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Neutronic Performance of Cold Moderators in the JAERI 5 MW Pulsed Spallation Source

N. Watanabe, M. Teshigawara, H. Takada, H. Nakashima,
J. Suzuki, K. Aizawa, Y. Oyama
Japan Atomic Energy Research Institute
Tokai-mura, Ibaraki 319-11, Japan

K. Kosako
Sumitomo Atomic Power Industries Ltd.
2-10-14 Ryogoku, Sumida-ku, Tokyo 130, Japan

ABSTRACT

We report the calculated results of neutronic performance of cold moderators in a reference target-moderator-reflector system at the projected 5 MW pulsed spallation neutron source in Japan Atomic Energy Research Institute (JAERI). The cold neutron intensities in present reference model are about 2.3-2.5 times higher than that from the decoupled solid methane (S-CH_4) and close to the values obtained at other facilities (LANSCE Upgrade, NSNS, etc.). The H_2O premoderator (PM) reduces the energy deposition in a liquid-hydrogen (L-H_2) moderator by about a factor of 2 compared with that in a decoupled L-H_2 moderator. The dependence of reflector on the neutron intensity and the energy deposition in the cryogenic moderators is also discussed. Although the pulse shapes were not obtained because of time consuming Monte Carlo calculations, we will discuss the pulse shapes based on experiments.

1. REFERENCE TARGET-MODERATOR-REFLECTOR SYSTEM

As a next-generation neutron source, the construction of a 5 MW (1.5 GeV) short pulsed spallation source is under planning in JAERI. In the early stage of the project one target station with one experimental hall is assumed from the financial reason, but one more is expected to be constructed in the final stage.

A horizontal beam injection scheme was adopted from a technical point of view. A reference target-moderator-reflector system is shown in Figure 1. Two coupled L-H_2 moderators with water premoderators [1-4] are located above the target both for high-intensity and high-resolution use (the highest peak intensity together with the highest time-integrated intensity). One high-resolution thermal neutron moderator (cryogenic, not specified yet) and one high-resolution light water moderator at room temperature are located below the target (Figure 1). A high-intensity thermal neutron moderator is not considered here. The ortho/para ratio of L-H_2 in the reference system is 75%/25% (normal hydrogen). Main parameters of the moderators studied are summarized in Table 1. At the present stage we assumed that experiments which utilize cold, thermal, and epithermal neutrons will occupy about one third of the total neutron beams, respectively. A tentative idea for the angular coverage of each moderator is shown in Figure 2 with tentative instruments.

In the reference system we adopted a non-separated target and a wing geometry in the target-moderator coupling scheme. In such configuration the neutron beam intensity strongly depends on the relative position of the moderator to the target, i.e., the axial distribution of leakage neutrons along the target axis. If one moderator takes the peak position, another has to take a relatively off-peak position, resulting in a lower intensity. A typical leakage neutron distribution from a Hg target is shown also in Figure 1. Although the distribution is somewhat broader than the case of 800 MeV protons, it is still too narrow to position two moderators at the highest-luminosity region. How to minimize the distance between two moderators is a key issue to obtain the maximum intensities from both moderators. After various considerations we arrived at a moderator layout in the reference geometry as shown in Figure 1. Two coupled moderators above the target share the backside PM in order to minimize the distance between the two and put both at the best position. Two different decoupled moderators are located below the target such that both can also take the best position as far as possible. For the upstream moderator below the target (high-resolution thermal), three candidates are under consideration; a decoupled L-H_2 (if necessary with interleaved poison sheet(s)), L-H_2 plus ZrH_2 and S-CH_4 particles plus L-H_2. Since we have not decided the moderator at this position yet, we tentatively put a decoupled S-CH_4 moderator there in the present calculation, as a reference cold neutron moderator for comparison with the coupled moderators above the target.

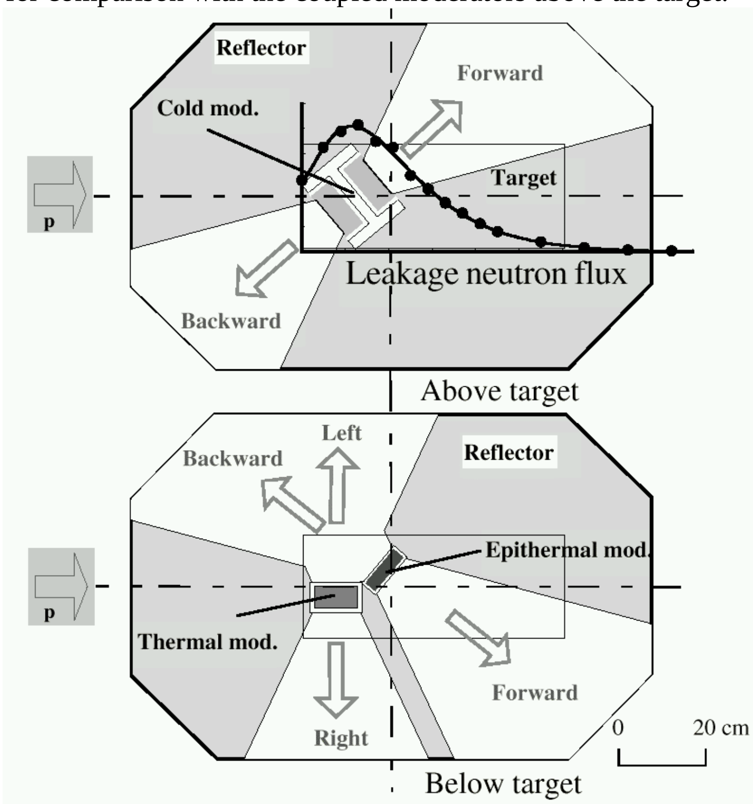

Figure 1. Layout of moderator and reflector.

Table 1. Moderators for calculational model.

	Cold neutron	Thermal neutron	Epithermal neutron
Purpose	High resolution and high intensity	High resolution	High resolution
Main moderator	L-H_2 (normal)	(CH_4 pellet+L-H_2) or (ZrH_2+L-H_2)	H_2O
(size cm)	(12 x 12 x 5)	(10 x 10 x 5)	(10 x 10 x 3)
Pre-moderator	H_2O (2.5 cm thick)	Non	Non
Coupling	Coupled	Decoupled*	Decoupled*
Cut - off energy (eV)	--	1	1
Angular coverage	50 x 2	50 x 2	50 x 2
No. of viewed surface	2	2	2
Moderator temp.	20 K	20 K	Room temp.
No. of moderators	2	1	1

*Decoupler is B_4C of 3 mm thick. Cut-off energy was controlled by changing the number density of B_4C.

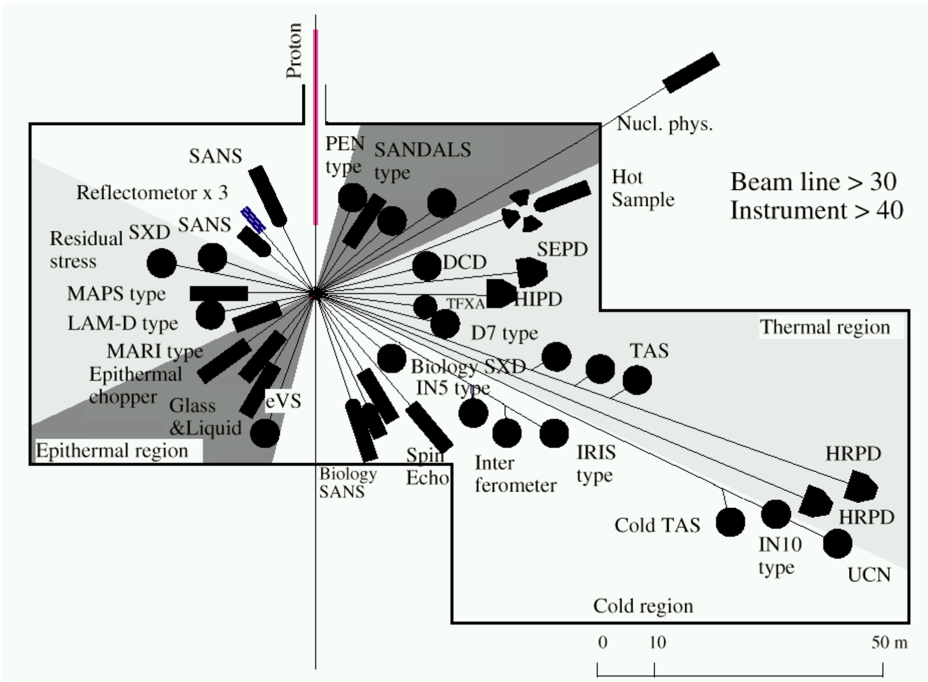

Figure 2. Layout of tentative instruments and angular coverage of each moderator.

2. NEUTRONIC PERFORMANCE

2.1 Time integrated neutron intensity

In order to predict the neutronic performance of each moderator in the reference system, especially in spectral intensity and energy deposition, and to find optimal parameters, we performed some neutronic calculations using code systems NMTC/JAERI [5,6] and MCNP-4A [7]. In the case of the mercury target, cross-sections recently evaluated at JAERI were used. The systems studied are summarized in Table 2. Figure 3 shows spectral intensities obtained for different moderators. Table 3 summarizes some results obtained by above calculations compared with some results obtained at other laboratories.

Table 2. Target - moderator - reflector systems studied.

	Proton beam			Target			Reflector	
Energy (GeV)	Profile	Cross-Section (cm)	Current density (mA/cm^2)	Material	Shape	Dimension (WxHxL cm^3)	Material	Dimension (WxHxL cm^3)
1.5	Uniform cylindrical	ϕ 9.36	48	Pb-Bi, Hg	Cylindrical	ϕ 12.36x60	-	-
	Uniform rectangular	10x6.88 20x3.44	48	Pb-Bi, Hg	Rectangular	14x9.88x60 24x6.44x60	-	-
	Uniform rectangular	10x6.88	48	Pb-Bi	Rectangular	14x9.88x60	Pb Be Small	80x160x120 80x160x120 60x140x90
				Hg	Rectangular	14x9.88x60	Pb Be	80x160x120 80x160x120

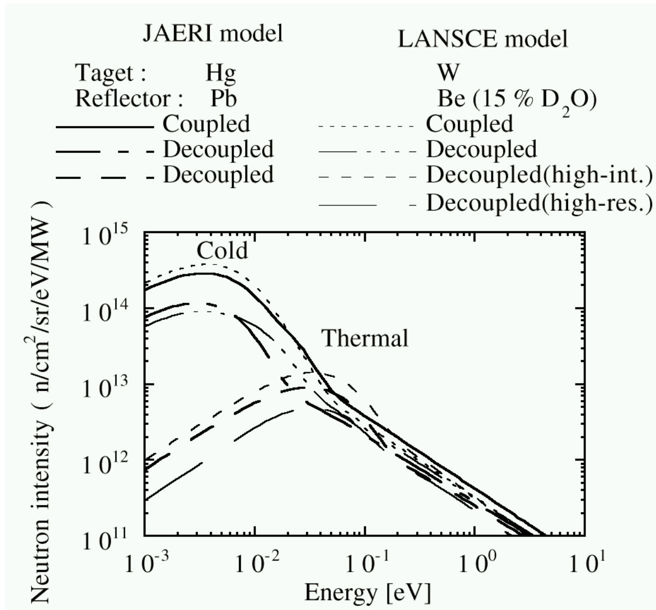

Figure 3. Spectral intensities obtained for different moderators

The results are summarized as follows;

(1) the cold neutron intensities from two coupled L-H_2 moderators are almost the same. We confirmed this by changing the moderator position relative to the target by 5 cm to both directions as shown in Figure 4;

(2) the neutron intensities at 1 eV from the two coupled moderators above the target are almost the same as calculated results by the Los Alamos group [8] on a coupled L-H_2 moderator without the PM in a flux-trap geometry, although the spectral intensities at the Maxwellian peak (the energy-integrated cold neutron intensity *J*) in the Los Alamos result is about 1.4 times higher than the present values. This is due to a different ortho/para ratio of L-H_2 they adopted (50%/50%). We also calculated with the same ratio and obtained the values close to theirs;

(3) the cold neutron intensities from the upper moderators are about a factor of 2.3-2.5 times higher than that from the decoupled S-CH_4 moderator (Table 3);

(4) the cold neutron intensities with two different reflector materials, Pb and Be, are almost comparable and a smaller Pb reflector gives slightly lower value (by about 10%) than the reference size Pb reflector (Figure 4);

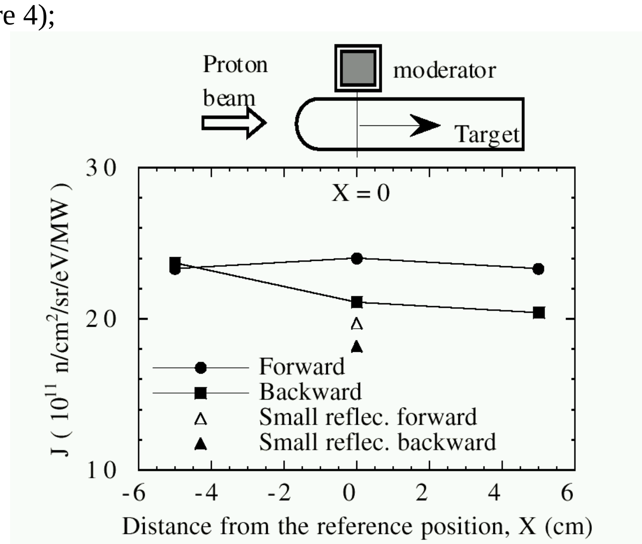

Figure 4. Cold neutron intensity for different relative positions to the target.

Table 3. Calculated results for cryogenic moderators compared with those in other projects.

Facility	Target /Reflector	Moderator		*J* (10^{11}n/cm^2/ sr/eV/MW)	E_T (meV)	ϕ at 1eV (10^{11}n/cm^2/ s/sr/MW)	Extraction
JAERI-SNS	Hg/Pb	L-H_2+P.M*	Coupled	25.0	3.3	4.2	Horizontal wing, Forward
	Hg/Be	L-H_2+P.M*	Coupled	23.7	3.3	3.4	Horizontal wing, Forward
	Hg/Pb	S-CH_4	Decoupled	10.2	3.0	3.2	Horizontal wing, Left
	Hg/Be	S-CH_4	Decoupled	10.9	3.0	2.8	Horizontal wing, Right
LANSCE UPGRADE	W/Be	L-H_2	Decoupled	7.5	3.1	3.1	Flux-trap
	W/Be	L-H_2	Coupled	36.3	3.6	3.3	Flux-trap
NSNS[9]	Hg/Be, Ni					2.8	Horizontal wing
IPNS UPGRADE[10]	Ta/Be	L-H_2	Decoupled	8.4		3.5	Horizontal, Flux-trap(R)

*P.M : 2.5 cm thick H_2O premoderator at ambient temperature.

2.2 Energy Deposition

Calculated results on the energy deposition in various moderators in the reference geometry are shown in Figure 5 as a function of the distance from the nearest end of the moderator to the target. The total energy depositions are summarized in Table 4.

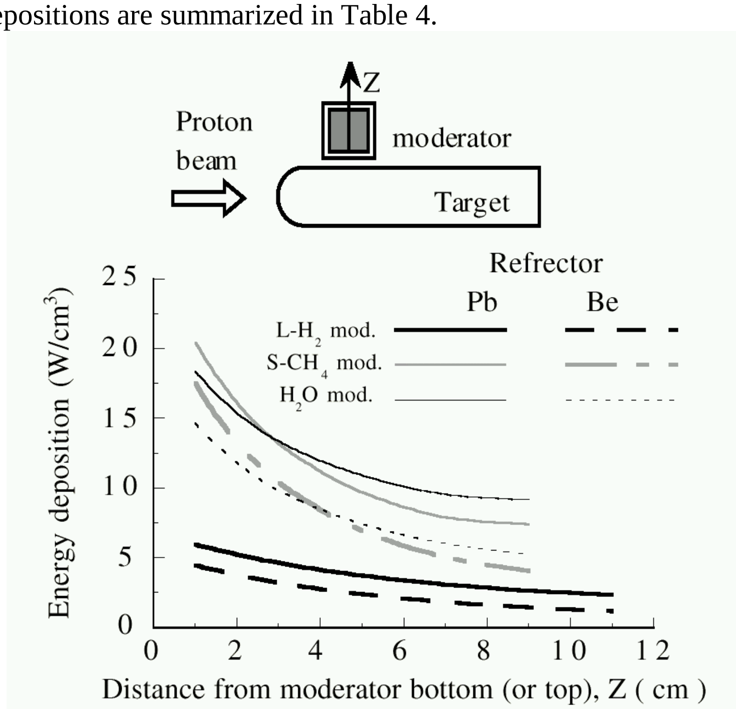

Figure 5. Energy deposition in moderators (1.5 GeV protons, 5 MW).

Table 4. Total energy deposition in moderators.

Target/Reflector	Total energy deposition (kW)*			
	L-H_2 (forward)	L-H_2 (backward)	S-CH_4	H_2O
Pb-Bi/Pb	3.0	2.5	5.9	4.0
Pb-Bi/Small Pb	2.8	2.4	5.7	3.8
Pb-Bi/Be	1.9	1.8	4.4	2.8
Pb-Bi/Pb (X=-5)	2.8	2.8	6.5	3.7
Pb-Bi/Pb (X=5)	3.0	2.1	4.9	4.2
Hg/Pb	2.7	2.4	5.9	3.7
Hg/Be	1.8	1.7	4.4	2.6

* for a proton beam power of 5 MW.

In case of S-CH_4 plus L-H_2 (for example, assuming 50% solid), the energy deposition is estimated to be about 75% of the pure S-CH_4 case. This value is still tremendous. The major results are summarized as follows;

- the values for the upper cryogenic moderators are relatively modest, but the value for the S-CH_4 is tremendous not only in the peak value but also in the total one, since in other similar projects as ESS and NSNS the proton beam power to a low repetition target, at which most cryogenic moderators are positioned, is only 1 MW (10 Hz), while in the JAERI case we must receive 5 MW;
- a 2.5 cm thick water PM reduces the energy deposition in L-H_2 by about a factor of 2 as shown in Figure 6, which is obtained by comparing the results for the coupled L-H_2 moderator with PM to those for the decoupled S-CH_4 moderator, taking into account the differences in the hydrogen number density and moderator volume. The present results are consistent with the result at Argonne for IPNS Upgrade [10]. As reported by Kiyanagi et al. in this Workshop, the neutron intensity from a mixed moderator of polyethylene particles plus L-H_2 is, roughly speaking, close to a linear combination of the performance of each moderator weighted by the volume fraction. This suggests that a solid fraction less than about 50% is less interesting for us. The most important problem we recognized is the maximum particle number density one can circulate in the mixed moderator. Thermal and hydraulic studies have started in JAERI for such mixed moderator. If S-CH_4 is replaced by L-H_2, the peak power deposition decreases to about 60% of the S-CH_4 case. However, if we employ a poisoned L-H_2 moderator, a larger volume (say, 10 cm x 10 cm x 10 cm) will be necessary, resulting in almost the same (or more) total deposition as is the case for S-CH_4.
- a Be reflector reduces the total energy deposition in cryogenic moderators by a factor of about 1.5 as compared to a Pb reflector as shown in Table 4.

We also performed some neutronic calculations for different target shapes (cylindrical and flat) with different proton beam profiles (cf. Table 2).

2.3 Pulse Characteristics

We discuss the pulse characteristics such as pulse width in FWHM, decay time, and pulse peak height based on the experimental results, since Monte Carlo simulations are very time consuming. Recently, it has been recognized that the figure of merit for a cold neutron source is almost proportional to the time-integrated cold neutron intensity per pulse for experiments such as small angle scattering, while for high-resolution experiments, it is proportional to the peak intensity, almost independent of the repetition rate in a range approximately above 15 Hz. This means that a shorter pulse width at a cost of the peak intensity is not interesting. However, if the time integrated intensity is the same, a shorter pulse provides a higher pulse height. If we compare the peak intensity from a coupled L-H_2 moderator with a PM to that from a coupled L-H_2 of a optimal size but without a PM, the former should give a higher peak height. Figure 7 shows such a possibility.

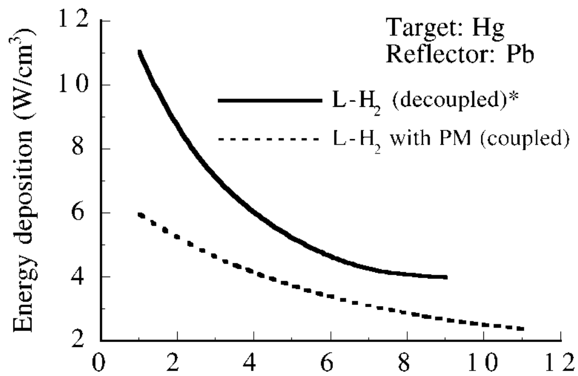

Figure 6. The effect of premoderator on energy deposition estimated from the results of coupled L-H_2 moderator with decoupled S-CH_4.

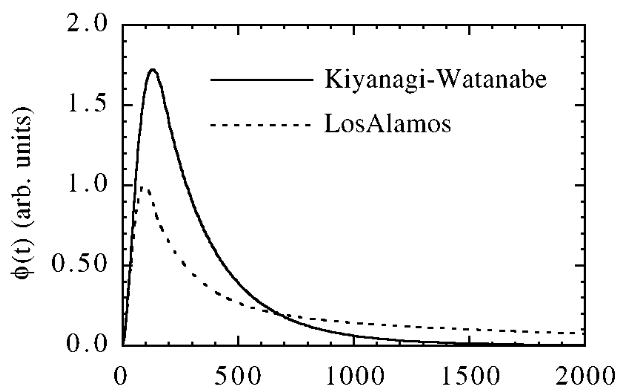

Figure 7. Comparison of pulse shape from a coupled L-H_2 moderator with premoderator (Kiyanagi-Watanabe) to that from a coupled L-H_2 moderator without premoderator (Los Alamos).

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