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How to Optimize Pulse Shape

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Abstract

It is very important to place moderators with pulse characteristics suitable for the neutron scattering spectrometers to construct a high performance spallation neutron source. However, choice of the moderators is rather complicated problem since the requirement from the spectrometer side is not unique and also no single moderator can satisfy the requirements although there are various kinds of moderator types giving a variety of neutronic characteristics. Therefore, to decide moderator types, we need to know the information of both neutronics and spectrometers. We have indicated that the pulse characteristics are affected by the type of moderator (coupled or decoupled), the choice of reflector material and decoupler, and so on. Here, we explain the methods to control the pulse characteristics and also show various neutronic characteristics we can obtain, in order to offer the data for the discussion of the moderator characteristics suitable for the instruments.

1. Introduction

Many kinds of moderator systems for a spallation neutron source have been proposed aiming to obtain good neutronic characteristics. A coupled liq. hydrogen is the moderator giving the highest cold neutron intensity(1). We have not been discussing effective usage of the moderator in detail since it is the new type moderator. Recent progress of the chopper type instruments is remarkable(2) and other new type spectrometers such as time-of-flight spin echo are being developed. These would require different type neutronic characteristics compared with the traditional spectrometers. In accordance with development of the spectrometer, choice of the moderator types at a spallation neutron source will become different from the previous one. So, mutual communication between moderator and instrument peoples is very important now to make the best choice of the moderator types.

Here, we explain main features of pulse characteristics from various moderators and how can we modify the pulse characteristics. These will be necessary data for the discussions with the instrument people in order to construct a high performance spallation neutron source.

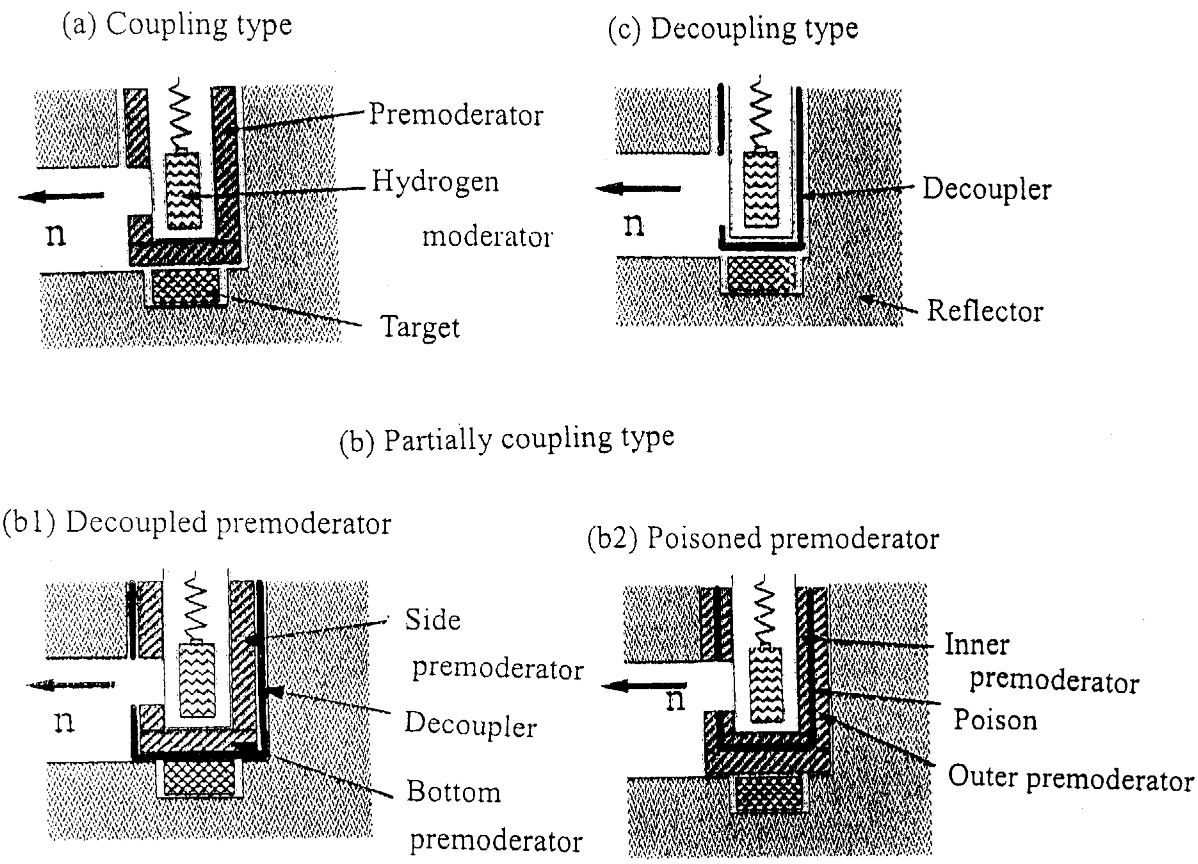


Fig. 1 Moderator types.

2.Moderator types

As moderator materials H_2O, H_2 and CH_4 are used so far. However, in a high power spallation neutron source monolith CH_4 in liquid and solid phases may not be usable due to radiation damage. In the Japan Spallation Neutron Source we are intending to use H_2 moderators since all instruments want to use wide energy range. Therefore, here we mainly explain the neutronic characteristics of H_2 moderator.

In this paper I define three types of moderators. Figure 1 indicates some examples of these.

(1) Coupling type (Fig. 1(a))

A moderator without absorber in a target-moderator-reflector system.

(2) Partially-coupling type (Fig. 1(b1) and (b2))

A moderator coupled to a part of a premoderator and/or reflector.

(3) Decoupling type (Fig. 1(c))

A moderator decoupled from a premoderator and a reflector.

3. How to control pulse shape

The pulse shapes are changed by the effect of size of moderator, decoupler, decoupling energy, reflector material and so on. We explain the effects of these elements on various moderator types.

3.1 Coupled moderator

A coupled moderator gives highest cold neutron intensity. Therefore, instruments viewing this moderator mainly use the cold neutron region. In the cold neutron region, the pulse shape of a coupled moderator is mainly determined by a reflector at tail, by a premoderator at first decay and by a moderator at main peak. The best combination of this moderator system has been proved as a hydrogen main moderator with a water premoderator since the H_2 coupled moderator gives almost the same cold neutron intensity compared with a coupled solid CH_4 moderator(3). Therefore, we can only change the reflector material. It is well known that Be gives higher integrated intensity than Pb but also gives longer pulse tail(4). Composite reflector is a candidate to control the pulse shape. We performed simulation calculations to study the effect of a Pb-Be composite reflector(5). We thought that tail came from Be part existing far from the moderator, so we looked for the minimum volume of the Be around the moderator with a condition of minimum decrease in intensity. Figure 2 shows geometry for the calculation, in which we put three moderators, a coupled moderator with a premoderator, a decoupled liq. methane moderator and a decoupled hydrogen moderator. This is used to be a model for the JHF project but the main feature of the pulse characteristics of the coupled moderator is not different from a model for Japan SNS. We calculated cold neutron intensity as functions of Be width, length and thickness, and found that there exist positions where the intensity begins to saturate. We decided the minimum size by these results and the geometry is shown in Fig. 3. Decrease in the cold neutron intensity is very little, only 5% compared with the pure Be reflector case. Figure 4 shows pulse shapes from coupled moderators surrounded by three kinds of reflectors. The composite reflector gives a pulse tail lying between Be and Pb cases and a little bit higher pulse peak intensity. Therefore, we can change the pulse characteristics by varying the composition of Be and Pb. However, it should be decided by the requirement from the instruments, namely, the question is which is more important between total integrated intensity and pulse peak intensity.

3.2 Partially coupled moderator

This type of moderator is a modification of the coupled moderator and have been developed to improve the pulse characteristics of the coupled moderator. The main neutron energy region useful for the instruments is also cold region. Many methods have been proposed to control the pulse shape. Reflector poisoning is an idea. We studied experimentally the effect of Cd sheet with a size of reflector cross section placed in the reflector just under the target to reduce the long pulse tail of the coupled moderator(6). This method reduced the tail as well as peak intensity. Succeedingly examined are the premoderator poisoning and the premoderator decoupling from the reflector. These are indicated in (b1) and (b2) of Fig. 1. Premoderator poisoning is the method to put an absorber in the premoderator and the premoderator decoupling is the method to put an absorber between the premoderator and the reflector. Figure 5 shows the experimental results of pulse shapes of these moderator systems at two wavelengths and Figure 6 shows the pulse widths in full width at half maximum. By using these methods the pulse width becomes narrower and the pulse peak becomes lower. The result indicates that the pulse shape becomes narrow only with the cost of reduction of pulse peak intensity and also that various pulse widths are produced. So, we can choose any kinds of pulse widths.

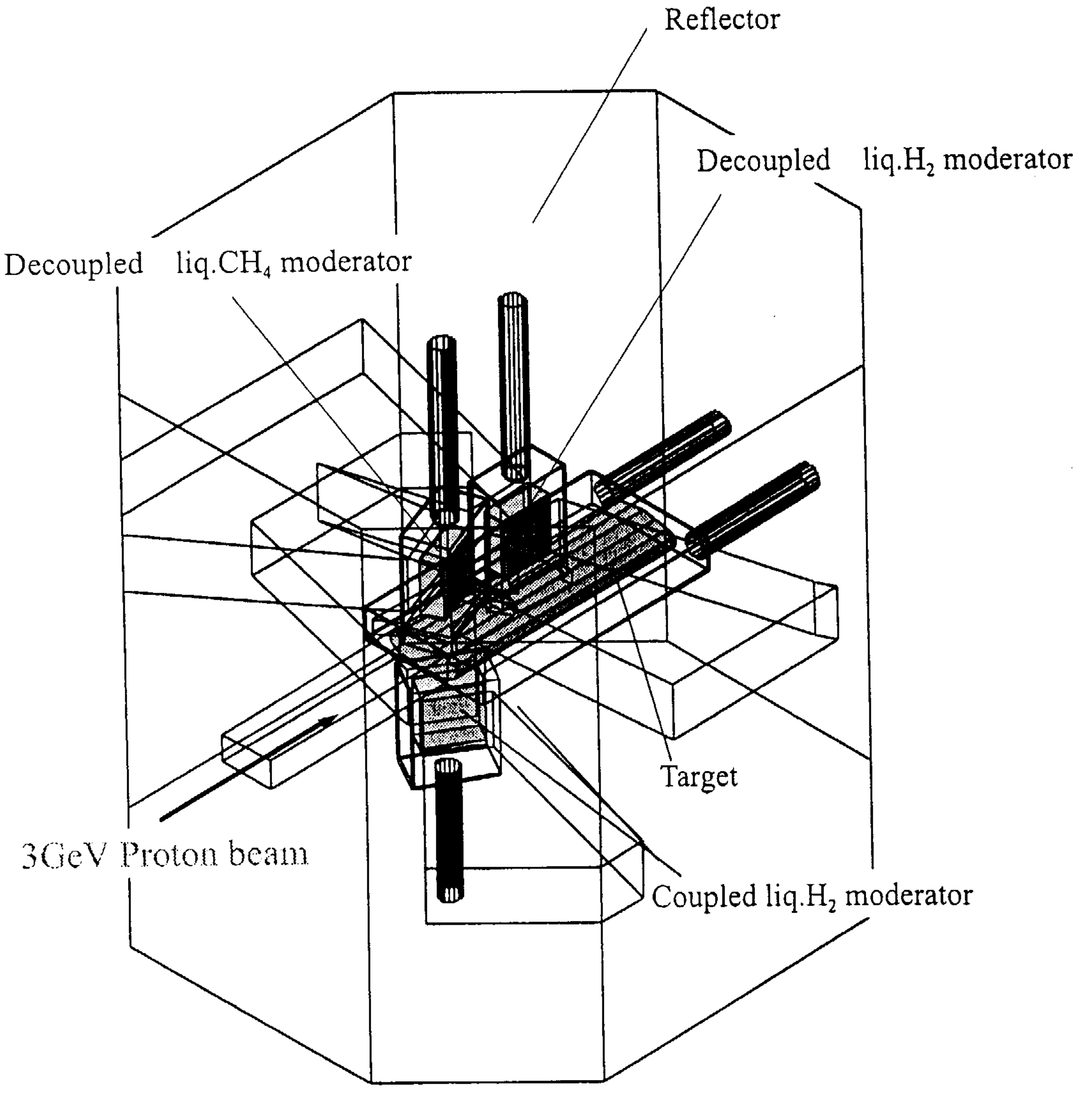


Fig. 2 Geometry for calculation designed for JHF.

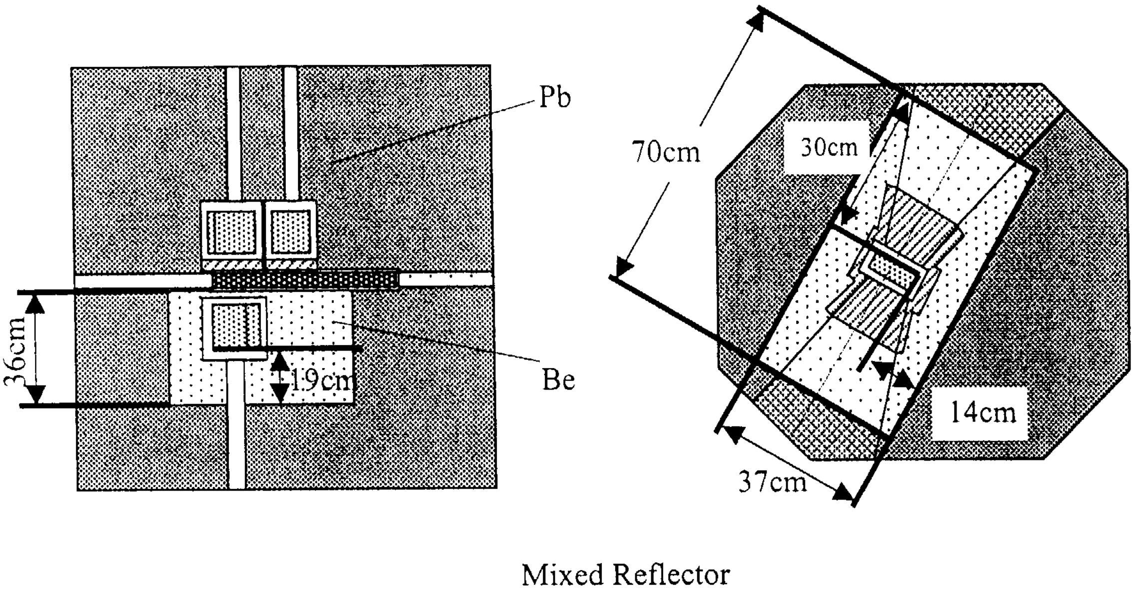


Fig. 3 Optimized size for Be in a composite reflector.

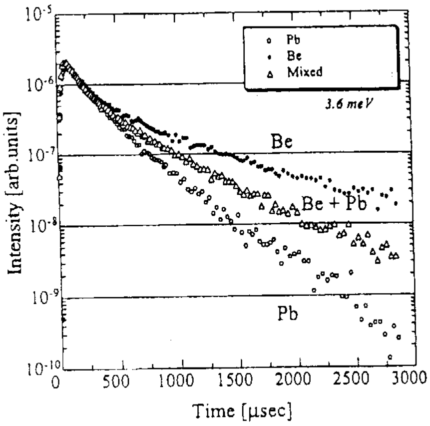
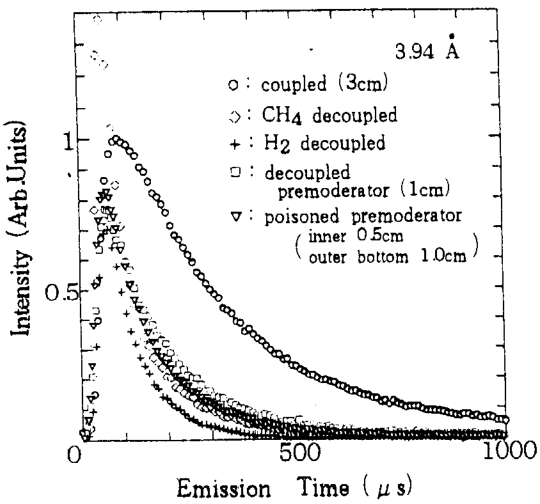


Fig. 4 Pulse shapes from a coupled H_2 moderator in three different reflector systems.



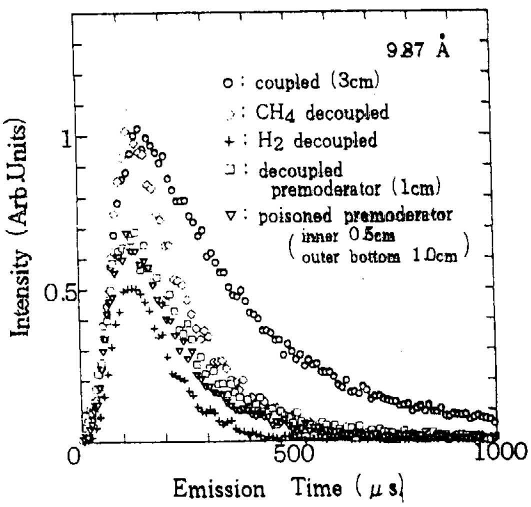


Fig. 5 Comparison of pulse shapes of neutrons from various moderators.

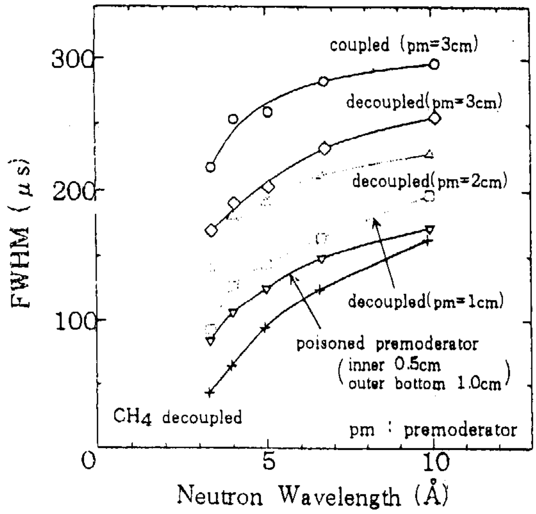


Fig. 6 Comparison of pulse widths of neutrons from various moderators.

3.3 Decoupled moderator

The instruments using a wide energy range, for example, from epithermal to cold will view a decoupled moderator. So, we should consider the pulse shape over wide energy range. Effects of reflector, decoupler and also moderator itself appear in different ways depending on the energy region.

3.3.1 Effect of reflector, premoderator and decoupling energy to pulse shapes

Even in the case of the same moderator size, the pulse shape is affected by following conditions:

a. Reflector materials, Pb and Be,

b. Premoderator in the case of Pb reflector system,

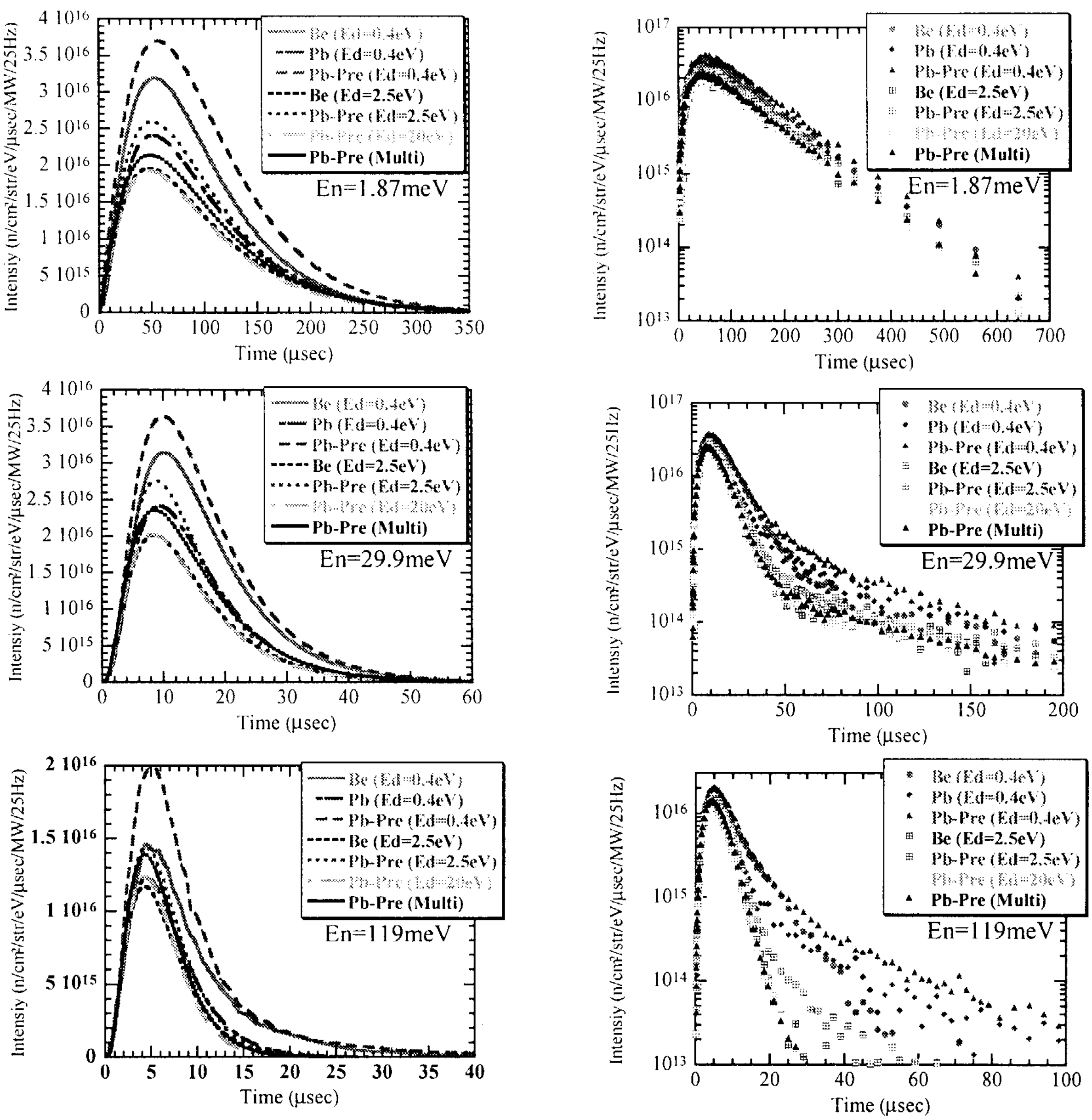
c. Decoupler materials, Cd and B_4C,

d. Decoupling energy in the case of B_4C, ,

e. Decoupling scheme. (New ideas are proposed such as a multi-layer decoupler and Hg reflector with a decoupler(7-8).

Figure 7 shows simulation results about change of pulse shapes at typical energies, cold, thermal and epithermal. Left figures are linear and right semi-logarithmic plots. Here, the case of a decoupling energy, Ed=0.4 eV, used a Cd decoupler and at higher decoupling energy B_4C was used. "Multi" means a new decoupler type arranging the decouplers along concentric circles. "Pre" means premoderator placed outside the decoupler, which increase the intensity very much.

In cold neutron region (see the upper figure of 1.87 meV data in Fig. 7) the neutron pulses from a hydrogen moderator in various systems have almost the same shape. The difference appears only in intensity. This means that in such low energy only the moderator affect the



119.6meV

Reflec tor	Decoupler	Pre	Peak Intensity	FWHM	1st Decay	2nd Decay
Be	Cd(Ed=0.4eV)	—	1.46	8.43	3.16	9.19
Pb	Cd(Ed=0.4eV)	—	1.24	7.22	4.04	17.20
Pb	Cd(Ed=0.4eV)	○	2	8.55	5.53	16.10
Be	B_4C(Ed=2.5eV)	—	1.17	6.7	3.06	5.83
Pb	B_4C(Ed=2.5eV)	○	1.44	6.87	3.16	9.19
Pb	B_4C(Ed=20eV)	○	1.22	6.51	2.37	8.23
Pb	B_4C(Multi)	○	1.39	6.55	2.50	6.76

10^{16}(n/am2/str/eV/μsec/MW/25Hz) (μsec)

Fig. 7 Variation of pulse shapes due to reflector material, decoupler material, decoupling energy and decoupling method.

pulse shape, and that other components affect the total neutron intensity. So, we control the pulse shape by poison in moderator or thickness as shown below. The intensity of Cd decoupled case is much higher than that of B_4C decoupled case. The difference is about 1.5-1.7.

At thermal energy region where neutrons are still in slowing-down in liq. hydrogen moderator (see the middle figure of 29.9 meV data in Fig. 7), we see some differences in the tail part of the pulse shape although main part of the pulse has almost the same shape. A longer tail is observed in the case of Pb reflector with Cd decoupler and premoderator, and lowest tail is obtained by a Be reflector with 2.5 eV decoupler.

At higher energy (see the lower figure of 119 meV in Fig. 7), the difference in pulse shapes is remarkable since this energy range is not far below the decoupling energy. Pulse shapes obtained by a moderator with Be reflector show rather quick decrease of pulse tail compared with a Pb reflector case at the same decoupling energy although the pulse peak intensity is higher in a Pb reflector case with a premoderator than a Be one. New decoupling systems give better pulse characteristics. As shown in the table below the figure, difference in pulse width is not so large but large difference appears in tail part, 2nd decay. We can reduce the pulse tail by adopting high decoupling energy and also by introducing new decoupling methods usually with the cost of pulse peak intensity. At this energy a high-Q measurement of neutron diffraction is performed. The intensity of the diffraction peak becomes lower due to Debye-Waller factor, and the inelastic and incoherent backgrounds become higher compared with lower energy. It is important to decide the allowable pulse tail for scattering experiments taking account the realistic background components in the scattering experiments.

From engineering aspect feasibility of the B_4C decoupler at a high intensity spallation source is one serious issue.

3.3.2 Effect of poisoning and moderator size to pulse shapes

As shown in previous section the pulse shape below far below the decoupling energy the pulse shape depends on the effective moderator size. One method to change the effective thickness is to insert a sheet of neutron absorber (poisoning) in the moderator. By inserting the absorber neutrons see whole thickness above cut off energy of the poisoning and a part of moderator in front of the poison below the cut-off energy. Which is better between poisoning and thin moderator? Figure 8 shows experimental data of various energy spectra from poisoned and un-poisoned moderators with Cd or B_4C

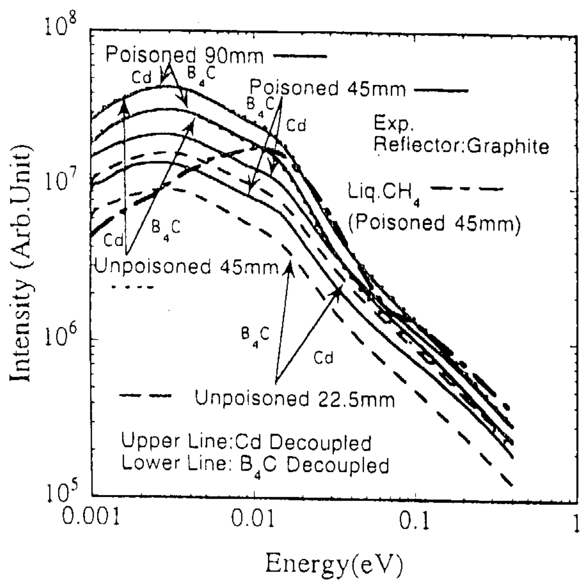
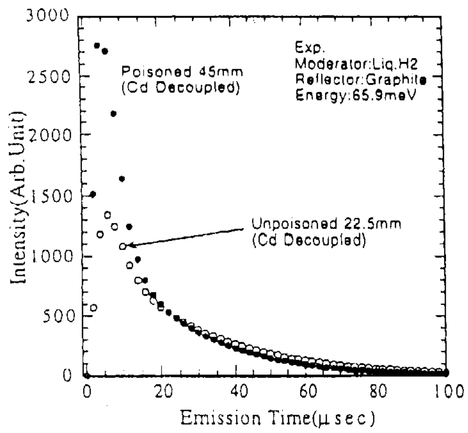
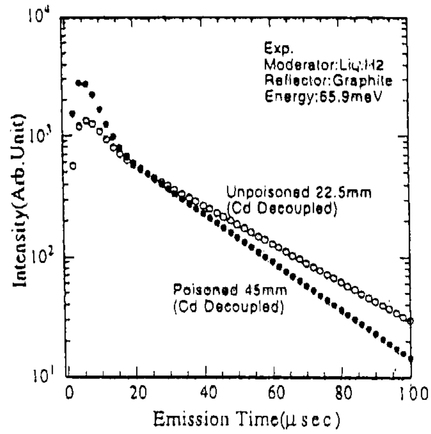


Fig. 8 Energy spectra from poisoned and unpoisoned liq.H_2 moderators.

decoupler. As a reference a spectrum from a liq. methane moderator is also shown. There is almost no difference in the spectral shapes from hydrogen moderators. The intensity in the case of Cd decoupler is much higher than that in B_4C. Figure 9 shows an example of the pulse shapes from a thin hydrogen moderator (22.5 mm thick) and a center poisoned hydrogen moderator (45 mm thick, namely, effective thickness 22.5 mm). It is clearly recognized that the poisoned moderator gives narrow and much higher pulse intensity. This feature was observed also at other energies. This would be due to the fact that the thin moderator cannot maintain the slowing down neutrons in the moderator. Figure 10 shows data for a 45 mm thick unpoisoned hydrogen moderator and a 90 mm thick center poisoned moderator. In this case the 90 mm center poisoned H_2 moderator (effective thickness is 45 mm) gives almost the same pulse shapes as a 45 mm unpoisoned one. Therefore, the results indicate that the poisoned moderator with the same effective thickness gives better pulse shapes than the unpoisoned thin moderator.

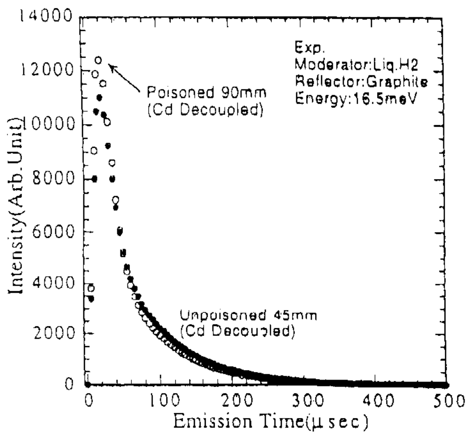


E=65.9meV
(Poisoned 45mm、Unpoisoned22.5mm)

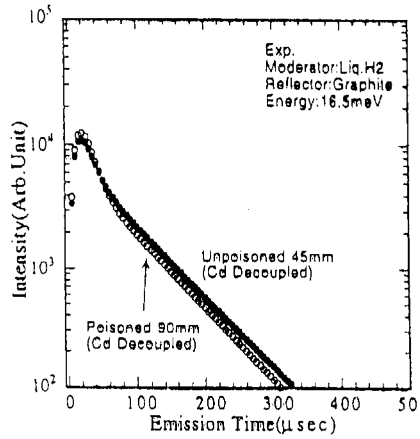


E=65.9meV
(Poisoned 45mm、Unpoisoned22.5mm)

Fig. 9 Poisoning effect (22.5 mm thick vs. 45mm center poison).



E=16.5meV
(Poisoned 90mm、Unpoisoned 45mm)

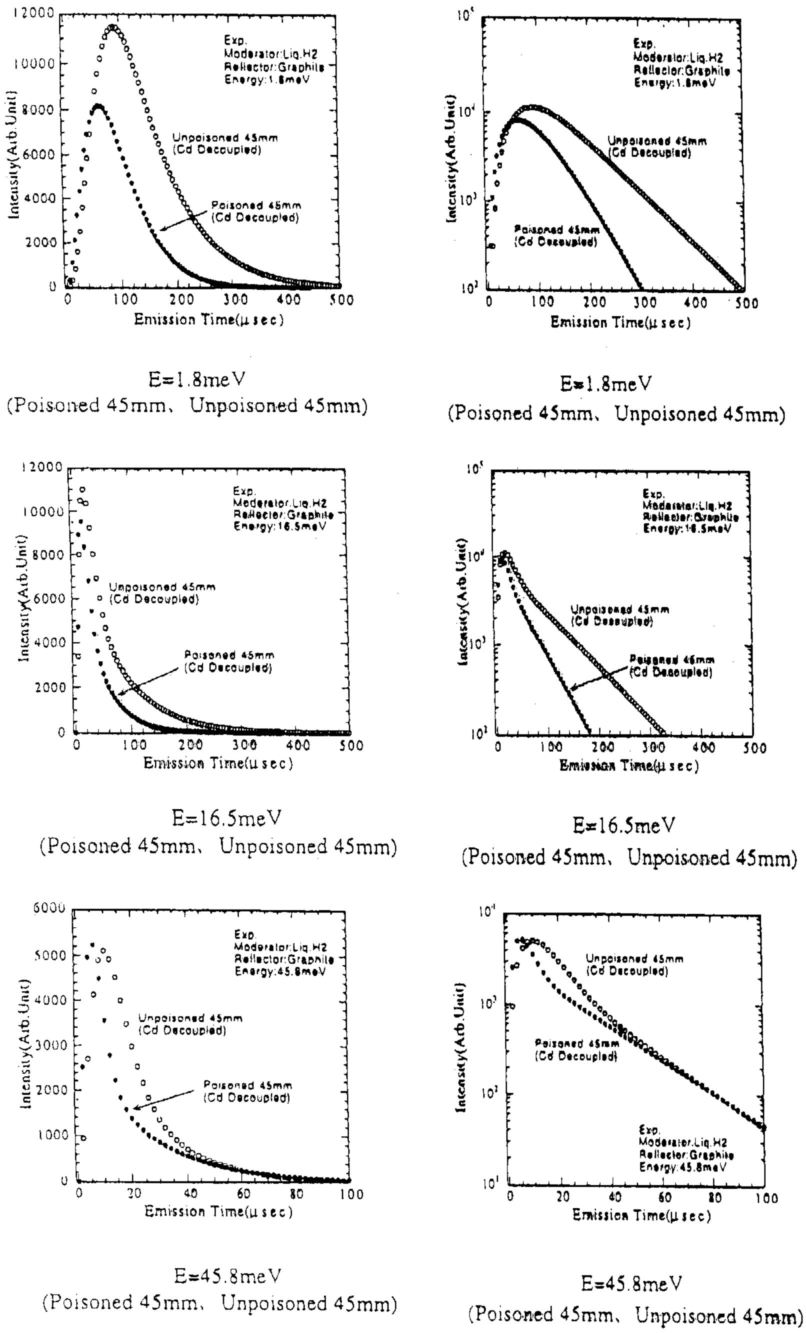


E=16.5meV
(Poisoned 90mm、Unpoisoned 45mm)

Fig. 10 Poisoning effect (45 mm thick vs. 90mm center poison).

How about the 45 mm thick poisoned and unpoisoned moderators? The experimental pulse shapes are indicated in Fig. 11. Comparison between 45 mm thick moderators with and without poison indicates that difference in peak intensity appears mainly at cold neutron region and the first decay is faster in poisoned one. The difference between them becomes small at high energy due to the cut-off energy of the poison.

We should use a poisoned moderator but the best position of the poison is unclear since thinner effective thickness causes narrower width and lower peak intensity. So, the choice strongly depends on the spectrometer type and also the required resolution.



E=1.8meV (Poisoned 45mm、Unpoisoned 45mm)

E=1.8meV (Poisoned 45mm、Unpoisoned 45mm)

E=16.5meV (Poisoned 45mm、Unpoisoned 45mm)

E=16.5meV (Poisoned 45mm、Unpoisoned 45mm)

E=45.8meV (Poisoned 45mm、Unpoisoned 45mm)

E=45.8meV (Poisoned 45mm、Unpoisoned 45mm)

Fig. 11 Poisoning effect (45 mm thick vs. 45mm center poison).

4. Effect of a target material on pulse shape

We have not studied effect of the target material on the pulse shape. From our experiences, even mercury will not affect pulse shape from a coupled moderator so much. For decoupled moderator the effect will be low. However, integrated neutron intensity is much affected by combinations of target and reflector materials. Figure 12 shows preliminary simulation results of the relative integrated intensities from various moderators at different target-reflector combinations. The intensities of the W-Be combination are normalized to unity. From overall feature Pb reflector give higher intensity and W is superior to Hg.

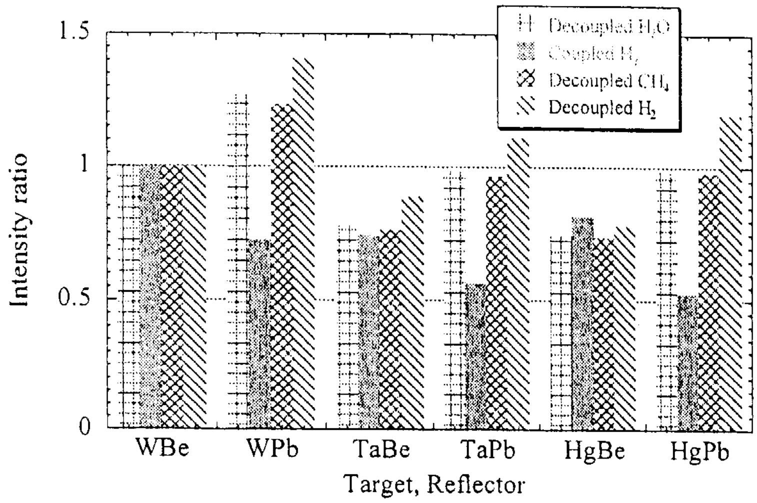


Fig. 12 Comparison of relative intensities from various target –reflector combinations.

5. Questions to instrument scientists

It is indicated from the results mentioned above that we can control the pulse characteristics in some extent. On the other hand it means that we should choose the best moderators for the scattering experiments so as to obtain the highest performance of a facility of a spallation neutron source. The main selections we need are summarized below.

(1) Coupled moderator

Which is important between integrated intensity and pulse peak intensity? Or compromise of both is better? The answer of this question influences the decision of the reflector material.

(2) Partially coupled moderator

Do we need some pulse modification to get medium pulse peak intensity and pulse width?

(3) Decoupled moderator

a) Around and over 100 meV regions

How low the pulse tail should be? For example, a tail of 2 orders below the pulse peak is allowable or not? To decide this, we should take into account the effect of natural background, incoherent background, inelastic component, and so on.

b) Around thermal equilibrium region

Which requirement is dominant between sharp pulses with low peak intensity or medium width with higher pulse peak? Or we need both types of moderator.

6. Summary

We can control the pulse characteristics although short pulse causes usually decrease of peak and integrated intensities. However, it may be rather laborious to simulate the spectrometer performance by using the pulse data of all these moderator systems. Therefore, important is insight taking into account whole system from the target to the spectrometer including neutron devices such as chopper, guide, and so on. After then, simulation of spectrometer should be performed.

The collaboration work between a moderator group and an instrument group is very important to construct a neutron scattering facility with high efficiency since the recent progress in the instruments have to be taken into account.

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