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Dosimetric characterization of ultra-high dose rate proton beams for FLASH radiotherapy using calorimetry

The recent discovery of the "FLASH"effect occurring delivering beams at average dose-rates exceeding 40 Gy/s and with a total irradiation time of < 300 ms, is leading to a growing interest in establishing the dosimetric and monitoring techniques that still assure the high level of accuracy needed for the clinical translation of FLASH radiotherapy [Romano et al., Med. Phys. 2022).
An experiment was recently carried out at the experimental room of the of the Trento Proton Therapy facility using ultra-high dose rate (UHDR) proton beams accelerated at 228 MeV by a IBA Proteus 235 cyclotron [Tommasino et al., NIM A 869 (2017) 15–20].
Aim of the experiment was to dosimetrically characterize the high energy UHDR proton beams using a newly developed portable graphite calorimeter specifically optimized for UHDR beams. The new dosimeter is an innovative and compact device recently developed at the National Physics Laboratory (NPL), which is the UK National Metrology Institute, acquired at the INFN Catania Division in the framework of the INFN CSN5 national call "FRIDA". The calorimeter is a portable secondary standard dosimeter composed by a simplified structure consisting of a central graphite core, 2 mm thick and 16 mm of diameter. The cylindrical core is connected to a single thermistor which forms one arm of a DC Wheatstone bridge providing, upon previous calibration, the measurement of the temperature rise during the irradiation, which is proportional to the absorbed dose [G. Bass et al., Br. J. Radiol. (2023)]. The calorimeter has been also calibrated in terms of absorbed dose at NPL under reference conditions using a Co60 source. Its response in terms of temperature increase upon irradiation and hence of absorbed dose was investigated varying the following beam settings: i) the beam current (from 10 nA up to 500 nA) and, hence, the average dose rate (up to 250 Gy/s) keeping the same total dose delivered; ii) the delivered dose (0.3-20 Gy) by changing the irradiation time (from 10 ms to 1 s), keeping the same beam current. The calorimeter was placed in air at the isocentre, at 2-3 meters far from the exit window. Before reaching the calorimeter, the proton beams were traversing the in-transmission double gap ionization monitor chamber supplied by the DE.TEC.TOR. company (named FLASHQ). The FLASHQ served as monitoring system during the whole experiment, thanks to a calibration in dose carried out using the IBA reference PPC05 ionization chamber placed at the same position of the calorimeter. No significant deviation from the linearity was observed for both the PPC05 and the in-transmission chamber at the explored rates. Alanine dosimeters were used to provide absolute dose measurements at the same irradiation point, whereas EBT-XD radiochromic films were used to evaluate the transversal dose distributions at the detector position and the beam uniformity.
After systematically demonstrating the dose rate independence of the calorimeter with UHDR proton beams and comparing it against the alanine dosimeters, absolute dose measurements at different proton beam currents were performed demonstrating the reliability and accuracy of the calorimeter for UHDR proton beam dosimetry. This system provides a very promising tool for accurate evaluation of dose in the perspective of future radiobiology and preclinical measurements.

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