Progress toward commissioning and plasma operation in NSTX-U

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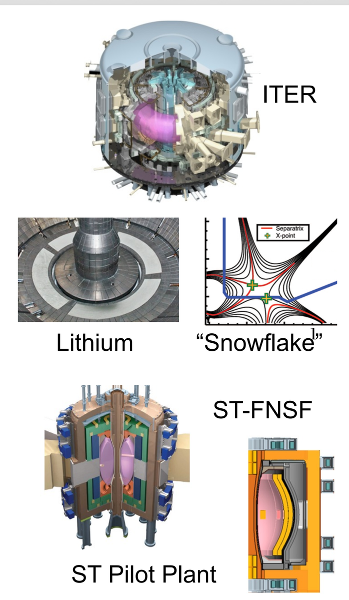
U.S. DEPARTMENT OF ENERGY | Office of Science

NSTX-U Mission Elements

- Explore unique ST parameter regimes to advance predictive capability - for ITER and beyond
- Develop solutions for the plasma-material interface challenge
- Advance ST as candidate for Fusion Nuclear Science Facility (FNSF)
- Develop ST as fusion energy systems



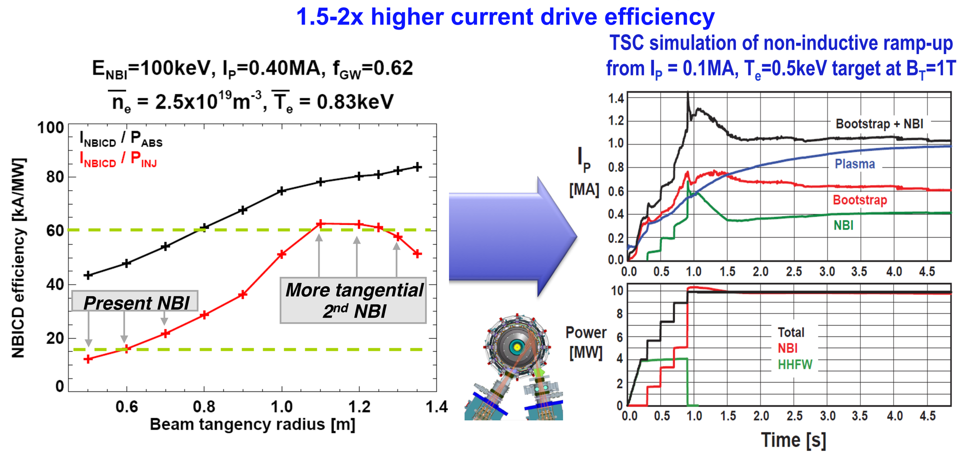
Non-inductive ramp-up from ~0.4MA to ~1MA projected to be possible with new centerstack (CS) + more tangential 2nd NBI

New CS provides higher TF (improves stability), 3-5s needed for J(r) equilibration

More tangential injection provides 3-4x higher CD at low I_p:

2x higher absorption (40→80%) at low I_p = 0.4MA

1.5-2x higher current drive efficiency

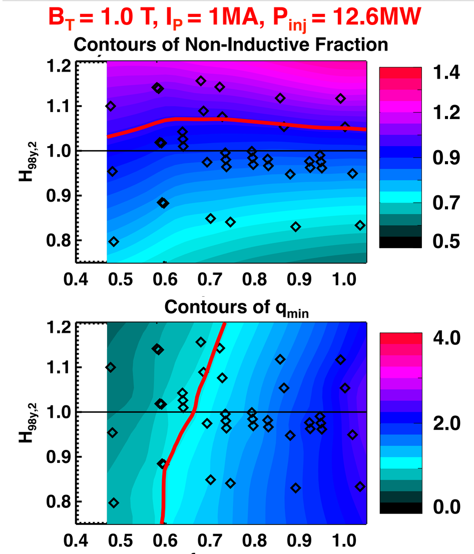


100% non-inductive operating points projected for a range of toroidal fields, densities, and confinement levels

B_T = 1.0 T, I_p = 1MA, P_{inj} = 12.6MW

Projected Non-Inductive Current Levels for κ~2.85, A~1.75, f_{GW}=0.7

B_T [T]	P_{inj} [MW]	I_p [MA]
0.75	6.8	0.6-0.8
0.75	8.4	0.7-0.85
1.0	10.2	0.8-1.2
1.0	12.6	0.9-1.3
1.0	15.6	1.0-1.5



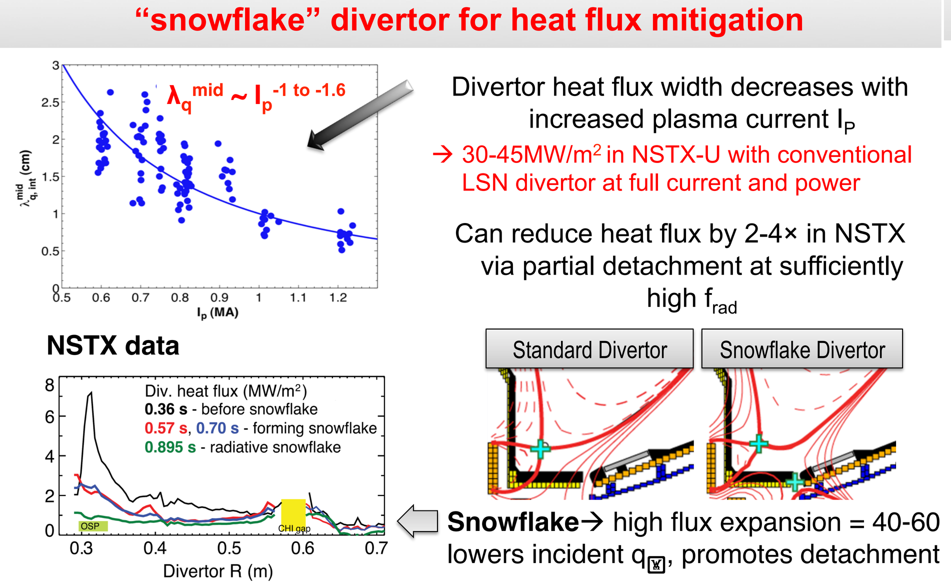
From GTS (ITG) and GTC-Neo (neoclassical):

$c_{i,ITG}/c_{i,Neo}$ ~ 10^{-2}

Assumption of neoclassical ion thermal transport should be valid

S. Gerhardt, et al., Nucl. Fusion 52 (2012) 083020

NSTX-U will investigate detachment and high-flux-expansion "snowflake" divertor for heat flux mitigation



Divertor heat flux width decreases with increased plasma current I_p

→ 30-45MW/m² in NSTX-U with conventional LSN divertor at full current and power

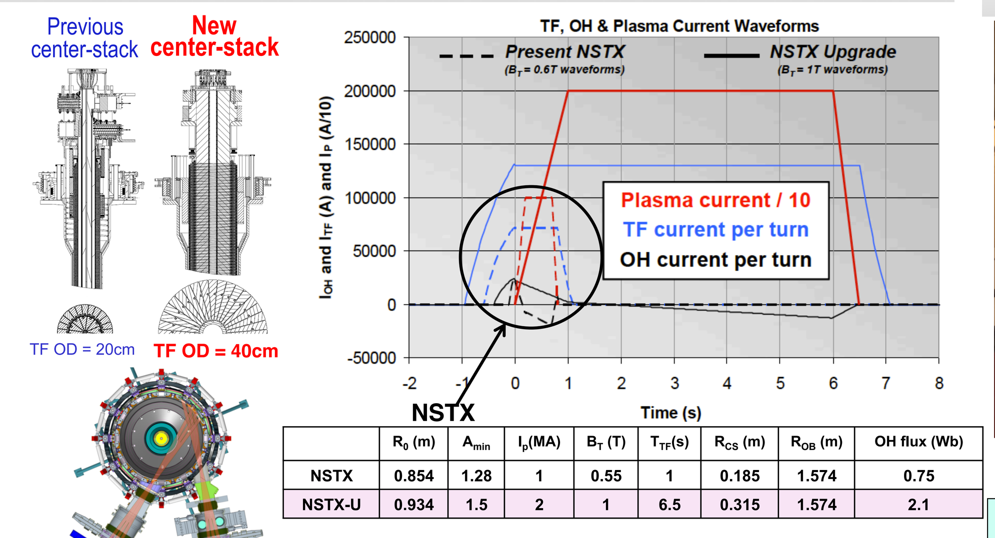
Can reduce heat flux by 2-4× in NSTX via partial detachment at sufficiently high f_{rad}

Snowflake→ high flux expansion = 40-60 lowers incident q_{div}, promotes detachment

NSTX-U: U/D balanced snowflake has < 10MW/m² at I_p = 2MA, P_{AUX}=10-15MW

Substantial Increase in NSTX-U Device / Plasma Performance

To provide data base to support ST-FNSF designs and ITER operations



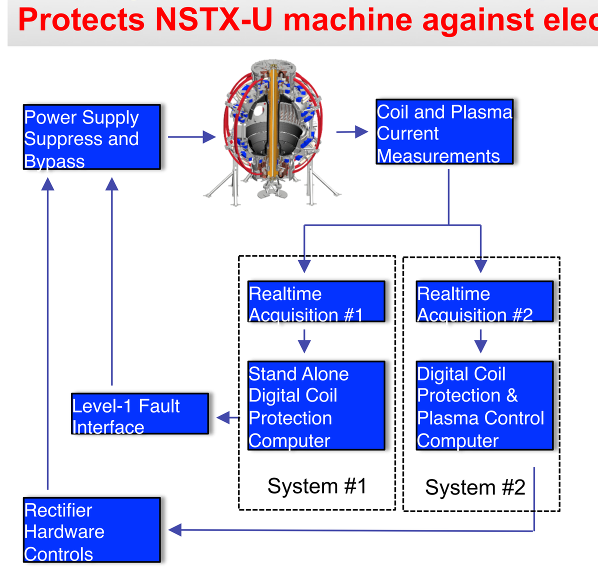
	R_0 (m)	A_{min}	I_p(MA)	B_T (T)	T_{FT}(s)	R_{CS} (m)	R_{OB} (m)	OH flux (Wb)
NSTX	0.854	1.28	1	0.55	1	0.185	1.574	0.75
NSTX-U	0.934	1.5	2	1	6.5	0.315	1.574	2.1

~ X 5 - 10 increase in nτT from NSTX

NSTX-U average plasma pressure ∝ $B_T^2 b_T$ (I^2/%) ~ Tokamaks

New Digital System Provides Comprehensive Coil Protection

Protects NSTX-U machine against electromagnetic loads



Computes forces and stresses in real-time based on reduced models of the full mechanical structure

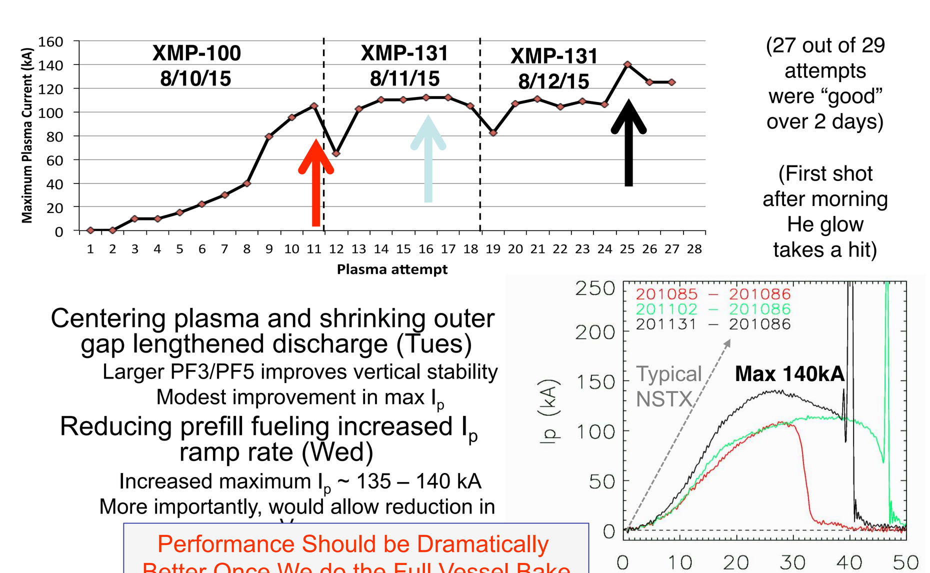
Redundant systems: both systems were available for CD-4!

System #1 is used during rectifier dummy-load testing, ISTP, and CD-4 plasma ops.

System #2 is also exercised and supported CD-4.

Full commissioning system will be a key part of early operations and it is working very well!

Continued Improvement in Plasma Current and Duration in Sixteen Plasma Shots over 1.5 Days



(27 out of 29 attempts were "good" over 2 days)

(First shot after morning He glow takes a hit)

Centering plasma and shrinking outer gap lengthened discharge (Tues)

Larger PF3/PF5 improves vertical stability

Modest improvement in max I_p

Reducing prefill fueling increased I_p ramp rate (Wed)

Increased maximum I_p ~ 135 – 140 kA

More importantly, would allow reduction in

Performance Should be Dramatically Better Once We do the Full Vessel Bake

D. Battaglia, PPPL

NSTX-U diagnostics to be installed during first year

All center stack sensors mounted & ex-vessel terminations completed

MHD/Magnetics/Reconstruction
Magnetics for equilibrium reconstruction
Halo current detectors
High-n and high-frequency Mirnov arrays
Locked-mode detectors
RWM sensors

Profile Diagnostics
MPTS (42 ch, 60 Hz)
T-CHERS: $T_i(R)$, $V_\phi(r)$, $n_c(R)$, $n_i(R)$, (51 ch)
P-CHERS: $V_\theta(r)$ (71 ch)
MSE-CIF (18 ch)
MSE-LIF (20 ch)
ME-SXR (40 ch)
Midplane tangential bolometer array (16 ch)

Turbulence/Modes Diagnostics
Poloidal FIR high-k scattering (installed in 2016)
Beam Emission Spectroscopy (48 ch)
Microwave Reflectometer,
Microwave Interferometer
Ultra-soft x-ray arrays – multi-color

Energetic Particle Diagnostics
Fast Ion D_α profile measurement (perp + tang)
Solid-State neutral particle analyzer
Fast lost-ion probe (energy/pitch angle resolving)
Neutron measurements
Charged Fusion Product

Edge Divertor Physics
Gas-puff Imaging (500kHz)
Langmuir probe array
Edge Rotation Diagnostics (T_i, V_ϕ, V_{pol})
1-D CCD H_α cameras (divertor, midplane)
2-D divertor fast visible camera
Metal foil divertor bolometer
AXUV-based Divertor Bolometer
IR cameras (30Hz) (3)
Fast IR camera (two color)
Tile temperature thermocouple array
Divertor fast eroding thermocouple
Dust detector
Edge Deposition Monitors
Scrape-off layer reflectometer
Edge neutral pressure gauges
Material Analysis and Particle Probe
Divertor VUV Spectrometer

Plasma Monitoring
FIReTIP interferometer
Fast visible cameras
Visible bremsstrahlung radiometer
Visible and UV survey spectrometers
VUV transmission grating spectrometer
Visible filterscopes (hydrogen & impurity lines)
Wall coupon analysis

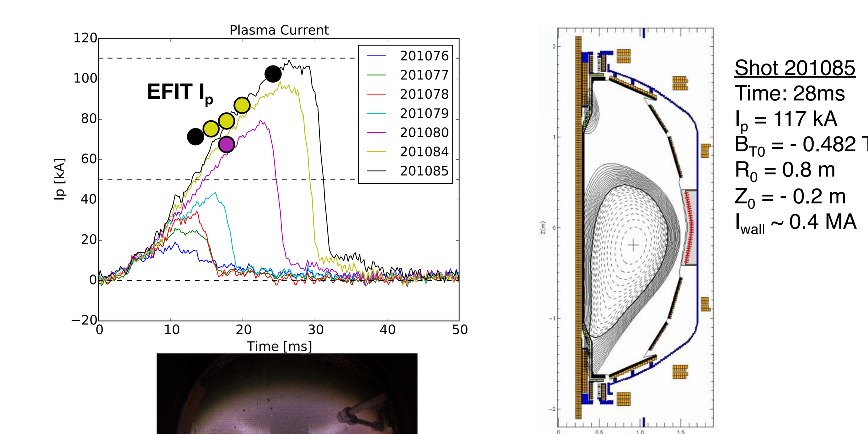
New capability, Enhanced capability

New Center-Stack Installed In NSTX-U (October 24, 2014)

- New CS provides higher x2 TF (improves stability), 3-5s needed for J(r) equilibration, increase nτT by x 5 – 10 from NSTX.

First NSTX-U test plasma achieved in August 2015

27 out of 29 attempts were "good" over 2 days

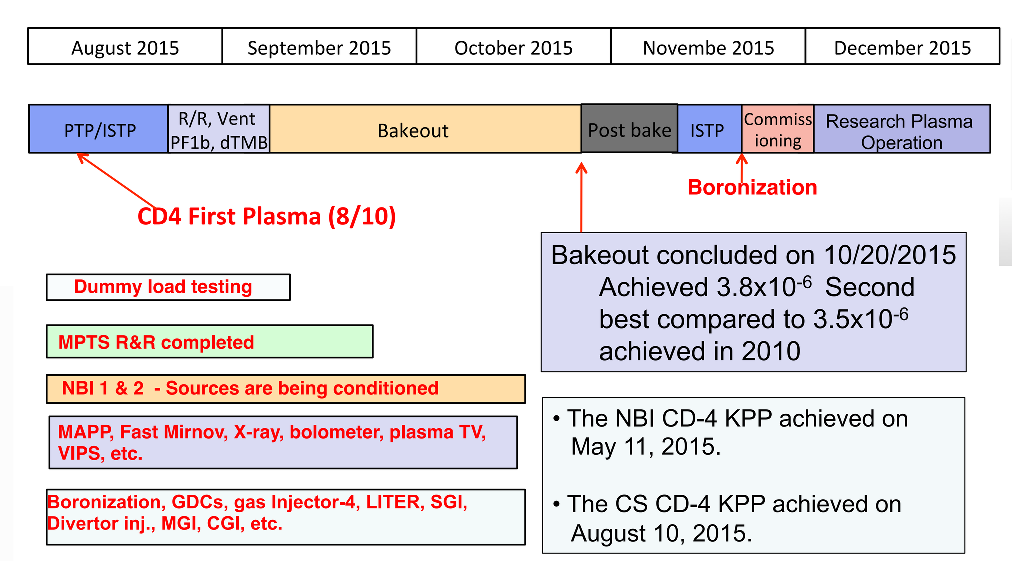


Calibrated and compensated magnetics, EFITs plasma movie all showed consistent pictures

Full bake-out complete and research operation is resuming shortly

Preparing to start FY 2016 plasma operations

Expected to run 14 – 16 run weeks in FY 2016



Bakeout concluded on 10/20/2015 Achieved 3.8x10⁻⁶ Second best compared to 3.5x10⁻⁶ achieved in 2010

- The NBI CD-4 KPP achieved on May 11, 2015.
- The CS CD-4 KPP achieved on August 10, 2015.

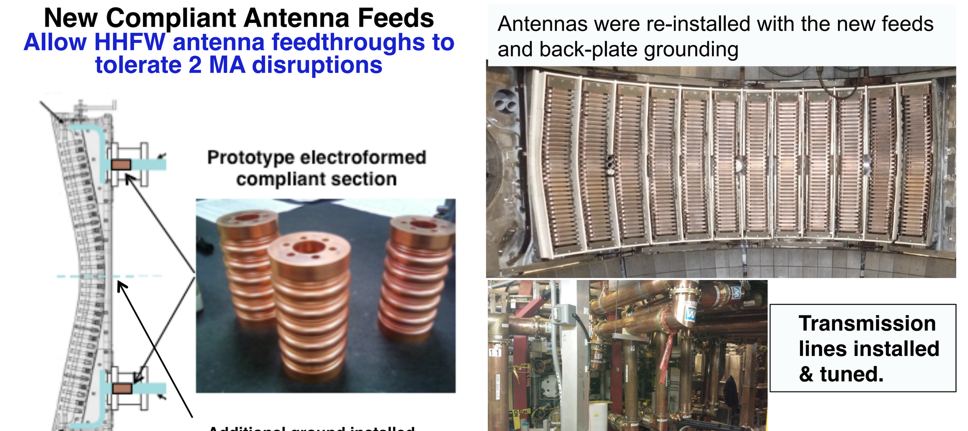
HHFW system preparation is going well

All sources are ready to start antenna conditioning

New Compliant Antenna Feeds

Allow HHFW antenna feedthroughs to tolerate 2 MA disruptions

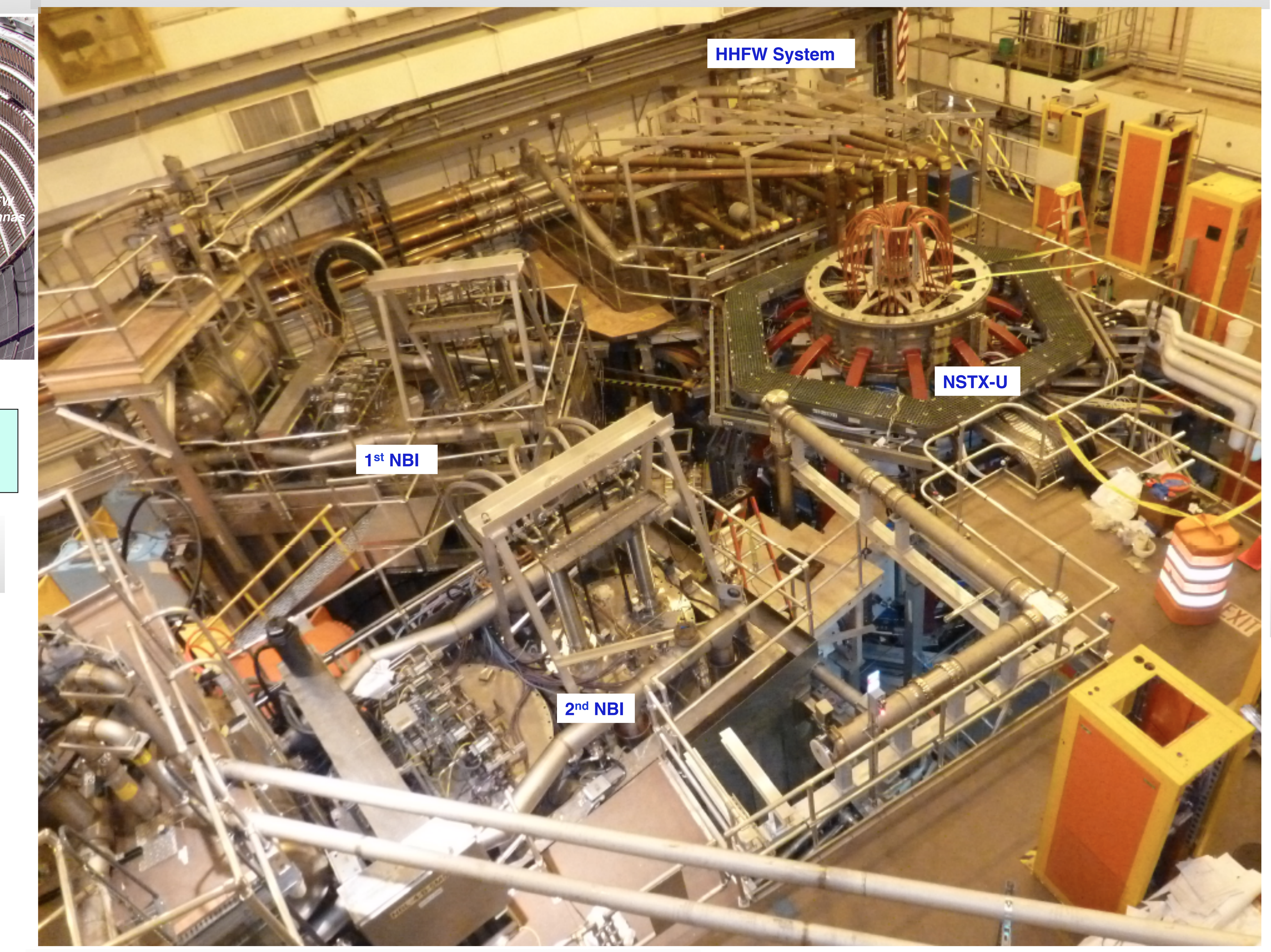
Antennas were re-installed with the new feeds and back-plate grounding



- Prototype compliant feeds tested to 46 kV in the RF test-stand. Benefit of back-plate grounding for arc prevention found.
- RF diagnostics also installed.

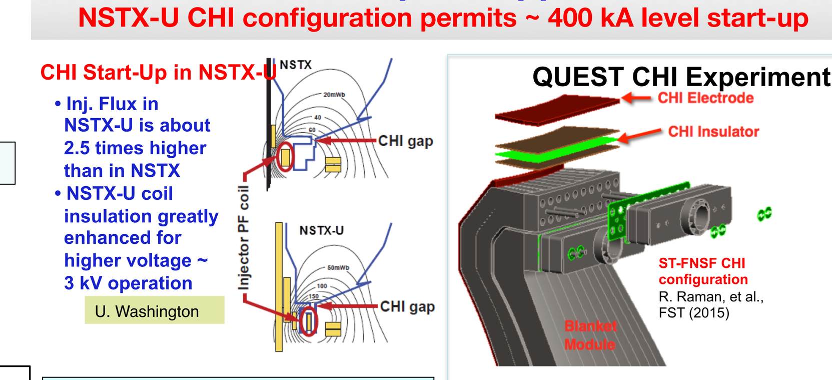
- All sources are ready. Conditioning is starting.

Recent Aerial View of the NSTX-U Test Cell



Solenoid-free start-up in support of ST-FNSF

NSTX-U CHI configuration permits ~ 400 kA level start-up



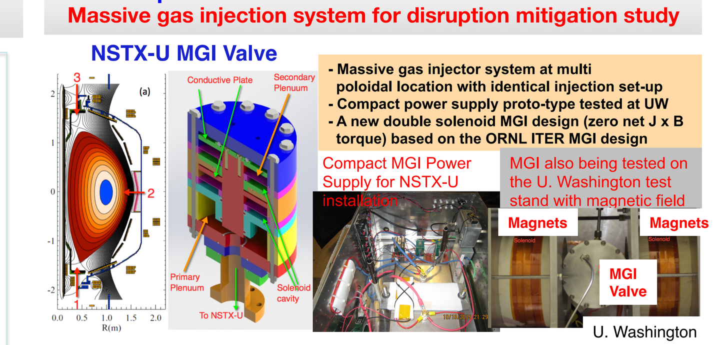
- Inj. Flux in NSTX-U is about 2.5 times higher than in NSTX
- NSTX-U coil insulation greatly enhanced for higher voltage ~ 3 kV operation

- CHI will start with the present 2 kV capability then enhanced to higher voltage as needed.
- Control system updates for the CHI cap bank have been completed, and the system is ready for remote testing.
- The CHI control room procedure has been updated.

- An ST-FNSF like CHI configuration will undergo plasma tests on QUEST after FY 2016 NSTX-U operation
- CHI electrodes installed in QUEST, CHI power supply and gas injection system fabricated at U-Washington

Disruption and Plasma Control Tools for NSTX-U

Massive gas injection system for disruption mitigation study

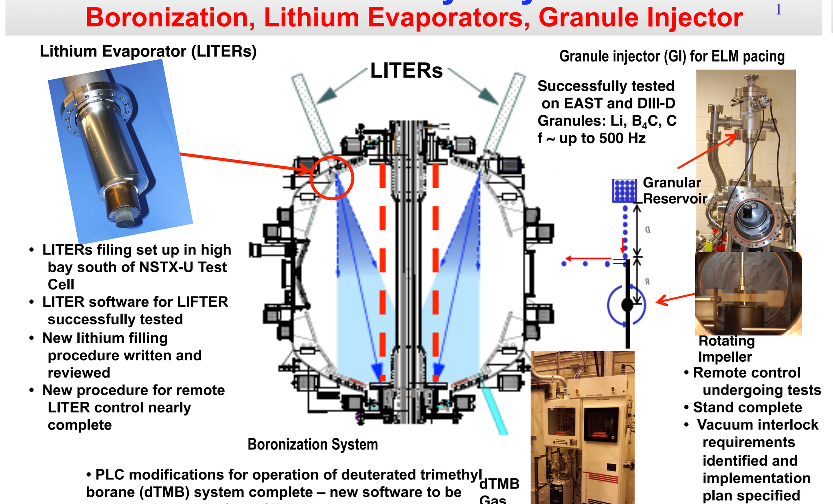


- Massive gas injector system at multi poloidal location with identical injection set-up
- Compact power supply proto-type tested at UW
- A new double solenoid MGI design (zero net J x B torque) based on the ORNL ITER MGI design

Status:
- Conceptual Design Review of MGI system was held on October 16. Recommended changes were incorporated into the power system hardware.
- A Real-Time Velocity (RTV) diagnostic is ready for plasma test with the plasma control system for feedback control of the plasma rotation profile.

First Year Boundary Physics Tools

Boronization, Lithium Evaporators, Granule Injector



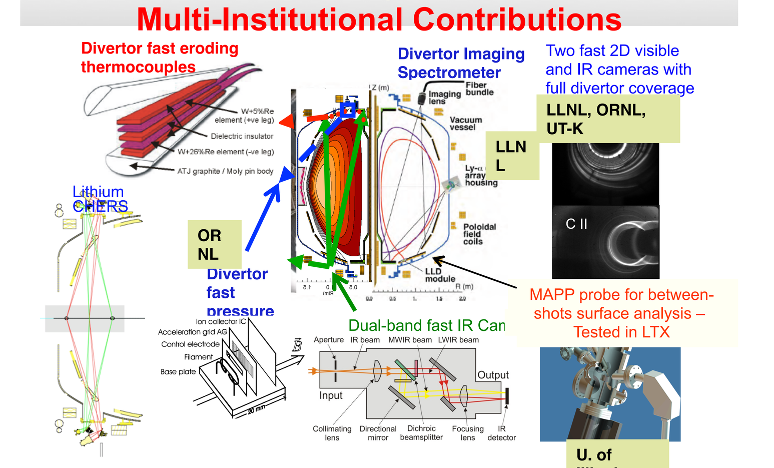
- LITERs filling set up in high bay south of NSTX-U Test Cell
- LITER software for LITER successfully tested
- New lithium filling procedure written and reviewed
- New procedure for remote LITER control nearly complete

- Remote control undergoing tests
- Stand complete
- Vacuum interlock requirements identified and implementation plan specified

- PLC modifications for operation of deuterated trimethyl borane (dTMB) system complete – new software to be loaded and tested after NSTX-U bakeout ends
- System commissioning in early November

Enhanced Capability for PMI Research

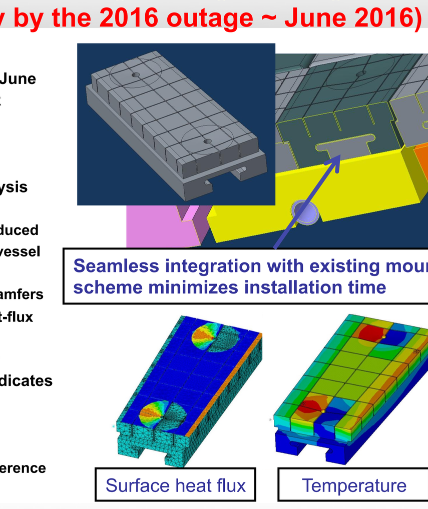
Multi-Institutional Contributions



High-Z Tile Design Progressing

(plan to be ready by the 2016 outage ~ June 2016)

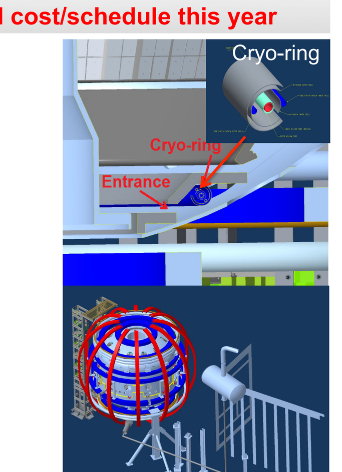
- Successful CDR held in June
  - 75% of CHIs resolved PDR planned for early Nov.
- Raw material procurement underway
- 2nd design iteration analysis nearly complete
  - Installation flexibility introduced to accommodate "as built" vessel tolerances
  - Edge and access-way chamfers introduced to reduce heat-flux peaking
- Thermal analysis of new leading edge geometry indicates ~30% reduction in peak temperature
  - 1000 °C lower peak surface temperature vs. graphite reference design



Divertor Cryo-pump Physics Design Activities Started

Develop engineering design and cost/schedule this year

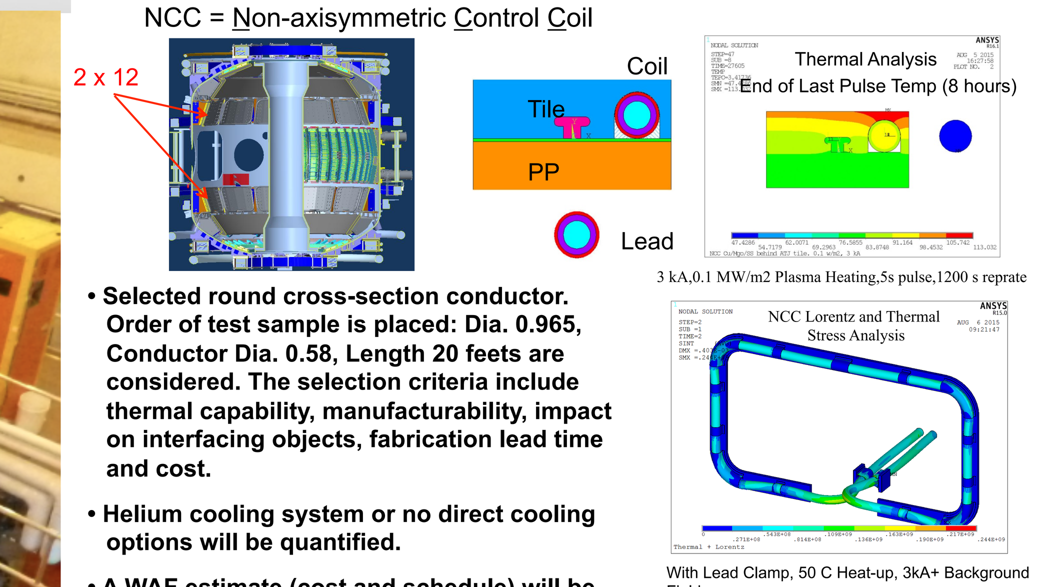
- Scoping work for the modified divertor & tiles has started
  - Engineer assigned to this task.
  - Requirements are being formulated
- Cost & Schedule continues to be developed
  - Working on scoping estimate to get through CDR
  - Will generate WAF when definition of job elements matures.
- PPPL & MIT are working on a agreement to fund MIT/PSFC staff to work on the in-vessel LHe pump design.
- Working on system integration.
  - A working group that will look at the impact of the new pump/divertor on the lower diagnostics will start meeting in October
- CDR - Q1 CY'16



NCC Coils Design Activity Made Significant Progress

Develop engineering design and cost/schedule

NCC = Non-axisymmetric Control Coil

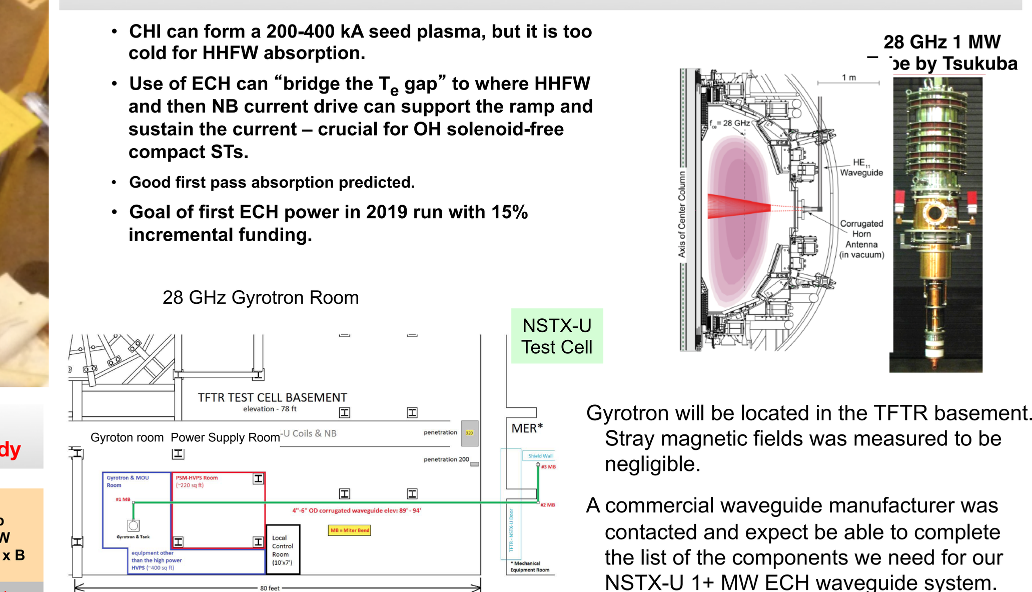


- Selected round cross-section conductor. Order of test sample is placed: Dia. 0.965, Conductor Dia. 0.58, Length 20 feets are considered. The selection criteria include thermal capability, manufacturability, impact on interfacing objects, fabrication lead time and cost.
- Helium cooling system or no direct cooling options will be quantified.
- A WAF estimate (cost and schedule) will be prepared as part of the CDR which is targeted for May, 2016.

28 GHz ECH System Design Progressing Well

Develop engineering design and cost/schedule this year

- CHI can form a 200-400 kA seed plasma, but it is too cold for HHFW absorption.
- Use of ECH can "bridge the T_e gap" to where HHFW and then NB current drive can support the ramp and sustain the current – crucial for OH solenoid-free compact STs.
- Good first pass absorption predicted.
- Goal of first ECH power in 2019 run with 15% incremental funding.



Gyrotron will be located in the TFTR basement. Stray magnetic fields was measured to be negligible.

A commercial waveguide manufacturer was contacted and expect be able to complete the list of the components we need for our NSTX-U 1+ MW ECH waveguide system.

Formulating Strategy Toward Full NSTX-U Parameters

After CD-4, the plasma operation could enter quickly into new regimes

	NSTX (Max.)	Year 1 NSTX-U Operations (2016)	Year 2 NSTX-U Operations (2017)	Year 3 NSTX-U Operations (2018)	Ultimate Goal
I_p [MA]	1.2	~1.6	2.0	2.0	2.0
B_T [T]	0.55	~0.8	1.0	1.0	1.0
Allowed TF I^2t [MA²s]	7.3	80	120	160	160
I_p Flat-Top at max. allowed I^2t, I_p, and B_T [s]	~0.4	~3.5	~3	5	5

- 1st year goal: operating points with forces up to ½ the way between NSTX and NSTX-U, ½ the design-point heating of any coil
  - Will permit up to ~5 second operation at B_T~0.65
- 2nd year goal: Full field and current, but still limiting the coil heating
  - Will revisit year 2 parameters once year 1 data has been accumulated
- 3rd year goal: Full capability

Five Year Facility Enhancement Plan (green – ongoing)

2015: Engineering design for high-Z tiles, Cryo-Pump, NCC, ECH