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Towards a high-efficiency pulsed cold neutron source

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Abstract

A high efficiency cold neutron moderator has been developed by adopting a fully extended premoderator of the optimized thickness in a coupled composite moderator system consisting of liquid-hydrogen and hydrogenous premoderator at ambient temperature. An additional gain factor of about 24% has been achieved in the time-integrated and peak cold neutron intensities compared with the reference moderator so far been studied, without sacrificing the pulse characteristics. In addition to the better neutronic performance the nuclear heating in liquid hydrogen can be decreased by about 19% with a fully extended premoderator.

1. Introduction

A coupled composite moderator system, which consists of liquid or supercritical hydrogen (H_2) plus hydrogenous premoderator (PM) at ambient temperature coupled to a reflector, was proposed [1,2] in order to improve the shortage in the time integrated cold neutron intensity in a decoupled H_2 moderator and extensive optimization studies have already been carried out [3-6]. An intensity gain factor of about 6 relative to a decoupled H_2 moderator has been confirmed with a polyethylene premoderator [3]. This gain is about 2 times larger even compared with a decoupled solid methane (CH_4) moderator at 20 K, the best pulsed cold neutron moderator so far been used. The peak intensity of pulsed cold neutrons from the composite moderator is approximately 2 times higher than that from a decoupled one and almost comparable to that from a decoupled CH_4 moderator [3]. If we replace polyethylene by light water, since polyethylene cannot be utilized at an intense spallation source and light water would be an unique material for premoderator, the gain factor decreases to a value of about 5 due to a lower hydrogen number density of water [5]. In spite of a great deal of efforts so far devoted to increase the gain factor, it has not succeeded to obtain a further gain except for the case of a coupled composite moderator utilizing a grooved H_2 moderator [7] and for a partially enhanced moderator (in the spatial distribution) [8]. Although a finite gain relative to the reference case (5 cm thick H_2 plus 2.5 cm H_2O) has been obtained in each case, the former is not practical for a supercritical hydrogen system with a very high mass-flow rate required and the application of the latter is limited to a certain class of experiments such as small angle scattering, reflectometry, etc.

We decided to use coupled composite moderators for high-intensity as well as for high-resolution experiments and performed extensive neutronic calculations to seek the optimal parameters and predict the performance of the proposed source [9,10]. We have confirmed excellent cold neutron intensities (per MW), which are at least comparable to a corresponding value obtained for a medium power source (a coupled H_2 moderator without premoderator but with a very large reflector in LANSCE Upgrade [11]). In the process of our optimization study based on the proposed target-moderator-reflector concept, we found that the energy deposition (nuclear heating) in H_2 was rather high in spite of the existence of a premoderator [9,10]. We thought this is due to the fast neutrons which obliquely incident upon the viewed surface of the H_2 moderator from a part of primary neutron source (target) through the beam extraction hole in the reflector, where no premoderator exists. We thought that, if this is true, by extending a bottom premoderator (target side) towards neutron extracting direction to some extent, it should be possible to decrease the energy deposition and hopefully increase the cold neutron intensity, since a very small but a finite intensity gain (about 5%) has already been confirmed by a measurement using an electron-linac-base pulsed-neutron-source [3]. Based on this idea we performed an optimization study by calculation on the proposed coupled composite moderator system. This paper reports the results of the present investigation.

2. Moderator model

The model target-moderator-reflector system used for the present calculations is the same as shown in Fig.1 in a separate paper [10]. The configurations of the H_2 moderators and premoderators used for the calculations are shown in Fig.1. The main moderator (H_2, we assumed normal hydrogen) has fixed dimensions of 12^W x 12^H x 5^L cm^3 and located at a fixed position on the target. Six cases were studied; three cases for different bottom premoderator thickness of 1.5, 2.5 (reference case) and 3.5 cm, one case for an extended bottom-premoderators of 2.5 cm thick and two cases for fully extended premoderators (the inside surface of the beam extraction hole in the reflector was completely covered by the premoderator and the bottom-premoderator thickness was 2.5 cm or 3.5 cm). For all cases we assumed a lead (Pb) reflector about 80^W x 160^H x 120^L cm^3 [9,10]. Table 1 summarizes the cases studied.

For the calculations a high-energy hadron transport code NMTC/JAERI and a low-energy transport code MCNP-4A were used with a cross section set (FSXLIB-JFF, FSXLIB-JFNS and THERXS) . For mercury the cross section set recently evaluated at JAERI was used. The num-

Table 1 Calculational model

	Proton beam	
Proton energy	Current density	Total beam power
1.5 GeV	48 μA/cm^2	5 MW
	Cryogenic moderator	
Temperature		Material
20 K		Normal H2 (Ortho para ratio = 75 :25)
	Premoderaotor	
Temperature		Material
Ambient		Light water
	Calculation	
Calculational model	Thickness of bottom PM (cm)	Extended/Normal
a	1.5	Normal
b (ref.)	2.5	Normal
c	3.5	Normal
d	2.5	Bottom extended
e	2.5	Full
f	3.5	Full

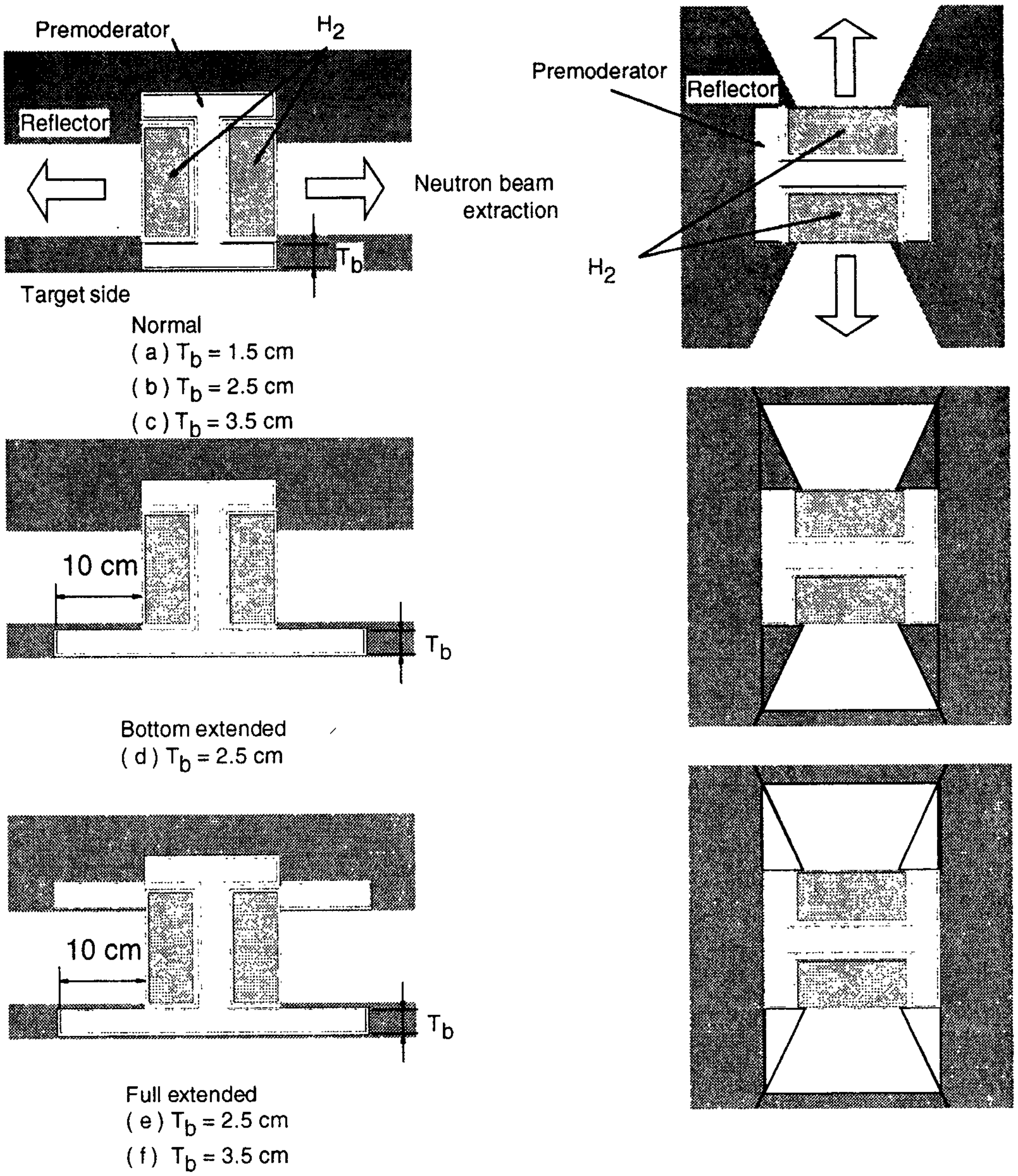

Fig. 1 Calculational model of H_2 moderator with premoderator

ber of protons used for the present calculations were in a range (0.6-1.2) x 10^6 for each calculation.

3. Results and discussions

3.1 Spectral intensity and energy deposition

Spectral intensities and energy depositions for three different bottom-premoderator thicknesses were calculated (cases (a)-(c)). The results are shown in Fig. 2. The time- and energy-integrated cold neutron intensity does not strongly depend on the thickness, but the thickness of 2.5 cm is approximately at the optimal as already known [4]. On the other hand the energy deposition exhibits a monotonic decrease with increasing bottom premoderator thickness. The fact suggests that a possible choice of a thicker premoderator, provided that the pulse width broadening is in an acceptable range. The pulse shapes will be discussed later.

Next, the effect of an extended premoderator (case (d) in Fig. 1) was studied. The result is also shown in Fig. 2. An appreciable intensity increase can be recognized with an additional decrease in the energy deposition. Encouraged by this result we examined fully extended premoderator cases ((e) and (f) in Fig. 1). Higher gain factors, more than expected, have been obtained with further decreases in the energy deposition as shown in Fig. 2.

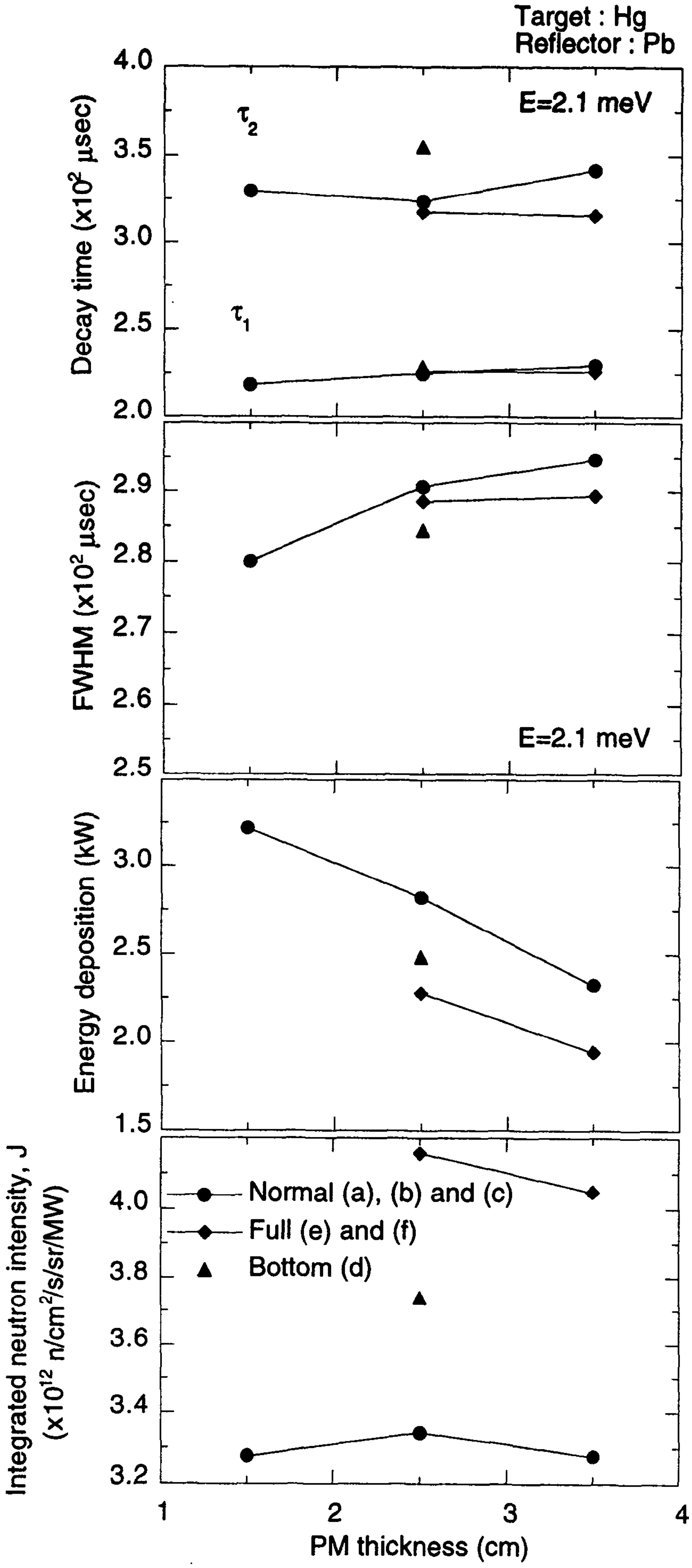

Fig. 2 Premoderator thickness dependence of integrated neutron intensity (J), energy deposition, FWHM and decay time

Table 2 Total energy deposition in H_2 for Pb reflected system

Calulational case	Total energy deposition (kW)
a	3.22
b (ref.)	2.82
c	2.33
d	2.49
e	2.28
f	1.94

The intensity gains relative to the reference case, (b), are plotted in Fig. 3 as a function of the neutron energy. For all moderators there is no energy dependence in the gain factor in the cold neutron region.

Figure 4 compares the spatial distribution of the energy deposition in H_2 for various cases. The ratios relative to the reference case are plotted in Fig. 5. Total energy depositions in H_2 for various cases are summarized in Table 2.

The above results clearly show that as far as the spectral intensity of cold neutrons and the energy deposition are concerned, a fully extended premoderator is much superior to the reference case.

3.2 Pulse characteristics

When we discuss the performance of a pulsed neutron source the time distribution is another important factor in addition to the spectral intensity (time-integrated intensity). Calculated pulse shapes of cold neutrons from the moderators in the reference case (b), with the extended bottom premoderator (d) and with the fully extended premoderator (2.5 cm thick bottom premoderator (e)) are compared in Fig. 6. The most distinguishing feature of the moderators (e) and (f) is that a higher gain factor is achieved in the time-integrated and the peak intensities without pulse

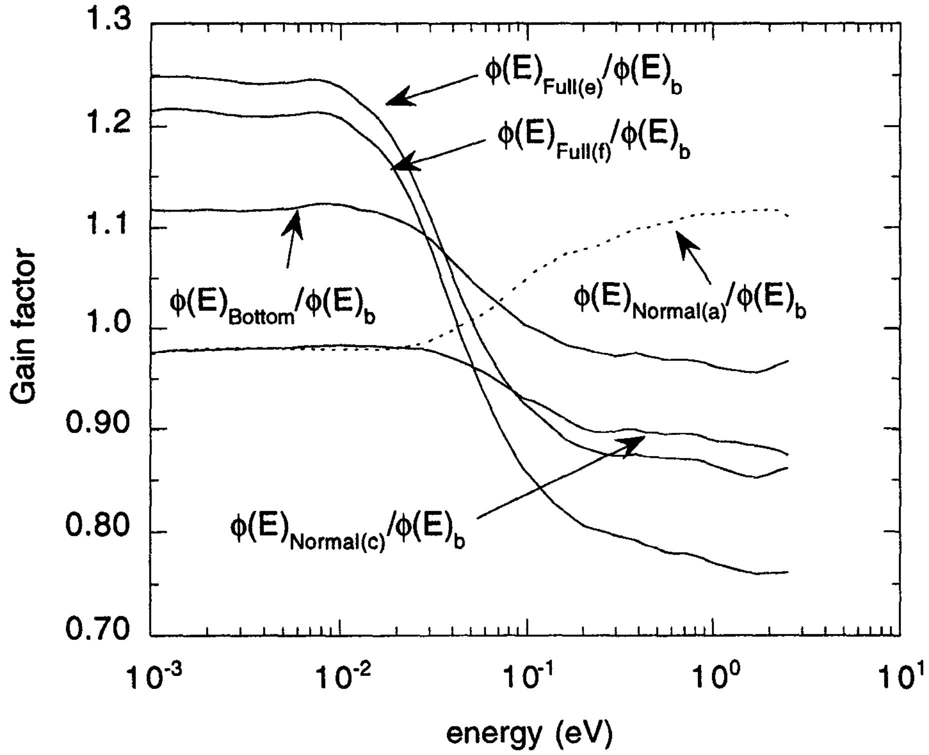

Fig. 3 Gain factor of neutron intensity relative to the reference case as a function of energy

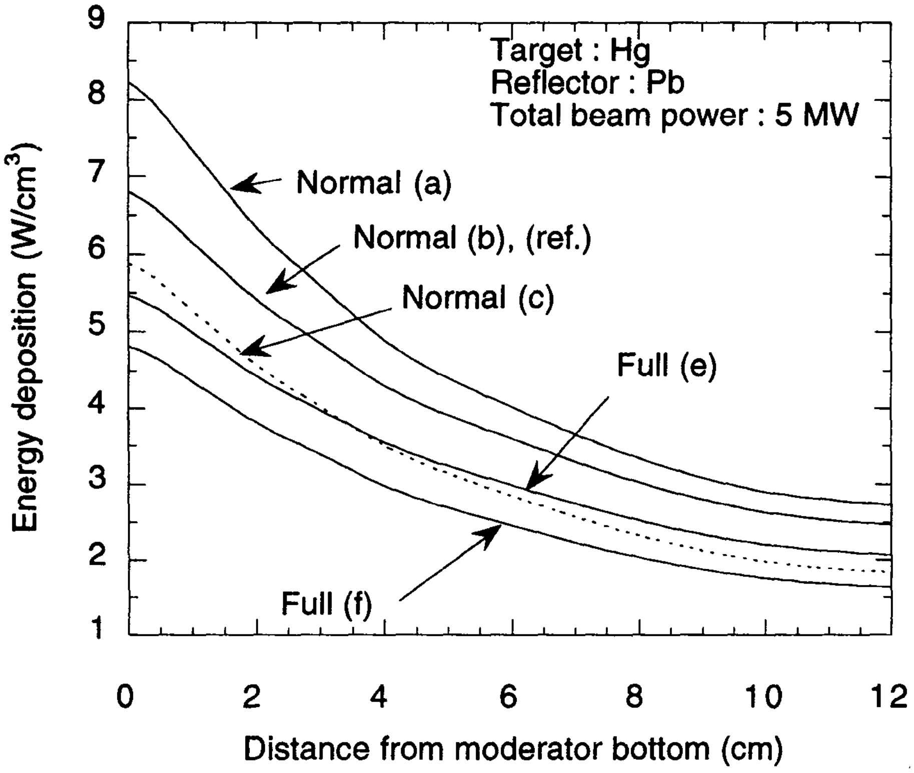

Fig. 4 Energy depsition in H_2 for different configulation of PM

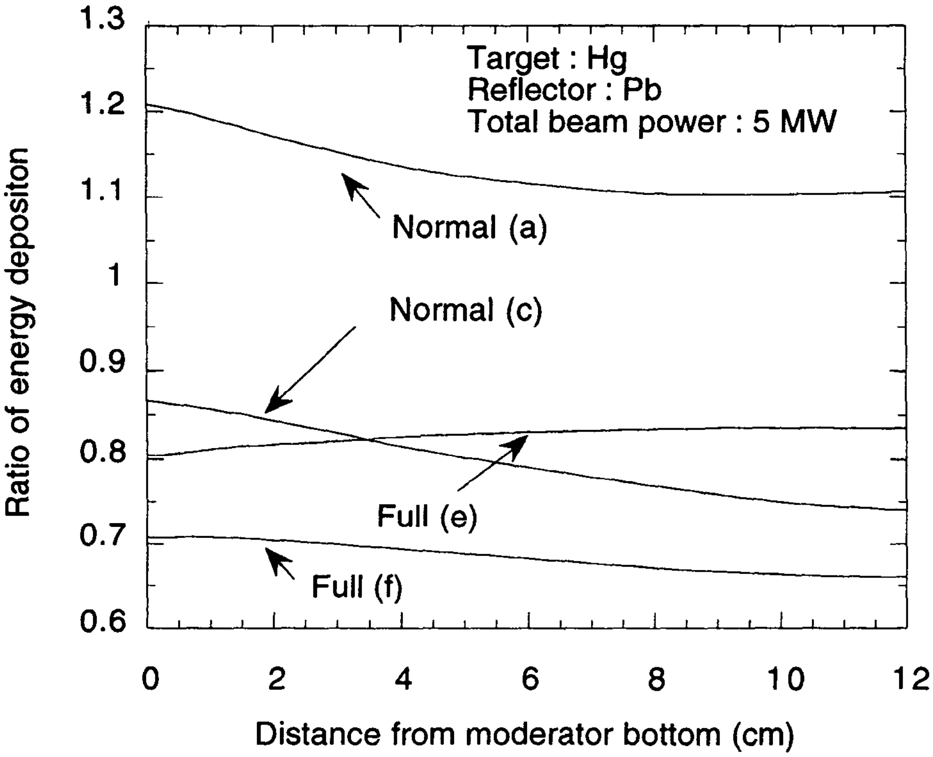

Fig. 5 Ratio of energy depositons relative to the reference case (b)

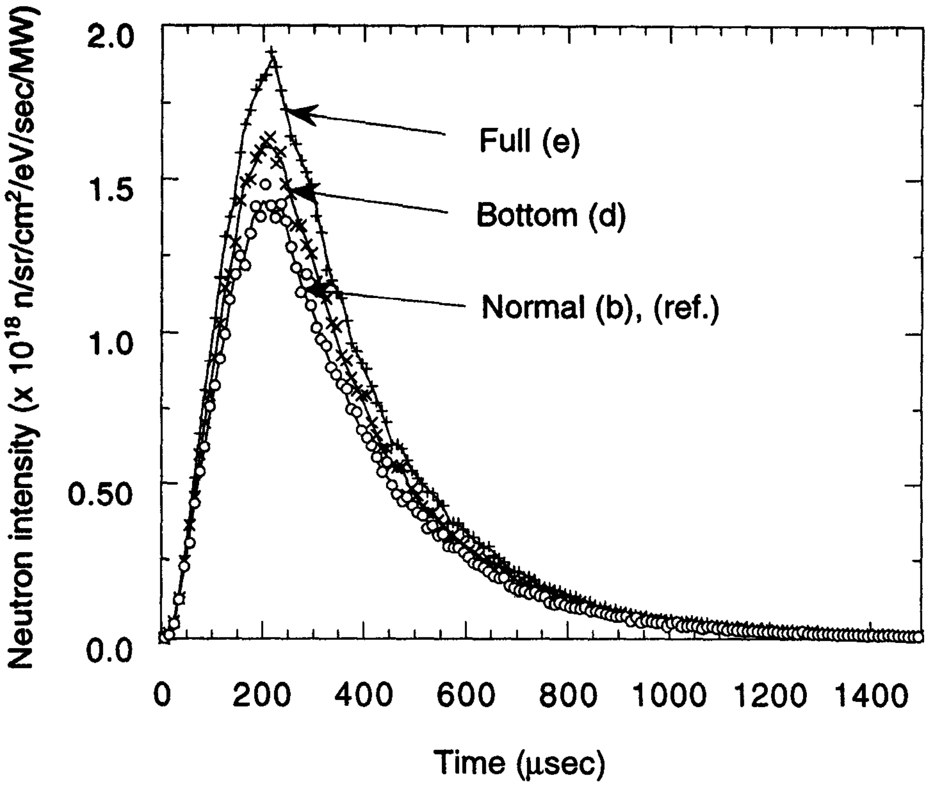

Fig. 6 Time distributions of neutrons at E=2.0-2.2 meV for cases (b), (d) and (e)

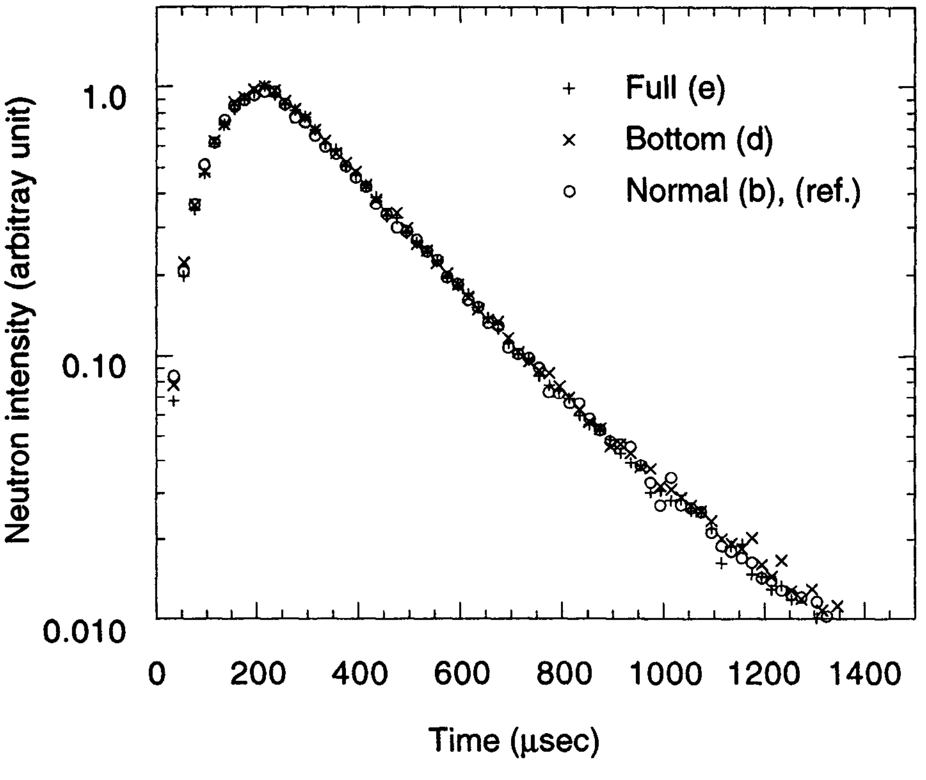

Fig. 7 Time distributions (E=2.0-2.2 meV) normalized at the peak in semi-logarithmic scale

width broadening: in the case (e) a relative gain factor to the reference case is about 24%. The pulse shapes for three different cases ((b), (d) and (e)) are plotted in Fig. 7 in a semilogarithmic scale normalized at the peak intensity. We cannot recognize any difference between the three. This is a great advantage for a pulsed cold neutron source. The pulse widths in full width at half maximum (FWHM) for all moderators are also plotted in Fig. 2.

In order to discuss the decay characteristics at a longer tail, the calculated pulse shapes were fitted by two exponentially decaying terms characterized by two decay times, τ_1 and τ_2, respectively, although there is no physical base to express the pulse shape only by two exponentially decaying terms. The decay times are also plotted in Fig. 2. Judging from the pulse width and two decay times, the pulse characteristics of the fully extended moderator is almost unchanged compared to the reference moderator.

4. Summary and conclusion

It has been shown that a coupled composite moderator of H_2 and a fully extended premoderator of the optimized thickness can provide a considerably higher time-integrated and peak cold neutron intensities compared to a conventional composite moderator so far been discussed, and that these advantage can be achieved without sacrificing the pulse characteristics and, furthermore, with a much lower energy deposition in H_2: triple merits have been realized simultaneously.

In concluding we could say that a coupled composite moderator consisting of H_2 and an optimally designed premoderator has a potential to improve the neutronic performance further with a reduced nuclear heating in the maim cryogenic moderator (H_2) by introducing various ideas. Such efforts are under progress.

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