JULY 12–16 2020 VIRTUAL
JOINT AAPM | COMP MEETING
EASTERN TIME [GMT-4]

Measurement of the Ion Collection Efficiency of Different Ion Chambers in Proton FLASH Irradiation

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INTRODUCTION

FLASH proton therapy studies involve ultra-high dose rates exceeding ~50 Gy/s and have been of great interest due to reduced normal tissue toxicity and equivalent tumor killing effect compared to conventional dose rates. However, the ionization chamber response to proton FLASH has not been evaluated and verified for a wide selection of commonly used ionization chamber designs.

AIM

Absolute dosimetry remains a challenging task for FLASH irradiations due to uncertainties in ion collection efficiency under ultra-high dose rate applications (FLASH). Our most recent work verified the ion collection efficiency of Advanced Markus chamber again Faraday cup (Diffenderfer E, et al., 2020). In the previous study (Patriarca A, et al., 2018), a 0.125cc cylindrical chamber (PTW 31010) was employed for absolute dosimetry with dose rate >40Gy/sec. However, based on our experience, cylindrical chambers might not be accurate enough for absolute dosimetry due to inefficient ion collection at high dose rate. This work aims at appropriately evaluating ion recombination corrections for different ionization chamber types and identify suitable ion chambers for accurate absolute dosimetry in proton FLASH irradiations.

METHOD

All measurements were performed in a dedicated research room with a fixed proton beamline. Protons at 230 MeV energy were extracted from the cyclotron with requested beam current of 360 nA. A passive scattering system was used to create a 2.6-cm diameter uniform field at the measurement location. The dose rate was measured at 114 Gy/s with an ADCL calibrated parallel plate chamber at the flat region of the proton beam. Subsequently, collected charge was recorded for seven other chambers (IBA-dosimetry PPC05, PPC40, CC03, CC13, Standard Imaging Extradin A12, A16 and A26) under the same irradiation conditions at the same location with two bias voltages (+400V and +200V).

RESULTS

The measurement setup is shown in Figure 1. The duration of FLASH proton beam is set at 50ms for this experiment. Dose rate was measured at 114Gy/sec at the point of measurement. Technically, the cyclotron produces a 2.4ns micro-pulse at 106.2MHz RF repetition rate, which means a 2.4ns micro-beam pulse approximately every 9.4ns. Typical ion collection time for the chambers used in the study is on the order of µs, which is much smaller than the beam on time, which is 50ms to give a typical delivered dose approximately 6 Gy. Therefore, we decided to use the two-voltage model for continuous beam in TRS 398 to calculate ion recombination correction factor ks :

$$k_s = \frac{\left(\frac{V_1}{V_2}\right)^2 - 1}{\left(\frac{V_1}{V_2}\right)^2 - \left(\frac{Q_1}{Q_2}\right)}, where\ V_1 = +400V\ and\ V_2 = +200V$$

As show in Table 1, all parallel plate chambers tested in this measurement demonstrated sufficient ion collection efficiency at 114Gy/sec dose rate, with k_s less than 1% from unity. Due to inefficient ion collection, k_s for Farmer chamber and CC13 chamber (similar to the PTW 31010 cylindrical chamber used by A. Patriarca, et al) are larger than 1.05 when dose rate reaches 114Gy/sec. The use of these ion chambers with high k_s correction in high dose rate could introduce large measurement uncertainties if the clinical application expects a wide range of dose rates in the measurement condition. Therefore, they are not suitable for absolute dosimetry for FLASH irradiations.

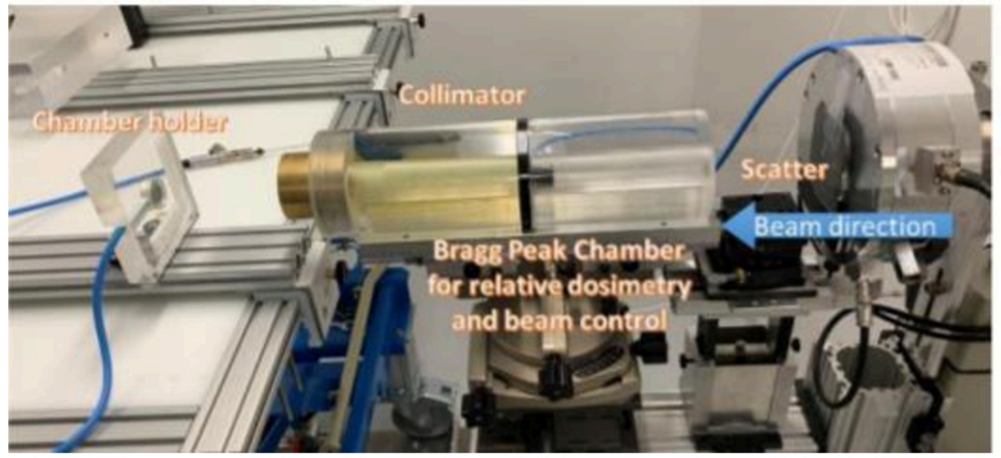

Figure 1 Experimental setup of k_s measurements in FLASH irradiation

Table 1. Measured ion-recombination factor k_s

Manufacturer	Model	Type	Sensitive volume	Measured k_s
PTW	Advanced Markus	Parallel plate chamber	0.02 cc	1.003
IBA Dosimetry	PPC 05		0.05 cc	1.006
	PPC 40		0.4 cc	1.007
	CC 13	Compact cylindrical chamber	0.13 cc	1.185
	CC 04		0.04 cc	1.007
Standard Imaging	Extradin A12	Farmer chamber	0.64 cc	1.077
	Extradin A16	Pinpoint cylindrical chamber	0.007 cc	1.003
	Extradin A26		0.015 cc	1.003

CONCLUSIONS

In addition to parallel plate chambers, small volume cylindrical chambers are surprisingly suitable for absolute dosimetry in proton FLASH irradiation. These “micro” chambers have excellent spatial resolution, which may find additional uses for small-field FLASH applications.

REFERENCES

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