# PROGRESS REPORT: SNS NEUTRONICS STUDIES

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## 1. Introduction

The proposed Spallation Neutron Source (SNS) facility (see Fig. 1) 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 that produces low-energy (<2-eV) neutrons and delivers them to the neutron scattering instruments. It will be a 60-Hz facility, delivering 6 x $10^{15}$ protons each second in 60 1-μs pulses with a linac length of 490 m and an accumulator ring circumference of 220 m.

This paper deals with the second part of the facility: the design and development of the SNS target station proposed for Oak Ridge National Laboratory (ORNL). Some of the more recent work will be presented, including a premoderator study, validation comparisons with experiment, sensitivity studies of cryogenic $H_2$ moderator output to assumed ortho/para admixtures, and the construction of a more detailed model geometry.

## 2. Methodology

The neutronic behavior of the target system can be obtained by using Monte Carlo techniques to track the progress of various subatomic particles as they proceed through the target geometry. For low-energy transport, the MCNP [1] code was used; for high-energy transport, the codes HETC [2] and LAHET [3] were used. The various target station geometries are discussed in more detail in Ref. 4.

## 3. Premoderator Study

A premoderator, used together with a cryogenic moderator, can be very effective in reducing the heat deposited in the moderator material. This combination reduces demands on the cryogenic system and allows it to be made more simply and cheaper.

For this study a $H_2O$ premoderator was placed between the target and the liquid $H_2$ moderator (see Fig. 2). The size of the premoderator in the plane parallel to the target surface was the same as the moderator. The thickness (distance from the side of the premoderator next to the

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surface of the target to the side of the premoderator next to the moderator itself) was varied to assess the premoderator performance.

Both the thermal neutron current and the energy deposition in the moderator are shown vs premoderator thickness in Fig. 3. As the thickness is increased, there is first an increase and then a decrease in the current 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 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 needed to remove the energy) can be decreased by a large amount with a much smaller decrease in the neutron current. A 3-cm premoderator can reduce the energy deposition by 50%, with only a 15% loss of neutron current.

In Fig. 4 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 corresponding to the peak in the spectrum is very small (5%), even with the large premoderator. As may be seen 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 ~30 meV, which is the approximate location of the peak in the spectrum from a $H_2O$ moderator. Thus appreciable loss occurs only for neutrons that 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 typically be obtained from a cryogenic $H_2$ moderator. A 3-cm premoderator is being incorporated into the SNS cryogenic $H_2$-moderator design.

## 4. Comparison with Activation Data [5]

In June of 1997 a series of experiments were performed at the alternative gradient synchrotron (AGS) facility at Brookhaven National Laboratory (BNL) to study the effects of proton bombardment of a container of Hg. One of the experiments consisted of placing foils at the edge of the Hg container and finding the resultant foil isotopic content by measuring the gamma-ray intensity and energy. The shape of the Hg container was that of a cylinder with a half-spherical nose on the end where the 1.5-GeV protons entered. The number of nuclei in each foil was calculated in the same manner and with the same codes being used in the SNS study. Thus the success or failure of the comparison with the activation data provides a strong test of the Hg cross sections used and of the general reliability of the SNS neutronic studies.

Typical results from this study are shown in Fig. 5, where the number of nuclei measured in the foil sample ($N_0$) is compared with the number calculated. This comparison is done as a function of z (the distance from the tip of the Hg longitudinally to the foil sample). In order to find the calculational prediction, one must know the total number of incident protons( $N_p$). Measured values for $N_p$ varied.[6] The calculated values for $N_0$ using the largest and smallest values for $N_p$ are shown in the figure. The points labeled "1-on" are for a series of foils with the same azimuthal angle. The points labeled "azimuthal average" are an average of points with the same z but with differing azimuthal angles. As may be seen, the measured values are close to or between the largest and smallest calculated values. These values are regarded as indicating a better-than-adequate agreement given the uncertainties. For more details, see Ref. 7.

## 5. Sensitivity Studies of Cryogenic $H_2$ Moderator Output to Output from Assumed Ortho/Para Admixtures

A continuing issue when using cryogenic $H_2$, particularly in the presence of radiation, is the ortho/para admixture. At room temperature, $H_2$ has a ~70%/30% ortho/para content. As the temperature is lowered to cryogenic values, the para content should increase because after a sufficiently long period of time the $H_2$ should have a 100% para content in the absence of radiation. However, the admixture in a cryogenic $H_2$ moderator in use is usually unknown. Comparisons with experiments where the calculated neutron spectrum is matched to the measured spectrum by varying the ortho/para content give a large para content. (Picton et al. [6] found a 100% para content, for instance). The SNS studies have routinely assumed a 100% para content. The neutron output from a $H_2$ moderator in typical SNS geometry is shown in Fig. 6 for varying ortho/para content. The smallest neutron flux from the moderator face occurs when a 100% para content is assumed. As expected, it rapidly increases when an admixture of ortho is included. It would, obviously, be very desirable to have a known admixture when doing design studies. However, the difference between the extremes is <50%, and the use of pure para underestimates the output. Thus the SNS studies are probably conservative in their projections of neutron output from $H_2$ moderators. Indications are, however, that the calculations are well within a factor of 2. It is unlikely that an exact admixture will be known for the SNS studies. It is planned that sensitivity studies will be done routinely for calculations where the admixture is likely to be important.

## 6. The Construction of a More Detailed Model Geometry

The SNS design is an iterative process where a specific engineering design is used to produce information that then changes the engineering design, causing different information to be produced, and so on. A new rather detailed neutronic model has been constructed recently to start a new cycle. The early Hg container and $H_2O$ shroud models used boxlike structures. The new neutronic model geometry for the current Hg container is shown in Fig. 7. The planned Hg cooling flow is represented in great detail. In the figure the main section is seen at the top with the central nose portion removed and rotated by 90°. The quarter spheres located on the sides of the nose are also shown. The main body of the Hg container,along with the surrounding $H_2O$ shroud, is seen again in Fig. 8. Analogous detail is contained in the rest of the geometry. This model will allow detailed calculations of the material damage needed for the proper selection of materials. It will also allow an accurate calculation of the energy deposition so that the heat removal system can be planned in more detail. Many other parts of the design process will also be done more accurately and with more confidence.

## 7. Summary

Several calculational studies were conducted for the proposed SNS. These studies were described briefly, and the results were presented. Certain conclusions may be drawn from the results of these studies: First, 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 loss at energies where a $H_2$ moderator would typically be used. Second, a comparison has been made between the results of the neutronics codes used in the SNS design and experimental activation data. This comparison tends to validate both the Hg cross sections used in the calculations and the general integrity of the neutronics calculations. Third, a sensitivity study has been made of the effect of the ortho/para admixture of $H_2$ in a cryogenic $H_2$ moderator on the neutron output of the moderator. This study indicates that the previous calculations of the $H_2$ moderator performance were conservative but were correct to better than a factor of 2.

A new geometry incorporating the latest engineering design features has been constructed and will be used to perform detailed studies, including calculations of neutron output, materials damage, energy deposition, shielding, and activation. The neutronics design and optimization analyses are now well beyond the infancy phase. It is anticipated that the general features of the SNS engineering design will be fixed in the next year and the neutronics modeling and calculations will be consistent with this design.

## References


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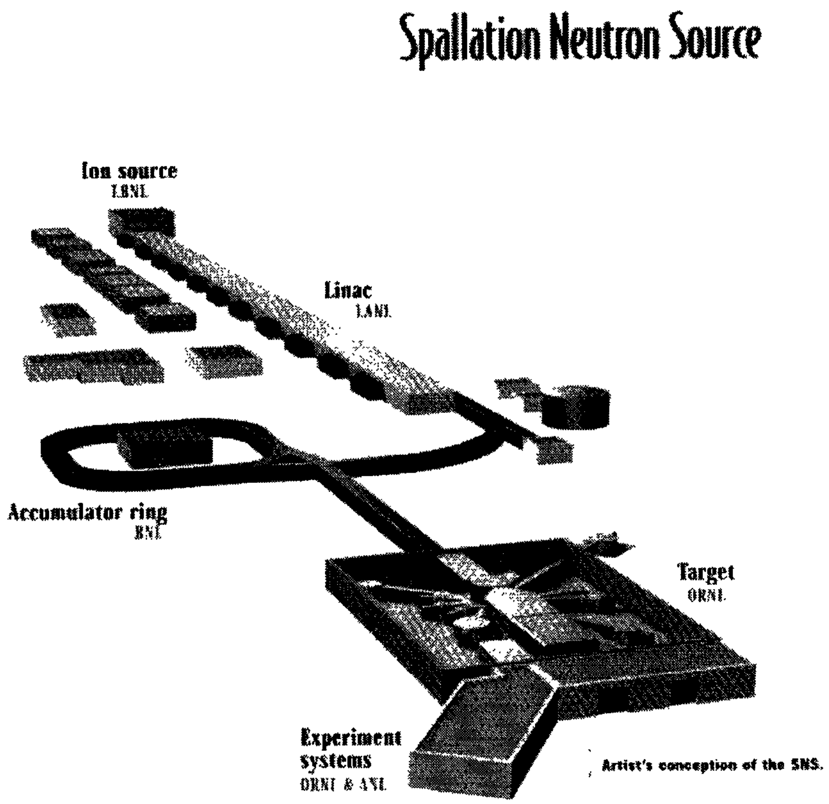



Fig. 1. Artist's conception of the Spallation Neutron Source (SNS).

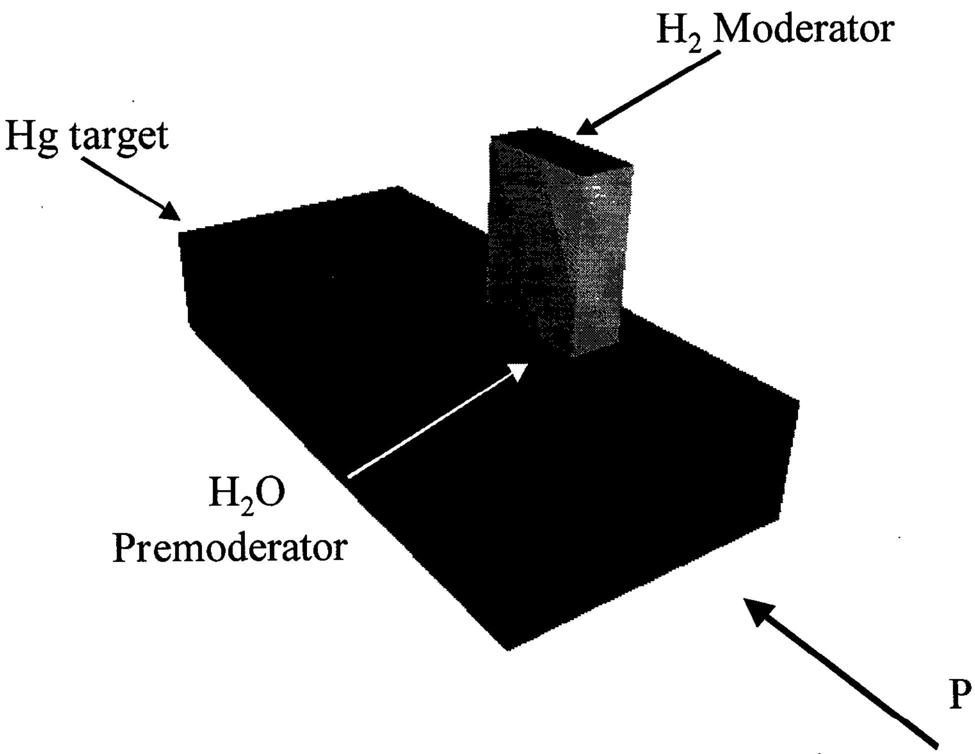



Fig. 2. Model geometry used for the premoderator study.

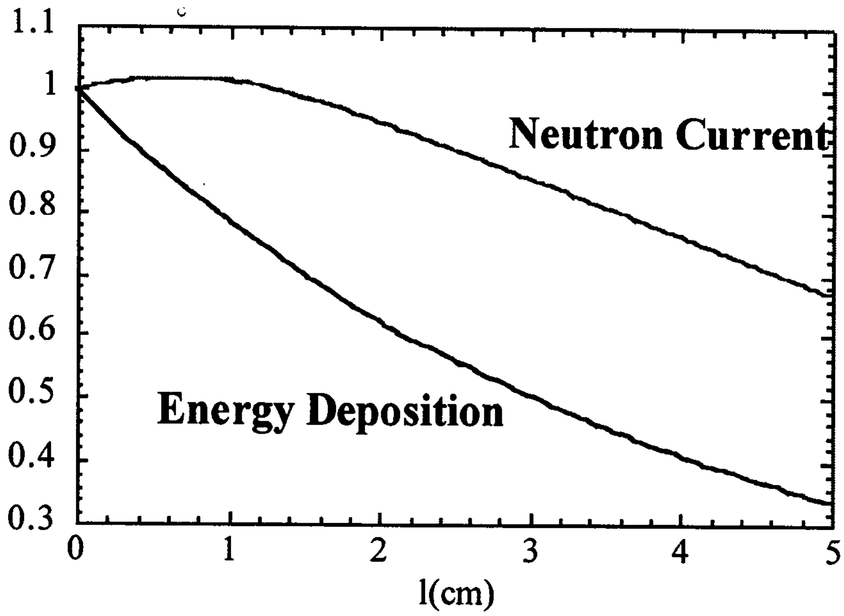
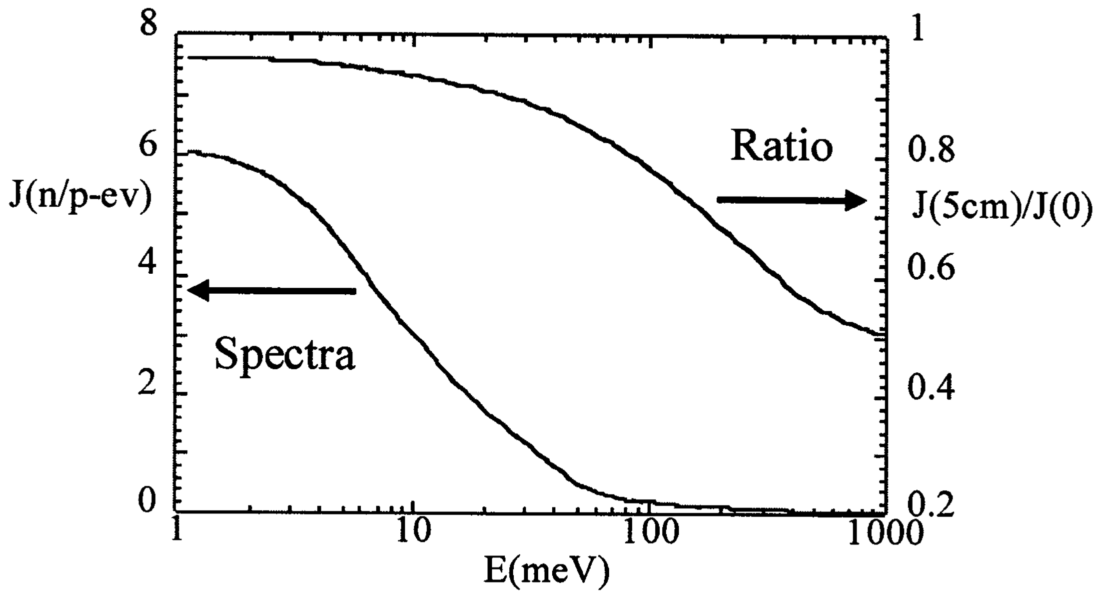



Fig. 3. Thermal neutron current and energy deposition vs the premoderator thickness (l).

Fig.4. Spectrum with no premoderator and the ratio of the spectrum with no premoderator to that




with a 5-cm premoderator included.

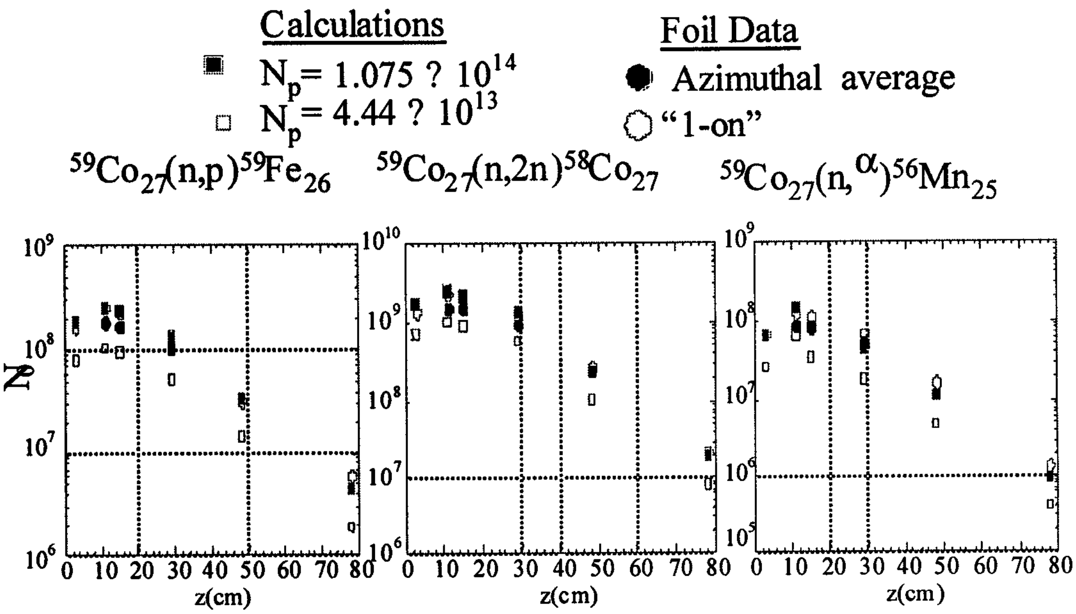



Fig. 5. Comparison between calculational and experimental results show good spatial agreement.

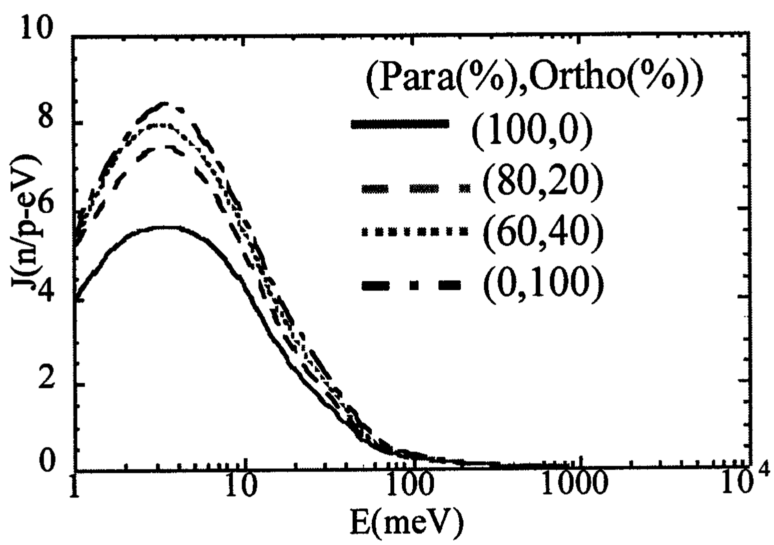



Fig. 6. Neutron spectra from cryogenic $H_2$ moderator for varying ortho/para admixtures.

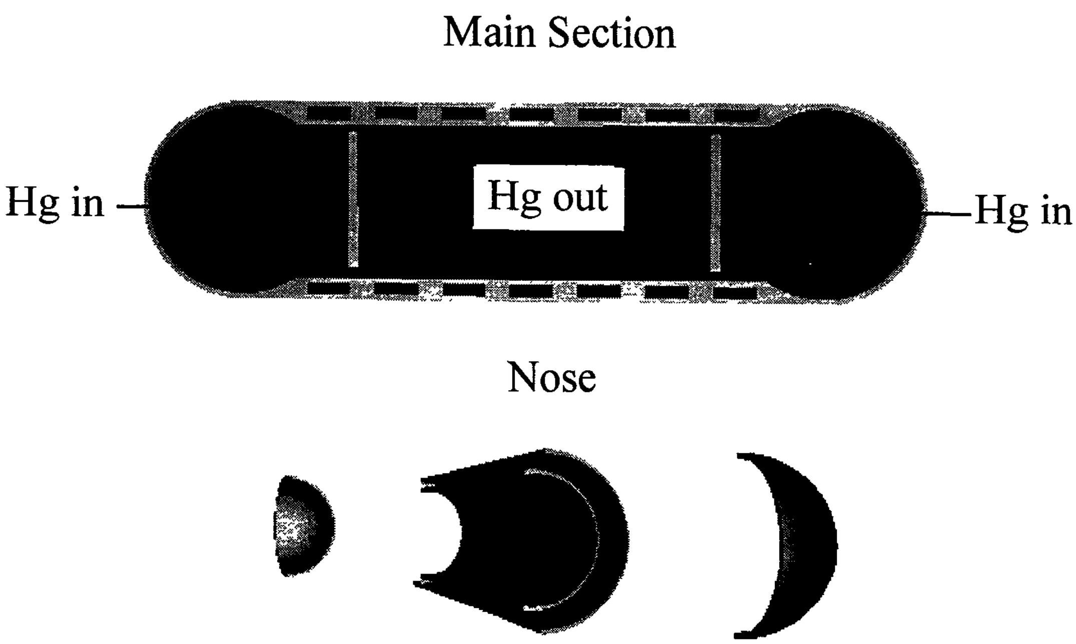



Fig. 7. New neutronic model: Hg container.

Fig. 8. New neutronic model: Main sections of the Hg container and $H_2O$ shroud.