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NSTX

Lithium Surface Coatings for Improved Plasma Performance in NSTX

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H. W. Kugel and NSTX Team

PPPL, Princeton University, Princeton, NJ

49th Annual Meeting
Division of Plasma Physics
American Physical Society

November 12-16, 2007
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Outline

- Motivation for investigating lithium plasma facing components
- Background for the work in progress
- Li Pellet Injection results motivating the Li evaporator experiments
- Description of LIThium EvaporatoR (LITER)
- LITER characterization and then as operational tool
  - databases showing sometimes improved results for reference shots immediately following Li deposition
  - examples of improvements
  - work in progress
- Future plans
- Other NSTX lithium related presentations

Motivation

- A decade of international research on liquid lithium indicates that it shows promise for providing a self-healing plasma facing surface in a DT reactor.

- NSTX near term research with *solid* and eventually *liquid lithium* is aimed towards using lithium to control <u>density</u> and <u>impurity influxes</u> in H-mode plasmas.

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

  I. Lithium Pellet Injector (2005-2009)

  II. Lithium Evaporator (2006-2009)

  III. Liquid Lithium Divertor (2009-2012)

- ***This phased approach is allowing NSTX operations, diagnostics, and research to be adapted to lithium wall conditions.***

  - Recent work has focused on H-mode plasmas which appear to be sensitive to lithium deposition even without pre-conditioning walls.

Background for the Work in Progress

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- NSTX solid lithium coatings pump:
  - D^+ and D^0 through the formation of lithium deuteride (LiD)
  - incident 500-2000 eV D to estimated pumping depth of ~100-250 nm
  - average Li deposition exceeds the pumping depth over ~50% of lower divertor strike point area
- Pumping capacity of lithium coating can be reduced by:
  - Coverage of some areas by less than full active depth
  - Localization of interaction to region around divertor strike point
  - Passivation of lithium by formation of compounds (*e.g.* LiOH, Li_2C_2)
  - Diffusion into the substrate

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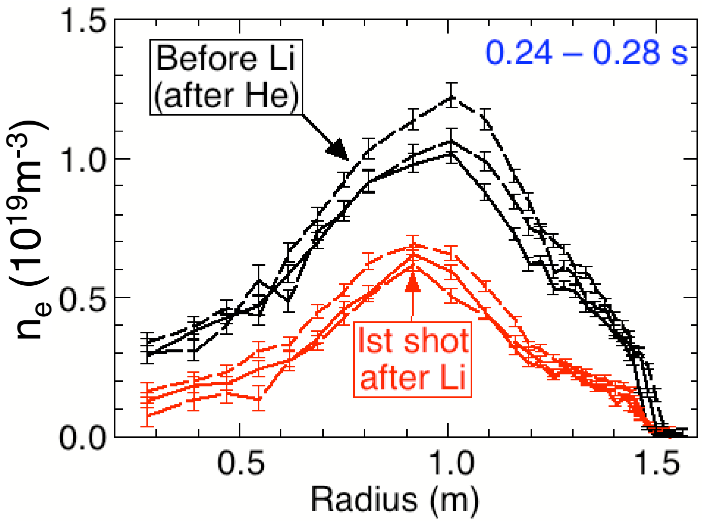
Lithium Pellet Injection (2005-2007)

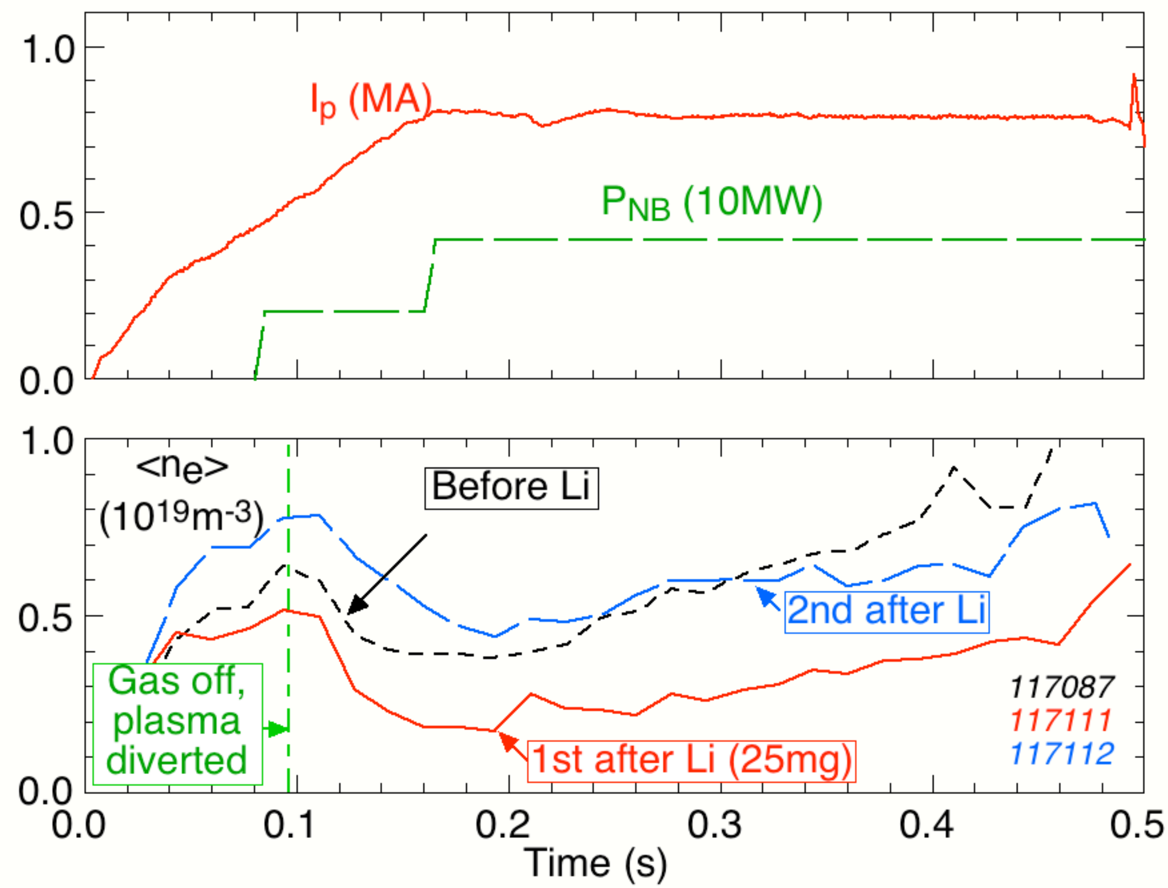
- To observe Li pumping, TFTR first used repeated Helium discharges to condition graphite PFCs (J. Strachan et al.,)
  - to remove D fuel gas (degassing)
- In NSTX, after similar Helium conditioning and Li pellet injection, we observed Li pumping in low density D LSN L-mode discharges (2005).
- Subsequently, NSTX without degassing graphite, observed Li pumping in high density D LSN H-mode discharges (2007).

After 25 mg LPI into He Plasmas, First D LSN L-mode Shot Exhibited Factor ~2 Decrease in Density

NSTX

- ***First, D degassed from graphite with Helium discharges, then Li deposited by LPI into Helium discharges***





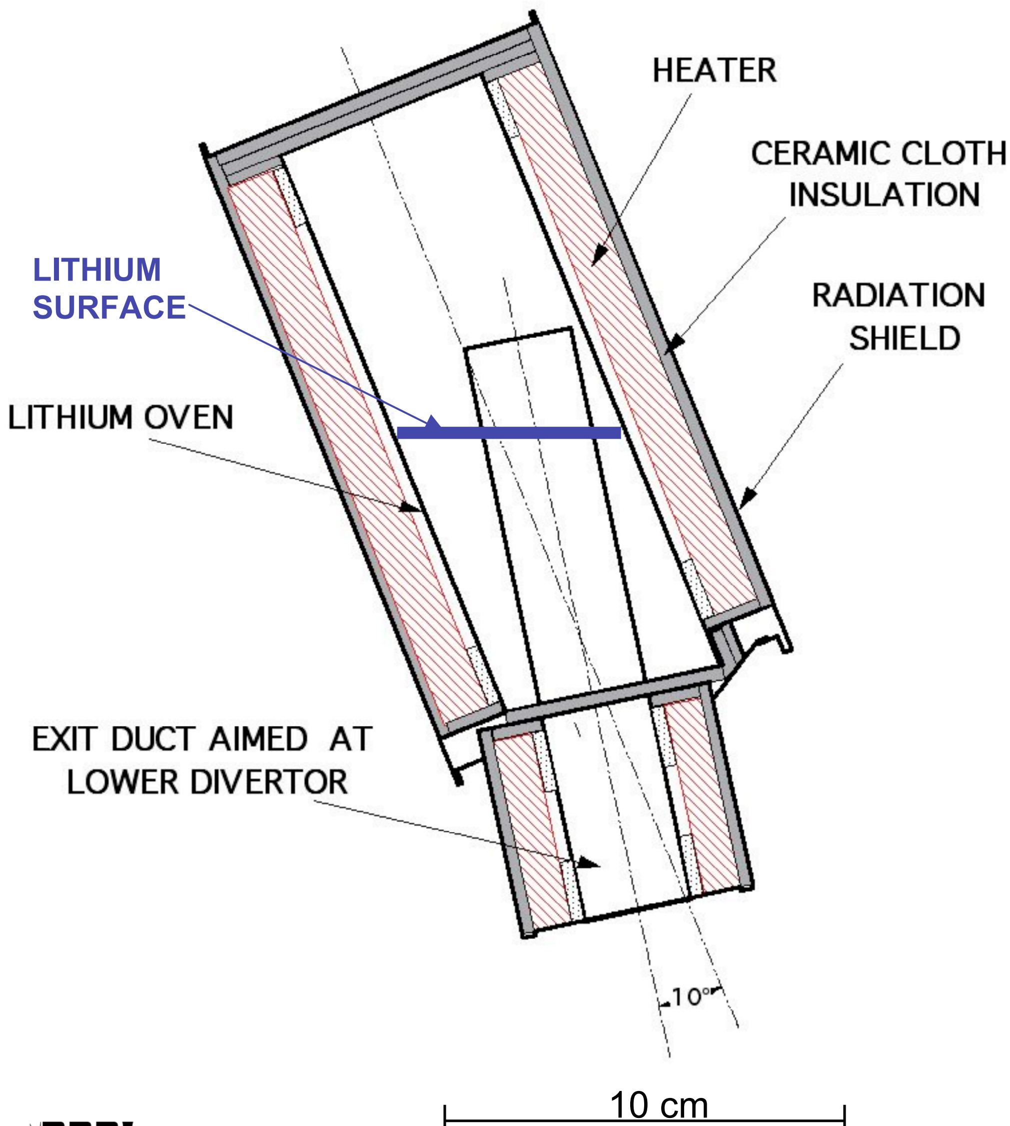
- Li pumping saturated after the 2-3 similar L-mode D discharges and returned to pre-Li wall conditions, in agreement with consumption of injected Li.(2005)
- Similar results following LPI into higher density H-modes without degassing graphite.(2007 after >9g of Li from 2006).

Lithium Evaporator (2006-2007)

• The 2005 pellet results motivated accelerated development of Li evaporation

- In 2006, Li evaporated *between* discharges and never into HeGDC. Run total = ~9 g.
- In 2007, Li evaporated *continuously* during the operation day. Run total =93 g. This day-long evaporation continued during:
    - *10 min HeGDC between discharges (resulting in codeposition of He and subsequent trapping in solid Li voids)*
    - *Subsequent 1sec D discharges*

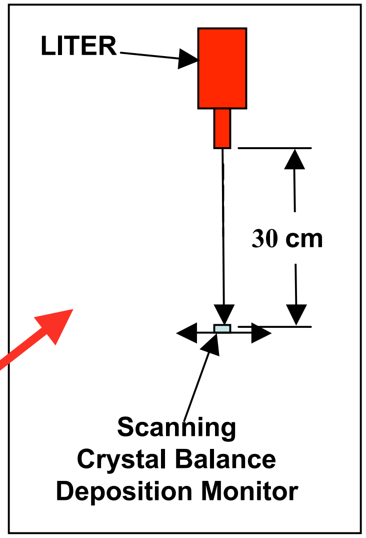
Design of LIThium EvaporatoR (LITER 2007) Shown in Operating Orientation



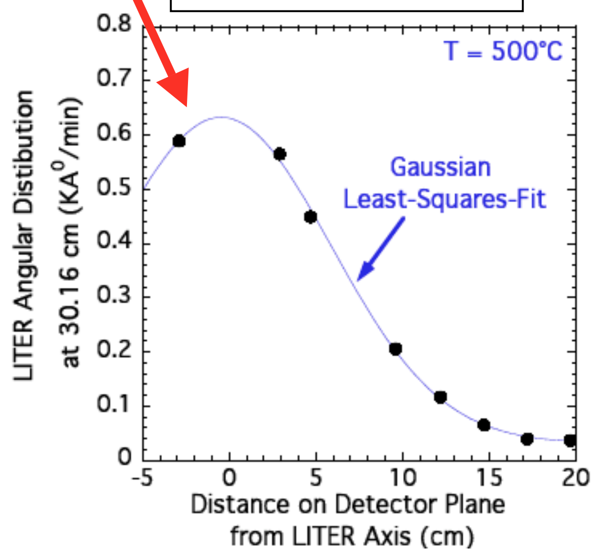
- LITER on probe & loaded with Li under argon
- Typical Operating Conditions
  - Capacity: 90 g Li
  - Oven Temp: 600-680°C
  - Rate: 1mg/min - 80mg/min

LITER Produces Collimated Lithium vapor Stream; Rate Varies Strongly with Temperature

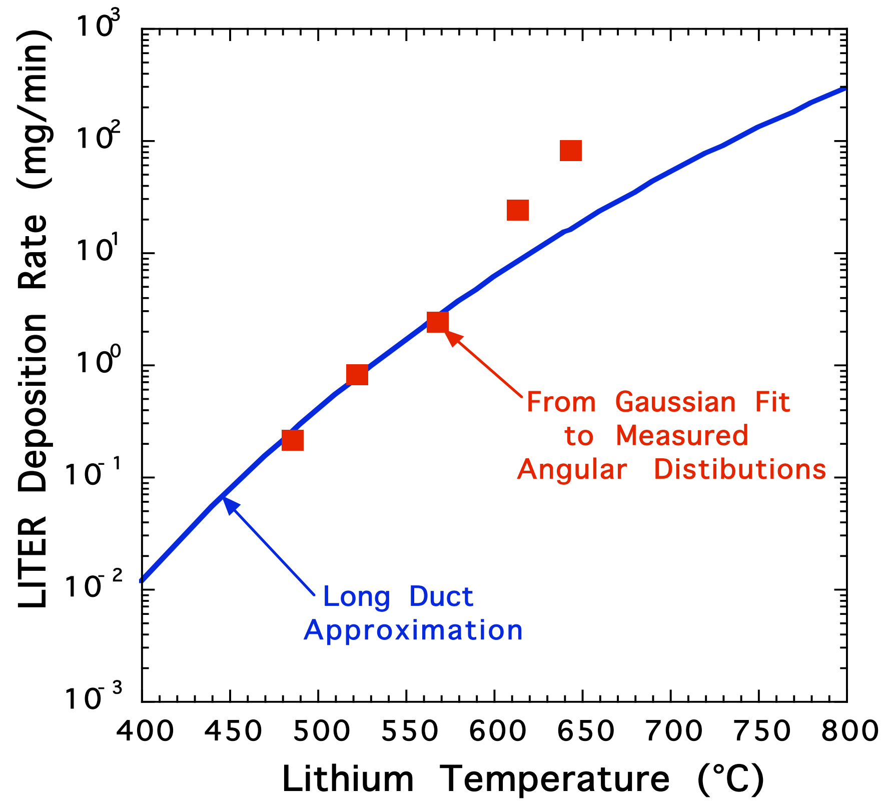
NSTX



LITER Angular Distribution Measurements



- Average Gaussian Half Width ~ 11° over temperature operating range



- Above 600°C, LITER evaporation rate increase may be due to non molecular flow (PM5.00002. L. Zakharov)

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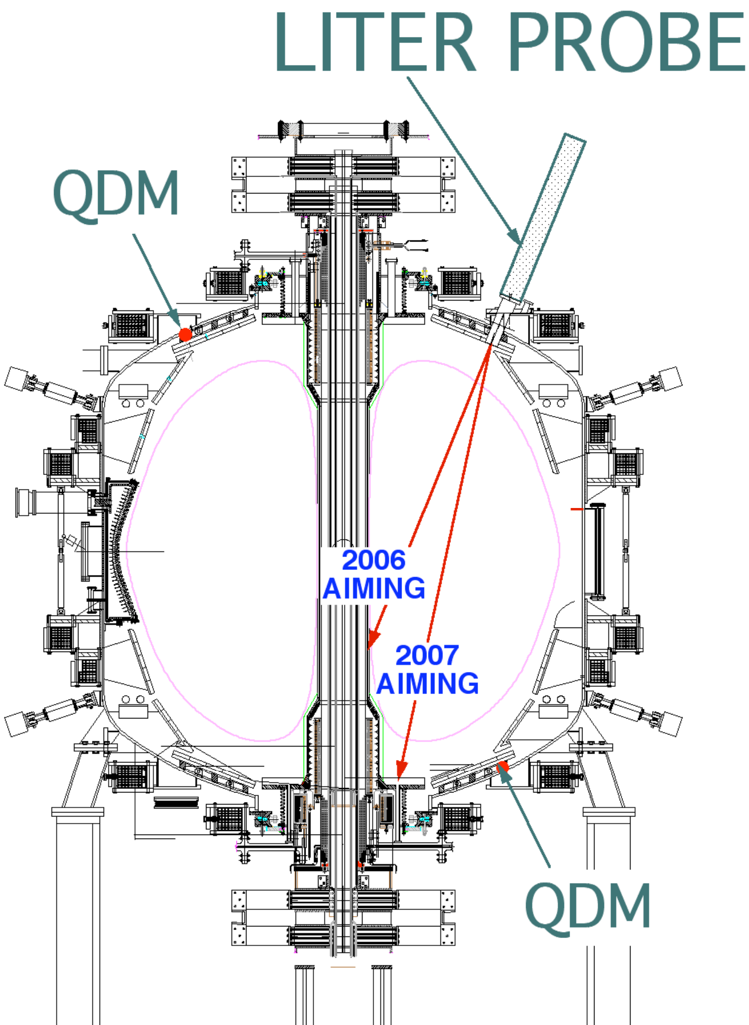
LITER 2006 Upgraded for 2007



LITER (LIThium EvaporatoR)
QDM (Quartz Deposition Monitor)

- **LITER 2006**

- aimed toward lower Center Stack
- cool-down time ~20 min
- short cool-down time allowed separate HeGDC and evaporation operations
- tube heaters brazed to oven run close to limits and suffered some failures

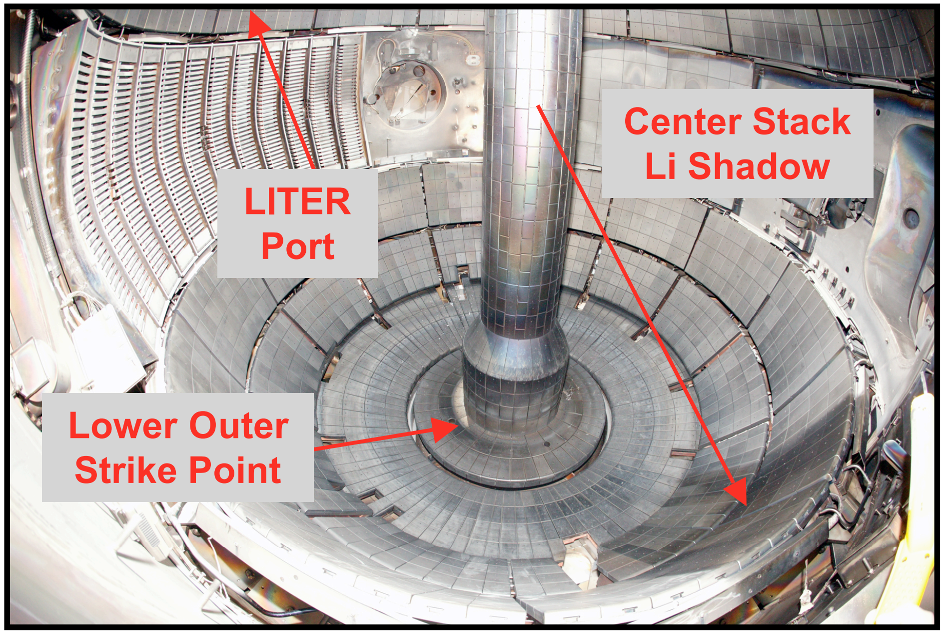
- **LITER 2007**

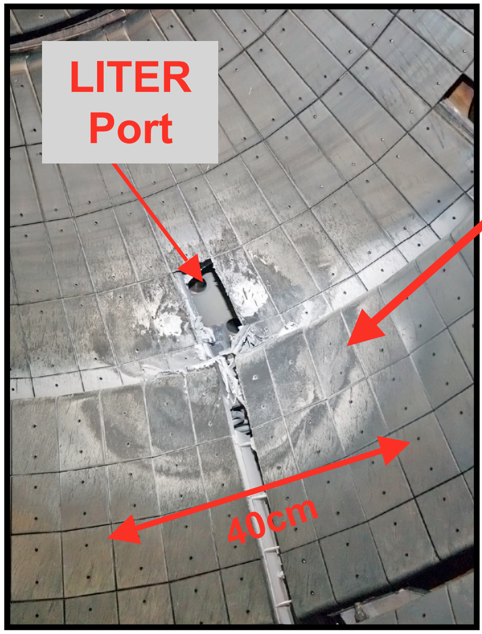
- reaimed toward lower divertor for increased divertor target deposition (x3)
- larger output aperture area (x1.7)
- larger capacity (x1.4)
- more robust heaters for higher evaporation rates (80 mg/min vs 10 mg/min)
- more mass slowed cool-down time ~1.5 hrs
- to maintain NSTX duty cycle, long cooldown time required evaporation into HeGDC

Areas of Lithium Deposition Visible After the Run Through Conversion to Stable Lithium Compounds

NSTX

Photos of Vessel Interior After 2007 Campaign (93 g of Li Deposited)





- Increased Li deposition around LITER due in part to:

  -Li^+ redirected by HeGDC electric field

  -Li scattering by He gas

- PFCs Whitened after Venting Due to Li_2CO_3 Formation (Li→LiOH →Li_2CO_3)
  - **Slow helium outgassing was observed following HeGDC and affected subsequent D discharges (time scale of 10s of min).**
  - **The pumping of helium codeposited with solid Li has been observed previously and is attributed to He trapping in Li interstitial voids (Mirnov, Evtikin, T-11; Hirooka, PSI 04).**

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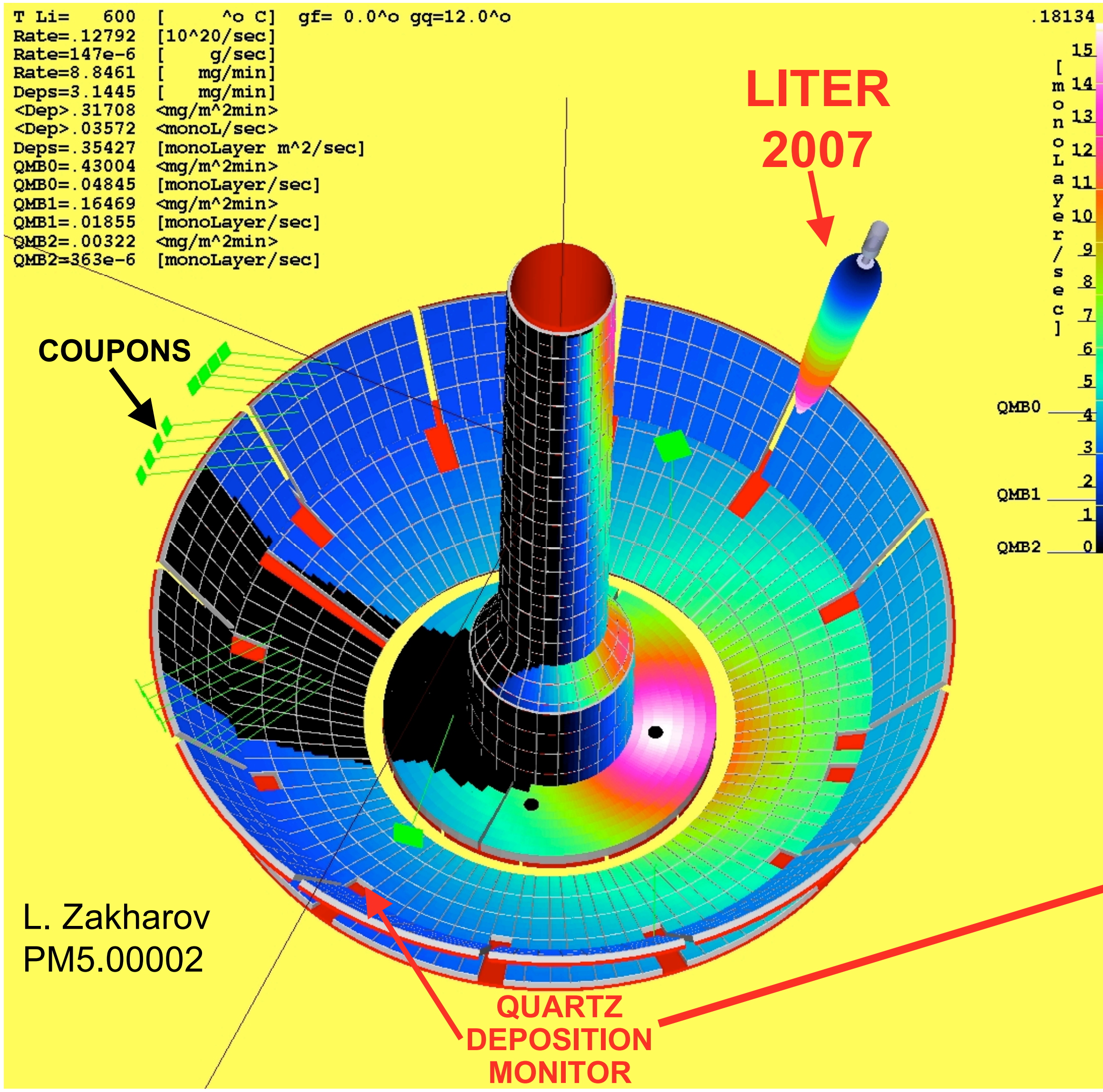
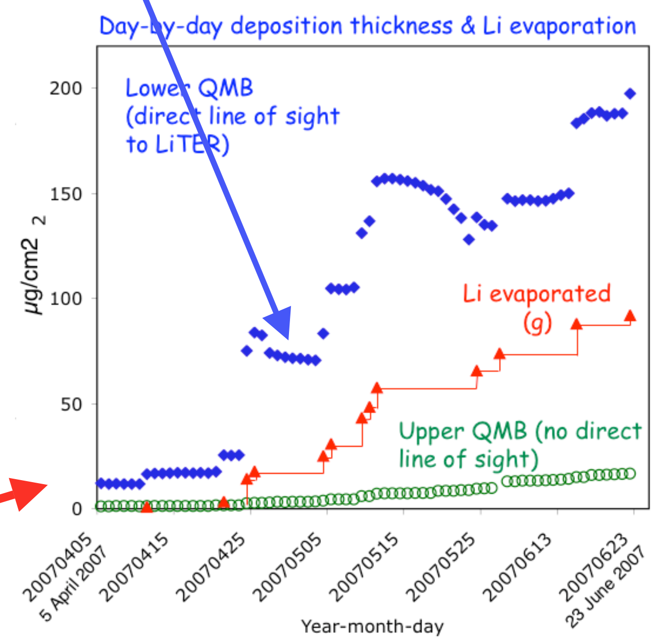
Simulation of Evaporated Lithium Distribution Reproduces Observed Features

NSTX



- **Lower QDM exhibits series of upward steps in response to increasingly high Li evaporation rates**



C. H. Skinner
PM5.00004,

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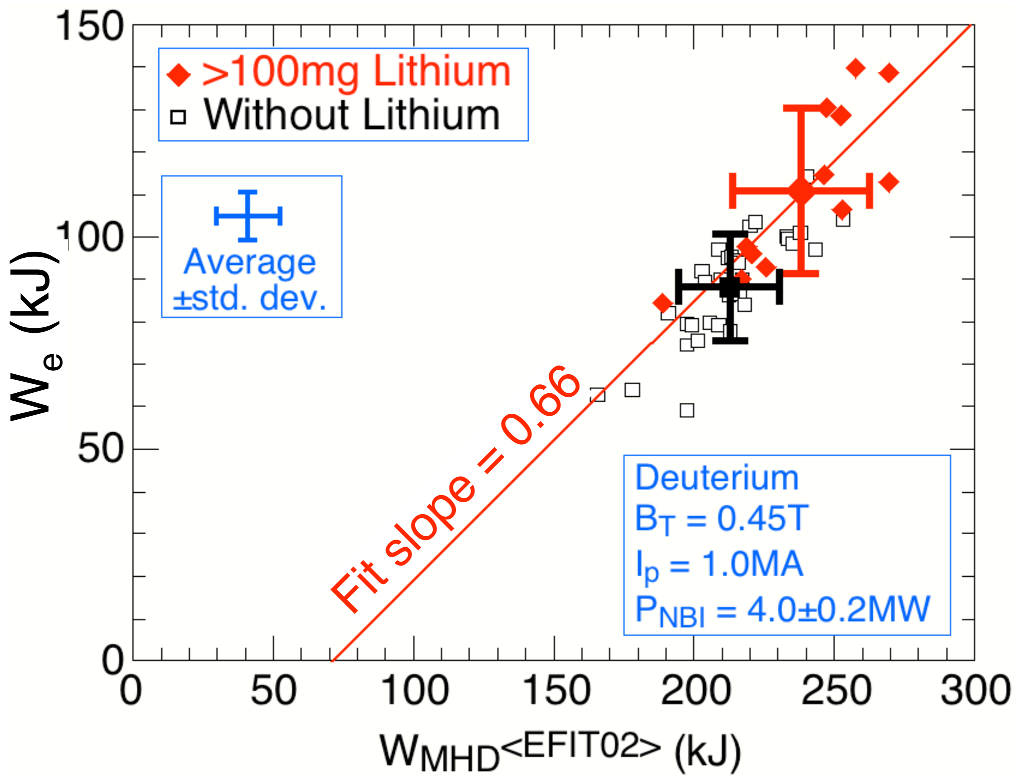
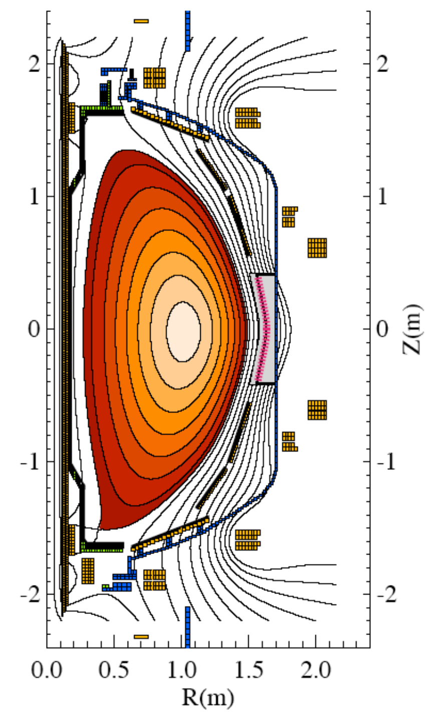
Stored Energy (W_{MHD}) Increases After Li Deposition Mostly Through Increase in Electron Stored Energy (W_e)

NSTX

- ***Benefits From Lithium Were Frequent but Not Always Seen***





M. Bell

- Includes all controlled discharges used to study initial LITER operation
- “Without Lithium” - similar discharges with no Li (*i.e.,* prior to LITER operation)
- Data sampled at time of peak W_e

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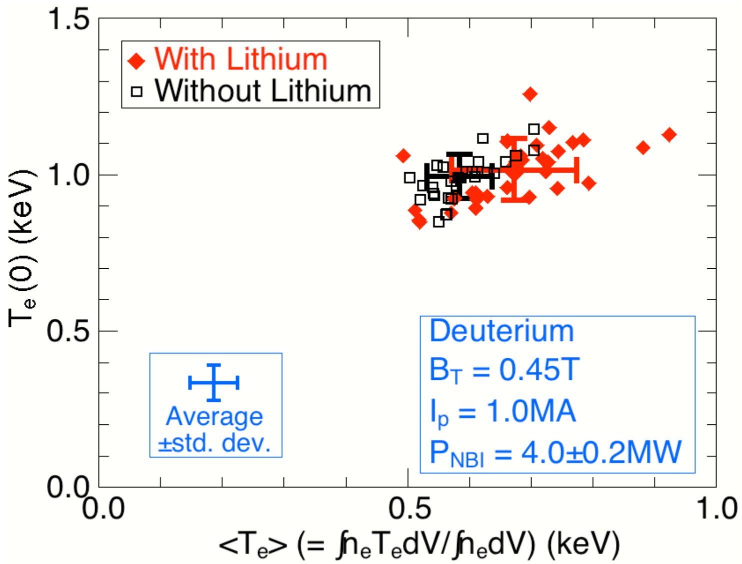
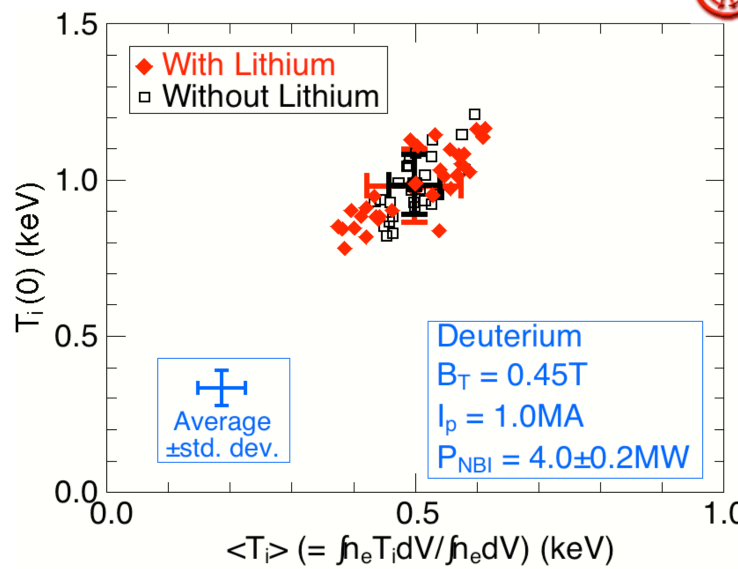
T_e Profile Broadens After Lithium but Central T_e and Profiles of Density and Ions Unaffected

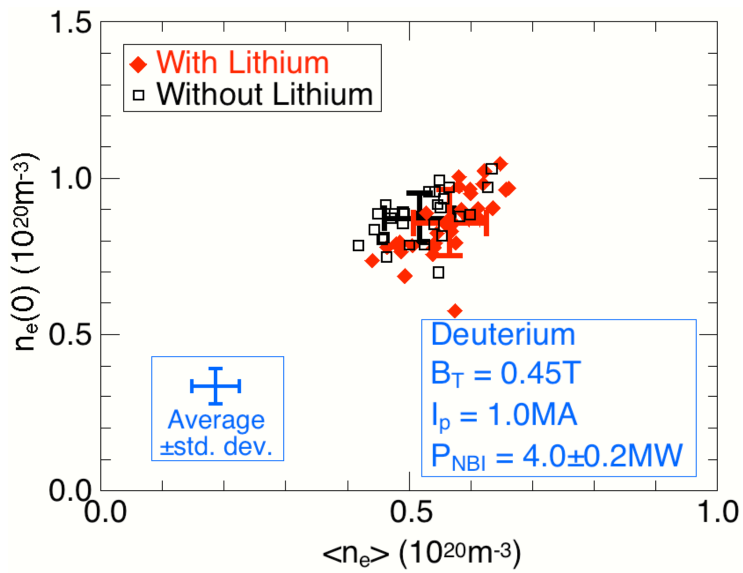
NSTX



• $T_e(0)$ no change, $\langle T_e \rangle$ increases after Li



• No effect on ions after Li



• Slight broadening of n_e profile after Li

- T_i from CHERS
- Shots after Li reached peak W_e ~50 ms later on average

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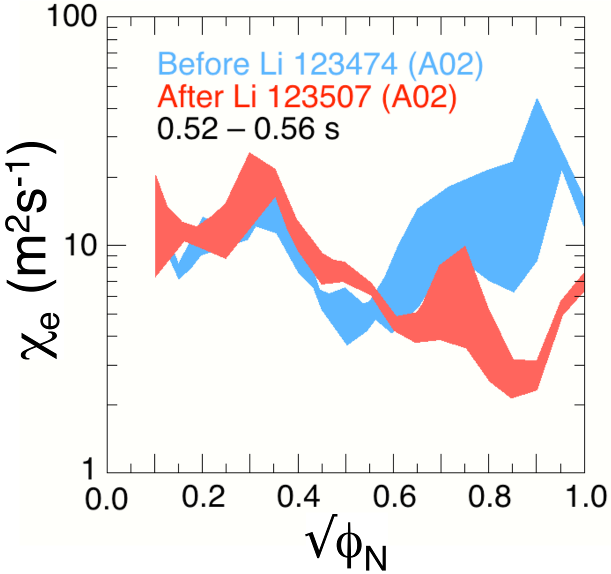
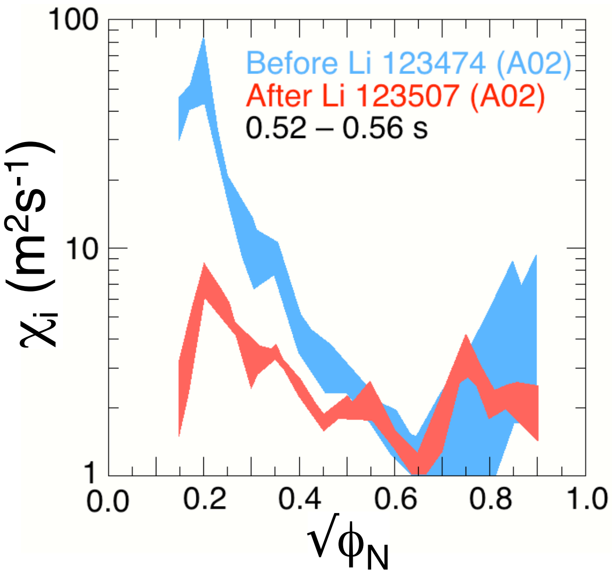
TRANSP Analysis Infers Edge χ_e, and Core χ_i, Decreasing Following Lithium Deposition

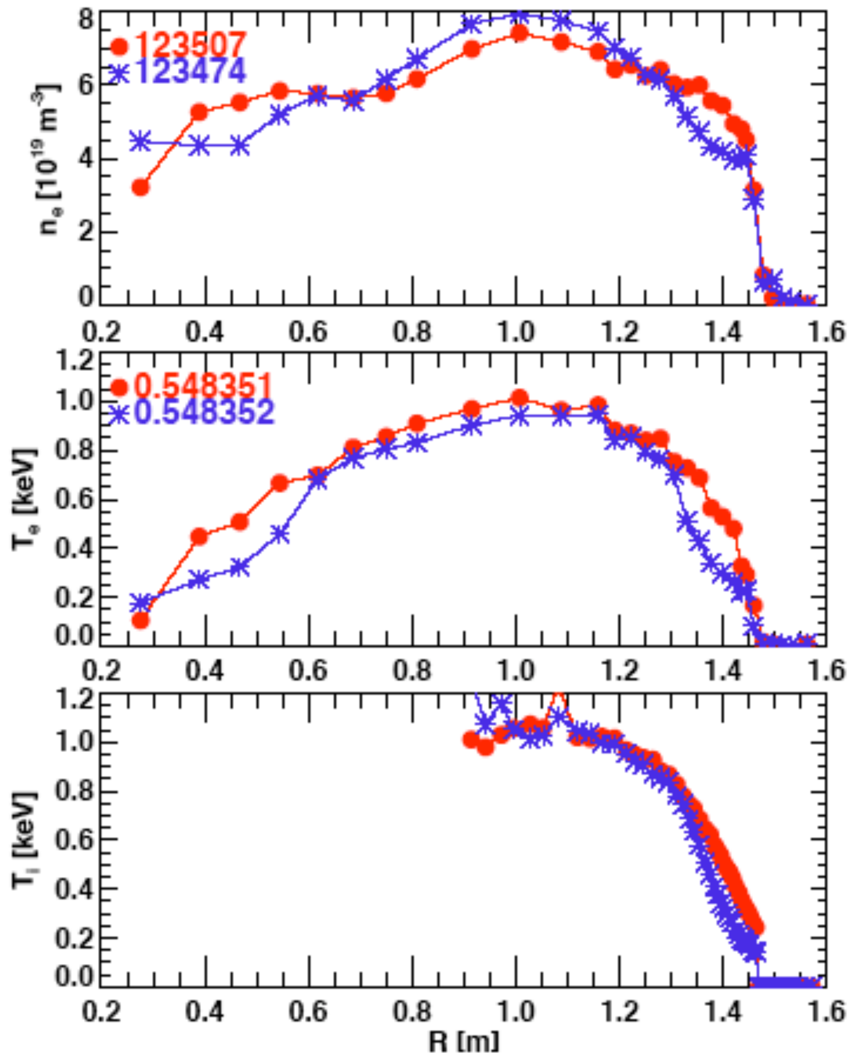
NSTX

- Edge χ_e decreasing following Li



- Core χ_i decreasing following Li





t = 0.54 s

M. Bell
S. Kaye
B. Le Blanc
R. Bell
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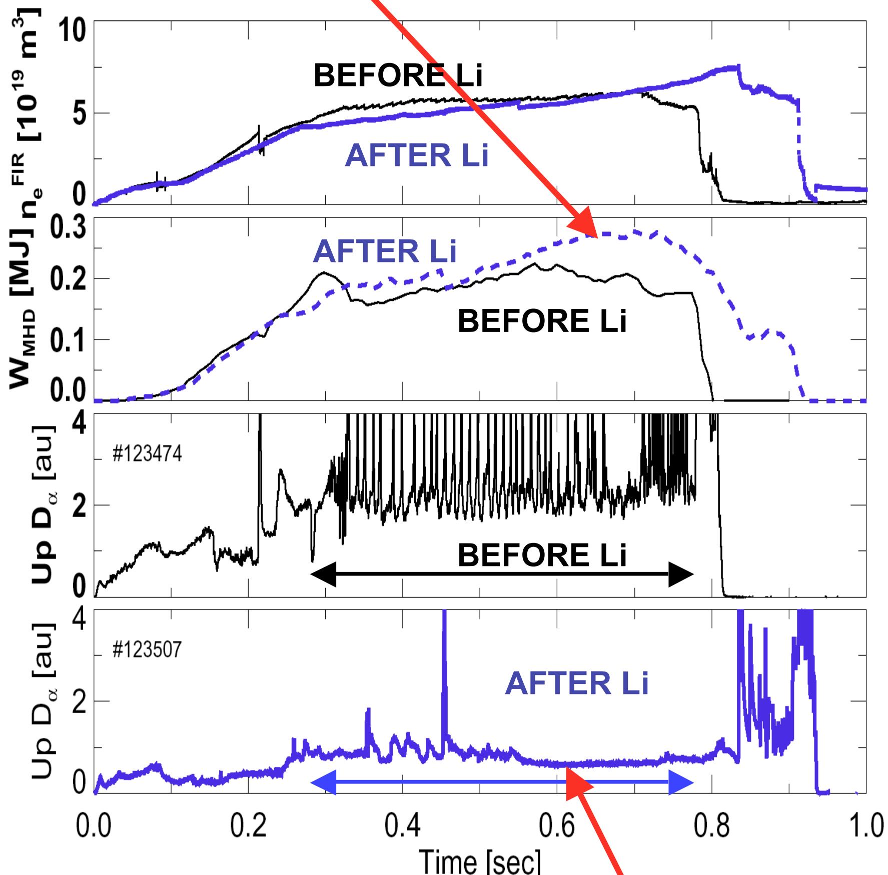
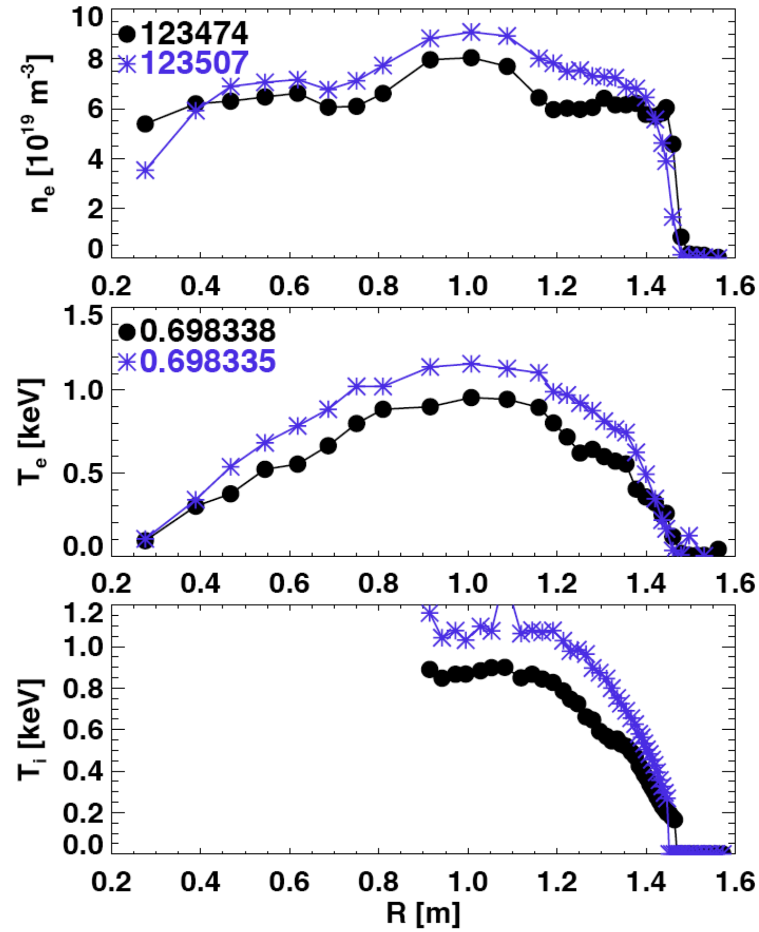
Lithium Deposition Reduced ELM Frequency and Yielded Quiescent Periods in Some Discharges

NSTX

- After lithium, W_{MHD} increased.





- After lithium, frequency of large ELMs greatly reduced. Note: quiescent time.

R. Maingi, ORNL

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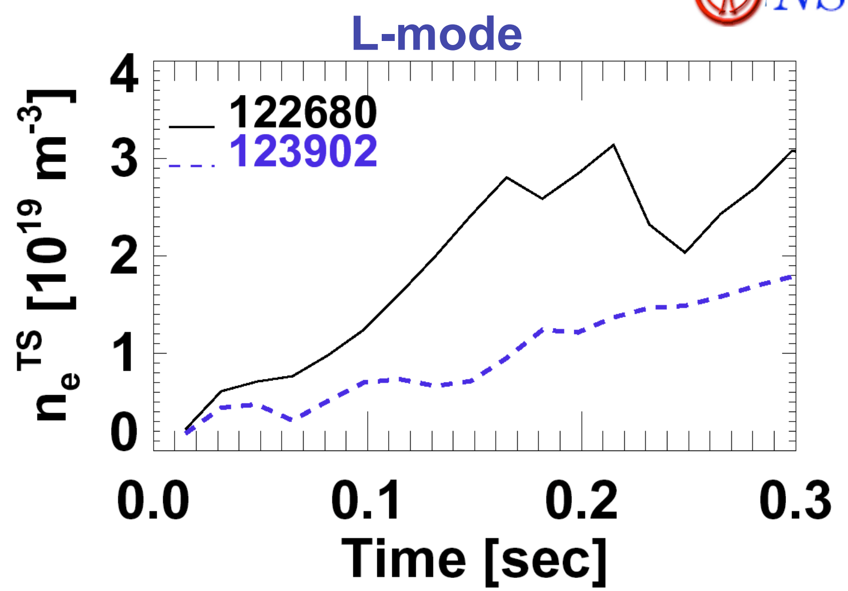
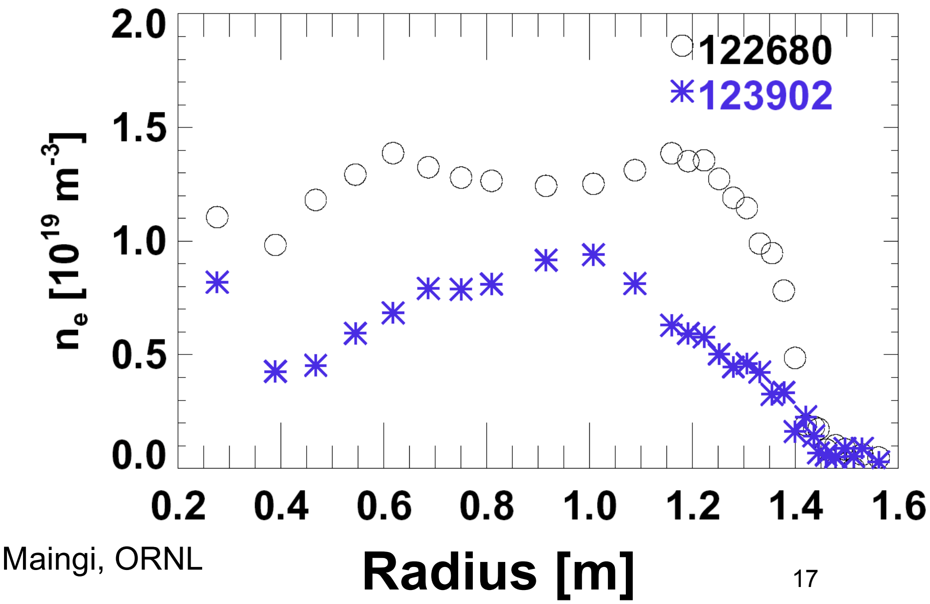
Significant D Pumping at Higher Li Evaporation Rates

• **Black: reference discharge before LI**

• **Blue: reference + 35mg/min LITER (Commonly used rate = 15-20 mg/min)**



• ***L-mode density reduced by 50% following high Li evaporation rate***



EBE Transmission Efficiency Increased With Lithium Evaporation Rate

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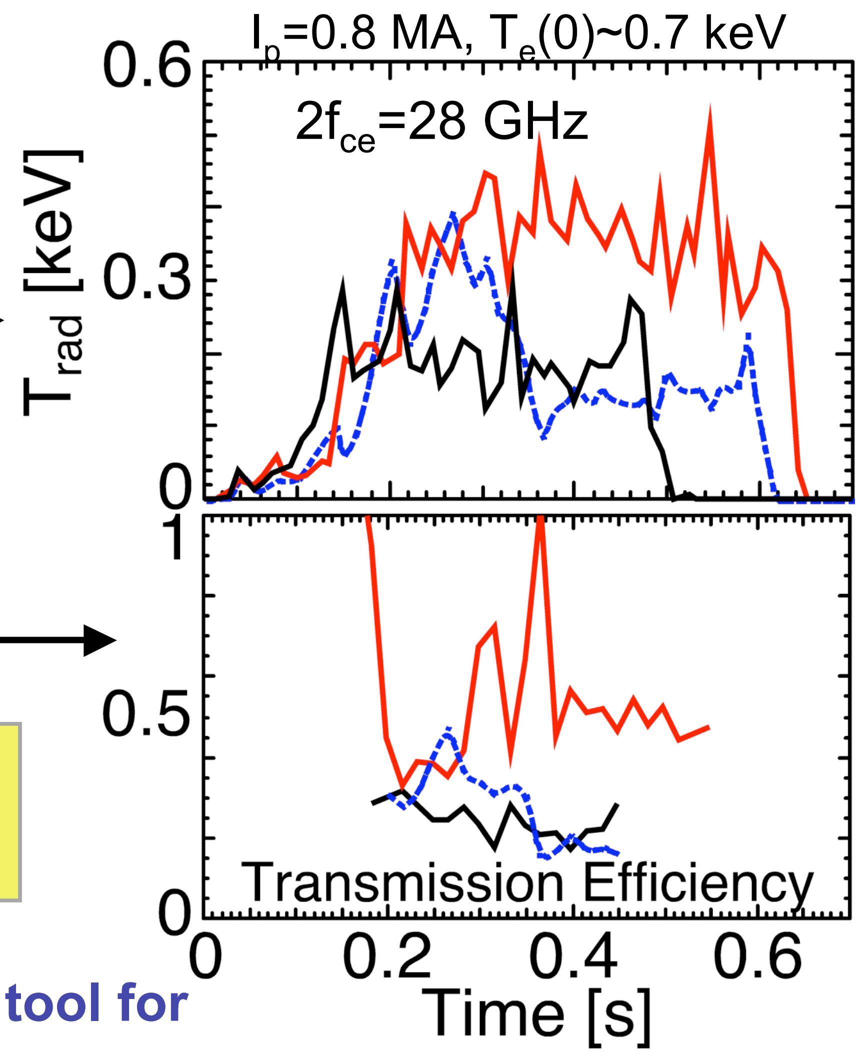
Lithium edge increases T_e and reduces L_n near B-X-O mode conversion layer

- 0 mg/min (124284)
- 11 mg/min, total = 171 mg (124290)
- 19 mg/min, total = 286 mg (124309)

Measured T_{rad} increased from 200 eV to ~ 400 eV →

Transmission efficiency increased with Li conditioning:
From 20% → 60% for f_{ce}=18 GHz
From 20% → 50% for $2f_{ce}$=28 GHz →



Edge lithium conditions may be reducing edge collisionality

CO3.00011 S. Diem

- **Lithium provided a tool for altering edge conditions**

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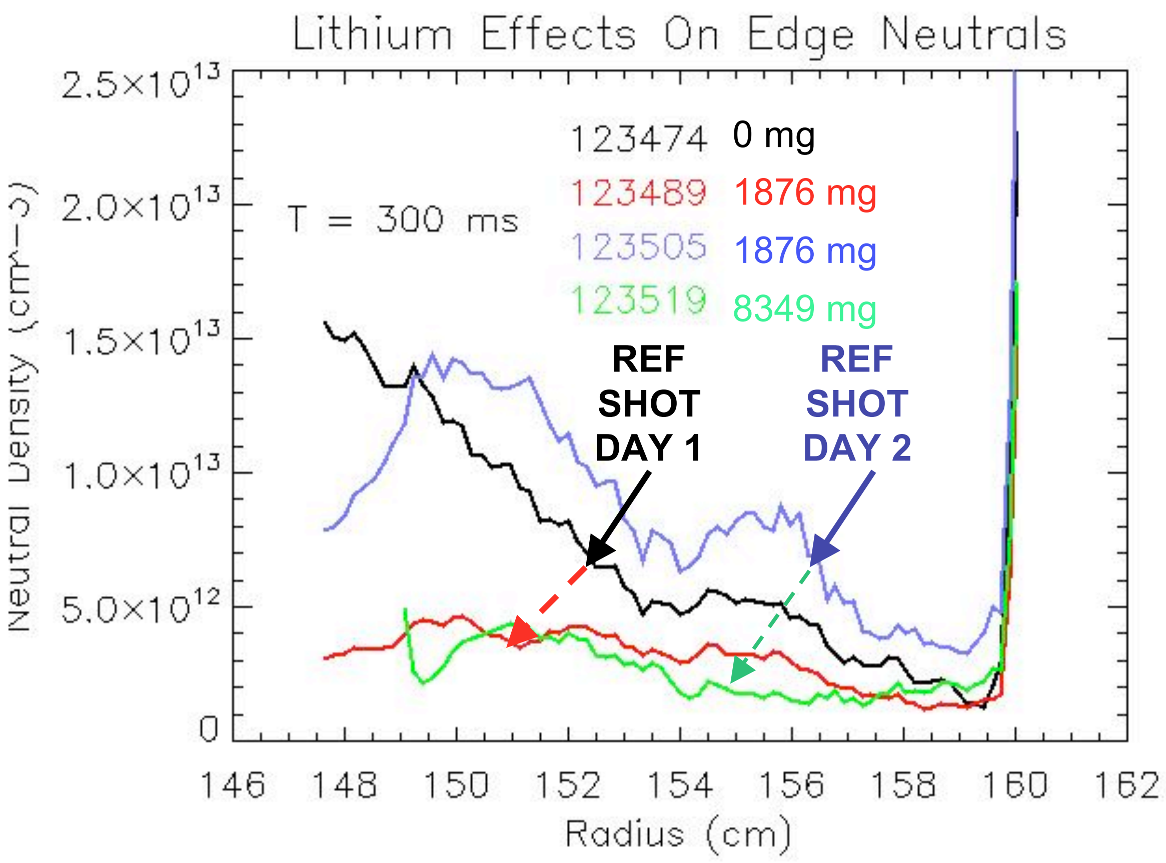
Example of Edge Neutral Density Decreasing During Lithium Deposition

NSTX

- **Pumping effect of Li decreases with time** ***- may be an indicator of Li reactions with graphite substrate and/or residual vacuum gases***

PRELIMINARY CALIBRATION



Day 2 = Day 1+ 64hrs

TP8.00073
P.W. Ross

- **Lithium is pumping strongly by the final shot of Day 1 but pumping effect completely disappeared by the reference shot of Day 2.**

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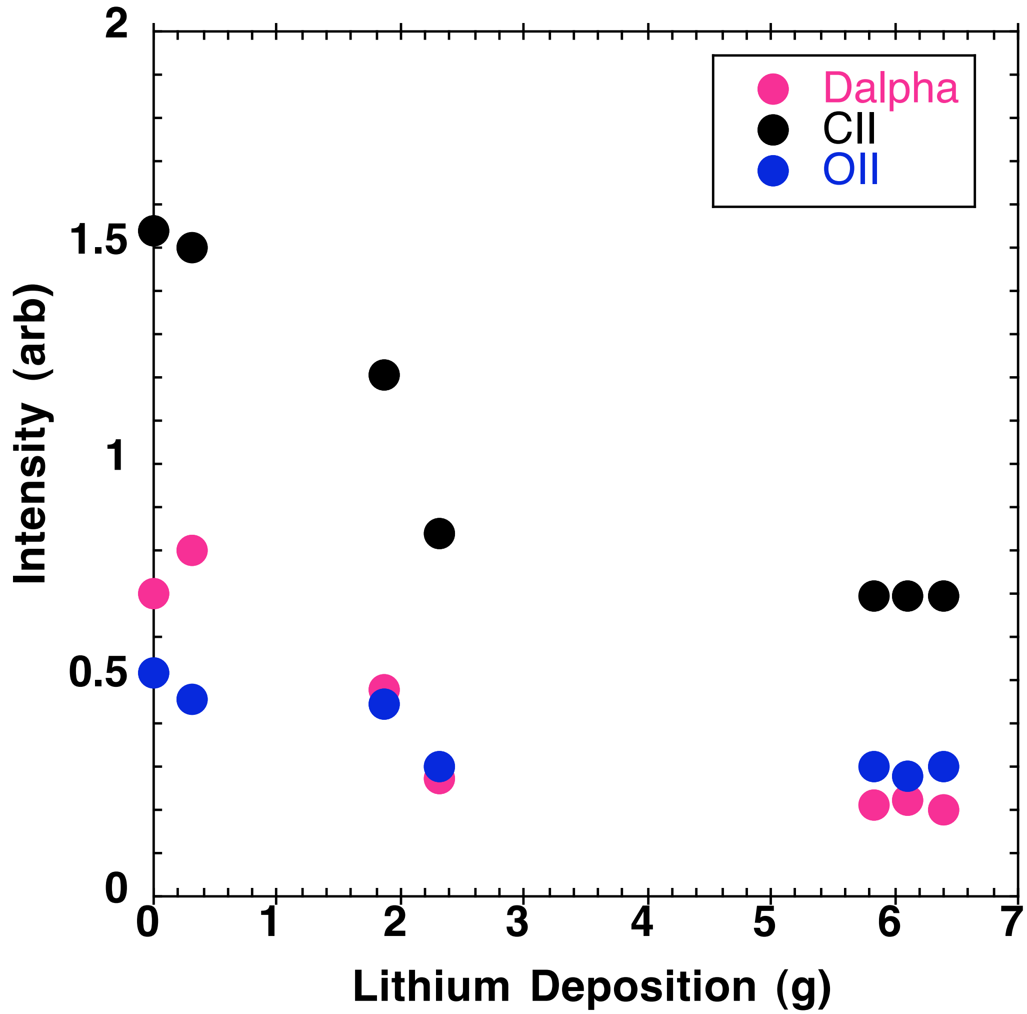
Lower Divertor Dα, C II, and O II Luminosity Decreased with Increasing Li Deposition



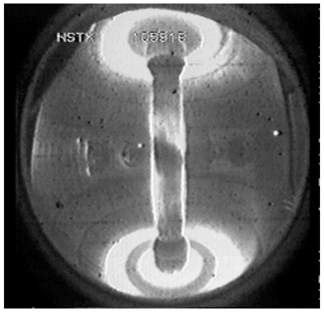
- Comparison of shots @ 200 ms with n_e within ±14% during Li deposition sequence

See also TP8.00066
J. A. Robinson

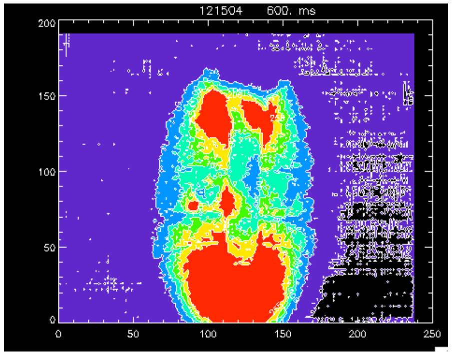
Edge Dα Luminosity Decreases Following Lithium Deposition

Plasma TV view

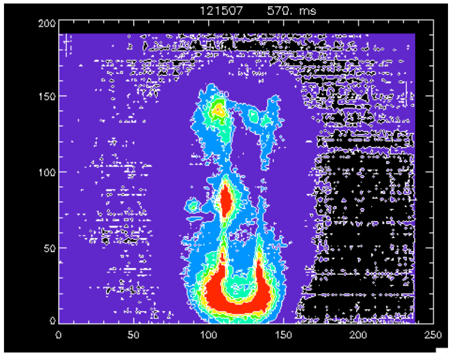
(w/o filtering)



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

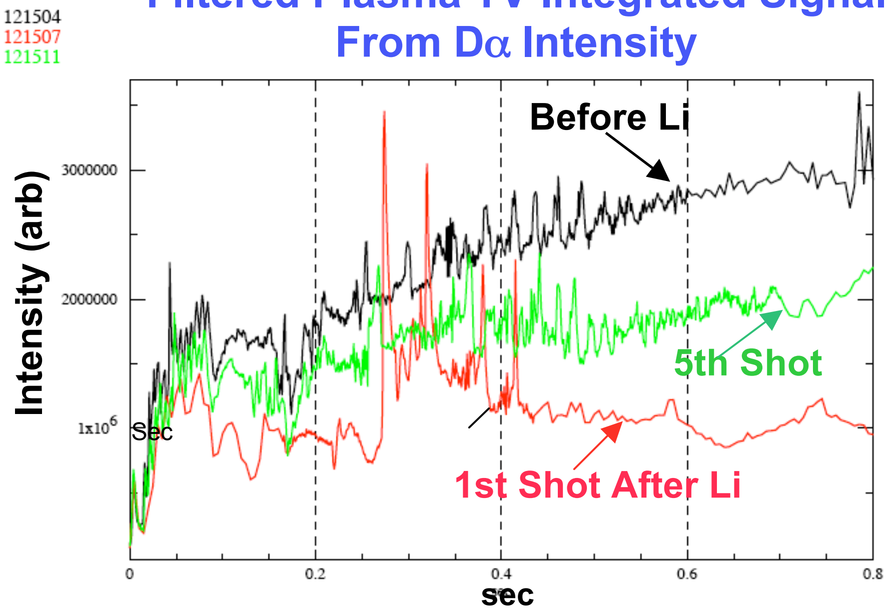


H-mode Before Li



H-mode 1st Shot After 4.8g Li

Filtered Plasma TV Integrated Signal From Dα Intensity



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

C.Bush, ORNL

Average Coverage of Li & D on 21 Graphite Tiles Measured at 2 Toroidal Locations After the 2006 Experimental Campaign

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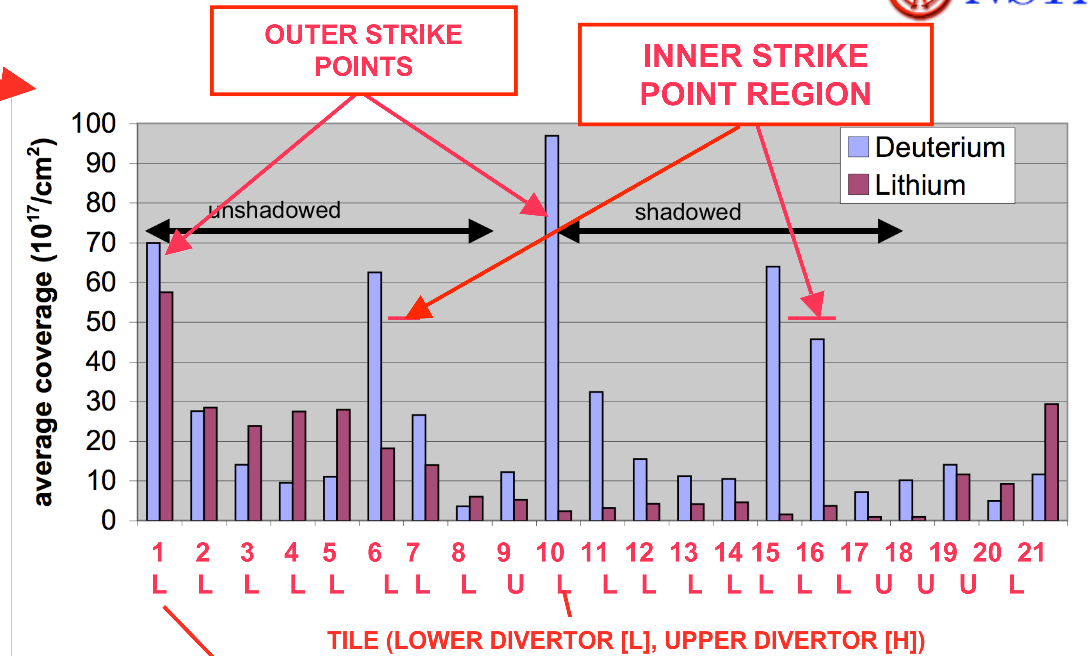
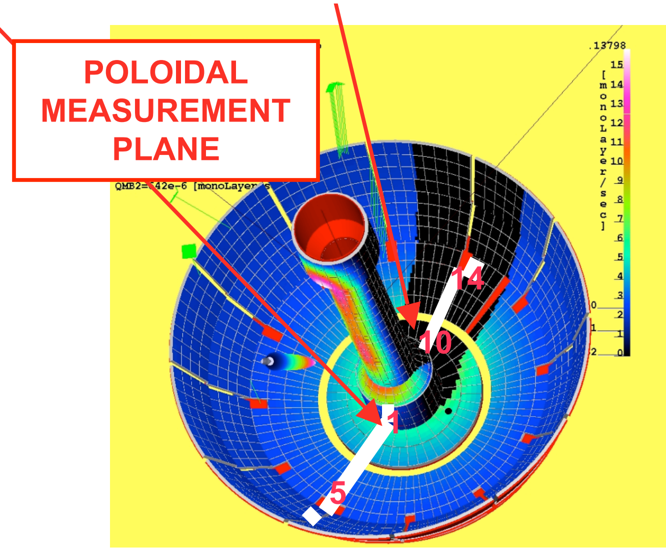
- SNL Ion Beam Analysis of 21 tiles in or near poloidal plane:
  - Lower tiles (L) exhibit more Li than upper tiles (U).
  - Tiles shadowed by the Center Stack have ~ 10x less Li than unshadowed tiles receiving direct Li deposition.
  - D coverage is similar in unshadowed and shadowed regions.
    - Li was within 5 μm of the surface everywhere. On tiles with low Li coverage the Li was within 2μm.

      -Li in mixed concentration with unresolved components.





PM5.00001
W.R. Wampler

PM5.00002
L. Zakharov

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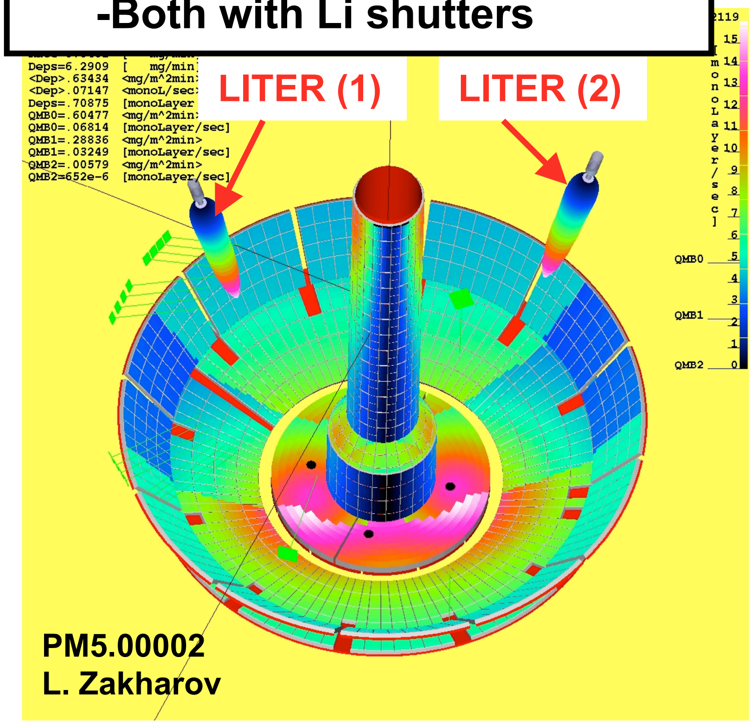
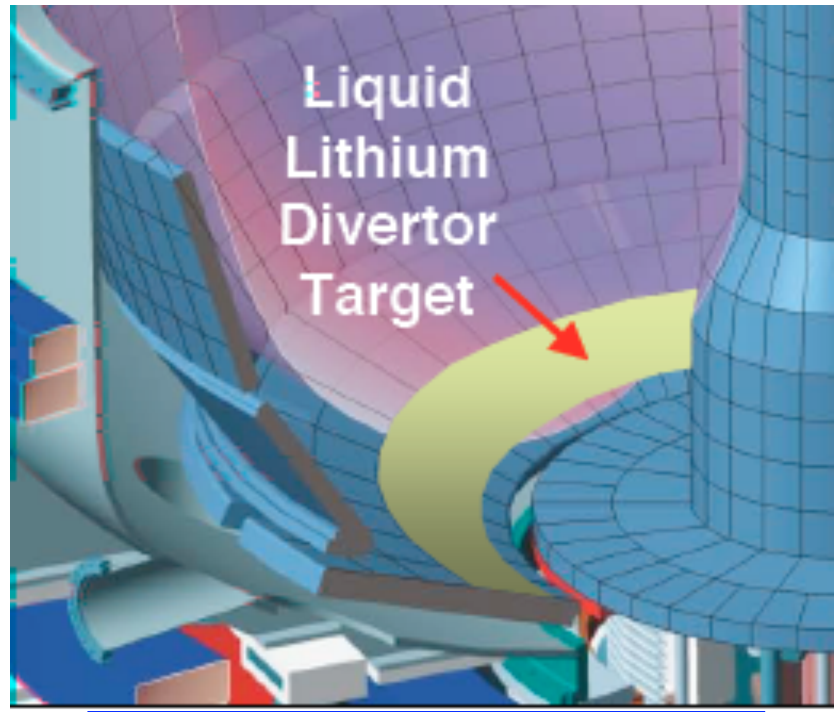
Future Plans: Liquid Lithium Divertor for Particle Control
- Unique Capability for Diverted H-mode

- **2008: Install 2nd LITER**
  - **-Both with Li shutters**



Results suggest Li thickness may be marginal
- **Fill in the shadowed region**
- **Increase active thickness in remote areas**
- **LITER Shuttered during HeGDC & shots**
- **Test Li powder injection into D shots**
  (TP8.0063, D.Mansfield)

- **Start LLD operation in 2009**



- **Improve LLD in 2010**
- **Optimize Divertor in 2012**
  - **- High power flux**
  - **- Longer pulse**
  - **- Core fueling**

Summary and Conclusions

- Effect on plasma pumping and performance of injected Li pellets and Li evaporated coatings applied immediately prior to reference shot sometimes improved results.
- Improvements observed sometimes include
  - *decreases* plasma density, inductive flux consumption, ELM frequency
  - *increases* in electron temperature, ion temperature, and quiescent time

- Work in progress:
  - the continued n_e rise, (small initial decrease in n_e, stronger increase on T_e)
  - the nature and duration of the lithium coatings,
  - reduction in ELM frequency and periods of quiescence
  - helium retention following HeGDC and perhaps eliminating HeGDC
  - diagnostic window depositions
  - operational issues with improved confinement, *e.g.,* increasing impurity content and core impurity radiation with discharge duration.(TP8.0065, S.Paul)
  - preparations for 2 LITER units and Li powder injection. (TP8.0063, D.Mansfield)

Other Related NSTX Presentations

CO3.00011, *Recent EBW Emission Results in NSTX,* S.J. Diem

CO3.00014, *Lithium Loaded Target Plate for Driving NSTX Toward High Performance,* L. Zakharov

PM5.00001, *Lithium and Deuterium on NSTX Carbon Tiles*, W.R. Wampler

PM5.00002, *Deposition on NSTX Plasma Facing Components by LITER-1 Evaporator in 2006*, L. Zakharov

PM5.00003, *Surface Analysis of Lithium Coatings in NSTX,* J.R. Timberlake

PM5.00004, *Mass Changes in NSTX Surface Layers with Li Conditioning as Measured with Quartz Microbalances,* C. H. Skinner

PM5.00005, *In-situ Elemental and Chemical State Characterization of Lithiated Surfaces Under Energetic Particle Bombardment*, J.-P. Allain

TP8.062, *Effects of Evaporated Li Coatings on Plasma Facing Surfaces in NSTX,* M.G. Bell

TP8.063, *NSTX Conditioning Experiment Using Injected Lithium Powder,* D. Mansfield

TP8.064, *Effects of Lithiumization on Electron Temperature and Density Profiles,* B.P. LeBlanc

TP8.065, *Measurements of Radiated Power During LITER operation in NSTX,* S. Paul

TP8.066, *Spectroscopy of NSTX Plasmas During Li Wall Conditioning Experiments,* J. Robinson

TP8.067, *XPS studies of NSTX tiles and in-situ analysis of Li exposed graphite simulating plasma-Li surface interactions,* J.P. Allain

TP8.068, *UEDGE Simulations of the NSTX Liquid Lithium Divertor Module* D.P. Stotler,

TP8.073, *Beam Modulation effects on NSTX Ion Power Balance*, P.W. Ross