NSTX-U Overview of NSTX Research Facility Upgrades and Plans

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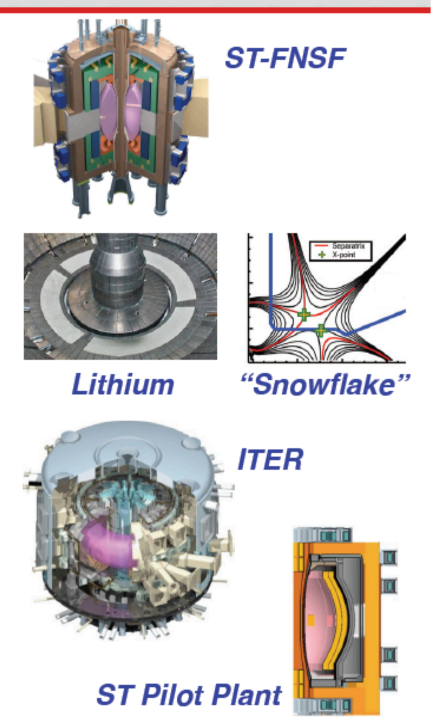
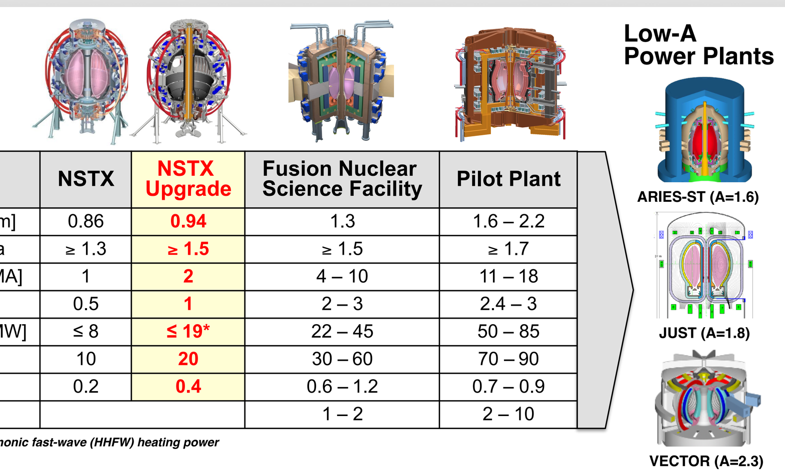
U.S. DEPARTMENT OF ENERGY | Office of Science

NSTX Mission Elements

- Advance ST as candidate for Fusion Nuclear Science Facility (FNSF)
- Develop solutions for plasma-material interface
- Advance toroidal confinement physics for ITER and beyond
- Develop ST as fusion energy system



NSTX Upgrade will access next factor of two increase in performance to bridge gaps to next-step STs



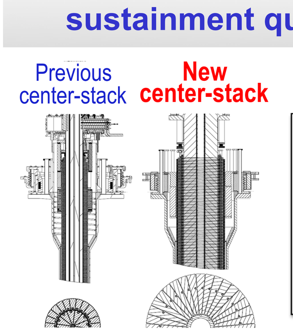
Parameter	NSTX	NSTX Upgrade	Fusion Nuclear Science Facility	Pilot Plant
Major Radius R_0 [m]	0.86	0.94	1.3	1.6 – 2.2
Aspect Ratio R_0 / a	≥ 1.3	≥ 1.5	≥ 1.5	≥ 1.7
Plasma Current [MA]	1	2	4 – 10	11 – 18
Toroidal Field [T]	0.5	1	2 – 3	2.4 – 3
Auxiliary Power [MW]	≤ 8	≤ 19*	22 – 45	50 – 85
P/R [MW/m]	10	20	30 – 60	70 – 90
P/S [MW/m²]	0.2	0.4	0.6 – 1.2	0.7 – 0.9
Fusion Gain Q			1 – 2	2 – 10

* Includes 4MW of high-harmonic fast-wave (HHFW) heating power

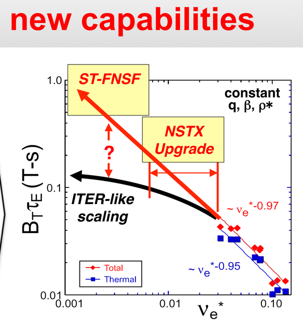
Key issues to resolve for next-step STs

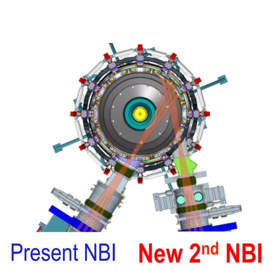
- Confinement scaling (electron transport)
- Non-inductive ramp-up and sustainment
- Divertor solutions for mitigating high heat flux
- Radiation-tolerant magnets (for Cu TF STs)

NSTX Upgrade will address critical plasma confinement and sustainment questions by exploiting 2 new capabilities

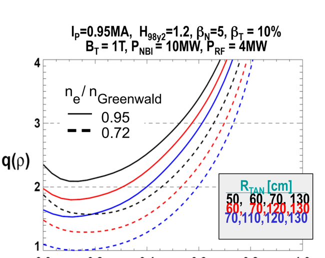


- 2x higher B_T and I_p increases T, reduces ν* toward ST-FNSF to better understand confinement
- Provides 5x longer pulses for profile equilibration, NBI ramp-up



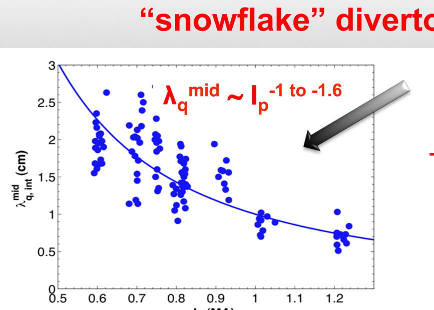


- 2x higher CD efficiency from larger tangency radius R_{TAN}
- 100% non-inductive CD with q(r) profile controllable by: tangency radius, density, position



J. Menard, et al., Nucl. Fusion 52 (2012) 083015

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



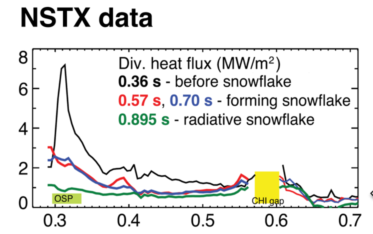
Divertor heat flux width decreases with increased plasma current I_p

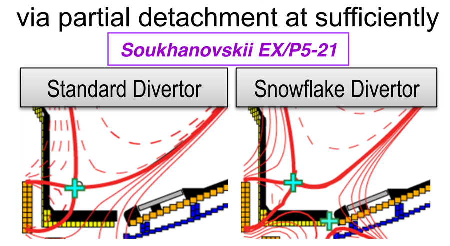
→ 30-45MW/m² in NSTX-U with conventional LSN divertor at full current and power

Can reduce heat flux by 2-4× in NSTX via partial detachment at sufficiently

Soukhanovskii EX/P5-21

NSTX data

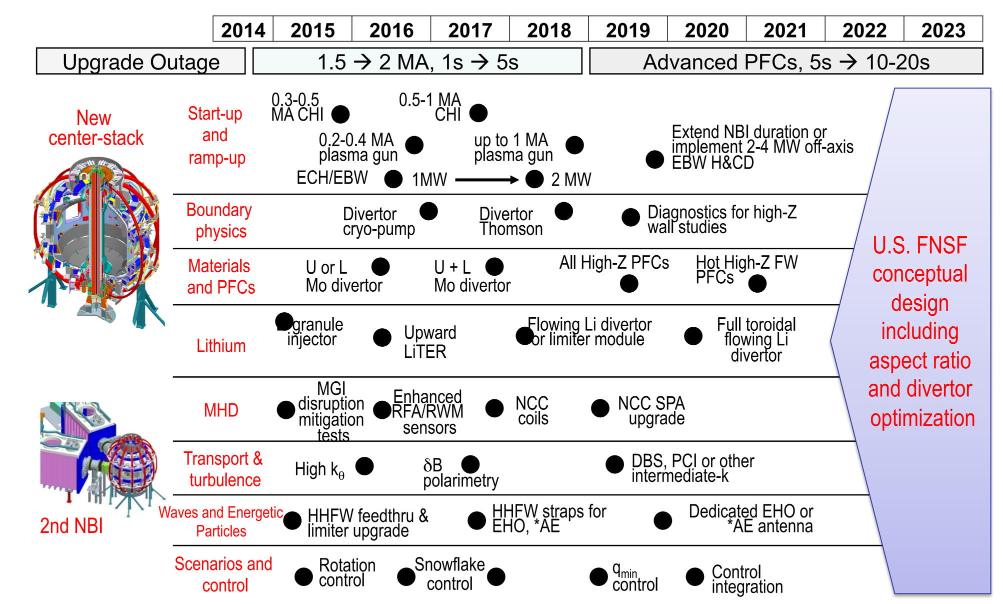




Snowflake→ high flux expansion = 40-60 lowers incident $q_\perp$, promotes detachment

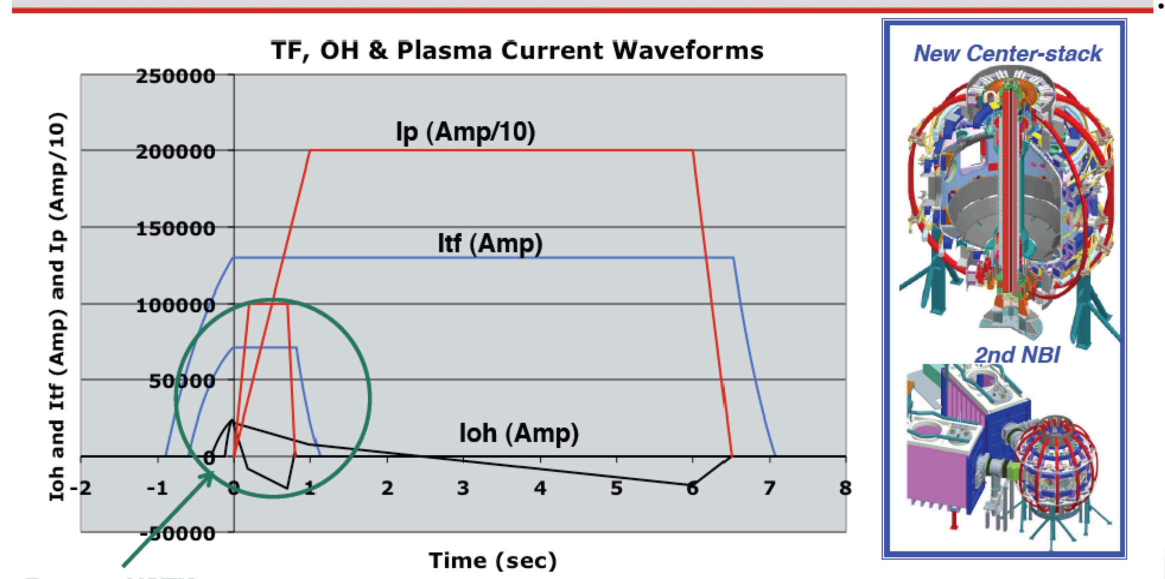
NSTX-U: U/D balanced snowflake has < 10MW/m² at I_p = 2MA, P_{AUX}=10-15MW

Developed comprehensive long-range plan for NSTX-U supporting ITER and FNSF – next step is to down-select based on priorities and budgets



Upgrade Substantial Increases B_T, I_p, τ_{pulse}, P_{NBI}

Higher B_T and Ip narrows gaps to Fusion Neutron Science Facility



Relative performance of Upgraded NSTX vs. Base:

- NBI power increased 2 x
- Available OH flux increased 3x, 3-5x longer flat-top
- I_p increased 2x, B_T increased 2x at same major radius
- Plasma stored energy increased up to 4x (0.25→ 1MJ)

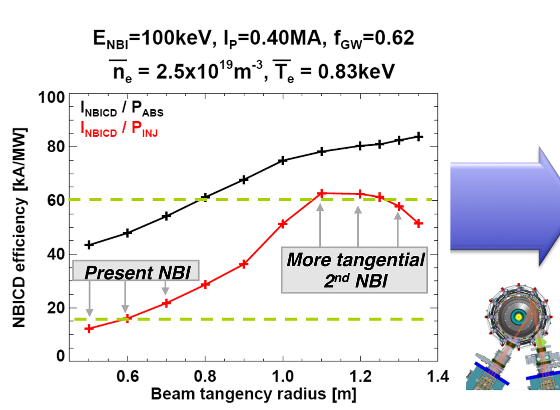
Non-inductive ramp-up from ~0.4MA to ~1MA projected to be possible with new centerstack (CS) + more tangential 2nd NBI

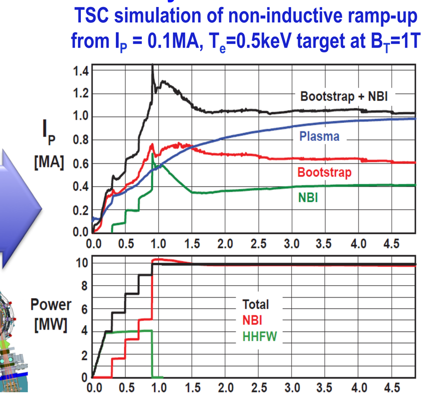
New CS provides higher TF (improves stability), 3-5s needed for J(r) equilibration

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

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

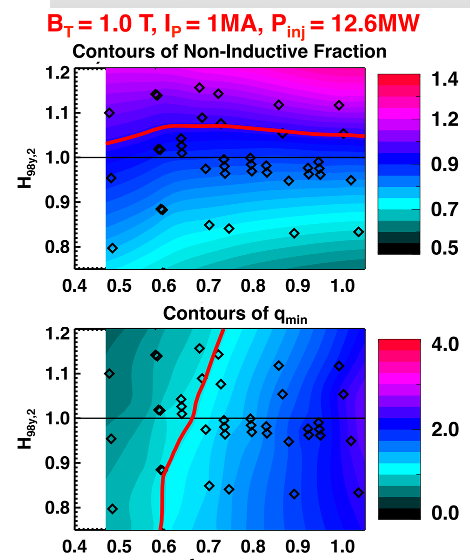
1.5-2x higher current drive efficiency





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

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



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

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

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

$\chi_{i,ITG}/\chi_{i,Neo} \sim 10^{-2}$

Assumption of neoclassical ion thermal transport should be valid

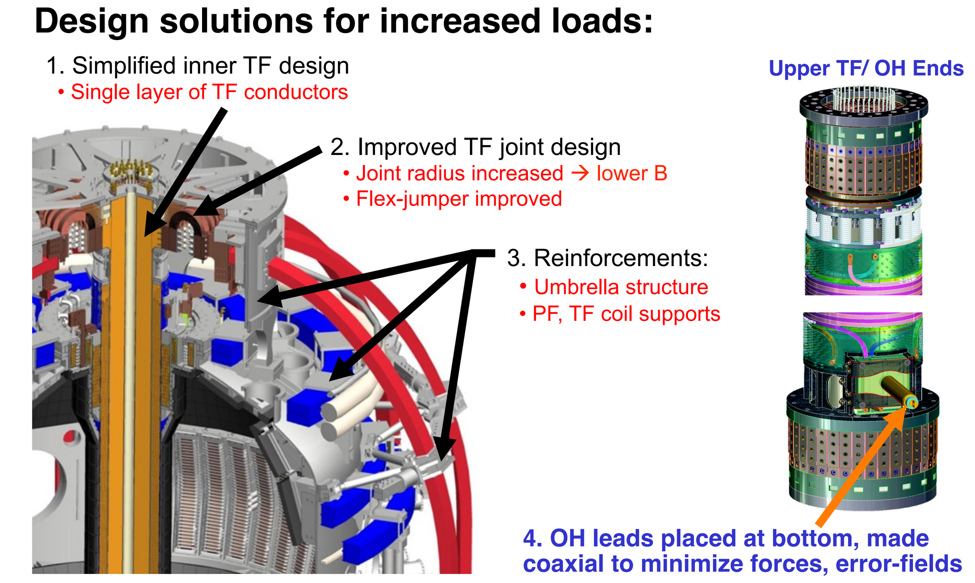
S. Gerhardt, et al., Nucl. Fusion 52 (2012) 083020

Major engineering challenge of NSTX Upgrade:

Field and current each increase 2× → E-M forces increase 4x

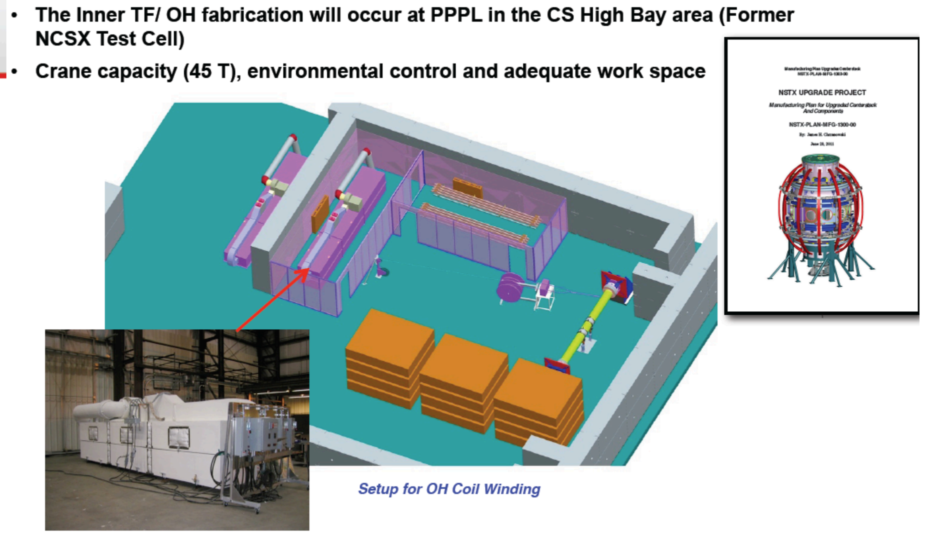
Design solutions for increased loads:

1. Simplified inner TF design
   - Single layer of TF conductors
2. Improved TF joint design
   - Joint radius increased → lower B
   - Flex-jumper improved
3. Reinforcements:
   - Umbrella structure
   - PF, TF coil supports
4. OH leads placed at bottom, made coaxial to minimize forces, error-fields

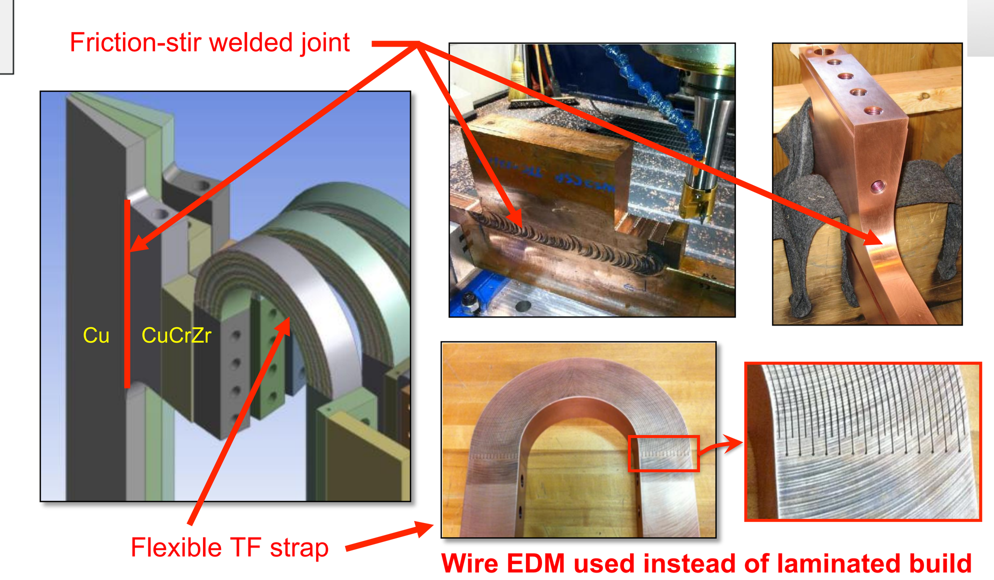


NSTX-U OH/TF Manufacturing Area

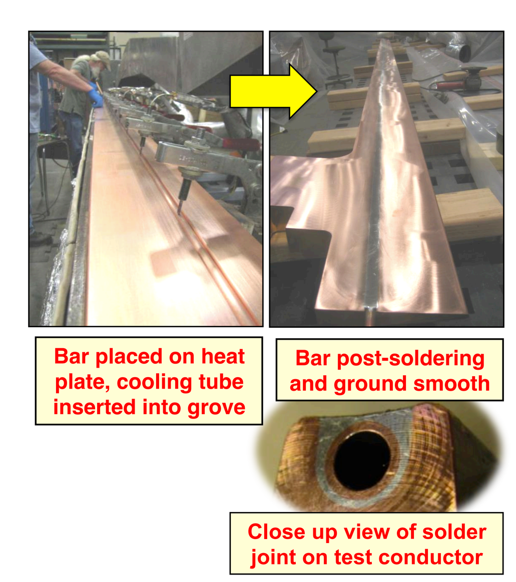
- The Inner TF/ OH fabrication will occur at PPPL in the CS High Bay area (Former NCSX Test Cell)
- Crane capacity (45 T), environmental control and adequate work space



Substantial R&D completed to achieve higher toroidal field with new center-stack

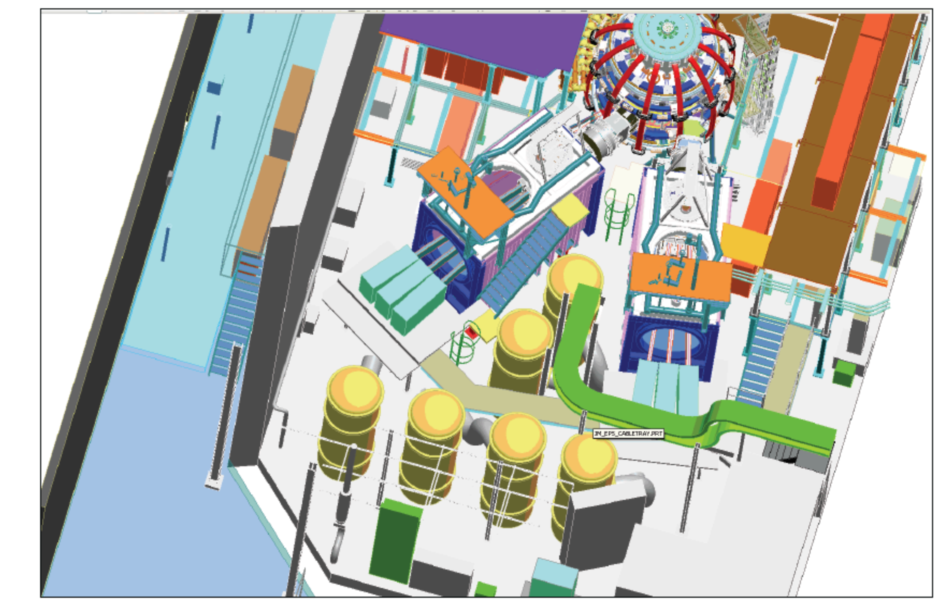


TF cooling tube soldering & flux removal process improved, 1st quadrant of TF bundle to be completed November 2012

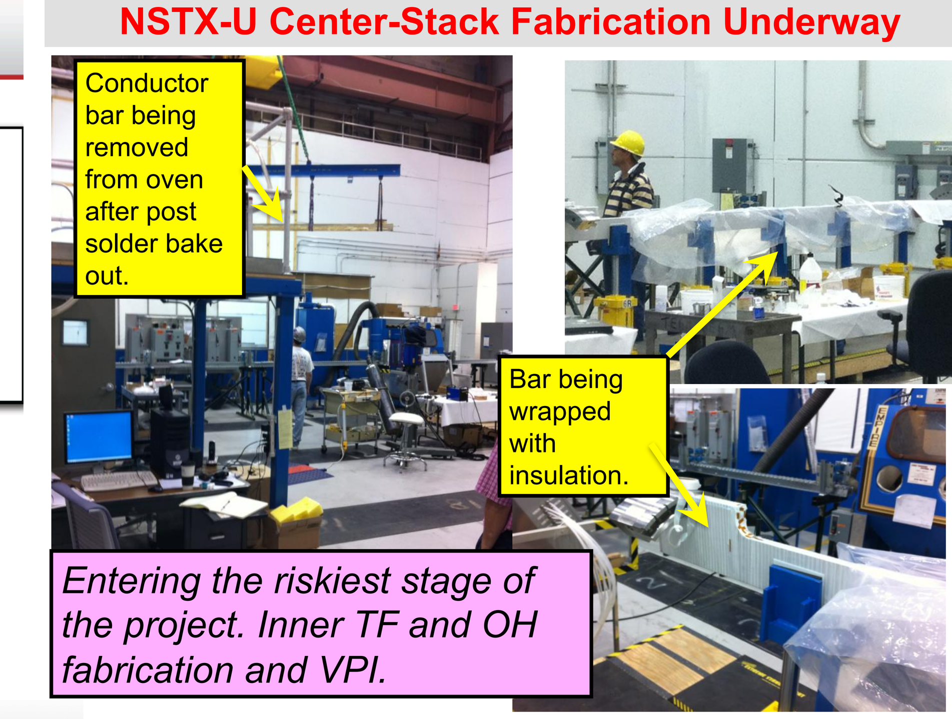


Vacuum-pressure impregnation (VPI) using special cyanate-ester epoxy blend (CTD-425) required for shear strength will be used for the inner TF assembly

NSTX-U Test Cell General Arrangement Drawing

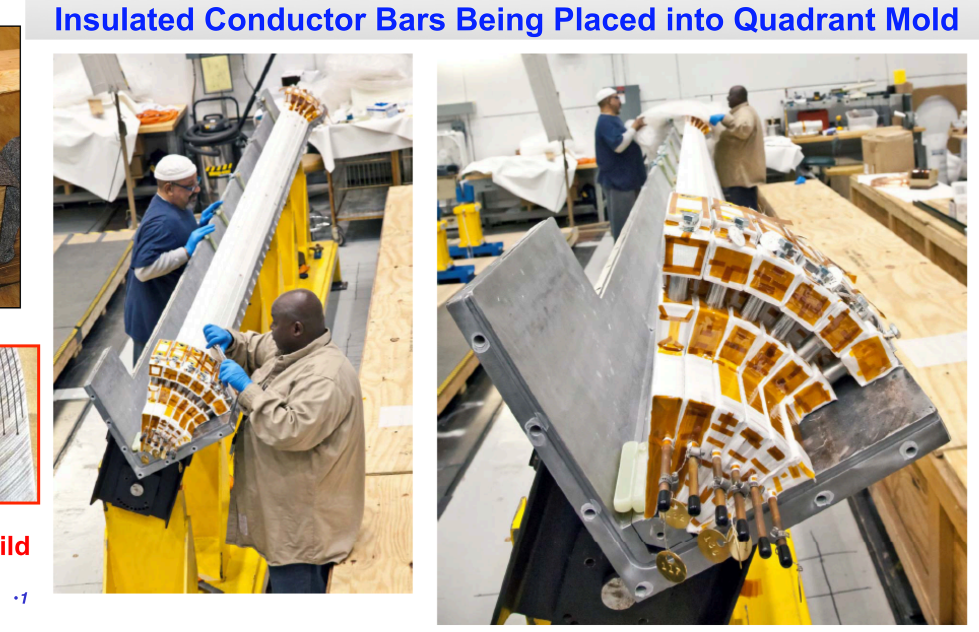


NSTX-U Center-Stack Fabrication Underway



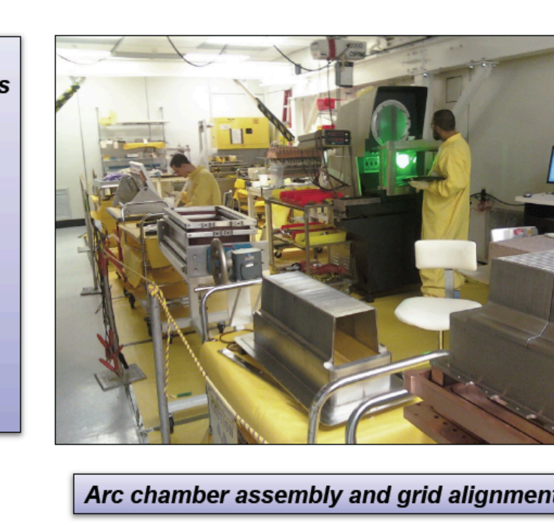
Center Stack – Inner TF Quadrant Assembly Underway

Insulated Conductor Bars Being Placed into Quadrant Mold

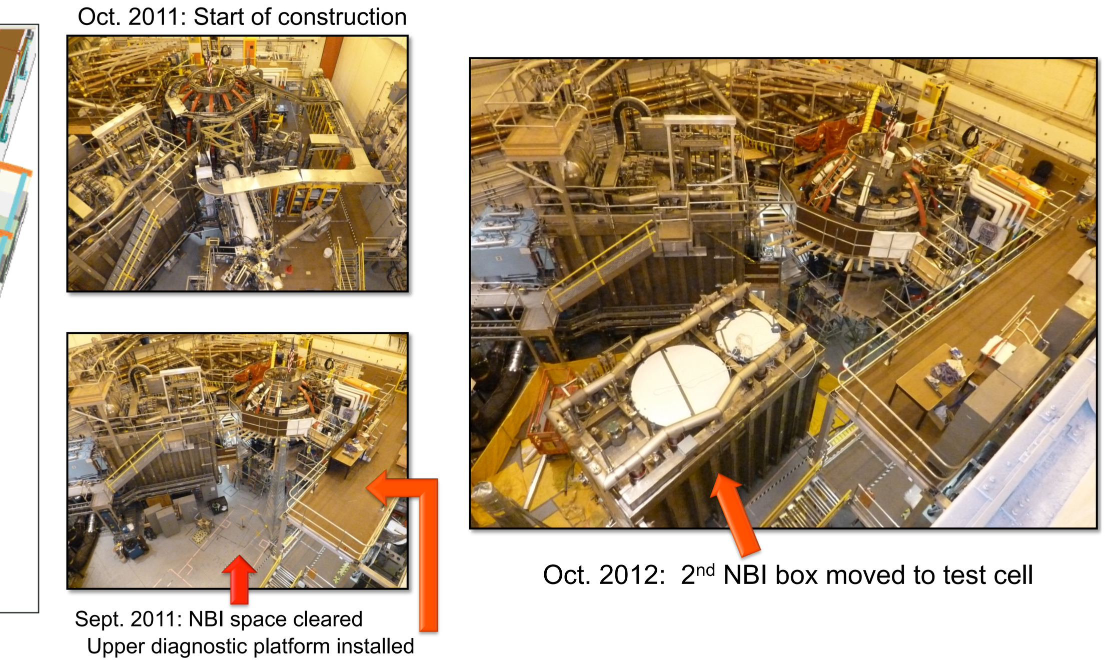


NSTX-U NBI – Refurbish Ion Sources

- Because BL1 did not support full 2011-2012 operations, BL1 sources are still viable and have been stored in place.
- Therefore, our three spares may be used for upgrade.
- Savings to project of approximately $900k.



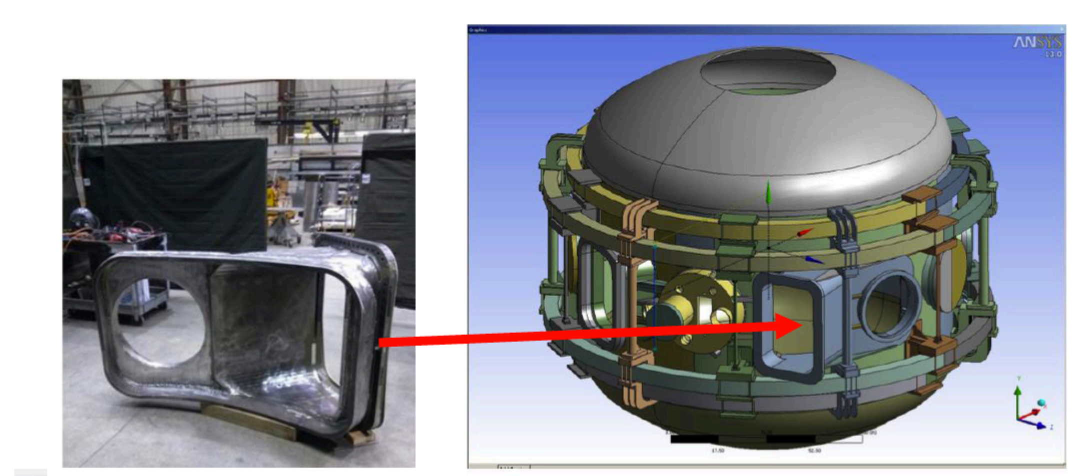
Significant progress made during past year to prepare NSTX-U test-cell and 2nd NBI



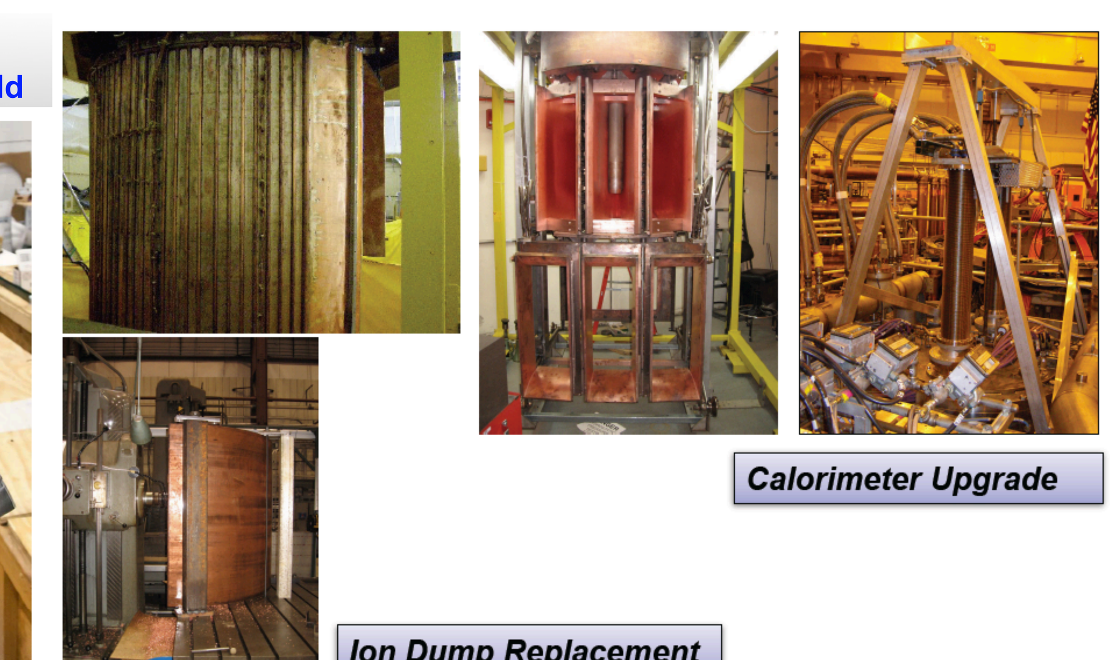
New NBI Port-Cap Has Been Received

Enables Tangential Injection for Non-Inductive Operations

- Materials, machining meet spec (but welds were re-worked)
- Preparing to plasma-cut hole in vessel for cap installation



BL Refurbishment: Ion Dump and Calorimeter - completed



BL Refurbishment: Box, Lid & Cryo panels, 90 inch Flange w/Neutralizers, and Magnet