MATHEMATICAL MODEL FOR CALCULATION OF THE LUNG DOSE FROM INHALED RADON-222 AND ITS DAUGHTERS

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ABSTRACT. A mathematical model of a human lung is described in this paper. Result obtained using by this model were compared with data taken from references.

INTRODUCTION

Inhalation of radon and its short lived daughters leads to the population absorbed dose which is under "normal situations" larger than any other component due to the natural radiation. In order to estimate corresponding risk one needs to relate measurable quantities, such as are concentrations of radon and its daughters in air, etc., with the absorbed dose in the human respiratory tract. There are few parameters upon which the dose in respiratory tract depends. In this paper we describe a mathematical human lung model we have developed and used and which enabled us to examine lung dose dependence on different relevant parameters.

MODEL

The developed mathematical human lung model is used for calculations of absorbed dose in the layer of basal cells per unit exposure to radon daughters in the whole T-B tree. This quantity is named "alpha dose factor"[1]. A computer program, called LUNGDOS was made to carry out calculations by using this model. The basic characteristics of the used approach are as follows:

-Yeh-Schum's geometrical model of the human lung was used[2];

-In order to calculate distance from the mucus layer to the basal cells the Gastineau's distribution[3] of the bronchial epithel thickness was used.

-It was assumed that α-emitters were distributed homogeneously in the mucus layer.

-Expression for the α-particles stopping power calculation in the tissue and air was taken over from reference[4].

-Radioactive aerosol deposition was calculated by using Landahl formula[5] in the first six generations, and Gormley-Kenedy equation[6] for the rest of T-B tree.

-Clearance of the deposited radioactive aerosols is carried out by mucus movement upwards toward the nose and mouth. The data for the mucus speed was adopted from reference[4]. Radioactive aerosol transport is the second important process which influences radioactivity decrease in the T-B tree. The transfer of the radioactive aerosols depends on their chemical form. According to reference[7] there is a "fast phase" which is transferred from T-B tree to the blood with transfer half time of 50 min (10%), and three slower phases with an average of transfer half times of 3^h (35%), 9^h (35%) and 45^h (10 %), and about 10 % is unknown.

In accordance with this it was estimated that the average half-transfer time into the blood was 3^h for the whole of the T-B tree, regardless of the bronchial generation.

According to the so far said four processes are responsible for the radon progeny activity in the T-B tree. They are: deposition, decay, clearance by the mucus movement and transfer to the blood. All these processes together lead to establishment of activity equilibrium in each bronchi of the T-B tree.

One needs to calculate the equilibrium activity in each bronchi of T-B tree. In order to do this it is necessary to set up and solve a set of differential equations of the 1^{st} order, such as

$$dN_{ij}/dt=B_{ij}/\lambda_i+A_{i-1,j}+\lambda_{c,j+1}N_{i,j+1}-(\lambda_i+\lambda_k+\lambda_{c,j})N_{ij} \quad (1)$$

In equation (1) N_{ij} - is the number of atoms of i^{th} radon daughter in the bronchi of the j-th generation; B_{ij} is deposition rate of the i-th progeny in j-th generation, given in Bq/s; λ_i is decay constant of the i-th radon progeny; A_{ij} is equilibrium activity of the i-th radon progeny in the j-th bronchi generation; λ_{cj} is the clearance constant by the mucus and λ_k is transfer constant to the blood. The solutions of the above differential equations are as follows:

$$A_{ij}=(\lambda_i A_{i-1,j}+\lambda_{c,j+1}A_{i,j+1}+B_{ij})/(\lambda_i+\lambda_{cj}+\lambda_k) \quad (2)$$

$i=1,2,3;\quad j=1,16$

System of equations (2) is solved by starting with the first progeny (i=1), from sixteenth (brochi) generation. The procedure is then repeated for i=2, and i=3. After that one repeats the whole procedure for 15^{th} generation. In order to solve the set of equation (2) it is necessary to know the deposition rate of the i^{th} progeny in the j^{th} generation. The entire described procedure is programmed and is a part of the program LUNGDOSE.

Equilibrium activities calculated in the just described way were calculated with corresponding conversion factor [8], in order to obtain the absorbed dose in the layer of the basal cells, for given bronchi.

RESULTS

Among many obtained results by using the described model, we presented here two- dose dependence on the aerosol diameter and on breathing rate.

-aerosol diameter-

The value of the median diameter of aerosols was varied and α- dose factor was calculated for whole T-B tree. Deposition of aerosols in T-B tree decreases with its diameter increase, and that is the reason that the dose factor decreases with increaseof the diameter. Results are shown graphicaly on Figure 1, parallelly with result from references [9] and [10]. For aerosols diameter of 0.1 μm the value obtained in this work is among the referent values, while for larger diameters thi value is for about 10 % higher. That comes from the difference in assumed breathing rate. In this work that velocity was 0.3 m^3/ks, while referent values were 0.2 m^3/ks.

Breathing rate

Dependance of the average dose factor for T-B tree as a whole on breathing rate was examined in this work too. Obtained results are shown in Fig.2. One can see a linear increase of the dose factor with increase of the breathing rate. For a change of the breathing rate from 0.11 to 0.38 m^3/ks (0.4 to 1.4 m^3/h) the dose factor increases from 0.27 up to 0.4 $mGy/(J \cdot s \cdot m^{-3})$. On the same figure are shown several data calculated based on (or simply taken from) different references[(1),(9),(10),(11)]. All models are showing similar bchaviour of the dose factor as a function of the breating rate. However, there is a rather large difference in absolute values for different models. This difference comes from the difference in assumed value of the epithelial depth. Results of our work presented by the full line on Figure 2, agree rather well with results of reference [(10)], beside that the line obtained in this work is with somewhat smaler slope.

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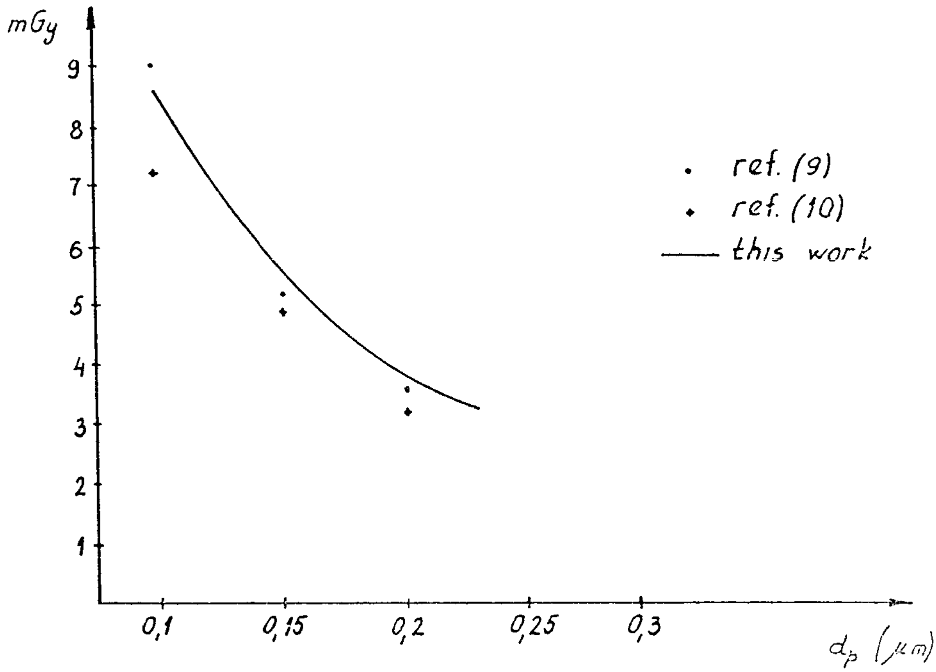

FIG. 1. Alpha dose factor dependence on particle diameter

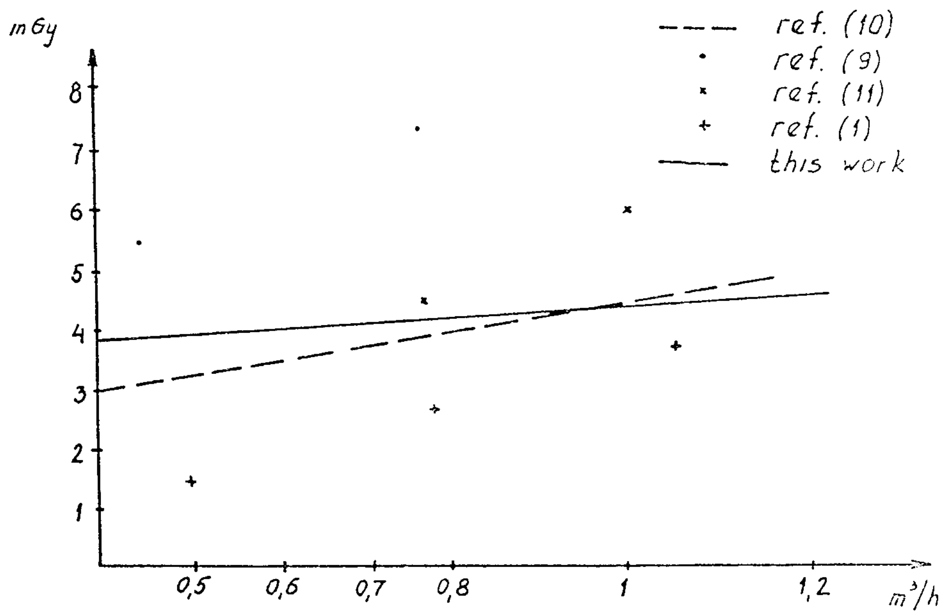

FIG. 2. Alpha dose factor dependence on breathing rate