NSTX

Thermal Modeling of the Surface Temperatures on the Liquid Lithium Surface and ATJ Tiles in the NSTX Divertor

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NNSA National Nuclear Security Administration

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Objectives for Thermal Model

- **Predictive model: $T_{surface}$ vs heat load, time**
  (subsequent viewgraphs)

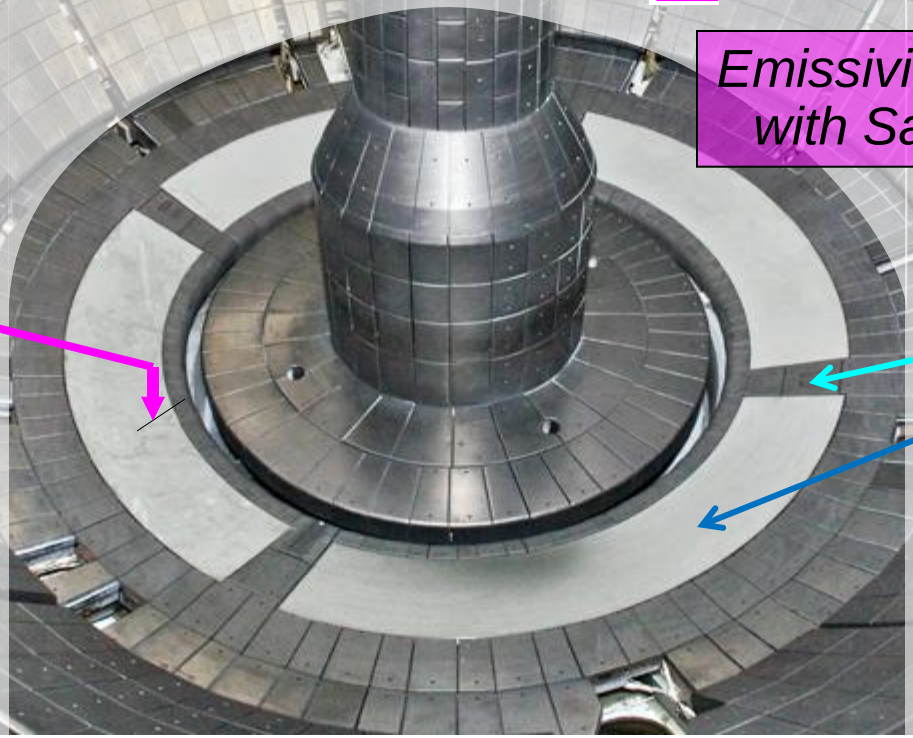
Relate modeling results to IR and TC data during operation

Thermal signatures
(relates to λ_q)
- LLD, heaters off
- ATJ tiles

- **Data on porous flame-sprayed Mo + Li**
  thermal conductance & emissivity ☒

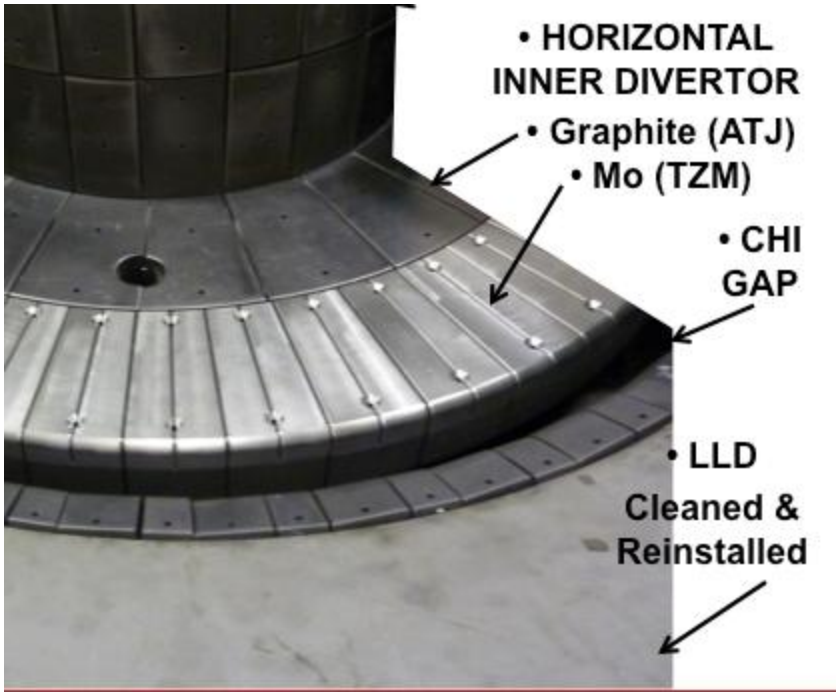
Emissivity test at Purdue with Sandia IR camera

LLD surface cross section: plasma sprayed porous Mo



ATJ tiles

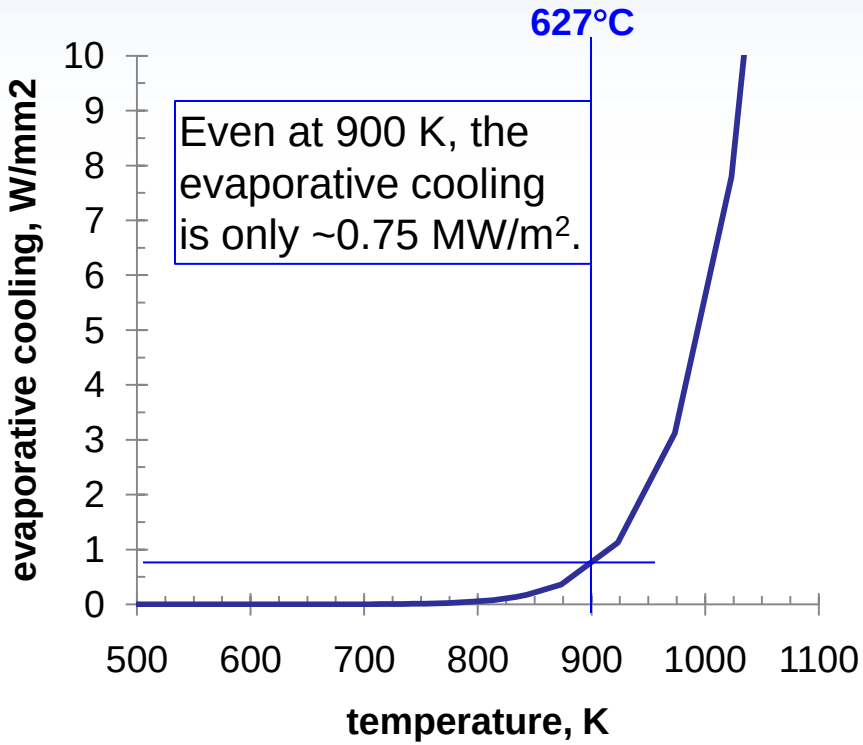
LLD plates (4) after installation


• HORIZONTAL
INNER DIVERTOR
• Graphite (ATJ)
• Mo (TZM)
• CHI
GAP
• LLD
Cleaned &
Reinstalled

Evaporative cooling in our model

Evap Cooling: We include this as a temperature-dependent loss channel. *[We could take into account other factors, e.g. sheath effects on Li^+ and large Larmor radius]*

Total Evap Li: We can estimate this separately (post-processing) based on the evolution of the temperature distribution across the face of the LLD.

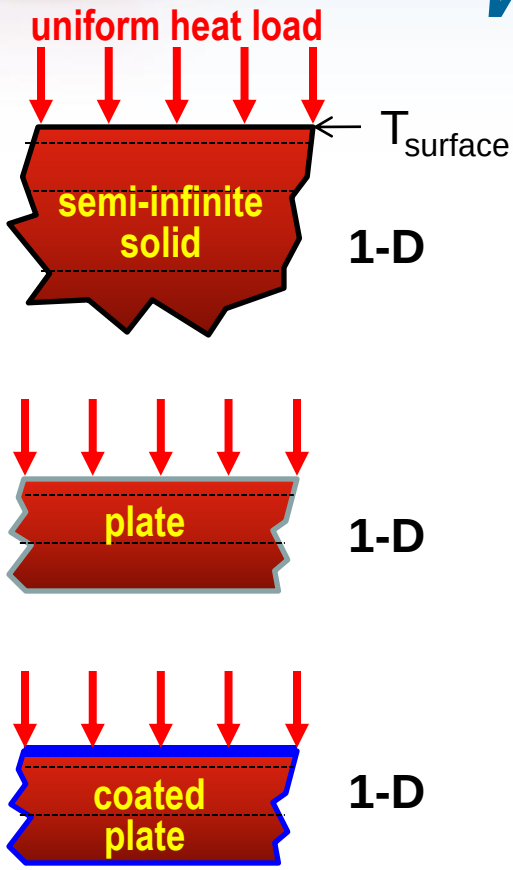


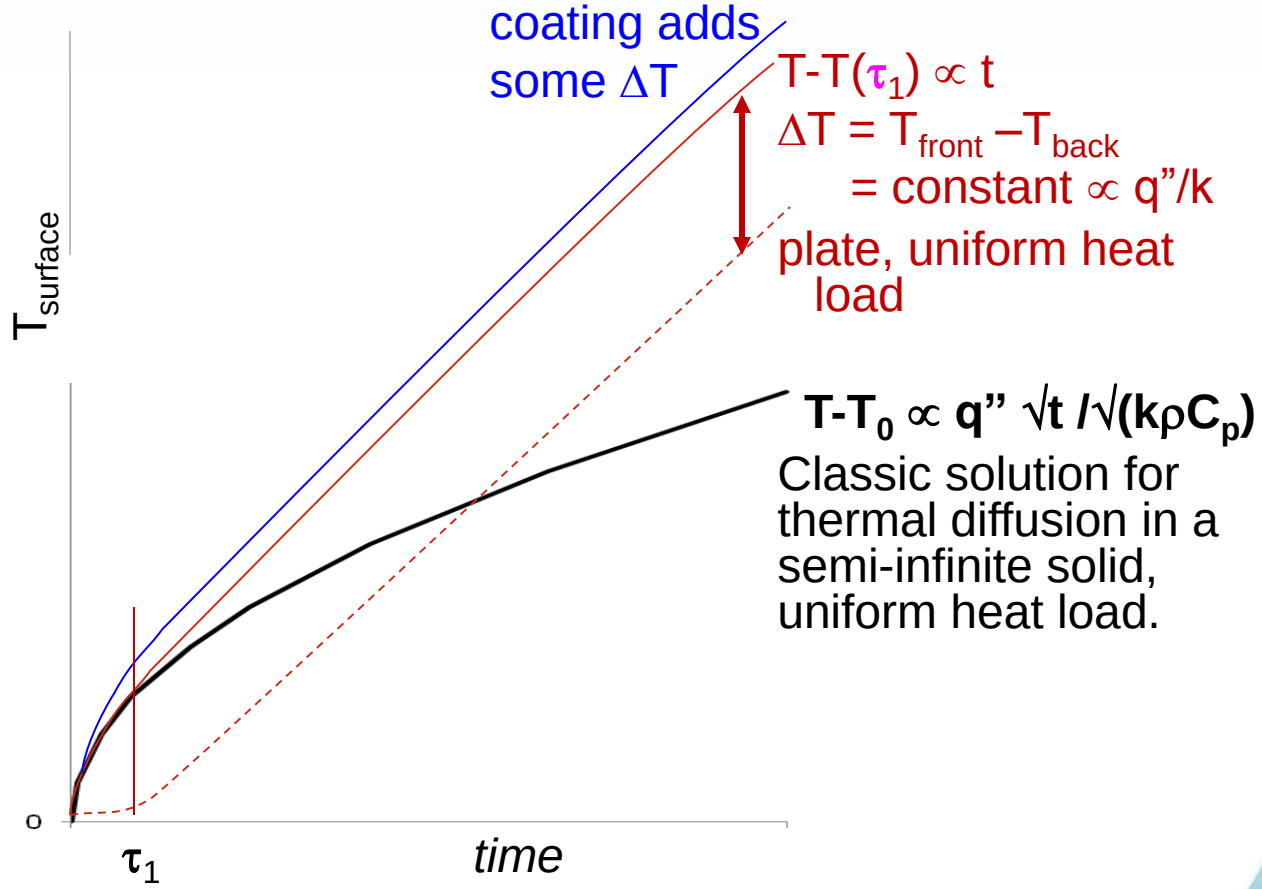
Cooling (W/mm^2) = 595.7 * [10^(8-8143/T] /SQRT(6.941*T)

Based on the expression for vapor pressure of 3.5E22 * [10^(8-8143/T] from Jensson et al. (old HEDL Report) and the equation below.

$$\text{Evaporation } \Gamma_{evap}\,(\text{atoms/cm}^2\text{-s}) = 3.5\text{x}10^{22}\,\frac{P(Torr)}{\sqrt{mass(a.u.)T}}$$

First - a thought experiment:
What might we expect?





Temperature of plate will rise faster than semi-infinite solid after characteristic time τ_1 when the temperature <u>gradients</u> equilibrate. For a thicker the plate, τ_1 is longer.

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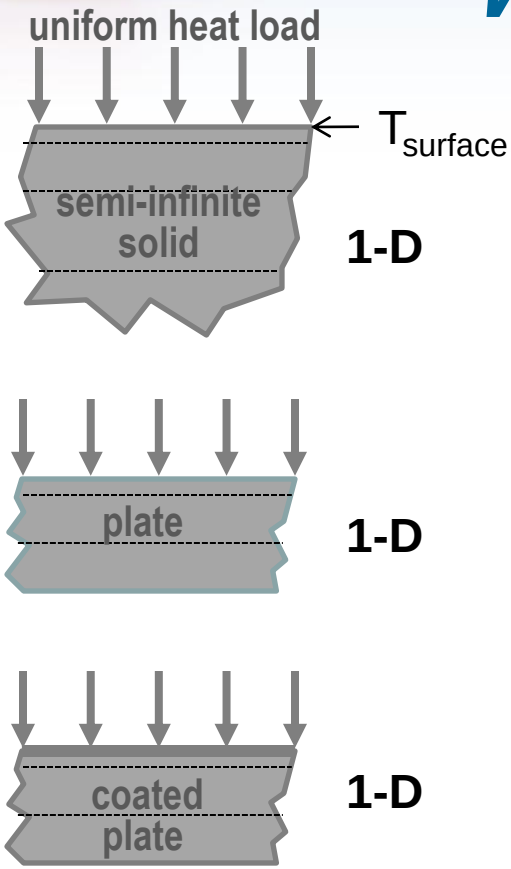
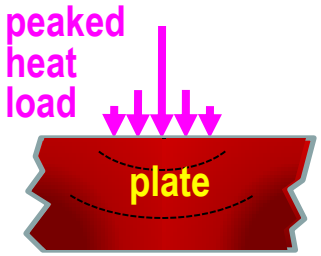
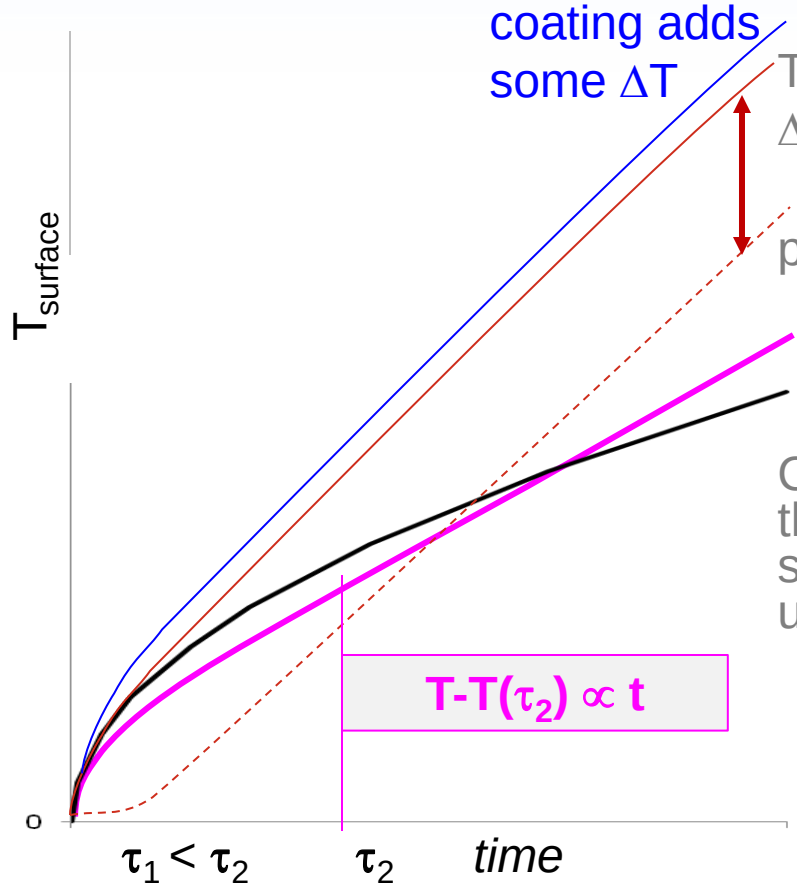
What might we expect?







$T-T(\tau_1) \propto t$

$\Delta T = T_{front} - T_{back}$

$= \text{constant} \propto q''/k$

plate, uniform heat load

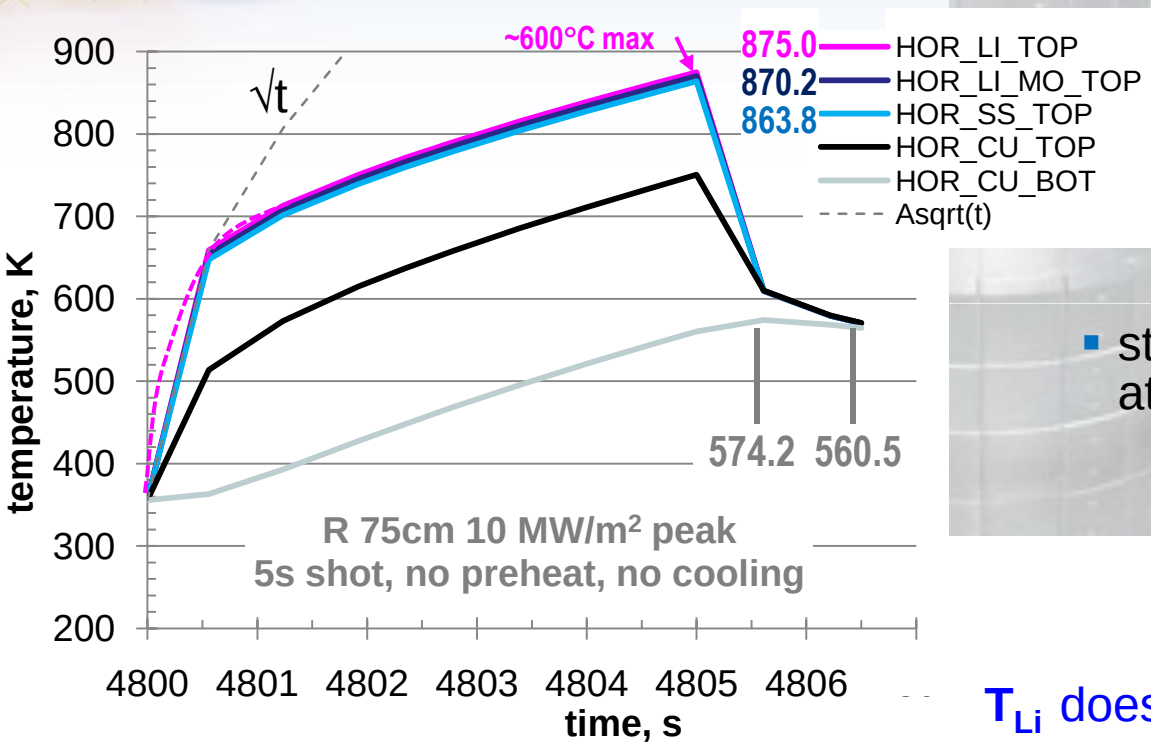
$T-T_0 \propto q'' \sqrt{t} / \sqrt{(k\rho C_p)}$

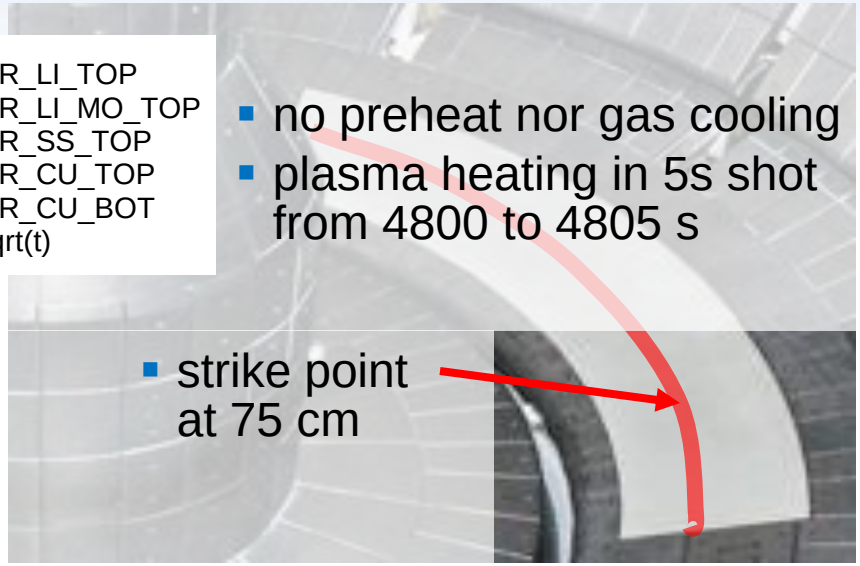
Classic solution for thermal diffusion in a semi-infinite solid, uniform heat load.

2D or 3D geometry-dependent solution in bounded plate; long lateral thermal gradients; $\tau_{1\text{-apparent}}$ and longer $\tau_{2\text{-system}}$.

We see this in our high heat flux tests in PMTF.

Sample of Results for R75cm 10MW/m^2





R630 1MW/m^2 Preheat

<u>4800.0s:</u> shot starts (heat on strike point)

<u>4800.5s</u>: heat penetrates to back of LLD; Li surface is ~140° higher than the underlying Cu (top surface).

<u>4805.0s</u>: Li goes from ~650 (0.5s) to 875K.

<u>4805s +</u>: As heating stops, temperatures near the surface drop; LLD goes toward its average temperature.

T_{Li} does not follow **√t** but rolls over.

- *What causes this "clamping"?*
- *Is evaporation important?*

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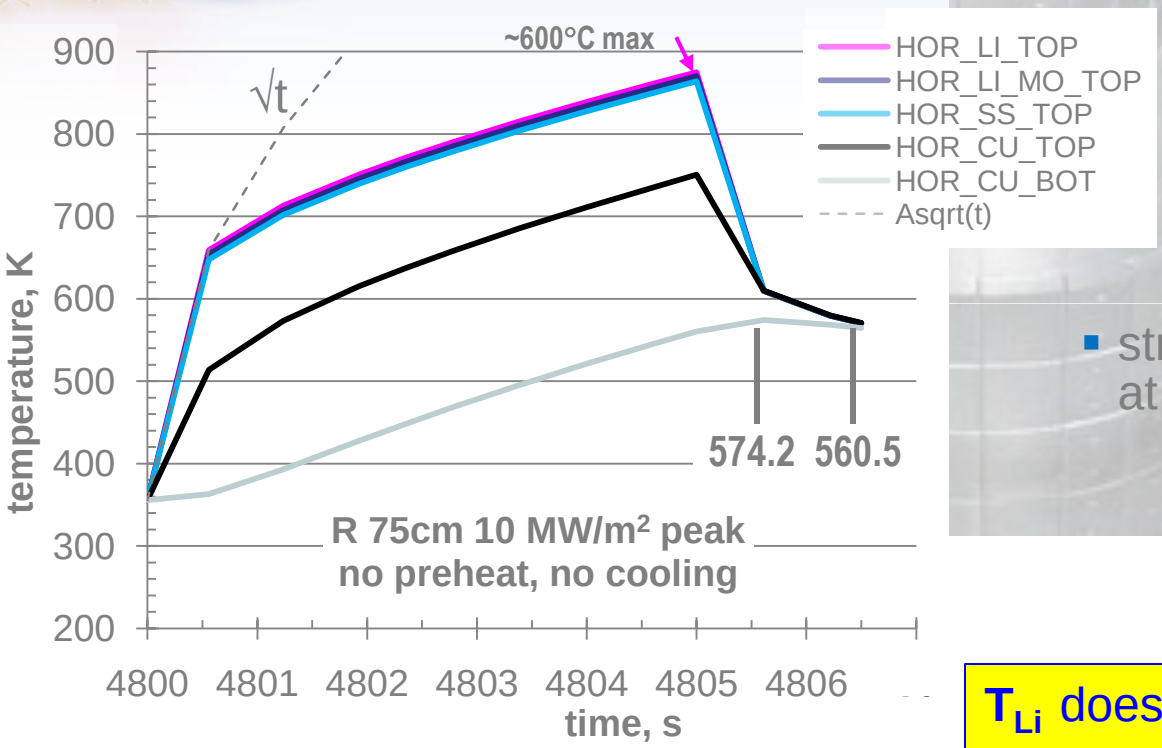

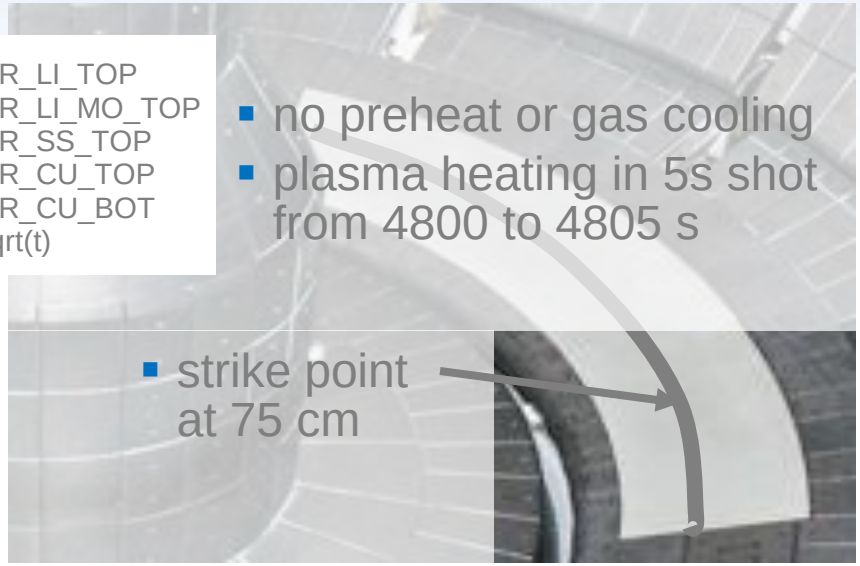

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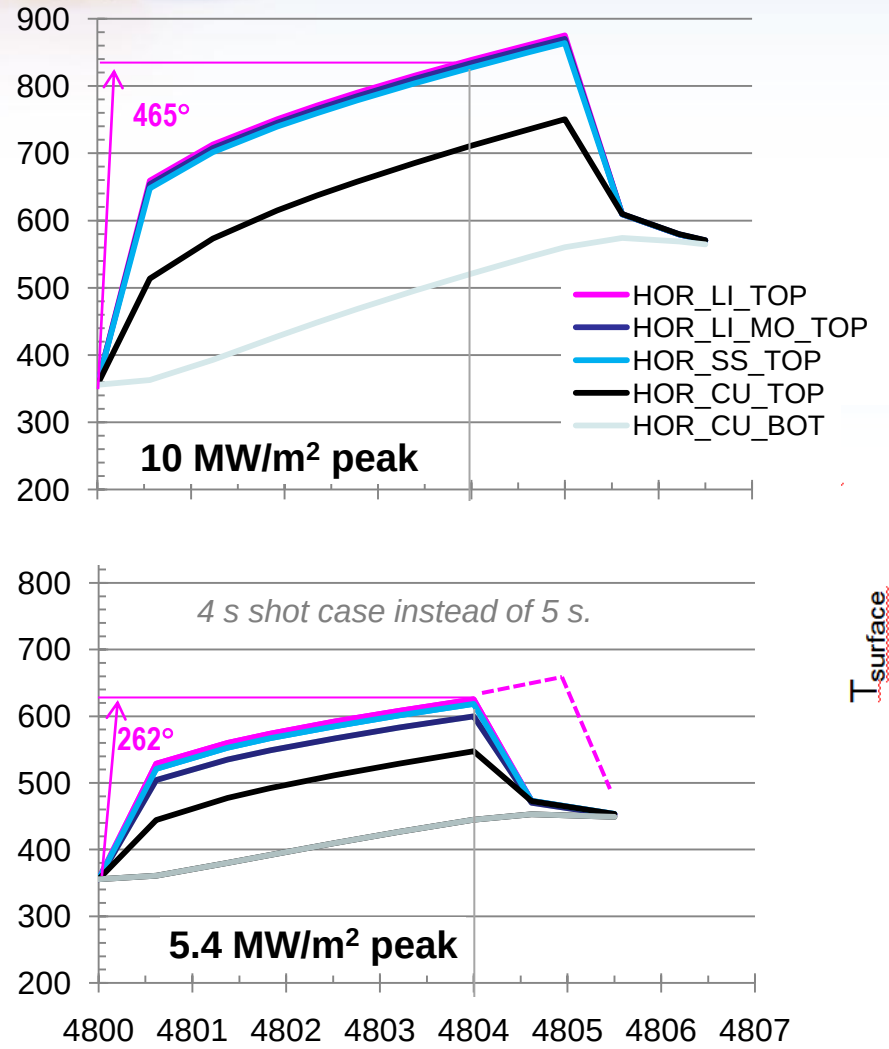
T_{Li} does not follow √t but rolls over.

The trend is similar to that for a plate with a uniform heat.

1. Initial temperature rise follows **√t**.
2. Temperature rise becomes linear with ΔT (T_{front} - T_{back}) constant.

Evaporation is likely very small.

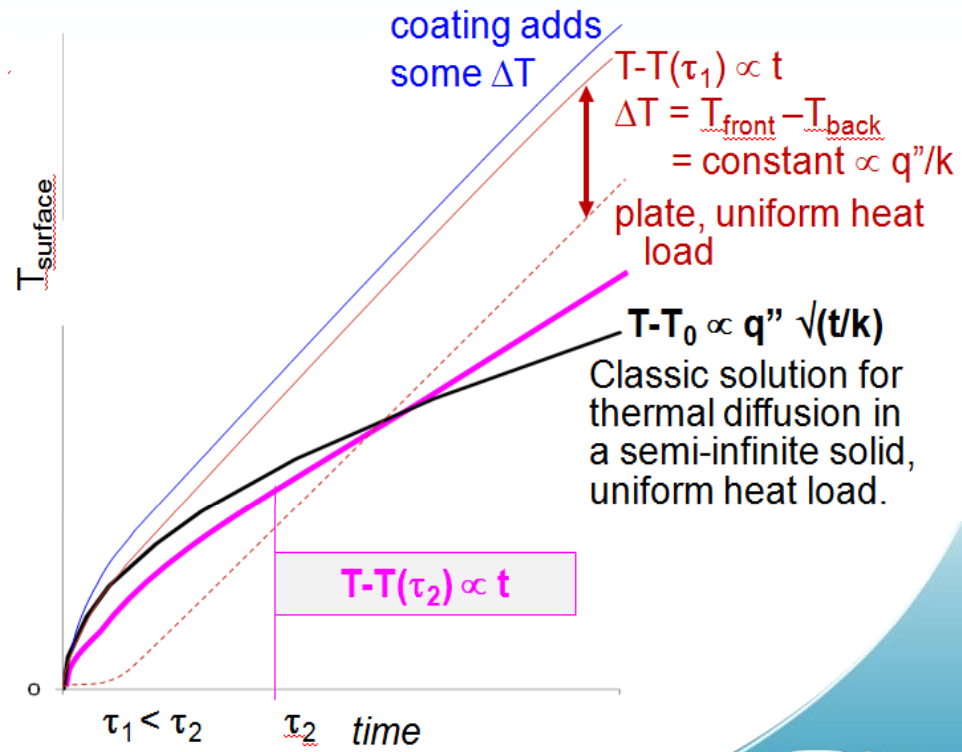
Results for R75cm at 5 & 10 MW/m²



Evaporation is not a big factor here.

$T_{Li\text{-}surface}$ rises in proportion to heat load.

- 4s, 10 MW/m²: the rise is 465°
- 4s, 5.4 MW/m²: the rise is 262°
- The rise in temperature divided by heat load is the same in each case, 46.6 deg per MW/m².



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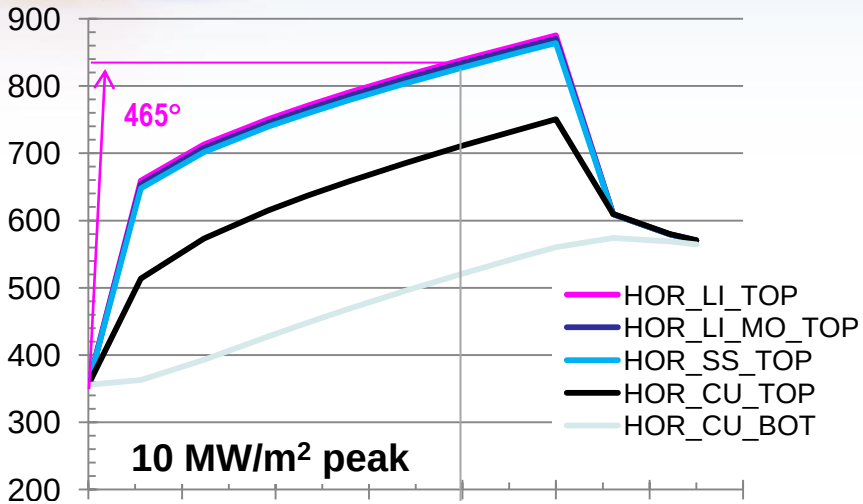

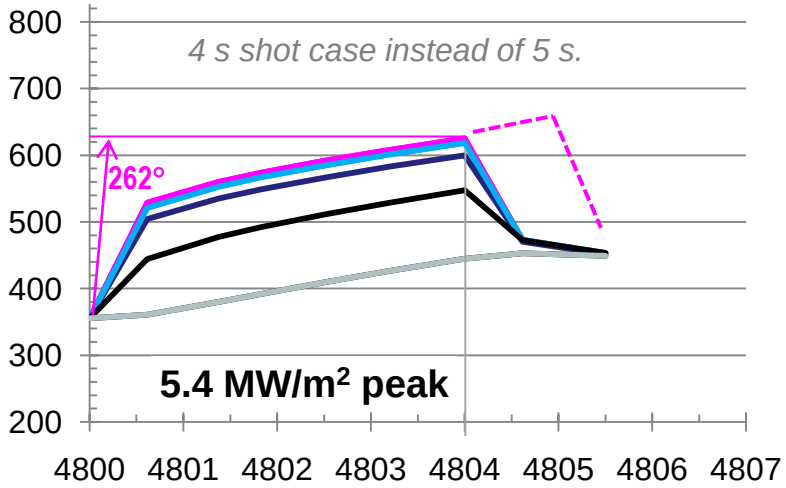

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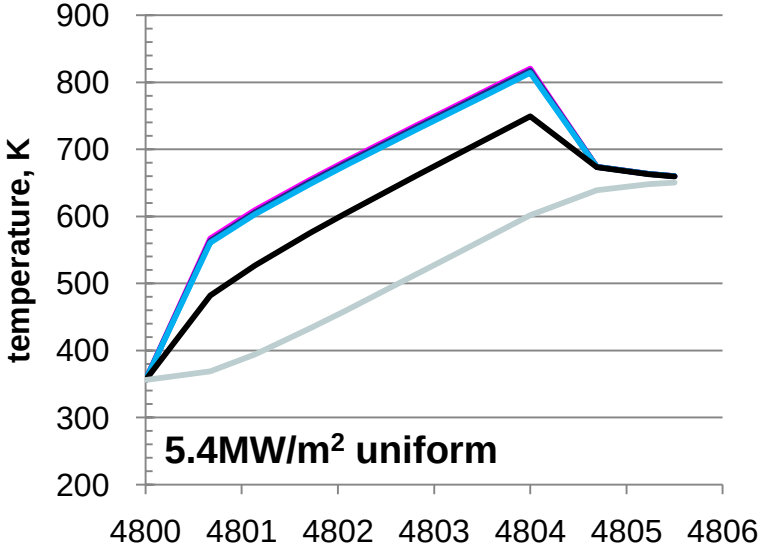
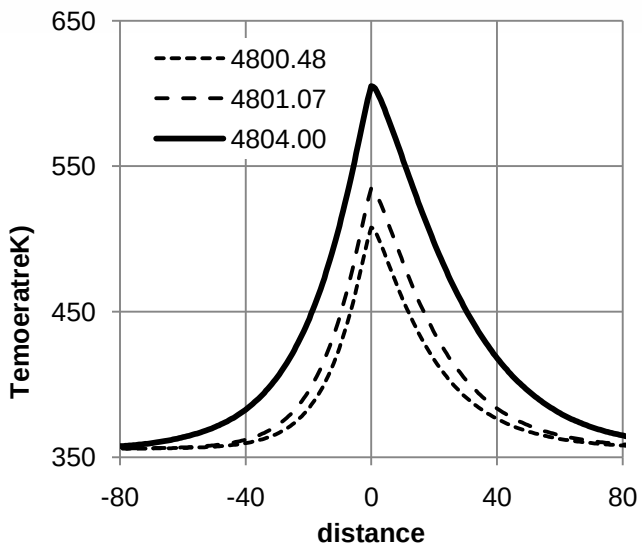
For uniform heating (below) at 5.4 MW/m^2, the rise in $T_{Li\text{-}surface}$ is much greater.

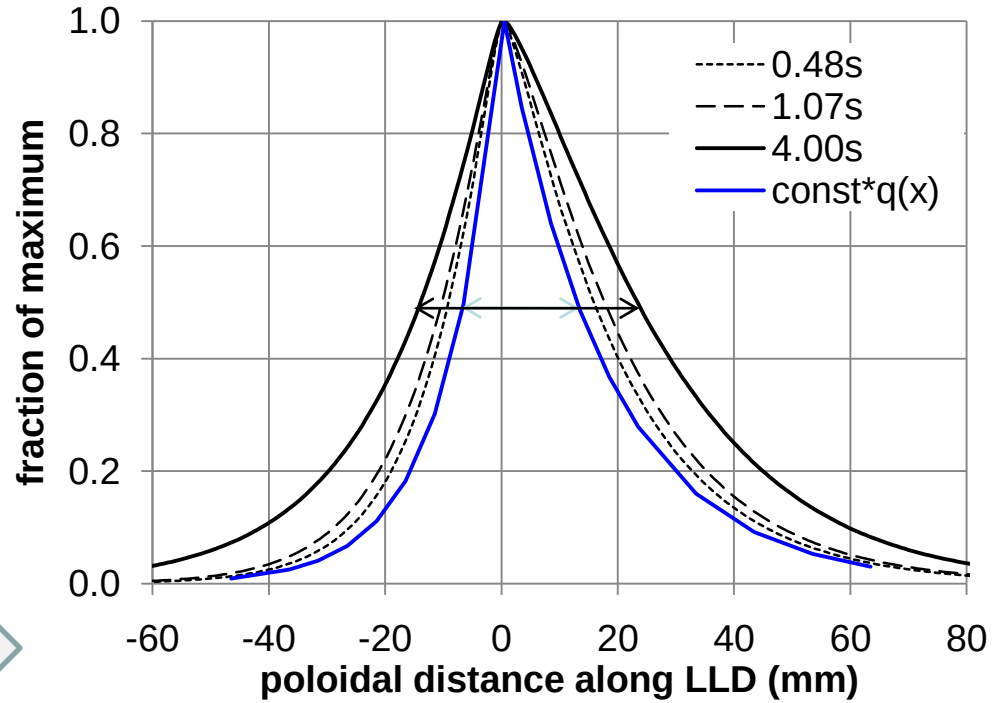
Evaporation of Li is not "clamping" the temperature.



Conclusion

Lateral heat conduction dominates "broadening" of the thermal footprint near the end-of-shot in these cases.





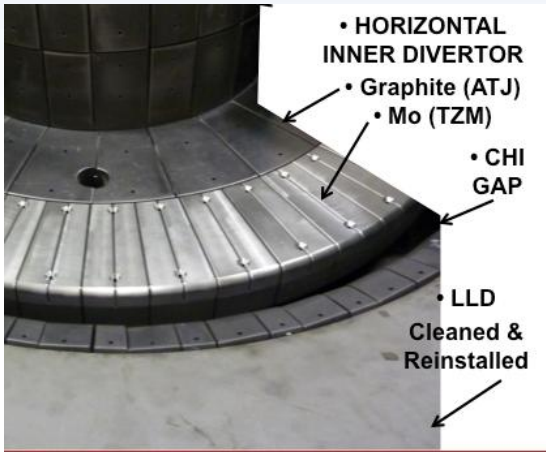
Normalize temperature profiles and compare to heat flux profile.

curve	*0.48s*	*1.07s*	***4.00s***	*const*q(x)*
FWHM	25.0	28.0	**37.3**	19.6
FWHM:19.6	x1.28	x1.43	x**1.90**	1.00

Broadening is almost X2 when one would measure near the end of the shot.

Final Comments – Future Work

- *Modeling of "cold start" (no preheat of LLD), effects of melting and evaporation of Li on temperature*
- *Thermal broadening for ATJ and Moly tiles*
- *Considerations for upgraded LLD*
- *LIMITS lithium loop at PMTF available (restarted, paper in Li Workshop)*
- *Experiments on the emissivity of lithiated surfaces*



Emissivity from which lithiated surface?

Evaporation of Li (lithium-bearing surfaces) is of interest.

The work function depends on surface chemistry and impurities.

We need to know emissivity to get temperature from IR data.

Sandia will collaborate with Purdue University and add an IR camera and software to PRIHSM.

With a heated Li target in PRIHSM, Sandia collaborators will monitor temperature with an IR camera while JP Allain and co-workers modify and monitor surface chemistry.

E N D

T H A N K Y O U