Evaluation of the response of semiconductor dosimeters with the radiation qualities used for mammography

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Abstract. The aim of this study is to evaluate the response of commercial semiconductor dosimeters to different radiation qualities used for mammography and to estimate deviations and uncertainties related to different calibration scenarios. Energy dependence of the response of six semiconductor dosimeters was determined for four different anode-filter combinations and tube voltages from 25 to 35 kV. The results showed that the calibration coefficients for different radiation qualities (anode-filter and tube voltage combinations) compared to a reference radiation quality (Mo-Mo, 28 kV) deviate up to 14%. The semiconductor dosimeters showed a large energy dependence depending on the choice of the target/filter combination.

1. Introduction

Mammography is the most effective diagnostic method for detecting breast pathologies. The use of mammography encompasses both screening and diagnostic procedures. The first is performed in asymptomatic patients for the purpose of detecting abnormality in the breast tissue and the second is performed in patients with signs or symptoms suggestive of breast cancer. The mammography equipment used in clinics require a high-image quality that depends on the x-ray beam energy, controlled by the peak voltage (kVp) and the target/filter combination. Traditionally, the conventional target/filter combinations that have been used in mammography units prior to the newer digital units are the molybdenum/molybdenum (Mo/Mo), molybdenum/rhodium (Mo/Rh) and rhodium/rhodium (Rh/Rh). However, dosimeters used for mammography are generally calibrated with reference to the X-ray quality of Mo/Mo, W/Al, and W/Mo combinations and it is not clear how the target/filter combinations will affect the calibration coefficients of the dosimeters and, in particular, the semiconductor dosimeters where the higher effective atomic number of the sensitive volume will result in a high energy dependence. In this study, we evaluated the impact on the calibration coefficients of semiconductor dosimeters used for mammography applications with a variety of target/filter combinations.

1. Materials and Methods

In this study, six semiconductor dosimeters were calibrated at the Metrology Laboratory of Ionizing Radiation of Nuclear Energy Department, UFPE (LMRI-DEN/UFPE) using four different anode-filter combinations and tube voltages from 25 to 35 kV. The dosimeters and the software used are listed in Table I. All the dosimeters, except E, require a preselection of the anode/filter combination using adequate software. The PTWptw using radiation fields whose proprieties are well known, according to IAEA TRS 457[1].

The reference standard dosimeter at the LMRI-DEN/UFPE is an ionization chamber (PTW Freiburg, TW34069-2,5 N/S:000317) connected to a PTW Freiburg, TW10009, N/S:90329 electrometer, calibrated at DAKKS- Deutsche Akkreditierungsstelle. The variation in energy response of this chamber is not more than 2% over the range of radiation qualities used in this study[2].

The mammographic x-ray beam qualities with molybdenum and tungsten anodes were generated with x-ray tube from Gulmay models CF-100-2/1 and GX-320, respectively. Table 2 presents the characteristics of the radiation qualities used in this study. To monitor the radiation beam, a transmission ionization chamber is positioned at the exit of the x-ray tube, after and close to the field limiting aperture.

The calibration factor was determined as the ratio of the reference value and the value indicated by the instrument under calibration. The reference air kerma was previously calculated using the equation:

$$Ref_{K,a} = M_{ref} \text{ x } N_k \text{ x } K_{TP} \qquad (1)$$

where: M_{ref} corresponds to the measured ionization current,
N_k to the calibration coefficient of the standard ionization chamber obtained by the calibration certificate and
K_{TP} is the correction factor for temperature and pressure.

The reference value and the value indicated by the instrument were corrected by the value indicated by the monitor ionization chamber. So the calibration factor was calculated by the equation:

$$Fc= (Ref_{K,a} / M_{ref}) / (Ls / M) \qquad (2)$$

where
$Ref_{K,a}$- is the value of the reference air kerma;
M_{Ref} – is the value of the monitor chamber associated with the $Ref_{K,a}$;
Ls is the response of the semiconductor dosimeter and M is the correspondent monitor ionization chamber measurement.

Table 1- Characteristics of the dosimeters evaluated in this study.

Equipment	Manufacturer	Detector assembly	Measuring assembly	Software
A	RTI Electronics AB	Internal detector	Piranha 305	Ocean 2014 Version 1.0.2.1892
B	RTI Group AB	Internal detector	Piranha Multi (657)	Ocean 2014 Version 1.0.2.1892
C	RTI Group AB	Dose Probe	Piranha Multi (657)	Ocean 2014 Version 1.0.2.1892
D	UNFORS	Xi R/f & Mam	Xi	RaySafe Xi
E	UNFORS - Ray Safe	X2 MAM	X2	RaySafe X2
F	Radcal	AGMS-M	Accu Gold	Accu Gold by Radcal Version: 1.8.1

Table 2 – Characteristics of the radiation qualities used in this study.

Radiation quality	Filtration	1 st HVL in mm Al			
		25 kV	28kV	30 kV	35 kV
MMV(Mo-Mo)	0.03 mm Mo	0.29	0.32	0.33	0.37
MMH(Mo-Al)	0.03 mm Mo+ 2mm Al	0.56	0.61	0.64	0.73
MRV(Mo-Rh)	0.025 mm Rh	0.34	0.38	0.39	0.43
WMV(W-Mo)	0.03 mm Mo	0.36	0.37	0.38	0.41

The uncertainty of the calibration coefficient was calculated and consists of uncertainties related to reference air kerma measurements and measurements performed with the semiconductor dosimeter. The uncertainty value in the calibration factor is 2.5% (k = 2.00).

2. Results

Tables 3 and 4 present the results of the calibration factors obtained for the six semiconductor detectors evaluated in this study for the different x-ray qualities. The measurements with the x-ray quality Mo-Al were not performed with equipment F because it does not have adjustments for this type of quality radiation.

Table 3- Calibration coefficients for the six semiconductor dosimeters evaluated in function of the radiation qualities Mo -Mo and Mo-Al.

Dosimeter	Mo-Mo				MMH			
	25 kV	28 kV	30 kV	35 kV	25 kV	28 kV	30 kV	35 kV
A	0.998	1.008	1.03	1.021	0,919	0,94	0,954	0,953
B	0.972	1.009	1.017	1.023	0,89	0,921	0,93	0,93
C	1.056	0.999	0.975	0.925	0,975	0,945	0,927	0,873
D	1.005	1.01	1.009	1.007	0,977	0,992	0,987	0,984
E	1.019	1.022	1.025	1.018	0,992	0,988	0,989	0,981
F	0.987	0.994	1.0	1.004	-	-	-	-

Table 4- Calibration factors for the six semiconductor dosimeters evaluated in function of the radiation qualities Mo -Rh and W-Mo.

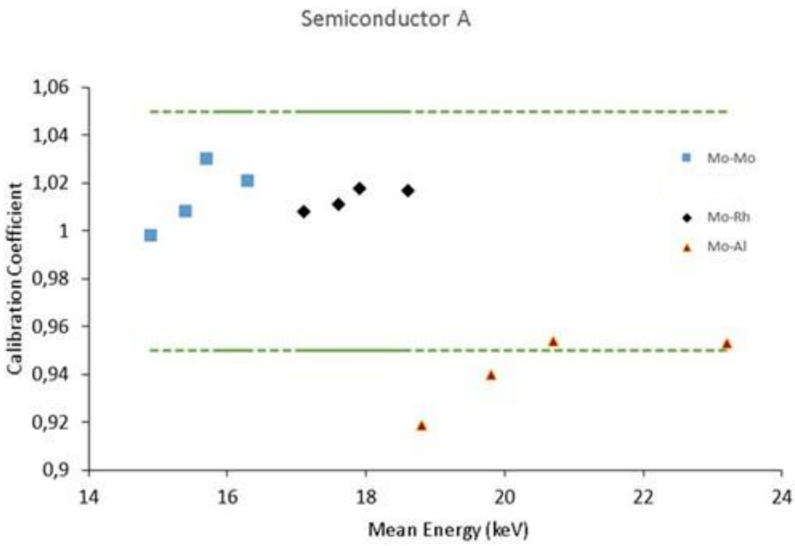
Dosimeter	Mo-Rh (MRV)				W-Mo			
	25 kV	28 kV	30 kV	35 kV	25 kV	28 kV	30 kV	35 kV
A	1.011	1.018	1.017	1.008	-	-	-	-
B	0.978	0.987	0.99	0.99	0.838	0.878	0.898	0.867
C	1.052	1.005	0.976	0.941	-	-	-	-
D	0.946	0.947	0.95	0.99	0.901	0.902	0.895	0.891
E	0.984	0.985	0.986	0.988	0.909	0.925	0.906	0.907
F	0.912	0.925	0,919	0.929	0.912	0.925	0.916	0.929

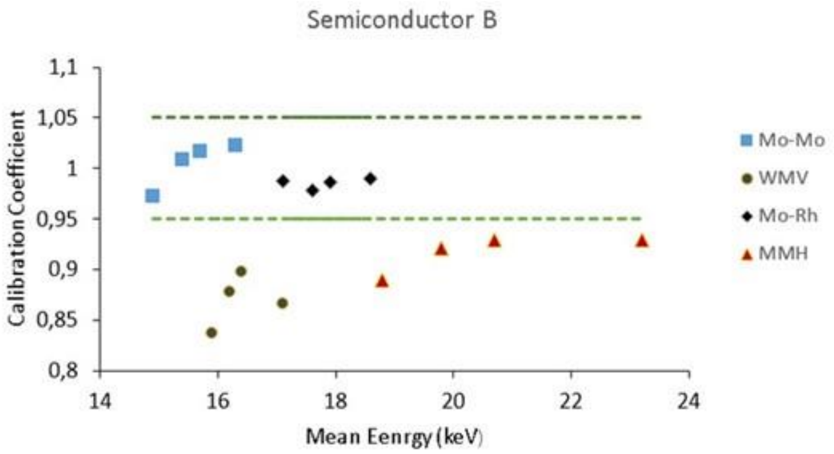
Figure 1 shows the calibration coefficients for the six semiconductor dosimeters evaluated as a function of the radiation energy. The horizontal dashed green lines represent ±5% tolerance level, as required by IEC 61267 [3]. The results show that equipment C has a high energetic dependence when compared to the other detectors. It is also observed that the calibration coefficient for the WMV (W-Mo) quality of the x-ray beam is out of the tolerance limits, for all the detectors. The calibration coefficient of this quality presents a deviation of up to 14% compared to the reference radiation quality Mo-Mo - 28kV.

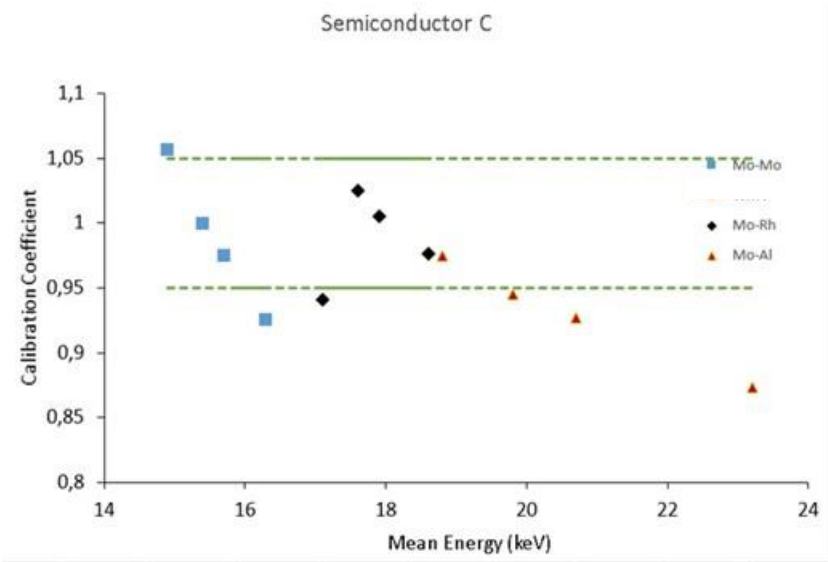
3. Conclusion

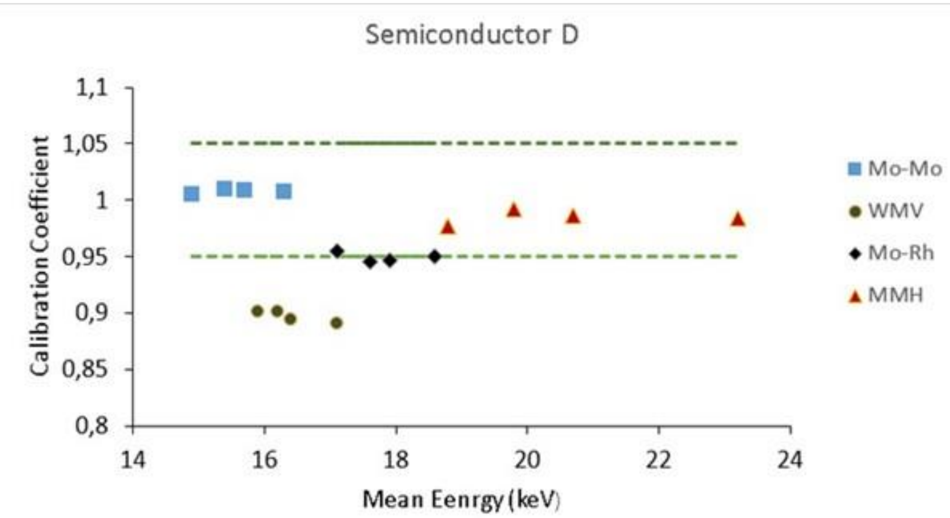
The semiconductor dosimeters evaluated present a response depending on the anode-filter combinations. Dosimeter C (Piranha Multi with the external probe) showed the highest energy dependence response. All the dosimeters presented a calibration coefficient outside accepted limits when the WMV x-ray quality is used. The calibration in this energy for the use of the dosimeter with MMV x-ray quality (28kV) can lead to a under-response in the measurement of air kerma by around 14%. It is recommended that dosimeters should be calibrated for all radiation qualities (anode-tube voltage and filtration) of interest for which they are intended to be used.

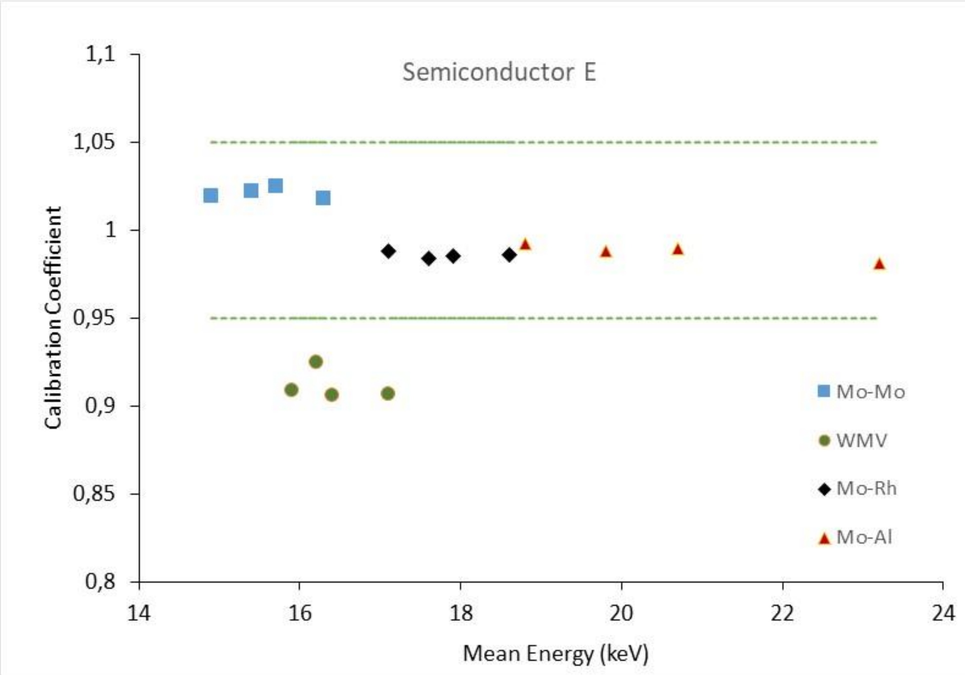
Figure 1- Calibration coefficients for the six semiconductor dosimeters evaluated as a function of the radiation energy.

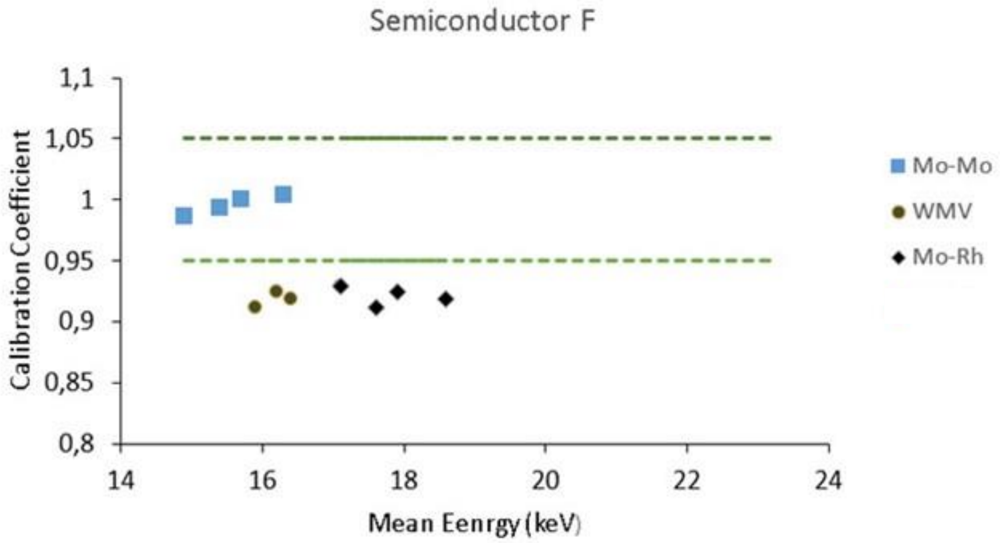



Semiconductor B
Calibration Coefficient
1,1
1,05
1
0,95
0,9
0,85
0,8
14
16
18
20
22
24
Mean Eenrgy (keV)
Mo-Mo
WMV
Mo-Rh
MMH


Semiconductor C
Calibration Coefficient
1,1
1,05
1
0,95
0,9
0,85
0,8
14
16
18
20
22
24
Mean Energy (keV)
Mo-Mo
Mo-Rh
Mo-Al


Semiconductor D
Calibration Coefficient
1,1
1,05
1
0,95
0,9
0,85
0,8
14
16
18
20
22
24
Mean Eenrgy (keV)
Mo-Mo
WMV
Mo-Rh
MMH





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[2] PTW Freiburg, Manual da Camara de Ionização 6 cm 3 flat mammo-chamber SFD 34069 https://www.ptwdosimetry.com/en/support/downloads/, acessado em 18/07/2023.

[3] International Electrotechnical Commission. NORME INTERNATIONALE CEI/IEC 61267: Medical diagnostic X-ray equipment- Radiation condition for use in the determination of characteristics; 2005.