NSTX-U

NSTX-U is sponsored by the
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Fusion Energy Sciences

Status and Plans for NSTX-U Recovery

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and the NSTX-U Research and Engineering Teams

SESSION JO4: SPHERICAL TOKAMAKS, OTHER
Room: 201AB at 14:00
59th APS-DPP Meeting
Milwaukee, Wisconsin
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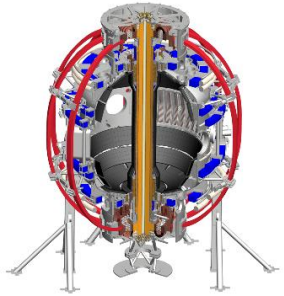
PPPL

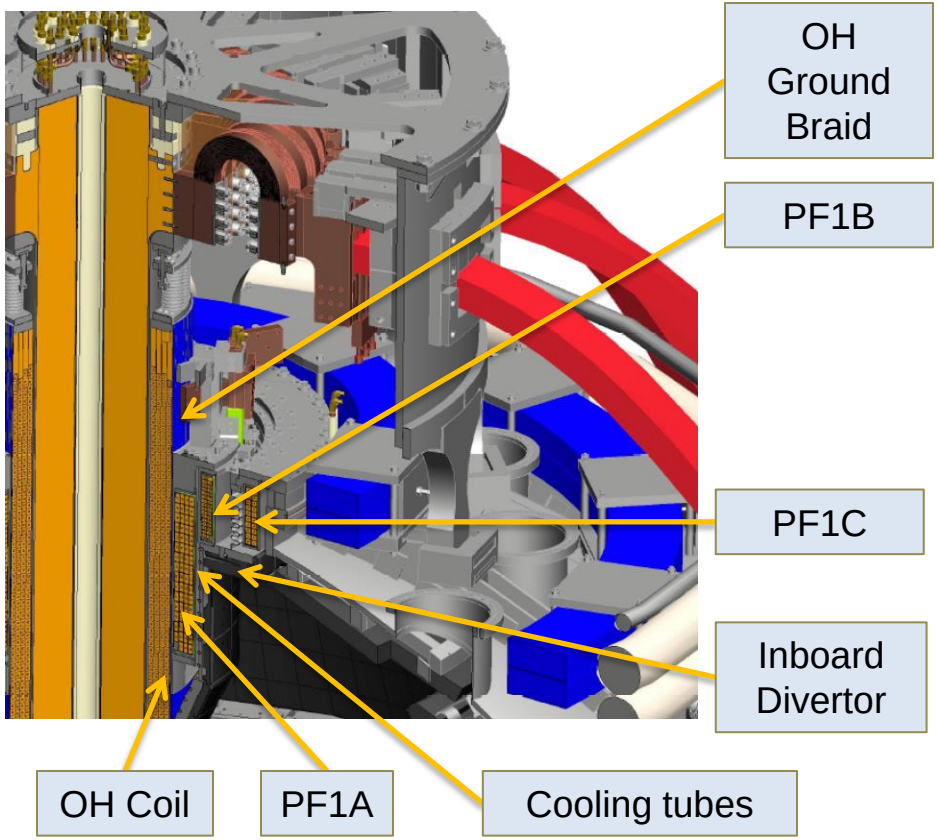


Background

- NSTX-U operated 10 weeks in FY2016
  - Rapidly accessed H-mode
  - Exceeded NSTX record pulse duration and magnetic field
  - Commissioned 2nd NBI (12MW total), most major diagnostics
  - Fast-ion physics discoveries (E. Fredrickson APS invited talk)
- But, several technical failures ended NSTX-U operations in July 2016 → 2 extensive reviews in 2017
  - Extent of Condition: Which designs, components are deficient?
  - Extent of Cause: Which practices, procedures are deficient?

What is NSTX-U "Recovery"?

- FY2017: DOE requested PPPL to review "Extent of Condition" and submit Corrective Action Plan (CAP)
- Extent of Condition motivated by:
  - 4/15: OH "Arc Flash" incident
  - 9/15: Inadequate inboard divertor bake
  - 5/16: CS cooling tubes wrong material, induced current/motion, breaches
  - 5/16: Bent PF1AU bus bar
  - 6/16: Internal short in PF1AU coil
- **Recovery = Implementation of Extent of Condition CAP**



NSTX-U Held 17 Reviews in FY2017

- 12 Design Verification and Validation Reviews (DVVRs)
  - 1170 “chits” covering **entire NSTX-U technical scope** → 443 “DVVR Issues”
  - Then evaluated issue/event probability, duration, and severity → categorize / prioritize
- 2 Extent of Condition Reviews
  - Assessed issues and conclusions of the DVVRs and the PPPL planned response
  - Issued 2 reports → recommendations to ensure safety and *reliability* of the ST core

Total of 47 external reviewers between Extent of Condition Reviews and DVVRs

- Design Integration Review
- Conceptual Design Review
- Cost and Schedule Review

→ 346 page report submitted: Recovery scope + CAP

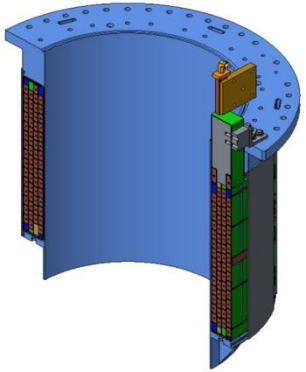
6 Major Scope Areas Define Recovery

Improved Reliability **Safety and Compliance**

1. Rebuild all six inner-PF coils with a mandrel-free design
2. Replace plasma facing components that cannot be qualified for the full range of mechanical and projected thermal loads
3. Improve the “polar regions” (machine top and bottom)
4. Implement mechanical instrumentation to assess quality of mechanical models, trend machine behavior
5. Eliminate the safety issues identified with the medium temperature water system used during bakeout, improve He distribution system
6. Improve the neutron shielding of the test cell

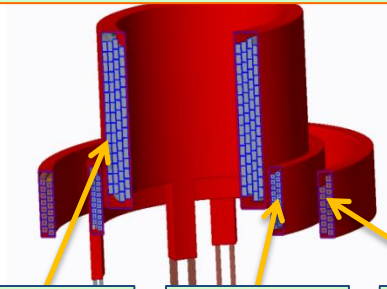
New Inner PF Coils
Designed to Improve Testability and Manufacturability

- Previous coils fabricated on permanent mandrels
  - Advantages: Precision winding surface, VPI mold, intrinsic structural support
  - Disadvantages: mandrel is passive conductor
    - Impacts turn-to-turn acceptance tests
    - Deemed unacceptable during extent of condition review
- New coils: removable mandrels
  - Requires winding tooling
  - Major schedule impact: had been intending to use permanent mandrels until mid-May 2017
- New coil design simplifies fabrication
  - Pure spiral winding (no “joggles”)
  - Single continuous Cu extrusion (no joints)
  - Softer copper (easier winding)



Original PF1A Coil with Mandrel

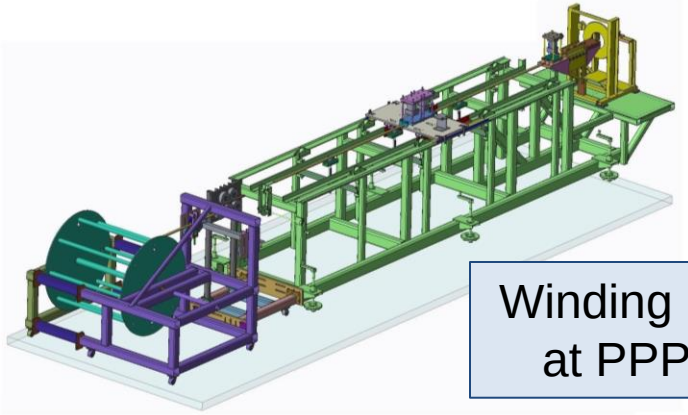
Three Mandrel-Free Coils



New Inner PF Coils
Fabrication Strategy Devised to Ensure Quality

- Address quality concerns: All coil manufacturers must first successfully produce a prototype PF1A coil
  - Quality will be assessed by:
    - On-site surveillance
    - High-pot and turn-to-turn testing
    - Destructive testing (sectioning)
- Will use 4 manufacturers
  - Three industrial + PPPL
  - Will have on-site surveillance for industrial suppliers
- All production coils will be tested to full current and full I^2t on a custom test-stand before installation on NSTX-U

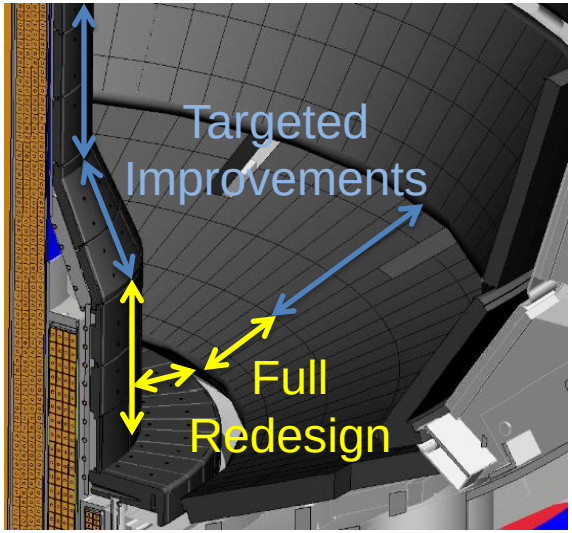
Portable Clean Room at PPPL



Winding line at PPPL

Improved PFC Designs

- Two significant issues found with as-installed PFC designs
  - Halo loads not fully accounted for in initial tile fixturing design
  - Narrower SOL width now projected



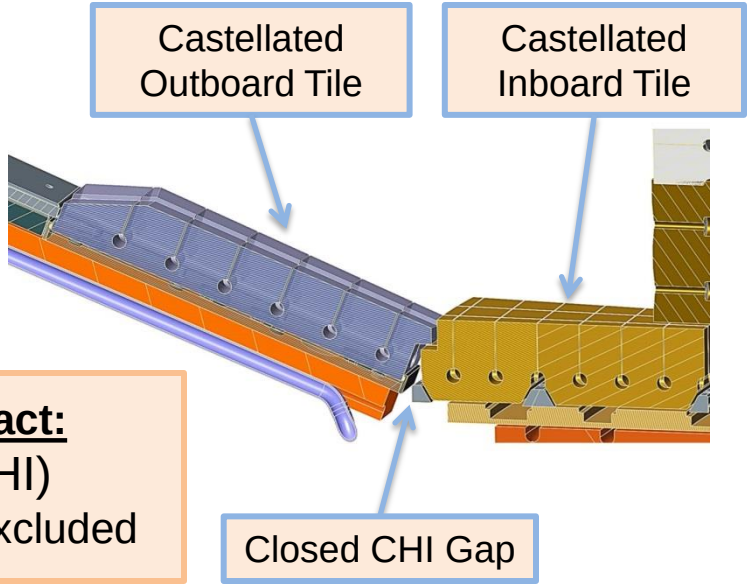
Path Forward

- Halo loads revisited based on NSTX, NSTX-U, MAST, other tokamak data
- 5 year plan research objectives + most recent SOL width models → updated heat flux specs
- Divide tile scope into 2 regions:
  - "Targeted Improvement" to chamfers, fixture scheme, material
  - "Full Redesign" to enhance thermal performance → **castellated tiles**
- All tiles will be designed to withstand B_T= 1.0 T, I_P=2.0 MA disruptions

Improving Design of Polar Regions
to Ensure High Performance and Reliability

- Issues identified
  1. PF1B coil limited divertor bakeout temperature
  2. 2 large ceramic insulators potential vacuum risk
  3. Use of single O-rings → potential for leaks
  4. Plasma can sometimes impinge on PF1C can
- Solutions
  1. PF1B supported by slings → thermally isolated
  2. Lower ceramic insulator eliminated
  3. Double O-rings with pumped interspaces
  4. Tiles will bridge the CHI gap

Tile gap between inner and outer vessels only large enough to accommodate thermal and mechanical motion, fit-up tolerances



Research / Programmatic Impact:
Coaxial Helicity Injection (CHI)
as previously implemented is now excluded

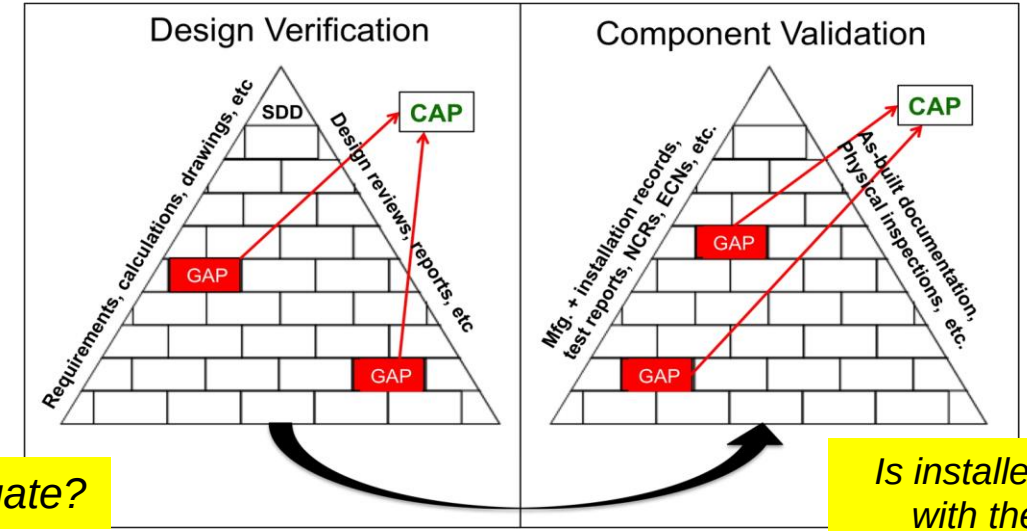
Summary

- Reviews have determined what needs to be repaired / replaced
- Developed new designs to repair and improve components
- Improving cost and schedule estimates
  - Following DOE O413.3B Program and Project Management guidelines
  - FY2017 / present NSTX-U operations budget ≈ sufficient to fund Recovery
    - Cost & Schedule Review estimated "Recovery" costs: $48M base + $15M contingency
    - Normal/planned outage costs for "Maintenance and Run Preparation": $34M + $4M cont.
  - New PF1 coils are critical path, followed by PFCs
  - Resume operations between fall 2019 and summer 2020
- Recovery will significantly enhance NSTX-U reliability & safety, provide highest-performance ST device as a robust user facility

Backup

Developed DVVR Process

DVVR = Design Verification and Validation Reviews



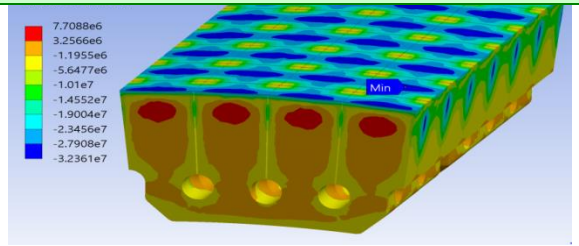
Is the design adequate?

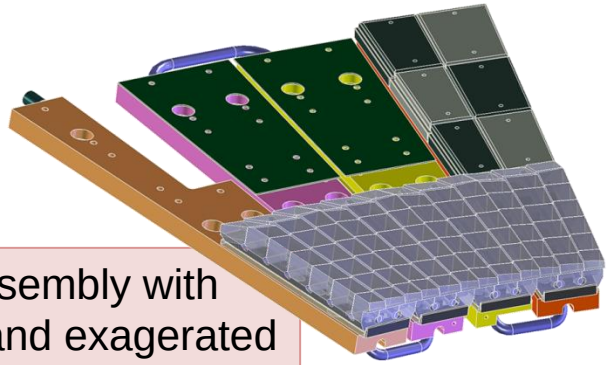
Is installed component consistent with the intent of the design?

- Prepared System Design Descriptions (SDDs) providing linkage to design-basis documentation
- Gathered manufacturing, installation, and test documents (dating back to the beginning of the NSTX project circa 1998)

New “Castellated” Design Provides For High Heat Handling Capacity and Ease of Implementation

Design allows individual castellation to thermally expand under heat flux w/o exceeding compressive stress limits
→ Lower material stress for a given tile surface temperature



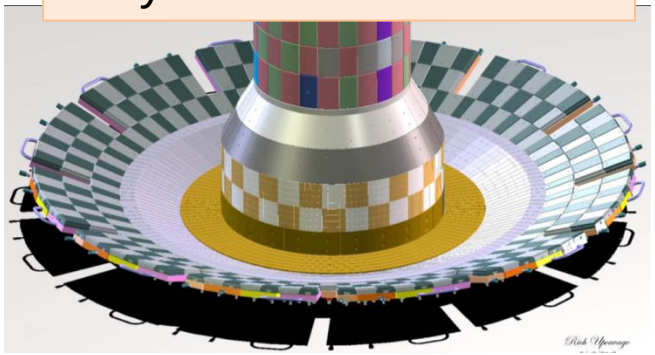


Outer divertor assembly with castellated tiles and exagerated fish-scale angles

Materials

- Considering a range of isotropic graphites
- Planning high heat flux tests using e-beam facilities at Applied Research Labs
- Study both isolated samples and full tile modules
- In collaboration with GA, ORNL

Fully Assembled Divertor



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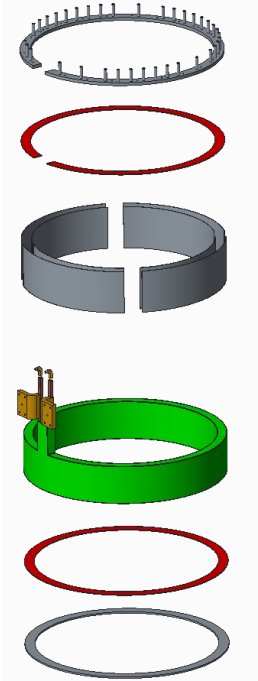
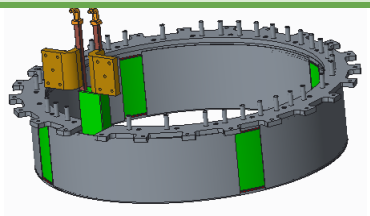
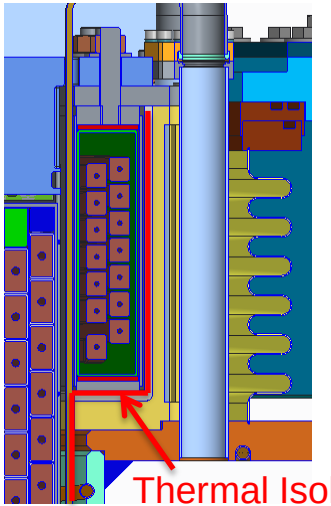
Mandrel-free coil mounted in slings, isolated from hot flanges







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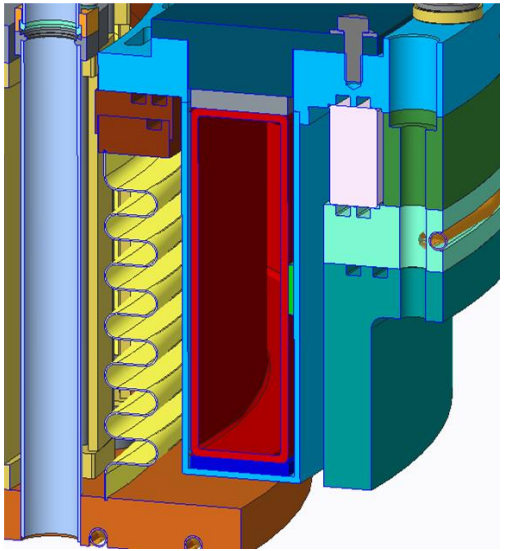
Top of Machine: Double O-Rings + Ceramic Break



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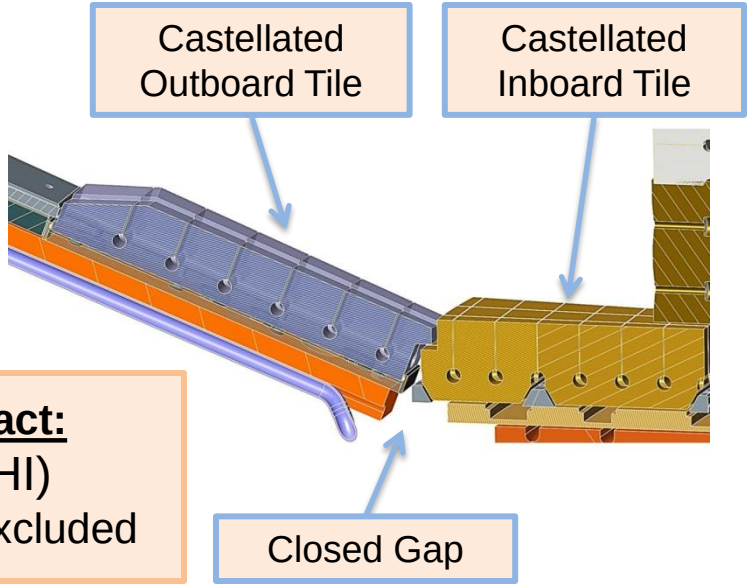

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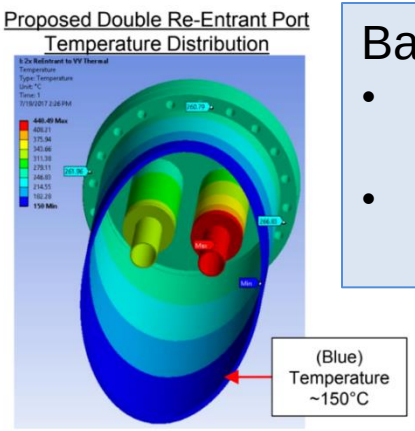
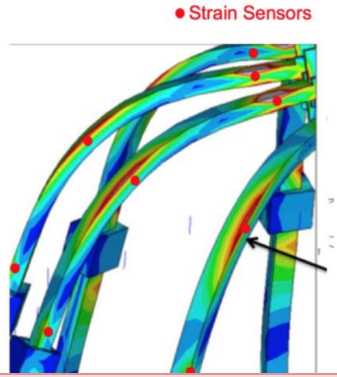
Bakeout, Instrumentation, and Shielding Scope will Improve Reliability and Safety



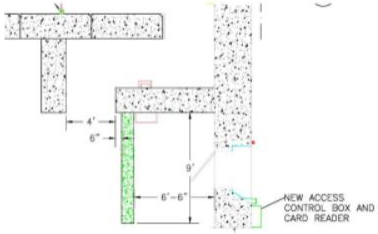
Bakeout Improvements

- Improved hot helium feed-throughs, flow control, and instrumentation
- Improved safety features on heated water system



Machine Instrumentation

- Model validation and trending
- Qualify design for full performance



Shielding Improvements

- Construct/improve labyrinths at doors
- Shielding in or in front of penetrations