UCSD-PISCES Program for Liquid Metal Plasma Facing Systems

S.C. Luckhardt, G. Antar, M. Baldwin, L. Cai, R. Doerner, E. Hollmann, S. Indrakanti, T. Lynch, R. Seraydarian, and the UCSD PISCES Group

Department of Mechanical and Aerospace Engineering
Center for Energy Research
UC San Diego

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FY02 Progress on ALPS Tasks

PPPL/UCSD/ CDX-U

- Develop a liquid lithium fill system for use in CDX-U tray limiter. A test facility was constructed at UCSD to test the phase separation and liquid lithium filling concept. The tests were successful and a clean liquid surface was generated and found to wet and flow throughout a test limiter tray. Two full sized phase-separator filling systems were then fabricated, tested, and shipped to PPPL as of 10/2002. They will be installed on CDX-U during Nov/Dec time scale.
- Continue collaborative experiments on CDX-U limiters. Collaboration papers have been written and published including an IAEA conference paper. Experimental collaboration on the tray limiter experiments will continue in FY03.

UCSD PISCES

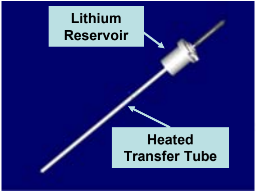
- Permeation/retention of He in liquid Li: Experiments have set an upper bound for the permeation retention of Helium in liquid lithium in FY02. We have modified our experiment to improve the time response of the measurement and to obtain better bounds on the helium retention. This new system will also be used to investigate the possibility of helium bubble formation as a transport mechanism during FY03.
- Measure Li-H permeation rate in liquid Li. Experiments on PISCES have been modeled using the Stokes-Einstein diffusion model for Li-H and appear to be consistent with this model. Permeation measurements were found to be dominated by surface recombination rate limiting process, and the temperature dependent recombination rate coefficient was measured. Further work will be needed, but the Stokes-Einstein model appears to be credible.
- Continue analysis of thermally enhanced erosion effect in liquid metals. During the past year we have completed measurements on this effect in liquid lithium and liquid gallium. It is found to be important in both cases. It now seems likely that this is a general property of plasma interaction with liquid metals. So for the various theoretical explanations proposed do not appear sufficient. We will continue this investigation in FY03.
- Assess PMI properties of various non-conductive and weakly conductive liquids. Additional liquids have been added to the data base and modeling for thermal load handling has been done. So far, it appears that several of the liquids can effectively pump hydrogen, but their application to fusion experiments is limited by the low heat conduction rates.

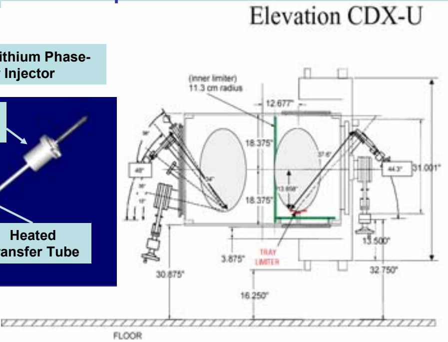
Topics

- Liquid lithium injector phase-separator for CDX-U limiter experiment
- Deuterium and helium retention and release experiments and modeling
- Some thermal transport results
- Temperature dependent erosion
- Future plans

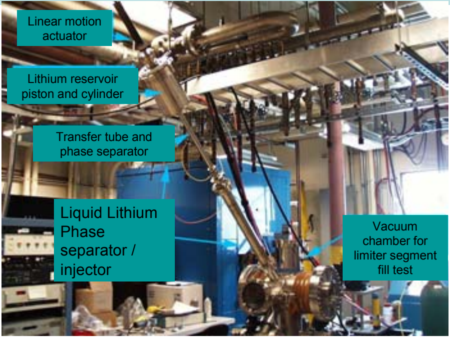
UCSD liquid lithium delivery system for liquid lithium limiter experiment on CDX-U

UCSD Liquid Lithium Phase-separator Injector

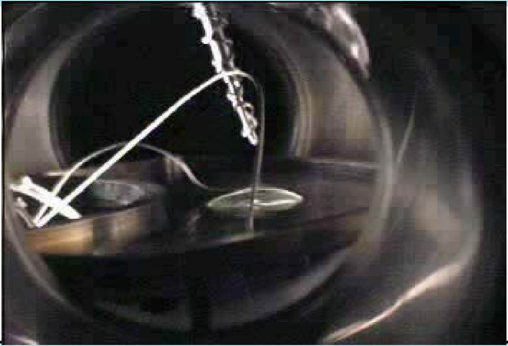




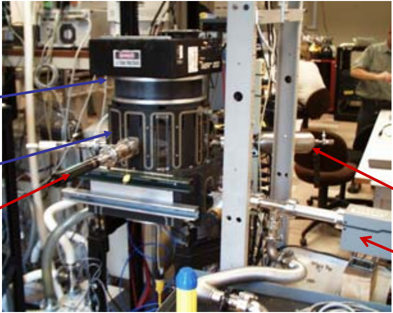
Liquid lithium phase separator/injector and test stand at UCSD PISCES Laboratory



Lithium injection system test at UCSD (video)



New plasma exposure facility: PISCES E deuterium retention studies with in-situ mass spectrometer



Helicon plasma source

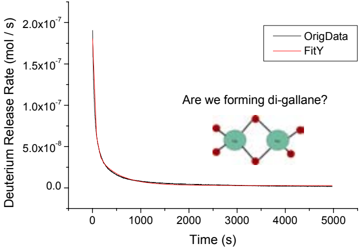
Magnet

Gallium Injector

D_2 Calibrated leak

Mass Spec.

Large retention of deuterium in liquid gallium observed. Release of 500 appm of deuterium with time constant ~ 60sec.



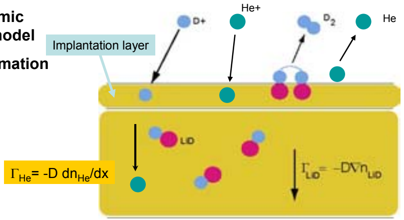
- Temp. = 400°C
- Duration 7200 s
- Retained D
  4.01×10^{-05} moles
  2.4×10^{19} atoms
- Retention ~ 500 appm

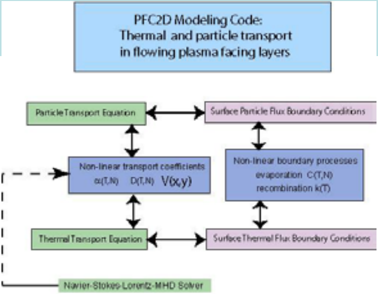
Helium permeation experiment sets upper bound. Helium partial pressure measurement indicates permeation factor of $\Gamma_{out}/\Gamma_{in} < 3 \times 10^{-6}$ consistent with theoretical prediction of $\Gamma_{out}/\Gamma_{in} \sim 1 \times 10^{-6}$.

Developed model for hydrogen and helium retention and release in liquid lithium and gallium metals:

- **Chemical reactions in the bulk and the surface**
- **Molecular and atomic species transport model**
- **Role of bubble formation and transport?**

Hydrogen/helium retention and release in liquid lithium



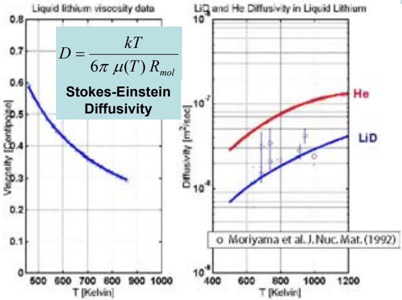


PFC2D capabilities and methods

- Finite element code
- Time dependent or time indepenent modes
- Neumann mixed bondary conditions, non-linear solver

Diffusion of atomic and molecular species in liquids fits Stokes-Einstein theory.

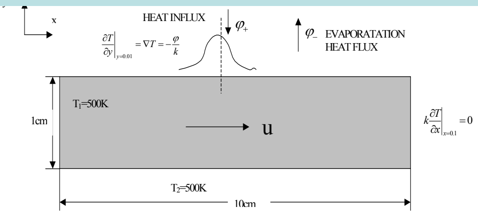
We have good transport coefficients for LiD, He in liquid lithium.



$$D = \frac{kT}{6\pi\ \mu(T)\ R_{mol}}$$

Stokes-Einstein Diffusivity

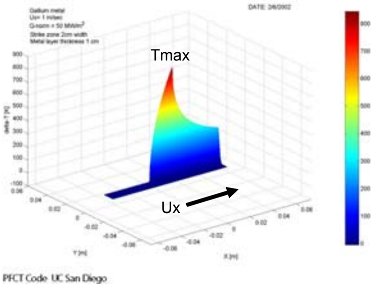
Heat transfer in a flowing divertor target: Convection, conduction, evaporation, non-linear transport coefficients.



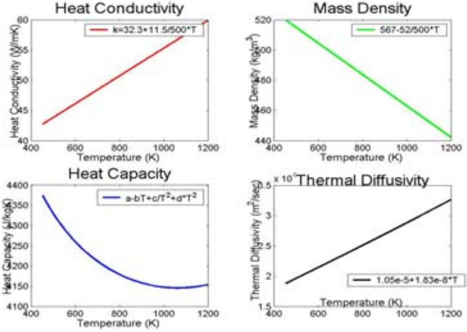
$$\varphi_+ = \varphi_0 e^{-\frac{(x-0.05)^2}{\Delta^2}} \qquad = 0.01m \quad \varphi_0 = 5MW \qquad \varphi_- = \frac{G}{M}\cdot\Delta H = \frac{P_{\mu b}}{2286}\left(\frac{1}{MT}\right)^{1/2}\cdot\Delta H$$

G=evaporative flux ($g/cm^2\cdot\sec$) M= atomic mass ΔH =enthalpy of evaporation

Thermal analysis in PFC2D calculation of flowing liquid metal divertor plate.

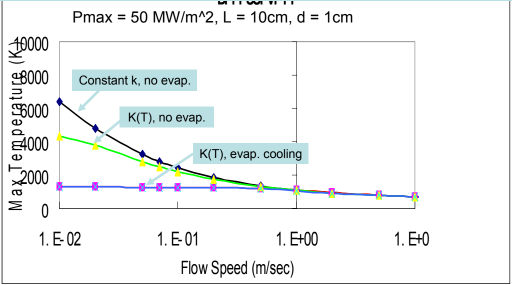


Thermal transport coefficients are temperature dependent

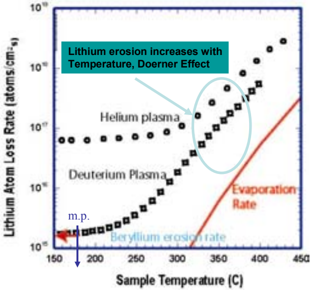


Example: Liquid lithium plate exposed to Pmax = 50MW/m².

Dominant non-linear heat transport effect is evaporative cooling. Important for low flow speeds and high heat fluxes. Flow speeds above 1 m/sec are sufficient to minimize evaporative cooling.



PISCES-B experiments find enhanced erosion rates of liquid lithium and other metals during deuterium plasma exposure. The net erosion is comparable to that of low Z solids for T<250C.



Bubble formation and droplet ejection to be investigated as an explanation. Search for micron scale droplets.

FY03 Plans Summary
CDX-U Experiment

- **Liquid lithium tray limiter performance**
- **Surface preparation and maintenance through discharge cleaning.**
- **Stability of the liquid in the tokamak environment, droplet ejection, bulk liquid motion.**
- **Impurity ion reduction**
- **Hydrogen recycling reduction**
- **Influence of limiter on plasma profiles: density profiles, ion and electron temperature profiles, radiation profiles.**

FY03 Plans
PISCES Experiments

- Hydrogen isotope retention in liquid gallium, temperature scaling, gallane chemistry.
- Investigate bubble formation in liquid gallium and lithium and its role in erosion and gas retention.
- Collaborate with D. Cowgill SNL on bubble transport modeling.
- Anomalous temperature scaling of liquid metal erosion. Bubble/droplet formation effects, surface modification effect.
- Laser scattering diagnostic needed to detect micron scale droplets.
- Modify helium permeation apparatus with factor x100 increase in plasma flux by transferring setup to an existing UCSD helicon plasma source, and addition of differential pumping capability to mass spectrometer.
- Investigation of flibe, flinabe, and other non-conducting liquids.

Equipment needs FY03

- Low power laser for scattering from micron range liquid metal droplets and bubble formation experiments: laser, optical detector, optics 15k.
- Helium permeation experiment modification (PISCES-E) for greater sensitivity, cold trap and getter pump 7k.
- Fast imaging video camera for liquid surface phenomena, bubbling, ejections, waves, etc. 11k
- Apparatus and safety review for flibe/flinabe experiments TBD.

Total equipment increment 33k