Spectra for little unusual anode/filter combinations, in the metrological and simulated cases

L B S Gatto¹, D Braz¹, L A G Magalhães², L Pacifico² and P Travassos²

1 COPPE – Universidade Federal do Rio de Janeiro (UFRJ), Horácio Macedo Avenue, 2030, Bloco G, Cidade Universitária, Ilha do Fundão, CEP 22194-914, Rio de Janeiro, Brazil

2 Laboratório de Ciências Radiológicas (LCR) – Universidade do Estado do Rio de Janeiro (UERJ), São Francisco Xavier Street, s1 136, 524, PHLC, CEP 20550-900, Rio de Janeiro, Brazil

*Corresponding author: leandrogatto2@gmail.com

Abstract. It is necessary to evaluate the spectra with an up-to-date solid-state detector in a mammographic system, utilizing exotic anode/filter combinations and PMMA phantoms from different thicknesses. It has seen that today dual energy mammography and tomosynthesis applications are using tungsten anode spectra up to 49 kV with exotic filters, such as silver (Ag), palladium (Pd), molybdenum (for the W/Mo combination), and so on. Based on this, this work was made an experiment in the metrological and simulated case. It was used a spectrometer with the W/Pd and W/Mo anode/filters, in some tube voltages with PMMA slabs, to find the respective spectra. The same situations were made for the simulations in the Monte Carlo, in the simulate case. Considering the uncertainty of the measurements, the spectra obtained are in agreement with the references provided by the equipment and with internationally adopted standards. Through, results obtained both in metrological and simulated cases can be validated for future uses in mammography.

1. Introduction
Mammography is a radiographic exam that is especially designate for breast cancer detection. Breast cancer is the type that more affect the women around the world, and in 2018 24% of the cases infected in the world [1]. In 2019, according Cancer National Institute (INCA) [2] only in Brazil breast cancer estimated for 2020 will be 66,280, with the percentual of 29.7%. The European Protocol for dosimetry in mammography in 2D [3] recommends the use of X-Ray spectra for different anode/filter combinations, so proving that the dosimetry can be applied for any breast glandularities. Standard mammographic radiation qualities are established by International Electrotechnical Commission (IEC), by the IEC 61267 [4], and by Physikalisch-Technischen Bundesanstalt (PTB) [5], for various combinations. Hernandez et al (2014) [6] assessed that in digital mammography can be used a tungsten anode (W) with exotic filter, such as Palladium (Pd) and Silver (Ag), for obtention of energy spectra up to 49 kV, or more than 40 kV, that is the usual voltage tube limit. Boone (1999) [7] assessed the useful of calculus of normalized glandular dose, for determine X-Ray spectra for several anode/filter combinations, such as tungsten-palladium (W/Pd) and tungsten-molybdenum (W/Mo). The results founded served as breast glandularities, ranging from 0 and 100%. Dance et al. (1990, 2000) [8-9] verified spectra for various anode/filter combinations, such as tungsten-palladium and tungsten-rhodium. Da Silva (2015) [10] verified that X-Ray clinic tube can be able a tool for evaluate the radiation field homogeneity in mammography. The experiments were made in a metrological
laboratory certified for the mammography radiological. David et al. (2012) [11] used a X-Ray spectrometer for found spectra with a X-Ray clinic tube and a molybdenum and a beryllium (Be) window, for some voltage tubes. The results were compared with simulations in Monte Carlo code and the references. This method was looked useful for future determinations of the photon beam voltage tubes, in a clinic mammography environment. Gholamkar et al (2016) [12] founded in the Monte Carlo N-Particle Extended (MCNPX) code, spectra for various energy in several anode/filter combinations, such as W/Pd, W/Mo and Rh/Al. So, it was observed that code is a useful tool for simulate X-Ray spectra in mammography. Cunha (2012) [13] was made in the Monte Carlo code for evaluate the glandular dose in several anode/filter combinations, such as W/Pd, and obtained in the voltage tubes 24 to 31 kVp, in several polymethyl methacrylate (PMMA) thicknesses. This work aims obtained spectra for unusual anode/filter combinations, such as W/Mo and W/Pd, in the clinic and simulated cases. The used materials were: an X-Ray spectrometer, a X-Ray clinic tube, PMMA slabs, and the Monte Carlo code, MCNPX. Two experiments were made, such as: from the metrological case, the determination of the spectra from the spectrometer (in which the photon beam was made through a X-Ray clinic tube); from the simulated case, spectra from MCNPX were assessed, through of the equipment from the mammograph. The results were compared with the currently references, for validation.

2. MATERIALS AND METHODS

2.1 PMMA phantoms and spacers

For the experiment with mammographs, PMMA phantoms were developed, which could simulated a typical breast, from different thicknesses. Moreover, PMMA spacers were made for be placed on top of the phantoms. Customized phantom thicknesses were ranging from 5 to 20 mm, in accordance from International Agency of Atomic Energy - IAEA (2011), published in Human Health Series 17 [14]. It was needed to obtain the average linear attenuation coefficient $\mu$ in the PMMA phantoms, since they were not manufactured from certified laboratories. The experiment was done in the Metrologic Laboratory (Labmetro), from Radiologic Science Laboratory, which becomes to State of Rio de Janeiro University (UERJ). That laboratory is certified by the Brazilian metrological Institute, the Technology, Quality and Metrologic National Institute (Inmetro), in the radiologic for calibration field, operating in the tertiary system. In the experiment was determined in each phantom three points of interest (C, D, E), as C the centre of mass. The objective was to determine the linear attenuation coefficient in the PMMA phantom, $\mu_{\text{PMMA}}$ in cm$^{-1}$. The distribution of the points in each one of the phantoms is showed in the figure 1. It was used the COMET clinic tube (serial number T20697/B) for the X-Ray irradiation, applying a voltage tube of 28 kV. It was also included a collimator in front of the X-Ray clinic tube. From the left to the right, it were used the follow tools: a COMET X-Ray tube; a collimator; and PMMA phantom. That methodology was adapted from NEROBIN geometry. From the figure 1, the measure of the linear attenuation coefficient for all the phantoms was 0.2548 ± 0.0018 cm$^{-1}$. The HVL for each of the PMMA phantoms (HVL$_{\text{PMMA}}$) might be calculated, through the equation HVL$_{\text{PMMA}} = \ln 2/\mu_{\text{PMMA}}$. The measure found for the HVL was about 2.71 ± 0.0018 cm. Those coefficients were compared with the NIST measures [15], in the energy range for mammography (between 18 and 40 keV). The results were according to the previous reference, and the phantoms could be used in this work.
2.2 The X-Ray spectrometer

It was used a X-Ray spectrometer (Amptek, model X-123 and serial number 002161), with also the followed tools: a COMET X-Ray tube (serial number T20697/B); a pre-amplifier; a Amptek DP5 digital pulse processor. The nominal voltage in the detector was of about 500 V. The Silicium crystal dimensions were of 1mm thickness, the active area was of 9 mm², and moreover the beryllium window (Be) was measured 100 µm thickness. The energetic resolution from detection system was ranged from 1.2 keV and 2.5 keV. The filters used in this paper were of Molybdenum (Mo), 0.06 mm and of Palladium (Pd), 0.04 mm. PMMA phantoms were placed between X-Ray tube and the target, for verify the spectrum which related the anode/filter combination with the phantoms. In the W/Mo combination, phantoms with 45 thick were used, and in the W/Pd combination, phantoms with 40 mm, 60 mm and 80 mm were used. These experiments were made in the Labmetro, in State of Rio de Janeiro University (UERJ). The spectrometer was placed together with the X-Ray tube and the spectrometer. The spectrum was saved in the PC. Figure 2 shows a schematic diagram of the tools.

2.3 The MCNPX code

The MCNPX code [17] works with radiation particles transport, offering a 3D powerful tool and source modelling resources, applied for Radiation Physics. The Visual Editor (Vised) [18] is an auxiliary tool from MCNPX, and it was developed to assist the user to show the constructed geometries, and also the input edition. That tool allows that the user configures and modifies the MCNPX geometry easily. The information from the model can be made directly from plotting section. Furthermore, the code allows that the users to create an input through two dynamic windows easily, with 2D view. The input in MCNPX can be created through a text editor, if desirable. The model followed the instructions from the patent 5375158 [19] for the T1 tube, and the one 3610984 [20] for the T2 tube, respectively. Referring to the T1 tube, that document recommends that several materials
can be used for both anode and filter, such as tungsten, rhodium and silver. The ampoule of the X-Ray tube is composed of Pyrex®. The intern of the tube is made of vacuum for minimal losses of energy for the accelerate electrons in the anode. The mammographic housing is made of carbon steel. The modelled cathode was in rectangular mode. Figure 3 presents a slice of the X-Ray tube for T1 tube created in Vised, and its sight, in 3D, in the same program. The document from the T2 tube recommends that only the tungsten be used in the anode as a material, being that any materials can be used in the filter. Like the T1 tube, the compost, the cathode form and the intern part are the same for the T2 tube. Figure 4 presents a slice of the X-Ray tube for T2 tube created in Vised, and its sight, in 3D.

Figure 3 – X-Ray tube T1, modelled in Vised.

Figure 4 – X-Ray tube T2, modelled in Vised.

Figure 5 shows the following components in Vised, to up to down: X-Ray tube; Be window, of 0.63 mm thickness; Mo filter, of 0.06 mm thickness; Pd filter, also of 0.04 mm thickness; air detectors, representing spheres of 2 cm diameter each one, as pointed by Shultis et al. [21], for a better reliability to the results, representing solid state detectors; PMMA spacers, with 3 cm diameter and several thicknesses, such as 40 mm 60 mm and 80 mm and for 45 mm for the W/Pd and W/Mo combinations, respectively; PMMA phantom, with dimensions of 18 cm x 24 cm and thicknesses that ranged from IAEA (2011) data; support plate, from polycarbonate material and dimensions of 28 cm x 30 cm x 0.3 cm. The source-detector distance was above to 50 cm, and the air detectors and the support plate distance was superior to 2 cm. The chemical compositions from modelled components for the spectra were made with the X-Ray tube without angulations.
2.4 Obtention of the spectra
X-Ray spectra obtained from mammographic and clinical tube, and the reference were plotted from Siemens X-ray Toolbox spectra generator [22]. This tool yield mammographic spectra for tungsten, rhodium and molybdenum targets, and the voltage tubes ranges from 18 kVp up to 40 kVp. This tool produces non-attenuated X-Ray spectra through algorithms. The author made the experiments in X-Ray spectroscopy laboratories. In this work, the voltage tube, anode material, filter material, PMMA thicknesses and kerma were typed. The spectrum is downloaded in PC, and might be plotted in a spreadsheet. In MCNPX, the F5 tally was used for the photon fluency, in particles per square centimetre. Other command typed was the Forced Collision (FCL) that increased the photon population, in the regions of interest, as recommend by SHULTIS et al (2006) that were the air detectors. The compression plate was no modelled, because this could influence in X-Ray attenuation. Spectra were obtained from MCNPX output, and were plotted in a spreadsheet. Angles were not used for the X-Ray tube neither in MCNPX, nor in the other experiments. All the spectra were normalized for number of particles per square millimetre.

3. RESULTS AND DISCUSSIONS
Next, it will be showed the results and discussions from the spectra obtained with the spectrometer and the MCNPX experiments, made with W/Mo and W/Pd anode/filter combinations. All of them were compared with the current literature, in which was generate from the Siemens spectrometer.

3.1 Analysis from spectra for W/Mo, in the two experiments
Figures 6, 7 and 8 presents the spectra obtained from Amptek spectrometer, from MCNPX and by the reference, Hernandez et al. (2014) [23], by the W/Mo anode/filter, for the voltage tubes 26 kV, 28 kV and 30 kV, respectively. PMMA thicknesses used measured 45 mm in all voltage tubes. The peaks from those three spectra were generated from the same energy range and the change in the shape was due to the increase in the voltage tube. After 20 keV, for three spectra, as the voltage tube has increased, fluencies of 10^6 photons per square millimetres expressive increase and the decrease in the Mo filtration, has occurred. Though MCNPX and spectrometer spectra have produced some distortions, both were in concordance.
3.2 Analysis from spectra for W/Pd, in the two experiments

Figures 9, 10 and 11 present the obtained spectra from Amptek spectrometer and MCNPX, and by reference presents the spectra obtained by Amptek spectrometer, MCNPX and the reference, for the W/Pd combination. PMMA thickness has varied as the voltage tube has increased, respectively: 40 mm, for 26 kV; 60 mm for 28 kV; 80 mm for 30 kV. Despite the distortions, good concordances were noticed. The spectra inclinations occurred due to the increasing in the PMMA.
Figure 9 – Spectra from W/Pd, for the voltage tube 26 kV and 40 mm PMMA thickness.

Figure 10 – Spectra from W/Pd, for the voltage tube 28 kV and 60 mm PMMA thickness.

Figure 11 – Spectra from W/Pd, for the voltage tube 30 kV and 80 mm PMMA thickness.

4 Conclusions
After the verification of the results, phantoms produced good results, generating a high X-Ray filtration. In the metrological case, the spectrometer has noticed to be an important tool for the verification of the spectra in real time, with addition of materials used in mammography, such as PMMA. There were in Mo and Pd filtrations between 0 and 10 keV, for the spectrometer. In the simulated case, MCNPX has proved to be a crucial tool for measure of the dose and related quantities, generating spectra next to the references. In W/Mo combination, good approximation with references.
5 Acknowledgments
This author thanks the support by technical team from LCR/UERJ, in special to Labmetro, for availability of the spectrometer and the X-Ray clinic tube; the team who works in LCR/UERJ cluster, for the MCNPX simulations; to Radioprotection and Dosimetry Institute, who allowed the access to the cluster, for the simulations; and the financial support from CNPQ.

6 Bibliography

[5] Physikalisch Technischen Bundesanstalt 2012 Nomex Multimeter Commercial Note D9091990100
[14] International Atomic Energy Agency 2011 Quality Assurance Programme For Digital Ma-
mography, Human Health Series 17


[22] Siemens 2014 Siemens OEM Products: X-ray Toolbox