OAK RIDGE National Laboratory

Preliminary STS MRA Backbone Thermal Hydraulic Analysis

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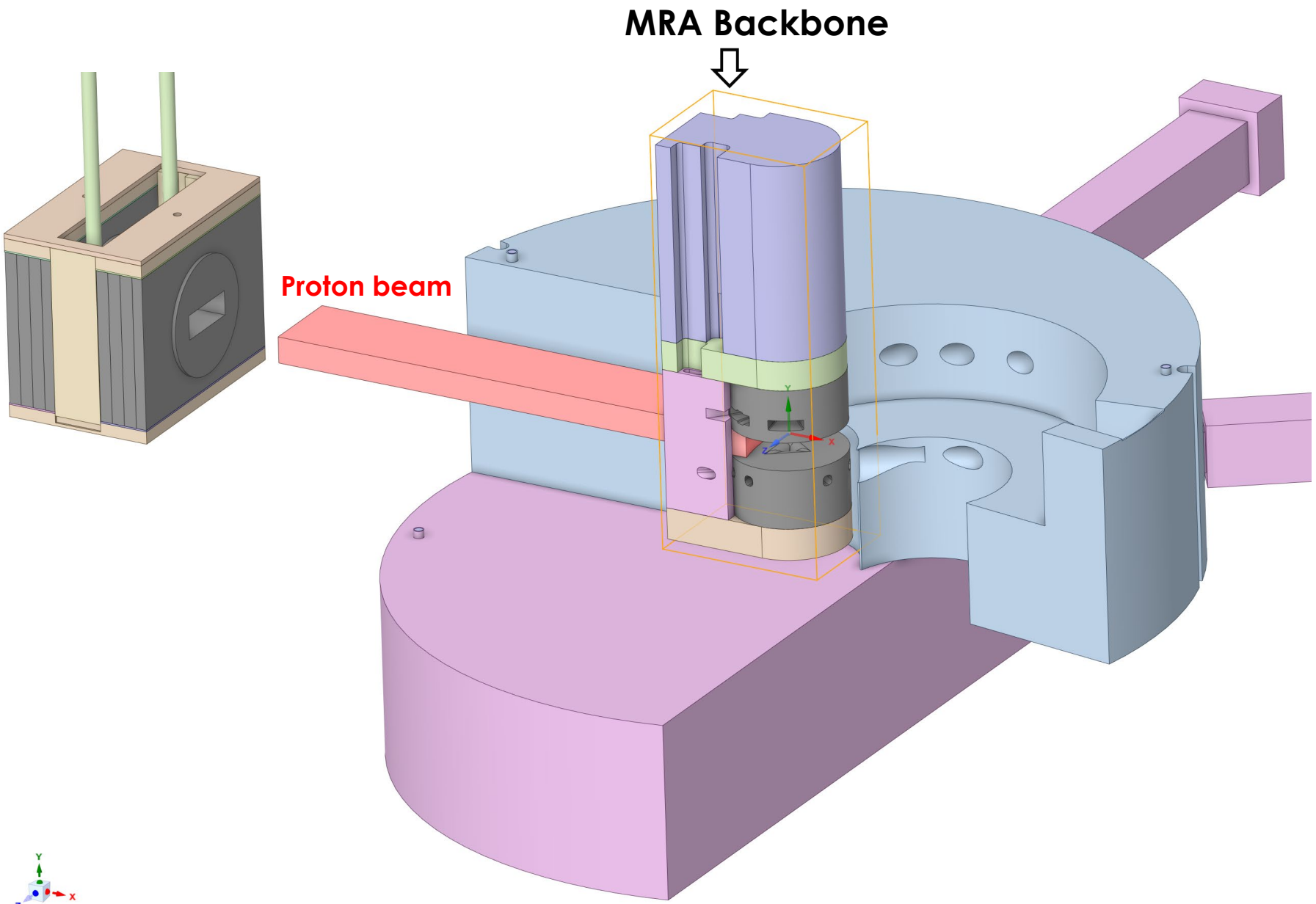
U.S. DEPARTMENT OF ENERGY

Purpose

- This thermal-hydraulic analyses were performed to demonstrate that the current MRA backbone design can meet the following requirements.
- **Requirements**
  - Maximum water temperature < 100°C
    - No water boiling
  - Maximum stainless-steel temperature < 200°C
  - Pressure drop < 0.5 psi
    - For the cooling loops 1 & 2
  - Pressure drop < 4.0 psi
    - For the cooling loops 3 & 4
- **Goal** : minimize stainless steel temperatures in order to minimize thermal displacements

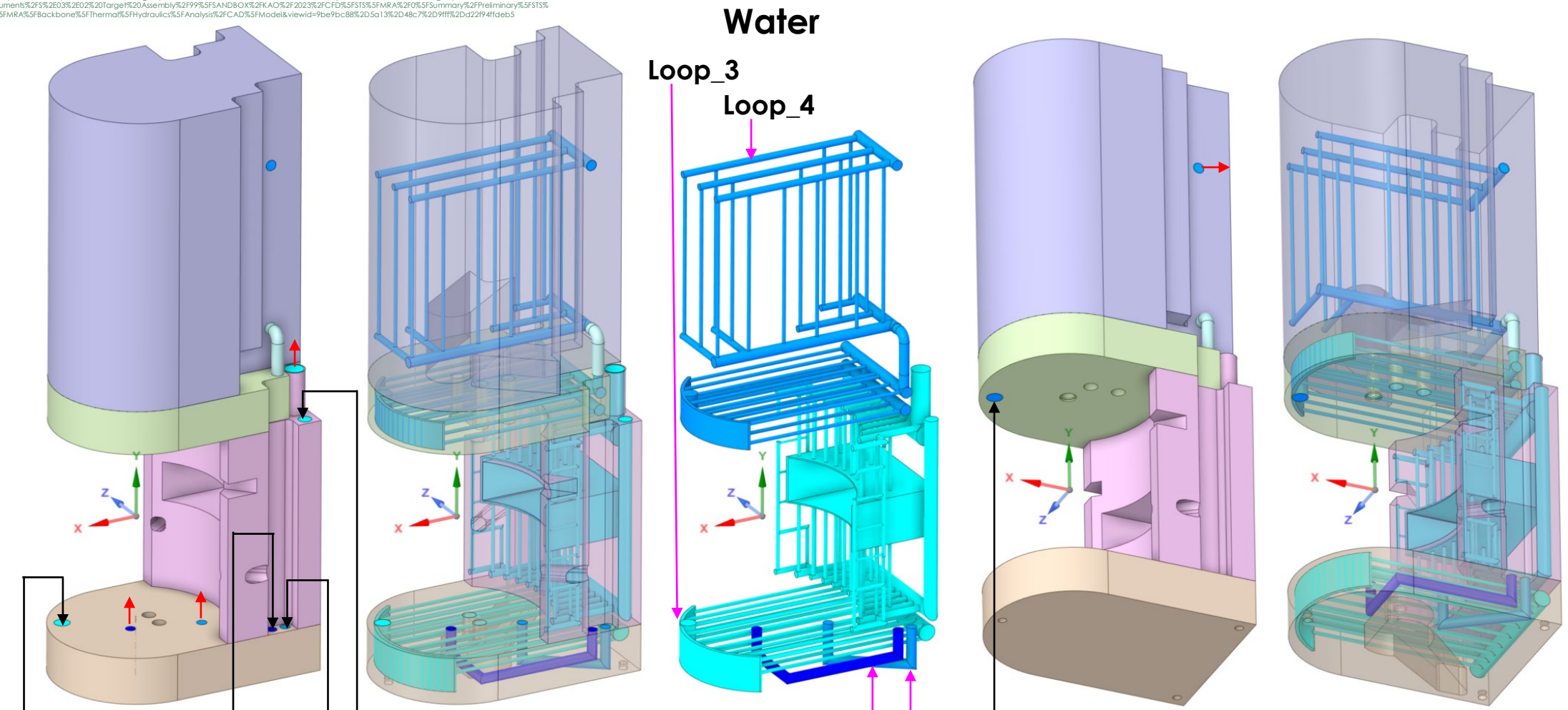
Geometry



MRA Full Backbone Geometry

Link to the CAD

https://ornl.sharepoint.com/sites/sts/targetsystems/Shared%20Documents/Forms/AllItems.aspx?id=%2Fsites%2Fsts%2Ftargetsystems%2FShared%20Documents%2FS%2E03%2E02%20Target%20Assembly%2F99%5FSANDBOX%2FKAO%2F2023%2FCFD%5FSTS%5FMRA%2F0%5FSummary%2FPreliminary%5FSTS%5FMRA%5FBackbone%5FThermal%5FHydraulics%5FAnalysis%2FCAD%5FModel&viewid=9be9bc88%2D5a13%2D48c7%2D9fff%2Dd22f94ffdeb5



Loop_3_1 & Loop_4: outlet temperatures from reflector vessel analyses

0.47 kg/s (7.5 GPM) , 35.0°C (**Loop_1: Lower Reflector Inlet**)

0.47 kg/s (7.5 GPM) , 35.0°C (**Loop_2: Lower Premoderator Inlet**)

0.94 kg/s (15 GPM) , 39.2°C (**Loop_3_1: Lower Reflector/Premoderator Combined Outlet**)

0.94 kg/s (15 GPM) , 35.0°C (**Loop_3_2: Middle Backbone Inlet**)

0.94 kg/s (15 GPM) , 38.7°C (**Loop_4: Upper Reflector/Premoderator Combined Outlet**)

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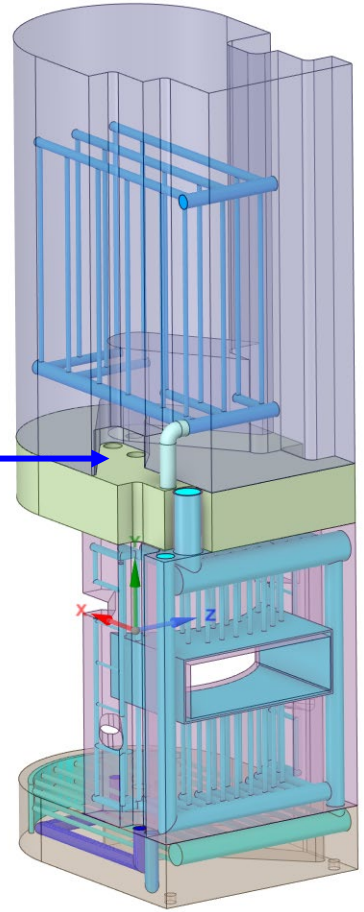
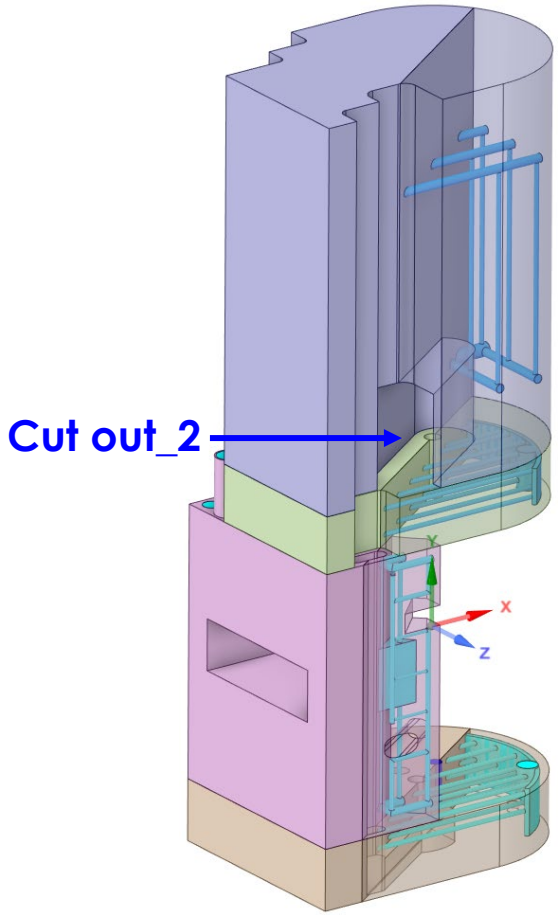
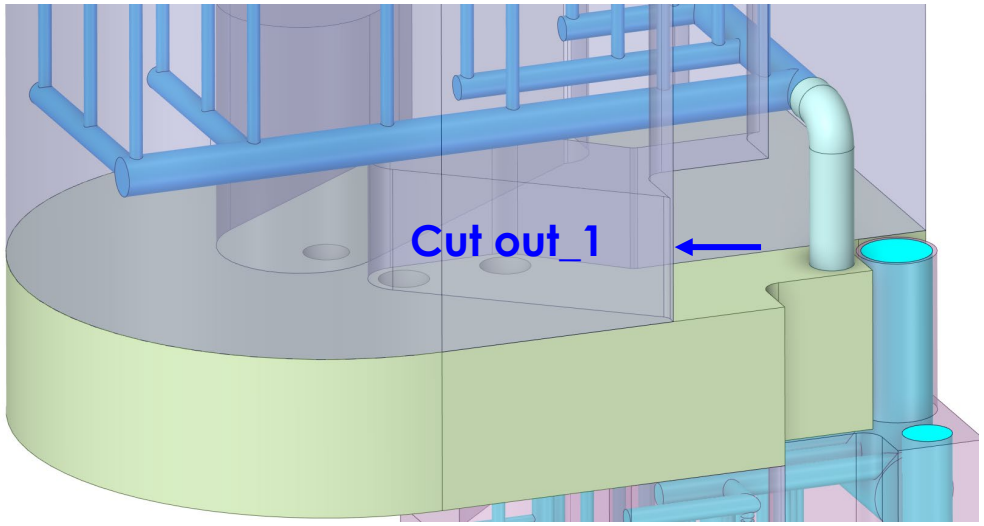
MRA Full Backbone Geometry, Pipe Cut Outs

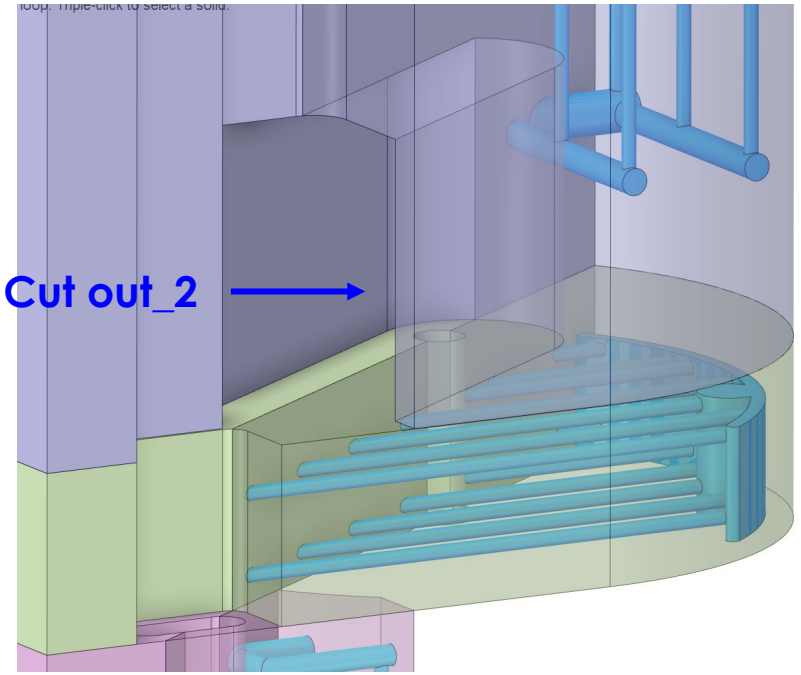
Higher temperature is expected around the **Pipe cut outs** (difficult to route cooling passages)

Pipe Cut Outs:
slots with clearance for routing piping to the component



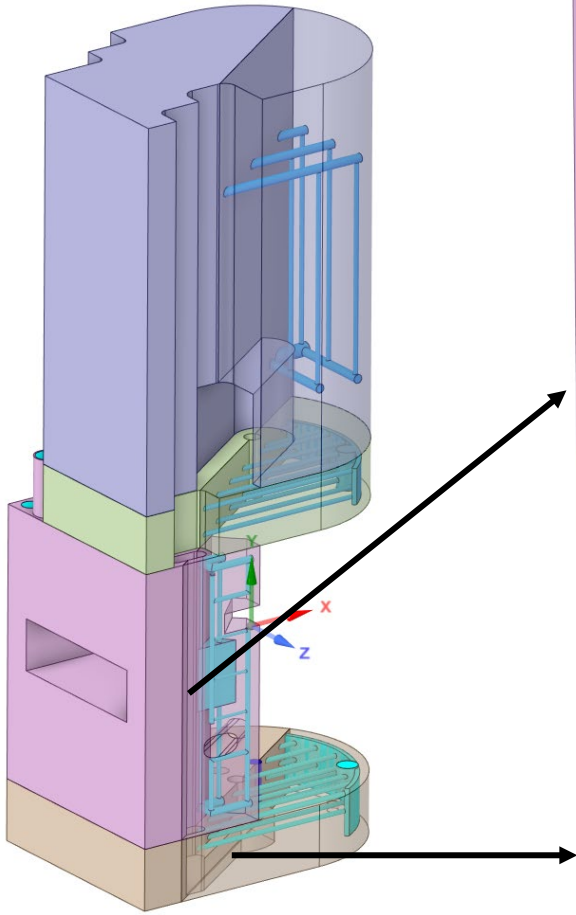


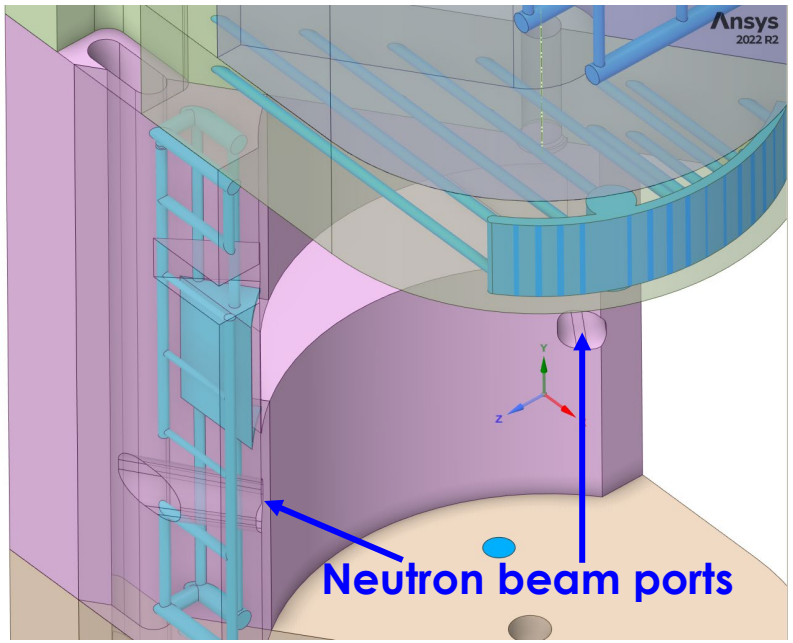




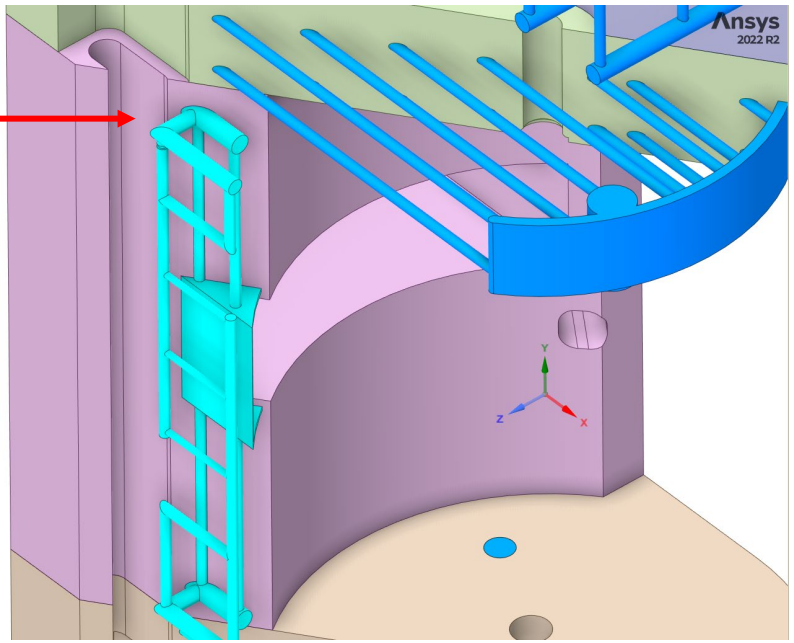
MRA Full Backbone Geometry, Vacuum Regions

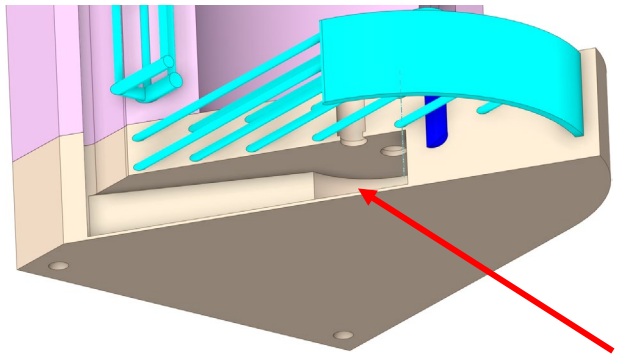
Higher temperature is expected around the vacuum regions (difficult to route cooling passages)

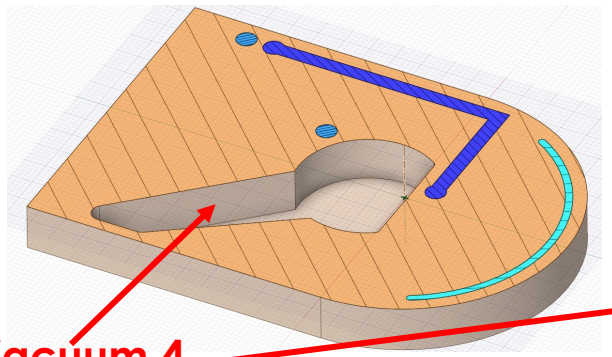




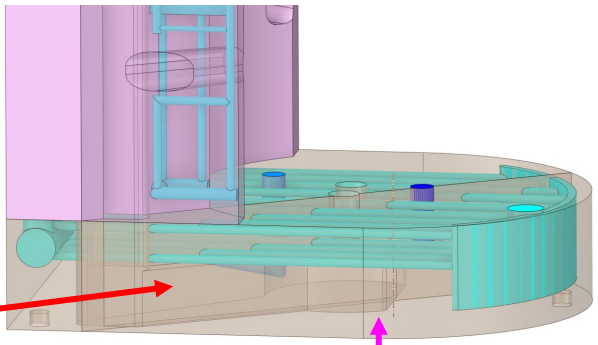
Vacuum 3







Vacuum 4



Higher T expected

MRA Full Backbone Heat Source

energy deposition from Lukas

$QSS = 26{,}054\ W$

Link:

https://ornl.sharepoint.com/sites/sts/targetsystems/Shared%20Documents/Forms/AllItems.aspx?id=%2Fsites%2Fsts%2Ftargetsystems%2FShared%20Documents%2FS%2E03%2E02%20Target%20Assembly%2F1%5FCALCULATIONS%2FCALC%2D016%20%2D%20MRA%2FMRA%5FRS%2FNeutronics&viewid=9be9bc88%2D5a13%2D48c7%2D9fff%2Dd22f94ffdeb5

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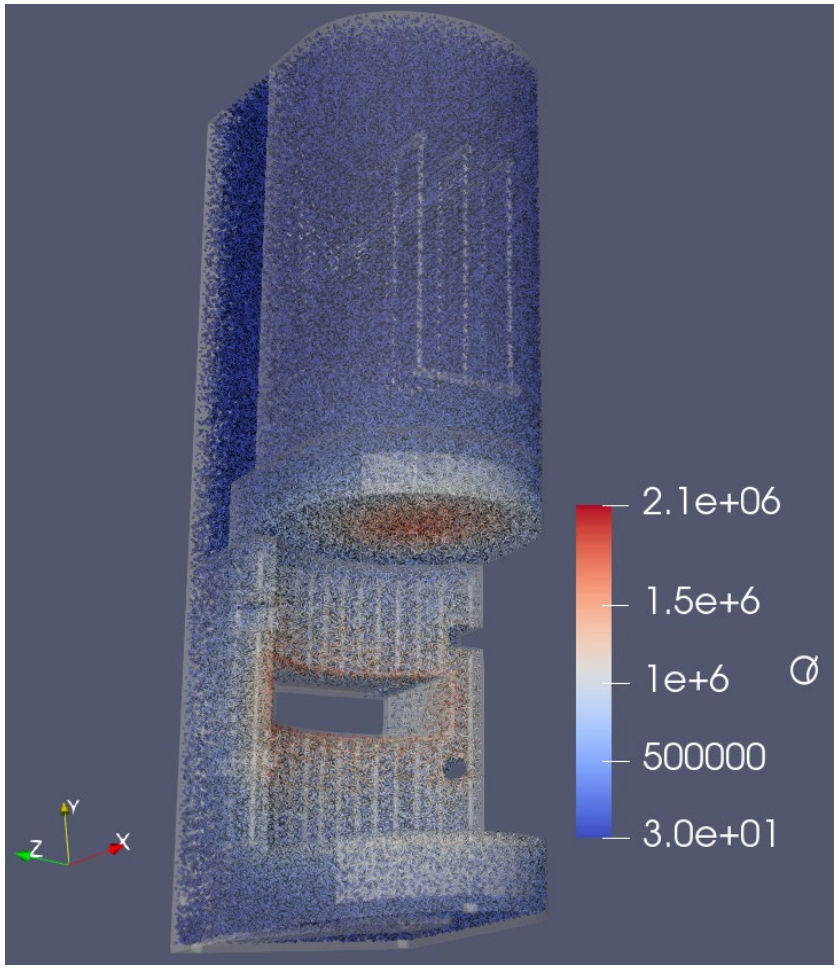

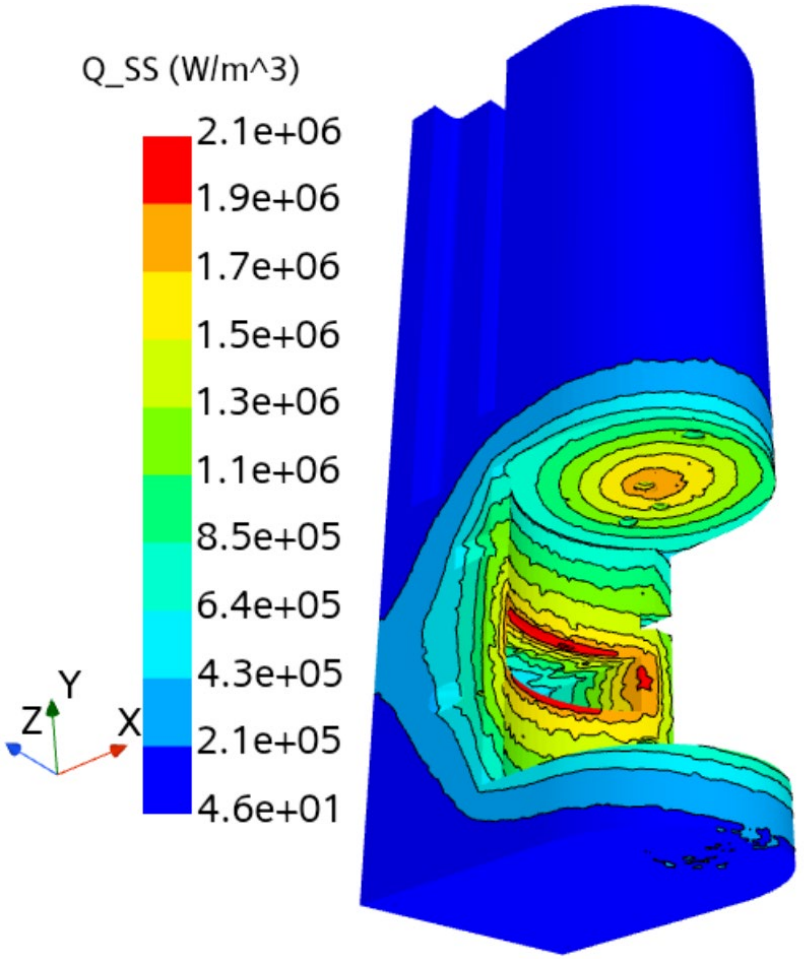

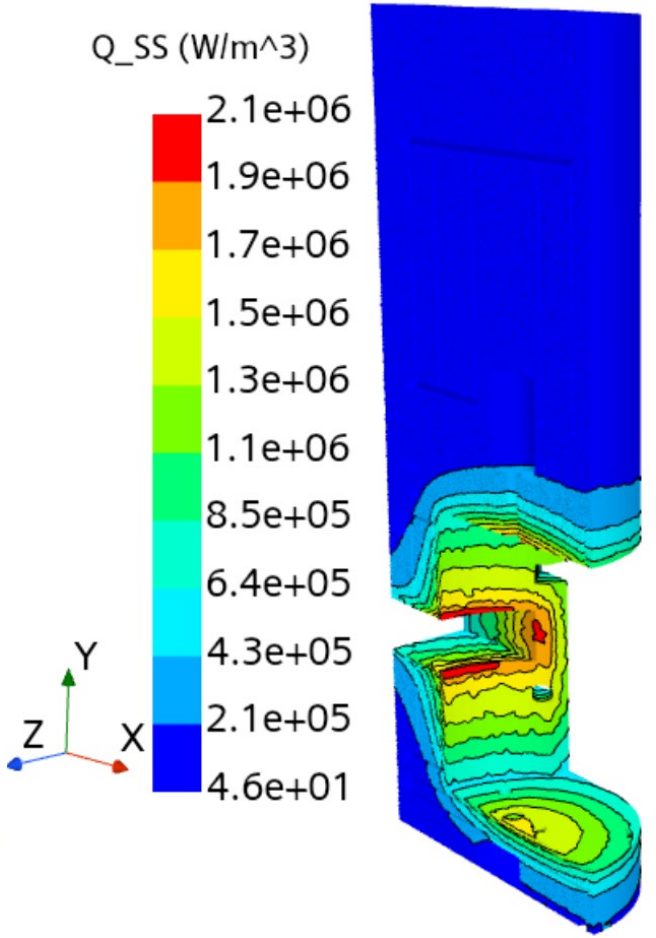

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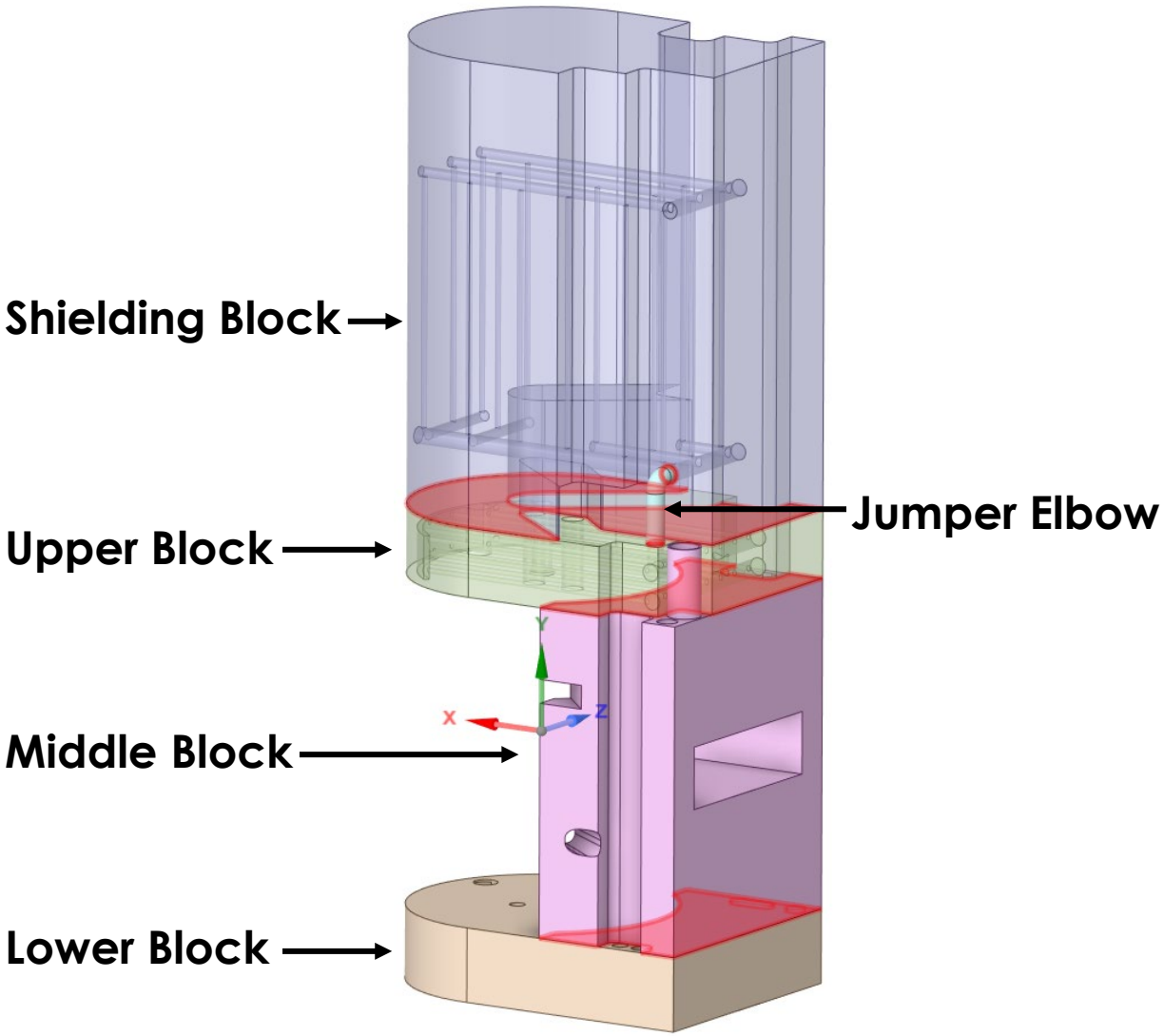
MRA Full Backbone Heat Source (Solid)

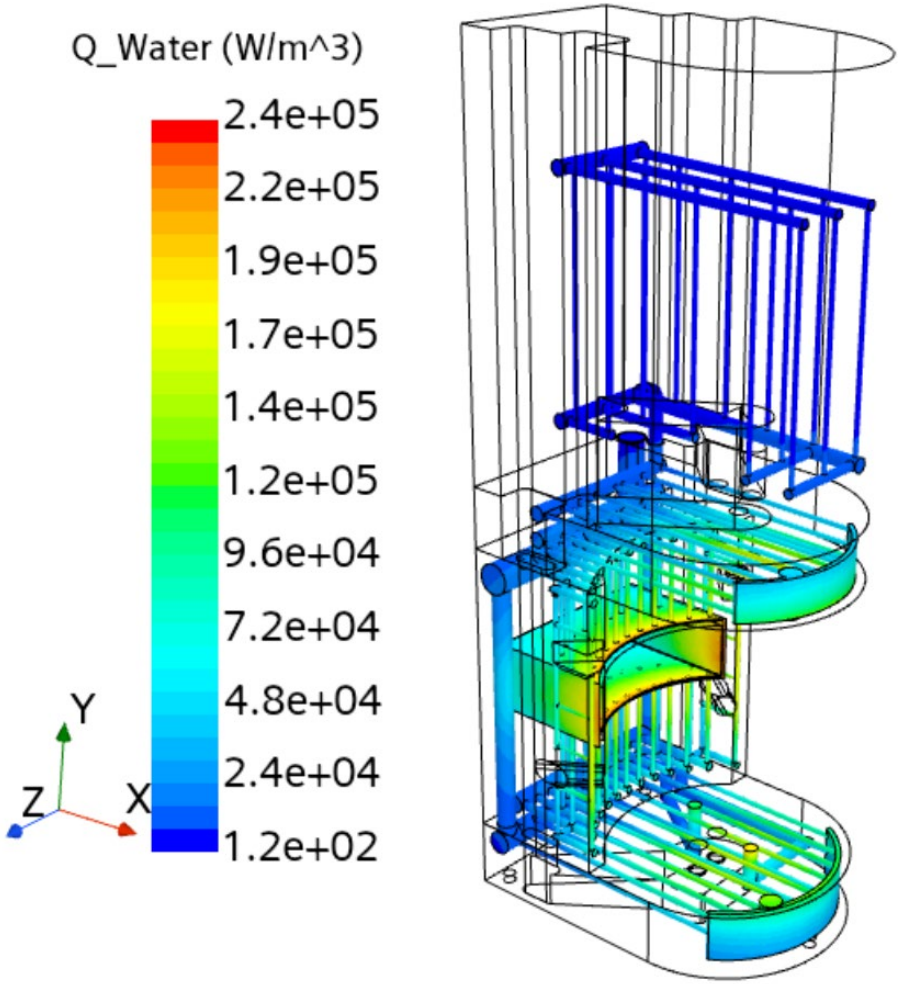


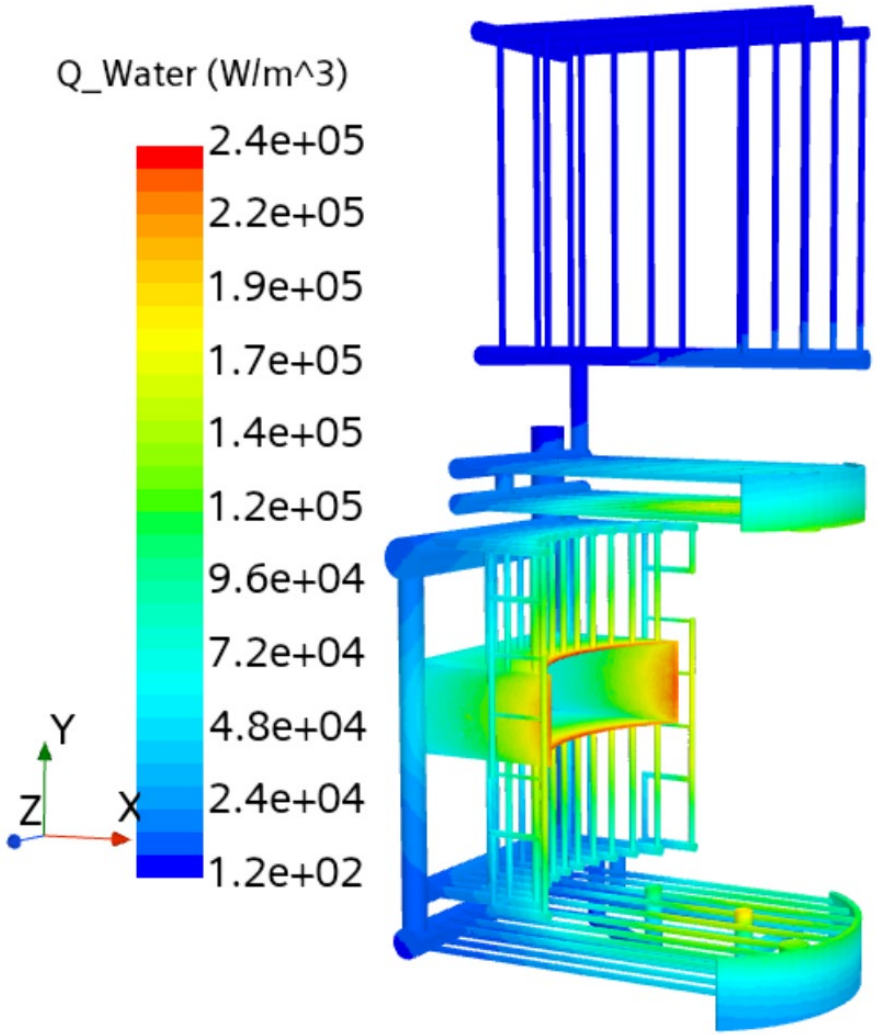
Part	Heat (W)
Shielding Block	2.157842e+03
Upper Block	6.494906e+03
Middle Block	1.199489e+04
Lower Block	5.405235e+03
Jumper Elbow	7.509197e-01

Heat Source in Water

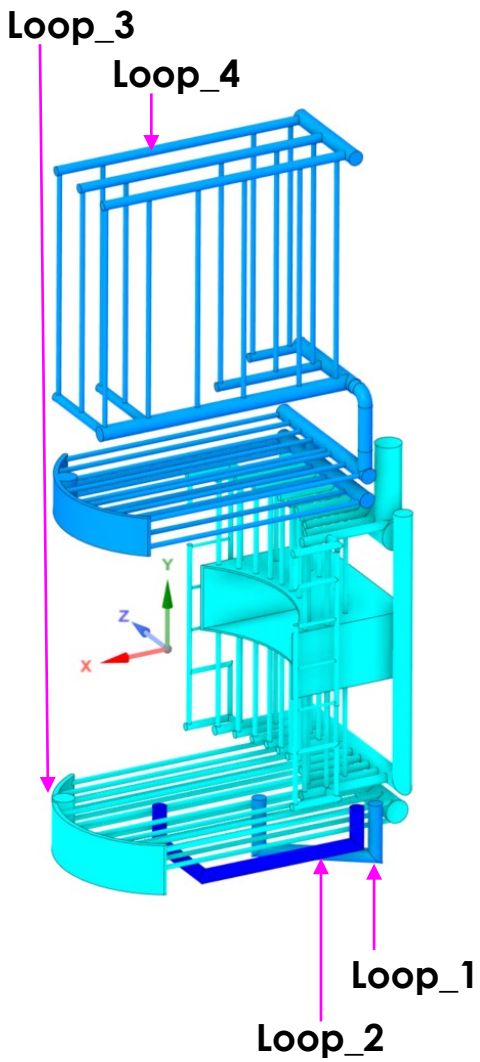
Q_Water approximation: $Q_{water} = QSS * \frac{\rho_{water}}{\rho_{SS}} = QSS * \frac{997.561}{7969}$

Q_{water} = 229.57W

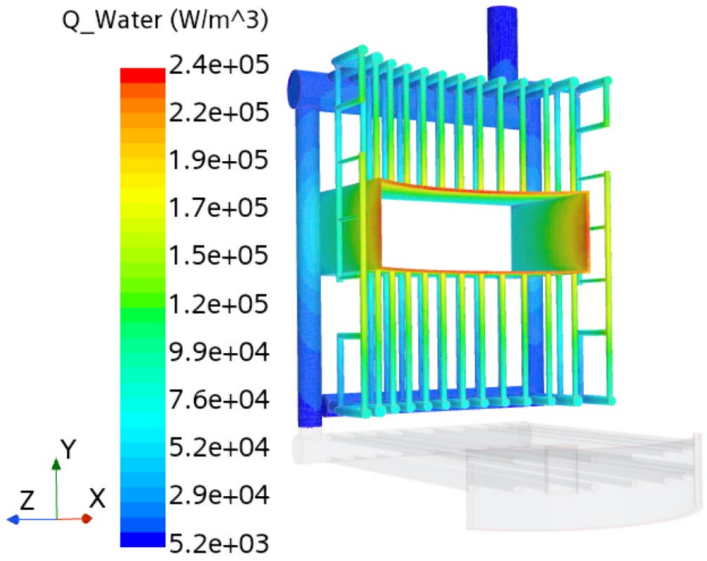




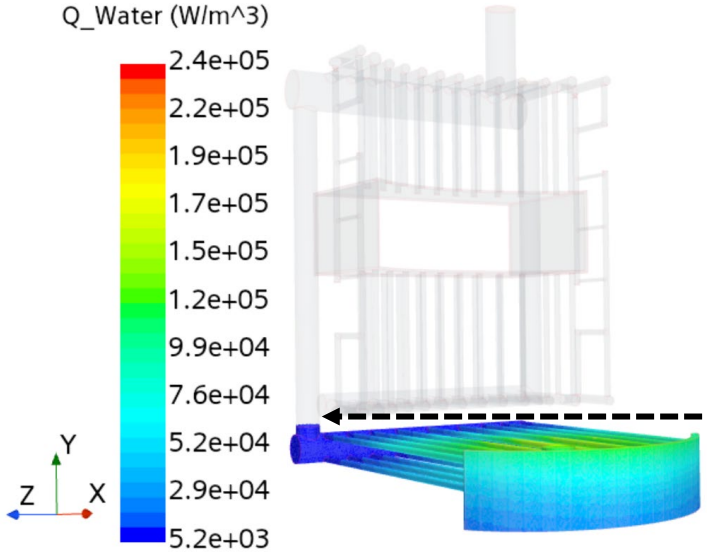
Heat Source in Water



Loop 3 Upper



Loop 3 Lower



Cut at y = -0.248m

Part	Heat (W)	Volume (m^3)
Water Loop 1	2.910981e+00	1.4010555470E-04
Water Loop 2	7.426260e+00	2.1190132240E-04
Water Loop 3	1.725499e+02	3.9162438768E-03
Water Loop 4	4.668117e+01	1.8178559604E-03
Sum	**229.57**	**6.0861067143E-03**
Water Loop 3 Upper	1.289333e+02	2.8504479941E-03
Water Loop 3 Lower	4.361658e+01	1.0656808517E-03

SS316 Material Properties from Ansys

SS316 Material Properties From Ansys

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

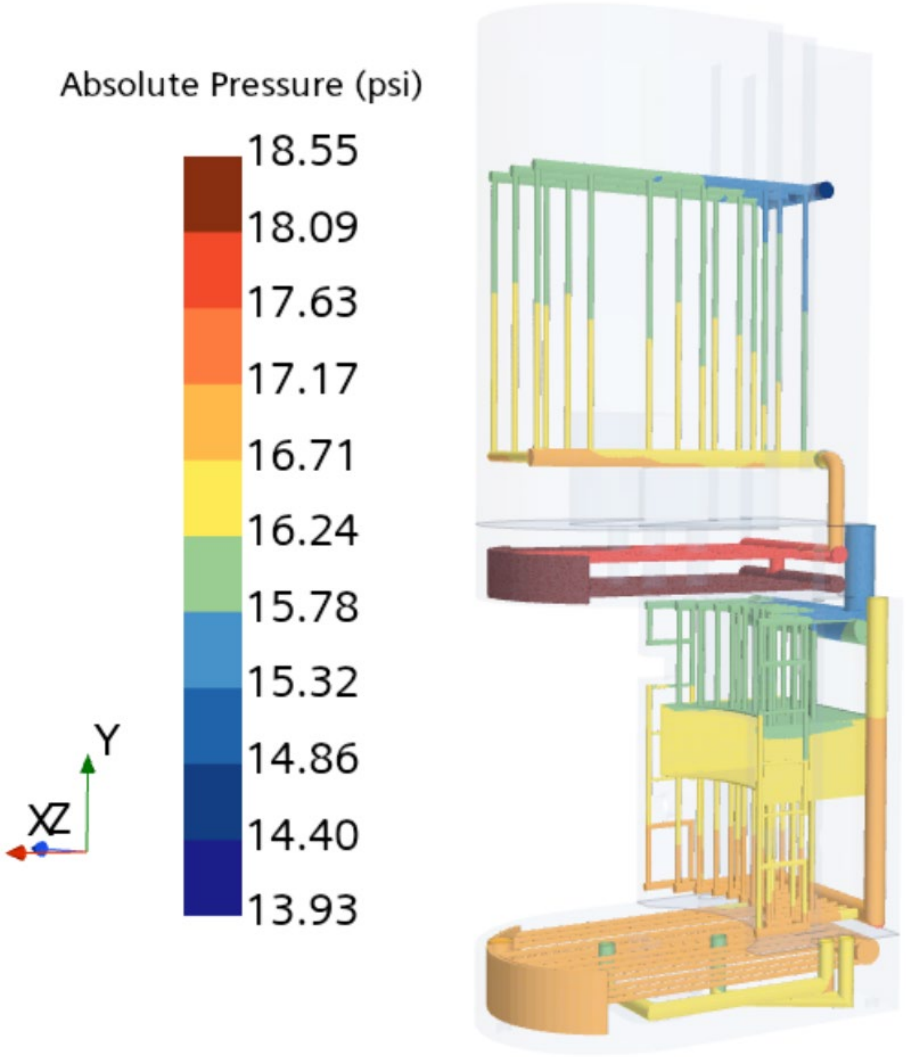
Density (kg/m^3)	**7969**
Coefficient of Thermal Expansion (1/K)	**1.61E-05**
Specific Heat (J/kg-K)	**486.1**
Thermal Conductivity (W/m-K)	**14.58**
Young's Modulus (Pa)	**1.95E+11**
Poisson's Ratio	**0.27**
Bulk Modulus (MPa)	**1.413E5**
Shear Modulus (MPa)	**76772**
Tensile Ultimate Strength (MPa)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

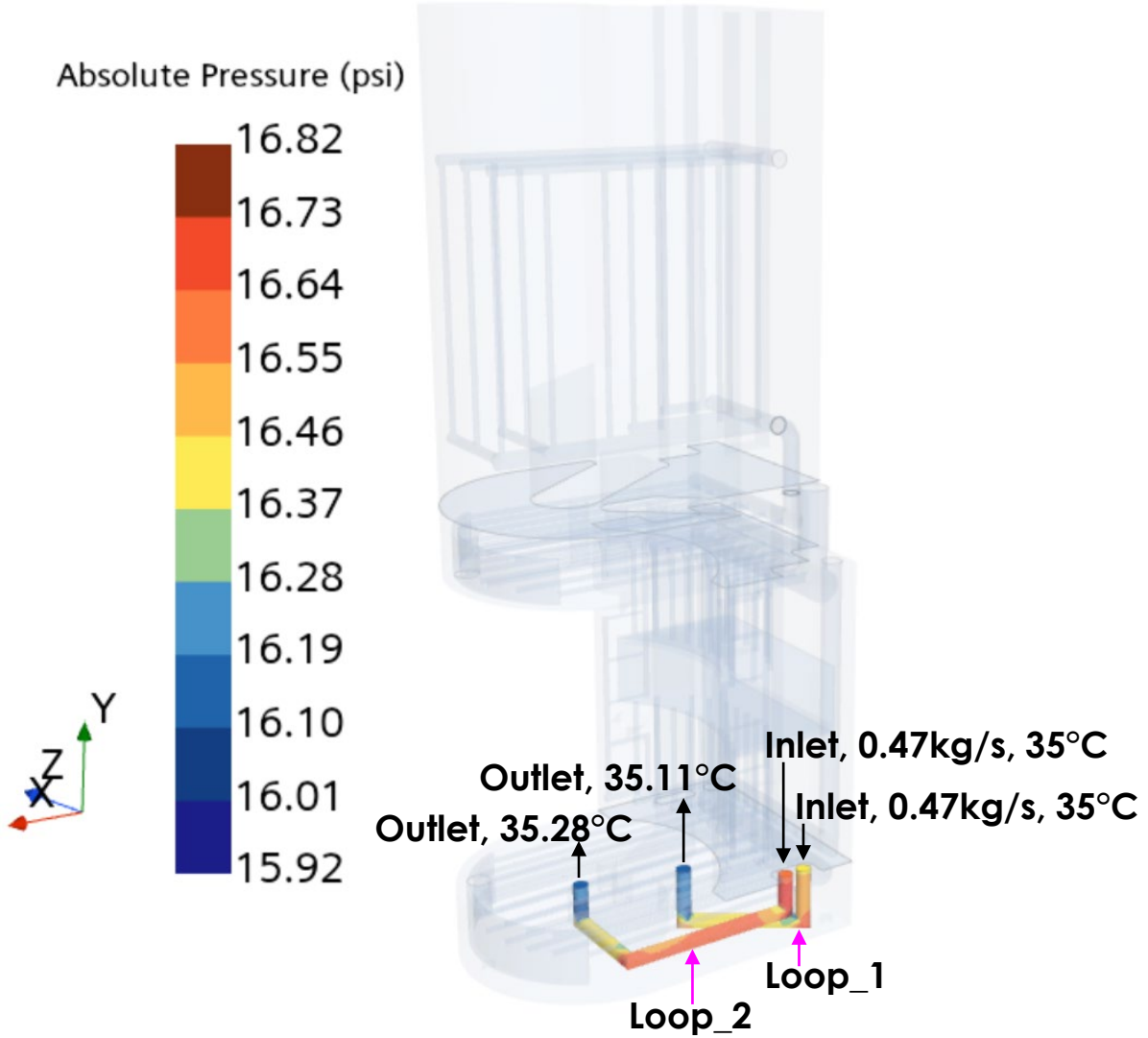
MRA Full Backbone, Water Pressure

Requirement: less than 0.5 psi for 7.5 GPM circuit

$$\Delta P_{inlet-outlet} = 0.255\ psi\ (Loop\_1\ ,7.5GPM)$$
$$\Delta P_{inlet-outlet} = 0.404\ psi\ (Loop\_2\ ,7.5GPM)$$

Loops_1-4





MRA Full Backbone, Water Pressure

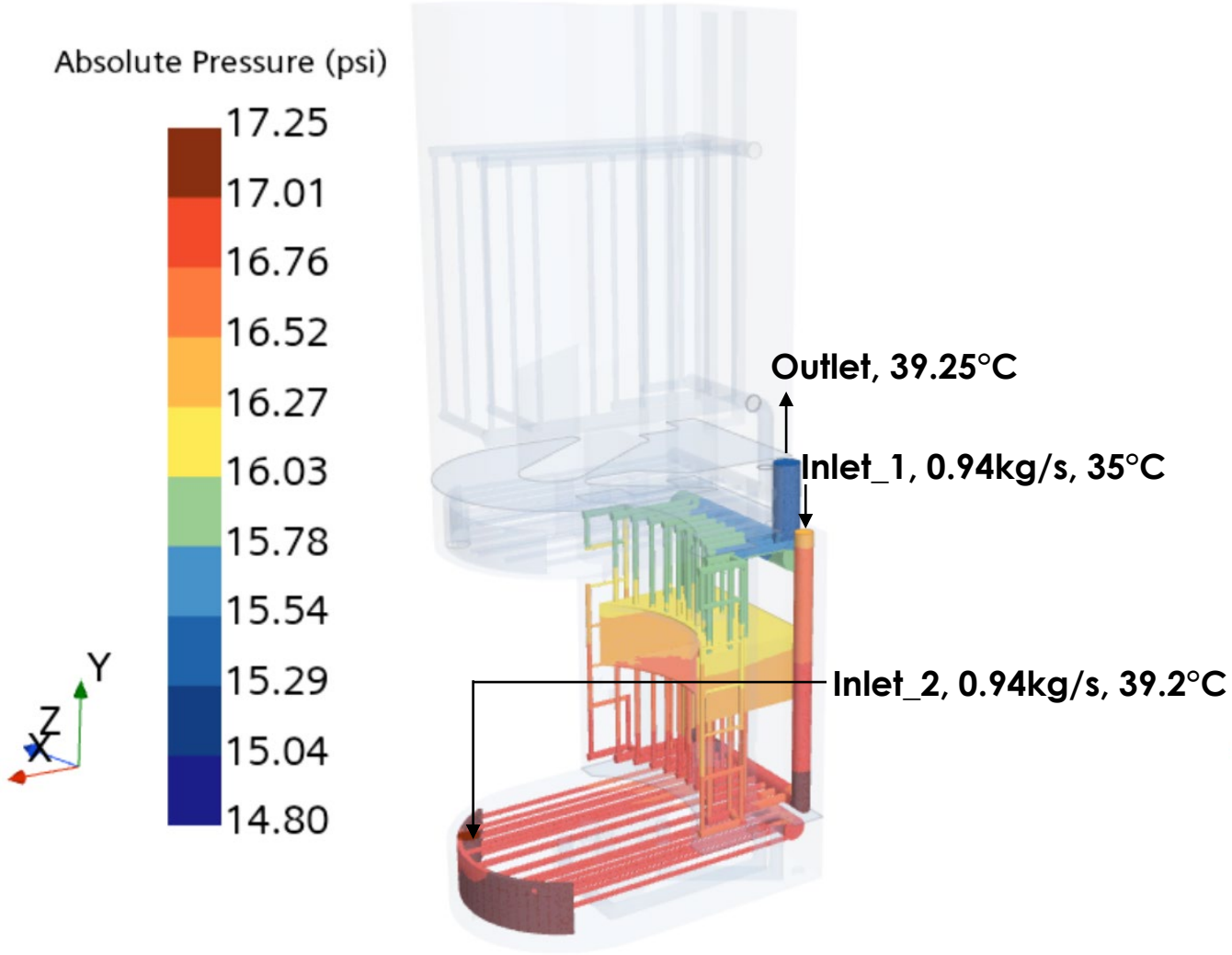
Requirement: less than 4 psi for 15 GPM circuit

$\Delta P_{inlet-outlet} = 1.64\ psi$ (Loop_3_1, 15 GPM)

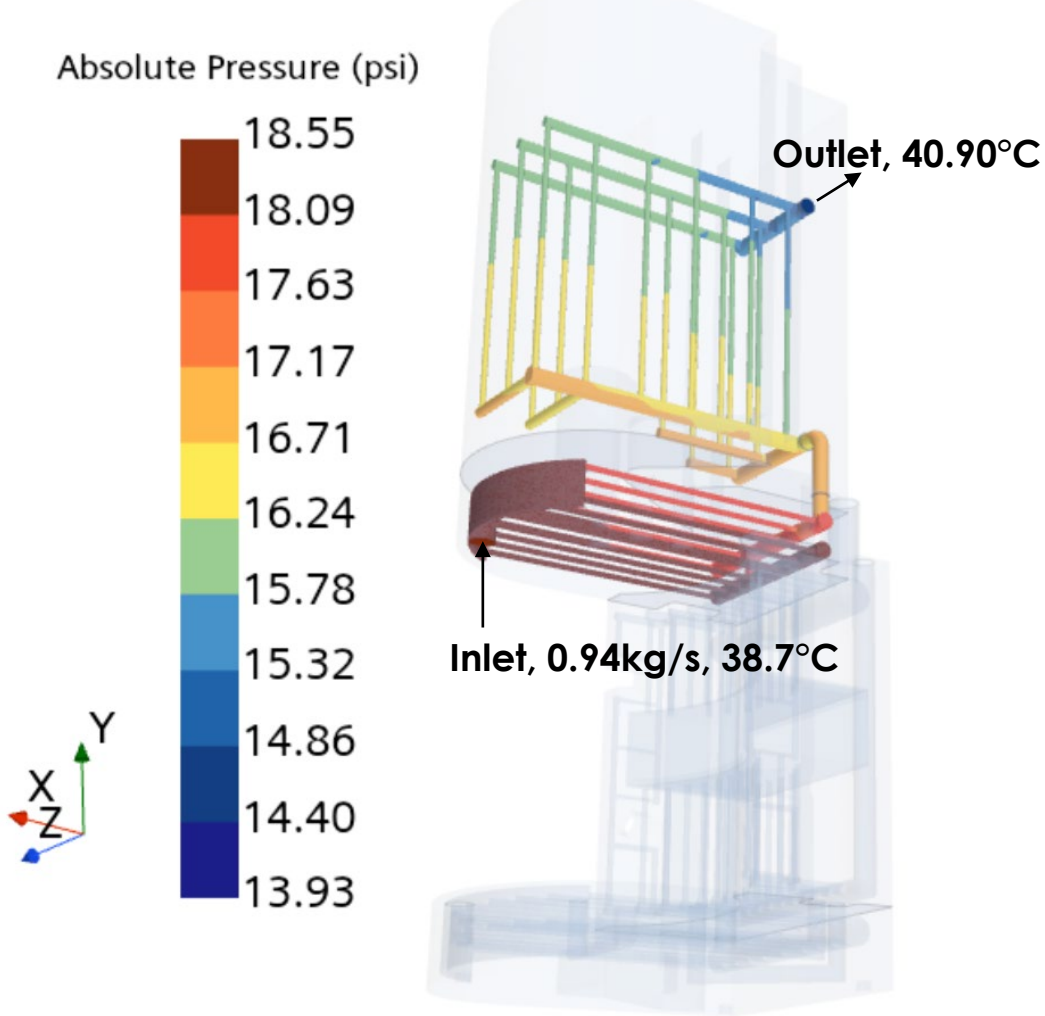
$\Delta P_{inlet-outlet} = 1.12\ psi$ (Loop_3_2, 15 GPM)

$\Delta P_{inlet-outlet} = 3.17\ psi$ (Loop_4, 15 GPM)

Loop_3



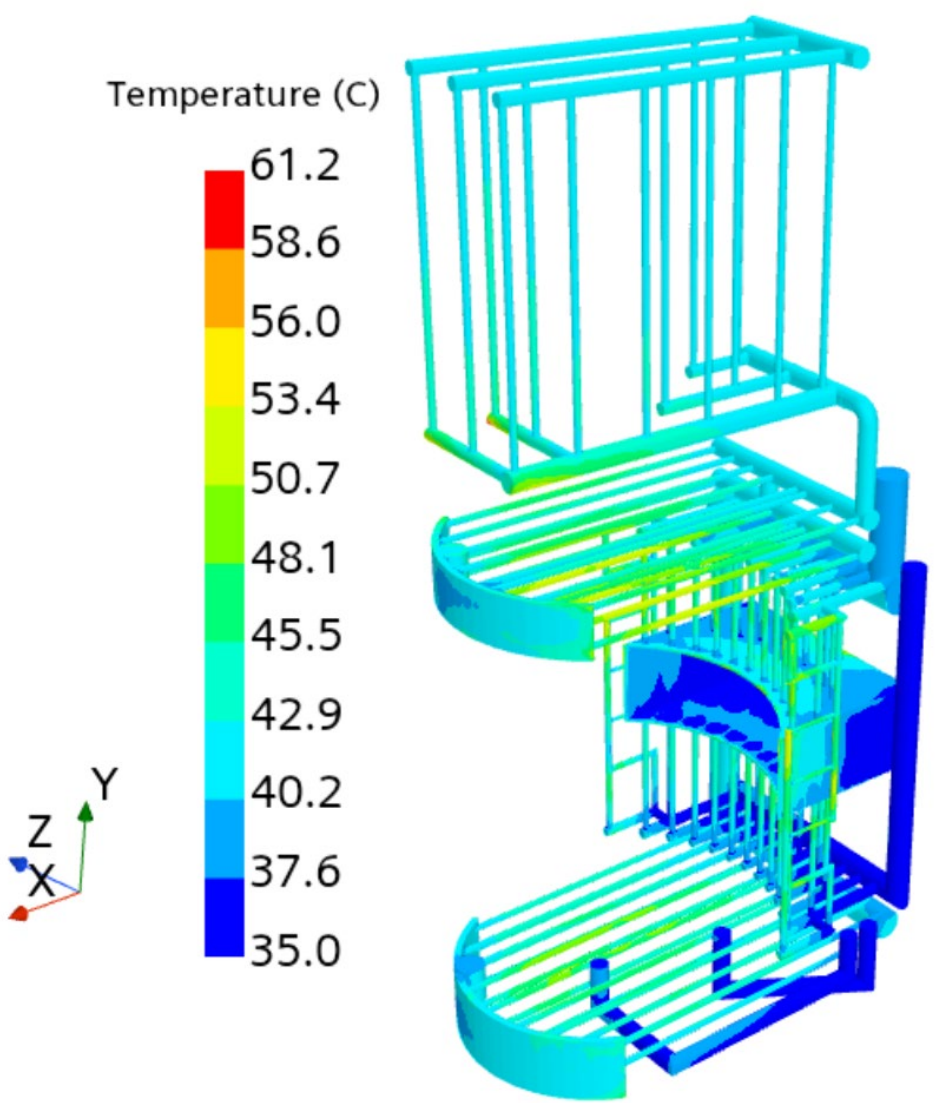
Loop_4

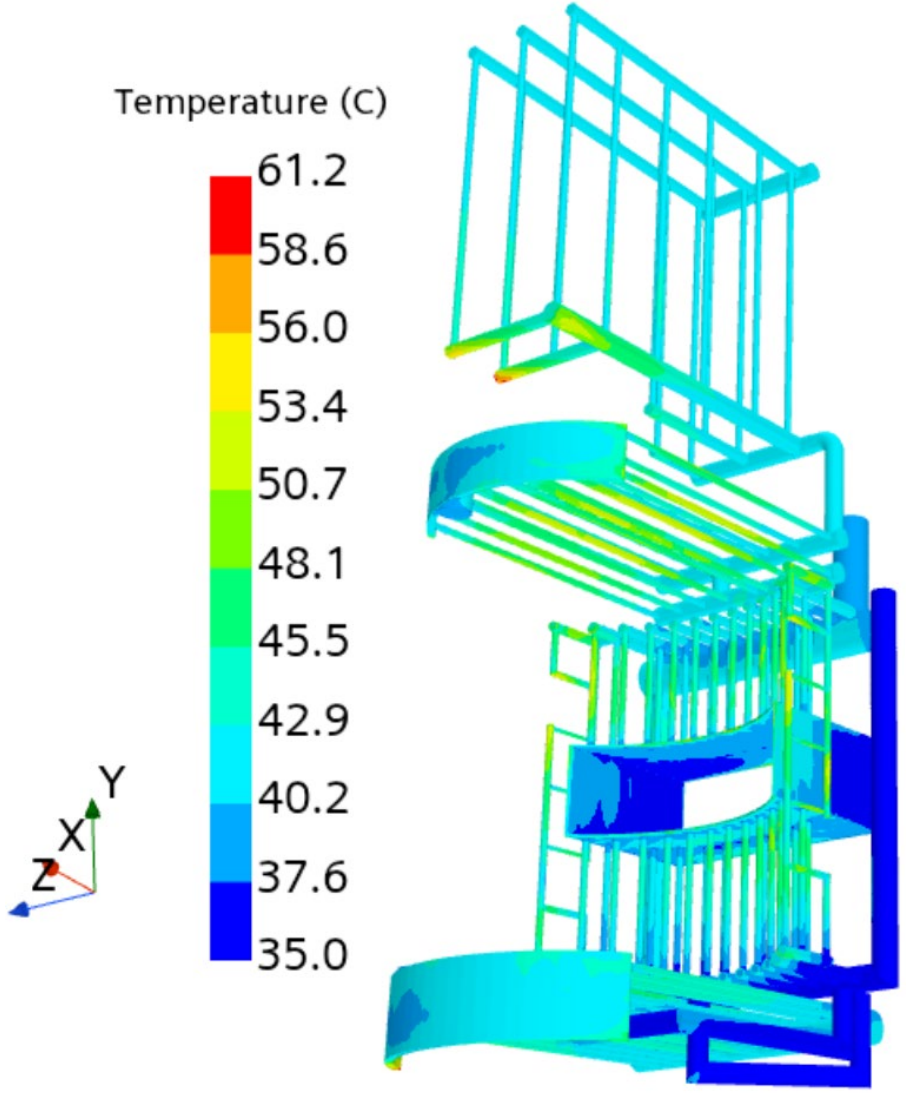


MRA Full Backbone, Water Temperature

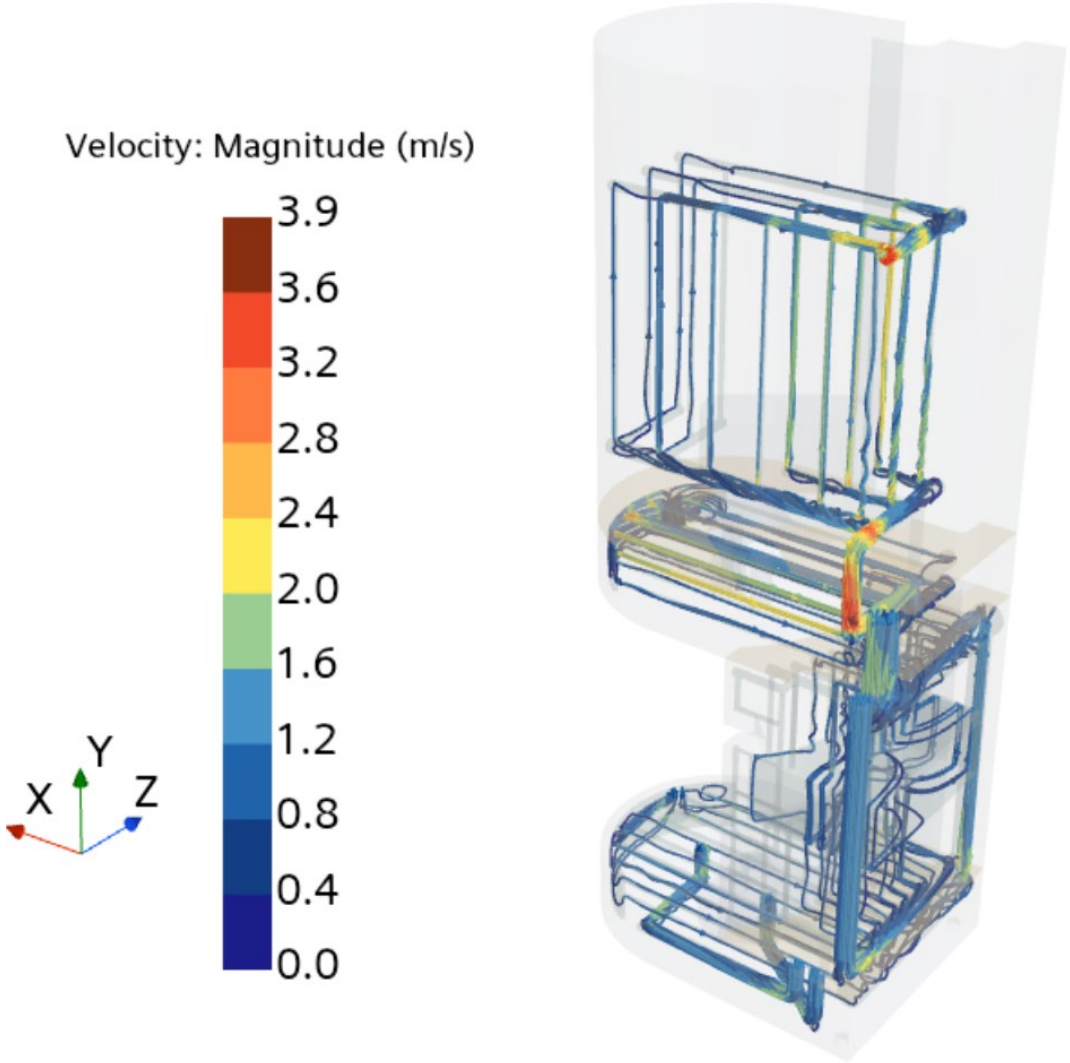
Requirement: Water temperature : < 100 °C

Peak : 61.2°C

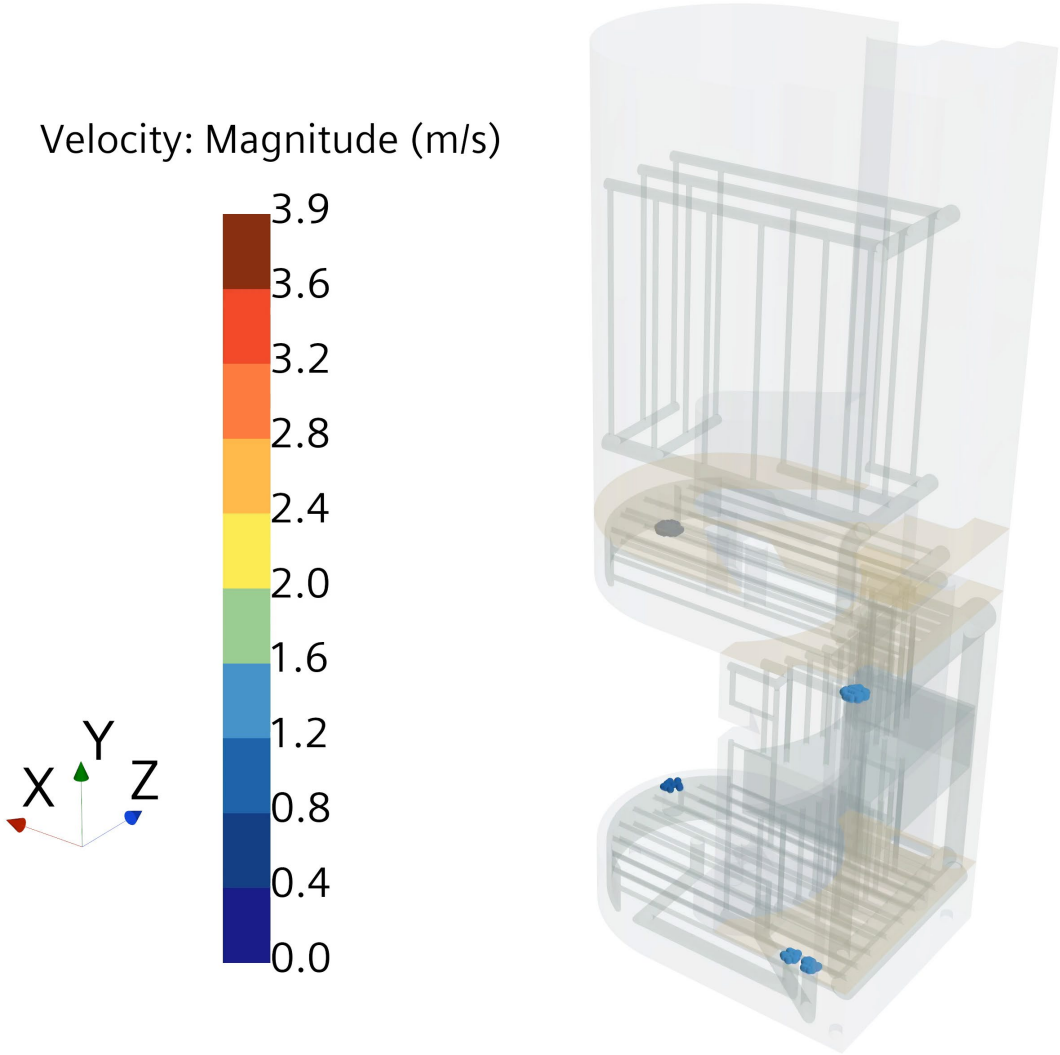




MRA Full Backbone, Water Streamlines



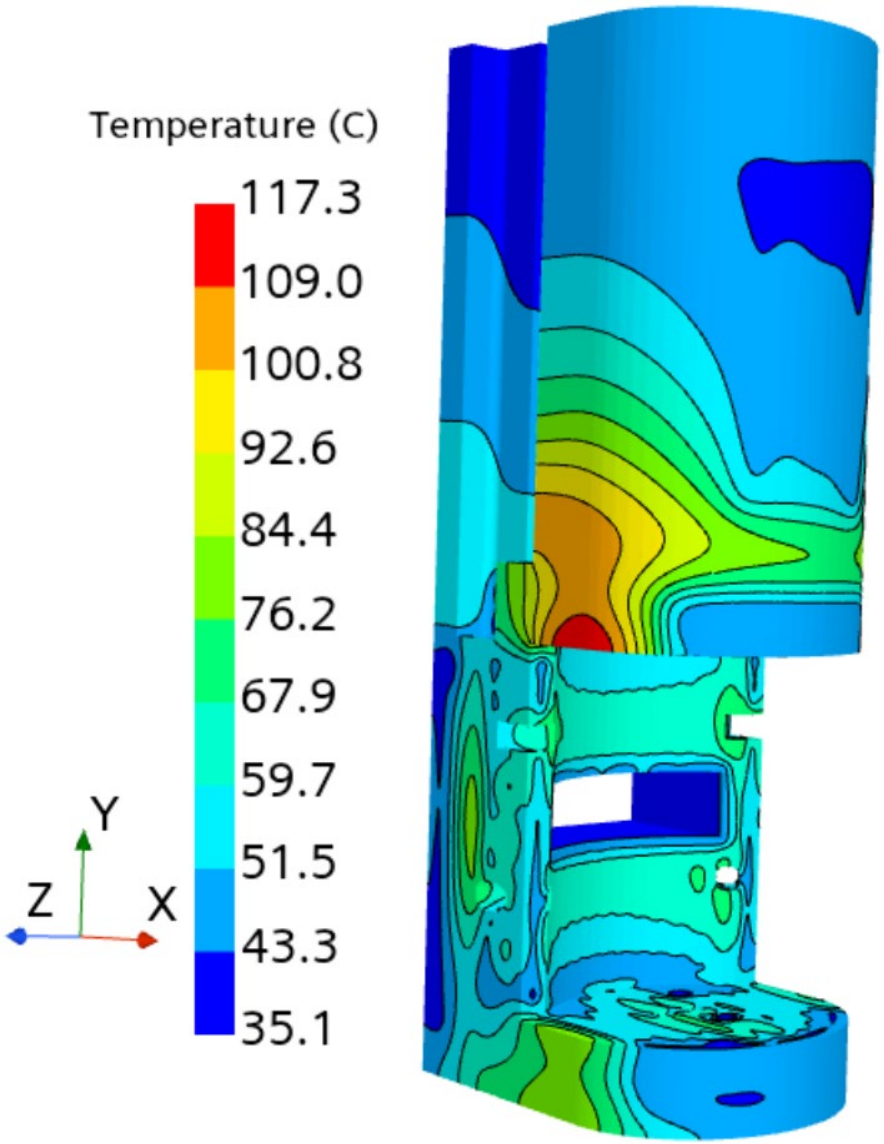
Streamline Animation

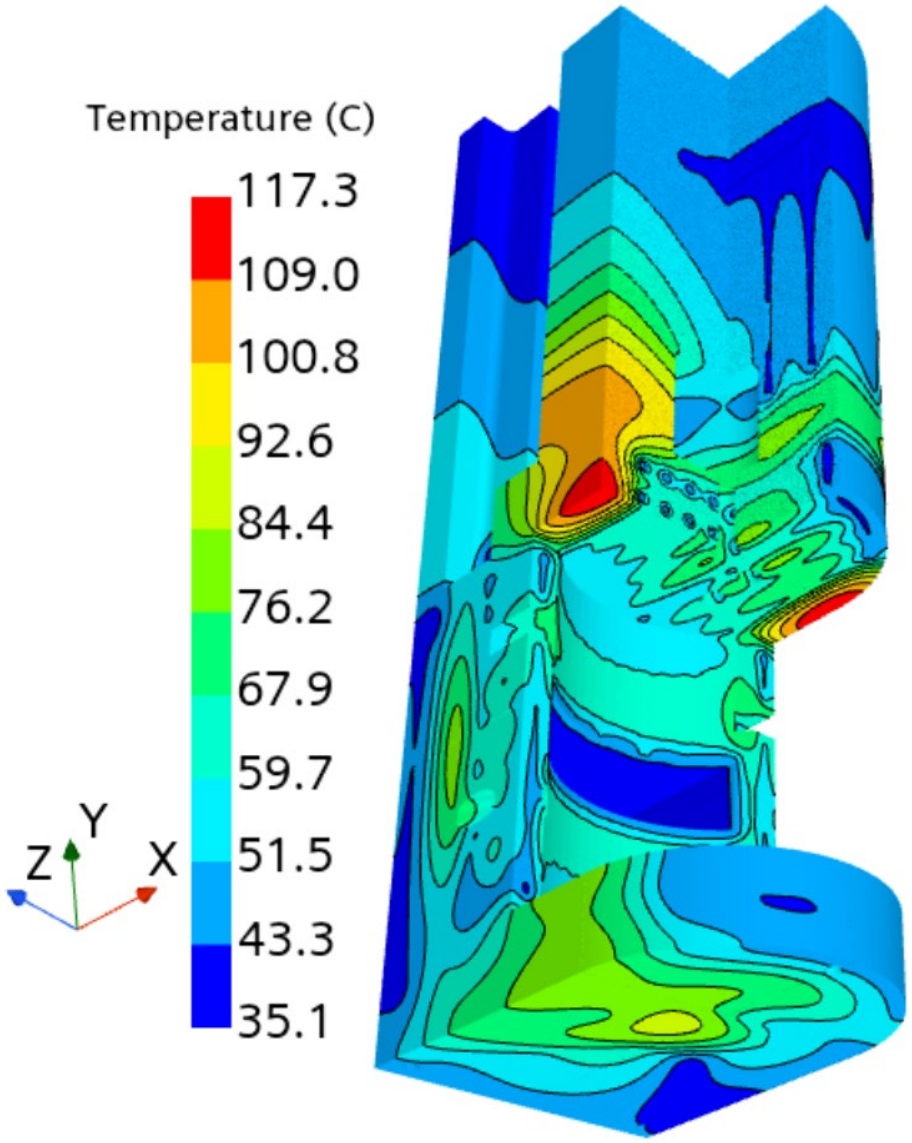


MRA Full Backbone, SS Temperature

Peak : 117.3°C

Requirement:
SS temperature: < 200 °C

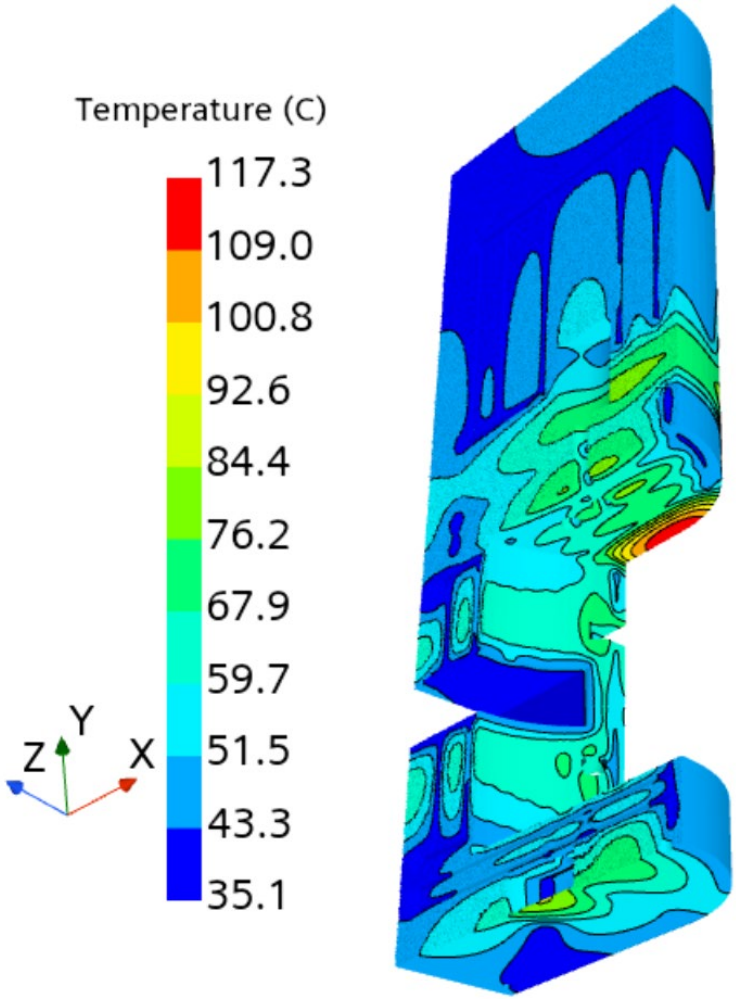


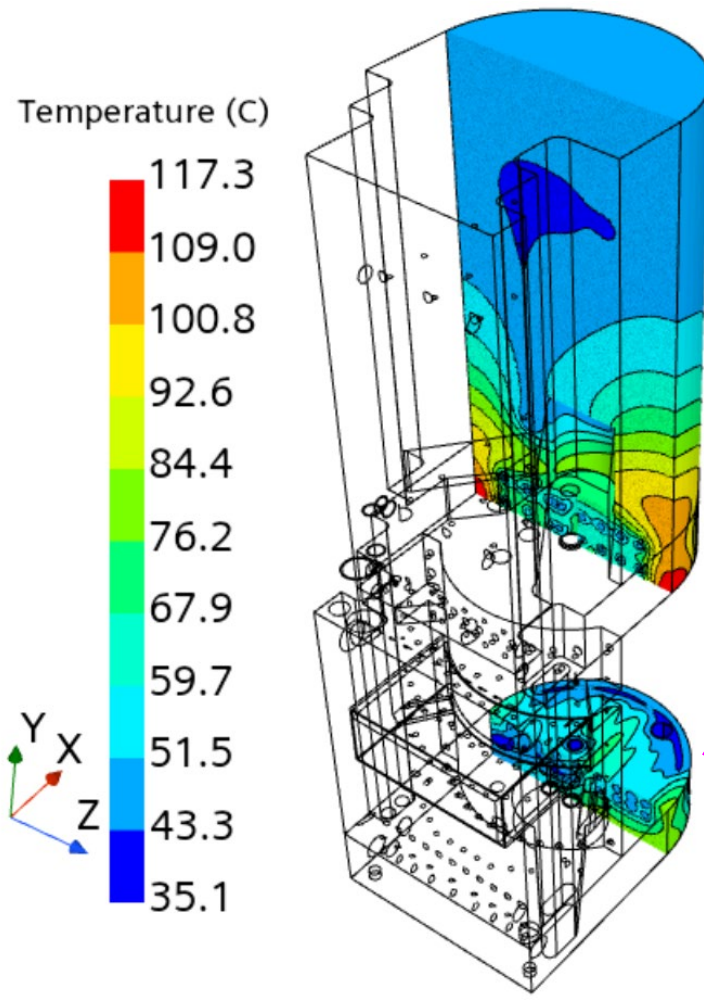


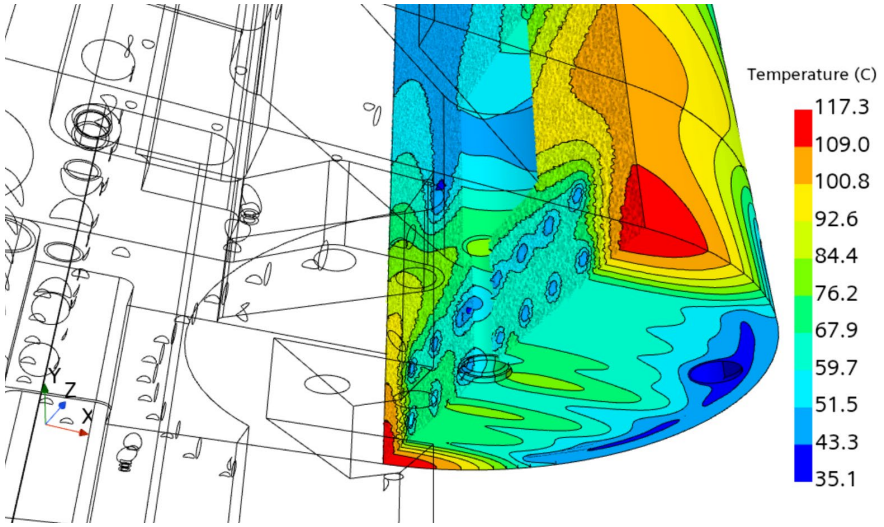
MRA Full Backbone, SS Temperature

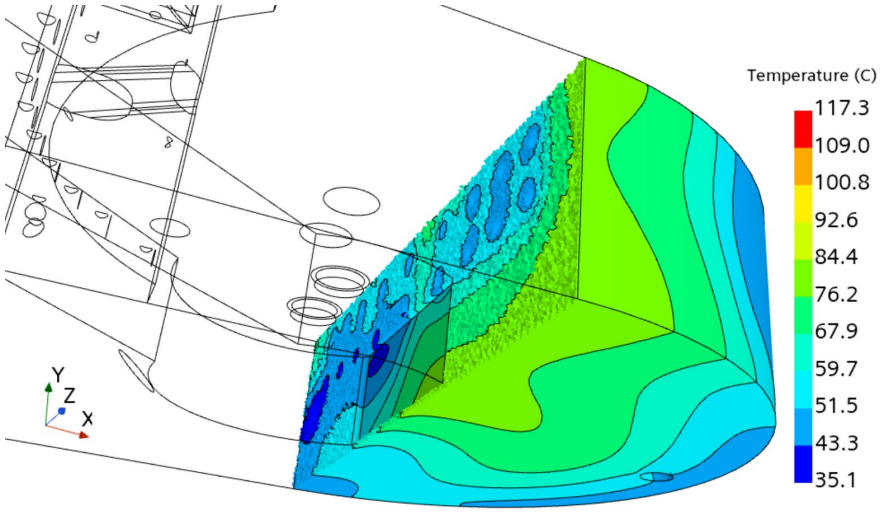
Peak : 117.3°C

Requirement:
SS temperature: 200 °C









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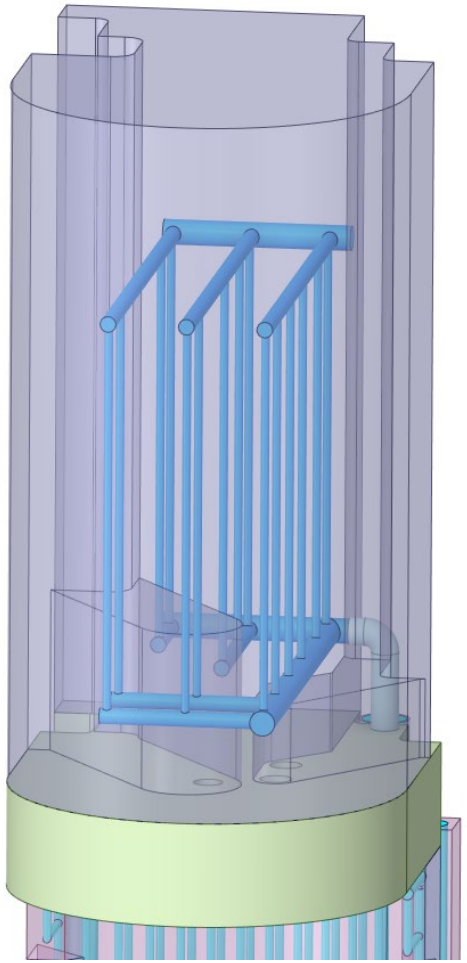
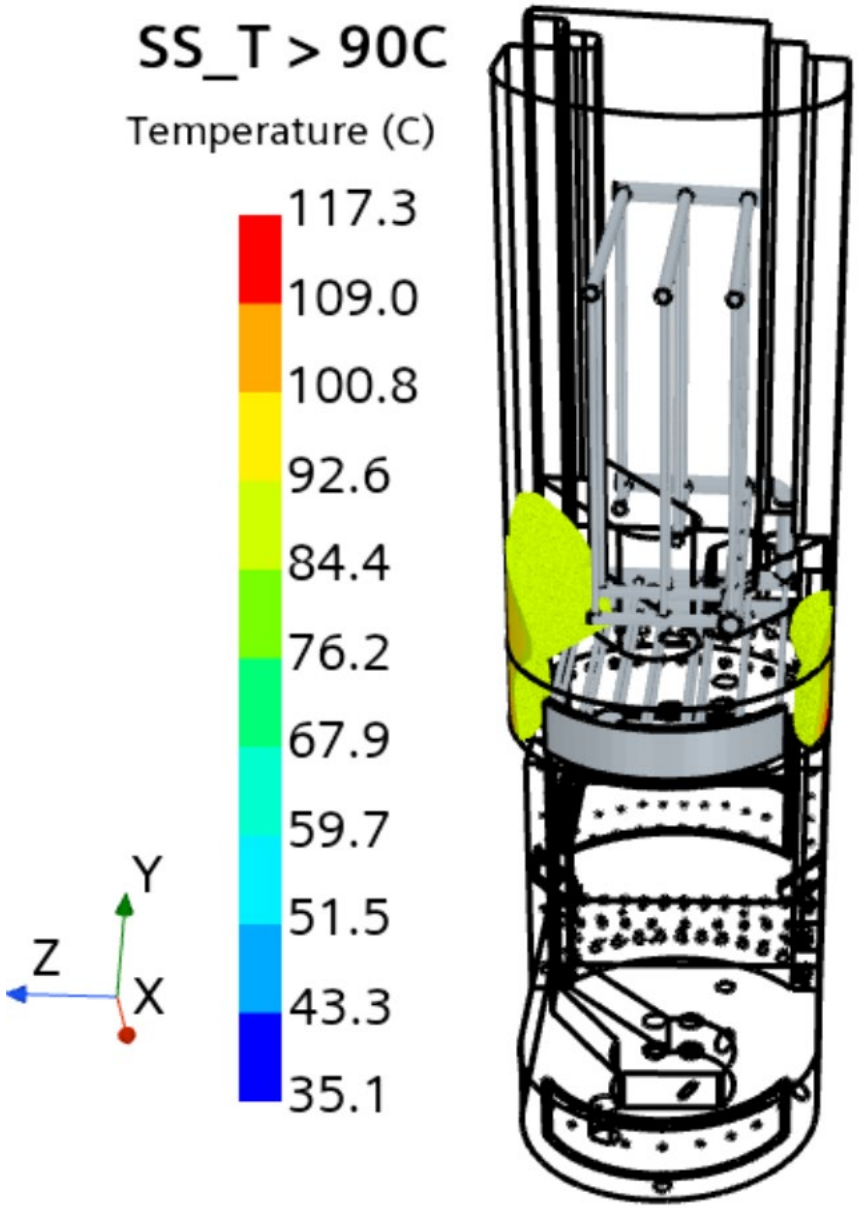
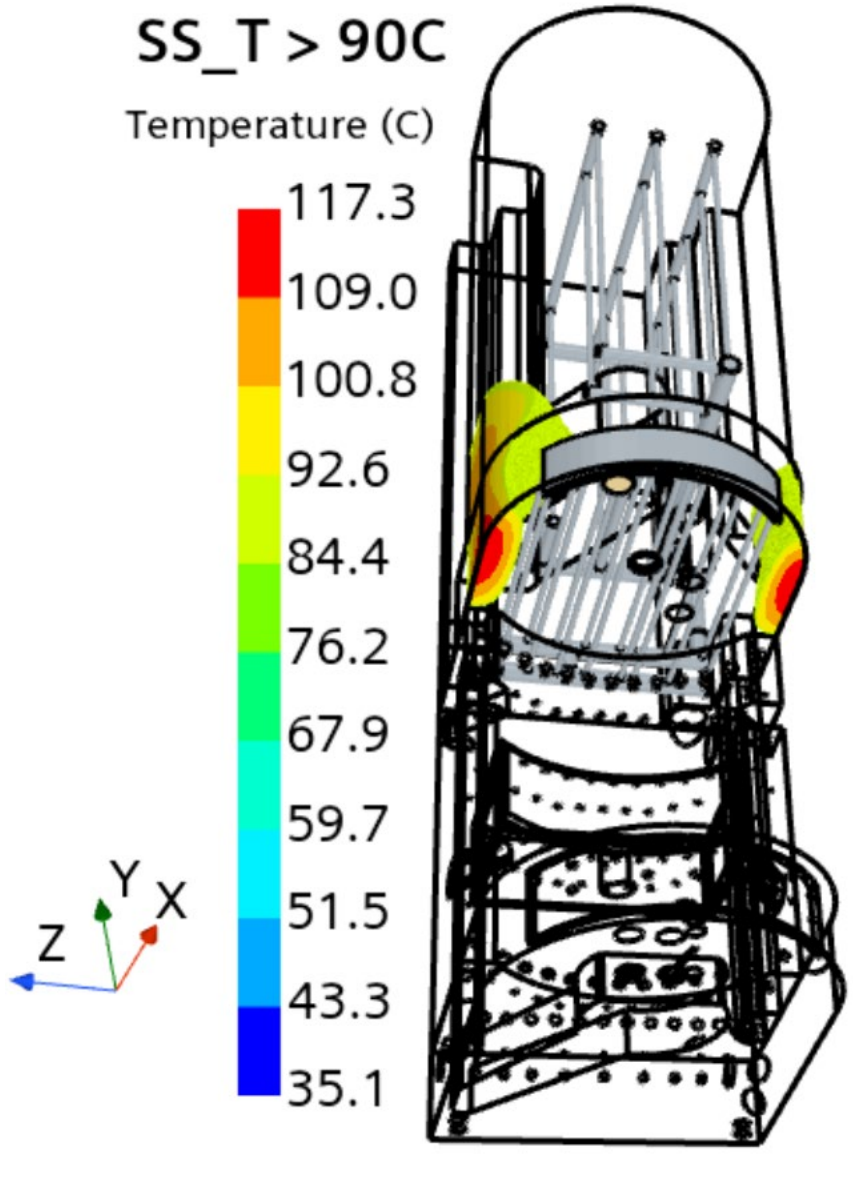
MRA Full Backbone, SS Temperature

Requirement:
SS temperature: 200 °C

Peak : 117.3°C



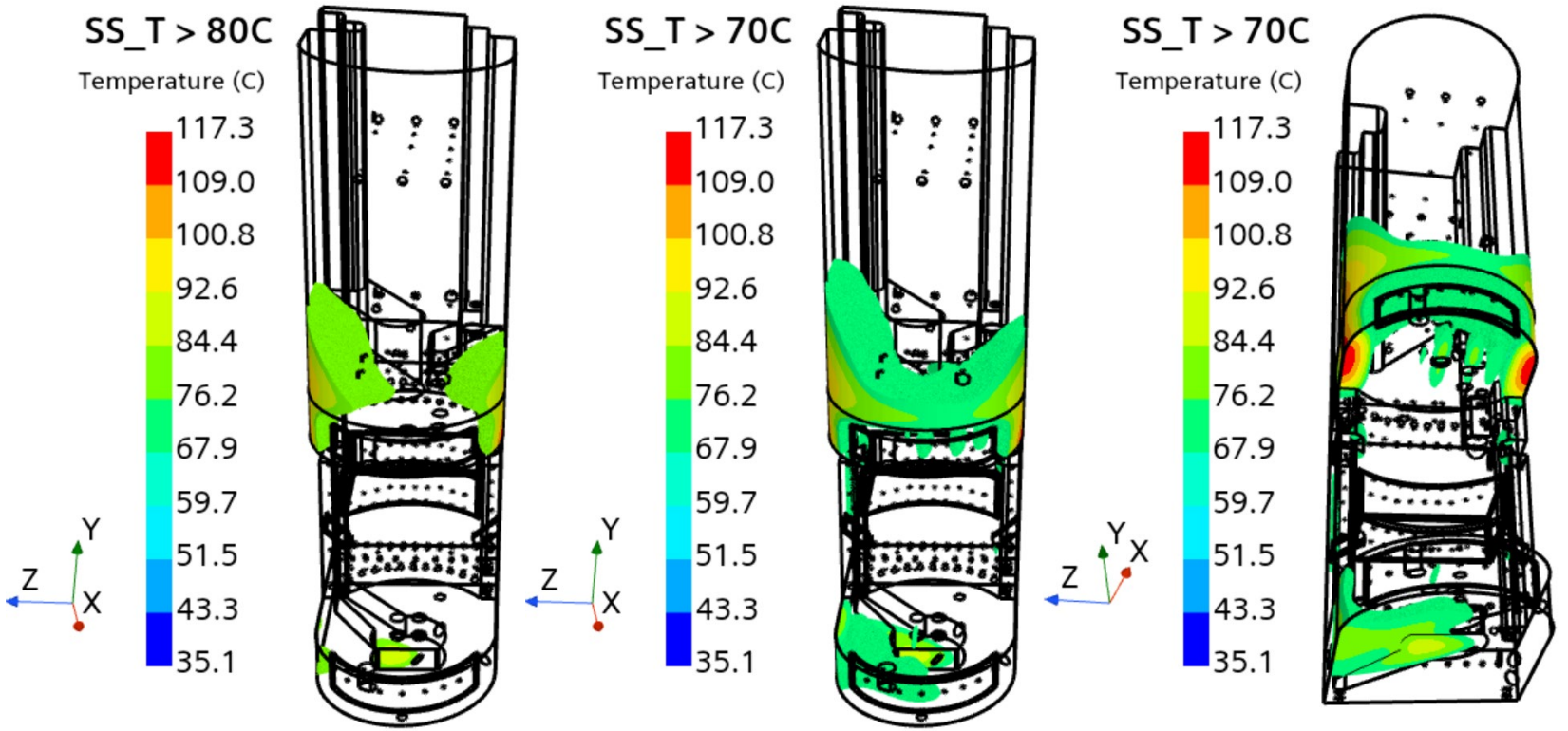


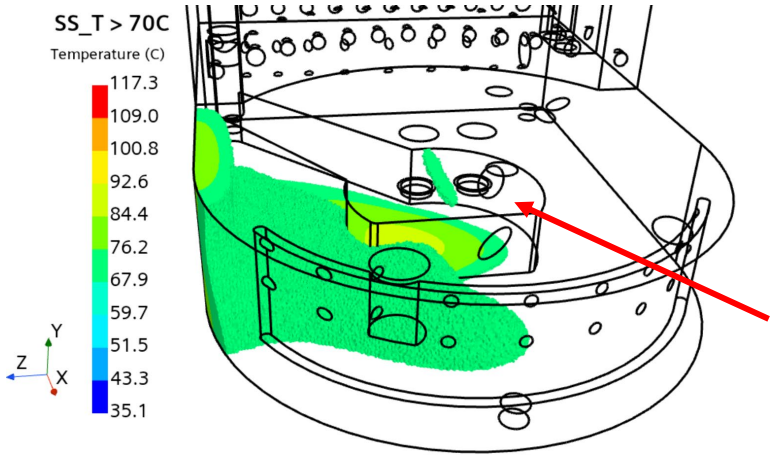


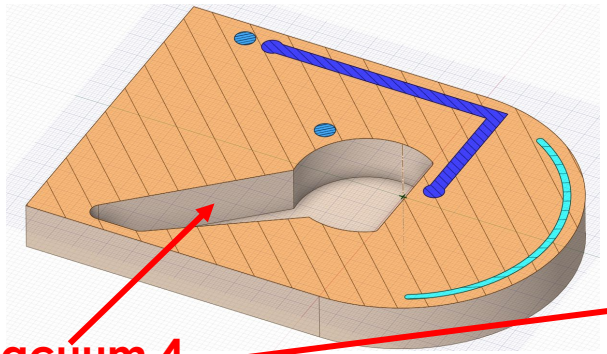
MRA Full Backbone, SS Temperature

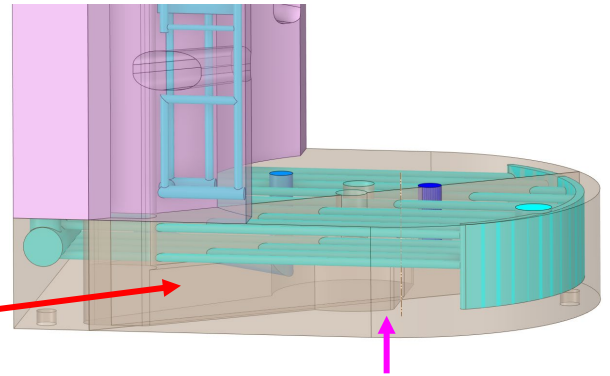
Requirement:
SS temperature: 200 °C

Peak : 117.3°C









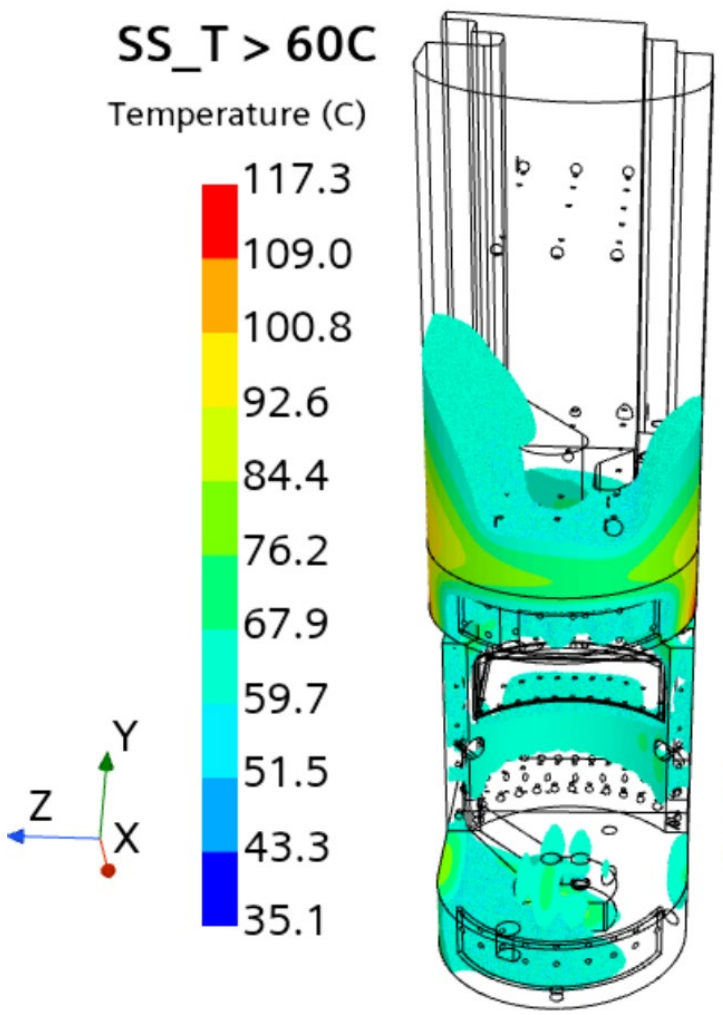
Vacuum 4

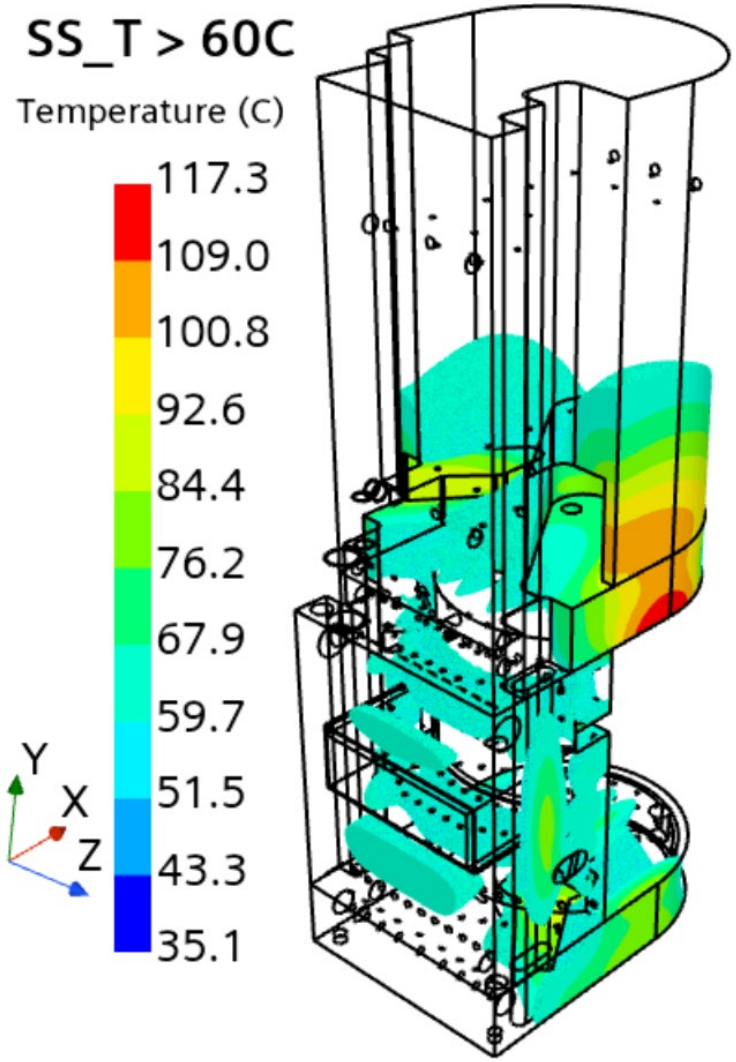
Higher T expected

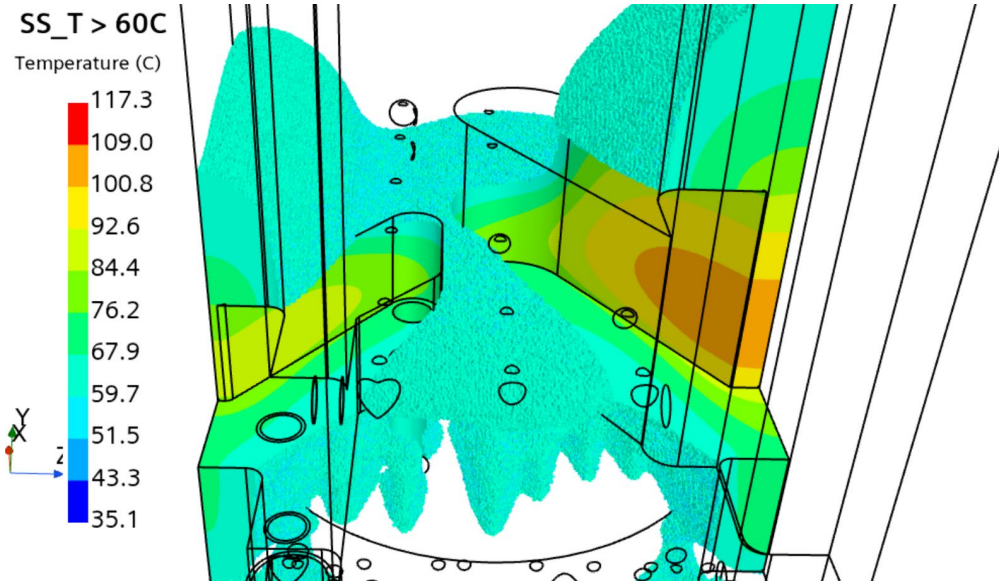
MRA Full Backbone, SS Temperature

Peak : 117.3°C

Requirement:
SS temperature: 200 °C



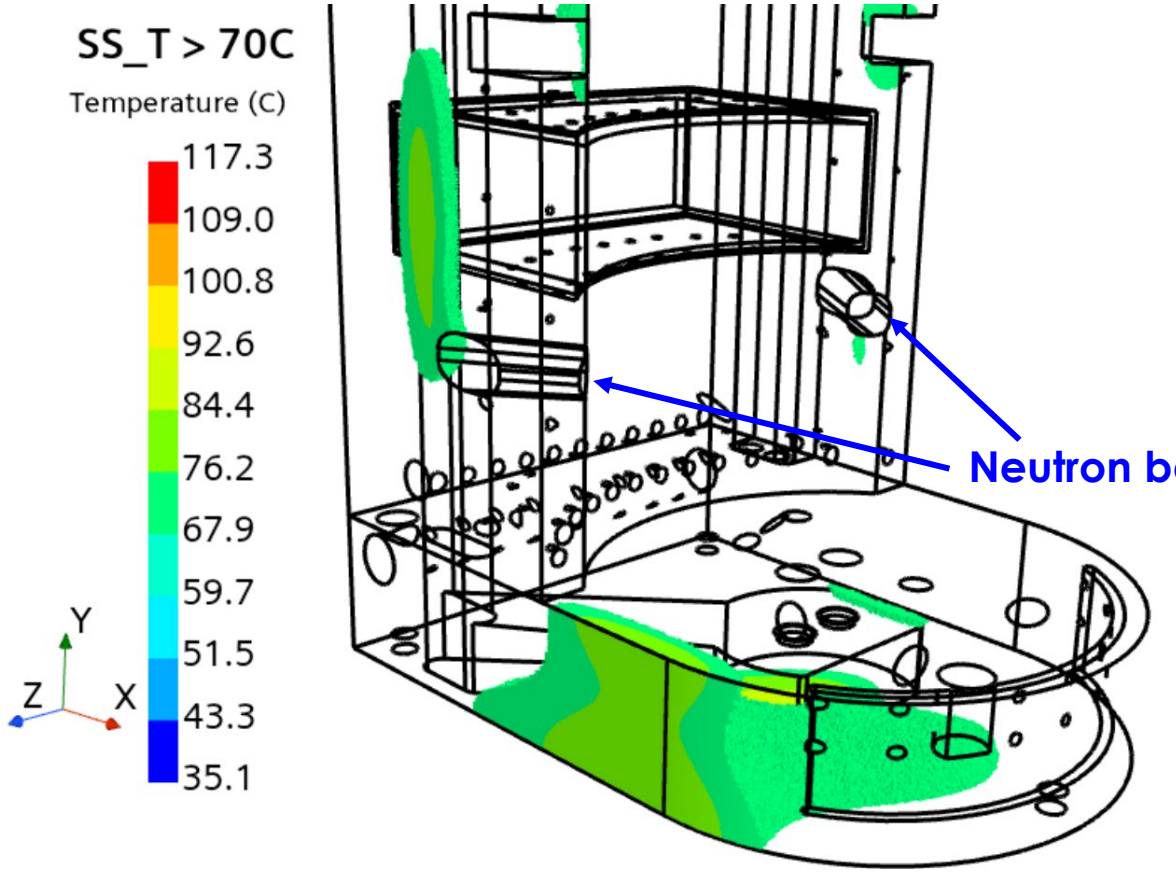




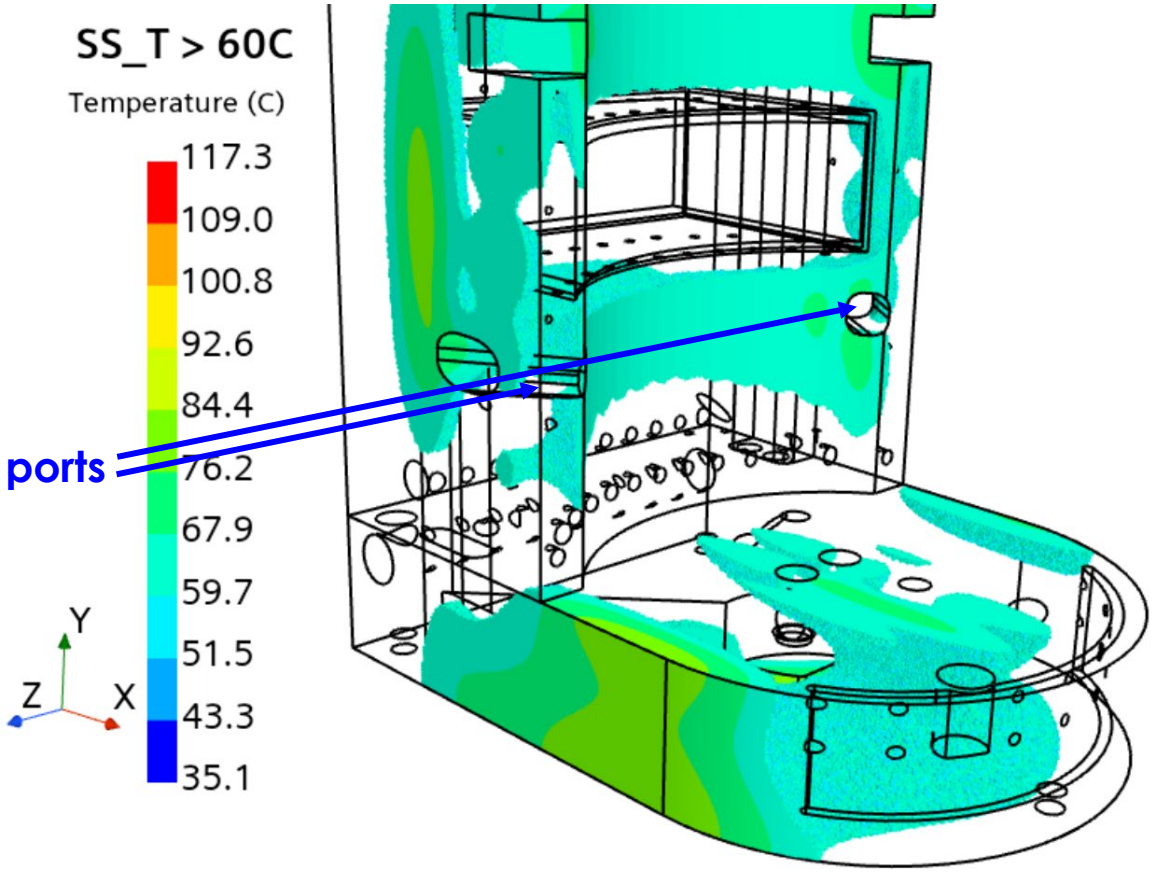
MRA Full Backbone, SS Temperature

Peak : 117.3°C

Requirement:
SS temperature: 200 °C



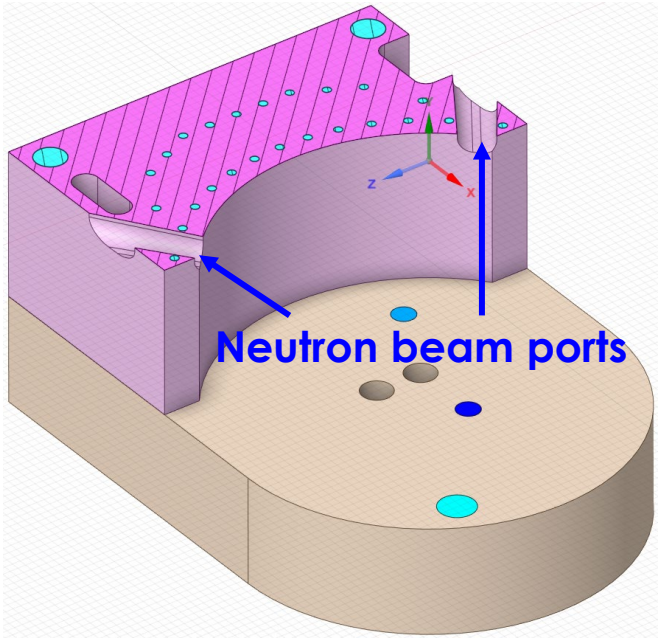
Neutron beam ports

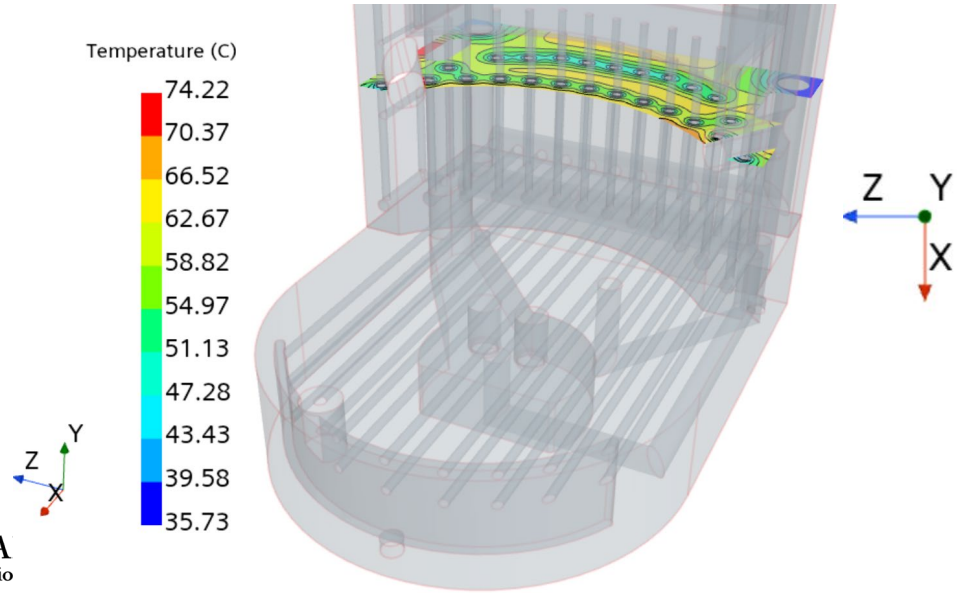


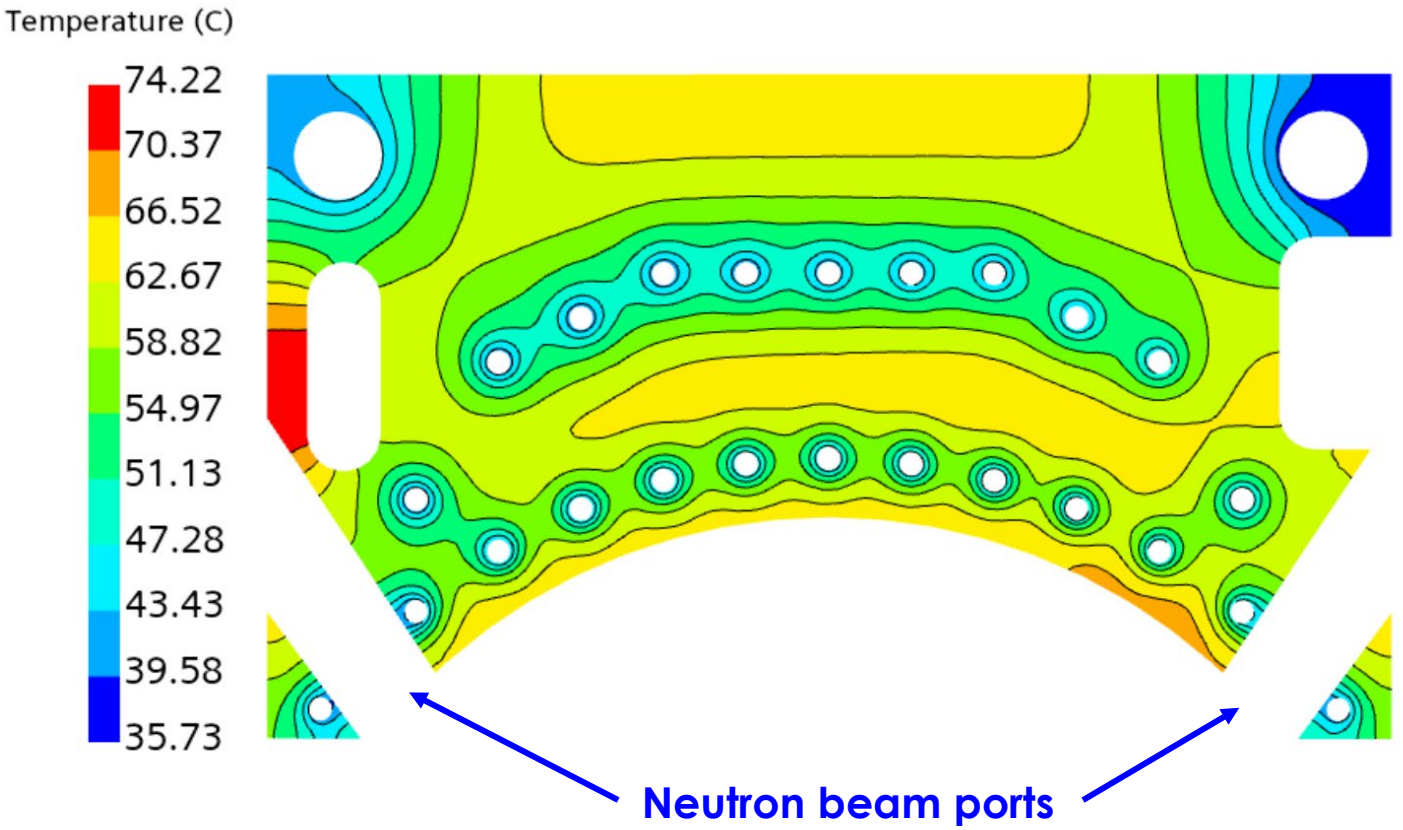
MRA Full Backbone, SS Temperature

Requirement:
SS temperature: 200 °C

Horizontal cross sections through the neutron beam ports

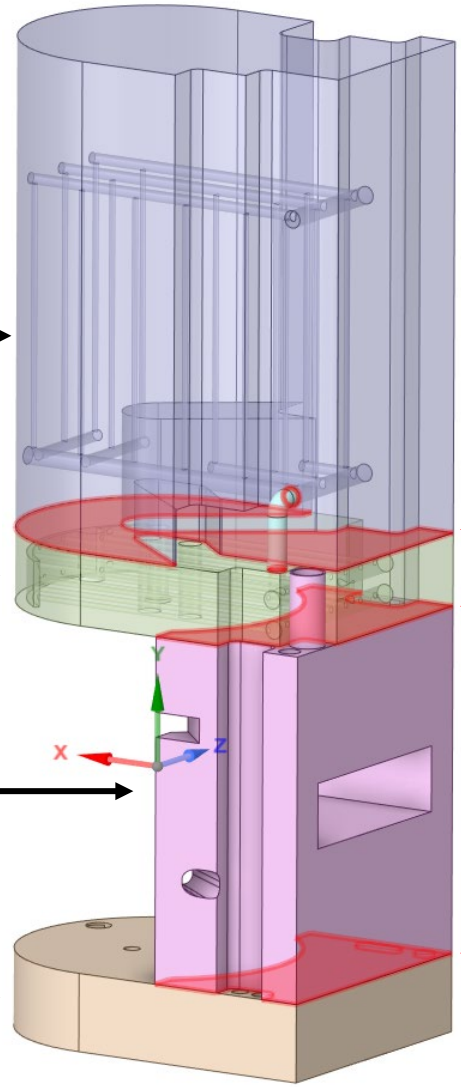






Perfect Contact (zero thermal contact resistance) was assumed before this slide.

Thermal Contact Resistance of MRA Backbone

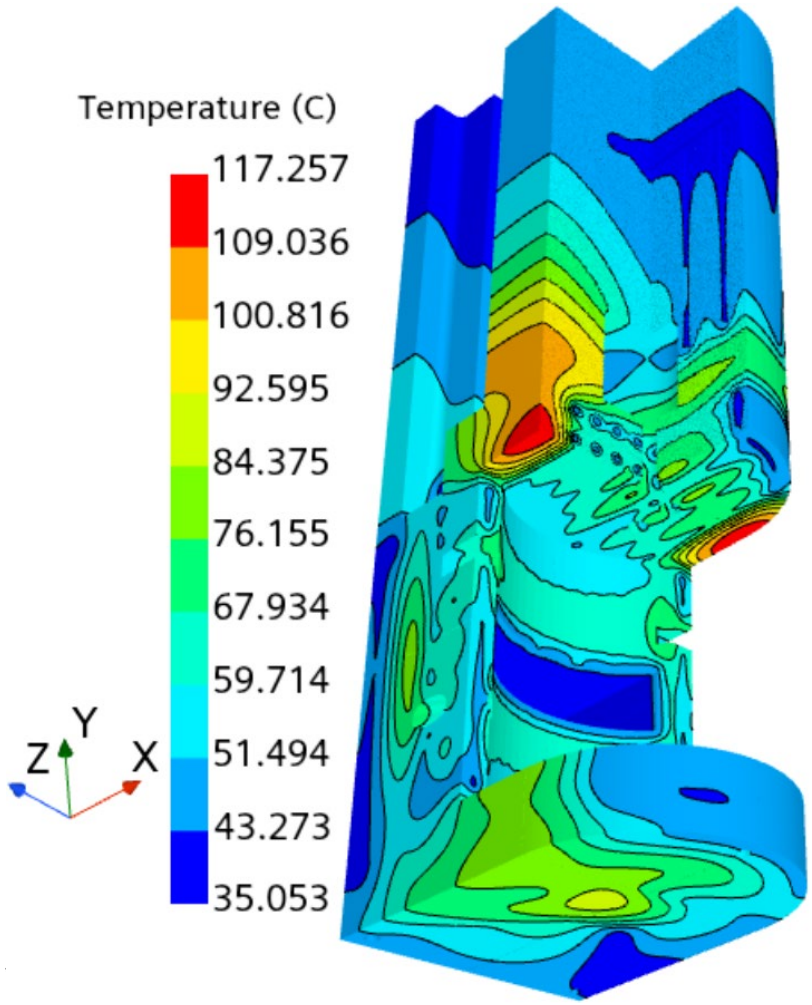


Contact	Gap Size, L (mm)	Helium, k (W/m-K)	R (m^2 -K/W)
Lower/Middle Blocks	0.1	0.154933	6.4544E-04
Middel/Upper Blocks	0.1	0.154933	6.4544E-04
Upper/Shielding Blocks	0.1	0.154933	6.4544E-04

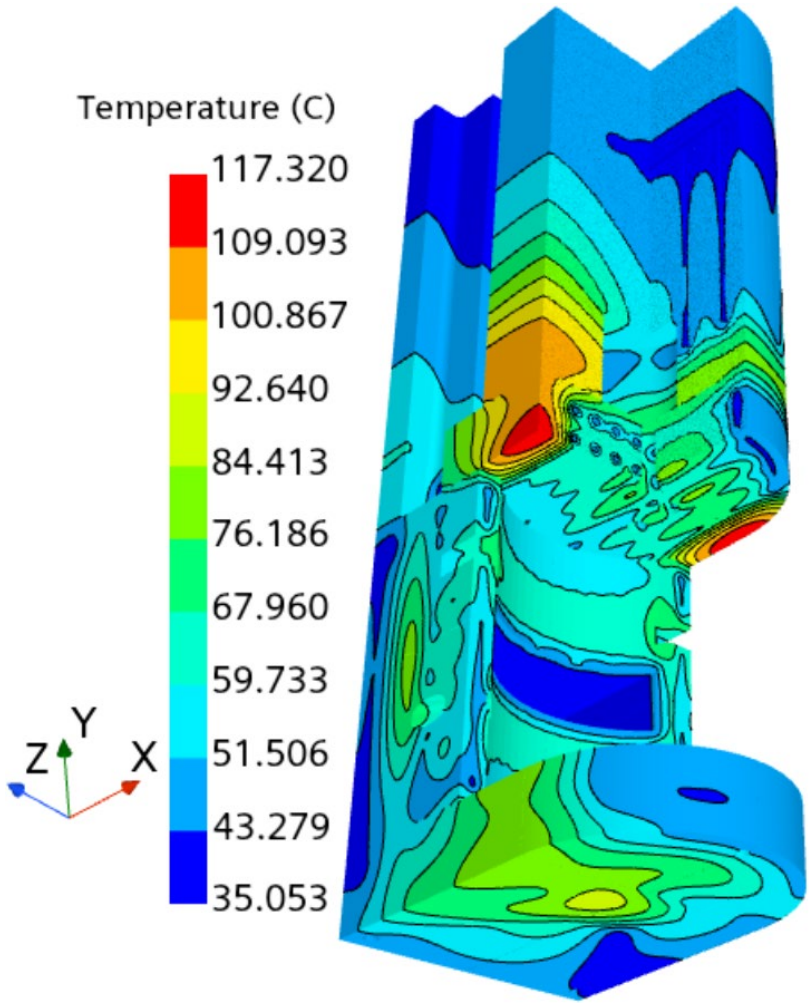
Contact	Gap Size, L (mm)	Helium, k (W/m-K)	R (m^2 -K/W)
Lower/Middle Blocks	1.0	0.154933	6.4544E-03
Middel/Upper Blocks	1.0	0.154933	6.4544E-03
Upper/Shielding Blocks	1.0	0.154933	6.4544E-03

MRA Full Backbone, SS Temperature Comparison

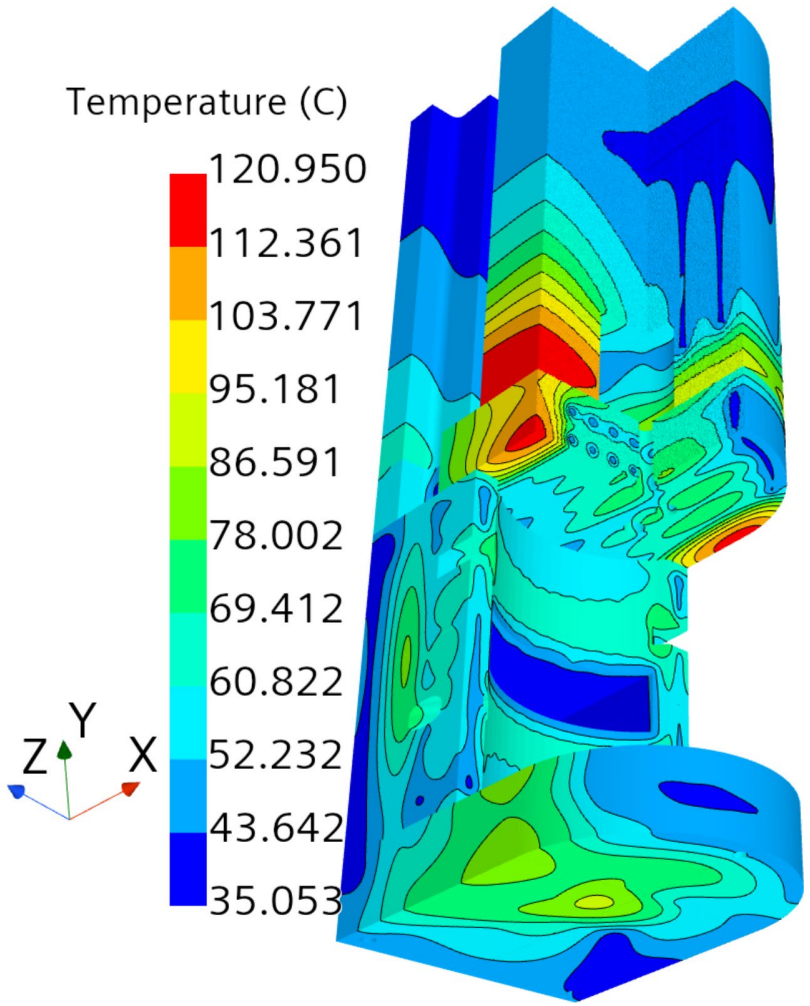
Perfect Contact



0.1 mm Helium Gap



1 mm Helium Gap



Comparison between Requirements and CFD Results

MRA Backbone

	Requirement	CFD Result
Maximum Water Temperature (°C)	< 100	61.2
Maximum Stainless-steel Temperature (°C)	< 200	117.3
Pressure Drop (psi) for Loop 1	< 0.5	0.255
Pressure Drop (psi) for Loop 2	< 0.5	0.404
Pressure Drop (psi) for Loop 3_1	< 4.0	1.64
Pressure Drop (psi) for Loop 3_2	< 4.0	1.12
Pressure Drop (psi) for Loop 4	< 4.0	3.17

Summary

- All requirements are met.
  - Water does not boil.
  - Stainless-steel temperature is less than 200°C
  - Pressure drops for loops 1 & 2 are less than 0.5 psi
  - Pressure drops for loops 3 & 4 are less than 4.0 psi.