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Optimization of decoupled hydrogen moderator

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Abstract

A decoupled hydrogen moderator (H_2 moderator) with a H_2O premoderator is the primary candidate as a high-resolution moderator in Japanese spallation neutron source (JSNS). However, it has already pointed out that a premoderator for a decoupled H_2 moderator has no merit (or attenuation) in both neutron time-integrated and pulse peak intensities in a Be reflector. On the other hand, for a Pb reflector system, we found that a premoderator can provide a higher time-integrated and peak intensities than those in the Be reflected case. It should be noted that the Pb reflector gave longer pulse tails (loner decay times) than the Be one due to a long slowing-down time of Pb.

In spite of such drawbacks, we found that it could be possible to provide a better performance with a Pb reflector by optimizing the material and the geometry of premoderator and by adopting a properly chosen decoupling energy: resulting in a higher peak intensity with a similarly short decay time as a Be reflector case.

From this point of view, we performed optimization studies on the moderator system in terms of moderator lateral dimensions and viewed surface sizes and position.

As a result, it can be concluded that the optimized premoderator is very effective not only to improve pulse characteristics (intensities and shapes), but also to decrease the energy deposition in H_2. Also, it should be stressed that the premoderator gives a larger separation between moderator and target, resulting in a higher signal to background ratio in neutron measurements and lower engineering load for the neutron beam line shieldings.

1. Introduction

The Japanese spallation neutron source (JSNS) is proposed to be constructed as a part of joint project of JAERI (Japan Atomic Energy Research Institute) and KEK (High Energy Accelerator Research Institute). Only hydrogen is candidate of the moderator material in a MW-class spallation neutron source because of high radiation damage. Three moderators system to be implemented are a coupled moderator (high intensity) and two decoupled moderators (high resolution) to satisfy various neutron pulse characteristics requested by neutron scattering experiments,. The one of decoupled moderator supplies the cold and thermal neutron pulses with narrow peak (high peak intensity and small FWHM) and a small tail. TMRA (Target Moderator Reflector Assembly) in JSNS is described in Ref. [1] in detail. To obtain higher neutoronic performance of the coupled moderator, it was suggested that a premoderator provided high intensity and reduced heat deposition of moderator in the Pb (Lead) reflector with a little sacrificing pulse shape, and that premoderator extension is very effective [2]. In the decoupled moderator, it is well known that the Pb reflector gave longer pulse tails (loner decay times) in the slowing-down region than the Be (Beryllium) reflector due to a long slowing-down time. It has already been thought that a premoderator for a decoupled H_2 moderator gave no merit (or attenuation) in the neutron time-integrated and pulse peak intensities with the Be reflector. We considered that the premoderator is effective also for the decoupled moderator in the Pb reflector system. When the premoderator is optimized to obtain better neutronic performance, a choice of the premoderator material is important. Further, the premoderator effect is related to decoupling energies, which are sensitive to a tail of pulse. Lastly, a study on effect of viewed surface size and moderator lateral size is important for the neutronic performance and engineering.

In viewing above, we have studied the optimization of decoupled hydrogen moderator for following items:

(1) Confirmation of premoderator effect for decoupled moderator with the Pb reflector,
(2) Optimization of premoderator geometry and thickness,
(3) Decoupling energy dependence of premoderator effect,
(4) Premoderator material,
(5) Optimization of viewed surface size and moderator lateral size,
(6) Comparison of a simple model with a detailed model,

2. Calculation

2-1. Basic model of calculation

For the calculation, a high-energy nucleon-meson transport code "NMTC/JAM" (above 20 MeV) [3] and a neutron transport Monte Carlo code "MCNP-4A" (below 20 MeV) [4] were used. Cross section data used in the MCNP-4A code is based on JENDL evaluated library [5]. The calculation model is schematically shown in **Fig. 1**. The liquid H2 moderator (Size: W 12 cm x H 12 cm x L 5 cm, ortho/para ratio is 3:1) was placed under the mercury target which had a dimension of W 40 cm x H 8 cm x L 75 cm. Proton beams of 3 GeV, 25 Hz, 0.33 mA were injected in the target. The beam profile of 13 x 5 cm^2 rectangle shape with uniform distribution was assumed. The moderator was decoupled with the reflector by 3mm in thick B_4C (Boron Carbide) decoupler. By controlling the B4C density, the decoupling energy was adjusted to 1 eV. The premoderator (H2O (light water)) surrounding the moderator and is extending to the neutron beam hole was placed outside of the decoupler. The reflector material studied were Pb or Be. The size of it is 120 cm in diameter and 120 cm in height. A neutron detector is located at the 2 m distance from the moderator surface. In this study, one decoupled moderator is modeled in the calculation.

2-2. Model of each study

2-2-1. Premoderator effect for decoupled moderator in Pb reflector

Hereafter, a term f near side denotes a location facing on the neutron source. The near side premoderator is in guess strongly sensitive to the increase in neutron intensity from moderator in Pb reflector. Only for the near side premoderator, neutronic performance is investigated with increasing of premoderator thickness. As the thickness increases, a separation between the target and the moderator increases.

2-2-2. Optimization of premoderator geometry thickness

Geometrical shapes and thickness of premoderator are optimized in terms of a neutron intensity gain. In the calculation model, the premoderator is divided to 2 parts (main premoderator and extended premoderator). 8 values of thickness or length are parameters shown in **Fig. 2**.

Firstly, parameter (1) is searched and fixed to get highest neutron intensity. Next, with the fixed parameter (1), parameter (2) is searched to get highest neutron intensity. Other parameter is searched in the same way and 8 parameters are determined to obtain highest neutron intensity.

2-2-3. Decoupling energy dependence

Increase of the decoupling energy in Pb reflector improves pulse tail strongly though the neutron intensity decreases. These effect is smaller than that in Be reflector. Neutron intensity and FWHM are calculated with different decoupling energies. Decoupling energies are changed by using B_4C or Cd (Cadmium) decouplers with adjusting their density.

2-2-4. Premoderator material

Along with H_2O, D_2O (heavy water) is candidate for the premoderator. Kiyanagi et al. indicated that D_2O was effective on neutronic performance for a decoupled moderator [6]. In this study, the pulse shape with H_2O premoderator is compared with that with D_2O premoderator. Thickness of D_2O premoderator optimized in Ref. [6] is used.

2-2-5 Moderator lateral size and viewed surface size

A choice of moderator lateral size and surface size is important in particular in an engineering design. In view of neutronic performance, they are also important factors for neutron intensity and neutron luminosity, which is neutron leakage flux per moderator lateral area unit. We calculated neutronic performance by changing the moderator lateral size and the viewed surface size.

2-2-6 Comparison of a simple model with a detailed model

In the calculation, we have adopted simplified models. However, as the system is so complicated, we have to examine a possible difference between the simple model and a more realistic detailed model, for example, reflector missing due to other moderator beam holes, etc. Sakata et al. indicate that the reflector missing cause an intensity loss of about 10 % for the coupled moderator [7]. Their calculated results in the simple model were compared with these in the detailed model.

3. Results and Discussion

3-1 Premoderator effect for decoupled moderator in Pb reflector

The result shows in **Fig. 3**. As the premoderator thickness increases, time-integrated neutron intensity increases without sacrificing FWHM, and the gain of 10 % saturates at 1.5 cm thickness. This is due to that the premoderator has energy softening function of neutron giving increases in the intensity. This provides a separation between the target and the moderator. On the other hand, heat deposition in the moderator decreases with increase of the premoderator thickness. The reduction rate of 30 % is obtained at 3.0 cm in thickness. These result indicated that the premoderator is very effective in Pb reflector for the decoupled moderator.

3-2 Premoderator geometry thickness

Figure 4 shows a gain of neutron intensity with increase of premoderator extension and thickness. The intensity is normalized to that with no premoderator. Figure 4 shows that the premoderator at near side gives more gain of intensity than that at far side. The optimized premoderator was an increase up to 40 %. **Figure 5** shows pulse shape for the optimized premoderator, comparing with that of no premoderator. It is clear that the premoderator increases the peak intensity without sacrificing any pulse tail increases. It is shown that heat deposition in moderator is reduced by 37% from that of no premoderator.

3-3 Decoupling energy dependence

Figure 6 shows the neutron intensity with increase of the decoupling energy for no premoderator, the optimized premoderators at decoupling energy 1eV, and the optimized premoderators at different decoupling energies. Premoderators optimized to geometry and thickness provide the highest intensity at each decoupling energy, and the intensity decrease with increase of the decoupling energy. As decoupling energy increases, the neutron intensity decreases with no premoderator. Especially, for the optimized premoderator at the decoupling energy of 1eV, the premoderator causes a loss of neutron intensity at decoupling energy 100 eV. This is because of an over energy softening effect for neutron flux. Though by using the optimized premoderator at corresponding decoupling energy gives a gain of neutron intensity, the gain is decreased with increasing decoupling energy. **Figure 7** shows the peak intensity at different decoupling energies in no premoderator and optimized premoderator with corresponding decoupling energies. Though FWHM is not changed much with increase of the decoupling energy, the peak intensity shows the same tendency of the neutron intensities as shown in Fig. 6. **Figure 8** indicates that the pulse tail component is decreased with increase of the decoupling energy in no premoderator and the optimized premoderator. There is no significant difference in the pulse tail in the each case. **Figure 9** shows pulse shape in Pb reflector with the optimized premoderator and in Be reflector with no premoderator as a function of the decoupling energy. At the same decoupling energy, the pulse tail in Pb reflector is longer than that in Be reflector. However, when decoupling energy is adjusted in the Pb reflector to be same tail shape in the Be reflector, the peak intensity in the Pb reflector is larger than that in the Be reflector.

3-4 Premoderator material

The time-integrated neutron intensity for H_2O premoderator is 10 % lower than that for the D_2O premoderator. As shown in **Fig. 10**, the peak intensity for H_2O is also 5 % lower than that for D_2O. On the other hand, FWHM and pulse tail for H_2O are better than those for D_2O. However, studies on other factors, such as reflector coolant effect, balance of other moderator and engineering problem and so on, premoderator material is still needed.

3-5 Moderator lateral size and viewed surface size

Table 1 shows time-integrated neutron intensity and luminosity changing both viewed surface size and moderator lateral size. Though the total leakage neutron intensity increase as moderator lateral size increase, the luminosity of leakage neutron is the largest at the moderator lateral size of 12 x 12 cm^2 and 14 x 14 cm^2, and the viewed surface size 10 x 10 cm^2.

On the other hand, the neutron intensity at different distances from target to viewed surface is shown in **Table 2**. The neutron intensity is high at location in the viewed surface which is the near side.

3-6 Comparison of a simple model with a detailed model

Figures. 11 & 12 show energy spectrum and time structure of a pulse for a simple model and a detailed model. Both neutron intensity and peak intensity for a detailed model are 30 % lower than those for the simple model in the whole energy region. On the other hand, FWHM in the detailed model is as same as that the simple model. The pulse shape in the both case is shown in **Fig. 13**. There is almost no difference in the pulse tail. These results suggest that pulse characteristic is independent of the difference between a simple model and a full model.

4. Conclusion

It is confirmed that the premoderator have much merit in the case of decoupled moderator and Pb reflector.

The result of optimization of premoderator indicated that if, in the case of Pb reflector, premoderator and decoupling energy is controlled to obtain best performance, decoupled H2 moderator with premoderator in the case of Pb reflector can provide better pulse characteristics than that without premoderator for Be reflector.

Then, H_2O premoderator provides short tail and D_2O premoderator provide high peak intensity. However it is not wise that premoderator material is decided without taking account of other factor.

The neutron intensity per viewed surface area is obtained by selecting that moderator lateral size and viewed surface size are 12 x 12 cm^2 and 10 x 10cm^2, respectively. Position of viewed surface had better to b installed close to the target.

Moreover, Neutron intensity in the case of the detailed model is 30 % loss lower than that of Simple model and pulse shape isn't difference between Simple model and Full model.

Finally other merit of using premoderator is separation between the moderator and the target. Larger separation between the moderator and the target provided better S/N ratio for the neutron scattering experiment and smaller neutron intensity generally. However, premoderator can provide larger spallation without loss of neutron intensity. Maekawa et al. indicate that fast neutron flux cause the background for the experiments is reduced with increasing the separation [8].

Acknowledgement

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Reference

[1The joint project team of JAERI and KEK, JAERI-Tech 99-056 (1999); KEK Report 99-4 (1999); JHF-99-3(1999).

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[6] Kiyanagi et al., private communication; Ooi, et al., to be published in Proc. ICNAS-VV.

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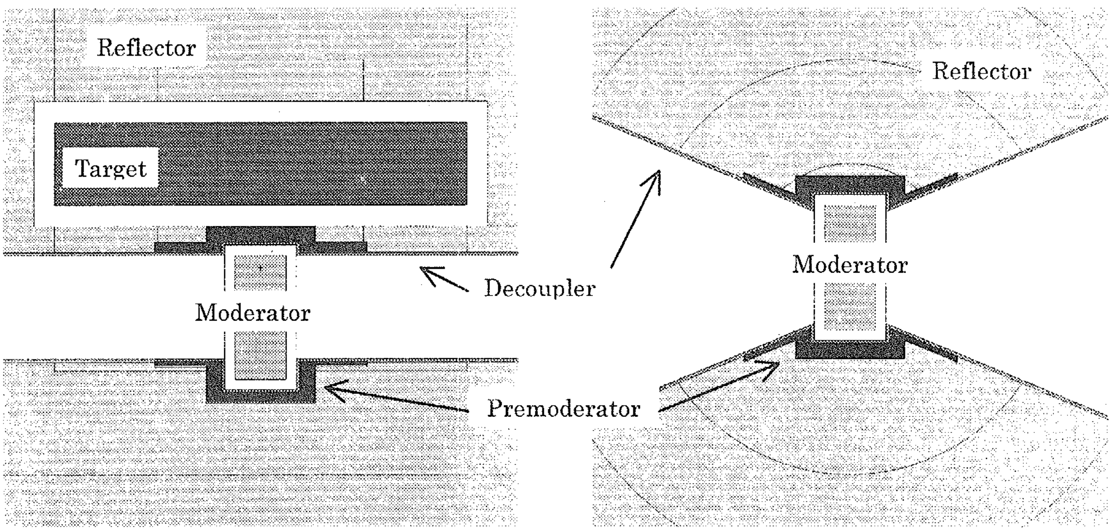
[8] Maekawa et al., to be published in Proc. ICANS-XV.

Table 1: Total and luminosity of neutron intensity in change of moderator lateral size and viewed surface

Moderator Lateral Surfac	10 x 10(cm^2)	12 x 12	14 x 14	14 x 14	16 x 16	16 x 16
Viewed Surface	10 x 10(cm^2)	10 x 10	10 x 10	12 x 12	12 x 12	14 x 14
Ratio	**1.00**	**1.22**	**1.26**	**1.09**	**1.09**	**0.95**
Total Intensity Ratio	**1.00**	**1.22**	**1.26**	**1.57**	**1.58**	**1.86**

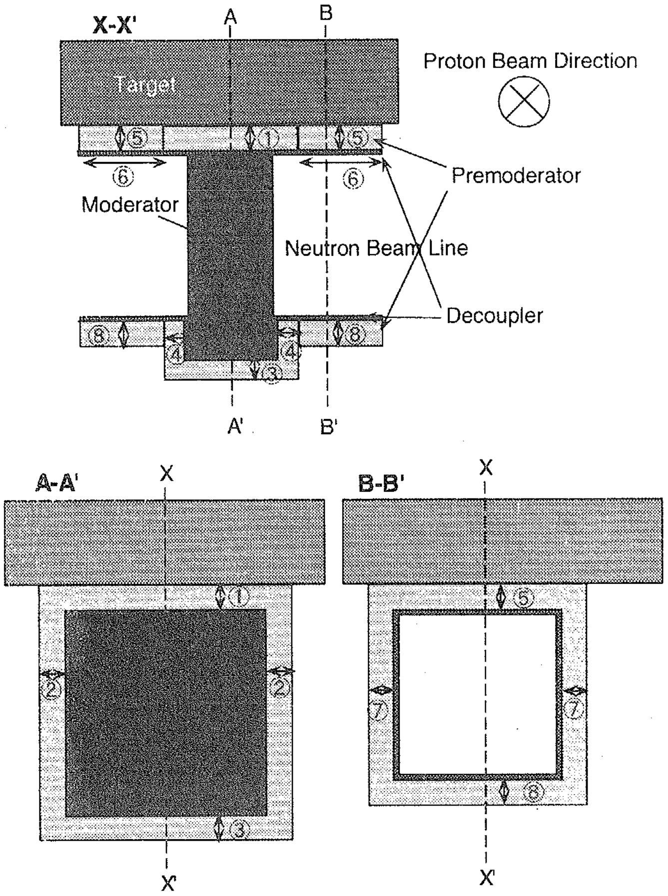
Table 2: Total neutron intensity in change of viewed surface position at the each energy region

Distance between Mod. Top	0	1
0 - 10 meV	**1.00**	0.99
20 - 120 meV	**1.00**	0.95
0.5 - 10 eV	**1.00**	0.93



(a): Vertical cross sectional view (b): Horizontal cross sectional view

Fig. 1: Schematic calculation model



Parameterized geometry and thickness

① Near side premoderator thickness
② Side premoderator thickness
③ Far side premoderator thickness
④ Beam extracted side premoderator thickness
⑤ Near side extended premoderator thickness
⑥ Extension length
⑦ Side extended premoderator thickness
⑧ Far side extended premoderator thickness

Fig. 2: Defined parameters of premoderator geometry and thickness

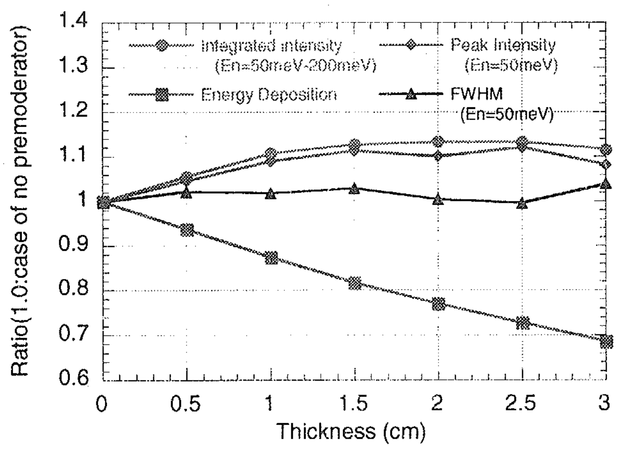


Fig. 3: Near side premoderator thickness dependence of time-integrated intensity, peak intensity, FWHM (Full width of half maximum) and heat deposition in moderator

These values are normalized to the value in the case of no premoderator, respectively. Time-integrated intensity is also integrated in the energy region from 50 meV to 200 meV and peak intensity and FWHM is the value at neutron energy 50 meV.

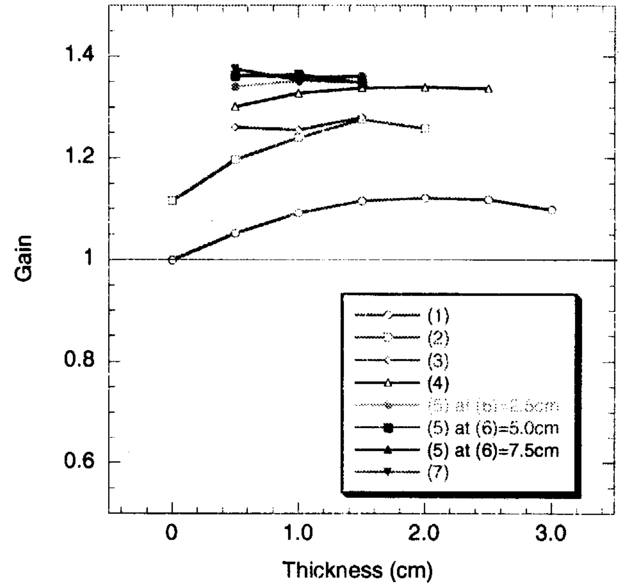


Fig. 4: Premoderator geometry and thickness dependence of time-integrated neutron intensity in the energy region from 50 meV to 200 meV in the Pb reflected case

These values are normalized to neutron intensity in the case with no premoderator.

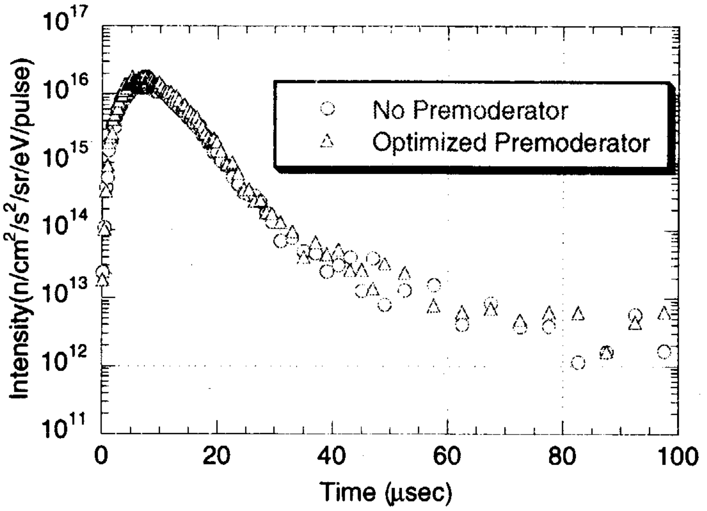


Fig.5: Comparison of pulse shape in the case of optimized premoderator with that in the case of no premoderator at En=50 meV

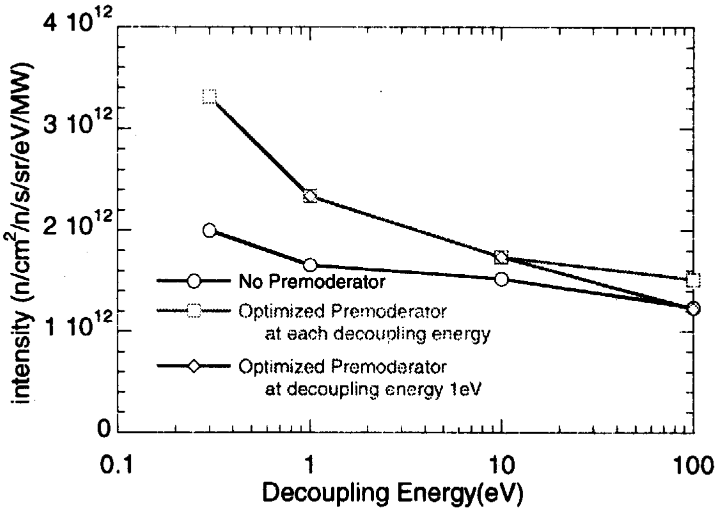


Fig.6: Decoupling energy dependence of time-integrated neutron intensity at 100 meV in the case of Pb reflector with no premoderator, optimized premoderator at each decoupling energy and optimized premoderator at decoupling energy 1eV

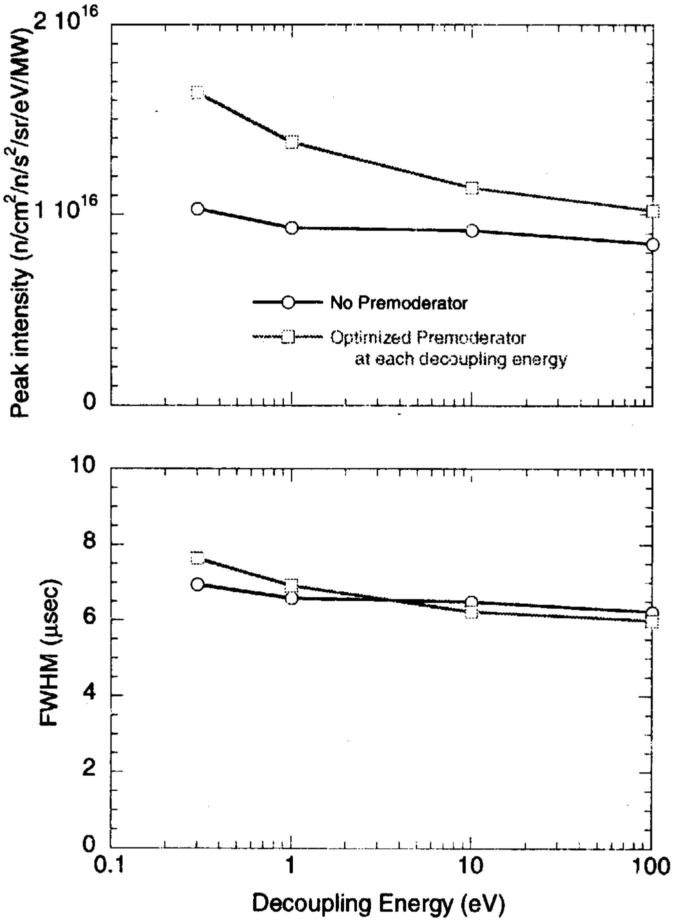


Fig. 7: Decoupling energy dependence of peak intensity and FWHM at 100 meV in the case of Pb reflector with no premoderator and optimized premoderator at each decoupling energy

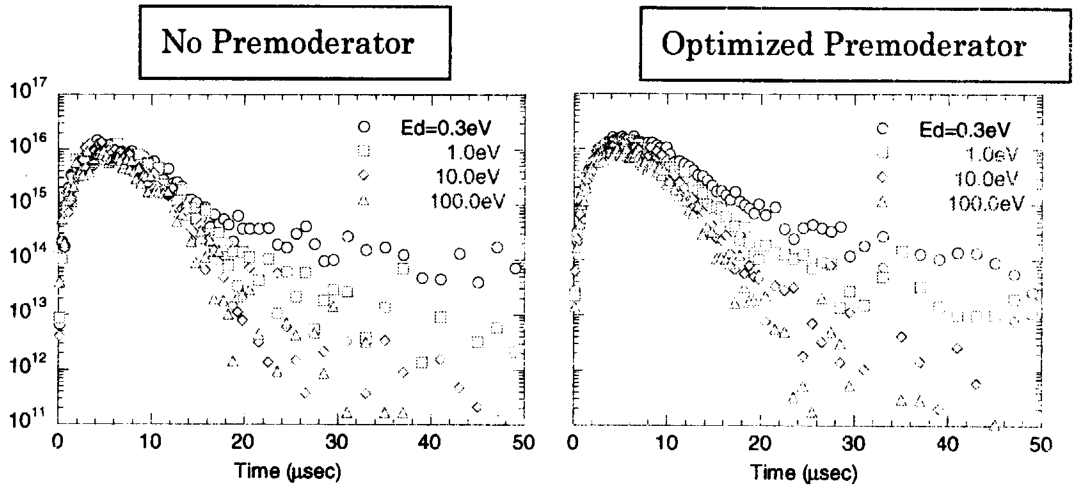


Fig. 8: Decoupling energy dependence of pulse shape at 100 meV in the case of Pb reflector with no premoderator and optimized premoderator at each decoupling energy

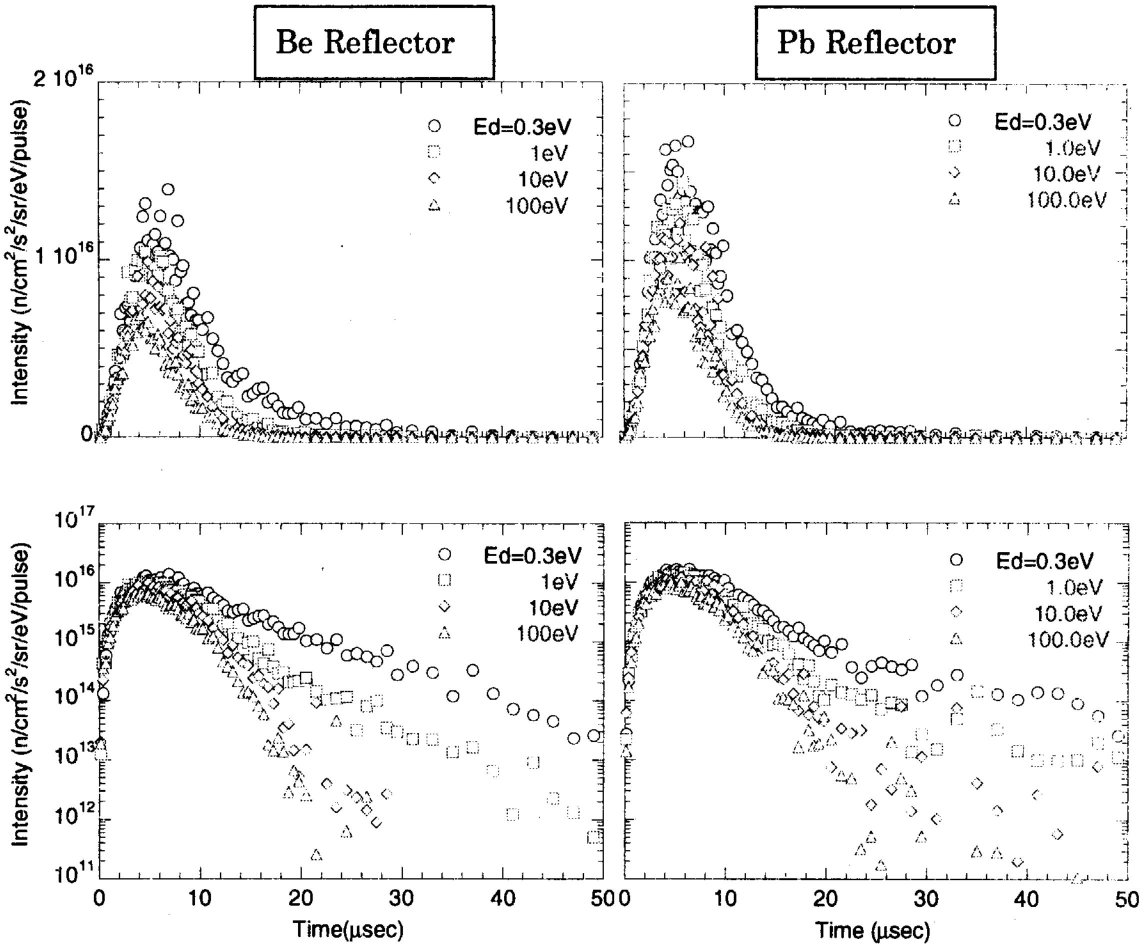


Fig. 9: Decoupling energy dependence of neutron intensity at 100 meV in the case of Pb reflector with premoderator and Be reflector with no premoderator (Upper : Linear Scale, Lower: Logarithm scale)

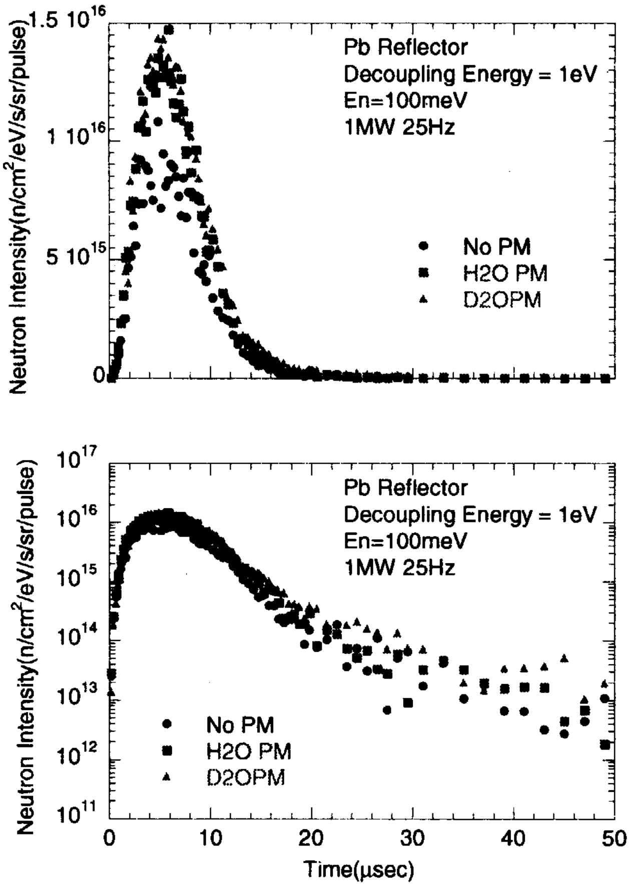


Fig. 10: Comparison of time structure in the case of H_2O premoderator with that in the case of D_2O premoderator at 100 meV
H2O Premoderator provide much gain of neutron intensity without sacrificing pulse tail

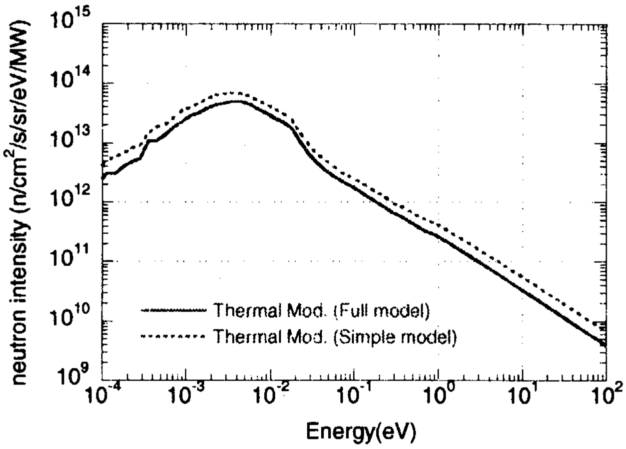


Fig. 11: Comparison of energy spectrum calculated in the simple model with that in the detailed model

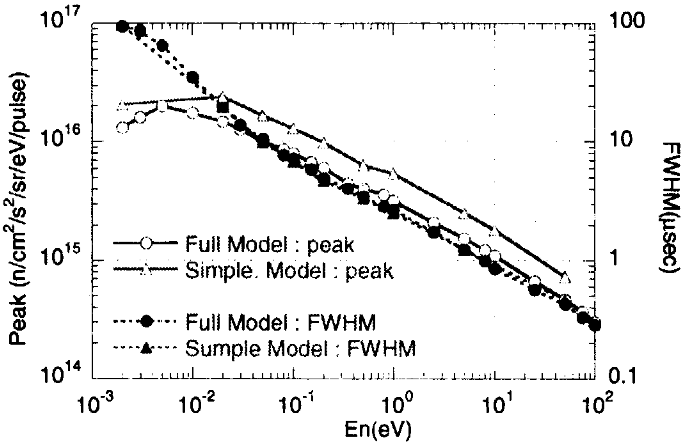


Fig. 12: Comparison of time structure calculated in the simple model with that in the detailed model

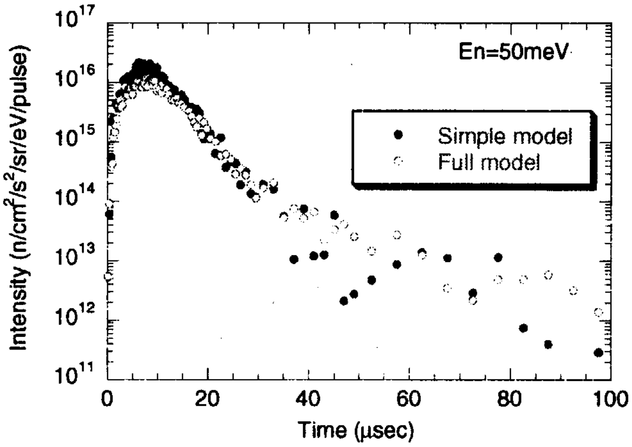


Fig. 12: Comparison of pulse shape calculated in the simple model with that in the detailed model