OAK RIDGE National Laboratory

Preliminary STS Lower Reflector Thermal Hydraulic Analysis

Min-Tsung Kao
Jim Janney

6/21/2023

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U.S. DEPARTMENT OF ENERGY

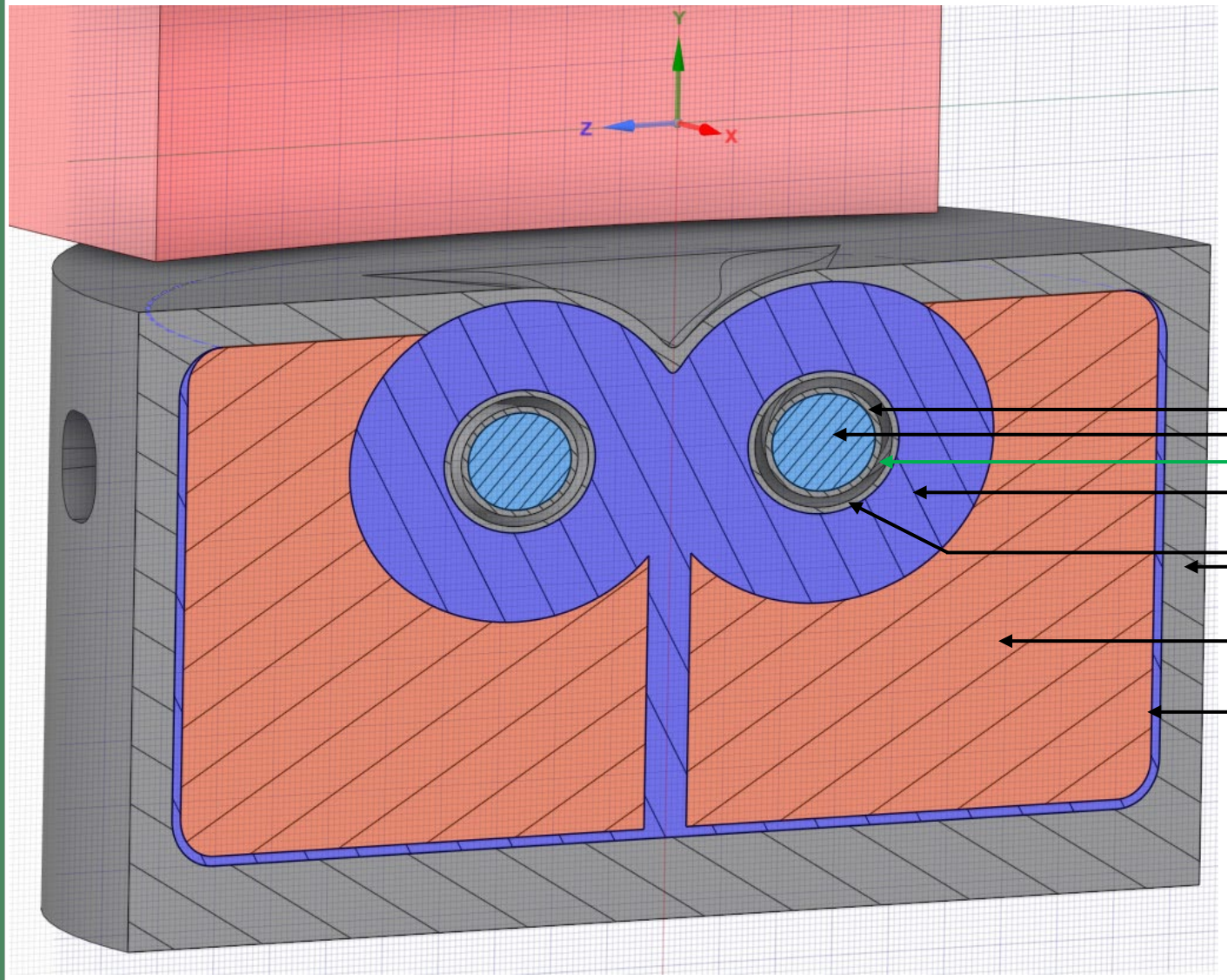
Background

- Previous MRA analysis (2020) done by Elvis (Elvis E Dominguez-Ontiveros) applied bounding curves for the heating. Bounding curve is a more conservative method, and the heating was overestimated by about a factor of 2.
- MRA geometry has been updated by Jim Janney and Ken Gawne since 2020.
- New heat sources were obtained from the MCNP energy deposition calculations done by Lukas Zavorka.
- The new MCNP calculations with Attila4MC unstructured mesh provides higher fidelity of heating results.
- Additional heating from 27Al(n,g)28Al reaction is also included in the new MCNP heating calculations.

Background

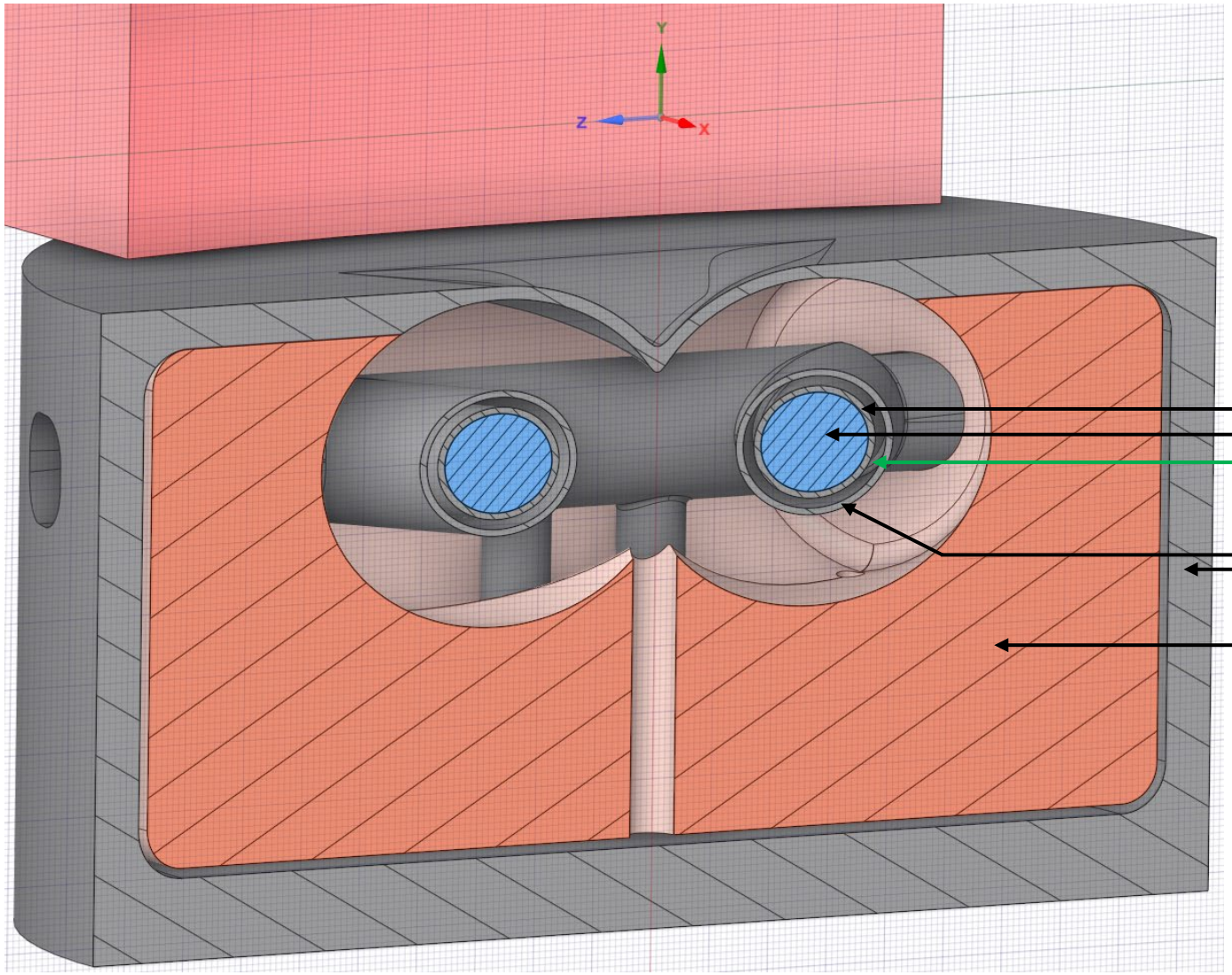
- This thermal-hydraulic analyses were performed to demonstrate that the current MRA design (without moderators, which were done in separate analyses and the results were also documented in a separate presentation) can meet the following requirements.
- Requirements
  - Pressure drop < 15 psi
    - Low pressure drop allows flexibility for CMS design
  - Maximum water temperature < 100°C
    - No water boiling
  - Maximum Aluminum temperature < 100°C
  - Maximum Beryllium temperature < 100°C

Geometry of Lower MRA



Lower Al for moderator
Lower moderator (para-H2)
Vacuum
Lower Premoderator (H2O)
Lower Al for Premoderator, reflector and Be
Lower Be
Lower Reflector (H2O)

Geometry of Lower MRA



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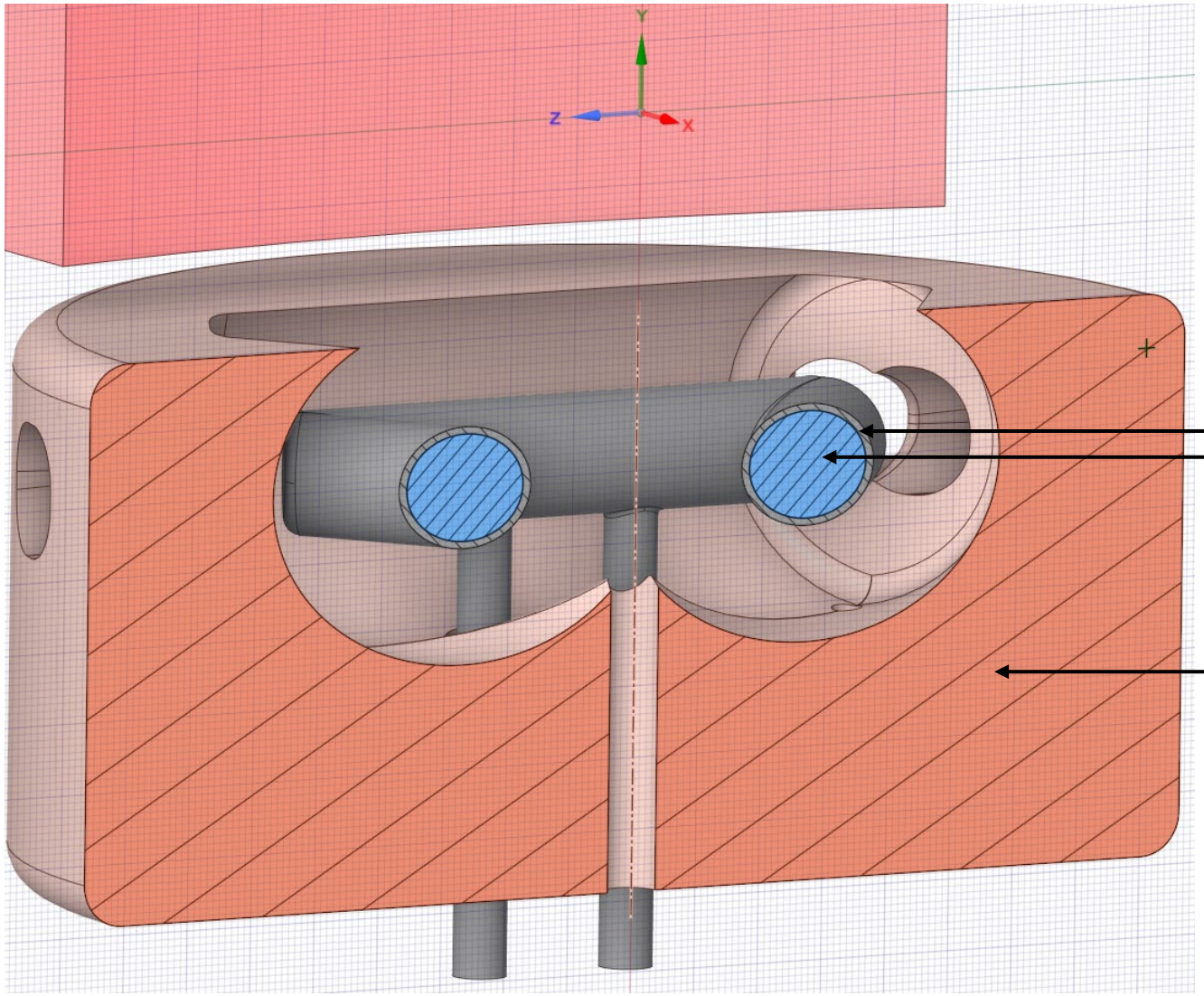
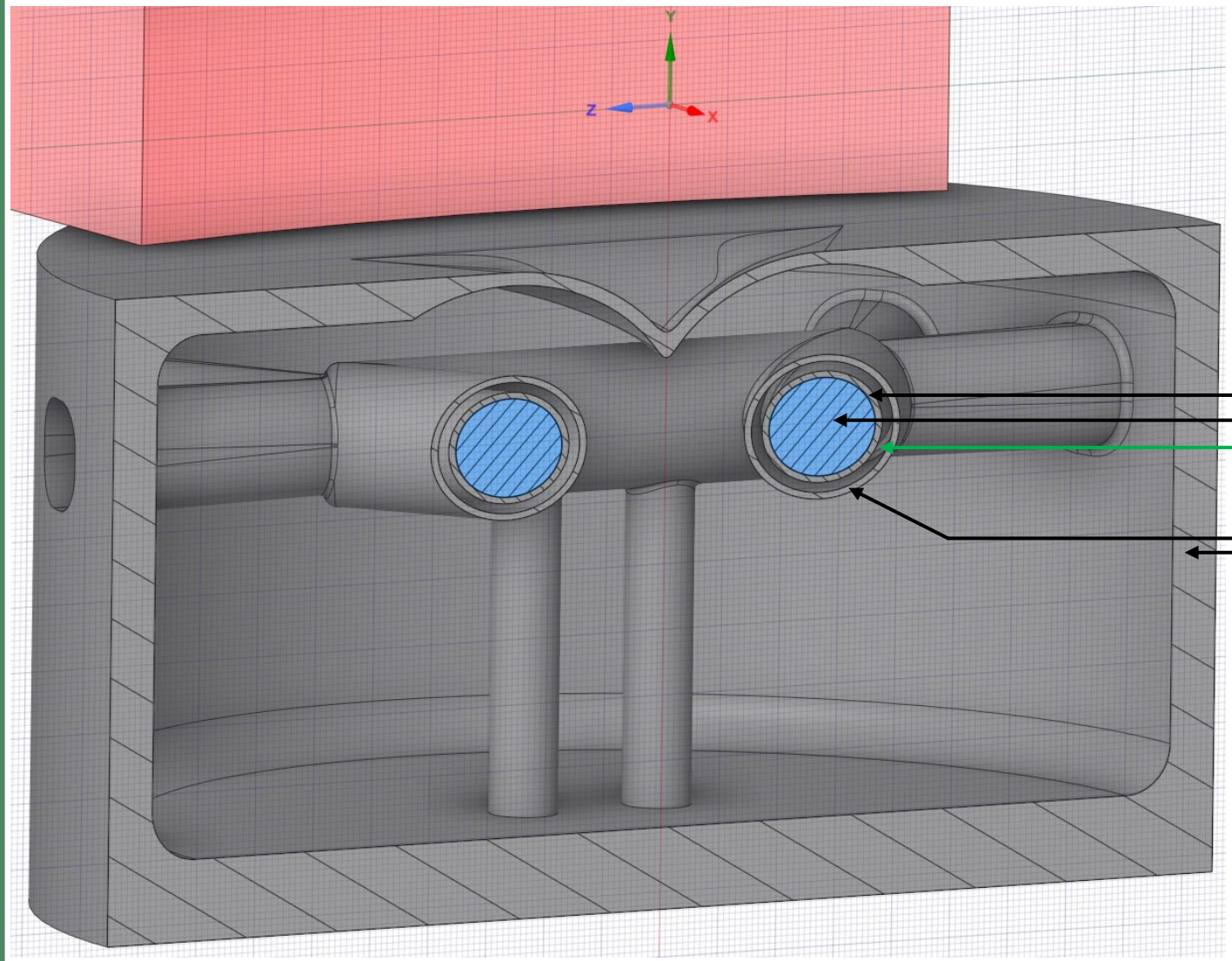
Geometry of Lower MRA



Lower Al for moderator
Lower moderator (para-H2)

Lower Be

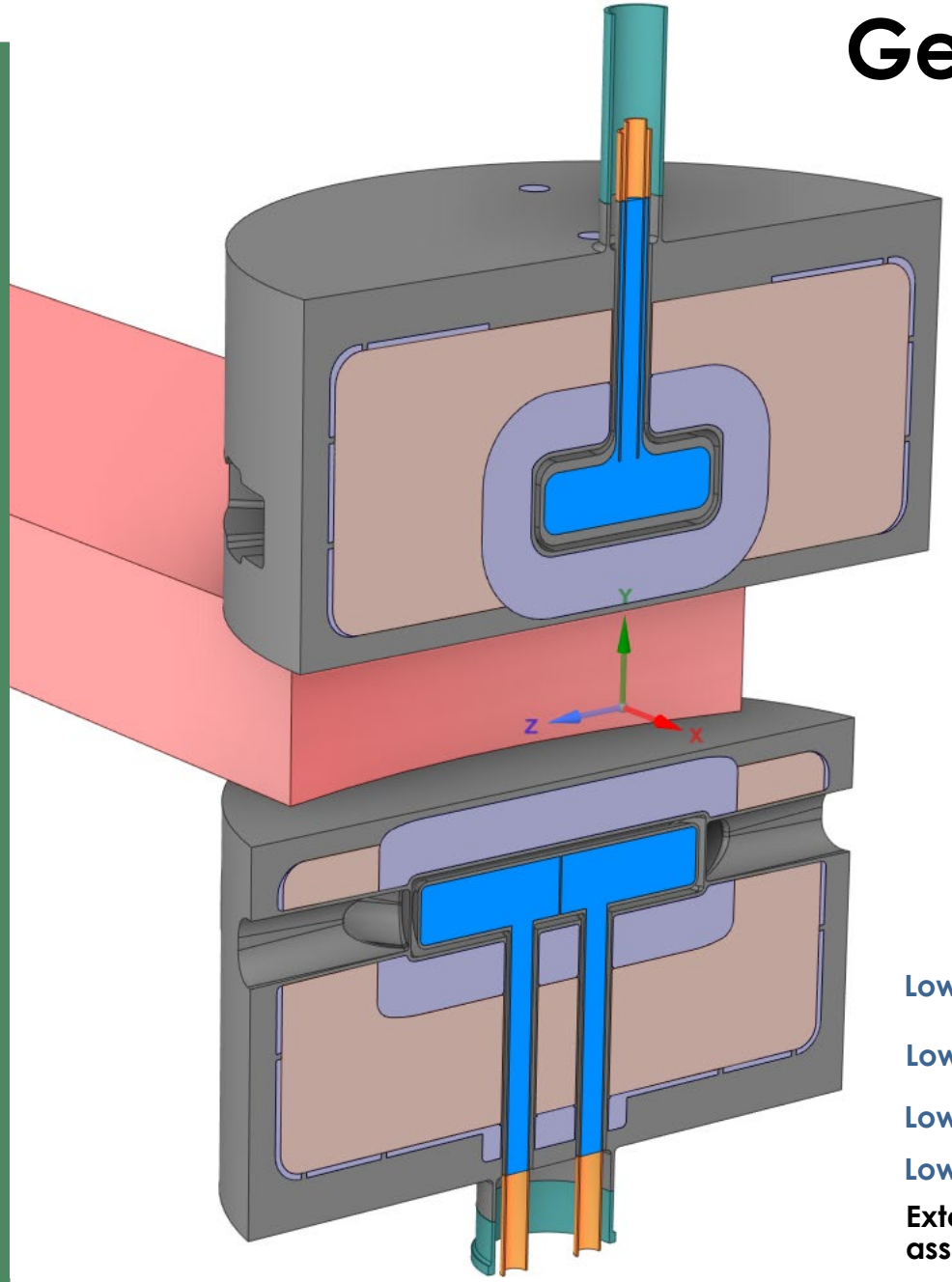
Geometry of Lower MRA

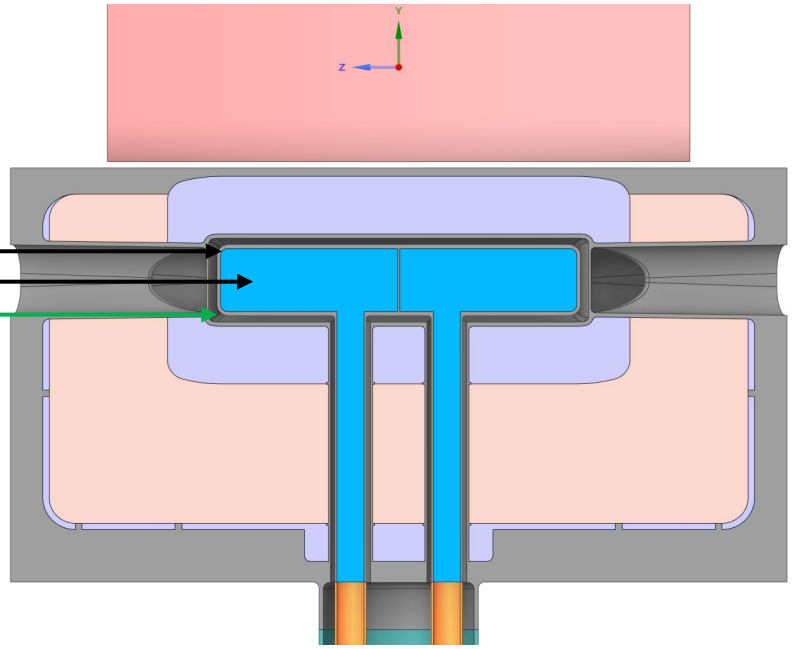


Lower Al for moderator
Lower moderator (para-H2)
Vacuum

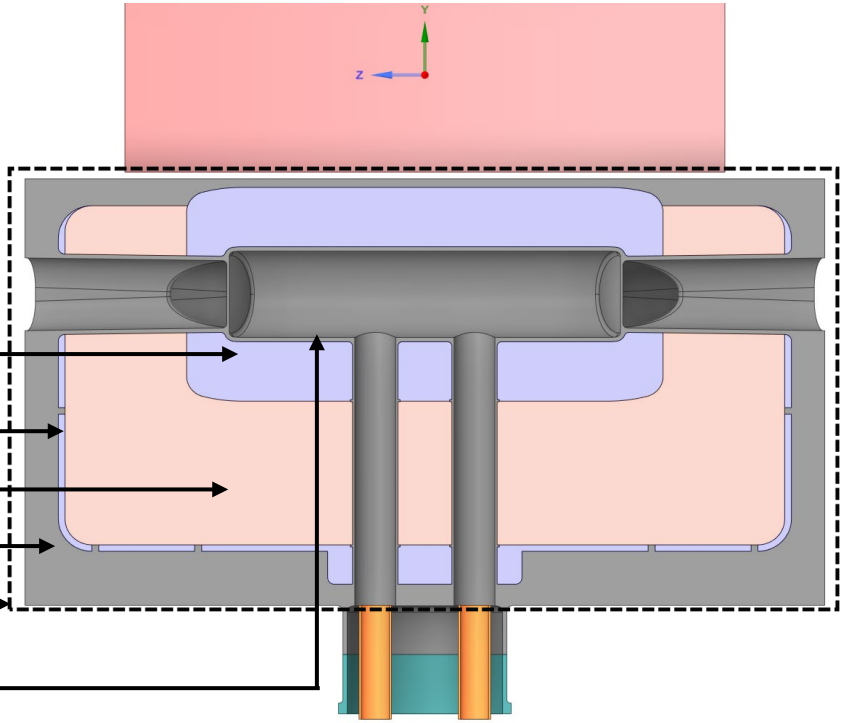
Lower Al for Premoderator, reflector and Be

Geometry of MRA





Lower Al for moderator
Lower moderator (para-H2)
Vacuum



Analyzed domain

Lower Premoderator (H2O)

Lower Reflector (H2O)

Lower Be

Lower Al for Premoderator, reflector and Be

Exterior aluminum wall is assumed to be adiabatic.

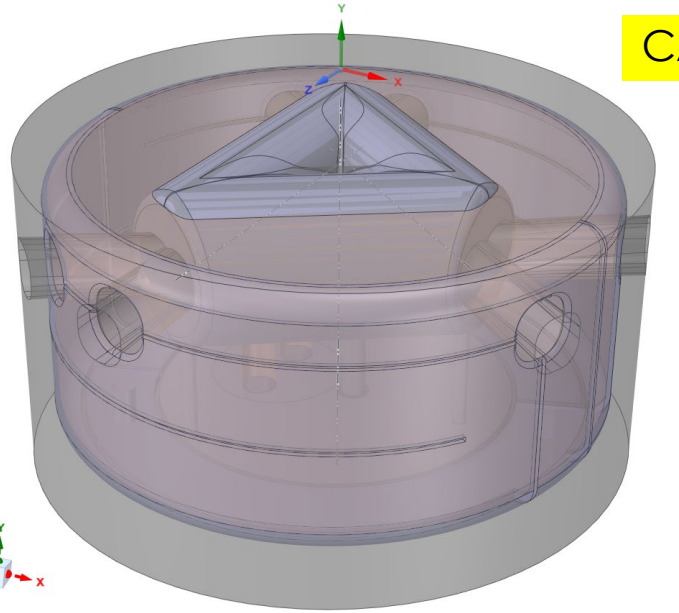
Interior aluminum wall is assumed to be adiabatic (vacuum environment).

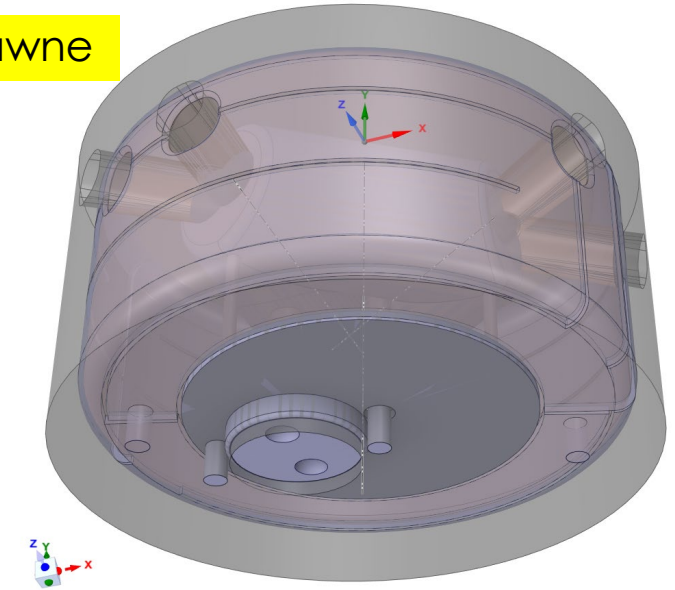
Steady State Heat Transfer Analysis for Lower MRA, Geometry

Link to the CAD

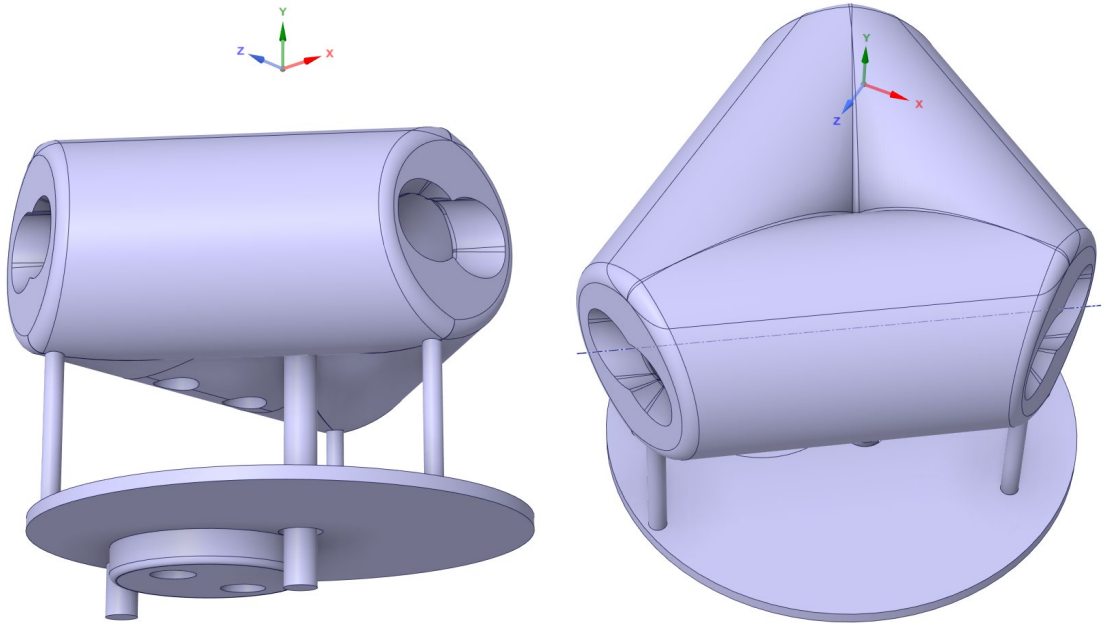
https://ornl.sharepoint.com/sites/sts/targetsystems/Shared%20Documents/Forms/AllItems.aspx?id=%2Fsites%2Fsts%2Ftargetsystems%2FShared%20Documents%2FS%2E03%2E02%20Target%20Assembly%2F99%5FSANDBOX%2FKAO%2F2023%2FCFD%5FSTS%5FMRA%2F0%5FSummary%2FPreliminary%20STS%20Lower%20Reflector%20Thermal%20Hydraulic%20Analysis%2FCAD%5FModel%2F2022%5F11%5F16%5FMRA%5FLower%5FReflector&viewid=9be9bc88%2D5a13%2D48c7%2D9fff%2Dd22f94ffdeb5

CAD model from Ken Gawne

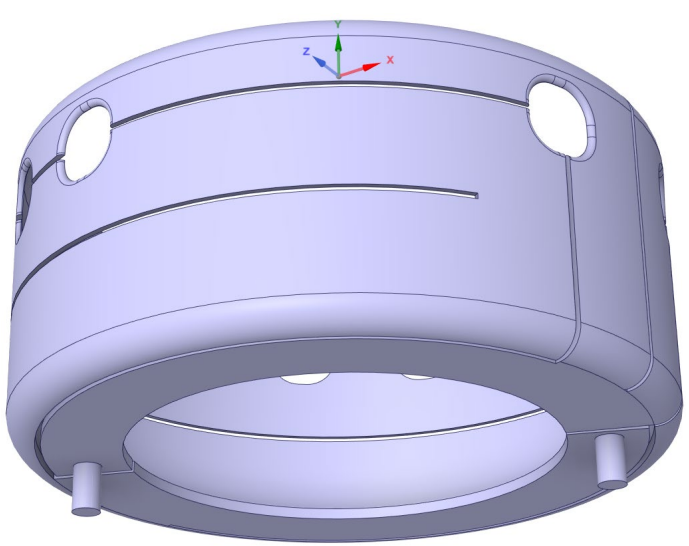


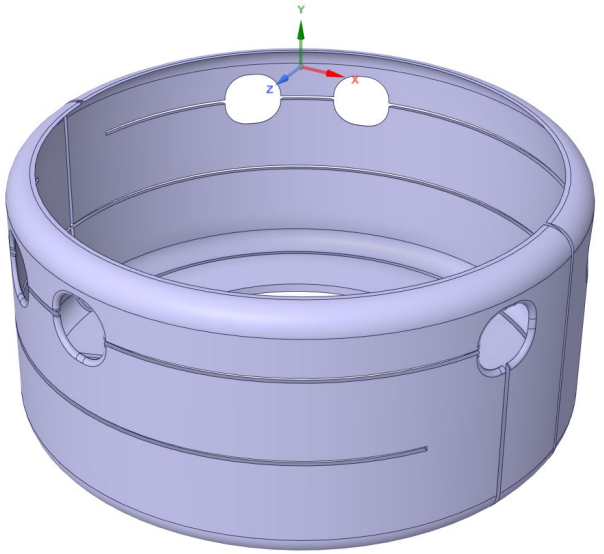


Lower Premoderator



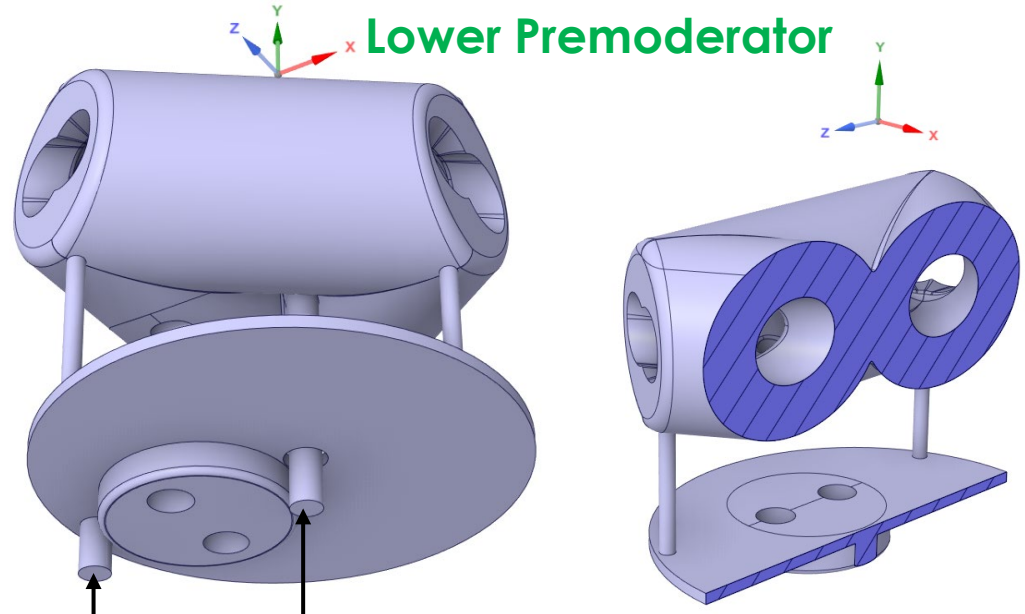
Lower Reflector





Steady State Heat Transfer Analysis for Lower MRA, Geometry

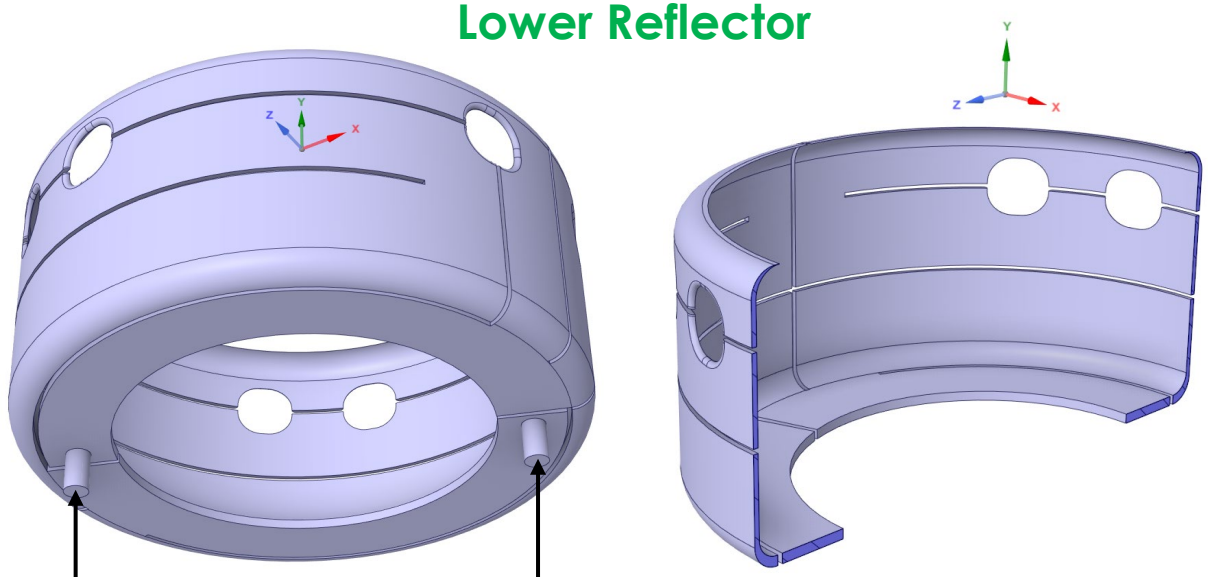
Lower Premoderator



Premoderator inlet (0.47 kg/s, 35°C H_2O)

Premoderator outlet (1 atm)

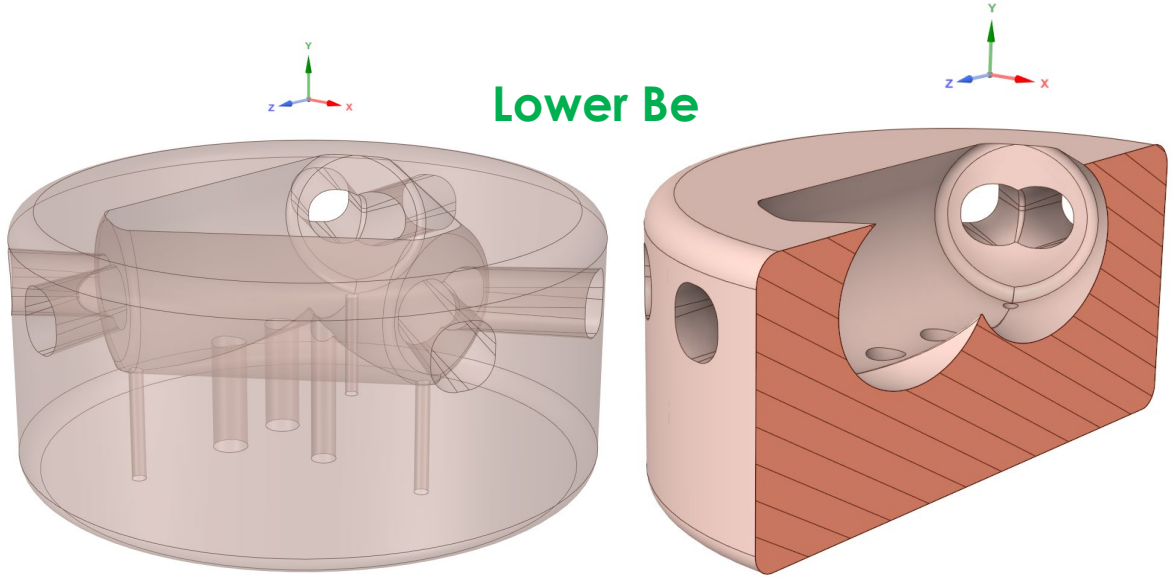
Lower Reflector



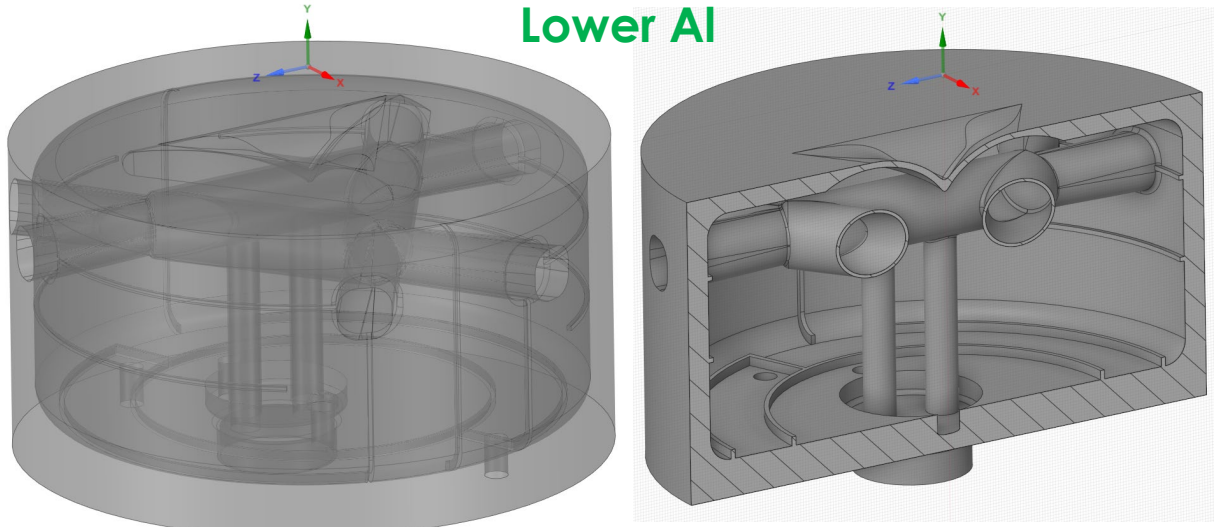
Reflector inlet (0.47 kg/s, 35°C H_2O)

Reflector outlet (1 atm)

Lower Be

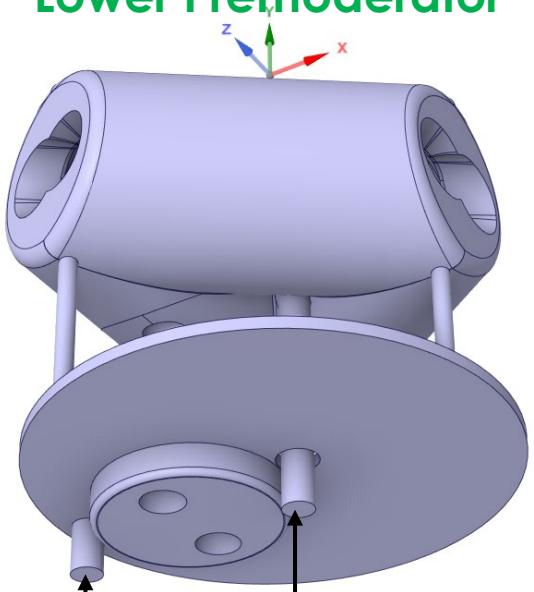


Lower Al

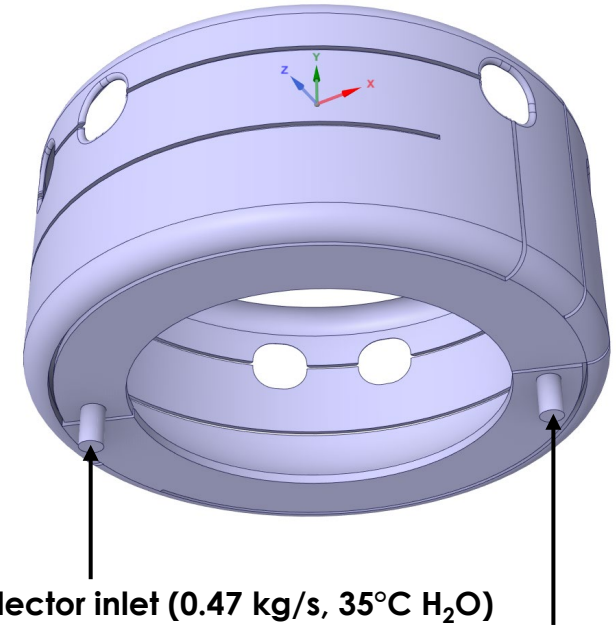


Steady State Heat Transfer Analysis for Lower MRA, Geometry

Lower Premoderator

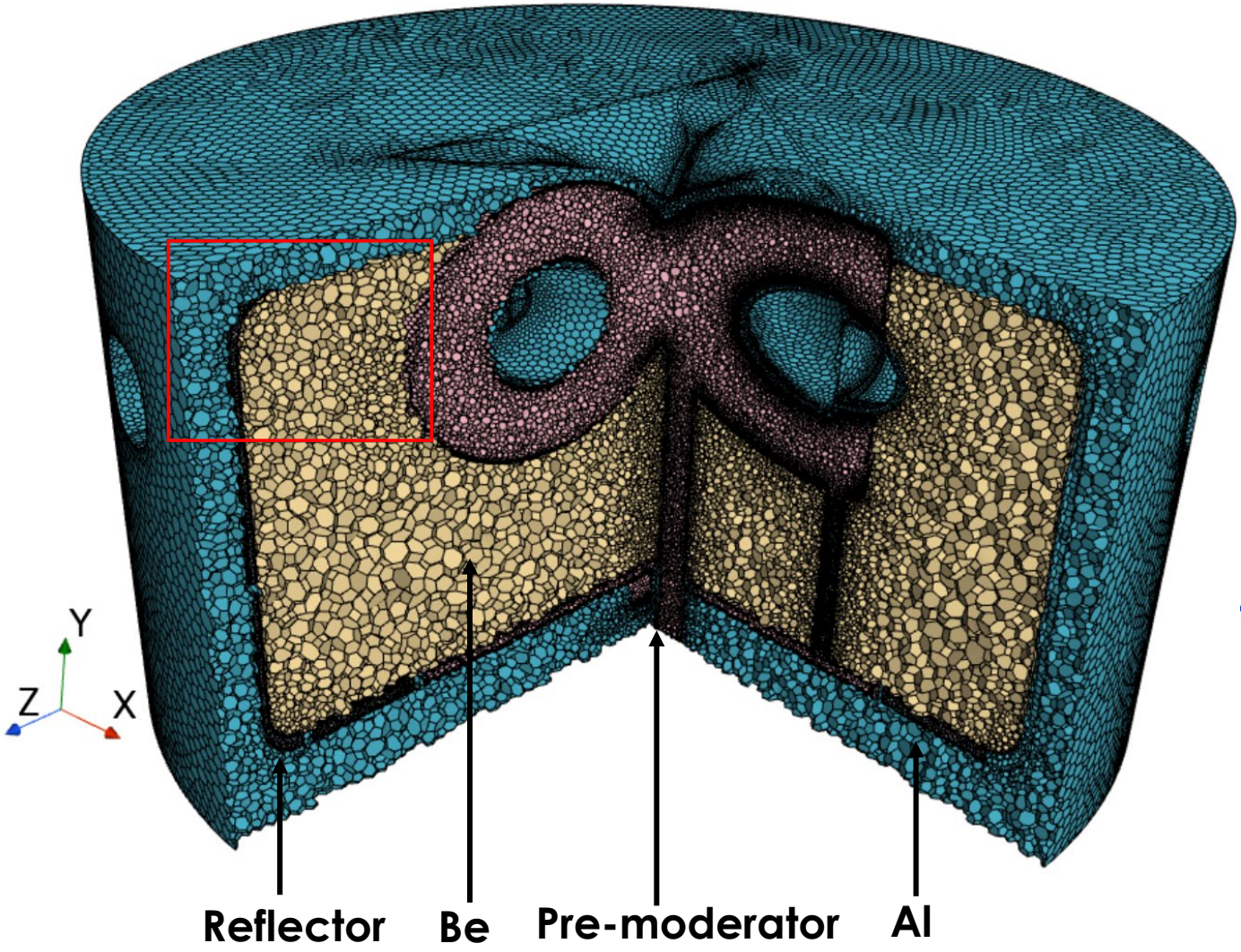


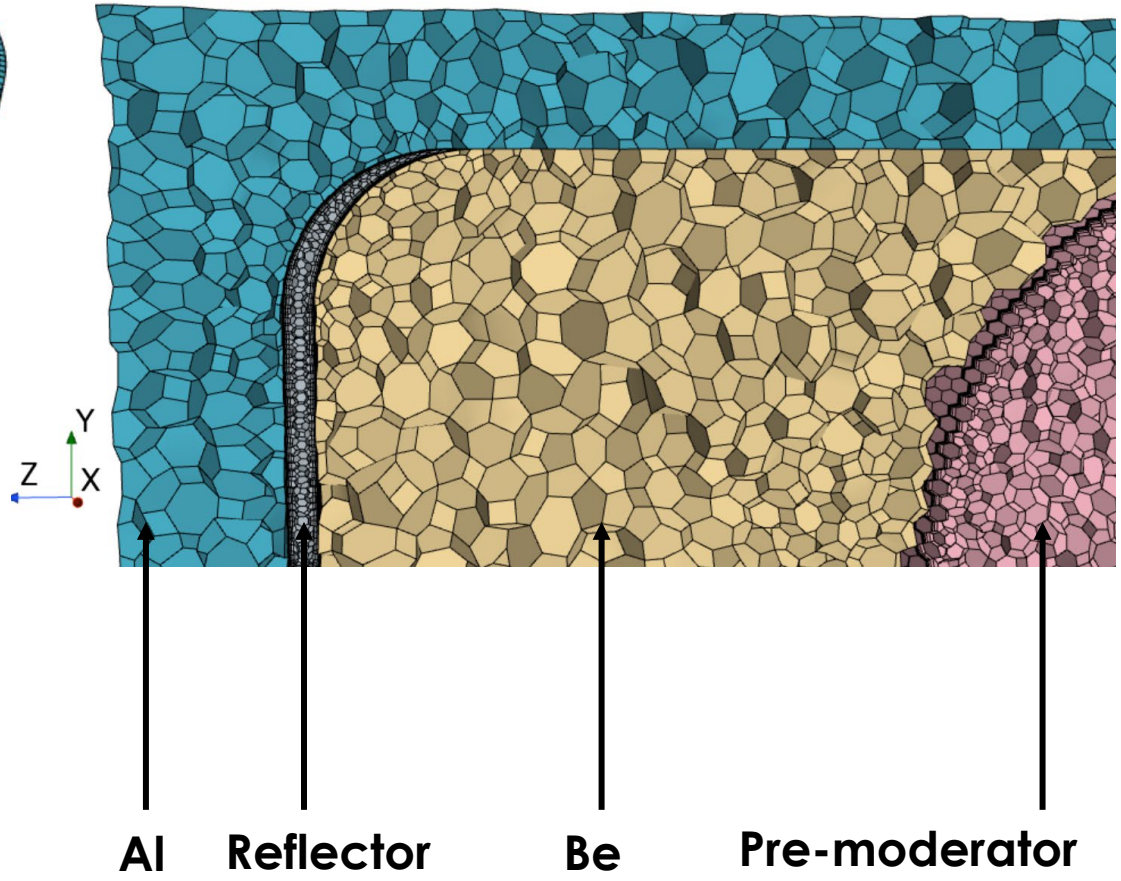
Lower Reflector



Part	Volume (mm^3)
Lower PreModerator	2579443.2754
Lower Reflector	773173.3373

Steady State Heat Transfer Analysis for Lower MRA, Mesh Configuration





Steady State Heat Transfer Analysis for Upper MRA, Mesh Settings

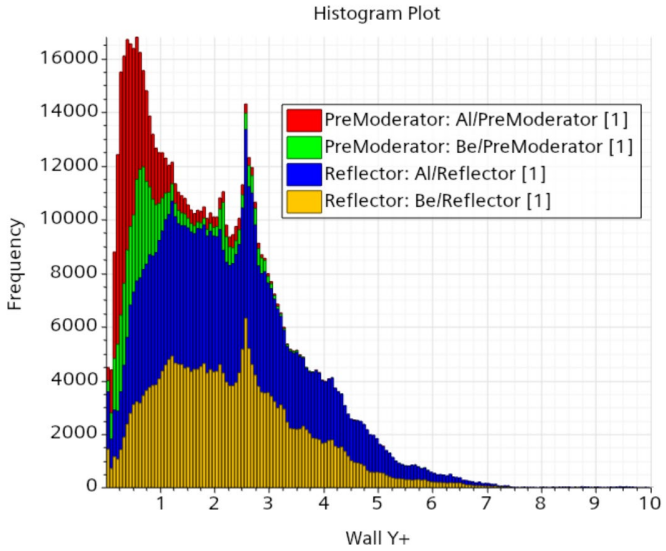
Lower MRA (Without Moderators)				
	Al	**Be**	**PreModerator (H2O)**	**Reflector (H2O)**
Mesh Type	Polyhedral mesh	Polyhedral mesh	Polyhedral mesh	Polyhedral mesh
Base Size (m)	1.00E-02	1.00E-02	4.00E-03	2.00E-03
Target Surface Size (m)	5.00E-03	5.00E-03	2.00E-03	1.00E-03
Minimum Surface Size (m)	1.00E-03	1.00E-03	4.00E-04	2.00E-04
Number of Prism Layers	0	0	8	5
Prism Layer Stretching	0	0	1.5	1.5
Prism Layer Total Thickness (m)	0	0	1.33E-03	5.34E-04
Number of Cells	**2.16E+05**	**1.61E+05**	**1.62E+06**	**3.73E+06**
Total Cells	**5.73E+06**			

CFD Modeling Details

- Simulation software: **Simcenter STAR-CCM+**
- Computer resource: **Libby cluster at ORNL**
  - ❖ Compute node:
    - ❑ Processors: two 16-core Intel Xeon E5-2683v4
    - ❑ 512 GB RAM
  - ❖ **1-3 nodes** used
- Solution time: **~ 1 day**
- Flow and Energy model: **Segregated solver**
- Turbulence model: **Realizable k-ε**
- Wall treatment: **Two-layer all y+**
- H2O mass flow rate**: 0.47 kg/s (7.5 gpm)**
- Unirradiated material properties
- Steady state simulation
- H2O inlet temperature: **35°C**
- H2O outlet pressure: **1 atm**
- Heat sources: **MCNP Neutronics (Lukas Zavorka)**

Mesh-Independent Study:
Mesh-independent studies were performed for earlier upper MRA concepts. Similar mesh settings were adopted for the current upper MRA design (without moderator) with 5.7 million cells. One case with 20.9 millions cells was run for the current design. From the results between two mesh configurations, the maximum temperature variations were less than 0.1°C for Al and Be, and less than 0.4°C for H2O. The wall y+ values for the upper MRA are also kept below 5 to ensure that the mesh configuration is appropriate for the usage of the two-layer all y+ wall treatment model in the CFD simulations.

Wall Y+ of Lower MRA



Thermal Properties

Material	Thermal Conductivity, k (W/m-K)	Density, ρ (kg/m^3)	Specific Heat, Cp (J/kg-K)	Viscosity (Pa-s)
Al	167	2800	880	N/A
Be	168	1850	1925	N/A
H2O (PreModerator & Reflector)	0.617	995	4173	7.98E-04

Energy Deposition from Neutronics Calculation (from Lukas Zavorka)

energy deposition data for MRA

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%5FR5%2FNeutronics&viewid=9be9bc88%2D5a13%2D48c7%2D9fff%2Dd22f94ffdeb5

From: Zavorka, Lukas <zavorkal@ornl.gov>
Sent: Monday, September 12, 2022 1:28 PM
To: Kao, Min-Tsung <kaom@ornl.gov>
Cc: Janney, Jim <janneyjg@ornl.gov>; Remec, Igor <remeci@ornl.gov>
Subject: MRA energy deposition

Min-Tsung,

The energy deposition data for MRA have been uploaded here:

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%5FR5%2FNeutronics&viewid=9be9bc88%2D5a13%2D48c7%2D9fff%2Dd22f94ffdeb5

Format as usual, i.e.,

X(cm), Y(cm), Z(cm), Energy(J/cc/pulse), Rel.error(neutrons and photons only), Volume(cm3)

in the .csv files for individual materials. This includes both MRA and backbone.

Total heating is also stored in "mra_total_numbers.xlsx", which gives 30.6 kW for MRA and 30.2 kW for backbone. Please check the total numbers if they match your import.

Please let me know if you have any questions about the data or if you find anything suspicious.

Thanks,

Lukas

Additional heating in MRA aluminum due to 27Al(n,g)28Al

Additional heating from the **27Al(n,g)28Al** reaction and **b-decay** in MRA hydrogen and reflector vessel.

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%5FR5%2FNeutronics&viewid=9be9bc88%2D5a13%2D48c7%2D9fff%2Dd22f94ffdeb5

Additional heating in MRA aluminum due to 27Al(ng)28Al

ZL Zavorka, Lukas
To Kao, Min-Tsung
Cc Janney, Jim; Remec, Igor
You replied to this message on 9/29/2022 8:13 AM.

Reply | Reply All | Forward
Thu 9/29/2022 2:47 AM

Min-Tsung,

Here:

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%5FR5%2FNeutronics&viewid=9be9bc88%2D5a13%2D48c7%2D9fff%2Dd22f94ffdeb5

were uploaded 4 files:
b01g_Al_NG_20K_hydrogen_cyl.csv
b01g_Al_NG_20K_hydrogen_tube.csv
b01g_Al_NG_300K_reflector_cyl.csv
b01g_Al_NG_300K_reflector_tube.csv

with the additional heating from the 27Al(n,g)28Al reaction and b- decay in MRA hydrogen and reflector vessel. (4 files are for tube and cylinder moderator and hydrogen and reflector vessel, as the names indicate). This refers to Igor's note: Al-27 (n, gamma) Al-28 → decay with e- emission with average energy of ~ 1.247 MeV.

This additional energy deposition is in the format as usual:

X(cm), Y(cm), Z(cm), Energy(J/cc/pulse), Rel.error(neutrons and photons only), Volume(cm3)

and shall be added to the original data for energy deposition in Aluminum. The calculations used the same UM model, meaning that the UM cell coordinates and volumes are the same, and adding the data to the previous set should be straightforward.

This heating in CYL hydrogen vessel is 36.37 W, which is additional 18.97% of the heating. (Agrees well with Igor's ~20% prediction)
This heating in CYL reflector vessel is 164.73 W, which is additional 3.42% of the heating.
This heating in TUBE hydrogen vessel is 34.73 W, which is additional 23.0% of the heating. (Agrees well with Igor's ~20% prediction)
This heating in TUBE reflector vessel is 182.93 W, which is additional 3.97% of the heating.

Please let me know if this format is good for you or if you want me to combine this additional heating with the original numbers.

Thank you,

Lukas

Heat Sources for CFD calculations were obtained by multiplying the energy deposition by 15Hz.

Link: 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%2F2022%2F0%5FCFD%5FSTS%5FMRA%2FMin%2DTsung%20Kao%5FSTS%5FMRA%5F2022%5F11%5F10%5FLower%5FMRA%5FUpdate%5F1%2FCFD%5FHeat%5FSources&viewid=9be9bc88%2D5a13%2D48c7%2D9fff%2Dd22f94ffdeb5

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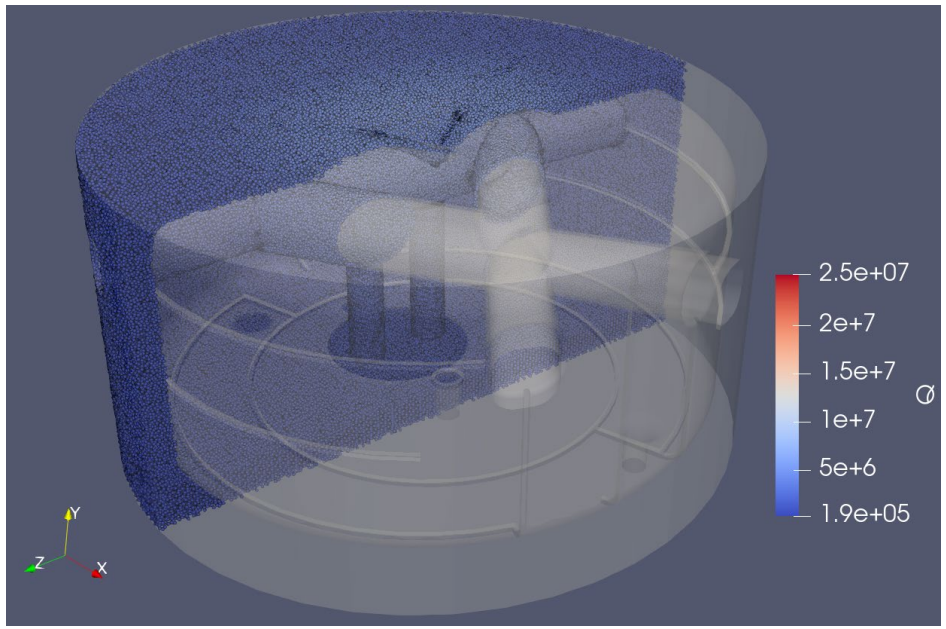
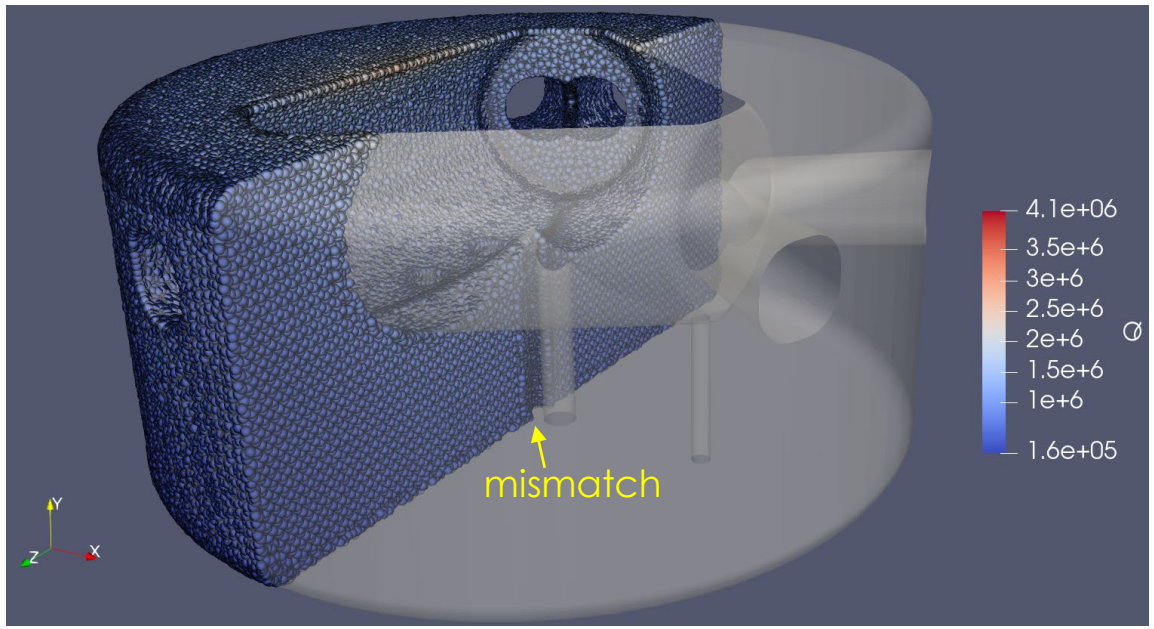
Steady State Heat Transfer Analysis for Lower MRA, Heat Source (Neutronics data &CFD geometry)

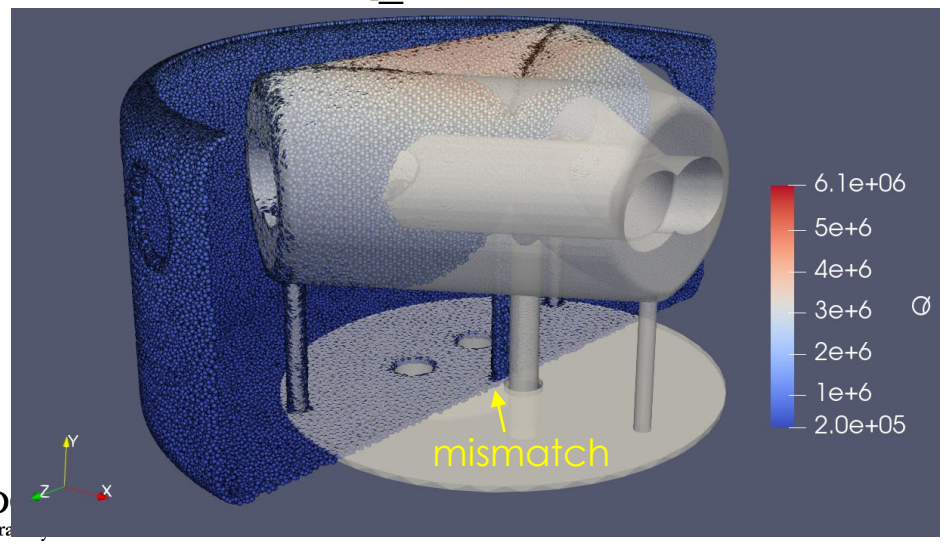
Q_Al



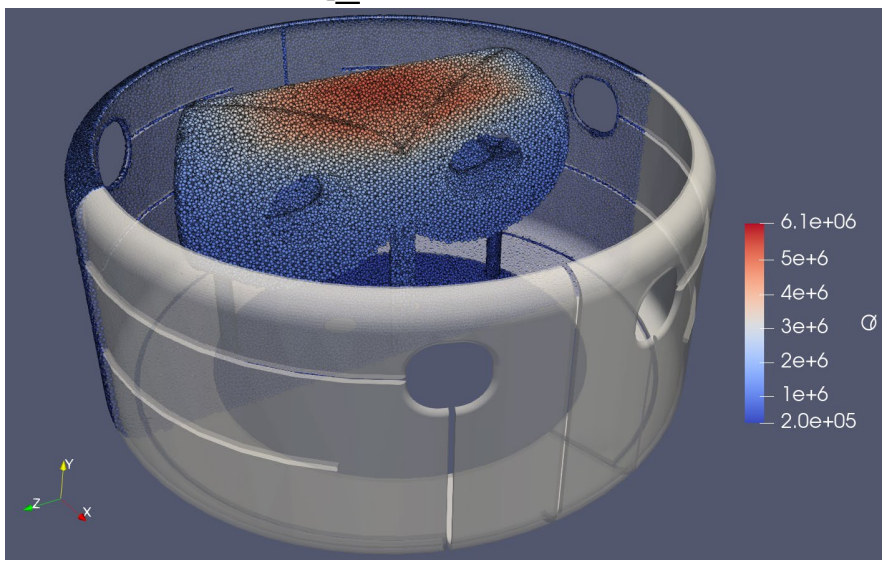
Q_Be



Q_PreModerator



Q_Reflector

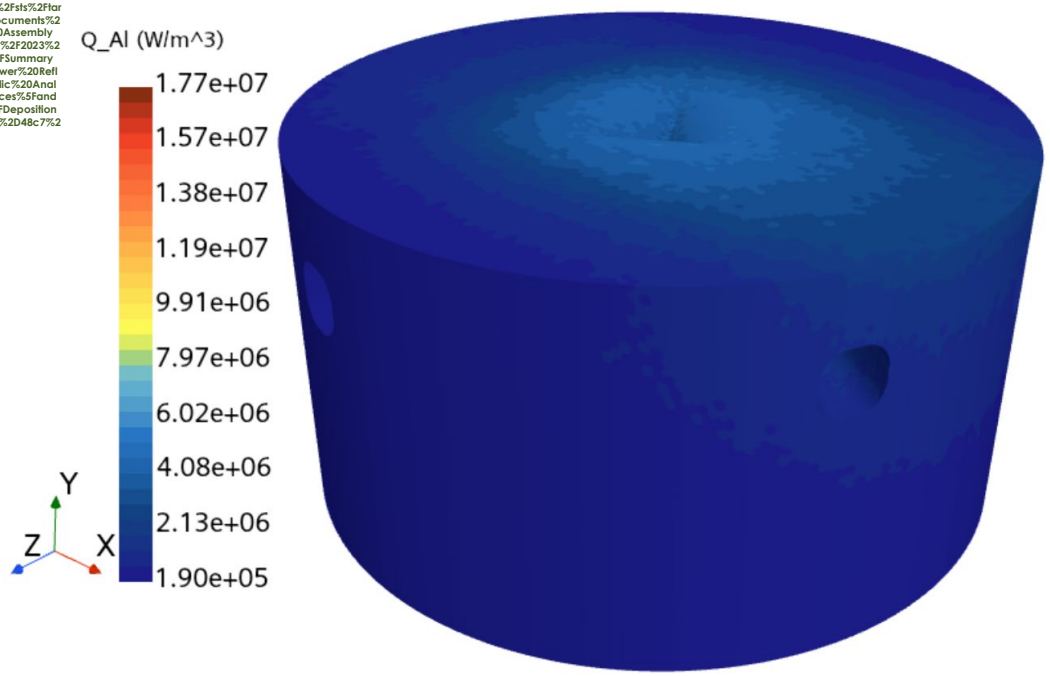


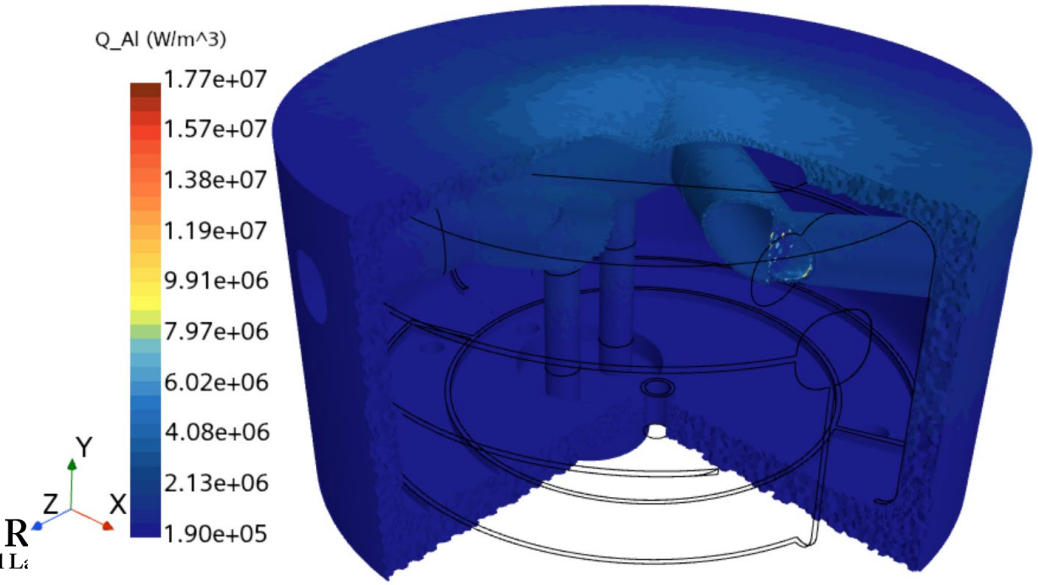
Steady State Heat Transfer Analysis for Lower MRA, Heat Source

Heat source link

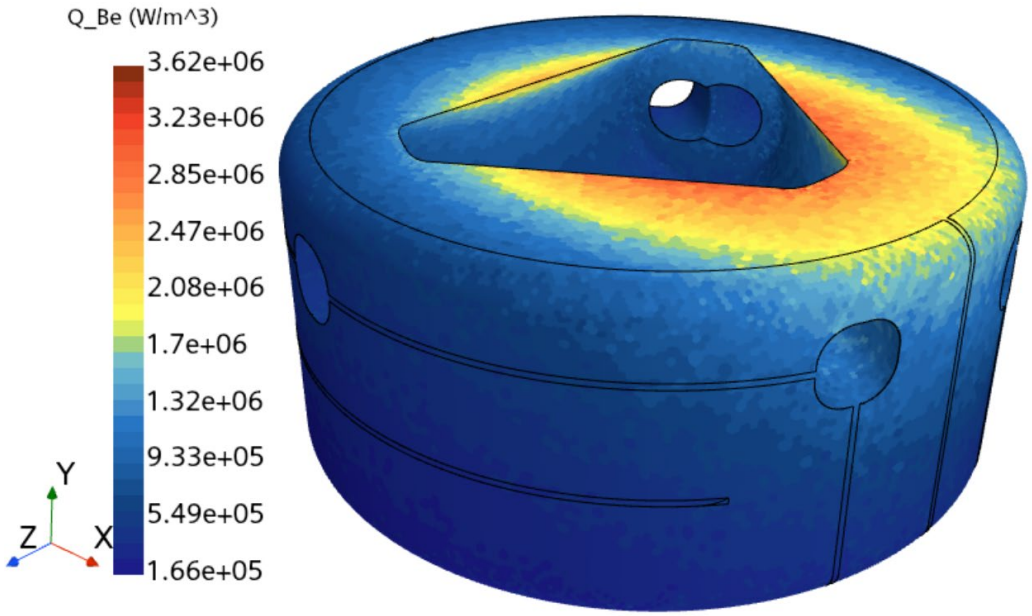
https://ornl.sharepoint.com/sites/sts/targetsystems/Shared%20Documents/Forms/AllItems.aspx?id=%2Fsites%2Fsts%2Ftargetsystems%2FShared%20Documents%2FS%2E03%2E02%20Target%20Assembly%2F99%5FSANDBOX%2FKAO%2F2023%2FCFD%5FSTS%5FMRA%2F0%5FSummary%2FPreliminary%20STS%20Lower%20Reflector%20Thermal%20Hydraulic%20Analysis%2FCFD%5FHeat%5FSources%5Fand%5FNeutronics%5FEnergy%5FDeposition&viewid=9be9bc88%2D5a13%2D48c7%2D9fff%2Dd22f94ffdeb5

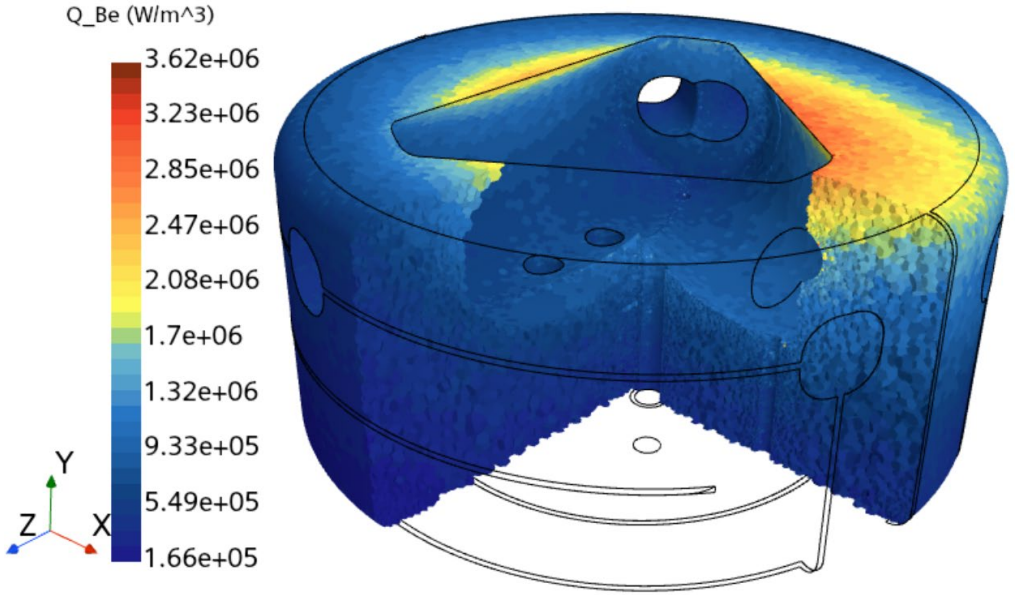
Q_Al





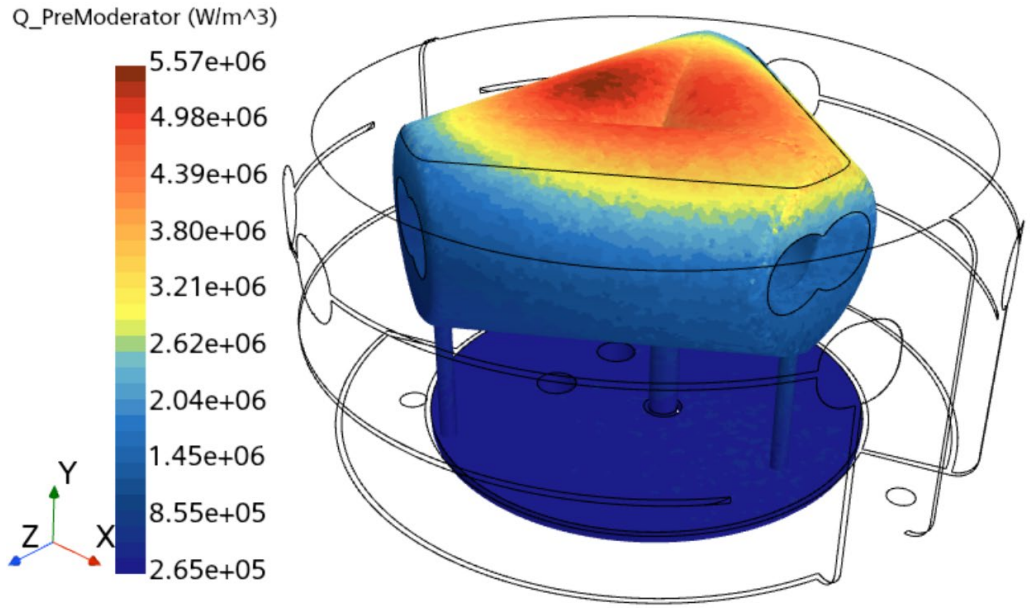
Q_Be

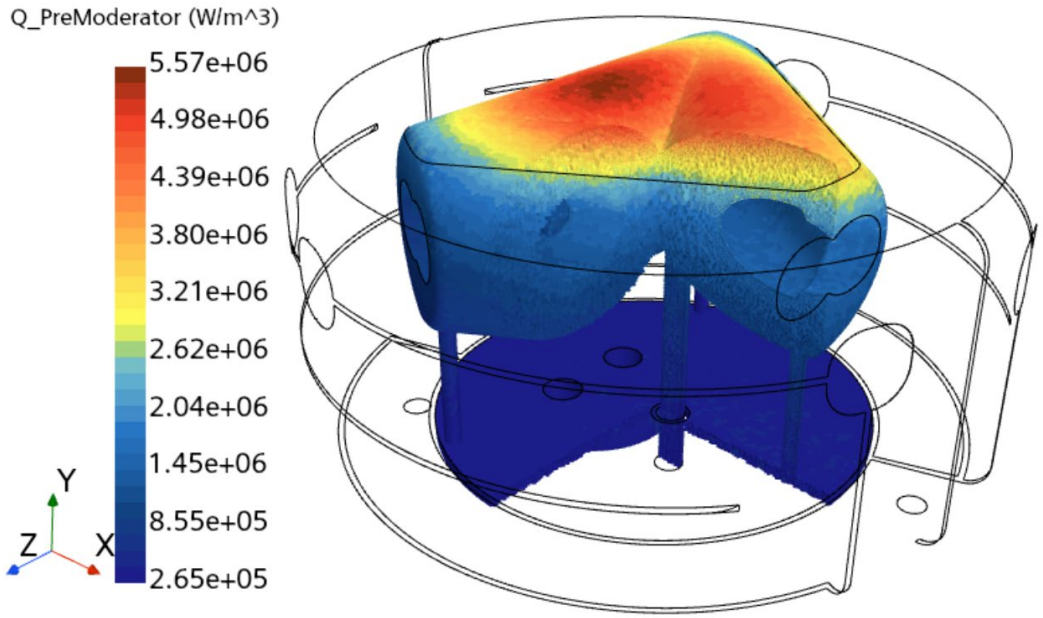




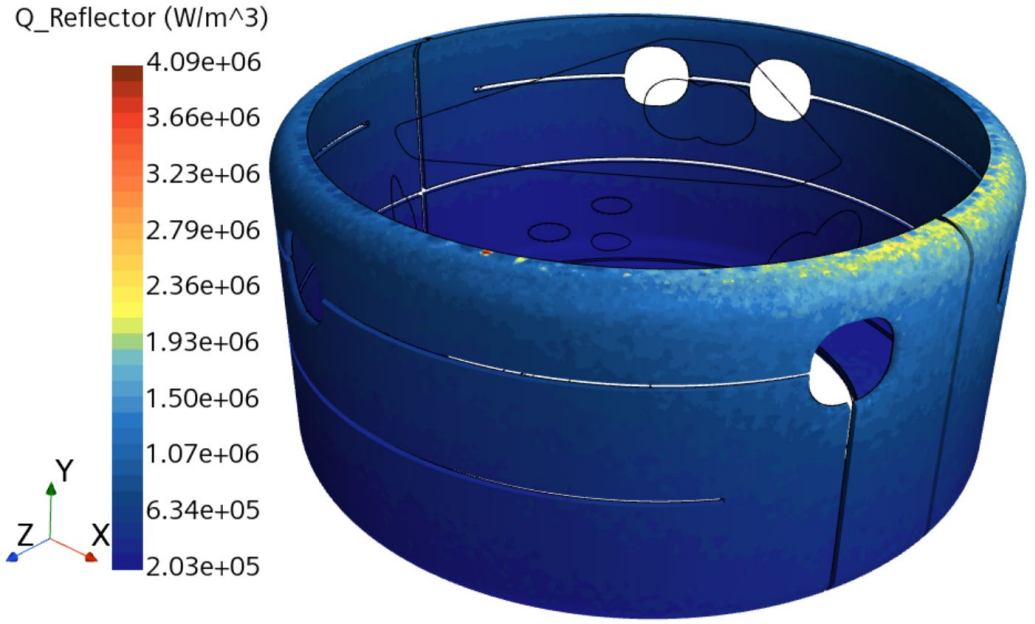
Steady State Heat Transfer Analysis for Lower MRA, Heat Source

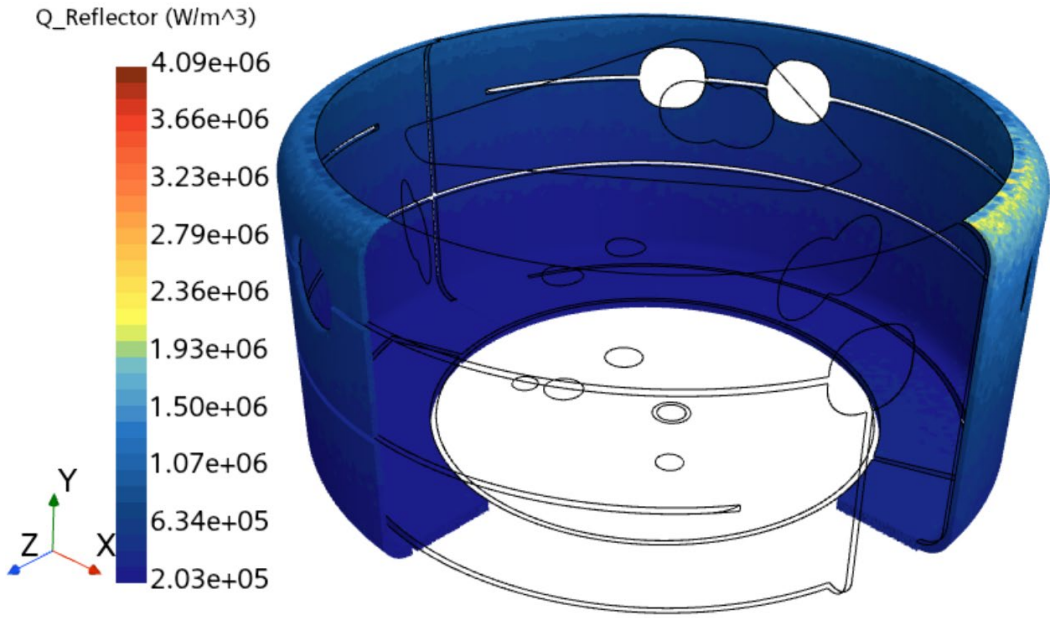
Q_PreModerator





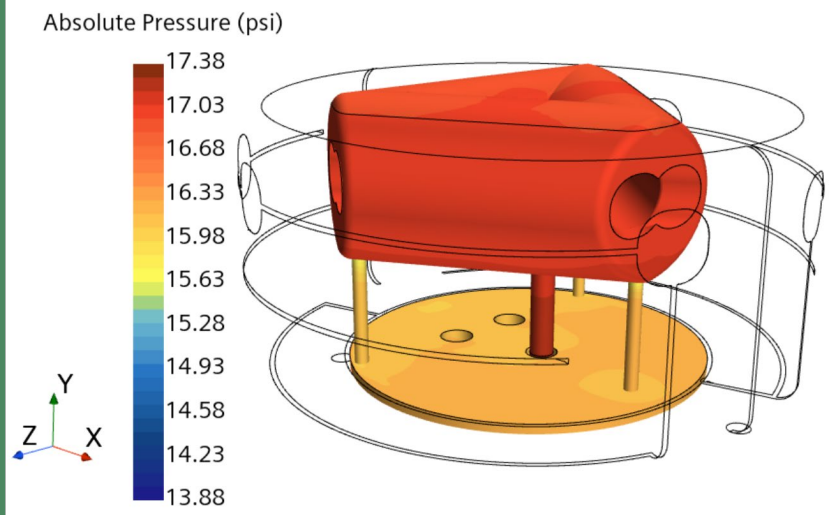
Q_Reflector

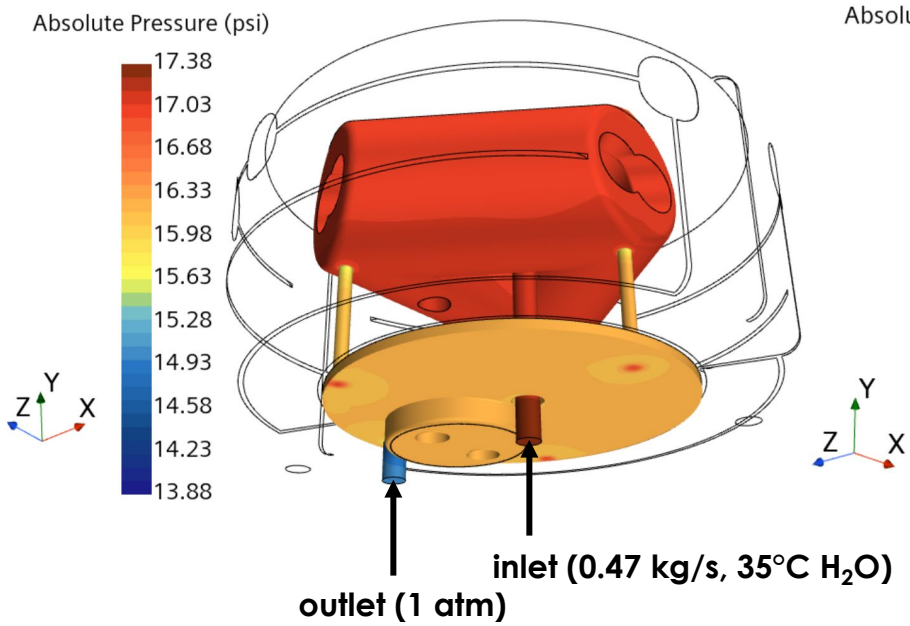


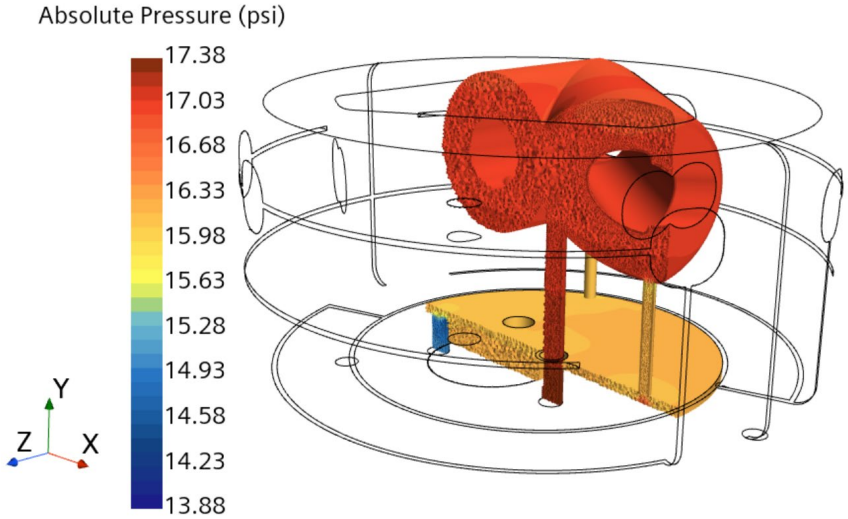


Steady State Heat Transfer Analysis for Lower PreModerator, Pressure

$\Delta P_{inlet-outlet} = 0.14$ bar $(= 14.3$ kPa $= 2.08\ psi = 0.14\ atm)$

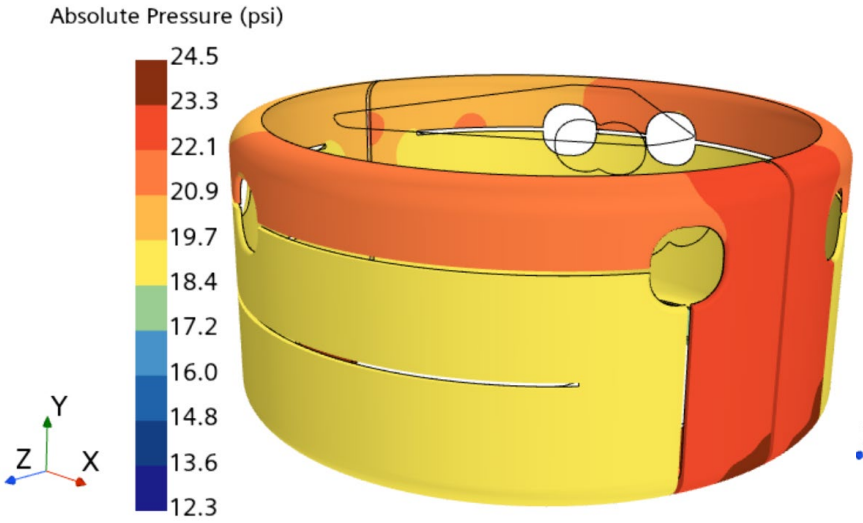


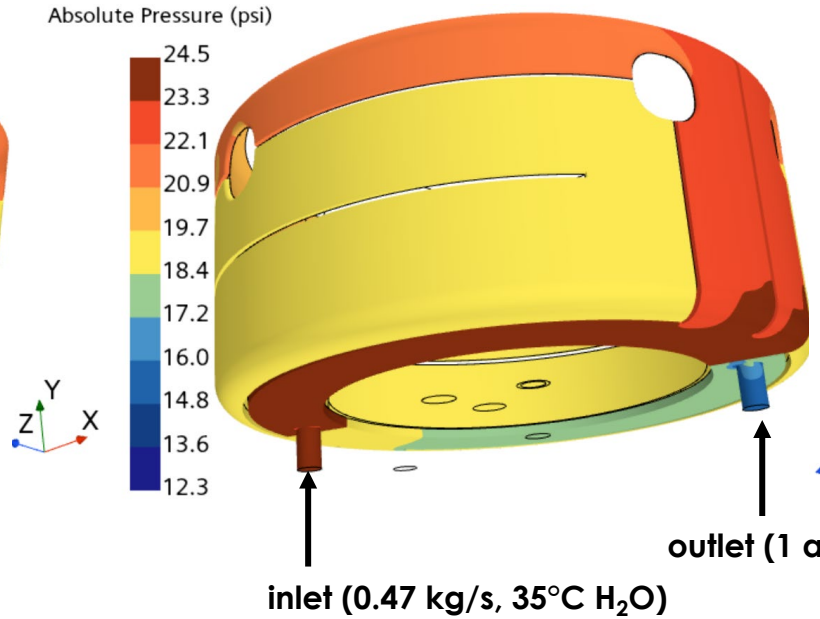


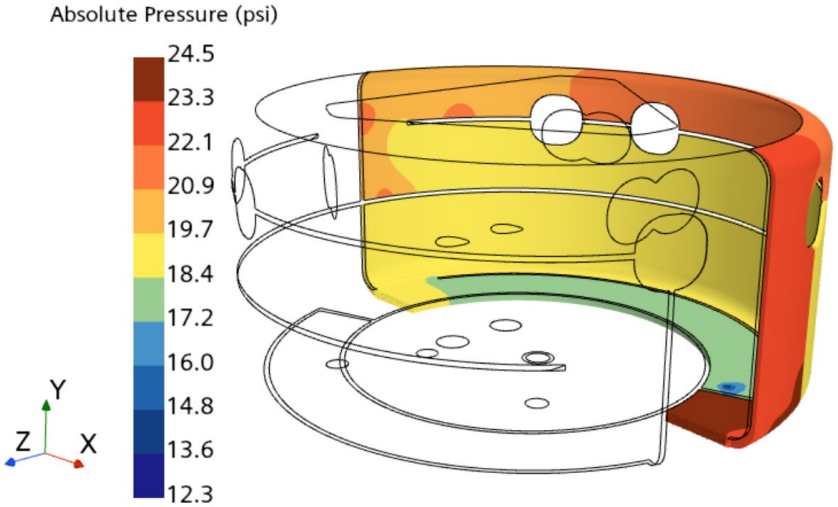


Steady State Heat Transfer Analysis for Lower Reflector, Pressure

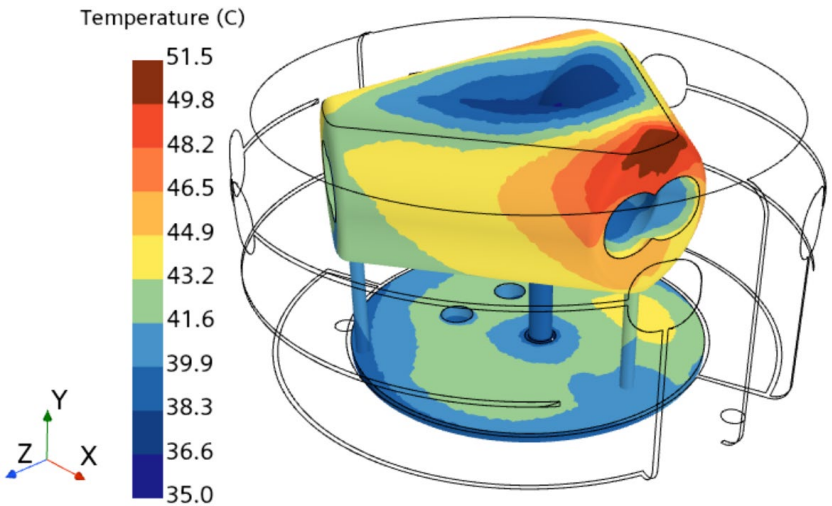
$\Delta P_{inlet-outlet} = 0.53$ bar $(= 53.4$ kPa $= 7.7\ psi = 0.53\ atm)$

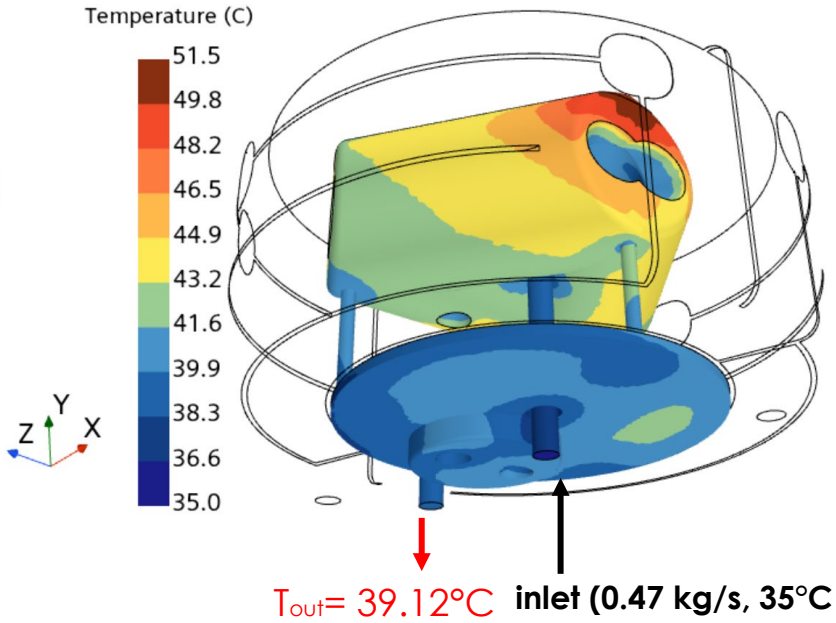






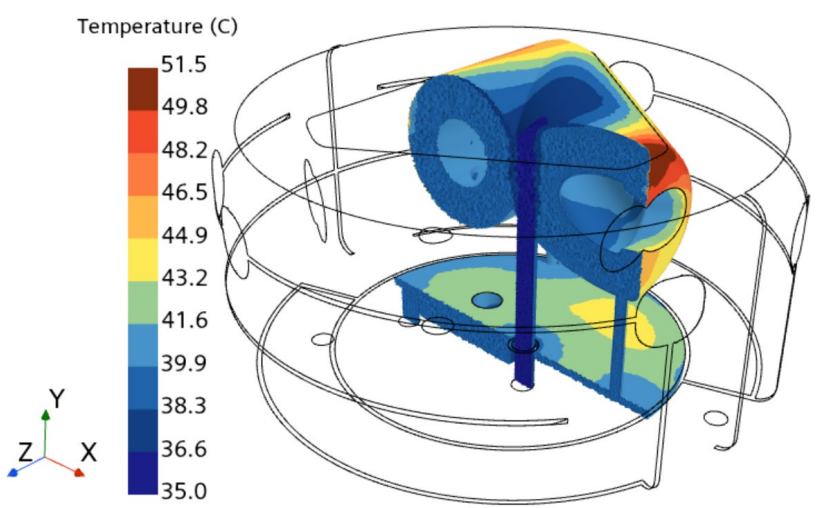
Steady State Heat Transfer Analysis for Lower PreModerator (H_2O), Temperature



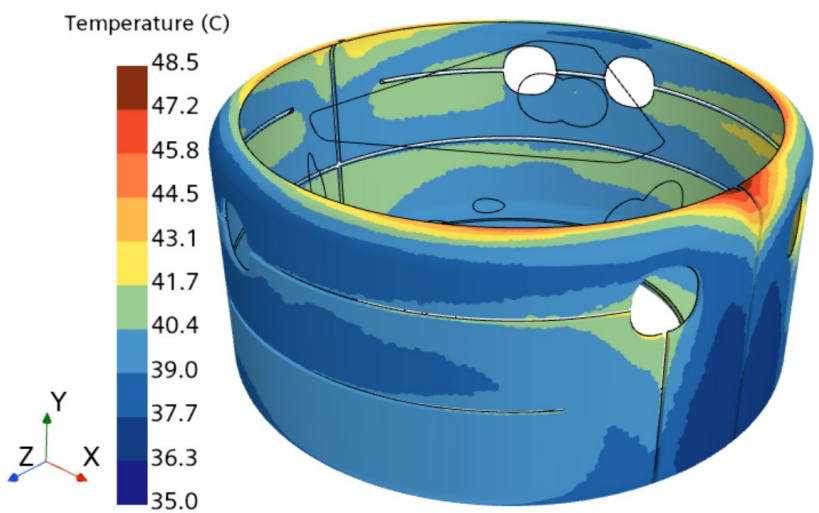


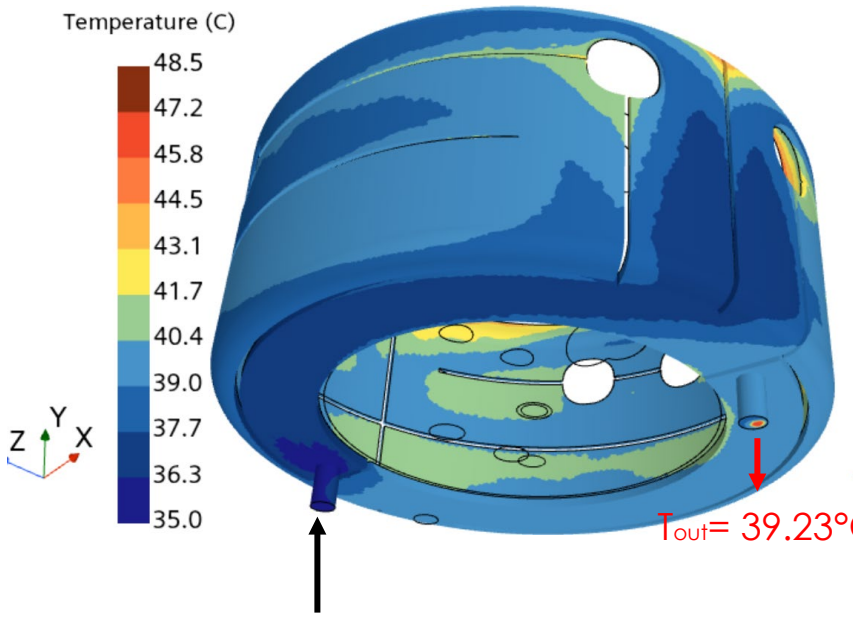
T_{out}= 39.12°C

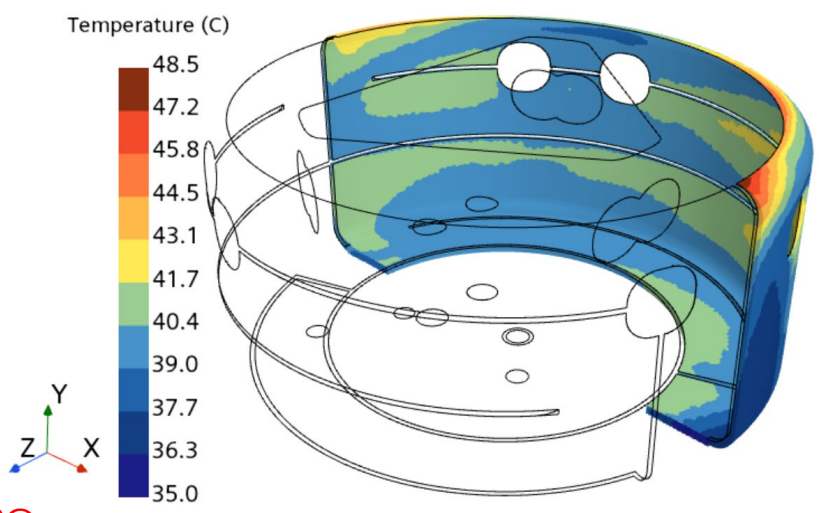
inlet (0.47 kg/s, 35°C H_2O)



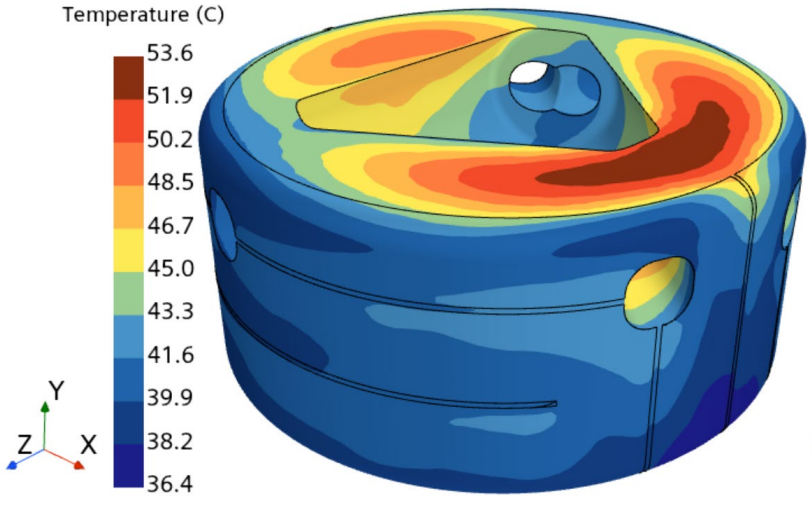
Steady State Heat Transfer Analysis for Lower Reflector(H_2O), Temperature

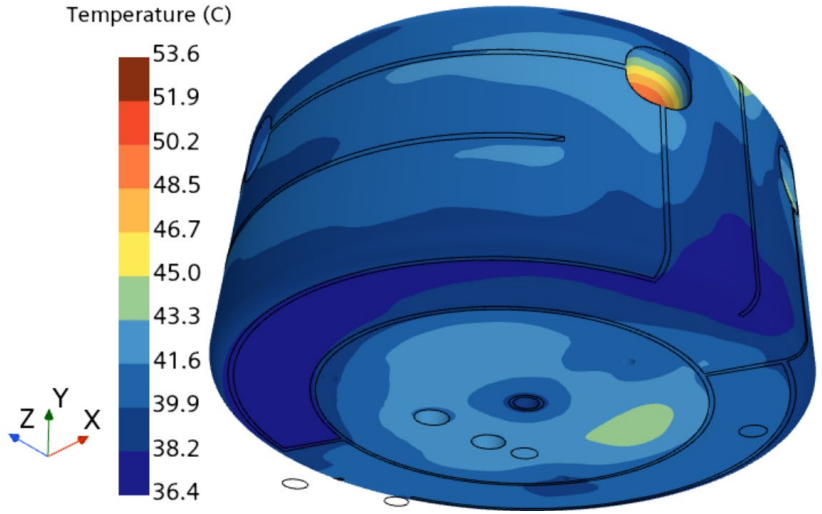


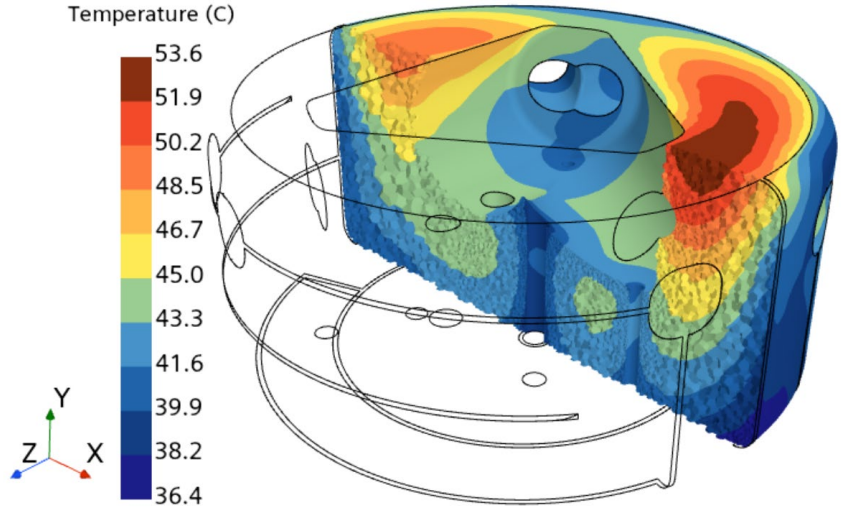




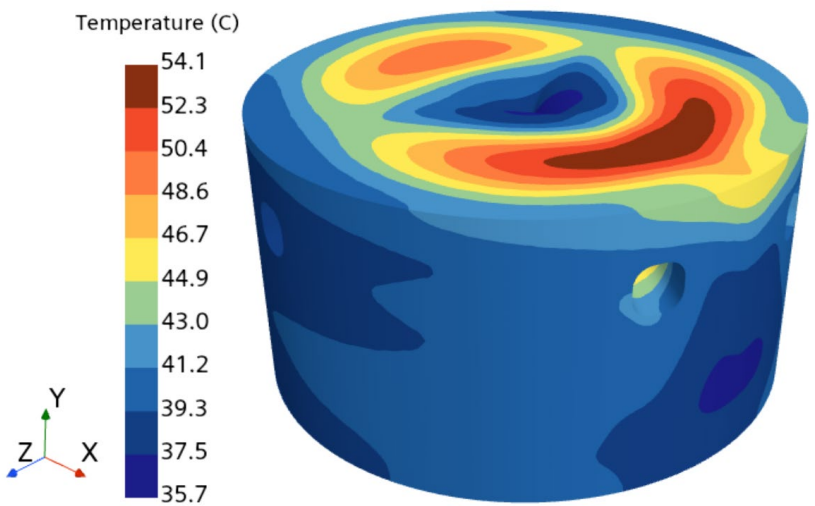
Steady State Heat Transfer Analysis for Lower Be, Temperature

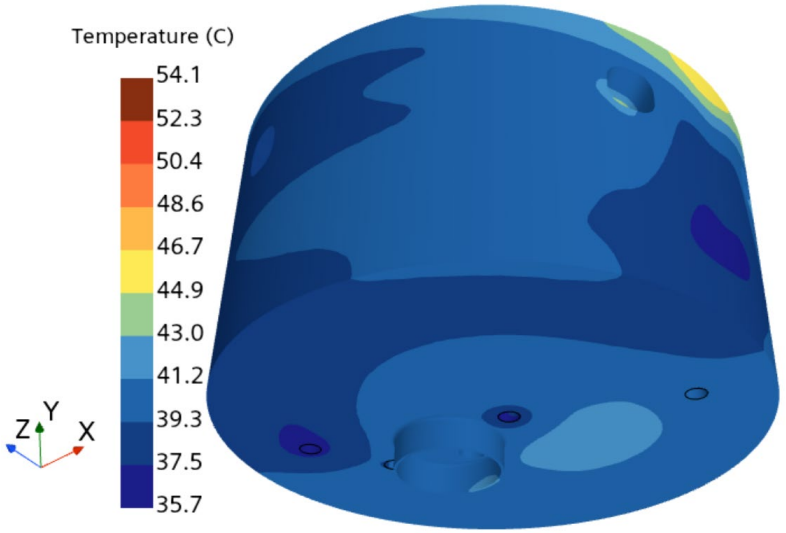


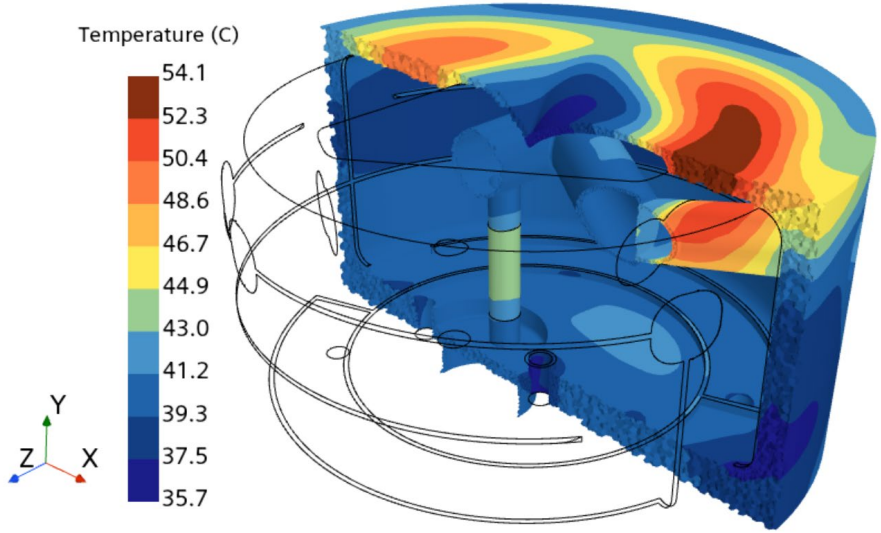




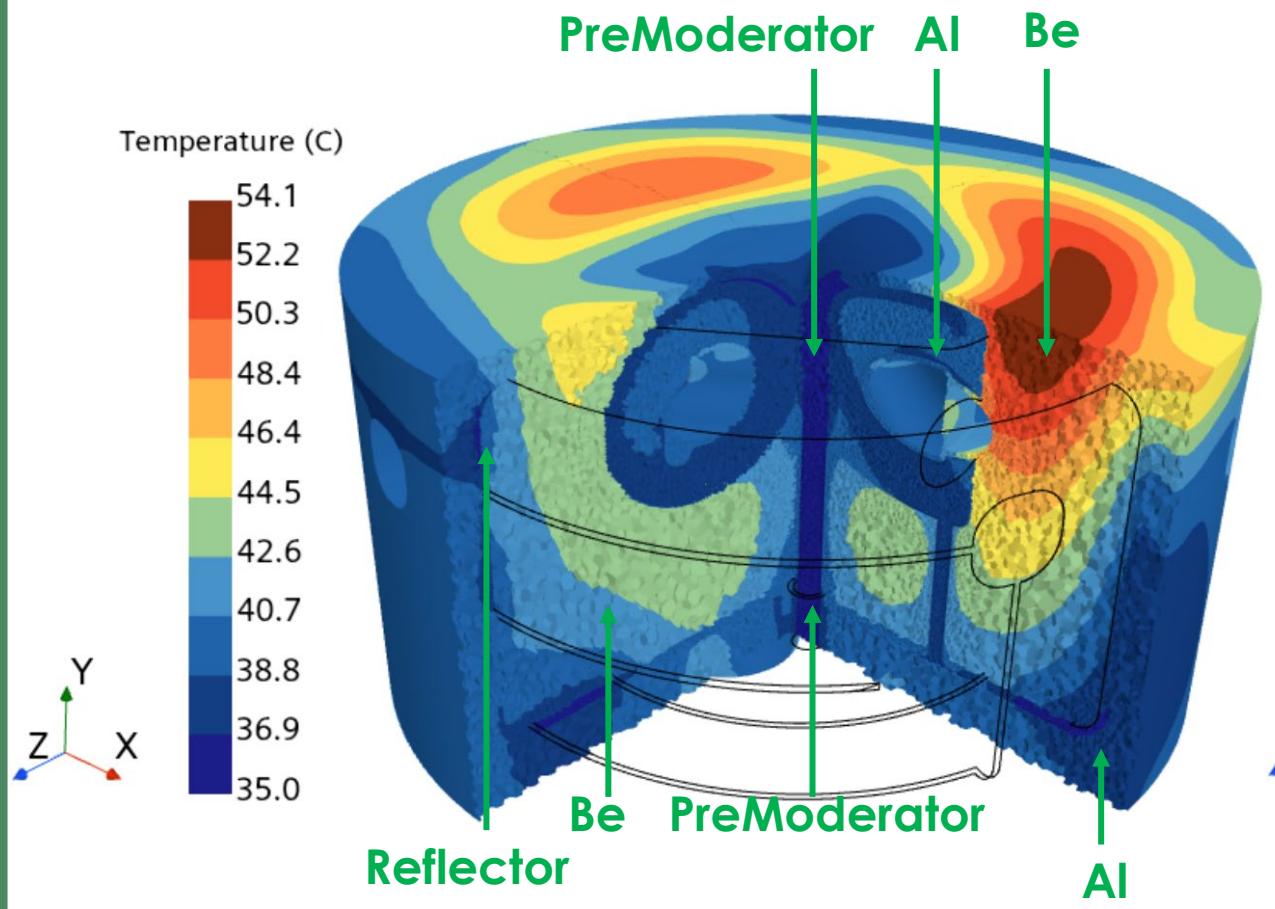
Steady State Heat Transfer Analysis for Lower Al, Temperature

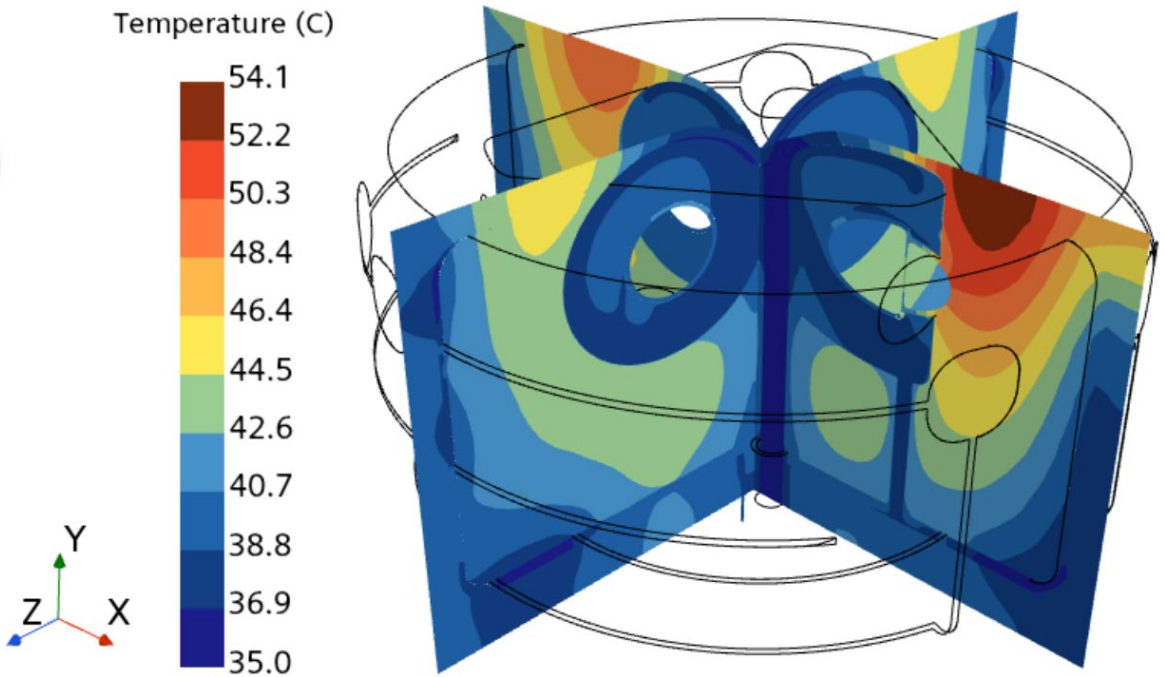






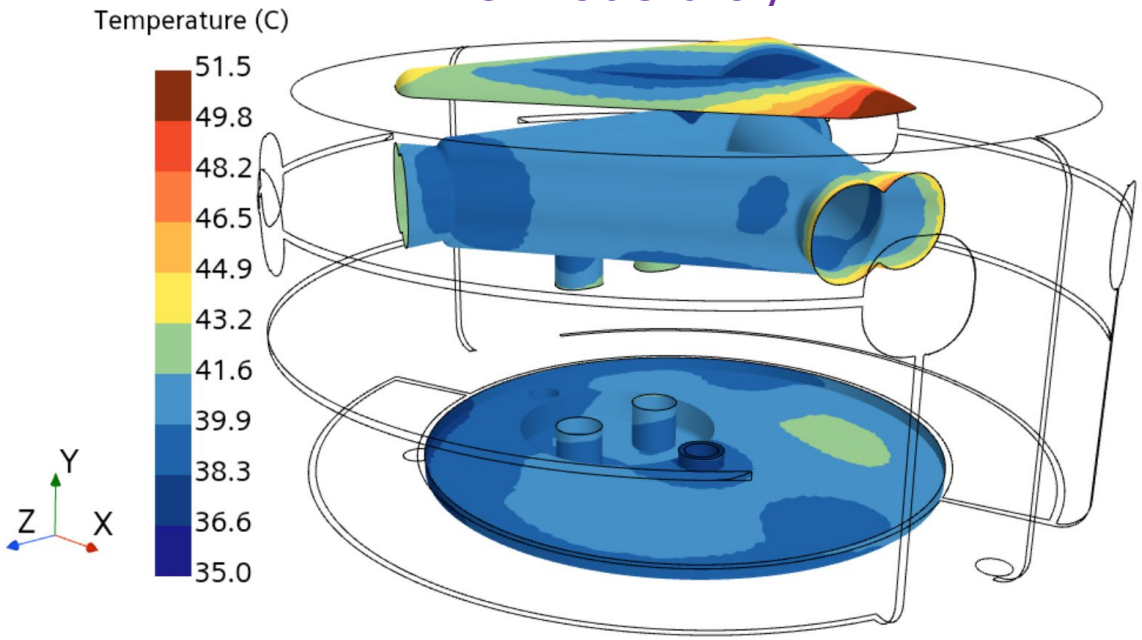
Steady State Heat Transfer Analysis for Lower MRA (without H2 Moderator), Temperature



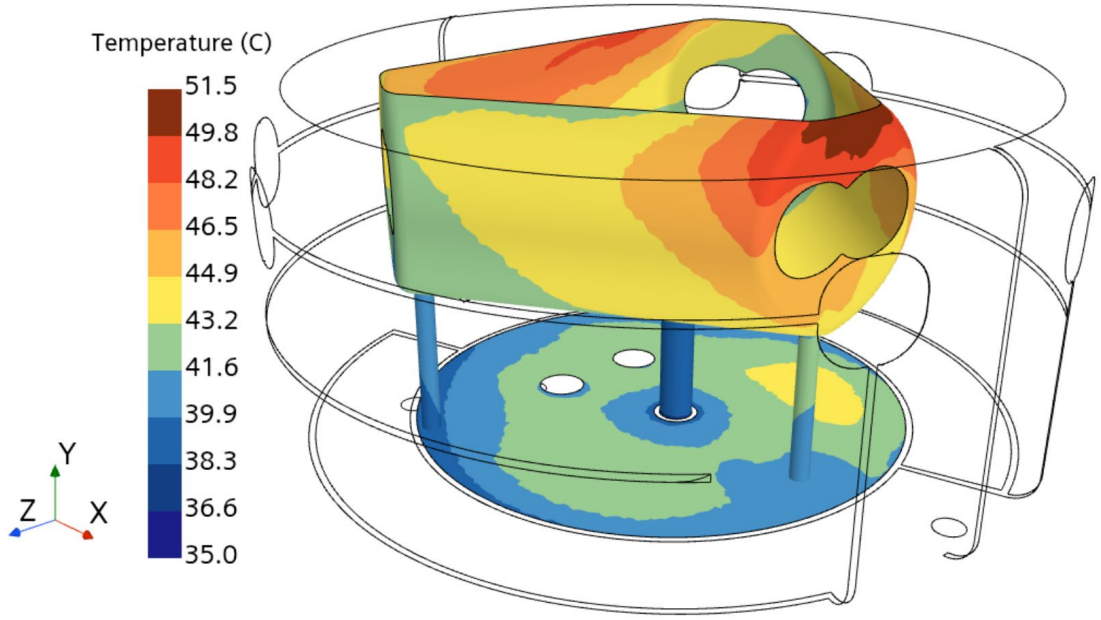


Steady State Heat Transfer Analysis for Lower MRA (without H2 Moderator), Interface Temperature

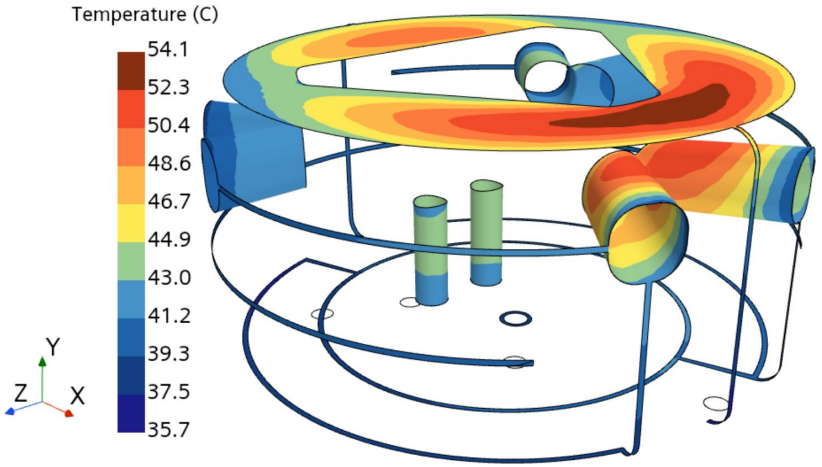
Pre-Moderator/Al



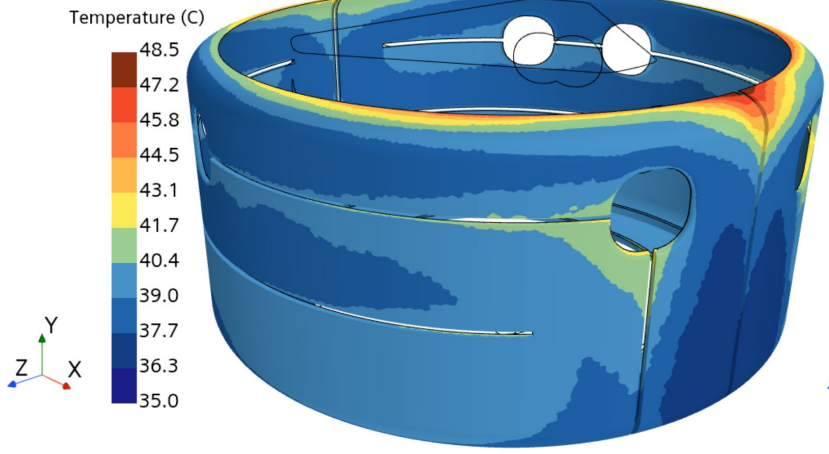
Pre-Moderator/Be



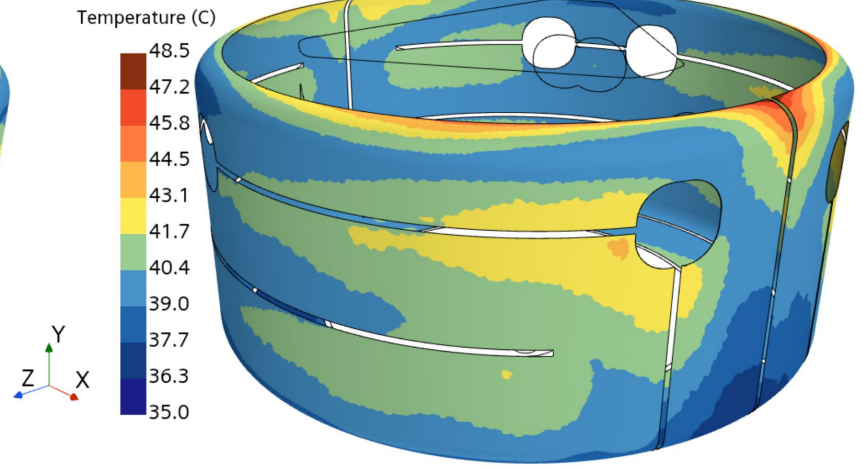
Al/Be



Reflector/Al

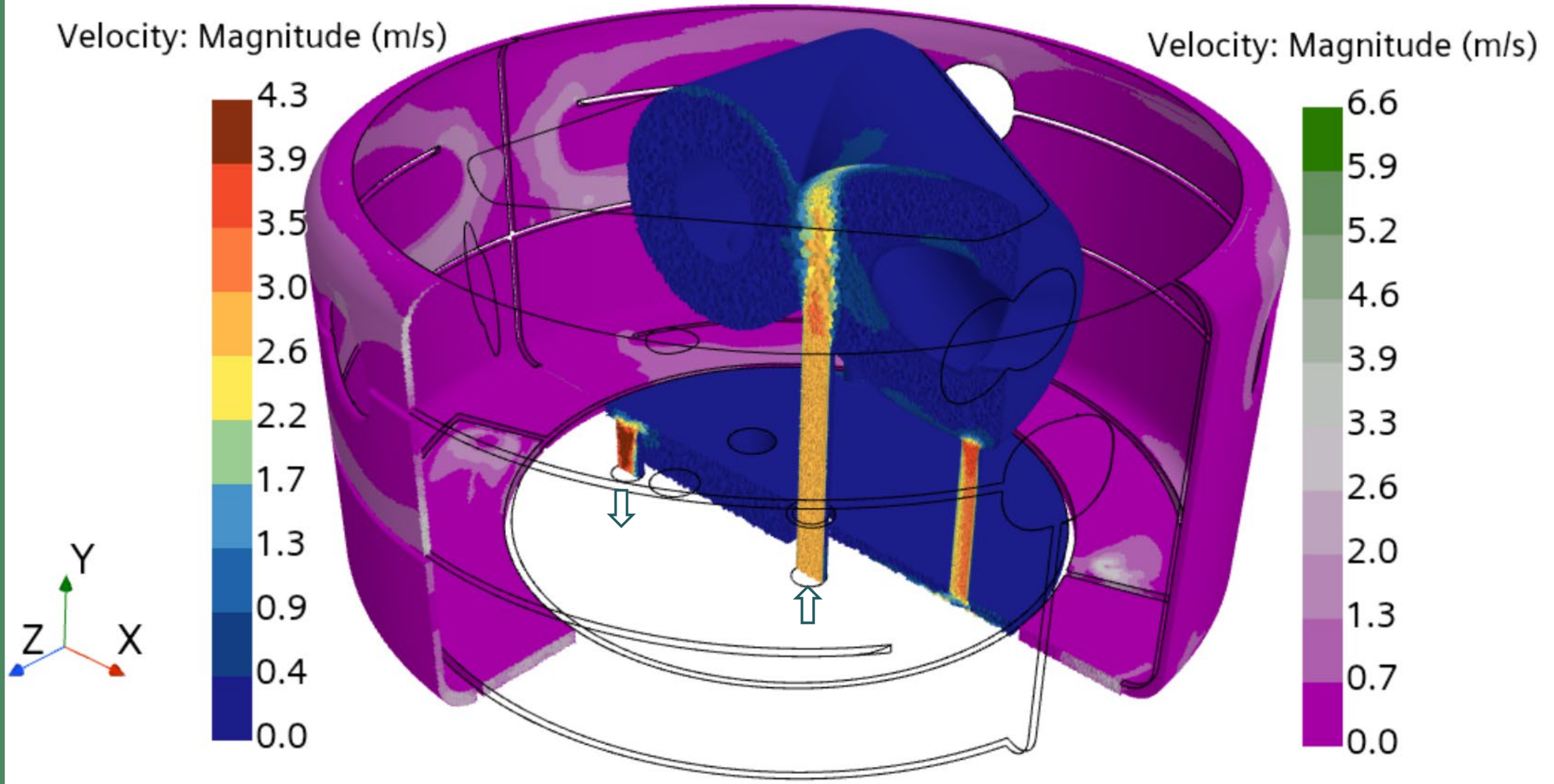


Reflector/Be



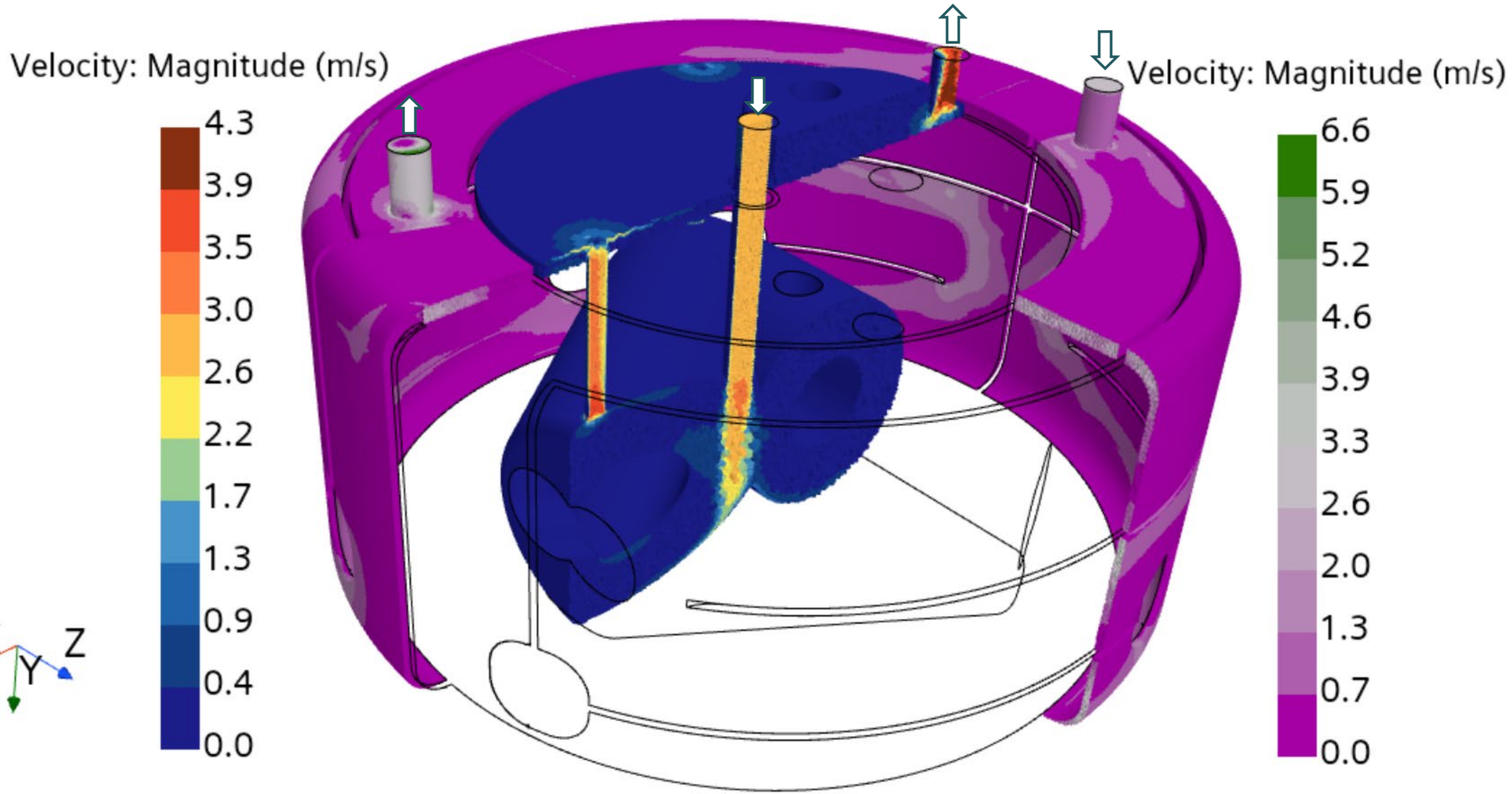
National Laboratory

Steady State Heat Transfer Analysis for Lower MRA, Velocity

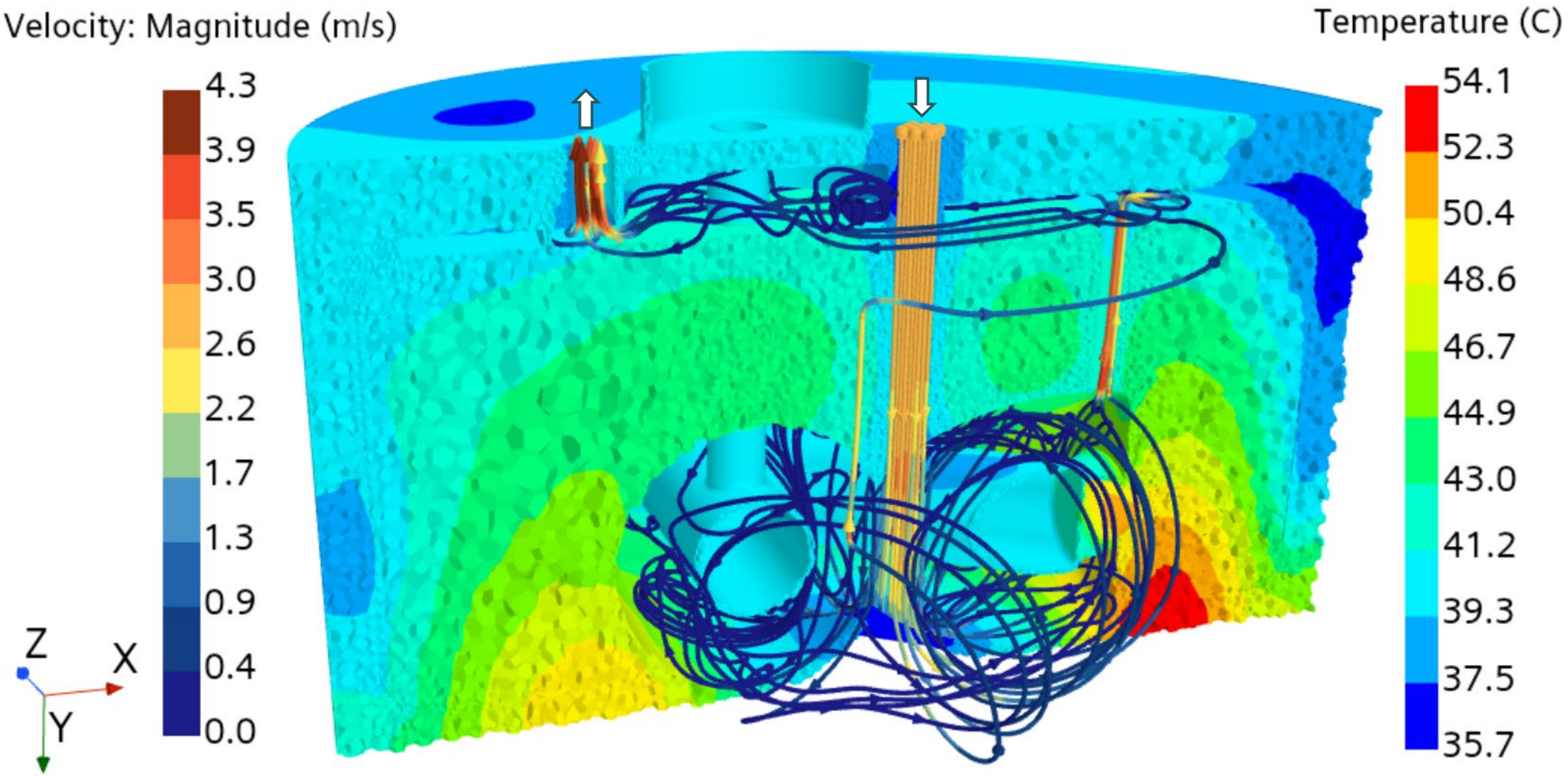


OAK RIDGE National Laboratory

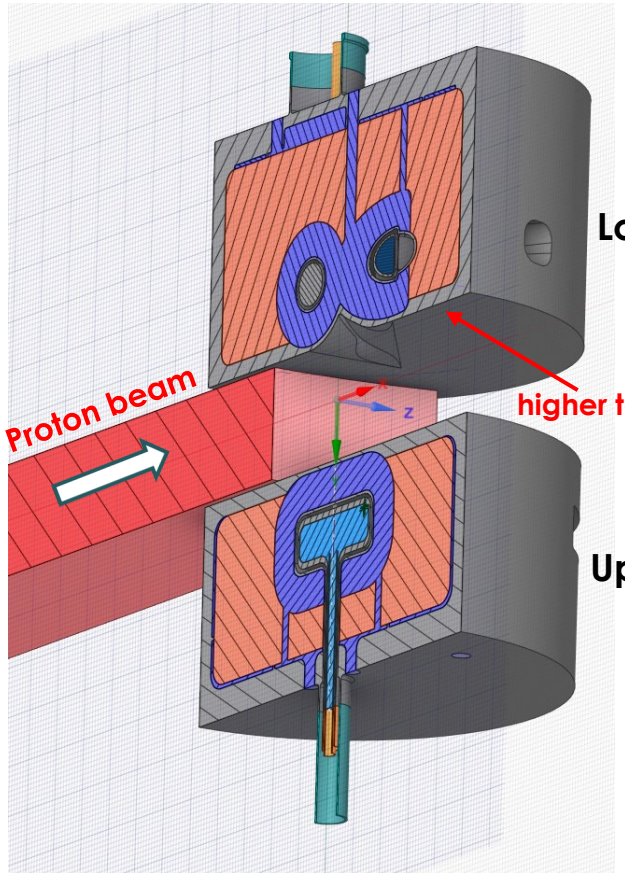
Steady State Heat Transfer Analysis for Lower MRA, Velocity

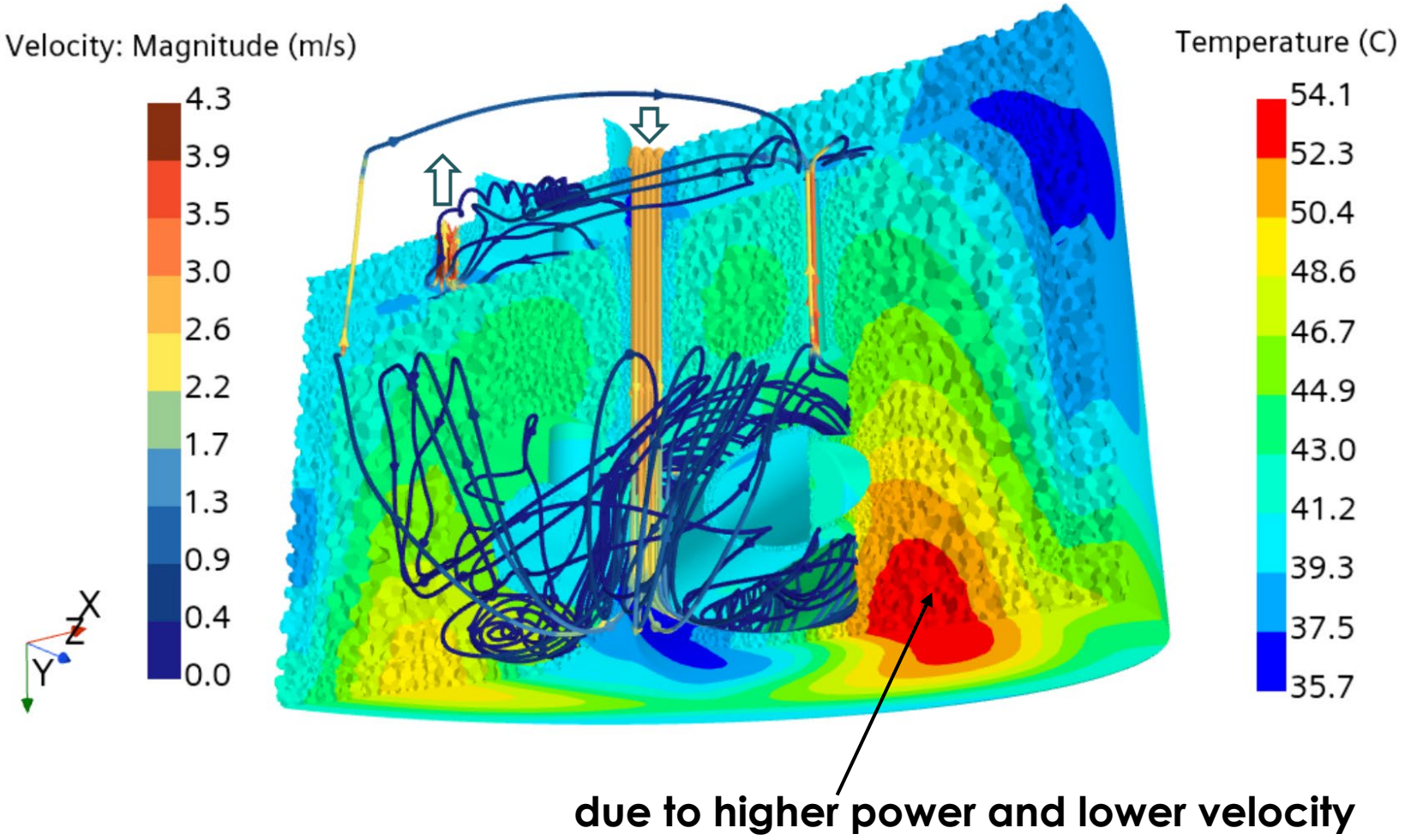


Steady State Heat Transfer Analysis for Lower MRA, Velocity & Temperature



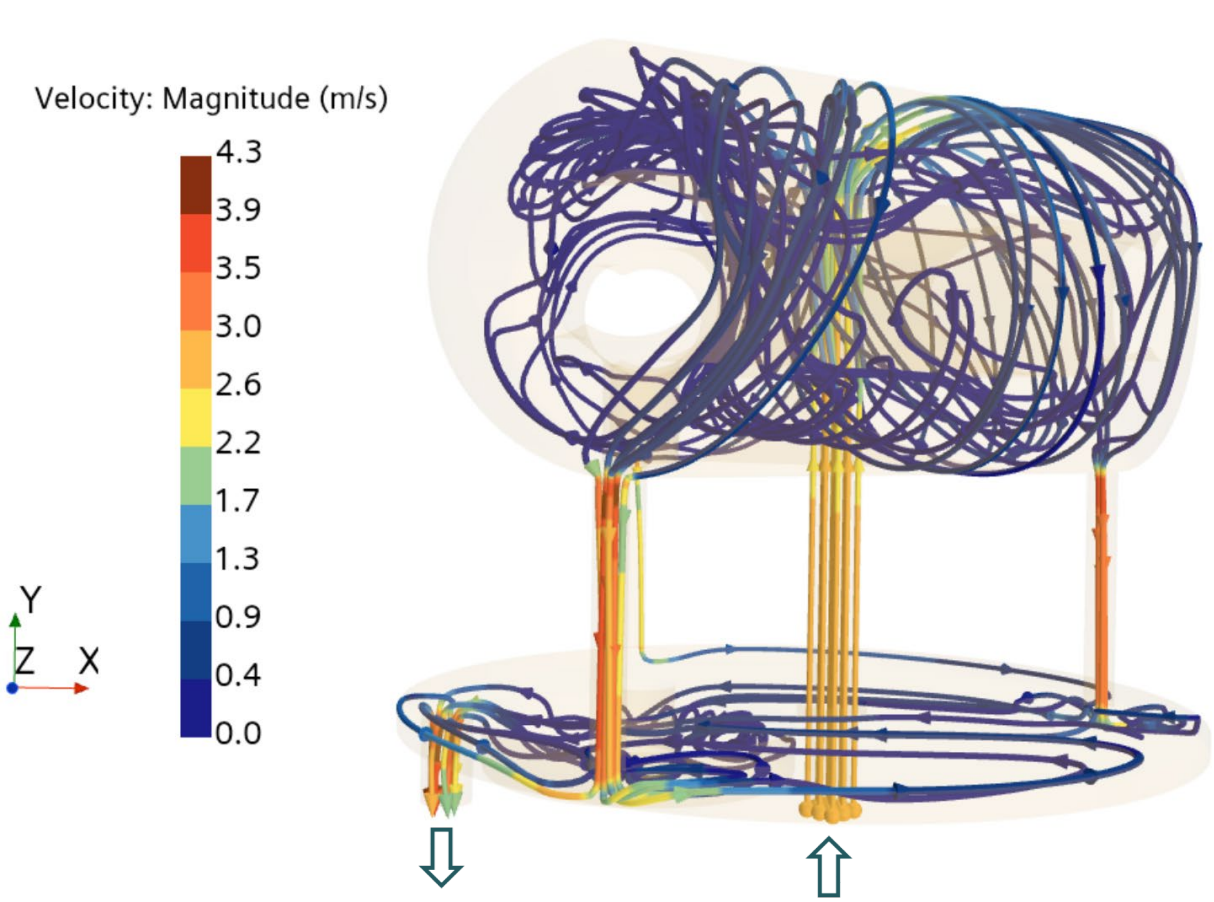
Steady State Heat Transfer Analysis for Lower MRA, Velocity & Temperature

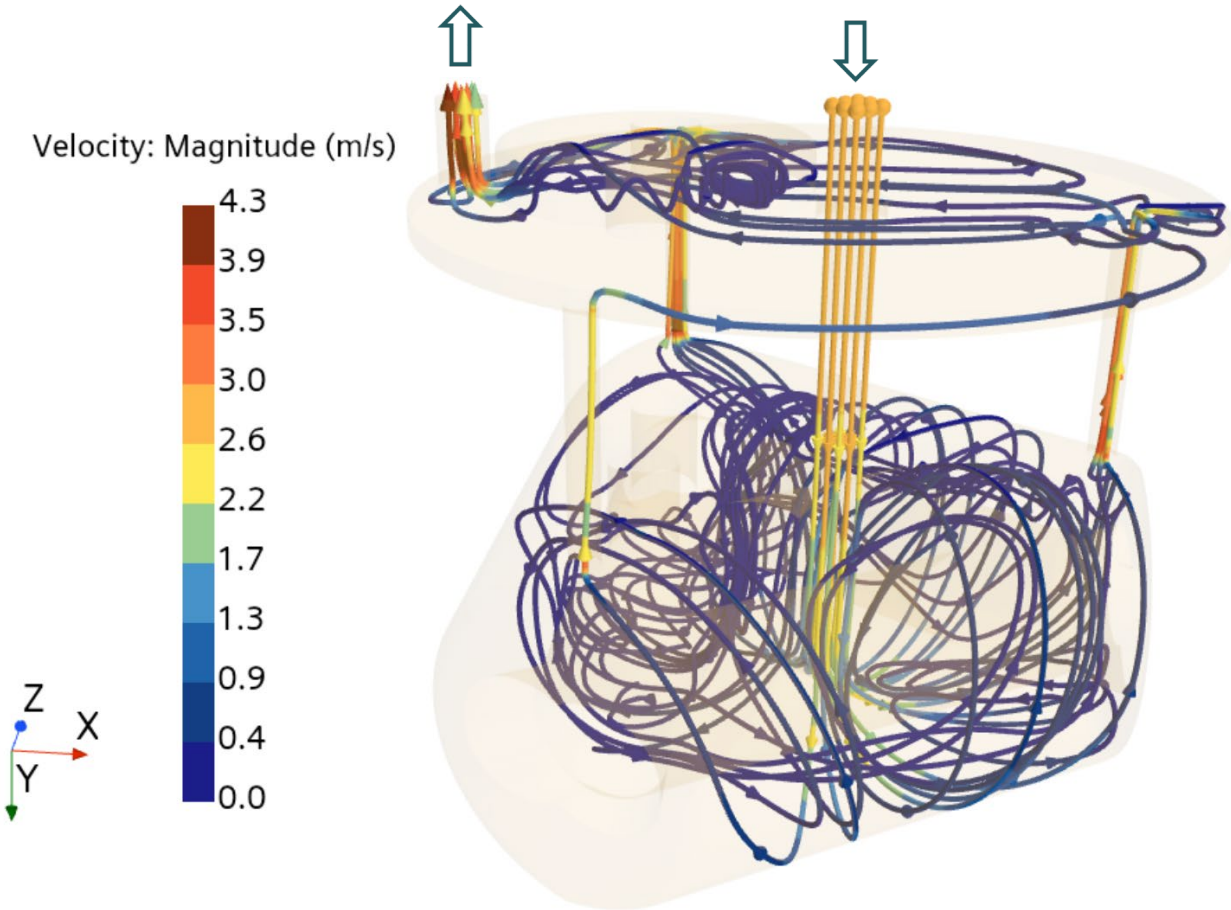




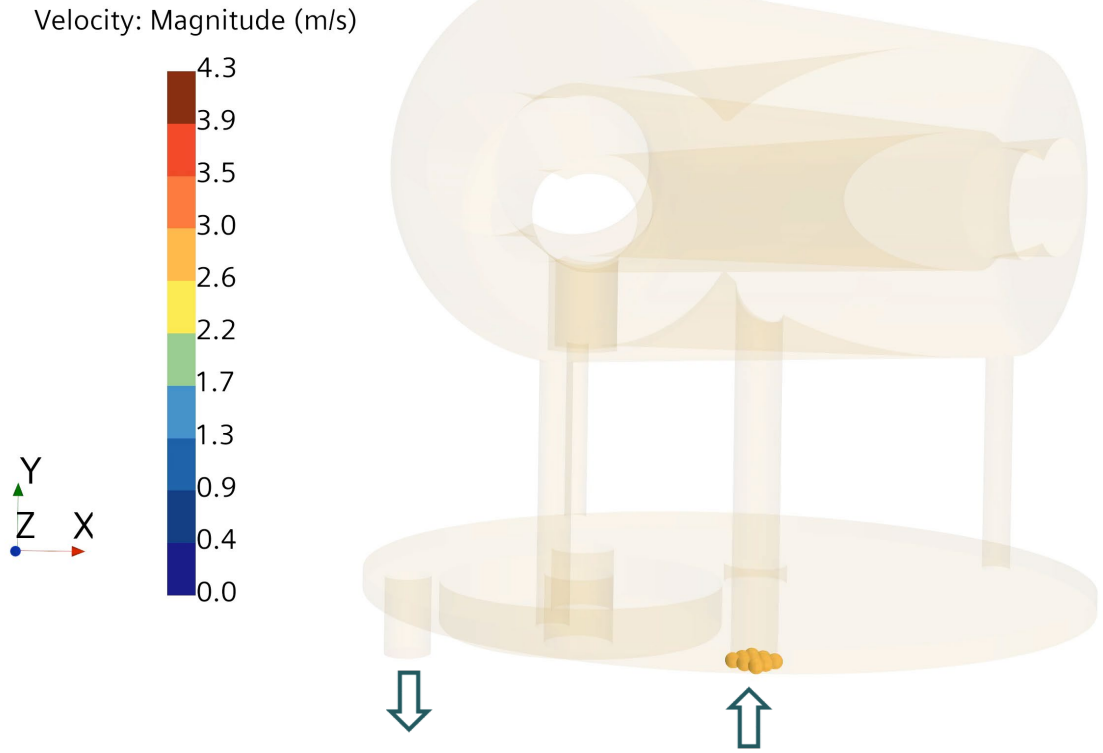
due to higher power and lower velocity

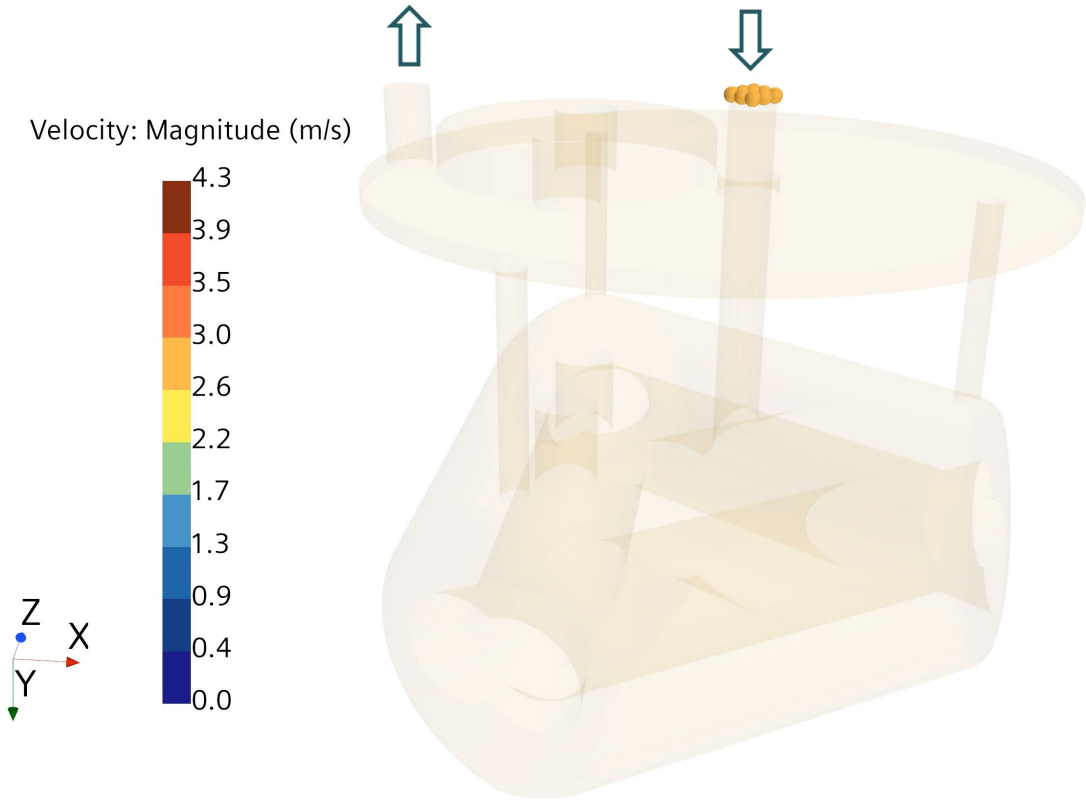
Steady State Heat Transfer Analysis for Lower PreModerator, Streamlines



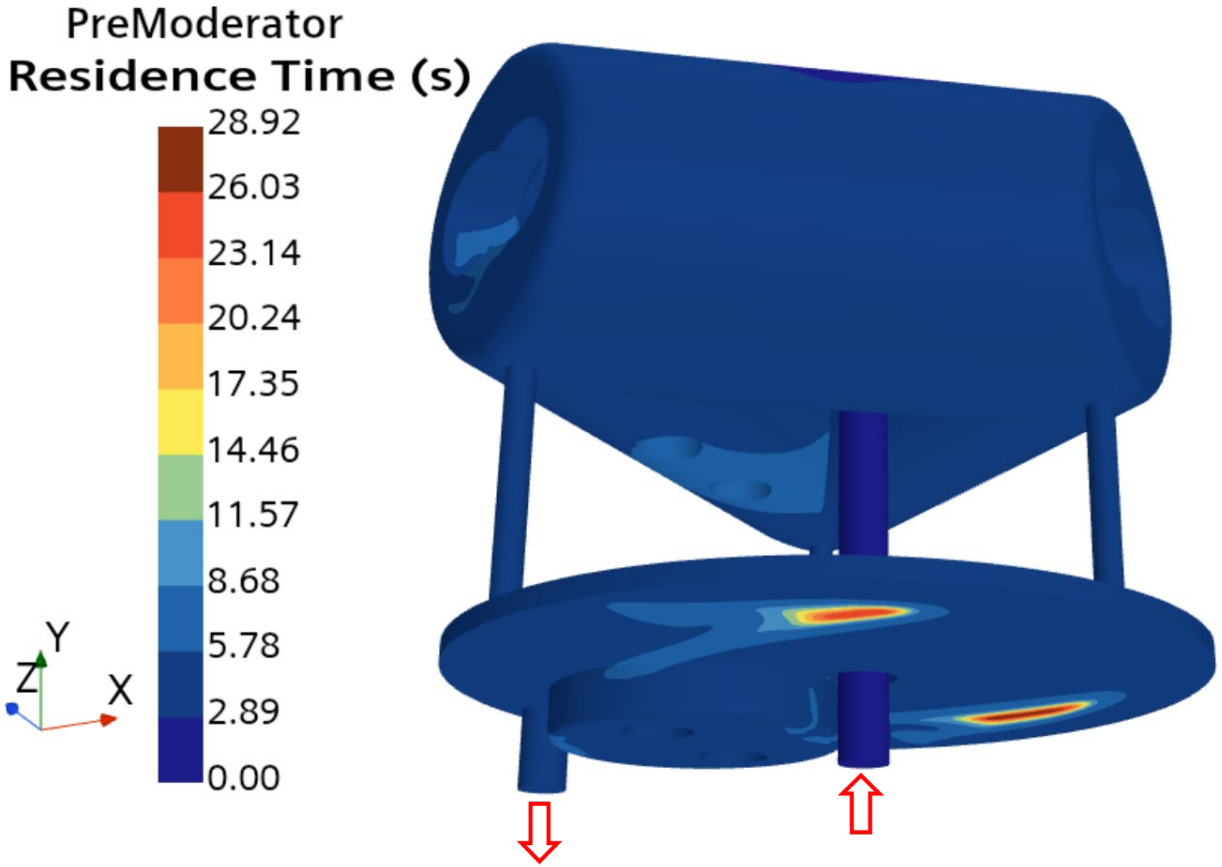


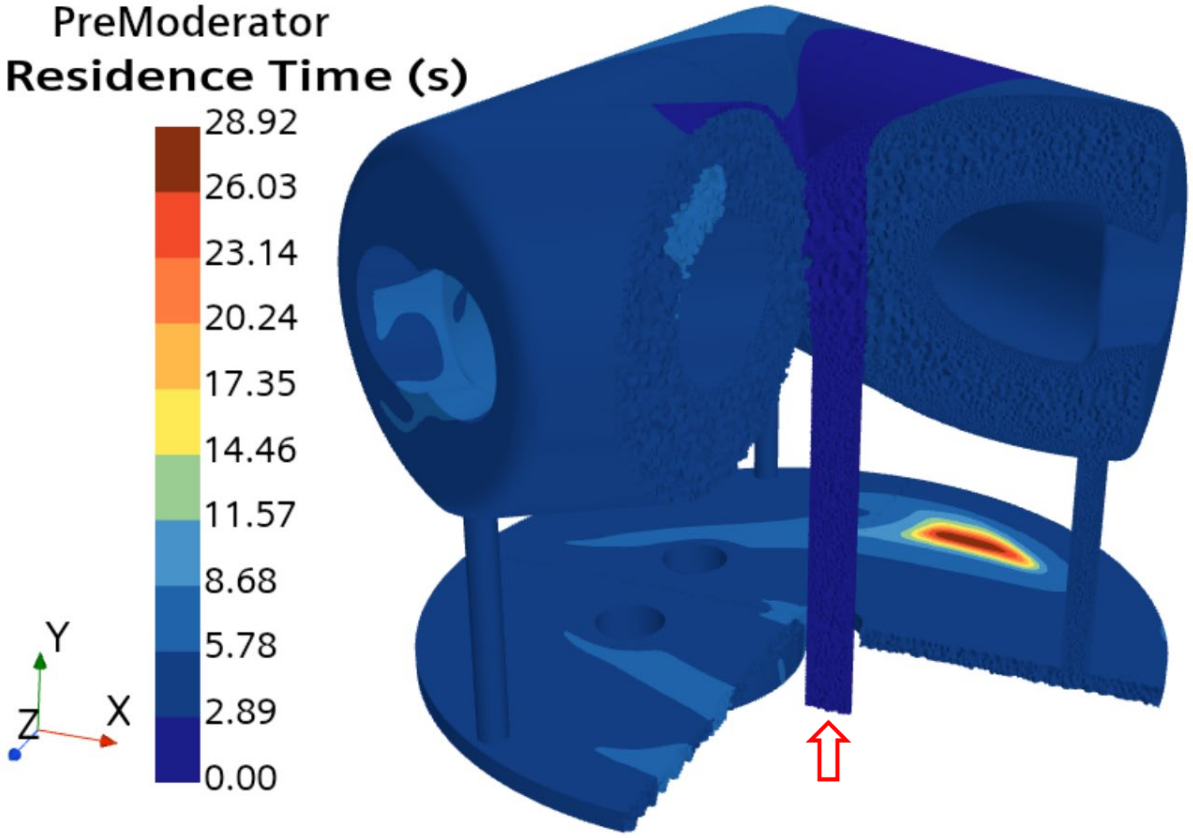
Steady State Heat Transfer Analysis for Lower PreModerator, Streamline Animation



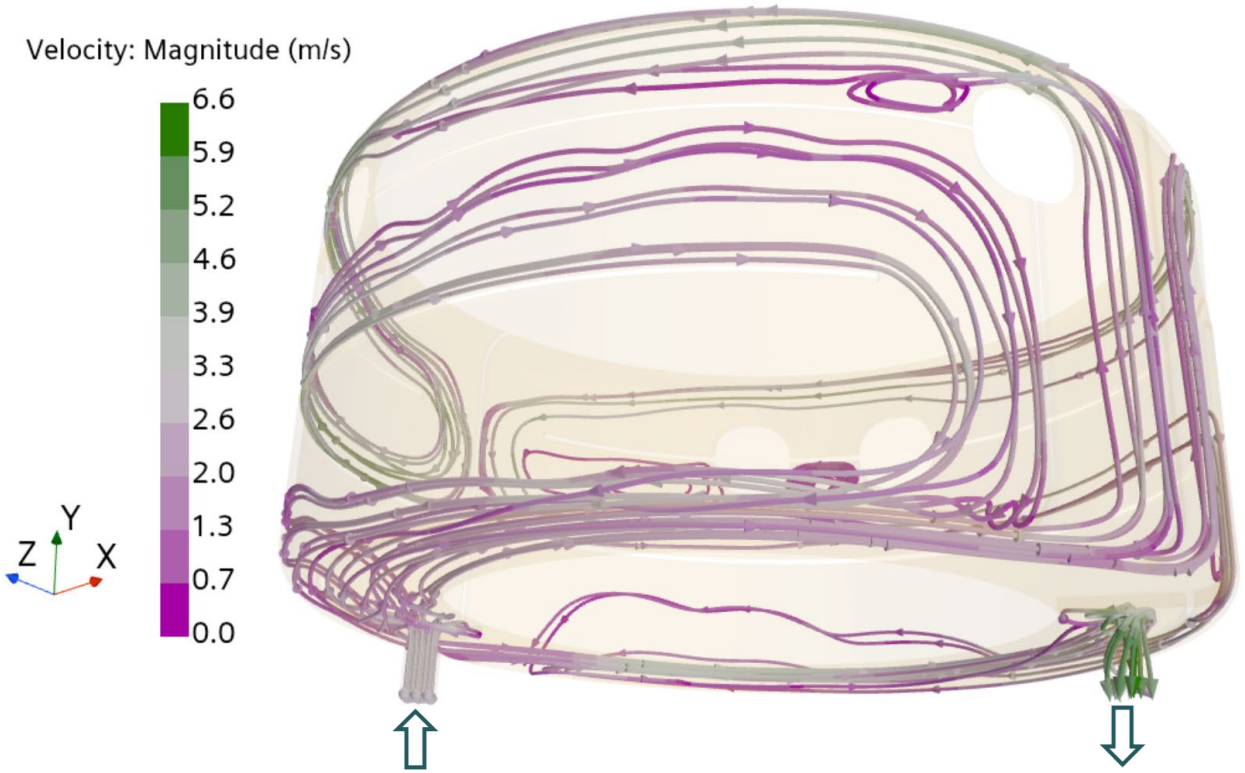


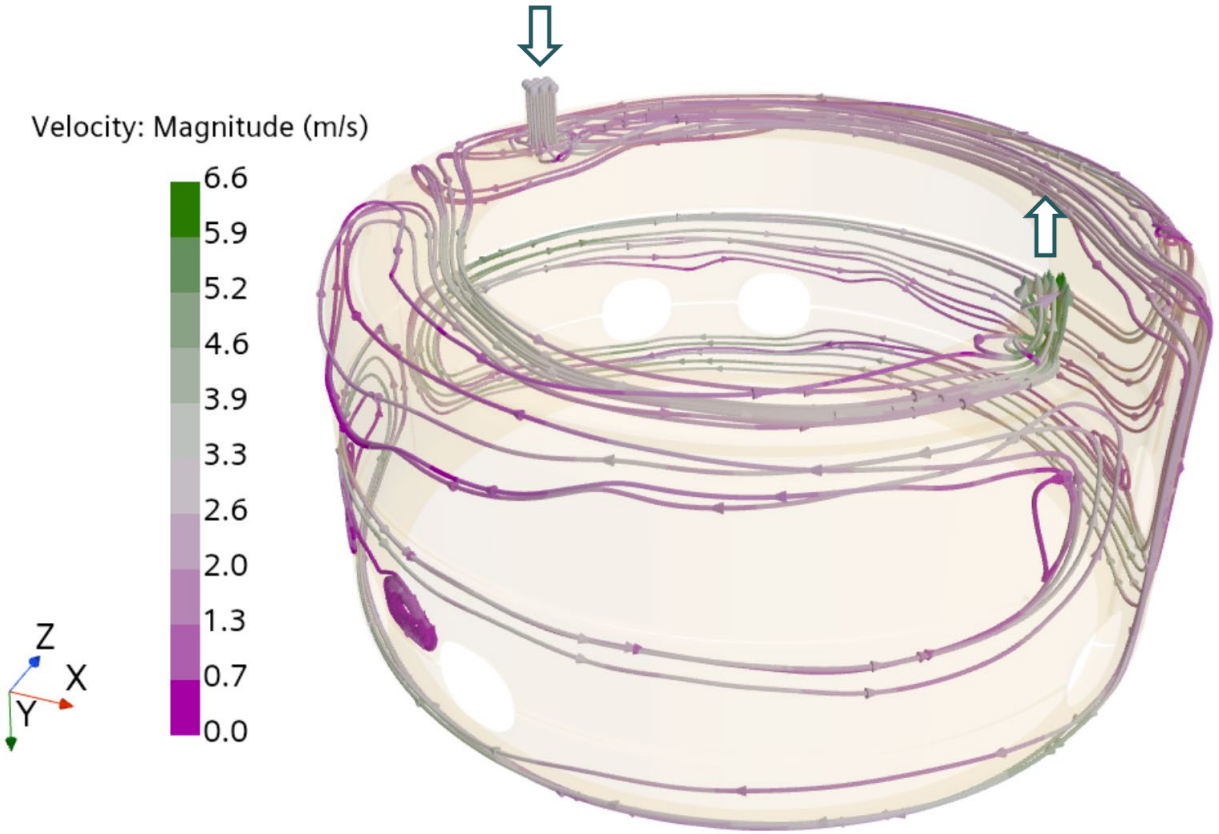
Steady State Heat Transfer Analysis for Lower PreModerator, Residence Time



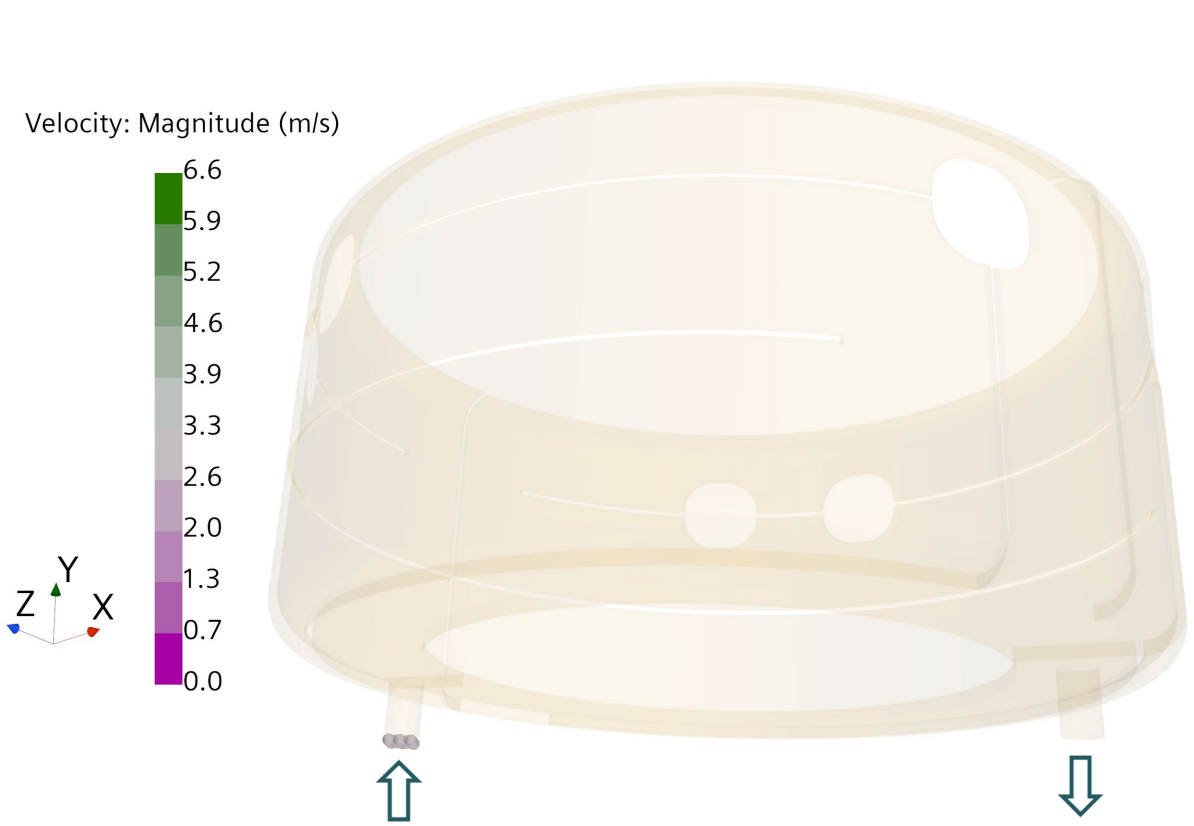


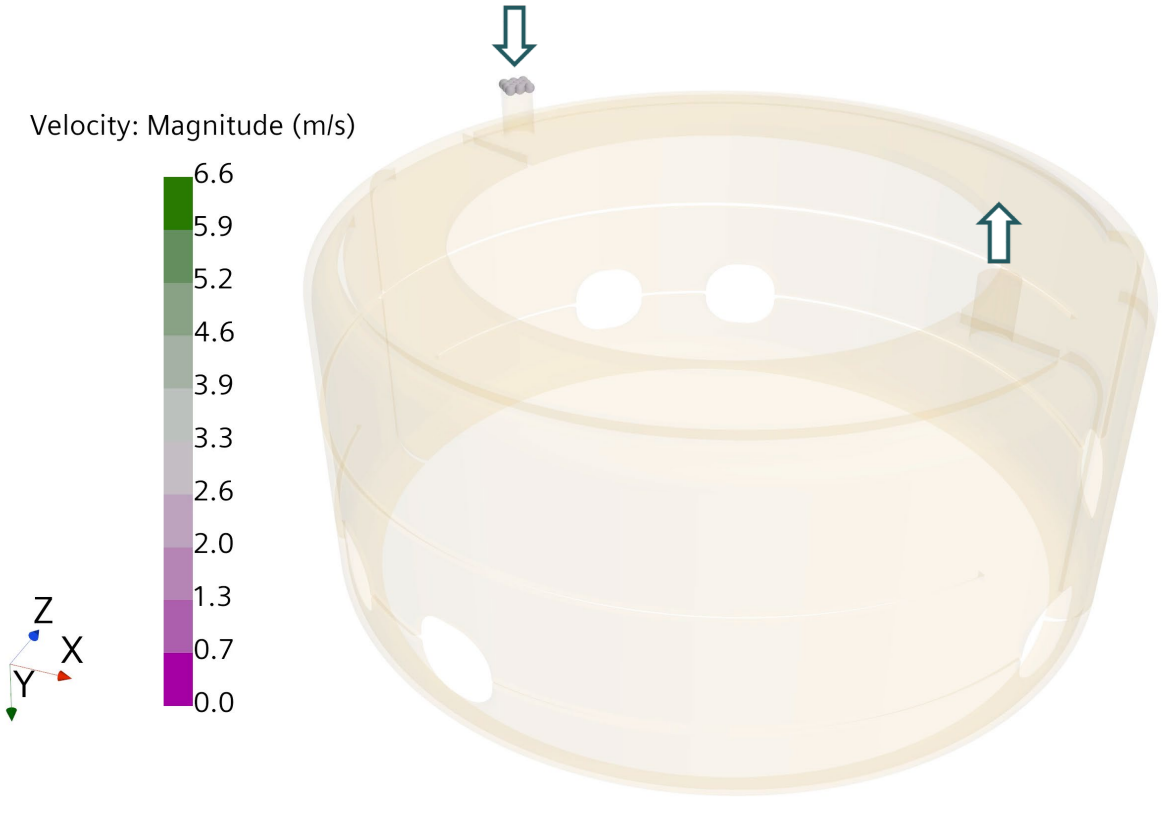
Steady State Heat Transfer Analysis for Lower Reflector, Streamlines



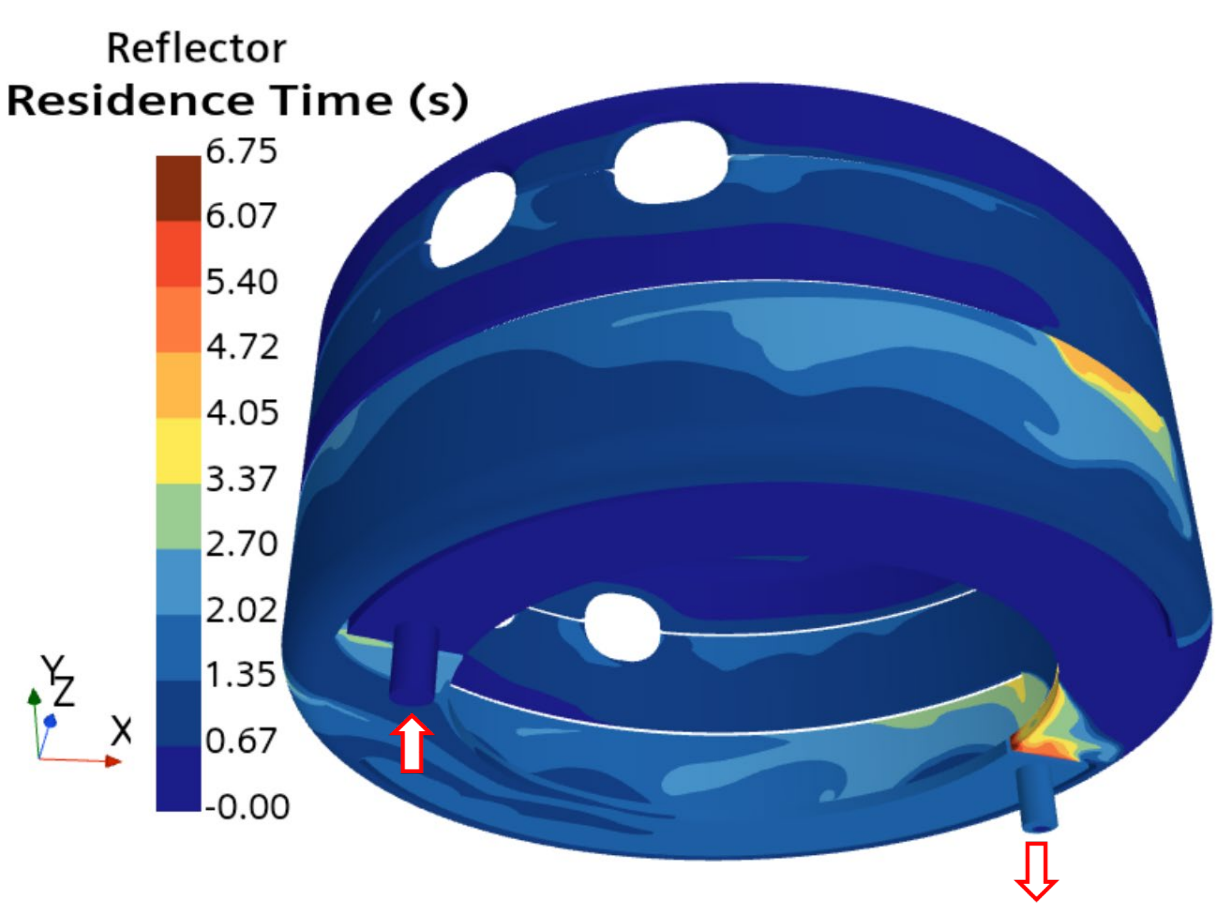


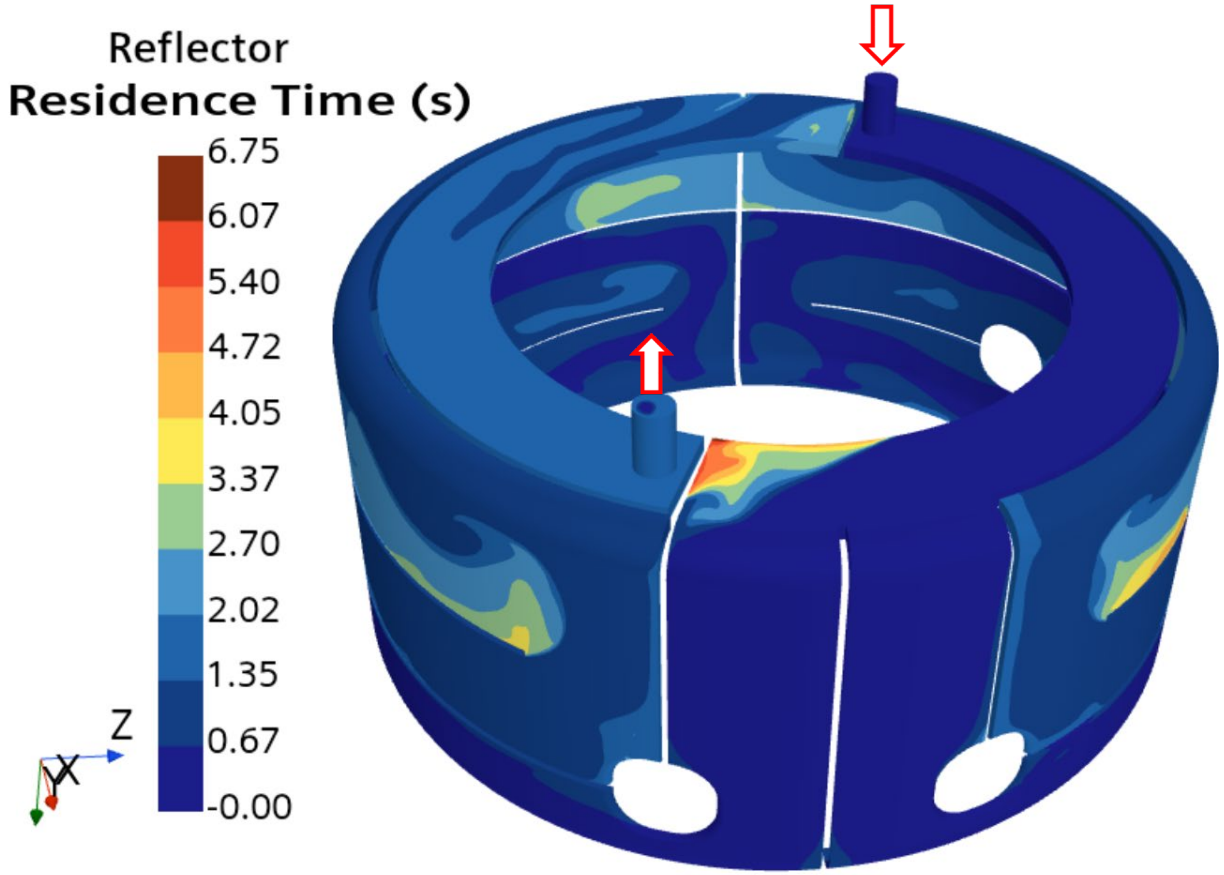
Steady State Heat Transfer Analysis for Lower Reflector, Streamline Animation





Steady State Heat Transfer Analysis for Lower Reflector, Residence Time





Comparison between Requirements and CFD Results

Lower MRA (without Moderator)

	Requirement	CFD Result	
Maximum Aluminum Temperature (°C)	< 100	54.1	
Maximum Beryllium Temperature (°C)	< 100	53.6	
		PreModerator	**Reflector**
Pressure Drop (psi)	< 15	2.08	7.7
Maximum Water Temperature (°C)	< 100	51.5	48.5

- All requirements are met with at least a factor of 1.95 margin
  - High confidence that margin to requirements is significantly higher than uncertainties

Summary

- The locations of the inlet and outlet for the reflector were adjusted several times to reduce the pressure drop from 22 psi to 8 psi. The main idea is to reduce the vortex near the outlet since the pressure within the vortex region is very low and thus the pressure would be increased.
- All requirements are met with large margins.
- Items to be included in final analysis
  - Update inlet/outlet geometry based on final backbone design
    - Preliminary backbone inlet/outlets are moved slightly from locations used in this analysis
  - Update inlet temperature to match final process systems inlet temperature – current estimate is 32.3 C
  - Include weld backer geometry for the reflector vessel welds