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Premoderator and reflector effect on the neutronic performance of a decoupled liquid hydrogen moderator

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Abstract

Adoption of a premoderator out side of a decoupled hydrogen moderator is one of methods to increase spectral intensity. The effect of premoderator on the neutronic characteristics of the moderator are expected to be depend on the premoderator material and also on the reflector materials, moderating and non-moderating. We examined to premoderator materials, H_2O and D_2O and two reflector materials non-moderating type reflector, lead, and moderating, graphite. Calculational studies also performed in order to compare the results between experiments and calculation and also to look for optimization condition.

In the case of moderating reflector we can get scarce intensity gain by using the premoderator. On the other hand, in non-moderating reflector, we can get large intensity gain. The intensity gain was larger by D_2O than by H_2O. There was large discrepancy in intensity gain between experiment and calculation.

1. Introduction

It is well known that conventional methane moderator cannot be used at high power spallation neutron sources although the neutronic performance is superior to other moderator materials. Therefore, liquid hydrogen is the most realistic material for the cold neutron moderator at present. But neutron intensity from this moderator is much lower than that from the solid methane moderator. It has been desired to increase the neutron intensity from the liquid hydrogen moderator. We previously applied a premoderator to a liquid methane moderator and get a little gain even in such a high hydrogen density material by using heavy water as a premoderator[1], and by LCS calculation, we confirmed that neutron intensity from a liquid hydrogen moderator increased by the premoderator placed, also in the liquid hydrogen moderator. The enhancement of intensity was much larger for a liquid hydrogen moderator with a lead reflector. To confirm the premoderator effect depending on premoderator material, we have performed experiments and optimization calculations.

2. Experiment

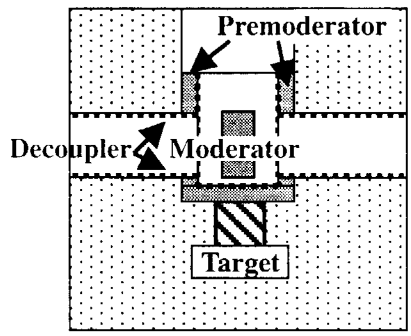

Fig.1 Exp. TMRS outline

The measurements were performed at the Hokkaido LINAC at Hokkaido Univ. Neutron energy spectrum from moderator was measured by time-of-flight method. Emission time distribution was measured by using Bragg reflection of PG crystal monochromator. Outline of the Target-Moderator-Reflector-system (TMRS) is shown in Fig. 1. Lead and graphite were used as reflector material. The moderator is installed over the target. Cadmium and B_4C resin was used for decoupler with decoupling energies of 0.4eV and 2.5eV, respectively. Heavy water and light water were used as premoderator, and the thickness of premoderator examined was 1 cm, 2 cm, and 3 cm. However, since there was almost no effect of side premoderator when calculated about the beryllium reflector, which is a slowing down type reflector. And the graphite that is similarly a slowing down type reflector, so premoderator was used only for the bottom of moderator. In the measurement, the distance from the target to the moderator is fixed.

Energy spectrum is measured for all combinations of reflectors (lead and graphite), premoderators (H_2O and D_2O), and decouplers (Cd and B_4C).

Pulse shape measurement performed so far were five cases: Graphite reflector with Cd or B_4C decoupler in the case without premoderator, lead reflector with Cd or B_4C decoupler in the case without premoderator, and lead reflector with B_4C decoupler in the case with D_2O premoderator.

3. Calculation

LCS was used for the calculations, with ENDF/B-V and VI cross-section data. One of purposes of calculation is comparison with the experiment. For the purpose we used geometry of a TMRS simulating the experimental setup. The other purpose is optimization of the TMRS with premoderator for JSNS project[2]. In the TMRS for JSNS, mercury was used as the target. Incidence proton energy is 3GeV and the neutron extraction hole was opened with an angle of 45 degrees. We survey materials and thickness of premoderator using a lead and a beryllium reflector. Influence of premoderator on pulse shape was investigated at the TMRS from which maximum intensity was obtained.

4. Result and Discussion

4-1. Hokkaido LINAC experiment

Figure2-1 shows experimental result of premoderator effect on neutron intensity from the liquid hydrogen moderator with lead reflector and Fig. 2-2 shows the effect in the case of graphite reflector. In these figure open symbols are for light water premoderator, closed symbols for heavy water premoderator. Triangle mark is for cadmium decoupled case and circle for B_4C decoupled one. In the case of graphite reflector, premoderator is not so effective to increase neutron intensity. On the other hand, in the case of lead reflector, premoderator gives 40% increase of intensity from B_4C decoupled moderator and 73% increase from Cd decoupled one. From these results, optimal thickness of light water premoderator for a decoupled hydrogen moderator is 1 to 1.5cm and that of heavy water premoderator is over 3cm. And more about neutron intensity, heavy water has better characteristics than light water from an intensity point of view.

Figure 3 shows comparison between experiment and calculation. Calculation results show similar tendency to experimental ones for all reflector-premoderator combinations, but

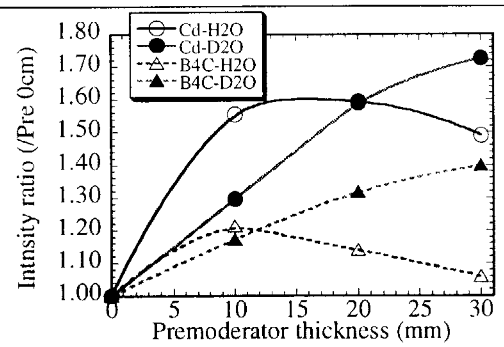

Fig.2-1 Premoderator effect for Lead reflector

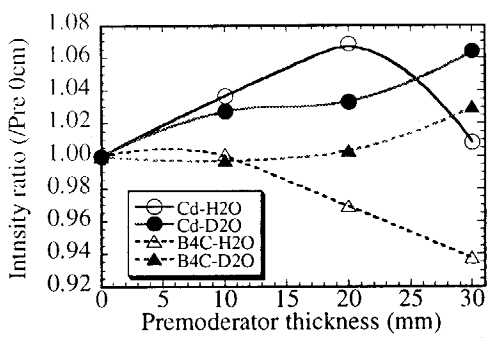

Fig.2-2 Premoderator effect for Graphite reflector

discrepancy between the calculation and the experiment is very large. The calculation gives twice as high as intensity gain of experiment in the lead reflector case. In the graphite reflector case, the results of calculation overestimate of the decoupled hydrogen intensity gain again.

Figure 4 shows measured FWHM moderator without premoderator in the graphite reflector and the lead reflector without premoderator (Ed=2.5eV for B_4C and Ed=0.4eV for Cd). B4C decoupled D_2O premoderator in the lead reflector among B_4C decoupled moderators. The pulse width are almost the

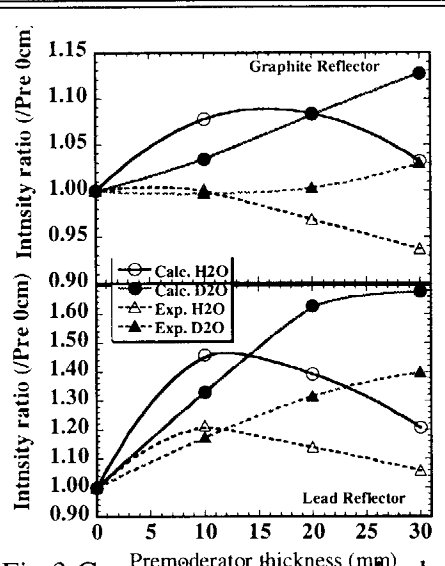

Fig.3 Comparison of exp. and calc.

same, but compared these FWHMs with these of Cd decoupled case, Cd decoupled case give wider pulse width. From these results, we can say pulse width depends mainly on decoupling energy. We compare the FWHM obtained by the experiment with calculational ones in Fig.5. Although the data show good agreement in cold neutron range, in thermal and epithermal range there is about 15% difference between experimental and calculational values.

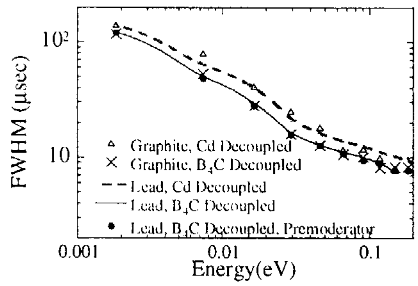

Fig.4 FWHM by experiments

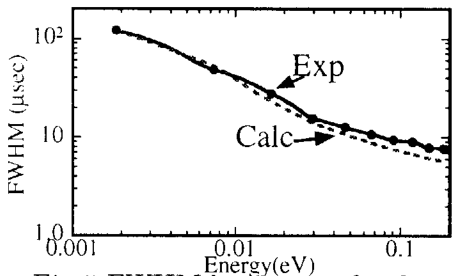

Fig.5 FWHM by exp. and calc. a moderator in lead reflector.

4-2. JSNS model calculations

From the results of premoderator optimization to JSNS model, optimal thickness of the premoderator is 2cm at the target side and 5 cm at the side if moderator in the case of heavy water. In this condition, neutron intensity increased by 52% compared with the case without premoderator. Similarly, optimization was done for beryllium reflector. The neutron intensity gain was little, since distance between a target and a moderator increases by putting the premoderator, normally, large distance decreases the intensity. Pulse shapes at 119meV from hydrogen moderators under various conditions are shown in Fig.6. We summarize B4C decoupled case. By introducing premoderator to the lead reflector system, peak intensity increases by 35% and FWHM spread by about 3%. Furthermore, the tail of the pulse decays becomes little bit slowly. In the case of beryllium reflector, peak intensity is lower than that in the lead reflector case but the FWHM and tail of pulse is better.

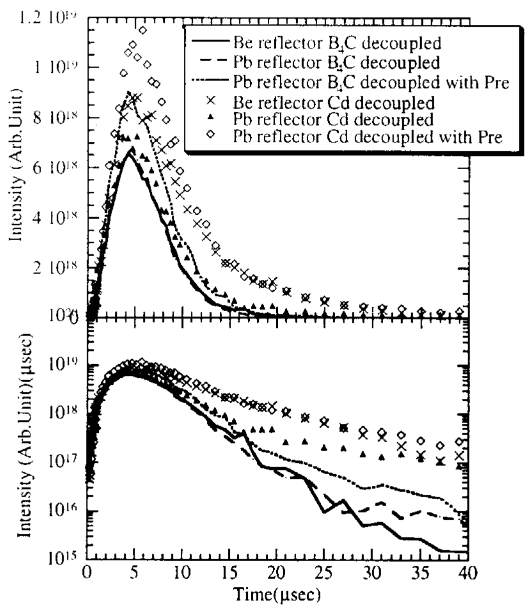

Fig.6. Calculated pulse shapes of Liq. H2. En=119meV

Next, the Cd decoupled case. By introducing premoderator to the lead reflector system, peak intensity increases by 70% and pulse width spread by about 15%. The tail of pulse becomes worse remarkably. In the case of beryllium reflector, FWHM is wider than these in the lead reflector system. However, when attention to the pulse decay, beryllium reflector system gives earlier pulse decay compare with the lead reflector case.

Thus, when the decoupling energy is high, reflector composition gives less effect on pulse shape. However, when cadmium is used for decoupler, reflector composition gives large effect on the pulse characteristic.

4-3 Consideration on effect of premoderator

If the low atomic number material like beryllium is used as a reflector, the reflector itself works as premoderator. So, neutrons are slowing down within a reflector. Then the neutron, which stayed on for a long time in the reflector, comes to be absorbed easily by decoupler, even if it decoupling energy is low. And decay of the neutron pulse becomes fast. From this reason by beryllium or the graphite reflector, the effects of premoderator will becomes very small or sometimes it will appear in negative.

On the other hand, since there is almost no slowing-down within a reflector in the case of the heavy material like lead, the neutrons arriving at the position far from the moderator return to the moderator with rather higher probability. As a result, intensity can be enhanced since many neutrons can enter into a moderator rather than the case of a beryllium reflector. On the other hand, the number density of hydrogen in liquid hydrogen is lower than that of light water or methane, so incident fast neutron will escape from a moderator before enoughly slowing down.

Figure 7 shows energy spectra incident on a moderator for three different conditions. It is clearly seen that the spectrum in the case of the lead reflector system without premoderator has very high intensity around 10^5eV compare with other systems. The spectrum becomes very soft by introducing premoderator and the spectrum shape is very similar to that in beryllium reflector case. The intensity of neutrons from the moderator in the case of lead reflector without premoderator is almost the same as that in beryllium case, which suggest that lower energy part of the spectrum of incident spectrum is effective to the neutron intensity from the moderator. From these spectra, we can easily recognize that the premoderator is not effective in beryllium system and also that higher intensity from the moderator in lead reflector system comes from the higher fast neutrons around 10^5eV probably produced in the reflector.

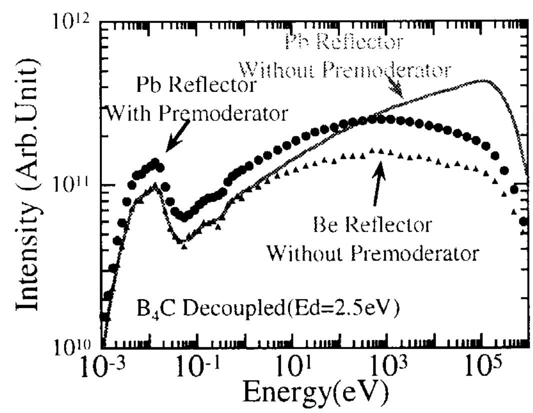

Fig.7. Premoderator effect on incident neutron spectrum.

Finally, premoderator is a technique for controlling a slowdown of the neutron within a reflector, and is a kind of a composite type reflector. Therefore, if the reflector and premoderator which character differs are combined, the influence will appear greatly.

5. Conclusion

Effectiveness of premoderator was confirmed by experiment and also by calculation, but the obtained intensity gain is different between experiment and calculation.

By introducing premoderator to lead reflector system, we can get higher intensity compared with beryllium reflector system.

Reference

[1] M. Konno, master's thesis (2000) 71

[2] M. Teshigawara, JSNS neutronics meeting report (11.19.1999)

Acknowledgement

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