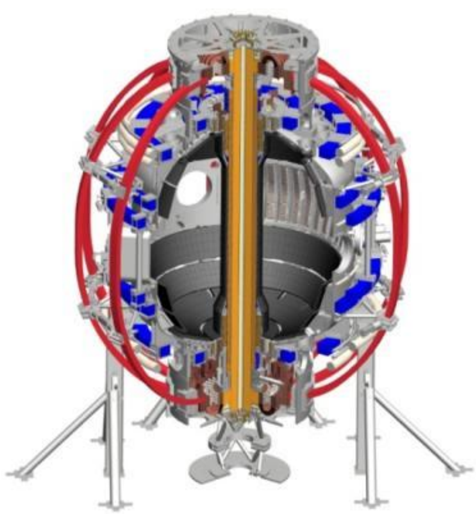
NSTX-U Project Status and 5 Year Plan Facility Overview

Masa Ono

for the NSTX-U Team

NSTX-U Five Year Plan Review Meeting
May 21 - 23, 2013



Columbia U
CompX
General Atomics
FIU
INL
Johns Hopkins U
LANL
LLNL
Lodestar
MIT
Nova Photonics
New York U
ORNL
PPPL
Princeton U
Purdue U
SNL
Think Tank, Inc.
UC Davis
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U St. Andrews
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Niigata U
U Tokyo
JAEA
Tsukuba U
Hebrew U
Ioffe Inst
RRC Kurchatov Inst
TRINITI
NFRI
KAIST
POSTECH
SNU
ASIPP
ENEA, Frascati
CEA, Cadarache
IPP, Jülich
IPP, Garching
ASCR, Czech Rep

Talk Outline

- Previous five year (FY2009-13) Project Summary and Status
- NSTX Upgrade Project Overview
- NSTX-U Operational Preparation Status
- NSTX-U Facility / Diagnostic Five Year Plans
- Budget
- Summary

NSTX Facility Achieved Nearly All Operational Targets

Facility Operated Safely for Over 2 Million Staff Work Hours

- All facility and diagnostic milestones achieved on schedule in FY2009 – 2012 except in FY 2011, the operational week goal was not met due to a TF coil failure (see back-up slides 38 - 43.)
- Achieved record number of total plasma shots and plasma shots per week for each of FY2009 and FY2010. Introduction of lithium improved shots/week by ~ 50 % since the pre-lithium operations.

NSTX Plasma Operation Statistics

Fiscal Year	Run Week Milestone	Achieved Run Weeks	Achieved Shots	Achieved Shots/Week	Lithium Operations (%)
2011	14	4.2	839	199	~ 100
2010	15	15.4	2941	191	~ 100
2009	16	16.8	2750	163	92
2008	15	16.5	2570	156	46
2007	12	12.6	1890	150	69
2006	11	12.7	1615	127	0
2005	17	18.0	2221	124	0

NSTX received the State of New Jersey Commissioner of Labor and Workforce Development's 2010 Continued Excellence Award for working 10 consecutive years (2,011,666 hours) without an away from work lost time injury/illness case.

Strong Publications and Conference Participations
Growing Number of Highly Capable Young Researchers

Calendar Year	Refereed Publication	PRLs	APS Invited	IAEA Papers
2008	40	2	6	20
2009	45	6	5	
2010	63	5	10	25
2011	58	5	8	
2012	56	1	4	30

- **Half of the publications and invited talks were led by collaborators**
- **9 of 17 PRLs published in 2009-2012 were led by students and junior researchers**

NSTX Research Team Membership:

- **Experienced research team consists of 70 PPPL researchers and 236 non-PPPL researchers with 59 APS Fellows, 3 Presidential Early Career Award winners, 4 DOE Early Career Award winners.**
- **Significant number of young researchers : 17 recent research staff, 14 post-docs, and 33 students.**

NSTX Researchers Received Community Recognition
Strong collaborator contributions

- *Stefan Gerhardt (PPPL) and Joshua Breslau (PPPL) received in 2009 and US DOE Presidential Early Career Awards.*

- *V. Soukhanovskii (LLNL), J.P. Allain (Purdue U), J-K Park (PPPL) and A. Diallo (PPPL) received 2010 and 2013 DOE OS Early Career Awards.*

- *S. Sabbagh (Columbia University) was honored at IAEA (Daejeon, Korea) for his 2009 Nuclear Fusion Paper Award.*

- *E. Fredrickson (2008-PPPL), R. Maingi (2009-ORNL), J. Menard (2010-PPPL) and S. Sabbagh (2010-Columbia University) were elected APS-DPP Fellows.*

- *J-K Park (PPPL) received the 2010 Marshall N. Rosenbluth Outstanding Doctoral Thesis Award.*

- *J-K Park received the 2011 Outstanding Young Researcher Award (OYRA) from Association of Korean Physicists in America (AKPA).*

- *NSTX "Snow-flake Divertor" team won the R&D 100 Award for 2012. Also featured in Oct. 2012 FES Science Highlights.*

Facility Upgrade Activity Comparison with 5 Year Plan

Facility Plan Evolved Due to Technical and Programmatic Changes

	FY 08	FY 09	FY 10	FY 11	FY 12	FY 13
Planned Run Weeks	15	15	15	15	Upgrade Outage	
Actual Run Weeks	16.5	16.8	15.4	4.2		

See the Upgrade Project Progress and Schedule slides for more detail

Center Stack
- Design/Procurement
- Fabrication
- Assembly/Installation
- New Center-Stack

Heating & CD
- Design/Procurement/Fabrication/Installation
- 2nd NBI
- HHFW Antenna Upgrade
- HHFW ELM resilience
- 350 kW ECH-PI

MHD
- Dual massive gas injector
- EF/RWM/RMP (SPA upgrade)

Boundary
- Improved LITER
- Two additional LITERS
- LLD-I
- Long-pulse divertor
- Moly inboard tiles
- Dual Lithium Dropper
- SGI Upgrade
- Core Fueling

CHI
- Staged bank firing
- CHI Cap Bank Upgrade
- Absorber control coils
- Initial PEGASUS/MST-like plasma guns

Legend:
- ● Additional Upgrades
- ● Postponed Upgrades

Diagnostic Upgrade Activity Comparison with 5 Year Plan

Diagnostic Plan Evolved Due to Technical and Programmatic Changes

	FY 08	FY 09	FY 10	FY 11	FY 12	FY 13
Planned Run Weeks	15	15	15	15	Upgrade Outage	
Actual Run Weeks	16.5	16.8	15.4	4.2		

Control
- FY 08: Improved EFC, RWM control; NBI control
- FY 09: HHFW loading control; β control (NBI)
- FY 10: Real-time V_ϕ; δ control (additional); V_ϕ control
- FY 11–12: Real-time MSE (postponed); MSE rt-EFIT (postponed)

Profile
- FY 08: P-CHERS(70 ch); MSE/CIF (16 ch)
- FY 09: MSE/LIF
- FY 10: MSE/CIF (19 ch); MPTS Higher Spatial Resolution
- FY 11: Multi Energy-Pedestal-SXR Array (additional); MPTS Third Laser (postponed)

MHD
- FY 08: Multi-Color-T_e(r); Divertor Halo Current
- FY 10: RWM State-Space Controller (additional)
- FY 11: Non-magnetic RWM-ID (postponed); Magnetic turbulence diagnostic

Turbulence
- FY 08: Corr. Reflect.; High-k Scattering
- FY 09: BES
- FY 11: High-k Scattering k-θ (postponed)

Energetic Particles
- FY 08: Remote-control Fast-ion D-alpha camera
- FY 09: FIReTIP (2 MHz)
- FY 10: Reflectometer 16 ch (additional)
- FY 11: Tangential FIDA (additional); Neutron Collimator (postponed); TAE Antenna (additional); High Frequency Mirnov Array (additional)

Waves
- FY 08: Improved EBW Radiometer
- FY 09: High-k HHFW (30 MHz)

Boundary
- FY 08: Dust Detector
- FY 09: Ion Flow Meas; Divertor Bolo.; Lithium CHERS (additional); Surface analysis probe; 99-element divertor probe (additional); Fast IR Camera
- FY 10: Edge USXR; Wide-angle divertor camera (additional); Divertor imaging spectrometer; Divertor Ly-alpha array (additional); Dual-Band IR Camera (additional)
- FY 11: MAPP Probe (additional); Optical Penning Gauge (additional); NIR Spectroscopy (additional); Fast Eroding Probe (additional); Wide-angle Dual-Band IR Camera (additional)

Diagnostic relocation for 2nd NBI

Legend: ● Additional Upgrades (red) ● Postponed Upgrades (blue)

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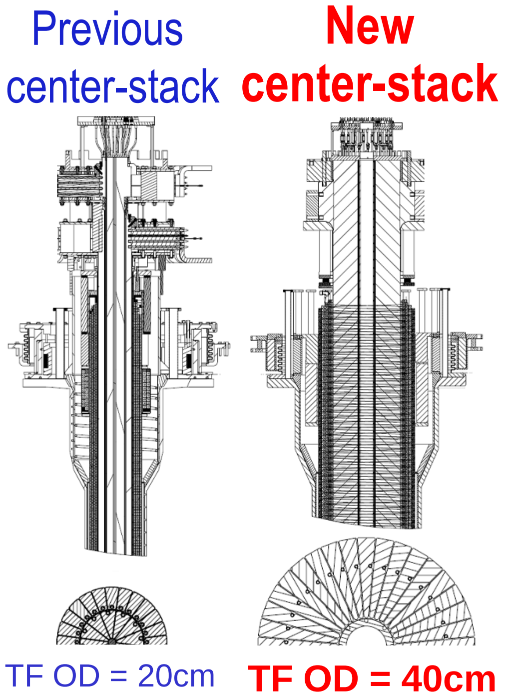
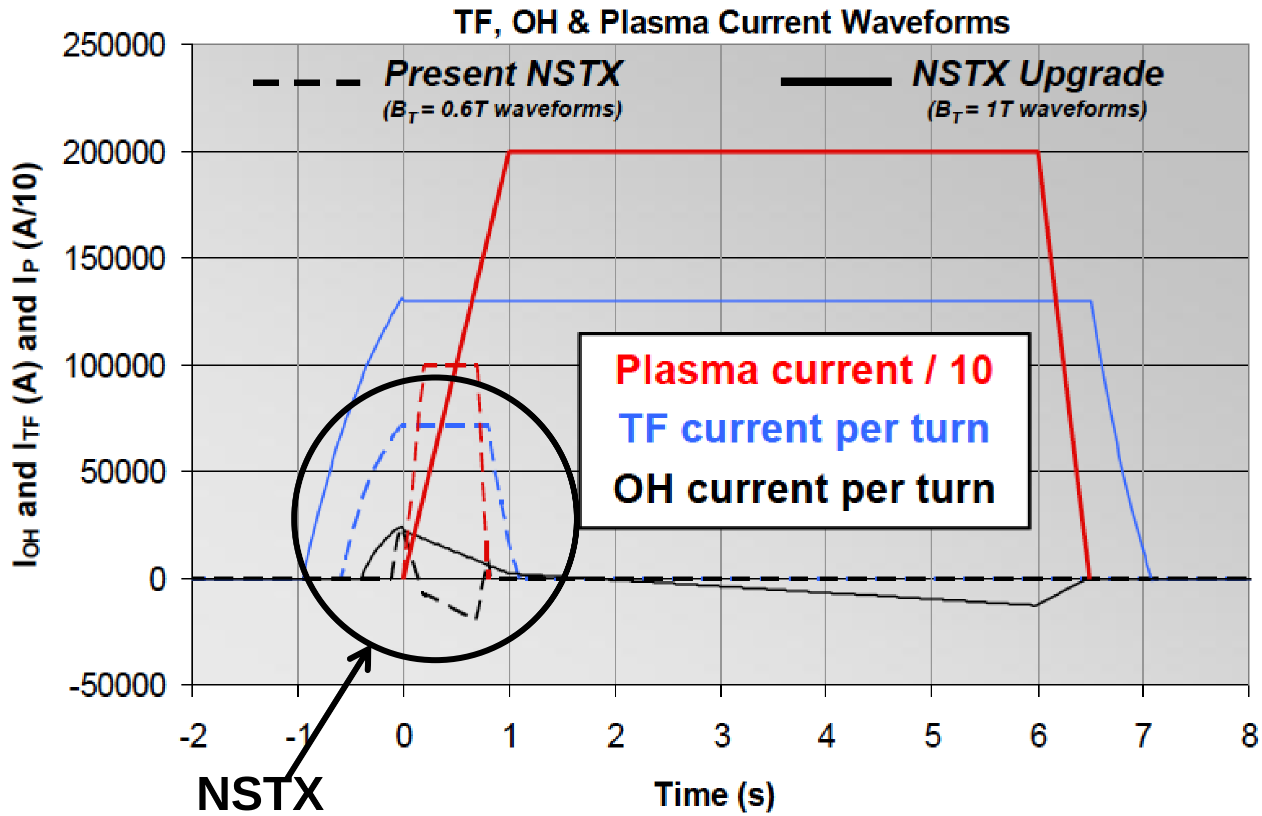
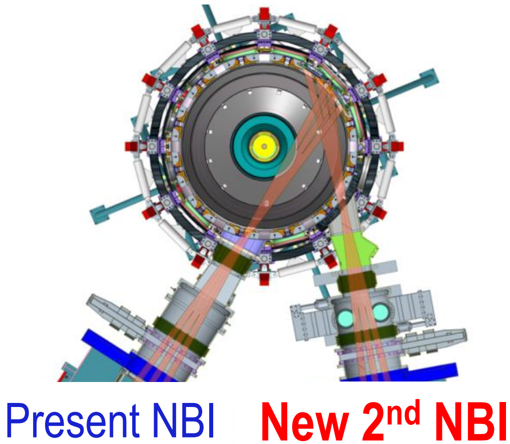
Substantial Increase in NSTX-U Device / Plasma Performance

Higher performance requires facility / infrastructure enhancements

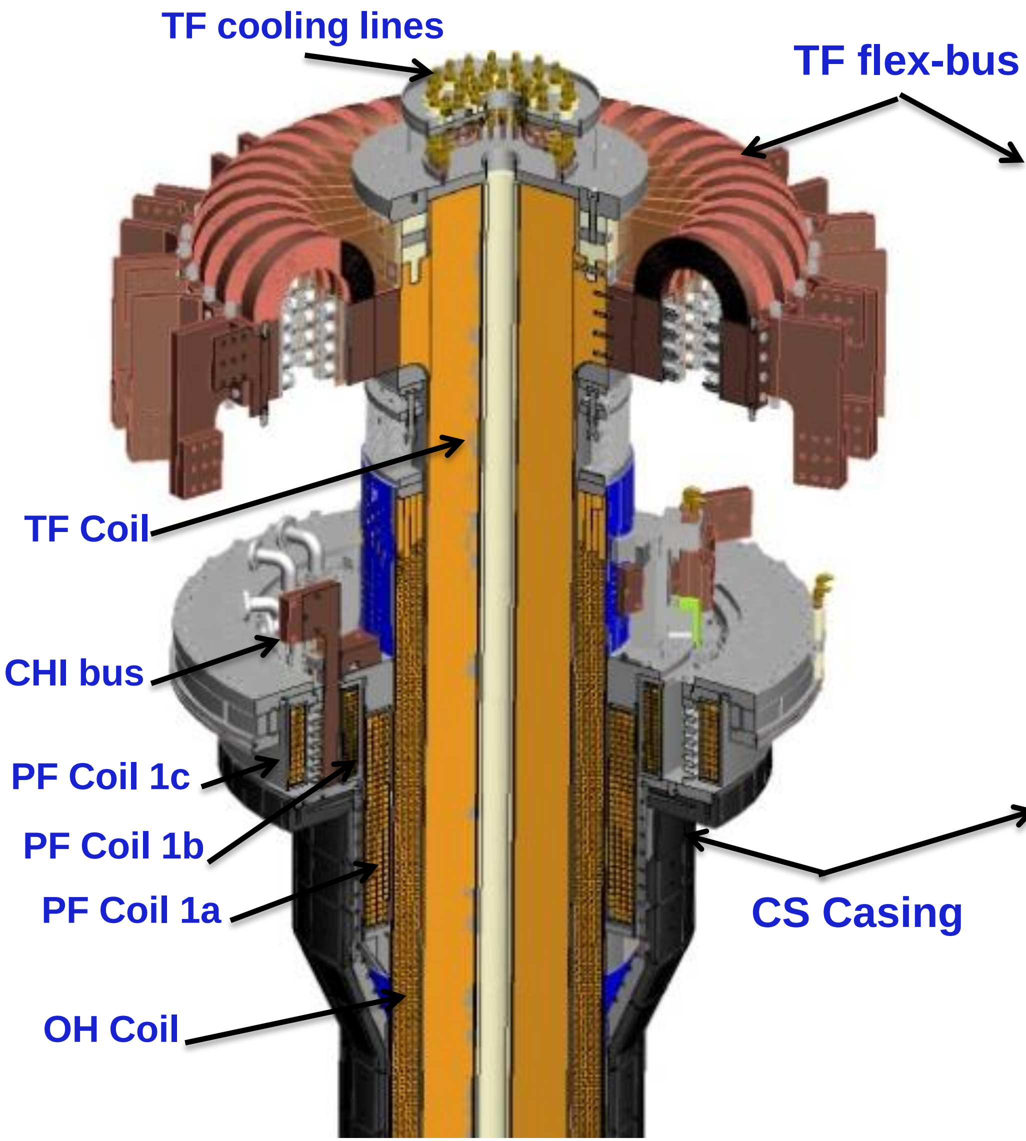


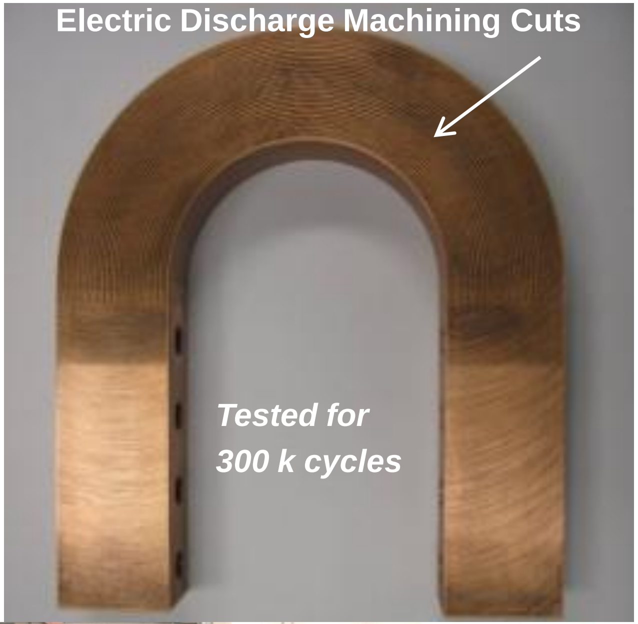




	R_0 (m)	A_{min}	I_p (MA)	B_T (T)	T_{TF} (s)	R_{CS} (m)	R_{OB} (m)	OH flux (Wb)
NSTX	0.854	1.28	1	0.55	1	0.185	1.574	0.75
NSTX-U	0.934	1.5	2	1	6.5	0.315	1.574	2.1

Improved Center-Stack Design to Handle Increased Forces
Identical 36 TF Bars and Innovative Flex-Bus Design





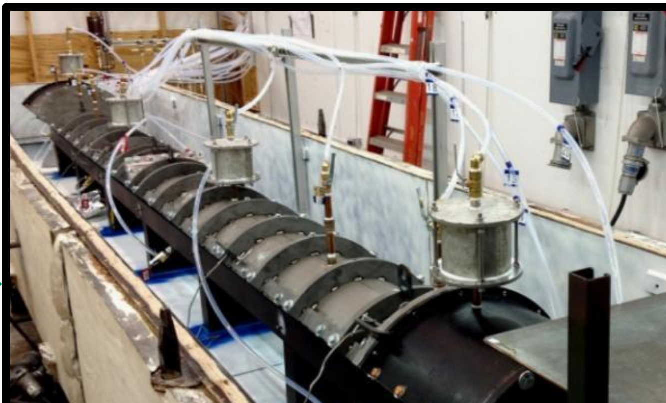
Center Stack Fabrication & Assembly Proceeding Well

Innovative manufacturing techniques developed

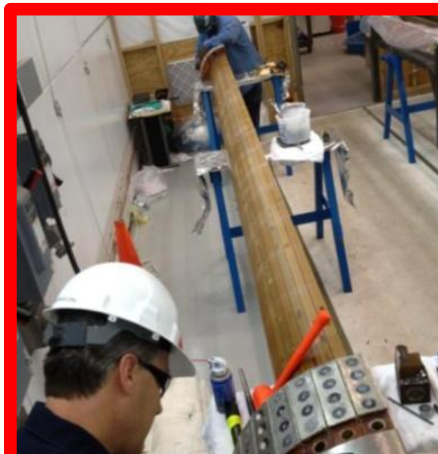
Cooling tube soldered with resin-based flux into inner TF conductor

Conductor being wrapped with fiberglass insulation

Insulated conductor being placed into mold

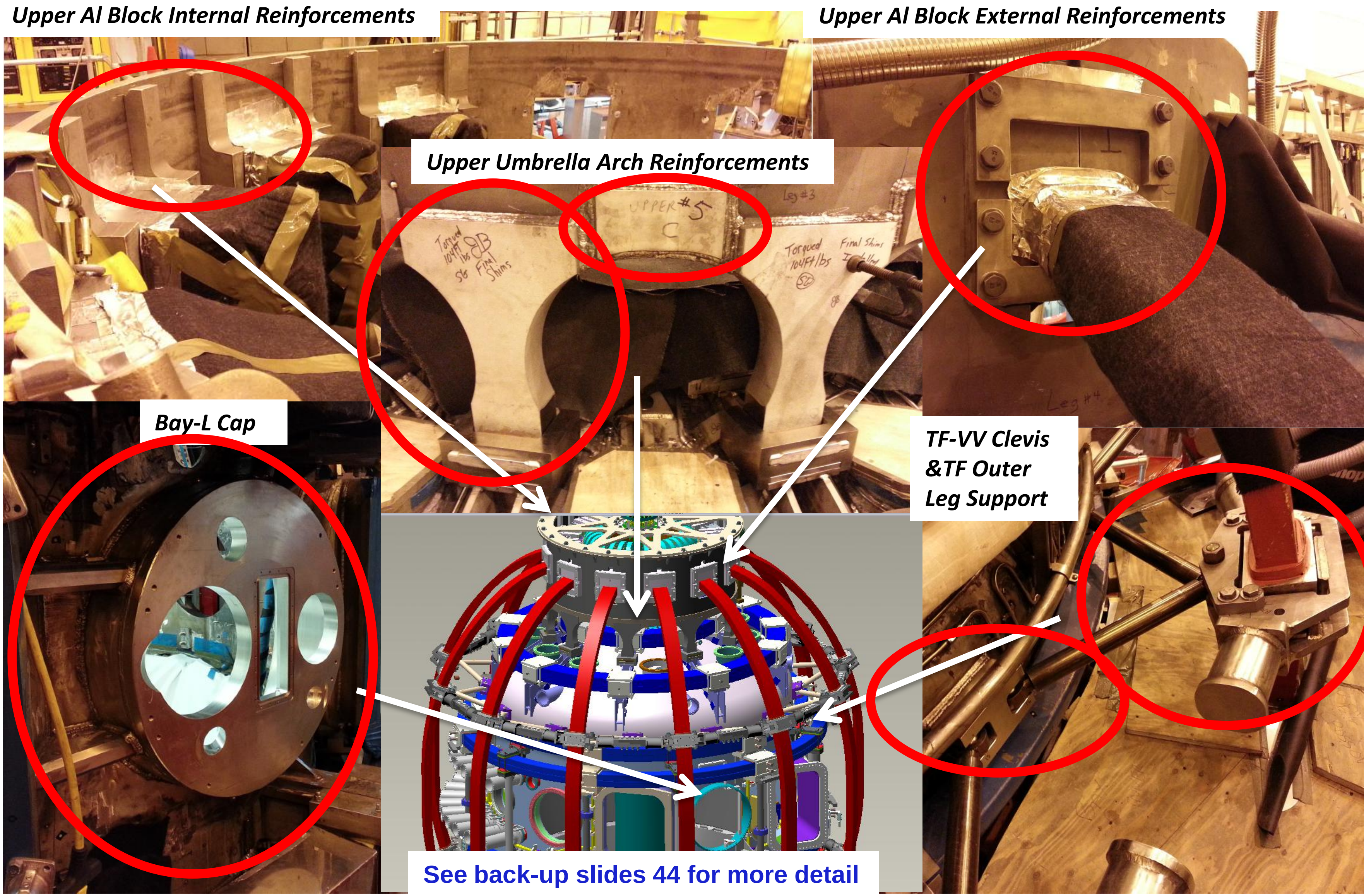


Assembled TF mold ready for Vacuum Pressure Impregnation with CTD-425



Three Quadrants successfully VPI'd !

Support Structural and Vacuum Vessel Upgrades
Must handle 4 x higher electromagnetic loads



Relocation of the 2nd NBI beam line box from the TFTR test cell into the NSTX-U Test Cell Complete.

TFTR NBI beam box and components successfully tritium decontaminated.

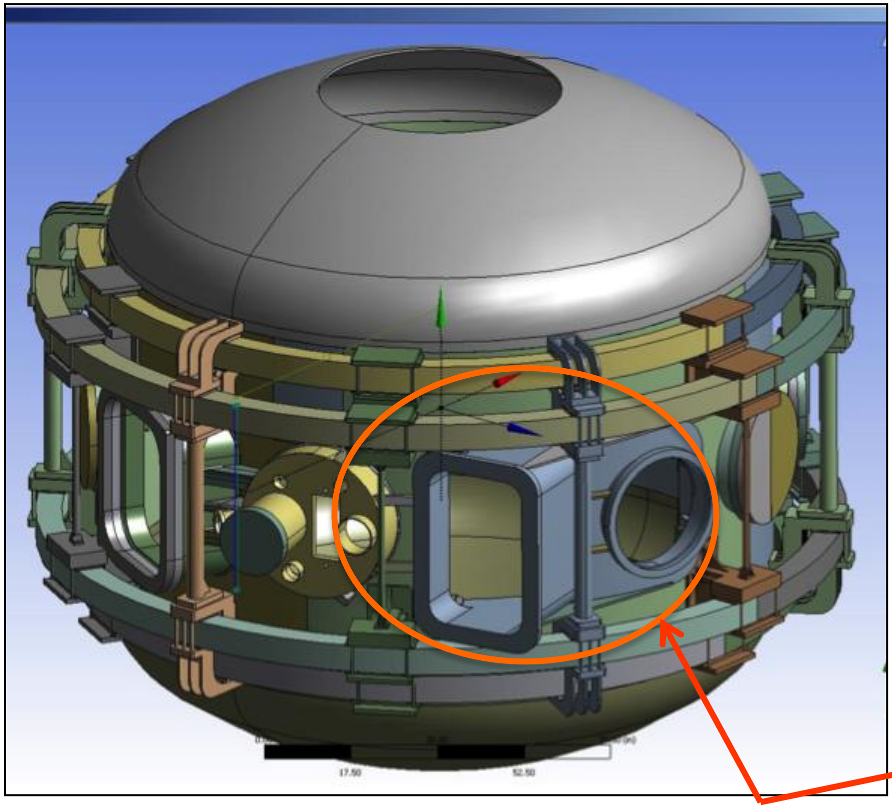
Beam Box being lifted over NSTX

Beam Box placed in its final location and aligned

Beam Box being populated with components

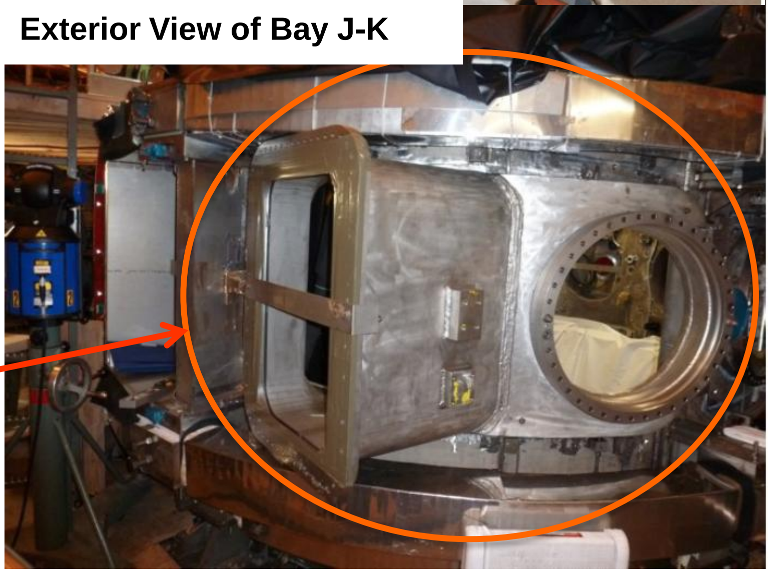
Highly Tangential 2nd NBI Enabled by JK-Cap

Outer Wall Radius Moved Outward to Avoid Beam Clipping



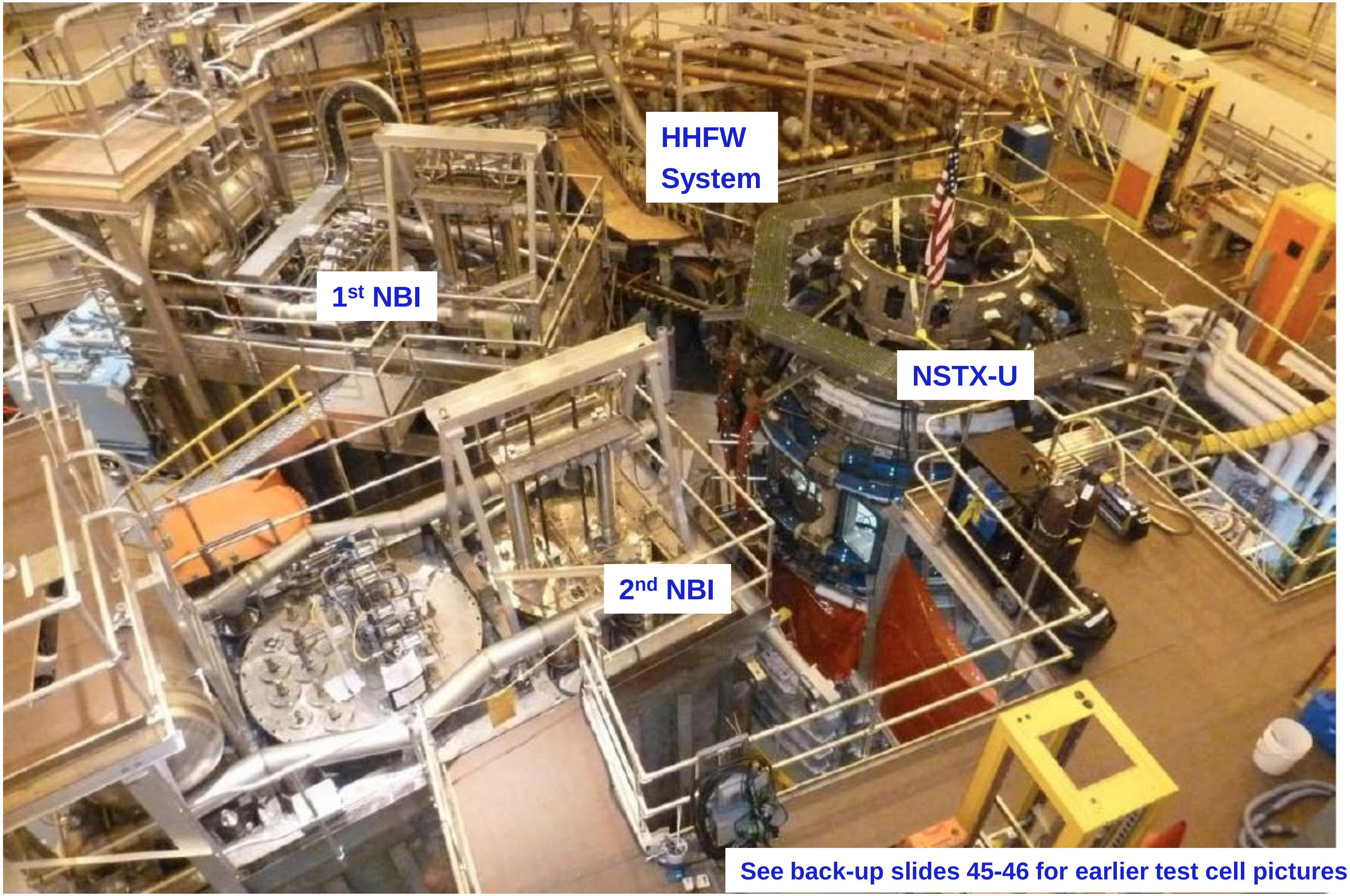
Interior View of Bay J-K

Exterior View of Bay J-K



JK cap

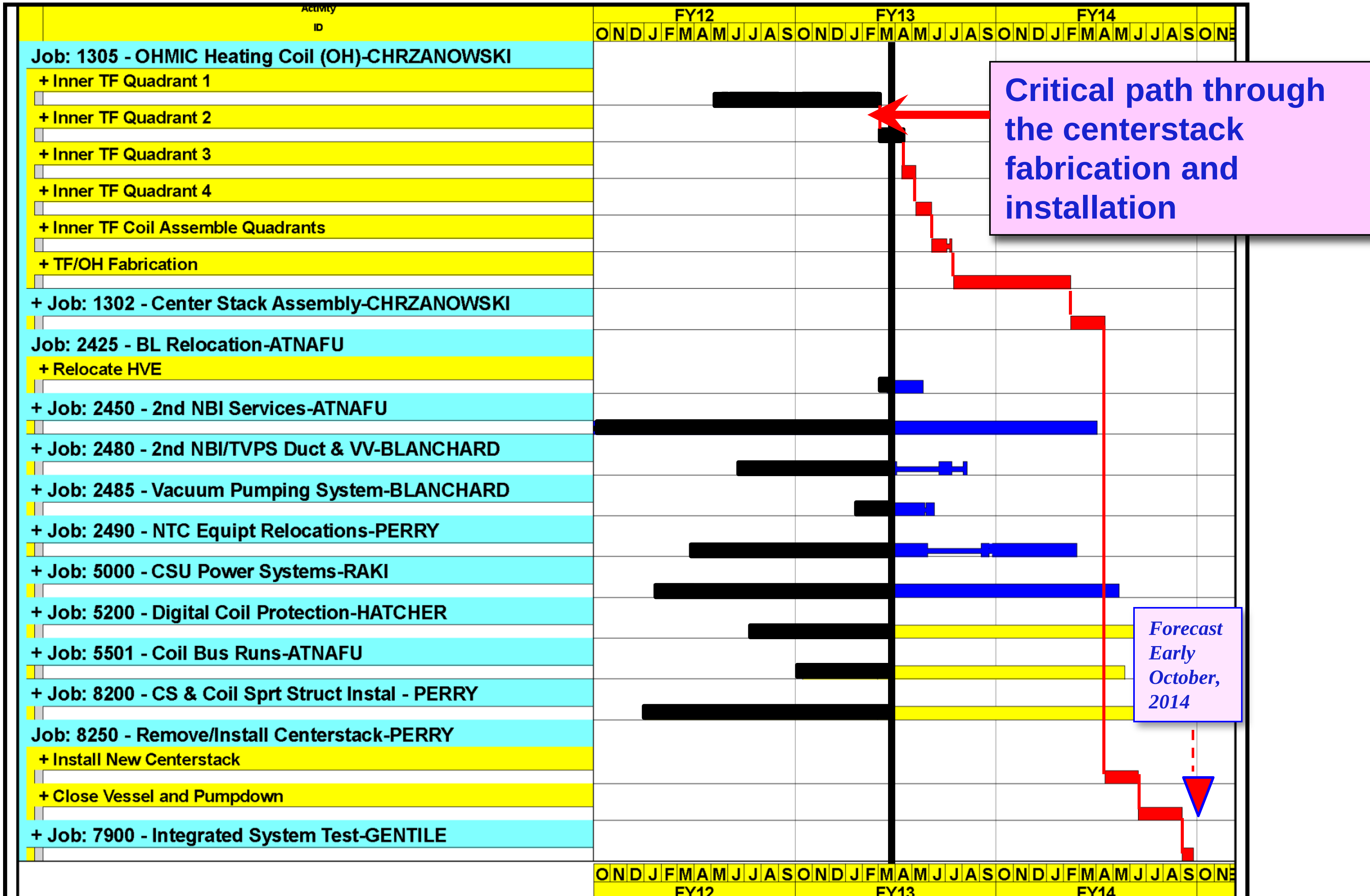
Aerial View of the NSTX-U Test Cell (April 2013)



See back-up slides 45-46 for earlier test cell pictures

Upgrade schedule on track for early finish

Aiming to start research operation in FY 2015



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Engineering and Research Operations Activities In Preparation for the NSTX-U Operations

- **The NSTX-U diagnostic and facility enhancement brainstorming meetings were held in July 2011 and Feb. 2012, respectively. Fifty eight diagnostics ideas and fifty one facility enhancement ideas were presented. The presentation material is available on the web URL:http://nstx.pppl.gov/DragNDrop/Five_Year_Plans/2014_2018/.**
- **Significant collaboration research contributions are being made in diverse science areas by the NSTX-U research team. A summary is available on the web: http://nstx.pppl.gov/DragNDrop/Collaboration/.**
- **Physics & Engineering Operations (see back-up slides # 47 – 50)**
  - **Improving the PFC geometry in the vicinity of the CHI gap to protect the vessel and coils due to ~ 10x higher divertor heat loads**
  - **Replacing electronics that control & protect rectifiers.**
  - **Upgrading the poloidal field coil supplies to support up-down symmetric snowflake divertors.**
  - **Upgrading the Plasma Control System (PCS) for NSTX-U.**
- **Fabricating new port covers to support high-priority diagnostics. (see back-up slide # 51)**

NSTX-U diagnostics to be installed during first 2 years
Half of NSTX-U Diagnostics Are Led by Collaborators

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: $T_i(R)$, $V_\phi(r)$, $n_C(R)$, $n_{Li}(R)$, (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 Microwave high-k scattering*
- Beam Emission Spectroscopy (48 ch)
- Microwave Reflectometer,
- *Microwave Polarimeter*
- 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
- Neutral particle analyzer (single channel)

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

Transition to operations - planning underway

NSTX-U Start-up Process Similar to NSTX

NSTX-U ISTP, Commissioning, and Startup will follow the same process as NSTX initial commissioning and startup from February 1999.

Pre-operational test of subsystems (PTP's) → *Activity Certification Committee (ACC) review* → *DOE Readiness assessment (RA)* → *Integrated system test procedure (ISTP) (per OP-NSTX-02 rev 14)* → *CD-4 Demonstrated Performance*

- ***Key Operations Milestones***
- *Begin Diagnostic Installation – August 1st, 2013*
- *Complete in-vessel construction work October 1st 2013.*
- *Complete Diagnostic installation & calibration – December 1st, 2013*
- *Rough Pump down – January 1st, 2014*

NSTX-U Team Development of XPs for FY 2015 run → *Shake-down* → *Commence operations, run XP's*

(see back-up slides # 52)

NSTX-U Operations Team Similar to NSTX

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 (2015)	Year 2 NSTX-U Operations (2016)	Year 3 NSTX-U Operations (2017)	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 [MA^2s]	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

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10 year plan tools with 5YP incremental funding

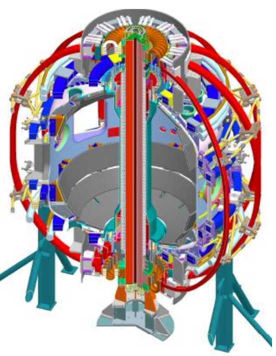
1.1 × (FY2012 + 2.5% inflation)

2014	2015	2016	2017	2018	2019	2020	2021	2022	2023

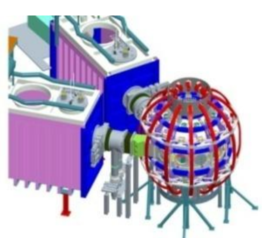
- Upgrade Outage
- 1.5 → 2 MA, 1s → 5s
- Metallic PFCs, 5s → 10-20s

Run Weeks: 20 16 16 20 22 6 18 22 22

New center-stack



2nd NBI



Start-up and Ramp-up
- Upgraded CHI for ~0.5MA
- 0.5-1 MA CHI
- up to 1 MA plasma gun
- Extend NBI duration to 10-20s and/or implement 2-4 MW off-axis EBW H&CD
- 1 MW ECH/EBW → 2 MW

Boundary Physics
- Lower divertor cryo-pump
- Divertor Thomson
- Upper divertor cryo-pump

Materials and PFCs
- High-Z tile row on lower OBD
- High-Z first-wall + lower OBD tiles
- High-Z PFC diagnostics
- All high-Z PFCs
- Hot high-Z FW PFCs using bake-out system

Liquid metals / lithium
- Li granule injector
- Upward LiTER
- LLD using bakeable cryo-baffle
- Flowing Li divertor or limiter module
- Full toroidal flowing Li lower OBD

MHD
- MGI disruption mitigation
- Partial NCC
- Enhanced MHD sensors
- NCC SPA upgrade
- Full NCC

Transport & Turbulence
- δB polarimetry
- High k_θ
- DBS, PCI, or other intermediate-k

Waves and Energetic Particles
- 1 coil AE antenna
- 4 coil AE antenna
- HHFW limiter upgrade
- Charged fusion product, neutron-collimator
- HHFW straps to excite EHO
- High-power AE antenna

Scenarios and Control
- Establish control of: Snowflake, $\bar{n}_e$, Rotation, q_{min}, Divertor P_{rad}
- Control integration, optimization
- Control integration, optimization with long-pulse and full metal wall

Inform U.S. next-step conceptual design to optimize: aspect ratio, divertor, and PFCs

5 year plan tools with 5YP base funding

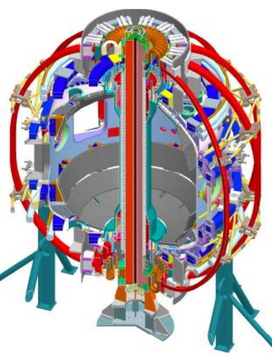
(FY2012 + 2.5% inflation)

2014	2015	2016	2017	2018

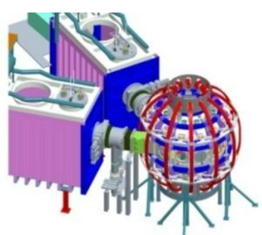
Upgrade Outage | **1.5 → 2 MA, 1s → 5s**

Run Weeks: 16 14 14 16

New center-stack



2nd NBI



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- High-Z tile row on lower OBD
- High-Z tile row on cryo-baffle
- High-Z PFC diagnostics
- All high-Z PFCs

Liquid metals / lithium
- Li granule injector
- Upward LiTER
- LLD using bakeable cryo-baffle
- Flowing Li divertor or limiter module

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Waves and Energetic Particles
- 1 coil AE antenna
- 4 coil AE antenna
- HHFW limiter upgrade
- HHFW straps to excite EHO
- Charged fusion product, neutron-collimator

Scenarios and Control
- Establish control of:
- Snowflake $\bar{n}_e$ Rotation
- q_{min} Divertor P_{rad}
- Control integration, optimization

Cryo-pump, high-Z tile row on cryo-baffle, and partial NCC would be installed in-vessel during ~1 year outage between FY2016 and FY2017

NSTX-U would operate 1st half of FY2016 and 2nd half of FY2017

Legend:
- Delayed scope
- Reduced scope
- Deferred scope

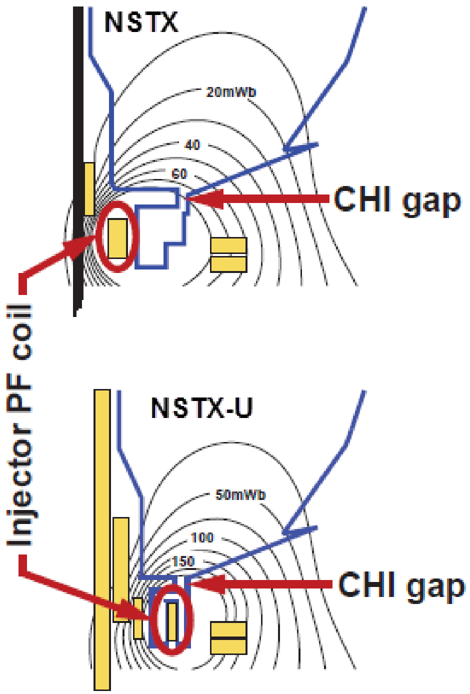
Solenoid-free Start-up

High priority goal for NSTX-U in support of FNSF

CHI Start-Up

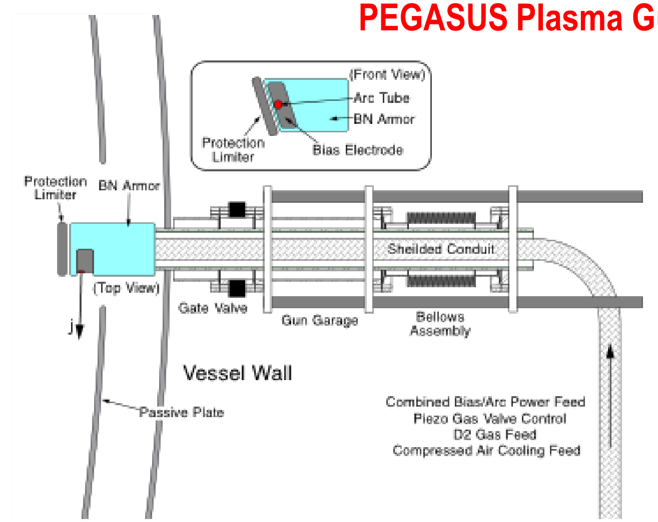
- Inj. Flux in NSTX-U is about 2.5 times higher than in NSTX
- NSTX-U coil insulation greatly enhanced for higher voltage ~ 3 kV operation

U. Washington



PEGASUS Point Source

PEGASUS Plasma Gun



U. Wisconsin

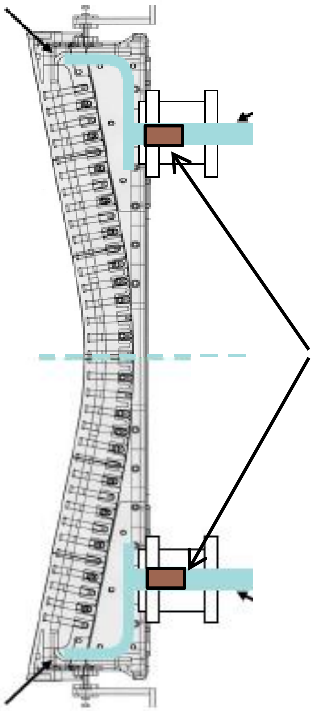
FY 2013-14 Non-Inductive Start-up Systems Design for Post-Upgrade Operations

- CHI will start with the present 2 kV capability then enhanced to ~ 3 kV higher voltage as needed.
- PEGASUS gun start-up producing exciting results Ip ~ 160 kA. The PEGASUS gun concept is technically flexible to implement on NSTX once fully developed. High current gun for the NSTX-U will be developed utilizing the PEGASUS facility in collaboration with University of Wisconsin.

Strengthen HHFW Antenna Feeds for Disruption Load

A MW-Class 28 GHz ECH System for Non-Inductive Operation

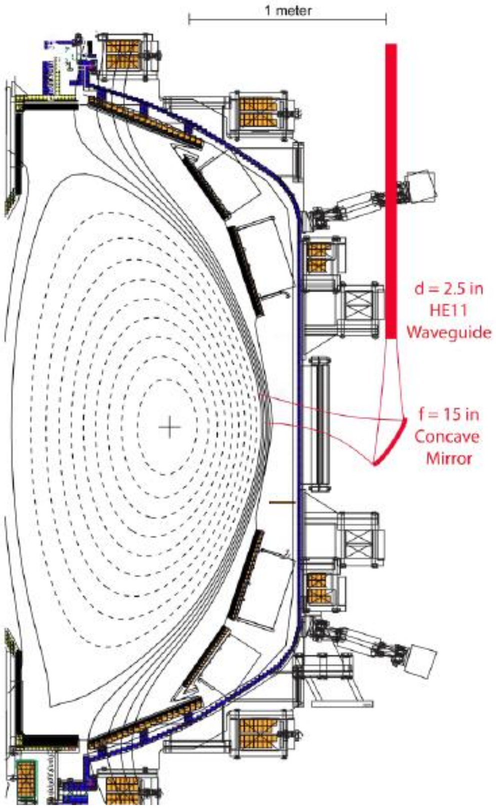
HHFW antenna feedthru modification for disruption loads



A compliant section

Photo courtesy of C-Mod Group

28 GHz, 1.5 MW Tsukuba Gyrotron



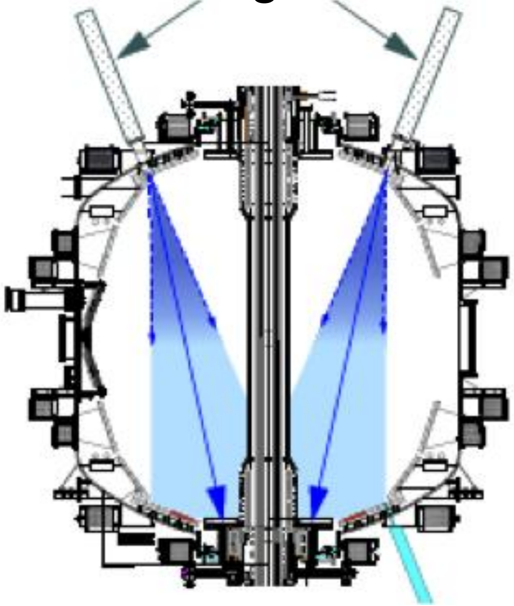
28 GHz ECH/EBWH waveguide and mirror concept

- **FY 2013/14 - HHFW Antenna feed enhancements against disruptive loads**
- **FY 2013/15 – Start MW-class ECH/EBW system conceptual design for non-inductive operations (MOU with Tsukuba University)**

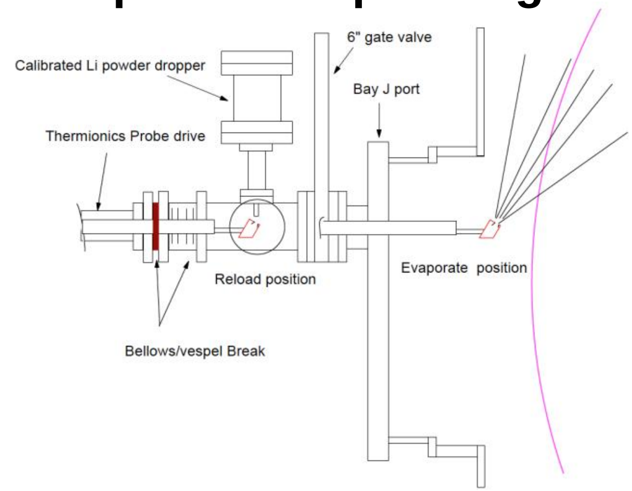
NSTX-U Lithium Capability During Initial Two Years

Lithium Evaporators and Granular Injector

Existing LITERS



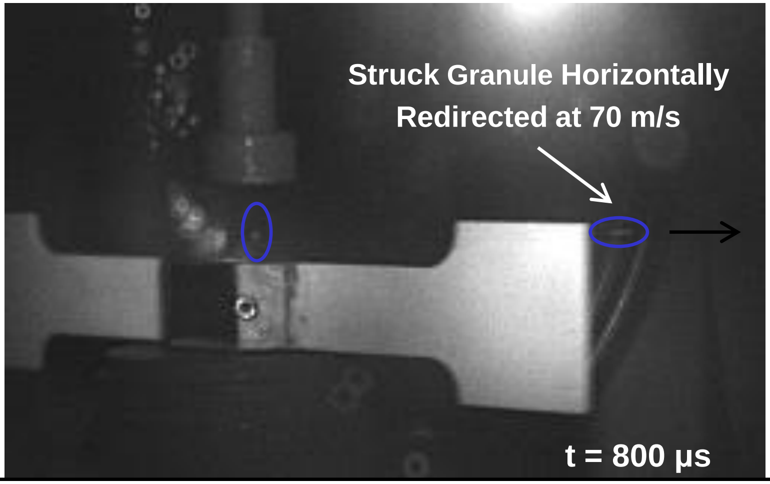
New Upward Evaporating LITER

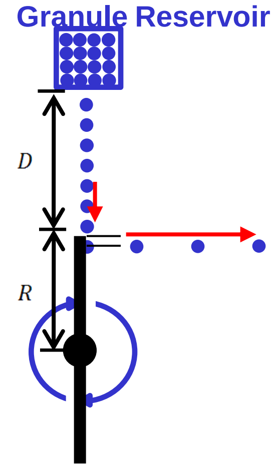


- Upward Evaporating LITER to increase Li coverage for increased plasma performance

NSTX-U lithium granular injector for ELM pacing

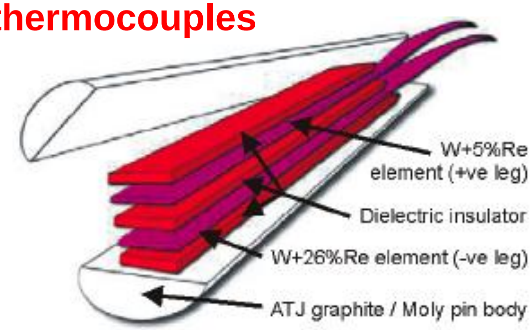
- High frequency ELM pacing with a relatively simple tool.
- ELM pacing successfully demonstrated on EAST (D. Mansfield, IAEA 2012)



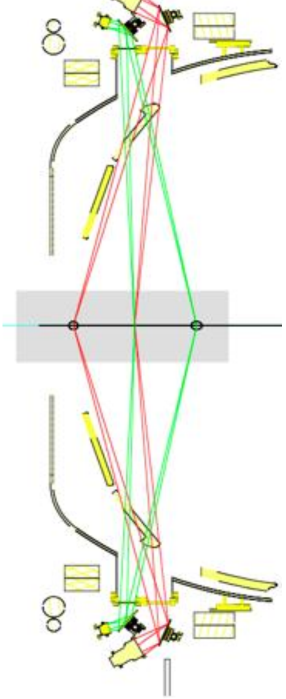


Baseline Capability for PMI Research
Supporting divertor and lithium research

Divertor fast eroding thermocouples

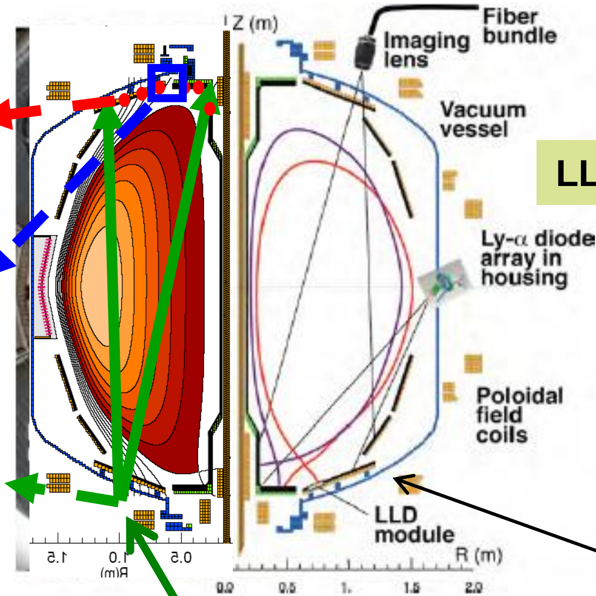


Lithium CHERS



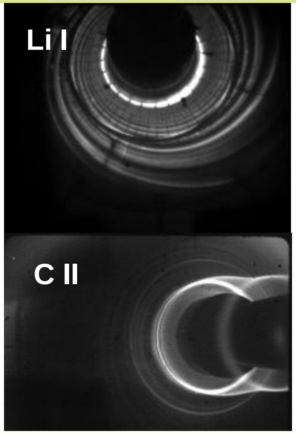
Divertor Imaging Spectrometer

LLNL



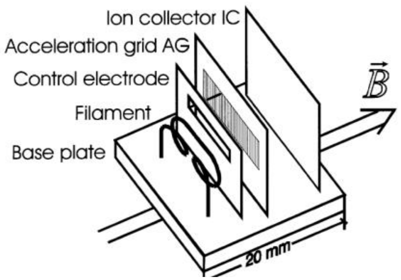
Two fast 2D visible and IR cameras with full divertor coverage

LLNL, ORNL, UT-K

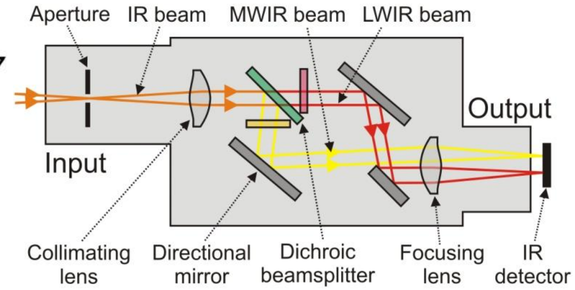


ORNL

Divertor fast pressure gauges



Dual-band fast IR Camera



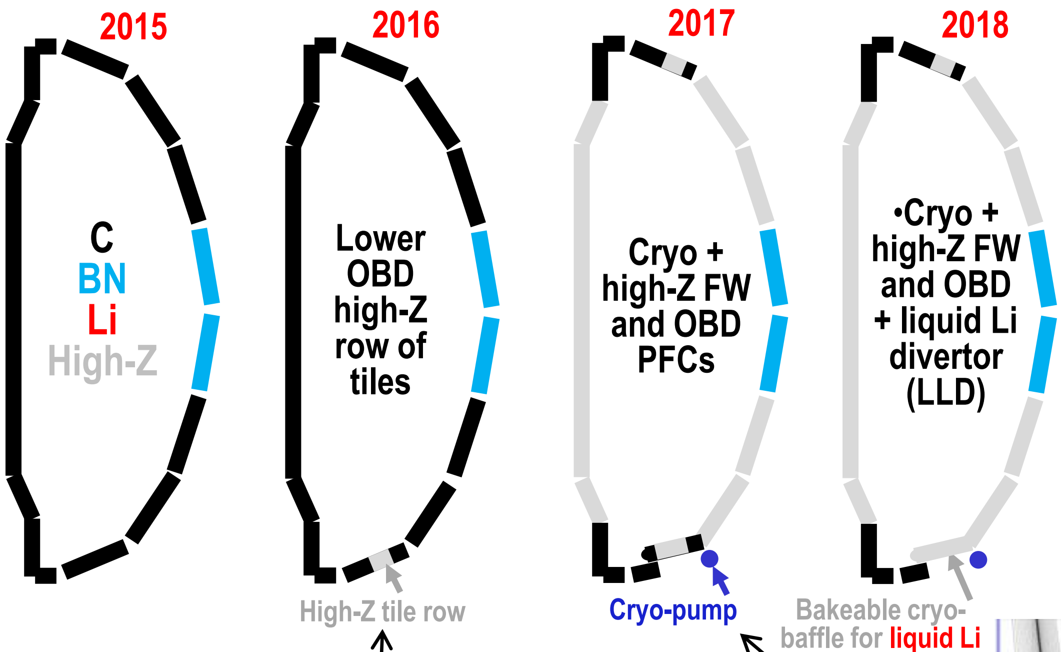
MAPP probe for between-shots surface analysis

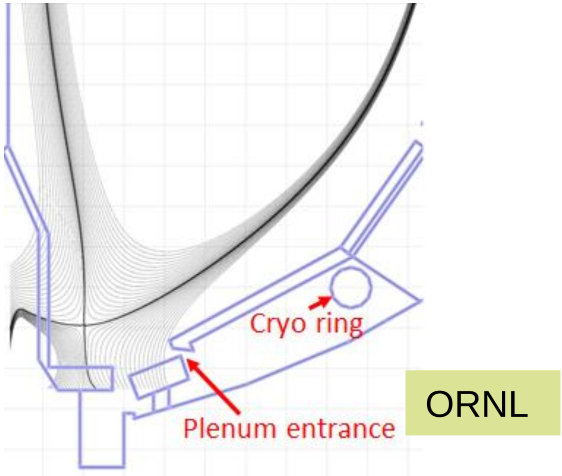
Purdue U.

(see back-up slides # 53 and 54)

Boundary Facility Capability Evolution

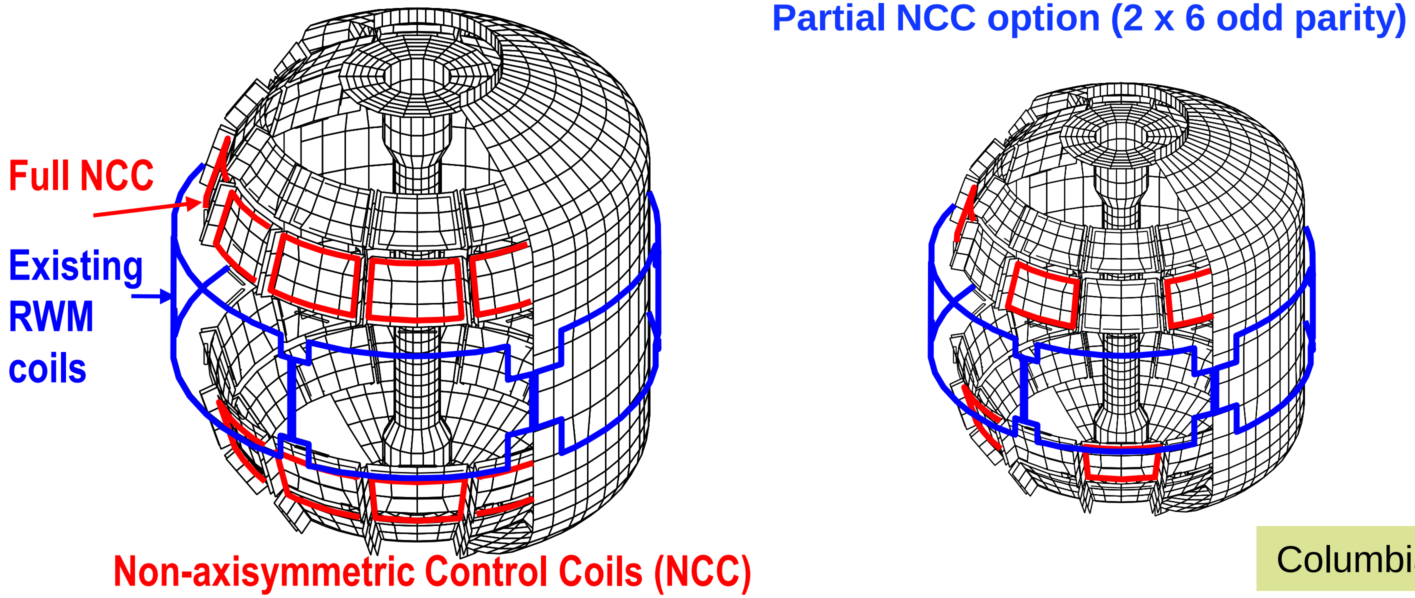
NSTX-U will have very high divertor heat flux capability of ~ 40 MW/m^2





New MHD and Plasma Control Tools for NSTX-U

Sustain β_N and Understand MHD Behavior Near Ideal Limit

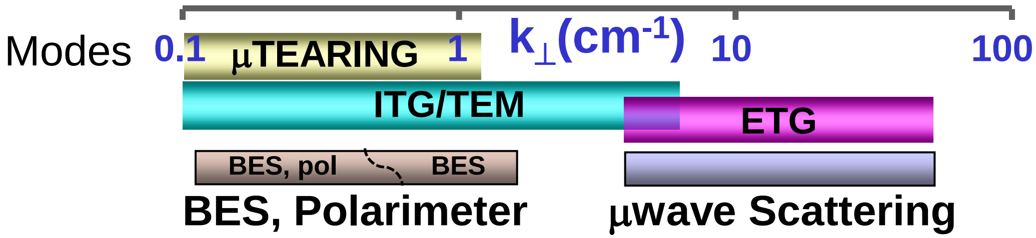


Columbia U., GA

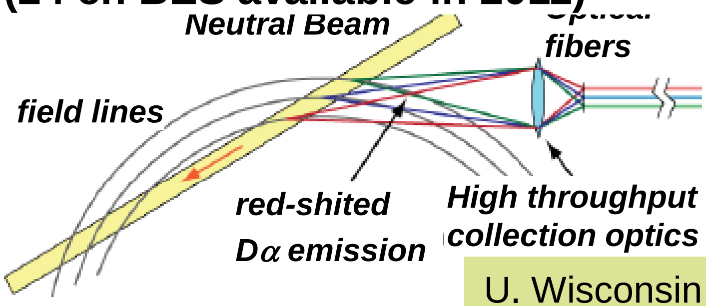
- **NCC can provide expanded RWM, NTV, RMP, and EF physics studies with more flexible field spectrum (n ≤ 6, or n ≤ 3 depending on set).**
- **2nd 3-channel Switching Power Amplifier (SPA) commissioned in July 2011 to power 6 independent currents in existing midplane RWM and NCC coils.**
- **An extended MHD sensor set to measure theoretically predicted poloidal mode structure and to improve mode control.**
- **A Real-Time Velocity (RTV) diagnostic in a new plasma rotation control system for active instability avoidance by controlling rotation profile.**
- **Multi-poloidal location massive gas injector system will be implemented.**

Transport and Turbulence

BES together with high-k to provide comprehensive turbulence diagnostic



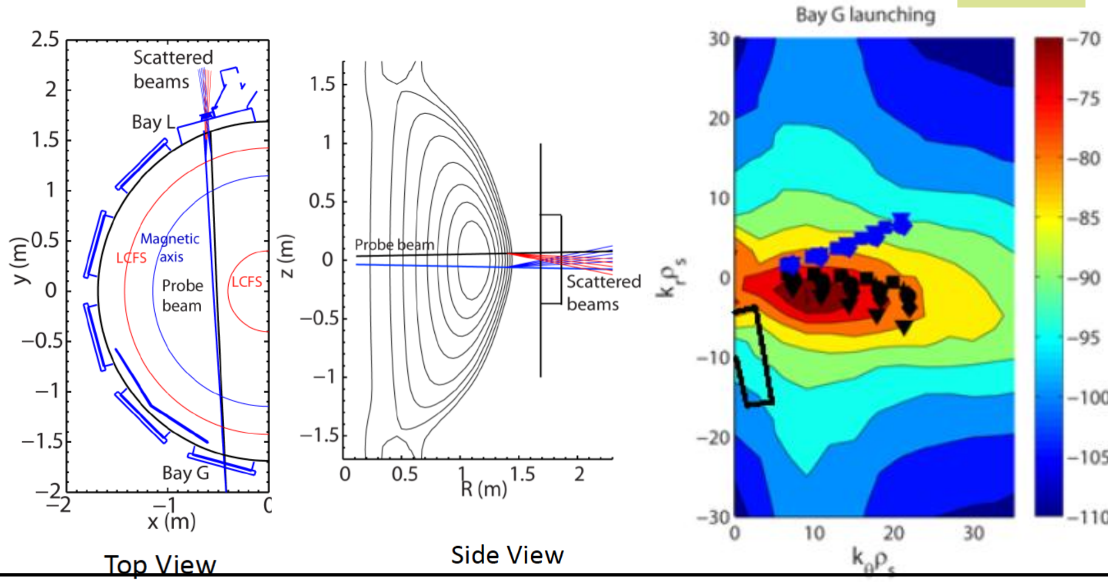
48 ch BES available for NSTX-U
(24 ch BES available in 2011)



U. Wisconsin

New high-k scattering system for allowing 2-D k spectrum

UCD



A 288 GHz polarimetry system for magnetic fluctuation measurements is being tested on DIII-D.

UCLA

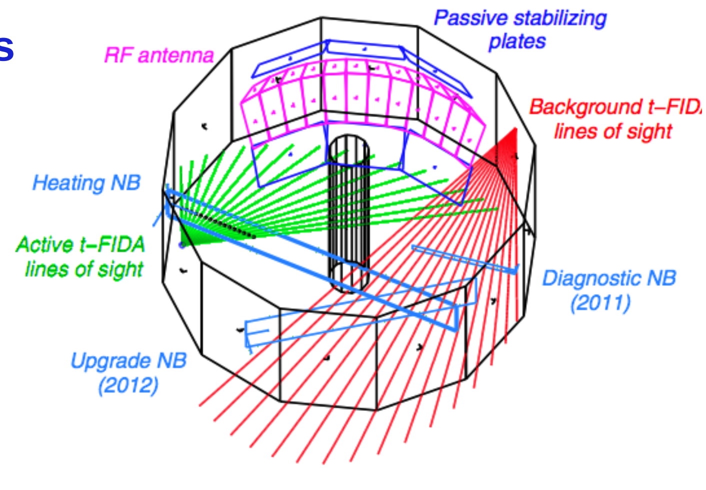
Energetic Particle Research Capabilities
For NBI fast ion transport and current drive physics

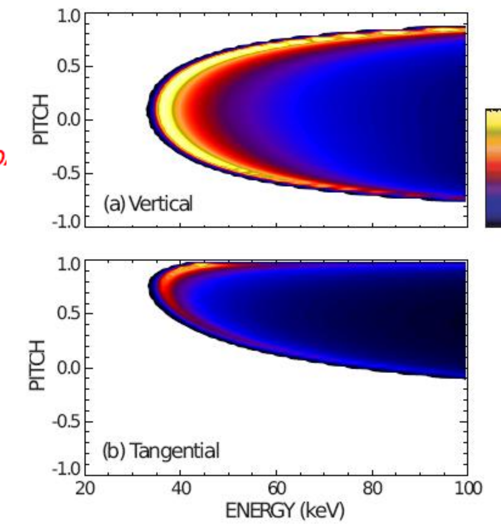
Fast Ion D-Alpha Diagnostics

UCI

FIDA Views

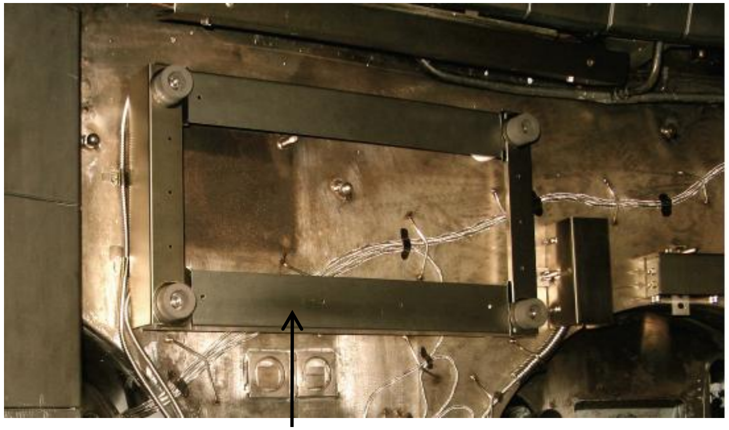
- **Vertical FIDA system measures trapped or barely passing (co-going) particles.**
- **New tangential FIDA system measures co-passing fast ions**
- **Both FIDA systems have time resolution of 10 ms, spatial resolution ≈ 5 cm and energy resolution ≈ 10 keV.**





FY 2013 - 14 Energetic Particle Conceptual Design and Diagnostic Upgrade

- **Solid State-NPA enhancement** UCI
- **Charged Fusion Product Array** FIU
- **Proto-type active TAE antenna**



5-turn radial active TAE antenna installed in 2011

Talk Outline

- Previous five year (FY 2009-13) Project Summary and Status
- NSTX Upgrade Project Overview
- NSTX-U Operational Preparation Status
- NSTX-U Facility / Diagnostic Five Year Plans
- **Budget**
- Summary

NSTX Five Year Plan Budget Summary ($M)

Special financial challenges to transition from construction to operation

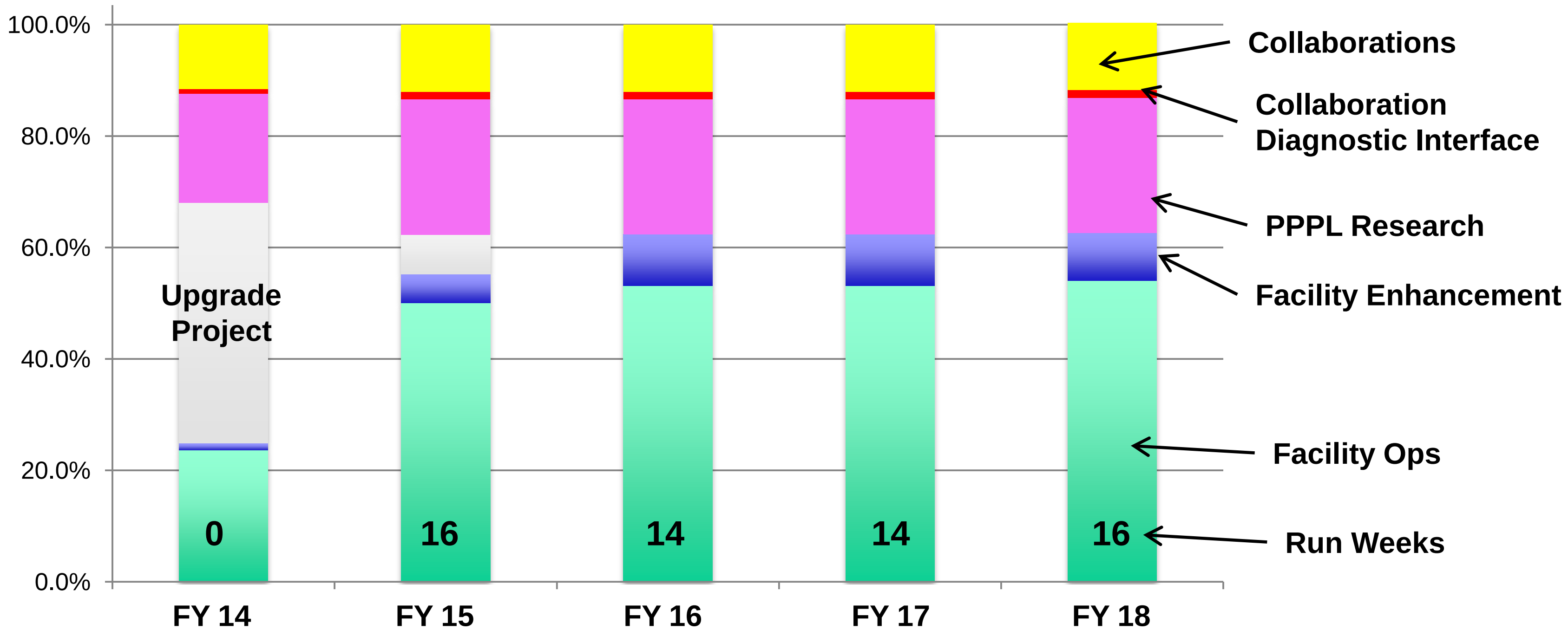
	FY14		FY15		FY16		FY17		FY18	
Budget Cases	**Base**	**10% Incr**	**Base**	**10% Incr**	**Base**	**10% Incr**	**Base**	**10% Incr**	**Base**	**10% Incr**
Run Weeks	0	0	16	4	14	2	14	2	16	4
Facility Ops	$12.7		$26.6	$1.0	$29.0	$0.5	$29.7	$0.5	$30.9	$1.0
Facility Enhancements	$0.7	$4.2	$2.8	$2.3	$5.0	$2.8	$5.1	$3.0	$4.9	$2.5
NSTX-U	$23.2		$3.8							
Facility Total	**$36.6**	**$4.2**	**$33.1**	**$3.3**	**$34.0**	**$3.3**	**$34.9**	**$3.5**	**$35.7**	**$3.5**
PPPL Research	$10.5		$12.9	$0.9	$13.2	$0.9	$13.5	$0.9	$13.9	$0.9
Collab Interface	$0.5	$0.5	$0.7	$0.5	$0.7	$0.5	$0.8	$0.5	$0.8	$0.5
Collaborators	$6.2	$0.6	$6.4	$0.6	$6.6	$0.7	$6.7	$0.7	$6.9	$0.7
Science Total	**$17.2**	**$1.1**	**$20.0**	**$2.0**	**$20.5**	**$2.1**	**$21.0**	**$2.1**	**$21.6**	**$2.2**
NSTX-U Total	**$53.8**	**$5.3**	**$53.2**	**$5.3**	**$54.5**	**$5.4**	**$55.9**	**$5.6**	**$57.3**	**$5.7**

- **FY 2014 and 2015 would be a transition period from construction to operation.**
- **Research and Operations team budget for NSTX-U is similar to that of NSTX.**
- **Base funding enables preparation and operation of NSTX-U while completing the Upgrade Project on schedule.**
- **Significant post upgrade facility/diagnostic enhancements will starts in FY 2016.**
- **Incremental scenario will enable full NSTX-U operation and timely implementation of the five year plan major facility and diagnostic enhancements.**

Base NSTX-U Five Year Plan Budget Summary

Base DOE Guidance Budget – Inflation adjusted flat FY 2012 budget

- **FY12 budget + 2.5% inflation**



- **In FY 14-15, the Upgrade Project needs to be completed.**
- **In FY 14-15, modest budget is available for 5 year plan long lead facility enhancements (e.g., ECH, Cryo-pump, and NCC), only enabling design and R&D activities.**
- **For FY 15 and beyond, the budget facility operations and PPPL/Collaboration research are based on similar operations and research staff coverage to NSTX.**

Optimized NSTX-U Five Year Plan Has been Developed

Exciting Opportunities and Challenges Ahead

- **Present NSTX Five Year Plan has been progressing well.**
  - Most of the research, facility, and diagnostic milestones have been achieved on schedule.
  - Research team has been active in conferences and publication areas.
  - Facility/diagnostic enhancements implemented during the period contributed to the research productivities.
- **NSTX upgrade outage activities are progressing well**
  - Diagnostics were stored and secured for the upgrade activities.
  - Researchers are working productively on data analysis, collaboration, next five year plan and preparation for the NSTX-U operation.
  - NSTX operations technical staff were shifted to the Upgrade Project tasks in FY 2012 – 13.
  - NSTX Upgrade Project is thus far progressing on budget and on schedule.
- **Exciting 5 Year Plan (FY 2014 – 18) has been developed**
  - Aiming to provide necessary data base for FNSF design and construction.
  - Strong contribution to toroidal physics, ITER, and fusion energy development.
  - 10% incremental budget would enable timely implementation of facility capabilities to support the exciting NSTX-U Five Year Plan.

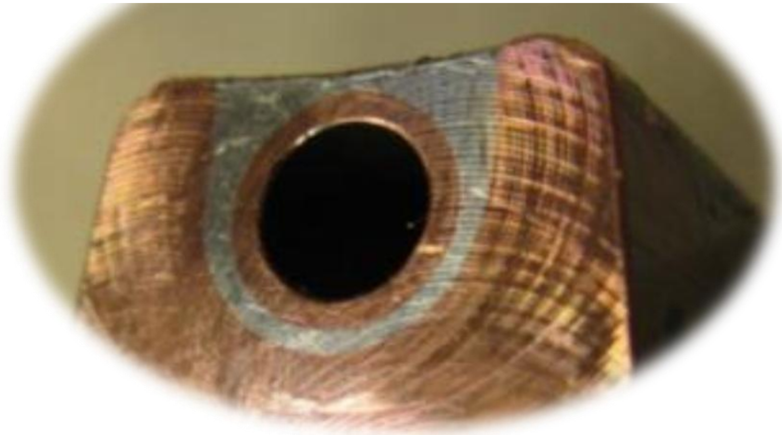
Back-up Slides

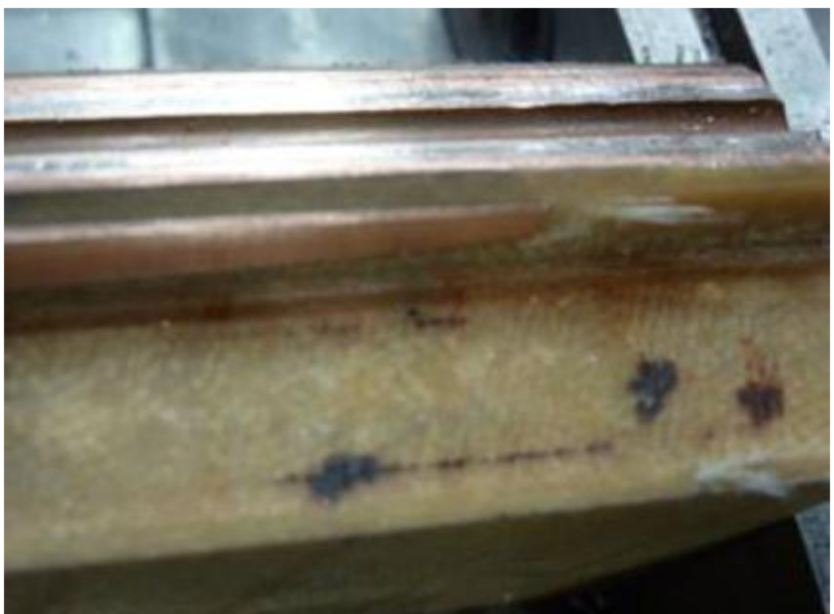
NSTX TF Fault Traced to Zinc Chloride Base Flux

Lessons Learned Applied to New TF Bundle Fabrication

- **Zinc chloride based flux used for cooling water tube soldering was the cause of insulation failure.**
- **An independent review endorsed the findings.**
- **Developed new soldering technique with resin-based flux for the new center-stack**

Close up views of new solder cross section





New TF conductor on soldering station

NSTX FY 09 Milestones

Milestone	Description	Baseline	Completed
JRM(09)	Particle control and hydrogenic fuel retention in tokamaks , NSTX to explore lithium surface	09/30/09	09/30/09
R(09-1)	Understand the physics of RWM stabilization and control as a function of rotation.	09/30/09	09/30/09
R(09-2)	Study how j(r) is modified by super- Alfvénic ion driven modes.	09/30/09	09/30/09
R(09-3)	Perform high-elongation wall-stabilized plasma operation.	09/30/09	09/30/09
F(09-1)	Operate NSTX Facility for 11 Experimental Run Weeks.	09/30/09	09/30/09
F(09-2)	Complete fabrication of the liquid lithium divertor target for particle pumping.	09/30/09	09/30/09
AF(09-1)*	Operate NSTX Facility for 5 additional Experimental Run Weeks	05/30/10	05/30/10
D(09-1)	Upgrade the divertor bolometer to three views with 20 channels.	09/30/09	09/30/09
D(09-2)	Complete fabrication of the Beam Emission Spectroscopy system for transport studies.	09/30/09	09/30/09
AD(09-1)*	Complete engineering design of MPTS Extra Channels.	11/30/09	11/30/09

* ARRA related milestones

NSTX FY 10 Milestones

FY 2010 Facility Joint Research Milestone

Improve understanding of the heat transport in the tokamak scrape off layer (SOL) plasma, strengthening the basis for projecting divertor conditions in ITER. The divertor heat flux profiles and plasma characteristics in the tokamak SOL will be measured in multiple devices to investigate the underlying thermal transport processes. The unique characteristics of C-Mod, DIII-D, and NSTX will enable collection of data over a broad range of SOL and divertor parameters (e.g., collisionality, beta, parallel heat flux, and divertor geometry). Coordinated experiments will generate data that will be compared with theory and simulation. (Completed)

FY 2010 NSTX Milestones

Research	**Milestone Description**	**Baseline**	**Completed**
R(10-1)	Assess sustainable beta and disruptivity near and above the ideal no-wall limit	Sept 10	Sept 10
R(10-2)	Characterize High-Harmonic Fast Wave heating, current drive, and current ramp-up in deuterium H-mode plasmas.	Sept 10	Sept 10
R(10-3)	Assess H-mode pedestal characteristics and ELM stability as a function of collisionality and lithium conditioning.	Sept 10	Sept 10

Facility	**Milestone Description**	**Baseline**	**Complete**
F(10-1)	Operate NSTX Facility for 14 Experimental Run Weeks.	Sept 10	Sept 10
F(10-2)	Commission the liquid lithium divertor target for particle pumping.	Sept 10	Sept 10
AF(10-1)	Operate NSTX Facility for 1 Experimental Run Weeks.	May 10	May 10
AF(10-2)	Complete the design of the additional Switching Power Amplifier Supplies for the EF/RWM/RMP control coil system.	June 10	June 10

Diagnostics	**Milestone Description**	**Baseline**	**Complete**
D(10-1)	Commission the Beam Emission Spectroscopy system for transport studies.	Sept 10	Sept 10
AD(10-1)	Complete key component procurements and begin assembly of the Laser Induced Fluorescence Motional Stark Effect diagnostic system.	Sept 10	Sept 10

NSTX FY 11 Milestones

FY 2011 Facility Joint Research Milestone

Improve the understanding of the physics mechanisms responsible for the structure of the pedestal and compare with the predictive models described in the companion theory milestone. Perform experiments to test theoretical physics models in the pedestal region on multiple devices over a broad range of plasma parameters (e.g., collisionality, beta, and aspect ratio). Detailed measurements of the height and width of the pedestal will be performed augmented by measurements of the radial electric field. The evolution of these parameters during the discharge will be studied. Initial measurements of the turbulence in the pedestal region will also be performed to improve understanding of the relationship between edge turbulent transport and pedestal structure. (Completed)

FY 2011 NSTX Milestones

Research	**Milestone Description**	**Baseline**	**Completed**
R(11-1)	Measure fluctuations responsible for turbulent ion and electron energy transport	Sept 11	Sept 11
R(11-2)	Assess the dependence of integrated plasma performance on collisionality.	Sept 11	Sept 11
R(11-3)	Assess the relationship between lithiated surface conditions and edge and core plasma conditions.	Sept 11	Sept 11
Facility	**Milestone Description**	**Baseline**	**Completed**
F(11-1)	Operate NSTX Facility for 14 Experimental Run Weeks. – Due to a TF failure, only 4.2 run weeks achieved.	Sept 11	Sept11
AF(11-1)	Complete commissioning of ARRA funded facility upgrades.	Aug11	Aug 11
Diagnostics	**Milestone Description**	**Baseline**	**Completed**
D(11-1)	Complete the design of a real-time CHERS system for rotation control.	Sept 11	Sept 11
AD(11-1)	Complete commissioning of ARRA funded diagnostic upgrades.	Aug 11	Aug 11

NSTX FY 12 Milestones

FY 2012 Facility Joint Research Milestone

Understand core transport and enhance predictive capability: Conduct experiments and analysis on major fusion facilities leading toward improved understanding of core transport and enhanced capability to predict core temperature and density profiles. In FY 2012, FES will assess the level of agreement between predictions from theoretical and computational transport models and the available experimental measurements of core profiles, fluxes and fluctuations. The research is expected to exploit the diagnostic capabilities of the facilities (Alcator C-Mod, DIII-D, NSTX) along with their abilities to run in both unique and overlapping regimes. The work will emphasize simultaneous comparison of model predictions with experimental energy, particle and impurity transport levels and fluctuations in various regimes, including those regimes with significant excitation of electron modes. **Work on NSTX, which will not operate in 2012, will focus on analysis of previously collected data and collaboration with C-Mod and DIII-D.** The results achieved will be used to improve confidence in transport models used for extrapolations to planned ITER operation. (Completed)

FY 2012 NSTX Milestones

Research	Milestone Description	Baseline	Completed
R(12-1)	Assess relationship between lithium-conditioned surface composition and plasma behavior	Sep 12	Sep 12
R(12-2)	Assess confinement, heating, and ramp-up of CHI start-up plasmas	Sep 12	Sep 12
R(12-3)	Assess access to reduced n_e and ν^* in high-performance scenarios	Sep 12	Sep 12

Facility	Milestone Description	Baseline	Completed
F(12-1)	Identify possible high priority facility enhancements for the post upgrade operations	Sep 12	Sep 12

Diagnostics	Milestone Description	Baseline	Completed
D(12-1)	Identify possible high priority diagnostic enhancements for the post upgrade operations	Sep 12	Sep 12

NSTX FY 13 Milestones

FY 2013 NSTX-U Facility Joint Research Milestone

Conduct experiments on major fusion facilities, to evaluate stationary enhanced confinement regimes without large Edge Localized Modes (ELMs), and to improve understanding of the underlying physical mechanisms that allow increased edge particle transport while maintaining a strong thermal transport barrier. ... Candidate regimes and techniques have been pioneered by each of the three major US facilities (C-Mod, D3D and NSTX). ... Exploiting the complementary parameters and tools of the devices, joint teams will aim to more closely approach key dimensionless parameters of ITER, and to identify correlations between edge fluctuations and transport. The role of rotation will be investigated. The research will strengthen the basis for extrapolation of stationary high confinement regimes to ITER and other future fusion facilities, for which avoidance of large ELMs is a critical issue. S. Gerhardt leading the NSTX effort.

FY 2013 NSTX-U Milestones

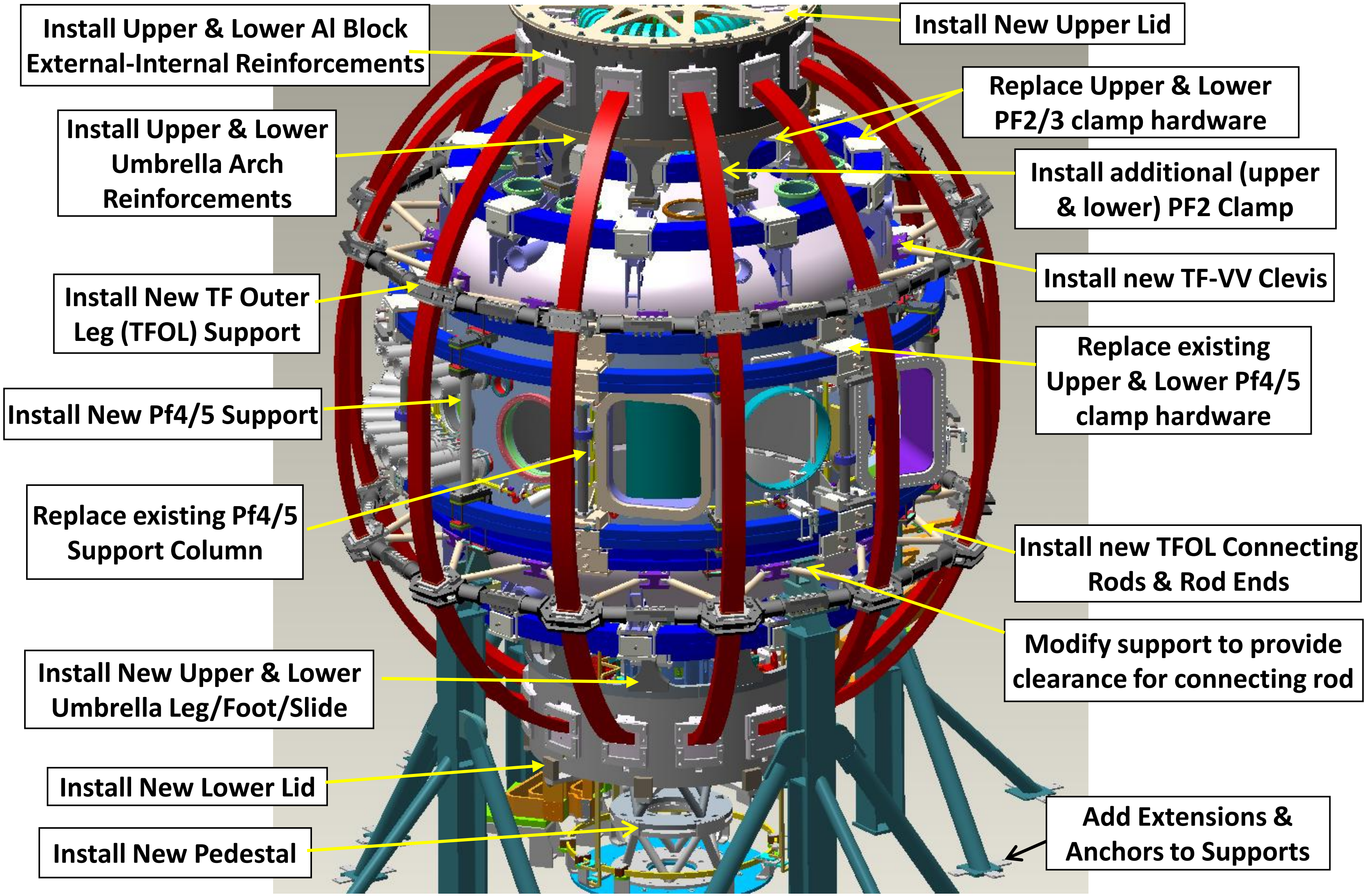
Research	Milestone Description	Baseline	Forecast
R(13-1)	Perform integrated physics and optical design of new high-k_θ FIR system	Sep 13	Sep 13
R(13-2)	Investigate the relationship between lithium-conditioned surface composition and plasma behavior	Sep 13	Sep 13
R(13-3)	Perform physics design of ECH and EBW system for plasma start-up and current drive in advanced scenarios	Sep 13	Sep 13
R(13-4)	Identify disruption precursors and disruption mitigation & avoidance techniques for NSTX-U and ITER	Sep 13	Sep 13

Facility	Milestone Description	Baseline	Forecast
F(13-1)	Develop conceptual designs for high priority facility enhancements for post upgrade operations	Sep 13	Sep 13

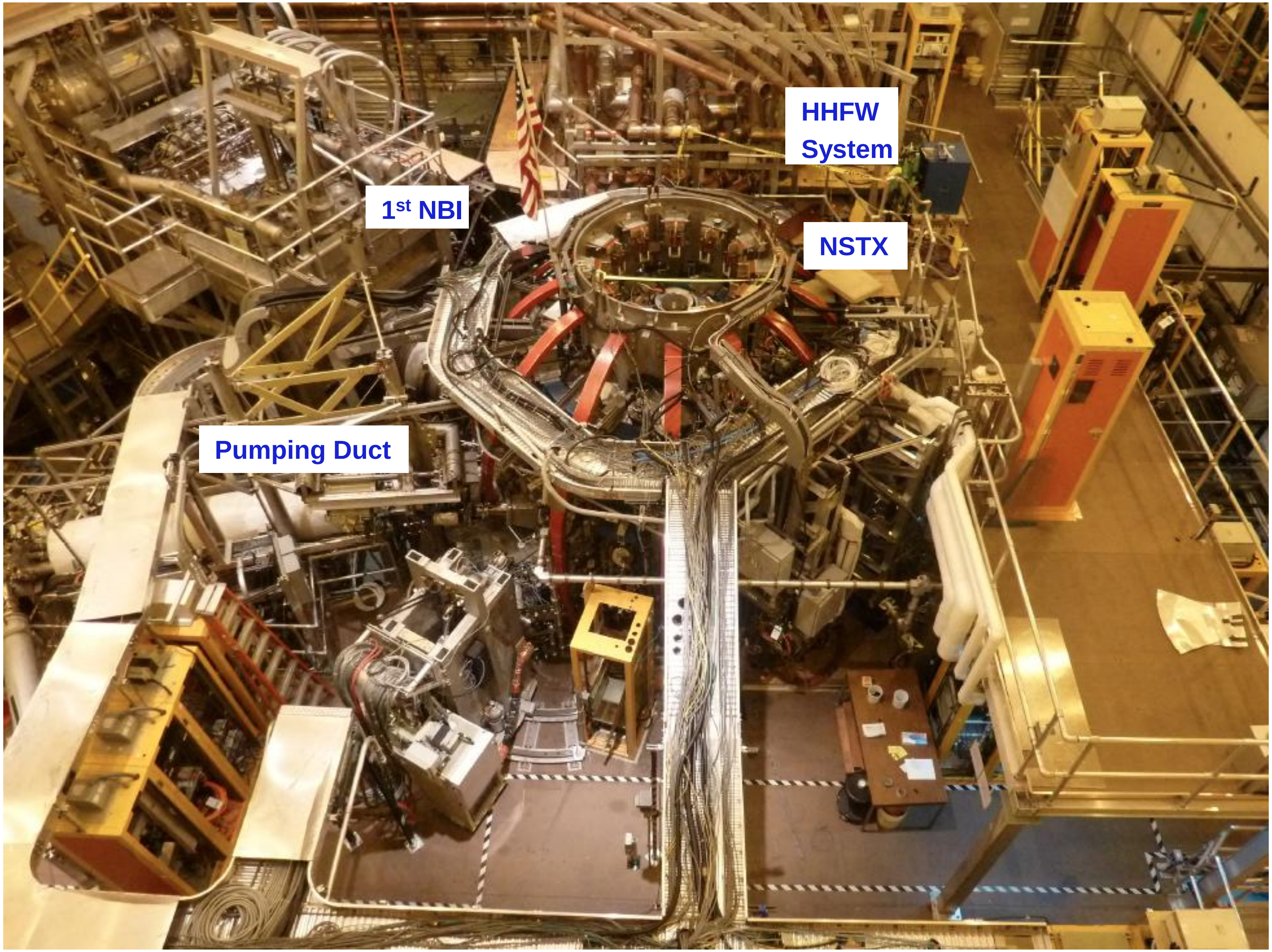
Diagnostics	Milestone Description	Baseline	Forecast
D(13-1)	Develop conceptual designs for high priority diagnostic enhancements for post upgrade operations	Sep 13	Sep 13

NSTX-U Support Structures Enhanced

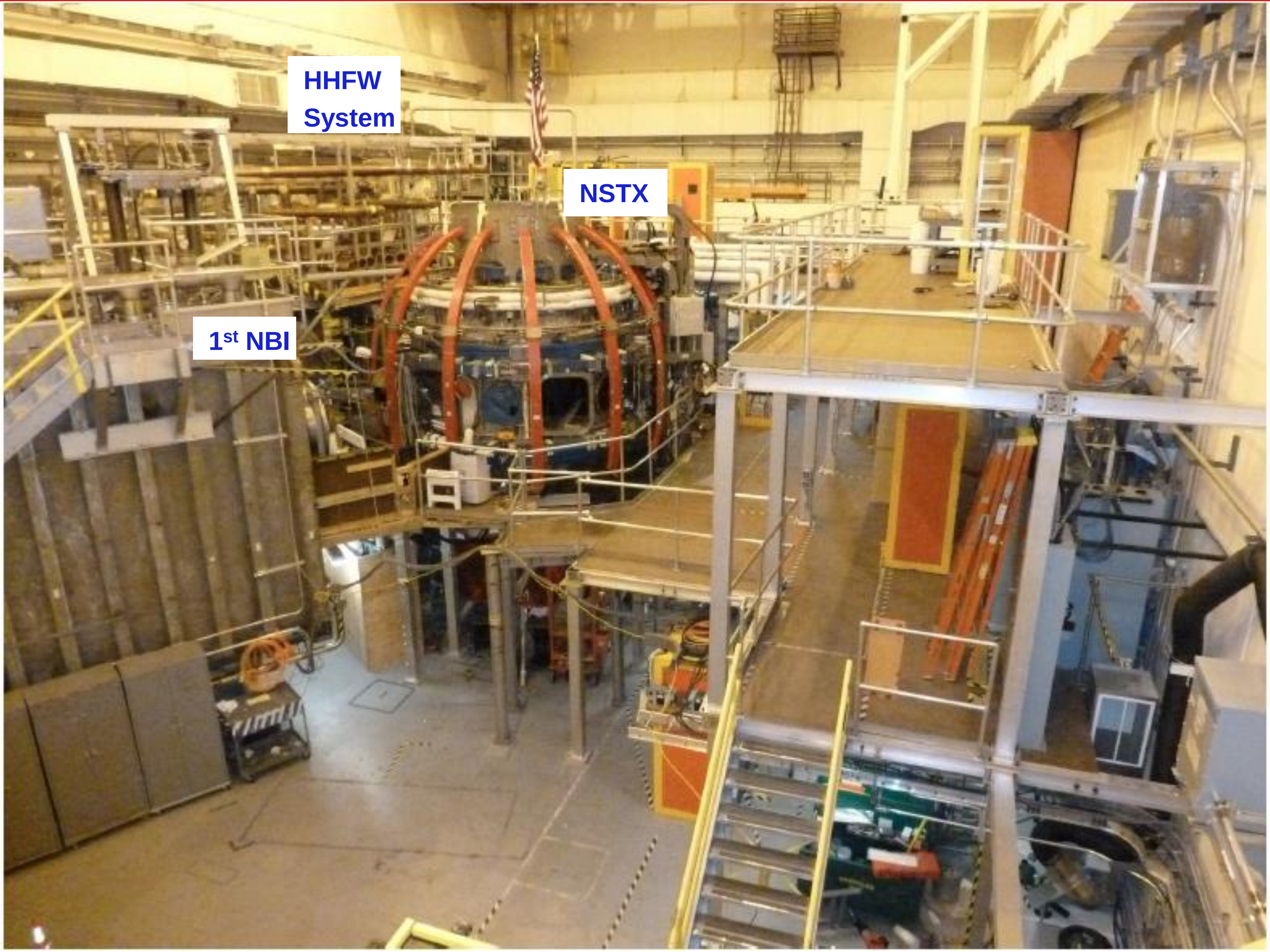
To Handle 4x Electromagnetic Forces



Aerial View of the NSTX Test Cell (Oct. 2011)

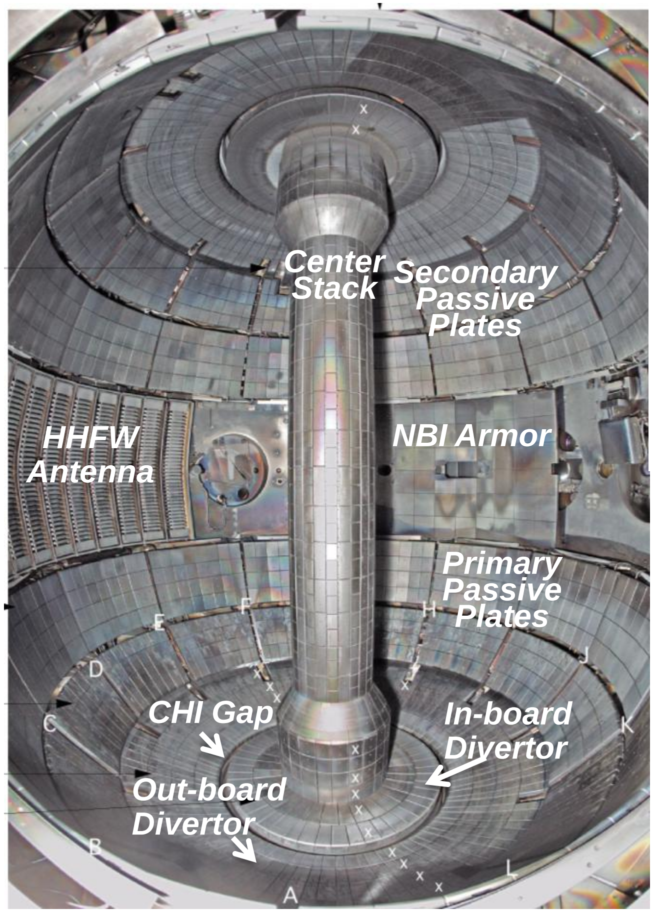


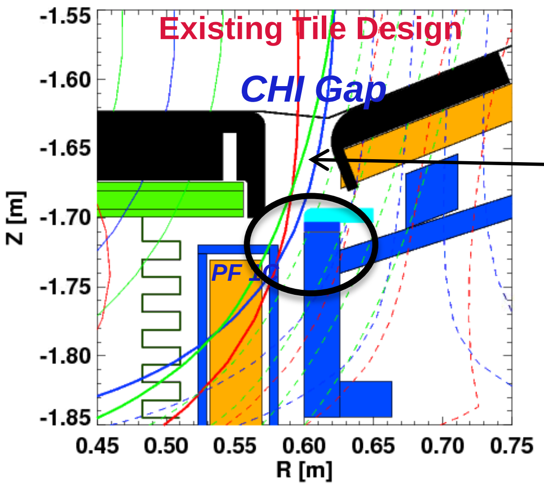
Aerial View of the NSTX Test Cell (Feb. 2012)



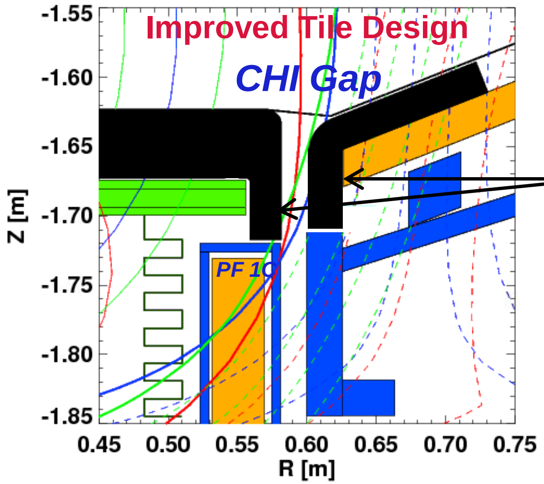
All Graphite PFC Day-1 NSTX-U Configuration

Improved gap tiles to protect PF1C and Exposed SS surfaces





- NSTX-U plasma operation may increase the gap area thermal loading by ~ x 10



- New Gap Overhung Tiles to provides necessary protection

Transrex AC/DC Convertors of the NSTX FCPC

Upgrading of Firing Generators and Fault Detectors

- **Transrex AC/DC Convertors of the NSTX Field Coil Power conversion System (FCPC) provide a pulsed power capability of 1800 MVA for 6 seconds. The modular converter concept of 74 identical (with a paired sections A & B), electrically isolated 6-pulse "power supply sections" was originally used on TFTR, and then adapted to NSTX.**
  - **Many parts from 1984 are nearing end-of-life due to age and wear, replacement parts are rare or unavailable, and that performance can be improved using more modern equipment.**
  - **Precise control of thyrister firing angles by the FCPC firing generators becomes more critical for the new 8-parallel, 130kA TF system configuration.**
  - **Ability to separately control the "A" and "B" sections of each power supply unit allows for more efficient utilization of the 74 available sections.**
  - **The new Firing Generator (FG) will deliver firing pulses with greater resolution, precision, and repeatability, and can receive and process separate commands to the A and B sections**

Status:

•The prototype FG has been fully tested in a Transrex rectifier, and production units are being fabricated.

•The new Fault Detector (FD) provides improved external interface compatible with the NSTX-U data acquisition system.

•The FD prototype has been completed in conjunction with the new FG in a Transrex rectifier.

NSTX-U Plasma Control System Upgrade

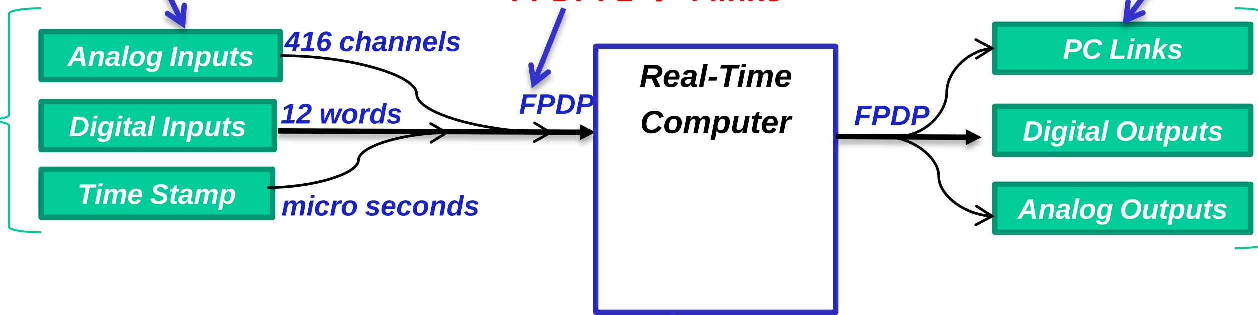
Migration to more modern computer for real-time applications

Sample rate: 5 → 20 KHz
Added 32 channels

FPDP: 1 → 4 links

PC Links replaced with much faster "Firing Generator" Serial Links

Analog Inputs
Coil Currents
Power Supplies
Magnetics
(including upgrades)
Neutral Beams
(1st and 2nd BLs)
Gas Injection
Vacuum
Rotation data
Pitch angle data



Power Supplies
(inc. 3 new coils)
Neutral Beams
(including new BL)
Gas Injection

Hardware Upgrades
New computer: cores: 8 → 32
Commercial Linux Real-Time operating system & advanced real-time debug tools.
New quad-port fiber optic FPDP I/O boards.
Software Upgrades
Ported PPPL code and GA PCS to 64-bit.
Generate commands for new firing generators .
Coil Protection (DCPS) functions incorporated in PSRTC.
Numerous new control algorithms.
PCS algorithms re-written using GA format.
PSRTC to be re-written.

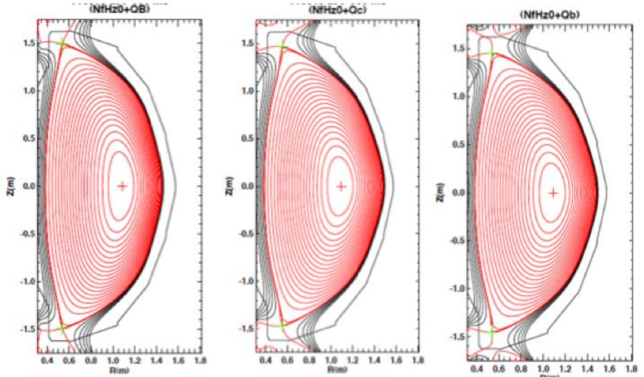
Physics Algorithms For Development Once Hardware/Software Infrastructure is Complete
Modified shape control
Snowflake Control
Dud Detection & Soft Landings
Rotation, Current, β_N
SGI and density control
new diagnostic algorithms

- **A second instance of this real-time computer will be acquired before operation providing a backup for NSTX-U operations and allowing parallel testing of control code during NSTX-U operations.**

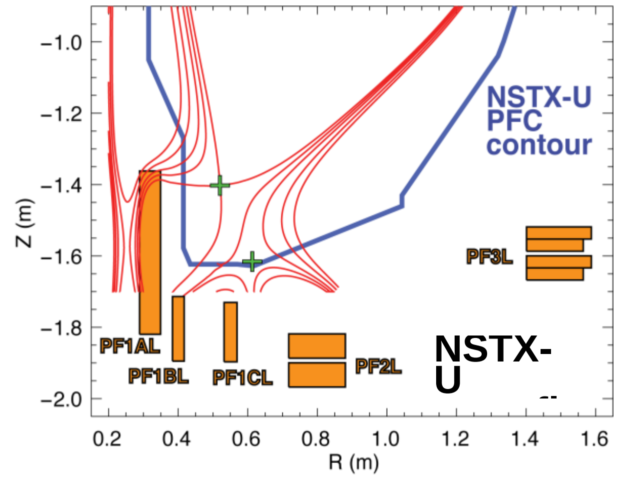
NSTX-U PF Coil Power System Upgrade

Enables up-down symmetric divertor operations

- **The first-year power supply capabilities of NSTX-Upgrade will yield considerable experimental flexibility, namely, up-down symmetric PF-1C coils compared to only at the bottom.**
- **By powering the PF-1A & PF-1C coils, it will be possible to generate up-down symmetric snowflake divertors**
  - **Capability did not exist in NSTX.**
  - **Bipolar PF-1C allows easy comparison between snowflake and standard divertors.**
- **The new configuration should provide better control for the CHI absorber region.**
- **Longer-term, upgrades to the power supply systems may add considerable new capability:**



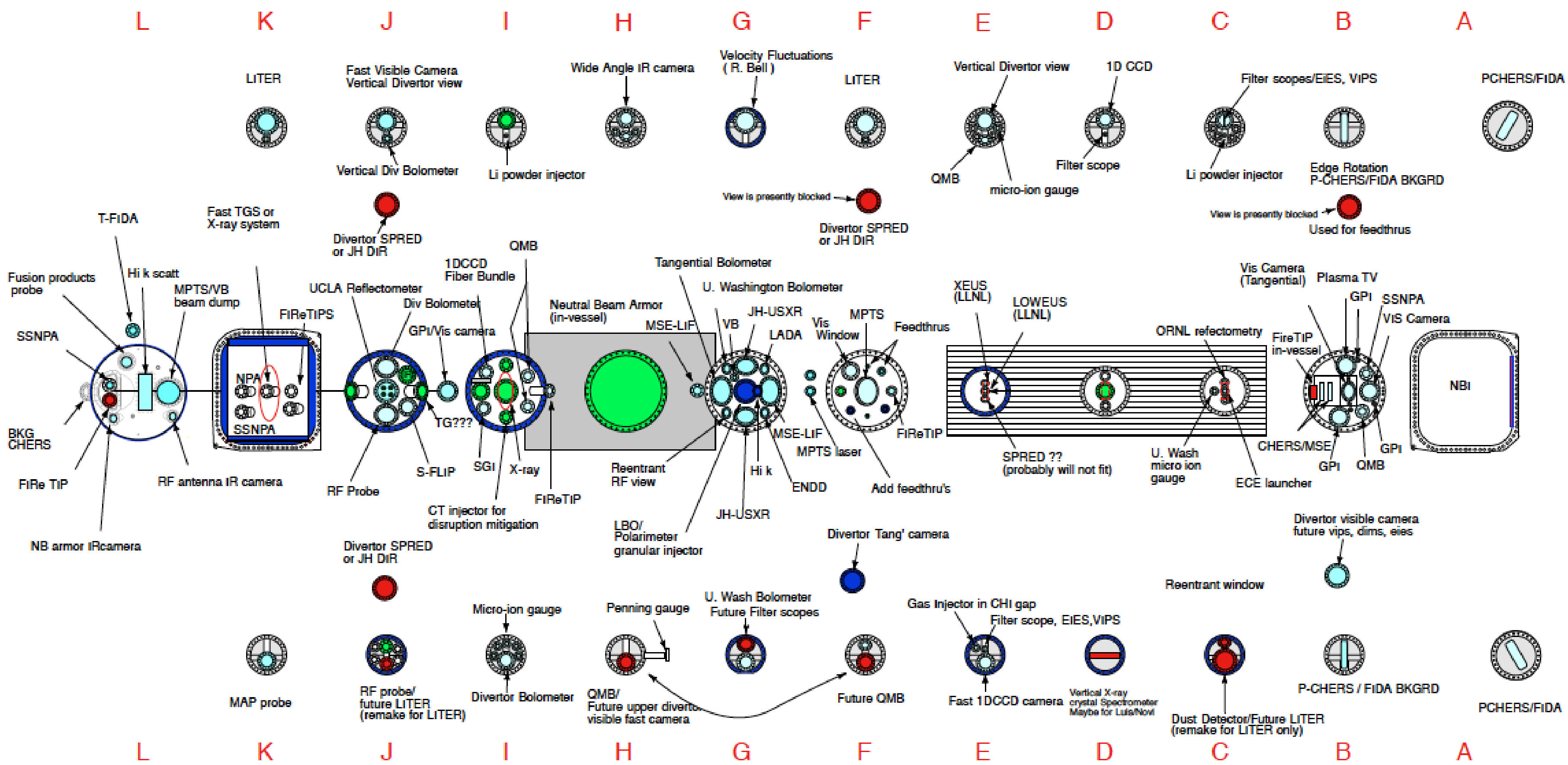
NSTX-U double-null | NSTX-U double-snowflake-plus | NSTX-U double-snowflake-minus



- The PF-2 coils may be upgraded to bipolar operations. This will allow those coils to either create the snowflake divertor or to control the lower plasma-wall gap in the high-triangularity shapes, without changes to the power supply links.

- The PF-1B coil, which will not be powered during initial upgrade operations, may be important for maintaining a steady snowflake divertor through the full OH swing.

NSTX-U facility/diagnostics port assignment
Port flanges designed and ordered



Plans to Rapidly Recover Physics Operations Capabilities

ISTP:
(Integrated Systems Test Procedure)
Establishes facility in state of readiness for operations.

Plasma Operations with:
$I_p \leq 1.0$ MA, $B_T \leq 0.5$
Develop:
Breakdown and current ramp scenarios
Shape & position control
Reliable H-mode
Diagnostic operations

Continue to add diagnostic & control capabilities while initiating physics experiments.

$I_p \leq 1.5$-1.6 MA
$B_T \leq 0.75$-0.8

July-Sept. 2014

ISTP-1 & CD-4 Prep	MPTS Calibrations, Bake Out, CD-4	Operations Commissioning	Phys. Ops	ISTP-2	Phys. Ops

~ 2-3 Months

Attempt 50 kA CD-4 plasma before bake-out. If water in PFCs prevents success, then repeat after bake-out.

ISTP-2
Required to increase the field and current for later research phase

Surface Analysis Facilities to Elucidate Plasma-Surface Interactions

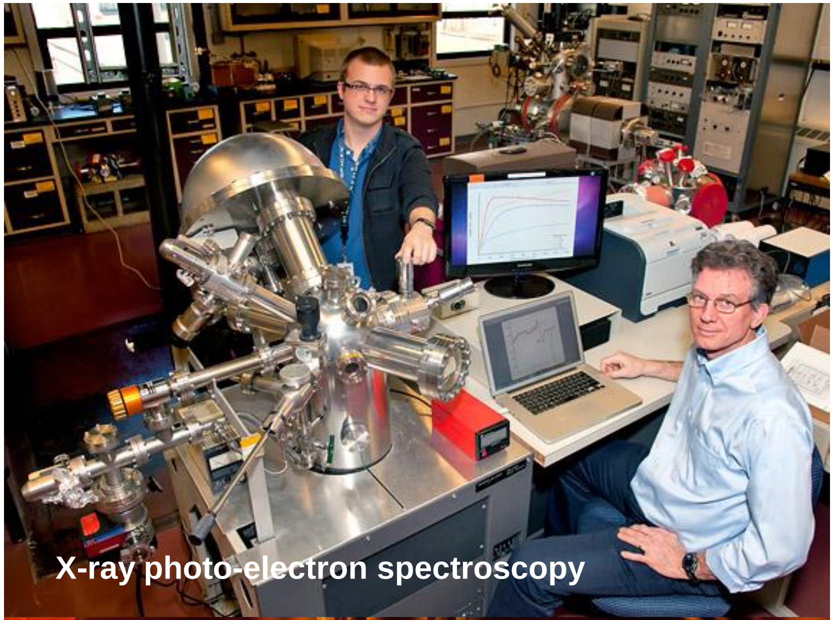
PPPL Collaboration with B. Koel et al., Princeton University

- **The Surface Science and Technology Laboratory (SSTL) with three surface analysis systems and an ultrahigh vacuum deposition chamber.**

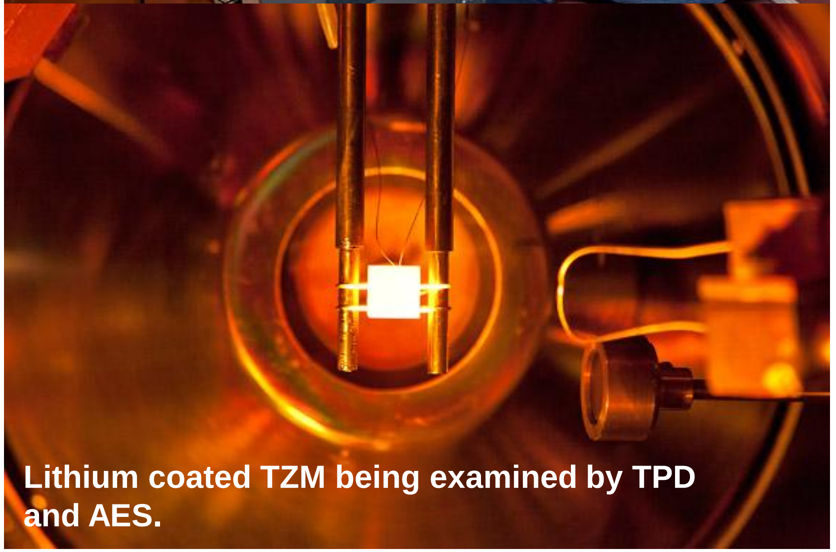
- **The Surface Imaging and Microanalysis Laboratory (SIML) with a Thermo VG Scientific Microlab 310-F High Performance Field Emission Auger and Multi-technique Surface Microanalysis Instrument.**

- **Recently solid lithium and Li coated TZM were examined using X-ray photoelectron spectroscopy (XPS), temperature programmed desorption (TPD), and Auger electron spectroscopy (AES) in ultrahigh vacuum conditions and after exposure to trace gases.**

- **Experiment on SSTL determined that lithiated PFC surfaces in tokamaks will be oxidized in about 100 s in the expected NSTX-U vacuum conditions.** (C. H. Skinner et al., PSI_20 accepted to J. Nucl. Mater.)



X-ray photo-electron spectroscopy

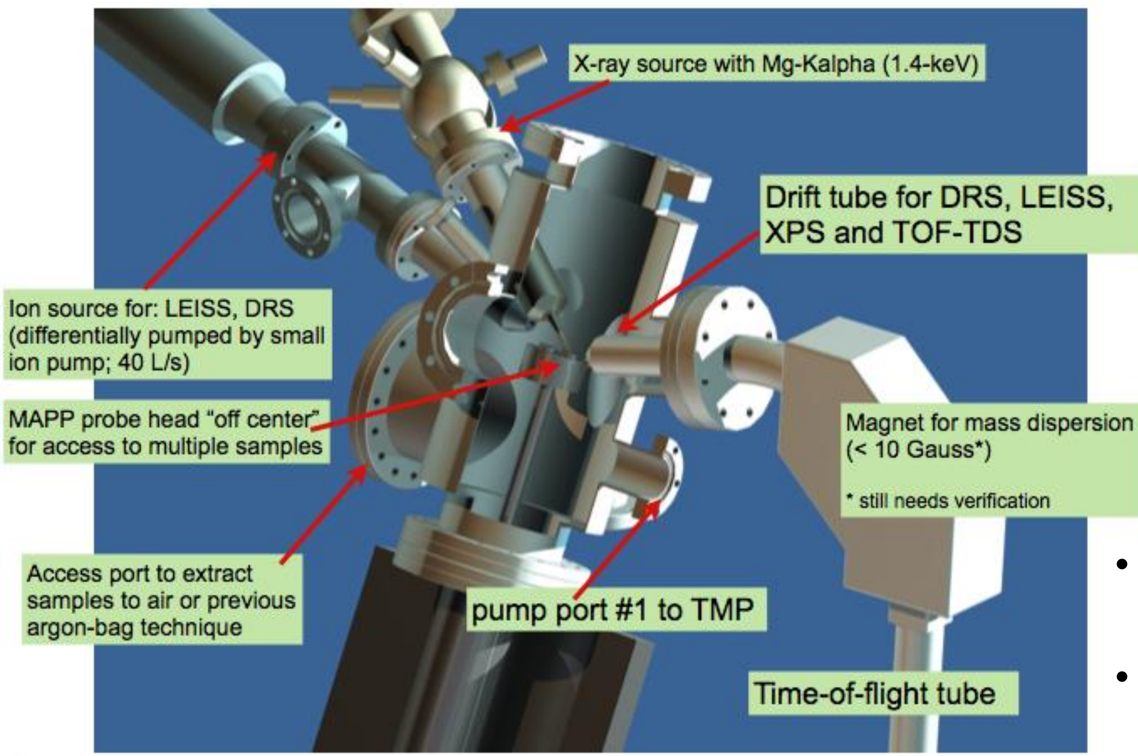


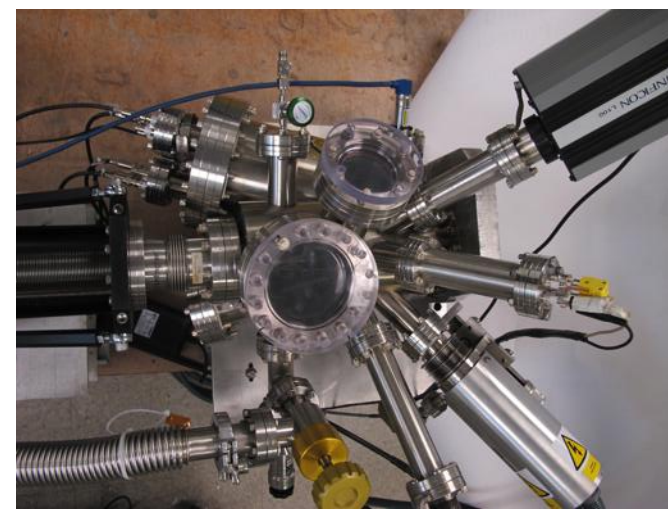
Lithium coated TZM being examined by TPD and AES.

Materials Analysis and Particle Probe – MAPP –

to relate PFC surface conditions and plasma behavior in "real time"

- **PFC analysis after run is difficult to relate to plasma behavior**
  - **Reflects cumulative effect of multiple evaporations and surface compound formation**
  - **Hard to determine determine surface conditions during any specific discharge**
- **MAPP provides in-situ and between-shots solution**
  - **PFC sample can be exposed during shot and withdrawn for between-shots analysis**





- **MAPP chamber showing diagnostics for sample analysis**
- **MAPP will be tested on LTX during outage**

J.P. Allain (Purdue), R. Kaita, et al.,