Development of Self-TOF neutron detector and its application
to concrete and iron shielding experiments

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Abstract

A new type detector, called ‘Self-TOF detector’, has been developed for high energy neutron spectrometry behind a shield. The detector consists of a veto counter, a set of radiators with 20 thin detectors, a start counter and a stop counter of nine segments. The measurement of the detector response function for high energy neutrons and the concrete and iron shielding experiments were done at the Heavy-Ion Medical Accelerator in Chiba (HIMAC) of National Institute of Radiological Sciences (NIRS), Japan. By using the response functions, neutron spectra behind shield were obtained by unfolding and the results were compared with the LAHET Code System (LCS).

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Keywords: High energy neutrons; Shielding experiment; Attenuation length

1. Introduction

Recently, high-energy and high-intensity particle accelerator has been used for various applications, such as high-intensity neutron source. For such a facility design, the shielding of high energy neutrons produced from a magnet, a beam dump and a target is important because of their strong penetrability. The information on neutron attenuation with good accuracy is quite essential in order to minimize the shielding cost of the facility building. But there are few reports on high energy neutron shielding experiments \cite{1,2}. One of the reasons is the limitation of the available active neutron detector having reasonable resolution in the high energy region.

Multi-moderator detectors have commonly been used in shielding experiments, but the response functions of the detectors scarcely change for neutrons over 20 MeV. Furthermore, the neutron spectrum obtained by the unfolding method strongly depends on the initial guess spectrum.

High energy neutrons outside the shielding has been very difficult to be measured so far, and we therefore developed a new type detector, called...
‘Self-TOF detector’, for high energy neutron spectrometry of better energy resolution behind a shield [3,4].

2. The Self-TOF detector

Fig. 1 shows the schematic view of the detector. The detector consists of a veto counter (150 mm × 150 mm × 5 mm thickness), a set of radiators with 20 thin detectors (100 mm × 100 mm × 6 mm thickness), a start counter (100 mm × 100 mm × 5 mm thickness), and a stop counter of nine segments (200 mm × 200 mm × 20 mm thickness each), which is set on a plane perpendicular to the neutron beam. These detectors are all NE102A plastic scintillators. An in-coming neutron produces charged particles in the radiator, then the charged particles emitted in the forward direction reach the stop counter through the start counter. The energy of a charged particle is determined by using the time-of-flight method between the start and stop counters. In this detector, we selected only proton events from H(n,p) and C(n,p) reactions and the proton energy spectrum was converted into the neutron energy spectrum by unfolding using the detector response function.

3. Experiment on detector response function

3.1. Experimental setup

The measurement of the detector response function for high energy neutrons was done at the Heavy-Ion Medical Accelerator in Chiba (HIMAC) of National Institute of Radiological Sciences (NIRS), Japan. Fig. 2 shows the experimental arrangement at the HIMAC.

The neutrons were produced by bombarding 400 MeV/nucleon $^{12}$C ion and 800 MeV/nucleon $^{28}$Si ion on thick (stopping-length) carbon and copper targets. The beam pickup detector was placed just behind the end window of a beam line to use as a start signal for conventional neutron time-of-flight method [5–7]. The Self-TOF detector was placed 516.5 cm downstream the target and the distance between the start and the stop counters was 1.2 m. It is already known that this radiation field includes a lot of charged particles generated by fragmentation reactions. The iron collimator of 60 cm × 60 cm × 40 cm thickness with a hole of 10 cm × 10 cm was set in front of the Self-TOF detector not only to decrease the contribution of charged particles incident to the Self-TOF detector but also to reduce neutrons scattered by floor. The veto counter was placed in front of the radiators to discriminate charged particles from neutrons.

3.2. Data analysis

The signals from the detectors were acquired using a CAMAC system with a data-taking software Kakuen Online Data Acquisition System (KODAQ) developed by Omata et al. [8]. The light output data were stored by the ADC. The time-of-flight of a charged particle between the start and stop counters was measured by the TDC. All data were recorded in an event by event mode when a trigger signal was generated by a coincidence signal between the start and stop counters.

The data were analyzed as follows: (i) select only the proton events generated in the radiators with using the light output data of the veto and the most downstream radiator; (ii) select the events caused by the single primary ion with using the light output data of the beam pick-up detector; (iii) convert TOF spectrum into proton energy spectrum.

The incident neutron energy is determined by the time-of-flight between the beam pick-up
detector and start counter by correcting the energy loss of protons in the radiators. We used the absolute value of neutron fluence which has already been measured at this beam line by Kurosawa et al. [5].

By repeating the analysis mentioned above with changing the ROI of the neutron energy, we can find the neutron response function matrices.

3.3. Calculation of the response function

The measured response functions in the energy range from 60 to 800 MeV were compared with those calculated with the LCS [9]. The neutron source was simulated as a 10 cm × 10 cm plane source. The results traced were recorded only for protons generated in the radiators and passed through the start counter, and reached the stop counter. The detector response for neutrons corresponds to the proton current crossing the surface of the stop counter because the detection efficiency of the counter for a charged particle is almost 100%.

The response functions obtained by the experiment and the LCS were exemplified for neutron energy regions of 180–220 MeV and 300–350 MeV in Figs. 3 and 4, respectively. In the figures, the LCS results have been folded with the detector energy resolution. The LCS result tends to underestimate the fluence in the lower energy region and to overestimate the fluence at the higher energy region. This discrepancy comes from the inaccurate cascade model in the code for light nuclei like carbon.

4. Shielding experiment

4.1. Experimental setup

The concrete and iron shielding experiments were also done at the HIMAC. The experimental arrangement was the same as in Fig. 1. The shield
has 100 cm x 100 cm size and 50, 100, 150 and 200 cm thicknesses for concrete, 20, 40, 60, 80 and 100 cm thicknesses for iron. The shield was set between the target and the iron collimator (see Fig. 1). The neutrons were produced by bombarding 400 MeV/nucleon $^{12}$C ions on the 5 cm thick copper target. The transmission-type ionization chamber was placed behind the end window of a beam line as a beam monitor.

4.2. Data analysis

In the data analysis, proton energy spectra can be obtained as mentioned above. We then got the neutron spectra by using the FERDO-U unfolding code [10] with the measured response functions.

In this Self-TOF detector, the proton energy spectral data were used instead of the usual light output data. Although the light output spectra do not change when the recoil proton range becomes larger than the detector size, the proton energy determined from the TOF change in higher energy region. Therefore, this detector could measure higher energy neutrons.

Neutron spectra behind the shield were also compared with the LCS. The measured data by Kurosawa et al. [5] was used for the source neutron spectra in this calculation. The neutron spectra on the front surface of the radiator were obtained.

5. Discussions

The neutron spectra behind concrete shield are shown in Fig. 5, and behind iron shield are shown in Fig. 6. The neutron spectra could not be determined above 600 MeV and below 100 MeV except for thick iron shield. In the experiment, we could not get enough neutron fluence above 600 MeV. On the other hand, for neutrons below 100 MeV, the detection efficiency decreased steeply because a proton which was generated from the upstream radiator stopped in the following radiator.

Comparison of the measured and calculated neutron fluences integrated from 100 to 600 MeV...
asa function of shield thickness is shown in Fig. 7. The LCS results tend to overestimate with increasing the thickness. The neutron attenuation lengths obtained from the slopes of the curves in Fig. 7 are indicated in Table 1.

### Table 1
Comparison of measured and calculated neutron attenuation lengths in the energy region from 100 to 600 MeV

<table>
<thead>
<tr>
<th></th>
<th>Exp. ($\lambda$(g/cm²))</th>
<th>Calc. ($\lambda$(g/cm²))</th>
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<tbody>
<tr>
<td>Concrete</td>
<td>86.9</td>
<td>101.2</td>
</tr>
<tr>
<td>Iron</td>
<td>120.5</td>
<td>137.7</td>
</tr>
</tbody>
</table>

6. Conclusion

A new type detector for high-energy neutron spectrometry was developed. The response function measurement for high energy neutrons and the concrete and iron shielding experiments were done at the HIMAC. With these experiments, we confirmed that the Self-TOF detector is available for high energy neutron spectrometry outside the shield.

We are now planning to measure the neutron energy spectrum below 100 MeV with a coupling use of an NE213 organic liquid scintillator.

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References