0D LLD Pumping Model – results and refinements

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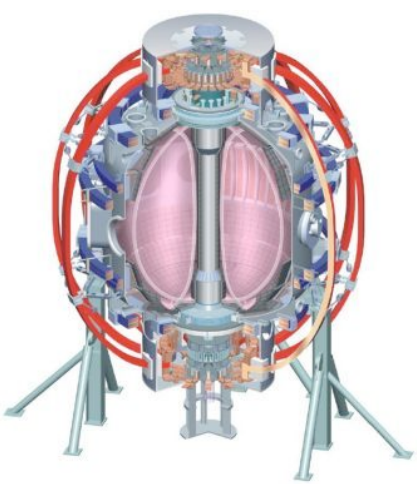
Li RTSG Meeting
5/5/10



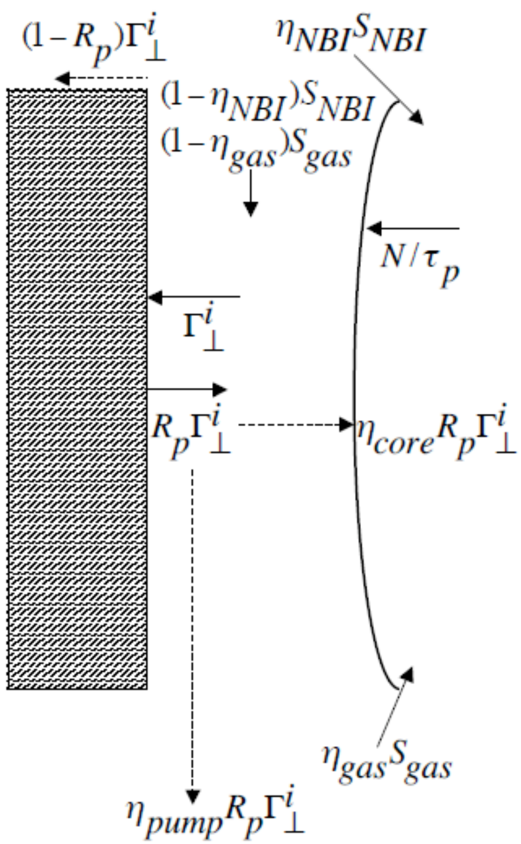
Overview

- What can 0D models tell us about the plasma density response to a pumping surface?
  - assumptions, data inputs, predictions
  - can we modify the models to be more in concert with observables in NSTX?
- How can we design experiments to verify and refine model predictions?
- Can 0D results be connected to more sophisticated 2D models?

0D Model

Particle Balance and Recycling Model

NSTX



- Consider core and SOL particle content equations

$$\frac{dN}{dt} = \eta_{NBI}S_{NBI} + \eta_{gas}S_{gas} - \frac{N}{\tau_p} + \eta_{core}R_p\Gamma_\perp^i$$

$$\frac{dN_i^{SOL}}{dt} + \frac{dN_0^{SOL}}{dt} = (1-\eta_{NBI})S_{NBI} + (1-\eta_{gas})S_{gas} + \frac{N}{\tau_p} - (1-R_p)\Gamma_\perp^i - R_p\Gamma_\perp^i(\eta_{pump}+\eta_{core})$$

- Assume SOL neutral and ion density in steady state

$$\frac{dN}{dt} = (1+\beta-\beta\eta_{NBI})\eta_{NBI}S_{NBI} + (1+\beta-\beta\eta_{gas})\eta_{gas}S_{gas} - \frac{N(1-\beta)}{\tau_p}, \text{ where}$$

$$\beta = R_p\eta_{core} / \left[(1-R_p) + R_p(\eta_{pump}+\eta_{core})\right]$$

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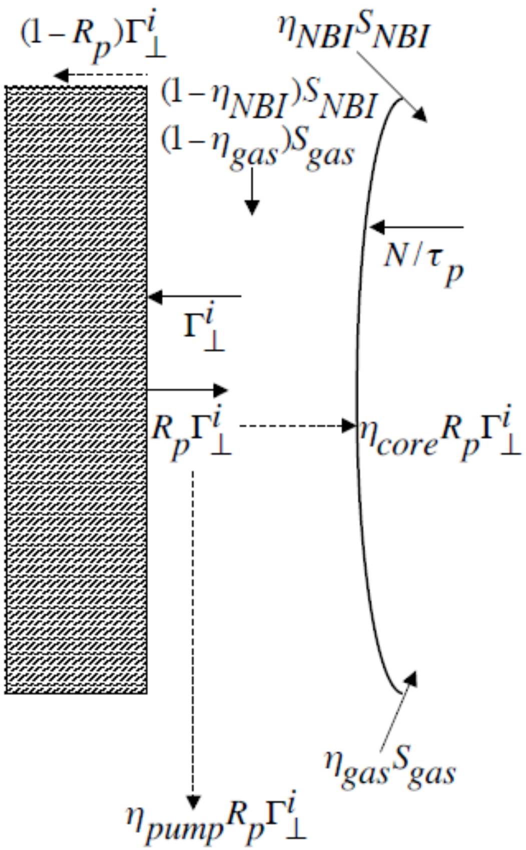
0D Model II

Simplified Particle Balance and Recycling Model

NSTX



- Define $\tau_p^* = \tau_p/(1-\beta)$
  - Steady state: $\tau_p^* = N/(S_{NBI}+S_{gas})$
- Normal assumptions:
  - $\eta_{NBI} \sim 1$
  - $R_p(\eta_{pump} + \eta_{core}) >> (1-R_p)$
  - η_{pump}, η_{core} independent of time
- Particle balance equation becomes:

$$\frac{dN}{dt} = S_{NBI} + (1+\beta(1-\eta_{gas}))\eta_{gas}S_{gas} - \frac{N}{\tau_p^*}$$

Let $S = S_{NBI} + (1+\beta(1-\eta_{gas}))\eta_{gas}S_{gas}$

Solution:

$$N(t) = S\tau_p^{*,1} + S(\tau_p^{*,2} - \tau_p^{*,1})\exp-(t/\tau_p^{*,2})$$

- Has been used to model step change in τ_p (L-H) and pumping ($\eta_{pump}>0$)

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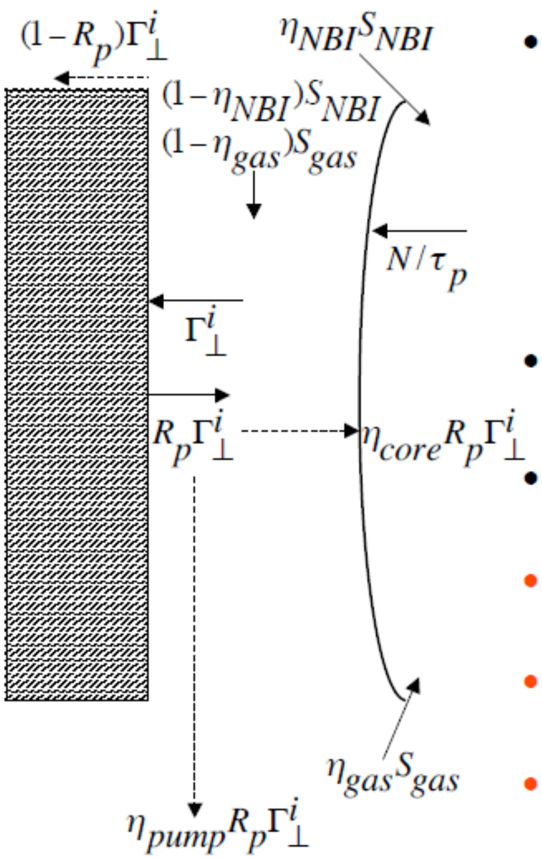
0D Model III

Simplified Particle Balance and Recycling Model

NSTX



- Density reduction factor

  $n_e^{red} = \tau_{p,pump}^* / \tau_{p,nopump}^*$

  $= (1-\beta)_{noLi} / (1-\beta)_{Li}$ {constant τ_p}

- $\beta_{noLi} = \eta_{core}R_p/((1-R_p)+ R_p{*}\eta_{core})$
- $\beta_{Li} = \eta_{core}R_p/((1-R_p)+ R_p{*}(\eta_{core}+\eta_{pump}))$
- **Need prescription to estimate η_{Li}**
- **Is η_{core} really independent of n_e?**
- **Is τ_p really independent of n_e?**

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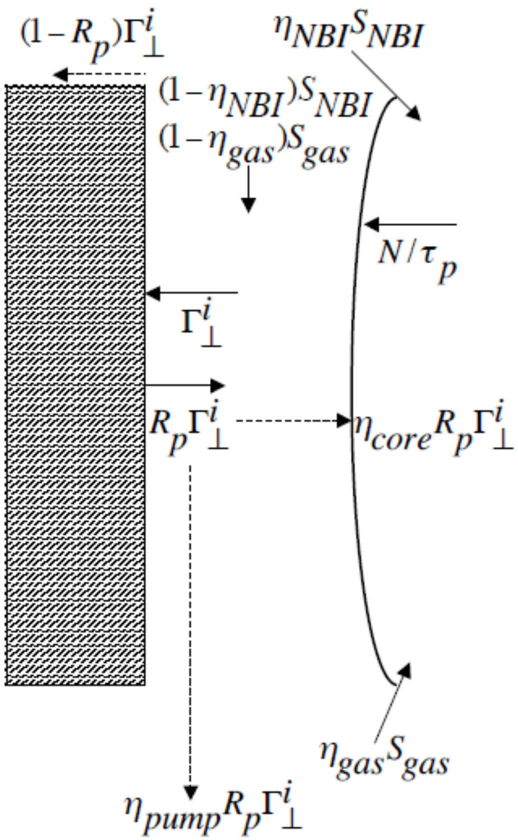
0D Model IV

Limits of Particle Balance and Recycling Model

NSTX



- Note $\tau_p^*/\tau_p = 1/(1-\beta)$
- Pump off: $\tau_p^*/\tau_p \sim 1+ \eta_{core}R_p/(1-R_p)$
  - $\tau_p^*/\tau_p \sim 6$
- Pump on: $\tau_p^*/\tau_p \sim (\eta_{core}+\eta_{pump})/\eta_{pump}$
  - $\tau_p^*/\tau_p \sim 2$

➢ n_e should go down by 2/3 w/pumping

⇒Smaller n_e reduction observed, maybe due to increased core fueling probability at low n_e

- Input data (from DIII-D studies):
  - $R_p \sim 0.98$ for carbon (reference?)
  - $\eta_{core} \sim 0.1$ (Rensink, PoF B 1993)
  - $\eta_{pump} \sim 0.1$ (Maingi, NF 1999)

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0D Model V

Method to Relate 0-D Pump Probability to Divertor Plasma and Lithium tray parameters

NSTX

Li surface particle sticking probability - 0.85

In/out particle flux ratio - 0.8

Tray toroidal coverage - 0.9

$$\eta_{pump} \cong \gamma_{Li}^{sticking} \frac{\int_{R_{\min,tray}}^{R_{\max,tray}} \Gamma_{\perp}(R) R dR}{\int_{R_{\min}}^{R_{\max}} \Gamma_{\perp}(R) R dR} \left(\frac{\Gamma_{out}}{\Gamma_{in} + \Gamma_{out}} \right) \left(\frac{\Gamma_{down}}{\Gamma_{up} + \Gamma_{down}} \right) f_{\phi}$$

Impact of R_{tray}, Δ_{tray}, $(R_{OSP} - R_{tray})$
(*Γ available from Vlad*)

Up/down particle flux ratio 0.5 (δ_r^{sep} important)

*Red items to be estimated from Vlad's CCD camera data

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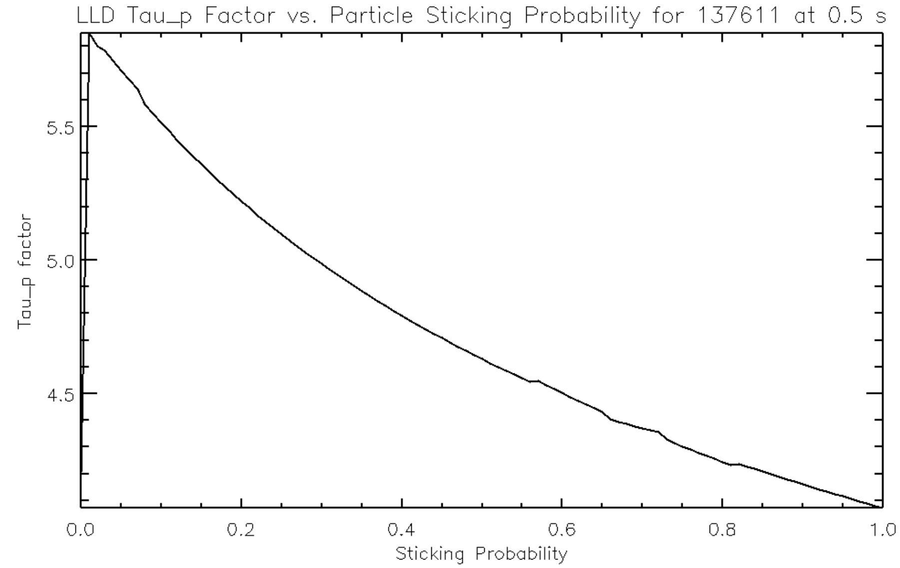
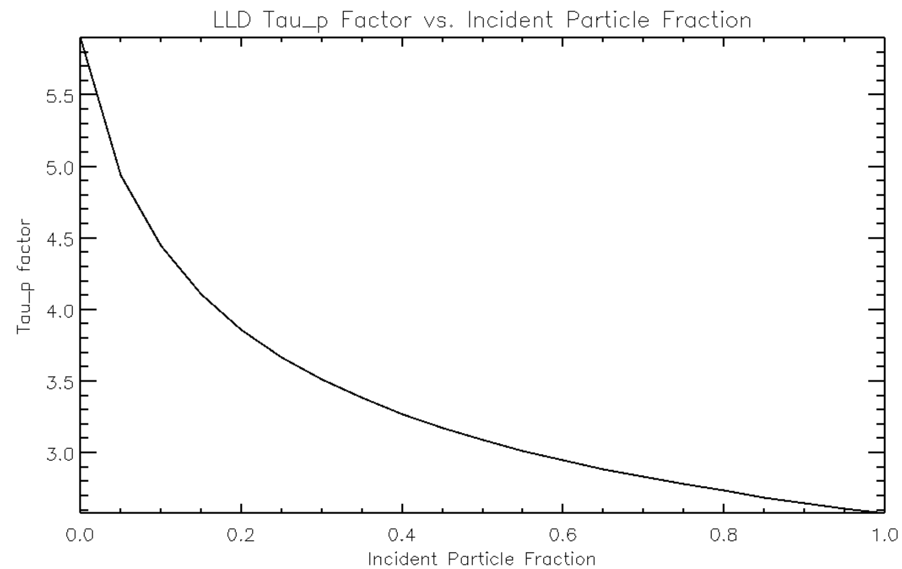
Limits and Uses of 0D Model

- Depends heavily on S/XB number from D_α to calculate relative particle flux to LLD
  - can improve S/XB accuracy with local measurements from both inboard and outboard Langmuir probes
  - more direct flux measurements possible with IR and probe data
- Was designed to provide *fraction of total pumping due to LLD*, not specific information about overall pumping
  - more relevant number is *fractional reduction in* τ_p^* *due to LLD, or* $1/(1-\beta)$ ← measurable both by density pumpout and fueling requirements
- Does not tell us about expected changes to SOL density, assumes steady state
  - but we can eventually modify it to look at just N_{SOL} response

Some dependencies of the model

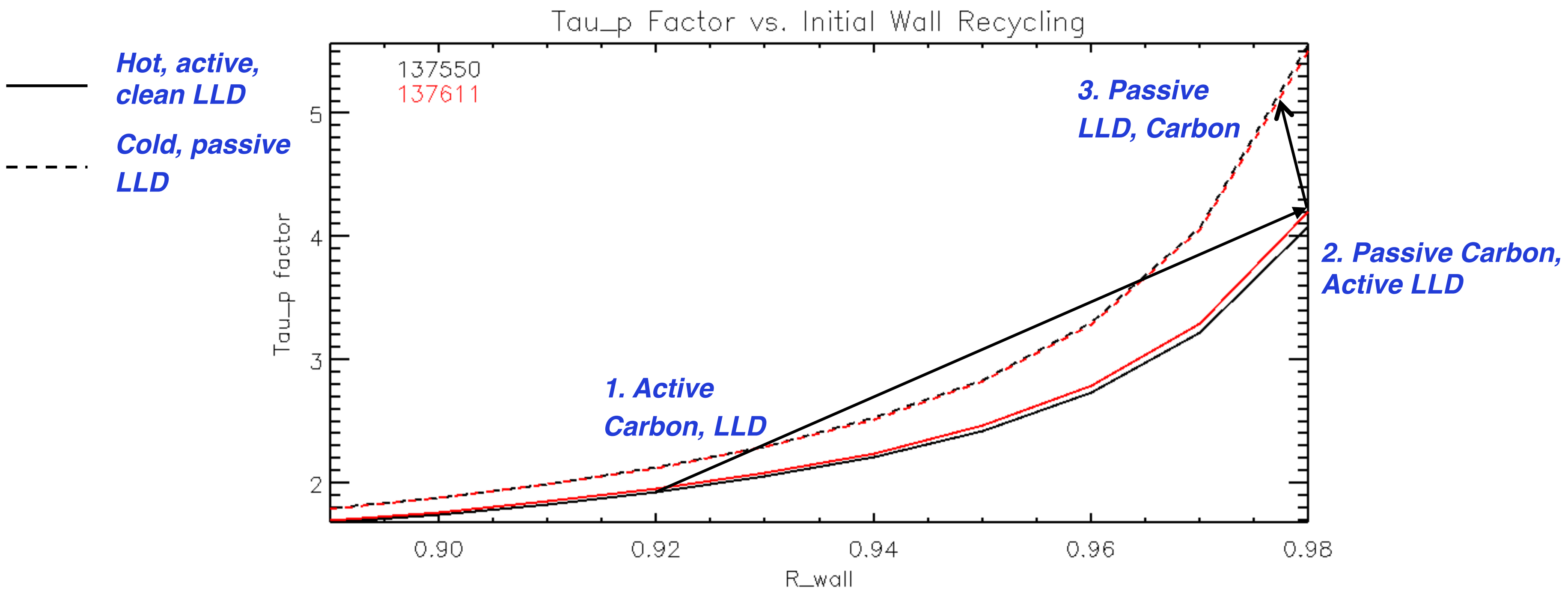
- Sticking probability is dependent on LLD surface properties
  - has ~30% effect on density pumpout
  - can we refine this number with lab experiments?
- Incident particle fraction is determined mainly by magnetic geometry
  - depending on inboard divertor detachment and OSP location, can be close to 90% for shots on LLD
  - could result in 20-30% changes in efficiency as OSP moves inboard
  - can be related to S/XB, refined with probe measurements





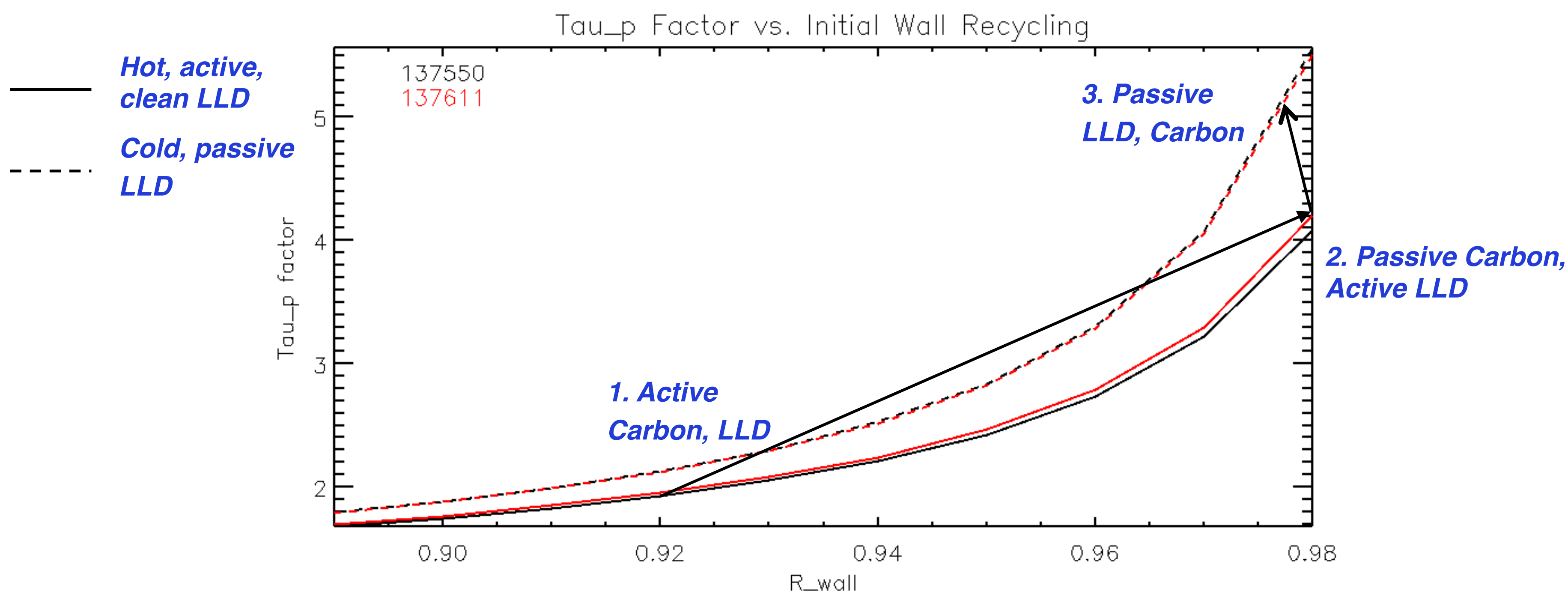
0D model predicts changes to particle lifetime with and without LLD presence

- Scan in Rp, recycling of carbon walls
  - according to J. Canik, should be 92% for pumping, 98% for passivated
- Two cases (more can be added later, but probes measure OBD)
  - R = .63 (137550), R = .7 (137611)
- Should provide expected particle lifetimes for active/inactive LLD with and without actively pumping carbon tiles



Results of model suggest experimental sequence

- Start at point 1 on figure: hot LLD, fresh Li on tiles – highest pumping scenario
- As carbon tiles passivate, particle confinement time is predicted to increase and fueling requirements will decrease → point 2
  - need enough Li inventory in LLD to ensure it stays active
  - if point 2 should have reproducible density response as pumping conditions stay constant
- As LLD eventually saturates and/or cools, should head towards point 3 with weakest pumping, highest particle lifetime and lowest fueling requirements
  - cooling LLD, passivating surface (without saturating bulk Li), and then reheating (back to point 2) could demonstrate recovery of LLD surface conditions



XP 1001 will be able to test predictions of 0D model

- Sequence of shots as surrounding tiles passivate can form database for particle confinement time, fueling requirements
  - exponential density decay will give τ_p^*
  - TS data can show density response of core plasma to SGI gas puff
  - change in overall fueling requirements should be measurable
- Langmuir probes can be used to characterize SOL density response at various SOL depths
- Cold, passive LLD will form basis for comparison
  - does it actually behave like Li on carbon when cold, or does it saturate differently?
  - will give baseline confinement time data with and without active walls (top curve in previous figure)

Future work and more model connections

- Model needs to be adapted to SOL to allow for correlation with edge plasma measurements from probes
- Allow for more data inputs into model, such as time resolved measurements for source terms and flux balances (in/out, up/down)
  - IR camera, visible camera, reflectometer… etc?
- Does UEDGE (or another 2D model) agree with 0D results
  - can 0D results be integrated into UEDGE to provide core or SOL boundary conditions?
- As always, more analysis of dependence of terms in model on LLD surface conditions
  - sticking coefficient may evolve during a discharge due to saturation levels and breakup/formation of surface impurities