ICANS-XIII
13th Meeting of the International Collaboration on
Advanced Neutron Sources
October 11-14, 1995
Paul Scherrer Institute, 5232 Villigen PSI, Switzerland

# RECENT PROGRESS IN DEVELOPING HIGH-EFFICIENCY CRYOGENIC MODERATORS

N. Watanabe, Y. Kiyanagi* and M. Furusaka

National Laboratory for High Energy Physics, 1-1 Oho, Tsukuba-shi, Ibaraki 305, Japan
* Department of Nuclear Engineering, Hokkaido University, Sapporo 060, Japan

## ABSTRACT

Extensive experimental efforts have been devoted to develop high-efficiency cryogenic moderators for: (1) cold intense, (2) cold sharp, and (3) thermal sharp neutron pulses based on a composite moderator concept. Various ideas to enhance the cold neutron intensity have been examined. New moderators, such as a decoupled composite moderator and a composite moderator with poisoned premoderator, have been proposed and tested in order to realize a narrower cold neutron pulse without sacrificing the peak height. At a longer wavelength region (say >6 Å), the performance of the new moderator is close to that of a decoupled solid methane moderator.

## 1. Introduction

In a high-power pulsed spallation neutron source, it is rather difficult to expect a higher target efficiency, as in a low-power one; generally, he neutronic efficiency of the target decreases with increasing proton-beam power. Thus, R&D of a high-efficiency moderator system becomes important to increase, or at least to keep up with, the total neutronic efficiency of the existing sources. R&D of the moderator is also important, since moderators are the final devices of a pulsed-neutron source, which determine the quality of experiments.

Extensive efforts have been devoted to develop three kinds of high-efficiency cryogenic moderators for: (1) intense cold neutron pulses for any pulse width; (2) narrower cold neutron pulses with the highest peak height; and (3) narrower thermal neutron pulses, under the condition that solid and liquid methane cannot be used at intense sources. Thus, liquid-hydrogen (L-$H_2$) becomes only one cryogenic moderator material. Our moderators under development are all based on L-$H_2$.

## 2. Development of composite moderators for intense pulses of cold neutrons

For experiments such as small angle neutron scattering (SANS) and critical scattering (reflectometry), the time-integrated intensity of cold neutrons per pulse is, in principal, only

---

Keywords: Pulsed neutron, Cryogenic moderator

important (independent of repetition rate) within a realistic range of the repetition rate. In this case, the figure-of-merit (FOM) for a pulsed source is written as [1]

$$\mathrm{FOM}(\lambda) \propto \int I_1(\lambda, t)\, dt,$$

where $I_1(\lambda, t)$ is the neutron intensity per pulse at wavelength $\lambda$ and emission time t. A coupled composite moderator of L-$H_2$ and a hydrogenous premoderator at ambient temperature is best for this purpose among the moderators which we studied. Here, we summarize the results of R&D already achieved on this moderator system and future plans.

### *2.1 Already achieved or studied*

*(1) Gain factor*

A gain factor of about 6 has been obtained compared to that of a typical decoupled L-$H_2$ moderator (coupling gain factor 3 × premoderator gain factor 2). [2]

*(2) Premoderator material*

Polyethylene, light water ($H_2O$) and zirconium hydride ($ZrH_2$) were compared.[3] Polyethylene gave the highest gain factor. $H_2O$ gave a lower gain factor (about 90% of the polyethylene gain factor ). $ZrH_2$ was the worst.

*(3) Function of premoderator*

Thermal and epithermal neutron intensities from premoderator boxes (without L-$H_2$) comprising polyethylene, $H_2O$ and $ZrH_2$ of various thicknesses were compared. From this comparison it was found that the cold-neutron intensity is almost proportional to the thermal-neutron intensity produced inside the premoderator box. [3]

*(4) Realistic premoderator material*

Polyethylene cannot be used at an intense source. Thus, $H_2O$ becomes the best premoderator material, although the gain factor is slightly loywer than that of polyethylene.

*(5) Gain factor vs. premoderator thickness*

From a neutronic point of view, there is an optimal premoderator thickness (beyond which the gain factor starts to decrease) for each material. The optimal thicknesses are about 2 cm for polyethylene and 2-3 cm for $H_2O$. [2-4]

*(6) Choice of premoderator thickness*

It is now well known that a premoderator plays an important role not only to enhance the cold neutron intensity from a cryogenic moderator, but also to reduce the energy deposition in it. For the latter purpose, a thicker premoderator is better. Therefore, a compromise is necessary in determining the premoderator thickness.

*(7) Coexistence of coupled and decoupled moderators*

In the large-scale facilities under planning, two target stations dedicated to low and high repetitions are being considered. Usually, in a low-repetition-target station, both coupled and decoupled moderators must be installed in one target-moderator-reflector assembly. In this case it is important to know how much the gain factor of a coupled moderator decreases in the presence of decoupled moderators. This problem was studied experimentally.[2] The decrease is about 16%.

*(8) Various efforts to increase the intensity*

How to increase the cold neutron intensity from a coupled composite moderator system is one of the most important tasks in the R&D of this kind of moderator. Various efforts have been devoted to this purpose. The results are briefly described below :

(a) Grooved premoderator

It is already known that in a wing geometry the premoderator gain factor is most sensitive to the thickness of the bottom premoderator adjacent to the target. We therefore expected that grooving the bottom premoderator might increase the intensity. The additional gain by this procedure was only 3%.[2]

*(b) Optimal thickness of L-$H_2$*

Our previous result showed that the cold neutron intensity from a coupled composite moderator with 2 cm thick L-$H_2$ was considerably lower than that with 5 cm thick L-$H_2$,[4] suggesting a further intensity gain with a thicker L-$H_2$. However, the measured result with 6.5 cm thick L-$H_2$ showed no further gain (the gain factor decreases beyond at 5 cm thick).[5]

*(c) Be reflector- filter*

A 1.5 cm thick Be reflector-filter cooled down to 20 K was attached in front of the L-$H_2$, expecting a further gain. The result was pessimistic; no additional gain was found.[5]

*(d) Partial enhancement of intensity*

For cold-neutron experiments, such as SANS and reflectometry, only a part of the moderator is viewed by instruments. By masking the remaining surface of the moderator by an additional premoderator, a further gain of about 15% has been achieved.[5]

*(e) Solid methane with a premoderator*

It may be interesting to know whether a coupled composite moderator with solid methane as a main cryogenic moderator can give a higher intensity than that with L-$H_2$, although solid methane cannot be used at an intense source. The result of direct comparison measurements showed that a composite moderator with solid methane can not surpass a coupled composite with 5 cm thick L-$H_2$.[4]

### *2.2 Other ideas for increasing intensity*

The following ideas should be examined:

*(1) Grooved composite moderator*

A coupled composite moderator with a grooved L-$H_2$ would be interesting to test. A cryogenic moderator chamber (total thickness of 9 cm with 4.5 cm deep grooves, 12 cm wide and 12 cm high) has been arranged for this test.

*(2) Overlap composite moderator*

In simple decoupled moderators at room-temperature in a flux-trap geometry we were successful to obtain a 40-50% higher intensity than that of a conventional configuration, by overlapping part of the moderator with the target.[6] This idea will also be worth testing in the case of coupled composite moderators.

## 3. Development of a composite moderator for narrow pulses of cold neutrons

Another important field of a scattering experiments utilizing cold neutrons is high-resolution ($\mu$ eV or sub $\mu$ eV ) spectroscopy. A simple inverted-geometry-type spectrometer is typical for this purpose, since the instrument has high efficiency (for example, LAM-80ET at KENS and IRIS at ISIS), and a very wide energy window compared to the corresponding reactor instruments. In this application the FOM of the cold-neutron source is proportional to the peak height of the neutron pulse $\hat{I}_1(\lambda, t)$ as[1]

$$\mathrm{FOM}(\lambda) = \hat{I}_1(\lambda, t) ,$$

provided that the required length of the neutron guide is available between the moderator and the sample. We have proved experimentally that a coupled composite moderator with 5 cm thick L-$H_2$ can provide about a 2-times higher pulse height than the typical decoupled L-$H_2$ moderator. However, from a practical point of view, a longer guide tube (say more than 200 m) may not be acceptable. A moderator which can provide a narrower pulse without sacrificing the peak height then becomes more acceptable. From extensive measurements, we found that the pulse width (FWHM) and the long-time tail can be controlled to some extent (as described below).

*3.1 Already achieved or studied*

*(1) Effect of a premoderator and reflector*

It was found that the pulse width is mainly determined by the premoderator, while the long-time tail is mainly affected by the deflector.[7],[8]

*(2) Decoupled composite moderator*

Therefore, by decoupling a composite moderator from a reflector, one can eliminate or improve the long-time tail. On the other hand, by reducing the premoderator thickness, one can squeeze the pulse width (see Fig. 2 in ref.8 ). For example, a decoupled composite moderator with the 5 cm thick L-$H_2$ and a 1 cm thick premoderator can reduce the pulse width down to 40% at a cost of the peak intensity about 20% (see Fig. 2 in ref.8 ). A simple coupled 5 cm thick L-$H_2$ moderator without a premoderator can bring about a similar improvement in the pulse width without sacrificing the peak height, as shown in Fig. 1. However, the long-time tail from the decoupled composite moderator is largely improved compared to the simple coupled one.

*(3) Poisoned premoderator*

It is well known that in a decoupled moderator an interleave poison can improve the pulse characteristics (pulse width and long-time tail) at a cost of the time-integrated intensity. It is interesting to examine what would happen with a composite moderator comprising 5 cm thick L-$H_2$ with a poisoned premoderator. In recent experiments based on this idea, the following results were obtained. A composite moderator with 5 cm thick L-$H_2$ and a poisoned bottom premoderator (0.5 cm thick $H_2O$ inside the Cd interleave poisoning plate and 1 cm outside for bottom premoderator ) gives better pulse characteristics than does a decoupled composite moderator with 5 cm thick L-$H_2$ and a 1 cm thick $H_2O$ premoderator (a slightly higher peak height, a narrower pulse width and a faster decay time), as shown in Fig.4 in ref.8 .

### *3.2 Can a composite moderator equal decoupled solid methane ?*

As far as the time-integrated intensity is concerned, it has already been proved that a coupled composite moderator with 5 cm thick L-$H_2$ and a 3 cm thick $H_2O$ premoderator can provide about a 2-times higher cold-neutron intensity than a decoupled 5 cm thick solid-methane moderator. For narrow-pulse use, an important question is whether the decoupled composite moderator described in (3) in the foregoing section can equal solid methane? It is one of the most important targets of our R&D work to seek a new moderator by which a decoupled solid methane moderator can be replaced. At the present stage it can be said that the performance of the composite moderator described in (3) is very close to that of the decoupled solid methane at a longer wavelength region (say above 6 Å), but not yet at a shorter wavelength region(~4 Å).[8]

### *3.3 Other ideas*

The following ideas should be examined.

*(1) Use of a non-moderating reflector*

The use of a non-moderating reflector (for example, iron) will allow a decoupler to be removed in both simple and composite moderators. This may bring about a better result in intensity without deteriorating the decay time or long-time tail.

*(2) Thinner L-$H_2$*

The pulse width of cold neutrons from the decoupled composite moderator described in (3) is close to that from a simple decoupled 5 cm thick L-$H_2$ moderator. The premoderator of this thickness has little effect on the pulse width. This result suggests that a composite moderator with a thinner ($<5$ cm) L-$H_2$ may bring about a better result.

*(3) Removing the side premoderator*

In the composite moderator described in (3), we have confirmed that the cold neutron intensity was somehow increased by removing the outside premoderator in the side premoderator.[8] We have not yet measured the pulse characteristics of this moderator, which should be better than those of the former.

## 4. Moderator for a narrow thermal-neutron pulse

For such experiments as high-resolution powder diffraction and high-resolution spectroscopy using thermal neutrons, narrow thermal-neutron pulses are essentially important; a solid-methane moderator (KENS) or poisoned liquid-methane (L-$CH_4$) moderator (ISIS) has been used up to now. The use of an L-$CH_4$ moderator becomes more and more difficult with increasing proton-beam power due to radiation damage. Thus, R&D of a new moderator which can replace a poisoned L-$CH_4$ moderator becomes important. One idea is a decoupled composite moderator with L-$H_2$ and $ZrH_2$ at low temperature (20K). A thin L-$H_2$ moderator is used in this case with a hydrogenous moderator which can compensate for any shortage of the hydrogen number density of L-$H_2$, and must be free from radiation damage. $ZrH_2$ will be a good candidate due to its higher hydrogen number density and higher resistance against radiation damage. In this application $ZrH_2$ must be cooled down to a low temperature in order to suppress any pulse-width broadening. A preliminary experiment was performed on this kind of moderator.[9] However, the instrumental time-resolution for measuring the pulse shape was not sufficient at a shorter wavelength region (say, below 1.5Å) to judge the pulse width from such moderators. A new time-focusing crystal analyzer having a large solid angle is under preparation. Measurements of various moderators will be performed after the completing the new instrument.

## References

[1] N.Watanabe and Y. Kiyanagi : Physica B 180 &181 (1992) 893.

[2] Y.Kiyanagi, N.Watanabe and H.Iwasa : Nucl. Inst. Methods A 312 (1992) 561.

[3] Y.Kiyanagi, N.Watanabe and H.Iwasa : Nucl. Inst. Methods A 343 (1994) 558.

[4] Y.Kiyanagi, S.Satoh, H.Iwasa, F.Hiraga and N.Watanabe : Physica B 213 & 214 (1995)857.

[5] Y.Kiyanagi, Y.Ogawa, N.Kosugi, H.Iwasa, M.Furusaka and N.Watanabe : Further optimization of coupled liquid hydrogen moderator for intense neutron sources, on this proc.

[6] Y.Kiyanagi, N.Watanabe and M.Nakajima : Nucl. Inst. Methods A 343 (1994) 550.

[7] Y.Kiyanagi, J.M.Carpenter, N.Kosugi, H.Iwasa, F.Hiraga and N.Watanabe : Physica B 213 & 214 (1995) 854.

[8] Y.Kiyanagi, N.Kosugi, Y.Ogawa, H.Iwasa, F.Hiraga, M.Furusaka and N.Watanabe : High-efficiency cryogenic moderator system for short pulse use, on this proc.

[9] Y.Kiyanagi, J.M.Carpenter, N.Watanabe, H.Iwasa and M.Nakajima : Proc. ICANS-XII (Abingdon, UK, 24-28 May , 1993) T206.

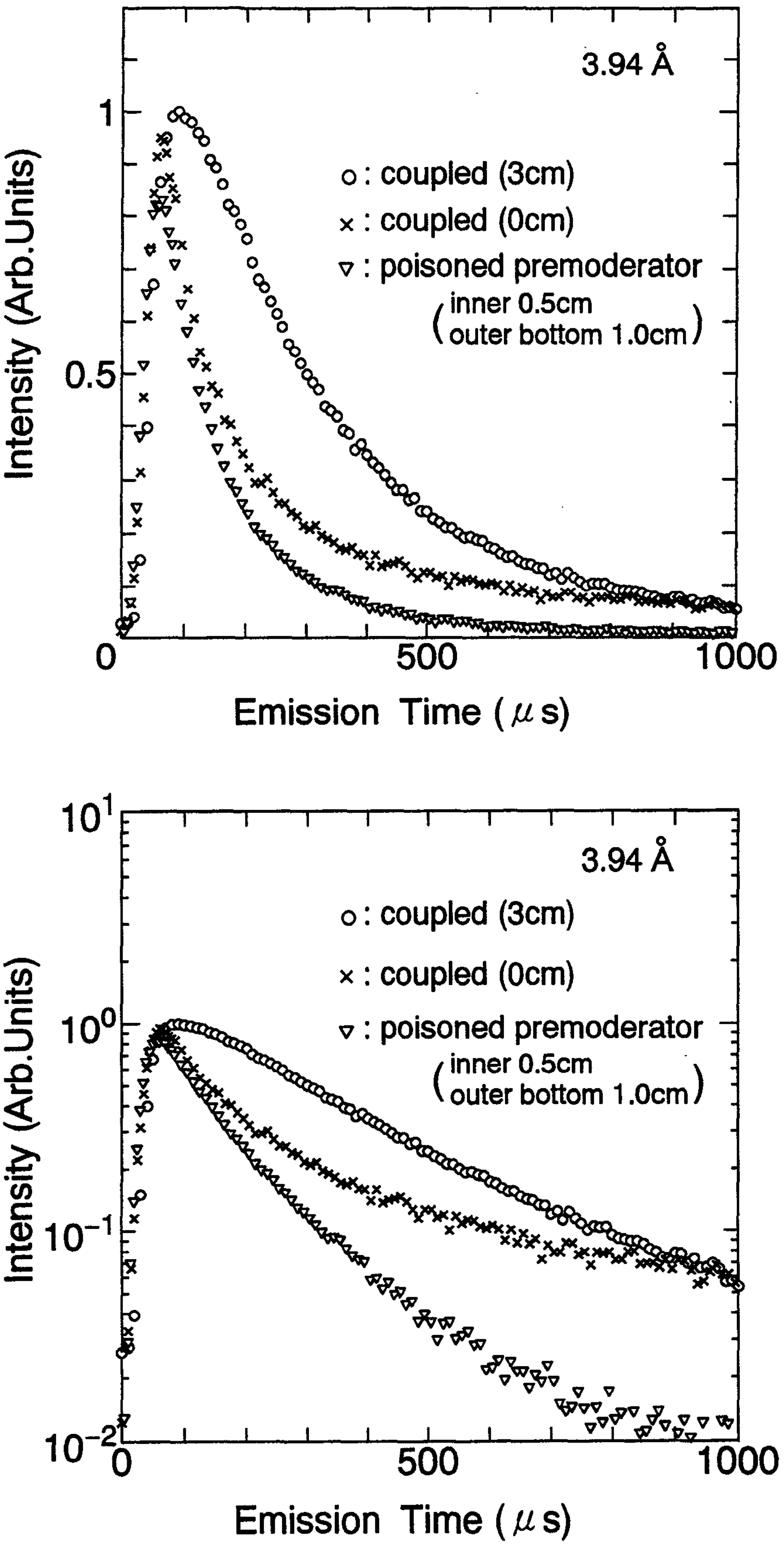

Fig.1 Comparison of cold-neutron pulse shapes (linear and semi log plots) from three moderator systems: a coupled 5 cm thick L-$H_2$ with 3 cm $H_2O$ premoderator (coupled (3 cm)), the same L-$H_2$ without premoderator (coupled (0 cm)), and the same L-$H_2$ with a poisoned premoderator.