National Spherical Torus eXperiment Upgrade

NSTX-U Team Meeting

September 14, 2018

J. Menard, S. Gerhardt, R. Feder, S. Kaye

Agenda

- Recovery Director's Review Outcome and Next-Steps – Jon (15+10)
- Brief summary of Recovery technical progress – Stefan (15+10)
- Recovery Project Management - near-term goals – Russ (15+10)
- NSTX-U Research Program progress and plans – Stan (10+5)

National Spherical Torus eXperiment Upgrade

Director's Review Outcome and Next-Steps

September 14, 2018

J. Menard and the Recovery Project team

PPPL PRINCETON PLASMA PHYSICS LABORATORY

PRINCETON UNIVERSITY

Purpose of "Director's Review"

- Next major steps in Recovery Project:
  - CDE-2: Approve cost and schedule baseline for the project
  - CDE-3: Approve start of construction/fabrication
- Recovery fabrication/approval planned to be staged/phased into either 2 parts (3A,B) or possibly 3 parts (3A,B,C)
- Present approach (not required) is to combine CDE-2/3A into first review
  - 3A scope: New PF1 coils, plasma facing components, PF1B power loop
- **Must succeed (small number of minor chits) at CDE-2/3A review**
- Director's Review is external assessment of current status and readiness of Recovery Project to proceed to DOE OPA CDE-2/3A review
  - Reports to PPPL Director + FY2018 Notable Outcome → report shared with FES
  - Uses same/similar charge questions as expected at actual OPA review
  - Outcome influences timing of DOE OPA review

National Spherical Torus eXperiment Upgrade

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U.S. DEPARTMENT OF ENERGY | Office of Science | PPPL | NSTX-U

Upcoming and Past NSTX-U Meetings:

- **NSTX-U Recovery Director's Review** to be held at PPPL September 5-7, 2018

Link to Director's Review website and agenda:

https://sites.google.com/pppl.gov/dricereview/presentations

Quick Links for Additional Information:

- Monday Physics Meetings
- Presentation templates:
  - 4x3: PPT PPTX LaTeX
  - 16x9: PPT PPTX
  - Templates and Graphics Folder

Charge questions from DOE (1)

1A. Are designs supporting the Recovery Project technically sound and likely to meet performance specifications?

1B. Are all design interfaces appropriately defined?

1C. Is the CDE-3A scope appropriate?

1D. Is the design sufficiently mature to establish the baseline and initiate CDE-3A long-lead procurement?

2. Are project risks properly identified and are appropriate mitigation strategies in place?

3A. Are the cost and schedule estimates credible and realistic to support establishment of the baseline?

3B. Do they include adequate contingency based on project risk and uncertainty analysis?

3C. Are the cost estimates traceable and appropriately integrated with the project schedule?

Charge questions from DOE (2)

4A. Is the project being managed (i.e., properly organized and adequately staffed) as needed to complete final design and support the project through construction to successful completion?

4B. Is the risk management process being effectively managed?

4C. Are project assumptions (technical/cost/schedule) appropriately documented?

5A. Are environmental, safety & health aspects being properly addressed given the project's current stage of development?

5B. Are integrated safety management principles being followed?

6. Have the recommendations from previous reviews been appropriately addressed?
7. Is the project documentation (e.g., PEP, HAR) complete and ready for approval?
8. **Is the project ready for CDE-2/3a approval?**

Charge questions from PPPL Director

- Please provide your assessment of whether the Recovery project scope has appropriate QA/QC oversight and staffing.

- Similarly, please provide your assessment of whether PPPL engineering policies and procedures adequately support the NSTX-U Recovery project.

....

- The project has been asked (by me) to consider options to shorten the project duration by deferring (and/or possibly accelerating) scope required to meet the ultimate performance objectives of the facility. Please provide your assessment of the Recovery team's proposals for these options.

Scope Contingency? Simplicity? Risk reduction? Faster delivery?

Director’s Review Committee Members

Subcommittee (SC)	SC #	Name	Role	Institution
Director's Review		John Post	Chair	LLNL
Technical	1	Steve Renfro	Chair	LANL
		Greg Tietbohl		Retired
		Tom Todd		Retired
		Ken Fouts		SLAC
Commissioning / TTO / ASO	2	Mike Bebon	Chair	BNL
		Stefan Bosch		IPP / W7-X
		Ian Evans		SLAC
ES&H / QA	3	Peter Grivins	Chair	MSU
Cost / Schedule / Risk	4	Diane Hatton	Chair	BNL
		John Bielecki		Tecolote
		Karl Flick		SLAC
		Doug Gray		ICE Consult
Management	5	George Srajer	Chair	ANL
		John Post		LLNL
		Ronald Lutha		DOE Chicago

SC1 – Technical

1A. Are designs supporting the Recovery Project technically sound and likely to meet performance specifications?
Yes.

1B. Are all design interfaces appropriately defined?
No, the interfaces have been identified but the definition is in process.

1C. Is the CDE-3A scope appropriate?
Yes. The scope for magnets, PFC's and PF-1b loop is appropriate for long lead procurement.

1D. Is the design sufficiently mature to establish the baseline and initiate CDE-3A long-lead procurement?
Yes. We reviewed Magnets, and PFC's in detail and the engineering design process is in place and the project could support CDE-3a.

2. Are project risks properly identified and are appropriate mitigation strategies in place? **Yes**, project risks are properly identified and **No**, appropriate mitigation strategies are not in place.

SC1 – Technical

B. Please provide your assessment of whether the Recovery project scope has appropriate QA/QC oversight and staffing. Similarly, please provide your assessment of whether PPPL engineering policies and procedures adequately support the NSTX-U Recovery project.
   - The QA/QC oversight and staffing appear to be adequate for the project.
   - The engineering policies and procedures have been recently updated and the project is actively engaged in implementing these updates and using them to benefit the project preparation for baselining.

Recommendations:

- Complete the verification and validation plan which is critical to defining how the deliverables will be completed. This plan should be in draft form prior to CDE-2/3A.
- Institute a safety note process for personnel hazard calculations; e.g., tiles bolted to the inside of vessel that could fall on personnel working inside.

SC2/3 – ASO / Commissioning / TTO / ES&H

5A. Are environmental, safety & health aspects being properly addressed given the project's current stage of development?

For the most part yes. The exception is the Access Control System (see Stefan's talk).

5B. Are integrated safety management principles being followed?

Yes. There is a DOE-Approved ISM Program and Worker Safety and Health Program. There was evidence of implementation of ISM core functions and guiding principles.

Recommendations:

- Revisit decision to reuse existing ACS vs providing a new system
- Expand the PHAR to include a more extensive look at credible "what if" scenarios
- Revisit the current plan to conduct two ARRs (A&B):
- Develop a resource-loaded schedule for all readiness preparation activities and deliverables, then integrate with project schedule.
- Clarify DOE expectations for CD-4E relative to G413.3 16A "Project Completion/Closeout Guide" requirements (e.g. Transition to Operations Plan required?).

SC4 – Cost / Schedule / Risk (1)

2. Are project risks properly identified and are appropriate mitigation strategies in place? **Yes**, project risks are properly identified and **No**, appropriate mitigation strategies are not well documented.

3A. Are the cost and schedule estimates credible and realistic to support establishment of the baseline?

No, the basis of estimate was not yet fully documented.

3B. Do they include adequate contingency based on project risk and uncertainty analysis? **No**, not until 3A above is addressed.

3C. Are the cost estimates traceable and appropriately integrated with the project schedule? **Yes**, the numbers can be traced from the control account plan to the schedule.

4A. Is the project being managed (i.e., properly organized and adequately staffed) as needed to complete final design and support the project through construction to successful completion? **Yes**, but the team appears stretched thin and likely could benefit from staff augmentation.

SC4 – Cost / Schedule / Risk (2)

4B. Is the risk management process being effectively managed? **Partially**. The tools exist and implementation is under way.

4C. Are project assumptions (technical/cost/schedule) appropriately documented? **No**, there were no cost and schedule assumptions documented. See comments.

8A. Is the project ready for CDE-2/3a approval? **Not yet**.

C. The project has been asked to consider options to shorten the project duration by deferring (and/or possibly accelerating) scope required to meet the ultimate performance objectives of the facility. Please provide your assessment of the Recovery team's proposals for these options.

- The project team has examined alternatives and provided a summary that showed a relatively small amount of cost savings and a ~6 month schedule reduction;
- however, the Cost/Schedule/Risk sub-committee believes it is too late in the process to significantly alter the project plan and still be ready for a CDE-2/3A.
- Using some of the options as scope contingency could be beneficial.

SC4 – Cost / Schedule / Risk (3)

- **Recommendations to implement prior to CDE-2/3A**
  - Develop a comprehensive cost estimate document that captures relevant cost estimate Assumptions, Ground Rules, Rates (labor, material, burdens, escalation), and documents the Basis of Estimate (BOE) for each element of the estimate.
  - Finalize the estimate for the recently-changed work elements
  - Schedule should be reviewed by an experienced scheduler.
  - Update the Risk Management Plan and Risk Registry as noted in comments relating to these documents.
  - Re-evaluate the estimate uncertainty model, the schedule Monte Carlo model, and cost Monte Carlo model using post-mitigation, three-point input distributions.

SC5 – Management (1)

6. Have the recommendations from previous reviews been appropriately addressed?

   Recommendations from 3 previous reviews (NSTX-U Recovery Cost and Schedule Review held September 6-8, 2017, OPA Report Phase 1 - held February 6-8, 2017 and OPA Phase 2 - held March 14-16, 2018 were appropriately addressed.

7. Is the project documentation (e.g., PEP, HAR) complete and ready for approval?

   Yes. The Project posted a Preliminary PEP (PPEP) but was not fully signed. The Committee feels that the PPEP is basically a PEP, but urges the Project to get appropriate signatures. Other documentation is in a various stages of completion

8. Is the project ready for CDE-2/3a approval?

   The project has made tremendous strides towards being ready for CDE-2/3A. Once the project addresses traceability of cost estimate (Charge 3C), the Committee believes that the project will be ready for CDE-2/3A.

JEM remark: Actually, Recovery needs to better address Charges 2, 3

SC5 – Management (2)

C. The project has been asked to consider options to shorten the project duration by deferring (and/or possibly accelerating) scope required to meet the ultimate performance objectives of the facility. Please provide your assessment of the Recovery team's proposals for these options.

- The Committee cannot provide an assessment because the project did not provide sufficient information.

JEM remarks:

- *Context here is that Recovery must first establish a credible baseline before the baseline can be compared to alternative scenarios.*
- *Changes in project scope (after baselining) could potentially be implemented using baseline change control process as defined in the PEP*

- **Recommendations**
  - In concert with PSO and FES, develop a formal tailoring document for application of O413.3B.
  - Complete all required documentation prior to CDE-2/3A review.
  - Attend/observe/participate in other Office of Science reviews.

Response to Director's review is under way

- **Developing new "Roadmap to CDE-2/3A" with ~140 tasks so far**

- Cost Estimate Updates
- PDR/FDR Planning
- Critical Decision Tailoring
- Updated Rates
- Update and Finalize WAFs
- Cost/Schedule finalization
- Risk Management Updates
- PEP Updates
- ASO / ARR / Commissioning Updates
- ES&H Updates
- Systems Engineering Updates
- Project Management Updates
- CDE-2/3A Presentation Prep
- CDE-2/3A Document Prep and Post
- Hold CDE-2/3A Review

- Presently understood critical path runs through developing requirements and cost-estimate for ACS if ACS is included in project baseline

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Recovery Project Technical Progress

NSTX-U Team Meeting

Stefan Gerhardt → Thanks to all contributors!

Friday, September 14, 2018

Princeton Plasma Physics Laboratory

This Talk Will Address 7 of the 10 Major Scope Areas within Recovery

Improved Reliability	Safety and Compliance	Transition to Ops

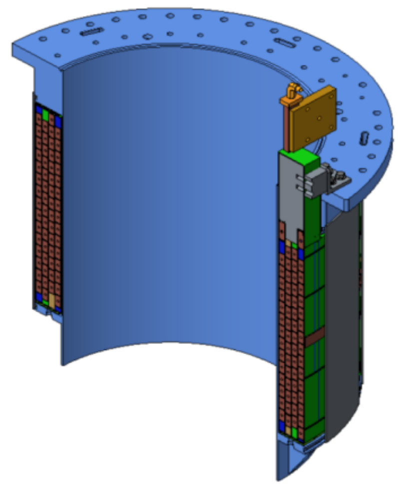
1. Rebuild all six inner-PF coils with a mandrel-free design
2. Replace plasma facing components that do not meet updated requirements
3. Improve the "polar regions" (machine top and bottom)
4. Remedy issues with the passive plates
5. Implement mechanical instrumentation to assess quality of mechanical models, trend machine behavior
6. Improve hot He distribution system used during bakeout; eliminate the safety issues identified with the bakeout medium temperature water system
7. Improve the test cell neutron shielding and access control system
8. Reassemble the machine (KPP #1)
9. Implement the Accelerator Safety Order
10. Commissioning: Bakeout (KPP#2), Test Coils (KPP#3), Create First Plasma (KPP#4)

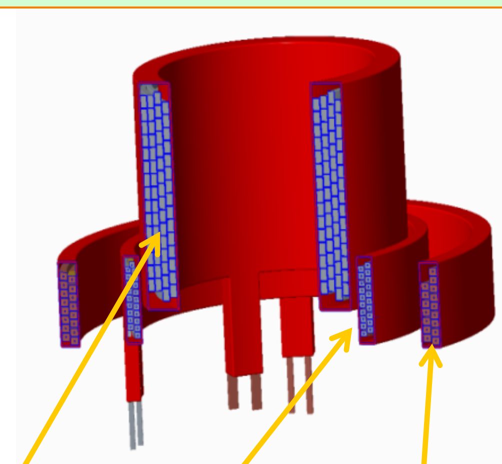
Outline

- Design and Prototyping Progress
- OH/TF Trial Fit
- Technical Results from the Director's Review

New Inner PF Coils are Designed to Improve Testability and Manufacturability

- Reminder of path:
  - Build 6 new PF-1 coils (PF-1a/1b/1c, upper & lower)
  - Use designs that facilitate turn-to-turn testing
    - Previous coils fabricated on permanent mandrels
    - New coils: removable mandrels
- New coil design simplifies fabrication relative to the previous inner-PF coils
  - Simplified winding pattern
  - No braze joints
  - Softer copper
- Prototyping is a key element of our plan



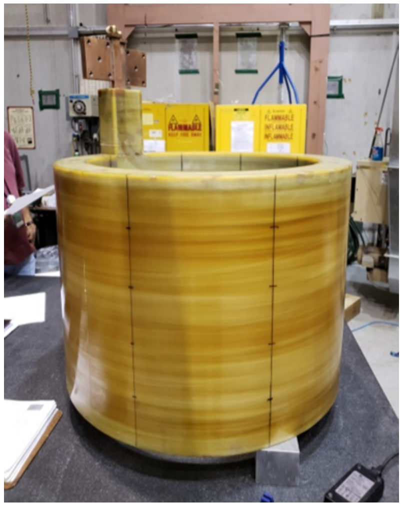
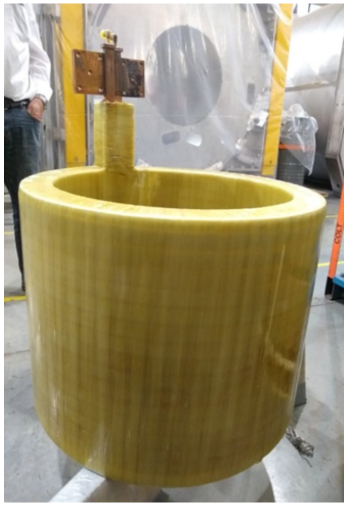


Status: FDR on March 30th

We are Completing the Prototyping Phase on Coils

Our approach: Any vendor that makes production coils must first be qualified by making a prototype coil, having that coil go through a rigorous inspection and test procedure.

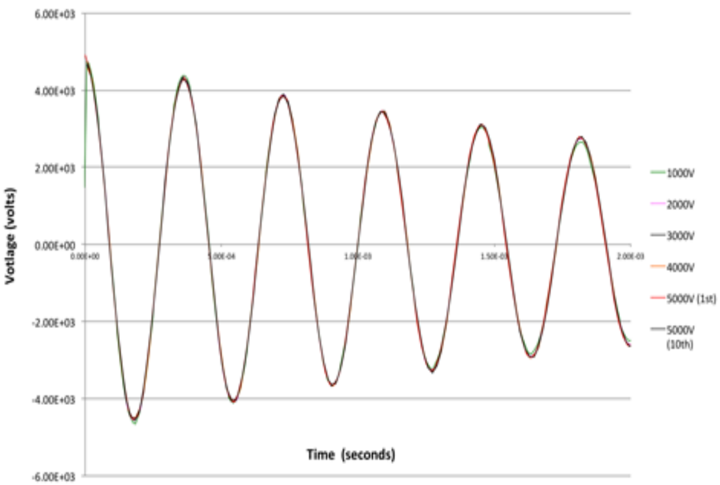


- **Fabricated prototype coils at four locations**
  - All prototype coils are complete
- **Prototype coils are being evaluated preceding award of contract for production coils**
  - Testing of three coils is complete
  - Testing of final coil is nearing completion

Prototype Tests Have Gone Well

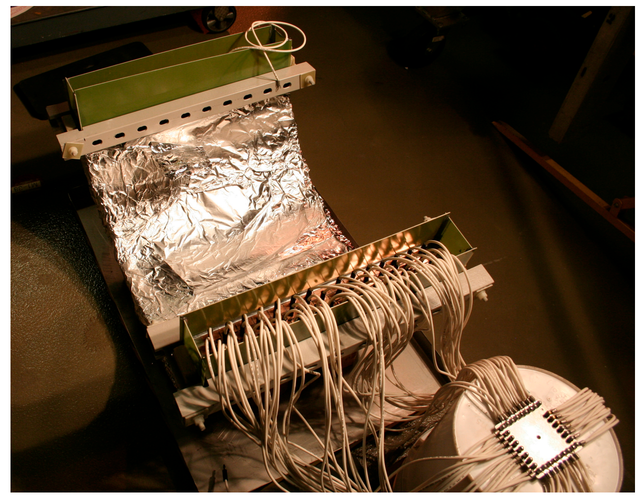
Surge tests showing similar ringing waveforms from 1 kV to 5 kV ← Assess turn insulation



Vendor # →	1	2	3	4
R_{20} (mΩ)	5.67	5.66	5.67	5.7
Inductance (mH @ 10 Hz)	1.8	1.79	1.79	1.81
Parallel Resonance (kHz)	73.3	69.6	72.0	75.9

Section and inspect coil ← Assess VPI quality and workmanship

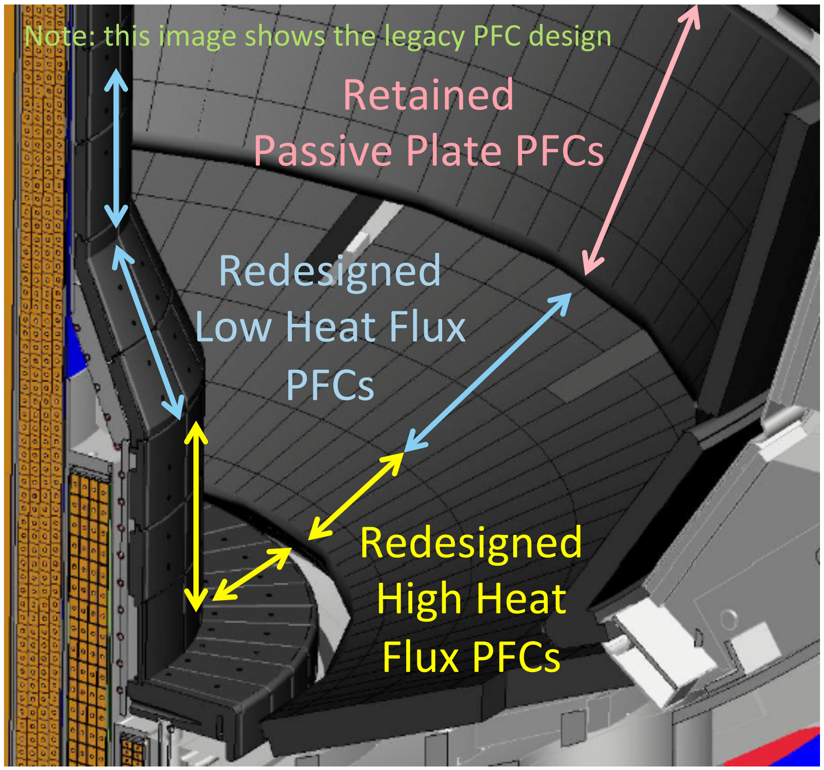
High-voltage tests on ground and turn insulation ← assess ground and turn insulation



3 of 4 coils have completed the battery of tests

All coils have (so far) passed all tests

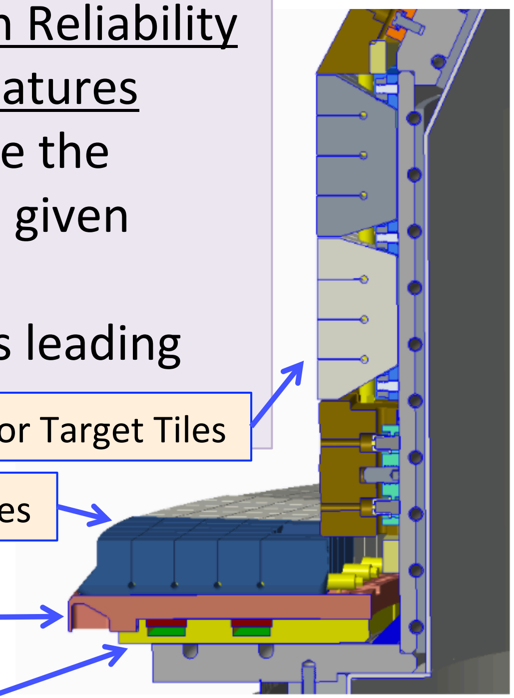
Plasma Facing Component are Being Designed to Meet Full Performance Thermal and EM Loads



<u>High Heat Flux Region Reliability Enhancement Features</u>

→ Castellations reduce the material stresses for a given surface temperature

→ Fishscaling protects leading edges



Status: PDRs on Sept. 29 & Nov 15, 2017

FDR in Sept. 2018

High Heat Flux- Full EM loads, with aggressive heat flux requirements: ~5.5 MW/m^2, 5 seconds @ 5 degrees incident angle, no toroidal leading edges

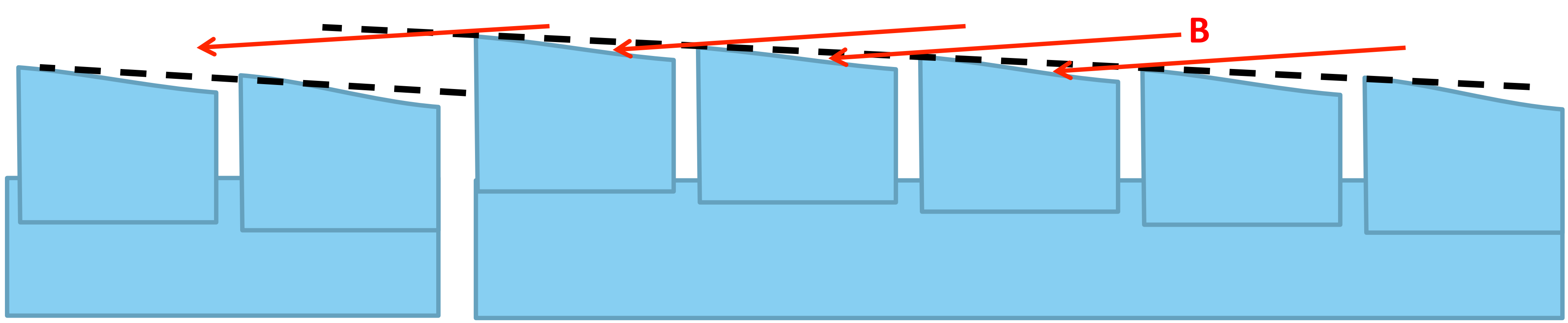
Low Heat Flux Region- Full EM loads, but modest heat flux requirements: ~3 MW/m^2, 5 seconds @ 8 degrees incident angle, leading edges allowed

Manufacturing and Physics Optimization has Lead to the Choice of Final Fishscale Angles

- Fish-scaling protects the leading edges of tiles against overheating
  - Prevents large carbon sources and potential edge cracking from thermal stresses
  - Required angle depends on the maximum incident angle, dimensions and tolerances
- Steeper fish-scale angles:
  - Facilitate a loose tolerance budget ← Good
  - Allows for erosion while preserving leading edge shielding ←Good
  - Results in increased heat flux in the non-shadowed regions ← Not Good

Schematic Drawing of Castellations

← Toroidal Direction



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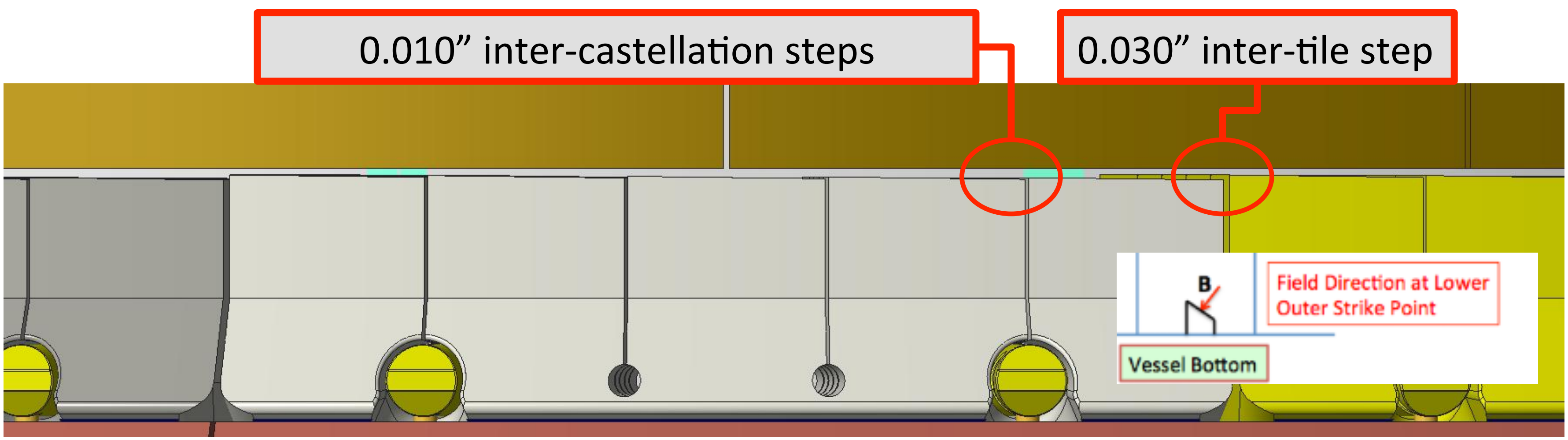
- Steeper fish-scale angles:
  - Facilitate a loose tolerance budget ← Good
  - Allows for erosion while preserving leading edge shielding ←Good
  - Results in increased heat flux in the non-shadowed regions ← Not Good
- Trade-off study → Requirement to "robustly" shield leading edges
  - Results in ~0.7-1 degree fishscale angle
  - Factor of ~1.5-2 heat flux enhancement at 1 degree incident angle.

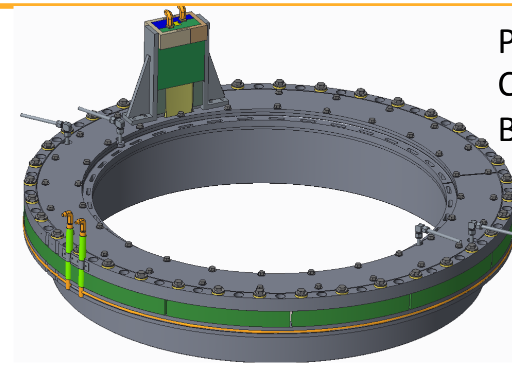
See PFC-180706-MAJ-01

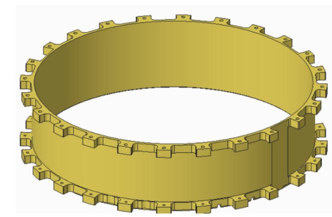


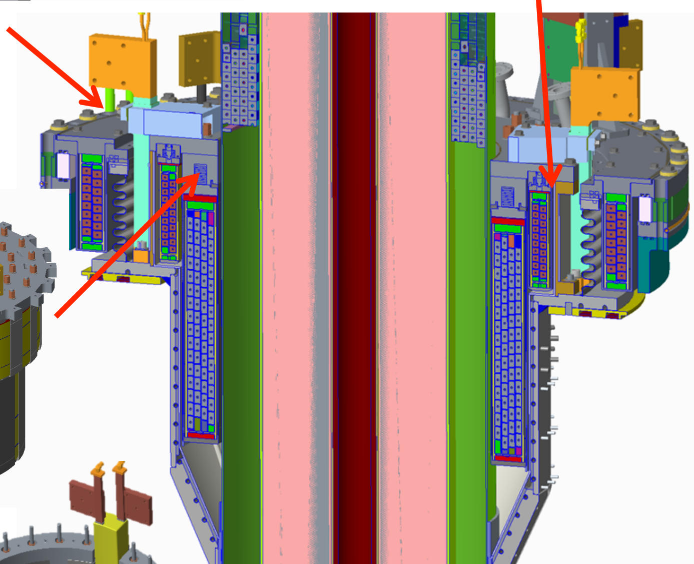
Polar Region Design Developed to Robustly Support the Coils and Provide a Highly Reliable Vacuum Boundary

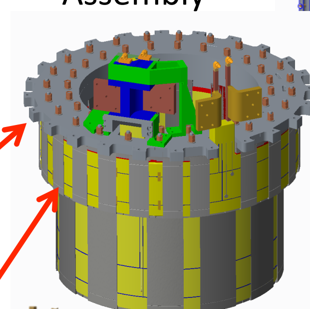
Design Features

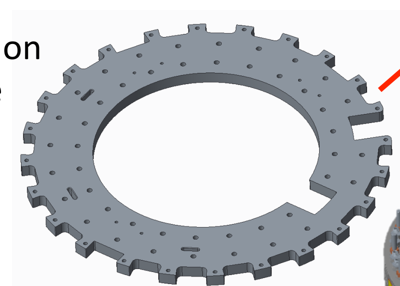
- Supports mandrel-free coils against all static and transient EM loads, provides preload
  - Isolates coils from hot regions during bakeout ←remedies previous bakeout issue
- Provides mounting structures and heat/cooling for Plasma Facing Component (PFC) Tiles
- Provides robust elements of vacuum boundary, w/ double O-ring seals
  - Response to Extent of Condition recommendation to eliminate large single O-ring seals

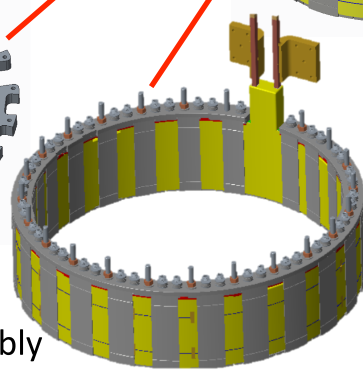

PF-1c and Ceramic Break

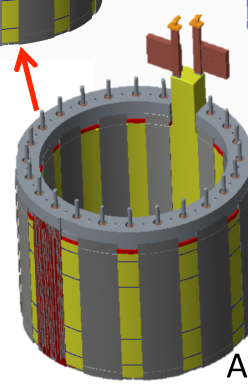

Collar


Full Upper Polar Region


PF-1a/1b Assembly


Common Flange


PF-1b Assembly


PF-1a Assembly

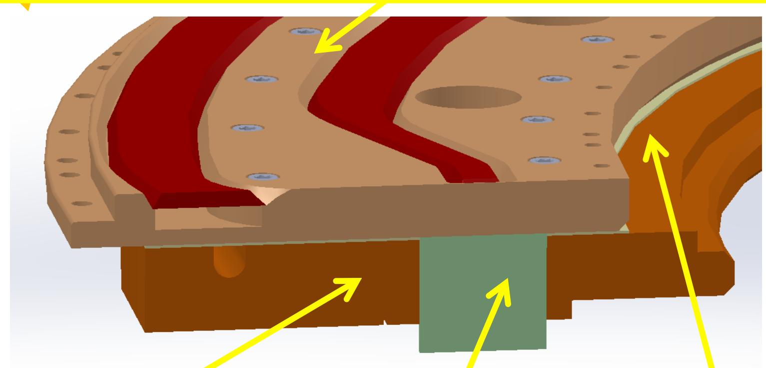
Status: PDR on August 2nd

New Heating/Cooling Features are Being Added to the CS Casing

Requirements:

- Remove heat from tiles during normal operation, supporting a 20 minute repetition rate
- Add heat to tiles during bakeout, supporting >300 C bakeout for all tiles.
- No use of water in the vacuum boundary

2: Inconel 625 Heat Transfer Plate- vacuum side cooling channels for hot or cold He

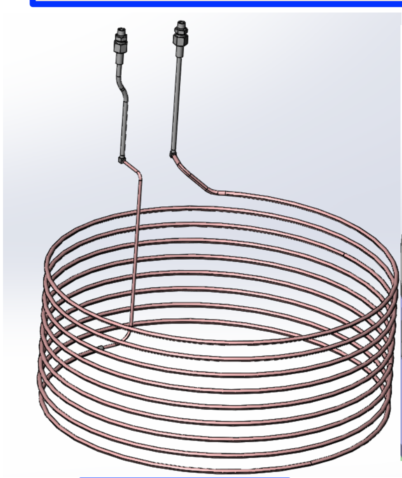


Casing Flange

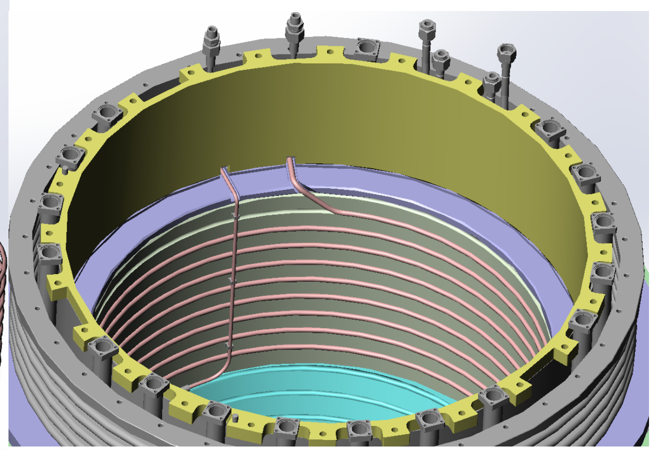
Feedthrough Puck

Grafoil

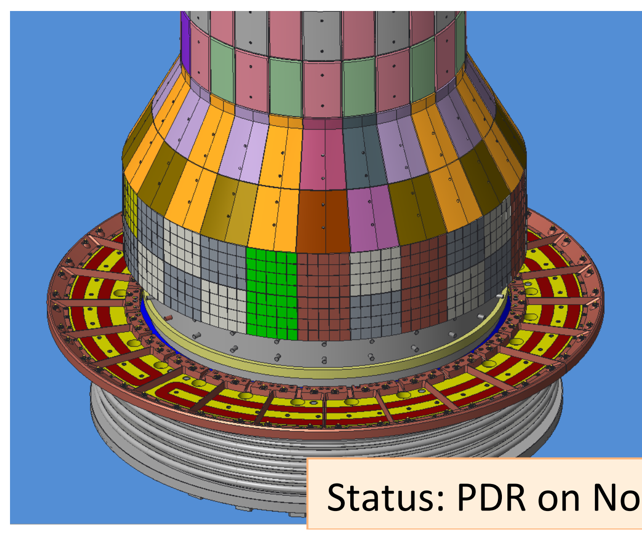
1: Heat Transfer Tubing – no angle section cooling



Formed



Installed



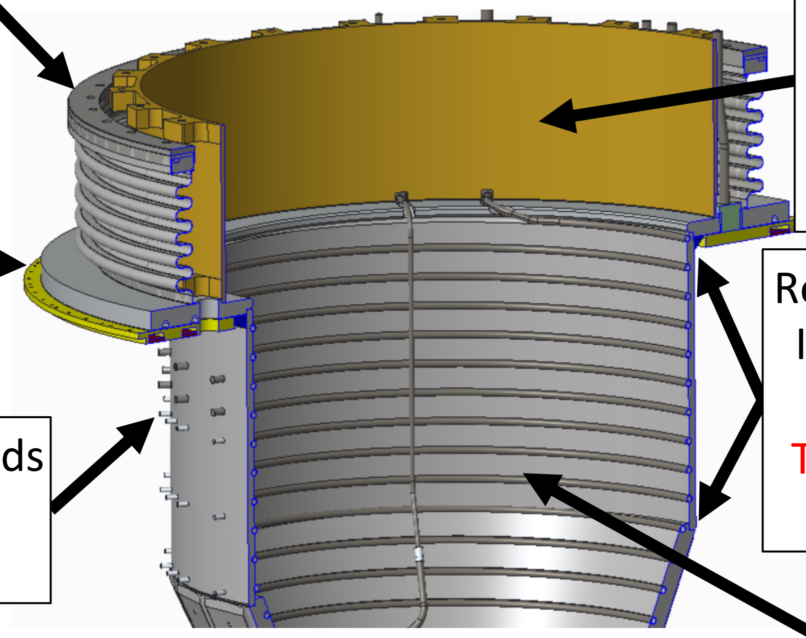
Status: PDR on Nov 30th 2017

Work on the Casing Itself is Now a Primary Focus

Replace Bellows Flange
To Accommodate Double O-Rings
Replace Bellows
To Remedy Fatigue Issues

Add Heat Transfer Plate – Many Tapped Holes
To Facilitate Bakeout and Operations Cooling

Remove (192) & replace (180) studs
To Accommodate the New Tile Mounting Scheme



Install Interfacing Features to CSC Collar Support
To Facilitate New Inner-PF Coils

Remediate Potentially Insufficiently Strong Welds
To Mitigate Thermal Stress Concerns

Install Heat Transfer Tubing
To Facilitate the Cooling of the Vertical Target

All scope here repeated top and bottom of the casing

Work on the Casing Itself is Now a Primary Focus

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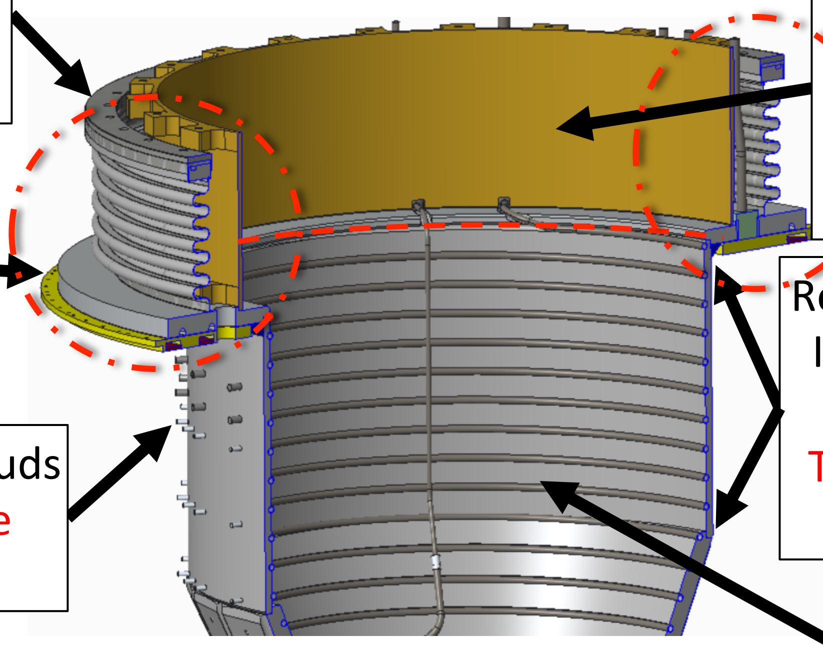

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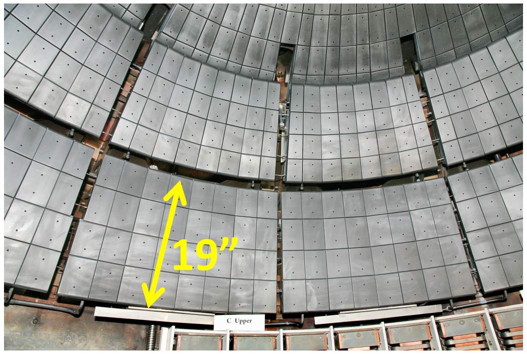
All scope here repeated top and bottom of the casing

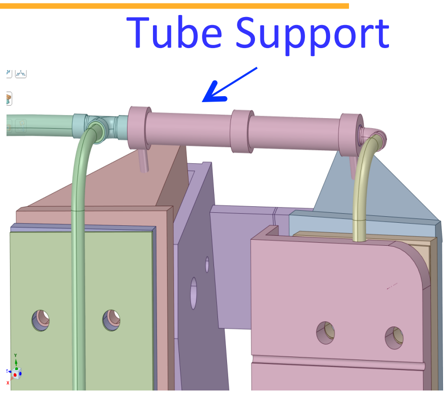
Best Path Looking to be Parting the Casing at the Horizontal Target Flange, Followed by Fabrication of New End Components

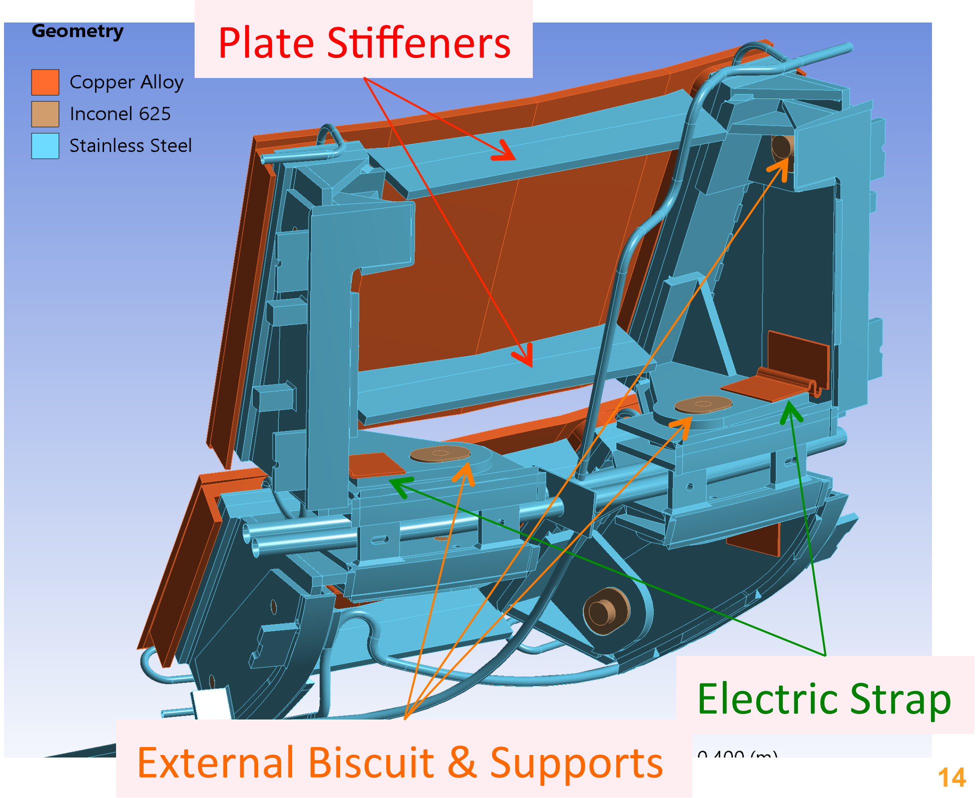
Passive Plate Motion Issues are Remedied with New Designs

- Passive plates are Cu plates covered by graphite tiles
  - provide stabilization to plasma instabilities
- Issues and resolution:
  - Flexing under EM disruption load →plate back stiffeners
  - Unacceptable play in their bracketry →stronger bolts and in-situ fastening augmentation
  - Non-uniform electrical resistivity →Dedicated electrical connections
  - Excessive EM loads on the He lines →support for lines.
- Solutions can be implemented w/o significant disassembly

Status: PDR on July 25^{th}





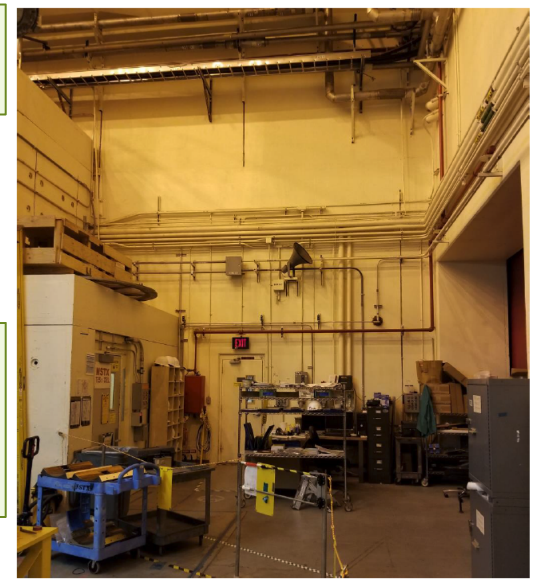


Shielding Designs Have Been Developed via MCNP Calculations

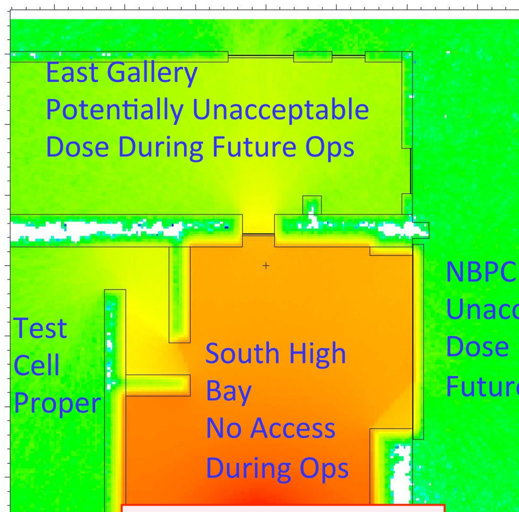
- Measurements both during the run and with a D-T generator after the run identified most problematic penetrations.
- MCNP calculations have been done to shielding designs that attenuate ~99.9% of neutrons through doors/windows
  - Example calculation for south east door places source in middle of south high bay
- Now working on:
  - mechanical designs of shielding structures
  - Assessment of whether our ALARA goals can be met with some design simplifications

Status: PDR on August 6

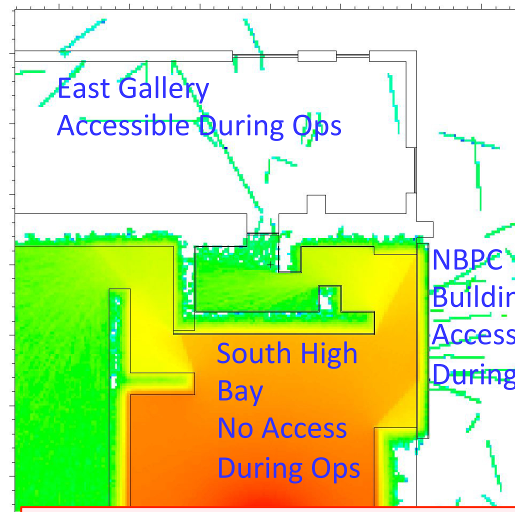
Neutrons come over shield wall, can exit through door.



In South High Bay, Looking toward Gallery Door



Present Status



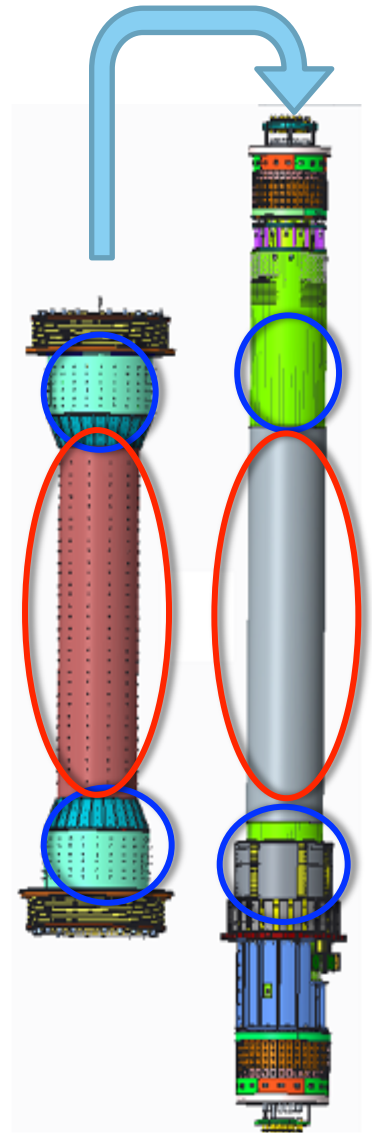
After Poly-Lined Labyrinth

Outline

- Design and Prototyping Progress
- OH/TF Trial Fit
- Technical Results from the Director's Review

Trial Fit Activity Initiated to Ensure Casing Could be Aligned w/ Adequate Clearances

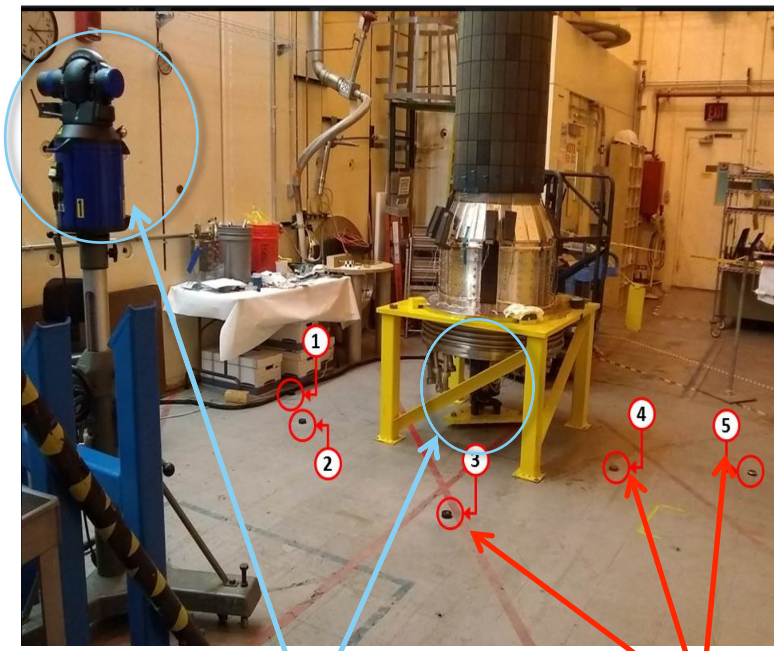
- Issues from 2016 run
  - Casing was significantly tilted relative to the bundle.
  - Microtherm insulation showed signs of damage when the casing was removed.
- Note: these issues primarily related to the central portion of the casing; largely independent of work on the ends
- Trial fit activity was initiated to assess alignment capability and clearance.

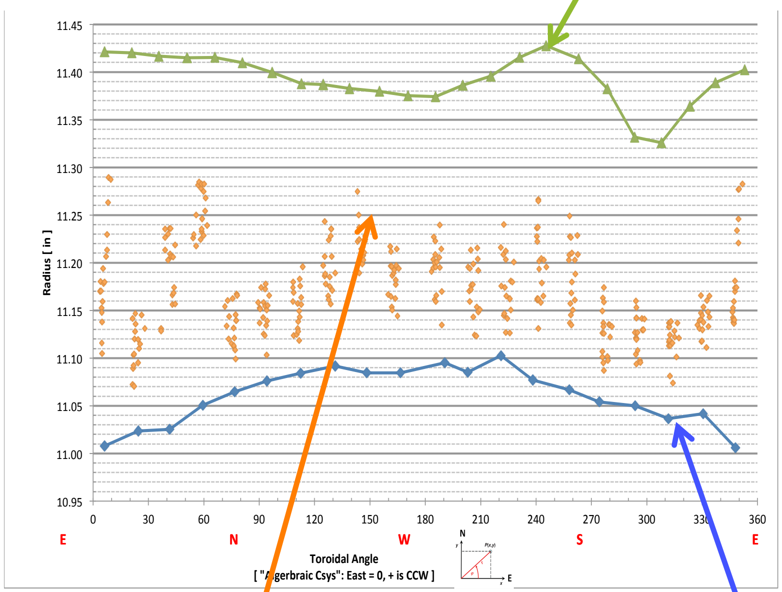


Metrology on the Casing and Bundle Gave Confidence the Fit Would be Successful

Casing measurements relied on two consistently aligned laser trackers → **sophistication bodes well for future efforts during machine reassembly**

Detailed metrology on the casing and OH bundle showed a clearance gap between casing ID and bundle OD





Envelope of Casing ID

Laser Trackers

Monuments

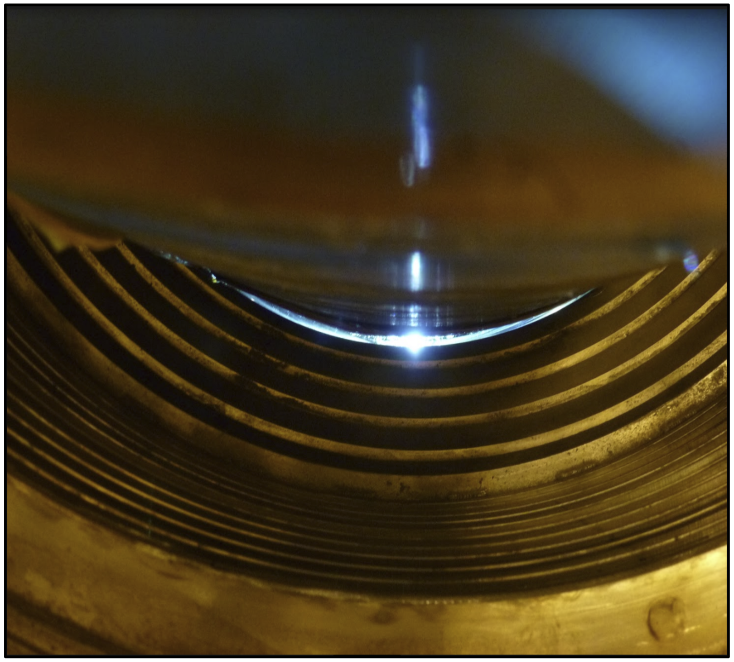
Measurements of Radius w/ Diagnostics and Microtherm

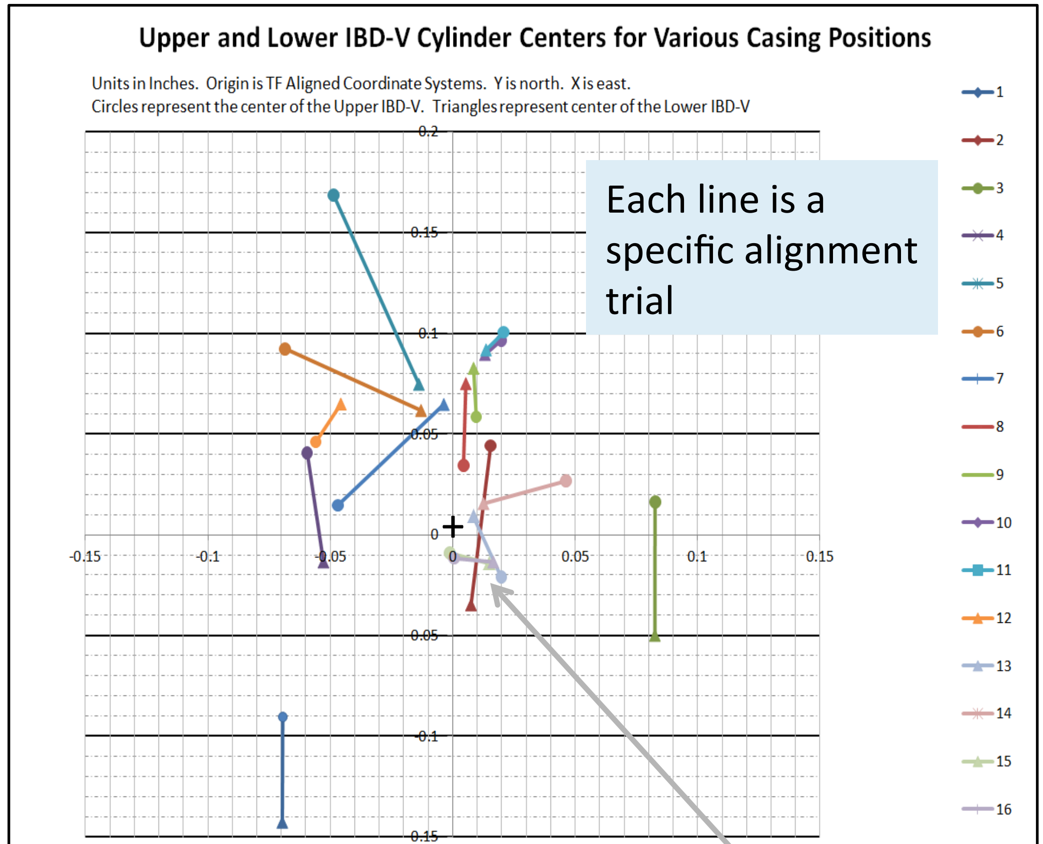
Envelope of OH Coil OD

Trial Fit Was Successful in Aligning the Bundle

Image showing light visible the full length of the casing.

Each line connects points at top and bottom of the casing
Plot origin is centered on the TF coil
Units are inches





	-RD-11 Requirement	Achieved
tilt [mrad]	0.4	0.14
shift [in]	0.078	0.015

Final position of best alignment

Full Machine Metrology Capability Being Developed

- Key need: a means to provide alignment for components both inside and outside the vessel.
- Method → *Contract vendor to establish a VV coordinate system which links internal* <u>*and*</u> *external monuments*
- Multiple passes used to "stitch" together a coordinate system.
- Can then calibrate our metrology hardware against those monuments as needed.
  - Vendors will also be asked to provide positional measurements of the outer-PF coils and the vessel nozzles.
    - Directly supports alignment of the outer-PF coils.

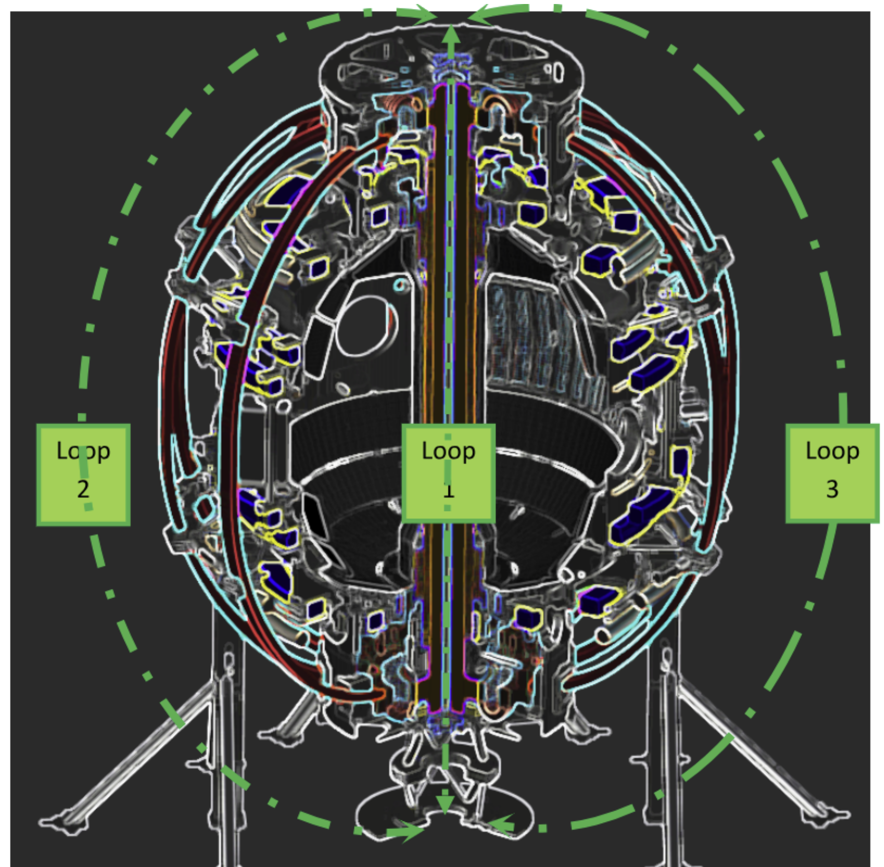


Figure 2

Vendor team was here last week, we are now preparing for their return to make measurements

Outline

- Design and Prototyping Progress
- OH/TF Trial Fit
- Technical Results from the Director's Review

Technical Findings From Director's Review Were Positive

- Q: Is the design sufficiently mature to establish the baseline and initiate CDE-3A long-lead procurement?
  - A: Yes. We reviewed Magnets, and PFCs in detail and the engineering design process is in place and the project could support CDE-3a.
- Select Findings/Comments:
  - The vendor interface and control process for the PF coils has been very successful in mitigating risks with the coil fabrication process.
  - Design engineering requirements development, interface control, design request, document control, and change request processes exist and are documented.
  - Design review process exists and has been executed in a robust way.

ES&H & Commissioning Committee Findings were Positive, but with a Warning

- Q: Are environmental, safety & health aspects being properly addressed given the project's current stage of development?
  - A: For the most part yes. The exception is the Access Control System.
- Select Comments/Findings/Recommendations
  - Planning for achieving readiness to commission is underway with full engagement of operations manager and appropriate support staff.
  - An Accelerator Safety Order Manager with a strong operations background and experience has been assigned.
  - Project and Operations staff have been reaching out to other accelerator labs and the accelerator safety community, and participating in community activities.
  - Revisit decision to reuse existing ACS vs. providing a new system

Activity to Revisit Access Control System Requirements is Underway

- Definitions
  - Access Control System (ACS) → the complete set of systems used to ensure that we are not in the test cell (or other areas) when hazardous sources of energy are present.
  - Hardwired Interlock System (HIS) → the door switches, e-stops, and associated relay logic.
  - Our systems are fundamentally based on the TFTR design
- DR team provided us with updated standards (ANSI N43.1, Radiation Safety for Design and Operation of Particle Accelerators) and examples of requirements from other labs.
- Have formed an NSTX-U team looking to establish requirements
  - LoI #1 → Establishing provenance of legacy drawings and requirements
  - LoI #2 → Industrial and Accelerator Standards
  - LoI #3 → Functional and configuration requirements
  - LoI #4 → Accelerator community best practices
  - LoI #5 → Extent of the credited control

Technical Summary

- Great progress has been made in the technical design of the NSTX-U core.
  - Casing scope is the last awaiting full PDR.
- Largely positive technical findings at the Director's Review
- Access Control System and CS Casing are area of intense technical focus, in addition to the ST core components.

Backup

Bakeout Scope Will Improve Both Safety and Performance

- >300 C bakeout required to remove H_20, CO_2, other air constituents from graphite tiles.
- Achieve bakeout by:
  - Pumping ~400 C He through tubing in tile backing structures
  - Resistive heating via 8 kA through casing
  - Using 150 C water in pipes on the outer vessel

Major Scope Item #1

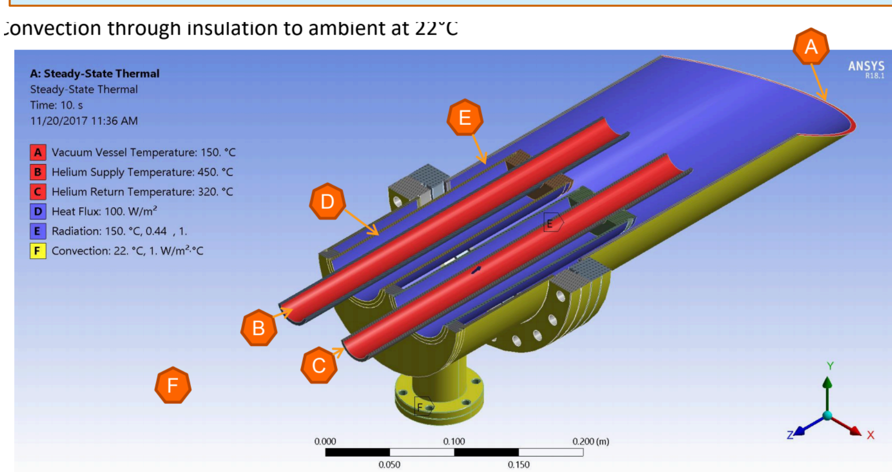
Add additional interlocks and safety devices to mitigate risk of explosive vaporization of the 150 C water if the covering-pressure is lost.
"BLEVE" = "Boiling Liquid Expanding Vapor Explosion"

Major Scope Item #2

Implement 6 new hot-He feedthroughs to replace existing designs that exceed thermal stress allowable

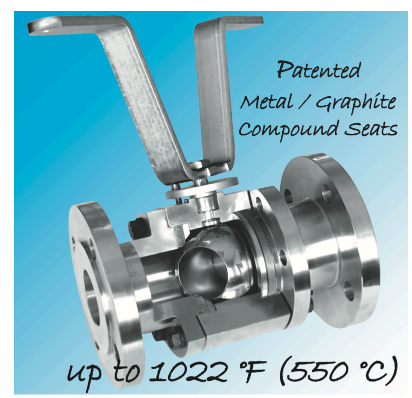
Major Scope Item #3

Improve the measurements and control of the hot He distribution



He flow and Temp. Sensor

Flow Control Valve



Status: PDRs on Dec. 1, Jan. 11, Feb. 1, April 5th

See available talk by J. Petrella

The NSTX-U Project is Implementing the Accelerator Safety Order

- NSTX-U was put under DoE O 420.2c *Safety of Accelerator Facilities* in late 2016:
  - It fits the accelerator definition → accelerates charged particles and generates a radiation area
  - The order is the standard for operational excellence for this type of facility.
- We have laid out a draft plan to achieve compliance, and begun the work:
  - Started working on a 420.2c compliant SAD
  - Implemented a USI screening system and a screener role
  - Improved aspects of our work permit system
- We have hired an individual to work full time on the ASO implementation.

See talks by J. Malo, T. Stevenson, R. Camp, M. Cropper, J. Levine for more on ASO, TTO, ES&H

Summary

- Comprehensive reviews have determined what needs to be repaired / replaced → these defined the Recovery Project.
- We have revisited and reconstituted the requirements basis for the project, in order to support the 2 MA, 1T, 5 second operating point.
- We have developed and are implementing new designs to repair and improve components
  - Strong focus on designs that improve the long-term reliability of the facility.

Recovery will significantly enhance NSTX-U reliability & safety, providing highest-performance ST device as a robust user facility

Other On-Project Scope

- Machine assembly – See available talk
- Adding a power loop for the PF-1b coil
  - Coils were installed in original Upgrade device, and being refabricated during Recovery, but no power supplies connected.
  - See available talk.

PF-1b power loops are CDE-3a Scope

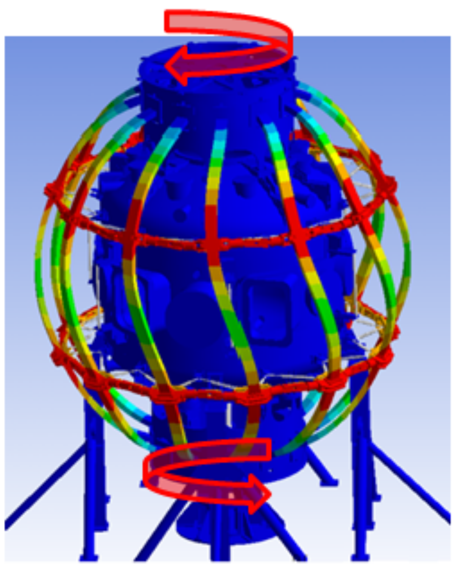
- Adding a system to pump the interspaces of double O-rings seals
- Feeding the bakeout DC current at the top of the machine.
  - Previously fed at the bottom; change required by removal of a ceramic insulator as suggested by E. of Condition committee.
- A number of modest corrective actions on the vessel, vessel supports, and plasma diagnostics
- Adding an ODH monitor and High Radiation Area Annunciators to test cell
- Improved realtime detection of coil turn-to-turn faults

Machine Instrumentation Will Improve Our Ability to Diagnose and Trend Machine Behavior

Goals:

- Validate structural models of the machine that are the basis for our designs and coil protection systems ← "Is the machine behaving like we expect?"
- Trend behavior of critical components of the machine ← "Are there components whose performance is degrading in time?"

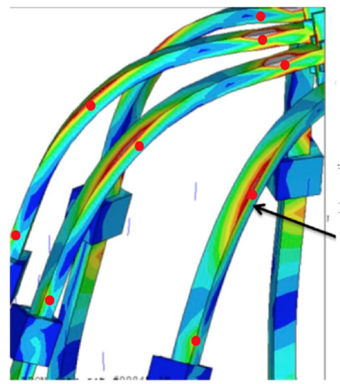
1: Global EM Torque on Coils, Transferred to Vessel



Status: PDR on March 22

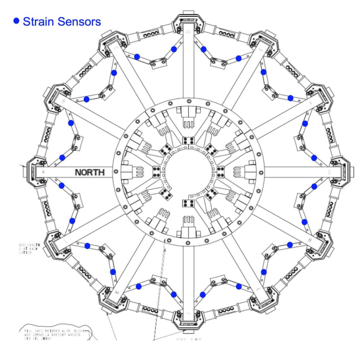
See NSTX-PLAN-12-207, Available talk by R. Ellis.

2: Requirement for Strain Sensors on Coils & Trusses

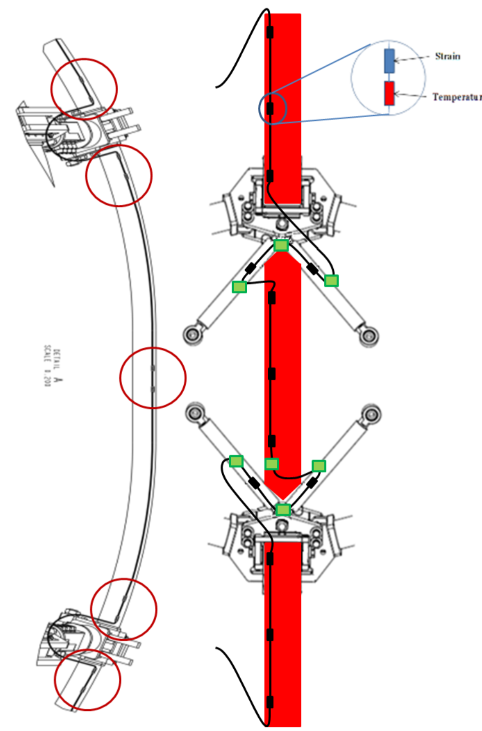


High Stress Region of Outer-TF Coil

● Strain Sensors



3: Design utilizing high sensor count fiber Bragg technology



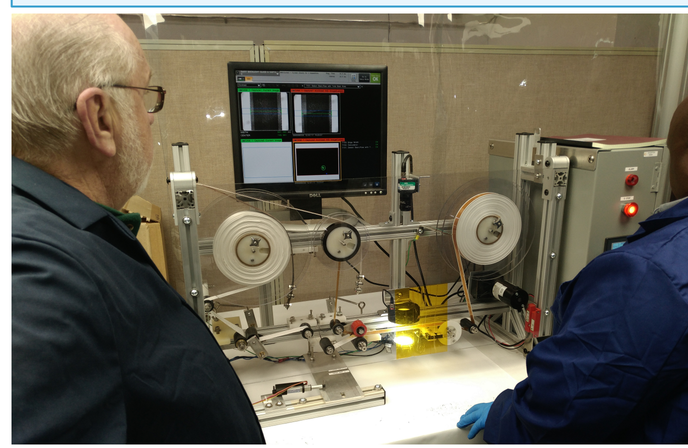
New Inner PF Coils

Fabrication Strategy Devised to Ensure Quality

- Address quality concerns: All coil manufacturers must first successfully produce a prototype PF1A coil
- Prototype quality will be assessed by:
    - On-site surveillance
    - High-pot and surge testing
    - Destructive testing (sectioning) and inspection
    - turn-to-turn testing on sectioned coils
- Will use up to 4 manufacturers
    - Three companies + PPPL all manufacturing prototypes
    - on-site surveillance for industrial suppliers maintained through production phase
- 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

Kapton-Glass co-winding with machine vision inspection



See Talk by M. Kalish for More Details

Summarizing Key Research Impacts of Recovery Redesign

Programmatic Benefits

- All inner-PF coils retained, supporting flexible magnetic geometry
- Bakeout system will be significantly improved, in both safety and function, providing well conditioned plasma facing components for high performance operations
- Leak probability and O-ring permeation significantly reduced
- Elimination of lower ceramic insulator benefits future liquid lithium research
- Tile designs are highly optimized for heat flux handling

Programmatic Impacts

- CHI program eliminated in its previous form.
  - Elimination of lower ceramic insulator improves system reliability, at the expense of this research capability
  - CHI design with purely internal electrodes may be realized
- Ramped tiles will provide a favored helicity.
  - However, a modest "reversed helicity" requirement is retained for regions where the intermediate legs of snowflake divertors may land

DVVRs Developed Findings on the Full Technical Scope of the Recovery

- Conducted 12 DVVRs between Jan. 18th and April 20th 2017
- Addressed component design, analysis, fabrication, installation, operations
- Collected 1170 "chits"

Topic	#chits	Topic	#chits
Integrated design	94	Power Systems	84
VV & Internal Hardware	216	Heating Systems (NBI+RF)	96
Magnets	147	Real-Time Control & Protection	93
Vacuum & Fueling	64	Central Instrumentation & Control	101
Cooling Systems	71	Bakeout System	76
Diagnostics	104	Test Cell	24

- Collapsed these into 443 "DVVR Issues" for the Extent of Condition Review
- "Scored" the Issues with a system that involved event probability, duration, and severity

The Two Extent of Condition Reviews Assessed PPPL Response to DVVRs

- 4 day reviews in each of March and May, 2017
- Issued 2 reports with many recommendations focused on ensuring the *reliability* of operations.

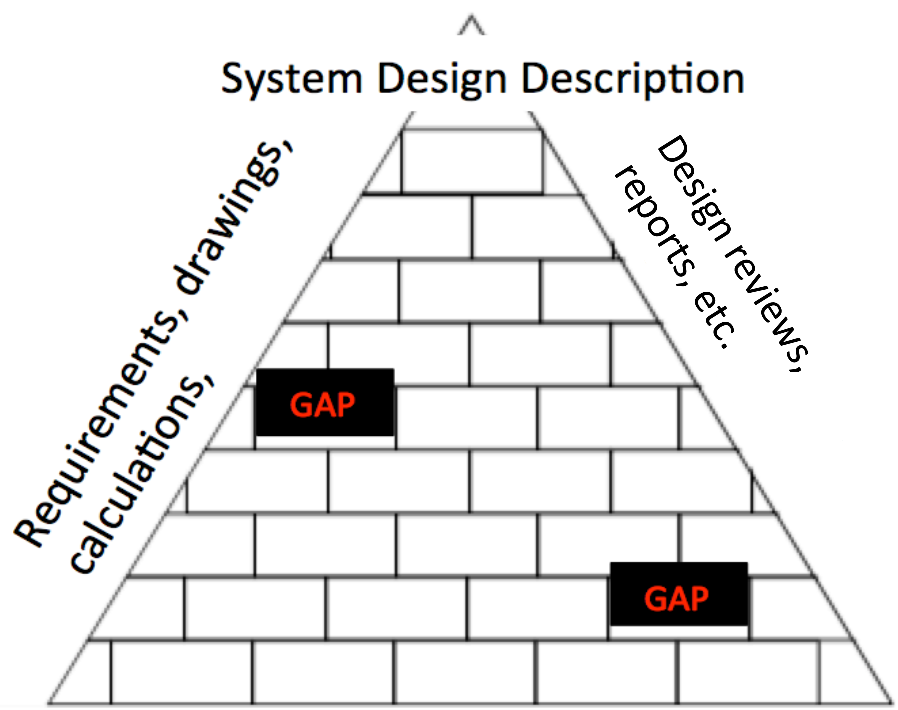
Individual	Institution		Individual	Institution
Tom Todd, (chair)	UKAEA, retired		Ursel Fantz	IPP-Garching
Rem Haange	ITER, retired		Ron Parker	MIT
Rich Callis	General Atomics, retired		John Smith	General Atomics
Frank Casella	ORNL		Michel Huget	ITER, retired
Martin Cox	CCFE		Dennis Youchison	ORNL
Brian LaBombard	MIT		Graeme Murdoch	ORNL
Arnie Kellman	General Atomics			

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

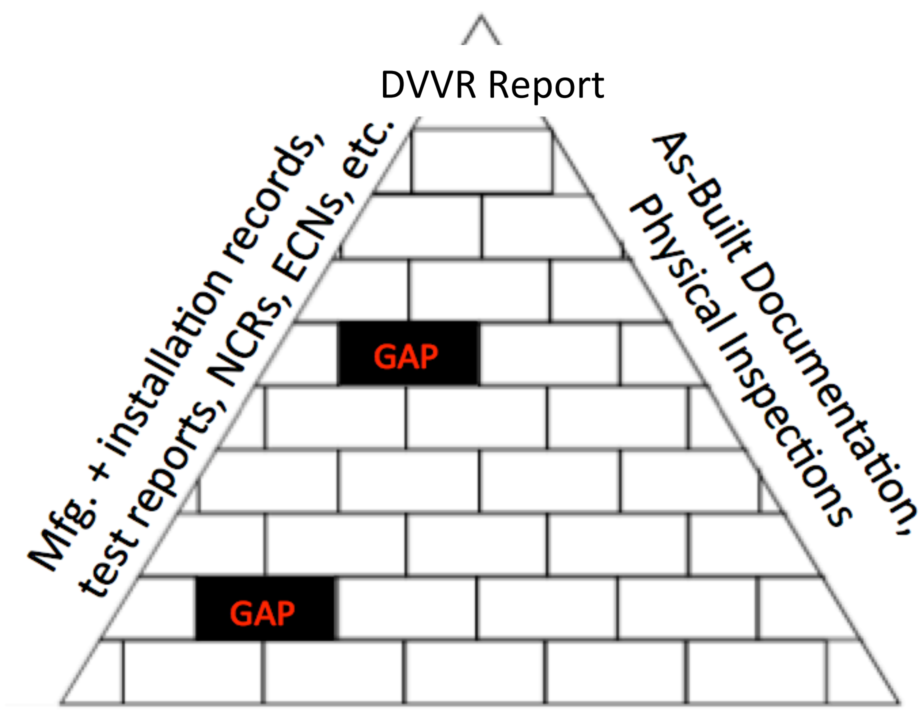
Design Verification and Validation Reviews (DVVRs) Examined Issues from Design through Operations

- For each of 12 major systems, the Responsible Engineer and their team prepared:
  - a System Design Description (SDD)
  - A DVVR report summarizing all known issues

Design Verification



Component Validation



New Requirements are Captured in a Hierarchy of Documents

NSTX-U General Requirements Document
NSTX-U-RQMT-GRD-001

- NSTX-U RD- Disruption Requirements NSTX-U-RQMT-RD-003
- NSTX-U RD- Thermal Scenarios NSTX-U-RQMT-RD-012
- NSTX-U RD- Mag. Materials NSTX-U-RQMT-RD-010

3 RDs Functioning as GRD Annexes

Systems Requirements Documents

- NSTX-U SRD - Magnets NSTX-U-RQMT-SRD-002
- NSTX-U SRD – Vacuum Vessel & Internal Hardware NSTX-U-RQMT-SRD-004
- NSTX-U SRD – Power Systems NSTX-U-RQMT-SRD-006
- NSTX-U SRD – RC&P NSTX-U-RQMT-SRD-008
- NSTX-U SRD – Test Cell NSTX-U-RQMT-SRD-010
- NSTX-U SRD – Plasma Facing Components NSTX-U-RQMT-SRD-003
- NSTX-U SRD – Auxiliary Systems NSTX-U-RQMT-SRD-005
- NSTX-U SRD – Heating and Current Drive NSTX-U-RQMT-SRD-007
- NSTX-U SRD – Central I&C NSTX-U-RQMT-SRD-009
- NSTX-U SRD - Diagnostics NSTX-U-RQMT-SRD-011

Design Requirements Documents (examples)

- NSTX-U RD- PFC Diag. & Fuel NSTX-U-RQMT-RD-004
- NSTX-U RD- CS Air Side Diag. NSTX-U-RQMT-RD-005
- NSTX-U RD- NTC O_2 Monitor NSTX-U-RQMT-RD-006
- NSTX-U RD- Machine Inst. NSTX-U-RQMT-RD-008
- NSTX-U RD- Rad. Shielding and Monitoring NSTX-U-RQMT-RD-008
- NSTX-U RD- OH Pre-Heater Software NSTX-U-RQMT-RD-008

Every document written for the Recovery

See talk by P. Dugan for more on requirements management

Castellated and Fish-Scaled Tiles Significantly Reduce the Risk of Tile Failure For High Heat Flux PFCs

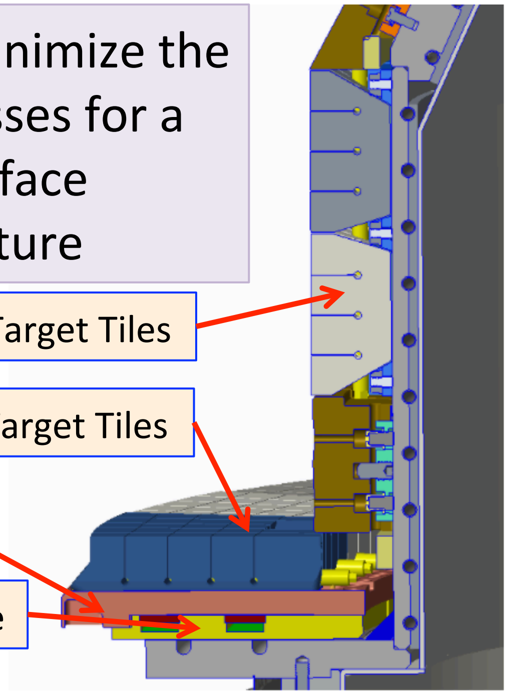
Castellations minimize the material stresses for a given surface temperature

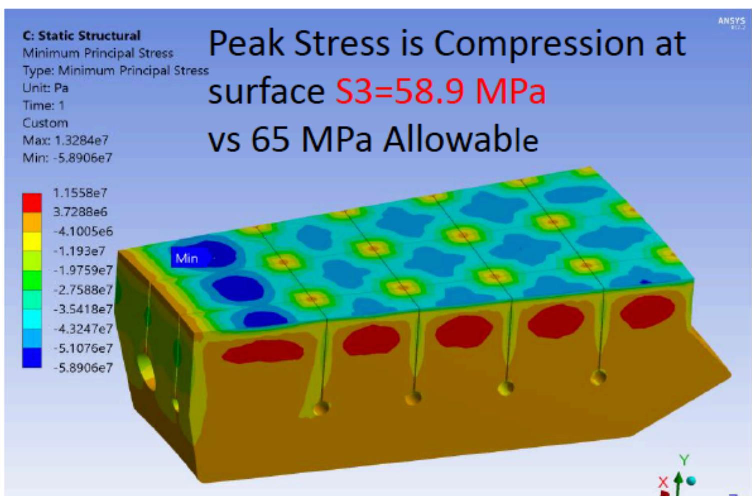
Vertical Divertor Target Tiles

Horizontal Divertor Target Tiles

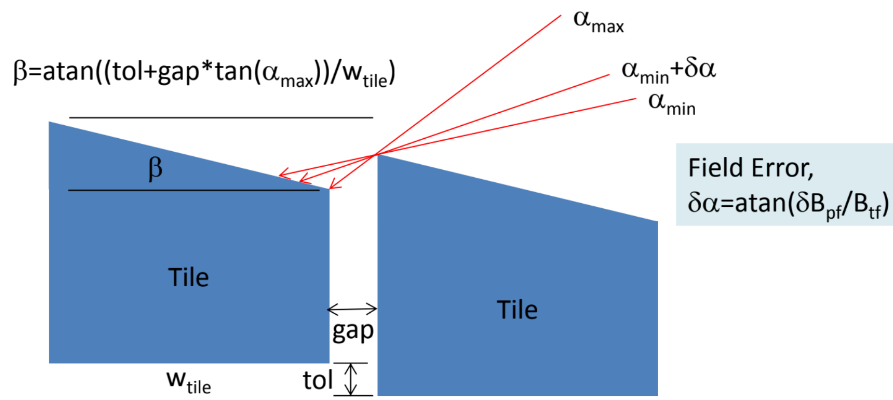
Tile Tray

Heat Transfer Plate





"Fishscaling" ensures that manufacturing and installation tolerances never result in the leading edge of a tile being heated



Typical Angles and Dimensions:

Field Line Angle α: 1-5°

Gap: 0.04" Tol: ~0.01"

Width w_{tile}: ~4"

Fishscale Angle β: ~0.8-1°

National Spherical Torus eXperiment Upgrade

Progress Towards the Recovery Project Baseline

NSTX-U Team Meeting Sept 14, 2018

Russell Feder and the Recovery Project team

Bringing NSTX-U Back On-Line as an FES National User Facility

Restore the device and supporting infrastructure to a reliable operating state at scientifically relevant performance levels

Scope defined through DVVR and CAP
Reliability issues and design deficiencies
Safety issues and safety enhancements identified in DVVR and CAP process

Scope defined through preliminary design phase
Scope uncovered through Recovery Project design progress
Scope from PPPL prime contract…ASO

Requirements are defined to restore NSTX-U Performance Goals
Toroidal Field of 1 Tesla
Plasma flat top pulse of 5 s
Plasma flat top current of 2 MA
Neutral beam heating of 10 MW

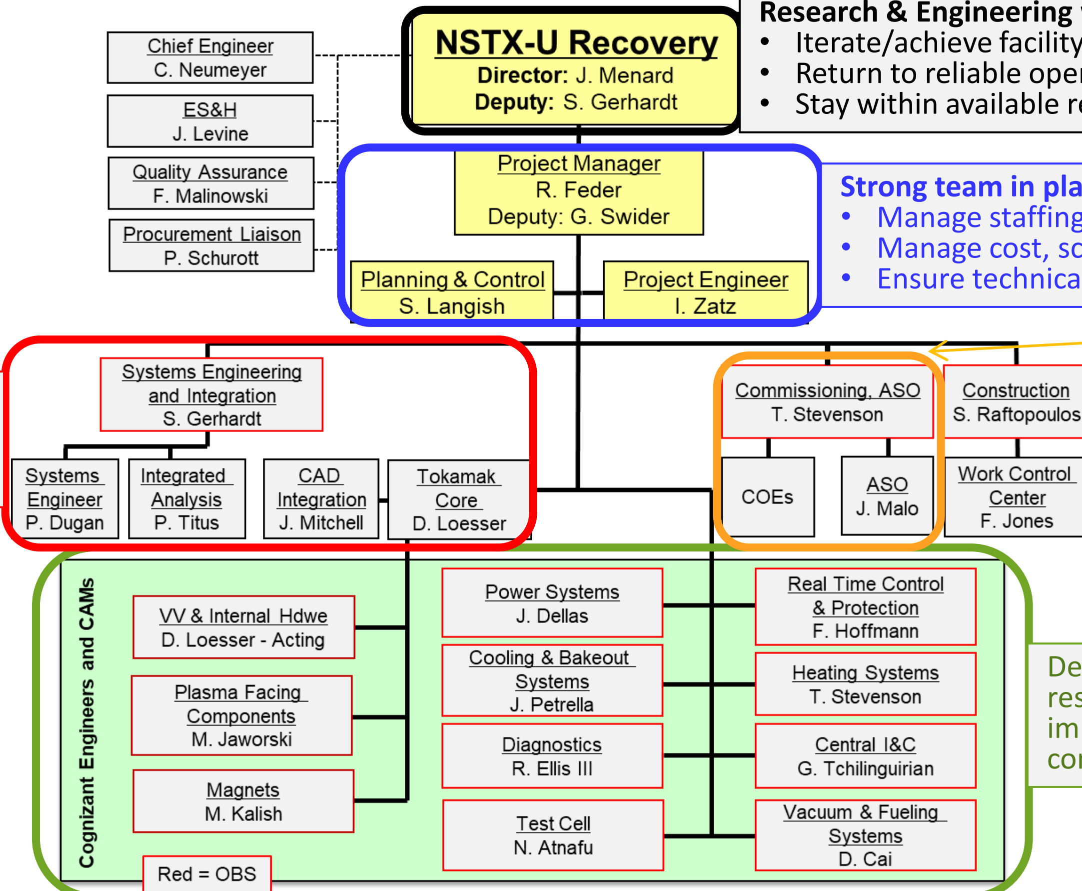
Major Recovery Project Scope Areas
Inner Poloidal Field coils
Polar Region and Center Stack Casing
Passive Plates
Plasma Facing Components (PFCs)
Improved bake capability
Instrumented structures
Well-aligned reassembly
Test cell shielding and Access Control
Commissioning under ASO

Key Performance Parameters (KPPs)
K1. Inner-TF to PF-5 Alignment
K2. PFCs 260 C bake
K3. Combined field test shots
K4. First Plasma

Ongoing D-site maintenance and operations

Ongoing enhancements of PPPL enterprise processes and procedures

Features of Recovery Organization and mapping to Director's Review Subcommittees (SCs) and presentations



Research & Engineering working together
- Iterate/achieve facility requirements
- Return to reliable operation ASAP
- Stay within available resources

SC5

Strong team in place to:
- Manage staffing, procurements, risks
- Manage cost, schedule, planning, EVMS
- Ensure technical rigor, resolve issues ASAP

SC4,1

SC2/3

Commissioning and ASO staff embedded in project to ensure achievement of KPPs and successful ARRs

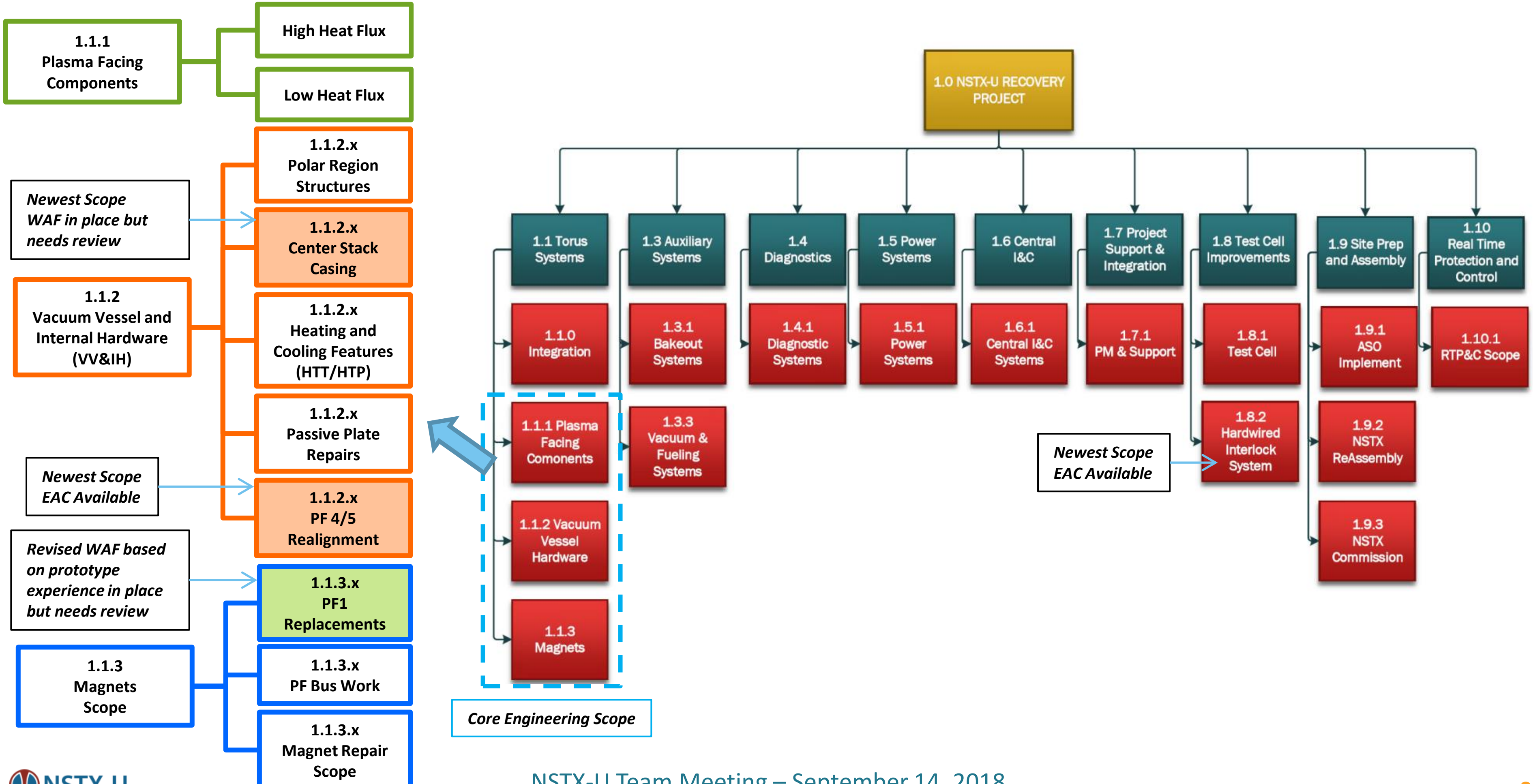
Increased emphasis on systems engineering and integration

Plenary / SC1

Dedicated engineering team responsible for overseeing and implementing scope from conception into operations

SC1

All major Recovery scope has been identified



New and expanded scope have contributed to project cost estimate growth and schedule stretch

New Scope added between CD and PF/FD phases	Metrology and alignment of magnets, PFCs and Structures	For KPP #1: Inner-TF to PF-5 Alignment
	Outer PF4/5 Alignment	
	ASO Implementation	To comply with PPPL prime contract
	Access Control System (ACS)	
	Commissioning scope moved from Ops to Recovery	

Expansion of original scope between CD and PF/FD phases	A much larger well staffed project office	To meet the demands of the project
	Address requirements of QAPD and new ENG procedures	To comply with PPPL-wide quality improvements
	Rigorous inner PF prototype program with a 4th vendor	Schedule risk mitigation
	Consideration of multiple PFC material candidates	
	Center Stack Casing (CSC) flange mods added to Polar Region scope	Scope developed as Polar Region reached preliminary design

FY18 and FY19 PEMP Notable Outcomes

FY18

Goal 2.0 - Design, Fabrication, Construction and Operation of Research Facilities		Key Event	Late Finish	4/26/18 Status
2.1	FES: For the NSTX-U recovery project, complete final design reviews for six inner poloidal magnetic field coils (viz., PF1A-upper, PF1A-lower, PF1B-upper, PF1B-lower, PF1C-upper, and PF1C-lower) by March 31, 2018.	Inner PF FDR	3/31/2018	Complete
2.2	FES: For the NSTX-U recovery project, build at least one prototype PF1A inner poloidal magnetic field coil. Qualify the coil by operating it at both the maximum required current and at maximum joule heating. Verify the quality of the coil insulation system through electrical testing followed by destructive sectioning and inspection. Submit a final report documenting the results by July 15, 2018.	PF1A Prototype Power Test and Section	7/15/2018	Complete
2.2	FES: For the NSTX-U recovery project, complete a preliminary design review (PDR) for the passive plates and helium bake-out line supports by July 31, 2018.	Passive Plate PDR	7/31/2018	Complete
2.2	FES: For the NSTX-U recovery project, complete a final design review (FDR) for improved and re-designed plasma facing components by September 30, 2018.	PFCs FDR	9/30/2018	FDR planned for 9/26
Goal 4.0 - Contractor Leadership/ Stewardship				
4.2	SC/FES: The University, in concert with PPPL leadership, shall ensure that the necessary support is provided for efficient and effective management of the NSTX-U Recovery effort, such that this project will have completed a Director's Review by September 30, 2018.	Director's Review	9/30/2018	Complete

FY18 and FY19 PEMP Notable Outcomes

FY19				
Goal 2.0 - Design, Fabrication, Construction and Operation of Research Facilities		*Key Event*	*Late Finish*	
2.1	***FES: For the NSTX-U recovery project, complete a final design review(s) for the integrated casing assembly including the heat-transfer tubing and plates and associated attachment hardware, the vertical and angled sections of the center-stack casing, the horizontal divertor end-flanges, bellows, collars, and organ pipes by December 31, 2018. (Objective 2.1)***	***CSC FDR***	***12/31/2018***	***Planned for 12/19***
2.2	***FES: For the NSTX-U recovery project, award a sub-contract(s) for the procurement of the integrated casing assembly including the heat-transfer tubing and plates and associated attachment hardware, the vertical and angled sections of the center-stack casing, the horizontal divertor end-flanges, bellows, collars, and organ pipes by March 31, 2019. (Objective 2.2)***	***CSC Procurement***	***3/31/2019***	***TBD***
2.2	***FES: For the NSTX-U recovery project, fabricate at least one production inner poloidal magnetic field coil. Verify the quality of the coil through electrical testing and dimensional inspection by September 30, 2019. (Objective 2.2)***	***Fabricate and test a production PF1 coil***	***9/30/2019***	***TBD***

The project execution strategy hinges on CDE-2/3A timing and FDR completion

	Status or Early Finish Plan	Scope of Review
CDE-0	Complete Mar 14-15 2018	OPA Mission Need
CDE-1	Complete Through CY17	DVVRs, CAP, CDRs
	Complete Feb 6-8, 2018	OPA Capability Review
CDE-2/3A	*Oct-Dec 2018*	Baseline Review + Approve Coils and PFCs Fab
CDE-3B	*Optimal plan in development*	Continue to group key procurements by priority and order of FDR completion
CDE-3C		
ARR-A	*July 2020*	Review processes and procedures
ARR-B	*Nov 2020*	Observe commissioning operations
KPPs	*Feb 2021*	
*CDE-4**	*Feb 2022**	*Ready for CDE-4 (*late finish date shown, 12-months of float)*

CDE-3A FDRs	CDE-3A Motivation
Inner PF Replacement Coils FY18 PEMP, Complete 3/21/2018	• Start making 6X Upper and Lower PF1-A, B and C coils
Plasma Facing Components (PFCs) FY18 PEMP, Planned 9/26/2018	• Start making ~400 new graphite tiles
PF1B Bipolar Circuit Planned Week of Sept 17th	• Need FDR for pre-authorized work to start

High Priority FDRs	Motivation
Center Stack Casing (CSC) and Attached Polar Region Planned Mid-Nov 2018	• Critical Path • Have pre-approval from DOE to start fab with FDR
Polar Coil Support Structures FDR	• Needed for Inner PF Coil packaging and for machine assembly
Heating and Cooling Tubes and Plates (HTT/HTP)	• Needed before PFCs can be installed on Center Casing
Ip Rogowski Diagnostic Coils	
PFCs Diagnostics	• Needed for start of in-vacuum assembly work
Passive Plate Repairs	

CDE-2 PDRs and CDE-3A FDRs

PDRs

1.1.1.1 Low Heat Flux PFCs	9/28/2017	9/28/2017
1.1.1.1 High Heat Flux PFCs	11/15/2017	11/15/2017
1.1.2.4 Cooling Tubes	11/30/2017	11/30/2017
1.1.3.1 Inner PF Coils	12/14/2017	12/14/2017
PF1A Conductor Size Peer Review	12/19/2017	12/19/2017
Turn-to-Turn Testing Peer Review	12/21/2017	12/21/2017
Alignment I Peer Review	1/18/2018	1/18/2018
Alignment II Peer Review	2/1/2018	2/1/2018
1.5.1.3 PF1B Bipolar Circuit	2/27/2018	2/27/2018
1.1.2.1 Polar Region - Inner PF Coil Supports	3/27/2018	3/27/2018
1.8.1.1 NTC Shielding	4/10/2018	4/10/2018
ASO WAF Review	6/8/2018	6/1/2018
1.1.2.1 Polar Region - CS Casing/Flanges/O-Rings/Insulators/Supports	6/21/2018	8/2/2018
1.1.2.2 Passive Plates + Helium Line Supports - FY18 PEMP	7/31/2018	7/26/2018
1.8.1.3 NSTXU Reassembly	7/31/2018	8/1/2018
1.1.0.1 Integration Scope (Project PDR)	8/1/2018	8/15/2018
1.8.1.1 NTC Shielding PDR #2	8/6/2018	8/6/2018
X.X.X.X PF Bus Support PDR	*10/25*	
X.X.X.X CSC PDR	*10/16*	
1.1.3.6. PF4/5 Realignment	*Need Replan*	
1.8.2 Access Control System ??	*Need Replan*	

FDRs

1.1.3.1 Inner PF Coils - FY18 PEMP	3/30/18	3/30/18
CS Casing Trial Fit	5/17/18	5/17/18
1.5.1.2 Inner PF Coil Power Test Process and Tooling FDR	5/9/18	5/9/18
1.5.1.3 PF1B Bipolar Circuit	9/20/18	
1.1.1 Plasma Facing Components - FY18 PEMP	9/26/18	
1.1.3.1 Inner PF Coil Delta-FDR ??	***????***	

Remaining "3B" Design Work

PDRs

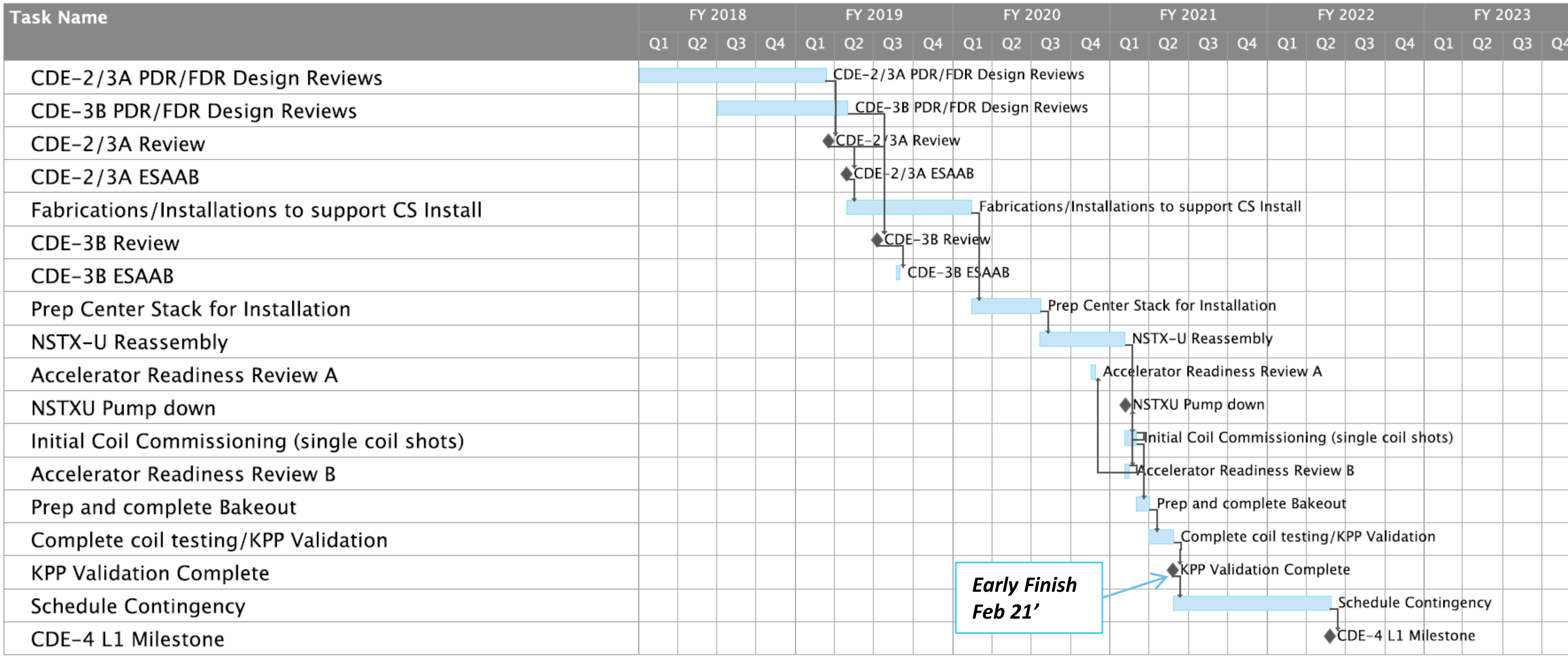
1.3.1.1 Helium Bake System - Feedthrough Re-Design	12/1/2017	12/1/2017
1.3.3.3 Interspace Pumping	12/20/2017	12/20/2017
1.4.1.2 PFC Diagnostics	1/4/2018	1/4/2018
1.3.1.1 Helium Bake System - Gas Piping	1/11/2018	1/11/2018
1.3.1.2 exVessel Heating System	2/1/2018	2/1/2018
1.1.3.4 Magnet RP Scope - M6-2 Modify Cooling Water System Controls	2/20/2018	2/20/2018
1.1.2.3 VVHW Field Scope - Part I	2/23/2018	2/23/2018
1.1.3.4 Magnet RP Scope - M9-1 Inspect Outer PF Coils/Repair	3/13/2018	3/13/2018
1.4.1.1 Vessel/Coil Instrumentation	3/22/2018	3/22/2018
1.1.3.4 Magnet RP Scope - TF/OH Bundle Reliability M9-3,5,7,9	4/3/2018	4/3/2018
1.3.1.5 DC Current to Top NSTXU	4/5/2018	4/5/2018
1.8.1.2 NTC O2 Monitor	8/14/2018	8/14/2018
1.8.1.3 NTC Door Rad Monitor	8/14/2018	8/14/2018
1.4.1.3 Aerodag Replacement *w/ Bay-K Beam Armor ??*		
1.4.1.5 Field Seal Repairs		
1.4.1.7 BES Shutter		
1.4.1.6 Halo/Flux Loops		
1.1.2.3 VVHW Field Scope - Part II		
1.7.2.1 Turn-to-Turn Fault Monitoring		
1.7.2.1 PCS Enhancements		
1.3.3.5 Private Flux Region Fuelling		

FDRs

1.3.2.1 OH Preheater	3/28/2017	3/28/2017
1.6.1.2 NSTXU Camera Surv	4/18/17	4/18/17
1.3.3.1 TVPS Backing Pump	1/12/2018	1/12/2018
1.7.2.1 PCS Enhancements	2/8/2018	2/8/2018
1.1.2.4 Cooling Tubes (HTT/HTP)	*10/24/18*	
1.1.2.1 Polar Region FDR #1 - Center Stack Casing - **FY19 PEMP**	*12/19/18*	
1.1.2.1 Polar Region FDR#2		
1.4.1.2 PFCs Diagnostics		
1.1.2.2 Passive Plates		
1.4.1.4 Ip Rogowski Coils		
1.1.3.6 PF4/5 Metrology Monuments and other Prep FDR		
1.1.3.6. PF4/5 Realignment		
1.8.1.1 NTC Shielding		
1.1.3.3 PF Bus Support		
1.8.2 Access Control System		
1.9.1. ASO and Commissioning Implementation FDR ??		
1.4.1.3 Aerodag Replacement w/ Bay-K Beam Armor ??		
1.4.1.5 Field Seal Repairs		
1.4.1.6 Halo/Flux Loops		
1.4.1.1 Vessel/Coil Instrumentation		
1.4.1.7 BES Shutter		
1.1.3.4 Magnet RP Scope - TF/OH Bundle Reliability M9-3,5,7,9		
1.3.1.1 Helium Bake System - Feedthrough Re-Design		
1.3.3.3 Interspace Pumping	*10/26/18*	
1.1.2.3 VVHW Field Scope		
1.3.1.2 exVessel Heating System		
1.6.1.5 Network Segregation		
1.3.1.1 Helium Bake System - Gas Piping		
1.1.3.4 Magnet RP Scope - M6-2 Modify Cooling Water System Controls		
1.8.1.2 NTC O2 Monitor		
1.8.1.3 NTC Door Rad Monitor		
1.3.1.5 DC Current to Top NSTXU		
1.3.3.2 Startup Tasks - GDC Anode		
1.7.2.1 Turn-to-Turn Fault Monitoring		
1.7.2.1 PCS Enhancements		
1.3.3.5 Private Flux Region Fuelling		
1.8.1.3 NSTXU Reassembly		
1.1.3.5 Magnet RP Scope - M9-6 RWM Field Mods ???		

The current PPEP Base plan projects an early finish in Q2FY21

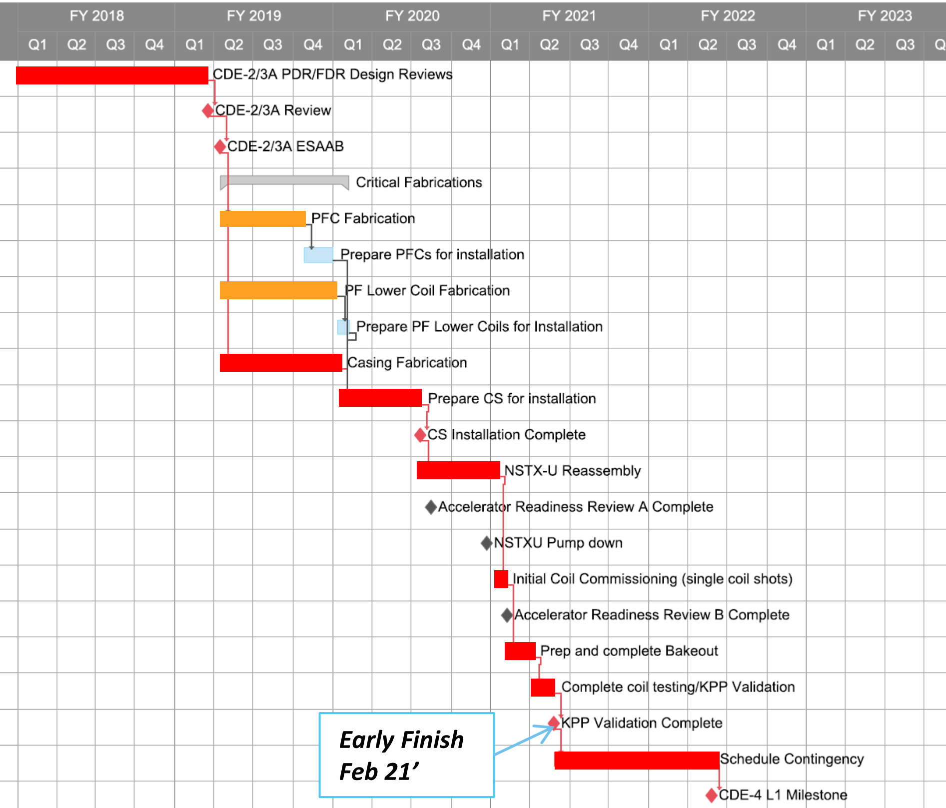
PPEP Gantt Chart Shown



The current PPEP Base plan projects an early finish in Q2FY21

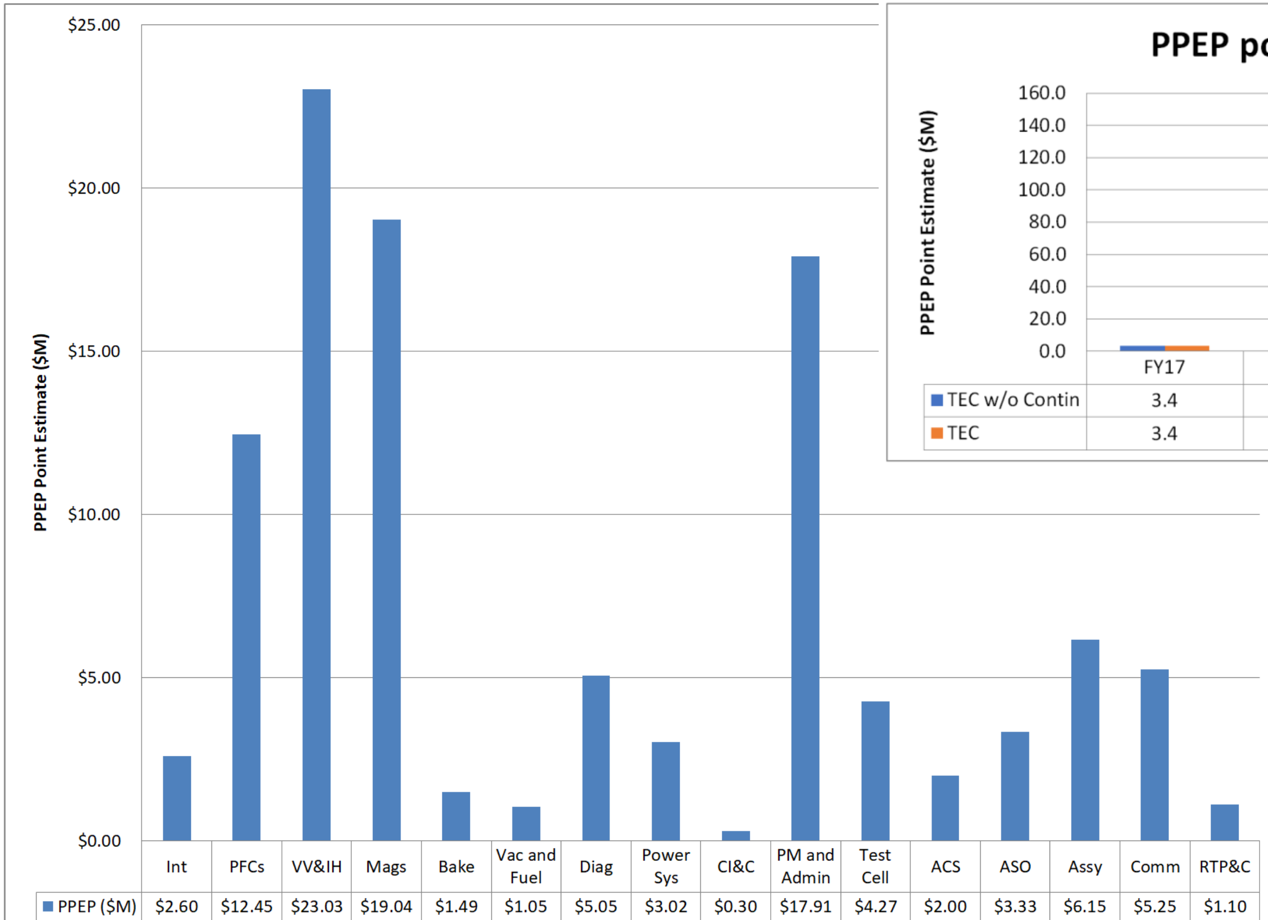
Critical path schedule shown

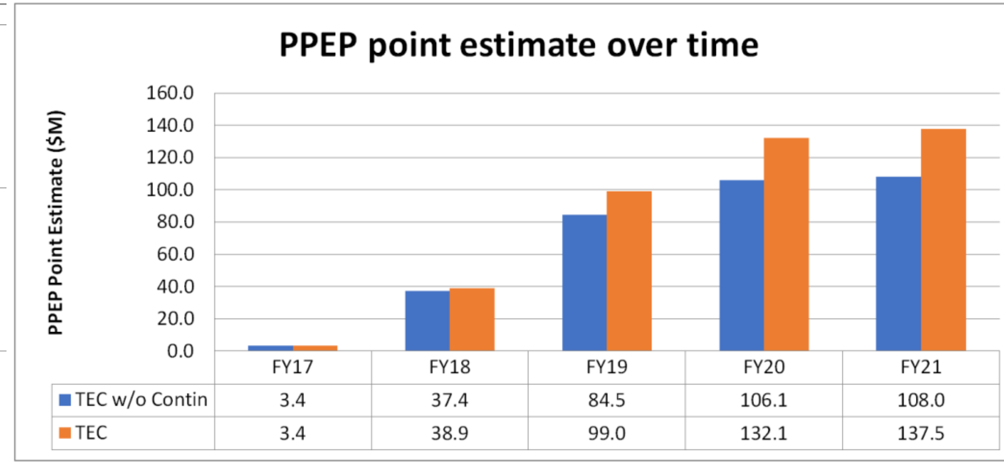
Task Name	Start	Finish
CDE-2/3A PDR/FDR Design Reviews	10/02/17	12/10/18
CDE-2/3A Review	12/17/18	12/17/18
CDE-2/3A ESAAB	01/14/19	01/14/19
Critical Fabrications	01/15/19	11/04/19
PFC Fabrication	01/15/19	07/25/19
Prepare PFCs for installation	07/26/19	10/01/19
PF Lower Coil Fabrication	01/15/19	10/10/19
Prepare PF Lower Coils for Installation	10/11/19	11/04/19
Casing Fabrication	01/15/19	10/16/19
Prepare CS for installation	10/17/19	04/20/20
CS Installation Complete	04/20/20	04/20/20
NSTX-U Reassembly	04/21/20	10/12/20
Accelerator Readiness Review A Complete	05/14/20	05/14/20
NSTXU Pump down	09/21/20	09/21/20
Initial Coil Commissioning (single coil shots)	10/13/20	11/02/20
Accelerator Readiness Review B Complete	11/06/20	11/06/20
Prep and complete Bakeout	11/03/20	01/05/21
Complete coil testing/KPP Validation	01/06/21	02/25/21
KPP Validation Complete	02/25/21	02/25/21
Schedule Contingency	02/26/21	02/25/22
CDE-4 L1 Milestone	02/25/22	02/25/22



→ **The critical path runs through the center stack casing but inner PF coil and PFCs are also near critical path.**

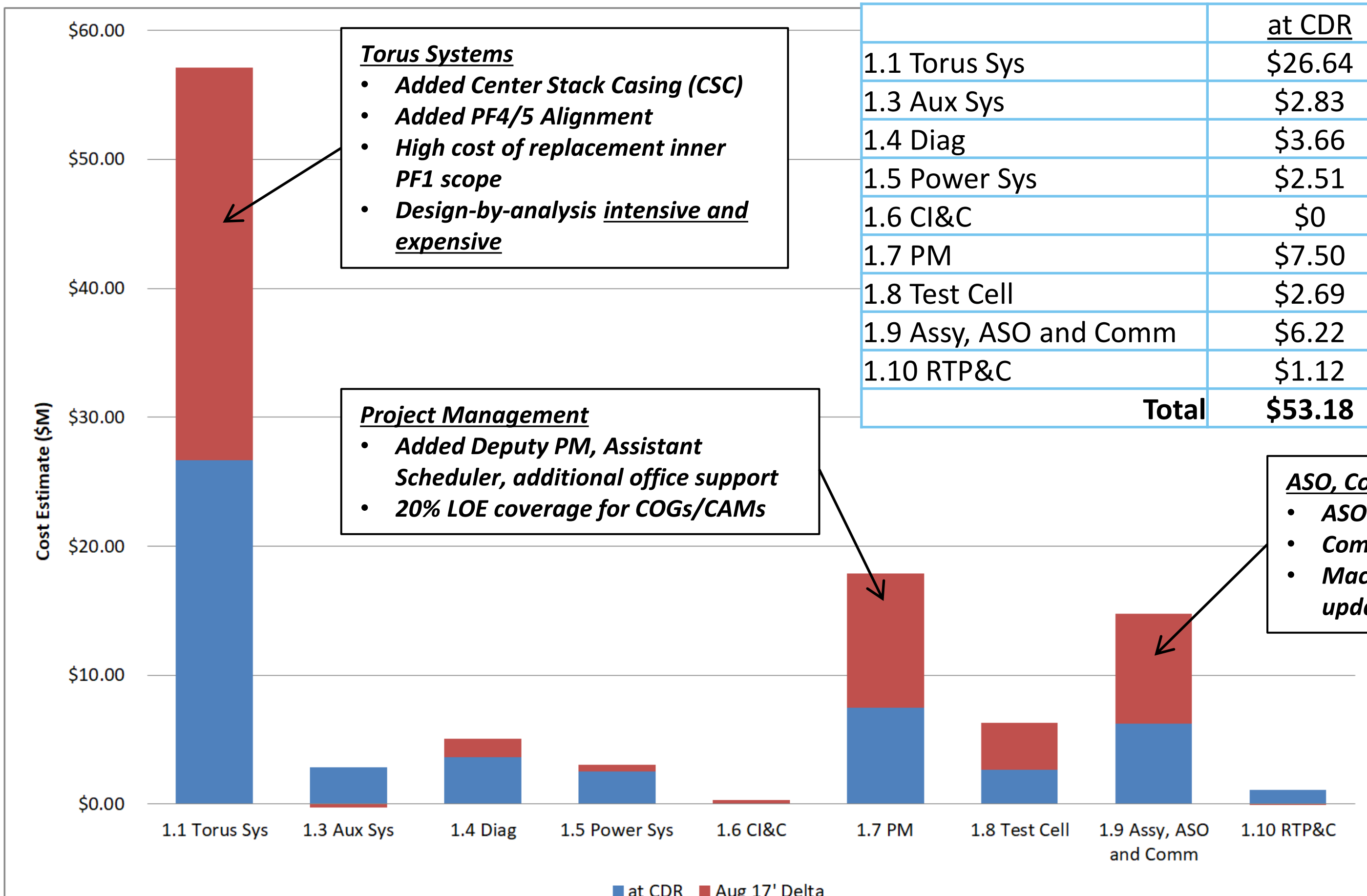
Total estimated cost (TEC) is $108M with ~$14M in M&S. The project is more than 85% labor.





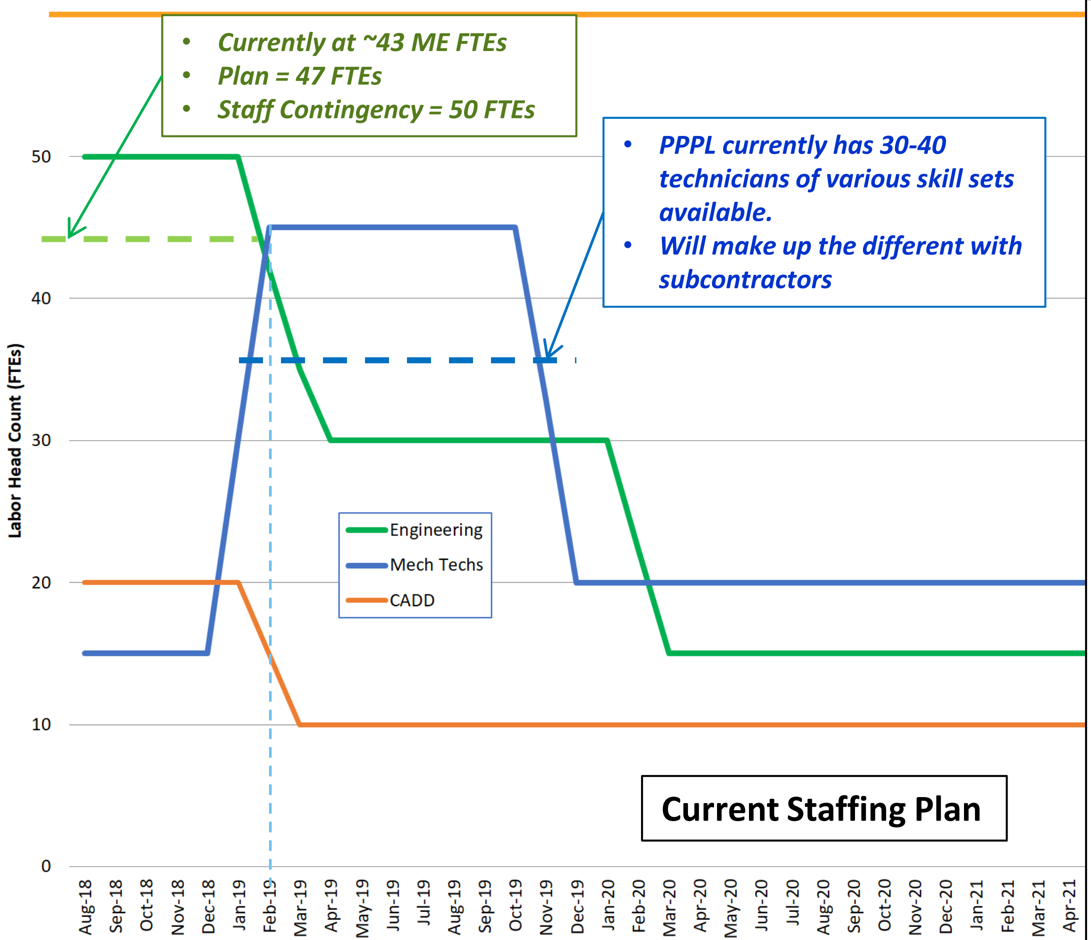
	PPEP Point Estimate (k$)
OPC	**$16,800**
TEC w/o contingency	**$108,035**
Estimate to Complete (ETC)	**$83,066**
Contingency on ETC (35%)	**$29,500**
TPC	**$154,335**

Recovery Project cost estimates have increased significantly from conceptual through preliminary design



	at CDR	Aug 18'	Aug 18' Delta
1.1 Torus Sys	$26.64	$57.11	$30.48
1.3 Aux Sys	$2.83	$2.53	($0.29)
1.4 Diag	$3.66	$5.05	$1.39
1.5 Power Sys	$2.51	$3.02	$0.51
1.6 CI&C	$0	$0.30	$0.30
1.7 PM	$7.50	$17.91	$10.41
1.8 Test Cell	$2.69	$6.27	$3.58
1.9 Assy, ASO and Comm	$6.22	$14.73	$8.51
1.10 RTP&C	$1.12	$1.10	($0.02)
Total	**$53.18**	**$108.0**	**$54.85**

The key to the Recovery Project is adequate and continuous staffing



- **A staffing plan is in place and WAFs account for resource availability**
- **The project and staffing plan is very dynamic as we integrate new scope and re-deploy key staff to meet schedule demands**
- **Design and procurement phase is mostly mechanical and project engineering. The project is pushing towards 50 FTEs of ME-flavored labor with PPPL staff, subcontractors and ORNL assistance**
- **~10 FTEs of critical support from indirect PPPL functions: QA/QC, Procurement and other departments**
- **Next wave of work requires ~45 FTEs of mechanical technicians. PPPL currently has 30-40 available depending on skill mix. Planning is underway for onboarding additional staff, training, and supervision.**

The NSTX-U Recovery Project is on track to enhance NSTX-U reliability and safety and provide a high performance user facility

"Plans are only good intentions unless they immediately degenerate into hard work."
-Peter F. Drucker

Members of the NSTX-U Recovery staff

Agenda

- Recovery Director's Review Outcome and Next-Steps – Jon (15+10)
- Brief summary of Recovery technical progress – Stefan (15+10)
- Recovery Project Management - near-term goals – Russ (15+10)
- NSTX-U Research Program progress and plans – Stan (10+5)

National Spherical Torus eXperiment Upgrade

Research Activities Update

NSTX-U Team Meeting, Sept. 14, 2018

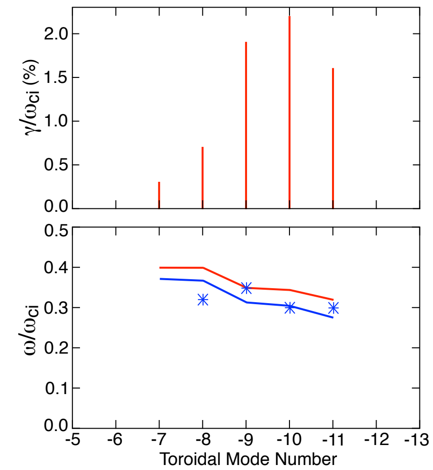
S.M. Kaye for the NSTX-U Team

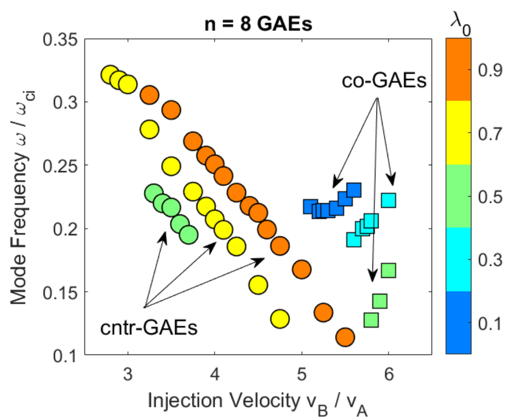
Researchers have continued to be actively engaged during Recovery outage

- Both NSTX(-U) and collaborative research
- ~45 to 50 publications in peer reviewed journals for CY18 to date
- Nearly completed JRT18 and FY18 Milestones
  - JRT18: Conduct research to test predictive models for fast ion transport by multiple Alfvén eigenmodes (Podesta)
  - R18-1: Develop and benchmark reduced heat flux and thermo-mechanical models for PFC monitoring (Reinke)
  - R18-2 Develop simulation framework for ST breakdown and current ramp-up (Battaglia)
  - R18-3: Validate reduced transport models for electron thermal transport (Guttenfelder)
  - R18-4: Optimize EP distribution function for improved performance (Podesta)

Focus of NSTX(-U) work has been on EP/Transport physics

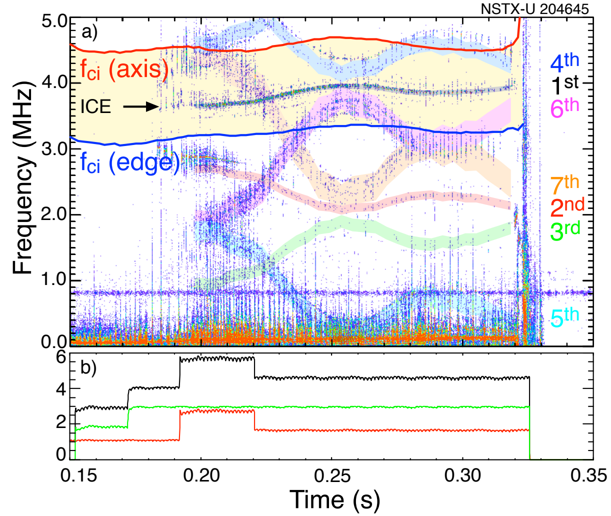
- GAE suppression by off-axis NB (NSTX-U)
  - Supported by analytic theory, HYM calculations
- Relation between microturbulence and non-linear GAE mode coupling (e.g., Avalanches) explored
  - Nonlinear interactions reduced in presence of microturbulence
  - STs more stable to microturbulence, more prone to Avalanches
  - Supported by GTS microturbulence simulations
- EP-modified GAE modes (HYM calculations)
  - Mode characteristics modified by pitch, energy of EPs
- Counter-propagating TAE with off-axis NBI (NSTX-U)
  - Need to consider full phase space effects (gradients in real and vel.-space)





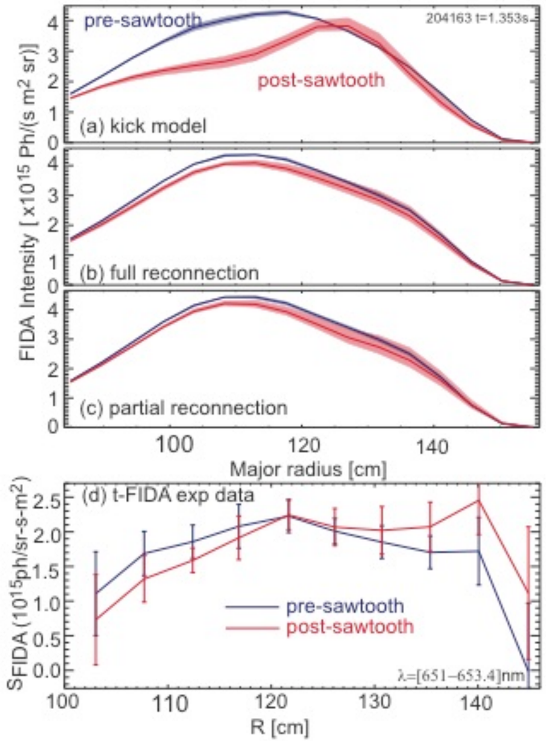
NSTX(-U) continued

- Investigating ICE in NSTX-U
  - Possible EP diagnostic for ITER



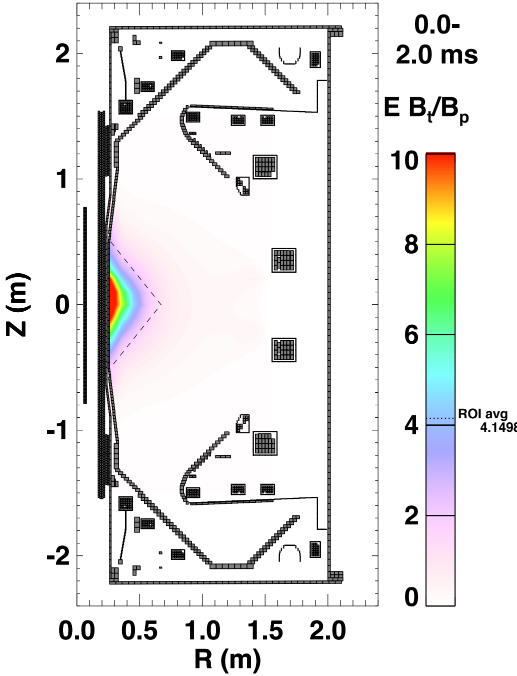
NSTX(-U) continued

- Investigating ICE in NSTX-U
  - Possible EP diagnostic for ITER
- EP behavior during sawteeth
  - Different views of FIDA, ssNPA map out EP distribution changes in real space
  - Need sophisticated kick modeling to explain results
- Models being further developed
  - Kick at low-f (f/b, s/t, NTM), RBQ1D
- G-K calculations for L-mode, high-β H for FY18 Transport milestone



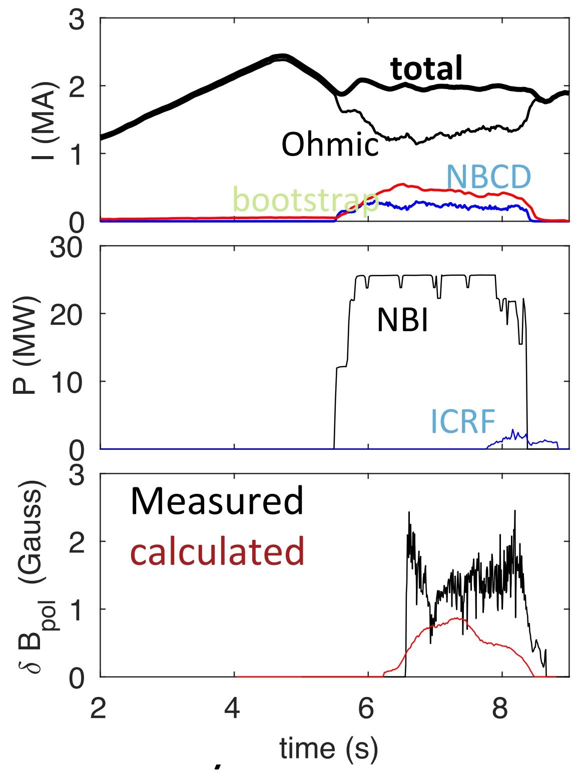
Research through collaborations (much through I&T for PPPLers)

- MAST-U
  - Vacuum field calculations using LRDFIT support magnetic calibrations and inductive startup scenario development (onsite)
  - Kick model for f/b analysis
  - Equil. Reconstruction, divertor and transport physics



Research through collaborations (much through I&T for PPPLers)

- MAST-U
  - Vacuum field calculations using LRDFIT support magnetic calibrations and inductive startup scenario development (onsite)
  - Kick model for f/b analysis
  - Equil. Reconstruction, divertor and transport physics
- JET
  - Faraday cup (EP) to measure lost α's, divertor diagnsotics
  - TRANSP modeling for D-T scenario development
    - EP transport by MHD
    - MRE for NTM onset (areas for model improvement identified)

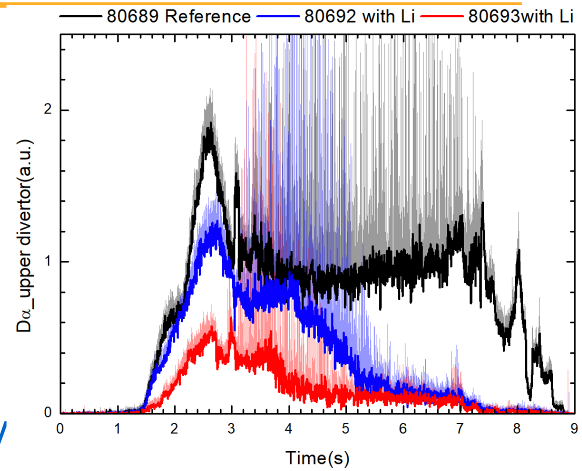


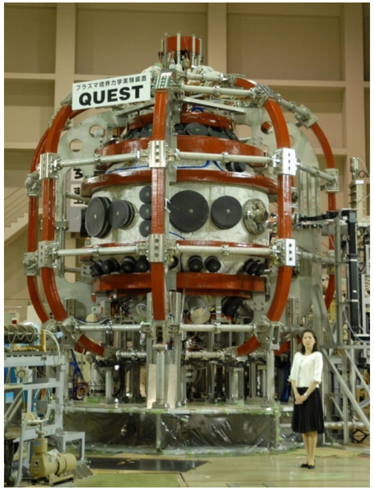
Research through collaborations (much through I&T for PPPLers)

- KSTAR
  - Scenario development (TRANSP), including "flight simulator" for control algorithm testing/optimization
  - 3D field phase space control for ELM stabilization with good confinement (article in NATURE PHYSICS)
  - Disruption forecasting (with NSTX/-U, DIII-D, TCV
  - B dropper for long pulse scenarios
  - EP physics expts (planning): 2 on-axis, 2 off-axis NB
- DIII-D
  - EP: imaging NPA, fast ion instabilities in hybrids
  - G-K pedestal analysis for ELMy H-modes
  - Bursting high-frequency activity between ELMs

Research through collaborations (much through I&T for PPPLers)

- EAST
  - Li dropper, granule injector for conditioning, ELM control
  - Flowing liquid lithium limiter (initial expts performed)
- AUG
  - B dropper for conditioning
- QUEST (Non-inductive startup)
  - Prototype CHI without insulator as part of vacuum boundary (50 kA achieved)
  - 28 GHz ECH as NSTX-U prototype for startup (86 kA achieved)
- H-Mode DB update/analysis with JET-ILW, AUG-W data
- Harbin Institute of Technology (China)
  - Optimized magnetic geometry, engineering for SPERF (PI)
  - Proposed 3D reconnection expts





FY19 Research (Collaboration-based)

- JRT19: Conduct research to understand the role of neutral fueling and transport in determining the pedestal structure
- R19-1: Assess H-mode energy confinement and pedestal characteristics with higher field, current and heating power (MAST-U)
- R19-2: Demonstrate optimized ramp-up in STs (MAST-U)
- R19-3: Validate tearing mode physics for tearing avoidance in high performance scenarios (DIII-D, KSTAR, MAST-U)
- R19-4: Assess effects of NB injection parameters on EP distribution function of NB current drive profiles (DIII-D, MAST-U, KSTAR?)

- Have to revisit MAST-U based Milestones due to delay in MAST-U ops

Theory work (ongoing and new)

- VDE, wall current halo forces
- Error fields
- Disruption mitigation modeling
- Global e-m PIC code development
- Collisionality scaling from various turbulent mechanisms
- SOL heat flux width modeling
- Neoclassical transport
- AE modes and self-consistent interaction with EP population