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Response and Monte Carlo evaluation of a reference ionization chamber for radioprotection level at calibration laboratories

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HIGHLIGHTS

- A special ionization chamber, inserted in a slab phantom, was designed and evaluated.
- This dosimeter was utilized for the $H_p(10)$ determination.
- The evaluation of this dosimeter followed international standards.
- The PENELOPE Monte Carlo code was used to evaluate the design of this dosimeter.
- The tests indicated that this dosimeter may be used as a reference dosimeter.

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ABSTRACT

A special parallel plate ionization chamber, inserted in a slab phantom for the personal dose equivalent $H_p(10)$ determination, was developed and characterized in this work. This ionization chamber has collecting electrodes and window made of graphite, and the walls and phantom made of PMMA. The tests comprise experimental evaluation following international standards and Monte Carlo simulations, employing the PENELOPE code to evaluate the design of this new dosimeter. The experimental tests were conducted employing the radioprotection level quality N-60 established at the IPEN, and all results were within the recommended standards.

1. Introduction

One of the first steps to maintain an accurate measurement system is to evaluate the performance of the dosimetric equipment (as ionization chambers) and the characteristics of the X-ray qualities utilized at calibration laboratories (IAEA, 2007).

Since body related dose quantities, such as the effective dose, are not directly measurable and cannot be used directly in radiation protection monitoring, operational quantities, such as the "personal dose equivalent" and "ambient dose equivalent" were defined (ICRU, 1993). For purposes of routine radiation protection, it is desirable to characterize the potential exposure of individuals in terms of a single dose equivalent quantity. For individual monitoring, the $H_p(10)$ was created, that is the dose equivalent in tissue at the depth of 10 mm below a specified point in the human body (10 mm is used for strongly penetrating radiation beams).

For calibration of personal dosimeters, different types of phantoms, i.e., phantoms consisting of water, PMMA, ICRU tissue-equivalent material, polycarbonate, among others, are necessary to satisfy the $H_p(10)$ definition. In this scenario, Ankerhold et al. (2001) developed the first prototype of a secondary standard ionization chamber to measure the personal dose equivalent $H_p(10)$ (Ankerhold et al., 2001, 1999) and other quantities such as the $H^*(10)$ (Ankerhold, 2006; Hupe and Ankerhold, 2007).

Considering that the calibration of instruments used in radioprotection measurements is essential for monitoring procedures, and that about 20% of the instruments used in those routines present problems during their calibration and may require some adjustments (Green et al., 1999), special methodologies for the calibration of these kinds of instruments were established at the Calibration Laboratory of IPEN (Potiens and Caldas, 2002), as well as the development of new dosimeters to be employed as reference systems (Maia and Caldas, 2005; Perini et al., 2012). The methods may be applied in the calibration procedures of personal

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dosimeters such as those used for radiation protection measurements, instruments utilized in direct beams, and quality control of instruments in many different applications (Hupe and Ankerhold, 2006; Bartlett, 2006).

At the Calibration Laboratory (LCI) of the Instituto de Pesquisas Energéticas e Nucleares (IPEN/CNEN-SP), a new dosimeter was developed, intended to be used as a reference instrument for the determination of the $H_p(10)$. In this dosimeter, the ionization chamber is inserted in a slab phantom, which allows the direct measurement of the $H_p(10)$, without the use of correction factors. The main differences of this dosimeter and another one recently reported (Silva et al., 2011) are the dimensions, sensitive volume and the use of graphite as collecting electrode material, as well as the guard ring (instead of a PMMA plate coated with graphite). Furthermore, in this work, several operational tests were presented, in order to fully characterize this dosimeter, and the responses compared to international standards (IEC, 1997, 2011).

The objective of this work was to develop and characterize a new plane parallel ionization chamber, to be applied as a reference standard for the determination of the $H_p(10)$ at the LCI. This characterization was carried out employing the IEC 61674 and IEC 60731 standards (IEC, 1997, 2011) and Monte Carlo simulations. The simulations were used to evaluate the influence of the collecting electrode, guard ring and screws on the energy deposition at the sensitive volume.

2. Materials and methods

The plane parallel ionization chamber, built at the LCI, has a graphite collecting electrode and a window made of a very thin layer (about 0.032 mm in thickness) of graphite ink. It also has an inner graphite electrode, composed of a ring of 50 mm in diameter and 2 mm in thickness, a guard ring made of graphite with 100 mm in diameter, and a hole in the center with 50.5 mm in diameter (assembled as the ionization chamber developed by Ankerhold et al., 2001). The slab phantom, where the ionization chamber is inserted, was developed with 12 PMMA plates juxtaposed. These plates are all connected with PMMA pins, in order to support the plates and the ionization chamber.

The painting process of the electrode was obtained as follows: the PMMA disk and parts were cleaned, to remove dust, oil and moisture; after that, the material was heated until 35 °C for 5 min (to dry the disk); the plates were inserted in a rotary system (a dish with constant speed) for the application of the graphite spray (Aerodag G^{TM}). This technique allows a better homogeneity in the disk. At the end of the painting process the material was dried again, but now with 30 °C, during 15 min. Many initial tests were carried out (with different kinds of inks) until the best ink was selected. A scheme of the ionization chamber developed and characterized in this work is shown in Fig. 1.

A Pantak/Seifert X-ray generator, model ISOVOLT 160HS (160 kV), was utilized for the tests. The X-ray qualities, radioprotection level (ISO, 1997), established in this equipment are listed in Table 1. The air kerma rates were determined using a standard ionization chamber, traceable to the German Primary Dosimetry Laboratory, Physikalisch-Technische Bundesanstalt (PTB). This ionization chamber is a Physikalisch-Technische Werkstätten (PTW), model 32002, with a sensitive volume of 1000 cm^3, and it was connected to a PTW electrometer, UNIDOS 10001. This is a secondary standard dosimeter for X-ray beams, radioprotection level.

The assembled ionization chamber was tested in relation to its operational characteristics according to the recommendations of the IEC 61674 and IEC 60731 standards (IEC, 1997, 2011) depending on the tests. For all tests in this work the ISO N-60 X-ray beam recommended by ISO 4037-1 (ISO, 1997) was utilized.

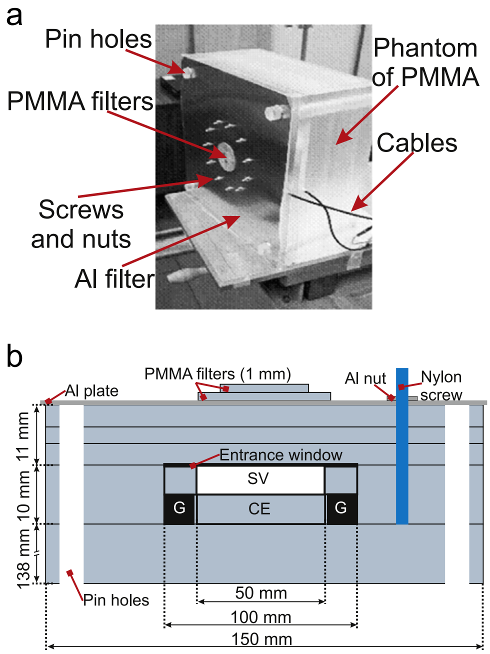

Fig. 1. (a) Photo of the ionization chamber inserted in a slab phantom (PMMA, with dimensions of 300 mm × 300 mm × 150 mm), and (b) detailed scheme where it is possible to observe the ionization chamber and its main components, as the sensitive volume (SV), collecting electrode (CE), and guard ring (G). In (b) some components are out of proportion for a better visualization.

Table 1
Characteristics of the X-ray qualities, radioprotection level, established at the Calibration Laboratory of IPEN, as recommended by ISO (1997).

Radiation quality	Voltage (kV)	Additional filtration[a] (mm)	HVL (mmCu)	Air kerma rate[b] ($mGy\,h^{-1}$)
N-60	60	0.60(Cu)	0.250	19.90
N-80	80	2.00(Cu)	0.612	10.50
N-100	100	5.00(Cu)	1.14	5.01
N-150	150	2.50(Sn)	2.40	41.50

[a] In all cases, 4.0 mm of Al was added to the Cu and Sn filtration.
[b] Air kerma rates for a focus-chamber distance of 2.5 m, X-ray tube current of 20 mA and a circular field diameter of 42.0 cm.

The simulations of this new dosimeter were carried out with the PENELOPE/penEasy Monte Carlo code for radiation transport (Salvat et al., 2008; Sempau et al., 2011). As this new dosimeter was developed at the LCI, all dimensions and materials are known, and they were used as input for the simulations. The spectrum of the LCI irradiation system was not available, and therefore, the one used in the simulations was obtained experimentally from the PTB (Büermann, 2004).

The industrial X-ray unit, Pantak Seifert, model ISOVOLT 160 HS operates from 5 to 160 kV, has a 0.8 mmBe window and a W-anode angle of 21°. The spectra from PTB were acquired in a 450 kV Yxlon facility with a tube of type “B450-1H450” from Thales, at a distance of 100.0 cm from the X-ray focus. The W-anode angle was 21° and the window was 7.0 mmBe. As shown elsewhere (Perini et al., 2013), for CT radiation qualities, the difference between experimental measurements and simulated results was below 3.0%, but still within the expanded statistical (type A) uncertainties. These results pointed out that the PTB spectra may be employed to represent the LCI equipment. In this work, the spectrum representing the ISO N-60 radiation quality (the standard radiation quality at the LCI), was employed for all the simulations.