Characterization of novel ferrofluid for intraocular photon shielding by Monte Carlo and film dosimetry methods

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INTRODUCTION

Ocular melanoma patients undergoing brachytherapy receive extremely high doses to normal structures of the eye, causing unwanted side effects such as blindness and loss of vision. We propose an intraocular shielding method using ferrous magnetite nanoparticles suspended in a polymer fluid, known as ferrofluid (PDMS-Fe_3O_4)[1]. The particles are drawn toward the tumor with a magnetic plaque, creating a ferrofluid shield for normal tissue structures (see Figure 1).

To evaluate the effectiveness of the ferrofluid as a radiation shield, we studied its attenuation properties using Monte Carlo simulation and film dosimetry methods

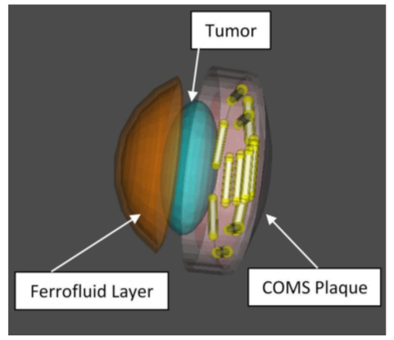

Figure 1. *Proposed ferrofluid shield created with a magnetic plaque.*

AIM

To investigate the radiological properties of a magnetite polymer (PDMS-Fe_3O_4), including linear attenuation coefficient (μ) and half value layer (HVL) utilizing:

A. GafChromic film dosimetry
B. GEANT4-GAMOS Monte Carlo dosimetry
C. Analytical calculations

METHOD

A. GafChromic film dosimetry

- *Calibration*: EBT3 GafChromic film was calibrated using a single low energy (E_{avg} = 28 keV) I-125 source
- *Attenuation measurements*: A custom depth phantom was used to create a 1 mm layer of ferrofluid and hold the film and source at a reproducible distance

B. GEANT4-GAMOS Monte Carlo dosimetry

- *Benchmarking:* An IsoAid advantage source was benchmarked in GAMOS, comparing TG-43 parameters such as Dose Rate Constant, Radial Dose Function, and Anisotropy Function to previously simulated MCNP models [2-5]
- *Attenuation Measurements:* 1 mm ferrofluid attenuation is determined with a single simulated source in an identical set up as film measurements (see Figure 2)

C. Analytical calculations

- Utilizing the analytical formula for weighted mass attenuation coefficients (below) and the known composition of PDMS-Fe_3O_4 [6], and linear attenuation coefficient (μ), and mass attenuation coefficients were calculated as follows:

$$\frac{\mu}{\rho} = \sum_i w_i \frac{\mu}{\rho_i}$$

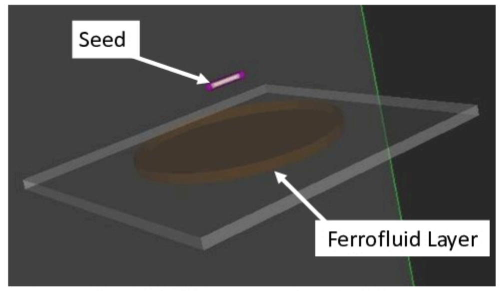

Figure 2. *GAMOS setup of an I-125 source attenuation, with a 1 mm thick layer of ferrofluid placed adjacent to dose-scoring detector*

RESULTS

The I-125 IsoAid Advantage seed modelled in GAMOS compared well with previous MCNP studies. The dose rate constant was within 5% of previous study data, and within 3% of the NIST evaluated dose rate constant of 0.981 cGy/h/U (see Table 1). Anisotropy and radial dose functions were within 5% of previous data. Figure 3 visually demonstrates the radial dose comparison.

Film measurements and GAMOS calculations for HVL were very similar, with about 2% difference (see Table 2). The analytical hand calculation measured a lower (more attenuating) HVL. Figure 4 highlights the film and GAMOS difference in attenuation measures across a 1 mm layer of PDMS-Fe_3O_4. There appear some difference between film and GAMOS measurements. This is likely due to an imperfectly geometry, as the fluid layer may not have been completely flat. Future aims work to limit imperfect geometries.

GAMOS Benchmarking

Table 1. *Dose Rate Constant Benchmarking shows agreement with NIST accepted dose rate constant and previous literature.*

Table 1. Dose Rate Constant Comparison

Study	Dose Rate Constant (cGy/h/U)
Oare et al. (this work)	0.986± 0.075
Meigooni et al.	0.990 ± 0.080
Solberg et al.	0.962 ± 0.005
NIST/ADCL	0.981 ± 0.050

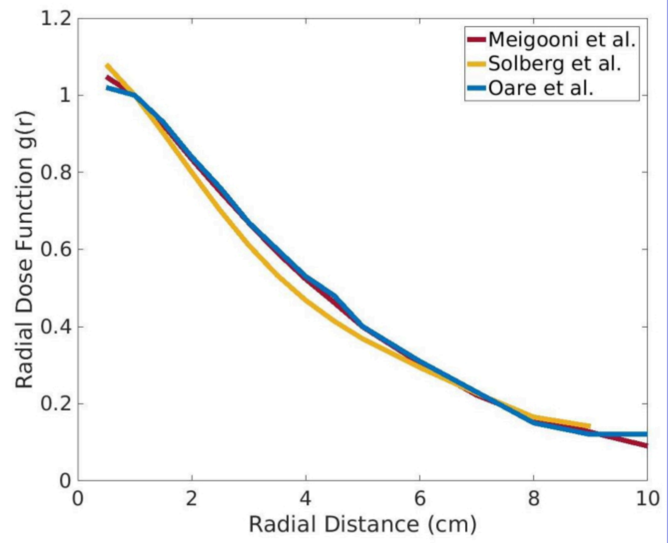

Figure 3. *Radial Dose Function comparison. The radial dose function of the modelled GAMOS seed is in excellent agreement with MCNP literature for IsoAid ADVANTAGE. The radial dose function is in agreement within 5% of previously reported Monte Carlo studies.*

Attenuation Study Results

Table 2. *The attenuation properties were investigated. The Film and GAMOS measurements show excellent agreement, within 3%.*

Table 2. Linear attenuation coefficient and HVL calculation results

Method	μ (mm^{-1})	HVL (mm)
Film	0.507 ± 0.047	1.37
GAMOS	0.518 ± 0.006	1.34
Analytical	0.551 ± 0.080	1.26

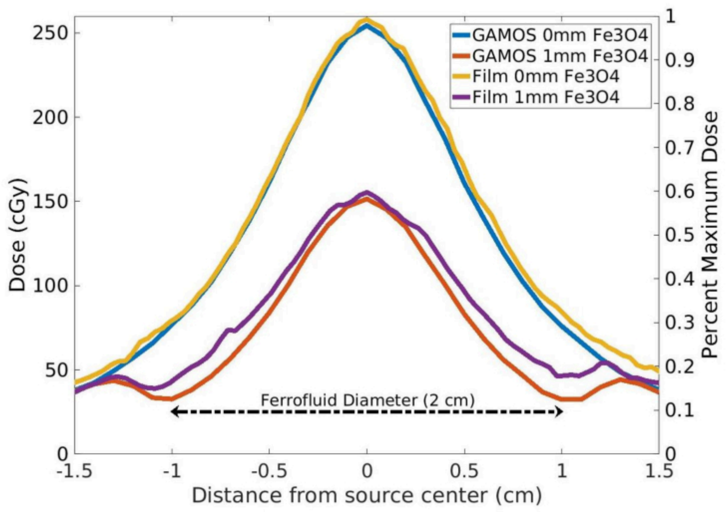

Figure 4. *Attenuation with 1 mm thick layer of PDMS-Fe_3O_4. The GAMOS and Film attenuation measurements are compared. Dose along the seed axis is displayed for each method. Attenuation is visible in the presence of ferrofluid.*

CONCLUSIONS

An I-125 seed was modelled with GAMOS and validated versus previously reported Monte Carlo data. The GAMOS source was within 0.5% of NIST dose rate constant, and within 3% of previous literature reported values. The radial dose function and anisotropy functions fell within 5% of previous literature reported values.

EBT3 GafChromic film was calibrated for a low energy I-125 source, providing a fifth-degree polynomial calibration curve (R^2 =0.999). Our determined linear attenuation coefficient for PDMS-Fe_3O_4 was approximately 0.51 and 0.52 mm^{-1} from film and GAMOS, respectively. Therefore, **a 1 mm layer of this PDMS-Fe_3O_4 can attenuate photons by 40%**, making the material an effective shield to protect the structures of the eye from excessive dose during intraocular brachytherapy. This magnitude of dose reduction to the lens, macula, and optic nerve can potentially reduce the incidence of radiation-induced side effects.

Future work includes calculated doses to structures of the eye in the presence of ferrofluid and a magnetic field.

ACKNOWLEDGEMENTS

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CONTACT INFORMATION

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