment: unattached fraction of the potential α energy concentration (PAEC) = 0.08; activity median diameter of unattached radon progeny $AMD_u = 1.1$ nm and AMD_a of attached radon progeny = 200 nm. The radiation weighting factor for α radiation $w_R = 20$ was used. Tissue weighting factors w = 0.5 for basal and secretory cells in bronchial region were adopted. The dose in secretory and basal cells were multiplied by 0.5 and summed up. The tissue weighting factor in the bronchiolar region where secretory cells are the only sensitive cells

Table 6
Dose conversion coefficients for Chinese males, Chinese females and Caucasian males for the rest condition

d_p(μm)	Exposure dose conversion coefficient (mGy/WLM)		
	Breathing rate (m^3/h)		
	0.4374 (Chinese male)	0.3106 (Chinese female)	0.54 (Caucasian male)
(a) Basal cells			
0.0011(unattached)	14.28	11.20	20.47
0.02	11.19	10.69	13.39
0.15	1.42	1.41	1.62
0.25	0.88	0.88	1.00
0.30	0.76	0.77	0.87
0.50	0.60	0.61	0.67
(b) Secretory cells in bronchial (BB) region			
0.0011(unattached)	40.03	32.05	55.71
0.02	22.39	21.27	26.68
0.15	2.84	2.82	3.24
0.25	1.77	1.76	2.00
0.30	1.54	1.53	1.74
0.50	1.22	1.21	1.35
(c) Secretory cells in bronchiolar (bb) region			
0.0011 (unattached)	3.47	1.99	6.59
0.02	34.88	32.35	42.18
0.15	4.82	4.75	5.48
0.25	2.94	2.91	3.32
0.30	2.53	2.51	2.85
0.50	1.90	1.89	2.10

was taken as 1. The total dose is then evaluated as the sum of the doses in the bronchial and bronchiolar regions which have been multiplied by 0.333 (as was recommended by ICRP66). The DCCs are obtained as 0.59 and 0.52 mSv/(J s/m^3) (7.4 and 6.5 mSv/WLM) for Chinese males and females, respectively, which are 80 and 70% of the value 0.73 mSv/(J s/m^3) (9.2 mSv/WLM) for Caucasian males.

Here we can see that, by using a different lung morphometry model, i.e. the Yeh–Schum model, we have obtained a somewhat lower DCC of 9 mSv/WLM for Caucasian males. Although this is still some distance from the epidemiologically derived value of about 5 mSv/WLM, it causes a much smaller discrepancy than the value of 15 mSv/WLM (Birchall & James, 1994). This natural reduction of the dosimetric DCC has relieved the immediate urgency to call for some drastic approaches such as the reduction of the quality factor of α particles as suggested by Birchall and James (1994), especially, when we know that there are yet quite a number of uncertainties in the parameters employed in the dosimetric lung model. For example, from the results for Chinese males and females, we see that different

Table 7
Dose conversion coefficients for Chinese males, Chinese females and Caucasian males for different physical activities at $d_p = 150$ nm

d_p(nm)	Exposure dose conversion coefficient (mGy/WLM)			
	Breathing rate[a]			
	Sleep	Rest	Light exercise	Heavy exercise
(a) Basal cells				
Caucasian males	1.52	1.62	2.29	2.92
Chinese males	1.33	1.42	2.00	2.54
Chinese females	1.32	1.41	2.00	2.53
(b) Secretory cells in bronchial (BB) region				
Caucasian males	3.04	3.24	4.59	5.85
Chinese males	2.67	2.84	4.02	5.10
Chinese females	2.64	2.82	3.99	5.06
(c) Secretory cells in bronchiolar (bb) region				
Caucasian males	5.14	5.48	7.74	9.77
Chinese males	4.52	4.82	6.82	8.59
Chinese females	4.44	4.75	6.74	8.50

[a] Breathing rates for different categories of people: for Caucasian males: sleep = 0.45, rest = 0.54, light exercise = 1.5, heavy exercise = 3.0 m^3/h; for Chinese males: sleep = 0.3645, rest = 0.4374, light exercise = 1.215, heavy exercise = 2.43 m^3/h; for Chinese females: sleep = 0.2588, rest = 0.3106, light exercise = 0.8627, heavy exercise = 1.7253 m^3/h.

lung dimensions (i.e. with different scaling) will affect the DCC and can easily bring the value down to 80 or 70%.

4. Conclusions

For both basal and secretory cells, the DCCs for physical conditions of sleep, rest, light and heavy exercise, have been obtained for Chinese males and females for unattached progeny and for attached progeny of diameters 0.02, 0.15, 0.25, 0.30 and 0.50 μm. The DCCs calculated for Chinese males and females have been found to be lower than the corresponding values for Caucasian males. Moreover, the DCCs have the highest values for unattached progeny and decrease with the particle size of the attached progeny. Furthermore, the DCCs increase with the breathing rate, which agrees with previous results.

The overall DCCs calculated for a typical home environment are 0.59 and 0.52 mSv/(J s/m^3) (7.4 and 6.5 mSv/WLM) for Chinese males and females, respectively, which are 80 and 70% of the value, 0.73 mSv/(J s/m^3) (9.2 mSv/WLM), for Caucasian males.

Acknowledgements

The present research is supported by the CERG grant CityU1004/99P from the Research Grant Council of Hong Kong.

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