NSTX

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ASC 5-Year Plan Discussion: TSG Goals and Diagnostic Requirements

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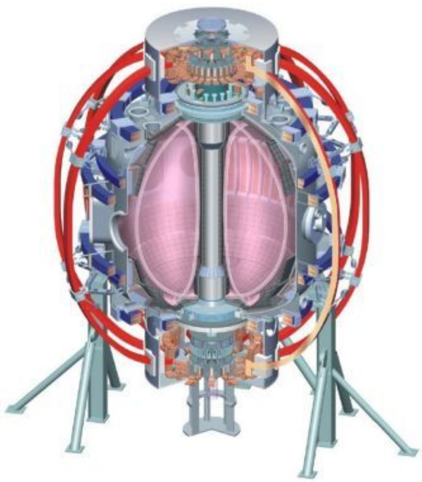

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Outline

- Discussion of preliminary plan elements from JEM spreadsheet.
  - Thrust 1: 100 % non-inductive sustainment.
  - Thrust 2: Use of 2nd NB for J-profile control, NB + NTV for Ω-profile control.
  - Thrust 3: Development of the long-pulse and high-current partial inductive scenarios.

- Some comments & facilitating capabilities.

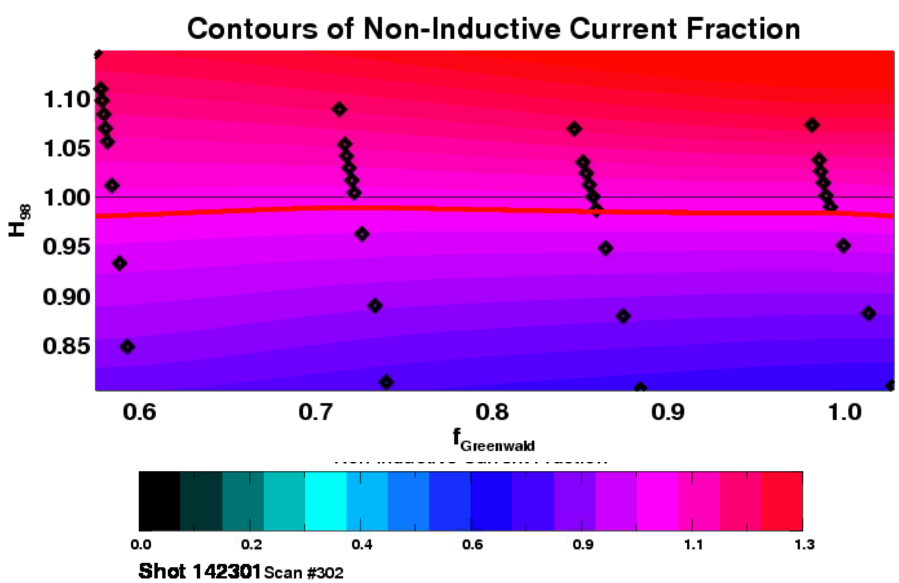
- Diagnostics requirements

Everything is up for discussion

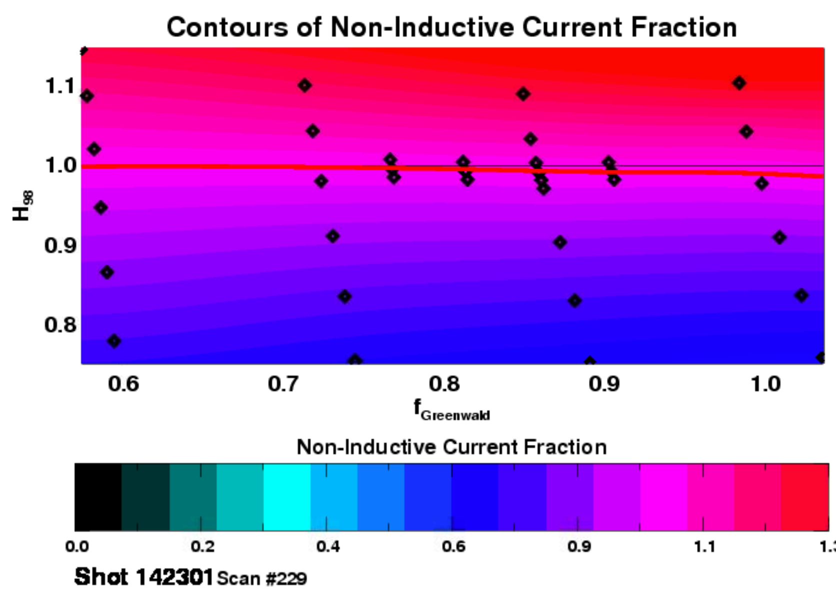
Thrust 1: 100% Non-Inductive Scenario Development

- Outage: Modeling of NSTX and NSTX-U scenarios.
- Year 1: Sustain 100% non-inductive for a few τ_E.
- Year 2: Sustain 100% non-inductive for a single τ_R.
- Year 3: Sustain 100% non-inductive in a fully relaxed profile.
- Year 4: Integrate with non-inductive initiation & ramp.
- Full research thrust can be carried out at B_T=0.75 T.
  - 1 T not required, but would raise the non-inductive current level.
- Will not require active heat flux mitigation.

Voltage on Six Sources (kV)	Non-Inductive Current at 1 T (kA)
80	870-1200
90	975-1300
100	1100-1450



1.0 T, 950kA, A=1.75, κ=2.8, R_{tan}=[50,60,70,110,120,130] 90 kV Beams



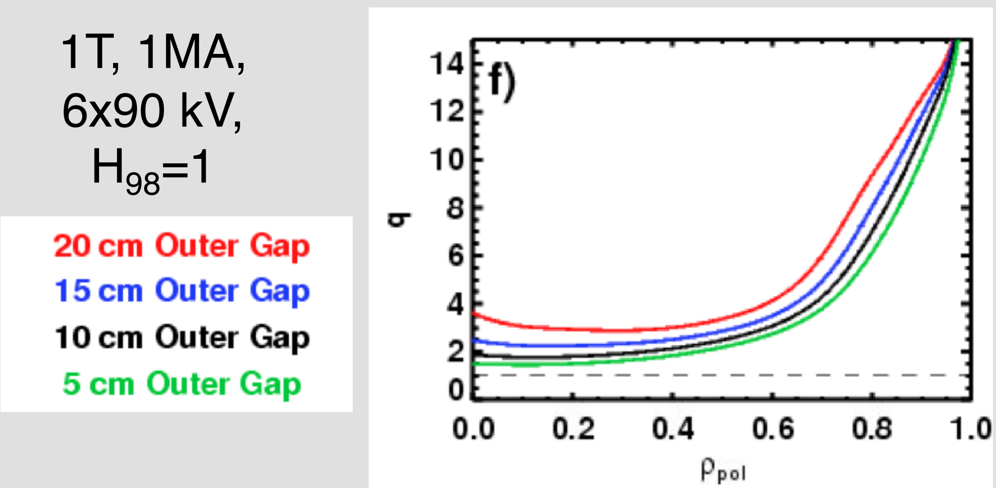
0.75 T, 800kA, A=1.75, κ=2.8, R_{tan}=[50, 60, 70, 120, 130] 90 kV Beams

Thrust 2: Current & Rotation Profile Control

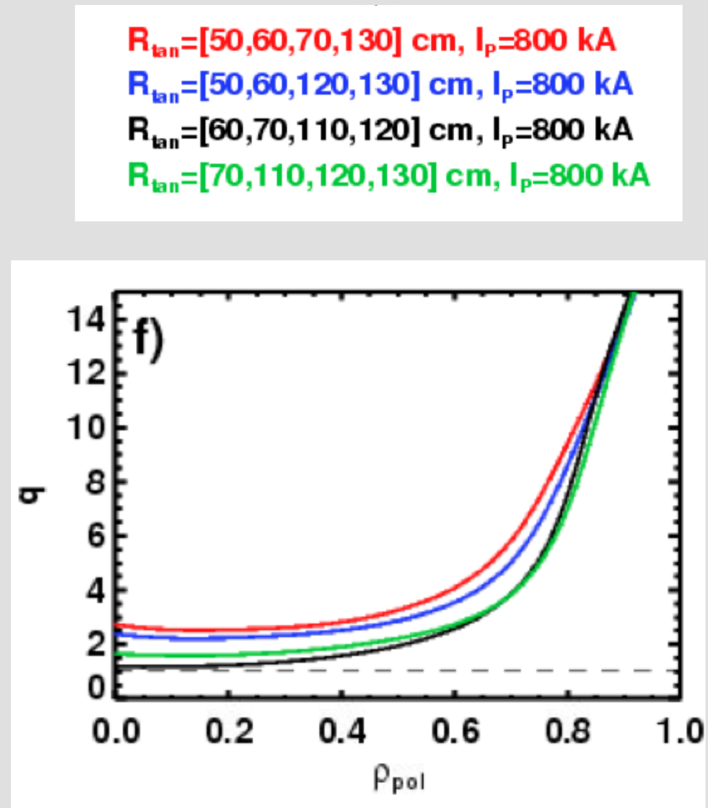
Rotation Control Desired in year 1 (MS), J control in year 3 (ASC)

- Outage: Study effect of anomalous D_{FI} on NBCD for Upgrade, Design J-profile control (using TRANSP runs for system-ID), finalize rotation controller. *Develop common format for β, J, RFA, and V_ϕ control to interact with beams.*
- Year 1: Demonstrate q_{min} variation with varying NBI mix.
- Year 2: Optimize the NB mix for transport and stability.
  - Tearing mode avoidance, reversed shear maintenance?
- Year 3: Develop realtime current profile control.
  - rtEFIT constrained by rtMSE, NBCD and shape for q_{min} control.
- Year 4: Use realtime current profile control.
- Comments:
  - Progress should be possible without heat flux mitigation.
  - Should include outer gap in studies of NBCD and q_{min} variation.

1T, 1MA, 6x90 kV, H_{98}=1



1T, 0.8MA, 4x90 kV, 15 cm outer gap, H_{98}=1



Thrust 3: High-Current and Long-Pulse Partial Inductive Sustainment.

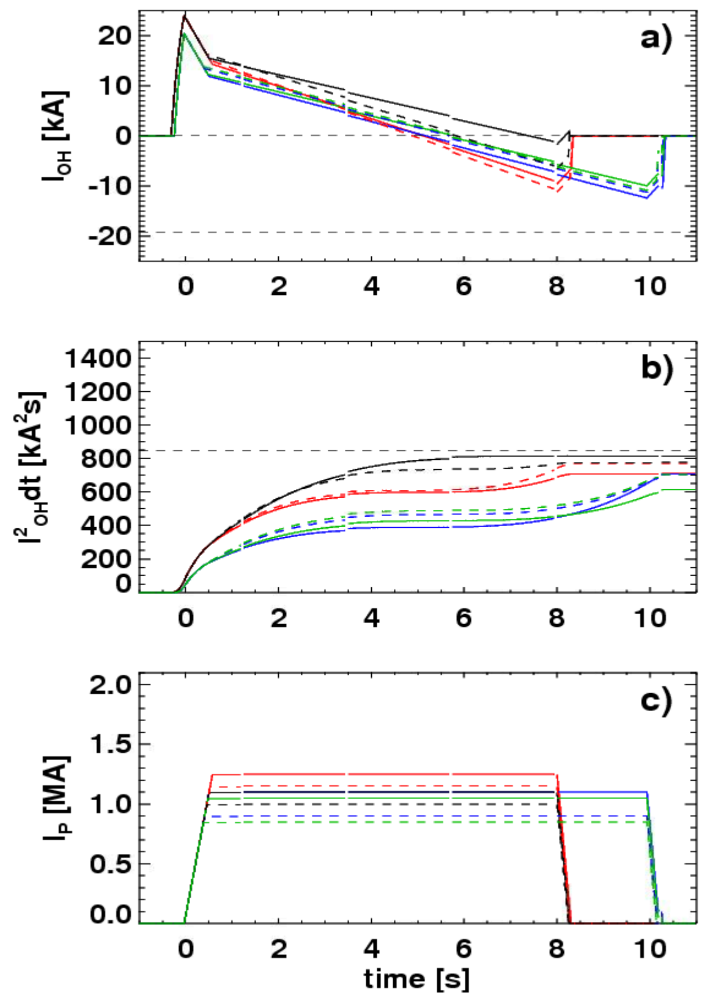
- Outage: Study low-n_e startup results, implement density feedback.

aLaP=
As Long As Possible

	Year 1	Year 2	Year 3	Year 4
1 MA	2-4 sec.	5 sec.	aLaP	---
1.5 MA	1-2 sec.	2-4 sec.	5 sec.	---
2.0 MA	--	1 sec.	2-4 sec.	aLaP

- Toroidal field levels to facilitate the research.
  - Year 1: 0.65-0.75 T for 5 sec.
  - Year 2: 0.75 T for > 5 sec., 1.0 T for 2 sec.
  - Year 3: 1.0 T for 4 seconds.
  - Year 4: 1.0 T for full I^2t limit.
  - Remains unclear if this aggressive schedule will be allowed.
- Divertor performance and fuelling likely quite important for this research agenda.
  - See next slides.

8 sec at 65 kV, six sources
10 sec at 80 kV, Modulated
B_T=0.75 T, Various profile and confinement assumptions, q_{min}>1.



In What Year Would Tile Heating in a Standard DN Configuration, Unmitigated, with Graphite Tiles, Prevent Meeting These Goals?

$$\lambda_q = 1.0 I_P^{-1.76}$$

$$T(t) = 53.7 Q_{peak} \sqrt{t}$$

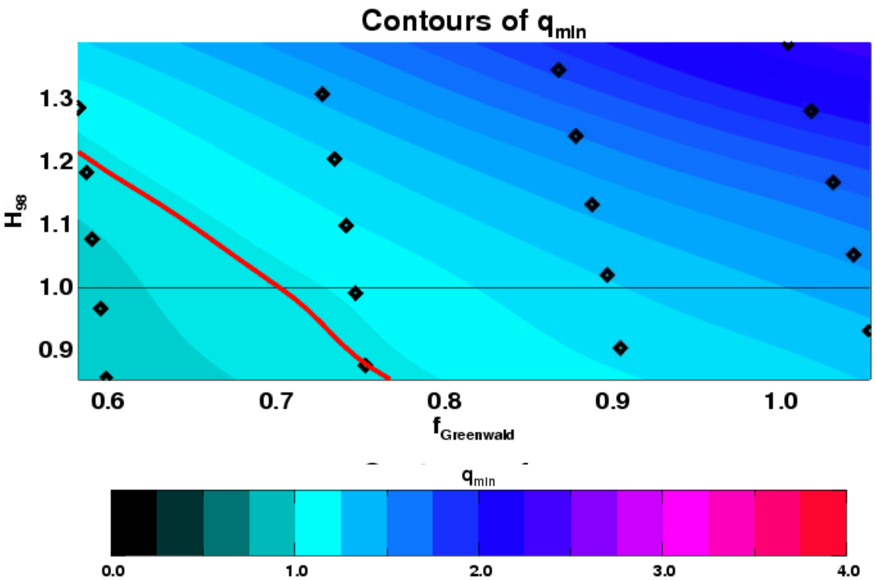
$$Q_{peak} = \frac{P_{loss} f_{div}}{2\pi R_{OSP} \lambda_q f_{exp}}$$

Time, in seconds, to achieve a given T_{max}.

I_p (MA)	P_{inj} (MW)	f_{exp}=14, f_{div}=0.4, T_{max}=1200	Year Is a Problem	f_{exp}=14, f_{div}=0.33 T_{max}=1500	Year Is a Problem
1	5	27	never	64	never
1	8	10.8	never	24	never
1	12	4.8	Year 2	10.9	never
1.5	8	2.6	Year 2	6.0	never
1.5	12	1.15	Year 1	2.6	Year 2
2	10	0.6	Year 2	1.39	Year 3
2	15	0.27	Year 2	0.61	Year 2

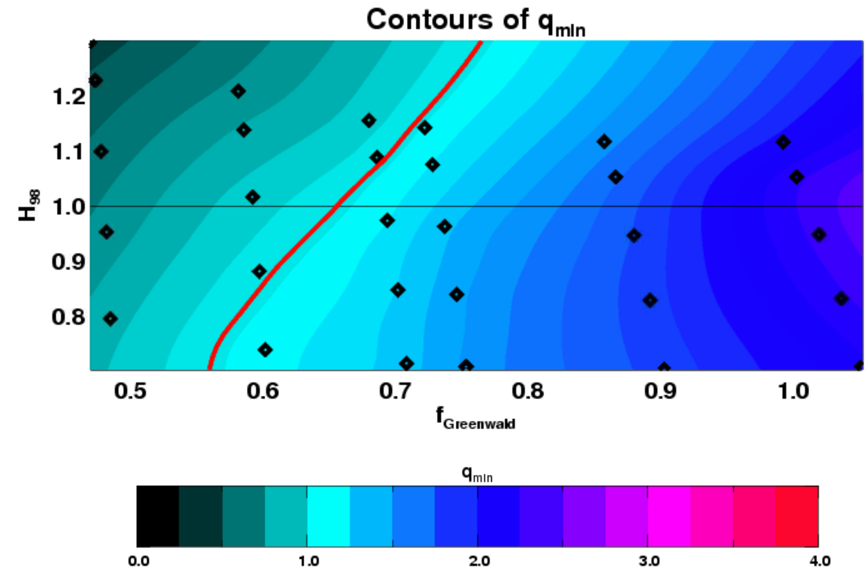
- Very long pulse, 100% NI, and J-profile control programs can very likely succeed without any active mitigation or SFD.
- Appears likely that at least some 1.5 MA scenarios will be OK without active mitigation.
- 2 MA scenarios are likely impossible without mitigation.
- If the divertor material changes, then this table also changes.

Controlled Densification Will Be Important



Shot 142301 Scan #396

0.75 T, 1200kA, A=1.75, κ=2.8, R_{tan}=[60,70,120] 80 kV Beams



Shot 142301 Scan #31

1.0 T, 1000 kA, A=1.73, κ=2.7, R_{tan}=[50,60,70,110,120,130] 90 kV Beams

- Will need to achieve f_{GW} greater than 0.6-0.7 within (1-2)τ_{CR}.
  - In a controlled fashion.
  - Need to limit Z_{eff} to 2-2.5.
  - Need efficient fuelling so as not to overwhelm the plasma.
- We need to stop the density ramp once desired value is achieved.
- May be the largest single barrier to utilizing the upgrade coil and heating upgrades.

Divertor Physics Will Certainly Play an Important Role In These Research Tasks

- Need a strategy for particle control.
  - Cryo-pumps not in the outage scope.
    - Need a design that can pump the optimally shaped plasmas.
    - May wish to run the Upgrade for some period to accumulate data on optimal shapes, particle fluxes before finalizing design?
      - If not, must rely on TRANSP to determine scenario impact of shape changes.
  - Lithium?
    - Mega-evaporations provide pumping for many shots in sequence…encouraging
    - Not ready with impurity control techniques.
  - This topic is primarily the responsibility of the BP TSG, with ASC support.
- Comment on research plan for heat flux mitigation.
  - Divertor geometry optimization and magnetic control would start in year 1.
    - In collaboration with BP TSG.
    - Already made some rtEFIT changes in preparation of SFD control.
  - Realtime temperature & detachment measurements for control can be:
    - Tested offline in year 1.
    - Tested online in year 2.
    - Used for closed loop control in year 3.

Good Discharge Termination Will Facilitate This Goal

- I_P=2 MA and B_T=1 T are likely the cases with the lowest collisionality, and are of interest for other topics such as SOL width scaling
  - 6 x 90 kV: W_{MHD}= 1.0 -1.2 MJ @ f_{GW}=0.55, 1.1-1.4 MJ @ f_{GW}=0.9,
  - 6 x 110 kV: W_{MHD}= 1.25 -1.45 MJ @ f_{GW}=0.55, 1.3-1.6 MJ @ f_{GW}=0.9,
  - Stick of dynamite: 2.1 MJ.
- All these cases evolve to q_{min}<1 for 10 cm outer gaps (although τ_{CR}=1 s for these cases).
  - …sawteeth or coupled 1/1 + 2/1 modes -> are thus prone to disruption.
  - …and these disruptions will/may have the largest thermal and mechanical loads.
- Will want to be sure of our operational procedures before trying these.
  - Need a location ("category") in PCS to determine when a discharge is approaching a disruptive state:
    - Basic tests (data already in PCS): Approaching the solenoid current limit, solenoid I^2t limit, large locked modes (RWM sensors).
    - Advanced tests (data not in PCS): rotating MHD modes, rotation slowing, P_{rad} excursions…
    - Can be expanded to trigger MGI.
  - Need to automated the P_{inj} and I_P rampdowns (at least).
- Automatically ramp down I_{TF} once plasma vanishes.
  - Eliminate "wasted" full power TF shots.

Should Anything Be Added to the Large-Scale Research Goals…Discussion…?

- Code benchmarking.
  - NICD calculations (maybe assumed…).
  - Reduced transport model *scenario* predictions and validation.
- 100% non-inductive scenarios.
  - Controllability of these scenarios:
    - What happens if you turn off solenoid I_p control?
  - Optimal q-profile for non-inductive sustainment?
    - Differs from the general J-profile control task, where inductive currents may be allowed.
- Impact of heat-flux reduction strategies on global confinement and performance.

Diagnostic Considerations

Caveat

Assume that off-line total neutrons, MPTS, MSE, toroidal CHERS are available, as is on-line n=1 detection.

If not, then these are the highest priority diagnostic requests.

Rough priority order indicated…***open for discussion***.

Thrust 1 Diagnostic Considerations
100% Non-Inductive Sustainment

1: Measurements of fast-ions are critical.

- Comparisons to TRANS/NUBEAM must be possible, and a wide operating range in terms of currents and density is required.
- Discrimination against different NBCD profiles would be great.
- Neutron collimator, fusion product detectors, FIDA can make complementary measurements.

1: MSE-LIF

- Eliminate the coupling between heating beam voltages and MSE measurements.

3: Realtime density measurement for n_e feedback.

- Required to control densification.
- Needs to be highly reliable.

4: Routine estimates of the edge neutral density would help.

- Constrain the beam charge exchange loss in TRANSP for better power and NBCD accounting.

Thrust 2 Diagnostic Considerations
Profile Control

- Same comments as previous slide, and…

1: Realtime MSE is a requirement for current profile control.

- Design should consider and accommodate most likely scenarios for J-control (80 or 90 kV? Modulation constraints).
- Optimized rtEFIT setting should be considered.
- Control in year 3 means rtMSE should be implemented by start of year 2.

1: Realtime toroidal rotation is a requirement for rotation profile control.

- Nearly implemented for the FY-11/12 run.
- Do we have a background view solution?
- Research plan for years 1-4 is in the MS group, with ASC involvement.

3: rtMPTS could be beneficial.

- EFIT02 like isobar constraint.
- Better outer gap in realtime.
- Useful for realtime resistivity estimates, for control algorithms.
- Could use for an l_i controller instead of q_{min}…
  - …if it constrains l_i well enough w/o MSE.

Thrust 3 Diagnostic Considerations
Long Pulse and High-I_P Scenario Development

All of the "Thrust 1 diagnostics", plus

1: Divertor control diagnostics likely important:

- Discuss details of realtime temperature and detachment diagnostics in BP meeting.
- Some ideas:
  - Any diagnostics that can help constrain the rtEFIT snowflake geometry?
  - Can we replace dr_{sep} control with dT control?:

$$dT = T_{upper} - T_{lower}$$

$$\Delta I_{PF-3} = P \cdot dt + I \int dT dt$$

  - Must keep SPs fixed. & what happened during detachment?

2: Realtime diagnostics that aid in discharge health assessments:

- Rotating n=1 modes, toroidal rotation, rtMPTS

Other Diagnostics That May Contribute

- Specifically:
  - Profile reflectometry (UCLA).
    - Improved reconstructions of density profile and MHD equilibria.
  - ERD Upgrade (Podesta)
    - Constrain edge $T_{i.}$
  - SOLC Tracing (Takahashi)
    - For n=0 stability.
- Generally:
  - Any diagnostic that facilitates improved n=1 control or physics understanding (MS TSG).
  - *AE diagnostics that help diagnose the effect of various modes on NBCD (WEP TSG).
  - Improved impurity diagnostics (BP & T&T TSG).
    - Can be important for TRANSP analysis in discharges where Carbon is not the only impurity.