LANSCE target system performance

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ABSTRACT: We measured neutron beam fluxes at LANSCE using gold foil activation techniques. We did an extensive computer simulation of the as-built LANSCE Target/Moderator/Reflector/Shield geometry. We used this mockup in a Monte Carlo calculation to predict LANSCE neutronic performance for comparison with measured results. For neutron beam fluxes at 1 eV, the ratio of measured data to calculated varies from ≈0.6-0.9. The computed 1 eV neutron leakage at the moderator surface is 3.9 x 10^{10} n/eV-sr-s-μA for LANSCE high-intensity water moderators. The corresponding values for the LANSCE high-resolution water moderator and the liquid hydrogen moderator are 3.3 and 2.9 x 10^{10}, respectively. LANSCE predicted moderator intensities (per proton) for a tungsten target are essentially the same as ISIS predicted moderator intensities for a depleted uranium target. The calculated LANSCE steady state unperturbed thermal ($E < 0.625$ eV) neutron flux (at 100 μA of 800 MeV-protons) is 2 x 10^{13} n/cm^2-s. The unique LANSCE split-target/flux-trap-moderator system is performing exceedingly well. The system has operated without a target or moderator change for over three years at nominal proton currents of ≈25 μA of 800-MeV protons.

1. Introduction

The Manuel Lujan, Jr. Neutron Scattering Center (LANSCE)[1] is a state-of-the-art pulsed spallation neutron source. The origin of the 800-MeV protons for LANSCE is the Clinton P. Anderson Meson Physics Facility (LAMPF)[2]. LAMPF 800-MeV protons feed the ***P***roton ***S***torage ***R***ing (PSR)[3] which produces short (270 ns), intense proton pulses for LANSCE. An international user community utilizes LANSCE for condensed matter and nuclear physics research. The LANSCE target system needs to be operated efficiently, and continually upgraded to remain competitive worldwide. The LANSCE ***T***arget/***M***oderator/***R***eflector/***S***hield (TMRS)[4] provides spectrometers with potent neutron beams with appropriate time-structure and energy-spectral distributions.

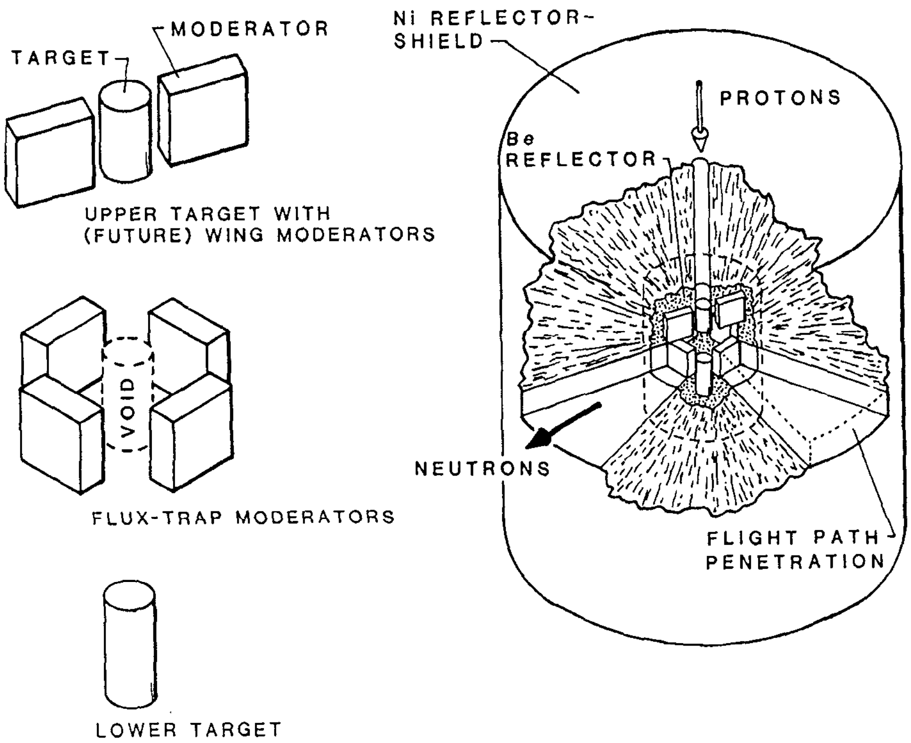

Fig. 1 Illustration of the LANSCE target system consisting of a split-target, an inner beryllium/nickel reflector region, and an outer nickel reflector/shield. Three water slab-moderators and a liquid hydrogen slab-moderator are in flux-trap geometry between two tungsten targets. The system is one meter in diameter and one meter high.

The LANSCE TMRS is depicted in Fig. 1. Presently, there are four slab-moderators in flux-trap geometry between the split targets. The four flux-trap moderators service twelve existing flight paths. Two additional moderators are envisioned adjacent to the upper target (in either wing- or slab-geometry) to service four new neutron flight paths. These two "upper-moderators" are part of the LANSCE upgrade project, scheduled for completion in 1992.

The LANSCE TMRS has four unique features:

- There is ***no crypt*** per se (void region) surrounding the TMRS.
- The target is ***not in one piece***, but split into two unequal segments separated by a void.
- Moderators are ***not*** located adjacent to the target as in the more conventional

wing-geometry design. In the LANSCE target system, the moderators are in slab-geometry located in a flux-trap arrangement where there is no target material. They lie ***between*** the two target segments and surround a central void region.

- A conventional all-beryllium reflector is ***not used***; the LANSCE TMRS employs a composite (beryllium/nickel) reflector/shield arrangement.

One significant advantage of our flux-trap geometry is that all four flux-trap moderators are high-intensity. This is in contrast to conventional wing-geometry moderators employed at ISIS[5] and IPNS[6]. At the latter spallation sources, moderators are located at both the front and back of the target to increase the number of flight paths serviced simultaneously. Because neutron production from spallation targets is strongly dependent on axial location, moderators in the fore position are nominally a factor of two more intense than aft placed moderators. This relative performance of fore and aft moderators in wing-geometry has been predicted theoretically[7] and observed experimentally. LANSCE flux-trap moderator performance should be akin to high-intensity, wing-moderator performance.

The twelve existing LANSCE neutron flight paths are depicted in Fig. 2. The four LANSCE TMRS flux-trap moderators are shown in Fig. 3; each moderator services three flight paths. Three of the moderators are ambient temperature water. Two of the water moderators are heterogeneously poisoned at 2.5 cm from the exit face with gadolinium and have cadmium decoupler/liners. We call these two moderators "high-intensity" moderators. The third water moderator is heterogeneously poisoned with gadolinium at 1.5 cm and has a boron decoupler/liner (1/e transmission at ≈3 eV). We refer to this moderator as the "high-resolution" moderator.

For thermal neutrons, the ***poison*** neutronically defines the thickness of a moderator viewed by an experiment. ***Decouplers*** surround a moderator and neutronically isolate it from the reflector. ***Liners*** neutronically isolate the moderator "viewed surface" from the reflector/shield.

We recognize the importance of cold neutrons in condensed matter research, and our fourth flux-trap moderator is liquid para hydrogen at ≈20 K. The liquid hydrogen moderator has no poison, a gadolinium decoupler, and a cadmium liner.[4]

The LANSCE TMRS was installed in August 1985, and has operated reliably (with no target or moderator changes) since its inauguration. Proton currents over the 3-year period were a nominal 25 μA. During the run cycle recently completed, the average proton current to LANSCE was ≈35 μA.

2. Approach

Because the LANSCE TMRS is an innovative design (unique worldwide) for a

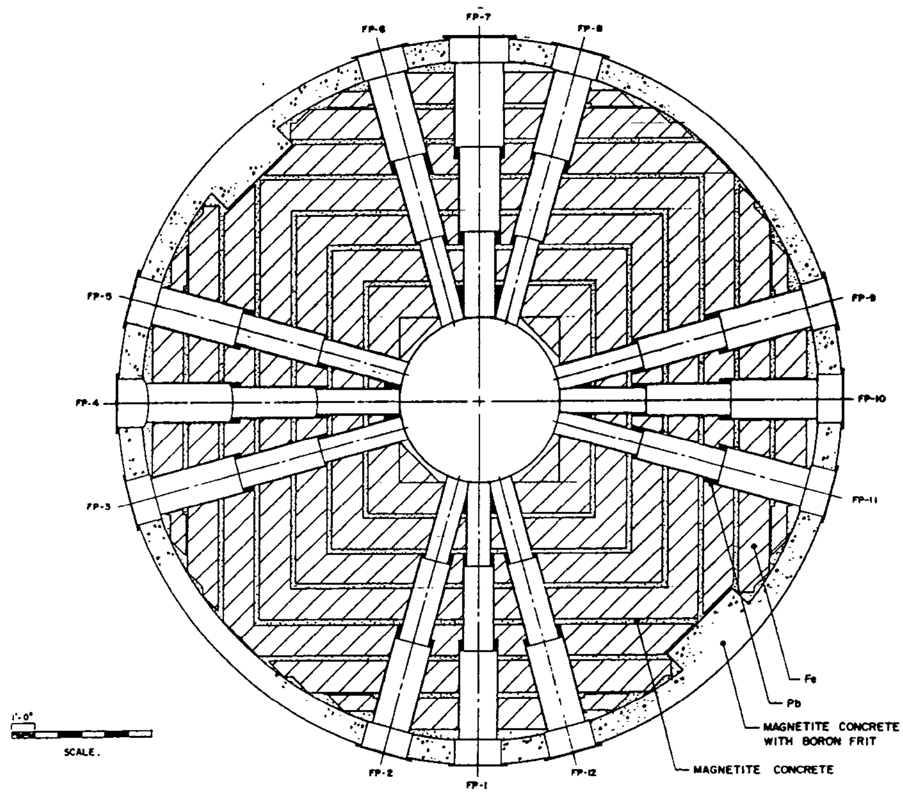

Fig. 2 Plan view of the LANSCE moderator and flight path arrangement.

spallation neutron source, it is imperative that we measure and calculate the neutronic performance of the as-built LANSCE target system. We must also compare the LANSCE absolute neutronic performance with those spallation neutron sources using conventional wing-geometry design.

We measured neutron beam fluxes using gold foil activation techniques. The details of these measurements are given in Ref. 8; the measurements were carried out on flight paths 1, 3, 7, and 8. During the design phase of the LANSCE target system, Russell[4,7] did preliminary calculations to estimate the neutronic performance. In order to directly compare measured and calculated neutron performance, Hughes[9] did a very detailed geometric mockup of the as-built LANSCE TMRS, and used the powerful Los Alamos Monte Carlo code system[10] to calculate the neutronic performance of LANSCE.

In this paper we concentrate only on neutron intensity, but the time behavior of neutrons is of paramount importance for a pulsed neutron source.

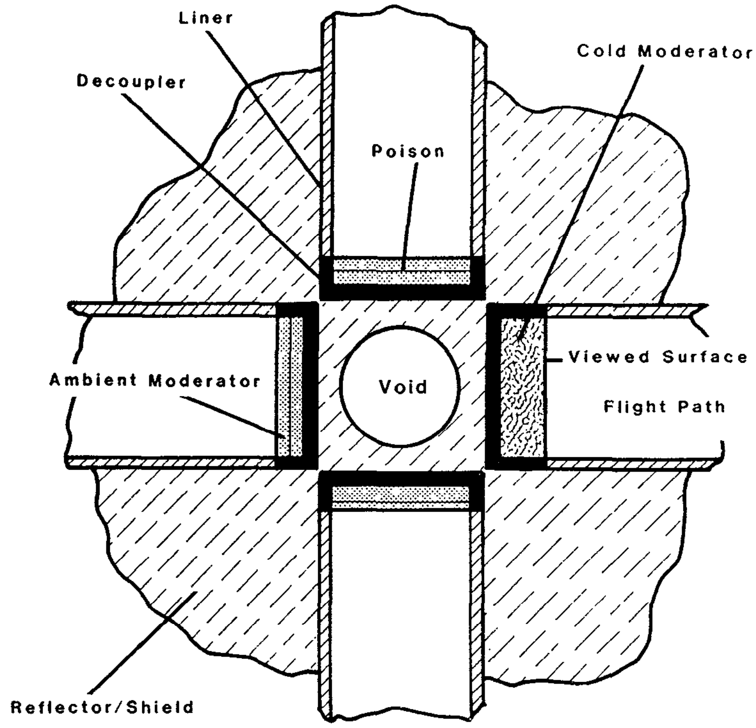

Fig. 3 Expanded plan view schematic of the LANSCE target/moderator arrangement. The liquid hydrogen moderator is depicted on the right side.

3. Results

3.1 LANSCE Neutron Beam Fluxes

LANSCE instrument designer/users are interested in the ***neutron beam flux*** at their sample location. We measured LANSCE neutron beam fluxes for flight paths 1,3,7, and 8[8], and did a detailed calculation of the corresponding neutron beam fluxes.[9] The results are shown in Table I.

In Table I, one can see that the ratio of measurement/calculation varies from 0.58-0.90. These are slightly larger variations than the preliminary values presented at the ICANS-X meeting. The differences are due to our changes in the assumed moderator field-of-view for each flight path. Subsequent to the ICANS-X meeting, Robinson[8] redetermined the moderator fields-of-view for each flight path where measurements were taken. He reviewed the actual flight path drawings, and applied a consistent definition of moderator field-of-view to all the flight paths. Hughes[9] recalculated the neutronic performance using the new fields-of-view.

Table 1 Measured and Calculated LANSCE 1 eV Neutron Beam Fluxes

Flight Path	Moderator Type	Moderator Field-of-View (cm^2)	1eV Neutron Beam Flux Measured $(n/eV \cdot cm^2 \cdot p) x 10^9$	Calcuclated $(n/eV \cdot cm^2 \cdot p) x 10^9$	Ratio Measured to Calculated
1	High-Resolution H_2O	141.2	0.44	0.49	0.90
3	High-Intensity H_2O	131.5	5.26	7.66	0.69
7	High-Intensity H_2O	139.8	2.61	3.93	0.66
8	High-Intensity H_2O	50.8	3.40	5.90	0.58

There are several variables that strongly influence the agreement between measured and calculated neutron beam fluxes. They are:

- The number, spatial distribution, and position of protons striking the target.
- The flight path collimation system and the resulting moderator field-of-view.
- The alignment of the flight path collimation system within the LANSCE bulk shield.
- Flux depression, multiple scattering, effective cross section corrections, etc. to the measured data.

At LANSCE, we presently have no direct measurement of the number, spatial distribution, and position of protons striking the LANSCE target. Gilmore[8] overestimated the number of protons striking the LANSCE target by assuming that ***all*** the protons passing through his aluminum monitoring foil struck the LANSCE target. The proton monitoring foil was located in the LANSCE beam line upstream from the LANSCE 90° bending magnet system. This conservative position would underestimate measured LANSCE neutron beam fluxes. Discrepancies in determining flight path collimation or the practical alignment of a collimation system in the LANSCE bulk shield will affect both measured and calculated data. Also, more work needs to be done using calculated neutron spectra to ascertain appropriate correction factors for the measured gold foil data.

3.2 LANSCE Neutron Source Intensities

Spallation neutron source designers typically quote ***neutron source intensity***, which is the angle dependent neutron leakage at the moderator surface. Calculated neutron leakage at 1 eV and E < 0.625 eV (thermal neutrons) are shown in Table II for 1 μA of protons. The 1 eV neutron leakage is 3.9 x 10^{10} n/eV-sr-s-uA for the two LANSCE high-intensity water moderators. The corresponding values for the LANSCE high-resolution and liquid hydrogen moderators are 3.3 and 2.9 x 10^{10}, respectively. These LANSCE neutron leakages are respectable values for a spallation

Table II Calculated Neutron Leakage Currents at Various LANSCE Moderator Surfaces for a 12x12 cm Field-of-View

Flight Paths	Moderator Type	1eV Neutron Leakage Current $(n/eV{\cdot}sr{\cdot}s{\cdot}\mu A)x10^{-10}$	Thermal(<0.625eV) Neutron Leakage Current $(n/sr{\cdot}s{\cdot}\mu A)x10^{-11}$
1, 2,12	High Resolution H_2O	3.3 ± 0.4	0.98 ± 0.07
3, 4,. 5	High-Intensity H_2O	3.9 ± 0.5	2.0 ± 0.1
6, 7, 8	High-Intensity H_2O	3.9 ± 0.5	1.9 ± 0.1
9, 10, 11	Liquid Hydrogen	2.9 ± 0.4	1.7 ± 0.1

Table III Calculated Neutron Leakage Currents at Various LANSCE Moderator Surfaces for a 12x12 cm Field-of-View

Flight Paths	Moderator Type	1eV Neutron Leakage Current $(n/eV{\cdot}sr{\cdot}p)x10^3$	Thermal(<0.625eV) Neutron Leakage Current $(n/sr{\cdot}p)x10^2$
1, 2,12	High Resolution H_2O	5.3 ± 0.7	1.6 ± 0.1
3, 4,. 5	High-Intensity H_2O	6.3 ± 0.7	3.2 ± 0.2
6, 7, 8	High-Intensity H_2O	6.3 ± 0.7	3.1 ± 0.2
9, 10, 11	Liquid Hydrogen	4.7 ± 0.6	2.7 ± 0.1

source employing a tungsten target. Thermal neutron leakages for a spallation neutron source are not usually quoted. The LANSCE moderator neutron leakage values are given in Table III on a per proton basis.

In the design of the LANSCE TMRS, Russell[4] used a simplified mockup employing only two (not four) flux-trap moderators. He also did not dilute material atom densities with cooling passages. A "rule-of-thumb" engineering factor of 0.7 was assumed to estimate the as-built LANSCE TMRS performance from the simplified mockup. The actual factor is 0.62, as derived by comparing results from Russell's simplified mockup with the detailed simulation by Hughes.[9]

We show computed neutron leakage spectra at the LANSCE moderator surfaces in Figs. 4-6. In Fig. 4, we compare the performance of a LANSCE high-intensity water moderator to the high-resolution water moderator. The effect on thermal neutron flux of tailoring moderator performance for resolution is shown in Fig. 4. The ratio of high-intensity/high-resolution thermal neutron leakage is about a factor of 2. However, the neutron pulse widths for the high-resolution moderator are narrower. The calculated neutron leakage spectra from the LANSCE liquid hydrogen, high-intensity, and high-resolution moderators are shown in Figs. 5 and 6. Cold moderators are used at pulsed spallation sources for two reasons: a) to extend the slowing-down (1/E) region to lower energies thereby retaining narrow neutron pulse widths; and b) to produce low-energy neutrons. The ability of the LANSCE liquid hydrogen moderator to produce low-energy neutrons is evident in Figs. 5 and 6.

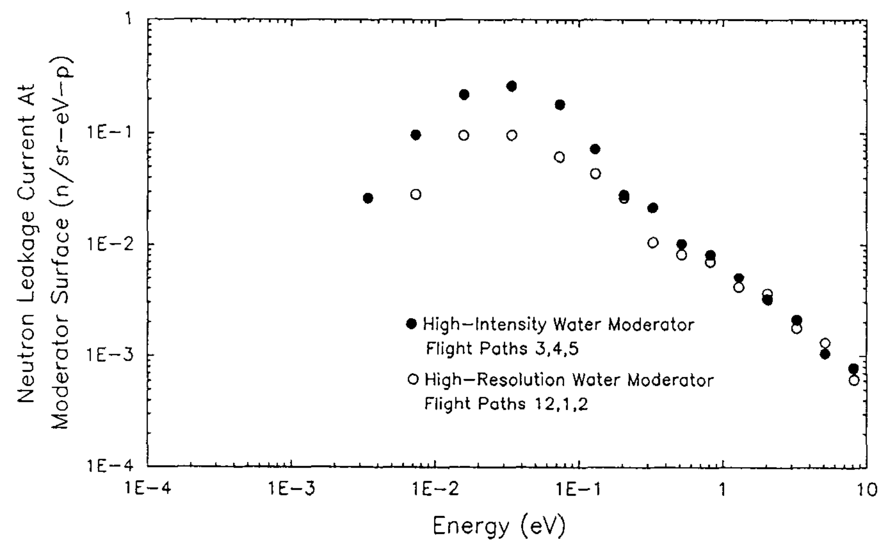

Fig. 4 Calculated neutron leakage spectra for LANSCE moderators showing the differences between high-intensity and high-resolution water moderators.

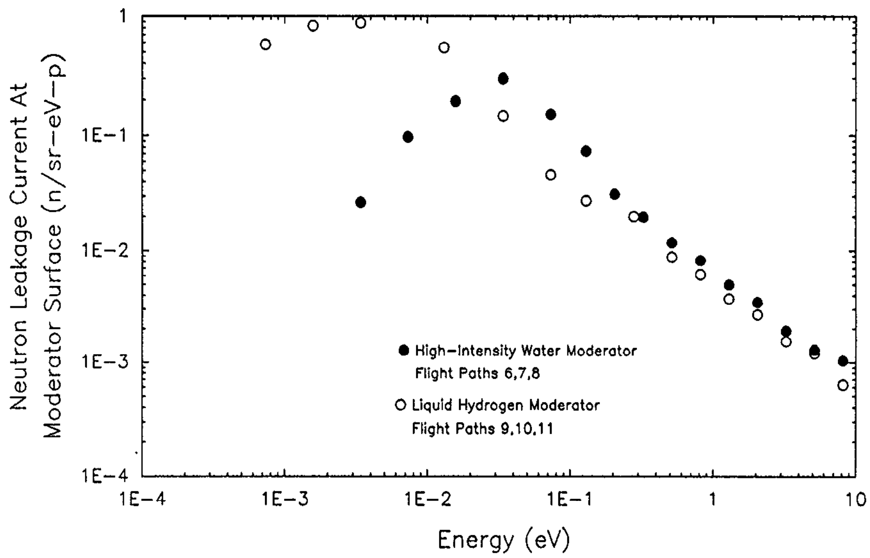

Fig. 5 Calculated neutron leakage spectra for LANSCE moderators comparing a high-intensity ambient temperature water moderator with the liquid hydrogen moderator at ≈20 K.

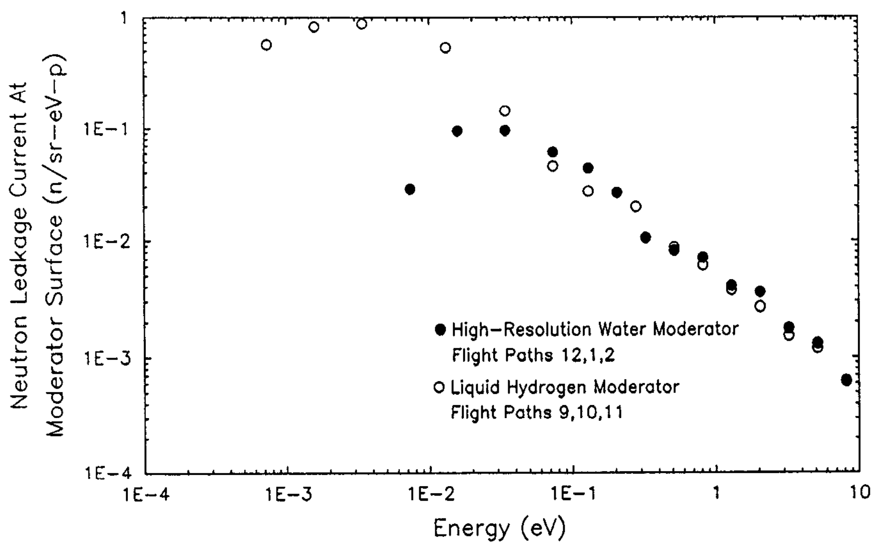

Fig. 6 Calculated neutron leakage spectra for LANSCE moderators comparing the high-resolution ambient temperature water moderator with the liquid hydrogen moderator at ≈20 K.

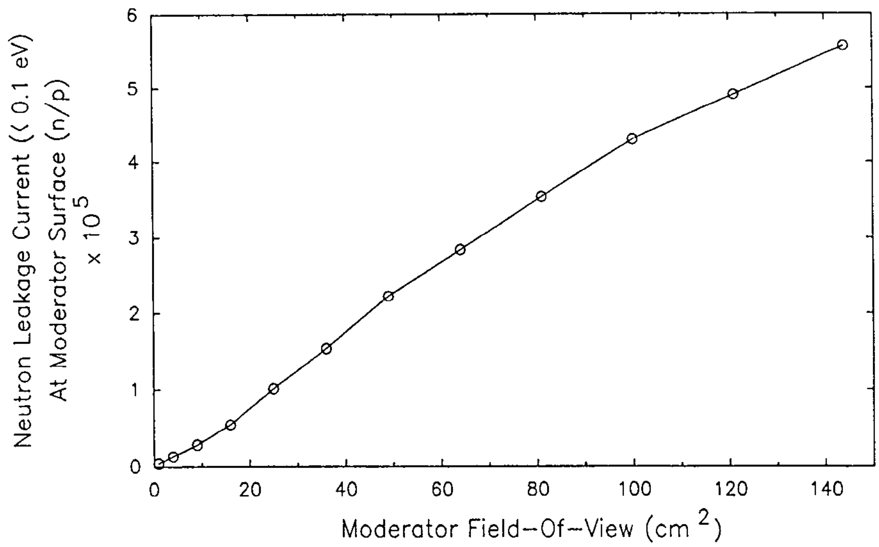

Fig. 7 Calculated neutron leakage current from a high-intensity ambient temperature water moderator showing the effects of different moderator fields-of-view.

3.3 LANSCE Moderator Field-of-View Study

One advantage of the LANSCE flux-trap moderators is that they are in slab-geometry without directly looking at the target (see Fig. 3). This allows significant gains to be made to neutron intensities by using larger fields-of-view at the moderator. The neutron leakage current from a LANSCE high-intensity water moderator as a function of the moderator field-of-view is given in Fig.7. For example, an increase in the field-of-view from 100 to 144 cm^2 augments the neutron intensity < 0.1 eV by ≈30%.

3.4 LANSCE Angle-Dependent Neutron Flux at a Moderator

We looked at the angular distribution of leakage neutrons < 0.1 eV relative to the normal to the moderator surface. The results of the calculation are shown in Fig. 8. For angles < ≈40 degrees, the distribution is cosine-like; at larger angles, the intensities appear to fall off more rapidly than a cosine function.

3.5 LANSCE Steady State Unperturbed Thermal Neutron Flux

For a pulsed spallation neutron source, a "thermal" (E < 0.625 eV) neutron flux can be calculated which is a comparable entity to a steady state reactor "thermal" neutron flux. This spallation source neutron ***flux*** is the spatial maximum of the unperturbed steady state thermal (E < 0.625 eV) neutron flux inside a moderator.[11] For LANSCE at 100 μA of 800 MeV protons, this calculated flux is 2×10^{13} n/cm^2-s.[11]

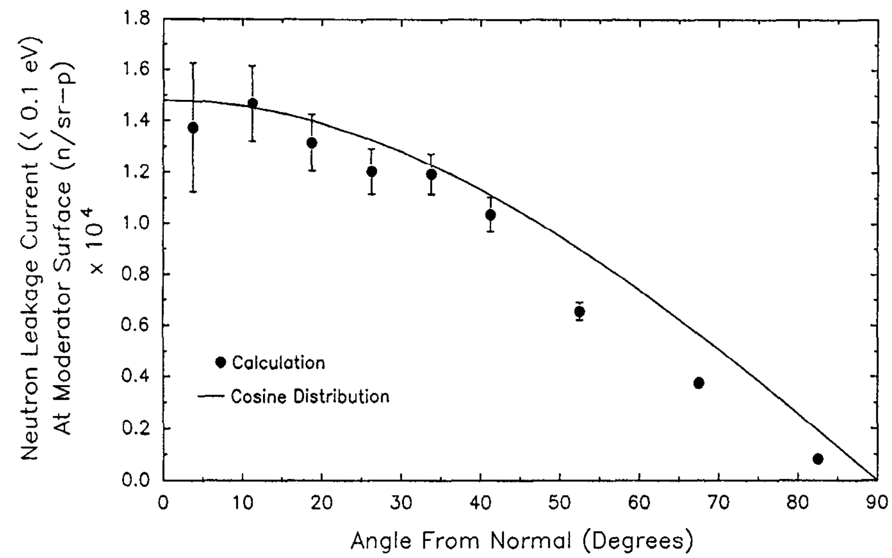

Fig. 8 Calculated angle-dependence of neutrons leaking from a LANSCE high-intensity ambient temperature water moderator. The angle is relative to the surface normal.

4. Conclusions

The Monte Carlo computer codes used to predict low-energy neutron transport give sensible agreement with a variety of measured data.[12-14] This provides reason to believe that calculated predictions of 1 eV neutron beam fluxes should correspond to measured results to within ≈20%. Not all the LANSCE measured and calculated neutron beam fluxes agree to this accuracy.

The strong dependence of LANSCE calculated neutron beam fluxes on the moderator field-of-view emphasizes the importance of collimation systems and their correct alignment (in a practical sense). One possible scenario for explaining the discrepancies between LANSCE measured and calculated neutron beam fluxes is that some flight path collimation systems are either misaligned or misunderstood. Also, at LANSCE the number, spatial distribution, and position of protons striking the target is uncertain; this situation needs improvement. The discrepancies between LANSCE measured and calculated neutron beam fluxes could also be real, requiring further explanation.

The LANSCE target system employs a tungsten target; the ISIS target system uses a depleted uranium target. Calculated LANSCE neutron leakages (per proton) at the various moderator surfaces are essentially the same as moderator leakages predicted for ISIS[15-17].

Given that the LANSCE TMRS is complicated and unique worldwide, the measured and calculated absolute neutron intensities for the as-built TMRS are particularly gratifying.

The LANSCE target system has performed admirably for over three years. We intend to continue to understand and improve the neutronic performance of LANSCE; the calculational tools recently developed will aid those endeavors. We plan further measurements of neutron beam fluxes as new neutron beam lines are developed.

The LANSCE upgrade (which will add two new moderators adjacent to the upper target) is scheduled for completion in 1992. Our current thinking (subject to change) is to employ the following moderators at upgrade: a) two liquid methane moderators at ≈77 K; b) two liquid hydrogen moderators at ≈20 K; and c) two ambient temperature water moderators.

5. Acknowledgements

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