Status and Progress in the Domestic Liquid Metal Plasma Facing Component Design Program

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A domestic liquid metal PFC design study was initiated in FY 2020

- **Goal**: design LM PFC concepts for a nuclear device
- **Options**: cooling with Li, with Li and He, and other fluids
- **Potential issues**: MHD flow instabilities, Li pumping through a strong magnetic field, corrosion/erosion, plasma/material interactions….

➢ **Design window identification** - high heat removal capability while meeting all the limitations with scoping calculations and 3D analysis

➢ **Experiments** for model validation and to test material and flow properties conducted in test stands and linear flow experiments with applied B

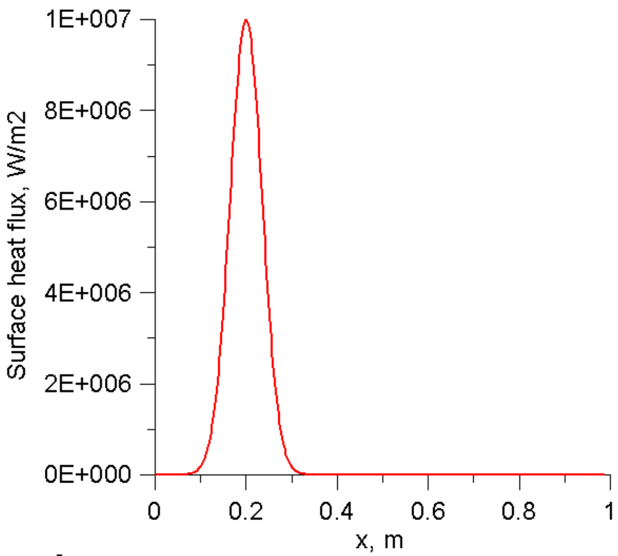
Goal: develop LM PFC concepts for reactors

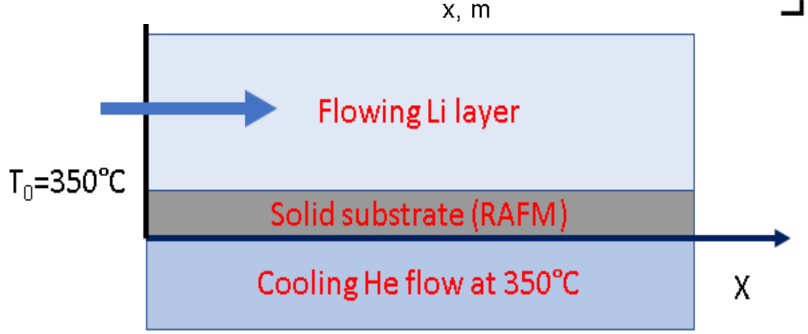
- First step: evaluate liquid Li divertor PFCs for FNSF, $T_{surf} \leq$ 450 C°, variable flow speed
  - T < 450 C° low evaporation, T > 450 C° high evaporation
  - Li flows over a porous medium
  - Cooling options: by He flow, Li + He, Li flow
- Heat transfer and MHD drag calcs (UCLA, PPPL, ORNL
- Plasma response and transport, incl. sheath (ORNL, UIUC)
- Material compatibility issues, e.g. corrosion, embrittlement, wetting, dryout (ORNL, UIUC)
- Prototypical flow in linear Liquid Metal eXperiment (PPPL/PU)

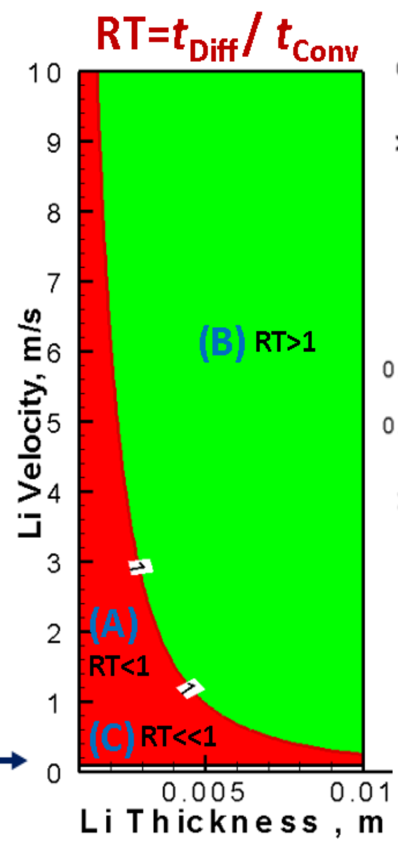
Summary of progress in FY20

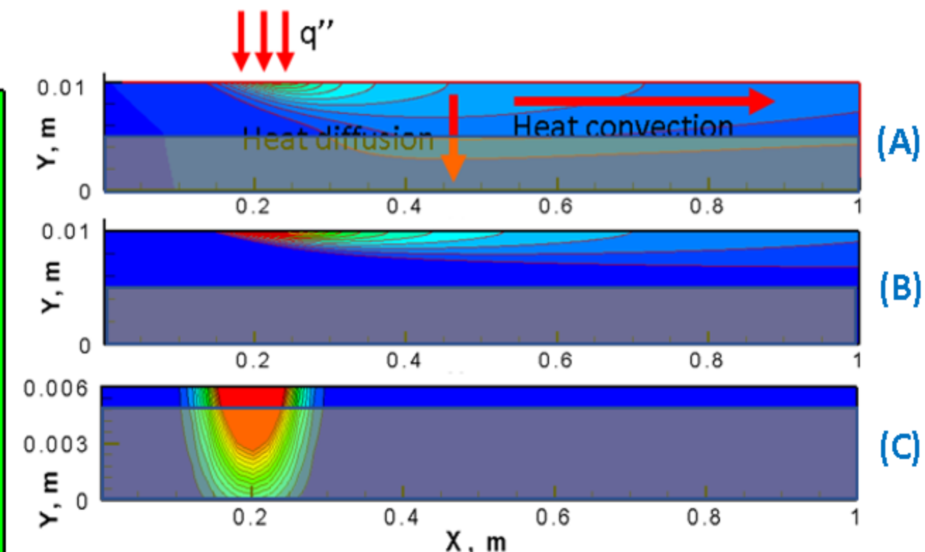
- Heat transfer by flowing liquid Li can reach 10 MW/m^2 for flow speeds below 10 m/s at 450 C°
  - Multiple calculations show this (Smolentsev, Khodak, ~Youchison which is still in progress)
  - Khodak assessing MHD pumping power requirement
- Plasma transport and sheath model update calculations initiated
- Preparations for liquid metal corrosion, embrittlement, wetting, etc. initiated in test stands
- Flow experiments in LMX prepared

Different heat flux exhaust modes identified









(A) Heat removed by Li and He

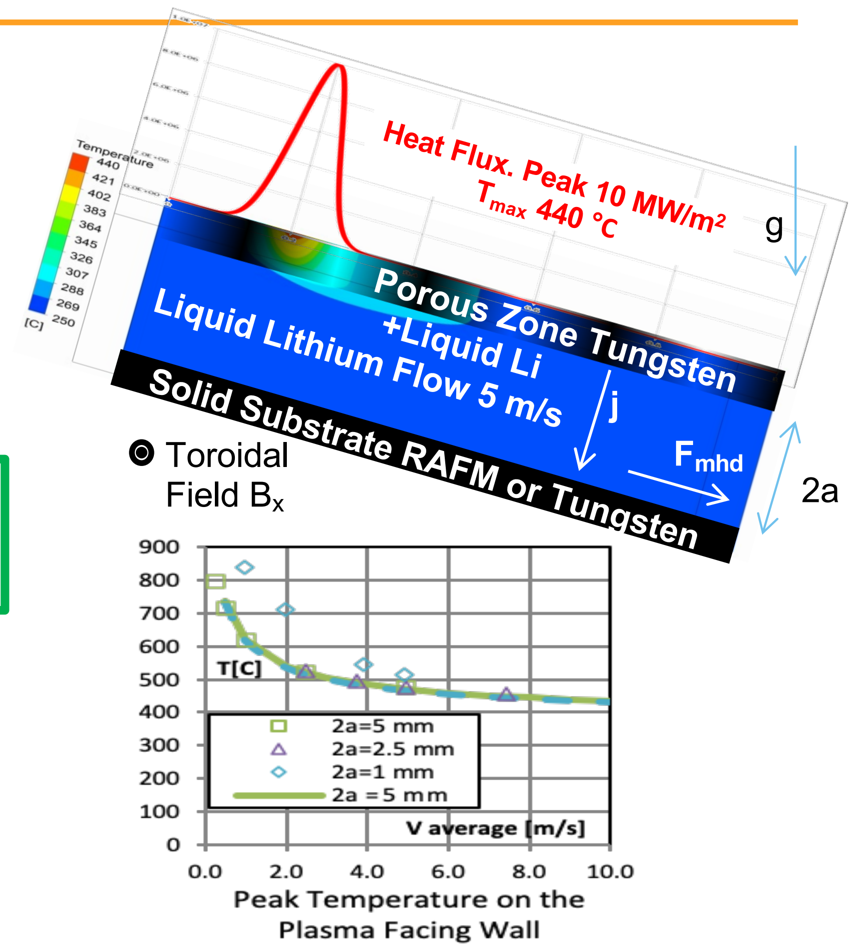
(B) Heat removed by only Li: 10 MW/m^2 @ 7 m/s, T_{surf} = 450 C^o

(C) Heat removed by He $\leq$ 0.5 MW/m^2

S. Smolentsev, UCLA

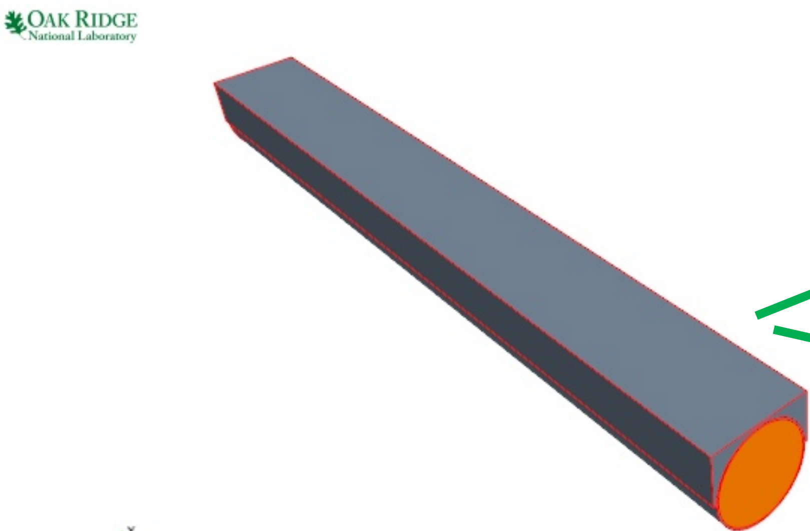
Concept: use Li as coolant in a porous wall

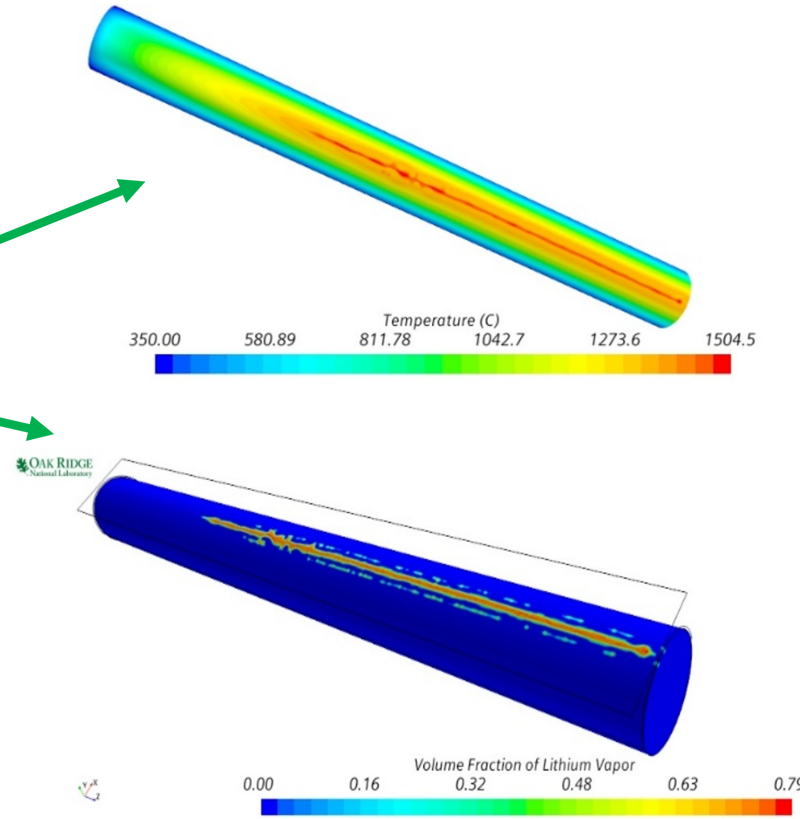
- Liquid Li flowing along the heated wall
- Porous wall placed on top of the liquid Li coolant and stabilizes the surface of the flowing coolant
- Liquid Li flow under porous wall organized into a series of rectangular channels normal to B_t
- Channel walls provide structural support for the porous wall, & serve as a current conduit for MHD pumping
- Analytical and numerical modeling, including evaporation effect on heat transfer, identifies surface T consistent with 10 MW/m^2 heat flux removal and input Li velocity
- MHD pumping creates constant pressure condition in the Li, allowing a free-flowing surface on the porous media
- Calculated power required to pump liquid Li through channel < 5% of the incident plasma heat flux



A. Khodak *et al*, NME (2020) subm.; PPPL Invention Disclosure

Heat transfer evaluated from thin-walled, low pressure Li cooling (calcs. still in progress)

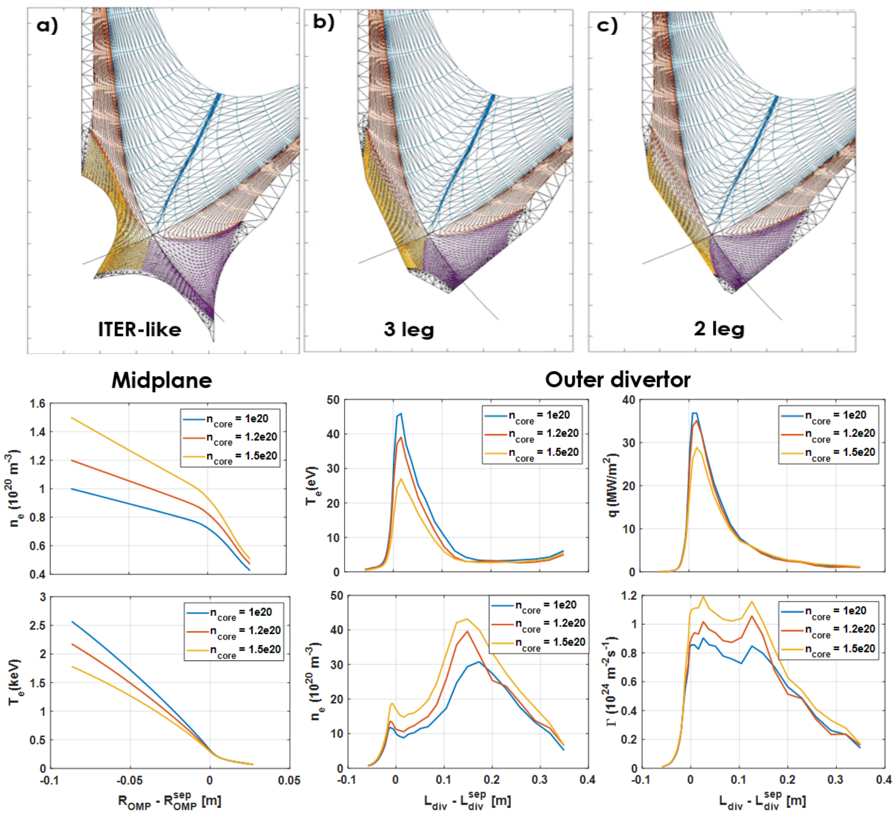




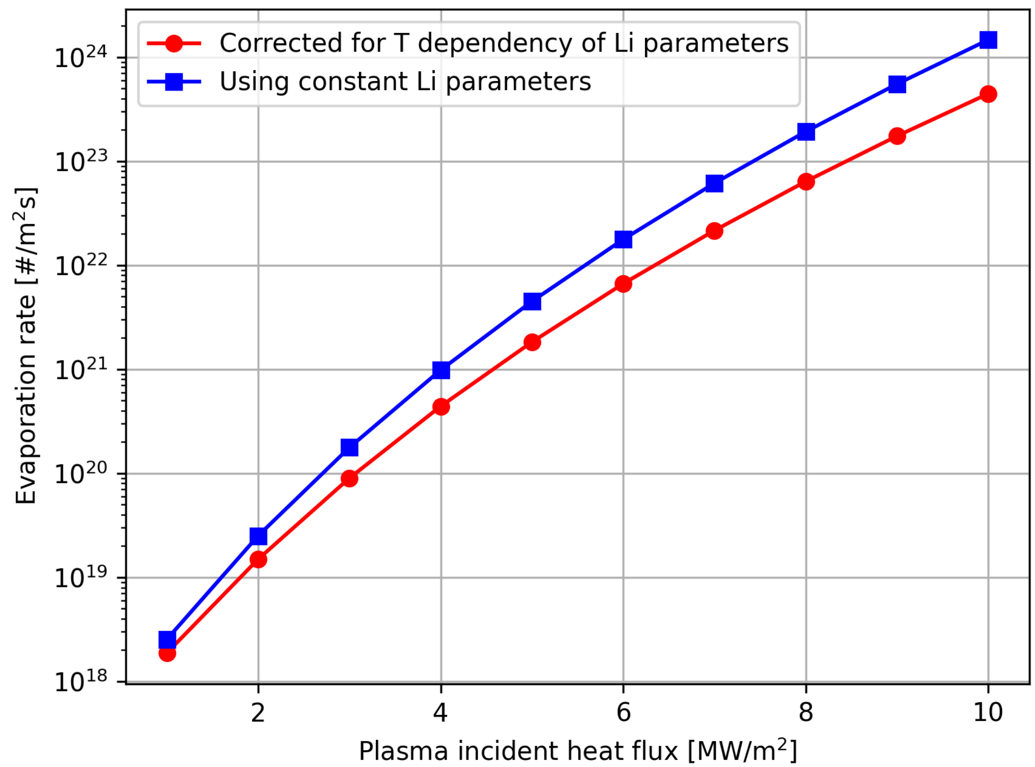
- **Up to 20 MW/m² can be exhausted with $T < 450$ C°, 60 MW/m² with $T < T_{boil}$**
- **He and siloxane cooling was worse**

D. Youchison, ORNL

Plasma transport and sheath calculations started

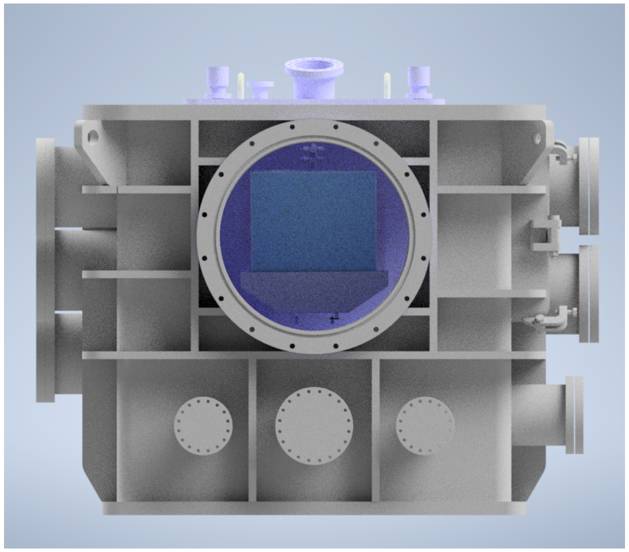


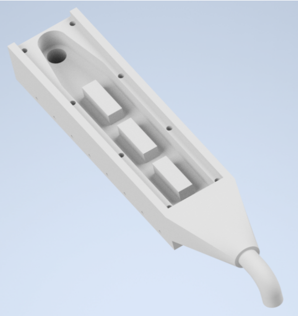
Baseline non-Li and Li SOLPS calculations initiated
J. Lore, ORNL



First calculations from updated sheath model
D. Curreli, UIUC

Test stands preparing to do embrittlement, corrosion, injection tests



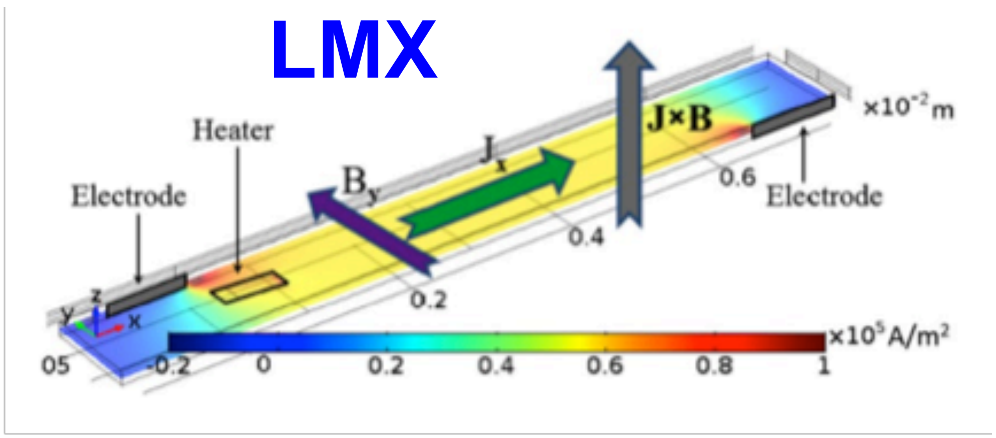


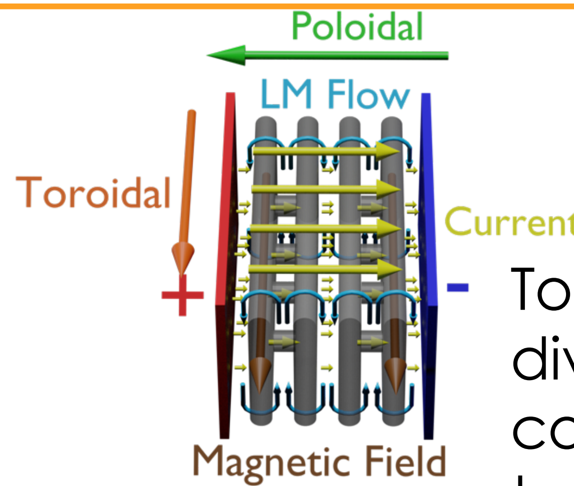
Literature reviewed for Li corrosion and evaporation losses
C. Kessel, ORNL

Development of Li corrosion and injection tests in MEME
D. Andruczyk, D. Curreli, UIUC

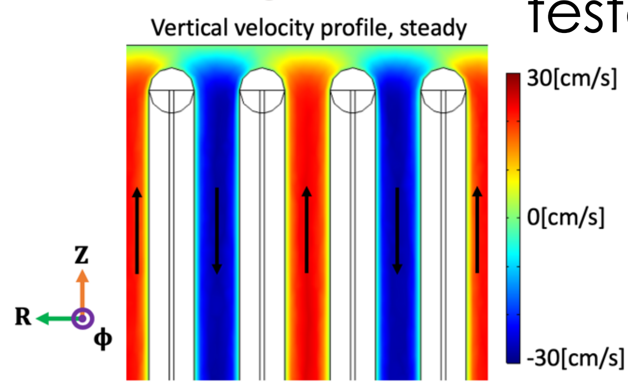
Preparation of RAFM steel tensile specimens for liquid Li embrittlement test
B. Pint, J. Jun, ORNL

Divertorlets concept being tested in LMX; potential upgrades identified





Toroidal divertorlet concept being tested



- Increased the current and J X B substantially in LMX
- Upgrade of the magnetic field by ~ 3x to 1T designed

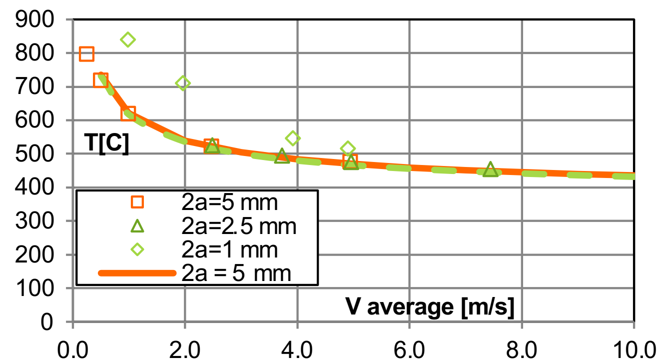
A. Fisher, E. Kolemen, PPPL/PU

Summary and Near-Term Directions

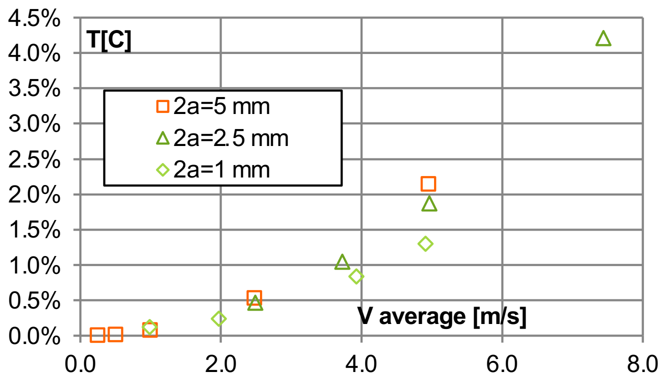
- **Conclusion**: flowing liquid Li most efficient for heat exhaust
  - Flow < 10 m/s exhausts 10 MW/m^2, better than He or other cooling
  - MHD pressure drop and required pumping being assessed
- Continue heat transfer and MHD pumping calculations, and expand to allow higher surface temperatures
  - Document results in 2021 conferences
- Finish plasma calculations including Li evaporation, using new sheath model results of evaporative flux
- Complete first set of corrosion, embrittlement, wetting experiments in test stands
- Complete first divertorlet experiment, and finish costing of the LMX upgrade designs

Backup

Backup: Thin wall design (Khodak)

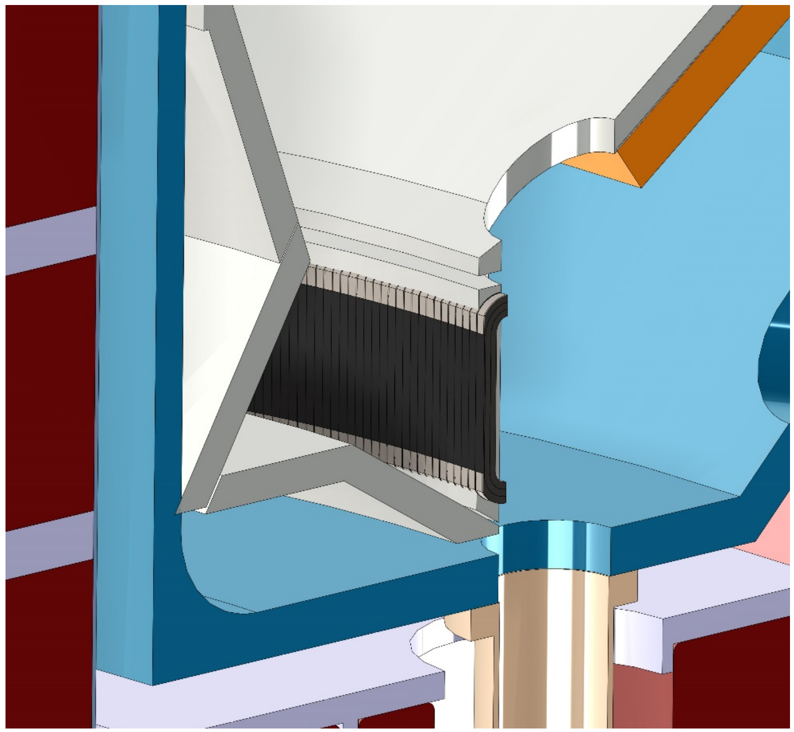


Peak Temperature on the Plasma Facing Wall



MHD pumping loss as a percentage of incoming heat

Scaled model of the liquid lithium cooling system in the divertor



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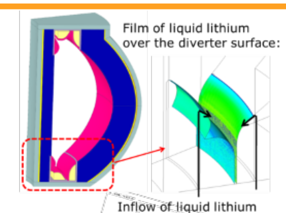
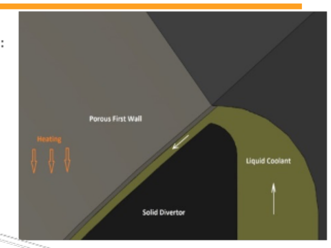
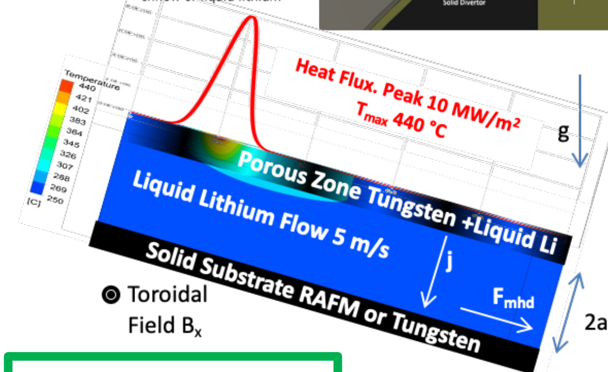
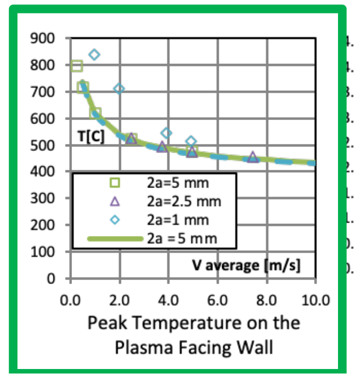
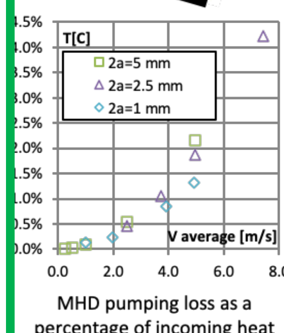
A. Khodak, PPPL, NME (2020) subm.











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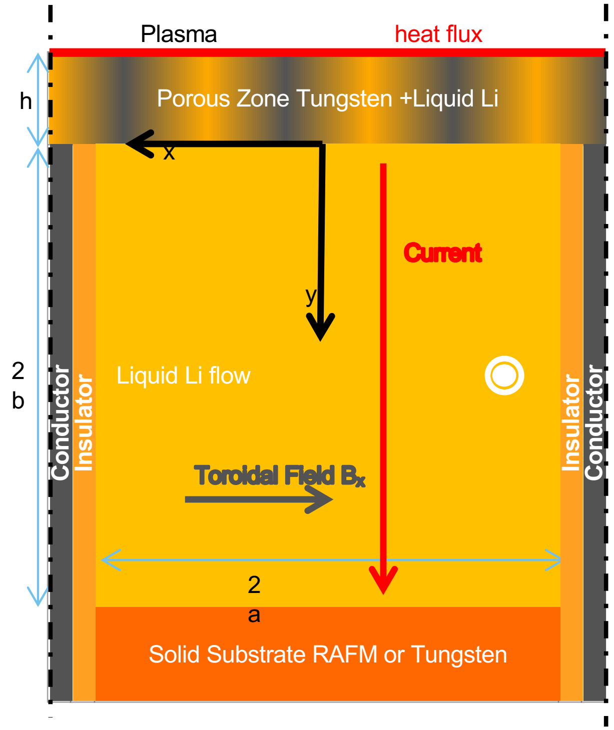
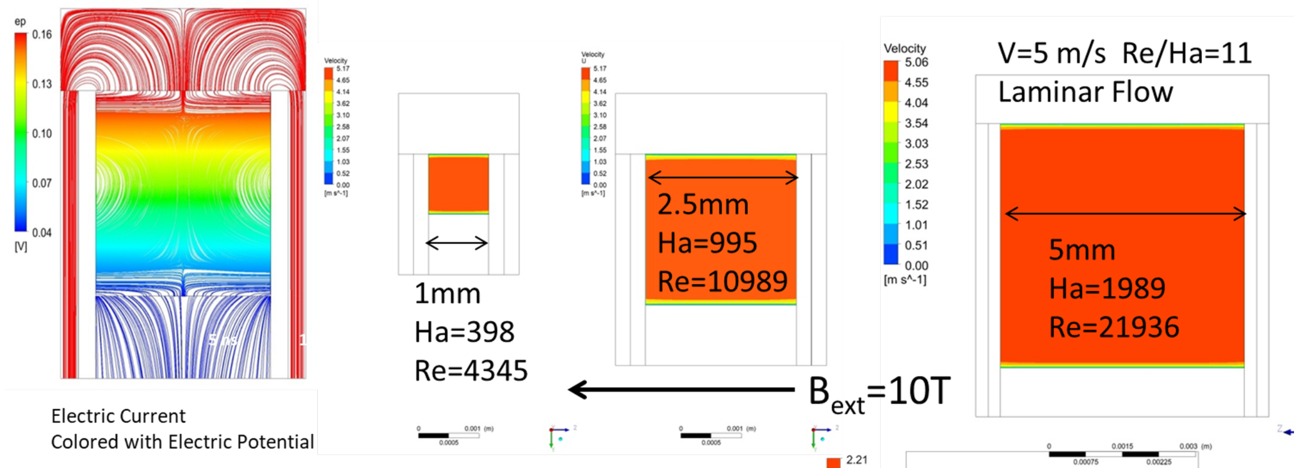
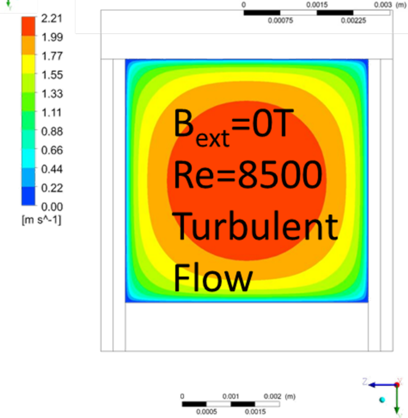


Cross-section of liquid lithium channel with porous wall



- For the parameters we considered MHD flow is laminar
- MHD velocity structure is favorable for heat transfer: flat core and thin boundary layer
- With magnetic field flow in 5 mm vertical channel is turbulent



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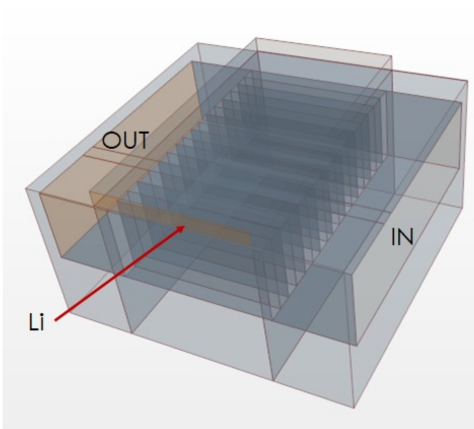
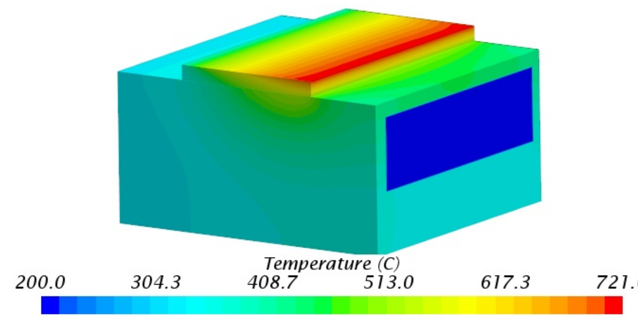
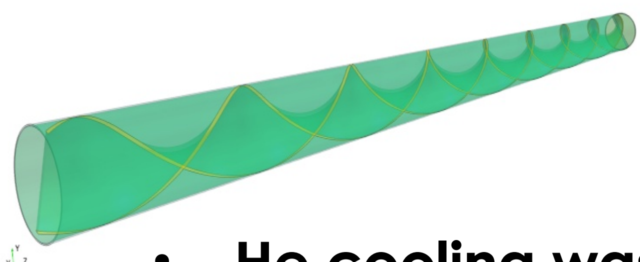
Heat transfer evaluated from parallel and swirl tube heat sinks (q=20 MW/m^2, siloxane cooling)

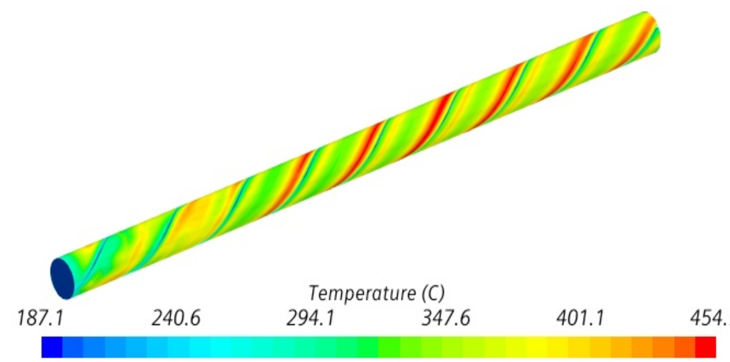


Parallel heat sinks





Swirltube heat sinks



- He cooling was worse

D. Youchison, ORNL