NSTX

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Summary of First Preliminary Results from LLD

From LRTSG meetings chaired by
Charles H. Skinner, Robert Kaita PPPL

NSTX Physics Meeting LSB-B318, PPPL
April 26th, 2010

College W&M
Colorado Sch Mines
Columbia U
CompX
General Atomics
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LANL
LLNL
Lodestar
MIT
Nova Photonics
New York U
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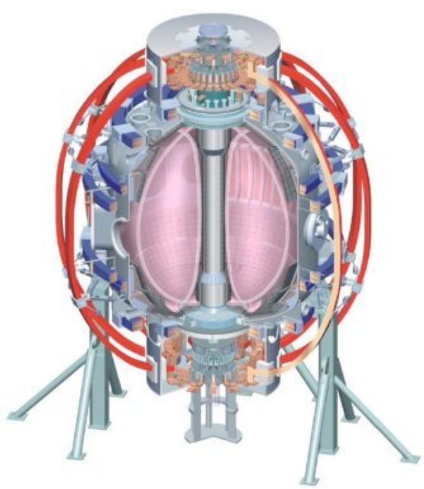

Culham Sci Ctr
U St. Andrews
York U
Chubu U
Fukui U
Hiroshima U
Hyogo U
Kyoto U
Kyushu U
Kyushu Tokai U
NIFS
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Hebrew U
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KBSI
KAIST
POSTECH
ASIPP
ENEA, Frascati
CEA, Cadarache
IPP, Jülich
IPP, Garching
ASCR, Czech Rep
U Quebec

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.

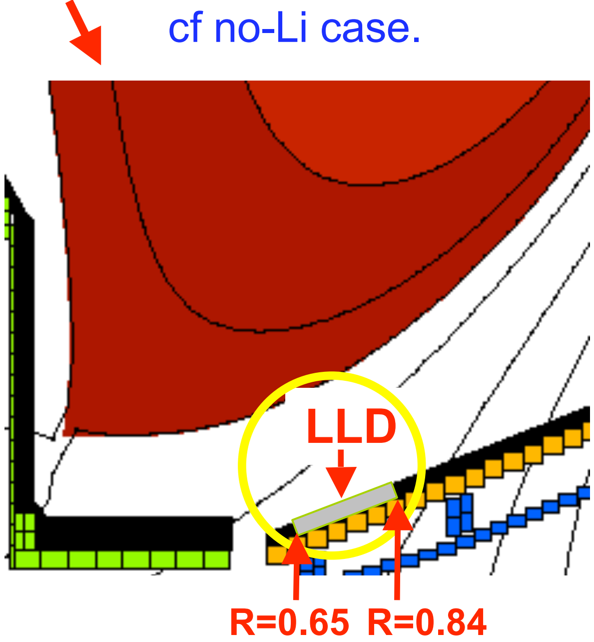
FY10 goal: test LLD predictions of 33% - 56% reduction in Ne with LLD compared to no-Li.

- 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.

FY11 priority: Milestone R11-3:

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

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



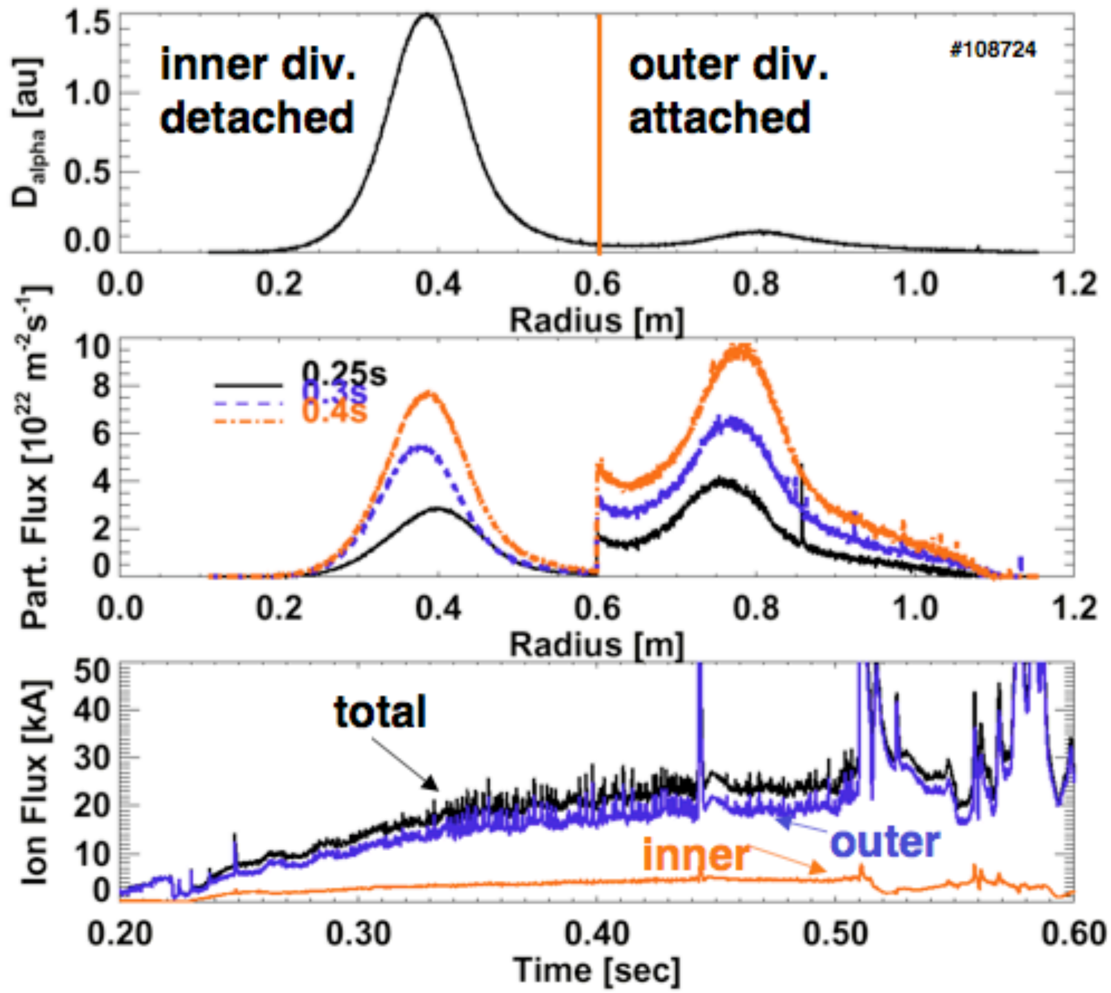
Low δ: n_e reduced by 56% cf no-Li case with strike point on LLD.

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

Liquid lithium divertor physics design discussion Princeton, NJ April 3, 2007
“Liquid Lithium Divertor 0-D Pumping Projections and Sensitivities”
R. Maingi, ORNL *With Acknowledgement to V.A. Soukhanovskii for Lower Divertor D α data

NSTX D_α Peaked on Inboard Side, but Particle Flux Peaked on Outboard side because Inner Divertor is Usually Partially Detached

NSTX

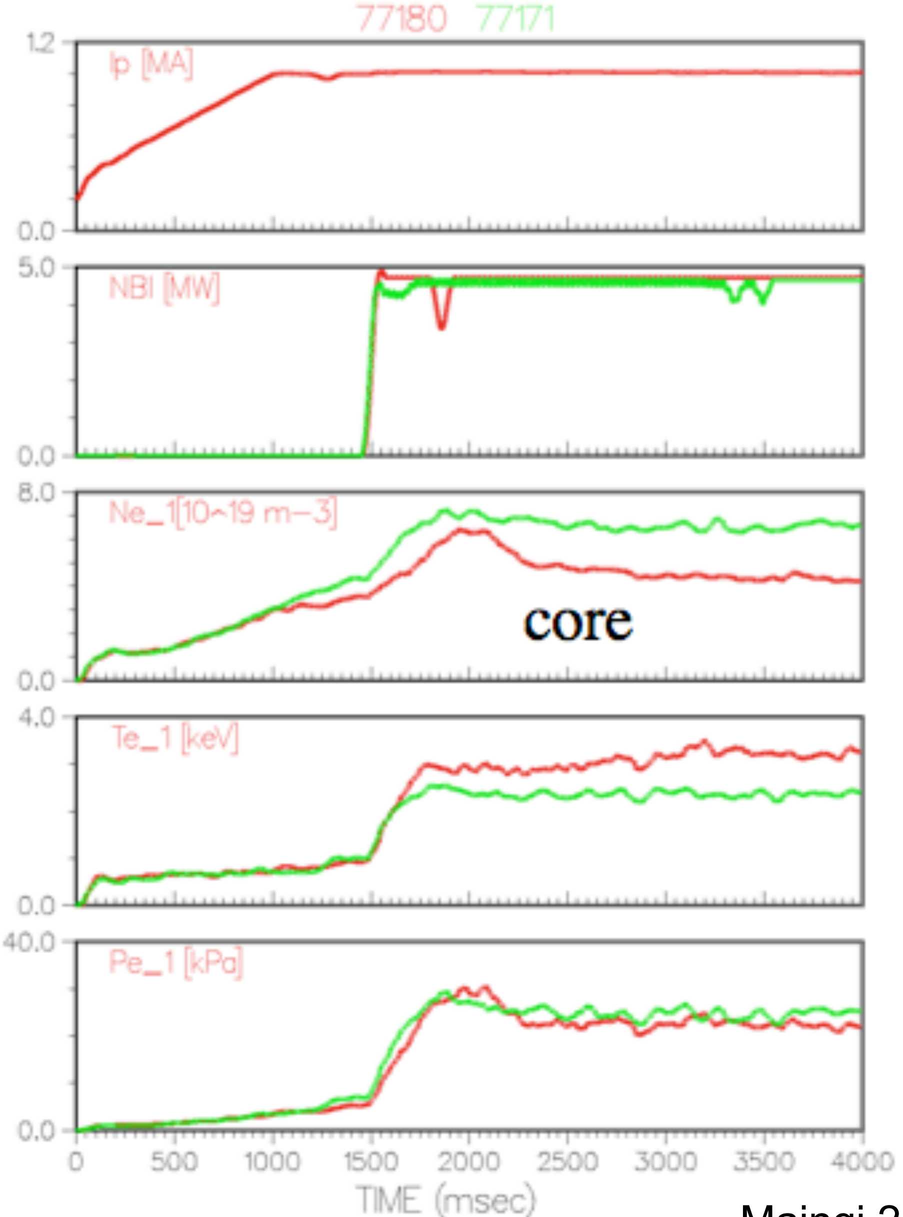


- Inner side detached
- Outer side attached
- Ions/photon =1 (detach)
- Ions/photon =20 (attach)
- Division at R ~ 0.6m
- Out div. has ~ 4x times current of inner div.

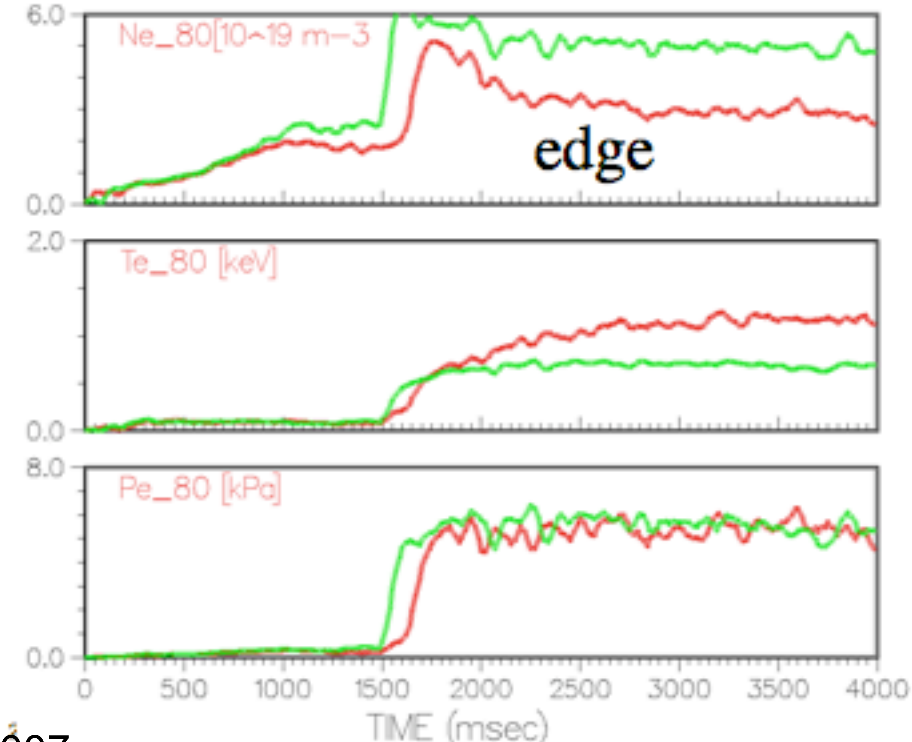
low δ

Comparison of Unpumped and Pumped DIII-D Discharges

NSTX



- Edge electron pressure holds constant as n_e reduced
- Relative change in edge n_e larger than core



Maingi 2007

Summary

- LLD prefill 24 March, 16 g-Li evaporated, 2,253 nm-Li at lower QMB (281 nm-Li if 8x area).
- XP1000 ran 2nd, 5-8th April

- Executive summary:

1. Evidence suggests no significant additional D pumping by LLD so far.
2. Insufficient Li in LLD a potential reason.
   A 50% LLD Li fill is under consideration.
3. LLD surface contamination levels and effects are unknown.
4. Divertor Imaging spectrometer, Two color IR calibration, air heating of 4th LLD quadrant, LADA… should arrive soon.
5. C128 and Purdue experiments planned on porous Mo reflectivity, effective evaporation rate (including porosity and surface impurity effects), surface cleaning, faster Li fueling.
6. Plans to benchmark Li evaporation codes against QMB measurements.

1-slide each from following:

Lithium Research Topical Science Group Meetings 4/14/10, 4/15/10

Presentations:

- Skinner *Introduction*
- Kugel *"XP1000 LLD Results & Next Steps"*
- Jaworski *"Necessary conditions for pumping with liquid lithium."*
- Kallman *"LLD lithium inventory and outgassing studies."*
- McLean *"Status of two-color IR on NSTX"*
- Scotti *"LLD Fast Visible Camera Diagnostics Preliminary Results"*
- Skinner *"Li / D balance in LLD."*
- Soukhanovskii: *"Mo, D-alpha (recycling) and change in Ne (given by Skinner)".*
- Zakharov *"Modeling of evaporation from LiTER to LLD"*
- Stutman *"First spectra from Transmission Grating Spectrometer"*
- Paul *"SPRED spectrum"*
- Allain *"Surface chemistry analysis of hot lithium coatings on porous Mo substrates"*
  - *Discussion*

PPPL/Purdue lab experiments coordination meeting organized by Josh Kallman 4/16/10

See also:

- "*A Few Observations on Global Particle Balance During XP-1000"*
  Gerhardt presented at Monday 12 April NXTX physics Mtg.
- *"XP1000 LLD Characterization Preliminary Results"*
  H. W. Kugel and the NSTX Research Team NSTX Monday Physics Meeting B-318, 12-APR-2010
- Maingi *"Liquid Lithium Divertor 0-D Pumping Projections and Sensitivities"* presented April 3 2007.

- All Presentations and 4-page summary available in
  - http://nstx.pppl.gov/DragNDrop/Topical_Science_Groups/Meetings/lithium_research/20100414_LLD_1stResults/

From Kugel Presentation: “XP1000 … Next Steps”

Filling LLD to 50-100% of Lithium Capacity Gives Highest Probability of Observing Pumping Effectiveness of Liquid Lithium

- Filling LLD to >50% Li capacity decreases the physical to geometric area ratio and by passes or minimizes 5 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.
    - Li to impurity ratio higher
- Filling LLD >50% using LITER requires many work shifts (next slide).
- Testing the LLD after filling to >50% capacity can be done in 2 ways

Start XP w/cold LLD	***Start XP w/220°C LLD***
• Fill 50% @220°C • Cool to RmTemp (RT) • Keep LITER on • Do controls tuning • Degas to 320°C, then cool to RT • Do R=70cm • Do Tile + LLD pumping • Turnoff Tile pumping and test duration of LLD pumping	• Fill 50% @220°C. • Keep at 220°C • Keep LITER on • Do controls tuning • Degas to 320°C, then cool to 220°C • Do R=70cm • Do Tile + LLD pumping • Turnoff Tile pumping and test duration of LLD pumping

From Jaworski: “Necessary conditions…”

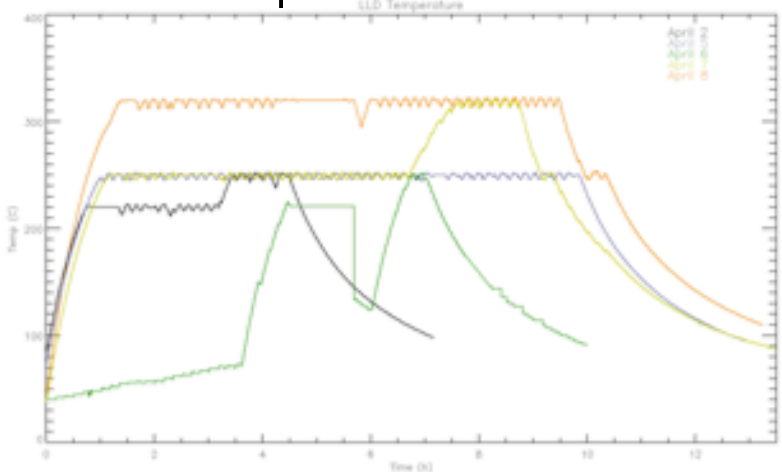
Summary and caveats

- Three necessary conditions for pumping described
  - Fluence limitation
  - Flux limitation
  - Impurities (feeding into 1 and 2)
- May not be exhaustive list
  - Surface physics between incident plasma and bulk diffusion not considered here
  - Something like PMI probe / MAPP or other could help address these issues intershot
- Serious deficiency in literature regarding diffusivity
  - If CDX-U and PISCES are indications, probably not an issue

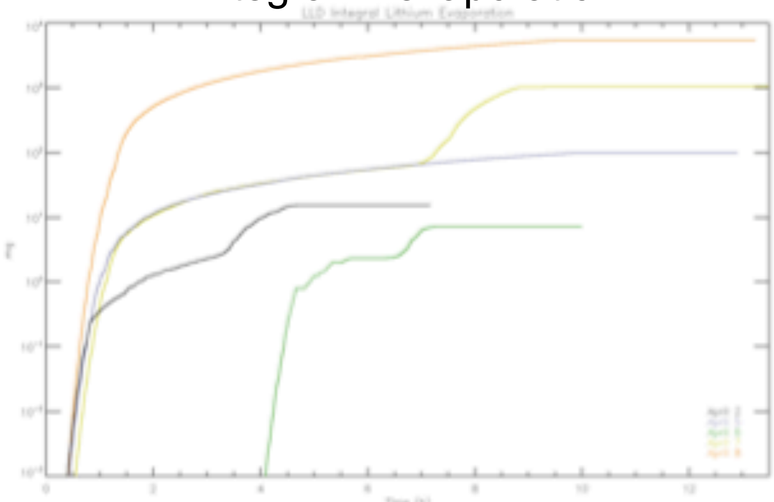
From Kallman: “LLD Li inventory…”

LLD Lithium Inventory

LLD temperature



LLD integral Li evaporation

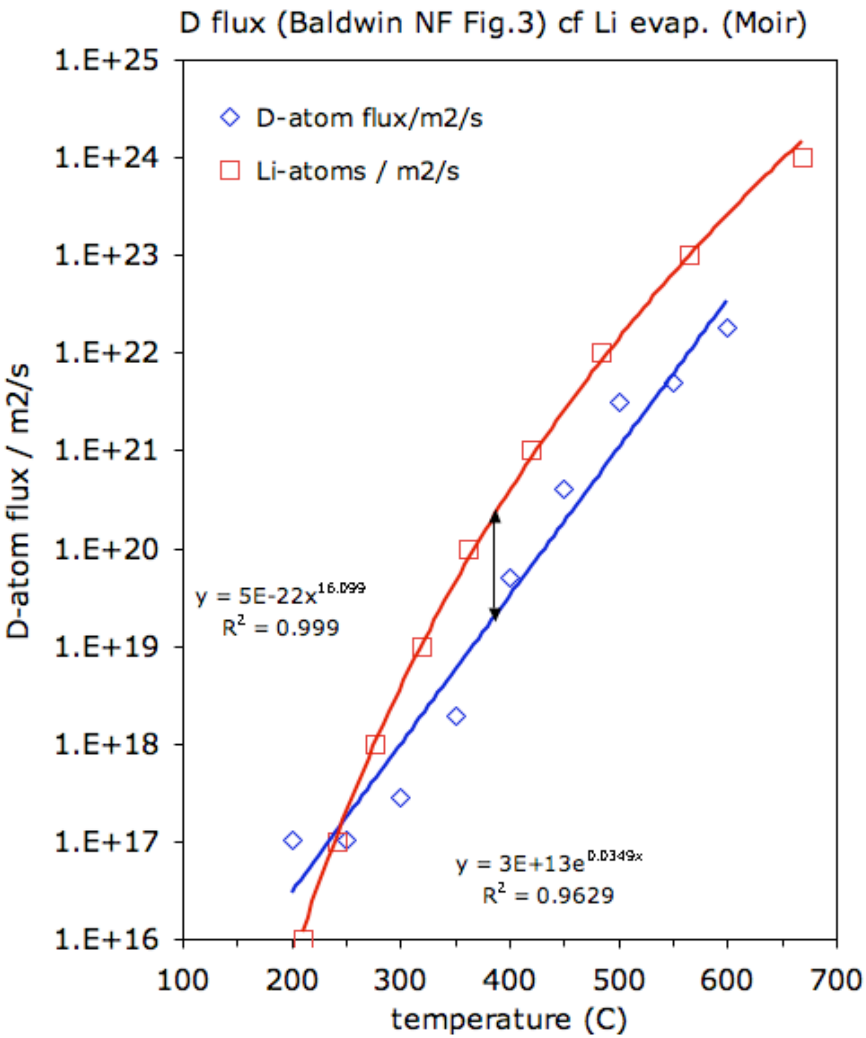


- LLD temperature data from EPICS (plate averaged from bulk TCs) used in previous equation (with ‘effective’ surface area correction of 1.33) to calculate evaporation
- LITER rates account for 3 functioning plates – from Hans spreadsheet
- Leonid calculates only 4.5% LITER efficiency!

Date	LITER	LLD	Net	Total
Pre	2310	0	2310	2310 mg
4/2	237	15	232	2542
4/5	425	100	325	2867
4/6	268	7	261	3128
4/7	396	1036	-640	2488
4/8	306	5441	-5135	?

From Skinner: “Li/D balance in the LLD”

Li evaporates faster than D outgases



Starvation Diet

- We typically supply 0.9 e21 Li-atoms to heatable LLD between discharges.
- Typical D fueling is 4 e21 D-atoms (137605).
- LLD is on ‘starvation diet’. It can only supplement pumping by graphite and lithiated graphite.
Need substantial Li prefill every shot for large LLD pumping effect.

- Li evaporation rate at 260 C = 3 e17 Li-atoms/m^2/ s (Moir)
- For an effective area of LLD of 8x geometric for 600s = 1.1 e21 Li-atoms
- Potential Red Queen situation @ 260 C
  – No net filling of LLD with Li !

Evaporation drops steeply with temp.:

- 241 C = 3.6 e20 Li-atoms / m^2 / s
- 210 C = 3.6 e19 Li-atoms / m^2 / s

Li evaporation from 320 C LLD to upper QMB lower than expected or missing
D2 outgassing from LLD on RGA lower than expected

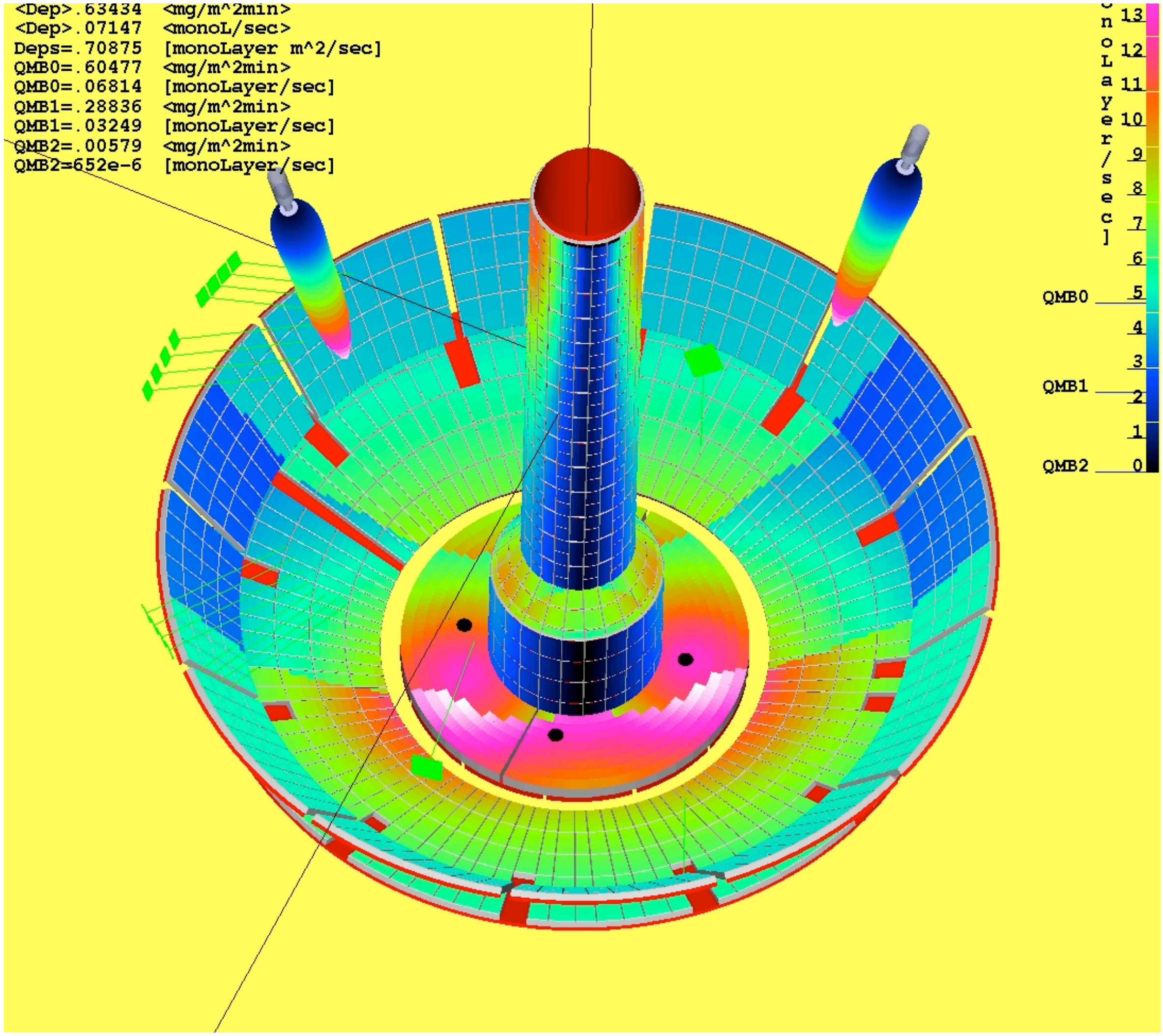
From Soukhanovskii:

Good News

1. No steady-state molybdenum influx observed from LLD, except in several shots where singular transient events interacted with lower divertor and Mo I lines were clearly seen (from VIPS 2 spectra, Bay C location).
2. In general, D-alpha intensity was always higher on LLD than on bullnose carbon tile (from 1D CCD, Bay D location). Will use Langmuir probe ion flux to calculate recycling coefficients.
3. D-alpha on LLD typically increased with the 220-250-320 C temperature trend (from 1D CCD, Bay D location).
4. Li II emission was increasing with the 220-250-320 C temperature trend (from 1D CCD, Bay D location).
5. In hotter LLD divertor (320 C vs 220 C), it appears that 1) much reduced oxygen flux was observed 2) much higher LiD molecular flux was observed (VIPS 2 spectra, Bay C location).
6. No clear trend was seen in core deuteron inventories and deuteron densities (from CHERS analysis) with LLD cold, warm, hot trend and strike point trend.
7. Propose to run XP 1001 ASAP to document LLD regime through an accurate particle balance accounting and tau-p-star measurements.

From Zakharov:

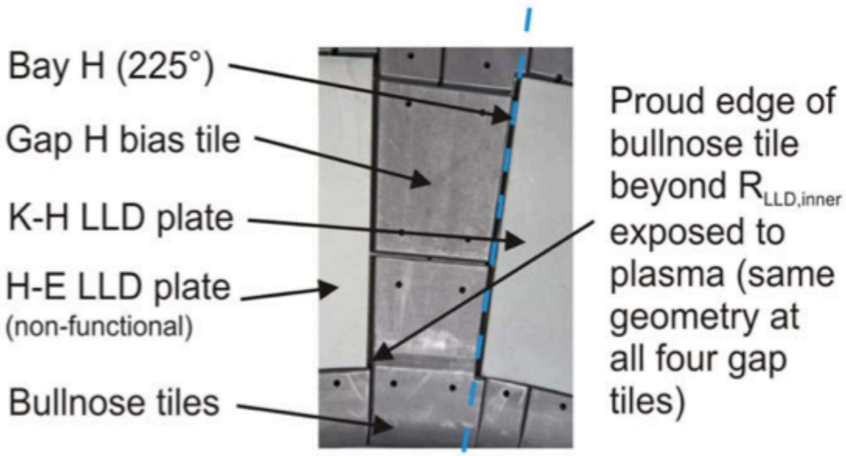
Leonid's model now includes LLD, and balance between LiTER evaporation <u>to</u> LLD and evaporation <u>from</u> LLD. Plan is to make it available in Control Room.

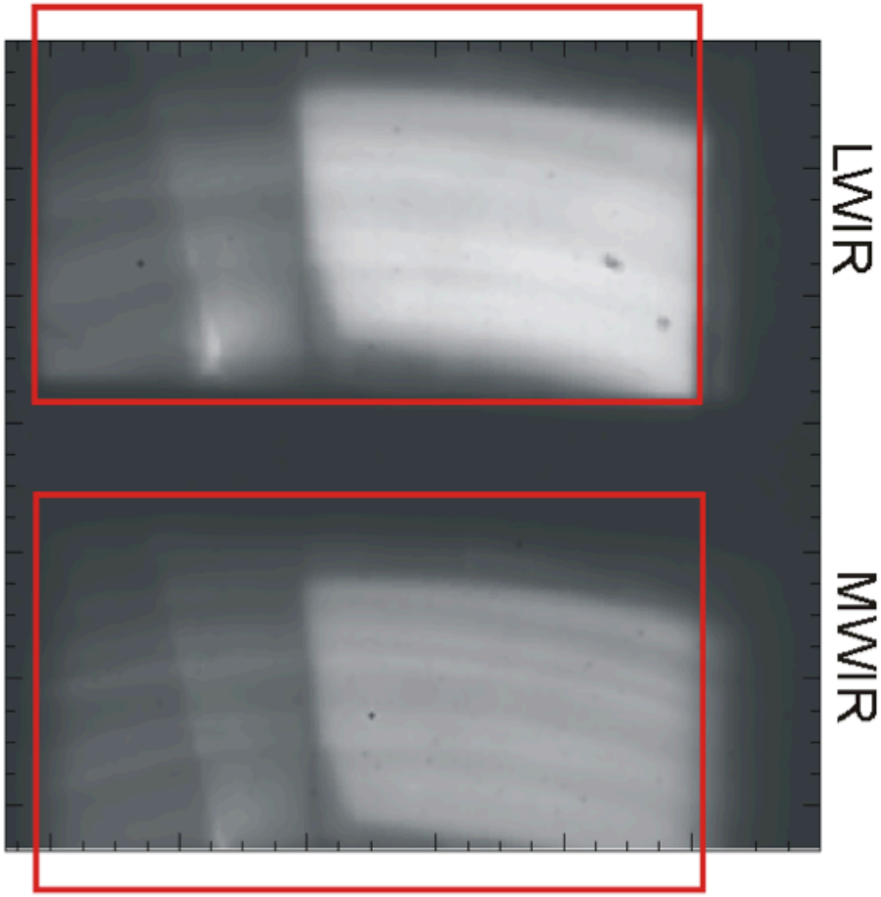


From McLean "Status..two-color thermography…:

Sample data from April 7, 2010

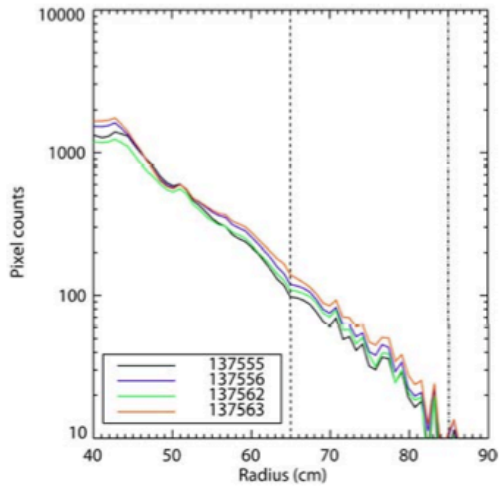
- Clear view of OSP on hot and cold LLD plates, heat flux on gap tile
- Higher intensity on LWIR channel indicates temperature <400°C
- Significant heating of exposed edge on gap bullnose tile
- Figures demonstrate some of the challenges in overlapping two channels to acquire ratio



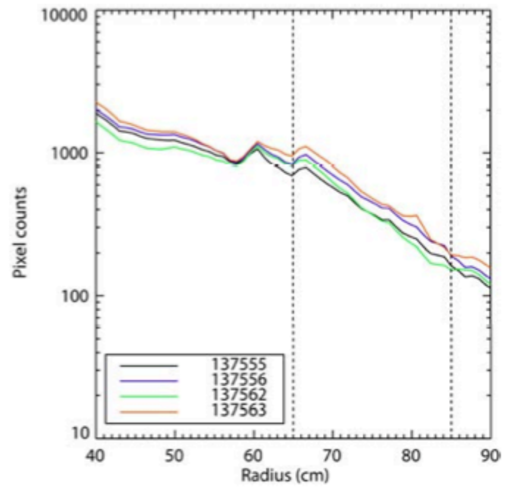


From Scotti “Fast Camera Diagnostic:

Cold segment



Warm segment



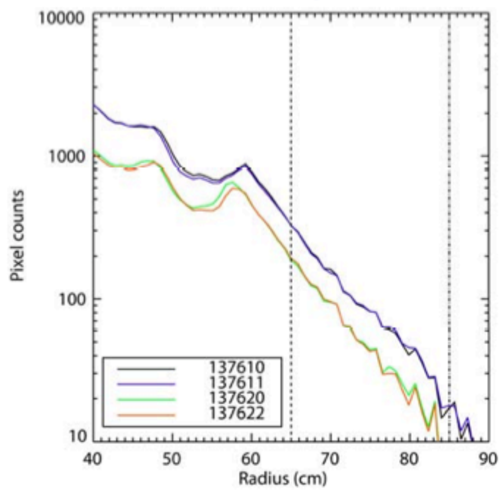
R=0.63 m

- ***137555-T=273C***
- ***137556-T=295C***
- ***137562-T=315C***
- ***137563-T=315C***

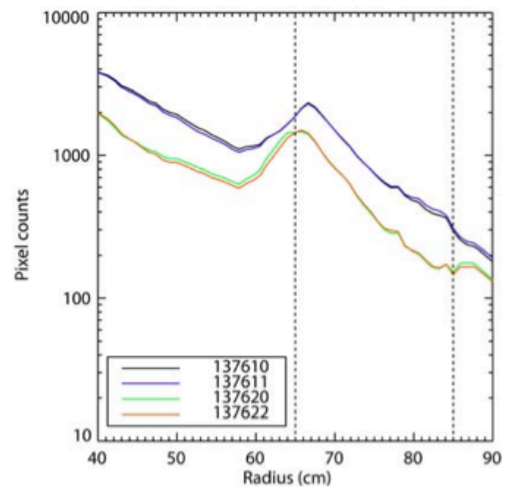
- ***D alpha emission***
- ***Time averaged (0.5-0.6 s)***
- ***No ELMs***

> **•Higher D-alpha emission with warm LLD**
>
> **•No big difference between cold and warm segment, same trend**

Cold segment



Warm segment

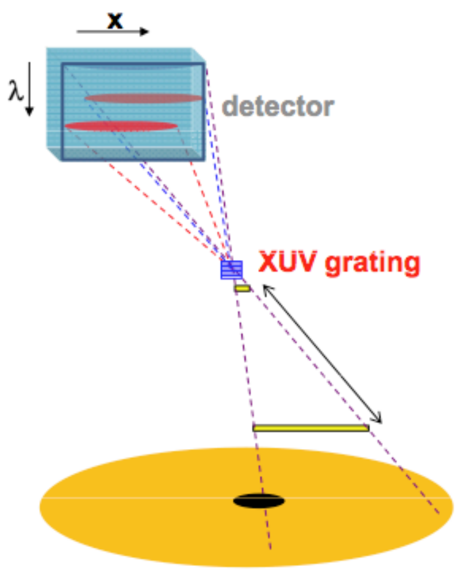


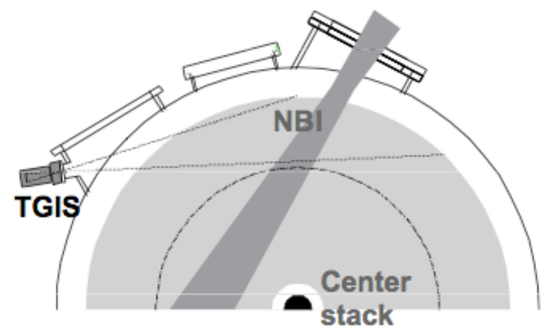
R=0.67 m

- ***137610-T=320C***
- ***137611-T=320C***
- ***137620-T=250C***
- ***137622-T=200C***

- Effect of LLD temperature on divertor D-alpha emission - Higher D-alpha emission with warm LLD
- Effect of OSP position on divertor D-alpha emission - Higher D-alpha emission with OSP on LLD
  No big difference between cold and warm segment
- Effect of LLD temperature on divertor Li ion influxes - Practically no change
- Effect of OSP position on divertor Li ion influxes - Practically no change

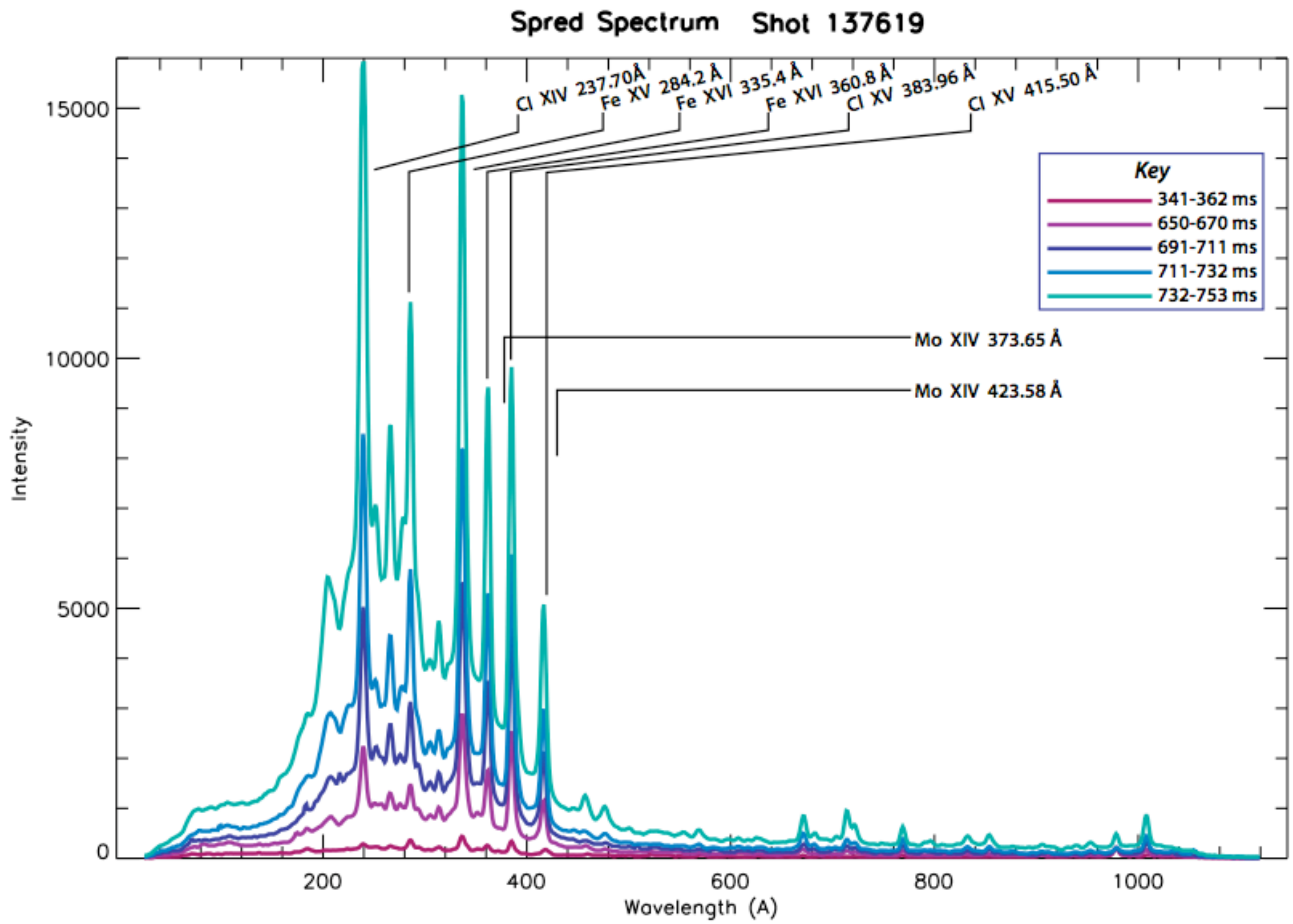
From Stutman "Transmission Grating Spectrometer"





- Sees NB excited + electron excited emission
- 2 frames per shot at present
- Seem to see (in addition to C) , O, N?, Cl?, Cu?
  Not much iron, moly in 137622
- Fe, Cl accumulation at the end of some shots e.g. 137619
- Moly possibly seen in divertor 137622

From Paul "SPRED spectra"



- Sees Cl, Fe emission

From Allain et al: “Surface Chemistry Analysis:

Lab Experiments at Purdue:

- Movies show Li melting on porous Mo surface, and no mirror coating at 509 C!.
- Li deposition / D irradiation / heating of porous Mo samples:

  XPS peaks shift when Li melts. Surface is 72-82% Li, 7-22% O.
- Surface chemistry results show typical lithium hydroxide formation for solid Li deposited films and more “metallic” chemical state of Li for melted Li coatings.
- Melted surfaces show diffusion and percolation of liquid lithium through the porous Mo microstructure observed by the existence of Mo 3p XPS peaks and their absence for solid lithium coatings for depositions of 2-5 micron equivalent thickness.
- TDS (thermal desorption spectroscopy) conducted *during and post* deuterium irradiation at the in-situ facilities at Purdue. Results identify a weakly-bonded implanted deuterium state with formation temperatures ranging from 250-400 C.
- During D irradiation, emission of D_2O and HDO into the gas phase is observed while maintaining the temperature between 250-270 C. Post-irradiation TDS shows peak D_2 and HD emissions at about 400 C.

  This data remains preliminary and further investigation is still necessary.

Coordinated Laboratory Experiments at Purdue and PPPL

(currently planned highest priority)

- PPPL: C128 and L112
  - Surface recovery “recipe development” with LITER including Argon vent (this week and next)
  - Effective evaporation rate from LLD surface (next week)
  - Radiative heat transfer properties of LLD surface (~1 week)
  - Heat flux response testing of LLD sample (~3 wks)
  - Recovery recipe testing after carbon deposition (~3-5 wks)
  - Gas desorption testing with varying Li fill (~8 wks)
- Purdue
  - Surface impurity content before/after recovery steps and controlled vents (this week and next)
  - Lithium chemistry study on flat Mo substrate – effect of morphology (~2 weeks)
  - Controlled carbon deposition and analysis of impurity content during recovery steps (~3 weeks)
  - Gas desorption studies with impurity content measurements (1-4 weeks)
  - Evaporation rates from LLD sample with impurity content of the surface, with angular distribution measurement (~7 weeks)