

## COMPARISON BETWEEN TWO HOMEMADE DOSIMETERS FOR COMPUTED TOMOGRAPHY: AN IONIZATION CHAMBER AND A SEMICONDUCTOR DETECTOR

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### ABSTRACT

Recently a cylindrical ionization chamber and a dosimetric system using a commercial semiconductor detector were developed at the Calibration Laboratory of IPEN (LCI) and at the Nuclear Instrumentation Laboratory of CRCN-NE (LIN), respectively. The ionization chamber was produced using Brazilian low cost materials and the semiconductor dosimeter was a low cost commercial radiation detector. Their main application is in dosimetry of computed tomography (CT) equipment. Several tests were performed to characterize these detectors; no comparison of the response of such radiation detectors, under the same conditions, was found in the literature. This type of comparison is important to determine their advantages and disadvantages. The CT ionization chamber produced at LCI was made of PVC and PMMA, with a collecting electrode of aluminum. The sensitive volume walls were made of PVC coated with graphite. The dimensions of this ionization chamber are: 6.70 mm of internal diameter, wall thickness of 0.26 mm and a sensitive length of 100.0 mm. The photodiode BPW34FS from OSRAM was the tested semiconductor device. Some characteristics of this photodiode are: dimension of 4.5 mm x 3.7 mm; photosensitive area of 2.65 mm x 2.65 mm; and spectral range of sensitivity from 780 to 1100 nm. The performed tests were: linearity of response, angular and energy dependence. All tests were conducted using the same setup, to allow geometrical reproducibility. The responses of the radiation detectors were within the international recommendations of the IEC 61674, except for the angular dependence of the semiconductor detector due to its asymmetric structure.

## 1. INTRODUCTION

The effective doses from computed tomography (CT) procedures are typically higher than those associated to other common types of diagnostic radiology procedures. Dose measurements in CT can be taken using ionization chambers, thermoluminescent dosimeters (TLD) or semiconductor detectors, among other types of radiation detectors.

For CT dosimetric procedures, there is a special type of ionization chamber named pencil ionization chamber. This ionization chamber is very long compared to its diameter; it is able of integrating the dose over the thickness of a single beam. The length of the sensitive volume (about 3 cm<sup>3</sup>) of a typical pencil ionization chamber is 10-15 cm [1]. Other very utilized radiation detectors used for clinical dosimetry in CT procedures are the thermoluminescent dosimeters, mainly LiF:Mg,Ti (TLD-100) [2, 3]. Thermoluminescent dosimeters (TLD) are of great interest, because of their following advantages: i) wide useful dose range, ii) small physical size, iii) no need for high voltage or cables. Another detection method is the use of semiconductor detectors [4, 5]. They have some advantages to be applied as detectors, as high sensitivity, small physical size, no need for high voltage and ability of instantaneous readout.

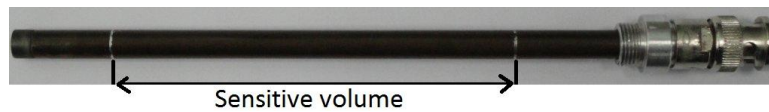
The objective of this work was to compare the performance of two radiation detectors in standard CT radiation beams: a homemade ionization chamber developed at the Calibration Laboratory of IPEN (LCI) and a commercial semiconductor device as a homemade dosimetric system, in relation to the following operational tests: linearity of response, angular and energy dependence.

## 2. MATERIALS AND METHODS

In this work a homemade ionization chamber developed at LCI and a commercial photodiode BPW34FS from OSRAM were utilized. The technical specifications of the homemade ionization chamber are listed in Table 1. The homemade ionization chamber can be seen in Figure 1. For the measurements, the homemade ionization chamber was connected to an electrometer PTW Unidos E.

**Table 1. Technical specifications of the homemade ionization chamber developed at IPEN**

Characteristics	Specifications
Electrode material	Aluminum
Wall material	PVC coated with graphite
Electrode thickness	1.2 mm
Chamber inner diameter	6.7 mm
Chamber wall thickness	0.26 mm
Chamber sensitive length	100.0 mm
Chamber sensitive volume	3.40 cm <sup>3</sup>



**Figure 1. Homemade ionization chamber developed at LCI.**

The characteristics of the photodiode are listed in Table 2. The photodiode is shown in Figure 2a. The photodiode detection system consists of: the photodiode; a Flip-flop electrometer (EFF) developed at the Nuclear Instrumentation Laboratory of CRCN-NE (LIN); and the DoseX<sup>®</sup> software, which controls the EFF (Fig. 2b). The semiconductor device was soldered in a printed circuit board, and a cylinder cap was used to avoid the environmental light.

**Table 2. Technical specifications of the Photodiode BPW34FS from OSRAM (as stated by the manufacturer)**

Characteristics	Specifications
Dimensions	4.5 mm x 3.7 mm
Photosensitive area	2.65 mm x 2.65 mm
Spectral range of sensitivity	from 780 to 1100 nm
Encapsulation	Black plastic



(a)



(b)

**Figure 2. a) Photodiode BPW34FS from OSRAM; b) the dosimetric system: the detector, the Flip-flop electrometer, a computer with DoseX<sup>®</sup> software.**

The performed tests were: linearity of response, angular and energy dependence. The comparison was made at LCI using an industrial X-ray unit, Pantak/SEIFERT, model ISOVOLT 160HS, operating from 5 to 160kV. The standard diagnostic radiology qualities were RQT8, RQT9 and RQT10 [6]. The linearity of response results and angular dependence of the homemade ionization chamber were already reported [7].

For the angular dependence test, a goniometer, OPTRON, model GN1 200, was also utilized. In all tests the detectors were positioned at 1.00 m from the X-ray tube, and all ionization currents were corrected for the standard conditions of temperature and pressure.

Table 3 describes the characteristics of the diagnostic radiology qualities, established at LCI, according to IEC 61267 [6].

**Table 3. Standard computed tomography qualities at the Pantak/Seifert X-ray equipment, using a constant tube current of 10 mA**

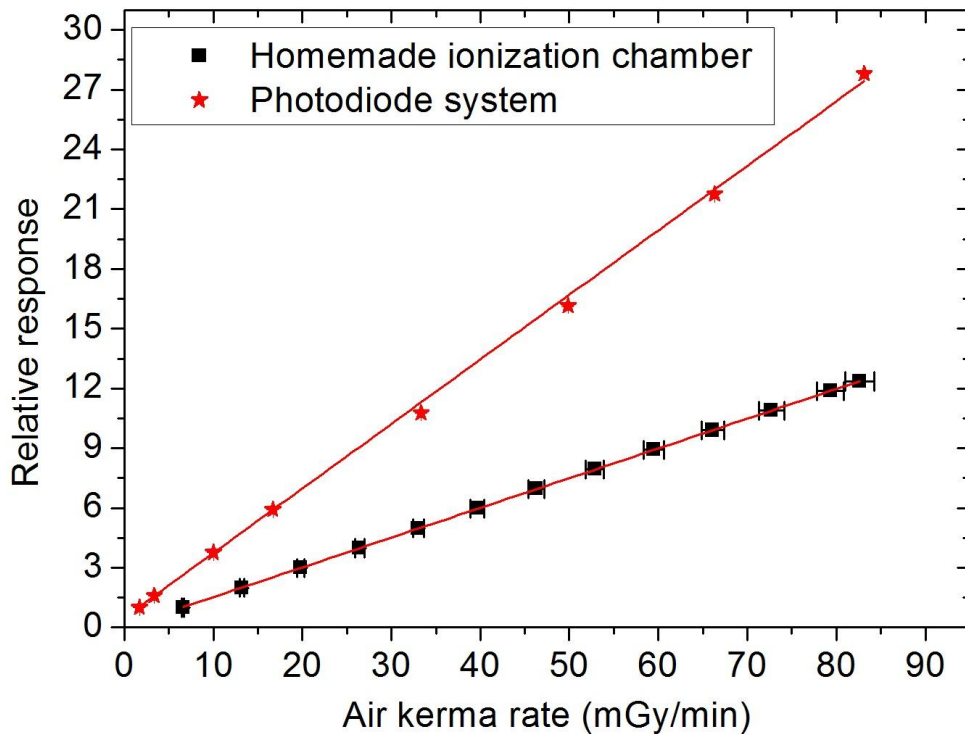
Radiation quality	Voltage (kV)	Additional filtration (mmAl)	Half-value layer (mmAl)	Air kerma rate (mGy/min)
RQT8	100	3.2Al+0.30Cu	6.90	22.0 ± 0.33
RQT9	120	3.5Al+0.35Cu	8.40	34.0 ± 0.51
RQT10	150	4.2Al+0.35Cu	10.1	57.0 ± 0.86

The air kerma rate was determined using a Radcal ionization chamber, type RC3CT. This chamber has traceability to the German primary standard laboratory Physikalisch-Technische Bundesanstalt (PTB).

### 3. RESULTS AND DISCUSSION

#### 3.1. Linearity of response

The tube current was varied from 2 mA to 25 mA for the ion chamber, and from 0.5 mA to 25 mA for the photodiode, for a fixed voltage of 120 kV and the additional filtration of 3.5 mmAl + 0.35 mmCu (RQT 9 beam). The irradiation time of each detector was 15 s. Figure 3 shows the results for the chamber and the photodiode response. For the ionization chamber, the response was normalized for a current of 2 mA, and for the photodiode, the response was normalized for a current of 0.5 mA. Linear fits were obtained, and the uncertainty in the angular coefficient was only 0.01% for the ionization chamber and 0.002% for the photodiode. The correlation coefficients  $R^2$  were 0.99999 and 0.99959, for the ionization chamber and photodiode system, respectively.

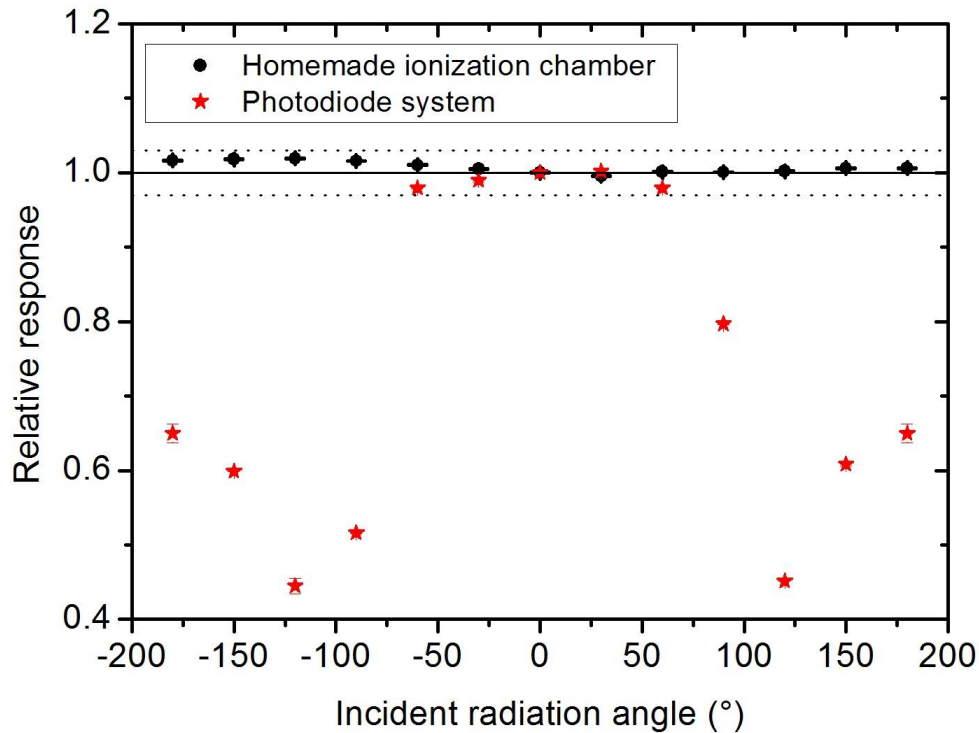


**Figure 3. Linearity of response of the homemade ionization chamber developed at IPEN/CNEN-SP [7] and of the photodiode. The maximum uncertainty for the photodiode response was 1.8%, not visible in the figure.**

### 3.2. Angular dependence test

The detectors were rotated around their central axes from  $-180^\circ$  to  $+180^\circ$ , in steps of  $30^\circ$ . The standard diagnostic radiology quality used in this test was RQT9 beam.

Figure 4 shows the angular dependence test for both dosimeters. For the ionization chamber, the maximum variation obtained was 1.9%, in agreement with the IEC 61674 standard [8], which allows a maximum variation of 3% in relation to  $0^\circ$  position. For the BPW34FS commercial photodiode, the maximum variation obtained in the angular dependence was 56%. This high angular dependence occurs due to the asymmetric structure of the photodiode: it has a thick metal substrate where the silicon chip rests. Even considering this high angular dependence, apparently this is not a problem for computed tomography dosimetry, because the X-ray tube of a tomograph performs complete rotations irradiating equally the radiation detector.



**Figure 4. Angular dependence test of the homemade ionization chamber developed at IPEN/CNEN-SP [7] and the BPW34FS commercial photodiode. Normalization was performed in relation to 0°. The dotted lines represent the limits recommended by the IEC 61674 standard [8].**

### 3.3 Energy dependence

The X-ray energy dependence of both radiation detectors was analyzed for the radiation qualities RQT8, RQT9 and RQT10 which correspond to the voltages of 100, 120 and 150 kV, respectively. The electrical current was fixed at 10 mA.

Table 4 shows the correction factors obtained in the energy dependence test of the ionization chamber and the photodiode for the three radiation qualities that are represented on the *x*-axis by the corresponding half-value layers (HVL).

The energy dependence obtained for the homemade ionization chamber was 4.3% and for the photodiode was 38.1%. Since the sensitivities are not identical for each radiation quality, the application of a calibration factor is necessary, depending on the radiation quality.

**Table 4. Correction factors of the homemade ionization chamber and the photodiode system in standard computed tomography (RQT qualities) beams**

Radiation quality	Half-value layer (mmAl)	Correction factors	
		Homemade ionization chamber	Photodiode system
RQT8	6.90	0.979±0.021	1.170±0.020
RQT9	8.40	1.000±0.021	1.000±0.011
RQT10	10.1	1.021±0.022	0.847±0.004

#### 4. CONCLUSIONS

In this work two detectors were tested and compared for use in CT beam dosimetry: a homemade ionization chamber and a homemade dosimetric system using a commercial photodiode. The tests performed were: linearity of response, angular and energy dependence. All tests achieved satisfactory results within the international recommendations, except for the angular dependence of the semiconductor detector. Apparently this is not a problem for computed tomography dosimetry, because the X-ray tube of a tomograph performs complete rotations irradiating equally the detector.

#### ACKNOWLEDGMENTS

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