*2013 International Nuclear Atlantic Conference - INAC 2013*
*Recife, PE, Brazil, November 24-29, 2013*
*ASSOCIAÇÃO BRASILEIRA DE ENERGIA NUCLEAR - ABEN*
***ISBN:*** **978-85-99141-05-2**

# A brachytherapy model-based dose calculation algorithm - AMIGOBrachy

**Gabriel P. Fonseca[1,2], Paula C. G. Antunes[1], Brigitte Reniers[2], Hélio Yoriyaz[1], Frank Verhaegen[2]**

[1]Instituto de Pesquisas Energéticas e Nucleares (IPEN / CNEN - SP)
Av. Professor Lineu Prestes 2242
05508-000 São Paulo, SP
gabriel.fonseca@usp.br

[2]Department of Radiation Oncology (MAASTRO)
Maastricht University Medical Center
Maastricht 6201 BN, the Netherlands

## ABSTRACT

Brachytherapy treatments have been performed based on TG-43U1 water dose formalism which neglects human tissues density and composition, body interfaces and applicator effects. As these effects could be relevant for brachytherapy energy range, modern treatment planning systems (TPS) are now available that are based on model-based dose calculation algorithms (MBDCA) enabling heterogeneity corrections, which are needed to replace the TG-43U1 water dose formalism for a more accurate approach. The recently published AAPM TG-186 report is the first step towards to a TPS taking into account heterogeneities, applicators and human body complexities. This report presents the current status, recommendations for clinical implementation and specifies research areas where considerable efforts are necessary to move forward with MBDCA. Monte Carlo (MC) codes are an important part of the current algorithms due their flexibility and accuracy, although, almost all MC codes present no interface to process the large amount of data necessary to perform clinical cases simulations, which may include hundreds of dwell positions, inter-seed attenuation, image processing and others time consuming issues that can make MC simulation unfeasible without a pre-processing interface. This work presents the AMIGOBrachy interface tool (Algorithm for Medical Image-based Generating Object - Brachytherapy module) which provides all the pre-processing task needed for the simulation. This software can import and edit treatments plans from BrachyVision™ (Varian Medical Systems, Inc., Palo Alto, CA) and ONCENTRA™ (Elekta AB, Stockholm, Sweden), and also create a new plan through contouring resources, needle recognition, HU segmentation, combining voxels phantoms with analytical geometries to define applicators and other resources used to create MCNP5 input and analyze the results. This work presents some results used to validate the software and to evaluate the heterogeneities impact in a clinical case performed using an HDR 192Ir source.

## 1. INTRODUCTION

Brachytherapy treatments have been performed based on TG-43U1[1,2] water dose formalism which neglects human tissues density and composition, body interfaces and applicator

effects. As these effects could be relevant for brachytherapy energy range, modern TPS are now available that are based on MBDCA enabling heterogeneity corrections, which are needed to replace the TG-43U1 water dose formalism for a more accurate approach. The recently published AAPM TG-186[3] report is the first step towards to a TPS taking heterogeneities, applicators and human body complexities into account. This report presents the current status, recommendations for clinical implementation and specifies research areas where considerable efforts are necessary to move forward with MBDCA. This work presents a software called AMIGOBrachy, which can import and edit treatments plans from BrachyVision™ and ONCENTRA™, and also it has the capability to create a new plan through contouring resources, needle recognition, HU segmentation, combining voxels phantoms with analytical geometries to define applicators and other resources used to create the MCNP5 Monte Carlo code input and analyze the results. The software validation has been done by comparing the results obtained with AMIGOBrachy/MCNP5 against the results obtained with a grid based Boltzmann solver, ACUROS™ (Transpire, Inc., Gig Harbor, WA), which can handle heterogeneities, for a cubic phantom and for a clinical case performed using an HDR 192Ir source.

## 2. MATERIAL AND METHODS

### 2.1. Score grid resolution and material definition

Clinical cases can be simulated with AMIGBrachy/MCNP5 employing a virtual grid to score the dose distribution using a user-defined resolution. The effect of the score grid resolution was analyzed using a water phantom surrounded by air (Fig. 1), composed by (100x100x100) voxels with 1 mm resolution positioned concentrically in the middle of the phantom. This phantom was created using BrachyVision™, which was also used to create a dose distribution for a HDR 192Ir source, GammaMed Plus[4], using score grid resolutions of 0.50 mm, 1.00 mm, 2.50 mm and 5 mm. The dwell positions are defined over a line connecting the central point of two opposite faces with an inter-dwell distance of 0.5 mm and using a geometrical optimization algorithm to create an approximately uniform dose distribution in a line parallel to the longitudinal source axis.

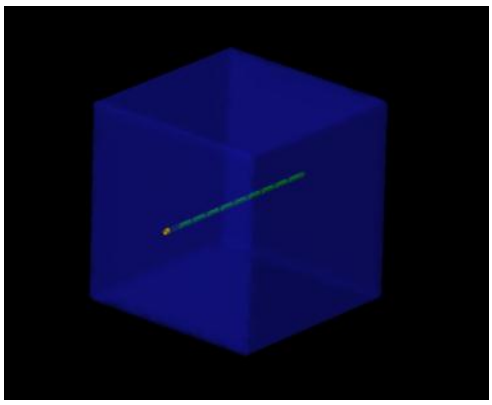

**Figure 1: water phantom used for AMIGOBrachy/MCNP5 validation.**

In order to evaluate the phantom composition effects, simulations were performed replacing the phantom material for air, lung, adipose tissue, muscle, cartilage and bone, which include all the materials defined in the ACUROS™ library and they were defined according to the ICRP75[5]. All the simulations were performed with 2 billion particles resulting in an uncertainty (1σ) lower than 1% for all voxels.

### 2.2. Clinical case

A gynecological treatment (Fig. 2) was created for a GammaMed-Plus HDR 192Ir source using a hollow cylinder applicator of 35 mm external diameter and a polysulfone wall of 4 mm with one needle in the center of the applicator and three needles distributed near the lower surface of the applicator totaling 100 dwell positions and a total dwell time of 556 s. All treatment data were imported by AMIGOBrachy and the simulations were performed for two situations: a) infinite water medium, which was created by adding at least 20 cm of water at each side of the body;[6] b) heterogeneous medium composed of five materials, air ($\rho$ = 0.0012041 g/cm$^3$), water ($\rho$ = 1.0 g/cm$^3$), adipose tissue ($\rho$ = 0.92 g/cm$^3$), muscle ($\rho$ = 1.06 g/cm$^3$) and bone ($\rho$ = 1.85 g/cm$^3$) defined using Hounsfield units (HU). Simulation uncertainty (1σ) was lower than 1% inside the 50% isodose region.

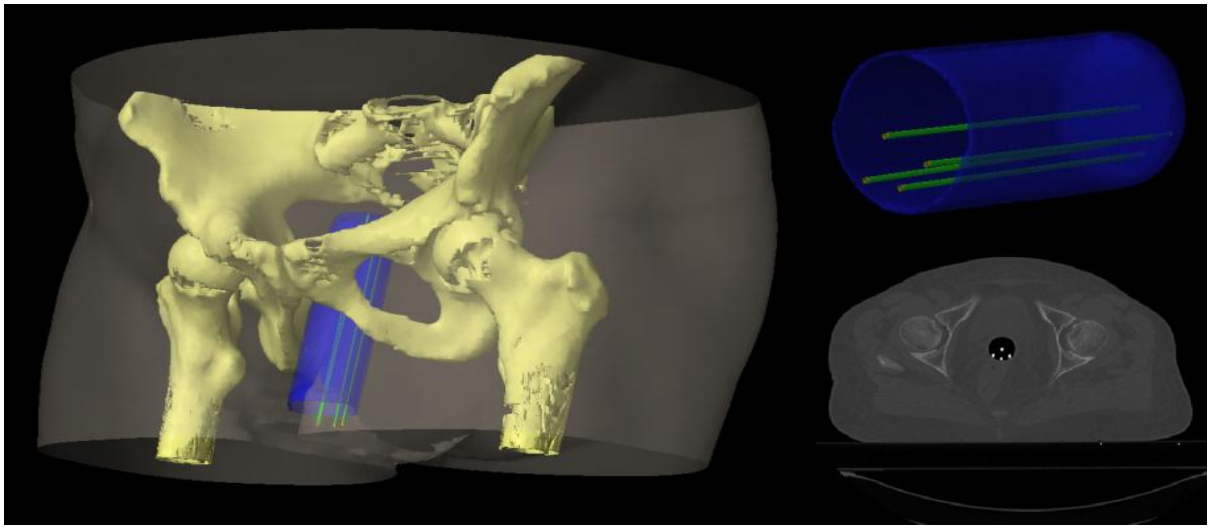

**Figure 2: Gynecological case representation showing a 3D reconstruction, the applicator and a tomographic slice.**

## 3. Results and Discussions

### 3.1. Software validation

Figure 3.a shows the mean ratio per phantom slice between MCNP5 and ACUROS™, between ACUROS™ and TG-43U1 and also between MCNP5 and TG43-U1 for a score grid

resolution of 1 mm. The difference between ACUROS$^{TM}$ and MCNP5 is lower than 2% for more than 98% of the voxels showing a small offset since the mean ratio is always lower than 1. This is probably related to the parameters adopted to convert MCNP5 dose units (MeV.g$^{-1}$.particle$^{-1}$) to absolute dose (Gy). Both MCNP5 and ACUROS$^{TM}$ showed differences up to 20% when compared against TG-43U1, as expected since the TG-43U1 formalism does not take into account the air surrounding the phantom. The same agreement between ACUROS$^{TM}$ and MCNP5 was observed for all score grid resolutions as can be observed by the ratio between the results obtained with 1 mm resolution and the results obtained with the remaining evaluated resolutions (Fig. 3.b).

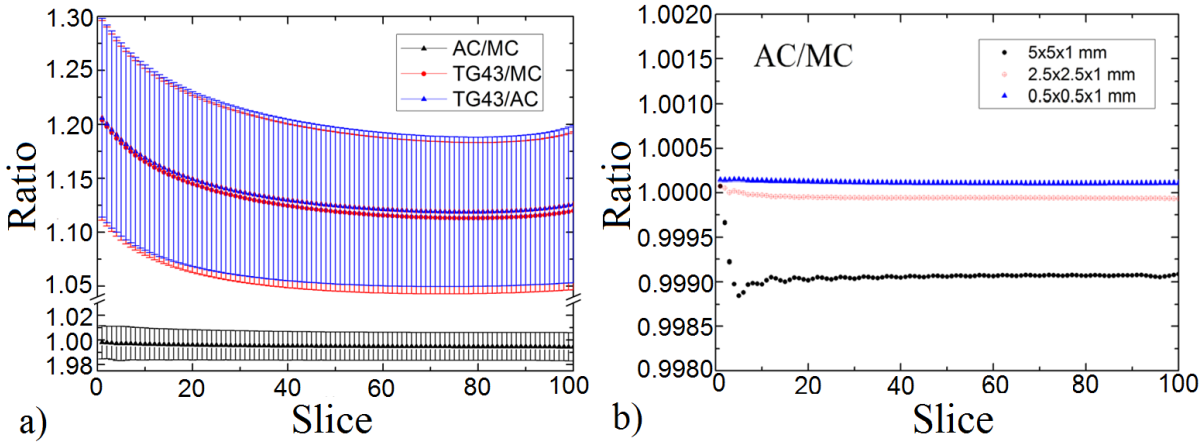


**Figure 3: a) Mean ratio per phantom slice between the adopted methodologies with the error bars corresponding to the standard deviation (1σ). b) Ratio between the results obtained with 1 mm score grid resolution and 0.5 mm, 2.5 mm and 5 mm.**

The results obtained using different materials were divided by the water phantom results (Fig. 4.a) showing no significant differences (<0.05%), although an apparent dose related behavior can be observed (Fig 4.b) since the ratio increases with the dose for materials with density lower than the water density and decreases for materials with higher density.

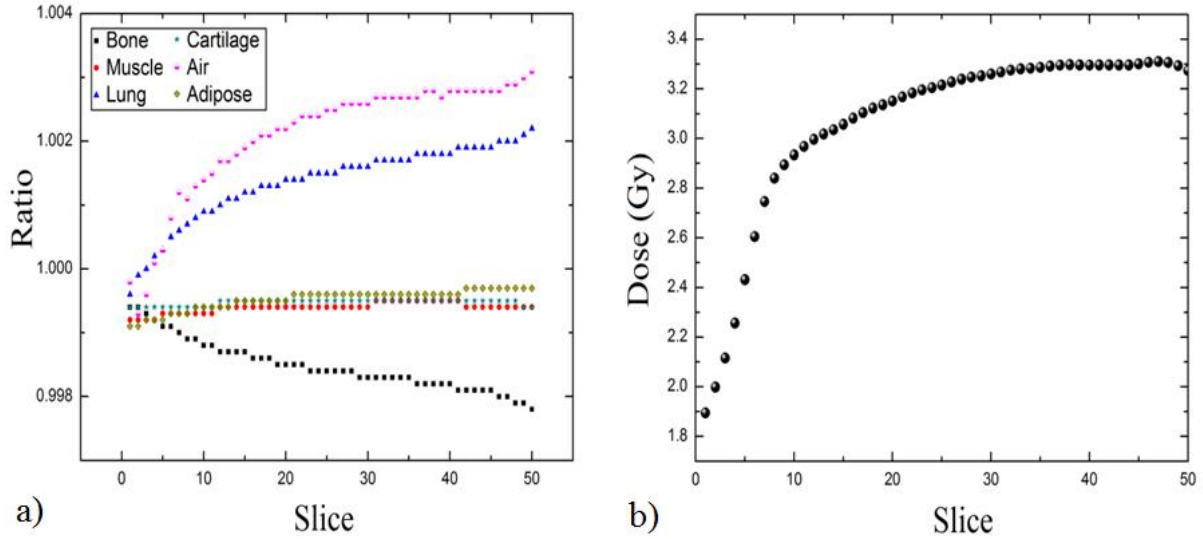


**Figure 4: a) Mean ratio per slice between the indicated materials and water. b) Mean dose per slice.**

### 3.2. Clinical case

ACUROS™ and AMIGOBrachy/MCNP5 dose values compared against TG-43U1 presented differences up to 10.0% with differences inside the 100% isodose region around 2.5% as illustrated by figure 5.a. These differences are mainly due to the air gap inside the applicator since the mean difference inside the 100% isodose region when using a hypothetical homogeneous water applicator is about 1%. ACUROS™ and AMIGOBrachy/MCNP5 presented good agreement with differences lower than 2% and 5% for 92% and 98% of the voxels of the scoring volume (Fig. 5.b), respectively. The mean difference was also calculated separately for each tissue (bone, muscle and adipose tissue) and is within 1.0±0.1%, which represents no significant difference due the tissue composition. However, some regions show differences of about 5%, especially near the applicator's tip which can be partially attributed to the applicator misplacement and also to the algorithm employed by ACUROS™ which solves the Boltzmann equation by discretizing its six variables.

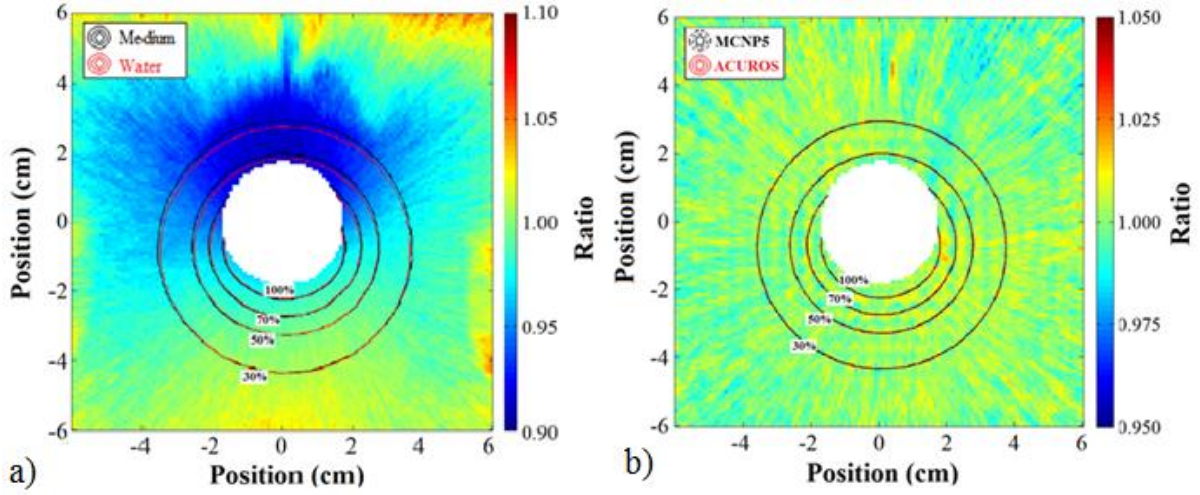


**Figure 5: a) Ratio between the results obtained using the TG-43U1 dose formalism (water) and AMIGOBrachy/MCNP5 (medium). b) Ratio between the results obtained with ACUROS™ and AMIGOBrachy/MCNP5.**

## 3. CONCLUSIONS

The effect of heterogeneities can be significant due to the applicator considered in this case and it seems to be a relevant aspect due to the several types of applicators commercially available. ACUROS™ and AMIGOBrachy/MCNP5 have shown similar results with no apparent dependence of the tissue composition, however, dose differences can be higher in some regions which need to be evaluated in more detail.

## ACKNOWLEDGMENTS

This work was supported by *Fundação de Amparo à Pesquisa do Estado de São Paulo* (FAPESP), grant numbers 2011/01913-4, 2011/23765-7 and 2011/22778-8.

## REFERENCES


1. R. Nath, L. L. Anderson, G. Luxton, K. A. Weaver, J. F. Williamson, and A. S. Meigooni, "AAPM Technical Report 51: Dosimetry of Interstitial Brachytherapy Sources: Recommendations of the AAPM Radiation Therapy Committee Task Group No. 43," *Med. Phys.* **Vol. 22**, pp. 209-234 (1995).
2. M. J. Rivard, B. M. Coursey, L. A. DeWerd, W. F. Hanson, M. S. Huq, G. S. Ibbott, M. G. Mitch, R. Nath, and J. F. Williamson, "Technical Report 84 - Update of AAPM Task Group No. 43 Report: A revised AAPM protocol for brachytherapy dose calculations," *Med. Phys.* **Vol. 31**, pp. 633-674 (2004).
3. L. Beaulieu, A. C. Tedgren, J. F. Carrier, S. D. Davis, F. Mourtada, M. J. Rivard, R. M. Thomson, F. Verhaegen, T. A. Wareing, J. F. Williamson "Report of the Task Group 186 on model-based dose calculation methods in brachytherapy beyond the TG-43 formalism: Current status and recommendations for clinical implementation," *Med. Phys*. **Vol**. **39**(10), pp. 6208–6236 (2012).
4. R. E. P. Taylor, D. W. O. Rogers, "EGSnrc Monte Carlo calculated dosimetry parameters for 192Ir and 169Yb brachytherapy sources," *Med. Phys*. **Vol. 35**(11), pp. 4933-4944 (2008).
5. International Commission on Radiological Protection, "Report on the Task Group on Reference Man," ICRP Publication No. 23, *Pergamon*, Oxford (1975).
6. J. Perez-Calatayud, D. Granero, F. Ballester, "Phantom size in brachytherapy source dosimetric studies," *Med. Phys*. **Vol. 31**(7), pp. 2075-2081 (2004).