SAND2010-7325P

Advances in Porous Media Modeling for Helium Cooling Applications

Dennis Youchison, Joe Garde
Sandia National Laboratories
Albuquerque, NM

October 22, 2010

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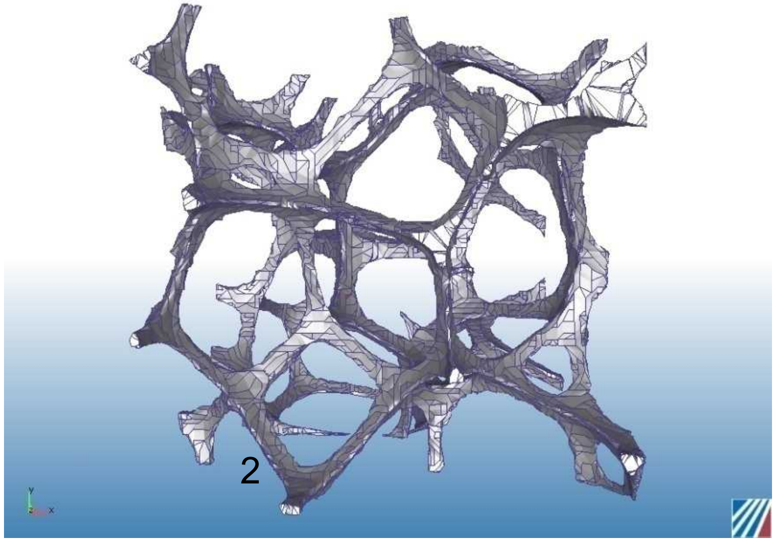
Outline

- Porous media - Foam geometry
- Computerized microtomography
- Model generation
- Meshing
- Conjugate heat transfer with CFD
- Heat exchanger applications
- Thermal stress analysis

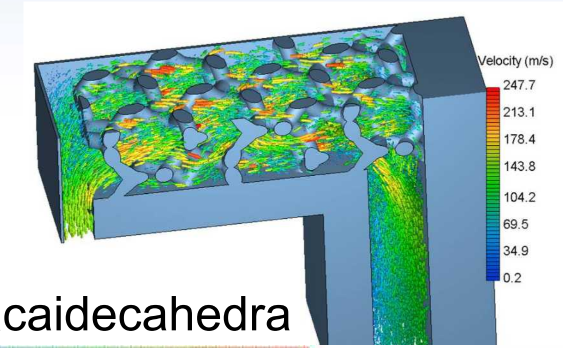
We perform CFD modeling of foam porous media heat transfer on the microscale.

- Computerized X-ray microtomography was completed at Sandia on Ultramet supplied foam samples. The smaller files were translated from stereolithography format to ACIS solid modeling format.
- The solid models of the detailed foam microstructure were meshed and analyzed by commercial computational fluid dynamics (CFD) codes (CFDesign and CCM+) to determine the effective permeability and ligamental heat conduction.
- Foam models derived from computerized x-ray tomography were closed with facesheets of SiC on one side and steel on the other inside CCM+.
- The CCM+ tet mesh was exported to Abaqus for stress analysis.
- Deflections, inelastic strains and stresses were computed in the ligaments and permeation barrier facesheets using Abaqus.

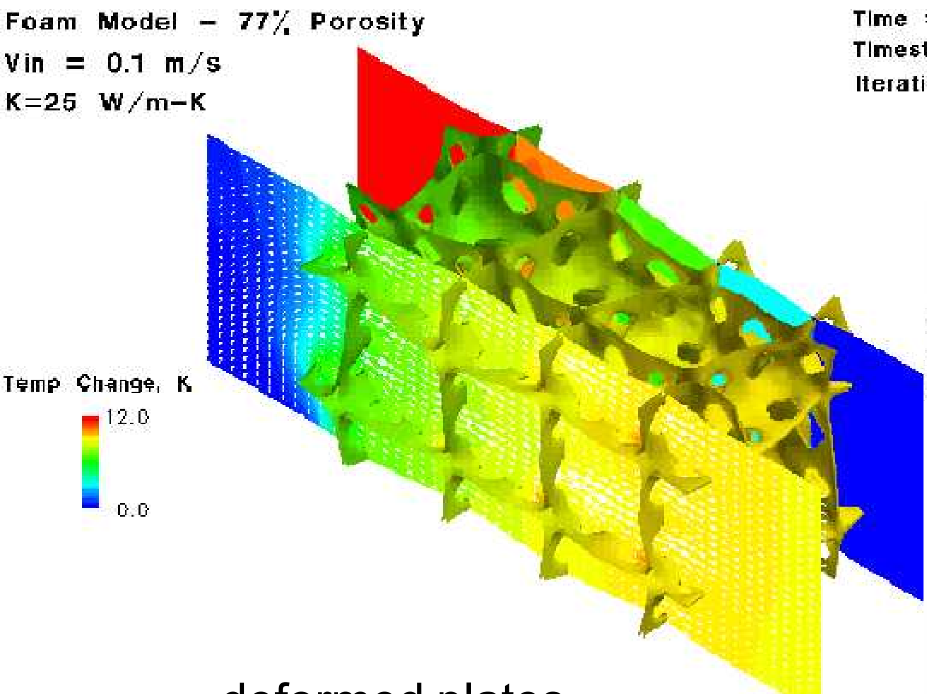
X-ray microtomography file of carbon foam after translation to ACIS solid modeling format.



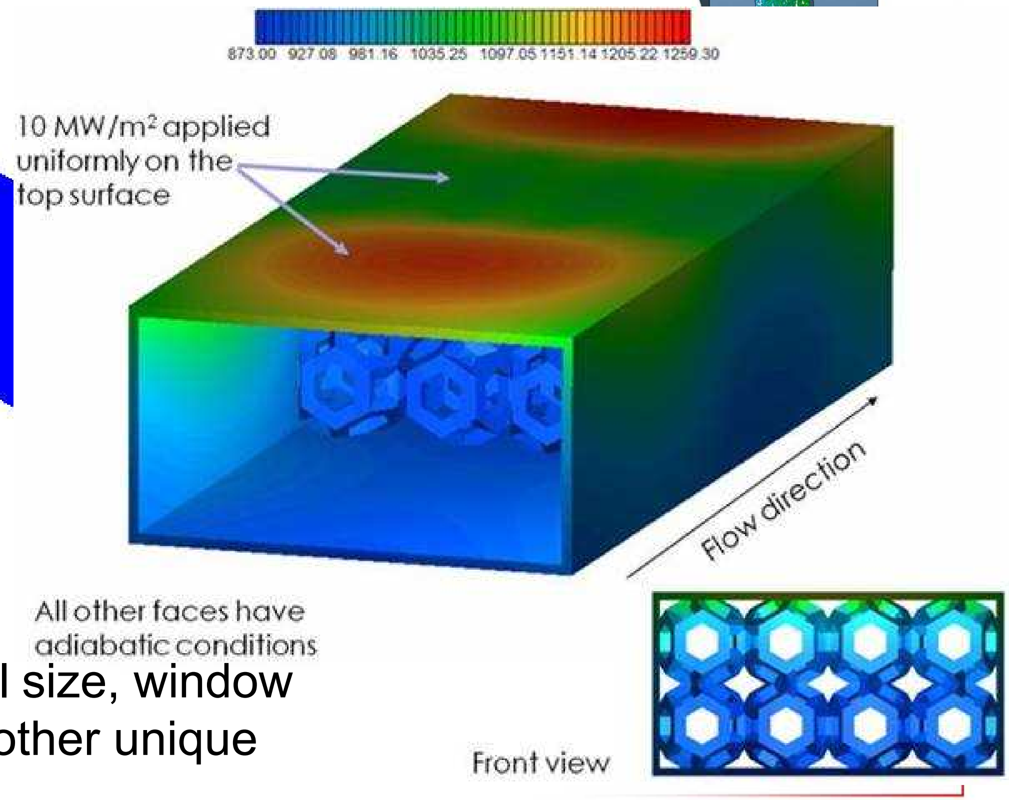
Previous modeling relied on periodic structures.



tetracaidecahedra



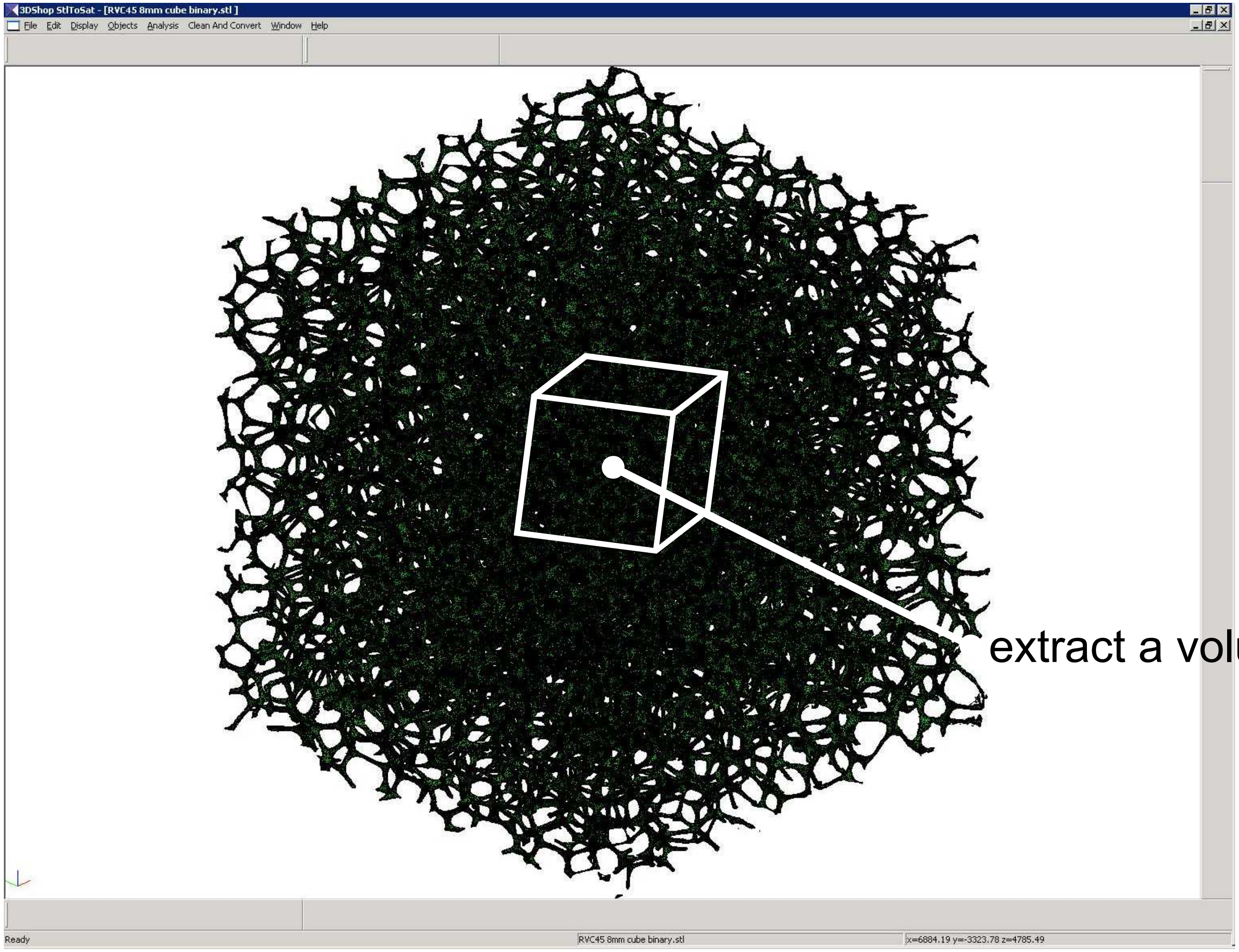
deformed plates



Failed to capture the randomness in cell size, window orientation, non-uniform ligaments and other unique characteristics of commercial foams.

Processing geometry and meshing are greatest challenge.

8 mm x 8 mm x 8 mm 45 ppi RVC skeleton



extract a volume

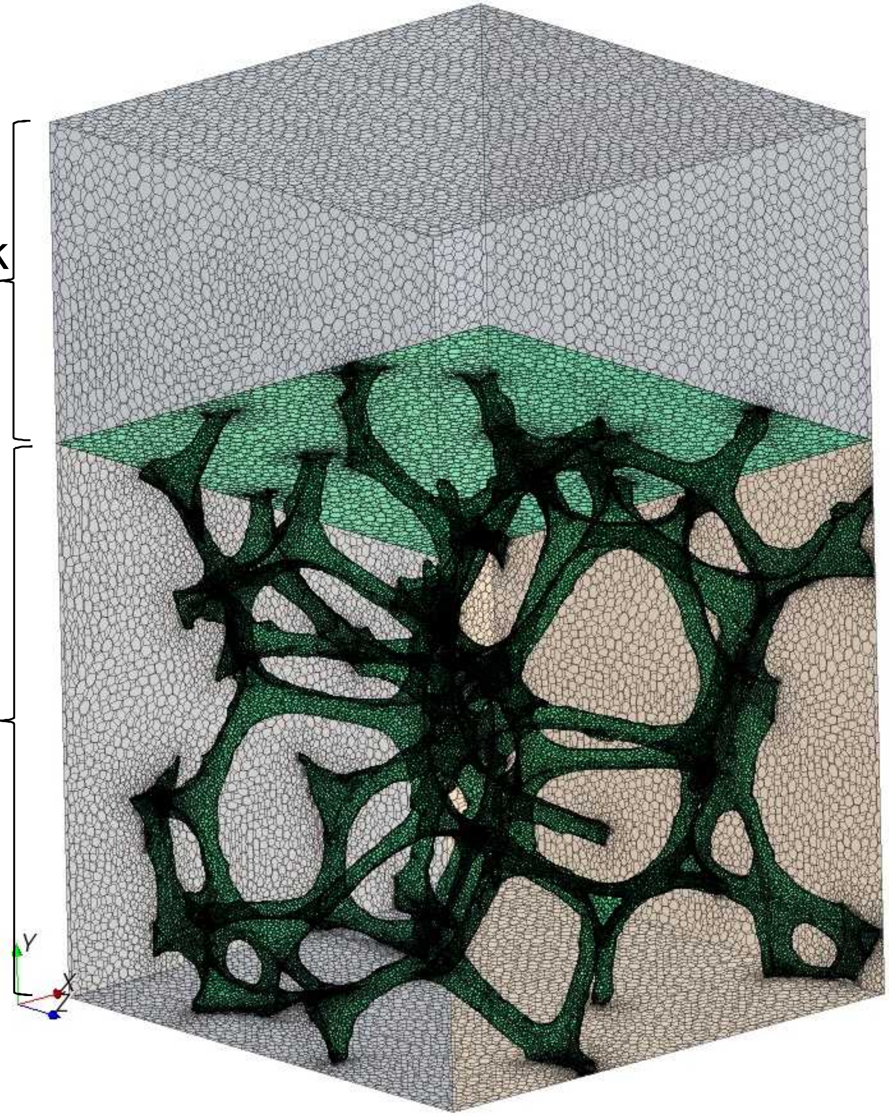
Tomography
•VGStudio MAX by Volume Graphics

File translation
•3dShop by C4W
•Rhino 3d
•Cubit
•Star CCM+

Modeling is computationally expensive.

1 mm thick solid wall

foam-filled channel



Commercial CFD Codes
- Star-CCM+ v5.04
- Cfdesign v10

One-million element polyhedral mesh with three prism layers at all solid/gas interfaces.

1.7 mm x 1.7 mm x 2.7 mm high. Arbitrarily chosen volume extracted from 8x8x8 mm^3 volume shown earlier. Wall added in CCM+.

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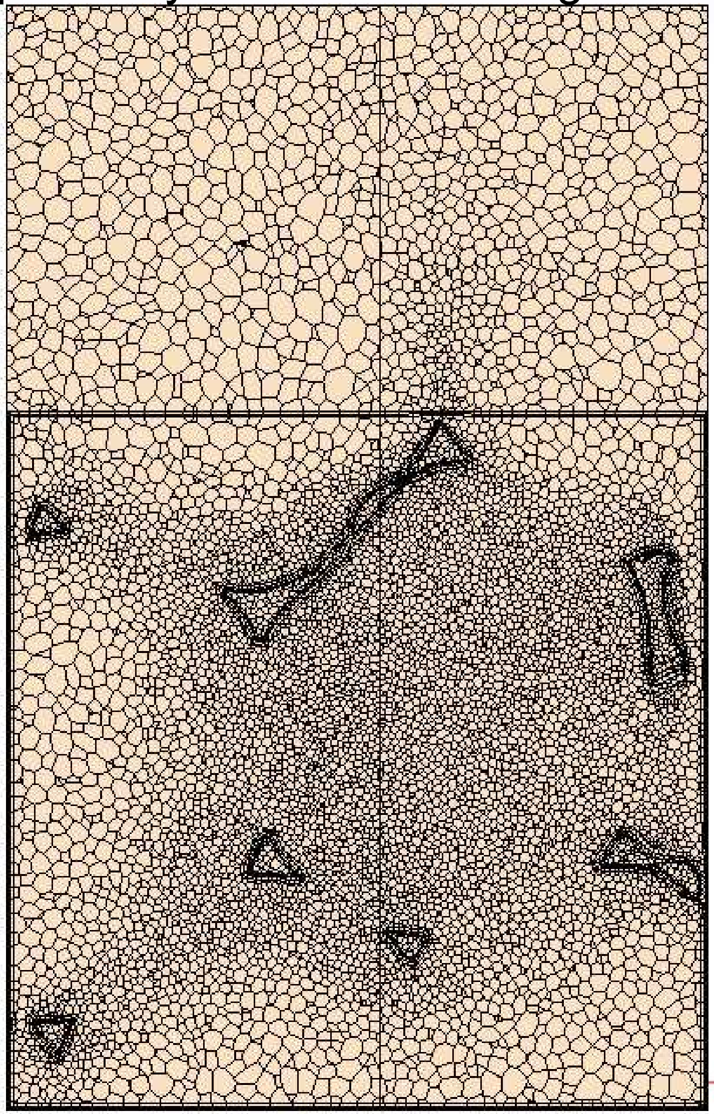
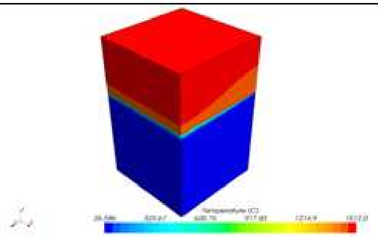
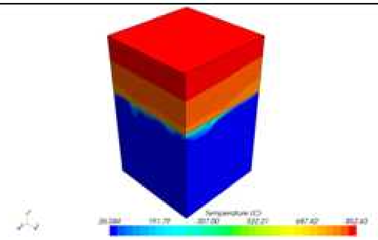
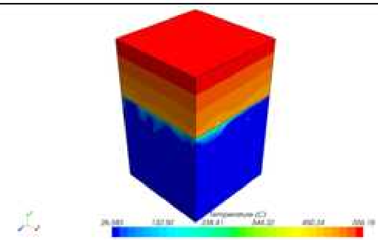
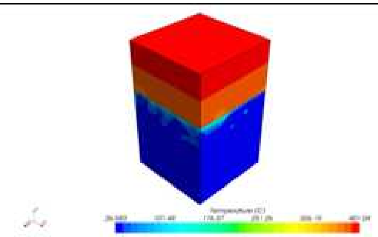
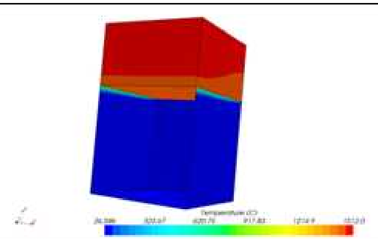
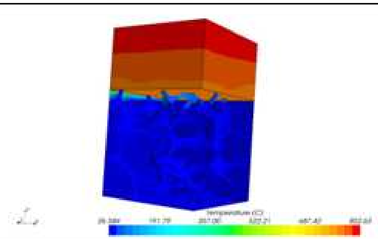
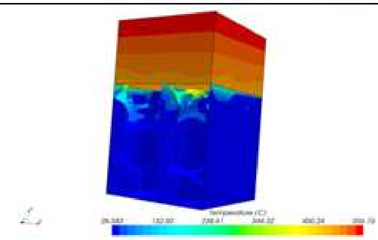
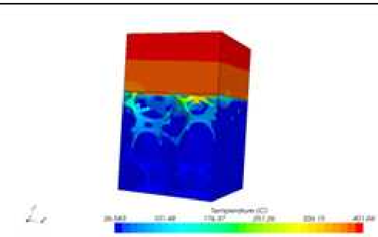
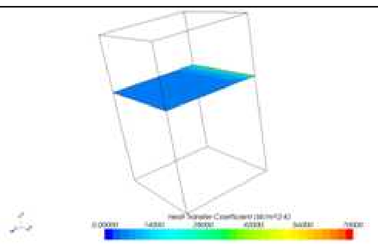
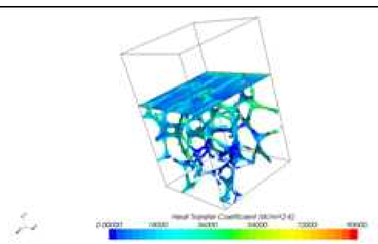
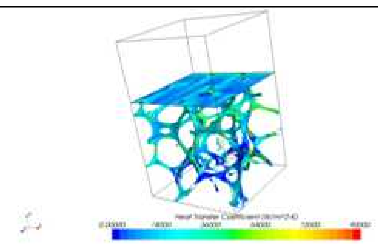
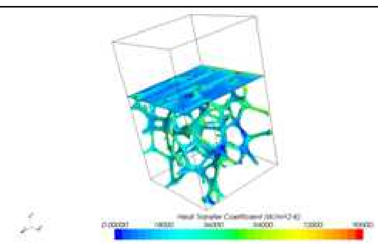
Imprint and merge 3 solids and a fluid

3 prism layers at walls and ligaments



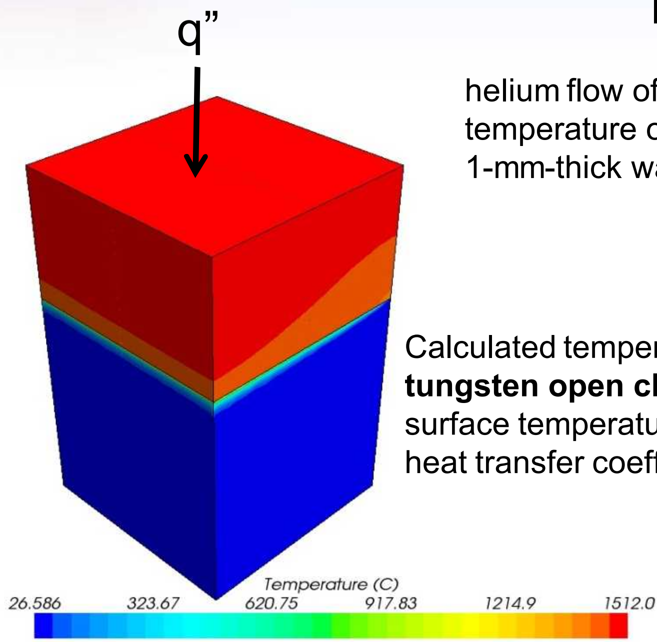
Porous media is effective in enhancing gas cooling.

Table 1. Comparison of Foam Effectiveness to Open Channels

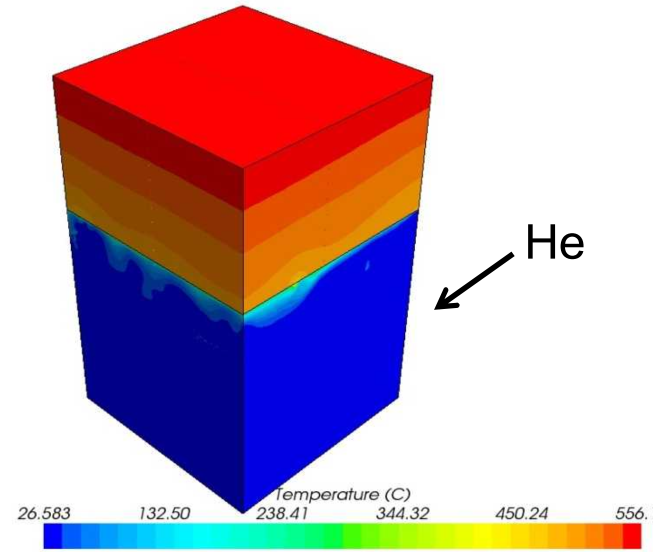
Open Channel	Unconnected 45-ppi W foam	Connected 45-ppi W foam	Connected 45-ppi Cu foam
			
			
			
h=7100 W/m2K	h=13,200 W/m^{2}K	h=21,500 W/m^{2}K	h=28,350 W/m^{2}K

Conductivity of foam can affect performance.

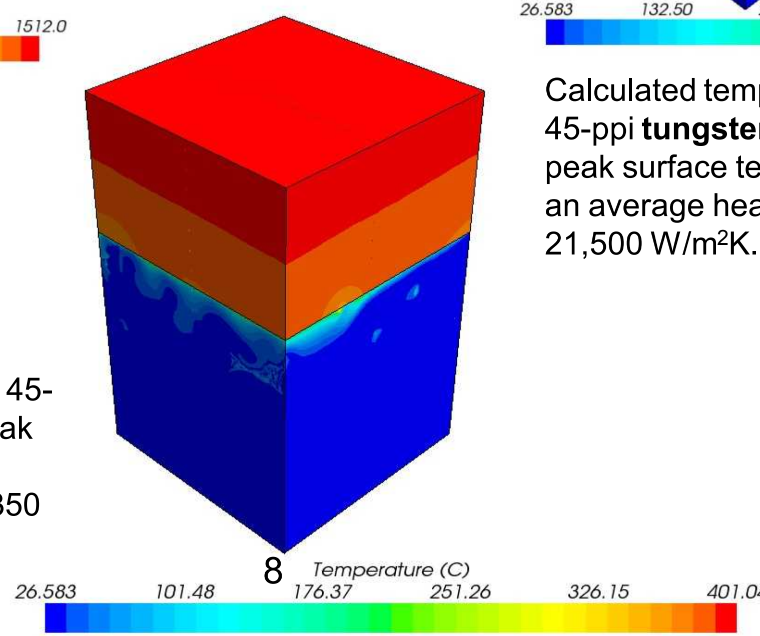
helium flow of 1 g/s at 4 MPa with an inlet temperature of 26.8 ^{o}C.   q”=5 MW/m^2 on a 1-mm-thick wall.



Calculated temperature distribution in a **tungsten open channel** duct reveals a peak surface temperature of 1512 ^{o}C with an average heat transfer coefficient of 7100 W/m^{2}K.

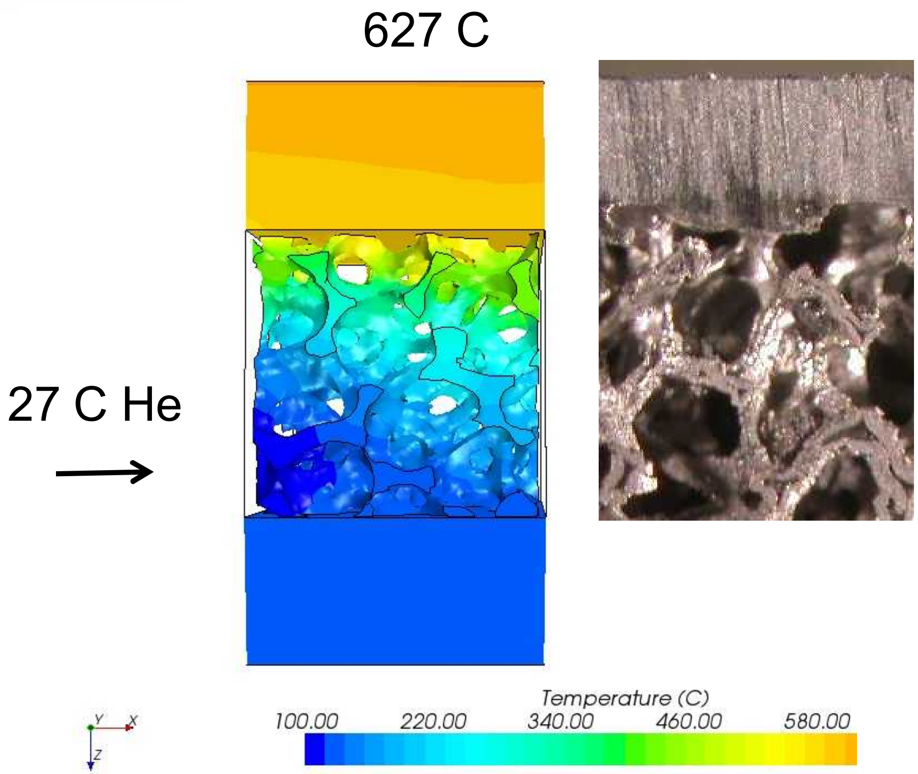


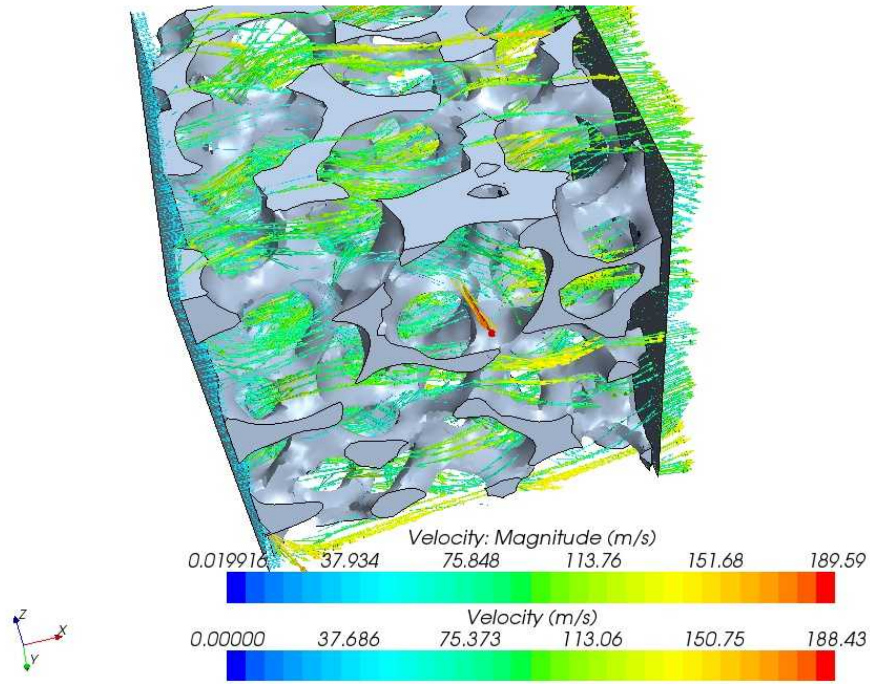
Calculated temperature distribution in a 45-ppi **tungsten foam channel** reveals a peak surface temperature of 556 ^{o}C with an average heat transfer coefficient of 21,500 W/m^{2}K.



Calculated temperature distribution in a 45-ppi **copper foam channel** reveals a peak surface temperature of 401 ^{o}C with an average heat transfer coefficient of 28,350 W/m^{2}K.

Analysis reveals turbulent mixing and fin effect created by foam.





Convection models for 2 mm x 2 mm 65 ppi, 10% dense moly foam attached to 1 mm thick moly walls. Temperature distribution is shown on left with velocity vectors and streamlines through the foam on the right.

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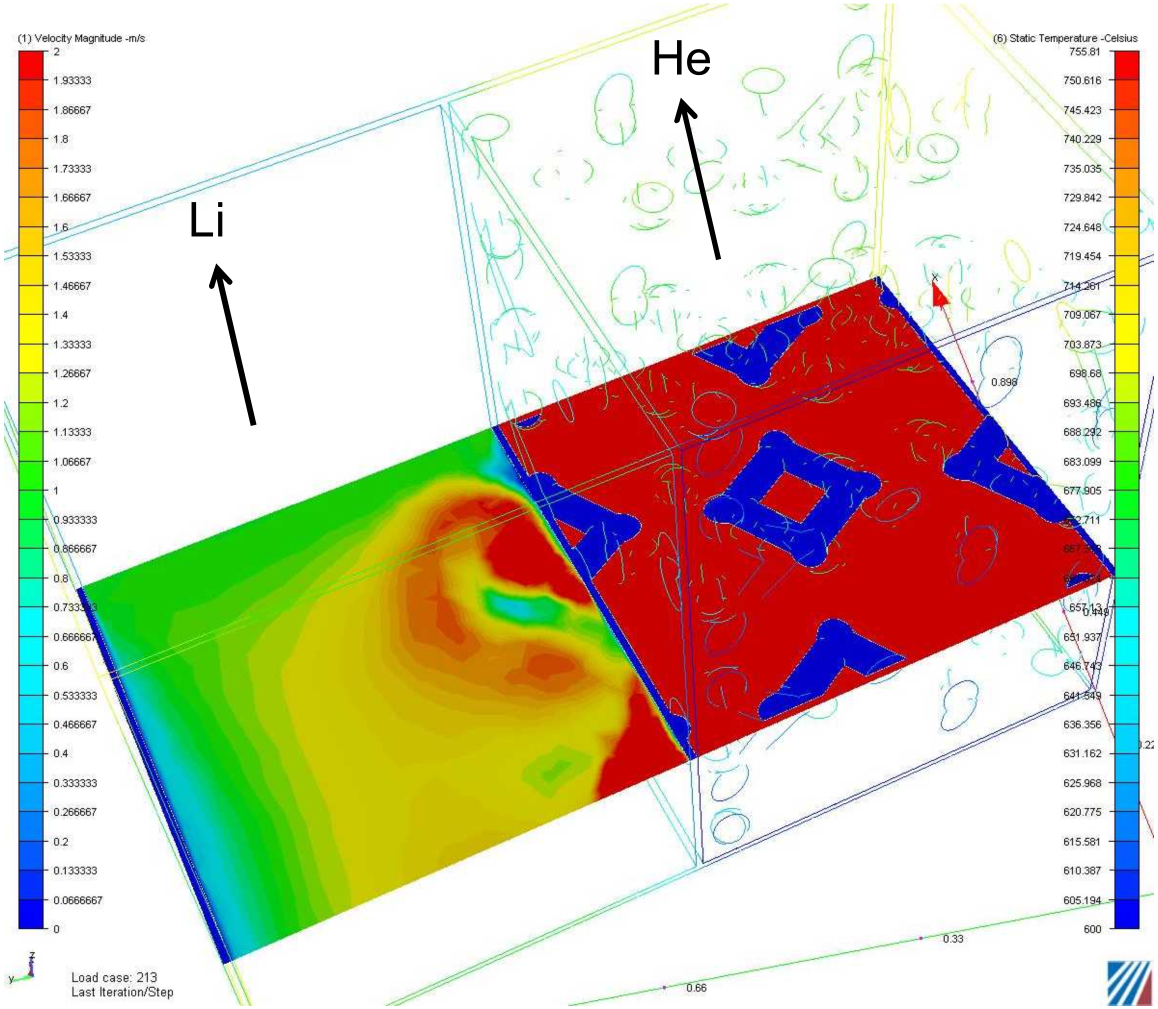
Foams can enhance heat transfer in open channels of dual coolant schemes if the foam is bonded to the intervening wall.



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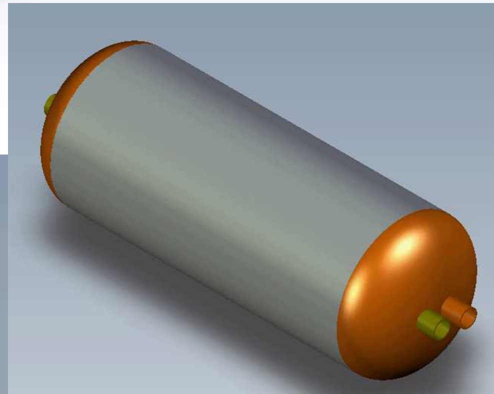
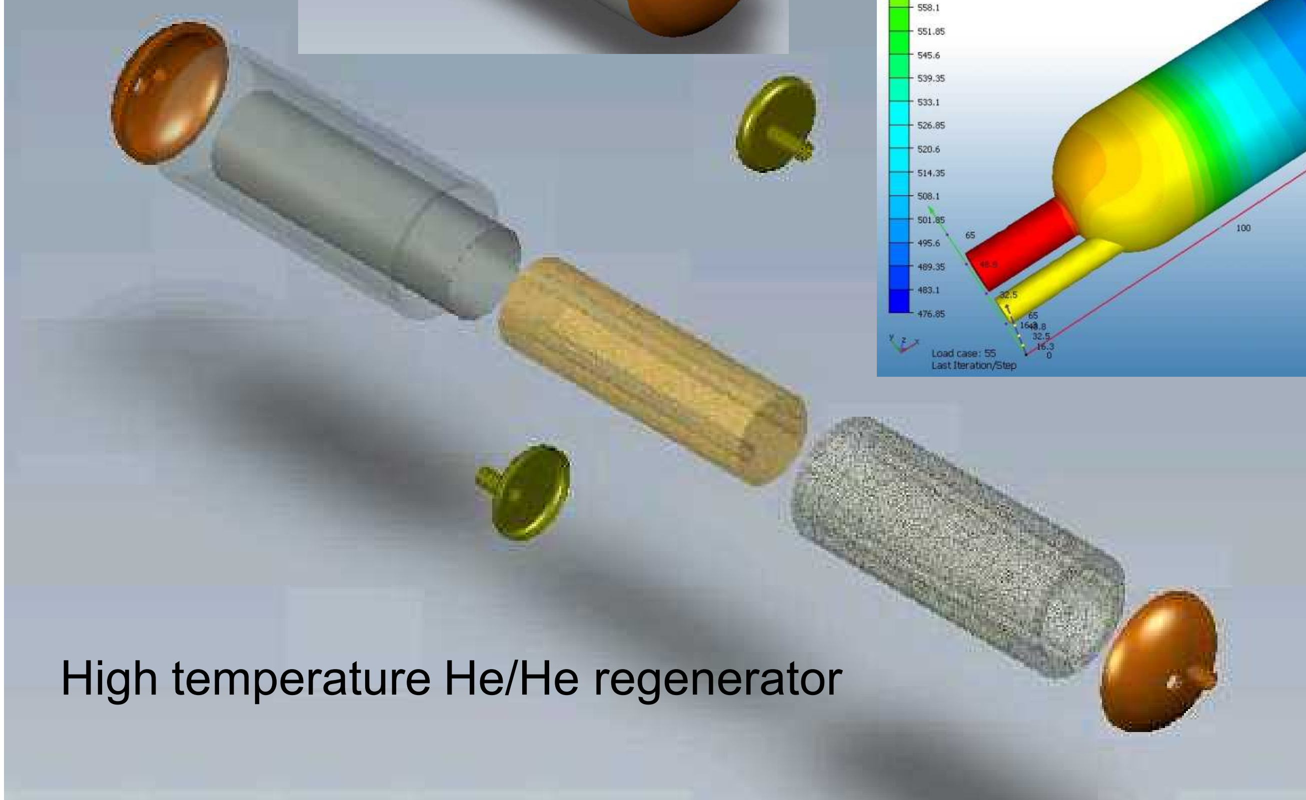
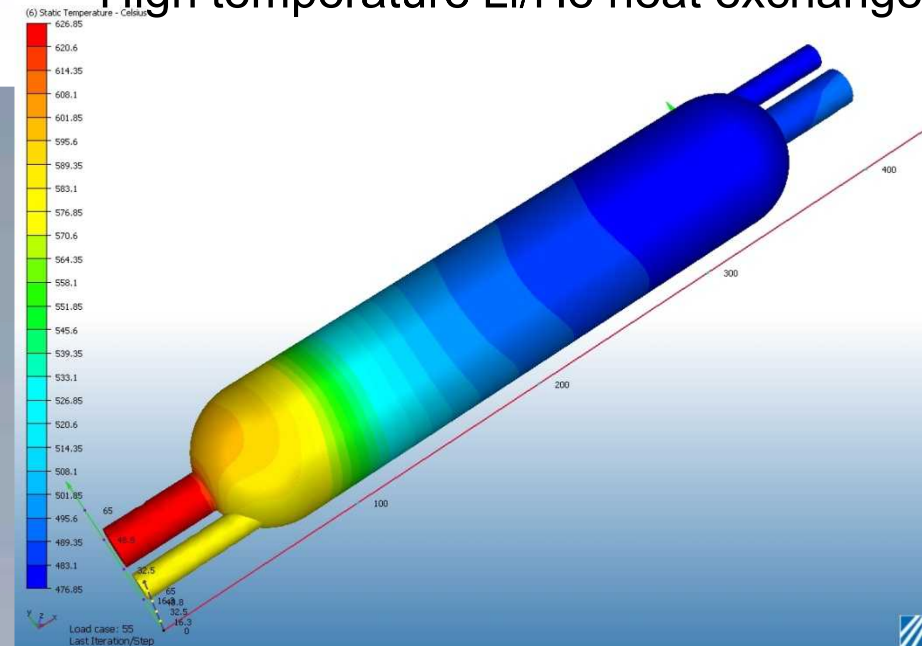
Refractory heat exchangers are under fabrication.



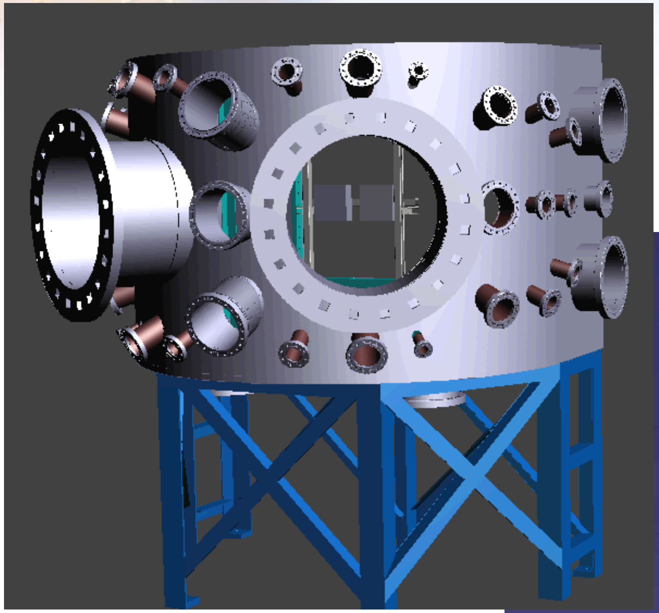


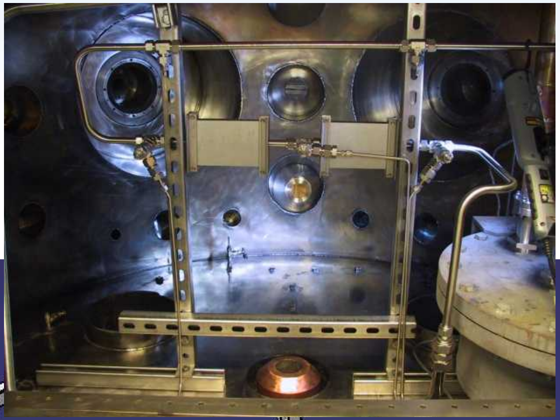
High temperature He/He regenerator

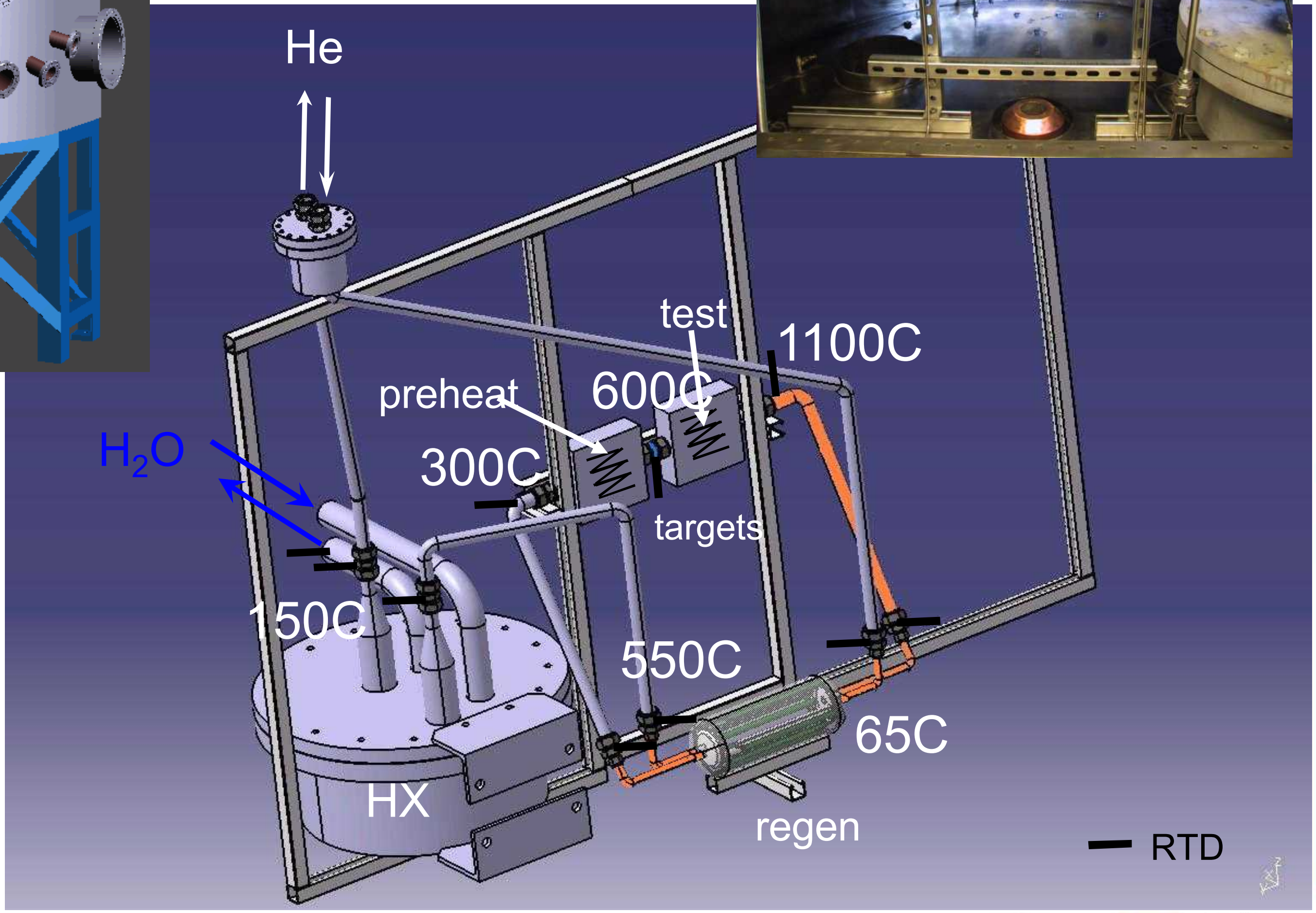
High temperature Li/He heat exchanger



HHF testing of helium-cooled panels underway at PMTF.







- Short hi-temp runs (Mo)
- In-vacuo
- Experimental
- Low cost
- Small impact on HeFL loop

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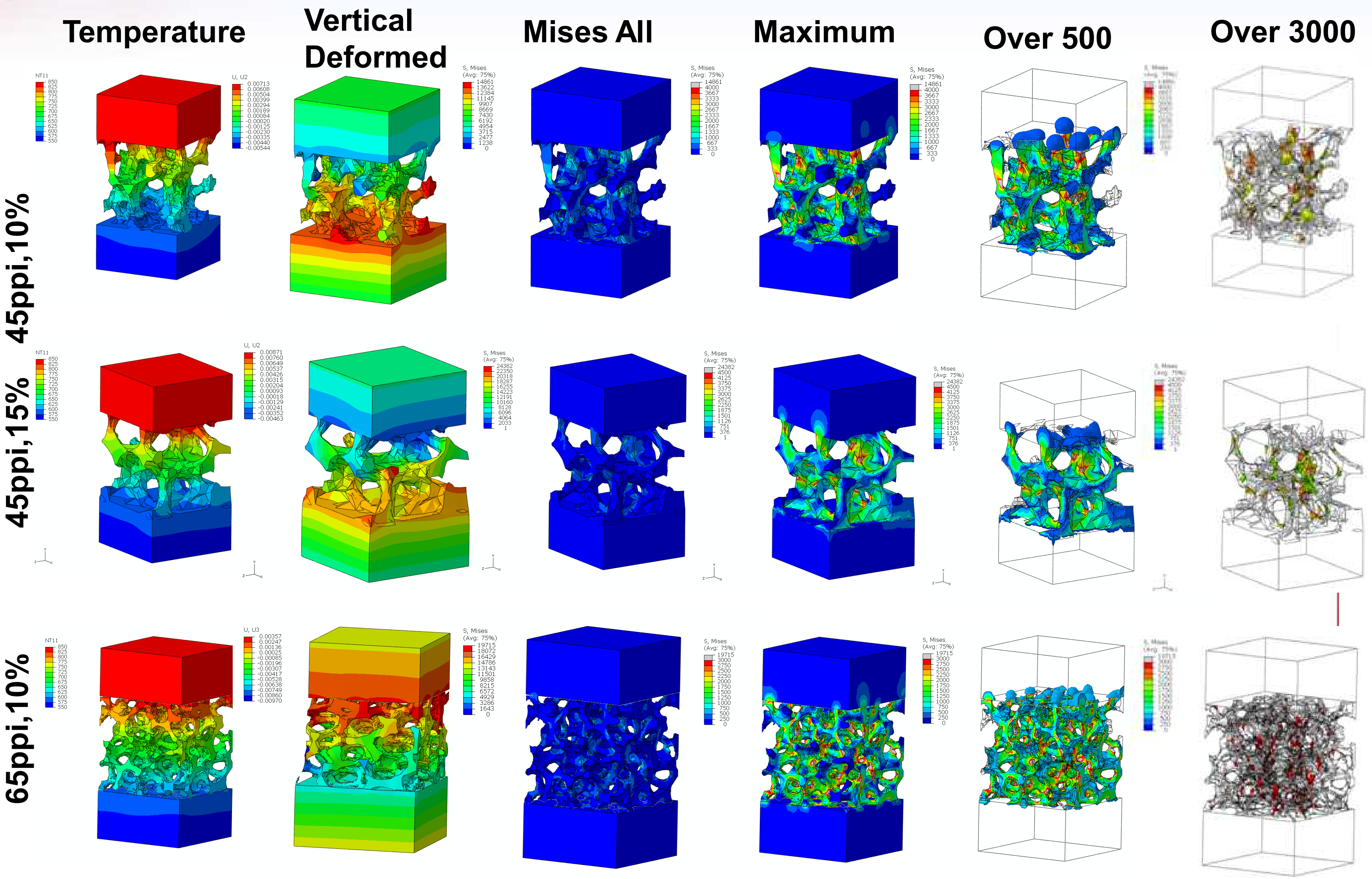
Modeling of SiC Foam



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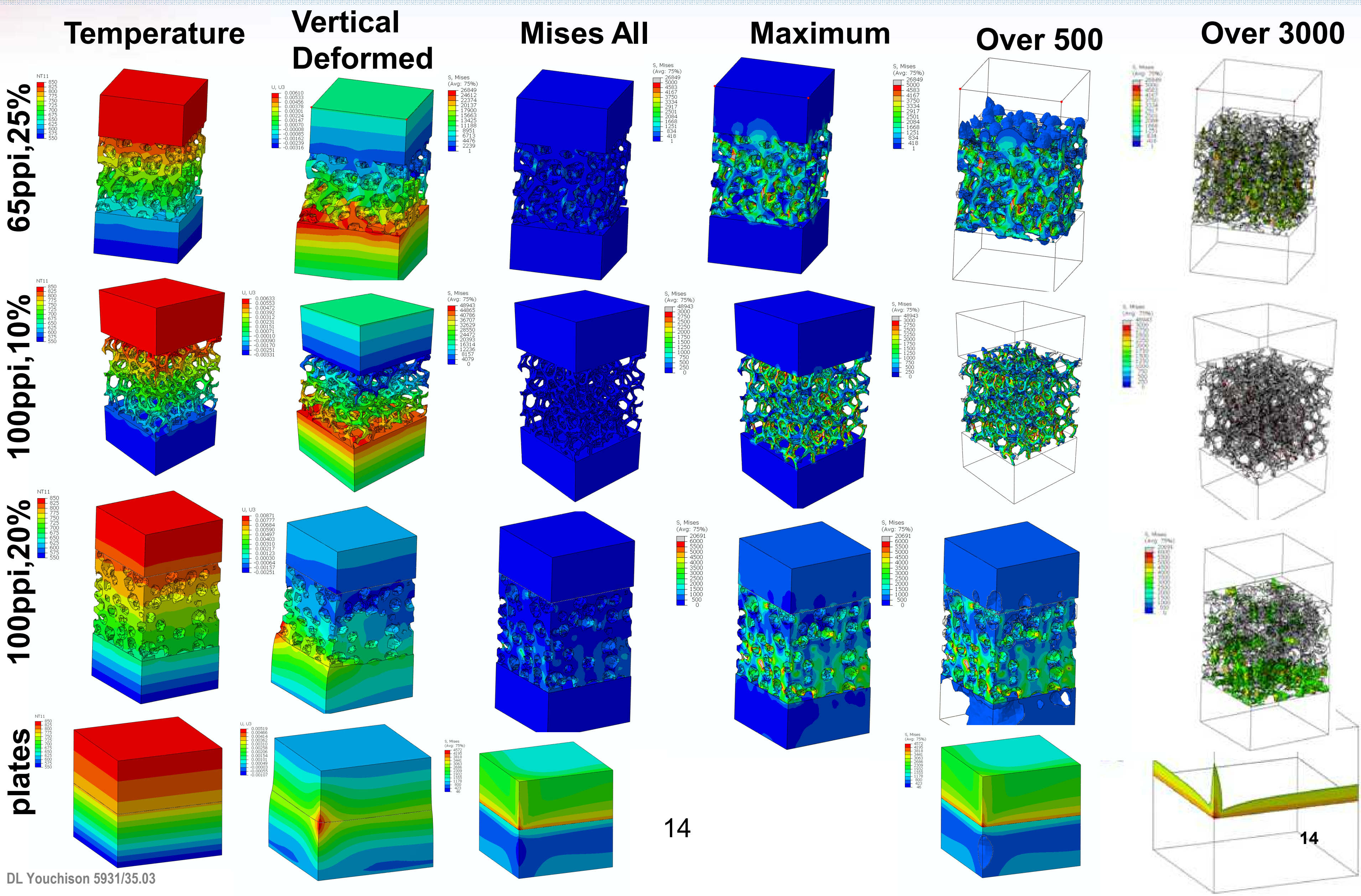
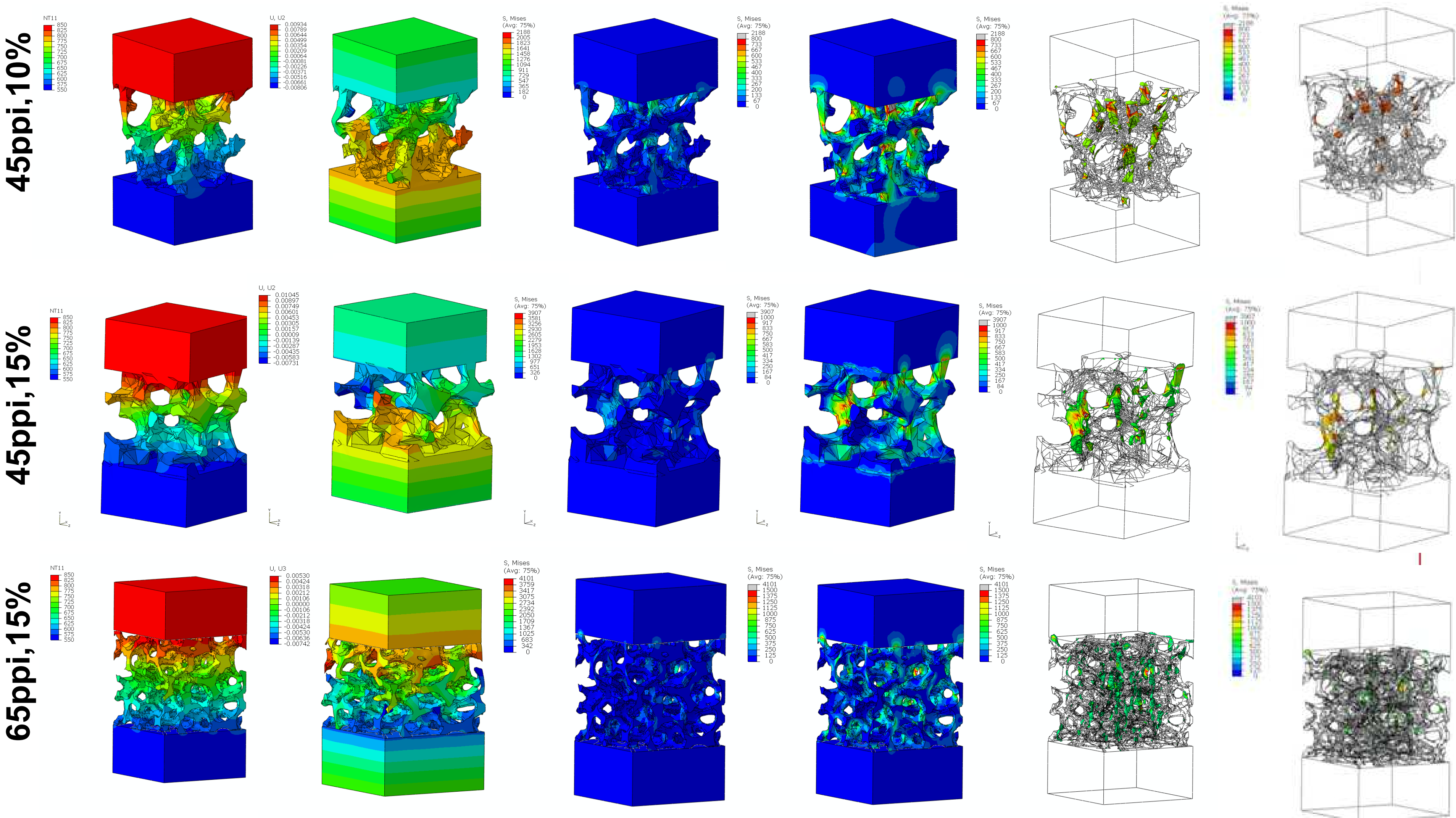
Modeling of SiC Foam

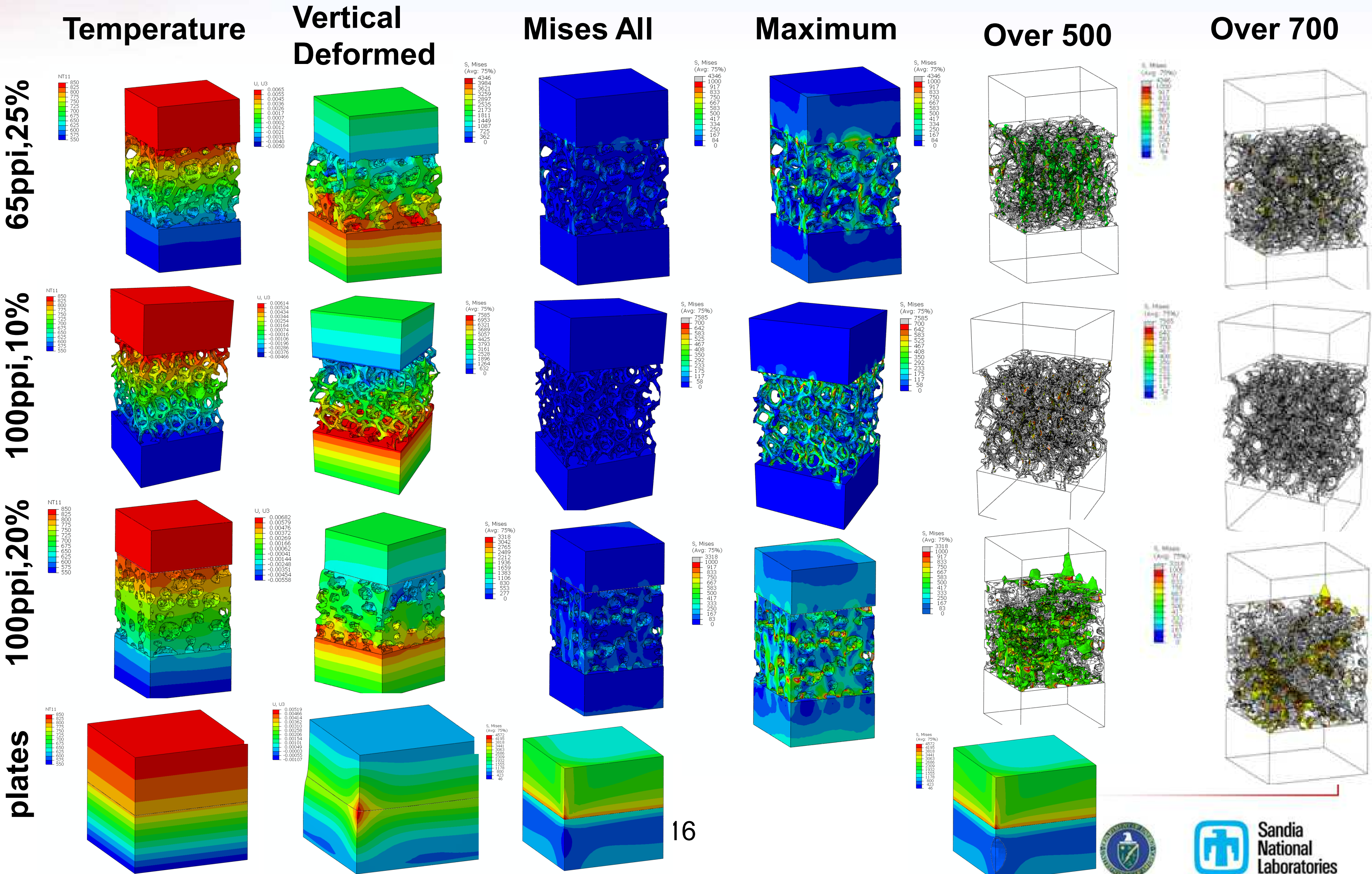


Modeling of Nb Foam

Temperature | Vertical Deformed | Mises All | Maximum | Over 500 | Over 700



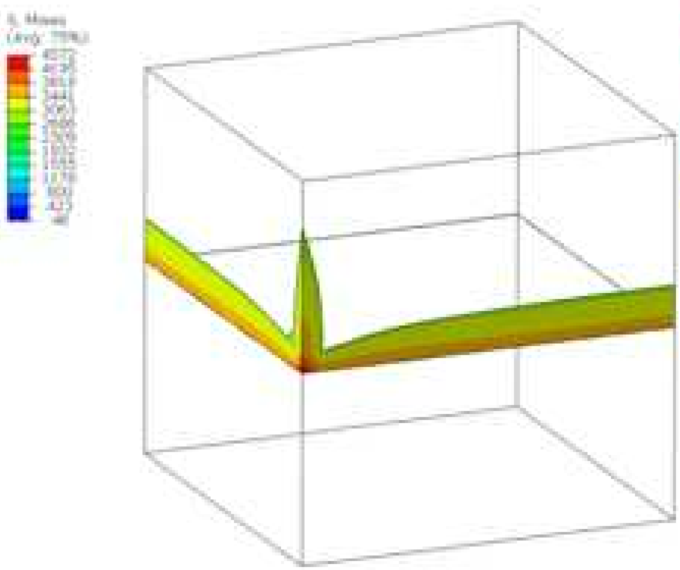
Modeling of Nb Foam



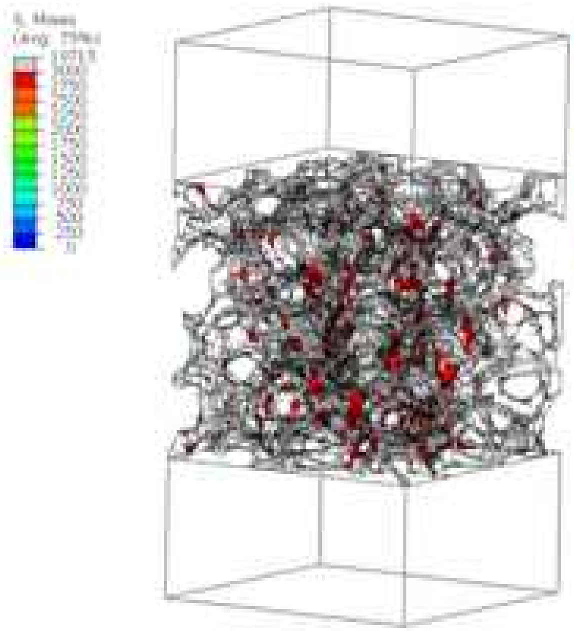
Thermal stress summary

•Nb foam with 45ppi 10% dense has the lowest thermal stress of all.
•The SiC foam with 65 ppi 10% density has the lowest stress for the SiC foams. The 100 ppi cases were higher.
•Stresses increased with ppi and density.
•In all cases the foam reduces the stress in the faceplates as expected, the Nb foam by an order of magnitude.
•The SiC foam was not as effective because of higher stresses in the ligaments, but stresses in the faceplates were still very low.

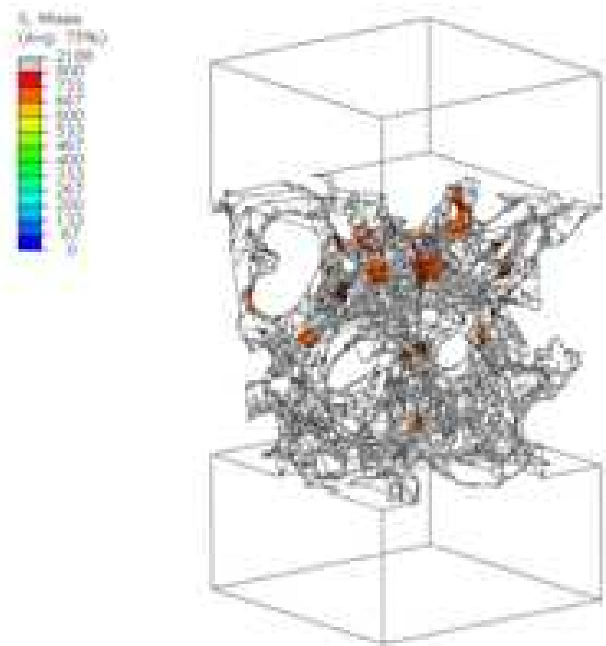
Plates (over 3000)



65ppi, 10% SiC foam (over 3000)



45ppi, 10% Nb foam (over 700)



Concluding remarks

- modeling of porous media on micro-scale now possible
- 64-bit, 4 to 16-node MPI computations, 98 GB ram
- tomography useful for reverse engineering
- improvements in file translation and meshing, but still challenging
- Investigated effectiveness of foams to improve heat transfer
- CFD and thermal stress analysis of porous media
- refractory high temperature foams for Brayton applications
- applications to various gas/gas heat exchangers, recuperators, regenerators, LM/gas heat exchangers
- modeling of foams for thermal stress reduction and insulation