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Second Target Station Project: Moderator Reflector Assembly Loss of Cooling Water Analysis

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MODERATOR REFLECTOR ASSEMBLY LOSS OF COOLING WATER ANALYSIS

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ABSTRACT

The Moderator Reflector Assembly features cryogenic hydrogen in close proximity to water cooling passages. If the water flow to those cooling passages is lost while the hydrogen flow continues, heat transfer to the hydrogen boundary could initiate freezing of the water passages. The time to the initiation of freezing of water in the Moderator Reflector Assembly upon loss of water cooling is estimated so that freezing can be mitigated.

1. INTRODUCTION

The Moderator Reflector Assembly (MRA) features 2 liquid hydrogen moderators and hydrogen transfer lines to deliver hydrogen from the Cryogenic Moderator System transfer lines to the moderators, as seen in Figure 1.1. The liquid hydrogen in these structures will operate between 18 and 22 K and is vacuum insulated to minimize heat transfer from the surrounding structures to the cold surfaces. The vacuum insulation boundaries are heavily integrated into the MRA structure to improve neutronic performance and to cool the vacuum boundaries from neutronic heating as seen in Figure 1.2.

If the water flow to the MRA is lost, stagnant water will now be present in the MRA cooling passages, presenting the possibility for freezing of the water if sufficient heat transfer to the cryogenic hydrogen occurs prior to restarting of the water flow. Unfortunately, the first European Spallation Source Moderator Reflector Plug suffered catastrophic damage when this hypothesized freezing occurred [1].

This document will estimate the time to the initiation of freezing in the Moderator Reflector Assembly during a loss of cooling event so that guidance can be given to future STS operations on when to release the hydrogen from the Cryogenic Moderator System to prevent the possibility of freezing within the MRA.

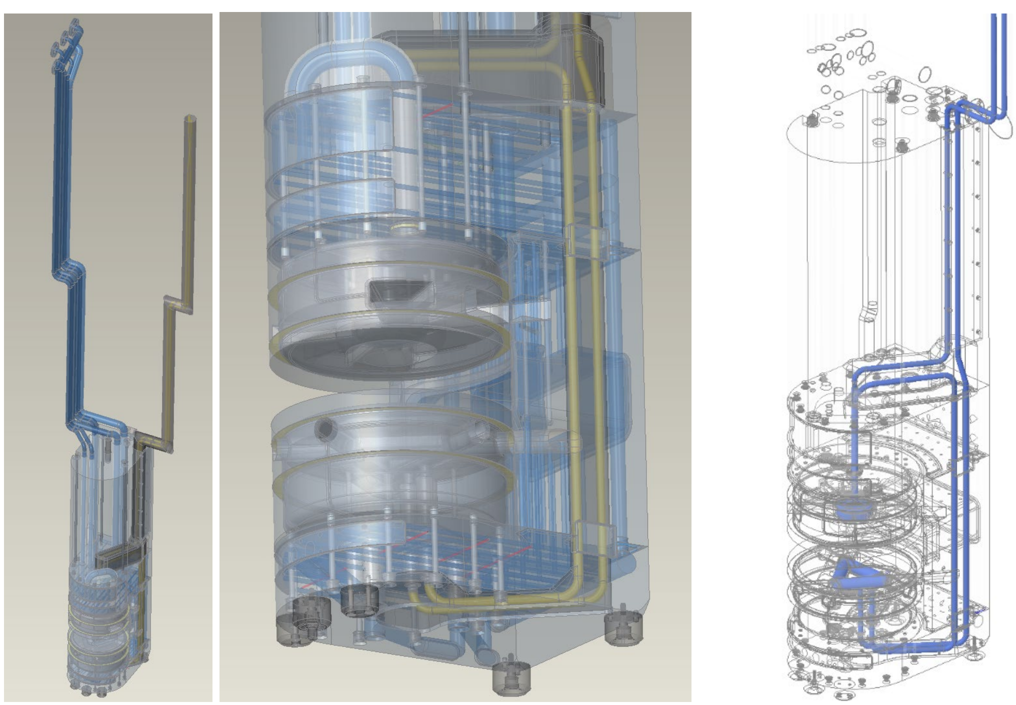

Figure 1.1 MRA Hydrogen Transfer Lines (yellow) Integrated into the MRA (left), MRA Hydrogen Boundary (blue) (right)

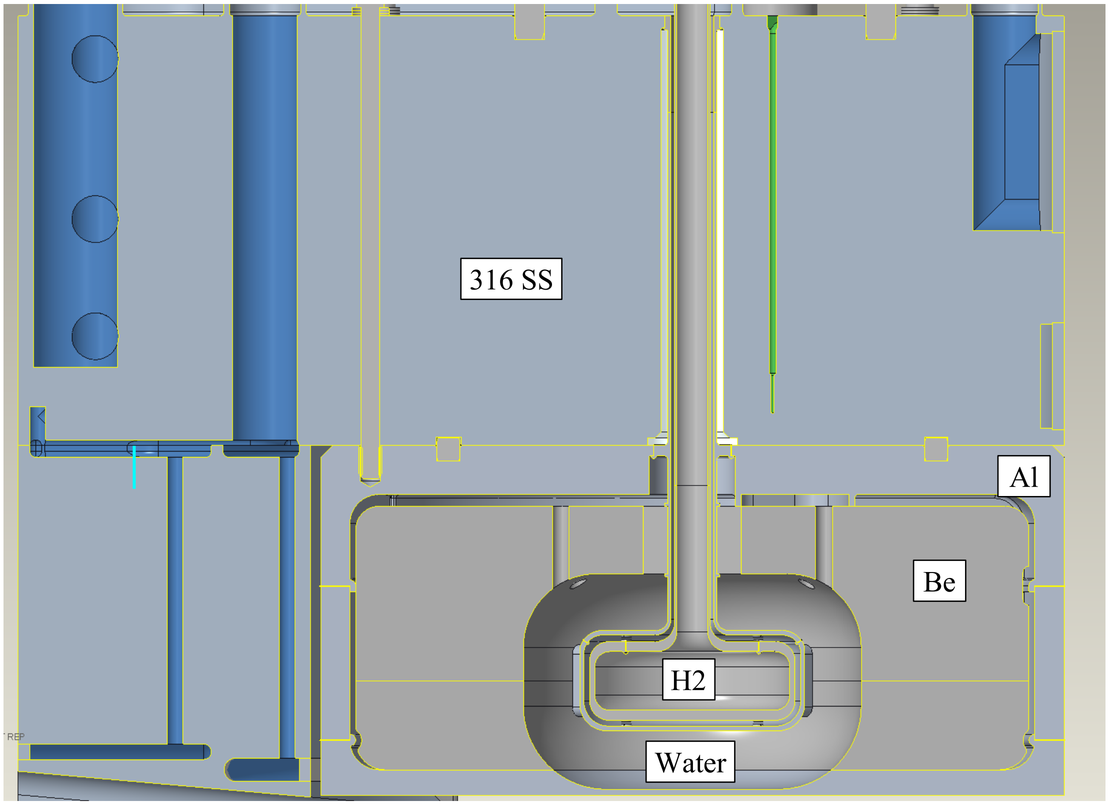

Figure 1.2 Upper Reflector Vessel Cross Section

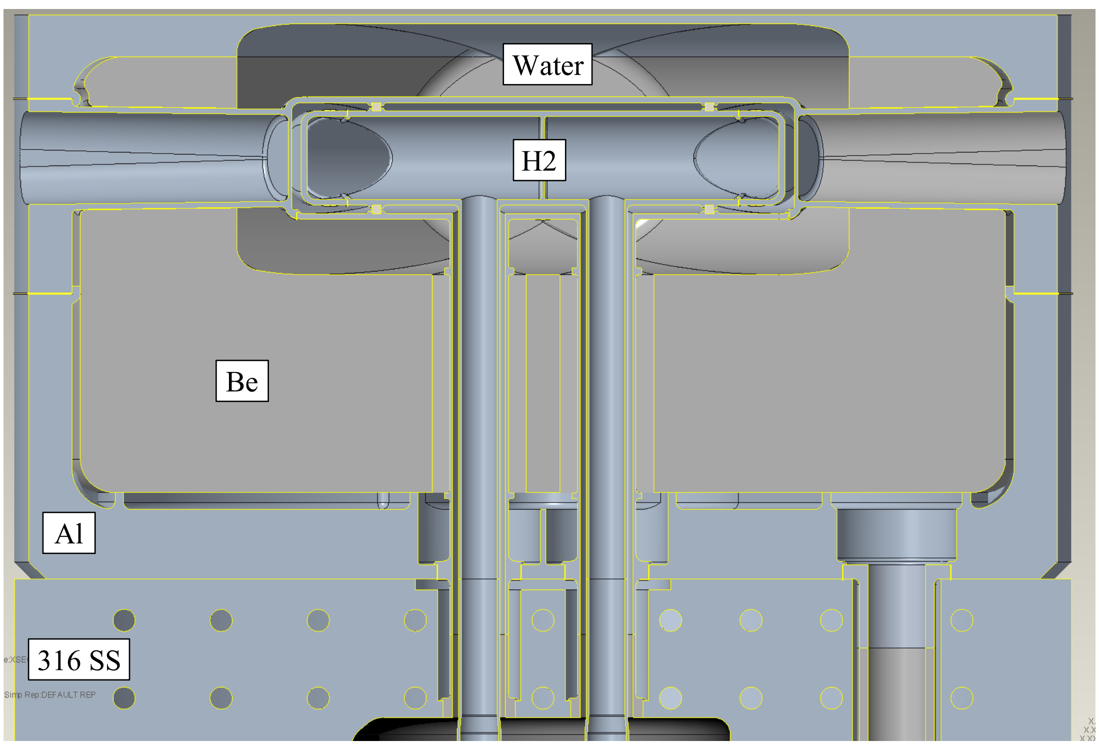

Figure 1.3 Lower Reflector Vessel Cross Section

2. ASSUMPTIONS

The MRA is assumed to be in the unirradiated condition with beam off at the start of the loss of cooling so that the initial temperatures are as low as possible and no decay heat is present.

Freezing is assumed to initiate when the temperature of part of the MRA containing water reaches 0°C. We will not take credit for the heat extraction required to actually freeze the water.

Because of the low heat transfer rates and long time durations, the sections of the MRA will be treated as lumped masses at constant temperature. We will not model the heat transfer details within each section.

Heat transfer rates are calculated at initial beam off conditions and assumed to remain constant. This assumption in conservative as heat transfer will slow down as the MRA cools down.

No heat transfer is assumed between the reflector vessels and the backbone.

The heat transfer occurring in the transfer line is applied to the backbone as the transfer line is welded to the backbone.

3. CALCULATION

The enthalpy change associated with cooling each MRA structure from beam off condition at 32.2°C to 0°C can be calculated once the mass and the heat capacity of each material are known. The static heat loads for the MRA hydrogen boundary from radiation and conduction have been calculated previously [2]. The time to initiate freezing can then be calculated. The minimum time to initiate freezing for an MRA structure is 32.8 hours for the upper reflector vessel as seen in Table 3.1.

Table 3.1 Time After Loss of Water Cooling to Initiate Freezing in MRA Structures

	Material	Mass (kg)	c_p (J/kg-K)	$\Delta H_{32\text{-}0}$(J)	q (W)	$t_{32\text{-}0}$ (hr)
Upper Reflector	Aluminum	18.32	896	5.29E+05		
	Beryllium	17.19	1950	1.08E+06		
	Water	2.56	4112	3.39E+05		
	Total			1.95E+06	16.47	32.8
Lower Reflector	Aluminum	19.71	896	5.69E+05		
	Beryllium	21.08	1950	1.32E+06		
	Water	3.31	4112	4.39E+05		
	Total			2.33E+06	16.85	38.4
Backbone	Stainless	637.97	500	1.03E+07		
	Water	7.95	4112	1.05E+06		
	Total			1.13E+07	43.24	72.8

4. CONCLUSIONS

The Moderator Reflector Assembly features hydrogen boundaries which operate at 18 K within a vacuum insulating boundary in close proximity to water passages, presenting the possibility of freezing water and damaging surrounding structures if the water flow is lost. The minimum time from the loss of cooling to the initiation of freezing for any MRA structure has been estimated to be 32.8 hours for the lower reflector assembly. This amount of time is sufficient for significant evaluation and troubleshooting of the loss of cooling condition; however, due to the severity of damaging the MRA, action to remove the hydrogen from the MRA should be considered after 12 hours without water flow.

5. REFERENCES

[1] Kickulies and Bessler, "Freezing of the Moderator Plug 1 (MRP 1) at ESS," in *ICANS XXV Oral Presentation*, 2026.

[2] Janney, "Moderator Reflector Assembly Hydrogen Static Heat Load Analysis," S03040000-DAC10015, 2026.