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# Construction of a Computational Tracheobronchial Model to Simulate Radon Progeny Deposition with Computational Fluid Dynamics

L. C. Takahashi[1], M. Â. B. C. Menezes[1], T. O. Santos[1,2], A. A. C. Santos[1], M. P. B. Filho[1,2], G. A. M. Vidal[1], R. Huebner[2], D. J. Ribeiro[2], A. D. Neto[1], R. G. Passos[1] e Z. Rocha[†1]

[1] laura.c.takahashi@gmail.com, *Nuclear Technology Development Center – CDTN/CNEN*
*Av. Presidente Antônio Carlos, 6627, 31270 – 901, Belo Horizonte, MG*
[2]talitaolsantos@yahoo.com, *Federal University of Minas Gerais – UFMG*
*Av. Presidente Antônio Carlos, 6627, 31270 – 901, Belo Horizonte, MG*

## 1. Introduction

Radon is a natural and radioactive gas; its chain decay generates a sequence of radionuclides, alpha emitters, known as progeny. These radionuclides are in the solid-state present in the atmosphere attached or not to other aerosol and may also be represented by small agglomerations or attached to the water molecule [1,2]. As aerosol in the air, radon progeny enters in the human respiratory system, predominantly through the nasal cavities, during breathing and may be deposited in the airways [2]. The energy derived from the alpha decay of the deposited progeny is fully absorbed by lung tissue and might contributes to the development of several diseases such as tumor processes [3,4]. The International Agency for Research on Cancer (IARC) [5] classifies radon and its progeny as a class I carcinogenic factor for human health. Also, the World Health Organization (WHO) [6] indicated that radon caused more than 15% of lung cancer in the world and classified it as the second leading cause of lung cancer.

The effective dose assessment to the individual from radon can be done through epidemiological and dosimetric models [7]. The epidemiological model is based on observations and estimates of lung cancer and the time of radon exposure compared to the damage in individuals. The dosimetric model takes into account complementary aspects, such as respiration rate, distribution of aerosol size, detached fraction, fractional deposition in the airways, mucosa rate, target cell location [7, 8]. Currently, ICRP 137 (2017) recommends that radon be treated like other radionuclides, thus the dose should be calculated based on biokinetic and dosimetric models, like ICRP models [9]

Computational or mathematical models are becoming an advantageous methodology for studies of biological systems. These have advantages when compared with experimental methods and can be used in situations that the experimental model causes risks to the individual's health. To determine airflow in the airways it is possible to adopt the numerical method Computational Fluid Dynamics (CFD), which is widely used in biomedical engineering. CFD is widely used to model and simulate fluid and particulate dynamics in the airways [10]. The application of CFD in the pulmonary tract consists, for example, of predicting patterns of particulate deposition and studying various diseases [11, 12]. To simulate particle deposition in the bronchial airways, it is necessary to construct a morphological or geometric model of the respiratory tract [13].

The structure of the airways is complex, especially due to bifurcations, which makes it difficult to study the characteristics of the fluids that flows through them [10, 13]. The construction of a computational model identical to the real model is impossible [14]. However, it is necessary to use other techniques to replace experimental measurements and study respiratory physiology, for this reason, computational models can be used [10]. Geometry can be built with real images from diagnostic imaging tests, such as Computed Tomography (TC) and Magnetic Resonance Imaging (MRI). Although this technique faithfully represents the respiratory tract, complications may occur during mesh generation during CFD modelling, due to the irregular surface and imperfections of the branches, which can cause numerical errors. Therefore, it is recommended that the geometry of the airways be constructed from cylinders [13].

In order to study the deposition of radon progeny in human airways, the objective of this work was to construct a computational model of the lung to be applied in the studies of radon dosimetry and its decay products.

## 2. Methodology

The computational model allows quantifying how many particles are deposited in the airways during inhalation of radon progeny particles not attached and attached to aerosols in the air. For this, is necessary construct a computational tracheobronchial model to simulate radon progeny deposition with CFD, which can make with five main steps:

A. Choice of techniques and software to be used. Ansys R18.0 Academic was the main tool used.
B. Construction of three-dimensional airway geometry (trachea, bronchi and bronchioles). The present work, used InVesalius 3.1, which are a free software, for reconstruct CT chest images available on InVesali*us* website
C. Treatment of geometry in Meshmixer, a free software, where cutting functions were applied for selection of the area of interest, reconstruction of the surface area of the lung and treatment of the surface of the airways.
D. Elaboration of a cylindrical model from the anthropometric measurements obtained in the reconstruction of the tomography; SolidWorks, licensed software, was used for this purpose.
E. Export to Ansys R18.0 Academic, licensed software, and generate the mesh of the geometry.

## 3. Results and Discussion

The combination of software (InVesalius, Meshmixer, SolidWorks and Ansys) selected to build a computational model was compatible to work in a complementary way. The first attempt to elaborate the tracheobronchial computational model was through 3D reconstruction of chest CT images imported into InVesalius with soft tissue mask application and treated in Meshmixer, the result obtained can be seen in Fig. 1. The model obtained initially was considered to have a difficult-to-handle geometry for a first approach. Therefore, it was selected only the main airways (trachea + main bronchi + first bronchioles), and the new geometry model is presented in Fig. 2.

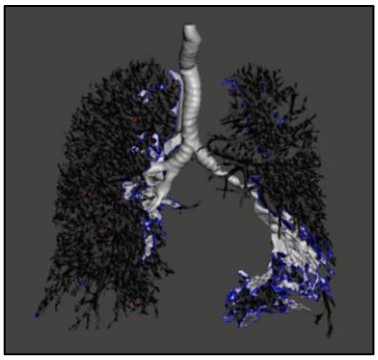

Figure 1: 3D reconstruction of the complete lung.

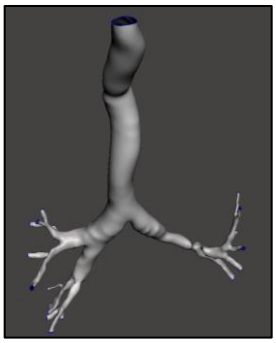

Figure 2: Ttracheobronchial model.

After obtaining the geometry, the construction of the mesh started from the model presented earlier, which allows to perform the simulation. Given the complexity of the geometry, it was treated to present less surface complexity, in order to enable the numerical simulation to be carried out. The treatment of the mesh, in this case, consisted of the joining of the "colored" elements in larger parts to group (yellow region) and thus make possible the reconstruction of new elements, as shown in Fig. 3. However, the complexity of the geometry still did not allow the construction of a viable mesh. Therefore, obtaining the mesh from the 3D reconstruction of CT images would be interesting for future studies. Although it was not feasible to use the CT model for simulation, from it was possible to remove anthropometric measurements that allowed to build a model from cylinders in SolidWorks software, which was used in the simulation, as shown in Fig. 4.

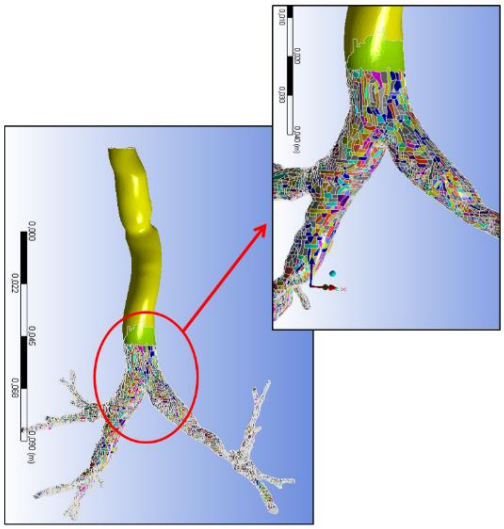

Figure 3: Treatment of the mesh of the CT airway model.

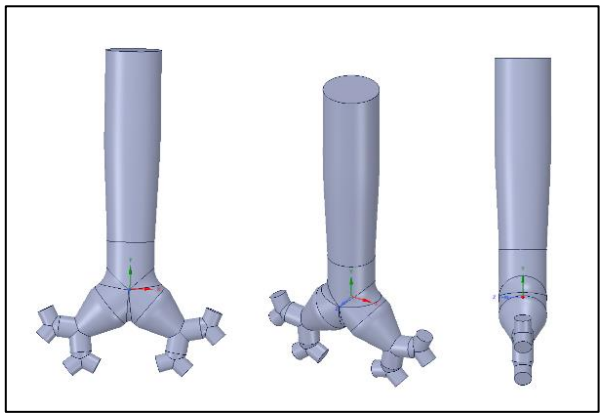

Figure 4: Tracheobronchial model built in *SolidWorks.*

## 4. Conclusions

The present study built as a first approach a computational model of the lung to be applied in the studies of radon dosimetry and its decay products. As a first approach, therefore needs an improvement to represent more realistic airways human anatomy. According with the authors cited along this work and the practical experience of the author of the present work, there are several ways of constructing the

models to perform the simulation and all of them can be used. In cases of complex geometries, especially when dealing with anatomical regions, it is suggested a greater simplification of the same and even perform a combination of the TC model with the parts built in SolidWorks. The present computational model is able to be use for simulate radon progeny deposition in human respiratory airways using CFD.

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