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Evaluation of an extrapolation chamber for dosimetry in computed tomography beams using Monte Carlo code (MCNP5)

Maysa C. Castro[a,*], Natália F. Silva[a], Lucas R. Santos[b], Felipe B. Cintra[a], Linda V.E. Caldas[a]

[a] Instituto de Pesquisas Energéticas e Nucleares, Comissão Nacional de Energia Nuclear (IPEN / CNEN- SP), Av. Professor Lineu Prestes, 2242, 05508-000, São Paulo, SP, Brazil

[b] Instituto Federal de Educação, Ciência e Tecnologia de São Paulo (IFSP), Av. Mutinga, 951 – CEP, 05110-000, São Paulo, SP, Brazil

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ABSTRACT

Computed tomography (CT) is responsible for the highest dose values to the patients during the exams. Therefore, the radiation doses in this procedure must be accurate. However, there is no primary standard system for this kind of radiation beam yet. A homemade extrapolation ionization chamber was preliminary evaluated for the establishment of a CT beam primary standard. The aim of this study was to determine the influence that the various components of the extrapolation chamber may present on the energy deposited in its sensitive volume. Different materials for its collecting electrode were also studied for this type of radiation beam. The evaluation of the homemade extrapolation chamber showed the highest influence of 25.9% for the collecting electrode, and the best material for the collecting electrode for CT radiation beams was graphite.

1. Introduction

Computed Tomography (CT) has shown a growing use when it concerns the implementation of diagnostic tests; this is due to technological advances of this equipment as the process of obtaining images became faster (Boone, 2007). Therefore, there is an increased concern regarding the dose received by the patients to undergo this kind of imaging procedure.

For the dosimetry of CT beams, the radiation detector is usually a pencil-type ionization chamber. This type of dosimeter presents a uniform response to the incident radiation beam from all angles, which makes it suitable for such equipment since the X-ray tube executes a circular movement around the table during irradiation (Suzuki and Suzuki, 1978). The commercial chamber used to perform the quality control testing of the equipment has usually a 10 cm length of the sensitive volume.

However, there is no established primary standard system for this kind of radiation beam yet. So, an extrapolation ionization chamber, built at the Calibration Laboratory (LCI) of the Instituto de Pesquisas Energéticas e Nucleares (IPEN), was preliminary evaluated for the establishment of a CT primary standard (Dias and Caldas, 1998, 2001). An extrapolation chamber is a parallel-plate ionization chamber that allows the variation of its sensitive air volume. Usually, this kind of ionization chamber is utilized in beta radiation dosimetry (Dias and Caldas, 1998), but this chamber was already used for low-energy radiation beams too, and it showed results within the international recommended limits (Dias and Caldas, 2001; Neves et al., 2012).

The advantage to establish a CT primary standard using an extrapolation chamber is the fact that it may be used for the calibration of pencil-type ionization chambers without the need to consider the kerma-length product (P_{KL}), once there exist pencil-type ionization chambers with different lengths of the sensitive volume. Therefore, the process will be more accessible and easy to perform.

For calibration laboratories, it is very important that the characteristics of the dosimeters are widely known, as well as the influence that the various components of the extrapolation chamber may present on the energy deposited in its sensitive volume. Different materials for its collecting electrode were also studied for this type of radiation beam. This study will show if it is a good idea to change the collecting electrode material for aluminum once this is the most suitable material for X-rays.

This evaluation was carried out employing the MCNP5 Monte Carlo code (LOS ALAMOS LABORATORY, 2008). This database and the code were extensively utilized for the characterization of extrapolation chambers, showing consistent results for the use of other codes. This code allows to simulate the transport of protons and electrons with energies between 10^3 eV to 10^{10} eV, so the radiation energies used in this study are within those recommended. Moreover, the geometry system is very detailed compared to the other Monte Carlo codes (Wulff et al., 2008; Briesmeister, 2000; Xu et al., 2019)

* Corresponding author.
E-mail addresses: maysadecastro@gmail.com, mcastro@ipen.br (M.C. Castro).

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Fig. 1. Homemade extrapolation chamber.

Table 1
Dimensions of the extrapolation chamber.

Component	Material	Dimensions (mm)	
		Thickness	Diameter
Chamber Body	Aluminum	126	31.0
Aluminum Base	Aluminum	10.0	75.0
Screw Control	Aluminum	24.5	11.0
Collecting Electrode Support	PMMA	14.5	60.0
Collecting Electrode	Graphite	3.50	30.0
PMMA Ring	PMMA	3.50	Internal 30.0 External 38.0
Guard Ring	Graphite	3.50	Internal 38.0 External 60.0
Entrance Window	Mylar Aluminized	0.008	60.0
PMMA Cap	PMMA	40.0	Internal 150 External 160

2. Materials and methods

An extrapolation chamber with a graphited collecting electrode of 30 mm in diameter, entrance window made of aluminized polyethylene terephthalate and a graphited guard ring was simulated in this work. Fig. 1 shows the extrapolation ionization chamber, and in Table 1 are presented the dimensions of the extrapolation chamber developed and measured by Dias and Caldas (1998, 2001) at the LCI.

In the simulation some components were treated as groups, internal and external components. The external components are the PMMA cap and the chamber body; the internal components are the aluminum base, the screw control and the collecting electrode support. In section Results and Discussion the image obtained from the simulation will be presented showing the components and their materials.

For the simulation using the Monte Carlo code it was necessary to obtain the energy spectra for the computed tomography beams. The characteristics of the radiation qualities for CT are shown in Table 2, and this information is based on the equipment Pantak/Seifert X-ray system (ISOVOLT 160 HS model) operating up to 160 kV, available at LCI.

The spectra were obtained using a program called *Speakcalc*; in this program it is necessary to add some information about the beam (tube voltage, tube current, angle), because very similar energy spectra are simulated.

The simulation was obtained using the MCNP5 (Monte Carlo N-Particle) radiation transport code, developed by the Los Alamos National Laboratory (LANL) (LOS ALAMOS LABORATORY, 2008). To determine the influence of each component on the extrapolation chamber response and the influence obtained for different materials of the collection electrode, it is necessary to calculate the ratio between the values obtained when the component is not considered (importance = 0) and when it is considered (importance = 1) in the simulation.

3. Results and Discussion

Initially are presented the results obtained by applying the Monte Carlo method using the radiation quality for computed tomography beams for the extrapolation chamber. Fig. 2 shows all components, and Fig. 3 features the material for each component.

The influence values on the response of the homemade extrapolation chamber for each component obtained are presented in Table 3 for all radiation qualities for CT standard beams. These influence values were obtained according to the explanation presented in the materials and methods section.

As observed in Table 3, the highest influence is 25.9% for the collecting electrode in the radiation quality RQT 10; this influence is due in large part to the radiation scattered by the components in the sensitive volume, and as shown in literature (Neves et al., 2012), it can reach 50%, depending on the incident radiation energy. Therefore, all results obtained for the influence values for each component for the extrapolation chamber are less than the recommended value (Perini et al., 2013; Neves et al., 2013).

For the collecting electrode material, the results obtained can be seen in Table 4 for the homemade extrapolation chamber.

The results show that graphite is the best material for the collecting electrode, but considering that the influence could be 50% depending on the incident radiation energy, the other appropriate material for it would be aluminum, independent of radiation qualities for computed tomography beams.

The motivation for running this simulation is due to the need to know if aluminum is appropriate for the collecting electrode, because

Table 2
Characteristics of the CT standard beams based on the IEC (IEC, 2005).

Radiation Quality	Tube Voltage (kV)	Tube Current (mA)	Air Kerma Rate (mGy/min)
RQT 8	100	10	22.0
RQT 9[a]	120	10	34.0
RQT 10	150	10	57.0

[a] Reference CT radiation quality at LCI/IPEN.

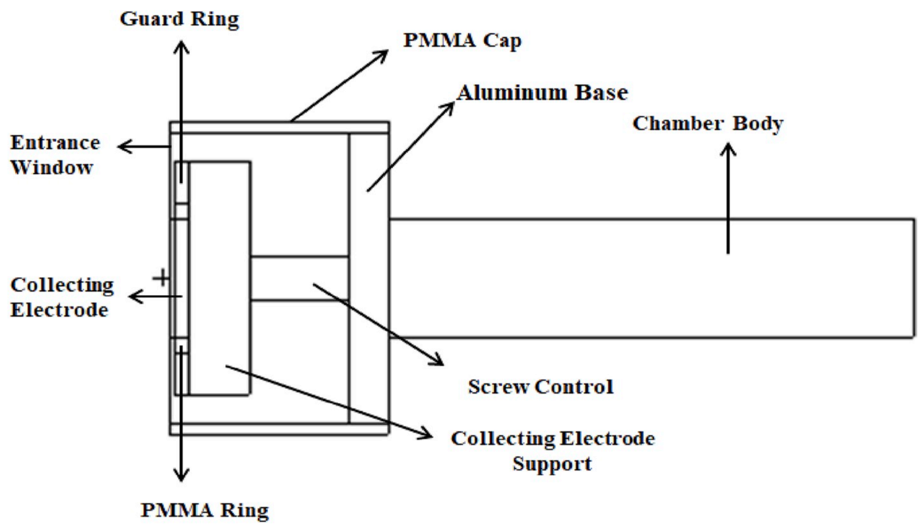

Fig. 2. Cross-section of the extrapolation chamber modeled by the Monte Carlo code, visualized in the software Vised X22S.

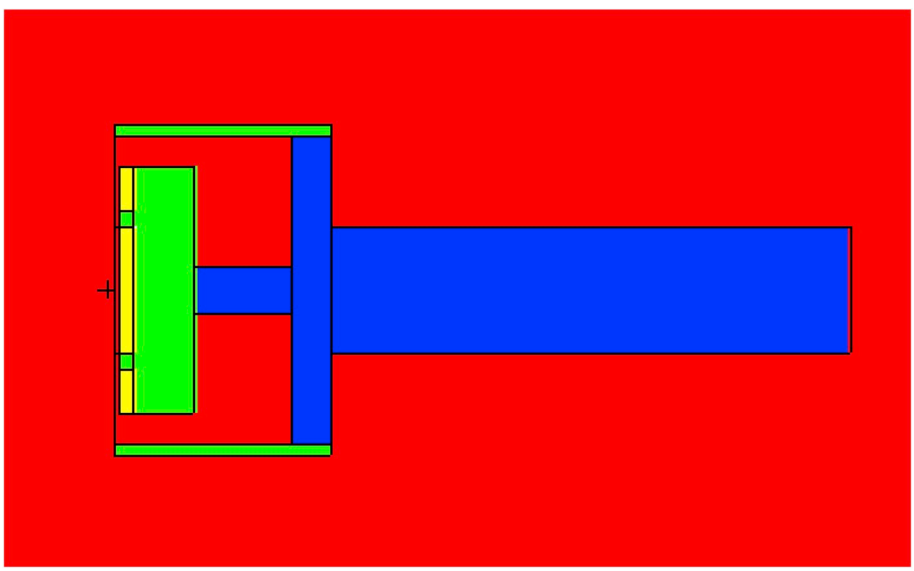

Fig. 3. Geometry of the extrapolation chamber with the materials. The red color represents dry air; green is PMMA; yellow is graphite; blue is aluminum. (For interpretation of the references to color in this figure legend, the reader is referred to the Web version of this article.)

Table 3
Influence values obtained for each component of the extrapolation chamber in the CT standard beams.

Component	Influence (%)		
	RQT 8	RQT 9	RQT 10
Collecting Electrode	24.2	25.3	25.9
External Components	15.9	3.92	16.7
Internal Components	5.56	6.12	5.85
PMMA Ring	6.86	6.81	6.95
Guard Ring	3.59	3.58	3.01

Table 4
Influence values obtained for different materials of the collecting electrode in the CT standard beams.

Collecting Electrode Material	Influence (%)		
	RQT 8	RQT 9	RQT 10
Graphite	24.2	25.3	25.9
Aluminum	44.3	44.3	44.3
Iron	54.7	54.8	54.7
Silver	62.8	62.5	62.8

most of the X-rays detectors present aluminum collecting electrodes. After this confirmation, the current material (graphite) will be substituted by the new material (aluminum) for the attempt of the establishment of a CT primary standard.

4. Conclusion

The results obtained for the studied components for the homemade extrapolation chamber in standard computed tomography beams showed the highest influence of 25.9% for the collecting electrode in all radiation qualities.

From the results obtained for the different materials of the collecting electrode, the best material for CT radiation beams was demonstrated to be graphite, but as the results showed, aluminum is another good option once the influence values obtained for this material were less than 50%. Therefore, in the future the material for the collecting electrode will be changed and tested in order to try to establish a primary standard for CT beams using an extrapolation ionization chamber, because as known the best material for collecting electrodes for X-rays detectors is aluminum.

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