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Energy Dependence: 3D-printed TLD Holder for Eye Lens Dosimetry

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1. Introduction

Lens dosimetry is a topic of increasing relevance in radiation protection, especially after the revision of equivalent dose limits for the lens promoted by the International Commission on Radiological Protection (ICRP) in Publication 103 [1] and reinforced by ICRP report 118 [2]. The annual limit was reduced from 150 mSv to 20 mSv, making a more rigorous approach mandatory in the individual monitoring of workers exposed to ionizing radiation in diagnostic and interventional procedures [3].
Lithium fluoride dosimeters doped with magnesium and titanium (LiF:Mg,Ti), commercially known as TLD-100, are widely used in individual dosimetry due to their tissue-like response characteristics and the robustness of the thermoluminescent signal [4]. However, in lens dosimetry applications, the development and validation of specific supports, called dosimeter holders, is required to ensure reproducible positioning and compatibility with the protective equipment used. 3D printing using FFF (Fused Filament Fabrication) technology has proven to be a viable and low-cost alternative for manufacturing these supports [5, 6].
In this context, the present work aims to evaluate the energy dependence of LiF:Mg,Ti TLDs when positioned in a new model of dosimeter holder for crystalline lenses, produced by 3D printing with PLA filament. The study was carried out in the radiation protection qualities of the N series (narrow-spectrum) normalized by the ISO 4037-1 standard [7], covering the energy range from 48 to 118 keV (average energy).

2. Methodology

The TLD-100 (LiF:Mg,Ti) chip-format dosimeter was chosen for use during the measurements performed during the tests. The dosimeter holder design was developed in Fusion 360 software and manufactured on a Raise3D Pro2 FFF 3D printer using polylactic acid (PLA) filament. The dosimeter holder is designed to accommodate up to 2 TLDs and be positioned on the professional's eyeglass frame. Two phantom models were used for positioning the dosimeter holder: (a) anthropomorphic head and neck model, and (b) cylindrical model recommended by the ICRU (Report 57) [8]. Irradiations were performed with a Pantak/Seifert irradiator system, in the Radiation Protection (N) qualities corresponding to voltages of 60, 80, 100 and 150 kV, according to the recommendations of the ISO 4037-1 standard [7], presented in Table I. The reference dose was 10 mGy. The dosimeter holders were positioned in the direction of the radiation beam.

Table I: Available and utilized quantity N (ISO 4037-1).

Quantity	Voltage (kV)	Energy (keV)
N-60	60	48
N-80	80	65
N-100	100	83

N-150	150	118

Two TLD-100s were used per dosimeter holder for each irradiation cycle, totaling 4 cycles for each phantom (1 per quantity), with a total of 16 TLDs used.

The readings were taken using a Harshaw 5500 thermoluminescent reader. The heat treatment was performed in two stages: (1) heating at 400 ºC for 1 hour and then abrupt cooling; (2) heating at 100 ºC for 2 hours and cooling to room temperature (~ 20 ºC).

To relate the thermoluminescent signal to the absorbed dose, a calibration factor F_c was determined. This factor is responsible for converting the reading in charge supplied by the reader into the dosimetric quantity of interest, and is obtained by the ratio between the reference dose irradiated in the dosimeter and the net reading, according to Equation 1:

$$F_c = \frac{D_{ref}}{L - L_{bg}} \tag{1}$$

- D_{ref}: Reference dose
- L: Reading (nC)
- L_{bg}: Reading background (nC)

For spectral characterization of the beams employed, the spectra of the four N qualities were simulated using the SpekPy v2.0 software [9,10], an open-source Python-based tool for modeling X-ray tube spectra. The simulations considered a tungsten (W) anode with a 15° angle, inherent filtration of 4.0 mm Be associated with 1.0 mm Al, and instrumental FWHM of 2.0 keV, according to ISO 4037-1 specifications. Figure 1 presents the calculated spectra, showing the photon fluence as a function of energy for each quality, with the respective half-value layer (HVL_1) and average energy ($\bar{E}$) values. The presence of the characteristic K peak of tungsten (~ 59 and 67 keV) is evident in the N-80 and N-100 qualities, a fact that directly influences the dosimetric response of the TLDs at these energies.

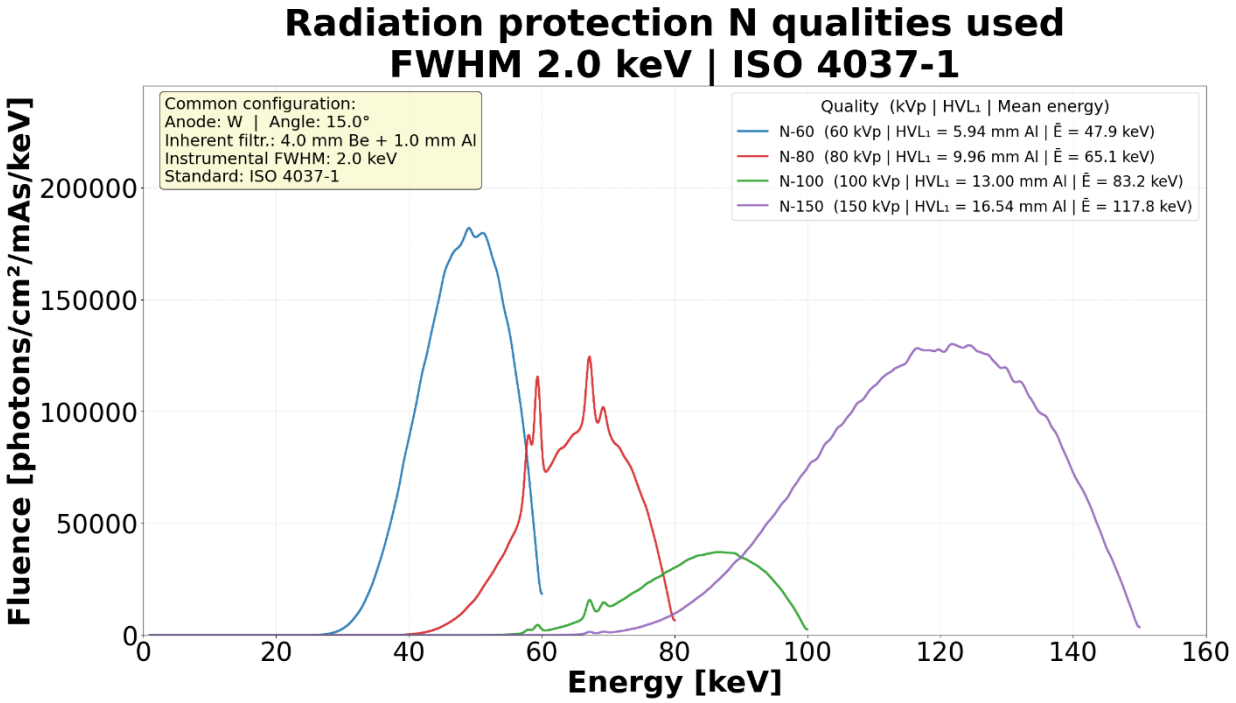

Figure 1: Spectra of the radiation protection qualities of the N series (ISO 4037-1) simulated with SpekPy v2.0, showing the photon fluence as a function of energy, along with the half-value layer (HVL_1) and the average energy ($\bar{E}$) for each quality.

3. Results and Discussion

Table II presents the calibration factor results found for each phantom and energy level. The calibration factor for 100 kV is reduced due to its characteristic peak and specific attenuation.

Table II: Calibration factors (F_c) per phantom and beam quality.

Phantom	60 kV	80 kV	100 kV	150 kV
Anthropomorphic	13.54	12.72	1.12	10.60
Cylinder	14.75	15.31	1.38	11.73

The results demonstrate that, for the two phantom models used, the received dose remained within the range of 9.99 to 10.39 mGy for the anthropomorphic model and 10.01 to 10.24 for the cylindrical model. These values are within the acceptance criterion of ±5% established for dosimetric systems. Figure 1 shows the results of the received dose per phantom and quality type N, for a dose of 10 mGy.

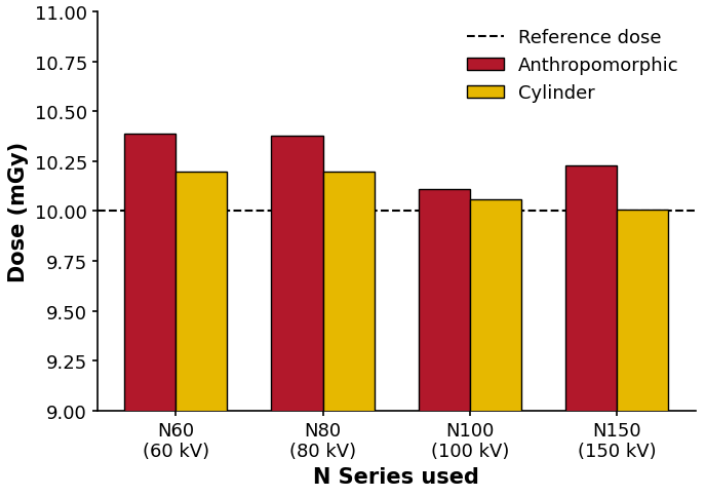

Figure 2: Absorbed dose measured in each phantom (anthropomorphic and cylindrical) for the four N radiation protection qualities, with a reference dose of 10 mGy.

4. Conclusions

The study demonstrated that the dosimeter holder model developed for lens dosimetry exhibits energy dependence compatible with the acceptance requirements in the 60 to 150 keV range. The doses received deviated by a maximum of ±5% from the reference dose of 10 mGy, meeting the established acceptance criterion.

The results validate the use of these dosimeter holders in individual lens monitoring programs, especially for workers exposed in interventional radiology and nuclear medicine procedures. The use of FFF 3D

printing proved to be a viable and low-cost alternative for the manufacture of dosimetric holders, enabling the customization of geometries for different clinical applications.

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