NSTX-U Project Status

Masa Ono

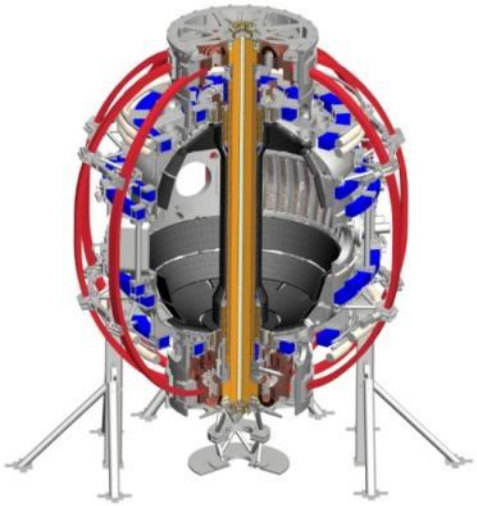
for the NSTX-U Team

NSTX-U FY 2013 Q4 Review Meeting

October 22, 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
UC Irvine
UCLA
UCSD
U Colorado
U Illinois
U Maryland
U Rochester
U Washington
U Wisconsin

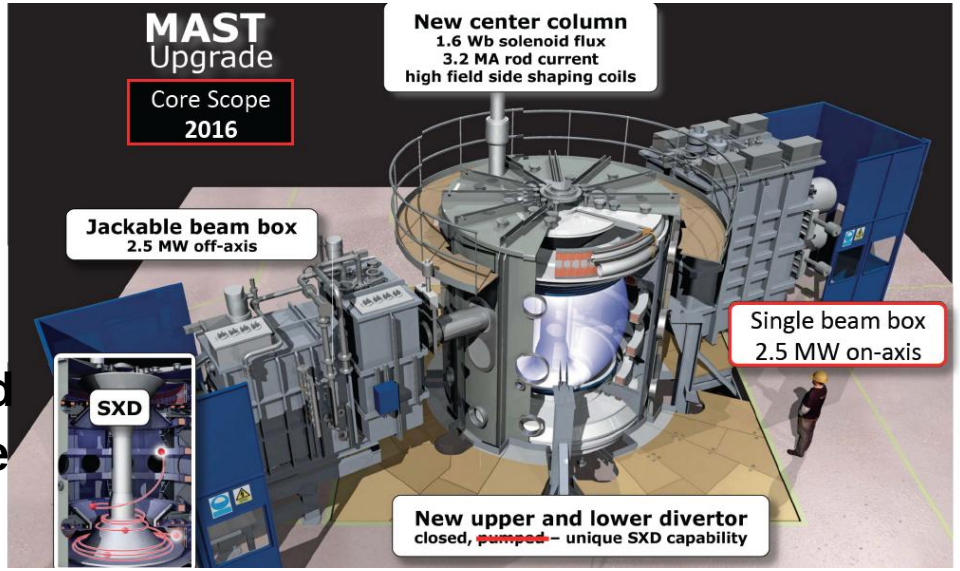
Culham Sci Ctr
U St. Andrews
York U
Chubu U
Fukui U
Hiroshima U
Hyogo U
Kyoto U
Kyushu U
Kyushu Tokai U
NIFS
Niigata U
U Tokyo
JAEA
Tsukuba U
Hebrew U
Ioffe Inst
RRC Kurchatov Inst
TRINITI
NFRI
KAIST
POSTECH
SNU
ASIPP
ENEA, Frascati
CEA, Cadarache
IPP, Jülich
IPP, Garching
ASCR, Czech Rep



International ST Workshop in York UK

Sept 16 – 19, 2013, http://www.york.ac.uk/physics/ypi/istw2013/

- NSTX-U related presentations were NSTX Upgrade Project (M. Ono), NSTX Upgrade Program (J. Menard), FNSF Design (J. Menard), CHI (B. Nelson, UW), HHFW Theory/Modeling (M. Peng, ORNL)
- Many nice science talks particularly from the MAST team.
- MAST-U generated 70 kA with 70 kW of ECH at 28 GHz. QUEST also generated ~ 65 kA with ECH at 28 GHz.
- A. Sykes of Tokamak Solutions talked about very compact ST reactor concept with R_0 ~ 1 m using high temperature SC with minimal neutron shields.
- GLOBUS-M is now upgrading the machine for GLOBUS-M2. It aims to increase the toroidal field B_T and plasma current I_p by a factor of 2.5 to 1 T and 0.5 MA.
- MAST has concluded its operation and started its upgrade outage. Plan to be operational by 2016.



Third International Li Symposium in Rome, Italy

Oct. 7 - 11, 2013, http://www.isla2013.enea.it

- Over 50 presentations from US, China, Russia, Japan, Italy, and Spain, Israel, Latvia, Ukraine, Kazakhstan, Greece, and Netherlands. Fusion Devices: FT-U NSTX, HT-6, EAST, T-10, T-11M, RFX, TJ-2, Lithium Facilities: IFMIF, KTM, UI, MAGNUM-PSI, TJ-2.
- NSTX Invited: "RLLD/ARLLD" by M. Ono, "High-temperature, LL plasma-facing component research for NSTX-U" by M. A. Jaworski, and "Li sputtering from lithium-coated graphite plasma facing components in NSTX divertor" by F. Scotti (PU).
- NSTX Orals: "Divertor deuterium recycling and oxygen influxes in Li experiments on NSTX" by V. A. Soukhanovskii (LLNL), "Measurements and Interpretive 2D Edge Modeling of Lithiated NSTX Discharges" by T.K Gray (ORNL), "Erosion and re-deposition of Li coatings on TZM molybdenum and graphite during high-flux plasma bombardment" by T. Abrams (PU), "An apparatus for the repetitive injection of Li granules into fusion research devices" by D. K. Mansfield, "A LL dripper for fueling and ELM pacing in NSTX-U" by D. Andruczyk (UI), and "E-beam flash evaporator for NSTX-U" by A.L. Roquemore.
- NSTX Poster: "Effect of Charge Exchange on Lithium Cooling in the Tokamak Scrape-Off Layer near the Divertor Surface" by M. Constantin (PU).
- R. Nygren (SNL) led a special session on Lithium-Safety and Lithium Handling,
- R. Goldston (PPPL) led a Panel Discussion on lithium feasibility for fusion reactors.

Successful Implementation of FY13 Milestones

Mainly Through Data Analyses, Theory/Modeling, and Collaborations

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. Stefan Gerhardt of NSTX-U coordinated the FY 2013 JRT and the final report has been submitted to DOE.

FY 2013 NSTX-U Milestones

Research	Milestone Description	Baseline	Achieved
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	Achieved
F(13-1)	Complete procurement of components and begin installation of refurbished D-Site Rectifier Firing Generators	Sep 13	Sep 13

Diagnostics	Milestone Description	Baseline	Achieved
D(13-1)	Complete final design of the Multi-Pulse Thomson Scattering (MPTS) diagnostic modifications and begin installation of the modifications	Sep 13	Sep 13

F(13-1) *Complete procurement of components and begin installation of refurbished D-Site Rectifier Firing Generators*

- **The D-site rectifiers (74 identical Transrex AC/DC Convertors of the NSTX Field Coil Power conversion System (FCPC)) provide a pulsed power capability of 1800 MVA for 6 seconds every 300 seconds.**
- **The new 34 Firing Generator (FG) delivers firing pulses to 68 convertors with far greater resolution, precision, and repeatability for NSTX-U. Becomes particularly critical for the new 8-parallel, 130kA TF system configuration.**

Status:

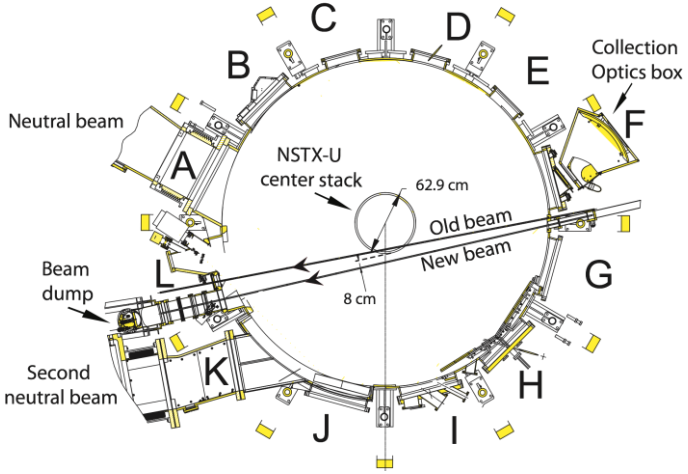
- **All 34 Firing Generators have been completed and delivered to FCPC. More than half have been installed in rectifiers.**
- **Fiber-optic control/communication links to be installed by end of November. Controls testing is expected to be complete by the end of the CY.**
- **Open circuit rectifier testing will be in progress by the early spring. Multiple rectifier power testing is expected by June, 2014.**

Transrex AC/DC Convertors

D(13-2) Complete final design of the Multi-Pulse Thomson Scattering (MPTS) diagnostic modifications and begin installation

- **Modification of the MPTS system is needed to accommodate the larger diameter NSTX-U Center Stack - Re-aim the laser beam, the light collection optics, redesign the beam dump, and calibration probe to be ready for the first plasma.**

MPTS Midplane Cross Section



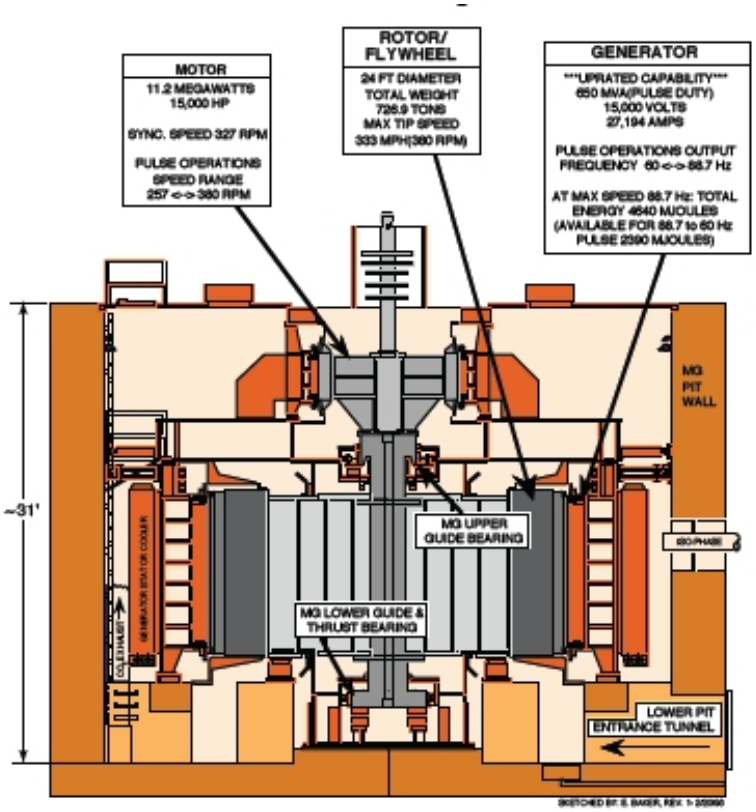
FY 13 Accomplishments:

- **Design of the reconfigured MPTS system to meet these requirements was completed in FY2013 and three final design reviews were held to validate the design of the ex-vessel components.**
- **The new laser exit port and the new laser input port were installed on the vacuum vessel in FY2013.**
- **Fabrication and procurement of many of the needed ex-vessel components is underway and fabrication drawings for the remaining ex-vessel components are being prepared.**
- **The reconfigured MPTS diagnostic will be installed in FY2014 prior to NSTX-U first plasma and commissioned in early experimental operation following first plasma.**

- **Ahmed Diallo recently received an Early Career Research Program award - will install a fast rep rate (10-15 kHz) burst mode (5 ms) third laser for studies of ELMs and other fast phenomena in FY15.**

Repair of the Motor Generator (MG#1)

- In 2004, Magnetic Particle Inspections identified cracking in the weld fillet of multiple joints between the radial arms of MG#1. Cracks were in primary load paths, taking that set out of service. MG#2 is in limited operations (run and monitor at reduced parameters) with cracks in "stiffener" welds intended to limit elastic deformation (not in primary load paths).
  - Over 250" of welds in 19 rotor spider joints will be ground out and replaced to restore MG#1 to its original design configuration.
  - A jacking system has been engineered to relieve all loads on the rotor assembly during the repair.
  - PPPL and GE engineering collaborated on the detailed repair procedure (D/NSTX-RP-MG-07).

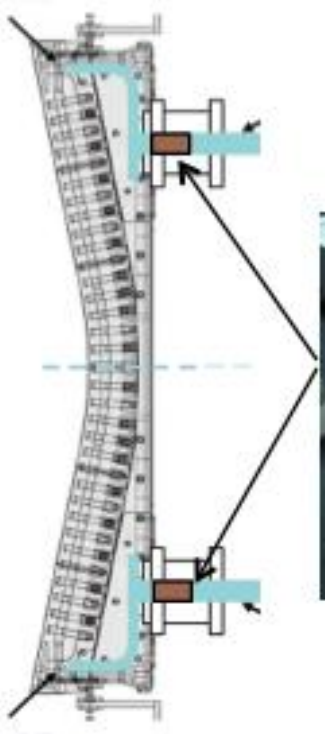


Status: Target completion date in Feb. 2014

- A Statement of Work to perform the scope described in the repair procedure has been reviewed and approved.
- Fixed-price proposals for the weld repairs have been received. A WAF capturing all project costs (PPPL and Sub-contractor) is being generated.
- A draft Project Management Plan has been developed.

New Compliant HHFW Antenna Feeds

Will allow antenna feedthroughs to tolerate 2 MA disruptions



Prototype electroformed compliant section

Installation on feed-thru

HHFW antenna tests planned in RFTF

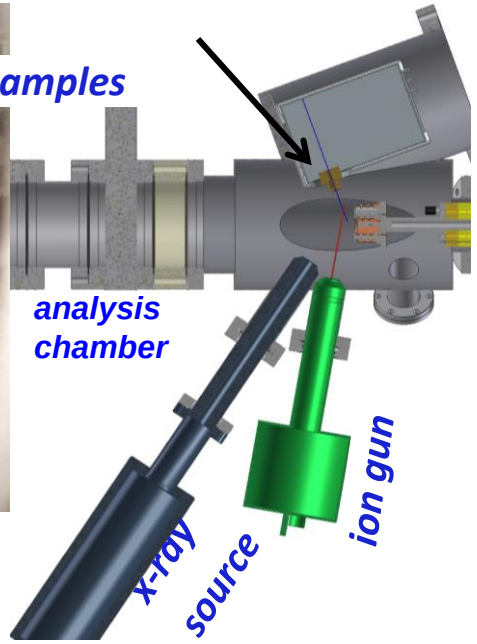
Inside of RF Test Stand with one antenna assembly.

- Prototype feeds procured.
- Feeds to be tested in the RF test-stand before FDR, installation in spring 2014.

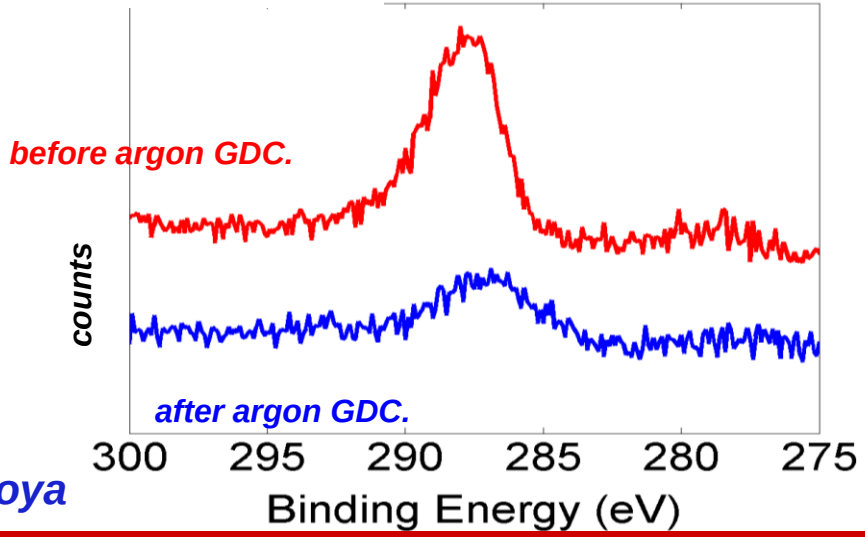
MAPP measurements of LTX surface after wall conditioning

Contributed to R13-2 Milestone

- The Materials Analysis Particle Probe (MAPP) enables the prompt analysis of components exposed to tokamak plasmas.
- Lithium Tokamak Experiment is dedicated to the study of liquid lithium as a plasma-facing component (PFC).
- Argon Glow Discharge Cleaning (GDC) on LTX:
  - doubled the tokamak plasma current to > 20 kA
  - extended the duration to 25 – 30 ms.
- MAPP X-ray photo-electron spectroscopy showed reduction of surface carbon with GDC.
- Direct measurements of effect of GDC on surface of tokamak plasma-facing components.



Carbon XPS spectra



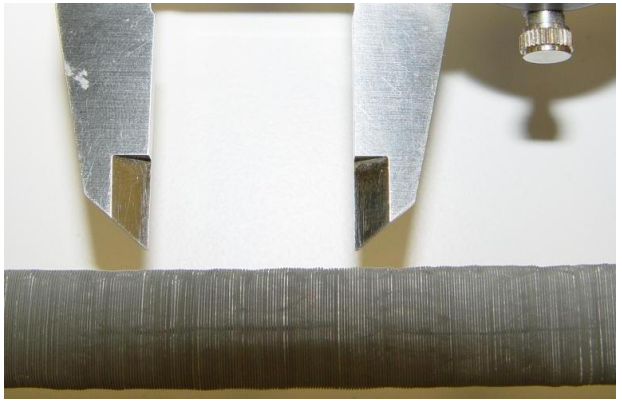
R. Kaita, M. Lucia J.P. Allain, F. Bedoya

Most Center Stack Diagnostics Fabricated

- **Manufacture of Mirnov coils and Rogowski coils complete**
  - **Includes extra Mirnov coils and "segmented" Rogowski coils for halo current measurements**
- **All copper and thermocouple wires procured**
  - **Satisfy specialized material and insulation requirements for installation under plasma-facing components**
- **Graphite Langmuir probe tips complete**
  - **Fabrication of all center stack diagnostic components will be finished when insulators for probes in tiles are machined**
- **Procedures nearly complete for installation of diagnostics when center stack is ready**

Plasma Current Rogowski Coil

Halo Current Rogowski Coil



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

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

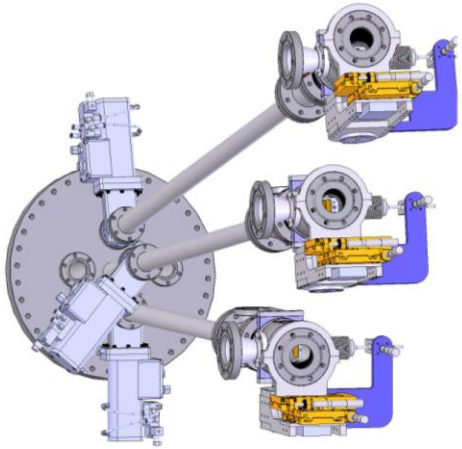
New capability, Enhanced capability

New Port Covers Have Been Designed For Bays E, I, J, and L

Detailed Design to Accommodate Enhanced NSTX-U Diagnostic Access Needs

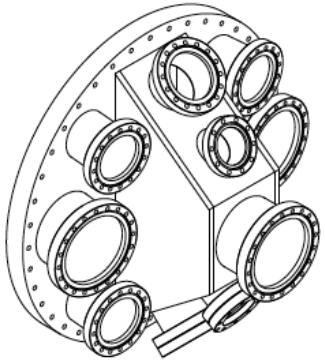
Bay E Supports 3

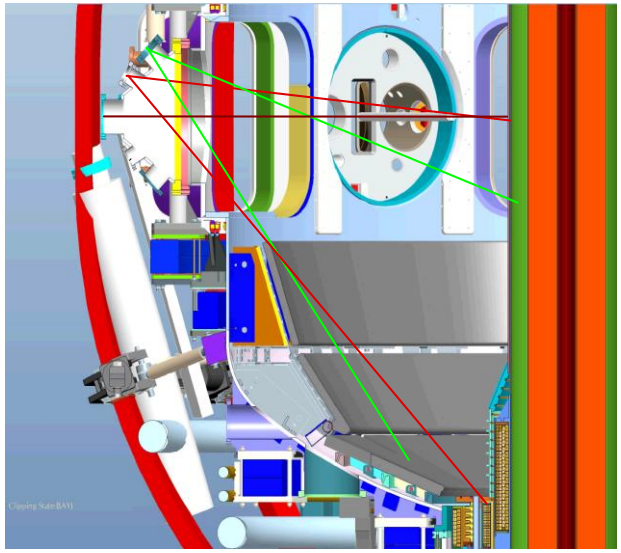
UV Spectrometers (LoWEUS, XEUS, MonaLisa) and MIG1



Bay J Supports

IR and Visible Cameras, UT-K and Divertor Spectrometers, Upward LITER, UCLA Reflectometer and Polarimeter, LBO, RF Probe.

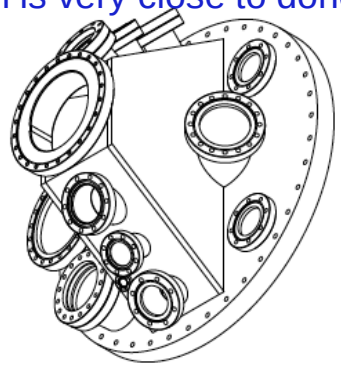


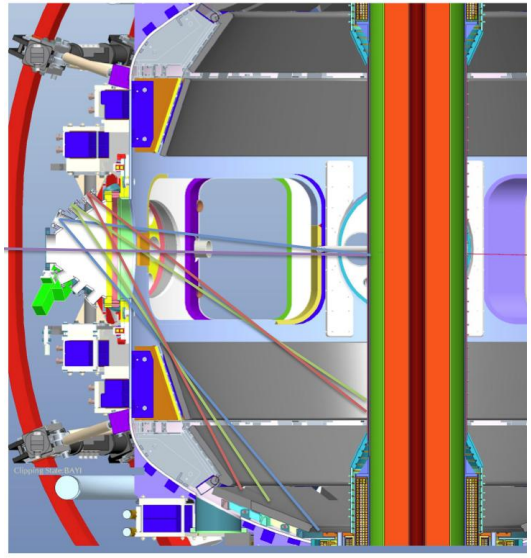


Bay I Supports

XCS, TGS, IR & Visible Cameras, SSNPA, SGI, 1D CCD & EIES, Microwave Imaging, QMB, Bolometers

Design is very close to done.



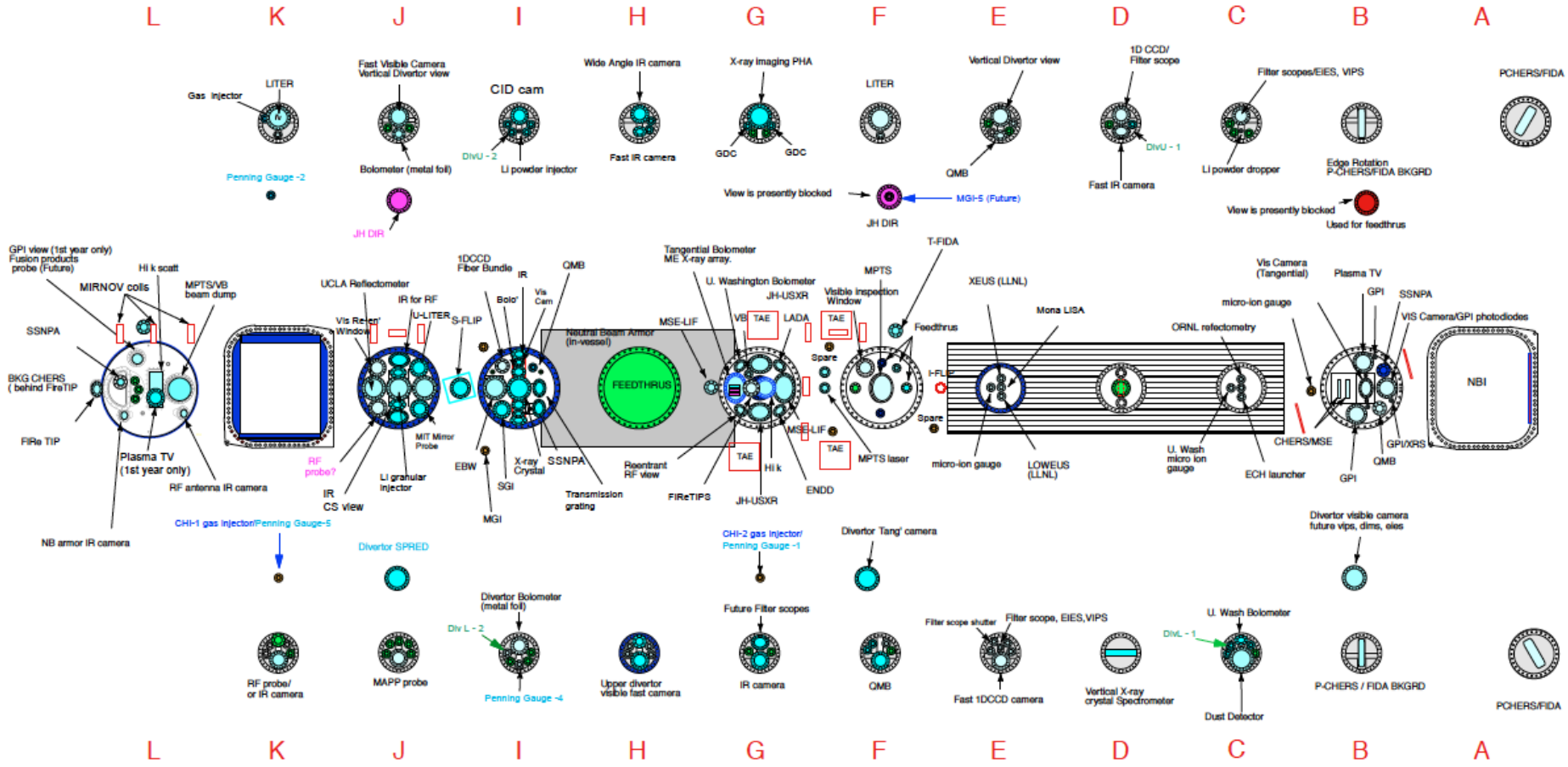


Bay-L Cap (not shown) Supports

MPTS exit window, High-k exit, plasma TV+GPI view, SSNPA, spectroscopy & CHERS view, GDC feedthroughs, magnetics feedthroughs.

NSTX-U facility/diagnostics port assignment

Port flanges designed and being procured



Engineering and Diagnostic Development/Operations Supporting Numerous Diagnostic Upgrades

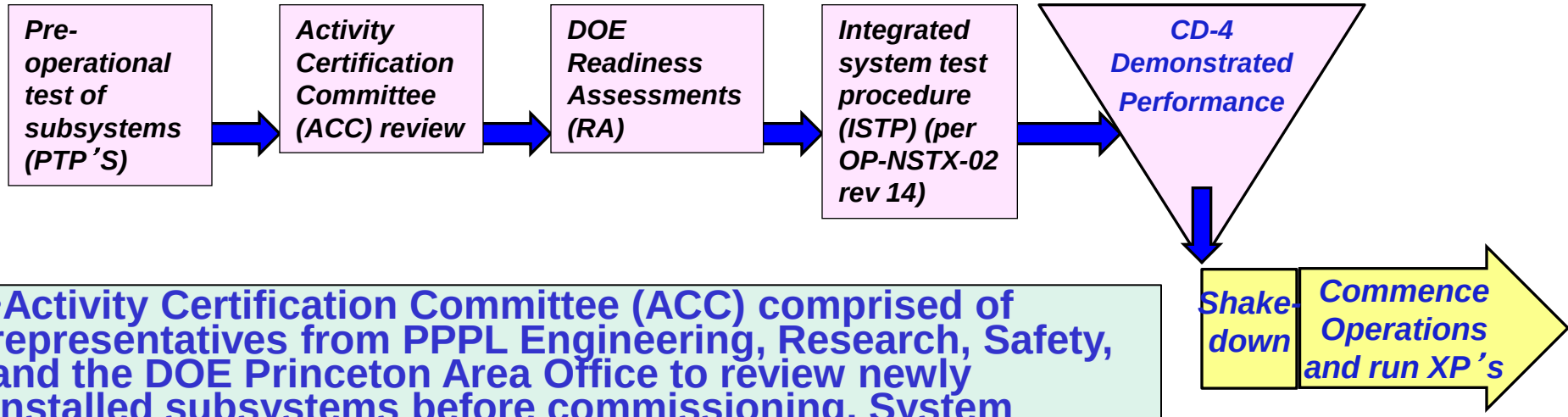
- **Oct. 1 - Dec. 13: Basic diagnostic interface installation, first calibrations.**
- **Dec. 16 - Feb. 28: Test pump-down, leak checking and repair.**
- **March 1 - April 15: Finish diagnostic installations and calibration.**

- **Mid-plane Port Covers:**
  - **Bay E port cover is finished and ready for installation.**
    - **Supports suite of LLNL EUV instruments.**
  - **Bay J port cover is nearly finished…needs some modifications at vendor.**
    - **Supports LITER, Reflectometer & Polarimeter, RF Probe, various spectroscopy**
  - **Bay I port cover design is at the vendor…working out final details of their fabrication plan.**
    - **Supports SSNPA, TGIS, Bolometry,XICS, IR Cameras, QMB,…**
- **Diagnostic systems that are unchanged will be installed as part of a generic procedure.**
- **Diagnostic systems that are new or heavily modified will need dedicated installation procedures.**
- **Key near term task: get as many diagnostic vacuum interfaces as possible on machine by December.**

Transition into 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.



- Activity Certification Committee (ACC) comprised of representatives from PPPL Engineering, Research, Safety, and the DOE Princeton Area Office to review newly installed subsystems before commissioning. System reviews are performed at completion of construction activities.
- Led by the DOE Princeton Site Office (PSO), a Operational Readiness Assessment (ORA) will be made based on ACC and QA Audit reports before the project moves to start-up.
- Safety Certificates allowing Power and then Plasma Operation will be issued upon the recommendations of the ORA.

NSTX-U Coil Energization

- A programmable Digital Coil Protection System (DCPS) with control algorithms appropriate for NSTX-U parameters is being developed to protect both coils and structures.
- Includes data acquisition, user interfaces, auto-testing, and standalone codes for algorithm verification and scenario development.
- Systems are currently being installed with plans to begin pre-operational testing in Feb. 2014, and full system commissioning in June 2014.
- 1st year operating space parameters will be established and control algorithms verified.
- Same algorithms will be applied to the Power Supply real Time Control System (PSRTC).
- DCPS/PSRTC systems will be configured to support limited FCPC rectifier dummy load testing in Mar. 2014.

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

Aug-Nov. 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

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

NSTX-U Operation Preparation Well Underway

Exciting Opportunities and Challenges Ahead

- **NSTX-U Team has been quite productive in all areas.**
- **NSTX-U researchers participated strongly in ISTW-2013 (STs) and ISLA-2013 (Lithium) workshops.**
- **All of the NSTX-U FY 2013 milestones accomplished on schedule.**
- **NSTX upgrade outage activities are progressing well**
  - **Diagnostics were stored and secured for the upgrade activities. Collaborator diagnostics are being refurbished and enhanced.**
  - **Researchers are working productively on data analysis, collaboration, preparation for the NSTX-U operation.**
  - **NSTX operations technical staff were shifted to the Upgrade Project tasks in FY 2012 – 13. They will be shifted back to the NSTX-U operational preparation in FY 2014 as the Upgrade Project scopes are completed.**
  - **NSTX Upgrade Project is thus far progressing on budget and on schedule.**
  - **NSTX-U operational preparation is well underway.**
  - **Diagnostic reinstallation are starting.**
  - **Various engineering operations tools are being refurbished / upgraded including CHI gap, rectifier control, motor generator, plasma control system, and PF control.**