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Lujan Center , Los Alamos National Laboratory
November 15, 2017

Review Committee

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Executive Summary

The 1L Target Moderator Reflector System (TMRS) at the Lujan Center will need to be replaced before the CY 2020 operating cycle. A Physics Division design team investigated options for improving the overall target performance for nuclear science research with minimal reduction in performance for materials science. This review concluded that devoting an optimized arrangement of the Lujan TMRS upper tier to nuclear science and using the lower tier for materials science can achieve those goals. This would open the opportunity for enhanced nuclear science research in an important neutron energy range for NNSA. There will be no other facility in the US that will compete in the keV energy range provided flight paths and instrumentation are developed to take advantage of the neutron flux and resolution.

Background

The purpose of this internal review was to assess the neutronics design of a proposed modification to the Lujan Center Mark-III target. The new target design is a significant evolution of the currently installed target with changes needed to address the expanding nuclear science mission of the Lujan Center. The goals of the Mark-IV neutronics design are to 1) improve the source performance at keV energies and 2) preserve the source performance in the thermal and cold regions vital for the traditional neutron scattering mission. It is anticipated that the existing Lujan Center Target will need to be replaced before the CY 2020 run cycle.

Committee Charge:

1. Is the proposed Mark-IV target neutronics design likely to achieve a significant performance boost for nuclear science while substantially preserving source performance for the neutron scattering mission?
2. Are the preliminary cost estimate and contingency reasonable?

3. Do you see any opportunities for further optimization beyond that which has been presented?

Neutronic Performance Summary

At the Lujan Center, the proton beam enters the target vertically. That allows the Lujan Center target to serve two tiers of neutron flight paths using a target-moderator-reflector system that efficiently produces thermal and cold neutrons with intensity and resolution optimized for materials science experiments. In each tier, instruments view moderators, and do not see the high-energy neutron and gamma rays produced by the tungsten target.

The upper tier of the Mark-III target presently serves four flight paths, three of which are in use, or planned to be used, by nuclear science instruments (Flight Paths 12, 13,and 14). The lower tier serves an additional 12 flight paths, of which four are in use by material science (MS) instruments (Flight Paths 2, 4, 5, and 11). Separation of missions for the two tiers offers the possibility of optimizing the performance of the upper tier of the target for nuclear science (NS) and largely preserving the performance of the lower tier for materials science.

Nuclear science instruments at Lujan Center rely on neutron time-of-flight (TOF) to provide neutron energy information for experiments. The quality of the obtained energy information depends directly on the neutron pulse width (that is, the neutron yield as a function of time at a given neutron energy) from the Lujan Target (also known as the 1L Target because it is the first target area to the left of the beam line). The goal for nuclear science instruments is to improve the TOF resolution with adequate flux to enable improved cross section experiments in the resolved and unresolved neutron resonance range.

Material science instruments, operate with the 125 ns Full-Width-at-Half Maximum (FWHM) pulse from the proton storage ring (PSR) striking a large tungsten target surrounded by water and liquid hydrogen moderators surrounded by a large beryllium reflector and a lead reflector/shield. This gives an acceptable pulse width at high intensity for thermal and cold neutron research.

The 1L Target Team used MCNPX to simulate the neutron production and moderation for nuclear science experiments in the keV region. In order to provide a basis for redesigning the upper tungsten target tier, the 1L Target Team developed performance metrics for average flux, peak flux, resolution, pulse repetition rate and background. The upper-tier flight paths were originally developed to look off the center-line of the Mark-III system in order to view the moderators for MS experiments. As a result, the team calculated the performance for two instrument fields of view, one as is presently aligned, called the 'Real' field of view, and one centered on the proposed target, called the 'Center' field of view.

Calculations showed that for the Mark-III system, the large amount of reflector material surrounding the target and moderators gave neutron pulses with broad asymmetric tails thus limiting the applicability and utility of nuclear science experiments. The simulated pulse widths were in good agreement with cold neutron measurements from Lujan Center, confirming the need to make design modifications in order to improve performance.

The 1L Target Team conducted a thorough investigation, through simulation, of different designs. They concluded that removing the Beryllium reflector, moving a slice of the tungsten neutron production target into the instrument field of view, optimizing the target geometry and moderator orientations, and realigning the nuclear science flight paths to center the field of view were needed for improved performance.

The team used a figure of merit similar to ones in previous studies to optimize their choice of target performance for nuclear science: $FOM(E) = \phi(E)/FWHM(E)^2$, where $\phi(E)$ is the neutron flux at energy E, and FWHM(E) is the full-width-at-half maximum of the neutron pulse at energy E. They investigated multiple combinations of the upper-tier target/moderator geometry before concluding that a compact tungsten disk with a water moderator provided increased keV to MeV neutron flux and significantly improved neutron pulse shapes with approximately a 26 - 28% lower-tier neutron flux reduction relative to that of the Mark-III target under current operating conditions (20 Hz, 100 μA, 125 ns FWHM proton beam)..

The material science instrument performance was optimized in the Mark-III design, but the team suggested the possibility of modifying the FP-2 High-Resolution moderator to allow either High-Resolution or High-Intensity operation of the SMARTS instrument and suggested that 30 Hz, 150 μA operation would be beneficial for some SMARTS experiments on FP-2 and that FP-5, HIPPO (FP-4), and ASTERIX (FP-11) could potentially use that mode of operation. They pointed out that existing chopper systems would have to be tested and brought into operation for this mode.

Nuclear science operation for the proposed disk target design under current operating conditions (20 Hz, 100 μA, 125 ns FWHM proton pulse width) would be substantially improved compared to the Mark-III target. Figure 25, from LA-UR-17-29834, 'Proposed Science Design for the Mark-IV 1L Target' shows the FOM from 1eV to 100 keV for the two Upper-Tier target configurations presented to the committee. In that figure, the four curves correspond to rod and disk target options in the 'Real' configuration, and in a 'Center' configuration. In all cases the FOM is improved over the Mark-III system, with improvement for the disk target/moderator arrangement with the present flight path alignment ranging from factors of nearly 10 at 1 keV, to above 500 at 100 keV.

The actual FOM improvement for a particular instrument will depend on other factors beyond the FOM used in these studies. In order to estimate that, performance enhancements for the DANCE instrument were calculated. In that case, under current operating conditions, the flux in the range from 10 – 100 keV increased by factors of 6 to 12, pulse resolutions reduced by 7 – 10%, and the FOM increased by 6 – 15. At 30 Hz, 150 μA the FOM would increase by 10 – 23 over the same energy range.

With an improved upper-tier target design, the 125 ns FWHM proton pulse width will be a limiting factor for some experiments. The team also looked at operation at 30 ns FWHM proton beam width at 30 Hz and 36 μA. In that case, the FOM would increase by a factor of 32 to 91 for DANCE experiments with the flux for material science experiments decreasing by a factor of 2.8. Operation at 30 Hz regardless of proton pulse width to the Lujan target would reduce the beam current to the WNR facility by 10%.

Cost Estimate Summary

The review team was given an overview of the estimated $8.37M Mark-IV cost for several different annual spending profiles, all of which are limited to a total of $8.37M. The estimate uses detailed information from the Mark-III target fabrication and installation as the cost basis, with results of the present design study providing an adjustment for the upper-tier changes.

The lower-tier system is similar to that of Mark-III target with the only major changes being those to the water moderator viewed by FP-2, and inclusion of a middle tungsten target.

The upper-tier target was based on using one of the clad spare tungsten disks from Mark-III and adding the water moderator. Removal of the beryllium reflector material from the upper-tier target as proposed in the design study was estimated to lower the materials cost by ~$1M from that of Mark-III.

Additional adjustments to the Mark-III cost estimate are based on being able to use the Mark-III spares, using the Mark-I cask, and lifting fixture. The total material is estimated to cost $2.95M with $1.38M of that based on firm-fixed-price-quotes obtained in 2016 for the Mark-III target. The labor estimate used the actual cost for Mark-III. Both were escalated by 3%/year compounded annually. The team assumed that the above material and labor costs are accurate, so that 79.5% of the cost estimate is based on known numbers, leaving $1.57M (26%) of the cost estimated with a 44% contingency.

Committee Charge:

1. Is the proposed Mark IV target neutronics design likely to achieve a significant performance boost for nuclear science while substantially preserving source performance for the neutron scattering mission?

Committee Response

The committee believes that the design presented to the committee, or slight modifications to that design, will increase the neutronics performance in the 10 keV to 100 keV energy range by the amount necessary to make the facility valuable for many NNSA missions. Further, there will be no other facility in the US that will compete provided flight paths and instrumentation are developed to take advantage of the neutron flux and resolution. The roughly 28% decrease in materials science performance will, in the opinion of the committee, not have a significant impact on the materials science program. Improvements in accelerator performance or increased proton pulse rate can overcome this reduction for many measurements.
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2. Are the preliminary cost estimate and contingency reasonable?

Committee Response

The cost estimate is reasonable for this stage of the project (physics design of the upper-tier target) as it is based on past experience with detailed, escalated firm-fixed-price bids for components and known labor charges. Contingency for the 26% of the project not based on past labor cost or firm-fixed-price bids is 44%, which is somewhat low, but there is an uncertainty in potential labor rates with the upcoming contract change that may also impact the estimate.

3. Do you see any opportunities for further optimization beyond that which has been presented?

Committee Response

Although the presentations included the importance of improving the number of protons/pulse, the committee would like to reiterate the importance of making that improvement as it not only would improve the source strength for Lujan Center, it would improve WNR performance.

Once the upper-tier modifications are made, realigning the collimation of the NS flight paths will make best use of the improved source.

In the event there are MS experiments requiring higher intensity, or times when NS experiments are not operating, developing the capability to move the NS target out of the beam would be a useful option.

It may be possible to further decouple the lead shielding neutron return in order to reduce the pulse tails further and reduce gamma ray backgrounds, for example by adding boric acid to the to the water in the 4-cm water layer.

The moderator suite in the lower-tier may be further optimized using instrument-specific FOMs.

Increasing the design study scope to include NS flight paths and shielding requirements in order to understand the impact of high-energy neutrons on existing and proposed instruments would help ensure success.

Overall Target Design Observations

- The 1L Target Team did a thorough investigation of integrating new nuclear science capabilities into the Lujan target.
- The choice of $\phi(E)/FWHM(E)^2$ is a reasonable way to optimize the upper-tier target design.
- The neutron flux and resolution requirements are only two of many parameters necessary to optimize the performance for an experiment in order to obtain the required results with other factors such as flight path length, collimation, and shielding playing important roles.
- The upgrade broadens the space for NNSA nuclear science missions and will likely attract new users in the nuclear data field as there exists no facility in the US that will compete in flux and resolution
- The materials science mission is at first glance not significantly impacted by introducing a nuclear science target.
- Operating the facility with multiple missions simultaneously could complicate scheduling.

Overall Cost Estimate Observations

- The cost estimate approach based on past experience and firm-fixed-price quotes with escalation appears to be reasonable at this stage of the project.
- The impact of the upcoming contract change adds uncertainty to the preliminary labor cost estimate of $5.13M out of a total of $8.37M.
- No critical spare parts are included in the present cost estimate.

Overall Target Design Findings

- The improvement in FOM for nuclear science experiments compared to Mark-III is significant in the energy range of interest.
- The largest improvement to the nuclear science capability will come from the proposed changes to the upper-tier target-moderator geometry coupled with increased repetition rate and reduced proton pulse width at the expense of more complicated

experiment scheduling and reduced operations for material science

- The option of operating Lujan Center at 30 Hz at 150 μA could more than compensate the slight performance losses of the lower-tier moderators for most of the instruments presently operated
- WNR would be negatively impacted by 10% for 30 Hz operation; the material science instruments will require the utilization of the existing but not currently used choppers.

Overall Cost Estimate Findings

- The cost estimate at this stage of the project appears sensible with 44% contingency on 26% of components not firm fixed priced.
- The cost estimate uses a non-standard contingency, but it appears to be reasonable assuming past experience numbers.
- The cost estimate has some risk in using $3M in spare parts for the Mark-IV fabrication assuming no failure of the Mark-III target until year 2020.

Overall Target Design Recommendations

- Implement the flat standing slab configuration of the nuclear-science (NS) target-moderator
- Explore additional geometrical configurations for the NS target-moderator (rectangular, thinner disk, etc.)
- Implement the three chamber high-resolution/high-intensity moderator to establish a high-intensity capability and slightly higher fluxes in the high-resolution mode for SMARTS and NPDF
- Maintain the lower-tier liquid hydrogen moderator for serving cold neutrons to ASTERIX and for keeping the options for future developments
- Develop appropriate diagnostic instrumentation to optimize the tuning of the beam to target (spot-size and position, thermal performance of the Nuclear Science (NS) target, proton pulse width, neutron output for NS and MS)
- Investigate the impact on the permanent shielding resulting from removing the upper tier beryllium.

- Investigate the adequacy of existing flight-path shielding for the high-energy fast neutron flux from the directly-viewed tungsten.
- Investigate the impact of the high-energy neutron flux from the upper-tier tungsten target on proposed nuclear science instruments.

Overall Cost Estimate Recommendations

- Develop a resource loaded schedule to make sure that the labor force is not overcommitted and that material orders are placed in a timely way.Update the estimated cost based on the final physics design to include detailed engineering design information
- Update the cost estimate to more accurately reflect the impact of longer or shorter spending profiles.
- Develop a priority-based list of critical spare parts and use any left-over funds to fabricate them.

Opportunities for further optimization

- Improving the number of protons/pulse would mitigate the impact on WNR and improve the source strength for Lujan Center
- Realigning the collimation of the NS flight paths to make best use of the target
- Developing the capability to move the NS target out of the beam
- Improving the neutron decoupling from the lead shielding to reduce the pulse tails further and reduce gamma ray backgrounds
- Optimizing the moderator suite in the lower-tier using instrument-specific FOMs.

Attachment 1

Mark IV Target Neutronics Design Review
Wednesday, November 15, 2017

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TA-53, Bldg. 622, Lujan Auditorium

8:30	Welcome and Committee Charge	Gus Sinnis
8:45	General Design Considerations	Paul Koehler
9:15	Design Optimization Studies	Michael Mocko and Lukas Zavorka
10:15	Break	
10:30	Expected Mark IV Performance	Paul Koehler
11:00	Project Cost and Schedule	Joe O'Toole
12:00	Lunch	
13:00	Committee Deliberation	Committee Only
15:30	Closeout	All
16:00	Adjourn	