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Second Target Station Project: Fabrication Strategy for the Moderator Reflector Assembly

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July 2026

OAK RIDGE National Laboratory

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FABRICATION STRATEGY FOR THE MODERATOR REFLECTOR ASSEMBLY

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00	Initial Release
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CONTENTS

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 to support successful fabrication.

2. 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]. Note that the hydrogen vessels are slightly oversized at room temperature so that they are the desired size at 20K operating temperature.

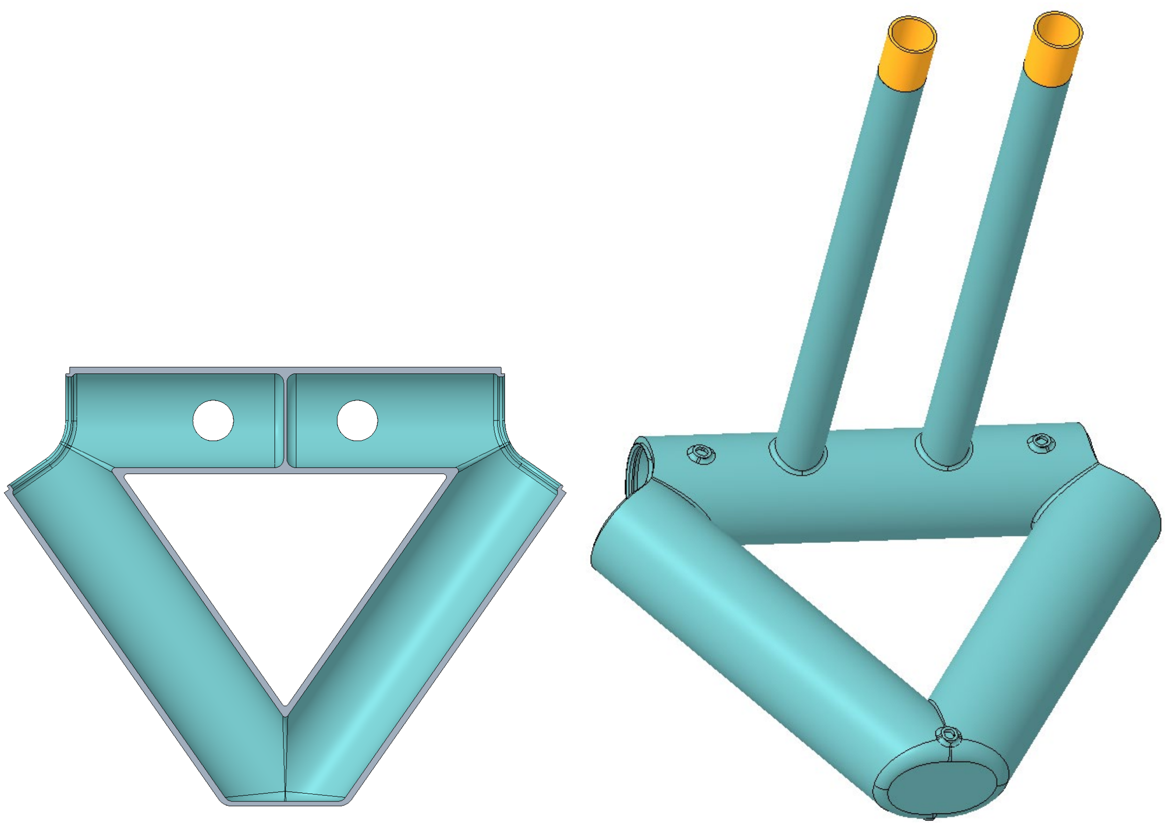

Figure 2.1 Tube Hydrogen Vessel Body machined after friction welding of Invar transition pieces to Al 6061-T6 Forging

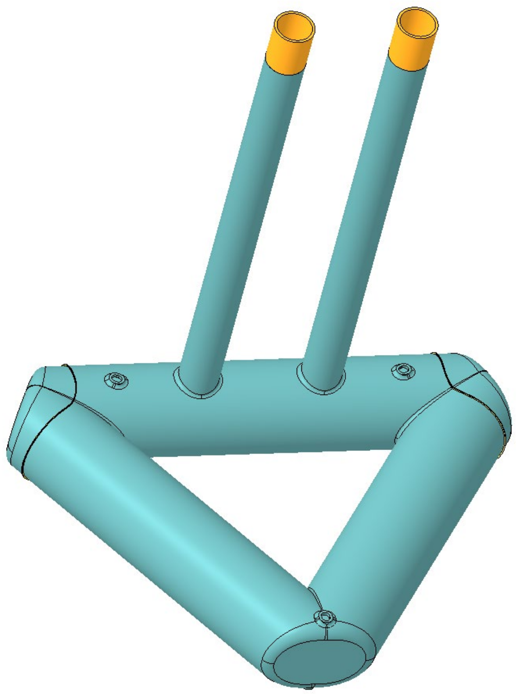

Figure 2.2 Tube Hydrogen Vessel Welded with 2 welds joining caps to body. Welds are designed to be electron beam welded in 2 passes. Each pass is a ½ rotational tube weld followed by a translation to join to the other ½ tube weld.

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 [4]. 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. Significant stock is left on the vacuum vessel body and cap to reduce weld distortion, although the bottom of the tube shape is finished so that datums for final machining can be established. After welding, the vacuum vessel weldment is machined to its final geometry, assuring proper fit up with beryllium and the reflector vessel caps.

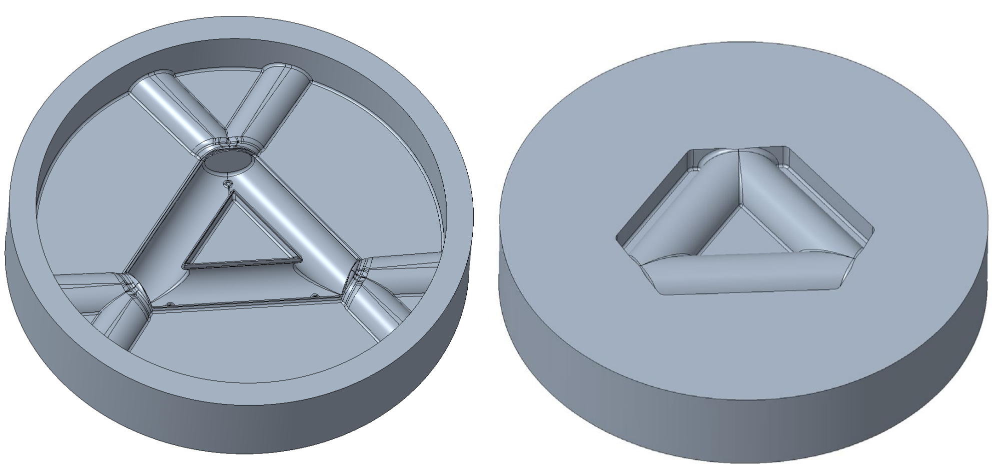

Figure 2.3 Tube Vacuum Vessel Body machined from Al 6061-T6 forging

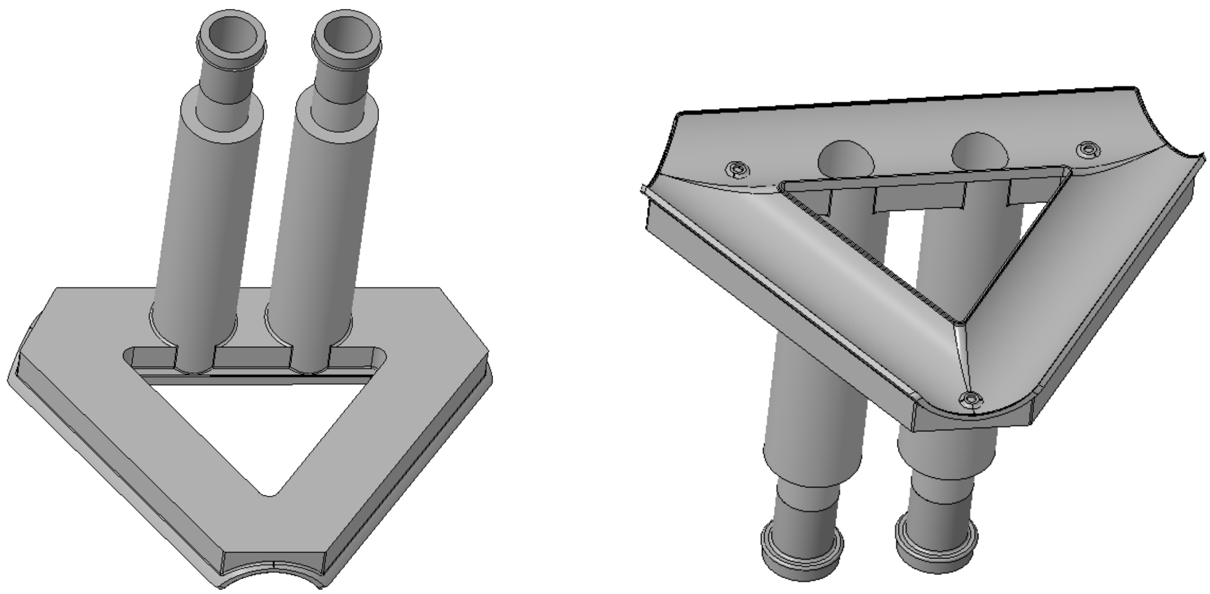

Figure 2.4 Tube Vacuum Vessel Cap machined from Al 6061-T6 forging after friction welding of 316L vacuum tube extensions

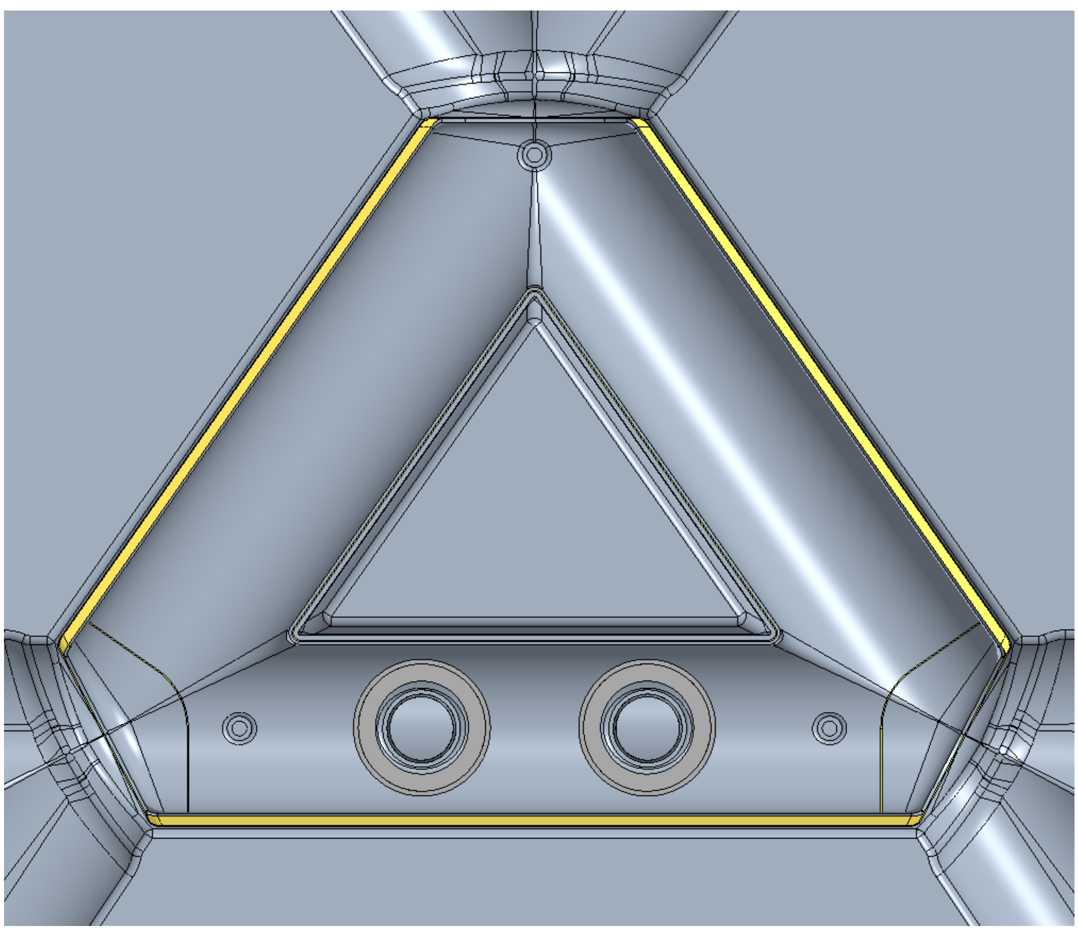

Figure 2.5 Tube Hydrogen Vessel Assembled into Tube Vacuum Body along with Vacuum Spacers. The opening in the Vacuum Body is designed to just allow the Hydrogen Vessel to pass through.

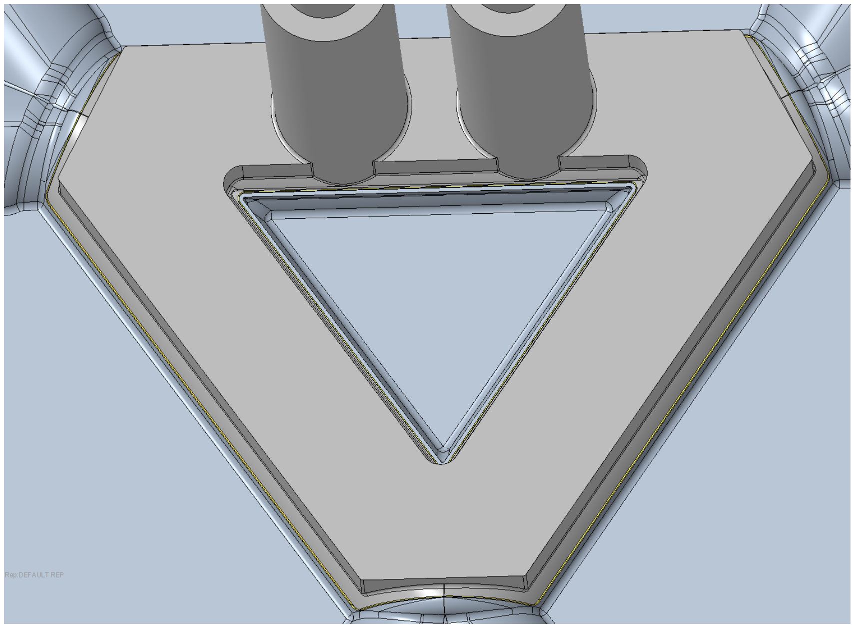

Figure 2.6 Tube Vacuum Cap welded to Tube Vacuum Body in 2 welds. The Inner weld is a simple straight down weld in a single plane. The Outer weld will be made in 6 passes. Each tube intersection will be welded by starting in the straight, but not perpindicular to the face. The weld will then translate 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.

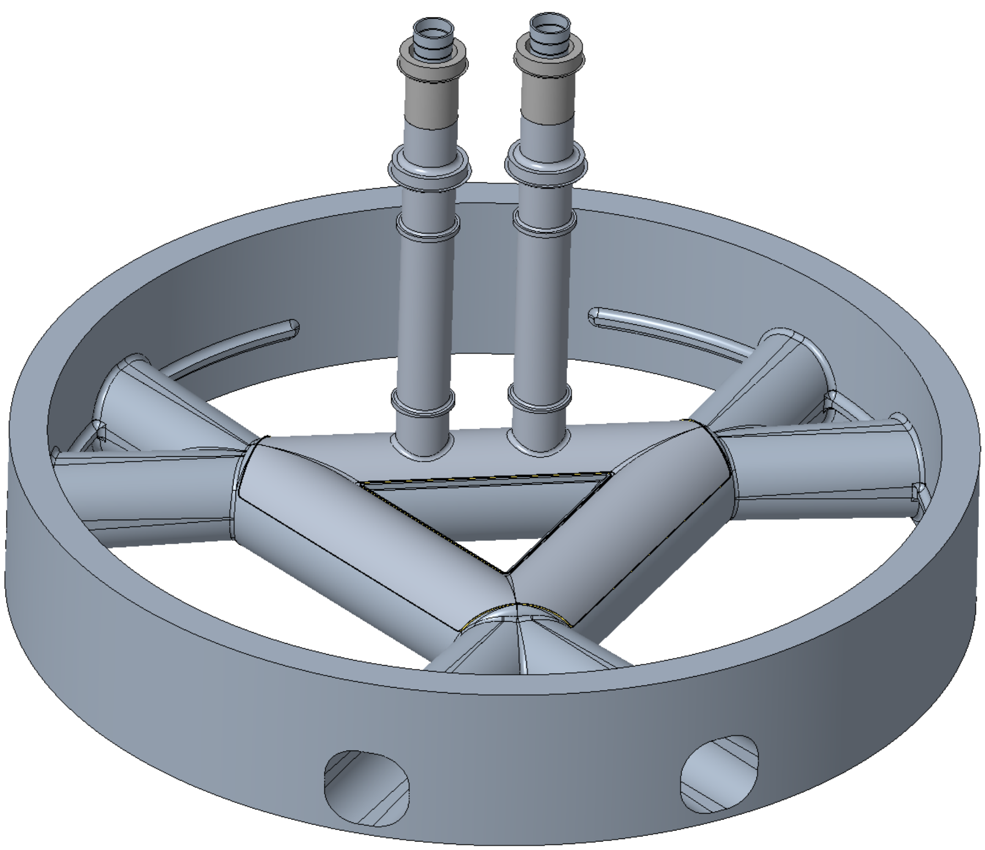

Figure 2.7 Vacuum Vessel Weldment after all final machining

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.

3. 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, except for recesses to allow reflector cooling water bypass the reflector vessel weld backers, 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. Additional split beryllium pieces install around each vacuum tube, allowing the large beryllium piece to pass over the vacuum tube weld flanges.

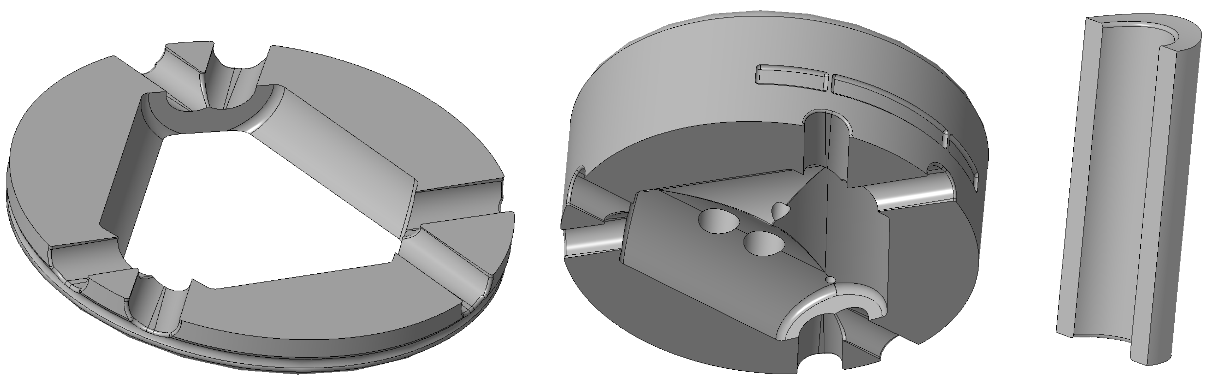

Figure 3.1 Small, large, and split lower beryllium reflector sections.

4. REFLECTOR VESSEL PART MACHINING

The reflector vessels parts are simple aluminum parts that will be technically straightforward to machine with the exception of the flow baffles. These parts include the weld backers for the reflector vessel circumferential closure welds. Additional small parts will be machined from friction welded aluminum to stainless steel to form transitions, which will also be technically straightforward.

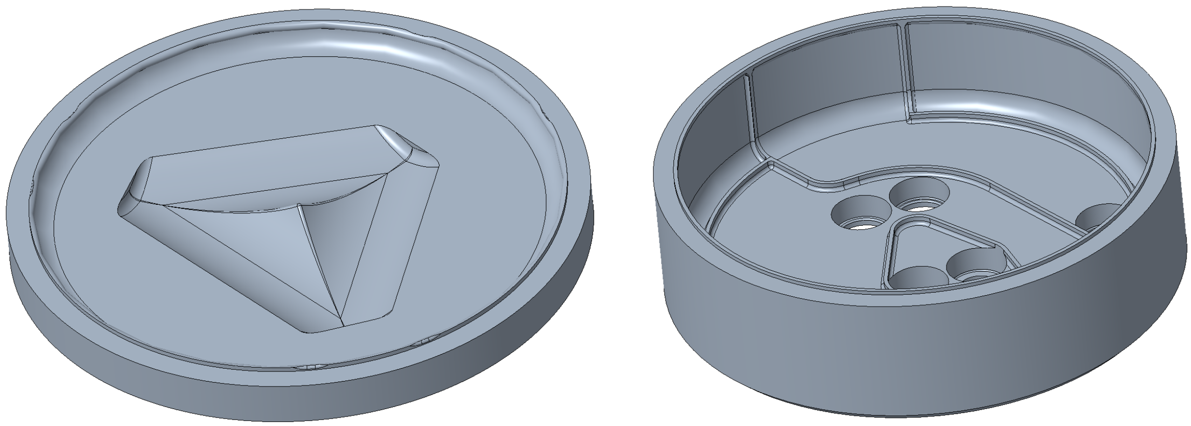

Figure 4.1 Small and large lower reflector vessel caps.

5. REFLECTOR VESSEL ASSEMBLY

The moderators, beryllium reflectors, and reflector vessel parts will be integrated to form the reflector vessel assemblies. The small beryllium reflector and reflector vessel cap will be installed first to the vacuum vessel assembly, followed by the split beryllium reflectors which are locked around the vacuum tubes by the subsequent installation of the large beryllium reflector. The large reflector vessel lid can then be installed. Once the reflector vessels are assembled, the two circumferential welds 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. Next, the vacuum extension weld is completed. The reflector vessel water inlet and outlet transitions can then be welded to the reflector vessel assemblies, completing the reflector vessel assembly process.

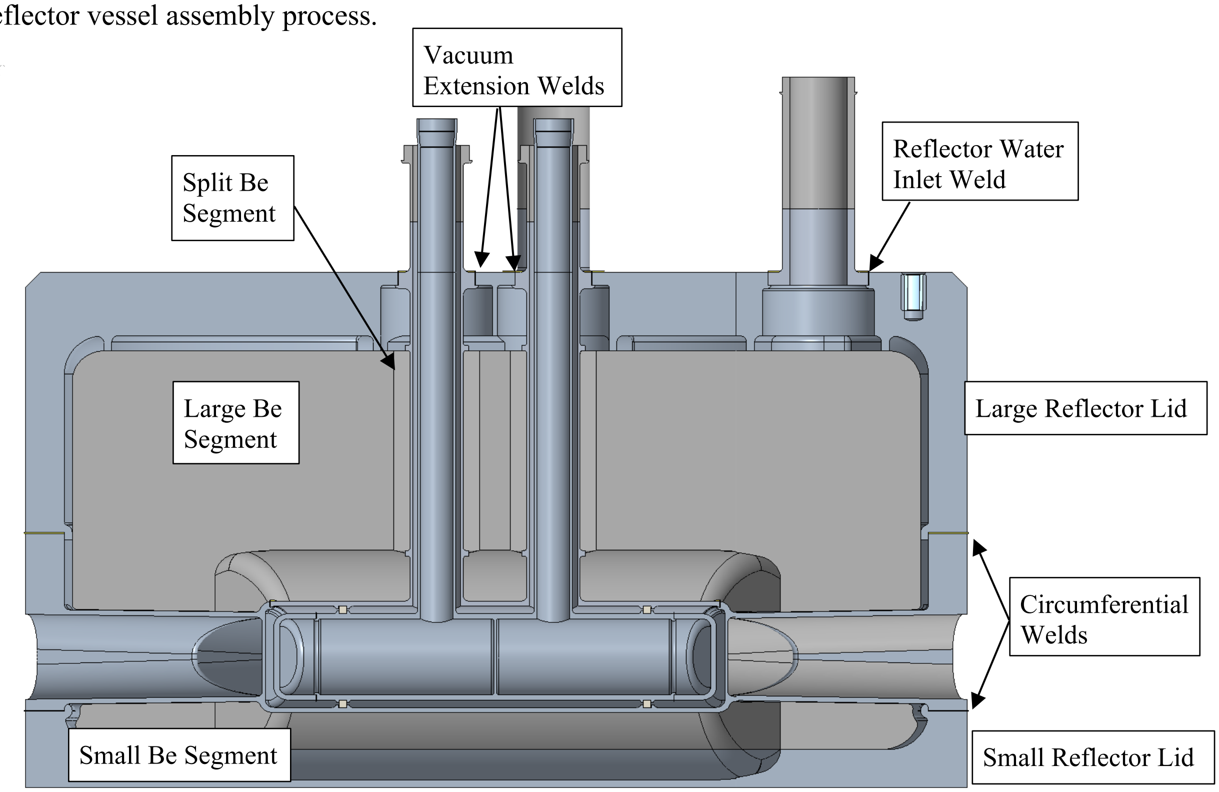

Figure 8.2. Lower reflector vessel closure welds.

6. 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 large diameter water plenums on the opposite end of the plates. Additional holes and penetrations will be included for water supplies and vacuum penetrations.

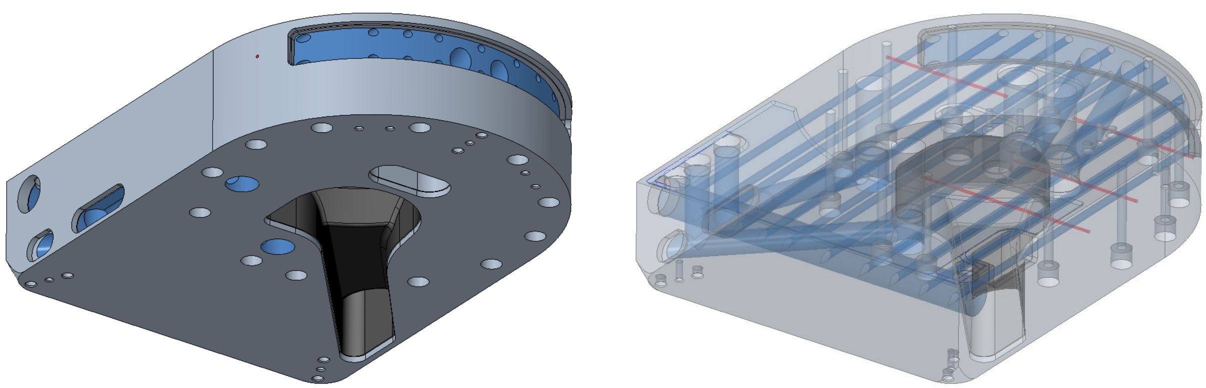

Figure 9.1. Lower backbone plate machined from stainless steel plate. Cooling holes are shown in blue, bolt holes in grey, and leak check access holes in red.

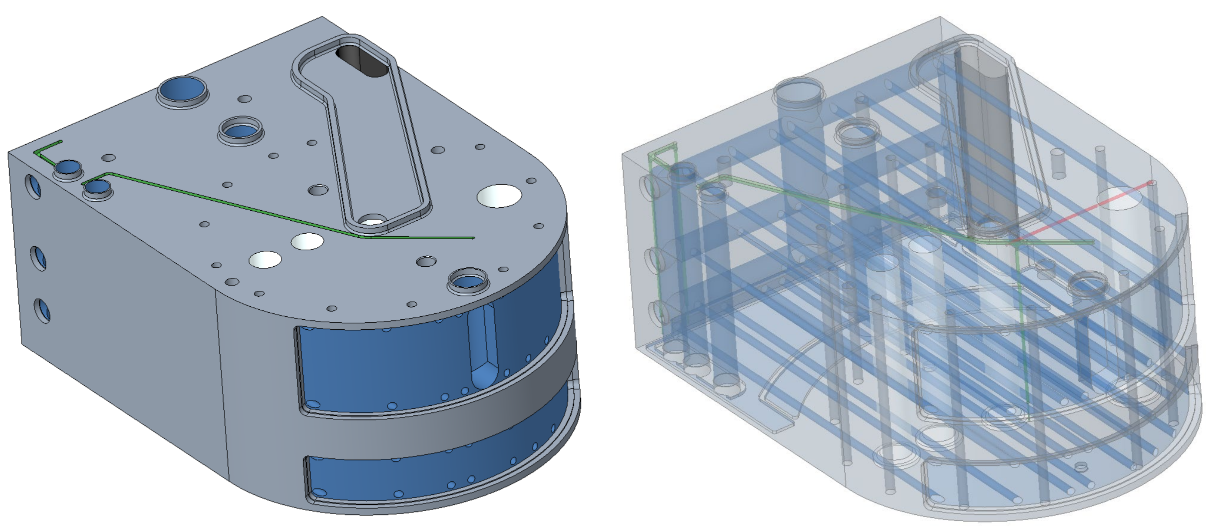

Figure 9.2. Upper backbone plate machined from stainless steel plate. Cooling holes are shown in blue, bolt holes in grey, leak check access hole in red, and thermocouple wells and routing in green.

The middle backbone will be machined from a stainless steel plate. 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 noncylindrical profile. The proton beam port cooling channels in the middle backbone will be machined with slot cutters and or plunge EDM from both sides of the part, leaving a rib in the center of the part.

After machining, the cover plates for the cooling passages in each backbone piece will be EB welded closed. 4 holes in the middle backbone must also be plug welded closed.

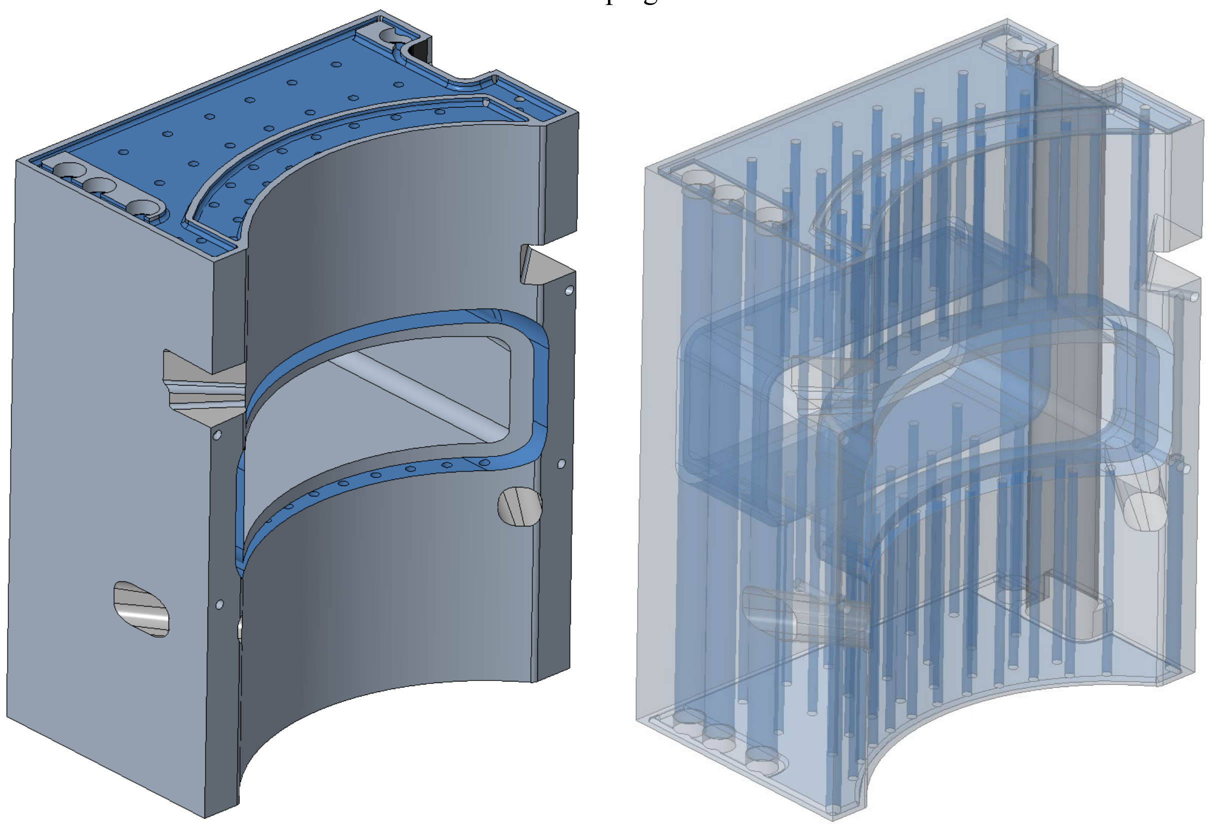

Figure 9.3. Middle backbone machined from stainless steel plate. Cooling holes are shown in blue.

The lower, middle, and upper backbone will be welded together. First, an outer structural weld will be made around the circumference of their interfaces, reinforced with a fillet weld on the reflector vessel side of the joints. Then, the vacuum passages will be sealed with cover plates. Post weld machining of the mating surfaces to the lower and upper reflectors is expected, as well as machining weld fit ups for all reflector vessel connections, the fit up for the shield block, and the fillet welds between the backbone sections. Machining the fillet welds is necessary to improve fatigue lifetime against thermal stress.

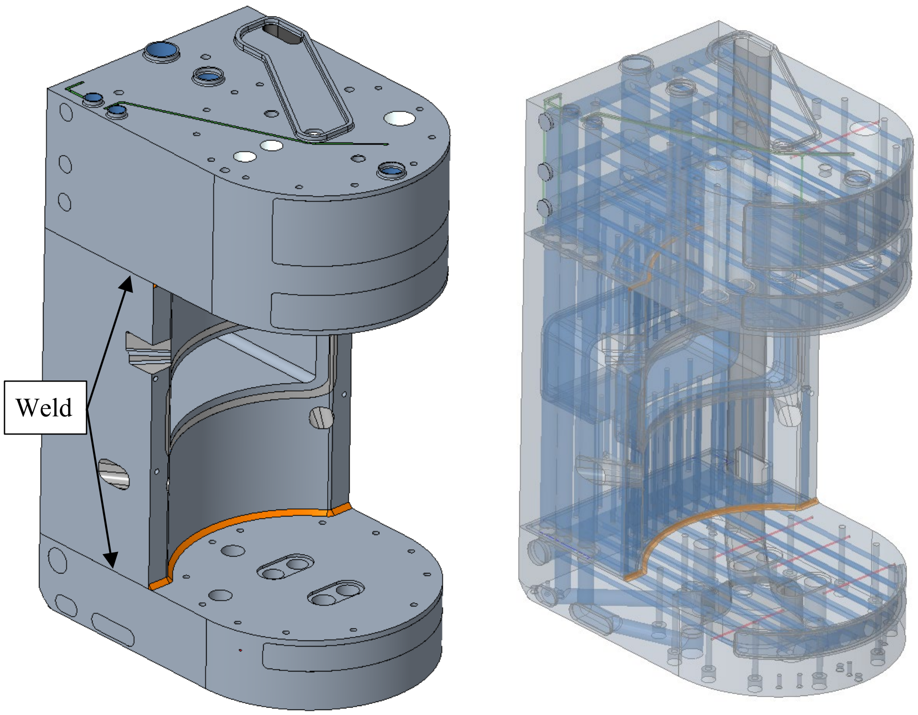

Figure 9.4. Backbone assembly after welding of lower, middle, and upper backbone.

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.

7. PIPING FABRICATION

The piping of the MRA is made up of 6 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 8 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. The top jog is designed so that the horizontal vacuum section can be slid around the corner of the inner tube bends while the lower jog horizontal section is divided into 2 to allow assembly.

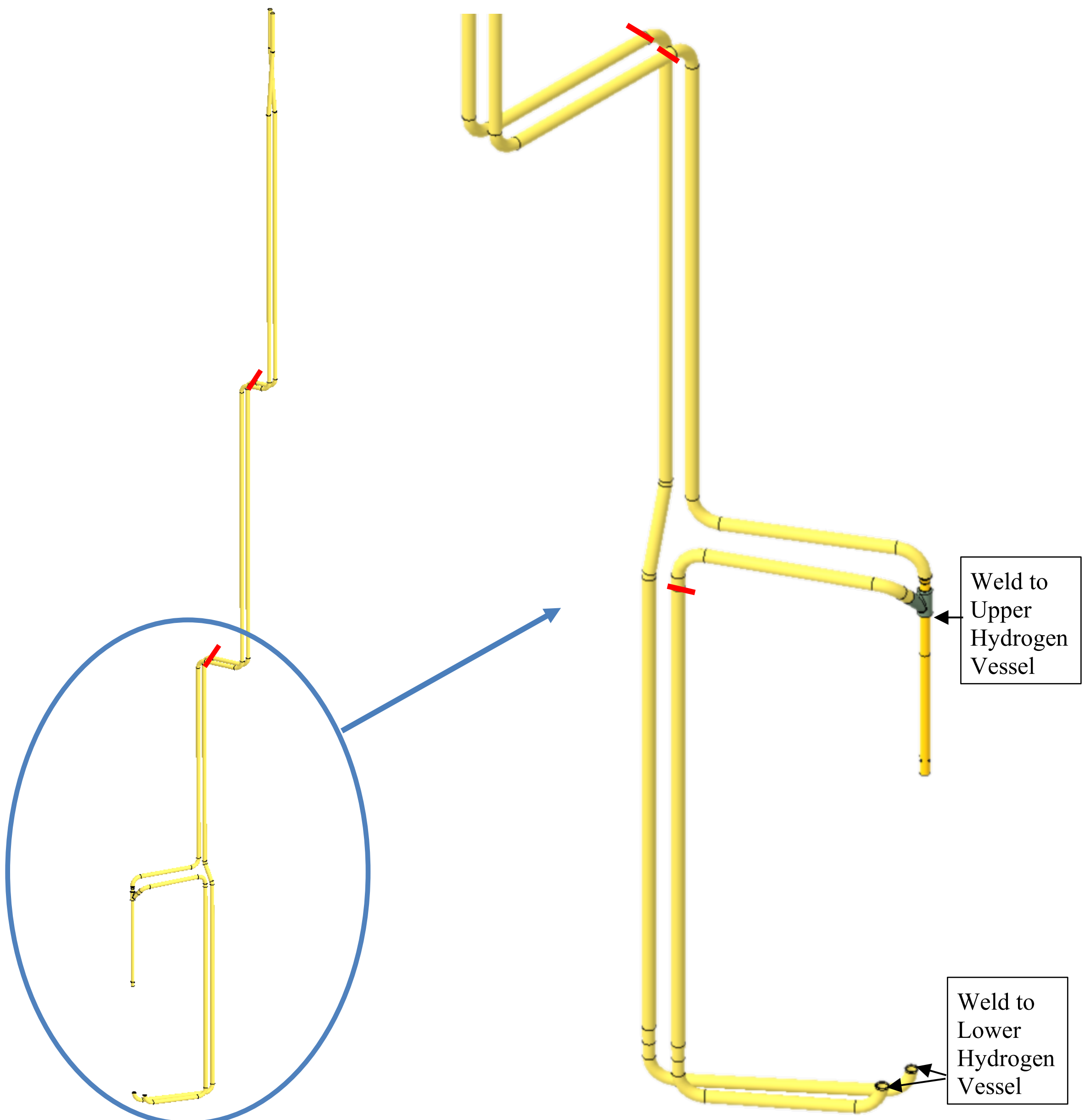

Figure 10.1. Hydrogen piping layout with divisions (to be welded at final assembly) shown in red.

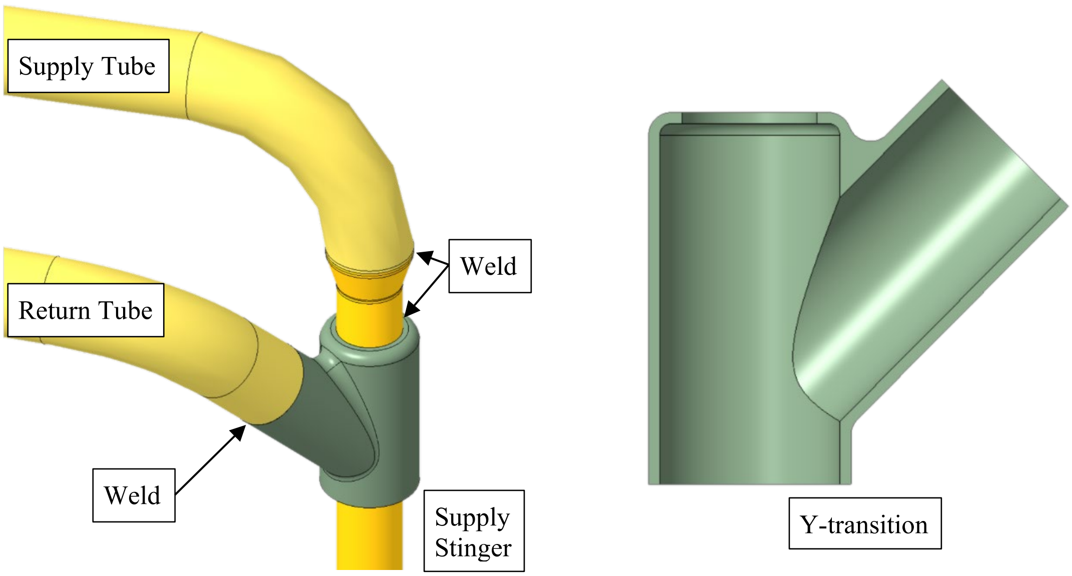

Figure 10.2. Upper hydrogen vessel supply and return. Y-transition and supply stinger tube are machined parts.

8. SHIELDING FABRICATION

The MRA backbone shield block will be machined from a large A36 steel forging. Chases and passages for routing of water and hydrogen lines will be required, as well as clearance for the upper vacuum cap and fasteners. The shield block will be nickel plated after machining is completed to improve corrosion resistance.

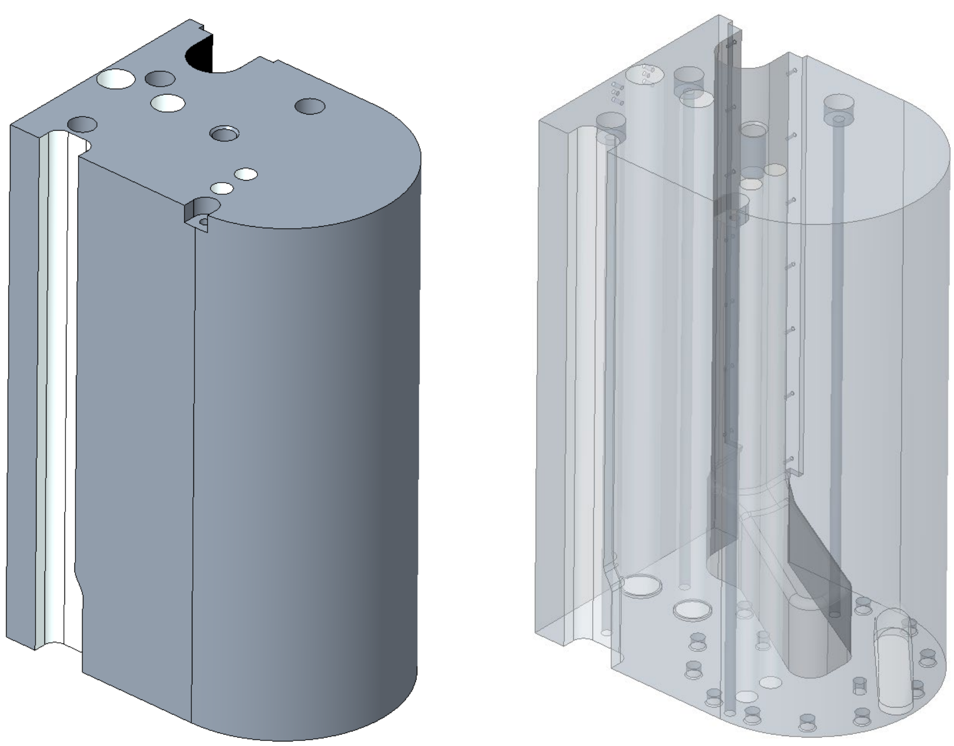

Figure 11.1. MRA Shield Block.

9. FINAL ASSEMBLY

The final assembly of the MRA will integrate the reflector vessel assemblies, backbone sections, piping, and shield block. 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 bolts preload is ensured by flattening Belleville washers. The water and vacuum 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.

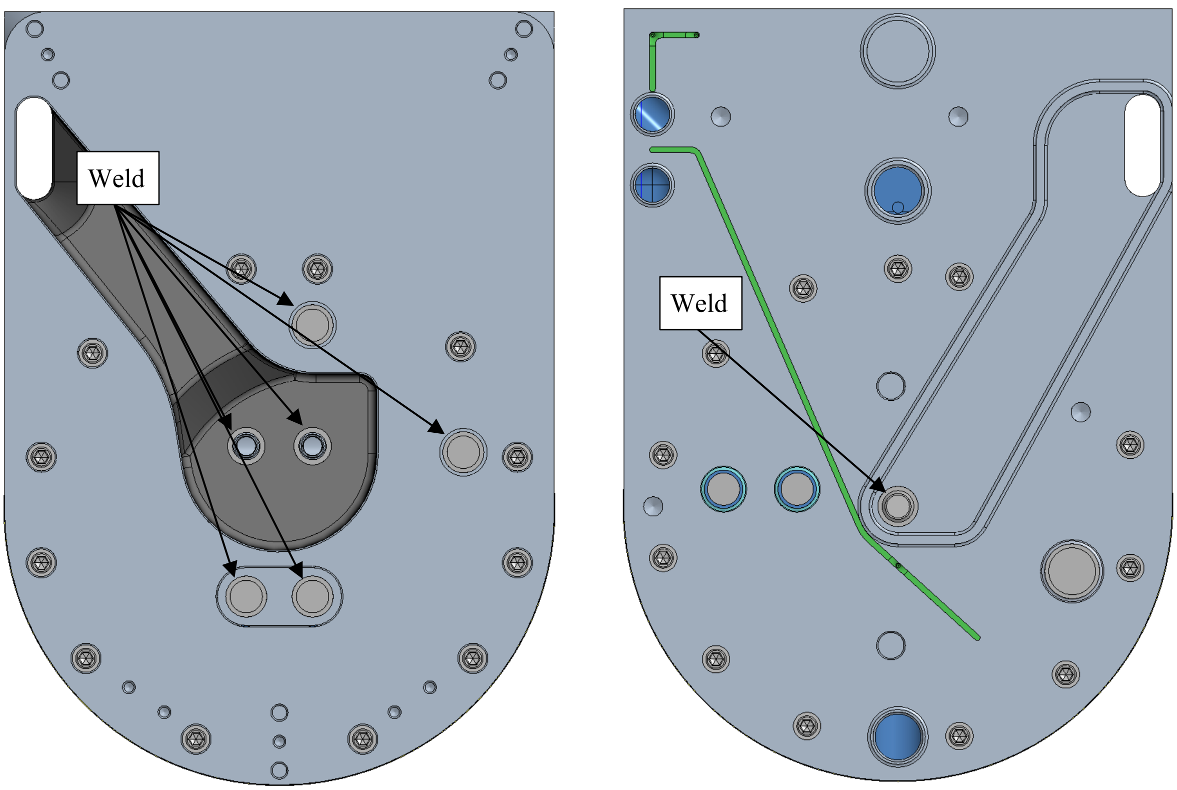

Figure 12.1 Lower (left) and upper (right) reflector vessel to backbone connection welds.

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.

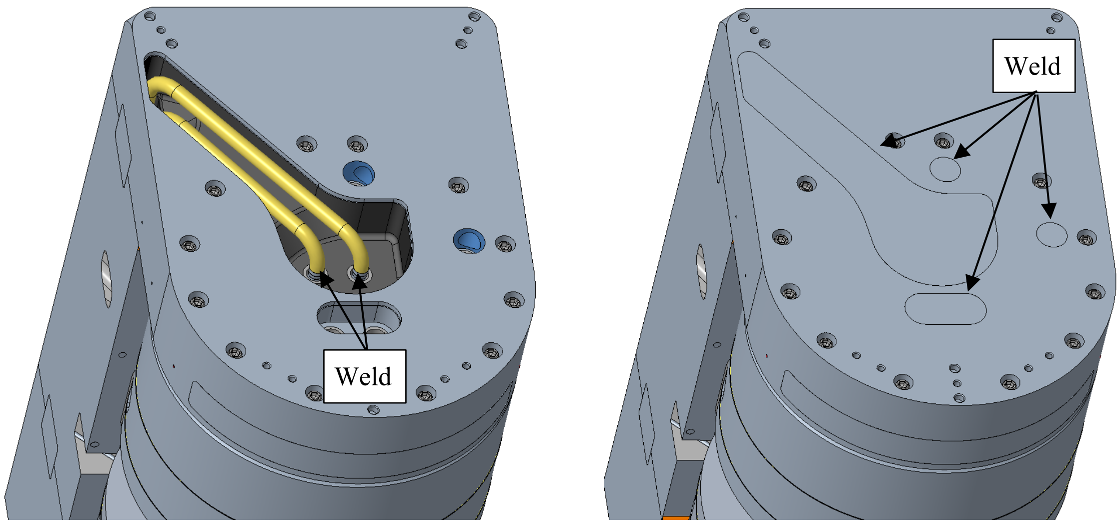

Figure 12.2. Lower hydrogen line welding (left) and lower cover plate welding (right).

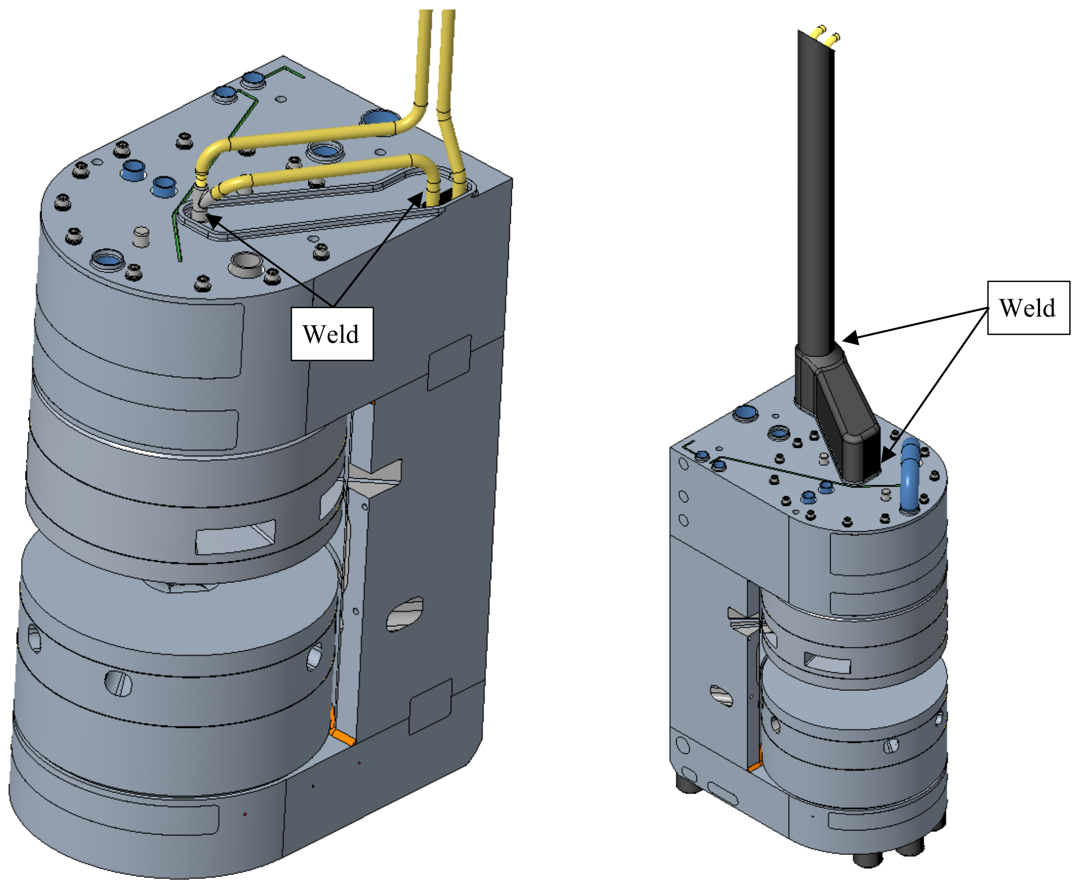

Figure 12.3. Upper hydrogen line welding (left) and upper vacuum cap and tube welding (right).

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.

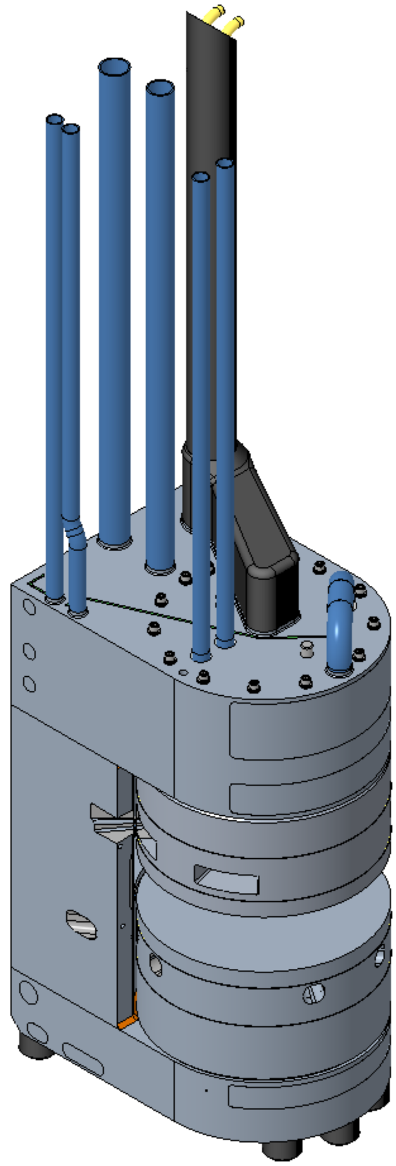

Figure 12.4. Water piping welded to the backbone water inlets/outlets.

After all welding to the upper backbone, thermocouples are installed in the thermocouple wells and routed in the thermocouple routing recesses. Then, the MRA shield block is added to the top of the assembly and bolted in place with long tie rods. Care must be taken to not damage the piping and thermocouples during installation. Preload of the tie rods will be ensured by flattening belleville washers.

Finally, the sections of piping above the upper backbone shield block will be added. This piping includes 6 water lines and 1 hydrogen transfer line. It is anticipated that a pipe routing jig will be required to ensure pipe routing in this region meets design tolerances. 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. This process is repeated for the transfer line upper jog, except the jog is short enough that the whole horizontal vacuum tube can be slid into place, completing the MRA hydrogen transfer line. The water lines must be welded sequentially above the backbone to allow welding access. Any welds required for the water lines upper jog must be welded before the spools are installed as the pipes are too close together. After all piping is completed, the thermocouples leads can be routed along the water piping to the top of the MRA. 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.

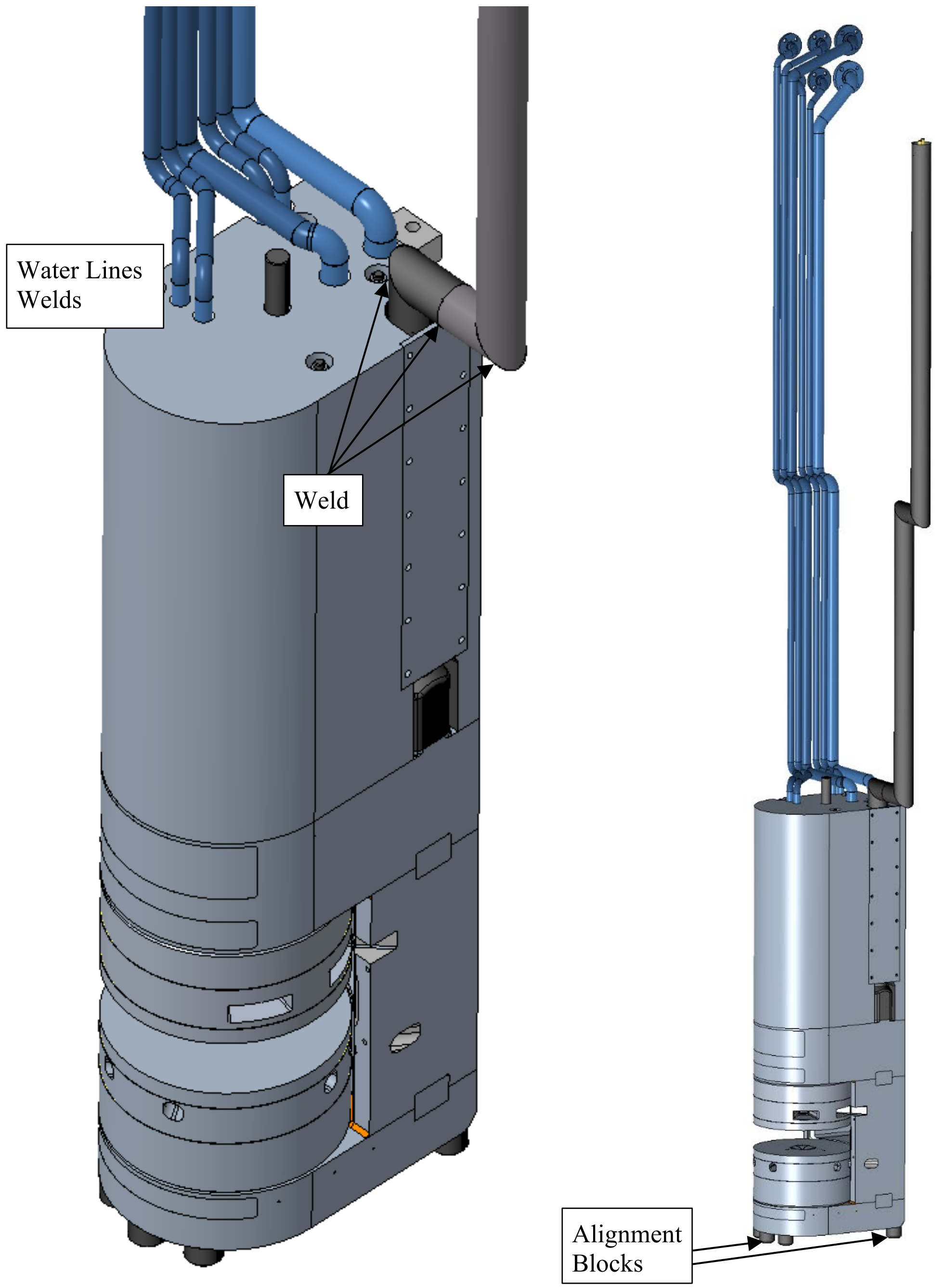

Figure 12.5 Piping welds above the shield block and overall MRA view.

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.

10. 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.

11. 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.

12. REFERENCES

Ref	Document Titles	Document Number
[1]	Cylinder Moderator Prototype Manufacturing Report	S07030200-TRT10000
[2]	Tube Moderator Prototype Report	S07030200-TRT10007
[3]	MRA Hydrogen Vessel Structural Analysis	S03040000-DAC10012
[4]	Moderator Reflector Assembly Structural Analysis	S03040000-DAC10013