

EXAMINATION OF FRAGMENT DOSE CONTRIBUTION IN HEAVY ION RADIOTHERAPY

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Abstract: Heavy-ion radiotherapy is an efficient method for the treatment of deep-seated tumors, because the stopping of ions in a tissue delivers the maximal absorbed dose to the tumor-affected areas with minimal damage to the healthy tissues. However, heavy ions can undergo nuclear reactions, giving products with lower Z-values and hence a longer range in the tissue. This causes a dose increase beyond the mean range of the primary beam. The contribution of such reaction products was examined in an experiment where a stack of tissue-like targets interleaved with CR-39 etched track detectors (ETD) was irradiated with heavy ions. The analysis was performed using a recently developed technique of trajectory tracing, which enables the spectroscopy of fragments with different Z-values.

Key Words: Etched Track Detectors, Heavy Ions, Radiotherapy, Fragments, Trajectory Tracing

INTRODUCTION

Therapy with ions up to neon is one of the promising methods for the treatment of deep-seated tumors, especially those located in the vicinity of vital tissues, due to the completely different nature of the energy deposition compared to electromagnetic radiation. The dose increases with depth and reaches a high and narrow maximum at the end of the ion range (the Bragg peak) [1]. However, this high selectivity and accuracy in targeting is reduced by nuclear reactions which these ions can undergo - fragmentation, break-up or total disintegration - where the emitted products with lower Z-values have a longer range in the tissue and thus cause a deterioration of the sharp dose contour of the primary beam. These dose contributions were studied with an irradiation of a stack made of tissue-like targets interleaved with ETD. Passing the detector, the charged particles leave latent tracks that are later chemically etched into small holes visible with an optical microscope. The energy and charge of the particle can be determined from the geometric and optical properties of the tracks.

METHODS

For the purposes of the stack analysis, a special method of trajectory tracing was developed in our laboratory [2]. In each detector foil, the tracks are counted on

both sides using an automated track analysis system called TRACOS [3]. The basis of this new technique is the creation of a set of tracks on consecutive surfaces belonging to the same particle - connecting them into a matching trajectory. The current study represents an upgrade of this method with further analysis, where the track sizes in individual trajectories were examined and all significant deviations were detected. The software for connecting trajectories is not capable of finding a perfect match, which is the reason for some of the deviations, but the majority of them actually represent nuclear reactions. Most of those that occur in the stack can be detected and their parameters (energy and coordinates, product identification (charge, mass, energy) and angular distributions) can be calculated.

EXPERIMENT

In this study, the method described above was applied in the analysis of a stack of four 6 mm thick paraffin targets interleaved with pairs of ~0.6 mm thick ETD. The stack was exposed to a 110 MeV/u ^{12}C beam at NIRS-HIMAC (Chiba, Japan). After chemical etching (7M NaOH, 80°C, 14 h) and polishing (PEW, 80°C, 1 min.) the detectors were counted and the tracks later connected into trajectories. All the trajectories with parts composed of consistently smaller tracks than those of the primary particles at equivalent depth represent reaction-product trajectories. They were joined with the trajectories of originating particles and sorted into groups according to the number of reaction products, which is important for later particle identification. The reaction is found with intersection distance calculation of all the candidate trajectories (on the order of a few μm). Approximately 80% of all the reaction trajectory candidates were joined in reactions.

RESULTS AND DISCUSSION

Firstly, all the track size distributions were measured on all the detector surfaces. Fig. 1 shows track radius distributions behind individual targets. A maximum that corresponds to a given reaction product (ion) is still clearly visible after the 2nd target, whereas after the 4th target, due to the differences in stopping power and the depth of the reaction, some maxima merge. With trajectory tracing, we preserve the information on particle behavior on all the previous surfaces. Fig. 2 shows primary beam attenuation, fragment build-up and their ratio. By knowing the reaction kinetics, all the products can be identified successfully. At this point, the development of the method is at the stage of successful reaction finding; the next step is its implementation with so-called trajectory labeling (particle's energy, charge and mass) and the calculation of corresponding dose contribution. Current results confirm the suitability of the trajectory tracing technique for fragment spectroscopy.

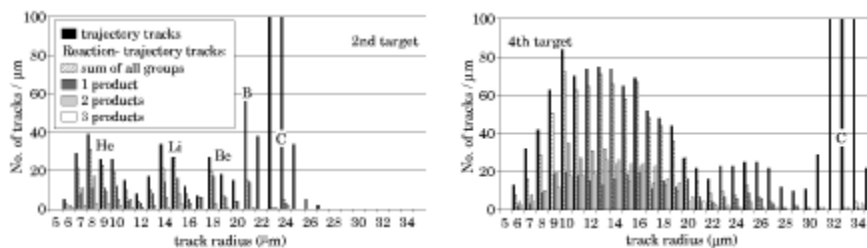


Fig. 1. Track size distribution on the detector surface after the 2nd and 4th paraffin targets (y-scaling was adjusted for fragment values). The black columns depict the total number of tracks, the grey ones depict only those that are also part of a reaction trajectory, the hatched ones depict the sum of the tracks in all the reaction groups (with 1, 2 or 3 products). Using solely the track size distribution method it is impossible to distinguish the tracks of different ions at greater depths.

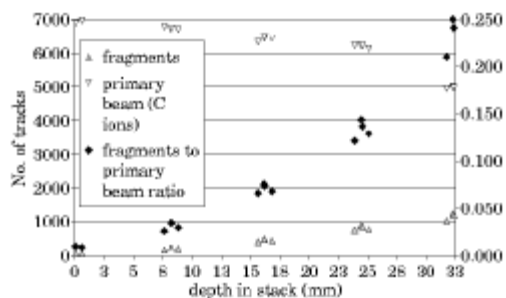


Fig. 2. Primary beam attenuation and fragment build-up ($Z \leq 5$) at different depths in the stack.

REFERENCES

1. Kraft, G. Tumor therapy with heavy charged particles. **Prog. Part. Nucl. Phys.** 45 (2000) 473-544.
2. Skvarč, J. and Golovchenko, A. N. A method of trajectory tracing of $Z \leq 10$ ions in the energy region below 300 MeV/u. **Rad. Meas.** 34 (2001) 113-118.
3. Skvarč, J., Ilić, R. and Kodre, A. Digital evaluation of ${}^6\text{Li}(n,\alpha)$ reaction product tracks in CR-39 detector. **Nucl. Instrum. Meth. B** 71 (1992) 60-64.