Lithium Research Topical Science Group Mid-run Assessment 27 August 2010

Charles Skinner for LRTSG

Outline:

- Motivation for LLD (as presented to PAC Feb 2010)
- List of XPs prioritized at research forum.
- XP reports so far
  - XP1000 (Kugel) LLD commissioning (5 days)
  - XP1001 (Soukhanovskii) LLD pumping (0.5 day)
  - XP1002 (Soukhanovskii) Impurity reduction (0.5 day)
  - XP1041a (Kugel) LLD Pumping doc (1 day)
  - XP1059 (Kugel) LLD Characterization II (2.5 days)
- Considerations / recommendations for future Kugel/Kaita/Maingi/Skinner.

Eisenhower on eve of World War II: "I have always found that planning is indispensable but plans are useless."

Motivation for LLD as presented to PAC Feb'10

- **LLD to extend density control for NB CD**
- **LLD compatible with high flux expansion divertor solutions.**

FY10 priorities:

- Develop and understand high-performance operating scenarios utilizing a liquid lithium divertor (LLD) for pumping and particle control.

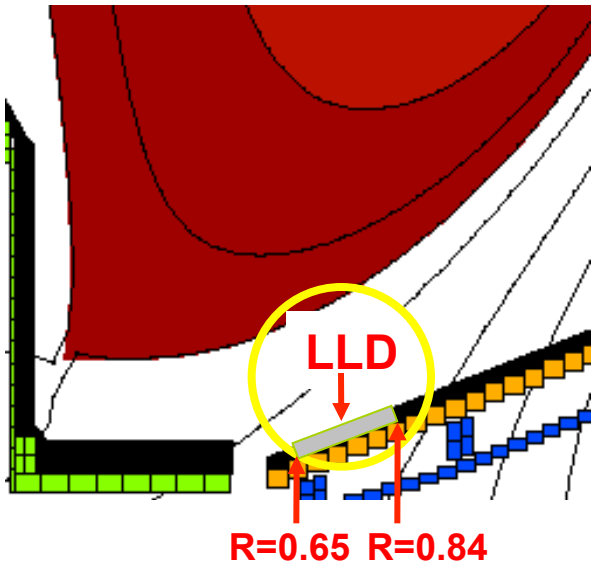
FY11 priority: Milestone R11-3:

- Assess the relationship between lithiated surface conditions and edge and core plasma conditions.

FY10 goal: test LLD predictions of 33% - 56% reduction in Ne with LLD compared to no-Li.

- Analyse results with particle balance models and 2D fluid (e.g. UEDGE) modeling.
- Study pumping in SGI-fueled discharges vs.
  - strike point location,
  - core ion density,
  - divertor ion flux (vary by SGI fueling),
  - LLD temperature
- Qualify a range of I_P and P_{NB} scenarios for subsequent XPs.

Particle balance model [R. Maingi]:
High δ: n_e reduced by 33%
cf no-Li case.



Low δ: n_e reduced by 56%
cf no-Li case with strike point on LLD.

Look for LLD effect with LLD molten Li @ 210°C but LiTER shuttered.

Priority 1 XPs from Research Forum and *later XPs

				Allocation	Actual/ *scheduled*
LR/CC	XP1000	Kugel	LLD Commissioning	3d	5d
LR	XP1001	Soukhanovskii	LLD Pumping Group XP	2d	0.5d
LR	XP1002	Soukhanovskii	Impurity and Prad reduction…	1d	0.5d *0.5d*
LR	XP1024	Skinner	Impurity Reduction by Diffusive Li Injection	0.75d	
LR*	XP1041a	Kugel	LLD Pumping doc.		1d
LR/CC	XP1054	Kugel	LLD decommissioning	0.5d	
LR	XP1056	Mansfield	Impurities reduction with Dropper…	0.75d	*0.75d*
LR	XP1057	Skinner	D retention with LLD	1d	
LR*	XP1059	Kugel	LLD 50% fill Characterization II		2.5d
LR*	XP1065	Skinner	Impurity sources via CD4 screening		

XP1001

From: Vlad Soukhanovskii vlad@pppl.gov

Date: August 27, 2010 10:12:57 AM EDT

To: Charles Skinner <cskinner@pppl.gov>Cc: Henry Kugel <hkugel@pppl.gov>, Robert Kaita rkaita@pppl.gov

Subject: Re: status of XP 1001

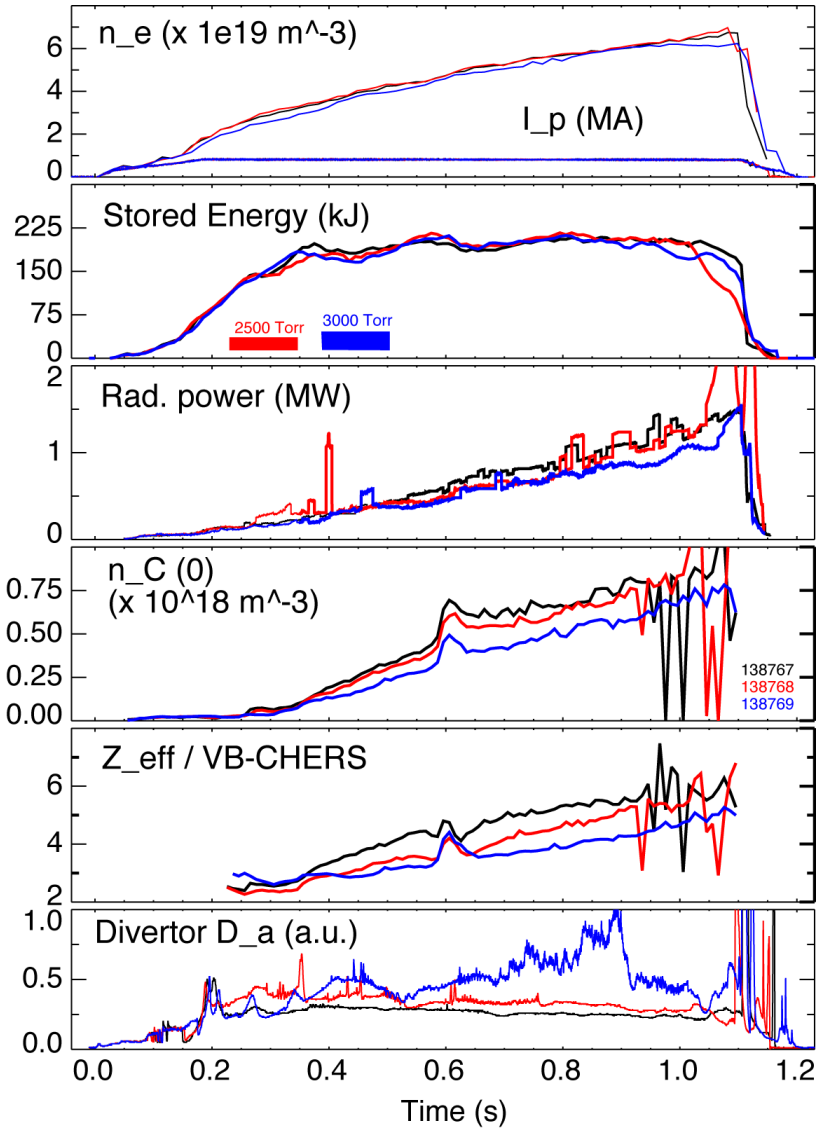
Charles, My apologies, it is now looking unlikely that I will send you a slide on XP 1001. I spent all day yesterday in the control room, and I am still here to support Loarte's experiment, also working on my presentation for the mid-run assessment. I was planning to show the SGI gas pulse recycling on the LLD and its dependence on LLD lithium as we turned off the LITERs over several shots. As you know we ran XP 1001 too late when the heaters were broken and the LITERs had to be used since the mega-evaporation layer was wearing off. Thank you.

Vlad Soukhanovskii

Small divertor D_2 injections are used to reduce core impurity accumulation in XP 1002 (V. Soukhanovskii)

- Goals:
  - reduce Z_{eff} (carbon, oxygen density) and P_{rad} (metals) in ELM-free H-modes with lithium conditioning
  - reduce n_e and N_e due to impurities
  - study the physics mechanism
    - SOL/divertor impurity sputtering reduction?
    - impurity entrainment in increased SOL viscous flow
    - edge neoclassical pinch reduction?
- Status:
  - Ran 0.5 day, successful start
  - Need 0.5 day to complete

- Shown: reference 4 MW shot in black, two shots w/ divertor gas in red and blue



XP1000: Liquid Lithium Characterization (137385-623)

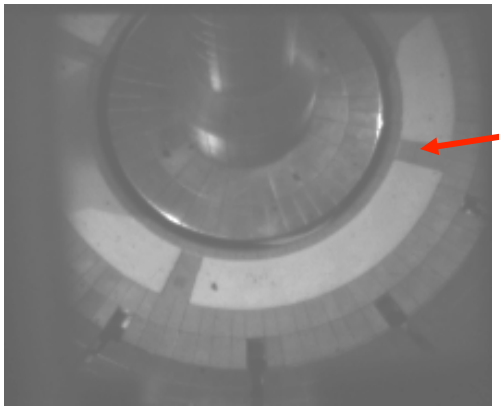
- Original Goals:
  - commission LLD for plasma operations
  - obtain discharges w/OSP at R=0.35, 0.50, 0.63 0.75m with LLD heated (30-220°C)
  - vary NBI to obtain early, ELM-free, H-modes that stay below beta limit
  - measure relative change in fueling due to LLD
  - measure persistence of pumping effects with and without LITER coating renewal
  - match $n_e(t)$ fueling with both HFS and SG

- Results
  - LLD and associated diagnostic systems have been commissioned successfully.
    - No apparent damage to LLD or LLD inter-quadrant diagnostic tiles observed
    - No significant molybdenum influxes or halo current effects observed.
  - Obtained discharges w/OSP at R=035, 0.50, 0.63, 0.71m with 1 LLD plate unheated (initially 30-50°C) and 3 LLD plates heated (220-320°C).
  - As lithium deposition increased, reproducible, ELM-free, H-modes were rapidly obtained and exhibited noteworthy and reproducible energy confinement and flux consumption relative to non-lithium plasmas.
  - Fueling with LLD in ~5% filled liquid state and lithium evaporated on the graphite tiles, exhibited little difference compared to previous evaporated lithium depositions over the same region prior to installation of LLD.

XP1000: Liquid Lithium Characterization (137385-623)

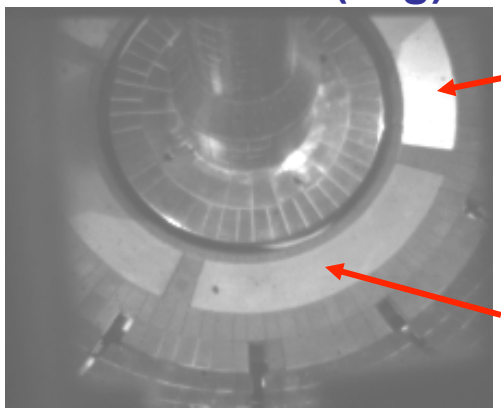
- Unheated plate exhibits higher reflectivity than heated plates as Li soaked into the porosity of the heated plates

Pre Lithium (unheated)



Major radius of 99-probe array

Post Lithium (12g)



Unheated during Li deposition

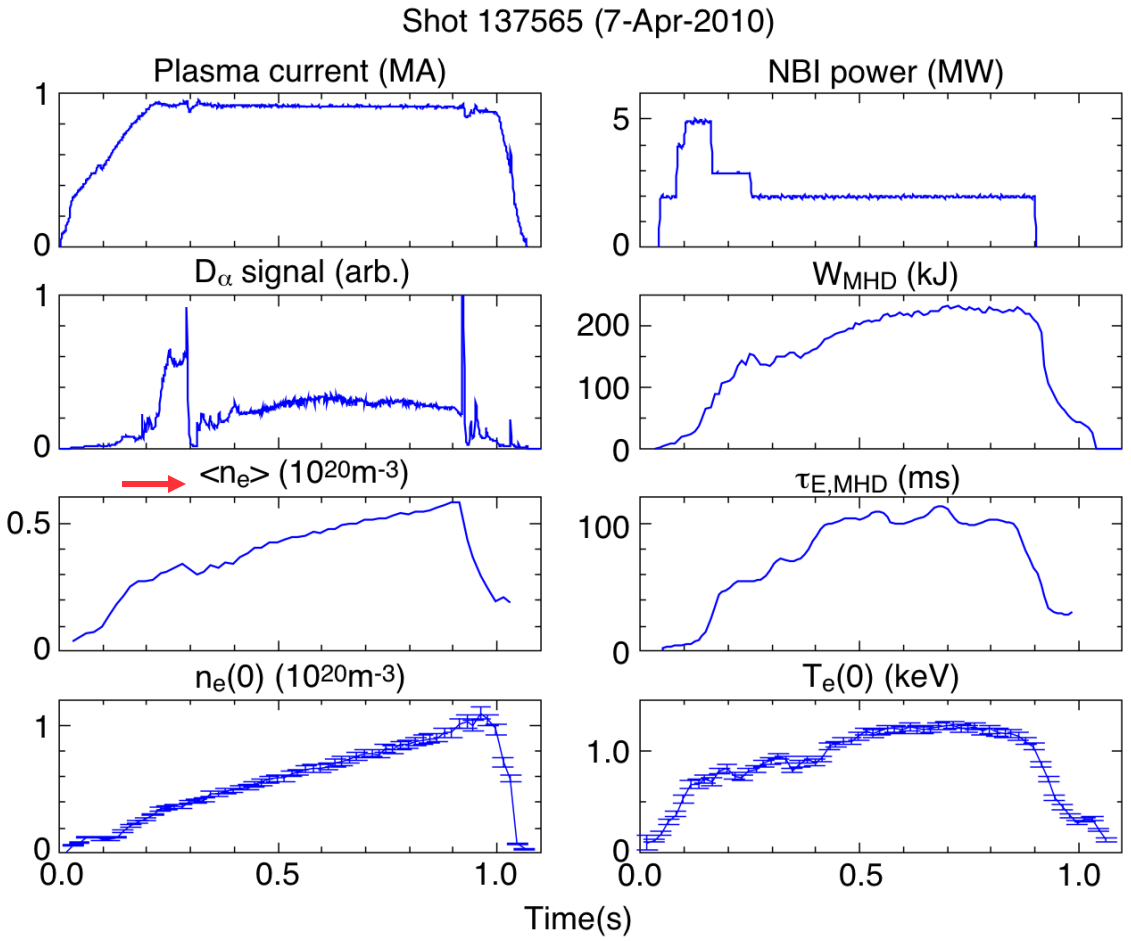
220°C during Li deposition

F. Scotti

XP1000: Liquid Lithium Characterization (137385-623)

- LLD Operation w/LITER Improves Inner Divertor Discharges

137565: OSP=0.50m, LLD T_0 319°C, LITER 21.2mg/min



M.Bell

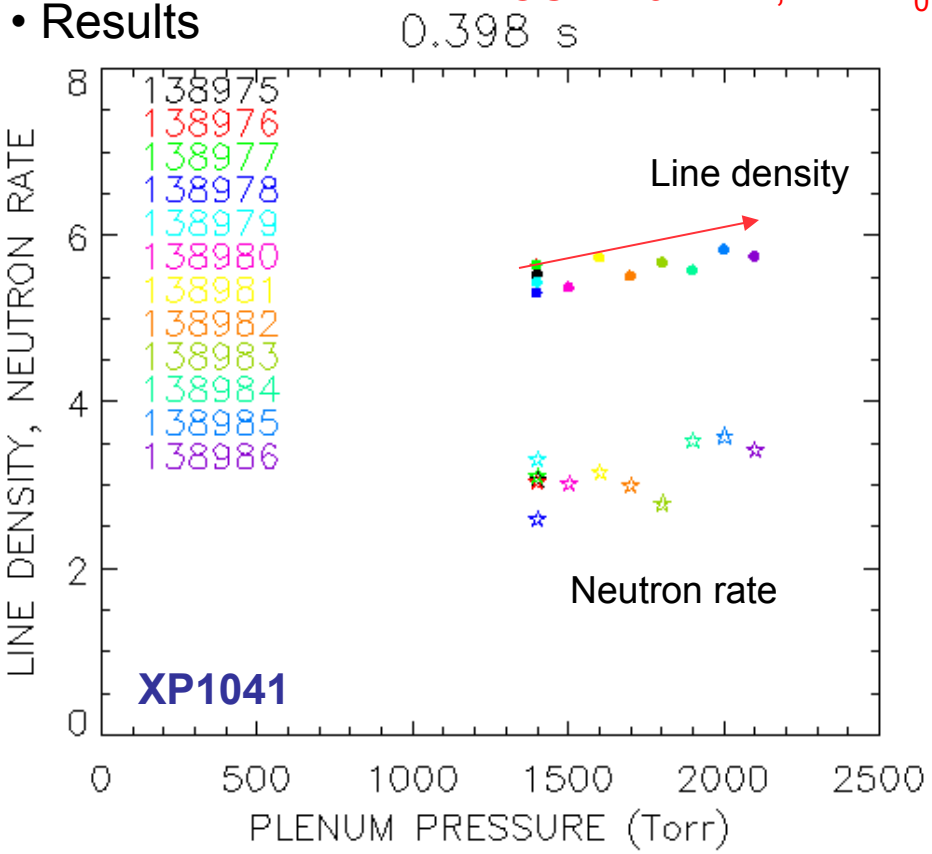
XP1041A: Auto Plasma Heating of LLD (139375-414)

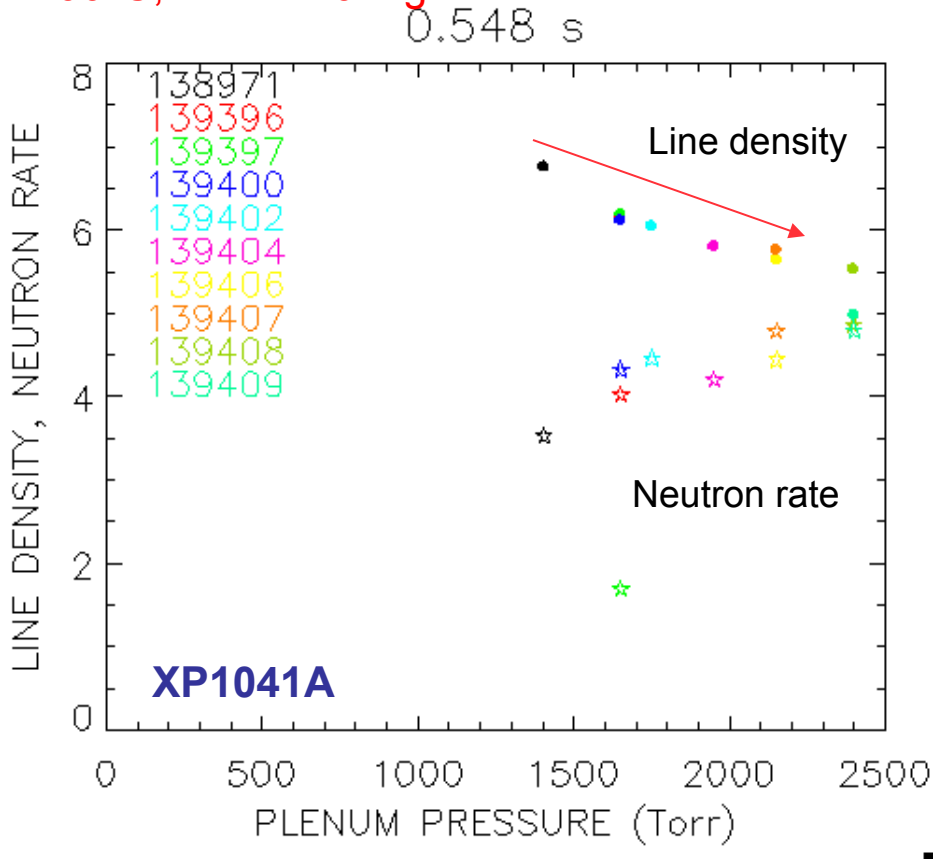
• Goals:

Reproduce and investigate the plasma fueling and Liquid Lithium Divertor characteristics observed in the XP1041, R=0.77m discharge sequence 138971-138987.

OSP = 0.77 m, LLD T_0 = ~90°C, LITER 20 mg/min

• Results





• XP1041, LSN, OSPR=0.75m, higher X-pt: With increasing HFS fueling, *density increases.*

• XP1041A, LSN, OSPR=0.75m, lower X-pt: With increasing HFS fueling, *density decreases, peaking factor increases, neutron rate increases*.

R.Bell

XP1059: Liquid Lithium Characterization (139570-782)

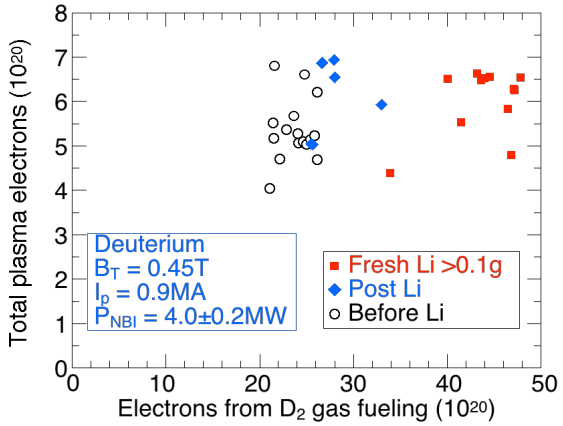
- **Goals: At OSPR=0.68cm, LLD T0=118°C, No LITER**

  Test filling the LLD to >40-50% Li capacity. This decreases the physical to geometric area ratio and bypasses or minimizes 6 issues:
  - desorption of deuterium exacerbated by the high surface area of the porous Mo
  - mass-limited diffusion into the Li
  - mass-limited retention
  - effective range uncertainty
  - impurity strata due to repeated hot-cold-hot cycles
  - Li to impurity ratio higher

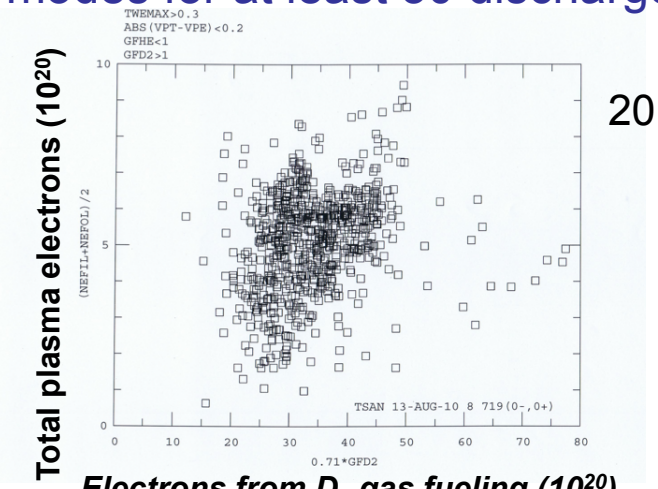
- **Results**

1. ***Rate of LLD Pumping***: required fueling with LLD warm or cold with OSP on or off-LLD is similar to that for 2008-2009 solid Li coatings on graphite.
2. ***Duration of LLD Pumping***: with OSP on LLD, and LITER-off, LLD provides Li edge conditions yielding ELM-free H-modes for at least 30 discharges.

2008



2010



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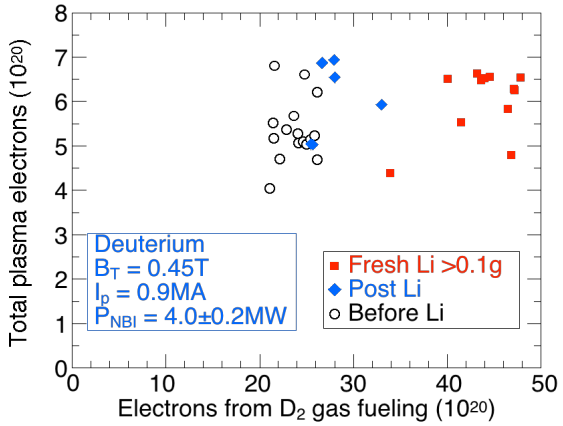
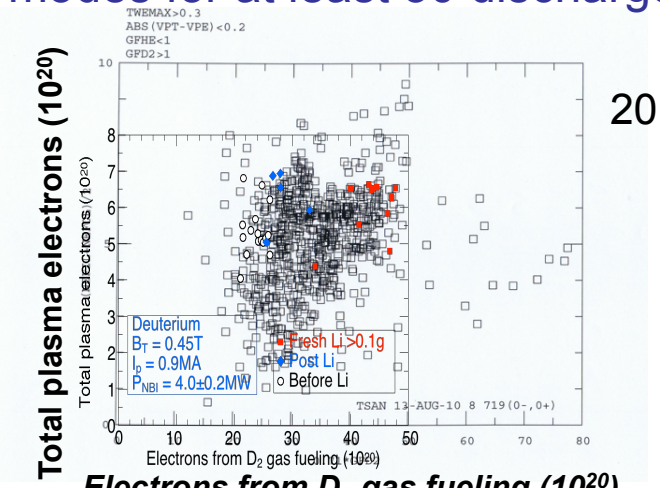


2010



Electrons from D_2 gas fueling (10^{20})

Recommended Actions to Complete Before End of Run

H. Kugel

- Using DIMS and 1D CCD cameras, measure C, O, D radial contours from ISP outward to across the LLD as OSP is scanned from R=68 to 78cm.
- With OSP at R = 70cm, measure effects on fueling, density, and impurities as X-point height is scanned (next slide).
- Determine via SGI diagnostic measurements if particle confinement time versus OSP changes from R=50 to 78 cm
- Determine if strike point, in-out, power deposition ratio changes with LLD pumping, i.e, is there any evidence that LLD pumping causes edge flows to change.
- Condition of hot, full LLD without LITER deposition not achieved.
  Need to accelerate installation of air heating capability
  - need data on pumping versus temperature, and impurity effects
  - would also facilitate the ability to document cooling full LLD without LITER

IAEA: H.W.Kugel et al., "NSTX Lithium Technologies and Their Impact on Boundary Control, Core Plasma Performance, and Operations"

Suspect heavy lithium and/or LLD allows for a wider density/fueling operation window; maybe more so in high X-point discharges?
R. Maingi

- Dedicated Experiment needed to confirm
  - Run standard fiducial and see fueling rate window for good discharges
  - Run high delta, high X-point shot and document fueling rate window
  - Run low delta, high X-point shot and document fueling rate window
  - Run low delta, high X-point shot with LLD warm
  - Probably should have low lithium evaporation rate between shots?

Maqueda: LLD fill with dropper:

"Just in case nobody mentioned this before, one possible mini-XP for the last day of the run is to try filling the last working LLD section using the dropper. This comparing the observation of "prepositioned" dust with the C dropper when the LLD cold and comparing to the same "drop" when the LLD is hot. If less dust seen, it then got stuck on the LLD. Thanks, Ricky"

Lessons and recommendations for LLD

- Surface reactivation of LLD
  - Already done in FY10?
    - Strike point appears to "reactivate" LLD so effect of lithium "persists" in absence of evaporation between shots
    - Could be serving same function as long period of Ar GDC in CDX-U
      - *Reminiscent of electron beam heating of lithium-filled CDX-U tray?*
    - Need to confirm by comparing with plasmas not having strike point on LLD and evaporation between shots
- Recommendations for FY11/12
  - Begin with low-triangularity fiducial plasmas with unloaded LLD
  - Fill with LLD in situ using liquid lithium loader
    - Keep hot and run low-triangularity plasmas without strike point on LLD
    - Compare performance with unloaded LLD fiducials
    - Determine if performance improvement – if observed – "persists" with hot LLD
  - Let LLD cool and compare performance when "hot"
    - "Reactivate" with strike point on LLD plus heat
    - Compare with low-triangularity plasmas without strike point on LLD
- Ideas for long-pulse after NSTX upgrade
  - Offline tests seem to indicate ability of LLD to withstand MW/m^2-range power densities for three seconds
  - Consider replacing inner horizontal inboard divertor section at minimum
    - Think of developing flowing lithium system in conjunction with LTX

Focus on LLD surface conditions ?

C. Skinner

IMHO Priority 1: need more attention to Li surface conditio to realize potential for D pumping

- Modest changes so far suggest D pumping by LLD is similar to lithiated graphite.
- Dedicated cleaning was necessary on PISCES and CDX to realize strong D pumping (ref. talks at LLD Fest).
- NSTX does have strong interaction of strike point with LLD.
- But edge plasma has carbon etc… impurities.
  - (Laundry with dirty water ???)
- Consider new LLD cleaning techniques:
  - ICRH conditioning of LLD ?
  - Biased LLD next year with GDC (like CDX).
- Spectroscopic diagnostics key to monitoring LLD surface conditions.
- Porous Mo tests in C128 ongoing...

Priority 2: impurity control needed to achieve 5 s pulse on NSTX_U e.g.

- *XP1024 (Li > He) based on XP1023?*
- *XP1065 CD4 screening*
- *…*

PISCES: