**Artigo Original**

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# Determination of the sensitive volume of the PTW N23361 ionization chamber by micro-computed tomography

## Determinação do volume sensível da câmara de ionização PTW N23361 por microtomografia computadorizada

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**Abstract**

The determination of the sensitive volume of ionization chambers is essential to ensure the best possible accuracy in dosimetric procedures, especially in the context of radiotherapy and radiation protection. This work presents a geometric analysis of the ionization chamber manufactured by PTW, model N23361, whose nominal volume is 30 cm³ as declared by the manufacturer. The three-dimensional reconstruction was performed using images obtained through micro-computed tomography (micro-CT) with the Baker Hughes GE Phoenix V|tome|x M300 system, enabling detailed internal visualization and precise segmentation of the sensitive cavity, with the complete exclusion of the central electrode. The determined volume was 30.7 cm³, revealing a difference of +0.7 cm³ (+2.3%) in relation to the value provided by the manufacturer. The use of micro-CT proved to be an effective metrological tool for the non-destructive evaluation of ionizing radiation measurement devices, allowing for more accurate analyses than conventional methods. This study is part of a broader initiative aimed at implementing a primary air-kerma standard at the Department of Radiological Sciences (DCR).
**Keywords**: ionization chamber-1; micro-computed tomography-2; sensitive volume-3; metrology-4; radiation protection-5.

**Resumo**

A determinação do volume sensível de câmaras de ionização é fundamental para garantir a exatidão em procedimentos dosimétricos, especialmente em contextos de radioterapia e proteção radiológica. Este trabalho apresenta uma análise geométrica da câmara de ionização fabricada pela PTW, modelo N23361, com volume nominal de 30 cm³ declarado pelo fabricante. A reconstrução tridimensional foi realizada utilizando imagens obtidas por microtomografia computadorizada (microCT) por meio do sistema Baker Hughes GE Phoenix V|tome|x M300, possibilitando a visualização interna detalhada e a segmentação precisa da cavidade sensível, com a completa exclusão do volume do eletrodo central. O volume determinado foi de 30,7 cm³, revelando uma diferença de +0,7 cm³ (+2,3%) em relação ao valor fornecido pelo fabricante. A aplicação da micro-CT demonstrou ser uma ferramenta metrológica eficaz para avaliação não destrutiva de dispositivos de medição da radiação ionizante, permitindo análises mais precisas do que métodos convencionais. Este estudo integra uma iniciativa mais ampla voltada à implementação de um sistema padrão primário de kerma no ar para radioproteção no Departamento de Ciências Radiológicas (DCR).
**Palavras-chave**: câmara de ionização-1; microtomografia-2; volume sensível-3; metrologia-4; proteção radiológica-5.

### 1. Introduction

Ensuring quality in ionizing radiation measurements is a fundamental requirement for safety in medical, industrial, and research environments. Within the field of radiological protection, the reliability of measuring instruments depends on traceability to national and international standards, making the existence of primary measurement standards in laboratory services essential.

In this context, ionization chambers play a central role, being the most used device for determining the air kerma rate in gamma radiation beams. Traditionally, national metrology laboratories maintain high metrological quality of spherical, parallel plate or cylindrical primary standard chambers, with the sensitive volumes and associated correction factors rigorously determined to minimize measurement uncertainties.

The present study aims to implement, at the Department of Radiological Sciences (DCR), a reference system capable of operating as a primary standard for radioprotection services. To this end, the feasibility of using a cylindrical ionization chamber TK30 (manufacturer: PTW, model N23361) is being investigated as a potential primary standard. This initiative involves:

- The accurate determination of the chamber's sensitive volume using independent methods;
- The study of the chamber's geometric and structural characterization using computed microtomography;
- The evaluation homogeneity of the DCR's $^{137}Cs$ radiation field;
- The determination of specific correction factors, with particular emphasis on the wall correction factor ($k_{wal}$).

Accuracy in determining the sensitive volume of the chamber is a fundamental requirement for any system that aims to serve as a primary standard. The sensitive volume is directly proportional to the charge collected by the chamber when exposed to a known radiation field, and small uncertainties in its value may compromise the traceability of the entire system.

For this purpose, high-resolution computed microtomography was used, allowing a non-destructive three-dimensional characterization of the chamber's internal geometry. The use of the Baker Hughes GE Phoenix V|tome|x M300 system, combined with advanced reconstruction and segmentation tools, enabled the creation of a precise digital model of the sensitive volume.

This work presents the results of this investigation, focusing on the volumetric determination of the TK30 chamber, representing a key step in the process of consolidating DCR's metrological infrastructure, aiming at its role as a reference in radiological protection.

## 2. Materials and Methods

### *2.1. PTW N23361 Ionization Chamber*

The analyzed chamber is a vented cylindrical type with symmetrical geometry, designed for dosimetry applications in radiological protection. Its main characteristics, according to the manufacturer, are:

- Reported nominal volume: 30 cm³
- Length: 33.5 cm
- Internal diameter: 3.1 cm
- External diameter: 3.3 cm
- Wall: PMMA with a thickness of 0.1 cm and an additional 0.03 cm internal layer of graphite
- Central electrode: graphite-coated aluminum

The linear measurements of this ionization chamber were obtained from tomographic reconstruction, as described below.

### *2.2. Micro-CT Acquisition*

The three-dimensional characterization of the ionization chamber was performed using the Phoenix V|tome|x M300 system by Waygate Technologies (Baker Hughes), installed at the Nuclear Instrumentation Laboratory of the Federal University of Rio de Janeiro (LIN/COPPE/UFRJ). This equipment represents an advanced solution for metrology and 3D analysis via industrial computed tomography (CT), being the first micro-CT system featuring scatter|correct technology, which automatically removes scatter artifacts, thereby enhancing image quality.

Capable of operating at 300 kV and optionally equipped with a 180 kV nanofocus tube, the system offers high accuracy with optimized scanning speeds, making it ideal for demanding laboratory and industrial applications.

The Phoenix V|tome|x M300 system offers a wide range of applications in high-precision three-dimensional analysis of instruments used in ionizing radiation metrology. In addition, its key capabilities include the evaluation of assembly processes and fit inspections, applications in scientific research such as the characterization of 3D-printed materials, composites, ceramics, battery cells and modules, and medical devices. It also enables three-dimensional radiation metrology with a high degree of accuracy and allows for the comparison between nominal (CAD) and actual (measured) geometries for dimensional evaluation.

The TK30 ionization chamber was scanned in the microCT using the following image acquisition parameters:

- Tube voltage: 70 kV
- Current: 200 μA
- Voxel size: 88.54 μm
- Acquisition matrix: 2014 × 2024 pixels
- Exposure time per projection: 500 ms
- Number of projections: 1000
- Frames per projection: 5

Volumetric reconstruction was performed using the Phoenix Datos|x CT Reconstruction software. The segmentation of the sensitive cavity was carried out using VGStudio v.3.0, applying histogram-based threshold, region-based refinements, and manual adjustments.

## 3. Results

The three-dimensional reconstruction of the PTW N23361 ionization chamber, performed via computed microtomography, enabled a complete visualization of its internal structure, including the wall, central electrode, and sensitive volume (Figure 1). Segmentation of the sensitive volume excluding the central electrode entirely allowed a precise determination of the cavity volume, which was found to be 30,695.29 mm³, equivalent to 30.7 cm³.

This value represents an increase of +0.7 cm³, or +2.3%, compared to the nominal volume reported by the manufacturer.

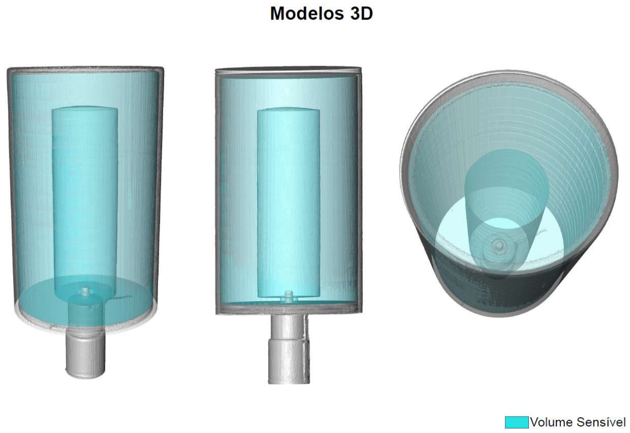


**Figure 1.** Three-dimensional reconstruction of the PTW N23361 ionization chamber obtained via micro-CT, highlighting the segmentation of the internal volume.

In addition to the volumetric analysis, linear measurements were performed based on the reconstructed images to provide information for evaluating the uncertainty associated with the volume determination. The main results obtained are the Ionization chamber reference point at 27 mm, the Central electrode diameter: internal 12,928 mm, external: 14,236 mm, figure 2.

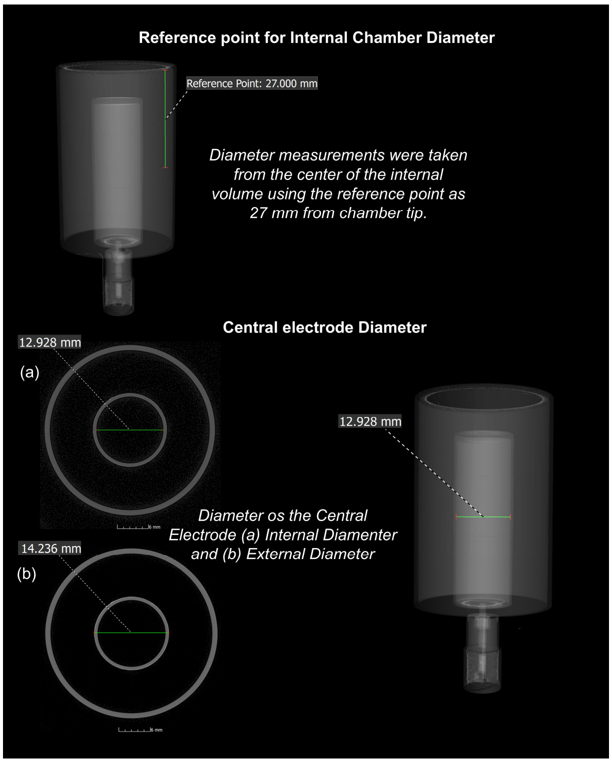


**Figure 2.** Linear dimensions of the ionization chamber. A reference point is set at 27 mm from all measurements. Cross-sectional views show the central electrode's internal diameter (a) is 12.928 mm and its external diameter (b) is 14.236 mm.

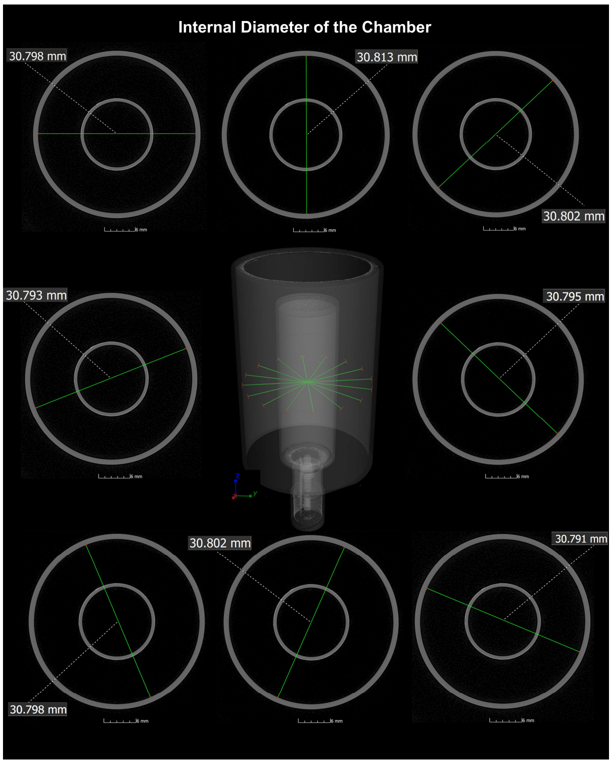


**Figure 3.** Cross-sectional CT images displaying measurements of the internal diameter of the ionization chamber at various points. The results show high dimensional uniformity, with a maximum variation of 0.022 mm.

The wall thickness of the chamber (measurements at different positions):

- 0.999 mm, 1.000 mm, 0.997 mm, 0.999 mm, 0.997 mm, 1.001 mm, 1.000 mm, 1.001 mm. Average value: 0.999 mm

Also, the internal diameter of the ionization chamber (values obtained from different axial sections):

- 30,798 mm, 30,813 mm, 30,802 mm, 30,793 mm, 30,795 mm, 30,798 mm, 30,802 mm, 30,791 mm, as we can see in figure 3 below. The Average value is 30,799 mm.

### *3.1. Uncertainty Calculation*

Considering that the ionization chamber cavity is a cylinder, we have:

$$V = \pi.\left(\frac{d}{2}\right)^2.h = \frac{\pi.d^2.h}{4} \qquad (1)$$

Where:
d is the average inner diameter.
h is the effective internal height.
V is the volume.

Calculation of the mean and standard deviation of the measurements:

a) Internal diameter ($d$)

Values obtained by analytical calculation of the reconstructed images (in mm): 30,798; 30,813; 30,802; 30,793; 30,795; 30,798; 30,802; 30,791.

Mean:

$$\bar{d} = \frac{\sum d_i}{n} = \frac{246{,}392}{8} = 30{,}799\ mm. \qquad (2)$$

Standard deviation:

$$\sigma_d = \sqrt{\frac{\sum(d_i - \bar{d})^2}{n}} = 0{,}0069\ mm \qquad (3)$$

*b)* Height *h*

The height was obtained from the manufacturer's information, 52 mm considering the inner part. For this reason, we will assume that the standard uncertainty is 0.1 mm.

#### *3.1.1. Uncertainty propagation*

$$V = \frac{\pi.d^2.h}{4} \qquad (4)$$

The combined standard uncertainty $u(V)$ is given by:

$$u(V)^2 = \left(\frac{\partial V}{\partial d}.u(d)\right)^2 + \left(\frac{\partial V}{\partial h}.u(h)\right)^2 \qquad (5)$$

Calculation of the partial derivatives:

$$\frac{\partial V}{\partial d} = \frac{\pi.d.h}{2} \qquad (6)$$

$$\frac{\partial V}{\partial d} = \frac{\pi.d^2}{4} \qquad (7)$$

Substituting the values:

$d$ = 30,799 mm
$h$ = 52 mm
$u$(d) = 0,0069 mm
$u$(h)= 0,1 mm

$$\frac{\partial V}{\partial d} = \frac{\pi.30{,}799.52}{2} = 2517{,}6\ mm \quad (8)$$

$$\frac{\partial V}{\partial d} = \frac{\pi.(30{,}799)^2}{4} = 745{,}1\ mm \quad (9)$$

Substituting into the formula for $u$(V):

$$u(V)^2 = (2517{,}6\ .\ 0{,}0069)^2 + (745{,}1\ .\ 0{,}1)^2 \quad (10)$$

$$u(V)^2 = (17{,}38)^2 + (74{,}51)^2 \quad (11)$$

$$u(V)^2 = 302{,}2 + 5552{,}1 = 5854{,}3 \quad (12)$$

$$u(V) = \sqrt{5854{,}3} = 76{,}5\ mm^3\ ou\ 0{,}0765\ cm^3 \quad (13)$$

Expanded uncertainty (k = 2):

$$U = 2\ .\ 76{,}5 = 153\ mm^3\ ou\ 0{,}153\ cm^3 \quad (14)$$

Final volume with uncertainty (95% confidence level):

$$V = (30{,}7\ \pm 0{,}153)\ cm^3$$

## 4. Discussion

The difference of +0.7 cm³ between the nominal value and the value measured by micro-CT represents a variation of +2.3%, which can be attributed to manufacturing mechanical tolerances and the indirect methods used for the volume estimation by the manufacturers. The use of this technique allows an accurate and non-destructive characterization of the sensitive volume of the chamber, proving to be an effective alternative compared to traditional methods, with significant advantages in terms of reproducibility, geometric detail, and the final accuracy.

The results obtained are of great relevance to the objectives of the present work, which aims to qualify the TK30 chamber as a primary standard for radiation protection. The precision in determining the volume is crucial to ensure traceability and reliability of the dosimetric results, essential for the operation of standards used with metrological purpose.

## 5. Conclusions

This study demonstrated that micro-CT is an effective tool for evaluating the sensitive volume of ionization chambers. The PTW N23361 chamber showed a measured volume of 30.7±0.153 cm³, which is higher than the nominal value of 30.0 cm³, highlighting the importance of independent geometric validation to ensure the accuracy of metrological standards.

The next steps of the project involve determining correction factors, such as the wall factor, and characterizing the radiation field of the gamma room at the LCR. These steps are essential to consolidate the necessary infrastructure, enabling the laboratory to serve as a reference for radiation protection.

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