Study on the Fluence and LET Distribution of Projectile Fragments Produced from Heavy Ion Therapeutic Beams

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ABSTRACT

Fluence and LET spectrum for 290, 400 MeV/u ^{12}C and 400 MeV/u ^{20}Ne beams have been measured by a ΔE-E counter telescope. Total charge-changing cross sections are deduced from measured fluence. The measured cross sections agree with previous measurements, however, they are disagreement with a model calculation. To dose-averaged LETs, the model calculation can reproduce the measured LETs except for peak LETs at Bragg peak region.

Keywords: heavy ion radiotherapy, fragmentation, fluence, dose-averaged LET.

1. INTRODUCTION

Production of fragment particles in a patient's body is one of the important problems on heavy charged particles therapy. High energetic heavy charged particles are broken into some fragment particles by a spallation reaction when traveling through a matter. Velocity of projectile fragments is nearly equal to the velocity of primary particle at the reaction point. Therefore, the projectile fragments, which have lower Z than primary particles are transported to deeper region compared with the range of primary particles and cause unwanted exposure to normal tissues there. In addition the production of fragment particles also complicates biological effectiveness of the therapeutic beam because relative biological effectiveness (RBE) of radiation is a function of the kind of particle and its linear energy transfer (LET) – so called 'beam quality'. In our treatment planning, the beam quality has not been fully taken into account yet because of the lack of reliable model and data. The aim of this study is to investigate the beam quality using experimental methods, and consequently to brash up calculational model used on ongoing treatment planning.

2. MATERIALS AND METHODS

Experiments were carried out at biological experiment port at HIMAC. Fig. 1 shows the experimental setup. Incident beam was formed to therapeutic broad beam of 100 mm in diameter at isocenter with wobbler magnets and scatterer. The beam energies were 290 MeV/u and 400 MeV/u for ^{12}C beams and 400 MeV/u for ^{20}Ne beams, respectively. The beam intensity of about 10^4 particles/sec. was drastically reduced than the intensity for therapy to enable us to count particles one by one. A stack of plates made of PMMA (*polymethyl methacrylrate* (Lucite), $\rho=1.16$ g/cm^3, $(C_5H_8O_2)_n$) was used as a target. The thickness was variously changeable in the range from 0 mm to 512 mm by 0.5 mm step.

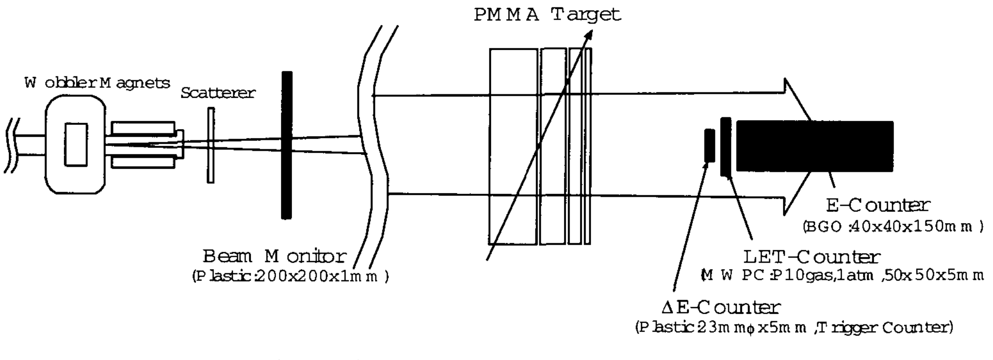

Fig. 1. Schematic view of the experimental setup

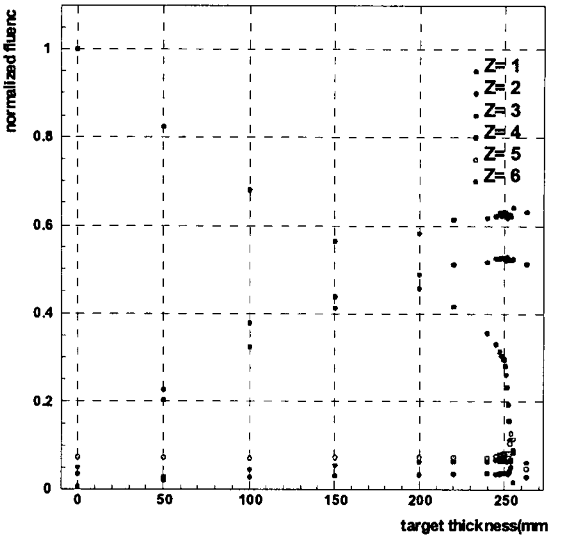

Fig.2 Normalized fluence of 400 MeV/u ^{12}C beam as the function of the target thickness.

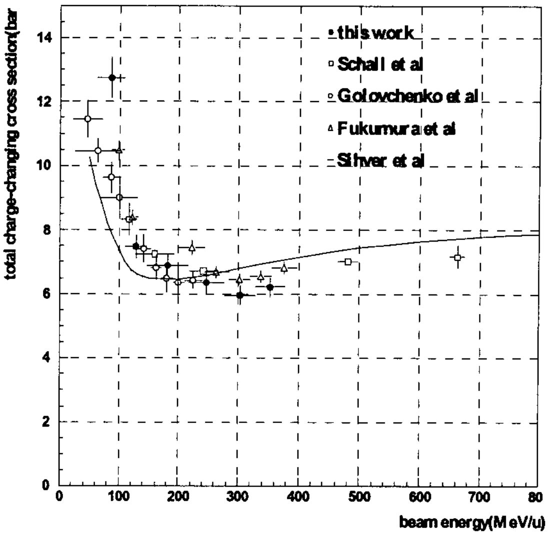

Fig.3 Total charge-changing cross section of a Lucite target for ^{12}C beams.

We configured the measurement system of the beam quality based on counter telescope method. A NE102A plastic scintillation detector of 1 mm in thickness (beam monitor in Fig. 1) was placed at the upstream position in the experimental room to count the number of primary particles. Output from this counter was fed into a visual scalar to count the number independently. The other counters were placed at the isocenter, 300 mm downstream from the target. The first detector was a NE102A plastic scintillation detector of 5 mm in thickness and 23 mm in diameter. It was used as a ΔE counter to identify the kind of particle by counter telescope method. Also, it was used as a trigger counter of this detector system. The second detector was a multiwire proportional counter to measure the LET spectrum. The LET counter had a thickness of 5mm and the active area of 50x50 mm. It was operated with gas mixture of 90 % argon and 10 % methane at 1atm. Finally the third detector was a BGO scintillation detector, which had the active area of 40x40 mm and the thickness of 200mm. The detector was used as an E counter. Outputs from these counters were fed into NIM modules and stored in a Windows computer in list mode via CAMAC bus.

3. RESULTS

The fluence and LET spectrum are measured down to the energy range of Bragg peak region. The fluence of fragment particles is measured down to helium appropriately, but a part of hydrogen is not measured because of the small output of the ΔE counter. Fragment particle is well identified by ΔE-E scatter plot each other. The number of particles are counted for each element and normalized by total number of incident primary particles measured by the beam monitor. Fig. 2 shows the normalized fluence of 400 MeV/u ^{12}C beam as a function of the target thickness. The fluence of the primary carbon beam reduces to 30 % at Bragg peak region while the fluence of helium and hydrogen are two times greater than the carbon one. The other elements are amount of 20-25 % of the carbon fluence. To compare the measured fluence data with previous one, a total charge-changing cross section should be introduced. To obtain the cross section, the carbon fluence is fitted by an expression of the third order polynomial function. Supposing that λ is the slope of the fluence in $(\mathrm{g/cm^2})^{-1}$, the total charge-changing cross section, σ_{tot}, is given by the following equation,

$$\sigma_{tot}(barn) = 10^{24} \times \lambda \times A_t \div N_A \ ,$$

where A_t and N_A are atomic or molecular weight of the target material and Avogadro's number, respectively. The energies of the beams after passing through the target of the thickness x is numerically calculated using the following relation,

$$x = \rho \int_E^{E_0} \{S(E')\}^{-1} dE \ ,$$

where ρ is the density of the target, E_0 and E are initial energy of the beam and the energy to be calculated respectively, and *S(E')* is a stopping power of the target for the beam with energy *E'*. Fig.3 shows our measured data in comparison with values of previous measurement, Schall et al [1], Golovchenko et al [2], and Fukumura et al [3]. Also the values

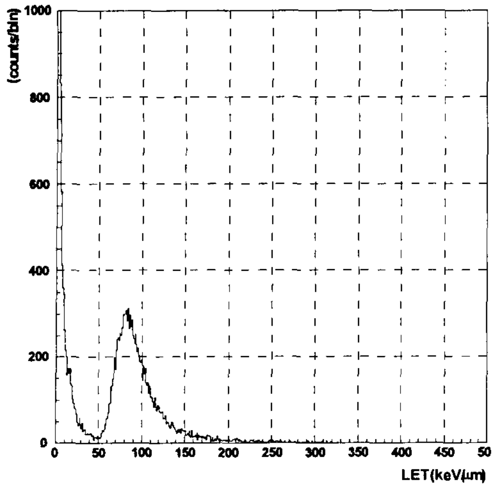

Fig. 4 LET spectra for 290 MeV/u ^{12}C beam at residual range of 2mm.

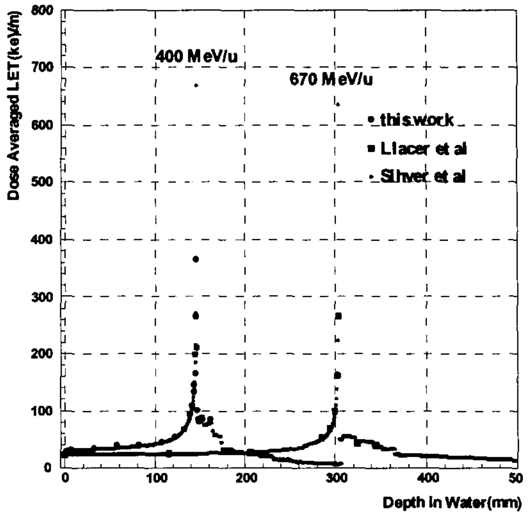

Fig.5 Dose-averaged LETs for ^{20}Ne beams

calculated by Sihver model [4], which is used in our treatment planning are shown in this figure. The results of this work agree with other measurements. It appears that the Sihver model underestimates in the energy region less than 200 MeV/u and overestimates in the region more than that. In this work, the fluence of the fragment particles were identified therefore partial charge-changing cross section will be driven, but is in still in progress. Fig. 4 shows our measured LET spectra for 290 MeV/u ^{12}C beam at a residual range of 2mm in water. The low LET components, which originate from the fragment particles occupy half of the total fluence. Fig. 5 shows our measured dose-averaged LETs for 400 MeV/u ^{20}Ne beam in comparison with a previous data for 670 MeV/u ^{20}Ne beam measured by Llacer et al [5], and the value calculated by Sihver model. In this figure, the thickness of Lucite target and ΔE counter is converted into a water equivalent length. The peak value of our measurement is grater than the value of previous because of greater survival rate of primary ones. It is found that the model calculation can reproduce the measured data except for the peak value at Bragg peak region.

4.CONCLUSION

The fluence and LET spectrum are measured for 290, 400 MeV/u ^{12}C and 400 MeV/u ^{20}Ne beams. Our total charge-changing cross section of Lucite for ^{12}C beam is in a agreement with previous measurements. The cross sections calculated by Sihver model tend to under estimate for the energy region less than 200 MeV/u. To dose-averaged LETs the model calculation can reproduce the measured data except for the peak LETs at Bragg peak region.

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