Micro X-Ray Irradiator Dosimetry Using Partial-Volume Techniques with Thermoluminescent Dosimeters

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INTRODUCTION

Microbeam delivery, and more broadly, small-field irradiations are motivated by clinical needs for the treatment of tumors. Microbeams have shown normal-tissue tolerance, suggesting the dose to tumor can be escalated. This drives the need for accurate tools to perform dosimetry of small fields in which unique challenges arise due to the small size and highly localized nature of the beam [1]. TLDs, while advantageous for their small sensitive volume and tissue-equivalent properties, are larger than the microbeam itself, leading to complexities in accurately quantifying dose within a confined region [2-3]. Thus, a partial-volume correction method was investigated using a custom built microbeam X-ray irradiator, called the Focused X-Ray Source (FXRS).

MATERIALS AND METHODS

Materials

- Focused X-Ray Source (FXRS) with rhodium target and 50 kVp
- TLD-100 chips of type LiF:Mg,Ti (3.2 mm × 3.2 mm × 0.89 mm)
- Harshaw model 5500 automatic nitrogen gas reader equipped with an ET Enterprises Type 9125B24 photomultiplier tube (PMT)

Annealing

- TLDs were
  - set in a 400 °C oven for 1 hour then cooled to room temperature
  - set in an 80 °C oven for 24 hours
  - cooled to room temperature for a minimum of 24 hours before irradiation
- Irradiations performed within 3 days of annealing

Sorting

- 3 cycles of annealing, exposure, and readout for each individual TLD
- Sensitivity within 2% of the mean reading and reproducibility within 3%

Irradiation with FXRS

- Focal spot aligned to the center of the chip depth at 0.445 mm
- Several irradiations of moving stripes–sets of 3 or 5 stripes (figure 2)–were performed at dose prescriptions of 2, 4, and 6 Gy
- The emission current was set to 800 µA and the line pitch was set to 200 µm

Readout

- TTP for each TLD was used to heat from 80 °C to 350 °C at 15 °C/s
- Max temperature held until a total time of 26.7 seconds was met

Calibration Curve

- Created using the Co-60 source at the UW ADCL to determine chip coefficients by individually irradiating three TLD chips to 0.5, 1, and 4 Gy

$$D_{stripe} = (M_{raw,i}^{meas} - M_{bkgd}) \cdot k_{PMT,i} \cdot k_Q \cdot k_{cal,norm}$$

- $k_{cal,norm}$ indicates the calibration coefficient normalized to volume to account for sensitivity

RESULTS

A cuboid shape was assumed for the irradiated volume. The width of the stripe was determined by finding 95% of the full width of the intensity line profile from scanned EBT4 film (figure 1).

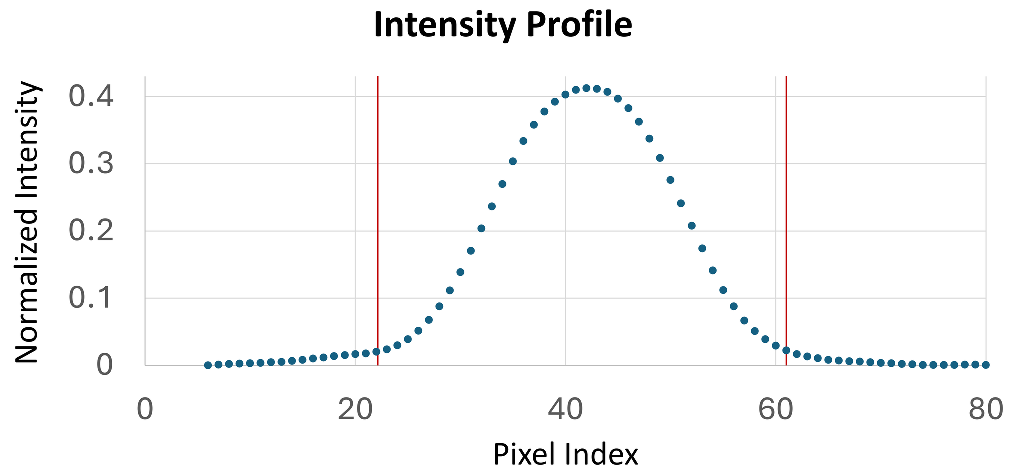

Figure 1. Example line profile of microbeam stripe used to determine the 95% full width (red line).

The irradiated volume (0.89 mm x 3.4 mm x 0.16 mm) of each TLD was computed by a summation of the number of stripes delivered (table 1).

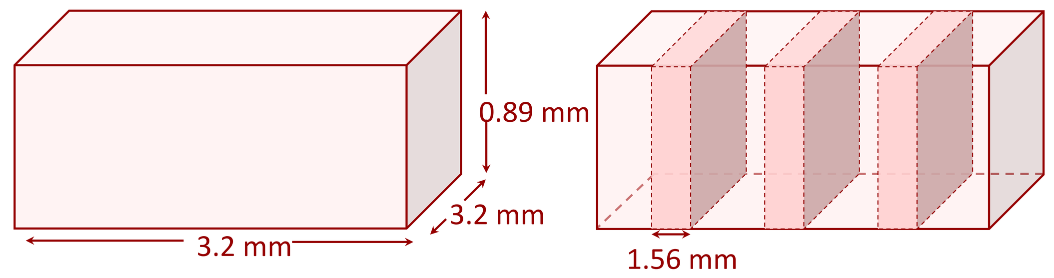

Figure 2. Depiction of the TLD before irradiation with the FXRS (left) and the TLD after a 3-stripe irradiation where dark shaded regions indicate the irradiated volume (right).

	Volume Irradiated (mm³)	Percent of TLD-100 Chip Irradiated (%)
TLD-100	9.11	100%
3x Stripes	1.33	14.6%
5x Stripes	2.22	24.4%

Table 1. Volume of TLD-100 chips irradiated for different irradiation prescriptions.

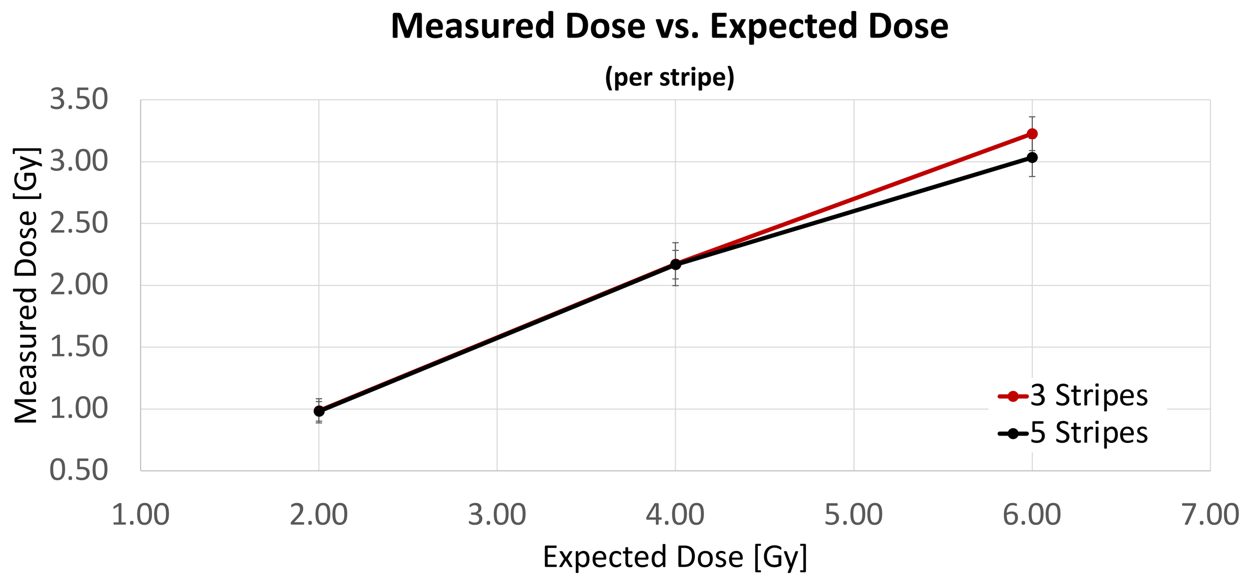

Figure 3. The measured dose normalized to the estimated mass irradiated of the TLDs compared to the expected dose (predetermined via film).

DISCUSSION

- The measured dose is approximately half the expected dose (figure 3); there is a need for clarification in the manufacturer definition of expected dose per stripe is for the FXRS.
- A slight difference between the 3-stripe and 5-stripe method, which is not present at the lower doses, emerges at the 6 Gy irradiation scheme (figure 2).
- Discrepancies between focal spot alignment and the center of the TLD may generate differences in lateral scatter and penumbra leading to inconsistencies in the energy deposition of the beam, as well as a discrepancy between the assumed cuboid shape and the effective irradiated volume.

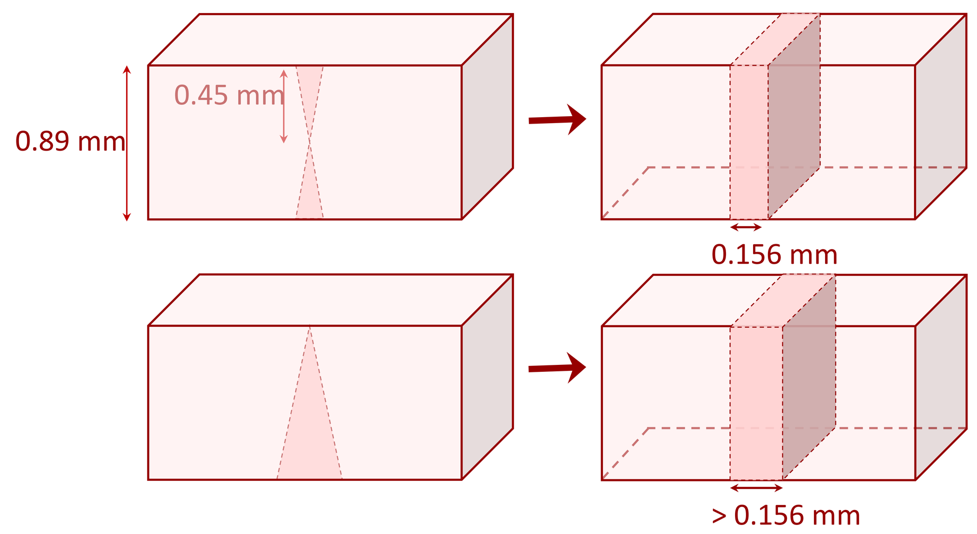

Figure 4. Depiction of TLD focal spot alignment to the middle of TLD (top) and to the top of TLD (bottom) and their hypothesized resulting irradiation volume.

- Future studies will investigate effects of different focal spot alignments within the TLD (example in figure 4).
- Despite the low measured dose and discrepancy between methods at at 6 Gy, TLD-100s show promise for initial dosimetric characterization of X-Ray microbeams by using a partial-volume TLD correction and may contribute to refining dosimetric techniques.
  - Future studies will utilize an increased sample size to reduce uncertainty and improve the robustness of the study.

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