Abstract—Background: The Target-Moderator-Reflector System (TMRS) is the neutron source for nuclear physics experiments in the Lujan Neutron Scattering Center user facility. The TMRS is an assembly consisting of tungsten targets plus a network of moderators, reflectors and flight paths that deliver neutrons of specified energies and fluxes to surrounding experiments and detector stations. The second-generation TMRS (MK II), operational for 5 years, is scheduled for replacement in 2010. While many features of MK II will remain unchanged this paper describes the engineering design of important new features: 1) The tungsten components of the targets will be clad in tantalum to minimize erosion and consequent contamination of the water cooling system, and 2) A new liquid hydrogen moderator with a beryllium reflector/filter that doubles the neutron flux.

I. INTRODUCTION

This paper discusses the design of the Target-Moderator-Reflector-System (TMRS) MK III. The TMRS is the neutron source for the Lujan Neutron Scattering Center located at Los Alamos Neutron Science Center (LANSCE) at the Los Alamos National Laboratory. The Lujan Center is availability for users, both national and international, to conduct research. The TMRS MK III, designed using the SolidWorks* CAD system, has several new features including (1) tantalum clad tungsten targets that result in significantly reduced radioactive contamination of the target water cooling system, (2) a new design for the lower liquid hydrogen (LH) moderator with its beryllium reflector/filter that results in a doubling of the cold neutron flux for the same beam current, (3) a design change that significantly improved the performance of the upper LH moderator, and (4) two redesigned lower water moderators each employing central webs containing gadolinium.

II. THE LUJAN NEUTRON SCATTERING CENTER - A USER FACILITY

The Lujan Neutron Scattering Center within the Los Alamos Neutron Science Center (LANSCE) develops instrumentation in support of research employing neutrons to investigate issues of interest to its user community.

The Lujan Center has 16 neutron beamlines arranged around an upper and a lower tier of moderators, Fig. 1. The upper tier has one liquid hydrogen moderator and one water moderator. The lower tier has one liquid hydrogen moderator and three water moderators. The new generation of the Lujan TMRS MK III will increase the flux of cold neutrons for three instruments, (1) Surface Profile Analysis Reflectometer (SPEAR), (2) Low-Q Diffractometer (LQD), and Asterix.

III. OVERALL DESIGN OF THE TMRS MK III

The TMRS is located within the Crypt which is surrounded by shielding consisting of steel plates within heavy concrete. The Crypt, Fig. 2, has a vacuum shell containing steel shielding, the TMRS, and a beam stop.

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The TMRS MK III is based on the MK I and MK II designs. It has an instrument insert, a window insert, and a target moderator reflector (TMR) insert.

The **Instrument Insert** supports a HARP to measure particle beam position so that the beam can be steered into the TMRS.

The **Window Insert** supports the particle beam window that forms the vacuum boundary between the particle beam and the crypt. While the particle beam is under high vacuum, the Crypt is under a low vacuum so that air will not interfere with the neutron source. The Window is machined from Inconel 718 and its two main parts are EB welded together. Water flows between the two thin hemispherical surfaces to cool the Window. Beam position is monitored by a set of four thermocouples.

The **TMR** includes a pair of targets, four water moderators, two liquid hydrogen (LH) moderators, beryllium moderators, three water cooled heatsink plates, three lower port liners, two steel reflectors, and a steel insert. The window insert contains the particle beam window that separates beam vacuum from TMRs vacuum. The instrument insert supports a HARP used to determine particle beam position by excitation of grids of orthogonal wires.

A. **Steel Reflectors**

The upper and lower Steel reflectors are machined from 304L stainless steel. They have water cooling passages throughout.

B. **Beryllium Reflectors**

There are three layers of beryllium reflectors that serve to contain the neutrons so that neutrons will preferentially escape through the single upper and four lower port areas. The Lower beryllium reflector is machined from a single piece 6 inches thick, 24 inches in diameter, and supports the lower target. The middle layer consists of a set of four beryllium parts that surround the four lower ports, three water moderators, and the lower LH moderator. The upper layer consists of two sub-layers. The lower sub-layer has six parts that form the upper port. The port area itself has two upper parts as its ceiling and two more as its floor. The upper sub-layer has four parts. All of these parts surround the upper water moderator and upper LH moderator. The beryllium parts purchase order was the single highest one at approximately one million dollars.
C. Heatsink Plates

The three water cooled aluminum heatsink plates serve to cool the beryllium. Cooling passages have EB welded covers. The middle heatsink plate supports the upper target assembly.

D. Steel Insert

The steel insert serves as a shield plug, is supported on its set of three large horizontal pins, supports the components below it, and is not actively cooled.

IV. THE TMRS MK III TARGETS DESIGN – TANTALUM CLAD TUNGSTEN

There are two targets, an upper target consisting of seven disks of various thicknesses and a lower target consisting of one rod. All of these are fabricated from very high-density tungsten. The finished tungsten target components are clad with tantalum. The targets are contained within Inconel 718 housings. Each housing has 304L stainless steel water cooling pipes. Each of the two target assemblies has a set of thermocouples.

A. Tantalum Clad Tungsten Targets

The MK I/II had high radiation contamination, due to tungsten erosion product, raising water system maintenance issues. The very high density tungsten targets are clad with 0.010 inch thick tantalum by HIPing, reducing high water flow rate erosion thus mitigating maintenance staff exposure.

For the upper target disks tantalum cans were draw formed and trimmed to the various lengths needed, Fig. 5. Tantalum covers were formed. All of the “standard” covers are the same and were sized for the thinnest upper tungsten target disk. These covers jog up onto the side of the cans and their upper edge is EB seal welded in a vacuum to their cans. After HIPing the bump resulting from the jog is machined off. Development of the fabrication process was a significant effort.2

The lower target rod has a sheet of tantalum rolled around it and EB seam welded along its length after which a pair of “standard” covers are assembled as done for the upper target disks.

B. Inconel 718 Target Housings with 304L Stainless Steel Piping

The housings are machined from Inconel 718 as are there associated components, Fig. 5. A set of spacers maintain the proper water flow between the clad target disks. The top cover is EB welded in place. The integral water manifold chambers have TIG welded covers, manifold parts, and a pair of support angles. The lower target housing has a set of four internal integrally machined ridges that serve to rotate the water flow around the target as it flows from top to bottom. The housing has an upper and lower cover each EB welded in place. The two support tabs are integrally machined. Each of the two target assemblies has a pair of 304L stainless steel water cooling pipes.

C. Target Thermocouples

Each of the targets has a set of thermocouple. The thermocouples are ordered mounted on thin stainless steel sheets so that the sheets can be welded to the component. The upper target has a set of five upper and four lower thermocouple positioned to aid in determining particle beam position. The lower target has a single central thermocouple on its upper cover. Thermocouples are located on the inlet and outlet cooling pipes near each of the target housings.

V. LOWER LH MODERATOR - DOUBLING THE PERFORMANCE OF THE LUJAN CENTER COLD NEUTRON SOURCE WITHOUT INCREASING THE BEAM CURRENT3

The lower cold neutron moderator has a water pre-moderator sized to reduce the heat load on the LH2 cryogenic system to no more than the same level as that of the MK II design so that a costly increase in cooling capability is avoided. Next a liquid hydrogen filled moderator tank, mounted in a vacuum tank, is employed to create the cold neutrons. This is followed by a beryllium reflector/filter that is contact cooled by the LH2 tank. Using this arrangement, and maintaining the same particle beam parameters as for the MK II design, the cold neutron performance is increased by a factor of two.

A. TMRS New MK III Optimized Design vs. MK II

A proof of concept test was conducted. This test placed a cryogenically cooled piece of beryllium within a neutron beam and measured the change in neutron flex.

A MCNP neutronic model was employed and the model was bench marked against the existing design and its measured performance. The MCNP model was employed to investigate design options. The mechanical design was developed using SolidWorks CAD software and the MCNP model was updated to reflect the detail of the mechanical CAD design.

Elements of the optimized design include:
• A water pre-moderator reduces the heat load on the cryogenic system to no more than that of the existing MK II design
• LH₂ and vacuum tank outer walls “windows” 2 mm thick
• No LH₂ film on outer surface of Be reflector filter
• Premoderator (H₂O) = 2 cm
• Moderator (LH₂) = 4 cm
• Be reflector = 13 cm

This design results in a MK III neutron flux (\(\lambda \geq 4 \, \text{Å}\)) that is a factor of 2 higher than original MK I and the current MK II, Fig. 6.

![Graph](image1)

**Fig. 6.** MCNP based calculations shown for FP-9 and LH₂ ortho/para = 25%/75%.

**B. Target Moderator Reflector System MK III Lower LH₂ Moderator Design Features**

The MK III lower LH₂ moderator with its liquid helium cooled beryllium reflector/filter is located within the TMRS where the existing MK II has its lower LH₂ moderator at the lower tier, Fig. 7. A pair of vacuum jacketed transfer lines supplies the liquid helium to the moderator.

A number of design options were investigated. First a concept featuring a separate tank for the beryllium reflector/filter where it could be cooled from all sides by a separate supply of LH₂ coolant was considered.

Second, a design featuring the beryllium reflector/filter located within the LH₂ tank where it could be cooled from all sides was considered. This design would eliminate the need for a separate set of coolant lines. It would also reduce the number of aluminum walls between the LH₂ and the beryllium since one would not need a wall for the LH₂ vessel, nor a space between the two tanks, nor a wall for the beryllium tank. The space between the water pre-moderator and the cylindrical outer side surface of the TMRS is fixed. This design concept would also allow the thickness of the beryllium to be larger without the need for these walls.

Third and final, a design, Fig. 8, that placed the beryllium reflector/filter outside the LH₂ tank but up against it with upper and lower cooling chill plates integral to the LH₂ tank was selected.

It was found that even a thin layer of LH₂ located downstream, i.e. at the surface farthest from the neutron source, of the beryllium reflector/filter was detrimental to the neutronic performance. Even if one could keep the beryllium located within a LH₂ tank up against the outer wall of a LH₂ tank after cool down, structural deflection of the outer wall of the LH₂ tank due to the pressure of the LH₂ would permit LH₂ to enter the space between the beryllium and the outer LH₂ tank wall created by these deflections. This is especially true because the neutronic analysis showed that a “window” was needed in the outer wall of the LH₂ tank. This window is an area where the wall of the LH₂ tank is thinner, at 2 mm. Structural analysis shows that even if the wall would not fail it would deflect excessively.

![Diagram](image2)
The design features the beryllium reflector/filter being located immediately against the outer surface of the LH₂ tank where it supports the “window” area, Fig. 8. The pressure load on the “window” area is immediately transferred to the beryllium as the “window” leans up against the beryllium. The beryllium has an upper and a lower tab that extends across its entire width. These tabs fit into matched slots in the integral aluminum chill plates that are a portion of the LH₂ tank. Here the pressure load from the “window” area is transferred from the supporting beryllium into the LH₂ tank where it balances with its equal and opposite tank internal pressure loading.

Since the aluminum will contract more than the beryllium during cool down to liquid helium temperature, the space at room temperature between the face of the beryllium and the LH pressure vessel will completely close. This design ensures good thermal contact between the tank containing the LH₂ and the beryllium that needs to be cooled. In that portion of the moderator between the LH₂ tank wall and the downstream surface of the beryllium tab the aluminum chill plate will contract more than the beryllium. The downstream surface of the slots in the chill plates will pull the beryllium up against the main portion of the LH₂ tank. In this symbiotic design the required thin “window” is supported by the beryllium beaming the pressure load to the top and bottom of the LH₂ tank while at the same time ensuring good thermal contact over the entire surface to promote heat transfer so the beryllium is adequately cooled. The space at room temperature between the face of the beryllium and the LH pressure vessel helps to reduce stress in the tabs during cool down.

A custom fabricated shim plate ensures proper fit at the upper surface of the beryllium reflector/filter. A set of three fasteners at the top and three at the bottom ensure good thermal contact between the neutron heated beryllium and the LH₂ tank chill plates. The fasteners each have a flat washer followed by a Belleville washer under the fastener’s head. The fasteners are tightened so that the Belleville washers are compressed to one quarter of their free height. This design accommodates the differential thermal contraction between the steel fasteners, aluminum pressure vessel flanges while ensuring a compressive clamping load is applied to promote thermal conduction of heat from the beryllium to the chill plates.

The curvature of the outer wall of the vacuum tank helps to support the “window” area in its outer wall. The normal operating condition has vacuum on both sides of this window. It is “normal” during maintenance to have a vacuum on either side with atmospheric pressure on the opposite side.

Extensive thermal and stress analysis was performed to support the design effort. Even small changes in the design can drastically change the performance for the worse.

The beryllium reflector/filter must be kept near LN₂ temperature (~120K or less) to have required material properties for neutronic performance.

The beryllium reflector/filter is located outside LH₂ tank and is cooled by integral chill plates, because one cannot have LH₂ outboard of the beryllium and deflections of the LH₂ tank would allow LH₂ into the space between the beryllium and the LH₂ tank if the beryllium was positioned inside LH₂ tank. “Windows,” thinner aluminum walls, are located in the outer LH₂ tank and vacuum tank walls.

The LH₂ tank “window” leans up against the beryllium. The beryllium “bridges” the LH₂ pressure load on the thin LH₂ tank “window” to the upper and lower portions of the LH₂ tank.

Curvature of the outer vacuum tank wall helps to support possible vacuum pressure on its window. The normal operating condition has vacuum on both sides of this window. Integral aluminum chill plates shrink more than beryllium upon cool down. A design gap at room temperature between beryllium and LH₂ tank at room temperature reduces stress in tabs during cool down.

Steel fasteners, flat washers, and Belleville washers are employed to achieve sufficient clamping pressure to ensure heat transfer, while not yielding the aluminum chill plates due to the differential thermal shrinkage between steel fasteners and aluminum chill plates.

VI. IMPROVED UPPER LH MODERATOR – RESTRICTED USE OF MACOR

A design change significantly improved the performance of the upper LH moderator. The existing MK I and II designs employed MACOR as a thermal isolator at the bottom of the LH₂ tank. This sheet covered the entire bottom of the pressure vessel. It was found that boron oxide in very small quality in the MACOR can significantly reduce neutronic performance. The design of the MK I/II was revised to minimize the use of MACOR. Just as for the MK I/II design, the LH pressure vessel has an integral cylindrical radial support at its bottom. For the MK III design the pressure vessel’s support fits into a matching cylinder in the bottom of the vacuum vessel.
Between these is a MACOR ring. The pressure vessel sits on a set of four MACOR posts. This arrangement was employed on both the upper and lower LH moderators.

VII. REDESIGNED LOWER WATER MODERATORS – CENTRAL WEBS CONTAINING GADOLINIUM

The MK I/II featured a single lower tier water moderator that employed a central web containing gadolinium placed such that prescribed thicknesses of water was located on either side of the web. It also had a layer of gadolinium in one of the faces of the tank. This layer was removed for the MK III.

The other two lower tier water moderators were redesigned so that they also have central webs containing gadolinium with prescribed thicknesses of water on each side. All of the lower water moderators have their exterior cadmium plated leaving a “window” in the cadmium where the neutrons pass through the water moderators into the ports.

VIII. PORT LINERS

The lower tier has three port liners. Each port liner is fabricated from aluminum and cadmium plated on its interior surfaces. Each port liner is bolted to the lower heatsink plate and subsequently filet welded along its two edges to promote thermal conduction.

IX. SUMMARY

The TMRS MK III design is based on the MK I/II design but has significant improvements. The most notable improvement is the design of the lower LH moderator design that doubles the cold neutron flux at the same particle beam parameters. Key design features are critical to obtaining the design performance.

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