NSTX Accomplishments and NSTX-U Research Plans in Support of Fusion Next-Steps

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X Science LLC

Jon Menard (PPPL)

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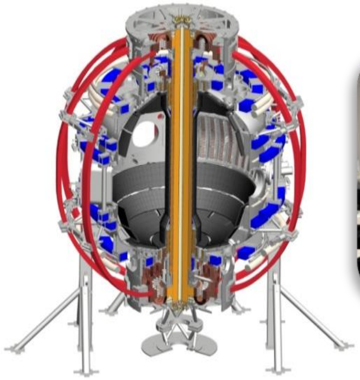
25th Symposium on Fusion Engineering (SOFE)
June 10-14, 2013
The Stanford Court Hotel
San Francisco, California



Culham Sci Ctr
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Kyoto U
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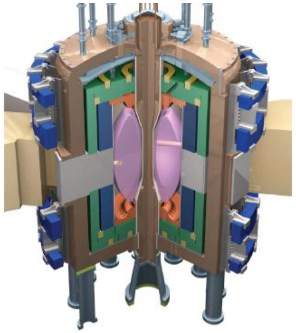
ASIPP
CIEMAT
FOM Inst DIFFER
ENEA, Frascati
CEA, Cadarache
IPP, Jülich
IPP, Garching
ASCR, Czech Rep

Outline

- NSTX-U mission and capabilities
- NSTX results highlights, NSTX-U goals
  - Non-inductive current drive
  - Heat-flux mitigation
- Progress toward completing NSTX-U Project
- Proposed longer-term (5 year plan) enhancements
- Summary

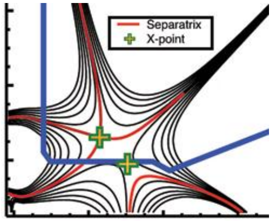
NSTX Upgrade mission elements

- **Advance ST as candidate for Fusion Nuclear Science Facility (FNSF)**
  - Motivation for ST as FNSF: high neutron wall loading, potentially smaller size, cost, and tritium consumption, accessible / maintainable
- **Develop solutions for the plasma-material interface challenge**
  - Exploit strong heating + smaller R → high P/R and P/S approaching FNSF/Demo levels
- **Explore unique ST parameter regimes to advance predictive capability - for ITER and beyond**
  - Fast-ion instabilities and transport
  - Electromagnetic turbulence
  - High β, rotation, shaping, for transport, MHD
- **Develop ST as fusion energy system**

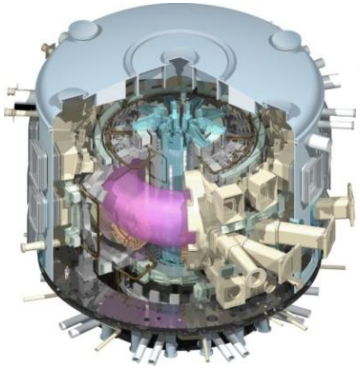


ST-FNSF

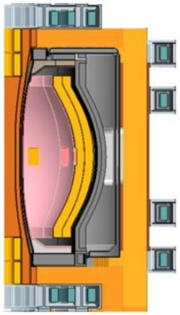
Lithium



"Snowflake"



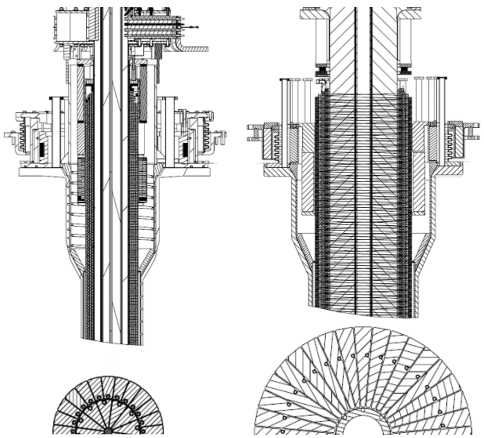
ITER



ST Pilot Plant

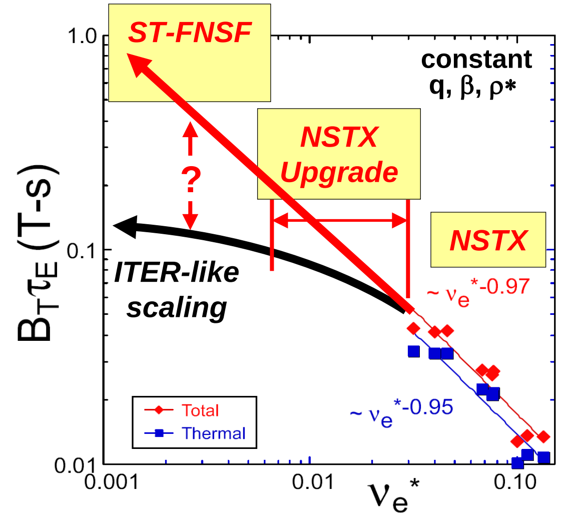
NSTX Upgrade incorporates 2 new capabilities:

Previous center-stack | New center-stack

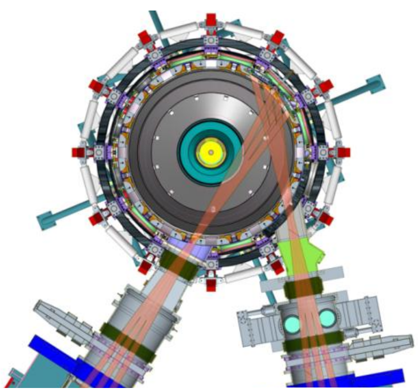


TF OD = 20cm | TF OD = 40cm

- Expect 2x higher T by doubling B_T, I_P, and NBI heating power
  - Reduces ν^* → ST-FNSF values to understand ST confinement
- 5x longer pulse-length
  - q(r,t) profile equilibration
  - Test non-inductive ramp-up

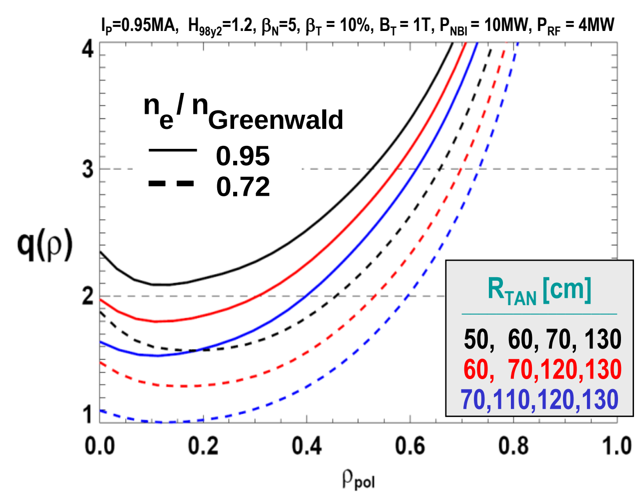


Normalized e-collisionality $\nu_e^* \propto n_e / T_e^2$



Present NBI | New 2nd NBI

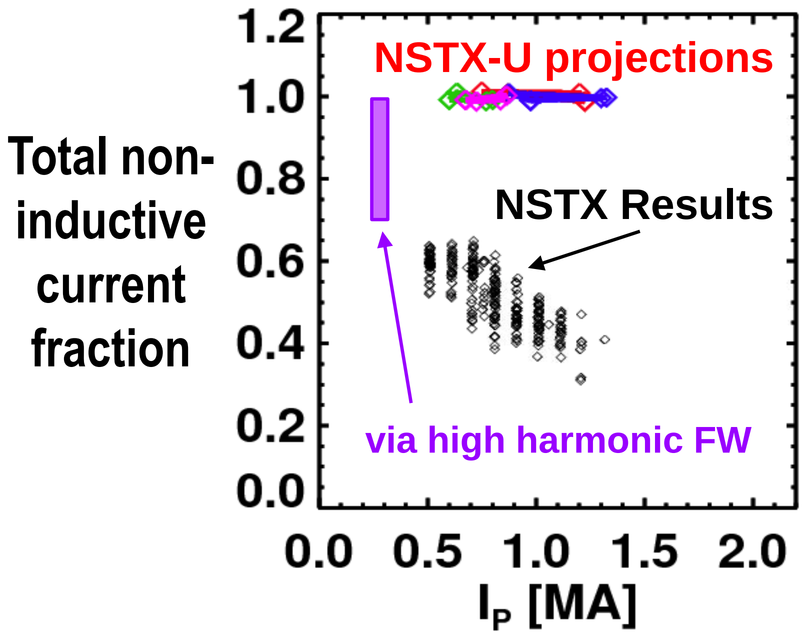
- 2x higher CD efficiency from larger tangency radius R_{TAN}
- 100% non-inductive CD with core q(r) profile controllable by:
  - NBI tangency radius
  - Plasma density, position (not shown)



100% non-inductive current drive is essential for steady-state operation of AT/ST next-steps – including FNSF

NSTX achieved:

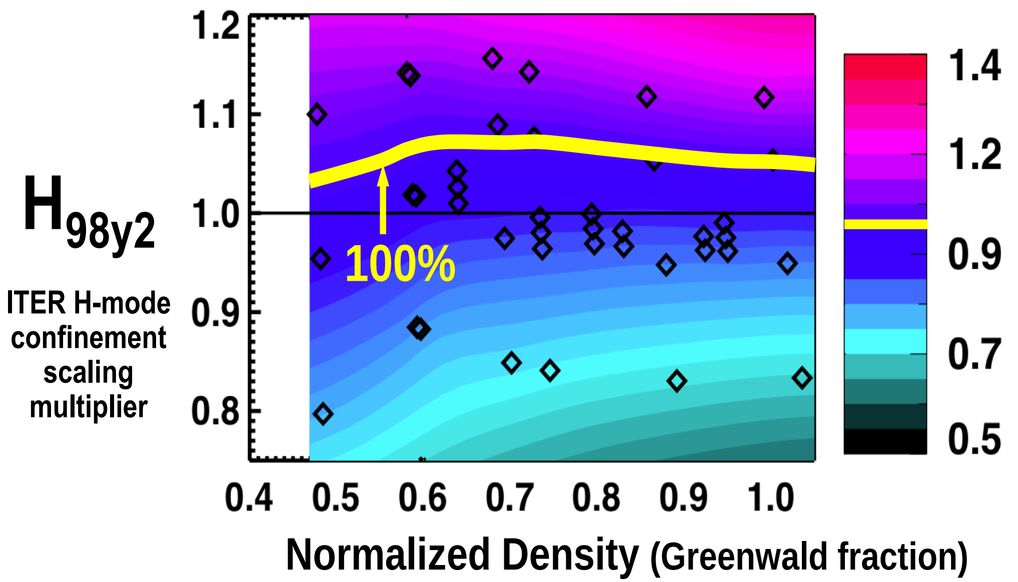
- Maximum sustained non-inductive fractions of 65% w/NBI at I_P = 0.7 MA
- 70-100% non-inductive transiently with HHFW current-drive + bootstrap



NSTX-U projections (TRANSP):

- 100% non-inductive at I_P = 0.6-1.3MA for range of power, density, confinement

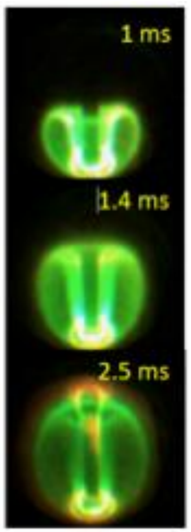
Contours of Non-Inductive Fraction

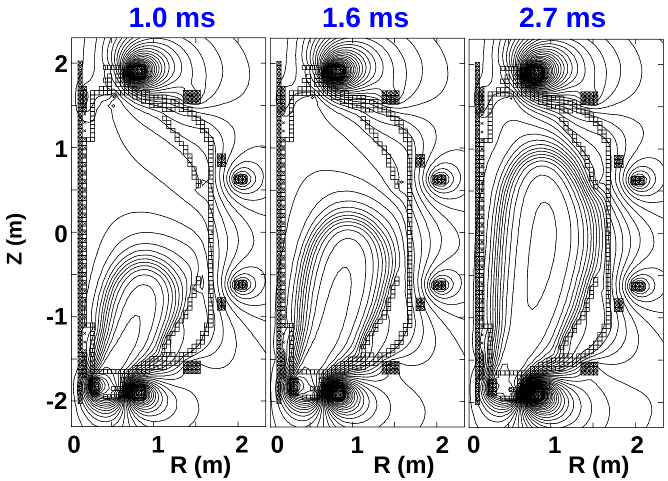


I_P=1 MA, B_T=1.0 T, P_{NBI}=12.6 MW

Simulations indicate NSTX-U can test plasma initiation with small or no transformer – required for an ST-based FNSF

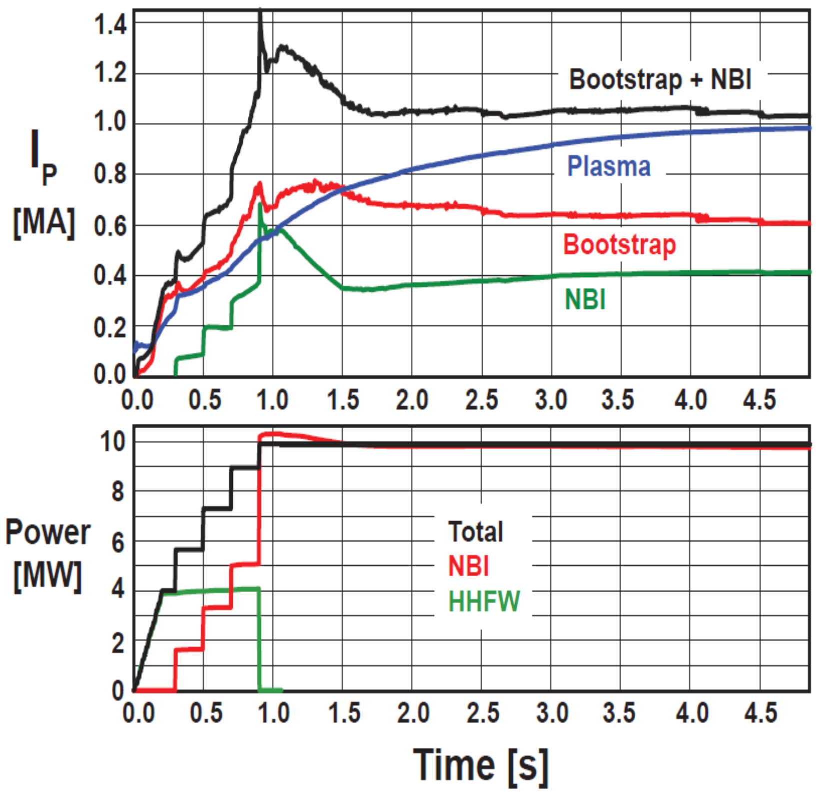
- TSC code (2D) successfully simulates CHI I_P ~200kA achieved in NSTX



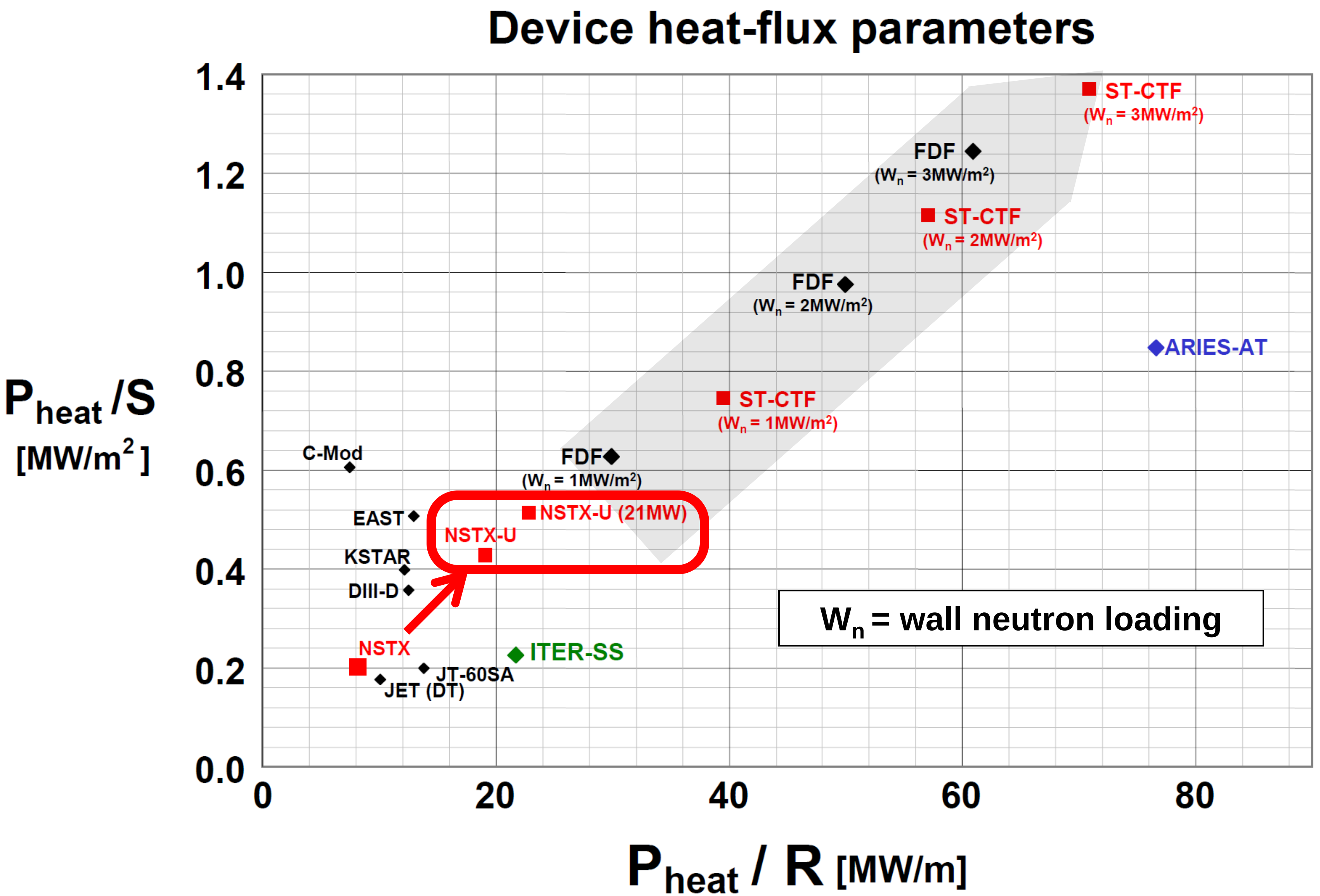


- TSC + proposed tools support CHI I_P → 400kA in NSTX-U
  - Higher injector flux, B_T, and CHI voltage
  - 1MW 28GHz ECH (increases T_e)

- TRANSP: NSTX-U more tangential NBI → 3-4x higher CD at low I_P (0.4MA)
- TSC: non-inductive ramp-up from 0.4MA to 1MA possible w/ BS + NBI

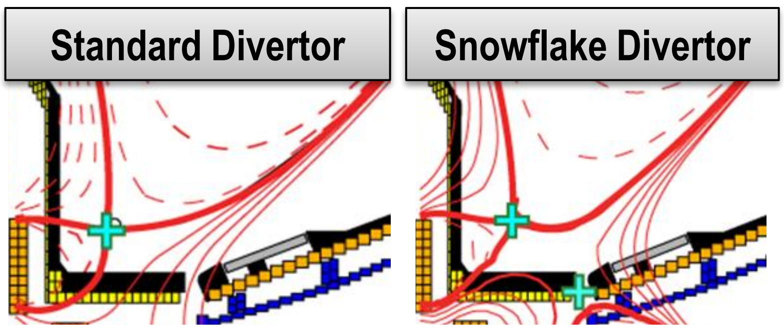


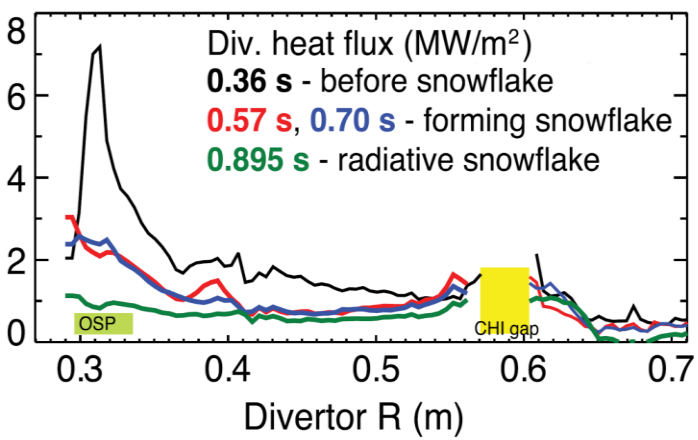
NSTX Upgrade will extend normalized divertor and first-wall heat-loads much closer to FNSF and Demo regimes



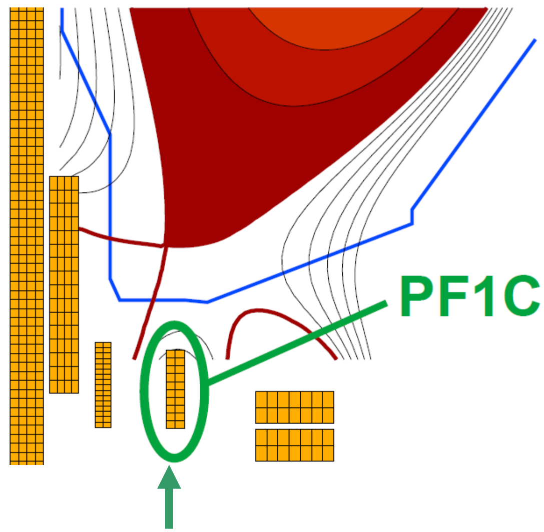
NSTX-U will test ability of radiation and "snowflake" divertor to mitigate very high heat-fluxes

- NSTX: reduced heat flux 2-4× via partial detachment (radiation)
- Snowflake → additional x-point near primary x-point
  - Lower B_P → high flux expansion = 40-60 lowers incident $q_{\perp}$
  - Longer field-line-length promotes temperature drop, detachment





NSTX-U peak heat fluxes will be up to 4-8× higher than in NSTX



NSTX-U has additional coils for up-down symmetric snowflakes, improved control

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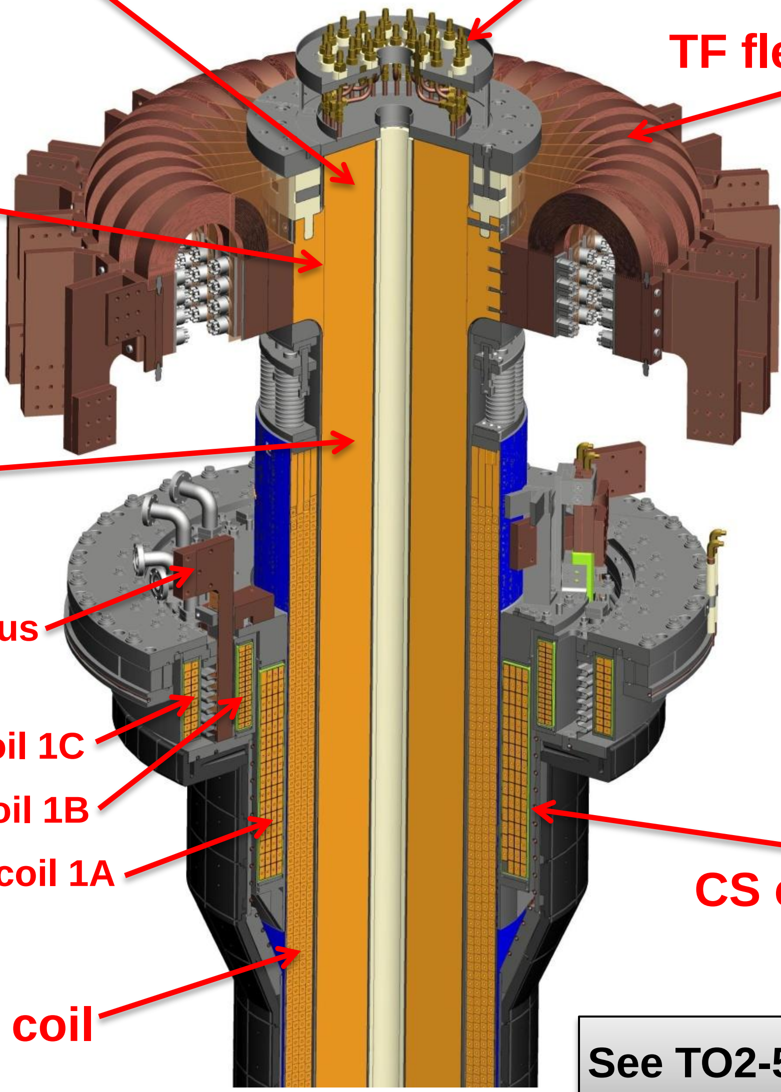
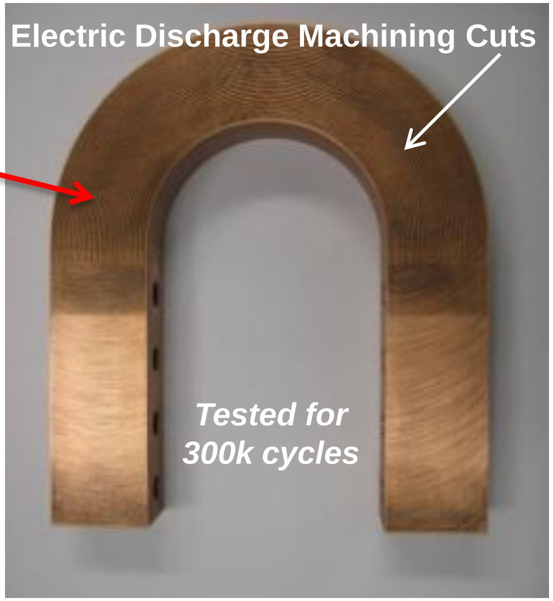
Improved center-stack design to handle increased forces
Identical 36 TF conductors and innovative flex-bus design





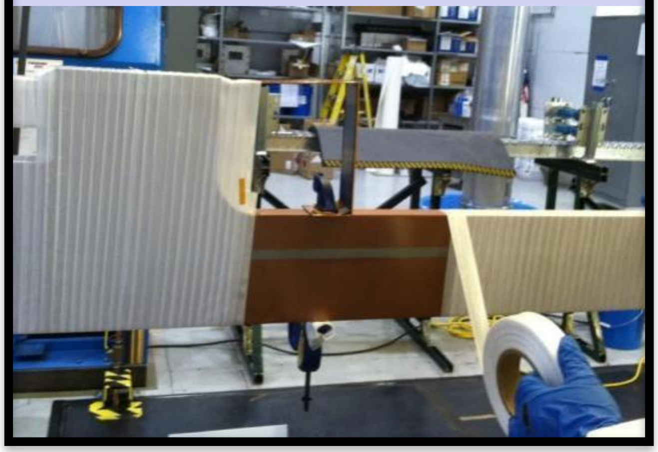
See TO2-5 by S. Raftopoulos today at 12:15PM

Center-stack fabrication & assembly proceeding well

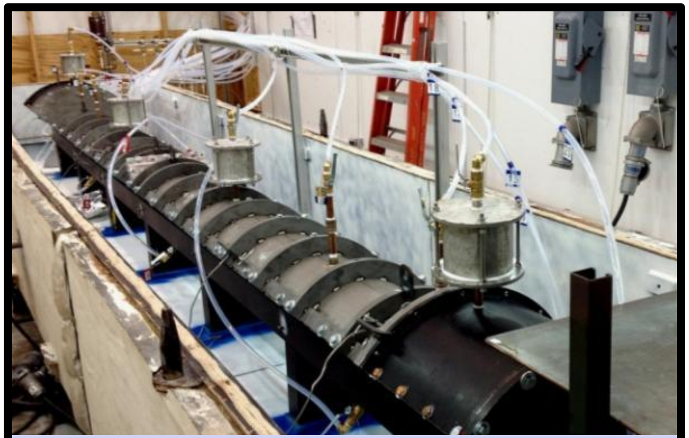
Innovative manufacturing techniques developed

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 (VPI) w/ CTD-425

3 of 4 quadrants successfully VPI'd !

Substantial structural and vacuum vessel upgrades

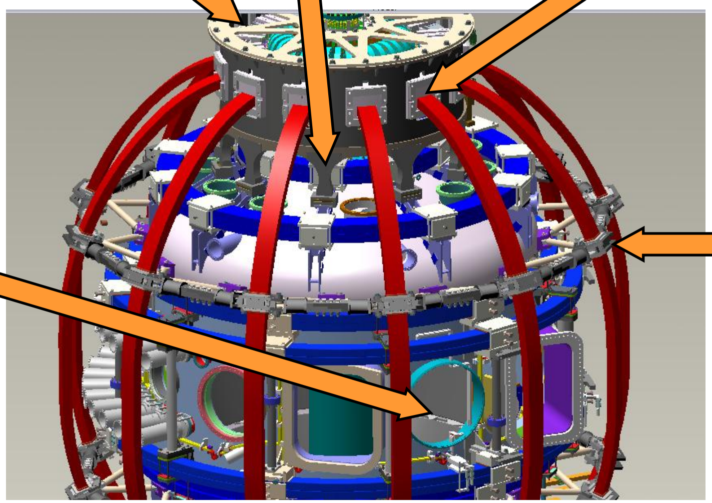
Must handle 4x higher electromagnetic loads

Upper Aluminum Block Internal Reinforcements

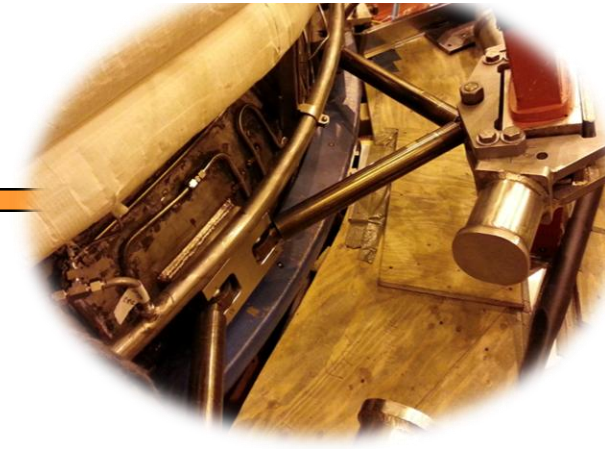
Upper Umbrella Arch Reinforcements

Upper Aluminum Block External Reinforcements

Bay-L Cap



TF-Vessel Clevis, TF Outer Leg Support



Relocation of the 2nd NBI beam line box from the TFTR test cell into the NSTX-U test cell completed

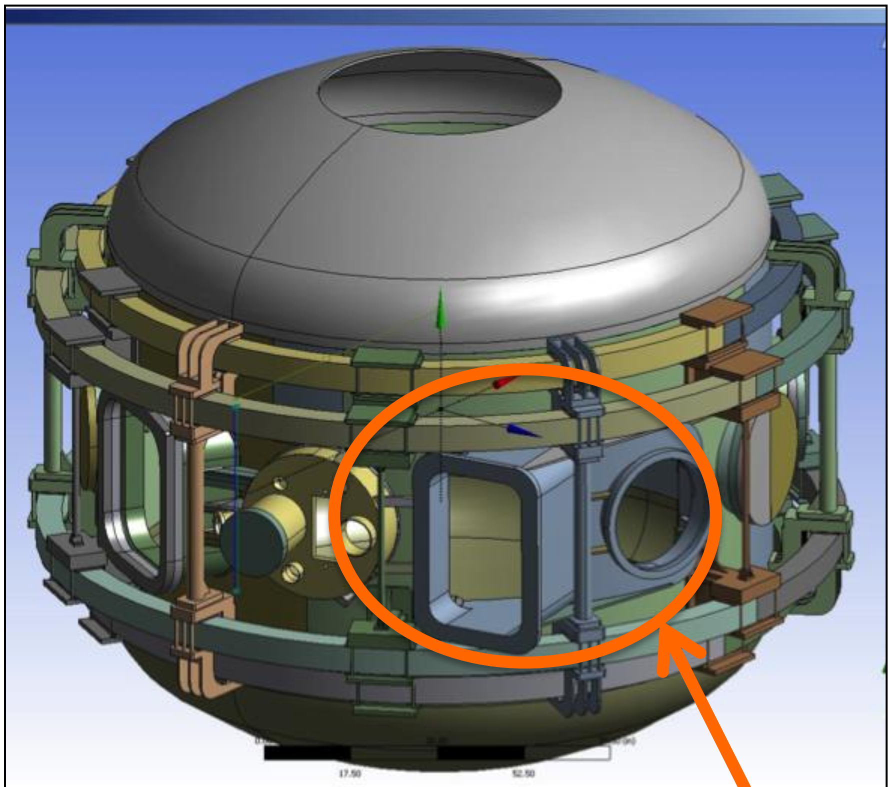
TFTR NBI beam box and components successfully tritium decontaminated

Beam Box being lifted over NSTX

Beam Box placed in its final location and aligned

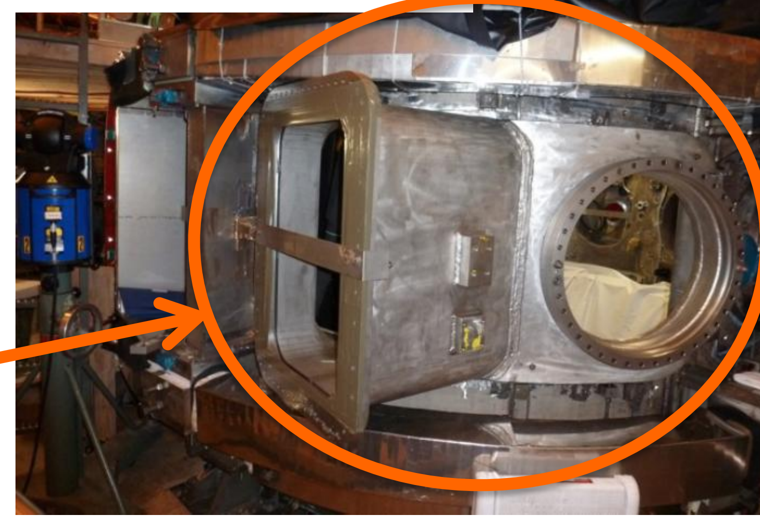
Beam Box being populated with components

Highly tangential 2nd NBI enabled by new port
Outer wall radius moved outward to avoid beam clipping



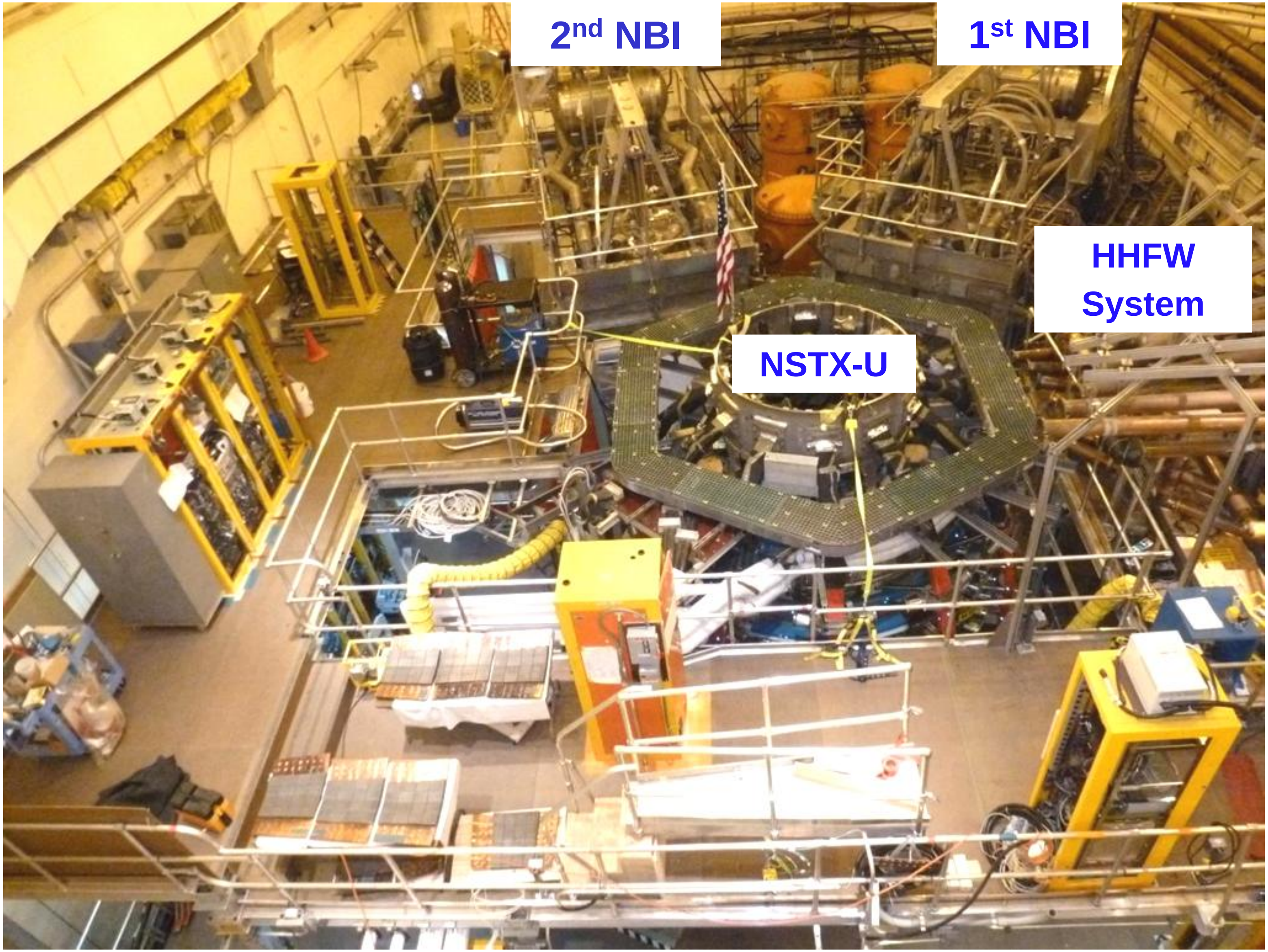
Interior View of Bay J-K

Exterior View of Bay J-K



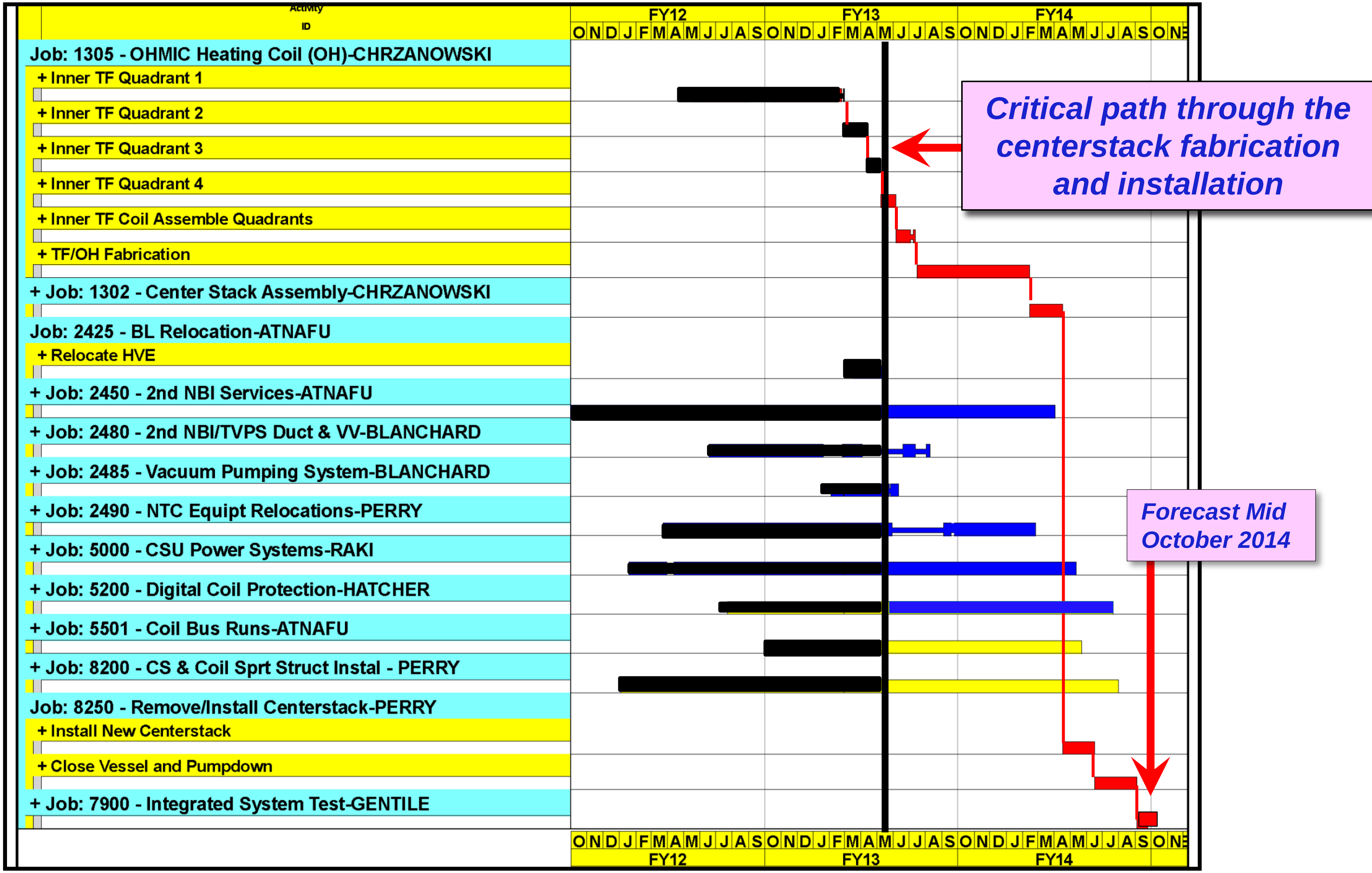
JK cap

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



Upgrade schedule on track for early finish

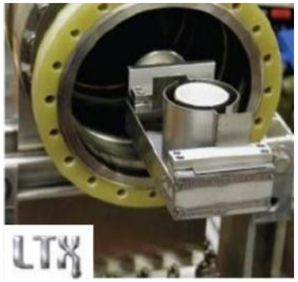
Aiming to start research operation in early FY 2015



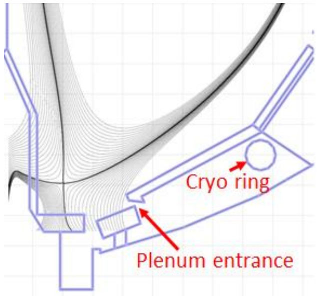
NSTX-U team is proposing longer-term facility enhancements to fully utilize Upgrade capabilities, support ITER and FNSF

- **Improved particle control tools**
  - Control deuterium inventory and trigger rapid ELMs to expel impurities
  - Access low ν^*, understand role of Li

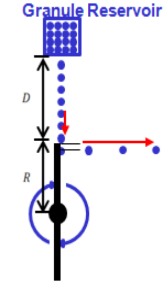
Upward Li evaporator



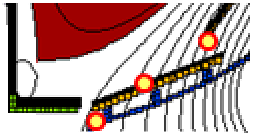
Divertor cryo-pump



Li granule injector (LGI)

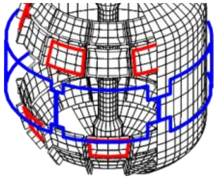


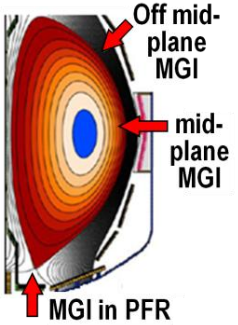
- **Disruption avoidance, mitigation**
  - 3D sensors & coils, massive gas injection



Extended low-f MHD sensor set

Midplane + off-midplane non-axisymmetric control coils (NCC)





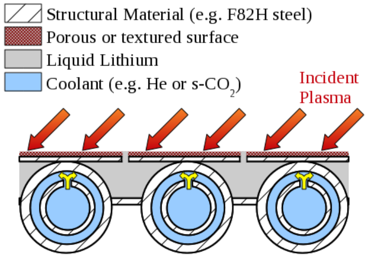
- **ECH to raise start-up plasma T_e to enable FW+NBI+BS I_P ramp-up**

1-2MW 28 GHz gyrotron

- **Begin transition to high-Z PFCs, assess flowing liquid metals**

High-Z tiles

Actively-supplied, capillary-restrained, gas-cooled LM-PFC



Summary: NSTX-U will make leading contributions to fusion science and next-step applications

- **Provide ST basis (and assist AT) for FNSF and for ITER**
  - Actuators + controls for 100% non-inductive at high confinement, β
  - Non-inductive formation and ramp-up - needed for ST, benefits AT
  - RWM control, disruption warning, novel disruption mitigation
  - Non-linear Alfvénic mode dynamics, turbulence at high β and low ν^*

- **Novel plasma-material-interface solutions for next-steps**
  - Lead "snowflake" development, combine with radiation/detachment
  - Lead in liquid metals for recycling/erosion control, vapor-shielding

- **NSTX-U project is on cost and schedule**
  - Project ~65% complete
  - First plasma projected for October 2014

NSTX-U and ST-FNSF presentations

NSTX Accomplishments & Plans
Jon Menard
Oral - Tuesday 11:00

NSTX Upgrade

NSTX Vacuum Vessel Modification
Neway Atnafu
Poster Thursday 2:00-4:00

Power & control system changes
Raki Ramakrishnan
Posters (2) Tuesday 2:00-4:00

Digital Coil Protection System (DCPS) Software
Keith Erickson
Oral -Thursday 12:05

- **DCPS Overview**
  Ron Hatcher
  Poster Thursday 2:00-4:00
- **DCPS I/O & Data subsystem**
  Greg Tchilinguirian
  Poster-Thursday 2:00-4:00

Magnet Design & Fabrication
Steve Raftopoulos
Oral - Tuesday 12:15

- **TF Bundle Failure Cause**
  Larry Dudek
  Poster Tuesday 2:00-4:00
- **Coolant Tube Solder Technique**
  Steve Jurczynski
  Poster Tuesday 2:00-4:00
- **Aqua pour coil winding**
  Mike Mardenfeld
  Poster Tuesday 2:00-4:00
- **Divertor Tile Modif. (CHI gap Protection)**
  Kelsey Tresemer
  Poster- Thursday 2:00-4:00

NSTX Operations

- **CHI System**
  Roger Raman
  Poster Tuesday 2:00-4:00
- **Lithium Flash Evaporator**
  Lane Roquemore
  Poster-Thursday 2:00-4:00
- **NSTX Lithium Pellet Fueling**
  Daniel Andruczyk
  Poster-Thursday 2:00-4:00

ST-FNSF

Poster Tuesday 2:00-4:00

TBR and Shielding - L. A. El-Guebaly
Configuration - T. G. Brown
Mission and Performance - J. Menard
Power and Particle Exhaust - J. Canik

Oral -Thursday 11:35
CS TF Radial Cooling - R. D. Woolley