Monte Carlo simulation for the treatment of male breast cancer

N.A. Guimarães¹, A. X. da Silva², J. P.R. Junior², J. M. Lopes², W. J.L. Garção¹
¹ Teacher, Instituto Federal do Rio de Janeiro - IFRJ Campus Volta Redonda, Rua Antônio Barreiros, 212, Volta Redonda, Rio de Janeiro, BRA
² Universidade Federal do Rio de Janeiro - COPPE/ Programa de Engenharia Nuclear Av. Horácio Macedo, 2030, Bloco G, Cidade Universitária, Rio de Janeiro, BRA
E-mail: nilmara.guimaraes@ifrj.edu.br

Abstract. The rate of male breast cancer occurrences has been increasing over the last years and, in the absence of proper protocols, the treatment proposed for male breast cancer follows the one established for the female breast neoplasia. The objective of the present study is to simulate the treatment of male breast cancer through the Monte Carlo N-Particle (MCNP) code, using the voxelized Alderson Rando phantom, following the protocol used on female breast cancer and compare the simulated results with the experimental values obtained with thermoluminescence dosimeters (TLD). A treatment configuration using the Alderson Rando phantom with placement of TLDs was performed, which had reproducibility on the simulation. The results obtained in the simulation were up to 12% greater than the doses planned, and up to 15% lesser than the measurements with TLDs. The results suggest that the treatment of male breast cancer using the treatment protocol for female breast neoplasia must be reviewed, once higher dose values are observed in comparison to those obtained by the planning system.

1. Introduction
The second most deadly type of cancer in the world is breast cancer, which may also affect men [1], [2] but, due to its smaller occurrence, it is little studied. It represents about 1% of every breast cancer, being responsible for less than 0.1% of deaths in men [3], [4].

The cancer may be treated by several means: surgery, chemotherapy, radiotherapy or a combination of those. In the lack of proper protocols, the proposed treatment for male breast cancer follows the one established for female breast neoplasia, based on the surgical treatment, followed or not by radiotherapy, chemotherapy and, mainly, hormone therapy [5].

The objective of the present study is to assess whether the proposed treatment for female breast cancer is really able to be used in male breast, besides performing the validation of the Monte Carlo simulation in order to aid future treatments. The concern with the fact that the structure and volume of the male breast are different from the female's, resulting in radiotherapy treatments with dose distributions that should be differentiated motivated this study.

2. Radiotherapy by Teletherapy and Dose Distribution
Radiotherapy is a method of application of ionizing radiation in a way to overcome or stop the reproduction of tumor cells. The treatment consists basically in the application of a (previously calculated) dose of radiation over a tissue volume which comprises the tumor, for a certain period of
time. The relation between the damage and the benefits of the treatment must be considered to cause the least possible damage to normal cells surrounding the tumor.

In teletherapy, the radiation emitted by a device towards the body region to be treated, with the patient lying down, is applied in sessions. The equipment used comprises cobalt ($^{60}$Co) therapy units and linear accelerators.

### 2.1. Dose distribution

Dose distribution refers to the dose values in points surrounding and within the irradiated volume. In radiotherapy, a detailed analysis of dose distribution allows to take conclusions on the preservation of healthy tissues bordering the target volume. Thus, it is important to make the dose prescribed by the doctor concentrate on the target volume, in such a way that the healthy tissue will not receive a dose above the tolerance limits proposed in the literature [6].

#### 2.1.1. Ionizing radiation dosimeters

Ionizing radiation dosimeters are devices in which a physical phenomenon happens when exposed to that type of radiation. If there is a well-established relation between the intensity of the physical phenomenon and the amount of radiation energy absorbed per mass of the device, it can be used to dose the energy, as long as it is properly calibrated. Dosimetric systems are the set of dosimeters and equipment capable of quantifying the physical phenomenon induced by ionizing radiation. The result of a measurement is the value of a dosimetric magnitude expressed by a numerical value associated to its unit. There are several types of radiation dosimeters, but not all of them satisfy the characteristics necessary for the intended use. Thus, it is necessary to choose the most appropriate one, considering the demands of the measurement situation. Some types of dosimeters available in the market are: ionizing chambers, radiographic films, radiochromic films, luminescence dosimeters (TLD) and semiconductors (diode) [7].

#### 2.1.2. Thermoluminescence dosimeter

The thermoluminescence dosimeter is a dose gauge resulting from the thermoluminescence phenomenon, which occurs when there is the emission of light after excitation of a material mean by thermal energy. The emission of light may occur by fluorescence, when it is spontaneous, and by phosphorescence, when it is necessary to apply energy in order to observe the light emission. TLDs may be found in several forms and compositions, as shown in Figure 1.

![Figure 1. Types of thermoluminescence dosimeters [8].](image)

Some of the main TLDs are: LiF:Mg,Ti; CaF$_2$:Dy; CaSO$_4$:Dy; CaF$_2$:Mn; LiF:Mg,P,Cu; and Li$_2$B$_2$O$_3$:Mn. The dosimeter-on-a-chip, composed by lithium fluoride, is generally the most used in dosimetry, for it is easy to be handled, besides presenting good repeatability and reproducibility conditions.
3. Materials and Methods
The thermoluminescence dosimeters were characterized and calibrated with irradiations in a known dose rate in the SIEMENS teletherapy equipment ONCOR Expression, installed at Clínicas Oncológicas Integradas (COI). The accelerator used in the characterization was the same used for irradiation, that is, a photon beam of 6.0 MV and, therefore, it was not necessary to determine the energy dependence factor [6].

The thermoluminescence dosimeters used were the TLD-100 chip type (LiF:Mg,Ti), with dimensions of 3.2 mm x 3.2 mm x 0.9 mm, manufactured by Thermo Fischer Scientific Inc., commercially, Harshaw TLD.

3.1. Anthropomorphic Simulators or Phantoms
The anthropomorphic simulators are used to reproduce the characteristics of absorption and scattering of the human body, or parts of it, when subject to a radiation field. The main simulators are: mathematical, physical and voxel phantoms [9]. The physical phantoms are structures, normally manufactured in acrylic, filled with water to simulate the human body and they are used for dosimetry and imaging tests. The most popular is the Alderson Rando anthropomorphic simulator (Figure 2), which consists of a skeleton surrounded by rubbers which are equivalent to the soft and pulmonary tissues, besides following the standards of ICRU-44 [10]. This phantom is 175 cm high and weighs 73.5 kg and is horizontally sectioned in slices 2.5 cm thick. Each slice contains holes that are connected to pins of equivalent tissues, which may be: soft, pulmonary or bone tissues. Such pins may be replaced by powdered TLD pins or by pins with spaces for the insertion of the TLDs chip-type. The TLDs were distributed on the left side of the Alderson Rando phantom, between slices 13 and 20, a region of interest of the torso. Figure 3 shows a matrix of 5 mm diameter holes, 3 cm apart from each other, where the TLDs are placed.

3.2. Planning System of Male Breast Cancer
The planning system used to simulate the treatment of male breast cancer, following protocols of female breast cancer, was Prowess Version 5.11.

Prowess has an algorithm which can manage information on dose, monitor units, acquisition and image merging, besides transporting the planning directly to the linear accelerator where the treatment shall take place.

The planning was performed with the imaging obtained in the Alderson Rando phantom by the Siemens Emotion Duo scanner. The treatment consisted on the irradiation of two oblique fields with...
prescription of 200 cGy in 100% of the isodose line. The first field had the following irradiation configuration: 303º angulation, source to surface distance (SSD) of 88.1 cm, 10 cm x 12 cm field, 30º filter, which resulted in a monitor unit with a value of 241 MUs. On the second stage, the gantry was positioned at 123º, with SSD of 88.5 cm, a 10 cm x 11 cm field and monitor unit of 241.8 MUs, remaining with the same filter.

For comparative purposes of the planned results with the results obtained by the TLDs, it was necessary to insert in the planning system some points of interest, that is, specific locations for the TLD, as presented in Figure 4. Thus, it was possible to generate a report in which the planned doses were determined, in the locations of the points of interest.

![Figure 4. Prowess graphic display with the inserted points of interest [6].](image)

3.3. Monte Carlo Simulation in MCNP
For validation purposes, the results obtained by the planning system and by the use of TLDs were compared to the results simulated in MCNP.

In MatLab, the tomographic images of the Alderson Rando phantom were converted in a *.txt input file, which MCNP was able to read and simulate. The phase space file was used for the reuse of the photon spectrum, reducing the computational time.

4. Results and Conclusions
4.1. Results Obtained with the Alderson Rando Voxel Phantom
The male voxel phantom used in the present study was implemented in the MCNP [12] code for the modeling and simulation of male breast cancer treatment, following the same experimental configuration used for the measurements with thermoluminescence dosimeters.

Figure 5 presents the image obtained by the software Moritz, of the male voxel phantom simulated in MCNP. Figure 5 represents the experimental scenario of slice 16 of the Alderson Rando phantom, where the tumor location was simulated, which is represented along with the wedge filter of the linear accelerator.
Figure 5. Visualization of the simulation of breast cancer treatment on MCNP obtained by the software Moritz [13].

Table 1. Comparison among the results obtained through the simulation of male breast cancer treatment and the results presented by the planning system and by the TLD dosimetry.

| TLD | Planned Dose (cGy) | Simulated Dose (cGy) | Reference Dose of TLD (cGy) | Difference between planned and simulated doses (cGy) | Difference between planned and simulated doses (%) | Difference between reference and simulated doses (cGy) | Difference between reference and simulated doses (%) |
|-----|-------------------|----------------------|-----------------------------|----------------------------------------------------|-------------------------------------------------|-----------------------------------------------------|-----------------------------------------------------|
| e02 | 187.78            | 177.18               | 200.34                      | -10.60                                             | -6%                                             | -23.16                                              | -13%                                                |
| b01 | 181.31            | 194.69               | 199.77                      | 13.38                                              | 7%                                              | -5.08                                               | -3%                                                 |
| n03 | 189.25            | 209.37               | 195.76                      | 20.12                                              | 10%                                             | 13.61                                               | 6%                                                  |
| c04 | 197.45            | 225.15               | 202.26                      | 27.70                                              | 12%                                             | 22.89                                               | 10%                                                 |
| d20 | 202.47            | 212.08               | 208.41                      | 9.61                                               | 5%                                              | 3.67                                                | 2%                                                  |
| l01 | 199.45            | 199.45               | 198.92                      | 0.00                                               | 0%                                              | 0.53                                                | 0%                                                  |
| h09 | 205.29            | 204.46               | 208.81                      | -0.83                                              | 0%                                              | -4.35                                               | -2%                                                 |
| e03 | 199.73            | 212.78               | 205.02                      | 13.05                                              | 6%                                              | 7.76                                                | 4%                                                  |
| i11 | 207.10            | 210.44               | 221.54                      | 3.34                                               | 2%                                              | -11.10                                              | -5%                                                 |
| b15 | 190.35            | 175.67               | 202.35                      | -14.68                                             | -8%                                             | -26.68                                              | -15%                                                |
| n20 | 203.82            | 197.37               | 208.63                      | -6.45                                              | -3%                                             | -11.26                                              | -6%                                                 |

Table 1 presents a maximum difference between planned and simulated doses of 12%; in relation to the reference (TLD) the maximum difference was of -15%. All simulated doses presented a combined uncertainty of ±5%, given that such results were determined by two simulations, the first for a 123°
angle and the second for a 303° angle. In the simulations, only the places where the TLDs were positioned with results above 50 cGy were considered as points of interest.

5. Conclusion
The Monte Carlo simulation presented results up to 12% greater than the planned doses, and up to 15% lesser than the measurements using TLDs. Such a result is satisfactory and validates the use of the Alderson Rando phantom simulation by MCNP for further studies with male breast and other organs, aiding future implementations of a new specific treatment for the male breast.

The results suggest that the treatment of male breast cancer using the treatment protocol for female breast neoplasia must be reviewed, given the observation of greater dose values than those obtained by the planning system.

References
[1] PAIVA S. M M. Avaliação da qualidade de vida de pacientes oncológicos em tratamento quimioterápico adjuvante. Ribeirão Preto, 2006. 111 p. Dissertation.
[2] Hill T. D.; Khamis H. J.; Tyczynski J. E. and Berkel H. J Comparison of male and female breast cancer incidence trends, tumor characteristics, and survival. Ann Epidemiol. 2005; 15(10): 773-80.
[3] Giordano S. H. A review of the diagnosis and management of male breast cancer. Oncologist. 2005; 7(10): 471-9.
[4] Carmalt, H. L.; Mann, L. J.; Kennedy, C. W.; Fletcher, J. M. and Gillet, D. J. Carcinoma of the male breast: a review and recommendations for management. Aust and N Z J Surg. 1998; 68(10): 712-5.
[5] Leme L. H. S. and Souza G. A. Câncer de mama em homens: Aspectos epidemiológicos, clínicos e terapêuticos. Rev. Ciênc. Méd., Campinas, 15(5): 391-398, set./out., 2006.
[6] Guimarães N. A. and Crispim, V. R. (2014) Male Breast Cancer-Dosimetry Evaluation in Teletherapy. International Journal of Medical Physics, Clinical Engineering and Radiation Oncology, 3.
[7] Izewska J. and Rajan G., "Radiation Dosimeters" In: Podgorsak, E.B. (ed), Radiation Oncology Physics: A Handbook for Teachers and Students, chapter 3, Vienna, Austria, International Atomic Energy Agency-IAEA, 2005.
[8] Da Rosa L.A.R., Dosimetria Termoluminescente Aplicada à Física Médica, Instituto de Radioproteção e Dosimetria - CNEN, Rio de Janeiro, 2001.
[9] Boia L.S..Metodología Computacional para Geração de Modelos Antropomórficos de Voxels para Simulação por Monte.Carlo de Tratamentos Radioterápicos/ Leonardo da Silva Boia. – Rio de Janeiro: UFRJ/COPPE, 2010. (Thesis)
[10] ICRU, International Commission on Radiation Units and Measurements. Tissue substitutes in radiation dosimetry and measurement, Report 44, Bethesda, MD, USA (1989).
[11] Guimarães N. A. and CRISPIM V. R. Dosimetric Evaluation in Teletherapy to Treatment of Male Breast. INAC – 2013, Pernambuco. (Article)
[12] Pelowitz D. B. MCNPX User’s Manual Version 2.6.0. Los Alamos, NM: Los Alamos National Laboratory; 2008.
[13] Guimarães, N. A. Avaliação Dosimétrica em Teleterapia para o Tratamento de Câncer de Mama Masculina, 2015 (Thesis) – Rio de Janeiro: UFRJ/COPPE, 2015