



Characterization of a 3D prototyping semi-automated filter holder system for RQR radiation qualities

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ARTICLE INFO

Handling Editor: Dr. Chris Chantler

Keywords:

Kerma-area product
Dosimetry
Calibration method
Spectroscopy

ABSTRACT

Characterizing radiation measurement systems, such as diagnostic radiology systems for RQR and RQA, is essential for ensuring reliable results in standardized instrument calibration laboratories. Quality control of dosimetry devices, such as patient dose calibrators (PDCs), a reference meter, is crucial for ensuring accurate measurements. This study demonstrates the use of spectrometry and ionization chambers to characterize a set of semi-automated 3D prototyping filter holder systems, developed in a previously project, designed for applications such as Kerma-Area Product (KAP) meter calibration. The set of 3D prototypes were adjusted to a filter wheel and characterized using an X-ray spectrometer, followed by an ionization chamber, according to international standards. The characterization of radiation qualities from 50 to 150 kV in diagnostic radiology was performed using the substitution method: first with an ionization chamber, then with a PDC. The PDC was calibrated for KAP and Air Kerma quantities, considering the conditions of the X-ray system and factors such as temperature, humidity, and pressure. Spectrometric analysis and the use of an ionization chamber were effective in determining these parameters. Spectral characterization allowed for accurate measurements to establish proper quality control, then it is possible to use the PDC calibrated for calibration procedures for KAP meters. Future studies intend to compare these results with computational simulations using the TOPAS Monte Carlo code to validate the calibration method.

1. Introduction

The Calibration Laboratory (LCI) of the Nuclear and Energy Research Institute (IPEN/CNEN) provides calibration services for radiation measurement instruments used in radiation protection, diagnostic radiology, and radiotherapy. LCI produces radiation qualities and irradiation conditions that comply with national and international standards (Betti, 2007; Rodrigues, 2013). To establish the recommended radiation qualities for diagnostic radiology, X-ray beams generated in the laboratory were properly characterized for the irradiation conditions required for the calibration of healthcare equipment (Corrêa, 2010; Almeida Junior et al., 2021). To complement and expand the capacity of the filter wheel, an additional filtration system was developed in a previous project to be adapted to the existing filter system at LCI (Franciscatto, 2009). The filter support was coupled to the PTW® Filter Wheel, installed in the LCI X-ray system (Fig. 1a).

The semi-automatic calibration system of the LCI-IPEN/CNEN

(Fig. 1), includes accessories for gathering environmental data and for selecting additional filtration, for each radiation type using a filter wheel. Additionally, the previous system, designed by the authors in OpenSCAD, (Schneider et al., 2017), was manufactured using PLA (polylactic acid) filament, via fast prototyping with 3D printing (Fig. 2a) employing the FFF (fused filament fabrication) technique (Almeida Junior et al., 2021). Printing parameters were configured for enhanced precision, adjusting the holder to the support (Fig. 2b).

The models were also designed to precisely fit each individual drawer for the specific filters used in the laboratory's daily operations. These models are integrated with sensors tailored to fit the designated spaces within the support component. Furthermore, a microcontroller based on Arduino, along with microswitches (depicted in Fig. 2b), and both low- and high-level programming, enable the monitoring of drawer status and the seamless integration of information with the laboratory's control system. This system facilitates the identification of the inserted filter within the drawer through sensors attached to the support. Fig. 3

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<https://doi.org/10.1016/j.radphyschem.2024.111897>

Received 4 March 2024; Received in revised form 28 May 2024; Accepted 2 June 2024

Available online 3 June 2024

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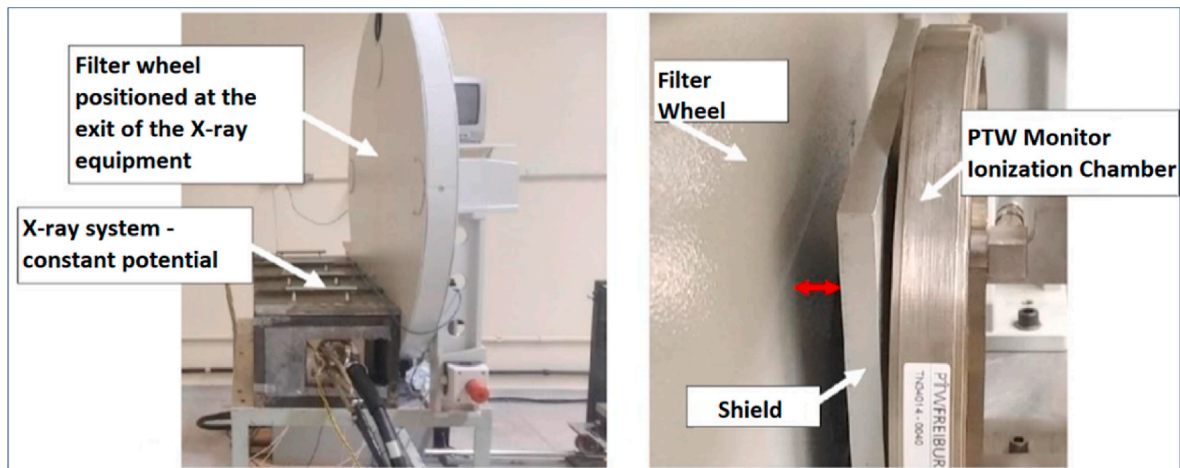


Fig. 1. a) Image of the Filter Wheel with the X-Ray equipment, placed before the wheel; b) in detail, location of the support-filter-holder system, to be inserted next to the filter wheel exit (pointed with the red arrow) before the collimator and ionization chamber screen.

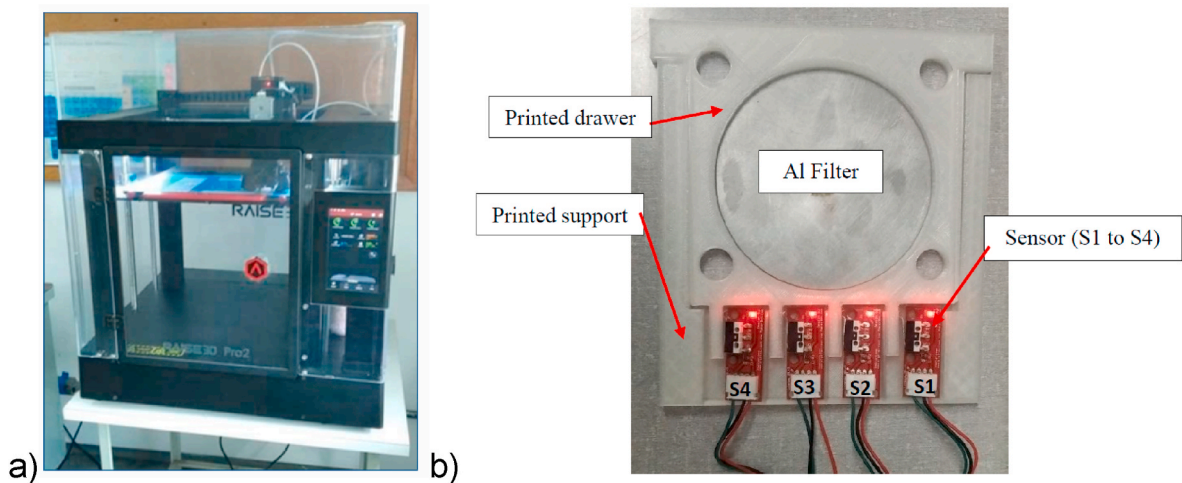


Fig. 2. a) FFF 3D Printer (Raise3D PRO); b) the prototype of support and holder, with the sensors connected.

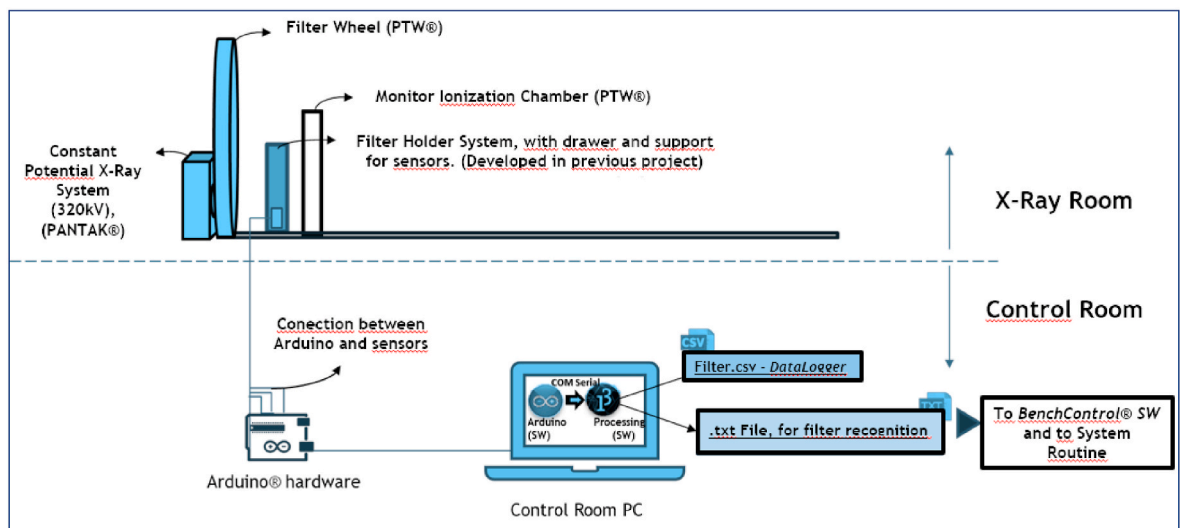


Fig. 3. Schematic of the complete system (Almeida Junior et al., 2021), including indication of the structure for generating the file used together with the existing filter wheel routine.

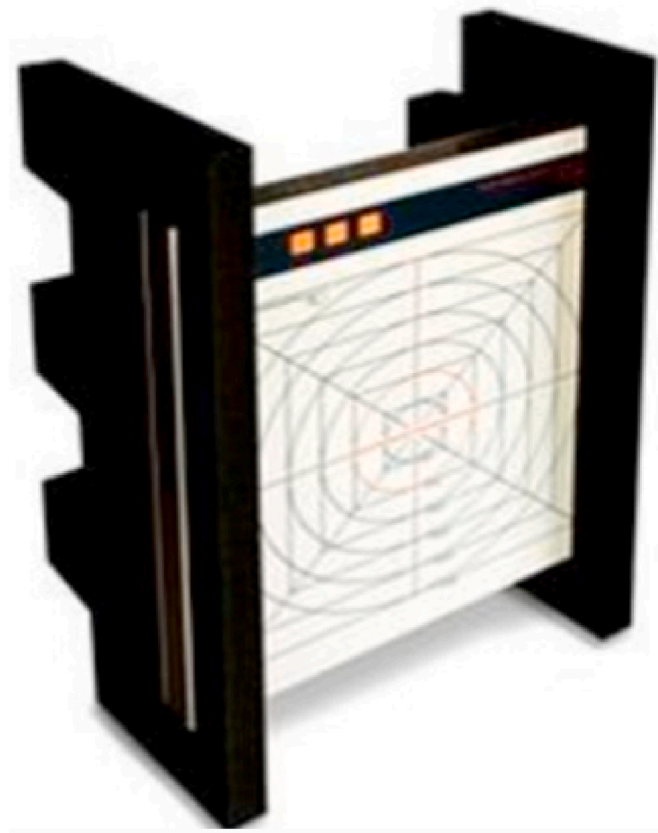


Fig. 4. Patient Dose Calibrator (PDC), with attached support.

illustrates the schematic setup for filter recognition and registration.

The semi-automated filter positioning system, now implemented, is being utilized in this project for calibrating medical equipment. Initially, it is being applied to calibrate Kerma-Area Product (KAP) meters.

2. Materials and methodology

Dosimetry in diagnostic radiology and radiation protection is crucial

for maintaining accuracy standards and ensuring safety. The characterization of radiation measurement systems, such as the previously developed system, is vital for guaranteeing measurement accuracy in calibration laboratories. Furthermore, quality control of dosimetry equipment, such as the patient dose calibrator (PDC) depicted in Fig. 4, is essential for ensuring reliable results (Schneiderei et al., 2017; Costa, 2013).

The characterization of RQR radiation qualities, essential for calibrating KAP meters, was conducted utilizing the semi-automated 3D prototyping filter holder system alongside spectrometry and a reference ionization chamber. The characterization process involved (Fig. 5):

- CdTe spectrometer (Amptek®, model XR-100T-CdTe, with CdTe diode as detector; Superficial Area: 9 mm², with 1 mm width, and density of 6,2 g/cm³, for X-ray spectrometry (from 50 to 150 kV), depicted in Fig. 5a
- Radiation control unity (Fig. 5b), from Radcal®, model 9010 with conversor model 9060 and ionization chamber model 10x5-180.

The calibration and spectrometry procedures conform to international standards such as TRS-457 (2007), IEC-61267 (2005), and IEC 60580 (2019). Additionally, tests for the quality control program are ongoing, including assessments of homogeneity, reproducibility, and stability over time. Following the characterization of diagnostic radiology radiation qualities, the calibration is carried out using the substitution method (Costa, 2013; Almeida Junior et al., 2011), wherein the reference ionization chamber, is utilized to calibrate the PDC (Fig. 6).

After its calibration, the PDC (Costa, 2013; Almeida Junior et al., 2011) will serve as a reference meter for the calibration of KAP meters. The PDC can be used as a reference instrument for local calibration, considering the characteristics of each X-ray equipment with KAP meters.

3. Results

The spectra obtained with the CdTe detector (Fig. 7) were corrected for energy resolution, with counts normalized to the maximum number of counts in each spectrum. These corrected spectra were then compared with the theoretical and experimental diagnostic radiology radiation qualities (Santos, 2017). The theoretical spectra were generated using SpekCalc software, adjusting the kVp, radiation beam exit angle, and both inherent and additional filtration. Calibration coefficients for the

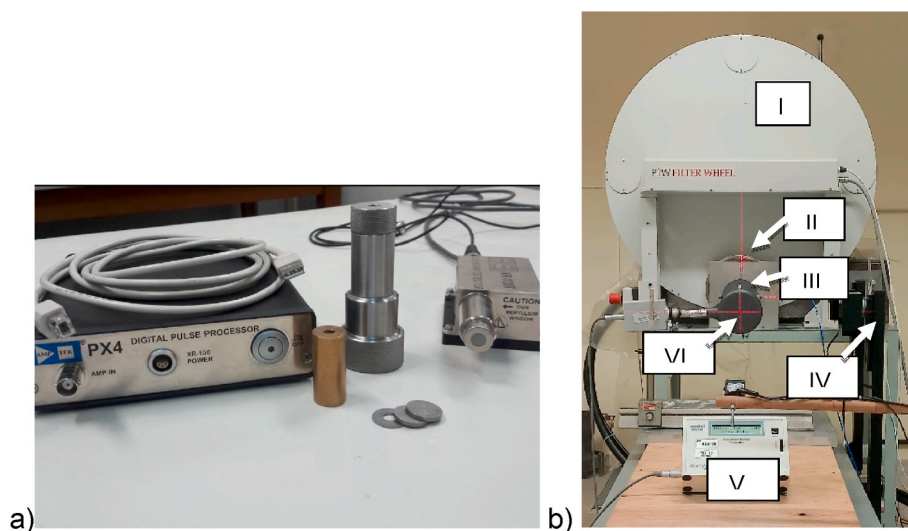


Fig. 5. (a) CdTe Detector System (Amptek®), and (b) ionization chamber system (Radcal®), mounted in the structure of LCI X-Ray System (with I. filter wheel, II. Monitor ionization chamber (PTW® model 34014), III. Colimator of 5,08 cm diameter, for diagnostic radiology. IV Laser system for alignment, and V converter model 9060 for reference ionization chamber model 9010, od Radcal®).

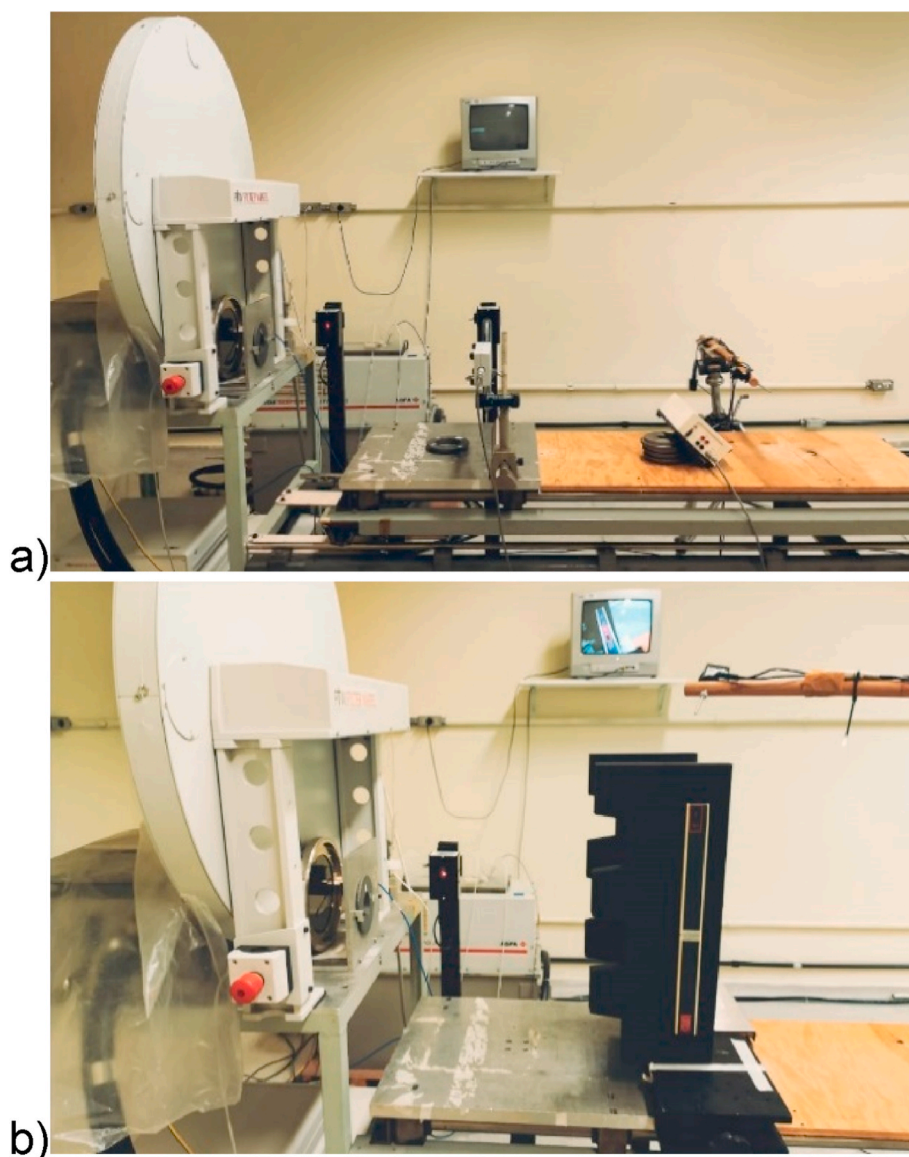


Fig. 6. a) The structure to evaluate Kerma and KAP using the reference ionization chamber (Radcal®). b) the PDC is placed in the position of the ionization chamber to be calibrated for Kerma and KAP.

standard ionization chambers were determined for RQR 3, RQR 5, RQR 8 and RQR 10.

After spectrometry, the calibration with the reference ionization chamber (Radcal®) is conducted for kerma and KAP. Subsequently, the PDC is positioned in the location of the reference ionization chamber system, utilizing the substitution method, to perform the KAP meter calibration routine, as depicted in the diagram of Fig. 8.

The results showed that the system meets the requirements of international standards (IEC-61267, 2005), for X-ray spectrometry, utilizing the CdTe detector, considering corrections for energy resolution. The system demonstrated good reproducibility in Kerma measurements ($\pm 2\%$), with reliable energy response and linearity across all radiation qualities. During the calibration process, the PDC exhibited good reproducibility in measuring KAP, with values differing by $\pm 3\%$ compared to those measured with the reference ionization chamber (Radcal®), qualifying it as a reference meter for KAP according to IEC 60580 (2019). Additionally, the PDC displayed good response in the homogeneity test, with variations within 2% when positioned 4 cm to the left, 4 cm to the right, 4 cm up, and 4 cm down.

Therefore, the use of spectrometry and ionization chambers proved

effective in determining these parameters. The spectra characterization enabled the establishment of an adequate quality control, ensuring precise measurements. This correlation allowed the reference ionization chamber to be used for calibrating the PDC, a KAP meter, which showed good performance in KAP calibration.

In the future, the PDC will be used to calibrate clinical meters used in interventional radiology procedures. For this purpose, the LCI system will be structured using the TOPAS Monte Carlo code simulation to evaluate the energy dependence of the PDC, compare the results with those of the KAP clinical meter, and validate the method.

4. Conclusion

The semi-automated filter holder system for RQR was characterized using spectrometry and an ionization chamber. Following this characterization, the structured system was utilized to calibrate the PDC, using the substitution method, and a quality control program for the PDC was established. Subsequently, the system will be employed to calibrate KAP meters in interventional radiology equipment. Moreover, the laboratory's experimental setup geometry for PDC calibration will be

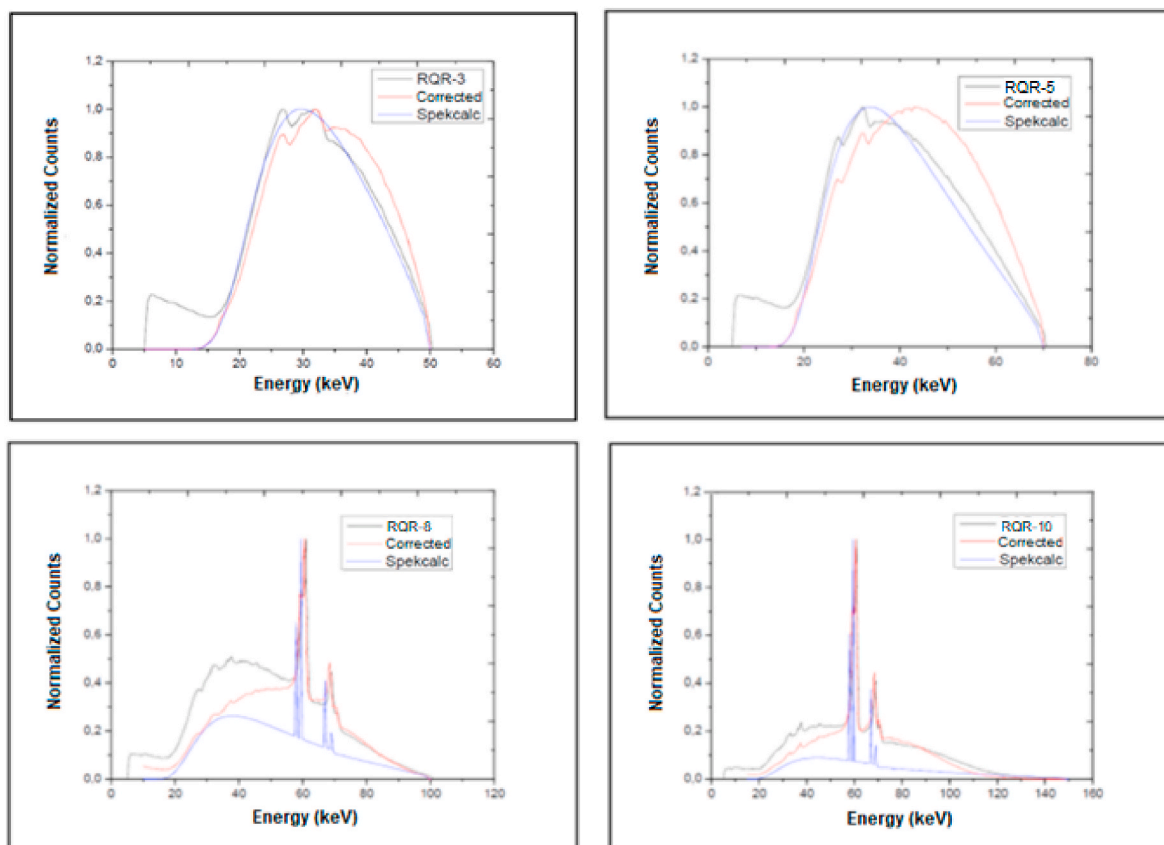


Fig. 7. Spectra obtained with CdTe for radiation qualities RQR 3, 5, 8 and 10 (Santos, 2017).

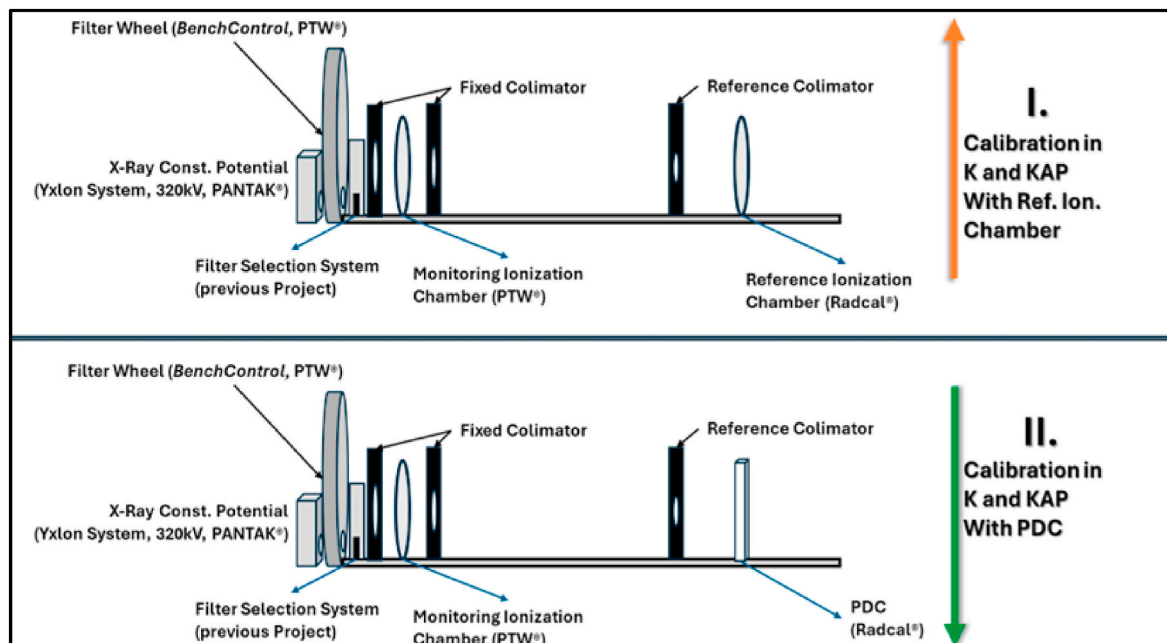


Fig. 8. The schematic of the complete system, illustrating the geometry used to calibrate the PDC by the substitution method, includes: (I) the reference ionization chamber, and (II) the PDC (placed in the same position as the reference ionization chamber).

simulated using the TOPAS Monte Carlo code to validate the calibration method.

CRedit authorship contribution statement

José Neres de Almeida Junior: Writing – review & editing, Writing – original draft, Visualization, Validation, Project administration,

Methodology, Investigation, Funding acquisition, Formal analysis, Data curation, Conceptualization. **Maria da Penha Albuquerque Potiens:** Writing – review & editing, Visualization, Validation, Supervision, Methodology, Formal analysis, Data curation, Conceptualization. **Orlando Rodrigues Junior:** Writing – review & editing, Writing – original draft, Validation, Supervision.

Declaration of competing interest

The authors declare the following financial interests/personal relationships which may be considered as potential competing interests: Jose Neres de Almeida Junior reports financial support was provided by Brazilian Nuclear Energy Commission. If there are other authors, they declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

Data availability

Data will be made available on request.

Acknowledgements

The authors express their gratitude for the support received from the Instituto de Pesquisas Energéticas e Nucleares (IPEN) of the University of São Paulo, and the Comissão Nacional de Energia Nuclear, CNEN-Brasil (SEI grant process No. 01342.004839/2020 61). They also acknowledge the funding provided by the Conselho Nacional de Desenvolvimento Científico e Tecnológico (CNPq) (Grant number: 140564/2023-7) for the research grant of the current project, as well as for the partial financial support from the Fundação de Amparo à Pesquisa do Estado de São Paulo (FAPESP) (Grant Number: 2018/05982-0).

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