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Lithium Loaded Target Plate for driving NSTX toward high performance

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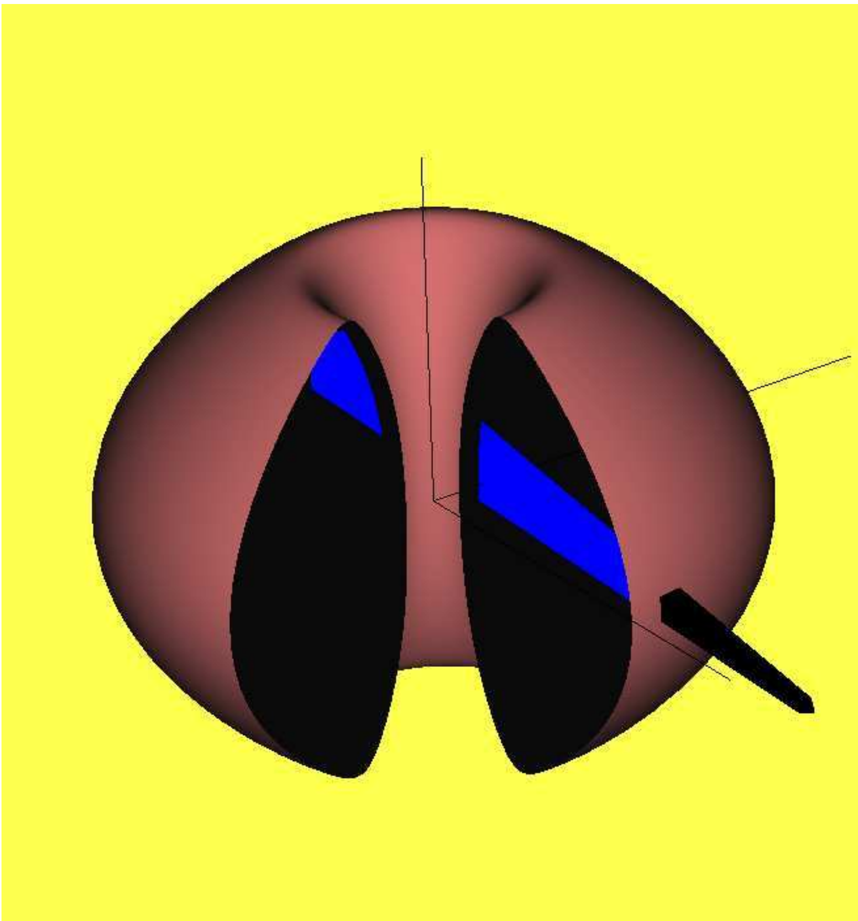
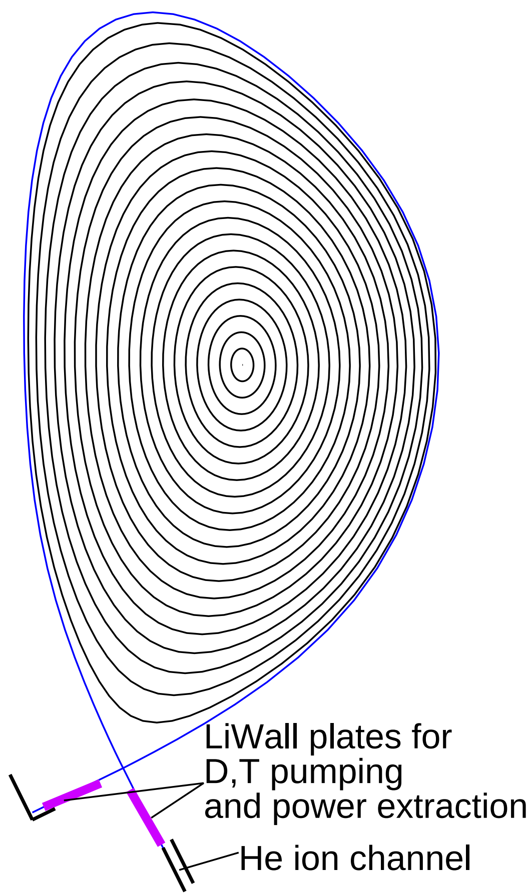
Contents

1 The idea of the Lithium Wall Fusion (LiWF)

What will happen if: (a) Neutral Beam Injection (NBI) supplies particles into the plasma core, while (b) a layer of Lithium on the Plasma Facing Surface (PFC) absorbs all particles coming from the plasma ?

(Assume that Maxwellization is much faster than the particle diffusion.)





1 The idea of the Lithium Wall Fusion (LiWF) (cont.)

The answer is very simple: because there is no cold particles in the system (other than Maxwellian)

The plasma temperature will be uniform over entire cross-section. Plasma physics is not involved in this answer.

Ion/electron temperature gradient instabilities (ITG,ETG) would be eliminated automatically.

In fact, any thermo-conduction loos would be eliminated. Energy from the plasma will be lost only due to particle diffusion.

For the first time theory reveals a possibility of a regime which is insensitive to anomalous electrons

In addition, LiWF regime is ELM-free, eliminates the thermo-force driving impurities from PFCs into the plasma, and is consistent with other aspects of a stationary plasma.

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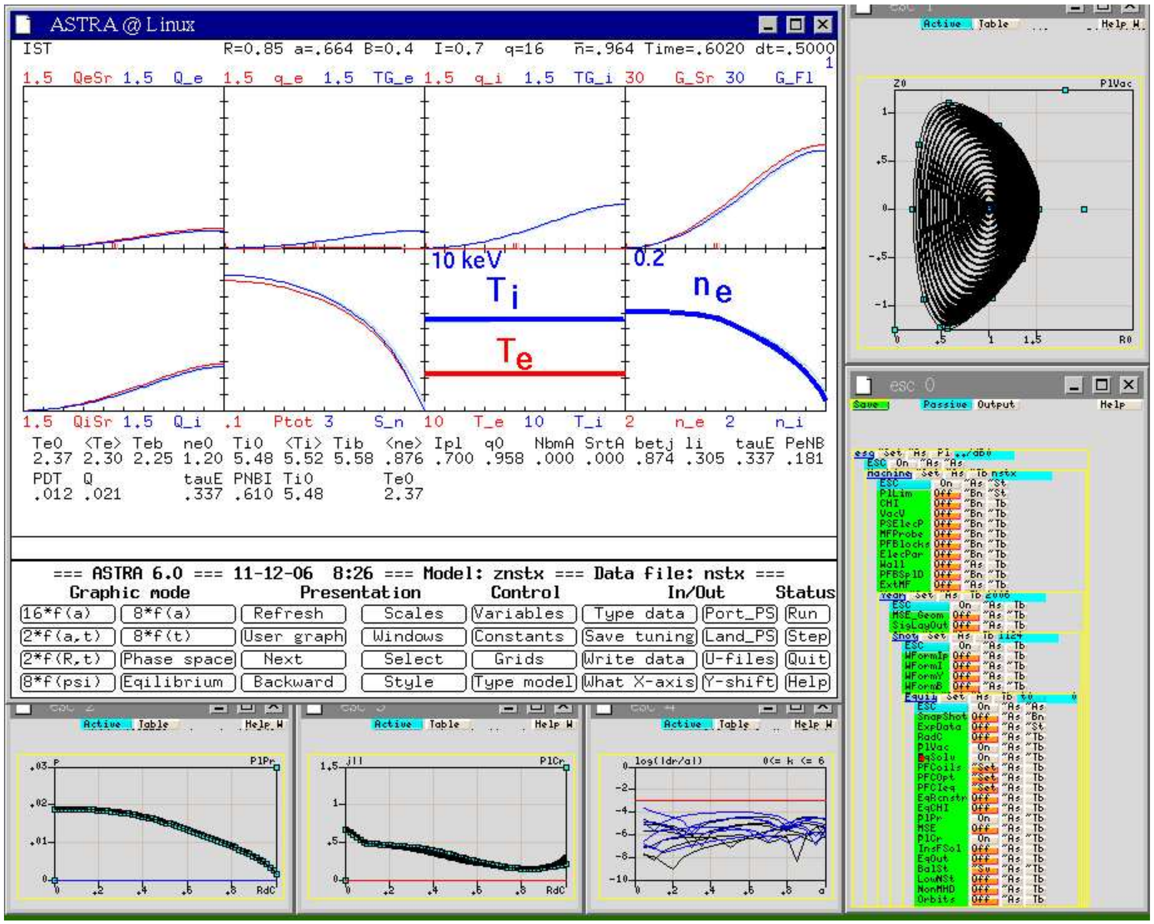
ASTRA-ESC simulations of NSTX, B=0.4 T, I=0.7 MA, 0.6 MW, 20 keV NBI



$$D = \chi_i^{neo-classics},$$
$$\chi_e = \chi_i^{neo-classics},$$
$$\chi_i = \chi_i^{neo-classics}$$

Hot-ion mode:

$$T_i = 5.5 \text{ [keV]},$$
$$T_e = 2.5 \text{ [keV]},$$
$$n_e(0) = 0.14 \cdot 10^{20},$$
$$\tau_E = 0.33 \text{ [sec]},$$
$$P_{NBI} = 0.61 \text{ [MW]}$$

E_{NBI} *should be consistent with the plasma temperature:*

$$E_{NBI} \simeq 20 \text{ [keV]}$$

LiWall regime is an extension of QHM or low-collisionality H-mode beyond their plasma density limitations

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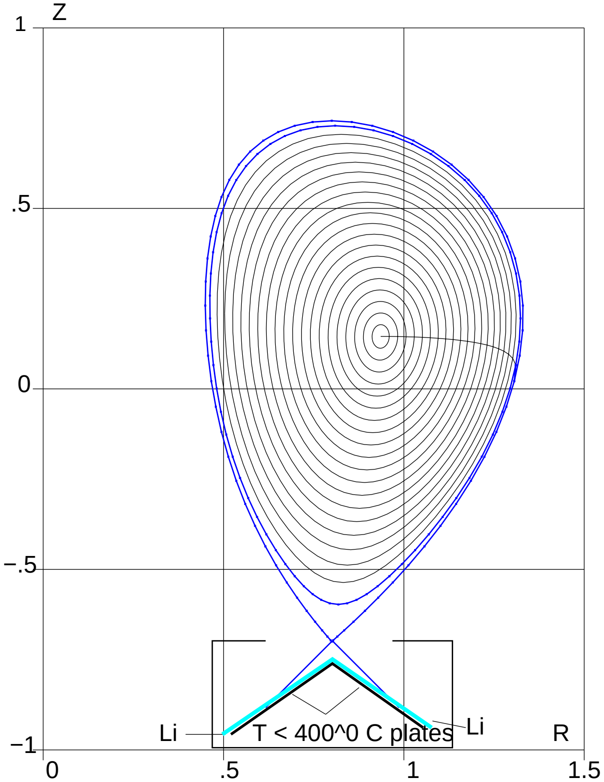
3 The concept of the Pumping Lithium Divertor (PLD)

PLD $\equiv$ actively cooled plates with flowing $h \simeq 0.1$ mm Li layer



Gravity, Marangoni effect, residual $\mathbf{j} \times \mathbf{B}$ *forces,*

$$\begin{aligned} V_g &= \frac{\rho g h^2}{2\nu}\sin\theta = 0.049\sin\theta\ [m/s], \\ V_M &= \frac{d\sigma(T)}{dT}\frac{h\nabla T}{\nu} = 0.8h\nabla T\ [m/s] \end{aligned} \qquad (3.1)$$

are sufficient for replenishing Li surface.

Lithium can accept 5-10 MW/m^2 *and keep* $T_{Li} < 400^oC$

$$\begin{aligned} \chi_{Li} &= 47.6, \\ \Delta T\ [^oC] &= 100\frac{q}{4.7}\cdot h\left[\frac{MW}{m^2}\cdot mm\right]. \end{aligned} \qquad (3.2)$$

For any PFC (W,C,Li) power extraction is limited **by the coolant temperature,** *rather than by the temperature of PFC surface.*

No Li rivers, Li water-falls, evaporation, Li dust, pellets, LiLi trays, meshes, sponges, or thick ($\geq$ 1 mm) Li on the target plate

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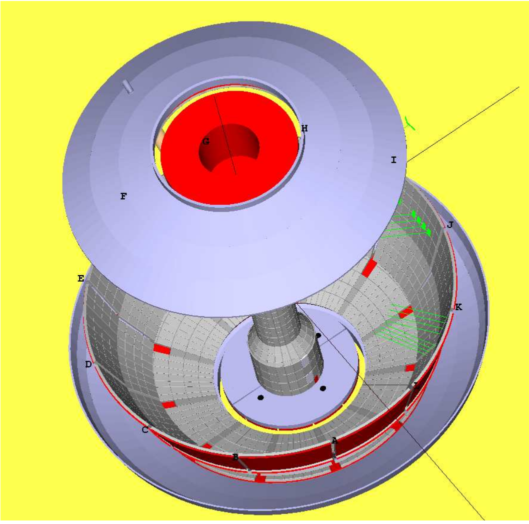
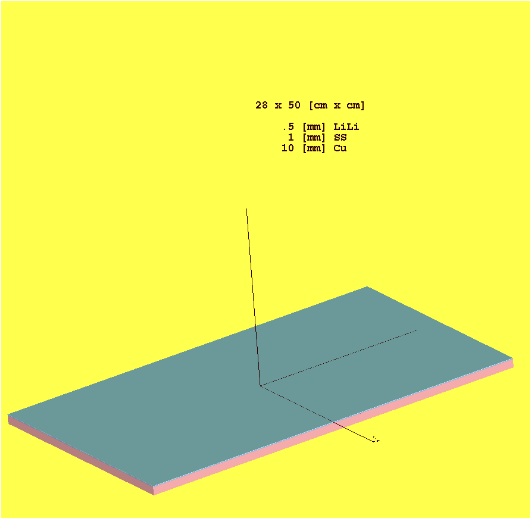
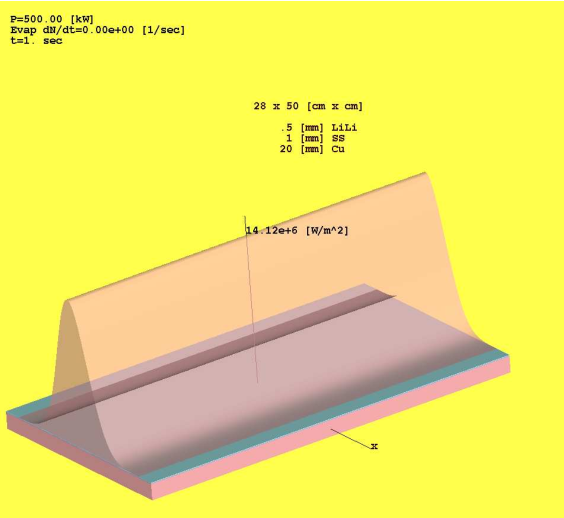
10000 active monolayers or $\simeq 3\mu m$ x 0.75 m^2 of molten Li, needed for NSTX, can be provided by Lithium Loaded Target Plate (LLTP)



Li coated plate in low inner divertor



Li/SS/Cu (0.5mm/1mm/10mm) sandwich with a trenched surface

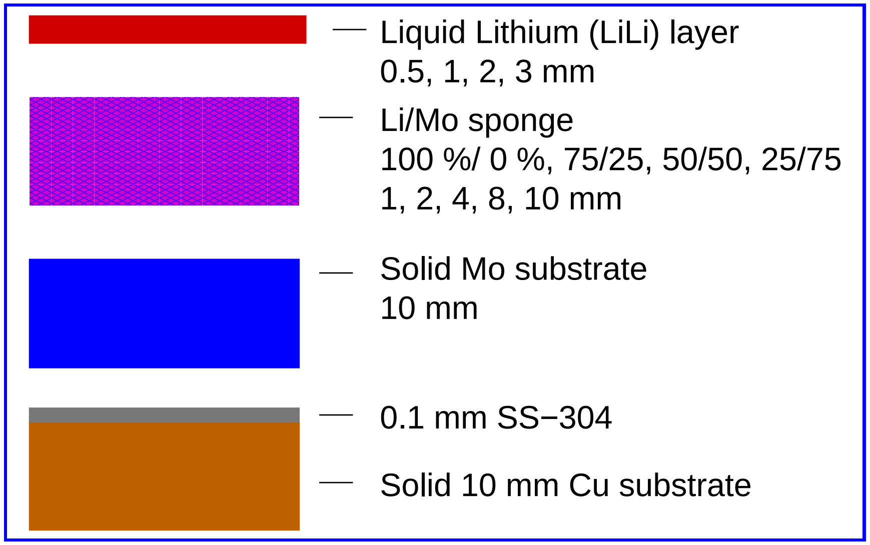


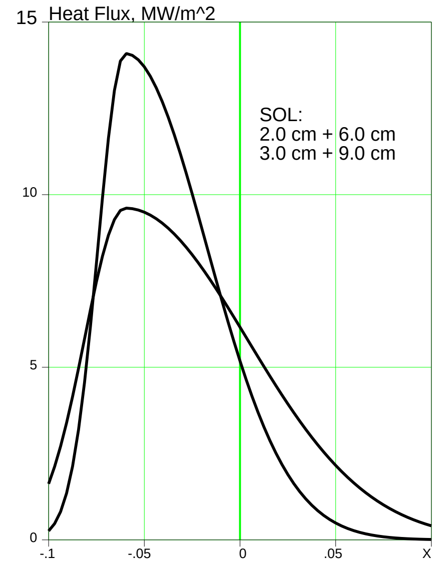
Gaussian (8 cm wide) heat deposition profile

$$S \simeq 0.75\ [\mathrm{m}^2], \quad L_{SOL,m} = 2.5, \quad V_{Li} \simeq 0.35\ [\mathrm{L}], \quad M_{Li} \simeq 175\ [\mathrm{g}],$$
$$V_{Li,cm/sec} = (2-5)\cdot B_{tor}\frac{h^2_{Li,mm}}{0.01}\frac{0.1}{w_{SOL}}\frac{I_{SoL,MA}}{I_{ion}}, \quad I_{ion,MA} = \frac{(0.4-1)\cdot 10^{-3}}{1.6} \tag{4.1}$$

The simple Li/SS/Cu plate could be a real first step toward PLD and LiWF regime

Both Liquid Lithium (LiLi) and Li/Mo CPS were considered





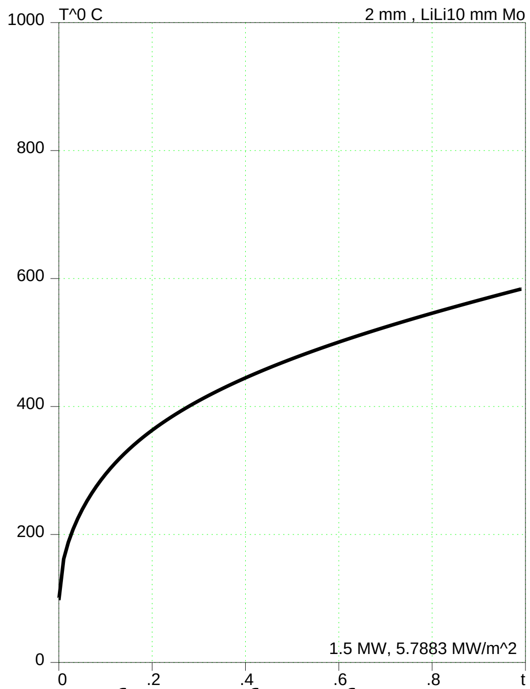
Heat flux profile from the SOL

$$Q_{SOL} = Q_0 \exp\left[-\left(\frac{x - x_0}{d(x)}\right)^2\right], \qquad \begin{cases} d = d_{out}, & x \geq x_0 \\ d = d_{in}, & x < x_0 \end{cases} \qquad (4.2)$$

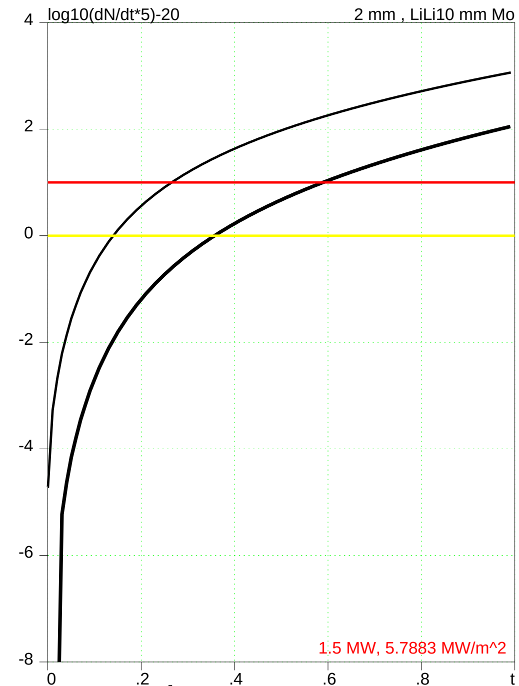
Characteristic scale lengths, mm

d_{in}	d_{out}	Δ_{LiLi}	$\Delta_{Li/Mo}$	Δ_{SS}	$\Delta_{Mo,Co}$	Li/Mo CPS
20,30	$3d_{in}$	0.5, 1,2,3	1,2,4,8,10	.1	10	4/0, 3/1, 2/2, 1/3, 0/4

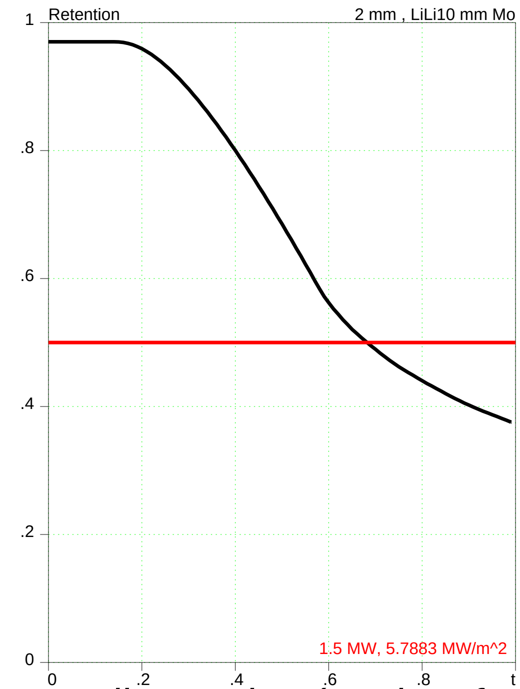
3-D Cbebm code (written for Marangoni effect) is used to simulate heating of Li surface



Waveform of surface temperature T_{Li}



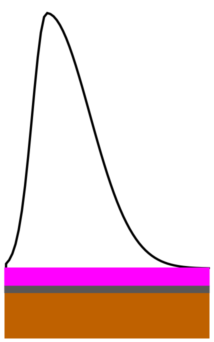
Evaporation $\log_{10}(dN/dt) - 20$

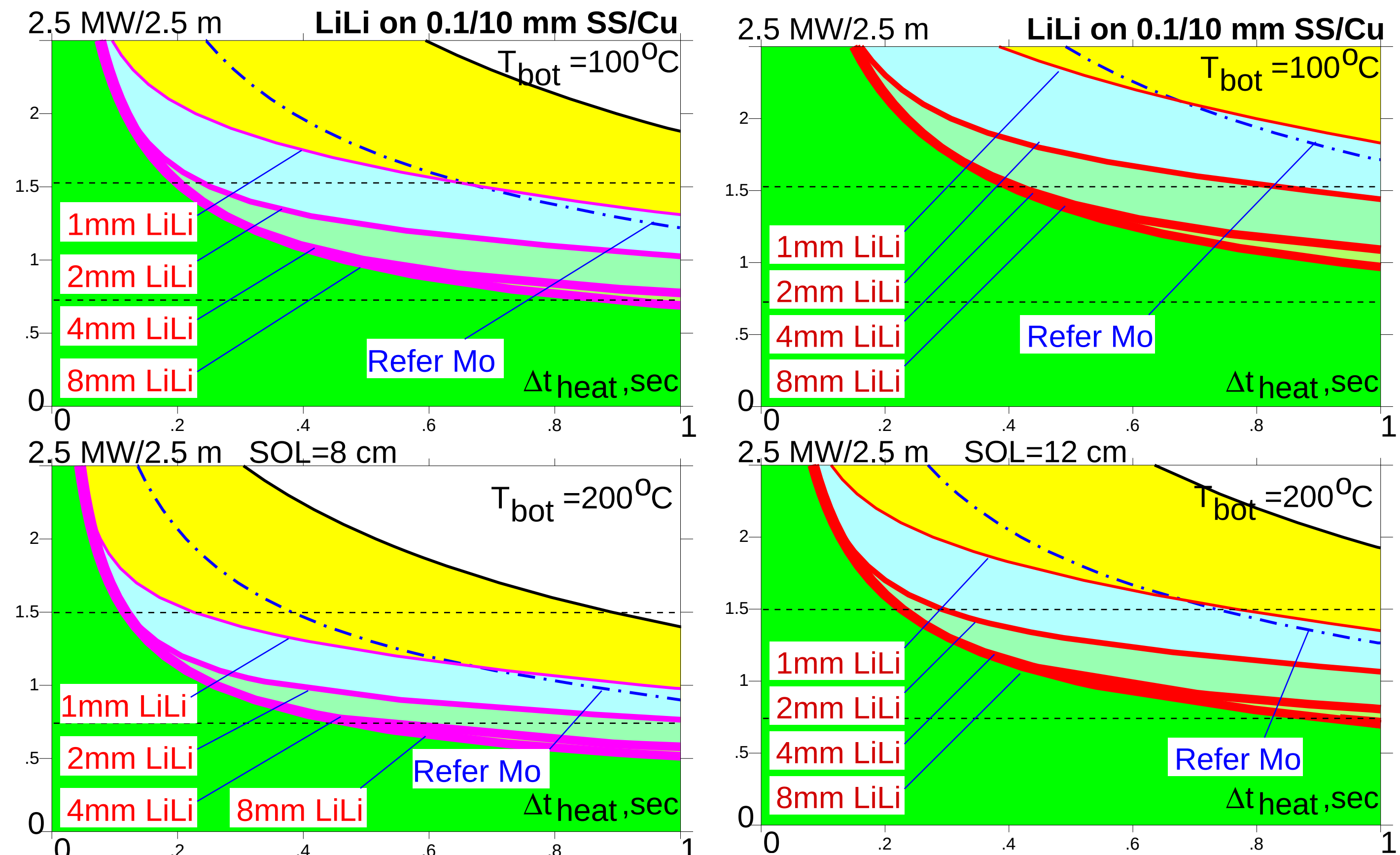


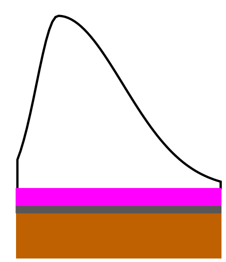
Overall retention (no data for $T > 350^o$ *C)*

Evaporation limit, $dN/dt \le 10^{21}/sec$, determines the operational space P_{NBI} vs Δt_{NBI}

The plate 0.1-1 mm of Li on 0.1/10 SS/Cu provides the operational space for LiWall regime in NSTX



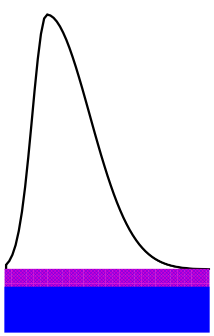


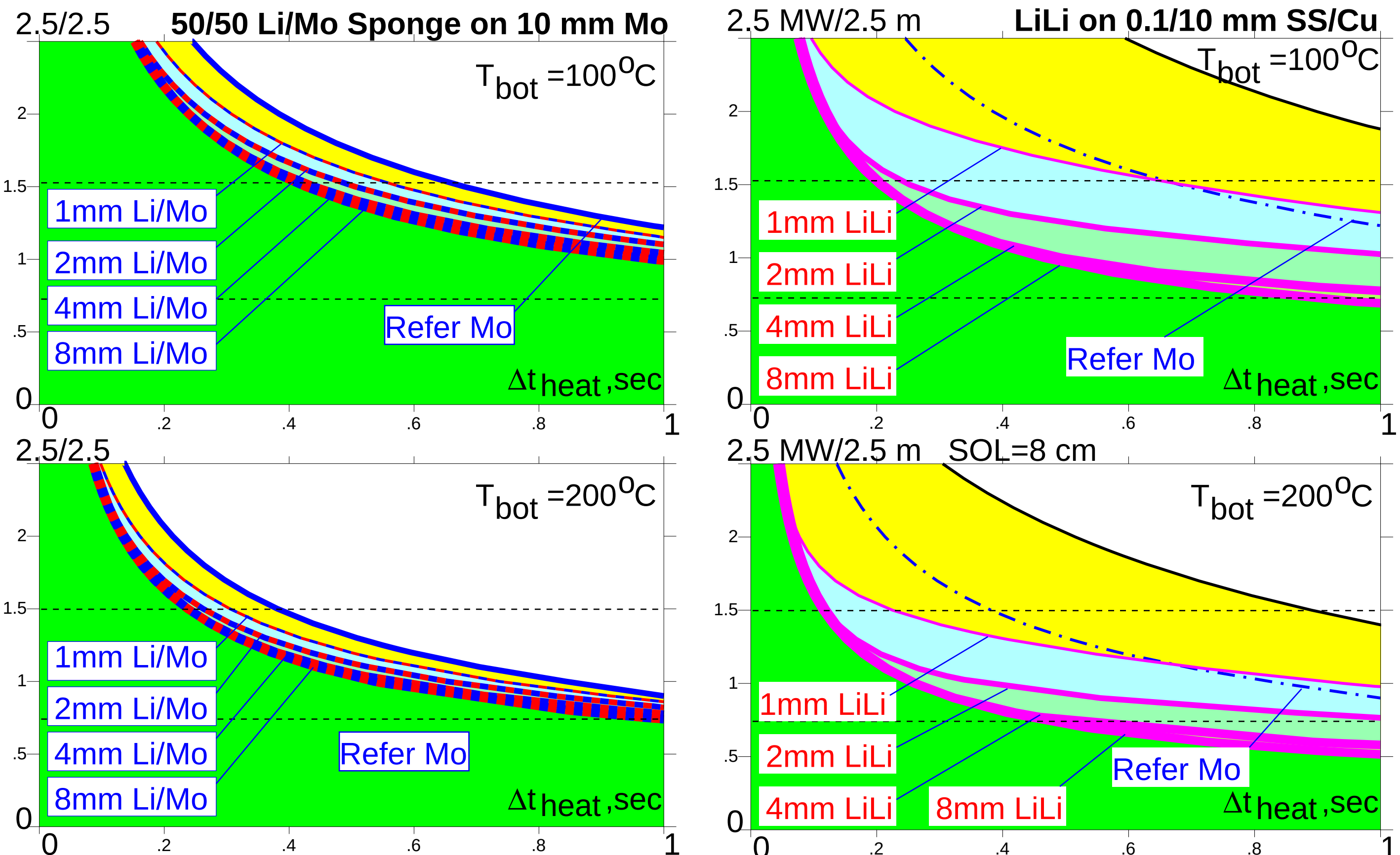


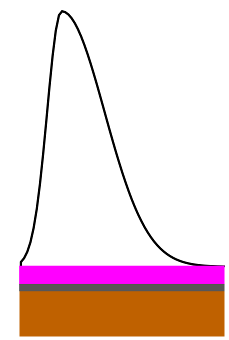
$d_i = 2, d_e = 6$ cm $d_i = 3, d_e = 9$ cm

The heat flux profile in the SOL is a crucial unknown

1/0.1/10 mm Li/SS/Cu plate outperforms 10 mm Li/Mo CPS







$$d_i = 2, d_e = 6 \text{ cm} \qquad d_i = 2, d_e = 6 \text{ cm}$$

The plate also has fewer technology unknowns

Even short term experiments with LLTR can provide initial information on

1. *effects of wetting, wicking, adhesion of Li with large metal surfaces in the plasma environment,*
2. *rate of passivation of Li surface in a specific NSTX device with C-walls*
3. *electric currents in the SOL*

The goal of experiments with LLTP is limited (1-2 campaigns), realistic and well specified:

1. *To clarify the system compatibility with molten Li using a simple Lithium Loaded Target Plate*
2. *To reproduce the T-11M (1998) level of plasma pumping using the LLTP in divertor configuration.*
3. *To collect sufficient information for redesigning the divertor area of NSTX for a long lasting PLD and other aspects of a LiWF regime.*

This approach will pave a way for

Conversion of NSTX into ST0 in order to demonstrate the feasibility of the LiWF regime, by achieving $\tau_{E,ST0} > 2\tau_{E,NSTX}$

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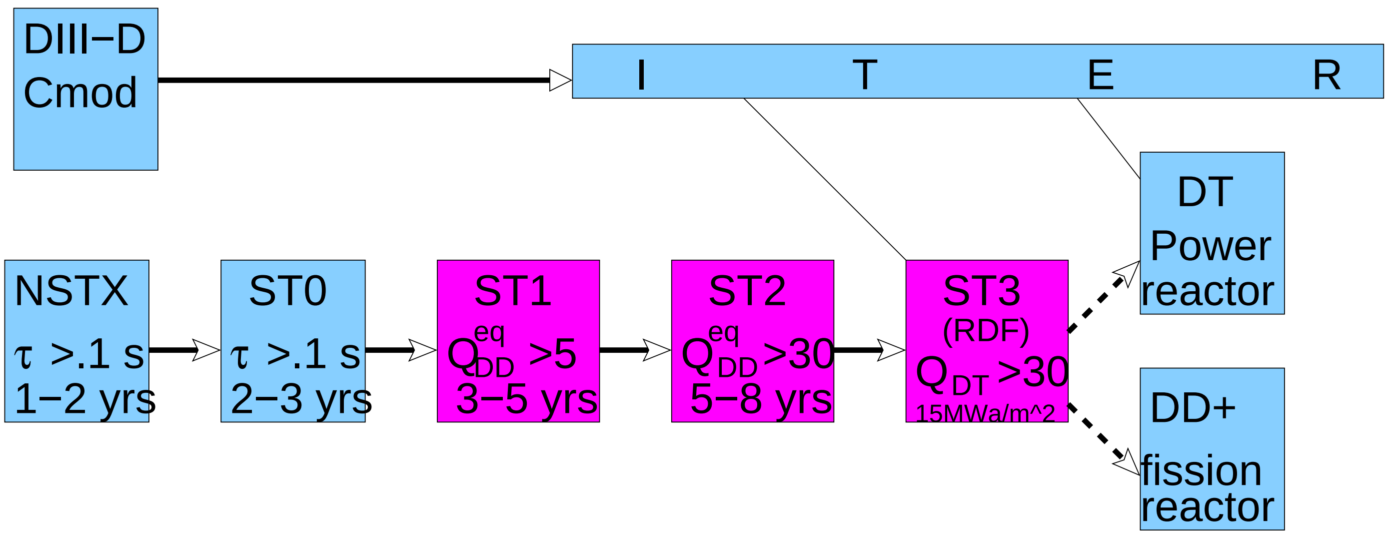
Installation of LLTP plate gives NSTX a chance to contribute to the Orbach/Bodman initiative for domestic fusion

NSTX, and then ST0, are well suited to motivate the 3 Step Program for a Reactor Development Facility, with a clear strategic role for STs.



The success of ST0 would be crucial for bootstrapping funding for domestic fusion and the ST program

The next ST1 machine ($B = 1.5$ T, $I_{pl} = 3 - 4$ MA, $R_{outer} = 1.65$ m can reach the ignition level of $nT\tau_E$