

CONF-980921--

## NEUTRONIC MODERATOR DESIGN FOR THE SPALLATION NEUTRON SOURCE (SNS)

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## ABSTRACT

Neutronics analyses are now in progress to support the initial selection of moderator design parameters for the Spallation Neutron Source (SNS). The results of the initial optimization studies involving moderator poison plate location, moderator position, and premoderator performance for the target system are presented in this paper. Also presented is an initial study of the use of a composite moderator to produce a liquid methane like spectrum.

## I. INTRODUCTION

The proposed Spallation Neutron Source (SNS) facility will consist of two parts: 1) a high energy (1 GeV) and high powered (1 MW) proton accelerator (linac) and accumulator ring, and 2) a target station which converts the protons to low-energy ( $<2$  eV) neutrons and delivers them to the neutron scattering instruments. It will be a 60 Hz facility delivering  $6 \times 10^{15}$  protons each second in 60  $\mu$ s pulses with a linac length of 490 m and an accumulator ring circumference of 220 m.

Work is now underway to optimize the SNS design. In section II a study of the effect of varying the moderator poison plate location is presented with a moderator position study given in section III. The use of a premoderator was considered and the results of this consideration are given in section IV. It was found that a composite moderator could be very useful and the basis for the finding is given in section V. In the last section a summary and conclusions are presented.

## II. VARIATION OF PULSE PARAMETERS WITH POISON PLATE LOCATION

The pulse width can be reduced by varying the location of a gadolinium poison plate. The plate in the present study is parallel to the viewed moderator face and placed the distance between the viewed face and the poison is varied. The effect this has on the neutron pulse from the moderator face is shown in Figure 1. To

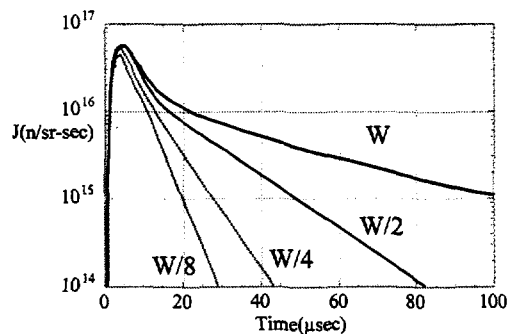


Figure 1. Neutron pulse ( $\lambda = 0.6$  to  $1.0$  Å) for various locations of a gadolinium poison plate. The distance  $W$  is measured from the viewed moderator face (the width of the moderator is  $W$ ).

produce these results, we moved the plate from a location where the distance from the plate to the viewed moderator face was the total width divided by 8 ( $W/8$  in the figure) to a location at the face opposite the viewed moderator face ( $W$ ). This latter location is equivalent to having no poison since the effect of the poison is to reduce the moderator width as seen by low-energy ( $E_n < \sim 0.3$  eV) neutrons. With no poison ( $W$ ), the neutron intensity drops by less than two orders of magnitude in 100  $\mu$ s. With the poison at the other extreme ( $W/8$ ), the neutron intensity drops by three orders of magnitude in

\* Managed by Lockheed Martin Energy Research Corporation for the U.S. Department of Energy under Contract No. DE-AC05-96OR22464.

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30  $\mu$ s. Note that the peak neutron flux drops by only 20% from one extreme location of the plate to the other. Thus, the poison plate location offers effective control over the pulse width with little change in the peak neutron intensity. The present recommended location for the poison plate is  $W/2$ , but further optimization will use the behavior shown in Figure 1 to better fit the moderator neutron output to the instrument needs.

### III. MODERATOR POSITION

In order to study the optimum moderator position and size, we used a simple model. The simple model contained a mercury target with a rectangular cross section but with dimensions approximating those of the target. Four moderators were used. In accordance with the present requests of the instrument designers, both  $H_2O$  moderators and the upstream  $H_2$  moderator were decoupled and poisoned. The downstream  $H_2$  moderator was coupled and unpoisoned. A Be reflector of equivalent size to the planned target station was used. It was found that the pulse width was roughly independent of the moderator location and thus only the magnitude of the neutron current needed to be considered when optimizing the neutron output. In Figs. 2 and 3 the neutron current is shown as a function of the distance ( $L$ ) of the center of the moderators from the front of the Hg target. The separation was maintained at 21.5 cm. For the  $H_2$  moderators (Fig. 2), the upstream current peaked when the front of the moderator was at the front of the Hg target ( $L=6$  cm). The current in the downstream moderator increased monotonically as the moderator moved upstream. The much smaller upstream current is due to the decoupling and poisoning which not only decreases the pulse width but also decreases the

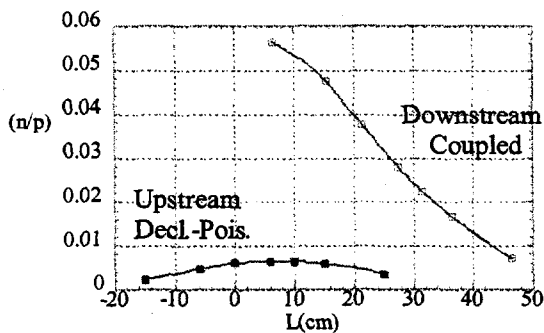


Fig. 2. Thermal neutron current from  $H_2$  moderators.

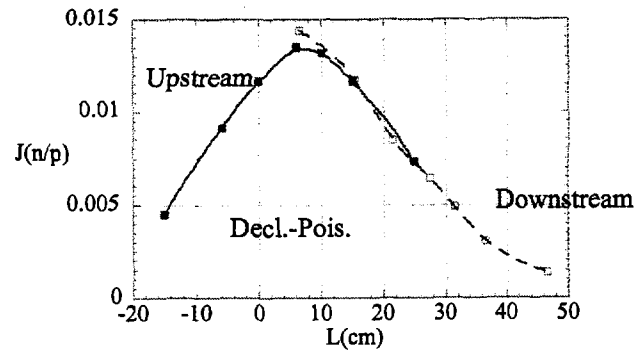


Fig. 3. Thermal neutron current from  $H_2O$  moderators.

current. The current in the upstream moderator also peaks for the upstream  $H_2O$  moderators (Fig. 3) when the upstream edge of the moderator is at the upstream edge of the Hg, and the current in the downstream moderator also increases monotonically as the moderator moves toward the upstream edge of the Hg. Since both  $H_2O$  moderators are decoupled and poisoned, the current is equal when they are at the same position.

Since there are 12 neutron beam tubes coming from the front moderators and only 6 from the back, it was desirable to maximize the current in the front moderators independent of the back. This is accomplished by placing them with their upstream edges at the upstream edge of the Hg. After the optimization of the upstream moderators, the currents from the downstream moderators are optimized by placing the moderators as close to the front as possible. This procedure could fail, however, if the location of one of the moderators has a large effect on the other. The effect of the downstream moderator on the upstream is negligible. The effect of the upstream on the downstream is addressed in Fig. 4 where the variation in the current in the downstream moderator is plotted as a function of  $L$  both when the front moderator is present (i.e., with moderator interaction) and when it isn't (i.e., with no moderator interaction). As may be seen, the presence of the front moderator reduces the current in the back moderator when they are close together (due to a decrease in the nearby reflector volume) but it doesn't cause a decrease in the current as the back moderator is moved forward. It is still desirable to have the back moderator as close to the front as possible. Thus, the above optimization procedure is still valid.

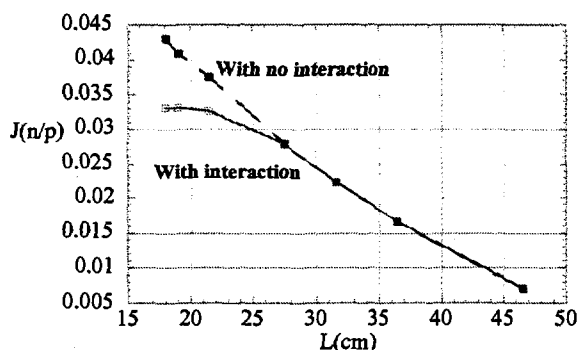


Fig. 4. Effect of moderator interaction on downstream coupled  $H_2$  moderator output. Upstream moderator is a decoupled poisoned  $H_2O$  moderator located at  $L=6\text{cm}$ .

#### IV. PREMODERATOR STUDY

A premoderator used together with a cryogenic moderator can be very useful in reducing the heat deposited in the moderator material. This reduces demands on the cryogenic system and allows it to be made more simply and smaller. This reduction, in turn, can allow the active moderator material to be placed closer to the source and thus give a larger useful neutron flux.

The model geometry shown in Fig. 5 was used for the premoderator study reported here.

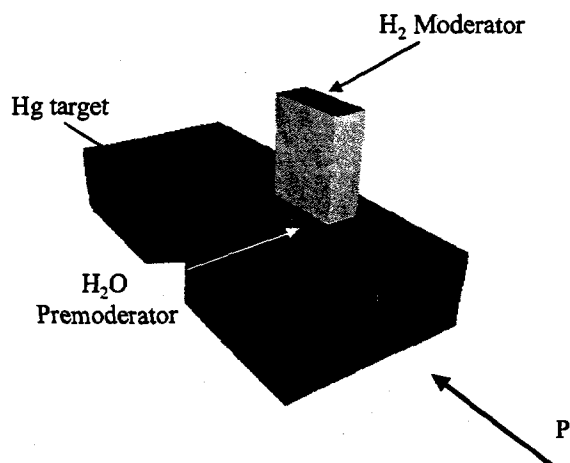


Fig. 5. Model geometry used for the premoderator study.

A  $H_2O$  premoderator was placed between the target and the cryogenic  $H_2$  moderator. The size of the premoderator in the plane parallel to the target surface was the same as that of the moderator. The thickness (distance from the side of the premoderator next to the surface of the target to the side of the premoderator next to the moderator itself) was varied to assess the premoderator

performance. With zero premoderator thickness the model geometry was identical to that used for the moderator position study discussed earlier.

Both the thermal neutron current and the energy deposition in the moderator are shown vs. premoderator thickness in Fig. 6 (the moderator dimensions are held fixed). As the premoderator thickness is increased, there is first an increase in the current and then a decrease

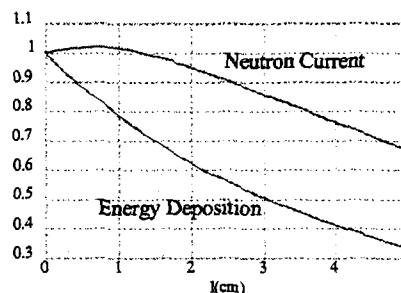


Fig. 6. Thermal neutron current and energy deposition vs the premoderator thickness( $l$ ).

along with a continuous decrease in the energy deposition. Both are normalized to unity when no premoderator is present. The decrease in the current (expressed as a fraction of the the zero-thickness current) is a good deal less than the decrease in the energy deposition (also expressed as a fraction of the zero-thickness energy deposition). The energy deposition (and thus the cost of the cryogenic system) can be decreased by a large amount with a much smaller decrease in the neutron current. A 3-cm-thick premoderator can reduce the energy deposition by 50% with only a 15% loss of thermal neutron current. A 3-cm-thick premoderator is being incorporated into the SNS cryogenic  $H_2$  moderator design.

In Fig. 7, the neutron spectrum with no premoderator is shown along with the ratio of the current when a 5 cm premoderator is used to that when no premoderator is used. The current loss at an energy

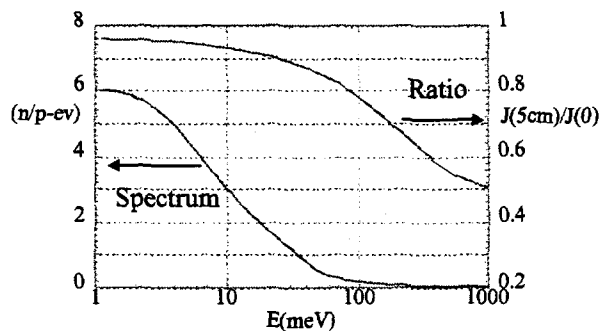


Fig. 7. Spectrum with no premoderator and the ratio of the spectra with no premoderator to that for a system with a 5-cm premoderator.

corresponding to the peak in the spectrum ( $\sim 1$  meV) is very small (5%) even with the large premoderator. The thermal current loss shown in the previous figure comes mainly from higher energy neutron loss. As the energy is increased, the current loss reaches 10% at  $\sim 30$  meV which is the approximate energy at the peak in the spectrum from a  $H_2O$  moderator. Thus appreciable loss occurs only for neutrons which would be better obtained from a  $H_2O$  moderator. The penalty, in terms of current loss, is very small for neutrons in the energy range that would normally be obtained from a cryogenic  $H_2$  moderator.

## V. COMPOSITE MODERATOR DEVELOPMENT

Neutrons with a spectrum which peaks at  $\sim 20$  meV were requested by many neutron experimentalists at the Spallation Neutron Source's (SNS) User's Meeting. Neutrons with this wavelength can be produced by moderators containing cryogenic liquid hydrogen (L- $H_2$ ) (pure para  $H_2$  is assumed for all the calculations shown here) and with moderators containing ambient water ( $H_2O$ ). However, a moderator with liquid methane (L- $CH_4$ ) can produce 2-3 times as many neutrons at this energy (See Fig. 8). For the SNS (at powers  $>1$  MW) and similar devices, however, the neutron flux is too high to use L- $CH_4$  because of its rapid polymerization in a high flux field.

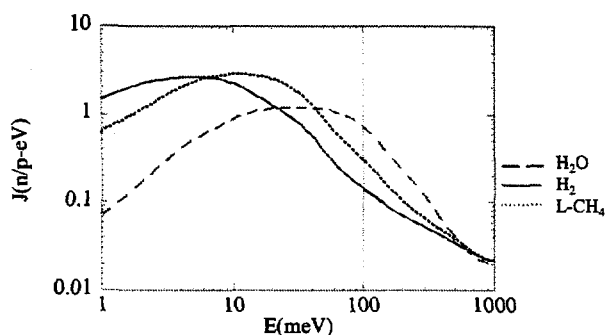


Fig. 8. Comparison: Neutron output from L- $H_2O$ , L- $CH_4$  and L- $H_2$  moderators.

One approach that produces a moderator with the potential to generate a spectrum very similar to L- $CH_4$  is to use a composite moderator in which part of the moderator volume would contain one material and part of the volume would contain another (this was suggested by the work in Ref. 7). Since  $H_2$  has a spectrum which peaks below L- $CH_4$  (in energy) and  $H_2O$  has a spectrum which peaks at an energy above L- $CH_4$  (See Fig. 8), they provide natural candidates for a composite moderator with a spectrum similar to L- $CH_4$ . They are also good

candidates since no problems are expected for either material at the high flux levels and, in fact, both materials are already being used separately as reference SNS design moderators.

A preliminary study was performed, using Monte Carlo calculations and assuming an SNS-like geometry, to see if a composite could reproduce the desired L- $CH_4$  spectrum. It was found that if the moderator were viewed from the side which contained  $H_2O$ , a spectrum was seen that strongly resembled that for  $H_2O$ . However, if the moderator were viewed from the  $H_2$  side, the spectrum seen resembled that for an admixture of  $H_2O$  and  $H_2$  (See Fig. 9).

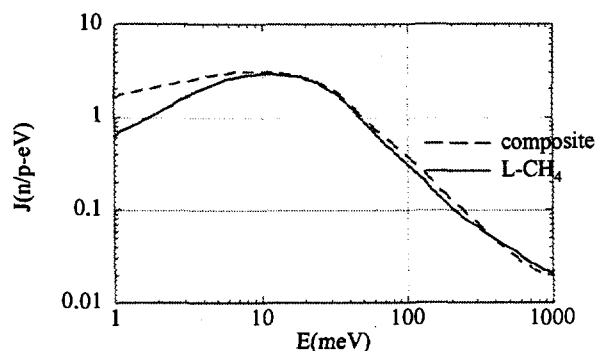


Fig. 9. Comparison: Composite moderator ( $1/4 H_2 - 3/4 H_2O$ ) and L- $CH_4$ .

## VI. SUMMARY AND CONCLUSIONS

The neutronics design and optimization analyses are now in progress to support initial selection of target system design features, such as moderators, for the proposed SNS. Initial optimization studies involving moderator poison plate location, moderator position and moderator performance with the use of a premoderator have been performed. If it is desired that the upstream moderator be optimized independently of the downstream then the upstream edge of the upstream moderator should be at the upstream edge of the Hg. The downstream moderator is then optimized by placing it as close to the upstream as possible. Moving the poison plate has a strong effect ( $\sim$  factors of 2 to 3) on the neutron pulse width and only a modest effect ( $\sim 20\%$ ) on the neutron pulse intensity. The use of a premoderator allows the energy deposition in a cryogenic  $H_2$  moderator to be greatly decreased with little penalty in neutron current at energies where a  $H_2$  moderator would normally be used. A  $H_2O/H_2$  composite moderator can produce a L- $CH_4$ -like spectrum. Such a moderator

should not have the high power problems with polymerization that are typical for L-CH<sub>4</sub> moderators.

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