Measurements of Differential Thick Target Neutron Yield for Fe, Cu(p,xn) reactions at 35 and 50 MeV

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Abstract

Differential thick target neutron yields (TTY) for ^{nat}Fe, ^{nat}Cu(p,xn) reactions were measured at 35 and 50 MeV at several laboratory angles between 0- and 110-deg using the time-of-flight method with the Tohoku Univ. AVF cyclotron and a beam-swinger system. We determined neutron energy spectra from ∼0.4 MeV to the highest secondary neutron energy. The experimental results were compared with the LA150 data library.

1 Introduction

By the development of accelerator technology, high intensity and high energy accelerators are now available. Uses of the accelerators are expanding to material studies, medical treatment, radiobiology studies and environmental science as well as nuclear physics. Now some accelerators with high energy and intensity are under construction or in plan e.g., Japan Proton Accelerator Research Complex (J-PARC, which is promoted by the corporation of JAERI and KEK), Spallation Neutron Source (SNS, United States), and European Spallation Source (ESS). For the design of accelerator shielding and the accelerator-based neutron sources, differential thick target neutron yields (TTY) data are required. Data are required to be obtained with high energy resolution over a wide energy and angle range. However, such nuclear data files are not good enough in quality for high energy accelerators, and experimental data covering wide range of secondary neutron energies are very few.

In the present experiments, we obtained the TTY data for the ^{nat}Fe, ^{nat}Cu(p,xn) reaction at 35 and 50 MeV. These elements are very popular element for beam-lines and beam-dumps in accelerators. Therefore, it is important to know secondary neutron spectra from these elements bombarded by accelerated charged particles. The experiment was carried out as a part of the series of TTY measurements using a time-of-flight (TOF) technique at the Cyclotron and Radioisotope Center (CYRIC)[1], Tohoku University with the K=110 AVF cyclotron and the beam-swinger system.

2 Experiment

The experimental setup is shown in Fig.1. A proton beam accelerated by the AVF cyclotron was transported to the target room No.5 of CYRIC equipped with a beam-swinger system and a neutron TOF channel [2]. The beam swinger system changes the incident angle of the beam onto the target from

0-deg to 110-deg and enables to measure angular distributions with a fixed detector setup. The targets of Fe and Cu were plate of natural elements. Their sizes are shown in table 1. The target chamber was shielded with a 2.5 m thick concrete wall having a beam channel for collimeters which enable to measure neutrons under a low background environment. Emitted neutrons were detected by a NE213 liquid scintillation detector, 14 cm-diam × 10 cm-thick or 5 cm-diam × 5 cm-thick equipped with a pulse-shape-discriminator (PSD). The larger and smaller detectors were placed around ∼11 m and ∼3.5 m from the target, respectively. The shorter flight path was adopted to measure the low energy part (∼0.4-3 MeV) of the neutron spectrum by low pulse-height bias (∼0.4 MeV). The TOF, PSD and pulse-height data were collected event by event as three parameter list data for off-line analysis [3].

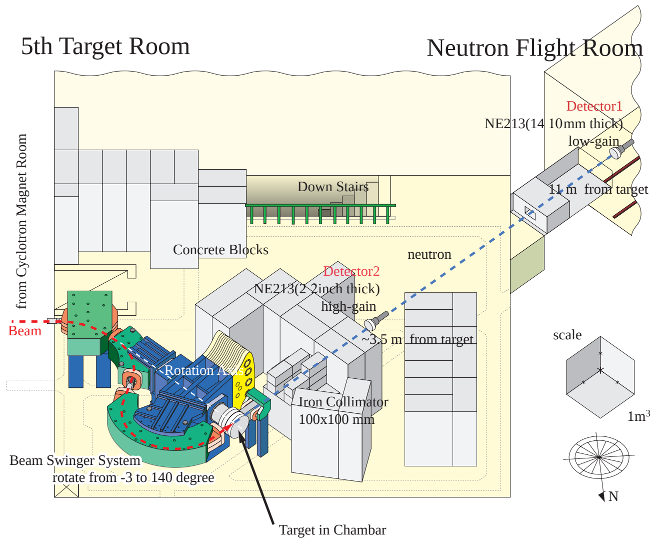

Fig 1: 5th target room and TOF room

3 Experimental procedure

The pulse width of proton beam was generally less than 1 ns in FWHM, and the beam current on the target was around 5 ∼ 10 nA. The beam current was digitized and recorded by a scaler for normalization of the neutron TOF spectrum. The TOF data were obtained at five laboratory angles (0, 30, 60, 90, 110).

Table 1: Present measurements and target size

Proton energy [MeV]	**Target**	**Angle [deg.]**	**Stopping range [mm]**	**Thickness [mm]**
35	Fe	0, 30, 60, 90,110	2.26	3
	Cu		2.11	
50	Fe	0, 30, 60, 90,110	4.24	5
	Cu		3.93	

4 Data analysis

Neutron TOF spectra gated by the PSD signal and the lower pulse-height bias were converted into energy spectra. The efficiency *vs.* energy curves of the detectors were obtained by the calculation with a SCINFUL-R, whichi is revised version of the Monte Carlo code SCINFUL [4] and was verified to be accurate within ± 5 % up to 80 MeV [5]. The spectra were normalized by the integrated beam current.

5 Results and discussion

5.1 Experimental data

Figures 2 and 3 show the present results of differential thick taget neutron yield from the ^{nat}Fe, ^{nat}Cu(p,xn) reactions at 35 and 50 MeV. The data have not been corrected yet for the effect of neutron attenuation in the target and air. As shown, both spectra show almost similar feature with no marked structures. The neutron spectra show pronounced increase in lowest energy region because of evaporation neutrons and the yields are larger than light nulide like ^{nat}C and ^{nat}Al. The angular dependence of the spectra becomes stronger with increasing neutron energy.

In Fig.4, the present results are compared with the data by Nakamura et al., at E_p=52 MeV obtained by the unfolding technique [9]. The data by Nakamura et al. are limited in energy range but in fair agreement with the present one in the overlapping energy region.

5.2 Comparison with LA150

In the following, experimental data are compared with the TTY data derived from LA150. The TTY predicted by LA150 [6][7] was derived by using the following equation [8].

$$\frac{d^2Y(E_0)}{d\Omega} = N\int_0^T \frac{d^2\sigma\left(E_0 - \int_0^t \left(\frac{dE}{dt}\right) dt\right)}{dEd\Omega} \times e^{-N\sigma_{nonel}\left(E_0 - \int_0^t \left(\frac{dE}{dt}\right)dt\right)t} dt \qquad (n \cdot MeV^{-1} \cdot sr^{-1} \cdot projectile^{-1}),$$

where, E_0 is incident particle energy [MeV], N is density of target nulide [#/cm^3], T is thickness of the target [cm], σ_{nonel} is nonelastic cross section [cm^2], dE/dt is stopping power of incident particles [MeV/cm].

Figures 5 and 6 show comparison of the present results with the LA150 data library. Both data for ^{nat}Fe and ^{nat}Cu show marked disagreements with LA150 in higher energy region. Such disagreement with LA150 was observed also in the case of heavy nuclide as tungsten and tantalum [10].

In the future, we are planning to correct for the effect of the attenuation of neutron in the taget and air, and also do measurements for thin target to clarify the difference.

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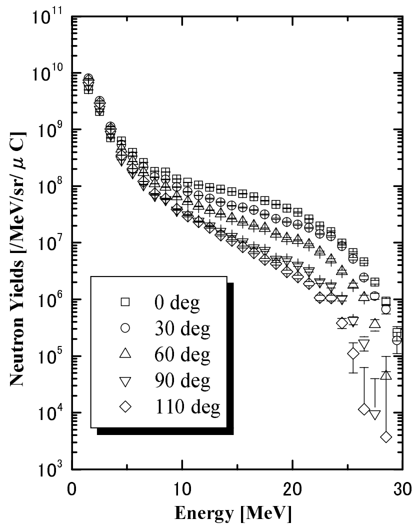
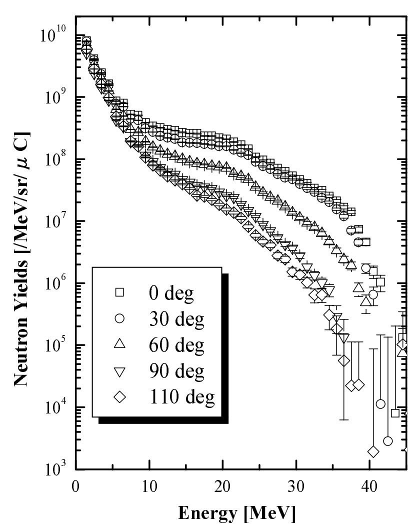
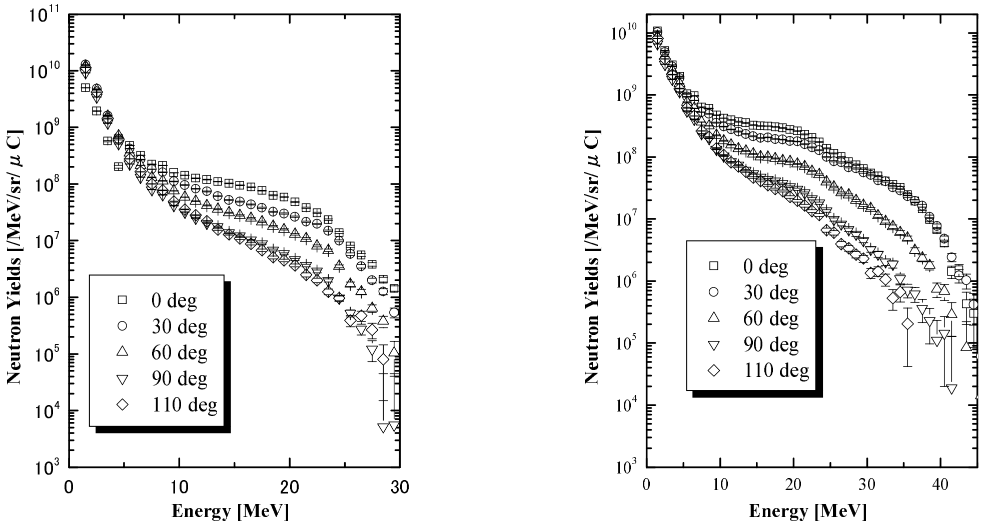


(a) $E_p = 35$ MeV



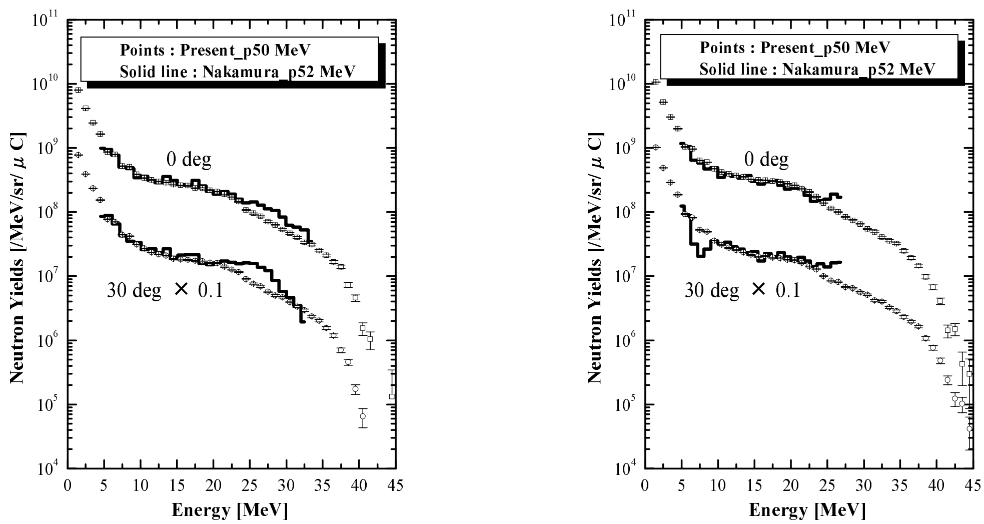
(b) $E_p = 50$ MeV

Fig.2 : Experimental data for ^{nat}Fe(p,xn)



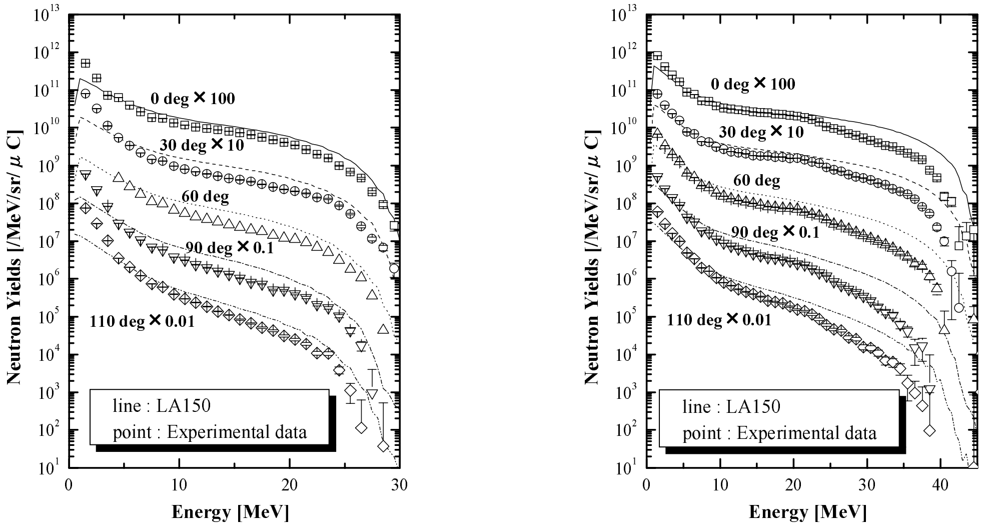
(a) E_p = 35 MeV　　　(b) E_p = 50 MeV

Fig.3 : Experimental data for ^{nat}Cu(p,xn)



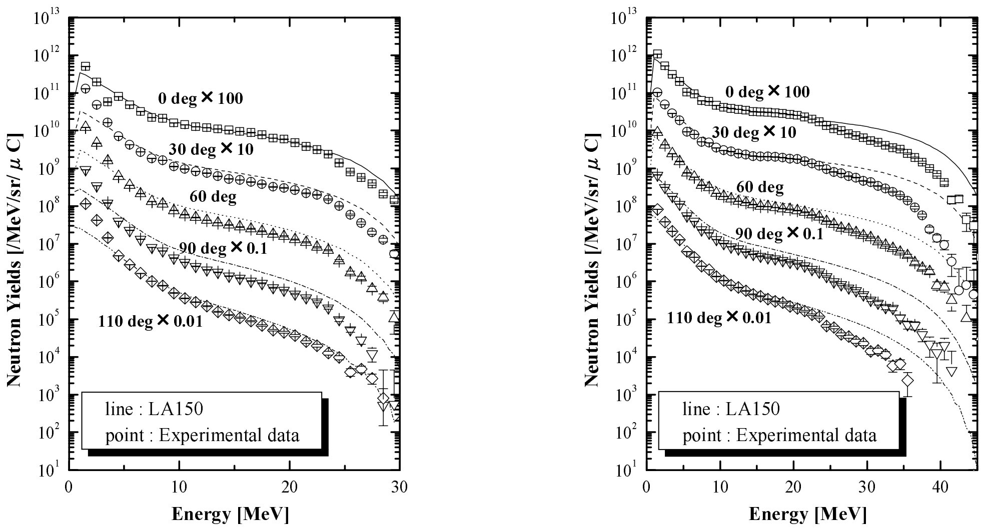
(a) Fe　　　(b) Cu

Fig.4 : Comparison with Nakamura's data



(a) E_p = 35 MeV (b) E_p = 50 MeV

Fig.5 : Compariosn with LA150 for ^{nat}Fe(p,xn)



(a) E_p = 35 MeV (b) E_p = 50 MeV

Fig.6 : Compariosn with LA150 for ^{nat}Cu(p,xn)