Profile and Dose Distribution for Therapeutic Heavy Ion Beams

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ABSTRACT

The purpose of this work is acquiring some parameters of therapeutic heavy ion beams after penetrating a thick target. The experiments were performed using a pencil-like ^{12}C beam of about 3 mm in diameter from NIRS-HIMAC, and the data were taken at several points of the target thickness for ^{12}C beam of 290 MeV/u and 400 MeV/u. By the simultaneous measurements using some detectors, the atomic number of each fragment particle was identified, and the beam profile, the dose distribution and the LET spectrum for each element were derived.

Keywords: fragmentation reaction, heavy ion beam, beam profile, dose distribution.

1.INTRODUCTION

In order to achieve precise heavy-ion radiotherapy, it is necessary to investigate a fragmentation reaction which changes a primary particle to some lighter secondary particles. The purpose of this work is acquiring the 'beam quality' and the beam profile of therapeutic heavy ion beams. The 'beam quality' contains some parameters such as the atomic number, the fluence and the LET value of heavy ions.[1)] In our experiments, the special attention was paid to the particle identification and the LET measurement for fragment particles. For the analysis of fragmentation reactions, the events with the multiplicity equal to or grater than two are important. In such cases, the measured LET value was divided into the number of particles in proportion to the energies deposited by particles in the fiber scintillators to make a spatial dose distribution. The beam profiles are compared with a theoretical formula to check the reliability of the experiments.

2.EXPERIMENTAL PROCEDURE

The measurements were performed using ^{12}C beams of 290 MeV/u and 400 MeV/u from HIMAC which are used in clinical trials at NIRS. The beams were focused about 3 mm in diameter on the surface of a water target. Figure 1 shows the experimental setup. A position-sensitive counter, an LET counter and a ΔE-E counter telescope are placed behind a water target. The position-sensitive counter consists of 48 fiber scintillators coupled to a multi-anode photomultiplier tube. Each fiber has a cross section of 1 mm by 1 mm and a sensitive length of 48mm. Therefore the position-sensitive counter can determine the lateral position of a particle with a spatial resolution of 1 mm and the energy deposited by the particle in a fiber of 1 mm thick. The LET counter is a multi-wire proportional counter whose sensitive thickness is 5 mm. Since P10 gas (90% Argon, 10% Methane) of atmospheric pressure flows through the counter into the air, the counter thickness is equivalent to water about 6.9 μm. The ΔE-E counter telescope which determines the atomic number is composed of an NE102A scintillator of 5 mm thick and a BGO scintillator of 300 mm thick. A beam monitor was placed in front of the target. A signal generated by the beam monitor triggers the data acquisition. The data from the detectors are stored in a computer by event-by-event mode, and they are analyzed off-line.

3.RESULTS

The lateral distribution of the averaged LET is obtained by the simultaneous measurements of the LET counter and the position-sensitive counter. Figure 2 shows the averaged LET of the fragment particles with various atomic numbers produced by ^{12}C beam of 400 MeV/u in a water target of 260 mm thick. The fragment particles were expected to have different LET values, because each fragment particle is produced at a different reaction point. However, the averaged LET was almost constant in the region of the measurement. The data, especially for carbon, on both sides of Fig.2 are scattered due to the low statistics.

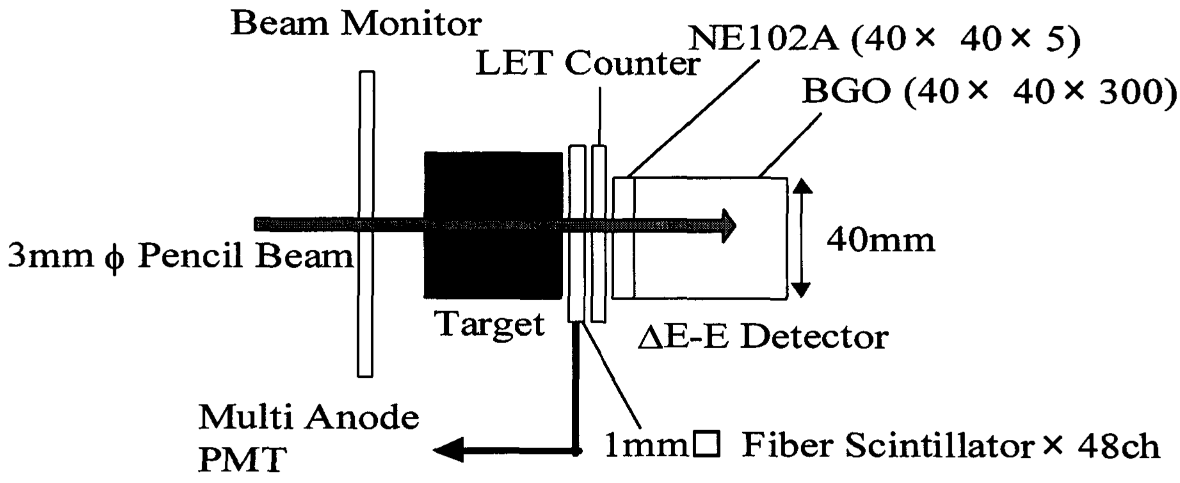

Fig.1 Experimental setup

The beam profiles were obtained at several points of water thickness from 0 to about the maximum range of ^{12}C beam of 290 MeV/u and 400 MeV/u. Figure 3 shows the beam profile and the dose distribution for ^{12}C beam of 400 MeV/u after passing through the water target of 260 mm thick. Here, the peak heights of both distributions were adjusted to the same value so that the width can be compared. The dose distribution is under the strong influence of carbon with high LET values, while the influence of the fragment particles becomes dominant, especially in the peripheral region, for the beam profile. Therefore it is understood that the dose is rather concentrated in the center of the region, even if the beam profile is spread by the fragment particles. Figure 4 shows the profiles for the fragment particles under the same condition. Each profile is fitted to a Gaussian distribution and the standard deviation σ is derived. Figure 5 shows the experimental values of σ and the theoretical curve calculated by Moliere's formula[2)] for ^{12}C beam of 400 MeV/u as a function of the water thickness. The experimental values are in good agreement with the theoretical curve. Although the results for ^{12}C of 290 MeV/u are scattered around the theoretical curve more than those for ^{12}C of 400 MeV/u, they are consistent with the theory. By these results, it was proved that our system could accurately obtain the beam profile for at least carbon. Comparison of the σ for the fragment particles with the theory is also now in progress.

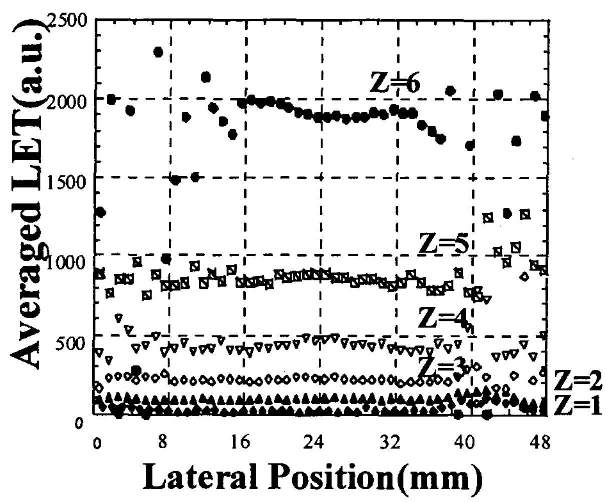

Fig. 2. Averaged LET of fragment particles

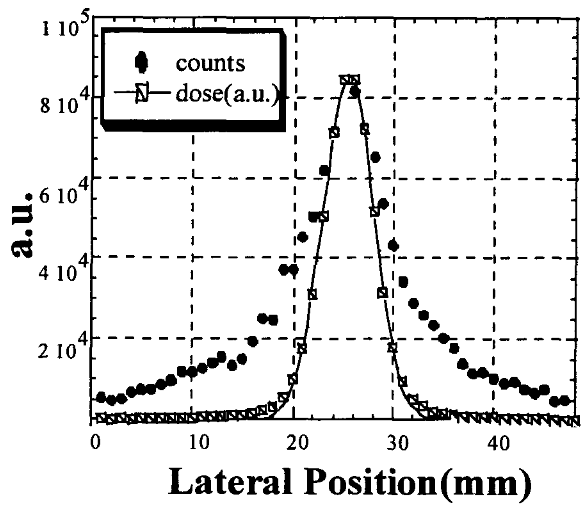

Fig. 3. Beam profile and dose distribution

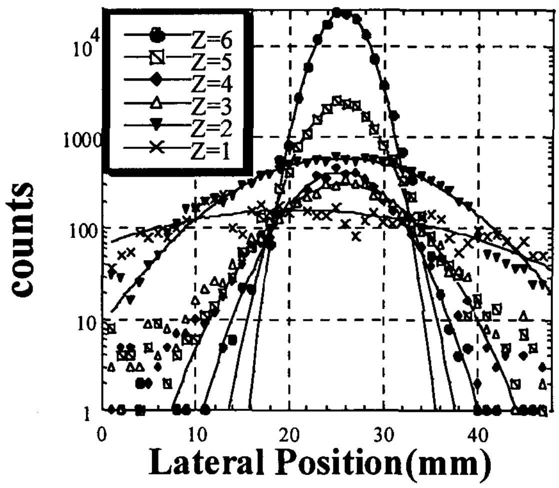

Fig. 4. Profiles for carbon and fragment nuclei

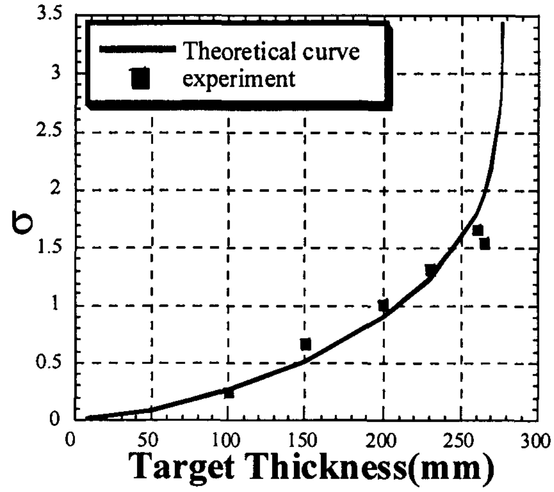

Fig. 5. Experimental values of □ and the theoretical curve

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