IL NUOVO CIMENTO Vol. 29 C, N. 3 Maggio-Giugno 2006
DOI 10.1393/ncc/i2005-10237-7

Portable CdTe detection system for mammographic X-ray spectroscopy

A. La Manna(1)(*), L. Abbene(1)(**), F. Fauci(1)(2), G. Gerardi(1)(2), G. Raso(1)(2), S. Del Sordo(3), L. Barone Tonghi(4) and S. Stumbo(5)(6)

(1) *Dipartimento di Fisica e Tecnologie Relative dell'Università - Palermo, Italy*
(2) *INFN, Sezione di Catania - Catania, Italy*
(3) *IASF/INAF, Sezione di Palermo - Palermo, Italy*
(4) *Unità Operativa di Fisica Sanitaria dell'A.R.N.A.S., Ospedale Civico - Palermo, Italy*
(5) *Struttura Dipartimentale di Matematica e Fisica dell'Università - Sassari, Italy*
(6) *INFN, Sezione di Cagliari - Cagliari, Italy*

(ricevuto il 21 Dicembre 2005; approvato il 14 Febbraio 2006; pubblicato online il 21 Giugno 2006)

Summary. — This paper describes a portable apparatus to be utilized in mammographic X-ray spectroscopy under clinical conditions. The system, based on a CdTe solid-state detector, is able to directly measure mammographic X-ray tube spectra. Good system response to monoenergetic photons was measured using X-ray and γ-ray calibration sources (^{109}Cd and ^{241}Am). The measured molybdenum X-ray spectra, in agreement with simulated spectra, show the good spectral capability of the system also at high photon fluence rates, as typical of clinical mammography. Low tailing, no secondary X-ray escape and low pile-up distortions in the measured spectra indicate that this portable system is suitable for mammographic X-ray spectroscopy.

PACS 29.30.Kv – X- and gamma-ray spectroscopy.
PACS 87.66.Pm – Solid state detectors.
PACS 87.56.Fc – Quality assurance equipment.

1. – Introduction

Quantitative X-ray spectra information is very important for quality assurance in radiographic systems. Mammographic X-ray tube spectra measurements are essential for many procedures, such as radiation protection calculation, patient dosimetry and measurement of radiographic imaging properties (Detective Quantum Efficiency). Several

(*) E-mail: lamanna@difter.unipa.it
(**) E-mail: abbene@difter.unipa.it

Fig. 1. – The portable detection system.

authors [1-4] have proposed germanium (HPGe or Ge(Li)) or silicon solid-state detectors for mammographic X-ray spectroscopy. Ge and Si detection systems have shown good spectral performances, due to their excellent charge transport properties; however, spectral distortions appeared in the measured spectra, due to inherent detection efficiency and to secondary X-ray escape; moreover, the narrow band gap (Si: $E_G \sim 1.1\,\mathrm{eV}$; Ge: $E_G \sim 0.7\,\mathrm{eV}$) for both materials, has required the use of large cryogenics systems so as to reduce thermal noise. Hence, small room temperature detectors, such as CdTe detectors, may be preferred for mammographic X-ray spectroscopy under clinical conditions. In this paper a portable system, based on a CdTe solid-state detector able to perform a direct measurement of mammographic X-ray tube spectra, is described. The shaped detector signal was recorded by an ADC card with a 10 MHz sampling rate; a dedicated software was able to recognize and correct for pile-up events. In order to evaluate the spectroscopic performances and to calibrate the system, preliminary measurements were carried out by using laboratory radioactive sources. Then, we measured the X-ray spectra from a Siemens mammographic X-ray tube that is currently used in the Radiology Unit of Maurizio Ascoli Oncological Hospital (Palermo, Italy).

1˙1. CdTe *detectors in mammographic X-ray spectroscopy*. – In recent years, CdTe solid-state detectors have been considered as promising detectors for X-ray spectrometry [5-7] due to their physical properties. The high atomic number (Cd: 48, Te: 52) and the high density ($\sim 5.9\,\mathrm{g\,cm^{-3}}$) of CdTe crystals ensure high detection efficiency for photons with energy below 100 keV even for thin detectors [7, 8]. The wide band gap ($E_G \sim 1.5\,\mathrm{eV}$) enables CdTe detectors to be operated at room temperature without cryogenics. A small Peltier cooler is enough to improve the CdTe detector response without modifying the detection system compactness. Poor charge properties are the main drawback of the CdTe detectors; the charge carrier trapping, especially for holes, reduces the output pulse height of the CdTe detectors, that is no more proportional to the energy deposited by the X-rays. The incomplete charge collection leads to spectral distortion as shown by asymmetric full energy peaks and long low-energy tails in the CdTe measured spectra. Additionally, the escape of Cd and Te K-fluorescent X-ray produces further

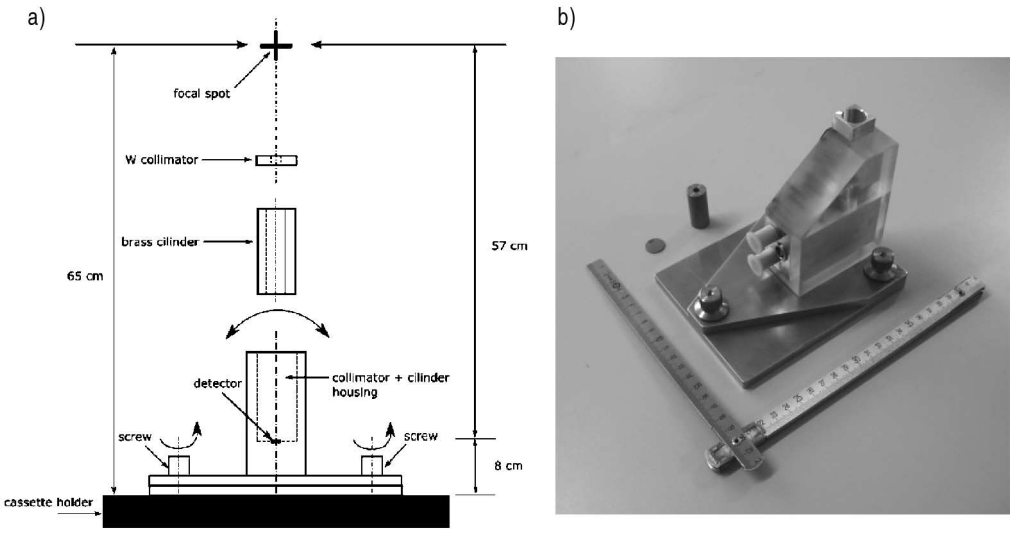

Fig. 2. – a) The experimental set-up for mammographic X-ray spectroscopy under clinical conditions. b) The CdTe detector and the collimation system.

spectral distortions in the low-energy region of the measured spectra. These spectral distortions are negligible for low X-ray energies, especially in the mammographic energy range (10–35 keV). Hence, CdTe detectors may be suitable for mammographic X-ray spectroscopy.

2. – Materials and methods

2˙1. *Detection system.* – The portable detection system is shown in fig. 1; it consists of four blocks: a detector case, a shaping amplifier, an ADC card and a notebook computer. The CdTe detector and the preamplifier were both within the detector case (Amptek XR-100T-CdTe). The CdTe crystal size was $2 \times 2\,\mathrm{mm}^2$ and 1 mm thick. Indium (In, anode) and platinum (Pt, cathode) electrodes allowed us to use the detector as a Schottky diode (CdTe diode). The very low leakage current of the CdTe diode enables to apply a high electric field ($4\,\mathrm{kV\,cm}^{-1}$), with a significant improvement in the charge collection. The thermoelectric cooling (Peltier cooler, $-20\,^{\circ}\mathrm{C}$) of both the CdTe crystal and the preamplifier input FET ensured a small detector-electronic noise and a good system stability. The pulses from the preamplifier were processed by the shaping amplifier (Amptek PX2T) with a shaping time (FWHM) of about 620 ns. The shaped pulses (Gaussian) were recorded by a 12 bit ADC card (ADLink Tecnology NuDAQ PCI 9812), with a 10 MHz sampling rate. A dedicated software [9] calculated the incident photon count and the energy spectrum by analyzing the sampled output of the ADC card.

2˙2. CdTe *detector response.* – The detector response to monoenergetic photons was measured using X- and γ-ray calibration sources (^{109}Cd: 22.1 keV and 24.9 keV; ^{241}Am: 59.5 keV). A tungsten disc (1 mm ϕ and 2 mm thick) was used to collimate the beam onto the crystal centre of the detector was used.

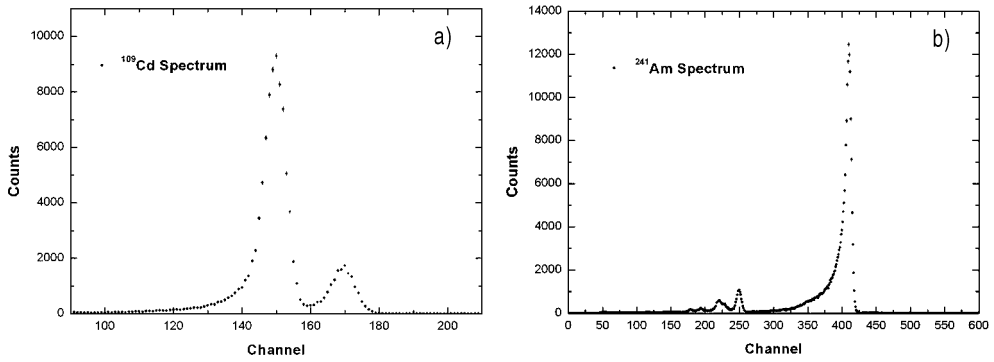

Fig. 3. – a) Measured X-ray spectrum of ^{109}Cd (22.1 keV and 24.9 keV); tailing, due to carrier trapping, is minimal and no secondary X-ray escape appears. The CdTe detector shows an energy resolution of about 4.4% at 22.1 keV. b) Measured γ-ray spectrum of ^{241}Am (59.5 keV); tailing and escape peaks are evident. The CdTe detector shows an energy resolution of about 1.9% at 59.5 keV.

2˙3. *Mammographic X-ray spectroscopy.* – X-ray spectroscopy was performed in a mammographic unit under clinical conditions. A Siemens Mammomat X-ray unit was employed in this work; the X-ray tube had a molybdenum (Mo) target, a 1 mm thick beryllium (Be) window and an additional Mo filtration (0.03 mm). The compression paddle was removed during the measurements.

The experimental set-up is shown in fig. 2 a). The detector was placed on the cassette holder with a 57 cm focus-detector distance. A collimation system was used to reduce the photon fluence. The high photon fluence rate of the mammographic tube (about 10^6–$10^7\,\gamma/\mathrm{mm}^2\,\mathrm{s}$), necessary for good-quality images, increases the probability of pile-

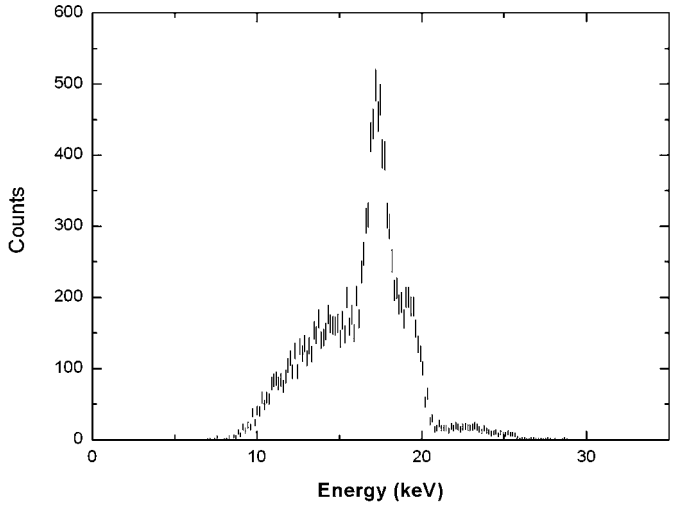

Fig. 4. – Molybdenum X-ray spectrum measured with the portable device under clinical conditions. The tube setting parameters were: current time product 40 mAs and voltage 28 kV.

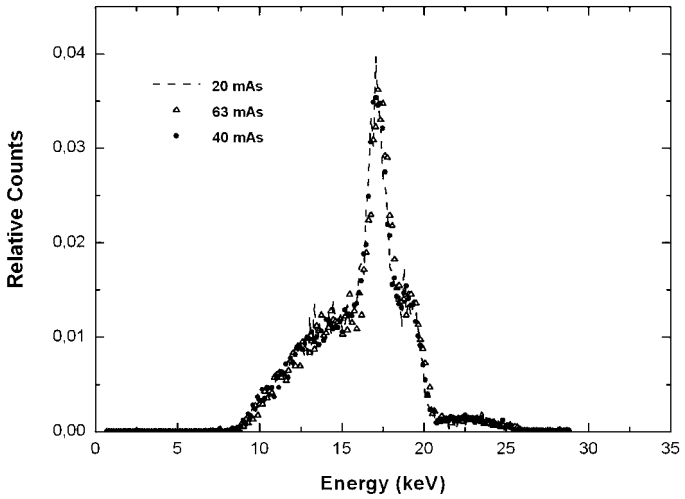

Fig. 5. – Measured molybdenum X-ray spectra at different current time product values (20 mAs, 40 mAs and 63 mAs; 28 kV); the spectra were normalized to the area.

up distortions in the measured spectra; therefore, a collimator with small aperture was necessary so as to minimize pile-up distortions. We used a tungsten collimator (50 μm ϕ; 1 mm thick) placed in front of a brass cylinder; the collimator and the cylinder were within an aluminum housing mounted on the detector window by a plexiglass support (fig. 2 b)); the brass cylinder was employed to shield the detector from L-fluorescent X-rays from the tungsten collimator. In order to optimize the alignment between the collimator axis and the X-ray beam, we positioned the detector (with the collimation system) on an aluminum plate; three micrometric screws allowed us to change the plate orientation. Preliminary focal spot-detector alignment was carried out with a laser device positioned within the aluminum housing. The best alignment was obtained by changing the plate orientation looking for the maximum of the measured photon count. A dedicated software was used to measure the photon fluence and the energy spectrum of the X-ray tube, by analyzing the Gaussian signal of the shaping amplifier, sampled at 10 MHz by the ADC card (acquisition time 1s). The software, recording both full shape and the temporal position of the photon pulses, allowed to discriminate pile-up events; the pile-up events were reconstructed by a fit based on the Marquardt-Levenberg algorithm [10]. Despite the high mammographic photon fluence, we obtained good performances (only about 2% of unrecognized pile-up events).

3. – Measurements and results

3˙1. *Measured* CdTe *detector response.* – In fig. 3 there is shown the X-ray spectrum of ^{109}Cd (22.1 keV and 24.9 keV) and the γ-ray spectrum of ^{241}Am (59.5 keV). The full-energy peaks were analyzed using a typical model spectrum [11] which takes into account both the symmetric and the asymmetric peak distortion effects. The detector shows good spectral performances ($\sim$ 4.4% at 22.1 keV and $\sim$ 1.9% at 59.5 keV). Low tailing characterizes the full-energy peaks of ^{109}Cd spectrum (fig. 3 a)) and escape peaks do not appear. In the high energy range (^{241}Am spectrum, fig. 3 b)) distortions, due to carrier

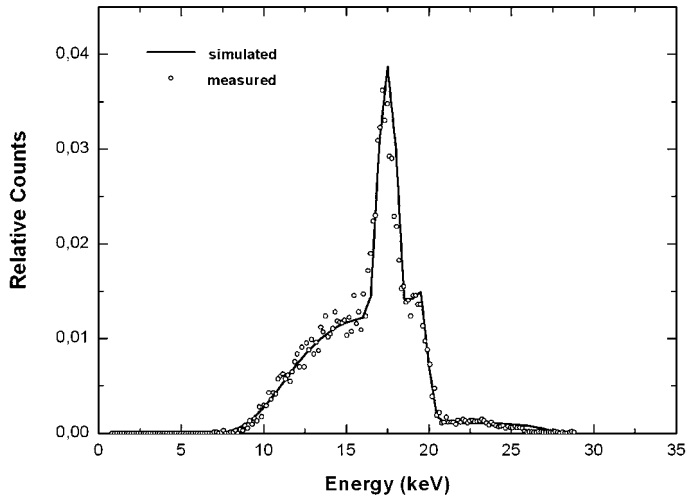

Fig. 6. – Measured molybdenum spectrum (40 mAs, 28 kV) compared with the simulated spectrum [12]. Both spectra were normalized to the area.

trapping and to X-ray escape, are evident. These results confirm that carrier trapping effects and escape of secondary X-rays are not severe in the mammography energy range.

3˙2. *Mammographic X-ray spectra.* – A measured spectrum of the X-ray mammographic tube (molybdenum target) is shown in fig. 4. The tube setting parameters were: current time product 40 mAs and voltage 28 kV. The system reproducibility was verified by measuring X-ray spectra several times. Table I shows the average result from 10 measured molybdenum spectra. Good system reproducibility is also evident in the measured

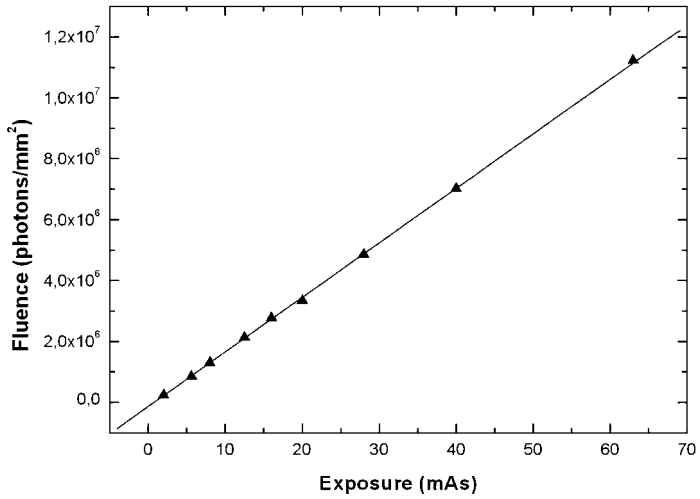

Fig. 7. – Measured fluence-current time product curve of the mammography X-ray tube.

TABLE I. – *Photon count results for ten molybdenum X-ray spectra measured at different times (40 mAs, 28 kV). Mean value and standard deviation are shown.*

Detected photon events	Recognized photon events	Photon fluence rate ($\gamma/\mathrm{mm}^2\,\mathrm{s}$)
14370 ± 130	14150 ± 130	$(7.21 \pm 0.07) \cdot 10^6$

spectra at different current time product values (fig. 5). Figure 6 presents the measured molybdenum spectrum and a simulated spectrum; the simulated spectrum is obtained convolving the CdTe response with a simulated molybdenum spectrum (IPEM Rep. 78 Catalog of Diagnostic X-ray Spectra [12]). A good agreement between the two spectra is well evident. Finally, we measured the fluence-current time product curve of the X-ray tube (fig. 7).

4. – Conclusions

A portable detection system was employed in mammographic X-ray spectroscopy under clinical conditions. The apparatus, based on a CdTe detector, was able to measure X-ray spectra and X-ray fluence of a mammography X-ray tube. The ^{109}Cd response showed good spectral performances of the system in the mammographic energy range; we observed good energy resolution, low tailing and no X-ray escape in the measured spectra. The measured molybdenum X-ray spectra showed no pile-up distortions and a good capability in pile-up identification and pile-up reconstruction (about 2% of unrecognized pile-up events at $\sim 7 \cdot 10^6\,\gamma/\mathrm{mm}^2\,\mathrm{s}$). In addition, the compactness and its easy operation make the system suitable for X-ray spectroscopy under clinical conditions. Future works will be focused on mammographic X-ray spectroscopy, dosimetry and imaging.

REFERENCES

[1] WILKINSON L. E. *et al.*, *Phys. Med. Biol.*, **46** (2001) 1575.
[2] O' FOGHLUDHA F. and JOHNSON G. A., *Nucl. Instrum. Methods A*, **377** (1981) 291.
[3] FEWELL T. R. *et al.*, *Radiology*, **128** (1978) 211.
[4] AOKI K. and KOYAMA M., *Med. Phys.*, **16** (1989) 529.
[5] CASTRO E. D. *et al.*, *Phys. Med. Biol.*, **29** (1984) 1117.
[6] TSUTSUI H. *et al.*, *IEEE Trans. Nucl. Sci.*, **39** (1992) 2282.
[7] MIYAJIMA S. *et al.*, *Med. Phys.*, **30** (2003) 771.
[8] SCHLESINGER T. E. *et al.*, *Semicond. Semimetals*, **43** (Academic Press) 1995.
[9] BOTTIGLI U *et al.*, *Med. Phys.*, **31** (2004) 2763.
[10] MARQUARDT D. W., *J. Soc. Ind. Appl. Math.*, **11** (1963) 431.
[11] DEL SORDO S. *et al.*, *Nuovo Cimento B*, **119** (2004) 257.
[12] CRANLEY K. *et al.*, *Catalogue of diagnostic x-ray spectra and other data*, IPEM Report 78, York:IPEM (1997).