Some Optimization Studies on Flux-Trap Moderators for Increasing The Slow-Neutron Beam Intensity

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Abstract

A flux trap geometry has various possibilities to increase the slow-neutron intensity, compared with the traditional wing geometry. We compared the slow-neutron intensities from various flux-trap moderators (extended, overlap and back-scattering) by computer simulations and mock-up experiments. The results show that those moderators are useful for enhancing the intensity. A gain factor of more than 1.5 is obtainable. It was found that back scattering moderators give a higher intensity with a narrower pulse width, compared to normal extraction.

1. Introduction

Flux-trap moderators have been discussed extensively.(1)-(4) We have shown that a flux-trap moderator can provide a comparable slow-neutron intensity to that of a wing type.(4) In the flux-trap geometry, however the combination of target and moderator is more flexible than in the traditional wing geometry, which suggests the possibility to increase the slow-neutron intensities more than the latter. Among the various possible combinations in the target and moderator, we examined extended, overlap and back-scattering moderators by computer simulation as well as by mock-up experiments.

Since the pulse characteristics are sensitive to the ralative position of the primary neutron source, we can expect a different pulse shape with a back-scattering moderator compared to that from normal extraction. To confirm this we performed some pulse-shape measurements for both moderators.

It will also be important to compare the slow-neutron intensity from the flux-trap moderator with those from other types of target-moderator couplings (wing and slab). For this purpose it is necessary to define a reference case which is reasonable for each type coupling. Nevertheless, we tried to perform a direct comparison for a very simple system by computer simulation in order to obtain a crude scope concerning its problem.

2. Calculation

2. 1. Calculational Model and Codes

The calculations were performed for a proton energy of 1 GeV, since this energy has been proposed for the KENS-II, the next-generation pulsed-spallation neutron source in Japan. For simplicity, a cylindrical beam profile of a radius 2.35 cm was assumed (typical in existing facilities). The calculational model of the target-moderator-reflector system is shown in Fig. 1. The target is split into two parts: the first target onto which protons are injected, and the second target after the void space. The length of the first target was kept at 7.5 cm (the optimal length) and the target radius at 5 cm.(3) For simplicity, the targets were assumed to be made of pure tungsten metal, and not diluted by the coolant and cladding materials, as in the case of LANSCE, Los Alamos National Laboratory. The total target length is fixed at 34.5 cm, which is sufficient for 1-GeV protons. As a reference system, four decoupled light-water moderators ($10 \times 10 \times 5$ cm^3) are placed around the void space between the two target halves with a center line distance between the target and moderator of d = 9.5 cm. A beryllium reflector (at least 30 cm thick) is used as shown in the figure. The beam holes in the reflector are lined with B_4C decouplers. The decoupling energy was adjusted to 20 eV. The moderators are also covered by the same decouplers, except for the viewed surfaces. The height and the opening angle of the beam-extraction holes in the reflector are 10 cm and ±25 degrees, respectively. For low-energy neutron transport calculations a Monte-Carlo code, MORSE-DD,(5)(6) was used in combination with a high-energy hadron transport code, NMTC/JAERI. An S_N neutron transport code, TWOTRAN-II,(7) was used to calculate the spatial distributions of the low-energy neutrons. For both calculations the cross-section library ENDF-B/IV(8) was used.

2. 2. Extended Moderator

What will happen if we increase the height (h) of the moderator with a larger separation (l) of the target halves? Figure 2 shows the calculated results. The beam intensities are normalized to that for the reference case (l = 14 cm, d = 9.5 cm, $10 \times 10 \times 5$ cm^3 moderators at the center of the void height). Although the beam intensity decreases with a larger separation of the target halves, it increases almost linearly with the moderator height (up to 2.3 at h = 26 cm with l = 30 cm). One

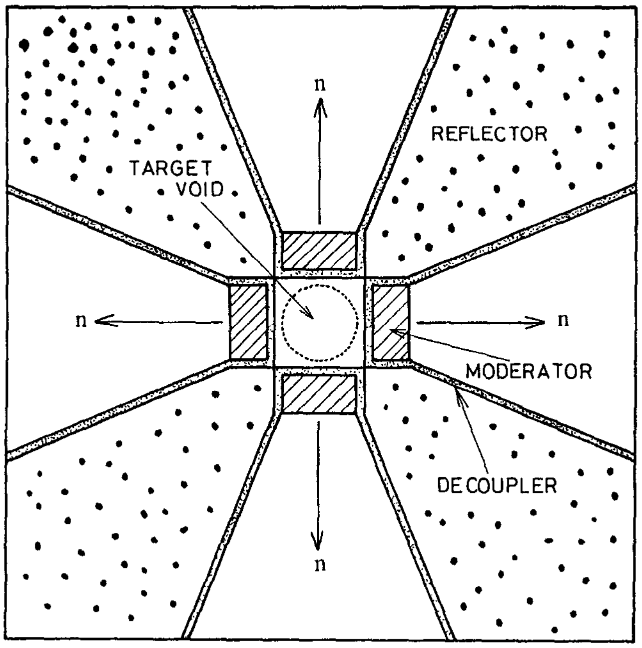

Fig. 1 Calculational model of the flux-trap type target-moderator-reflector system.

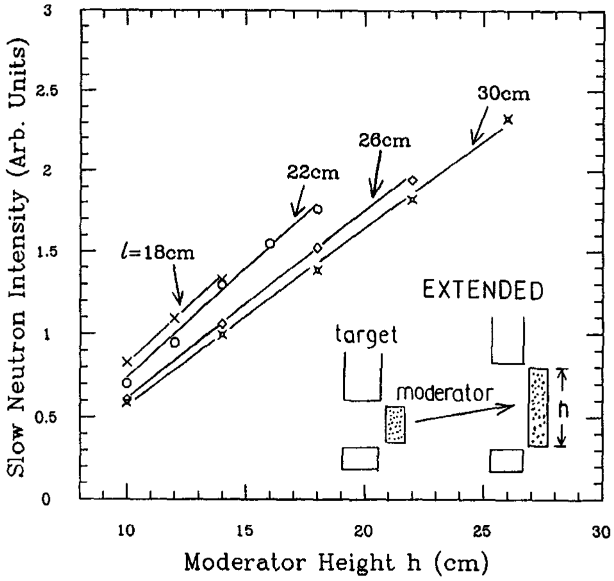

Fig. 2 Slow-neutron intensities from extended moderators.

can take full advantage of a higher beam intensity obtained with such an extended moderator in some classes of experiments in which the vertical beam collimation is not so important. In order to understand the above results, we calculated the spatial distribution of the neutron intensities on the viewed surface along the proton beam direction. Since a three-dimensional Monte-Carlo calculation is very time consuming to obtain the required statistics, we performed a two-dimensional calculation using TWOTRAN-II for a two-dimensional model (Fig. 3); the moderator is an annulus with a thickness of 5 cm at d = 9.5 cm and l = h + 4 cm. Figure 4 shows the results of the distributions of slow-neutron beam intensities along the proton beam direction(Z). The distributions are rather more flat and symmetric than those for a wing-geometry moderator in which the asymmetry (peaking towards the target) is more enchanced. This is the reason why the intensities increase linearly with the moderator height (h). For a reference, the calculated results of the spatial distributions on the viewed surface of the moderator of h = 10 cm during the slowing-down process are shown in Fig. 5. The distribution in the fast-neutron region (E_n = 0.821 ~ 1.35 MeV) strongly reflects the distribution of the first collision density of neutrons in the moderator. With decreasing energies the distribution becomes more flat.

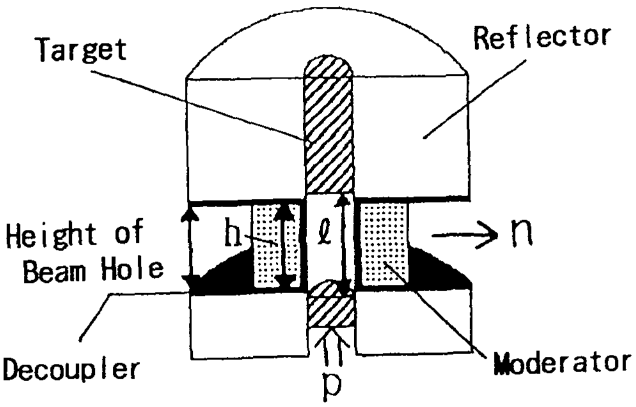

Fig. 3 Calculational model for a two-dimensional calculation.

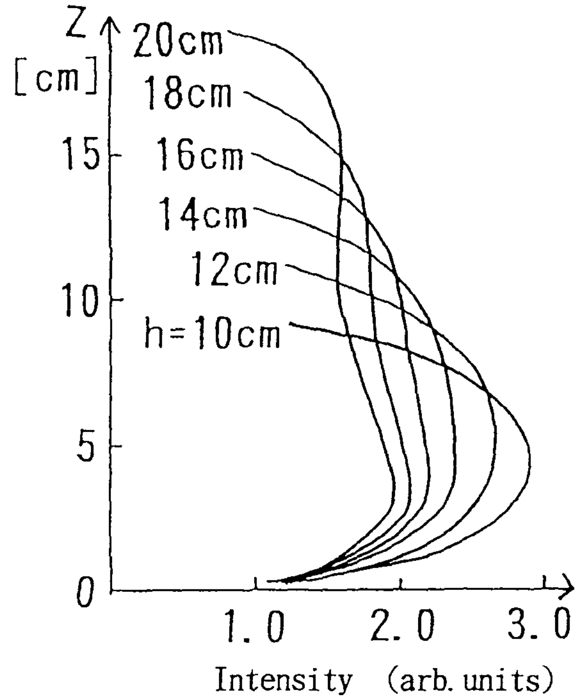

Fig. 4 Vertical spatial distributions of the slow-neutron intensities on extended moderators.

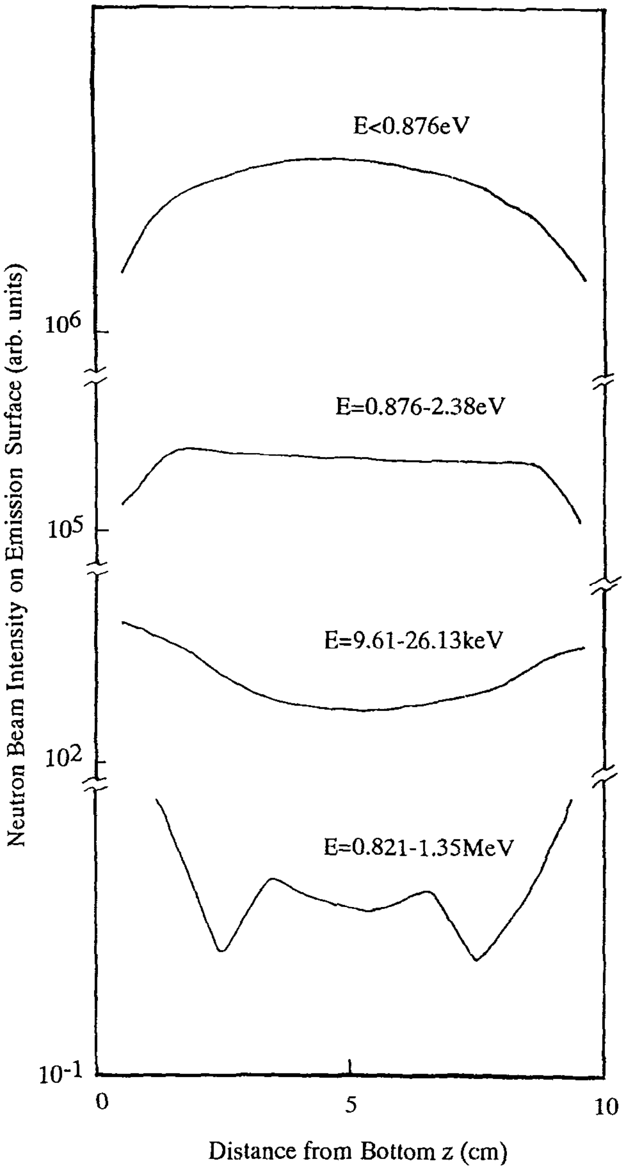

Fig. 5 Spatial distributions of neutrons during the slowing-down process.

2. 3. Overlap Moderator

Even in the case that neutrons from such extended moderators cannot be utilized, due to the required vertical collimation of the neutron beams, those moderators with a limited viewed surface of 10 x 10 cm^2 will give a higher slow-neutron intensity than the reference moderator of 10 x 10 x 5 cm^3, by overlapping the moderator with the target, as shown in the inset of Fig. 6, keeping the separation of the target halves at 14 cm. We examined such moderators and obtained the results shown in Fig. 6. A moderator with a larger height gives a higher intensity by about 10%. When the width of the moderator (w) is also increased to 12 cm, a gain about 1.3 results in total for the case of a 10 x 10 cm^2 viewed surface and about 1.5 for a larger viewed surface of 10 cm high by 12 cm wide. The vertical spatial distributions were also calculated for this moderator system. The results are shown in Fig. 7. The increase in the intensity is mainly due to the flatter distributions with an unchanged peak height.

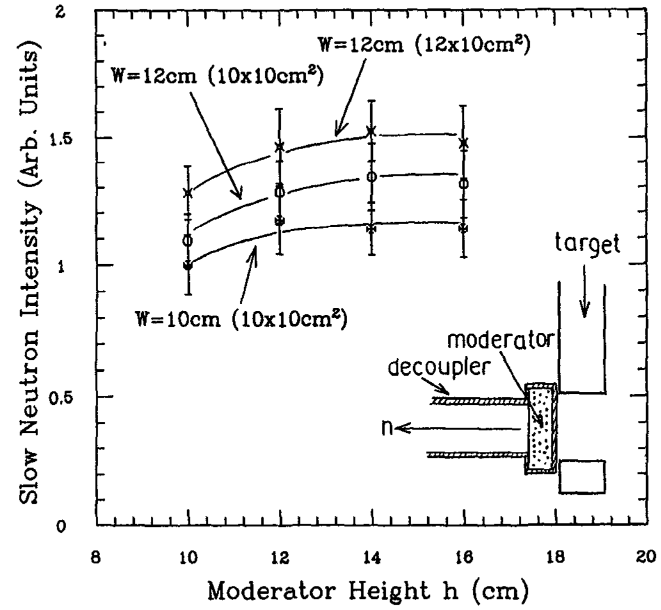

Fig. 6 Slow-neutron intensities from overlap moderators. The moderator size is h cm x w cm x 5 cm thick. w is moderator width. Areas of viewed surfaces are indicated in parentheses (y cm wide x 10 cm high).

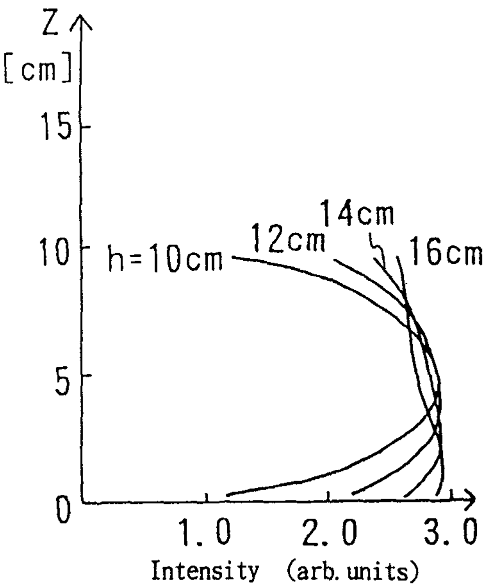

Fig. 7 Vertical spatial distributions of the slow-neutron intensity on the viewed surfaces of the overlap moderators.

3. Mock-up Experiments

3. 1. Simulation by an Electron Linac Neutron Source

We aimed at performing mock-up experiments of those moderator systems mentioned above, since the statistics of the calculated results were rather poor and information concerning the time distribution of the neutron pulse was not given. More reliable data can be obtained by measurements. However, such experiments using the proton beam are very difficult; there are almost no opportunities to use proton accelerators in this energy range. We, therefore, tried to utilize an electron linac pulsed-neutron source for this purpose. It seems to be almost impossible to simulate a split-target geometry by an electron-based neutron source, due to the completely different spatial distribution of neutrons produced in the target. However, if we consider only the contribution of fast neutrons from the first target, a simulation by an electron linac would be reasonable, since the geometry between the neutron source and the moderator is not so much different. The contribution from the second target would be close to a reflected image of that from the first target with a proper coefficient, determined by the ratio of both contributions. Therefore, the variation of the neutron-beam intensity from different moderators can be estimated by a simple mock-up with one target. Figure 8 shows the layout of this mock-up, where a lead block was placed downstream of the void space in order to simulate the second target material. The moderator is a polyethylene block ($10 \times 10 \times 5$ cm^3 at room temperature for the reference case). Cd sheets were lined inside the beam-extraction holes in the graphite reflector.

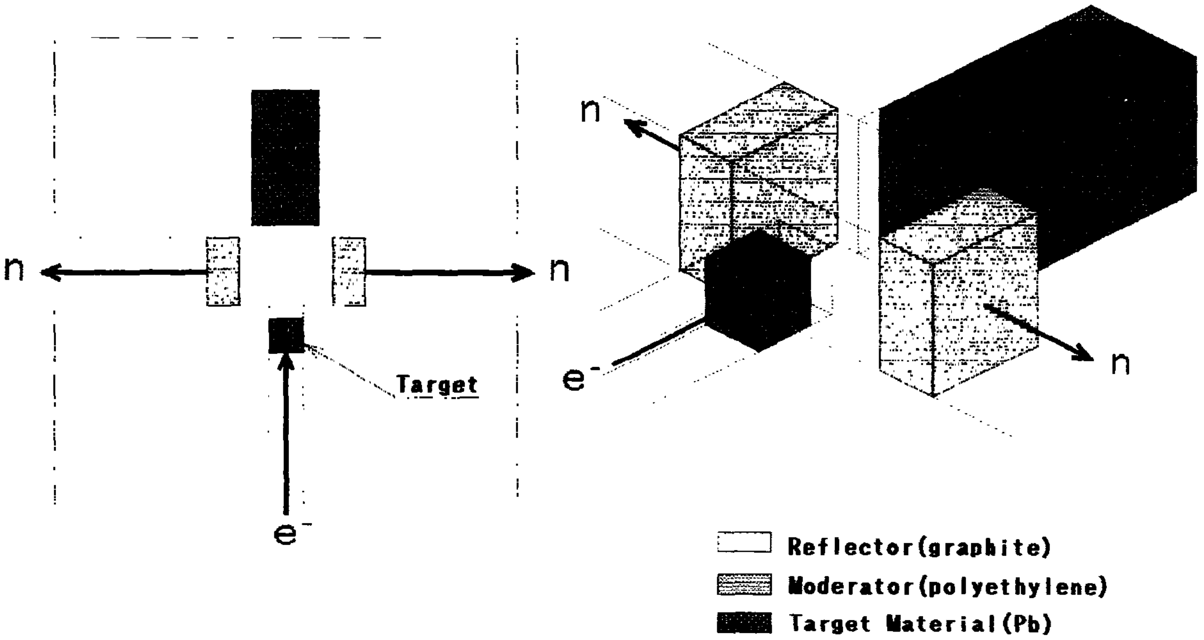

Fig. 8 Mock-up of the flux-trap moderator system.

To compare the present measured results with calculations for 1-GeV protons, we performed independent calculations for a system that was almost the same as that shown in Fig.1, except for the different beam-extraction hole (a rectangular shape in this case).

3. 2. Measured Results

A. Moderator Thickness

The moderator thickness-dependent slow neutron intensity is a good measure for characterizing the coupling nature between the target and the moderator. Figure 9 shows the measured thermal-neutron intensities for various moderator thicknesses. The lateral dimensions of the moderators were 10 cm × 10 cm. The solid curve is the calculated results after smoothing. The agreement between the measurement and the calculation is fairly good. The thickness dependence of the slow-neutron intensities is rather closer to that in a slab geometry than in a wing type: the coupling nature of this system is closer to that of the slab geometry.

B. Extended Moderator

Figure 10 shows the measured thermal-neutron intensities from extended moderators of different dimensions along the target axis. The agreement between the measurement and the calculation (solid curve) is satisfactory. The difference in the gain factor from those in Fig. 2 is due to the different opening angles of the beam-extraction hole in the reflector (this mock-up has only one rectangular straight beam-extraction hole).

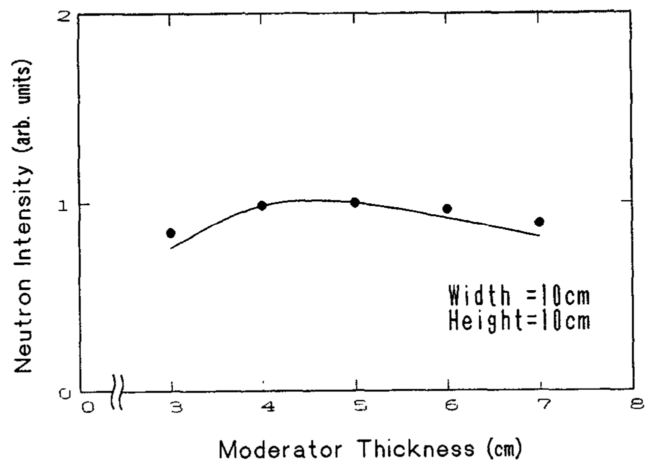

Fig. 9 Measured moderator thickness-dependent thermal-neutron intensity. The solid curve is the calculated one after smoothing.

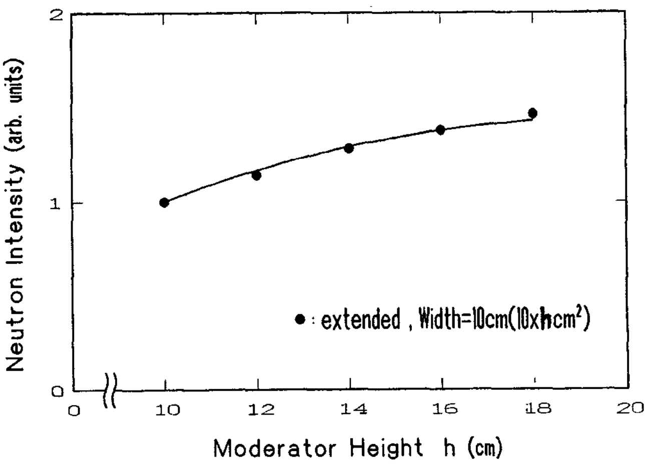

Fig. 10 Measured thermal neutron intensities from extended moderators. The solid curve is the calculated one after smoothing.

C. Overlap Moderator

Figure 11 shows the measured thermal-neutron intensities from the overlap moderators, as shown in Fig. 6. The agreement between the measurements and the calculation (solid curves) is again very good. The gain factors in Fig. 11 are almost the same as in Fig. 6, since in the overlap moderator system the missing reflector is not as large as that in the extended moderator system.

D. Optimal Moderator Position and Back-scattering Moderator

The slow-neutron intensity is sensitive to the location of the moderator relative to the target. We can expect an additional gain factor by positioning the moderator optimally. Furthermore, beam extraction from the other side can provide a higher intensity than under normal extraction. This moderator is called a "back-scattering moderator". We experimentally confirmed the performance of a back-scattering moderator. Fig. 12 shows the measured results. The moderator size is 10 × 10 × 5 cm^3. In normal extraction if one can put the moderator on the center line of the target, a gain factor of about 1.5 relative to the reference position (d = 9.5 cm) can be obtained. Technical efforts to put the moderator as close as possible to the target center line should be pursued.

In back-scattering extraction, a higher gain factor than normal was confirmed: about 1.22 at the reference position (d = 9.5 cm). The maximum value is the same as that of normal extraction. However, the maximum value is almost conserved up to about d = 3.5 cm. This relaxes various engineering difficulties. We also confirmed experimentally that a further gain factor of about 1.2 is obtainable by putting a plug reflector in the beam hole at the opposite side.

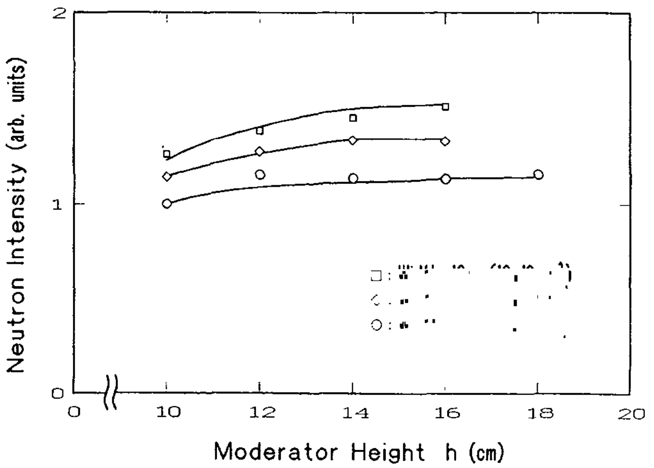

Fig. 11 Measured thermal neutron intensities from overlap moderators. The solid curves is the calculated ones after smoothing.

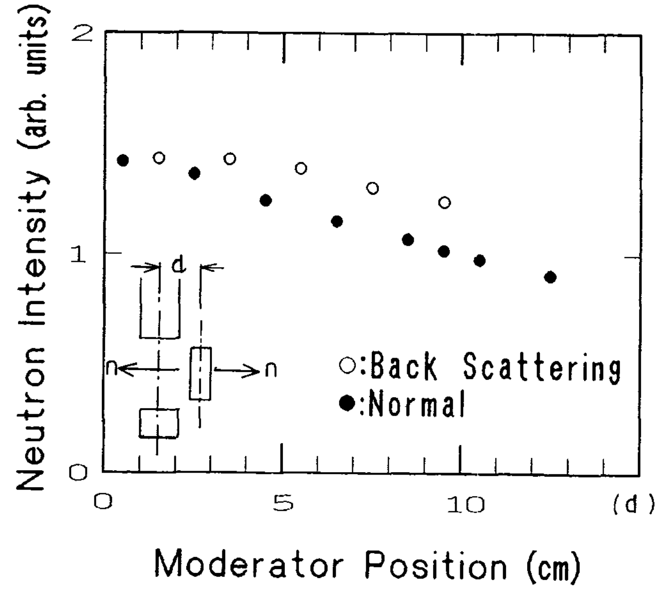

Fig. 12 Measured thermal-neutron intensities from the reference moderator (10 × 10 × 5 cm^3) as a function of the moderator position.

3. 3. Pulse Shape

We performed measurements of the pulse shapes of thermal neutrons using the device described in a reference.(9) Figure 13 shows a typical result measured at the reference moderator position (d = 9.5 cm). The superiority of the back-scattering moderator is clearly demonstrated: a higher peak intensity with a narrower pulse width (FWHM). Fig. 14 shows plots of the pulse widths for both extractions as a function of the neutron energy.

4. Discussions

We have shown various possibilities for increasing the slow-neutron beam intensities from flux-trap moderators. With an overlap moderator and a back-scattering moderator a gain factor of about 1.5 has already been achieved. This value is considerable. We now compare the present results with a typical performance of a slab-type moderator which is well known for providing the highest intensity among the three configurations of target-moderator coupling. However, the slab configuration has not been adopted in any pulsed spallation neutron sources, since in this configuration a huge amount of fast and high-energy neutron background cannot be avoided. A combination of the slab moderator with a burst-suppression chopper and/or a curved guide tube is sometimes discussed as a possibility for realizing a higher intensity. Our calculation confirmed that the relative intensity of a reference slab moderator to the reference flux-trap type is about 1.5; this

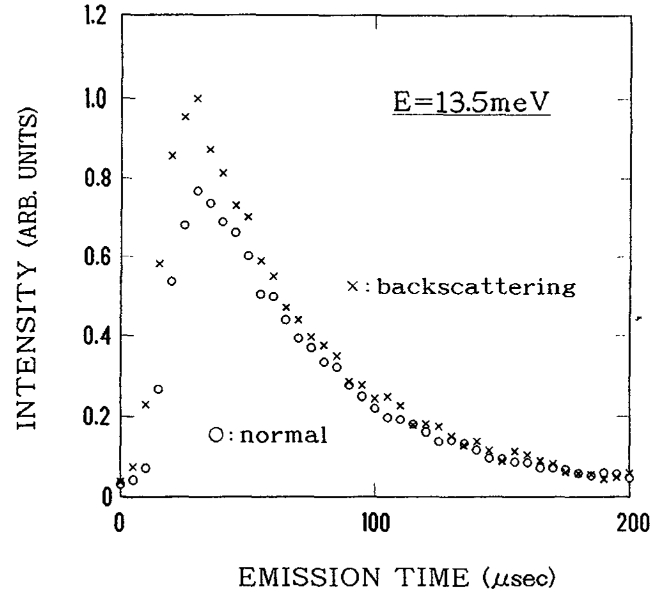

Fig. 13 Measured thermal-neutron pulse shapes for both extractions from the reference moderator at the reference position (9.5 cm).

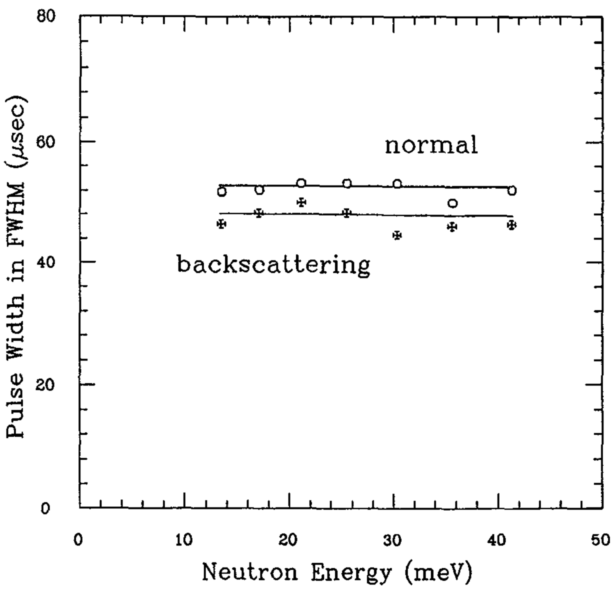

Fig. 14 Measured pulse widths of thermal neutrons for both extractions as a function of the neuron energy.

is the same as the above gain factor. The present geometry is therefore much better than the slab one: much less fast and high-energy neutron backgrounds.

For a direct comparison of the flux-trap moderator to the wing type, we calculated the intensity for both reference moderators. The relative value of the flux-trap to that of the wing was about 0.94, almost comparable. However, by adopting the extended (l = 30 cm, h = 26 cm), the overlap (h = 14 cm, w = 12 cm, l = 14 cm; viewed surface 10 × 12 cm^2) or the backscattering (d ~ 3.5), we obtain a gain factor of about 2.3 × 0.94 = 2.2, 1.5 × 0.94 = 1.4 or 1.5 × 0.94 = 1.4, respectively, relative to the reference wing moderator.

We performed mock-up experiments using an electron linac neutron source to simulate the flux-trap moderator, and obtained consistent results with the calculated ones. The present results show that this method, using an electron linac, is reasonable for estimating the performance of the flux-trap moderator system.

We reported that a coupled liquid-hydrogen moderator with a hydrogenous premoderator at ambient temperature in a wing geometry can provide a much higher cold-neutron beam intensity: about 6-times higher than a typical decoupled one.$^{(9)}$ Such moderators at a flux-trap geometry are expected to have a similar advantage to the ambient-temperature moderator in this geometry. This possibility is to be studied experimentally.

Reference

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