Computational evaluation of a pencil ionization chamber in a standard diagnostic radiology beam

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Abstract: In this work a pencil ionization chamber was evaluated. This evaluation consisted in the determination of the influence of the ionization chamber components in its response. For this purpose, the Monte Carlo simulations and the spectrum of the standard diagnostic radiology beam (RQR5) were utilized. The results obtained, showed that the influence of the ionization chamber components presented no significant influence on the chamber response. Therefore, this ionization chamber is a good alternative for dosimetry in diagnostic radiology.

Keywords: ionization chamber, Monte Carlo simulation, standard diagnostic radiology beam

Resumo: Neste trabalho, uma câmara de ionização tipo lápis foi avaliada. Esta avaliação consistiu na determinação da influência dos componentes da câmara de ionização na sua resposta. Para este propósito, simulações de Monte Carlo e o espectro do feixe de radiação padrão para radiodiagnóstico (RQR5) foram utilizados. Os resultados obtidos mostraram que a influência, dos componentes da câmara de ionização, foi insignificante na sua resposta. Portanto, esta câmara de ionização é uma boa alternativa para dosimetria em radiodiagnóstico.

Palaras-chave: câmara de ionização, simulação de Monte Carlo, feixe de radiodiagnóstico padrão

1. INTRODUCTION

The first method for determining dose was the radiation-induced erythema. In 1908, Paul-Ulrich Villard proposed a new technique for determination of radiation dose, based on the ionization generated in the air under standard conditions of temperature and pressure. This concept of dose determination was adopted at the Second International Congress of Radiology in 1928 and has been used in medical dosimetry since its discovery [Dewerd and Wagner, 1999].

In diagnostic procedures such as x-ray examinations, nuclear medicine and computed tomography (CT), the knowledge of dose received by the patient is important to optimize image quality and also for radiation protection purposes. Several dosimeters were developed to determine the radiation doses involved in diagnostic radiology procedures. A dosimeter widely utilized for this purpose is the ionization chamber. There are several types of ionization chambers for different applications, such as the pencil ionization chamber.

Pencil ionization chambers were developed and applied to CT dosimetry. These chambers have a special configuration and some particular properties. They are similar to the cylindrical ionization chambers, however, they are thinner and longer than cylindrical chambers.

Currently, it is not common to use pencil ionization chambers for dosimetry of other radiation beams, in addition to CT beams. In the literature it is possible to find a work of Maia and Caldas (2003), showing that the energy dependency of a commercial pencil ionization chamber in standard diagnostic radiology beams, was only 1.3%.

Recently, at the Instituto de Pesquisas Energéticas e Nucleares (IPEN) a pencil ionization chamber was developed. This ionization chamber presents differences in relation to commercial ionization chambers. These differences are related to the material used in its construction and also the geometrical arrangement of its components, such as the BNC connector position.

The objective of this work was to investigate the influence of the components of the pencil ionization chamber on the energy deposition in its sensitive volume. For this purpose, the Monte Carlo simulations and a diagnostic radiology beam (RQR5) were adopted. Furthermore, we intend to extend the use of this ionization chamber for dosimetry in diagnostic radiology. This will help hospitals and clinics that have only this type of ionization chamber to expand its use, improving the quality of the sectors that work with X-ray dosimetry.

2. MATERIALS AND METHODS

The pencil ionization chamber evaluated in this work (figure 1) was designed and assembled at the IPEN. The technical specifications of this dosimeter are listed in table 1. The pencil chamber was manufactured with PMMA, graphite-coated PVC, aluminum and co-axial cables.

Figure 1. Pencil ionization chamber prototype developed at the IPEN.

Table 1. Pencil ionization chamber technical specifications.

Characteristics	Specifications
Collecting electrode material	Aluminum
Wall material	PVC coated with graphite
Collecting electrode diameter (mm)	1.22±0.02
Chamber inner diameter (mm)	6.72±0.03
Chamber wall thickness (mm)	0.26±0.02
Chamber sensitive volume (cm^3)	3.4±0.1

To simulate the pencil ionization chamber, we used the MCNP-4C Monte Carlo code [Briesmeister, 2000]. This code allows to simulate the transport of different types of ionizing radiation. The simulation was based on the actual dimensions of the ionization chamber as shown in table 1 and figure 1.

The spectrum used in the simulations was the standard diagnostic radiology beam (RQR5). The main characteristics of this standard quality are: tube voltage of 70 kV, half-value layer of 2.58 mmAl and air kerma rate of (37.88 ± 0.32) mGy/min.

This spectrum was provided by the Primary Standard Laboratory of Germany Physikalisch Technische Bundesnstalt (PTB) [Büermann, 2012]. This spectrum was acquired at the PTB 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, same distance utilized in the simulations .

The number of simulated histories was 2.1x10^9, and the deposited energy was obtained using *tally* F6.

3. RESULTS AND DISCUSSION

The components of the pencil ionization chamber were studied to evaluate their respective influences on the energy deposited in its sensitive volume.

The interest of the simulations was to determine the energy deposited in the material (air) of the ion chamber sensitive volume. The influence of some components (collecting electrode, PMMA body and BNC connector) on that quantity was estimated by replacing each studied component with air but without altering the scoring volume. The simulation results were then divided by the value obtained for the complete ionization chamber. The influence of the wall material was obtained as the ratio between the PVC wall and the PMMA wall responses.

The simulated ionization chamber with the various components is shown in figure 2, and the results obtained were presented in table 2.

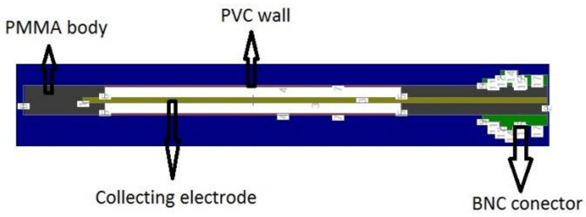

Figure 2. Pencil ionization chamber simulated by the MCNP-4C Monte Carlo code.

Table 2. Influence of the ionization chamber components on the energy deposition in the sensitive volume for the RQR5 radiation quality.

Studied component	Ratios of the energy deposition
BNC conector	1.00±0.01
Collecting electrode	1.02±0.01
PMMA body	0.99±0.01
PMMA instead PVC	1.06±0.01

From the table 2, it is possible to observe that the BNC connector and the body of PMMA have a negligible influence on the pencil chamber response.

The collecting electrode made of aluminum presented a small influence. This is justified by the fact that Compton recoil electrons and photoelectrons produced by interactions of photons with the collecting electrode contribute to the energy deposited in the sensitive volume. In the literature [Muir and Rogers, 2011] the influence of the collecting electrode, made of aluminum, was up to 50.0% for an 200 kVp incident beam.

The wall material was the last component studied. The simulated response for the ionization chamber with a PMMA wall was lower than that corresponding to the same prototype but with a PVC wall. This might be caused by the higher effective atomic number of PVC for photon interactions.

4. CONCLUSIONS

In this work a pencil ionization chamber was evaluated by Monte Carlo simulation. These simulations helped to estimate the influence of different components of the ionization chamber on the energy deposition in the sensitive volume. The simulations showed that there is no influence in the new BNC connector position while the wall made of PVC coated with graphite presented a considerable influence, when compared with PMMA wall. Considering the results obtained, it is possible to conclude that the studied pencil ionization chamber may be a good alternative for dosimetry in diagnostic radiology.

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References:

BRIESMEISTER, J.F. 2000. *MCNP - A general Monte Carlo N-particle transport code, Version 4C Report LA-13709-M*. Los Alamos National Laboratory.

BÜERMANN, L. 2012. PTB *Radiation qualities for calibration of secondary standards.* Avaiable in: <http://www.ptb.de/en/org/6/62/625/pdf/strhlq.pd>f. Acess date: 05/08/2012.

DeWERD, L.A and WAGNER, L.K. Characteristics of radiation detectors for diagnostic radiology. *Applied Radiation and Isotopes*, v.50 (1), p.125–136, 1999.

MAIA, A. F. and CALDAS, L.V.E. Performance of a pencil ionization chamber in various radiation beams. *Applied Radiation and Isotopes*, v. 55 (5), p. 595–601, 2011.

MUIR, B. R. and ROGERS, D. W. O. The central electrode correction factor for high-Z electrodes in small ionization chambers. *Medical Physics*, v.38, p. 1081–1088, 2011.