NSTX-U is sponsored by the
U.S. Department of Energy Office of Science
Fusion Energy Sciences

Contributed Oral Presentation YO5.00002:
Status and Plans for the NSTX-U Recovery Project

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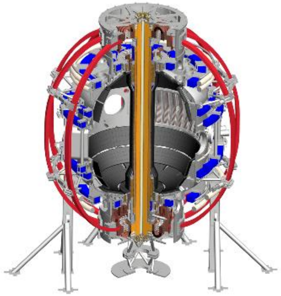
for the NSTX-U Recovery and Research Teams

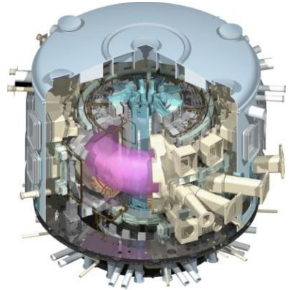
PPPL

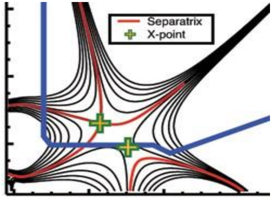


NSTX-U Mission Elements

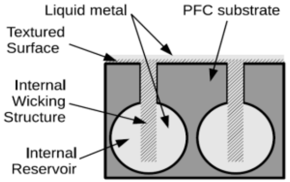
- Exploit unique Spherical Tokamak (ST) parameter regimes to advance predictive capability - for ITER and beyond
- Develop solutions for plasma-material interface (PMI) challenge
- Explore ST physics towards reactor relevant regimes (Fusion Nuclear Science Facility, low-A Pilot Plant)

ITER



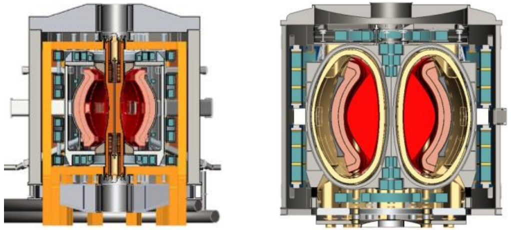


Advanced divertors



Liquid metals

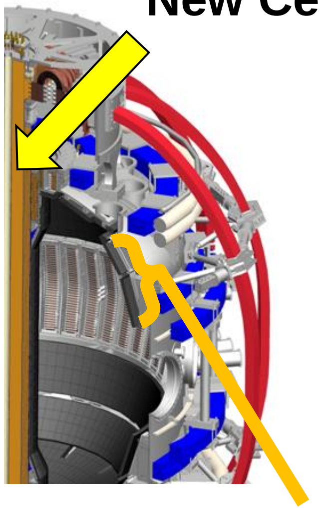
ST-FNSF / Pilot-Plant

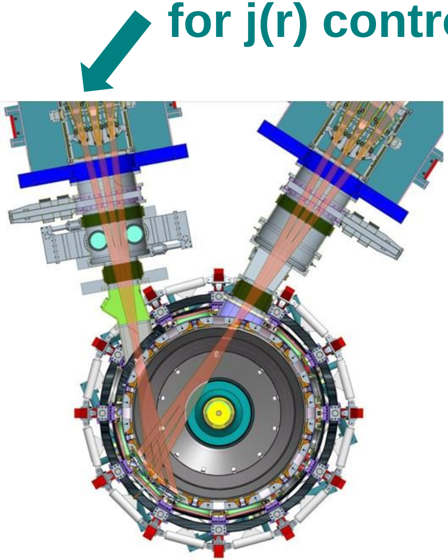


NSTX-U vital for addressing key ST / fusion questions

Maximum Parameters

		NSTX	NSTX-U
I_p	≤	1.4	2 MA
RB_T	≤	0.47	0.94 m-T
P_{NBI}	≤	6	15 MW
P_{RF}	≤	6	6 MW
τ_{pulse}	≤	1-2	5-10s

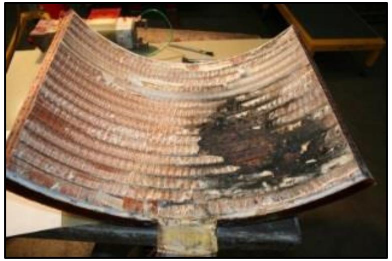




- **Higher B_T (1 T at R_0) ➔ projected largest range in β and (lower) ν_* in an ST**
- **Higher stability β_N / l_i ≤ 14 + flexible NBI ➔ high / full non-inductive current**

Need Recovery to reliably achieve NSTX-U full performance

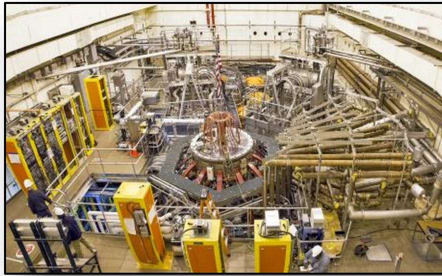
- NSTX-U had scientifically productive FY16 run
  - H-mode on 8th day of 10 weeks of operation
  - Surpassed magnetic field and pulse-duration of NSTX
  - Discovered new 2nd NBI suppresses Alfvénic instabilities
  - **…ceased operations due to failed divertor PF coil**



Section of failed PF1AU

- FY2017: "Extent of Condition" review identified additional deficiencies needing "Recovery"

- FY2018 primary Recovery activities:
  - PPPL-DOE agreement on Recovery Project scope
  - (Re-)design critical and/or long-lead components
  - Develop initial cost and schedule estimate for Project



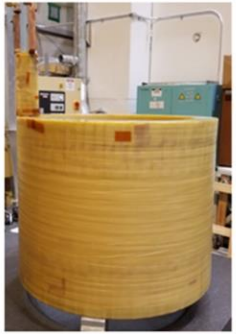
Recovery scope critical for robust research facility

1. Rebuild all 6 inner-PF coils
2. Improve the “polar regions”
3. Strengthen passively conducting plates
4. Replace plasma facing components that cannot be qualified
5. Reassemble with improved alignment of magnets & structures
6. Design and install improved Bakeout System
7. Implement mechanical instrumentation
8. Improve neutron shielding of test cell, safety order & systems

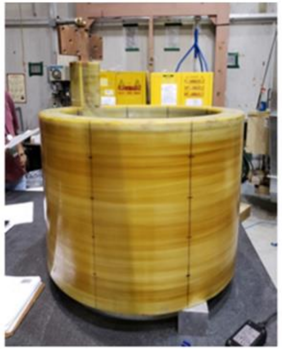
Commissioning, achieve key performance parameters, 1^{st} plasma

1. Nominal prototype PF1 coil testing completed

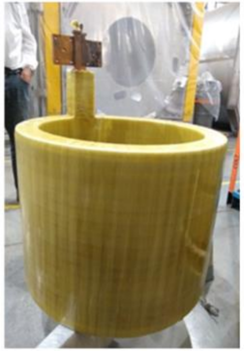
ETI



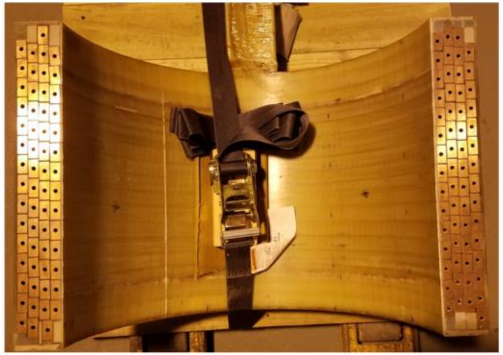
PPPL



Sigmaphi



Tesla



PPPL PF1 prototype section

Technicians preparing for electrical testing of one of the sectioned PF1 prototype coils

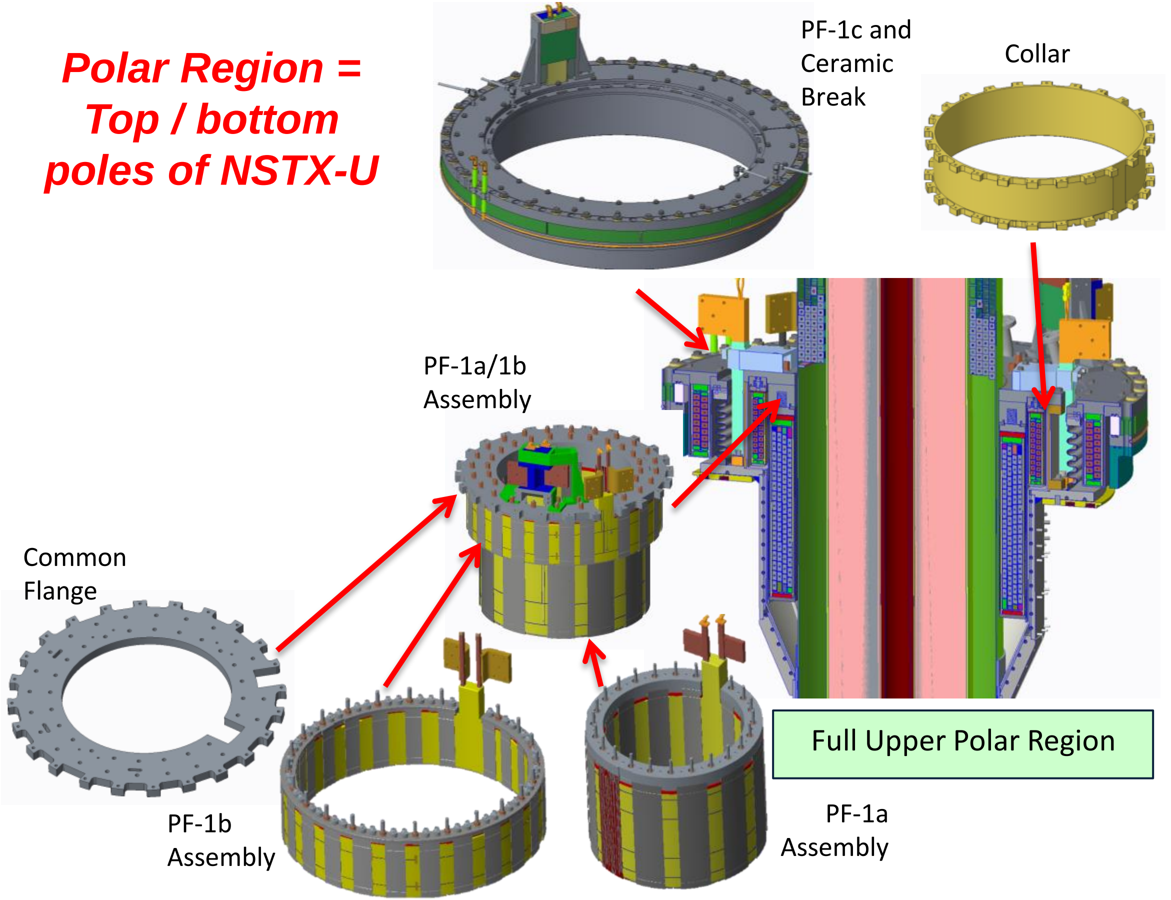
- Built 4 prototype PF1A coils
- All prototypes passed electrical tests
- VPI inspections indicate 2 vendors qualified, other 2 vendors may qualify with remediation
- Request for Proposal prep underway including all 3 external vendors
- Performing lifetime/corona tests on section of coil with largest VPI voids

2. Robust polar region design developed

Design Features

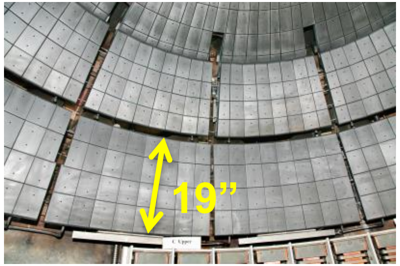
- Supports mandrel-free coils against all static and transient EM loads, provides preload, improves bakeout
- Provides mounting structures and heating / cooling for Plasma Facing Component (PFC) Tiles
- Provides robust elements of vacuum boundary, with double O-ring seals

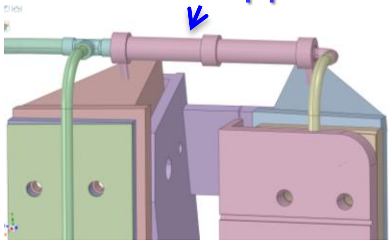
Polar Region = Top / bottom poles of NSTX-U

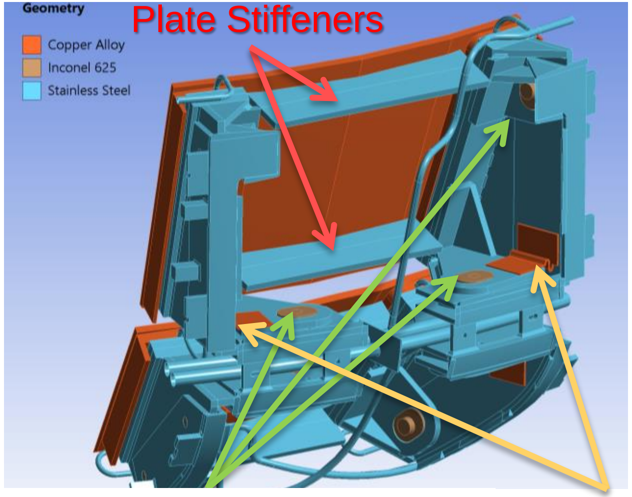


3. Passive plate issues remedied with additional hardware

- Passive plates are Cu conductive plates covered by graphite tiles
  - Plates suppress plasma instabilities
- Issues, and → resolution:
  - Plates flexing under disruption EM load
    →Plate back stiffeners
  - Unacceptable motion in plate bracketry
    →Stronger bolts, augment in-situ fasteners
  - Non-uniform electrical resistivity
    →Dedicated electrical connections (straps)
  - Excessive EM loads on He bakeout tubes
    →Dedicated tube supports
- Solutions can be implemented without significant disassembly

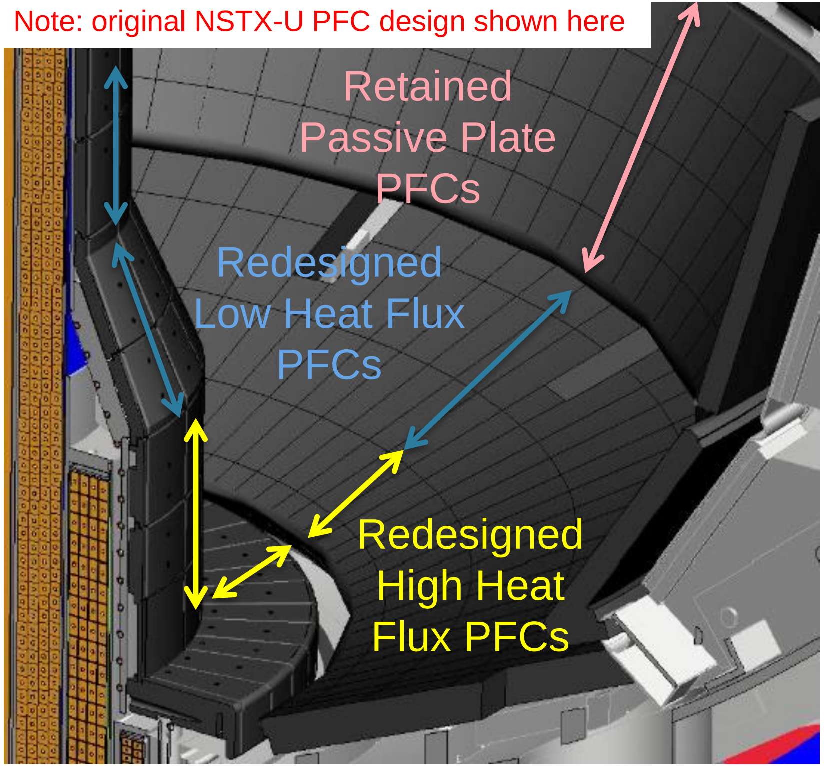






4. New tile designs meet thermal and EM load requirements

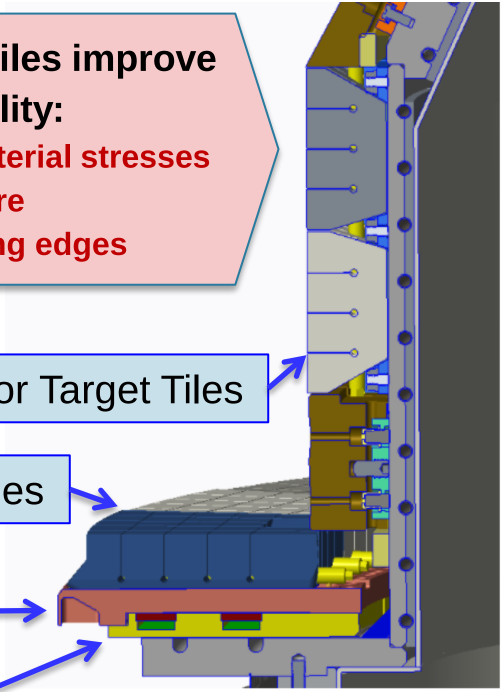
Note: original NSTX-U PFC design shown here



Re-designed high-heat-flux tiles improve thermal performance, reliability:

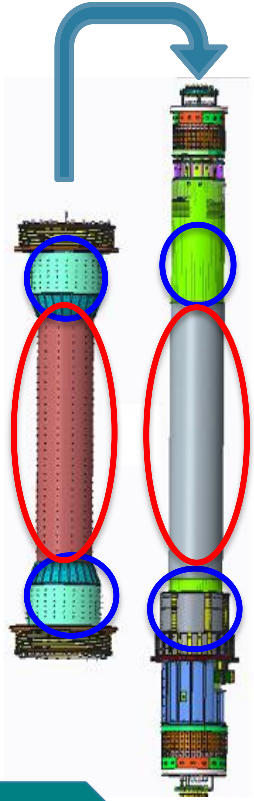
→ **Castellations minimize the material stresses for a given surface temperature**

→ **Fish-scaling protects all leading edges**



5. Alignment / tolerances managed via systems engineering

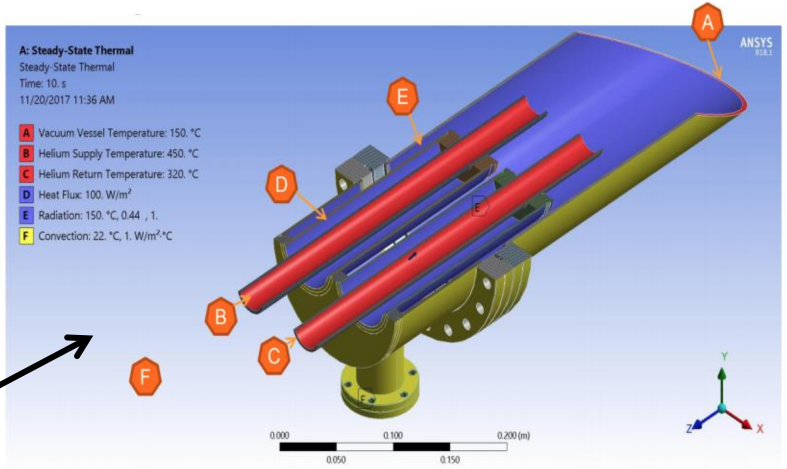
- Issues from NSTX-U / 2016 run:
  - Casing significantly tilted relative to TF, TF tilted relative to VF → locked modes, NTV rotation damping degraded global stability
  - Casing-OH micro-therm insulation showed signs of damage when casing was removed
- Recovery: comprehensive alignment requirements and tolerance allocations
  - TF and divertor PF coils / divertor targets → non-axisymmetric heat fluxes on divertor PFCs
  - Inner TF / vertical field coils → global stability
  - **FY18: Successful casing/TF-bundle trial-fit**



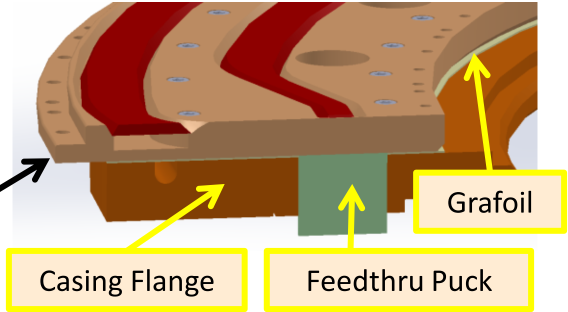
	Requirement	Achieved
tilt [mrad]	0.4	0.14
shift [in]	0.078	0.015

6. Bakeout scope will improve safety and performance

- Additional interlocks/safety devices to mitigate risk of vaporization of 150C water for vessel bake
- Implement 6 new hot-He feed-thrus to replace existing designs that exceed thermal stress allowable



- Improve measurements and control of hot He distribution
- Heat transfer plate to improve He bake

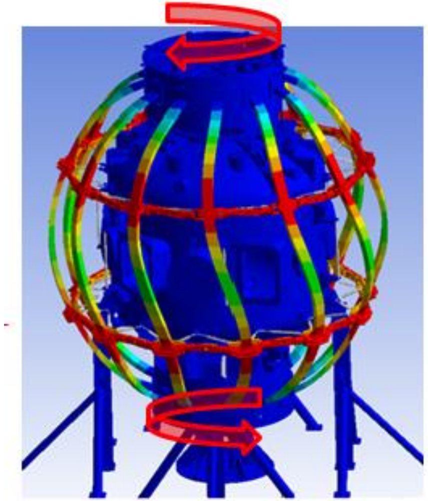


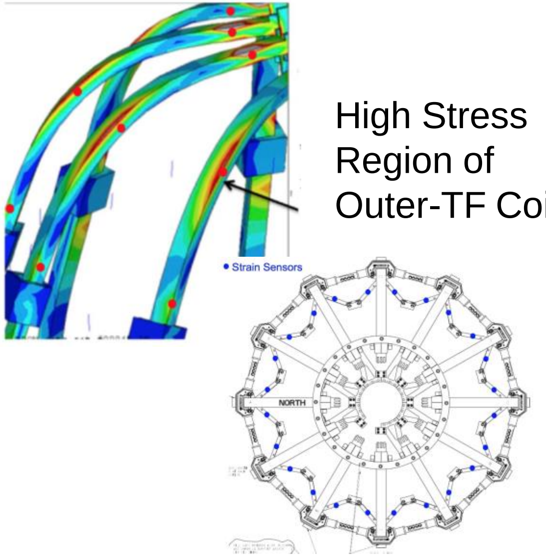
7. Machine instrumentation will diagnose and trend machine behavior

1: Global EM Torque on Coils, Transferred to Vessel

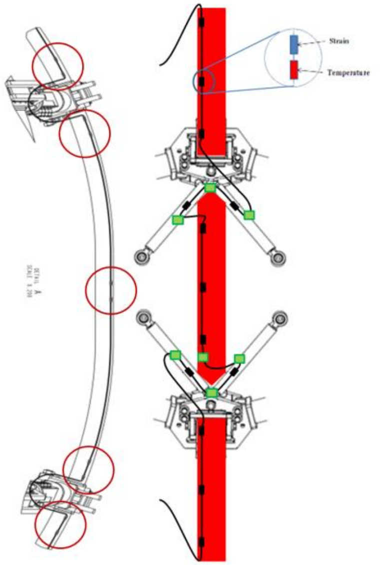
2: Requirement for Strain Sensors on Coils & Trusses

3: Design utilizing high sensor count fiber Bragg technology





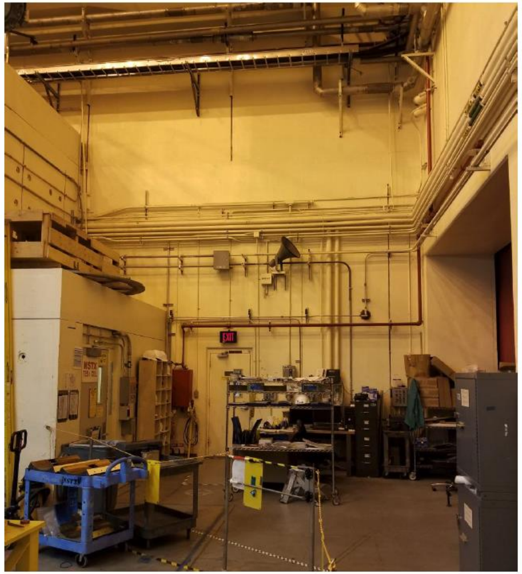
High Stress Region of Outer-TF Coil



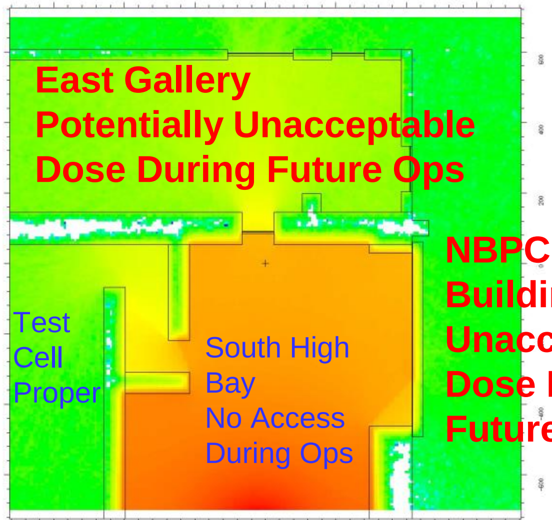
- Validate structural models that are basis for designs and coil protection systems
- Trend behavior / degradation of any critical components of the machine

8. Neutron shielding designs support NSTX-U full performance operation (2MA, 1T, 10MW, 5s)

In south high bay, looking toward gallery door

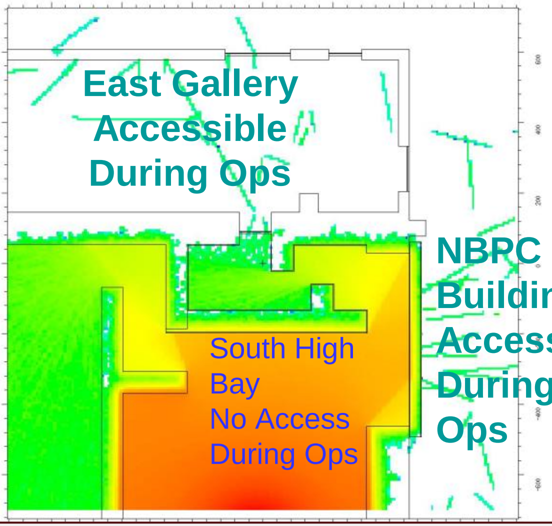


Present Status



Neutrons come over shield wall, can exit through door.

After additional Labyrinth



MCNP: Attenuate 99.9% neutrons through doors/windows

Summary

- NSTX-U Recovery critical for U.S. to retain world-leading improved-reliability user facility for ST science
- Recovery technical scope has progressed significantly
- Project execution plan, integrated project team in place
- Timeline:
  - FY19: Baseline project, complete design, initiate fabrication
  - FY20: Fabrication, installation
  - FY21: Final installs, commission, 1st plasma, resume research

Backup

Recovery scope is critical to Research program

1. Rebuild all 6 inner-PF coils
   - Ensure overall core device reliability and availability for users
   - Strong shaping / high β, divertor heat flux mitigation, advanced divertors
2. Improve the "polar regions" = top and bottom-most regions of vacuum chamber
   - Ensure high vacuum / reduce impurities for high confinement, lithium
3. Repair passively conducting plates
   - Access strongest shaping and highest β at full field and current (1T, 2MA) to stay world-leading
4. Replace plasma facing components that cannot be qualified
   - Support device full performance: 1T, 2MA, 10MW, 5s to stay world-leading, ensure reliability
5. Reassemble NSTX-U with improved alignment of magnets and structures
   - Maximize plasma performance: high rotation, β, confinement, exhaust power handling
6. Design and install improved Bakeout System
   - Eliminate safety issues, potential reliability issues
7. Implement mechanical instrumentation
   - Verify machine performance consistent with engineering models, ensure reliability
8. Improve test-cell neutron shielding, implement ASO and Personnel Safety System (PSS)
   - Facility operational excellence, support higher performance and increased DD neutron yield