NSTX, SNL, UCSD Collaboration to Develop and Operate a Liquid Lithium Lower Divertor

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LLD Workshop-1

Feb. 27, 2007

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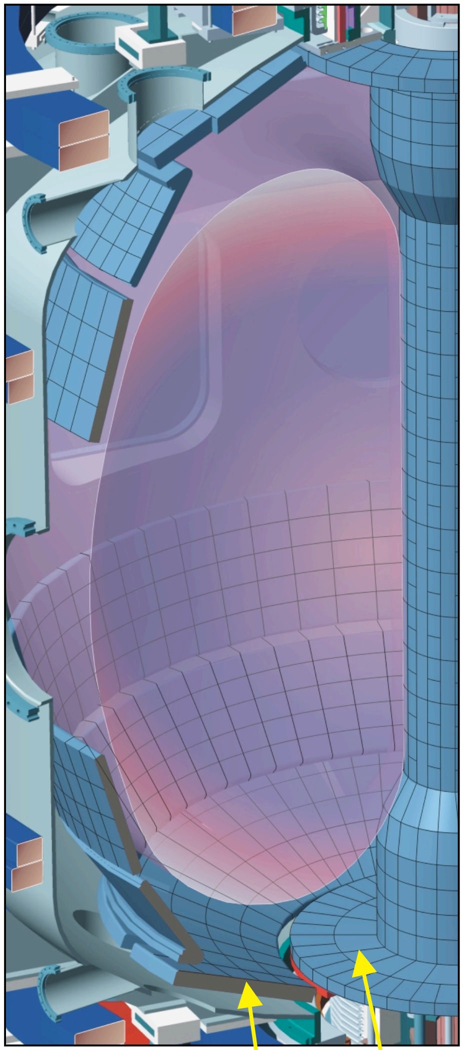
NSTX 5 Yr Plan Investigating on Lithium for Reduced Recycling Using a 3 Phased Approach: (I) Li Pellet Injection, (II) Li Evaporators, (III) Liquid Li Divertor



- The present 3 Phase NSTX 5-Year Lithium Plan for Particle Control and Power Handling is moving aggressively toward starting the 3rd Phase which will extend into the next 5 Year Plan:

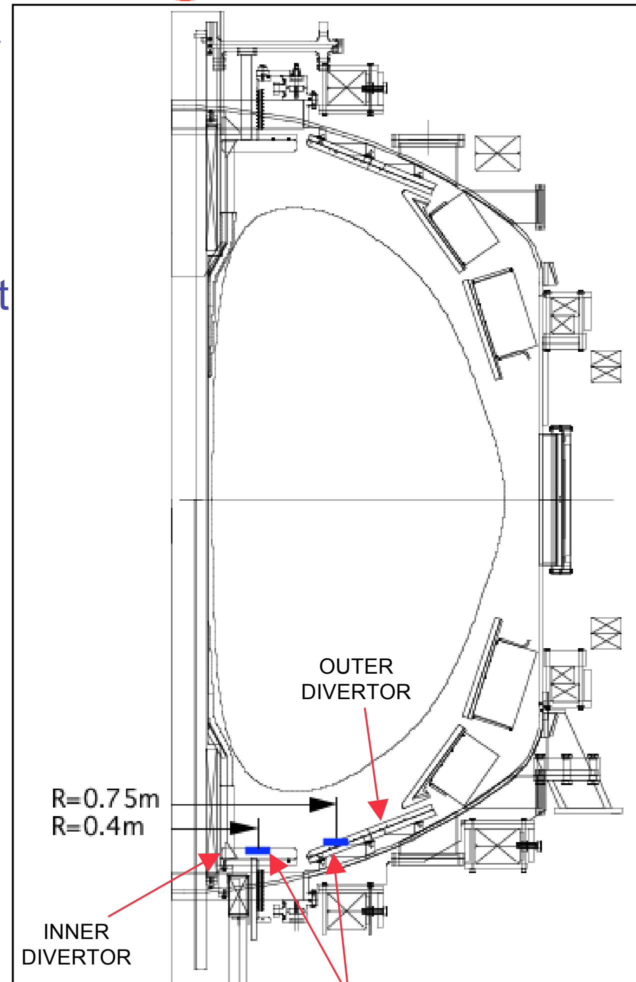
I. Lithium Pellet Injector (2005)

II. Lithium Evaporator (2006)

III. Liquid Lithium Divertor (2008)

- Phase III will enable access to the very low recycling regime for the first time in high power diverted plasmas.

- 2007 Experimental Proposals will investigate open questions using Li Pellet Injector and Li Evaporator.



- Two candidate locations for a toroidal, Liquid Lithium Divertor at lower outer strike-point

Lithium PFCs Will Have Significant Positive NSTX Program Impact and May Resolve Outstanding PFC Issues for Future High Power Devices

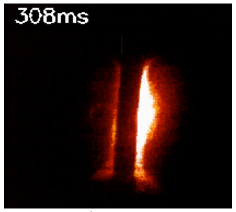
- CDX-U/LTX has achieved very low recycling in lithium limited ohmic plasmas. These noteworthy results (PSI-17, IAEA-06) are promising for the implementation of lithium plasma-facing components in NSTX and in future reactor scale devices.

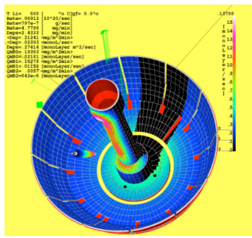
- NSTX Phase III Liquid Lithium Divertor operation will enable access to the very low recycling regime for the first time in high power diverted plasmas and may yield significant changes in plasma performance.

- After these experiments, the Liquid lithium Divertor design will allow for convenient removal and cleanup for the restoration of high recycling graphite PFC conditions, if desired.

NSTX Liquid Lithium Divertor Builds on CDX-U Results and Synergizes with LTX Research to Develop Lithium PFC Concepts for NHTX

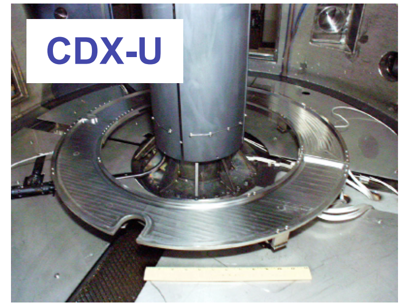
NSTX





• Lithium pellet injection

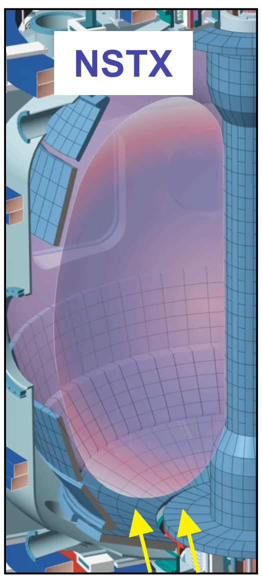
• Lithium evaporation



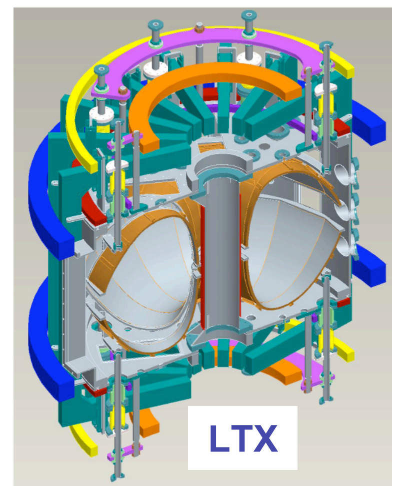
• Low recycling
• High power handling

• High confinement

• Liquid lithium local mesh and toroidal tray limiters
• Lithium loading and evaporation technology



• NSTX upgrade to non-recycling PFC's



• Liquid lithium divertor
• High performance plasma

• Fully-nonrecycling liquid lithium PFC's
• Profile control with core fueling
• Flat-temperature "Li-Wall" regime

DIVERTOR OPERATION

NON-RECYCLING PFC OPERATION

NHTX

• Candidate locations for Liquid Lithium Divertor

A SNL, UCSD, NSTX Collaboration Will Develop and Operate a Liquid Lithium Divertor for the 3rd Phase Starting in the Present NSTX 5-Year Lithium Plan

NSTX

• Sandia will supply NSTX with liquid lithium surface divertor hardware for an outer strike point target (e.g. a boat concept containing mesh or sintered porus medium).

• The collaboration between the SNL and NSTX teams will include the design of the hardware, specification of interfaces and responsibilities, and development of an operational plan, as well as the installation and shakedown of this divertor and participation in experiments in NSTX with this divertor.

• UCSD will participate in the collaboration through a subcontract with SNL and will provide two removable lithium feed systems or other hardware for alternate schemes for filling the liquid lithium divertor.

Present and Next 5 Year Plan Research to Characterize the Performance of the Liquid Lithium Divertor

• In FY09, the NSTX, SNL, UCSD collaboration will initially characterize the performance of the liquid lithium divertor during 2 MW of neutral beam heating at 300 msec pulse lengths.

• Measurements will be performed from low to high volume-averaged plasma densities of the shape and the associated plasma density profiles, recycling, fueling efficiencies, and core electron and ion temperatures, and neutron yields.

• The performance of liquid lithium divertor and plasma conditions during long pulse, high power neutral beam and RF heating will be characterized in the FY10 phase.

Candidate Plasma Parameters for LLD Design & Modeling

- **LLD Plasma Parameters for Design and Modeling**
  - I_p pulse length = 2 sec
  - Plasma density ~5 x 10^{13} cm^{-3}
  - Particle confinement time $\tau_p \sim \tau_E$ from stored energy ~50 ms
  - Adopted fueling efficiency ~0.3
  - Adopted total fueling ~50 torr-liters

- **LLD Geometry Parameters to be Adopted**
  - Major Radius - TBD 4/15/07
  - Width - TBD 4/15/07

LLD Heating, Heat Extraction, and Vessel Armor

- LLD heating design needs to accommodate
  - Adopted temperature range (from SNL experiments)
  - Feedthru availability
  - Possible armor for divertor/vessel safety
  - Divertor region issues (instrumentation, divertor gas fueling ports …)

- Heat extraction via inertial conduction and radiation may be sufficient

- Is divertor armor needed under LLD to stop burn-thru failure mode (e.g. install LLD on existing divertor tiles)? This and other failure modes will need to be addressed for NSTX for the following:
  - Failure Modes and Effects Analysis (FMEA)
  - Safety Assessment Document (SAD)
  - Safety Review Committee (SRC)
  - Activity Certification Committee (ACC)
  - Executive Safety Board (ESB)

Geometry of Lower Divertor Region

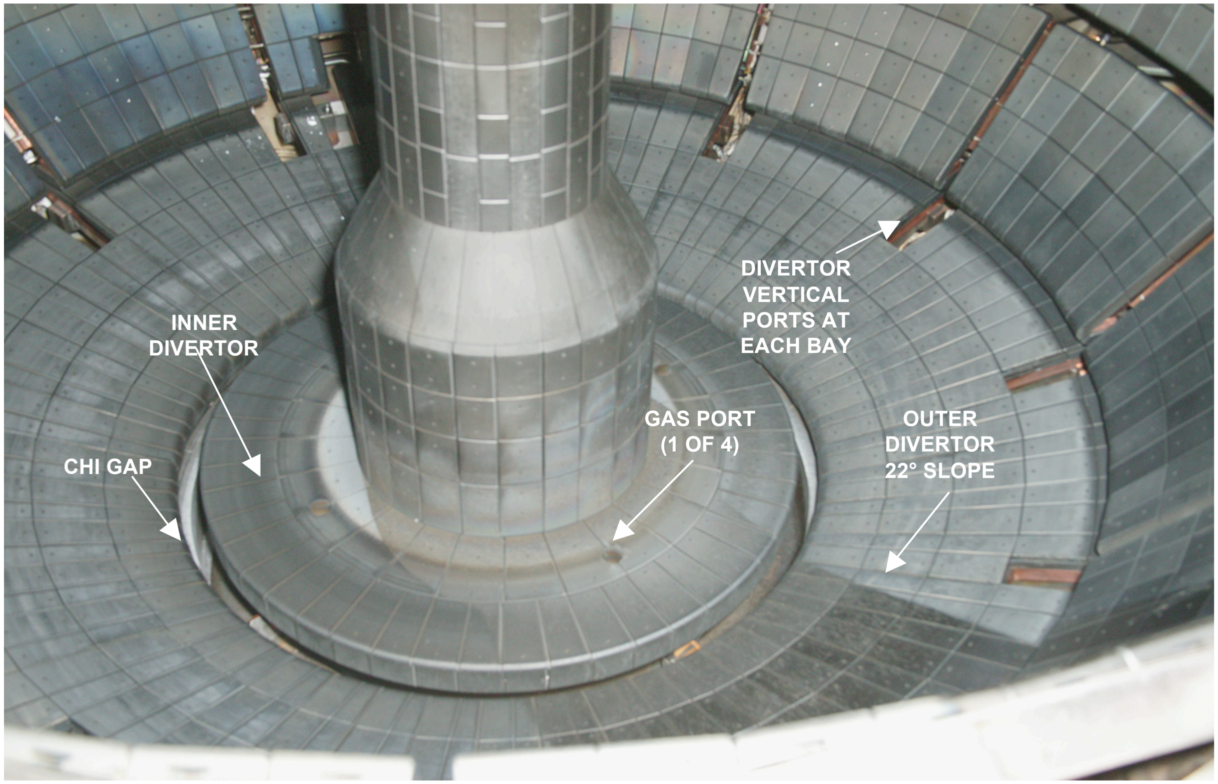
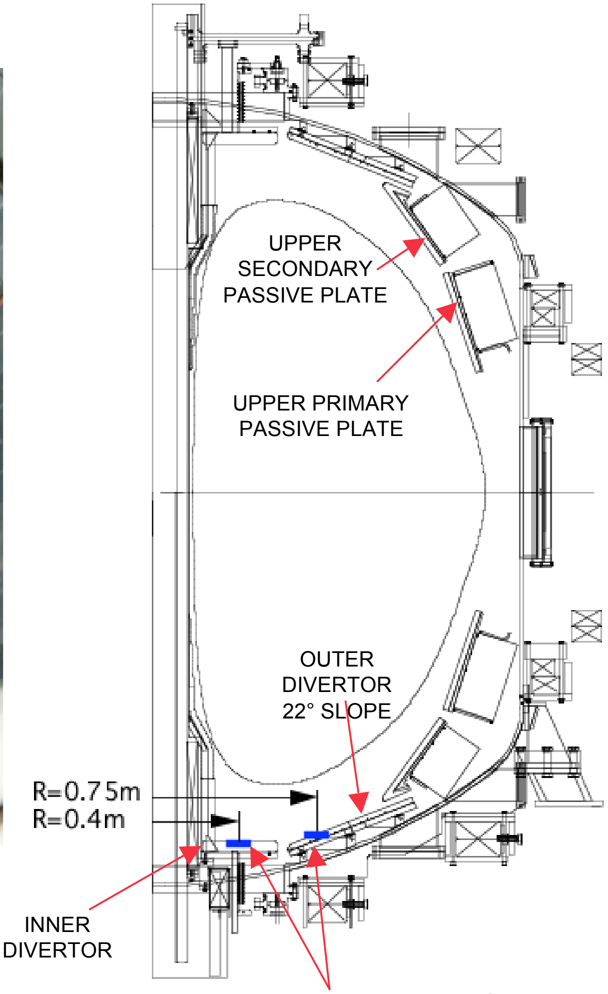


Photo of Lower Divertor after Lithium Evaporation



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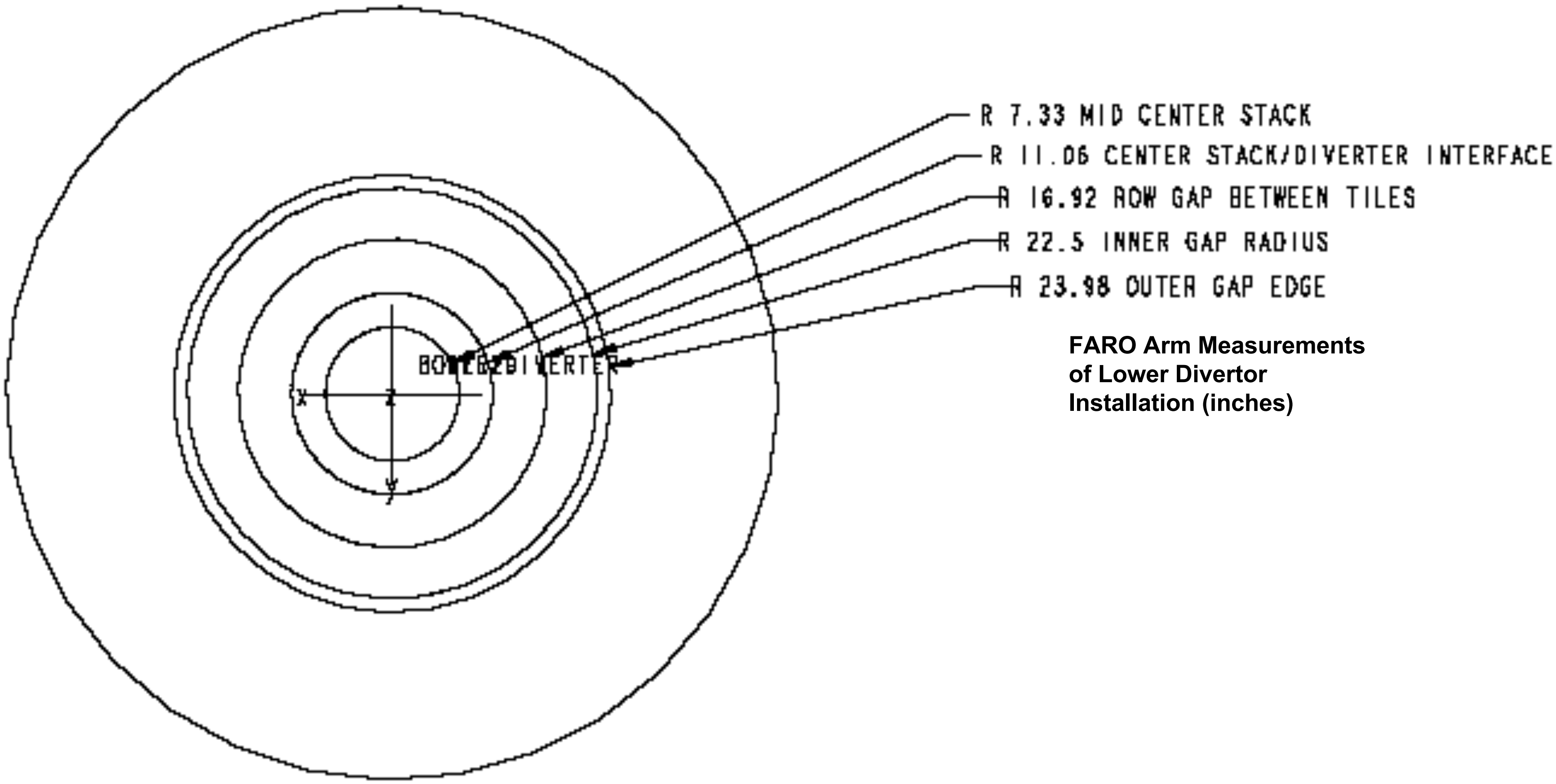
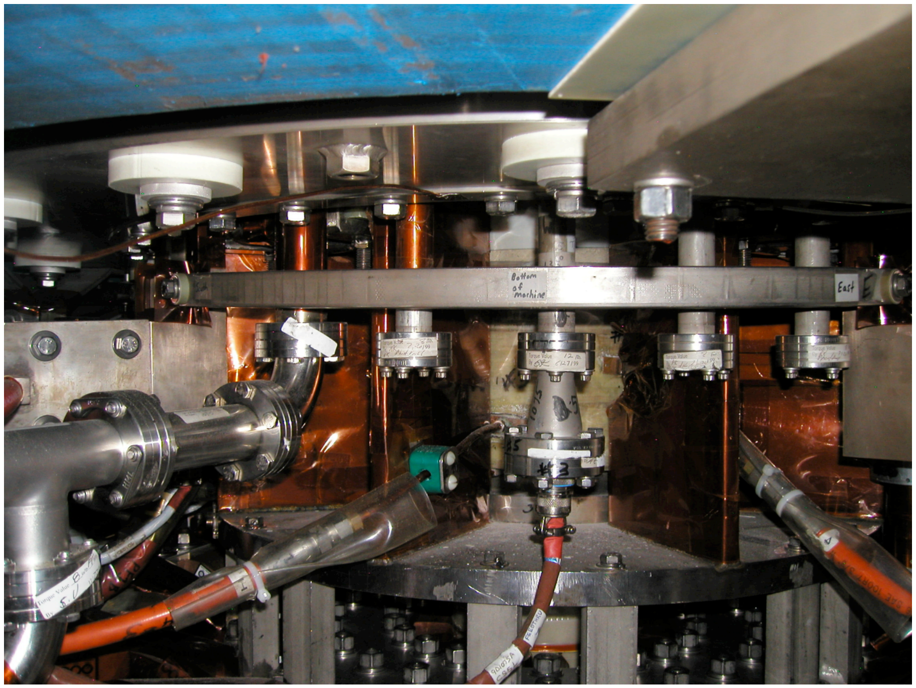
FARO Arm As-Built Measurements of Lower Divertor

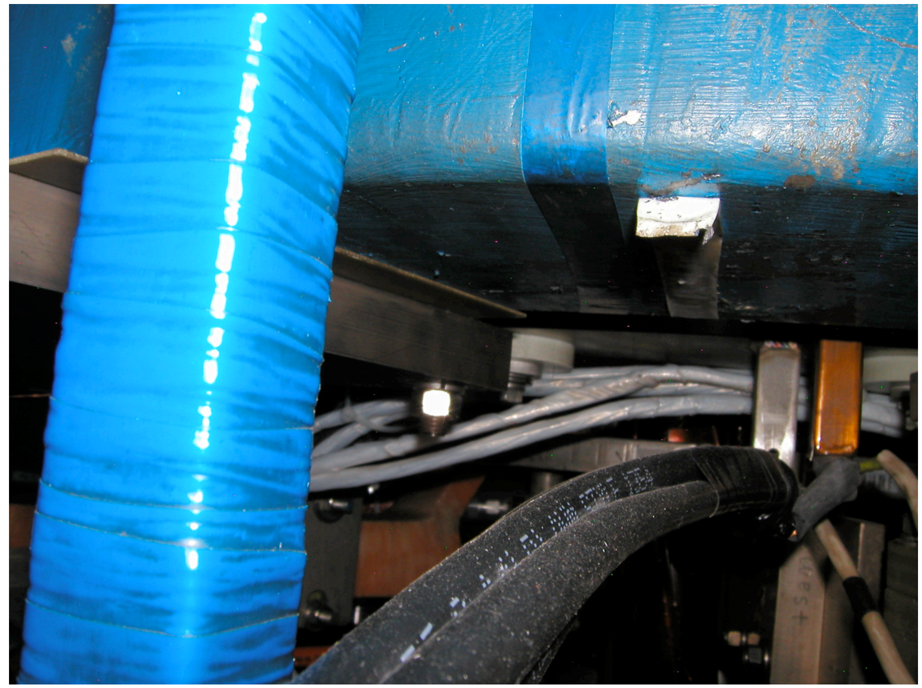


FARO Arm Measurements of Lower Divertor Installation (inches)

Limited Access to Inner Divertor Ports & Feedthrus



Some Inner Divertor Ports Visible
From Outer Umbrella Structure



Some Inner Divertor Ports Not Visible
From Outer Umbrella Structure

Preliminary Merits, Demerits, Issues for LLD Radius & Width

MAJOR RADIUS & WIDTH	MERITS	DEMERITS / ISSUES
Inner-half, Lower Inner Divertor	+ Lowest R/a. + Allows high performance plasmas. + Graphite outboard for other XPs. + Smallest circumference (7').	- Biggest impact if malfunction during run. - Difficult to reach Inner Vessel feedthrus. - Lower Inner Divertor gas ports. - ~137cm Li feed stroke from HorizDiv Port. - Possible CHI issues
Outer-half, Lower Inner Divertor	+ Graphite on inboard side for other XPs.	- Difficult access to Inner Vessel feedthrus. - Lower Divertor gas ports. - ~117cm Li feed stroke. - Possible CHI issues
Entire, Lower Inner Divertor	+ Allows wide range of strike points and XPs with no interference from nearby graphite.	- Difficult access to Inner Vessel feedthrus. - Lower Inner Divertor gas ports. - ~117cm Li feed stroke from HorizDiv port. - Possible CHI issues
Inner-half, Lower Outer Divertor	+ Minimal impact if malfunctions during run. + Allows majority of XPs to use Inner Divertor as presently. + Nearby large ports. + Minimal feedthru issues. + No apparent CHI issues. + Higher R/a, NHTX-like XPs. + Allows characterization of heat flux footprint for higher-aspect-ratio NHTX-like plasmas.	- Largest circumference (15.5'). - Sloping installation on conical section more difficult. - Flat installation on conical section may have edge issues. - Allows LLD test, but unusable for present smaller R/a high performance plasmas. -~102 cm Li feed stroke from HorizDiv Port (~46 cm from VertDiv Port)

LLD Diagnostic Implications Need to Be Determined

- Effect of Lithium sources between discharges
  - Possible mild evaporation from LLD
  - Possible evaporation from LITER-type evaporators
- Effect of Lithium sources during discharges
  - Plasma transport
  - Sputtering
- Hardware and measurement issues
  - Shields
  - Shutters
  - Double TIVs for window replacement during Run
  - Window transmission
    - In situ calibration sources
    - Transmission monitoring innovations

Preliminary NSTX FY07 and FY08 Support Tasks

NSTX

FY07

- Adopt LLD Major Radius and Width (4/15/07)
- Perform precision in-vessel measurements for LLD development
- Analyze available port options for LLD cables.
- Relocate existing in-vessel cabling and sensors to accommodate LLD
- Design, fab, install 360° IR and visible camera viewing capability for LLD
- Install shielding and in situ window calibration sources
- Install special electronic rack.
- Make vessel accommodations for Li loading scheme and identify required ports.
- Perform controls engineering.
- Prepare Safety documentation with SNL

FY08

- Engineer and fabricate special tiles, fixtures,and hardware for LLD as required.
- Install LLD in-vessel.
- Install Lithium Loading Probes.
- Install all required cabling and controls.

Conclusions

• This NSTX lithium research will be the latest step in the decade-long, multi-disciplinary, and multi-institutional US research program to develop lithium as a plasma-facing system that can withstand the high surface heat fluxes and neutron wall loads expected in ITER-like devices and future fusion reactors.

• NSTX is confronting these particle flux and edge heat management issues through its unique program on lithium coatings and its investigation of liquid lithium as a long-term solution for particle and power handling in ITER and future burning plasma fusion reactors.