MONTE CARLO DERIVATION OF FILTERED TUNGSTEN ANODE X-RAY SPECTRA FOR DOSE COMPUTATION IN DIGITAL MAMMOGRAPHY

Lucas Paixão[1], Bruno Beraldo Oliveira[1], Carolina Viloria[2], Marcio Alves de Oliveira[3], Maria Helena Araújo Teixeira[4], Maria do Socorro Nogueira[1/2/5]

[1] Post-graduation in Science and Technology of Radiations, Minerals and Materials - CDTN
Pres. Antônio Carlos 6.627, 31270-901, Belo Horizonte, Brazil
E-mail: lpr@cdtn.br

[2] Post-graduation in Nuclear Sciences and Techniques – DEN/UFMG
Pres. Antônio Carlos 6.627, 31270-901, Belo Horizonte, Brazil.
E-mail: carolinaviloriab@gmail.com

[3] Department of Anatomy and Imaging – UFMG
Prof. Alfredo Balena 190, 30130-100, Belo Horizonte, Brazil.
E-mail: m_alvesoliveira@yahoo.com.br

[4] Dr Maria Helena Araújo Teixeira Clinic
Guajajaras 40, 30180-100, Belo Horizonte, Brazil.
E-mail: clinicamariahelena@oi.com.br

[5] Nuclear Technology Development Center – CDTN.
Pres. Antônio Carlos 6.627, 31270-901, Belo Horizonte, Brazil
E-mail: mnogue@cdtn.br

Abstract

It is widely accepted that the mean glandular dose (D_G) for the glandular tissue is the more useful magnitude for characterizing the breast cancer risk. The procedure to estimate the D_G, for being difficult to measure it directly in the breast, it is to make the use of conversion factors that relate incident air kerma (K_i) at this dose. Generally, the conversion factors vary with the x-ray spectrum half-value layer (HVL) and the breast composition and thickness. Several authors through computer simulations have calculated such factors by the Monte Carlo (MC) method. Many spectral models for D_G computer simulations purposes are available in the diagnostic range. One of the models available generates unfiltered spectra. In this work, the Monte Carlo EGSnrc code package with the C++ class library (egspp) was employed to derive filtered tungsten x-ray spectra used in digital mammography systems. Filtered spectra for rhodium and aluminium filters were obtained for tube potentials between 26 and 32 kV. The half-value layer of simulated filtered spectra were compared with those obtained experimentally with a solid state detector Unfors model 8202031-H Xi R/F & MAM Detector Platinum and 8201023-C Xi Base unit Platinum Plus w mAs in a Hologic Selenia Dimensions system using a Direct Radiography mode. Calculated HVL values showed good agreement compared to those obtained experimentally. These results show that the filtered tungsten anode x-ray spectra and the EGSnrc MC code can be used for D_G determination in mammography.

Keywords: Mammography; x-ray spectra; HVL; Monte Carlo; EGSnrc.

1.- INTRODUCTION

The radiographic breast imaging (mammography) is indicated for the detection, diagnosis and clinical management of cancer. Moreover, mammography is the most widely used imaging modality for breast cancer screening [Chevalier *et al.*, 2004]. Breast dosimetry is an important part of the quality assurance program, provides means for defining and verifying the standards of good practice, and also in the optimization of radiological protection [ICRU 2009; Oliveira *et al.*, 2011].

It is widely accepted that the mean glandular dose (D_G) for the breast glandular tissue is the more useful magnitude for characterizing the breast cancer risk [Dance *et al.*, 1999; ICRU 2009]. The procedure to estimate the D_G values, because of the difficulty to measure it directly in the breast, it is to make the use of conversion factors that relate incident air kerma (K_i) at this dose value. Generally, the conversion factors vary with the x-ray spectrum half-value layer (HVL) and the breast composition and thickness. Several authors through computer simulations have calculated such factors by the Monte Carlo (MC) method [Wu *et al.*, 1994; Dance *et al.*, 2000; Boone 2002; Dance *et al.*, 2009]. The MC simulations of the radiation transport are recognized as an important tool in dose calculations in various fields related to Medical Physics [Rogers 2006]. MC codes can be used in radiology to simulate and characterize photon beams produced as well as the radiation dose absorbed by the patient's organs.

Many x-ray spectral models for D_G computer simulations purposes are available in the diagnostic range [Ay *et al.*, 2005; Cunha *et al.*, 2013]. One of the models available [Boone *et al.*, 1997] generates polyenergetic x-ray spectra for molybdenum, rhodium, and tungsten anodes. The spectra that are produced by this model do not include any added filtration except by the 0.5 mm beryllium window of the x-ray tube and any self-filtration by the anode itself.

The objective of this work is to use MC simulations to generate filtered x-ray spectra used in digital mammography systems from unfiltered spectra. Therefore, the Monte Carlo EGSnrc code package with the C++ class library (egspp) was employed to derive filtered tungsten x-ray spectra. Filtered spectra for rhodium filter were obtained for tube potentials between 26 and 32 kV. The half-value layers of simulated filtered spectra were compared with those obtained experimentally with a solid state detector in a digital mammography system to validate the results. The results were also compared with the values recommended by the Technical Reports Series no. 457 of the International Atomic Energy Agency [IAEA 2007].

2.- MATERIALS AND METHODS

2.1.- Geometric model

The geometric model adopted in the simulations was based in the Hologic Selenia Dimensions system (Hologic, Inc., Bedford, MA) of a mammography clinic located in Belo Horizonte city, Brazil. This mammography system has a focal spot of 0.3 mm, a 0.63 mm beryllium window and 0.050 mm rhodium filter. The distance between the breast support and the focal spot is 67.5 cm.

In the simulations, a 0.13 mm Be window was modelled at 5 cm and the Rh filter was modelled at 7 cm. Since the HVL measurements are performed in the presence of the compression plate, it was modelled a 3 mm polymethylmethacrylate (PMMA) compression plate at 10 cm [IAEA 2007]. The aluminium attenuators were positioned at 20 cm and its thickness ranged from 0.4 and 0.8 mm. All distances are relative to focal spot. An air sphere of 6 cm^3 was centred laterally at 66.37 cm from the tube focal spot and 6 cm from the chest wall edge as a detector. The breast support and x-ray scatter reduction grid were not modelled.

2.2.- Monte Carlo simulations

The Monte Carlo EGSnrc code package [Kawrakow *et al.*, 2010] with the C++ class library (egspp) was employed [Kawrakow *et al.*, 2009]. The tungsten x-ray spectra for tube potentials between 26 and 32 kV from Boone et al., [1997] were simulated. The radiation beam was collimated into a rectangular shape of 1.13 cm side. Thus the collimated beam impinges directly on the modelled detector.

Electrons and photons are followed down to a threshold energy of 10 keV. Bound Compton scattering, Electron Impact Ionization, Rayleigh scattering and atomic relaxations are turned on. NIST and XCOM are the cross sections selected for bremsstrahlung cross sections and photon cross sections, respectively [Mainegra-Hing and Kawrakow 2006]. The number of histories simulated was 5×10^7 for all studied cases, which represents a statistical error of the order of 3% on the calculated HVL. The simulations were performed in a personal computer with an Intel® Xeon® Quad CPU of 3.30 GHz.

2.3.- HVL measurements

Irradiations were carried out using the W/Rh target/filter combination and a Selenia Dimensions model Hologic DBT system using a Direct Radiography mode. Measurements were performed using a calibrated set manufactured by Unfors, composed of the solid state detector, model 8202031-H Xi R/F & MAM *Detector Platinum* Series 181096, connected to the base unit model 8201023-C Xi *Base unit Platinum Plus* w mAs, Series 190046. The solid state detector sensitive volume was centred laterally at 65 cm from the tube focal spot and 6 cm from the chest wall edge. The x-ray tube voltage was varied from 27 to 31 kV at intervals of 1 kV. The HVL values using the solid state detector were obtained directly by averaging three measurements in mmAl. All irradiations were done with a tube loading of 50 mAs. It is worth noting that irradiations were performed with the compression plate in contact with the detector. This was necessary for future use of the HVL values in determination of D_G conversion factors from Dance [1990] and Dance et al., [2000].

3.- RESULTS

The W/Rh target/filter combination x-ray spectra HVL values obtained by the MC simulations and experimentally are shown in Table 1. The experimental values for 26 and 32 kV were estimated from a linear fit of the remaining values. The uncertainty of all results was estimated as 3% (1σ). The main sources of uncertainty in the experimental values are calibration (2%) and energy dependence (2%) of the detector. The values are also shown in Figure 1, along with values recommended by TRS-457 [IAEA 2007]. Linear fits of the data along with its equation and the R^2 coefficient are also shown in Figure 1.

Table 1.- HVL values for each voltage and W/Rh target/filter combination.

	HVL (mmAl)	
kV	Experimental	MC
26	0.511[a]	0.513
27	0.518	0.527
28	0.528	0.535
29	0.537	0.552
30	0.545	0.565
31	0.552	0.574
32	0.562[a]	0.585

a estimated values

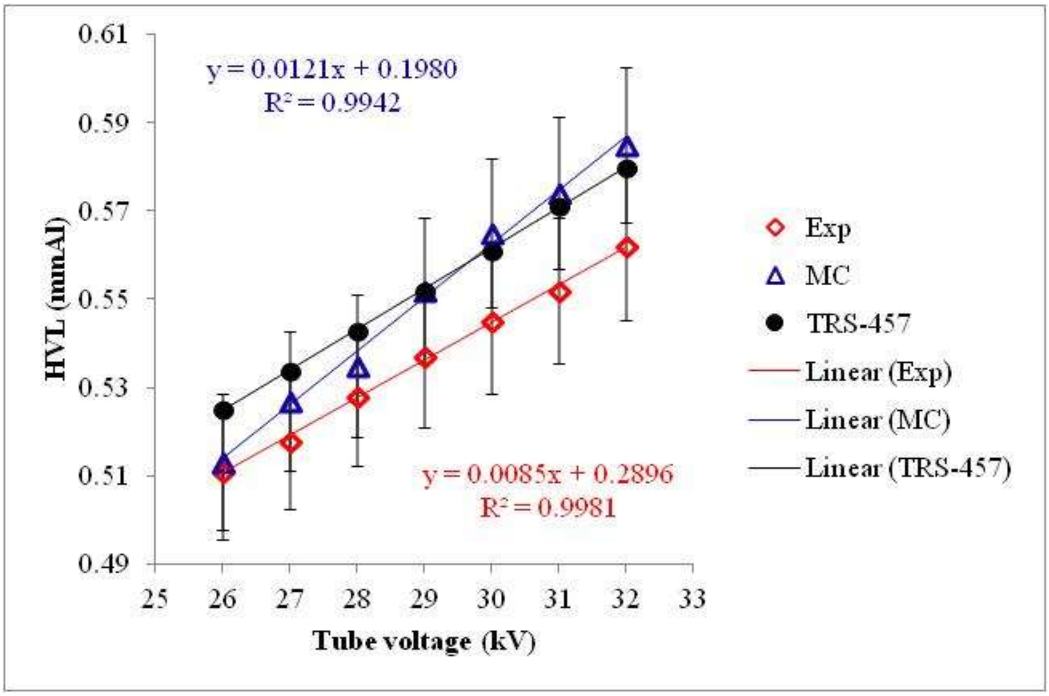

Figure 1.- HVL values for each voltage and W/Rh target/filter combination.

4.- DISCUSSION

Calculated HVL values showed good agreement compared to those obtained experimentally. The largest relative difference between the MC calculated HVL values and experimental HVL values was 4%.

Taking into account the values recommended by TRS-457, the relative difference for MC calculated HVL values ranged between 0 and 2% and was 3% for all experimental values. These results show that the EGSnrc MC code generates the x-ray spectra with adequate filtration. For example, a MC obtained W/Rh target/filter combination x-ray spectra for 29 kV is shown in Figure 2.

The filtered tungsten anode x-ray spectra can be used for D_G studies in mammography. When using the filtered spectrum instead of the unfiltered spectrum in dose simulations, one can gain in computational time.

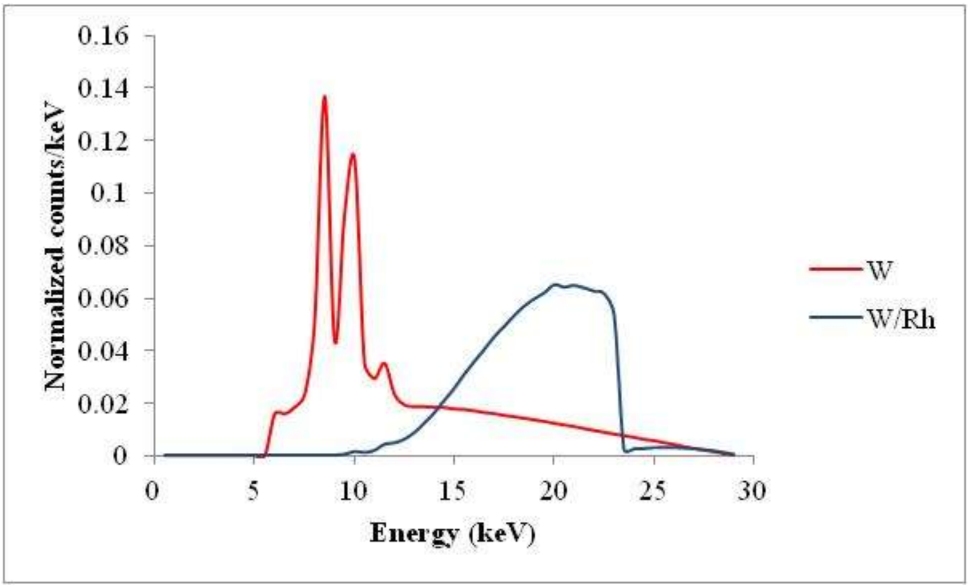

Figure 2.- Tungsten target x-ray spectra [Boone *et al.*, 1997] and MC obtained W/Rh target/filter combination x-ray spectra for 29 kV.

5.- CONCLUSIONS

In this work, the MC code EGSnrc was employed for simulation of filtered x-ray spectra used in digital mammography. The differences in the values of HVL were less than 4% for all tube voltages. These results showed that the code EGSnrc provides a filtration of the raw x-ray spectra in good agreement with those determined experimentally. The W/Rh target/filter combination x-ray spectra obtained in the simulations may be used in future MC simulations studies in digital mammography.

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