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Spallation Source Neutron Target Systems

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Abstract

This is the final report for a two-year, Laboratory-Directed Research and Development (LDRD) project at the Los Alamos National Laboratory (LANL). The project sought to design a next-generation spallation source neutron target system for the Manuel Lujan, Jr., Neutron Scattering Center (LANSCE) at Los Alamos. It has been recognized for some time that new advanced neutron sources are needed in the US if the country is to maintain a competitive position in several important scientific and technological areas. A recent DOE panel concluded that the proposed Advanced Neutron Source (a nuclear reactor at Oak Ridge National Laboratory) and a high-power pulsed spallation source are both needed in the near future. One of the most technically challenging designs for a spallation source is the target station itself and, more specifically, the target-moderator-reflector arrangement. Los Alamos has demonstrated capabilities in designing, building, and operating high-power spallation-neutron-source target stations. Most of the new design ideas proposed worldwide for target system design for the next generation pulsed spallation source have either been conceived and implemented at LANSCE or proposed by LANSCE target system designers. These concepts include split targets, flux-trap moderators, back scattering and composite moderators, and composite reflectors.

1. Background and Research Objectives

Recently it has been proposed that, for a certain class of neutron scattering instruments, a long-pulse spallation source (LPSS) driven by a 1-MW proton accelerator can deliver performance nearly equal to or even better than the performance of the same class of instruments at the world's most powerful neutron scattering facility, the Institute Laue Langevin (ILL) in Grenoble, France. The purpose of this project was to design and cost a LPSS target station for placement in Area A of the LANSCE facility, and use the existing

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1-mA, 800-MeV LANSCE accelerator to drive the LPSS. In addition to providing neutron beam lines that service neutron scattering instruments, the LPSS facility would include a target test cell for testing high-power spallation target concepts, an ultracold neutron (UCN) source that would provide very low energy (~1 meV) neutrons for fundamental physics experiments, a dedicated beam line for high-energy neutron radiography, and possibilities for materials irradiation and isotope production.

2. Importance to LANL's Science and Technology Base and National R&D Needs

The LPSS will contribute enhanced support for DOE mission objectives in Energy Research and Defense Programs. It will support condensed matter and materials research as well as address some of the research needs of the nuclear weapons stockpile management program. The LPSS will provide the scientific and industrial communities with a neutron scattering user facility that exceeds current US capabilities in some areas of research. The LPSS supports Los Alamos core competencies in nuclear science, plasmas, and beams as well as complex experimentation and measurement. It will also play a significant role in the Laboratory's Science-Based Stockpile Stewardship program. Establishment of this facility at Los Alamos would make available to Laboratory staff unique capabilities for materials science research. As a national user facility, it would enhance the Laboratory's ability to recruit and retain high-caliber scientists and engineers.

3. Scientific Approach and Results to Date

3.1 LPSS Facility Layout

The LPSS neutron production target will be located in Area A. Figure 1 shows the overall floor plan of the LPSS experimental area, including the flight paths. A monolithic steel and concrete biological shield consisting of 4.5 m of steel and 1.5 m of concrete will occupy the central part of Area A. The shield is sized to limit the radiation dose at the exterior boundary of the monolith to 0.1 mrem/h.

The neutron production target and moderators will be located at the center of the monolith with 15 beam tubes arranged radially. A hot cell will be adjacent to the shielding monolith directly downstream of the target system as shown in Figure 2. Moderators will be withdrawn vertically from the target chamber and placed into a remotely operable shielded cask that can be moved on rails to a position above the hot cell. The moderators can be lowered into the hot cell for servicing.

Targets will be removed horizontally from the target chamber and placed into the hot cell for servicing. This approach ensures that the most highly activated component in the system (i.e., the target) will all be shielded and contained. To provide unimpeded user access to experiments and to simultaneously isolate radioactive targets and moderators in a controllable manner, neutron beam experiments and target handling will be conducted on separate levels of the LPSS facility. Operations in the hot cell will be performed with remote handling systems. A pre-conceptual design of the LPSS has been documented, as well as the rationale for the installation of a spallation neutron source test facility.

3.2 Reference LPSS Target System

Figure 3 shows the LPSS reference target system composed of a split target, two liquid hydrogen moderators in wing geometry, and a water moderator viewed both in transmission geometry from one side and in backscattering geometry from the opposite side. A moderator composed either of solid deuterium or superfluid liquid helium is being evaluated for ultracold neutron production. Its integration into the LPSS will be part of the detailed design of the LPSS moderator system. A neutron reflector, composed of beryllium and lead in the reference design, will surround the target and moderators. This reflector will enhance the neutronic performance of the moderators and produce neutron pulse shapes that are suitable for scattering experiments. Heavy water will be used to cool both the target and reflector.

3.3 Calculation of Neutronic Performance

The Los Alamos High-Energy Transport (LAHET) code system is used to calculate the neutronic performance of the LPSS target system. This Monte Carlo code system has been used extensively in the design and optimization of spallation target systems and has been shown in many practical instances to provide an excellent representation of actual spallation target performance.

Considerable engineering detail has been incorporated into the geometrical model of the reference LPSS design as it is known to influence target performance significantly. Examples of these engineering details are: dilution of the target and reflector materials by the heavy water coolant; inclusion of the double-walled moderator canisters; and clearance gaps around the target. A series of parametric studies have been performed to optimize the target system performance. An example is shown in Figure 4, where moderator source brightness is plotted as a function of the position of the wing moderators relative to the target. It shows that the optimum placement of the wing moderators occurs when the center of the moderators are 2 cm upstream of the front face of the target.

Neutronic performance of the reference 1-MW LPSS target system was estimated by calculating average moderator source brightness and moderator pulse shapes. The calculated cold source brightness of the 1-MW LPSS reference geometry is compared to the calculated

brightness for the ILL liquid deuterium source in Figure 5. Based on this calculation, the source brightness of the LPSS reference target system is expected to be about one quarter that of the ILL of the whole wavelength range plotted in Figure 5.

The performance of an LPSS for neutron scattering depends on the time-averaged neutron flux generated by the target system and on the shape of the neutron pulses. These two quantities may be traded against one another by, for example, altering the relative amounts of beryllium and lead in the reflector surrounding the target-moderator system.

3.4 Target System Shielding

One of the major costs associated with construction of the LPSS is the shielding monolith surrounding the target system. An accurate estimate of its size is required in order to assess its cost. With the recent incorporation of geometry splitting into LAHET, a series of detailed Monte Carlo calculations were carried out that gave the dose-rate source term and the dose-rate attenuation coefficient of a steel shield, at both 90° and 0° to the proton beam direction. These calculations showed that, at 90°, 4.5 m of steel followed by 1 m of ordinary concrete is sufficient to attenuate the dose rate to 0.1 mrem/h. This result is shown graphically in Figure 6. This work has been documented in an internal memorandum.

3.6 Cost and Schedule

Preliminary cost estimates indicate that the LPSS can be constructed at LANL for approximately \$95M. Total cost is in terms of FY1995 dollars and includes a 30% contingency. Current estimates indicate that the facility can be designed, fabricated, and commissioned in three years.

The estimates for cost and schedule were developed using engineering models, costs of previous equipment for accelerators and spallation target systems, and preliminary quotes for major subsystems. In addition, the estimates were based on experience at Los Alamos in the following areas: remote handling operations within Area A; target and shielding monolith design, fabrication, and installation at LANSCE and WNR; and accelerator development, fabrication, and operations.

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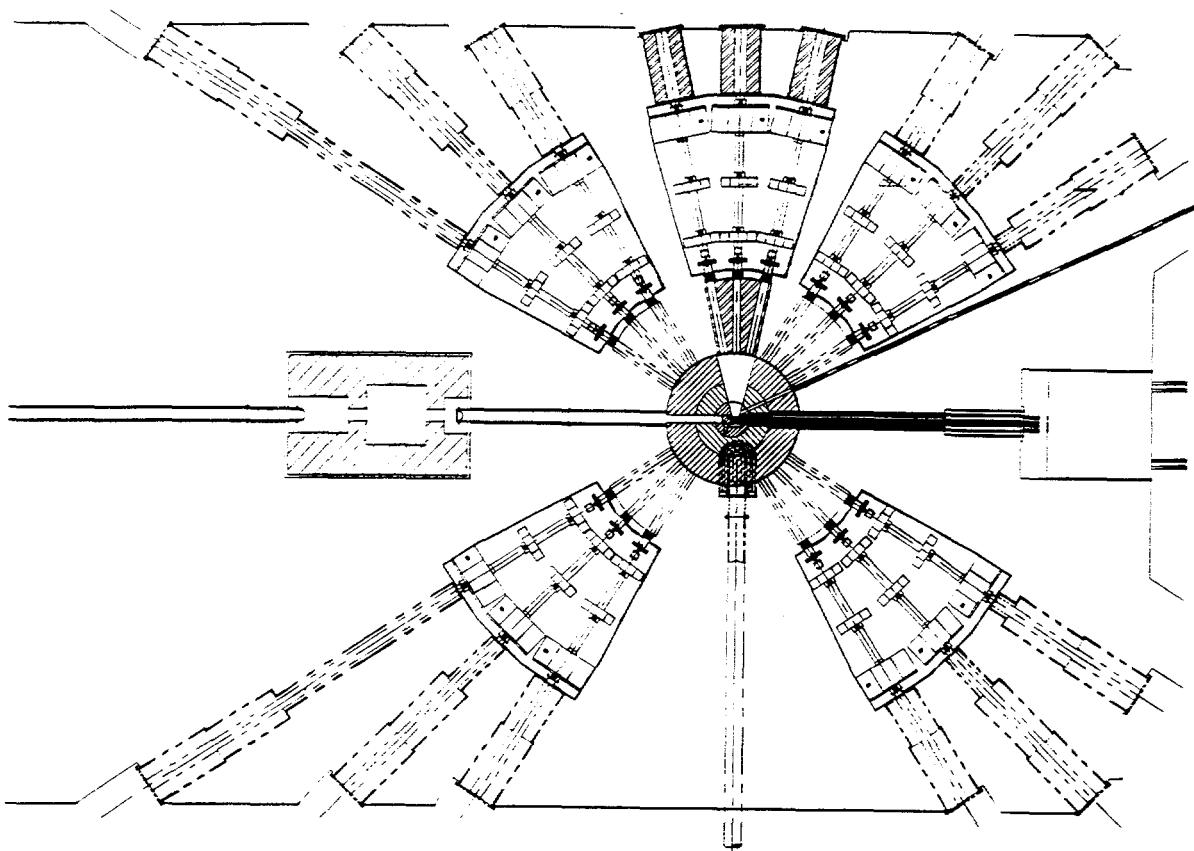


Figure 1. Layout of the LPSS. The target test facility appears on the left. At center is the target-moderator-reflector assembly with the neutron light paths emanating radially outward through the shielding monolith. The U-shaped assembly just below the target is the ultracold neutron source.

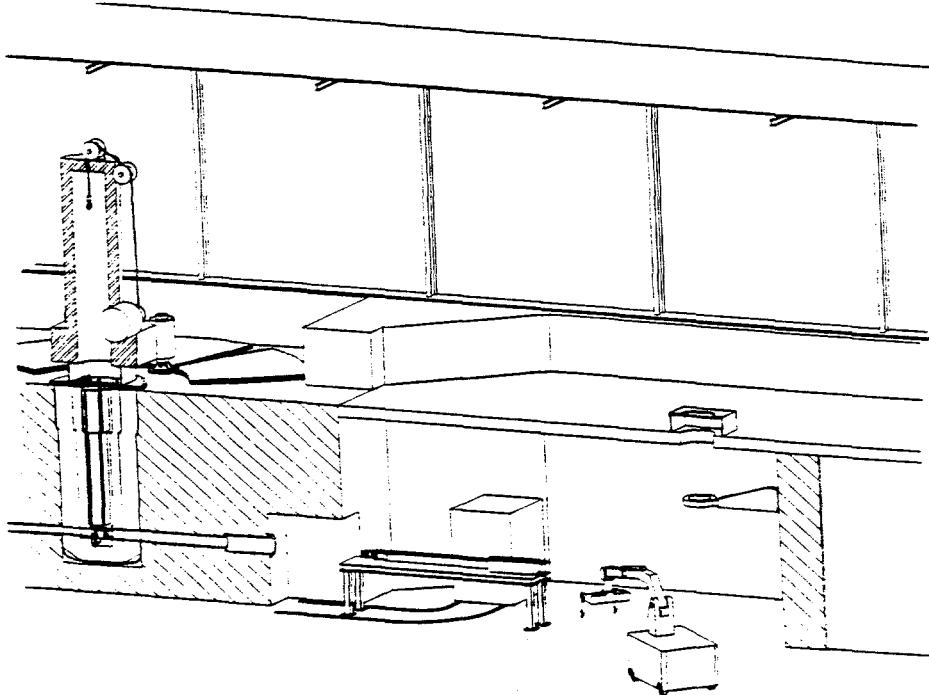


Figure 2. Hot cell downstream of the LPSS shielding monolith. Here, the horizontally-extracted target module is shown laying on a table in the hot cell.

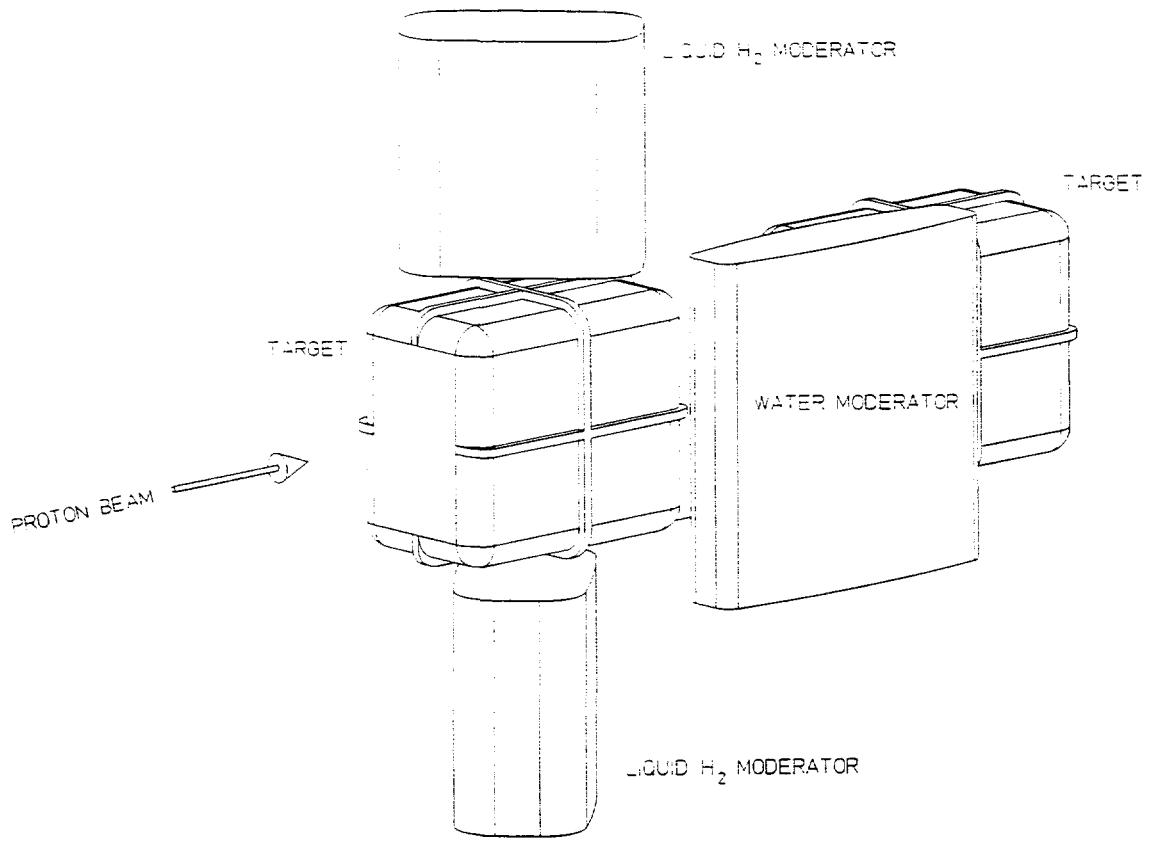


Figure 3. LPSS target-moderator configuration.

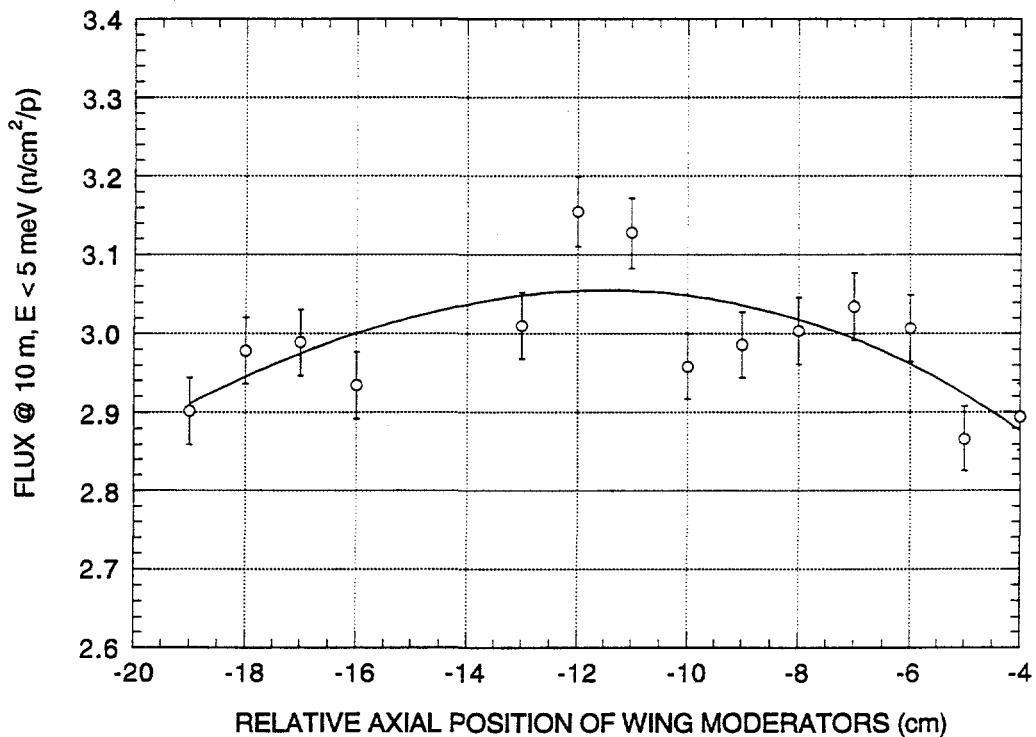


Figure 4. Optimization of the wing moderator position in the direction of proton beam propagation.

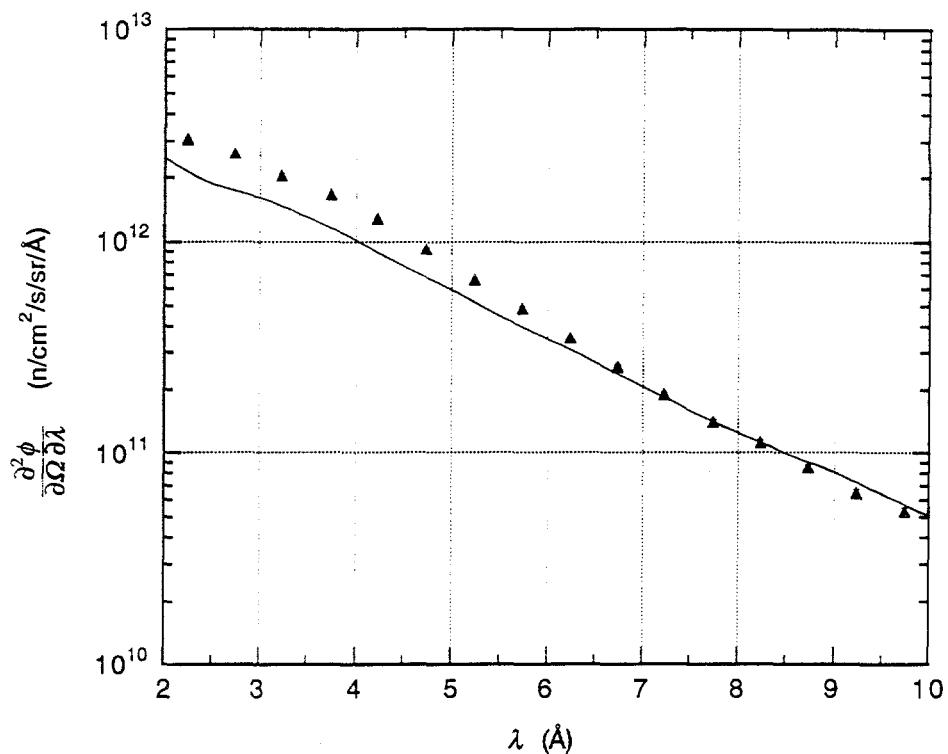


Figure 5. Calculated source brightness of the LPSS (triangles) compared to the calculated brightness of the ILL (solid line) at one-quarter of full power.

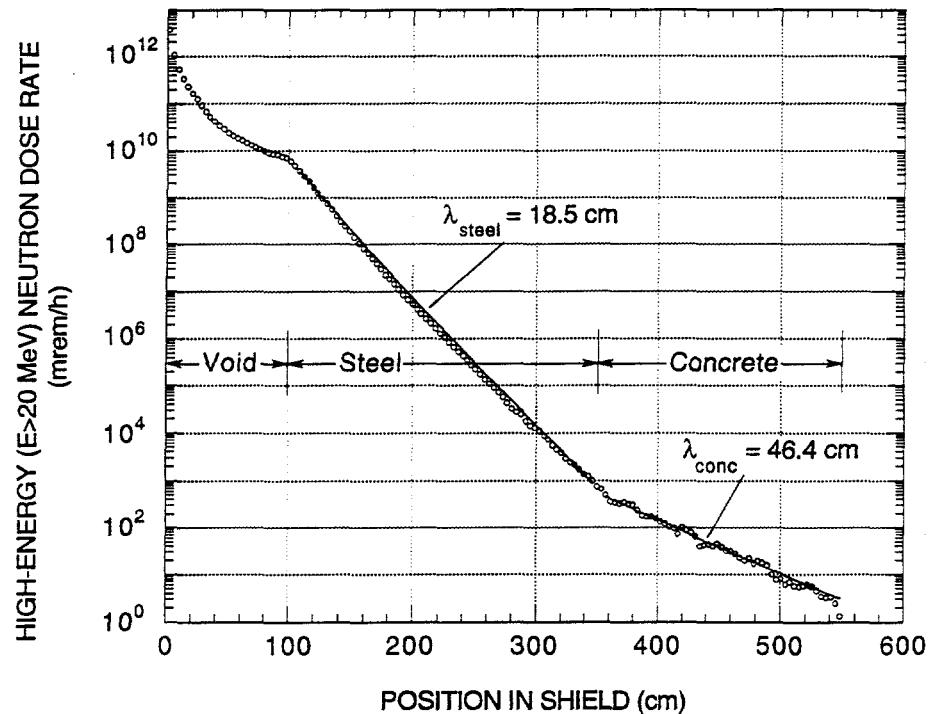


Figure 6. High-energy neutron dose rate attenuation through a steel/concrete shield. From the calculated attenuation coefficients for the steel and concrete, a shield composed of 4.5 m of steel and 1 m of concrete will attenuate the high-energy neutron dose rate to less than 0.1 mrem/h.