NSTX Experiments with Lithium Plasma-Facing Components – Recent Results and Future Plans*

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50th Meeting of the American Physical Society Division of Plasma Physics
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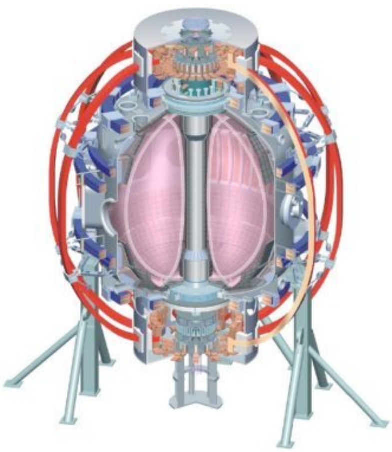

NSTX
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Abstract*

Recent NSTX high power, H-mode divertor experiments have shown significant and recurring benefits from active lithium coatings on PFC's. Two lithium evaporators were used to routinely evaporate lithium onto the NSTX lower divertor region between discharges. The major improvements in plasma performance from these lithium depositions include: 1) plasma density reduction as a result of lithium deposition; 2) suppression of ELMs; 3) improvement of energy confinement in a low-triangularity equilibrium; 4) improvement in plasma performance for standard, high-triangularity discharges; 5) reduction of the required HeGDC time between discharges; 6) increased pedestal electron and ion temperature; 7) reduced SOL plasma density; and 8) reduced edge neutral density. The next step in this work is installation of a liquid lithium divertor (LLD). Physics design and progress in implementation will be discussed.

* Work supported by USDOE Contract DE-AC02-76CH03073.

Motivation

- **A decade of international research on liquid lithium indicates that it has promise for providing a self-healing plasma facing surface in a DT reactor.**
- **NSTX 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.**
- **NSTX has embarked on a multi-phase plan to use lithium for particle control and power handling:**

  I. Lithium Pellet Injector (2005-2009)

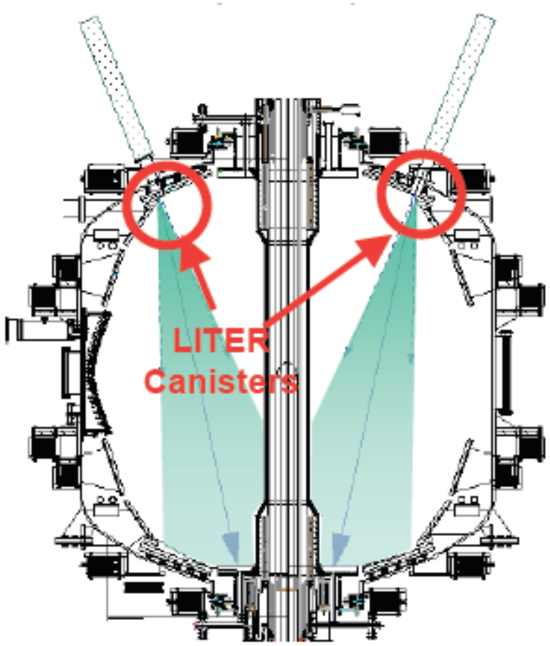
  II. Lithium Evaporator (2006-2009)

  III. Liquid Lithium Divertor (2009-2012)

- ***This phased approach is allowing NSTX operations, diagnostics, and its research program to be adapted to lithium wall conditions.***
- **Research in 2008 to date has focused on the use of 2 <u>LIT</u>hium <u>E</u>vaporato<u>R</u>s (LITER) for full coverage of the lower divertor region and high deposition rates.**
- ***NSTX is moving to Phase III with preparations for the installation in 2009 of a module to provide a liquid lithium surface in the lower divertor region.***

Dual LIThium EvaporatoR (LITER) 2008 Configuration

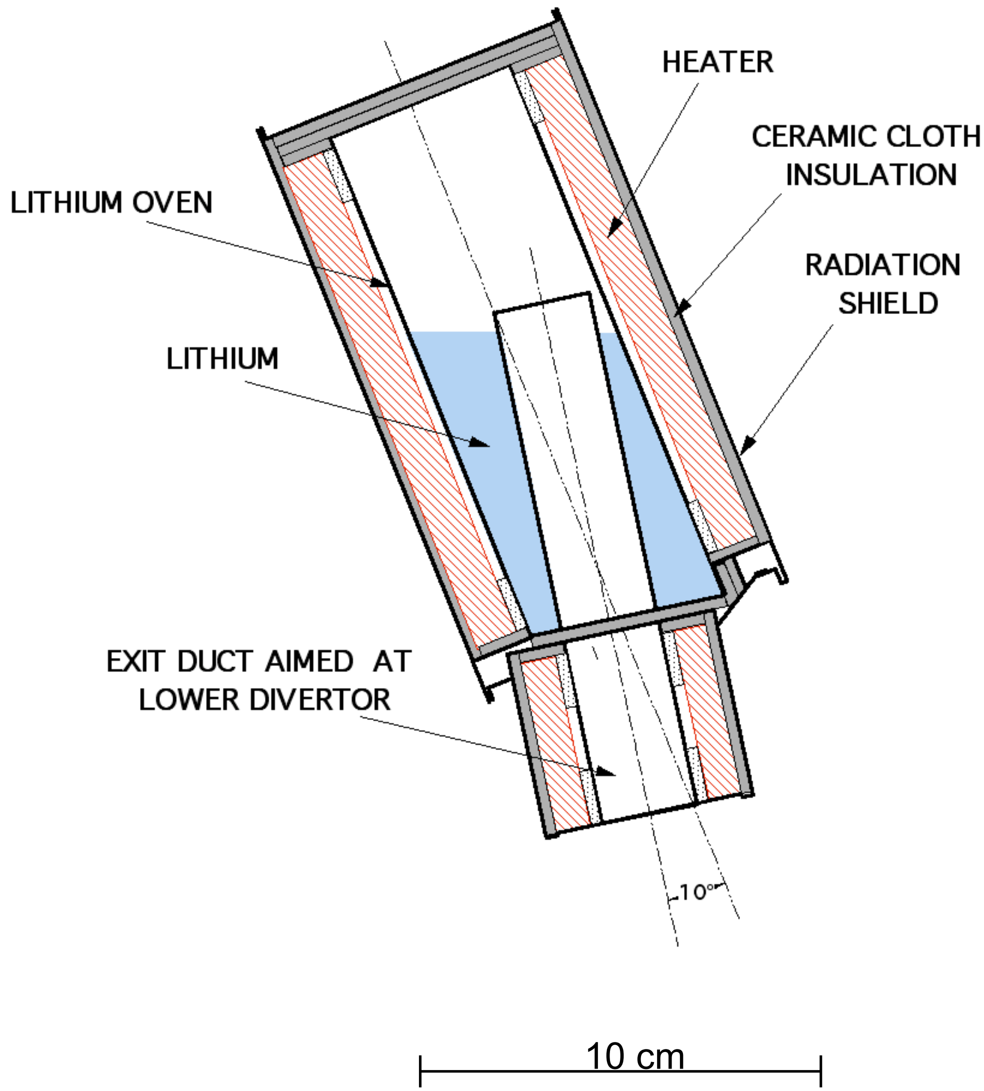
Dual LIThium EvaporatoRs (LITERs) deposited lithium on entire lower divertor



- LITER central aiming axis to graphite divertor and gaussian angle at 1/e (dashed)

- During 2008 LITER evaporated 120 g of Li into vessel and 43 g on each LITER shutter

Design of LIThium EvaporatoR Shown in Operating Orientation



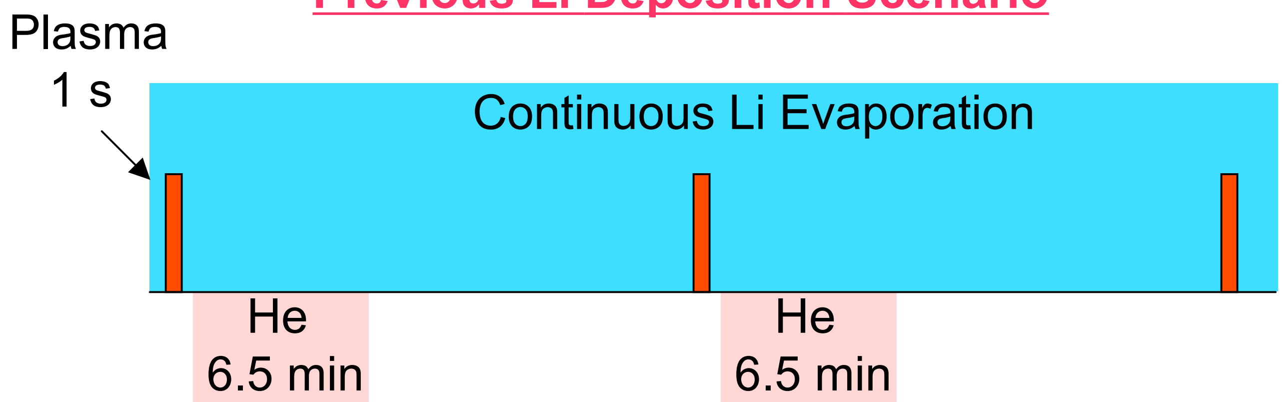
- **LITER on probe & loaded with Li under argon**

•Typical Operating Conditions

- **Capacity: 90 g Li**
- **Oven Temp: 600-680°C**
- **Rate: 1mg/min - 80mg/min**

Newly-Installed LITER Shutters Allow More Flexible Lithium Wall Conditioning

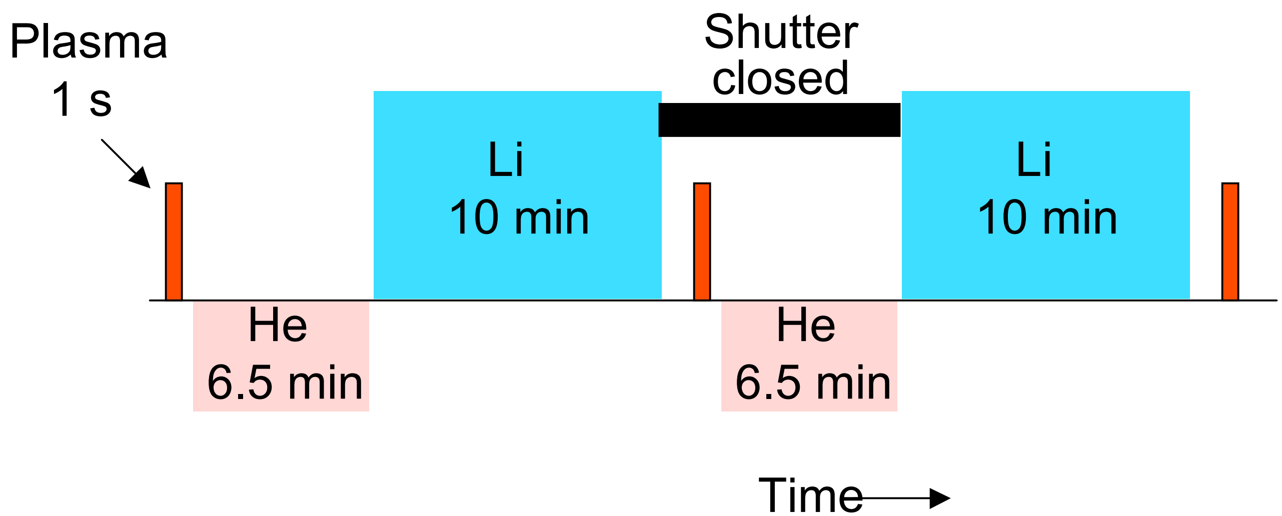
Previous Li Deposition Scenario



Disadvantages

- Window coating during discharge
- Codeposition of Li and He during HeGDC
  - Causes He dilution of D plasma

New Li Deposition Scenario Using Li Shutters

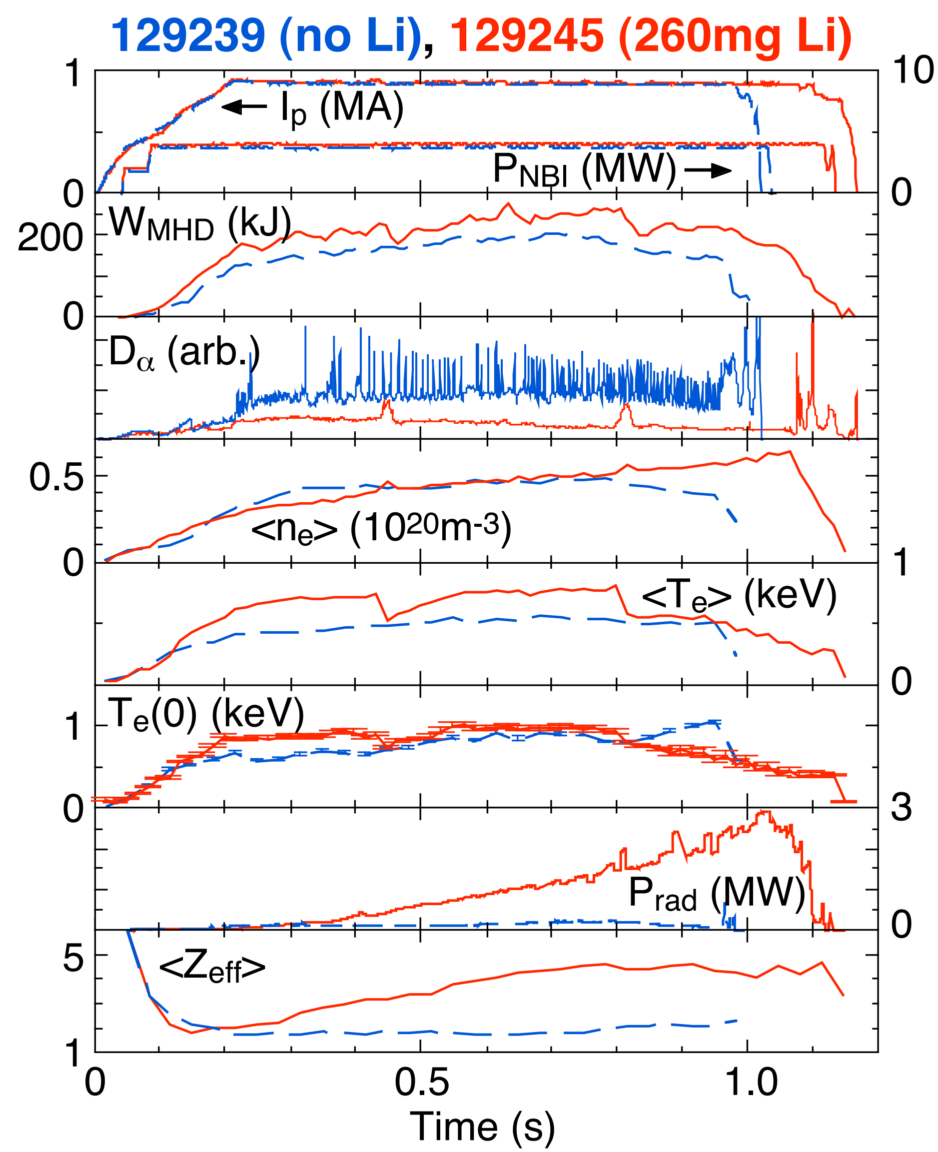


Advantages

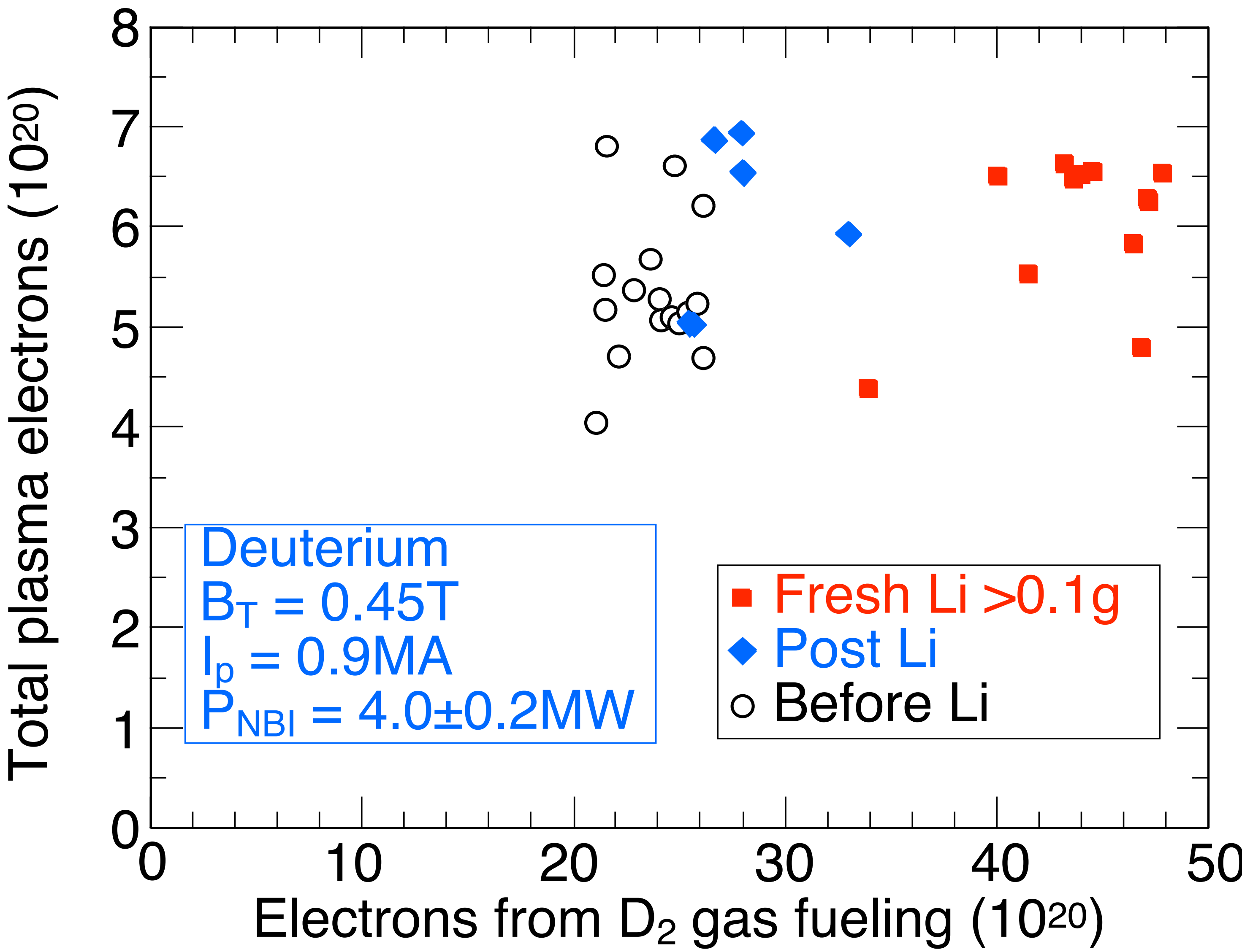
- No window coating during discharge
- No codeposition during HeGDC
  - Avoids He dilution

Solid Lithium Coating Reduces Deuterium Recycling, Suppresses ELMs, Improves Confinement

- Broader T_e reduces internal inductance l_i and inductive flux consumption.
- In time, the lack of ELMs causes the density in the discharge with Li to overtake the shot without Li.
- Without ELMs, impurity accumulation increases P_{rad} and Z_{eff}
- Similar effects produced by injecting stream of lithium powder into scrape-off

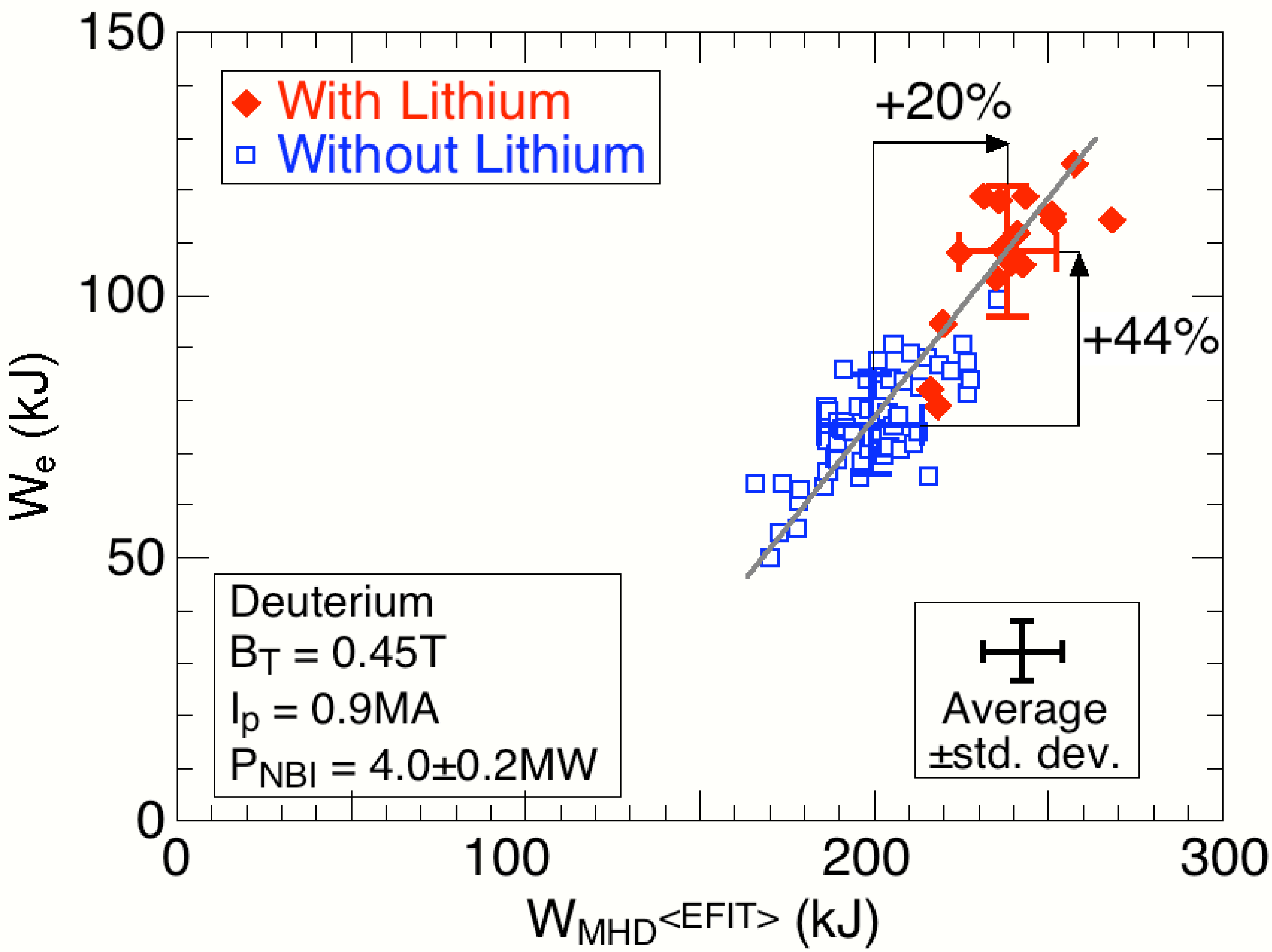


Lithium Edge Conditions Require Large Fueling Increases to Maintain Density



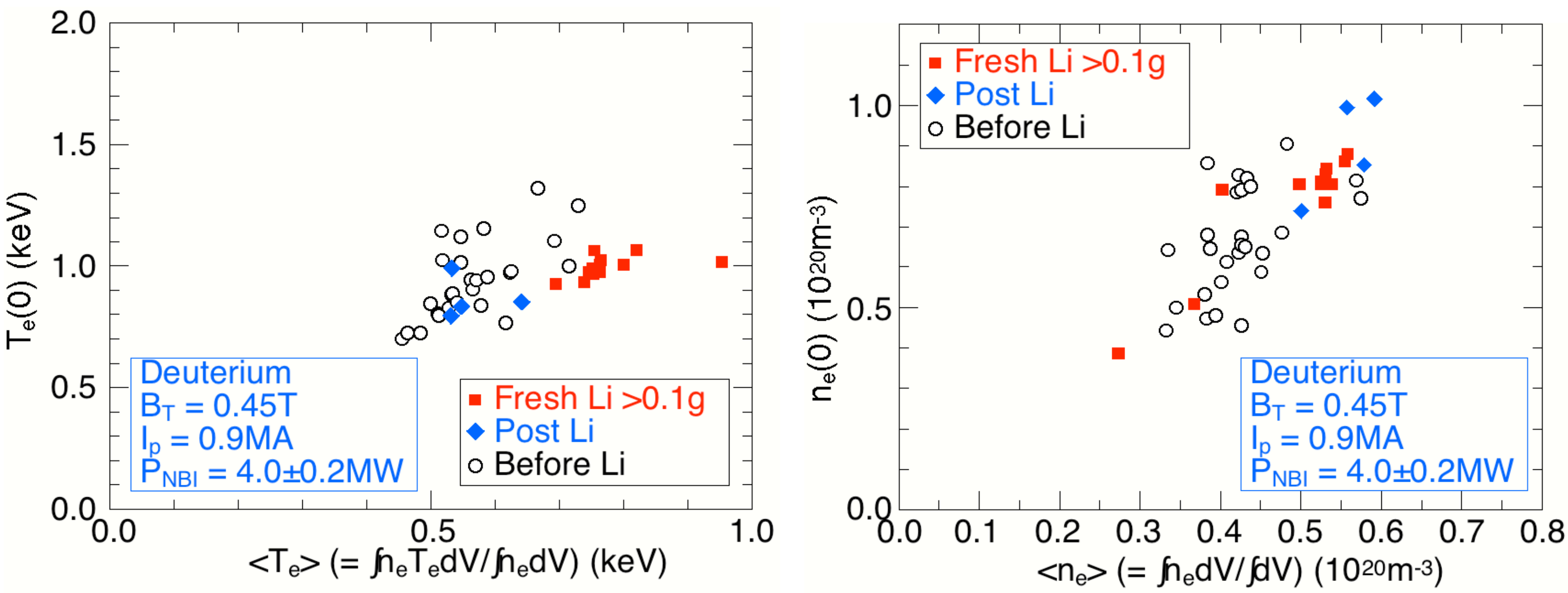
M. G. Bell

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



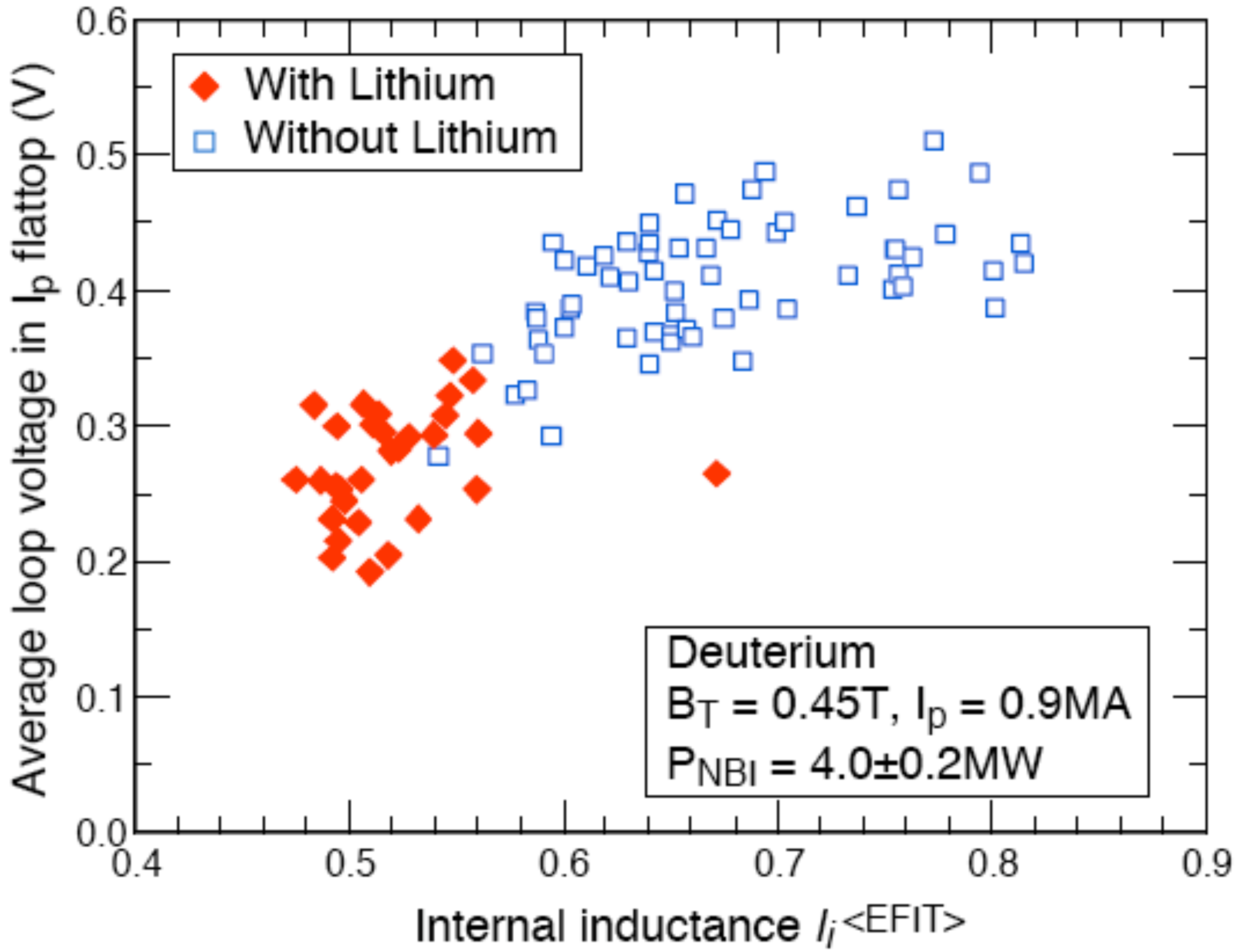
G. Bell

Lithium Edge Conditions Broaden Electron Temperature Profile but Density Profile Unaffected



M. G. Bell

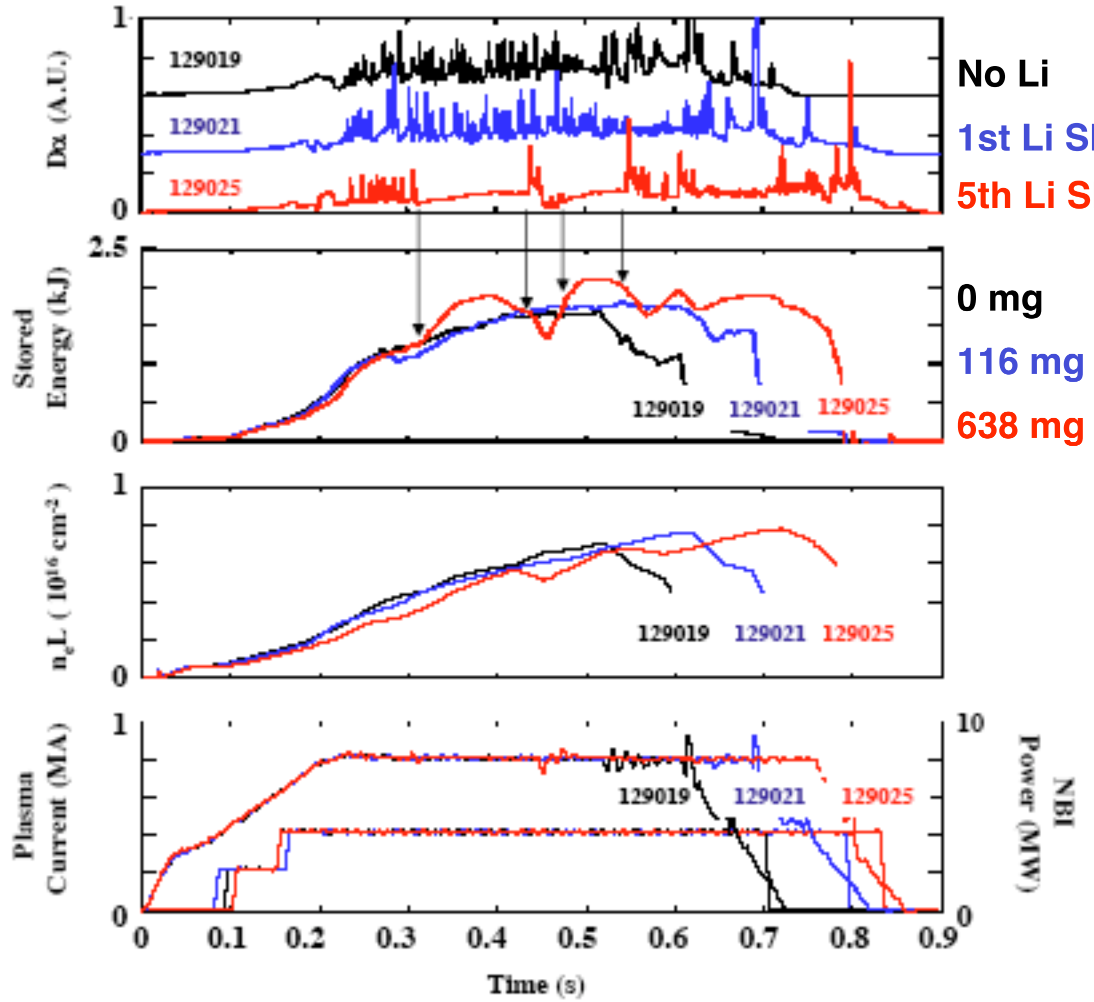
Lithium Edge Conditions Yield Lower Average Loop Voltages and More Efficient OH Flux Consumption



M. G. Bell

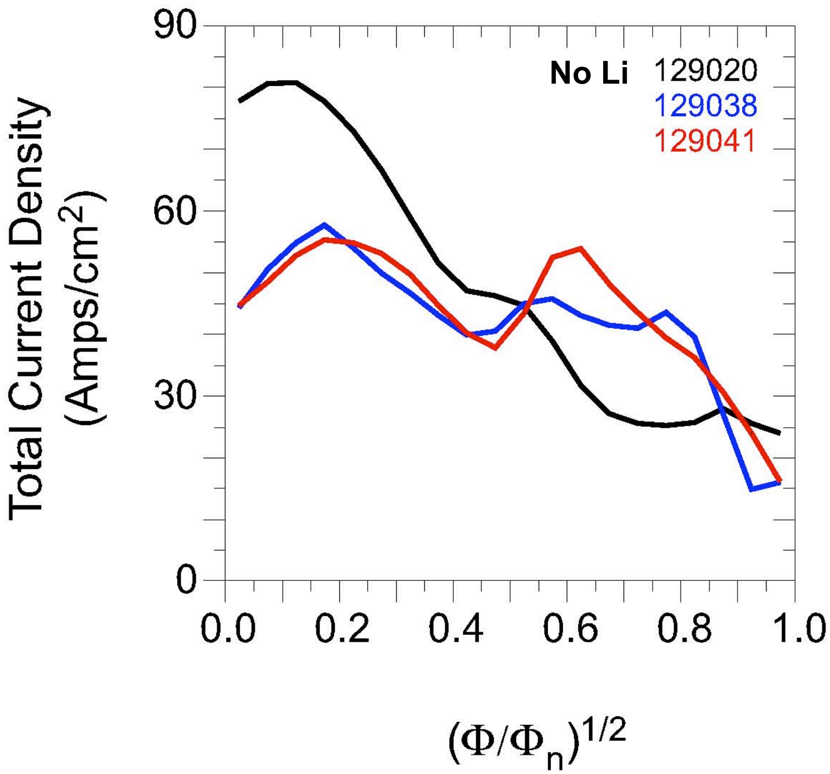
ELM Suppression by 5th Discharge With Li
No ELMs ⇒ Immediate Increase in Stored Energy

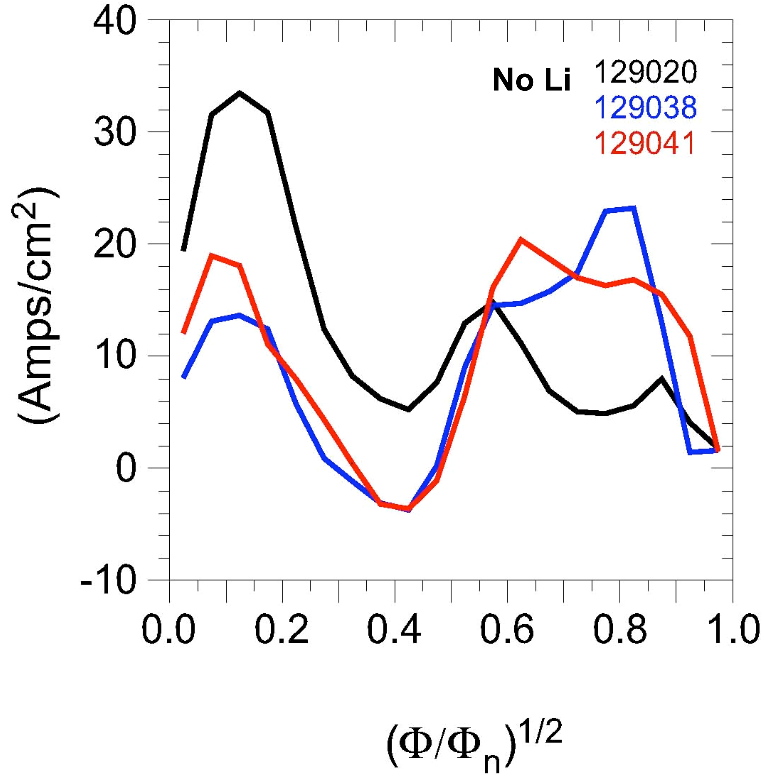
- As Li increases
  - ELMs decrease
  - Stored energy increases
  - Pulse lengthens
- At higher Li evaporation rates and higher PFC accumulations, complete ELM suppression occurs
  ⇒ higher confinement



D. Mansfield

Lithium Edge Conditions Yield ELM Suppression
TRANSP Analysis Finds Increase in Edge Current

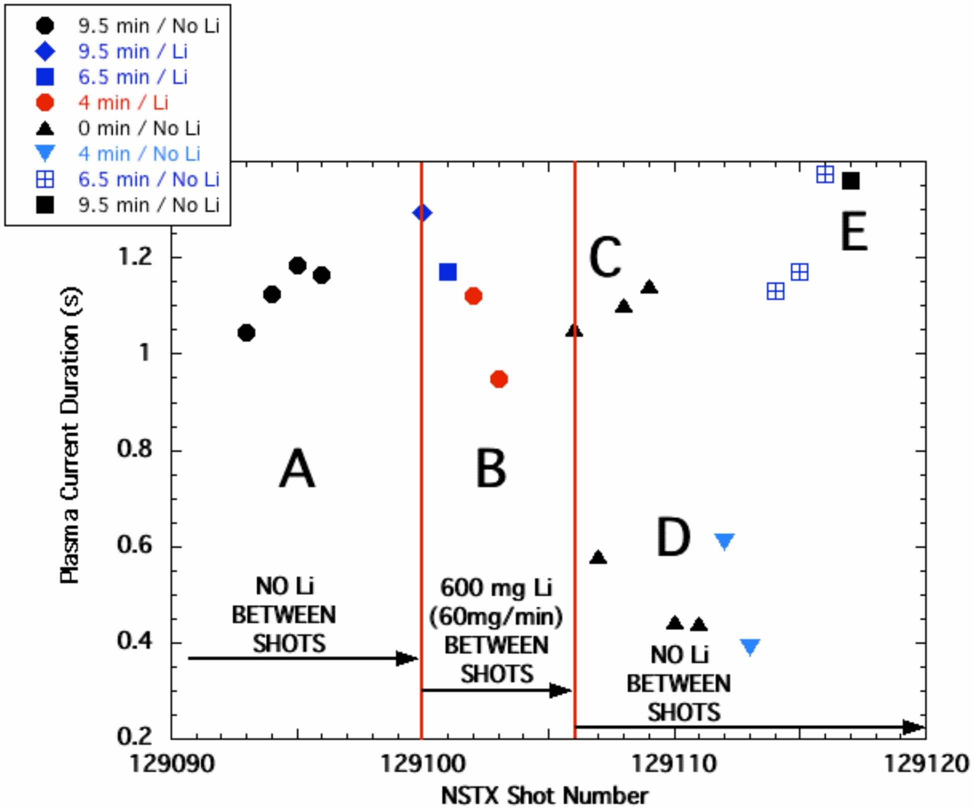




Stability Analysis in Progress

S. Kaye

Lithium Edge Conditions Allowed Long H-mode Plasmas with Reduced or No HeGDC

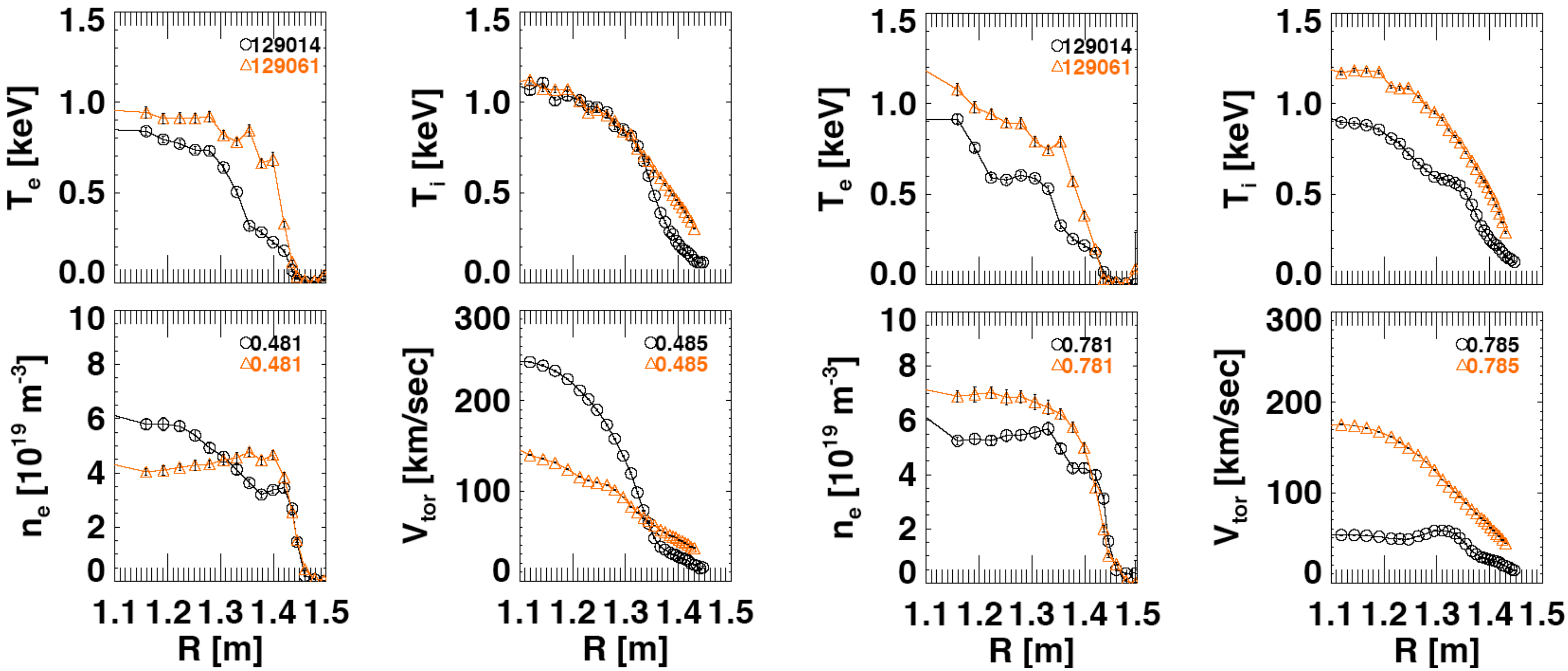


- **A - Reference shots with 9.5 min of HeGDC and no Li between shots.**
- **B - HeGDC shortened from 9.5 to 4 min followed by 10 min Li deposition.**
- **C - No HeGDC followed by no Li deposition.**
- **D - Initially at C no change, but by D conditions degrade.**
- **E - Reapplication of HeGDC restored and exceeded initial conditions (A).**

Lithium Edge Conditions Increased Pedestal Electron and Ion Temperature

- Li
- No Li

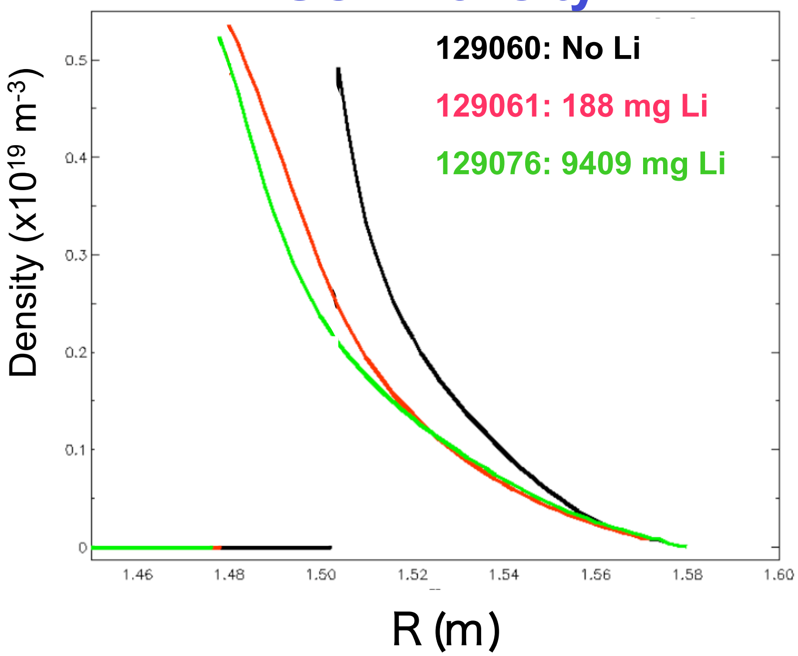
481 ms *TIME* → **781 ms**

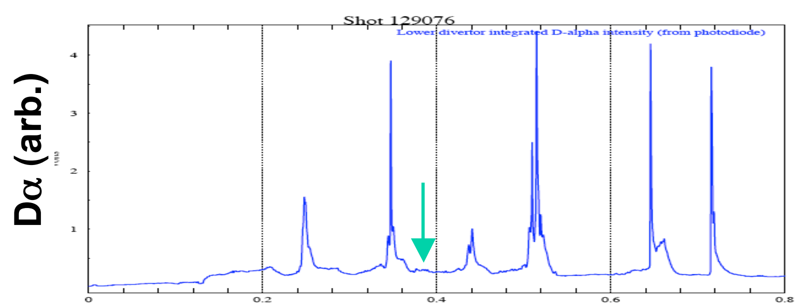


R. Maingi, ORNL

Lithium Edge Conditions Reduce SOL and Edge Neutral Density and Suggest Lower Recycling

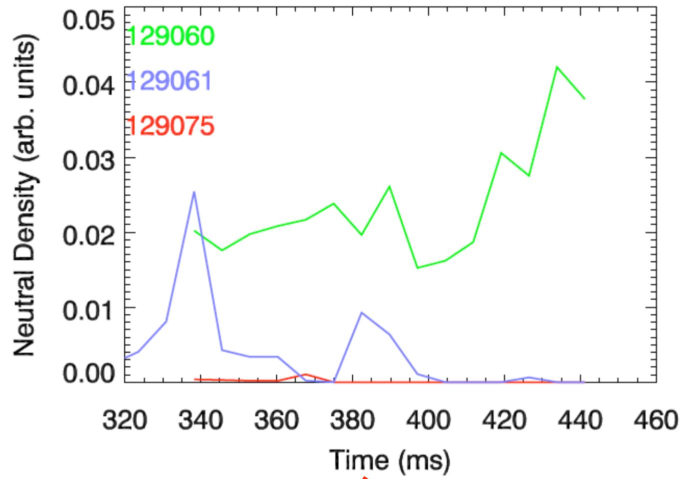
SOL Density*

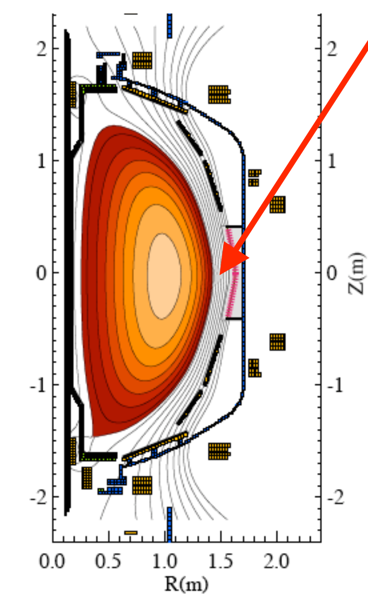




*J. B. Wilgen et al., Rev. Sci. Instrum. 77, (2006) 10E933.

Edge Neutral Density

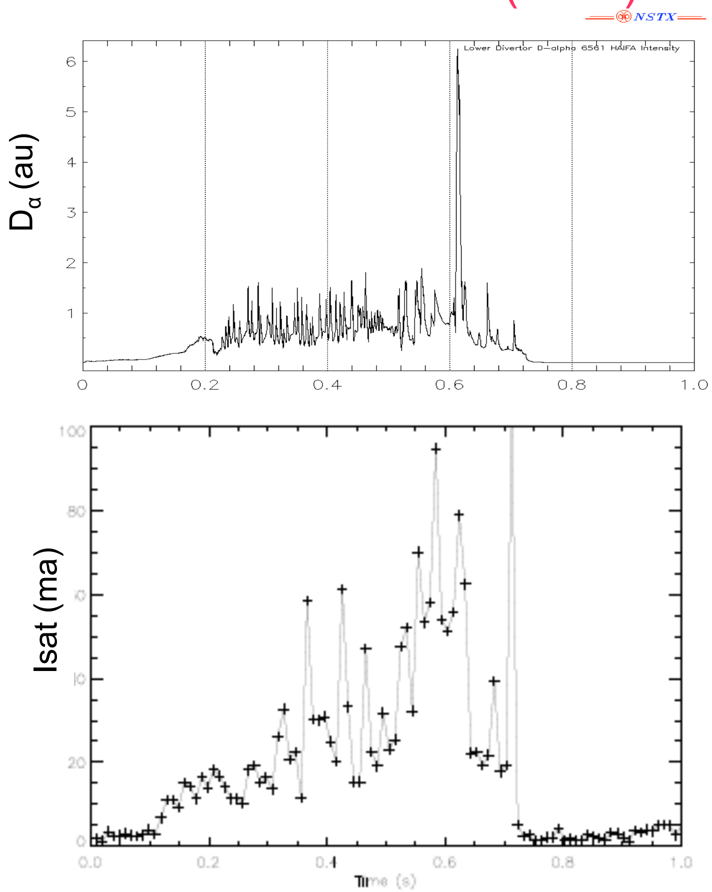




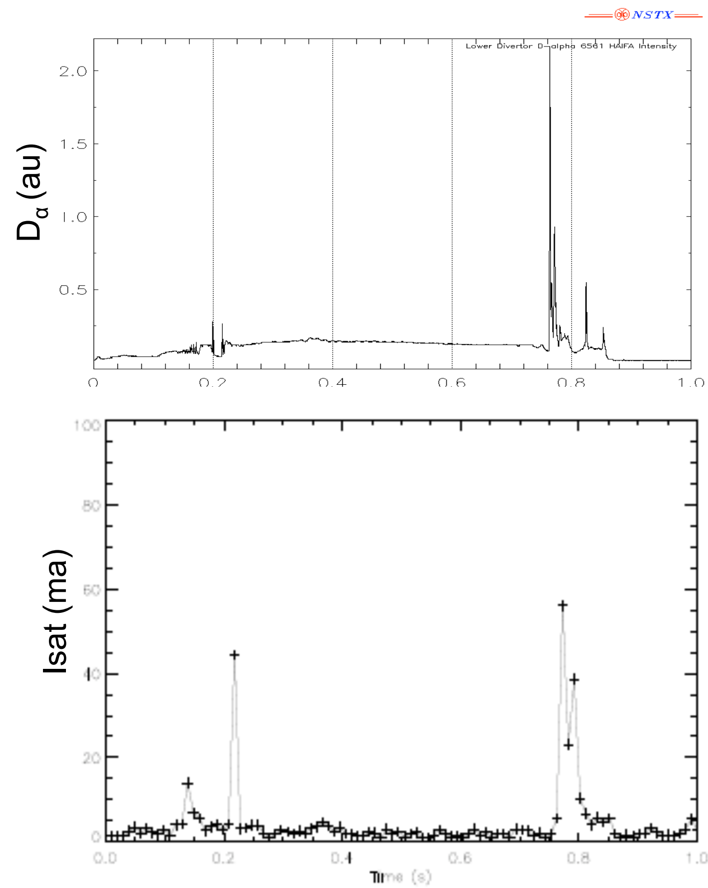
P. W. Ross

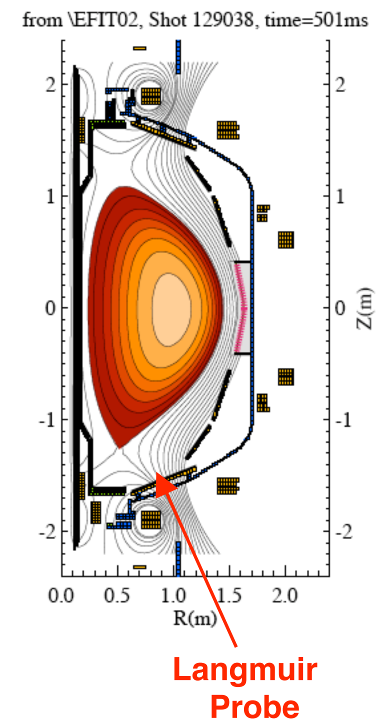
During Lithium Edge Conditions ELM Suppression Reduces Flux to Divertor Langmuir Probe Outside Separatrix

Shot 129019 (no Li)



Shot 129038 (Li, 5734 mg)



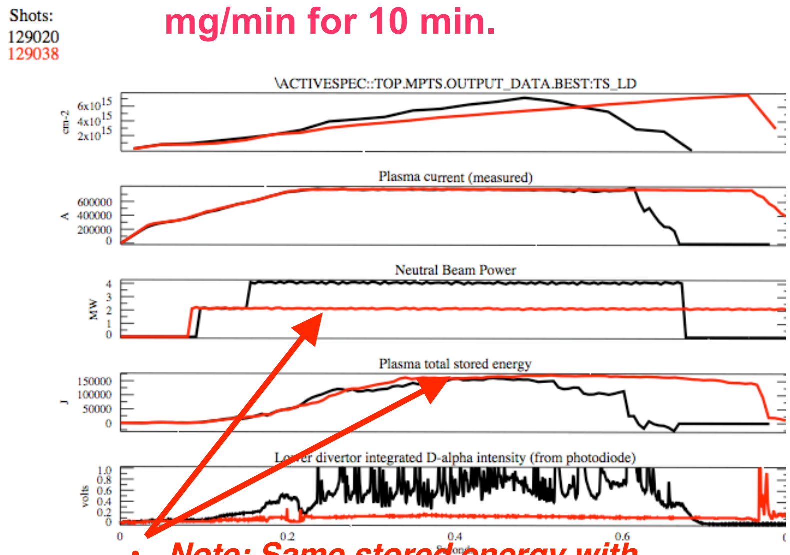


- **Tile mounted Langmuir probe is located at r = 0.91 m, z =- 1.52 m, on lower outer divertor. Radius of outer strike point is ~0.8 m.**

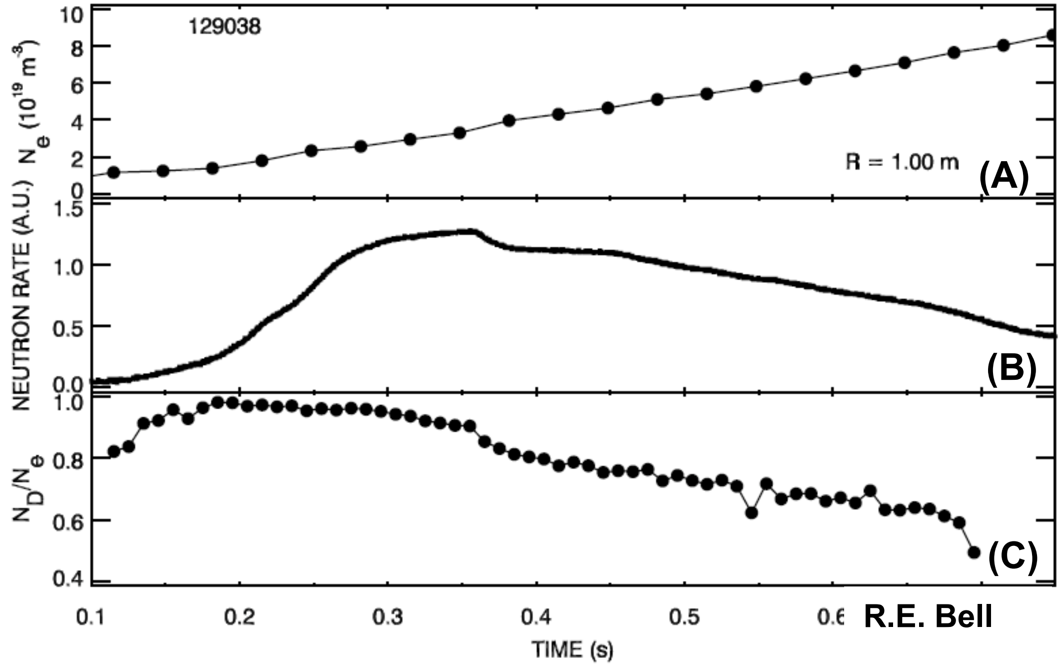
J. Kallman

Uncontrolled Density and Impurity Rise Due to Increasing Confinement: Deuterium-to-Central Density Ratio Decreases, Neutron Rate Decreases

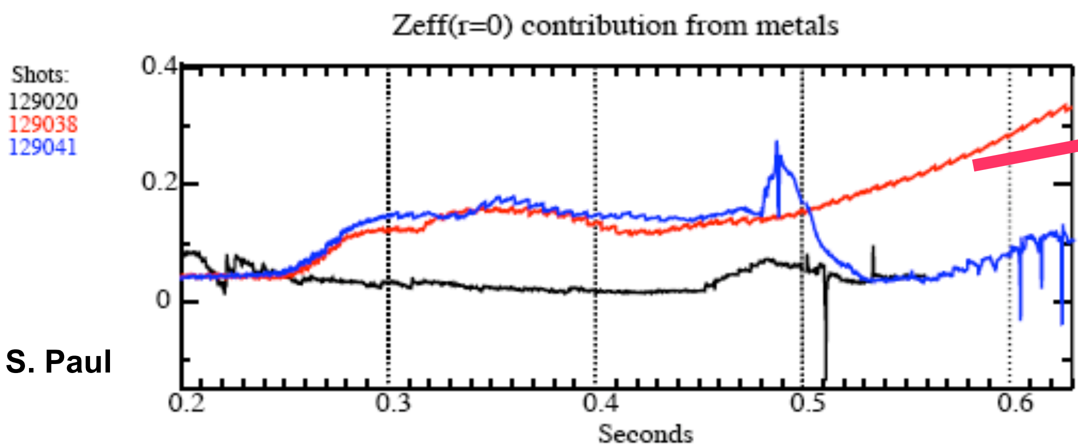
- **Li Deposition Before Shot: 70 mg/min for 10 min.**



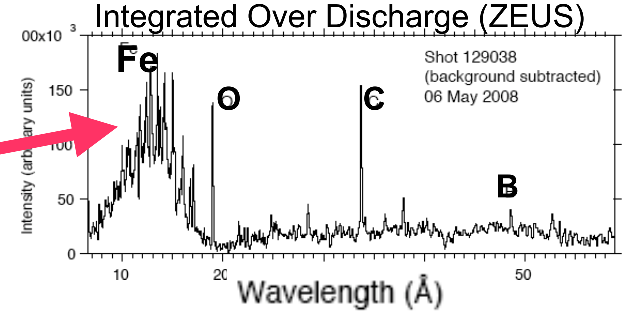
- *Note: Same stored energy with half the Input power*



R.E. Bell



S. Paul



J.K.Lepson, UCB SSL
P.Beiersdorfer, LLNL

Summary of Recent Results

- In recent experiments, the dual LIThium EvaporatoR (LITER) evaporated more than 100g of Li into NSTX
  - The LITERs routinely deposited lithium on the lower divertor target for 10 min, at combined rates of 10-70 mg/min
  - Prior to each discharge, the LITERs were withdrawn behind shutters
  - The shutters remained close during a subsequent period of HeGDC
  - The shutters were then reopened and the deposition cycle repeated
- The effects of the lithium on standard discharge scenarios include:
  1. Reduced plasma density in the early phase of the discharge
  2. Suppression of ELMs
  3. Improved energy confinement
  4. Reduced flux consumption for standard, high-triangularity discharges
  5. Reduced HeGDC time between discharges to maintain the H-mode
  6. Increased pedestal electron and ion temperature
  7. Reduced SOL plasma density and edge neutral density
  8. Discharges longer after lithium when combined with n=1 and n=3 mode control by the external non-axisymmetric coils due to reduced MHD activity

Future Plans: NSTX Will Test the Potential Benefits of a Liquid Lithium Divertor (LLD) for Integrating High Plasma and PSI Performance

- **LLD-1**
  - *The Outer Divertor is the initial lowest technical and programmatic risk location for LLD-1 to the high performance, high δ, ST research program*
  - LLD-1, 20 cm wide pumping on Outer Divertor provides reduction in density for increased neutral beam current drive capability

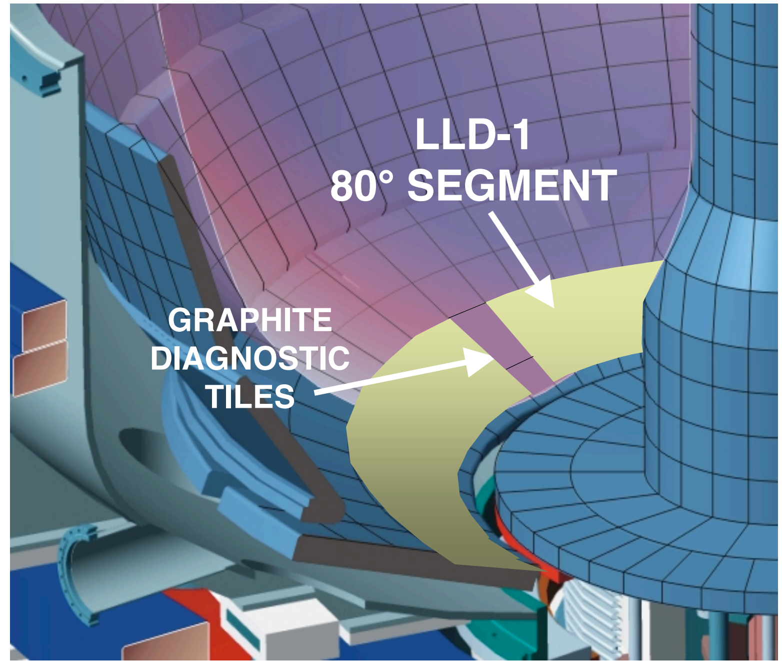
- **LLD-2**
  - Enable n_e scan capability in long pulse H-mode
    - Increase filling rate (powder, capillary) to wider area Mo mesh or foam
    - Test ability to operate at significantly lower density (NHTX, CTF)

- **LLD-3**
  - Investigate power handling for long-pulse with high heat-flux
    - *long pulse (5s) power handling surface with active cooling (capillary flows,swirl tubes, helium gas, hypervaportrons, evaporative cooling) for 16 MW (2NBI + RF) operation*
    - Higher lithium fill rates (capillary flow replenishment planned for FTU)

- LLD-1 Status
  - Final Design Review successful. SNL for procurement in progress.
  - Successful PDR for LLD-1 Diagnostics. LLD Controls FDR scheduled for Dec.08
  - Planning to complete installation for 2009 operation.

2009: LLD-1 Plate Design With Thin Lithium Film on High-Z Bonded to Copper is Highest Confidence Approach

- Location - lower outer divertor in four 90°sections.
- Width - 20 cm starting 5 cm outboard of CHI gap.
- Shape - replaces present graphite tiles.
- Structure - 0.01cm Mo flame-sprayed on 0.02 cm SS brazed to 1.9 cm Cu. Resistive heaters and cooling lines maintain 200-400°C.
- Li Loading - 2 lithium evaporators.



- Each toroidal section electrically grounded to vessel at one mid-segment location to control eddy currents

- Each toroidal section fastened at 4 corners to divertor copper baseplate with fasteners providing structural support, electrical isolation, and accommodating thermal expansion (design adopted from JET PPPL collaboration)

- Narrow graphite tile transition regions between sections contain thermocouples, Langmuir probes, and magnetic & current sensors