OAK RIDGE
National Laboratory

August 2026

Target Assembly: Shaft Design

Lukas Bearden

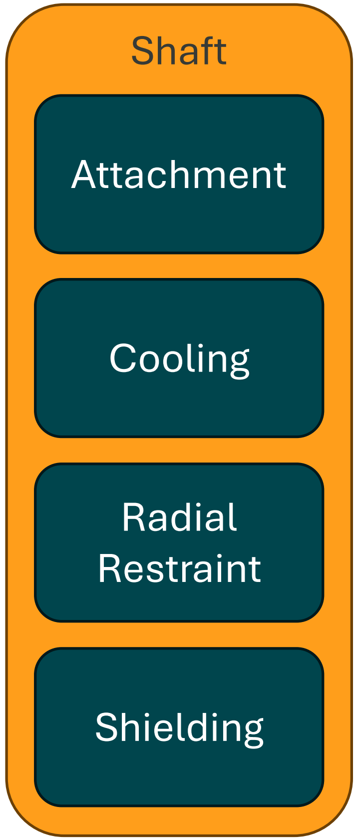
Second Target Station

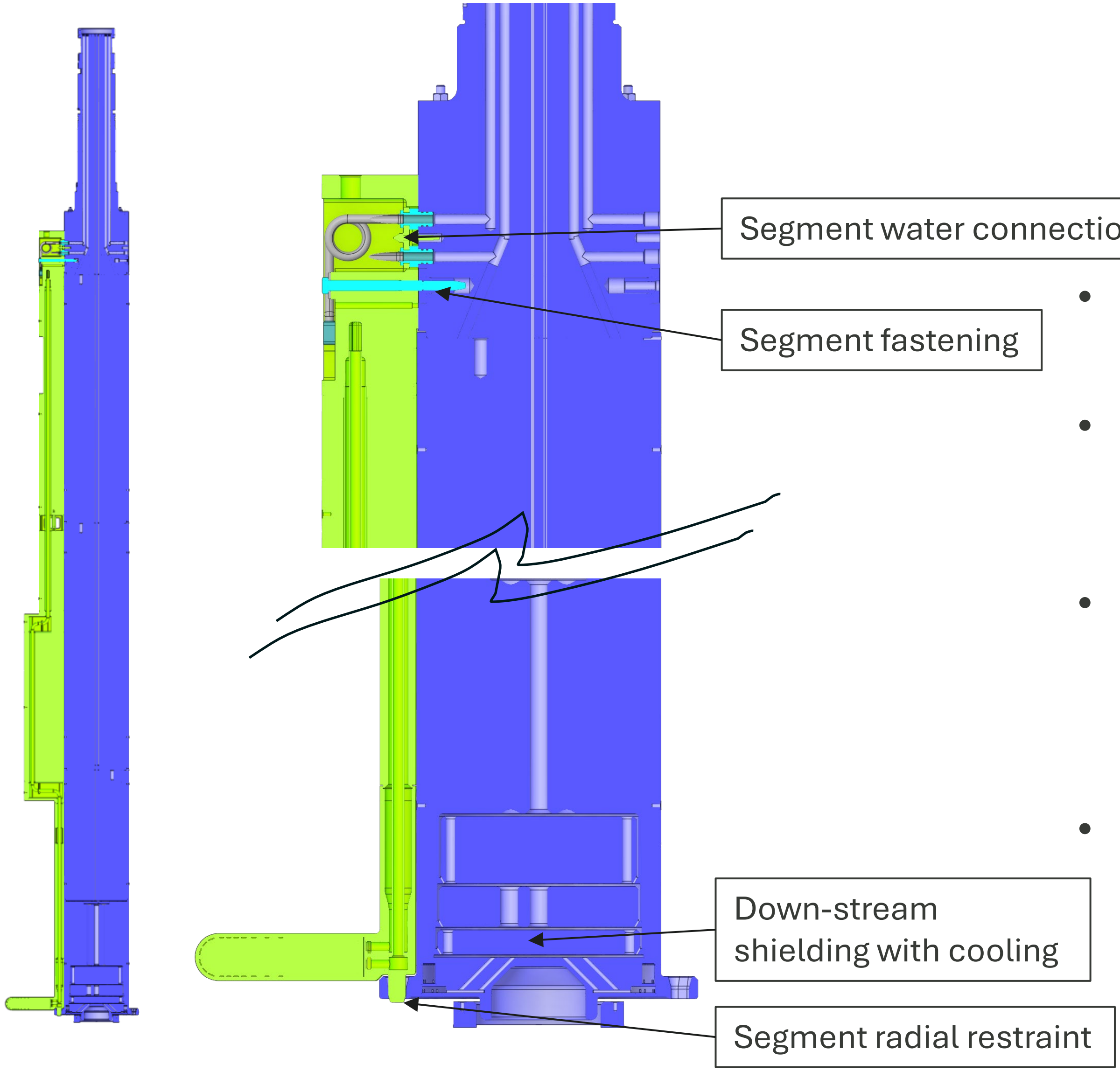
Charge Question 2: Has the design been shown to meet the requirements?

Charge Question 3: Do DACs and other supporting documentation adequately support the final design?

Question 5: Is the design sufficiently mature to proceed with finalizing the procurement package?

Shaft provides a backbone, restraint, and cooling transport for the Segments as well as shielding at the spallation level.





- Upper portion of the Shaft restrains and vertically positions the Segment
- Also provides supply and return connections for Segment cooling water
- Lower portion provides a radial restraint to keep the segment near the shaft during rotation and seismic events.
- Also provides down-stream shielding for beam that passes through the target

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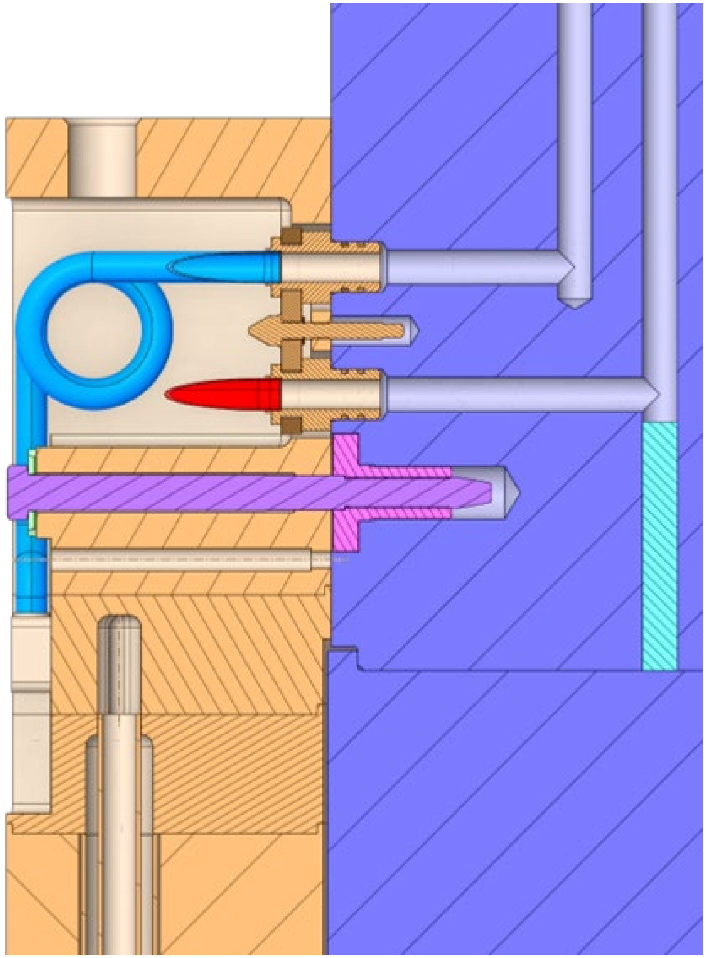
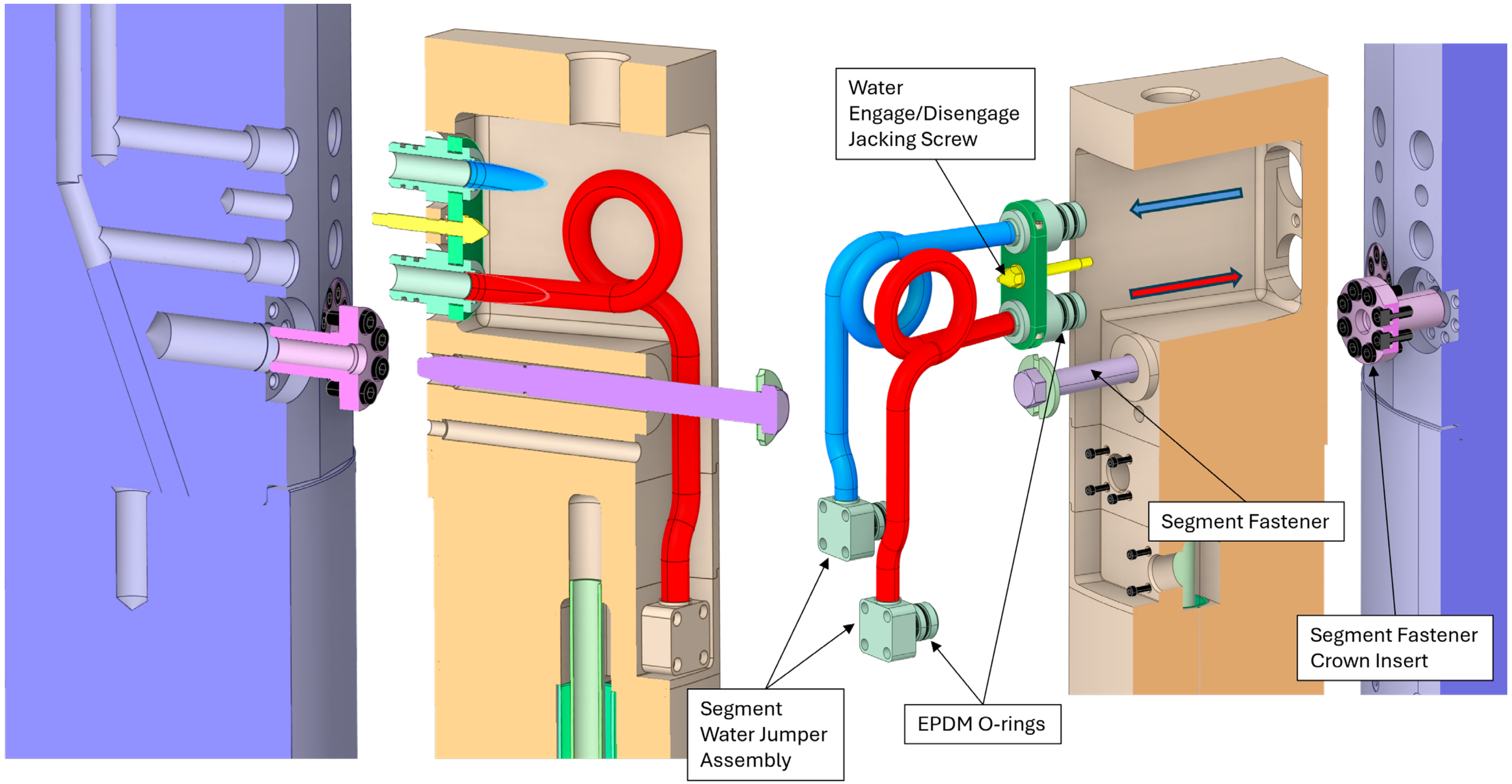
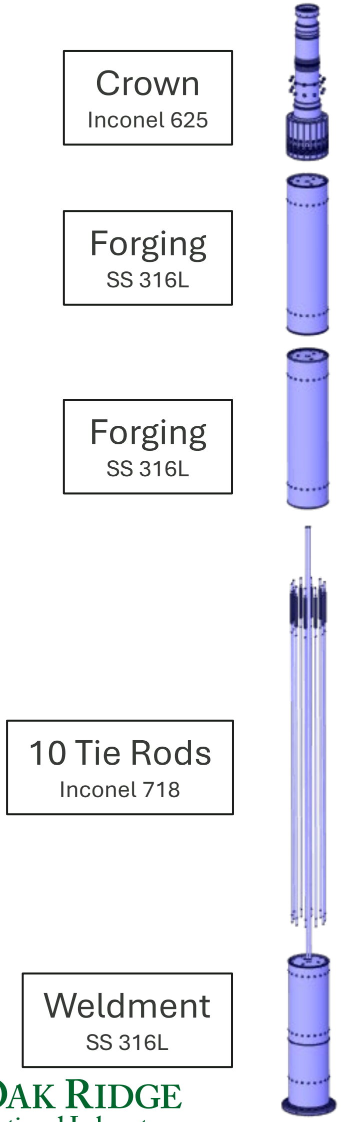
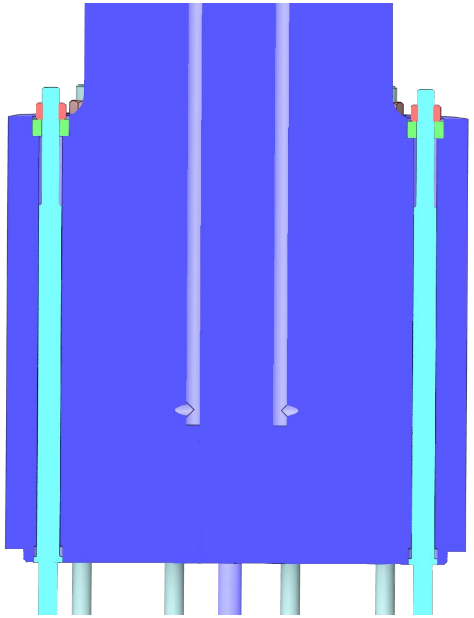
Segment Upper attachment covered in Segment presentation



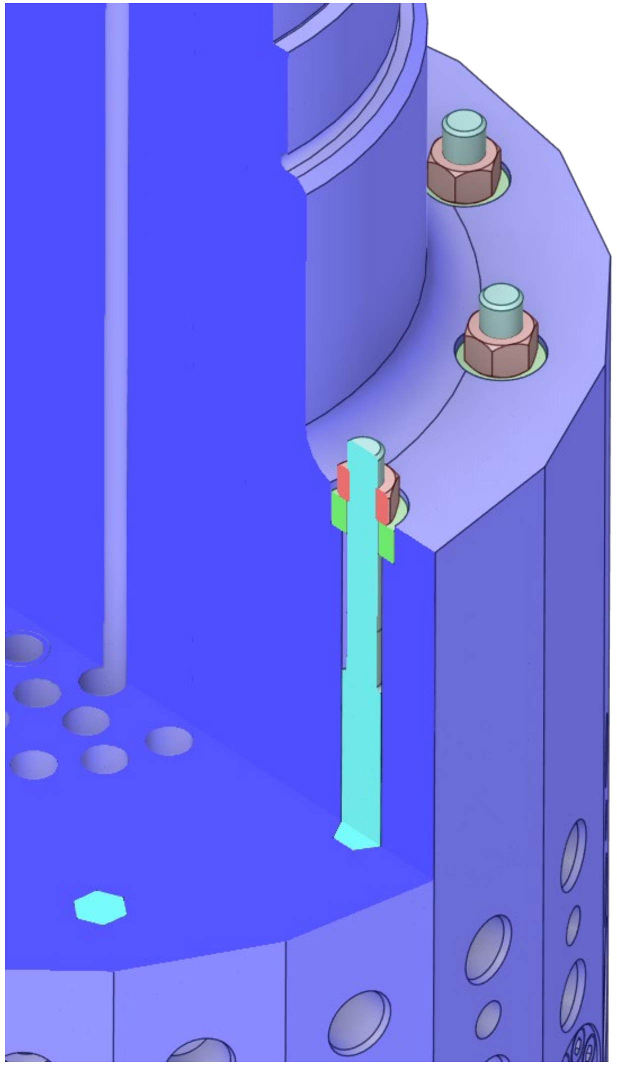


Shaft consists of 4 primary sections, bound together by 10 tie rods





- 10 Tensioned and pre-loaded tie rods
- Anchored in lower welded portion
- Pass through 2 forged sections
- Pass through lower ring of crown
- Thick load-bearing washers and nut



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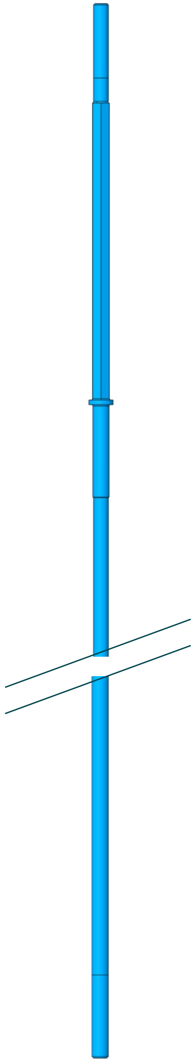
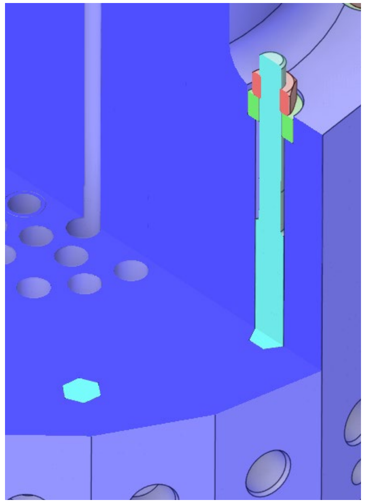
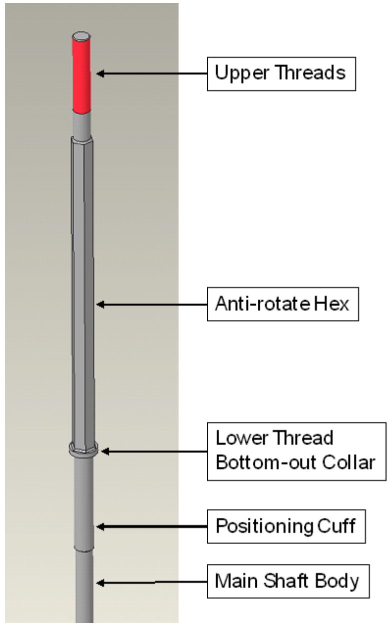
Tie Rod Calculations determined diameter, preload, and thread pull-out

- Inconel 718
- 16 mm diameter
- M16 x 2 threads
- Hex upper portion
- Pre-tensioning snugging flange







Preload: 73.4 kN (16.5 kips)
UTS.Inc718: 965 MPa

$K_{nut} := 0.25$

$L_{wrench\_arm} := 6ft$

$T_{nut} := K_{nut} \cdot F_{PL\_85} \cdot TR_{D\_max} = 293.486 N \cdot m$ Torque on nut to exert 73 kN on Tie Rod

$P_{hand\_force} := \frac{T_{nut}}{L_{wrench\_arm}} = 160.48 N$

$P_{hand\_force} = 36.077 lbf$ Force on long wrench 6ft from the nut.

Tie Rod Preload:

Tie Rod thread size: M16x2

$TR_{D\_max} := 16mm = 0.63 \cdot in$ Major diameter.

$TR_{D\_eff} := 14.376mm$ Minor diameter.

$UTS_{Inc718} = 9.653 \times 10^{8} Pa$

$CA_{Eff} := \frac{\pi \cdot TR_{D\_eff}^{2}}{4} = 162.318 \cdot mm^{2}$

$CA_{Nom} := \frac{\pi \cdot TR_{D\_max}^{2}}{4} = 201.062 \cdot mm^{2}$

$FailForce_{TR} := UTS_{Inc718} \cdot CA_{Eff} = 156.68 \cdot kN$ This shows that the tie rod will fail before the threads shear.

Calculations from Mechanicalc.com:
https://mechanicalc.com/reference/bolted-joint-analysis#preload-values

$F_{PL\_85} := 0.9 \cdot 0.85 \cdot YS_{Inc718} \cdot CA_{Eff} = 73.371 \cdot kN$ Peload to 85% tensile proof strength.

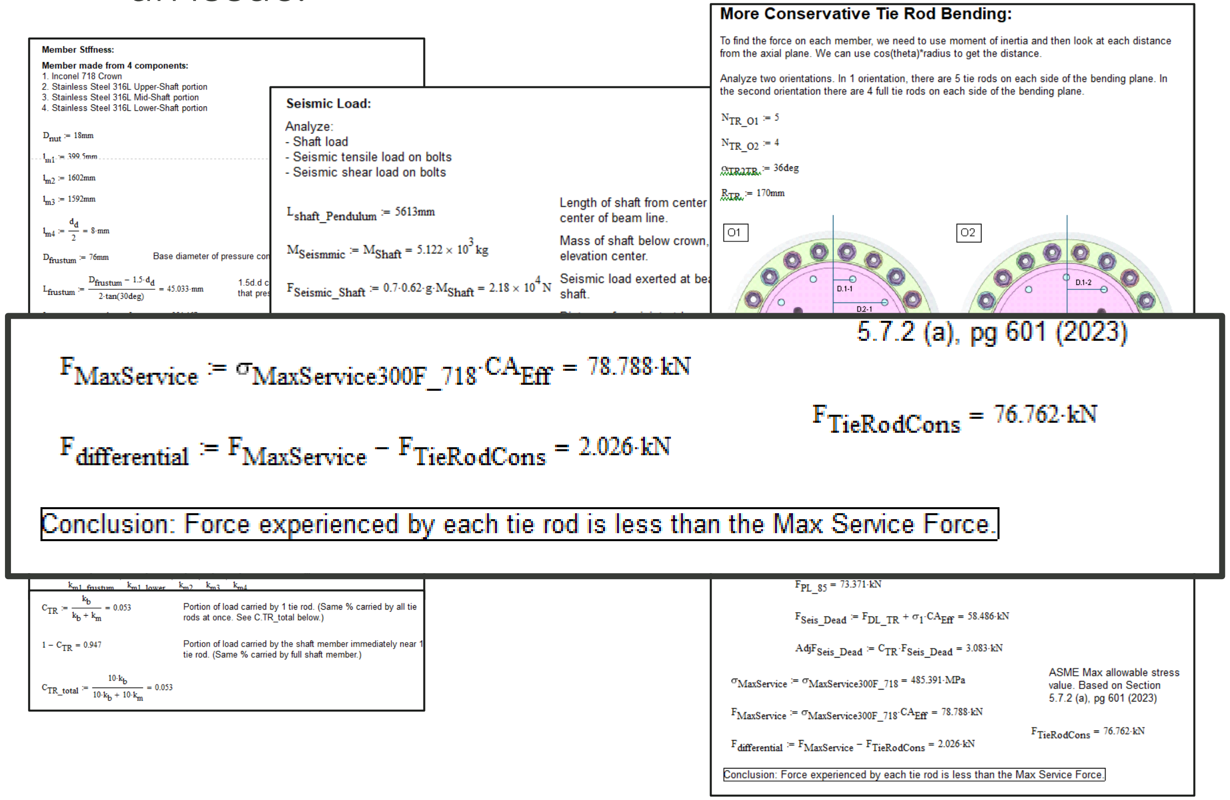
$F_{PL\_85} = 16.495 \cdot kip$

- Tie Rod pulls together
  - Lower SS 316L Threaded Body
  - 2x SS 316L thick forgings
  - Upper Inconel 625 Crown Body
  - Custom thick Inconel 718 washer
- Joints between shaft components must not open in bending or under dead load.

Tie Rod Calculations determined diameter, preload, and thread pull-out

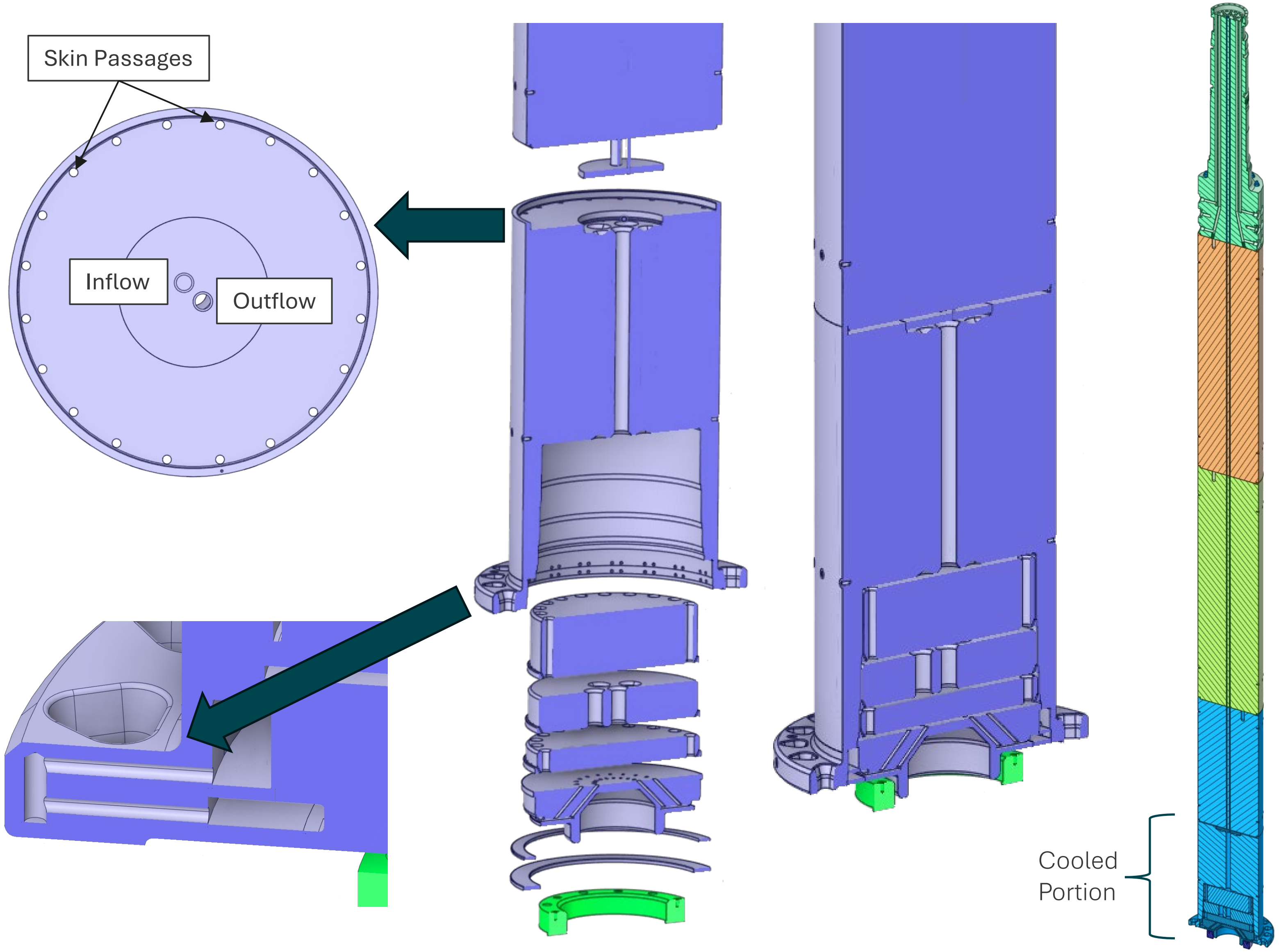
- Calculated stiffness of Tie Rod
- Calculated stiffness of washer, Inconel crown portion, both thick forgings, and anchor component.
- Calculated the joint constant to determine the load carried by the tie rods vs the joint
- Analyzed seismic load
- Determined bending load
- Determined that all load combinations stayed below material limits

- Verified that thread pull-out from the Stainless Steel body, thread stripping from the Inconel 718 tie rods, and thread pull-out from the Nitronic nuts would not be an issue.



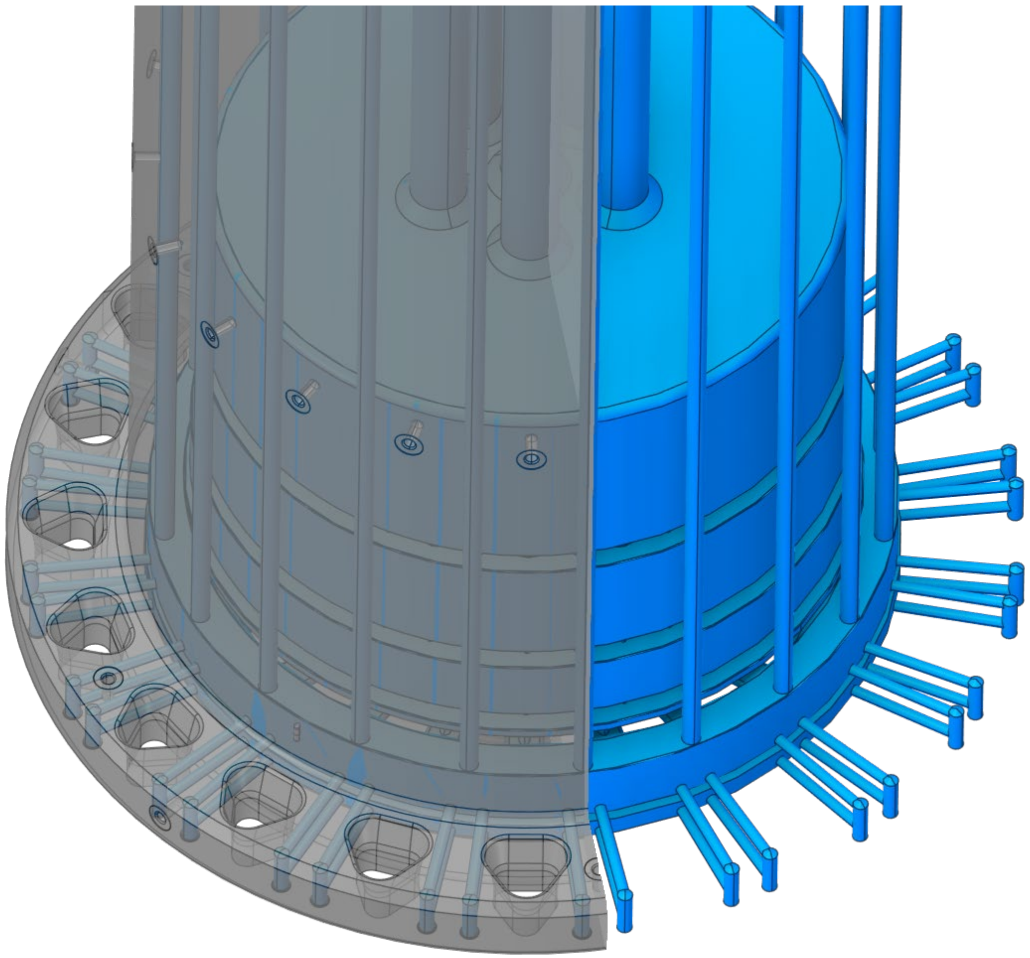
The lower ~1/6th of the shaft requires internal cooling due to the energy pass-through and scatter from the Target Segments

- Incorporating a stacking structure to create internal cooling passages.
- Water flows from crown to the top of the cooled area of the shaft.

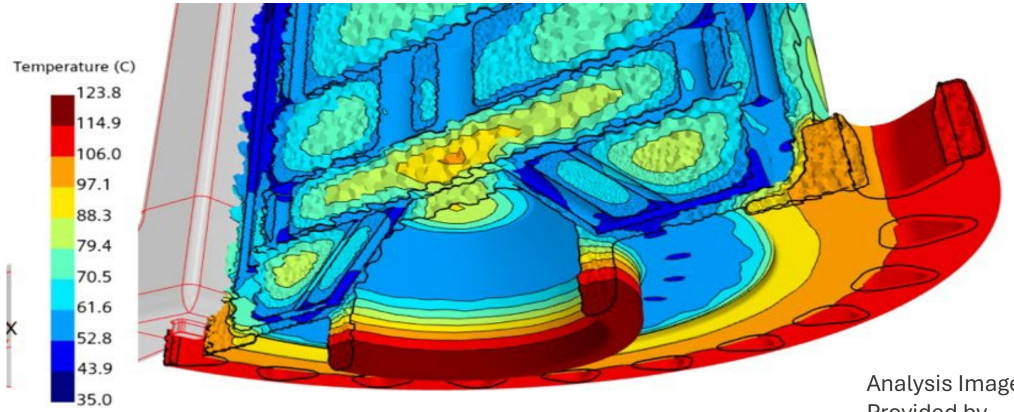


The lower flange of the Shaft provides Segment restraint, while also requiring cooling.

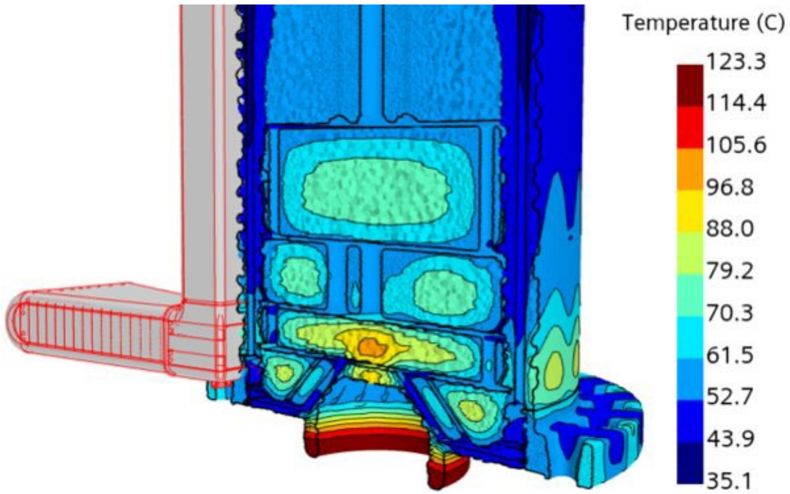
- Cooling between segment-restraint pockets to reduce flange temperature and therefore reduce thermal stresses.



Without Flange Cooling



With Flange Cooling



Analysis Images Provided by Min-Tsung Kao

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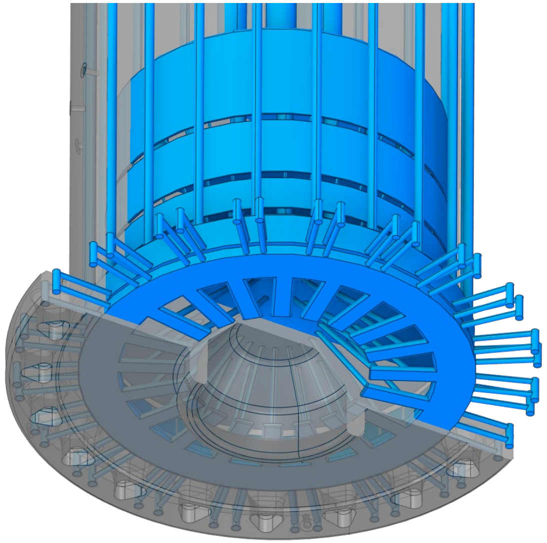
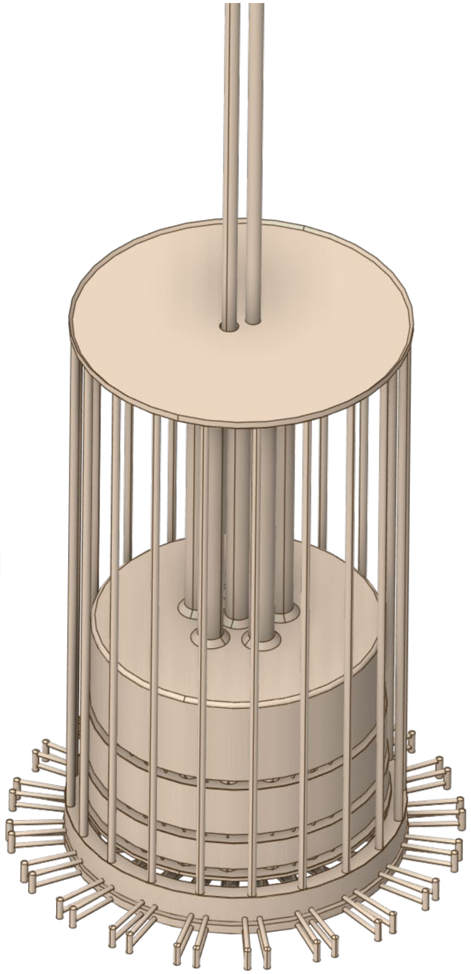
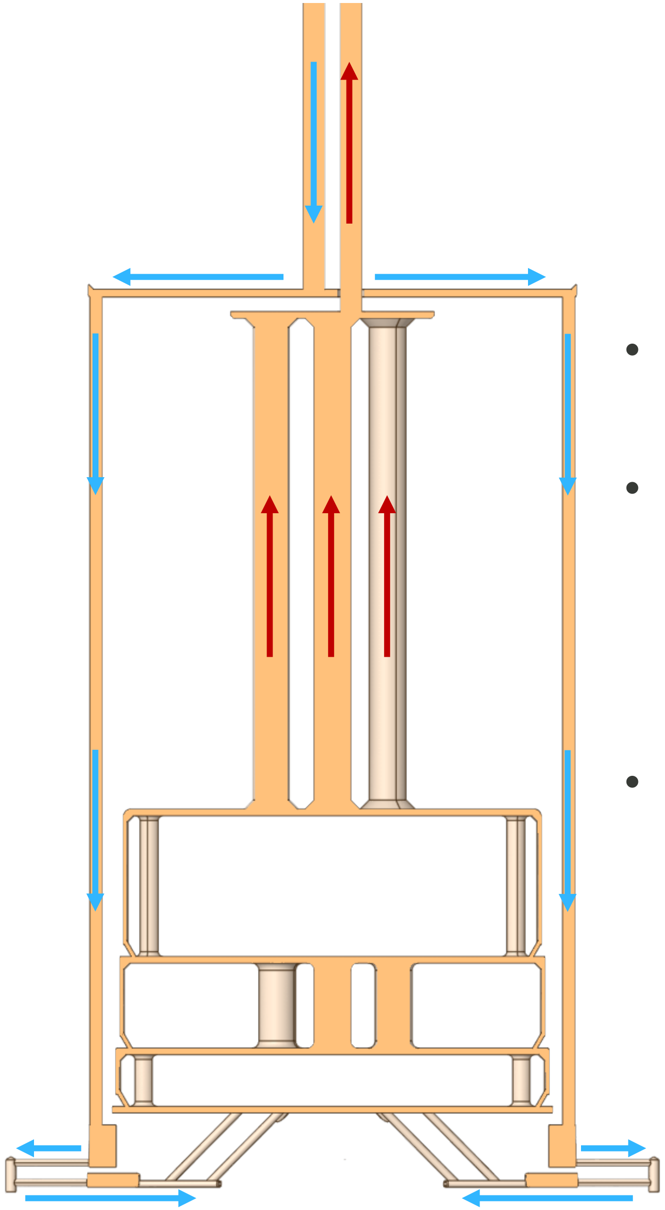
Cooling routed to high-heat and therefore high thermal stress zones.

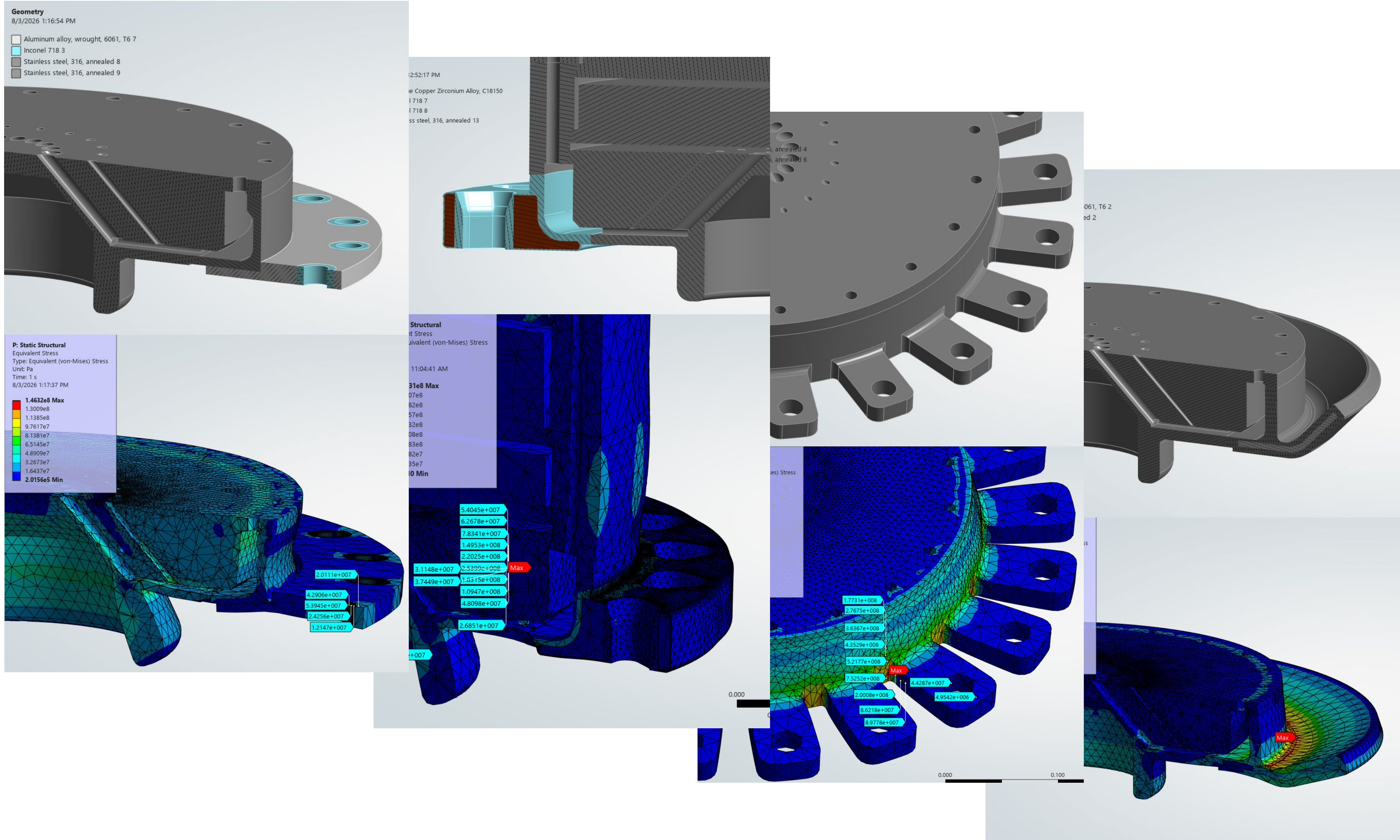






- Disperses around the skin passages, and down through the flange.
- It then travels from the flange area to the center of the shaft, and starts flowing upward following an out and then in pattern pushing the cooling water upward.
- Then water then travels back up the shaft and through the crown.

Shaft Flange and Segment Pocket Required multiple iterations to determine how to best deal with thermal stress



- Nature of uncooled ring with pockets created high-stress points
- Attempted to bond thermally conducting materials, but presented complexity and debonding risks
- Settled on cross-drilled passages between pockets and plug welds

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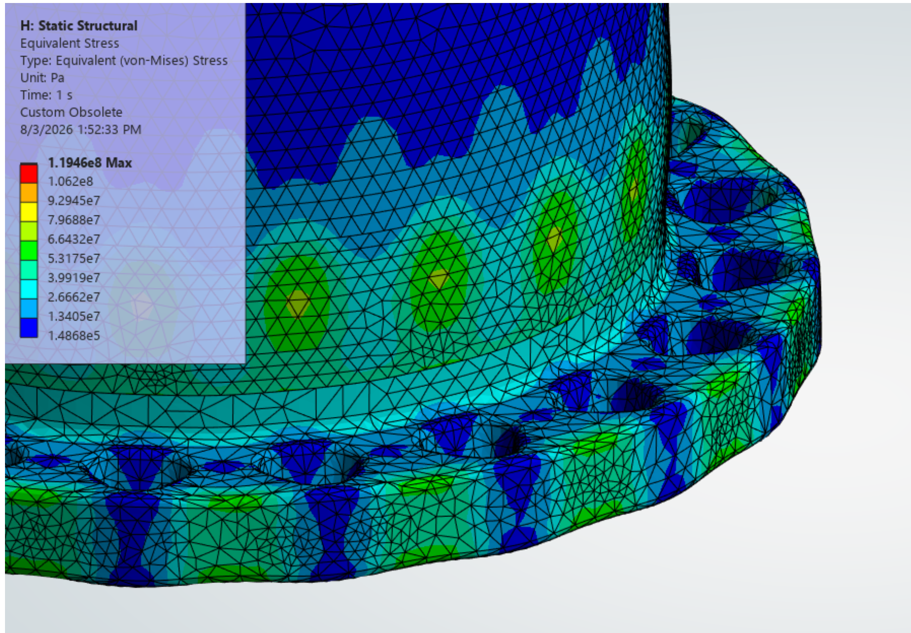
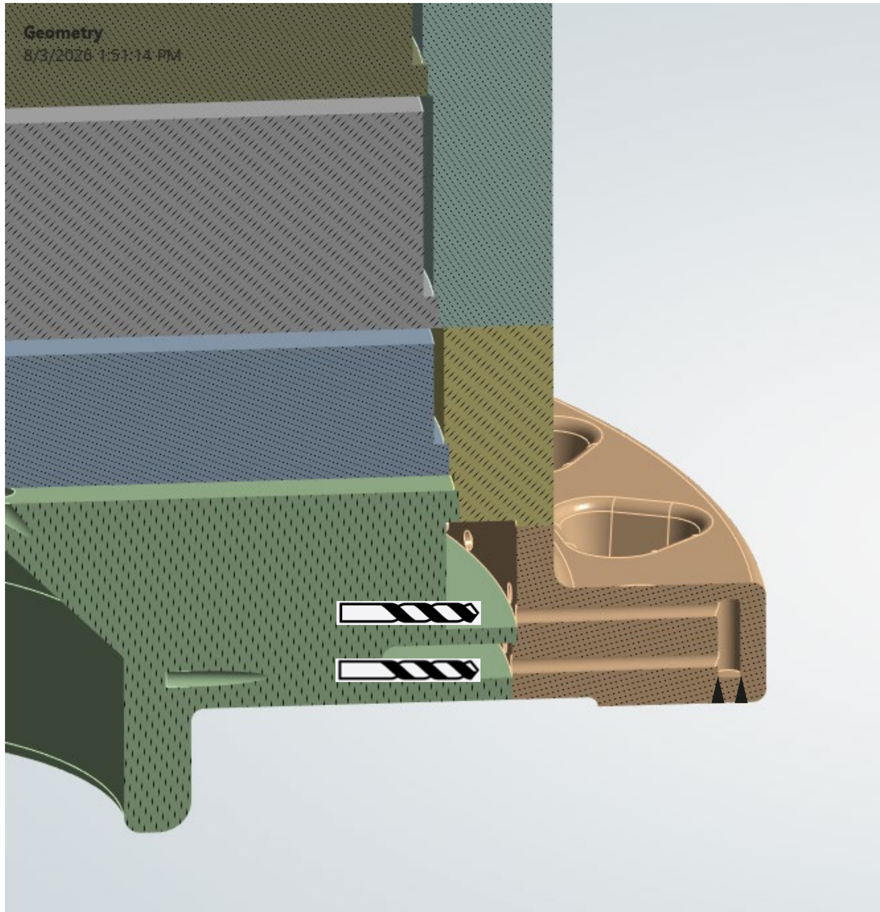
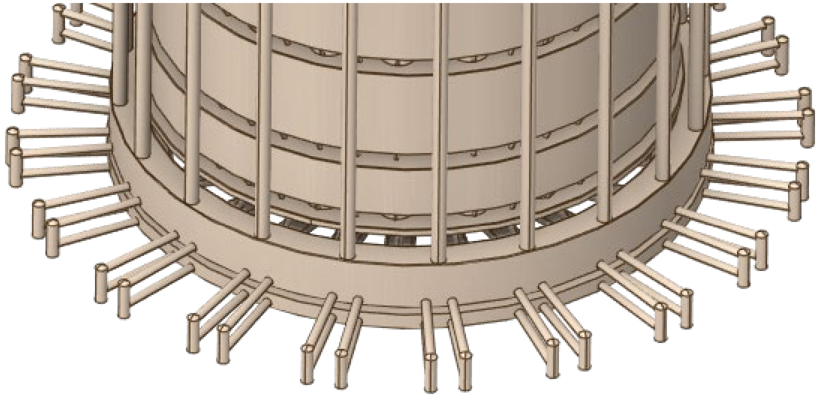
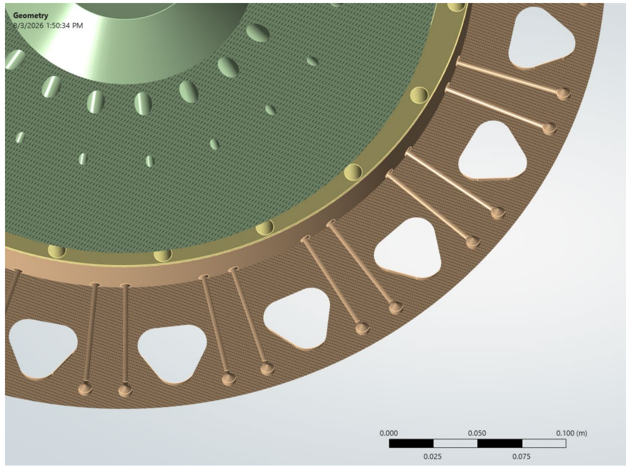
Flange with cross-drilled passages and plug welds

- Drill radial holes from inside of ring – pre weld to shaft
- Drill and plug vertical holes
- Treat Segment pockets
- Weld to shaft

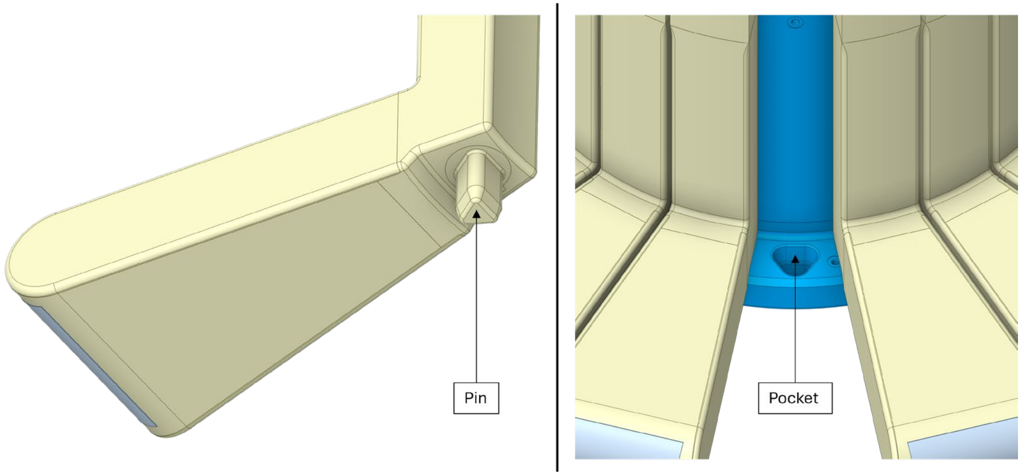


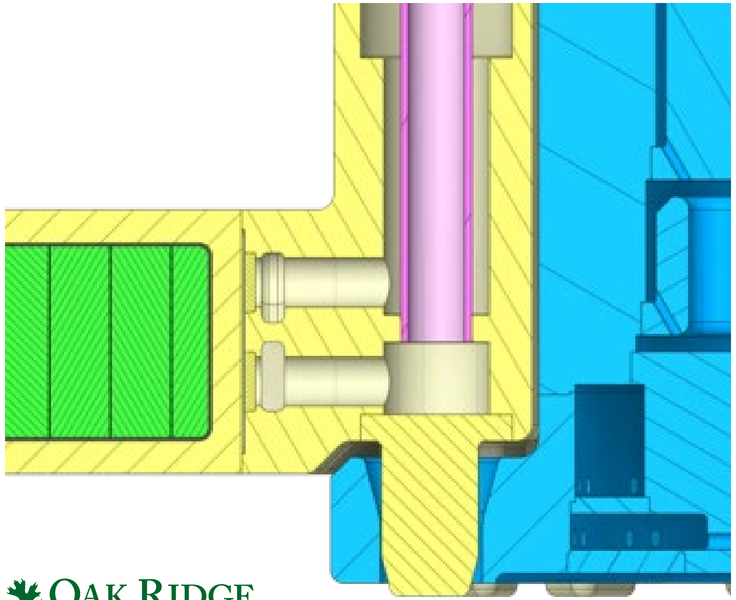




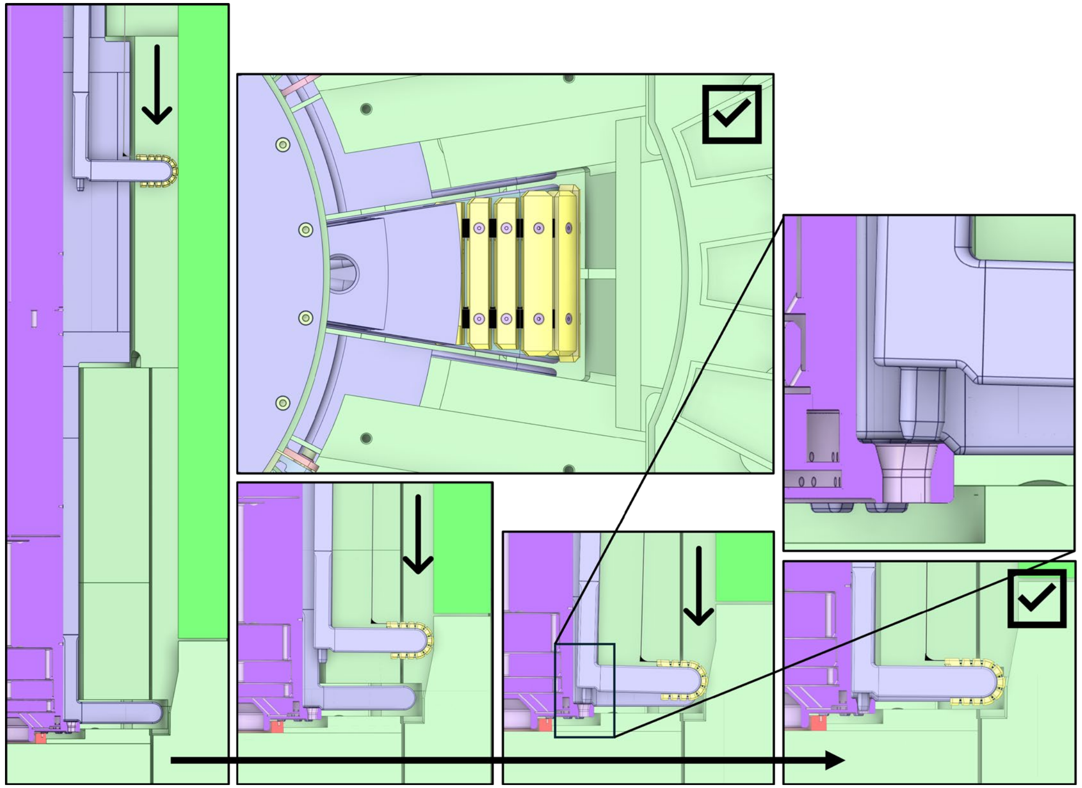


Shaft Pocket location helps guide Segment Pin. Works with Core Vessel Shielding



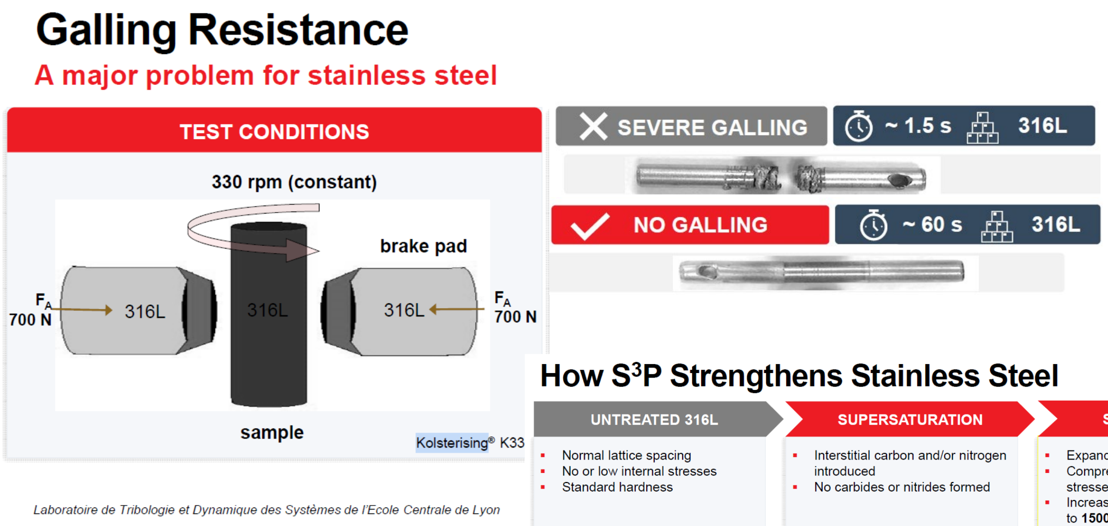


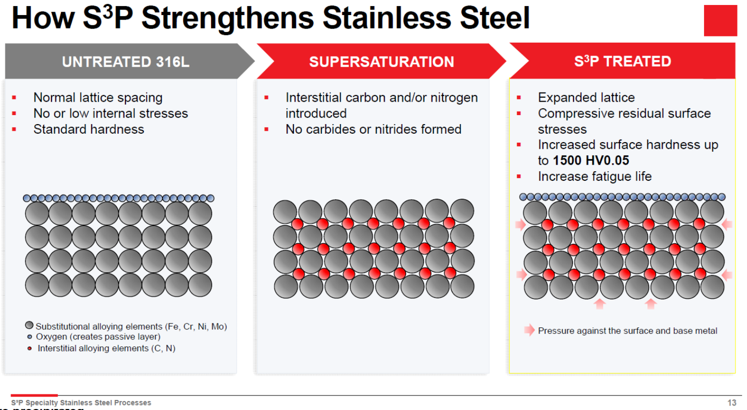
- The pin and pockets are hardened via two separate propriety Bodycote processes.
- See next slide

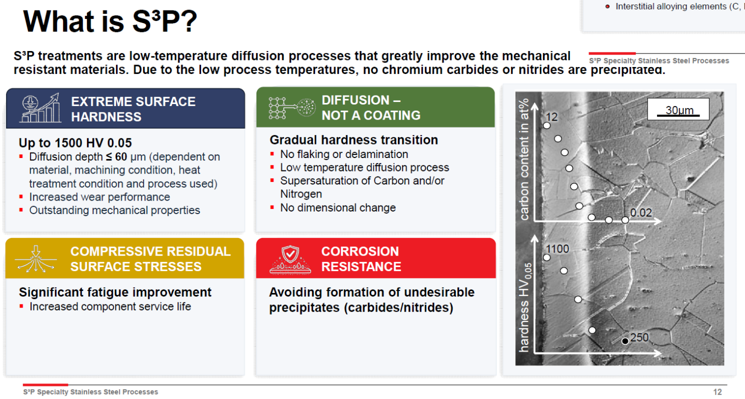


The lower Segment pockets on the Shaft, and the Segment pins are both surface hardened to prevent galling

- The Shaft pockets will undergo a process called ADM by Bodycote, giving them a 1500 HV 0.5 surface hardness
- The Segment pins will undergo a surface hardening process called Kolsterising (S^3P) giving them a 1500 HV 0.5 surface hardness
- SS 316L typically in the 155 HV range
- Greatly reduce chance of galling or fretting of surfaces.
- ADM & Kolsterising are similar:
  - ADM = line-of sight
  - Kolsterising = full-part treatment (size limited)
- Used in the SNS Mercury target to resist cavitation damage







Courtesy of Bodycote Specialty Stainless Steel Process (S^3P) Documentation. May 2026

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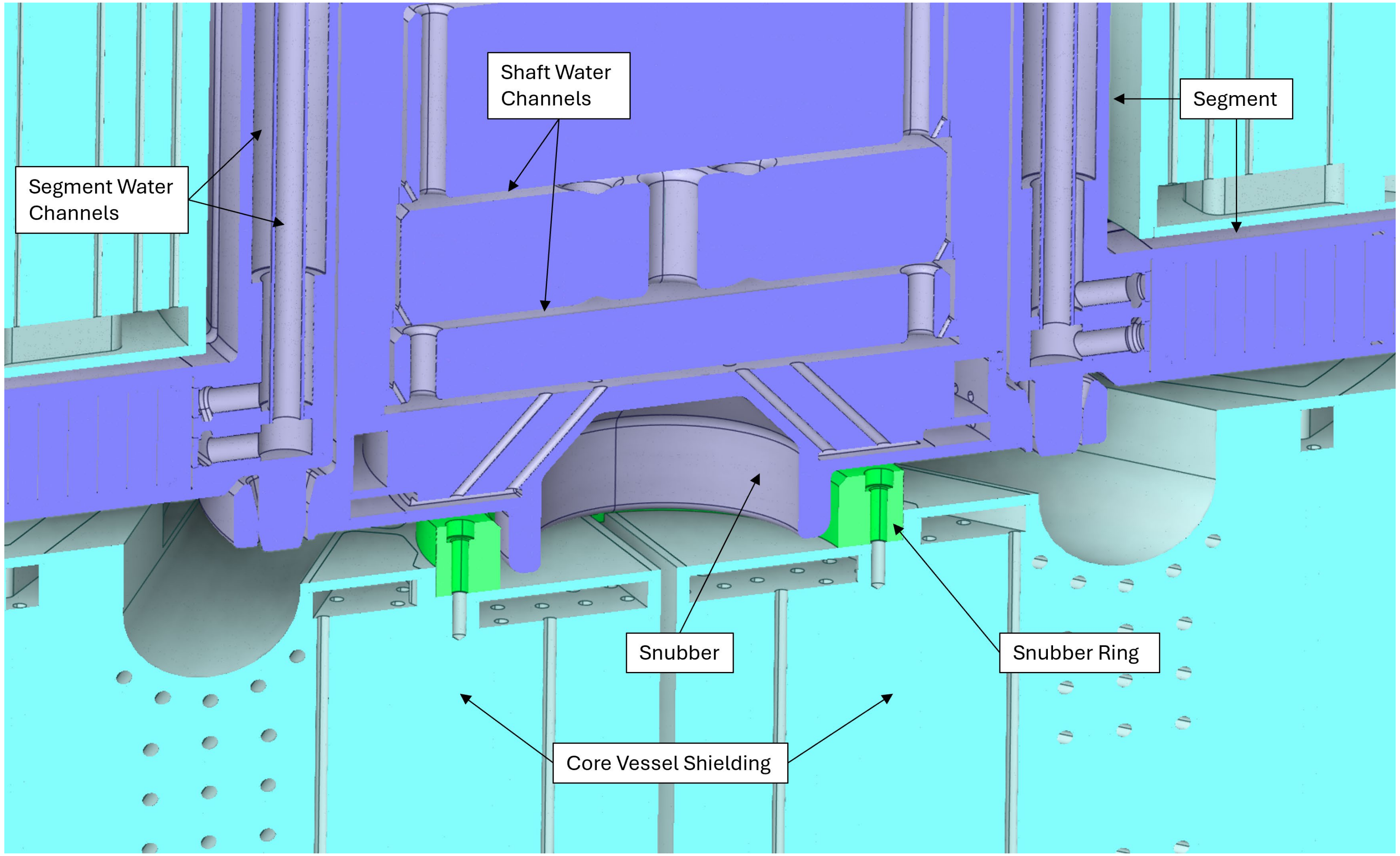
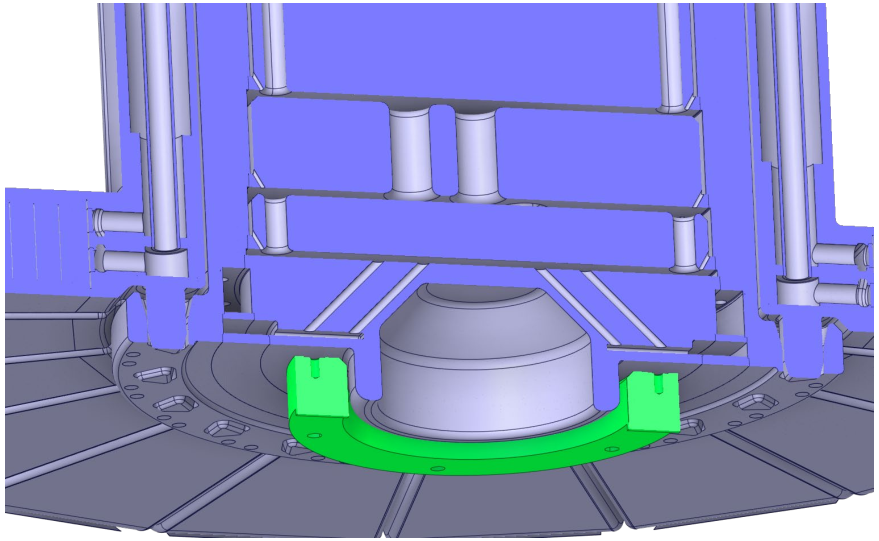
The seismic snubber at the lower most extremity of the Shaft interfaces with a ring mounted to the Core Vessel shielding

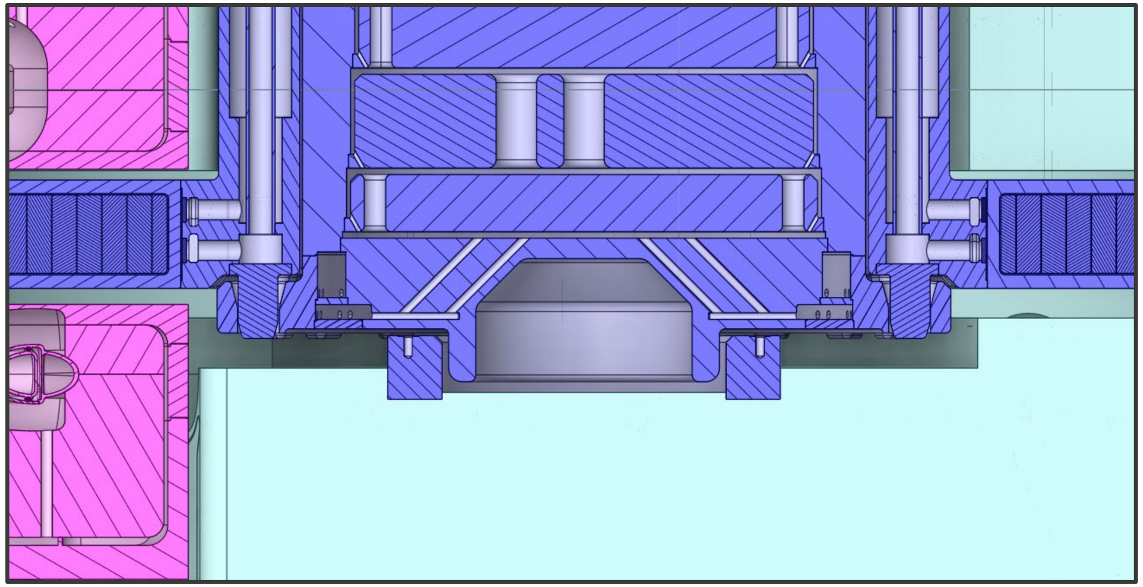


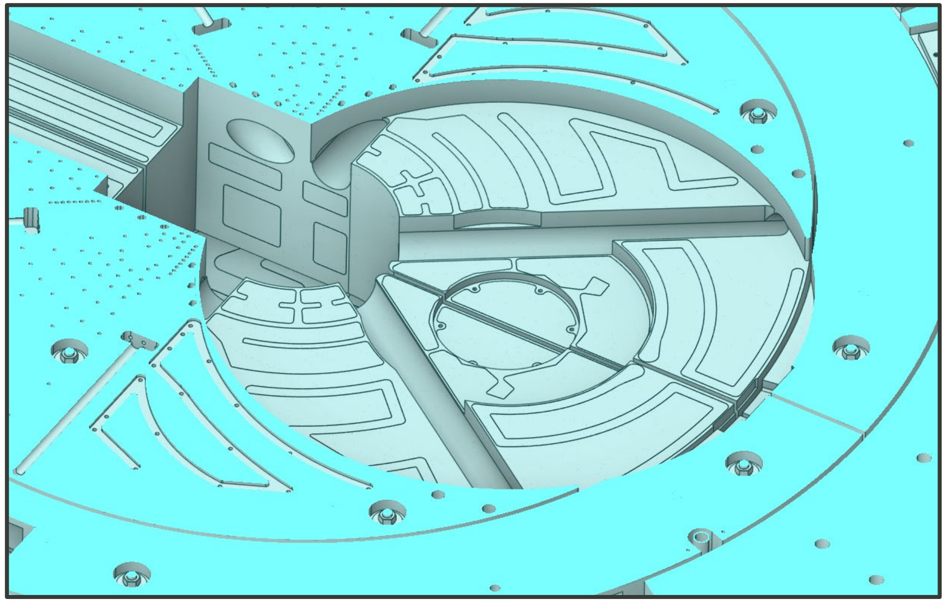
- Prevents excessive swing motion of the shaft during a seismic event.
- Based on the gap size between the Snubber and the snubber ring, as well as the gap analysis that was discussed previously, the Target cannot hit the MRA.

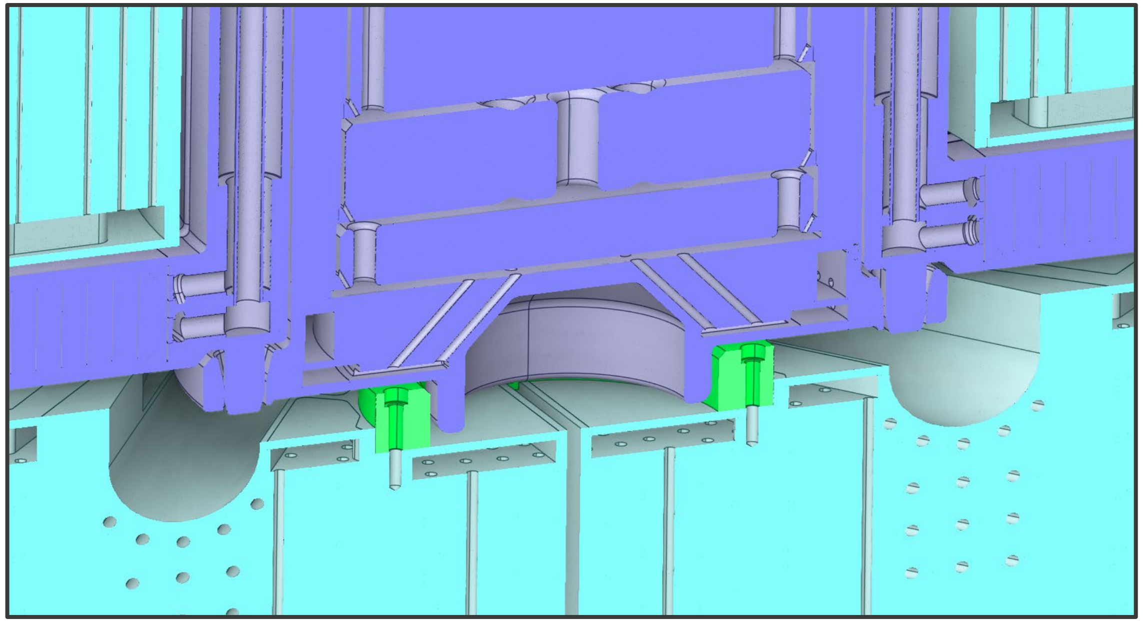


Snubber Ring machined to fit post shielding installation

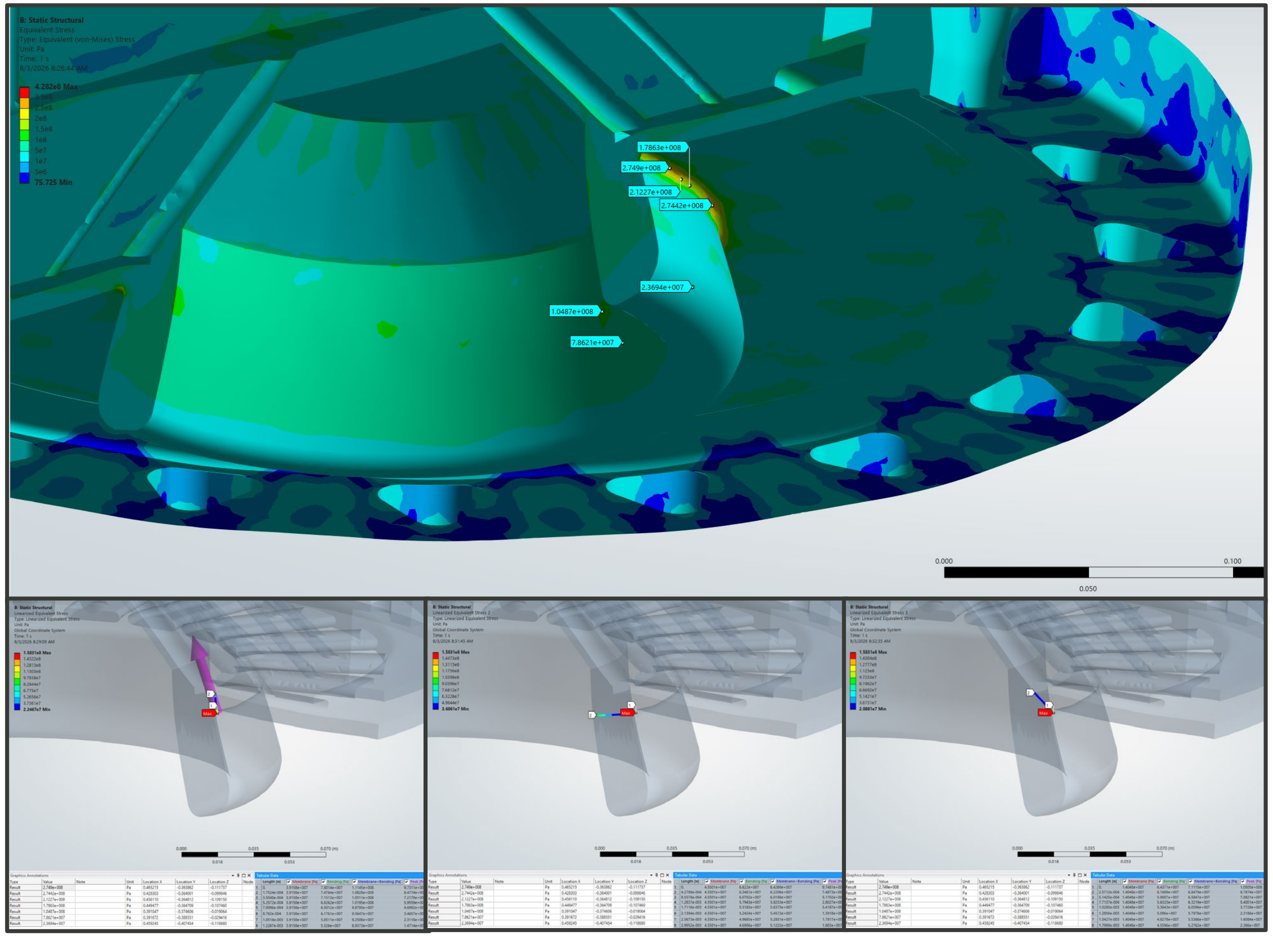
- When Level 2 shielding is installed and fixed in place in the Core Vessel, the position and shape of the pocket in the shielding for the snubber ring is measured.
- The snubber ring is machined to fit and to ensure that the center of the opening is appropriately located to “World Center”
- The ring is then mounted and measured in place to aid in positioning of the upper portion of the shaft.







Snubber Verification Analysis: 1) thermal stresses during operation



- Yield strength of SS 316L is in the 205 MPa range.
- Root of ring in the 180 MPa range, with hotspots approaching 275 MPa
- Stress was linearized through the thickness of the snubber, through the thickness of the material above the snubber, and show that the stresses were very localized
- Thermal stresses deemed a non-issue

Snubber Verification Analysis : 2) seismic structural integrity under load

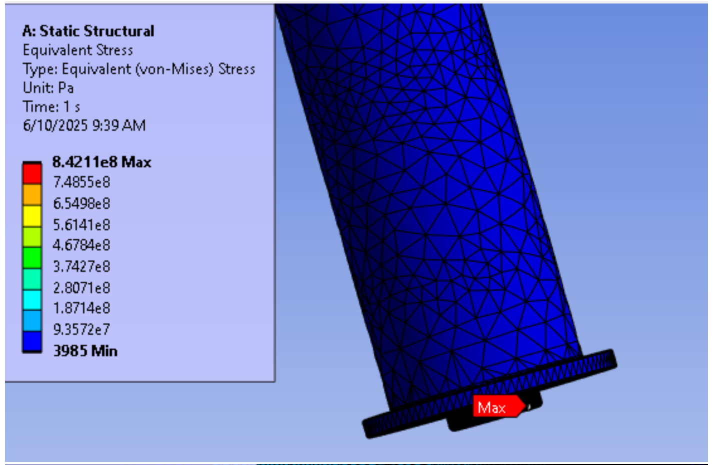
Sesismic Force on Snubber

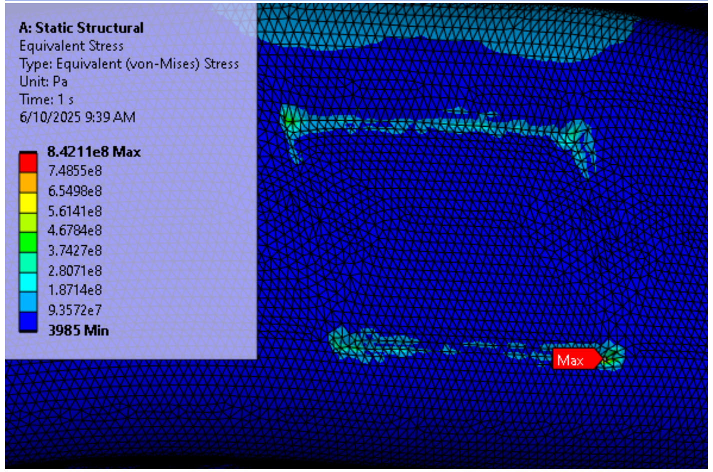
$$F_{ShaftSeg\_Seismic} := 0.7 \cdot 0.62 \cdot g \cdot \left(M_{Shaft} + 20 \cdot Weight_{eachSegment} \right) = 6.819 \times 10^{4}\,N$$

$$ShearStress_{snub} := \frac{F_{ShaftSeg\_Seismic}}{CA_{snub}} = 6.029 \cdot MPa$$

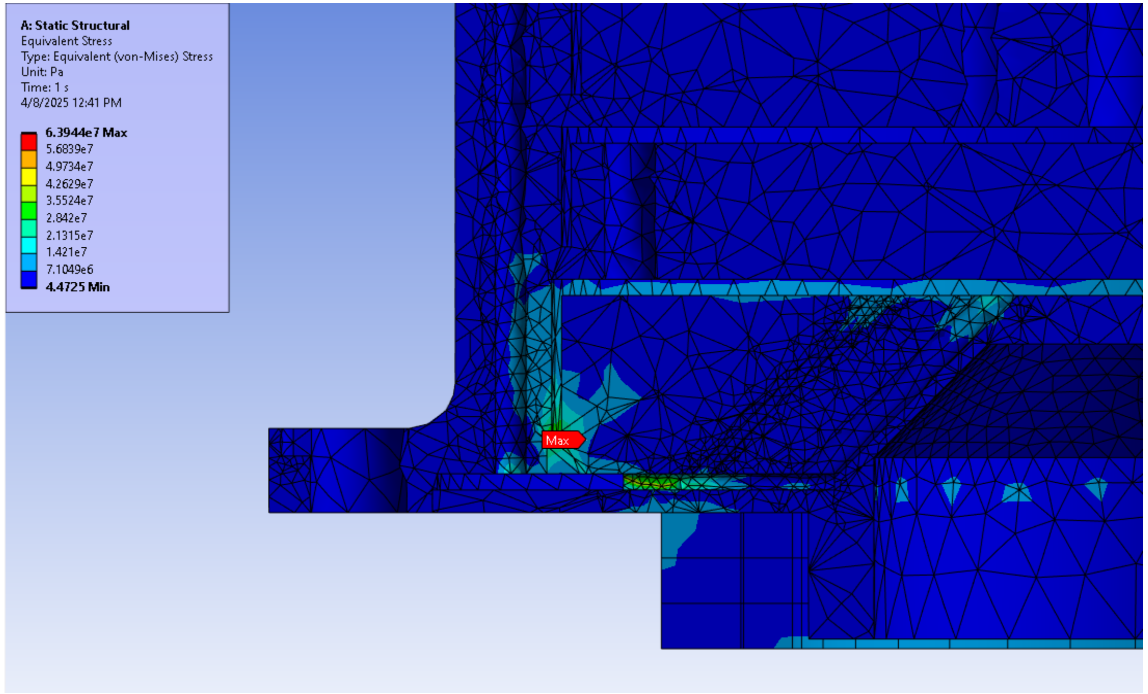
This is well below the yield strength of Stainless Steel 316L.

- 6 MPA shear force not a seismic concern
- Contact simulation shows high localized stresses, but compliant average stresses. Due to the seismic nature, there is low concern with localized stresses that might cause surface pitting or localized deformation.
- The primary concern is preventing the Target from contacting the moderator, and analysis shows that snubber collapse is not a concern.



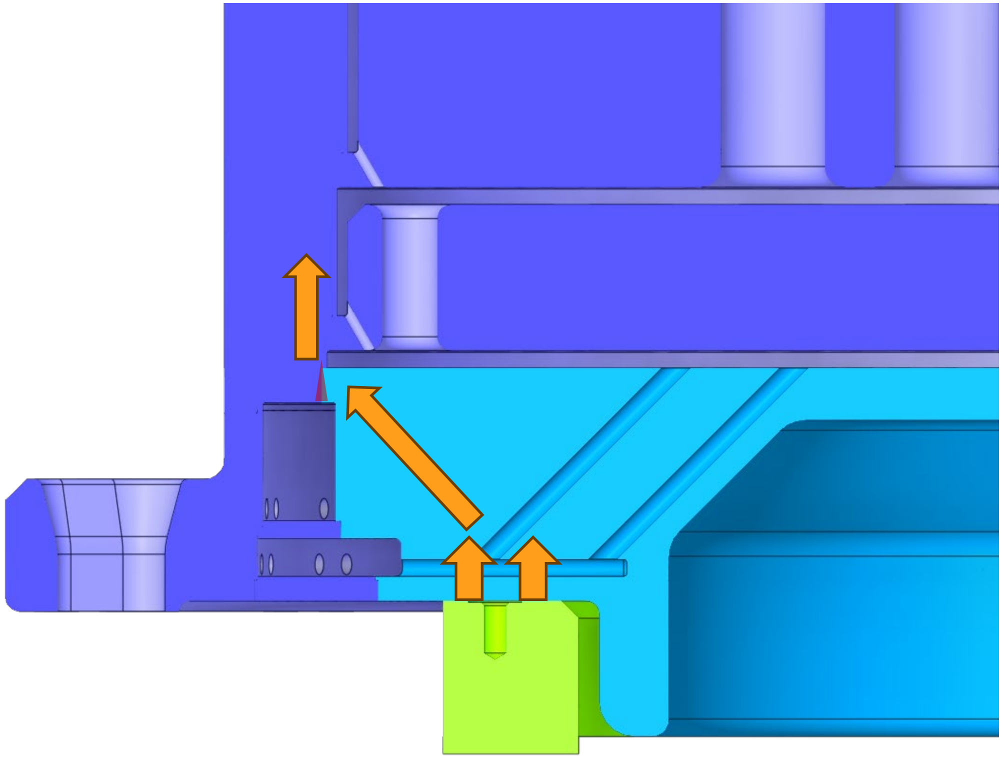


Shaft Rests on Snubber Ring during Installation and possibly special maintenance instances



63 MPa max vs 115 MPa ASME BPVC Section VIII, Division 2 material limit for SS 316L

- Analyze lower surface of Shaft to ensure good structural integrity. No concern.



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Snubber Requirements

Second Target Station (STS) » Trackers » Target Assembly Requirements » Lower Target Assembly Requirements (Snubber)
Snubber Nominal Gap - Horizontal #10792 HEAD / v4

Description

The restraint ring at the bottom of the target shall have a nominal radial gap of 6mm between rotating and static faces.

Second Target Station (STS) » Trackers » Target Assembly Requirements » Lower Target Assembly Requirements (Snubber)
Snubber Nominal Gap -Vertical #10791 HEAD / v3

Description

The restraint ring at the bottom of the target shall have a nominal vertical gap of 8mm between rotating and static faces.

Second Target Station (STS) » Trackers » Target Assembly Requirements » Lower Target Assembly Requirements (Snubber)
Profile Tolerance #10674 HEAD / v6

Upstream References S.03-1478

Description

The profile tolerance of the lower target extremity (snubber) shall be radially within +/-0.875mm from nominal.

Second Target Station (STS) » Trackers » Target Assembly Requirements » Lower Target Assembly Requirements (Snubber)
Radial Deflections During Normal Operation #10676 HEAD / v10

Description

The lower extremity (snubber) shall not deflect in the radial direction more than +/-0.5mm during the worst case combination of:

- L - Live loads (imbalance target rotation)
- P - Operational pressures (Core Vessel and component operating pressures)
- T - Operating thermal loads (beam on, cooling water)

Note 1: All deflections are measured relative to the mounting point (base) of the target assembly. (Deflection of the target assembly in isolation).
Note 2: Deflections are measured relative to the installed state of all Target Systems components at ambient temperature and pressures.

Second Target Station (STS) » Trackers » Target Assembly Requirements » Lower Target Assembly Requirements (Snubber)
Vertical Deflections During Normal Operation #10677 HEAD / v11

Description

The lower extremity shall deflect in the vertical direction <2mm (down) and< 0.2mm (up) during the worst case combination of:

- L - Live loads (imbalance target rotation)
- P - Operational pressures (Core Vessel and component operating pressures) and pressure testing (MAWP)
- T - Operating thermal loads (beam on, cooling water)

Note 1: All deflections are measured relative to the mounting point (base) of the target assembly. (Deflection of the target assembly in isolation).
Note 2: Deflections are measured relative to the installed state of all Target Systems components at ambient temperature and pressures.

Radial gap around Snubber

Vertical gap around Snubber

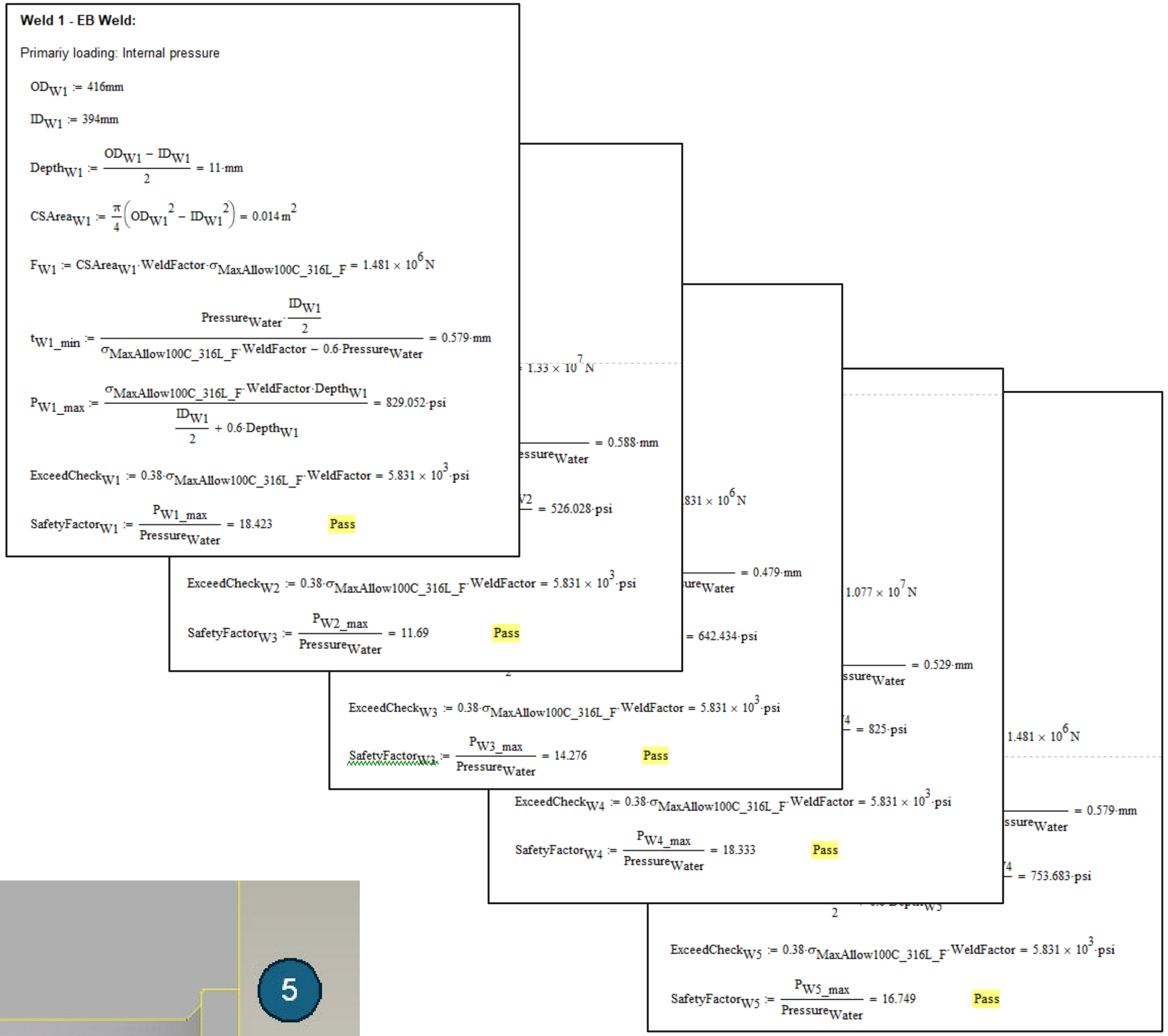
Snubber radial profile tolerance

Normal operation radial deflection limit

Normal operation vertical deflection limit

Lower Shaft Weld Evaluation

- Performed initial weld calculations of water boundary welds on the lower extremity of the shaft.
- Official weld analysis provided by “Target Assembly Structural Analysis”
- All welds passed with a wide margin.



Weld 1 - EB Weld:

Primariy loading: Internal pressure

$OD_{W1} := 416mm$

$ID_{W1} := 394mm$

$Depth_{W1} := \frac{OD_{W1} - ID_{W1}}{2} = 11 \cdot mm$

$CSArea_{W1} := \frac{\pi}{4}\left(OD_{W1}^2 - ID_{W1}^2\right) = 0.014\, m^2$

$F_{W1} := CSArea_{W1} \cdot WeldFactor \cdot \sigma_{MaxAllow100C\_316L\_F} = 1.481 \times 10^6\, N$

$t_{W1\_min} := \frac{Pressure_{Water} \cdot \frac{ID_{W1}}{2}}{\sigma_{MaxAllow100C\_316L\_F} \cdot WeldFactor - 0.6 \cdot Pressure_{Water}} = 0.579 \cdot mm$

$P_{W1\_max} := \frac{\sigma_{MaxAllow100C\_316L\_F} \cdot WeldFactor \cdot Depth_{W1}}{\frac{ID_{W1}}{2} + 0.6 \cdot Depth_{W1}} = 829.052 \cdot psi$

$ExceedCheck_{W1} := 0.38 \cdot \sigma_{MaxAllow100C\_316L\_F} \cdot WeldFactor = 5.831 \times 10^3 \cdot psi$

$SafetyFactor_{W1} := \frac{P_{W1\_max}}{Pressure_{Water}} = 18.423$ Pass

$ExceedCheck_{W2} := 0.38 \cdot \sigma_{MaxAllow100C\_316L\_F} \cdot WeldFactor = 5.831 \times 10^3 \cdot psi$

$SafetyFactor_{W3} := \frac{P_{W2\_max}}{Pressure_{Water}} = 11.69$ Pass

$ExceedCheck_{W3} := 0.38 \cdot \sigma_{MaxAllow100C\_316L\_F} \cdot WeldFactor = 5.831 \times 10^3 \cdot psi$

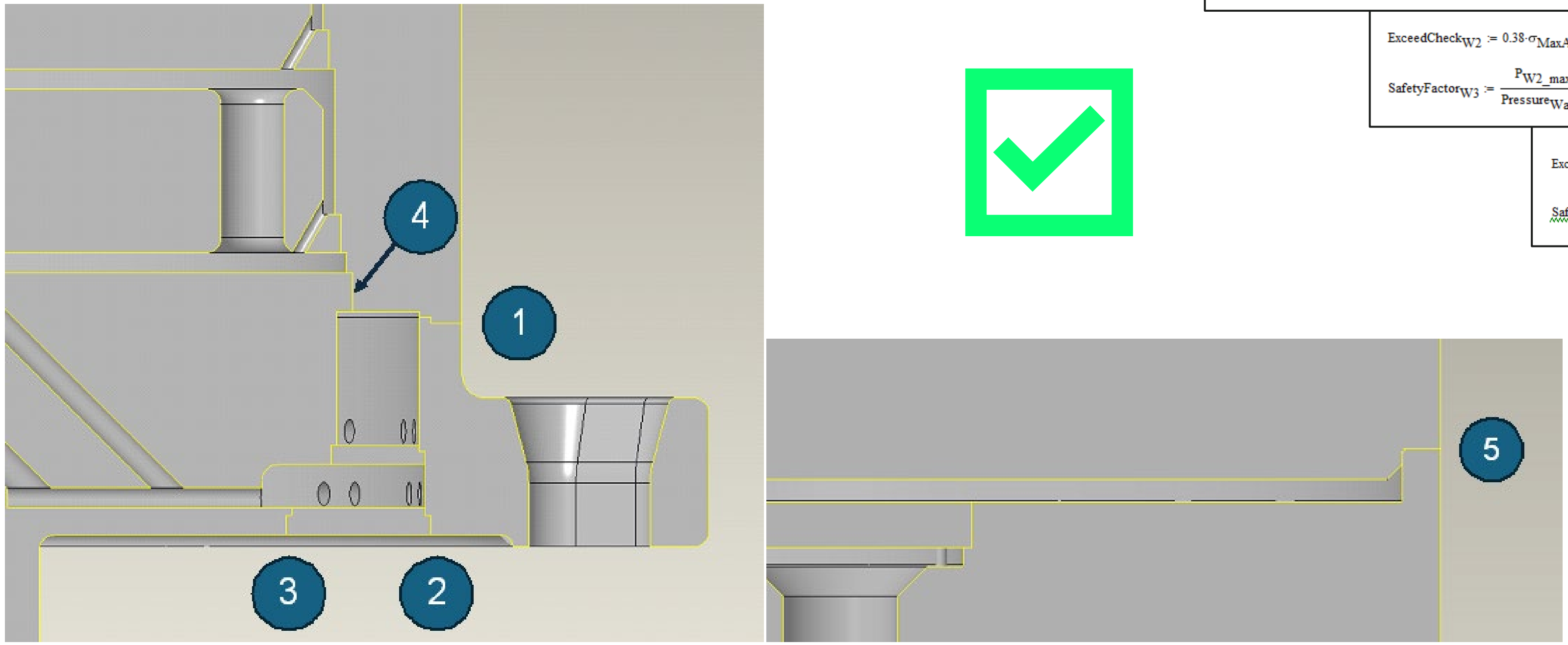
$SafetyFactor_{W3} := \frac{P_{W3\_max}}{Pressure_{Water}} = 14.276$ Pass

$ExceedCheck_{W4} := 0.38 \cdot \sigma_{MaxAllow100C\_316L\_F} \cdot WeldFactor = 5.831 \times 10^3 \cdot psi$

$SafetyFactor_{W4} := \frac{P_{W4\_max}}{Pressure_{Water}} = 18.333$ Pass

$ExceedCheck_{W5} := 0.38 \cdot \sigma_{MaxAllow100C\_316L\_F} \cdot WeldFactor = 5.831 \times 10^3 \cdot psi$

$SafetyFactor_{W5} := \frac{P_{W5\_max}}{Pressure_{Water}} = 16.749$ Pass



Shaft Requirements

Second Target Station (STS) » Trackers » Target Assembly Requirements » Mounting Interface Requirements

Lower restraint - adjustment allowance #10735 HEAD / v6

Description

The lower restraint of the target assembly shall be able to withstand adjustment relative to the shield mounting points of:

Horizontal: +/- 3.5mm

Vertical: +/- 1.5mm

Enable adjustment of snubber ring to permit alignment into CV

Second Target Station (STS) » Trackers » Target Assembly Requirements » Mounting Interface Requirements

Structural capacity during relative motion #10698 HEAD / v11

Upstream References S.03-1478

Description

The target assembly shall be capable of maintaining structural integrity under a horizontal relative motion between base and lower extremity (snubber ring) of up to: 13mm.

Permit movement between the top mounting point of the Target Assembly and the snubber ring and maintain structural integrity of the Target Assembly

All shaft design requirement have been met, and all calculations and analysis have verified appropriate functionality and geometry robustness.

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