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INFLUENCE OF LUNG PARAMETER VALUES FOR THE BRAZILIAN POPULATION ON INHALATION DOSE

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ABSTRACT

The Human Respiratory Tract Model (HRTM) proposed by the ICRP Publication 66 accounts for the morphology and physiology of the respiratory tract. The ICRP 66 presents deposition fraction in the respiratory tract regions considering reference values from Caucasian man. However, in order to obtain a more accurate assessment of intake and dose the ICRP recommends the use of specific information when they are available. The main objective of this study is to evaluate the influence in dose calculation to each region of the respiratory tract when physiological parameters from samples of Brazilian population, in different levels of exercise, are applied in the deposition model.The dosimetric model of HRTM was implemented in the software EXCEL for Windows and committed equivalent dose was determined for each respiratory tract region. First it was calculated the total number of nuclear transformations considering the fractional deposition of activity in each source tissue obtained by apllication of physiological and morphological Brazilian parameters in the deposition model and then it was calculated the total energy absorbed per unit mass in the target tissue.The variation in the fractional deposition in the compartments of the respiratory tract in changing the physiological parameters from Caucasian to Brazilian adult man causes variation in the number of total transformations and also in the equivalent dose in each region of the respiratory tract. The variations are not the same for all regions of the respiratory tract and depend on levels of exercise.

1. INTRODUCTION

The Human Respiratory Tract Model (HRTM) adopted by INTERNATIONAL COMMISSION ON RADIOLOGICAL PROTECTION (ICRP) in its Publication 66 [1] simulates the deposition and clearance of inhaled radioactive aerosols and also calculates the correspondent equivalent dose coefficients accounting for the physicochemical form of the material and the morphology and physiology of the individual. The uncertainty in particulate deposition in the adult lung model includes the respiratory physiological parameters [2]. HOFMANN et al [3] evaluated the intersubject variability of particle deposition in the human lungs and their results suggest that structural and volumetric differences of lung morphologies among different individuals are primarily responsible for the observed variability in total and regional deposition. In order to obtain a more accurate assessment of the intake and the dose the ICRP recommends the use of specific information of the individual. Owing to the complexity of the model some software were developed to facilitate the use of the HRTM. The software LUDEP

enables the user to calculate doses to each region of the respiratory tract and all other body organs, excretion rates and retention curves for bioassay purposes and also to change the parameters of interest [4]. The software MONDAL 2 enables the users to estimate intake activity and the resulting effective doses from bioassay measurements [5]. REIS et al [6-7] implemented in software EXCEL for Windows (version 2000) the deposition model for inhaled particulate in the respiratory tract presented by ICRP Publication 66. The results obtained were in agreement with those presented by ICRP 66, however it was observed significant differences for some regions of respiratory tract when physiological parameters from samples of Brazilian population were applied in the deposition model considering different levels of exercise [7]. These results suggest that EXCEL is a good tool to implement the dosimetric model of the respiratory tract and allows changing parameters of interest for specific information about the individual exposed and the exposure conditions. It can be used to assess the individual equivalent dose in the regions of respiratory tract model since it is considered the morphological and physiological parameters of the exposed individual. The main purpose of this study is to evaluate the influence in dose calculation to each region of the respiratory tract when physiological parameters from samples of Brazilian population are applied in the deposition model.

2. METHOD

The purpose of the dosimetric model is to evaluate doses to each tissue of respiratory tract that is potentially at risk from inhaled radioactive materials. The target tissues in the respiratory tract are represented in the deposition and clearance model, described in Chapter 7 of ICRP Publication 66 [1], for the compartments ET_1 and ET_2 (extrathoracic region), BB (bronchi region), bb (bronchioles region), AI (alveolar region) and LN (lymphatic nodes).

The dosimetric model of HRTM described in Chapter 8 of ICRP Publication 66 [1] was implemented in the software EXCEL for Windows (version 2000.) The equivalent dose $\boldsymbol{H_T}$ was determined in two stages. First, it was calculated the number of total nuclear transformations, $\boldsymbol{U_S}$, considering the fractional deposition of activity in each source tissue and then it was calculated the total energy absorbed per unit mass ***SEE***, in the target tissue ***T***, suitably modified for the radiation weighting factor. The number of nuclear transformations of radionuclide in each source organ ***S*** within the respiratory tract is obtained by solving the compartment model of clearance described in chapter 7 of ICRP Publication 66 [1]. The activity present in each compartment of the respiratory tract model as function of time is given by solution of generic equation 1,

$$\frac{dQ_i}{dt} = D_i(t) + \sum_j Q_j(t)\lambda_{ij} - Q_i(t)\sum_k \lambda_{ik} \qquad (1)$$

where $\boldsymbol{Q_i(t)}$ is the activity present in compartment ***i*** in the time ***t***, $\boldsymbol{Q_j(t)}$ is the activity present in compartment ***j*** in the time ***t***, $\boldsymbol{D_i(t)}$ is the function of rate of deposition material in compartment ***i***, $\boldsymbol{\lambda_{ij}}$ is the activity translocation rate from compartment ***j*** to compartment ***i*** and $\boldsymbol{\lambda_{ik}}$ is the activity translocation rate from compartment ***j*** to other compartments ***k***.

The fractional deposition in the regions of the respiratory tract model was those obtained from the clearance model implemented by REIS et al [6]. The total number of disintegrations was calculated by multiplying the compartmental residence time by the fractional activity deposited

in the organ source. Equation 2 [1] was used to calculate the specific energy absorbed per unit mass in the target ***SEE***,

$$SEE(T \leftarrow S;t) = \sum_R \frac{W_R E_R Y_R AF(T \leftarrow S;t)_R}{M_T(t)} \quad (2)$$

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 energy of radiation ***R*** emitted in ***S*** which is absorbed in the target tissue ***T*** at age ***t*** and $M_T(t)$ is the mass of the target tissue at age ***t***. The values of $AF(T \leftarrow S; t)_R$ for discrete values of the mean energy of short-range are presented by ICRP 66 in annex H (Tables H.1– H.6) as well as the formulas used to calculate $AF(T \leftarrow S)$ as function of energy for any radionuclide that emits alpha particles, electrons or beta particles. The committed equivalent dose is calculated by the product of the total number of transformations of the radionuclide in tissues sources ***S***, over a period of fifty years after incorporation, and of the energy absorbed per unit mass in the target tissue ***T***, for each radiation emitted per transformation in tissue source ***S***.

Firstly, it was implemented the example presented by ICRP 66 (chapter 9) where it is assumed a radionuclide type "S" long half-life alpha emitter, with average energy of 5.15 MeV. Then, the implementation was extended to other radionuclides of interest: ^{234}U, ^{235}U, ^{238}U, ^{237}Np, ^{238}Pu, ^{239}Pu, ^{241}Am and ^{244}Cm.

2.1. Structure of Implementation

The implementation of the dosimetric model of the respiratory tract model in EXCEL was connected to the implementation of the deposition and the clearance model performed also in EXCEL. It allows changes to the parameters of interest when they are available.

The data entered in the spreadsheet are reference parameters published in the literature or individual parameters. The model includes the trachea diameter [d_0 (cm)], the bronchioles diameter [d_9 (cm)], and the terminal bronchioles diameter [d_{16} (cm)], in order to represent the anatomy of exposed individuals. The functional residual capacity [FRC (mL)], the tidal volume [V_T (mL)], the breathing rate [B (m^3/h)], the dead space volume [V_D (mL)], the respiration frequency [f_R (min^{-1})] and the breathing habit, represented by the parameter F_n that is the fractionation of airflow through the nose and mouth were included to the model to represent the respiratory physiology. The exposure condition is characterized by the concentration of activity airborne [C_A (Bq/m^3)], the exposure duration (h), the Activity Median Aerodynamic Diameter [AMAD (μm)], the windspeed [U (m/s)], the particle shape factor (χ) and the particle density [ρ (g/cm^3)]. The user can choose one of the radionuclides available in the software and the default absorption into blood: type F (fast absorption), type M (moderate absorption) and type S (slow absorption). The spreadsheet correspondent to the data entered shows the results of equivalent dose as function of AMAD for 0.5, 0.7, 1, 2, 3, 4, 5, 6, 7, and 8 μm. Other spreadsheets can be consulted in the software for other values of AMAD. The software presents the fractional deposition in the regions ET_1, ET_2, BB, bb and AI of the respiratory tract and also in extrathoracic region and lung as results.

2.2. Parameters of Brazilian Population

The parameters utilized in the model were obtained from morphological [6] and physiological respiratory studies of Brazilian population available on literature. The Table 1 presents the respiratory volumes obtained by NEDER et al [8]. The ventilation rates depend on level of exercise and breathing habit. The parameters presented in Table 2 consider the nose breathing and different levels of exercise: resting (R), sitting (S) and heavy exercise (H).

Table 1: The respiratory volumes of Brazilian population [8].

Respiratory Volumes	Values
Total Lung Capacity (TLC)	7.12 L
Functional Residual Capacity (FRC)	3.45 L
Vital Capacity (VC)	5.12 L
Dead Space (V_D)	0.149 L

Table 2: The respiratory parameters of Brazilian population for different levels of exercise.

Parameters	Values
Tidal volume (V_T)	0.637 L (R) [9] 0.780 L (S) [10] 2.417 L (H) [9]
Ventilation rate (B)	0.64 $m^3 h^{-1}$ (R) [9] 0.6 $m^3 h^{-1}$ (S) [9] 5.8 $m^3 h^{-1}$ (H) [9]
Minute volume (V_E)	10.65 L min^{-1}(R) [9] 9.8 L min^{-1} (S) [10] 75.76 L min^{-1} (H) [9]

3. RESULTS AND DISCUSSION

A test was performed concerning the implementation of the dosimetric model considering the example presented by ICRP 66 where it was assumed a radionuclide type "S" long half-life alpha emitter, with average energy of 5.15 MeV. The result obtained for the equivalent dose $\boldsymbol{H_T}$ in the lung was 4.7×10^{-5} Sv and in the extrathoracic region was 7.9×10^{-5} Sv. The values calculated through the implementation of the dosimetric model were the same presented by ICRP 66. Other comparison was made with parameters published by ICRP 71 [11] for the same radionuclides and the results obtained from the implementation of the dosimetric model are in

agreement with those from ICRP 71 as can be observed from Fig. 1. Considering ^{238}Pu and ^{241}Am there is some variation but not greater than 4%.

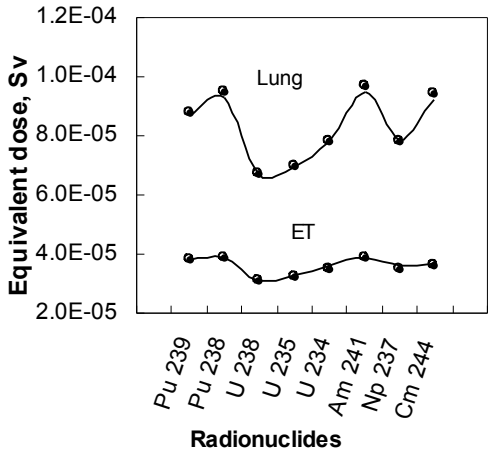

Figure 1. Comparison among the results obtained by the implementation and the results published by ICRP 71. The solid curves are the values presented by ICRP 71 and the circles are the values calculated in the implementation.

After the dosimetric model was implemented, the fractional deposition in the region of respiratory tract was obtained using the physiological parameters from samples of Brazilian population and comparisons among the results from Brazilian and Caucasian parameters were performed. The Fig. 2 and the Fig. 3 show the variations in equivalent dose $\boldsymbol{H_T}$ for a range of AMADs in the extrathoracic and thoracic regions respectively, for three levels of exercise. The equivalent dose calculated for Brazilian was divided by the equivalent dose calculated for Caucasian.

It can be observed from Fig. 2 that variations in extrathoracic region are greater for smaller values of AMADs and the equivalent dose is greater when Brazilians parameters are applied.
From Fig. 3 it can be observed for smaller values of AMADs the equivalent dose is greater to Brazilian in heavy work and in resting conditions. The variation for heavy exercise condition decreases with increases of AMAD, and for resting and sitting conditions the variations increase with AMAD values. The values of AMAD recommended by ICRP are 1 μm for public and 5 μm for worker. It is observed from Fig. 2 and Fig. 3 that the greatest variation in the committed equivalent dose occurs mainly for AMAD = 1 μm. The variations observed for 1 μm are summarized in Fig. 4. The equivalent dose calculated for Brazilian was divided by the equivalent dose calculated for Caucasian.

For 1 μm AMAD, considering individual resting, no significant variation in equivalent dose was observed in the lung, but was around 40% greater to Brazilian than Caucasian in extrathoracic region. This result could be explained by variation on fractional deposition, because it was around 40% greater in extrathoracic region and in thoracic regions the fractional deposition is greater 24% in BB region, lower 25% in bb region and no significant (< 1%) in AI

region. It results no variation in equivalent dose in lung, because it is like recompense in fractional deposition in thoracic region.

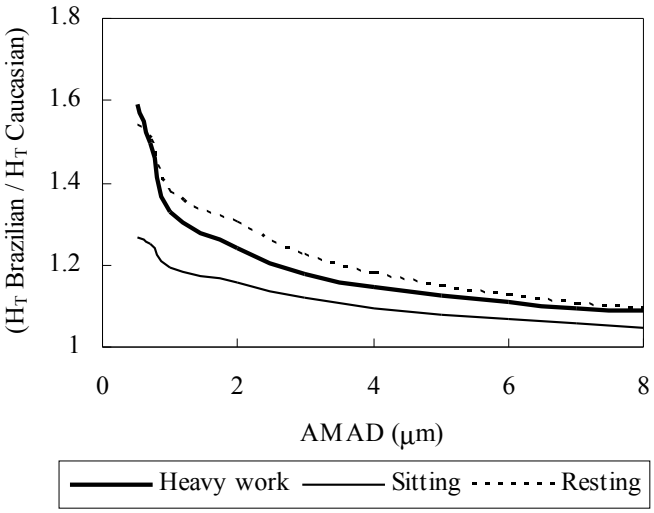

Figure 2: The variation observed in the equivalent dose in the extrathoracic region for three levels of exercise.

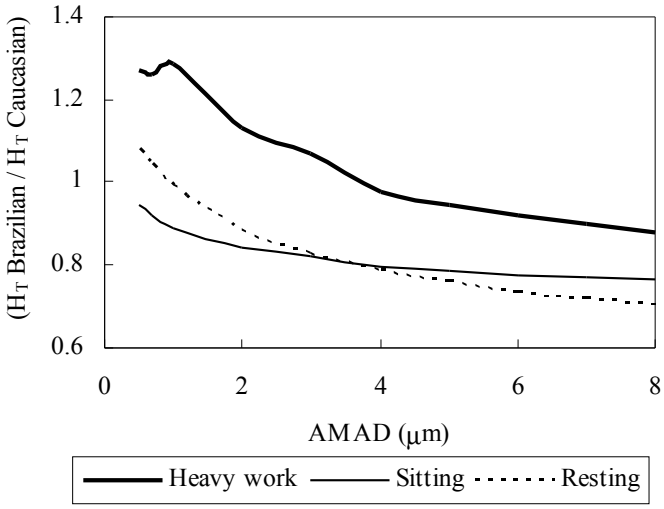

Figure 3: The variation observed in the equivalent dose in the lung for three levels of exercise.

Considering sitting as the level of activity the variation observed for the equivalent dose in the lung was around 10% lower to Brazilian than Caucasian and it was around 20% greater to Brazilian than Caucasian in extrathoracic region. It could be addressed to the fractional deposition variation for this level of activity. The analysis to the extrathoracic region the fractional depositions are 20% greater. Considering the thoracic region the fractional deposition is 10% greater in BB, 10% lower in bb and 15% lower in AI.

For individual in heavy exercise the variation observed for the equivalent dose in the lung and in extrathoracic region was around 30% greater to Brazilian than Caucasian. This result could have a relation with variation deposition. For extrathoracic region the fractional deposition is greater to Brazilian, around 40% in ET_1 and around 33% in ET_2. For the thoracic region, it is around 75% greater in BB, 10% greater in AI and 30% lower in bb.

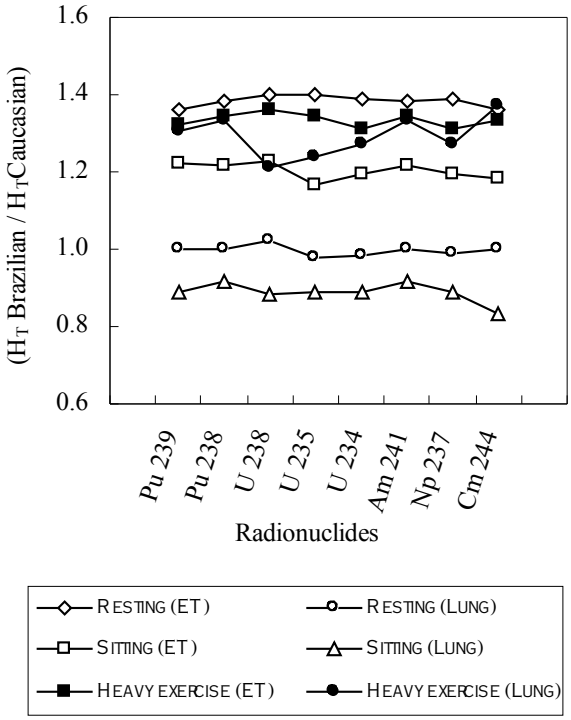

Figure 4: The variation observed for 1 μm AMAD in the equivalent dose in the extrathoracic region and in the lung for three levels of exercise.

For 5 μm AMAD, the variation for the equivalent dose $\boldsymbol{H_T}$ in extrathoracic region was 12% for heavy work, 8% for sitting and 15% for resting greater to Brazilian parameters. It is the same variation in fractional deposition in ET_1 and ET_2 for each level of exercise [6]. In thoracic region a reduction on $\boldsymbol{H_T}$ was observed for three levels of exercise. For heavy exercise it was not observed a significant variation in $\boldsymbol{H_T}$ in the lung (lower 4%). For resting and sitting the variation of $\boldsymbol{H_T}$ was around 30% lower. In the lung, the fractional deposition in BB was 25% greater for heavy exercise in the lung. It was not observed significant variation to other levels of activity. In bb it was lower 45% for resting, 25% for sitting and 50 % for heavy work. In AI it was lower 20% for resting, 25% for sitting and 30% for heavy work.

3. CONCLUSION

The results obtained for the implementation of the example presented by ICRP 66 and the results for some radionuclides that were compared with ICRP 71 showed that the software EXCEL is a good tool to implement the dosimetric model of the human respiratory tract. It is

encourage extending the implementation to calculate the effective dose. The differences from 20% to 50% in fractional deposition addressed to the application of parameters from Brazilian population samples in deposition model causes variation until 40% in equivalent dose H_T in regions of respiratory tract. It was observed a direct relation between variation in fractional deposition and equivalent dose in the respiratory tract regions. It is important to observe the compensation in thoracic region owing to increase and decrease of fractional deposition within this region did not cause variation in equivalent dose for resting as level of activity, as well as the result obtained for H_T in the lung (lower 4%) for heavy work to 5 μm AMAD. For different levels of activity the variation in equivalent dose is not the same. But can be considered the same in a level of activity for radionuclides studied. It can be observed from Figure 3, with exception to ^{238}U in a heavy work for lung region. It is important to evaluate the influence these results in effective dose.

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