Edge Physics - ETG Meeting
for
Review and Adoption
of a
Proposed LLD Radius and Width

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May 22, 2007

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Outline

- SNL Liquid Lithium Divertor Proposal Structure
- SNL Proposal NSTX Milestone Action Item
- The Adopted LLD Operating Design Goals
- Decision Process / Workshop Design Talks
- Status of Radius and Width Decision Process
- Summary and Conclusion

The SNL, UCSD, NSTX Collaboration Will Develop and Operate a Liquid Lithium Divertor Starting in the Present NSTX 5-Year Lithium Plan

- **Sandia will supply NSTX with**
  - LLD hardware for an outer strike point target (e.g. a boat containing a sintered Mo porus medium).
- **SNL and NSTX collaboration will include**
  - design of the hardware, specification of interfaces and responsibilities, and development of an operational plan.
  - installation and shakedown of the LLD and participation in LLD experiments in NSTX.
- **UCSD will participate through a subcontract with SNL**
  - provide removable lithium feed systems or other hardware for alternate schemes for filling the LLD.

SNL Proposal Milestone Calls for NSTX to Adopt LLD Radius and Width Specifications

- The Requested Geometry Design Parameters
  - Major radius R
  - Width

- Additional Parameters to be determined from SNL and NSTX Engineering Analysis and SNL Experiments
  - Number of segments
  - Gaps between segments
  - Clocking of segments (ϕ_{min}–ϕ_{max})
  - Orientation (horizontal or sloped)
  - Mechanical support and fastening method
  - Heating method & operating temperature
  - Cooling method and duty cycle

The Design Milestones for LLD Operation Adopted from Present 5 Year Plan and ISD Requirements

NSTX

- **Design Milestones for LLD Operation**

1) Achieve inductionless current drive density control capability in the range:

  - Option 1

    n_e = 3 x10^{19} m^{-3} at Ip = 700 kA (n_e/n_{GW}) ~0.4-0.5
    [from Previous 5 Yr plan, ISD scenario]

  - Option 2

    n_e ~ 5 x10^{19} m^{-3} at Ip = 700 kA (n_e/n_{GW}) ~0.65-0.8
    [from more recent estimates (~15-25% decrease in n_e from recent exps)]

[FY09]

2) Allow for n_e scan capability in H-mode (e.g.,~ x2)

[FY10]

3) Investigate up to 7.5 MW NBI incident power for 2 sec (15 MJ of energy)

[FY10]

NSTX Completed the LLD Design Workshop Process for Arriving at the Radius and Width Decision

NSTX

• LLD Radius and Width Design Workshop Talks

1) Basic Scope of Sandia Effort - R. Nygren, 2/27/07
2) NSTX , SNL, UCSD LLD Collaboration - H. Kugel, 2/27/07
3) Progress Toward Design Goals and the Process - H. Kugel, 3/09/07
4) Physics Considerations for the Design of the LLD for NSTX - R. Maingi (ORNL), 3/9/07
5) Liquid Lithium Divertor 0-D Pumping Projections and Sensitivities - R.Maingi (ORNL), 4/03/07
6) Near Term Plans - H. Kugel, 4/24/07
7) Particle Flux and Recycling Analysis in NSTX - V. Soukhanovskii (LLNL), 4/24/07
8) Lithium Chemistry in NSTX - J. R. Timberlake, 4/24/07
9) Fast Ion Loss to NSTX Divertor Region and Implications for the LLD - D. Darrow, 5/02/07
10) Recycling and Particle Fluxes in NBI H-mode Plasmas - V. Soukhanovskii (LLNL), 5/02/07
11) LLD Update - H. Kugel, 5/10/07
12) Liquid Lithium Divertor CHI Implications - R. Raman (U. Washington), 5/10/07
13) A Very Short Summary of CDX-U Lithium Regimes - R. Majeski, 5/10/07
14) Thermal Regime of LLD - L. Zakharov, 5/10/07

Status of the LLD Radius and Width Decision Process

- The Design Workshop discussions and analysis used to:
  - Identify technical constraints on the candidate geometries.
  - Simulate particle balance and recycling physics.
  - Discuss analysis of available data.
  - Update Decision Matrix.

- The remaining steps are:
  > Edge Physics - ETG review and adoption of a proposed radius and width.
  - NSTX Physics Meeting for review of the Edge Physics - ETG proposal.
  - Management Review

Elements of the Decision Matrix
Used for the LLD Radius and Width Analysis

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1. Experimental program impact on high performance low R/a discharges, if LLD component failure occurs.
2. Radial & width variation of the LLD pumping speed.
3. Installation technical complexity (in- & ex- vessel).
4. Lithium-filling issues.
5. Diagnostic Issues.
6. Lithium inventory.

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Summary of Analysis of Experimental Program Impact on High Performance Low R/a Discharges, If LLD Component Failure Occurs

• Simplest Gedanken: Assume an LLD whose pumping speed is independent of radius, it functions for a few weeks, and then has a component failure.

RADIUS & WIDTH	PROGRAM RISK LEVEL	COMMENTS
Inner-half, Lower Inner Divertor	Highest	This is the high performance, low R/a region. If LLD malfunctions, stop the run, vent, and fix malfunction
Outer-half, Lower Inner Divertor	Medium	If LLD malfunctions could maybe run inboard if LLD is narrow, but flux expansion would overlap LLD
Inner-half, Lower Outer Divertor	Lowest	If LLD malfunctions could run in high performance, low R/a region almost unchanged

• Under the above assumptions, the lowest risk location for the LLD to high performance, low R/a discharges is the Outer Divertor.

Summary of Analysis of LLD Pumping Speed Variation with Radius & Width

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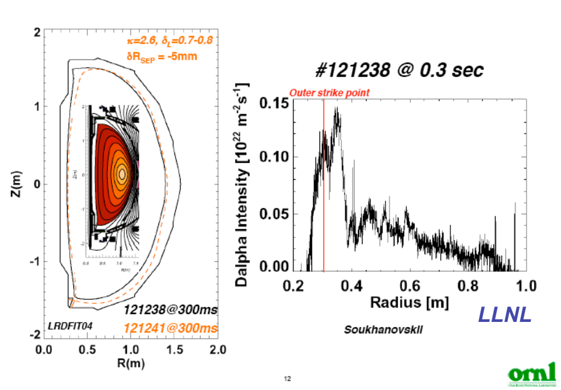
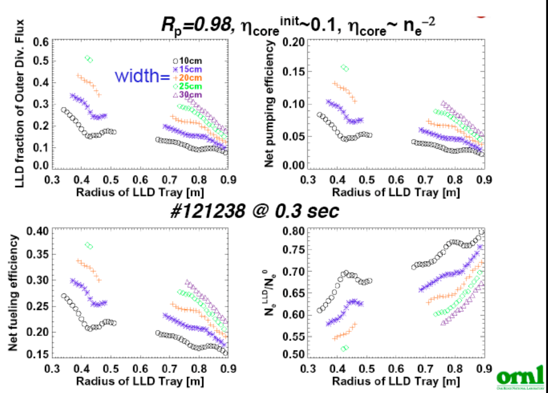
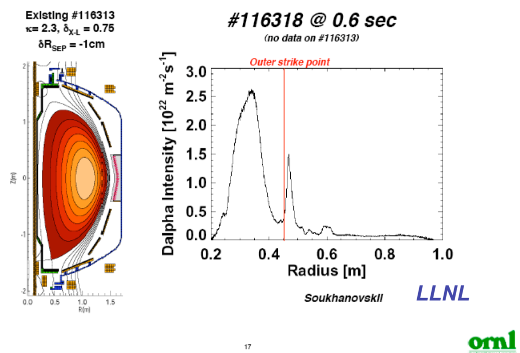
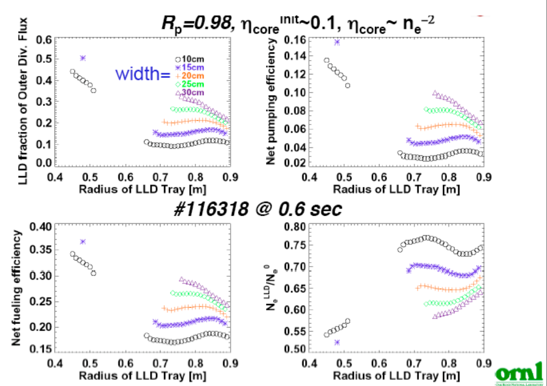
Broad SOL Dα profile in high δ (pf1a) #121238



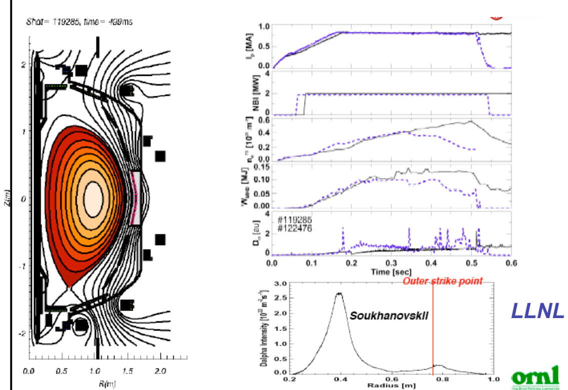


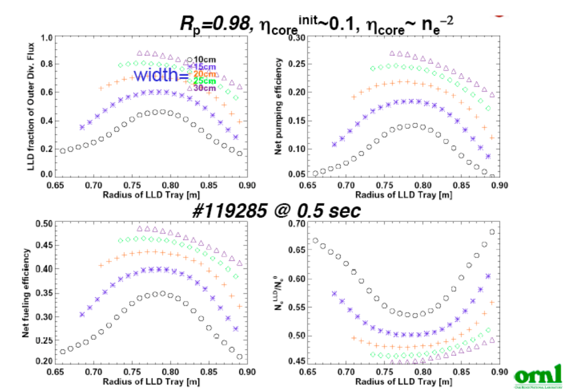
Narrow SOL Dα profile in medium δ (pf1b) #116318





Narrow SOL Dα profile in low δ (pf2) #119285





- **LLD 20 cm Wide Pumping on Outer Divertor Provides ~20% Reduction in Density for High Performance ISD Inductionless Current Drive**

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Summary of Analysis of LLD Radius Location and In- & Ex-vessel Technical Complexity

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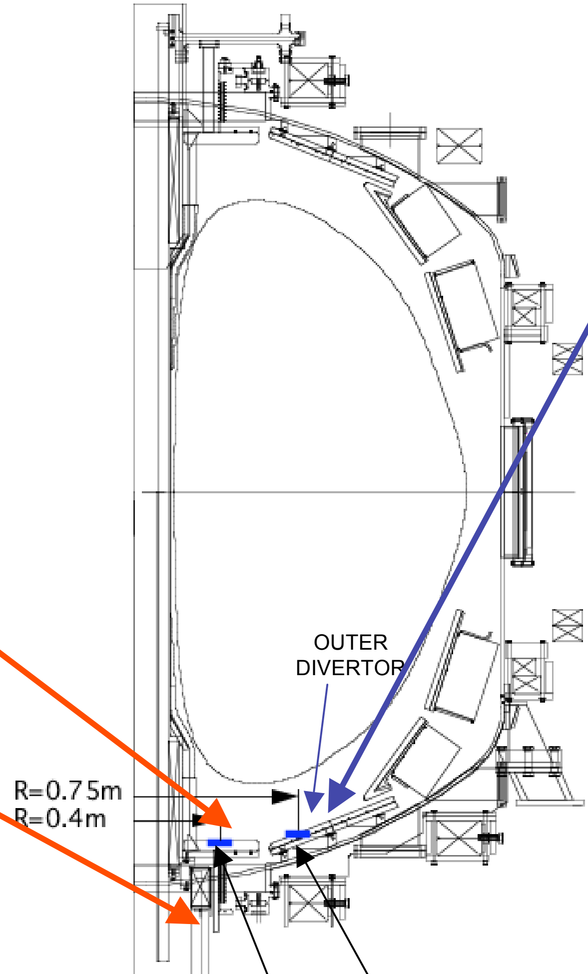
INNER DIVERTOR

- Interference with Lower Inner Divertor gas ports.

- Difficult to reach Inner Vessel feedthrus. Cannot be reached during operations.



- **Candidate locations for toroidal, LLD at Inner or Outer Divertor**

OUTER DIVERTOR

- **Either**
  - **Flat installation on conical section**
- **Or**
  - **Sloping installation on conical section more difficult**

- ***Convenient access to feedthrus and easiest modification of instrumentation***

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Summary of Analysis of LLD Lithium-filling Issues

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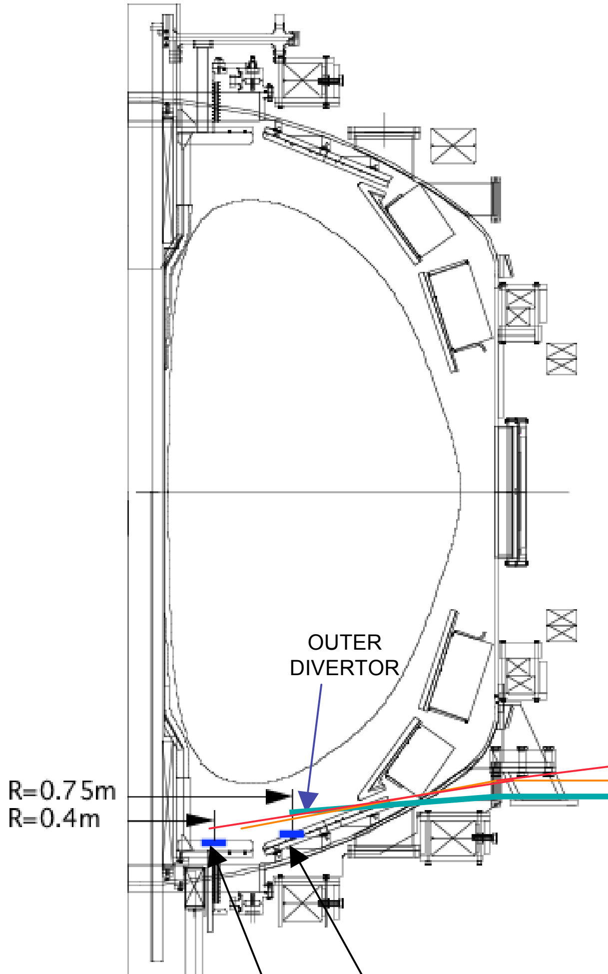


• **Candidate locations for toroidal, LLD at Inner or Outer Divertor**

INNER-HALF INNER DIVERTOR

- Li feed stroke ~137 cm from Horizontal Divertor Port

OUTER-HALF INNER DIVERTOR

- Li feed stroke ~117 cm from Horizontal Div Port

INNER-HALF OUTER DIVERTOR

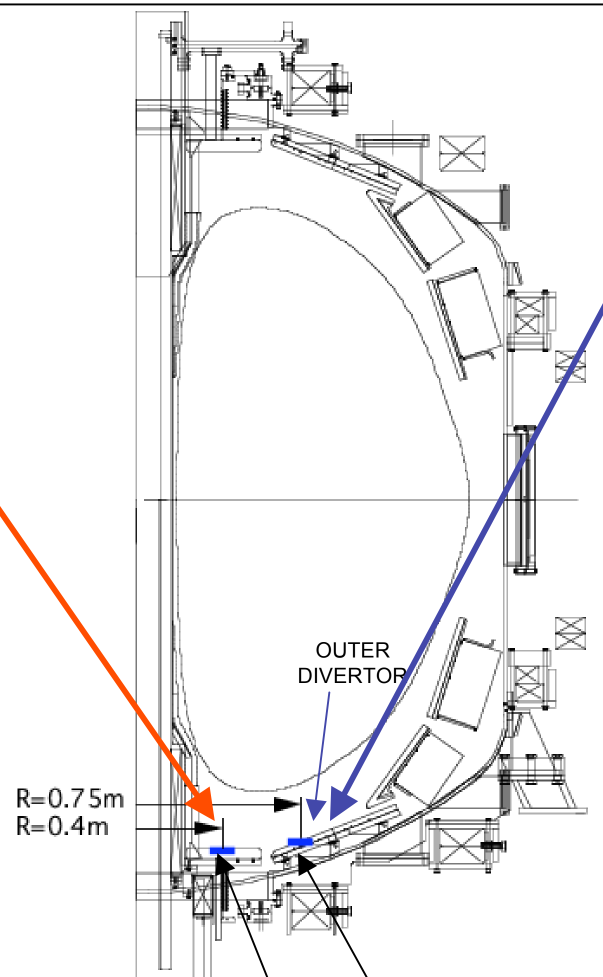
- Li feed stroke ~102 cm from Horizontal Divertor Port.

- minimum feed stroke for outer divertor location

Summary of Analysis of LLD Diagnostic Issues

INNER-HALF INNER DIVERTOR
- Loss of 1 or 2 Bz coils
- Loss of 2 TC
- Loss of 2 LP

OUTER-HALF INNER DIVERTOR
- Loss of 1 or 2 Bz coils
- Loss of 2 TC
- Loss of 2 LP spaces



- **Candidate locations for toroidal, LLD at Inner or Outer Divertor**

INNER-HALF OUTER DIVERTOR
- Loss of 2 Bz coils
- Loss of 2 TC
- Loss of 1 LP spaces
- FL response changes

- ***In-vessel Instrumentation easier to modify on outer divertor***

Summary of Analysis of Lithium Inventory

LLD Liquid Lithium Inventory Requirement

Fuel per Shot
The adopted specification for LLD design calculations for deuterium fueling per shot is 50 T-liters.

D_2 moles/shot
50T-liters D_2/shot = 50 T-liters x (1mole/18250 T-liter) = 2.740×10^{-3} D_2 moles/shot

D moles/shot
D moles/shot = 2 x D_2 moles/shot = 5.479×10^{-3} moles/shot

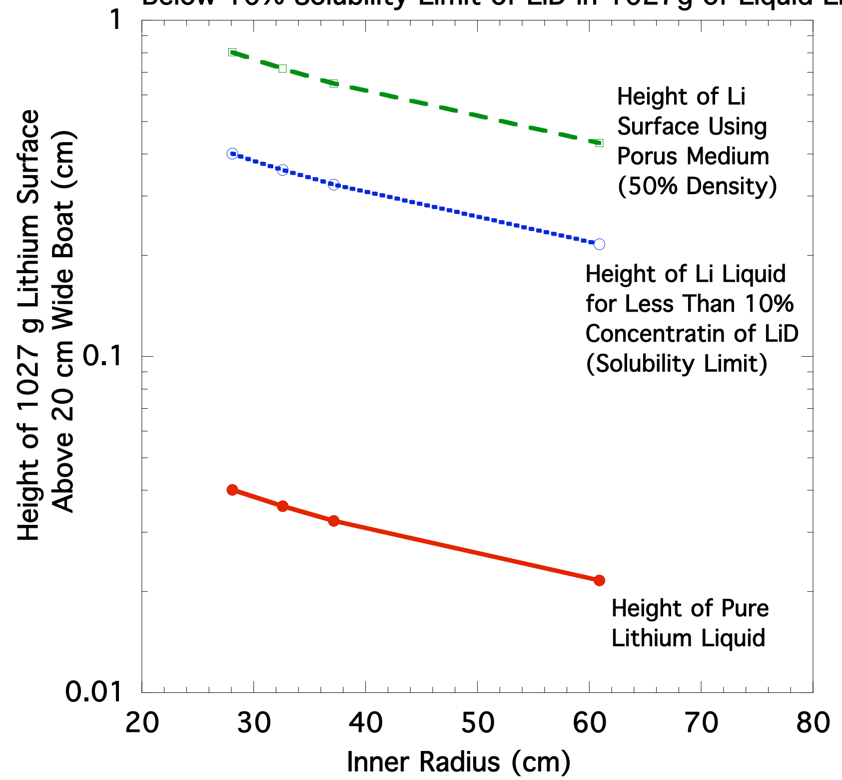
Li mass consumed /Shot
The amount of Li needed to convert the total D fuel inventory into LiD per shot is $M_{Li} = (5.479 \times 10^{-3}$ moles-Li/shot) x 6.94 g/mole-Li = 3.80×10^{-2} g = 38.0 mg

Total Number of Shots per 18 Week Run
Assume best case of 30 shots /day Total shots = (30 shots/day) x (5 days/wk) x (18 weeks) = 2.700×10^3

Total Minimum Li Mass Consumed per 18 Week Run
$m_{total} = (3.80 \times 10^{-2}$ g/shot) x $(2.700 \times 10^3$ shots) = 1.027×10^2 g

Minimum Mass Required to Not Exceed 10% Solubility Limit for LiD in Li
$M_{total} = 10 \times m_{total} = 10 \times (1.027 \times 10^2$ g) = 1.027×10^3 g

For 102.7 g of Lithium Consumed at 30 Discharges/day, During a 2700 Discharge 18 Week Run Assuming An Average Fueling of 50 T-liters D2 per Discharge at 38 mg of Lithium Consumed per Discharge While Remaining Below 10% Solubility Limit of LiD in 1027g of Liquid Li



- **1027 g of Li Needed for 18 Wk Run**

Summary and Conclusion

- For comparable pumping speeds, the lowest risk location for the LLD to high performance, low R/a discharges is the Outer Divertor

- LLD 20 cm wide pumping on Outer Divertor provides reduction in density for high performance ISD Inductionless Current Drive milestone

- LLD on Outer Divertor provides easiest access to feedthrus and easiest modification of instrumentation

- LLD on Outer Divertor provides minimum lithium-filling feed stroke

- In-vessel Instrumentation easier to modify on Outer Divertor

- All LLD locations require 1027 g of Li for 18 Week Run to remain above the 10% solubility limit for LiD in liquid lithium

- **The preliminary adoption of a 20 cm wide LLD on the Outer Divertor, about 2.5 cm Outboard of the CHI-gap optimizes NSTX requirements**