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THE REVISED INTERNATIONAL COMMISSION ON RADIOLOGICAL PROTECTION (ICRP) DOSIMETRIC MODEL FOR THE HUMAN RESPIRATORY TRACT- AN OVERVIEW

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<A>THE REVISED INTERNATIONAL COMMISSION ON RADIOLOGICAL PROTECTION (ICRP) DOSIMETRIC MODEL FOR THE HUMAN RESPIRATORY TRACT--AN OVERVIEW

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<B>INTRODUCTION

A task group* of the International Commission on Radiological Protection (ICRP) has revised the dosimetric model of the respiratory tract used in ICRP Publication 30[1]. The revised model is intended to be applicable to all members of the world's population, of all ages, to smokers and nonsmokers, and to those with healthy or diseased respiratory tracts. While the model was developed for use with airborne radioactive particles and gases, it can also be used for nonradioactive substances.

To address the great differences in radiation sensitivity among the numerous tissues and cells in the respiratory tract, the new model provides for calculation of doses to specific tissues in defined regions of the respiratory tract, rather than averaging doses over only the lung mass as was done in calculating annual limits on intakes of radionuclides in Publication 30 (ICRP, 1979). Finally, the model was developed with the objective of accommodating the use of bioassay data to calculate radiation doses to the respiratory tract.

<B>MORPHOMETRIC CONSIDERATIONS

For modeling purposes the respiratory tract was divided into regions based on anatomical, physiological, radiobiological, and aerosol deposition and clearance considerations. These regions are: the extrathoracic (ET), comprising the anterior nose (ET_1) and the posterior nasal passages, larynx, pharynx, and mouth (ET_2); the bronchial region (BB), comprising the airway generations 0 through 8 (trachea through the bronchi); the bronchiolar

region (bb), comprising the airway generations 9 through 15; and the alveolar interstitial region (AI), comprising the airway generations 16 through 26 (respiratory bronchioli through alveolar sacs). There are two thoracic lymph node regions, LN_{ET}, draining the extrathoracic region, and LN_{TH}, draining the bronchial, bronchiolar, and alveolar interstitial regions. For dosimetry purposes, morphological and cytological dimensions are assigned to these regions. To scale for age and gender, the dimensions of the extrathoracic airways are considered to be related to the diameter of the trachea, which is related to body height. The dimensions of the respiratory airways can be scaled by the one-third power of the functional residual capacity after age 2 yr, when the structure of the lungs is completely developed. The diameter and length of the bronchioles are assumed to decrease exponentially from the 8th to 16th generation. The mass of the AI region is assumed to vary with age, gender, and race, in proportion to body weight. The thickness and cellular structure of epithelial tissues are considered to be independent of age, gender, and body size.

<B>PHYSIOLOGY

Respiratory parameters that influence the volume and rate of air inhaled and the proportions entering through the nose and mouth determine the quantity of radionuclides inspired and the penetration into the respiratory tract. A model for the respiratory tract applicable to all populations must allow for great differences in respiratory parameters that depend upon body size, level of activity, respiratory tract diseases, and smoking habits. Therefore, ranges of values for the most critical parameters are recommended, and reference values are given for the adult worker and members of the general population: 3-mo old; 1-, 5-, 10- and 15-yr olds; and adult males and females. Breathing

only through nose or mouth and breathing through the nose augmented by mouth breathing are all considered in the model.

<B>DEPOSITION

In the deposition model regions of the respiratory tract are represented by equivalent particle filters acting in series. The fraction of an airborne material present in a person's breathing zone that is deposited in each region is expressed as a function of the efficiency of the equivalent filter in unidirectional flow. The regional efficiencies are determined by particle size, airway dimensions, flow rates, or resident times. The ET region functions as two filters, one on inhalation and another on exhalation. The model addresses inhalability of aerosols, which is dependent upon particle size but largely independent of breathing rate. Particles are largely deposited at two sites in the ET_2 region, the posterior nasal passages and the larynx. The model assumes that, during nasal breathing, deposition of particles is half in ET_1 and half in ET_2; during mouth breathing, deposition of particles occurs only in ET_2. Deposition efficiencies for the BB, bb, and AI regions are calculated for both aerodynamic and thermodynamic processes over the particle size range of 0.0005-μm activity median thermodynamic diameter (AMTD) to 100-μm activity median aerodynamic (AMAD). Reference values of regional deposition are provided, and guidance is given for extrapolation to specific individuals and populations. As an example of the deposition model, Figure 1 shows the projected fractional deposition in each region of the respiratory tract for an adult Caucasian male engaged in light exercise and breathing through the nose. Deposition is expressed as a fraction of the activity present in the volume of ambient air that is inspired, and activity is assumed to be lognormally distributed as a function of particle size (density of particles is 1 g cm^{-1}).

CLEARANCE

The model describes three clearance pathways (Figure 2). Material deposited in ET_1 is removed by extrinsic processes, such as nose blowing. For the other regions, clearance of inhaled material is competitive between particle transport processes (such as macrophage uptake and ciliary action) to the G.I. tract and to lymph nodes and absorption into blood; the rate of clearance by each process is a time-varying factor of the residual amount. It is assumed that the rates of clearance by particle transport are the same for all materials. Rates were derived from studies with human subjects. These rate constants, shown in Figure 2, are reference values in d^{-1}. Absorption into blood is material-specific, acts in all regions except region ET_1, and is assumed to occur at the same rate from all regions. Absorption into blood is a two-stage process: dissociation of the particles into material that can be absorbed into the blood (dissolution); absorption into blood of inhaled soluble material and of material dissolved from particles.

The model can use observed rates of absorption for compounds for which reliable human or experimental animal data exist. The absorption rates of other compounds are specified as "fast (F)," "moderate (M)," or "slow (S)". Initially these will be based primarily on their current D, W, and Y classification (ICRP,1979), but eventually they should be replaced since this system combines clearances by both particle transport and absorption processes. The default values are 100 d^{-1} ($t_{1/2}$ ~10 minutes) for F materials that are rapidly absorbed into blood; 0.1 d^{-1} ($t_{1/2}$ ~3 d) for 50% and 0.005 d^{-1} ($t_{1/2}$ ~100 d) for 50% of M materials with intermediate rates of absorption; and 0.0001 d^{-1} ($t_{1/2}$ ~7000 d) for S materials (relatively insoluble).

<B>DOSE CALCULATIONS

Rather than treat the lung and lymph nodes as a single organ and calculate an average dose, as currently [1], the revised model provides for calculating doses to tissues in anatomical regions identified in Figures 1 and 2. The calculation of doses follows the method of ICRP 30[1], in which the committed equivalent dose in a target tissue is determined by the energy absorbed per unit mass from the radiation emitted from a source organ. Target tissues selected for dose calculation are those identified in humans or experimental animals as the most sensitive to radiation and those that receive the highest doses. These are: keratinized epithelium of the anterior nasal passages, ET_1; stratified squamous epithelium of the naso-oropharynx and larynx, ET_2; ciliated epithelium of the bronchi containing secretory and basal cells, BB; ciliated epithelium of the bronchioles containing secretory and basal cells, bb; alveolar-interstitium, AI; and extrathoracic and thoracic lymph nodes ,LN_{ET} and LN_{TH}. The tissue masses used to calculate dose are defined by the surface area and the target cell depth specified for each region.

<B>CONSIDERATIONS OF RADIATION DETRIMENT

ICRP Publication 60[2] focuses on protection of workers and the public from the total radiation detriment. This detriment includes the probability of attributable fatal and nonfatal cancers, hereditary effects, and length of life lost if harm occurs. For the purpose of this lung model, it is assumed that the relative sensitivities of the various tissues of the respiratory tract to all radiation-induced deleterious effects are the same as for cancer. Since data are inadequate to provide risk estimates for each region or tissue, it was assumed that the relative distribution of spontaneous regional cancers in unexposed persons reflects relative sensitivities of the regions to

radiation-induced cancer. A major uncertainty in this approach is the potential effect of cigarette smoking and inhalation of other toxic materials on the regional distribution of "spontaneous" cancers. The radiation detriment is partitioned among the regions as follows: Extrathoracic Region, ET_1 anterior nose 0.001; ET_2 posterior nasal passage, larynx, pharynx, and mouth 1; LN_{ET} lymphatics 0.001; and Thoracic Region, BB bronchial 0.8; bb bronchiolar 0.15; AI alveolar interstitial 0.05; and LN_{TH} lymphatics 0.001.

Regional doses, adjusted with these factors for radiation detriment, are summed to give a value of committed equivalent dose for the extrathoracic region and another for the thoracic region. The appropriate ICRP tissue weighting factors can be applied to these two values in calculating effective doses as described in ICRP Publication 60[2].

<B>**SUMMARY**

The new respiratory tract model is based on the premise that the large differences in radiation sensitivity of respiratory tract tissues, and the wide range of doses they receive, argue for calculating specific tissue doses rather than average lung doses for radiation protection purposes. The new model is more complex than the current lung model because it describes deposition of inhaled radioactive material in and clearance from several tissues and regions of the respiratory tract and is applicable to the worldwide population of both workers and the public.

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Figure 1: Fractional deposition in each region of the respiratory tract for an adult Caucasian male engaged in light exercise and breathing through the nose.

Figure 10, Chapter 5 (April 1991)

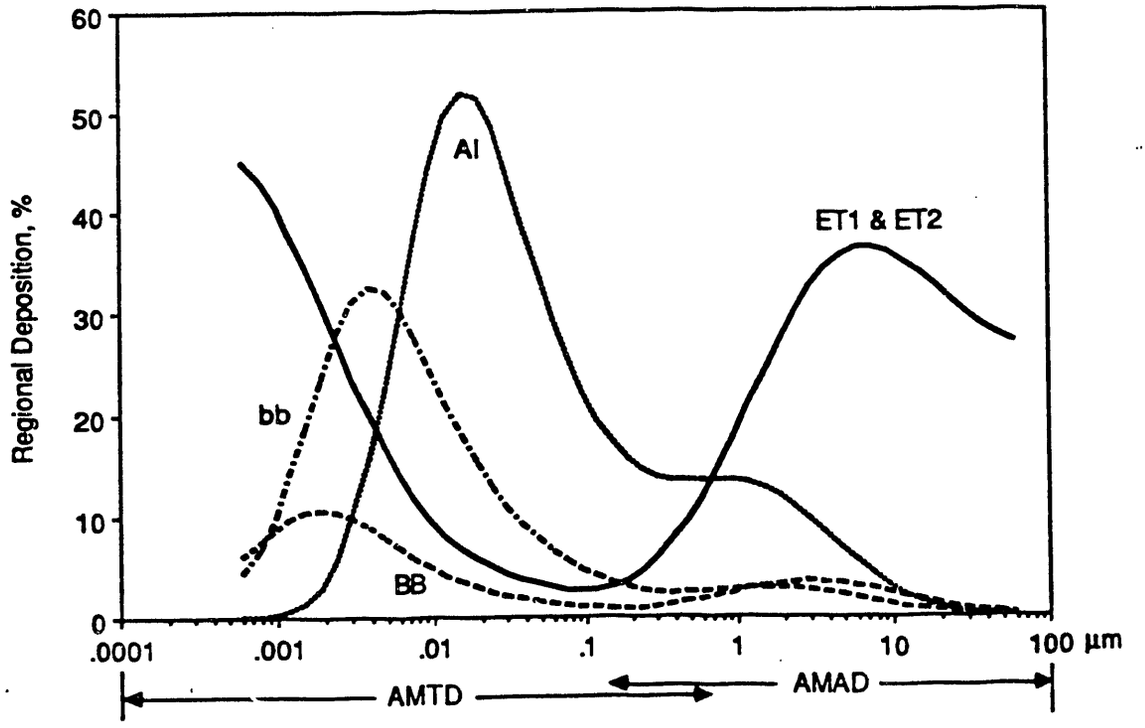
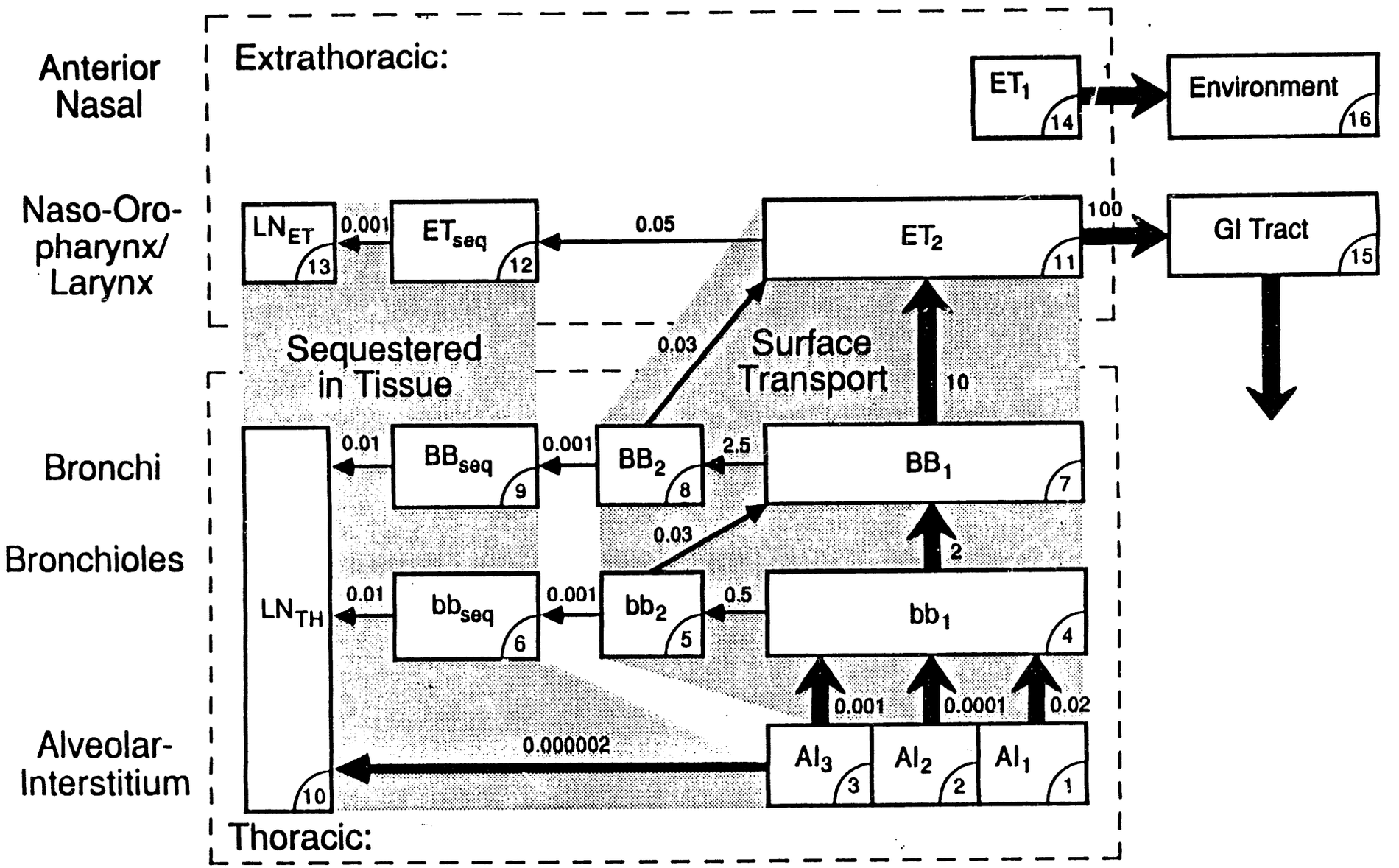


Figure 2: Compartment Model to Represent Time-Dependent Particle Transport from Each Region. Clearance rate constants shown are reference values in d^{-1}. Compartment numbers shown define clearance pathways, thus $m_{4,7}$ is the particle clearance rate from bb_1 to BB_2 ($2\ d^{-1}$).



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