Preliminary optimization experiments of coupled liquid hydrogen moderator for KENS-II

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ABSTRACT: As a preliminary optimization experiment on the cold-neutron source for KENS-II, energy and time distributions of cold neutrons emanating from coupled liquid-hydrogen moderators with and without a premoderator in a graphite reflector were measured and compared with those from a decoupled liquid-hydrogen moderator. The results showed that the energy spectra from the coupled liquid-hydrogen moderators are almost the same as those from a decoupled one. Relative gain of the former to the latter is fairly high, more than 5, and further increases with increasing wavelength. The broadening of the neutron pulse width in coupled moderators at the cold-neutron region is not so significant and only 1.5 times compared to the solid methane moderator presently operated at KENS-I'.

Introduction

Development of a high-intensity cold neutron source is one of the most important R&D programs for KENS-II, the next generation pulsed neutron source in Japan. We are aiming at the realization of one order of magnitude higher beam intensity of time-averaged cold neutrons than ISIS with the nearly same proton beam intensity. The reason why we need it and a philosophy for the cold-neutron source in KENS-II are described in a separate contribution (Watanabe). As a first step of this program we decided to study coupled liquid-hydrogen moderators with a graphite reflector.

Bauer, et al., have already performed measurements on such a system and reported a fairly large gain with a premoderator but an unexpectedly higher value of the effective neutron temperature T_N. Higher gain is the most important advantage of this kind of moderator, but higher T_N is a fatal disadvantage. Since we could not understand the reason why they observed such high T_N, we planned to perform careful measurements of energy spectra from these systems. In the present paper we report the measured results on energy and time distributions from a liquid-hydrogen moderator with and without premoderators in a graphite reflector.

Experiment

The electron linac at Hokkaido university was used as a neutron generator for the present optimization experiment. A target-moderator-reflector assembly is shown in

Fig. 1. The neutron generating target is a lead block of the dimensions shown in the figure. Energy and time-averaged electron beam current were 45 MeV and 60 nA, respectively, with a repetition rate of 47 Hz. The electron beam power was 27.5 W, which corresponds to the fast neutron production rate of 6.9 x 10^{10} n_f/sec, assuming that the neutron yield from a non-fissionable heavy metal target is 2.5 x 10^{12} n_f/sec/kW for this electron energy.

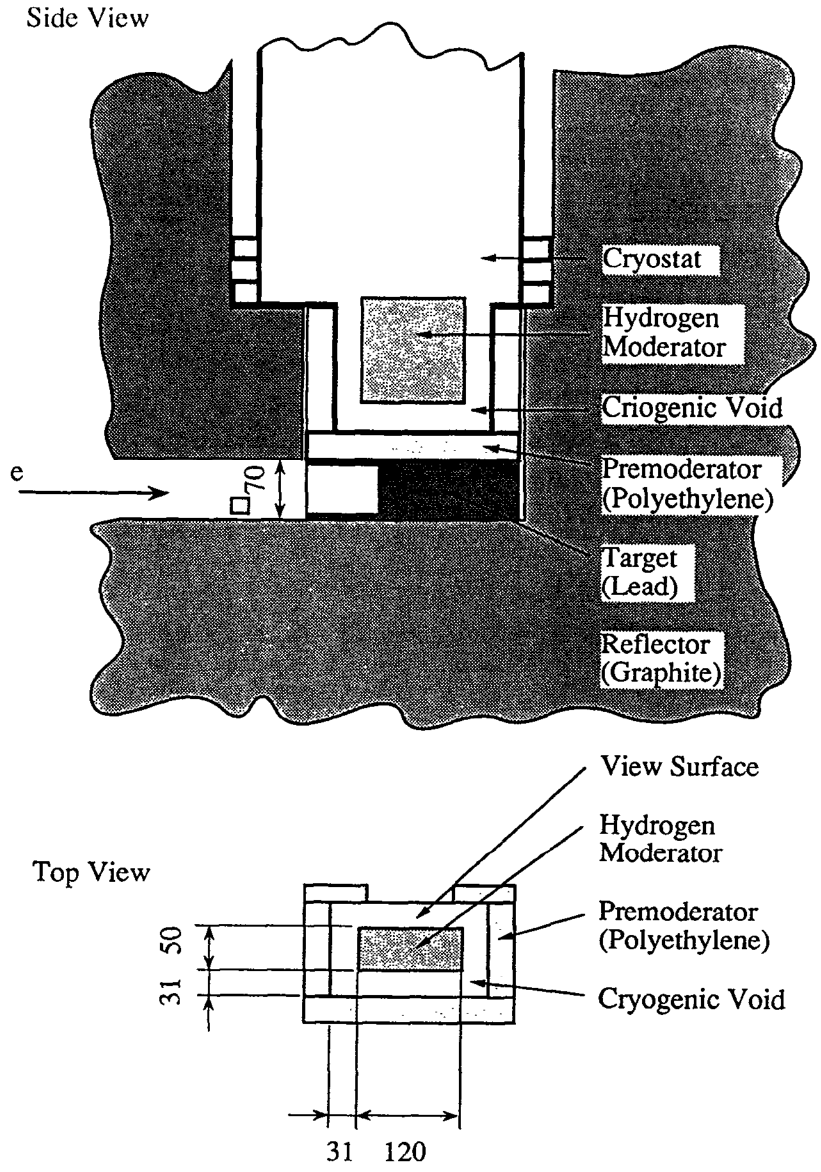

Fig. 1 Schematic representation of the target-moderator-reflector assembly used in the present experiment.

The cold moderator under study is liquid hydrogen, 12 cm wide x 12 cm high x 5 cm thick condensed in an aluminum container cooled by circulating low temperature helium. We initially performed measurements on a 5-cm-thick hydrogen moderator for convenience because it has already been shown that the gain factor of a coupled hydrogen moderator is not sensitive to the moderator thickness (Bauer, et al.) Polyethylene plates were used as the premoderator and the relative gain of the cold neutron beam intensity was measured as a function of the premoderator thickness. The target and the moderator were covered by a graphite reflector of the dimensions shown in Fig. 2, which has only two holes for the electron beam entrance and the neutron beam extraction. Figure 2 shows the layout of the experimental set-up. A helium-3 gas proportional counter of 1 inch in diameter and filled to 10 atoms. was used as a neutron detector. The detector was shielded by a sufficient amount of B_4C and borated resin. The detector was placed at about 6 m from the spectrum source for measurements of energy spectra by time-of-flight (TOF). In the case of the time distribution measurements, a crystal analyzer system shown in the figure was used. A mica crystal was used as analyzer crystal with Bragg angle $2\theta_B = 160°$ to obtain the required time resolution.

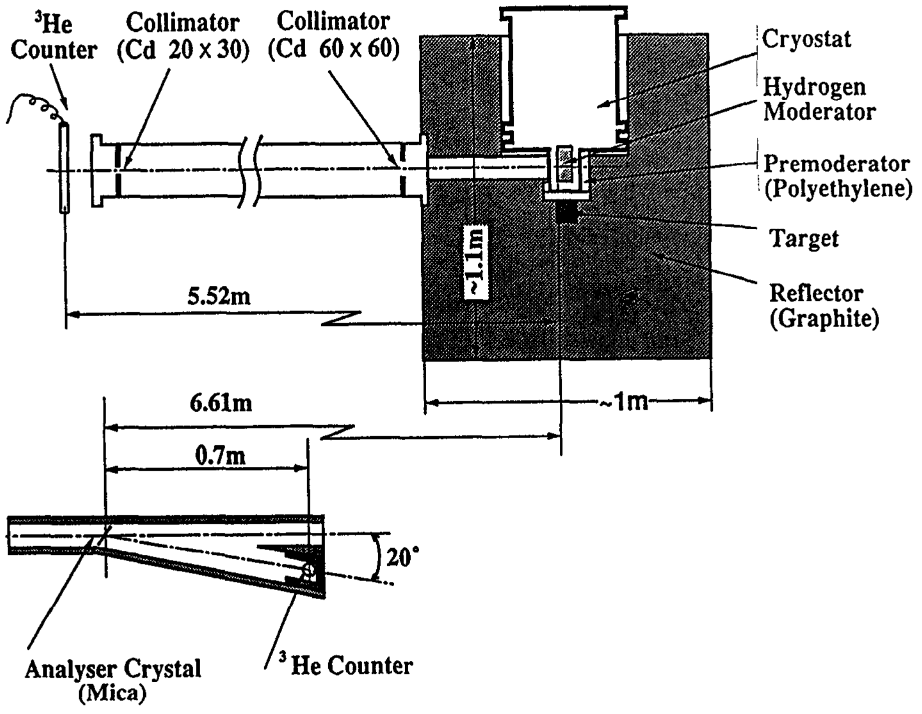

Fig. 2 Layout of the experimental set-up. The lower figure of the detecting system shows the crystal analyzer system used in the measurements of time distribution.

At the neutron beam exit of the target-moderator-reflector assembly, a beam slit made of cadmium with an opening of 60 mm x 60 mm was carefully positioned so the detector could view only the spectrum source. This is very important to obtain a correct T_N from a coupled moderator. Another cadmium slit with an opening of 20 mm x 30 mm was placed in front of the detector or the crystal analyzer system. Hydrogen gas was condensed in the moderator container cooled by a heat exchanger at the top of the moderator container. In the measuring time hydrogen was almost parahydrogen. The cryostat used in this preliminary experiment was not optimized for this purpose but was just an existing cryostat after the minimum modification. The cryostat, therefore, has a large volume above the moderator container and, consequently, removed considerable parts of the upper premoderator and the upper graphite reflector as shown in Fig. 2. Nevertheless, this system provided a fairly large gain factor as described later.

Energy spectra

TOF spectra of neutrons from a cadmium-decoupled liquid-hydrogen moderator and various coupled ones in a graphite reflector, with and without premoderator, were measured. A bare liquid-hydrogen moderator was also measured for comparison. Measuring time was 2000 sec for each moderator. Figure 3 shows the energy spectra obtained from the TOF spectra after necessary corrections. The relative gain of the coupled moderators are considerably higher than either the bare moderator or the decoupled one.

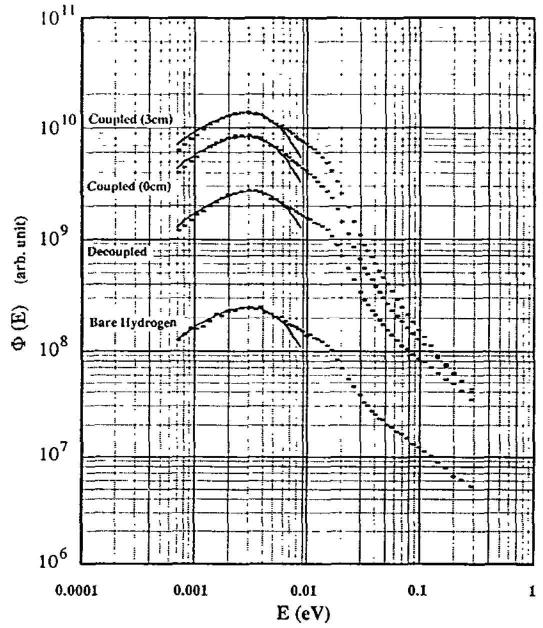

Fig. 3 Energy spectra from various moderators; from the top a coupled 5-cm-thick liquid hydrogen moderator with a 3-cm-thick polyethylene premoderator, a coupled one without premoderator and a decoupled one all in a graphite reflector, and a bare one. Solid curves show the Maxwell distributions fitted to the measured data below 5 meV.

It is well known that the energy spectrum from a liquid-hydrogen moderator is not expressed by a Maxwellian, but we fitted the spectra at lower energy region by Maxwellians as shown in Fig. 3 (solid curves). As obvious from the figure, the Maxwellian fits are not so bad if we restrict the energy range below 5 meV. The effective neutron temperatures T_N obtained by these fits are listed in Table 1. T_N's of the coupled moderators with and without a premoderator are reasonably low and almost the same as that of the decoupled or the bare moderator. Present results are very much different from those by Bauer, et al. We confirmed T_N ~33K, while they reported a value of T_N ~80K. The present results show that the increase of the gain comes mainly from the coupling with reflector, and that the existence of the premoderator gives an additional gain that is not as large as the former.

Table I Effective temperature of neutrons from various moderators.

Moderator	T_N (K)*
Coupled (with polyethylene 3 cm thick)	33.2
Coupled (without premoderator)	32.8
Decoupled	36.5
Bare	34.8

*accuracy of T_N is about ±1 K

Next we studied the effect of the premoderator thickness on the relative gain. Here we define the relative gain as the ratio of the integrated cold-neutron-beam intensity below 5 meV from the coupled moderator to those from the decoupled one. Figure 4 shows the relative gain as functions of the bottom (between target and liquid hydrogen) and the side premoderator thickness. The relative gain increases with increasing bottom premoderator thickness and saturates at about 3 cm. The increase of the side premoderator thickness brings further increase of the relative gain, but it is rather modest and also saturates at about 3 cm as shown in the figures. The present results show that the optimal premoderator thickness is about 3 cm.

In Fig. 5 we plot the ratio of neutron beam intensity from the coupled moderator with the 3-cm-thick premoderator to that from the decoupled one as a function of neutron wavelength. The ratio increases slightly with neutron wavelength. This is also a benefit of the coupled moderator.

Time distributions

We performed the measurement of neutron time distributions at various energies from the coupled moderator with the 3-cm-thick premoderator and from the decoupled moderator using the crystal analyzer system described in the preceding section. The results at selected energies are shown in Figs. 6 to 9 where the time distributions from both moderators are compared with each other. Solid curves show the enlarged profile from the decoupled moderator normalized at the pulse peak for direct comparison. The coupled moderator gives broader pulses than the decoupled one as expected, but the broadening is rather modest and the increase in the peak intensity is unexpectedly high. This means that the larger gain of the coupled moderator is not mainly due to the increase of the pulse width, but to the increase in the peak intensity. This feature is very much favorable for a pulsed cold-neutron source.

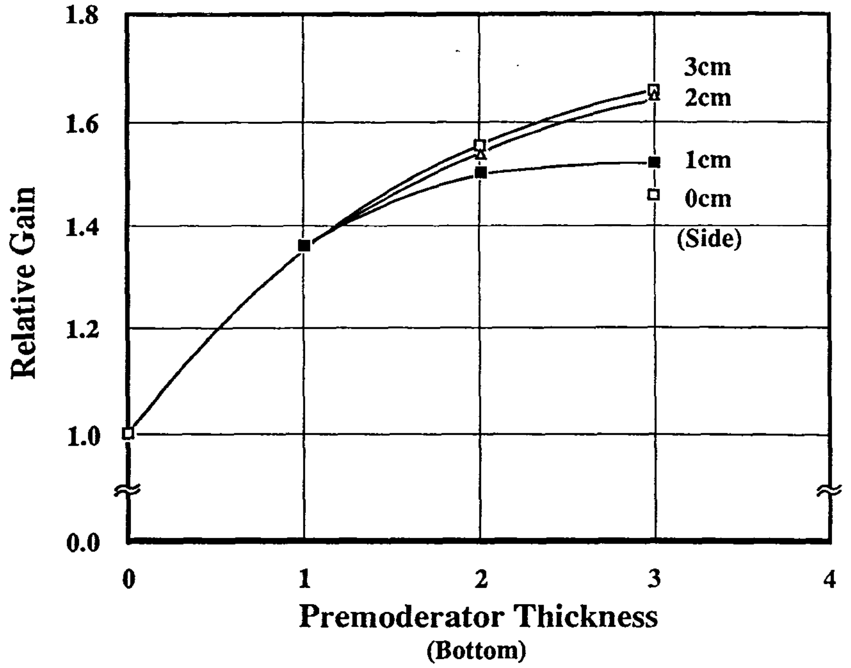

Fig. 4 Relative gain of coupled moderators below 5 meV as functions of bottom and side premoderator thickness.

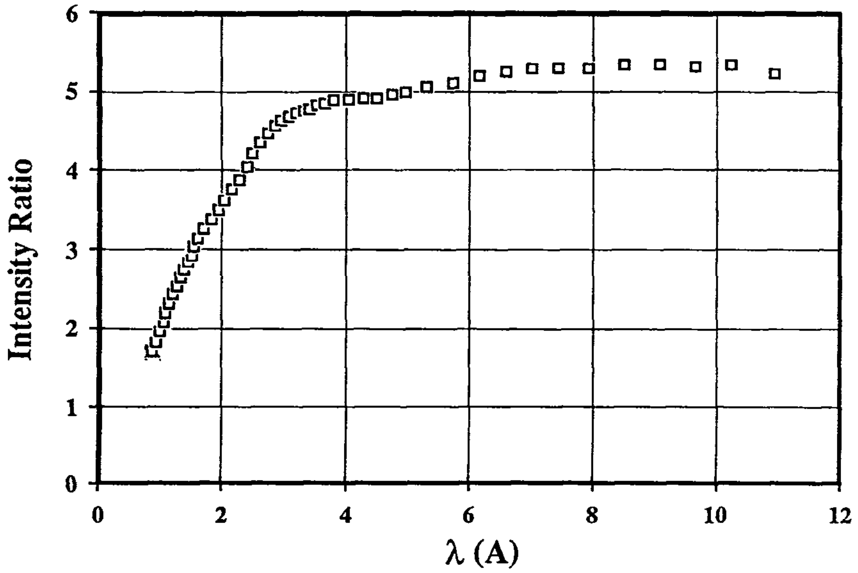

Fig. 5 Ratio of neutron beam intensity from the coupled moderator with a 3-cm-thick premoderator to that from decoupled one as a function of neutron wavelength.

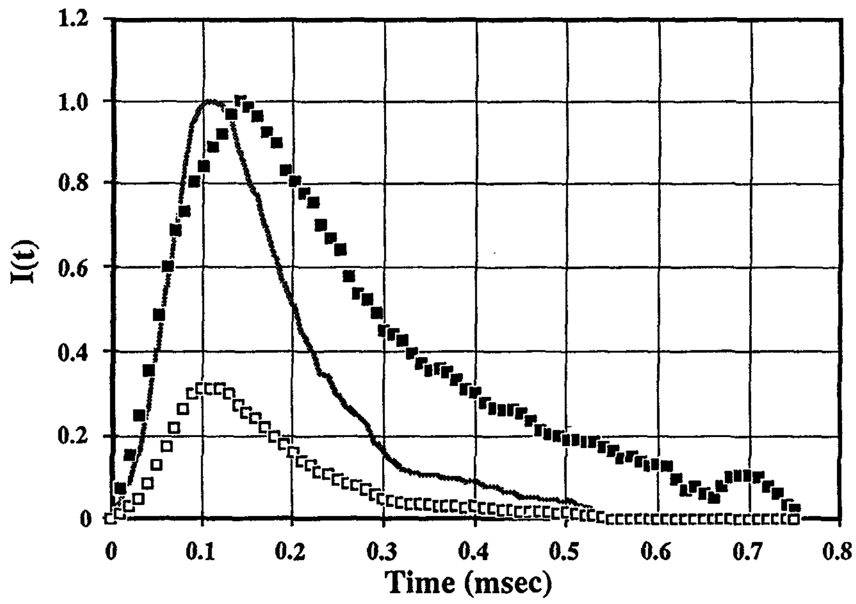

Fig. 6 Time distributions of 0.82 meV neutrons emanating from the coupled moderator (solid square) and the decoupled one (open square). Solid curve shows the latter normalized at pulse peak for direct comparison.

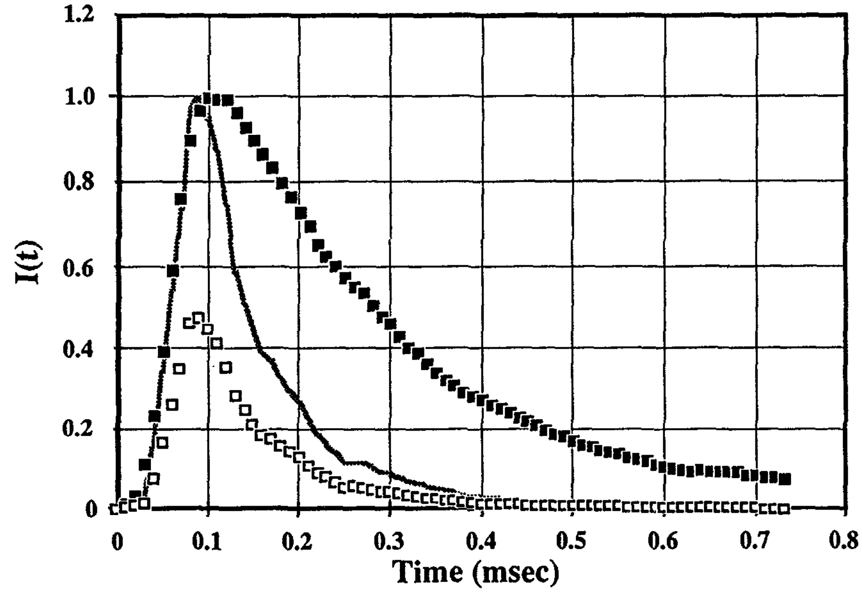

Fig. 7 Time distributions of 5.1 meV neutrons emanating from the coupled moderator (solid square) and the decoupled one (open square). Solid curve shows the latter normalized at pulse peak for direct comparison.

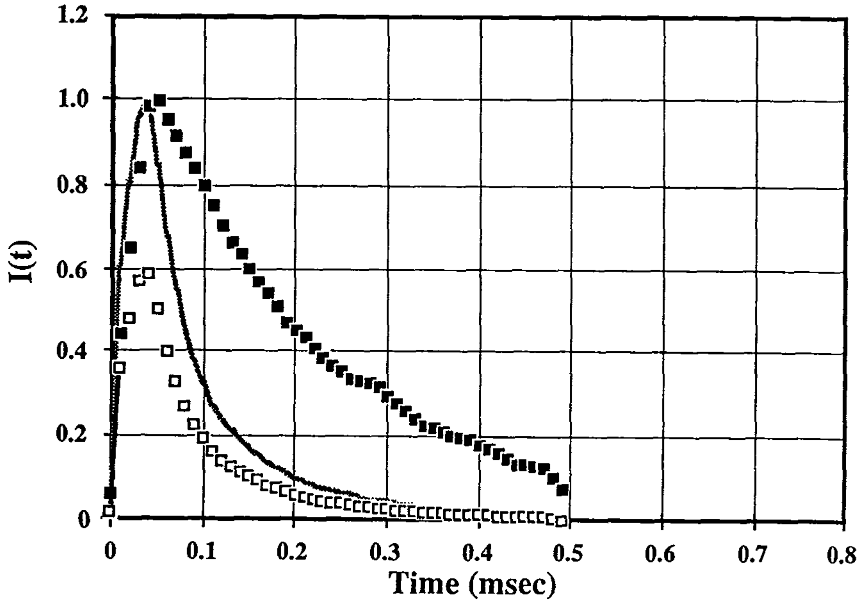

Fig. 8 Time distributions of 16.5 meV neutrons emanating from the coupled moderator (solid square) and the decoupled one (open square). Solid curve shows the latter normalized at pulse peak for direct comparison.

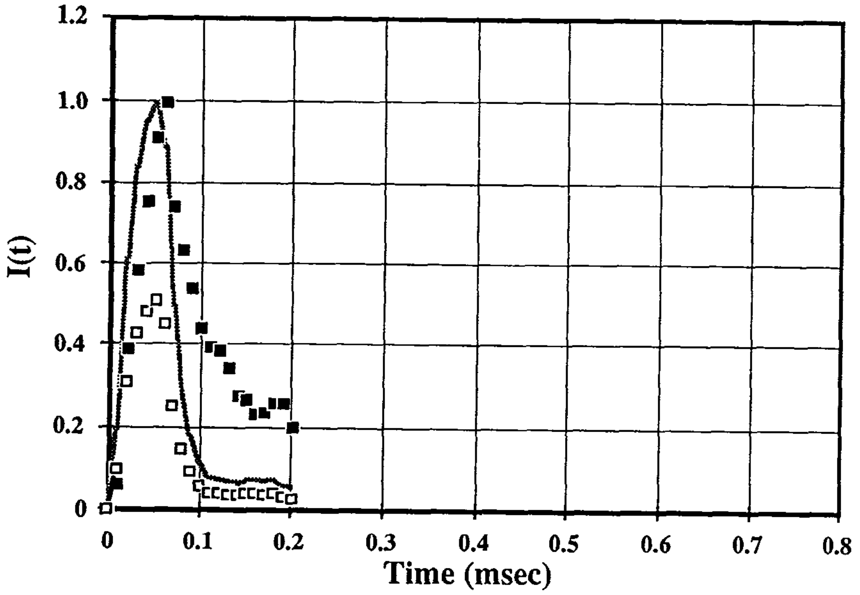

Fig. 9 Time distributions of 40.1 meV neutrons emanating from the coupled moderator (solid square) and the decoupled one (open square). Solid curve shows the latter normalized at pulse peak for direct comparison.

As obvious from the direct comparison with the data from the decoupled moderator (solid curves), the rising characteristics of the neutron pulses from the coupled moderator are almost the same as those from the decoupled one. This will be another important merit of this type of moderator. The present values, however, are considerably larger than those of the KENS solid methane moderator.

Neutron pulse widths, in full width at half maximum (FWHM), from these two moderators are plotted in Fig. 10 as a function of neutron wavelength. The corresponding values from the solid methane moderator at 20 K presently used at KENS are also shown by a solid curve for comparison. The pulse widths from the coupled moderator are about a factor of two broader than those from the decoupled one and only about a factor of 1.5 if we compared with those from the present KENS solid methane.

Figure 11 shows the semi-logarithmic plots of the time distributions displayed in Fig. 7. Reciprocal decay time α's at various wavelengths are obtained from these plots and shown in Fig. 12.

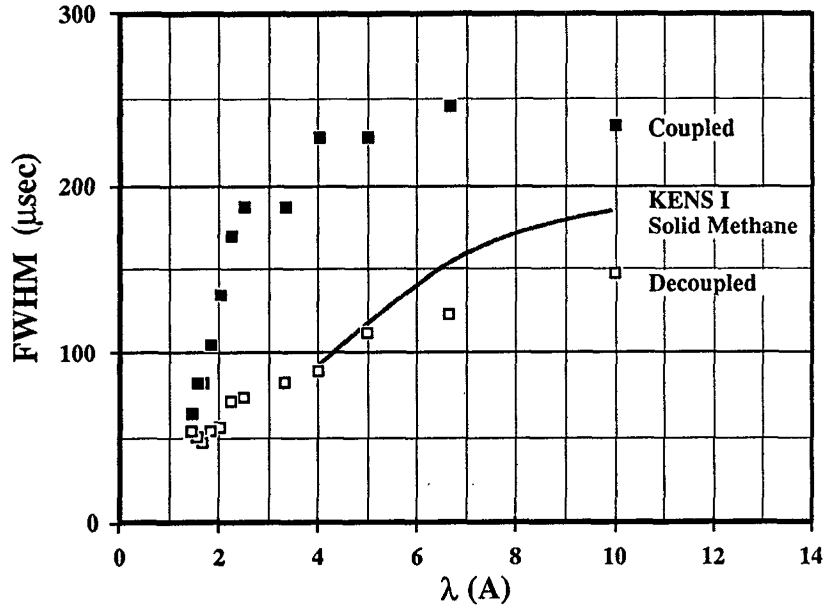

Fig. 10 Neutron pulse widths (FWHM) from the coupled (solid square) and decoupled (open square) moderators as a function of neutron wavelength. Solid curve shows the corresponding values of the present KENS solid methane at 20 K.

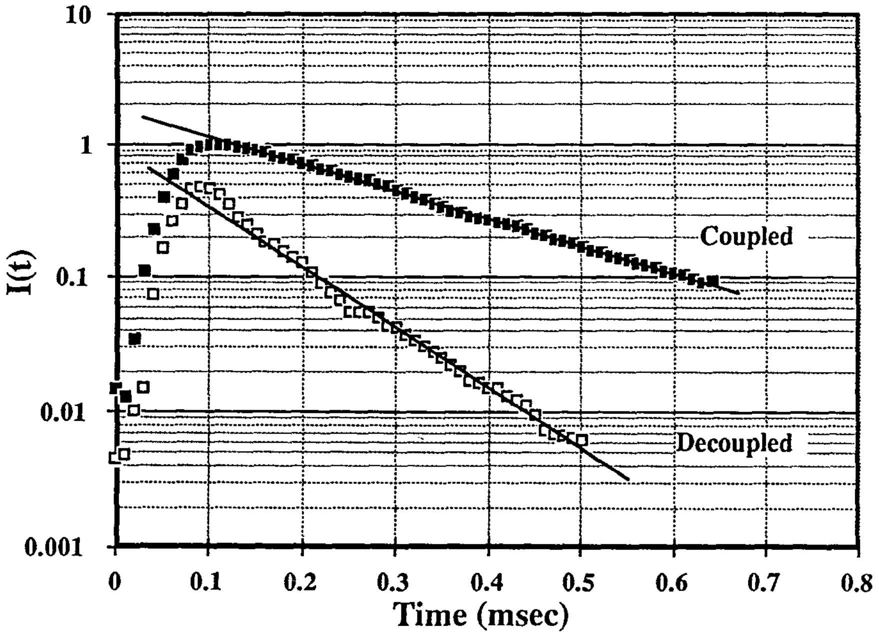

Fig. 11 Semi-logarithmic plots of the time distribution of 5.1 meV neutrons. Reciprocal decay time α's were determined from the straight line.

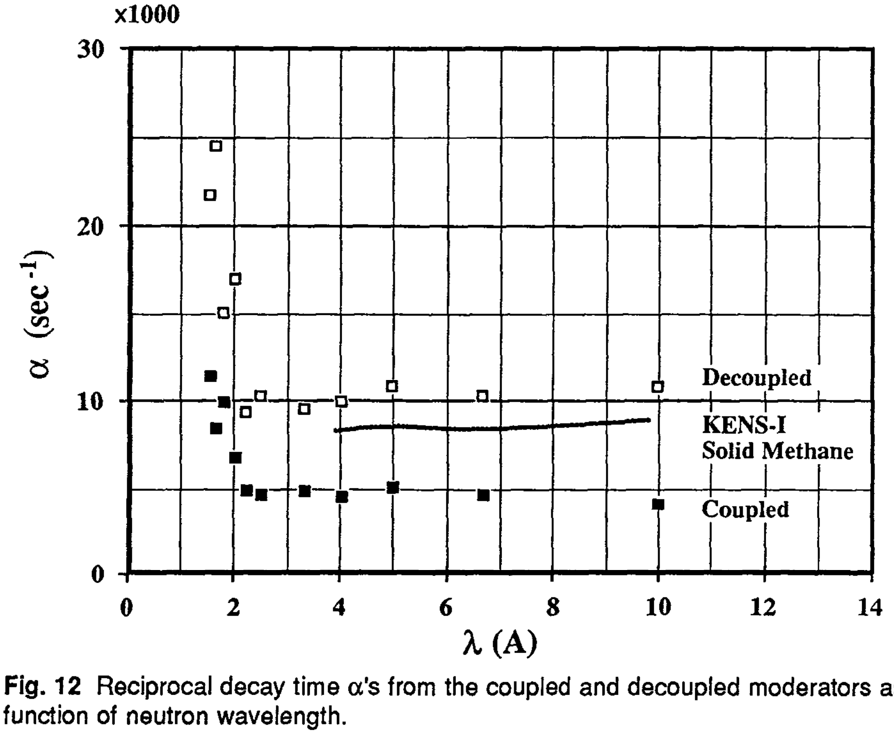

Fig. 12 Reciprocal decay time α's from the coupled and decoupled moderators as a function of neutron wavelength.

Discussions and conclusions

In the present experiment on the preliminary optimization of coupled cold moderator, we confirmed a fairly large gain relative to the decoupled hydrogen moderator with a reasonably lower effective neutron temperature. The pulse characteristics of the coupled moderator turned out to be more encouraging than we expected; modest broadening in pulse width, higher peak intensity, and the same rising time as the decoupled one. The present experiment, however, is not absolute measurements but the relative ones. It is, therefore, difficult to argue about the absolute value of the conversion efficiency (cf. contribution by Watanabe). However, we estimated a rough value of the conversion efficiency achieved with the present coupled moderator, which is already better than the value in the present KENS solid methane moderator. Further optimization experiments with a dedicated cryostat are in progress.

References

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