Premoderator Studies for a Coupled Liquid-Hydrogen Moderator

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Abstract

A coupled liquid-hydrogen moderator with a premoderator is one of the most promising candidates for a cold neuron source at an intense pulsed spallation neutron source. The choice of the premoderator material is especially important since the neutronic performance strongly depends on the material. Premoderators of polyethylene, water and zirconium hydride have been studied experimentally. The cold neutron intensity from a moderator system with a ZrH_2 premoderator is unexpectedly low: about 75 % of that from a reference coupled liquid-hydrogen moderator with a polyethylene premoderator. However, the pulse widths (FWHM) are narrower than those from the reference modeartor, and the peak intensities are almost unchanged. We also discuss the function of the premoderator.

1. Introduction

We have developed a high-efficiency pulsed cold-neutron source: a coupled liquid-hydrogen moderator (5 cm thick) with premoderator at ambient temperature. (1) A gain factor of about 6 has already been achieved with a 2-cm thick polyethylene premoderator. What material is the best for the premoderator? In order to obtain a better understanding of this moderator system and to seek the best material we performed some experiments with three different premoderators of H_2O, ZrH_2 and, as a reference, polyethylene. At an intense pulsed spallation neutron source polyethylene cannot be used due to serious radiation damage; H_2O would be only one hydrogenous liquid material which could work under such conditions. ZrH_2 has often been proposed as one of the best candidates, probably because it has a high hydrogen density and a large cross section of the hydrogen local mode at about 130 meV, which may play an important role for supplying rich epithermal-neutrons to liquid hydrogen.

2. Experimental

The experimental set up used in the present experiments is shown in Fig. 1; it is the same as that used in previous measurements (1) The size of the liquid-hydrogen moderator is 12 cm wide, 12 cm high and 5 cm thick. The temperature of the liquid hydrogen was about 18 K. The liquid-hydrogen moderator with the premoderator was coupled to a graphite reflector having a size of about 1 m^3.

H_2O and ZrH_2 powders were contained in alminium boxes to form the necessary shape for a premoderator having a given thickness. The hydrogen content of the ZrH_x powder was confirmed to be x = 2.0 from a measurement of the lattice constant by x-ray diffraction as well as a chemical analysis. The number density of protons in the ZrH_2 powder filled in the container was 0.64×10^{24} $/cm^3$. As a pulsed-neutron source, the electron linac at Hokkaido University was used. The energy spectra and time-distribution of neutrons at various energies were measured by the usual time-of-flight method and a crystal analyzer system used in the previous measurements.[1]

3. Neutrnonic Performance of a Coupled Moderator System with Various Premoderators

Figure 2 shows the premoderator gain factors as a function of the premoderator thickness. The maximum gain factor is obtained at about 3 cm thick for ZrH_2 and 2 ~ 3 cm for H_2O, which should be compared with 2 cm thick for polyethylene. Figure 3 shows the energy spectra from those

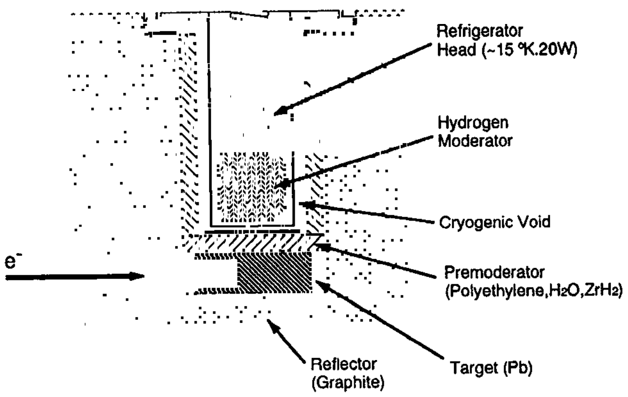


Fig. 1 Target-moderator-reflector assembly for a coupled liquid-hydrogen moderator with a premoderator.

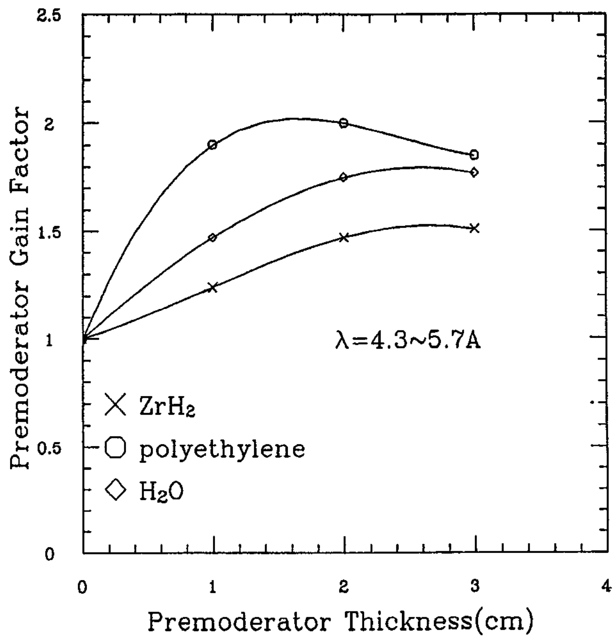


Fig. 2 Premoderator gain factors for a coupled liquid-hydrogen moderator with three different premoderators as a function of the premoderator thickness.

moderators with three different premoderators at the optimal thicknesses. The spectra are almost unchanged. Figure 4 shows the relative values of the premoderator gain factor for ZrH_2 (3 cm thick) and H_2O (3 cm thick) to polyethylene (2 cm thick) as a function of the neutron wavelength. The gain factor for H_2O is slightly less than unity: almost the same as in the polyethylene case. The gain factor for ZrH_2 is about 75% of that for polyethylene. This is due to the fact that ZrH_2 has no appreciable energy-exchange cross-section below 130 meV. From this result it can be concluded that the most important neutrons supplied to liquid hydrogen from premoderator are not epithermal neutrons, but thermal.

Figure 5 shows the time distributions of cold neutrons emitted from the coupled liquid-hydrogen moderator with a 3 cm thick ZrH_2 premoderator, compared with the 2 cm thick polyethylene premoderator case at two different wavelengths (left side is linear plots and the right semi-logarithmic plots). From the semi-logarithmic plots the decay seems to comprise at least two components: early decay and a long tail. The decay time for the former depends on the premoderator, while that of long tail is almost unchanged with the premoderator. This may be due to the fact that the reflector plays an important role for the decay of the latter component. Tailoring

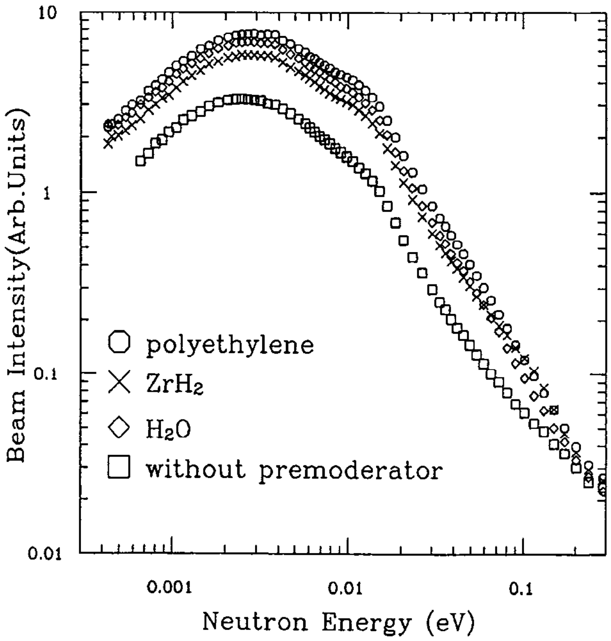


Fig. 3 Neutron energy spectra from a coupled liquid-hydrogen moderator with three different premoderators at the optimal thickness.

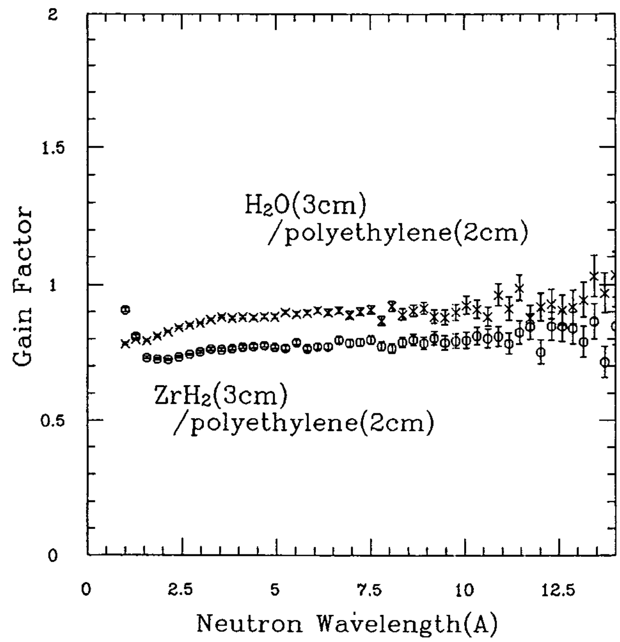


Fig. 4 Relative gain factors for ZrH_2 and H_2O systems to polyethylene as a function of the neutron wavelength.

of the long tail will be reported elsewhere in these proceedings (J. M. Carpenter et al.). The full-width-at-half-maximum (FWHM) pulse widths are plotted in Fig. 6 as a function of the neutron wavelength. The values of FWHM for the ZrH_2 system is about 75-80% of the polyethylene system. This means that the peak intensity is not so much decreased, as shown in Fig. 7. For high resolution neutron-scattering experiments, we proved that the figure-of-merit of the neutron source is proportional only to the pulse peak height, provided that a neutron guide tube of the required length can be used.(2) However, since a guide tube beyond 200 m long is unrealistic, narrower pulses are more acceptable as long as the peak intensity is conserved.

4. Function of Premoderator

In order to understand the neutronic characteristics obtained above we performed some elementary experiments. As the first stage we measured bare rectangular parallelepiped moderators of each premoderator material. The energy spectrum from each moderator was measured in a slab geometry at three different thickness. Figure 8 shows the results for ZrH_2 and polyethylene moderators. In the case of polyethylene, the thermal equilibrium (Maxwellian) spectrum is already recognized at 2 cm thick, while for ZrH_2 the spectrum is far before equilibrium. The result for H_2O is close to that of polyethylene. The result gives a qualitative explanation for the measured thickness dependence of the premoderator gain factors shown in Fig. 2. Figure 9 compares the spectrum from each bare moderator of the optimal thickness for the premoderator. The neutron intensity from the 3 cm thick ZrH_2 is much smaller than those from 3 cm thick H_2O and 2 cm thick polyethylene.

We then measured the neutron intensities from each premoderator (hydrogen moderator is removed from the system shown in Fig. 1). Figure 10 shows the result where the energy spectrum from the

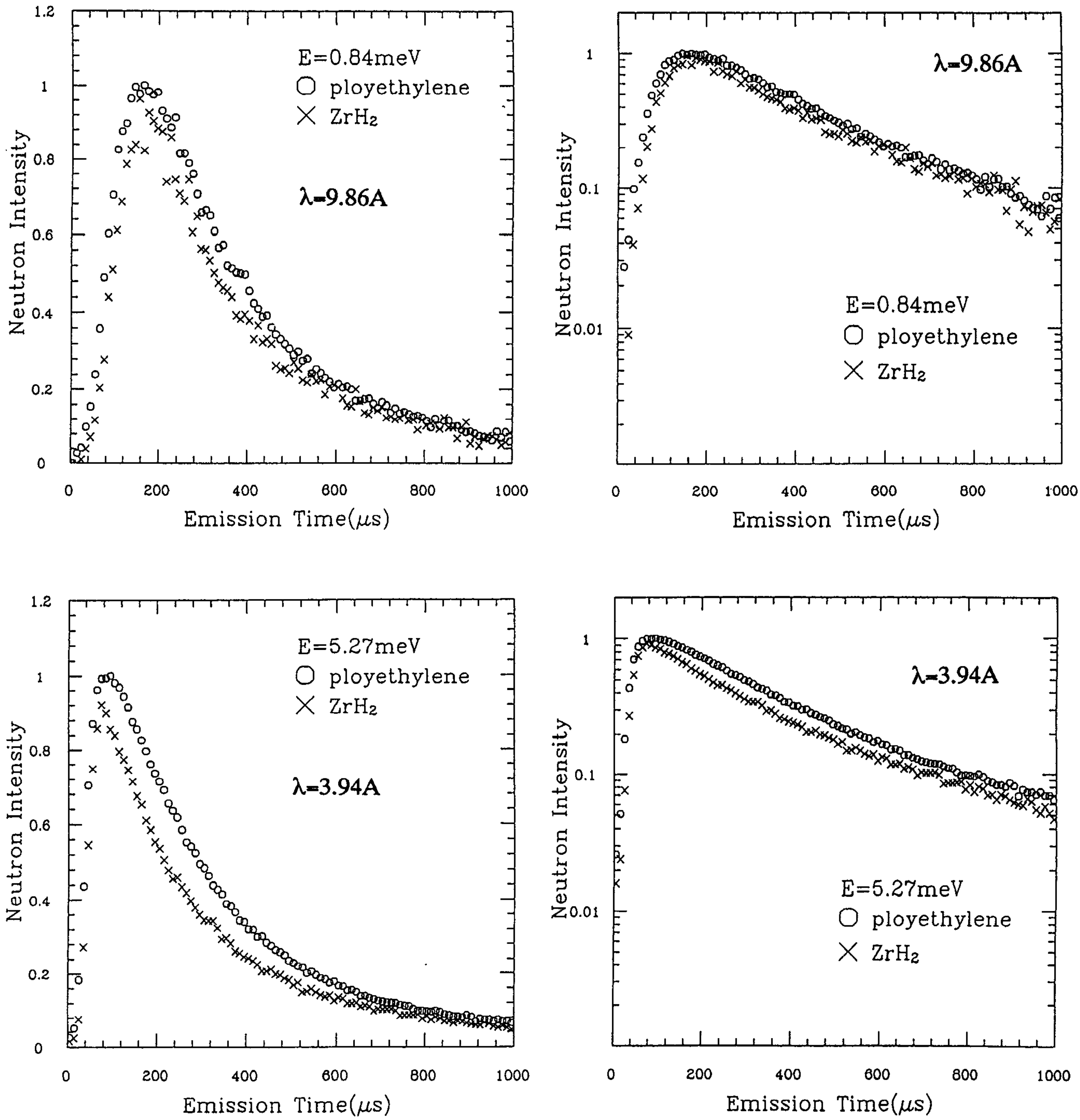


Fig. 5 Time distributions of cold neutrons at two different wavelengths from ZrH_2 and polyethylene systems.

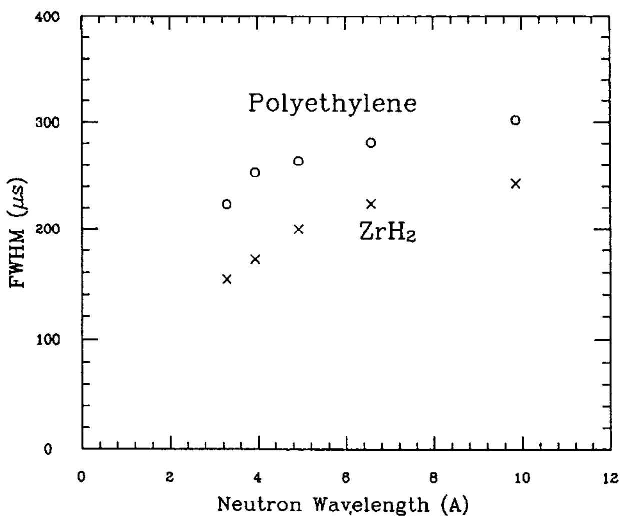


Fig. 6 Pulse widths (FWHM) for ZrH_2 and polyethylene systems as a function of the neutron wavelength.

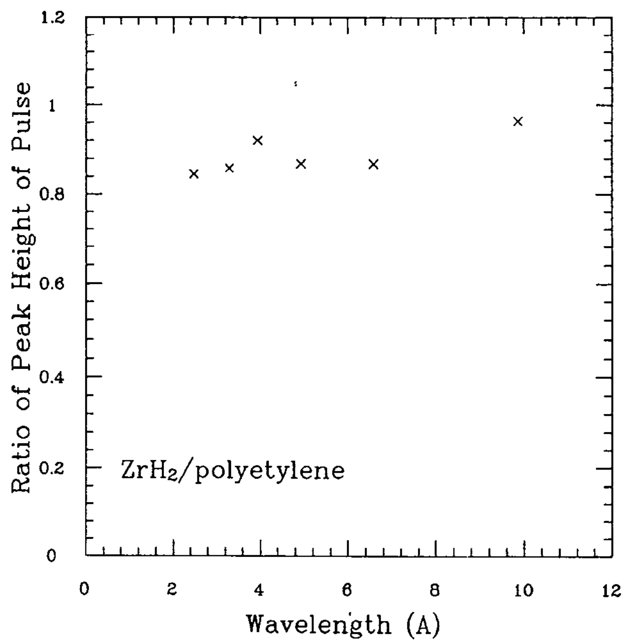
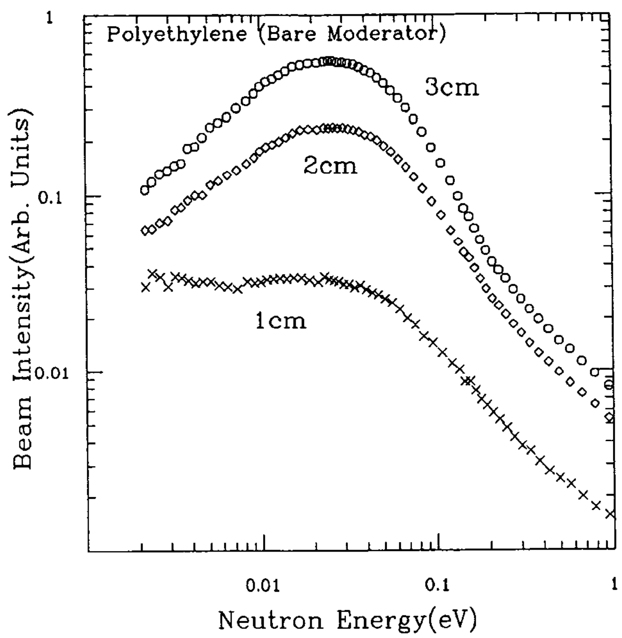


Fig. 7 Peak heights of the neutron pulses from the ZrH_2 system relative to polyethylene as a function of the neutron wavelength.



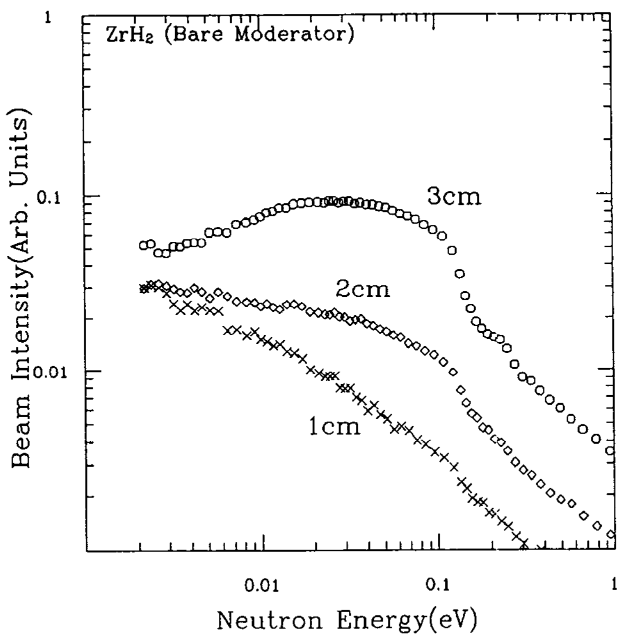


Fig. 8 Neutron energy spectra from bare ZrH_2 and polyethylene moderators of three different thicknesses.

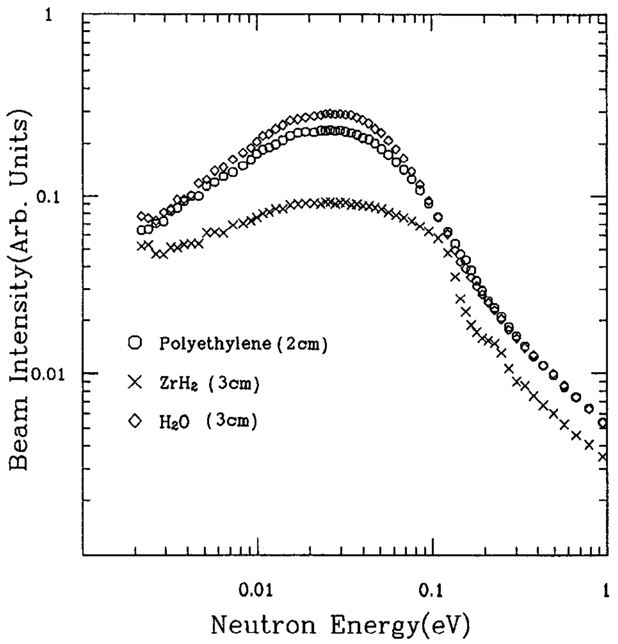


Fig. 9 Comparison of the neutron-energy spectra from each bare moderator of the optimal thickness for the premoderator.

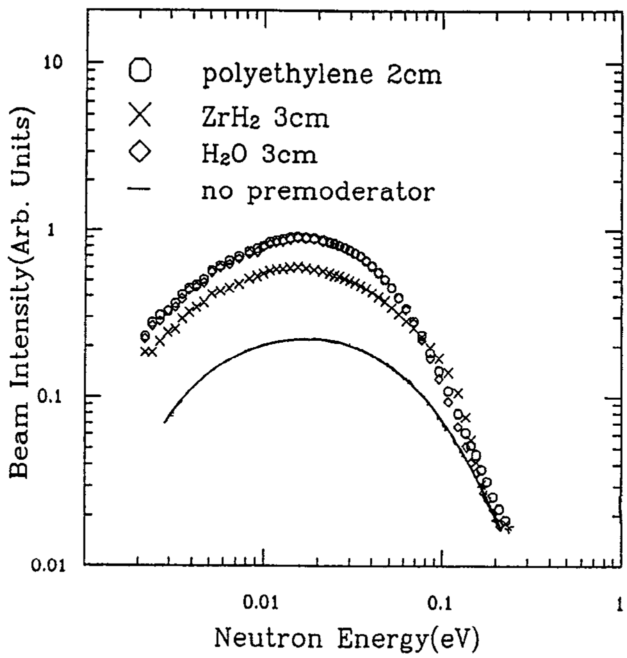


Fig. 10 Comparison of the neutron energy spectra from each premoderator box coupled to the reflector.

ZrH_2 box becomes more Maxwellian like and the intensity difference from the other two becomes much smaller than that of the simple bare moderator. This is because we measured the neutrons from a sort of re-entrant hole in a large hydrogenous moderator coupled to the reflector. The measured premoderator gain factors shown in Fig. 4 are almost governed by the thermal-neutron intensity ratios. This result again proved that the source neutrons to the liquid-hydrogen moderator are not epithermal neutrons, but thermal.

5. Conclusions

Although the ZrH_2 premoderator gives lower cold-neutron intensity than do polyethylene and H_2O premoderators in a coupled liquid-hydrogen system, the pulse widths are narrower than in the polyethylene case. This result indicates that the pulse shape can be controled by the choice of the premoderator material as well as by adjusting the premoderator thickness. Further studies towards this direction are in progress.

It is also concluded that in intense spallation neutron sources, H_2O is the best realistic premoderator material to obtain the highest gain factor.

References

(1) Y. Kiyanagi, N. Watanabe and H. Iwasa: Nucl. Instrum. Methods, A312, 561 (1992).
(2) N. Watanabe and Y. Kiyanagi: Physica B 180&181 (1992) 893.