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Neutronic studies on a grooved moderator for a small accelerator-based neutron source by Monte Carlo simulation

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ABSTRACT

A grooved moderator is well known as a moderator to enhance the local neutron intensity on the moderator surface, and the locally enhanced intensity will be useful for some neutron experiments. At small neutron sources the moderator optimized to the neutron spectrometer is necessary. We studied the grooved cold moderators at a small accerelator-based Be(p,n) and Li(p,n) neutron sources. The moderator materials studied were methane and mesitylene. The optimal positions of the groove in the moderator were found. The neutron intensities were calculated at two cylindrical groove sizes, re-entrant holes. The difference between the methane moderator and the mesitylene moderator was not so large, and the intensity increase rate compared with a flat surface moderator at the groove position was higher in the mesitylene moderator than the methane one. The results suggest that the grooved moderator is effective and the mesitylene grooved moderator will be comparative to the methane one.

1. Introduction

A small accelerator based pulsed neutron source is very useful to develop a new idea, education, and so on. The researches at the small neutron source are indispensable for supporting the activities at the large neutron source facility. However, the neutron intensity at the small neutron source is not so high. Therefore, total optimization is very important considering the all items from the accelerator to the spectrometer.

A small angle neutron scattering (SANS) is considered as an important application performed at the small neutron source. Recently a mini-focusing SANS (mfSANS) has been proposed [1]. This instrument uses a mirror focusing the incident neutrons from the small aperture and a sample is placed at a position between the mirror and the focal position. This configuration enables us to make a much smaller SANS instrument compared with a traditional one with the same resolution. From this principle, brightness of the neutron intensity at a small area of the moderator surface is important. Therefore, it is strongly desired to increase the brightness of the neutron flux at the definite area of the moderator.

Digging a groove in the moderator is one of the effective methods [2]. Usually we consider a rectangular shape groove but in the case of the mfSANS a cylindrical shape hole such as a re-entrant hole is preferable. We study the performance of the re-entrant type groove for two moderator materials, methane and mesitylene, since methane is usually the best moderator material and the mesitylene is the second best [3,4].

As a small accelerator based neutron source we consider two kinds of neutron generation targets, namely, Li and Be. Li(p,n) reaction is efficient for low energy protons around 3 MeV. The Li target bombarded with 2.5 MeV protons produces relatively low energy neutrons below about 0.8 MeV but the yield is not so high, the generated neutron intensity is about 8.8x10^{11} n/sec at 1 mA proton current. Due to the low energy this system is expected to be a very compact source [5]. On the other hand, for higher energy protons of around 10 MeV a Be target is more efficient than Li. The Be target bombarded by 11 MeV protons produce neutrons with higher energy than the Li case and the yield is about 2.2x10^{13}n/sec at 1mA. One can choose one of these neutron generation systems depending on one's need and restriction. However, a long-life target system of the Li case has not been established.

Here, we present the neutronic performance of the cold moderator with a re-entrant hole based on these two kinds of neutron generation systems using an accelerator.

2. Simulation

We performed the simulation calculations by using PHITS code [6]. ENDF-B/V is used all materials other than mesitylene. For mesitylene Granada kernel is used [7]. Calculated geometries are a wing and a slab geometries as shown in Fig. 1. Moderator materials are methane and mesitylene, and the area of the viewed surface is 12cm x 12cm. The temperature is about 20K. The thickness is one of the parameters to be optimized. Reflector is Be with a thickness of 50 cm. Premoderator is polyethylene. Proton energies are 2.5 MeV for the Li target and 11 MeV for the Be target. We chose 2.5 MeV to get the generated neutron intensity of the order of 10^{12} n/sec and 11 MeV to get 10^{13} n/sec. In the Be case we could get the angular dependent neutron spectra only at this energy [8]. The angular dependent neutron spectrum was calculated by using a code [9]. The thickness of the target is 0.2 cm in the simulation. However, in a real system the thickness of the Li target should be less than 1 mm since the 2.5 MeV proton stops within 1 mm.

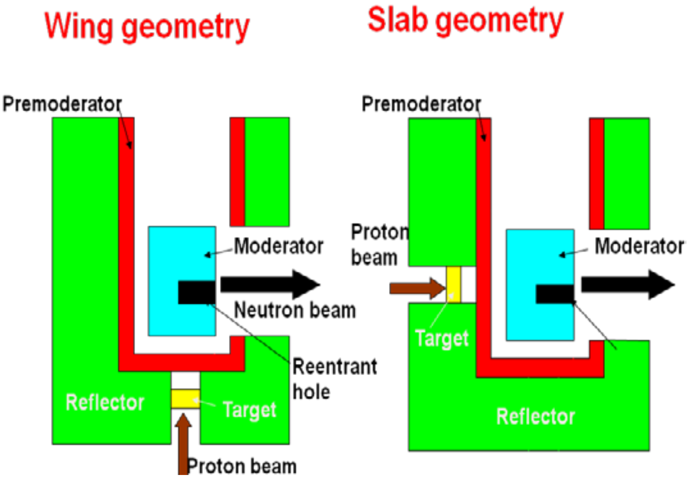

Fig. 1 Target-moderator-reflector systems used for the calculation. Left figure is wing geometry, and right figure is slab geometry. In the wing geometry we assume an upward injection of proton beam.

3. Neutronic performance of the re-entrant hole moderators

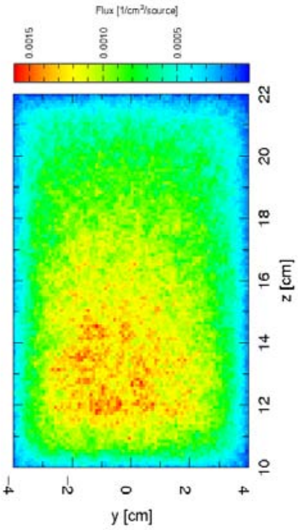

Fig. 2 Cold neutron intensity distribution in a wing geometry moderator. y-axis corresponds to the thickness orientation and z-axis to the height.

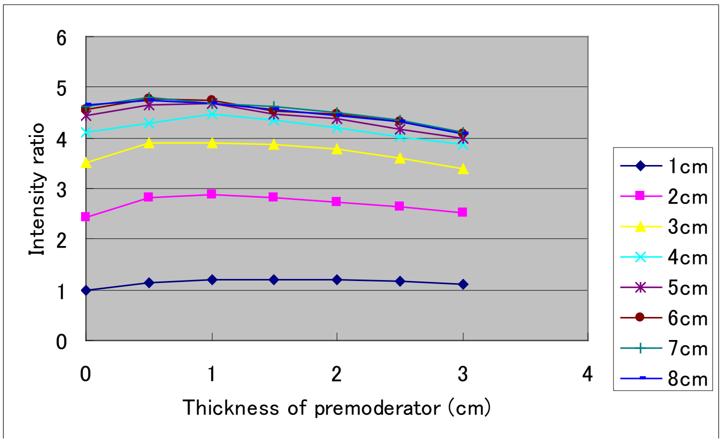

Fig. 3 Premoderator thickness dependence of the maximum cold neutron intensity in the mesitylene moderator in the wing geometry in the case of Be target.

Figure 2 shows a cold neutron intensity distribution in the wing geometry moderator. In this case the target was placed under the moderator, so the highest intensity appeared around 2 cm from the moderator bottom. For the re-entrant hole moderator, first we need to find the thickness where the highest neutron intensity is obtained in the moderator. After then we decide the position(h) and the depth of the hole(d). Here, we select two sizes of the hole, radius r=0.5 cm and 1.0 cm. Figure 3 shows premoderator thickness dependence of the maximum cold neutron intensity in the moderator at the moderator thicknesses from 1 cm to 8 cm in the case of the wing geometry mesitylene moderator on the Be target. Here, the cold neutron region is defined as the region less than 5 meV. The maximum intensity is almost unchanged over 5 cm of thickness and the optimum premoderator thickness is about 1 cm. Similar calculations were performed for other combinations. From the intensity distributions in the moderators we obtained the positions of the highest intensity in each case. The optimal moderator thicknesses, premoderator thicknesses, height from the moderator bottom and the depth from the viewed surface are summarized in Table I and II. Figure 4 shows the energy spectra from each moderator. At cold neutron region the intensities from the mesitylene moderators are less than the intensities from the methane moderator but around 0.1eV the intensities from the mesitylene moderators surpass those form the methane moderators. Much larger number of high energy neutrons around 1 MeV comes to the sample position in the slab type moderator than in the wing one. Figure 5 is comparison of the spatial distributions of the optimal size flat moderator and the re-entrant hole moderator. The distance between the centre of hole and the moderator bottom is 4 cm and the hole radius is 0.5 cm. The intensity from the flat moderator is higher than the re-entrant moderator one at the position higher than the hole and it is recognized that the intensity from the hole is much higher than the intensity around the hole. Figure 6 is the comparison of the spatial distributions from the re-entrant moderators composed of methane and mesitylene. The optimal hole position is different from each other mainly due to the hydrogen number density. The intensity of methane is much higher than that of mesitylene in the area other than the hole. On the other hand, intensity increase in the re-entrant hole is much larger in the mesitylene moderator than in the methane moderator. As a consequence the intensity from the mesitylene moderator is comparable to that of the methane moderator. The ratios of the intensity at the re-entrant hole to that of the flat moderator at the position corresponding to the hole position. The intensity increase is almost three times in the case of the mesitylene moderator. The Li target case gives a little bit larger intensity gain compared with the Be target case. The difference between the wing geometry and the slab geometry is not so large. Therefore, the wing geometry is superior to the slab geometry since the high energy neutron background is much less than the slab case.

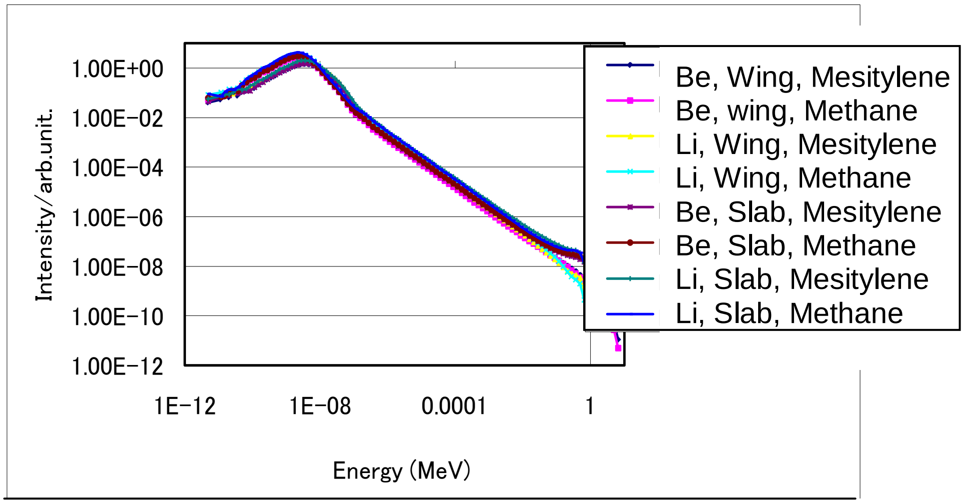

Fig. 4 Energy spectra from the moderators in the slab and wing geometries in the case of Be and Li targets.

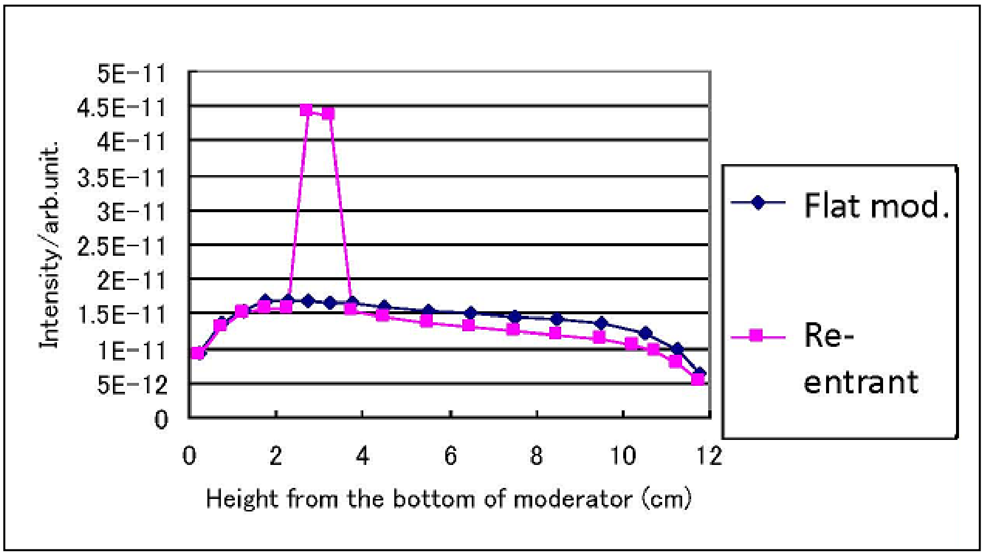

Fig. 5 Spatial distributions of the optimal size flat moderator and the re-entarant hole moderator of mesitylene in the case of the Be target.

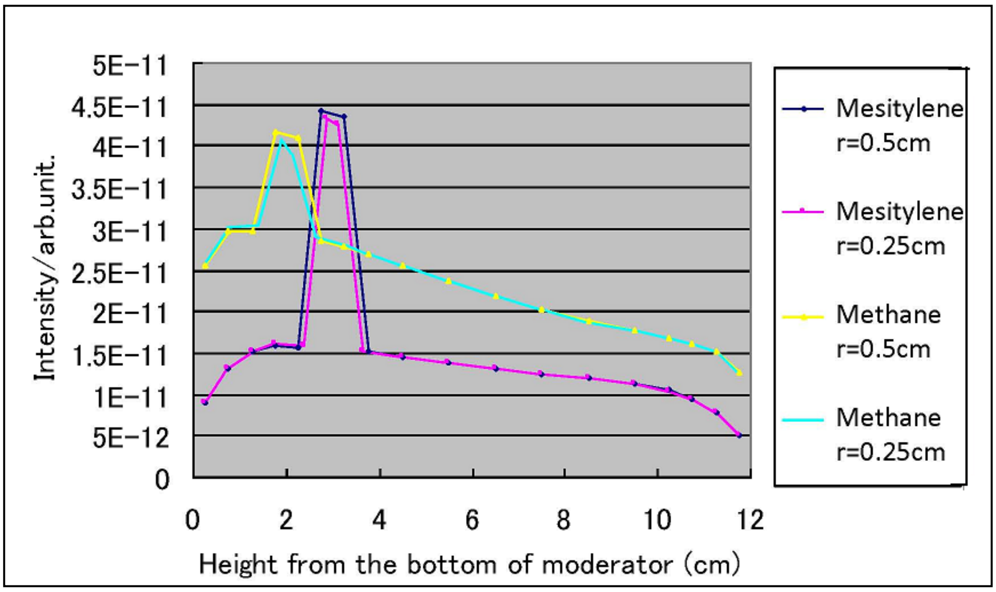

Fig. 6 Comparison of the spatial distributions of the mesitylene moderator and the methane moderator with a reentrant hole.

Table I Optimal sizes of the moderator, the re-entrant hole positions, the neutron intensities, and the ratios of the re-entrant cases to the flat ones for the Be target case

	Mod. Thick.. (cm)	Premod. Thickness (cm)	h (cm)	d (cm)	r (cm)	Cold neutron intensity at 10m (/mA/cm2/sec)	Ratio: Re-entrant /Flat
Wing Mesitylene	7	0.5	3	4	0.25	3.30×10^3	2.58
Wing Methane	8	0.5	2	4	0.25	3.02×10^3	1.4
Slab Mesitylene	6	0.5	5	4	0.25	3.19×10^3	2.65
Slab Methane	6	0.5	5	4	0.25	2.87×10^3	1.33

※ Produced neutron intensity=2.15×10^{13} (n/sec/mA)

Table II Optimal sizes of the moderators, the re-entrant hole positions, the neutron intensities, and the ratios of the re-entrant cases to the flat ones for the Li target case

	Mod. Thick. (cm)	Premod. Thickness (cm)	h (cm)	d (cm)	r (cm)	Cold neutron intesity at 10m (/mA/cm2/sec)	Ratio: Re-entrant /Flat
Wing Mesitylene	10	0.5	3	5	0.25	2.14×10^2	3.1
Wing Methane	10	0.5	2	4.5	0.25	2.16×10^2	1.74
Slab Mesitylene	8	0.5	5	5	0.25	2.21×10^2	3.02
Slab Methane	7	0.5	6	4.5	0.25	2.14×10^2	1.59

※ Produced neutron intensity= 8.80×10^{11}(n/sec/mA)

4. Conclusions

The wing type re-entrant hole moderator gives higher intensity ratio to the flat one than the slab type one gives, and the Li target case also does than the Be target case. Intensity increase from the mesitylene moderator is about 2.5 times in the case of Be target, and about 3.0 times in the case of Li target. Consequently the mesitylene moderator gives almost the same intensity as the methane one. If we limit our use only on the re-entrant hole area, it is much easier to handle the mesitylene moderator than the methane moderator. In this case mesitylene would be a good candidate for the moderator. However, there may be some ambiguity in the simulation results. Therefore, it is required to perform experiments to verify the results.

5. References

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