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Comprehensive Study on the Fragment Reaction of Relativistic Heavy Charged Particles for Heavy-Ion Radiotherapy

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INTRODUCTION

The production of projectile fragments is one of the important, but not yet perfectly solved, problems to be considered when planning for the utilization of high-energy heavy charged particles for radiotherapy. The aim of this study is to investigate on the fragments' fluence and LET spectra produced from various incidents by an experimental approach to reveal the physical quality of the beams. The results are also compared with that by a fragment reaction simulation code [1] to reveal the problem involving the code.

METHOD

An experiment was carried out at a beam port for biological experiments at HIMAC. Incident beam was as follows: 150 MeV/n of ^{4}He, 290 MeV/n of ^{12}C, 400 MeV/n of ^{20}Ne, 490 MeV/n of ^{28}Si and 550 MeV/n of ^{40}Ar. The beam was broadened in the same manner as in the case of therapy, *i.e.,* laterally 10 cm in diameter by a pair of wobbler magnets and axially 6 cm by and a ridge filter, respectively.

PMMA, as a substitute for the human body, was used as a target. A binary filter made of PMMA plates was equipped 300 mm upstream from the irradiating point, which is 4200 mm downstream from the beam exit window. A thin NE102 scintillator (1 mm in thickness) was positioned immediately downstream of the beam exit window to count the total number of incident primary particles. A ΔE-E counter telescope with a NE102 plastic scintillator (5 mm in thickness) and a BGO scintillator (300 mm in thickness) was positioned at the irradiating point to identify the kind of fragment particles based

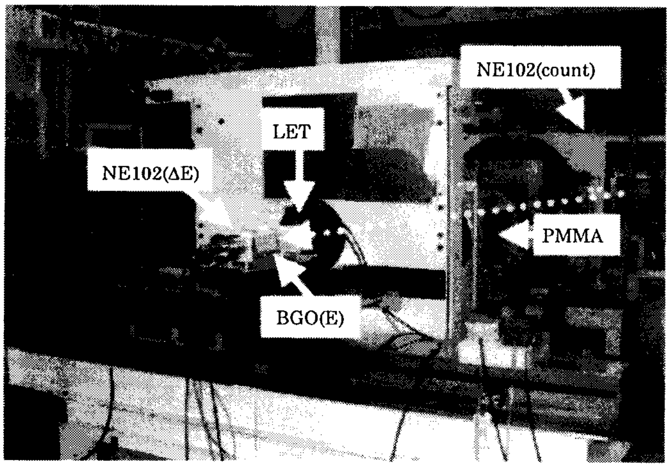

Fig.1 A layout of the experiment system.

on differences in the elements. To monitor any gain drifting of the ΔE-E counters, stabilized green light emitted from a 1N6094 LED was used.

A gas-flow proportional counter was combined with a counter telescope system to measure LET spectra. P10 (Ar-90% / CH_4-10%) was used as a counting gas because it showed the most uniform gas multiplication among other easily-obtained gases. Besides, stopping power of P10 gas relative to water for carbon ions can be regarded as being constant within 3 % even at a non-relativistic energy region. The thickness of the gas was 5 mm at NTP. An energy loss of 290 MeV/n of carbon ions in 5 mm thickness of P10 gas equals to that in 6.9 μm thick liquid water, which is close to the thickness of an individual cell. Fig. 1 shows a layout of the detector system.

The energy of the primary particles after passing through any thickness of PMMA was deduced by comparing its depth-dose profile measured with a parallel-plate ionization chamber with a result of calculation by the fragment reaction simulation code.

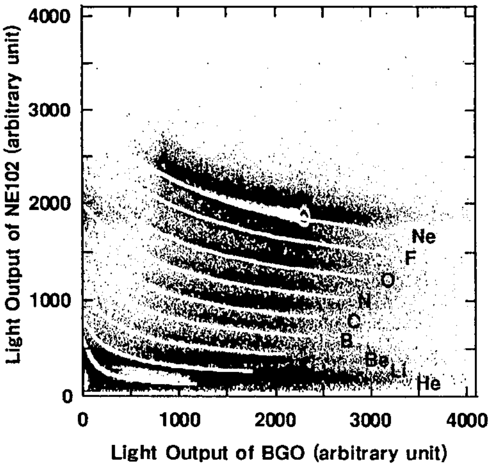

Fig.2 ΔE-E scatter plot for particle identification.

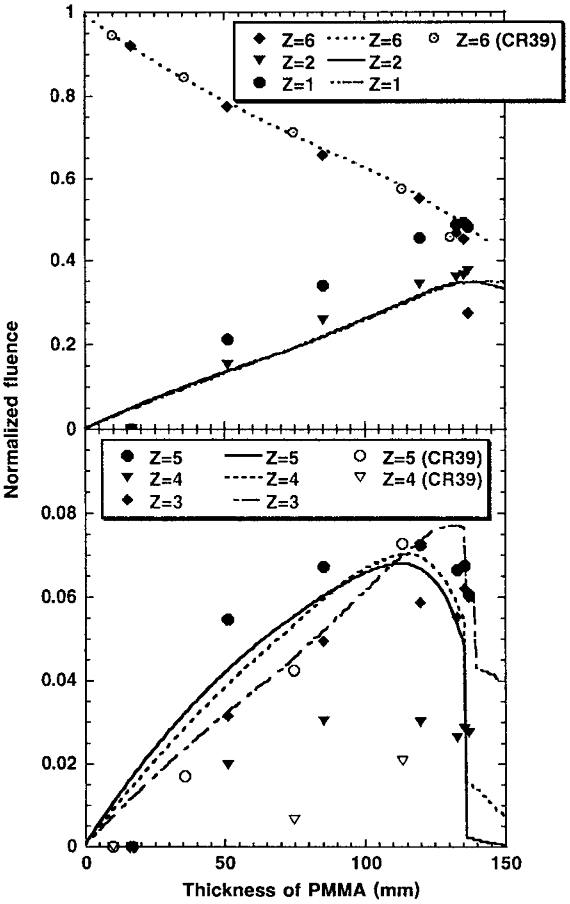

Fig.3 Fluence of fragments as a function of PMMA thickness produced by the incidence of 290 MeV/n of 12C beams.

RESULT & CONCLUSION

Through this study, response of BGO and NE102 scintillator was obtained in this energy region for the first time. Particle-species dependency of the responses was parameterized by AZ^2 of the incident particles. Fragment particles produced between incident particles and the PMMA target were well identified down to hydrogen by ΔE-E scatter plot, and the fluence of each fragment element was deduced. Fig. 2 depicts a two-dimensional scatter plot obtained for a 400 MeV/n of ^{20}Ne beam and 60.0 mm of PMMA. The solid lines in the figure trace the reproduced light output of both scintillators from their deduced responses.

Fig. 3 shows the fluence of fragments as a function of the PMMA thickness produced by the incidence of 290 MeV/n of ^{12}C beams. The closed symbols and lines denote the experimental value and the calculated expectation by the simulation code. For the sake of comparison, the experimental results taken with a CR-39 track detector [2] are plotted as open symbols. The difference of fluence from the calculational results with a simulation code suggests the need for theoretical research and the establishment of a reliable nuclear reaction model in this energy region.

The LET spectra were also derived by each element. Fig. 4 shows the dosimetric LET spectra of a ^{12}C beam on each fragment element at PMMA thicknesses of 0, 90 and 130 mm. The result reveals that the greater part of the dose is delivered by primary particles, though many light fragments are produced.

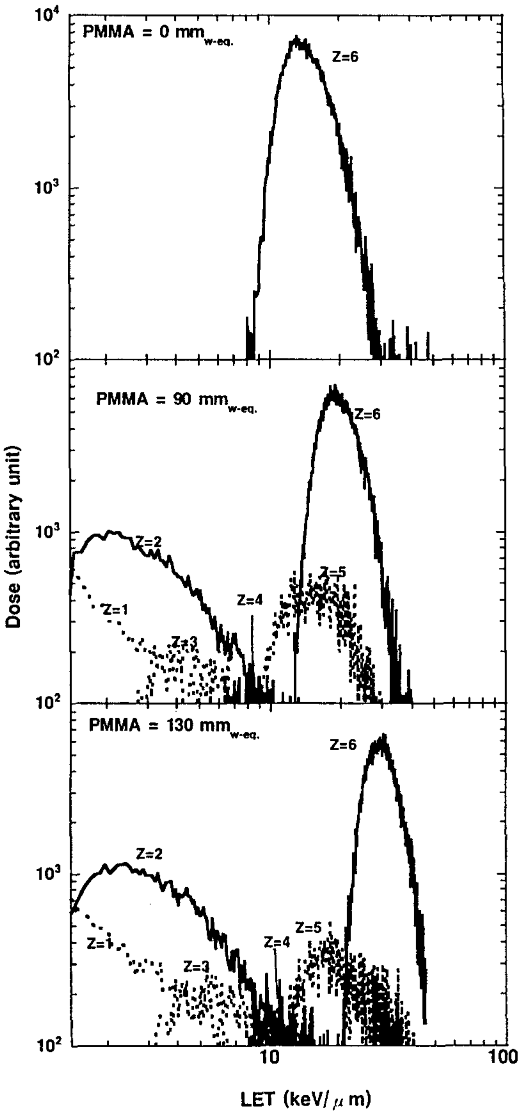

Fig.4 LET spectra of 12C beam on each fragment element at PMMA thickness of 0, 90 and 130 mm.

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