Lithium Vapor Divertor: Materials Show-and-Tell

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Outline

- Key Design Constraints
- Capillary Porous System Materials
- Integrated System Design for NSTX-U

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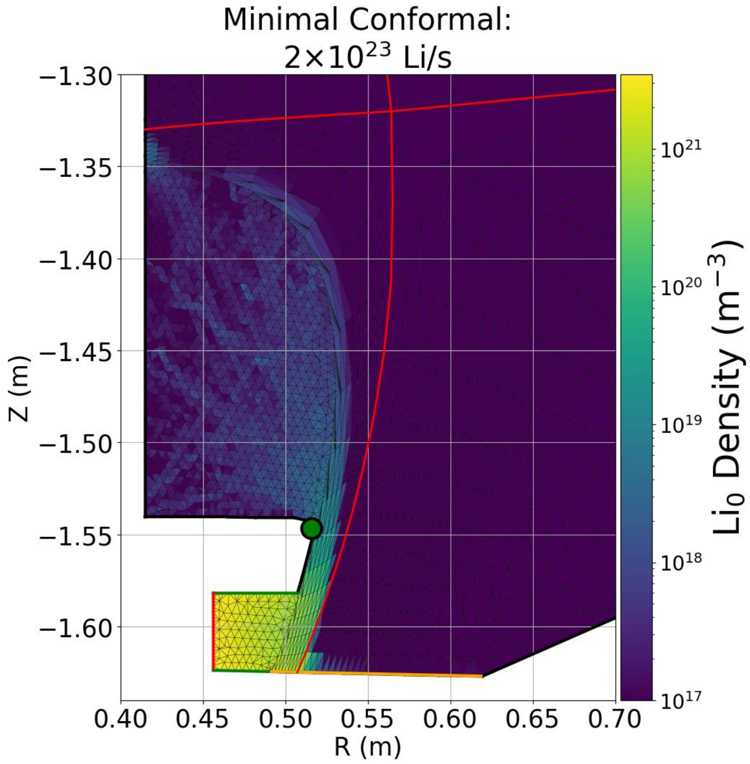
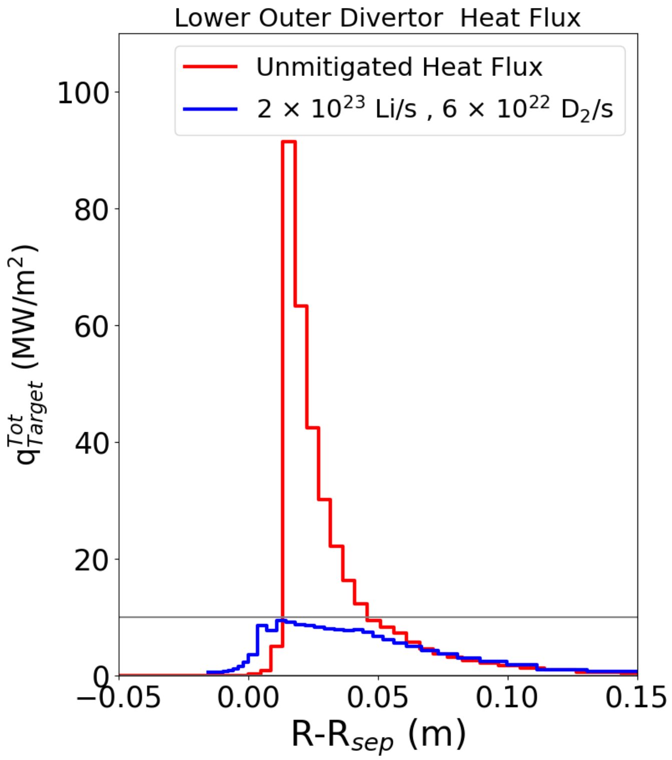
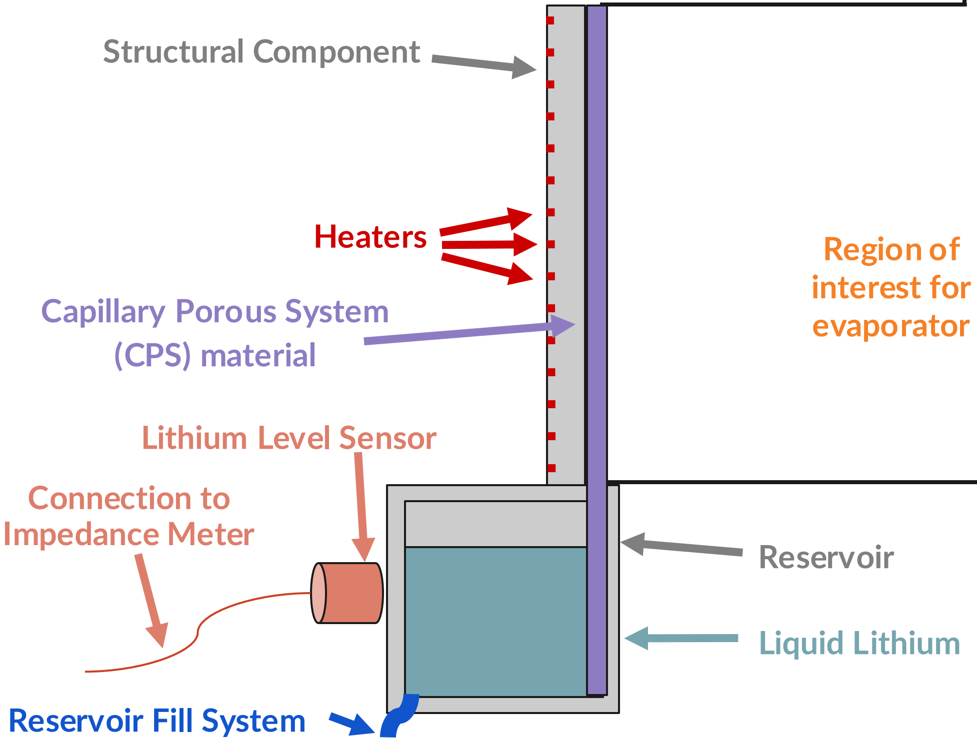
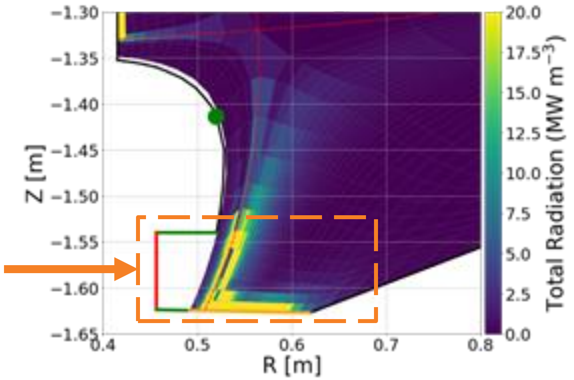
Operational Target:
Li evaporation rate of ~ 10^{23} s^{-1} needed to mitigate $q_{\|}$ ~ 100 MW/m^2

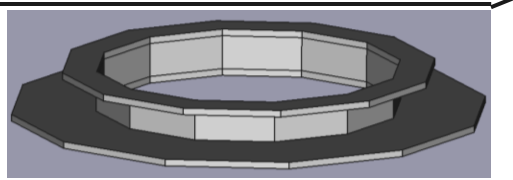




Lithium Vapor “Cave” Components

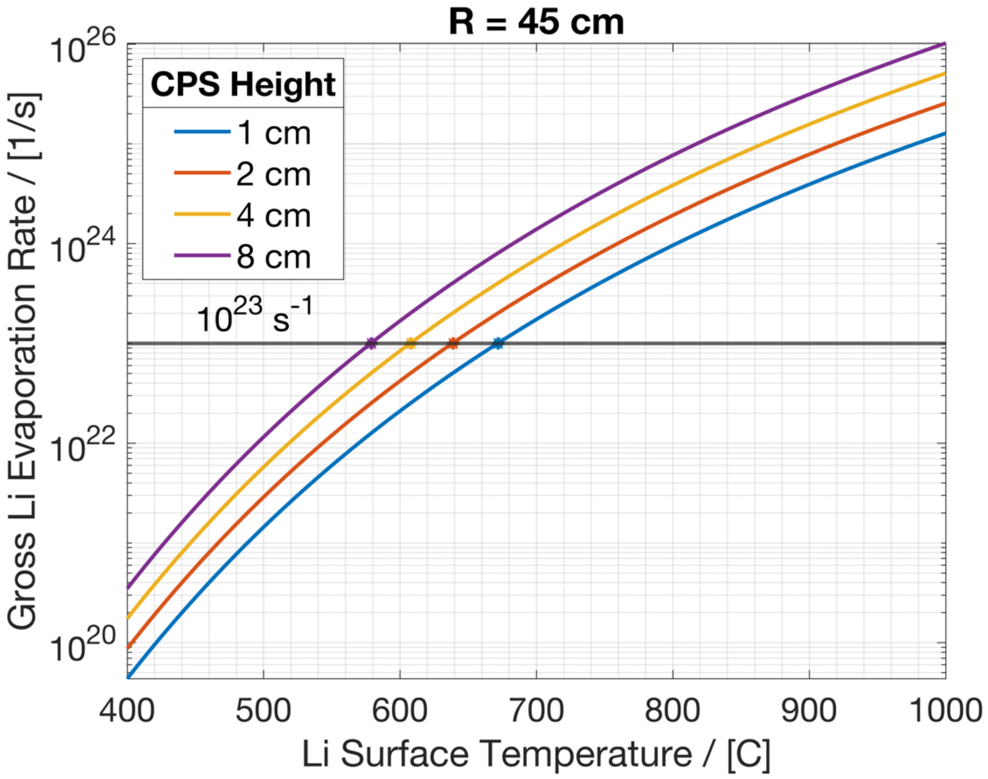






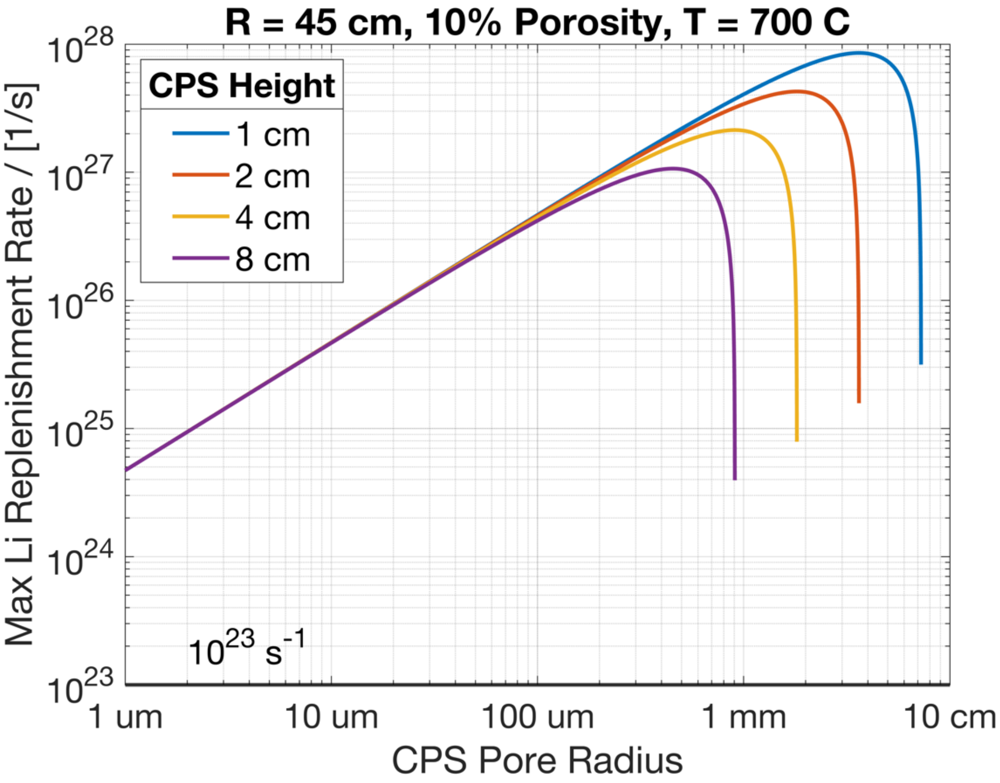
Envisioned here as
12 separate modules

Key Design Constraint #1: Evaporation rate depends on Li CPS surface area and temperature



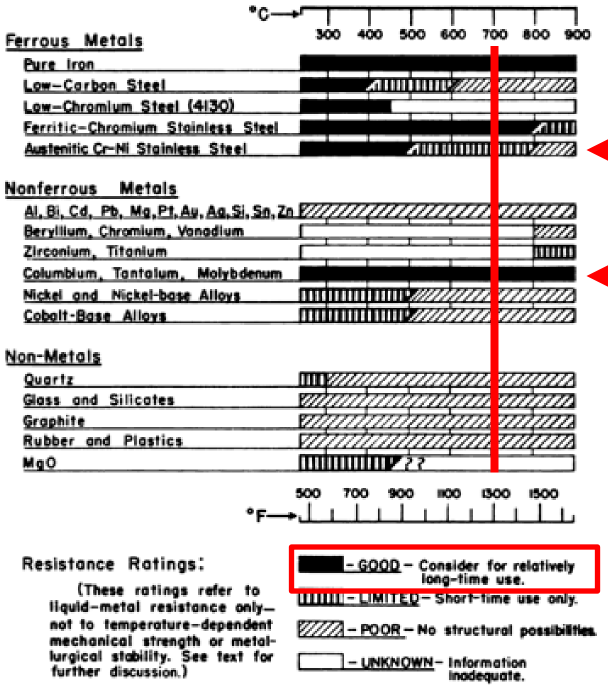
- Evap. rate is highly nonlinear function of temp.
- Increasing the surface area reduces temp. req.
- Expect to operate in range 600 – 700 C

Key Design Constraint #2:
Max Li replenishment rate depends on pore size and system height



- Volume transfer rate is a balance between the capillary force and gravity
- At small pore size, capillary force dominates and increased pore radius is favorable
- When pores become too large, gravity dominates and limits max height
- To allow CPS heights up to ~ 10 cm, use pore radius up to ~500 um
- Replenishment rate requirement easily satisfied with only 10% porosity

Key Design Constraint #3:
Tradeoff between operating temperature and materials options



Non-magnetic Stainless Steels

Refractory Metals / Alloys

Initial focus of our work on Molybdenum

Figure from: Liquid Metals Handbook, AEC 1952

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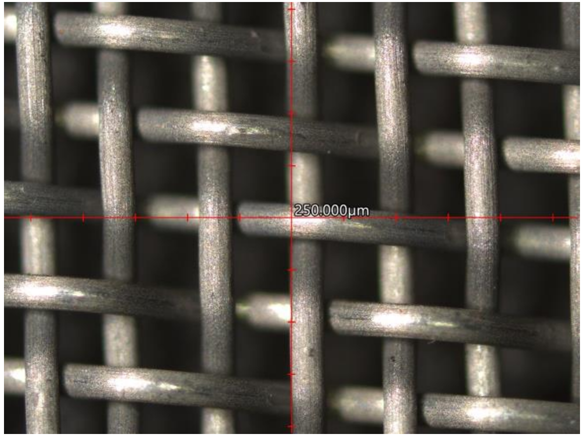
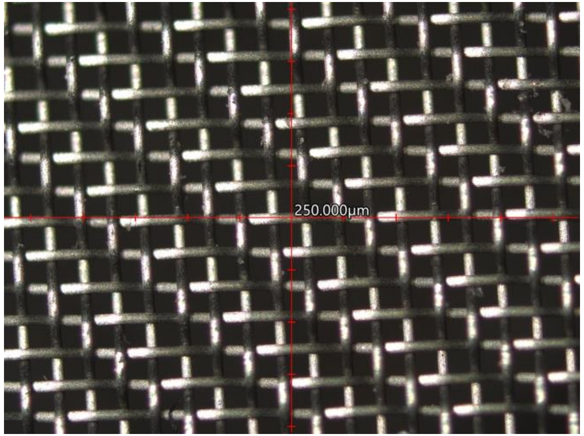
Woven metal meshes are a well-established technology

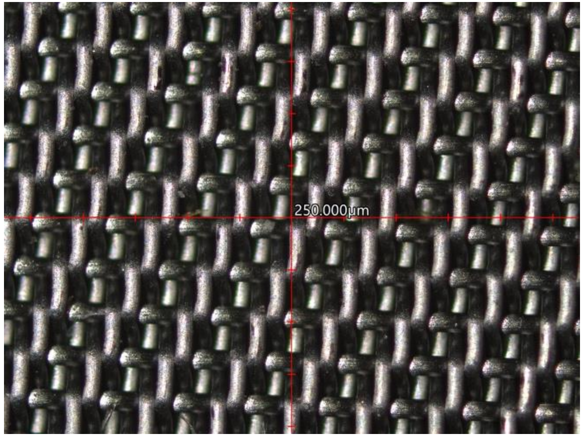
Princeton University Imaging and Analysis Center



60 x 60 Twill, 0.0064”
Pore size ~ 250 um

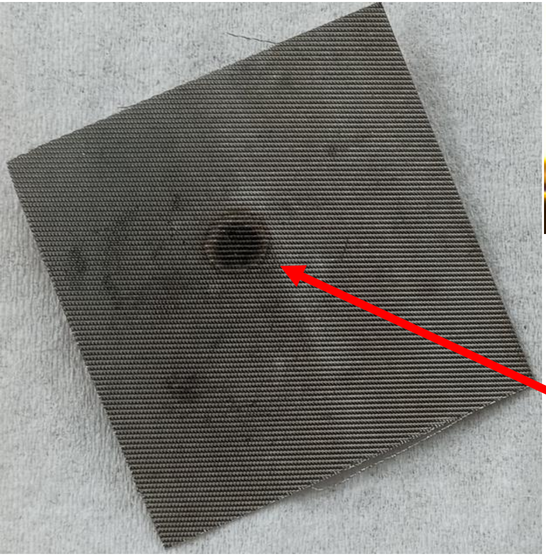


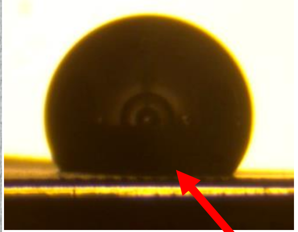
165 x 165 Twill, 0.002”
Pore size ~ 90 um



120 x 290 Filtercloth
Pore size ~ 70 um
(pores not ⊥ to surface)

… but meshes are hard to secure to flat surfaces, leading to poor Li wetting





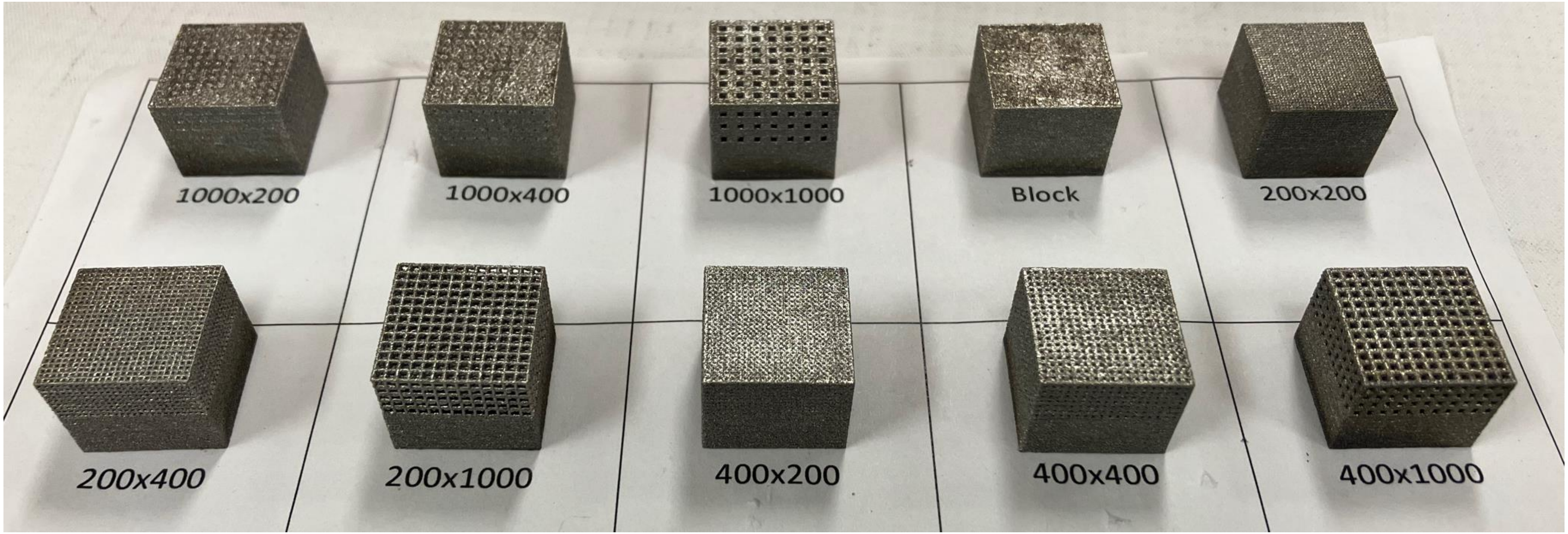
No apparent capillary action
(in-plane spreading)

Some imbibition
(“sinking” through the mesh)

Samples of Mo mesh sent to
Penn State for lithium wetting tests.

Unpublished result from EAST shows poor
Li wetting on spot-welded SS 316 mesh.
Photo courtesy of Guizhong Zuo

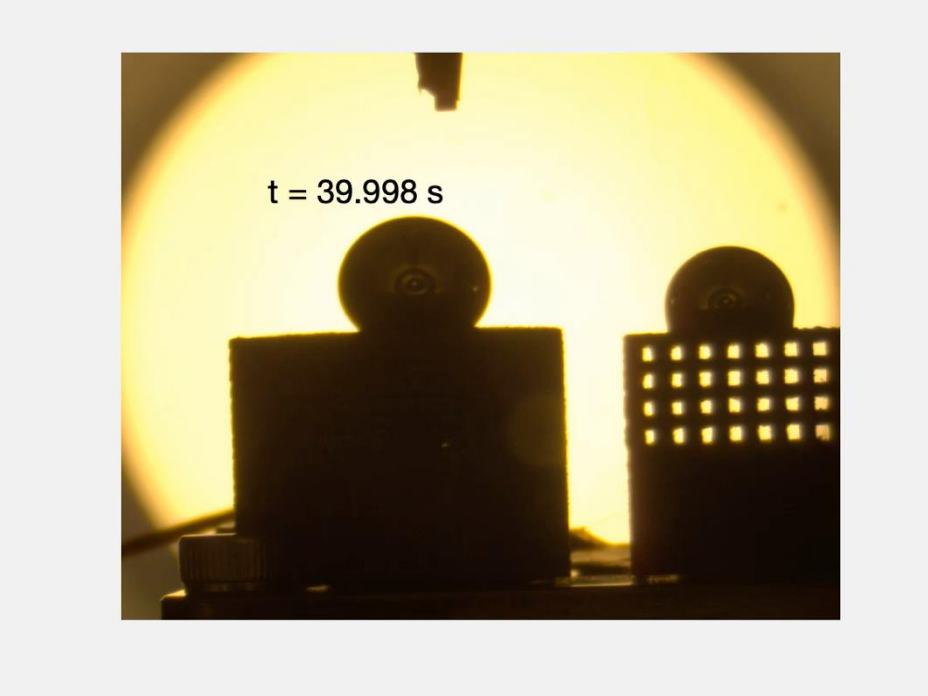
3D printed refractory metals are relatively unexplored



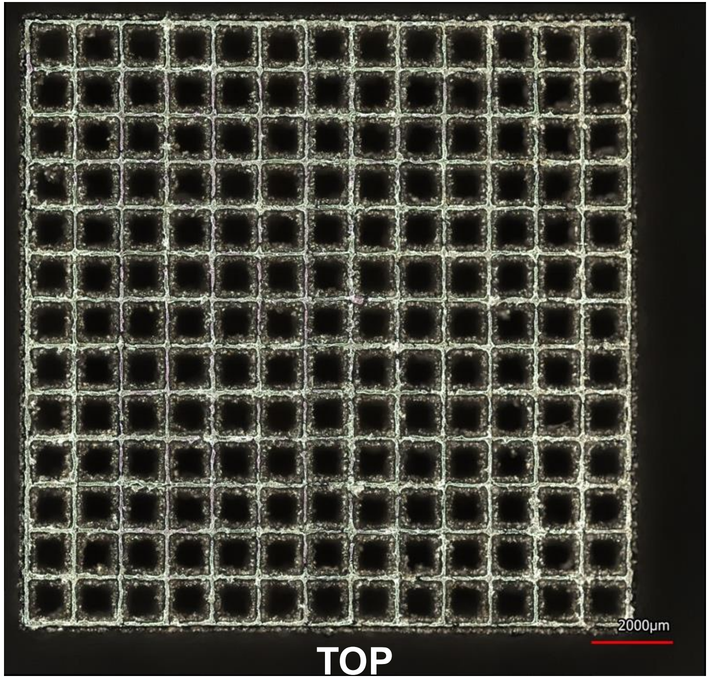
Wall Thickness (um) x Pore Width (um)

~1.5 cm cubes

Successful Li wetting test conducted with ~250 um pore CPS
Tests Performed at Penn State IGNIS-2 facility



3D printing of overhanging features leads to inexact print quality



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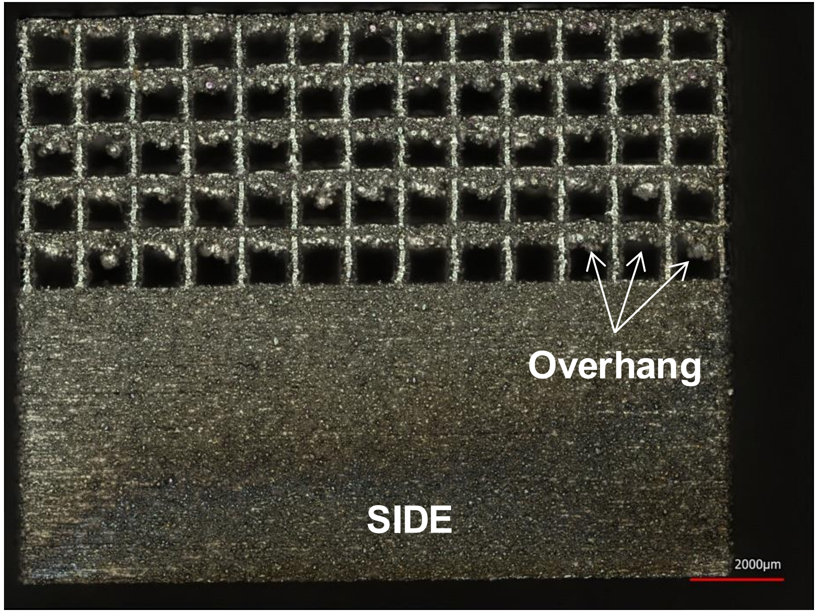

200 um wall x 938 um pore

All samples show clogging, with smallest pores fully-clogged

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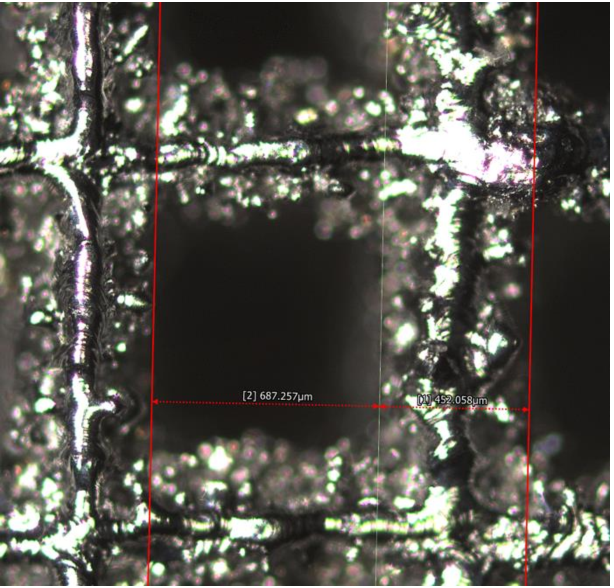
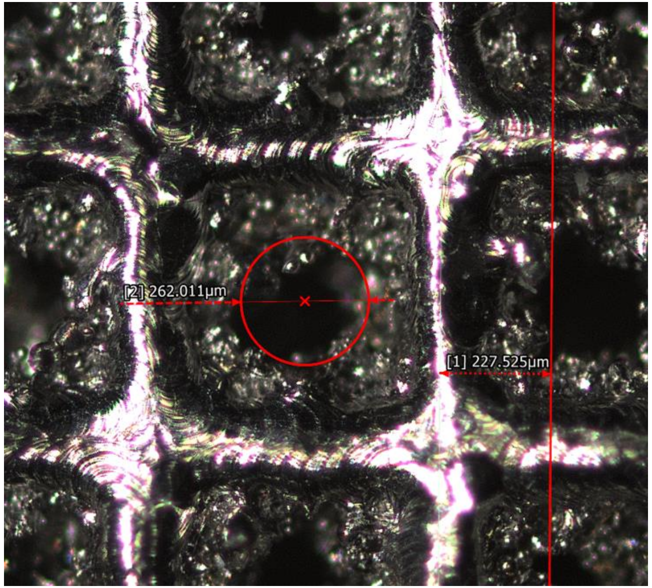
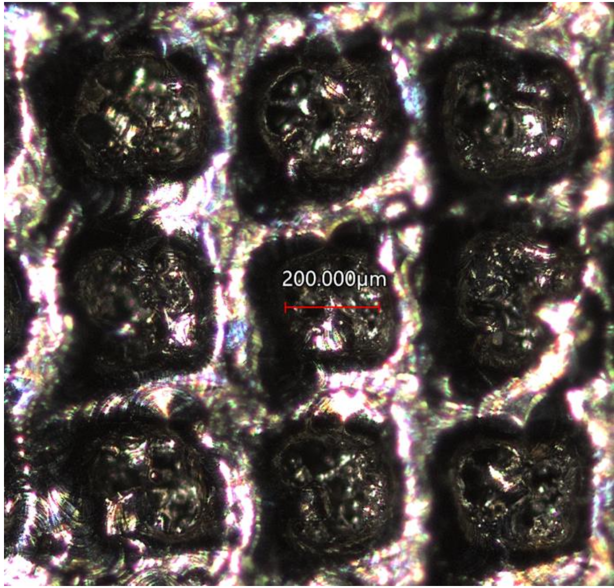


200 um wall x 938 um pore
actual pore size ~690 um

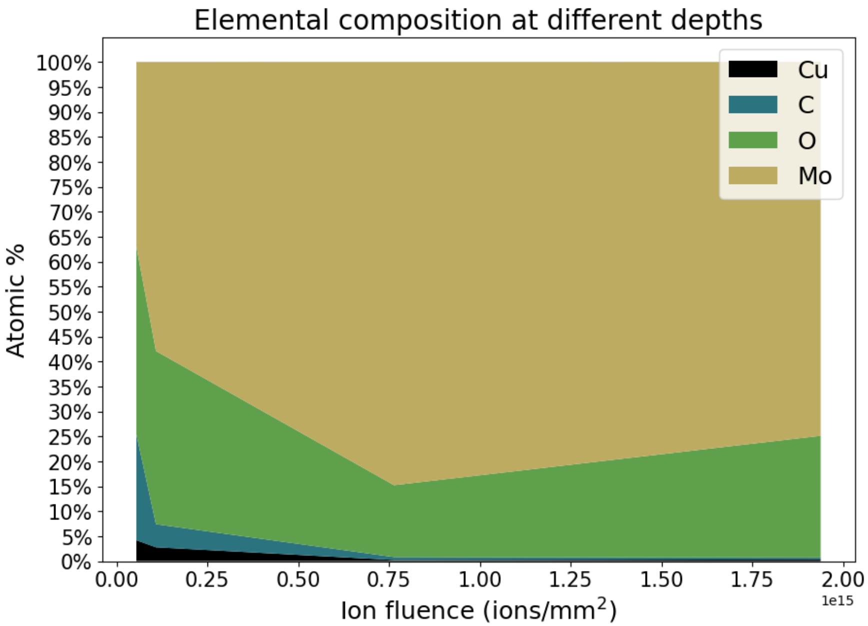


200 um wall x 417 um pore
actual pore size ~250 um



200 um wall x 211 um pore
fully clogged pores

Samples from two manufacturers analyzed, both showed high impurity content and other issues



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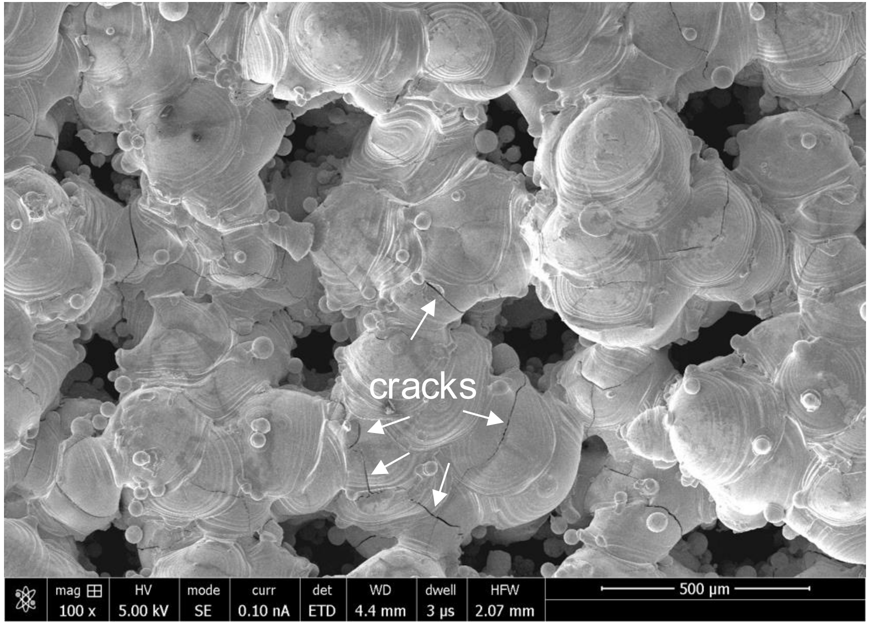
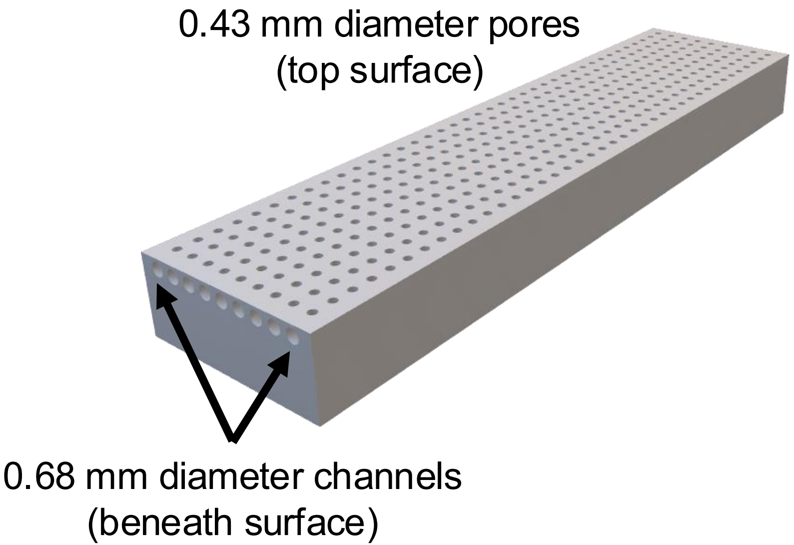
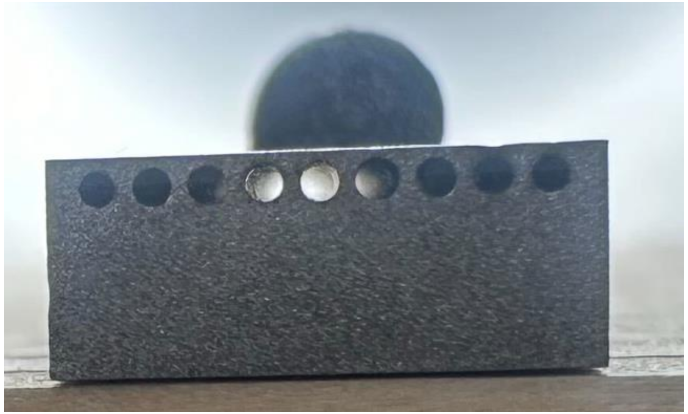


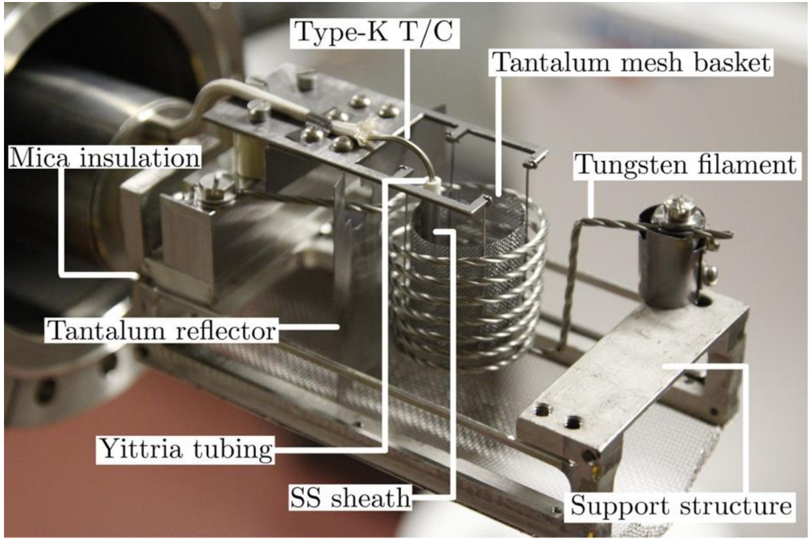
Maya Avida, Junior Paper 2025

Unsuccessful wetting test of SS 316 channels fabricated with Electric Discharge Machining Small-Hole Drilling

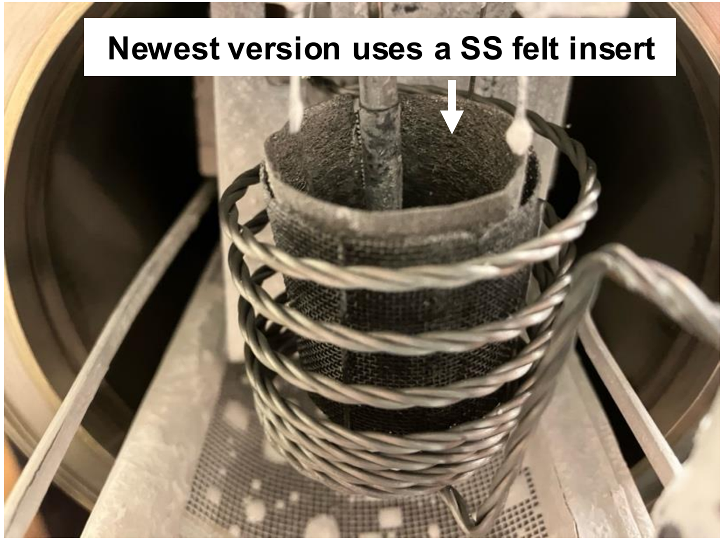




LTX-β has demonstrated usability of SS felt above 600 C



A. Maan *et al* NME 35 (2023)



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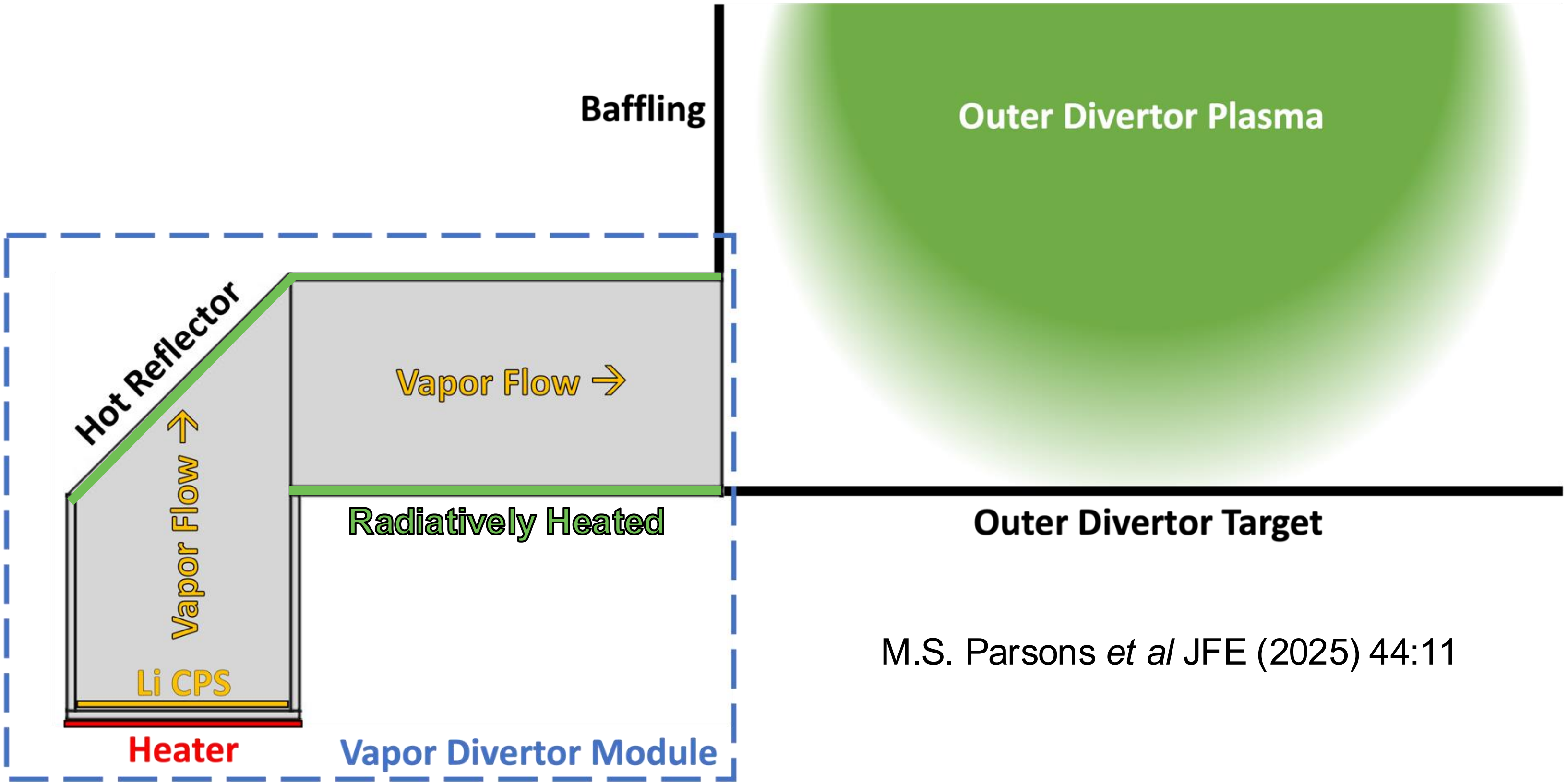
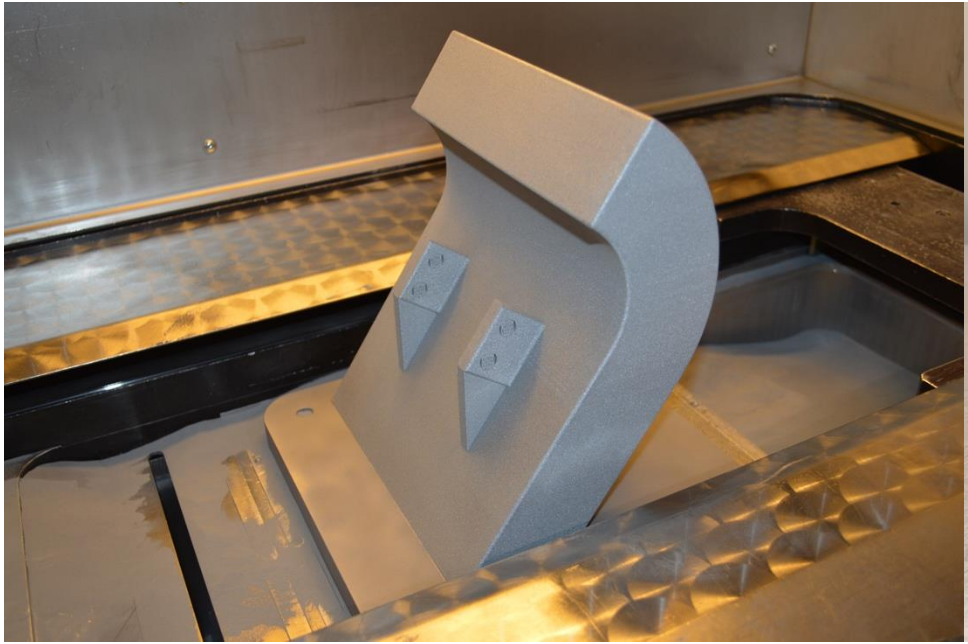
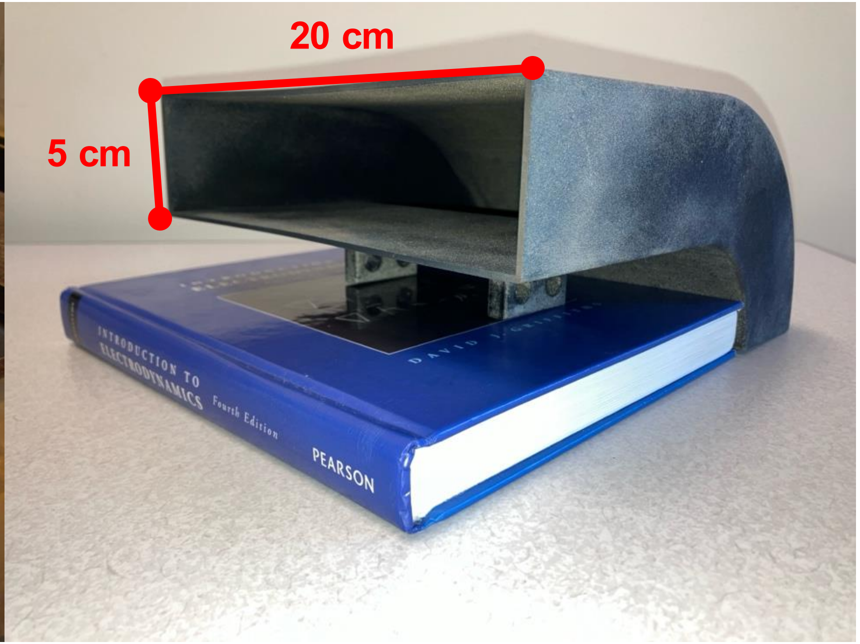
New conceptual design removes the Li CPS from the line-of-sight of the plasma radiation



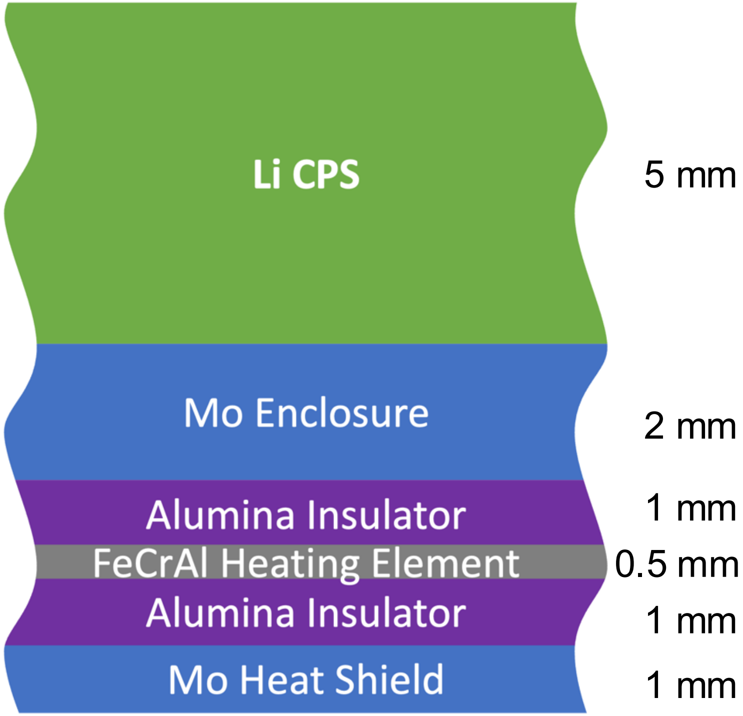
M.S. Parsons *et al* JFE (2025) 44:11

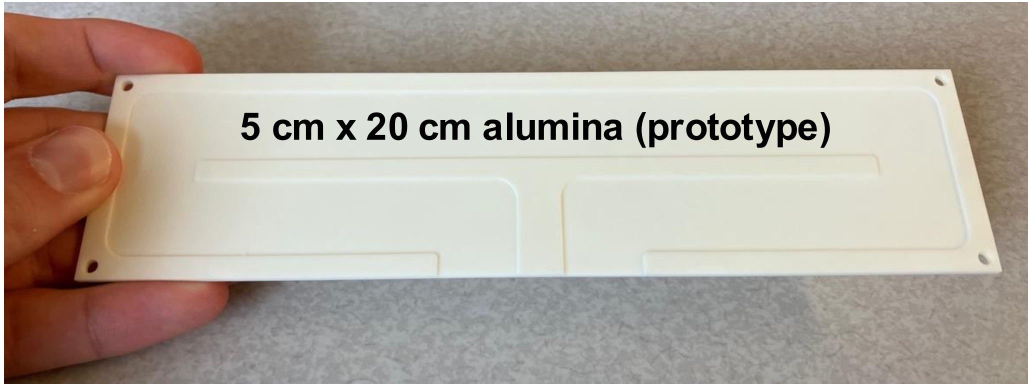
3D printed divertor module has large-scale bowing



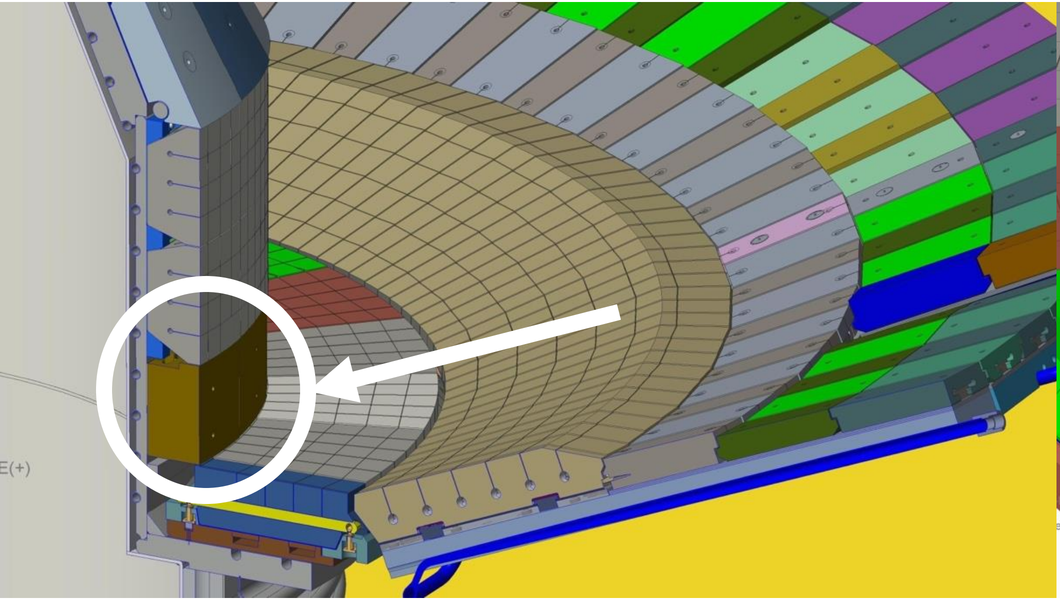


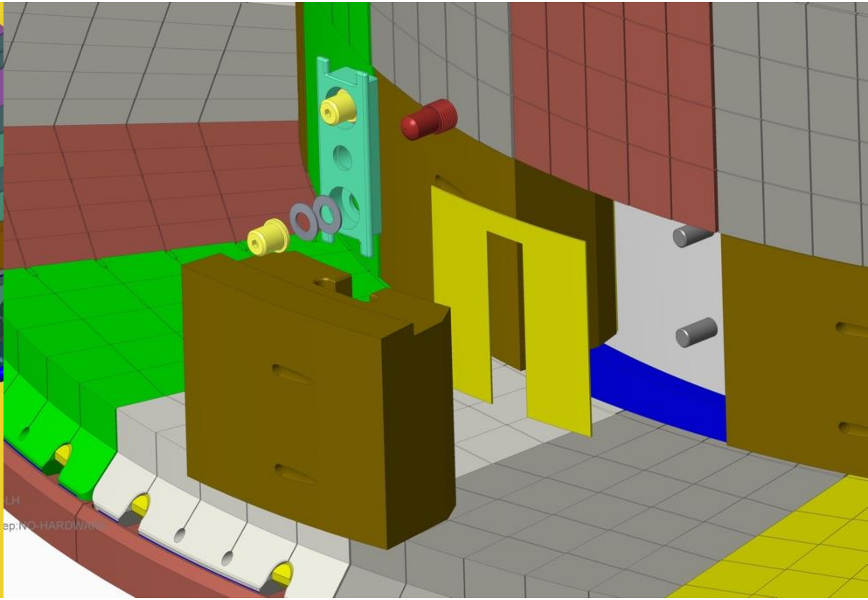
Conceptual Design:
Heater made of thin layers to minimize thermal mass



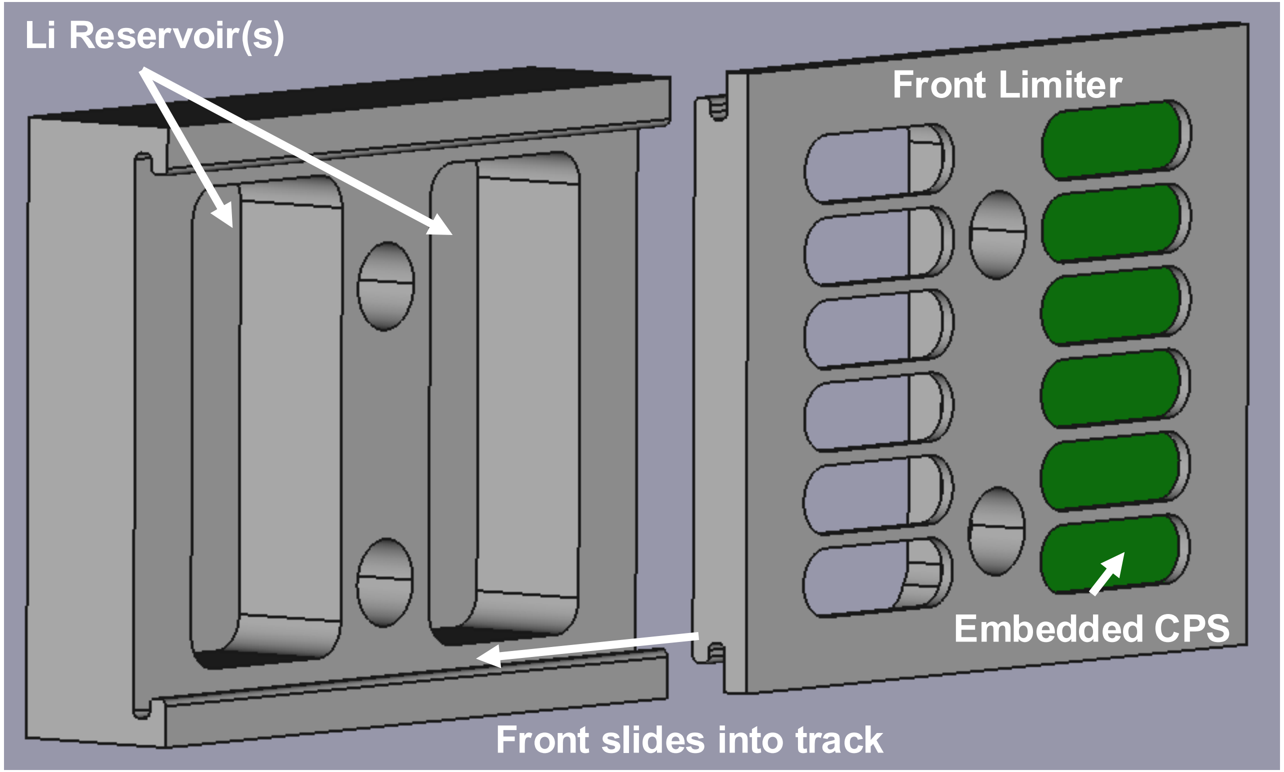


Exploring options to install a Li evaporator in NSTX-U as a 1:1 tile replacement in divertor





Prefilled Li tile offers simplest 1:1 tile replacement option (Conceptual design)



Highlights and Future Work

- Examined properties of several novel Capillary Porous System materials
  - Wire meshes show poor Li wetting characteristics
  - 3D printed Mo shows good Li wetting, but has many fabrication challenges
  - Shifting focus toward traditional machining techniques and proven materials

- Analyzed operating characteristics of a full divertor system for NSTX-U
  - Divertor geometry must be designed to allow controllability of Li temperature
  - Heating requirements exceed commercially available options
  - Developing technology for high power-density heater
  - Beginning conceptual design of 1:1 tile replacements for early NSTX-U expts.