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Effects of different deposition models on the calculated dose conversion factors from ^{222}Rn progeny

D. Nikezic [1], A.K.M.M. Haque, K.N. Yu *

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

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Abstract

Regional lung deposition for radon progeny (size range, 1 nm to 1000 nm, monodispersed) has been determined employing Gormley–Kennedy, Ingham, Cohen–Asgharian and Yu–Cohen expressions (which describe diffusion deposition), together with Gurman and Cheng formulae for impaction and sedimentation, respectively. The deposition values have been compared with those obtained by using the algebraic expressions recommended by ICRP66. The behavior of the deposition curves for breathing rates of 0.45, 0.78 and 1.2 $m^3\ h^{-1}$ are similar, with a broad maximum in the range (1–100) nm. In the particle size range (1–100) nm, where the thermodynamic efficiency predominates, there are large differences among the five approaches, with ICRP values lying somewhat in the middle. Dose Conversion Factors nearly follow the regional deposition trends, Cohen–Asgharian and Ingham, close to the highest values, Yu–Cohen the lowest and ICRP, again, somewhat in the middle.

Keywords: Natural radioactivity; Radon; Dosimetry; Monte Carlo methods

* Corresponding author. Tel.: +852-2788-7812; fax: +852-2788-7830.
E-mail address: peter.yu@cityu.edu.hk (K.N. Yu).
[1] On leave from University of Kragujevac, Faculty of Science, 34000 Kragujevac, Yugoslavia.

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1. Introduction

Inhalation of radon progeny ^{218}Po, ^{214}Pb, and ^{214}Bi(Pb) in homes and working places constitutes the highest exposure to natural radiation (ICRP, 1981; NCRP, 1984; Sinnaeve, Clemente, & O'Riordan, 1984; ICRP, 1994a; Zock, Porstendörfer, & Reineking, 1996) for the general public. Traditionally, a dosimetric approach is employed to derive the Dose Conversion Factors (Chamberlain & Dyson, 1956; Altshuler, Nelson, & Kuschner, 1964; Haque & Collinson, 1967; Harley & Pasternak, 1972; Jacobi & Eisfeld, 1980; James et al., 1991; NRC, 1991). The Dose Conversion Factor (hereafter referred to as DCF) in mSvWLM^{-1}, is defined as the effective dose per potential alpha energy exposure. A better understanding of the lung model parameters, and the availability of more reliable values for these, have led to increasing certainty in the values of DCFs.

One of the important factors, which profoundly affects the DCFs (and radiation dose) is the deposition behavior of radon progeny in the respiratory tract. The ICRP66 report (ICRP, 1994b) has proposed an algebraic model to predict particle deposition in different anatomical regions of the respiratory tract. The data used in developing their model are scattered and there are no experimental results for particles smaller than 1 nm (ICRP66, Fig. D.18, page 263). Furthermore, some questions related to this deposition model (referred to as the ICRP66 approach) have remained unanswered. The present paper is devoted to exploring two of these questions, namely (1) whether the DCFs derived from the ICRP66 approach and those derived from previous approaches are directly and meaningfully comparable, and (2) whether the use of previous approaches instead of the ICRP66 approach will help alleviate the discrepancy between the calculated DCF and the epidemiological derived value.

As regards our first objective, it is known that there have been different approaches to the deposition issue adopted by different groups of investigators. These approaches include the employment of the Gormley–Kennedy (1949) (G–K) expression (Gormley & Kennedy, 1949), without or with corrections given by Martin and Jacobi (1972) (I) expression; empirical expressions of Cohen and Asgharian (1990) (C–A) and equations of Yu and Cohen (1994) (Yu–C). The following are examples of groups of investigators who have adopted different approaches: G–K have been used by Porstendörfer (1996) and Leung, Tso, Ho, and Hung (1997); I by Zock, Porstendörfer, and Reineking (1996), Nikezic, Yu, Cheung, Haque, and Vucic (2000), Hofmann et al. (1996), ICRP (1994b); C–A by Harley, Cohen, and Robins (1996); Yu–C also by ICRP (1994b). The first objective of the paper is to employ each of the above five approaches to calculate regional deposition values and dose conversion factors (and dose values) for bronchial (BB) and bronchiolar regions (bb) for various breathing rates, and then to answer whether the DCFs derived from the ICRP66 approach and those derived from previous approaches are directly and meaningfully comparable. This study will also bring out the uncertainties in the present situation of DCF calculation into focus. It is also hoped that the inter-comparison will also reinforce the need for more extensive experimental work with casts, together with deposition study with particles smaller than 1 nm.

As regards our second objective, a well-known paradox in radon research is the

significant discrepancy between the calculated DCF and the epidemiologically derived value. From an epidemiological consideration, ICRP (1994a) recommends for radon progeny a DCF of about 5 $mSvWLM^{-1}$. On the other hand, calculations from the dosimetric approach (ICRP, 1994b) have led to considerably higher values of DCF under varied conditions (Zock, Porstendörfer, & Reineking, 1996; Birchall & James, 1994; Porstendörfer & Reineking, 1999; Marsh & Birchall, 2000). In order to implement the ICRP recommendation, Birchall and James (1994) have calculated the DCF to be around 14 $mSvWLM^{-1}$ for mines and homes, which is significantly higher than the epidemiological value of 5 $mSvWLM^{-1}$. Various efforts have been devoted to resolve the discrepancy. The second objective of the paper is to explore whether the use of approaches other than that of ICRP66 will help alleviate the discrepancy between the DCF values.

2. Background information for the calculation of regional deposition and dose conversion factors

2.1. Gormley–Kennedy expression

The theory of Gormley and Kennedy (1949) considers the Brownian motion of particles in a laminar cylindrical airflow. The resulting deposition probability, f, by diffusion to the walls of a cylindrical tube is given by

$$f = 1-0.8191e^{-7.314h}-0.0975e^{-44.6h}-0.0325e^{-114h} + \ldots \quad (1)$$

for $h>0.0156$, and

$$f = 4.07h^{2/3}-2.4h-0.446h^{4/3} \quad (2)$$

for $h<0.0156$; h is given by

$$h = \frac{\pi lD}{2V} \quad (3)$$

where l is the length of the tube, D is the diffusion coefficient ($cm^2\ s^{-1}$) of the particles and V is the rate of flow ($cm^3\ s^{-1}$) through the tube. Landahl (1963) considered the non-laminar flow through the tube and calculated the deposition probability, f, to be

$$f = \frac{4}{d}\sqrt{\frac{DV}{v}}\left(1-\frac{4}{9d}\sqrt{\frac{DV}{v}} + \ldots\right) \quad (4)$$

where D is diffusion coefficient, d is the diameter of the tube and v is the volume of the tube; the ratio V/v corresponds to the transient time of the air in the tube.

Martin and Jacobi (1972) have carried out deposition experiments with radioactive aerosols in a plastic model and have compared Eq. (3) and Eq. (4) with the experimental results. The authors have estimated correction factors due to the non-laminar flow in the upper airways.

2.2. Ingham deposition equation

Ingham (1975) gave the following expression for the deposition efficiency in a cylindrical tube with parabolic, laminar flow:

$$\eta_{th} = 1-0.819e^{-14.63\Delta}-0.097e^{-89.22\Delta}-0.0325e^{-228\Delta}-0.0509e^{-125.9\Delta^{2/3}} \quad (5)$$

where

$$\Delta = \frac{\pi l D}{4V}$$

with airway length l, the diffusion coefficient D and V the flow rate.

2.3. Cohen–Asgharian deposition equation

A large body of data for deposition in replicate casts of the upper bronchial airways has been reported by Cohen and Asgharian (1990) with the inspiration flow rates of 300–600 $cm^3\ s^{-1}$, and a range of particle diameters of 40–200 nm. It has been claimed that the deposition fraction η_D of these aerosols for all conditions is predicted well by the equation

$$\eta_D = a_0\Delta^{a_1} \quad (6)$$

where a_0=2.965, a_1=0.568, $\Delta=\pi lD/4V$; l is the airway length and D is the diffusion coefficient. According to the authors, for a value of $\Delta\approx10^{-4}$, the equations of Gormley and Kennedy, and that of Ingham for deposition in cylindrical tubes from developed flow, converge with the measured deposition in casts. The difference is due to turbulence or convective diffusion in the first few branching airways.

2.4. Yu and Cohen thermodynamic deposition efficiency

Yu and Cohen (1994) derived an expression for the thermodynamic efficiency of the form given below,

$$\eta_{th} = aRe^bSc^c\left(\frac{1}{R}\right)^d = a\left(\frac{2V}{R\pi v}\right)^b\left(\frac{v}{D}\right)^c\left(\frac{1}{R}\right)^d \quad (7)$$

where the Reynolds number (Re) and the Schmidt number (Sc) include the airway radius R and the kinematics viscosity v. The coefficients a=1.2027, b=−0.6027, c=−0.5108 and d=0.5081 gave the "best fit" to the experimental cast data. Yu and Cohen's analysis of the experiment showed that the enhancement of diffusion deposition caused by non-laminar bronchial airflow is given by

$$\Psi_{th} = 1 + 100\exp\left\{-\left[\log_{10}\left(100 + \frac{10}{d_{th}^{0.9}}\right)\right]^2\right\} \quad (8)$$

where d_{th} is the particle thermodynamic diameter.

The G–K, I, C–A and Yu–C approaches lead to thermodynamic diffusion depo-

sition efficiency. However, other deposition mechanisms, such as impaction and sedimentation, can also be operative in the human lung. Impactional deposition η_{IM} can be calculated using the Gurman expressions (Gurman, Lippmann, & Schlesinger, 1984) as follows: $\eta_{IM} = aS_{tk}^{b}$, where a=6.4 and b=1.43 for generations 1 to 3, and a=1.78 and b=1.25 for other generations (Egan, Nixon, Robinson, James, & Phalen, 1989), and S_{tk} is the Stokes number. Calculations have shown that impactional deposition is small after the fifth generation in comparison to diffusion deposition in the entire range of aerosol diameter of interest.

Deposition by sedimentation has been calculated using the expression given by Chang et al. (1991) as follows:

$$\eta_{sed} = 1-\exp\left(\frac{4\boldsymbol{g}C\rho r^2 L\cos\phi}{9\pi\mu R v}\right)$$

where $\boldsymbol{g}$ is the acceleration due to gravity, η_{sed} the sedimentation deposition probability, ρ the density of the particle, ϕ the inclination angle relative to horizontal, C the Cunningham slip correction factor, r the radius of the particle, R the radius of the airway, μ the viscosity of the fluid and v the mean flow velocity of air. Impaction and sedimentation are more important for larger particles, while diffusional deposition is dominant for small particles.

2.5. ICRP66 algebraic model for regional lung deposition

The simplified and concise description of the model that follows is in the spirit of that of ICRP66, Human Respiratory Tract Model for Radiological Protection (ICRP, 1994b).

ICRP66 recommends a set of algebraic expressions which give reliable estimates of regional deposition within the lungs (in ET1, ET2, BB, bb and AI), for widely varying breathing conditions. These expressions are given in ICRP66 report (Table 12, page 45). The coefficients have been derived by combining empirical analyses given in Sinnaeve, Clemente, and O'Riordan (1984) and Zock, Porstendörfer, and Reineking (1996), with the theoretical model of Egan and coworkers (Egan, Nixon, Robinson, James, & Phalen, 1989; Egan & Nixon, 1985, 1987) on the basis of the mathematical formalism of Taulbee and Yu (1975) and Pack, Hooper, Nixon, and Taylor (1977). The algebraic model uses recursive convolution of deposition efficiencies in a series of filters both for aerodynamic and thermodynamic efficiencies. Appropriate values of the constants "*a*" and "*p*" in each expression of aerodynamic and thermodynamic regional deposition efficiency have been derived by using a parameter optimization procedure given by Birchall, Bailey, and James (1991) who also developed LUDEP (Lung Dose Evaluation Program), a software code for implementing the above-mentioned algebraic equations.

All the above five methods have been used in this paper to calculate regional deposition (in BB and bb) for particle equivalent diameters in the range 10^{-9}–10^{-6} m and breathing rates of 0.45 and 1.2 $m^3\ h^{-1}$. In order to be able to compare deposition values of ICRP66 with those obtained by employing G–K, I, C–A and Yu–C expressions, individual deposition values in generations 0 to 8 (BB) and those in

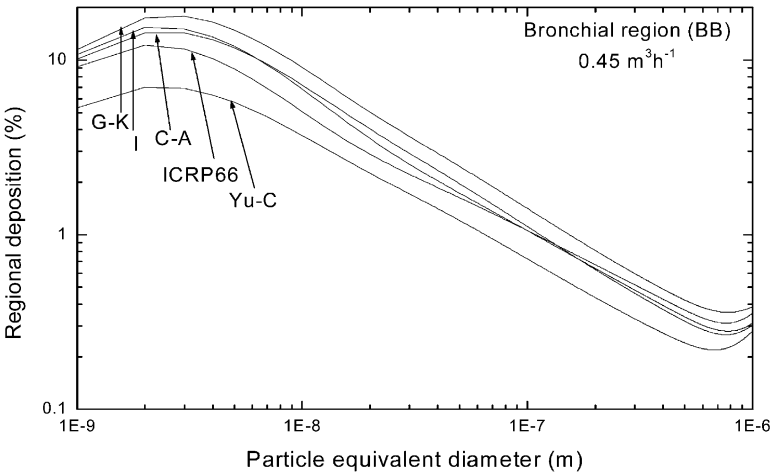

Fig. 1. Regional deposition in bronchial region (BB) for breathing rate of 0.45 m^3 h^{-1}.

generations 9 to 15 (bb) have been added up to give regional values. Deposition values so obtained have been plotted along with those of ICRP66 as regional deposition (%) vs. particle equivalent diameters (m) in Fig. 1 for BB and Fig. 2 for bb regions.

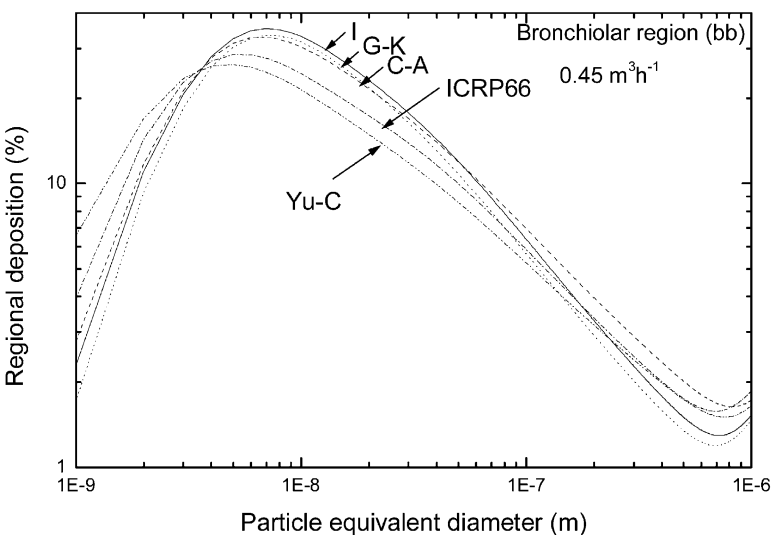

Fig. 2. Regional deposition in bronchiolar region (bb) for breathing rate of 0.45 m^3 h^{-1}.

3. Calculation method

In this work the regional deposition (RD) in regions BB and bb have been calculated. The RD (%) is defined as the fraction of inhaled activity deposited in the relevant region.

In order to calculate RDs in BB and bb, the RD values in all other regions should also be calculated in the following order: in ET1, ET2, BB, bb and AI during inhalation and in reverse order for exhalation. ICRP66 deposition expressions (Table 12, page 45) have been used for calculations of RD in ET1, ET2 and AI, while for deposition in BB and bb, the G–K, I, C–A and Yu–C expressions have been used. Each airway of BB and bb has been considered as a filter. The deposited activity A_i in all airways have been calculated and added up to give the total activities in BB (A_{BB}) and in bb (A_{bb}) as follows:

$$A_{BB} = \sum_{i=1}^{9} A_i 2^{i-1} \quad \text{and} \quad A_{bb} = \sum_{i=10}^{17} A_i 2^{i-1} \tag{10}$$

where the trachea is denoted by i=1.

The RD values are obtained as the ratios of the total activity in airways and an assumed initial inhaled activity $A_{inhaled}$, i.e.,

$$RD_{BB} = \frac{A_{BB}}{A_{inhaled}} \quad \text{and} \quad RD_{bb} = \frac{A_{bb}}{A_{inhaled}} \tag{11}$$

In addition, the RD values for BB and bb have been calculated using ICRP66 compartment expressions, i.e., Eq. (10) and Eq. (11) are not needed.

Dose conversion factors have been calculated using deposition formulae described above. The method for calculating DCFs is essentially the same as that described in Nikezic et al. (2000), and it will be shortly outlined here.

3.1. Calculation of the equilibrium activity

In our method, deposition of radon progeny is calculated in each airway; the different mechanisms affecting the material deposited in the tubes (decay, clearance, deposition) are described by a set of differential equations summarized in Eq. (12):

$$\frac{dN_{i,j}}{dt} = \frac{B_{i,j}}{\lambda_i} + A_{i-1,j} + 2\lambda_{c,j+1}N_{i,j+1} - (\lambda_i + \lambda_b + \lambda_{c,j})N_{i,j} \tag{12}$$

where, $N_{i,j}$ is the number of atoms of the ith Rn progeny in the jth generation of the tracheo–bronchial (T–B) tree, $B_{i,j}$ is the activity of the ith Rn progeny deposited in the jth generation per unit time (in Bq s^{-1} m^{-2}), $A_{i,j}$ is the equilibrium activity (in Bq m^{-2}), λ_i the decay constant of the ith Rn progeny, $\lambda_{c,j}$ the mucus clearance rate in the jth generation and λ_b is the transfer rate to blood (all λs in s^{-1}).

As a final result, the equilibrium activity of radon progeny in the mucus of the airway is obtained. In order to obtain the dose, this activity is multiplied by the

absorbed fraction of one alpha particle in the tissue of interest, which is transformed into dose conversion factors. The absorbed fractions for various combinations of sources and targets were adopted from the ICRP66 report (pages 463, 464).

3.2. Aerosol characteristics

Calculation of DCFs has been carried out for poly-dispersed particles with bimodal distribution that represent unattached and attached radon progeny. Both species were considered as log-normally distributed with the following parameters: for attached — median of 200 nm and geometrical standard deviation of 2.35; and for unattached — median of 1.5 nm and geometrical standard deviation of 1.1. The unattached fraction of potential alpha energy of radon progeny was 0.08 which is considered as typical for normal indoor conditions.

3.3. Morphometry

The morphometry used in the calculations using the G–K, I, C–A and Yu–C approaches was the ICRP66 morphometry model (ICRP66 report page 14). This model was obtained as an average among previous morphometry models (Weibel, 1963; Yeh & Schum, 1980; Phalen, Oldham, Beaucage, Crocker, & Mortensen, 1985) and adjusted to a standard functional residual capacity (James, 1988).

3.4. Targets

The targets were basal and secretory cells in the BB region and secretory cells in the bb region. The thickness and depth of various cell layers in the airway wall have been adopted from ICRP66 (pages 15 to 17) (ICRP, 1994b).

3.5. Mucociliary clearance

The mucus blanket was assumed to be of constant thickness throughout a region (5 μm of fast and 6 μm of slow cleared mucus in BB and 2 μm of fast and 4 μm of slow cleared mucus in bb). Based on NRC (1991) (page 206), the mucus clearance rate through the T–B tree was calculated according to the mucus transit time.

3.6. Transfer to blood

The half time for transfer to blood was assumed to be 10 hours (Booker, Chamberlain, Newton, & Stott, 1969; Hursh & Mercer, 1970; Greenhalgh, Birchall, James, Smith, & Hodgson, 1982; NRC, 1991).

3.7. Weighting the dose

The doses calculated in basal cells $D_{BB,bas}$ and in the secretory cells $D_{BB,sec}$ in the BB region are weighted assuming the same sensitivity of these cells, so that the dose

in BB was found as $D_{BB}=0.5\times D_{BB,bas}+0.5\times D_{BB,sec}$. The dose in the bb region, D_{bb}, is equal to the dose in secretory cells in this region. The dose in the T–B tree is then found as $D=0.333\times D_{BB}+0.333\times D_{bb}$. The effective dose, E, is calculated by $E=0.12\times 20\times D$, where 0.12 is the tissue weighting factor for the lung and 20 is the radiation weighting factor for alpha particles. These weighting procedures were proposed by ICRP66 (ICRP, 1994b).

3.8. Modifications from previous work

As mentioned above, for the calculation of DCFs, the method used is essentially the same as that in our recent paper (Nikezic et al., 2000) except that the present results are expressed in $mSvWLM^{-1}$ instead of $mGyWLM^{-1}$. Other trivial modifications have been made as described below. In the formulae $\eta_{th}=1-\exp(-kD^{1/2}V^{-1/8})$ for nasal thermodynamic filtration (Cheng, Yamada, Yeh, & Swift, 1988; James et al., 1991), the previous parameter k was 7.7, while it is now 18 as proposed by ICRP66 (page 247) (ICRP, 1994b; Swift et al., 1992). The change in k in the exponent results in a trivial change. Furthermore, the aerodynamic deposition in the nose and ET2, as well as in the alveolar interstitial (AI) region, were now calculated in a way strictly following the approach and formulae given by ICRP66.

Some relevant parameters used in the calculations are as follows: equilibrium factor between radon and its short lived progeny=0.4; particle density $\rho=1$ g cm^{-3}; particle shape factor $\chi=1$; hygrosopic particles growth=1; fraction of breathing through the nose=1.

4. Results

4.1. Deposition curves

The computational results for deposition have been plotted as regional deposition (%) vs. particle equivalent diameters (m) in Figs. 1 and 3 for BB, and in Figs 2. and 4 for bb, for breathing rates of 0.45 and 1.2 m^3 h^{-1}, respectively. The considered particle diameters ranged from 1 to 1000 nm. Calculations have also been performed for the breathing rate of 0.78 m^3 h^{-1}, but the general nature of these graphs is similar and they are not shown here. The first point to note is that for particle sizes in the range 1–100 nm, where thermodynamic deposition dominates, there are large differences (up to a factor of three, ratio of highest to lowest) in the values of regional deposition calculated using the five different approaches. The highest values are ascribed to the G–K expression and the lowest to Yu–C, with ICRP66 values lying in between. The values from C–A and I expressions lie close to each other and in general above those of ICRP66. The curves bunch together in the region of 100 nm, reaching a minimum around 0.5 to 1 μm.

Comparison of Figs. 1 and 3 (BB region) reveals that the regional deposition in BB decreases with increasing breathing rate. The reason for such behavior is the

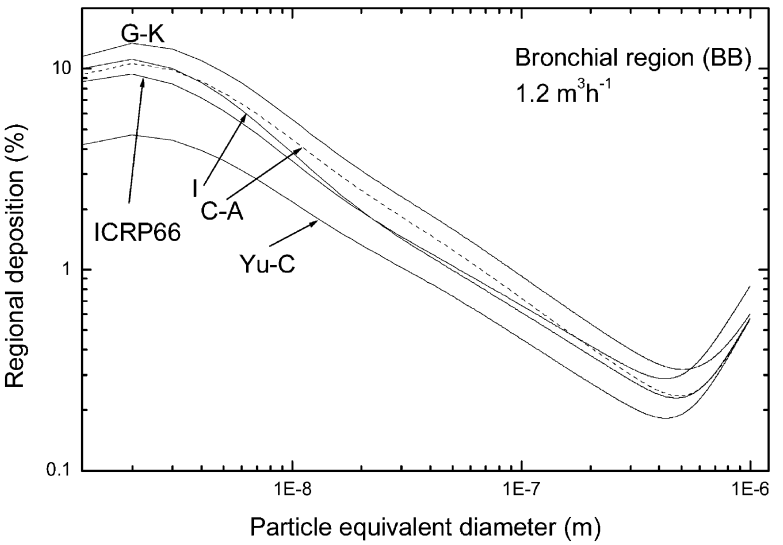

Fig. 3. Regional deposition in bronchial region (BB) for breathing rate of 1.2 m^3 h^{-1}.

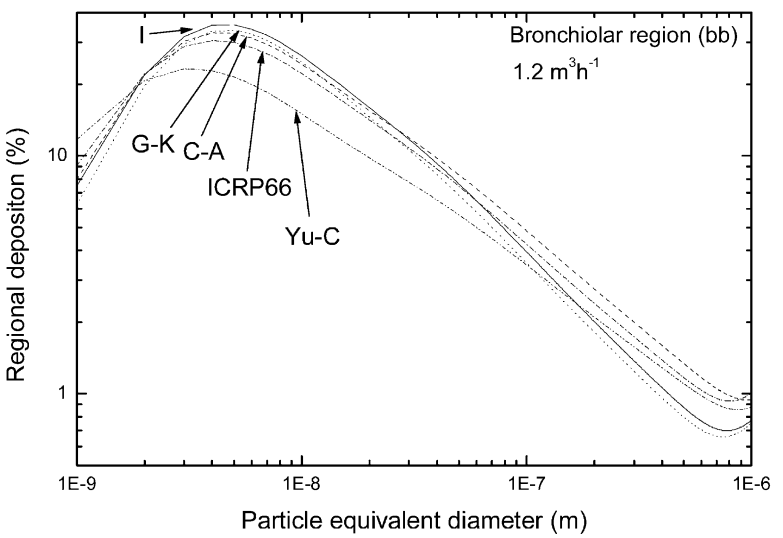

Fig. 4. Regional deposition in bronchiolar region (bb) for breathing rate of 1.2 m^3 h^{-1}.

shorter residence time of aerosols in bronchial airways, which reduces deposition by diffusion.

It is worth mentioning that in the particle size range about 1–300 nm, thermodynamic efficiencies predominate, and the contribution due to impaction and sedimentation together can be ignored. From about 0.5 μm to larger sizes, their contributions become comparable and become progressively higher.

4.2. DCFs

The results of DCF calculations are given in Table 1 for four different breathing rates, which represent different levels of physical activities of an adult Caucasian male — sleep: 0.45 $m^3\ h^{-1}$; light exercises: 1.5 $m^3\ h^{-1}$; heavy exercises: 3 $m^3\ h^{-1}$ (NRC, 1991); and average weighted physical activity: 0.78 $m^3\ h^{-1}$ (Marsh & Birchall, 2000).

The difference between DCFs obtained using various deposition formulae can be as much as 30%. This difference is not unimportant but it is still much smaller than the uncertainty introduced by other factors involved in DCF calculations (Birchall & James, 1994; Marsh & Birchall, 2000).

The range of DCFs obtained in the present work overlapped with the range given by Marsh and Birchall (2000), but the present results are slightly shifted to the smaller values. For example, according to Marsh and Birchall (2000), the DCF is between 10 and 25 $mSvWLM^{-1}$ if the breathing rate is changed from 0.45 $m^3\ h^{-1}$ to 1.5 $m^3\ h^{-1}$ while all other parameters are kept at their the best estimates. Our range is between 7 to 23 $mSvWLM^{-1}$ (considering all deposition models). The difference is probably due to the differences in the overall dosimetric models. We have used the "tube model", i.e., the absorbed dose is calculated in each generation of the T–B tree, and averaging is carried out according to the surface areas of the generations. In Marsh and Birchall (2000), the ICRP66 compartmental model was used in which the tube structure of the T–B tree is absent. There are also differences in the aerosol parameters, e.g., three modal distributions for the attached progeny were used by Marsh and Birchall (2000) while we only used one modal distribution.

5. Conclusions

In this paper, the influence of different deposition formulae on the calculation of dose conversion factors has been examined. Inconsistency among results obtained from different formulae has been identified for the small-particle region. The discrep-

Table 1
Dose conversion factors calculated by using different deposition formulae. The same program (except for ICRP66) has been used for all calculations

Breathing rate	Breathing frequency	Dose conversion factors (in $mSvWLM^{-1}$)				
($m^3\ h^{-1}$)	(min^{-1})	Ingham	Cohen–Asgharian	Gormley–Kennedy	Yu–Cohen	ICRP66 deposition
0.45	15	9.37	9.73	8.59	7.31	7.68
0.78	20	13.61	14.56	12.73	10.62	11.77
1.5	20	21.27	23.02	20.39	15.93	18.25
3.0	26	36.82	41.0	36.1	28.51	34.29

ancies can be caused by different assumptions and methods used in the derivations of the formulae.

The Gormley–Kennedy equation was derived by considering the transport of particles in a straight cylinder under a laminar flow. There are different corrections to the G–K equation for turbulence in the first few generation and Landahl correction is employed in our calculations. In contrast, the Cohen and Asgharian equation was derived from a fit to experimental data obtained in a cast of the upper bronchial airways, thereby taking into account non-laminar or developing flow conditions. The Ingham equation gave the deposition efficiency in a cylindrical tube for a parabolic laminar flow. Enhanced deposition in comparison to the Ingham equation caused by deviation from the parabolic shape of laminar flow was taken into account by the expression in Eq. (8). Yu and Cohen also derived the expression for thermodynamic deposition as shown in Eq. (7), with the consideration of enhanced deposition by a convective diffusion process. ICRP66 algebraic expressions were not related to cylindrical tubes as in the cases for other deposition formulae; instead they were related to the total deposition in some regions. The corresponding parameters were derived from a fit to the theoretical data given by Chang et al. (1991). The different methods used in the derivation of the formulae as well as the incompleteness of the experimental data are probably the reasons for the observed discrepancies.

The first group of results given in this paper are related to the regional deposition in the BB and bb regions. The largest difference among the results from various deposition formulae is found in the unattached particle range. However, unattached particles contribute significantly (although their contribution is smaller than attached progeny) to the dose so the unreliable deposition efficiencies in this region can introduce uncertainties in the final value for DCFs.

The second group of results are given in Table 1 where the calculated DCFs are presented. The DCFs determined using various deposition formulae differ by up to 30%, which we considered as a significant uncertainty.

With the exception of DCF values based on the Yu–Cohen equation, all deposition equations produce DCFs larger than the ICRP66 value, thus slightly widening the gap between the epidemiologically and dosimetrically derived dose conversion factors. Therefore the use of different deposition models does not alleviate the discrepancy. In addition, this discrepancy can be caused by other presently-adopted parameters.

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