Proposed Updating of the ICRP Human Respiratory Tract Model

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\textbf{Abstract.} The ICRP Task Group on Internal Dosimetry is developing new Occupational Intakes of Radionuclides documents, which will include revised dose coefficients for inhalation of radionuclides by workers. Application of the ICRP Human Respiratory Tract Model requires a review of the lung-to-blood absorption characteristics of inhaled materials of importance in radiological protection. It is planned that, where appropriate, material-specific absorption parameter values will be given, and for other materials, assignments to default absorption Types will be made on the basis of current information. Publication of the Occupational Intakes of Radionuclides documents provides an opportunity for updating the Human Respiratory Tract Model in the light of experience and new information. The main possibilities under consideration relate to the two main clearance pathways: absorption to blood and particle transport. The review of absorption rates is providing a database of parameter values from which consideration can be given to deriving typical values for default Types F, M and S materials, and element-specific rapid dissolution rates. Important new data on rates of particle transport from the nasal passages, bronchial tree (slow phase) and alveolar-interstitial region have come from recent human studies, some of which were conducted to address uncertainties identified by development of the model. These new results, and others, are being reviewed alongside those available in 1993 when the model was finalised, to propose revisions based on the best currently-available information. This paper reports on the current status of this work.

\textbf{KEYWORDS: ICRP; internal dosimetry; inhalation; HRTM.}

1. Introduction

The ICRP Publication 66 Human Respiratory Tract Model (HRTM) \cite{1} has been applied to calculate dose coefficients and bioassay functions for workers and members of the public \cite{2–5}. The ICRP Task Group on Internal Dosimetry (INDOS) is carrying out a full revision of the worker exposure documents \cite{2,5} to produce a new set of documents on Occupational Intakes of Radionuclides (OIR) \cite{6}. Application of the HRTM in the OIR requires a review of the lung-to-blood absorption characteristics of inhaled materials of importance in radiological protection. Where appropriate, material-specific absorption parameter values will be given, and for other materials, assignments to default Types will be made, based on current information. The OIR documents will provide new dose coefficients and bioassay functions, taking into account a number of factors, including new tissue weighting factors \cite{7}, radionuclide decay data, reference computational phantoms of the human body based on medical tomographic images, the Human Alimentary Tract Model (HATM) \cite{8}, and revised systemic models for many elements. They therefore also provide an opportunity for some refining and updating of the HRTM in the light of new information and about 15 years’ experience in its use. Suggestions have been put forward for discussion at recent international workshops on internal dosimetry \cite{9, 10}. This paper reports on the current status of the work. The main changes now under consideration all relate to clearance because of the availability of important new information on both major clearance pathways: absorption to blood and particle transport.

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In the HRTM the respiratory tract is represented by five regions, based on differences in radio-sensitivity, deposition and clearance (Fig. 1). The extrathoracic (head and neck) airways (ET) are divided into ET₁, the anterior nasal passage (front of the nose), and ET₂, which consists of the posterior nasal and oral passages, the pharynx and larynx. The thoracic regions (the lungs) are Bronchial (BB: trachea, generation 0, airway generations 1-8), Bronchiolar (bb: airway generations 9–15), and Alveolar-Interstitial (AI, the gas exchange region). Lymph nodes are associated with the extrathoracic and thoracic airways (LN_{ET} and LN_{TH} respectively). For consistency with the HATM, the oral passage will not be included in ET₂ as it is now [1]. This does not affect results obtained with the HRTM, because deposition in ET from air entering the mouth was taken to occur only in the larynx.

Target cells are identified in each region: e.g. the basal cells of the epithelium in both ET regions; basal and secretory cells in the bronchial epithelium. Reference values of dimensions that define the mass of tissue containing target cells in each region for dose calculations, are given. They are assumed to be independent of age and sex.

**Figure 1:** Respiratory tract regions defined in the HRTM (reference [1], Figure 1)

Reference values of breathing rates (frequency and volume) are recommended for children aged 3 months, 1, 5, 10 and 15 years, and adults, for four levels of exercise: sleep, sitting, light and heavy exercise, and taking account of both nose- and mouth-breathing. These were combined with habit survey data to give the reference volumes inhaled per working shift or per day. Deposition of particulate materials in each region was calculated as functions of particle size for each age group and exercise level, initially for particles of uniform size. The results were then applied to aerosols with log-normal particle size distributions, and reference values tabulated as a function of the median size [1]. No changes to target cells, breathing rates or regional deposition of particulate aerosols are envisaged.
For gases and vapours deposition in each region is related to their solubility in (and reactivity with) respiratory tract lining fluids. As for particulate forms of radionuclides, default parameter values are provided for use in the absence of more specific information. It is proposed that the general defaults for gases and vapours become 100% total deposition in the respiratory tract: 20% ET₂, 10% BB, 20% bb and 50% Al (with Type F absorption). This classification is different from that recommended in Publication 66 [1], but simpler to apply. In particular, no deposition in ET₁ is assumed by default. The SR-0, -1, -2, classification was found to be unhelpful and will no longer be used.

The HRTM describes several routes of clearance from the respiratory tract, involving three general processes. Material deposited in ET₁ is assumed to be removed by nose blowing and wiping. In other regions clearance results from a combination of movement of radionuclides from the respiratory tract into the blood and hence body fluids (absorption), and movement of particles towards the GI tract and lymph nodes (particle transport). It is assumed that all clearance rates are independent of age and sex.

2. ABSORPTION TO BLOOD

In the HRTM, absorption is treated as a two-stage process: particle dissolution and uptake into blood (Fig. 2). It is assumed that absorption rates are the same in all respiratory tract regions except ET₁, where none occurs.

Figure 2: Alternative compartment models representing time-dependent absorption to body fluids (dissolution and uptake). In model (a) a fraction \( f_r \) of the deposit is initially assigned to the compartment labelled “Rapid dissolution”, and the rest \((1-f_r)\) of the deposit is initially assigned to the compartment labelled “Slow dissolution”. In model (b) all the deposit is initially assigned to the compartment labelled “Particles in initial state”. Material in these compartments in both models is also cleared by particle transport, and at the same rate, determined by the particle transport model (Fig. 3). Material in the compartment labelled ‘Bound material’ is not cleared by particle transport at all. For other symbols see text.
2.1 Dissolution

Time-dependent dissolution (Fig. 2(a)) is represented by a rapid phase (fraction $f_r$ dissolving at rate $s_r$) and a slow phase (fraction $1-f_r$ dissolving at rate $s_s$). A limitation of the system in Fig. 2(a) is that it can only readily represent an overall fractional dissolution rate that decreases with time. To overcome this, the HRTM uses an equivalent system with the same number of variables, but which gives greater flexibility, shown in Fig. 2(b). In this, the material deposited in the respiratory tract is assigned to compartments labelled “Particles in initial state” in which it dissolves at a constant rate $s_p$. Material is simultaneously transferred (at a constant rate $s_{pt}$) to a corresponding compartment labelled “Particles in transformed state” in which it has a different dissolution rate, $s_t$. The initial dissolution rate is approximately $s_p$ and the final dissolution rate is approximately $s_t$. Thus with suitable choice of parameters, including $s_t > s_p$, an increasing dissolution rate can be represented. If the dissolution rate decreases with time, as is usually the case, either system could be used, and would give the same results, with the following values:

$$s_p = s_s + f_r (s_t - s_s); \quad s_{pt} = (1 - f_r) (s_t - s_s); \quad s_t = s_t$$

The system shown in Fig. 2(b) is that formally used in the HRTM, in that the default absorption parameter values (Table 1) are specified in terms of $s_p$, $s_{pt}$ and $s_t$, rather than $f_r$, $s_r$ and $s_s$. However, the system in Fig. 2(a) is much simpler to present, and often has advantages. In particular, it is generally more straightforward to estimate its parameter values from experimental data [11]. In practice it has become much more widely used. It is therefore proposed that default absorption parameter values should be specified in terms of $f_r$, $s_r$ and $s_s$.

Table 1: Default absorption parameter values for Type F, M, and S materials [1]. The model values $s_p$, $s_{pt}$ and $s_t$ in this table are reference values i.e., the recommended default values for use in the model

<table>
<thead>
<tr>
<th>Model parameters:</th>
<th>Absorption Type</th>
<th>F (fast)</th>
<th>M (moderate)</th>
<th>S (slow)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Initial dissolution rate (d$^{-1}$)</td>
<td>$s_p$</td>
<td>100</td>
<td>10</td>
<td>0.1</td>
</tr>
<tr>
<td>Transformation rate (d$^{-1}$)</td>
<td>$s_{pt}$</td>
<td>0</td>
<td>90</td>
<td>100</td>
</tr>
<tr>
<td>Final dissolution rate (d$^{-1}$)</td>
<td>$s_t$</td>
<td>-</td>
<td>0.005</td>
<td>0.0001</td>
</tr>
<tr>
<td>Fraction dissolved rapidly</td>
<td>$f_r$</td>
<td>1</td>
<td>0.1</td>
<td>0.001</td>
</tr>
<tr>
<td>Rapid dissolution rate (d$^{-1}$) (approximate)</td>
<td>$s_r$</td>
<td>100</td>
<td>100</td>
<td>100</td>
</tr>
<tr>
<td>Slow dissolution rate (d$^{-1}$) (approximate)</td>
<td>$s_s$</td>
<td>-</td>
<td>0.005</td>
<td>0.0001</td>
</tr>
<tr>
<td>Fraction to bound state</td>
<td>$f_b$</td>
<td>0</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>Uptake rate from bound state (d$^{-1}$)</td>
<td>$s_b$</td>
<td>-</td>
<td>-</td>
<td>-</td>
</tr>
</tbody>
</table>

2.2 Uptake to blood

Time-dependent uptake is represented by a fraction ($f_b$) of the dissociated material retained in a ‘bound’ state, from which it goes to blood at a rate $s_b$, while the rest goes instantaneously (Fig. 2). It is assumed by default that $f_b = 0$. It is expected that since the bound state applies to dissociated material, its characteristics, like that of the systemic model, will usually be specific to each element. Application of the HRTM in the OIR documents requires a review for each element of the absorption characteristics of inhaled materials relevant to radiological protection. One important objective of the reviews is to determine bound state parameter values for each element. Initial assessments made for some elements [11] suggest that binding needs to be considered for americium and plutonium but not for caesium or uranium.
2.3 Material specific parameter values

Where the reviews demonstrate that there are consistent \textit{in vivo} results for a material, specific absorption parameter values may be recommended for it. Reviews have been completed on about 15 elements. Suitable information was found to enable specific parameter values to be proposed for about 20 materials, which are mostly forms of thorium and uranium. It is likely that there will be a few more such materials for each of the other important actinides that remained to be reviewed. Where suitable information is not available, or where the material shows a range of behaviour too wide to enable specific values to be chosen, materials will be assigned to default Types using current information. Criteria to assign materials to Types F, M or S on the basis of experimental data \cite{3, 11} are defined in terms of the fraction of the deposit absorbed into blood in a given time:

- Assign to Type F (rather than Type M) if there is more absorption by 30 d after intake than for a hypothetical material with an absorption rate corresponding to a half-time of 10 d under identical conditions.

- Assign to Type S (rather than Type M) if there is less absorption by 180 d than for a material with absorption half-time of 700 d.

These criteria may need to be revised if the default parameter values are themselves revised (see below).

2.4 Default parameter values

The current default values for Types F, M and S \cite{1, 2} were not based on reviews of experimental data but on comparison with particle transport rates. The value of 100 d\(^{-1}\) for the rapid dissolution rate \(s_r\) was chosen to equal the particle clearance rate from the nose to the throat. Hence for Type F about half the material deposited in ET\(_2\) is absorbed into blood and the rest swallowed. The slow dissolution rate for Type S of 10\(^{-4}\) d\(^{-1}\) was chosen to equal the slowest particle transport rate from the AI region to the GI tract, to ensure that there was some long term lung retention. Type M values were simply chosen to be intermediate between the two. Consideration is now being given to selecting values that are more representative of materials that are generally considered to clear at 'fast', 'moderate' or 'slow' rates. In the review of each element, specific parameter values (from both \textit{in vivo} and \textit{in vitro} studies) are noted in the text of the draft OIR inhalation sections where available in papers or derived by the reviewer. About 70 sets of parameter values are now available. For each Absorption Type (F, M and S), values were collated for each parameter (\(f_r\), \(s_r\) and \(s_s\)), and geometric means calculated as central values because of the wide ranges observed. Although material-specific parameter values will only be recommended based on \textit{in vivo} studies, \textit{in vitro} results were included in this survey to provide a larger and broader sample. Present observations are as follows:

Rapid fraction \(f_r\): for Type F, most values are close to the current default value of 1.0; for Types M and S, central values are higher (about 0.2 and 0.01, respectively) than current defaults (0.1 and 0.001).

Rapid dissolution rate, \(s_r\): For Types F, M and S, central values are about 15 d\(^{-1}\), 1 d\(^{-1}\) and 3 d\(^{-1}\), respectively, all much lower than the current default of 100 d\(^{-1}\). However, these findings are heavily influenced by results for a few elements. Consideration is being given to element-specific values of \(s_r\).

Slow dissolution rate, \(s_s\): For Types M and S, central values are about 0.003 d\(^{-1}\) and 8 \(10^{-5}\) respectively, similar to the current default values of 0.005 d\(^{-1}\) and 10\(^{-4}\) d\(^{-1}\).

Thus the data currently available suggest larger typical rapid fractions for Types M and S materials but with lower rapid dissolution rates than current default values. This would have the effect of shifting the site of rapid absorption from the nose to the lungs. The rates for the slow fractions seem reasonable. However, further information is expected from the reviews of those elements that have yet to be completed.
3. PARTICLE TRANSPORT

The HRTM clearance model provides particle transport clearance rates from each compartment, which apply to all materials (Fig. 3). New studies enable more reliable parameter values to be chosen for the extrathoracic airways (ET); bronchial (BB); bronchiolar (bb) and AI regions.

Figure 3: Compartment model representing time-dependent particle transport from each respiratory tract region in the HRTM. Rates shown alongside arrows are reference values in units of d⁻¹. It is assumed that (i) 0.05% of material deposited in region ET₂ is retained in its wall (ET seq); (ii) the fraction of the deposit in BB and bb that is cleared slowly (BB₂ and bb₂) depends on particle size, and the fraction retained in the airway wall (BB seq and bb seq) is 0.7% at all sizes; (iii) the AI deposit is divided between AI₁, AI₂ and AI₃ in the ratio 0.3:0.6:0.1. This model describes the retention and clearance of an insoluble material. There is generally simultaneous absorption to blood of material from all the compartments except ET₁.

3.1 Particle transport: extrathoracic airways

The HRTM assumes that of material deposited in the ET airways, about 50% deposits in ET₁ (see Fig. 1), which is cleared by nose blowing at a rate of 1 d⁻¹, and the rest deposits in ET₂, which clears to the GI tract at a rate of 100 d⁻¹. However, there was little information available to quantify clearance from ET₁; indeed there were remarkably few experimental studies of the clearance from the nose of particles deposited by inhalation [1]. In experiments intended to address this [12], nine subjects inhaled 3-µm aerodynamic diameter (\(d_{ae}\)) radiolabelled insoluble particles naturally through the nose while sitting at rest. Smaller groups inhaled 1.5- or 6-µm \(d_{ae}\) particles at rest and 3- or 6-µm \(d_{ae}\) particles while performing light exercise. Retention in the nasal airways and lungs, and clearance by voluntary nose blowing were followed for about 2 days by gamma spectrometry. Preliminary analysis of the results [10] indicated that for 1–6 µm particles, only about 15% of the material deposited in ET deposits in ET₁ and is cleared by nose blowing (in about a day); about 60% deposits in ET₁ and is cleared to the GI tract (via ET₂) on a time-scale of hours to days, and the remaining 25% deposits in ET₂ and is cleared to the gastro-intestinal (GI) tract in about 10 minutes. Detailed analysis is now in progress. Application of the results would in many cases increase dose coefficients, because of the transfer from ET₁ to ET₂ and hence greater systemic uptake in ET₂ and the GI tract, but not greatly. The results also have important implications for interpretation of faecal samples: a considerably larger fraction of the material deposited in the nose (which is typically about 50% of the material inhaled) is cleared through the GI tract than is assumed in the HRTM [13].
3.2 Particle transport: bronchial and bronchiolar airways

3.2.1 Slow clearance

The HRTM includes a slow phase of clearance of particles deposited in the BB and bb regions (Fig. 3). It is based mainly on the results of experiments in which volunteers inhaled particles administered as a ‘shallow bolus’ i.e., a small volume (~50 cm$^3$) of aerosol at the end of each breath, to deposit them in the major airways [1, 14]. A two-component exponential function was fit to the lung retention data, and the intercept of the slower phase taken to be the ‘slow-cleared fraction’. This fraction was considered to show a better correlation with particle geometric diameter, $d_p$ than with $d_{ae}$ [1, 14]. The HRTM assumes that the slow-cleared fraction of particles deposited in BB and in bb ($f_s$) is 0.5 for $d_p \leq 2.5 \mu m$, and decreases for larger particles: $f_s = 0.5 \exp(-0.63(d_p -2.5))$ for $d_p > 2.5 \mu m$.

Its inclusion in the HRTM has a significant effect on inhalation doses for some important radionuclides [15], but was controversial and further experiments have been carried out. In particular, in a series of experiments large (6-µm $d_{ae}$) particles were inhaled extremely slowly [16, 17]. Theoretically most particles should deposit in the bronchioles. Retention at 24 hours was much greater than predicted Al deposition, supporting the concept of slow clearance in the bronchial tree, but the results suggest that slow clearance occurs mainly in the bronchioles, rather than in the bronchi, and with a clearance half-time of a few days [16] compared to the HRTM assumption of about 20 days. The effect of $d_p$ was investigated directly, by administering particles with the same $d_{ae}$, and hence the same lung deposition pattern, but different densities and so different values of $d_p$ ($d_{ae} \approx d_p \sqrt{\rho}$ where $\rho$ is the particle density) [17]. Volunteers inhaled 6-µm $d_{ae}$ polystyrene (PSL) or Teflon particles. Because the density of Teflon is higher (2.13 vs. 1.05 g cm$^{-3}$), $d_p$ is smaller (4.5 versus 6.1 µm), and $f_s$ is greater (14% versus 5%). However, retention of the two particles was similar in each subject.

More recent studies [18, 19] tested these alternative hypotheses more critically, by (i) administering particles with the same $d_{ae}$ but with a greater difference in densities, (ii) using the shallow bolus technique to minimise alveolar deposition; (iii) administering the two particles simultaneously, to ensure that deposition and clearance took place under the same conditions. In the first study [18] volunteers inhaled shallow boluses containing 5-µm $d_{ae}$ PSL and gold ($\rho = 19.3$ g cm$^{-3}$) particles. Corresponding $d_p$ are about 5 and 1.2 µm and values of $f_s$ about 10% and 50% respectively. Hence according to the HRTM, lung retention of the gold should be much greater than that of the PSL. However, no significant difference was observed between them in any subject. In the second study [19] volunteers inhaled 8-µm $d_{ae}$ PSL and gold particles. Corresponding $d_p$ are about 8 and 1.8 µm and $f_s$ about 2% and 50% respectively. The results were more variable than for the 5-µm particles. For one subject retention was very similar for the two materials. For the others, retention was greater for PSL than for gold, the opposite of the HRTM prediction.

The results of the recent studies are thus inconsistent with the dependence of $f_s$ on $d_p$ assumed in the HRTM. The most likely explanation seems to be that the inferred dependence on $d_p$ rather than $d_{ae}$ was fortuitous, resulting from scatter in the data. It should be noted that it was based mainly on measurements made with relatively large particles ($d_p$ or $d_{ae} >4 \mu m$), and there were only a few such measurements available at the time. Instead most recent studies suggest that it is related to the site of deposition, with slow clearance mainly in smaller airways. A review is in progress of the information on which the HRTM was based along with the results of the more recent studies to try to develop a model consistent with all the available data.

3.2.2 Sequestration in the airway walls

As noted in the caption to Fig. 3, the fraction of particles deposited in the BB and bb regions retained in the airway wall (BB$_{seq}$ and bb$_{seq}$) is 0.7% at all sizes, and this material clears to lymph nodes at a rate of 0.01 d$^{-1}$. When the HRTM was finalised the phenomenon had only been well quantified by Patrick and colleagues [1, 20], who followed retention of activity after deposition of radiolabelled particles onto the distal trachea of rats. Subsequently, Takahashi et al [21] conducted similar experiments, instilling $^{133}$Ba-labelled BaSO$_4$ onto the distal trachea of rabbits, dogs and monkeys. The
amounts retained 1 week after injection were 0.145%, 0.044% and 0.043% of the injected amount respectively. These are far lower than found in rats, suggesting inter-species differences. The values for dogs and monkeys are close to those chosen in the HRTM for retention of particles in the wall of the nasal epithelium, which was based on results for several different materials in several species. On that basis it is proposed that values for both the retained fractions and clearance rates from BB and bb to LNTH should be those selected in the HRTM for the nasal epithelium, i.e., 0.05% and 0.001 d\(^{-1}\). This is likely to have little effect on doses or bioassay, but means that the model will assume less transfer to LNTH from BB and bb, and so more transfer from the AI region, to provide the ratio of lung to LNTH contents observed in autopsy studies [1].

### 3.3 Particle transport: alveolar-interstitial (AI) region.

In the HRTM the AI region is represented by three compartments: AI\(_1\), AI\(_2\) and AI\(_3\), which mainly clear to the GI tract via the bronchial tree at rates of 0.02, 0.001 and 0.0001 d\(^{-1}\) respectively (approximate half times 35, 700 and 7000 d) (Fig. 3). Human lung clearance had been quantified in experimental studies up to about a year after inhalation [1]. Lung retention of insoluble particles over this time typically follows a two-component exponential function: about 30% with a half-time of about 30 d, and the rest a half-time of several hundred days, giving about 50% retention at 300 d. This information was used to define the parameter values for AI\(_1\). Measurements of activity in the chest after occupational exposure, and of activity in the lungs at autopsy, indicate that some material can be retained in the lungs for decades. However, the results were not used to set parameter values for AI\(_2\) and AI\(_3\) quantitatively, because it was possible that the published in vivo studies represented unusually slow lung clearance. It was noted [1] that: “The fraction of the AI deposit that goes to AI\(_3\) (a\(_3\)) is not easily quantified. Since only 50% IAD is retained at 300 d, a\(_3\) is less than 0.5. Since there is measurable thoracic retention at 5000 d after intake in some subjects (Figure E.10), a\(_3\) is likely to be at least a few percent of the IAD. As a rounded value it is assumed that a\(_3\) = 0.1, and, hence, by difference, that a\(_2\) = 0.6.”

A new study [22] seems to provide better information than that available previously, because a group of workers had a simultaneous brief inhalation exposure to particles containing \(^{60}\)Co, and most (seven) have been followed for about 15 years. Thus it is reasonable to assume that they are representative of nuclear industry workers. They all show much slower clearance than the HRTM predicts, and are also consistent with most of the other studies with measurements beyond 2000 days considered in ICRP Publication 66 [1]. A review of long-term lung retention data is therefore in progress, to inform revision of the parameter values for the AI region [23]. Two other major relevant studies have been identified that were published since the HRTM was finalised.

Philipson et al [24] followed lung retention in 10 subjects for about 3 years after inhalation of \(^{195}\)Au-labelled Teflon particles. The duration of this study was about three times longer, and it seems likely that there was less leakage of the radioactive label from the test particles, than for the experiments available when the HRTM was developed. It therefore provides more reliable information, especially at long times after intake. The results also suggest that the HRTM underestimates long-term lung retention of insoluble particles. For the seven non-smokers and ex-smokers, retention at 900 d was about 60% of that at 7 d (about 70% for smokers), compared to about 30% predicted by the HRTM.

Kuempel et al [25] developed a physiologically based kinetic model to predict long-term lung and lymph node particle retention in coal miners. The model (Fig. 4) has separate alveolar and interstitial compartments, reflecting the biological structure. It is considered that there is macrophage-mediated clearance from the alveolar compartment to the bronchiolar airways, and that particles that escape that mechanism penetrate to the interstitium, from which there is slow clearance to the hilar lymph nodes. The model was applied to a group of U.S. coal miners for whom there were exposure histories on which to assess particle mass deposition rates, and autopsy measurements of lung dust concentration (and in about 50% of cases lymph node concentration as well). The model was considered to be the simplest consistent with the data, and no evidence was found for impaired clearance at high lung loadings, over the range observed. The authors noted that the HRTM underestimated lung retention in the miners by about a factor of four.
Retention as a function of time $A(t)$ of the initial alveolar deposit $A(0)$ can be expressed as:

$$A(t) = A(0) \left[ L_{seq} + (1 - L_{seq}) \exp^{-mt} \right]$$

where $L_{seq} = m_I / (m_T + m_I)$ is the fraction sequestered in the interstitial region and lymph nodes; $m_I$ and $m_T$ are the rates of transfer from the alveolar region to the interstitial region and the bronchioles respectively; and $m = m_T + m_I$ is the overall clearance rate from the alveolar region. For the optimised fit made by Kuempel et al. to the miner data, $L_{seq} = 0.32$ and $m = 0.0015 \text{ d}^{-1}$. It was found [23] that although this model has fewer parameters than the HRTM AI model, it could adequately represent long-term lung retention in the $^{60}\text{Co}$ cases [22], although with different parameter values. It can also provide an adequate overall fit to the experimental data on which the HRTM [1] parameter values for AI were based, together with the Philipson et al [23] and Davis et al [22] data. In that case $L_{seq}$ is almost entirely determined by the long term $^{60}\text{Co}$ cases, and is approximately 0.6. The model is being tested on appropriate cases of accidental inhalation of insoluble materials with long-term lung retention data. Subject to satisfactory validation, it may well be proposed to replace the current HRTM representation of retention in the AI region, being both simpler and biologically more realistic.

4. Conclusions

The development of the OIR documents will include new inhalation dose coefficients for workers, and provides an opportunity to update the HRTM. A comprehensive review of the absorption characteristics of inhaled materials relevant to radiological protection is being carried out to apply the HRTM in the OIR documents. Where there are consistent in vivo results, material-specific absorption parameter values will be recommended, and this is likely to include about 25 materials, mainly forms of thorium, uranium and transuranic elements. The review also provides a compilation of information to enable reconsideration of the default absorption parameter values to be made. The data presently available suggest that lower values of rapid dissolution rate for all three Types, and higher values of the rapid fraction for Types M and S would be more appropriate than the present values. New information is also available which allows more realistic modelling of particle transport from the nasal passage, bronchial tree and alveolar region than in the current version of the HRTM.

REFERENCES


