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Optimization Studies on Coupled Liquid Hydrogen Moderator

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ABSTRACT

Optimization studies on a coupled liquid-hydrogen-moderator system were performed experimentally and the results were compared with those of decoupled liquid hydrogen and solid methane moderators. A very high gain factor is obtained. Pulse characteristics were also studied and it is found that the pulse broadening by coupling is rather modest.

I. INTRODUCTION

How to realize an intense cold neutron source is one of the most important objectives for KENS-II R&D . A coupled liquid-hydrogen-moderator is the most promising candidate for this. It was revealed by our preliminary experiments1) that the cold neutron intensity from a coupled hydrogen moderator in a wing geometry is very much higher than that from a decoupled one and also the pulse width is not broadened so much by coupling. These results encouraged us to perform further experiments using a dedicated cryostat to this moderator system.

The cryostat used in the preliminary experiments had a large void space above the moderator chamber, resulting in a large reflector missing. We prepared a new cryostat which has a slim neck above the moderator chamber. We studied the neutronic performance of coupled liquid-hydrogen-moderators in more detail and compared the results with those of a decoupled liquid-hydrogen and solid-methane moderators.

II. EXPERIMENTAL

Figure 1 shows a coupled liquid-hydrogen-moderator system used in the present experiments. The size of the liquid-hydrogen-moderator is fixed to $12\times12\times5$ cm^3. Polyethylene plates are attached to a cryostat to compose a

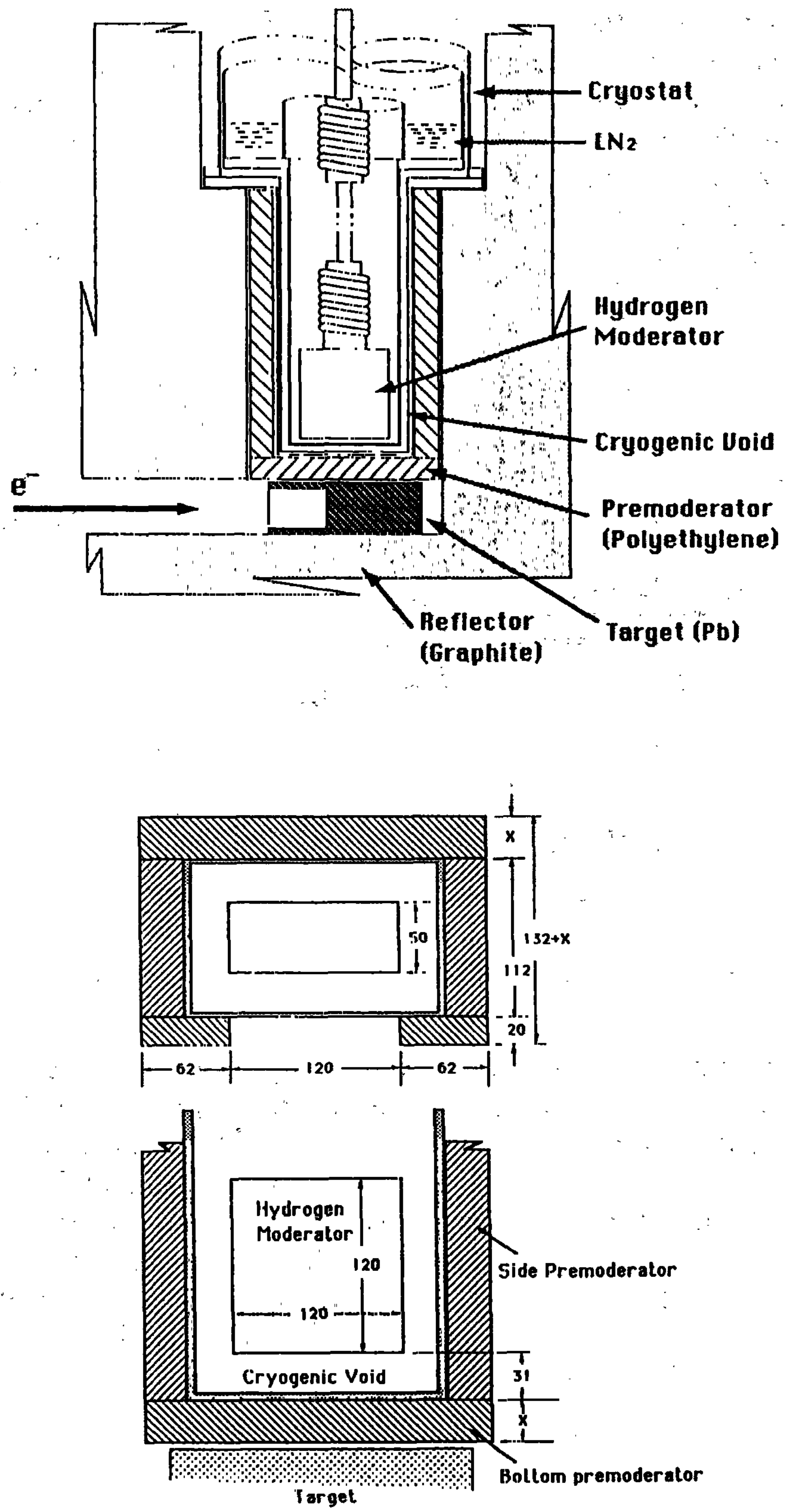

Fig. 1 Schematic representation of the target-moderator-reflector assembly for coupled liquid-hydrogen moderator with premoderator. The lower figure shows the layout of the premoderator.

premoderator. The front part of the premoderator has a window of 12x12 cm^2 for extracting the neutron beam. There is no decoupler between moderator, target and reflector; that means the system is a coupled one. Figure 2 shows the decoupled moderator system. The moderators have the same size of the coupled one and are decoupled from the reflector by 0.5 mm thick cadmium plate as shown in the figure. A neutron generating target is placed just below the premoderator or the cryostat to form a wing geometry. The target and the moderator are surrounded by a graphite reflector of about 1 m^3.

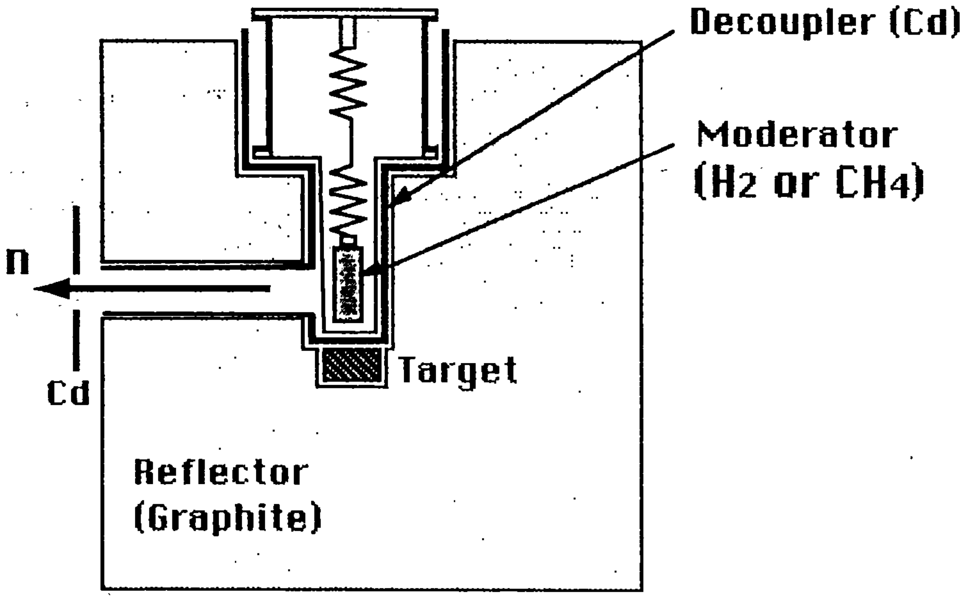

Fig. 2 Decoupled target-moderator-reflector assembly.

The electron linac at Hokkaido university was used as a fast neutron generator. Figure 3 shows the experimental arrangement for measurements of time-of-flight spectra. The flight path length between moderator and He-3 neutron detector is 5.6 m. A set of cadmium collimators is placed at both ends of an evacuated flight tube to define a viewed surface of the moderator 10×10 cm^2. The energy analyzer system used for the time distribution measurements is dipicted in the lower figure. A mica crystal is used as an energy analyzer with Bragg angle of 85°. The flight path length between moderator and analyzer crystal is 6.6 m.

III. COUPLED MODERAOTOR OPTIMIZATION

Slow neutron intensities from the coupled liquid hydrogen moderator without premoderator and the decoupled one were measured. The measured spectra are shown in Fig. 4 and the relative intensity of the coupled to the decoupled (coupling gain factor) is plotted in Fig. 5 as a function of neutron wavelength. The coupling gain factor almost saturates in

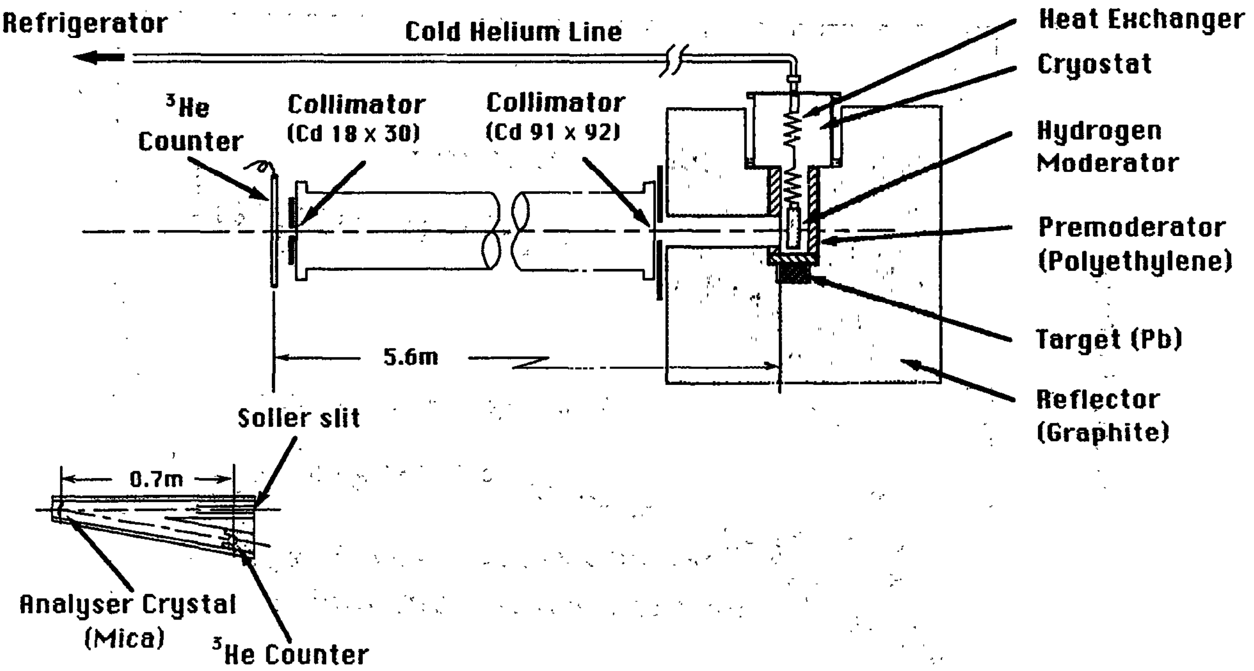

Fig. 3 Experimental arrangement for time-of-flight measurements. The lower figure shows the energy analyzer system for time distribution measurements.

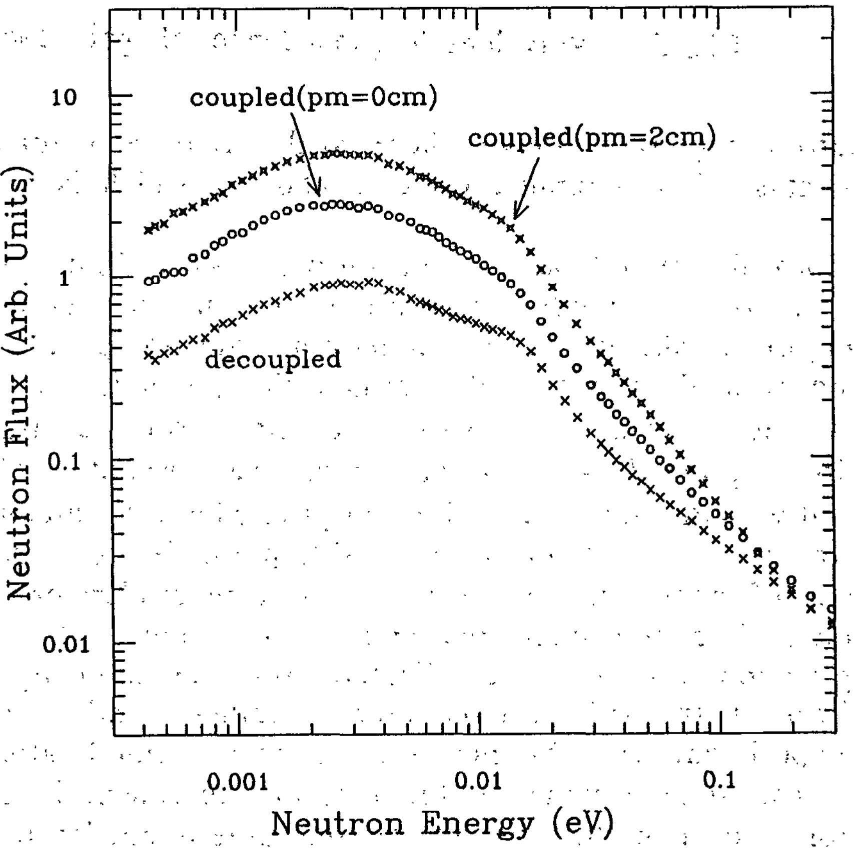

Fig. 4 Energy spectra of coupled and decoupled liquid-hydrogen-moderators. pm means premoderator thickness.

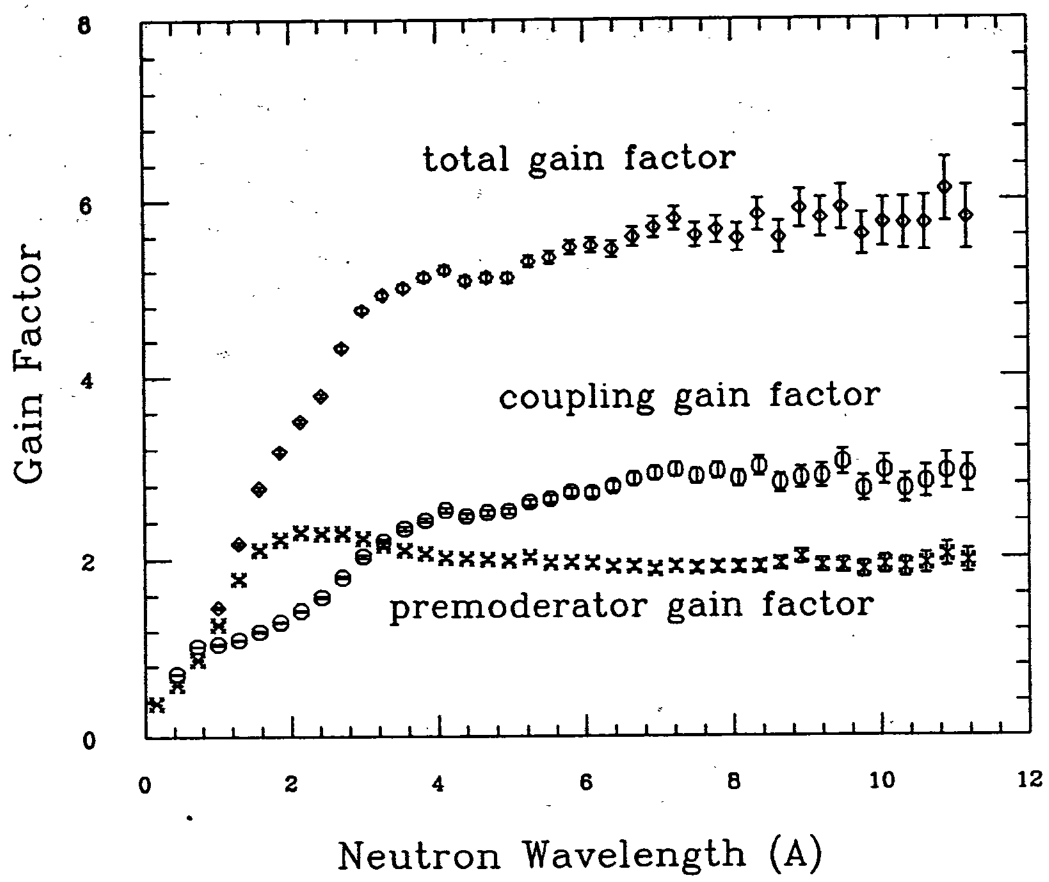

Fig. 5 Wavelength dependence of gain factors.

the cold neutron region although there still exists a gradual increase at longer wavelengths. The saturated value is about 3 which is a great.

Then we performed premoderator optimization. As a first step, we studied the effects of the premoderator thickness on the cold-neutron-beam intensity. Figure 6 shows the premoderator gain factor as a function of bottom premoderator thickness. We defined the premoderator gain factor as the ratio of the cold-neutron-beam intensity from a liquid-hydrogen-moderator with a premoderator to that from one without. The gain factor increases rapidly with increasing bottom-premoderator thickness and then saturates to a value of about 1.75. Side-premoderator brings about an additional gain of about 20 %, resulting in a premoderator gain factor of about 2 in total. The maximum appears at about 2 cm thick. We found that the bottom-premoderator is most effective for the intensity enhancement, while the effect of the side-premoderator is rather small. In the previous preliminary experiment we obtained the optimal premoderator thickness of about 3 cm. The smaller value in the present experiment is due to a better upper reflector and a higher height of the side-premoderator than in the previous.

The energy spectrum of neutrons from the coupled liquid-hydrogen-

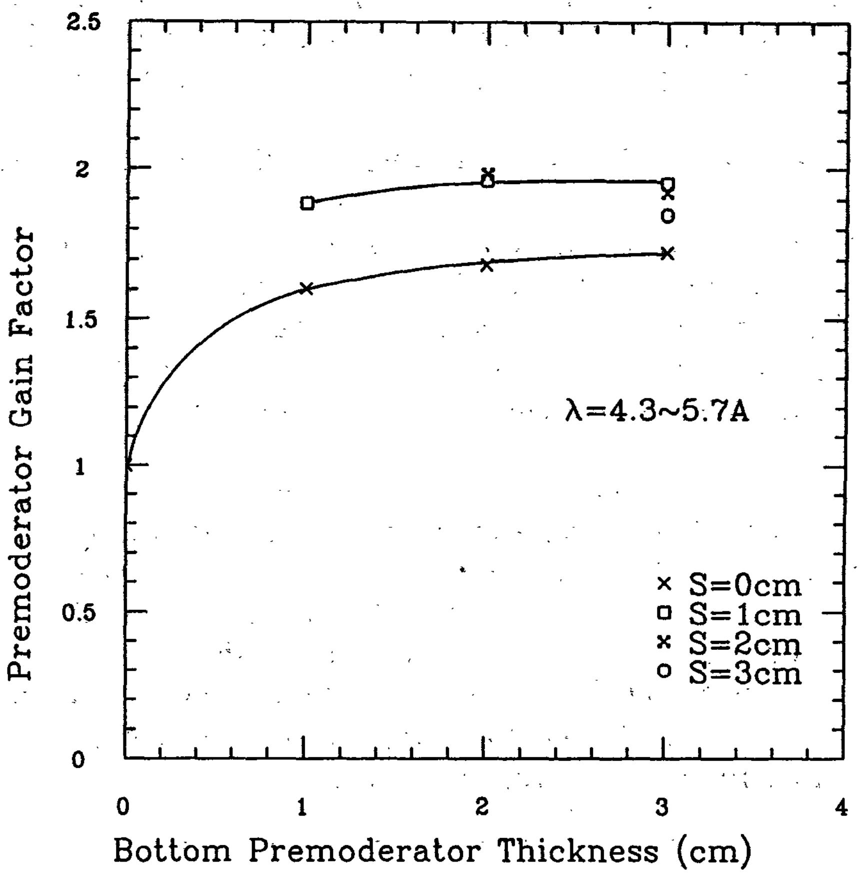

Fig 6 Premoderator gain factor at wavelength 4.3~5.7 A as a function of bottom-and side-premoderator thickness. S means side-premoderator thickness.

moderator with a 2 cm thick premoderator is also shown in Fig. 4. The energy spectra at the cold neutron region are not so different each other. The wavelength dependence of the premoderator gain factor of the liquid-hydrogen-moderator with the 2 cm thick premoderator is shown in Fig. 5. There is a broad maximum around 2.5 A and above this wavelength the gain factor approaches 2. It is also a considerable.

Grooved surface moderators were extensively studied so far and a finite gain has already been recognized. We examined a grooved-surface bottom-premoderator. The bottom-premoderator had grooves of 2 cm deep and 2 cm wide with 2 cm spacing (total thickness being 4 cm). A gain factor obtained by this was only 3 % which was unexpectedly small.

The total gain factor of the coupled liquid-hydrogen-moderator with the 2 cm thick premoderator (optimal thickness) is also shown in Fig. 5. The total gain factor is defined here as the ratio of the cold-neutron-beam intensity of this moderator to that of a decoupled 5 cm thick liquid-hydrogen-moderator. The total gain factor increases rapidly with increasing wavelength until about 3 A and approaches 6 in the longer wavelength region. Very large values of the total gain factor were attained. The values are almost as same as previous ones in the preliminary experiments. However, the absolute intensity obtained in this experiment is about 1.5 times higher than the previous. This is due to the better reflector saving in the present system.

IV. DIRECT COMPARISON WITH DECOUPLED SOLID-METHANE MODERATOR

In the choice of cold neutron moderator system, it is important to know the beam intensity in absolute scale or in relative value to the existing best moderator for the production of pulsed cold neutrons. A decoupled solid-methane moderator of 5 cm thick as used at present KENS was adopted for this. We also performed measurements on this moderator.

Figure 7 shows the energy spectra from both moderators for direct comparison. It should be stressed that the cold-neutron-beam intensity from the proposed coupled moderator is superior to that from the reference decoupled moderator of solid methane. Figure 8 shows the ratio of the intensity of coupled liquid-hydrogen-moderator to that of the solid-methane moderator. A gain of about 2 has been attained. There is a peak at about 2.5 A which is caused by the neutron trap at this wavelength in connection with ortho-para transition of hydrogen molecule.

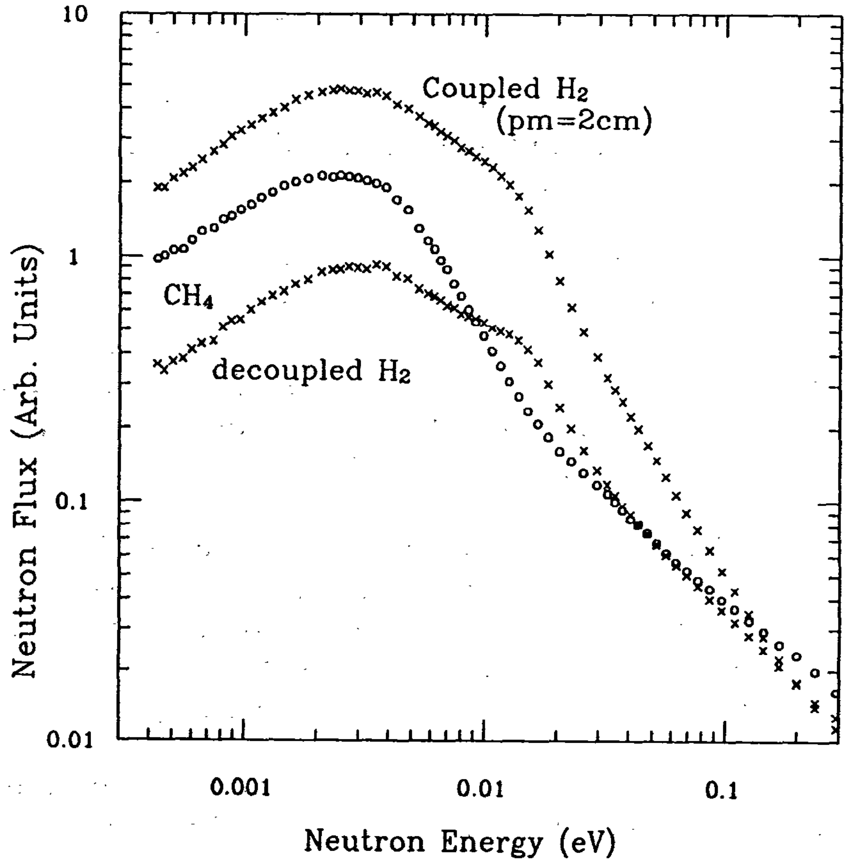

Fig. 7 Energy spectra from the coupled liquid-hydrogen-moderator with 2 cm thick premoderator and the decoupled solid methane moderator. As a reference the spectra from the decoupled liquid-hydrogen-moderator is also shown.

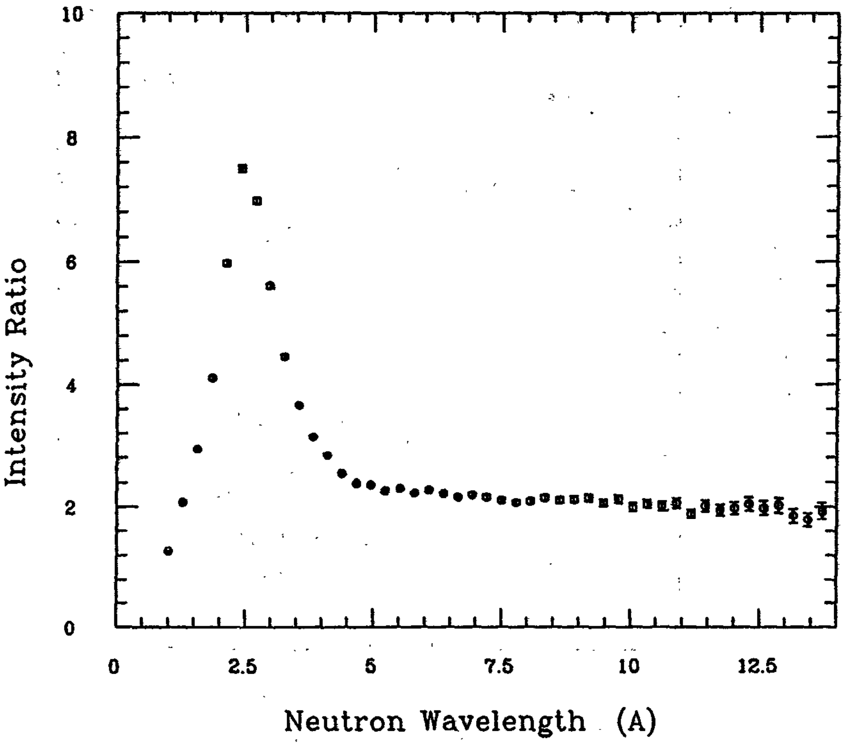

Fig. 8 Intensity ratio of the coupled liquid hydrogen moderator with 2 cm thick premoderator to the decoupled solid methane moderator.

Next, we measured spatial distributions of cold-neutron-beam intensity along the vertical direction of the viewed surface of the moderators, by scanning a cadmium slit of 1 cm-high at the entrance of the beam extraction hole (see Fig. 3). The results are shown in Fig. 9. The superiority of the proposed coupled moderator is clearly demonstrated. The peak in intensity appears close to bottom of the moderator. Such feature is enhanced more in the proposed coupled moderator. This is due to the fact that the bottom-premoderator feeds source neutrons of a more soft-spectrum to the liquid-hydrogen-moderator.

The target-moderator distance allowed for the target engineering design is one of the most important parameters, so, we measured the cold-neutron-beam intensity by changing the distance between the target and the moderator. Figure 10 shows the results. Intensities from each moderator are normalized to unity at zero distance by extrapolation. It is revealed that the intensity reduction with distance is rather modest and dose not depend on moderator.

V. PULSE CHARACTERISTICS

Time-distributions of cold neutrons from the proposed coupled liquid-hydrogen-moderator system were studied in comparison with other two decoupled moderators.

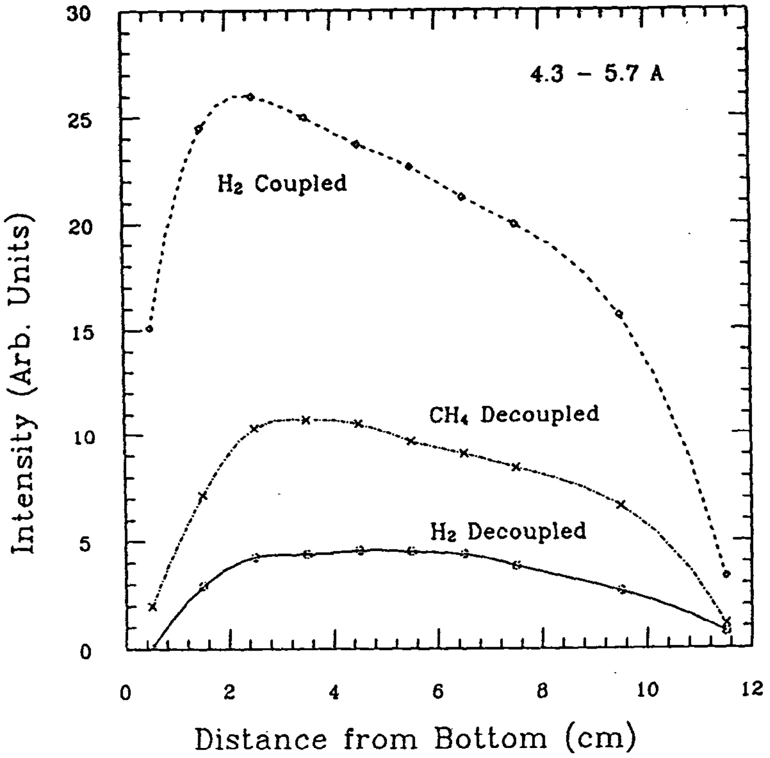

Fig 9 Spatial distributions of the cold-neutron beam intensity along the vertical direction of the viewed surface.

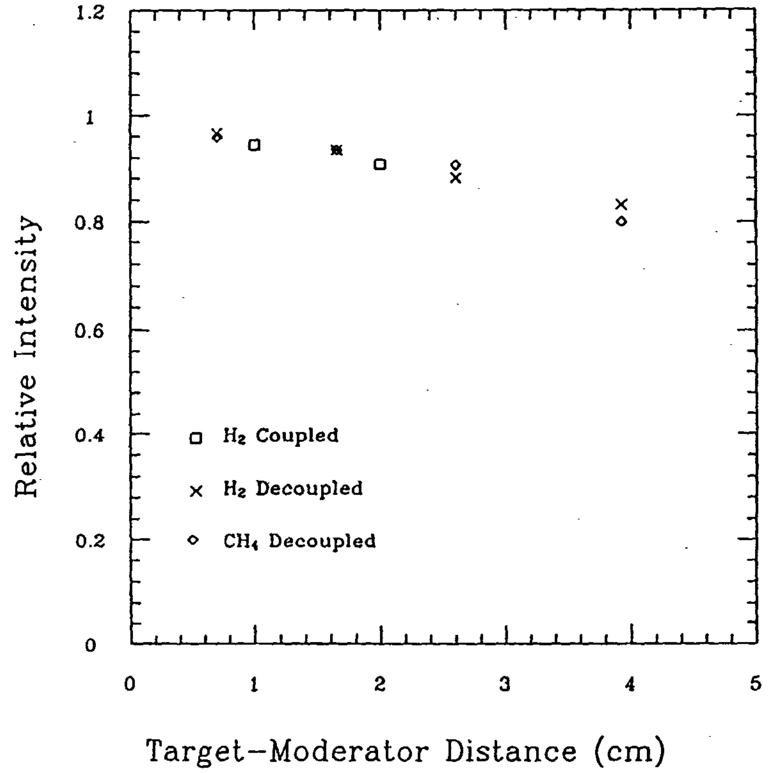

Fig 10 Cold-neutron-beam intensity as a function of moderator-target distance.

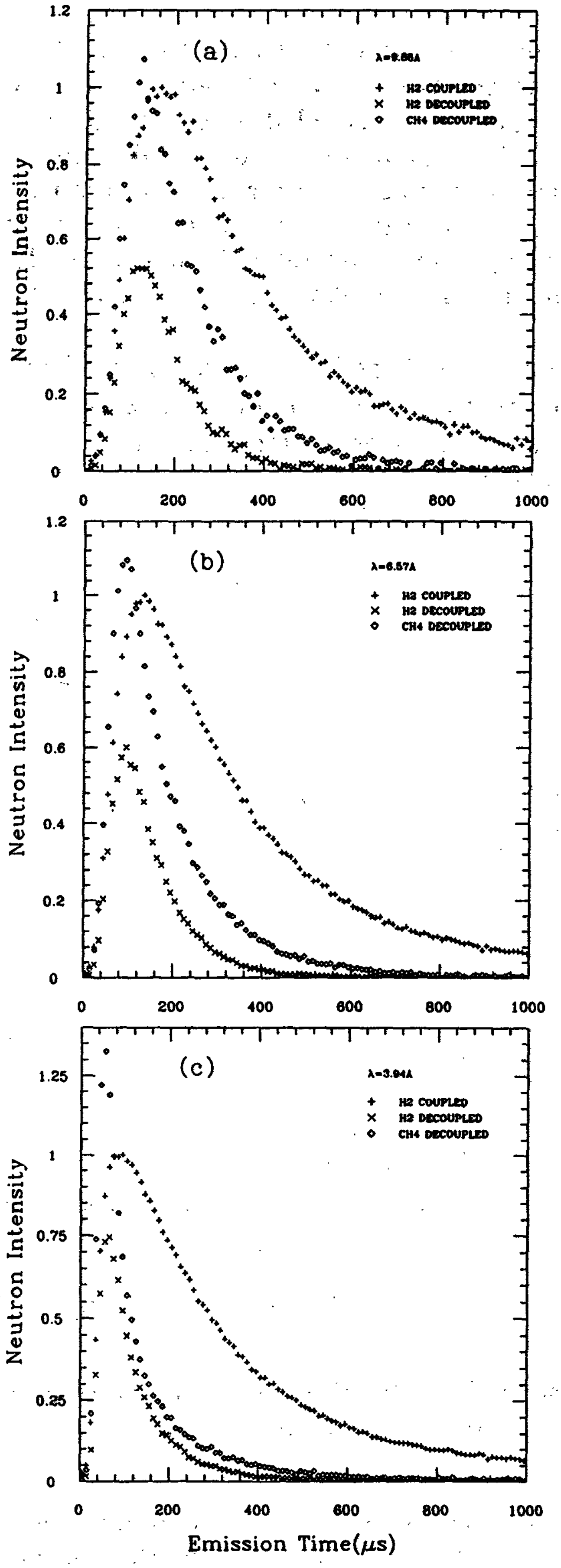

Fig 11 Time-distributions of neutrons from the coupled liquid-hydrogen-moderator with 2 cm thick premoderator and the decoupled methane and hydrogen ones at three wavelengths, (a) 9.86A, (b) 6.57 A and (c) 3.94 A.

Figure 11 compares time-distributions of cold neutrons from these moderators at three typical wavelengths. The coupled moderator gives broader pulses than the decoupled ones as expected, but the broadening is rather modest. The increase in the peak intensity is unexpectedly high compared to the decoupled hydrogen and almost comparable to the solid methane. This means that the larger gain of the coupled moderator to the decoupled liquid-hydrogen-moderator is not only due to the increase in the pulse width but also due to the increase in the peak intensity.

Pulse widths in full width at half maximum (FWHM) are plotted in Fig. 12 as a function of neutron wavelength. The pulse widths of the coupled moderator are about 2 times larger than those of the decoupled ones in the cold neutron region.

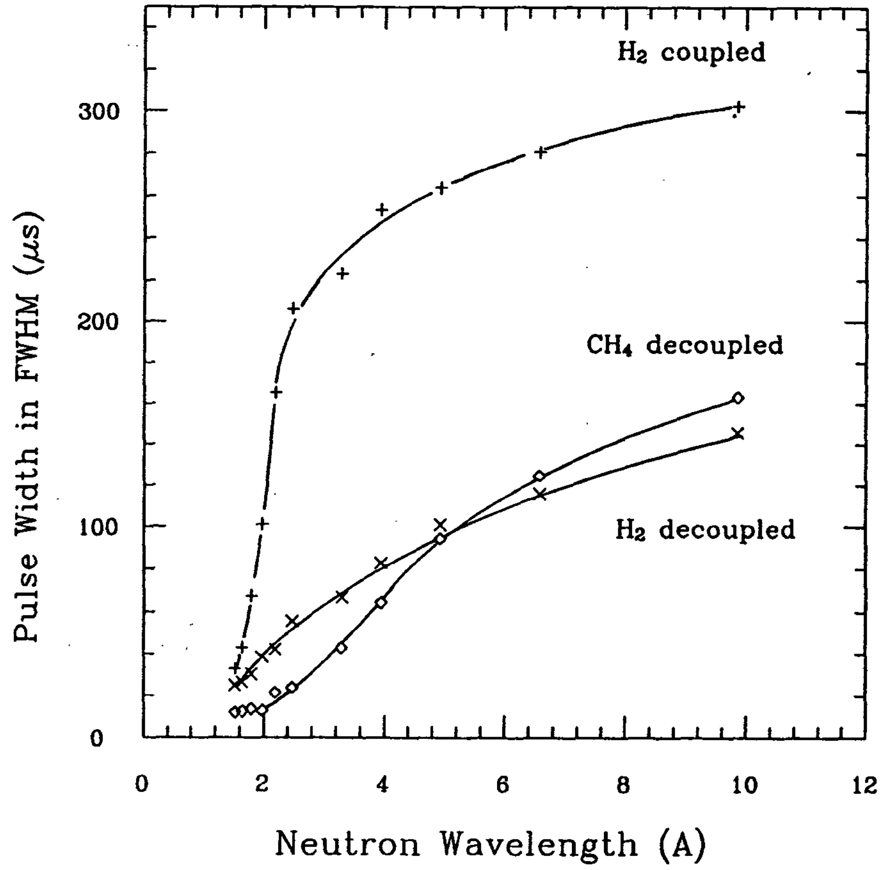

Fig 12 Pulse widths (FWHM) of neutrons from the coupled and decoupled moderators as a function of neutron wavelength.

Rising time of the neutron pulses is also plotted in Fig. 13. Here, the rising time is defined as the duration between 10 and 90 percent pulse height of the rising edge. The difference between the coupled moderator and the decoupled ones is not so large as in the pulse widths.

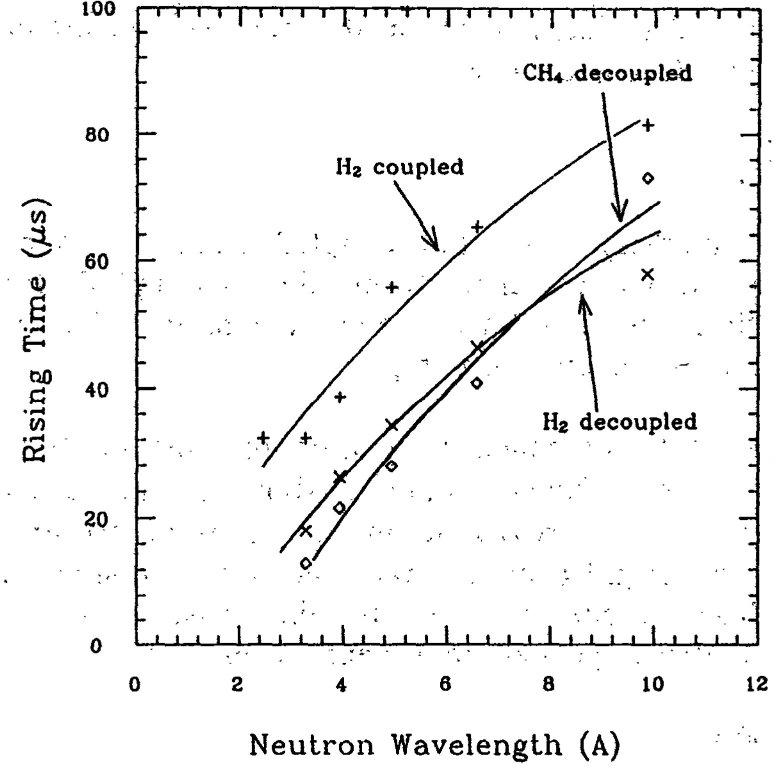

Fig. 13 Rising time of neutron pulses as a function of neutron wavelength.

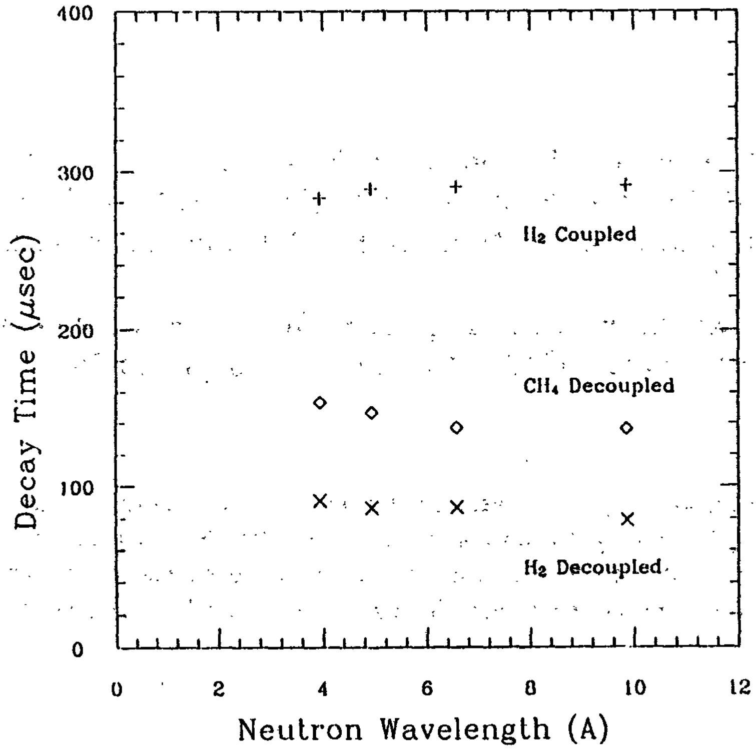

Fig. 14 Decay time of neutron pulses as a function of neutron wavelength.

Figure 14 shows the decay time of the neutron pulses as a function of neutron wavelength. The decay time of the coupled moderator is about 2~3 times as large as the decoupled one.

VI. CONCLUSIONS

The cold neutron intensity from the coupled liquid-hydrogen-moderator is about 6 times as large as that from the decoupled liquid-hydrogen-moderator and 2 times from solid-methane moderator. The increase of the intensity by coupling is considerably high.

It was so far believed by computer simulation that the pulse broadening in a coupled moderator is significant: about 5 times as broad as in a typical decoupled one2). It is revealed in the present experiment that the broadening is not as significant as expected by computer simulation. A coupled liquid-hydrogen-moderator will be the most intensive cold neutron moderator among realistic pulsed cold neutron moderators.

ACKNOWLEDGEMENTS

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Q(R.Pynn): What happens if we imagine the "premoderator" to be homogeneously embedded in the moderator? Would we gain anything by "feeding" the moderator from inside, rather than from outside?

A(Y.Kiyanagi): To feed thermal or epithermal neutrons to liquid hydrogen moderator is important for coupled hydrogen moderator. Therefore, the premoderator have to be placed outside the liquid hydrogen and may not be cooled down.