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SOFTWARE FOR MEDICAL IMAGE BASED PHANTOM MODELING

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ABSTRACT

Latest treatment planning systems depends strongly on CT images, so the tendency is that the dosimetry procedures in nuclear medicine therapy be also based on images, such as magnetic resonance imaging (MRI) or computed tomography (CT), to extract anatomical and histological information, as well as, functional imaging or activities map as PET or SPECT. This information associated with the simulation of radiation transport software is used to estimate internal dose in patients undergoing treatment in nuclear medicine.
This work aims to re-engineer the software SCMS, which is an interface software between the Monte Carlo code MCNP, and the medical images, that carry information from the patient in treatment. In other words, the necessary information contained in the images are interpreted and presented in a specific format to the Monte Carlo MCNP code to perform the simulation of radiation transport. Therefore, the user does not need to understand complex process of inputting data on MCNP, as the SCMS is responsible for automatically constructing anatomical data from the patient, as well as the radioactive source data. The SCMS was originally developed in Fortran-77. In this work it was rewritten in an object-oriented language (JAVA). New features and data options have also been incorporated into the software. Thus, the new software has a number of improvements, such as intuitive GUI and a menu for the selection of the energy spectra correspondent to a specific radioisotope stored in a XML data bank. The new version also supports new materials and the user can specify an image region of interest for the calculation of absorbed dose.

Key Words: MCNP, SCMS, phantom, JAVA language, medical images, nuclear medicine

1. INTRODUCTION

With the advent of information, new computer architectures are growing fast, especially in the processing time. The new generation of applications also supports a greater volume of data. Not only applications for daily use, such as operating systems and video editors that benefit from this improvement, but also, specific applications that require larger processing power, such as applications for simulation of radiation transport.

In addition, with increasing technological advances, more accurate ways of diagnostic medical imaging is emerging. Both CT and MRI techniques show the internal anatomy of the body with increasing resolution as each new generation is launched, ensuring greater diagnosis reliability.

Digital images are two-dimensional arrays composed by pixels. Their contents are necessarily integers, but they can carry different contents, ranging from integers to double precision numbers. Some programming languages also support objects, if they have forms of differentiation to define colors. Medical images are no different, but in this case, each image represents a cross-sectional slice of the body. The set of several sequential medical images composes a three-dimensional data that can be utilized for a digital representation of the human body called Phantom. Basically, it is a three-dimensional matrix where each element is formed by the pixel with the cross-sectional slice thickness. These volume elements are called voxels.

Recent studies [1,2,3,4] have been used these anatomical images with functional images, coupled to radiation transport simulation software to perform internal dosimetry in patients for nuclear medicine therapy [5,6,7]. Functional imaging systems as SPECT (Single Photon Emission Computerized Tomography) and PET (Positron Emission Tomography), provide the distribution of radionuclides in the patient to build the radiation source for the radiation transport software.

Absorbed dose can be calculated using radiation transport codes and one of the most utilized numerical techniques is based on stochastic models or Monte Carlo methods. Among the several codes existent in the literature, we highlight the EGS4 [8], Geant4 [9], Penelope [10] and MCNP [11]. Historically, the latter was widely used in neutron transport, but presently it is also commonly utilized in medical physics research. However, some of those codes can process medical images directly, others need an interface between them and the medical images systems. One of these interfaces, called SCMS [12], has been created and its preliminary version was developed in FORTRAN 77 to be used as an interface between the medical images and the Monte Carlo code MCNP.

The purpose of this present work was to create a new version of the SCMS software in JAVA language to be able to be coupled to others medical image software as IMAGEJ [13]. In this new version, called AMIGO (Algorithm for Medical Image-based Generating Object), several options and resources have been added to the old version.

2. MCNP

The MCNP is a computer program based on Monte Carlo method to simulate radiation transport. The current version allows the simulation of the interaction of three types of radiation with matter: neutron, photon and electron. It has certain advantages and geometric resources that make it attractive for medical applications. The range of energy covered for photon transport is 1 keV to 1 GeV and for electrons is 1 keV to 100 MeV. Important interactions that occur at low energies as production and transport of X-rays and Auger electrons are considered accurate for imaging.

Regarding to the geometry, the MCNP has extensive geometric modeling flexibility that allows the simultaneous use of combinatorial geometry features, with surface of up to fourth degree in conjunction with features of repeated structure option, which allows the modeling of voxel-based anatomic structures derived from digitalized medical images. Each voxel of the phantom geometry corresponds to an individual MCNP "cell" which is the smallest component in the geometric description, so that, a group of specific voxels with same identification number called "universe" can be used to define different regions or organs of the human body. Figure 1 illustrates different groups of voxels representing different tissues that could be present in the anatomy.

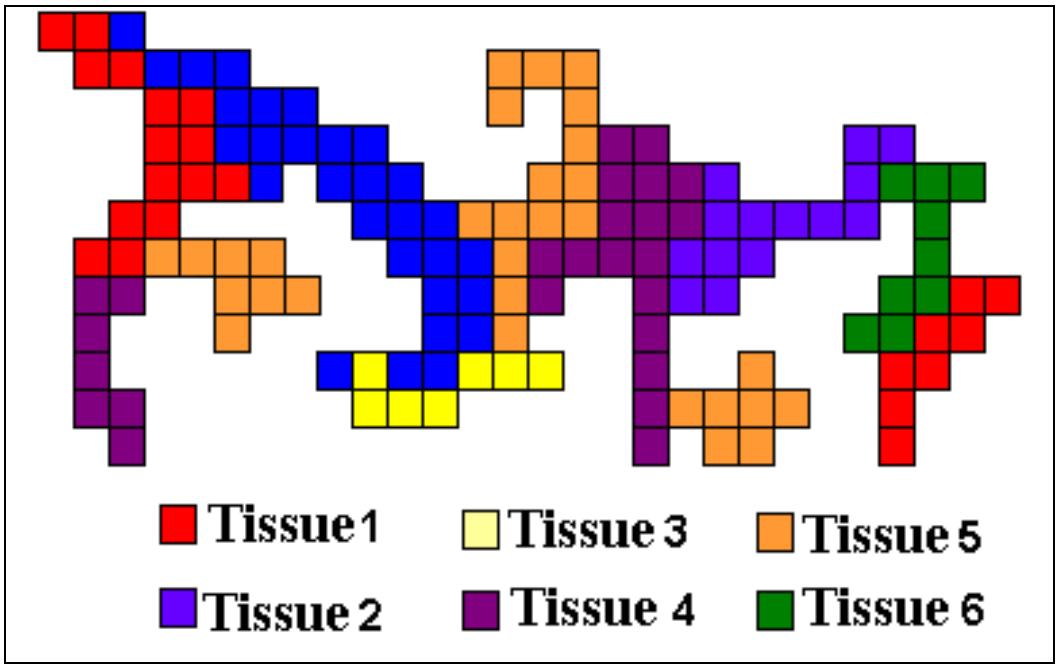

Figure 1 – Illustration of phantom voxels.

3. SCMS

SCMS, whose acronym stands for Segmented Construction of Mannequins Software, was firstly developed in FORTRAN 77 to serve as an interface software between the medical images and the MCNP code. It utilizes three ASCII format input files: a) the PHANTOM data file derived from the anatomic image data; b) the SOURCE data derived from the functional image data and; c) input file SINP which contains information about the two previous mentioned files regarding matrix sizes, type of radiation source, radiation energy and target organs for energy deposition calculation. All SCMS computational task is mainly based on matrix manipulation and extraction of relevant information for further absorbed dose estimates and basically required simple matrix mathematical operations as matrix reduction, vectorization and the creation of sub-matrixes. To accomplish those tasks the software is composed by 8 sequential modules as described below.

3.1 MAIN Module

The MAIN module reads the input data (SINP) where the user provides information of the image data to be read and other variables that specify the organs of interest (regions of interest), target and source organs, and average or dose distribution calculation options. All other modules are called by the MAIN module.

3.2 PHANTOM Module

The PHANTOM module reads the PHANTOM data which should be in ASCII format, transforming it into a 3D matrix (MVX matrix).

3.3 The RESIZE Module

In this module, all external voxel rows and columns outside the body area are subtracted from the MVX matrix, reducing the computer memory requirements. If the heterogeneous source distribution option is chosen, the activity map archive which is the SOURCE file is read and stored in another 3D matrix to be used for the construction of the MCNP source information.

3.4 The SETUP Module

The SETUP module has an option to divide each organ into small regions, according to the variable information provided by the user in the input file (SINP). Each organ can have different number of regions or just one region which corresponds to the entire organ volume. After dividing the organs into regions, each voxel is renumbered according to its localization and assigned a number corresponding to the region to which it belongs.

3.5 The UNIVMAP Module

A universe in MCNP can represent a collection of individual cells or an entire lattice. This concept is used in the UNIVMAP module where the new 3D matrix created in SETUP is rewritten in terms of MCNP universe numbers. Also a file containing the map of MCNP universes is optionally created for further utilization, for example, it can be used for the image reconstruction of important parameters as particle spatial flux distribution, dose or energy spatial distribution in the entire phantom or part of it.

3.6 The FILLCARD Module

The FILLCARD module writes all the geometric information contained in the 3D matrix in MCNP input format. The MCNP cells are defined and three different material compositions are possible (soft tissue, lung tissue and bone tissue).

3.7 The TALLIES Module

In the TALLIES module, the MCNP tally cards are written using the cell definition created in the FILLCARD module.

3.8 SOURCE Module

The input data configuration defines the number of source organs present in the problem. The SOURCE module uses this data and the identification number of each source organ to create the MCNP source cards. For heterogeneous source distribution, the SOURCE file stored previously is utilized for the source construction in MCNP.

4. AMIGO, THE NEW SCMS

The development of the AMIGO code followed the same structure of the original SCMS code, but explored the JAVA functionalities as: object orientation, libraries for building graphical user interfaces (GUIs) and multi-platform. It preserved its main structure; however, some minor changes had to be implemented in the code, for example, the implementation of a new method to write different types of materials in the output file, this new method was called *Material*. There are also some peculiarities in the code in FORTRAN 77 that could not be converted into Java and they had to be adapted, for example, how to load and/or save files in the hard disk and replace some FORTRAN statements for flags or labeled break statements.

In routine basis utilization, the AMIGO loads data (CT and PET) generated by the ICCT software [14], that converts DICOM format images into an ASCII tables, creating a density map and the list of materials. All this information is used by the AMIGO software to create the input file for the MCNP Monte Carlo simulation for dose distribution calculation. A great improvement implemented to the software is the graphical interface (GUI), that didn't exist in the original version and it is quite intuitive, as shown in Figure 2a and 2b. Figure 2b shows a combo box to set the source type.

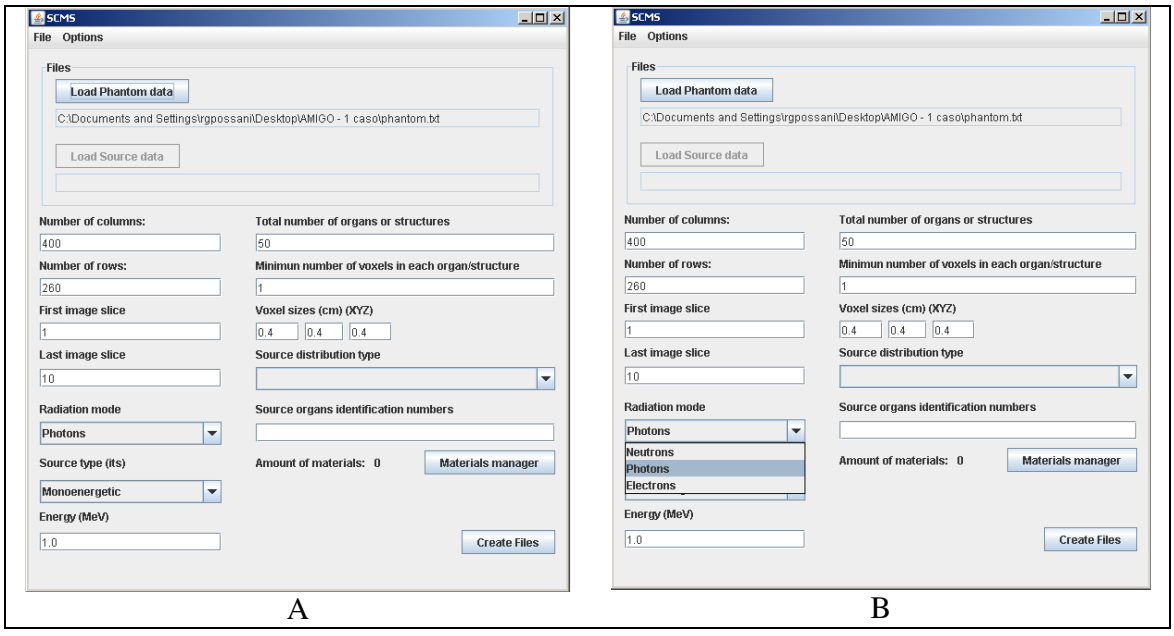

Figure 2 - Main interface window of the software.

Several parameters and options are already predefined with default values, but the user can modify them by introducing new parameters or configurations according to each problem and the last modifications will be saved to the next program execution.

In Figure 2, the items *Number of columns*, *Number of rows*, *First image slice* and *Last image slice* represent the phantom and source matrix dimensions. The combo box *Radiation mode* and *Source type* define the source particle type to be simulated and the source type (monoenergetic or spectrum), respectively. With the possibility to enter an energetic spectrum, a data bank has been created from where the user can choose the specific radiation source energy spectrum with the option to load new spectrum into the software. The activity map data is used to provide the spatial localization of the source, but the user can select it manually specifying in which material or body it is located.

Figure 3a shows a problem where the *source type* is set as "Spectrum", providing the possible options linked to the combo box that shows a list of available radioisotopes, to determine which spectrum will be used in the problem. Also the button "*Plot*" shows graphically the energy spectrum chosen, as shown in Figure 3b.

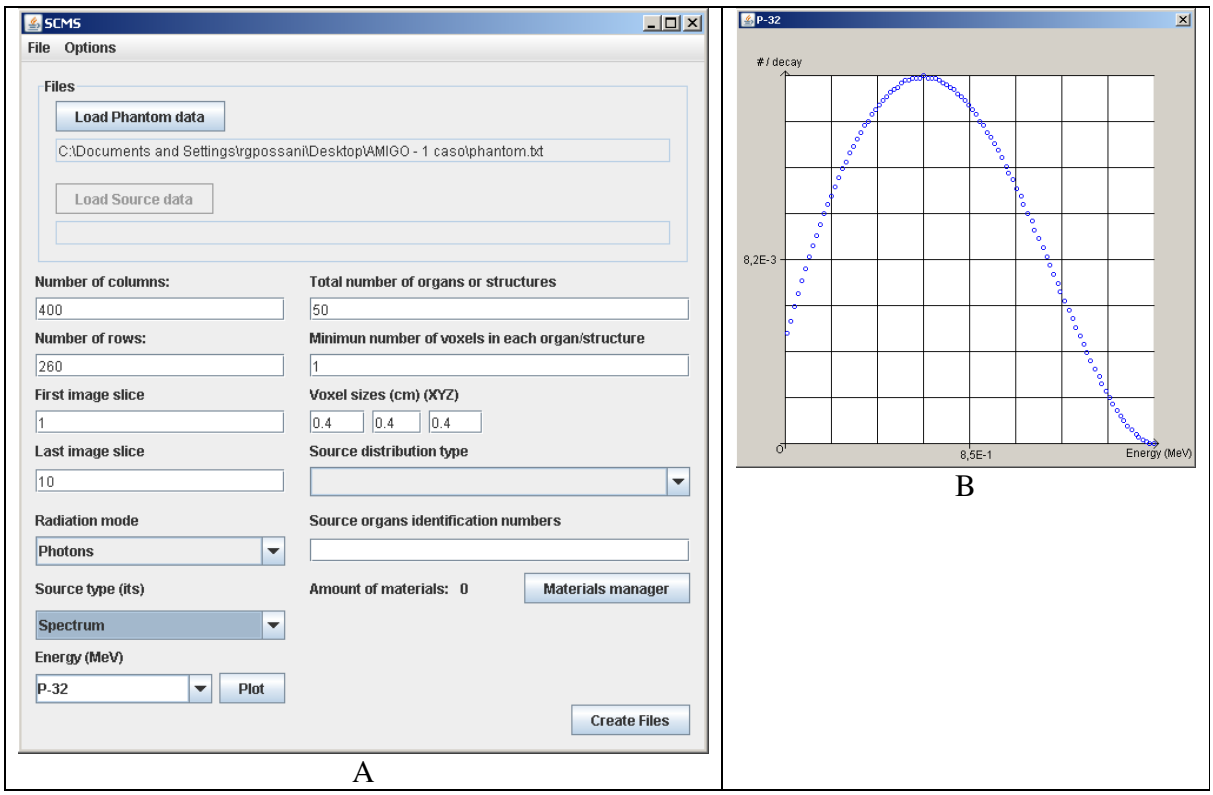

Figure 3 – Main screen where the user can choose a spectrum (A) and open a spectrum plot window (B).

The item "*Source organs identification numbers*" stores the information of the tissue or organ where the source will be localized. "*Voxel sizes*" stores the dimension of each voxel in the simulation. In the "*Source distribution type*" combo box the user can choose between homogeneous and heterogeneous source distribution. If the source is heterogeneous the button "*Load Source data*" will be active and the user will be able to choose the source data in the hard drive.
The original version allowed only three predefined materials: bone, lung and soft tissue. In this new version it is possible to introduce up to 60 materials. The limit is quite large, since only 25 different materials were used in actual tests with phantoms. In addition, there is a specific screen for the entry of new materials and configuration, as shown in Figure 4. This screen is activated when the user presses the "*Material manager*" button.

The materials manager window shows all the materials of the simulation. Those materials can be modified or deleted. Phantoms for radiation protection dosimetry are segmented into organs, so there is a text field in the materials manager window that links the number of the organ and the number of the material.

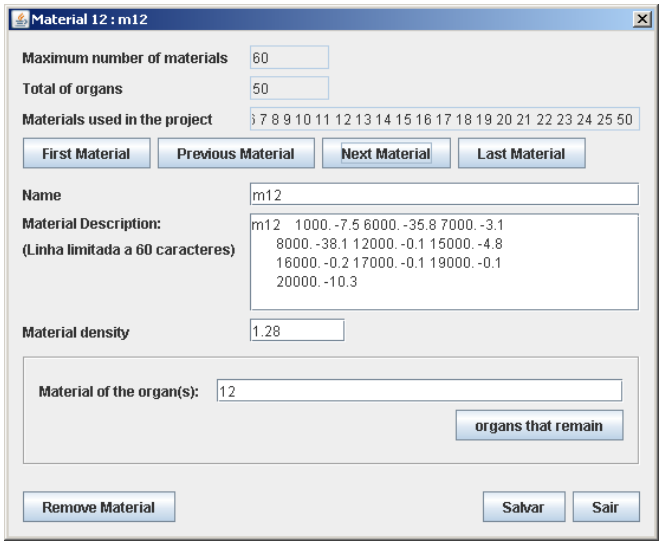

Figure 4 – Material screen manager

Another improvement included in the software is the selection of the region of interest screen where the user will be able to define the region(s) where the absorbed dose values will be calculated. Figure 5 shows an example of CT slice and a selected region (square) where the dose will be calculated. Each slice has its own region of interest (ROI) for dose calculation; also the user can select different regions in different slices.

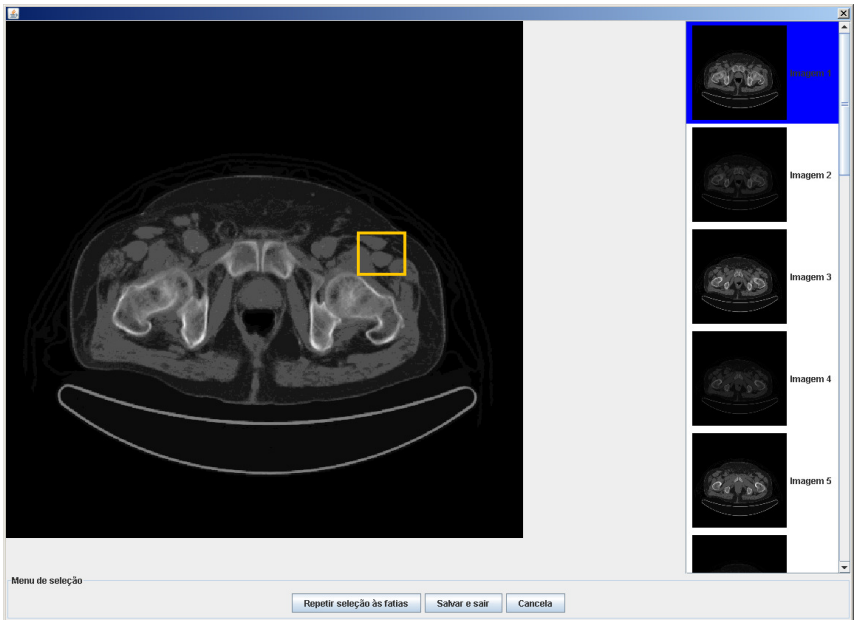

Figure 5 - Screen for the selection of the region of interest ROI where the absorbed dose values will be estimated

When the user presses the "*Create Files*" button, it starts a check for each component to verify if their values are entered correctly, almost of all them are integer values. The input file (the phantom) is also checked to verify its authenticity as input file, the same is done with the source file, if it exists.

3. CONCLUSIONS

The coupling of medical images and Monte Carlo radiation transport codes are needed to take advantage of all the anatomical and functional information at disposal for an accurate dose distribution estimate. However, for the realization of this procedure an interface software should be present to perform the intermediation between images information and the Monte Carlo codes. The software presented here demonstrates the feasibility to coupled image data to the Monte Carlo code MCNP through the development of a new version of the SCMS software. Several tests have been done successfully using a diversity of examples of anatomic and functional virtual images. This new version was written in Java language; however, as an interpreted language the performance dropped slightly when compared with the software in FORTRAN 77, however the construction of the input file, even large files, takes at most one minute to be built which was considered satisfactory. The AMIGO software is part of the development of an integrated computational dosimetric system which is being developed at IPEN for applications in nuclear medicine and radiotherapy.

REFERENCES

1. Grudzinski, JJ, Yoriyaz H, DeLuca PM, Weichert JP, "Patient specific treatment planning for systemically administered radiopharmaceuticals using PET/CT and Monte Carlo simulation," *Appl. Radiat. Isot*, **68**, (2010).
2. Haas B. et al, "Automatic segmentation of thoracic and pelvic CT images for radiotherapy planning using implicit anatomic knowledge and organ-specific segmentation strategies," *Phys. Med. Biol.,* **53**, (2008).
3. Bazalova M. et al, "Dual-energy CT-based material extraction for tissue segmentation in Monte Carlo dose calculations," *Phys. Med. Bio.,* **53**, pp.2439–2456 (2008).
4. Lee C, Lee C, Park S, and Lee J., "Development of the two Korean adult tomographic computational phantoms for organ dosimetry," *Med. Phys.*, **33**, (2006).
5. Sgouros G. et al, "Treatment Planning for Internal Radionuclide Therapy: Three-Dosimensional Dosimetry for Nouniformly Distributed Radionuclides," *J. Nucl. Med.*, **3l**, pp.1884-1891 (1990).
6. Jonsson L. et al, "The conjugate view method: evaluation of activity and absorbed dose calculations from Monte Cano simulated scintillation camera images using experimental data in au anthropomorphic phantom," *J. Nucl. Med.*, **39**, pp.234 (2000).
7. Yoriyaz H, Stabin M., "Use of MCNP 4B to calculate dose distributions in a voxelized phantom," *J. Nucl. Med.*, **39,** pp.83 (1998).
8. Nelson WR, Hirayama H, Rogers DWO., "The EGS-4 code system," Stanford Linear Accelerator Center, Report 265 (1985).
9. "Geant4: A toolkit for the simulation of the passage of particles through matter," http://geant4.cern.ch/ (2010).
10. Salvat F, Fernandez-Varea J-M, Acosta E and Sempau J, "PENELOPE-A Code System for Monte Carlo Simulation of Electron and Photon Transport," *OECD Publications*, Paris, (2001).
11. Briesmeister J.F., "MCNP: A general Monte Carlo N-Particle transport code, version 4C," Los Alamos National Laboratory Report. LA-13709-M, (2001).
12. Yoriyaz H., Santos A., Stabin M., "Absorbed fractions in a voxel-based phantom calculated with the MCNP-4B code," *Med. Phys.,* **27**, pp.1555–1562 (2000).
13. "The ImageJ User Guide – Verson 1.43," http://rsbweb.nih.gov/ij/docs/user-guide.pdf (2010).

14. Massicano. F, “Quantificação de imagens tomográficas para cálculo de dose em diagnose e terapia em medicina nuclear,” IPEN, 2010. Thesis (Master) – Instituto de pesquisas energéticas e nucleares, São Paulo, (2010).