Microdosimetric Measurements with a GEM-TEPC with 62 AMeV Carbon Ions

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INTRODUCTION

The microdosimetric characterization represents a useful method for the quality assessment of hadron beams [1,2]. These distributions can be measured by means of Tissue Equivalent Proportional Counters (TEPCs) [3]. Besides, the possibility of performing dosimetry and quality assessment at the same time allows a detailed picture of the physical properties of clinical beams and permits the investigation of the effectiveness of a therapeutic treatment [1,3]. For these reasons, efforts should be made for developing experimental techniques able to measure microdosimetric distributions in hadron beams. Yet standard TEPCs cannot sustain the particle current of clinical hadron beams, while miniaturized TEPCs (mini-TEPCs) are fairly complex and difficult to use [4]. A new kind of TEPC based on a GEM structure has been recently developed. It simulates a tissue-equivalent region of a micrometer size. The new detector has been tested with photons and fast neutron beams by the LNL laboratories [5], before being used to perform microdosimetric measurements with 62 AMeV carbon ions at the cyclotron facility of the INFN-Laboratori Nazionali del Sud (LNS, Catania, Italy).

The GEM-TEPC was irradiated at the cyclotron facility of the INFN-LNS with carbon ions accelerated up to 62 MeV/n. For degrading the beam and to achieve an enlargement of the Bragg peak, the beam line configuration includes two ripple-filters in Poly-MethylMethAcrylate (PMMA) at the relative distance of 10 cm. More details about the beam line configuration have been published elsewhere [7]. In order to characterize the carbon beam, measurements were performed at different depths by locating, at each measurement position, an adequate number of PMMA foils of different calibrated thickness in front of the GEM-TEPC. Figure 1 shows a picture of the detector at the measurement position with a stack of PMMA foils in front of it. Figure 2 shows the depth dose distribution across the PMMA irradiation set-up resulting from Monte Carlo simulations performed with Geant 4 [7] and superimposed the adopted measurement positions (points A-N, corresponding to 0.99, 2.5, 4.0, 4.8, 5.1, 5.5, 6.0, 6.35, 6.5, 6.7, 6.8, 6.9 mm respectively). These positions correspond to the sum of the calibrated PMMA foils thickness and the detector wall thickness, which correspond to 0.99 mm when scaled to the PMMA mass density (1.2 g·cm−3).

RESULTS

The measured pulse-height spectra were calibrated...
through the identification of a characteristic feature in the spectra themselves, the so-called carbon-edge, which corresponds to the maximum lineal energy $y_{C\text{-edge}}$ released by carbon ions in the simulated site. $y_{C\text{-edge}}$ has been calculated using stopping power tables of the ICRU-73 publication [8] to have a value of 1397 keV/µm in liquid water.

![Fig. 2. Depth dose distribution across the PMMA irradiation set-up resulting from Monte Carlo simulations [7]. Points A-N indicate the adopted measurement positions.](image)

At each depth, microdosimetric spectra measured for the different SVs were found to have the same shape. This is a consequence of the fact that the beam is uniform and has the same quality distribution at their location.

Eight spectra measured at different depths for one of these SVs are plotted in figure 3. Spectra measured at position B and C (2.5 and 4.0 mm of depth) have almost Gaussian shapes, centred at 69 and 91 keV/µm, respectively. With increasing depth, the peak of the spectra shifts to higher $y$-value and the spectra shape becomes asymmetric, with a long tail towards high $y$-value, up to $y_{C\text{-edge}}$. At the maximum depth of 6.8 mm, the peak is close to the carbon-edge value, as at this position the dose is more and more due to low energy ions, the maximum stopping power value of which is 931 keV/µm in water. At this position is also visible a peak between 30-40 keV/µm, due to the contribution of projectile fragments. Several lighter ions are in fact produced by non-elastic nuclear interactions of the primary carbon ion beams with the target nuclei, most of them coming from projectile fragmentation. They are produced at roughly the same velocity of the projectile, but considering their lower atomic number with respect to the primary carbon ions, they give rise to lower $y$-value energy deposition events and they are characterized by larger range. They therefore create a tail of dose beyond the Bragg peak of the incident carbon ions, as can be seen in figure 2. At the beam energy of this experiment, the contribution of these fragments to the dose is relatively low [7] and microdosimetric measurements were not performed in the tail region due to shortage of time. However, it should be mention that the fragments contribution increases with higher carbon beam energy, so that at 400 MeV/n (energy used in carbon clinical treatments) up to 70% of the primary carbon ions undergo fragmentation before stopping in the tissues [9]. The contribution of these particles to the predicted biological effect need to be carefully evaluated and microdosimetric measurements can be a useful tool to accomplish this task.

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