Experimental Studies on the Fragment Productions in Proton- and Neutron- induced Reactions

III. 2. Experimental Studies on the Fragment Productions in Proton- and Neutron- induced Reactions

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Energy and angular doubly differential cross-section data of fragments (secondary charged particles heavier than α particle) production for proton- and neutron- induced reactions are of importance for dosimetry and the evaluation of radiation effect such as single event upset (SEU) by cosmic ray because of their large local ionization. However, experimental data on the fragment production are very scarce due to experimental difficulties of fragment detection, i.e., low yield, and large energy loss in samples. For the reason, almost all of past experimental data were obtained by the activation method that does not provide energy and angle information. Furthermore, theoretical calculation treating fragment production is very few and uncertain. Therefore, it is important to obtain reliable experimental data of differential cross section of fragment production.

Typical methods for the charged-particle production cross-section measurement are 1) the activation method and 2) the counter telescope method (ΔE-E method). The activation method can be applied only to some reactions that result in radioactive residual nuclei and does not provide the energy and angle information. The method of 2) has been applied for the secondary light charged-particle measurement generally. In the case of fragment measurements in ten's of MeV energy region, the application of the method is very difficult due to the energy loss in the ΔE detector and the small detector solid angle. Therefore, an experimental method adequate for fragment measurement is required.

For fragment detection, we adopted 1) a Bragg curve spectrometer (BCS) providing almost all information on the particle with a single counter and 2) an energy-time of fight (E-TOF) method having the capability of mass identification in almost whole energy region for fragments.

BCS is a gridded-ionization chamber[1-3] as shown in Fig.1. The fragments can be identified on the basis of the difference of Bragg peak value[4,5] and the energy information can be obtained from the total charge produced. BCS has been mainly used for fragment measurement by charged particle induced reactions but not applied to neutron-induced reaction. We designed the BCS with special care to apply to a neutron beam in addition to a charged particle beam, and resulted in success to identify the fragments by proton- and neutron-induced reactions[7] as shown in Figs. 2, 3, 4 and 5. BCS proved very promising for fragments detection in neutron-induced reaction, while there are still some problems that should be solved[6].

For 2), we fabricated a special chamber as shown in Fig.6 and installed at No.2 target room in CYRIC to conduct the fragment measurement for proton-induced reactions using the E-TOF method[8]. In this method, the energy and TOF of the fragment is measured by SSD (silicon solid state detector) and MCP (micro-channel plate) with a thin carbon foil (50 $\mu g/cm^2$), respectively, and the mass number is derived by combing the energy, TOF and the energy loss information. Though this method is restricted only in charged particle-induced reactions due to the small detector solid angle, the dynamic range of fragment energy will be higher than in BCS, and much higher counting rate will be obtained. We conducted the test experiment by using the system and resulted in success to identify the fragments from polyethylene (4 μm) by 70 MeV proton-induced reactions as shown in Fig.7.

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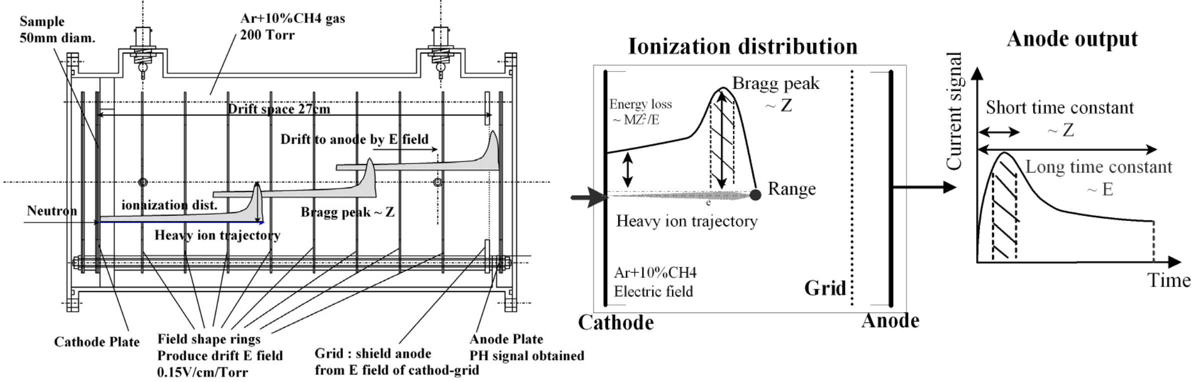

Fig. 1. Schematic diagram of the Bragg curve spectrometer.

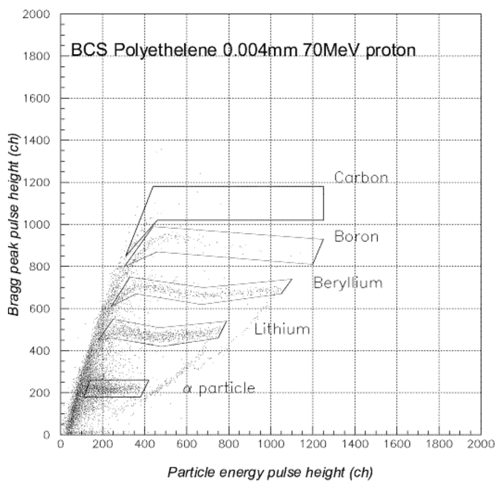

Fig. 2 Energy *vs* Bragg peak two-dimensional spectra for polypropylene (4 μm) induced by 70 MeV protons.

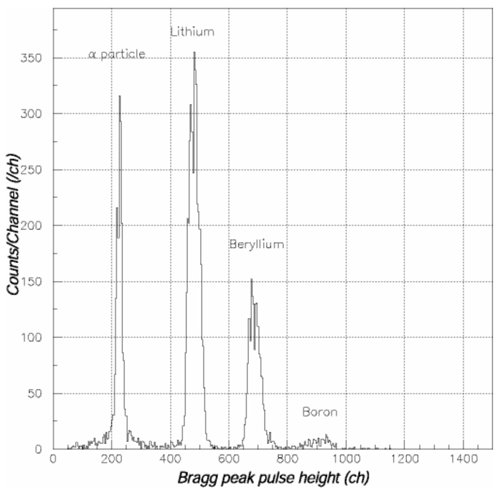

Fig. 3 Bragg peak spectrum over separation limits for polypropylene (4 μm) induced by 70 MeV protons.

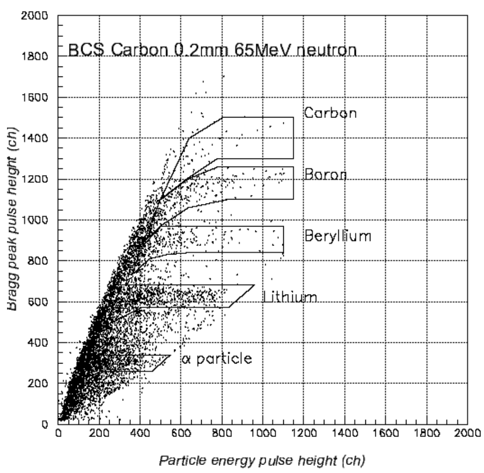

Fig. 4 Energy *vs* Bragg peak two-dimensional spectra for carbon (200 μm) induced by 65 MeV quasi-monoenergetic neutron[7].

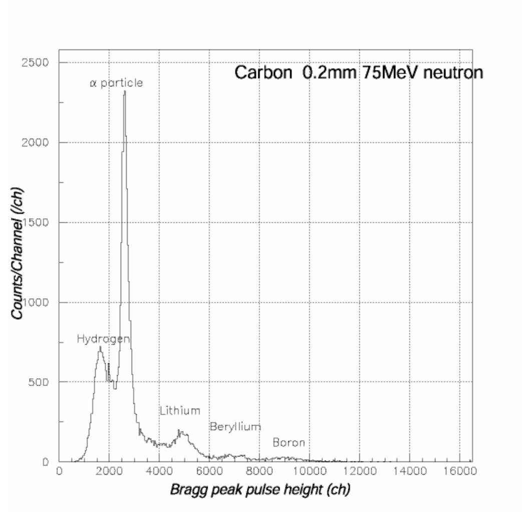

Fig. 5 Bragg peak spectrum over separation limits for carbon (200 μm) by 65 MeV quasi-monoenergetic neutron[7].

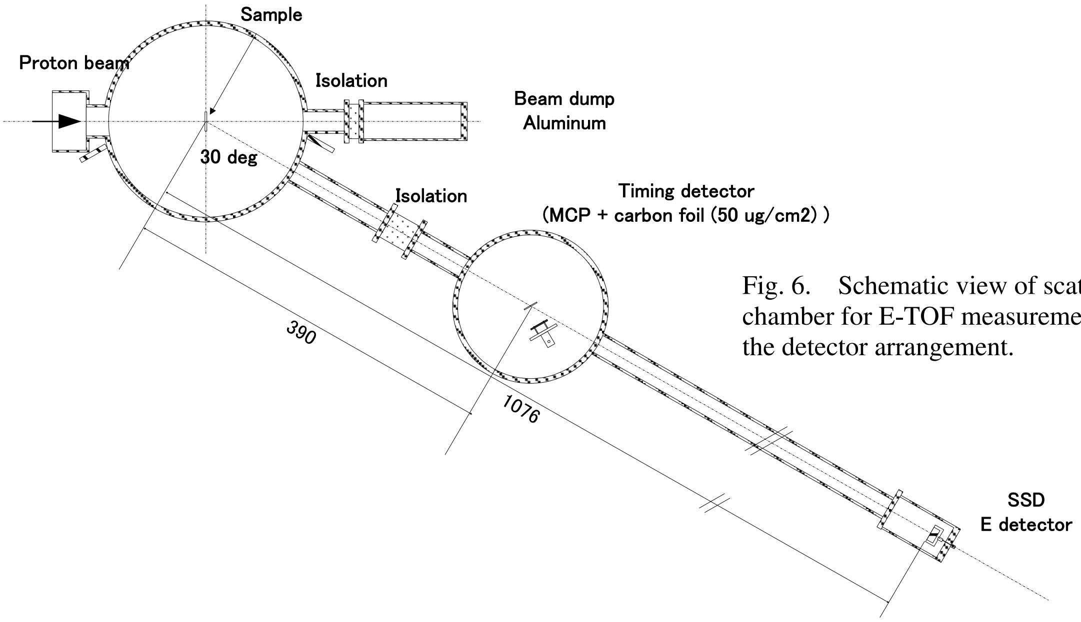

Fig. 6. Schematic view of scattering chamber for E-TOF measurement and the detector arrangement.

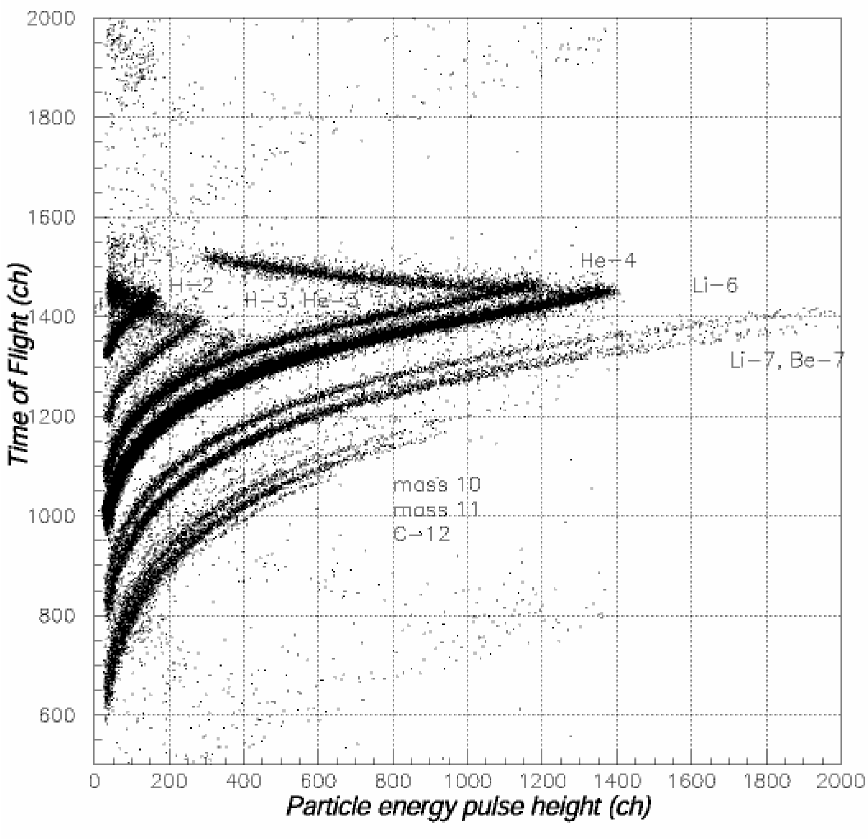

Fig. 7. Energy *vs* TOF two-dimensional spectra for polypropylene (4 μm) induced by 70 MeV protons.