Liquid Lithium Limiter/Divertor for Hydrogen Recycling Control in NSTX

S.C. Luckhardt

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

US ALPS Program: Near and long term applications of liquid PFC's

Potential advantages of flowing liquid PFC's

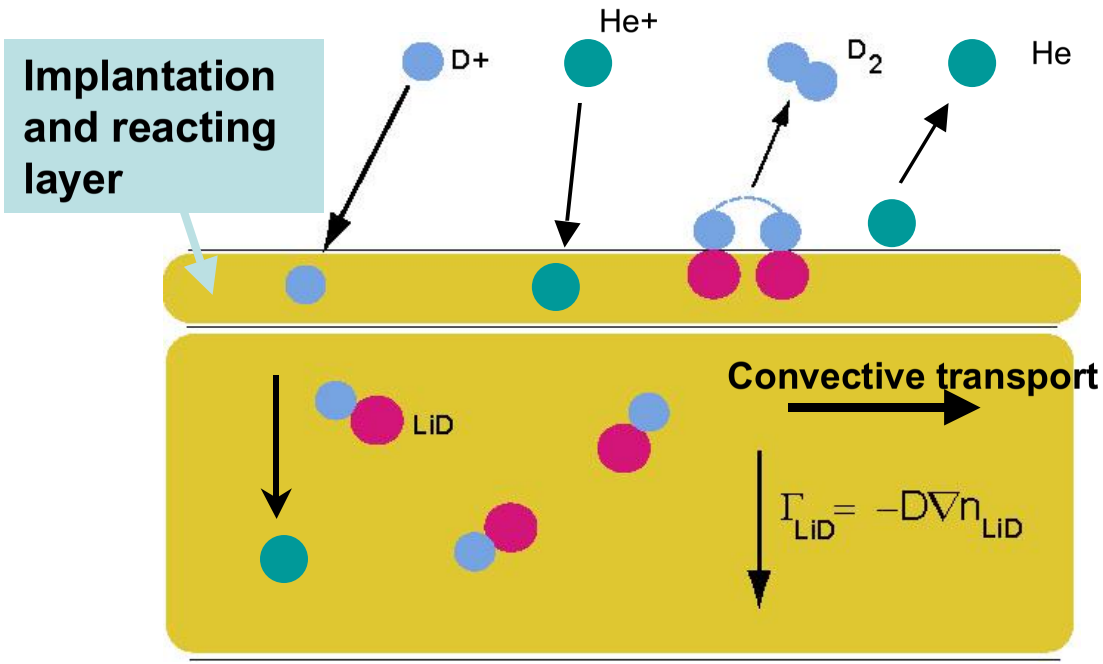
- **Continuously renewable surface: No erosion lifetime limit, Rapid recovery from disruptions/ELMS**
- **Natural Tritium removal/recovery**
- **High heat flux handling, bulk flow heat transport ~50 MW/m^2**
- **Low hydrogen recycling surfaces (CDX-U, NSTX, …)**

R&D issues for liquid PFC's

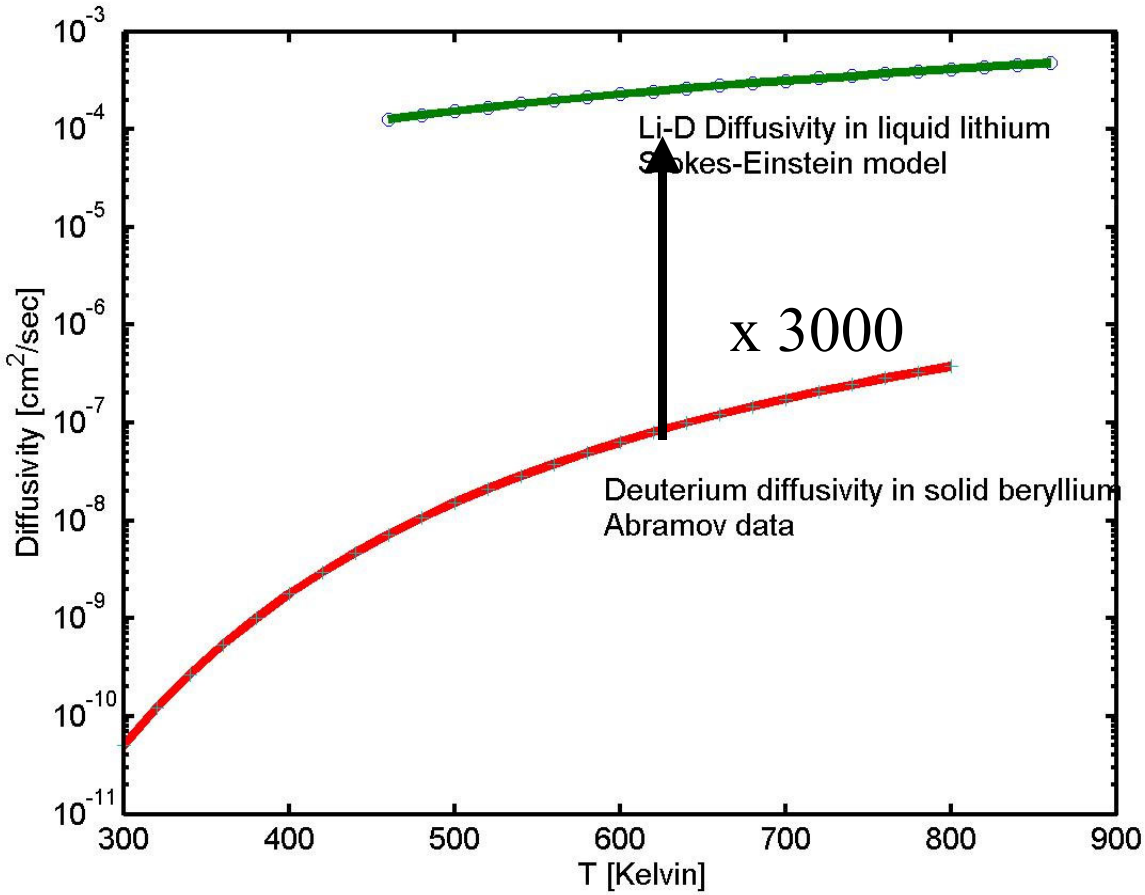
- **Erosion rates and influx rates for Lithium, Gallium, …**
- **Fluid body forces (JxB, dB/dt, pressure pulses)**
  - **Deflection and interruption of flow patterns**
  - **Ejection of droplets, jets, redeposition**
- **Removal rates, transport of H, H_2, He, …**
- **Removal of Hydroxide/oxide layers**

Physical picture for hydrogen isotope retention and release in liquid lithium. Lithium must be in the liquid state!

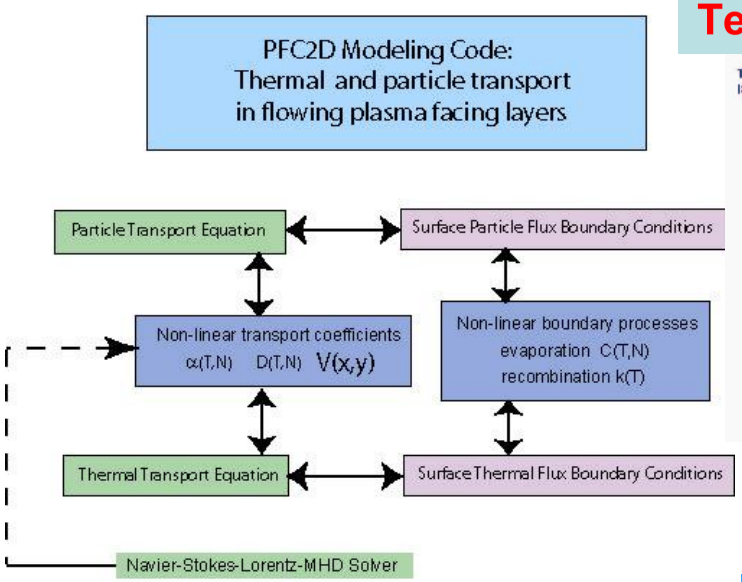
- Incident plasma ions implanted into thin surface layer. Hydrogen ions rapidly combine to form LiD in solution.
- Little H2/D2 released from solution.
- LiD transported into the bulk liquid by diffusion.
- LiD and heat removed from the plasma contact region by convection/diffusion.
- Coupled convection/ diffusion code (PFC2D).



LiD (LiH) diffuses rapidly into liquid lithium compared to H/D transport in solid materials. Increased diffusion keeps the lithium surface relatively pure and metallic. Hence low recycling sustained.



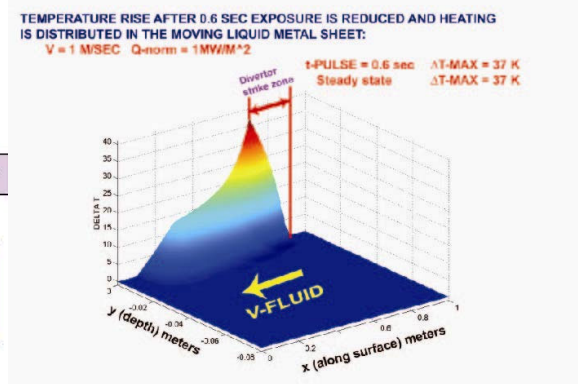
PFC2D modeling code calculates thermal and LiD transport within flowing liquid metals. Solves coupled thermal and particle convective-diffusion equations.



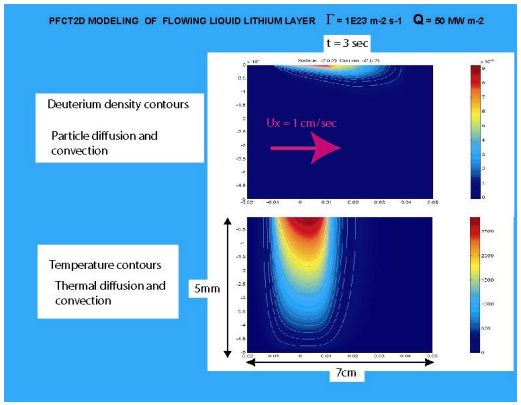
PFC2D capabilities and methods

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

Temperature profiles in 2D



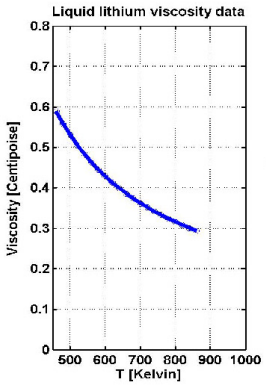
LiD density and Temp. profiles in 2D

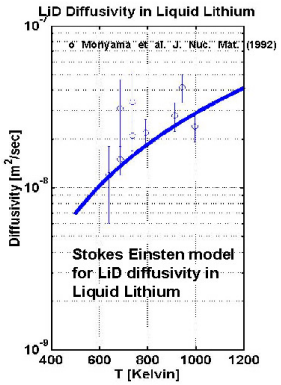


Accurate theory for diffusion in liquid metals:

Stokes-Einstein model.

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

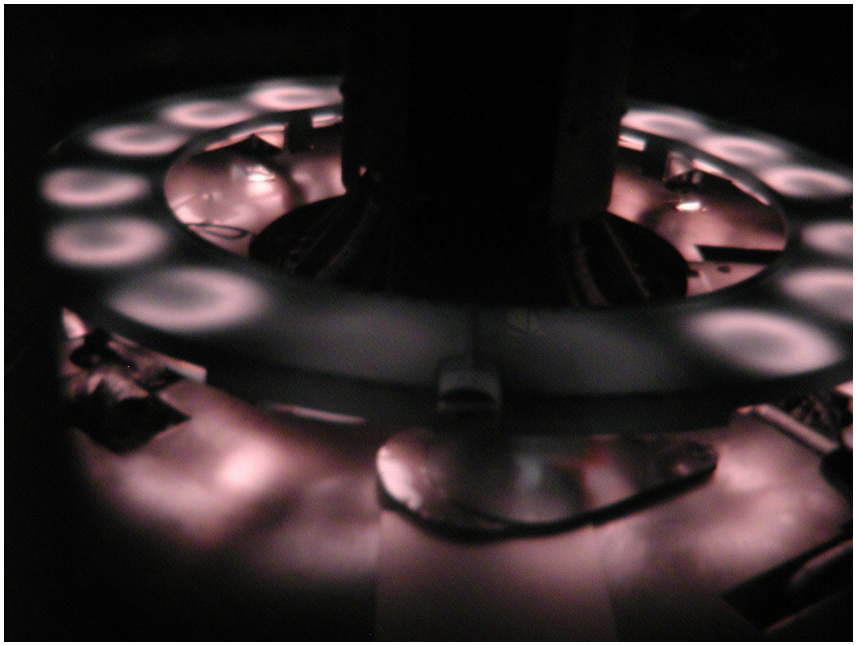


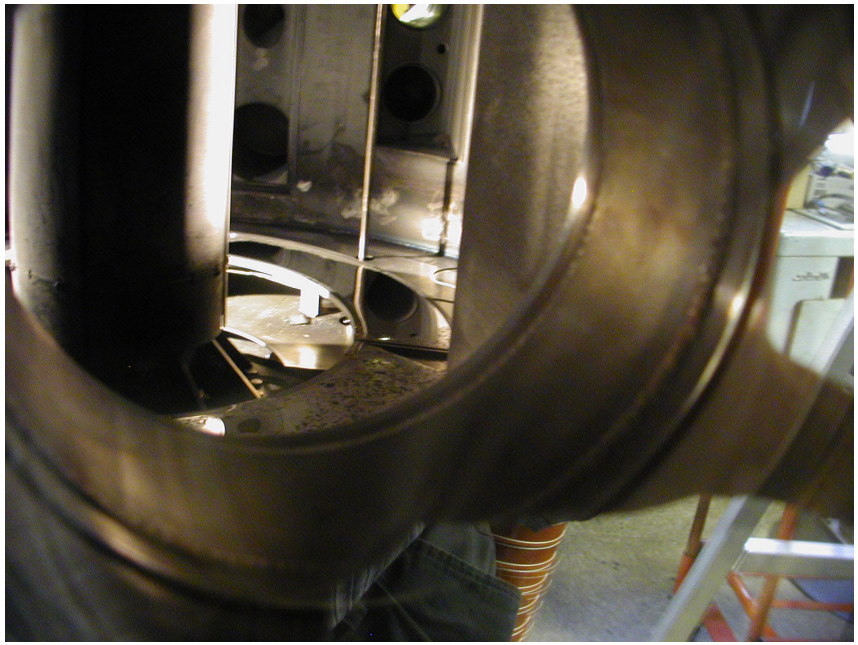


Experiments with toroidal liquid lithium limiter started in CDX-U May 2003

Lithium temperature controlled in CDX-U by heater system.

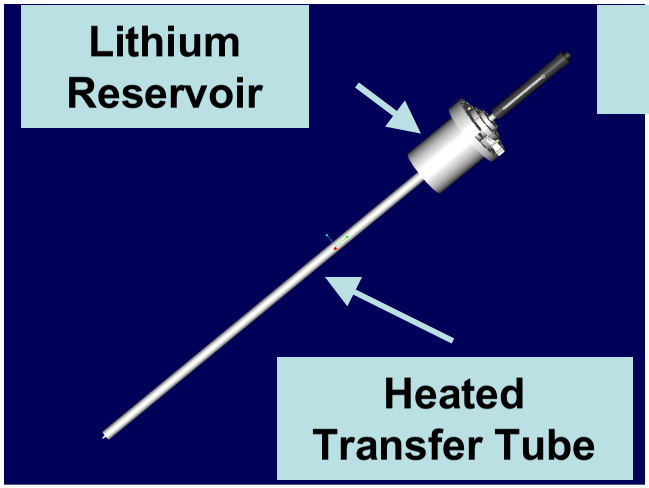
Surface impurity control and overall cleanliness of lithium surface were achieved.





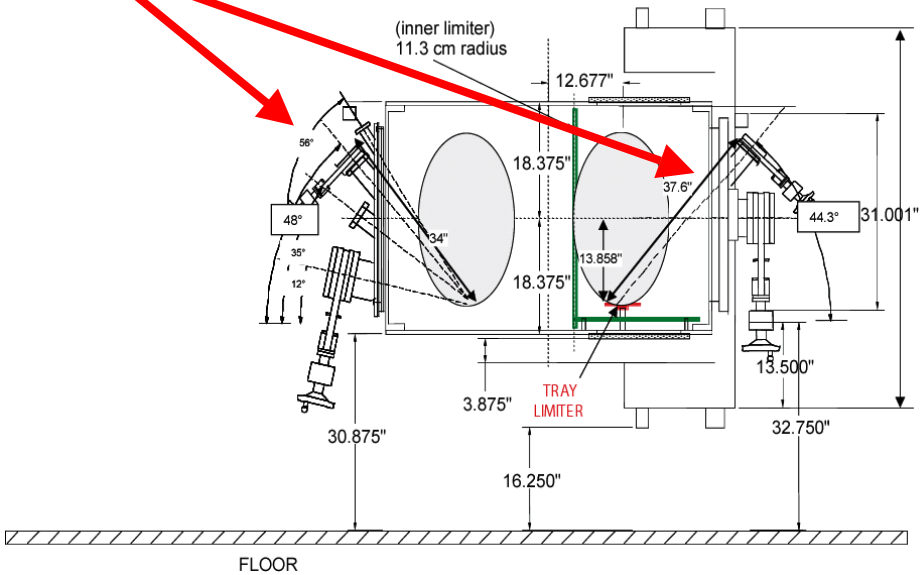
Experimental challenge: Can clean metallic liquid lithium surfaces be made and sustained during tokamak operation?

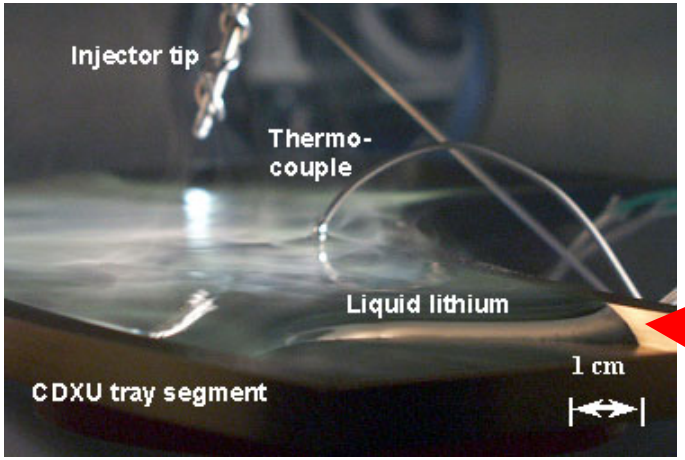
UCSD phase-separator flow delivery system for CDX-U limiter



UCSD Liquid Lithium Phase-separator Injectors

Elevation CDX-U



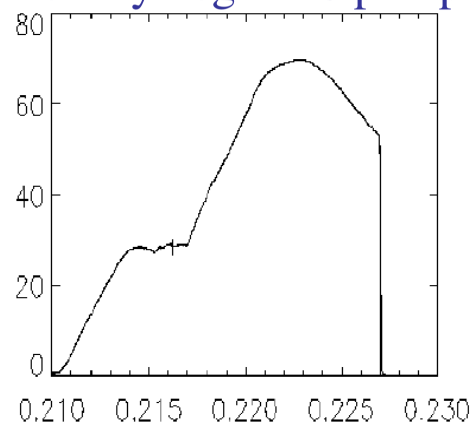


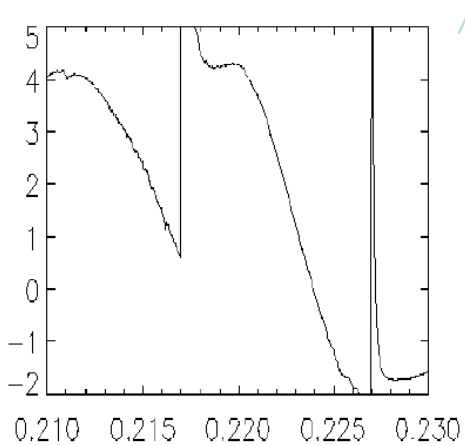
Clean liquid lithium pool formed by phase-separator Injector in test stand at UCSD.

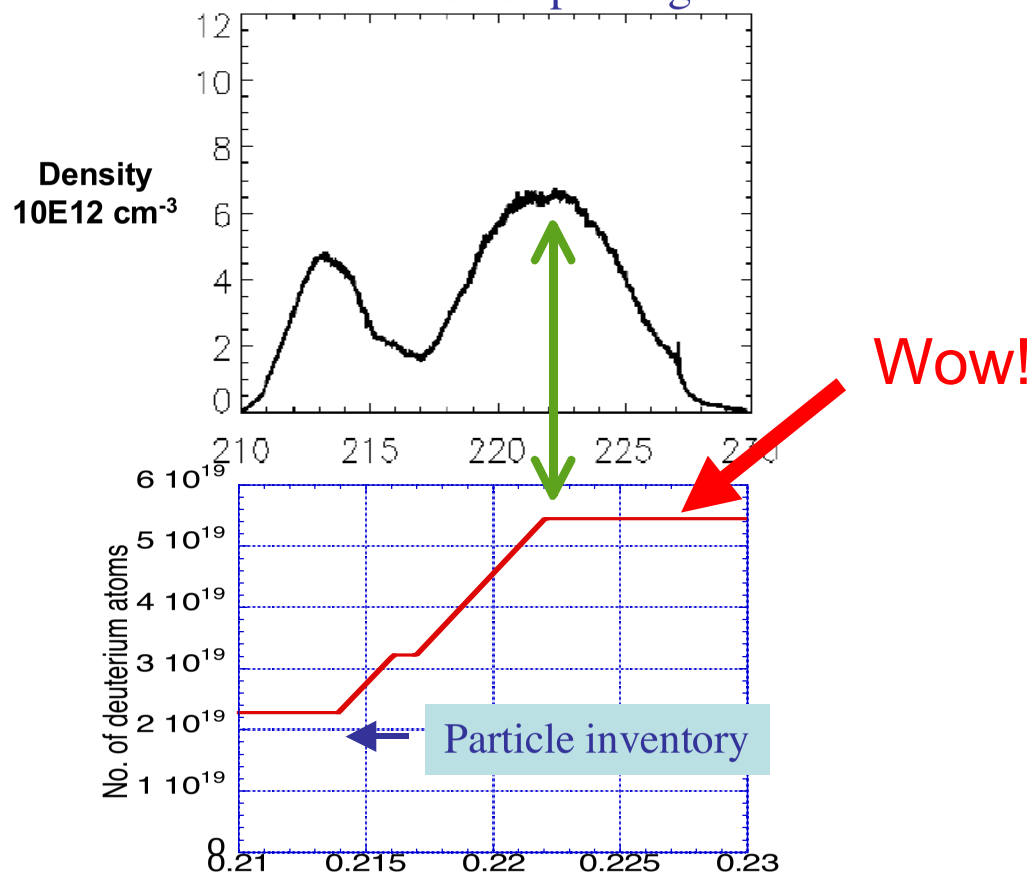
CDX-U plasma discharge with toroidal liquid lithium limiter

(R. Majeski et al. this meeting)

- 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.







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 relatively thick layer of liquid Li/LiH solution. Little H2 re-released at the surface.
- LLPFCs differ from recycling control by cryo-pumping which pumps neutral hydrogen species, H2/D2 molecules. Plasma ions must recombine to H2/D2 before they can be cryo-pumped.
- LLPFC's differ from wall metallic coatings (gettering) which retain hydrogen in the surface and near surface layers. Passivation limits duration of recycling control.

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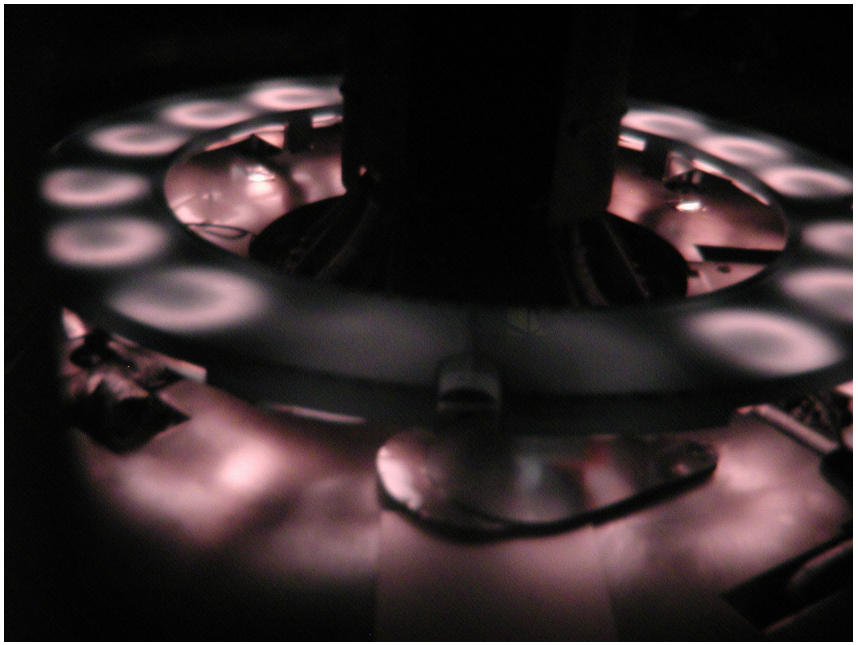
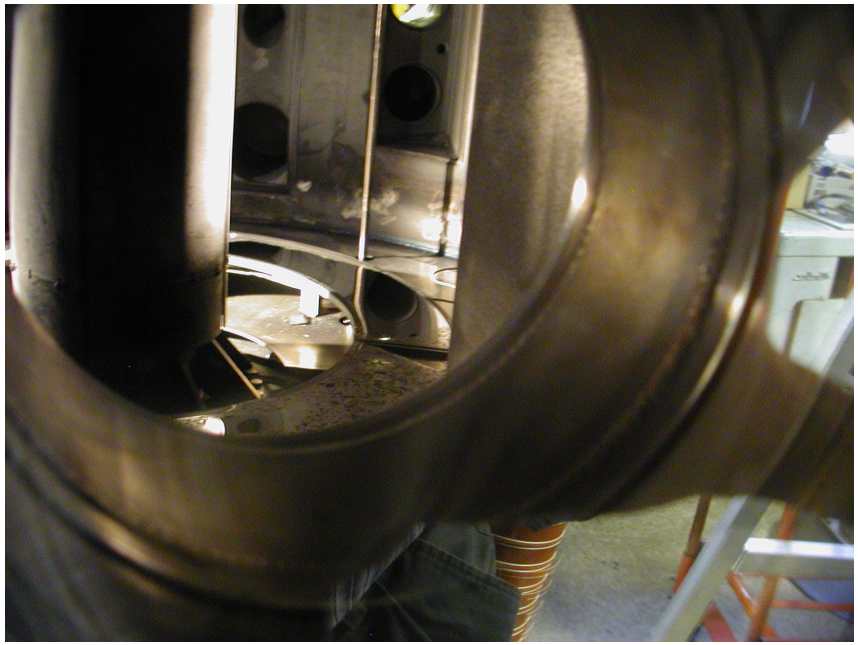
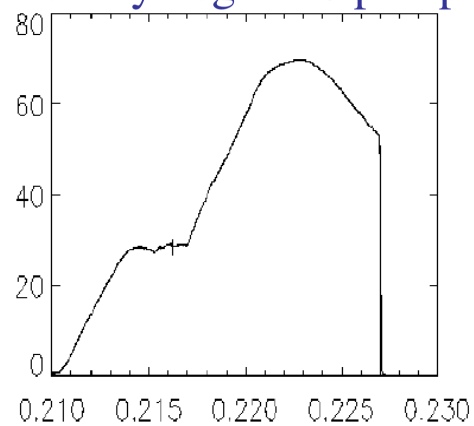
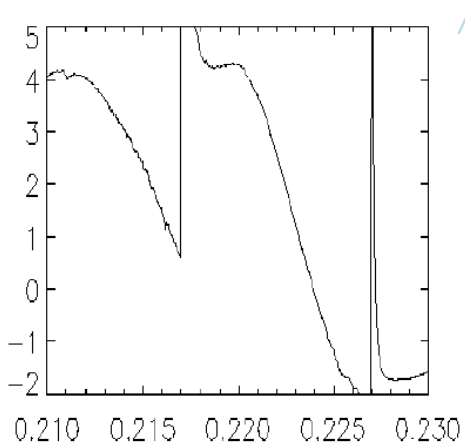


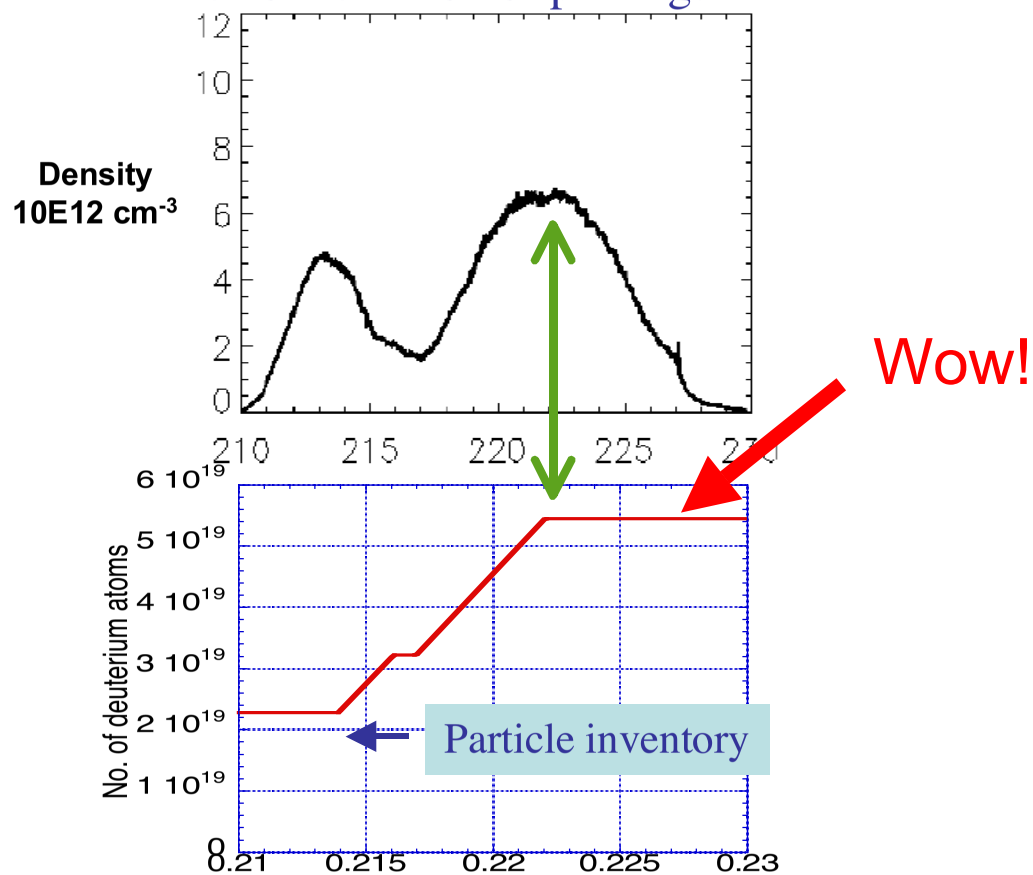


CDX-U plasma discharge with full liquid lithium limiter

- 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.







Success in deployment of liquid lithium limiter in CDX-U for recycling control motivates further steps at PPPL and US PMI program.

- PPPL NSTX 5 year plan endorses liquid/solid lithium PFC experiments.
- Lithium coating on carbon experiment would connect with TFTR lithium coating experiments.
- Module A: Thick liquid lithium layer on limiter/divertor tiles. Heat flux from plasma used to melt lithium layer.
- Module B: Flowing liquid lithium limiter/divertor. Decision point on flowing liquid lithium divertor module in FY06
- Supporting experiments at CDX-U and PISCES.
- Continue liquid lithium limiter experiments on CDX-U

ALPS/CDXU/NSTX Work on Liquid Lithium Limiter/Divertor

(US PFC Steering Committee and PPPL NSTX 5 year plan)

Extend liquid lithium technology to NSTX. Prepare for NSTX liquid lithium coating experiment Module A and longer term (FY06) Module B with flow.

FY04 PPPL/UCSD/Sandia Collaboration:

Develop evaporative coating system to apply microns thick coating of liquid lithium onto substrate to be used in tests on NSTX. (MODULE A). CDX-U to be used as a test bed for the NSTX experiment.

- Develop e-beam evaporator for CDX/NSTX (Sandia/UCSD)
- Design and build manipulator arm for evaporator system (UCSD)
- Determine compatibility of evaporated lithium coating with various substrate materials (UCSD)
- Model thermal response of lithium coating and substrate for NSTX conditions (Sandia/UCSD)
- Model effects of sweeping divertor leg (UCSD)
- Investigate composition of impurity layers on lithium formed in CDX/NSTX (UCSD)