ABSTRACT

The abstract is a very brief summary highlighting main accomplishments, what is new, and how it relates to the state-of-the-art. The powerful linear proton accelerator at the Los Alamos Neutron Science Center (LANSCE) generates pulses of 800 MeV protons, which after compression in the proton storage ring, impinge on a tungsten target producing spallation neutrons. This spallation neutron source, called the Lujan Neutron Scattering Center, operates as a user facility that serves a wide community of international users. Currently, the primary high-energy neutrons are further slowed down and moderated in a moderator-reflector-shield assembly to provide thermal and cold neutrons that are then available at 16 neutron Flight Paths (FPs). The current generation Target-Moderator-Reflector-Shield (TMRS) was optimized to deliver cold and thermal neutrons to neutron-scattering experiments. As the current TMRS approaches the end of its life, we are working on several conceptual physics design for the next generation TMRS. Four neutron FPs will provide a higher intensity in the epithermal and medium energy ranges while the other 12 FPs will preserve most of the thermal and cold neutron capabilities that currently support neutron scattering experiments. This new design will enable many new nuclear physics experiments that are currently limited by neutron intensity or energy resolution available at existing neutron FPs at LANSCE. Monte Carlo N-Particle eXtended (MCNPX) was used to model the complex Mark III TMRS design and compare it to various arrangements of the moderator/reflector/filter materials. Both neutron energy and time emission spectra were extracted from the simulation results and are presented in this paper.

KEYWORDS

Target moderator reflector shield; Spallation neutron production

1. INTRODUCTION

Lujan Center’s neutron production was optimized to deliver cold and thermal neutrons to neutron-scattering experiments [1]. A definition of the energy ranges used in this paper can be found in Table 1. Our goal is to extend the energy range of the Lujan Center’s target to enable new nuclear physics experiments in support of defence program applications that are currently limited by neutron intensity and energy resolution.

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Table I. Energy range definitions as used in this paper

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<thead>
<tr>
<th>Energy ranges</th>
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<tbody>
<tr>
<td>Cold neutrons</td>
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<tr>
<td>0.01 – 5 meV</td>
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<tr>
<td>Thermal neutrons</td>
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<tr>
<td>5 meV – 0.4 eV</td>
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<tr>
<td>Low energy neutrons</td>
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<tr>
<td>0.4 eV – 100 eV</td>
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<tr>
<td>Epithermal neutrons</td>
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<tr>
<td>100 eV – 10 keV</td>
</tr>
<tr>
<td>Medium energy neutrons</td>
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<tr>
<td>10 keV – 1 MeV</td>
</tr>
<tr>
<td>Fast energy neutrons</td>
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<tr>
<td>1 – 100 MeV</td>
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The current Mark-III TMRS consists of a split target design and moderators and reflectors as seen in the elevation plot in Fig 1. The split target consists of two W pieces to produce neutrons that are then scattered to 16 Flight Paths (FPs). The FPs are distributed over two tiers as follows: the lower tier consists of three chilled H$_2$O and one LH$_2$ + chilled Be moderators to deliver cold and thermal neutrons to 12 FPs. The upper tier consists of one LH$_2$ and one chilled H$_2$O moderators to deliver cold and thermal neutrons to 4 FPs. A cross section view of the lower and upper tier can be seen in Figure 2.
Currently, material science projects are conducted on the lower tier FPs. The four neutron FPs in the upper tier will provide a higher intensity in the epithermal and medium energy ranges while the other twelve FPs in the lower tier will preserve most of the thermal and cold neutron capabilities that currently support neutron scattering experiments. This new design will enable many new nuclear physics experiments that are currently limited by neutron intensity or energy resolution available at existing neutron FPs at LANSCE.

Since the upper tier and the lower tier are intrinsically coupled, any changes on the upper tier will affect the lower tier. The simulations that are presented in this paper were being conducted to monitor the changes on both tiers.

Figure 2. Cross section plot of the upper (left) and lower (right) tiers.

2. MCNPX MODELS

2.1. Raw Spallation Spectrum

The Monte Carlo N-Particle eXtended (MCNPX) software [2] was used to simulate the raw neutron spallation spectrum of a tungsten target hit by protons. The target was modeled as a solid cylindrical piece of tungsten with dimensions similar to the upper piece of the Mark III split target design (5.5 cm radius and 11 cm height).

The 800 MeV proton beam is perpendicular to the top surface area of the target. In this simple simulation, the plates of water that are used in the Mark III design to keep the target cool were ignored. The resulting neutron spectrum at the side surface area of the target can be seen in Figure 2.

The simulation results show that the intensity reaches a maximum in the range of 10 keV to 1 MeV. To optimize the neutron intensity of the four FPs located on the upper tier, we decided to model a design where the Be reflector and the moderators are removed and raised the upper target within the field of view of the upper tier (similar to the cross section view of Figure 7 but without the wings).
2.2. Neutron Spectrum

The neutron spectrum in the FPs of the upper tier and the lower tier for the proposed design is compared to Mark III in Figure 4. It shows an improvement up to two orders of magnitude in the upper tier in the medium energy range. However, in the thermal energy range, the intensity of the lower tier is divided by two due to the decrease of the solid angle caused by the translation of the upper target within the field of view of the upper tier plane.

![Figure 4. Proposed design neutron spectrum in upper (left) and lower (right) tier.](image)

To compare the gain we obtain in the upper tier with the translated target design, we integrated the curves over the medium energy range in Figure 4. We obtain $0.23 \times 10^{-6}$ n/p/cm$^2$ vs. $0.015 \times 10^{-9}$ n/p/cm$^2$, which corresponds to a gain of 15. However, if we integrate in the thermal range for the lower tier, we obtain $7 \times 10^{-9}$ n/p/cm$^2$ vs. $16 \times 10^{-9}$ n/p/cm$^2$, which corresponds to a loss of approximately 2.3.

2.2. Plate Study

The current Mark III upper tungsten target is made of seven plates of tungsten separated by a thin layer of water to dissipate the heat created by the interaction of the protons with the tungsten material. To address
the issue of lowering the intensity of the thermal neutrons in the lower tier with the proposed translated design, we studied the effect of translating the tungsten plates one by one to the Mark III location. Figure 5 shows four of the seven configurations.

![Figure 5. Elevation plot for four of the seven configurations of the plate study.](image)

Figure 6 shows the intensity of the upper tier in the medium energy range as a function of the intensity of the lower tier in the thermal energy range as we translate the plate. Each dot corresponds to the translation of one plate from the upper tier field of view to the location of Mark III. The intensity in the x and y-axis were normalized to one so that one can see the loss in the lower tier as a function of the gain in the upper tier. An intensity of one on the y-axis corresponds to the intensity in the medium energy range of the translated target ($0.23 \times 10^{-6}$ n/p/cm$^2$). An intensity of one on the x-axis corresponds to the intensity in the thermal range of Mark III ($16 \times 10^{-9}$ n/p/cm$^2$).

3. **NEUTRON TIME EMISSION SPECTRUM**

Present your summary and conclusions here. The time-of-flight (ToF) measurement is a technique used by physicists to measure the neutron energy with precision. For an energy given, the timing distribution of the neutrons varies with the initial position of the neutron and the time at which it is produced (and therefore the proton pulse). The neutron time emission spectrum was simulated with MCNPX. For fixed neutron energy, the time of arrival of the neutrons at the end of the FP was measured. Because ToF is used to measure the neutron energy experimentally, it is important to maintain or improve the timing resolution of the neutron time emission spectrum.
With the target translated in the field of view of the upper tier and with the removal of the moderators and the Be reflector, fast neutrons that scatter in the lead outer shield (blue in the Figure 7) can be transported in the FPs. This results in a tail to the right of the peak in the time neutron time emission spectrum as seen in Figure 8 (blue curve, no wings). To attenuate the backscattered neutrons, we simulated a model in which the target is surrounded by wings as seen in the cross section view of the upper tier in Figure 7. Several materials were modeled: Be, W and Pb. The thickness of the wings is similar to the diameter of the upper target (~10 cm). The dimensions are enough to protect the FPs from exposure to the lead outer shield opposite to the FP (8 cm); the height of the wings is the same as the upper target (10 cm).
4. CONCLUSION

It is possible to redesign the TMRS so that we provide a significant improvement, up to two orders of magnitude, in the epithermal and medium energy ranges in the upper tier. The addition of wings or material around the target, such as beryllium, is necessary in order to keep the backscattered neutrons from entering the upper tier FPs, which causes the degradation the timing resolution.

However, the translation of the upper target within the field of view of the upper tier causes the intensity of the thermal neutrons in the lower tier to drop by a factor of about two. By translating the plates of tungsten from the upper tier field of view to the Mark III location, we can regain some of the thermal neutron loss in the lower tier at the expense of the epithermal and medium energy neutrons in the upper tier.

We are going to continue to study the compromise between lower and upper tier by modeling other possible TMRS design with MCNPX.

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REFERENCES