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LLD Core Physics Survey, XP-1066 Team Review

NSTX Team

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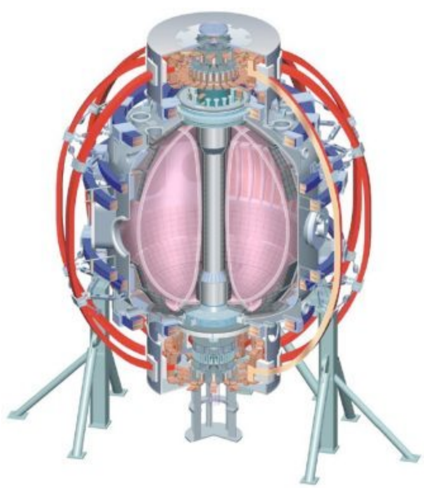

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Observations

- Commissioning XP should provide the starting point.
  - "Starting Point"=shape with reasonable pumping and a recommended fuelling scenario.
  - Likely to be an intermediate-δ configuration (κ~2.2, δ_L~0.5-0.6), which are typically not as forgiving as high-δ.
- ASC would like a long-pulse demonstration with and without LLD.
- Both MS and T&T would like a collisionality scan.
- T&T wants the scan at constant q.
- MS wants to perturb individual shots (braking pulses and RWM control studies) within a collisionality scan.
- Need to keep I_P high enough that NB ions are held in…remember the 10cm gap!
- Don't want to try for too-challenging configurations at the start.
- Various types of n=3 braking have been requested.
  - Magnetic braking.
  - Momentum transport.
  - EPH triggers.
- *Collisionality impact on core and pedestal physics is a common theme.*

Overall Proposal: Focus on a Constant-q Collisionality Scan
Repeat the Shot List Once with Warm LLD, Once With Cold LLD

- Develop a longish-pulse target at lower current and field.
  - Long pulse demonstration for ASC, low-field part of constant-q scan for T&T and mhd, long pulse for multiple braking steps for MS.
  - Apply various magnetic braking pulses.
  - Small power scan.
- Develop a high-current, high-field target, with same q.
  - Will provide the collisionality scan for MS & T&T, high-current and field SOL width studies.
  - Repeat key braking pulses.
  - Small power scan.

- Contingency for a further increase in the field and current.

- Develop a high-current, low-field target.
  - Low-q_{95}, low-l_i, high-β_T for ASC, MS.

VERY, VERY, VERY unlikely to finish all four major steps in 1 day.

Proposal, In Suggested Priority Order
Day 1 with Warm LLD, Day 2 with Cold LLD

- Configuration 1: 750 kA, 0.38 T (I_P/B_T=2000 kA/T)
  - Develop target to longest reasonable pulse length. (5 shots)
    - Likely start with 4 MW, increase/decrease power to most it can gracefully tolerate.
  - Apply n=3 fields. (5 shots)
    - See next slide.
  - Small power scan. (3 shots)
- Configuration 2: 1.0MA, 0.5 T (I_P/B_T=2000 kA/T)
  - Develop target to full TF waveform duration. (5 shots)
    - This shot should take all 6 MW, unless confinement is really good.
  - Repeat n=3 fields. (5 shots)
    - See next slide.
  - Small power scan. (3 shots)
    - 2,4 MW cases
  - *Contingency: Extend to 1.1 kA, 0.55 T (I_P/B_T=2000 kA/T)*
- Configuration 4: 1 MA, 0.38 T (like 134837)
  - Low-q_{95}, low(er)-l_i, high-β_T for ASC
  - Develop target to reasonable length (no braking pulses?) (5+ shots)

Plan (I)

3. Experimental run plan

Notes:

N1: These discharges will operate at intermediate triangularity. This may have a deleterious impact on the global stability, and may make the discharges more difficult to run at higher values of I_P/B_T.

N2: The shot list below is to be repeated twice, first with a warm LLD, then with a cold LLD. However, a priority is to be placed on the warm LLD portion of the shot list. See Decision Point #2.

N3: If mode locking early in the shot at low density is a problem, consider the addition of early error field correction. Example RWM category, smf algorithm, to load is 135779.

3.1 Low current and field, long pulse discharge development.

3.1.1 Load recommended discharge from LLD commissioning or pumping XPs. Lower field & current to 0.38 T and I_P=750 kA. Injected power will likely be 4MW, (1 shot)

3.1.2 Adjust beam power, fuelling, other parameters to achieve >1 sec pulse. (4 shots)

3.1.3 Repeat with shot in 3.1.2 with either/both larger or smaller power. (3 shots)

3.1.4 If steps 3.1.1-3.1.3 took less than 9 shots, then do n=3 braking studies described in 3.5. (4 shots)

Plan (II)

3.2 High current and field

3.2.1: Using the same shape, increase the current and field to 1.0 MA and 0.5 T Adjust gas and input power to achieve >700 msec of I_P flat-top. (4 shots)

3.2.1: Repeat with shot in 3.1.2 with either larger or smaller power. (2 shots)

3.1.3 If steps 3.2.1 and 3.2.2 took less than 9 shots, then do n=3 braking studies described in 3.5. (4 shots)

Decision Point #1: Proceed to yet higher I_P and B_T values (3.3), or to higher normalized current (3.4)

3.3: Highest current and field contingency

3.3.1 Increase the current to 1.1 MA and 0.55 T. Adjust gas and beam power. Should be a minor perturbation to the previous condition. These will be short discharges, so skip magnetic braking. (4 shots)

3.4 High-β_T discharge development contingency

3.4.1: Set I_P=1 MA and B_T=0.4 T. Adjust power and fuelling to achieve longest possible pulse. (4+ shots)

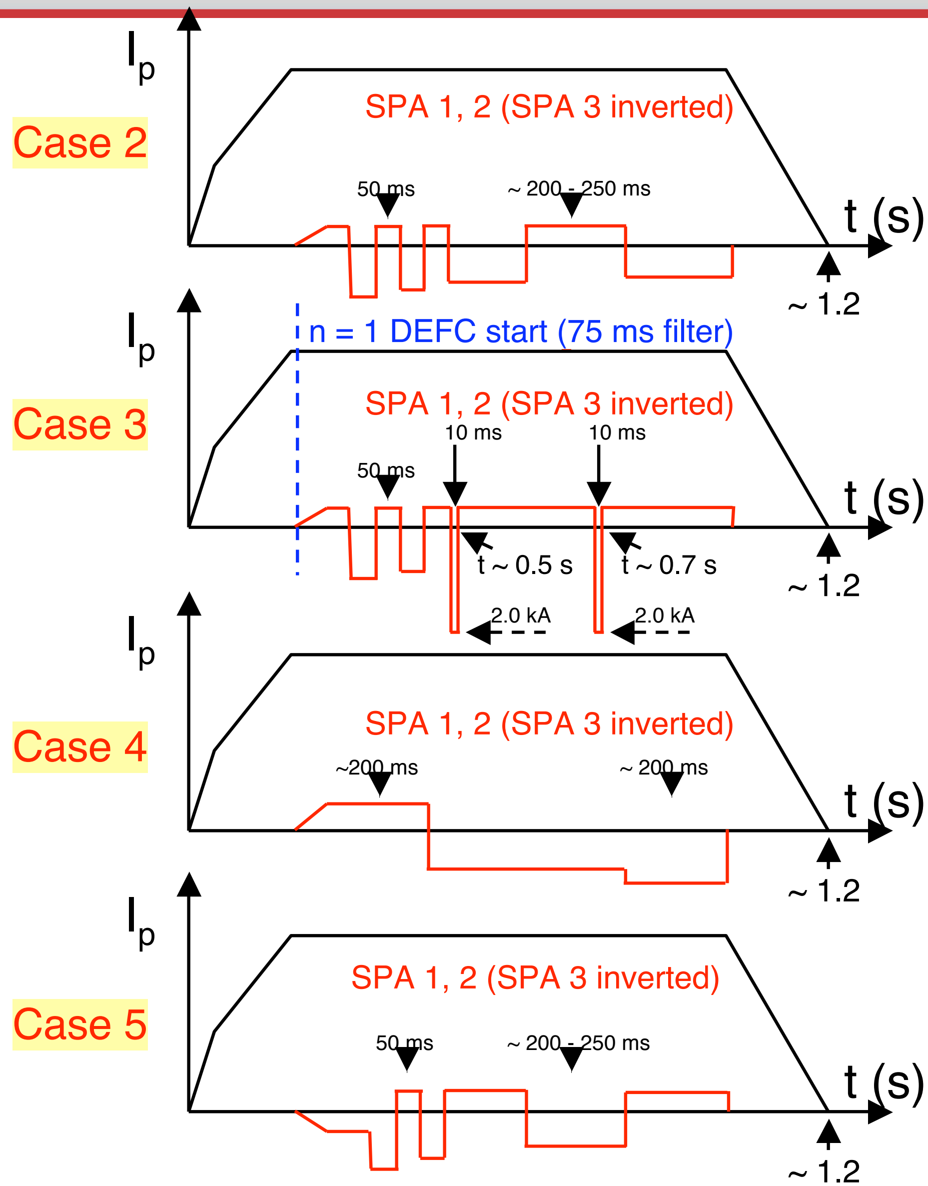
Note that this development is likely to be the most challenging, and so is last in the list.

Decision point #2: at end of day #1 with warm LLD:

If steps 3.1 and 3.2 are complete and the lithium surface of a "cold" LLD is not liquefied by plasma exhaust heat in this scenario, the then use day 2 for a repeat of discharges these discharges with a cold LLD.

If steps 3.1 and 3.2 are not finished, or if operation with a functionally "cold" LLD is not possible in this shape at the required power levels, then use day 2 to finish outstanding cases.

Suggested n = 3 braking field waveforms for XP1066: LLD Survey XP (Thanks SAS)



- Shots / waveforms / options
  - Case 1: n = 3 correction: use for most shots (0.25 kA correction)
  - Case 2: initial n = 3 correction, with braking pulses (1 shot)
    - I_{RWM} = 0.25 kA correction, ~ 0.5 kA braking (initial braking pulses larger ~ 0.6-0.8 kA), 0.05; 0.2-0.25 s durations
    - Long correcting / braking pulse durations to reach steady ω_ϕ
  - Case 3: initial n = 3 correction, n = 3 pert. pulses, ELM trig. pulses (1 shot)
    - I_{RWM} = 0.25 kA correction, pert. pulses ~ 0.6-0.8 kA, n=1 DEFC with 75 ms filter, ELM triggering pulses as shown
  - Case 4: initial n = 3 correction, then braking pulse to low ω_ϕ (1 shot)
    - I_{RWM} = 0.25 kA correction, 0.5 - 0.6 kA braking stepped up to be larger ~ 0.75 kA) to ensure access to low ω_ϕ, 0.25s correction duration
  - Case 5: initial short n = 3 braking pulses, long braking pulse (1 shot)
    - I_{RWM} = 0.5 kA braking, 0.25 kA correction, (initial braking pulses larger ~ 0.6-0.8 kA), 0.05; 0.2-0.25 s durations

Physics Operations Request

Brief description of the most important operational plasma conditions required:

The most important operational condition is to run in a shape where LLD pumping has been demonstrated, consistent with long(ish) pulse operation. A reduction in the flat-top density compared to a similar cold-LLD shot is the desired condition for this XP.

Previous shot(s), which can be repeated: To be provided by LLD Commissioning XP.

Previous shot(s) which can be modified: To be provided by LLD Commissioning XP

Machine conditions *(specify ranges as appropriate, strike out inapplicable cases)*

I_{TF} (kA): **3.8 kG-5.5 kG** Flattop start/stop (s): To I^2t limit of coil

I_P (MA): **0.7-1.1** Flattop start/stop (s): Longest consistent with rampdown for f_{dis}.

Configuration: **LSN**

Equilibrium Control: **Isoflux** (rtEFIT)**. S.P. control will likely be used.**

Outer gap (m): **0.1** Inner gap (m): TBD Z position (m): **-3cm <Z<0**

Elongation: **TBD** Triangularity (U/L): **TBD** OSP radius (m): **TBD**

Gas Species: **D_2** Injector(s): LFS + (SGI or HFS)

NBI Species: **D** Voltage (kV) **A:** 90 **B:** 90 **C:** 70-90 Duration (s): **full shot**

ICRF Power (MW): **0** Phase between straps (°): Duration (s):

CHI: Off Bank capacitance (mF):

LITERs: On Total deposition rate (mg/min): **TBD**

LLD: Yes Temperature (°C): 210-250

EFC coils: On Configuration: **Odd**

Diagnostic Checklist

Note special diagnostic requirements in Sec. 4

Diagnostic	Need	Want
Beam Emission Spectroscopy		√
Bolometer – divertor		√
Bolometer – midplane array	√	
CHERS – poloidal		√
CHERS – toroidal	√	
Dust detector		√
Edge deposition monitors		√
Edge neutral density diag.		√
Edge pressure gauges	√	
Edge rotation diagnostic		√
Fast cameras – divertor/LLD	√	
Fast ion D_alpha - FIDA		√
Fast lost ion probes - IFLIP		√
Fast lost ion probes - SFLIP		√
Filterscopes	√	
FIReTIP		√
Gas puff imaging – divertor		√
Gas puff imaging – midplane		√
Hα camera - 1D	√	
High-k scattering		√
Infrared cameras	√	
Interferometer - 1 mm		
Langmuir probes – divertor		√
Langmuir probes – LLD	√	
Langmuir probes – bias tile	√	
Langmuir probes – RF ant.		√
Magnetics – B coils	√	
Magnetics – Diamagnetism	√	
Magnetics – Flux loops	√	
Magnetics – Locked modes	√	
Magnetics – Rogowski coils	√	
Magnetics – Halo currents		√
Magnetics – RWM sensors	√	
Mirnov coils – high f.	√	
Mirnov coils – poloidal array		
Mirnov coils – toroidal array	√	
Mirnov coils – 3-axis proto.		

Note special diagnostic requirements in Sec. 4

Diagnostic	Need	Want
MSE	√	
NPA – E‖B scanning		
NPA – solid state		
Neutron detectors	√	
Plasma TV		√
Reflectometer – 65GHz		√
Reflectometer – correlation		√
Reflectometer – FM/CW		√
Reflectometer – fixed f		√
Reflectometer – SOL		√
RF edge probes		√
Spectrometer – divertor		
Spectrometer – SPRED	√	
Spectrometer – VIPS	√	
Spectrometer – LOWEUS	√	
Spectrometer – XEUS	√	
SWIFT – 2D flow		
Thomson scattering	√	
Ultrasoft X-ray – pol. arrays	√	
Ultrasoft X-rays – bicolor		√
Ultrasoft X-rays – TG spectr.		√
Visible bremsstrahlung det.	√	
X-ray crystal spectrom. - H		√
X-ray crystal spectrom. - V		√
X-ray tang. pinhole camera		√

Backup

Intro.

- Goals
  - Establish operation with a ***pumping LLD*** over a wider range of conditions than in commissioning XPs.
    - Get more info about how to run NSTX with a pumping LLD.
  - Establish some key physics trends.
    - Important to do this early, since LLD may or may not work as well at the end of the run as the beginning.
  - Gather data for further XP planning…first glance at interesting physics.
    - Not a surrogate for devoted XPs within the TSGs.
- Assumptions
  - Sufficient profile, pedestal, SOL and fluctuation diagnostics are functioning to make a cross-cutting XP worthwhile.
    - Assume "standard" B_P-based RWM/DEFC + n=3 correction is available and used.
  - NSTX is reasonably well conditioned, with early H-mode and at least 400 msec MHD-free I_P flat-top in the 900 kA/0.45 T reference.
  - The commissioning XP has demonstrated a shape with good LLD pumping + suggested fuelling scheme.
    - Henry's XP has this an an explicit goal.
- Dilemma
  - We have 2 days of run-time.
  - TSGs requested many more shots than can be accommodated in 2 run days.
  - Look for common physics themes among the groups.

ASC Group Wish-List

- Start with "warm" LLD, shape chosen as indicated before, run in priority order.
  - Load I_P=700 kA, B_T=0.48, P_{inj}=4MW (7 shots)
    - Repeat, raising/lower power to pin approximate β-limit
    - Be sure to ramp down I_P.
  - Change to B_T=0.4 (I_P=700 kA), P_{inj}=4MW. (7 shots)
    - Repeat, raising/lower power to pin approximate β-limit
    - Optimize power & gas waveforms for long(ish) pulse.
  - Change to I_P=1100 kA (B_T=0.4), P_{inj}=4MW. (7 shots)
    - Repeat, raising/lower power to pin approximate β-limit
    - May need to reduce I_P given the lower elongation and (potentially) triangularity.
  - Change to I_P=1100 kA (B_T=0.48), P_{inj}=4MW. (7 shots)
- Braking/RMP pulses could be added to select cases.
  - or NB pulses to probe modifications of ideal stability.
- Repeat each (some) scenario(s) with a cold LLD.
  - In each case, repeat with 4MW power, then an additional shot matching the approximate β-evolution of the warm-LLD case (more or less power)

Shot counts could be wildly off pending difficulty of LLD operations.

Macrostability Wish List

- Targets / control use
  - Reduced ν^* H-mode target over a large range of plasma current (3 - 4 shots)
    - ASC shot list has plan for high κ, I_p scan, including low l_i target – should suffice, need to specify (coordinate) what strikepoint configuration(s) to use – all high delta should be ok for Macro XPs
  - Full range of NBI power in H-mode targets at low and high ν^* (2 - 3 shots)
    - ASC shot list has cold/warm LLD and power scan – more specific definition of the actual shots to take should be made as a group
    - Suggestion is to choose two configurations yielding large range of ν^*, and have 3 NBI source scan for each (6 shots). One purpose of NBI source scan is to produce NTM (ramp n = 1 field?)
  - Run with n = 3 braking (1 - 2 “long pulse” shots; low/high ν^* comparison shots (2))
    - Can re-run XP933 shot 133743 for comparison, or add to any new H-mode target. Use long pulse to allow different n = 3 braking steps, reaching steady-state V_ϕ. (part of ASC shot list)
    - Run in high/low ν^* comparison shots; Run at least one shot down to very low rotation to reproduce superbanana plateau regime conditions (as done in CY 2009)
  - Run RWM control, B_p sensors and CY2009 settings to compare (2+ shots)
    - Can be added to any shot, but best done for boundary configuration close to CY2009 fiducial, now with LLD – cover both high and low ν^*, and low l_i. (easily added to ASC shot list)
    - One of these shots should include a condition spun down to low rotation (see “braking” above)
  - Run RWM control with B_p and B_r sensors (~ 2 shots)
    - Can be added to any shot, but suggest a limited number; use settings from 128487
  - Reduced q_{95} target as starting point for ELM stability, other studies (3+ shots)
    - Can use XP818 reduced q_{95} ELMing target 127889 (or later equivalent). If allowed, run LSN and USN variants.
    - Looking for an ELMing case, may need to run off a cold LLD and/or use USN variant

T & T Wish List

- Scan at constant q most important for T&T
  - Keep B_t/I_p constant allows same pitch angle for direct comparison of fluctuations for GPI and BES
- Prefers maximal scan range in B_t at constant q
- 700kA/0.35T (or 800kA/0.4T)
- 900kA/0.45T (or 950kA/0.48T)
- 1100kA/0.55T (Power scan here)
- Power scan at 1 setting, highest I_p, B_t point at which scan is possible
- BES, GPI, reflectometer, high-k should be consulted to be available

Boundary Physics

- No specific requests, but a few reminders:
  - Need to maintain outer-gap for optimal pedestal resolution (10 cm)
  - Keep biased down, say dr-sep=-1 cm.
    - Important for diagnostics and LLD operations
  - Maintain optimal OSP location for pumping.

Highlights from Group Review of the LLD Commissioning XP

http://nstx.pppl.gov/DragNDrop/Topical_Science_Groups/Meetings/lithium_research/2010_XP_reviews/Kugel_XP1000_17Feb10.pdf

- Suggested references tend to be B_T=0.45 & I_P=900 kA
  - I_P/B_T=2000 kA/T
  - 129015 at intermediate-δ, 129061 at high-δ
- Main focus is on scanning the OSP radius (and hence δ_L) in order to develop shapes with good LLD pumping.
  - Will try some/all of R_{OSP}≈0.55,0.64 (likely not 0.75, maybe not 0.35)
- Likely that R_{OSP}≈0.55 (or 0.65) is required for significant LLD pumping.
  - Standard highest-δ configuration is not thought to be a good candidate.
- For R_{OSP}=0.65 (bull-nose tile), the pulse length and/or input power may be highly constrained.
  - Limited by energy on LLD.
- Develop cases with HFS & SGI fuelling.
- Compare warm (liquid lithium) and cold (solid lithium) LLD cases.