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Study on electronic equilibrium of ^{137}Cs gamma radiation for 3D printed phantoms using OSL dosimetry

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Abstract. With the popularization of 3D printing technologies, it is now possible to develop patient specific simulators and various other accessories using this technology in medical physics and dosimetry. This work aims to evaluate the electronic equilibrium of 3D printed phantoms using PLA and ABS filaments compared to PMMA for ^{137}Cs gamma rays using OSL dosimetry. A Landauer microStar ii commercial OSL system was commissioned and it was used nanoDot dosimeters. Phantom plates with 2.5, 3.0 and 5.0 mm thickness were used to obtain electronic equilibrium for ^{137}Cs gamma rays. Measurements were compared with PMMA measurements at standard conditions. Results show that measurements with ABS and PLA thicknesses of 2.5 and 3.0 mm presents dosimetry results within irradiation uncertainty. More accuracy is obtained using 3.0 mm for both PLA and ABS phantoms, with differences in less than 0.5%. It can be concluded that PLA and ABS 3D phantom plates has similar properties of PMMA for ^{137}Cs gamma rays dosimetry and can be used for developing dosimetry accessories for this energy photon beam.

Keywords. 3D printing; ABS; PLA; OSL dosimetry

1. Introduction

3D printing technologies can produce three-dimensional objects using different materials. It has been evolved in recent years and provides potential for developing reproducible and sophisticated physical phantoms. 3D printing technology can help rapidly develop relatively low cost phantoms with appropriate complexities, which are useful in imaging or dosimetry measurements. The need for more realistic phantoms is emerging since imaging systems are now capable of acquiring multimodal and multiparametric data [1].

The use of 3D printing and filaments commonly found commercially for development of phantoms has been investigated [2] and research being performed on developments of quality assurance devices [3], CT imaging [4] clinical electrons dosimetry [5], etc. The application of this technique for development of low cost dosimetry phantoms requires a complex study of the interaction of printed materials with different radiation types and qualities, as well as characterization of printing set-ups. Performing these measurements, it is possible to find methodologies so they can correctly mimic human tissue and design appropriate and/or specific dosimetry accessories.



Thus, this paper aims to evaluate the electronic equilibrium of 3D printed phantoms using PLA and ABS filaments compared to PMMA for ^{137}Cs gamma rays dosimetry. Experimental results were obtained with printed plates and nanoDot OSL dosimeters from Landauer inc.

2. Experimental

2.1. 3D printing materials and set-up

For this study phantom plates were printed using the RAISE 3D PRO2 3D printer from IPEN (Fig. 1) with dimensions of $80 \times 80 \times 1 \text{ mm}^3$ using rectilinear $+45^\circ/-45^\circ$ orientation, layer thickness (z) of 0.2 mm and 100% infill and, for comparison, $100 \times 100 \times 1 \text{ mm}^3$ solid PMMA plates were used as material of reference (Fig. 2). Table 1 show the manufacture specifications [6] of the 3D printing materials.

Table 1. Manufacture characteristics for PLA and ABS

Material	Colour	Nominal Density (g/cm^3)	Nozzle Temperature ($^\circ\text{C}$)	Heated Bed Temperature ($^\circ\text{C}$)	Print Speed (mm/s)
PLA	Transparent	1.24	210 - 220	60	50
ABS	Pure/White	1.05	240 - 250	105	50



Figure 1. RAISE 3D PRO2 printer from IPEN (a) general view (b) detail on heated bed (c) detail on extruder nozzles

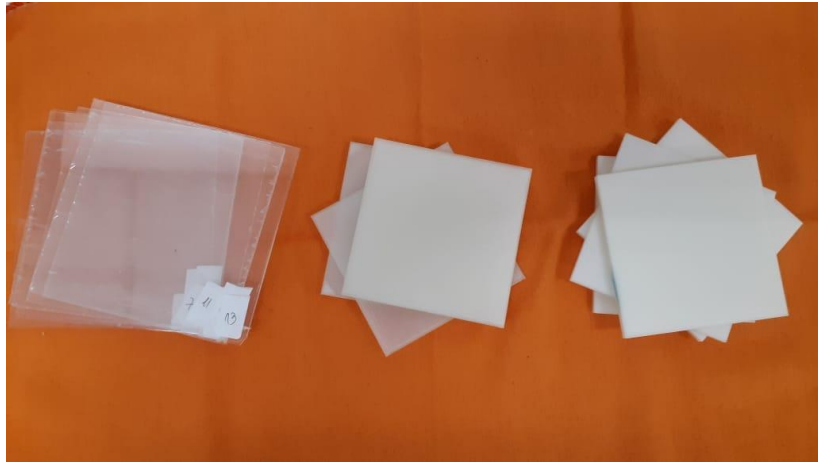


Figure 2. PMMA, PLA and ABS phantom plates used for radiation transmission measurements

2.2. Radiation source and OSL dosimetry system

For this study it was used a 4π geometry ^{137}Cs gamma irradiator (activity of 37.925 GBq at April 2014) from the Instruments Calibration Laboratory – LCI/IPEN. For radiation detection it was used the commercial OSL system Landauer microStar ii from SAPRA Landauer laboratory (São Carlos, SP – Brazil) and nanoDot dosimeters (Fig. 3).

The OSL reader was commissioned using calibration set irradiated with ^{137}Cs NIST traceable dosimeters provided by Landauer. The calibration factors for ‘weak’ and ‘strong’ beam of OSL stimulus were obtained and the reading repeatability evaluated.

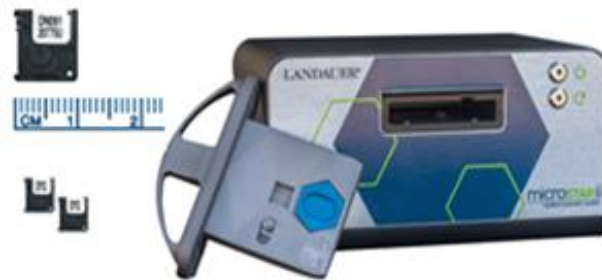


Figure 3. Landauer microStar ii comercial OSL system and nanoDot dosimeters

2.3. Experimental set-up and data analysis

To evaluate the electronic equilibrium conditions obtained with the 3D printed PLA and ABS phantoms in comparison of PMMA, samples were irradiated with absorbed dose of (10.00 ± 0.28) mGy over 60 cm distance of ^{137}Cs source as showed in Figure 4. For each irradiation 3 nanodots were used between PLA/ABS phantom plates, varying thickness of the beam ‘entrance’ side by 2.5, 3.0 and 5.0mm (Fig. 5). For backscattering it was used fixed 5 mm plates.

As reference conditions, 3 nanoDots were also irradiated within two 3mm thickness PMMA plates and dosimetry results compared with the results of dosimeter readings for the different thicknesses of PLA/ABS phantom plates.

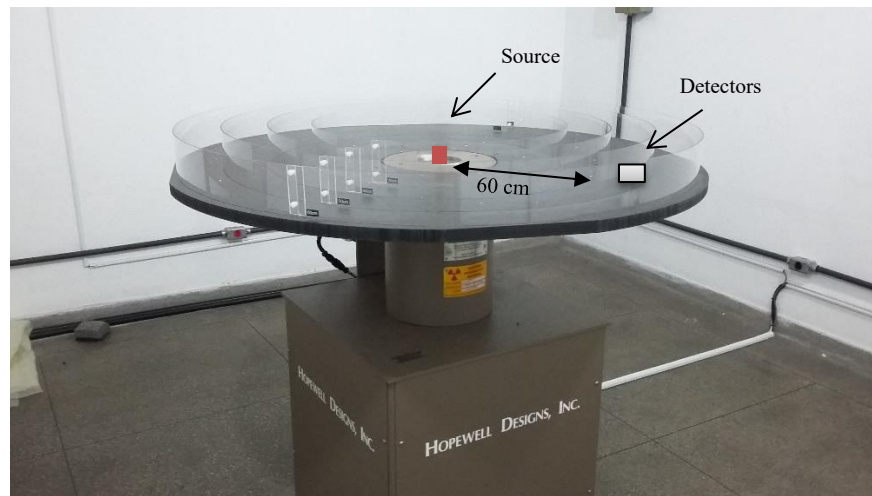


Figure 4. ^{137}Cs 4π irradiator set-up

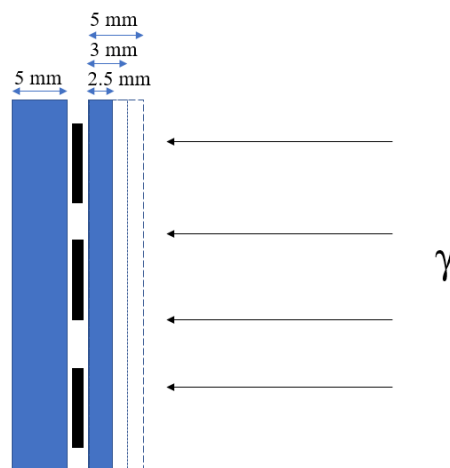


Figure 5. Schematic illustration on variations of thickness of the 3D printed phantom plates

Each nanoDot was read 5 times and the presented data was the mean of the three dosimeters results and the error bars are the experimental standard deviation. Signal-to-dose calculations were performed with the commissioned microStar ii OSL reader and data analysis performed with Origin PRO 9.1 software.

3. Results

3.1. microStar ii commissioning

Figure 6 shows the experimental dose-response curves obtained for Strong and Weak beams of stimulation, depending on the absorbed dose of the nanoDot. Though the slope of the linear fit, the experimental calibration factors obtained are (508.4 ± 0.6) counts.mGy⁻¹ and (67.5 ± 0.5) counts.mGy⁻¹ for strong and weak beams respectively. Repeatability of all measurements were within 4.0%.

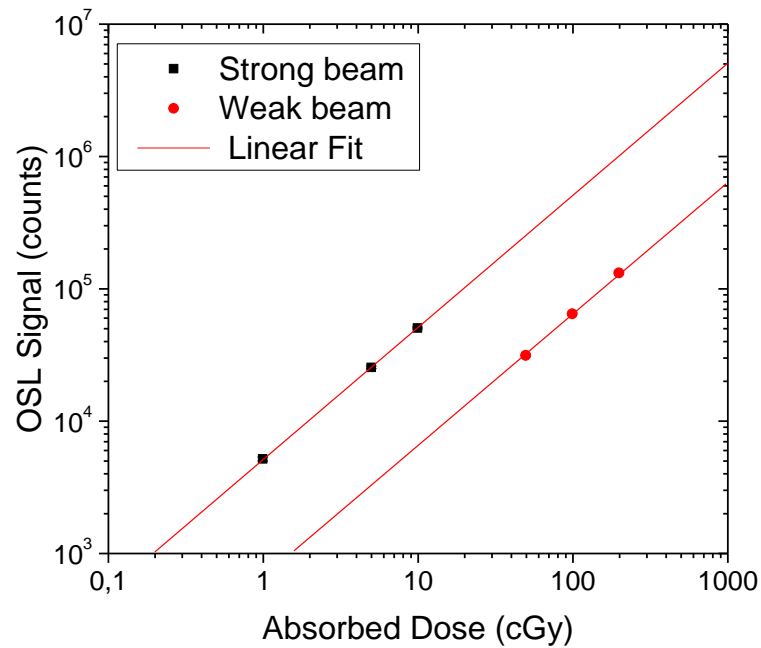


Figure 6. Dose response curves obtained with ^{137}Cs NIST traceable calibration set

3.2. Electronic equilibrium evaluation

The OSL samples with the 3D printed plates were irradiated and the agreement between the absorbed doses evaluated with different thickness of 3D phantom plates evaluated. Results relative to PMMA are presented in Figure 7 and Table 2.

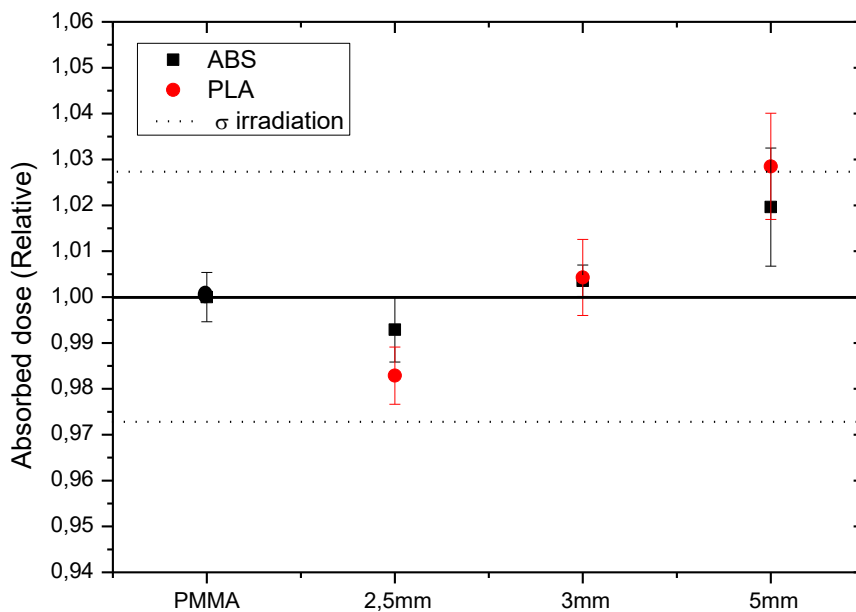


Figure 7. Agreement between PMMA and printed phantoms dosimetry

Table 2. Dosimetry results for ABS and PLA printed phantoms (relative)

	ABS		PLA	
	Mean	SD	Mean	SD
2.5 mm	0.993	0.021	0.983	0.019
3 mm	1.004	0.010	1.004	0.018
5 mm	1.020	0.038	1.029	0.035

4. Discussion

Though analysis of the obtained experimental results it can be observed that for the plates printed with ABS the absorbed dose values measured with the three thicknesses are within the irradiated dose uncertainty. For the PLA results, the mean value of absorbed dose with 5mm thickness is out of irradiation uncertainty (Figure 7).

Considering the accuracy of the experimental results, 3.0mm of PLA and ABS can be considered equivalent to the 3.0mm PMMA used in the reference measurement, with differences between the mean values of absorbed dose of 0.4% and standard deviations below 2.0%.

5. Conclusions

The OSL microSTAR ii dosimetry system and the nanoDot dosimeters with their associated uncertainties promote absorbed dose results within the irradiation uncertainties for the 2.5 and 3.0mm thickness for both PLA and ABS phantom plates. The thicknesses that resulted in the most accurate results were 3.0mm, the same as for PMMA in the reference measurement. It can be concluded that PLA and ABS have similar electronic equilibrium properties as PMMA, making it possible to develop 3D printed accessories for different ^{137}Cs gamma rays dosimetry applications.

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