NSTX

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Planning for the Liquid Lithium Divertor LLD-1 and Its Impact on Experiments

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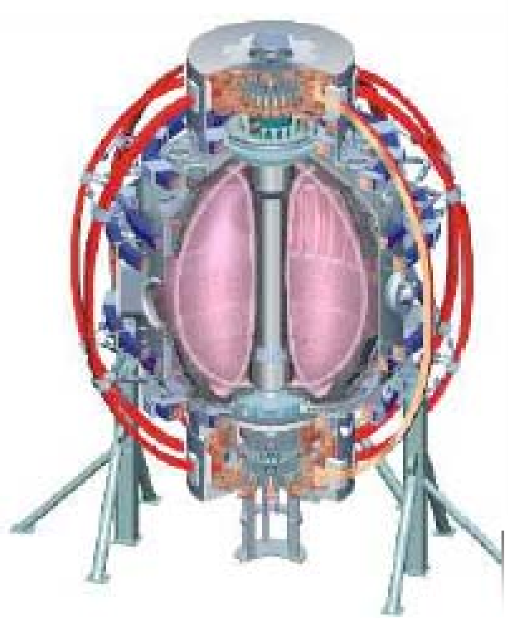
Michael Bell
for the LLD Team

Research Forum for FY'10
Dec 1, 2009



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The Liquid Lithium Divertor will be a Major New Element in NSTX Research for 2010

- Priorities for the Lithium and Boundary Topical Groups in FY2010
  - Develop and understand high-performance operating scenarios utilizing a liquid lithium divertor (LLD) for particle control
  - Understand and minimize the sources and accumulation of plasma impurities arising from lithium conditioning of the PFCs
  - Assess H-mode pedestal characteristics and ELM stability as a function of collisionality and lithium conditioning (Milestone R10-3)
    - ...Particle pumping and density control in these experiments will utilize the liquid lithium divertor (LLD). ...
  - Assess the relationship between lithiated surface conditions and edge and core plasma conditions (Milestone R11-3 — preparation)
    - ... To extend the duration of particle pumping, and to investigate the impact of liquid lithium on plasma performance, a liquid lithium divertor (LLD) will be installed in FY2010, and the relationship between lithiated surface conditions and edge and core plasma conditions will be determined. ...
- *The presence and operation of the LLD will affect all other experiments*

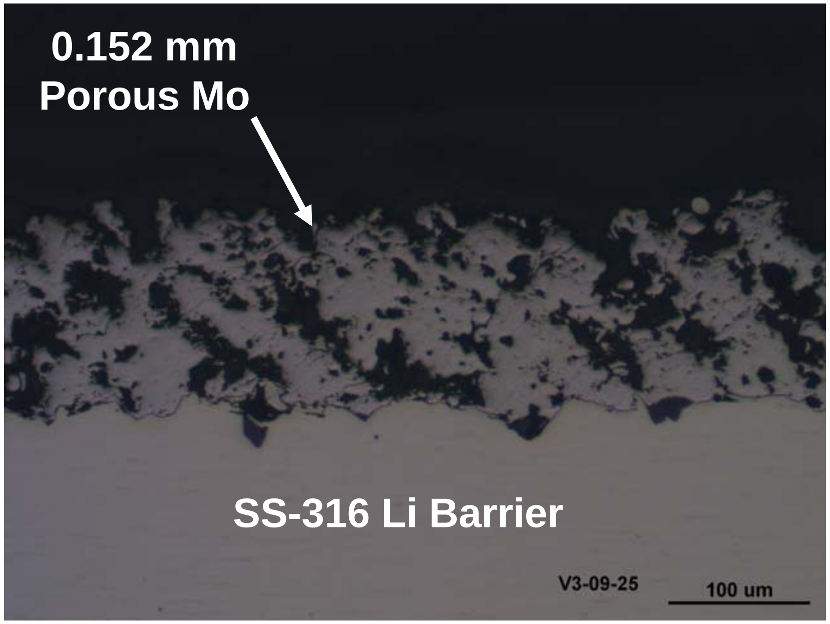
What and Where is LLD-1?

- LLD-1 consists of 4 metal plates forming part of a conical annular surface in the lower outer divertor plate close to flush with the surrounding graphite divertor tiles
- Plates are 20cm wide, covering R ≈ 0.65 – 0.85 m, and consist of a
  - copper backing 19mm thick, brazed to a
  - stainless-steel lithium barrier, 0.25mm thick, plasma coated with a
  - semi-porous (~45%) molybdenum plasma-facing layer, 0.165mm thick, on which lithium will be deposited and liquified
- Plates fabricated by Sandia Nat. Lab. and Plasma Processes, Inc.
- Plates are each temperature controllable between ~20 and >400 °C using electric heaters and an air-cooling tube
  - Lithium melts at ~180°C
  - At 400°C lithium begins to evaporate and LiD to decompose
- The sections are separated toroidally by graphite tiles in which are mounted diagnostic probes and sensors

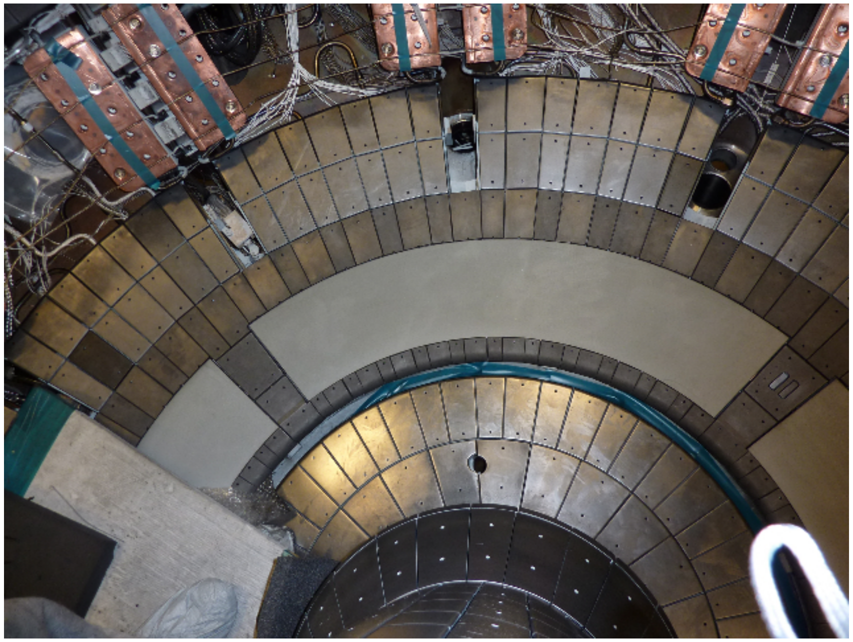
The LLD Plates, Their Connections and the Control System Are Now Installed

- Great effort by collaborators, technicians, electricians and engineers!

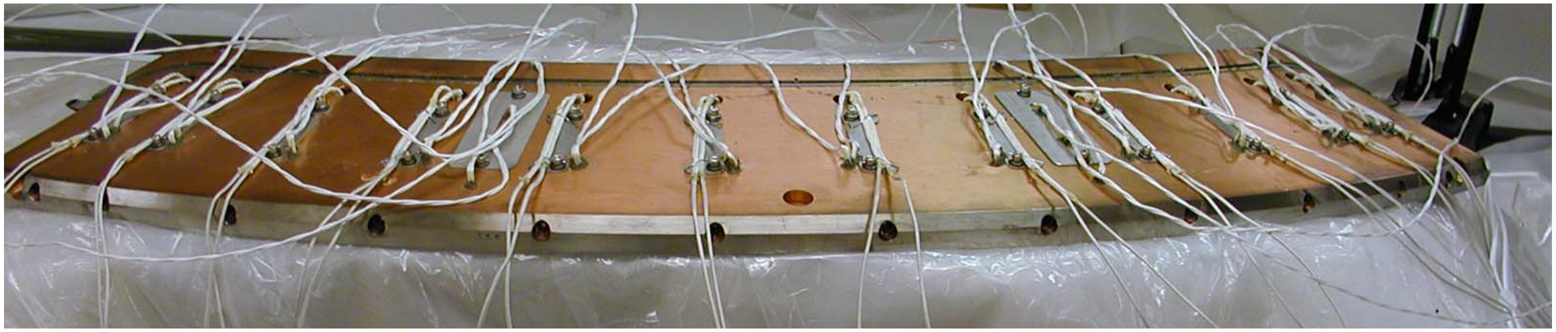
Micrograph of porous Mo layer



November 25, 2009



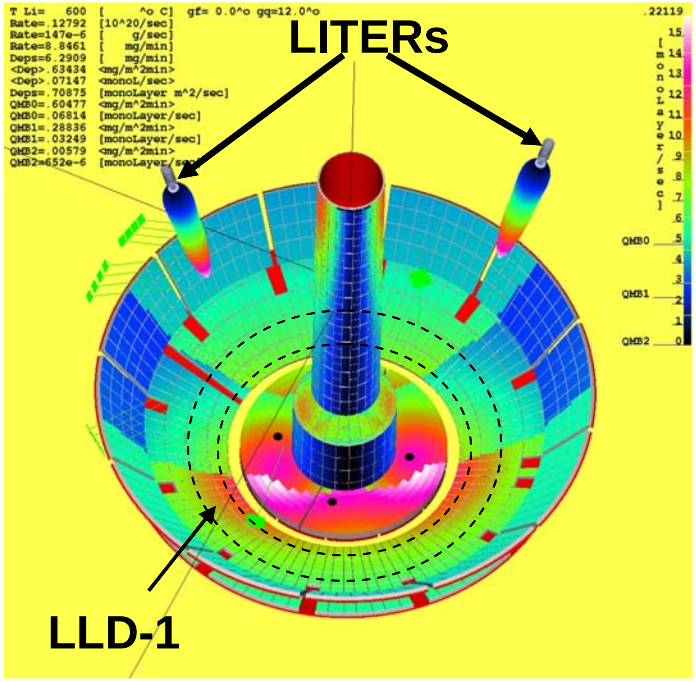
Back side of plate with heaters and thermocouples installed

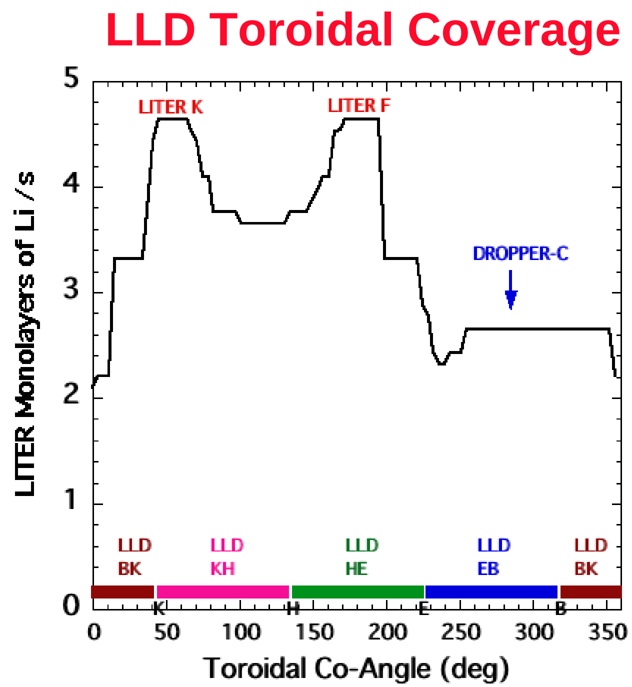


Several Steps Planned to Test and Commission LLD Prior to Start of Plasma Operation

- Test heaters and thermocouples to room temperature + 10C° for ~10s while vessel is still open (next 2 weeks) - PTP
  - Ensure integrity of connections, telemetry
- Run LLD plates to ~400°C in vacuum prior to bakeout - ISTP
  - Exercise LLD control system and interlocks
- Full vessel bakeout for 2 – 3 weeks is proposed
- Plates will be held ~10C° above carbon PFCs during bakeout to avoid condensation of residual gases and contamination of surface
- After vessel cooldown, operate LLD at initial operating temperature (200 – 220 °C).

Plan to Fill the LLD-1 with Lithium from Dual LITERs, Possibly Supplemented by Lithium Droppers





- Rely on liquid wetting the porous Mo surface to spread the lithium
- Only 7% of lithium evaporated by LITERs reaches LLD-1 plates
- Estimate ~40g lithium required to fill porous volume in Mo coating
  - ~600g evaporation to fill ⇒ 22 days at maximum rate & ~7 loadings
- Wettable area in porous Mo estimated at ~8 times plate area
  - 1.1g lithium would coat wettable area to 250nm penetration depth of incident D^+ ⇒ ~1 day at normal evaporation rate

LLD Operation will be Monitored with Several Diagnostic Systems

- Visible Cameras
  - Phantom-V710, Bay-E, Top re-entrant window
  - Phantom-V7.3, Bay-J, Top re-entrant window
- Plate surface temperature - *desirable to have data between shots*
  - Fast IR Camera, Bay-H Top
  - Slow IR Cameras, Bay-I Top, Bay-G Bottom
  - Thermocouple arrays in plates for calibrating surface emissivity
  - Also developing 2-color IR capability to avoid emissivity issue
- Lyman-α photodiode array (for recycling rate)
- Divertor region Sample Probe
- 3 Quartz Deposition Monitors
- Plasma conditions at plate
  - Langmuir probes in diagnostic tiles between plates

Operation Plan Must Avoid Damaging Porosity and Wetting Properties of Molybdenum Coating

- Key properties for LLD-1 surface
  - Ability of liquid Li to wet surface and flow to fill structure
  - Sufficient surface tension to hold Li in presence of JxB forces
  - Low thermal resistance to base to minimize Li temperature rise

⇒ **Need clean surface uncoated by boron or carbon compounds**

- To achieve this, it will be desirable to
  - Maintain LLD-1 as hottest surface in vessel throughout bakeout
  - Avoid boronization or extensive GDC (He or D) before initial Li coating of LLD and liquifaction to distribute Li
  - Avoid interaction of energetic ST plasmas with LLD prior to lithium coating to avoid thermal stresses in porous Mo layer
- Eliminating boronization & GDC will have a major impact on operation
  - Graphite tiles have been sanded and all plasma facing surfaces are being cleaned with dilute acetic acid to remove remaining oxidized lithium

⇒ **It will probably be necessary to use LITERs and thus to fill the LLD with some lithium to achieve satisfactory plasmas**

Initial Experiments of Lithium TSG Must Characterize LLD Operation and Limitations for Other TSGs

- Questions to be answered
  - Can previous operational scenarios be reproduced in the presence of the LLD when it is unheated?
  - What is the response of the unheated LLD to standard plasmas?
  - How much liquid lithium is needed on the LLD to produce effects?
  - At what rate is liquid lithium consumed by standard plasmas?
  - How sensitive are the effects of the LLD to the strike point location?
  - Does the LLD provide additional and more long lasting pumping than solid lithium on the PFCs?
  - What is needed to maintain or rejuvenate pumping by the LLD?
  - What is the response of the LLD to increasing power fluxes?
  - Are there indications of situations to avoid when the LLD is hot?
- Designing experiments to address these questions is challenging, *but*
- The LLD represents a new opportunity to enhance the capabilities of NSTX, and possibly influence the development of fusion