Radiation Physics and Chemistry 95 (2014) 217–220

Contents lists available at ScienceDirect

Radiation Physics and Chemistry

journal homepage: www.elsevier.com/locate/radphyschem

Comparison of beam quality parameters computed from mammographic x-ray spectra measured with different high-resolution semiconductor detectors

A. Tomal [a,b,*], D.M. Cunha [c], M.E. Poletti [b]

[a] Instituto de Física, Universidade Federal de Goiás, UFG 74001-970 Goiânia, GO, Brazil
[b] Departamento de Física, FFCLRP, Universidade de São Paulo, 14040-901 Ribeirão Preto, SP, Brazil
[c] Instituto de Física, Universidade Federal de Uberlândia, 38400-902 Uberlândia, MG, Brazil

HIGHLIGHTS

- ▸ The Si(Li), SDD and CdTe detectors were applied for mammographic x-ray spectroscopy.
- ▸ The x-ray spectra measured with these detectors are similar, showing differences only in the characteristic peaks.
- ▸ The mean energies and values of HVL computed from the measured spectra with these detectors also show small differences.
- ▸ The use of Si(Li) detectors and SDD is advantageous due to their better energy resolution.

ARTICLE INFO

Article history:
Received 28 September 2012
Accepted 1 January 2013
Available online 9 January 2013

Keywords:
Mammographic x-ray spectra
Quality parameters
Si(Li) detector
Silicon drift detector (SDD)
CdTe detector

ABSTRACT

In this work, the x-ray spectra of standard mammographic radiation qualities were measured with Si(Li), SDD and CdTe detectors. The x-ray source was an industrial x-ray tube with an Mo anode, operating at constant tube potentials between 20 and 35 kV, and adapted with filters of Mo and Al, in order to reproduce standard mammographic beam qualities. The measured spectra were corrected by the energy response of each detector, which were determined using Monte Carlo simulation. From the corrected spectra, values of *HVL* and mean energies were computed. The results show that, after correction by the energy response functions, all detectors provided similar bremsstrahlung spectra, whereas greater differences were observed in the characteristic peaks, due to the different energy resolutions of the detection systems. The comparison between values of *HVL* and mean energies calculated from the spectra obtained with each detector also show good agreement, with differences up to 5.5%. For most of the conditions studied, the differences between the measured values of *HVL* and those computed from the corrected spectra are lesser than the experimental uncertainties. Finally, our results show that, although the detectors Si(Li), SDD and CdTe provide similar spectra, the use of the first two detectors, which combine high energy resolution and low spectral distortions, is recommended, since they provide more accurate spectra from which several quality parameters can be determined.

1. Introduction

The accurate knowledge of spectra produced by an x-ray equipment is an important factor for quality control in mammography, for calibration purposes (David et al., 2012; International Electrotechnical Commission, 2005), and in the optimization of the imaging system, for radiological protection, improvement of image quality or reduction of absorbed dose (Wilkinson et al., 2001; Künzel et al., 2004; Cunha et al., 2012). The x-ray spectrum provides the most complete and accurate characterization of the radiation field, and from it, several radiation quality parameters can also be extracted, such as half-value layer (*HVL*) and mean energy (Peaple and Burt, 1969; David et al., 2012).

X-ray spectroscopy is usually performed using high-resolution semiconductor detectors, followed by a proper correction procedure by the energy response function of the detector (Di Castro et al., 1984; O'Foghludha and Johnson, 1981; Matsumoto et al., 2000; Wilkinson et al., 2001; Miyajima and Imagawa, 2002; Künzel et al., 2004; Abbene et al., 2007; Tomal et al., 2011, 2012). Thus, the use of a detector with good response function, which minimizes the spectral distortions and makes the

* Corresponding author at: Instituto de Física, Universidade Federal de Goiás, UFG 74001-970 Goiânia, GO, Brazil. Tel.: +556235211014.
E-mail address: alessandra_tomal@yahoo.com.br (A. Tomal).

0969-806X/$ - see front matter © 2013 Elsevier Ltd. All rights reserved.
http://dx.doi.org/10.1016/j.radphyschem.2013.01.002

correction procedure easier, is preferred for accurate x-ray spectroscopy (Miyajima, 2003; Tomal et al., 2012; Chen et al., 1980). Besides, the spectrum shape is also affected by the energy resolution of the detection system employed, which could influence the determination of beam quality parameters computed from those spectra.

In this work, mammographic x-ray spectra of standard mammographic radiation qualities were measured with the Si(Li), SDD and CdTe detectors, in order to investigate the more suitable detector for mammographic x-ray spectrometry. Finally, from the corrected spectra, the values of *HVL* and the mean energies were computed, in order to verify the influence of the detection system on the calculation of the quality parameters from the x-ray spectra. The computed values of *HVL* were also compared with those obtained experimentally, using an ionization chamber.

2. Material and methods

2.1. Mammographic x-ray spectra measurements

The mammographic x-ray spectra (Tomal et al., 2011) were generated by an industrial x-ray tube (Philips, PW 2215/20) with a stationary molybdenum (Mo) target, with anode angle of 20°, and a 0.3 mm beryllium (Be) exit window. The x-ray tube is powered by a constant-potential generator (Phillips PANalytical, PW 3830), operating at tube potentials between 20 and 35 kV. At the tube exit, filters of Mo or Al with 99.9% of purity and suitable thicknesses were inserted to reproduce the standard x-ray mammographic beam qualities recommended by International Electrotechnical Commission (2005) and Physikalisch-Technische Bundesanstalt (2010), as described in detail by Tomal et al. (2011).

The spectra were measured with three different detectors:

1. A Si(Li) detector (Canberra, model SL30165), with thickness of 3 mm and active area of 30 mm^2, and an 8 μm thick Be window. The detector was connected to an H.V. power supply (providing a bias voltage of −500 V) and to a pre-amplifier (Canberra, 2008D). The energy resolution of the detection system was 165 eV at 5.9 keV.
2. A Silicon Drift Detector (SDD) (Amptek, model XR-123SDD), coupled to digital pulse processor DP5 (Amptek). A nominal bias voltage of −200 V was applied to the detector. The dimensions of the silicon crystal in the detector was 450 μm thick and 7 mm^2 active area, and it was located behind a 12.5 μm Be window. The energy resolution of the detection system was 149 eV at 5.9 keV.
3. A CdTe diode detector (Amptek, model XR-100T-CdTe), with thickness of 1 mm and 9 mm^2 nominal area, and a Be window of thickness 100 μm. The pulses from the detector were processed by an Amptek PX4 amplifier. The nominal bias voltage was 400 V. The energy resolution of the detection system was 260 eV at 5.9 keV.

The energy calibration and the resolution of the each detection system were determined by using γ and x-spectra of radioactive sources of ^{55}Fe, ^{137}Cs, ^{137}Ba and ^{241}Am (Tomal et al., 2011, 2012).

The measurements of x-ray spectra were made at a distance of 1 m from the focus. A tungsten pinhole collimator (2 mm thick and 0.5 mm diameter) was utilized in front of each detector in order to reduce the fluence rate, and consequently, pile up effects and dead time losses on the x-ray spectra. The rise time discrimination (RTD) circuit of all detectors was switched off during the measurements (Miyajima, 2003).

Measured x-ray spectra were corrected by the respective response functions of each detector, using the stripping method (Di Castro et al., 1984; Tomal et al., 2011). The response functions of each detector were calculated through Monte Carlo (MC) simulations, using the PENELOPE code (Salvat et al., 2003), slightly modified to include carrier transport effects and the finite detector energy resolution, as described in details by Tomal et al. (2012). Finally, the x-ray spectra were normalized by the energy width of the detector channels.

2.2. Determination of quality parameters from the corrected spectra

The *HVL* values and the mean energies ($\overline{E}$) were computed from the corrected spectra obtained with each detector (Künzel et al., 2004). The computed *HVL* values were compared with those determined experimentally using an ionization chamber (Radcal, model 10X5-6M), coupled to an electrometer (Radcal, model 9015 RM-S), and placed at 100 cm from the focal spot.

3. Results and discussions

3.1. Mammographic x-ray spectra

Fig. 1 compares the corrected x-ray spectra obtained with Si(Li), SDD and CdTe detectors, for the Mo/Mo combinations at 30 kV, respectively, representing the mammographic standard radiation qualities established by Tomal et al. (2011). All spectra were normalized to unit area.

As shown in Fig. 1, the x-ray spectra measured with the three detectors, and corrected by the respective response functions of each detector, have similar distribution shapes. In general, good agreement is observed for the bremsstrahlung region of the spectra obtained with all detectors. On the other hand, greater differences were noticed in the intensity and width of the characteristic peaks measured with the three detectors, due to the different energy resolutions of the detection systems. The spectra measured with the CdTe detector show the lowest intensity and largest peaks, due to its poor energy resolution. Moreover, the SDD detector provides the most realistic spectra, with the highest and narrowest characteristic peaks.

3.2. Quality parameters

Table 1 shows the values of *HVL* and the mean energies ($\overline{E}$) computed from the corrected spectra obtained with the Si(Li), SDD and CdTe detectors, for the Mo/Mo and Mo/Al combinations,

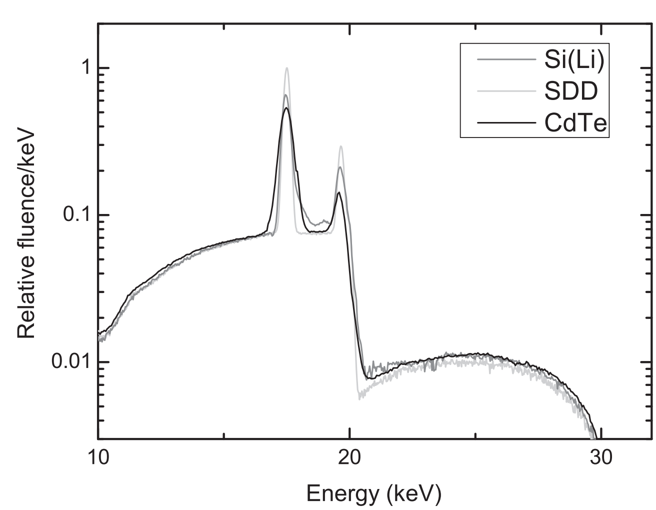

Fig. 1. Corrected x-ray spectra obtained with Si(Li), SDD and CdTe detectors for a Mo/Mo anode/filter combination at 30 kV.