S03040000-DES10000-R00

SECOND TARGET STATION (STS) PROJECT

Moderator Reflector Assembly Design Description

Jim Janney

3/18/2024

OAK RIDGE NATIONAL LABORATORY
MANAGED BY UT-BATTELLE FOR THE US DEPARTMENT OF ENERGY

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1. PURPOSE

This document describes the preliminary design of the Second Target Station (STS) Moderator Reflector Assembly (MRA). The requirement decomposition from Target Systems level to the MRA is described. The MRA design is described, along with how it meets its requirements. Requirements verification, and specifically requirements which have yet to be evaluated or are not met by the preliminary design, is discussed. Finally, plans for meeting these unverified requirements during final design are outlined.

2. REQUIREMENTS DECOMPOSITION

The following Target Systems Requirements[1] decompose to the MRA Requirements [2]. Most of the requirements decompose in a straightforward way; however, the following sections offer additional explanation where warranted.

Table 2.1. Relevant Target Systems Requirements to the Moderator Reflector Assembly Requirements.

[S03-1028] R01	The Target Systems shall accept a pulsed proton beam of 700 kW, 1.3 GeV, 15 Hz from Accelerator Systems.
[S.03-1029] R02	The Target Systems shall convert the proton beam pulses into cold neutron pulses using high-brightness moderators that will meet or exceed the peak brightness of $2x10^{14}n/cm^2/sr/Å/s$ at the neutron wavelength 5Å.
[S.03-1030] R03	The Target Systems shall distribute neutrons to 22 beamlines.
[S.03-1031] R04	The Target Systems design shall consider instrument background.
[S.03-1032] R05	The Target Systems design shall allow for a lifetime of forty years of operation. *Note: Components of the Target Systems that are not expected to be operational for the specified lifetime must be identified by the design.*
[S.03-1033] R06	The Target Systems design shall allow for greater than five thousand hours of proton beam on target per year with accommodation for maintenance intervals in accordance with the STS operating schedule.
[S.03-1034] R07	The Target Systems design shall allow for greater than 95% availability.
[S.03-1035] R08	The Target Systems design shall allow safe operation.
[S.03-1036] R09	The Target Systems design shall prevent release of contamination and limit exposure ALARA in accordance with the STS Radiation Safety Policy and Plan.
[S.03-1037] R10	The Target Systems design shall include a replacement scheme and disposal path for all perishable components.
[S.03-1041] R14	The Target Systems shall provide the means to measure proton beam position and profile delivered by the Accelerator Systems.
[S.03-1042] R15	The Target Systems design shall provide for monitoring and operation and will accommodate timing triggers provided via the SNS control system.

The MRA also has interfaces with other STS systems, both inside and outside of Target Systems, which also decompose to requirements. These interfaces are documented in interface sheets for the MRA-Instrument Systems Interface [3], MRA-CMS Interface [4], MRA-Process Systems Interface [5], MRA-MRA Instrumentation and Controls [6] and Target Assembly-MRA-Vessel Systems Interface [7].

2.1 MRA PIPE CUTTING REQUIREMENT

Table 2.1.1. MRA Pipe Cutting Requirement

MRA Pipe Cutting Requirement	The MRA piping shall be designed for cutting above the upper shield block with a hydraulic shear.	[S.03.04-2329] - MRA Remote Handling Requirement	2331

The MRA must be designed for cutting of its upper piping so that it can fit into a reasonable handling cask for transport to the service cell. This requires that the piping arrangement should be feasible for cutting and that the radiological conditions in the target drive room are acceptable for performing the cutting operation.

2.2 MRA REMOVAL AND INSTALLATION REQUIREMENTS

Table 2.2.1. MRA Removal and Installation Requirements

MRA Removal Requirement	The MRA shall be capable of vertical removal from core vessel after the removal of 3 target segments.	[S.03.04-2329] - MRA Remote Handling Requirement	3589
MRA Installation Requirement	The MRA shall be capable of vertical installation after the removal of 3 target segments.	[S.03.04-2329] - MRA Remote Handling Requirement	3590

The MRA removal and installation are planned after removal of 3 target segments and subsequent rotation of the segment void to the MRA location. The MRA must fit though the segment void, as well as the core vessel shielding and lid above.

2.3 MRA LIFETIME REQUIREMENT

Table 2.3.1. MRA Lifetime Requirement

MRA Lifetime Requirement	The MRA design shall allow for a lifetime of at least 5 years of operation.	[S.03-1032] - Operational Life	2337

The MRA has been identified as a component which will require replacement to meet the target systems 40 year lifetime. The MRA lifetime must be at least 5 years in order to allow for the required longer maintenance outages for replacement.

2.4 MRA REPLACEMENT REQUIREMENT

Table 2.4.1. MRA Replacement Requirement

MRA Replacement Requirement	The MRA shall be designed to be replaced in a 3 month maintenance outage.	[S.03.04-2344] - MRA Availability Requirement	2347

The MRA replacement outages are longer than the standard 1 month STS maintenance outages defined within the target systems requirements. This is acceptable due to the long interval between expected replacements.

2.5 MRA-INSTRUMENT SYSTEMS INTERFACE DERIVED REQUIREMENTS

Table 2.5.1. MRA-Instrument Systems Interface Derived Requirements

MRA-Instrument Systems Interface Sheet	Requirements derived from the MRA-Instrument Systems Interface Sheet, S01020500-IS0023.	[S.03-1029] - Peak Brightness,[S.03-1030] - Number of Beamlines,[S.03-1031] - Consider Background Effects	2885
MRA Neutron Beam Requirement	The MRA shall deliver 18 neutron beams with the characteristics and locations described in S01020500-IS0023. The peak brightness of all neutron beams shall be greater than 2x10^14n/cm^2/sr/Å/s at the neutron wavelength 5Å.	[S.03.04-2885] - MRA-Instrument Systems Interface Sheet	2887
MRA Moderator Hydrogen Density Requirement	The hydrogen in both moderators shall have a minimum average density of 72.0 kg/m^3.	[S.03.04-2887] - MRA Neutron Beam Requirement	2888
MRA Moderator Hydrogen Maximum Temperature Requirement	The hydrogen temperature shall at no point in the moderators exceed 32 K.	[S.03.04-2887] - MRA Neutron Beam Requirement	2889
MRA Moderator Alignment Requirement	The MRA shall position the moderator viewed faces within +/- 1 mm of their ideal locations during installation.	[S.03.04-2887] - MRA Neutron Beam Requirement	2323
MRA Moderator Operational Displacement Requirement	The MRA moderators shall have a displacement of 0.3 mm or less relative to the MRA mounting points from installation to 700 kW operation.	[S.03.04-2887] - MRA Neutron Beam Requirement	2892

Note – Indented requirements with grey backgrounds are derived from the above white requirement

The MRA-Instrument Systems Interface Sheet [3] decomposes 3 target systems requirements, peak brightness, number of beamlines, and consider background effects. Furthermore, the interface sheet is an agreement with instrument systems that the neutron beams described in the interface sheet are desirable for meeting instrument performance requirements, as well as the STS project Key Performance Parameters. Therefore, the MRA geometry that produces the desired neutron beams is the basis for MRA design. Additional requirements on hydrogen state in the moderators and moderator location tolerances are decomposed to ensure that neutron performance is not significantly degraded by the engineering of the MRA. Note – these additional decomposed requirements are not a part of the interface sheet but are decomposed within the MRA to provide the required neutronic performance.

2.6 MRA SAFE OPERATION

Table 2.6.1. MRA Safe Operation Related Requirements

MRA Hydrogen Transfer Line Requirement	The MRA hydrogen transfer lines shall be designed and fabricated to ASME B31.12	[S.03.04-2348] - MRA Leak Rate Requirement	2349
MRA Hydrogen Vessel Requirement	The MRA hydrogen vessels shall be designed to the intent of the ASME BPVC	[S.03.04-2348] - MRA Leak Rate Requirement	2354
MRA Vacuum Vessel Requirement	The MRA vacuum vessels shall be designed to the intent of the ASME BPVC	[S.03.04-2348] - MRA Leak Rate Requirement	2893
MRA Hydrogen Boundary Pressure Requirement	The MRA hydrogen boundary MAWP shall be 19 bara.	[S.03.04-2320] - MRA-CMS Interface Requirements	2357
MRA Vacuum Boundary Pressure Requirement	The MRA vacuum boundary MAWP shall be 2 bara.	[S.03.04-2320] - MRA-CMS Interface Requirements	2358
MRA Vacuum Venting Requirement	The MRA vacuum space shall be designed to support venting of hydrogen leaks without exceeding the MAWP.	[S.03.04-2320] - MRA-CMS Interface Requirements	3591
MRA Hydrogen Venting Requirement	The MRA hydrogen lines shall be designed to support venting of hydrogen after loss of transfer line vacuum without exceeding the MAWP.	[S.03.04-2320] - MRA-CMS Interface Requirements	3592
MRA-Target Assembly-Core Vessel Interface Requirements	Requirements derived from the MRA-Target Assembly-Core Vessel Interface Sheet, S01020500-IST10205	[S.03-1035] - Safe Operation,[S.03-1034] - Availability	2373
MRA Boundary Requirement	The MRA nominal boundary shall match the boundary defined in the MRA-Target Assembly-Core Vessel Interface Sheet	[S.03.04-2373] - MRA-Target Assembly-Core Vessel Requirements	2374
MRA Profile Tolerance Requirement	The MRA shall have an overall profile tolerance of +/- 1mm to the ideal boundary after installation.	[S.03.04-2373] - MRA-Target Assembly-Core Vessel Requirements	2995
MRA Deflections Requirement	The MRA outside surfaces shall not deflect more than +/- 1mm from their installed locations under any expected loading conditions.	[S.03.04-2373] - MRA-Target Assembly-Core Vessel Requirements	2994
MRA Seismic Requirement	The MRA shall be capable of withstanding the loads outlined in ASCE 7 within the limits defined by the ASME BPVC, ASME B31.12, and ASME B31.3	[S.03-1035] - Safe Operation	2894

The MRA must meet the requirements imposed by the Preliminary Hazard Analysis Report (PHAR) [8] for safe operation of the STS facility. Note, many of these requirements are decomposed from other Target Systems requirements, in addition to the Safe Operations requirements. The requirements for the MRA from the PHAR, listed above, all relate to preventing release of hydrogen by designing pressure boundaries to ASME BPVC and ASME B31.12 for all expected loading scenarios, including seismic. Note that the MRA-CMS Interface Sheet [3] transfers the scope for performing B31.12 piping analysis and all venting analyses to the Cryogenic Moderator System, where the majority of the hydrogen piping resides.

The PHAR also includes a requirement that seismic loads on surrounding components shall not cause interaction with the hydrogen boundary that would cause a release of hydrogen. Rather than attempt to define uncertain interactions, target systems will prevent contact between the MRA and surrounding structures as described in [7]. This requirement decomposes to the MRA as a nominal boundary and an allowable deviation from the boundary under all loading scenarios.

Finally, it should be noted that the seismic load guidance for target systems components is still under development, and as such, no seismic analysis has occurred for the MRA. Given the low masses of the hydrogen containing components, these criteria are not expected to impact their designs; however, the MRA as a whole is quite top heavy and bracing against the Vessel Systems shielding is anticipated to be required to prevent rolling of the MRA and subsequent undesirable loading of the hydrogen transfer line.

3. MRA DESIGN

3.1 OVERVIEW

In the STS design, a pulsed proton beam is converted to pulsed high brightness cold neutron beams optimized for neutron scattering experiments. The Target Systems group is responsible for designing a Target Assembly to produce neutrons from the pulsed proton beam and a Moderator Reflector Assembly to convert the neutrons emitted from the target to cold neutron beams useful for neutron scattering experiments on the instruments designed by Instrument Systems group.

During conceptual design [9], a rotating solid tungsten target was chosen as the target concept for the STS. In order to produce the required neutron performance, two compact liquid hydrogen moderators are located adjacent to the target: a cylinder directly above and a triangular arrangement of three tubes directly below, as shown in Figure 3.1.1 and drawing [10]. The moderators are surrounded by light water premoderators and beryllium reflectors within the reflector vessels in order to improve neutron performance. The geometry of the rotating target requires the reflector vessels be supported on the upstream end, relative to the proton beam. This C-shaped support structure, called the backbone, must have a proton beam port large enough to allow the proton beam to pass through to the target without significant interaction. The upper side of the proton beam port is also enlarged to allow the Target Viewing Periscope (TVP) a full view of the proton beam incident on the target face. The backbone is just wide enough to allow utilities (hydrogen and water) for the lower moderator and reflector vessel to pass on either side of the proton beam port. A backbone shield has been added above the reflector support portion of the backbone, extending 1 m above the proton beam centerline, in order to consolidate all water cooled shielding above the reflector vessels into the MRA. In order to provide precise location of the moderators, the backbone is supported by kinematic mounts and is precisely cooled in order to limit thermal displacement of the moderators.

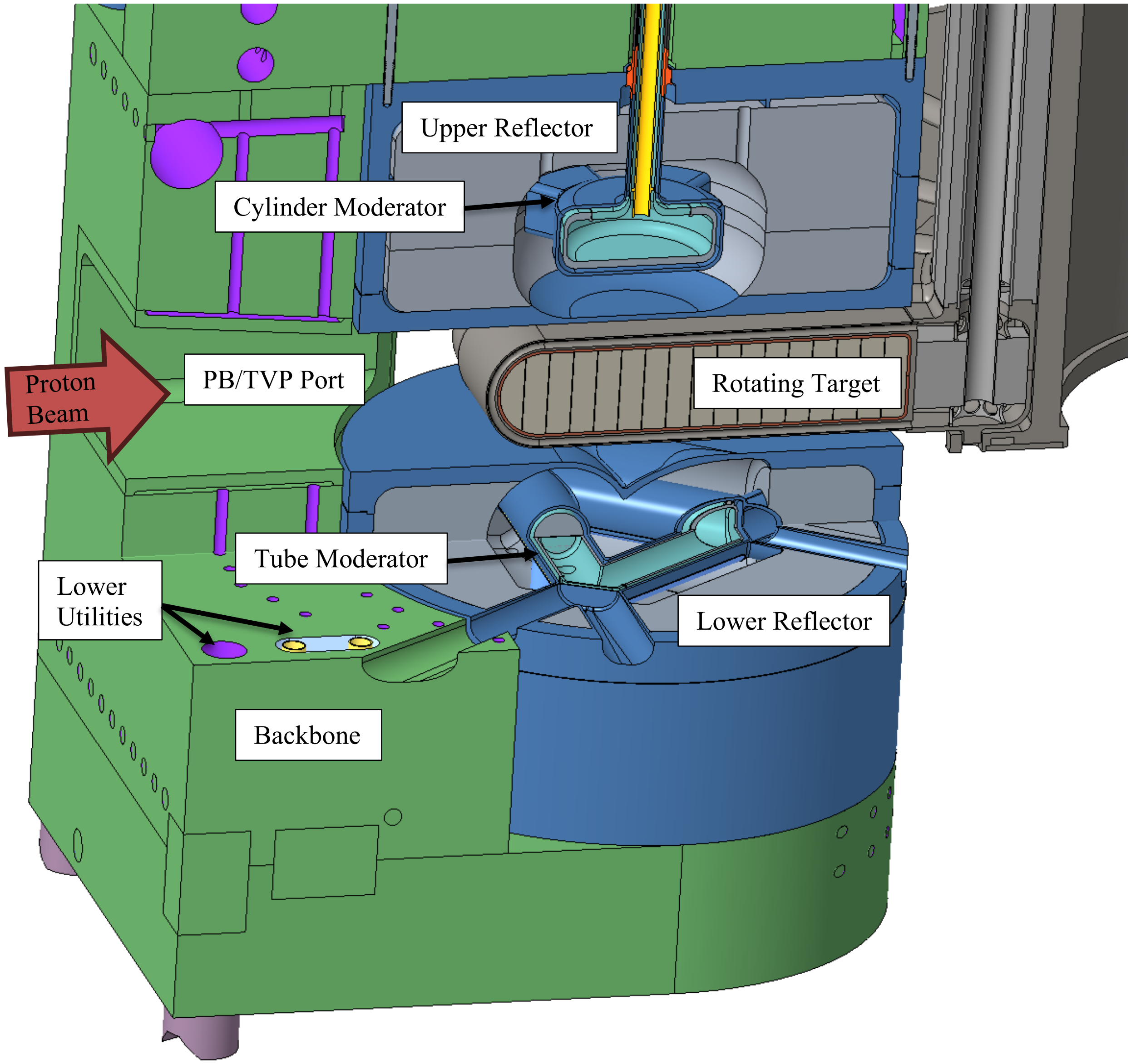

Figure 3.1.1. Moderator Reflector Assembly and Target Assembly Layout.

The number of moderators, number of beamlines, and angular orientation of the beamlines to be included in the STS design have been determined during the conceptual design phase of the project [9] while the characteristics of those neutron beams such as the size of the viewed area of the moderator [11], the maximum acceptance aperture of the guide entrance, the distance of the guide entrance from the viewed face of the moderator, and the desired neutron beam characteristics have been determined by the Instrument Systems group in collaboration with the Target Systems group during early preliminary design. Note that in 2023, the STS project reduced the number of beamlines from 22 to 18 to give each instrument a larger angular segment for equipment and to reduce project cost. This change has been documented in the latest MRA-Instrument Systems Interface Sheet [3] but will not be incorporated into the MRA design until final design.

During conceptual design, the MRA was simplified to ease manufacturing difficulty while still maintaining the desired cryogenic hydrogen vessel, vacuum vessel, light water premoderator and beryllium reflector topologies. The helium layer which existed around the SNS first target station moderators was eliminated to ease manufacturing and increase neutronic performance, resulting in the vacuum vessels being integrated into the reflector vessels, and was justified in [12]. The premoderator vessels were eliminated as the beryllium could be used to define the premoderator boundary while the light water premoderator was used to remove heat from the beryllium. This elimination removed the option of using heavy water as a coolant for the reflector and instead light water will be used; however, because of the relatively low power of STS and the compact size of the reflectors, cooling can be accomplished from the premoderator zone and the outer surfaces of the reflector which minimizes the neutronic performance penalty from light water reflector cooling. The described topology was analyzed with varying hydrogen and beryllium sizes to create curves for hydrogen vessel, vacuum vessel, and reflector vessel wall thicknesses as described in [13]. These wall thickness curves were then used in the MRA neutronics optimization to add feedback from engineering reality to the neutronics optimization.

3.2 MRA NEUTRONICS OPTIMIZATION

Early in preliminary design, the Neutronics Team completed a moderator optimization which determined optimal MRA configurations for peak brightness, time-average brightness, and a middle configuration between the two for each moderator, as shown in Tables 3.2.1 and 3.2.2 [14]. Source files for all configurations for both moderators were supplied to the Instrument Systems group for further evaluation. After detailed analysis on representative instruments, the Instrument Systems group decided that the middle configuration resulted in the best instrument performance for both the upper, cylinder moderator and lower, tube moderator [15].

Table 3.2.1: Preliminary Cylinder Moderator Optimal Parameters

Optimized for	Para-H Radius (mm)	Lower Premod. (mm)	Radial Premod. (mm)	Top Premod. (mm)	Be Radius (mm)	Offset[1] (mm)
Peak	40	27.5	20	20	162.5	87
Mid	**50**	**30**	**29**	**29**	**172.5**	**87**
Tave	62	30	33	33	182.5	87

[1] Offset is the distance from the front edge of tungsten to the vertical axis of the cylindrical moderator.

Table 3.2.2: Preliminary Tube Moderator Optimal Parameters

Optimized for	Para-H Tube Diameter (mm)	Para-H Tube length[1] (mm)	Premod. Thickness (mm)	Be Radius (mm)	Offset[2] (mm)
Peak	30	125	25	182.5	87
Mid	**30**	**170**	**27.5**	**182.5**	**87**
Tave	30	210	27.5	182.5	87

[1] The length of the tube perpendicular to the proton beam

[2] Offset is the distance from the front edge of the tungsten to the point defined by the intersection of angular bisectors of the tube moderator.

3.3 PRELIMINARY ANALYSIS MODEL

The moderator middle configurations optimized by the neutronics team and chosen by the instrument systems team serve as the basis for the preliminary MRA design. The only adjustment to these basic parameters was to make both beryllium reflectors the same radius, 172.5 mm, due to the insensitivity of performance to beryllium radius and the high cost of beryllium. Additional details, such as the groove in the neutron extraction port to allow extraction of the QIKR neutron beams at angles offset from horizontal were added to the model. Even though the wall thickness curves used in the moderator optimization predicted the required wall thicknesses, these wall thicknesses were reoptimized for the preliminary configuration based on internal pressure loadings to create the Preliminary MRA Analysis Model [16].

The water cooling flow patterns for the MRA were also developed as part of the Preliminary MRA Analysis Model. Both beryllium reflectors and reflector vessels are cooled by light water in the premoderators and on the outside edges of the reflectors, except on the target side of the reflectors, which are fed by 2 water supplies per reflector vessel, as shown in Figure 3.3.1. The water in the reflector vessels joins together in both reflectors just before exiting into the backbone on the flat sides opposite the target. Note, in the preliminary reflector vessel analyses, the water from the premoderator and reflector cooling exits independently. This inconsistency will be corrected during final design. After exiting the reflector vessels, the water then travels through the backbone in arrays of long drilled holes from the downstream proton beam end of the upper and lower plates back towards the middle backbone, as shown in Figure 3.3.2. An independent backbone cooling line feeds water to the bottom of the middle backbone which then travels up through an array of holes, around the proton beam port, and then through an upper array of holes to the top of the middle backbone. The flow from the lower and middle backbone join into a return pipe at the top of the middle backbone. This pipe, along with all 5 MRA water supplies, are routed in chases and passages through the backbone shield block. The flow from the upper backbone continues into the backbone shield block, running in deep holes from top to bottom before exiting into a return pipe. All the water pipes jog into a chase where they are aligned in a row at the top of the backbone shield block. This row of water pipes takes one additional jog about halfway to the top of the core vessel shielding. Above the core vessel shielding the water lines are connected at flanges to flexible jumpers supplied by vessel systems which route water to and from Process Systems.

The transfer line routing patterns were also developed during preliminary design. Early in preliminary design, the CMS was envisioned as two independent hydrogen loops feeding the moderators independently. Maturing of the CMS design resulted to a switch to a single hydrogen loop with the moderators being supplied in series. Note, the preliminary hydrogen vessel thermal hydraulic analyses used boundary conditions for two independent hydrogen loops and will be updated to be consistent with current CMS design during final design. Therefore, the hydrogen now enters the MRA in a single transfer line from the CMS transfer line, as shown in Figure 3.3.3. Above the upper backbone plate, the hydrogen supply is routed to the upper moderator. The return from the upper moderator is an annular channel around the supply, which is broken off at a Y above the upper backbone plate. The return is then routed back towards and through the middle backbone to reach the lower moderator. The lower moderator return is then routed back to and through the middle backbone and back into the return of the transfer line. The transfer line makes only one jog, at the top of the backbone shield block, in order to ease fabrication difficulty. The hydrogen boundary is surrounded by an uninterrupted, all welded, vacuum boundary, which is connected to and supplied vacuum by the CMS transfer line vacuum space.

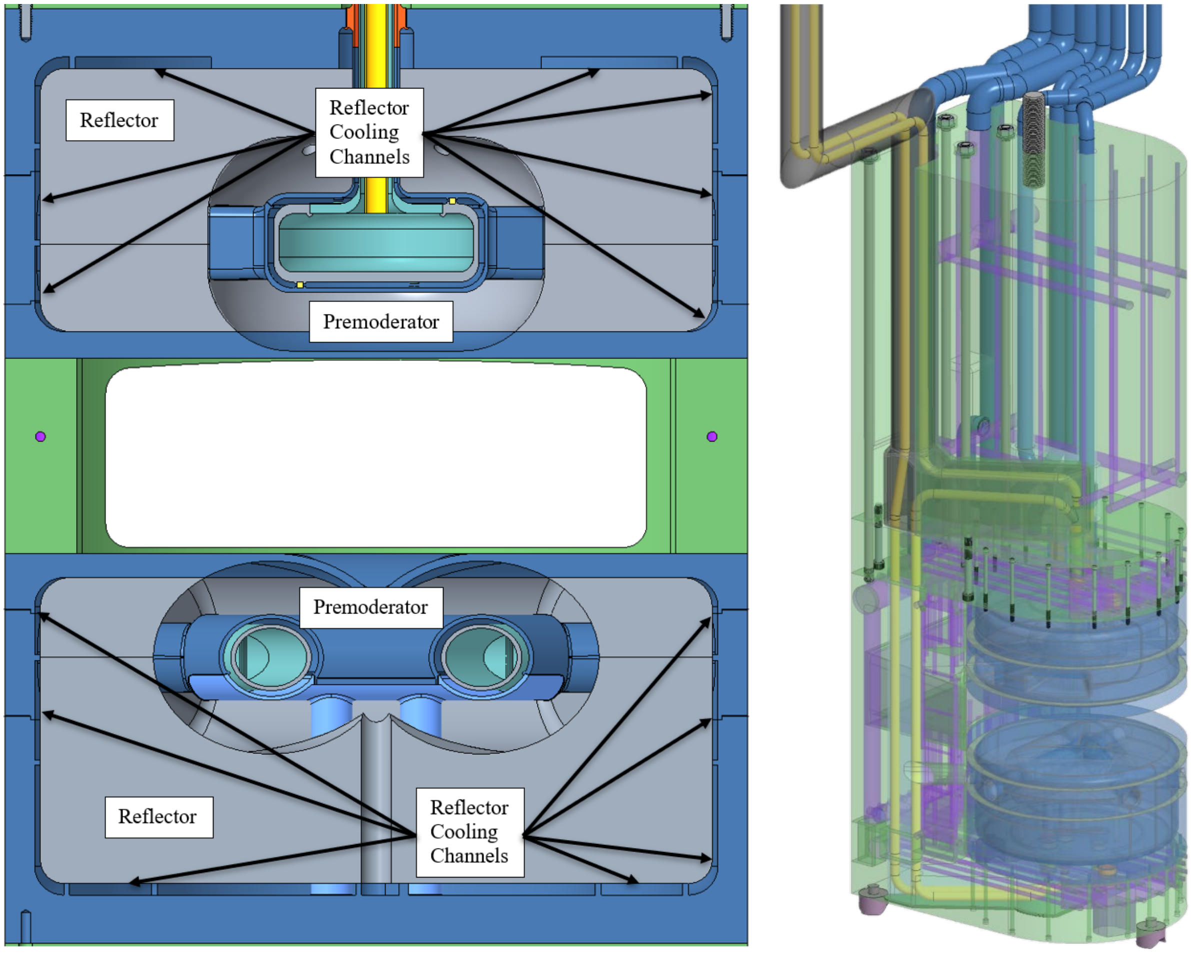

Figure 3.3.1 & 3.3.2. Reflector Vessel (left) and Backbone (right) Cooling Scheme.

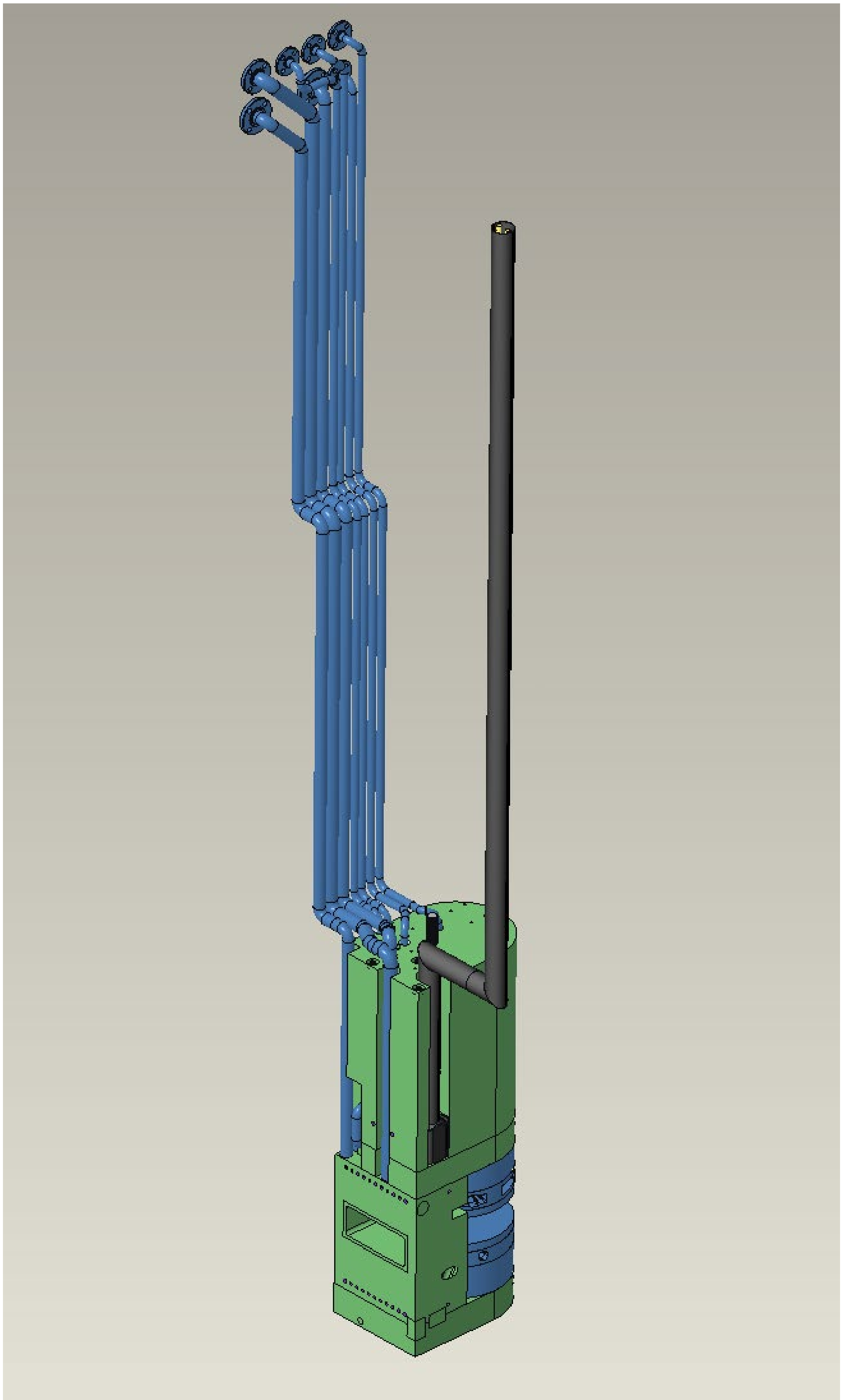

Figure 3.3.3. Preliminary MRA Utility Routing – chases around the upper utility lines are formed by the Vessel Systems shielding.

3.4 NEUTRONICS ANALYSIS

The first step to take with this analysis model was to confirm that the performance predicted by the optimization was not degraded by the additional engineering details. The neutronic analysis [17] of the preliminary analysis model confirmed no degradation of performance, and in fact showed a slight performance improvement due to additional optimization of wall thicknesses, as shown in Figures 3.4.1 and 3.4.2.

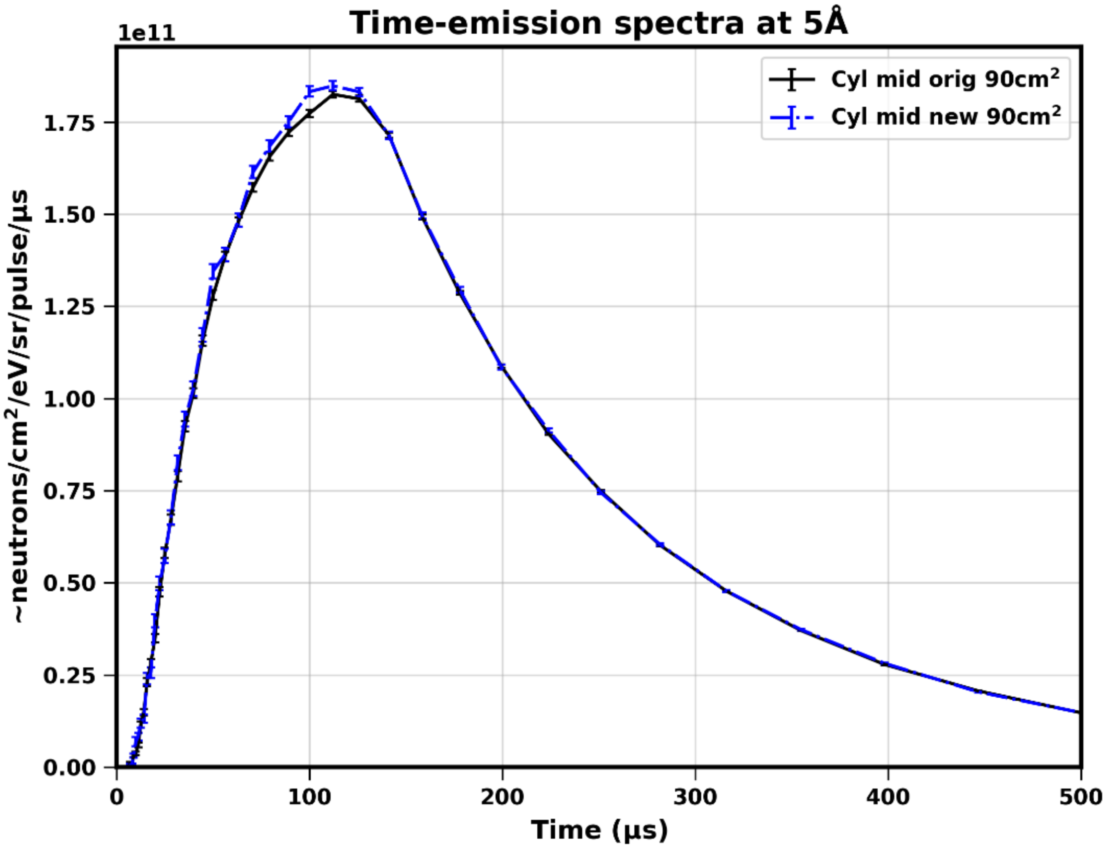

Figure 3.4.1: Time-emission Spectra Comparison between As Optimized (Cyl mid orig 90 cm^2) and Preliminary MRA Analysis Model (Cyl mid new 90cm^2) for the Cylinder Moderator

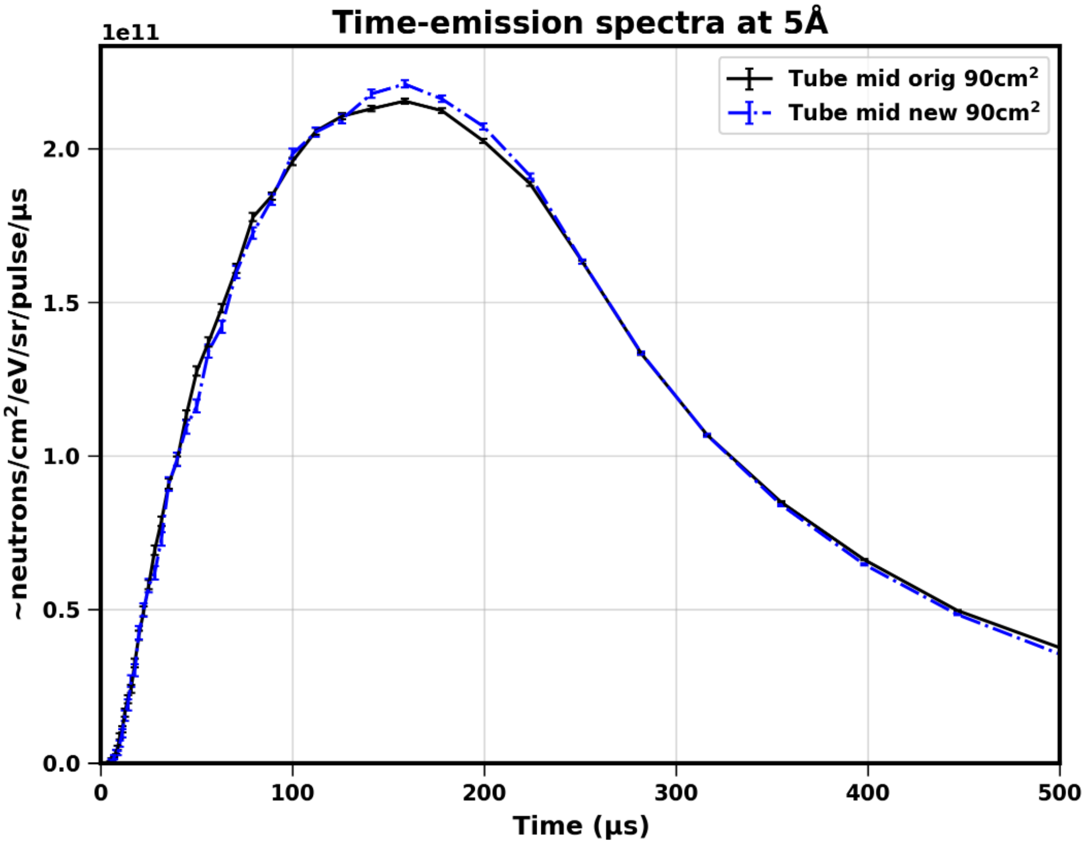

Figure 3.4.2: Time-emission Spectra Comparison between As Optimized (Tube mid orig 90 cm^2) and Preliminary MRA Analysis Model (Tube mid new 90cm^2) for the Tube Moderator

Once the neutronic performance was confirmed, the neutronics analysis continued to provide energy deposition data for the MRA. Detailed data was provided for the reflector vessel structures, while the backbone structures were modeled as a homogenized mix of 95% Stainless Steel and 5% water. This energy deposition data was used to provide the heat loads for the MRA interfaces with the CMS [4] and Process Systems [5]

3.5 THERMAL HYDRAULIC ANALYSIS

This data was also used as input for thermal hydraulic analyses for the hydrogen vessels [18], reflector vessels [19,21], and backbone [21]. An MRA preliminary thermal hydraulic summary [22] was created to integrate the analyses for informing relevant interfaces. The thermal hydraulic analyses provided verification of all temperature and pressure drop requirements. Additionally, hydrogen state requirements for density and temperature in the moderators were confirmed ensuring expected neutronic performance.

3.6 STRUCTURAL ANALYSIS

The temperature profiles from the thermal hydraulic analyses were used as input to structural analyses for the reflector vessel [23] and the backbone [24]. Note that because the coefficient of thermal expansion of aluminum is nearly 0 at 20K, no thermal stress analysis was performed for the hydrogen vessels, and their structural analysis only considered internal pressure [25,26]. Structural analysis of the reflector vessels and backbone also considered internal pressure. The internal pressures used for the structural analyses were the maximum allowable working pressures defined in the interfaces with CMS [4] and Process Systems [5] – 2 bar for vacuum boundaries, 19 bar for hydrogen boundaries, and 5 bar for water boundaries. These structural analyses demonstrated that the hydrogen, vacuum, and reflector vessels were designed to the intent of the ASME BPVC. Note, no cyclic loading was considered during preliminary design, but will be analyzed during final design. The structural analyses also provide verification that the moderator displacement limit was not exceeded [27]. The MRA boundary deflection limits were shown to be slightly exceeded in the reflector vessels adjacent to the target. This region will be improved during final design by thickening or dishing the plates in those regions.

3.7 ADDITIONAL NEUTRONICS ANALYSES

Additional neutronics analyses were performed to confirm other MRA requirements [17]. A material damage rate analysis was performed, revealing an expected MRA lifetime of 6.5 years, limited by dpa damage. A streaming analysis was performed for the preliminary target station shielding, revealing significant streaming from the MRA hydrogen transfer line chase but no problematic streaming from the MRA water piping chase. The MRA hydrogen transfer line routing will be reworked during final design to mitigate this streaming, but a small additional shield block may be required above the exit of the line from the shielding. An activation analysis was performed to determine the dose rates in the target drive room once the Vessel Systems MRA Shield Blocks are removed to allow access to the MRA after 6 years of operation. The dose rates in the target drive room were evaluated to be too high to allow the planned activities for MRA removal; however, adding an additional 600 mm of shielding above the preliminary MRA backbone shield was shown to lower the dose rates to acceptable levels. This shielding will be added to the MRA design during final design. Finally, the MRA radionuclide inventory was determined after 10 years of operation and 1250 hours of cooldown time [28] in order to support preliminary MRA Waste Classification.

3.8 MRA DISPOSAL

The MRA radionuclide inventory after operation was evaluated against waste classification guidelines in order to predict the MRA classification at end of life [29]. The predicted MRA nuclide inventory was determined to meet the classification requirements for Class C waste, indicating that the activated MRA would have a feasible disposal path. The activated MRA was not evaluated against radiological requirements for shipment in the TN-RAM shipping cask; however, this analysis will be performed during final design. The MRA design was confirmed to meet the size and weight limits for the TN-RAM cask.

3.9 INSTALLATION

The installation of the MRA is straightforward other than the final preparation of the initial assembly to meet alignment requirements based on the as installed mounting interface which is described in the MRA Installation Plan [30].

3.10 REMOTE HANDLING

The MRA was designed to allow for remote handling and replacement following operation. A Ziplift stud was included over the center of gravity of the MRA with its piping fully intact to allow for remote installation and replacement. The MRA piping was designed to allow for cutting above the upper shield block with a hydraulic shear, as seen in [30]. The pipes were spaced to allow access as they run across the backbone shield, although the pipes must be cut sequentially to allow access. Neutronics analysis indicated that dose rates for performing this operation are too high with the current MRA backbone shield, so 600 mm of additional shielding will be added during final design to reduce dose rates. The water pipes must be capable of blowdown prior to cutting the piping, which has yet to be evaluated. Finally the MRA allows for vertical removal and installation after the removal of 3 target segments. The void in the target must be rotated under the MRA to prepare for removal. The MRA water piping and hydrogen transfer line have been designed to fit through the MRA access port in the Core Vessel Lid. The estimated time for replacement of an MRA is less than 3 months, including the removal and replacement of the target segments that allow for MRA removal.

3.11 AVAILABILITY

The MRA was designed for high availability. Because of the radiological conditions after operation, any maintenance below the top of the core vessel shielding is not possible. Therefore, the MRA will be designed to require no maintenance (no moving parts, no seals requiring replacement) and instead use all welded connections (including friction welds or explosion bonds for dissimilar metals) on all pressure boundaries.

3.12 MANUFACTURABILITY

While not an explicit requirement of the MRA, manufacturability was a key goal of the preliminary design. Similar components at other neutron scattering facilities are extremely complex, risky, and expensive to fabricate, so every opportunity to simplify the MRA was taken. The MRA Fabrication Plan details all the steps necessary to fabricate an MRA [32]. In general, the following goals were used to guide improved manufacturability – reduce the number of pressure boundaries, reduce the number and complexity of welds, especially in aluminum, and reduce risky steps which offer limited recovery from options.

The most complex manufacturing involved in the MRA fabrication is the moderator fabrication. In order to reduce risk around moderator fabrication, prototypes of both the cylinder and tube moderator were manufactured. Both prototypes were successful in proving the planned moderator manufacturing strategy [33,34] and in demonstrating the tolerances used in the Moderator Deflection and Tolerance Analysis [27].

4. REQUIREMENTS VERIFICATION

The MRA Requirements Verification Plan [35] summarizes the status of requirements verification at the end of preliminary design, as well as verifications planned during final design. Throughout the above text, requirements which have yet to be verified or were not met by the preliminary design were noted. These outstanding requirements are listed in table 4.1, with yellow indicating not verified and red indicating requirement was not met.

Table 4.1. MRA Outstanding Requirements at the Preliminary Design Review.

Requirement		**Verification**	
Summary	**Description**	**PDR**	**FDR**
MRA Remote Handling Requirement	The MRA design shall include features to allow for remote handling and replacement	Derived Requirement Verification	Derived Requirement Verification
MRA Pipe Cutting Requirement	The MRA piping shall be designed for cutting above the upper shield block with a hydraulic shear.	MRA Remote Handling Document	MRA Remote Handling Document
MRA Blowdown Requirement	The MRA shall be capable of blowdown of water passages such that the subsequent water level is below the upper shield block.		MRA Blowdown Analysis
MRA Disposal Requirement	The MRA shall be capable of shipping to and disposal at a waste facility at the end of life.	Derived Requirement Verification	Derived Requirement Verification
MRA Shipping Requirement	The MRA shall meet the radiological requirements for shipping in the TN-RAM cask after operation and decay time of 1 year or less.		Neutronics Analysis
MRA Lifetime Requirement	The MRA design shall allow for a lifetime of at least 5 years of operation.	Derived Requirement Verification	Derived Requirement Verification
MRA Cyclic Loading Requirement	The MRA shall be designed for a lifetime of 5 years (25000 hours of 700 kW beam power operation) or more with respect to cyclic loading.		Neutronics, Thermal Hydraulic, and Structural Analysis
MRA Leak Rate Requirement	The MRA shall maintain leak rates less than what would cause degradation of the core vessel environment or the insulating vacuum surrounding the hydrogen boundary.	Derived Requirement Verification	Derived Requirement Verification
MRA Hydrogen Transfer Line Requirement	The MRA hydrogen transfer lines shall be designed and fabricated to ASME B31.12		Piping Analysis
MRA Water Piping Requirement	The MRA water piping shall be designed and fabricated to ASME B31.3		Piping Analysis
MRA-CMS Interface Requirements	Requirements derived from the MRA-CMS Interface Sheet, S01020500-IST10148	Derived Requirement Verification	Derived Requirement Verification

MRA Vacuum Venting Requirement	The MRA vacuum space shall be designed to support venting of hydrogen leaks without exceeding the MAWP.		Venting Analysis
MRA Hydrogen Venting Requirement	The MRA hydrogen lines shall be designed to support venting of hydrogen after loss of transfer line vacuum without exceeding the MAWP.		Venting Analysis
MRA-Target Assembly-Core Vessel Interface Requirements	Requirements derived from the MRA-Target Assembly-Core Vessel Interface Sheet, S01020500-IST10205	Derived Requirement Verification	Derived Requirement Verification
MRA Deflections Requirement	The MRA outside surfaces shall not deflect more than +/- 1mm from their installed locations under any expected loading conditions.	Structural Analysis	Structural Analysis
MRA Seismic Requirement	The MRA shall be capable of withstanding the loads outlined in ASCE 7 within the limits defined by the ASME BPVC, ASME B31.12, and ASME B31.3		Structural & Piping Analysis

5. FINAL DESIGN

The final design phase presents an opportunity to meet all currently unverified requirements as well as improve the neutronic performance of the MRA. A Target Assembly-MRA-Proton Beam simultaneous optimization is underway which will provide guidance for an additional iteration of MRA design. Both reflector vessels are planned to be redesigned based on this final optimization and the recent update to the MRA-Instrument Systems Interface Sheet. The MRA design will also continue to be updated based on design changes in the adjacent structures and shielding. For example, the Cryogenic Moderator Systems location has been moved to the opposite side of the building, so the MRA water and hydrogen transfer lines must be mirrored during final design to reflect this design change. All analyses performed during preliminary design will be updated during final design, providing opportunity to correct inconsistencies between preliminary analysis and design such as the exits from the reflector vessels and the boundary conditions for the moderator hydrogen supply.

The MRA final design has a straightforward path to meeting requirements which were not met at preliminary design. The shielding on top of the MRA will be increased to reduce dose rates during pipe cutting after operation. The hydrogen transfer line routing will be modified to reduce streaming and additional shielding will be added above the transfer line exit from the core vessel shielding if required. The target facing flat sides of the reflector vessels will be dished so that internal pressure loading does not cause them to violate their boundary requirements.

Additional analyses are also planned to verify requirements which were not verified at the end of preliminary design. Many of these analyses will be performed within the Cryogenic Moderator System design including certification of the hydrogen transfer line design to B31.12 and venting analyses of hydrogen through the hydrogen transfer line and insulating vacuum space, as agreed to in [3]. Other outstanding analyses include additional waste characterization analysis, water blowdown analysis, addition of cyclic loading to structural analyses, water piping analysis, and seismic analysis. The results of these analyses are not expected to alter the design of the MRA.

6. CONCLUSIONS

The preliminary design of the Moderator Reflector Assembly has been presented. Requirements and their decomposition from Target Systems requirements have been discussed. The preliminary MRA design has been shown to meet most of the MRA requirements, and requirements which are not met or not verified have been clearly identified. Plans for the final design have been outlined and simple paths for meeting outstanding requirements have been identified.

7. REFERENCES

Ref	Document Title	Document Number
[1]	System Requirements Document for Target Systems	S03000000-SR0001
[2]	System Requirements Document for Target Systems Moderator Reflector Assembly (MRA)	S03040000-SR0001
[3]	MRA-Instrument Systems Interface Sheet	S01020500-IS0023
[4]	MRA-CMS Interface Sheet	S01020500-IST10148
[5]	MRA-Process Systems Interface Sheet	S01020500-IST10186
[6]	MRA-MRA I&C Interface Sheet	S01020500-IST10126
[7]	Target Assembly-MRA-Vessel Systems Interface Sheet	S01020500-IST10205
[8]	Preliminary Hazard Analysis Report	S01030000-ES0002
[9]	Conceptual Design Report	S01010000-TR0001
[10]	MRA Drawing	S03040000-M8U-8800-A10000
[11]	The Suitability of Compact Neutron Moderators for the Initial Suite of STS Instruments	S04130200-DDD10000
[12]	Hydrogen Tertiary Inert Blanket Omission Report	S030400000-TRT10000
[13]	MRA Thickness vs. Size Curves	S03040000-TR0001
[14]	Preliminary Moderator Optimization Report	S030400000-TRT10001
[15]	Moderator Selection Report	To Be Released
[16]	Preliminary MRA CAD Models	S03040000-DDD10000
[17]	Preliminary MRA Neutronics Analysis	S030400000-TRT10002
[18]	Preliminary Moderator Thermal Hydraulics Analysis	S03040000-DAC10000
[19]	Preliminary Lower Reflector Thermal Hydraulic Analysis	S03040000-DAC10001
[20]	Preliminary Upper Reflector Thermal Hydraulic Analysis	S03040000-DAC10002
[21]	Preliminary Backbone Thermal Hydraulic Analysis	S03040000-DAC10003
[22]	Preliminary MRA Thermal Hydraulic Analysis Summary	S03040000-DAC10004
[23]	Preliminary Reflector Vessel Structural Analysis	S03040000-DAC10005
[24]	Preliminary Backbone Structural Analysis	S03040000-DAC10006
[25]	Preliminary Lower Hydrogen Vessel Structural Analysis	S03040000-DAC10007
[26]	Preliminary Upper Hydrogen Vessel Structural Analysis	S03040000-DAC10008
[27]	Preliminary Moderator Deflection and Tolerance Analysis	S03040000-DAC10009
[28]	Target Systems Bulk Activation Calculation	S03120100-TRT10005
[29]	Preliminary Radionuclide Characterization of Moderator Reflector Assembly	S03040000-ESH10000
[30]	MRA Installation Plan	S03040000-TDO10000
[31]	Preliminary MRA Remote Handling Document	S03100500-TDO10000
[32]	MRA Fabrication Plan	S03040000-MFP10000
[33]	Cylinder Moderator Prototype Manufacturing Report	S07030200-TRT10000
[34]	Tube Moderator Prototype Report	S07030200-TRT10007
[35]	MRA System Verification Plan	S03040000-SRD10000