Measurement of neutron spectra produced in the forward direction from thick graphite, Al, Fe and Pb targets bombarded by 350 MeV protons

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Abstract

Neutron energy spectra at 0-degree produced from stopping-length graphite, Al, Fe and Pb targets bombarded by 350 MeV protons were measured at the neutron TOF course at RCNP of Osaka University. The experiments were performed by the time-of-flight technique with the flight path length of 11.4 and 95 m, and neutron energy spectra were obtained in the energy range from 10 MeV upto the maximum energy 350 MeV. Monte Carlo calculations by MCNPX, PHITS and MARS15 were performed to compare the obtained experimental data, and these simulation results at 0-degree generally underestimated the experimental data for all targets in the energy range above 20 MeV.
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1. Introduction

Various Monte Carlo transport codes have been widely employed for the shielding design of proton accelerator facilities. In such design calculations, it is important to estimate secondary particles, especially neutrons, produced by beam losses in thick materials of beam line modules or beam dump as source terms. The accuracy of simulation results has been generally determined by benchmark experimental data. The double differential neutron spectra in stopping-length targets in the incident proton energy region above 100 MeV were measured at LANL with 113 and 256 MeV protons on C, Al and Fe [1,2], and at RIKEN with 210 MeV protons on Fe [3]. In the results of study at RIKEN, it was found that the calculation results of the MCNPX [4] code underestimate the experimental ones at 0-degree in the neutron energy region above 20 MeV. No other experimental data is available to confirm the accuracy of neutron productions at 0-degree from thick target in this energy region. Therefore, it is important to compare the calculation results with the experimental data at 0-degree using various targets.

In this work, we measured neutron spectra produced in the direction of 0-degree from thick graphite, Al, Fe and Pb bombarded by 350 MeV protons at the TOF course of the

RCNP (Research Center of Nuclear Physics) ring cyclotron, Osaka University. Calculations by the MCNPX, PHITS [5] and MARS15 [6] codes were performed to compare with the obtained experimental data.

2. Experiment

The experiments were carried out at the neutron TOF course of the RCNP ring cyclotron of Osaka University. A schematic view of the experimental arrangement is illustrated in Fig. 1. The characteristics of the targets used in this work are summarized in Table 1. The targets were covered with aluminum foil to absorb secondary electrons emitting from the targets and were set in a vacuum chamber. The neutrons produced at 0-degree were transported to the TOF course through the 150-cm-thick iron collimator of a 12-cm high and 10-cm wide opening, while charged particles were rejected by a vertical bending magnet equipped in the collimator.

The neutron TOF measurements were performed using an NE213 organic liquid scintillator (12.7 cm diameter by 12.7 cm long) placed at either 11.4 m (short path) or 95 m (long path) from the beam-incident surface of the target. The long path measurement was carried out to get good time resolution in higher energy region. In the measurements, the currents of the proton beam were kept in the range of 0.5–0.6 nA for the short path and 17–20 nA for the long path.

A block diagram of measurement circuit is shown in Fig. 2 with simplified drawing. Two detector signals were sent through different delay cables to the two analog-to-digital converter (ADC) (Lecroy FERA 4300B) channels to
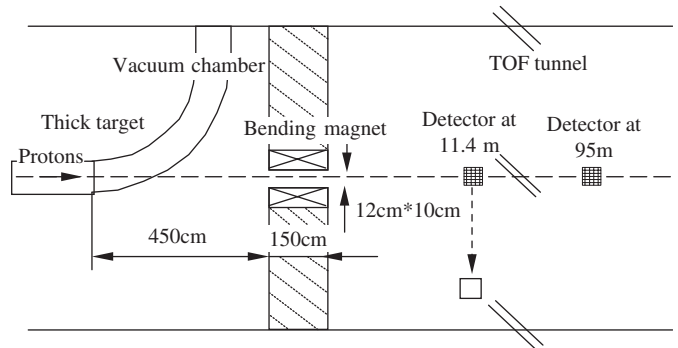

Fig. 1. Illustration of experimental set-up at RCNP.

Table 1
Target characteristics and stopping range of 350 MeV protons in the target

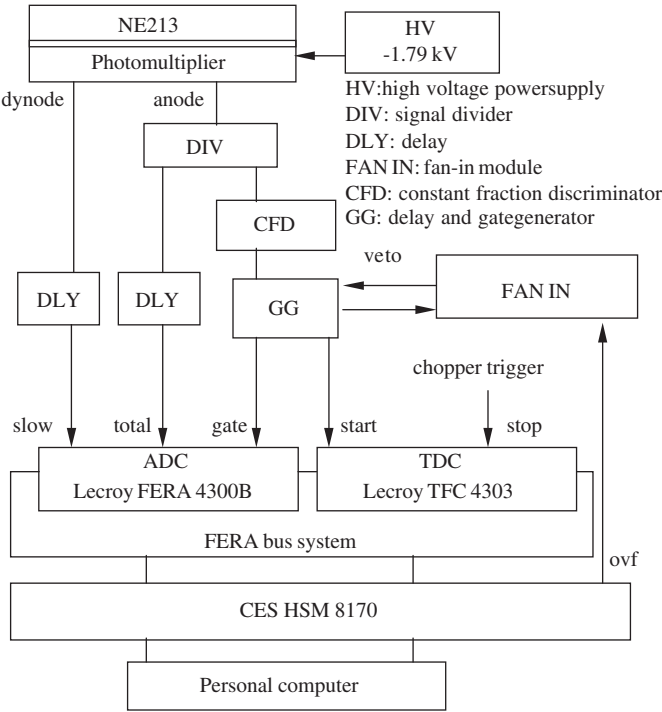| Material	Density (g/cm^3)	Shape (cm)	Stopping range (cm)
Graphite	1.76	$6.0 \times 6.0 \times 46.0$	41.2
Al	2.72	$\Phi 6.0 \times 34.5$	31.3
Fe	9.12	$\Phi 6.5 \times 13.5$	12.0
Pb	11.3	$6.0 \times 6.0 \times 12.5$	11.6

Fig. 2. Block diagram of the circuit for the TOF measurement.

measure the total and slow light components for neutron-gamma pulse shape discrimination. The time-to-digital converter (TDC) (Lecroy TFC 4303) was used to measure the neutron TOF spectra. The start signal of the TDC was delivered from the photomultiplier and the chopper trigger signal was used as the stop signal. The converted data from the ADC and the TDC were accumulated in a high-speed memory, the CES HSM 8170 through the FERA data bus and then transferred to a personal computer. The overflow signal of the HSM (ovf) was used to inhibit the ADC gate and the TDC start pulse while the HSM was busy. The beam current was monitored with a current integrator coupled to the targets.

3. Data analysis

The TOF distributions of only neutrons were converted to the neutron energy spectra. In the TOF distribution analysis, neutron events above the Am–Be (4.2 MeVee) bias were summed up for the short path measurement, and neutron TOF distributions in wide energy range above 10 MeV to maximum energy were obtained. On the other hand, for the long path measurement, 37.8 MeVee bias was chosen to eliminate a contamination of low-energy neutron events of previous beam cycle.

Neutron detection efficiencies were obtained from calculation results of the CECIL code [7]. The results of CECIL agree with the measurements within 15% in the energy region between 10 and 206.8 MeV for 4.2 MeVee bias [8]. In the neutron-gamma discrimination, the pulse shapes from high-energy neutron events in which recoil