HUMAN RESPIRATORY TRACT MODEL FOR RADIOLOGICAL PROTECTION - A REVISION OF THE ICRP DOSIMETRIC MODEL FOR THE RESPIRATORY SYSTEM

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The need for standardized values for various parameters describing the inhalation, deposition, retention and translocation of airborne radionuclides in workers for the purpose of deriving exposure limits was addressed in Tripartite Conferences on Radiation Protection from 1949 to 1953 (NVO 1984). At conferences held at Chalk River, Canada, September 29-30, 1949, and at Arden House in Harriman, New York, March 30-April 1, 1953, agreement was reached on a model for calculating radiation doses resulting from inhalation of radioactive aerosols when specific data were not available. This model was used in the 1959 report of the ICRP Committee II on Permissible Dose for Internal Radiation (ICRP 1959). It was assumed that 50% of an inhaled aerosol is deposited in the upper respiratory tract, 25% is exhaled and 25% is retained in the lungs. For soluble particles, it was assumed that the 25% is absorbed and translocated to other tissues in the body. For insoluble particles it was assumed that 12.5% is cleared in 24 hours and the remaining 12.5% is retained in the lungs with a half-time of 120 days.

This simple model of deposition, retention and clearance of inhaled aerosols was the basis for the limits for exposure to radionuclides and for calculations of doses to exposed individuals for both assessment and predictive purposes until ICRP Publication 30 appeared in 1979, using much more sophisticated dosimetric and metabolic models (ICRP 1979). The model used was a slight modification of that published in 1966 by a special Task Group on Lung Dynamics of ICRP Committee II, chaired by Dr. Paul Morrow (ICRP 1966). Major innovations were introduced by this task group, including a deposition model not only based on but using dust sampling data. Deposition was described for three anatomical compartments, which had both physiological and radiobiological implications. The model made possible consideration of both particle size of inspired aerosols and respiratory rate with respect to fraction deposited in each region: nasal, bronchial and pulmonary.

A quantitative kinetic clearance model was introduced that accounted for material deposited in each of the three regions. Perhaps of greatest impact was the classification of chemical compounds according to estimates of their expected tendency to be retained in the respiratory tract. This is the D, W, Y classification; D class for those compounds expected to be cleared from the respiratory tract with a half-time less than 1 day; W class for compounds with clearance half-time of a few days to months; and Y class for compounds that are expected to be retained with half-time of 6 months to years. This model also provided for the transfer of inhaled particles to the thoracic lymph nodes. The effort of the task group was a major scientific accomplishment. It used and expanded upon the total relevant technical data available and reflected the outstanding expertise and extraordinary insight of the members.

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The deposition and retention models developed by the task group provided a sound scientific basis for ICRP Committee II to calculate radiation doses from inhaled radionuclides leading to recommendations for Annual Limits on Intake and Derived Air Concentrations that appeared in Publication 30. Task group models went further than Committee II was prepared to go in some areas, such as the transfer of radionuclides to thoracic lymph nodes (Committee II elected to combine the lymph nodes and lungs), but failed to address others, such as the nasal passages. However, the omissions were insignificant compared with the magnitude of the advances in knowledge of inhaled particles stimulated by the task group's report. After publication of the 1966 report, research on the deposition, retention, clearance and translocation of inhaled aerosols intensified with studies on both humans and experimental animals. This new knowledge led to the ICRP's decision to initiate a review of the dosimetric model for the respiratory tract and a possible revision or development of a new model. In 1984, the ICRP appointed a task group of Committee II to undertake the assignment. The members of the task group were selected to assure that the broad spectrum of biological, physiological, chemical, and radiological aspects of inhaled radioactive aerosols could be competently addressed. The members of the multinational task group are Fredrick Cross, Richard Cuddihy, Peter Gehr, Anthony James, John Johnson, Roland Masse, Monique Roy, Willi Stahlhofen, and William Bair, Chairman. In addition, numerous corresponding members were invited to provide technical assistance and to review drafts of the report. The following describes the status of the effort in October 1987. The dosimetry model eventually adopted by the ICRP may be quite different, since much work remains to be done.

Following a review of the current ICRP lung model, a basis was established for a revision. Principal inadequacies of the current model would be addressed, such as calculation of radiation doses to the nasal and oral passages; replacement of the D, W, and Y classification system for clearance of inhaled materials where adequate information is available; and calculation of doses for inhalation of gases. The revised model would use new knowledge of deposition and retention of very small particles (well below 0.1 μm diameter), regional deposition of inhaled particles, the distribution of and absorption of inhaled gases, and clearance kinetics for numerous radioactive compounds determined in humans and experimental animals. Knowledge of the morphology and the physiology of the respiratory tract has increased, the relative regional sensitivities of the respiratory tract to cancer induction is better understood, and dosimetry modeling concepts and approaches have greatly expanded. The major developments in computer technology during the last few years have opened numerous possibilities for not only modeling the intake of radioactive materials but also utilizing the model for projecting and assessing radiation doses. The task group determined that a new model should facilitate calculation of biologically meaningful doses; should be consistent with morphological, physiological and radiobiological characteristics of the respiratory tract; should incorporate current knowledge; meet radiation protection needs and be user-friendly by not being too sophisticated; should be adaptable to development of computer software to allow calculation of relevant radiation doses from knowledge of a few readily measured exposure parameters; should be equally useful for assessment purposes as for calculating ALIs; should apply to all members of the world population; and should consider the influence of smoking, air pollutants and disease.

The task group's approach was to converge separately developed morphological, radiobiological, physiological, deposition, clearance, dosimetric, and bioassay considerations into a comprehensive multiparameter dosimetric model for the complete respiratory tract. All will be addressed in considerable detail in the report. An anatomical representation of the model is shown in Figure 1, along with the regional compartments that can be identified with respect to measuring deposition, clearance and retention of inhaled aerosols and to the occurrence of neoplastic diseases, the somatic effects of principal concern in radiation protection. These compartments are the extrathoracic, ET, comprising the nose, mouth, pharynx and larynx; the thoracic fast-clearing region, T(f), comprising the 0 through 16th airway generation (trachea through the terminal bronchioli); and the thoracic slow-clearing region, T(s), comprising the 17th through 23rd airway generation (respiratory bronchioli through alveolar sacs) plus the thoracic lymph nodes.

Since the revised lung model is to be applicable to essentially all members of the world's population under both working and nonworking conditions, reference values for numerous physiological parameters will be given. Lung volumes, flow rates and respiratory rates either will be given for Caucasian, Asian and African male and females of varying height and weight as a function of age, or guidance will be provided for deriving these values for use in calculating radiation doses to the respiratory tract under conditions of interest. The model will apply to both oral and nasal breathing, separately and in combination; e.g., at ventilation rates several times the resting value, it will be assumed that half of the intake is through the nose and half through the mouth. The task group considers it necessary that the dosimetric model accommodate a wide range of physiological parameters because they influence the amount of radioactive gases and particles inspired from a contaminated environment, as well as regional and total deposition of particles within the respiratory tract.

The proposed revised model addresses inhalability of aerosols and deposition in extrathoracic tissues such as the nasal passages, pharynx, larynx, and vocal cords. Deposition in the T(f) region is assumed to include material rapidly cleared essentially by mechanical processes from airway generations 0 through 16 (Figure 1). Deposition in the T(s) region includes material slowly cleared from airway generations 17 through 23 by both mechanical and solubilization processes as well as material infinitely retained such as in lymphatic tissues. Calculation of deposition of particles in these regions as well as in various tissues within these regions will be based on morphometric models and experimental data from human subjects inhaling test aerosols over a broad range of particle sizes.

In the proposed model, clearance of particles is competitive, occurring either by mechanical or absorption processes, and is assumed to be nonlinear, with excretion a time-varying factor of the residual amount. Mechanical clearance rates will be obtained from studies with human subjects. For compounds for which reliable human data exist or for which data can be extrapolated from animal experiments, the model will use observed rates of absorption. For other compounds, default values will be used based on the current D, W, and Y classification system. Mathematical models for calculating radiation doses to various tissues of the respiratory tract will be developed incorporating expressions describing the deposition and retention of radionuclides. Rather than treating the lung and lymph nodes as a single organ and calculating an average dose, the revised model will provide for calculating doses to tissues in all anatomical regions identified in Figure 1. To provide some perspective to the calculated doses, the task group will assess the relative sensitivity of these tissues to the induction of cancer

Airway Generation	Anatomy	Compartments: New Model	Compartments: Old Model
		ET Extrathoracic (Nasal-Laryngeal or N-L)	N-P
0	Trachea	T(f) Thoracic-Fast-Clearing (Tracheo-Bronchiolar or T-B)	T-B
1	Main Bronchi		
2-10	Bronchi		
11-15	Bronchioli		
16	Terminal Bronchioli		
17-19	Respiratory Bronchioli	T(s) Thoracic-Slow-Clearing (Parenchymal-Nodular or P-N)	P
20-22	Alveolar Ducts		
23	Alveolar Sacs		
	Lymph Nodes		L

FIGURE 1. Proposed Revised ICRP Lung Model

by radiation. This will also be useful in future partitioning a weighting factor that might be assigned to the total respiratory tract for calculating effective dose equivalent. The calculation of doses will follow the method of ICRP 30 in which the committed dose equivalent in a target tissue is determined by the energy absorbed per unit mass from the radiation emitted from a source organ. Compared with the current model, the proposed model is expected to simplify calculating respiratory tract doses from bioassay data. The task group expects computer software will facilitate but not be necessary for using the revised dosimetric model for the respiratory tract.

This work is being coordinated with a similar effort undertaken by the National Council on Radiation Protection and Measurements in the United States to minimize differences in the respiratory tract dosimetric models adopted by the two organizations.

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