FLASH Proton Therapy in Clinical PBS Gantry: Reference Dosimetry Inter-Comparison Including Ion Chambers and a Calorimeter

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INTRODUCTION

Recent pre-clinical studies showed that ultra-high dose rate, called FLASH radiotherapy significantly reduce normal tissue toxicity while maintaining tumor control [1-2]. Cincinnati Children's Hospital and University of Cincinnati Medical Center Proton Therapy Center (CPCT) in collaboration with Varian, Inc. has upgraded the existing research-dedicated gantry room for clinical FLASH proton radiotherapy. Therefore, it is important to understand the basic dosimetry, especially the absolute dose measurements.

AIM

A calorimeter based reference dose is obtained from a direct measurement of absorbed dose, not requiring $N_{D,W}$. The purpose of this work is to compare the absorbed dose to water in ultra-high dose rate (~65 Gy/s) pencil beam scanning proton beams measured with ion chambers and a calorimeter from the National Physical Laboratory (NPL) in UK as a reference.

METHODS

A total of 8 rectangular 250 MeV single layer fields (5×6, 5×8, 5×10, 5×12 cm² and transposed fields for each) were developed for treating bone metastasis of extremities using plateau region of the field. The absolute dose measurements at 5 cm water equivalence depth (WED) for each field were performed to compare dose determination [3] by the Advance Markus (AMC) and PPC05 ion chambers and a graphite calorimeter. Gafchromic film was used as a secondary validation tool as well for the verification of 2D dose uniformity and field size. Measurements setup are shown in Figure 1.

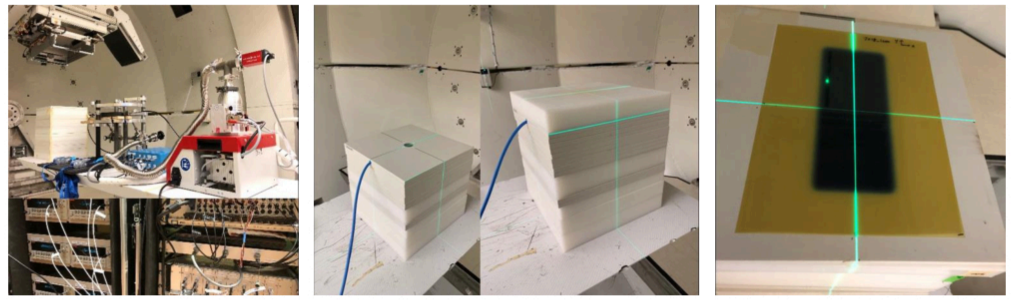

Figure 1 Measurements setup of calorimeter (left), ion chamber (middle) and film (right)

RESULTS

The measured absolute dose of 5×6 (5×12) cm² field with calorimeter is 8.415±0.004 (8.514±0.004) Gy as our reference RBE dose. The ratio of AMC dose to the calorimeter reference dose is 1.006 (0.995). PPC05 chamber showed ~3% higher reading. The dose measured with Gafchromic film shows ~2% over-response.

Field Size	Dosimeter	RBE Dose (Gy)	Standard Deviation (1σ)	Ratio (Chamber/Calorimeter)
5 x 6 cm²	Calorimeter	8.415	0.004	n/a
	Adv Markus	8.463	0.029	1.006 ± 0.029
	PPC05	8.715	0.025	1.036 ± 0.025
	Film	8.600	n/a	1.022
5 x 12 cm²	Calorimeter	8.514	0.004	n/a
	Adv Markus	8.471	0.026	0.995 ± 0.026
	PPC05	8.765	0.024	1.029 ± 0.024
	Film	8.599	n/a	1.010

Table 1. Summary of absolute dose measurements with AMC and PPC05 chambers, EBT3 Gafchromic film and calorimeter and their ratio to the calorimeter measurement for 5 x 6 cm² and 5 x 12 cm² Fields.

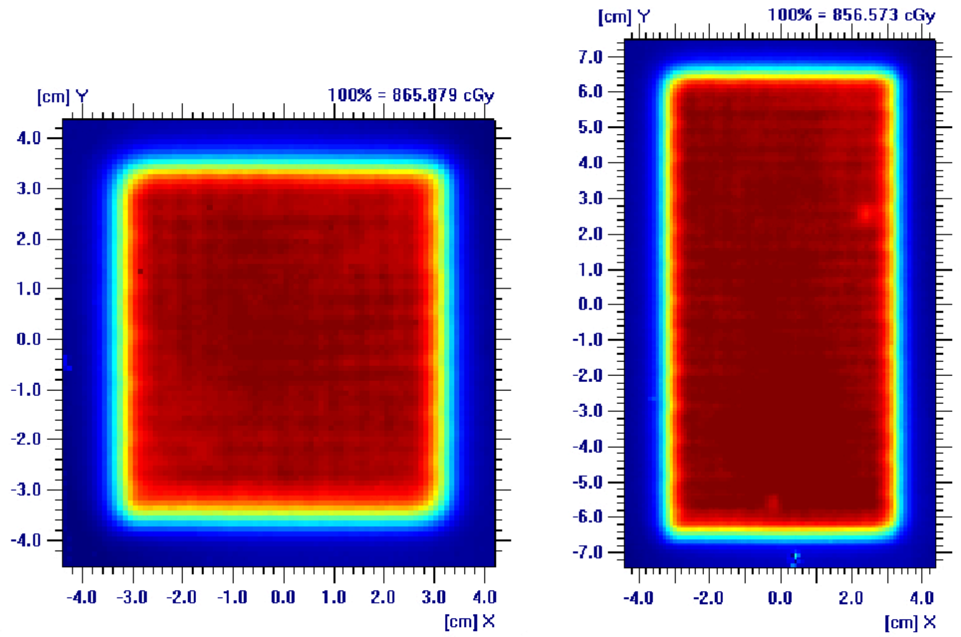

Figure 2 Gafchromic film measurements at 5 cm depth for 5×6 cm² and 5×12 cm² fields. Absolute dose is measured 2.2% and 1.0%, respectively higher compared to the reference dose from calorimeter.

AMC as well as PPC05 chamber showed no signal loss due to ion recombination for bias voltage greater than 200 Volts (Figure 3). Both K_s and K_{pol} measurements in FLASH dose rates showed no difference from conventional dose rate as well.

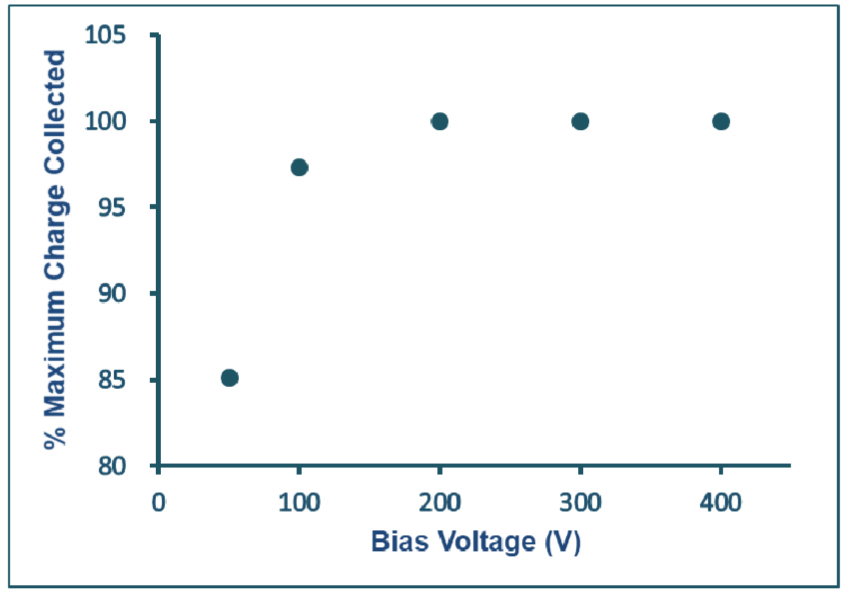

Figure 3 AMC saturation curve as a function of bias voltage.

CONCLUSIONS

AMC absolute dose measurement agreed with a calorimeter reference dose within 0.02%. PPC05 chamber showed 3% over-response compared to the reference dose measured with the calorimeter. Both AMC and PPC05 chambers demonstrated the reproducibility as well as the stability as a reference dosimeter in ultra-high dose rate PBS proton radiotherapy. Gafchromic film may be an excellent secondary dosimeter for 2D dose distribution.

Standard deviation in the reference dose with the calorimeter is only from multi-day measurements variation. Other uncertainties including Monte Carlo based correction are on-going now. Multi-institutional inter-chamber variation is being investigated. Some uncertainty (2-3%) from Gafchromic film is mainly due to uncertainties from film scanning/analysis process including calibration and its LET dependence [4]. This can be further improved by following more well-defined film calibration and analysis protocol.

REFERENCES

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