S03040000-MFP10000-R00

SECOND TARGET STATION (STS) PROJECT

Fabrication Strategy for the Moderator Reflector Assembly

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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 fabrication strategy for the Moderator Reflector Assembly. The intent of this document is to show that the Moderator Reflector Assembly design is feasible for fabrication and that the fabrication process has been thoroughly thought through.

2. SCOPE

The scope of this document is the fabrication strategy of the Moderator Reflector Assembly from part machining through final assembly.

3. ACRONYMS AND DEFINITIONS

MRA	Moderator Reflector Assembly
SSC	Structure, System or Component
STS	Second Target Station

4. REFERENCES

4.1 DOCUMENTS APPLICABLE TO THE FABRICATION OF THE MRA

Ref	Document Titles	Document Number
[1]	Cylinder Moderator Prototype Manufacturing Report	S07030200-TRT10000
[2]	Tube Moderator Prototype Report	S07030200-TRT10007
[3]	Preliminary Lower Hydrogen Vessel Structural Analysis	S03040000-DAC10007
[4]	Preliminary Upper Hydrogen Vessel Structural Analysis	S03040000-DAC10008
[5]	Preliminary Reflector Vessel Structural Analysis	S03040000-DAC10005

5. MODERATOR FABRICATION

Moderator fabrication techniques were developed early in the preliminary design phase of the MRA and subsequently tested through the fabrication of moderator prototypes [1,2]. In general, the moderator designs emphasize reduction of welding and welding complexity, often at the expense of machining complexity. Note, in this report we will focus on the tube moderator and reflector geometry, as it is more complicated, but the assembly sequence is nearly the same for both.

The hydrogen vessel bodies are designed to include as much of the hydrogen vessel boundary as possible, as well as the locating features which interface to the vacuum spacers, while allowing access for machining of internal cavities. The hydrogen caps/lids make up the remainder of the hydrogen vessel to create the desired hydrogen geometry. The weld joints have been designed for electron beam welding and feature simple weld paths and constant weld thicknesses. The welds have also been located in low stress regions of the vessels and have been confirmed as acceptable by the structural analysis [3,4].

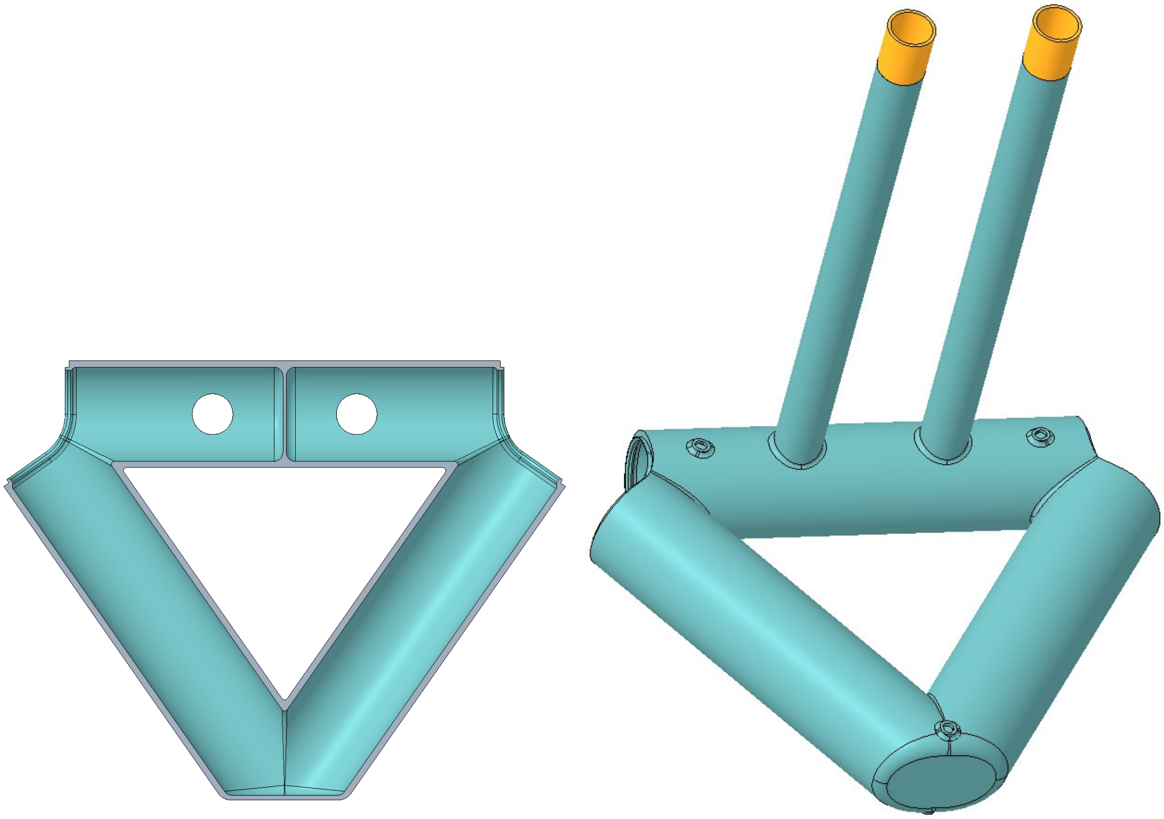

Figure 5.1. Tube Hydrogen Vessel Body machined after friction welding of Invar transition pieces to Al 6061-T6 Forging

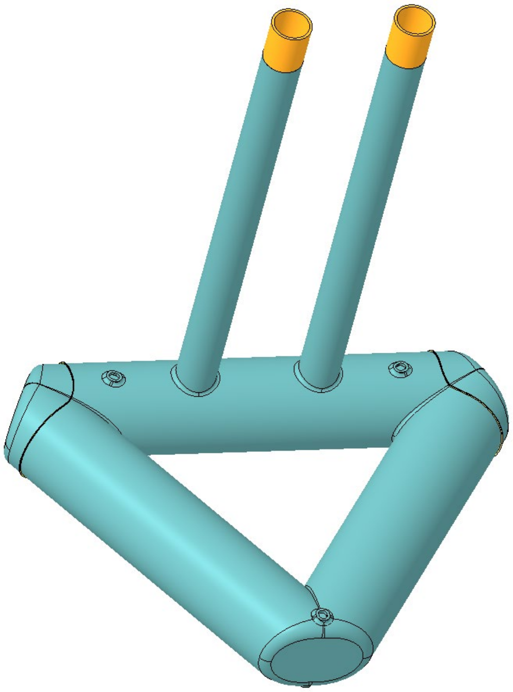

Figure 5.2. Tube Hydrogen Vessel Welded with 2 welds joining caps to body. Welds are designed to be electron beam welded in 2 passes. Each pass is a ½ rotational tube weld followed by a translation to join to the other ½ tube weld.

The vacuum vessels have been integrated into the reflector vessels for simplicity and, as a result, they are supported by the neutron beam extraction ports. To minimize welding, the vacuum vessel body, neutron extraction ports, and middle portion of the reflector vessel are all machined from a single aluminum forging. The openings in the vacuum vessel bodies are just large enough to allow the hydrogen vessels to fit through for installation. Again, the welds have also been located in low stress regions of the vessels and have been confirmed as acceptable by the structural analysis [5]. The weld joints have been designed for electron beam welding and feature as simple as possible weld paths, although the tube moderator vacuum vessel weld is the most challenging weld of the whole MRA.

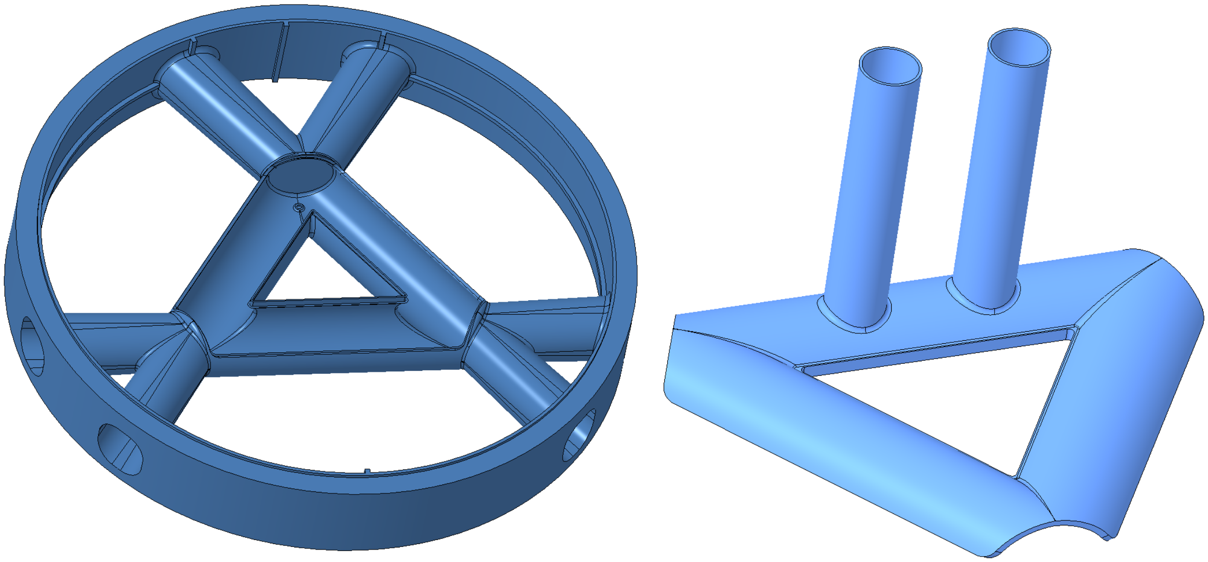

Figure 5.3. Tube Vacuum Vessel Body and cap machined from Al 6061-T6 forgings

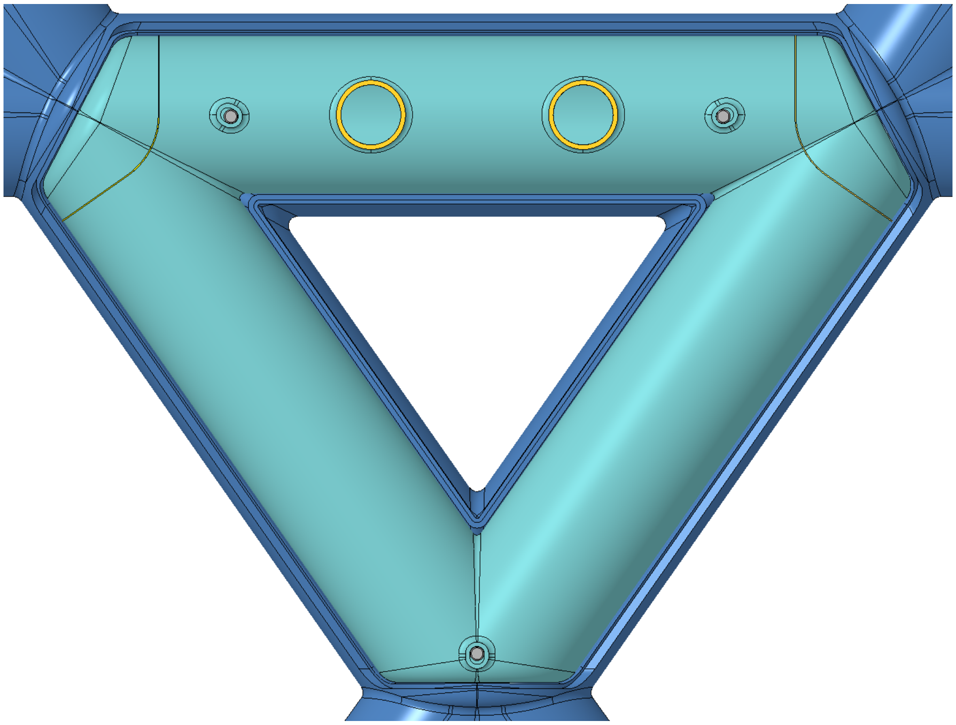

Figure 5.4. Tube Hydrogen Vessel Assembled into Tube Vacuum Body along with Vacuum Spacers. The opening in the Vacuum Body is designed to just allow the Hydrogen Vessel to pass through.

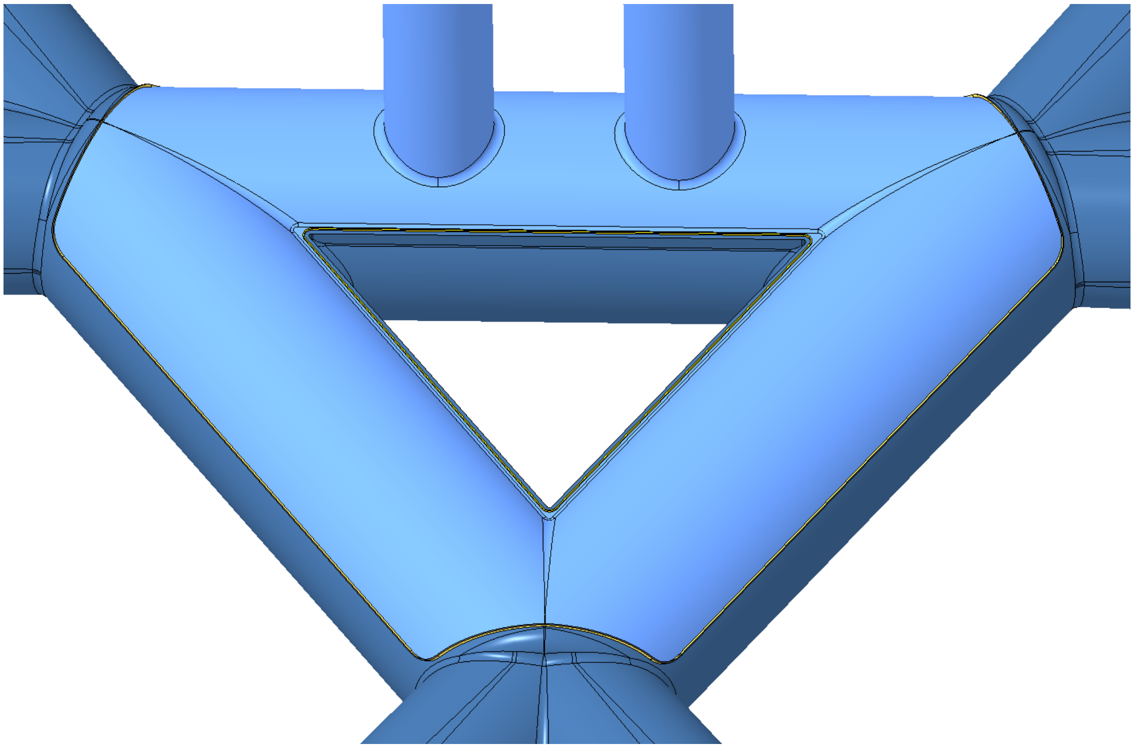

Figure 5.5. Tube Vacuum Cap welded to Tube Vacuum Body in 2 welds. The Inner weld is a simple straight down weld in a single plane. The Outer weld will be made in 6 passes. Each tube intersection will be welded by starting in the straight, but not perpindicular to the face. The weld will then translate around the corner before rotating around the tube intersection before translating back to the next straight. The straight sections will then be welded to join the tube intersection welds.

The moderator prototyping effort provided opportunity to troubleshoot the intended fabrication methods. Extreme care was taken with the electron beam welding preparation, including micro waterjet machining of all weld shims, pickling to clean and remove oxide and moisture from parts, and nitrogen bagging parts until insertion into the EB weld chamber. These techniques proved successful and no issues from weld contamination were experienced. The weld geometries from the cylinder moderator were very successful, largely due to the advantages inherent in the simple geometry, and will be maintained for the production MRA. The weld geometries for the tube moderator are more complicated and, although successful during prototyping, will be simplified for the production MRA. The updated weld paths introduce additional starts and stops in order to break the weld path into more segments; however, doing so allows the weld thickness and gun to part distance to remain nearly constant throughout the welds. The updated weld paths have been reviewed with a potential supplier and will be thoroughly developed early in the MRA fabrication.

6. BERYLLIUM FABRICATION

The beryllium fabrication is technically straightforward but complicated by the hazards associated with beryllium. Each beryllium reflector is split horizontally into two sections at the moderator centerline to allow for installation around the moderator vessel. The beryllium geometries are straightforward for machining with round outer diameters and features for defining the premoderator boundaries and clearing the neutron extraction ports. The beryllium parts further from the target also have holes for supplying and returning water to the premoderator zone.

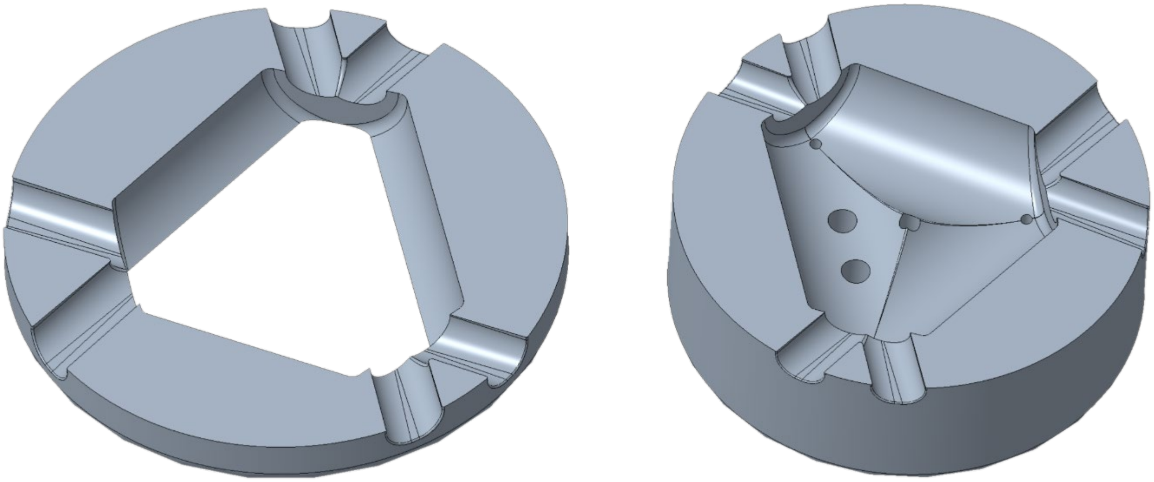

Figure 6.1. Inner and outer lower beryllium reflector sections.

7. REFLECTOR VESSEL PART MACHINING

The reflector vessels parts are simple aluminum parts that will be technically straightforward to machine. Additional small parts will be machined to form aluminum to stainless steel transitions, which will also be technically straightforward.

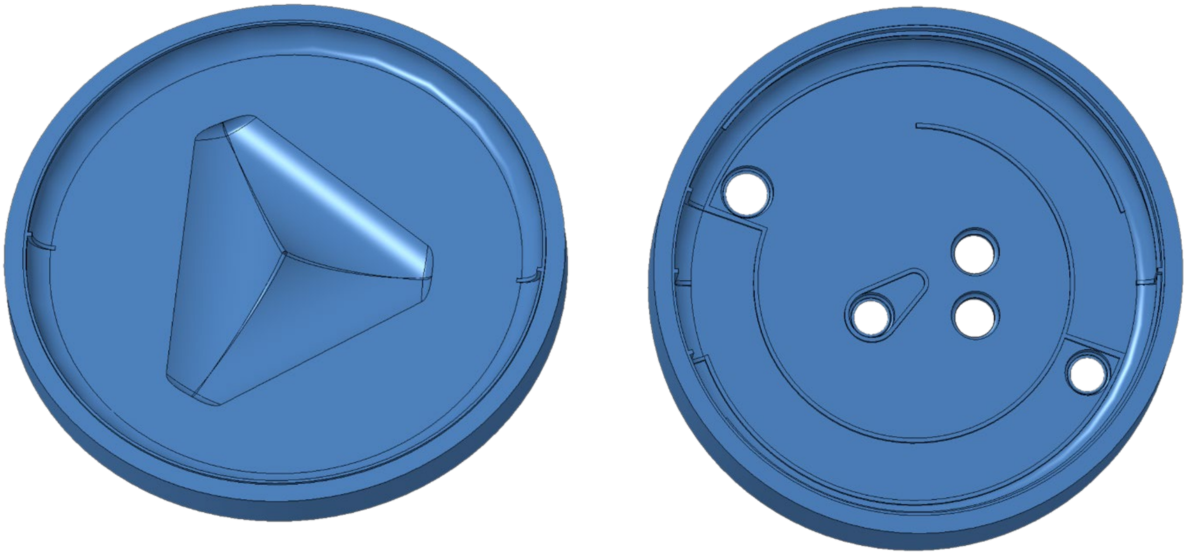

Figure 7.1. Inner and outer lower reflector vessel parts.

8. REFLECTOR VESSEL ASSEMBLY

The moderators, beryllium reflectors, and reflector vessel parts will be integrated to form the reflector vessel assemblies. While the welding involved should be straightforward, it must be performed sequentially.

The first step in assembling the reflector vessels is to extend the vacuum vessel tubes, which must occur after the installation of the large beryllium reflectors. Note, the fit up of this beryllium reflector with the vacuum tube that passes through it and the neutron beam extraction ports could be problematic because of the thin walls of the aluminum and the hazards associated with machining beryllium. The gaps around the vacuum tubes must be considered carefully. After the larger reflectors are installed, the vacuum tube extensions will be GTAW welded to the vacuum tubes. The access for this weld will be tricky but the welds are straightforward tube welds. The vacuum tube extensions provide an interface for EB welding the vacuum tubes to the reflector vessel. Once the vacuum tube extensions are installed, fit up with the outer reflector vessels must be confirmed to assure appropriate gaps for EB welding both the vacuum tube extension and the middle reflector vessels.

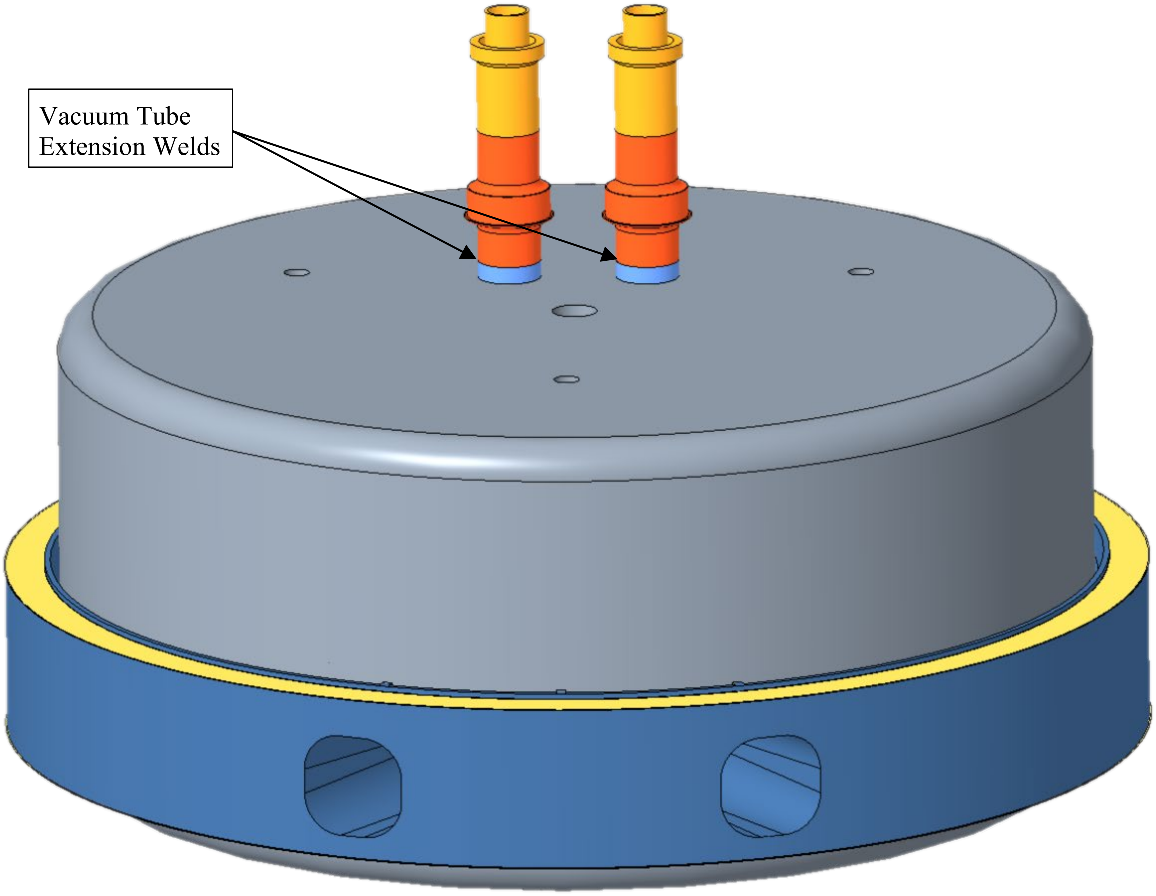

Figure 8.1. Vacuum tube extension welds after installation of outer beryllium segment.

Once fit up is confirmed, the reflector vessels are ready for closure. The outer reflector vessel lids will first be installed over the already installed beryllium reflectors. The assembly will then be inverted to allow installation of the remaining beryllium parts and the inner reflector lids. Once the reflector vessels are assembled, the two circumferential welds and the weld to the vacuum extension will be tacked to ensure weld distortion does not affect subsequent welds. Then, the circumferential closure welds will each be welded in a single pass, followed by the vacuum extension weld. The reflector vessel water inlet and outlet transitions can then be welded to the reflector vessel assemblies, completing the reflector vessel assembly process.

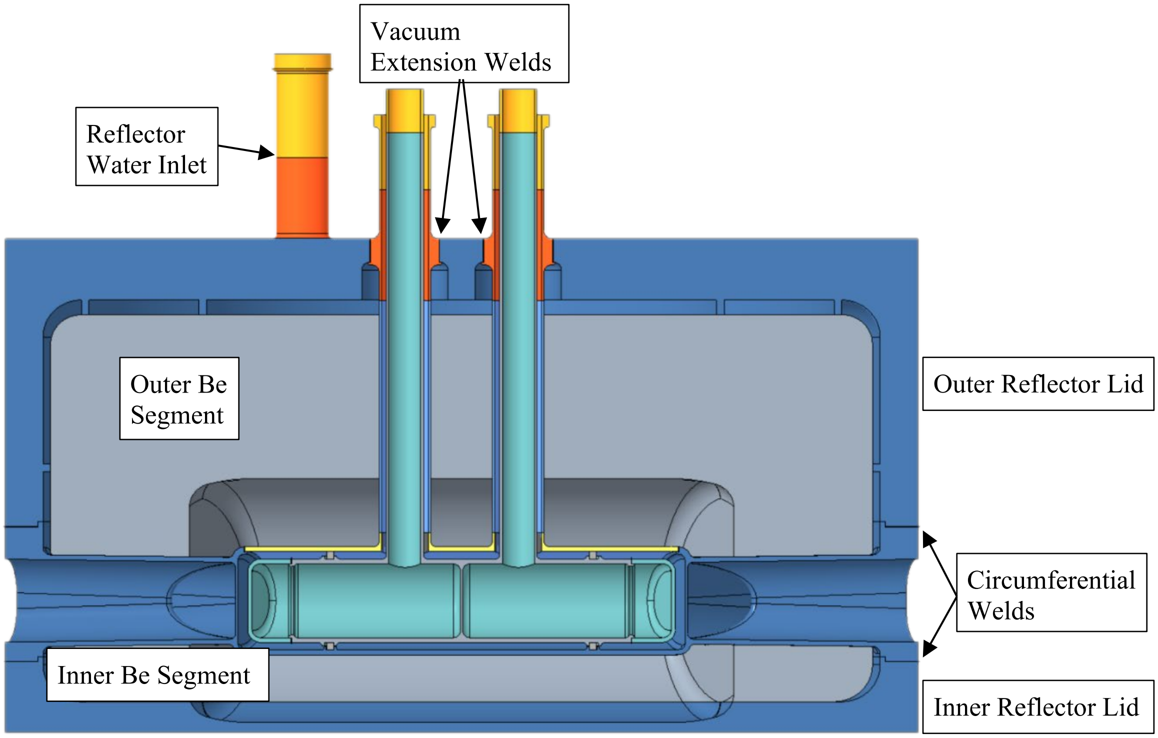

Figure 8.2. Lower reflector vessel closure welds.

9. BACKBONE FABRICATION

The backbone fabrication will be made up of 3 stainless steel parts which have many water cooling passages due to their proximity to the proton beam and neutron production zone. The general strategy for these parts is to use long drilled holes for water cooling passages, with subsequent plug welding to close the holes, where feasible. The upper and lower backbone plates are functionally very similar and will be described together.

The upper and lower backbone plates will each be machined from a single thick stainless steel plate. The rounded end of the plate will feature a curved water plenum that will be machined and subsequently welded closed from the reflector side of the plate. The long drilled holes will travel along the long axis of the plate until they intersect the a large diameter water plenum on the opposite end of the plate. The holes will subsequently be plug welded where they penetrate the curved plenum. Additional holes and penetrations will be included for water supplies and vacuum penetrations.

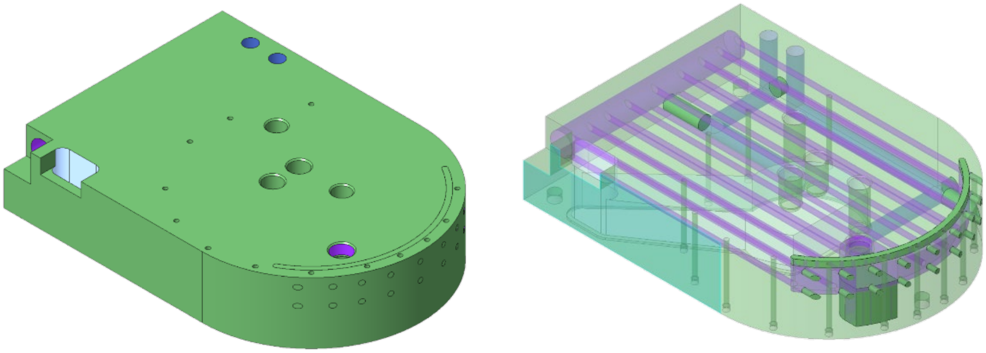

Figure 9.1. Lower backbone plate machined from stainless steel plate.

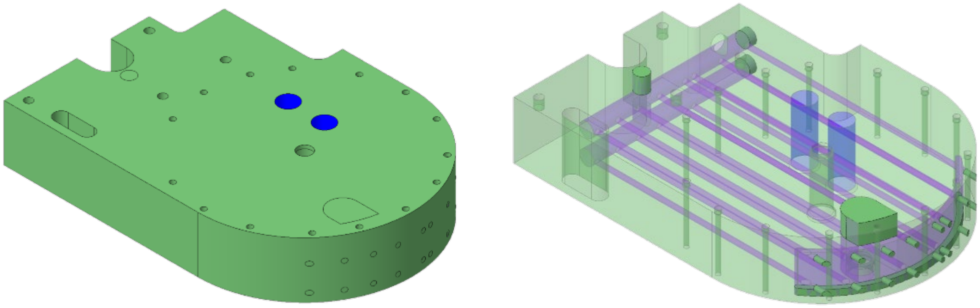

Figure 9.2. Upper backbone plate machined from stainless steel plate.

The middle backbone will be machined from a stainless steel forging. Many vertical long drilled cooling passages must be drilled and subsequently plug welded, along with horizontal feeding holes. The vacuum space for the hydrogen transfer line through the middle backbone must be wire EDMed due to its non-cylindrical profile. The proton beam port through the middle backbone will be formed by a separate machined part which is subsequently welded into the middle backbone on both ends of the part.

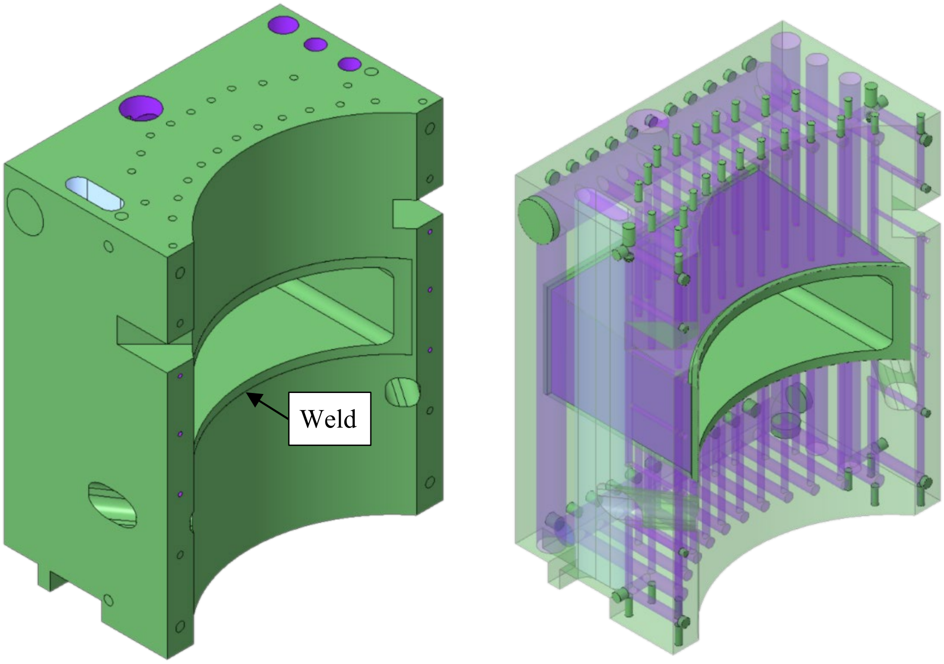

Figure 9.3. Middle backbone assembly.

The lower, middle, and upper backbone will be welded together. First, an outer structural weld will be made around the circumference of their interfaces. Then, the water passages and vacuum passage will be sealed internally and then subsequently with a cover plate. Post weld machining of the mating surfaces to the lower and upper reflectors is expected.

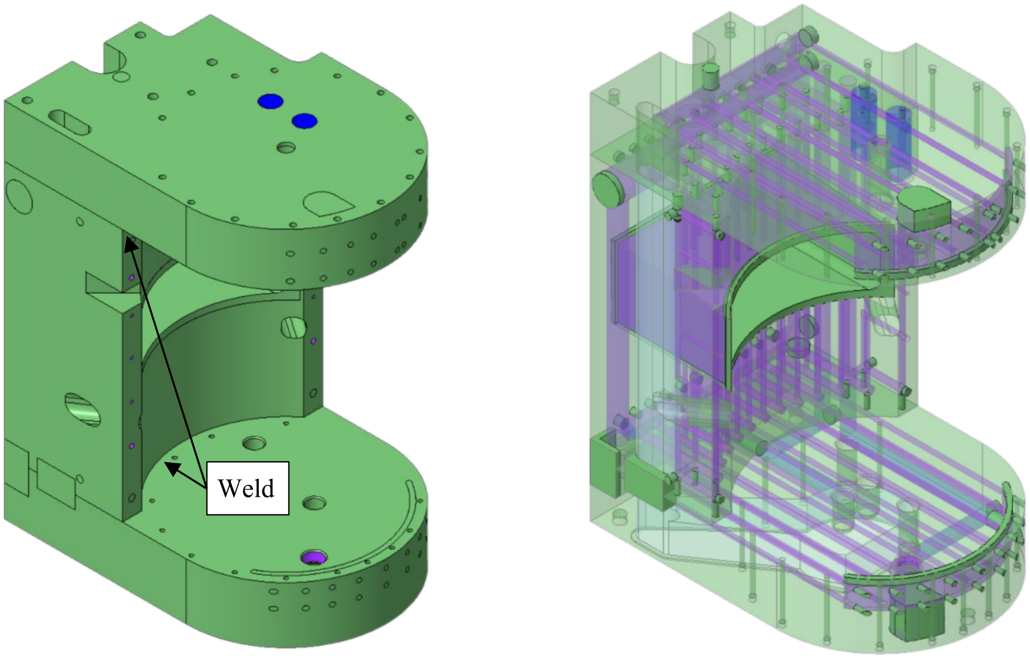

Figure 9.4. Backbone assembly after welding of lower, middle, and upper backbone.

Vacuum covers are required where both hydrogen transfer lines exit the reflector vessels through the backbone plates. These covers cannot be installed until after the hydrogen lines are installed at final assembly.

10. PIPING FABRICATION

The piping of the MRA is made up of 7 water pipes and a single hydrogen transfer line. The water pipes will be made up of commercially available bent stainless steel pipe and pipe fittings. The hydrogen transfer line will be made from custom Invar tubing and has been designed to all be a single size. No fittings are available in Invar, so all piping must be bent, or fittings machined. The hydrogen line design requires that 6 bent segments of tubing be fabricated for installation and welding at final MRA assembly. The only welding required prior to final assembly is welding associated with the upper hydrogen vessel supply and return. The vacuum line surrounding the hydrogen line will be made from commercially available stainless steel tube. The vacuum line is designed with miter bends and intended to be installed and welded over the hydrogen lines at final assembly of the MRA.

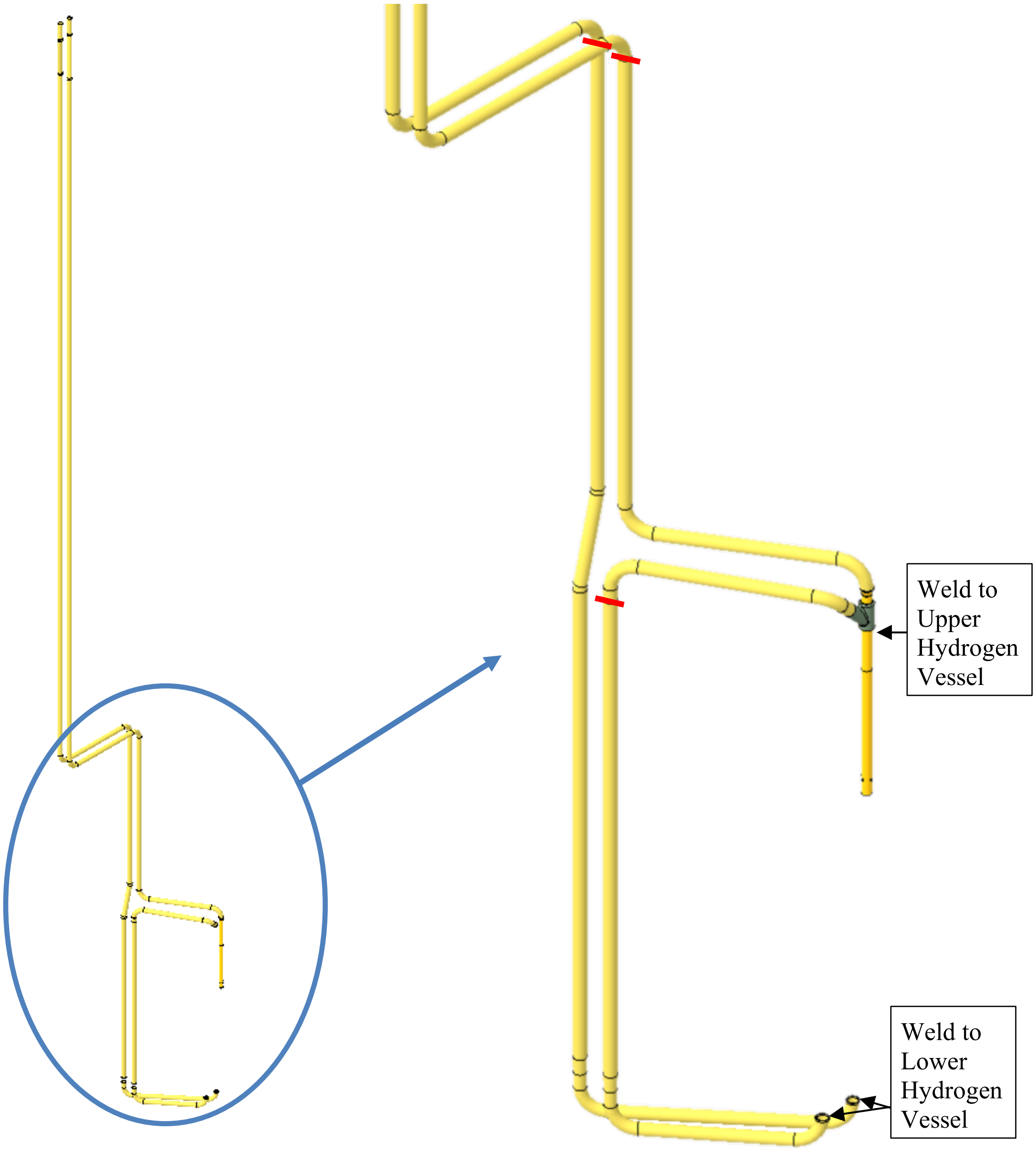

Figure 10.1. Hydrogen piping layout with divisions (to be welded at final assembly) shown in red.

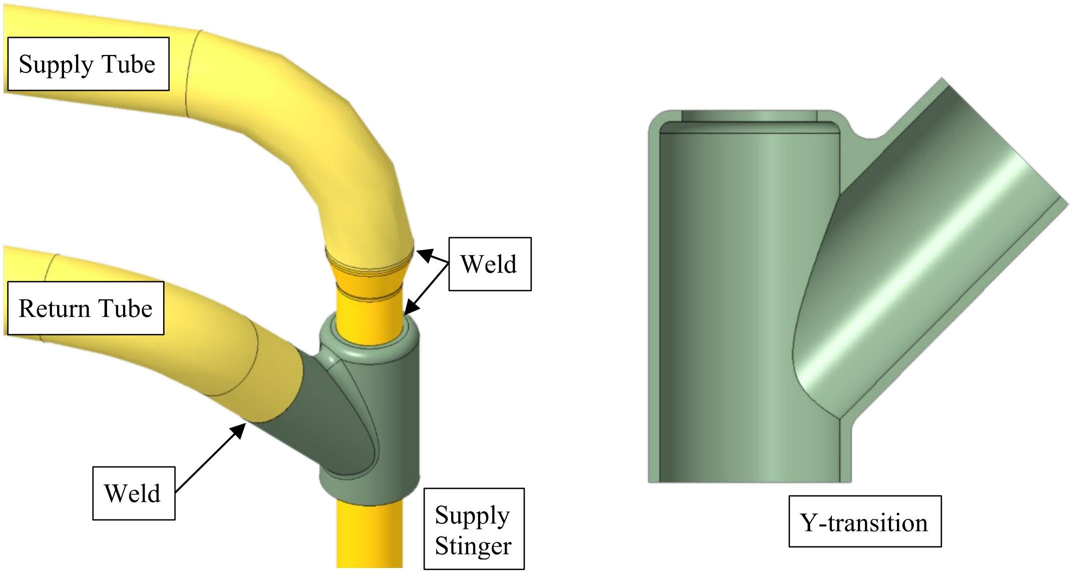

Figure 10.2. Upper hydrogen vessel supply and return. Y-transition and supply stinger tube are machined parts.

11. SHIELDING FABRICATION

The MRA backbone shield block will be machined from a large stainless steel forging. Like the other backbone parts, it will feature long drilled holes; however, they are much less dense in the shield block. The long drilled holes will be plug welded closed. Chases and passages for routing of water and hydrogen lines will also be required.

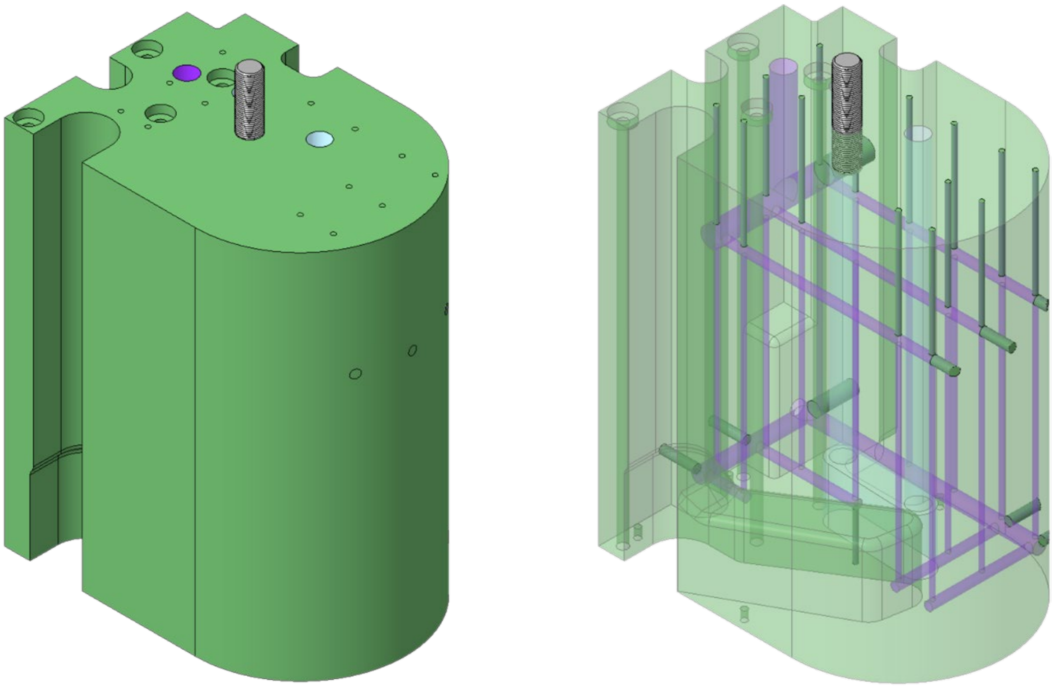

Figure 11.1. MRA Backbone Shield Block.

12. FINAL ASSEMBLY

The final assembly of the MRA will integrate the reflector vessel assemblies, backbone sections, piping, and shielding. Hydrogen, vacuum, and water boundaries must welded at the interfaces between these components.

The first step to final assembly is to install the reflector vessel assemblies to the backbone plates, which are bolted together at the outer diameter of the reflector vessels. The water tubes that interface to the backbone plates and the vacuum tubes must be sealed to the backbone plates. These connections are all planned to be electron beam welded to reduce residual stresses in the nearby aluminum to stainless transitions. For the water connections, cover plates will subsequently be welded over the welding access holes to close the water boundaries.

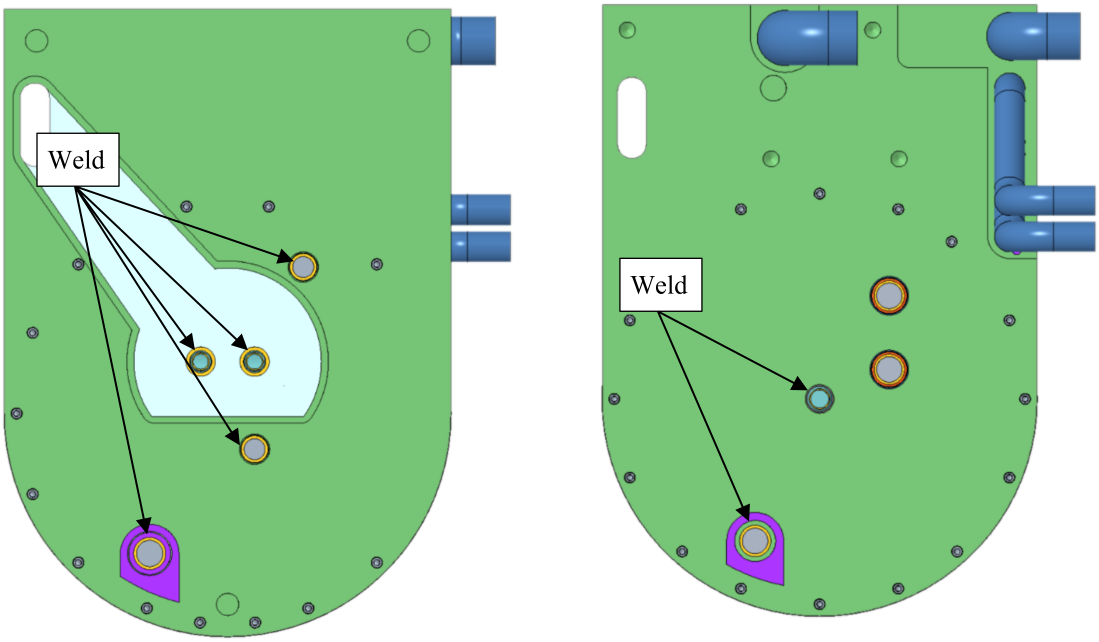

Figure 12.1 Lower (left) and upper (right) reflector vessel to backbone connection welds.

Next the hydrogen lines must be added to the assembly. The hydrogen lines to the lower moderator are inserted through the backbone vacuum passage from the bottom, and then welded to the lower moderator hydrogen tubes. Then the lower vacuum cover plate will be welded closed over the top of the hydrogen lines. The hydrogen lines to the upper moderator are then added, welding to the lower transfer line and upper moderator. Then the upper vacuum cap will be welded in place over the hydrogen lines, closing the vacuum boundary in the backbone section. The lower vertical section of vacuum tube is then added to bring the transfer line height above the future installed shield block height.

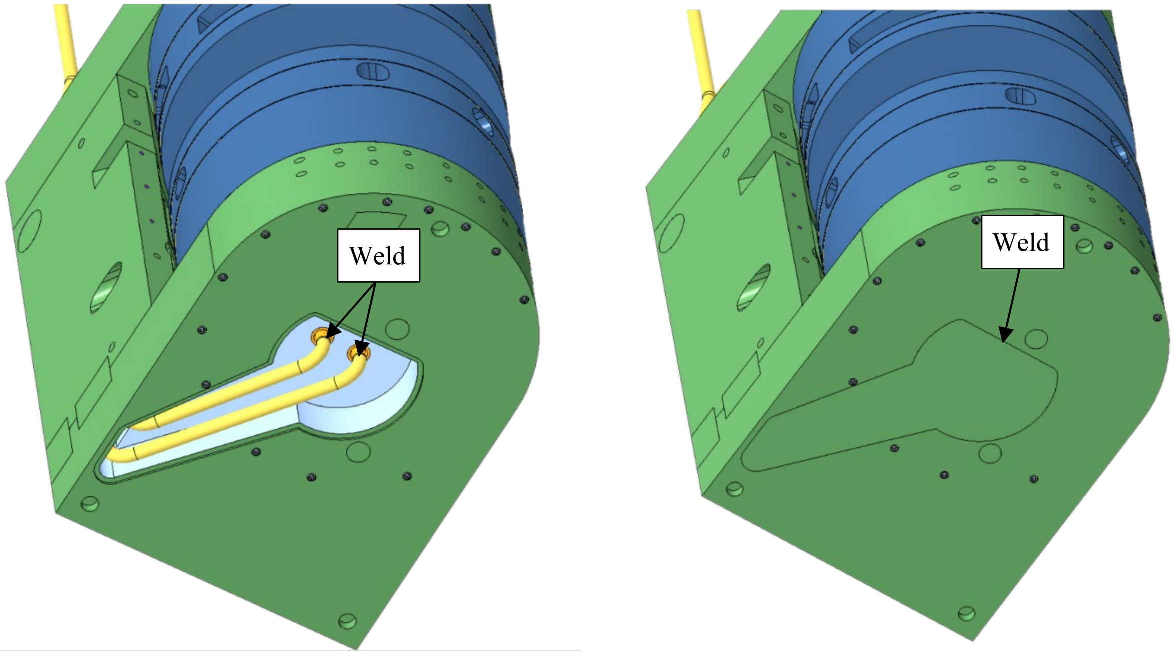

Figure 12.2. Lower hydrogen line welding (left) and lower vacuum cover plate welding (right).

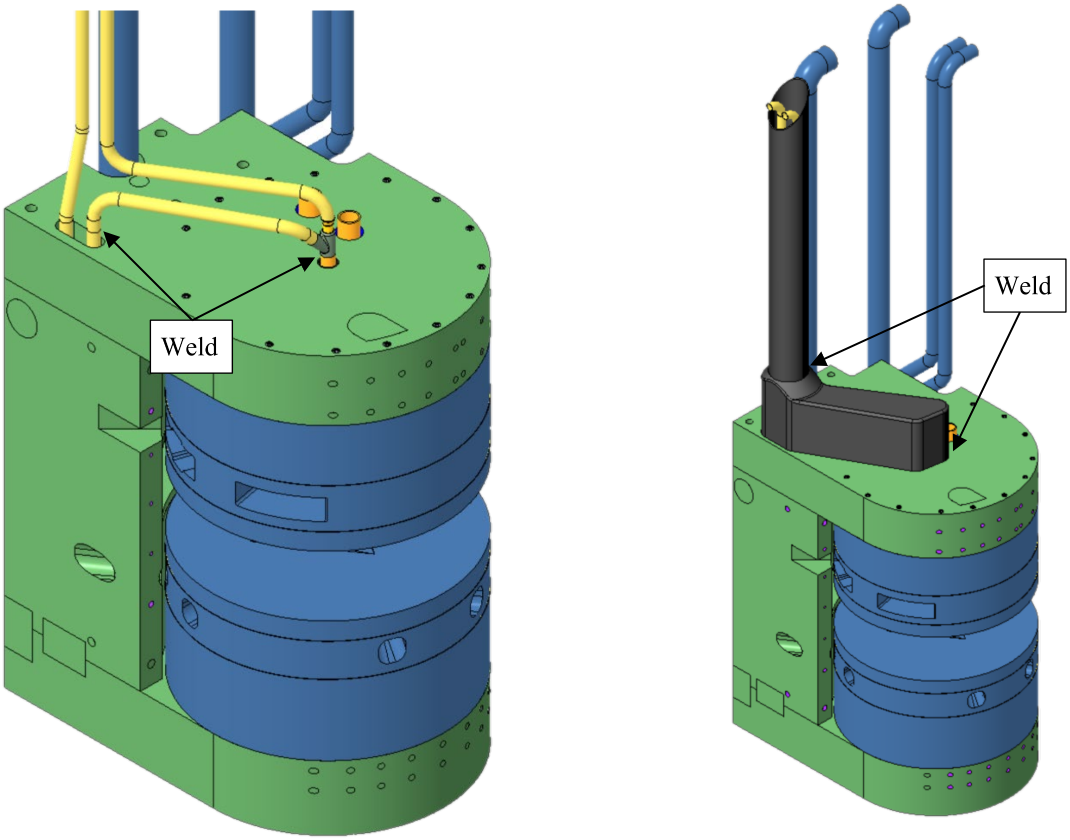

Figure 12.3. Upper hydrogen line welding (left) and upper vacuum cap and tube welding (right).

Next, the water lines will be added to the assembly. Only the sections of water line through the shield block should be added at this point to allow for installation of the shield block. These 6 lines must be welded to the water inlets/outlets from the backbone.

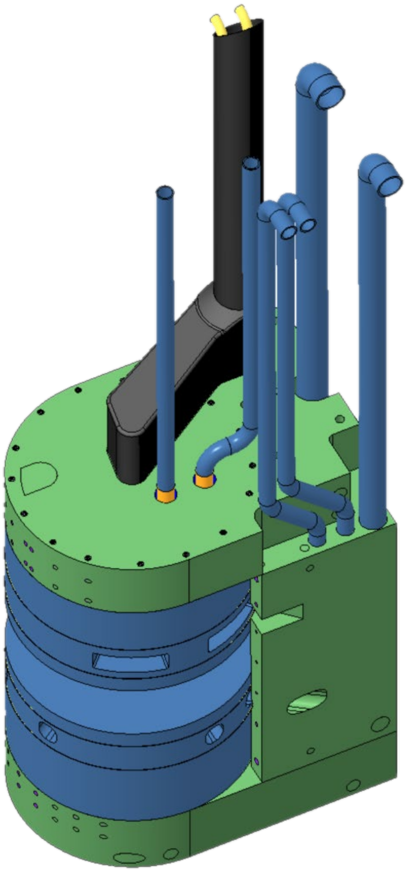

Figure 12.4. Water piping welded to the backbone water inlets/outlets.

Then, the backbone shield block is added to the top of the assembly and bolted in place with long tie rods. A water jumper must be welded between the upper backbone plate and shield block.

Finally, the sections of piping above the upper backbone shield block will be added. This piping includes 7 water lines and 1 hydrogen transfer line. It is anticipated that a routing jog will be required to ensure pipe routing in this region meets design tolerances. The water lines must be welded sequentially to allow welding access. The hydrogen lines are welded with the long section of horizontal vacuum tubing in place but slid out of the way. Next the long horizontal vacuum tubing is slid back into position and miter welded. Then the short horizontal vacuum tubing is slid over the hydrogen lines and around the corner into position, where it is welded to the long horizontal vacuum tube. Then the upper vertical section of vacuum tube is slid over the hydrogen transfer lines and miter welded, completing the MRA hydrogen transfer line. Note, this final piping assembly could be performed on site at STS in order to reduce the chance of damage during shipping to the long, exposed utility lines.

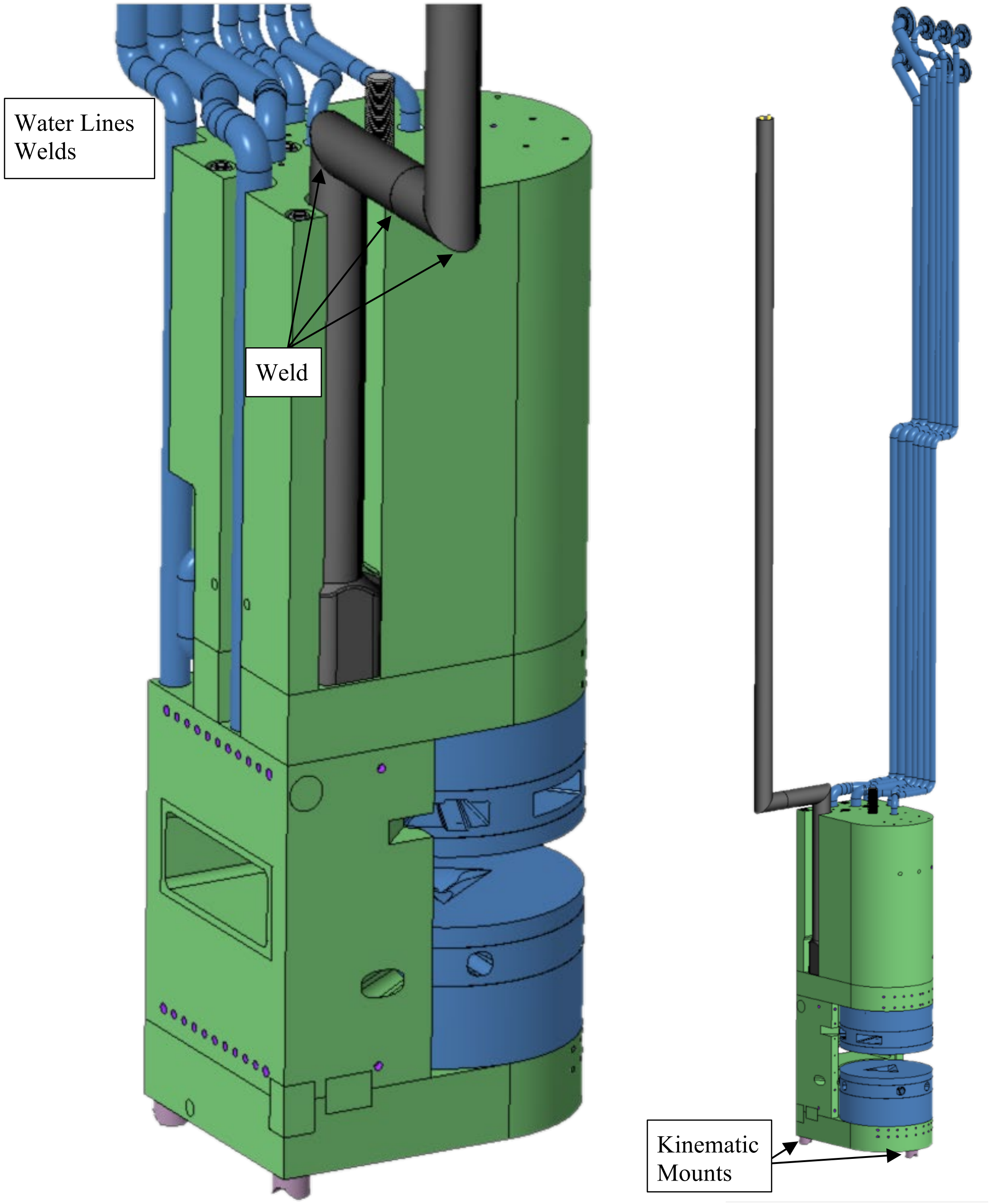

Figure 12.5 Piping welds above the shield block and overall MRA view.

For the first MRA, the final locations of the kinematic mounts will not be known until survey alignment results of the MRA mounting points in the core vessel shielding are available just before installation. As a result, the holes for the kinematic mounts will be machined in nominal locations in the lower backbone plate to allow for the assembly to progress and the kinematic mounts themselves will be custom machined after the final locations are determined. This will allow the first MRA to be adjusted to the as built mounting points in the core vessel shielding without significant project delay. After the first MRA, the mounting holes for the kinematic mounts can be machined in the correct locations for the use of standard kinematic mounts to position the MRA correctly based on the as built condition of the core vessel shielding, which will be known well in advance.

13. INSPECTION AND TESTING

Inspection and testing have not yet been mentioned in this document, but they will play a large role in the manufacturing of the MRA. All inspection and testing must be performed before the region to be inspected is rendered inaccessible by subsequent assembly steps. All welds will receive visual testing, penetrant testing, and, where possible, volumetric inspection. Additionally, all hydrogen and vacuum boundaries will be liquid nitrogen cold shocked to simulate thermal stresses associated with cryogenic temperatures. Finally, all welds will be leak checked to show no detectable leaks at the levels that are required for the boundary. These inspections and tests are expected to add substantially to the manufacturing time for the MRA and have been accounted for in manufacturing time estimates.

14. CONCLUSIONS

The MRA fabrication plan has been presented showing the assembly sequence from moderator part machining up until final assembly. All steps in the fabrication have been shown to be feasible and relatively simple given the overall complexity of the assembly. The fabrication plan will continue to evolve during final design, focused on improving welding and weld inspection access, but no major changes to the fabrication plan are anticipated.