OAK RIDGE National Laboratory | SECOND TARGET STATION

Target Loss of Cooling Thermal Evaluation

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8/12/2026

Two charge questions are addressed in this presentation

#2

Has the design been shown to meet the requirements?

#3

Do DACs and other supporting documentation adequately support the final design?

Second Target Station Project: Target Loss of Cooling Thermal Evaluation
S03020000_DAC10001

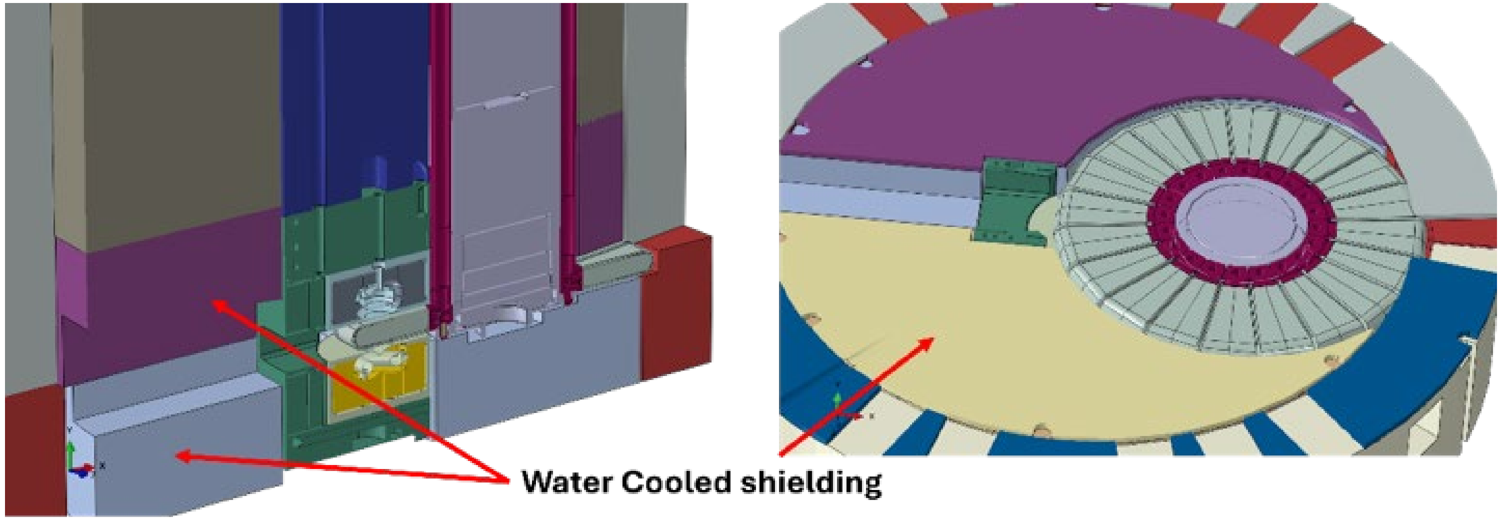
Loss of Cooling Thermal Analysis Objectives and Assumptions

- This analysis was done to bound the mitigated maximum target temperature after a loss of cooling compared to the requirement to be below the tungsten vaporization threshold of 800 °C in steam
- The potential of target segments drooping into the moderators due to a loss of strength at elevated temperature and causing a moderator failure was also evaluated

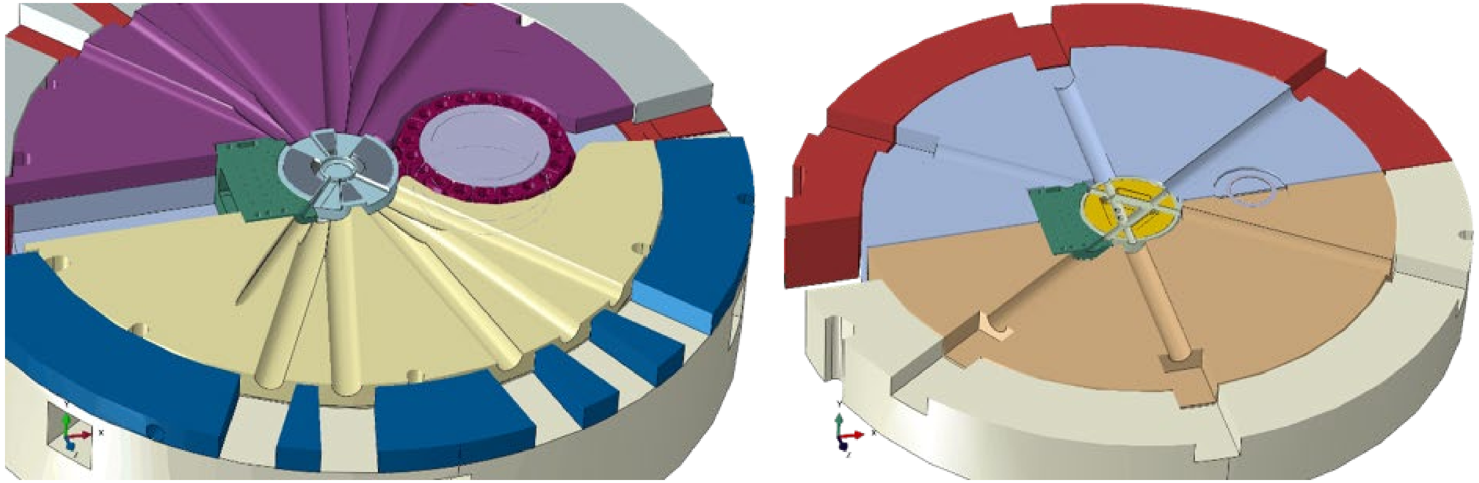
Principal Assumptions

- Proton beam tripped at start of loss of cooling
- All components at normal operating temperature at start of loss of cooling
- No credit for water in any components
- Vacuum mode core vessel operation
- Center Target between the moderator reflector vessels was evaluated as the bounding case because the aluminum reflector vessels have a much lower emissivity than the steel shielding.
- Simplified models were used with conservative assumptions.

Assembly with 20 targets, MRA and Core Vessel shielding



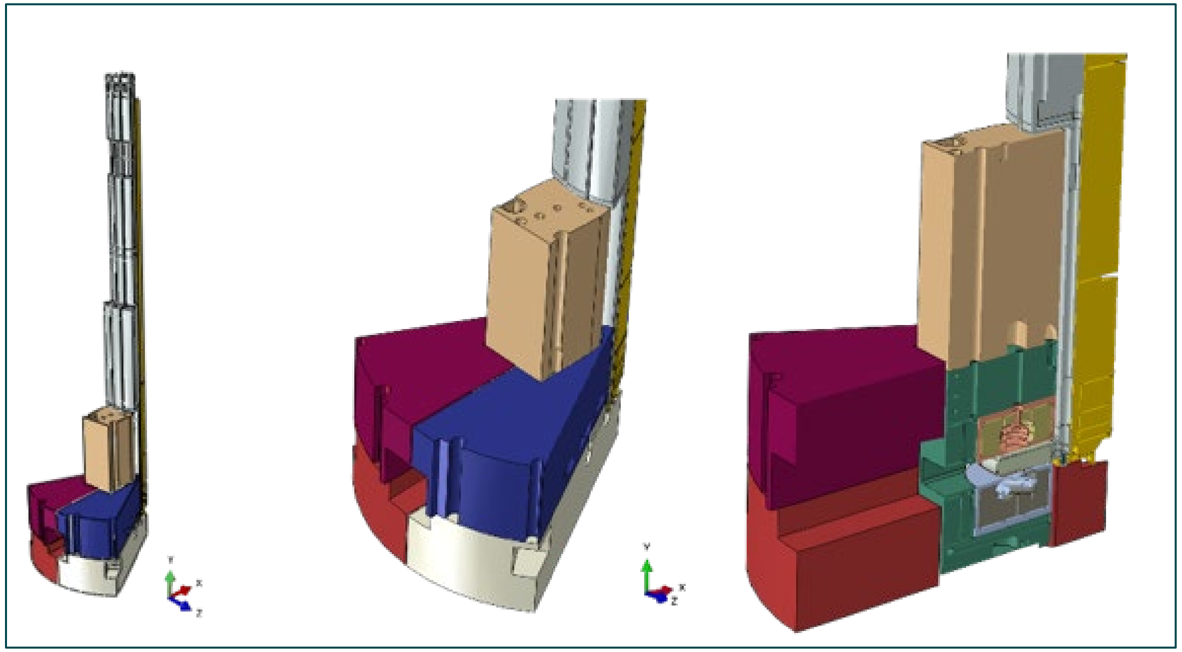
Initial model z=0 cut and y cut above targets



Initial Model view cut at the upper and lower beamline center elevations

Abaqus Analysis model

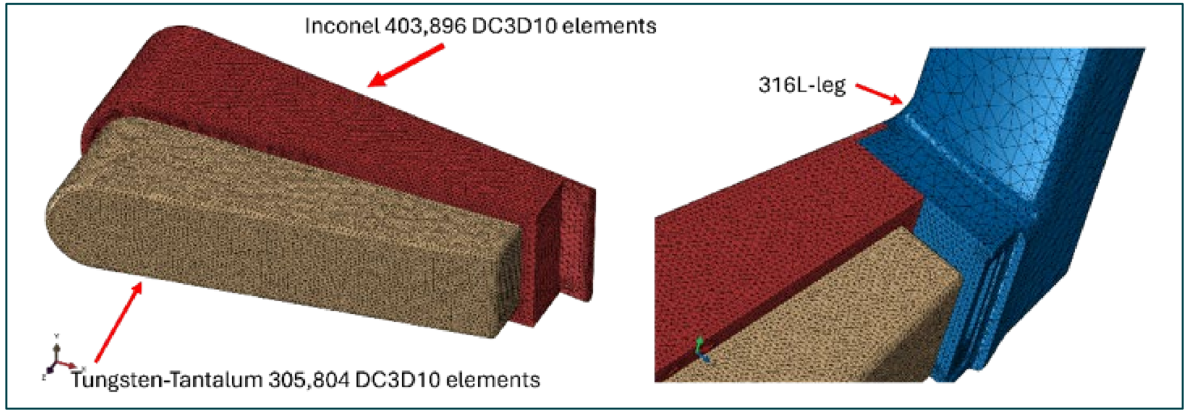
- A model was made to evaluate a target centered between the moderators which was expected to have the lowest thermal radiation from the top and bottom surfaces due to low aluminum emissivity
- The model included a 54-degree wedge centered on the shaft axis and the proton beam axis which includes the target location centered on the moderators and the nearest neighbors on each side
- Bounding calculation made by not accounting for rotation to regions with higher steel emissivity
- Only the four water cooled shielding blocks close to the targets were retained



Analysis Model 54° slice including 3 Target segments centered on MRA

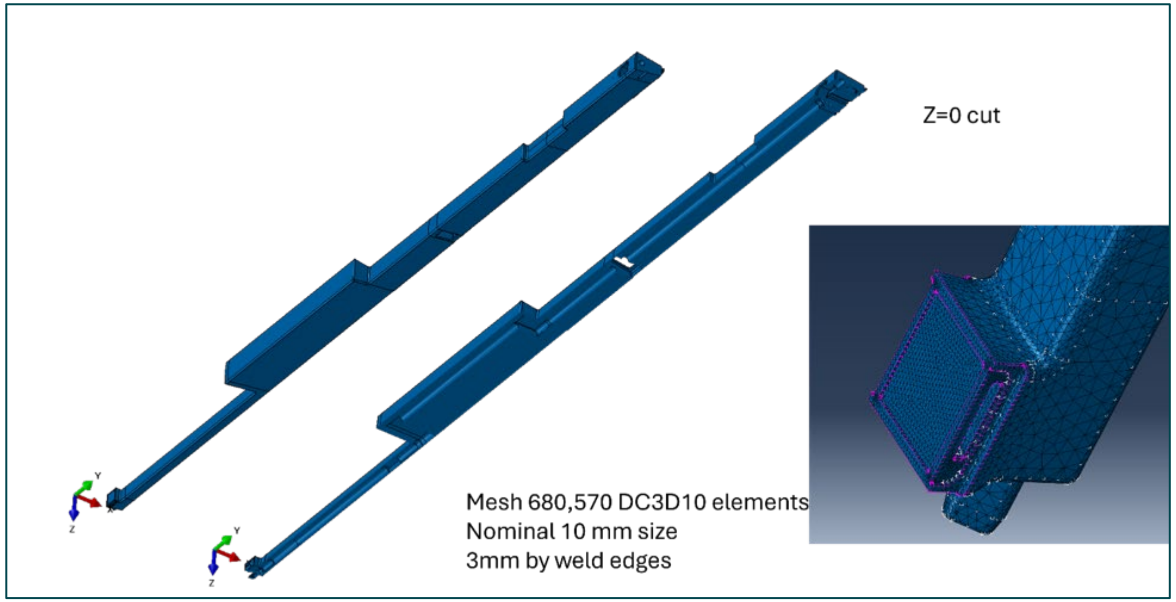
Assembly Segment Parts

Target foot with merged tungsten and tantalum



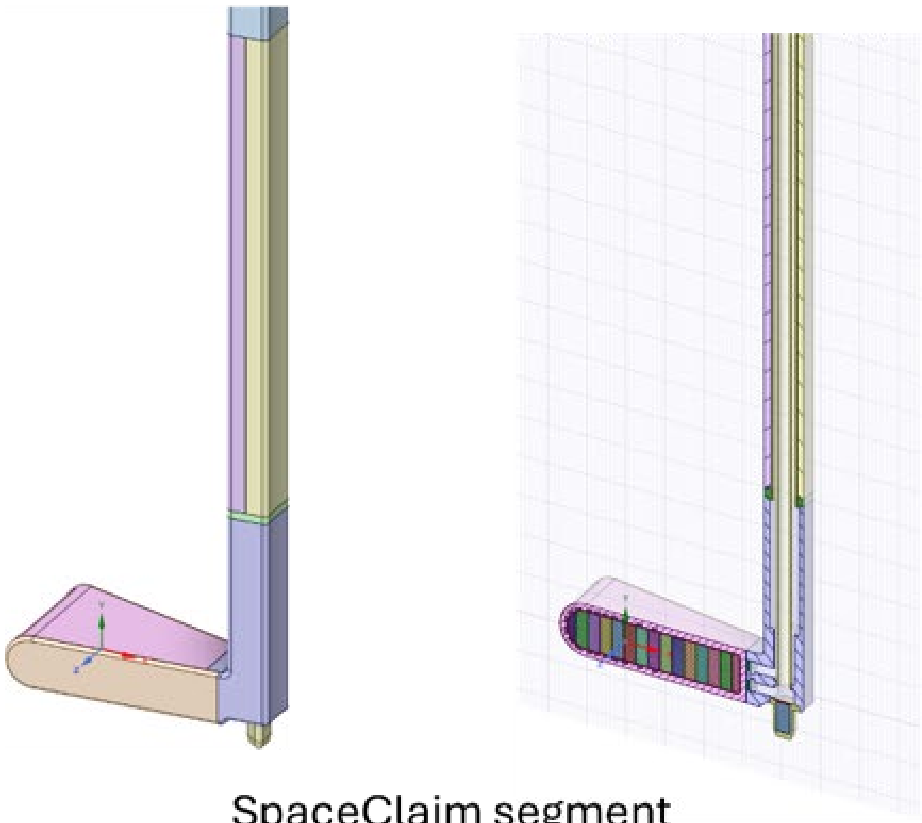
- The “Target Dummy” volume was .00173 m^3 including a tungsten volume of .00159 m^3 and a tantalum volume of .00014 m^3 (8%)
- Perfect thermal contact between Inconel and W/Ta
- 7e5 DC3D10 tet elements

Target segment stalk

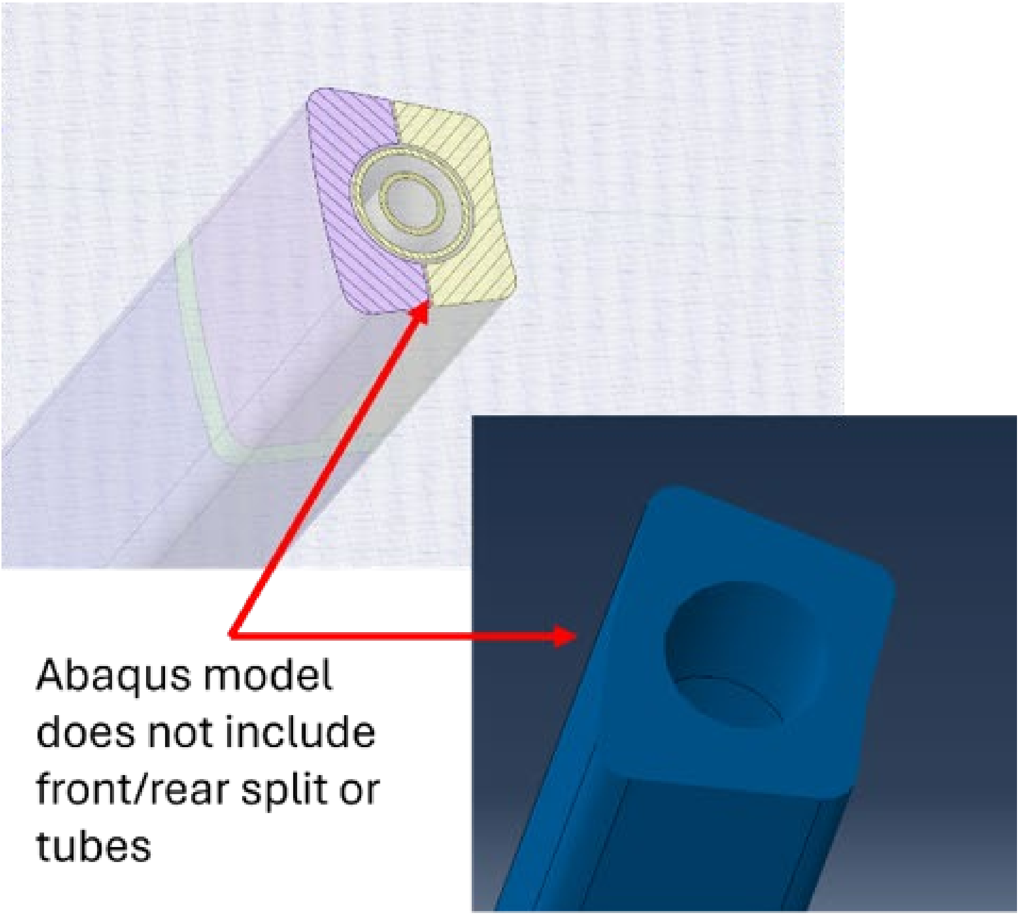


316L material
Internal cooling tubes not included
6.8e5 DC3D10 tet elements

SpaceClaim model of segment and Abaqus simplified stalk



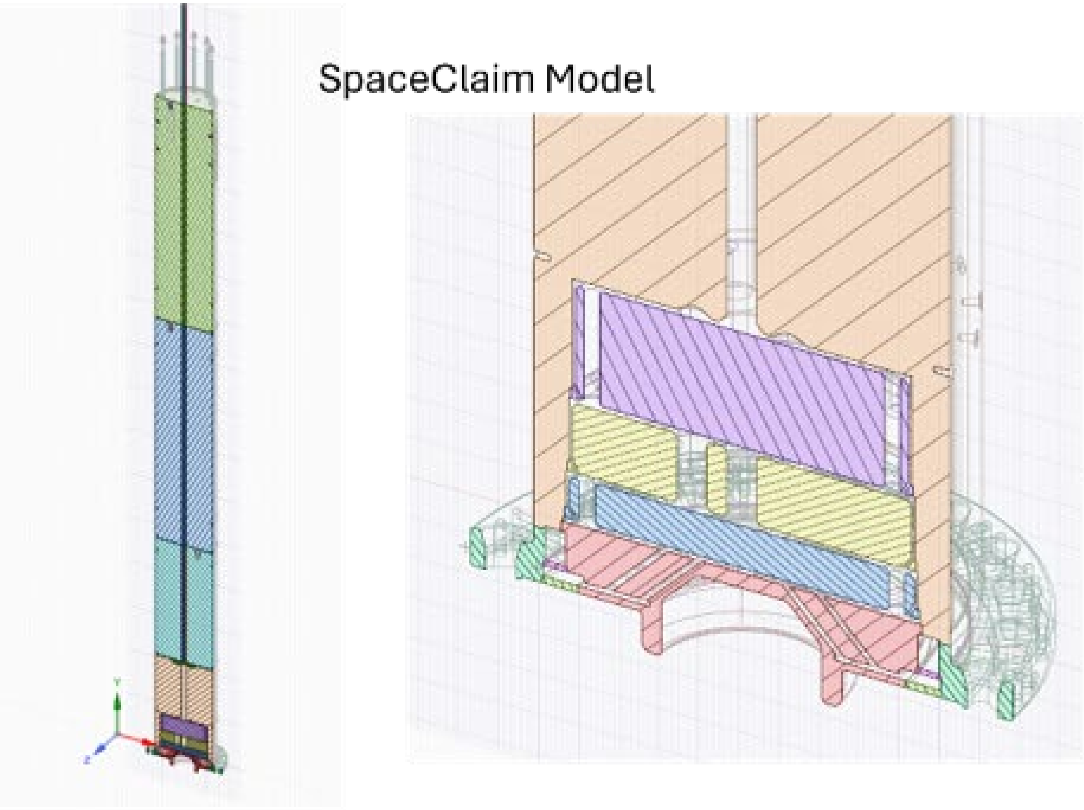
SpaceClaim segment

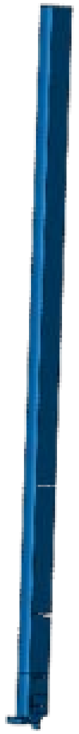


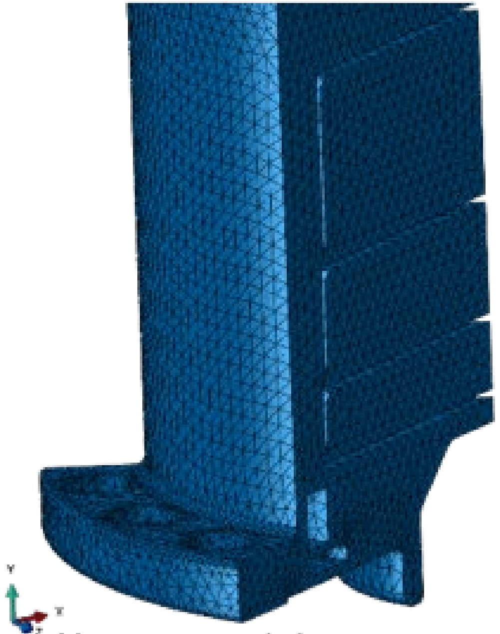
Abaqus model does not include front/rear split or tubes

Shaft SpaceClaim model and simplified Abaqus model with most cooling passages removed in flange

SpaceClaim Model



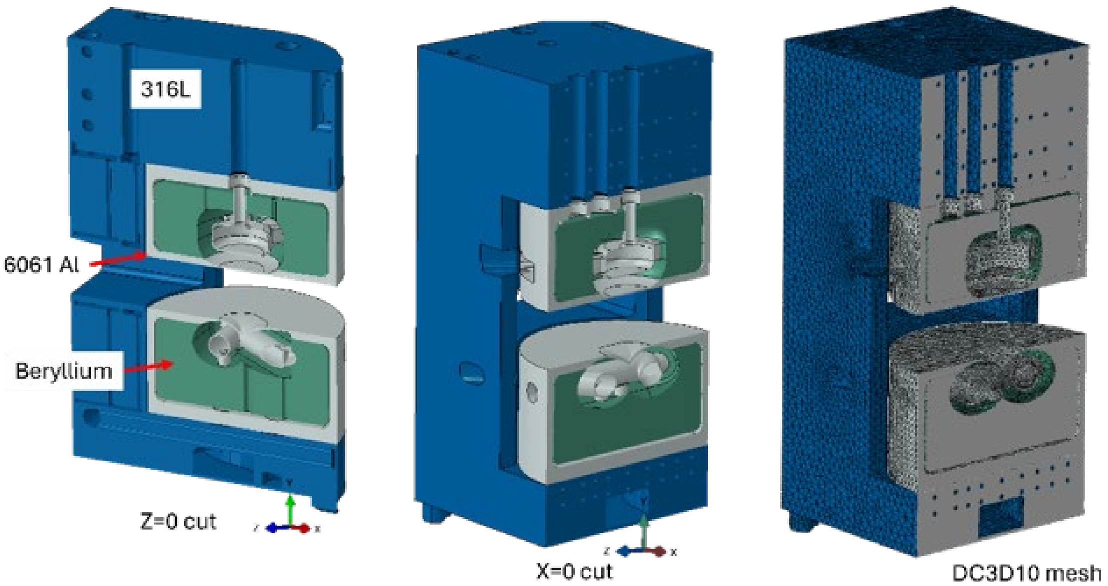




Abaqus model
Simplified without cooling passages
498,508 DC3D10 elements

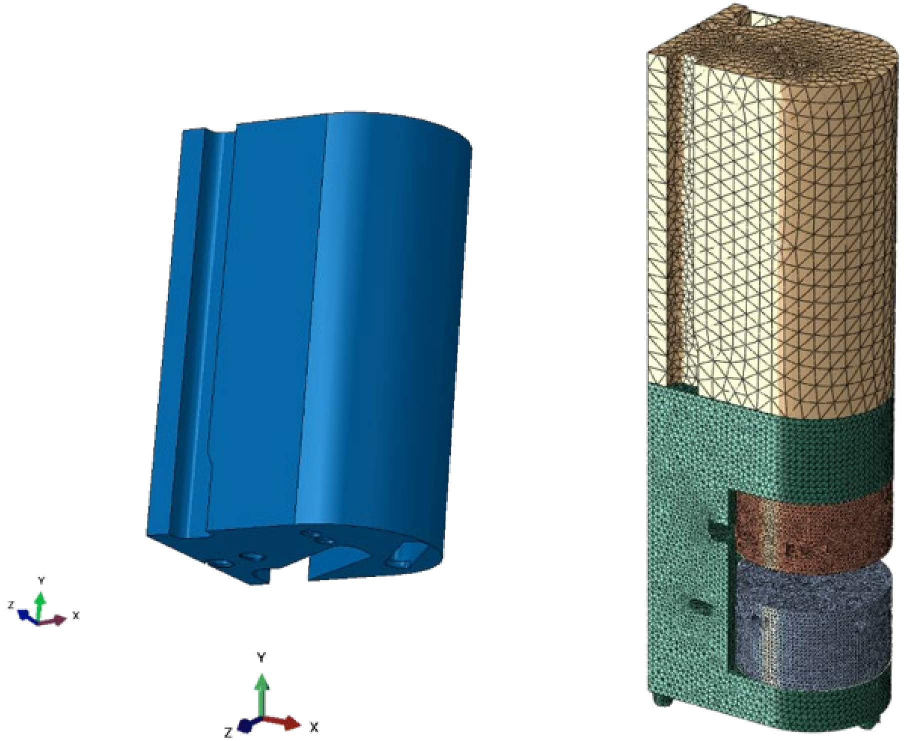
MRA Parts

MRA moderators and 316l Backbone



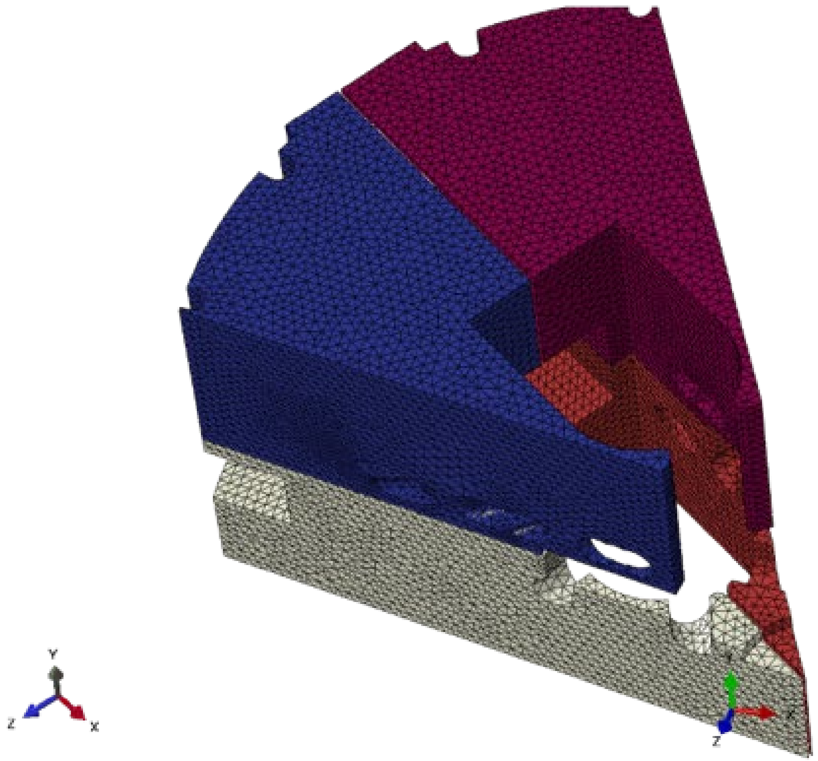
- The model did not include the internal hydrogen vessels or water
- Bolts, tie rods and most piping not included
- Conduction through bottom supports not included

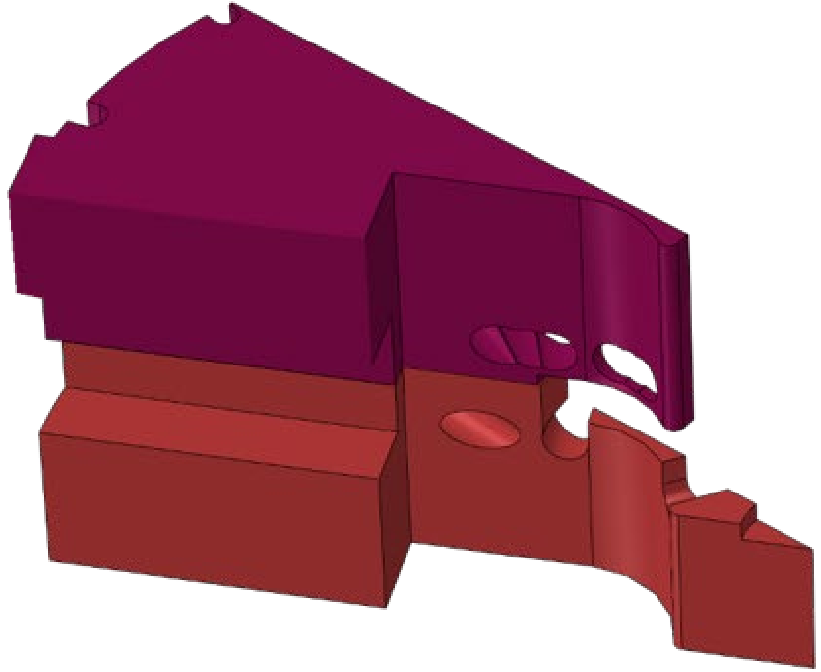
MRA Upper Shielding



Upper shielding modeled as 316L
2.4e6 DC3D10 element for full MRA

Core Vessel 316L Water Cooled Shielding





- Shielding further from the targets was not expected to affect the peak target temperature within 24 hours and were not included.
- The blocks used 193,961 DC3D10 tet elements with a nominal size of 25 mm. Internal cooling passages were not included

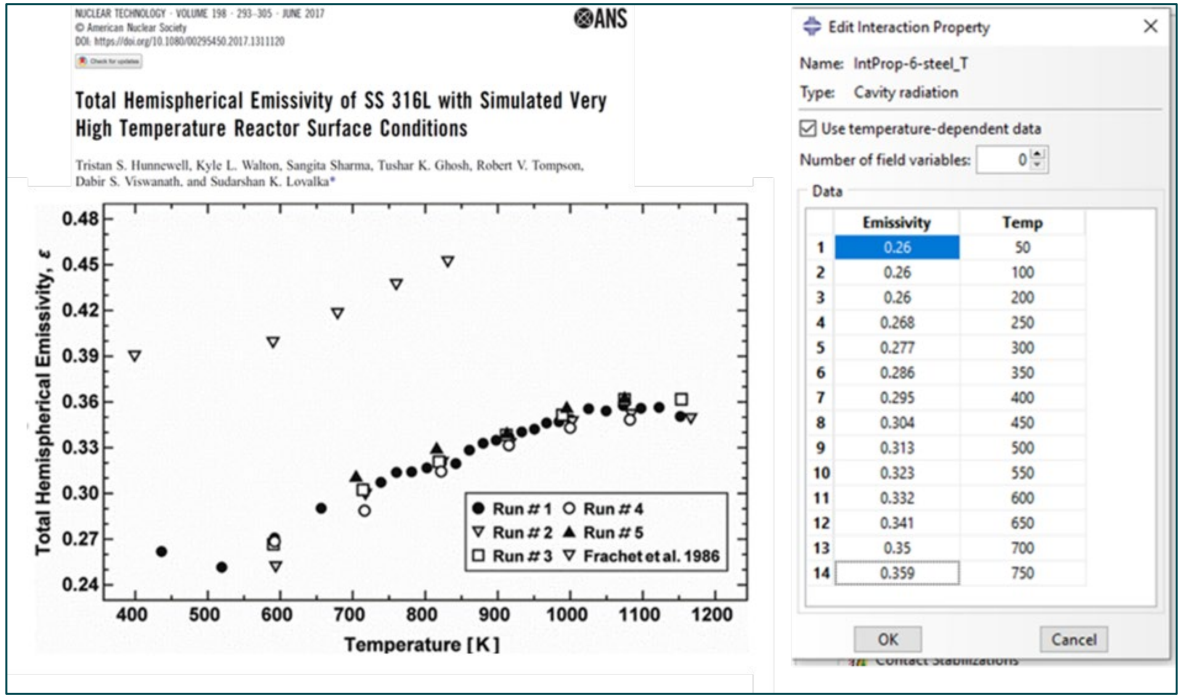
Material Properties and Emissivity’s

Material Properties

Material	Conductivity	Density	CTE/ reference Temperature	Specific Heat
	W/m-K	kg/m^3	/C	J/kg
6061T6 Alumi-num	180	2700	2.36e-5 / 20	896
Beryllium	216	1850	1.15e-5 / 20	1925
316L SS	14.3	7969	1.61e-5 / 20	500
Inconel	9.94	8190	1.28e-5 / 20	425
Target Dummy	87	19.4	1.6e-5 / 20	128.3
Copper Zr	368	8940	1.164e-5/20	385

Emissivity's

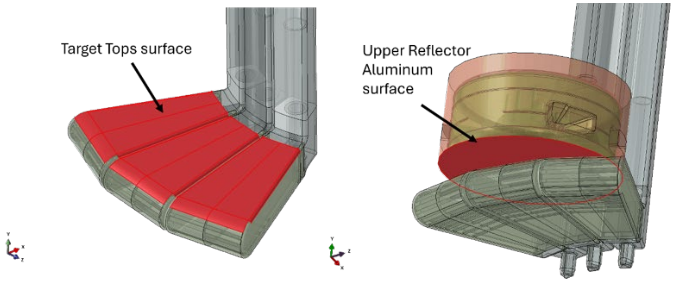
Aluminum 0.05
Inconel 0.24
316L - .24-34 (see figure)

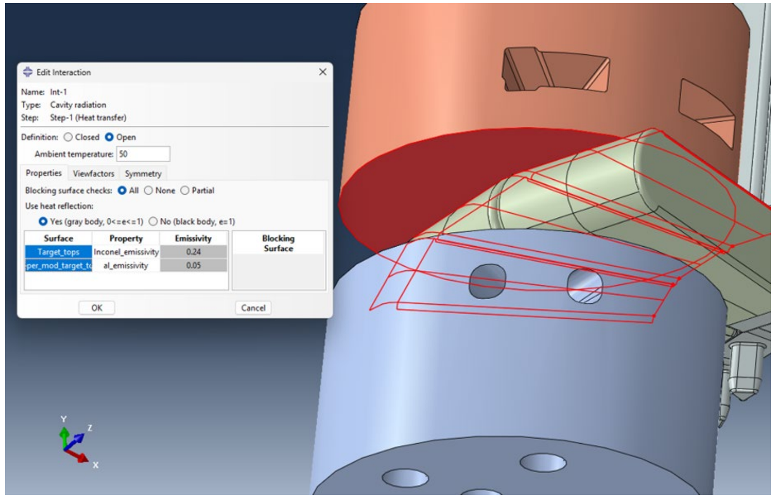


Total Hemispherical Emissivity of SS316 with Simulated Very High Temperature Reactor Surface Conditions. June pp293 305, s.l. : American Nuclear Society, 2017, Vol. 198.

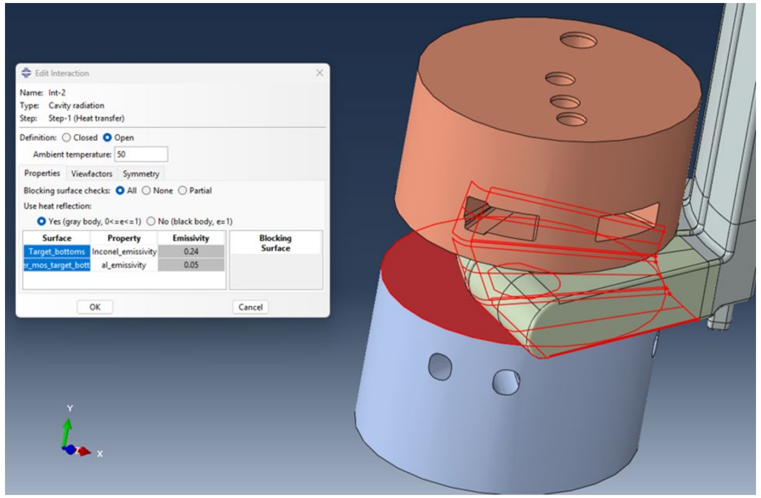
Target foot thermal radiation – Abaqus open cavity model used for all cases with 50°C ambient temperature assumption

Target tops to Upper Moderator

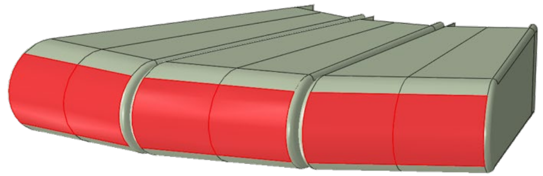


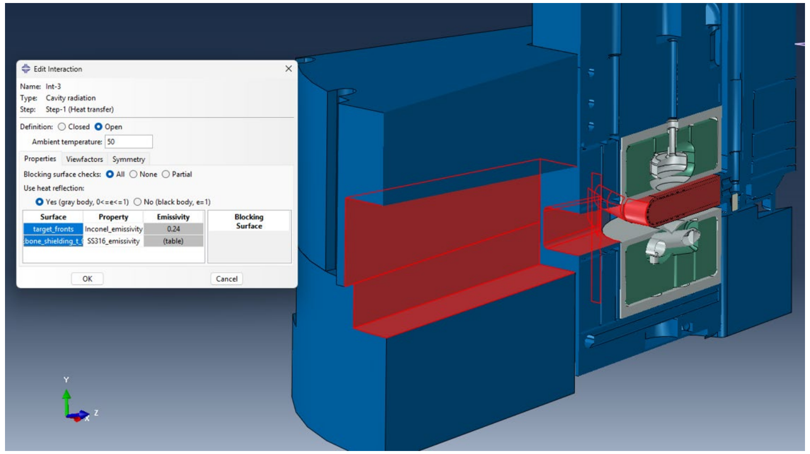


Target bottoms to lower moderator

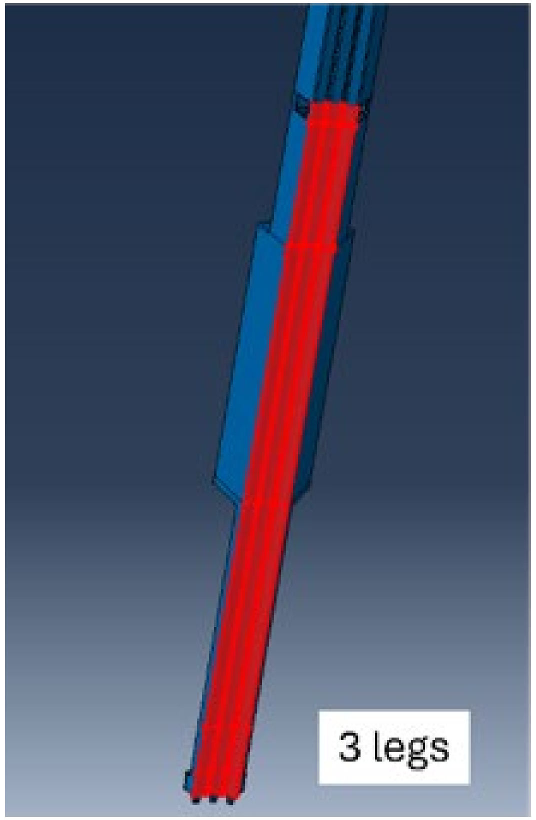


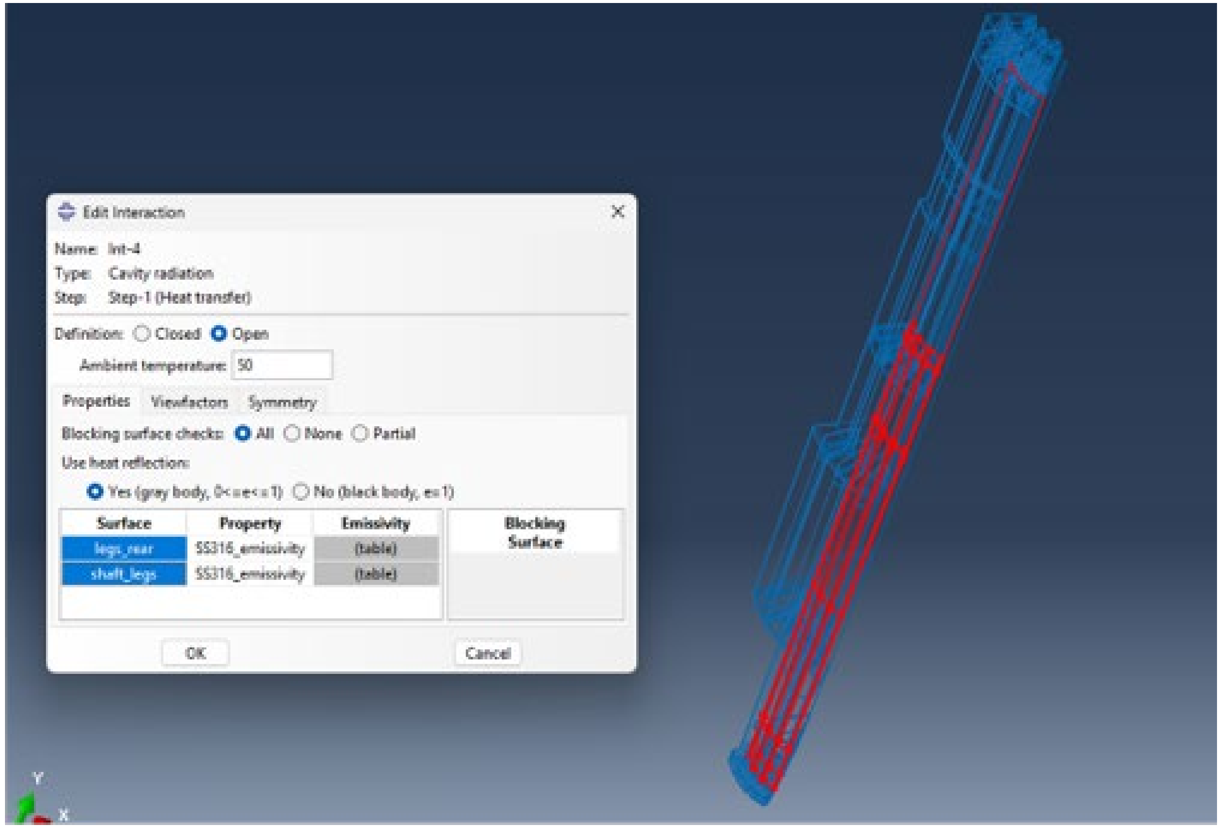
Target Front to PBW channel





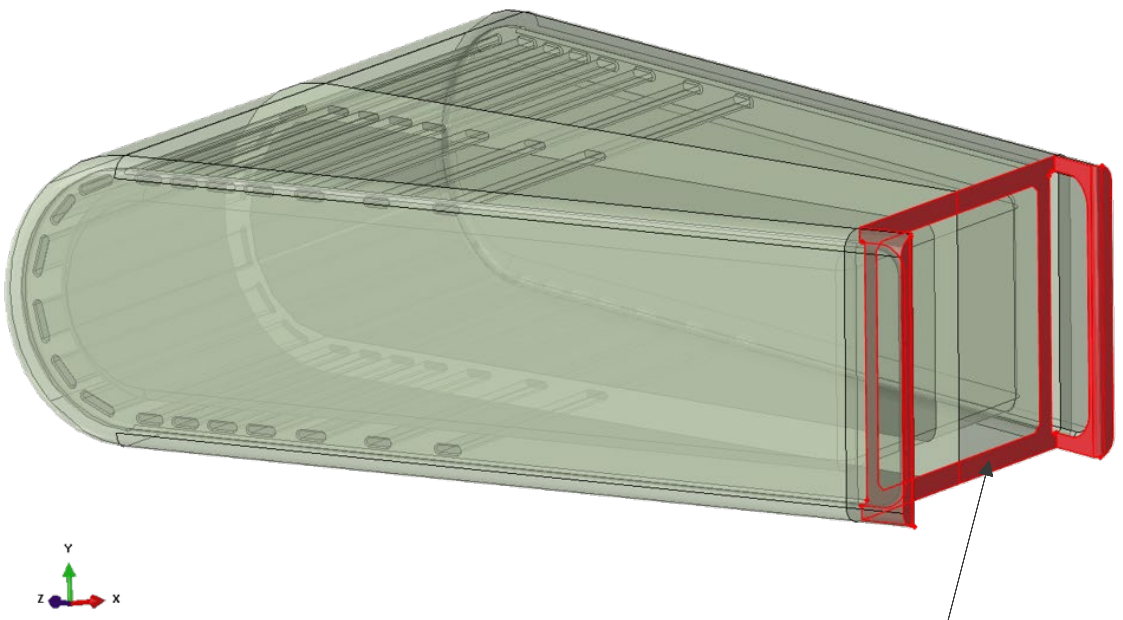
Target stalk to shaft thermal radiation interaction.





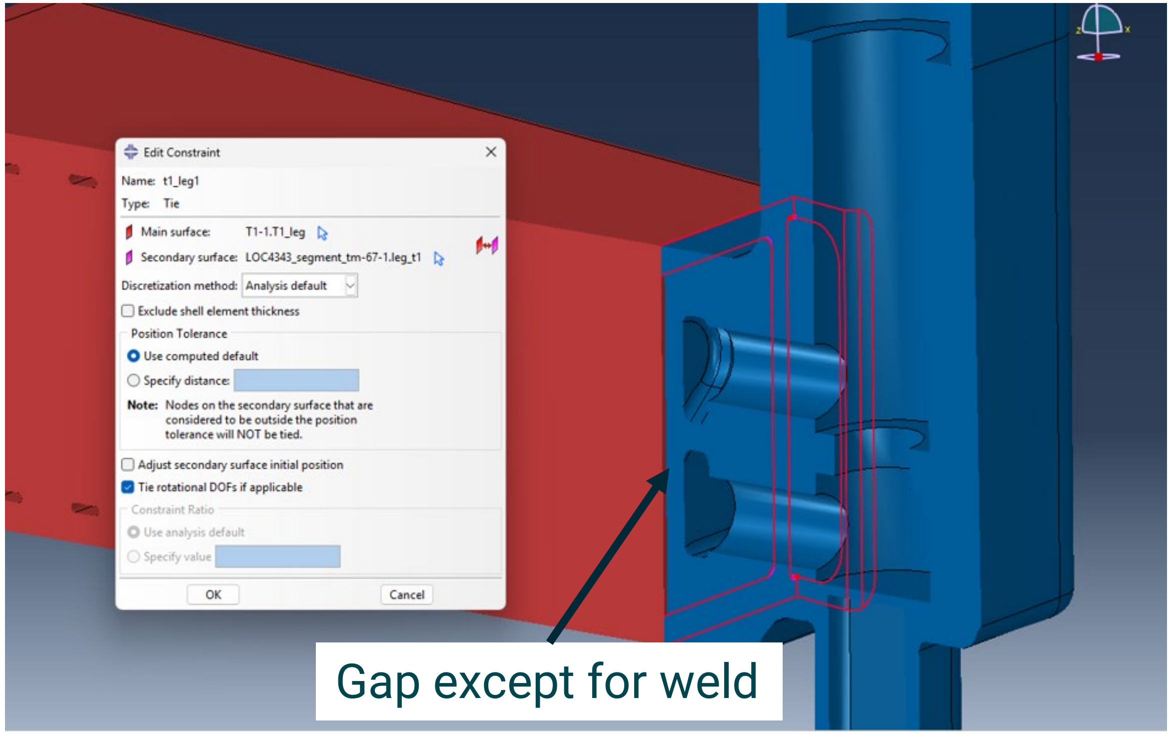
Segment typical tie constraint

Inconel to Stalk weld surface



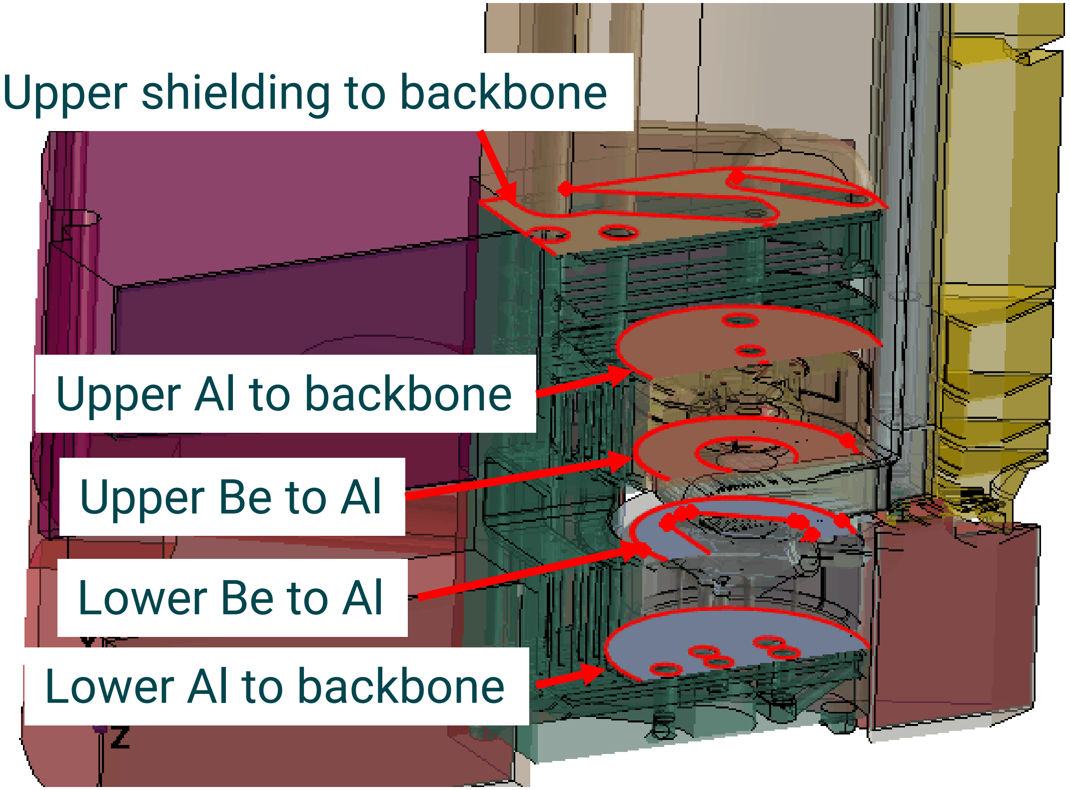
Tie surface for weld

Inconel to Stalk tie joint

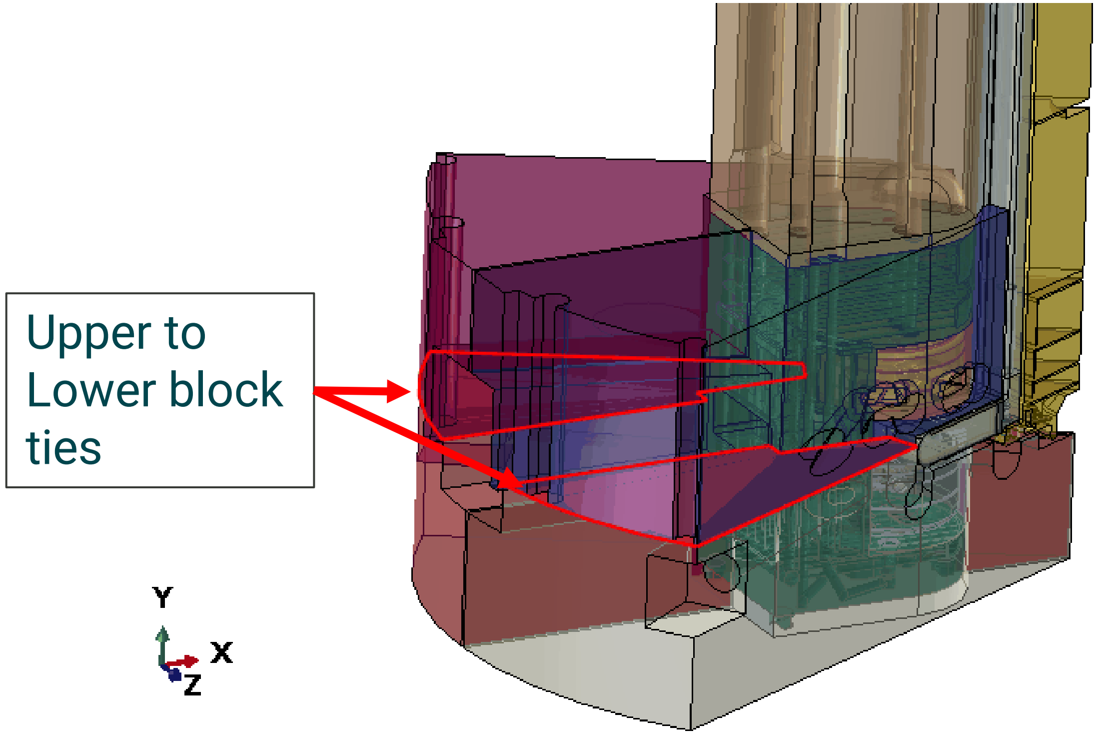


Surfaces tied for thermal analysis

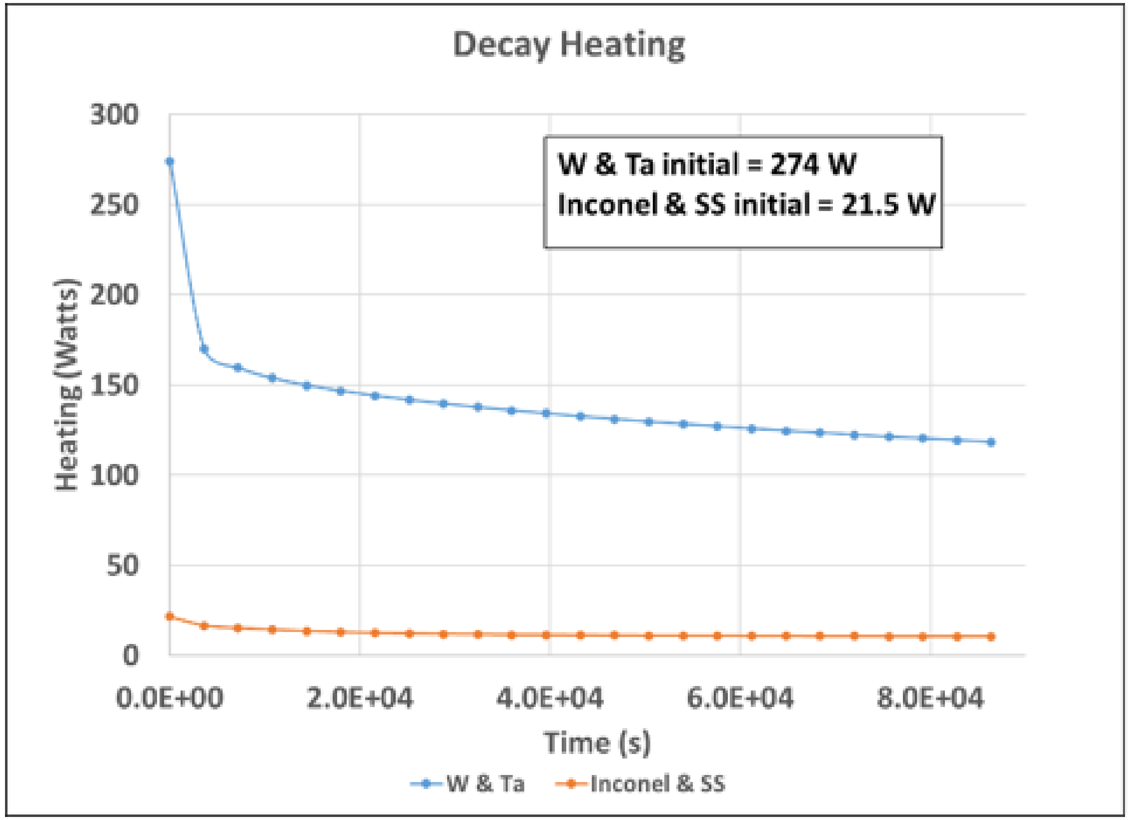
MRA thermal tie surfaces

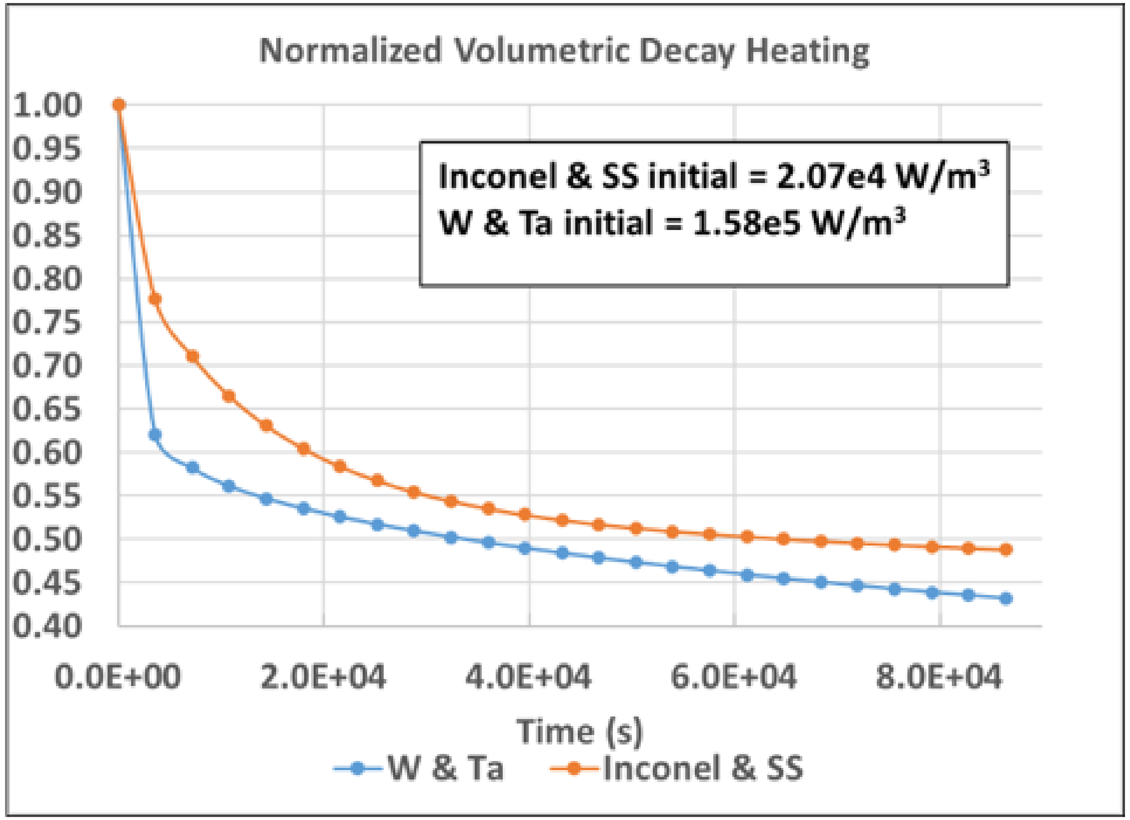


Water Cooled Shielding tie surfaces



Single target segment decay heat (W) and normalized volumetric decay heat versus time (s)

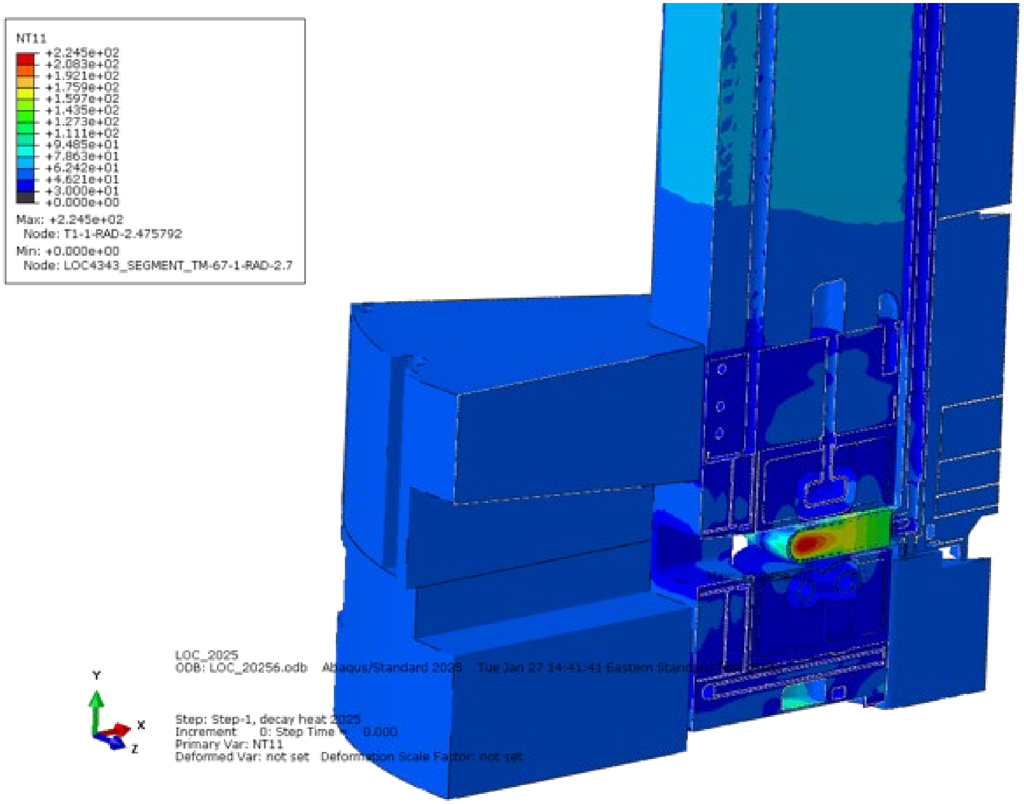




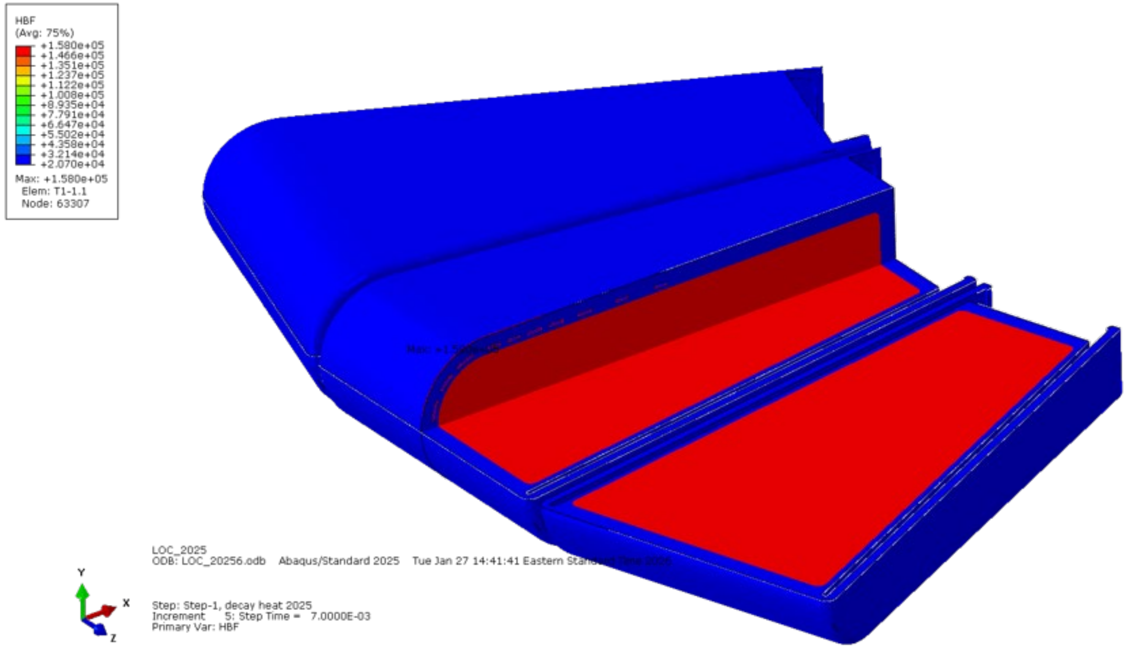
McClanahan, T. Neutronics - Decay heat & radionuclide Inventory. 2015 (data as of April, 2025). S03120100-TRT10012.

Initial Temperature distributions and Volumetric Decay heat immediately after loss of cooling

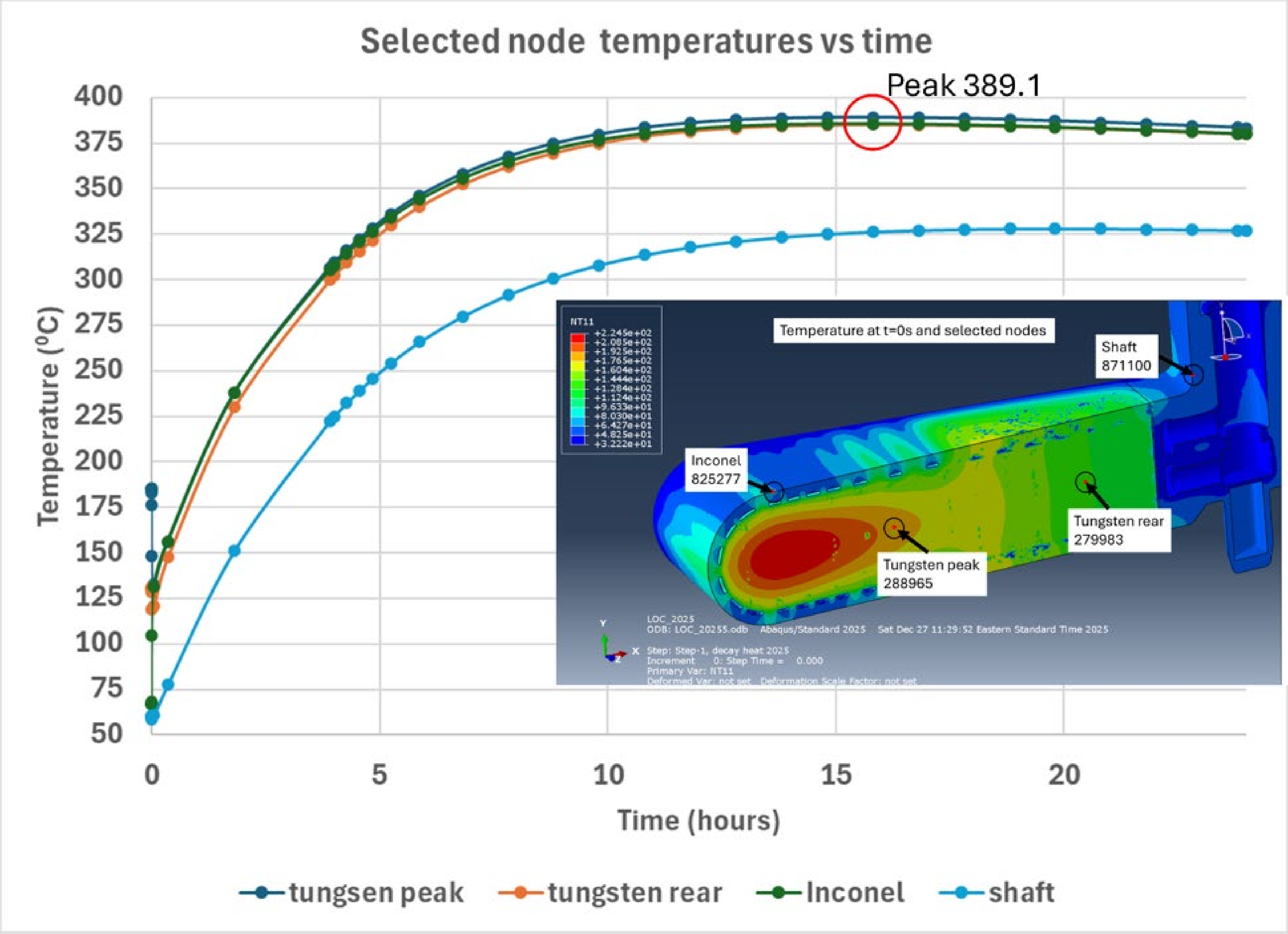
Initial Temperatures – 229 °C peak in tungsten



Decay heat at 7 ms – peak 1.58e5 W/m³

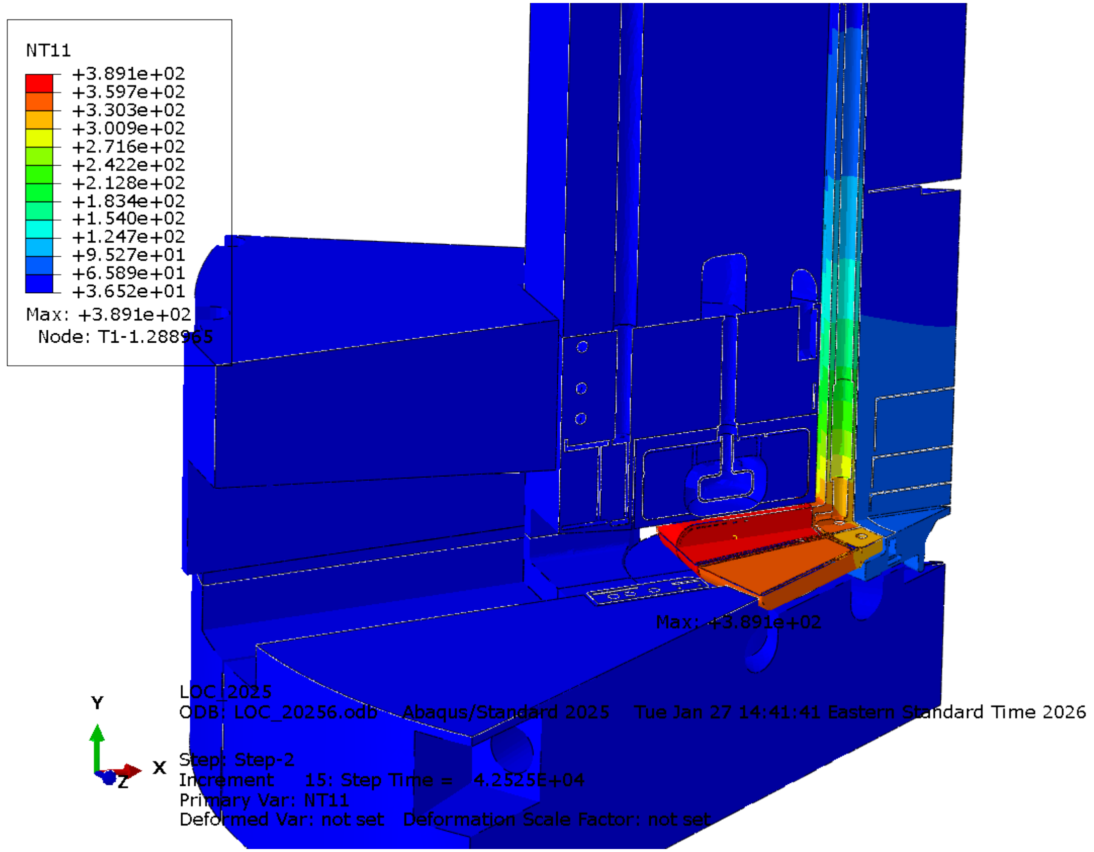


Temperature vs. time for selected nodes with peak of 389 °C at 15.8 hours

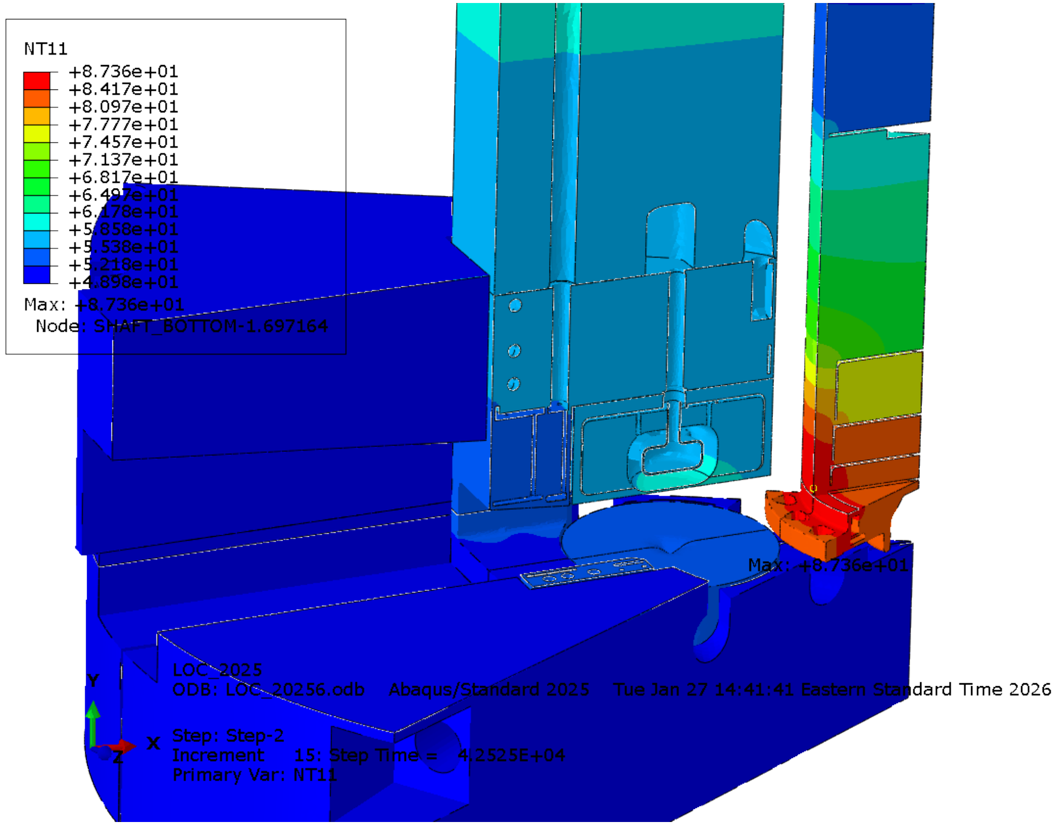


Temperatures at 15.8 hours (Step 15 @ 4.2525e4 seconds)

All with 389.1 °C peak in central target tungsten

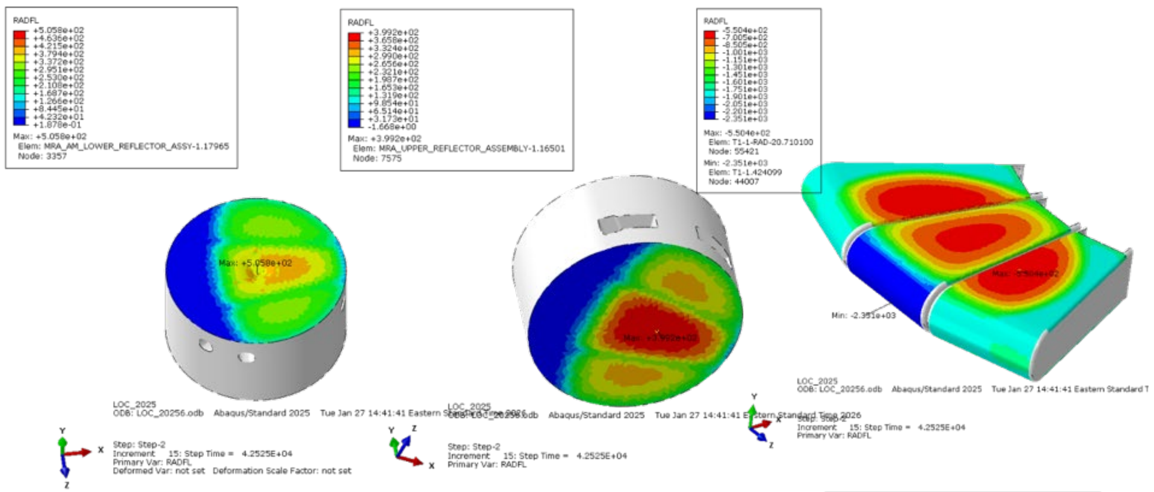


Without segments peak 87 °C in Shaft flange



Thermal Radiation and Target heat fluxes at 15.8 hours

RAD flux to reflector vessels and from targets

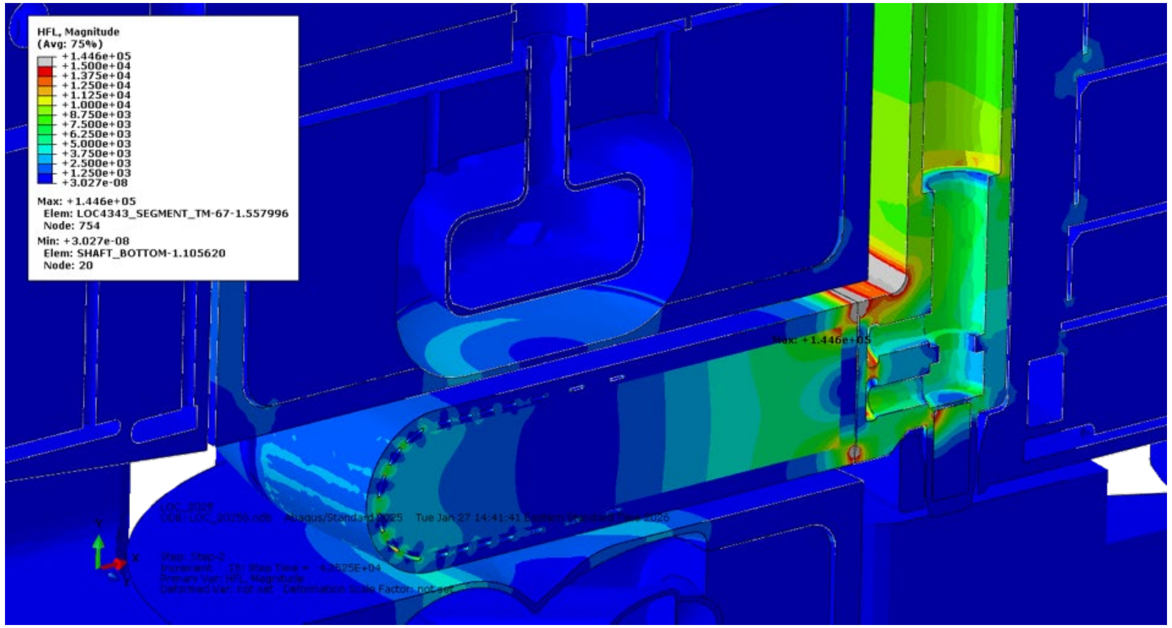


Lower MRA RADFL
Peak 506 W/m²

UPPER MRA RADFL
Peak 506 W/m²

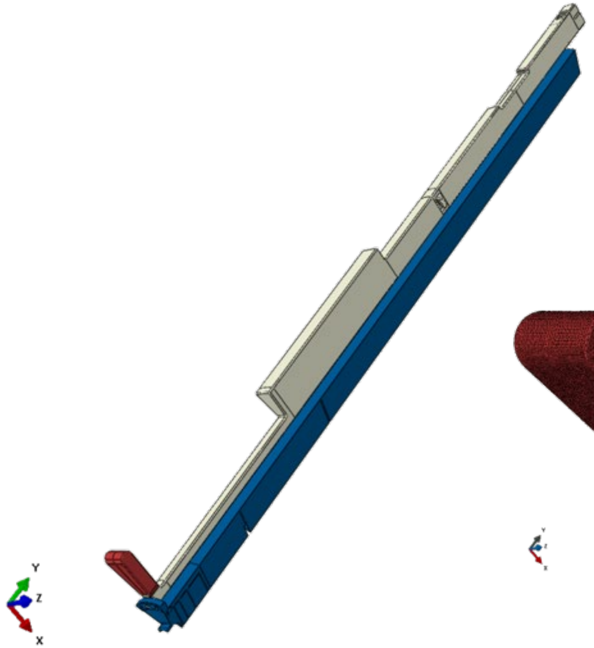
TARGET RADFL
MAX -506 W/m² (TOP)
MIN -2351 W/m² (T1 front)

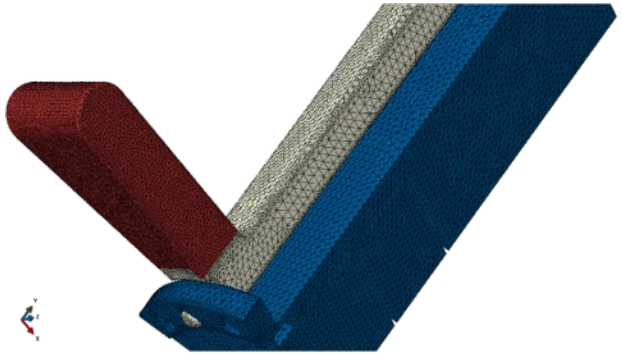
Heat Flux at 15.8 hours with 1.5e4 W/m² scale maximum



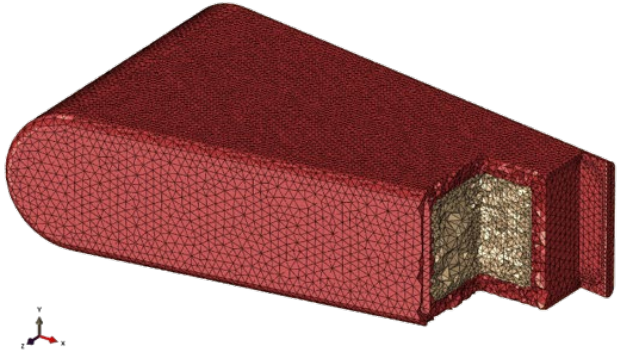
Structural Analysis for segment with peak temperatures

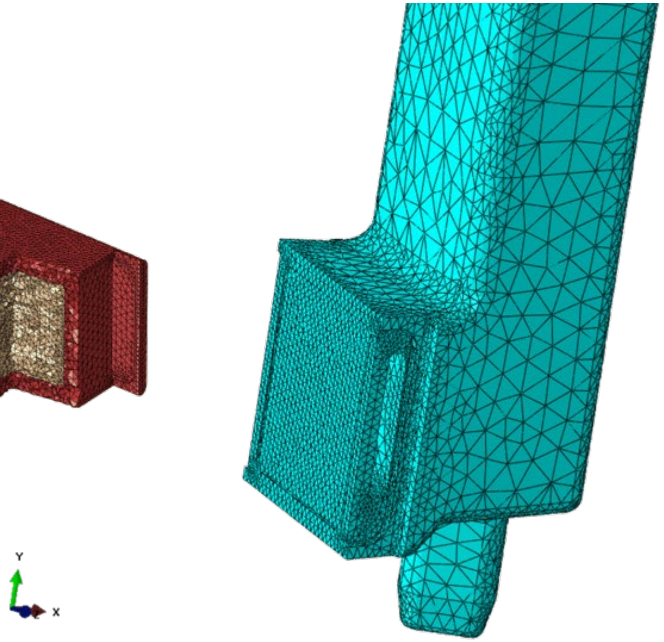
Model to evaluate target deflection



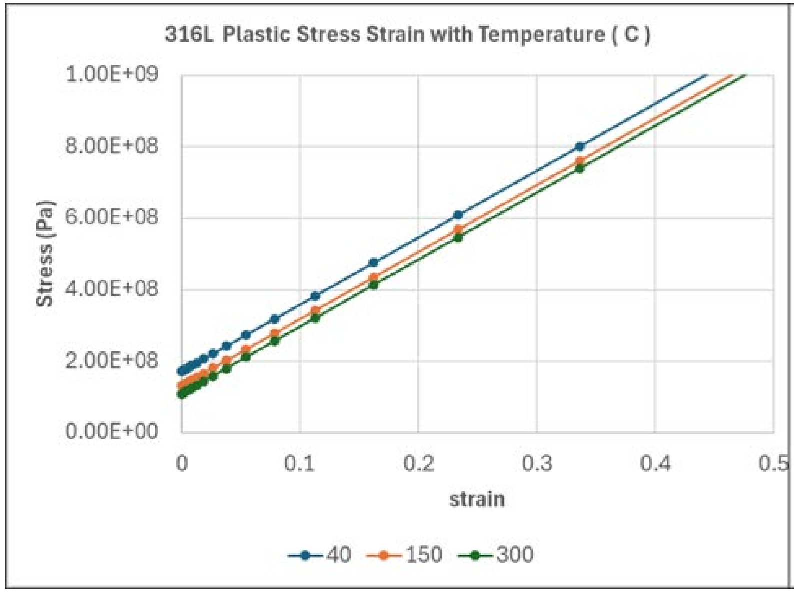


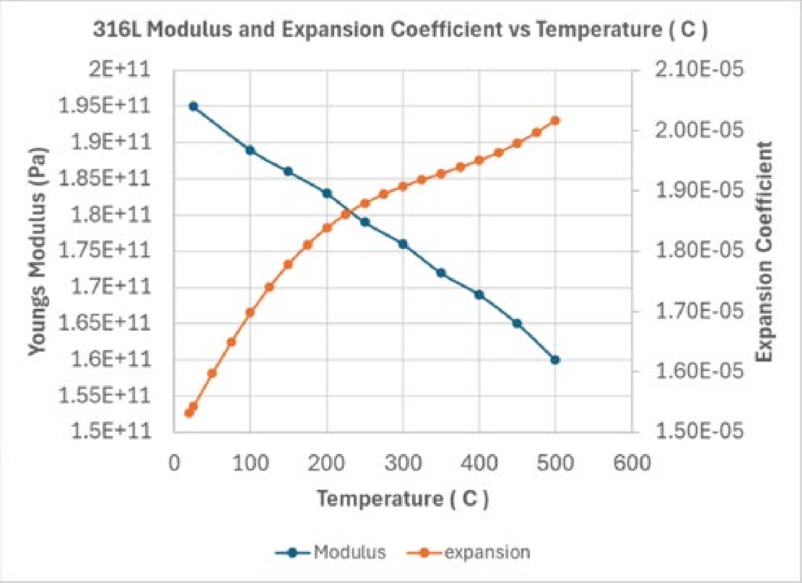
Mesh models with C3D10 elements

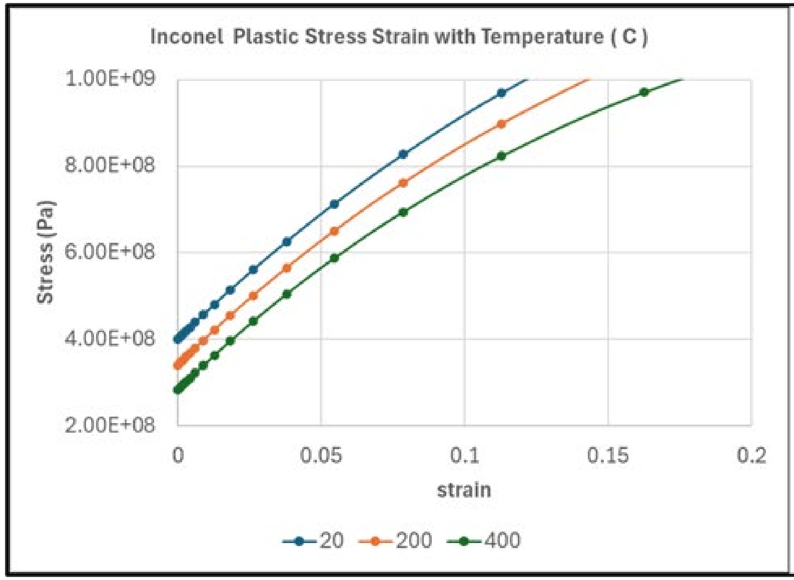


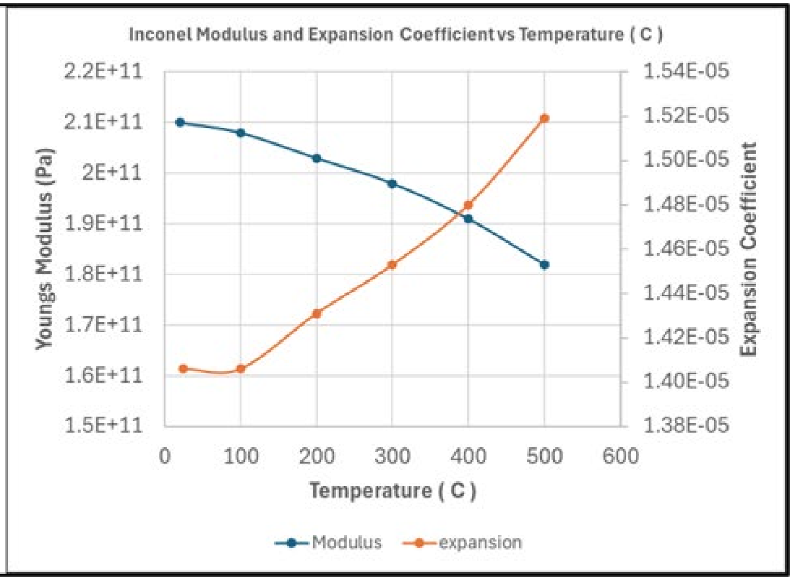


316L and Inconel elastic-plastic properties used

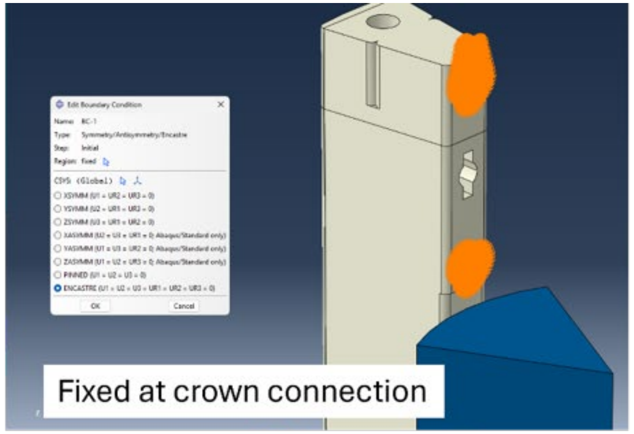


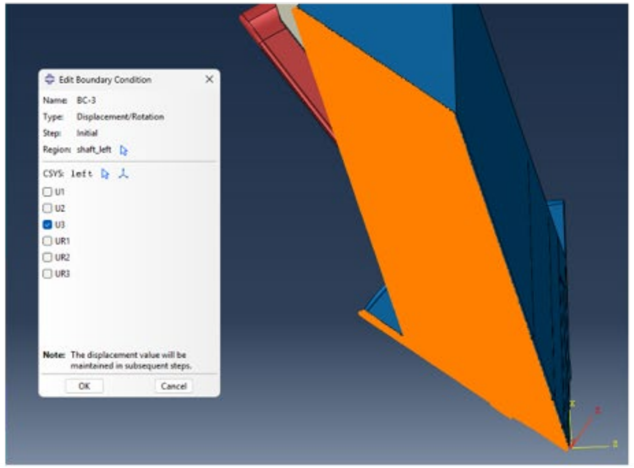




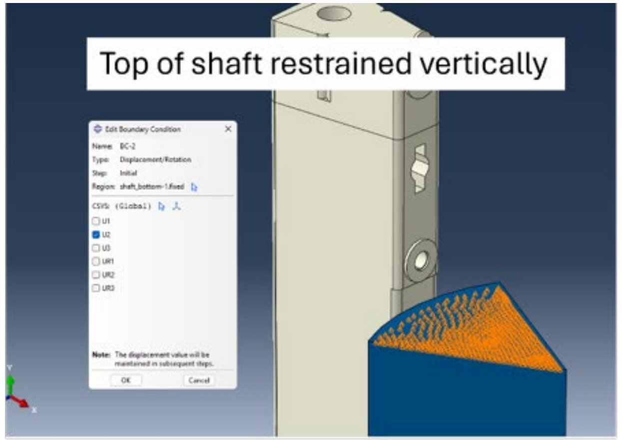


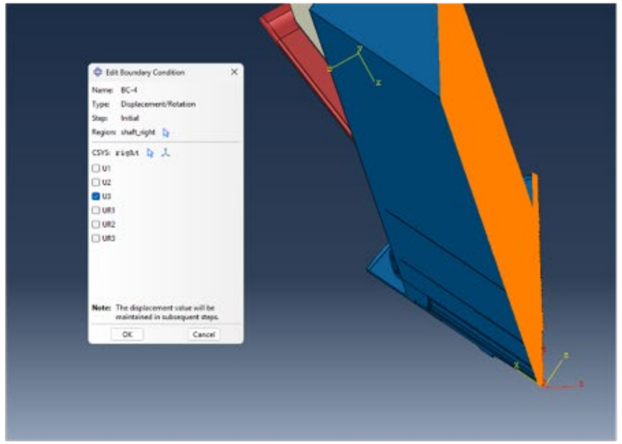
Boundary Conditions and segment pin interaction with shaft



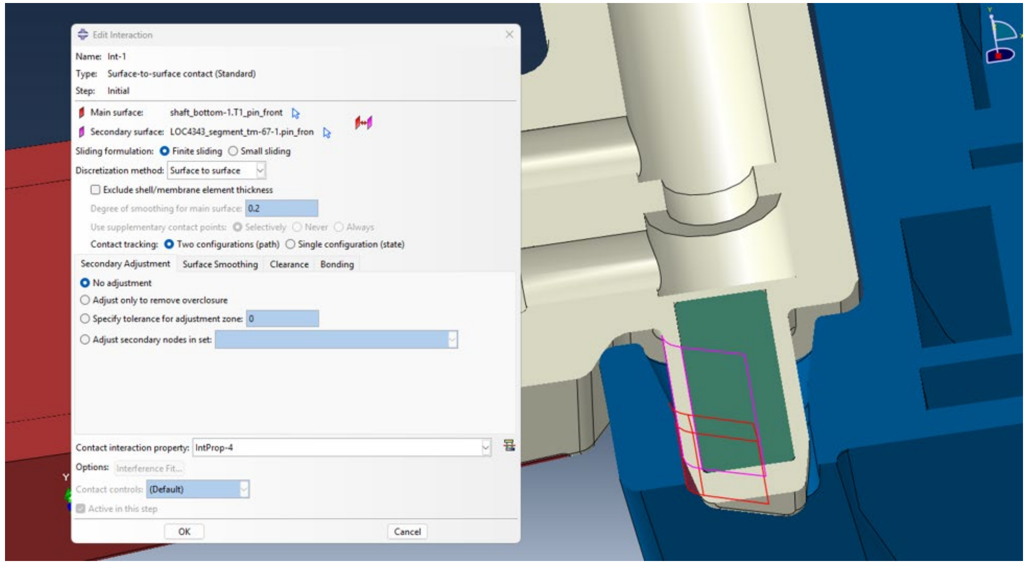


Shaft displacement normal to cut restrained





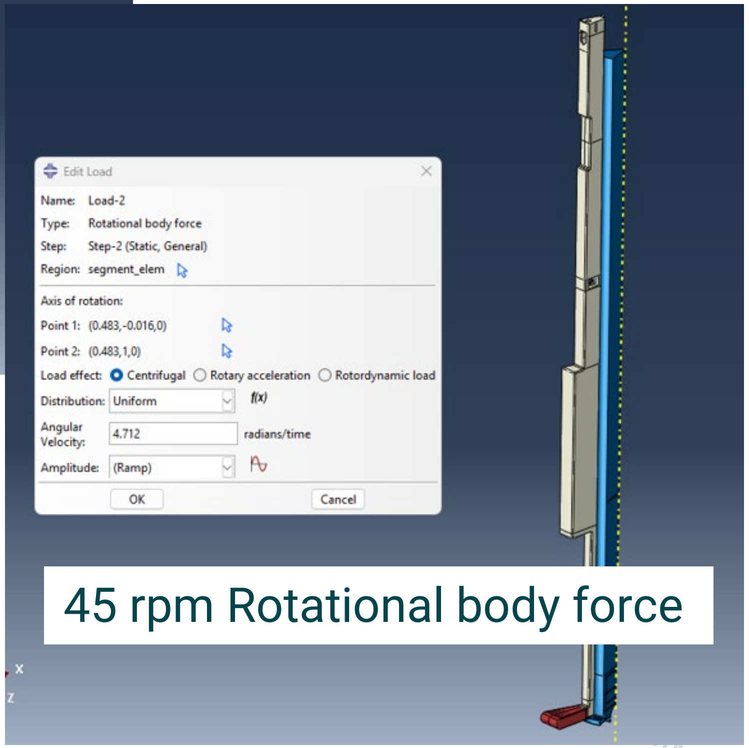
Shaft displacement normal to cut restrained



pin to shaft frictionless hard contact surface to surface interaction

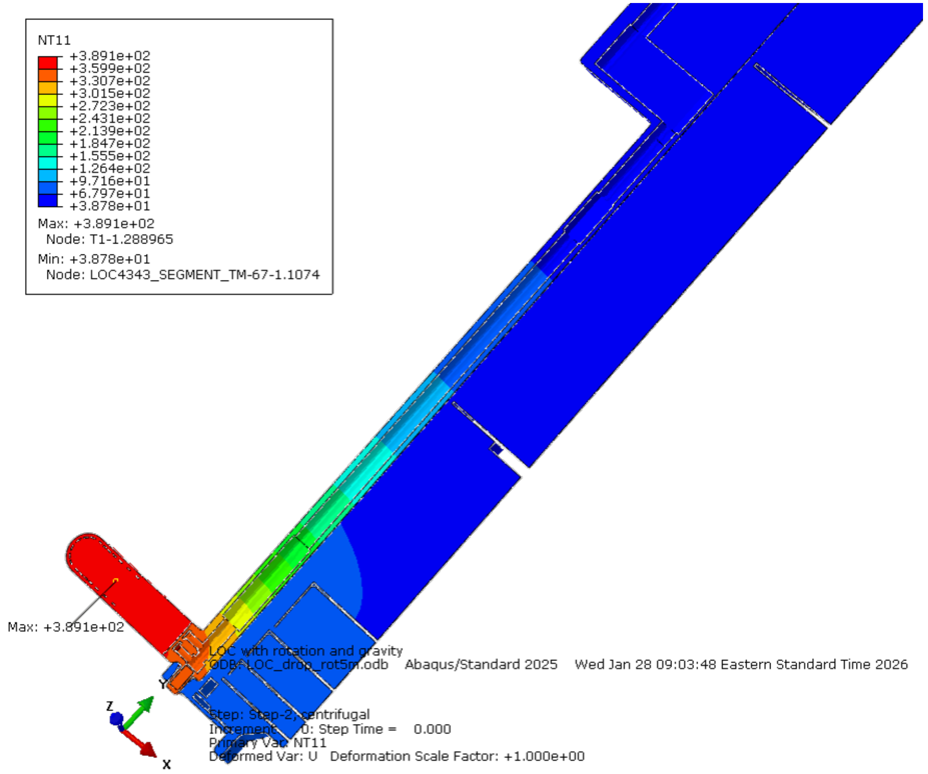
Analysis Steps and loads

Step	Temperature Profile	Gravity load	Centripetal load
Initial	20 C all nodes		
Step 1 segment	Peak temperatures profile @ 15.8 hr	9.8 m/s^2	0
Step 1 shaft	Peak temperatures profile @ 15.8 hr	9.8 m/s^2	0
Step 2 segment	Peak temperatures profile @ 15.8 hr	9.8 m/s^2	4.712 rad/s
Step 2 shaft	Peak temperatures profile @ 15.8 hr	9.8 m/s^2	0

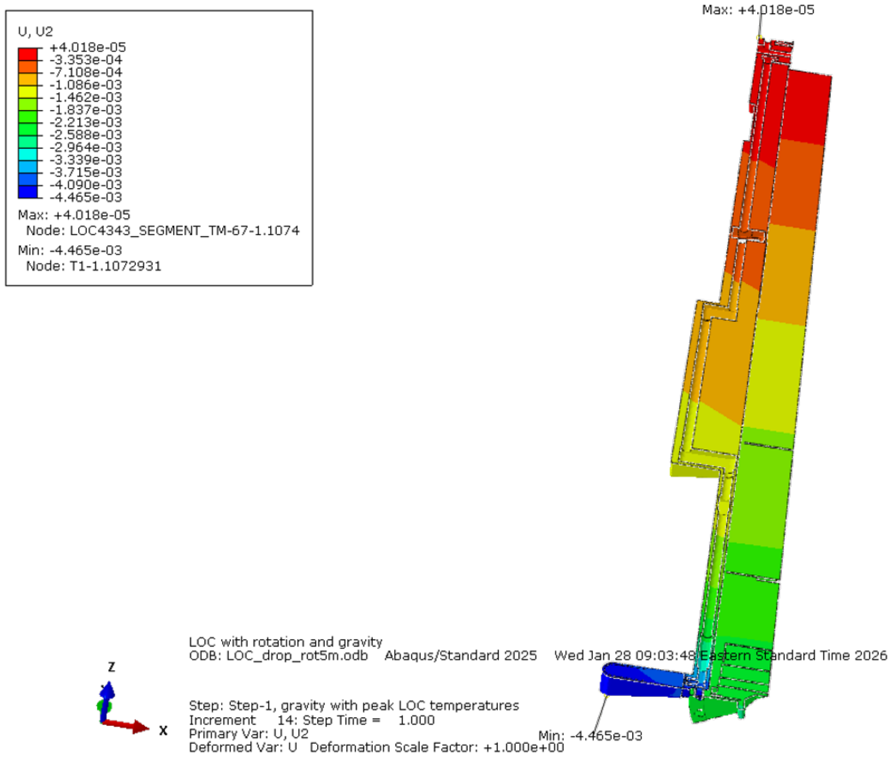


Step 1 Gravity and thermal loads - Vertical Displacement from 20 °C installation relative to crown attachment

Temperature profile with 389.1 °C peak

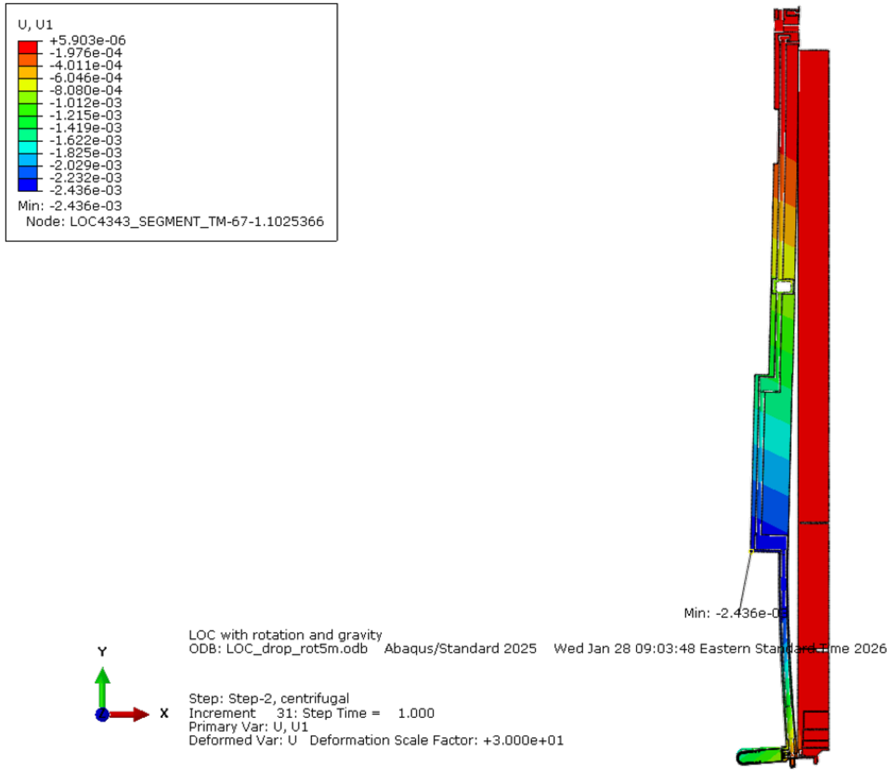


Peak displacement down 4.5 mm

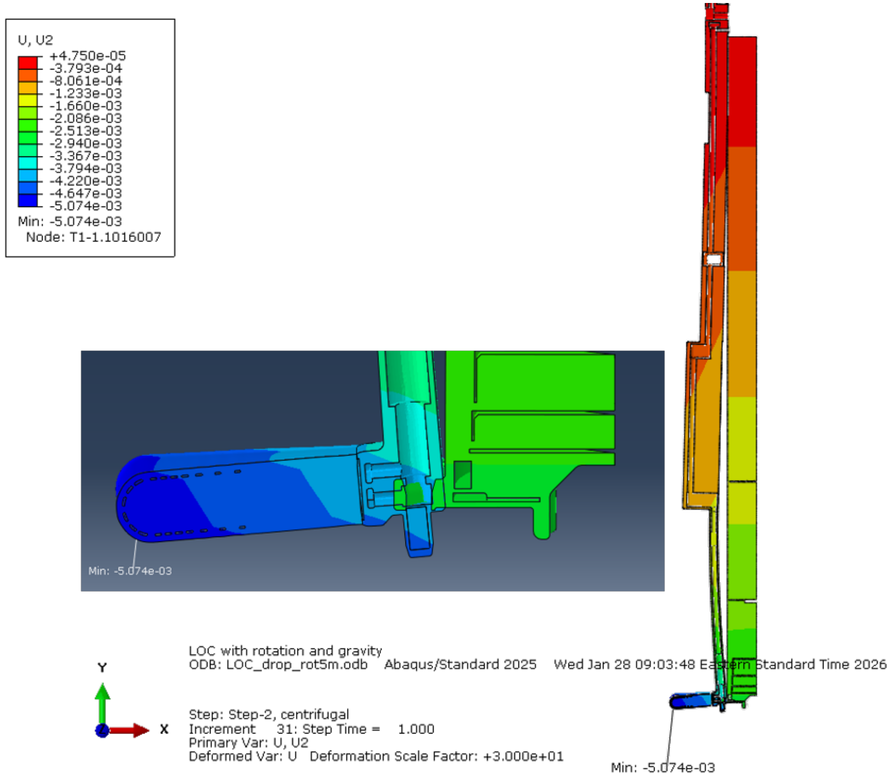


Step 2 Rotation, gravity and thermal – Horizontal and Vertical displacements

Peak horizontal displacement – 2.5 mm

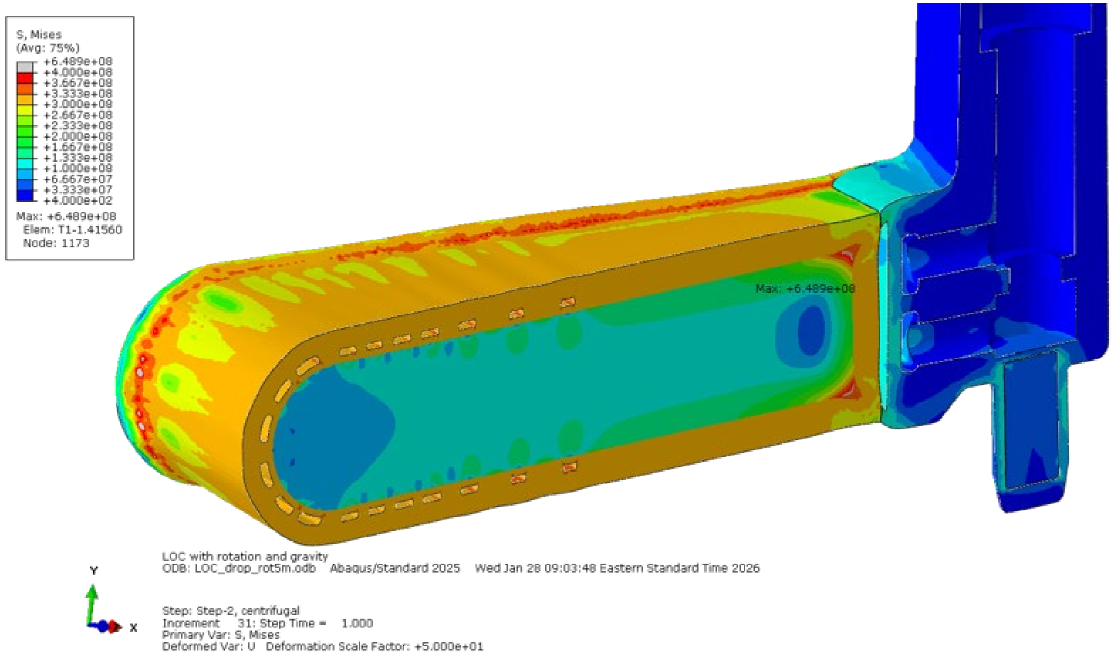


Peak displacement down – 5.1 mm

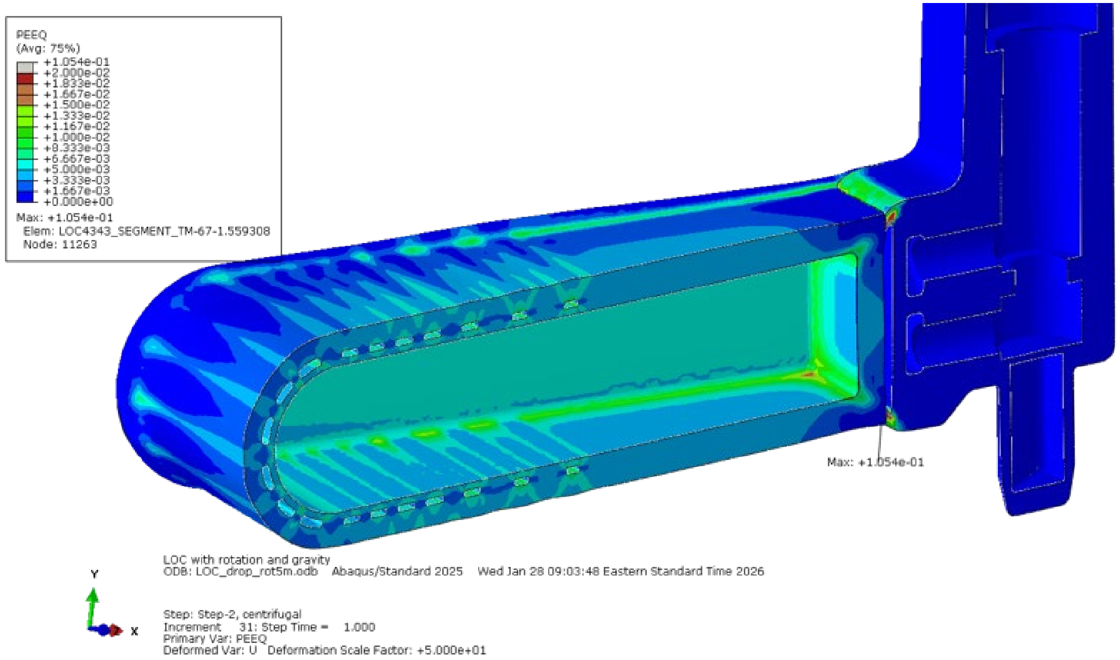


Mises Stress and Inconel PEEQ - 50x displacements

Stress – 400 MPa scale maximum

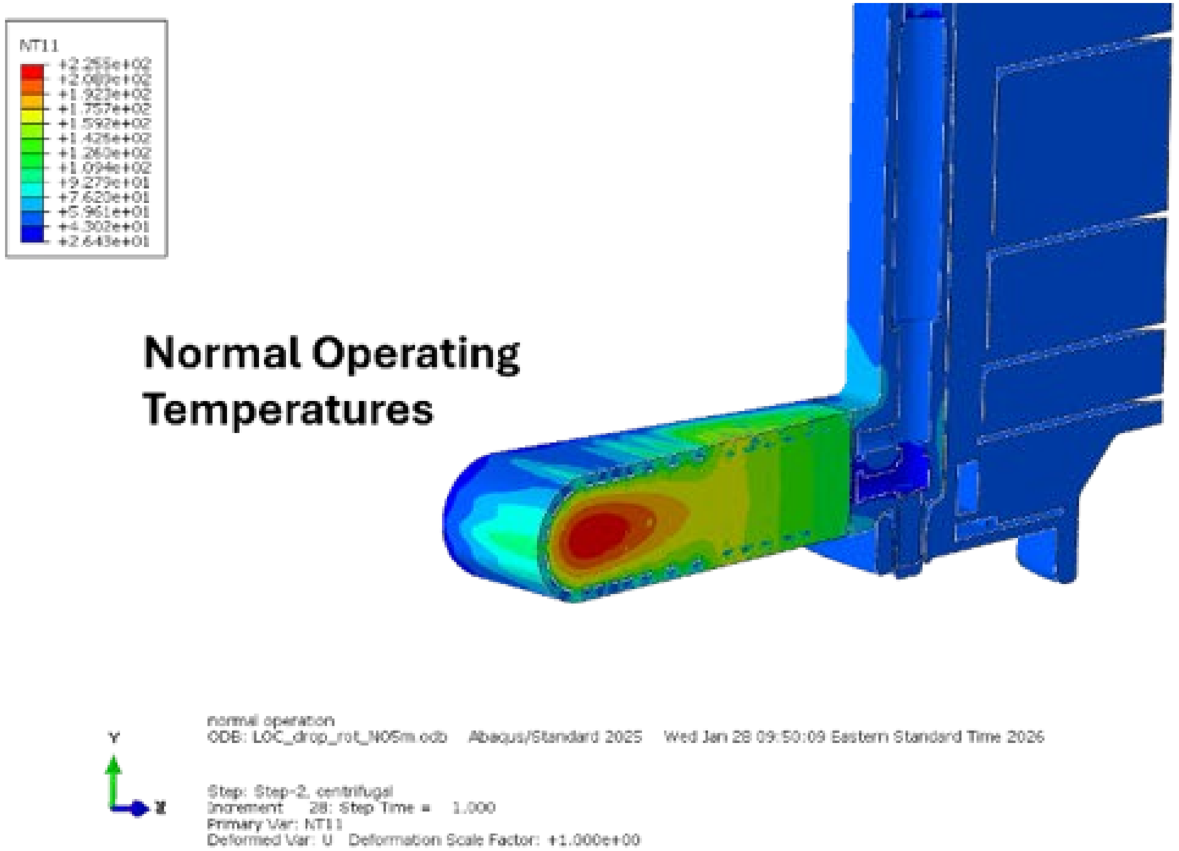


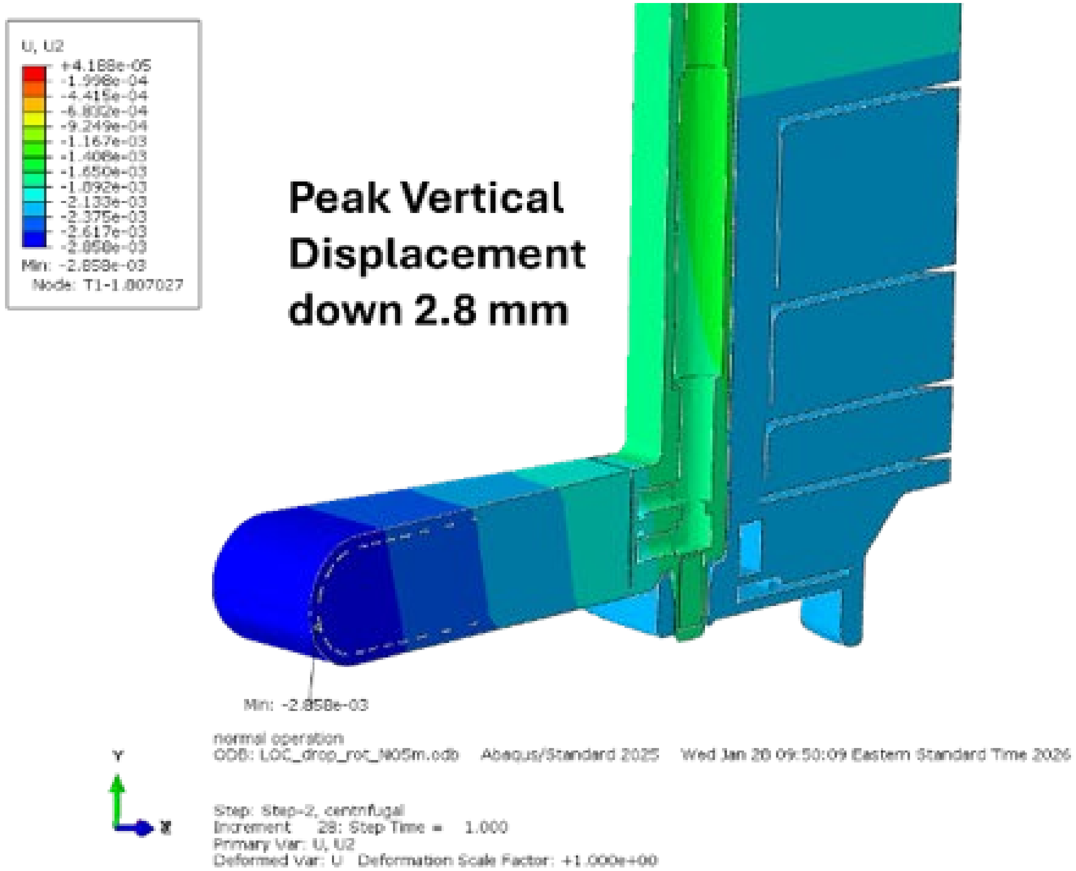
Plastic PEEQ .02 scale maximum



No significant plastic deformation which would allow contact with MRA

Normal operation with gravity, rotation and operating temperatures - displacement relative to fixed attachment and initial 20 °C installation





Loss of cooling only adds 2.3 mm downward displacement over normal operation

Conclusions

2.2 S.03.02-1564 Max Temperature without cooling & beam off

The steady state temperature in any portion of the tungsten shall not exceed 800°C during operation or

without cooling. (initiated immediately upon loss of beam

Pass- 389.1 °C peak with loss of cooling over 24 hours – very large margin over 800 °C with conservative assumptions

2.1 S.03.02-1566 Hot contact

The target shall not contact Moderator components during a loss of cooling event.

Note: This event occurs without rotation

Pass – Loss of cooling additional displacement down over normal operation was 2.3 mm including rotation compared to a nominal 10 mm gap