PMI Test Stand Meeting

assessing NSTX Upgrade needs

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NSTX-U Questions

- What is the maximum heat-flux that NSTX-U is likely to produce without taking special measures? What is the maximum heat flux it can produce if we want to push divertor technology? (Answers for 5 second and 10 second pulses, for SN, DN, high-delta, snowflake, any other geometry?)
- What range of pumping capability / recycling coefficient needs to be targeted? Do we need the capability to support operation with very low recycling and high edge temperature?
- How much lithium evaporation is acceptable from an operational standpoint? We had about 1 kg in FY10, what are we willing to tolerate in NSTX-U?
- Are there constraints against active water cooling and liquid lithium?
- Are there constraints against specific materials, for example: gallium, tin, tungsten
- What degree of performance confirmation is required before installing an advanced divertor in NSTX-U?
- Is the Removable Divertor Module an option?
- Can in-situ divertor surface diagnostics be accommodated, if they also require new access ports?

What is the maximum heat-flux that NSTX-U is likely to produce without taking special measures?

- Dual NBI capability (P/Δt): 15MW/1.5s, 10MW/5s, 5MW/10s
- TF flat-top capability: 1T for 6s, 0.75T for 10s, total OH flux = 2.1Wb
- $T_{carbon\text{-}tile} \leq 1200°C$ → Divertor peak heat flux limit = 10MW/m^2 for 5s

High-delta LSN — Lower Snowflake

$\beta_N \leq 5.5$, τ_E = ITER-98y2 H-mode scaling, SOL width scaling $\propto I_P^{-1.6}$

Reference Scenario	B_T [T]	I_P [MA]	Δt_{flat} [s]	NICD [%]	$n_e / n_{Greenwald}$	P_{NBI} [MW]	P_{RF} [MW]	P_{TOT} [MW]	Unmitigated divertor peak heat flux [MW/m^2] (f_{exp} = 20) (High-delta LSN)	Unmitigated divertor peak heat flux [MW/m^2] (f_{exp} = 60) (Lower Snowflake)	D pumping required (NBI fueling only) [10^{21} s^{-1}]
Long pulse	0.8	1	7	50-70	≤ 1	6	0	6	5	2	0.7
High non-inductive	1	0.8	5	80-100	≤ 1	8	0	8	5	2	1.0
High I_P	1	1.5	5	50-70	≤ 1	8	0	8	13	4	1.0
Max I_P	1	2	4-5	40-60	0.7-1	10	0	10	25	8	1.2
Max I_P & power	1	2	4-5	40-60	≤ 1	10	5	15	38	13	1.2

Plan to use U+L balanced snowflake at 2MA to reduce peak heat flux to 7-10MW/m^2
Detachment/radiation could further reduce peak heat flux by additional factor of 2-3

What is the maximum heat flux it can produce if we want to push divertor technology?

Start from high-delta LSN reference scenario at 2MA and 15MW → 38MW/m² (see previous page)

- Shorten pulse to 1.5s: 15MW NBI + 5MW RF = 20MW → 38MW/m² increases to 50MW/m²
- Low-delta LSN: f_{exp} 5× lower, radius 2× higher → 2.5× higher peak heat flux →

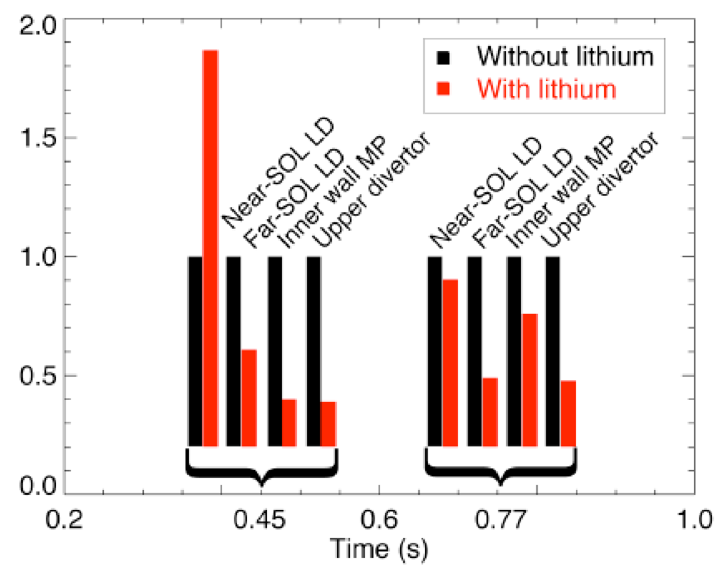
  If 15-20MW 2MA low-δ LSN is MHD-stable (questionable), then ~100MW/m² peak heat flux is possible (?!)

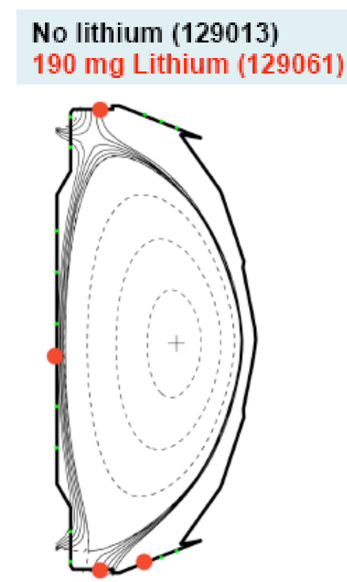
What range of pumping capability / recycling coefficient needs to be targeted?

- Long-pulse limit = NBI fueling only: 10MW → $\geq 1.2 \times 10^{21}$/s
  - Initial calcs for PAC-29 find cryo-pumps could possibly provide this pumping
- Baseline operating scenarios have Greenwald fraction ~ 0.7-1
  - Would like to be able operate down to 0.3-0.5 to scan NBI-CD fraction
    - Min n_e: Greenwald fraction = 0.3 at 0.8MA → line-average $n_e \sim 2.4\times10^{19}/m^3$
    - Max n_e: Greenwald fraction = 1.0 at 2.0MA → line-average $n_e \sim 2\times10^{20}/m^3$
- Recycling reduction obtained with LiTER (to ~0.5-0.7 away from strike-point) is sufficient to achieve low deuteron density and support initial Upgrade operation for at least ~1.5-2s

V. A. SOUKHANOVSKII, NSTX Results Review 2010, 11/30 -12/01/2010

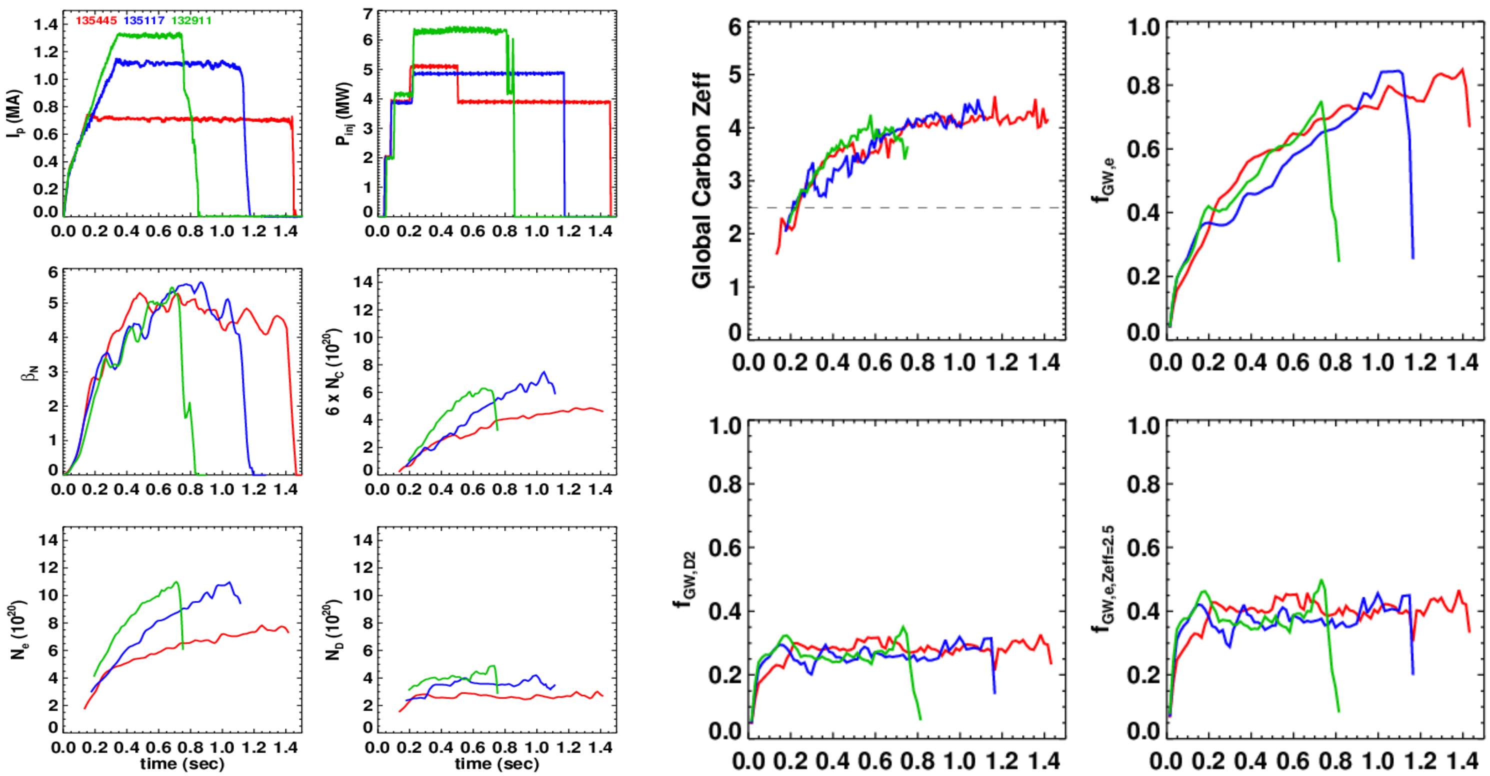
- Local recycling $R_{local} = \Gamma_i^{out} / \Gamma_i^{in}$
  - Ion flux into LLD Γ_i^{in} is measured by Langmuir Probes (LPs)
  - Ion outflux Γ_i^{out} estimated from measured Dα fintensity and S/XB (ionizations/photon) coefficient from ADAS





What range of pumping capability / recycling coefficient needs to be targeted?

- With LiTER, D inventory can be controlled for 1.4s at low equivalent Greenwald fraction = 0.3-0.4 → likely sufficient pumping for Upgrade
- Issues: Impurity accumulation leading to carbon Z_{eff} → 4
  - Need to control Z_{eff} to ~2.5 (ideas: Mo tiles/PFCs, ELM pacing, more Li, RF, ...)
  - Neoclassical impurity confinement with peaked n_e profiles may be problematic



Do we need the capability to support operation with very low recycling and high edge temperature?

- Apparent recycling ~0.5-0.7 achieved with LiTER is already quite low
- C sputtering increases ~2 orders of magnitude from 50eV to 200eV
- Does Li pumping and edge confinement improvement increase SOL plasma temperature and increase C sputtering at strike-pt?

M G Bell *et al*
Plasma Phys. Control. Fusion 51 (2009) 124054

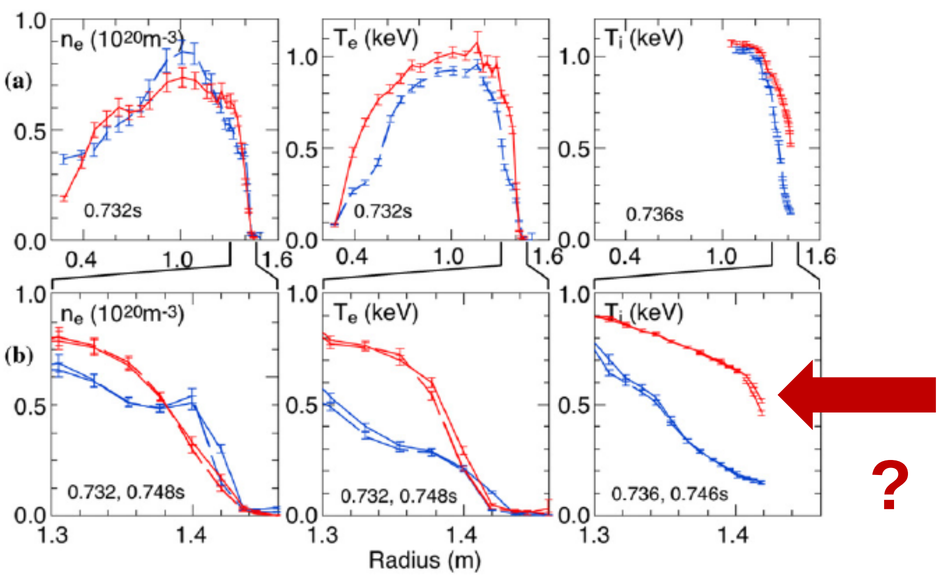
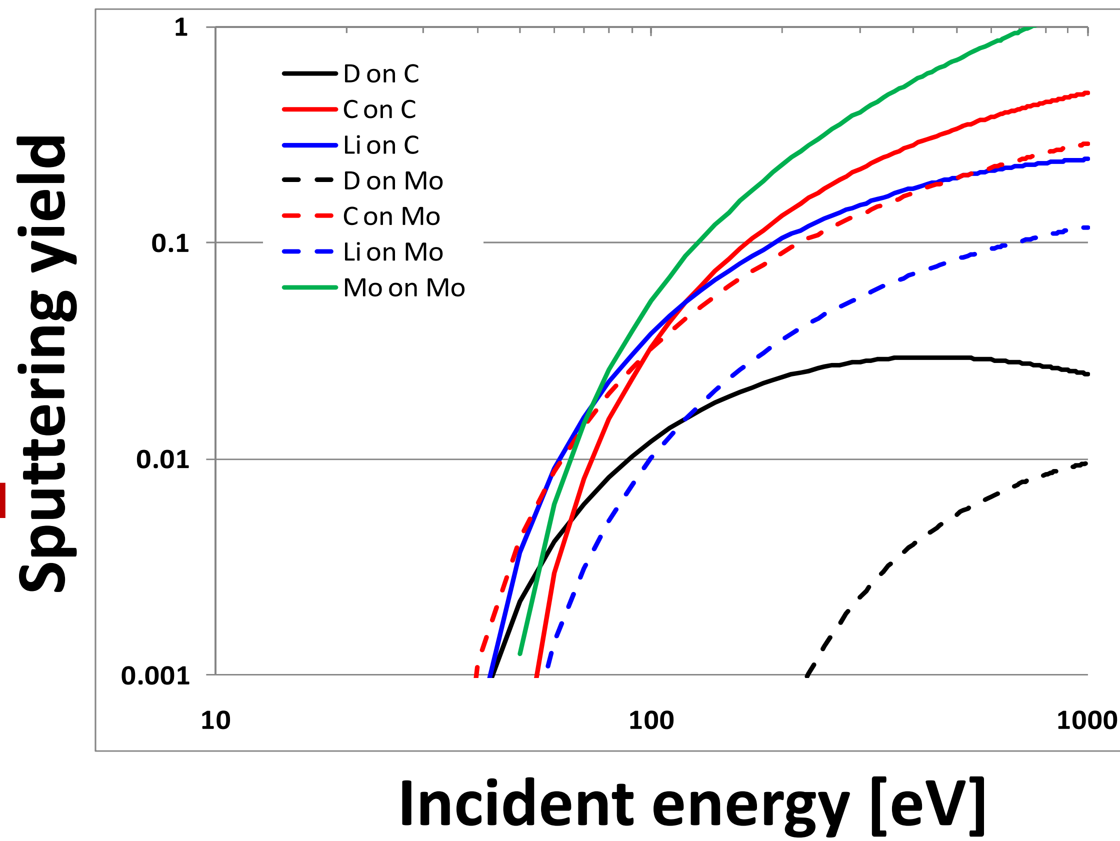


Figure 3. (*a*) Full radial profiles of the electron density and electron and ion temperature measured close to the time of peak stored energy for the discharges in figure 2 without (129239-blue) and with (129245-red) 260mg of lithium applied; (*b*) details of the profiles in the outer edge region for two successive Thomson scattering measurement times showing the changes in the edge after lithium coating.



How much lithium evaporation is acceptable from an operational standpoint?

- We need to avoid gate valve and shutter failure/clogging, and LiTER snout/aperture clogging.

- Empirically, this probably means limiting ourselves to the 2009 experience which was ~1/3-1/4 of the 2010 LiTER experience --> 400g total or 200g per LiTER.

- That said, we could add more LiTERs to the top, evaporate from the bottom or midplane, and probably get back to ~1kg total w/o major LiTER/shutter failures. (this is guesstimate of course).

- We could also develop alternative delivery schemes (e-static painting, evaporation into neutral gas, etc)

We had about 1 kg in FY10, what are we willing to tolerate in NSTX-U?

- Very crudely, about the same amount. We use 200-300g per run presently in NSTX.
- For the upgrade, due to higher power and longer pulses, we may need more - guesstimate of up to 5x more.
- So, 1kg isn't totally out of the question for the Upgrade. Also, a substantial fraction of the 1.3kg in FY2010 got stuck near the LiTER/shutter areas, so less likely got into the main chamber.

Are there constraints against active water cooling and liquid lithium?

- This seems like a bad mix and should probably be avoided.
- Think it is better to use gas cooling with liquid lithium, or use flowing Li instead, or even Li evaporative cooling.
- KTM will use other liquid metals I think (that is rather advanced though)

Are there constraints against specific materials, for example: gallium, tin, tungsten?

- Tend to think we should learn how to work with Li at low(er) temperature before moving to higher Z liquid metals.
- The answer depends on whether the liquid is just used for pumping in a baffled chamber that reduces interaction with the main plasma, or is a PFC with direct line of sight to the plasma.
- Might consider higher-Z liquid metals if part of an enclosed pumping and/or evaporative cooling divertor system.
- Skeptical the plasma will tolerate high-Z in it as well as Li is tolerated (i.e. Li doesn't get in, and even when it does it is low-Z and radiates less)

What degree of performance confirmation is required before installing an advanced divertor in NSTX-U?

This question cannot be answered without defining "advanced". But here is an answer anyway:

- On the bench/in lab, the object should be expected to NOT have a coolant leak, major melting or damage event for normal plasma ops (including disruptions) for an estimated period of 1 run campaign.

- What the divertor PMI (erosion, retention, etc) does to the plasma is part of the expected experimental study in the tokamak, may not be testable in the lab anyway.

Is the Removable Divertor Module (RDM) an option?

- Yes, but it will challenging and expensive to engineer (to survive disruptions, be heatable, have flowing metal, ability to install modules w/o breaking vacuum, etc – see recent LLD experience)

- Also, there are questions about the value/complexity of having a small sample or module in the midst of other materials, i.e. mixed materials at the strike-point could complicate the interpretation of results (e.g. C near LLD)
  - Could change surrounding divertor materials to be compatible?
  - Change surrounding tiles once per run-year?

Can in-situ divertor surface diagnostics be accommodated, if they also require new access ports?

- Probably – will depend on the size of the port
- Primary limitations are access to the divertor region, and size of port
- Will be limited by space constraints and possible structural impact of removing too much material from the vessel
- As for the RDM idea, need requirements and structural analysis very soon to have any chance of installation during Upgrade outage
  - Competes w/ Mo tiles, cryos, LLD-2, etc for resources

Possible long-term PFC plan for NSTX-U

- Convert all PFCs to Mo (assumes Mo success in FY11-12)
- Cryo-pumps for base D pumping
  - Enables comparison of divertor cryo-pumping to Lithium wall and divertor pumping
- Implement full Li coverage of walls (at least thin films)
- Have heatable divertor and passive-plates
  - Study H/D retention vs T
  - Study solid vs. liquid Li
- Capillary porous system in divertor
  - Assess how replenishable Li can pump D, protect Mo
  - Assess survivability w.r.t. ELMs and disruptions
- What are test-stand needs for such a plan?