OAK RIDGE National Laboratory

Vessel Systems (S.03.06)
Core Vessel Thermal Hydraulic Analysis

Min-Tsung Kao

09/06/2023

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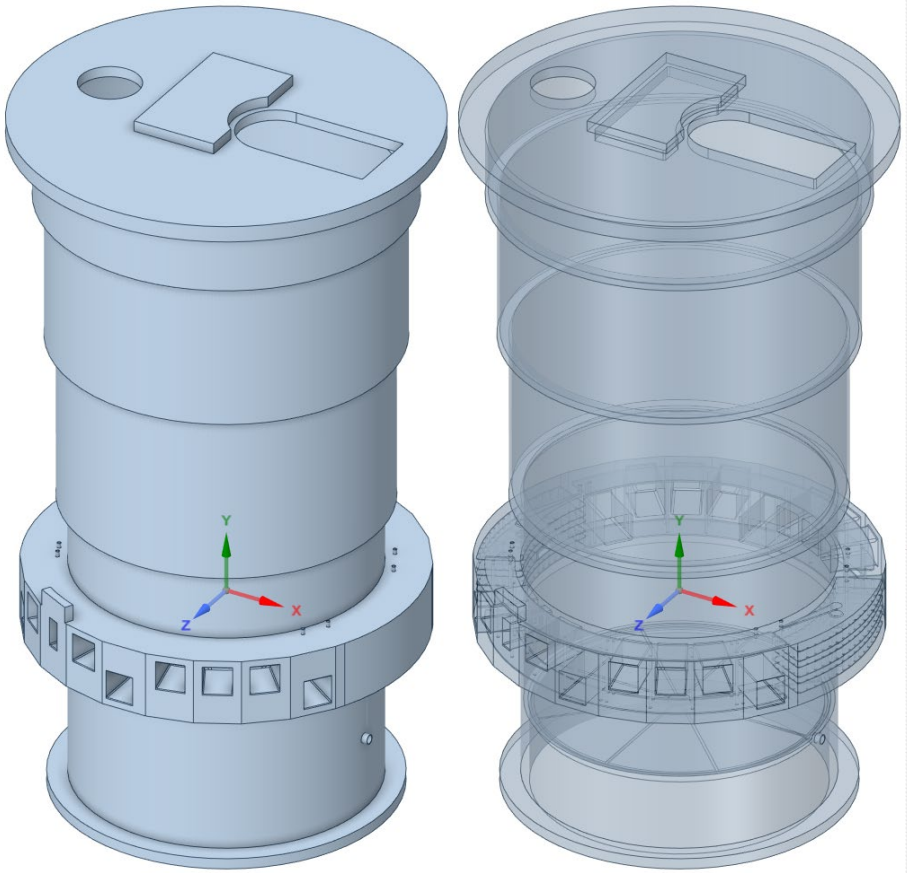
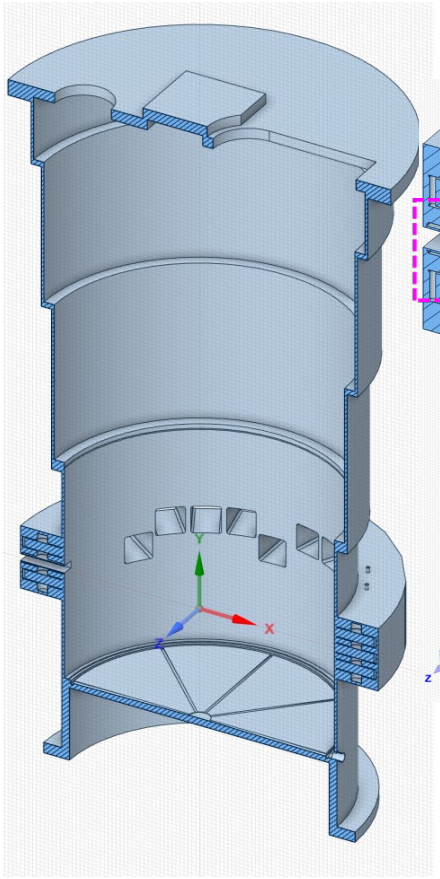
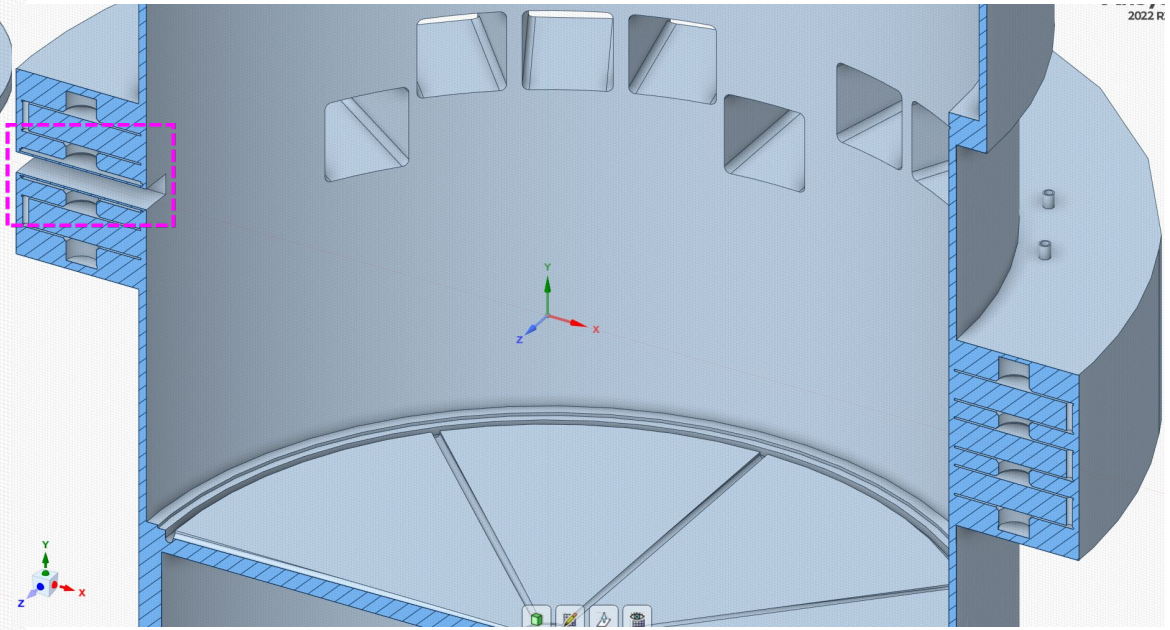
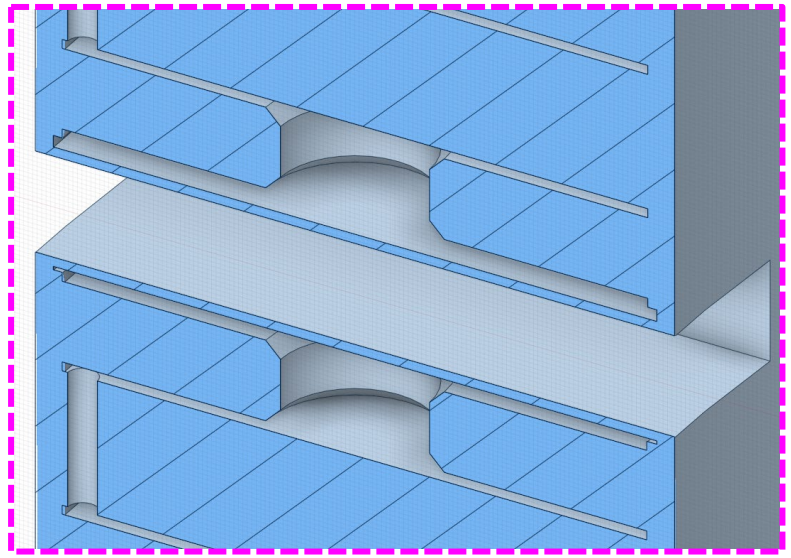
U.S. DEPARTMENT OF ENERGY

Core Vessel, Solid

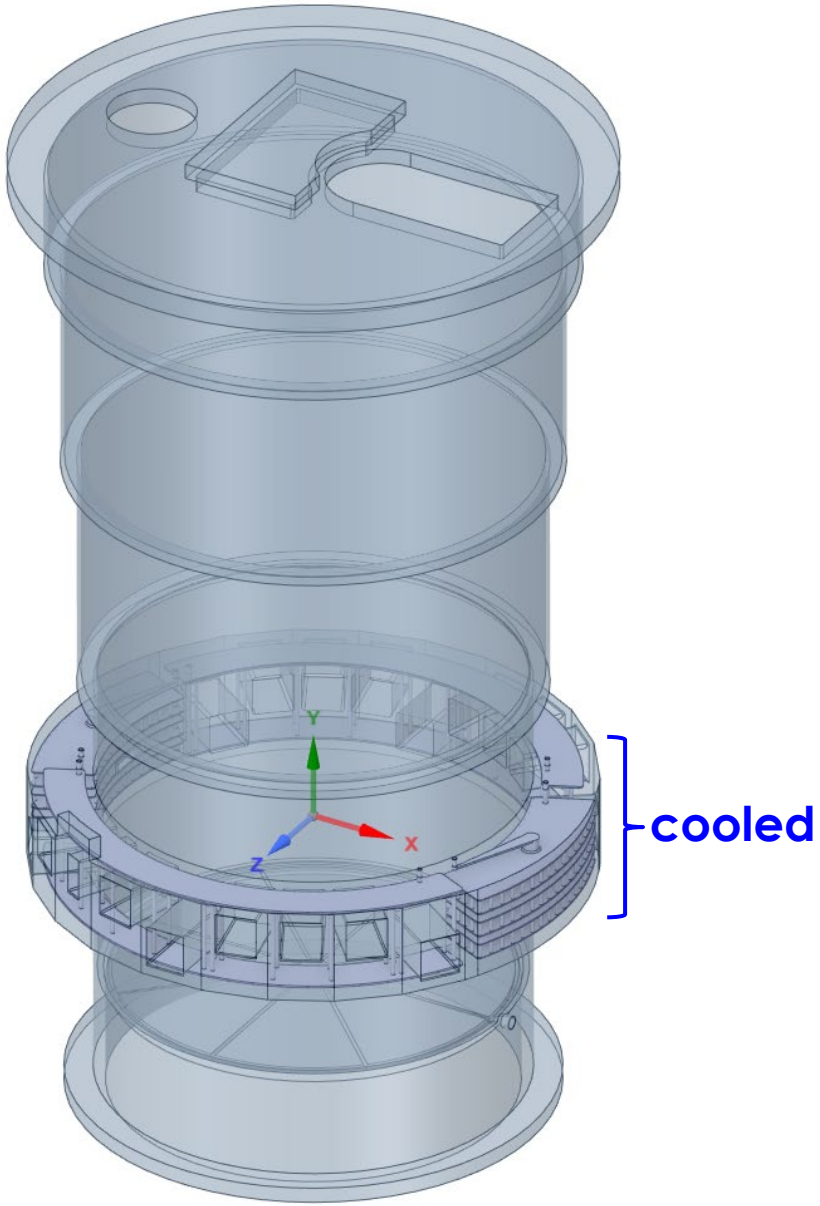


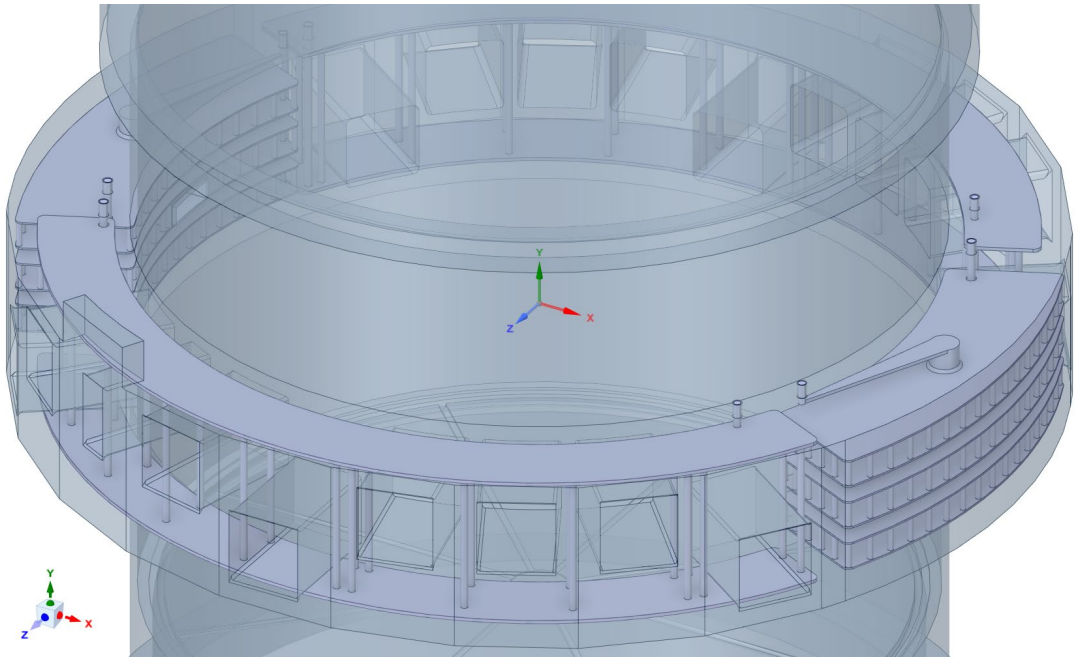


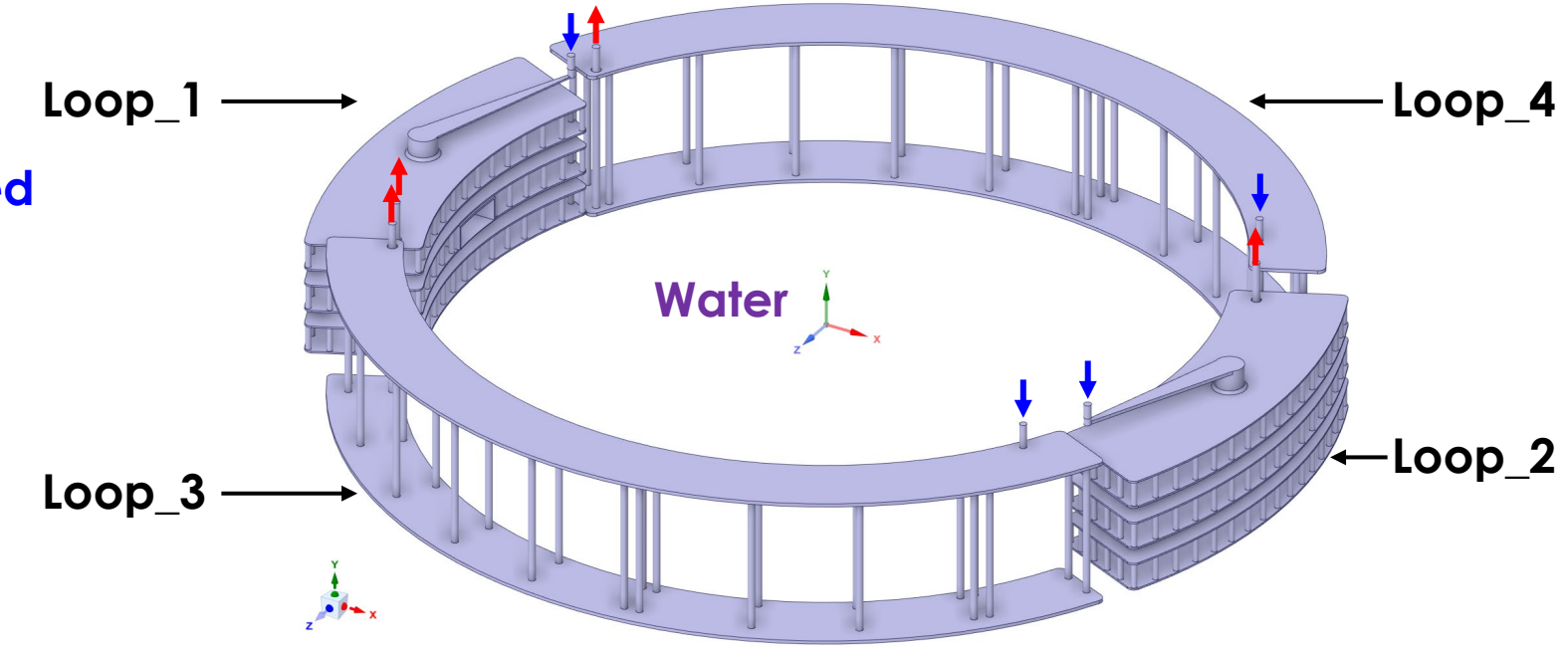




Core Vessel, Cooling Channel







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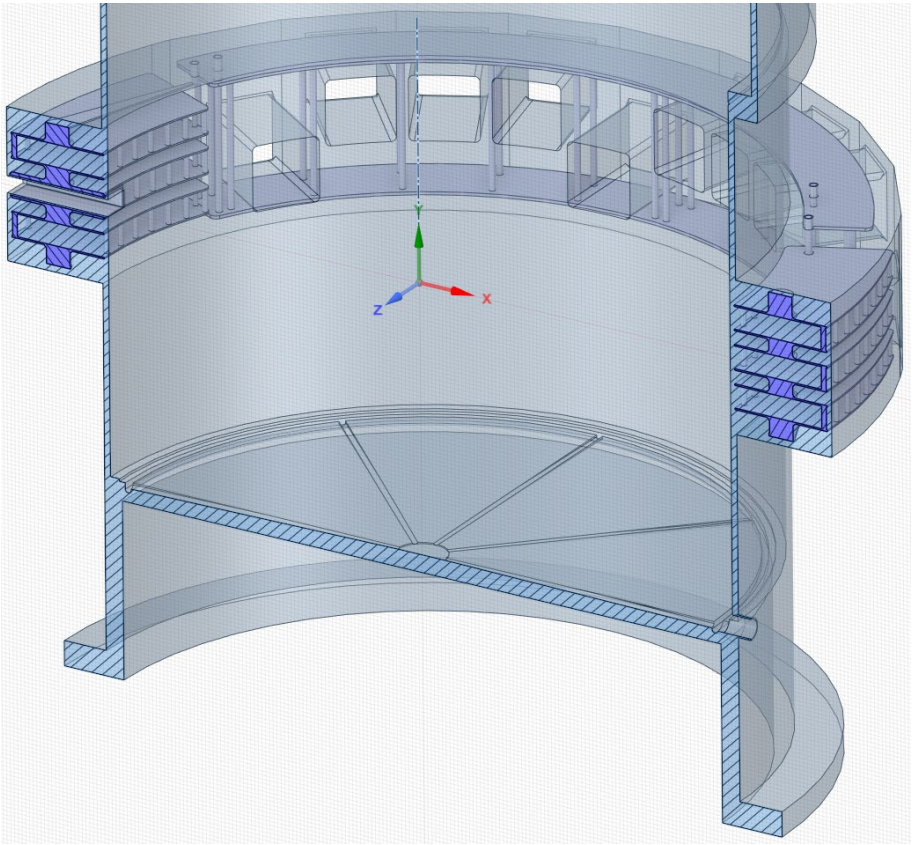
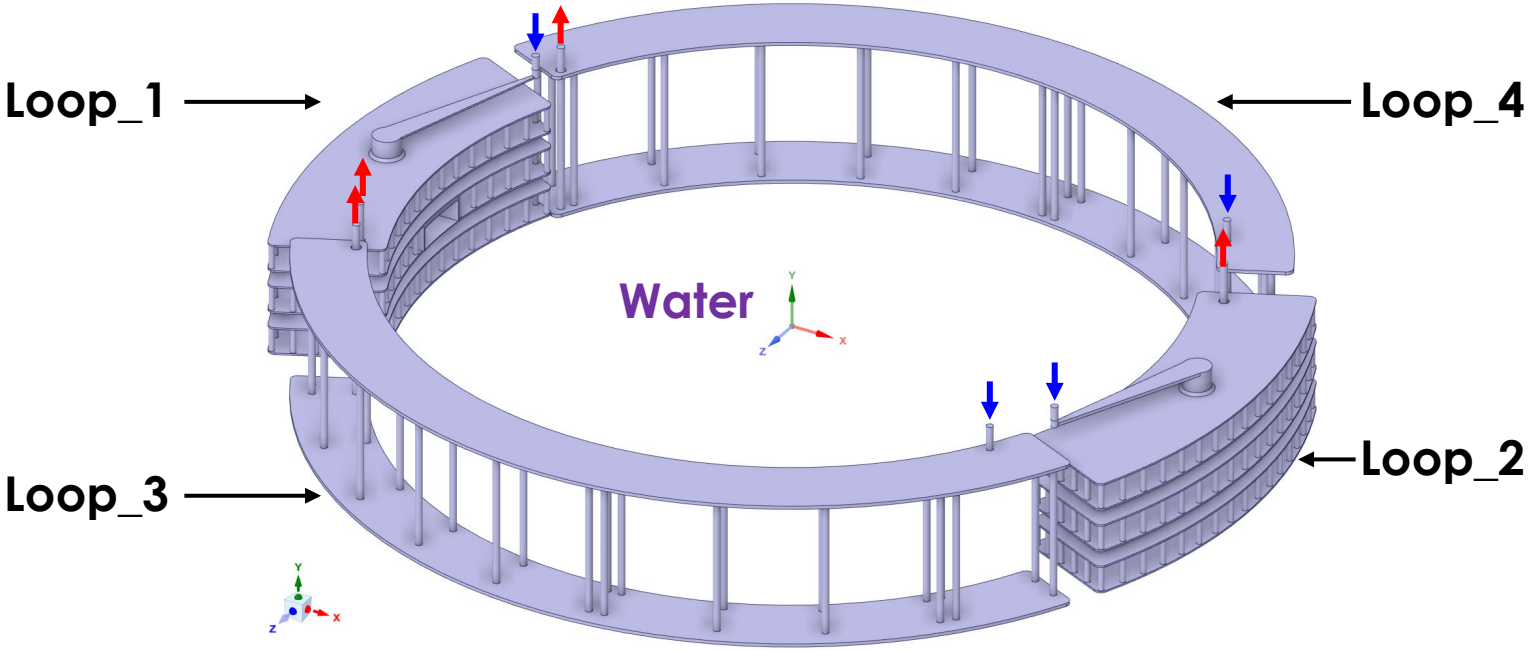
Core Vessel, Cooling Channel



↓ : inlet, 0.5 kg/s (8 GPM) 32.2°C H_2O

↑ : outlet, 45 psia



Material Properties

SS316 Material Properties From Ansys

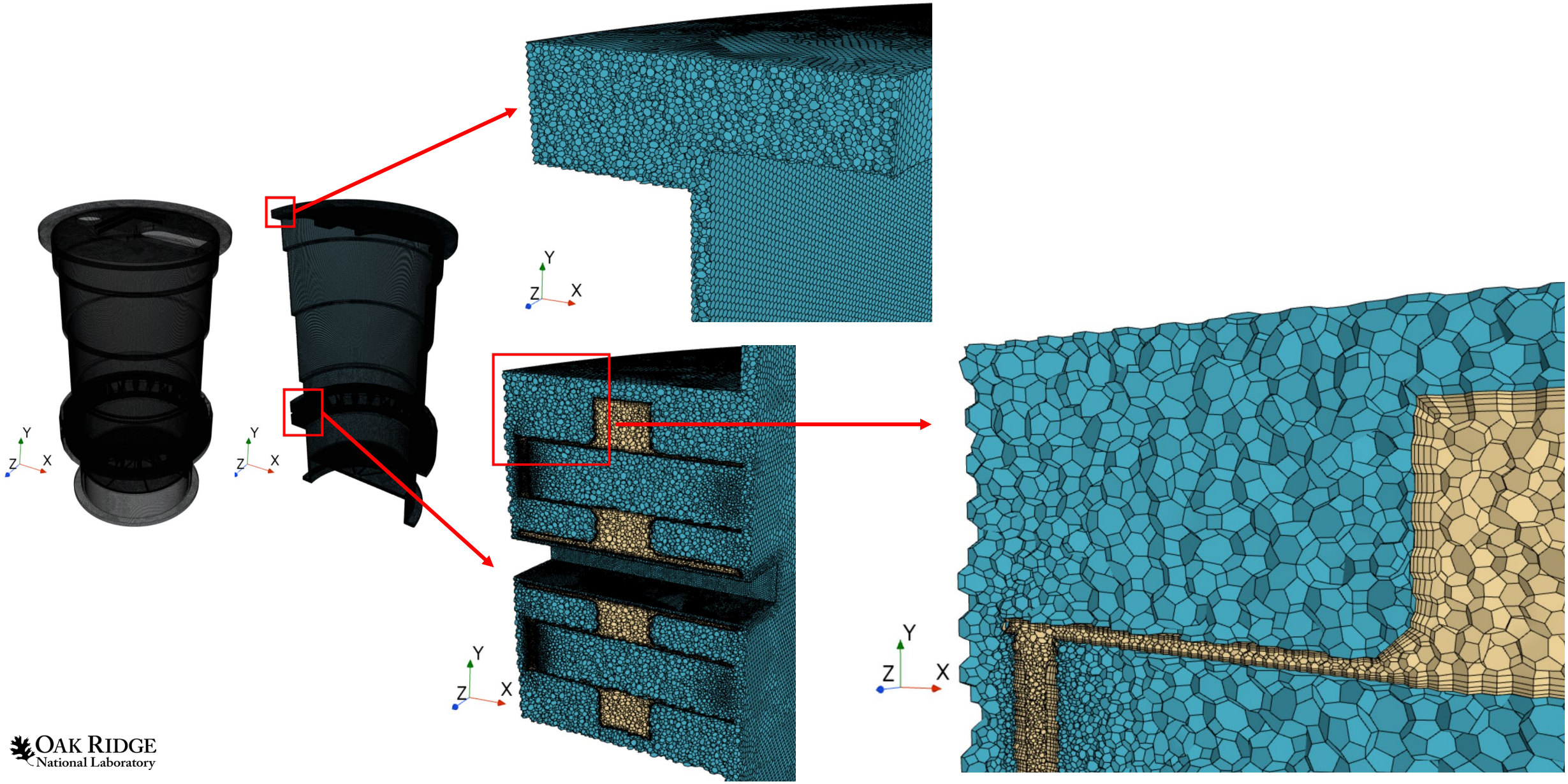
Stainless steel, 316, annealed
Data compiled by Ansys Granta, incorporating various sources including JAHM and MagWeb.

Density (kg/m^3)	**7969**
Coefficient of Thermal Expansion (1/K)	**1.61E-05**
Specific Heat (J/kg-K)	**486.1**
Thermal Conductivity (W/m-K)	**14.58**
Young's Modulus (Pa)	**1.95E+11**
Poisson's Ratio	**0.27**
Bulk Modulus (MPa)	**1.413E5**
Shear Modulus (MPa)	**76772**
Tensile Ultimate Strength (MPa)	**565.1**
Tensile Yield Strength (MPa)	**252.1**

Zero Thermal Strain Reference Temperature (°C)	**32.2**

Core Vessel, Mesh Configuration for CFD Analysis

Polyhedral meshes: 25,375,561



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Core Vessel, Heat Source (SS316)

energy deposition from Lukas

Link: https://ornl.sharepoint.com/sites/sts/targetsystems/Shared%20Documents/Forms/AllItems.aspx?csf=1&web=1&e=llwgp7&cid=939335e4%2D4ccc%2D4c00%2Da2d2%2D814c53b7125a&FolderCTID=0x01200064187E8E25420543ACAD0BF1C3490EAC&noAuthRedirect=1&id=%2Fsites%2Fsts%2Ftargetsystems%2FShared%20Documents%2FS%2E03%2E02%20Target%20Assembly%2F1%5FCALCULATIONS%2FCALC%2D018%20%2D%20CoreVessel%2FNeutronics&viewid=9be9bc88%2D5a13%2D48c7%2D9fff%2Dd22f94ffdeb5

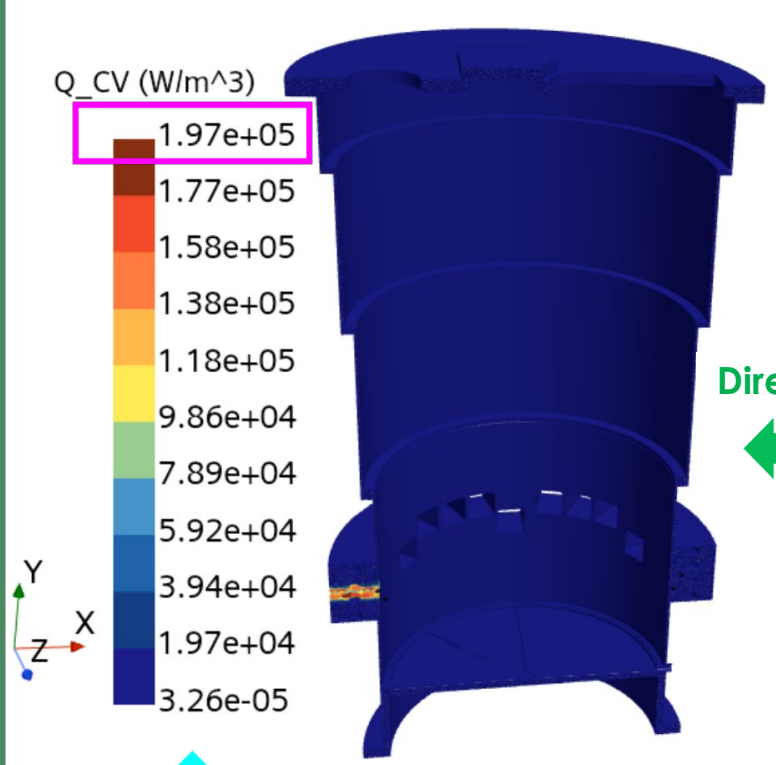
Combined (unit conversion)

- o07a_CVBeltDOWN_SS316L.csv
- o07a_CVBeltDOWN_SS316Water.csv
- o08b_CVBeltUP_SS316L.csv
- o08b_CVBeltUP_SS316Water.csv
- o09d_Center_SS316L.csv
- o09d_Center_SS316Water.csv
- o09d_Center_SS316Water_2.csv
- o09f_11_out_Bottom_SS304L.csv
- o09f_11_out_Bottom_SS316L.csv
- o09g_20_out_Top_SS316L.csv
- o09h_22_out_CVTop_above250cm_SS316L.csv

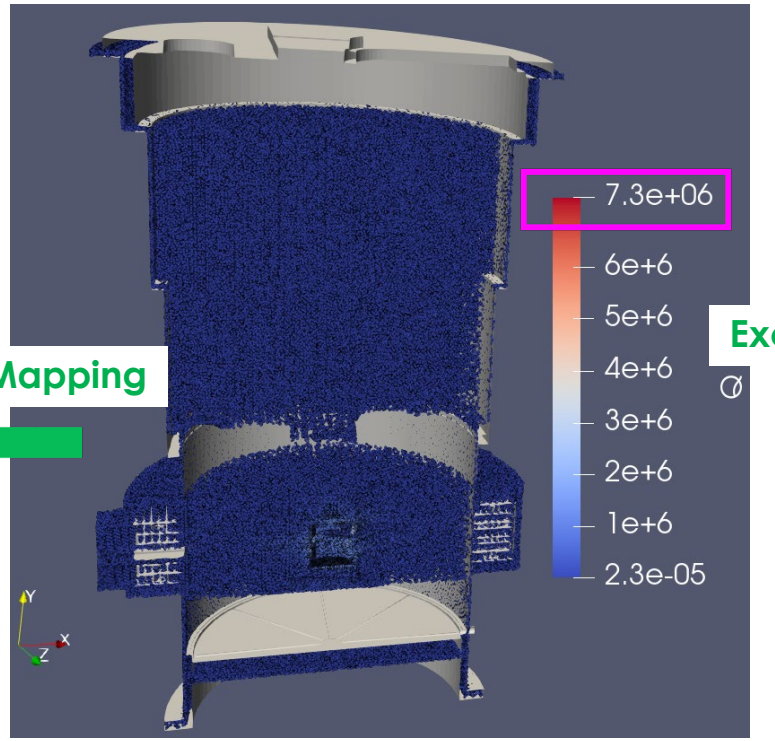
Heat Data Mapped onto CFD Meshes

Neutronics Heat Data from Lukas

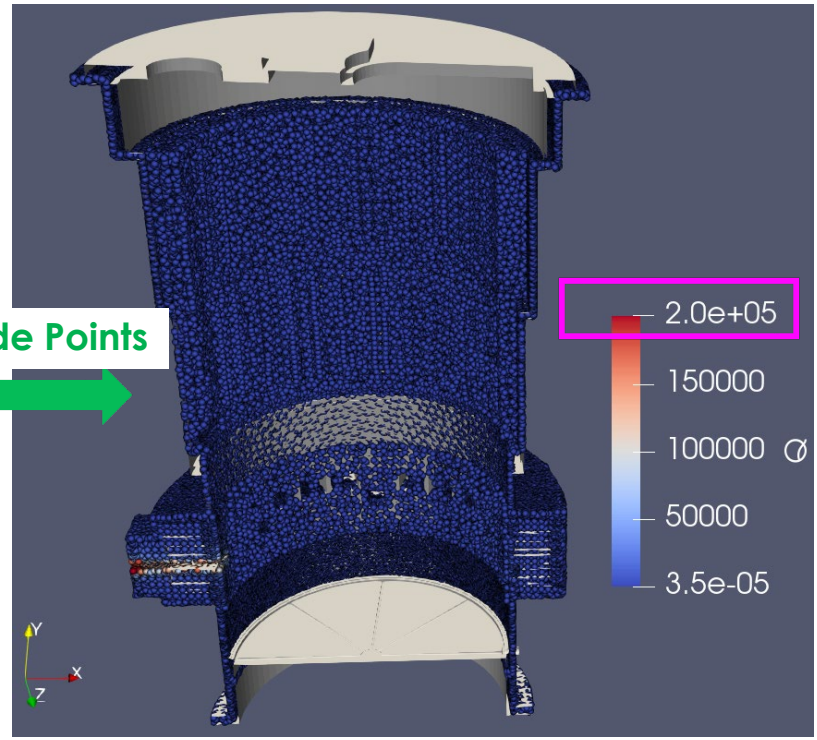
Exclude Neutronics Heat Data Points in Shield Blocks



Direct Mapping



Exclude Points



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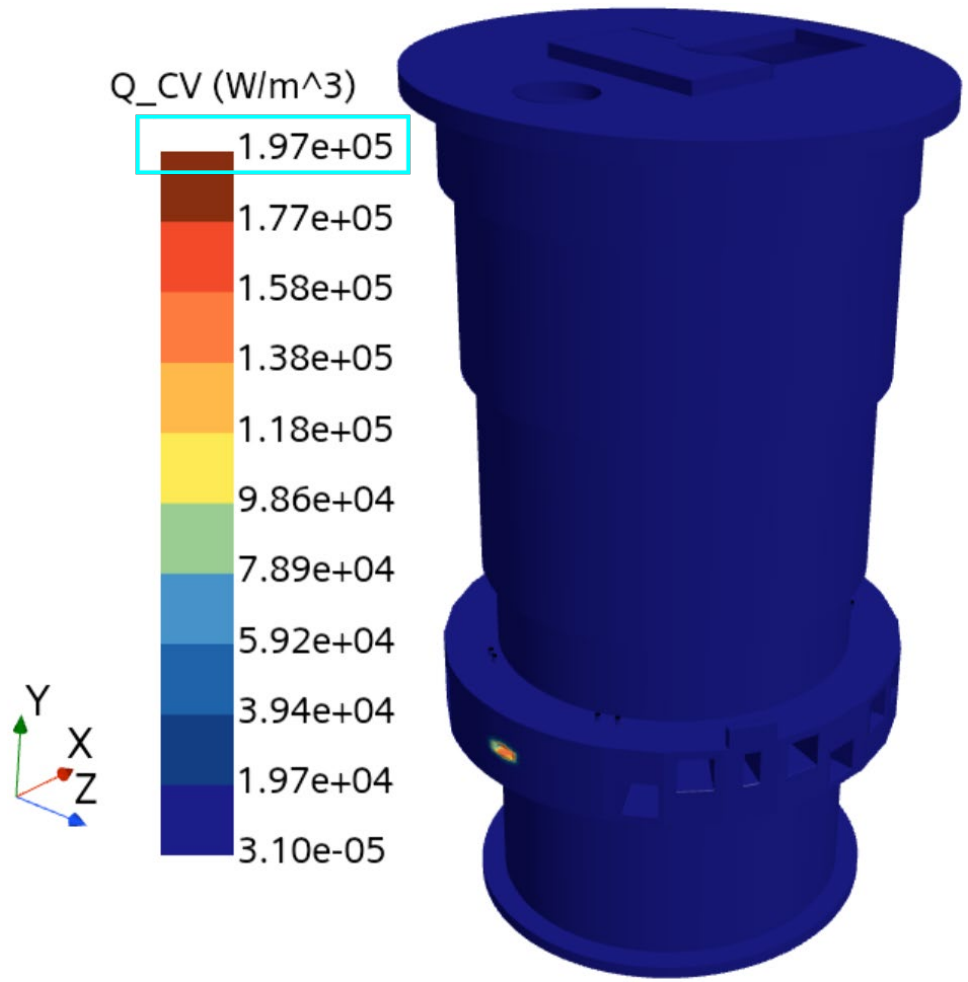
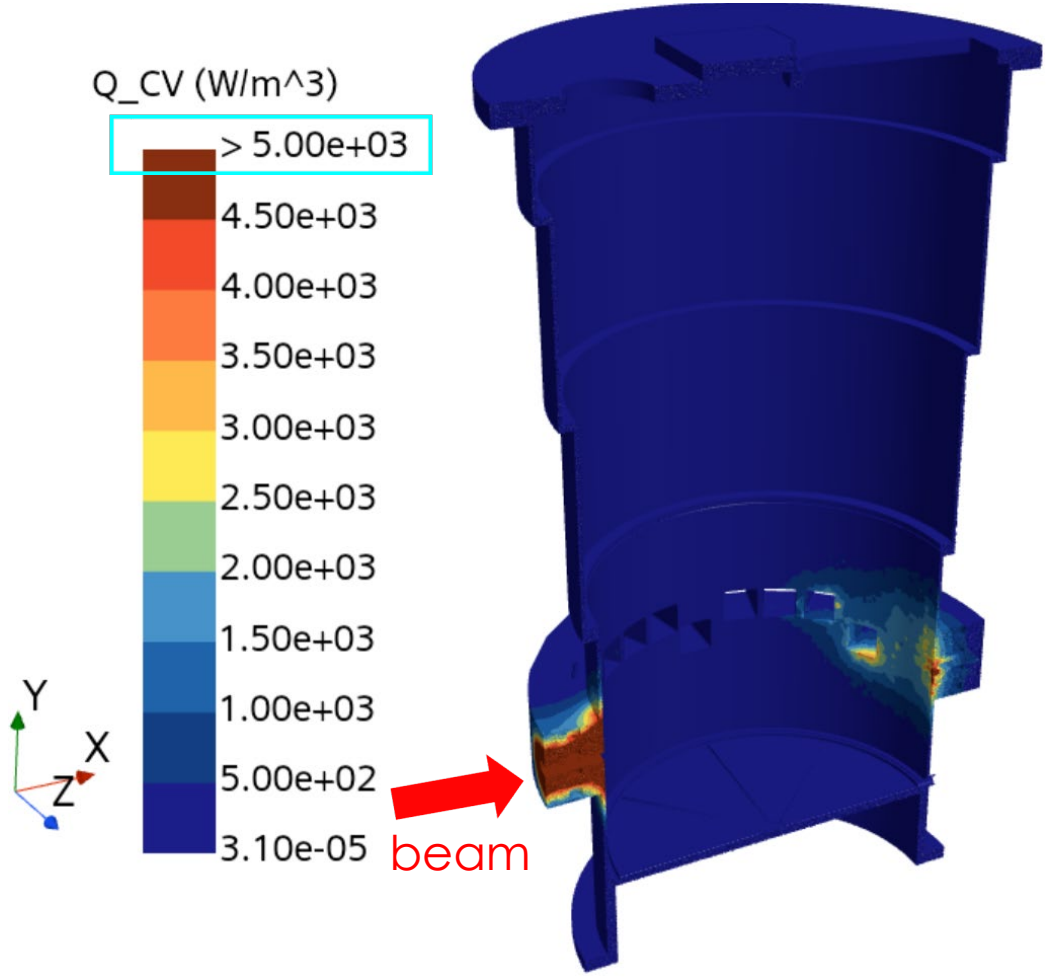
Core Vessel, Heat Source (SS316)

Q_{ss} = 1,868 W





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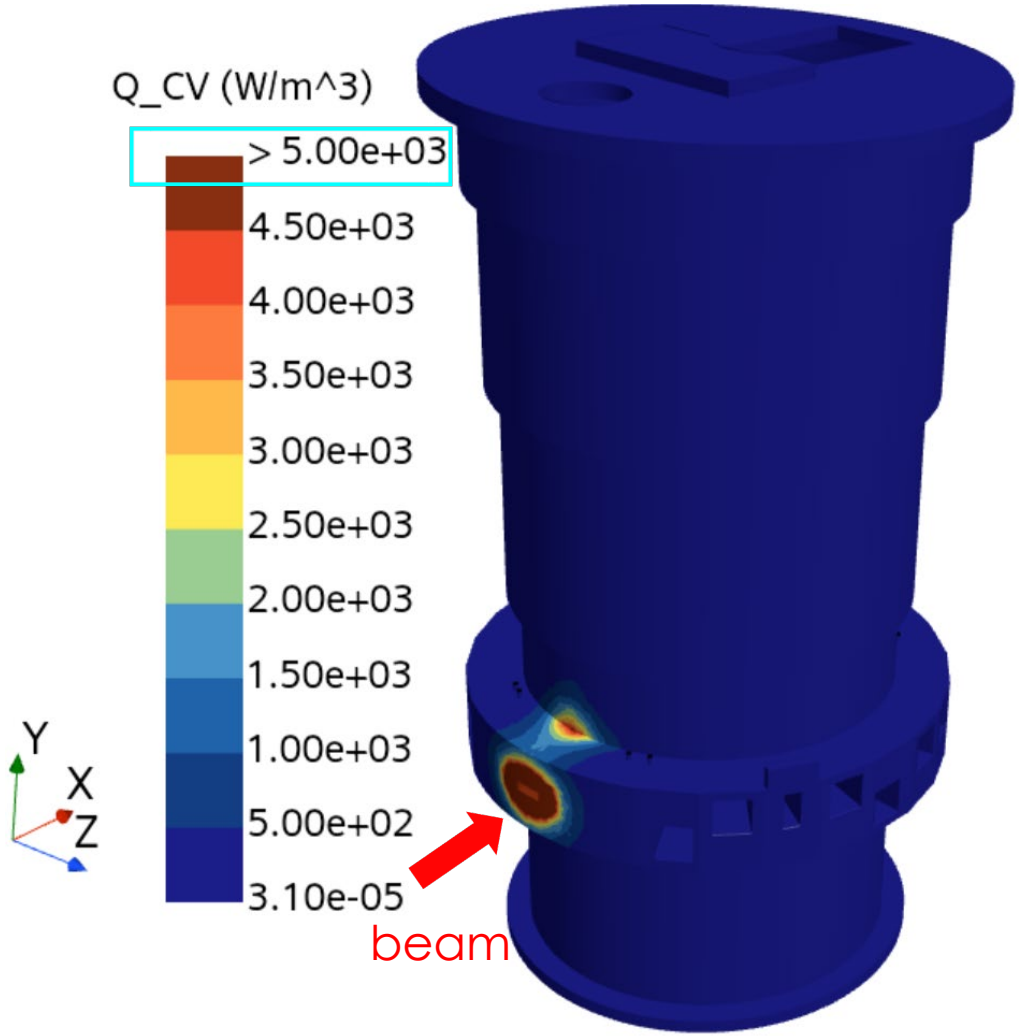
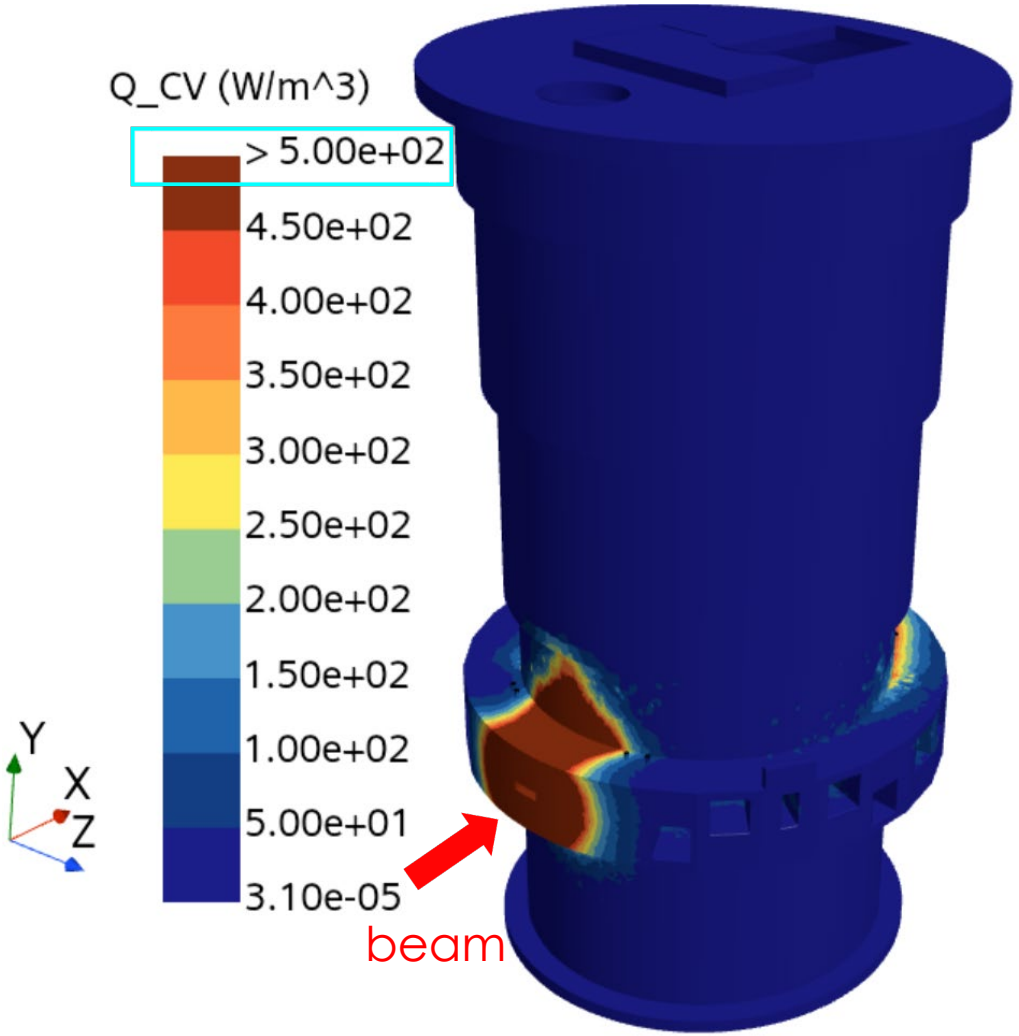


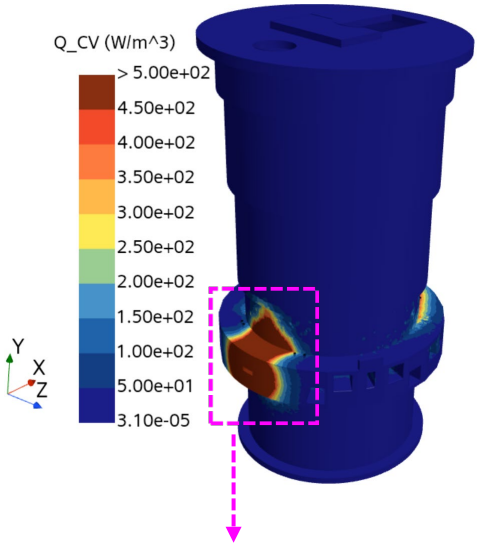
Front View

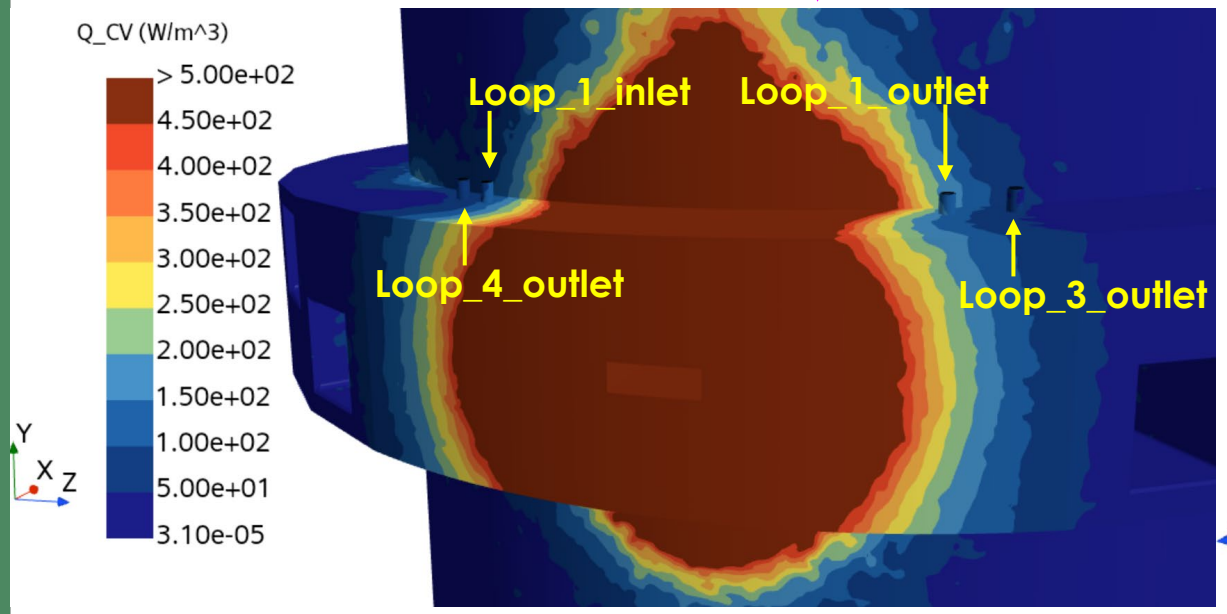


Front View

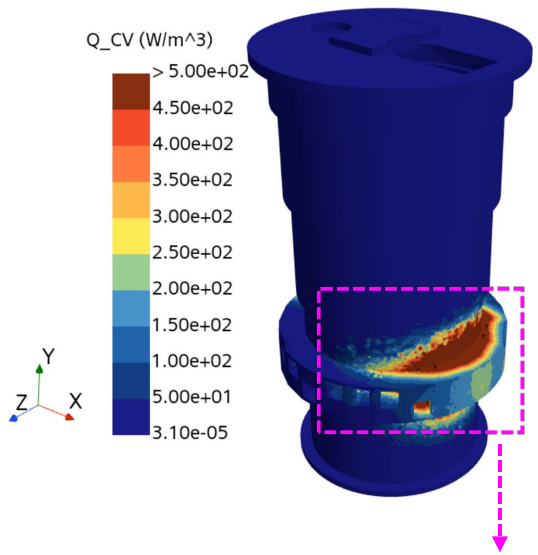
Core Vessel, Heat Source (SS316)

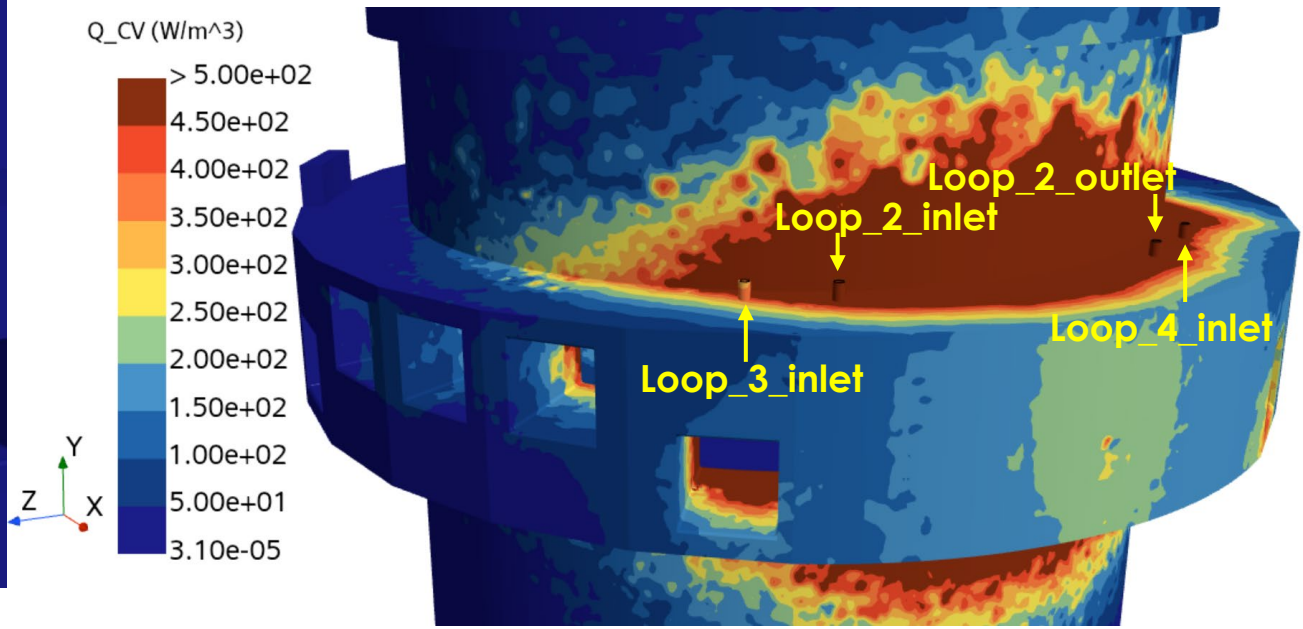
Front View





Rear View

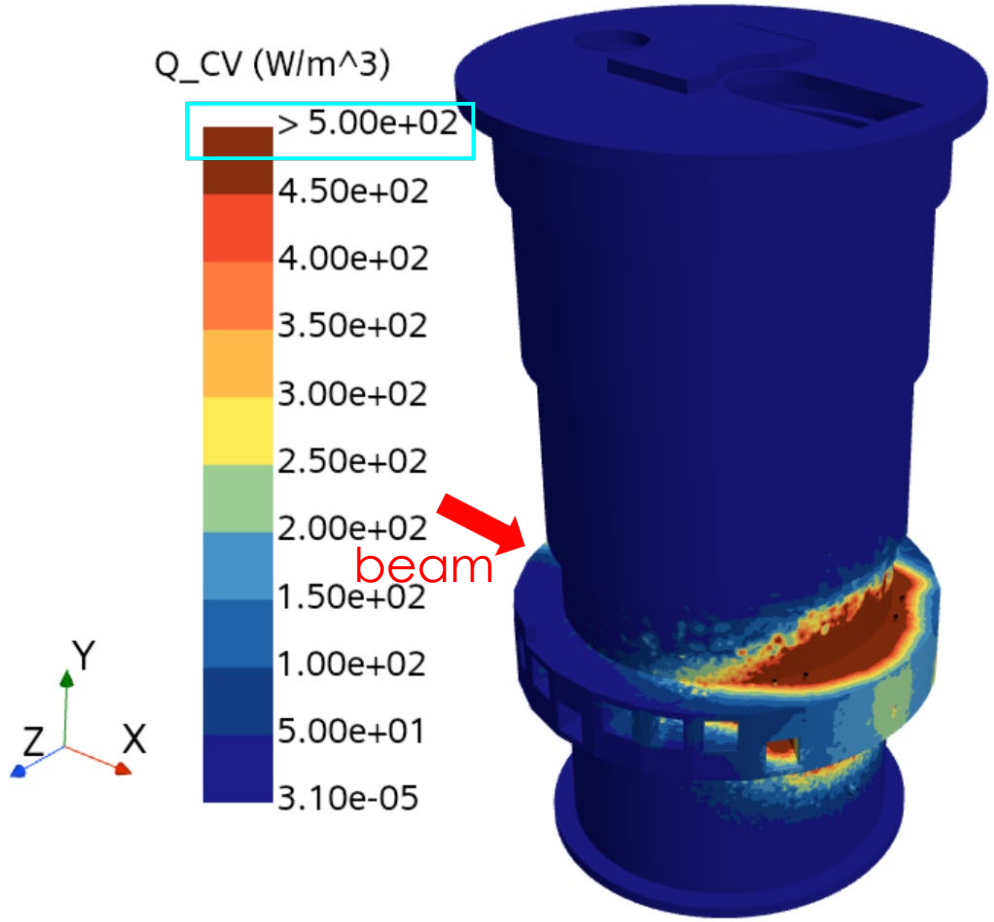


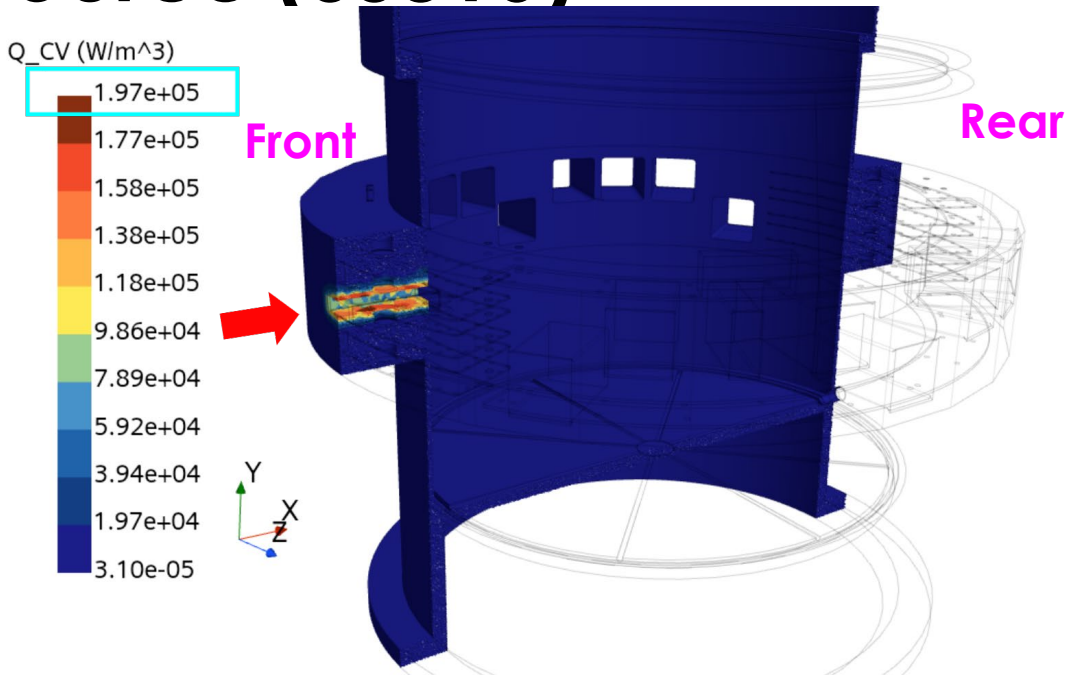


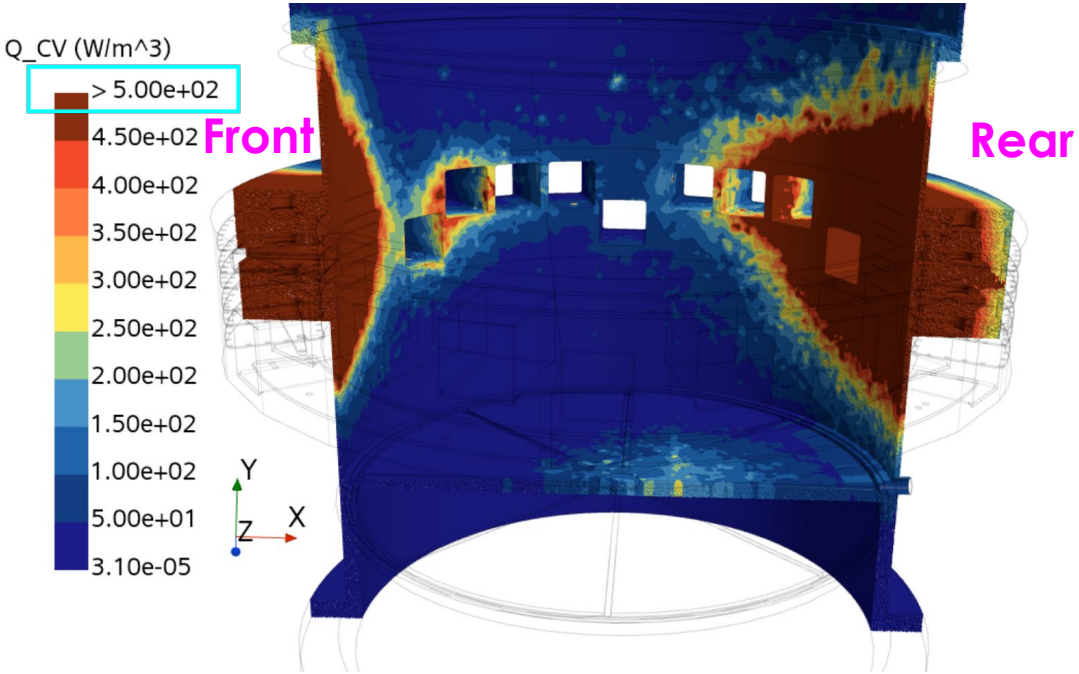
Core Vessel, Heat Source (SS316)

Q_{ss} = 1,868 W

Rear View

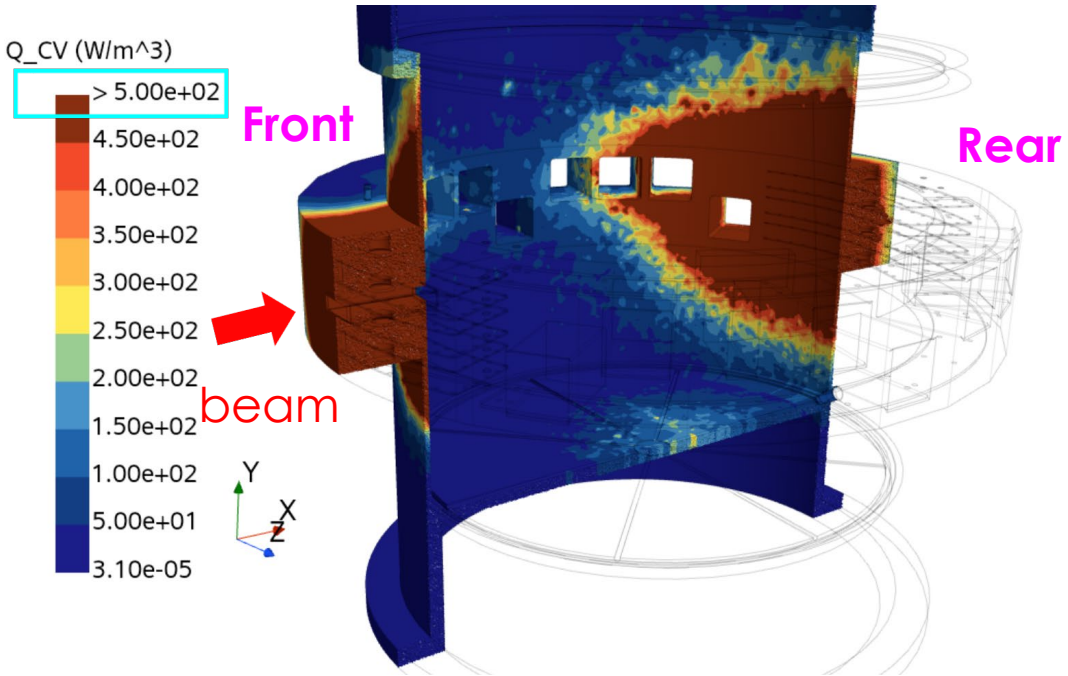




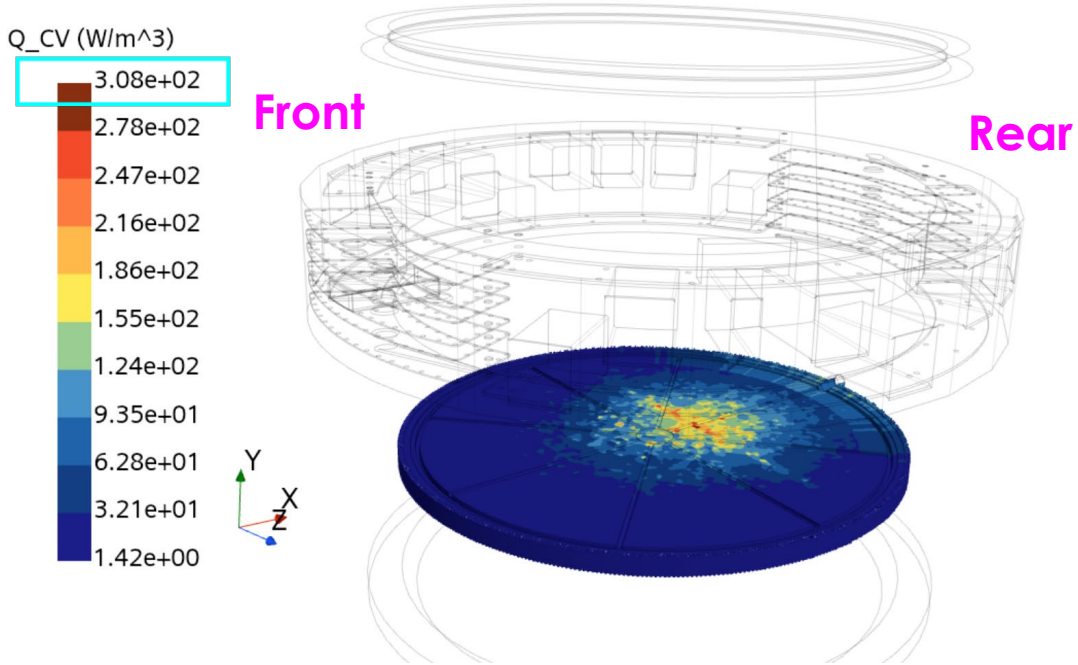


Core Vessel, Heat Source (SS316)

Q_{ss} = 1,868 W

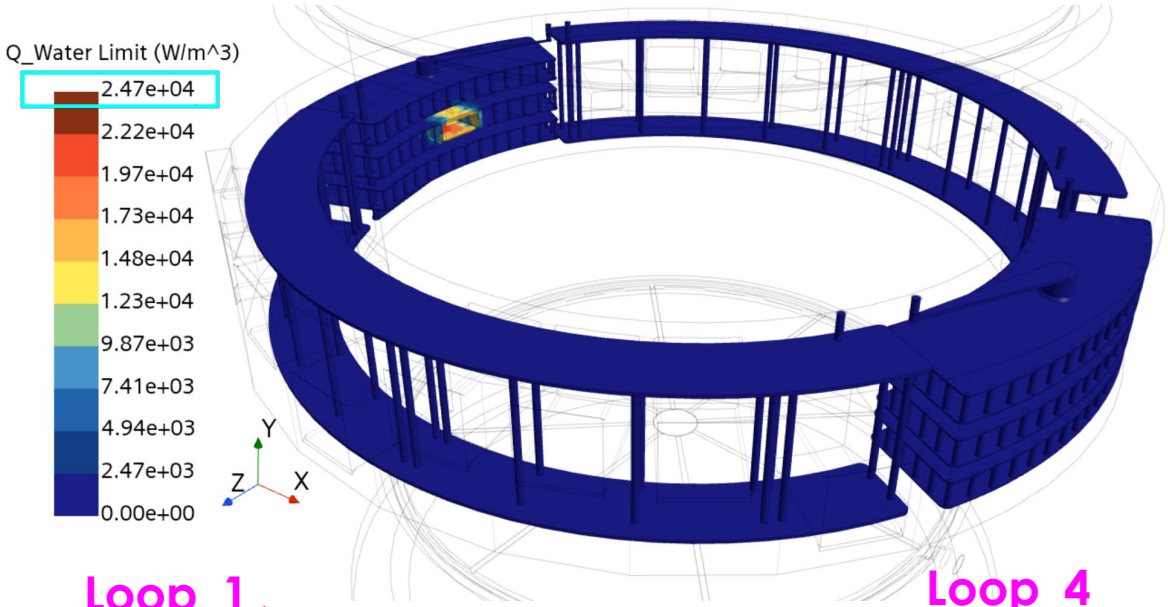


Bottom Plate



Heat Source in Water

Q_Water approximation: $Q_{water} = QSB_{heat} * \frac{\rho_{water}}{\rho_{SS}}$



Lower heating

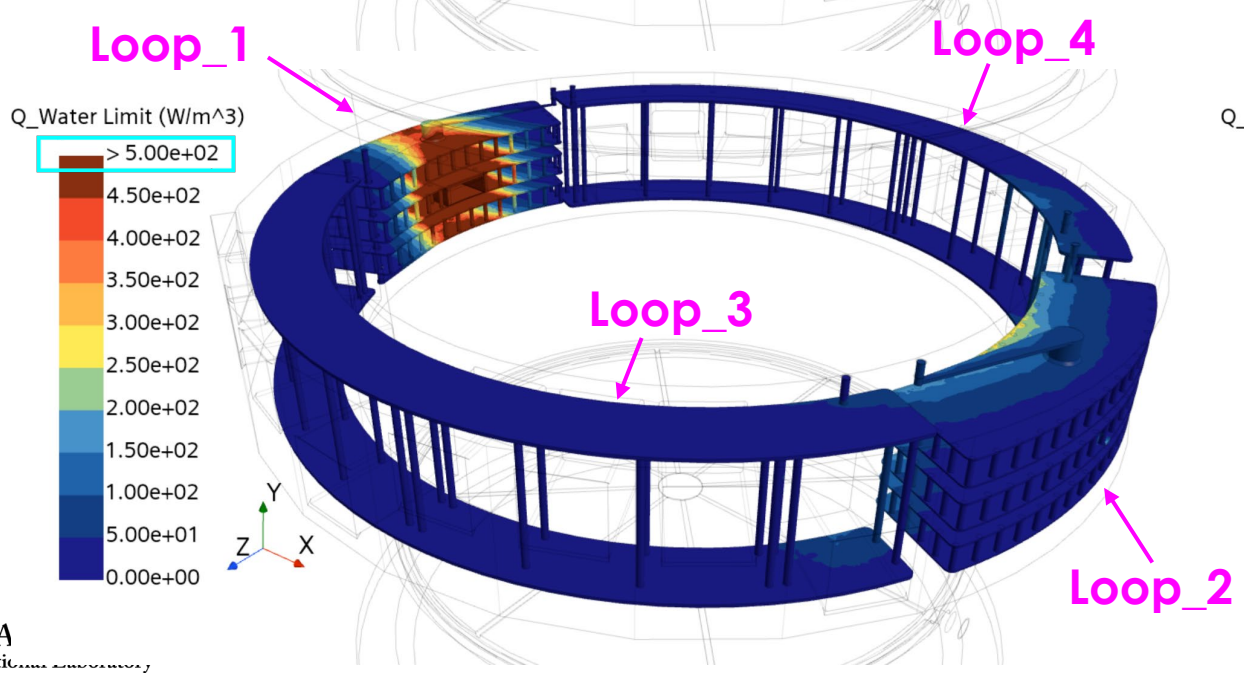
$Q_{water\_Loop\_1}$ = 49.74W

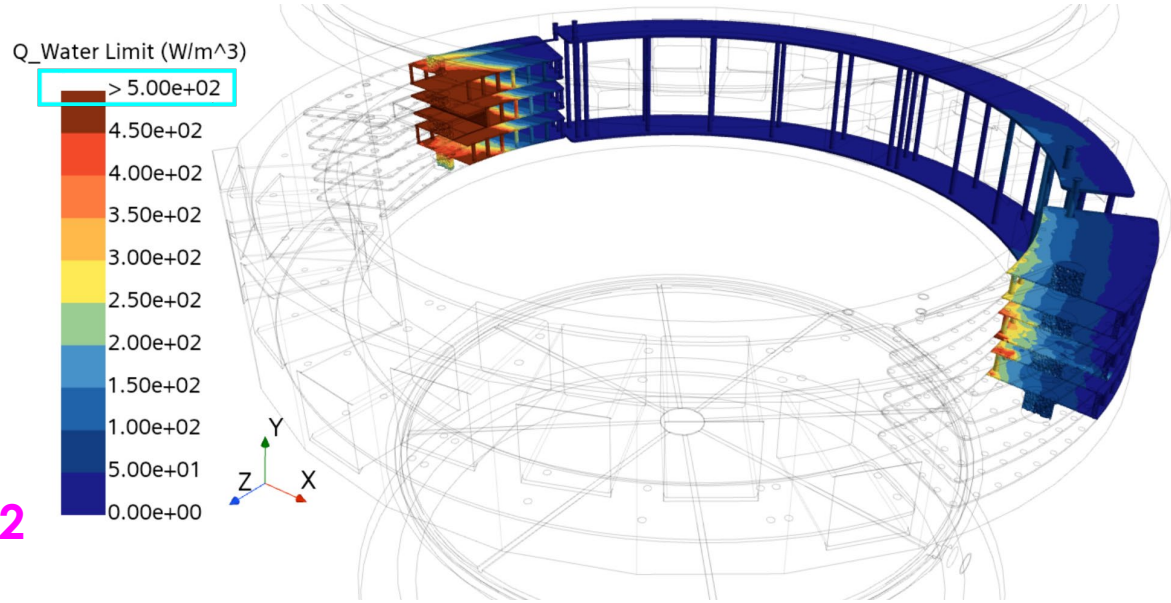
$Q_{water\_Loop\_2}$ = 2.29W

$Q_{water\_Loop\_3}$ = 0.32W

$Q_{water\_Loop\_4}$ = 0.61W

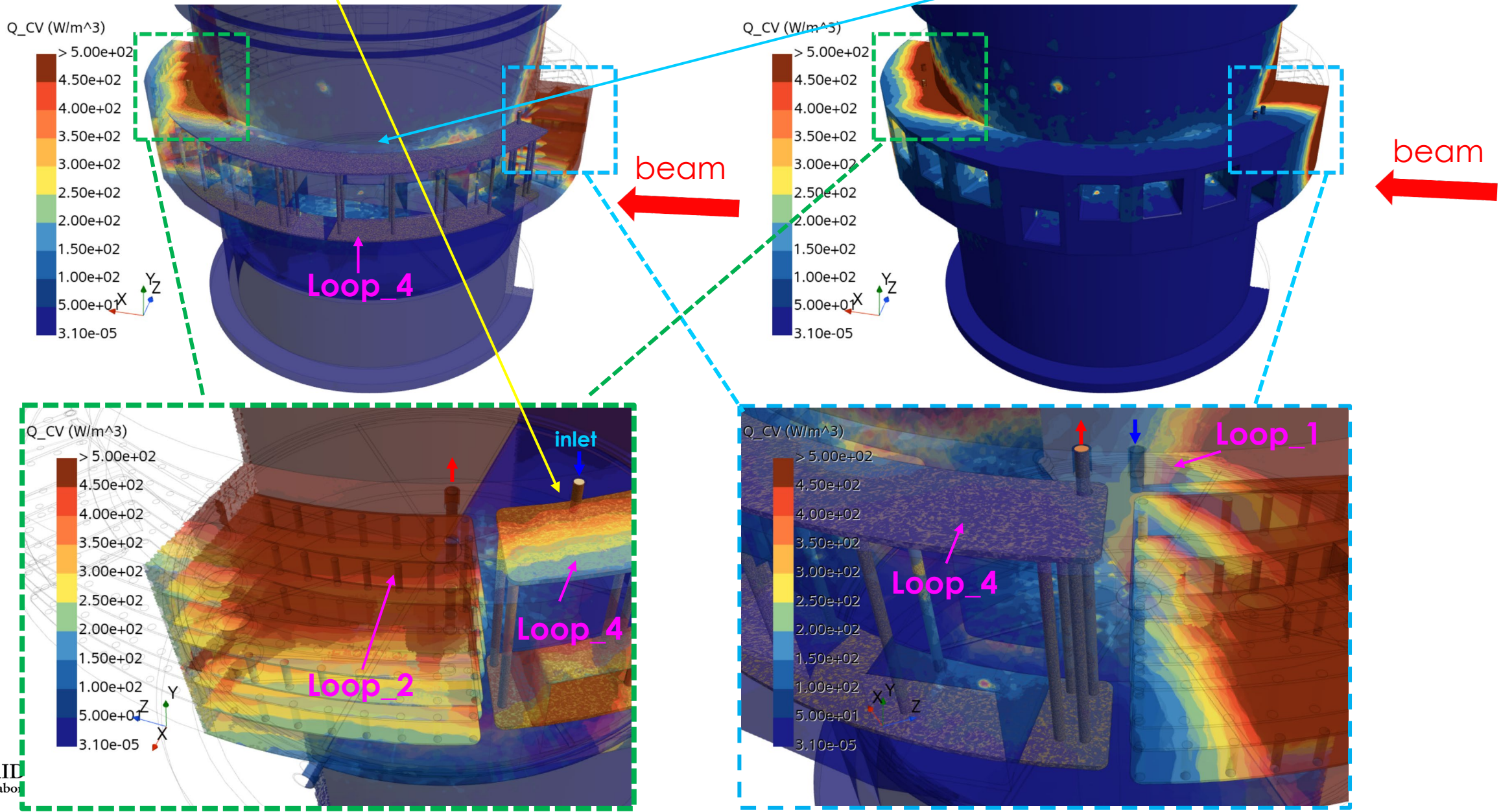
Q_{water_total} = 52.95W





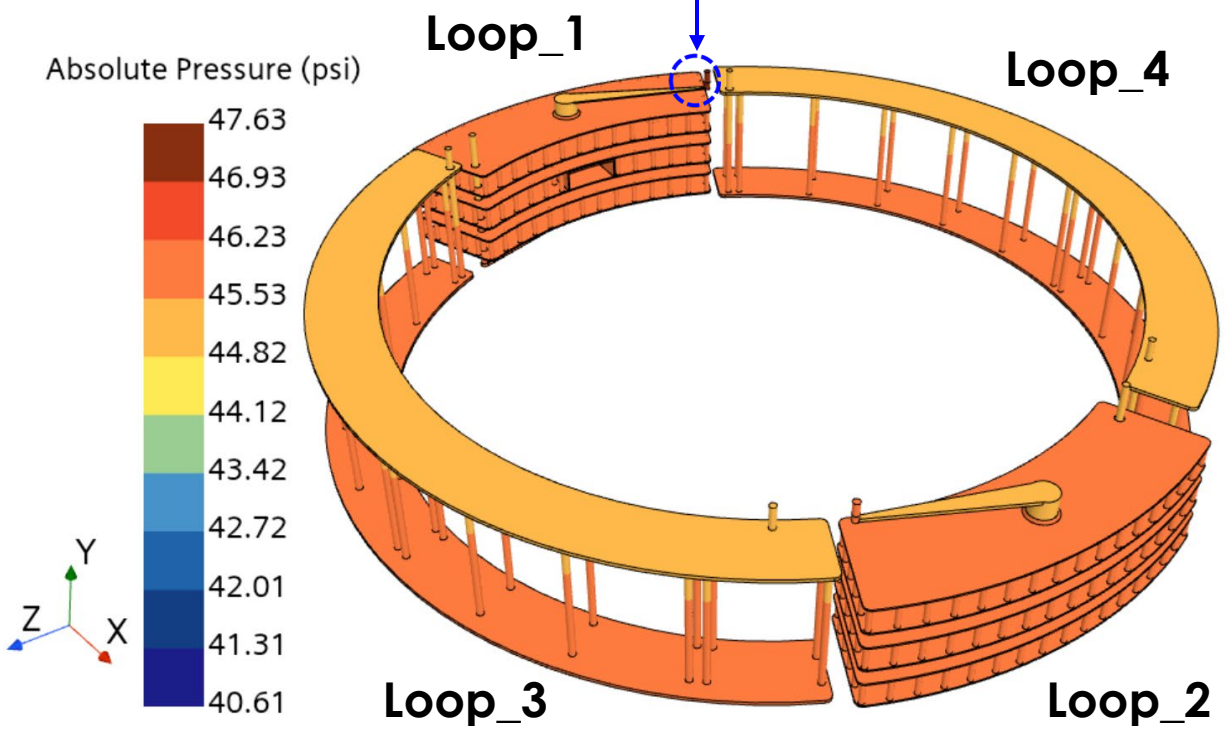
Heat Source (SS316) of Core Vessel and Cooling Channel

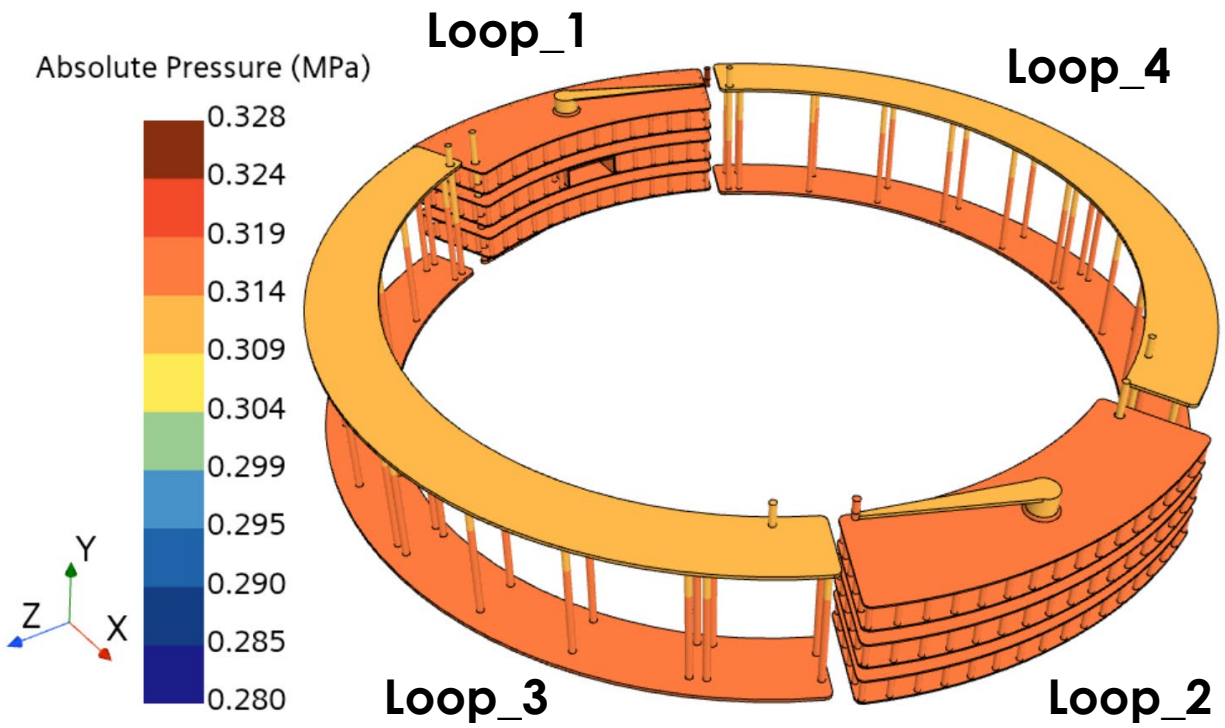
Only the region near the **inlet of Loop_4** has **higher heating**. The heating rate for the **rest of Loop_4** is **low** (**Loop_3** is similar).



Water Pressure

issue





$\Delta P_{inlet-outlet\_Loop\_1} = 0.17$ bar $(= 17$ kPa $= 2.47$ psi)

$\Delta P_{inlet-outlet\_Loop\_2} = 0.044$ bar $(= 4.37$ kPa $= 0.63$ psi)

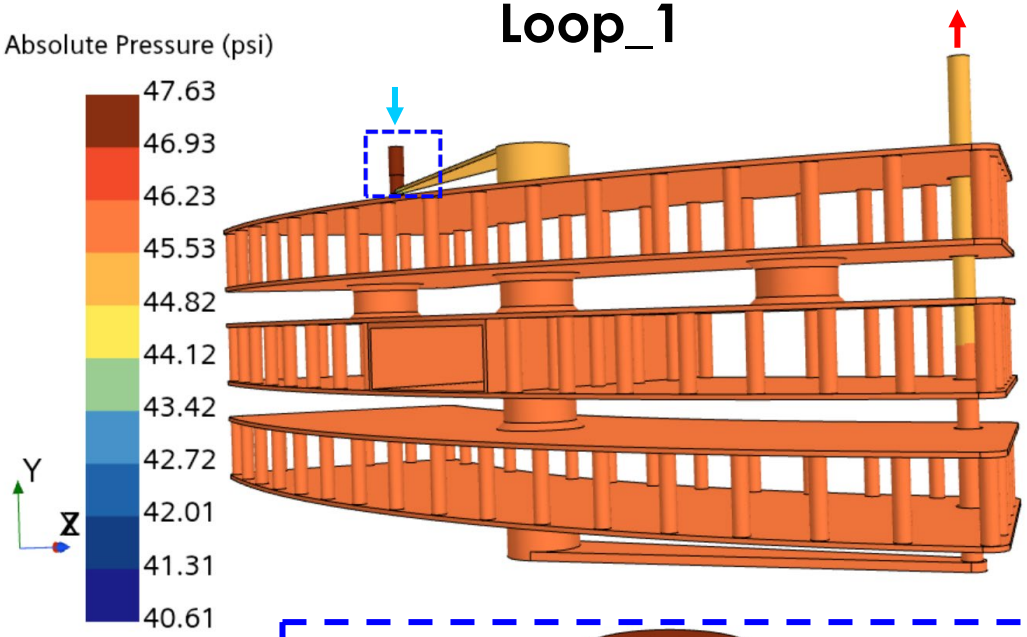
$\Delta P_{inlet-outlet\_Loop\_3} = 0.014$ bar $(= 1.43$ kPa $= 0.21$ psi)

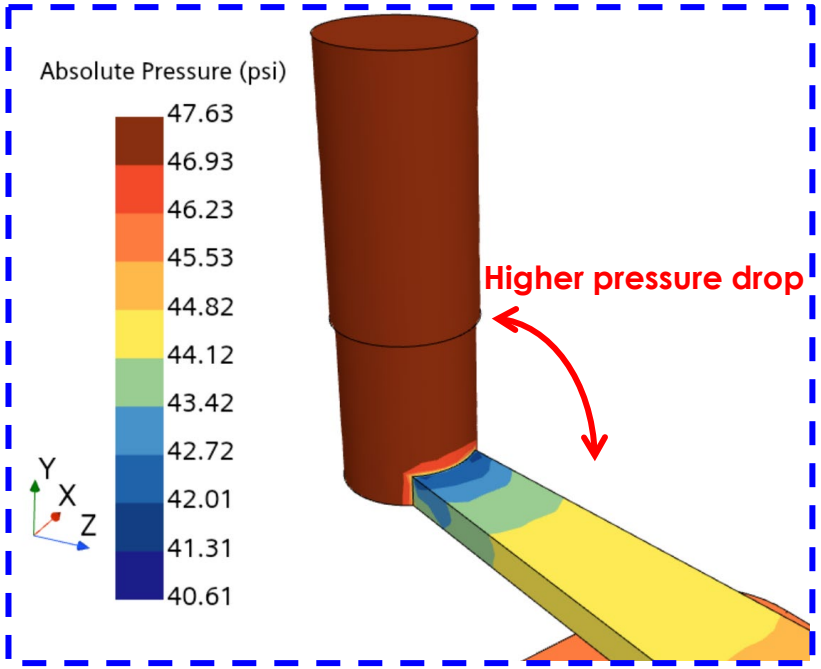
$\Delta P_{inlet-outlet\_Loop\_4} = 0.015$ bar $(= 1.51$ kPa $= 0.22$ psi)

Comparison in next 3 slides

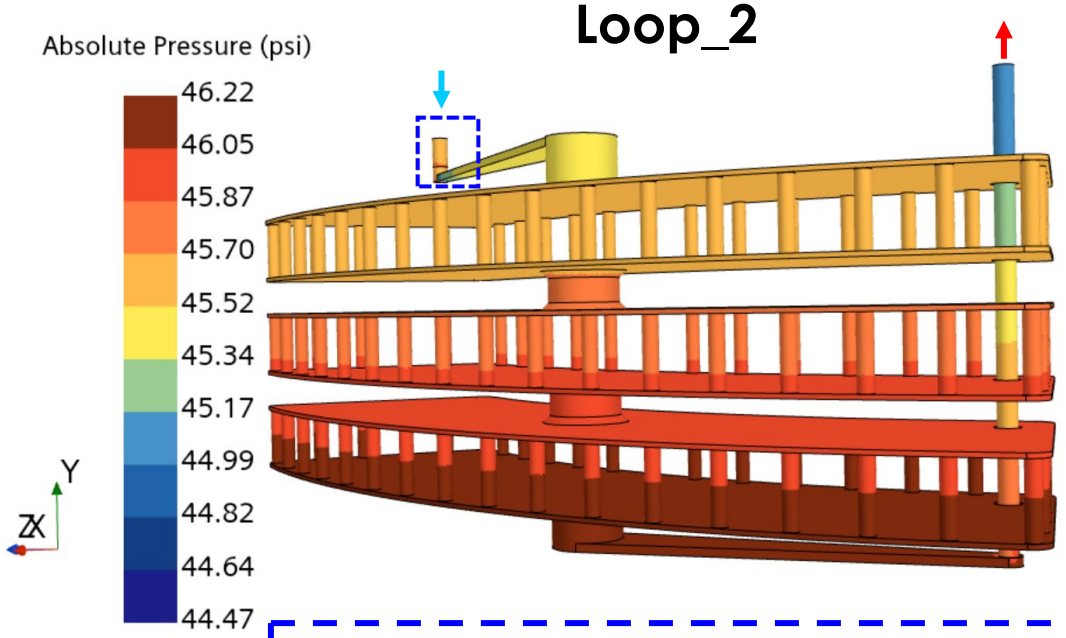
Water Pressure Loop_1 & Loop_2

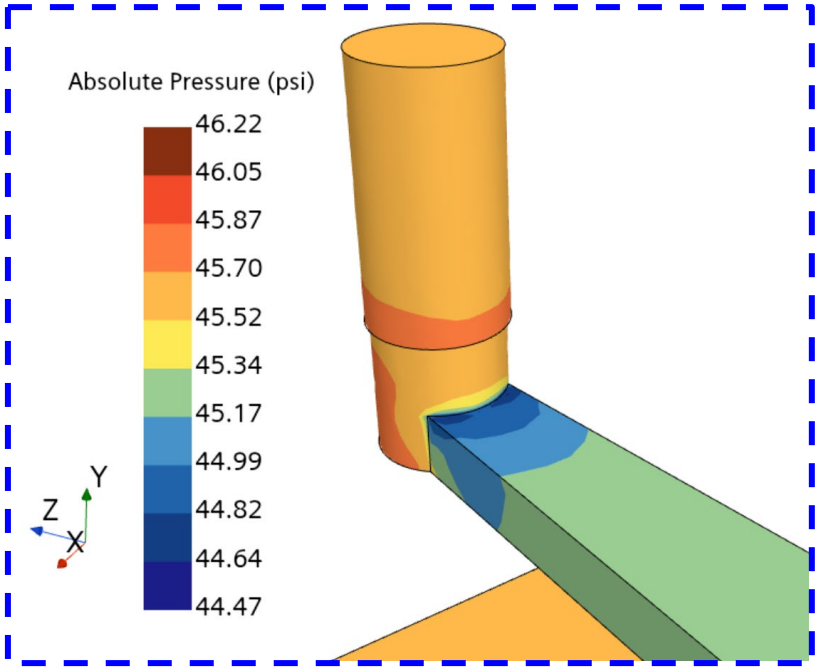
Loop_1





Loop_2



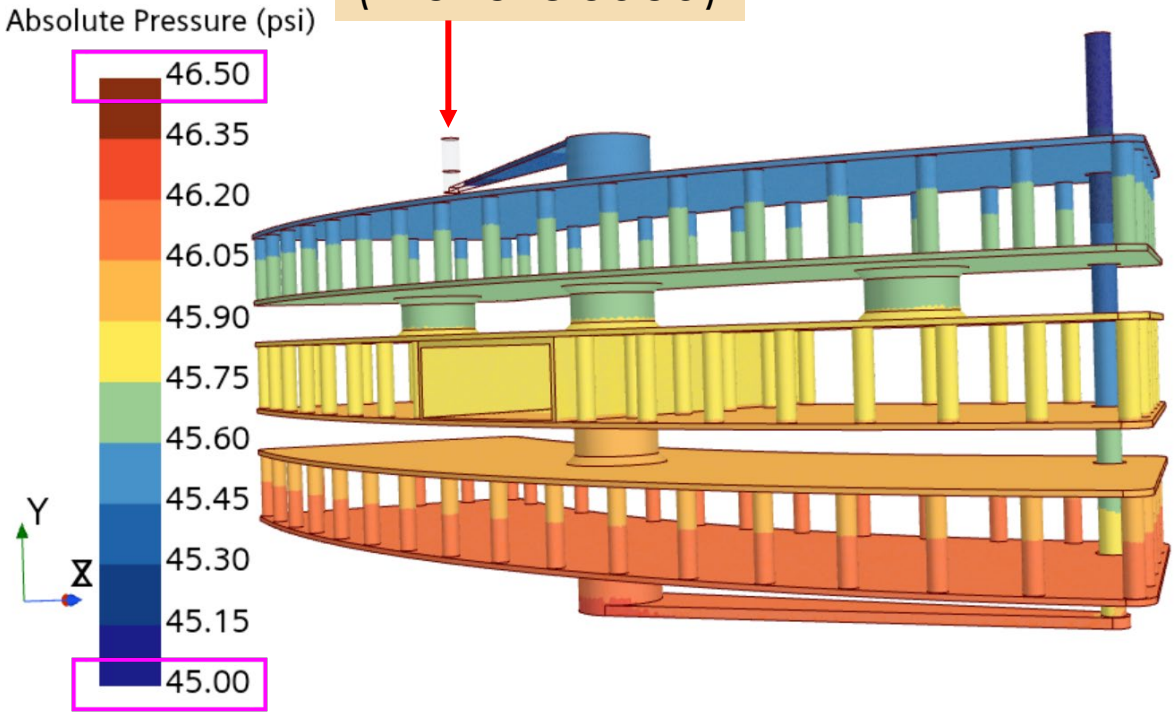


Water Pressure Loop_1 & Loop_2

Loop_1

Show the pressure distribution 45 psi ~ 46.5 psi

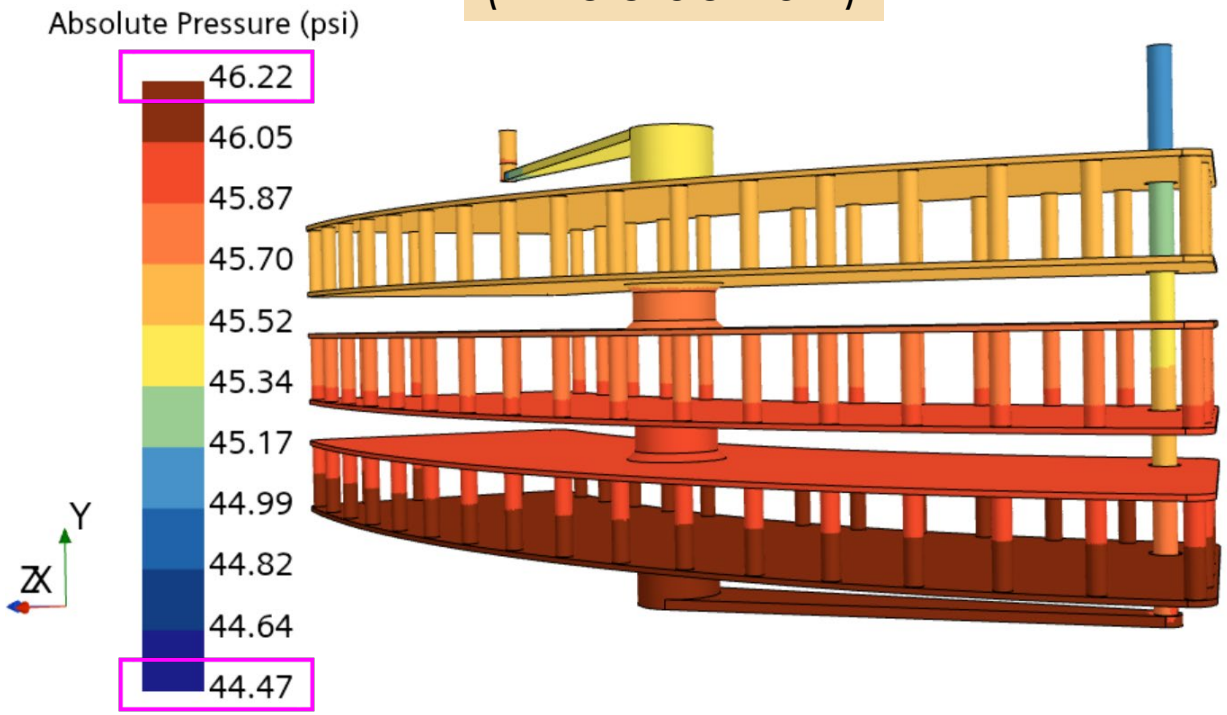
(inlet excluded)



Loop_2

Show the pressure distribution 44.47 psi ~ 46.22 psi

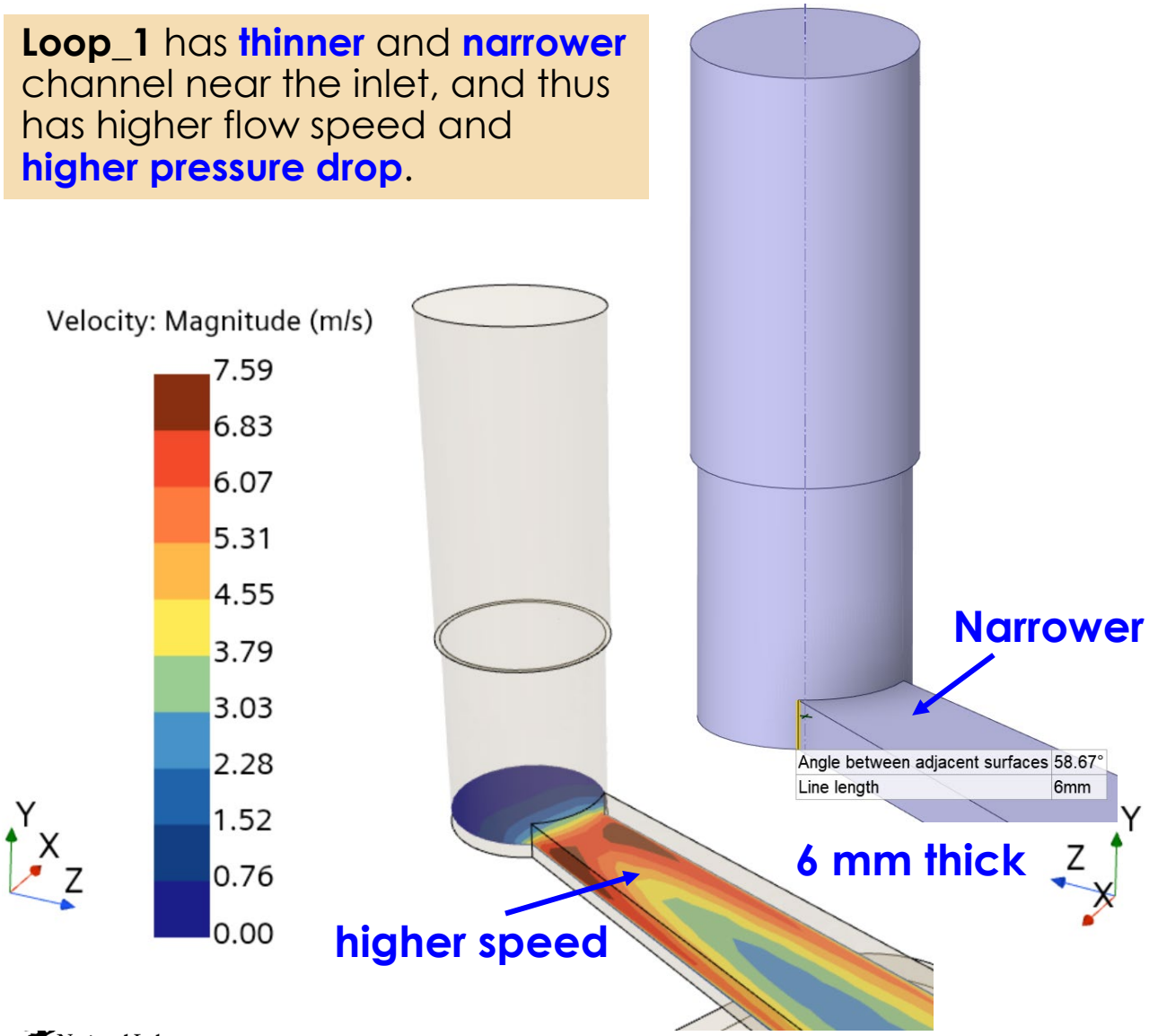
(Whole domain)



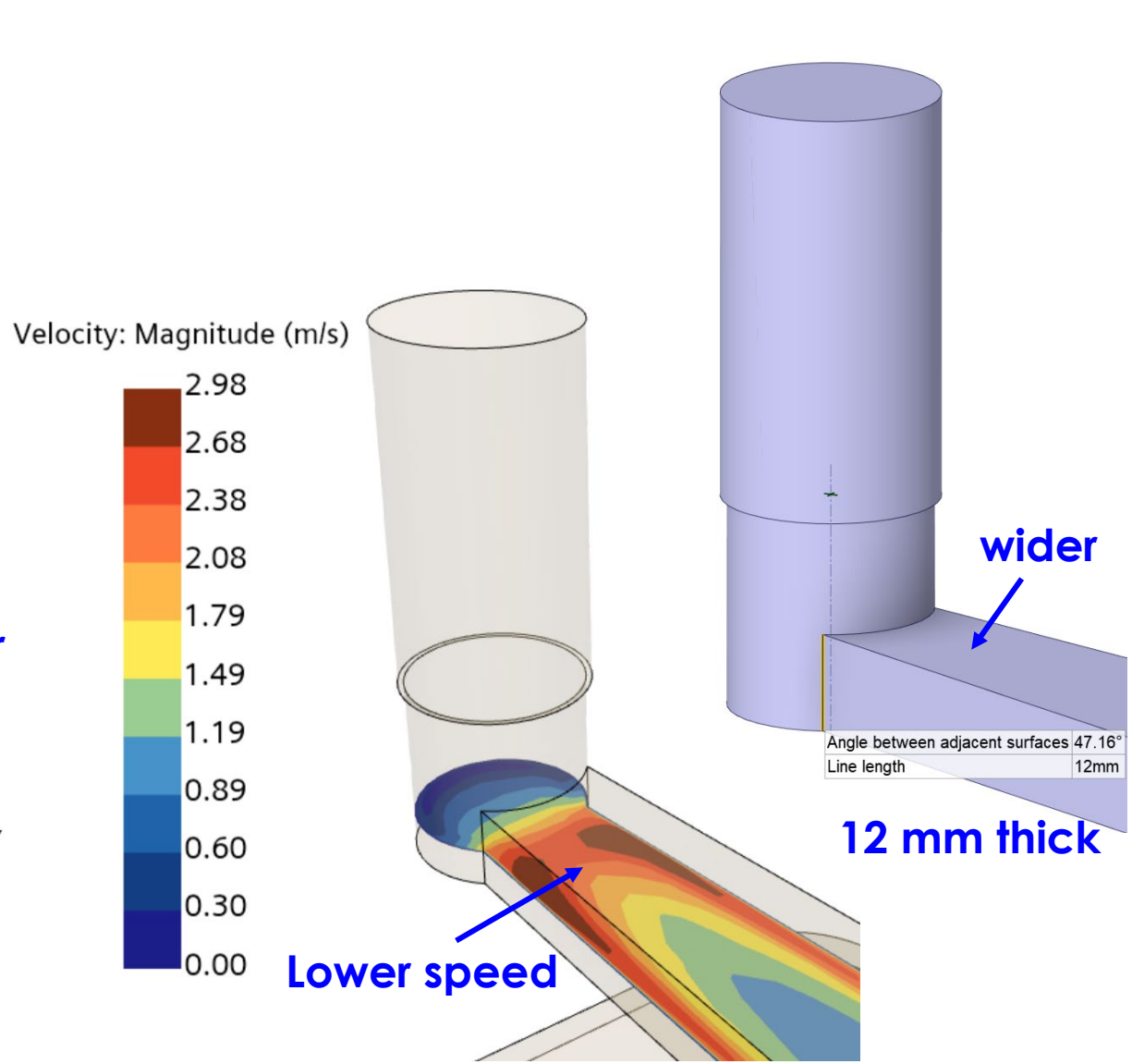
Velocity Loop_1 & Loop_2

Loop_1 has **thinner** and **narrower** channel near the inlet, and thus has higher flow speed and **higher pressure drop**.

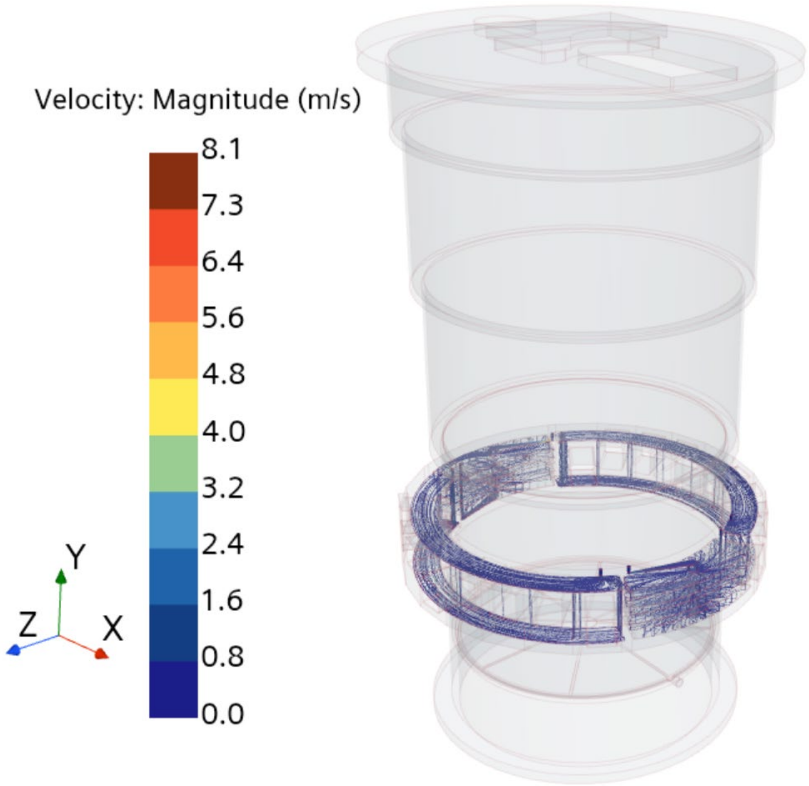
Loop_1

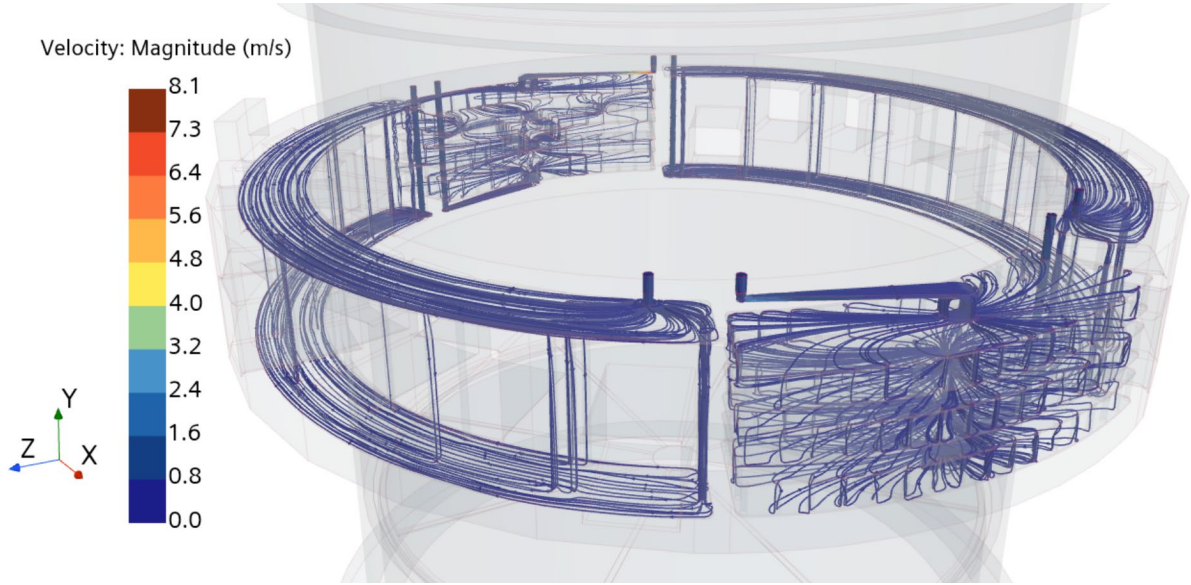


Loop_2

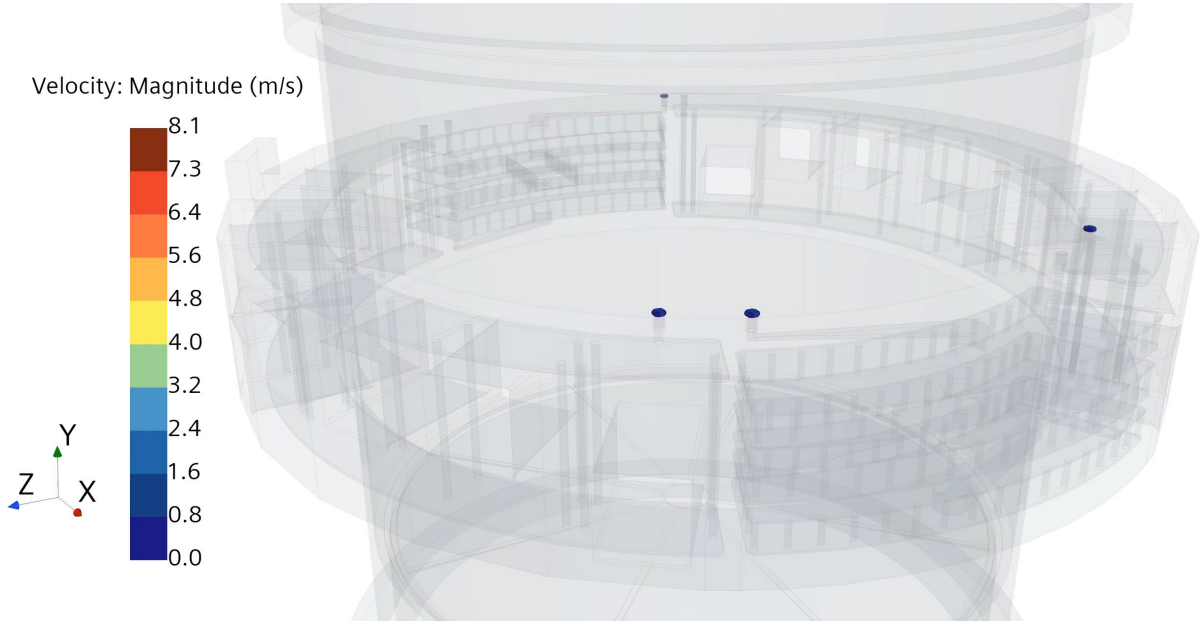


Core Vessel, Streamlines





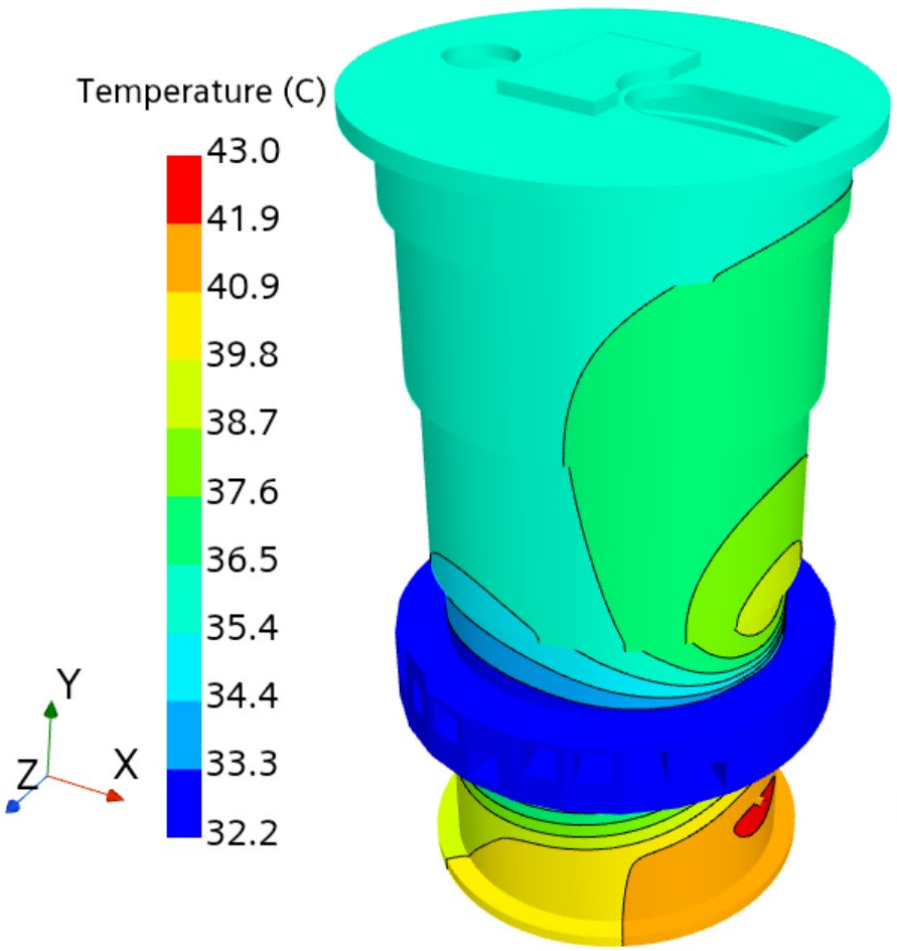
Streamline Animation

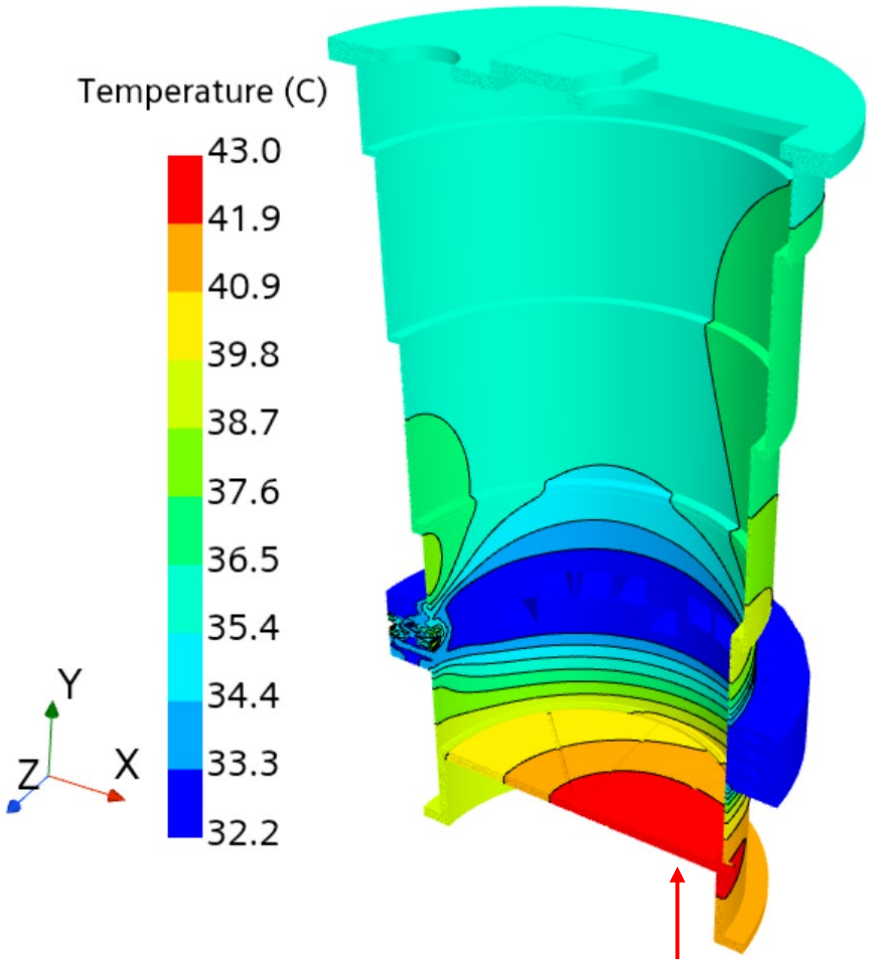


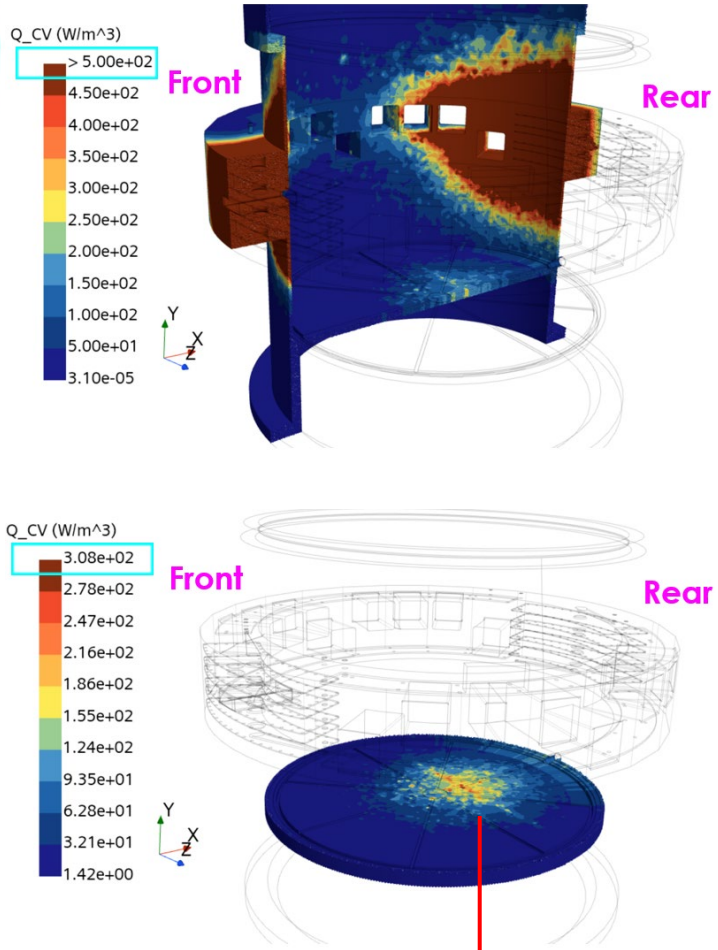
Core Vessel, Stainless Steel Temperature

Peak: 43°C

Heat Source



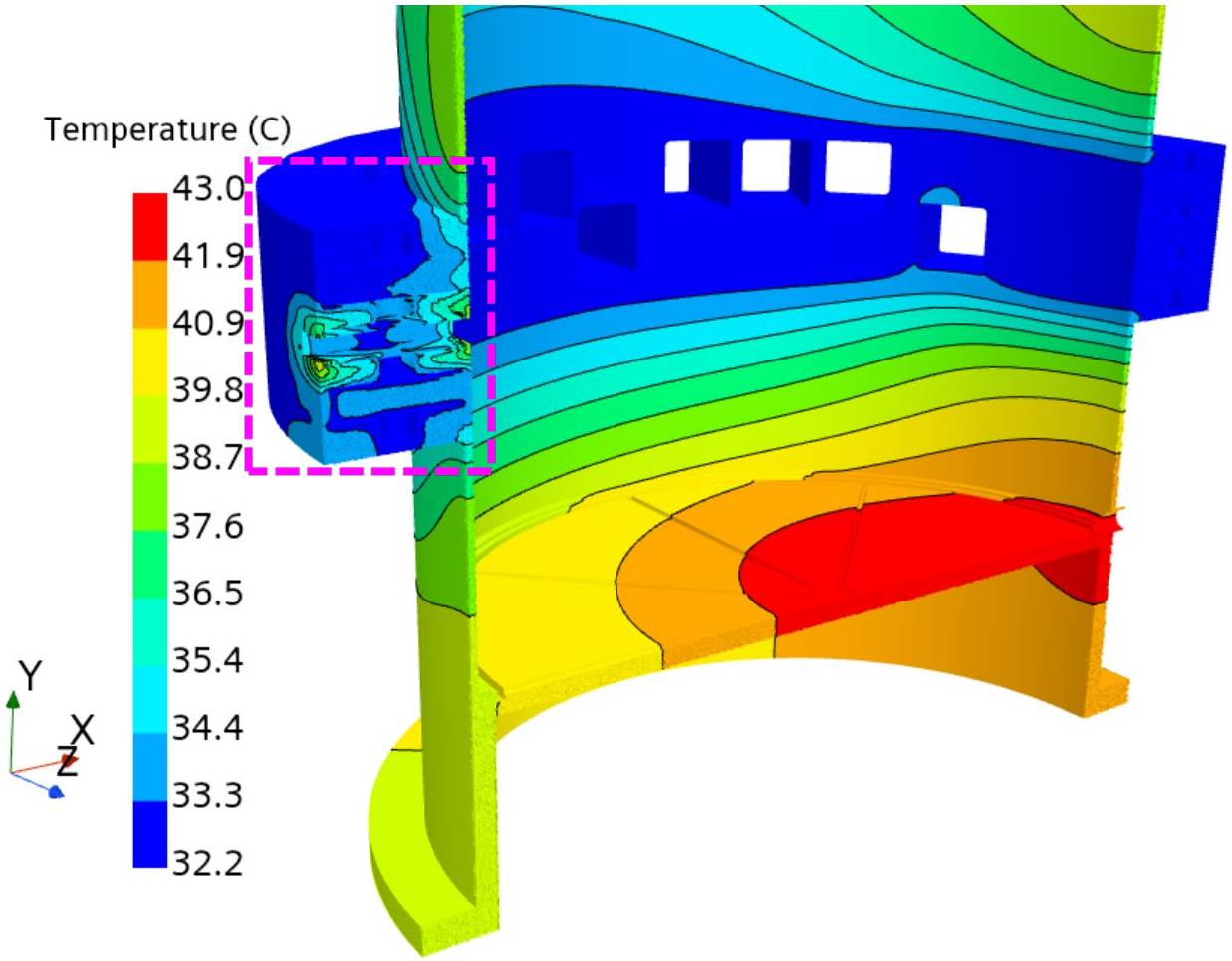


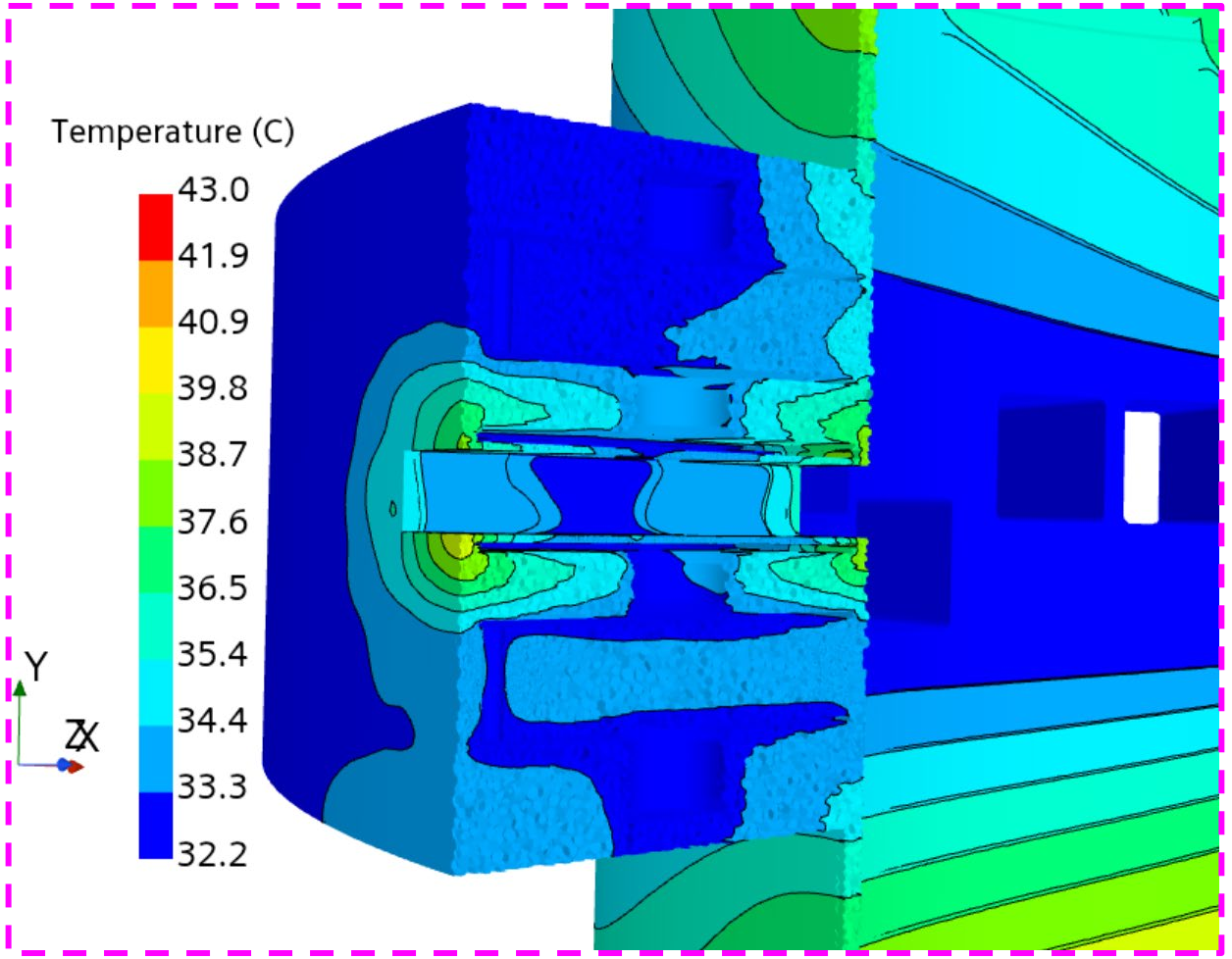


No cooling channel in this plate

Core Vessel, Stainless Steel Temperature

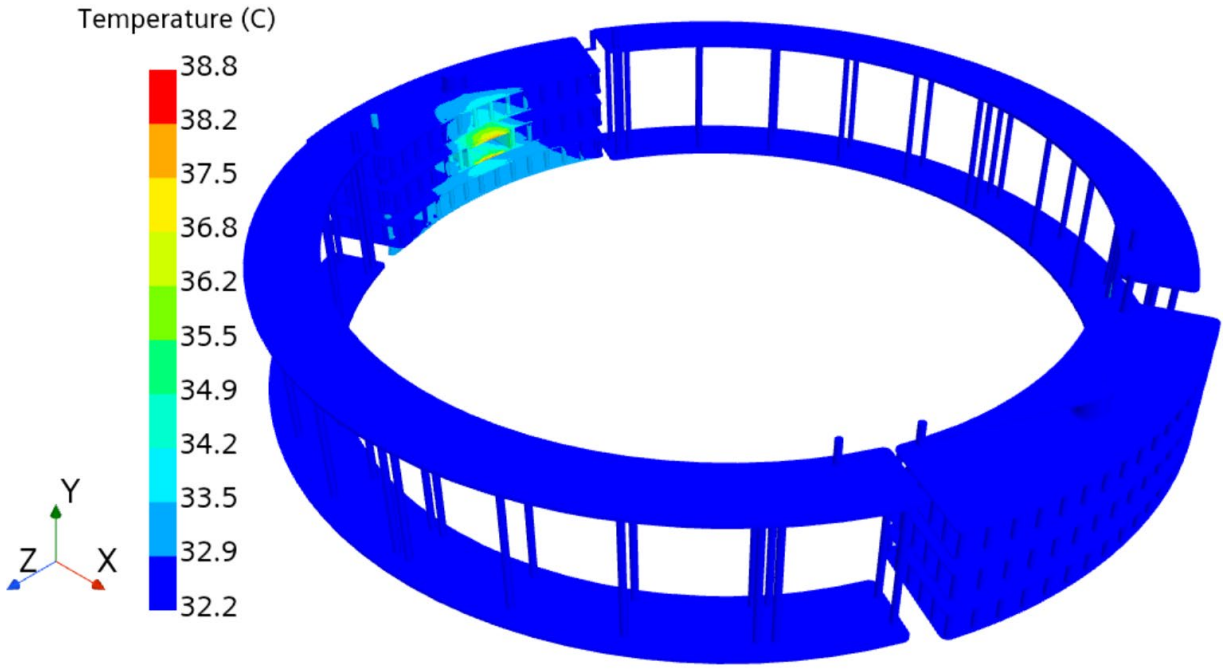
Peak: 43°C

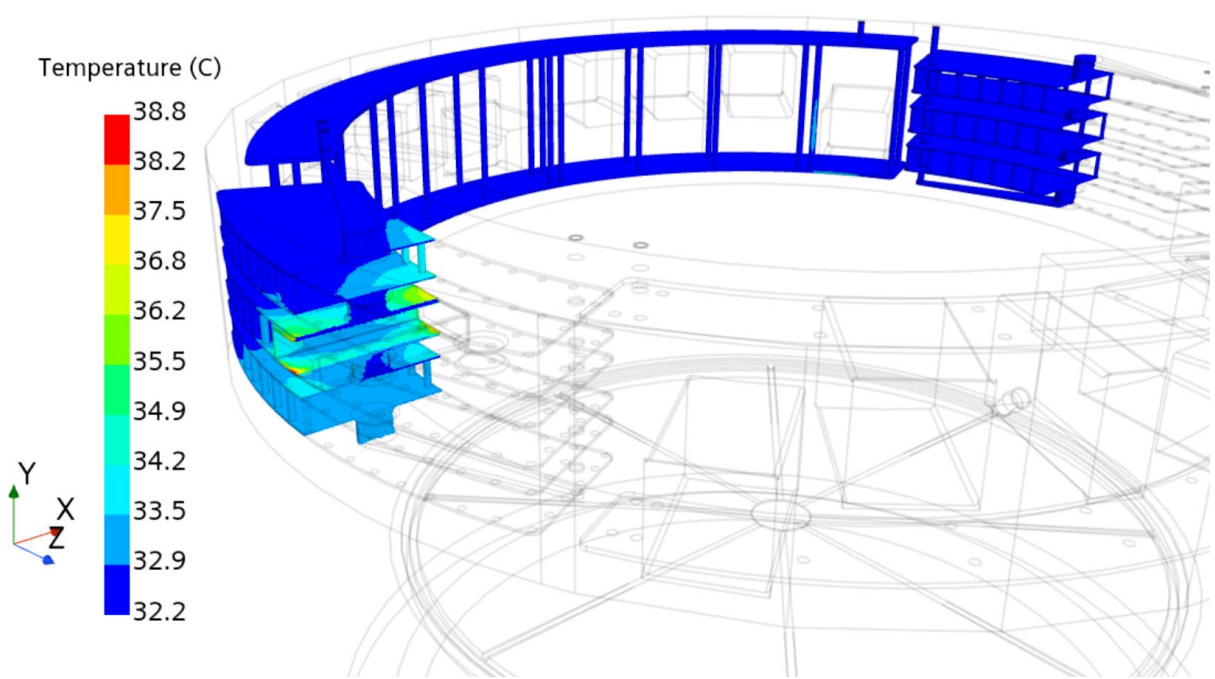




Core Vessel, Water Temperature

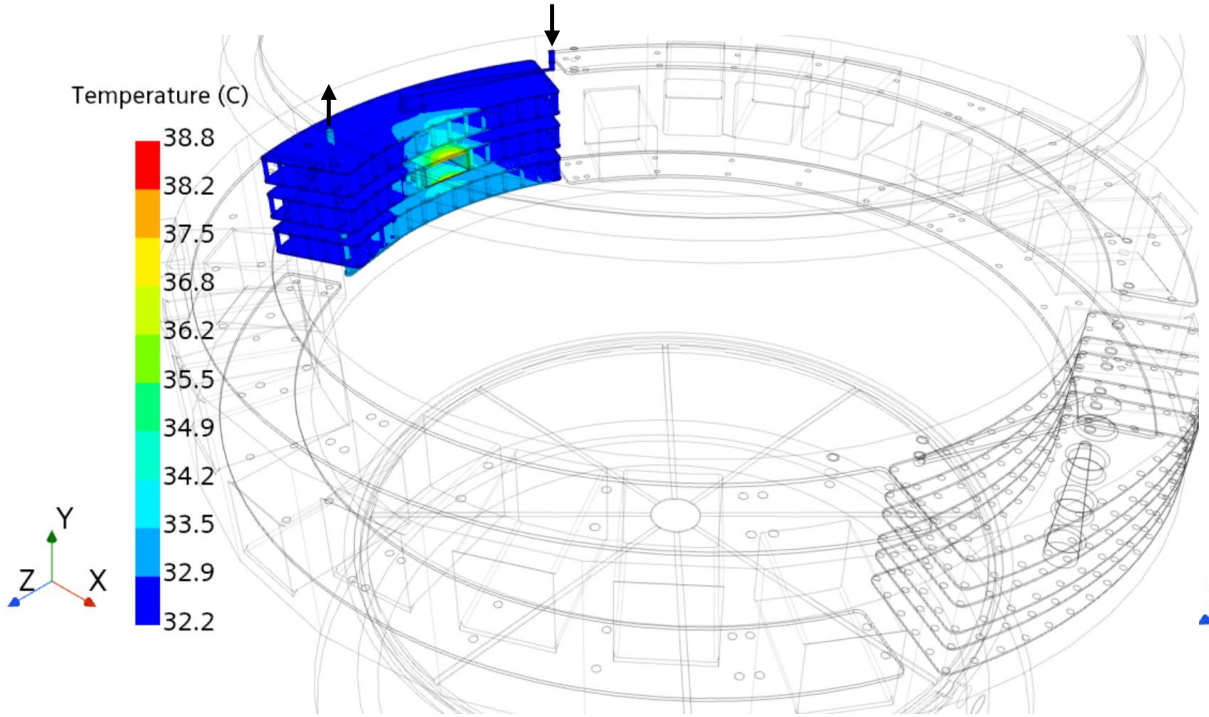
Peak: 38.8°C





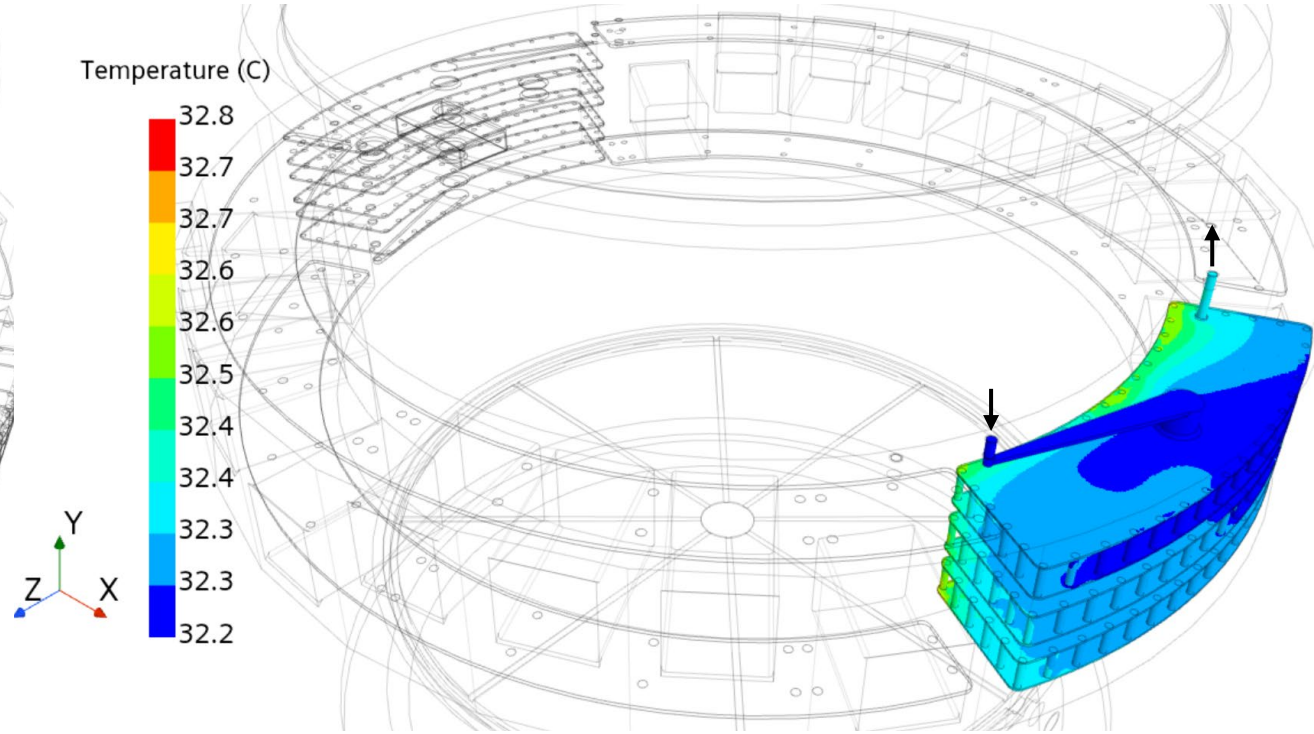
Core Vessel, Water Temperature

Loop_1



Inlet Temperature : 32.20°C
Outlet Temperature : 32.89°C

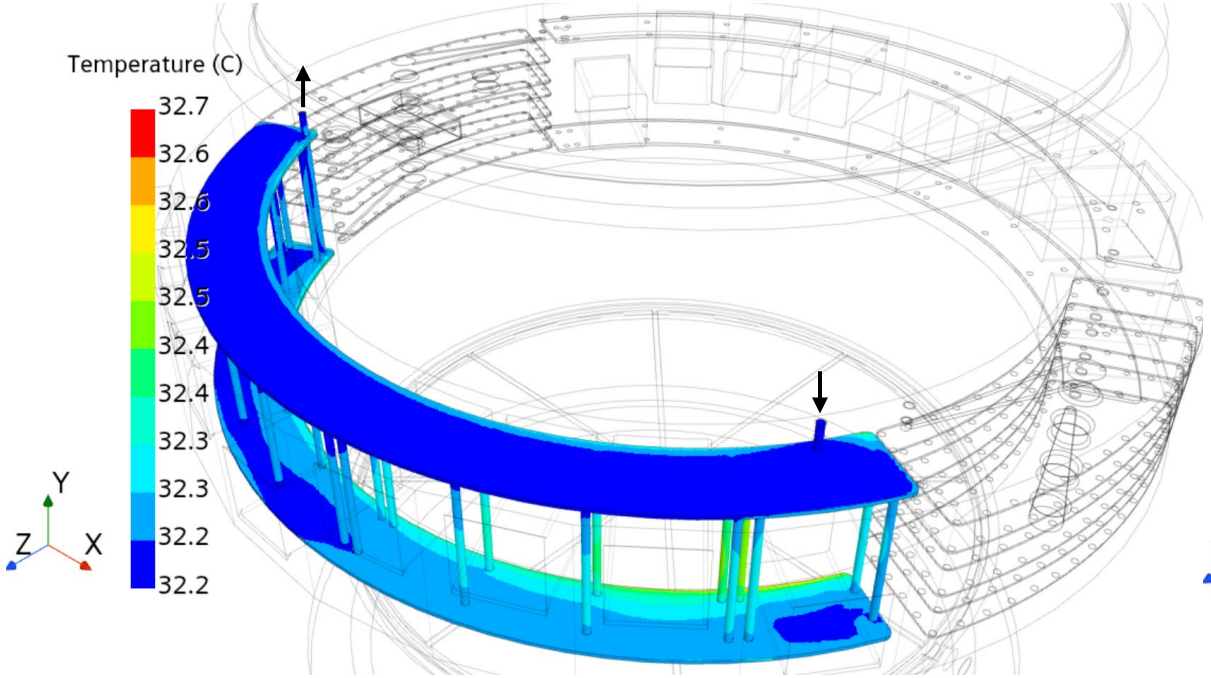
Loop_2



Inlet Temperature : 32.20°C
Outlet Temperature : 32.33°C

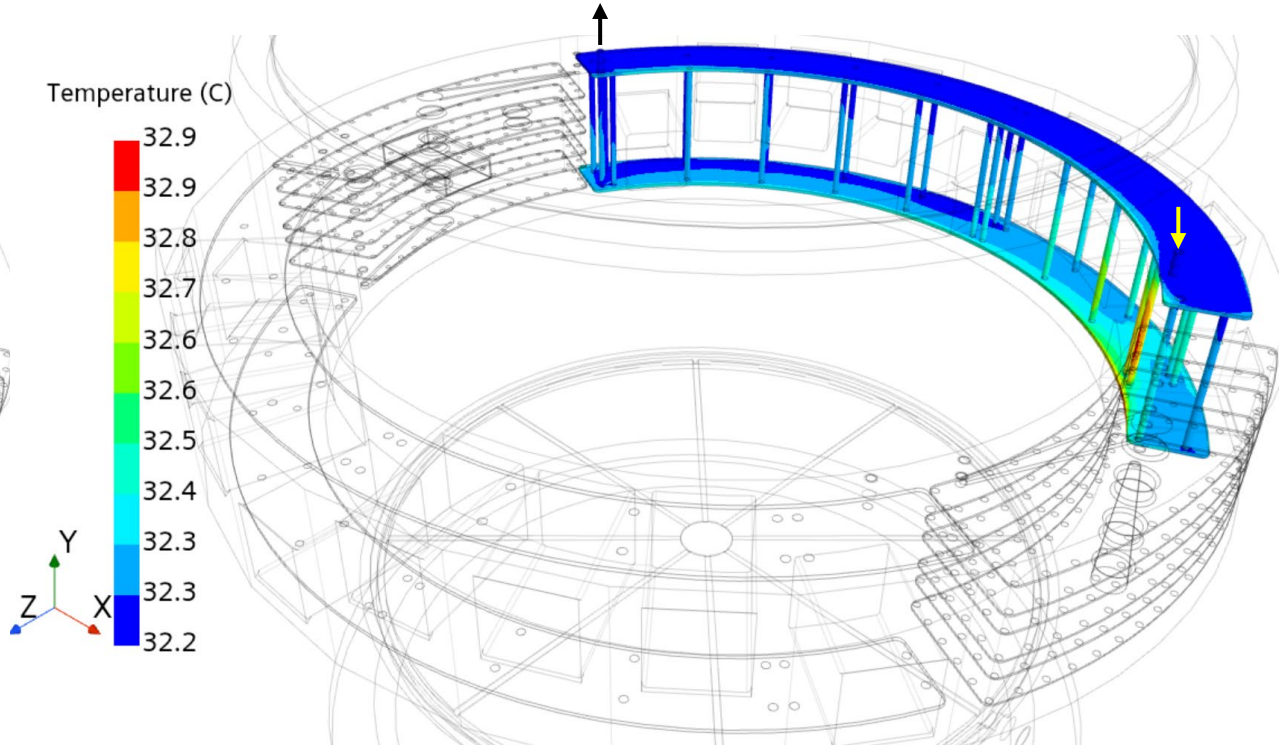
Core Vessel, Water Temperature

Loop_3



Inlet Temperature : 32.20°C
Outlet Temperature : 32.24°C

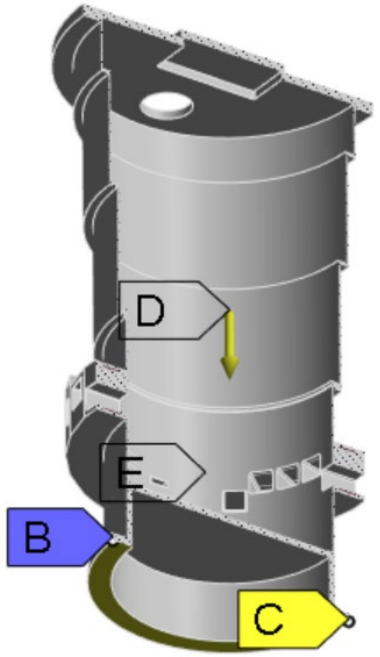
Loop_4



Inlet Temperature : 32.20°C
Outlet Temperature : 32.26°C

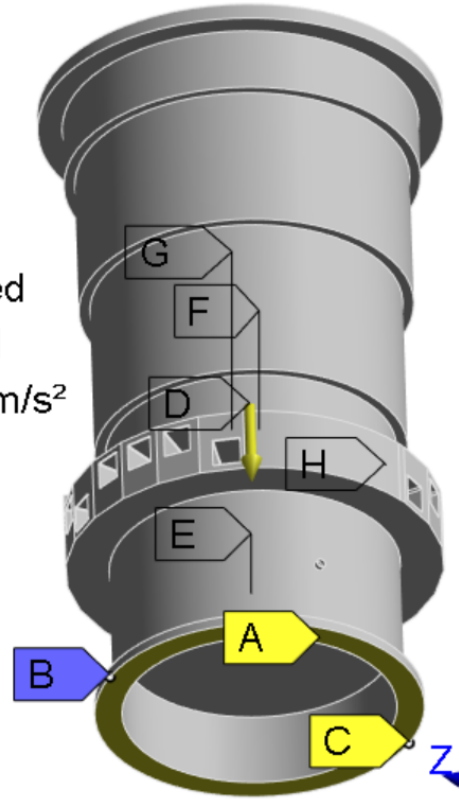
Core Vessel Structural Analysis

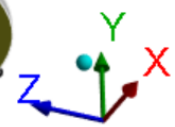
Core Vessel, All SS316, Structural BCs

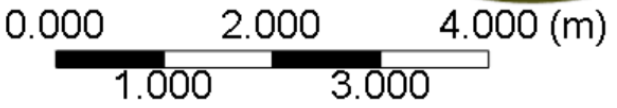


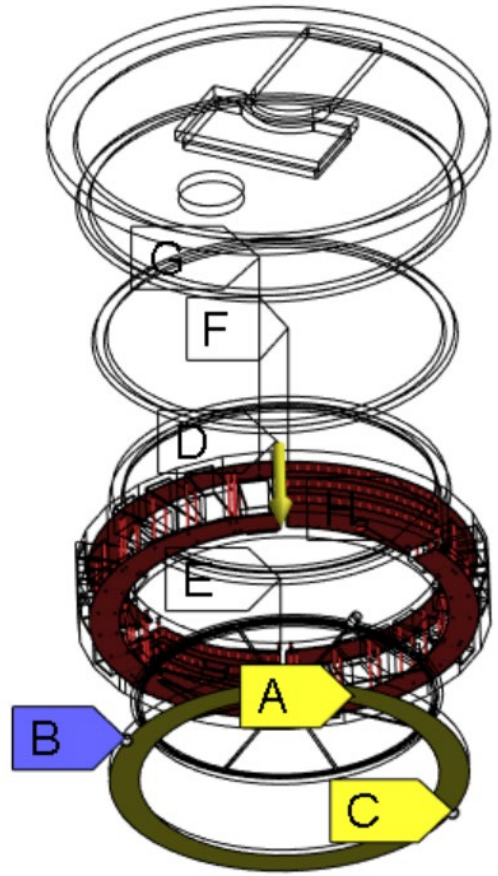
B: Static Structural
Static Structural
Time: 1. s

- A: Displacement_Plane_Y_Fixed
- B: Fixed Support_Vertex_XYZ_Fixed
- C: Displacement_Vertex_XY_Fixed
- D: Standard Earth Gravity: 9.8066 m/s²
- E: Imported Pressure_Loop_1
- F: Imported Pressure_Loop_2
- G: Imported Pressure_Loop_3
- H: Imported Pressure_Loop_4





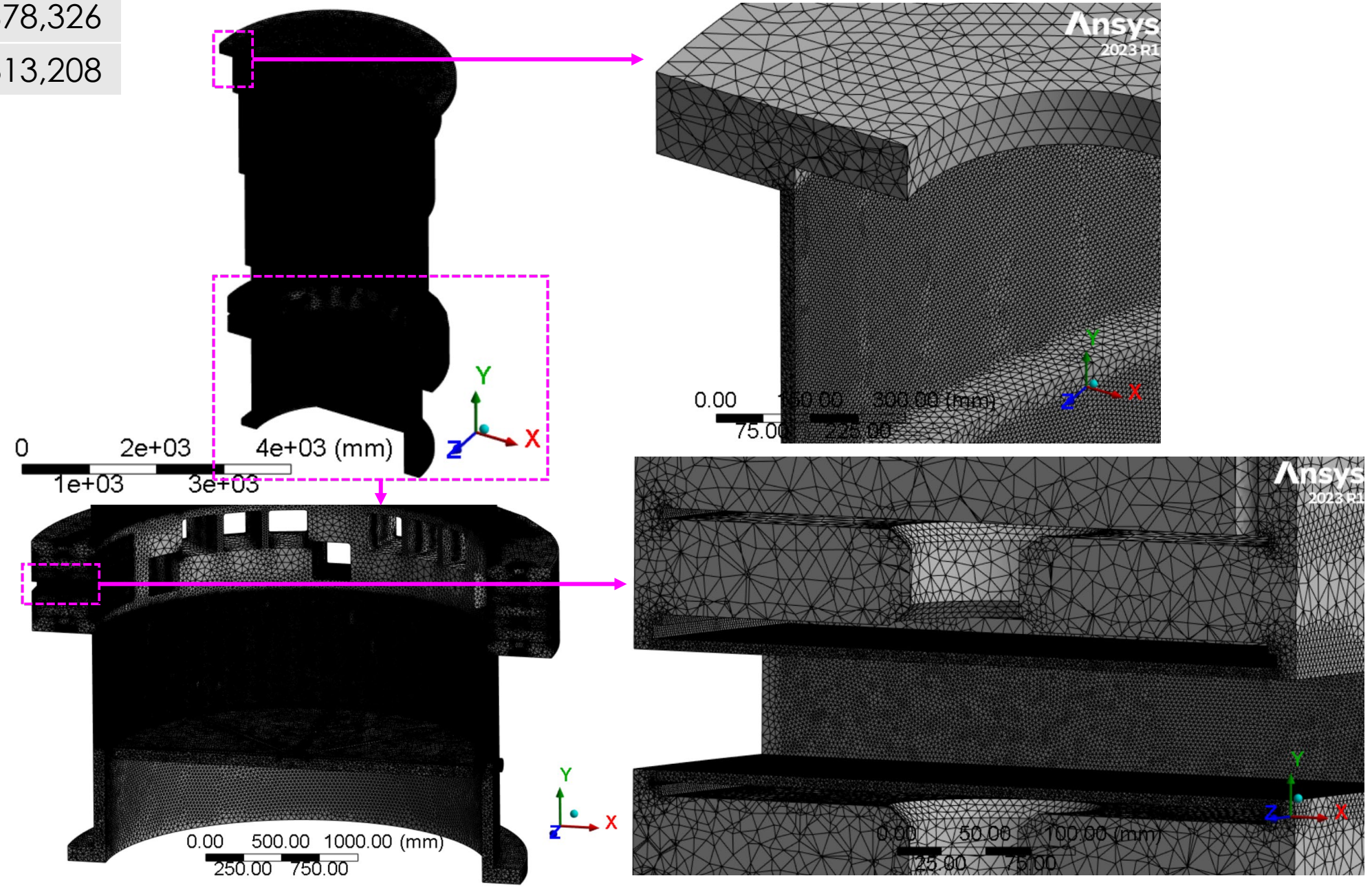




- **BC-A: Plane fixed in y**
  - Block rests on flat surface
- **BC-B: Point fixed in x, y and z directions**
  - Reference point
- **BC-C: point can only move in z direction**
  - Fixed in y : Block rests on flat surface
  - Fixed in x : symmetric, no rotation
- **BC-D: Gravity (-y direction)**
- **BC-E-H: Pressure from CFD simulation**

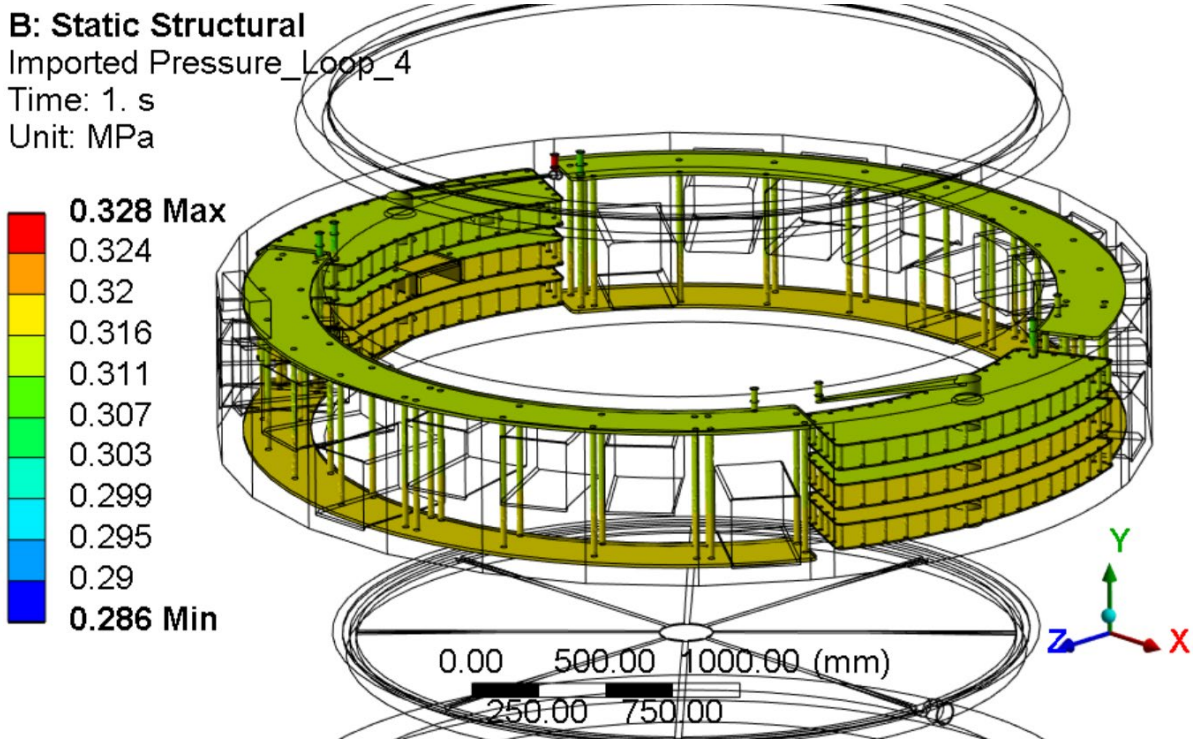
Core Vessel, Mesh Configuration

Nodes	31,678,326
Elements	20,813,208

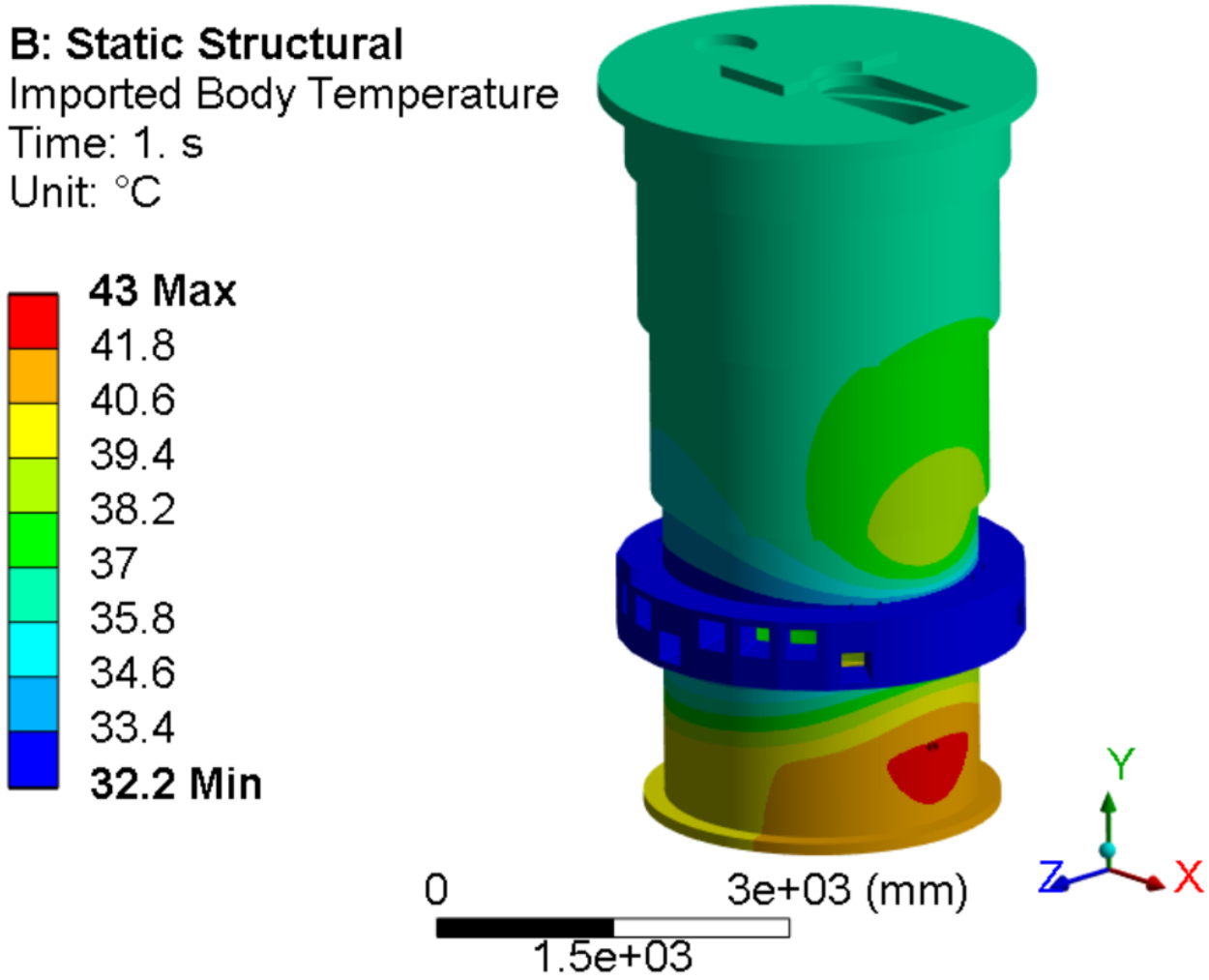


Pressure and Temperature Profiles from CFD (STARCCM+)

Imported Pressure

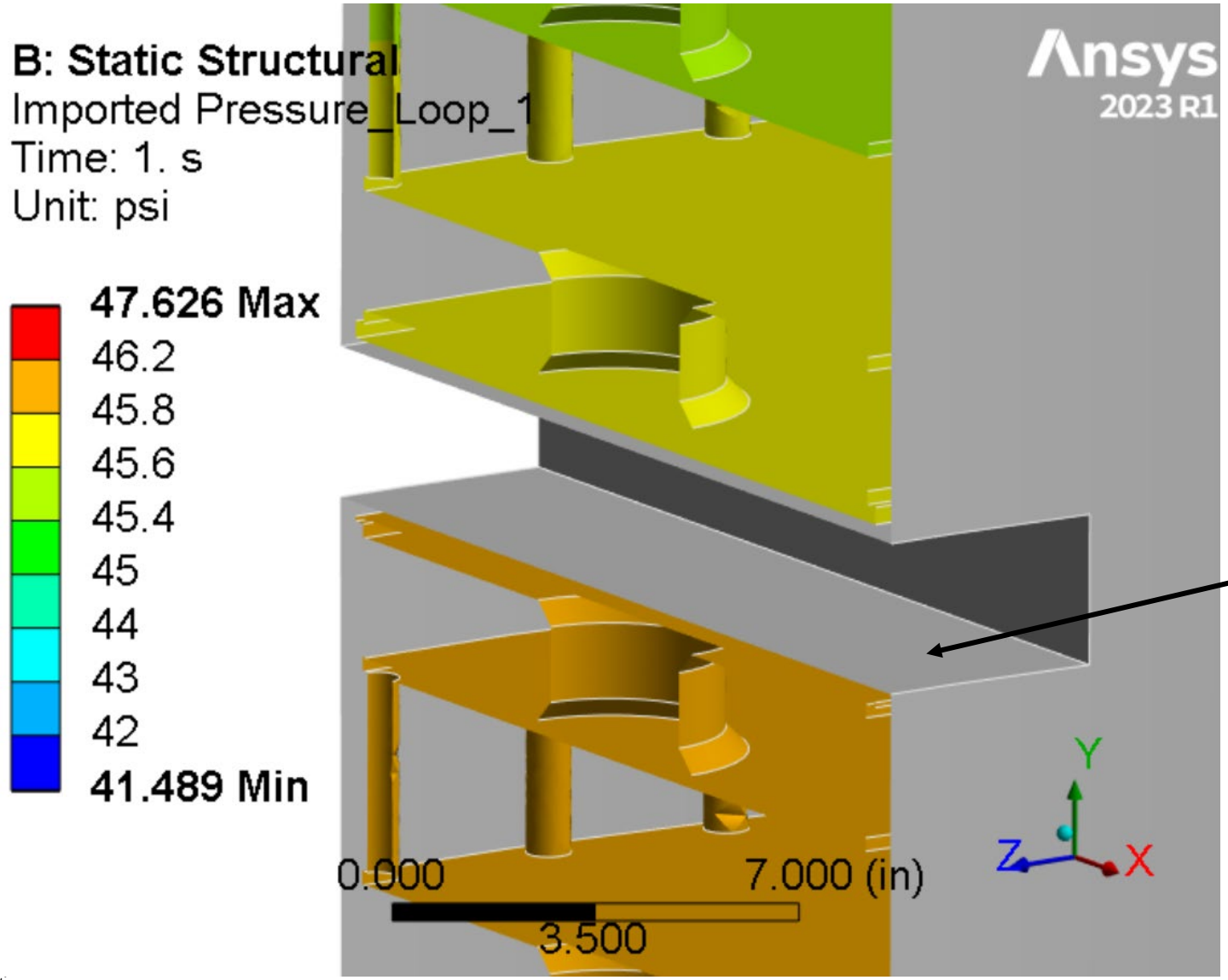


Imported Temperature



Pressure and Temperature Profiles from CFD (STARCCM+)

Imported Pressure

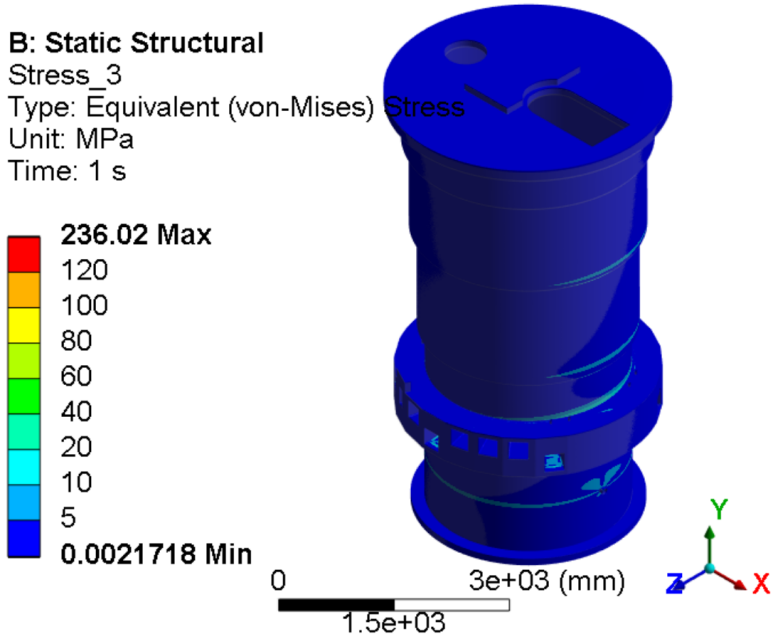


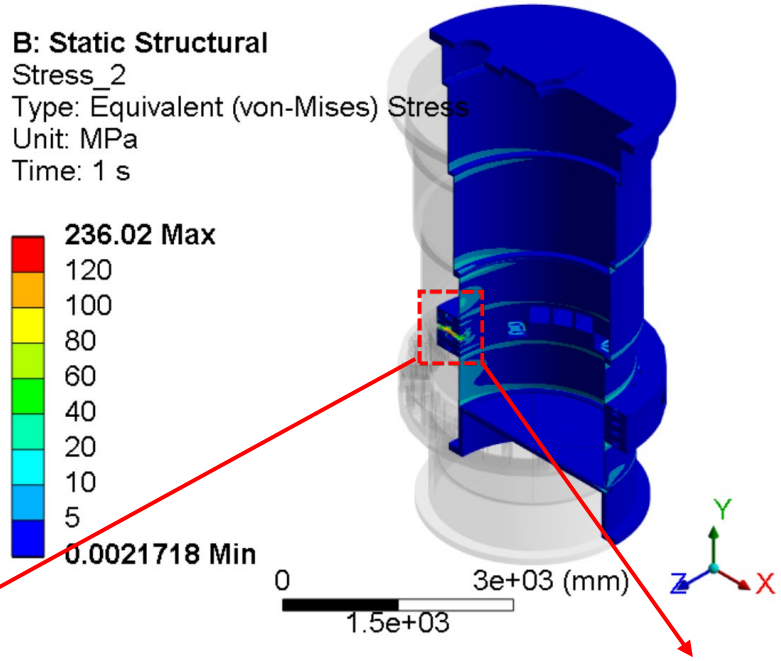
Previously, pressure was incorrectly mapped onto this surface.

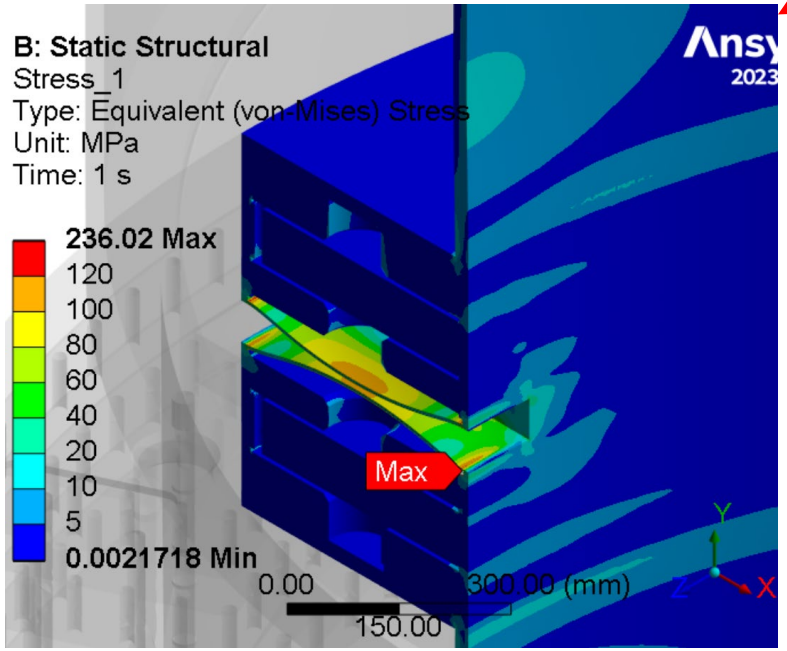
Water Pressure + Thermal + Gravity

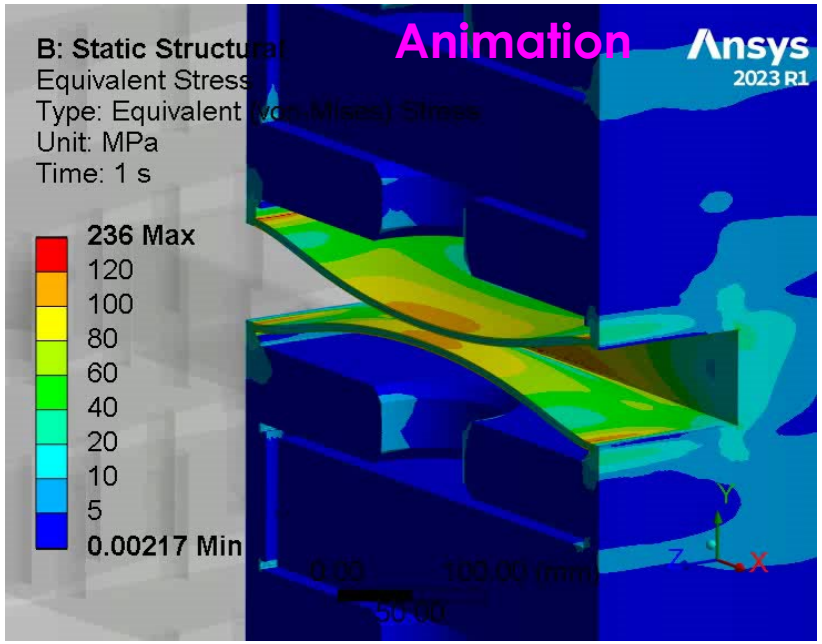
Von-Mises Stress

SS 316 Tensile Yield Strength: 252.1 MPa



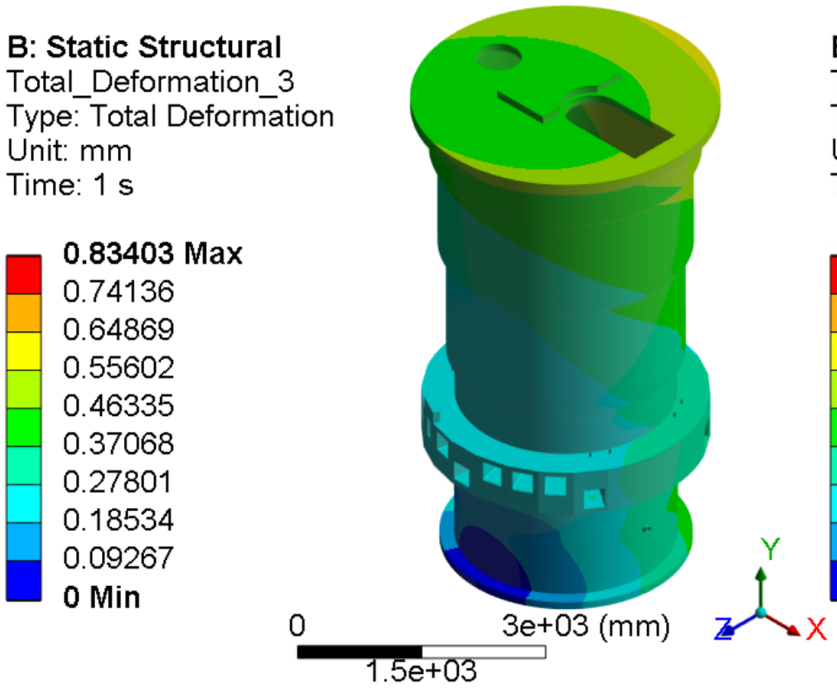


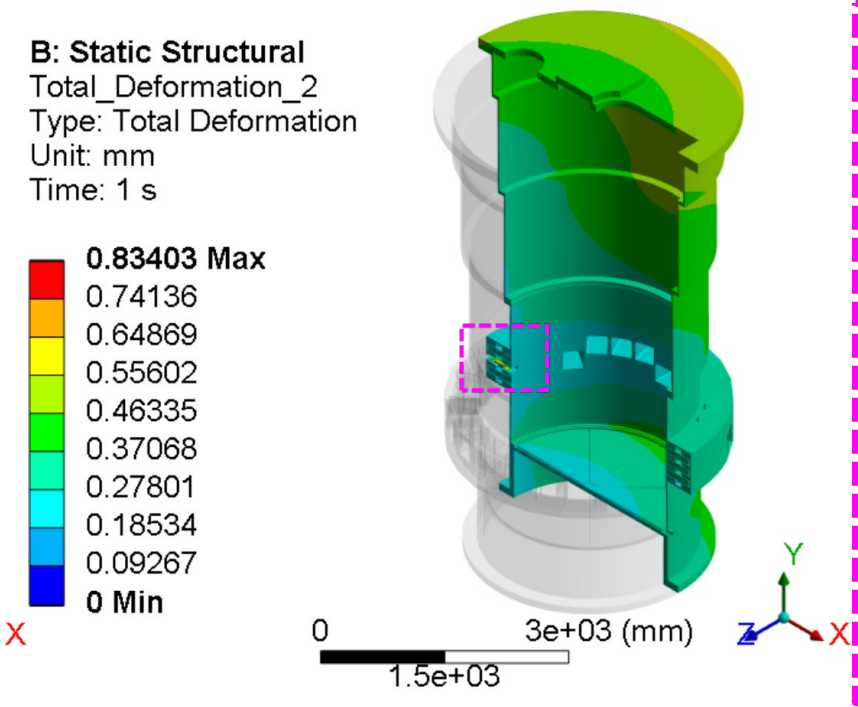


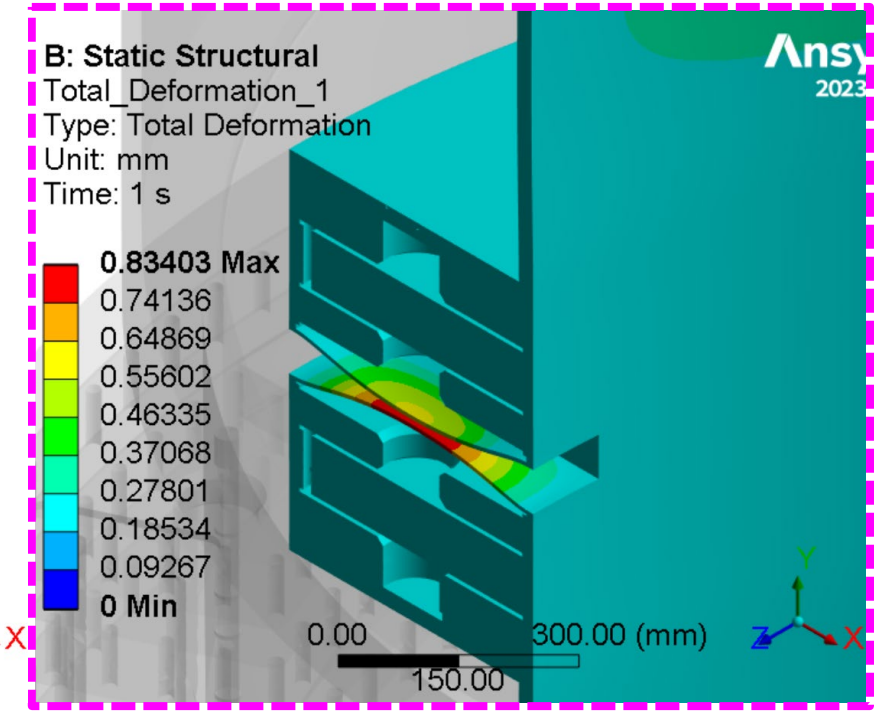


Water Pressure + Thermal + Gravity

Total Displacement

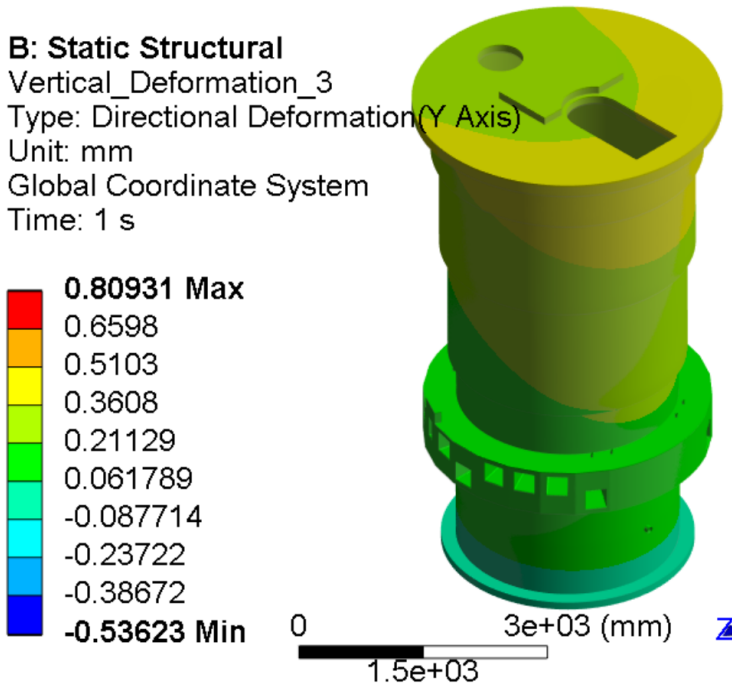


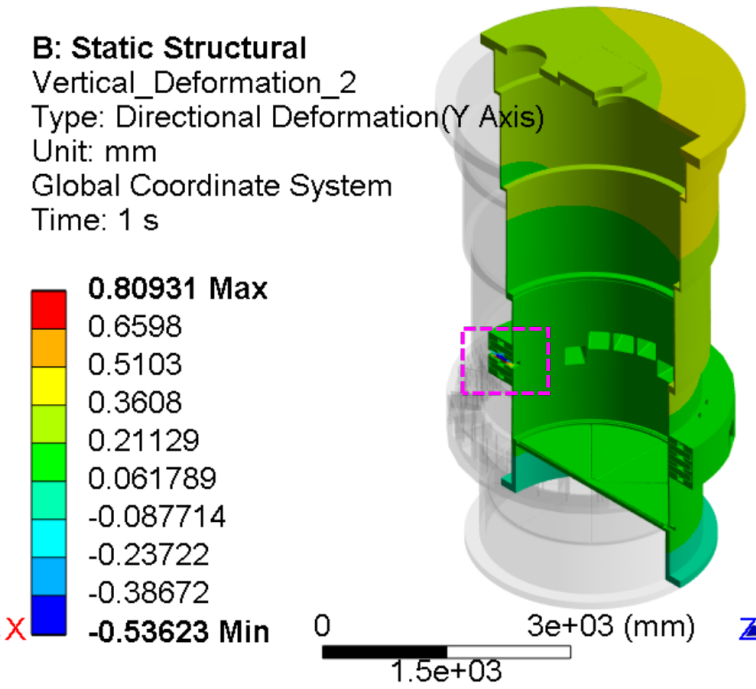


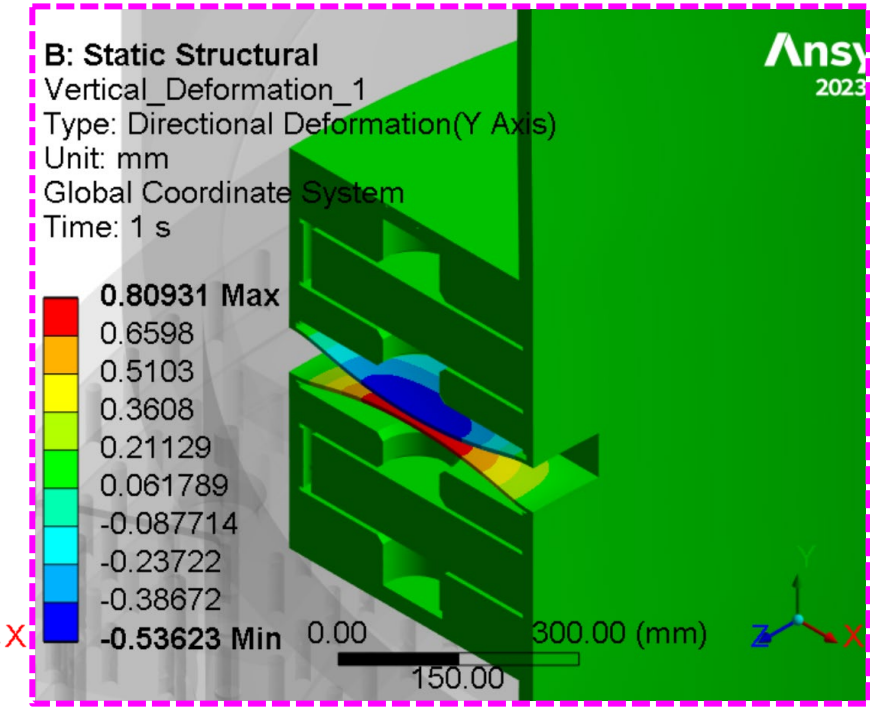


Water Pressure + Thermal + Gravity

Vertical Displacement







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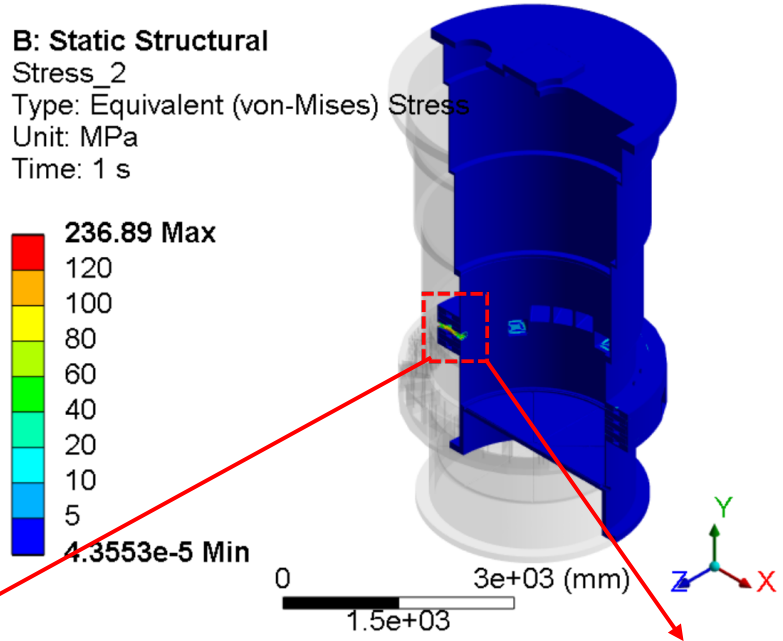
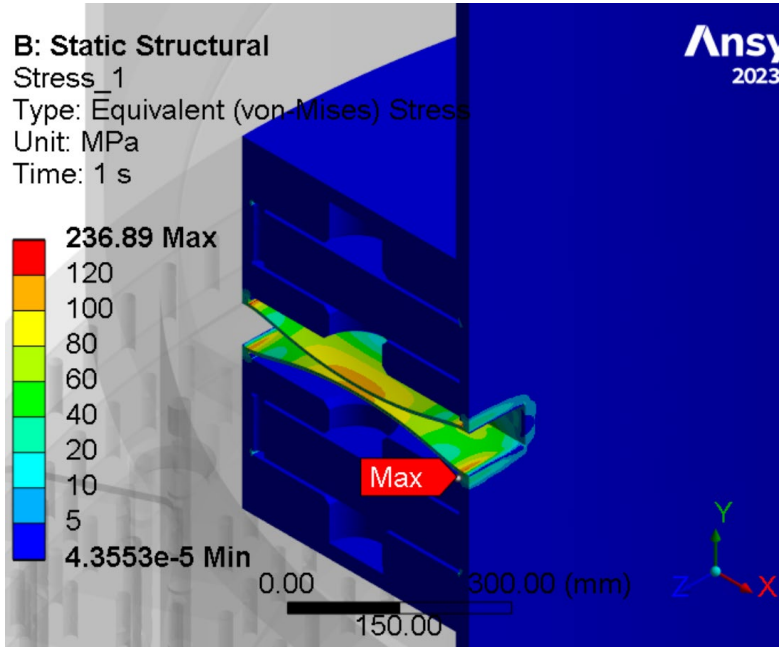
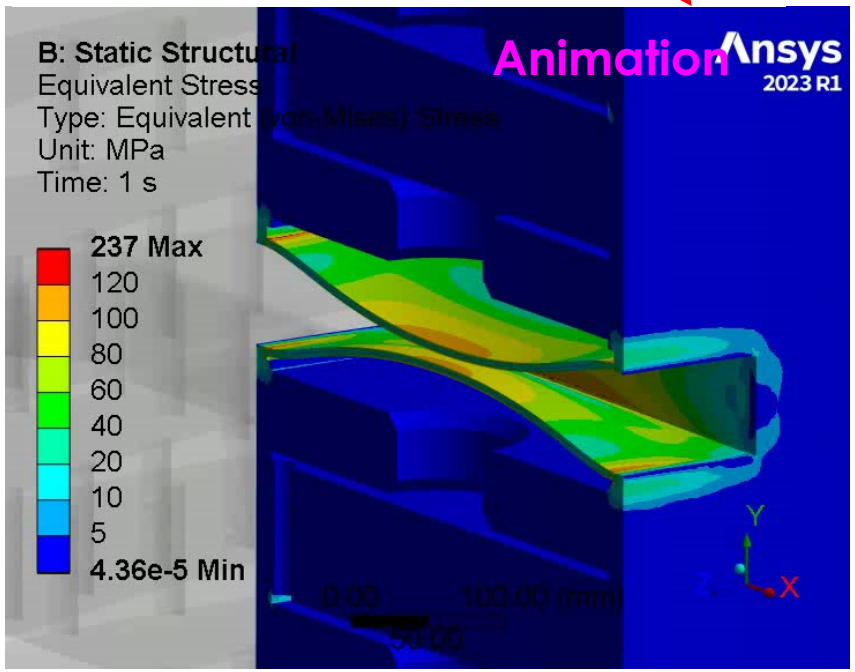
Water Pressure Only

Von-Mises Stress







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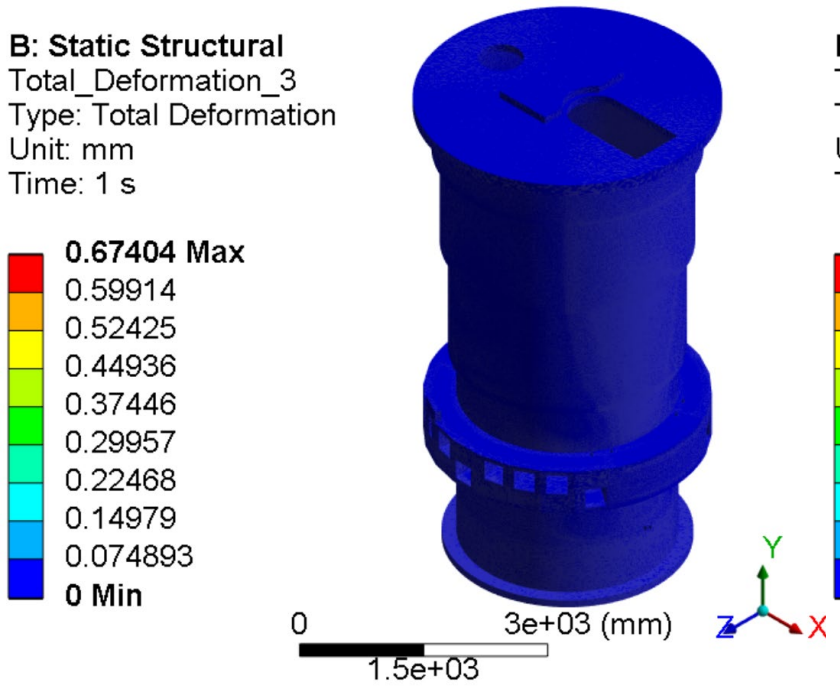
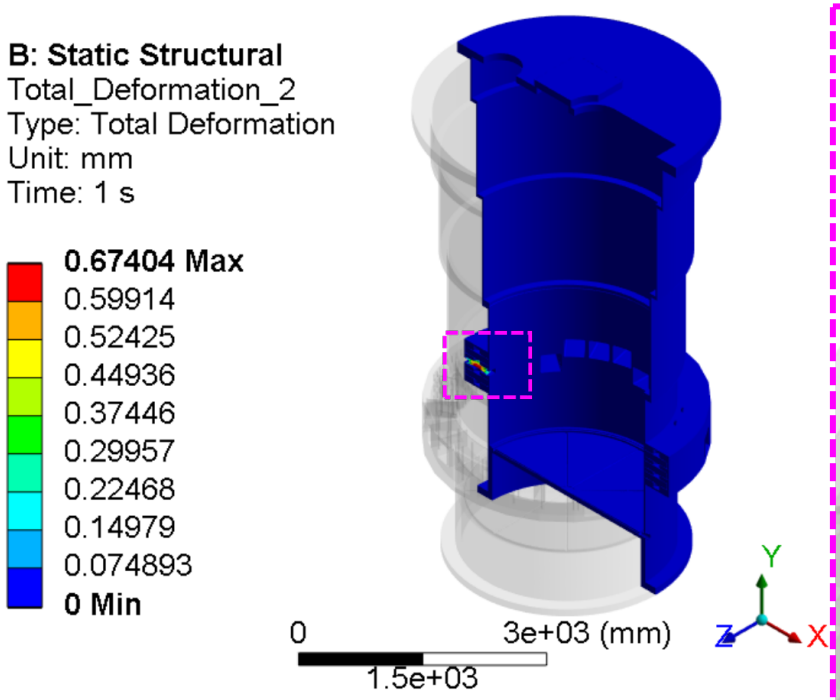
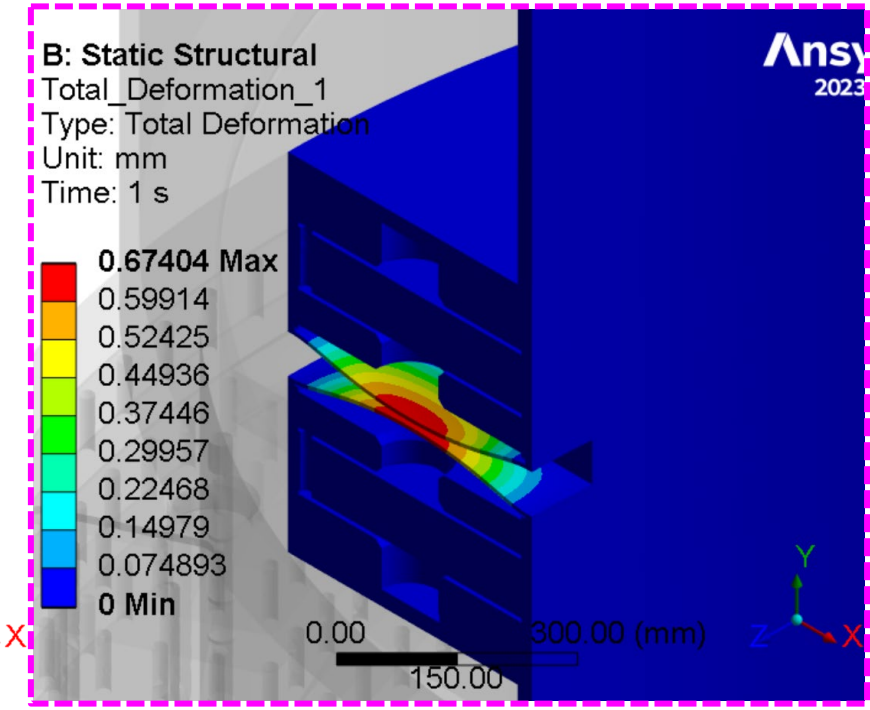
Total Displacement

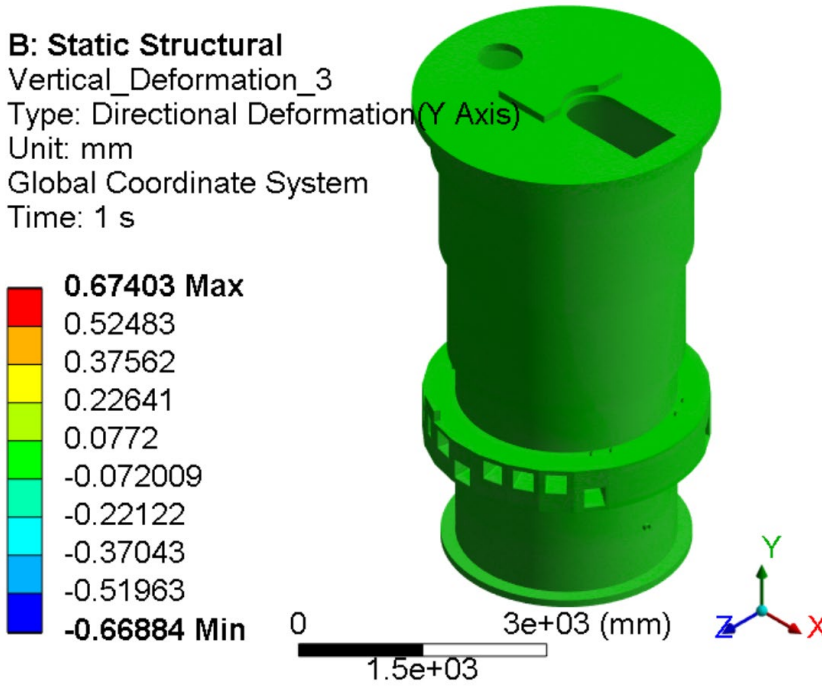


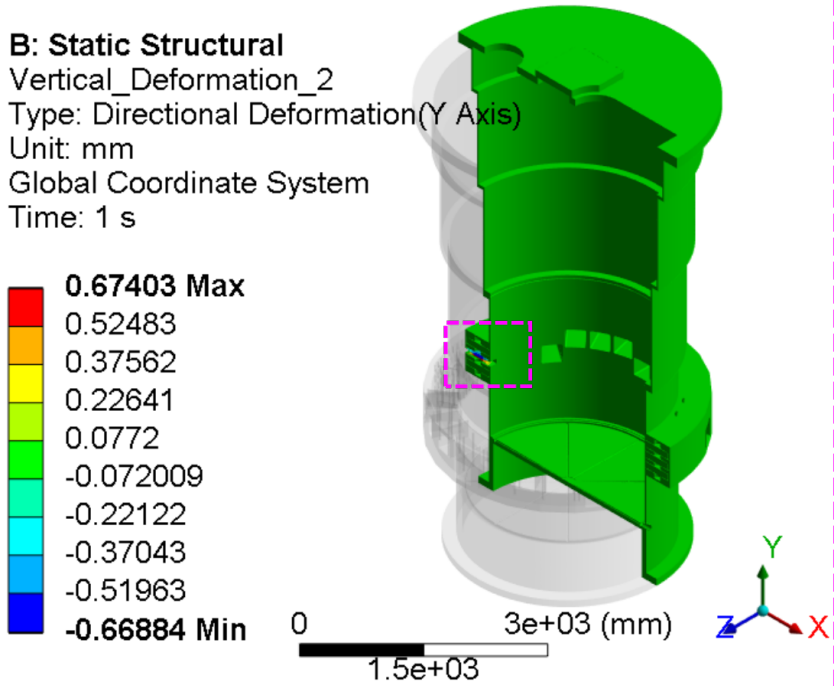


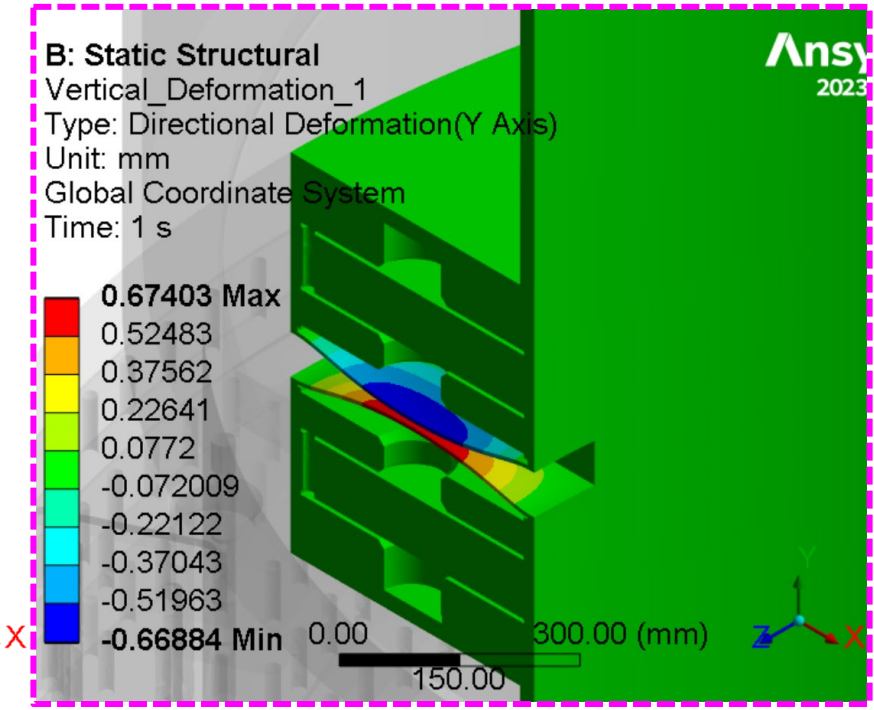


Water Pressure Only

Vertical Displacement







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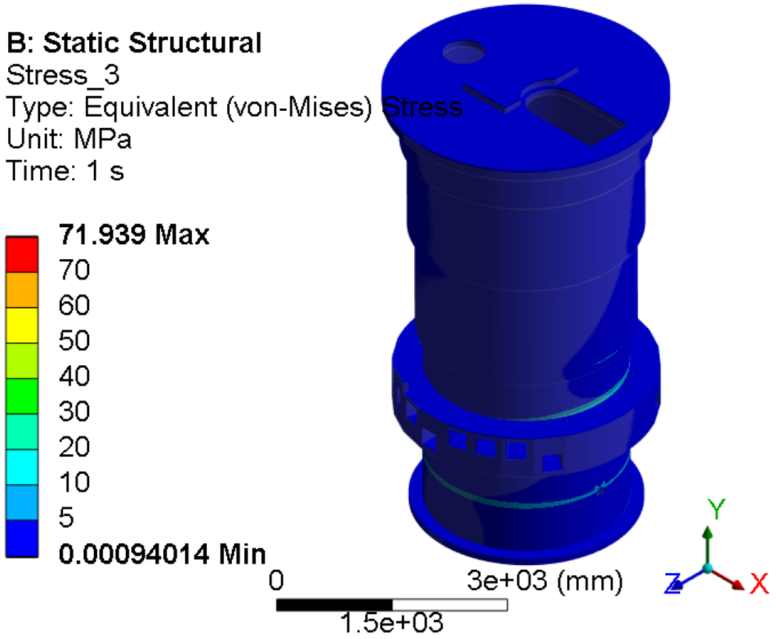
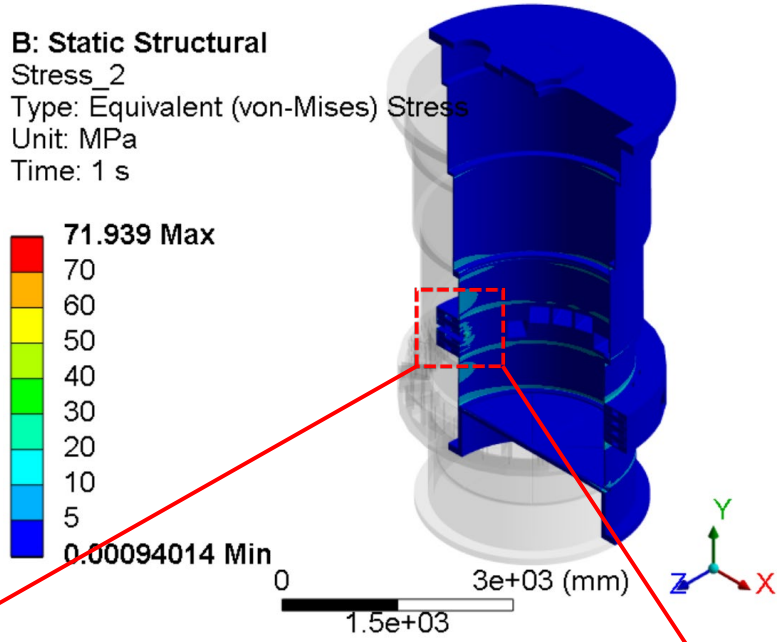
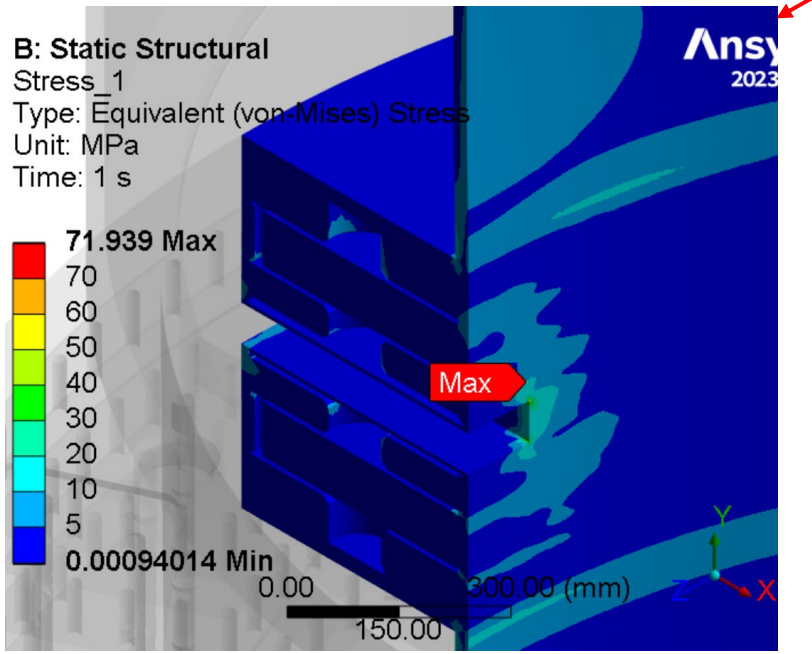
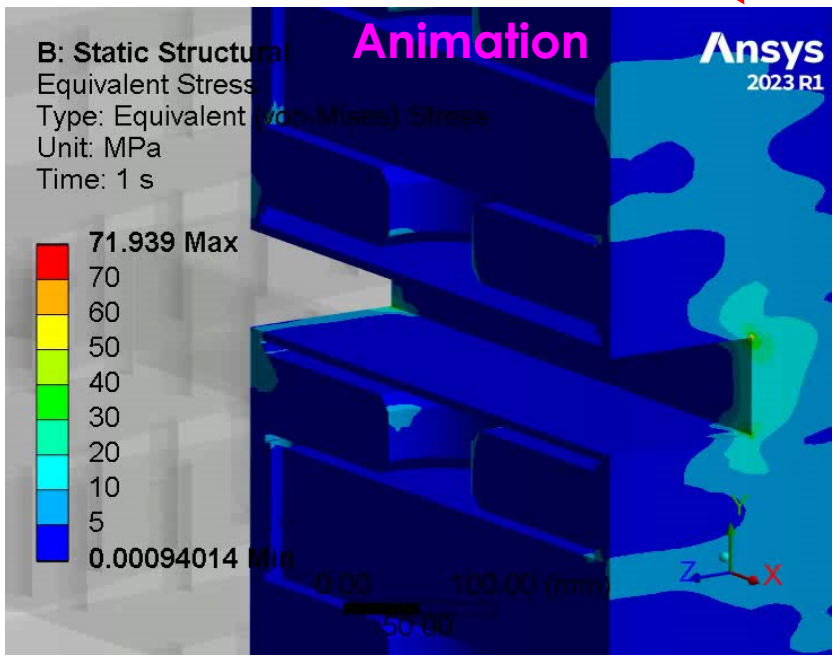
Von-Mises Stress









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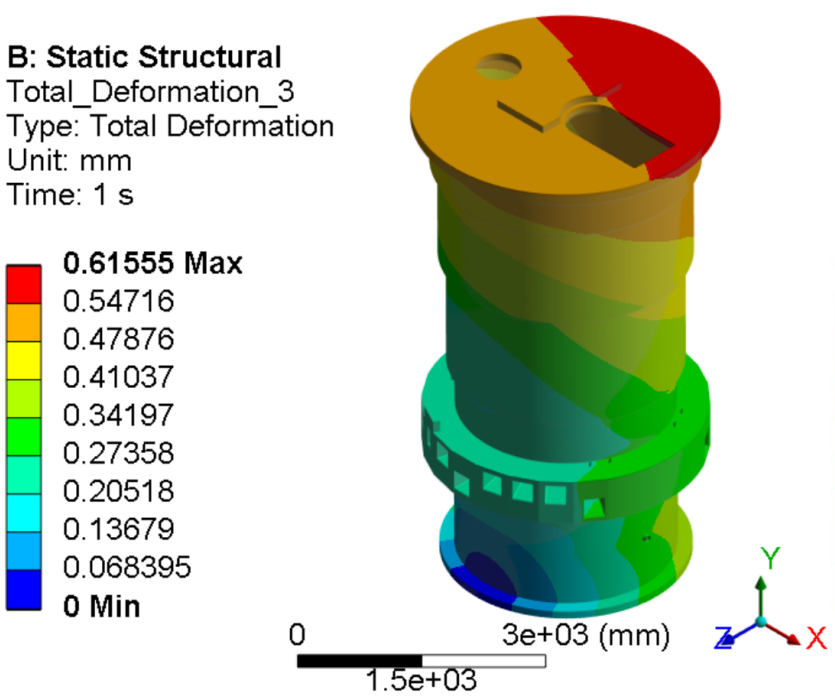
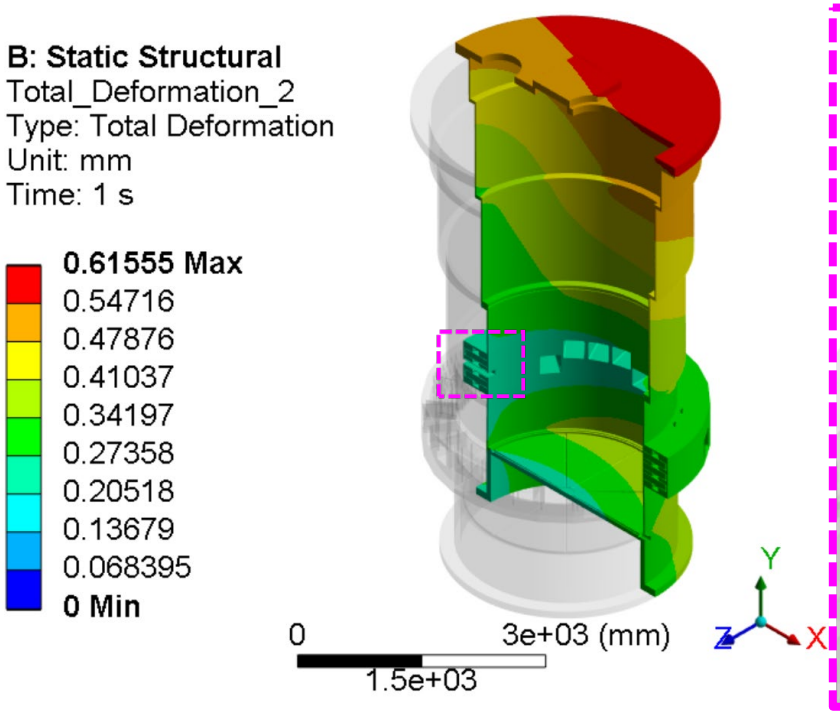
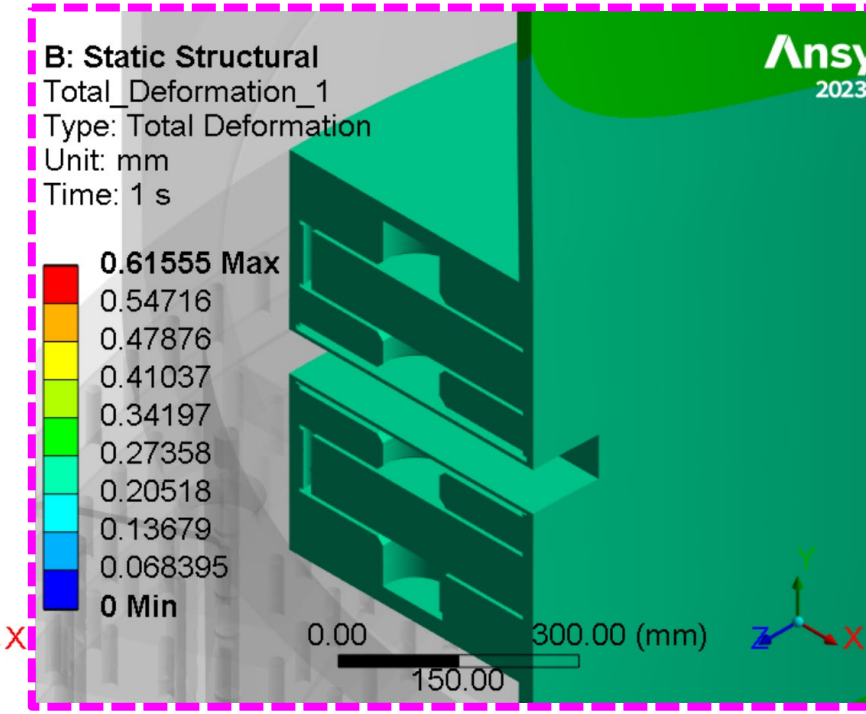
Total Displacement







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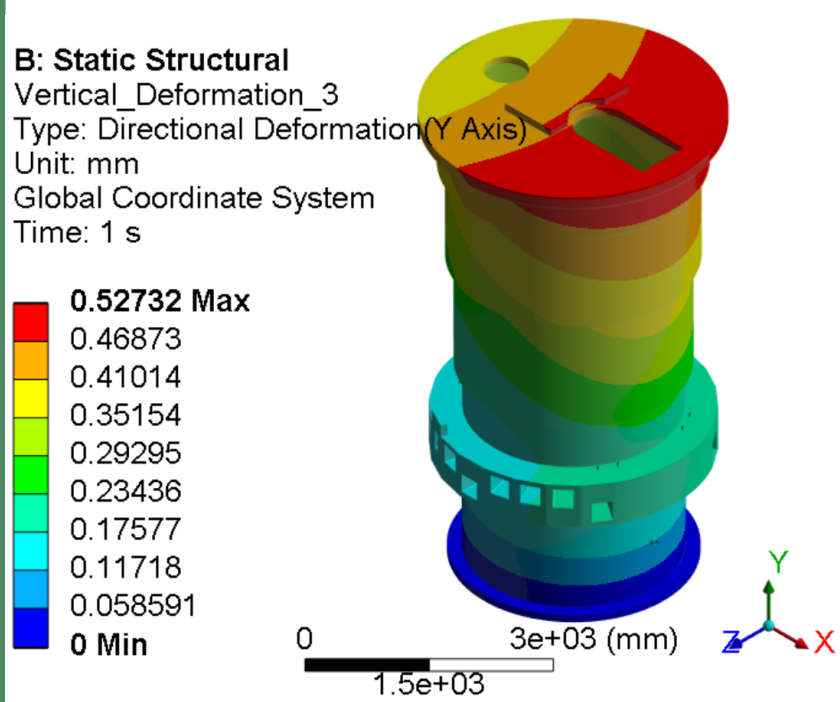
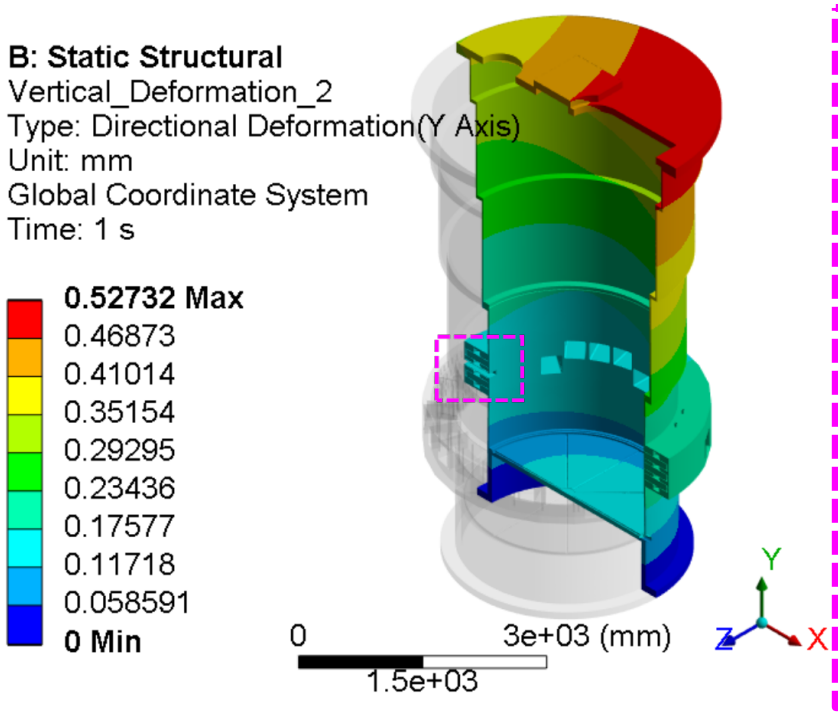
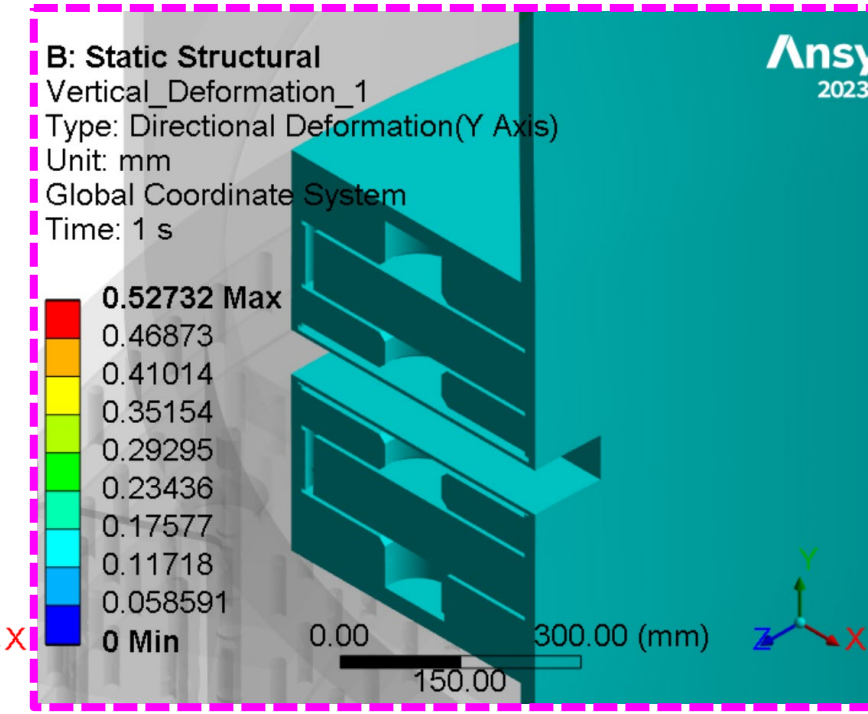
Thermal Only

Vertical Displacement







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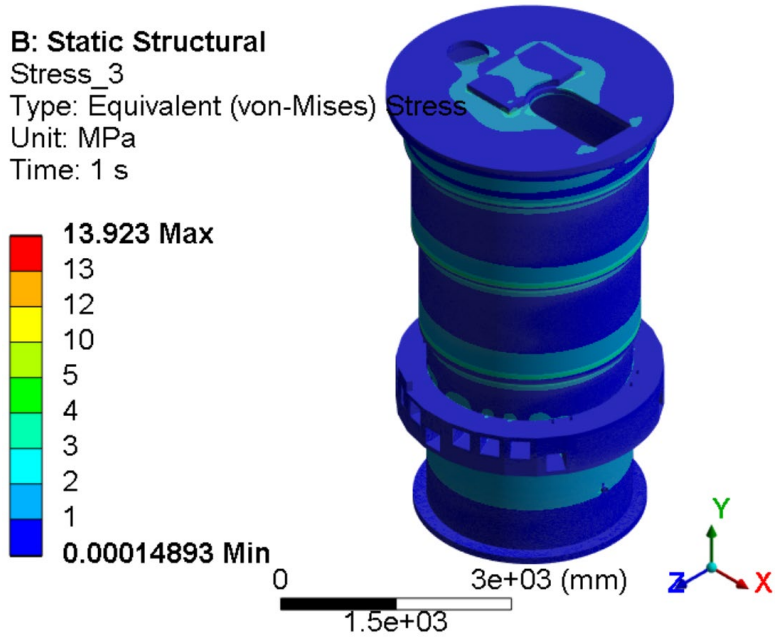
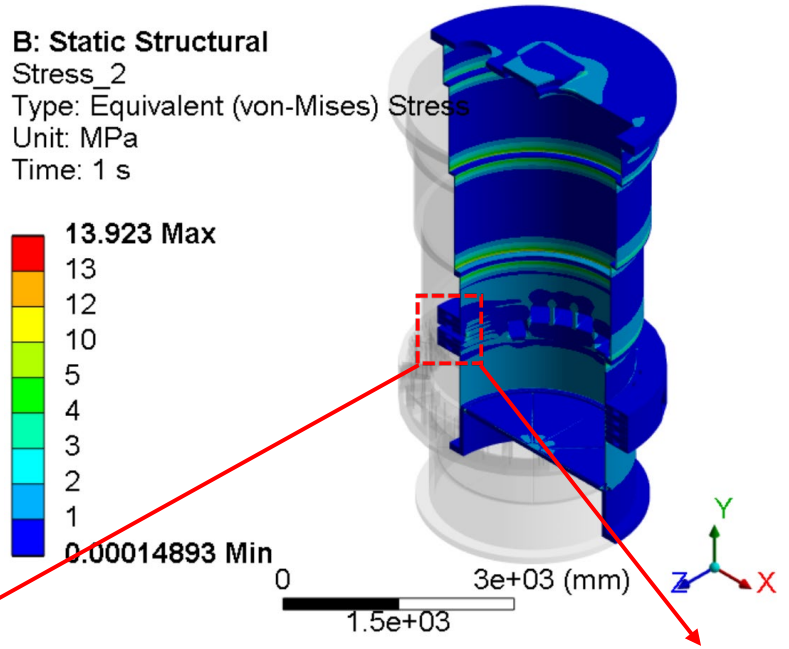
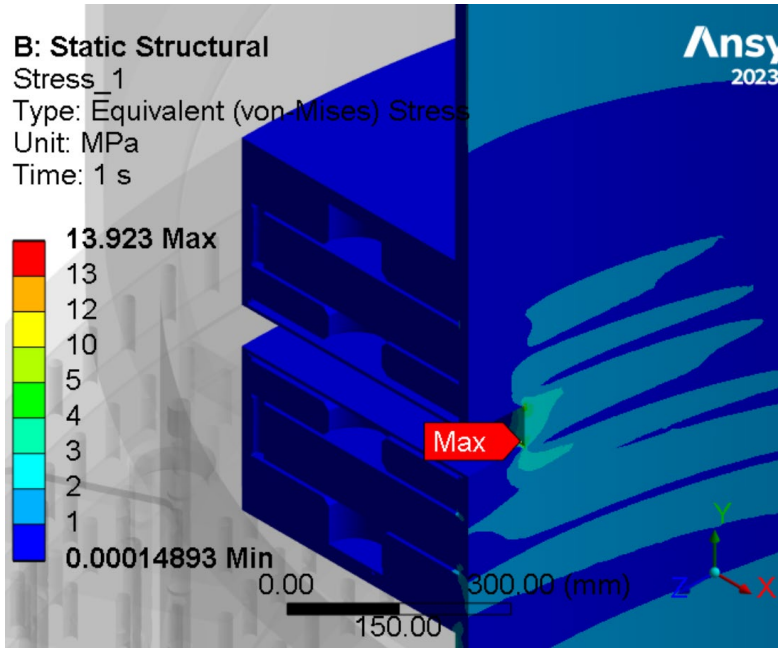
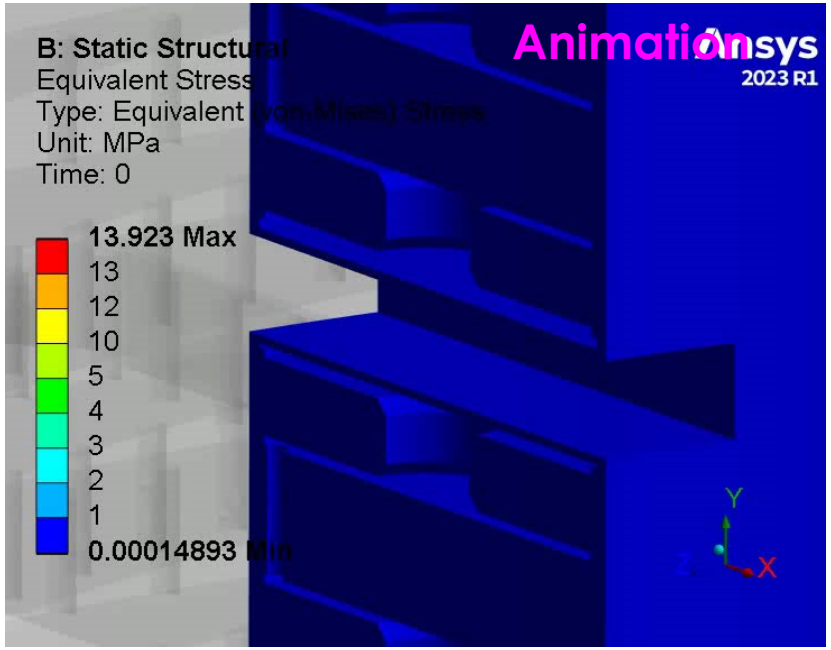
Gravity Only

Von-Mises Stress



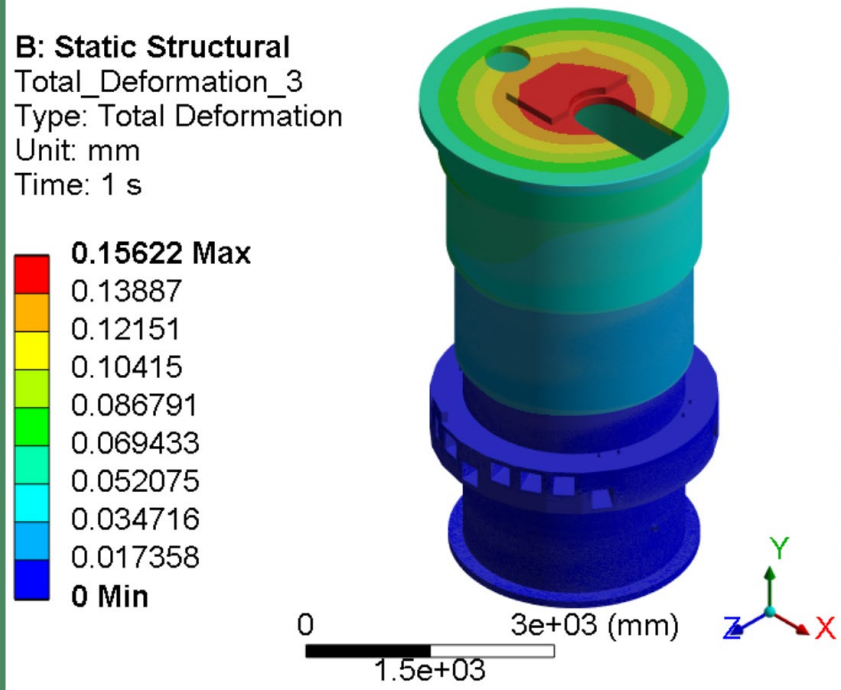


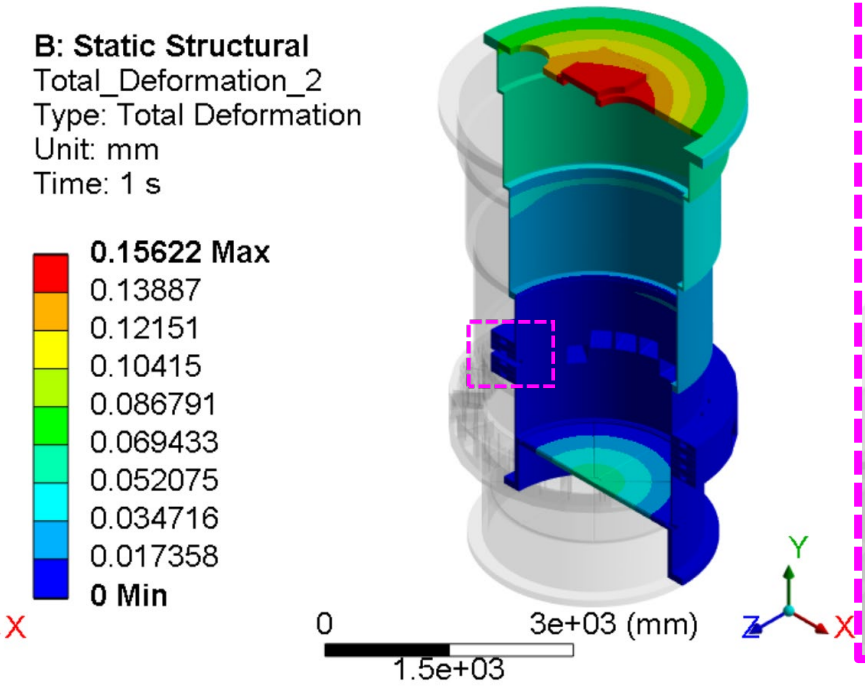


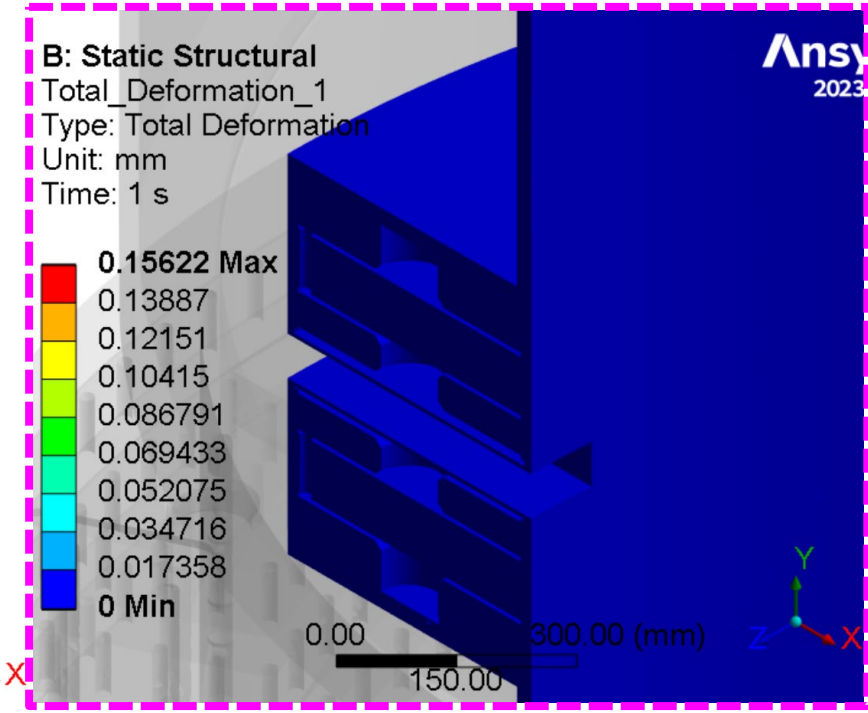


Gravity Only

Total Displacement

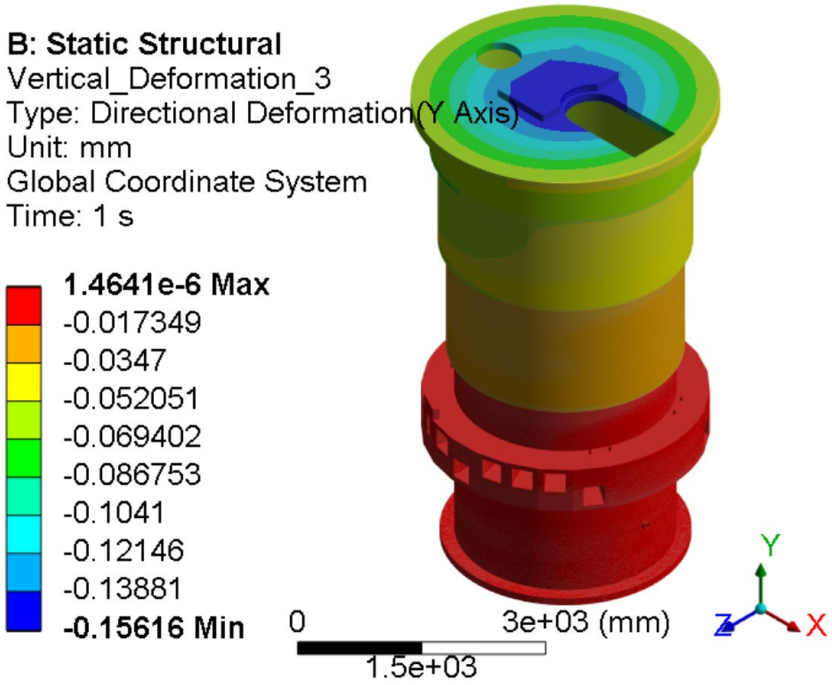


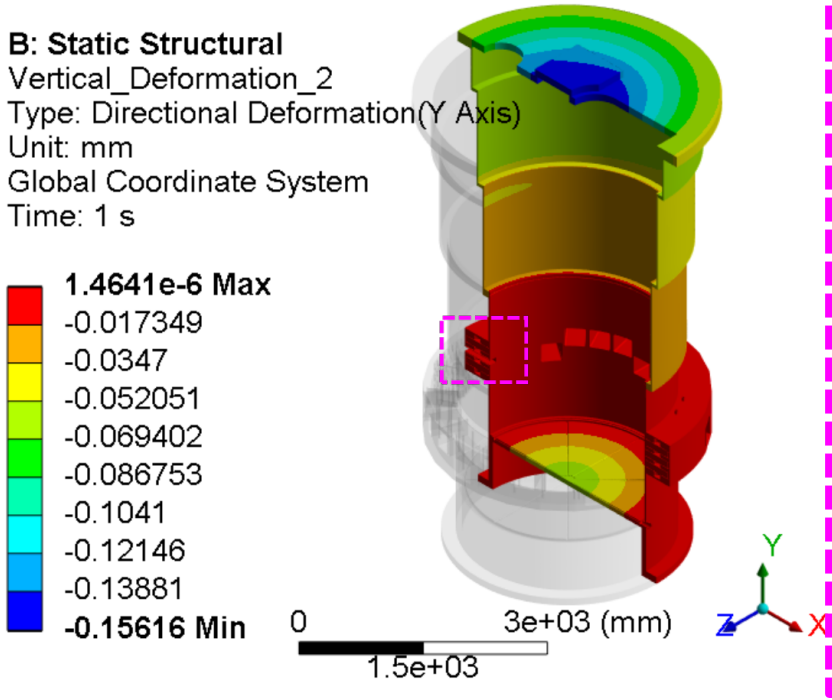


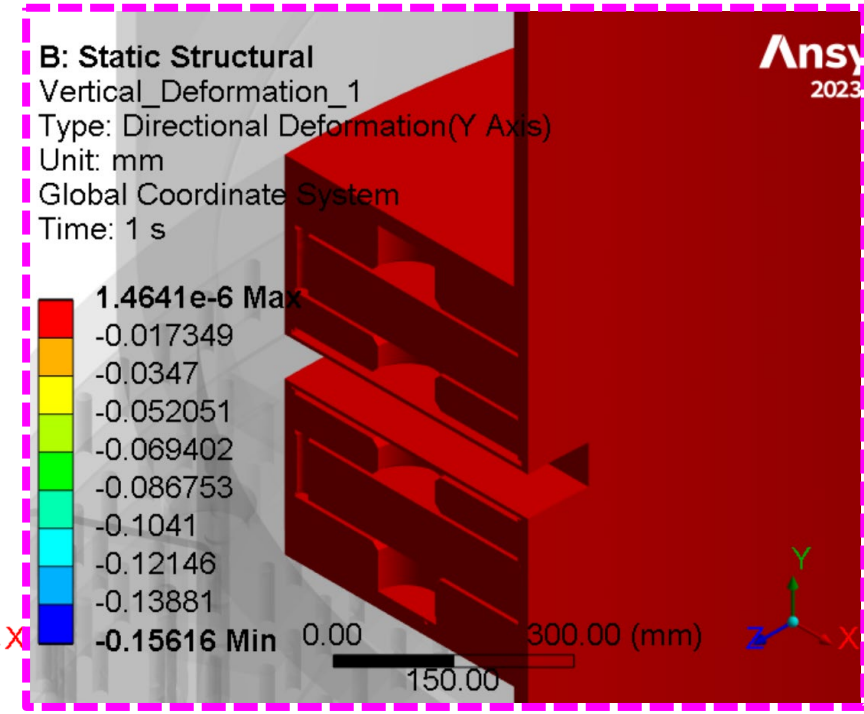


Gravity Only

Vertical Displacement







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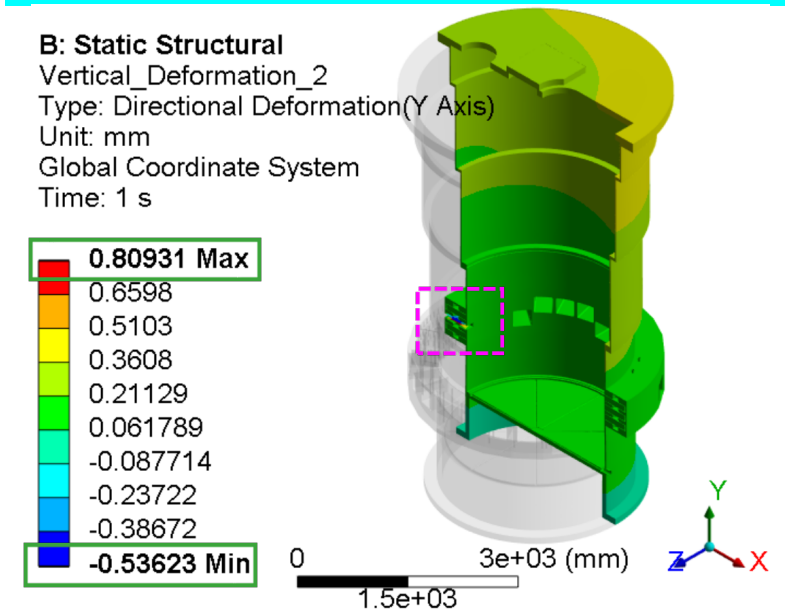
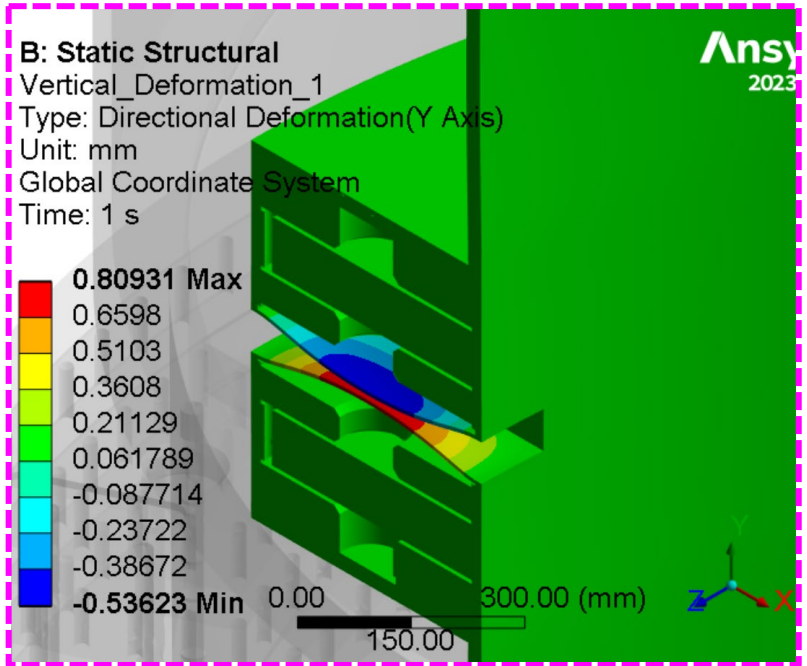
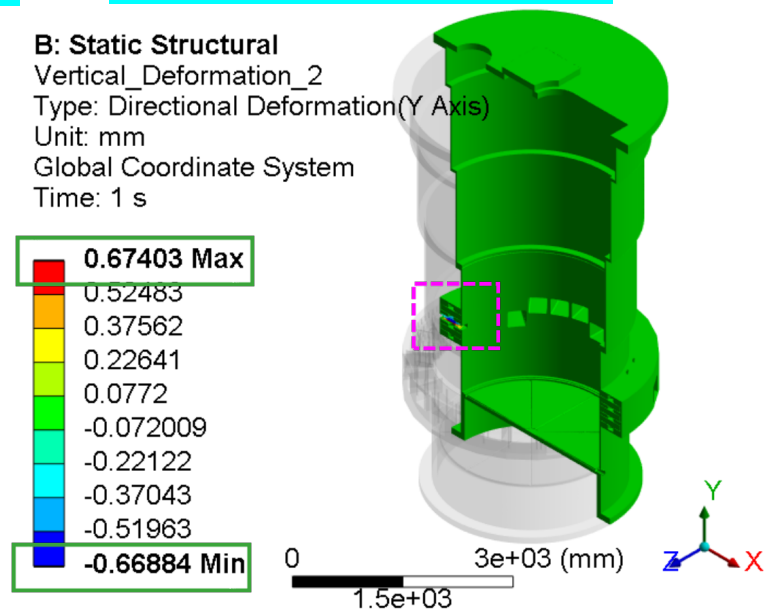
Comparison of Vertical (+/-) Displacement

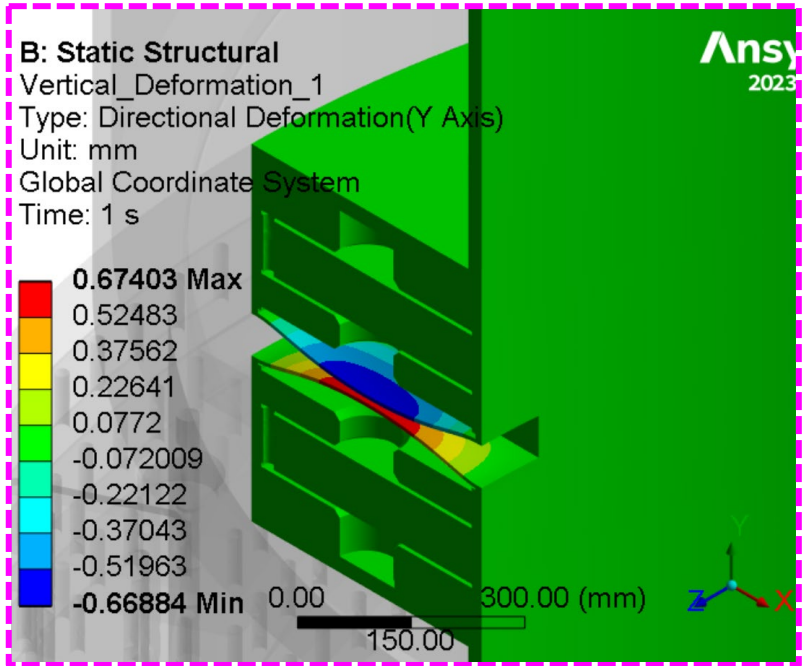
Water Pressure + Thermal + Gravity



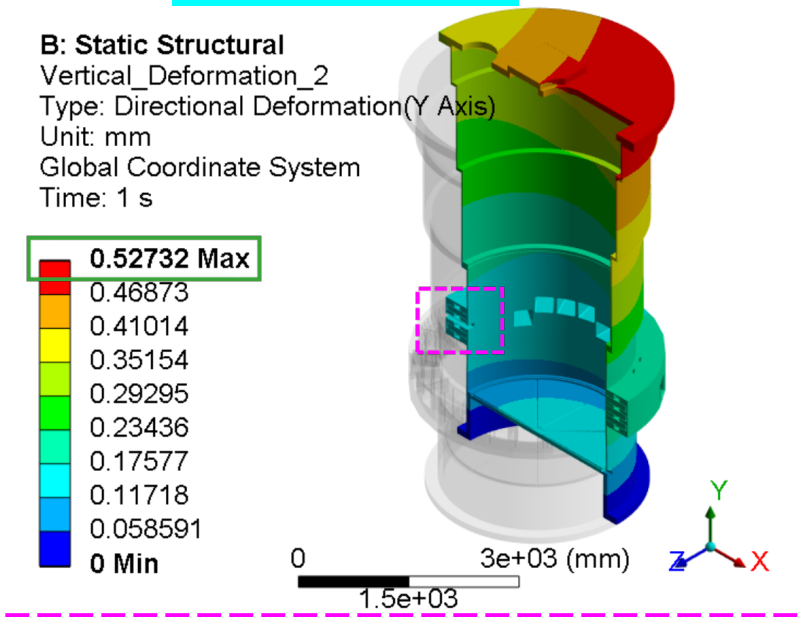


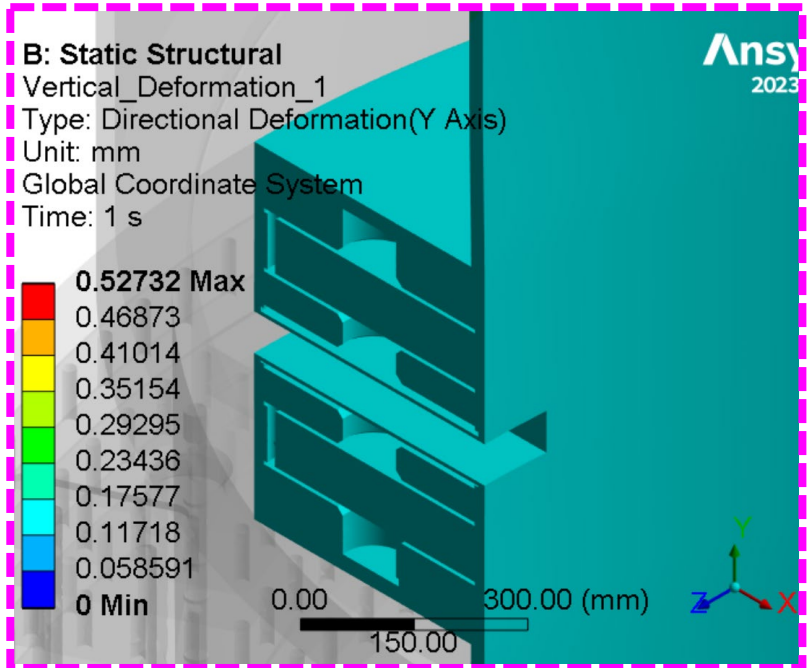
Water Pressure Only





Thermal Only





Summary

Core Vessel SS316 Tensile Yield Strength: 252.1 MPa ; SS316 Tensile Ultimate Strength: 565.1 Mpa			
	Max. Von-Mises Stress (MPa)	**Max. Vertical Displacement (mm)**	**Max. Total Displacement (mm)**
Water Pressure Effect Only	237	0.674/-0.669	0.674
Thermal Effect Only	72	0.527	0.616
Gravity Effect Only	14	-0.156	0.156
Water Pressure+Thermal+Gravity	**236**	**0.809/-0.536**	**0.834**

- The maximum stress/displacements due to different forces do not occur at different locations.
- Vertical displacement is directional (+/- sign).
- Total displacement is non-directional (absolute value).