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Design and Fabrication of a High-Temperature Helium Regenerator

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Abstract: Refractory metallic foams can increase heat transfer efficiency in gas-to-gas and liquid metal-to-gas heat exchangers by providing an extended surface area for better convection, i.e. conduction into the foam ligaments providing a “fin-effect,” and by disruption of the thermal boundary layer near the hot wall and ligaments by turbulence promotion. In this article, we describe the design of a high-temperature refractory regenerator (closed-loop recuperator) using computational fluid dynamics (CFD) modeling of actual foam geometries obtained through computerized micro-tomography. The article outlines the design procedure from geometry import through meshing and thermo-mechanical analysis and discusses the challenges of fabrication using pure molybdenum and TZM. The foam core regenerator is more easily fabricated, less expensive and performs better than refractory flat plate-type heat exchangers. The regenerator can operate with a maximum hot leg inlet temperature of 900 ^{o}C and transfer 180 kW to the cold leg using 100 g/s helium at 4 MPa. We also describe the high heat flux experiments on helium-cooled plasma facing components that will utilize the high temperature and high pressure capabilities of this unique regenerator. Similar components will be required to adapt future fusion reactors to high-efficiency Brayton power conversion systems and enable operation of advanced divertor and blanket systems.

Introduction

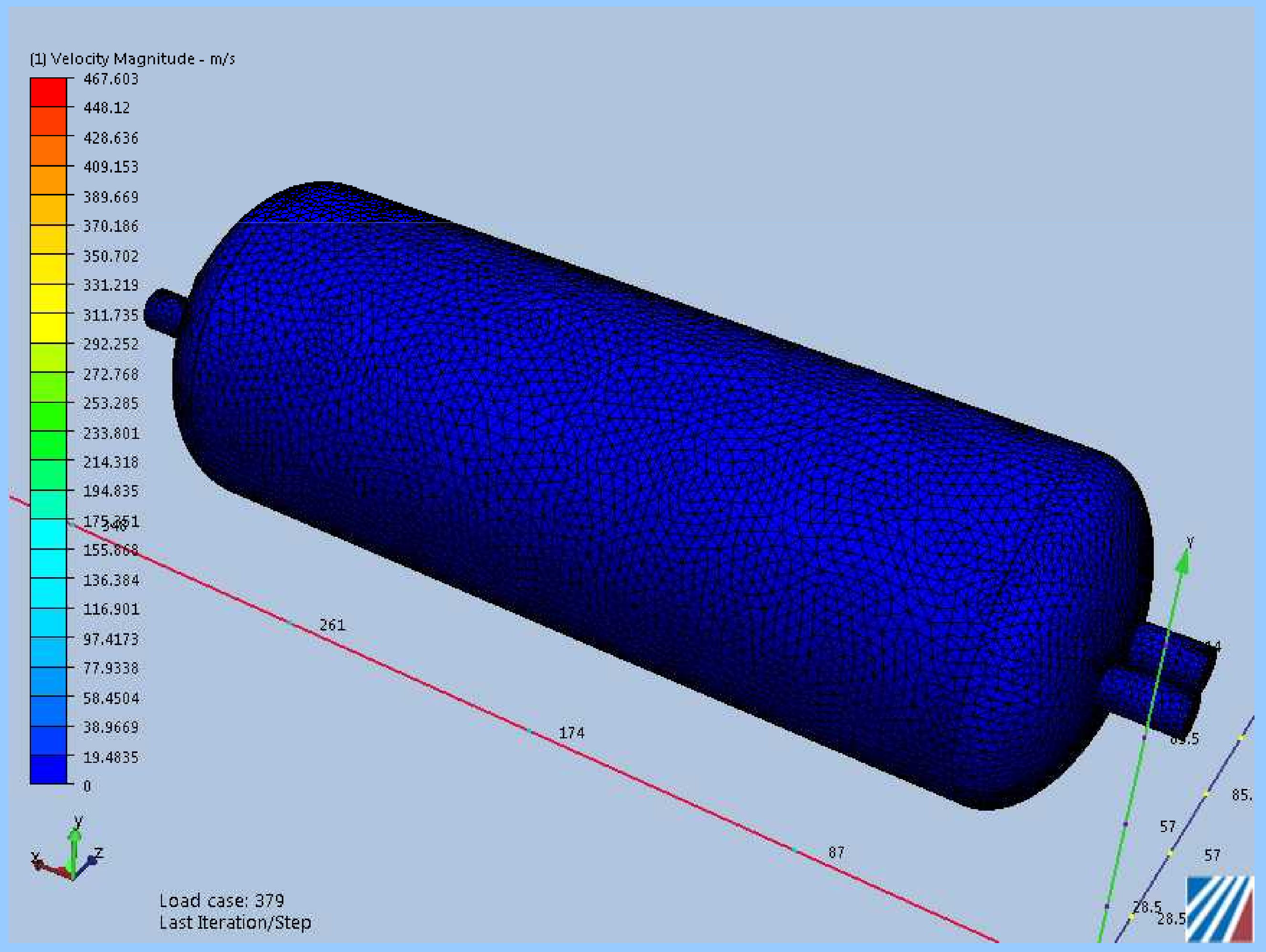
This study optimizes the geometry and flow distribution in a moly and TZM helium regenerator using CFD modeling of porous media both from a micro approach in modeling flow through actual foam structures and also from a lumped approach by utilizing the calculated permeability and efffective thermal conductivities of the moly foam to assisst in the global design. The regenerator is currently in the last stages of fabrication and will be utilized to test helium-cooled refractory divertor components.

Description

The helium regenerator is configured for cross flow and consists of an all moly foam core (hot leg) separated by a thin moly wall from a moly foam cylinder (cold leg) in a coaxial arrangement. TZM endcaps with supply and return tubes direct the helium into a circumferrential flow path through the foam. The regenerator is designed to operate with 4 MPa helium at 100 g/s with a maximum hotleg inlet temperature of 900 C . The reference case produces an outlet of 550 C using a cold leg inlet of 65 C.

Model

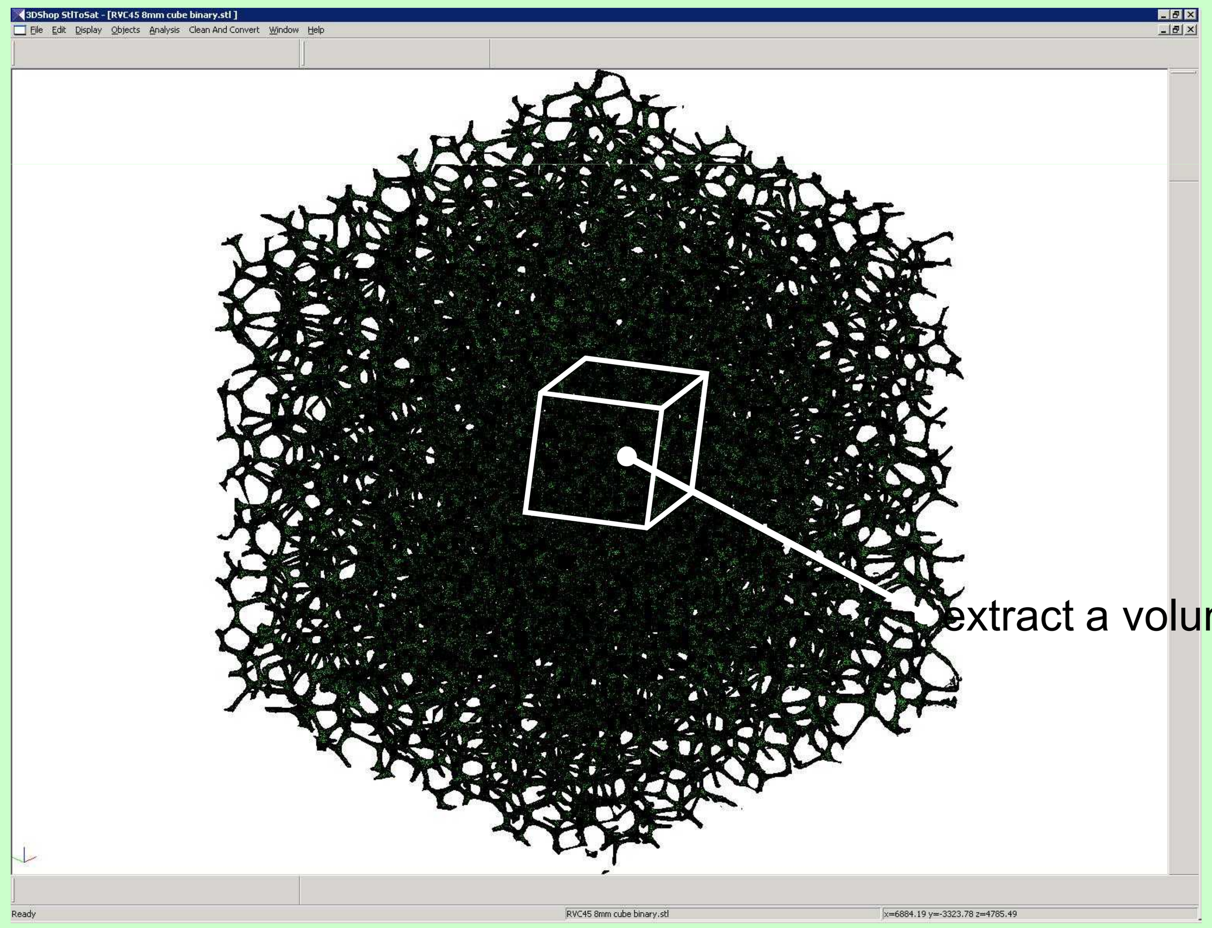
Crossflow regenerator



1.5 M cells

Tomography

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



Tomography
•VGStudio MAX
by
Volume Graphics

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

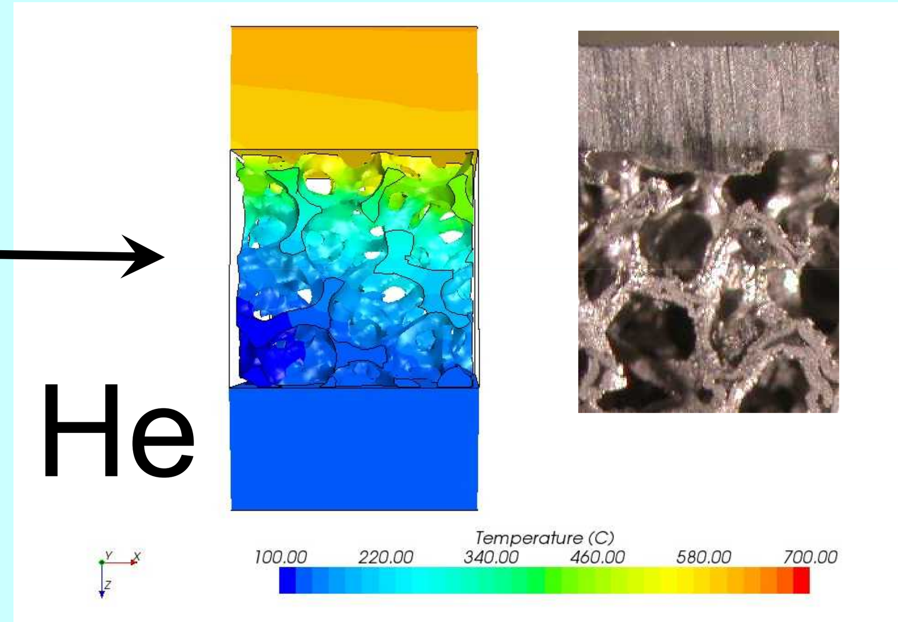
Processing geometry and meshing are greatest challenge.

Results

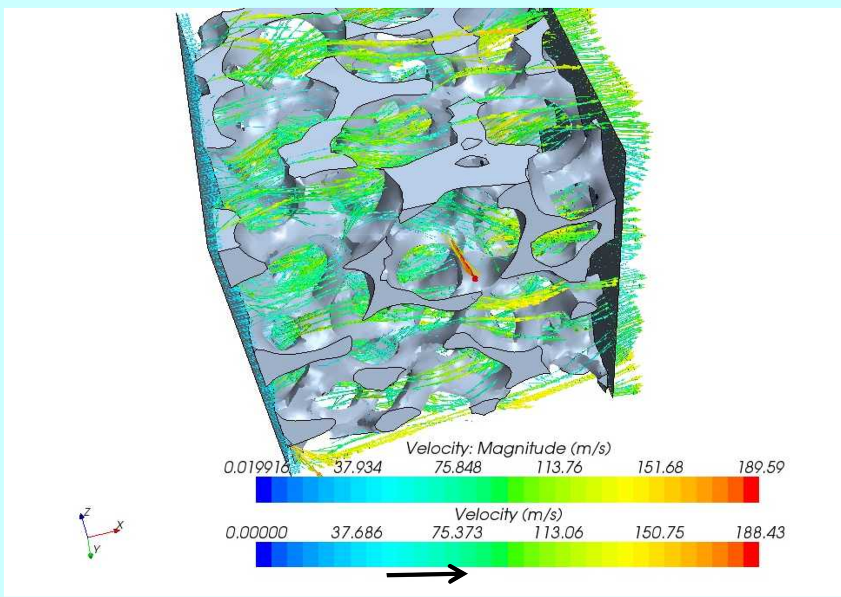
Moly foam micro models

627 C

27 C He



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.

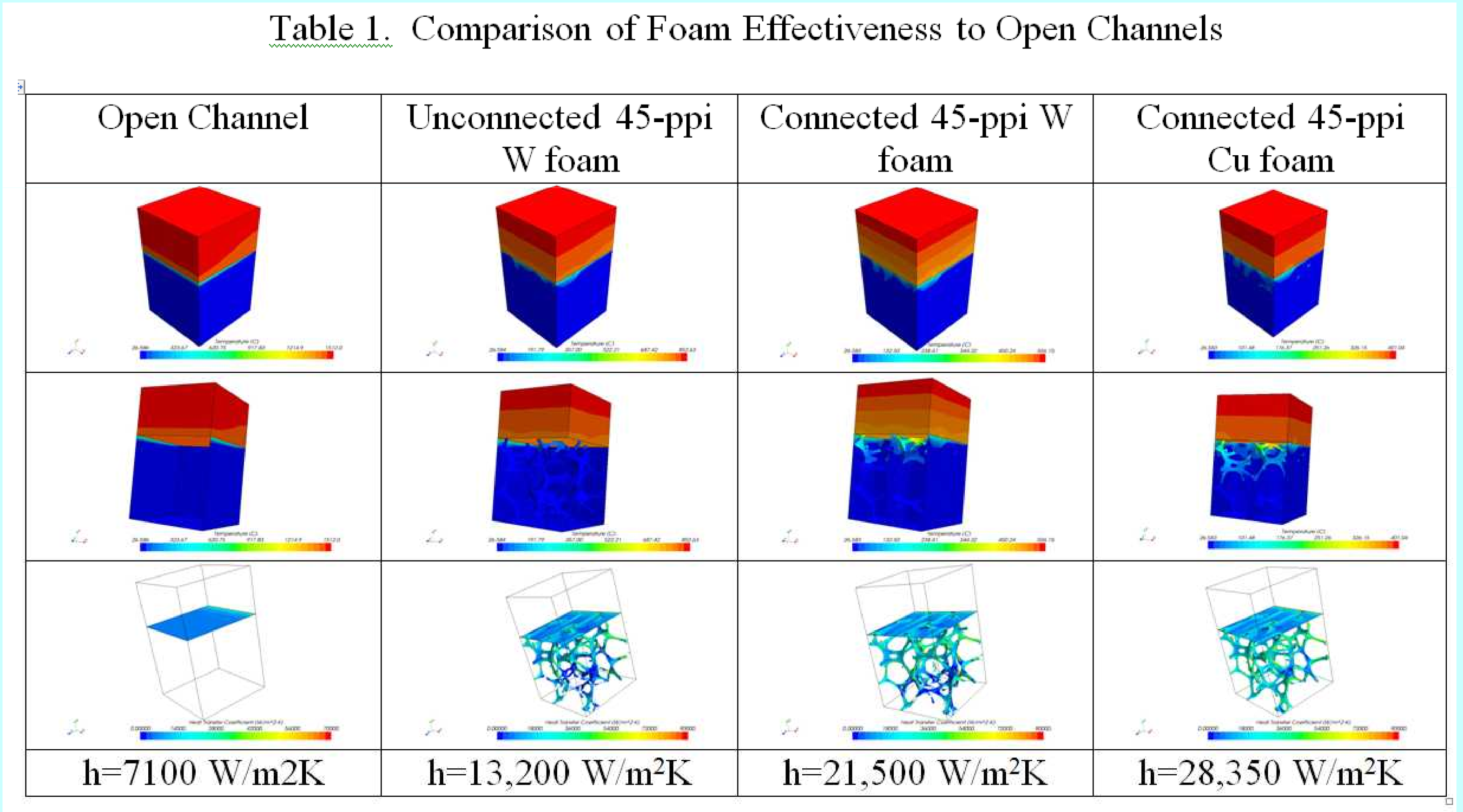
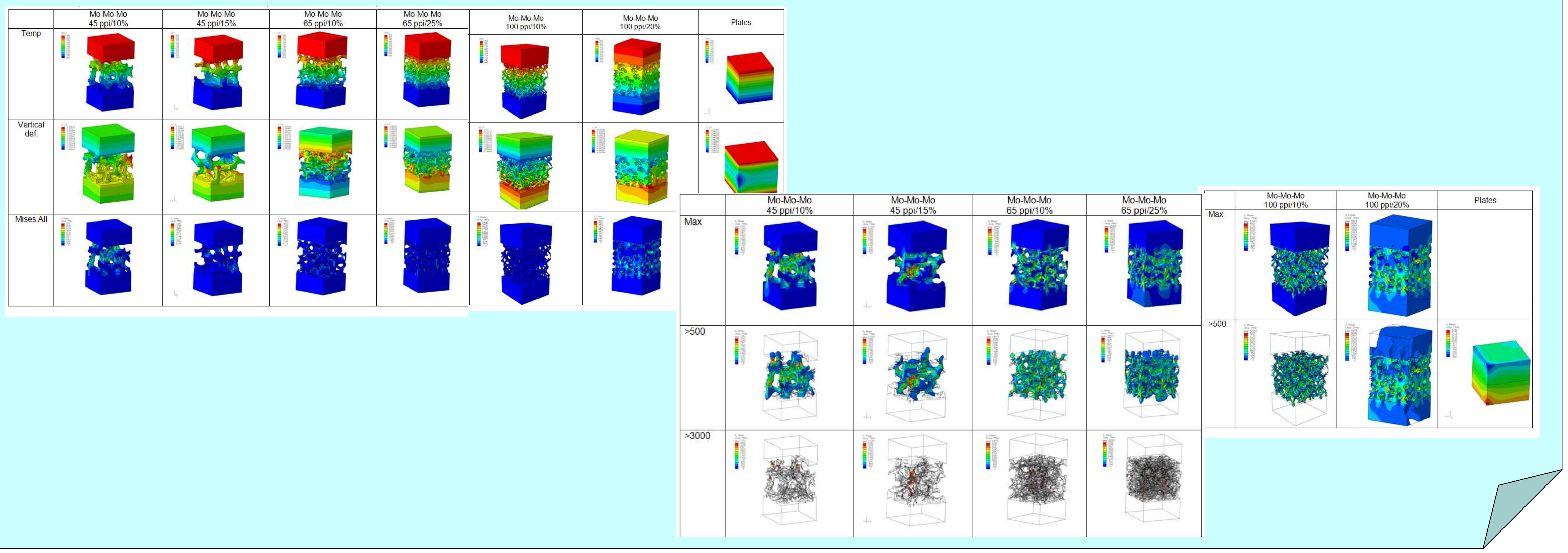


Table 1. Comparison of Foam Effectiveness to Open Channels

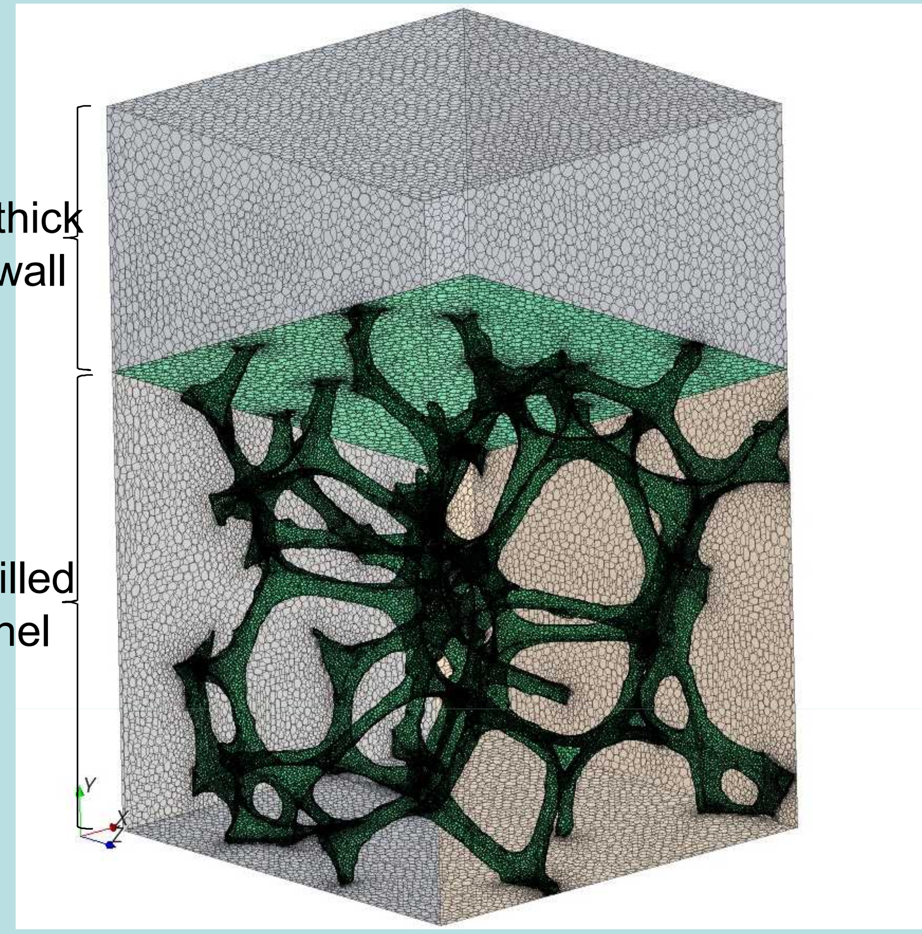
Open Channel	Unconnected 45-ppi W foam	Connected 45-ppi W foam	Connected 45-ppi Cu foam
h=7100 W/m2K	h=13,200 W/m²K	h=21,500 W/m²K	h=28,350 W/m²K

Stress analysis



meshing

Modeling is computationally expensive.



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

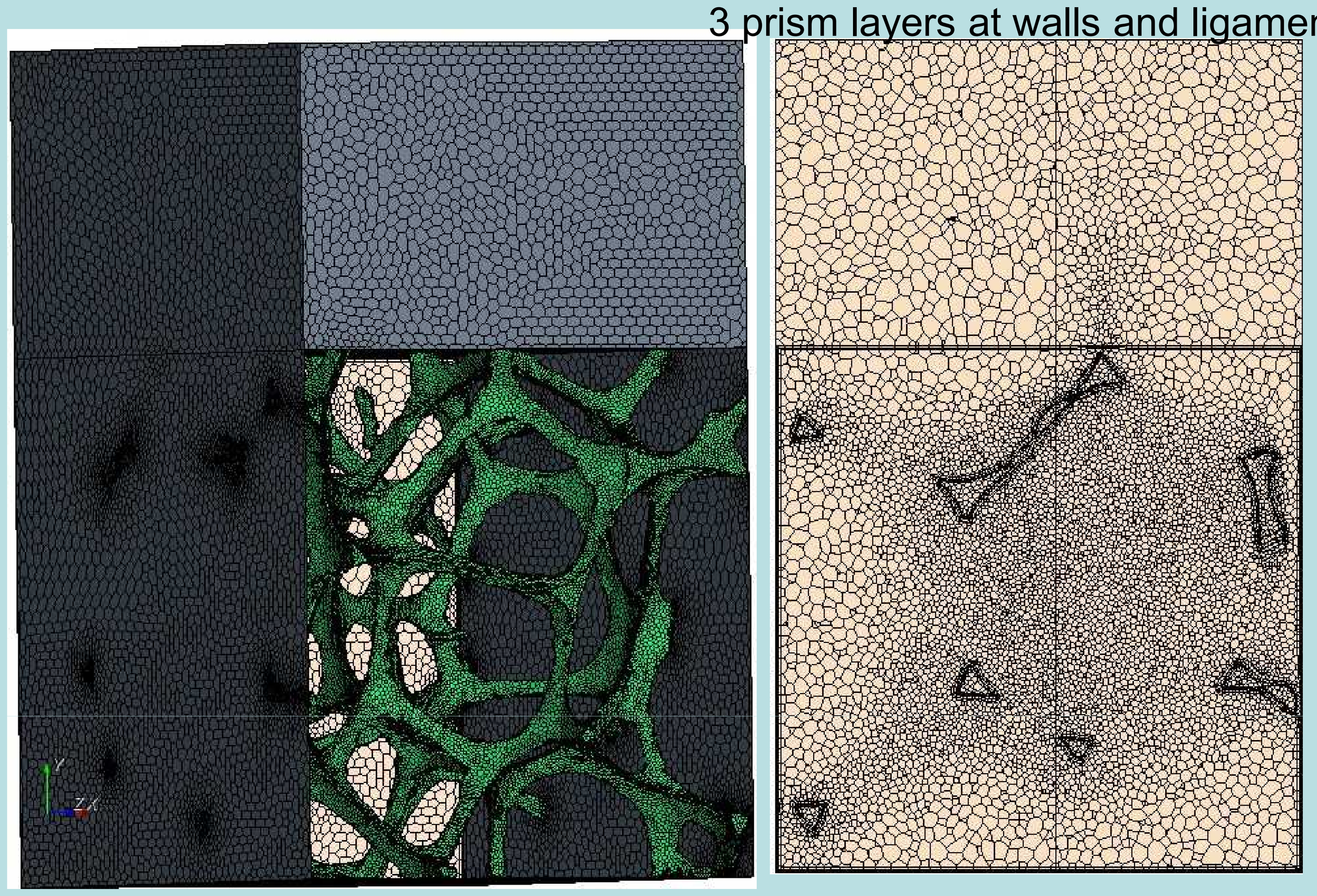
1.7 mm x 1.7 mm x 2.7 mm high. Arbitrarily chosen volume extracted from 8x8x8 mm³ volume shown earlier. Wall added in CCM+.

<u>Commercial CFD Codes</u>

- Star-CCM+ v5.04
- Cfdesign v10

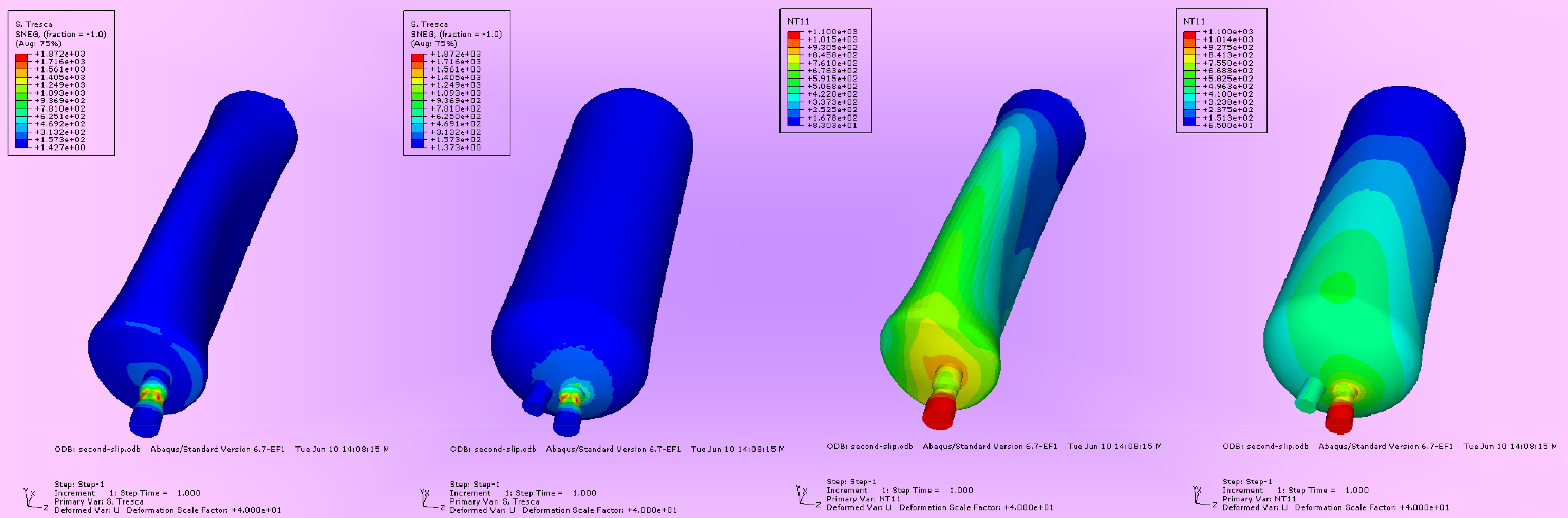
Imprint and merge 3 solids and a fluid

3 prism layers at walls and ligaments

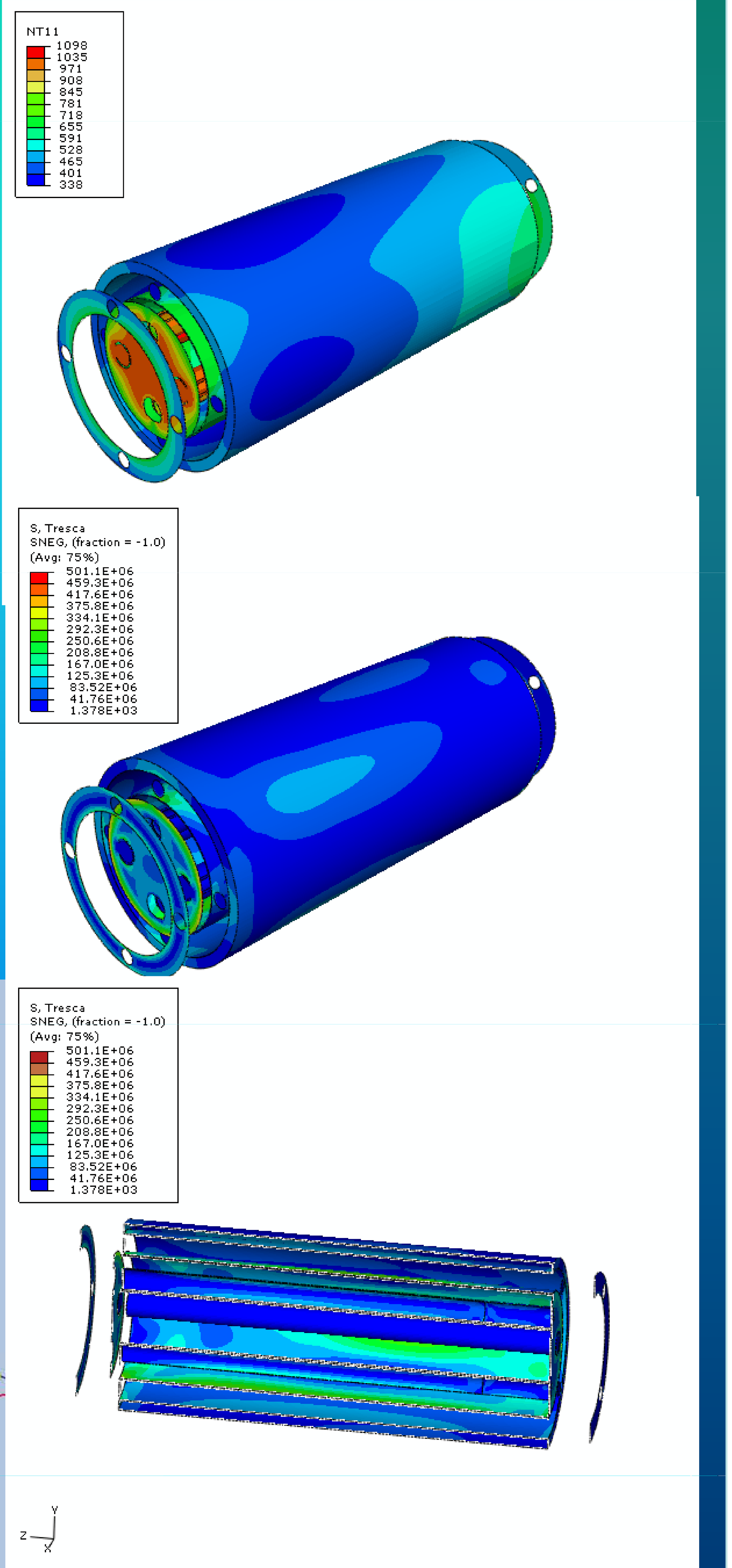


Lumped model – Temperature and Stress

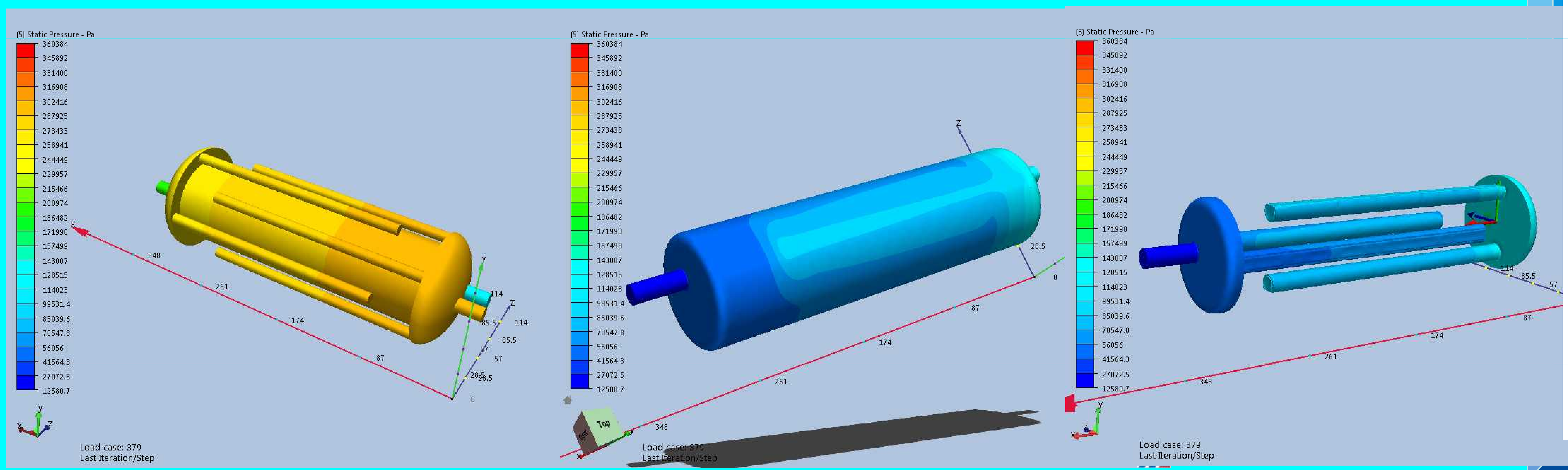
Permeability and effective thermal conductivity from micro models are used for design calculations.



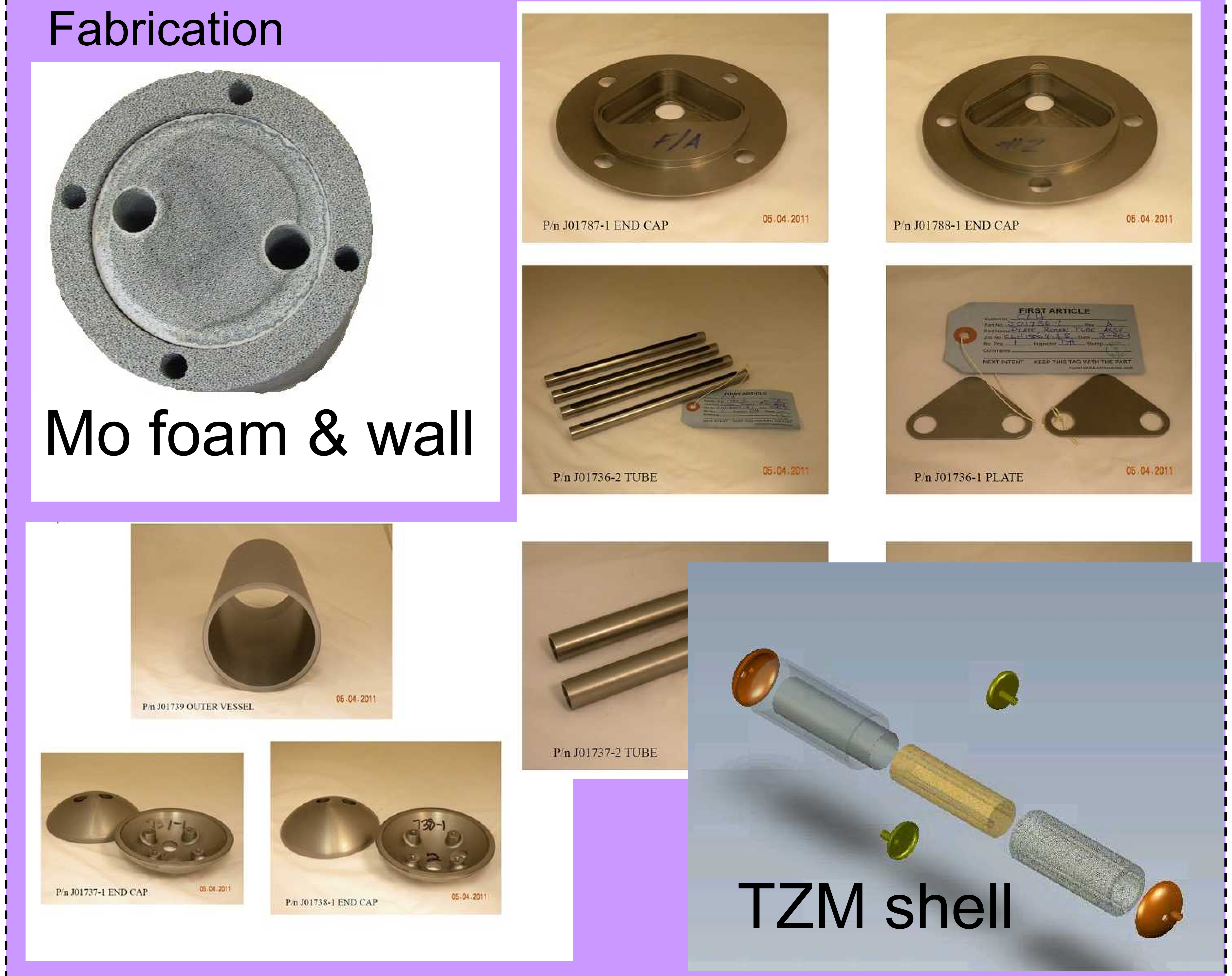
Tresca



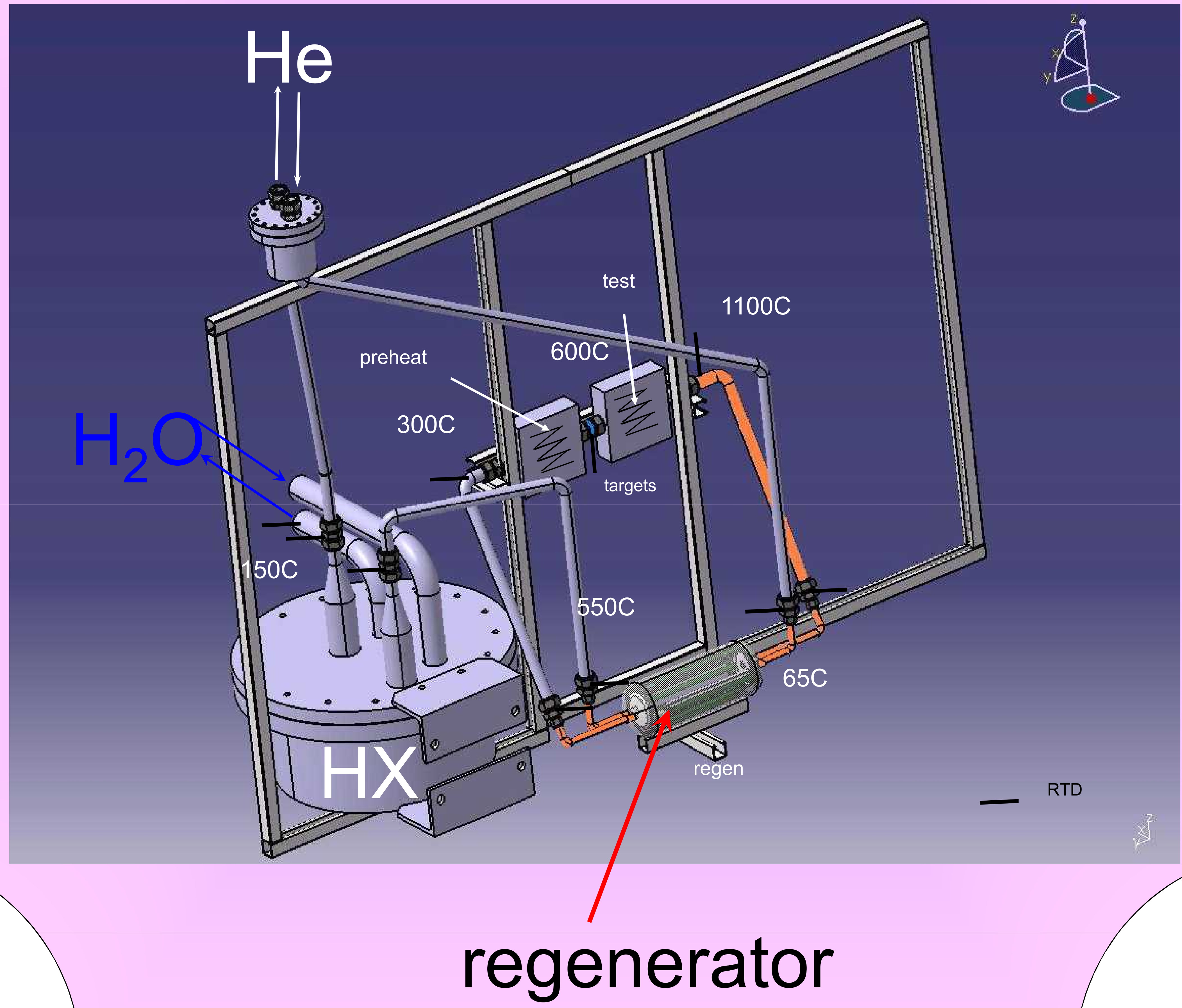
Pressure drop



Fabrication



Future Experiments



----- Conclusions -----

The high-temperature helium regenerator will allow HHF testing of helium-cooled refractory PFCs in the EB-1200 at Sandia's PMTF by transferring heat from the high temperature exhaust stream to the incoming helium stream. It permits high temperature testing by minimizing the hot piping and heat rejection required in these experiments. We have demonstrated that such components can be designed and fabricated for high pressure, high temperature gas applications. Scale-up of similar devices will be required to effectively utilize the Brayton cycle in the power conversion systems of any fusion DEMO plant.

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