MICRODOSIMETRIC APPROACH FOR LUNG DOSE ASSESSMENTS

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1. INTRODUCTION

The initial phase of every biological radiation induced reaction is characterized by primary physical energy deposition mechanisms at the cellular level. This energy absorbed by radiation sensitive sites within cells causes chemical and biological alterations, resulting finally in macroscopically observable effects.

The basis for the determination of the energy distribution of inhaled nuclides in the lungs is the detailed knowledge of the microdistribution of the deposited radionuclides in relation to the irradiated biological target. In particular in the case of short-range alpha radiation with highly localized energy deposition over several cellular diameters any radiobiological reaction depends on the superposition of this microdistribution with the distribution of the radiation sensitive cells.

2. METHODOLOGY

Conventional lung dosimetry is based primarily on the ICRP compartmental lung model as proposed by the ICRP Task Group on Lung Dynamics (3). According to the theory of compartmental systems, this model neglects the fine structure of nuclide deposition, the specific location of radiation sensitive targets and the non-uniformity of energy deposition along particle tracks through different cells. Therefore, a dosimetric method for inhaled alpha-emitting nuclides was developed, taking into account these above inhomogeneities. These cellular dose calculations are based on randomly selected tissue slices and LUMO - a computer lung model for inhalation of radioactive aerosols in the human respiratory tract (1).

The basic approach of this microdosimetric method is to superimpose alpha particle tracks onto magnified images of selected tissue slices on the monitor of an electronic image analyzer (Quantimet-720). Using adaptive pattern recognition methods the different cells in the lung tissue can be identified and their distribution within the whole organ determined. The probability of track-cell-interactions as well as the energy deposited there allows the calculation of cell-specific doses. Integration over all cellular doses results again in an organ dose, but now taking into consideration the inhomogeneity of both absorbed energy and lung tissue.

This microdosimetric concept is applied to the inhalation of very soluble short-lived radon decay products as well as of highly unsoluble PuO_2 particles. With regard to the nuclide distribution within

the respiratory tract these nuclides represent both extreme cases of more homogeneously located radiation sources as well as very localized "hot spots". The methodology developed is, however, not restricted to lung tissue, but is also applicable to other organs and tissues of the human body for dose calculations in practical health physics.

3. NUCLIDE DISTRIBUTION

Deposition and retention of inhaled particles in the human lung are functions of various superimposed anatomical, physiological and aerosol-specific parameters, For the simulation of their mutual influence on the resulting particle distribution a multiparameter deposition and retention model for inhaled alpha-emitting radionuclides, called LUMO, was developed. The anatomical basis for this computer model is the Weibel model A for regular dichotomy (7). These anatomical data, together with physiological parameters, such as respiratory frequency and tidal volume, show a significant dependence of age, sex and physical activity, influencing particle deposition to a large extent (1, 2). The surface activities of the nuclides in the single generations of the lung model, resulting from activity deposited, radioactive decay, mucus transport and other clearance mechanisms are calculated by solving a linear differential equation system,assuming first order kinetics in the lung model (2).

4. AUTOMATED PATTERN RECOGNITION OF LUNG TISSUE COMPONENTS

This investigation has been performed on 1 µm-thick lung tissue sections, obtained from adult Sprague-Dawly laboratory rats. The goal of the following analysis of the tissue sections was to discriminate between the various tissue components, such as specific lung cells and background. By definition this can be treated as a classical pattern recognition problem, that is to recognize certain pictorial subsets, such as surface epithelial cells, endothelial cells, or septal cells by quantitative image analysis. For example in order to recognize septal cells automatically a set-transformation with osmiophilic cytosomes, characteristic for septal cells, has been used. These cytosomes appear as dense and round bodies 0.2 to 1 µm in diameter on unstained, but OsO_4-incubated, semi-thin Epon sections within a medium light-optical resolution (300 x magnification). The 2-dimensional section shows clusters of 2 to 5 cytosomes for each septal cell (Fig. 1). After the cytosomes are segmented by thresholding a television frame, they are transformed iteratively by adding a "structuring element", e.g. an octagon to each cytosome (6). The algorithm stops when all cytosomes are "closed", giving a particle count of 1 instead of originally 2 or 5. This procedure detects automatically areas with cytosomes and discriminates the cytosomes from background particles (e.g. dust) and other cells.

5. SIMULATION OF ALPHA PARTICLE TRACKS IN TISSUE SECTIONS

For the simulation of α-particle tracks the idea of Boolean schemes, originated by G. Matheron (4), has been used. To simulate random set realizations, such as alpha particle tracks in lung tissue, we start with a "diffuse point process" in E_2 (Euclidian space of 2-

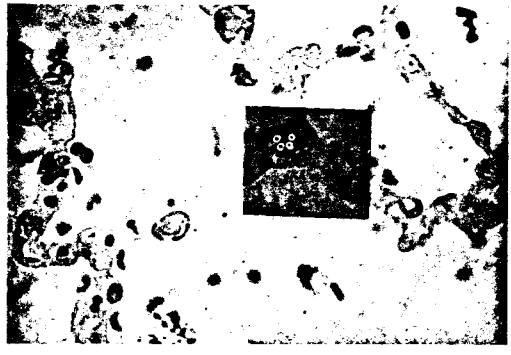

Fig. 1 Lung tissue section with recognized cytosomes

dimensions), e.g. the stationary Poisson point process with intensity θ, where the number of points within a bounded set A, N(A) is Poisson-distributed. The Boolean scheme can now be realized by implanting non-stationary, compact, convex random-sets (primary grains), such as line segments, in each Poisson-point realization within $|A|$ ($|A|$, Lebeque measure of A). For the present work such Boolean realizations have been used to simulate alpha particle tracks in lung tissue. Thereby advantage can be taken of some interesting properties of this scheme:

a) Stability of the model under sections: Alpha particle tracks are naturally occurring in 3-dimensions, but we can only observe their 2-dimensional sections. Fortunately it is possible that a Boolean scheme of 3-dimensions yields 2-dimensional sections, which are again Boolean schemes.

b) Indefinitely indivisible model: An increase in average lung dose always results in an increase of the same family of microdose distributions and does not change the nature of the underlaying process (fundamental Poisson property).

The simulation of highly localized alpha particle tracks, typical for PuO_2 "hot spots" or radon decay product concentrations at bifurcations of airways, may be gained as follows: Starting with a parent Poisson process of intensity θ, we can generate new points using some distributions D and a strongly concentrated frequency function f. This procedure, where the parent Poisson-points are the centers for new satellite points, leads to the center-satellite process of Neyman (5), with highly concentrated and clustered point-distributions. If a needle with a random-variable length from a uniform probability distribution and random orientation over the unit-circle is taken, a segment process is obtained, which is very similar to "hot spot"-caused track distributions (Fig. 2).

6. INTERACTION OF ALPHA PARTICLE TRACKS WITH LUNG TISSUE COMPONENTS

After automatic recognition of the most important tissue compo-

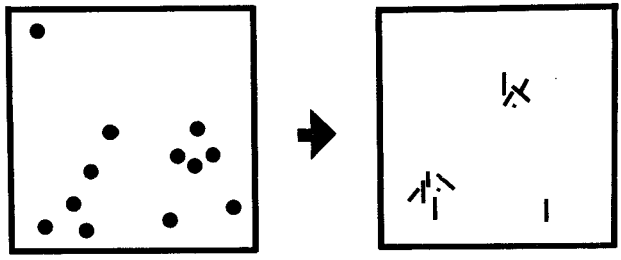

Fig. 2 Parent poisson process $\theta.|A|=12$ and its Boolean center-satellite scheme

nents and generation of alpha particle tracks by use of the Boolean scheme, both realizations can be intersected simultaneously. This leads to the consideration of conditional probabilities and their conditional distribution functions. If the random variable X is defined as the area of intersection between cell type I and alpha particle tracks originating from a Boolean scheme with intensity θ, the conditional distribution function of track intersection length under the condition of a given Boolean realization with $N_p=\theta.|A|$ has to be calculated. Under this condition a microdose for cell type I on its estimated distribution function can be assessed directly, i.e. the percentage of cell type I cells hit by tracks with a certain intensity. According to the stopping power function for alpha particles the intersection area has to be weighted by the energy loss along the track intersection length.

REFERENCES

1. Hofmann, W., Steinhäusler, F. and Pohl, E. (1979): Health Phys. 37, 517.
2. Hofmann, W., Steinhäusler, F. and Pohl, E. (1980): In: Proceedings, Natural Radiation Environment III, in press.
3. ICRP Task Group on Lung Dynamics (1966): Health Phys. 12, 173.
4. Matheron, G. (1967): Elêments pour une Théorie des Milieux Poreux. Masson, Paris.
5. Neyman, J. (1939): Ann. Math. Stat. 10, 35.
6. Serra, J. (1976): Lectures on Image Analysis by Mathematical Morphology. Unpublished Manuscript, Fontainebleau N-475.
7. Weibel, E.R. (1963): Morphometry of the Human Lung. Springer Verlag, Berlin-Göttingen-Heidelberg-New York.