Simulations of NSTX with a Liquid Lithium Divertor Module*

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NSTX Investigating Use of Lithium as a Plasma Facing Material

- Primarily for density control,

- And improved plasma performance.

- NSTX lithium program proceeding in stages:
  - Li pellets (FY 2005 - 2009)
  - Li evaporator (FY 2006 - 2009)
  - Liquid lithium divertor (FY 2009 - 2012)
  - In parallel, LTX will examine efficacy of Li as the primary PFC.

Developing a Liquid Lithium Divertor (LLD) to Provide More Pumping & Better Density Control

- Evaporated Li in NSTX has yielded positive results,
  - 2006 & 2007: L-mode density reduced 50% & H-mode density reduced 15%,
  - 2008: Improved $\tau_E > 100$ ms and ELM control; 1.8 s pulse length.
- But, density still increases monotonically during shot.
- $\Rightarrow$ Taking next step towards more aggressive use of Li as PFC.

The Liquid Lithium Divertor Is a Joint Collaboration Between Sandia, UCSD, and NSTX

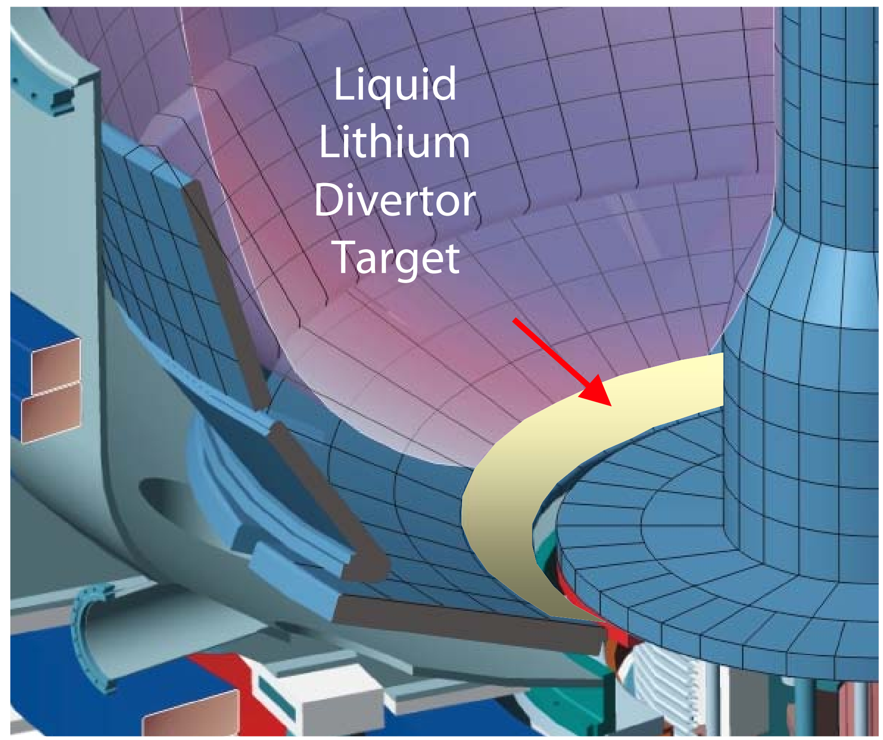
NSTX

● The LLD collaboration is the result of a DoE funded proposal led by Sandia National Laboratory (R. Nygren, PI).

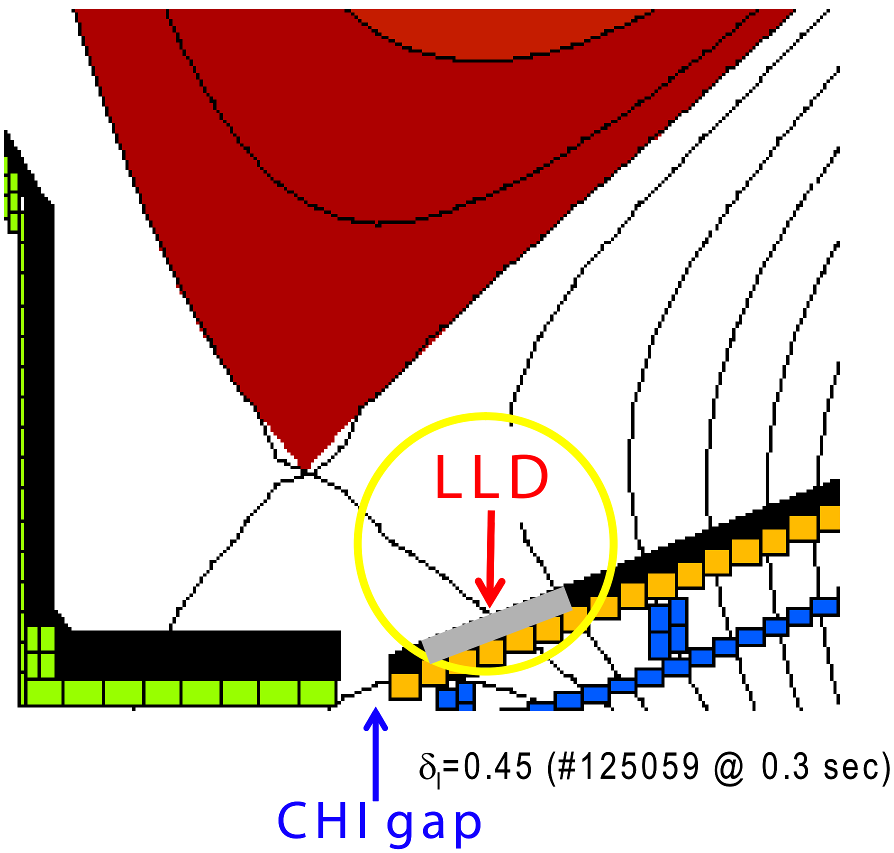
● The basic concept is of a toroidally extended lithium containing tray that would serve as a target for the outer strike point or divertor.

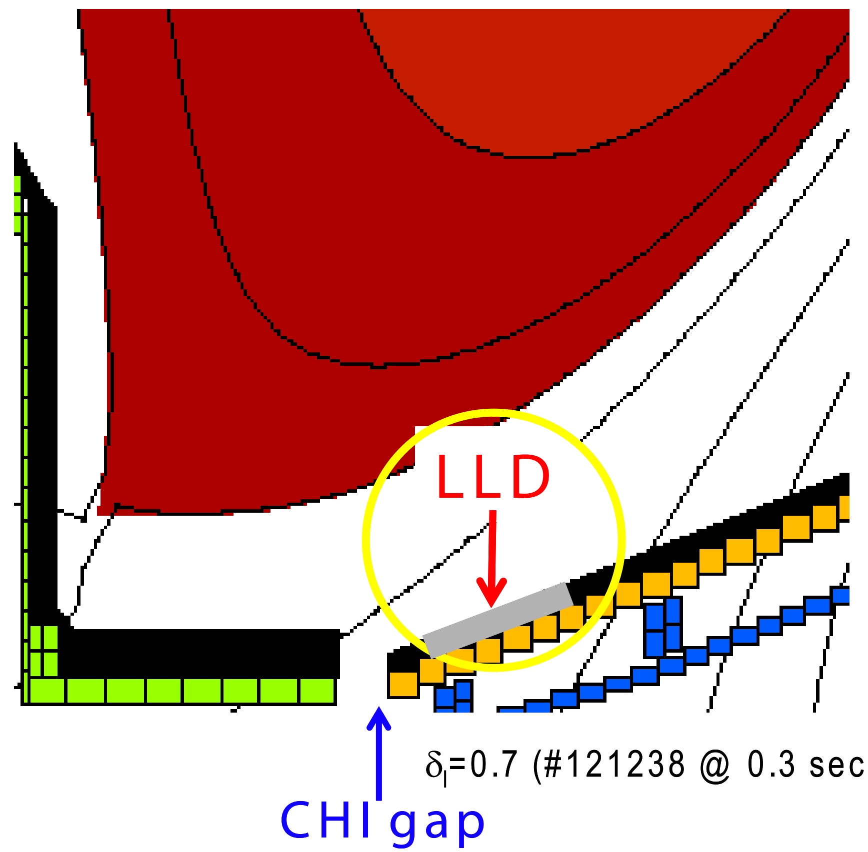
- Plan: SS bonded to thick Cu & sprayed with Mo. Evaporate ~ 1 mm Li on top.

- Alternative substrate: CV deposited Mo on carbon mesh.



Goal of LLD is to Provide Density Control in Both Low & High Triangularity Shapes





- For low triangularity, goal is 50% reduction in n_e.
- For high triangularity, 25%.
- Amount of pumping & density control will depend on distance of strike point from tray.

UEDGE is a 2-D Edge Plasma Transport Code

- Mesh based on experimental equilibrium with one coordinate following flux surfaces.

- Second coordinate orthogonal except near divertor surfaces.

- Solve equations for n_i, T_e, T_i, $u_\|$, ϕ,
  - Classical transport along field lines $+$ flux limits,
  - Anomalous transport across flux surfaces $\Rightarrow$ $blobs$.
  - Navier-Stokes equation for D atoms.
  - Not solving ϕ equation and ignoring $\mathbf{E} \times \mathbf{B}$ & ∇B drifts here.

Set Transport Coefficients to Match Midplane Profiles

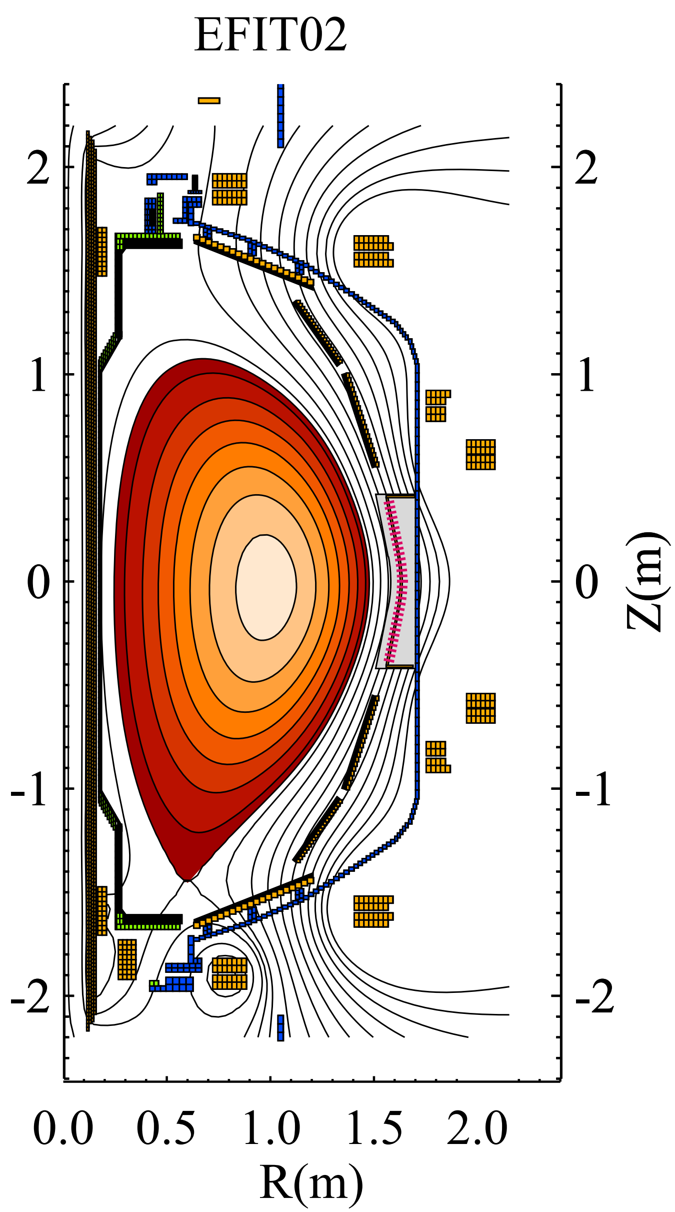
- Thomson scattering: $n_e = 4.3 \times 10^{19}$ m^{-3}, and $T_e = 130$ eV at core boundary,
  - No CHERS data here, but $T_i \simeq T_e - 15$ eV at smaller radii.
- Adjust D, χ_e, v to match midplane profiles,
  - Specify each at core, separatrix, and outer wall.
  - Linearly interpolate on radial mesh index,
  - Constant on flux surface.
  - $\chi_i = \chi_e$.

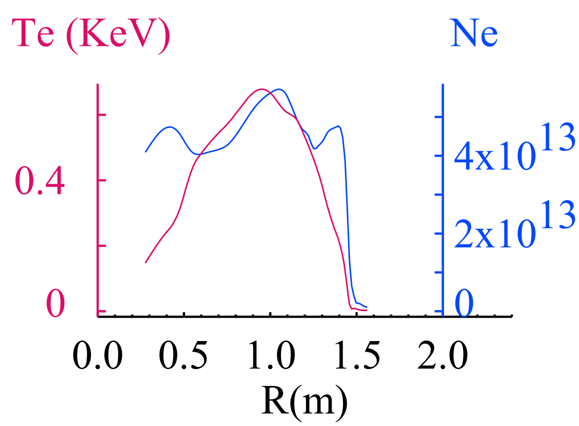
And to Match Input Power

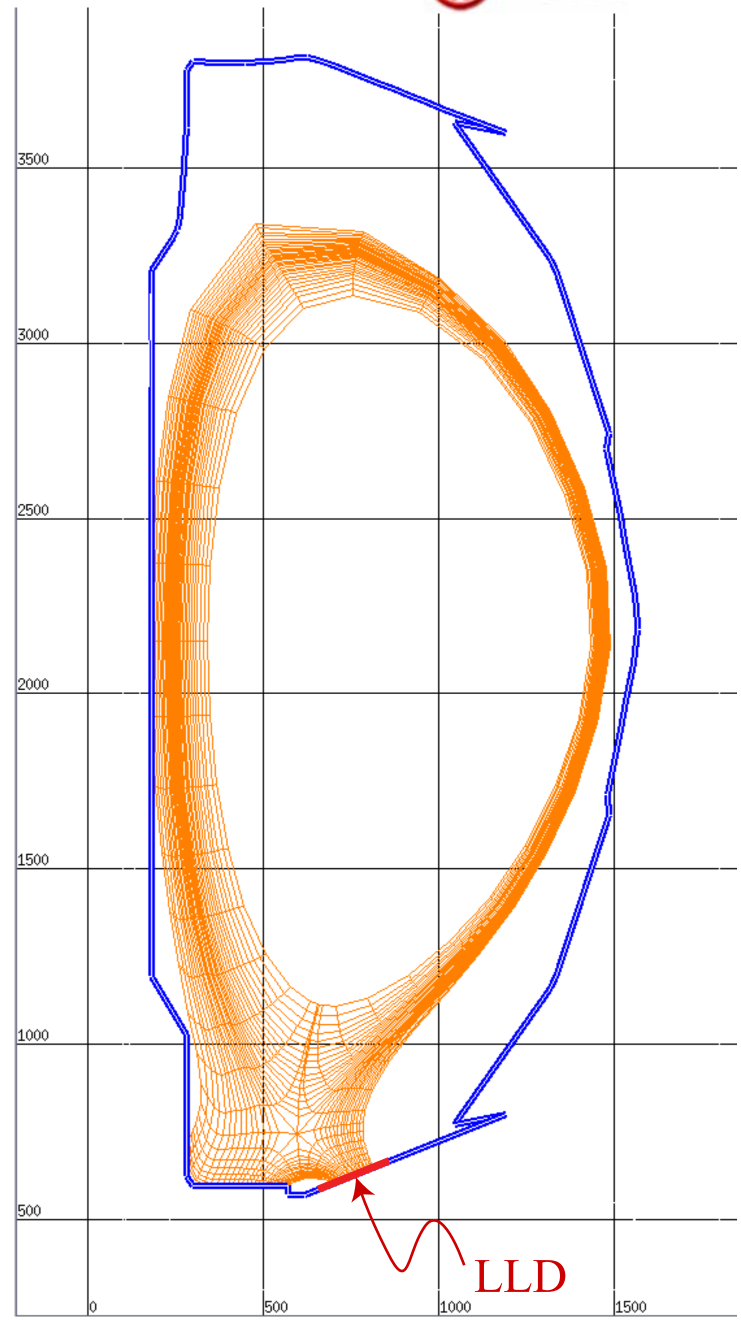
- Power flowing in from core:
  - $P_{\mathrm{NBI}} = 1$ MW -15% beam ion loss,
  - $P_{\mathrm{OH}} \simeq 1$ MW,
  - $P_{\mathrm{rad}} < 0.1$ MW,
  - $\Rightarrow P_{\mathrm{in}} = 1.7 - 1.8$ MW.

- Particle input:
  - Lump external fueling into core particle source,
  - Require magnitude consistent with center stack gas puff (400 A) $+$ NBI (18 A).

UEDGE Simulation Based on Shot 128339 @ 0.35 s







Use Midplane Profiles to Set Transport Coefficients

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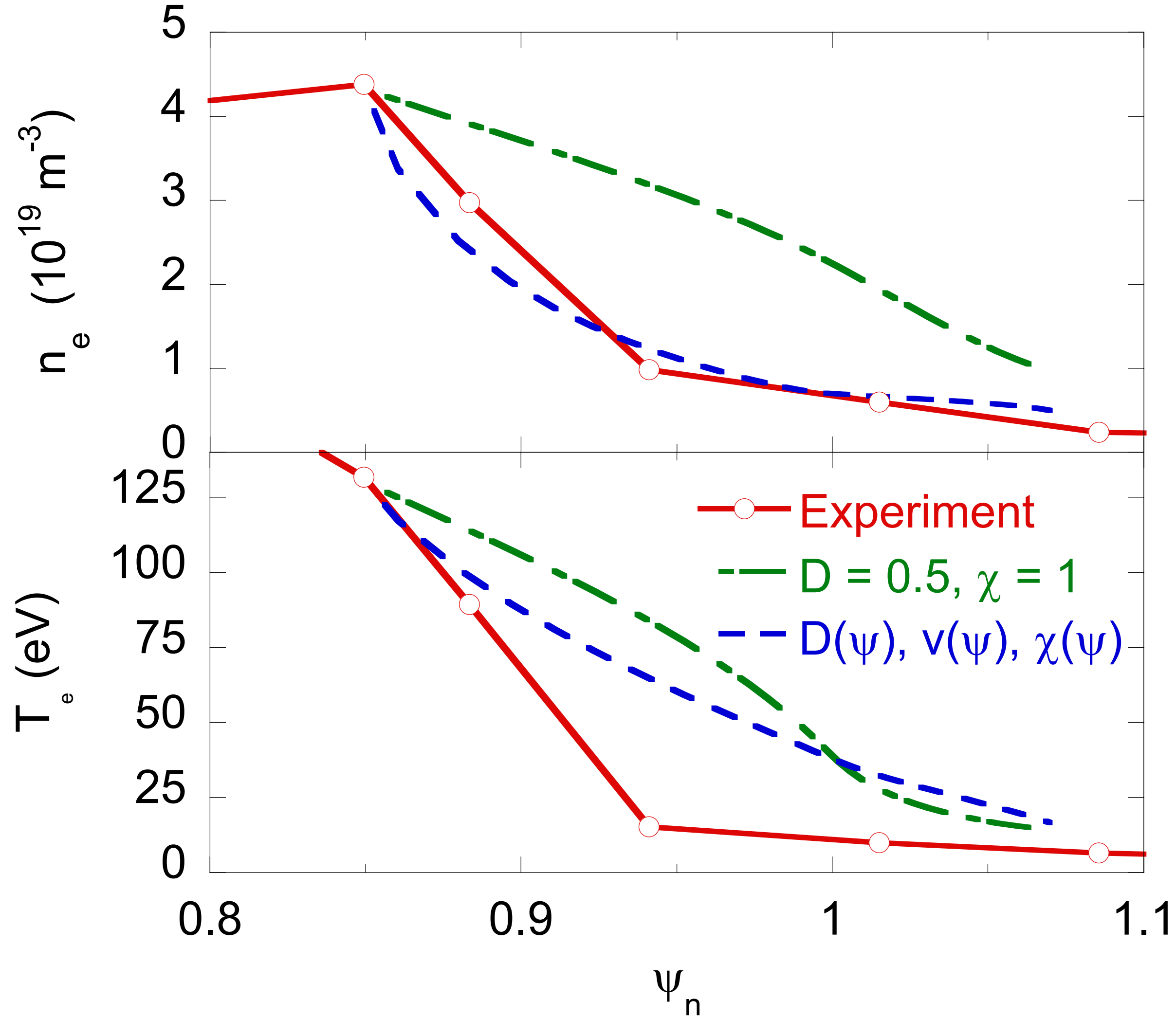

- $D(\psi)$ = 0.04 (core) → 0.1 (sep.) → 0.1 (wall) m^2/s,
- $v(\psi)$ = 0 → 25 → 30 m/s,
- $\chi(\psi)$ = 1.5 → 25 → 35 m^2/s.

- Core power: P_e = 0.98, P_i = 0.82, = 1.8 MW total,
- D+ current from core: 440 A; D current to core: 142 A.

Divertor Profiles Reasonable with Nominal Pumping

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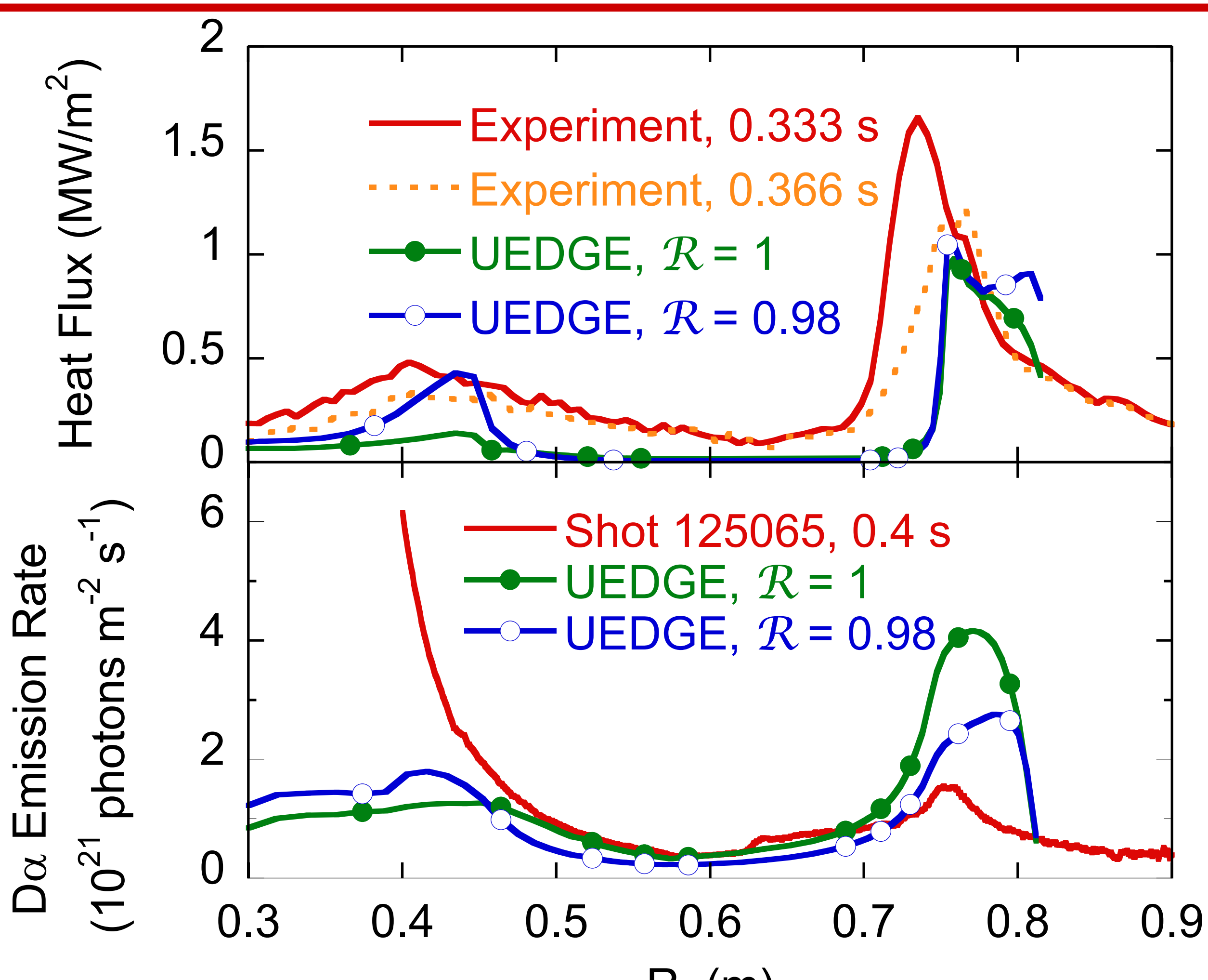


- Heat flux from IR camera,
- D_α from divertor camera,
- $\mathcal{R}$ = D^+ recycling coefficient
- $\mathcal{A}$ = D "albedo"
- $\mathcal{R}_w = \mathcal{A}_w = 0.95$,
- $\mathcal{R}_{id} = 0.99$, $\mathcal{A}_{id} = 1$,
- $\mathcal{R}_{od} = \mathcal{A}_{od} = 0.98$.
- Improving D_α agreement requires much more complex approach.

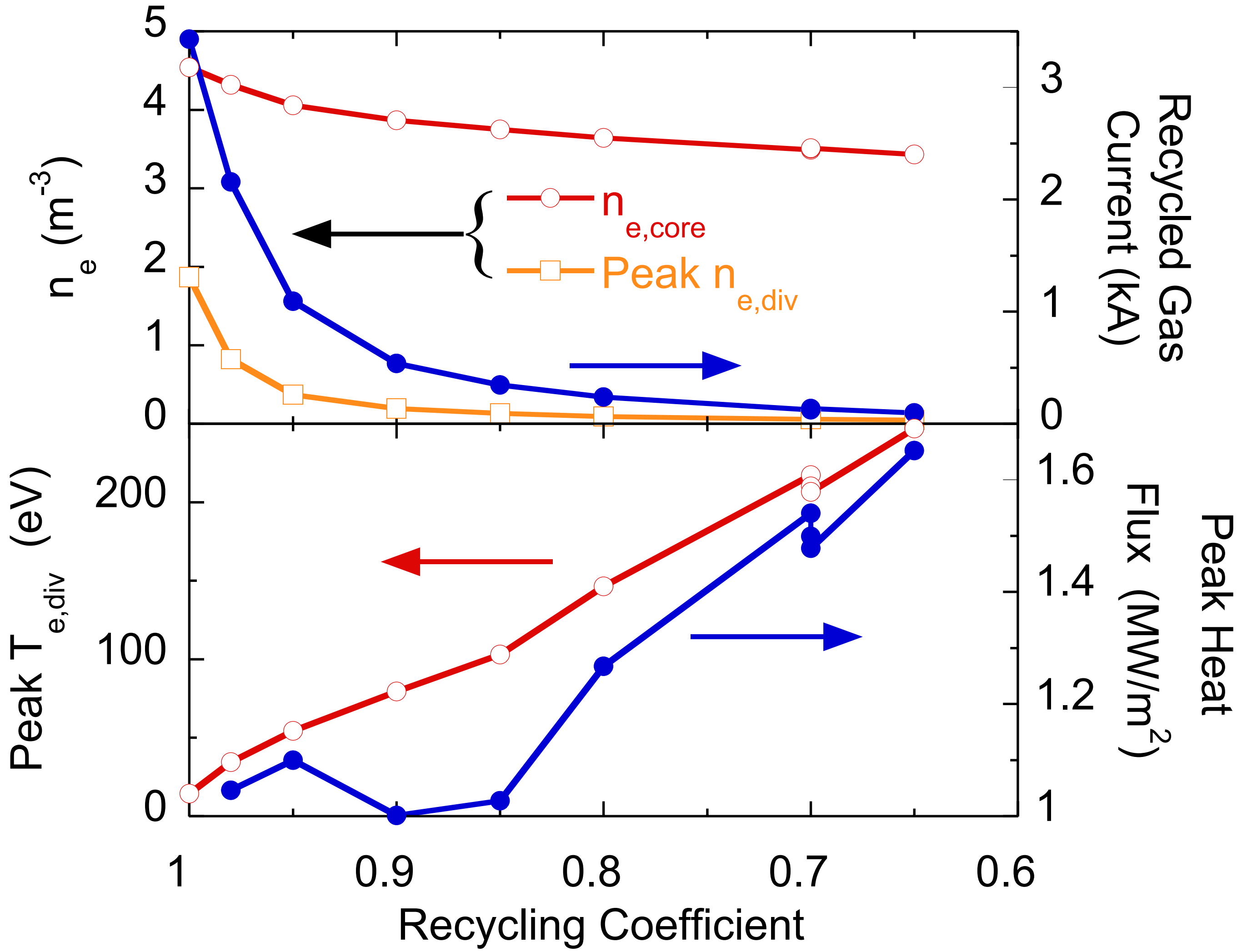
Scan of Recycling Coeffiecients

- Theoretical lower limit = 0.1 – 0.3,
  - Actual values higher due to variations in coatings & surface contamination.
  - Don't know *a priori* $\Rightarrow$ do scan.

- First change $\psi_n = 0.85$ boundary condition from specified n & T to specified particle flux & power,
  - Fix these & transport model as recycling varied.

- Introduce LLD as reduction in $\mathcal{R} \equiv \mathcal{R}_{od} = \mathcal{A}_{od}$,
  - Lower limit: $\mathcal{R} = 0.65$ set by ability of UEDGE to converge.

Scan of Recycling Coefficients will Feed into Future Work



- Will compare core density with 0-D particle balance calculations.
- Peak divertor n_e & T_e impact lithium transport.
- Total current drops 40 x,
  - Compare with 3 x drop in D_α in CDX-U $\Rightarrow$ Difficult to approach theoretical minimum recycling in practice.

Calculate Li Temperature Rise Using Heat Conduction Calculation

NSTX

- Surface temperature rise in semi-infinite solid:

$$\Delta T = (2F/K)\sqrt{\kappa t/\pi}$$

- LLD: Cu base with thin stainless steel barrier,
  - Film of Mo sprayed on top is Li substrate.
- $\Rightarrow$ LLD properties fall between those of Cu & Li.
- Calculate $\Delta T(t)$ using divertor heat flux at given $\mathcal{R}$.
- Initially, Li molten between 200 & 250 °C,
- Take upper limit $= 430$ °C $\Rightarrow \Delta T < 200$ °C,
  - $\Rightarrow$ allowable pulse length for each input power, substrate, $\mathcal{R}$.

Li Temperature Limit Could Be Reached at Maximum Input Power

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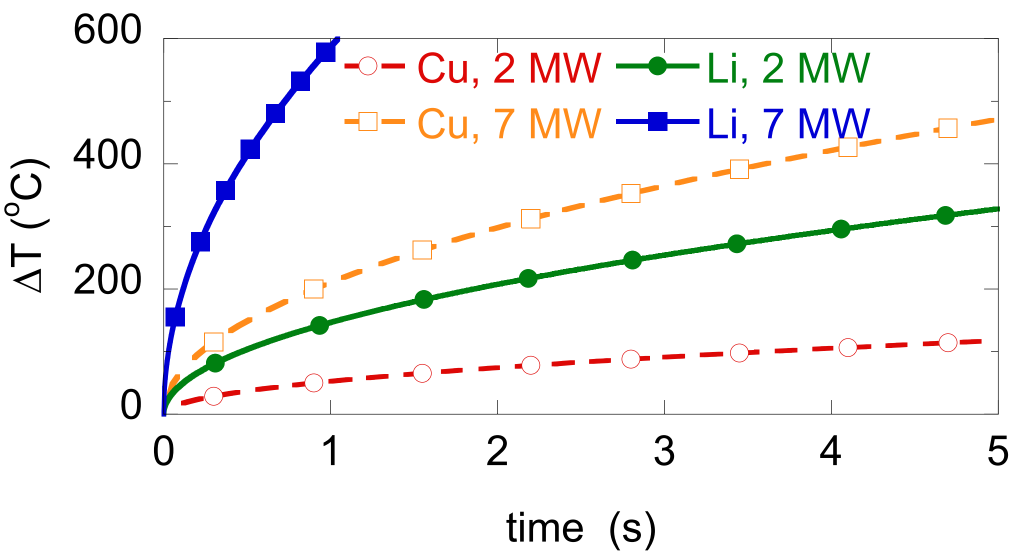

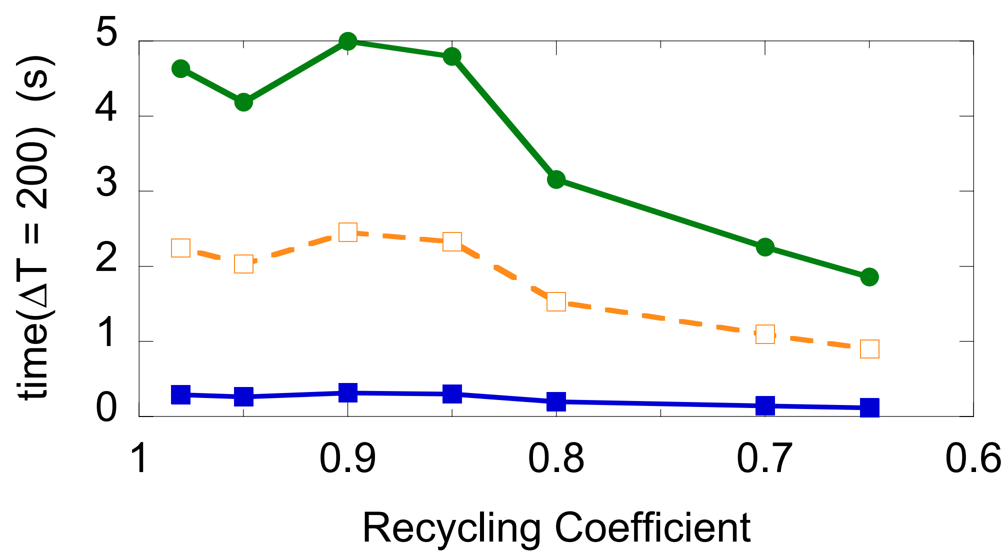

- ΔT shown for $\mathcal{R}$ = 0.65 case.
- Baseline has 1.8 MW input,
- Consider also 7.2 MW,
  - Scale heat flux x 4.
- 1.8 MW Cu case not shown, all > 5 s.
- Present 2 s discharges OK for 1.8 MW Li.
- But, pulse length restricted at 7
  - Especially if Li coating thick.

Discussion

- Simulation of existing & recycling scan will be used to check 0-D particle balance calculations,
  - Were utilized in selecting LLD radius & width.
- Use UEDGE profiles & thermal analysis to compute reflection, sputtering, evaporation of lithium,
  - Surface models based on coupled REDEP/WBC, TRIM-SP, & MD simulations.
- Self-consistent erosion / redeposition simulation $\Rightarrow$ net flow of Li away from surface,
  - Feed flux back to UEDGE $\Rightarrow$ Li distribution in core & SOL.