PPPL PRINCETON PLASMA PHYSICS LABORATORY

Lithium Material Transport and Liquid Metal Technologies for International Collaboration with ASIPP

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Overview

- Lithium issues and the need for this research
- Proposal overview
- Activities ongoing at PPPL ready to contribute to this work
- Benefits of the research to EAST and US programs
- Overview of research plan

Lithium has several outstanding issues to resolve if it is to have a future

- In-vessel inventory creates problems in steady-state
  - Continual increase of lithium if not removed
  - Tritium co-deposition detrimental to plant operation
- Technical implementation unproven on large-scale devices
- Power-cycle undeveloped which is integrated with lithium PFC temperatures

These are common objections to the liquid lithium in the US program and must be addressed

PPPL and ORNL are proposing to work on EAST and KSTAR to address these issues

- ORNL+collaborators is focused on KSTAR
- PPPL+collaborators is focused on EAST material migration and lithium technology
  - PPPL collaboration with Magnum-PSI and U-Illinois IIAX facility provide basic Li-coating data (e.g. sputter yield)
  - Purdue+PU+PPPL contributing surface science experiments and modeling of material migration
- Liquid metal technology program is a parallel effort
  - PPPL and U-Illinois focused on liquid metal PFC and associated loop
  - UCLA contributing LM-MHD simulations

PPPL is currently researching these topics due to NSTX Li usage

- NSTX has years of experience with Li evaporation, powder and, recently, Li on molybdenum liquid lithium divertor
- Several internally funded projects are underway which contribute to the technology aspects
- PPPL researchers have experience in laboratory and in confinement devices for understanding impact of Li on overall machine performance

Reliable operation is the goal of the Liquid Lithium Test Stand

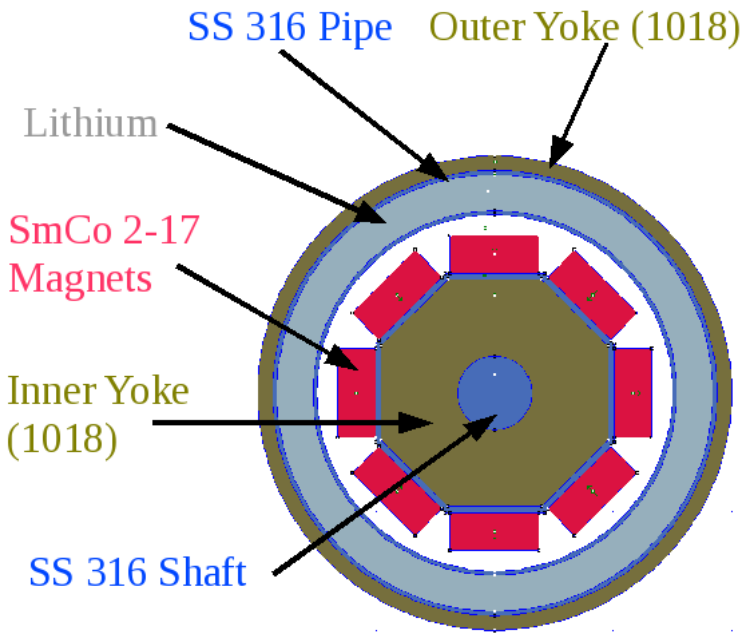
R037

- Project will demonstrate operation of a liquid lithium loop for tokamak campaign-relevant periods of time
  - E.g. 8 hours operation/day, 5 days a week, 15 run-weeks
  - Tokamak relevant vacuum (e.g. 1e-7 Torr base)
- Reliable startup, shut-down, and restart
- Reliable introduction and removal from vacuum system (free-surface flow in vacuum)

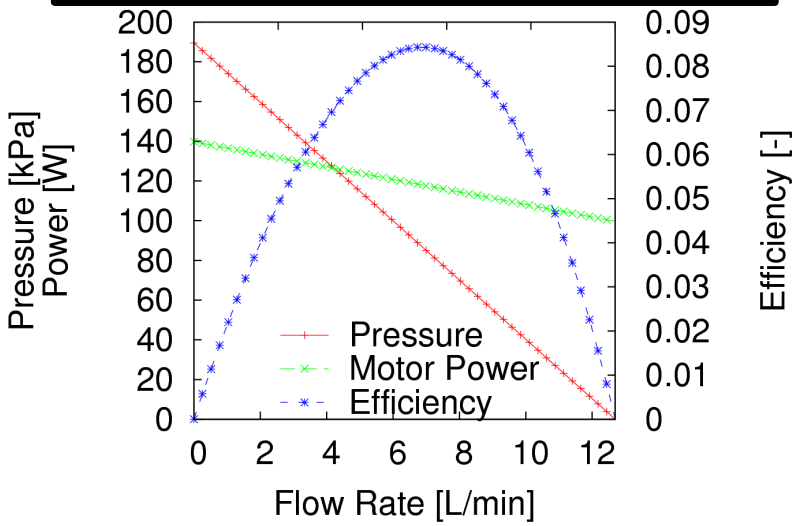
We are targeting robust and reliable operation in challenging environments to support a user-facility

New liquid metal pump will provide precise control of flow

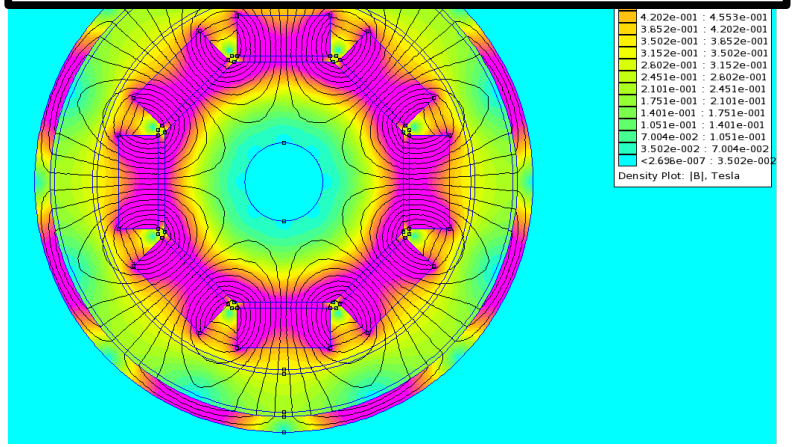
- Simple pump design developed for LDRD
- Fine control of system pressure through speed control of motor
- Avoids uncontrolled flow during Ar piston operation



Predicted pump performance



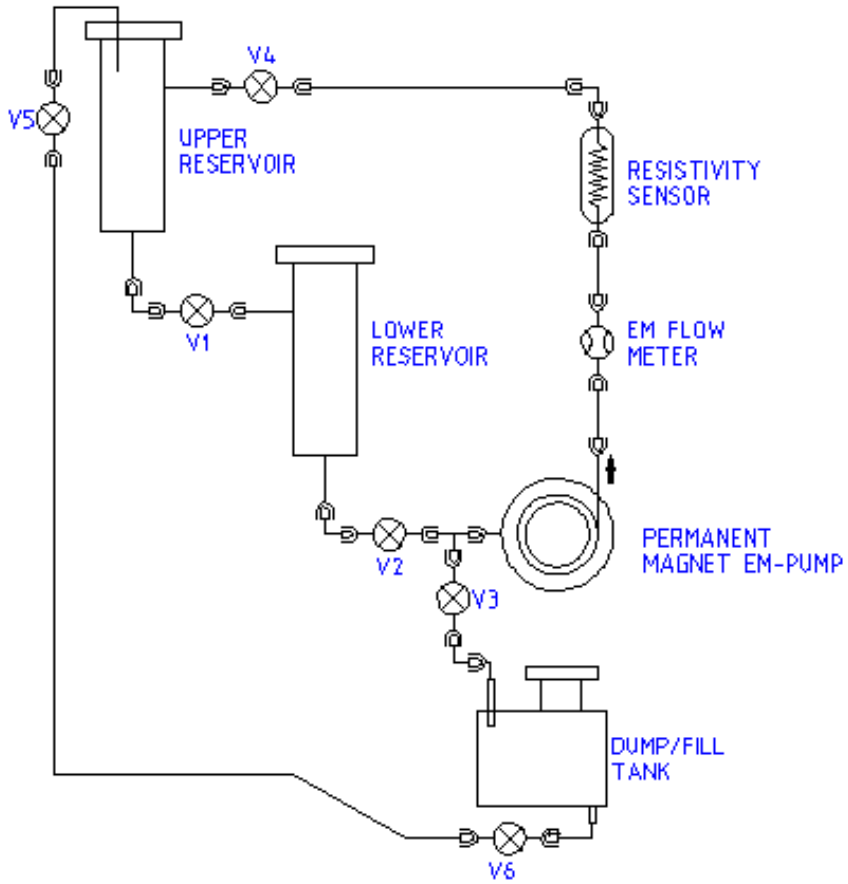
Magnetic field simulation with actual material properties



Project is on track to begin closed-loop testing in late June, vacuum in August

- Fabrication and assembly will occur in May and June
- First experiments will demonstrate loop operation alone
- Vacuum system integration to proceed in August

Liquid Lithium Test Stand Loop Diagram



Exploration of advanced cooling schemes is underway with "Next-step development..." R035

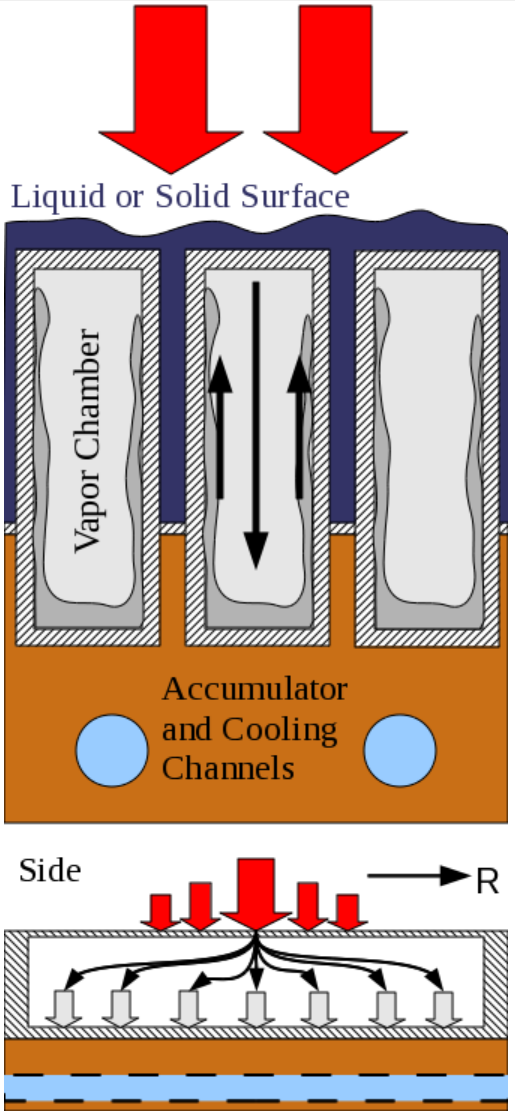
- Project carries forward engineering analysis of "soaker-hose" concept
  - A. Khodak performing thermal analysis
  - Optimization of gaseous cooling for liquid lithium PFCs
- Examining purification systems and other sub-systems for maintaining liquid metal system
- Scope and planning for on-site coolant plant to support experiments

We are advancing liquid lithium PFCs and loop systems for testing and long-term, on-site operation

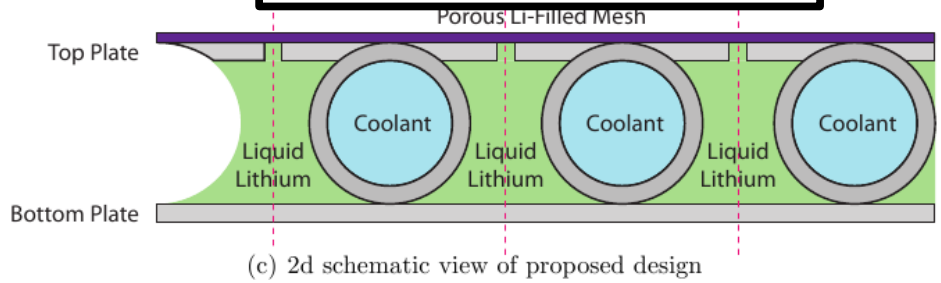
Advanced power extraction schemes impact solid PFC concepts as well as liquids

- Most concepts rely on active cooling
  - Thin, slow-flow LM concepts
  - Solid PFCs
- Efficiently dealing with heat flux *peaking* is important for divertor concepts
  - Impinging-jet cooling in T-tube and EU "finger" concepts
  - Vapor box/heat pipe another possibility
- Coolant channels used as generic term here

Vapor-box & accumulator concept for NSTX-U



Soaker-hose concept



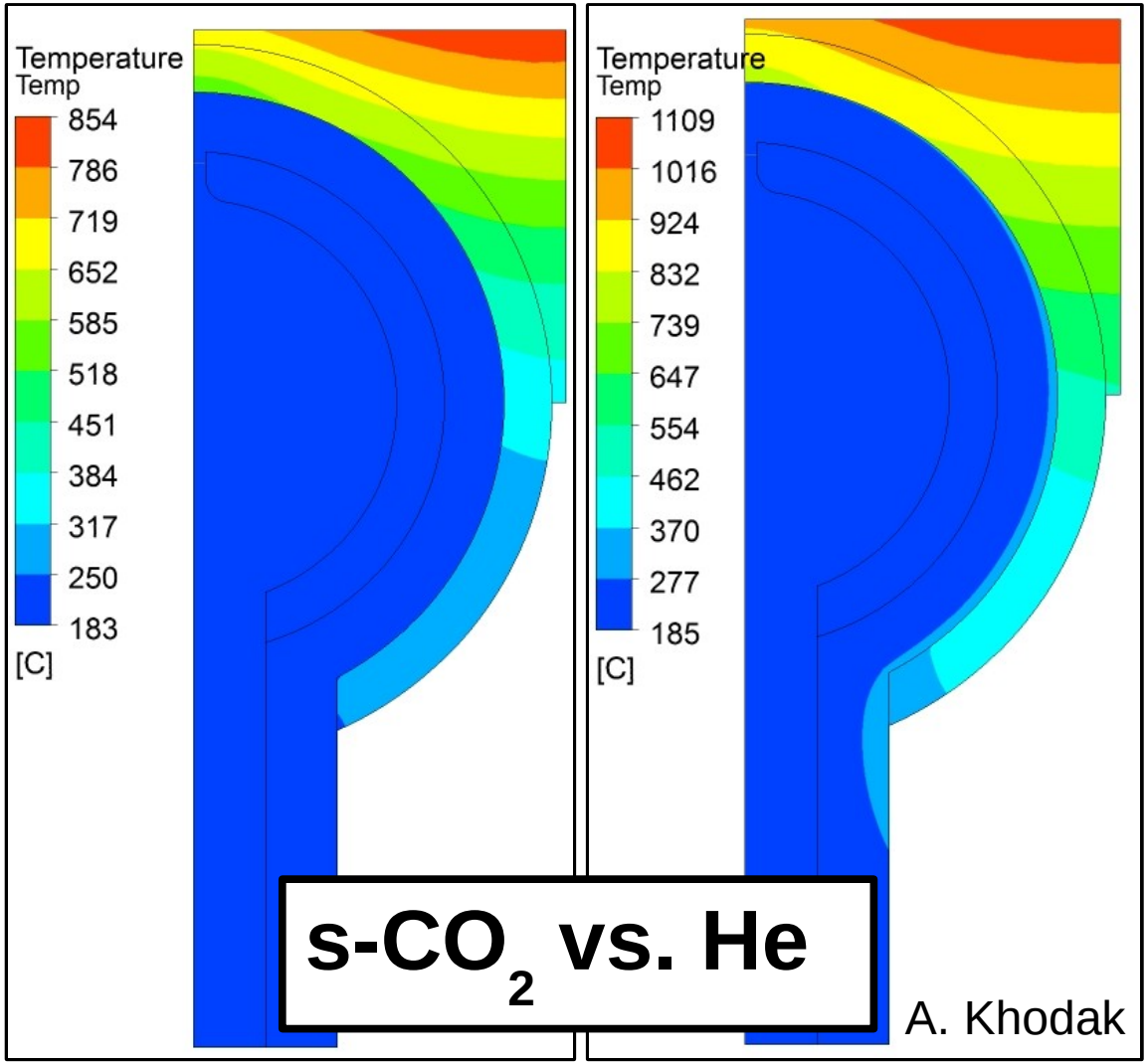
(c) 2d schematic view of proposed design

Goh, Goldston, and Jaworski

Initial studies show supercritical CO_2 more effective coolant than helium

- ARIES-CS T-tube simulation provides ANSYS/CFX check
  - Good agreement found with ref. k-ε turbulence model
  - Allows parameter study locally at PPPL
- Identical volumetric flow-rates modeled
  - s-CO_2 density 10x that of helium, both at 10MPa
  - 255C lower temperature
- Larger pressure drop (~10x) with s-CO_2

T_{max} = 854C vs. 1109C



A self-consistent power cycle using s-CO_2 addresses a key criticism of Li PFCs

- Low temperature PFCs (e.g. Li) often criticized for "throwing away" fusion power
- s-CO_2 cycles are operating now and under continuing development for fission power plants
  - Dostal found comparable thermal efficiencies for s-CO_2 at 550C and a comparable He cycle at 850C
  - s-CO_2 out-performs He at equivalent temperatures
- This LDRD is developing a self-consistent s-CO_2 cycle to complement the PFC cooling work
  - s-CO_2 not limited to low-temperature PFCs; could be utilized for high temperature PFCs as well

Completion of FY2012 objectives with current funding makes significant steps for LM-PFCs

- **R037** will demonstrate loop and flow in vacuum by August and conduct experiments on restart and handling
  - Design time and drafting has offset peak spending for procurements (project had March start date)
  - Technician/machinist/welding labor will utilize significant amount of budget in May-June
- **R035** will have 2D and 3D simulations, purification and coolant system design activities done by Sept.
  - Current simulation job originally estimated at 500hrs, can complete in FY2013
  - Other activities originally proposed for full year of FY2012 can be completed in FY2013 (e.g. free-surface diagnostic development)

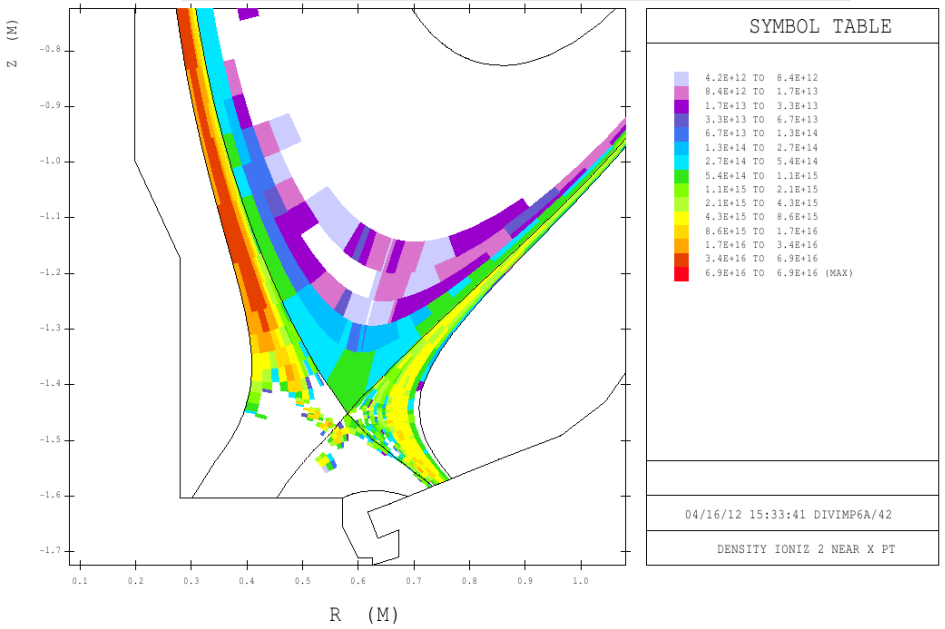
Overcoming the technical challenges facing liquid metal PFCs

- These projects are developing practical experience operating liquid metal loops here at PPPL
- We are developing new gaseous cooling schemes to control the PFC temperatures
- Questions of robustness and reliability are central to this work

Impurity transport codes already in use for interpreting NSTX data

- OEDGE code suite produces fluid background with EIRENE neutral hydrogen
- DIVIMP simulates impurity transport with Monte-Carlo methods
- DIVIMP can also run on SOLPS/UEDGE fluid backgrounds
- Local redeposition and transport can be modeled with WBC-Redep (Purdue)
- Simulations already being used for diagnostic development and radiation simulations

DIVIMP impurity transport modeling of Li in NSTX



We expect the collaboration to be mutually beneficial

- Material transport in EAST could be used to optimize Li injection and the achievement of long-pulse discharges
- Robust and reliable technology development is a central focus in support of operation on confinement devices (i.e. reliability, ease of use)
- Work addresses the question of whether in-vessel lithium (co-deposited T) can be controlled (introduction and removal) or if other liquid metals should be pursued (e.g. Sn, Ga)
- Provides technical experience with LM PFCs and associated components so that confinement devices can determine if or when it should be implemented

Proposed research plan

- Magnum-PSI and IIAX studies determine sputter yields on Li-coated PFC materials (years 1&2)
- Surface science studies ongoing to understand controlled physics and chemistry of Li surfaces (years 1-3)
- EAST studies to focus on material migration (years 1-3)
  - Accurate modeling of EAST edge plasma
  - Measurement of erosion/redeposition through existing and upgraded diagnostics (e.g. div. spectroscopy, marker tiles, isotope expts., QDMs)
  - Assessment of material migration from evaporated coatings, powder and granule injection, other means (e.g. ELI)
- Development of designs and testing of LM technologies so that EAST or others can implement in convenient timetable (years 1-3)
  - Multiple limiters possible (e.g. LIMIT, soaker-hose, FLiLi)
  - Basic loops, pumps, purification systems being developed at PPPL

Discussion questions for ASIPP

- Any feedback you have on the existing plan and your own research priorities would help us strengthen our proposal.
- Is there a written or definite plan for lithium usage on EAST or anything to help us refine timetables? Timetables of divertor/PFC upgrades?
- Would ASIPP/EAST commit to testing technology elements either within the first 3-year cycle or early in the second 3-year cycle?

Thank you for your consideration

Questions?