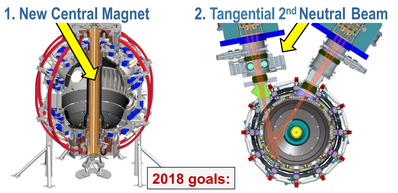
Progress toward commissioning and plasma operation in NSTX-U

M. Ono and NSTX-U Team

NSTX-U Mission Elements:

- Explore unique ST parameter regimes to advance predictive capability - for ITER and beyond
- Develop solutions for plasma-material interface (PMI)
- Advance ST as Fusion Nuclear Science Facility and Pilot Plant

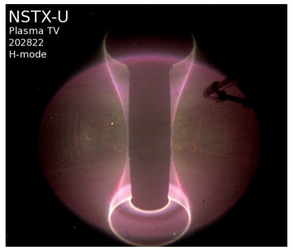
NSTX-U will have major boost in performance



- ➢2× toroidal field (0.5 → 1T)
- ➢2× plasma current (1 → 2MA)
- ➢5× longer pulse (1 → 5s)
- ➢2× heating power (5 → 10MW)
  - Tangential NBI → 2× current drive efficiency
- ➢4× divertor heat flux (→ ITER levels)
- ➢Up to 10× higher $nT\tau_E$ (~MJ plasmas)

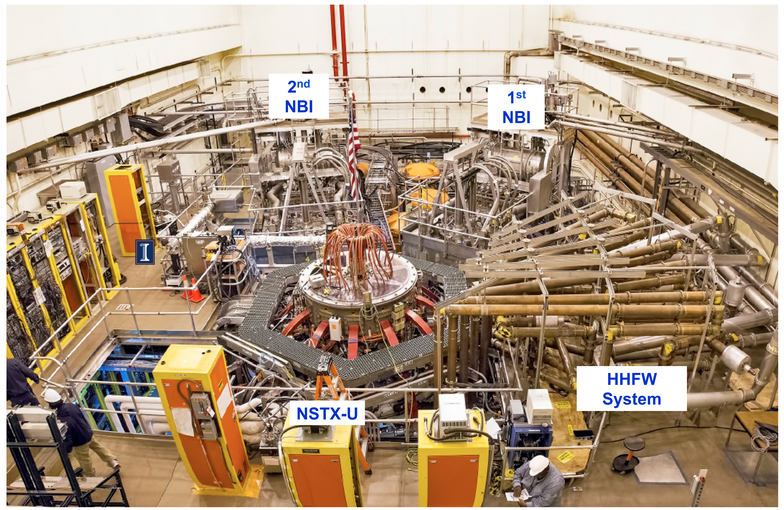
NSTX-U research run started

H-mode access achieved during first 2 weeks of operation in January 2016



NSTX-U Facility Came On Line This year

To demonstrate fully sustained high beta plasmas



NSTX-U device performance progression plan

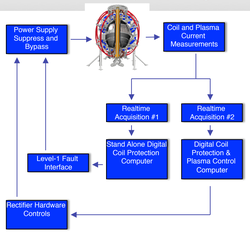
Will utilize this outage to prepare for full capability

- FY 2016: Limit forces to ½ way between NSTX and NSTX-U, and ½ of the design-point heating of any coil
  - Operated at B_T ~ 0.65T for ~ 2 sec for over 1000 shots. All joints came out clean and nominal.
- FY 2017 goal: Implement repair/enhancements needed to achieve full capability
  - Replace TF joint lead extension pieces, PF-1AU and –L, divertor cooling tubes
  - Replace poloidal CHERs passive plates and enhance passive plates as needed
  - Test plan being developed for PF-1A and -1C coils.
  - Install and test instrumentation to monitor coils and passive plates to full capability
- FY 2018 goal: Full capability

Parameter	NSTX (Max.)	FY 2016 NSTX-U Operations Achieved	FY 2017 NSTX-U Preparation	Year 3 NSTX-U Operations	NSTX-U Ultimate Goal
I_P [MA]	1.2	~1.1	2.0	2.0	2.0
B_T [T]	0.55	~0.65	1.0	1.0	1.0
Max Pulse length (s)	~ 1	~ 2	5	5	5

Digital System Provides Electromechanical Coil Protection

DCPS successfully supporting the research operations!



Protects the NSTX-U coils and mechanical structure against electromagnetic loads

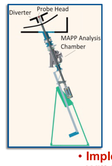
Computes forces and stresses in realtime based on reduced models of the full mechanical structure

Redundant systems

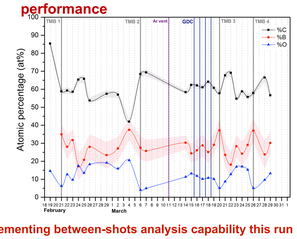
Full commissioning of the system went very well; DCPS is now routinely supporting operations.

Discussions ongoing with ITER for collaboration

Material Analysis & Particle Probe (MAPP) commissioning providing new measurements of surface evolution in NSTX-U



- **Correlating B, O evolution w/ plasma performance**



- **Implementing between-shots analysis capability this run**
- **Will help understand complex Li chemistry and evolution**

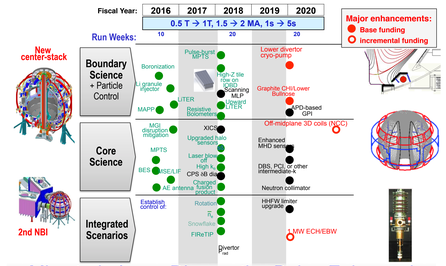
Restored NSTX control capabilities + added many enhancements for NSTX-U

New for NSTX-U

- Vertical control
  - Multi-sensor observer
  - Measurement filtering
  - Tuned in high-li scenarios
- rtEFIT
  - Updated model
  - Doubled plasma grid resolution to 65x65
  - Anti-aliasing for down-sampled signals
  - Vessel fitting, calculation of β_N, l_i, q, enabled by multithreading
- ISOFLUX
  - Code rewritten (75% reduction in # of lines) for maintainability
  - ISOFLUX control of limited and diverted discharges
  - X-point control, strike point control (MIMO gains)
  - dr_{sep} control (new method w/ self-consistent control points targets)
  - Inner gap control

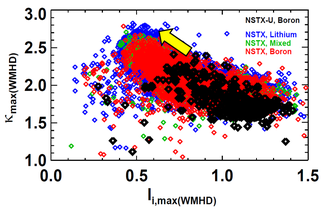
Five Year Facility Enhancement Plan (green – ongoing)

Incremental enables 5 year plan enhancements including DCP, NCC, ECH



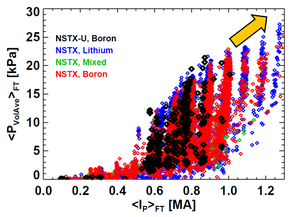
Post Run Assessments

On path to high I_P without tearing modes by elevating q_{min} with early heating + H-mode → l_i=0.5-0.6, κ=2.5-2.7



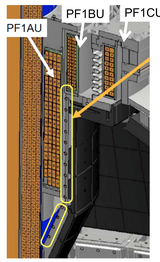
- Utilizing real-time EFIT / ISOFLUX (GA collaboration)
  - Also utilizing improved vertical motion detection

NSTX-U has matched NSTX highest flat-top pressures for plasma currents up to 0.9MA



- **Near-term: I_P → 1.1 – 1.3MA**
  - **Support core, pedestal, SOL scaling XPs, access higher W_{tot}, ⟨β⟩**

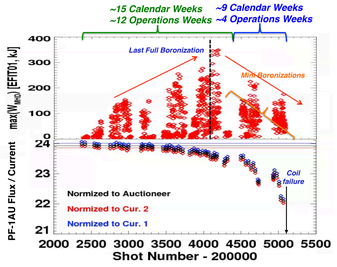
NSTX-U PF-1AU and CS Divertor Cooling Tube



- NSTX-U has six PF1 coils: PF1AU, PF1BU, PFCU in the uppder divertor region and identical coils for the lower divertor. Those six coils were manufactured in an outside shop.
- After six month operations period, PF1AU developed internal short.
- Further analyses of the PF-1AU coil data showed a gradual deterioration over ~ 3 months period.
- A forensic team is formed to investigate the cause of the internal short.

PF-1AU Failed After Six Months of Operations

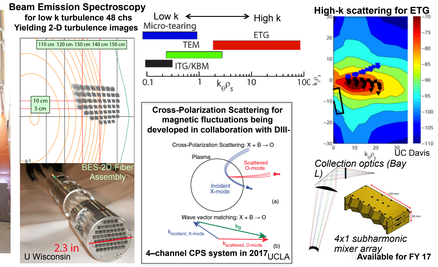
Plasma performance trending with PF-1AU coil degradation!?



For PF-1A Replacement, Coil Shop (left) and Tilt Fixture (right) in South High-Bay are readied

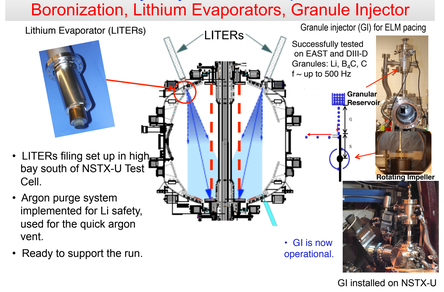
Microturbulence Diagnostics Being Enhanced

To measure ion to electron gyro-scale, magnetic fluctuations



Boundary Physics Tools Operational

Boronization, Lithium Evaporators, Granule Injector



- LITERs filing set up in high bay south of NSTX-U Test Cell.
- Argon purge system implemented for Li safety, used for the quick argon vent.
- Ready to support the run.

• GI is now operational.

GI installed on NSTX-U

Key Accomplishments During the Run: Diagnostics

Core Profile Diagnostics
- BES
- AXUV Core Bolometer
- Poloidal CHERS
- Toroidal CHERS
- ERD
- MPTS
- MSE-CIF
- MSE-LIF
- USXR Poloidal Arrays (2)
- rtVPhi
- ME-SXR

Fast Ion Diagnostics
- T-FIDA
- V-FIDA
- SNPAs (3)
- Neutron Detectors
- S-FLIP
- I-FLIP
- Fixed-f Reflectometer

Magnetics
- Operations Magnetics
- Diamagnetic Loop
- RWM sensors
- High-f and high-n arrays

Divertor
- Divertor AXUV Bolometer (LADA)
- Divertor Fast Cameras
- Divertor Intensified Cameras
- Infrared Video Bolometer
- Divertor Langmuir Probes
- U. Of Tennessee Spectroscopy
- 1D CCDs
- MAPP
- Divertor Tangential Imaging
- Wide Angle Infrared Camera
- Fast Infrared Cameras
- Divertor SPRED

Spectroscopy
- ENDD
- XEUS
- LOWEUS
- MonaLISA
- VIPS
- DIMS
- VB
- EIES (Filterscopes)
- DIBS

Other
- Plasma TV (2)
- Shunt Tiles
- GPI
- Penning Gauges

Operational
In Progress

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

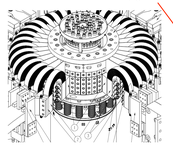
Transmission lines installed & tuned.

• All sources are now ready to support HHFW operations.

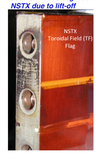
TF Joint Measurement and Examination Were Fine

Flex joints and lead extension were also fine

- In FY 2016, NSTX-U operated mostly at B_T ~ 6.5 kG up to ~ 2.2 s flat top for well over 1000 shots.
- The TF joint measurement were performed as the TF joints were disassembled.
- All measured joints are nominal based on design, installation procedure, modeling data, bench measurements, and in-situ measurements.
- Joint surfaces look very good.

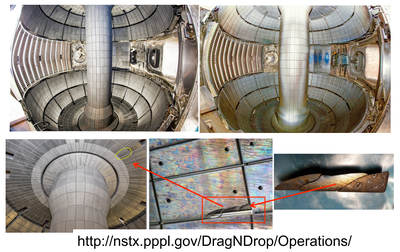


Joint surfaces degraded in NSTX due to lift-off



Initial Inspection of NSTX-U Vacuum Vessel Interior Lower divertor looks fine, one cracked tile in upper divertor

Before campaign 12/05/2014 — After campaign 09/19/2016



http://nstx.pppl.gov/DragNDrop/Operations/In_vessel_inspections/Post_run_2016/

Divertor Cryo-pump Design Making Good Progress

Successful CDR was held on August 3, 2016

Initial in-vessel geometry has been laid out.

MIT designed the cryo-ring.

Pump radius, throat dimensions taken from the modeling.

The entire lower outer divertor region to be reduild.

- Cryo-baffle design to be finalized.

Diagnostic access and cryo-ring maintainability were assessed.

Graphite PFC with bake-out capability considered.

A cost/schedule review of the design/installation plans of the new Cryo-pump Divertor (CPD) was held in Sept. 23.