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Operational Characteristics of Liquid Lithium Divertor on NSTX

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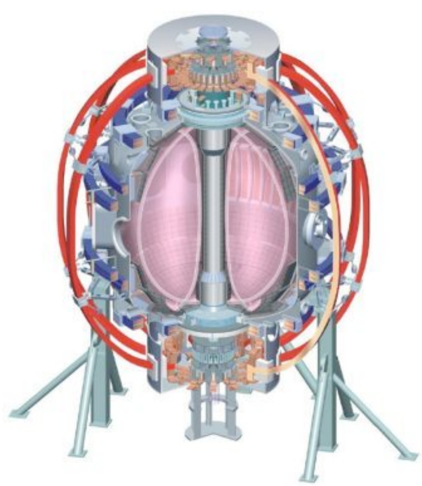
R. Kaita for the NSTX Team

Princeton Plasma Physics Laboratory

52nd Annual APS Division of Plasma Physics Meeting

Chicago, IL

November 10, 2010



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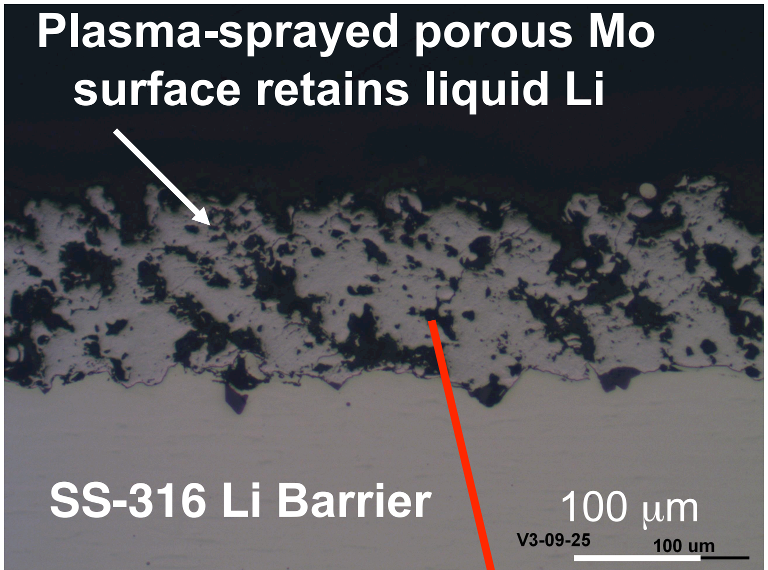
Outline

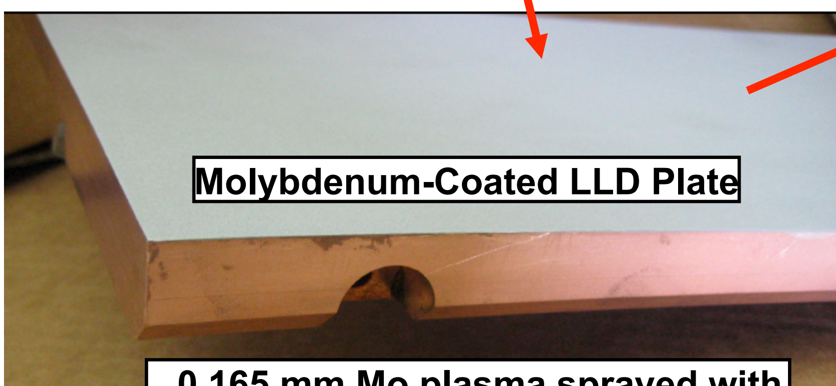
- Motivation for Liquid Lithium Divertor (LLD)
- Design features of LLD
- Effects of high power density on LLD
- Results of LLD sample testing
- Performance of LLD heaters
- Plasma behavior in presence of LLD
- Conclusions and future plans

Liquid lithium studies on NSTX motivated by promise as solution for fusion reactor first-wall challenges

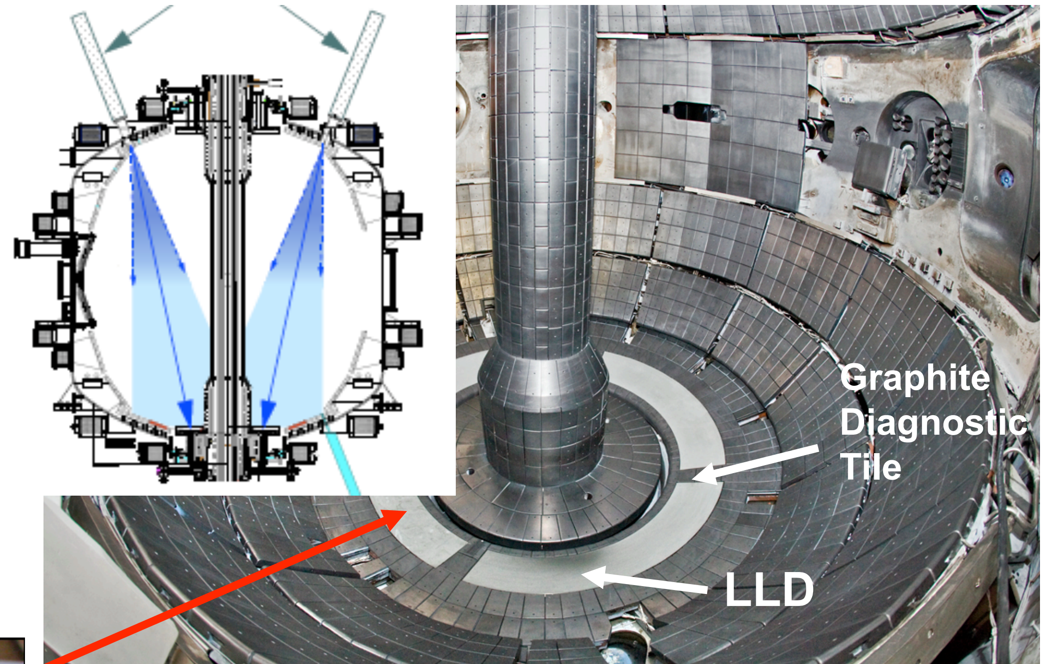
- NSTX lithium program on ***diverted H-modes*** grew from experience in TFTR, T-11M, CDX-U, and other limiter plasma experiments
- Goal is to use liquid lithium to control density, edge recycling, impurity influx, and eventually power handling
- Edge fueling requirements decrease as plasma D efflux incident on Li forms LiD
    - *Solid lithium adequate for short pulse capability but has limited LiD capacity*
    - *Liquid lithium has much higher LiD capacity and has potential for power handling and "self healing"*
    - *"Zero-D" simulations suggest potential for density control using liquid lithium divertor in NSTX*
- Long-term NSTX objective is to investigate capability of liquid lithium to provide common solution for key fusion issues
    - Divertor pumping over large surface area compatible with high flux expansion approach to power exhaust and low collisionality
    - Sustained improvement of confinement and ELM reduction and elimination
    - High heat flux handling

Liquid Lithium Divertor (LLD) installed in NSTX with low-sputtering porous molybdenum surface



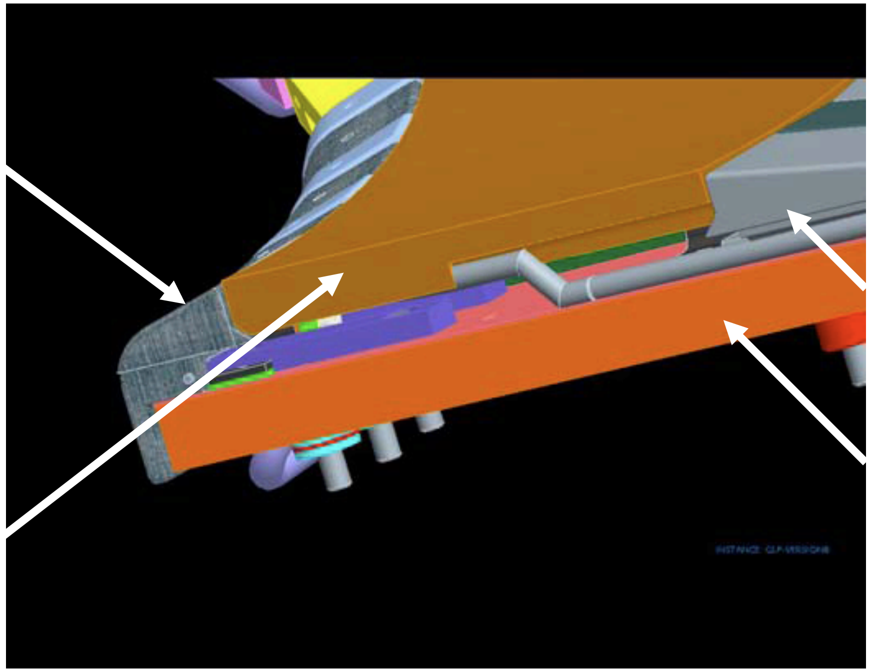


0.165 mm Mo plasma sprayed with 45% porosity on a 0.25 mm SS barrier brazed to 22.2 mm Cu.



- **Stainless steel on copper first used on Lithium Tokamak Experiment (LTX)**
- **4 heated plates (80°each) separated by graphite diagnostic tiles. Each section electrically grounded at one location to control eddy currents**
- **LLD loaded by lithium evaporators in upper dome as illustrated in inset**

NSTX operation with LLD successfully demonstrates basic soundness of mechanical design*

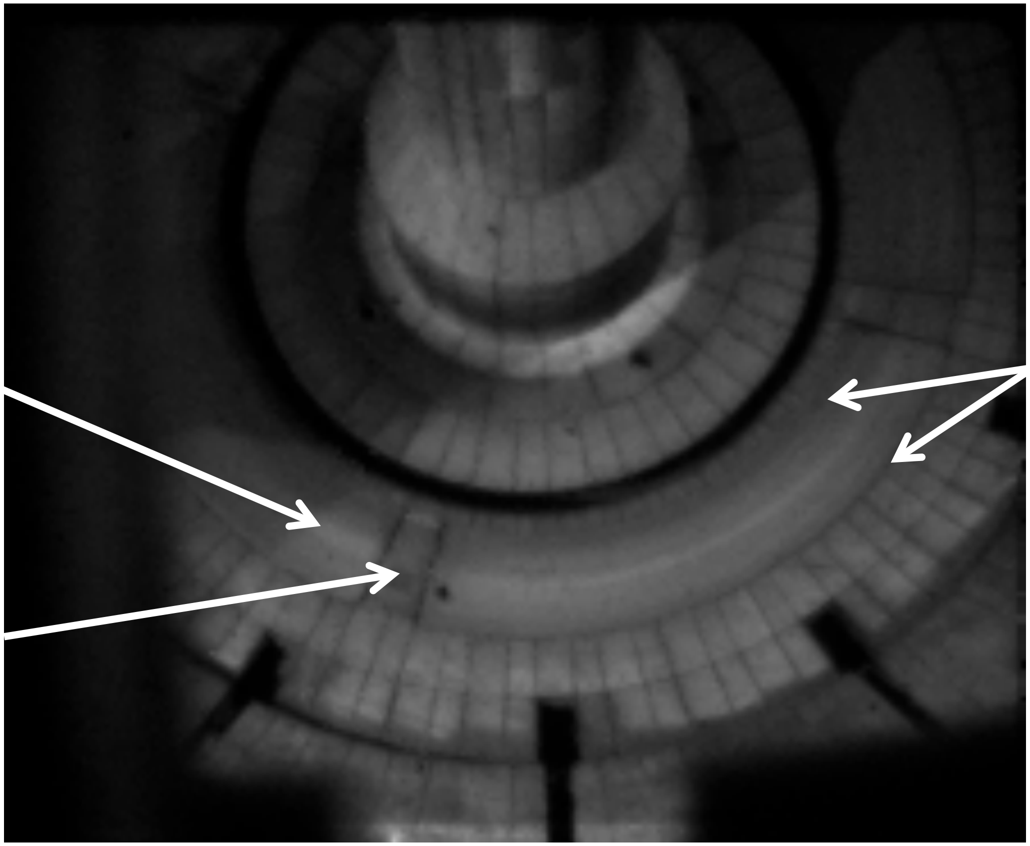


- **No excessive heating or deleterious introduction of impurities from LLD during high-power NSTX plasma operations**

- **No unanticipated LLD displacement due to thermal effects, eddy currents, or other potential sources of mechanical stress**

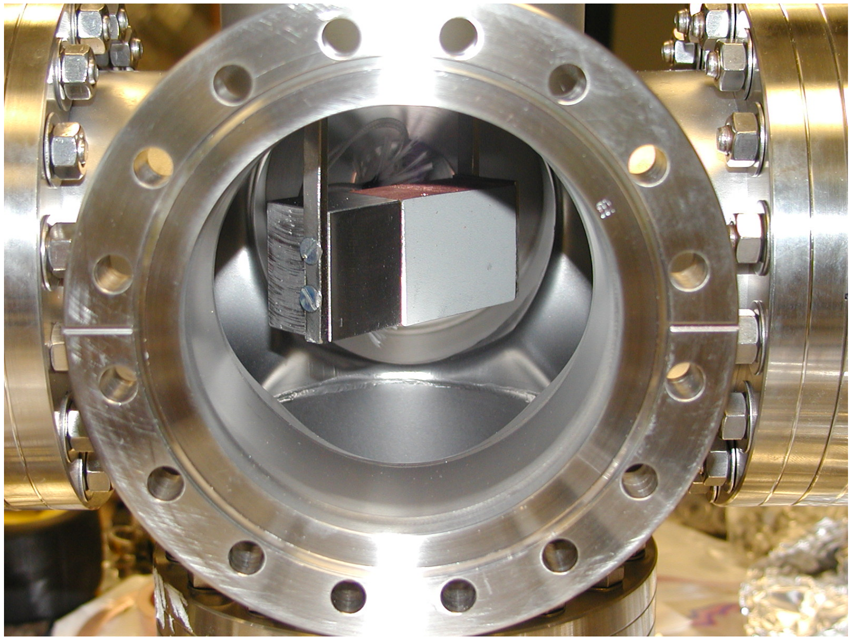
***See paper SP3C-32 by R. Ellis et al. in 36th International Conference on Plasma Science and 23rd Symposium on Fusion Engineering**

Discoloration only observation on LLD after high power neutral beam injection plasmas

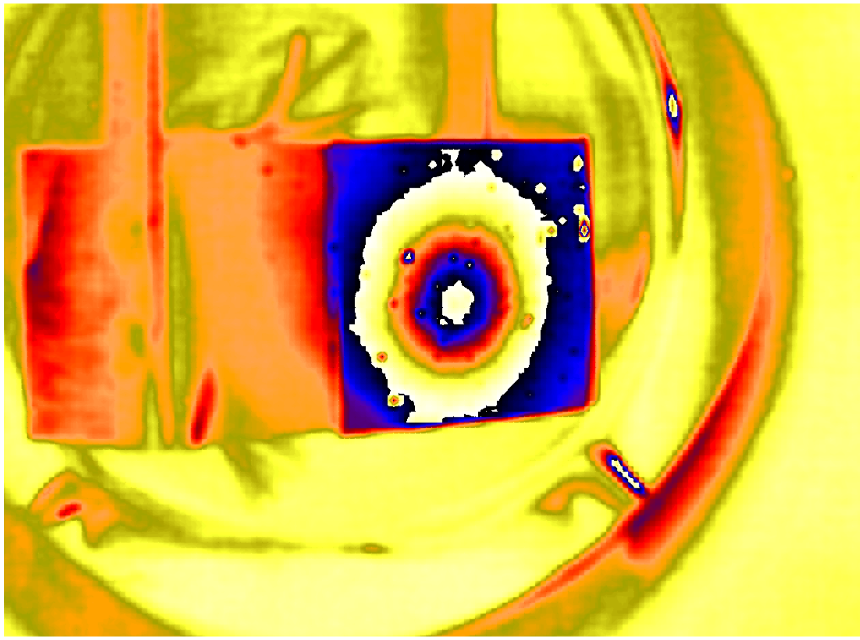


- No apparent damage to LLD or "diagnostic" tiles separating LLD quadrants observed with up to 4 MW of neutral beam injection

LLD sample exposed to neutral beam on test stand to investigate effect of high heat load



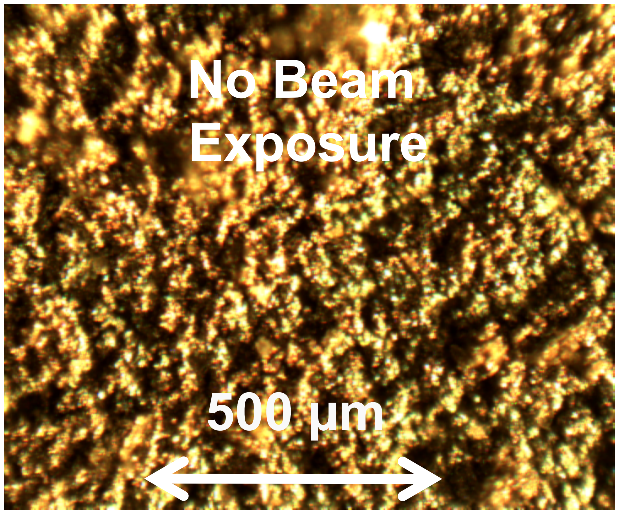
Test chamber showing LLD sample

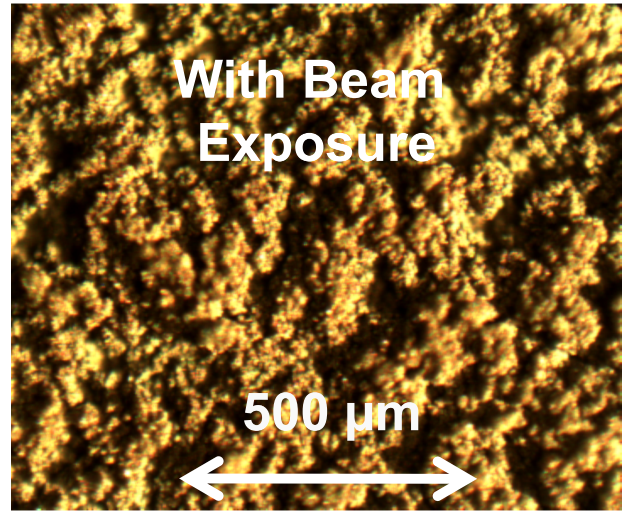


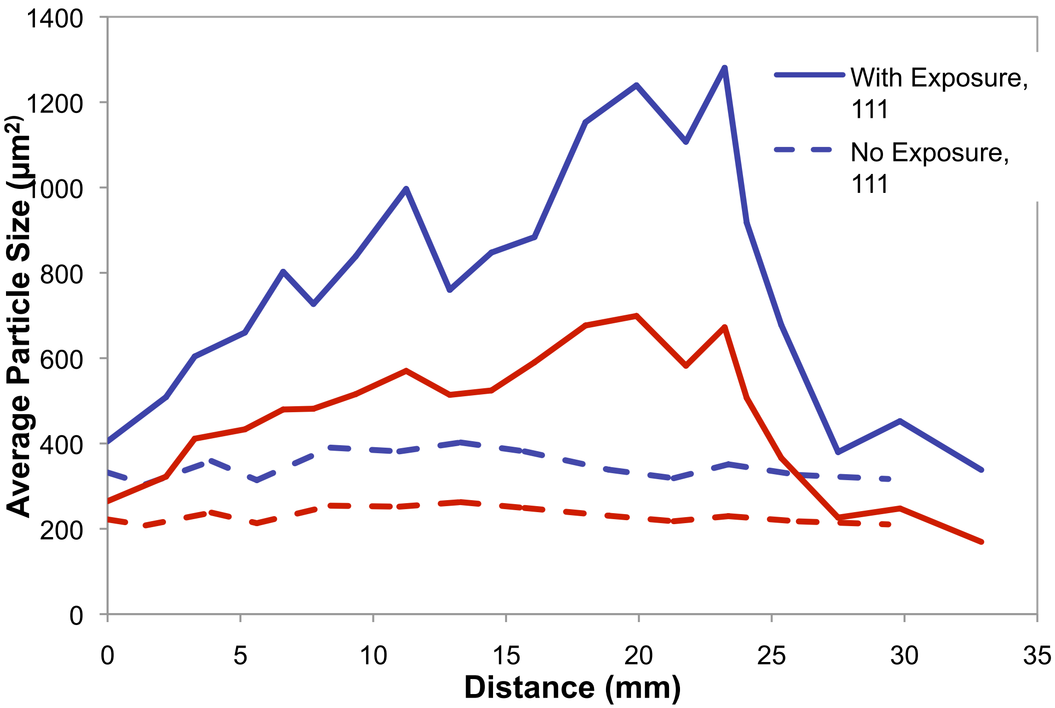
False color image of LLD sample during neutral beam exposure

- Diagnostic neutral beam (DNB) provided power density of over 1 MW/m^2
- LLD sample "plunged" in front of DNB for 1-3 s
- Front face temperature recorded by IR camera
- Back face temperature recorded by TCs

Analysis of microscope images indicate changes of surface morphology but no large-scale damage

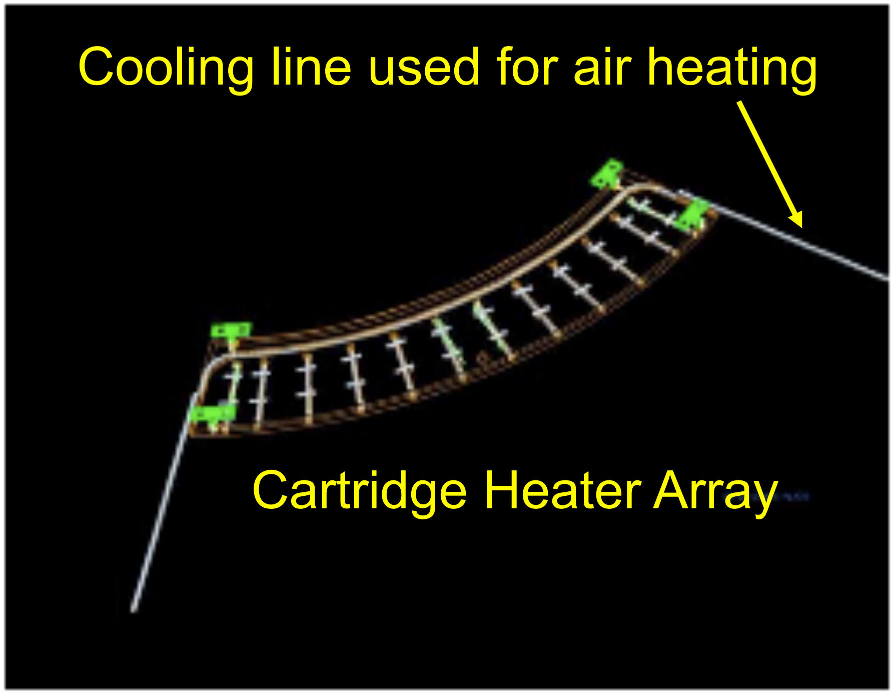






- **Two different particle size sorting criteria indicate change in surface morphology with DNB exposure**
- **Peaks reflect distribution on DNB power on surface of LLD sample**

LLD operation above lithium melting point relied on heating from plasmas and forced air system



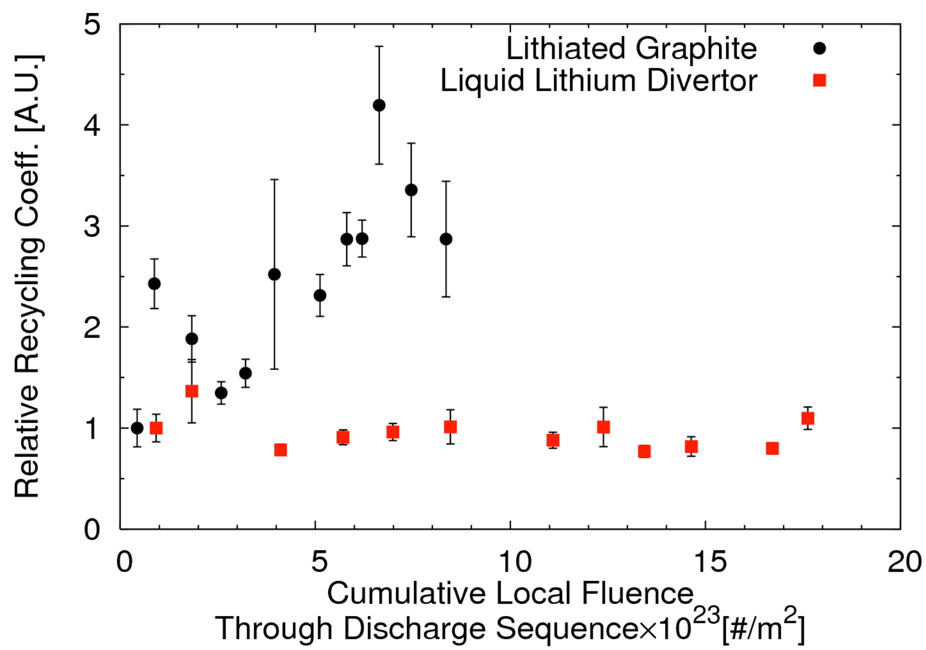
- **Electrical heaters on fourth LLD segment failed during test after full power application to heaters in remaining three without incident**
  - **Apparent insulation failure about 2 m from feedthrough**
- **Temperatures above lithium melting point in all four LLD segments achieved with heating from plasma and “pre-heated” air sent through cooling lines embedded in LLD**
  - **Plasma operations successfully conducted under both heating scenarios**

Lithiated graphite indicates increase in recycling with time unlike heated LLD

- **Single LITER evaporation of 7.5 g**
  - **Plasma shape and fueling comparable**
  - **Discharges repeated through entire day**
- **Systematic rise in relative recycling coefficient on lithiated graphite, but not on the LLD**
- **Multi-shot ion fluence indicates LLD has "reservoir" effect compared to Li-graphite**

$$R = \frac{\text{Flux into plasma}}{\text{Flux into PFC}} \propto \frac{D_\alpha \text{ Intensity}}{I^+_{sat}}$$

$$\begin{aligned} N_{inc} &= \text{Cumulative Fluence} \\ &= \sum_{Shots} \left(\int \frac{I^+_{sat}}{eA_{probe}} \text{dt} \right) \end{aligned}$$



Conclusions

- **LLD successfully installed & operated on NSTX**
  - **Loss of capability to liquefy lithium with original heaters compensated by plasma & forced air heating**
- **No large-scale damage to LLD surface caused by high power plasma operations**
  - **Consistent with results from exposing LLD test sample to neutral beam with high power density**
- **Effect on plasma changes as lithium liquefies**
  - **Role of fueling on impurities under investigation**

Future plans

- **Compatibility of LLD surface with divertor plasma operations supports consideration of molybdenum as high-Z PFC for NSTX**
  - **Inboard divertor tile replacement proposed in FY11**
- **Successful use at temperatures above liquid lithium melting point suggests efficacy of LLD for handling high heat loads**
  - **Motivates further investigation of liquid lithium as divertor PFC for long pulse operation**

NSTX Team Contributors and Acknowledgements*

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*Work supported in part by US DOE Contracts DE-AC02-09CH11466, DE-AC04-94AL85000, DE-AC52-07NA27344, and DE-AC05-00OR22725