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BEAM-QUALITY MEASUREMENTS ON HEAVY ION THERAPEUTIC BEAM OF HIMAC

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Abstract

Fluence spectra of fragment particles caused by spallation reactions between heavy ion beams and PMMA (polymethyl methacrylate; Lucite) target were measured with ΔE-E counter telescope method for each fragmented element. Measurements were carried out for carbon beams of 290 MeV/nucleon and 400 MeV/nucleon at Heavy Ion Medical Accelerator in Chiba (HIMAC), and 135 MeV/nucleon carbon beam at RIKEN Ring Cyclotron with changing the thickness of target material. Incident beam was broadened with a pair of wobbler magnets and a scatterer, in the same way of clinical trials which have been carrying out at HIMAC. Results were compared with the calculational expectations.

1. Introduction

In tumor therapy using heavy ion beams, it has been well known that incident heavy ion particles cause spallation reactions with the elements which compose the body. Hence, various kinds of particles were produced and hit the target. It is of importance to measure their fluence spectra for each fragmented element to estimate their influence on tumor therapy, and to brash up our treatment planning as well.

2. Experimental Setup

Figure 1 shows schematic diagrams of detector systems for measurements at RIKEN and HIMAC. According to Bethe formula, fragment particle can be identified with the parameter AZ^2 by measuring its total energy E and energy loss ΔE. The systems were based on the counter-telescope method [1]. Incident beam was sufficiently uniformed to 10.0 cm in diameter with the flatness of 95% at the iso-center by a pair of wobbler magnets and a scatterer[2]. A beam monitor, made of NE102A plastic scintillator of 1.5 cm in thickness, had front surface of 20.0 cm by 20.0 cm to count the total number of incident particles. The beam diameter was less than 5 cm at this beam monitor position. A stack of the plates of PMMA was selected as target material as it has similar composition with muscles. At the irradiation site, the detectors for the particle identification were placed. The detectors had comparatively smaller front surface to avoid entering plural fragment particles. In the setup at RIKEN, a coincidence detector, made of annular NE102A plastic scintillator, of 5.0 mm in diameter was positioned to distinguish an event by one fragment particle from those by noises. A proportional counter with tissue-equivalent gas was used to estimate the amount of energy transferred to biological system. A totally depleted silicon surface barrier detector of 11.3 mm in diameter and 1.0 mm in thickness was used as a ΔE counter to measure the energy loss ΔE in the detector and to make energy calibration. At the end of the beam line, a BGO scintillator was utilized as an E counter to measure the residual energy E of incident particle. The scintillator had a cylindrical form, 15.0 mm in diameter and 15.0 mm in length. The measurements were carried out for carbon 135 MeV/nucleon beam at E5 port.

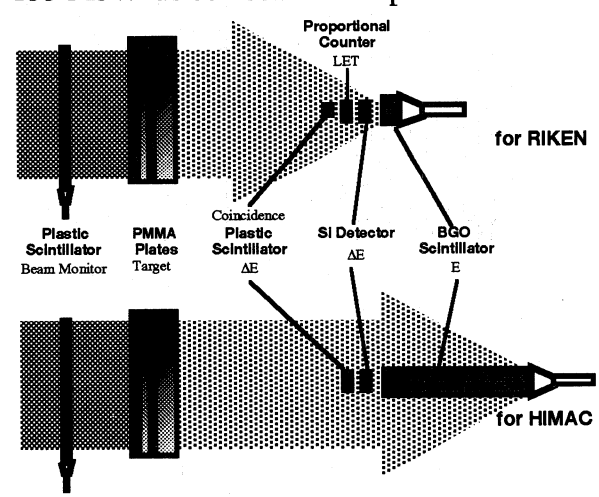

Fig.1 The schematic diagram of the detector system.

In the setup at HIMAC, a NE102A plastic scintillator of 40.0 mm by 40.0 mm and 5.0 mm in thickness was used as a ΔE detector instead of Si semiconductor detector. Energy

resolution of plastic scintillator is generally inferior to semiconductor detector, however, scintillator has very superior characteristic on particle identification regarding that the response function of scintillator tends to enhance the difference of AZ^2 on lighter elements such as hydrogen or helium which are important to be well identified on this work, whereas the output of Si semiconductor detector is strictly proportional to AZ^2. In this setup, Si semiconductor detector was used for energy calibration. A larger BGO scintillator of rectangular form of 40.0 mm by 40.0 mm by 300.0 mm was used as an E detector. Measurements were carried out for carbon 290 and 400 MeV/nucleon beams at the bio port, therapy port BHC and CHC of the HIMAC.

3. Analysis

Figure 2 illustrates an example of particle identification by E-ΔE scatter plot obtained from incidence of carbon 290 MeV/nucleon beam to the target material of 120.7 mm in thickness. The abscissa represents the residual energy E measured by the BGO scintillator and the ordinate denotes the energy

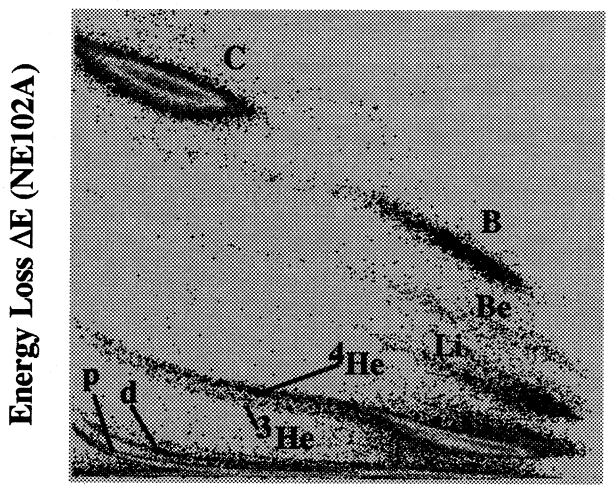

Fig. 2 The scatter plot of the residual energy E and the energy loss ΔE for 290 MeV/nucleon carbon beam in PMMA 120.7 mm in thickness.

loss ΔE from the plastic scintillator. Fragment particles were clearly separated to some groups.

To identify each group in the ΔE-E scatter plot, the amount of energy deposited in the Si semiconductor detector was compared with the calculational expectation for each fragmented element which was regarded on ΔE-E scatter plot as filled in Fig.2. Experimental energy deposition of each fragmented element was derived by picking up upper and lower channels of the distribution spectra on Si semiconductor detector. Here, the channel of Si semiconductor detector was calibrated by corresponding a peak channel of the group regarded as primary carbon with its amount of energy deposition calculated for each thickness of target material. As for calculational expectation of the energy deposition, maximum and minimum values were given by the fragment produced just before the detector and the fragment produced at an entrance of target material, respectively.

The result was summarized in Fig.3 for the incidence of 290 MeV/nucleon carbon beam in PMMA of 112.1 mm in thickness. The experimental and calculational range of deposited energy was well overlapped for each other on each fragmented element. Therefore, it can be said that fragment particles were clearly identified from carbon to hydrogen with the difference of Z and A by regarding the highest group as primary carbon in E-ΔE scatter plot.

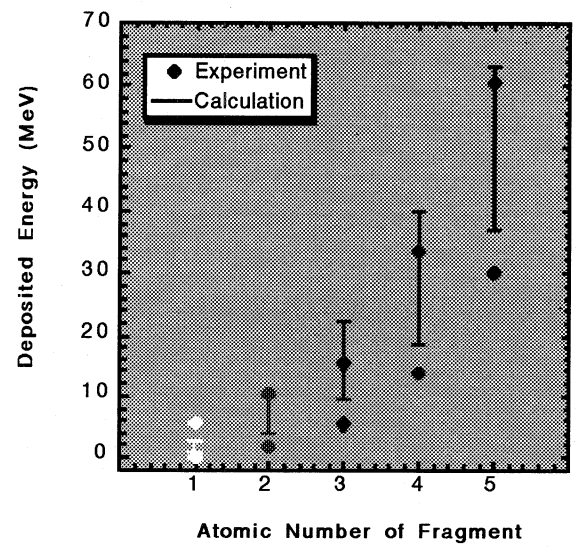

Fig.3 Experimental and calculational energy deposition on Si semiconductor detector for 290 MeV/nucleon carbon beam in PMMA of 112.1 mm in thickness.

Fluence spectra of each element were derived from the number of particles in each group by normalizing with the total number of incident particles because of the flatness and the broadness of the incident beam. Figure 4 to 6 displays the fluence spectra at the incidence of 135, 290 and 400 MeV/nucleon carbon beam respectively. In these figures, dots represents the results of this work and lines are

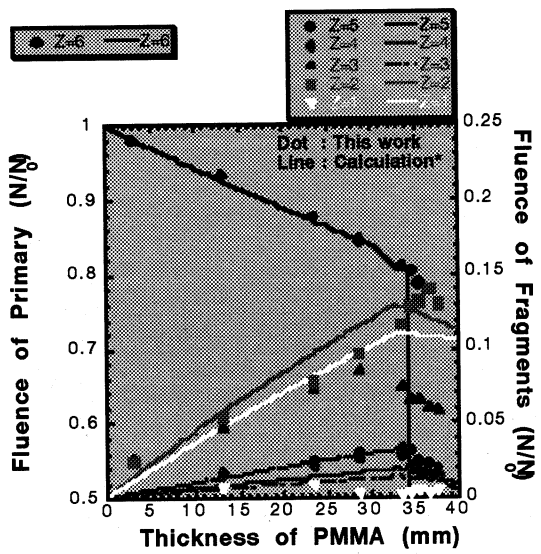

Fig.4 Fluence Spectra of fragments for 135 MeV/nucleon carbon beam.

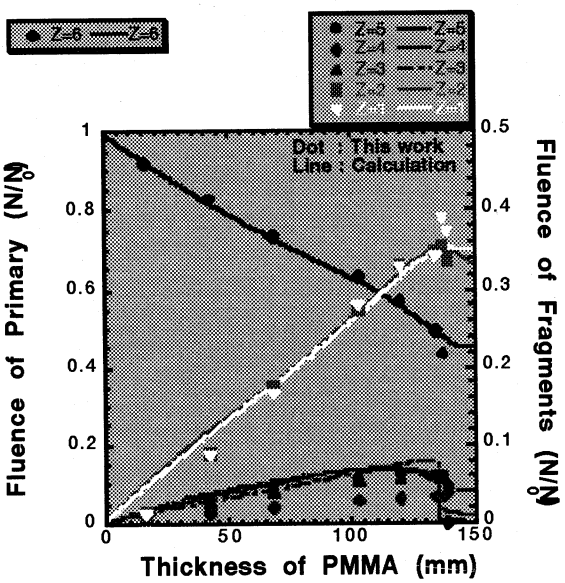

Fig.5 Fluence Spectra of fragments for 290 MeV/nucleon carbon beam.

calculational results by Sihver et al. [3] for the sake of comparison. The experimental data show good agreement with calculational ones.

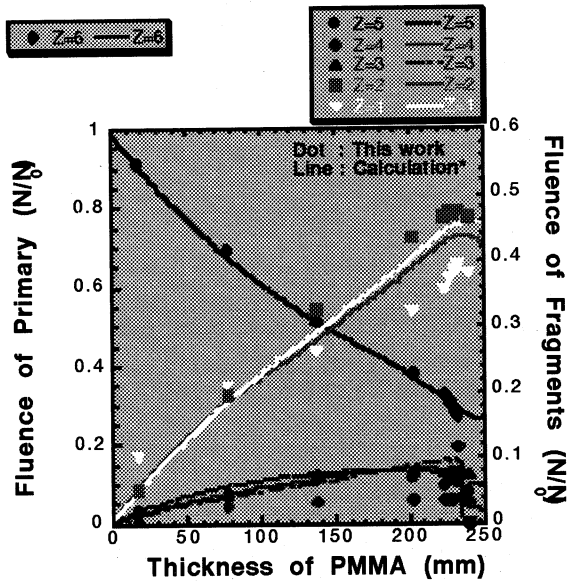

Fig.6 Fluence Spectra of fragments for 400 MeV/nucleon carbon beam.

4.Conclusion

Fragment particles included in the therapeutic beam were well identified with the ΔE-E scatter plot by a thin plastic scintillator and a BGO scintillator. The fluence spectra were obtained for each fragmented element and agreed well with the calculational expectations.

References

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[2] T. R. Renner and W. T. Chu, Med. Phys. **14** (1987) 825

[3] L. Sihver et al., Proc. of NIRS Intl. Sem. on the Appl. of Heavy Ion Accel. to Rad. Therapy of Cancer in connection with XXI PTCOG Meeting, to be published.