Calorimetry techniques for absolute dosimetry of laser-driven ions beams

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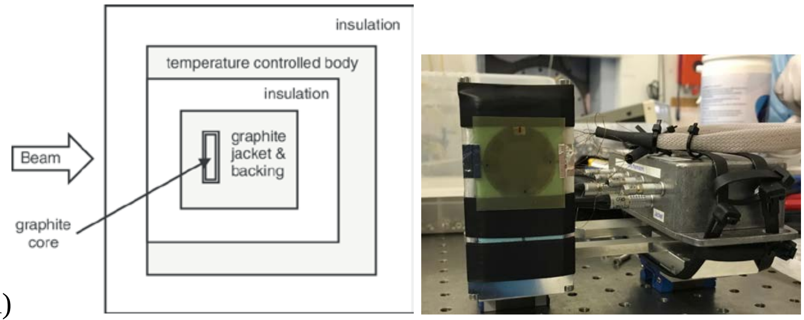
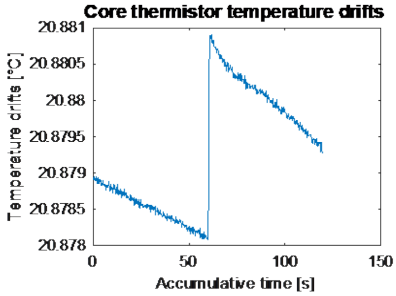
Recent advancements in accelerator technology has seen systems developed capable of generating beams of energetic particles with defining features, such as ultra-short pulse durations and ultra-high dose rates per pulse. This has allowed investigations of new innovative radiation therapy (RT) modalities characterized by dose deliveries that can exceed several hundred Gy/s, at which the so-called FLASH effect is induced. Studies of FLASH-RT at dose-rates greater than 40 Gy/s have demonstrated levels of tumor control in line with conventional therapies, with reduced normal tissue complication probability (NTCP), but are limited in their clinical implementation due to the huge size and cost of facility installation [1]. Alternative approaches have focused on laser-driven acceleration of charged particle beams through compact "plasma accelerators", with various experiments having already demonstrated the production of ions of several tens of MeV, lying within the range of interest for medical applications [2]. Furthermore, the ultrashort pulse durations of laser-accelerated ion beams (ns-ps) and typical doses per pulse of several Gy, leads to dose-rates of up to 10^9 Gy/s, offering the potential to provide almost instantaneous irradiations, aiming to seemingly extend the RT therapeutic window. Accurate dosimetry of high dose per pulse beams has proven to be technically challenging, and is further complicated for laser-driven accelerators due to the large electromagnetic pulses (EMP) generated during laser-matter interaction [2]. As such, the development of novel approaches in place of those already established for conventional radiotherapy, is necessary. In light of this requirement, National Physical Laboratory (NPL), proposed performing absolute dose measurements of high dose-rate per pulse proton beams, in the framework of the European Metrology Programme for Innovation and Research (EMPIR) UHDpulse project. Using a modified small portable graphite calorimeter that had been previously used for low energy proton beams, proof of principle measurements of the absorbed dose of laser-driven proton beams have been conducted at the Central Laser Facility of the Rutherford Appleton Laboratory, representing the first ever based on calorimetric techniques [3]. Proton beams accelerated to energies of up to 40 MeV were produced using the VULCAN petawatt laser system, with negligible EMP contribution to the signal to noise ratio and measurable doses per pulse of up to 3 Gy observed.

(a)


(b)


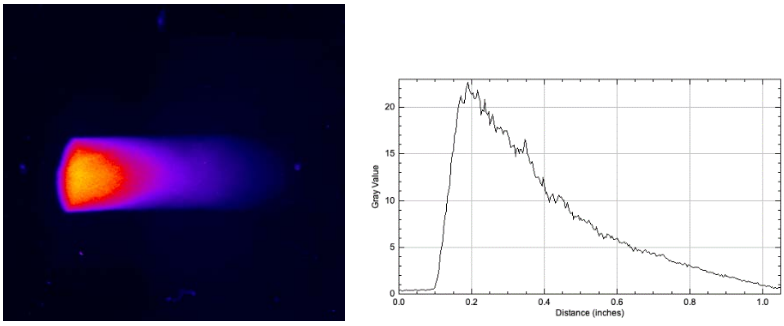
(c)


Figure 1; *(a)* Initial schematic of the small portable graphite calorimeter (left) from [3], and modifications for VULCAN test with insulating material removed leaving the front surface exposed to the atmosphere (right); *(b)* Radiation induced temperature rise in core thermistor; *(c)* 2D RCF dose distributions acquired at the same acquisition point as the calorimeter core, with dose distribution profile over the active layer area indicating an average delivered dose of 2.245 Gy.

[1] E. Schüler, et al., *Int J Radiat Oncol Biol Phys.* (2017) 1;97(1):195-203.

[2] A. Macchi, M. Borghesi, M. Passoni, *Rev. Mod. Phys. 85* (2013) 751–793.

[3] H. Palmans, et al., *Phys. Medicine Biol. 49* (2004) 3737-3749.