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PRE-CONCEPTUAL DESIGN AND PRELIMINARY NEUTRONIC ANALYSIS OF THE PROPOSED NATIONAL SPALLATION NEUTRON SOURCE (NSNS)

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Abstract

The Department of Energy (DOE) has initiated a pre-conceptual design study for the National Spallation Neutron Source (NSNS) and given preliminary approval for the proposed facility to be built at Oak Ridge National Laboratory (ORNL). The pre-conceptual design of the NSNS initially consists of an accelerator system capable of delivering a 1 to 2 GeV proton beam with 1 MW of beam power in an approximate 0.5 μs pulse at a 60 Hz frequency onto a single target station. The NSNS will be upgradable to a significantly higher power level with two target stations (a 60 Hz station and a 10 Hz station). There are many possible layouts and designs for the NSNS target stations. This paper gives a brief overview of the proposed NSNS with respect to the target station, as well as the general philosophy adopted for the neutronic design of the NSNS target stations. A reference design is presented, and some preliminary neutronic results for the NSNS are briefly discussed.

Introduction

The use of neutrons in science and industry has increased continuously during the past fifty years with applications now widely used in physics, chemistry, biology, engineering, and medicine. Within this history, the relative merits of using pulsed accelerator spallation sources versus reactors for neutron sources have been debated. A consensus from the neutron scattering experiment community has finally emerged endorsing short pulse spallation sources as a high priority option for the future. To address this future need, the Department of Energy (DOE) has initiated a pre-conceptual design study for the National Spallation Neutron Source (NSNS) and given preliminary approval for the proposed facility to be built at Oak Ridge National Laboratory (ORNL). The DOE directive is to design and build a short pulse spallation source in the 1 MW power range with sufficient design flexibility that it can be upgraded and operated at a significantly higher power at a later stage.

A diverse representation of scientific and technical disciplines are required to produce a successful spallation target station design, including engineering, remote handling, neutronics, materials, thermal hydraulics, and instrumentation. Within each of these disciplines, there are multiple layouts and designs which must be integrated into a reference design. Since target stations are vital components of spallation neutron sources, the design of the target stations is critical to determining the overall performance of the facility. Traditional concepts utilized in current facilities are being re-examined, and new concepts will have to be considered to meet the higher power challenge of the NSNS. A brief overview of the proposed NSNS with respect to the target station pre-conceptual design is presented in Section 2. The general philosophy adopted for the radiation transport analysis of the NSNS facility is presented in Section 3, and some of the preliminary neutronic results for the target station are briefly discussed in Section 4.

Pre-Conceptual NSNS Target Station Configuration

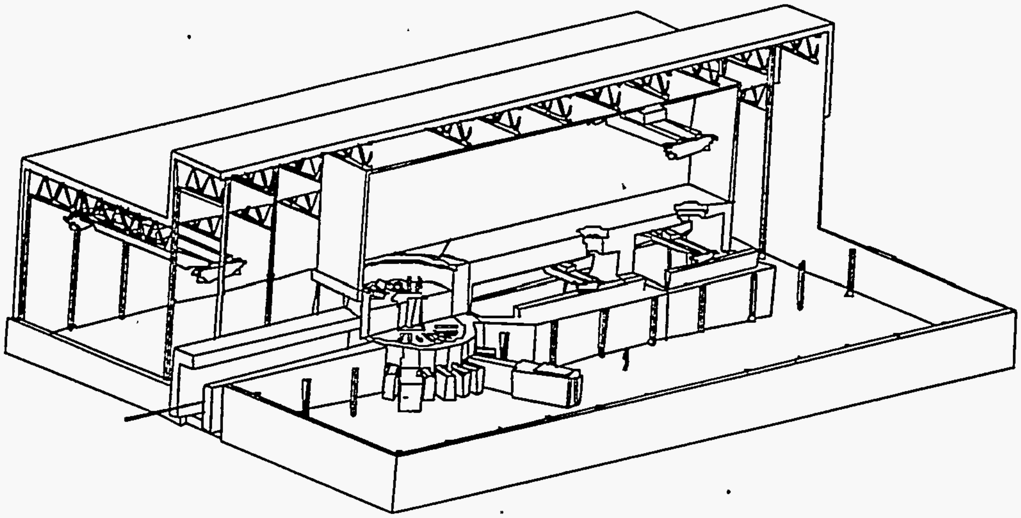
The pre-conceptual design of the NSNS initially consists of an accelerator system capable of delivering a 1 to 2 GeV proton beam with 1 MW of beam power in an approximate 0.5 μs pulse at a 60 Hz frequency onto a single target station. The NSNS will be upgradable to a significantly higher power level with two target stations (a high power station operating at 60 Hz and a low power station operating at 10 Hz). Each target station will contain four moderators (combinations of cryogenic and ambient temperature) and 18 beam lines for a total of 36 experiment stations.

The target station and experimental systems for the NSNS are located in a single building. As shown in Fig. 1, the target is positioned within an iron and concrete shielding monolith approximately 12 m in diameter. The proton beam enters horizontally and moderated neutrons used by the scattering instruments exit through 18 neutron beam tubes projecting from the sides. The majority of the 50 m x 75 m building is reserved for the scattering instruments located on the neutron beam lines, however, hot cells projecting from the back of the shielding are provided for handling the activated target, moderator, and reflector components. This region also contains utilities used for the target. Another cell for utility systems is located beneath the main floor level.

Liquid Mercury Target Design Concept

The reference design for the NSNS incorporates mercury as its target material. A liquid metal target was selected over a heavy water cooled solid target because: (1) increased power handling capability is possible with a liquid target, (2) the liquid target material lasts the entire lifetime of the facility, and (3) the radiation damage lifetime of a liquid target system, including its solid material container, should be considerably longer. The first advantage is due to the large power loads that can be convected away from the beam-target interaction region with a flowing liquid target. The second advantage results from avoiding the radiation damage that would occur in a solid target material, which eventually leads to embrittlement. Liquid target vessels will still need to be replaced periodically due to radiation damage to its container structure, but the liquid target material can be reused. The third advantage, longer irradiation lifetime, results from two effects. First, the target structural material used to enclose the liquid target can be selected based on its structural properties and resistance to radiation damage, independent of its neutron production capability, and second, with a liquid target, there is no solid material in the highest neutron flux regions.

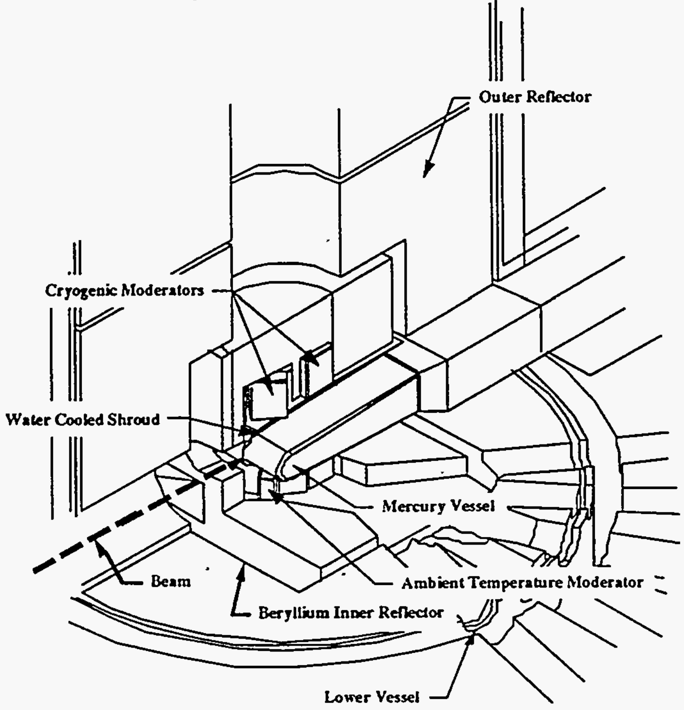
Figure 1. Cutaway view of target facility



Therefore the peak displacement damage rate in the window of a liquid target is greatly reduced compared to the peak value in a solid target. Mercury was selected as the reference liquid target material because it: (1) is a liquid at room temperature, (2) has good heat transport properties, and (3) has high atomic number and mass density resulting in high neutron yield and source brightness.

The mercury target shown in Fig. 2, has a width of 0.4 m, a height of 0.1 m, and a length of 0.65 m. The mercury is contained within a 316 stainless steel structure. Mercury enters from the back of the target, flows along the two side walls to the front surface (proton beam window), and returns through a rectangular passage in the middle of the target. The target window, i.e., portion of the target structure in the direct path of the proton beam is cooled by mercury which flows through the passage formed between two walls of a duplex structure. In this way, the window cooling and transport of heat deposited in the bulk mercury are achieved with separate flow streams. This approach is judged to be more reliable and efficient (minimal pressure drop and pumping power) than using the bulk mercury to cool the window. Also, the duplex structure used for the window has significant structural advantages that help to sustain other loads. Beside serving as flow guides, the baffle plates used to separate the inlet and outlet flow streams help to maintain the structural stability of the target. A safety shroud is provided around the mercury target to guide the mercury to a dump tank in the event of a failure of the target container structure. The shroud is a water-cooled duplex structure made from 316 stainless steel.

Figure 2. NSNS Mercury Target



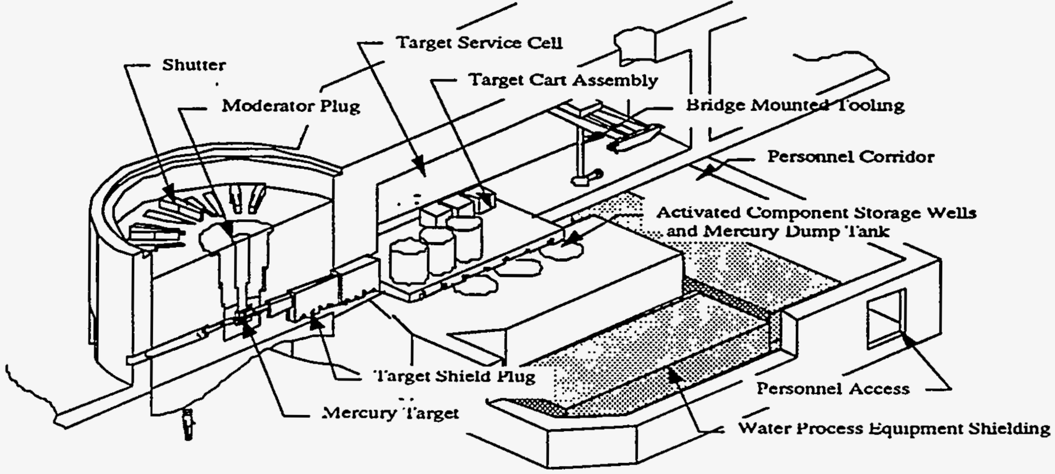
Target Station Design Configuration

The overall configuration for the liquid target system is shown in Fig. 3. The mercury target container and the water cooled shroud, which are in the proton beam, must be replaced on a regular basis. For this reason, all major liquid target system components, except the dump tank, are located on a mobile cart, which is retracted into the target hot cell for maintenance activities. The mercury contained in the target system is drained to the dump tank prior to retracting the target assembly. The mercury dump tank is located below all other components in the mercury system thus ensuring that most of the mercury can be drained to the dump tank even in a passive event, such as failure of the electric power system.

The heat deposited in the mercury target is transported away in the flowing mercury loop to a primary heat exchanger that is located on the target cart assembly, outside the target region shielding. The secondary (water) loop transports the heat to a secondary heat exchanger located in the floor below the target hot cell. The tertiary flow stream utilizes process water.

A 65-ton target shield plug (see Fig. 3) is designed to shield the equipment located in the target hot cell from the high energy, forward scattered neutrons produced in the mercury target. The shield plug, which is removed as part of the target assembly during maintenance operations, is constructed from water-cooled, bulk iron encased in a stainless steel liner. The cart assembly supports all of the mercury flow loop equipment, and provides the means for transporting the target assembly into the target hot cell.

Figure 3. Target System Configuration



Moderators The pre-conceptual design of the NSNS currently has one target station with four moderators (see Fig. 2). The two light water moderators are located in wing geometry below the mercury target and water-cooled shroud. The moderator vessel is made from 6061 aluminum. The upstream moderator has a thickness of 0.05 m, relative to the proton beam, and is decoupled and poisoned to give high temporal resolution of the neutron flux. The second moderator is 0.10 m thick and is coupled to produce higher neutron intensity but with less temporal resolution. Both moderators are approximately 0.12 m wide and 0.15 m high. The two cryogenic moderators, cooled with supercritical hydrogen, are located above the target as shown in Fig. 2. This configuration improves the cooling and warming characteristics of the moderators. Mechanically circulated supercritical hydrogen gas was chosen for the moderators because it improves the cooling operation, eliminates boiling and adds flexibility in operation. The hydrogen is maintained at supercritical pressures in all parts of the loop during normal operation.

Reflector Systems As identified in Fig. 2, the reflector system consists of two major subsystems, namely the inner reflector and the outer reflector. The inner reflector consists of a stainless steel case packed with beryllium rods and cooled with heavy water. Neutron decouplers made from boral are mounted on the inner surface of the case. The system is designed for removal of the reflector assembly vertically into a shielded cask for transport to the target assembly hot cell. The outer reflector consists of iron or nickel shielding which surrounds the beryllium reflector assembly and is contained within a 2 m diameter safety vessel.

Neutron Beam Transport Systems The neutron beam tube systems provide the paths for moderated neutrons to travel through the bulk shielding to the scattering instruments. The configuration assumed at present consists of 18 beam lines looking at the four moderators as shown in Figs. 1 and 2. Each moderator face which is viewed illuminates three beam lines, one normal to the face and two at plus or minus 13.75 degrees. The upper and lower forward moderators have two faces viewed and the two rear moderators each have one face viewed for a total of 6 viewed faces. This arrangement allows a 70 degree arc for the proton beam entrance region and a similar 70 degrees arc for the remote maintenance systems at the rear of the target.

Each beam line will contain a shutter concept similar to the vertical shutter design at the Rutherford Appleton Laboratory ISIS Facility. The shutters are in the form of stepped rectangular slabs, are lowered from the top, and put approximately 2 m of shielding in the neutron flight path. In the open position a hole in the shutter aligns with the neutron beam flight path and cross section. All shutters will be the same, except for the difference in beam elevation required between beam lines viewing the upper or lower moderators. The weight of one shutter assembly is approximately 25 tons.

Remote Handling Systems A target service cell is located behind the target assembly for the purpose of maintaining the highly activated target components. All work is performed via remote handling techniques behind concrete shielding walls. A general maintenance cell is located behind the target service cell primarily to maintain the moderator/reflector plug, proton beam window, neutron guide tubes and shutters. Generally all operations will be remote, however; personnel may enter the cell following extensive cleanup. The enclosed, unshielded high-bay above the target system and maintenance cells will provide the primary means of handling components in the target system. A 50-ton bridge crane provides access to all of the maintenance cells, storage wells and the transportation bay. The access bay is normally accessible to personnel, consequently all activated components will be shielded and contained during operations and during component transfers between the hot cells. To minimize downtime and personnel dose, operating equipment will be packaged in modular assemblies designed to be replaced with on-site spares. This enables operations to continue while time-consuming repairs are performed in off-line facilities.

Radiation Transport Analysis Strategy

The radiation transport analysis, which includes the shielding, activation, and safety analysis, is important for the construction of an intense high-energy accelerator facility because of its impact on conventional facility design, maintenance operations, and because the costs associated with incorporating the results of the radiation transport analysis comprise a considerable part of the total facility costs. A strategy utilizing coupled Monte Carlo and multi-dimensional discrete ordinates calculations is being implemented to perform the radiation transport analysis.

The radiation transport analysis of the NSNS can be subdivided into four categories: (1) neutronic performance; (2) energy deposition distribution; (3) material damage and activation; and (4) shielding design and analysis. Within each of these, there is an optimization procedure to follow which will yield the best design allowing for the interdependent relationships the four categories have with respect to each other and the implications associated with the overall facility design. Collaborative efforts interfacing the radiation transport analysis with the neutron and proton beam transport systems design, thermal hydraulic analysis, structural materials selection, remote handling/target maintenance requirements, and general facility layout are being implemented. The radiation transport analysis will incorporate the state-of-the-art cross-section data bases and computer codes modified and/or developed, and verified under the NSNS Neutron Source Systems Research and Development Plan.

The determination of the neutronic performance involves characterizing the target station and accelerator radiation environments. Calculations are being performed to determine the neutron, proton, heavy ion, and gamma-ray flux spectra as a function of time, energy, and space for all components of the target station (target, moderators, reflectors, etc.) and accelerator (linac, ring, beam dumps, etc.). These calculations will optimize (maximize or minimize) these distributions depending on the target station or accelerator component in question and desired design criteria. Within this analysis, target/moderator/reflector configurations and material selections will be determined to yield the optimum neutron source for the experiment stations.

The energy deposition distribution analysis is directly tied to neutronic performance and interfaces with the thermal hydraulic analyses to determine the optimum target station design with respect to heat transfer and fluid flow requirements. Energy deposition profiles are also being determined for the beam dumps associated with the accelerator design. These calculations are being performed for all components of the NSNS requiring heat removal and/or subjected to thermal shock phenomena.

Material damage and activation analyses are being performed to assess facility component lifetime estimates and aid in the structural materials selection process. It should be noted that preliminary results of the damage analysis are reported in a companion paper in these proceedings by Wechsler, et al.[1]. In particular, gas production, displacement damage, and primary knock-on atom (pka) spectra are being determined for target station and selected accelerator components. Material selections will be determined utilizing this information in conjunction with additional material issues (compatibility, machinability, costs, etc.). Activation analyses are being performed to determine facility radioactive waste streams, on-line material reprocessing requirements (mercury, liquid hydrogen, cooling water, etc.) and remote handling/maintenance requirements. Analyses are also being performed to determine background radiation levels within all parts of the facility for normal operation and postulated accident scenarios (single-failure/anticipated events and unlikely design basis accidents).

Shielding design calculations are being performed for all sections of the NSNS facility. Biological shields will be designed for the proton beam transport system and associated beam dumps, the target station, and the neutron beam transport systems. Shield designs will be integrated into the overall facility design and optimized to achieve as low as reasonably achievable dose to the facility personnel, visiting experimentalists, and sensitive electronic equipment.

All four of these principal categories impact the safety design of the NSNS facility. The NSNS facility safety (personnel, public, environment, equipment, etc.) will be assured through reliance on both instrumentation-based active safety systems and passive shielding. The top level document for accelerator safety regulation (DOE Order 5480.25, Safety of Accelerator Facilities [2]), the associated guidance [3], and lessons learned from existing facility experience [4], are being utilized in the design.

Neutronic Analysis

Two geometry models of the target station design described in Section 2 were developed for the computational analysis. The first model (Fig. 4) is a detailed representation of the target assembly, moderators, and inner beryllium reflector with cutouts for the proton beam window and neutron beam lines. This model is being used to compute the energy deposition data, material damage, and activation for the components of the target, moderators, and inner reflector. The model is also being used to optimize the neutron current and neutron pulse time width passing out of the moderator faces into the neutron beam channels which lead to the experimental area. A second geometry model (Fig. 5) was constructed to determine the energy deposition, material damage, activation, radiation flux spectra, and shielding requirements for the entire target station including the 12 m diameter biological shielding. In this geometry, the mercury target was represented with a simplified model since a detailed model already existed for analysis. With respect to both of these models, the HETC [5] and MCNP [6] Monte Carlo codes were used to track the protons, neutrons, gamma rays, and other particles as they proceed through the geometry.

In the early stages of design analysis, the pre-conceptual design of a target station is constantly changing as different problems/solutions arise. Consequently, some of the design analysis reported in this paper reference an earlier design of the target station that is slightly different than that described in Section 2. As such, the results reported here are representative of the types of results that will be obtained in the final analyses but their absolute magnitudes will be different.

For the initial study, a proton energy of 1.7 GeV, a power of 1 MW, a repetition rate of 60 Hz and a proton pulse width of approximately 0.5 μs were assumed. The target assembly out to the inner reflector, described in Section 2 with the exceptions noted below, is shown in Fig. 4. In this model, the inner beryllium reflector was represented as a 0.90 m x 0.90 m x 1.01 m rectangular parallelpiped with the square plane perpendicular to the proton beam direction. The mercury target is 0.64 m long with a half cylinder of radius 0.05 m on the end where the proton beam enters. Downstream from the half cylinder is a section with rectangular cross section width of 0.30 m and a height varying from 0.10 m upstream to 0.15 m at the extreme downstream end.

Figure 4a: Target assembly enclosed in the Beryllium reflector

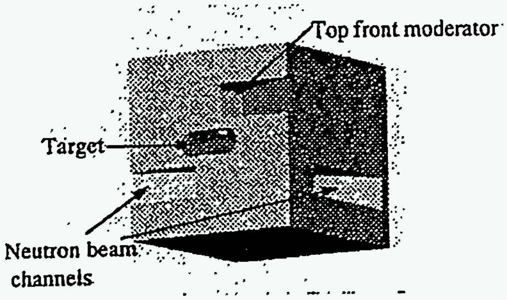


Figure 4b: Target, moderators, and the neutron beam channels as viewed from the bottom.

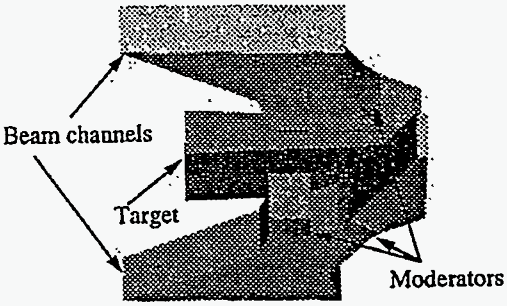
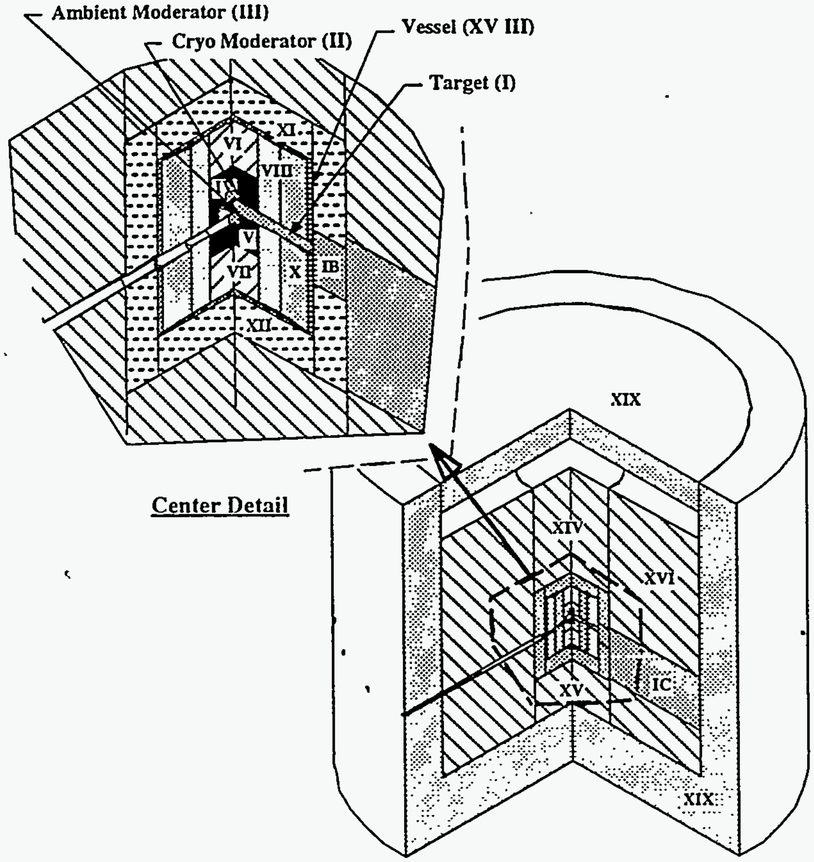


Figure 5. Neutronics models of overall target station



Liquid Mercury Target Versus Solid Target

The engineering arguments for the choice of a liquid mercury target over the more conventional solid tungsten or tantalum targets in operation today were discussed in Section 2 above. Consequently, the first priority of the radiation transport design analysis was to validate the assumption of superior neutronic performance of the liquid mercury target. To accomplish this, a series of calculations were executed using the first target geometry model (Fig. 4) and determining the thermal ($E<0.414$ eV) neutron current exiting the moderator faces into the neutron beam channels leading to the experimental area and the time width of the neutron pulse. Calculations were performed for a liquid mercury target, a D_2O cooled tungsten target, and a D_2O cooled tantalum target.

Table 1. Comparison of neutron fluxes at the moderator faces for Hg, W and Ta Targets at 5 MW

Cryogenic				
	NSNS		ESS	
Target	ϕ_{th}	R	ϕ_{th}	R
Hg	2.94×10^{14}	1.35	3.91×10^{14}	1.23
W	2.54×10^{14}	1.17	3.53×10^{14}	1.10
Ta	2.17×10^{14}	1.00	3.19×10^{14}	1.00

Ambient				
	NSNS		ESS	
Target	ϕth	R	ϕth	R
Hg	3.35×10^{14}	1.35	2.29×10^{14}	1.51
W	2.91×10^{14}	1.17	1.67×10^{14}	1.10
Ta	2.48×10^{14}	1.00	1.52×10^{14}	1.00

Units: ϕ_{th}(n/cm^2-s)

ESS results from D. Filges, R. D. Neef, and H. Schaal "Nucl. Studies of Different Target Systems for ESS," ICANS-XIII.

NSNS "effective" fluxes were converted from 2π steradian current calculations. The differing distances from the target to the moderator were also corrected for.

R is the ratio of the flux from the given target to that from a tantalum target.

The neutronic superiority of liquid mercury over the two commonly considered solid targets, tungsten and tantalum, is shown in Table 1. The results are reported for a 5 MW target station in order to facilitate the comparison with a similar study performed for the European Spallation Source (ESS). The results indicate the thermal neutron current from a short-pulse (<1 μs) neutron source is greater for a mercury target than for either heavy water-cooled tungsten or tantalum targets. This result is true for both cryogenic (liquid H_2) and ambient (H_2O) moderators. The increase in thermal neutron current was found to be slight at 1 MW but substantial at 5 MW due to the increase in the D_2O cooling needed for the solid targets at 5 MW. The deuterium in the water thermalizes some of the neutrons within the solid tungsten or tantalum target area. Since both tungsten and tantalum have large capture cross sections these thermalized neutrons are captured and lost. A comparison of the neutron spectra and pulse shapes indicated virtually identical characteristics except for the additional neutrons produced by the mercury target.

Moderator Enhancement Analyses

Upon validating the liquid mercury target with respect to total thermal neutron current exiting the moderator faces into the neutron beam tubes, the next step in the neutronic analysis was to optimize moderator performance utilizing various enhancement techniques. In most cases, this is accomplished by maximizing the neutron current emerging from the moderator and minimizing the time width of the neutron pulse. It should be noted that in the final design, the characteristics of the neutron pulse (intensity, wavelength, time width, etc.) will be determined by the needs of the experimentalists. Therefore, the moderator design and enhancement techniques that eventually will be used will also be determined by the experimentalists. The preliminary analysis presented here quantifies the relative magnitudes of the changes in the moderator performance as a function of enhancement technique.

Moderator poisoning and decoupling are used to manipulate the time width and magnitude of the neutron pulse. For poisoning, a thin layer of gadolinium is inserted into the moderator center parallel to the exit face(s), and for decoupling, the moderator and reflector are surrounded by cadmium on all sides except those through which the neutrons exit. Other thermal neutron absorbing materials may be used instead of gadolinium and cadmium. Both of these methods successfully reduce the neutron pulse width but they also reduce the thermal neutron current available to the experimentalists. Consequently, a trade off is required between thermal neutron current magnitude and width of the neutron pulse. As stated above, the optimum trade off will be determined by the requirements of the experimentalists.

In order to better understand the width/magnitude trade-off produced by each moderator enhancement method, the thermal neutron pulse energy distribution is compared. In Fig. 6a, the number of neutrons per incident proton leaving a top front cryogenic moderator face (See Fig. 4) is shown. Energy distributions are shown for a coupled (C) moderator (no decoupler or poison), a poisoned (P) moderator, a decoupled (D) moderator, and a poisoned and decoupled (P-D) moderator. The results indicate that either poisoning or decoupling will reduce the neutron current and both together reduces it further. Gadolinium poisoning changes the neutron spectrum only for energies below the gadolinium thermal cutoff energy of .1-.2 eV. The neutron capture in gadolinium above this energy is negligible. The cadmium decoupler modifies the neutron spectrum only for energies below the cadmium cutoff energy of approximately 0.414 eV. As with gadolinium, neutron capture in cadmium is negligible above this energy. Similar effects were seen for the ambient moderators, except that they are much less pronounced. This is

Figure 6a: Neutron energy distribution from the face of the front cryogenic moderator, C = coupled, P = poisoned, D = decoupled, P-D = poisoned and decoupled

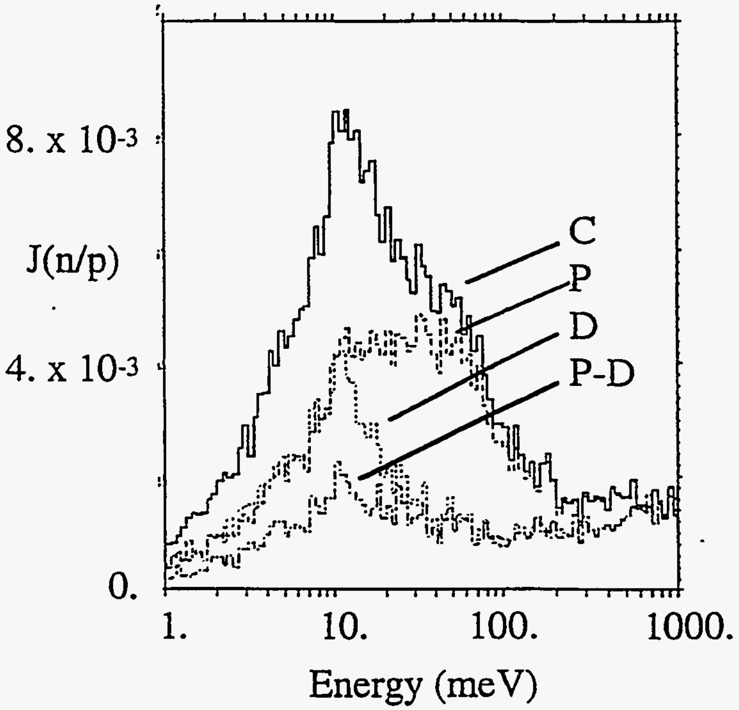
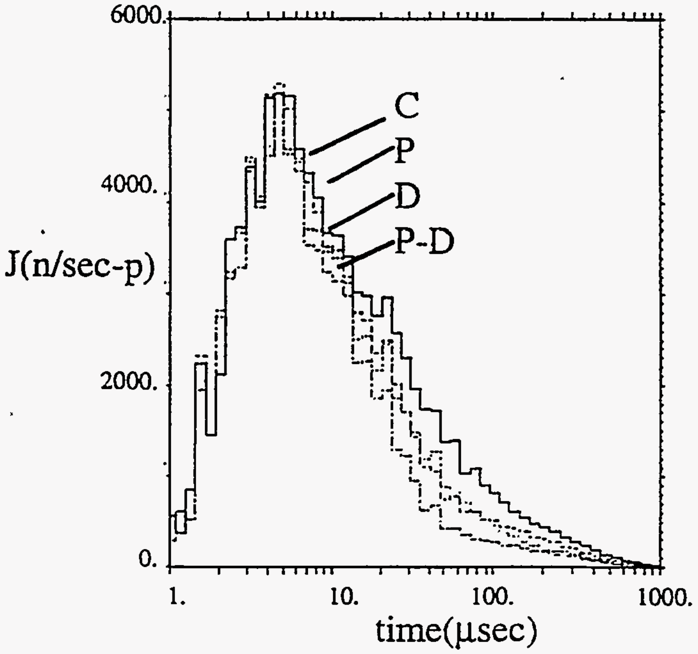


Figure 6b: Thermal neutron pulse from the face of the front cryogenic moderator.



primarily due to the fact that the peak in the energy distribution for the ambient water moderators is located at a much higher energy relative to the cutoff energies of cadmium and gadolinium. Consequently, a much smaller proportion of the neutrons that eventually moderate to the peak energy are affected by poisoning and decoupling. The threshold for poisoning with gadolinium and decoupling with cadmium occur at their respective cutoff energies. These thresholds are, however, much farther above the peak in the coupled energy distribution for the cryogenic moderator than for the ambient moderator.

The relative change in the neutron pulse shape for the cryogenic moderator due to poisoning and decoupling is shown in Fig. 6b. The decoupling and poisoning preferentially affect the low energy particles which take longer to reach the moderator face. For short time intervals (<10 µs), all pulses are approximately equal. Only for larger time intervals (>10 µs) do poisoning and decoupling reduce the current and thus produce the desired narrower neutron pulse width. As with the magnitude effects discussed above, the changes produced for a decoupled and/or poisoned ambient moderator are again smaller than for the cryogenic case due to the same reasons discussed above. The total thermal neutron currents from the moderator faces together with the pulse widths are shown in Table 2 for fully coupled moderators and moderators with both decoupling and poisoning. It should be noted that the moderator enhancement techniques mentioned above can be applied for any thermal energy range to optimize the moderator performance.

Table 2: Maximum (J_{mx}) and Average (J_{av}) Currents and Pulse Widths (W) for the Front Cryogenic (Faces 1 and 2) and the Front Ambient (Faces 3 and 4) Moderators (Note that 2π current is given instead of 4π flux which can make the values appear ~4 smaller)

	Neutron Currents and Pulse Widths					
	Coupled			Decoupled and Poisoned		
Face	J_{av} $(n/cm^2\text{-}s)$	J_{mx} $(n/cm^2\text{-}s)$	W (µs)	J_{av} $(n/cm^2\text{-}s)$	J_{mx} $(n/cm^2\text{-}s)$	W (µs)
1	6.73×10^{12}	9.53×10^{14}	38	1.90×10^{12}	8.17×10^{14}	15
2	6.66×10^{12}	9.20×10^{14}	38	1.73×10^{12}	7.83×10^{14}	14
3	7.06×10^{12}	1.74×10^{15}	30	3.28×10^{12}	1.60×10^{15}	17
4	7.87×10^{12}	1.91×10^{15}	26	3.97×10^{12}	1.80×10^{15}	17

Target Station Radiation Transport Analyses

The radiation transport analysis of the full target station has been initiated. Calculational efforts are in progress to determine the energy deposition, material damage, activation, radiation flux spectra, and shielding requirements for the entire target station. For this analysis, the full target station geometry model (Fig. 5) is being utilized, and the radiation transport strategy outlined above is being implemented.

Conclusions

Preliminary analysis of the NSNS pre-conceptual design indicates that a very attractive short-pulse neutron source operating at 1 MW of proton beam power can be constructed using liquid mercury as the target material. Within this effort, critical path research and development activities have been identified to validate design concepts and allow future upgrades to higher power levels. It is anticipated that high power spallation neutron sources like the NSNS will place significant demands on materials performance. The target system will be subjected to an aggressive environment that will significantly degrade the properties of the materials. Furthermore, the satisfactory performance of materials for sufficiently long time periods will be the determining factor for estimating target lifetime and replacement/maintenance schedules.

A radiation transport design strategy utilizing coupled low and high energy Monte Carlo calculations and multi-dimensional discrete ordinates calculations has been devised to characterize the neutronic performance of the proposed NSNS. Collaborative efforts interfacing the radiation transport analysis with the neutron and proton beam transport systems design, thermal hydraulic analysis, structural materials selection, remote handling/target maintenance requirements, and general facility layout are being implemented. The top level document for accelerator safety regulation (DOE* Order 5480.25, Safety of Accelerator Facilities), the associated guidance, and lessons learned from existing facility experience, are being utilized in the design.

Preliminary radiation transport analyses indicate a mercury target is neutronically better than a heavy-water-cooled tungsten or tantalum target, especially at the higher (>1 MW) power levels where the solid targets require more cooling. It should be noted that the solid/liquid target comparisons did not utilize fully optimized target configurations with respect to the choice of the target material. However, given the relative increase in neutronic performance indicated and the power handling and material issues alluded to, the liquid mercury target would probably still be the logical choice for the NSNS. Moderator enhancement techniques were studied and it was found that using a combination of decoupling and poisoning to enhance the moderator performance produced different results for the ambient water moderator than for a liquid hydrogen cryogenic moderator. For an ambient water moderator, the pulse width could be reduced by a factor of 2 which also resulted in a factor of 2 reduction in the neutron current. For a cryogenic moderator, the pulse width and current reduction was approximately by a factor of 3. Ultimately, the moderator design and use of moderator enhancement techniques (decouplers, poisons, pre-moderators, etc.) will be determined by the instrument requirements deployed by the neutron scattering community.

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