EPJ Web of Conferences **146**, 03031 (2017) DOI: 10.1051/epjconf/201714603031
ND2016

Analysis of energy resolution in the KURRI-LINAC pulsed neutron facility

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Abstract. In this study, we carried out Monte Carlo simulations to obtain the energy resolution of the neutron flux for TOF measurements in the KURRI-LINAC pulsed neutron facility. The simulation was performed on the moderated neutron flux from the pac-man type moderator at the energy range from 0.1 eV to 10 keV. As the result, we obtained the energy resolutions (ΔE/E) of about 0.7% to 1.3% between 0.1 eV to 10 keV. The energy resolution obtained from Monte Carlo simulation agreed with the resolution using the simplified evaluation formula. In addition, we compared the energy resolution among KURRI-LINAC and other TOF facilities, the energy dependency of the energy resolution with the pac-man type moderator in KURRI-LINAC was similar to the J-PARC ANNRI for the single-bunch mode.

1. Introduction

The electron linear accelerator at the Research Reactor Institute, Kyoto University (KURRI-LINAC) had been originally established in 1965 by the High Voltage Engineering Co., USA and started as a 23 MeV machine. In 1971, the machine power had been increased to 46 MeV. The KURRI-LINAC has two different operation pulse modes. One is a long mode with a maximum repetition rate of 120 Hz, a pulse width of 0.1–4.0 μs and a peak current of about 0.5 A for the measurement at low energies below 10 eV. Another is a short mode with a maximum repetition rate of 300 Hz, a pulse width of 2–100 ns and a peak current of about 5 mA for the measurement at high energies above 1 eV. It is worth noting that the peak current of short mode is ten times as large as that of long mode.

By using a target according to a research purpose, we can use various type of particle beam source, i.e. neutron, electron, and photon. Thus, the research regions in the KURRI-LINAC has covered a wide field of nuclear data acquisition with the neutron Time-Of-Flight (TOF) method and a lead slowing-down spectrometer, isotope production by the (γ, n) (γ, p) reaction, low-temperature electron irradiation, a photon activation analysis, and a spectroscopy with coherent THz radiation.

In measurements of nuclear data, a water-cooled tantalum (Ta) target as a photo-neutron target and a light water moderator has been used. There are two kinds of the moderators. One is a water tank type and another is an octagonal shape moderator called "pac-man type" as shown in Fig. 1. Researchers have usually adopted the pac-man type moderator to measure nuclear data in the past. In order to measure accurate nuclear data, it is very important to evaluate the energy resolution of a moderator. For example, the energy resolution for single bunch operation at ANNRI in J-PARC had been calculated about 0.5% between energy range of 0.1 eV from 10 keV [1]. Detail evaluation of energy resolutions for the moderator has not carried out in KURRI-LINAC, although the energy resolution has been evaluated by using the simplified evaluation formula [2].

Thus, the energy resolutions of the neutron flux from the pac-man type moderator at the short pulse mode with 100 ns width were evaluated from a result of Monte Carlo simulation in this study. The researchers usually employed the electron pulse width for the nuclear data measurement in the KURRI-LINAC. Thus, the electron beam pulse width was set to 100 ns in this study.

2. Monte Carlo simulation

A calculation of the neutron flux from the pac-man type moderator was performed by the Monte Carlo code PHITS [3] with JENDL-4.0 [4] to obtain the time structure of the pulsed neuron beam. The calculational geometry is shown in Fig. 2, Fig. 3 and Fig. 4. Figure 2 shows a target assembly. The target assembly is composed of 12 Ta plates with a total thickness of 29 mm in a cylindrical titanium case. Every gaps between Ta plates have 0.15 mm thickness. The gaps are filled with the coolant water (light water). The case has 50 mm diameter and 60 mm long. Figure 3 shows the pac-man type moderator. The light water moderator has an octagonal shape with 300 mm width, height and 100 mm thickness at the A in Fig. 3. In the center of moderator, there was a "dip" of 153 mm diameter and 50 mm thickness. There is a trade-off between increasing of neutron flux and energy resolutions. Thus, an effective thickness in the center of the pac-man type moderator was set to 5 cm for narrow energy resolutions and a thickness at the outside of "dip" was 10 cm to increase the neutron flux. In addition, a lead shadow bar, 50 mm in diameter and 100 mm long, was

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Figure 1. The pac-man type moderator and the Ta target in KURRI-LINAC.

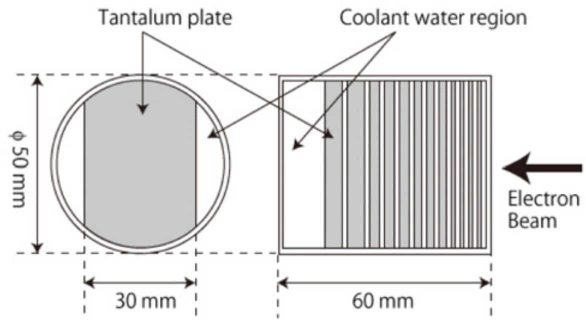

Figure 2. The tantalum target assembly.

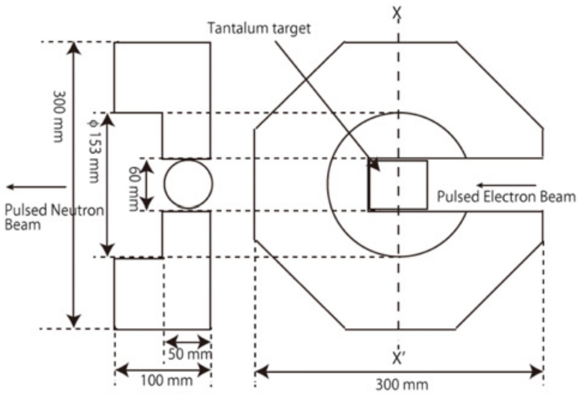

Figure 3. The pac-man type moderator. The left figure is a X-X′ plane in the right figure.

Table 1. Parameters of the neutron flux calculation.

Electron beam	
Energy	36 MeV
Diameter	ϕ10 mm
Pulse width	100 nsec

placed on the neutron beam axis in front of Ta target as shown in Fig. 4. The parameters used for the calculation are listed in Table 1. In this study, we performed the simulation including the injection of pulsed electron beam into the Ta target. The electron pules has a rectangle distribution with 100 ns width. A tally surface to record the neutron information was set on 35 cm distance from the target surface.

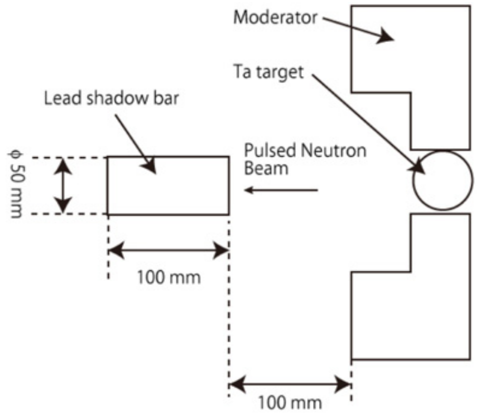

Figure 4. The Calculational geometry including the lead shadow bar.

3. Evaluation of energy resolution

Figure 5 shows time distributions of pulsed neutron at the tally surface obtained by the Monte Carlo simulation. The ordinate scales are linear and the peak heights are normalized to 1.0. In order to mean time structure, an expected value of time-delay is defined as following equation;

$$\overline{\Delta t} = \frac{\sum_i P_i \, \Delta t_i}{\sum_i P_i} \tag{1}$$

where, Δt_i is time-delay of neutron passing through the tally surface from the injection of electron beam into the Ta target. A P_i is probability distribution of Δt_i. The P_i were obtained from the histograms shown in Fig. 5, respectively.

Energy resolution $(\Delta E/E)$ is related to the time resolution $(\Delta t/t)$ by Eq. (2),

$$\frac{\Delta E}{E} = 2\frac{\overline{\Delta t}}{t} \tag{2}$$

where, t is flight time. The relation of the flight time and the neutron energy, E (eV), is expressed as follows;

$$t = \frac{72.298L}{\sqrt{E}} \approx \frac{72.3L}{\sqrt{E}}, \tag{3}$$

where, L is a flight path (m). In nuclear data measurement at KURRI-LINAC, we usually set a sample on a flight path of 10.0 m or 12.7 m from the Ta target. In this study, the energy resolution was calculated for the 10.0 m TOF distance. Table 2 shows the obtained energy resolutions. The energy resolutions are about 0.7% and 0.9% between 0.1 eV to 1 keV. On the other hand, the energy resolutions decrease above 10 keV, because the resolution has large contribution of injected electron beam with 100 ns pulse width.

Figure 6 shows comparison of the resolution between the results of this study and using a simplified evaluation formula. The definition of the formula is Eq. (4) [2].

$$\frac{\Delta E}{E} = \frac{2\sqrt{E}}{72.3L}\sqrt{(\Delta t)^2 + \frac{72.3^2}{E}(\Delta L)^2} = const \tag{4}$$

ΔL: uncertainty of neutron flight path

$$\Delta t = 2\sqrt{3}\tau_m \approx 1.85/\sqrt{E} \tag{5}$$

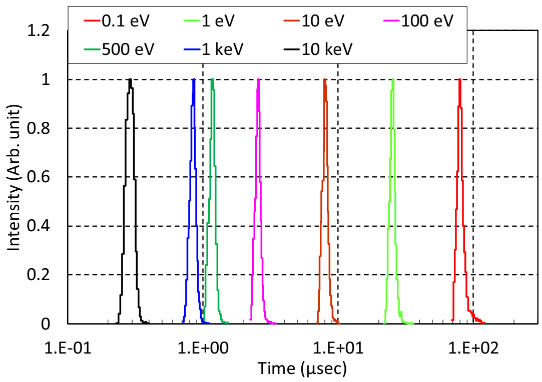

Figure 5. The time distributions of pulsed neutron at the tally surface.

Table 2. The energy resolutions with the pac-man type moderator.

Energy	Energy resolution (%)	Energy	Energy resolution (%)
0.1 eV	0.74	500 eV	0.80
1.0 eV	0.72	1 keV	0.93
10 eV	0.72	10 keV	1.30
100 eV	0.73		

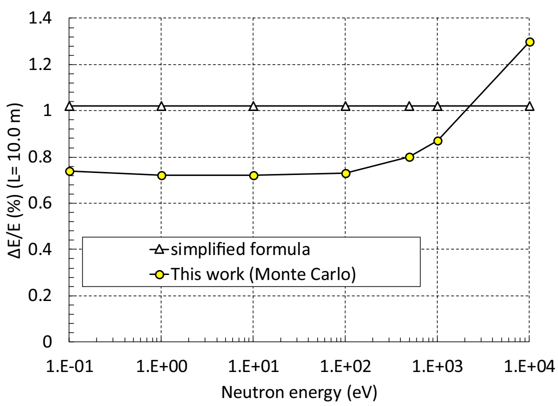

Figure 6. Comparison of energy resolution between the Monte Carlo simulation and the simplified evaluation formula.

$$\tau_m = 1/\Sigma_s \, v \tag{6}$$

Σs is a macroscopic scattering cross section of hydrogen and v is a neutron velocity. A τ_m is a mean collision time of neutron in a moderator. In addition, we assumed the ΔL was 0.05 cm. The flight path, L, was 10 m. As the results, the energy resolution was about 1.0% between 0.1 eV and 10 keV. The energy resolution obtained from Monte Carlo simulation was agreed with the resolution using the equation (4) as shown in Fig. 6.

The obtained resolution was compared with that of the J-PARC ANNRI and the LANCSCE. Table 3 shows comparison of energy resolutions. In the ANNRI, the energy resolution at 21.5 m from the moderator is about 0.5% between energy ranges of 0.1 eV from 10 eV for the single- and double-bunch operation. For the double-bunch, the resolutions decrease above 10 eV [1]. The energy resolution at the LANSCE is about 0.5% between energy ranges of 0.1 eV from 10 eV. The resolutions decrease above 10 eV. The flight path length was 8.08 m [5]. The energy dependency of the energy resolution with the pac-man type moderator in KURRI-LINAC is similar to the J-PARC ANNRI for the single-bunch mode.

Table 3. Comparison of energy resolutions.

Facility	Flight path (m)	Energy resolution (%)		
		0.1 eV–10 eV	100 eV	1 keV
KURRI-LINAC	10.0	0.7	0.7	0.9
LANSCE	8.08	0.5	0.7	1.0
J-PARC ANNRI	21.5	0.5	0.5* 1.0**	0.7* 2.0**

*Single bunch mode, **double bunch mode.

4. Conclusion

In measurements of nuclear data, it is very important to evaluate the energy resolution of a moderator. Thus, the energy resolution with the pac-man type moderator at KURRI-LIAC was evaluated by using Monte Carlo simulation.

As the result, we obtained the energy resolutions (ΔE/E) are about 0.7% to 1.3% at the energy range from 0.1 eV to 10 keV. On the other hand, the energy resolution evaluated by the simplified formula was about 1.0% between 0.1 eV and 10 keV. The energy resolution obtained by this study was agreed with the energy resolution evaluated by the simplified formula.

The energy dependency of the energy resolution with the pac-man type moderator in KURRI-LINAC was similar to the J-PARC ANNRI for the single-bunch mode.

In the future works, the method of energy resolution evaluation by using Monte Carlo simulation will be applied to the other moderators at KURRI-LINAC.

Present study includes the result of “Research and Development for accuracy improvement of neutron nuclear data on minor actinides” entrusted to the Japan Atomic Energy Agency by the Ministry of Education, Culture, Sports, Science and Technology of Japan (MEXT).

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