Study of deposited energy in lung tissue from radon's progeny calculated by Monte Carlo

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Because the deposited ^{222}Rn progeny distribution in lung airways, these sources can contribute hardly to critical cells absorbed dose in neighbourhood of alpha track by the alpha particles from ^{218}Po and ^{214}Po. According to epidemiological data [1], lung cancers are primarily bronchogenic and mainly originate in the first five airway generations of the bronchial tree. Generally for deposited energy calculations, uniform deposit in source layers and the whole layers as sources has been considerated too. Discretional point deposits in the diferent and most important bronqui (BB) and bronchial (bb) layers for main generations is a more realistic case. Because that facts we have calculated the average deposited energy by Monte Carlo in the most important different target cell layers for the main BB and bb branch generations considering the radioactive ^{222}Rn progeny puntual deposit in the source epithelium walls, from this location, It irradiate the neighbor cells in all directions.

Keywords: Radon; absorbed dose; bronchial; bronchiolar; secretory cell; basal cell.

Debido a la distribución de la progenie del ^{222}Rn en las vías aéreas del pulmón, estas fuentes contribuyen importantemente a la dosis absorbida en la vecindad de la trayectoria de las partículas alfa emitidas por el ^{218}Po y el ^{214}Po. Conforme a datos epidemiológicos, el cáncer de pulmón es principalmente broncogénico y se genera principalmente en las primeras cinco generaciones del árbol bronquial. Para realizar los cálculos de energía depositada generalmente es considerado el depósito uniforme de las fuentes en las capas celulares y las capas mismas completas como la fuente también. Un caso más real es el depósito puntual y discreto en los diferentes y más importantes capas bronquiales (BB) y bronquiolares (bb). Tomando en cuenta lo anterior hemos calculado la energía promedio depositada en las más importantes capas celulares blanco en las principales generaciones bonquiales y bronquiolares considerando el depósito puntual de la progenie del ^{222}Rn en la pared epitelial de las capas celulares fuente, desde su ubicación el material fuente irradia las células vecinas en todas direcciones.

Descriptores: Radon; absorbed dose; bronchial; bronchiolar; secretory cell; basal cell.

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1. Introduction

Alpha particles emitted by ^{222}Rn progeny deposited on inner surfaces of airways regions are the major contributors in imparted energy to lung structures. In human respiratory tract model secretory and basal layers in bronchial region and secretory layer in bronchiolar region are the main targets because their alpha particles sensitivity

Usually the dose in that lung structures is calculated for such as cell layers as ICRP 66 publication [2], or by microdosimetric method [3,4].

The present work evaluate the average alpha energy imparted for mentioned cell layers considering multiple puntual sources deposited in mucus and sol ephitelium layers for each generation from 1^{st} to 15^{th}. From that cell layer targets alpha particles from ^{218}Po and ^{214}Po are ejected to any directions.

2. Morphometric model

The dosimetric model considers the respiratory tract (Fig. 1) as four anatomical regions (1) and (2) The extrathoracic region (ET_1 and ET_2), (3) The bronchial region (BB) consisting of the trachea and bronchi from which deposited material is cleared by ciliary action; (4) The bronchiolar region (bb), consisting of the bronchioles and terminal bronchioles and (5) the alveolar-insterstitial region (AI), consisting of the respiratory bronchioles.

A simplified geometrical model to represent the locations of radionuclide sources and target tissue in airways within the ET, BB, and bb regions is basic for dosimetric calculations.

In each case, a typical airway is represented by a cylindrical tube of appropriate internal calibre and wall thickness [4].

Two of most dosimetric important regions are BB and bb. The BB region is part of the air conducting system within the thorax and consist of the trachea, the main bronchi, and the intrapulmonary bronchi, beginning with the trachea as generation 0 and ending approximately with generation 8 [5] .

The average length of the branches also decreases with increasing orders of generations, with the exeption of the 4^{th} generation branches, which are longer than the 3^{rd}one.

The simplified model of a section through the wall of a typical bronchus in region BB is shown in Fig. 2.

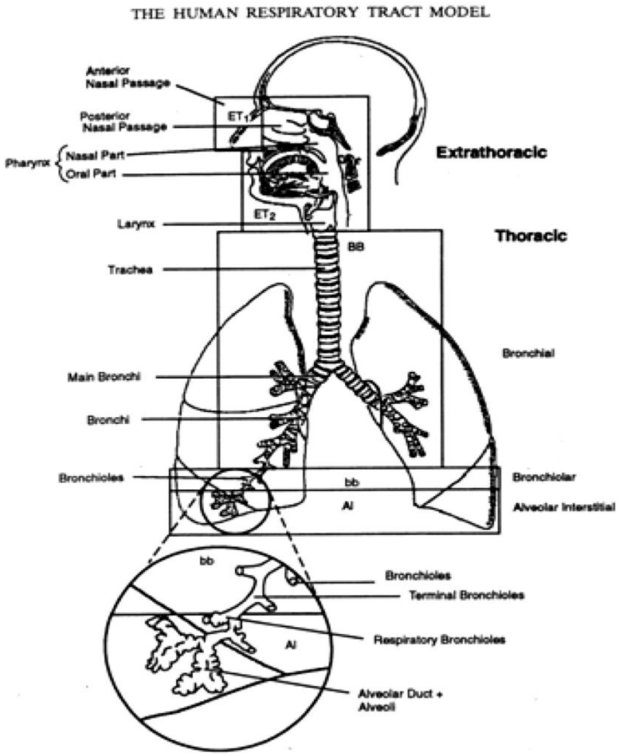

FIGURE 1. The human respiratory tract model ICRP 66.

TABLE I. Dimensional model of trachea-bronchiolar tree (ICRP 66)

Region	Generation number	Diameter m	Lenght m
Bronchi BB	0	1.6500E-02	9.10E-02
	1	1.20E-02	3.80E-02
	2	8.50E-03	1.50E-02
	3	6.10E-03	8.30E-03
	4	4.40E-03	9.00E-03
	5	3.60E-03	8.10E-03
	6	2.90E-03	6.60E-03
	7	2.40E-03	6.00E-03
	8	2.00E-03	5.30E-03
Bronchiolar bb	9	1.65E-03	4.37E-03
	10	1.35E-03	3.60E-03
	11	1.09E-03	3.01E-03
	12	8.82E-04	2.50E-03
	13	7.20E-04	2.07E-03
	14	6.03E-04	1.70E-03
	15	5.33E-04	1.38E-03

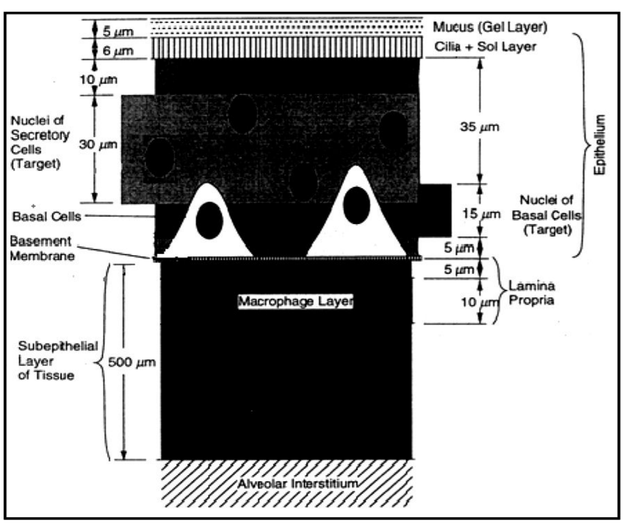

FIGURE 2. Model of target cell nuclei (secretory and basal cells) and the bronchial wall in the BB region. ICRP 66.

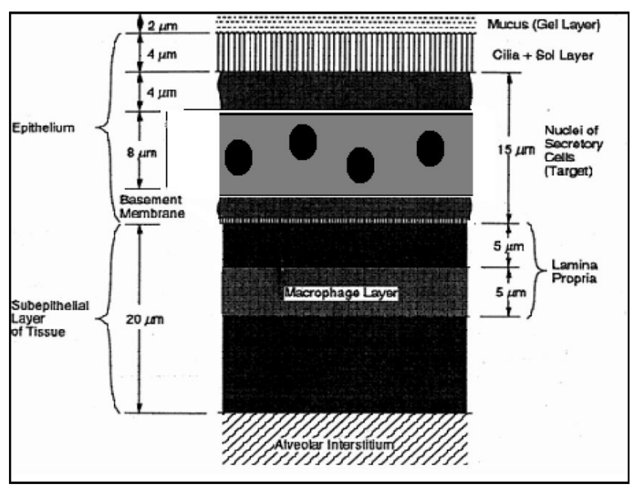

FIGURE 3. Model of target cell (secretory and clara cells) and bronchiolar cell in bb region.

The bronchiolar region bb is the second part of the air conducting system within the thorax. It consists of the bronchioles comprising generations 9 to 15. the branches of the last generations are called terminal bronchioles. BB and bb generation dimensions are shown in Table I.

The simplified model of a section through the wall of a typical bronchiole used for dose calculations is shown in Fig. 3.

3. Dosimetric principles

To evaluate doses to tissues of the respiratory tract and other organs throughtout the body, the formal procedure recommended in ICRP Publication 26 (ICRP, 1979) [6] and developed further in ICRP Publication 56 (ICRP, 1989) [7] and Publication 60 (ICRP, 1991a) [8] is applied to include contributions from all tissues wich radionuclides are retained. The committed equivalent dose, H_T, in each one of tissue, T, from radiation emitted in a tissue source, S, is determined by the product of two factors:

1) The total number of transformations of the radionuclide in tissue source S over a period of integration t, after intake of the radionuclide.

2) The energy absorbed per unit mass in the target tissue T, suitably modified for radiation weighting factor, for each radiation emitted per transformation in tissue source S.

The dosimetric formulations of ICRP Publication 30 have been extended to address age-dependence in ICRP Publication 56. The equivalent dose rate in target organ T includes contributions from the activity of the radionuclide present in organs of the body. The equivalent dose rate at age t in organ T of and individual of age t_o at the time of intake,

$$\dot{H}_T(t,t_0) = c\sum_s\sum_j q_{s,j}(t)SEE(T \leftarrow S;t)J$$

Where $q_{s,j}$ (t) is the activity of radionuclide j present in source organ S al age t; $SEE(T \leftarrow S;t)$ is the total energy absorbed per unit mass in the target T; the contributions of each radiation emitted by the radionucleide in source region S; and c is any numerical constant required by the units of q and SEE. The equivalent dose [9,10] in the target organ accumulated by age 70 y due a single intake of a radionuclide at age t_0, $H_T(t_0)$ is:

$$H_T(t_0) = \int_{t_0}^{70} \dot{H}_T(t,t_0)dt$$

For any radionuclide, the specific effective energy SEE at age t is defined as:

$$SEE(T \leftarrow S;t) = \sum_R \frac{w_R E_R Y_R AF(T \leftarrow S;t)_R}{M_T(t)}$$

Where w_R is the radiation weighting factor for radiation R, E_R is the energy of radiation R, Y_R is the yield of radiation R per nuclear transformation, AF(T $\leftarrow$S;t)$_R$ is the fraction of the energy of radiation R per nuclear transformation emitted in S, wich is absorbed in the target tissue T at age t, and M_T(t) is the mass of the target tissue at age t.

For the adult, the SEE is not a function of time and thus:

$$H_T(t_0) = c\sum_s\sum_j U_{s,j}SEE(T \leftarrow S)j$$

Where $U_{S,j}$ is the total number of nuclear transformations of radionuclide j in S over the 50-y period following the intake, *i.e*:

$$U_{s,j} = \int_0^{50} q_{s,j}(t)dt$$

Spatial nonuniformity of the radionuclide source in relation to the target cells has been taken into account in evaluating doses to the sensitive epithelial tissues in the ET, BB y bb regions of the respiratory tract for short-range radiations.

A simplified geometrical has been applied to represent the orientations of radionuclide sources and target tissue in airways within the ET, BB and bb regions. In each case, a typical airway is represented by a cylindrical tube of appropriate internal caliber and wall thickness. In each type of airway, the target tissue is then assumed to be distributed over a characteristic range of depths below the epithelial surface.

In all cases, the radionuclide source is assumed to be spread uniformly in association with the airway surface. For alpha, and low-energy electron, negatron and positron emitters, the effect of a more localized distribution of radioactive transformations over part of the airway surface would be to deliver higher doses to a part of the target cell population, and low or zero doses to the remainder. However, it is assumed that the stochastic effect on the target tissue is proportional to the average dose received by the cell population as a whole (ICRP, 1977, 1980). This average dose is thus independent of the degree of localization of the source on the airway surface.

The bronchial airways (BB)

The simplified model of a section trhough the wall of a typical bronchial region BB assume that the nuclei of both columnar secretory and short basal cells are consider to be the sensitive targets. These are assumed to occur uniformly throughout a 30 μm layer of tissue al 10 μm depth, and in 15 μm layer at 35 μm depth respectively.

In the bronchial airways, five distinct distributions of the radionuclide sources may occur, the most important are two:

Mucus, where the radionuclide concentration is assumed to be uniform within a 5 m thick layer. This sources represent the "fast" surface-transport compartment.

-Sol layer where the radionuclide concentration is asumed to be uniform within a 6 m thick layer. This sources represent the "slow" surface-transport compartment.

Usually the energy absorbed fractions, AF(BB$\leftarrow$S)$_R$, are calculated on the assumption that the bronchial airways have an average calibre of 5 mm.

The bronchiolar airways (bb)

The model of a section through the wall of a typical bronchiolus used for dose calculations assume that the sensitive targets are nuclei of secretory cells which occur uniformly throughout the 8 m thick layer of tissue at 4 μm depth.

The most important distributions of the radionuclide source in the bronchioles are:

- Mucus, wich is assumed to be 2 μm thick.

- Sol layer, which is assumed to be 4 μm thick.

The absorbed fractions, AF(bb$\leftarrow$S)$_R$, are calculated on the assumption that the bronchiolar airways have an average calibre of 1 mm.

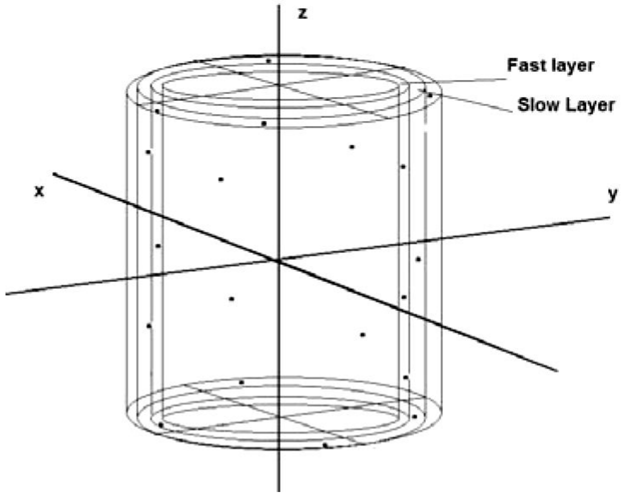

FIGURE 4. Cylinder Geometrical location.

TABLE II. BBsec region AF obtained values in this work compared with the ICRP values.

Target (T)	BBsec ICRP	BBsec This work	
Source (S)	Fast mucus	Fast mucus	Difference (%)
Energy (MeV)			
6	**0.249**	**0.236**	**5**
7.69	**0.353**	**0.326**	**8**
Target (T)	BBsec **ICRP**	BBsec **This work**	
Source(S)	Slow mucus	Slow mucus	Difference (%)
Energy (MeV)			
6	**0.272**	**0.271**	**0.2**
7.69	**0.355**	**0.336**	**5**

4. Method

Monte Carlo method simulations have been used to calculate the deposited energy in each generation layer. Most experiment consider radon progeny homogeneus distribution in inner surface of epithelium airways, from where the alpha particles are ejected in random directions, A large number of events guarantee cover practically all directions.

Each bronchi and bronchiolar generation could be seen like a cylinder with various layers walls, the atoms of radon progeny are deposited in inner wall.

To calculate the energy absorbed fractions AF(BB$\leftarrow$S)$_R$ and AF(bb$\leftarrow$S)$_R$, we have considerated distributed point deposit sources in the length of each one of the fifteenth generations. The cylinders were located in a 3-d coordinate system to make the Monte Carlo code geometries. The point radioactive sources are in the mucus and cilia inner layers where the alpha emitters are located.

We used the morphometric dimensions for the bronchi and bronchiolar epithelium and generations from ICRP 66, showed in Table I.

Every layer i was constructed like a cylinder with different ratio in agree with morphometric dimensions.

Each cylinder generation was defined in Montecarlo program like a set of right circular concentric cylinders centered in x=0, y=0, z=0 with diferent ratio to represent the air, mucus, cilia, secretory and basal layers for BB region and the same one for bb region except basal layer. (Fig. 4)

TABLE III. BBbas region AF obtained values in this work compared with the ICRP values.

Target (T)	BBbas **ICRP**	BBbas **This work**	
Source(S)	Fast mucus	Fast mucus	Difference (%)
Energy (MeV)			
6	**0.0217**	**0.0045**	$\gg$
7.69	**0.0893**	**0.0812**	**9**
Target (T)	BBbas **ICRP**	BBbas **This work**	
Source(S)	Slow mucus	Slow mucus	Difference (%)
Energy (MeV)			
6	**0.005**	**4.2 e-8**	$\gg$
7.69	**0.0857**	**0.0855**	**<1**

The statistical error is less than 1%.

TABLE IV. bbsec region AF obtained values in this work compared with the ICRP values.

Target (T)	bbsec **ICRP**	bbsec **This work**	
Source(S)	Fast mucus	Fast mucus	Difference (%)
Energy (MeV)			
6	**0.214**	**0.201**	**6**
7.69	**0.172**	**0.160**	**7**
Target (T)	bbsec **ICRP**	bbsec **This work**	
Source(S)	Slow mucus	Slow mucus	Difference (%)
Energy (MeV)			
6	**0.217**	**0.201**	**7**
7.69	**0.173**	**0.163**	**6**

Energies of 6 and 7.69 MeV from the alpha radiation of Po-218 and Po-214 respectively were used for all cases.

Sources were distributed in fast and slow layers for each mentioned energy.

200000 alpha particles were ejected from source position in each case.

5. Results

The average values of the energy absorbed fractions for first eight BB generations (except trachea) in secretory layers from 6 and 7.69 MeV alpha particles from fast and slow targets are showed in Table II.

The average values of the energy absorbed fractions for first eight BB generations (except trachea) in basal layers from 6 and 7.69 MeV alpha radiation from fast and slow targets are showed in Table III.

The average values of the energy absorbed fractions for 9 to 15 bb generations in secretory layers from 6 and 7.69 MeV alpha radiation from fast and slow targets are showed in Table III.

When results from ICRP homogeneus source are compared with the point source calculated values, for 6 MeV and BB region a difference of 2.6% is gotten. For 6 MeV and bb until the value difference is 6.5%.

For 7.69 MeV in BB region the value difference is 6%, while for 7.69 MeV and bb region the value difference is 6.5%.

6. Conclusions

Because the weight factor for the lung is 0.12 for effective dose calculation and this value is divided in three weight factors: BB region, 0.33; bb region 0.33 and for alveolar instertitial region is 0.33, the differences in the AF(T←S) gotten in this work represent only about 4 % in the final effective dose it‘s not an important difference, but the AF values in this work are light more near for the real value because a more realistic puntual case is choosen for the calculate, but there is not reason for not use the ICRP energy fractions.

For laboral dose might to consider the next one:

Only the most important BB and bb layers were considered, let it the rest of layers for a complementary work.

Altough The average absorbed energy is calculated for only one alpha emission at time, the absorbed dose for each layer is E(MeV)/(Bq s).

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