Journal of NUCLEAR SCIENCE and TECHNOLOGY, Supplement 4, p. 502–505 (March 2004)

Measurement of differential cross sections for evaluation of radiation dose of ten's of MeV neutrons

Toshiya SANAMI[1,*], Mamoru BABA[2], Masayuki HAGIWARA[2], Tsutomu HIROISHI[2], Mikihiro HOSOKAWA[2], Naoya HIRABAYASHI[2], Takuji OISHI[2], Hiroshi NAKASHIMA[3], Susumu TANAKA[4]

[1]*High Energy Accelerator Research Organization(KEK), 1-1 Oho, Tsukuba, Ibaraki 305-0801, Japan*

[2]*Cyclotron and Radioisotope Center, Tohoku University, Aoba-ku, Sendai 980-8578, Japan*

[3]*Tokai Establishment, Japan Atomic Energy Research Institute,Tokai-mura, Ibaraki 319-1195, Japan*

[4]*Takasaki Establishment, Japan Atomic Energy Research Institute,Takasaki, Gumma 370-1922, Japan*

Double differential cross sections of several ten's of MeV neutron induced reactions for elements composing the human tissue were measured using specially designed spectrometers at TIARA ^{7}Li(p,n) neutron source. In spectroscopy of particles from neutron induced reactions, a large solid angle and particle acceptance detector is indespensable. For particles from 5 MeV α to 70 MeV proton, a spectrometer consisting of three counter telescopes and a vacuum chamber was used. For heavier particles, a Bragg curve spectroscopy technique was adopted to neutron field. Double differential cross section of p,d,t,α emission for N and O were obtained using the former spectrometer. In the later method we fabricated a test spectrometer to check applicability and signal to noise ratio in neutron field. Using the spectrometer, energy spectra of heavier particles (Li, Be, B, C) from carbon were observed.

KEYWORDS: neutron, DDX, charged particle detector, heavy ion, TIARA, telescope, Bragg curve spectrometer

I. Introduction

To evaluate radiation dose of several ten's of MeV neutrons, double differential cross section (DDX) data are important since it is one of basic data for the radiation transportation and energy deposition. In the view point of neutron dosimetry, reliability of DDX data is important especially for elements composing the human tissue such as carbon, oxygen and nitrogen. In addition, DDX data are also key parameters to estimate irradiation effects of devices or instruments.

In JAERI-Universities joint research project on radiation safety in proton accelerator facilities, we engaged the measurement of DDXs for several ten's of MeV neutrons using a quasi-monoenergetic neutron field at TIARA facility of JAERI. In this paper, we describe the measurements of DDXs for secondary charged particles among our works in this project.

II. Secondary charged particle measurement in TIARA

Neutron source of the ^{7}Li(p,n) reaction in TIARA is well collimated and its intensity and spectrum are well-known.[1)] But the intensity is not so high because the distance from a neutron production target to an irradiated sample is long (about 5 m) and maximum beam current of primary proton is limitted at about 1 μA. In addition, to measure secondary charged particles, a thin sample must be used to minimize the energy loss in the sample. This fact makes counting rate and signal-to-noise ratio low. Thus, we have to adopt spectrometers having following features, 1) large detection efficiency and 2) large particle acceptance for simultaneous measurement of all particles. A spectrometer consisting of three wide-range telescopes and a vacuum chamber was adopted to measure light charged particles (lighter than α particles). For fragments (heavier than α particles), it is difficult to apply the spectrometer because of its small solid angle and existence of entrance window. Thus, we developed a Bragg curve spectrometer (BCS) optimized to obtain spectrum data of fragments from neutron induced reactions.

III. Light charged particle measurement

1. Apparatus

The schematic view of the spectrometer is shown in **fig. 1**. Three counter telescopes consisting of three detectors were mounted on a vacuum chamber which is important to reduce background events from air and energy losses of charged particles from the sample.

Samples were set at the center of the chamber. The samples were thin plate of Al_2O_3 (1.0 mm thick, 48 mm diam.) for oxygen measurement and AlN (1.2 mm thick, 48 mm diam.) for nitrogen one. Contributions of aluminum were subtracted using the data of Al measurement.

Charged particles from the samples were detected with three counter telescopes at 25°, 65° and 120° emission angles. **Figure 2** shows schematic view of the telescope. Each of the telescope consists of a low pressure gas proportional counter (GPC), a transmission type silicon surface barrier detector (SSD) and a BaF_2 scintillator.

The GPC was operated in a gas flow mode with $\sim 10^4$ Pa Ar-2.5%CO_2 gas. The entrance window was 5.4μm thick Mylar film. The window determined detection threshold of the GPC to lower than 5 MeV α particles. The SSD was a 150 μm thickness transmission type with 900 mm^2 effective area. The combination of GPC and SSD can measure α-particles up to 18 MeV. The other particles, i.e. proton, deuteron, triton and α particle above 18 MeV were measured by the combination of SSD and a BaF_2 scintillator (40 mm $\phi\times$ 22 mm long). The relationship between the particle energy and the

* Corresponding author, Tel. +81-29-864-5490, Fax. +81-29-864-1993, E-mail: toshiya.sanami@kek.jp

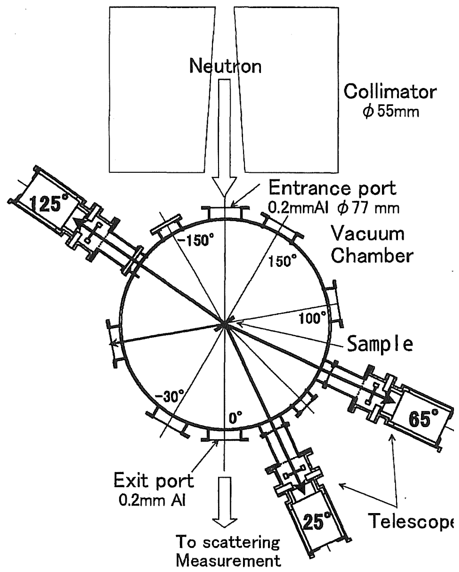

Fig. 1 Schematic view of the spectrometer. Three counter telescopes were mounted on a vacuum chamber at 25°, 65° and 125° with in respect to neutron beam axis. Samples were set at the center of the chamber.

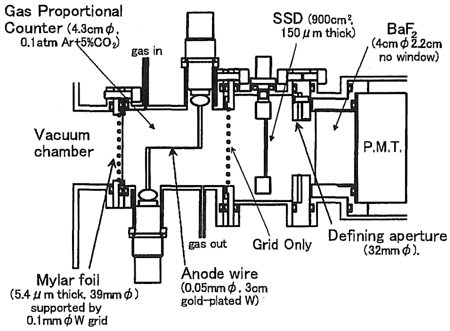

Fig. 2 Detail of detector array of the counter telescope

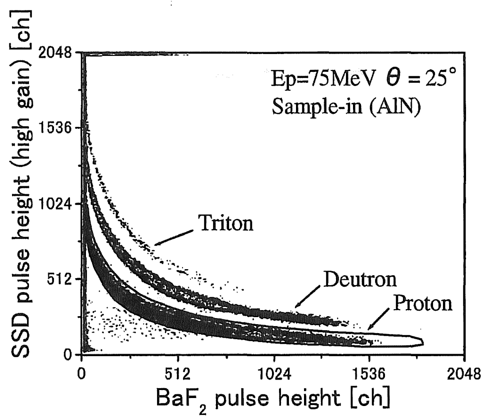

Fig. 3 SSD (high gain) vs BaF_2 ΔE-E spectrum for AlN sample at 25 deg.

light output of BaF_2 was measured using well known energy beam from cyclotron in National Institute of Radiolodical Science (NIRS).

2. Measurement and results

Cross section measurements were done for Al_2O_3, AlN, Al samples, and sample-out backgrounds. The background was considerably small owing to use of the vacuum chamber. The experimental time was about 20 hours with ~ 1 μA beam currents on the ^{7}Li target. **Figure 3** shows a typical ΔE-E spectrum for AlN sample at 25 deg. The separation between protons, deuterons and tritons is very clear. From this spectrum, particle identification is carried out. For each particle, TOF vs E plots are made in order to choose peak neutron events.

After particle identification and peak neutron event selection, channel data are converted to energy data by using the relation between light output and particle energy of BaF_2.[2] Then, energy loss correction is done for entrance window, transmission detectors and sample. For protons, deuterons, tritons and high energy α particles, the energy loss in the sample was estimated using an "average method".[3] For low energy α particles, the unfolding method based on Bayesian theorem[4] is adopted because of too much energy loss for the average method. The absolute value of the energy spectrum was determined based on the neutron flux[1] and the number of sample atoms. The contribution of Al in Al_2O_3 and AlN was eliminated by subtraction of the corrected spectrum for Al.

Figure 4 shows proton DDX for Al, O and N of 75 MeV neutrons at 25 deg. in comparison with the LA150 data.[5] The data are obtained by the SSD-BaF_2 combination. The high threshold is caused by non-liner response of the BaF_2 scintillator. The LA150 data are in good agreement with experimental data. In the O(n,xp) spectrum around 20 to 40 MeV, the LA150 data slightly underestimate the experimental data. High energy part of the N(n,xp) spectrum, LA150 overestimate the experimental one. The DDXs of 65° and 125° show the same trend.

Figure 5 shows deuteron DDX. The LA150 data trace experimental results well up to 40 MeV, but differs largely above 40 MeV. The discrepancy is largest for Al among three nuclei. Similar discrepancies are also observed in the deuteron spectrum of Ni and Fe.[6]

IV. Fragment measurement

1. Spectrometer for fragment measurement

In the case of a fragment measurement, larger solid angle and thinner particle identification detector are essentially needed to a spectrometer than for the case of the light particle detector since production rate and energy of fragments are very low in this energy range. To counter this requirement, we adopted a Bragg curve spectroscopy technique to neutron field. **Figure 6** shows a particle identification scheme of a fragment produced on cathode plate. A Bragg curve spec-

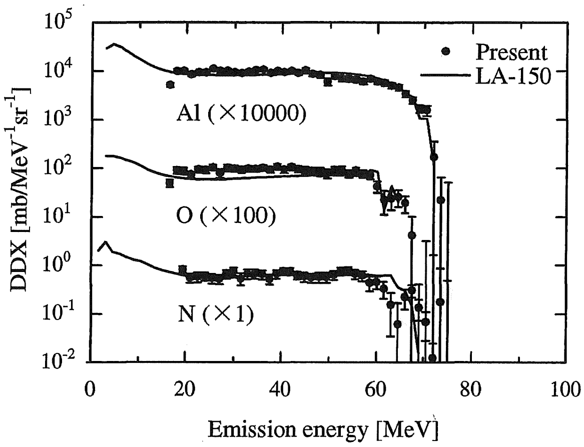

Fig. 4 Proton double differential cross section of Al, N and O at 25 deg.

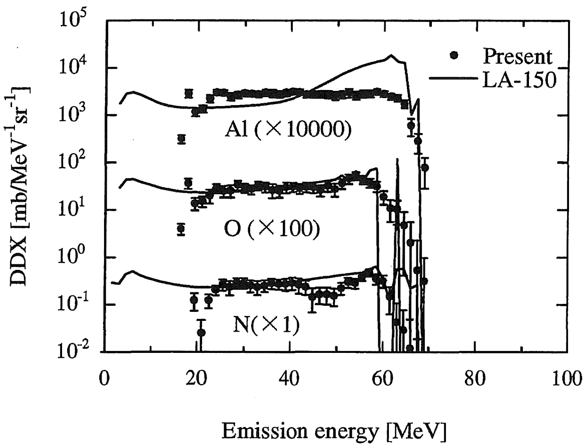

Fig. 5 Deuteron double differential cross section of Al, O and N at 25 deg.

trometer (BCS) is a parallel plate grid ionization chamber. A fragment makes ionization and stops between cathode and grid. Ionized electrons drift to the anode by electric field keeping it's distribution corresponding to the Bragg curve. Thus, time distribution of anode signal is equivalent to reverse of ionization distribution. We obtain signals which are proportional to the Bragg peak and the total energy by integrating the beginning and the whole of the anode signal, respectively. Since a Bragg peak height is strongly depend on fragment Z, we can identify fragments by relationship between Bragg peak height and the total energy.[7]

Figure 7 shows a schematic view of a test chamber for BCS. The chamber is a cylindrical shaped grid ionization chamber (27 cm long × 8cm diam. effective volume) filled with a low pressure Ar+10%CH_4 gas. Gas pressure was set to stop only fragments in the detector, almost all unnecessary particle such as proton can escape with a small energy deposition. Thus, we could easily discriminate such light particles. A sample of 5cm diameter plate was set on the cathode plate inside the chamber. In this condition, solid angle of the detector reaches more than 67 msr.

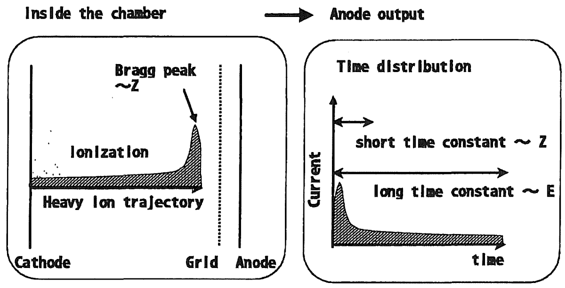

Fig. 6 Particle identification scheme of a Bragg curve spectrometer

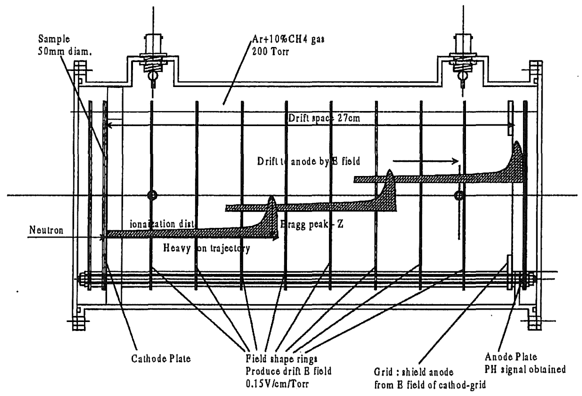

Fig. 7 Schematic view of BCS test chamber

2. Measurement and results

The detector was set at 5 m from the ^{7}Li(p,n) neutron production target on LC3 course at TIARA.[1] Peak neutron energy was set to 65 MeV. The output signal, anode, from BCS was divided to two after passing through a pre-amplifier and fed to two different shaping time amplifiers to obtain Bragg peak height and total energy of fragments. Samples were a thick carbon, a thick nikcel and a thin aluminum. Ni and Al were used to evaluate backgrounds. **Figure 8** shows two-dimensional spectrum of short (0.4 μs) and long (6 μs) shaping time for 200 mm thickness carbon sample. Fragments can be separated clearly.

The energy spectra of Li and Be for each sample are shown in figs. 9 and 10. As shown in these figures, the results of different thickness carbon samples are in good agreement. It means that the range of Li and Be in carbon is much shorter than those in samples. We can obtain energy spectrum of these fragments by subtracting appropriate background since the yields from Ni and Al are lower than one from C.

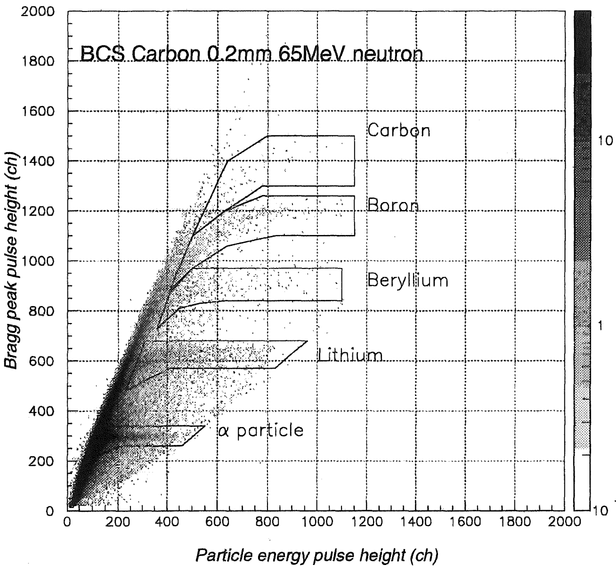

Fig. 8 Two-dimensional spectra for 200mm carbon sample

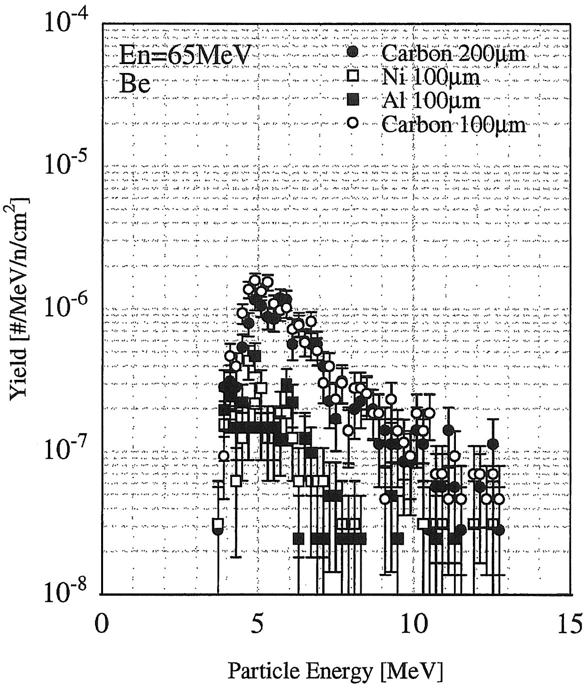

Fig. 10 The energy spectra of Be from each samples

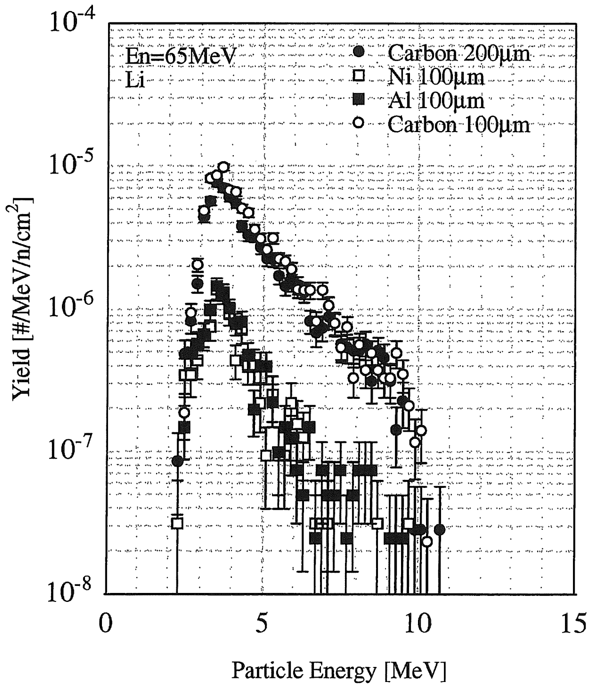

Fig. 9 The energy spectra of Li from each samples

V. Conclusion

Double differential cross sections of light charged particles and fragments which are important to neutron dosimetry were measured at TIARA neutron source. The large solid angle and particle acceptance detector is indispensable for the measurement. For light charged particles, we adopted a spectrometer consisting of three counter telescopes and a vacuum chamber which covers a wide energy loss region of the particles. Double differentail cross sections of particles of p,d,t and α paricles for oxygen and nitrogen were obtained at three laboratry angles by the spectrometer. For fragments, we developed a Bragg curve spectrometer which enables simultaneous measurement of particles heavier than α particles. A test of the spectrometer at a neutron field was carrid out. We obtained energy spectra of heavier particles than α from carbon with acceptable signal to noise ratio and detection efficeincy.

References

1) M. Baba et al, *Nucl. Instrm. Meth.*, **A428**, 454 (1999).
2) T.Sanami et al, *J. Nucl. Sci. Technol.* **Suppliment 2** (2002) 421.
3) Y. Nauchi et al, *J. Nucl. Sci. Technol.* **96(2)** (1999) 143.
4) S. Iwasaki, "A new approach for radiation inverse problems based only on the Bayes theory" *KEK Proc. 95-1*, Jan 1995, 319 (1995).
5) M. B. Chadwick et al, *Nucl. Sci. Eng.* **131**, 293 (1999).
6) M. Baba et al, "Measurement of differential neutron induced charged partcile emission cross sections for 5-75 MeV neutrons", *Proc. Tenth International Symposium on Reactor Dosimetry*, Osaka, Japan, Sept. 12-17, 1999, PB4.06 (1999).
7) A.B.Frawley et.al, *Nucl. Instrm. Methods*, **A306** 512 (1991)