III. 3. Measurements of Differential Thick Target Neutron Yield for Fe, Cu(p,xn) Reactions at 35, 50 and 70 MeV

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Introduction

By the development of accelerator technology, high intensity and high energy accelerators are now available. Now some accelerators with high energy and intensity are under construction or in plan e.g., Japan Proton Accelerator Research Complex (J-PARC, by the corporation of JAERI and KEK) and Spallation Neutron Source (SNS, United States) and so on. For the design of accelerator shielding and the accelerator-based neutron sources, differential thick target neutron yields (TTY) data are required. Data are required with high energy resolution over a wide energy and angle range. However, the experimental data covering wide range of secondary neutron energies are very few, and such the nuclear data files are not good enough in quality for high energy accelerators. We are considering series of TTY measurement for (p,xn) and (d,xn) reactions in ten’s MeV region.

In the present experiments, we obtained the TTY data for the natFe, natCu(p,xn) reaction at 35, 50 and 70 MeV. These elements are used 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), Tohoku University with the K = 110 AVF cyclotron and the beam-swinger system5).

Experiment and analysis

The experimental setup and the technique are same as in the past experiments2-4). The targets of Fe and Cu were plate of natural elements with full stop thickness (Table. 1).
The pulse width of the proton beam was generally less than 2 ns in FWHM. The repetition rate was 2.3 MHz and the average beam current on the target was around 5 ~ 10 nA. The TOF data were obtained at five laboratory angles (0, 30, 60, 90 and 110 deg.). The efficiency vs. energy curves of the detectors were obtained by the calculation with a SCINFUL-R\(^6\), which is a revised version of the Monte Carlo code SCINFUL\(^7\) and was verified to be accurate within ± 5 % up to 80 MeV\(^6\). The spectra were normalized by the integrated beam current.

Results and discussion

Figures 1 ~ 4 show the present results of TTY from the \(^{nat}\)Fe, \(^{nat}\)Cu(p,xn) reactions at 35, 50 and 70 MeV. The data have not been corrected yet for the effect of neutron attenuation in the target and air. As shown fig. 3 and fig. 4, both spectra show similar feature with no marked structures. Figure 1 shows pronounced increase in lowest energy region because of evaporation neutrons and the total neutron yields are larger than light nuclide like \(^{nat}\)C and \(^{nat}\)Al\(^1\). The angular dependence of the spectra becomes stronger with increasing neutron energy.

In fig. 2, the present results are compared with the data by Nakamura et al., at \(E_p = 52\) MeV obtained by the unfolding technique\(^8\). The data by Nakamura et al. are limited in energy range but in fair agreement with the present one in the overlapping energy region. Figure 3 show the comparison with the data by S. Meigo, at \(E_p = 68\) MeV using TOF method\(^9\) indicating very good agreement in the highest energy end.

In the following, experimental data are compared with the TTY data calculated by the Monte Carlo code MCNPX which employs the LA150 data\(^10\),\(^11\) and takes account of the particle transport. LA150. Figure 1 and 4 show the comparisons with the present results and the LA150 data. Both data for \(^{nat}\)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\(^1\).

We are conducting to measure net of the thin target neutron yield from same reaction to clarify the causes of such difference of experimental results and LA150 data.

References

9) Private communication

Table 1. The thickness of targets and proton stopping range.

<table>
<thead>
<tr>
<th>Proton Energy [MeV]</th>
<th>Nuclide</th>
<th>Stopping range [mm]</th>
<th>Thickness [mm]</th>
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<tbody>
<tr>
<td>35</td>
<td>Fe</td>
<td>2.26</td>
<td>3</td>
</tr>
<tr>
<td></td>
<td>Cu</td>
<td>2.11</td>
<td>3</td>
</tr>
<tr>
<td>50</td>
<td>Fe</td>
<td>4.24</td>
<td>5</td>
</tr>
<tr>
<td></td>
<td>Cu</td>
<td>3.93</td>
<td>5</td>
</tr>
<tr>
<td>70</td>
<td>Fe</td>
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<td>10</td>
</tr>
<tr>
<td></td>
<td>Cu</td>
<td>7.09</td>
<td>10</td>
</tr>
</tbody>
</table>

Fig. 1. Neutron yield for the natFe(p,xn) at 35 MeV.

Fig. 2. Neutron yield for the natCu(p,xn) at 50 MeV in comparison with Nakamura’s data at 52 MeV8).
Fig. 3. Neutron yield for the $^{56}$Fe(p,xn) at 70 MeV in comparison with Meigo’s data at 68 MeV.

Fig. 4. Neutron yield for the $^{64}$Cu(p,xn) at 70 MeV in comparison with LA150.