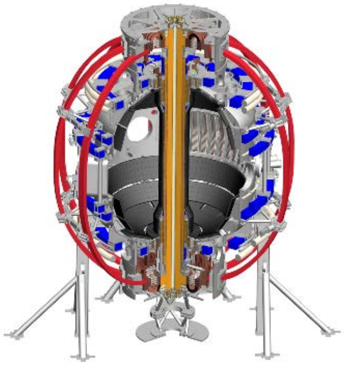
Questions and Answers from PAC-37

NSTX-U Team

NSTX-U PAC-37
PPPL
January 27, 2016



Questions from NSTX-U PAC-37 (1)

1. How many FY16 run-days are dedicated to the NSTX-U research milestones. (J. Menard)

2. Describe the code development plan for the 3 flagship codes in the theory partnership. Also, you should include TRANSP code development plans. Amitava's presentation was clear as to what's being done now, but there was relatively less on how the partnership and its activities evolve in the future. The context for the flagship codes is ok, but you can answer more broadly. (S. Kaye)

3. Describe the impact of the facility enhancements on your long-term / 10 year vision. An overarching sense of this question is, as you look to the future 5-10 years from now, how do you envision the capabilities of the cryo, NCC coils, and gyrotron mapping onto to the program you envision? You had a slide that showed the 5 and 10 programmatic perspective. How do you connect these three capabilities to that vision, and can you use the elements on that slide for illustration? (J. Menard will address this part). More specifically:
    a. What is the impact of each enhancement (cryo, NCC, ECH) on metal wall research / liquid metals program? (Jaworski / Maingi)
    b. Can the gyrotron be used for localized core electron heating in H-mode plasmas? (Perkins / Poli / Gerhardt)
    c. Please provide an overview of the engineering design status, and resources required (budget guesstimate) for the 3 major enhancements (+ high-Z tile job) (M. Ono)

Questions from NSTX-U PAC-37 (2)

4. Please summarize all of the ITER support contributions you are making (at a high level) on 1-2 viewgraphs. (Kaye)

5. How will you decide (measurements or engineering criteria, etc) when it is safe to progress to the next field and current performance level (as shown in Ono talk). (Gerhardt / Ono)
   a. Generate some kind of performance matrix indicating the risk thresholds, etc
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6. J. Menard showed bulletized list of 5 and 10 year goals for NSTX-U experiment / program. What are the corresponding most important 5 year theory results & partnership goals for each Science Group (Maingi, Kaye, Gerhardt each to provide 1 slide or state verbally)

7. For HHFW, is it only useful for start-up research? or could it contribute to a wider range of scenarios? (Guttenfelder / Perkins + all other TSGs)
   a. Also, if the HHFW program was not useful for start-up and was stopped, how much resource could be produced, and could this help pay for gyrotron? (Ono)

Q1: How many FY16 run-days are dedicated to the NSTX-U research milestones?

- R16-1 - Assess H-mode confinement, pedestal, SOL characteristics at higher B_T, I_P, P_{NBI}
- R16-2 - Assess effects of NBI injection on fast-ion f(v) and NBI-CD profile
- R16-3 - Develop physics + operational tools for high-performance: κ, δ, β, EF/RWM
- JRT-16 - Assess disruption mitigation, initial tests of real-time warning, prediction

TSG / TF	R16-1 run days	R16-2 run days	R16-3 run days	JRT-16 run days
Advanced Scenarios and Control (ASC)	0	0	10	0
Wave Heating and Current Drive (RF)	0	0	0	0
Solenoid-free Start-up and Ramp-up (SR)	0	0	0	0
Pedestal Structure and Control (PS)	2.5	0	0	0
Divertor and Scrape-off-layer (DS)	1	0	0	0
Materials and PFCs (MP)	0	0	1	0
Particle Control Task Force (PC)	0.5	0	1	0
Macroscopic Stability (MS)	0	0	0	6.5
Turbulence and Transport (TT)	2.5	0	0	0
Energetic Particles (EP)	0	4	0	0

TOTAL using Forum allocations (50 TSG run days)	6.5	4	12	6.5	Totals
x 1.1 for 18 run weeks (50 --> 55 TSG run days)	7.15	4.4	13.2	7.15	31.9
# run weeks	1.43	0.88	2.64	1.43	6.38
Fraction relative to 55 run days	13%	8%	24%	13%	58%

Matrix above is likely a lower bound – many other XPs will contribute in some way to milestones

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Q2: Plans for Theory Flagship Codes

- M3D-C[1]
  - Gyrokinetic and drift-kinetic models for fast ion species and pellet models for ELM pacing sims being implemented; impurity transport and impurity radiation model will be implemented
  - Disruptions, including current quench and wall-touching kink phase, predictions for halo currents that can be compared directly to NSTX-U measurements; mode locking and evolution into disruption; interaction of fast ions with nonlinear MHD, including sawteeth and ELMS.
- GTS
  - Implement e-m effects into generalized geometry; develop global, nonlinear GK capability for generic EP physics study
  - Contribution of e-m turbulence, including the MTM mode, to NSTX-U transport and confinement; the parametric dependence of e-m effects on beta and collisionality in ST regime; how finite-beta physics affects DTEM turbulence; consistently coupling turbulent and neoclassical physics to investigate plasma self-generated non-inductive current
- XGC
  - Implement kinetic electron/e-m effects to assess core turbulence (i.e., μtearing); incorporate DEGAS in XGC, including high-Z atomic physics
  - Impurity transport; kinetic study of 3D field penetration into plasma, and effect on pedestal transport and shape; pedestal shape effect on turbulence criticality and ELMs; L-H transition physics

Q2: Plans for Theory Codes (cont'd)

- HYM
  - Improve f_{fi} model, equilibrium solver, parallel effects, include plasma bulk rotation
  - Understand conditions for preferential excitation of GAEs and CAEs, Comparison of the relative importance of the energy channeling vs anomalous electron transport mechanisms
- M3D-K
  - Include thermal ion kinetic effects for simulations of beam-driven AEs in NSTX-U
  - Investigate nonlinear physics of TAE avalanche including mechanism of transition to avalanche and beam ion transport due to multiple TAEs

Q2: TRANSP (Strategic Plan developed 7/15)

- Development will focus on modularization of the code framework, which will allow evolution towards a “Whole Device Model” (Integrated Simulator)
- Used widely internationally, and is implemented within the IMAS framework at ITER (ongoing in steps); incorporate into other workflow managers (e.g., OMFIT)
- Key physics components development will include
  - Near-term (0-2 years)
    - Reduced Neoclassical Toroidal Viscosity (NTV) model
    - Incorporate AFID models (kick, CGM)
    - Parallelized GENRAY and CQL3D, especially for determining High Harmonic Fast Wave (HHFW) absorption on NSTX-U
    - Self-consistent calculation of interactions between RF waves and fast ions/alpha particles (TORIC/CQL3D – NUBEAM)
    - Core particle/multi-impurity species transport
    - Pedestal model via look-up table based on EPED
    - Incorporate rotation effects into the free-boundary ISOLVER equilibrium solver algorithm
    - Implement reduced NTM model

Q2: TRANSP

- Medium-term (2-5 years)
  - Couple TRANSP to models such as UEDGE or SOLPS through a workflow manager to develop a deeper understanding of the SOL and edge
  - Implement reduced NTV model for development of algorithm to control plasma stored energy
  - Implement sawtooth model with fast ion effects
- Long-Term (5+ years)
  - 2D, integrated core-edge model based on the 2D Braginskii equations with coupled atomic physics and simplified wall boundaries
  - 2D neutrals package to couple of above core-edge model

Adding one experienced big-code software developer to TRANSP CPPG team (starting Feb. 1)

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Q3: 5 year goal: Establish core physics/scenarios for ST
10 year goal: Integrate high-performance core + metal walls

First 5 years

Establish ST physics / scenarios:

- Confinement vs. β , collisionality
- Sustain high β with advanced control
- Non-inductive start-up, ramp-up
- Mitigate high heat fluxes
- Test high-Z divertor, Li vapor shielding

◄ Density / ν^* control important → cryo

◄ High β, Ω_ϕ, ELM control important → NCC

◄ Start-up: heating/CD in low n_e, T_e, I_P → gyrotron

◄ Particle control / pumping → cryo, ELMs → NCC

◄ High-Z divertor → cryo w/ heatable high-Z baffle

Inform choice of FNSF configuration:

- Lower A or higher A?
- Standard, snowflake, Super-X (MAST-U)?

Q3: 5 year goal: Establish core physics/scenarios for ST
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High-Z div. → cryo w/ heatable high-Z baffle ▶

NCC may require new tiles on plates → high-Z? ▶

Long-pulse density control important → cryo ▶

Sustained β, Ω_ϕ, ELM control important → NCC ▶

100% solenoid-free w/ metal walls → gyrotron ▶

10s may be possible at 5MW/ modulated NBI, 20s would require NBI pulse-length upgrade

Second 5 years

High-performance + metal walls

- Convert all PFCs from C to high-Z
- Static → flowing Li divertor module(s), full toroidal flowing Li divertor, high T_{wall}
- 5s → 10-20s for PFC/LM equilibration
- Assess ST with high-Z, high-Z + Li

Inform choice of FNSF / DEMO plasma facing materials:

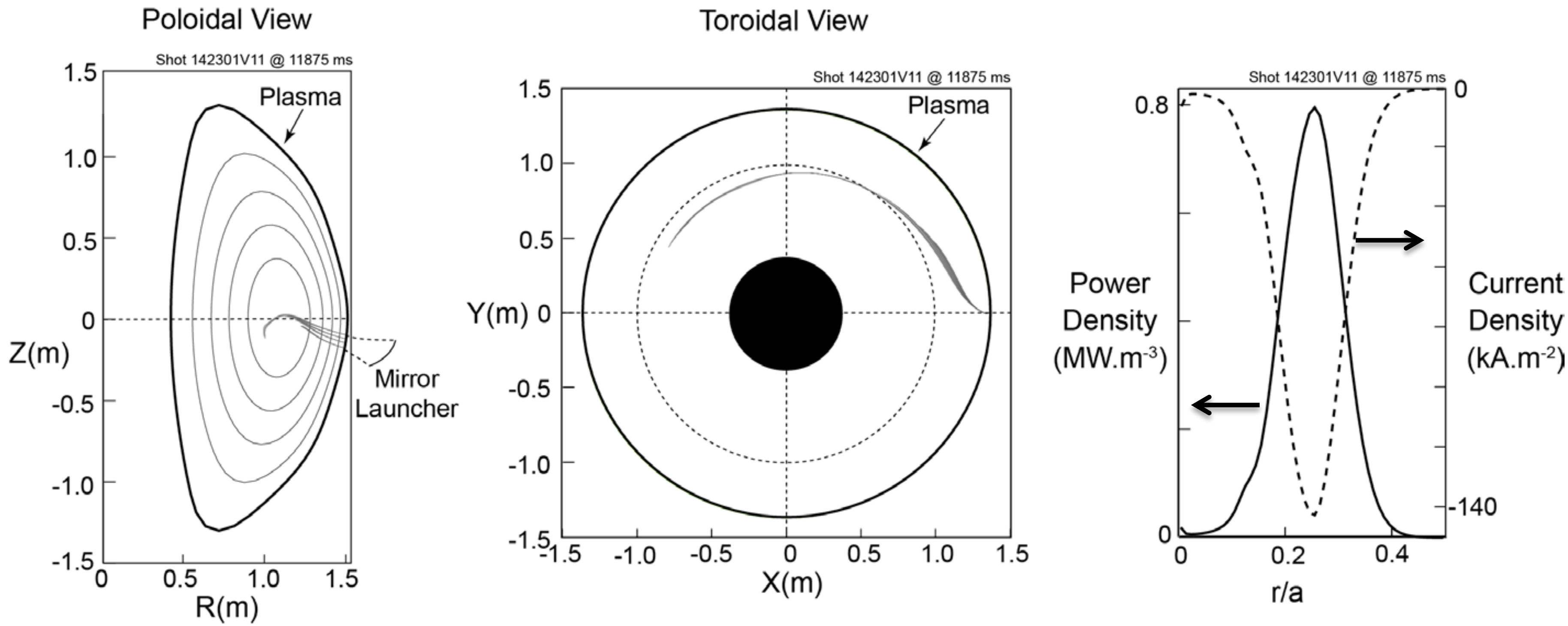
- High-Z consequences? need high-Z + Li?
- Assess for both divertor and first-wall

Question 3a: Impact of facility enhancements on high-Z and liquid metal program

- Cryo pump impact both technical and scientific
  - Divertor structural change provides opportunity to accelerate high-Z and liquid metal implementation
  - Allows assessment of changes in global recycling without changing impurity mix (Li vs. cryo experiments) and quantifies relative performance of Li vs. cryo
- NCC impacts both technical and scientific
  - Significant re-work of passive plate and associated PFCs may provide additional opportunity to accelerate high-Z
  - Strike-point splitting could modify divertor performance (attachment/detachment) and would need to assess and mitigate (ITER relevant)
  - Liquid metals: increased erosion not, in principle, an issue w.r.t. PFC lifetime however experimental interpretation could be complicated by split strike-point features
- ECH seems to present no technical difficulties
  - Input from Hosea/Perkins is that ECH should not deposit energy into the SOL potentially leading to increased erosion or heating
  - Current power levels (1-2MW) not clear if strong additional impact would be expected over the NBI+HHFW power levels available

Q3b: 28 GHz Gyrotron can be used for core EBW heating and current drive (CD) in NSTX-U

- GENRAY-ADJ modeling predicts good EBW access to core plasma in NSTX-U H-mode & efficient CD:
  - EBWCD efficiency up to 40 kA/MW at r/a ~ 0.2*



EBW ray trajectories for NSTX-U H-Mode show good access to core plasma

Well localized EBW power deposition & EBWCD

* G. Taylor *et al*, EPJ Web of Conference **87**, 02013 (2015)

3c. An overview of the engineering design status, and resources required (budget guesstimate) for the 3 major enhancements (+ high-Z tile job)

- We are largely utilizing the engineering resources becoming available from the NSTX-U upgrade project completion for the NSTX-U enhancements .
- However, those are engineers who are also supporting the NSTX-U operations.

- If some unexpected needs arise on NSTX-U, the engineering resources are moved to solve the issues on NSTX-U. The NSTX-U operation has the highest priority.

- For example, the arc incident has impacted the Cryo-pump design work because the engineering manager was also responsible for the NSTX-U magnet fabrication.

- The cost estimate is very preliminary except for the high-Z tiles. The ECH design has completed CDR so it cost estimate is relatively good. The cryo-pump and NCC has not completed CDR so the cost estimate is very preliminary.

if the HHFW program was not useful for start-up and was stopped, how much resource could be produced, and could this help pay for gyrotron? -

- HHFW will be focused on the ramp-up study initially and HHFW + NBI research. Once these experimentations are complete, the HHFW could be mothballed to support the gyrotron implementation. HHFW can be re-energized for the CHI+ECH+HHFW non-inductive start-up and ramp-up research once ECH is available.
- The rf group includes four rf engineers and three rf technicians. They support NSTX-U HHFW and rf collaborations. The NSTX-U HHFW utilized about 2/3 of the rf group effort.
- The PPPL labor need is modest until third year of the gyrotron project since the work is mainly procurement of gyrotron, power supplies, and waveguides which would only require modest effort by rf engineering.
- Once the gyrotron components arrive, we can utilize the HHFW engineers and technicians for certain rf related work such as gyroton testing and waveguide installations. However, much of the gyrorton work at PPPL is carried out by non-rf people (utility, computer division, shops, construction, etc).
- Gyrotron project:

1st year (procurement) – only modest impact (~ 1 rf engineer) – HHFW operation
2nd year (procurement) – only modest impact (~1 rf engineer) – HHFW operation
3rd year (construction) – significant impact (~ 2 rf engineer, 3 technicians) – Limited HHFW
4th year (commissioning and operation) – Essentially utilize all of the HHFW resource to ECH.

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Q4: Examples of ITER Contributions Specific to ITPA tasks – Many more contributions (see next vg)

- Pedestal
  - ELM destabilization and pacing via pellets (PEP-30); using impurity granules (Li, B4C, C) to destabilize and pace ELMs
- Transport and Confinement
  - Gyrokinetic predictions of momentum pinch in NSTX; also led, analyzed and performing GK analysis for MAST perturbative momentum transport experiment (TC-15)
- Energetic Particles
  - Study heat loads from fast ion losses due to 3D and ELM perturbations (EP-6), leading new JEX on NB-CD
- Macrostability
  - Global mode stabilization and control, specifically RWM physics, study of kinetic effects (lead, MDC-21); disruption forecasting, MGI, halo current asymmetries (lead on IAEA synopsis)
- Integrated Operational Scenarios
  - New activity on plasma termination (IAEA synopsis); experiments on NBI and RF control current rampdown (maintain H-mode), RF for impurity control during rampdown

Q4: 2016 NSTX-U Participation in ITPA

	Advanced Scenarios and Control
IOS-1.2	Divertor heat flux reduction in ITER baseline scenario (considering)
IOS-1.3	Operation near P_{LH} (considering)
IOS-2.1	Compare helium H-modes in different devices (considering)
IOS-3.3	Core confinement for q(0)=2 (considering)
IOS-5.2	Maintaining ICRH coupling in expected ITER regime
	Boundary Physics
PEP-26	Critical edge parameters for achieving L-H transition
PEP-28	Physics of H-mode access with different X-point height (considering)
PEP-29	Vertical jolts/kicks for ELM triggering and control
PEP-30	ELM control by pellet pacing in ITER-like conditions and consequences for plasma confinement
PEP-31	Pedestal structure and edge relaxation mechanisms in I-mode (considering)
PEP-37	Effect of low-Z impurity on pedestal and global confinement
DSOL-31	Leading edge power loading and monoblock shaping
DSOL-34	Far-SOL fluxes and link to detachment (considering)
DSOL-35	In-out divertor ELM energy density asymmetries (consdiering)
	Macroscopic Stability
MDC-1	Disruption mitigation by massive gas jets
MDC-8	Current drive prevention/stabilization of NTMs (considering)
MDC-15	Disruption database development
MDC-17	Active disruption avoidance
MDC-18	Evaluation of axisymmetric control aspects
MDC-19	Error field control at low plasma rotation
MDC-21	Global mode stabilization physics and control
MDC-22	Disruption prediction for ITER
	Transport and Turbulence
TC-9	Scaling of intrinsic plasma rotation with no external momentum input (considering)
TC-10	Experimental identification of ITG, TEM and ETG turbulence and comparison with codes
TC-11	He and impurity profiles and transport coefficients
TC-14	RF rotation drive (considering)
TC-15	Dependence of momentum and particle pinch on collisionality
TC-17	□* scaling of intrinsic torque (considering)
TC-19	Characteristics of I-mode plasmas (considering)
TC-24	Impact of resonant magnetic perturbations on transport and confinement (considering)
	Energetic Particles
EP-6	Fast ion losses and associated heat loads from edge perturbations (ELMs and RMPs)

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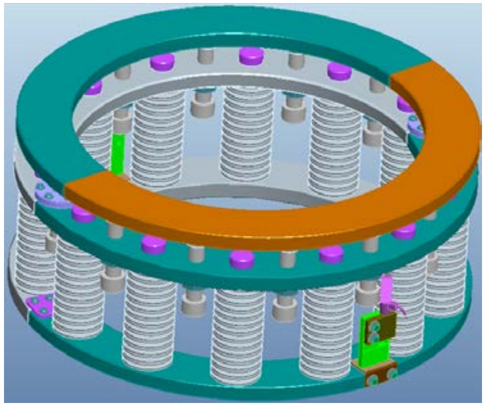
Q5: Machine Was Designed to Operate at 2MA and 1T

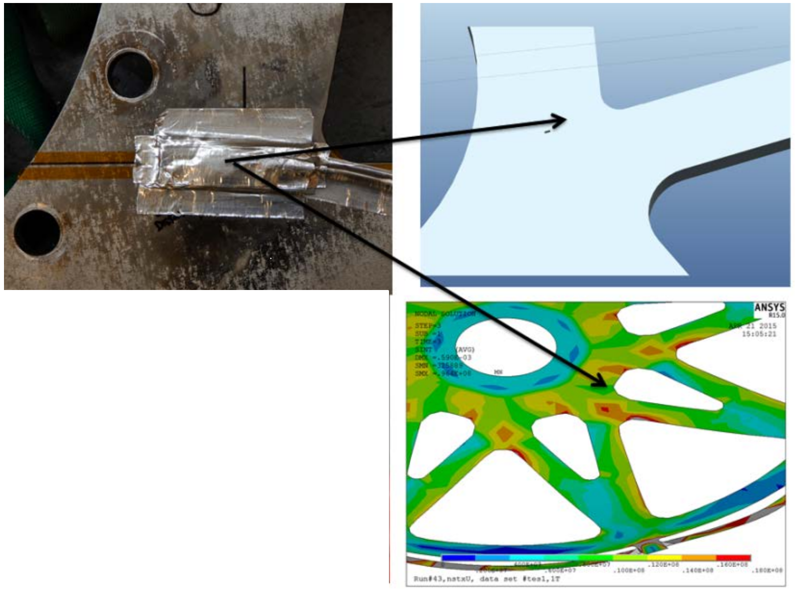
- PF/OH/TF (and their mechanical supports, current feeds,…) designed around a family of 96 plasma equilibria at B_T=1T, I_P=2 MA.
  - “The 96” include a large range of OH flux states, shapes, with control margin
- Extensive calculations and testing to support this design:
  - http://nstx-upgrade.pppl.gov/Engineering/Calculations/index_Calcs.htm
- Many key enhancements to the structure
  - Vastly improved TF joints.
    - Joint moved out from highest field region, reduced current bunching in joint.
  - Coaxial feed for OH.
  - Vertical field coil supports both larger, and more numerous.
  - Many enhancement to handle the increased torsional load
    - New clevis structures and outer tie rods on the TF
    - Reinforcements to the umbrella
    - New “spoked-lid” design
  - Approximately 800 lbs. (360 kg) of weld wire applied to NSTX through the construction phase.
- DCPS captures the limits determined in calculations
  - Typically based on fatigue considerations…tripping the DCPS is not a sign of imminent problems.

Q5: Near Term Activities For Transitioning from 0.65 T to ~0.75-0.8 T this Year

Note: Project Engineer in China right now, so I could not discuss these answers with him.

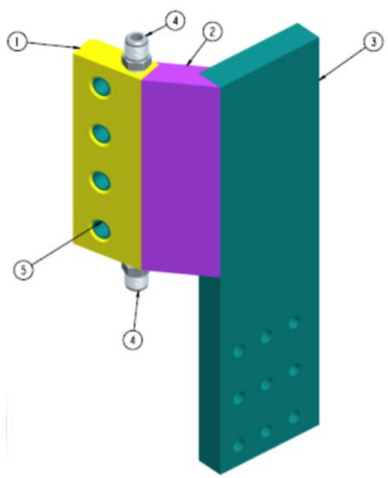
- Develop confidence in DCPS.
  - Basically done…DCPS is working well.
- Complete deployment of plasma shutdown software.
  - Useful for avoiding control transients, halo currents, during a disruption.
- Finish critical engineering validation.
  - Radially uniform cooling of OH coil (flow balancing, done).
  - OH pre-load and thermal growth assessment (in progress).
  - Benchmark outlet water temperatures against DCPS calculations (in progress)
  - Complete assessment of spoked lid torques
  - Halo currents on CS, in CHI bus
    - Digitizers, sensors being finalized this outage.
- Assess whether TF lead extensions are ready for higher TF. (next slide)

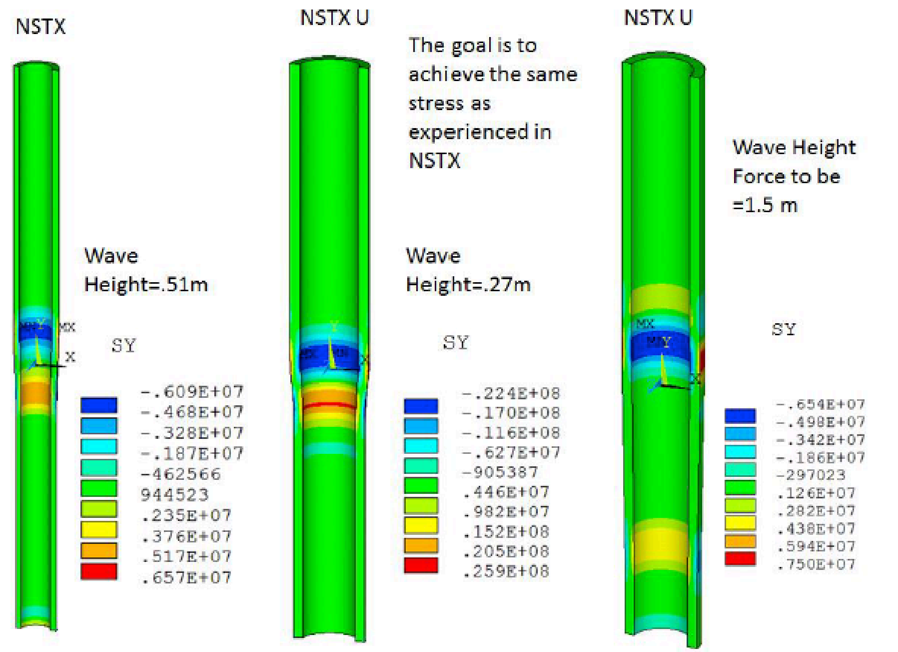




Q5: Tasks Required for Confidence in Full Field and Heating Operations (All During Next Outage)

- Replace some TF lead extensions
  - Complicated 3D CuCrZr shapes, challenging e-beam welds
  - Vendor UT is in retrospect suspect.
    - Dye penetrant tests were documented.
  - Present set must be replaced for full field.
  - ½ set being manufactured now, another ½ set will start fabrication.
- Replace some passive plates.
- Install OH water pre-heater.
  - OH coil can get large cool-down stresses from cold water entering bottom.
    - Fatigue tests on winding samples indicate that this is acceptable, but we want to be gentle.
  - Match the OH coil and water temperature, then ramp water temperature down.
- Complete specified inspections and maintenance.
- Finish instrumentation job.
  - Outer leg bending stresses
  - Outer leg trusses

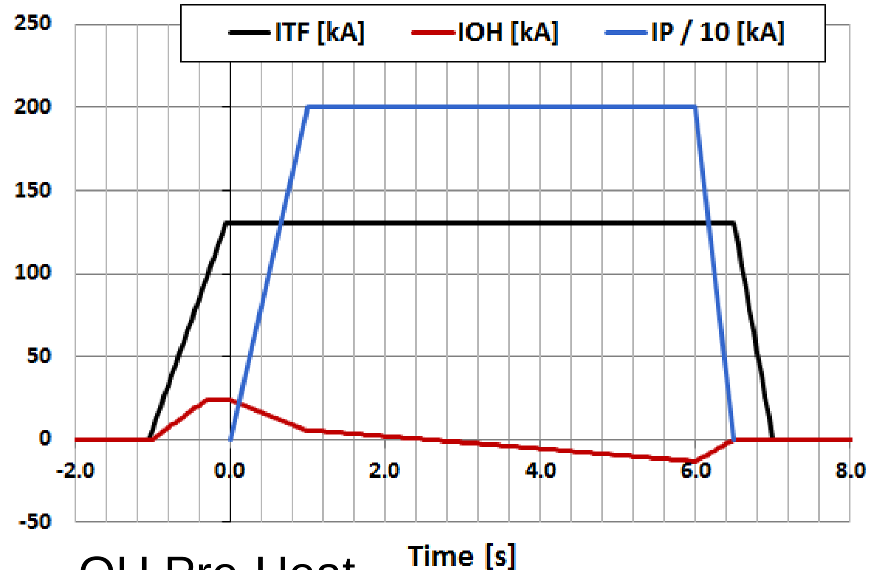




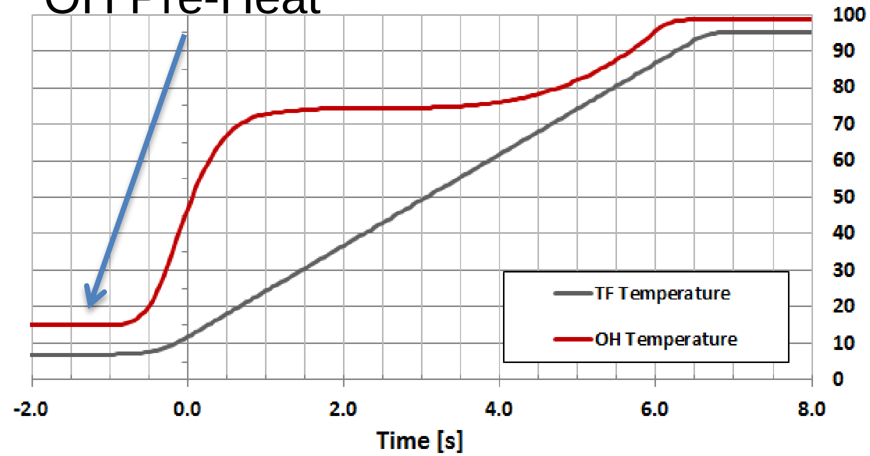
Q5: $T_{TF}<T_{OH}$ Constraint Can Be Managed By Appropriate Coil Programming

- Illustrative Example: 2 MA, 1T, 5 second.
- TF Coil:
  - Current is constant
  - Temperature is linear
- OH Coil:
  - current has a zero-crossing
  - Temperature has an “S-Shaped” curve.
- Options for maintaining $T_{TF}<T_{OH}$.
  - ***Pre-heat the OH coil*** using currents before the TF turns on.
  - Control the shape of the OH S-curve by ***adjusting the amount of pre-charge***.
- In this example,
  - Full 24 kA pre-charge
  - Extended pre-charge duration to provide heating.
- ***Every shot taken to date has used this pre-heat trick.***
  - ***DCPS enforces temperature difference.***

H_{98} = 1.2, $f_{Greenwald}$ = 0.75, P_{NBI} = 8MW, β_N = 4.6



OH Pre-Heat



Q5: Big Picture

	~1 MA/0.65 T	~1.5 MA / 0.8 T	~2.0 MA / 1.0 T
~1 s	Almost There	Minor facility checks and updates. Lead extension assessment.	Full mechanical validation, new TF lead extensions
~3 s	Permitted by present DCPS configuration. Near(ish) term goal.		Full mechanical validation, new TF lead extensions
~5 s	Minor increase in present machine parameters. Density/impurity/MHD control+ long-pulse NBI likely issues. Minimal $T_{OH}>T_{TF}$ impact.	Minor facility updates and checks. Lead extension assessment. Density/impurity/MHD control+ long-pulse NBI likely issues. Minimal $T_{OH}>T_{TF}$ impact.	Full mechanical validation, new TF lead extensions, full density/impurity/MHD control+ long-pulse NBI likely issues. Risk that $T_{OH}>T_{TF}$ constraint will impact shot efficiency .

- Durations of ~3τ_{CR} appear to be accessible at 1T, 2 MA for a large range of density and confinement, even with $T_{OH}>T_{TF}$.
- 5 second operation at lower current likely determined more by plasma physics and heating systems.

Questions from NSTX-U PAC-37 (2)

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5. How will you decide (measurements or engineering criteria, etc) when it is safe to progress to the next field and current performance level (as shown in Ono talk). (Gerhardt / Ono)
   a. Generate some kind of performance matrix indicating the risk thresholds, etc
   b. How much risk is there that you will not be able to achieve 5s coil operation at full performance?
   c. If you find that a technical issue (e.g., heating of coils) limits the pulse length to 3 s or less, what would be the impact on your long-pulse program plan? Have you considered contingencies for that possibility?

6. J. Menard showed bulletized list of 5 and 10 year goals for NSTX-U experiment / program. What are the corresponding most important 5 year theory results & partnership goals for each Science Group (Maingi, Kaye, Gerhardt each to provide 1 slide or state verbally)

7. For HHFW, is it only useful for start-up research? or could it contribute to a wider range of scenarios? (Guttenfelder / Perkins + all other TSGs)
   a. Also, if the HHFW program was not useful for start-up and was stopped, how much resource could be produced, and could this help pay for gyrotron? (Ono)

Q6: Boundary SG NSTX-U/Theory Partnership needs

- Continue to advance XGC (and GKEYLL) to
  - Add necessary atomic physics and validate for high recycling and partially detached divertor operation for power dissipation and heat flux footprint; in progress on DIII-D for low recycling cases
  - Model effects of lithium and other (low-Z) impurities for interpretation of NSTX and NSTX-U results, to get more at the heart of how low-Z impurities improve confinement; also continue interpretation of Enhanced Pedestal H-mode
  - Interpret physics mechanisms for inter-ELM instabilities observed in NSTX; long term goal is to aim for simulation of the ELM cycle
  - Add necessary high-Z atomic physics to simulate metal wall conversion in NSTX-U

Q6: Core SG NSTX-U/Theory Partnership needs for **Five** year goals

- Understand collisionality scaling of transport in ST core and edge. What modes are operative in which parameter regimes of NSTX-U? This will necessarily involve full incorporation of **e-m** effects in PIC and continuum gyrokinetic codes
- Refinement and/or development and implementation of reduced AFID models for truly predictive simulations
  - CGM and Kick models for TAE modes and avalanches: couple NOVA eigenmode structure calculation into TRANSP along with reduced models for self-contained prediction; extend to other modes
  - Develop reduced model for CAE/GAE-induced core electron transport and energy channeling through GAE/KAW coupling
- Further development and implementation of extended MHD codes for studying kinetic effects on global stability and disruption/halo physics,also including mode locking, ELM mitigation, 3D equilibrium reconstruction, and disruption prediction

Q6: Core SG NSTX-U/Theory Partnership needs for **Ten** year goals

- Multi-scale gyro kinetic simulations (PIC and/or continuum) for both the core and edge plasmas. This is an exascale computer application.
- Couple high-Z impurity transport models into high fidelity gyro kinetic codes to determine transport and turbulence **especially in the edge plasma** (pedestal and SOL)
- Develop reduced models of transport of thermal plasma and transport based on understanding of various turbulence regimes within the Five year goals (ref. first bullet in Five year goals)

Q6: Scenarios SG NSTX-U/Theory Partnership needs

- TRANSP – see previous development plan
- RF SciDAC, AORSA development work (Bertelli)
- NIMROD work for CHI optimization work, plasmoid physics and diagnostic upgrades.

Questions from NSTX-U PAC-37 (2)

4. Please summarize all of the ITER support contributions you are making (at a high level) on 1-2 viewgraphs. (Sabbagh or Kaye)

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   a. Generate some kind of performance matrix indicating the risk thresholds, etc
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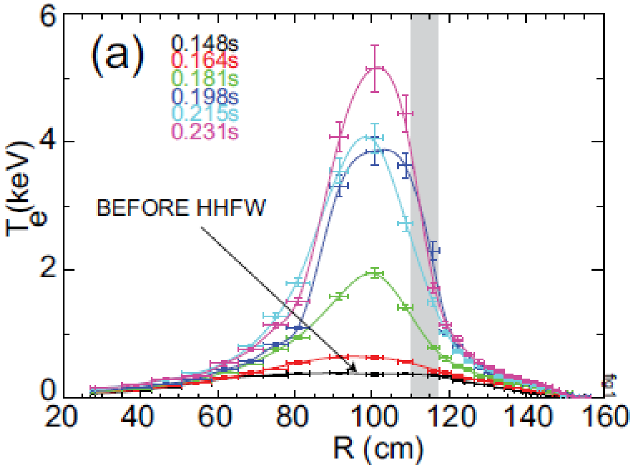
7. For HHFW, is it only useful for start-up research? or could it contribute to a wider range of scenarios? (Guttenfelder / Perkins + all other TSGs)
   a. Also, if the HHFW program was not useful for start-up and was stopped, how much resource could be produced, and could this help pay for gyrotron? (Ono)

Q7: HHFW supports a broad spectrum of science research (beyond its potential utility for solenoid-free start-up)

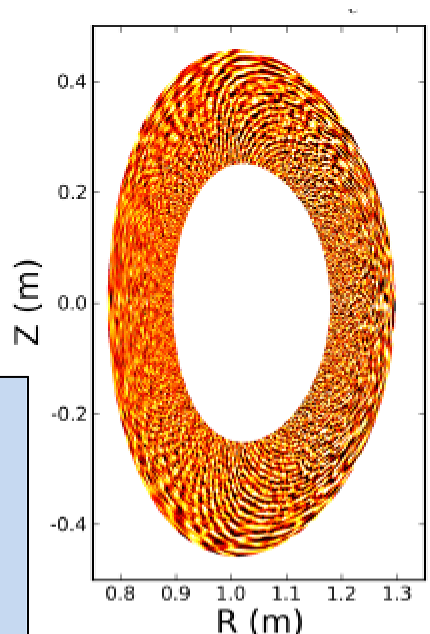
Record $T_e \geq 5$ keV using HHFW



(LeBlanc, 2009)

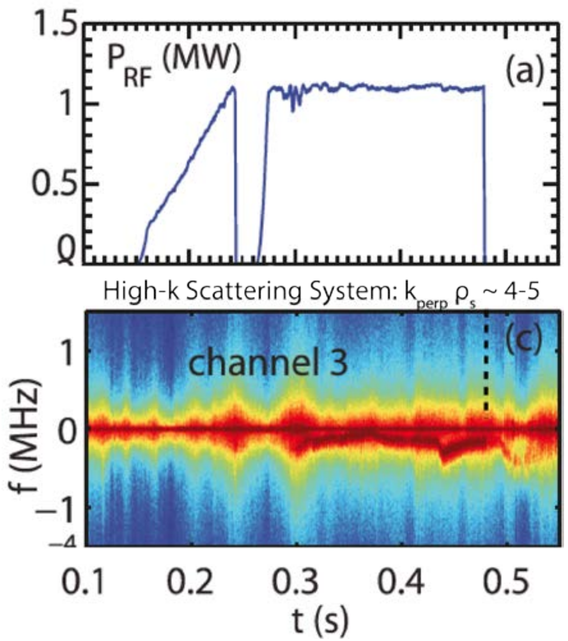
- HHFW influences impurity transport (XP proposed) → important for high-Z transport
- Modulated HHFW to uncover anomalous χ_e mechanisms
- Modified HHFW for edge-harmonic oscillations → control particle transport and ELMs [Park, NF 2014]

Validate ETG transport with high-k measurements, e.g. in e-ITB plasmas



(Yuh, PRL 2011; Peterson, PoP 2012)

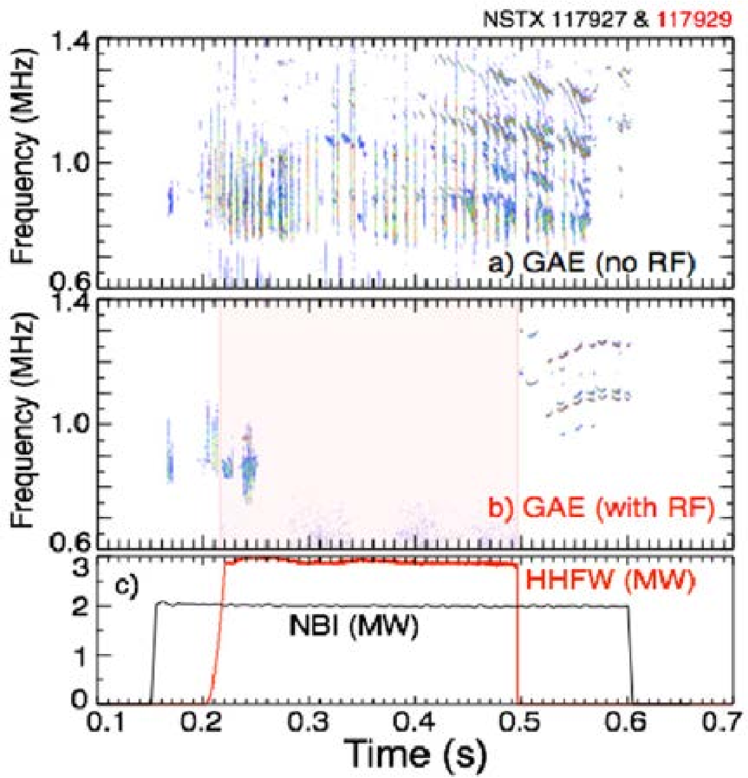
Perturbative electron transport studies investigating non-local transport



(Ren, PoP 2015)

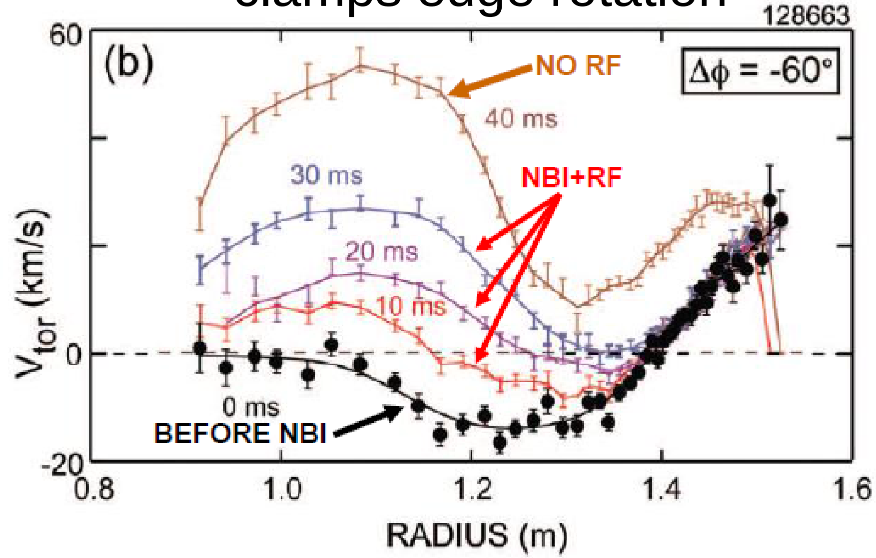
Q7: HHFW supports a broad spectrum of science research (beyond its potential utility for solenoid-free start-up)

HHFW influences EP/*AE activity



(Fredrickson, NF 2015)

HHFW influences rotation; clamps edge rotation



(Taylor, PoP 2010)

HHFW XP's proposed to investigate:

- change of fast ion phase space on EP instabilities, uncover importance of GAE/CAE-KAW on Te profiles (XP proposed)
- influence on rotation (XP proposed)
- NTV offset velocity with HHFW (zero-torque) (0.25 run day, priority 2)

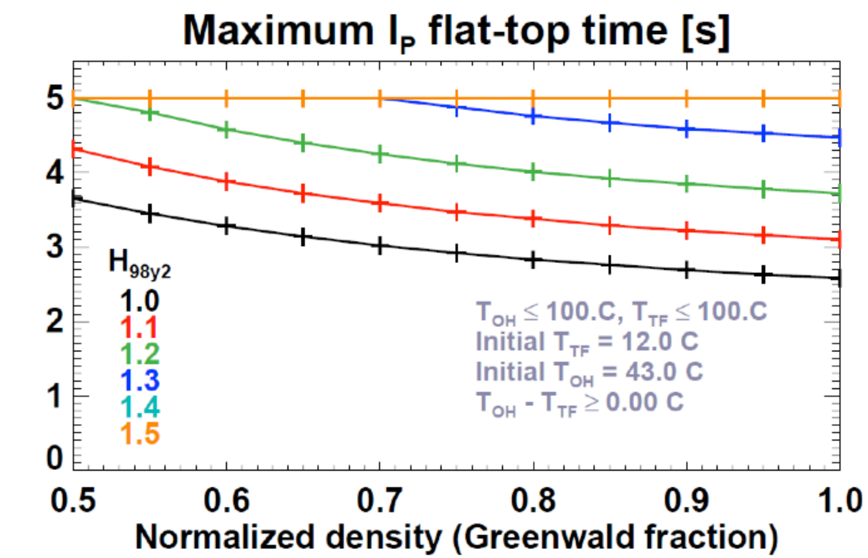
Q7: HHFW is complimentary to NBI and can be a powerful tool if coupling improves at higher B_T

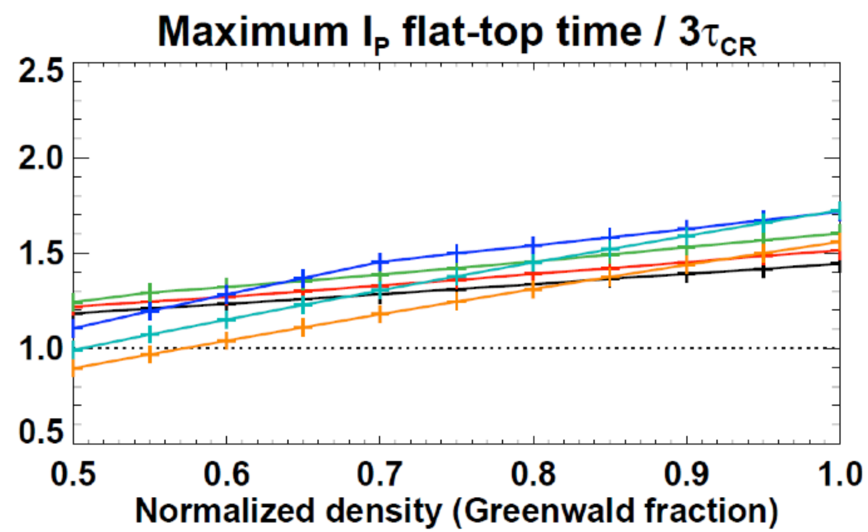
- HHFW provides heating without additional particle and momentum input
  - Study pedestal heights in NBI vs HHFW H-modes
  - Study NTV offset rotation in low-torque HHFW H-modes (0.25 run day, priority 2)
- XP's focus on improved H-mode coupling to make HHFW an accessible research tool
  - Characterizing SOL losses of HHFW in H-mode (Perkins, 1.75 run days)
  - HHFW absorption in NBI plasmas (Bertelli, 1 run day)
  - 2D BES measurements to resolve HHFW wavefield (Smith, 0.25 day)
- *HHFW performance expected to improve with increased B_T*
  - Expect decreased SOL losses
  - Expect decreased fast-ion interaction with HHFW antenna
- Expect a significant increase in requests for HHFW as coupling into NBI plasmas improves

Backup

Even With $T_{TF}<T_{OH}$ and Fixed Elevated T_{OH} at Start of Shot, Still Possible to Achieve $3\tau_{CR}$ Duration at 1 T, 2 MA

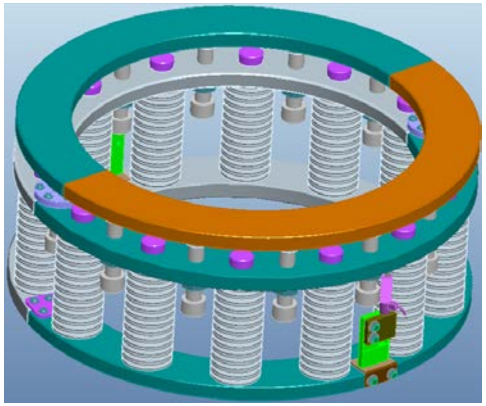
- Two thesis in this study:
  - The important normalization for the discharge duration is the $3\tau_{CR}$.
  - It will be an imposition to change the initial OH temperature all the time, so need to find an optimal single value.
- Fix the initial OH temperature to 43 C
  - Could be achieved, for instance, by a “standard” OH current pulse, or the water pre-heater.
- Durations in physical units lowered for H_{98}=1, but are greater than $3\tau_{CR}$ for essentially all densities and confinement.





Instrumentation and Testing Being Used to Validate Key Assumptions Used in Models and Get Trending Data

- Extensive in-situ measurements of TF joints.
  - Including comparisons to models of voltage distribution due to current bunching from to bends near joints.
- OH Displacement
  - Loss of pre-load due to coil a concern
- Disruptions
  - Sideways forces on the CS from non-axisymmetric halo currents
  - Passive plate accaleromtetr
- TF torque balance
  - Stresses in the spoked lid
  - Stresses in the TF outer leg trusses
  - Bending moments on outer legs.



Largest Long Term Technical Risk to Shot Duration Likely Comes from "Aquapoxy"

- OH is wound on TF, was designed with a small air gap between them.
  - Would allow free growth of OH and TF independent of each other.
- Air gap was to be maintained by winding the OH coil on "aquapour", a water soluble plaster-like material that would then be washed out.
  - But CTD-425 resin for the OH got into the aquapour during VPI, cured with it, forming a pumice-like material-"aquapoxy".
- Risk: As the TF thermally grows, it can pull on the OH, resulting in large stresses at the bottom of the coil.
- Mitigating factors:
  - Teflon sheets were installed, so there is a slip-plane between the coils.
  - Thick insulation systems on OH & TF means electrically is not an issue.
  - **We can use clever programming to avoid this interaction…just always keep $T_{TF}<T_{OH}$!**
- Reviewed by external committee on 7/8/2014 and $T_{OH}>T_{TF}$ enforced by DCPS