Liquid Lithium Limiter For Hydrogen Recycling Control

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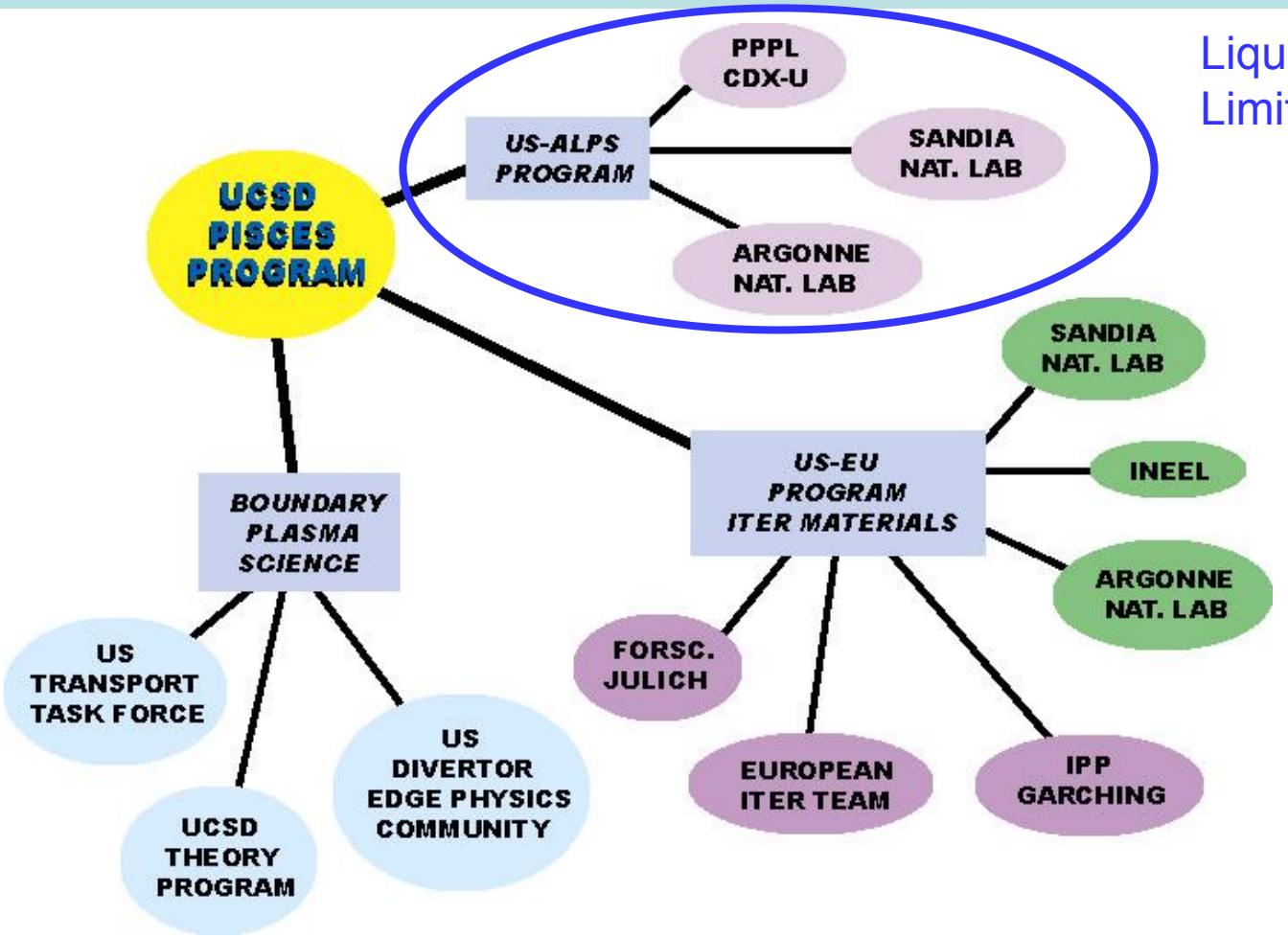
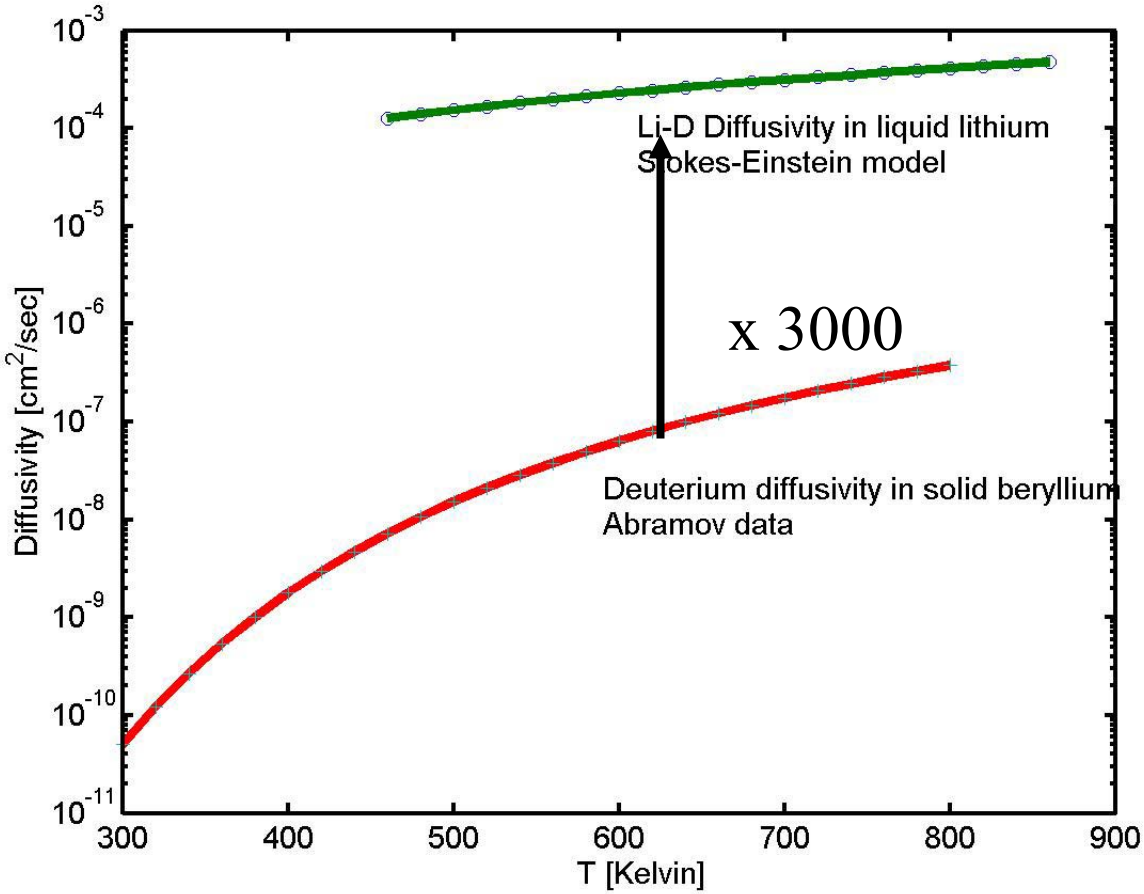
Liquid Lithium Limiter/Divertor



- Continuously renewable surface: No erosion lifetime limit, Rapid recovery from disruptions/ELMS
- Natural Tritium removal/recovery
- High heat flux handling, bulk flow heat transport ~50 MW/m^2
- Low recycling boundary option (near term applications)

  - Erosion rates and influx rates for Lithium, Gallium, …
  - Fluid body forces (JxB, dB/dt, pressure pulses)
    - Deflection and interruption of flow patterns
    - Ejection of droplets, jets, redeposition
  - Removal rates, transport of H, H_2, He, …
  - Removal of Hydroxide/oxide layers

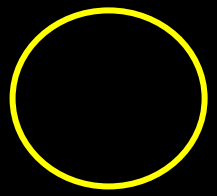
Hydrogen isotopes transport rapidly in liquid lithium compared to solid materials. Incident H,D,T ions react chemically and sequester as LiH,LiD,LiT.



Lithium materials samples exposed to plasma flux in PISCES-B

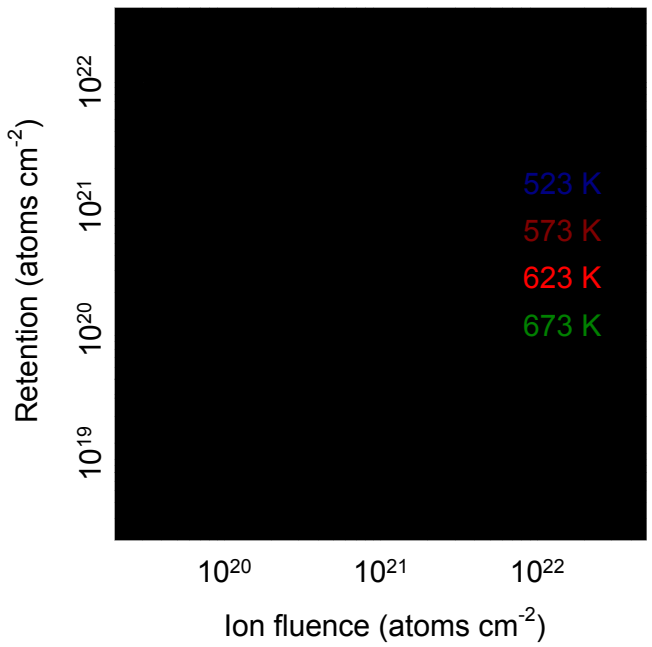
Deuterium plasma column

LiI light emission



Li sample holder

o). Incident flux converted to LiD/LiH.

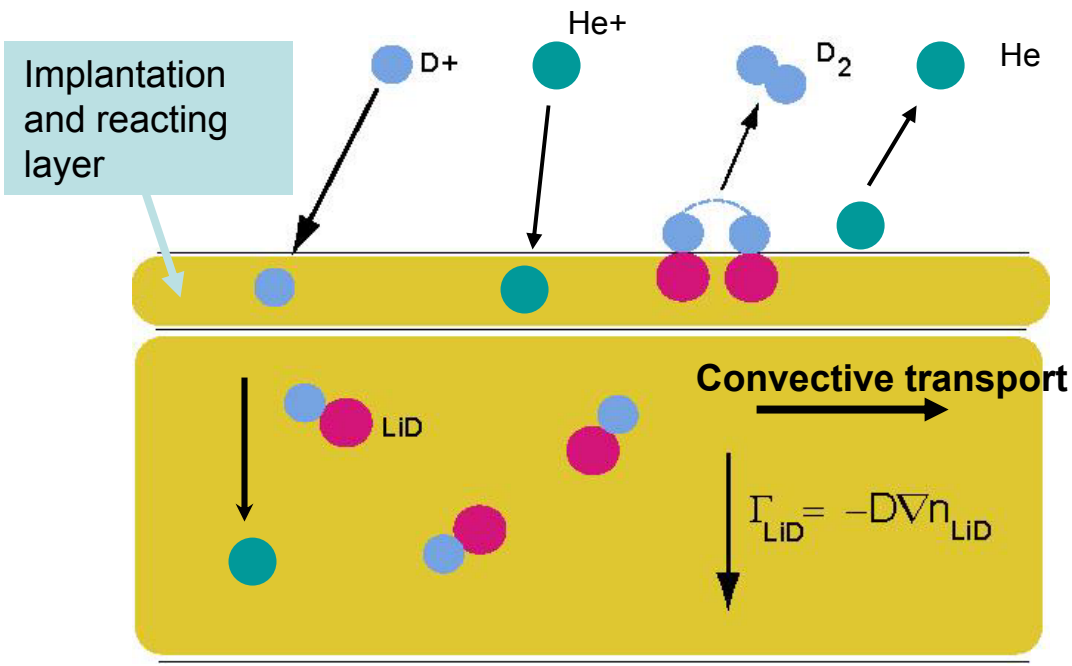


M. Baldwin, et al., J. Nuc. Mat.

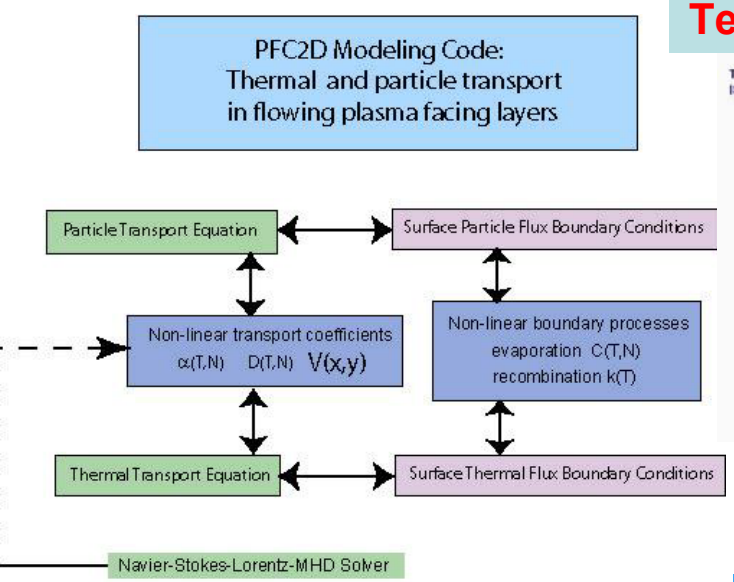
Physical picture for hydrogen isotope retention and release. Basis for UCSD PFC2D model for heat and particle removal by liquid lithium.

- **Chemical reactions in the bulk and the surface.**
- **Molecular and atomic species transport modeled.**
- **Transport coefficients and rates are temperature dependent.**
- **Coupled thermal modeling is needed.**
- **PFC2D code developed at UCSD.**

Hydrogen/helium retention and release in liquid lithium



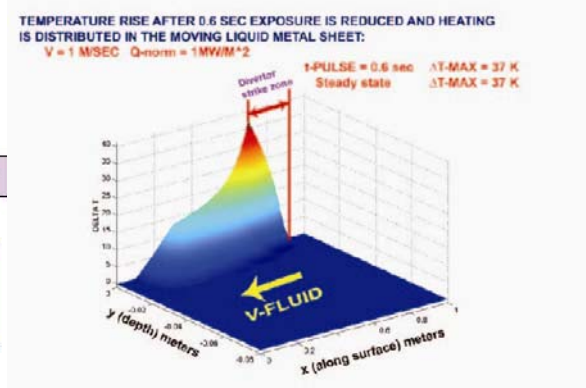
PFC2D modeling code calculates thermal and LiD transport within flowing liquid metals. Solves coupled thermal and particle convective-diffusion equations.



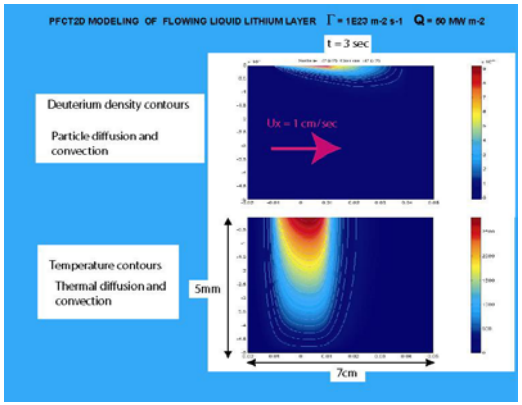
PFC2D capabilities and methods

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

Temperature profiles in 2D



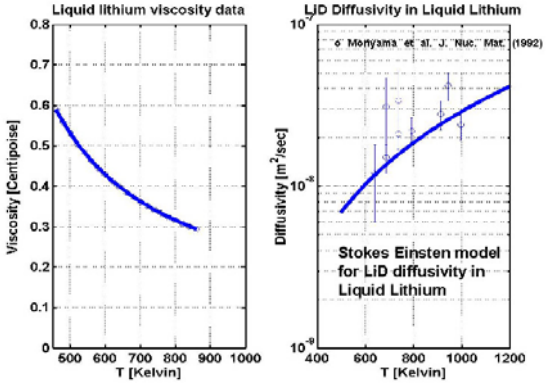
LiD density and Temp. profiles in 2D



Accurate theory for diffusion in liquid metals:

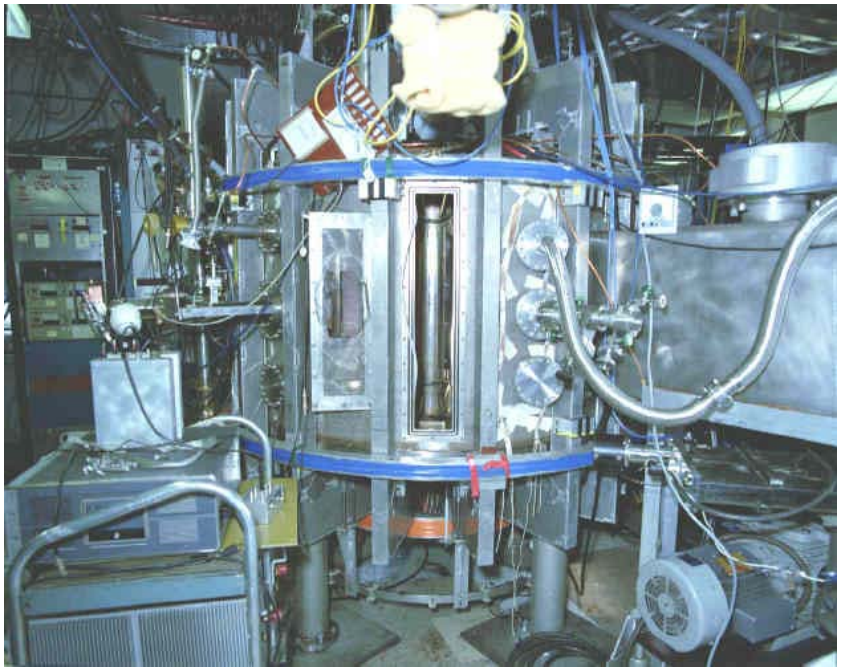
Stokes-Einstein model.

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

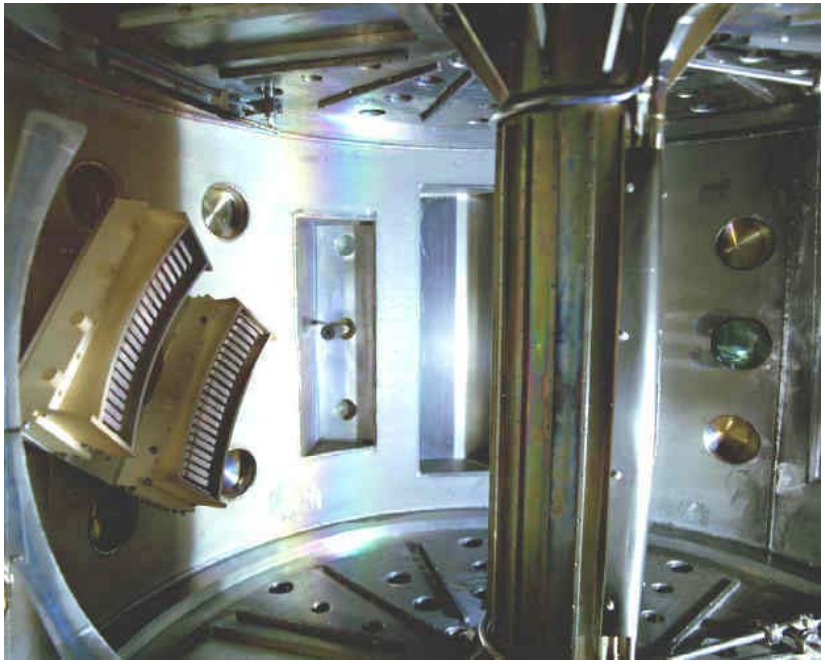


Present step: Laboratory experiment to demonstrate liquid lithium limiter. UCSD/PPPL collaboration on CDX-U Torus at PPPL

(Ro = 34 cm, a = 22 cm)



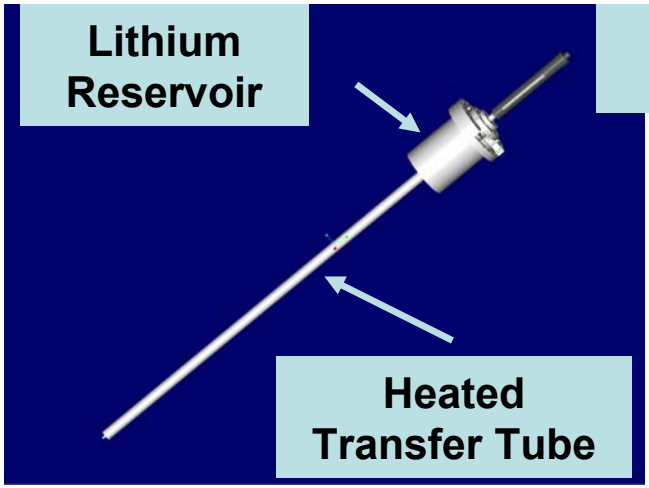
Exterior view



Interior view

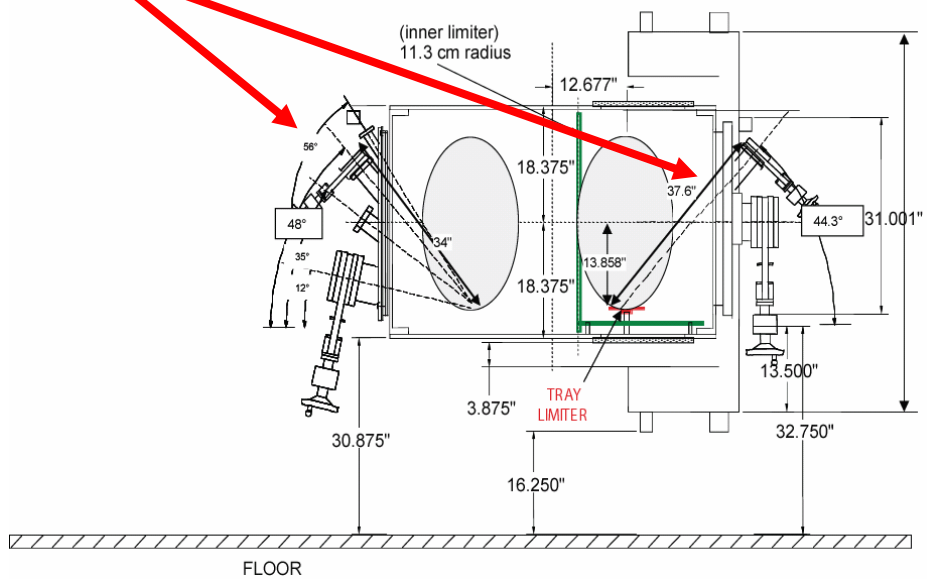
Experimental challenge: Can clean metallic lithium surfaces be made and sustained during tokamak operation?

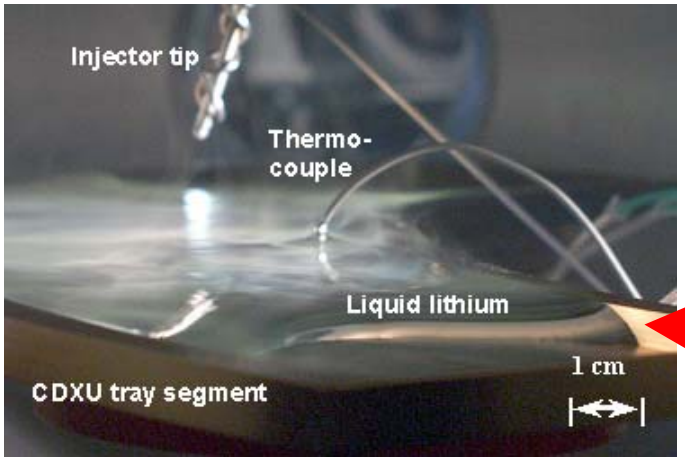
UCSD phase-separator flow delivery system for CDX-U limiter



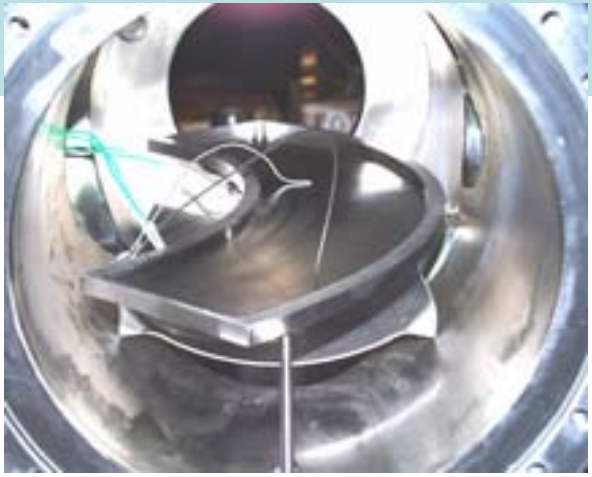
UCSD Liquid Lithium Phase-separator Injectors

Elevation CDX-U

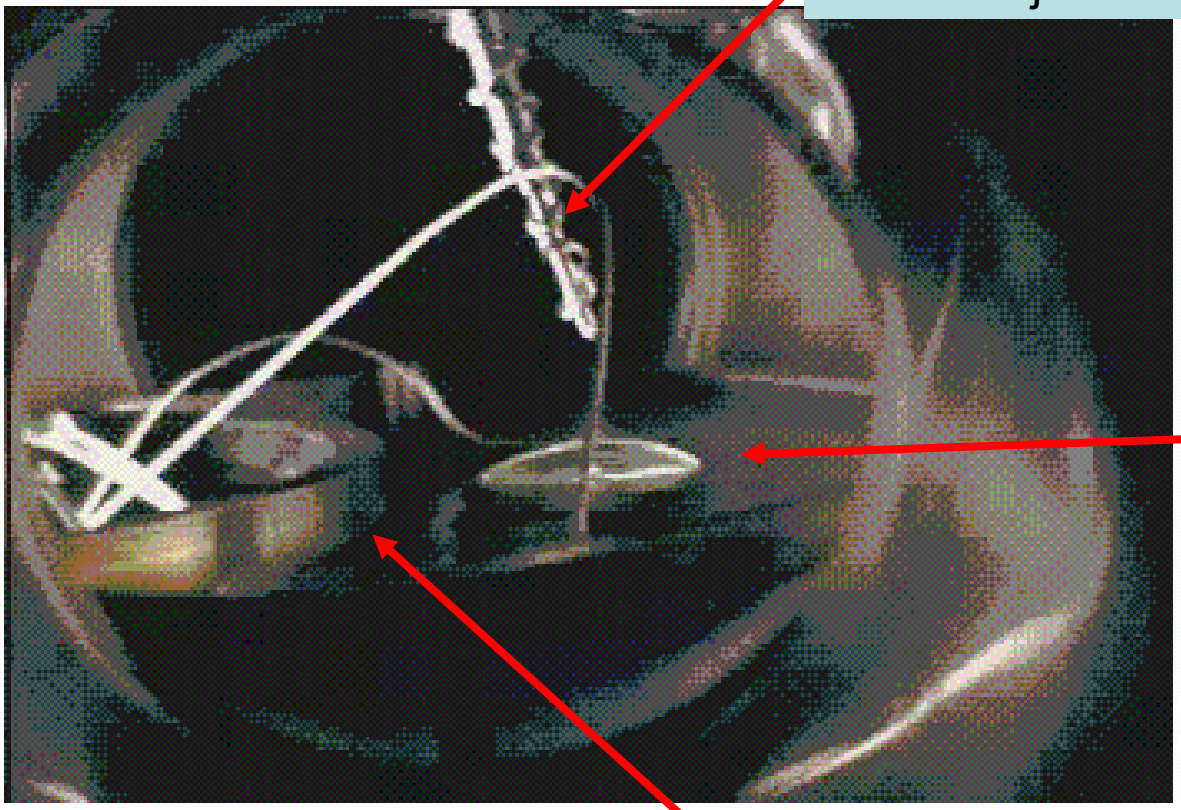




Clean liquid lithium pool formed by phase-separator Injector in test stand at UCSD.



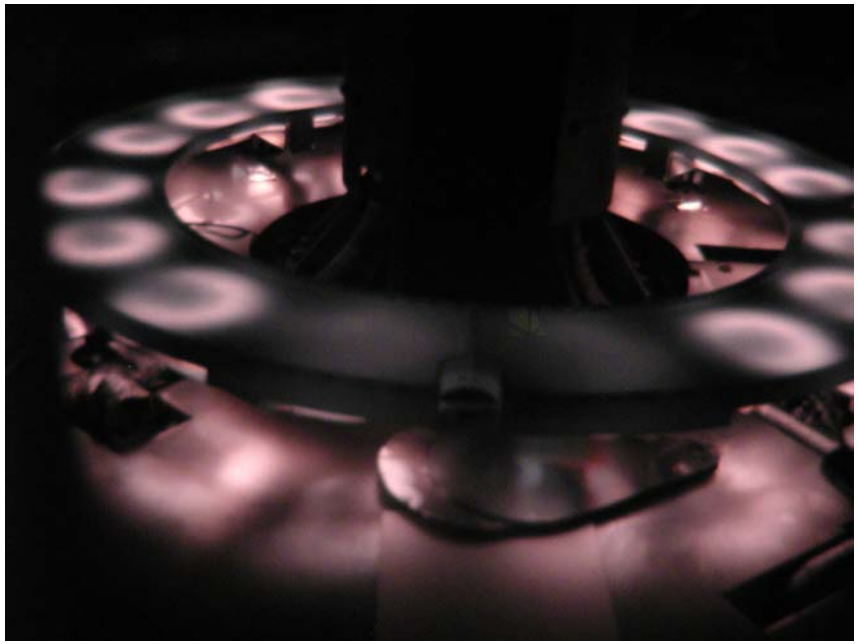
Formation of liquid lithium pool limiter

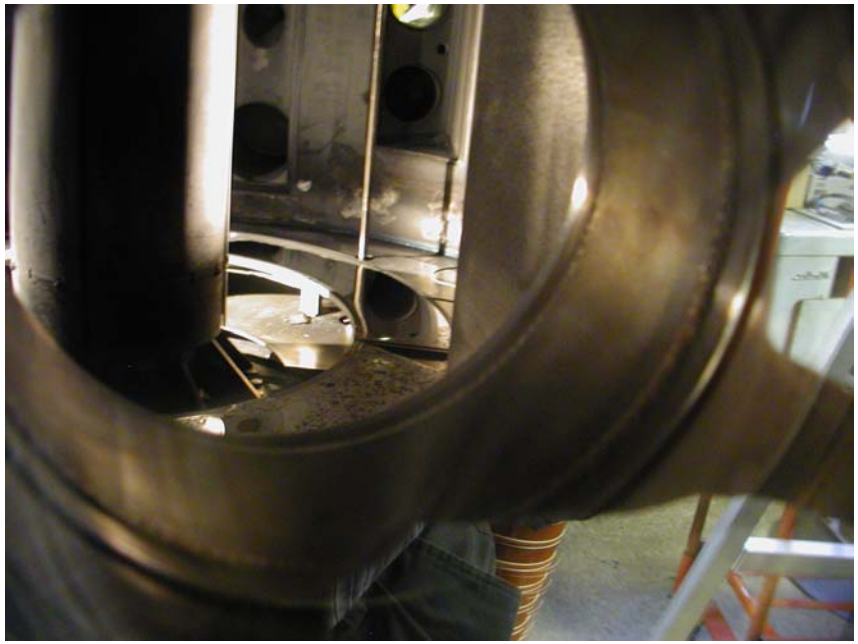


Experiments with toroidal liquid lithium limiter started in CDX-U May 2003

Lithium temperature controlled in CDX-U by heater system.

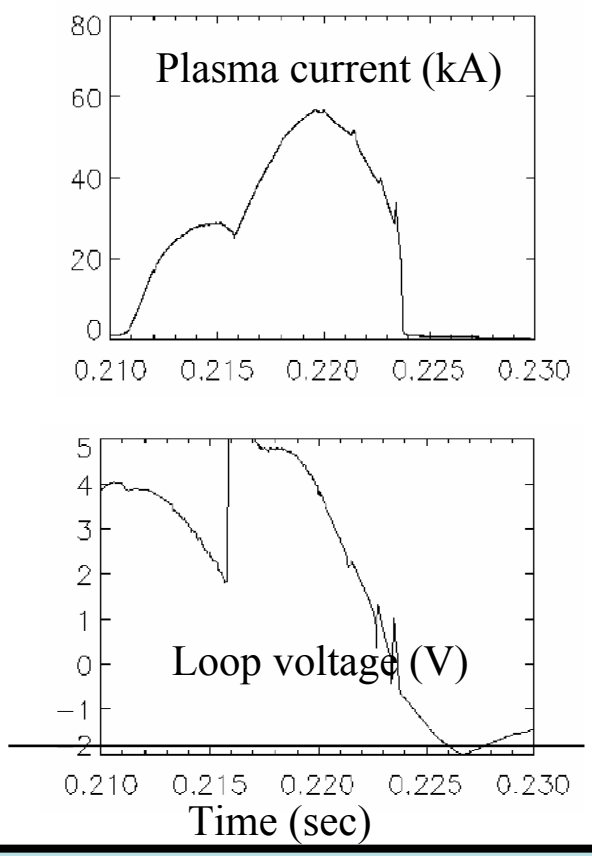
Surface impurity control and overall cleanliness of lithium surface were achieved.



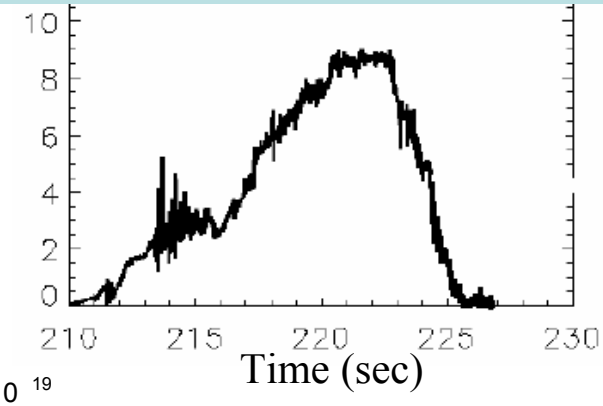


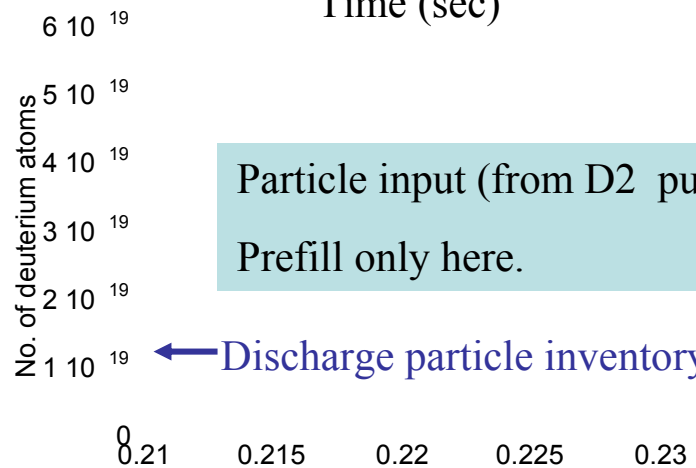
A pre-lithium plasma on CDX-U

- Plasma current requires 2V or more for sustainment. Terminates when $V_L \Rightarrow 0$
- H2 gas puff prefill fuels the entire discharge.



Line averaged density (10^{12} cm^{-3})





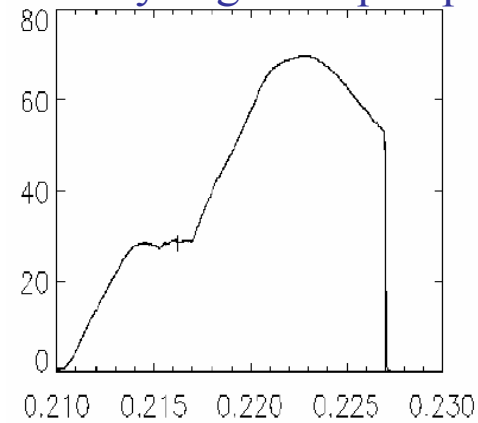
Particle input (from D2 puffing).

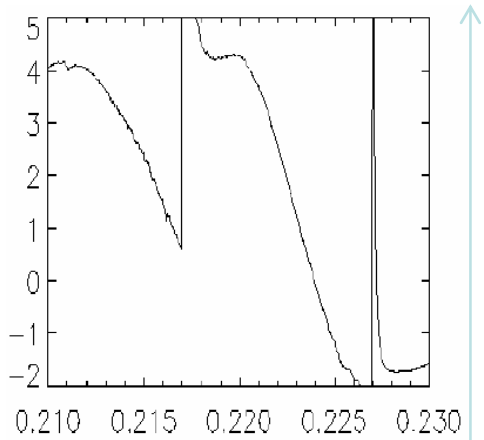
Prefill only here.

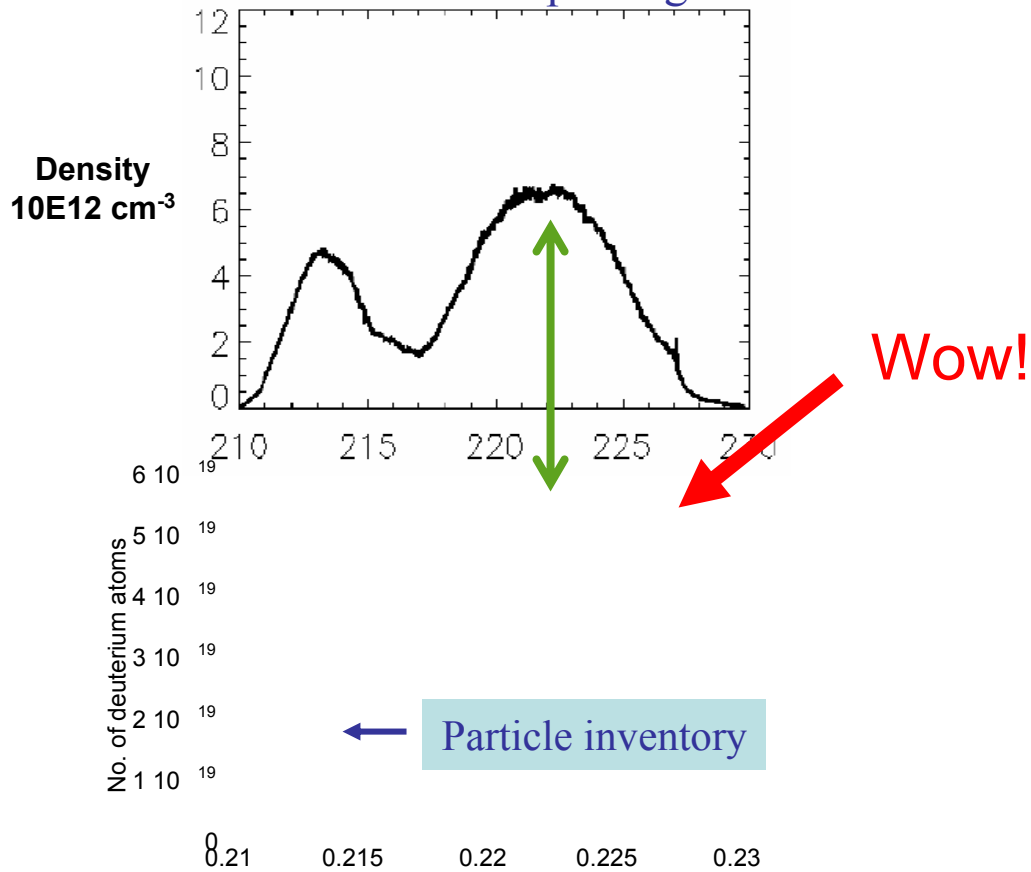
Discharge particle inventory

CDX-U plasma discharge with full liquid lithium limiter

- Plasma current requires only ~0.5V for sustainment. Does not terminate until $V_L \Rightarrow -2V$
- Density begins to pump out within ~1msec of cessation of puffing.

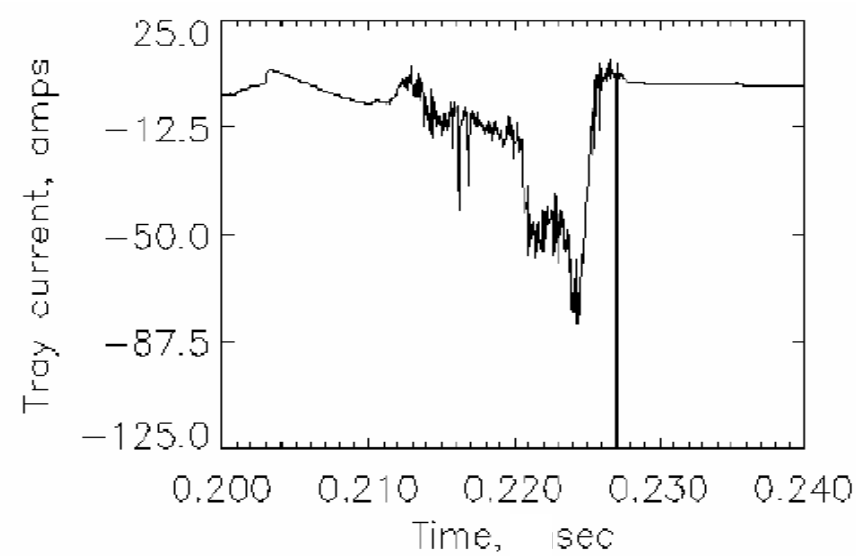


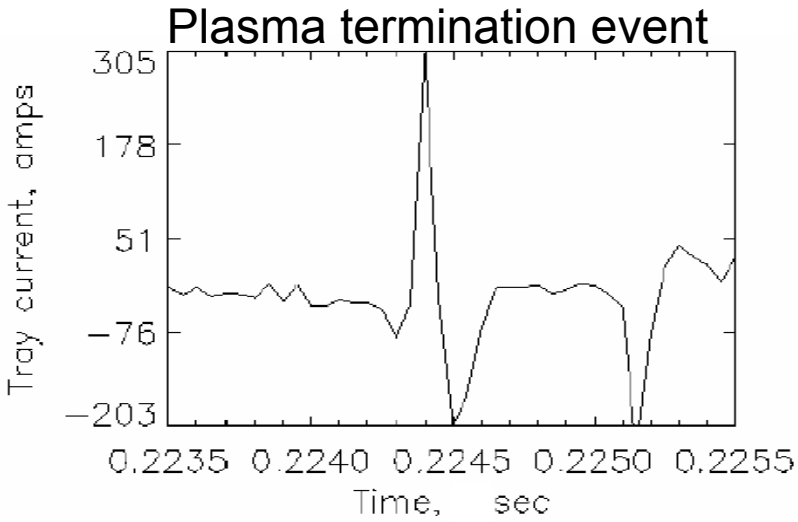




Liquid lithium PFC is mechanically stable in CDX-U

- No motion of the liquid has been observed with a fast framing camera
- No spatter, droplets, etc on the vessel floor
- Current to the liquid during a discharge is routinely ~100A to 500A or greater, during plasma termination





Summary and plans for LLPFC Limiter Experiments

- New liquid lithium filling technique developed at UCSD, successful at CDX-U. Thin hydroxide coatings appear after plasma operations, but can be removed in-situ. **NO** mobilization of lithium observed.
- Diagnostic improvements planned: Dα view, Thomson scatting Te profiles, time resolved fast framing camera imaging are planned.
- Success in reducing hydrogen recycling implies need for central fueling: pellet fuelling, hypersonic gas jet, planned for CDX-U.
- CDX-U results sufficiently interesting to motivate plans for experiments on the NSTX torus at PPPL.
- Invited paper, Special Liquid Metal Divertor/Limiter session (APS/DPP Meeting October 2003)

Some observations on differences between liquid lithium limiter/divertor and other methods of recycling control.

- Liquid lithium PFCs control recycling by retaining incident hydrogen ion flux (and monatomic H).
- LLPFC's retain hydrogen in an extended thick layer or a volume of liquid LiH solution. Little H2 released.
- LLPFCs differ from recycling control by cryo-pumping which pumps neutral hydrogen species, namely H2 molecules.
- LLPFC's differ from metallic coating/boronization which retain hydrogen in the surface and near surface layers. Passivation limits duration of recycling control.