

**A Design Concept of Target-Moderator-Reflector Assemblies for  
KENS-II  
-A High-Efficiency Pulsed Spallation Neutron Source-**

**N. WATANABE**

National Laboratory for High Energy Physics,  
1-1 Oho, Tsukuba-shi, Ibaraki 305 Japan

**ABSTRACT**

A design concept of KENS-II target-moderator-reflector assemblies is described. - one of the assemblies is dedicated to the cold neutron source, and the other, to the thermal and epithermal neutron source. A flux-trap type moderator-configuration was adopted with a vertical proton-beam injection scheme. All moderators for the cold neutron source are coupled liquid hydrogen moderators with premoderators. A new scheme of proton beam delivery is proposed. The new system can provide several times higher total performance than a reference system based on a traditional single assembly with all decoupled moderators in a wing geometry and with a horizontal proton-beam injection scheme.

**I. INTRODUCTION**

The traditional target-moderator-reflector assembly (TMRA) concept, based on a single assembly with all decoupled moderators in a wing geometry and a horizontal proton-beam injection scheme, has been widely adopted at existing pulsed spallation neutron sources. This concept has proved to be very useful by the successful operation of the existing facilities. The neutron scattering community has always requested more intense neutron sources, and consequently, proton accelerators with higher beam currents. The approach to an intense spallation neutron source with an intense accelerator would be orthodox, but very expensive and sometimes not realistic. When we consider a new source, generally speaking, it must be superior to the existing large scale ones, even though the proton beam power is comparable to those in existing large scale facilities. Thus, a new concept for a high-efficiency TMRA becomes indispensable. This is our situation for the fundamental design of KENS-II in the JHP project. To realize this, we proposed and developed a high efficiency cold neutron source with a coupled liquid hydrogen moderator with premoderator<sup>1-2),4-5)</sup> based on a

consideration of figures of merit (FOM's) of a pulsed cold neutron source for various scattering experiments<sup>3</sup>). We considered two typical experiments using pulsed cold neutrons: one is the small angle neutron scattering (SANS)-type, in which experiments on TOP, CRISP, spin echo machines, etc. are included, and the other is the LAM-type, high resolution spectroscopy using the time structure of the neutron pulse. We confirmed that the proposed moderator can provide much higher FOM's than a the traditional decoupled one. We have also performed detailed studies on the so-called "flux-trap type moderator", which is successfully used at LANSCE in Los Alamos. We confirmed that this moderator can provide 1.35-1.4 times higher slow neutron intensity than a traditional moderator in a wing geometry<sup>6</sup>). A new concept for the KENS-II TMRA described here is based on the ideas mentioned above.

## II. Design Concept and Assumptions

In the TMRA concept, we assume the followings.

- (1) All moderators are in a flux-trap type moderator geometry. This geometry can provide 1.35-1.4 times higher slow-neutron-beam-intensity than a traditional wing geometry not only for decoupled moderators, but also for coupled ones.
- (2) For high-efficiency cold-neutron-moderators, we adopt a coupled liquid hydrogen moderator with hydrogenous premoderator at room temperature. This provides about 6 times higher performance (FOM's relative to a decoupled liquid hydrogen moderator) for SANS-type experiments and 2-3 times (depending on the neutron wavelength) higher FOM's for LAM-type experiments<sup>3</sup>).
- (3) One TMRA is not adequate for the required angular coverage of the neutron-beam (almost  $360^\circ$ ) even with a 4-moderator configuration, because the maximum angular coverage for one viewed moderator surface is  $50^\circ$ , which corresponds to about 4 beams (due to the existence of other moderators). Consequently, two assemblies become necessary.
- (4) We propose a 2 TMRA concept: TMRA-1 dedicated to the cold neutron source with 3 coupled moderators, and TMRA-2, to the thermal/epithermal neutron source with 3 decoupled moderators as shown in Fig. 1. Coexistence of coupled and decoupled moderators in one TMRA is not desirable from an intensity point of view<sup>5</sup>). This concept makes it possible to provide neutron beams over an angular range of  $300^\circ$  or more.
- (5) We propose a new proton-beam delivery scheme as shown in Fig. 2 (scheme (1)). Since FOM's for both type of experiments are, to a first approximation, independent of the repetition rate of the neutron pulse within a realistic range<sup>3</sup>), we allocate 10 double pulses every sec. to the TMRA-1. This will provide 2 times higher FOM's than the original proton-beam delivery scheme of 50 single pulses (another 50 single pulses are

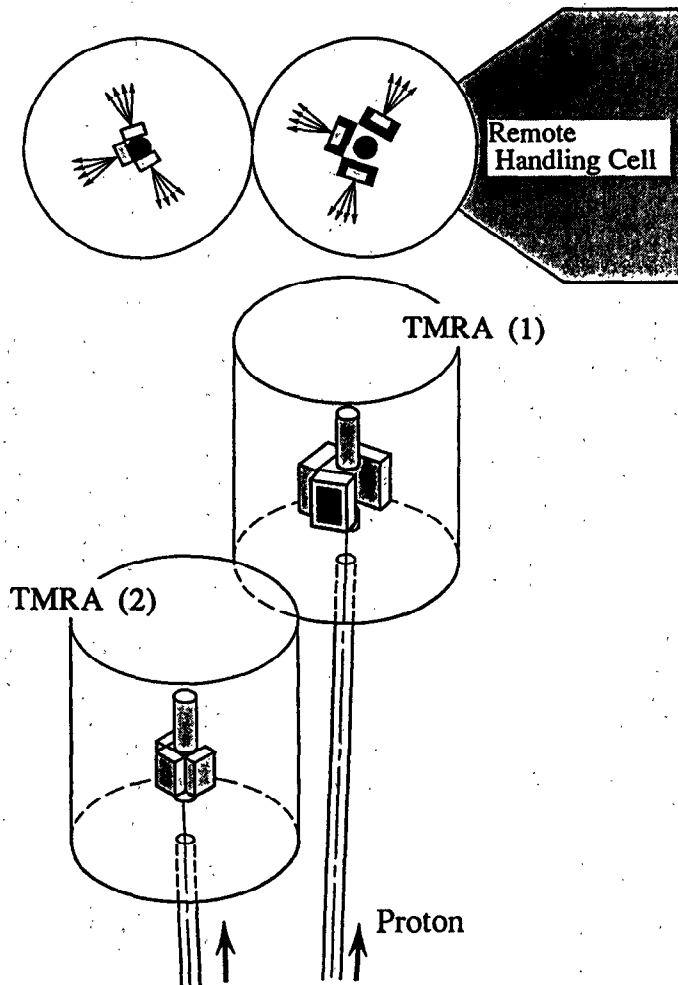


Fig. 1. Proposed TMRA's for KENS-II

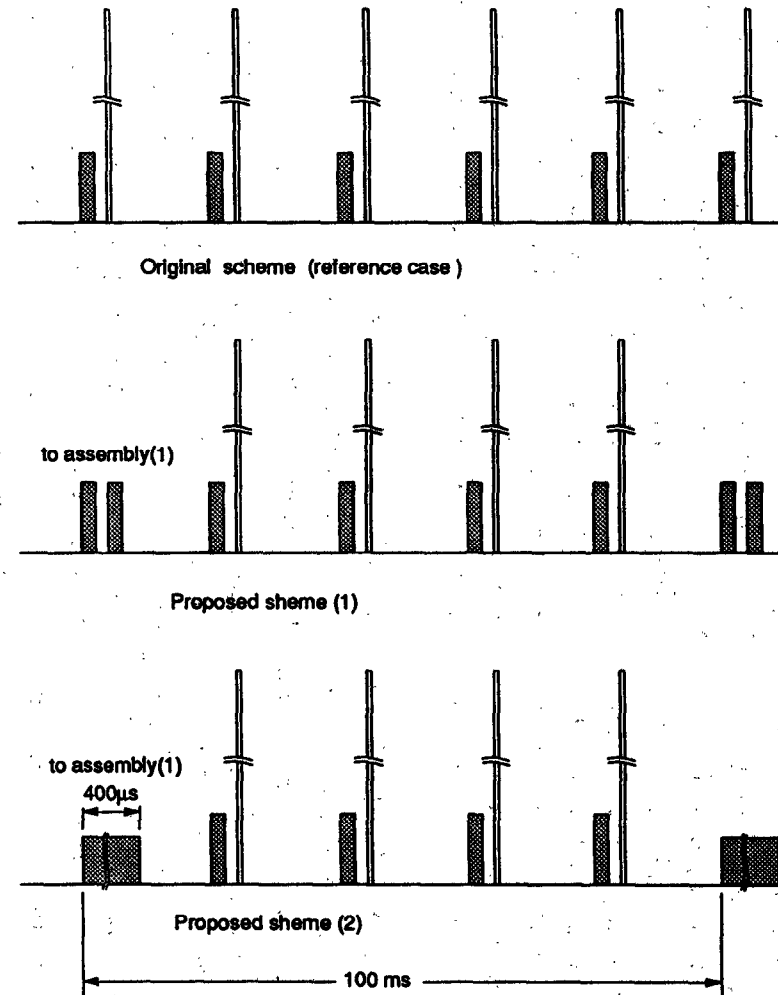


Fig. 2. Proposed proton-beam delivery schemes. Gray pulses are to the neutron facility and white ones to the meson facility. In the reference case all gray pulses are fed to one TMRA, while in the schemes (1) and (2) first pulse(s) are fed to TMRA (1) and another ones to TMRA (2).

delivered to the meson facility) with no significant losses. The remaining 40 single pulses are fed to TMRA-2. In the JHP project, it was decided to share the total proton-beam from the compressor/stretcher ring equally by the neutron and the meson facilities. Since the meson facility has a schedule to utilize the stretched beam for about 20% of the total beam, and the simultaneous use of pulsed and stretched beams is not possible, a macroscopic beam-time sharing becomes necessary. The additional beam for the neutron facility by double-pulse delivery to the TMRA-1 just meets the 20% reduction of neutron beam-time by the stretched beam use.

- (6) As an alternative to proton-beam delivery (scheme (2)), we propose to use long macro-pulses of  $H^-$  beam directly obtained from the linac, instead of double pulses from the compressor/stretcher ring. The time-averaged intensity of the  $H^-$  beam is  $400 \mu A$ , 2 times higher than the short pulse beam from the ring, but the pulse duration is  $400 \mu s$ . The use of this beam in the TMRA-1 gives 2 times higher FOM's for SANS-type experiments with unchanged FOM's for LAM-type experiments.
- (7) The number of neutron beams available with the KENS-II concept is about 24, which should be compared to a reference case of 18 when a tradition wing geometry and a horizontal proton-beam injection scheme is used, for example, as in ISIS. The larger number in the KENS-II concept is due to the vertical proton-beam injection scheme, in which the proton beam line with its massive shielding can be removed from the experimental hall and additional neutron beams can be extracted into the space saved.
- (8) It would be reasonable to allocate more neutron-beam lines for cold neutron experiments than in the existing facilities, because of the recent growth in the relative importance of cold neutrons even in spallation sources. We therefore assumed that 50% of the total neutron-beam lines are allocated for cold neutron experiments in both the reference and KENS-II cases. We also assumed that, among the cold neutron experiments,  $2/3$  are of the SANS-type and the remaining  $1/3$ , the LAM-type.

For convenience, we summarize in Table I the main parameters of the neutron source in the proposed KENS-II concept compared to the reference case.

### III. Total Performance and Gain Factor of Pulsed Neutron Sources

In a pulsed spallation neutron source, the total performance of the source relative to a reference case can be expressed as a sum of relative FOM's for each neutron beam,

$$\text{Total Performance} \equiv \sum_i (\text{FOM})^i / (\text{FOM})_{\text{ref}}^i .$$

For simplicity, we define

$$(\text{FOM})_{\text{ref}}^i \equiv 1,$$

Table I Main parameters of the neutron sources in the reference case and KENS-II concept

	Reference case	Kens-II Concept	
Proton-beam injection scheme	Horizontal	Vertical	
Target-moderator coupling geometry	wing	flux-trap	
Number of TMRA	1	2	
		TMRA-1 (for $n_c$ )	TMRA-2 (for $n_{th}/n_{epi}$ )
Number of proton pulses (pulse/sec)	50 single pulses	10 double pulses	40 single pulses
Macroscopic beam time, D (relative value)	1	0.8	
Number of Moderators	4 decoupled	3 coupled	3 decoupled
Gain factor of "Flux-Trap" relative to "Wing", $G_f$	1	1.35	1.35
Number of neutron beams for SANS-type exp, $N_{SANS}$	6		8
for LAM-type exp, $N_{LAM}$	3	4	
for $n_{th}/n_{epi}$ , $N_{th/epi}$	9		12
Relative moderator FOM for SANS-type exp, $FOM_{SANS}$	1	6	
for LAM-type exp, $FOM_{LAM}$	1	2.5	
for $n_{th}/n_{epi}$ , $FOM_{th/epi}$	1		1

n denotes neutrons and the subscripts c, th and epi refer to cold, thermal and epithermal, respectively.

Table II Gain factor of proposed neutron sources relative to the reference case

KENS-II concept with proton-beam delivery scheme(1)	KENS-II concept with proton-beam delivery scheme(2)
7.6	13.5

thus, the total performance of the reference system becomes equal to the number of neutron-beam lines, that is

$$\sum_{i=1}^{18} (\text{FOM})_{\text{ref}}^i = 18.$$

Let us calculate the total performance of the proposed concept for KENS-II, which can be expressed as,

$$\begin{aligned} & \text{Total performance} \\ & = D G_f \{ 2 (\text{FOM}_{\text{SANS}} N_{\text{SANS}} + \text{FOM}_{\text{LAM}} N_{\text{LAM}}) + (40/50) \text{FOM}_{\text{th/epi}} N_{\text{th/epi}} \} \end{aligned}$$

where the notations are defined in Table I, and the factor 2 in the above equation comes from the "double pulse" discussed in (4) in the preceding section. Using the values listed in the table, we have

$$\text{Total Performance} = 0.8 \times (1.35 \sim 1.4) \{ 2(6 \times 8 + 3 \times 4) + 0.8 \times 12 \} = 130 \sim 145.$$

The relative value of the total performance to the reference case (gain factor) is thus

$$\text{Gain Factor} = (130 \sim 145) / 18 = 7.3 \sim 8 = 7.6$$

If we adopt the alternative proton beam delivery scheme mentioned in (6) in the preceding section,  $\text{FOM}_{\text{SANS}}$  must be 12 instead of 6 in the above equation.

Then, we have

$$\text{Gain Factor} = 13.5.$$

Table II summarizes the result.

#### IV. DISCUSSIONS

We obtained a very large gain with a new concept of TMRA for KENS-II with new proton-beam delivery schemes. The large gain comes from cold neutron utilization (TMRA-1), and the overall efficiency of TMRA-2 is almost unchanged compared to the reference case. However, the gain factor 7.6~13.5 is great. In other words, the neutron source in the proposed concept is equivalent to a neutron source with a proton accelerator of one order of magnitude higher beam current than is present now, though more emphasis is placed on cold neutron experiments, which can well compete with those performed using a high flux reactor.

In addition to the advantage in the neutronic performance mentioned above, there are other merits to the proposed system:

(1) The heat load for Target-1 in the TMRA-1 with proton-beam delivery scheme (1) is 2/5 of the reference case (or a maximum of 4/5 in the case of proton beam delivery scheme (2)). This makes the engineering design

of the system more easy; for example, the use of a depleted uranium target becomes less difficult.

- (2) Power density and total power deposited in a liquid hydrogen moderator is almost one order of magnitude smaller than in the reference case, due to the factor mentioned in (1), and another factor saved by premoderation.
- (3) Fast and higher energy neutrons leaking from the neutron beam holes can be minimized with a flux-trap type moderator geometry without sacrificing beam intensity by increasing the height of the void space between 2 target blocks.
- (4) Smaller proton beam power, and consequently a smaller accelerator, is acceptable for a given total performance. This brings about lower costs for the construction and the operation of accelerator.
- (5) Relatively thinner radiation shielding for target station and neutron beam lines is required.
- (6) The radiation impact on the public is reduced.
- (7) A smaller area for the site is acceptable.

#### REFERENCE

- 1 N. Watanabe : Advanced Neutron Sources 1988 (Proc. ICANS-X), Institute of Physics Conference Series Number 97, Institute of Physics, Bristol and New York (1988) p-763.
- 2 N. Watanabe, Y. Kiyonagi, K. Inoue, M. Furusaka, S. Ikeda, M. Arai and H. Iwasa: *ibid* p-787.
- 3 N. Watanabe, M. Furusaka and Y. Kiyonagi : A design Concept for KENS-II Cold Neutron source, Proc. Int. Workshop on Cold Neutron Sources (Los Alamos, Mar. 5-8, 1990), in press.
- 4 Y. Kiyonagi, N. Watanabe, M. Furusaka, H. Iwasa and I. Fujikawa Proc. ICANS-XI (Tsukuba, Oct. 22-26, 1990) p-388.
- 5 Y. Kiyonagi, N. Watanabe, M. Furusaka and H. Iwasa : *ibid*, p-401.
- 6 Y. Kiyonagi and N. Watanabe : *ibid*, p-408.

Q(J.M.Carpenter): If your four flux-trap moderators were arranged two each on two levels, with greater separation of target halves, the moderators could be viewed from both sides and provide 24 beams.

A(N.Watanabe): Greater separation of target halves does not decrease the slow neutron intensity from four flux-trap moderators on one level, but more moderators at different levels bring about lower intensity due to the shadow effect.