Evaluation of a Brachytherapy Hyperspectral Plastic Scintillation System for Gamma Knife Small-Field Dosimetry

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ABSTRACT

- **Purpose**: To evaluate whether a hyperspectral plastic scintillation detector can accurately measure small Gamma Knife radiation fields.
- **Methods**: Detector measurements for 4, 8, and 16 mm collimators were compared with Monte Carlo simulations and EBT3 film, while positioning, rotation, phantom material, and correction factors were also assessed.
- **Results**: The detector measurements agreed closely with the simulations and film results, required only small correction factors, and showed that accurate submillimetre positioning is especially important for the 4 mm field.
- **Conclusion**: Preliminary findings suggest that the detector is a promising real-time, high-resolution option for Gamma Knife small-field dosimetry and quality assurance.

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INTRODUCTION

Leksell Gamma Knife® (GK) radiosurgery uses small, highly focused cobalt-60 fields with steep dose gradients. Accurate dosimetry is therefore challenging because detector size, material composition, and positioning can strongly influence measured output factors and beam profiles.

Diodes provide high spatial resolution but are not water-equivalent and may require field-dependent corrections. Plastic scintillation detectors offer a small sensitive volume, near-water-equivalent response, real-time readout, and minimal dose perturbation, making them promising for GK small-field dosimetry.

This study evaluates a hyperspectral plastic scintillation detector that has been used for brachytherapy and small fields for GK measurements using experiments and EGSnrc Monte Carlo simulations. Detector response, phantom material effects, positioning sensitivity, angular dependence, output factors, and beam profiles were assessed and compared with EBT3 film.

METHODS AND MATERIALS

- **Monte Carlo (MC) modelling:** EGSnrc simulations were performed for the 4, 8, and 16 mm Gamma Knife collimators in liquid water, Solid Water, ABS, PMMA, and polystyrene phantoms. The PRB-0019 scintillator and optical jacket were modelled explicitly to calculate output factors and detector correction factors (from TRS-483 for small fields).
- **Experimental measurements:** Output factors and crossline dose profiles were measured at isocentre using the Medscint HYPERSCINT® QA-200 system using the probe.
- **Detector sensitivity:** The effects of sub-millimetre positioning errors and probe rotation were evaluated for each collimator size.
- **Independent validation:** Selected measurements were compared with EBT3 radiochromic film.



Figure 1. The HYPERSCINT QA-200 system, obtained from [1].

RESULTS

- PSD output factors obtained were obtained from MC modelling.
- Measured values were 0.787–0.814 for 4 mm and 0.886–0.904 for 8 mm fields (within 1.5% of MC).
- EBT3 film measurements were consistent with PSD and MC results.
- Scintillator correction factors were small, ranging from approximately 1.003–1.015.
- A 0.5 mm positioning offset reduced the 4 mm signal by 11–13%.
- Residual angular dependence after stem correction was <1.8%.

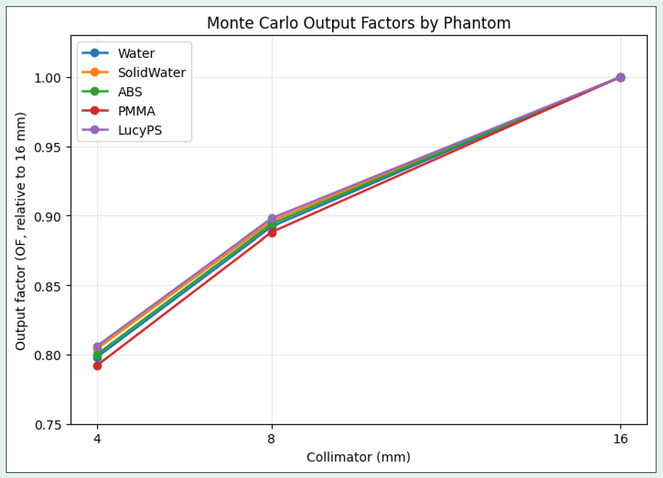


Figure 2. Monte Carlo output factors obtained for the scintillator for different phantom materials commonly used in GK, normalized to the 16 mm field.

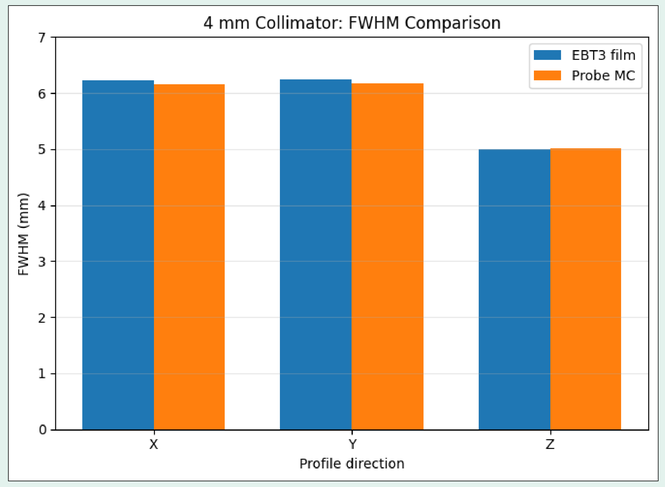


Figure 3. Comparison of FWHM results for 4 mm collimator comparing EBT3 film with MC probe.

Preliminary Small-Field Correction Factors for the Scintillator

Phantom	kPSD (4 mm)	kPSD (8 mm)	kPSD (16 mm)
Liquid water	1.013 ± 0.003	1.007 ± 0.003	1.003 ± 0.003
Solid Water	1.015 ± 0.003	1.009 ± 0.003	1.004 ± 0.003
ABS	1.014 ± 0.003	1.008 ± 0.003	1.004 ± 0.003

Table 1. Small field correction factors [2] for different field sizes obtained for the probe, which corrects for volume averaging, detector-material perturbation, field-size-dependent energy response, and scintillation quenching so the measured signal ratio represents the true dose-to-water ratio.

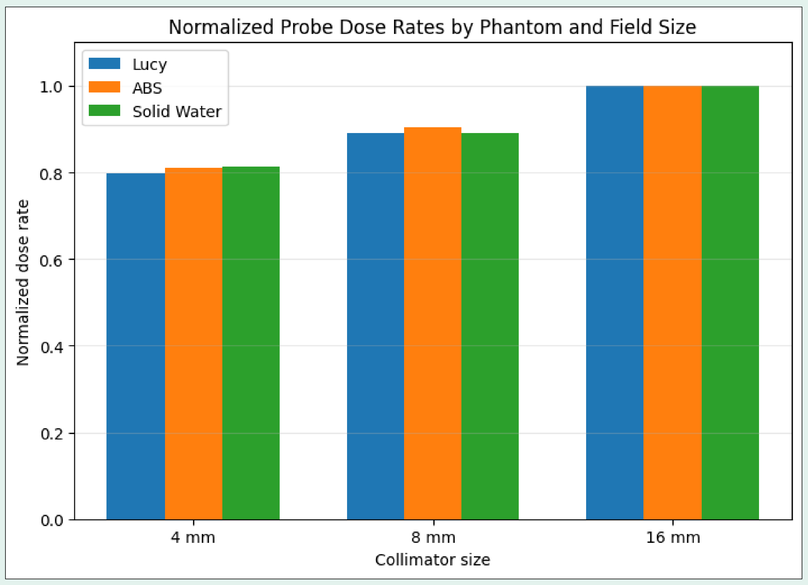


Figure 4. Comparison of dose rates for different phantom and field sizes, normalized to unity for 16 mm. Due to issues with detector calibration, results are preliminary.

DISCUSSION

- The small detector volume and near water-equivalent composition minimized volume averaging and detector perturbation.
- Agreement with MC and film supports the use of hyperspectral PSDs for Gamma Knife commissioning and QA.
- Accurate submillimetre positioning remains critical, particularly for the 4 mm collimator

CONCLUSION

The hyperspectral plastic scintillation detector provided accurate Gamma Knife output-factor and profile measurements with only small correction requirements. Its real-time response and high spatial resolution make it a promising alternative to conventional diodes, ion chambers, and film for small-field dosimetry. The work done is only preliminary results and will be assessed further.

REFERENCES

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