NSTX

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NSTX Lithium Research Status, Plans, and Future Liquid Lithium R&D Needs

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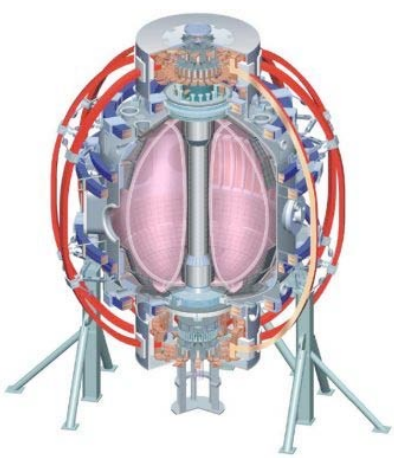
Henry W. Kugel, et al.

Rutgers PPPL Fusion Materials Discussion
Director's Conference Room
June 03, 2009



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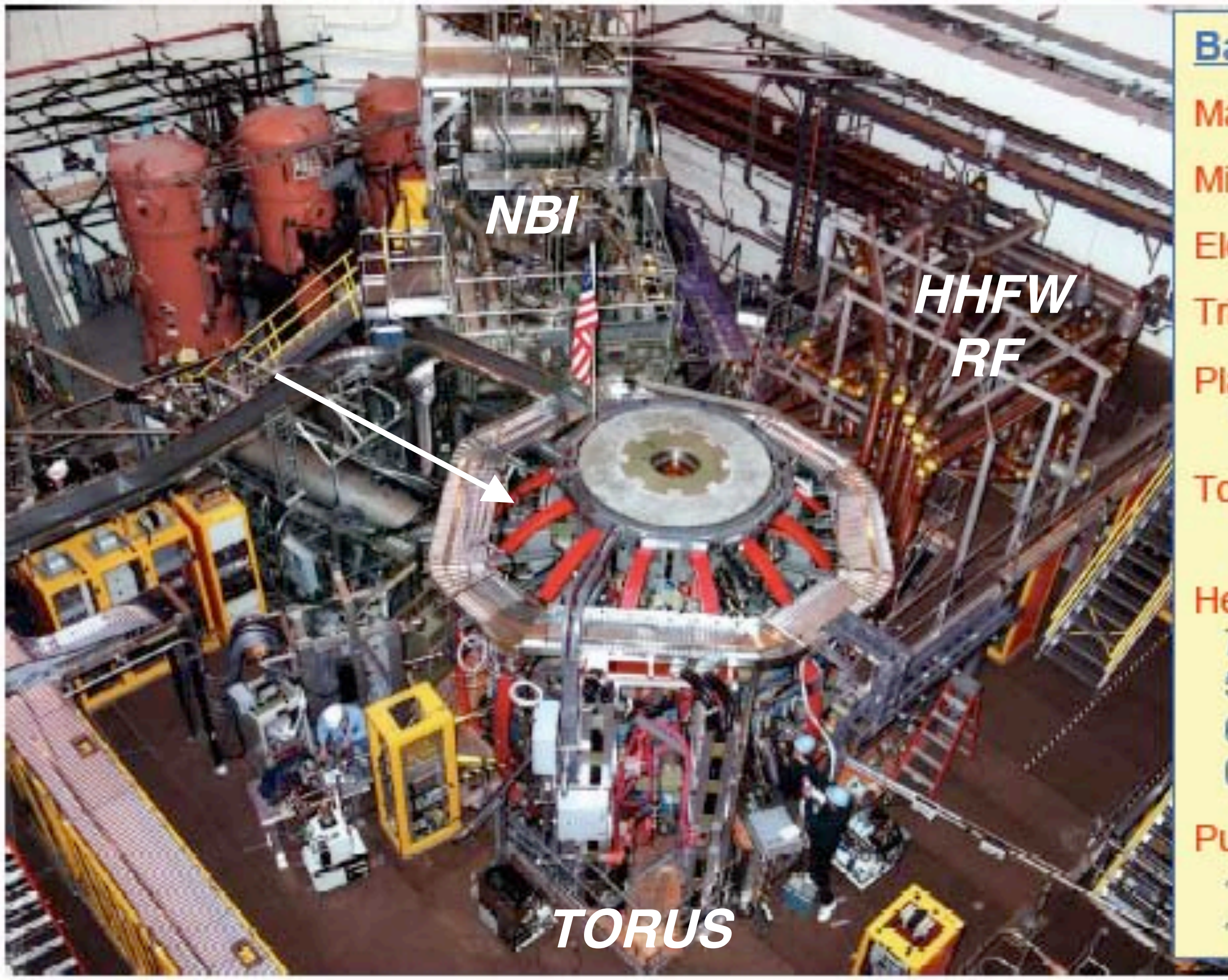
Outline

- NSTX facility
- Goals of NSTX lithium research
- Integrated approach to PPPL lithium research
- Candidate liquid lithium substrates
- Liquid Lithium Divertor (LLD) geometry
- Purdue collaboration using divertor region sample analysis probe
- Sandia collaboration using ion beam analysis of graphite tiles
- Lithiated materials modeling effort expanding
- LLD plans 2010-2012
- Future R&D needs
- Issues and Opportunities

NSTX Facility



Baseline Parameters

Major Radius 0.85 m

Minor Radius 0.68 m

Elongation 1.8 - 3.0

Triangularity 0.2 - 0.8

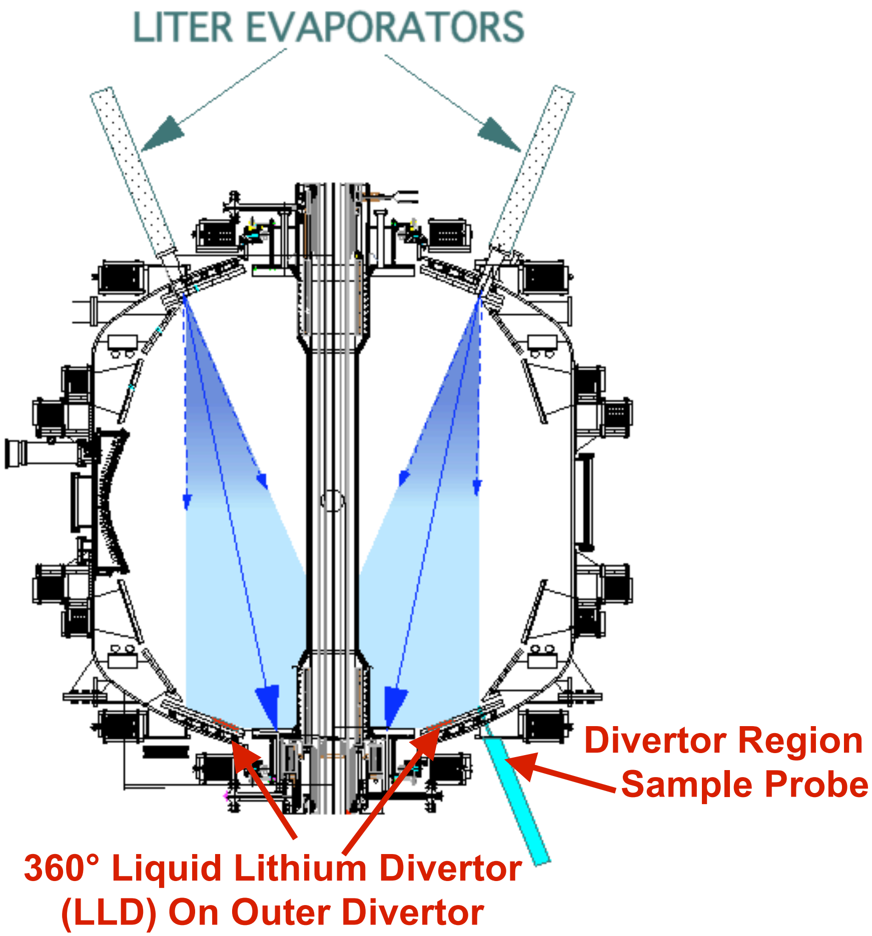
Plasma Current
1 MA (1.5 MA peak)

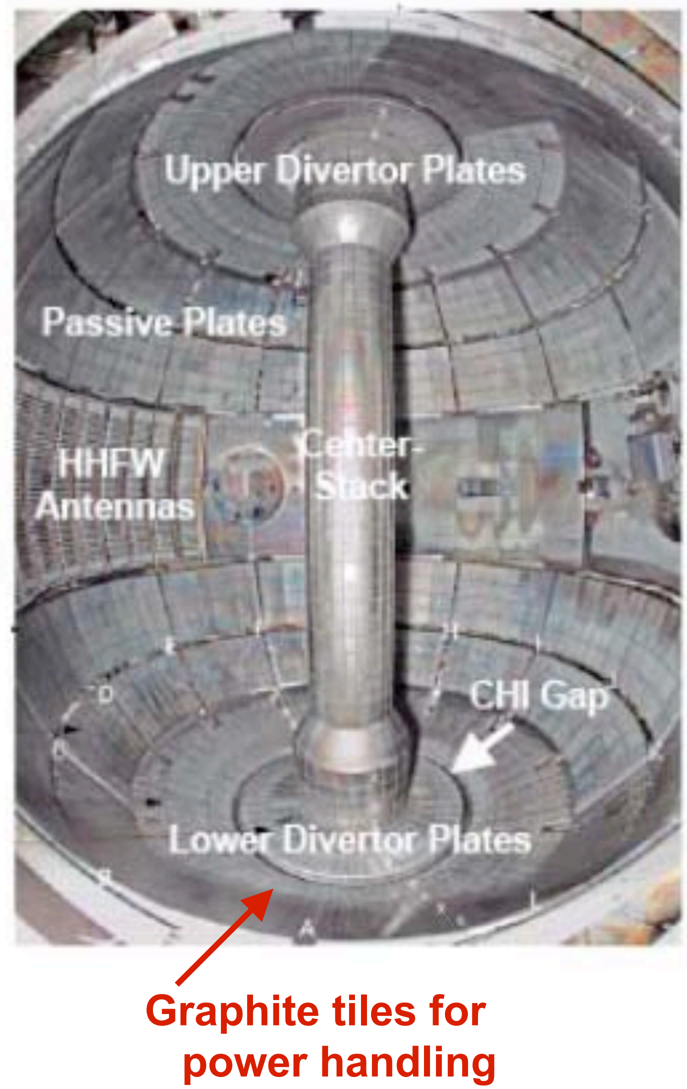
Toroidal Field
0.35 - 0.55 T

Heating and CD
7 MW NBI (2 sec)
5 MWNBI (5 sec)
6 MW HHFW (5 sec)
0.2 MA CHI

Pulse Length
~ 1 sec at 0.55 T
~ 2 sec at 0.38 T

NSTX Cross Section Showing Location of Li Evaporators, LLD, and Interior Photo of Plasma Facing Components





- D^+, D^o, and impurities incident on solid or liquid Li are sequestered as LiD and unavailable for recycling

The goals Li Research on NSTX are to Develop and Understand Novel Li-based PFC Solutions for NSTX, and Higher Power Next-step Devices

- **Current Goals:**
  NSTX research with solid lithium is aimed initially towards using liquid lithium to control density, edge collisionality, impurity influxes, and eventually power handling.
  - Solid Li (2005-2009) provides short pulse capability but has limited LiD capacity (LiD binds incident fuel & reduces recycling); liquid Li (2010) has much higher LiD capacity, and has potential for power handling and self healing

- **Operational Goals:**
  Implement liquid Li divertor for pumping, and investigate other potential benefits:
  - Improved energy and particle confinement
  - Reduction/elimination of plasma edge instabilities
  - Longer-term: steady-state high-heat-flux handling

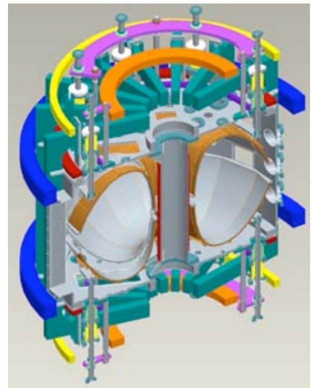
- **Physics Understanding Goals:**
  - Lithium surface physics and chemistry.
  - Relationship between lithiated surface conditions and edge and core plasma.
  - Role of carbon-Li interaction by comparison to LTX results (no carbon PFCs).

NSTX Lithium Research Is Integral Part of Broad Approach to Develop Lithium As PFC Concepts for Future Machines

LTX lithium handling facility

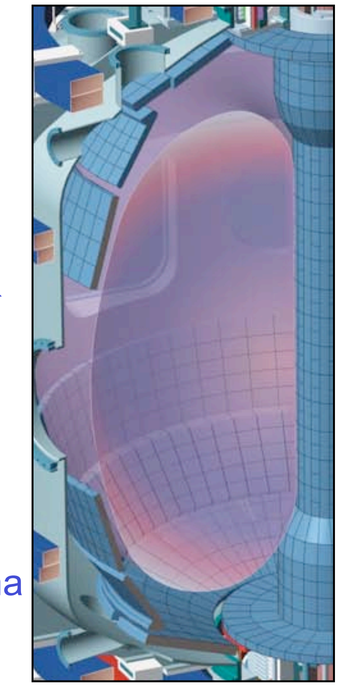
LTX PFC test facility

Purdue surface analysis facilities

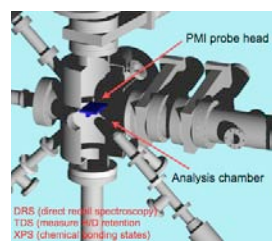


LTX
- Fully-nonrecycling liquid lithium PFC's
- Profile control with core fueling

NSTX
- Lithium evaporator
- Lithium powder
- Liquid lithium divertor
- High performance plasma



NSTX materials analysis probe



Erosion/deposition
H retention modeling

Next Step ST's

NSTX SNL Collaboration Has Considered Two Candidate Surfaces for the LLD

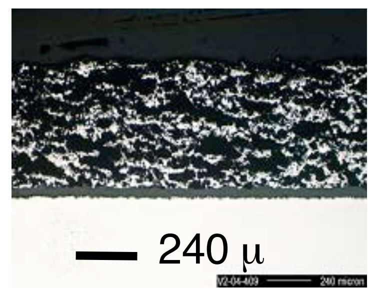
- Key properties for an acceptable LLD lithium surface
  - lithium retention in presence of JxB forces
  - ability of liquid Li to flow across a metal surface (wetting capability)
  - minimize temperature rate of rise of Li --> rapid heat transfer from Li to base

- Two candidate Li surfaces have been under investigation

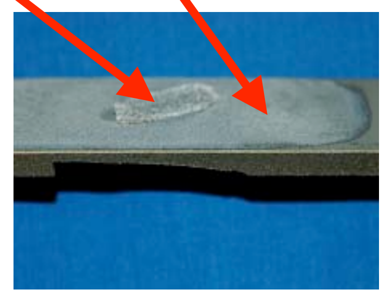
1) Thin flame sprayed porous Mo, on thin SS on thick Cu baseplate is highest confidence initial approach
   - LTX style plate (tested offline)
     (prepared by Plasma Processes Inc.
   - Experiments and simulations of LLD-1 behavior (porousity, gravity, thermal, JXB forces) in progress (NSTX, SNL, UIUC, UCLA)

2) Chemical vapor deposited Mo on vitreous carbon foam
   - under investigation at SNL (testing planned)
     (prepared by Ultramet Inc.)

- ***Solid Li melting***
- ***Liquid Li flowing over porous Mo***

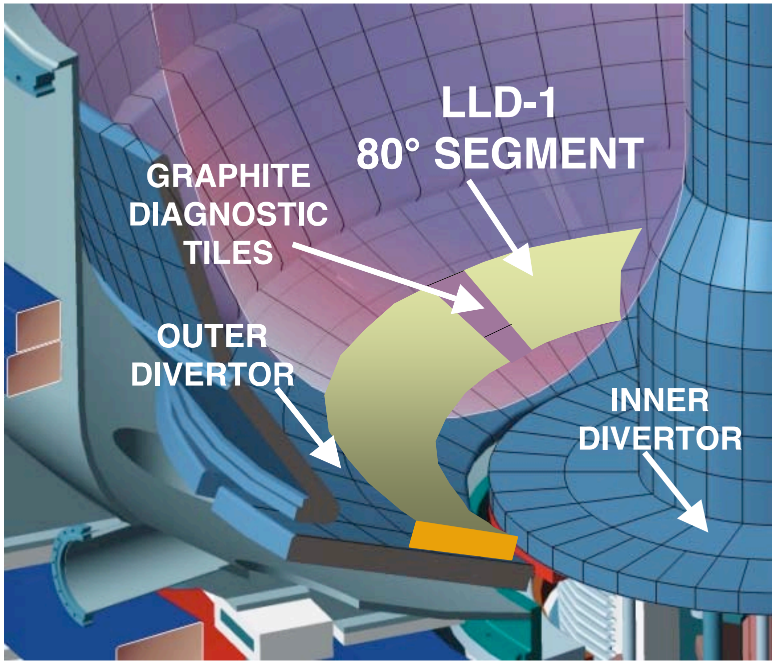


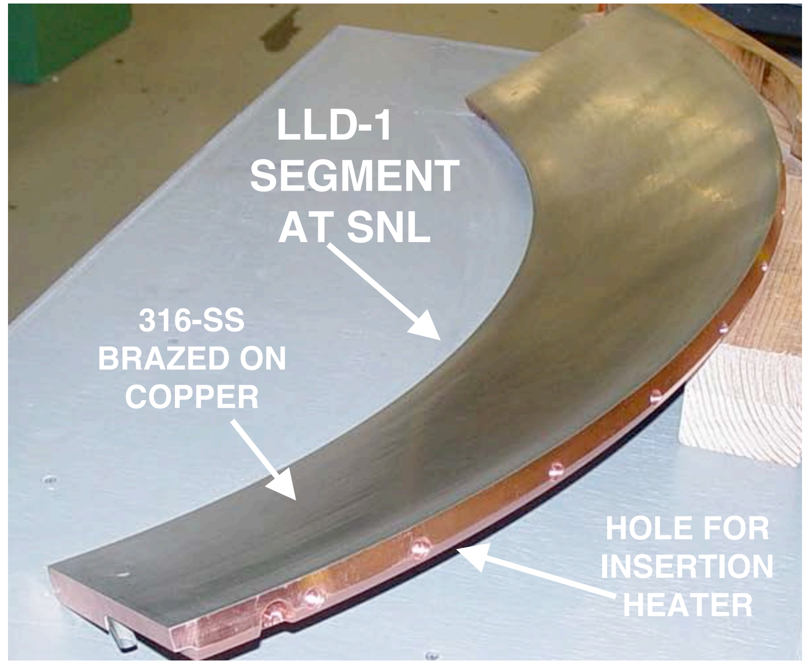
Micrograph of highly porous molybdenum



Successful lithium wetting test on porous moly

NSTX Liquid Lithium Divertor (LLD-1) Will Be Tested in 2010





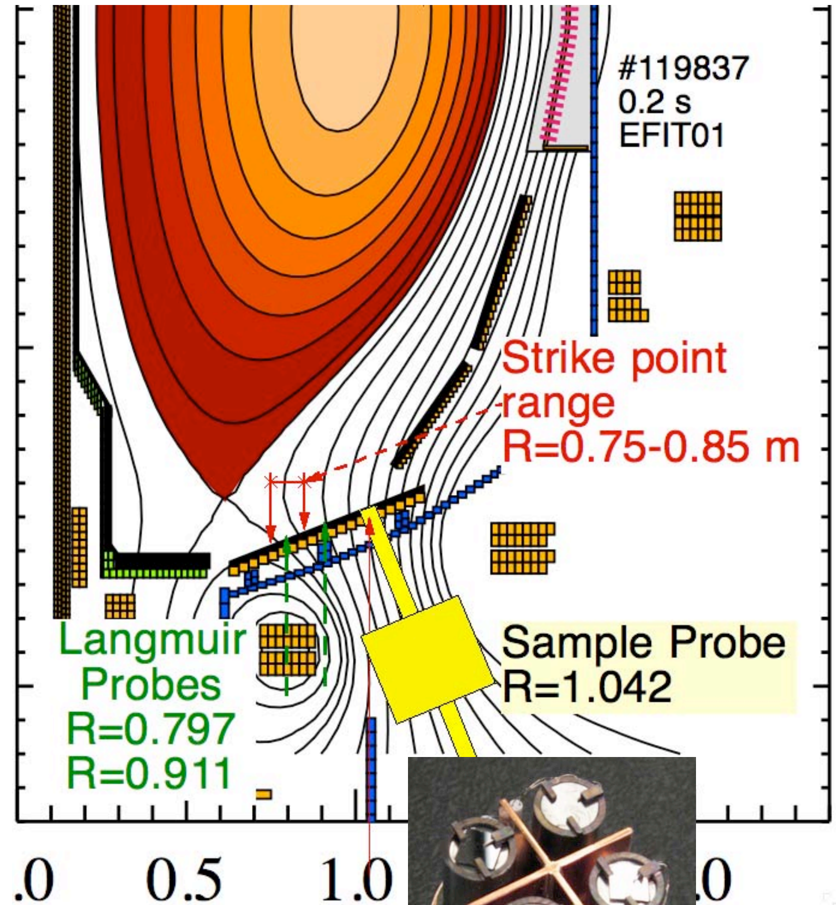
- SNL has completed 6 segments (4 for installation + 2 spares)
  (conical shaped the copper first, then brazed 316-SS to conical shaped copper).
- 6 units at Plasma Process Inc for coating with flame sprayed porous molybdenum.
- Control Rack assembly in progress.
- Installation begins after NSTX 2009 Experimental Campaign for operation 2010.

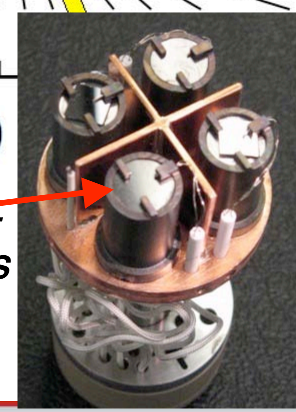
In-situ Surface Analysis of NSTX Plasma-exposed Surfaces

2009 Thermal Desorption Spectroscopy ex-vessel, promptly after plasma exposure (no air exposure) in progress. Sweep over fixed Langmuir probes to measure (D retained / D incident)

2010 sophisticated ex-vessel surface analysis station (TDS, LEISS, DRS…) for prompt analysis of ‘fresh’ samples to characterize deuterium retention and lithium bonding state.

TDS-thermal desorption spectroscopy
LEISS- low energy ion scattering spectroscopy
DRS-direct recoil spectroscopy

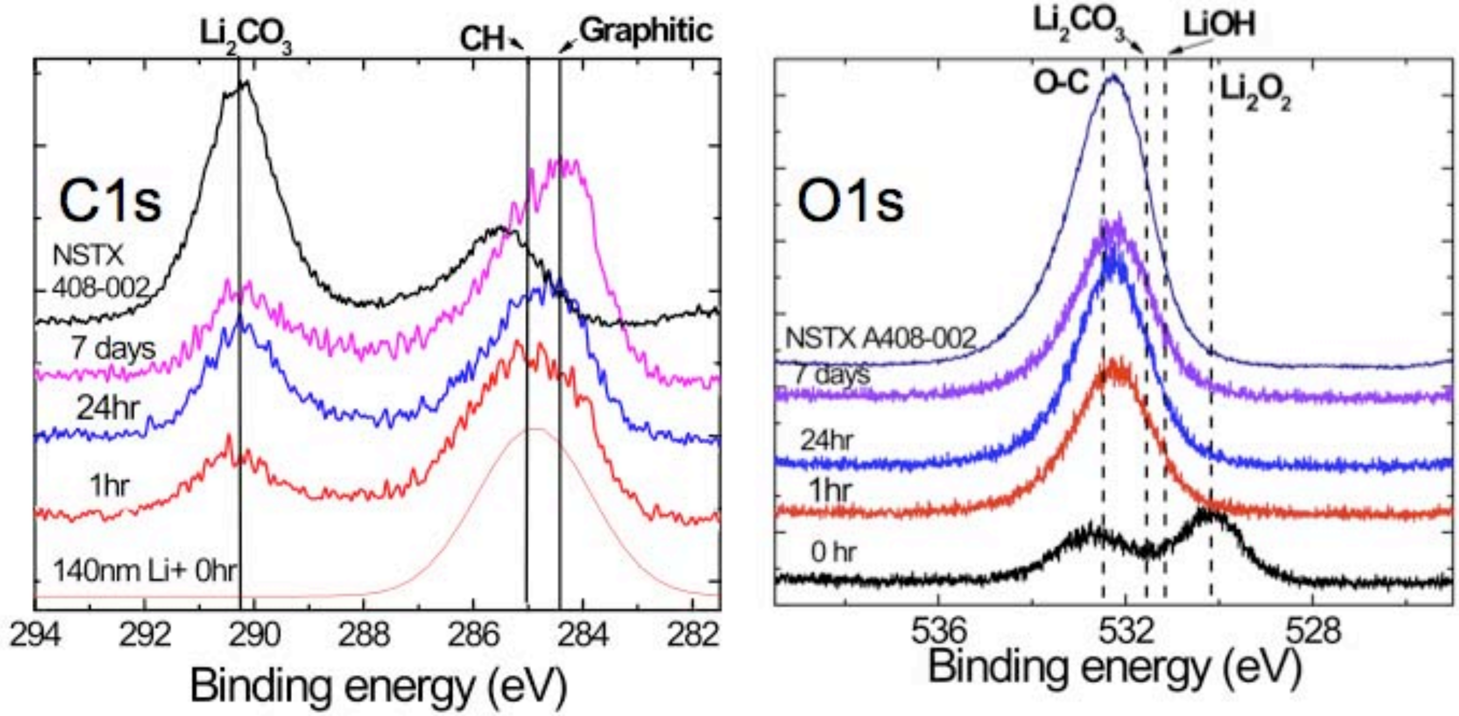




World leading direct shot-to-shot correlation of an in-situ PMI surface science measurement with plasma performance. **JP Allain (Purdue)**

Lithium Coated Graphite Has Complex Chemistry

Lithiated graphite chemical state WITH exposure to air

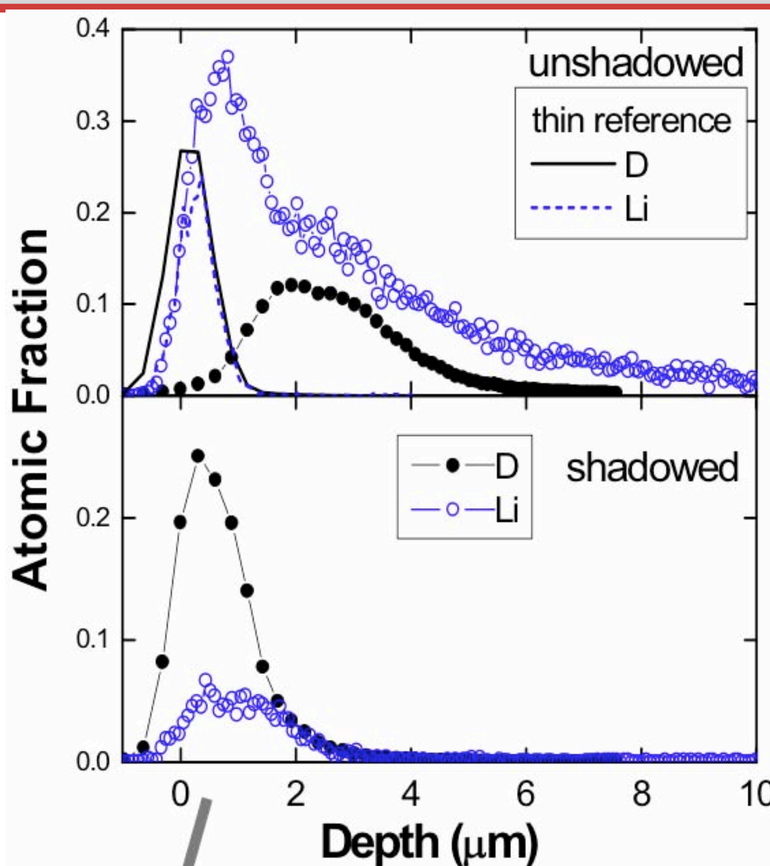


- Li_2O_3 layers are formed after exposing the sample to air
- Li_2O_3 XPS peak intensity increases with air exposure time and decreases
- Li_2O_2 O1s peak @ 530eV disappears after air exposure

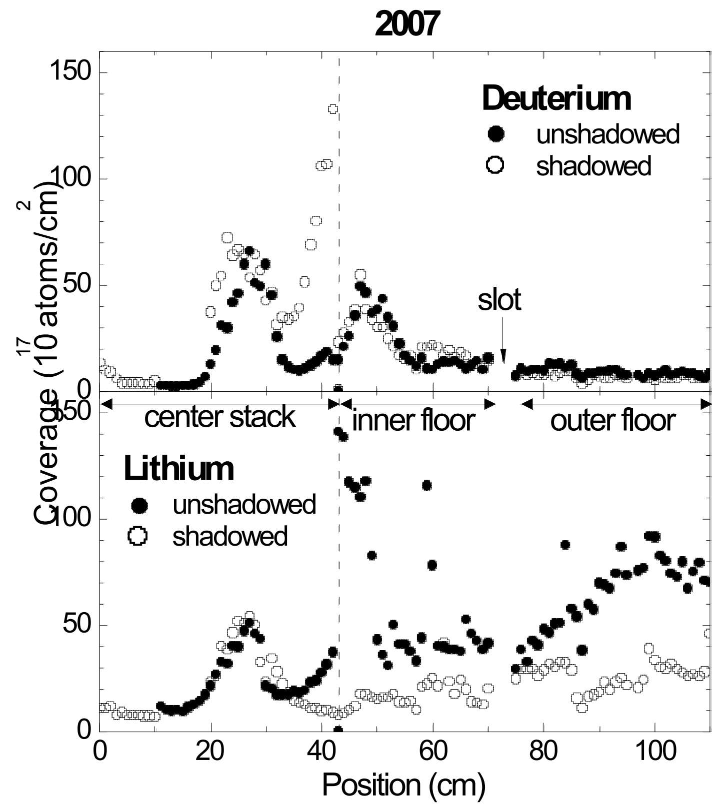
PURDUE UNIVERSITY

JP Allain

SNL Ion Beam Analysis of 2007 Graphite Tiles



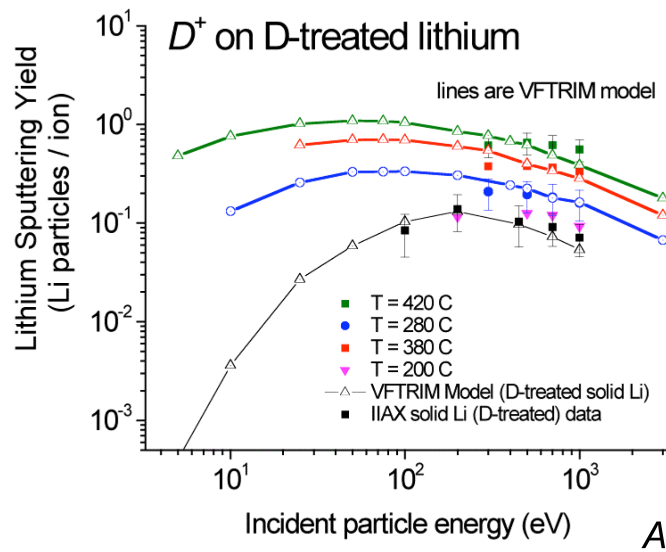
- Concentrations of D and lithium versus depth on 2007 tiles in regions facing the lithium evaporator (above) and shadowed from it (below) at the innermost edge of the lower inner divertor. The upper panel shows measurements on thin reference samples to indicate the depth resolution, which is about 1 μm FWHM at the surface. The references samples were 310 nm of LiF and 500nm of ErD_2.



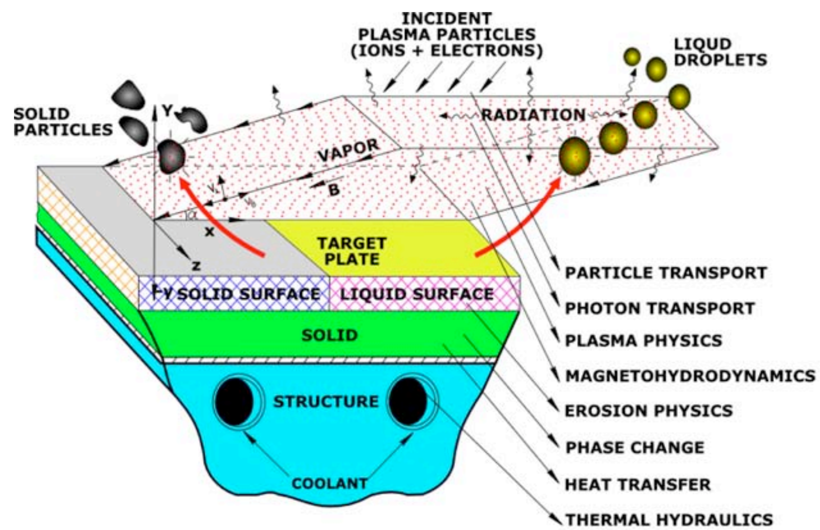
- Coverage of lithium and deuterium on the 2007 tiles. The position is measured downwards from the lower bevel on the center stack, then radially outwards across the lower floor.
- Analysis depth 15 μm Li, 4 μm D.
- W.R. Wampler et al., J. Nucl. Mater. (in press)

Detailed Modeling of Lithium Behavior in NSTX is Expanding

- Continued UEDGE simulations of Li migration & penetration into core, as well as D retention in Li (Pigarov (UCSD)).
- Simple estimate of global recycling coefficient via DEGAS 2 using available experimental data (Stotler).
- Erosion / redeposition modeling of lithium in Purdue laboratory experiments and NSTX (Brooks & Allain (Purdue)),
- Effect of ELMs & disruptions on liquid Li (Hassanein (Purdue)).
- Probe data from LLD diagnostic module will substantially enhance input data for modeling.



Allain, Purdue



Hassanein, Purdue

NSTX Plan for Testing the Potential Benefits of a Liquid Lithium Divertor (LLD) for Integrating High Plasma and PSI Performance

- **LLD-1(2010)**
  - Short pulse test (~300-500ms) of LLD-1 pumping capability from 20 cm wide liquid lithium surface on Outer Divertor
    - Outer Divertor is LLD-1 location offering lowest technical and programmatic risk to high-performance, high-δ ST research program.
    - LLD-1 surface to be coated with two existing Lithium Evaporators (LITERs)

- **LLD-2 (2011)**
  - Increase pumping capability to improve plasma performance
    - Improve lithium filling efficiency and longevity of active lithium surface (e. g., capillary instead of plasma-sprayed substrate).
    - Increase liquid lithium surface area (e. g., inner divertor).

- **LLD-3 (2012)**
  - Test power handling scheme for long-pulse with high heat-flux
    - Investigate feasibility of active cooling schemes (e. g., capillary flows, swirl tubes, helium gas, hypervaportrons, evaporative cooling)
    - Develop concepts for filling LLD-3 during discharges (e. g., capillary flow replenishment as planned for FTU)

NSTX Liquid Lithium PFC Future R&D Needs

- Need to address two current impediments to installation of liquid lithium PFCs in high power devices:
  - **power handing for long pulses**.
    - ~10-20 MW/m^2, >1sec.
      - need e-beam and ion-beam cyclic thermal stress testing of candidate concepts.
        - » test under operating conditions and test-to-failure.
  - **liquid lithium filling and replenishment.**
    - systems demonstrating fast flow-in and flow-out.
      - e. g., capillary, jets, …
    - surfaces permitting sufficient wetting to allow Li to flow to $\pm$1 m from inlet.
    - interfaces between favorable liquid transport method and PFC surface capable of handling high incident power densities.
    - schemes for confining liquid lithium to plasma-facing surface of PFC.
      - e.g., oxides,non-wetting metals, …

Issues and Opportunities

Presently:

- Li conditioning has led to significant improvements in plasma performance in TFTR, CDX-U and NSTX. Exciting results continue on NSTX…
- Recently, indications of density and impurity control have been observed.
- Li surface power handling capability untested.
- No predictive understanding (e.g. 'x' mg of Li -> 'y' plasma performance).

Near term:

- Expansion of instrumentation and modeling (e.g., Sample Analysis Probe,..).
- LLD introduces liquid lithium -> volume effect rather than surface:
  - Will liquid Li improve density and impurity control beyond that of solid Li?
  - Will D fueling be adequate as recycling decreases ?
  - What is heat flux limit for liquid Li in the applied magnetic field ?
  - Will there be any deleterious effects ?
- Possible impact of LTX results.

Manpower and capability limitations (scientific & technical staff, no in-house surface chemist, no e-beam for Li surface development.)