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NSTX

Effect of Evaporated Lithium PFC Coatings in NSTX

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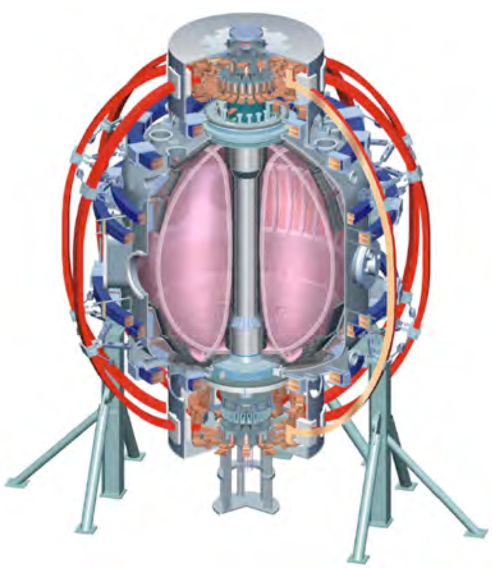

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Abstract

Two versions of a lithium evaporator (LITER-1) were installed in succession on an upper port aimed toward the graphite tiles of the lower center stack and divertor. Lithium temperatures in the range 450 – 680°C produced evaporation rates of 0.08 to 35 mg/min with a gaussian-like angular distribution with a 1/e full width of about 22°. A quartz crystal micro-balance in the gap between two tiles on the lower divertor was used to measure the lithium deposited. Twelve separate depositions, ranging from about 10 mg to 5 g of lithium were performed. Lower single-null L-mode and H-mode, and double-null reversed-shear plasmas were studied. After lithium coating, the reference ratio of oxygen to carbon emission was lower than achieved with boronization. Other effects of lithium coating were variable, but under some conditions, there were decreases in the density and increases in electron and ion temperature, and neutron rate, and reductions in H-mode ELM frequency. These results and future plans will be discussed.

*US DOE Contract DE-AC02-76CH03073.

In 2005 NSTX Lithium Pellet Experiments Were Guided by the TFTR Experience

- ***TFTR demonstrated benefit of partial Li coating on <u>conditioned</u> graphite PFCs***
  - *Strong edge pumping (reduction of recycling)*
  - *Improvement in energy confinement (x2)*
- NSTX used Lithium Pellet Injection (LPI) to create coatings that significantly pumped neutral-beam-heated plasmas

• Both Center Stack Limited (CSL) and Lower Single Null (LSN) discharges were studied

• Ohmic Helium discharges were used to *<u>degas</u>* the Center Stack and the Lower Divertor

1) Lithium pellets were injected into repeated CSL and LSN Ohmic Helium discharges to coat the plasma wetted surfaces and *<u>prevent lithium saturation by the fuel gas</u>*

2) CSL and LSN deuterium NBI reference plasmas were run to measure changes due to lithium pumping of the edge plasma

– Deuterium puffing was limited in reference plasmas to avoid saturating the available lithium pumping capacity

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In 2005 Lithium Pellet Injector Used to Reduce NSTX Recycling

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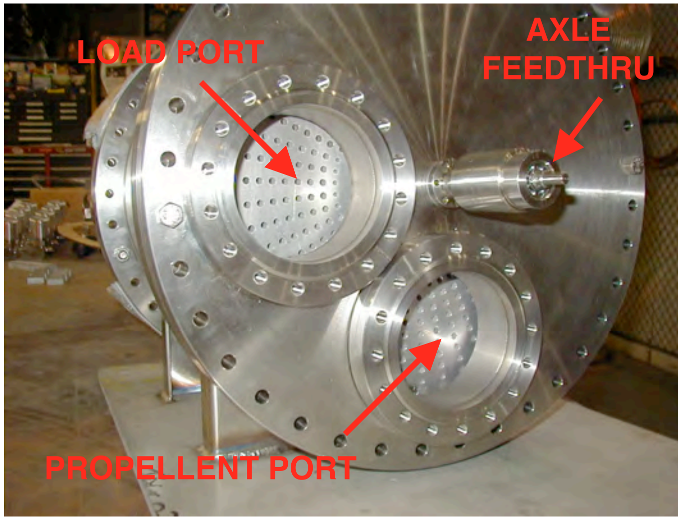
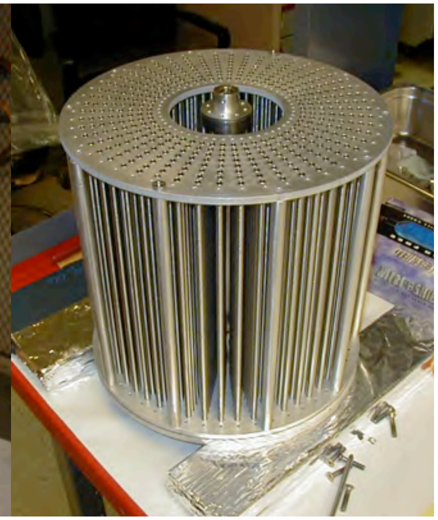
- **111 mg injected, using 1.7 to 5mg pellets, 100-150 m/s, 1-2 pellets/shot**



OUTBOARD VIEW



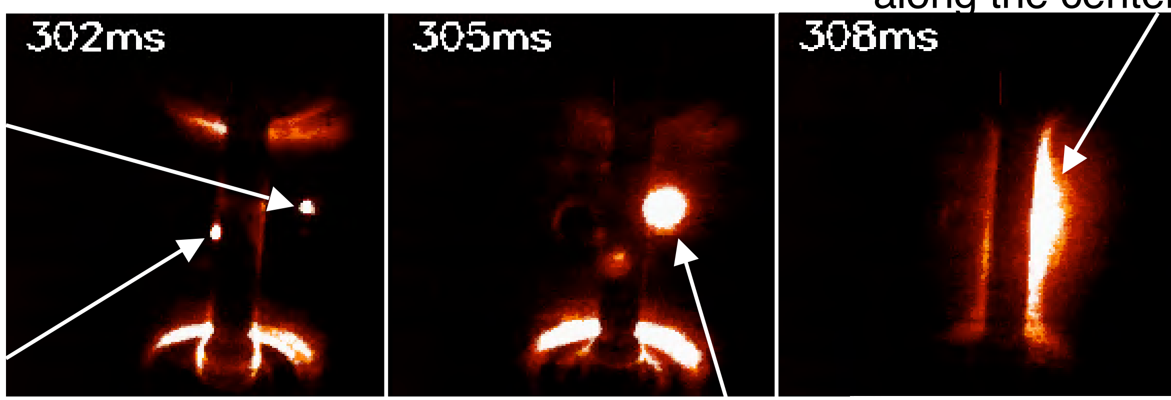
400 BARREL TURRET

- **Sabot (cartridge) style injector for injecting solid pellets ($\leq$ 5 mg) & powder (micro-pellets)**
- **50 – 200 m/s radial injection**
- **1 – 8 pellets per shot capacity**
- **400 pellet capacity**

Lithium vapor spreading along the center-stack

Lithium pellet moving through ohmic plasma after entering boundary

In-board gas injector



Li I Plasma-TV

Pellet plasmoid approaches center-stack

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In 2005 First LSN NBI D Shot After 25 mg of Li Pellet Injection Exhibited Factor ~2 Decrease in Density

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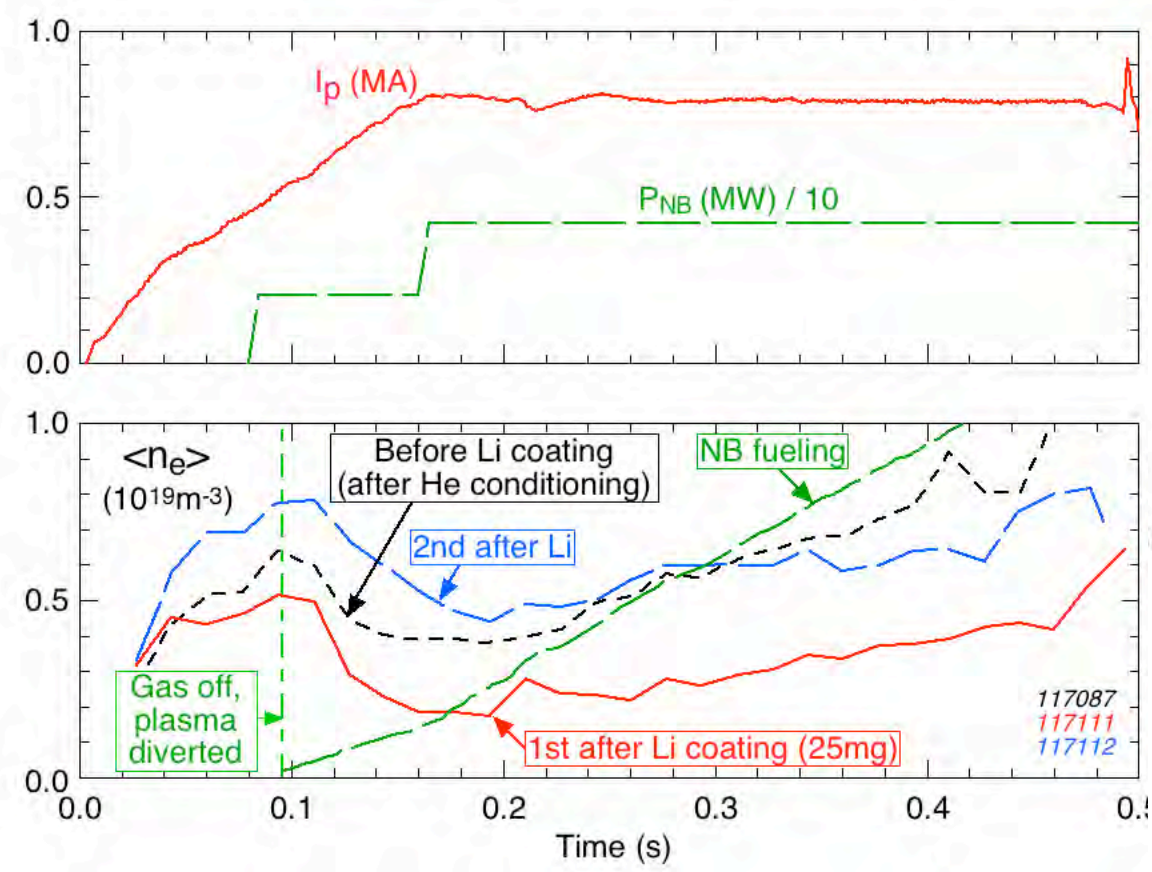
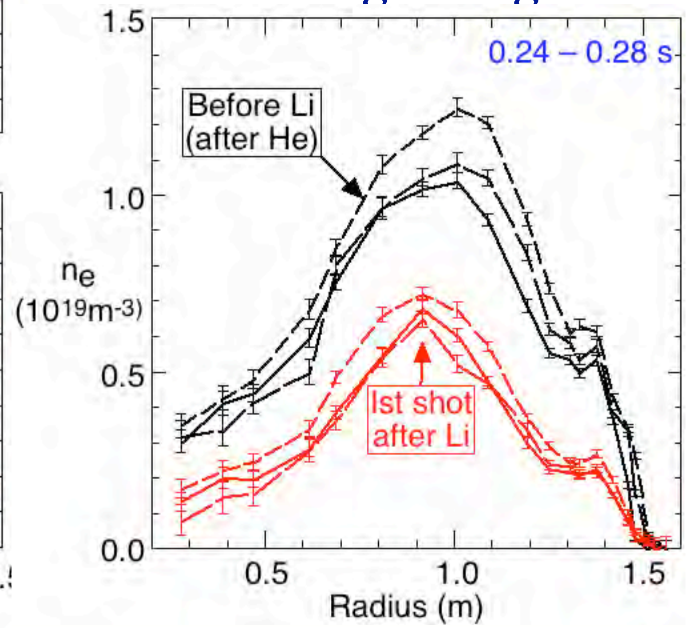


Lower single-null divertor discharges, 0.45T, D_2 gas fueling 3.5mg



- **25 mg of Li pumping of edge density saturated after the 3 similar D discharges and returned to pre-Li wall conditions, as expected if most injected gas reacts with the deposited Li.**
- ***Rate of density rise is below NBI fueling rate.***

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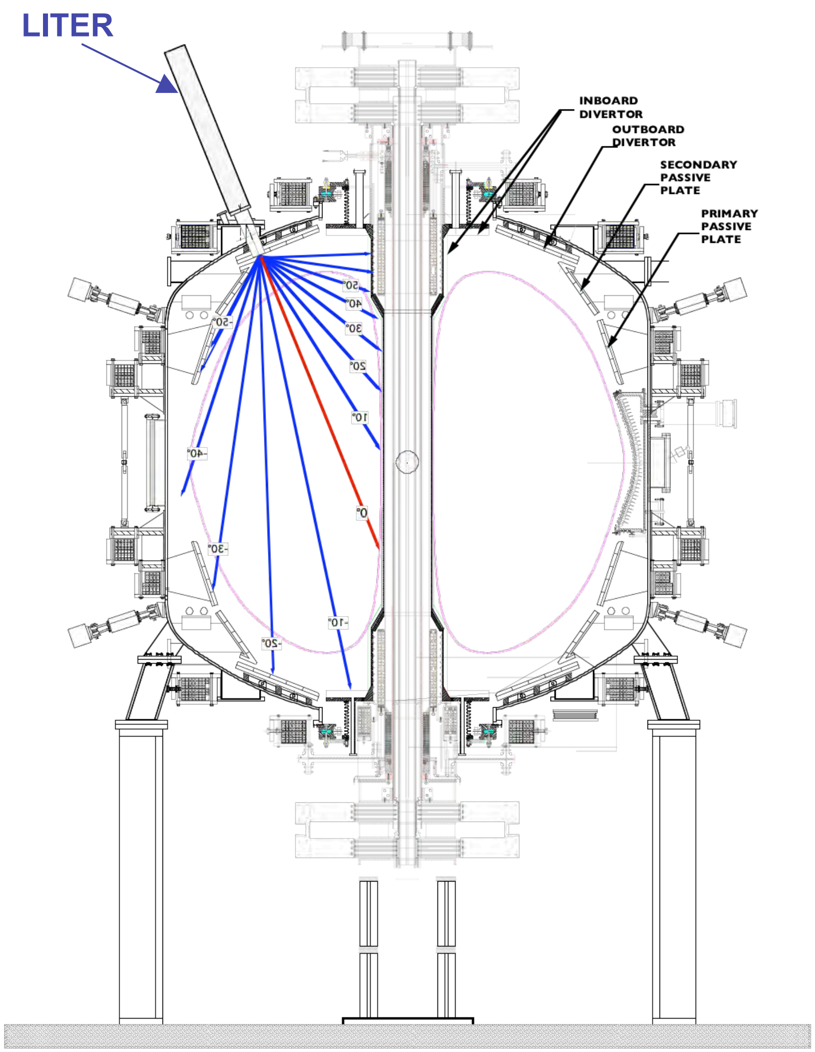
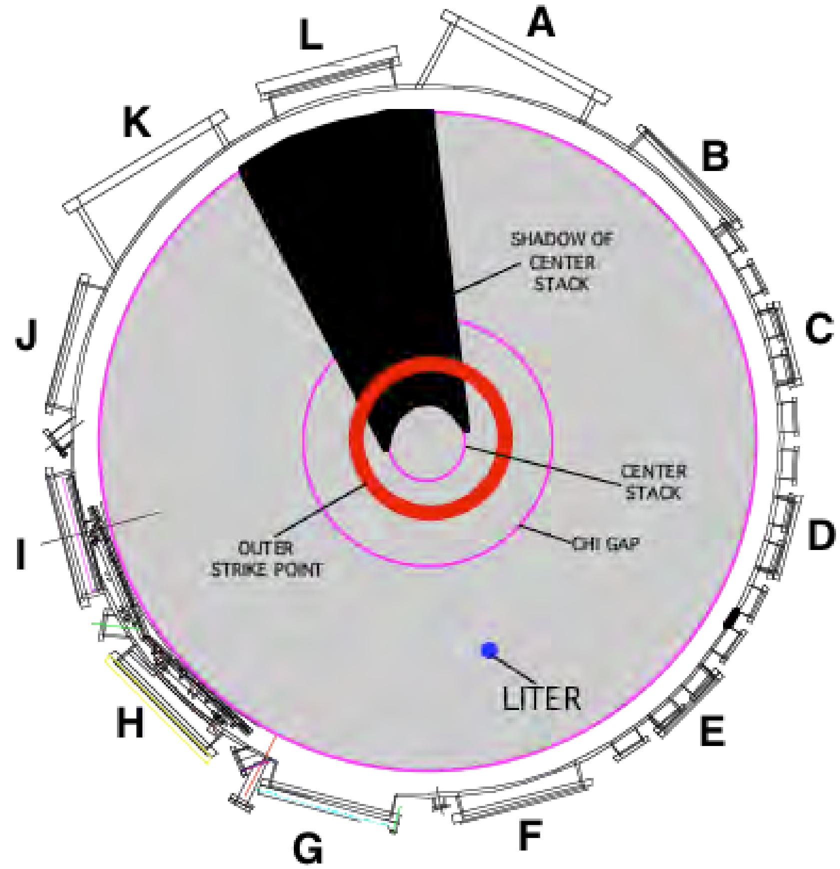
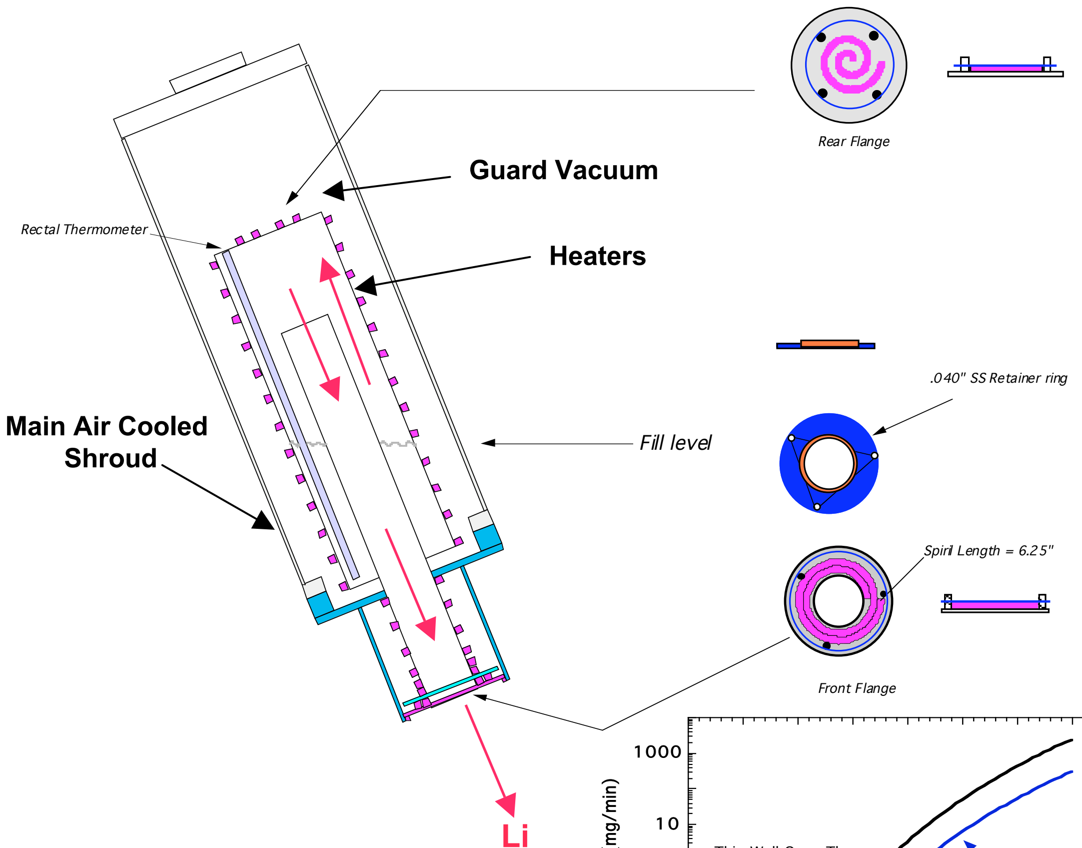
2005 Lithium Pellet Injection Results Motivated 2006 Development of Lithium Evaporator (LITER-1)

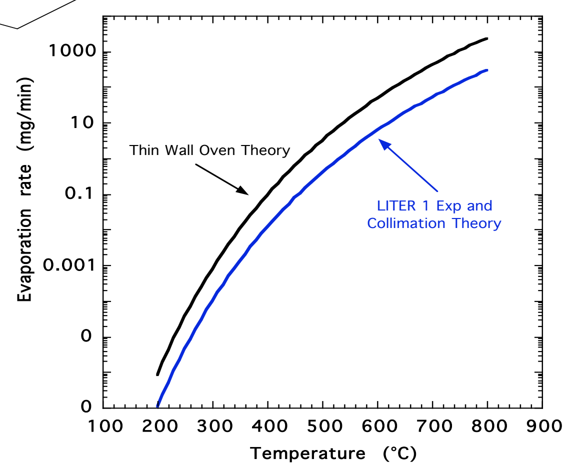




- Wide coverage over CS and Inner divertors for high performance DND plasmas
- Thick deposition on Lower Divertor for LSN plasmas

LITER-1 Designed for Fast Evaporations and to Control Liquid Lithium Surface Flows





LITER without air- cooled shroud

LITER with air- cooled shroud

FY06 Lithium Evaporator (LITER-1) Capabilities

- Lithium evaporator (LITER-1) installed on upper port aimed 22° downward toward of lower CS and divertor graphite tiles.

- LITER-1 temperatures (450–680°C) produced evaporation rates of 0.08 to 35 mg/min with a Gaussian-like angular distribution with a 1/e full width of about 22°.

- 12 separate depositions (1.6 mg to 4.8 g) of lithium were performed (9 g total, average thickness 420 nm).

- Lower Single-Null L-mode and H-mode, and Double-Null Reversed-Shear plasmas were studied.

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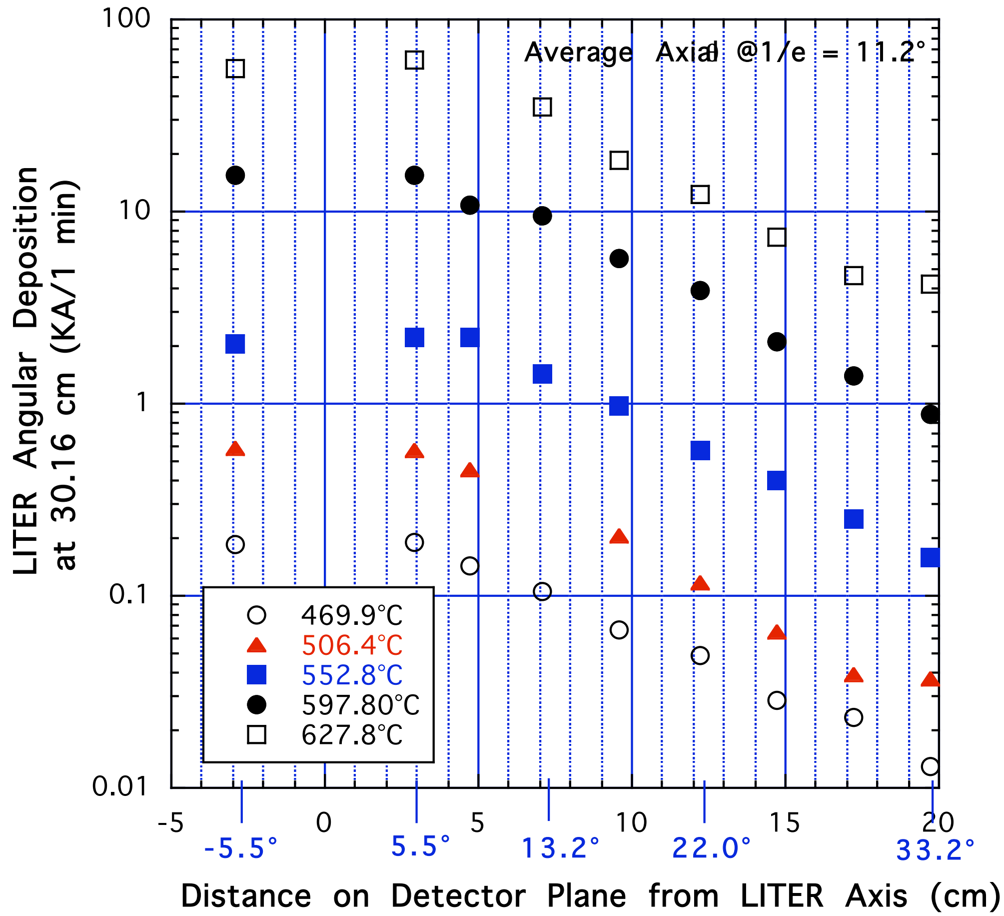
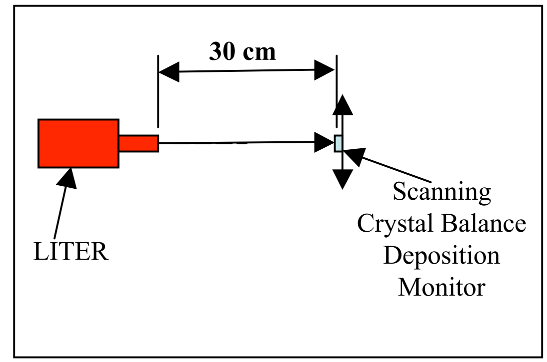
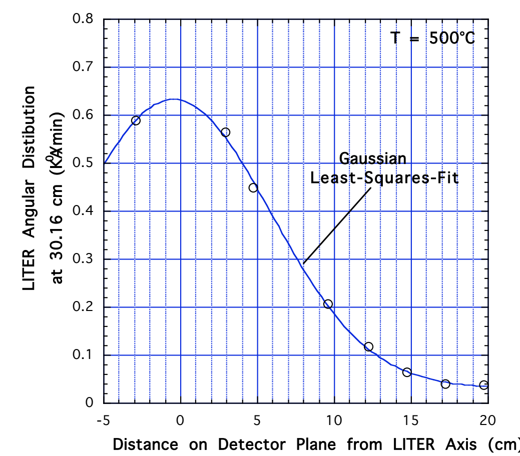
LITER-1 Angular Distribution Measurements







- Average Gaussian Half Width ~ 11.2° over temperature operating range

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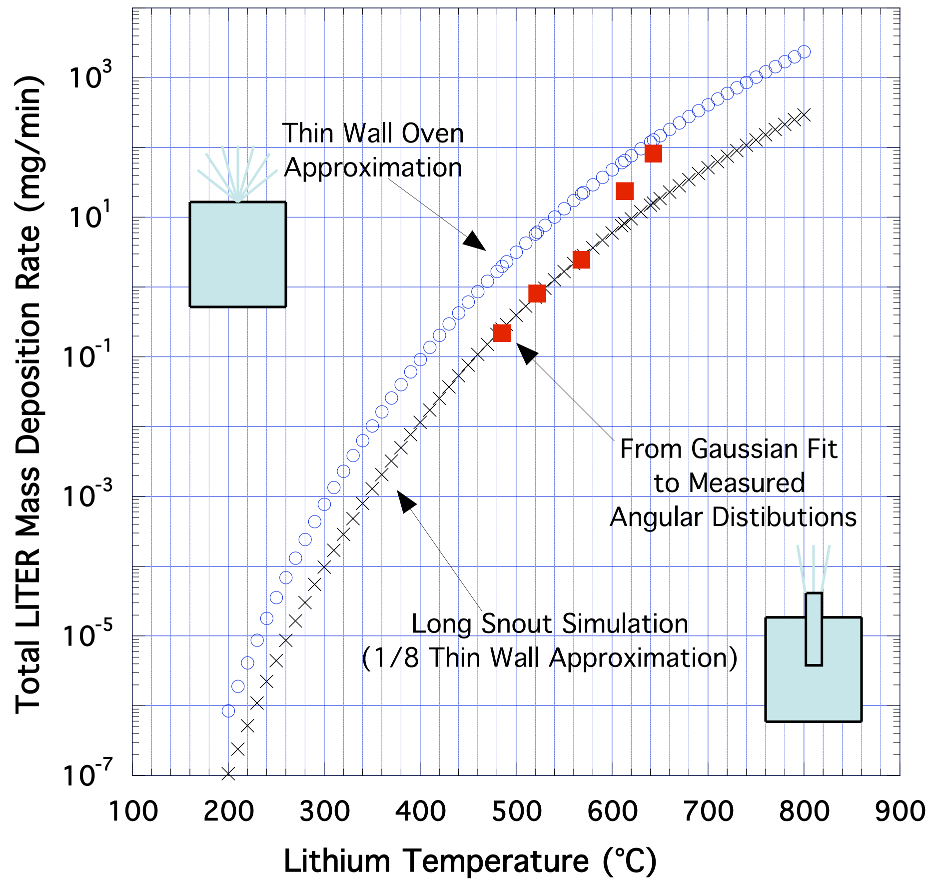
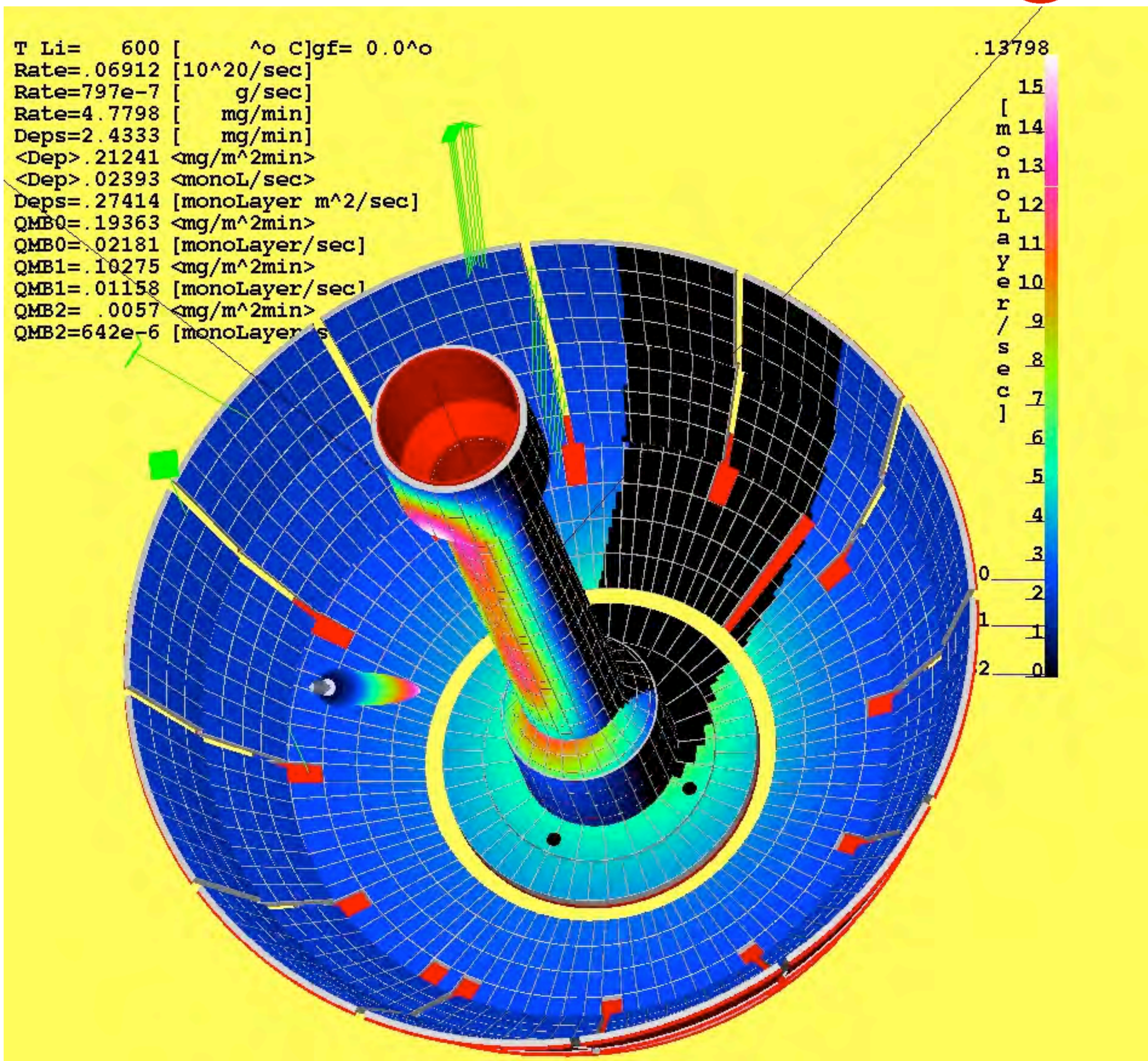
LITER-1 Total Evaporation Rate



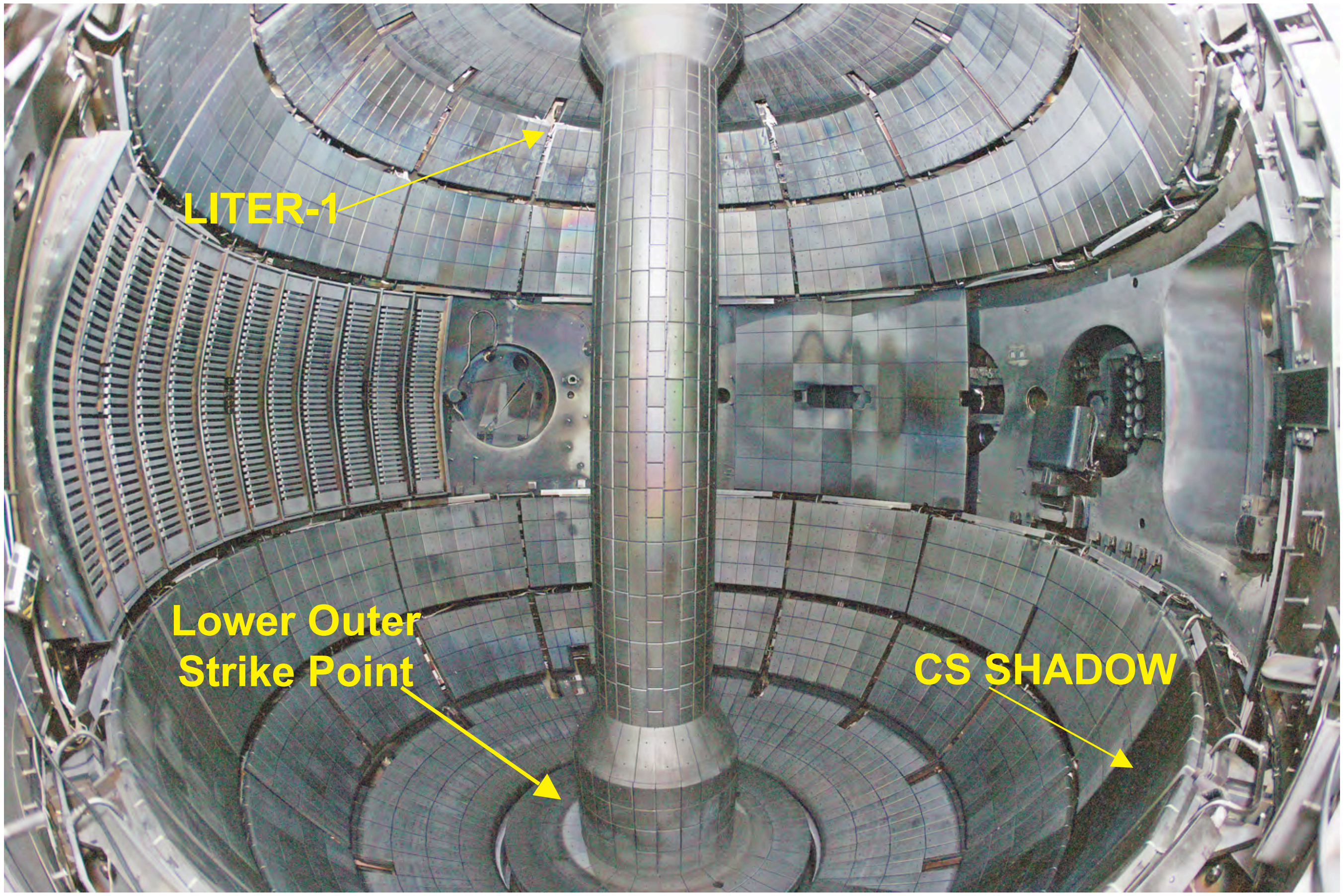
- Below 600°C, LITER evaporation rate is in collisionless regime
- Above 600°C, LITER evaporation rate may be entering viscous flow regime

Model of LITER-1 Lower Divertor Angular Distribution



L. Zakharov

Wide Angle View of Interior of NSTX After FY06 Experimental Campaign



Visible Lithium Coating on Components in the Line-of-sight of LITER Was Evident

Lithium Coating on Visible Lower Divertor after FY06 Experimental Campaign

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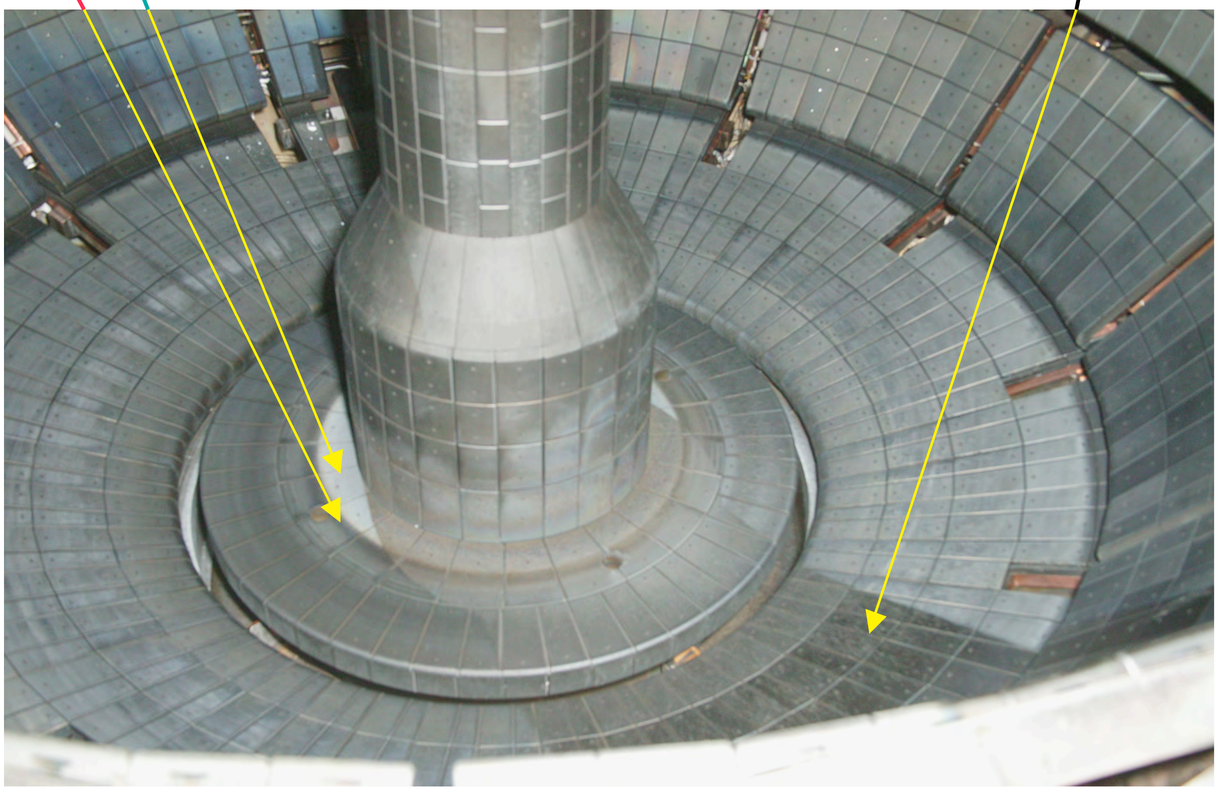
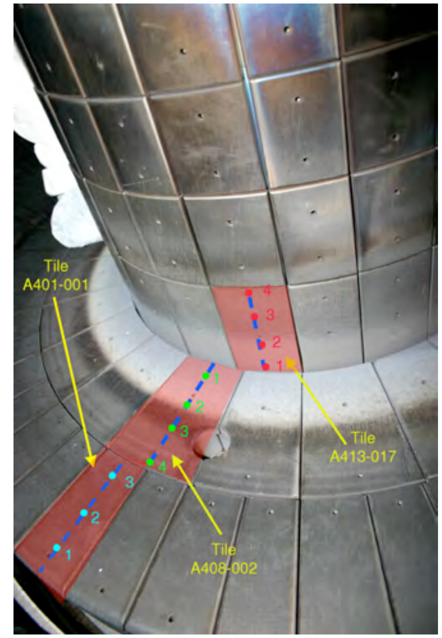
- Erosion on Lower Strike Point
- Private Flux region Thickly Coated
- Shadow of Center Stack





NSTX Tile Analysis of Lithium Evaporations in Progress at ANL and SNL

- **A clear indication of Li is being measured at various radial locations**

-J.P. Allain, M. Nieto (ANL)
- W.R. Wampler (SNL)

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Wall coatings from Lithium Evaporator Improved 2006 NSTX H-mode Discharges

- ***Short term changes in discharge following evaporation:***
  - Line-average n_e decreased by 15%
  - Z_{eff} (r = 0) decreased by 30%
  - T_e (r = 0) increased by 15%
  - T_i (r = 0) increased by 40%
  - v_{tor} (r = 0) increased by 50%
  - t_E relative to H98y2 scaling increased by 15%

- ***Longer term changes:***
  - Li-I recycling light returned with a 5 discharge e-folding
  - Core oxygen light decreased to below levels directly following boronization

- ***Threshold effect:*** **minimum deposition ~ 0.4-0.5g for density reduction without preceding He conditioning discharges**
  - More Lithium does not improve density control

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Lithium Evaporator Experimental Sequence

• *Conditioning Required to See L-Mode Effects; No Conditioning Required to See H-Mode Effects*

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Evaporation Number	mg	Evaporation Duration	Time to 1st Shot	He Discharge Conditioning	Type	Ref Shot	Compare Shot	Comments
E-1, 4/07/06	1.6	11 min		none	L	none		no change
E-2, 4/11/06	14.3	78 min	151 min	7 He, 4/10/0	L	119872	119854	no change
E-3, 4/11/06	77.0	128 min	11 min	none	L	119875	119854	no change
E-4, 4/12/06	215	128 min	167 min	none	L	119879	117087	no change
E-5, 4/12/06	0					none		
E-6, 4/13/06	643	369 min	85 min	none	L	119894	119887	no change
E-7, 5/04/06	**378**	**63 min**	**23 min**	**6 He, 5/04/06**	**L**	120474	120464	**1st noteworthy changes**
E-8, 5/05/06	0					none		
E-9, 6/09/06	**440 c)**	**76 min**	**75 min**	**none**	**H**	121323	121270	**similar changes**
E-10, 6/09/06	**203 a)**	**50 min**	**17 min**	**none**	**H**	121334	121270	**no change**
E-11, 6/09/06	**295 b)**	**36 min**	**25 min**	**none**	**H**	121336	121270	**marginal increase**
E-12, 6/22/06	**4780**	**12.3 hrs**	**160 min**	**none**	**H**	121507	121504	**similar changes**
E-13, 6/22/06	**1046**	**66 min**	**24 min**	**none**	**H**	121512	121504	**similar changes**
E-14, 6/22/06	**1008**	**28 min**	**8 min**	**none**	**H**	121521	121504	**similar changes**

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Lithium PFCs Reduced Edge Dα Luminosity

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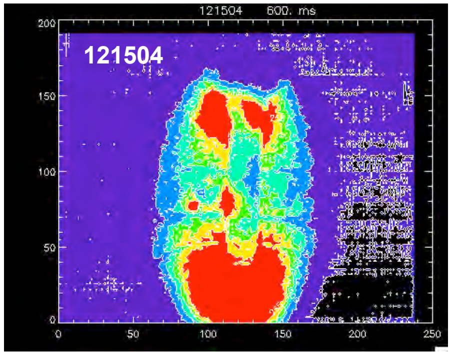
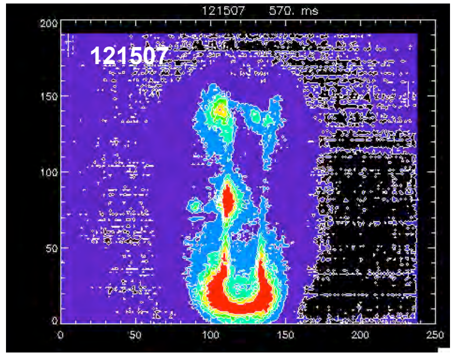
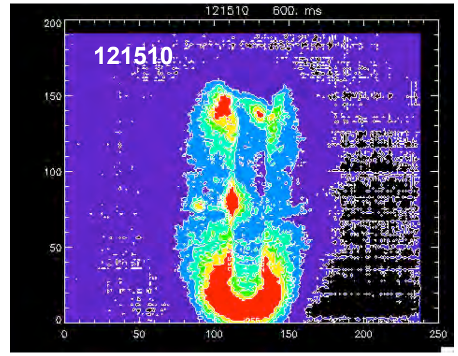
Plasma TV Dα Intensity Contours (same scale at 0.6s)



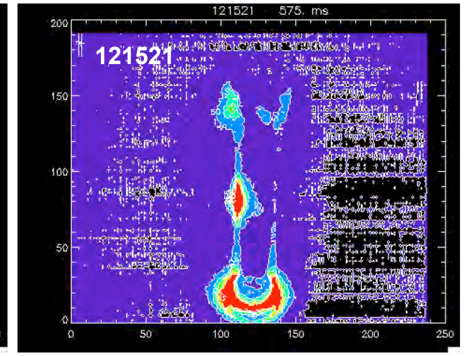
H-mode Before Li



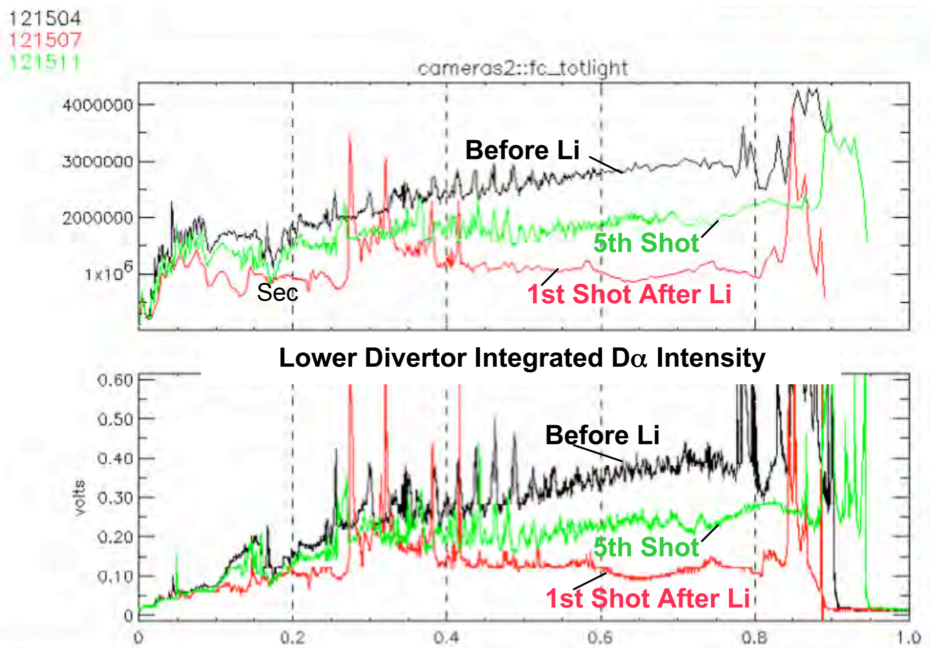
H-mode 1st Shot After 4.8g Li



H-mode 4 Shots Later Dα Increasing



H-mode After fast Deposition of 1 g Li Between Shots



sity

- Dα luminosity reduced x3 during 1st Shot following Li, and remained lower in following Shots

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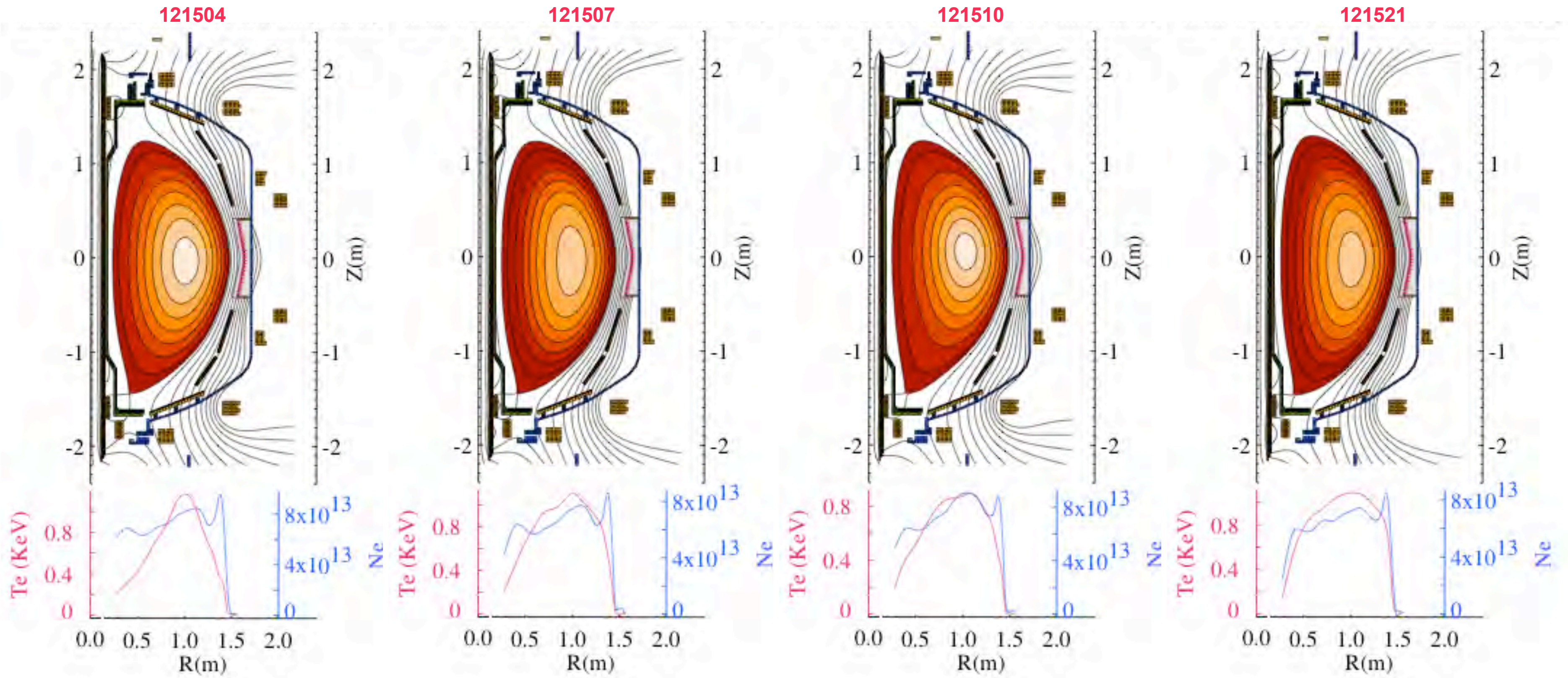
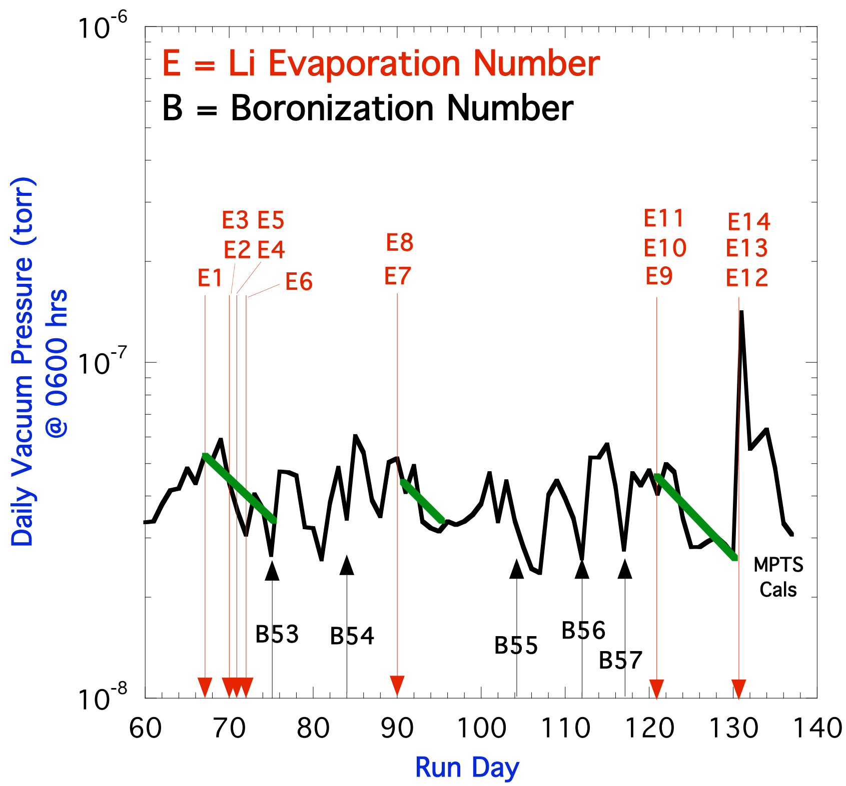
C.Bush, ORNL

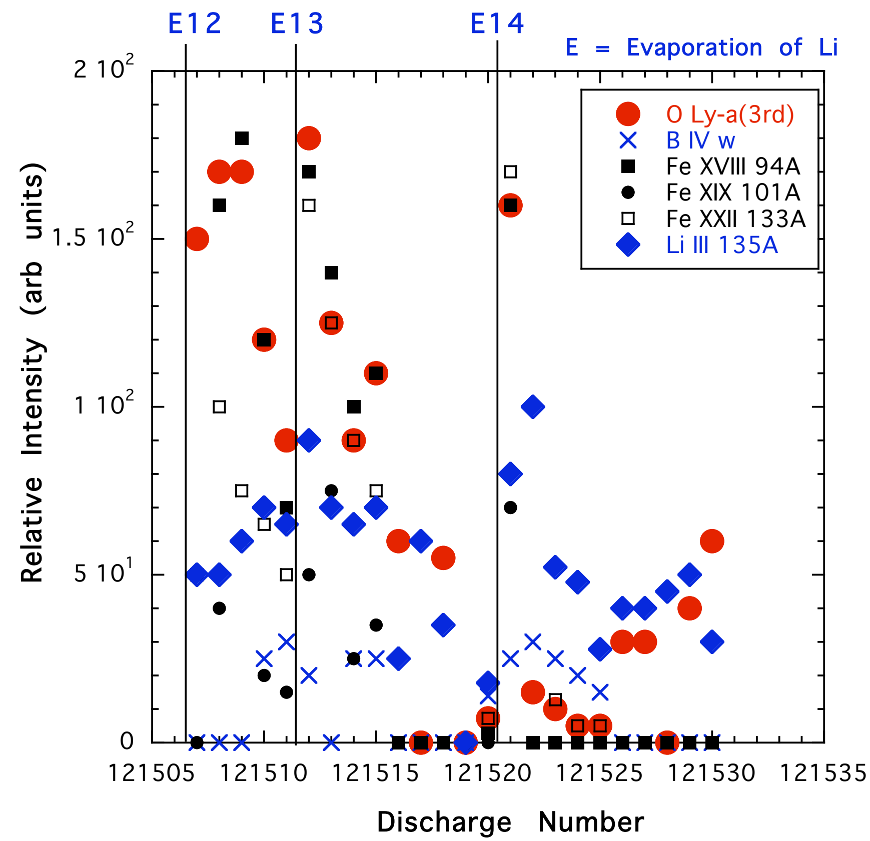
Lithium PFCs Yielded Broader Electron Temperature Profiles and Higher Edge Temperatures



H-mode Before Li	H-mode 1st Shot After 4.8g Li	H-mode 4 Shots Later Dα Increasing	H-mode After fast Deposition of 1 g Li Between Shots

Vacuum Conditions Improved After Lithium; Oxygen Decreased ~x2-10



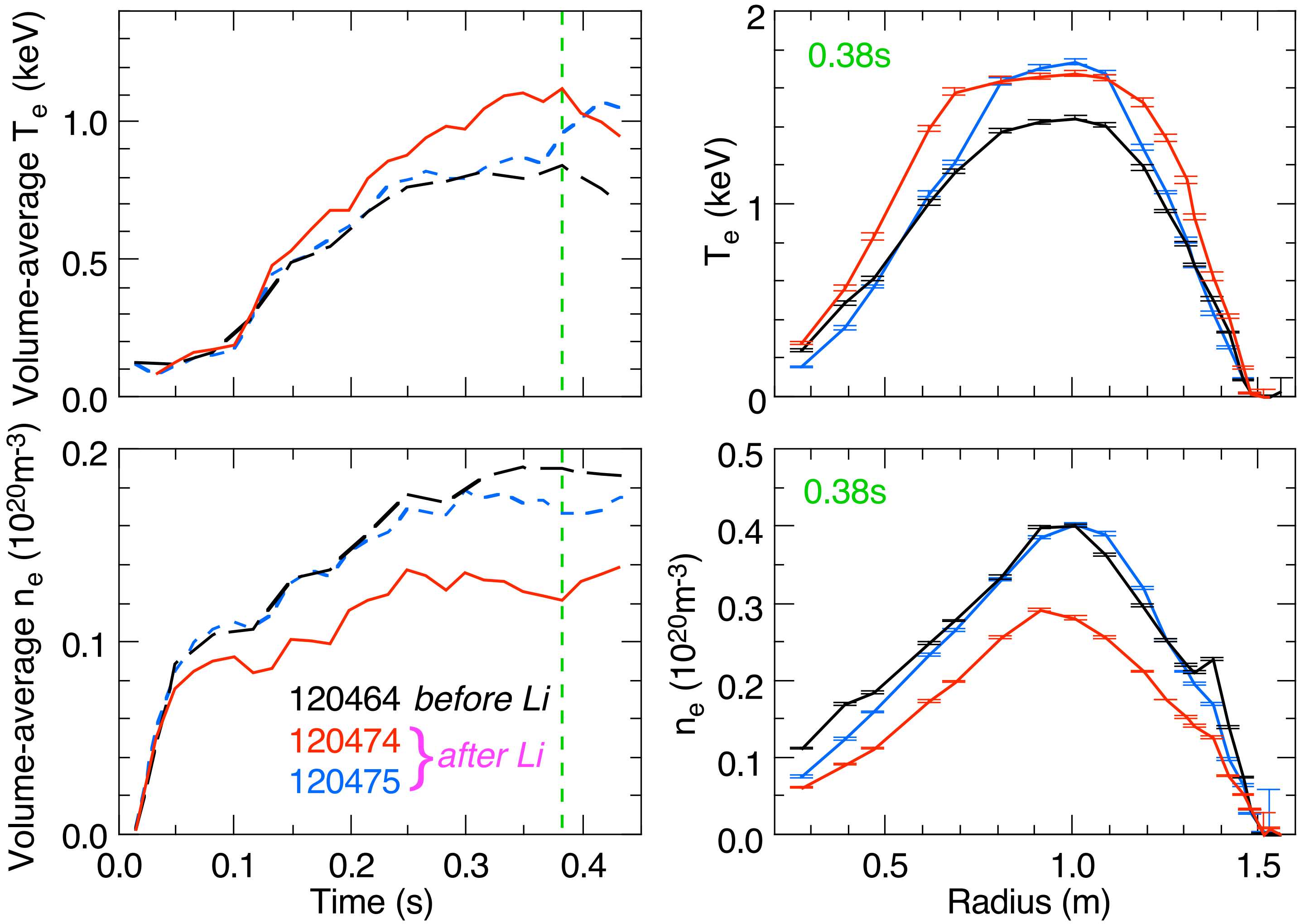


P. Beiersdorfer, LLNL

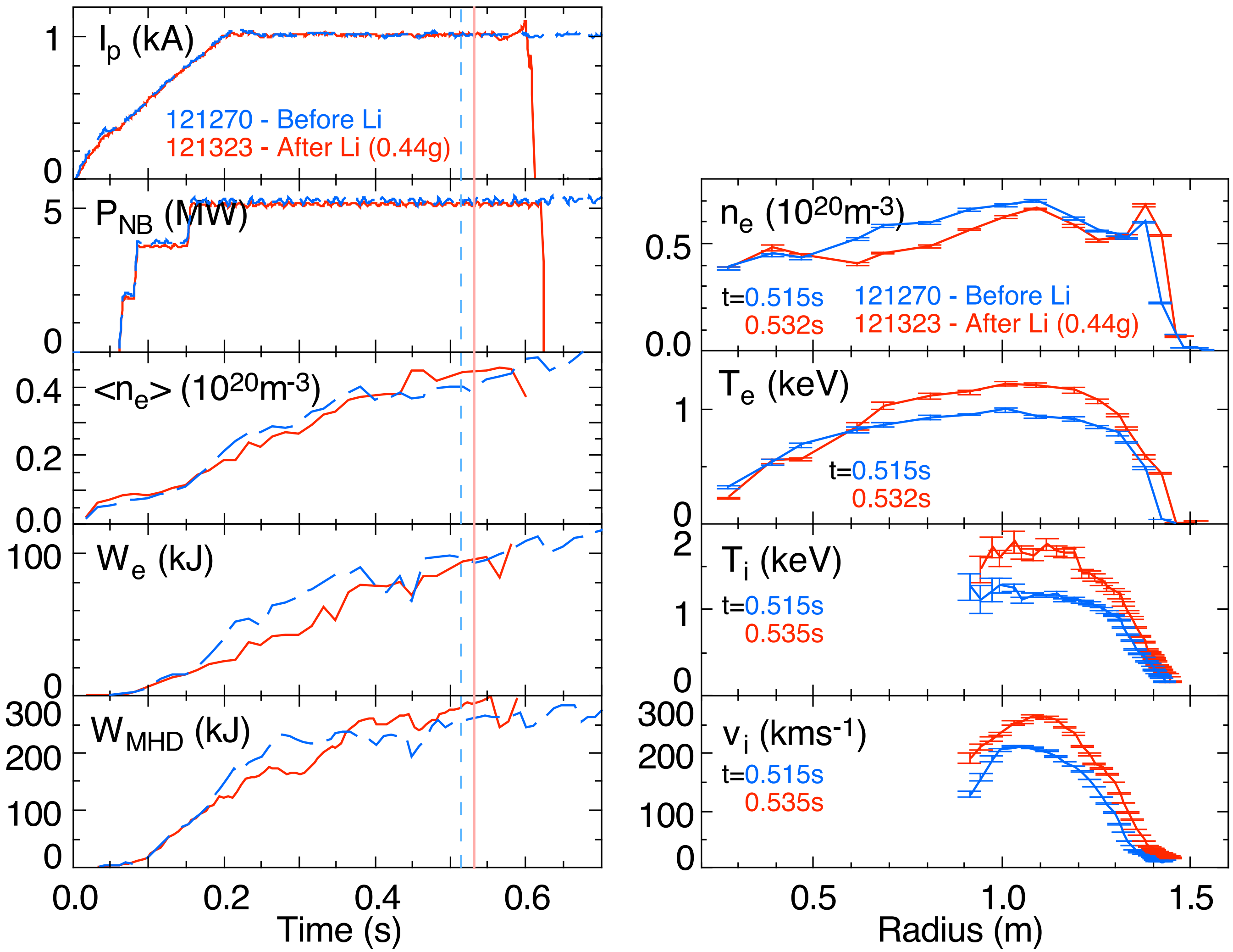
- After lithium, vessel base pressure prior to daily operations decreased

- After lithium, plasma impurities decreased

LSN L-mode Exhibited Changes After 0.38g Lithium PFC Coating



H-mode Exhibited Changes After 0.44g Lithium Coating without pre Helium Discharge Conditioning



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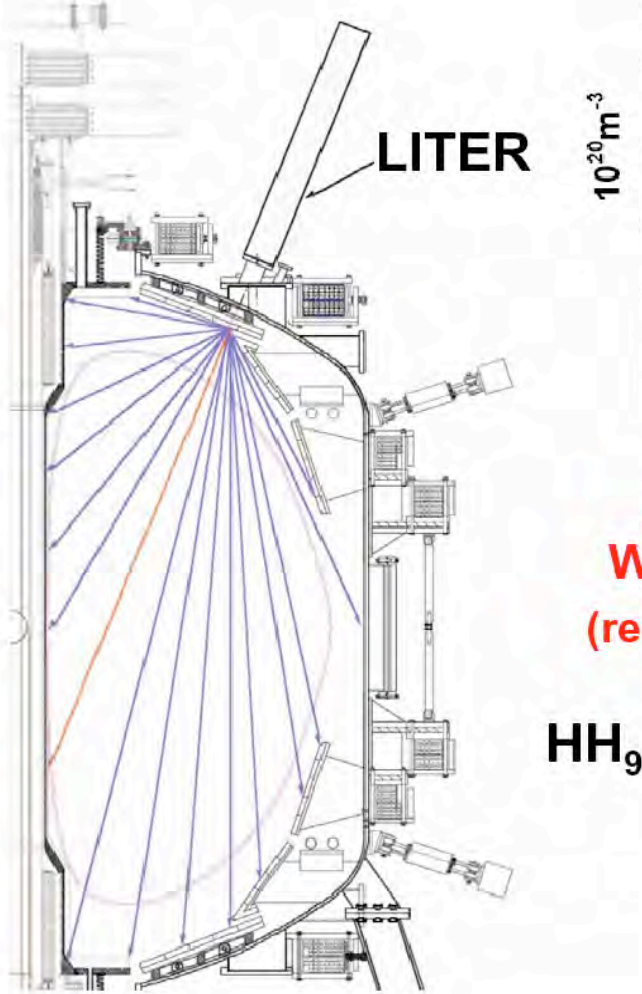
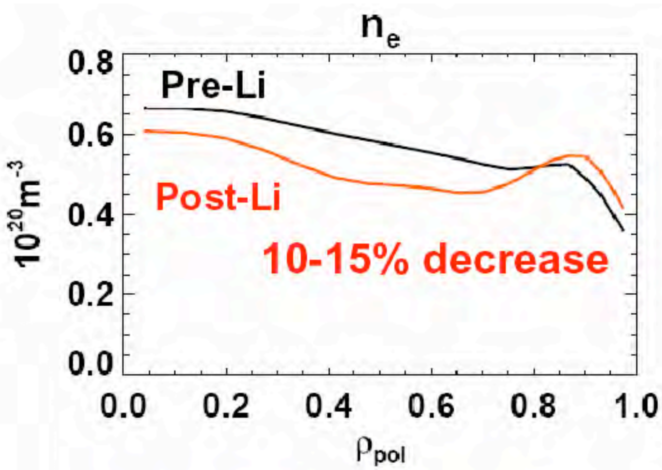
Measurable Density Decrease and Performance Enhancement Obtained in H-mode Discharges with LITER-1



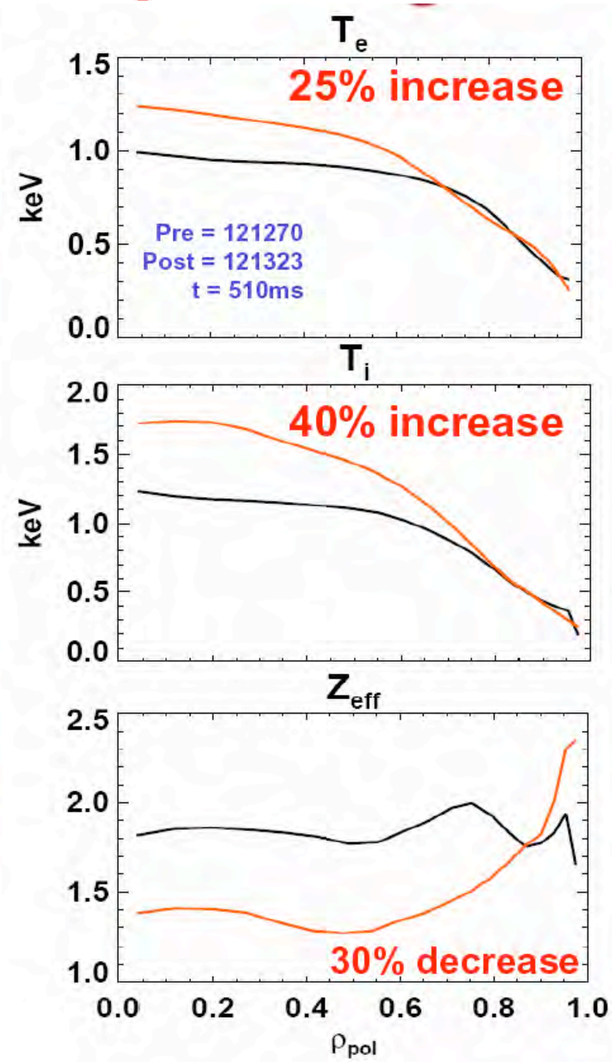


TRANSP analysis:

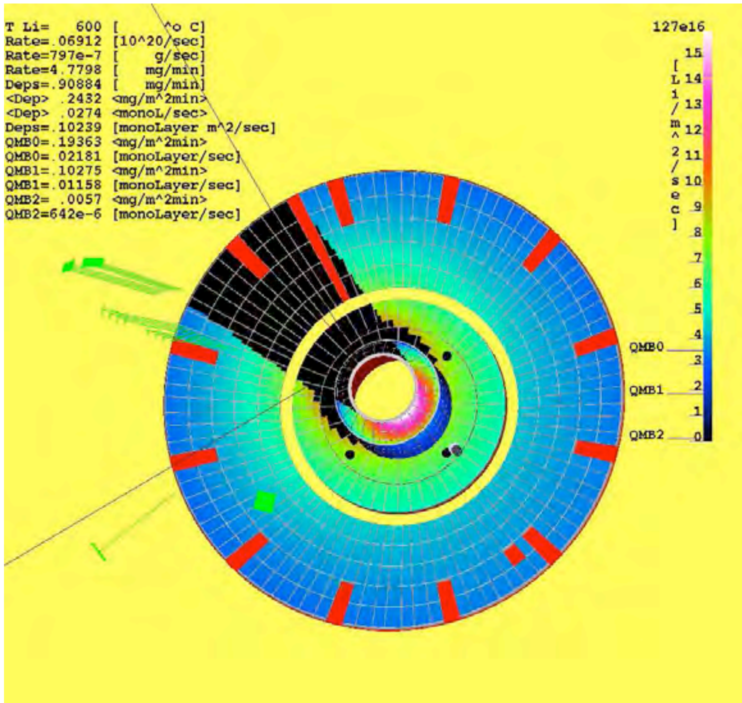
W_{TOT} 20% higher post-Li

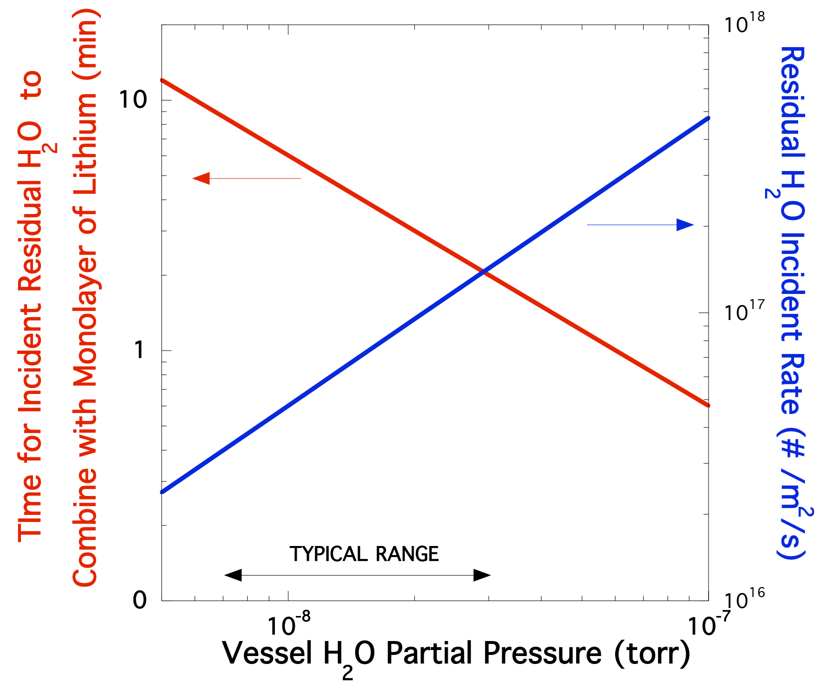
(reaches β-limit w/ same P_{NBI})

HH_{98y} = 1.07 → 1.25 post-Li



Lithium Deposition Rate Dominant Over H_2O and O_2 Fluxes from Residual Vacuum Partial Pressures





- Lithium deposition rate x100 greater than incident impurity rate

- Between discharges, residual H_2O combines with monolayer of Li in ~ 4 min

Summary and Outstanding Questions

- *Improvements observed in discharge performance*
  - Increased Te, Ti, $v_{tor,}$ t_E
  - Reduction in Z_{eff} due to reduced carbon in core, which wears off as Lithium recycling light decreases with discharge #
  - Longer term improvements in wall conditions
- Why does pumping effect on n_e wear out in 1 discharge?
- Why did pellet injection (25 mg deposition) produce similar density reduction as compared with LITER-1 (500 mg) in L-mode plasmas?
- What is the role of intercalation of Lithium into the graphite?
- What is the role of passivation of the Lithium after deposition and before the discharges?
- What are the relative roles of core fueling and improved particle confinement in limiting the reduction of dN/dt?

Future Plans

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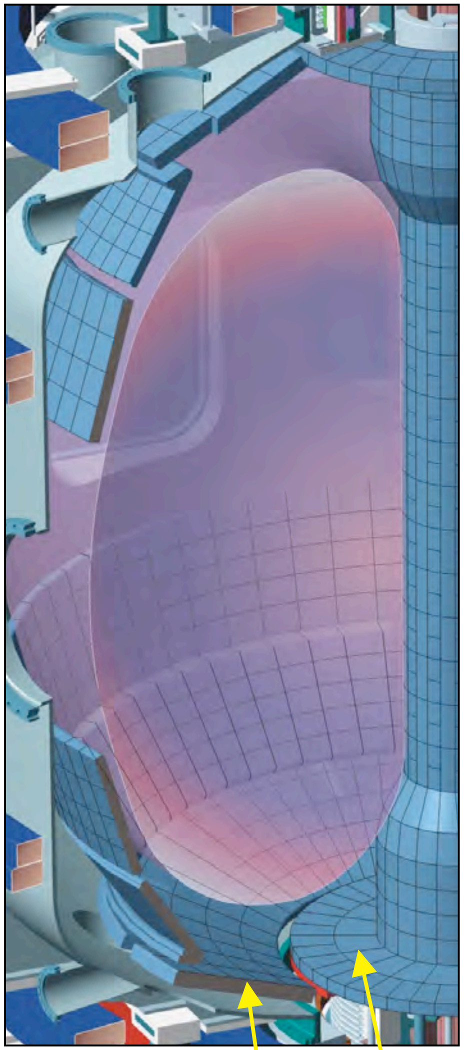


- The 3 Phase NSTX 5-Year Lithium Plan for Particle Control and Power Handling is moving aggressively toward the 3rd Phase:

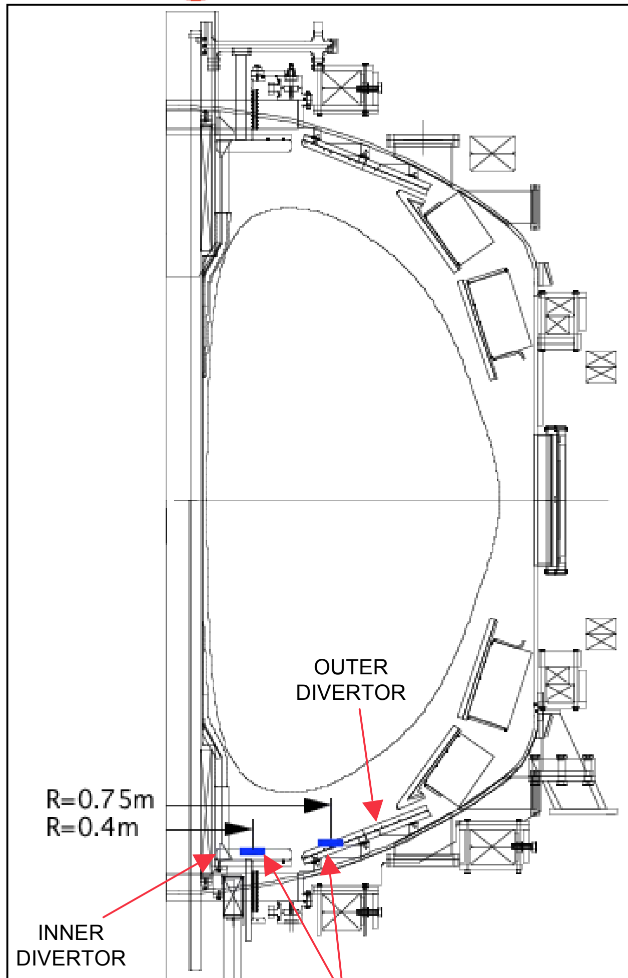
I. Lithium Pellet Injector (2005)

II. Lithium Evaporator (2006)

III. Liquid Lithium Divertor (2008)

- Phase III will benefit from much previous international lithium work.

- 2007 Experimental Proposals will investigate open questions using Li Pellet Injector and Li Evaporator.



- Two candidate locations for a toroidal, Liquid Lithium Divertor at lower outer strike-point

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2007 Experimental Proposals

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- Lithium Pellet Injection into LSN He discharges to measure Li effects on subsequent LSN Deuterium discharges
    - Effects on H-mode performance
      (previous LPI tested only L-mode)
    - Effects of Li intercalation into graphite
      (by varying LPI amount)
    - Effects of impurity passivation between discharges
      (by varying time to subsequent D discharge)
- The 2006 Lithium Evaporator initial results suggest the following experimental investigations:
    - Modify Lithium Evaporator for 2 output barrels and re-aim at strike-point region
      (more deposition on lower divertor target region)
    - Faster between-shot evaporation
      (shorter intercalation time, shorter passivation time)
    - Shorter duration between end of evaporation and subsequent discharge
      (shorter intercalation time, shorter passivation time)
    - Support other XP's exhibiting improved performance after lithium
      (e.g. long pulse H-modes, reverse shear discharges, impurity control)

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