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Second Target Station Project: Moderator Reflector Assembly Moderator Deflection and Tolerance Analysis

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MODERATOR REFLECTOR ASSEMBLY DEFLECTION AND TOLERANCE ANALYSIS

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July 2026

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ABSTRACT

Due to the compact viewed areas of the Second Target Station neutron moderators, their alignment is critically important to the facility neutron performance. This analysis will estimate worst case misalignment for the moderators by combing results from Moderator Reflector Assembly prototyping and thermal structural analysis as well as Vessel Systems thermal structural analysis.

1. INTRODUCTION

The Moderator Reflector Assembly (MRA) features 2 liquid hydrogen moderators in order to deliver high brightness cold neutrons to the Second Target Station (STS) instrument suite. The characteristic dimension of the moderator viewed areas is only 30 mm, so careful alignment is required to ensure the produced neutron beams reach the instrument guide optics entrances as desired.

The critical alignment for moderator performance is the moderator to instrument optics guide entrance. The alignment chain for the moderators goes through the MRA structure to the core vessel MRA alignment pins. The alignment chain for the instrument optics guide entrance goes to the core vessel beltline landing pads. Both the initial alignment of components in the alignment chain and thermal deflections from nuclear heating affect the alignment during neutron production and will be examined in this document.

2. TOLERANCES

2.1 MODERATOR PROFILE TOLERANCES

The hydrogen vessels which define the liquid hydrogen geometry are made from a hydrogen vessel body with cap(s) to close the vessel. The hydrogen vessel bodies are machined from a single forging with all alignment features to the vacuum vessel included on the body and an expected profile tolerance of 0.1 mm. The cap(s) are electron beam welded to the body to close the hydrogen vessel with a resulting profile tolerance of 0.25 mm. Prototypes of both the cylinder and tube moderator have confirmed the feasibility of these tolerances [1] [2].

2.2 MODERATOR ASSEMBLY TOLERANCES

The hydrogen vessels are supported within the vacuum vessel using 6 titanium pins constrained in bosses, 3 each on the top and bottom of each hydrogen and vacuum vessel pair. The bosses on the vacuum vessels are slotted to allow for thermal contraction of the hydrogen vessel to operating temperature. We expect the hydrogen vessels can be positioned within the vacuum vessels within +/- 0.375 mm. The reflector vessels are then positioned on the MRA backbone and the 3 MRA alignment blocks are added to the backbone to complete the alignment chain within the MRA. Each of these features will be machined to place the hydrogen vessels in their ideal location, resulting in an additional +/- 0.125 mm of assembly tolerance within the MRA. While hydrogen vessel positioning within the vacuum vessel was confirmed during prototyping, the prototypes did not cover the full chain of alignment, so some of these tolerances will need to be confirmed during MRA fabrication.

2.3 MRA INSTALLTION REPEATABILITY

The MRA alignment blocks rest on flat surfaces on core vessel shield block 1 and align to 3 MRA alignment pins pressed into the same block. The alignment blocks each have a slot that is 0.025 mm oversized from the MRA alignment pins. The slots are oriented to the center of the hydrogen vessels so that the vessels would not move from uniform temperature increases of the MRA. Note, the MRA temperature increase is not uniform but this design principle minimizes thermal deflection of the hydrogen vessels. The MRA installation repeatability is assumed to be +/- 0.25 mm or less.

2.4 INSTRUMENT OPTICS GUIDE ENTRANCE TOLERANCE

The instrument optics guide entrance will be aligned within +/- 1mm of the theoretical location [3]. This alignment tolerance has been confirmed through prototyping.

3. OPERATING DEFLECTIONS

Since the purpose of this document is to analyze operating performance during normal beam on operations, only normal operating conditions will be considered and not rare events such as earthquakes.

3.1 MRA DEFLECTIONS

The deflections of the vacuum vessel boss locations, which control moderator positioning, were tracked relative to the MRA alignment blocks at normal operating conditions in the Moderator Reflector Assembly Structural Analysis [4]. The results are shown in Table 3.1. The upper vessel had higher deflections than the lower vessel as it is located further from the MRA alignment blocks.

Table 3.1 MRA Vacuum Vessel Boss Nominal Positions and Displacements at Normal Operating Conditions

	Nominal Position (mm)			Displacement (mm)			
	X	Y	Z	ux	uy	uz	magnitude
Upper							
U1	-0.497	85.700	-38.733	0.161	0.165	-0.008	0.230
U2	-33.081	85.700	19.796	0.136	0.189	0.018	0.234
U3	33.787	85.700	19.796	0.178	0.168	0.023	0.246
U4	-0.290	132.280	38.964	0.166	0.091	0.033	0.192
U5	-34.048	132.280	-19.700	0.155	0.105	0.004	0.187
U6	34.048	132.280	-19.654	0.186	0.090	0.009	0.206
Lower							
L1	72.728	-81.651	0.039	0.011	0.11	0.015	0.111
L2	-43.697	-81.508	54.408	-0.029	0.066	0.028	0.078
L3	-43.697	-81.508	-54.408	-0.022	0.074	-0.015	0.078
L4	72.727	-121.349	-0.039	0.026	0.086	0.012	0.091
L5	-43.697	-121.492	54.408	-0.021	0.041	0.028	0.054
L6	-43.697	-121.492	-54.408	-0.014	0.048	-0.022	0.055

3.2 CORE VESSEL DEFLECTIONS

The core vessel supports both the MRA and the instrument guide optics entrance. The results of the deflections for the core vessel MRA alignment pins and guide optics entrance supports for normal operating conditions were calculated in the Core Vessel and Core Vessel Shielding Structural Analysis [5] and are shown in Table 3.2. The largest deformations are in the vertical direction, and the MRA alignment pins move in the same direction as the guide optics entrances, but with an average magnitude of 0.34 mm instead of 0.56 mm. All structures also see growth in the XZ plane, but this growth is nearly purely in the radial direction from the center of the core vessel, which has minimal impact on moderator to guide alignment. The worst case deviation from pure radial growth is less than 0.075 mm for the guide optics entrance and even less for the MRA alignment pins.

Table 3.2 Core Vessel MRA Alignment Pin and Guide Optic Support Displacements at Normal Operating Conditions

	Nominal Position			Displacement			
	X (mm)	Y (mm)	Z (mm)	X (mm)	Y (mm)	Z (mm)	Total (mm)
MRA Alignment Pin 1	160.5	-405.275	0	0.077996	0.34441	-0.00029	0.35313
MRA Alignment Pin 2	-315.5	-405.275	-160.5	-0.16146	0.33554	-0.07339	0.37953
MRA Alignment Pin 3	-315.5	-405.275	160.5	-0.16236	0.33551	0.073346	0.37988
Beam Line 1 Bottom	-1083.62	-215.8	-812.774	-0.2028	0.50607	-0.14068	0.56305
Beam Line 2 Bottom	-884.171	-5.45	-1026.23	-0.17931	0.53776	-0.19968	0.60101
Beam Line 3 Bottom	-44.2482	-215.8	-1353.84	-0.03418	0.51835	-0.26288	0.58221
Beam Line 4 Bottom	333.777	-5.45	-1314.03	0.023515	0.56718	-0.2793	0.63265
Beam Line 5 Bottom	626.658	-5.45	-1203.8	0.073216	0.5842	-0.2529	0.64078
Beam Line 6 Bottom	884.946	-5.45	-1027.11	0.1144	0.60269	-0.21184	0.64899
Beam Line 7 Bottom	1134.38	-215.8	-740.282	0.16681	0.58612	-0.14051	0.62539
Beam Line 8 Bottom	1134.53	-215.8	740.393	0.16893	0.58549	0.15105	0.62782
Beam Line 9 Bottom	884.171	-5.45	1026.23	0.11585	0.6016	0.22036	0.65108
Beam Line 10 Bottom	626.116	-5.45	1202.76	0.074046	0.58347	0.2614	0.64362
Beam Line 11 Bottom	333.497	-5.45	1312.89	0.023152	0.56647	0.28934	0.63651
Beam Line 12 Bottom	-44.2482	-215.8	1353.84	-0.03411	0.51842	0.27497	0.58782
Beam Line 13 Bottom	-333.17	-5.45	1311.55	-0.0948	0.54006	0.28726	0.619
Beam Line 14 Bottom	-625.479	-5.45	1201.53	-0.14397	0.53162	0.25611	0.6074
Beam Line 15 Bottom	-1083.46	-215.8	812.664	-0.20505	0.49894	0.15234	0.56053

3.3 MONOLITH OPTICS DEFLECTIONS

For the purpose of this analysis, monolith optics deflections will be considered negligible. The optics are well away from the target where nuclear heating is much less severe. The optics are about 4.3 m long so that the impact of any non radial deformation of the support point will not cause significant angular offset.

4. COMBINED DEFLECTIONS

4.1 MODERATOR COMBINED DEFLECTIONS

To estimate the impact of the MRA alignment pin deflections on the moderator locations, a rigid body model was built using Creo for aligning to the deformed MRA alignment pins. The moderator displacements were then measured to the nominal moderator position to project the MRA alignment pin deformations to the moderator locations, as seen in Figure 4.1 and Figure 4.2. Due to the MRA alignment blocks' design to minimize offset from uniform thermal growth in the XZ plane, the alignment pin deflections have minimal impact in plane but due introduce a vertical offset.

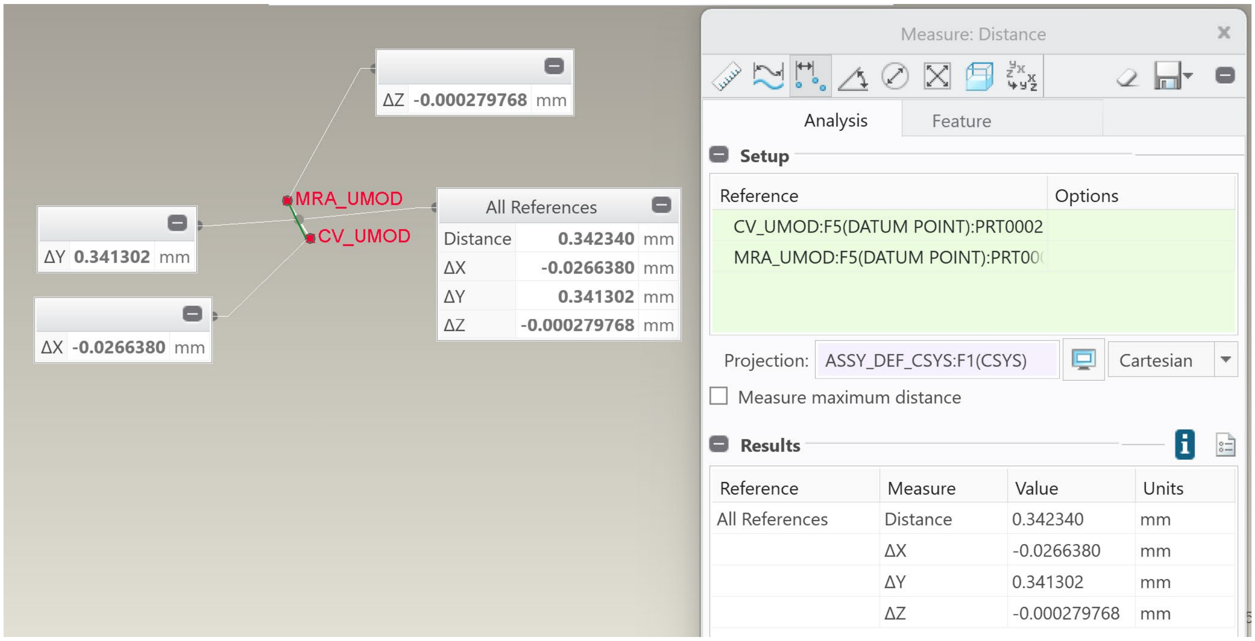

Figure 4.1 Upper Moderator Displacement due to Core Vessel MRA Alignment Pin Deflections

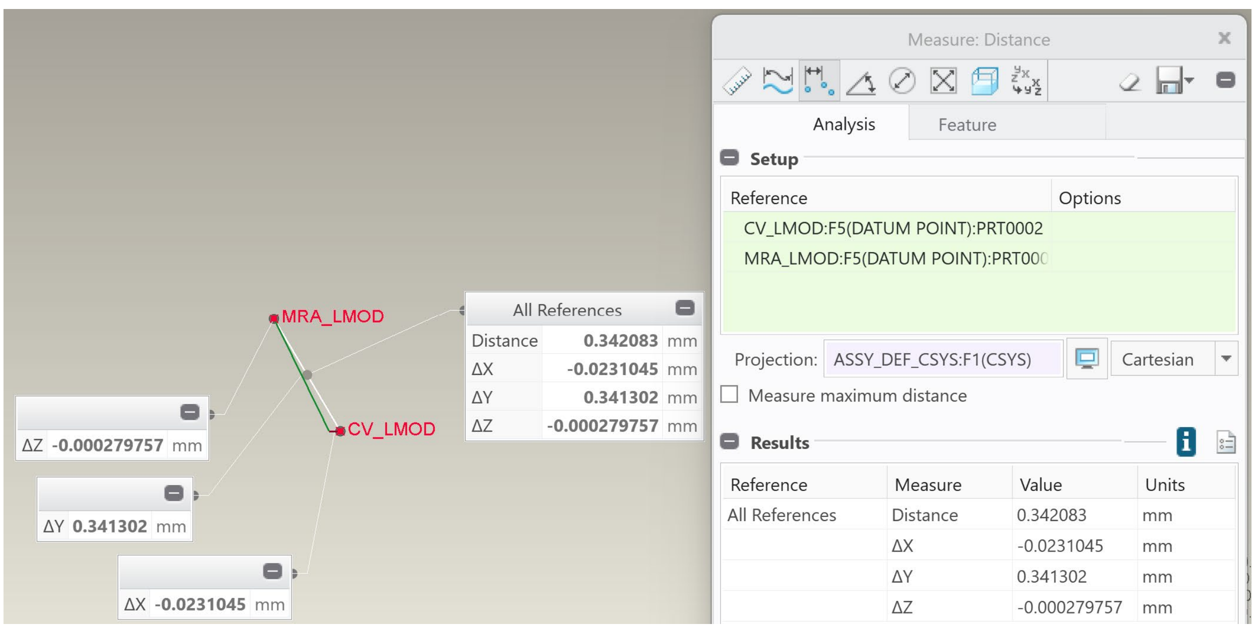

Figure 4.2 Lower Moderator Displacement due to Core Vessel MRA Alignment Pin Deflections

The displacements resulting from the core vessel can then be combined with the displacements that are internal to the MRA. The resulting maximum deflection is only 0.53 mm vertical and 0.16 mm in the XZ plane as seen in Table 4.1. The average vertical deflection is 0.48 mm for the upper moderator and 0.41 mm for the lower. In the XZ plane, all deflections are 0.03 mm or less except for the X direction deformation of the cylinder moderator, which averages 0.14 mm.

Table 4.1 MRA Vacuum Vessel Boss Combined Displacements from MRA and Core Vessel Normal Operating Conditions

		Nominal Position (mm)			Displacement (mm)			
	NODE #	**X**	**Y**	**Z**	**Ux**	**Uy**	**Uz**	**XZ magnitude**
Upper								
U1	**1387493**	-0.497	85.700	-38.733	0.134	0.506	-0.008	0.135
U2	**60962**	-33.081	85.700	19.796	0.109	0.530	0.018	0.111
U3	**1368983**	33.787	85.700	19.796	0.151	0.509	0.023	0.153
U4	**1158278**	-0.290	132.280	38.964	0.139	0.432	0.033	0.143
U5	**1604049**	-34.048	132.280	-19.700	0.128	0.446	0.004	0.128
U6	**1493301**	34.048	132.280	-19.654	0.159	0.431	0.009	0.160
Lower								
L1	**2010272**	72.728	-81.651	0.039	-0.012	0.451	0.015	0.019
L2	**151810**	-43.697	-81.508	54.408	-0.052	0.407	0.028	0.059
L3	**151761**	-43.697	-81.508	-54.408	-0.045	0.415	-0.015	0.048
L4	**2157730**	72.727	-121.349	-0.039	0.003	0.427	0.012	0.012
L5	**153775**	-43.697	-121.492	54.408	-0.044	0.382	0.028	0.052
L6	**152931**	-43.697	-121.492	-54.408	-0.037	0.389	-0.022	0.043

5. RESULTING ALIGNMENT

Now, we will combine the alignment tolerances and deformations detailed in the previous sections. The assembly and installation tolerances place both the moderator and the instrument optics guide entrance at +/- 1 mm from nominal position. The relative deflections from operating conditions in the monolith generally move the moderators and guide entrances in the same direction. The vertical deflection of the guide entrances ranges from 0.50 to 0.60 mm while the moderator vertical deflections range from 0.38 to 0.53 mm. The XZ plane guide entrance deflections are generally in the radial direction and have a negligible impact on alignment. The maximum XZ deflection is 0.16 mm for the upper moderator. Therefore, the normal operational relative deflections can be bound at +/- 0.25 mm from nominal alignment.

If we just add the resulting deflections, the worst case combination would give +/- 2.25 mm from nominal alignment. However, previous neutronic alignment studies have shown that neutron performance is far more sensitive to rotations than translation. Therefore we will conservatively consider the +/- 1 mm offset for the moderators to be applied as a pure rotation for the worst case scenario. The remaining +/- 1.25 mm offset is considered a translation as the guide optics displacements relative to lengths and core vessel relative displacements do not introduce significant rotation.

6. CONCLUSIONS

The alignment of the MRA moderators and instrument optics guide entrances is critical to neutronic performance of the STS facility. The deviations from ideal alignment are influenced by assembly tolerances, installation tolerances, and relative displacements during operation. The worst case alignment for neutronics performance has been shown to be a rotation of +/- 1 mm on the moderators and a translation of +/- 1.25 mm. This worst case alignment is slightly better than the worst case alignment found in the preliminary MRA deflection and tolerance study of +/- 1 mm rotation and +/- 1.5 mm translation [6]. Therefore, the preliminary worst case alignment neutronics analysis [7] will not be updated since it bounds the impact from the worst case alignment found in this study.

7. REFERENCES

[1] "Cylinder Moderator Prototype Manufacturing Report," S07030200-TRT10000.

[2] "Tube Moderator Prototype Report," S07030200-TRT10007.

[3] "Standard Monolith Insert Requirements Document," S04030200-SRD10000.

[4] "Structural Analysis of the Moderator Reflector Assembly," S03040000-DAC10013, 2026.

[5] "Core Vessel and Core Vessel Shielding Structural Analysis," S03060000-DAC10011.

[6] "Preliminary Moderator Deflection and Tolerance Analysis," S03040000-DAC10009.

[7] "Neutronics Performance, Energy Deposition, and Radiation Damage in ORNL's Second Target Station Moderator Reflector Assembly," S03040000-DAC10010.