Microdosimetric spectra measurements with alpha beams using the first solid-state microdosimetry multi-arrays for heavy ions

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Hadron therapy (HT) ensures extremely accurate dose conformity around tumor targets, reducing doses in adjacent healthy tissues and thereby providing enhanced safeguarding for at-risk organs. Heavier ions such as ^{4}He, ^{12}C, or ^{16}O could be more effective than protons due to their higher energy deposited per unit of track length (Linear Energy Transfer, LET) and their narrower Bragg peak, allowing for improved coverage conformity in the target volume and reduced total delivered dose. Despite these advantages, further radiobiological studies are needed, driving interest in a novel irradiation platform at the Accelerateur Lineaire et Tandem à Orsay (ALTO) named BioALTO, established at the Irene Joliot-Curie Laboratory in France. The experimental evaluation of LET maps at a high-resolution micrometric scale is imperative for characterizing the relative biological effectiveness (RBE) of ionizing particles, which are of interest to biologically optimized treatment plans in hadron therapy. For this purpose, the first solid-state microdosimetry multi-arrays for heavy ions, based on 3D cylindrical silicon micro-detectors [1, 2], have been manufactured in the National Center of Microelectronics (IMB-CNM, CSIC), Spain.

In this work, we measured microdosimetric spectra with alpha beams utilizing this newly developed microdosimetry pad-type system designed for the BioALTO platform. It comprises multi-arrays of 3 × 3 unit-cells of 3D cylindrical silicon microdetectors, with a 25 μm diameter, a 20 μm thickness and a 200 μm pitch, which covers 0.4 mm × 9 cm radiation sensitive region. In order to avoid the back-scattering contribution of the heavy ions, the back-side of the board was etched. Moreover, a multichannel data-acquisition (DAQ) system was specially designed for spectroscopy up to 2.75 MeV.

The energy calibration of this microdosimetry system was performed with continuous alpha beams with energies from 6 to 20 MeV delivered by the tandem accelerator at ALTO, which covers the dynamic range of the readout electronics. The systems were positioned at the beam exit, following a 12 μm-thick Mylar window. The pulse height spectra were gathered by the microdosimetry system. The system was irradiated with clinical equivalent fluence rates (~ 10^{8} $s^{-1}cm^{-2}$) without saturation effects. The results show that the dynamic range of the system has a linear behavior. The experimental results were crosschecked with Monte Carlo simulations using the GATE software, showing a good agreement. The results corroborate that the first solid-state microdosimetry multi-arrays for heavy ions, tailored for the BioALTO project, serves as a dependable tool for characterizing LET of heavy ions.

References:

[1] Guardiola, et al., Phys Med Biol. 2021 May 26;66(11).
[2] Bachiller-Perea, D., et al., Sci Rep. 2022 Jul 18;12(1):12240.