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Evaluation of characteristic-to-total spectrum ratio: Comparison between experimental and a semi-empirical model

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HIGHLIGHTS

- Primary X-ray spectra were measured in the range of 80–150 kV.
- Primary X-ray spectra were computed using the TBCmod code, from 80 to 150 kV.
- Characteristic to total spectrum ratio was used to validate the TBCmod code.
- X-ray spectra computed with TBCmod are in good agreement with experimental results.

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ABSTRACT

Primary X-ray spectra were measured in the range of 80–150 kV in order to validate a computer program based on a semiempirical model. The ratio between the characteristic and total air Kerma was considered to compare computed results and experimental data. Results show that the experimental spectra have higher first HVL and mean energy than the calculated ones. The ratios between the characteristic and total air Kerma for calculated spectra are in good agreement with experimental results for all filtrations used.

1. Introduction

Since the discovery of the X-ray radiation by Wilhelm Roentgen in 1985, many applications of X-ray beams have been developed. In these developments, special progress can be observed in medical applications for both therapy and diagnosis of diseases. Various issues are important for these medical applications of X-rays. A very important topic is the estimation of radiation doses of patients submitted to therapeutic or diagnostic procedures, which is strongly dependent of the radiation spectra. These spectra are also important for formulating radiation shielding models. On the other hand, routine measurements of X-ray spectra in diagnostic radiology are uncommon due to the complexity of the measurement procedures (Bhat et al., 1998). However, theoretical and semiempirical models have been developed in order to assist the estimation of the spectrum emitted by specific X-ray tube for energies in diagnostic range (Archer and Wagner, 1988; Baird, 1981; Birch and Marshall, 1979; Boone et al., 1997; Boone and Seibert, 1997; Tucker et al., 1991).

A semiempirical model for generating tungsten target X-ray spectra was proposed by Tucker et al. (1991) (TBC model). However, as originally presented, the TBC model fails in situations where it is necessary the production of X-ray spectra to an arbitrary waveform. The original model cannot also provide a realistic calculation of the spectra adopting the air Kerma quantity for the resulting amplitude. The modified TBC model, hereafter called TBCmod (Costa et al., 2007) was used in the present work. This model takes into account the waveform and a representation of the calculated spectra using the air Kerma quantity (Costa et al., 2007). The performance of the proposed model was evaluated by comparing values of mean energy and first half value layer (HVL) from computed and measured spectra for different voltages and filtrations. Finally, to evaluate the contribution of the characteristic photons to total spectrum, the ratio between characteristic-to-total spectrum was calculated (both measured and computed spectra) and compared.

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2. Materials and methods

2.1. X-ray spectra measurements and corrections

In the present work, the x-ray spectra were measured by a CdTe detector, model XR-100T-CdTe (Amptek Inc.). This device is an X- and Gamma ray detector mounted on a two-stage thermoelectric cooler. The Cadmium Telluride detector (CdTe) has a nominal area of 9 mm^2 and a thickness of 1 mm with a Schottky diode structure and Peltier cooling. The other element of the spectroscopy system was an Amptek PX4 processor that includes digital pulse shaping amplifier, integrated multichannel analyzer and power supplies.

The model XR-100T-CdTe has a Be window with 100 μm of thickness. Due to its high stopping power, CdTe detector is a good option for detecting photons with energies above 30 keV (Redus et al., 2009). On the other hand, a tungsten collimator with 2 mm diameter and 2 mm thickness and a brass spacer were used.

A Philips MG 450 X-ray system was used for generating the X-ray spectra. It consists of a control unit MGC 30 and a MCN 421 industrial X-ray tube with stationary Tungsten target. A constant-potential generator operating at tube voltage between 40 and 150 kV was used as power supply for the X-ray tube. The measurements were conducted with additional filters of Al with 3.04 mm, 4.71 mm and 5.98 mm of thicknesses. Table 1 presents the X-ray tube specifications used in this work. The X-ray beam area was defined by a collimator that produced a field of 6.91 cm × 5.76 cm diameters at 1 m of the focal spot.

Measurements of the air Kerma were made using an electrometer Unidos E (PTW), coupled to a 30 cm^3 PTW ionization chamber, model TW 23361. The ionization chamber and CdTe detector were located at 5.45 m and 5.60 m of the X-ray tube focal spot, respectively.

The energy calibration, linearity and resolution were determined using ^{241}Am and ^{152}Eu calibration sources. In CdTe detectors, the centroid of the photopeak are shifted by the asymmetry due to hole tailing effect. This centroid shift increases with energy (Redus et al., 2009). To correct this effect, it was used the peak channel rather than the centroid for identify photopeak energies of the ^{241}Am and ^{152}Eu sources, 59.4 keV and 121.7 keV, respectively. Origin 8.5.1 (OriginLab, Co.) software was used to fit the energy distribution for each calibration source, using the Gaussian distribution option of the fitting program.

The detector's response was corrected using a stripping procedure (Castro et al., 1984), considering the detector efficiency, escape peaks of Cd and Te K X-rays and escape of Compton-scattered photons. The response function was determined by Monte Carlo simulation. The simulation of the detector response was based on a previous work (Tomal et al., 2012) for mammographic energy range from 5 to 40 keV, and extended for diagnostic range, from 5 to 160 keV (Tomal et al., in press).

2.2. Software to generate semiempirical X-ray spectra

The TBCmod was published in a previous work (Costa et al., 2007). This code, used to generate diagnostic X-ray spectra, is based on the semiempirical TBC model (Tucker et al., 1991). The TBC model introduces a relativistic correction factor which is not applied on the derivation of the Birch and Marshall model (Birch and Marshall, 1979; Bissonnette and Schreiner, 1992) and both bremsstrahlung and characteristic X-ray production are assumed to occur at varying depths within the target (Tucker et al., 1991). In order to take into account the waveform and a representation of the calculated spectra using the air Kerma quantity, TBC model was modified to produce the TBCmod code. In addition, the TBCmod code is able to produce X-ray spectra for different target

Table 1
X-ray tube specifications.

Tube	Philips MCN 421
Type N°	9421 172 57032
Target	Tungsten
Target angle	22°
Emergent beam angle	30°
Inherent filtration value	2.2 mm Beryllium
Ripple	2.5 kV max.

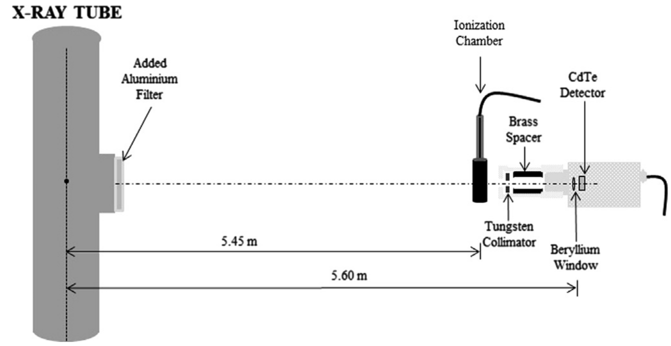

Fig. 1. Experimental setup to measure the spectra. The figure represents the Philips MG 450 X-ray system with the additional filter and the detection system composed by the ionization chamber and the spectroscopy device.

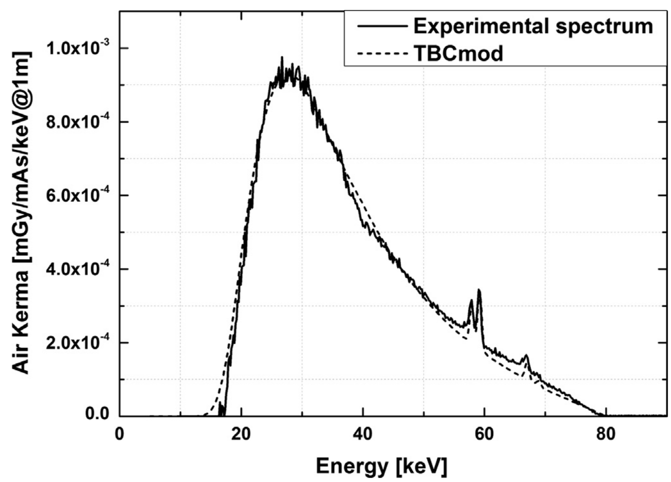

Fig. 2. Comparison between experimental (solid line) and computed (dashed line) data for 80 kV tube potential and 3.04 mm of additional Aluminum filtration.

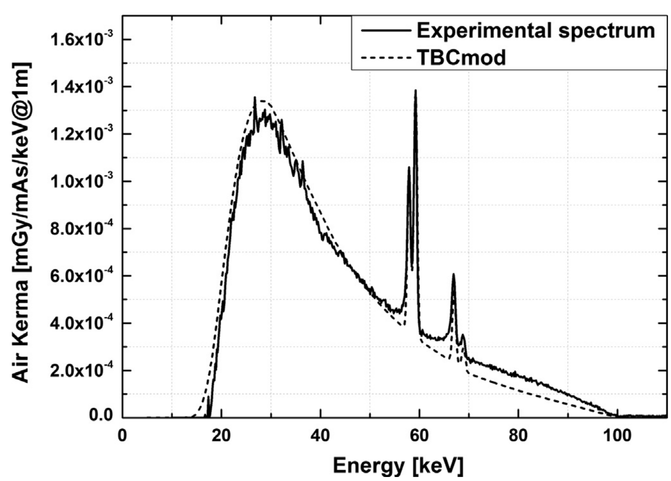

Fig. 3. Comparison between experimental (solid line) and computed (dashed line) data for 100 kV tube potential and 3.04 mm of additional Aluminum filtration.