National Spherical Torus eXperiment Upgrade

NSTX-U Team Meeting

J. Menard, S. Gerhardt, R. Feder, C. Neumeyer, and S. Kaye
for the NSTX-U Team

April 27, 2018

Princeton Plasma Physics Laboratory

MBG Auditorium

Agenda

- NSTX-U Recovery, Research Events & Reviews – J. Menard
- Overview of Technical Activities – S. Gerhardt
- Recovery Project Planning Status, Next-Steps – R. Feder

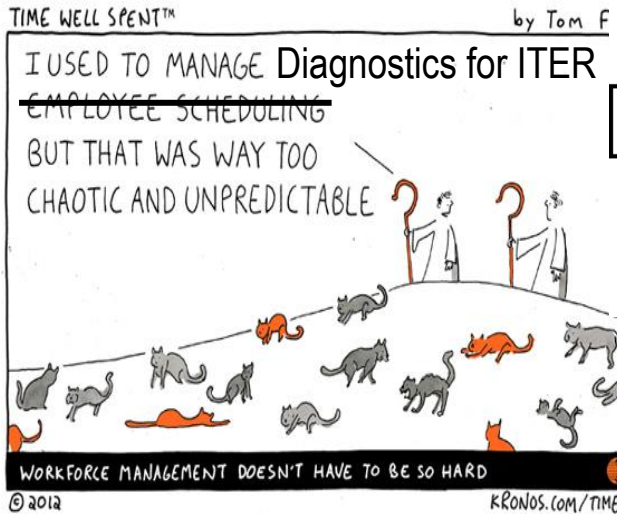
Need to team-meet more often!

- Last team-wide meeting was August 30, 2017
  - Had just completed CDR for 6 major scope areas
  - Had just transitioned to new PPPL and Recovery directorship
- Major NSTX-U Recovery reviews and events:
  - Cost and Schedule Review - September 6-8, 2017
  - Added new Project Manager Russ Feder – November 2017
  - New Quality Assurance Program Description signed – Dec 29, 2017
  - Research Program Advisory Committee – Jan 9-10, 2018
  - DOE/SC Assessment of NSTX-U Recovery #1 – Feb 6-8, 2018
  - Revised Notable Outcomes for FY2018 – Early March, 2018
  - DOE/SC Assessment of NSTX-U Recovery #2 – Mar 14-16, 2018
  - Recovery Project Advisory Committee – Mar 22-23, 2018
  - National Academy of Science meeting at PPPL – Apr 11-13, 2018
  - FY2018 omnibus spending bill signed – Mar 23, 2018

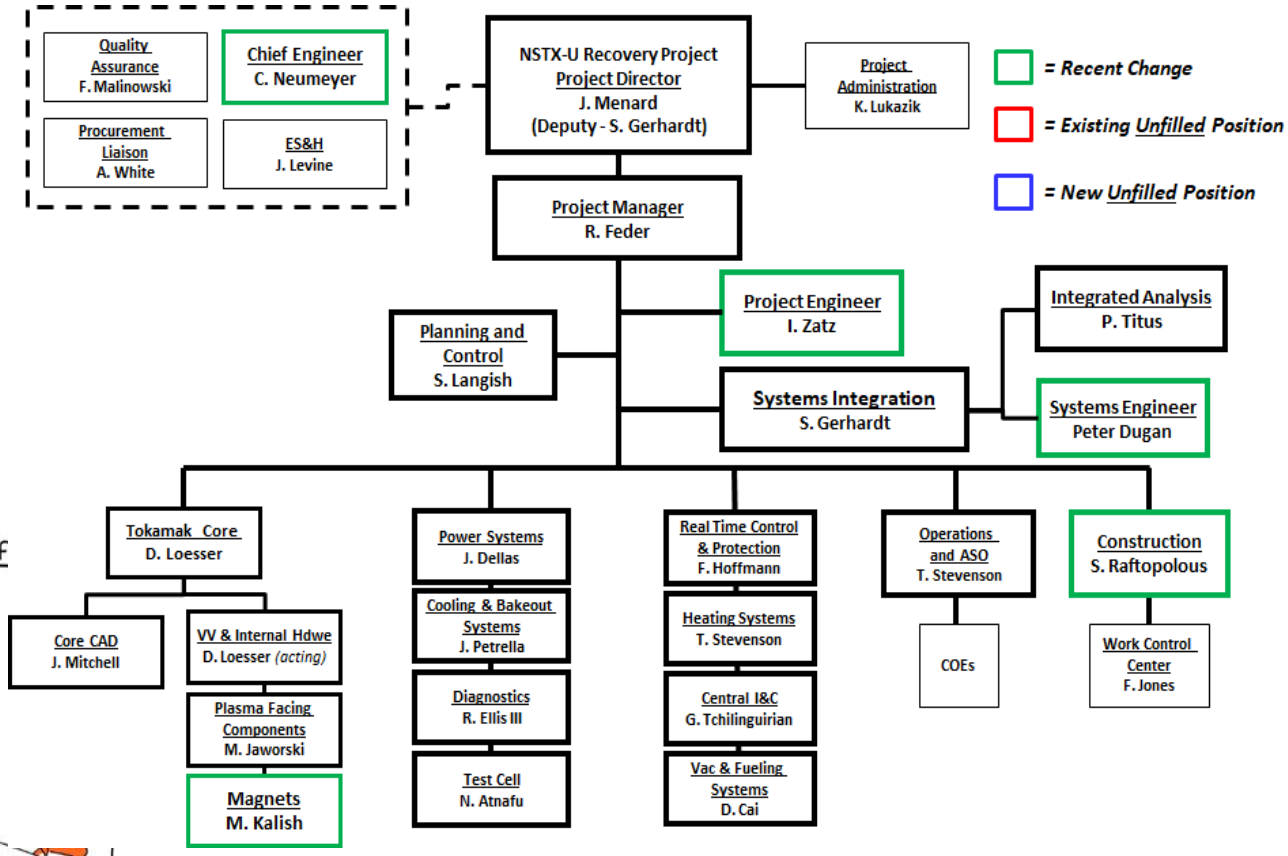
Steady progress during last 6 months

- Completing large number of technical reviews
- Increased design rigor and fabrication quality
- Enhanced project management team
- (Re-)confirmed compelling mission need for ST research and NSTX-U facility and program
- **Much work ahead to sustain and grow this progress – thank you for your efforts!**

Russ (thankfully) loves a challenge!



Diagnostics for ITER



Cost & Schedule Review

Sample of major recommendations + actions in response

- …"freeze" the technical requirements and publish the required documentation necessary to support the design, including the establishment of the "controlled" margins in the design
  - New/updated comprehensive DPSS, GRD, SRDs, RDs, + tolerance allocation
- Identify documents which define the configuration baseline at each stage of the project (requirements documents, interface documents, drawings, tech specifications, analysis reports, etc)
  - T-1m checklist, T-1w check, design reports at FDR… major improvement
  - Fabrication plan, travelers, training plan, QA plan - major improvements
- Establish a formal interface management process to ensure complete technical integration
  - New / extensive interface table(s) + systems engineer hired (P. Dugan)
- Hold integrated schedule reviews to identify inter-WBS logical relationships to increase confidence in the critical path and potentially near-critical activity pathways.
  - PM + P&C have implemented bi-weekly RE status/tracking meetings

PPPL/NSTX-U have increased engineering rigor

(Thanks for Valeria for this summary slide)

- Extensively revised QAPD was approved on December 29th, 2017
  - Establishes clear definition of graded approach
  - Defines minimum level of rigor for required controls and approval authorities based on importance and impact for the Laboratory
  - Represents a very conservative approach to Quality management
- Key roles and responsibilities revised and documented
  - Ownership of components, configuration management – Responsible Engineers
  - Engineering assurance functions - Chief Engineer and Technical Authorities
- Core procedures have been revised to implement QAPD
  - Core procedures are the subset of QA (4) and ENG (11) procedures most needed for the design and procurement phase of NSTX-U Recovery
  - Precursors of the new core procedures applied by NSTX-U since summer 2017
  - Effective from January 31st, roll out included training
- The rest of the lab-wide Engineering procedures are being revised as planned in ICAP (Integrated Corrective Action Plan)

OPA Assessment of Recovery #1 - Capability
Charge questions

4. Are PPPL's plans to repair and operate NSTX-U as a national user facility sufficiently defined at this point in the recovery effort?
5. Are all major risks to successful repair and startup identified along with appropriate mitigations?
6. Are plans to safely commission and start-up the facility realistic and adequately detailed?
7. Is the cost and schedule for the repair complete, reasonable, and traceable?
8. Is the proposed leadership, management, and resources (e.g., engineering, procurement, QA/QC) adequate and appropriate to successfully complete the recovery plans?

Design, Engineering, Work Control Recommendations (SC-2)

1. Scrub and prioritize the risks within the risk registry, for both Project and Maintenance and Repair, before CDE-2.
2. Make the cost estimate completely traceable, from BOE to the resource loaded schedule, at least 2 months before CDE-2.
3. Ensure the scope is reviewed and documented in a way such that the scope is well understood by all parties before CDE-2 like review.
   - ➢ Updated scope sort with crisper criteria for on/off-project sort
   - ➢ Next need to clearly document scope for CDE-2
4. Ensure all design review recommendations are closed out, and all documentation (specs, interfaces, …) finalized before procurement of any components.
   - ➢ Concern about chit logging, tracking, timely close-out for FDRs
5. Revisit the PF coil procurement plan to determine whether contracting with multiple vendors for manufacture is the best plan before CDE-3A.

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Operations and Safety Recommendations (SC-3)

1. The IPT needs to complete Accelerator Safety Order (ASO) Implementation Plan with DOE concurrence in conjunction with CDE-2.

2. Benchmark the "tailoring" of ASO implementation with accelerator community, and consider bringing a "mentor" into the IPT to help with the ASO implementation plan.

- Actively following up on both recommendations
- Stefan will provide more details in his presentation

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Cost and Schedule / Procurement / QA Recommendations (SC-4)

Cost and Schedule:

1. Complete the WAF revision process and input to P6 to allow for roll-up of the Recovery Project cost well before CDE-2 review, so it's a confident representation of the estimate.
   - Major push by Russ and Steve, Emil, Tony get cost and schedule initial set of updates complete in June (final set in August)
   - **CAMS/REs need to support Russ to maintain baseline review schedule**
2. Check schedule logic for high float activities and correct prior to CDE-2
3. Further develop the risk register, and time-phase the project risks to ensure proper focus on near-term risks prior to CDE-2
4. Closeout Cost and Schedule recommendations from September 2017 review prior to CDE-2

QA Recommendation:

1. Consider re-evaluating the application of NQA-1 requirements to all repair-related activities, for this may not be necessary/possible, and incorporate the graded approach and risk assessment processes.

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Project Management Recommendations (SC-5)

1. There should be clear agreement as soon as possible between DOE program office, the lab and Office of Project Assessment about deliverables required for baselining so "rules of the game" are clear
   - **Very active topic for Integrated Project Team**
2. The laboratory and DOE should agree on a schedule for the baseline review to take place at a time when the design work is sufficiently mature, new management processes are reasonably well established, and proper preparation can be completed to ensure a successful OPA baseline review and at a time that meets DOE's needs.
   - **See Russ' presentation**
3. In order to reduce the possibility of future problems, the involved DOE offices should understand what prevented their early awareness of the PPPL weakness in project, engineering, QA and other processes that were underlying causes of the NSTX-U past failures.

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Project Management “bottom line” (SC-5)

- “The laboratory seems to be on the right track but only time will tell."
- “There is still a real possibility that without strong, sustained leadership that stays vigilant about the past the old problems are likely to resurface.”

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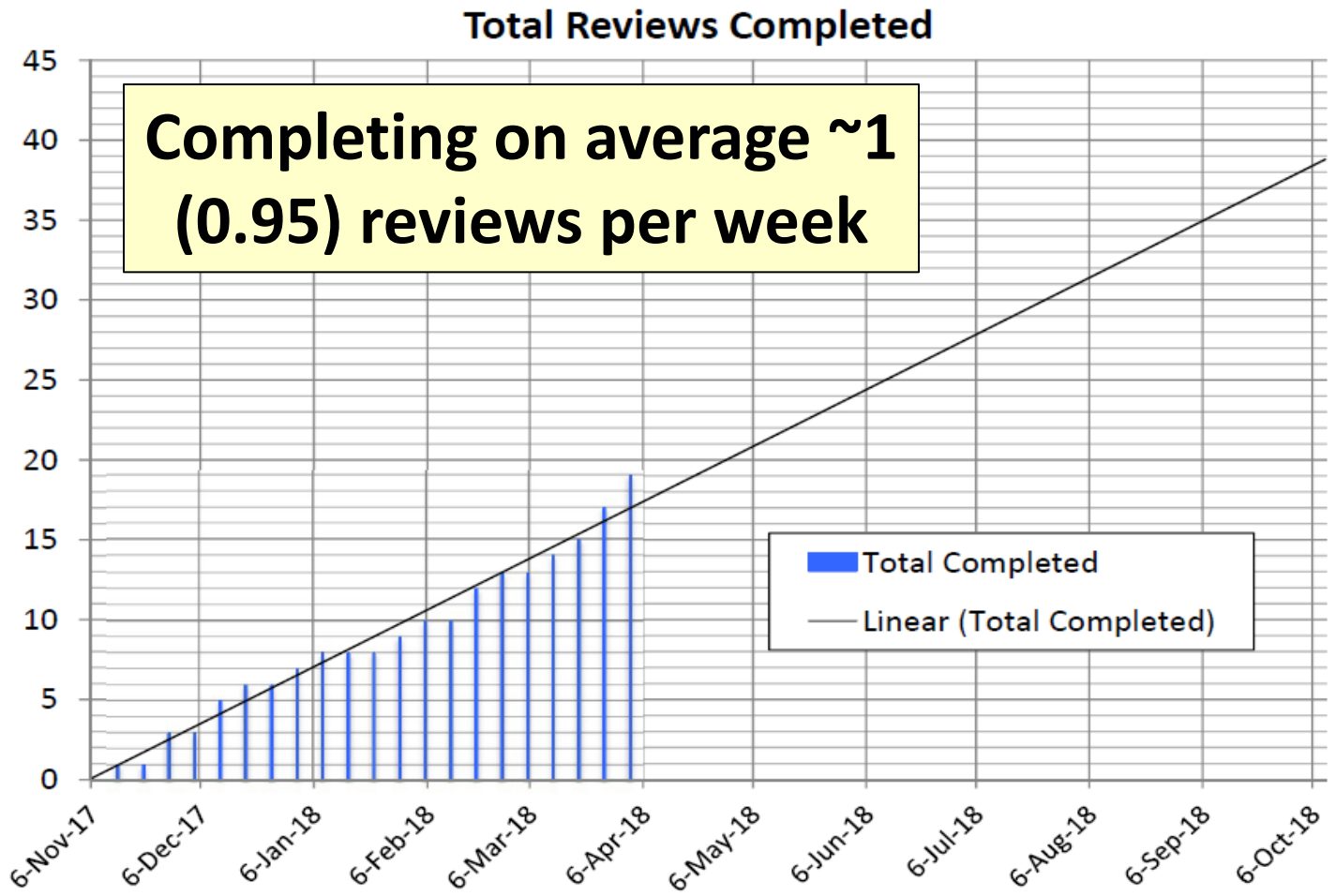
DOE Notable Outcomes for FY2018

- 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 **(Complete).**
- 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's insulation system through electrical testing followed by destructive sectioning and inspection.
  - **Submit a final report documenting the results by July 15, 2018.**
- Complete a preliminary design review (PDR) for the passive plates and helium bake-out line supports by July 31, 2018.
- Complete a final design review (FDR) for improved and re-designed plasma facing components by September 30, 2018.
- Complete a Director's Review by September 30, 2018.

New from early March

Institutional KPI target from January:
Complete 46 reviews (design + project) in FY18

- Present trajectory is to complete ~39 reviews in FY18
- KPI has been ~0.85 - need to get this to 42 to get above 0.9



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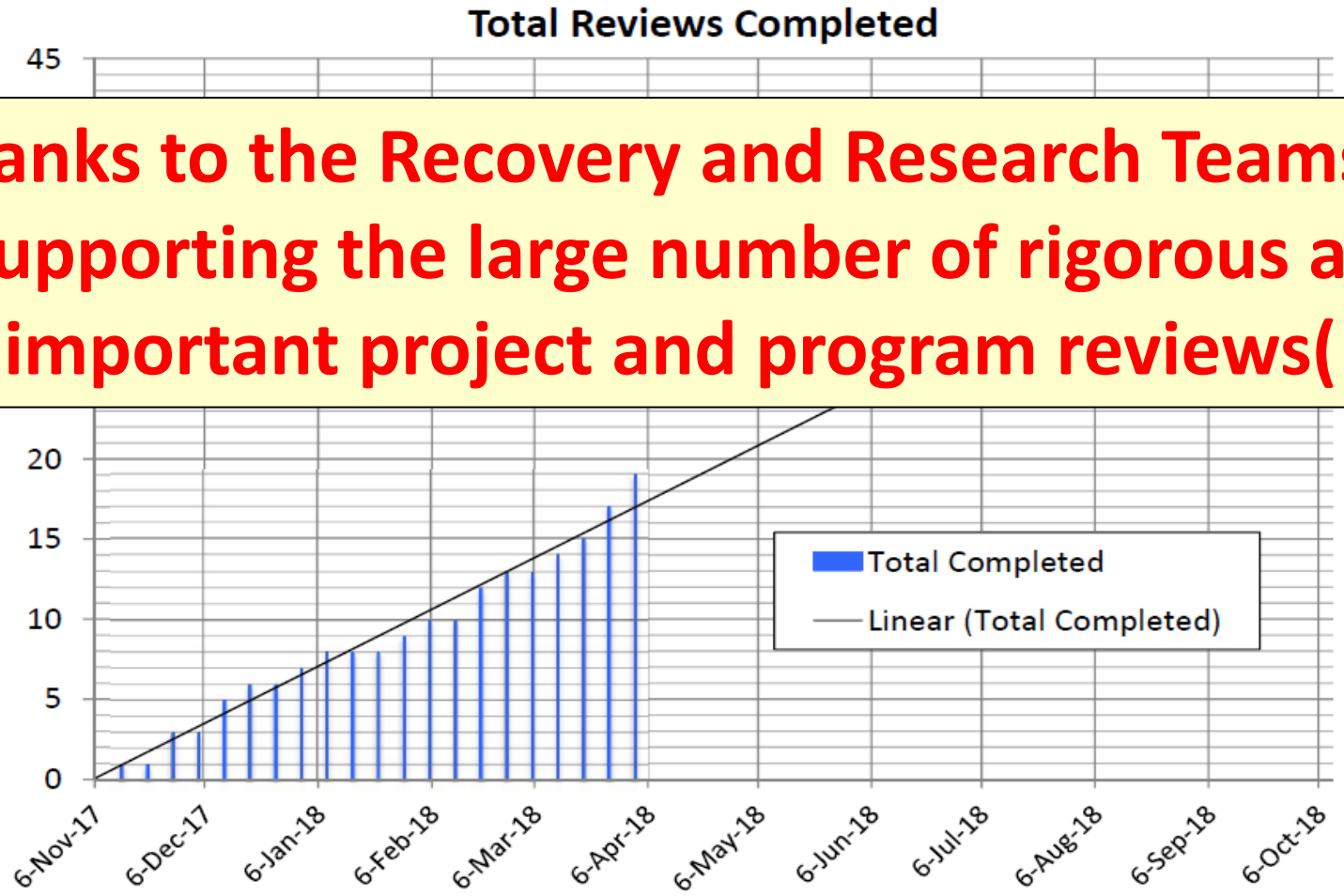

Thanks to the Recovery and Research Teams for supporting the large number of rigorous and important project and program reviews(!)

Recovery Project Advisory Committee
Sample of major recommendations + actions in response

- Regarding QAPD: "…The recommendation of the Committee is accordingly that once an acceptable culture is deemed to have been established, joint PPPL, Princeton University and DOE consideration ought to be given to possible appropriate reduction of this administrative burden and implementation of a risk based graded approach."
  - Response: Not ready yet, but will consider in future
- "As work under the new system progresses, the impact will become more evident, and the Committee recommends that periodically, but frequently, the actual cost and schedule be reviewed against the estimates, so that adjustments can be made."
  - Agree: important for baselining and successful project execution
- Clarify R&R and interplay of Recovery management positions
  - Agree: Important internally, and for director's and CDE-2 review

Agenda

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NSTX-U Research PAC
Sample of major findings and recommendations

- PAC charge: Help prepare for mission need assessment
- Finding: "The high field ST Pilot Plant is a compelling and exciting vision that can motivate the NSTX-U Program"
  - The PAC Recommended "leading with this vision when presenting arguments for the program and the recovery and improving linkage of underlying physics issues and facility capabilities to this vision."
    - *JEM Note: SC does not build pilot plants, but this vision could motivate science*
- Finding: "NSTX-U has many unique aspects"
  - "NSTX-U remains the world-leading spherical tokamak in many aspects of its capabilities and strongly complements the capabilities of MAST Upgrade. When compared with MAST-U, NSTX-U will have *(the following)* unique aspects"
- Finding: "NSTX-U will both compete worldwide and complement the world program in ST research"
- The PAC recommends "the addition of either a cryo-pump or a faster implementation of a Li metal wall in NSTX-U for addressing the mission critical non-inductive sustainment goals of NSTX-U."

OPA Assessment of Recovery #2 – Mission Need

Sample of major recommendations + actions in response

- "Overall, the NSTX-U facility can be expected to generate a wide-ranging and challenging research program with the potential for significant advances in fusion science."
- "The NSTX-U project is a world leading device that will address critical areas in magnetic confinement, notably in conjunction with the MAST-U spherical tokamak operated at the Culham Centre for Fusion Energy (CCFE), UK."
- "…research on lithium as a liquid wall material should be maintained, further developed…"
- Area for improvement: "PPPL management should explain the value of ST research generally, and the role of NSTX-U research in particular, to the realization of fusion energy.
  - The Laboratory should attract the interest and involvement of the full fusion community in its programs through a series of outreach efforts, both in the U.S. and abroad"

NAS meeting at PPPL - NSTX-U team played important role in representing possible U.S. strategic elements for fusion

- PPPL Long-term Fusion Vision, Strategy, and Role: M. Zarnstorff
- Options and Strategies towards Fusion Net-Electricity: J. Menard
- NSTX-U: An Essential Science Facility for US Fusion Innovation, S. Gerhardt
- Upside Potential for Controlling Fusion: Nat Fisch, PPPL
- SPARC: A Critical Step On The High-Magnetic-Field Path To Practical Fusion Energy: MIT & CFS Teams: Presented by Martin Greenwald
- A new approach to funding, accelerating, and commercializing fusion: R. Mumgaard,CEO -Commonwealth Fusion Systems
- High Field Superconducting Magnets - Promises & Challenges: S. Prestemon, LBNL
- Plasma-Materials and Divertor Options for Fusion: J. Rapp, VLT/ORNL
- First-wall, plasma-material interaction, and liquid metals, for fusion: Mike Jaworski

Fusion Funding Status

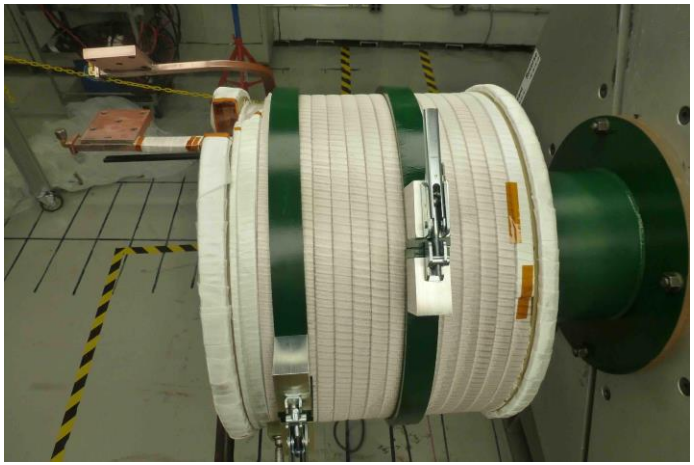
- From FIRE website (any mistakes are Dale's ;-)

k$	FY17 Enacted	Omnibus 2018	FY19 Request
BP Foundations	$212,027	$277,665	$190,350
BP Long Pulse	$41,569	$52,246	$38,500
Discovery Plasma Science	$76,404	$80,200	$36,150
Domestic Mag Fusion	$330,000	$410,111	$265,000
ITER	$50,000	$122,000	$75,000
Total Mag Fusion	$380,000	$532,111	$340,000

- Earlier in FY were considering 20% cut - flat funding at best
  - **March 23: FY2018 non-ITER funding up +24% (!)**
- Do not have final FY18 numbers for Recovery, but indications are positive that funding **will not** impede Recovery progress in FY2018 (and FY19 is only 5 months away…)
  - Russ: increasing staff (and scope completion rate) to hold to schedule

Recovery Project transitioning from review and design to prototype fabrication and testing

- Must be vigilant regarding safety and hazard analysis + mitigation in all of our work:
  - Prototype coil fabrication
  - Prototype coil testing
  - Planned TF/OH CS casing trial fit-up
  - Device disassembly, reassembly
  - And much more…



Tesla Engineering, in Storrington, West Sussex (Picture: Google)

Thank you!

Any questions?

National Spherical Torus eXperiment Upgrade

Overview of Technical Activities

NSTX-U Team Meeting

S.P. Gerhardt & the NSTX-U Recovery Engineering Team

April 27, 2018

Outline

- Technical Overview
- Technical Progress
- Accelerator Safety Order Implementation

Project Key Performance Parameters (KPPs) Have Been Defined

KPPs are capabilities that must be demonstrated before a 413.3b capital project can be closed

KPP	Short Title	Full Description
1	TF/OH Alignment	The TF/OH bundle axis shall be aligned to the PF-5 coil mutual axis with an accuracy bounded by a straight line through the [shift,tilt] points [0,6.] and [6.,0] [mm,mrad]
2	Perform PFC Bakeout	A bakeout will be conducted where the minimum average temperature for any region is at least 260 C
3	Demonstrate Plasma-Like Vacuum Test-Shot(s)	Combined-field vacuum test-shot(s) using OH/TF/PF waveforms expected for a 1.4 Mega Ampere, 0.85 Tesla, 4 second plasma with 2 second plasma current flat-top
4	Demonstrate First Plasma	Produce an ohmically-heated plasma discharge with plasma current exceeding 50,000 Amperes at a toroidal magnetic field exceeding 1,000 Gauss

Engineering Design is in all Cases Driven by More Strict Project Requirements

Numerous Technical Reviews Have Occurred Since the Last Team Meeting

- Project Conceptual Design Review → August 2017
- Now in the Preliminary Design Review (PDR) phase (list incomplete):
  - New Center Stack Cooling Features
  - Hot Helium Vessel Feedthrough Redesign
  - Hot Helium Ex-Vessel Distribution Improvements
  - Medium Temperature Water System Safety Improvements
  - Bakeout DC Power Relocation to Top of Machine
  - Interspace Pumping System for Double O-rings
  - PFC Diagnostics
  - Machine Instrumentation
  - PF-1b Power Circuit (coil not powered in 2016)
  - Low Heat Flux PFCs
  - High Heat Flux PFCs
  - Inner-PF Coil Support Structures
  - NSTX-U Test Cell Shielding
- Have had one significant project Final Design Review
  - Inner-PF Coils
- Alignment-Related Peer Reviews and Design Reviews

Covered in This Short Talk

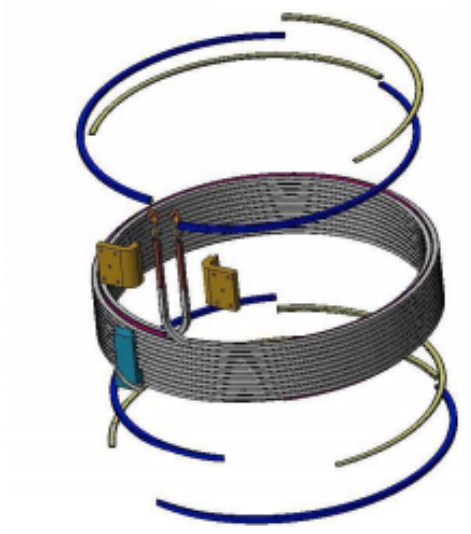
Technical Progress

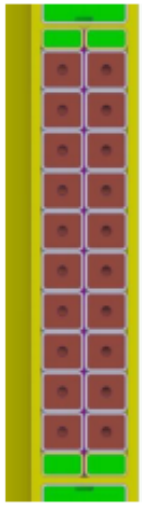
Inner-PF Coil Final Design Completed

- Review on March 30th
  - Satisfied a Laboratory Notable Outcome to complete FDR of inner-PF coils by end of March.
- Very large team effort:
  - M. Kalish, Y. Zhai, S. Raftopoulos, P. Titus, W. Wang, J. Fang, T. Willard, J. Hennessey, J. Mitchell, J. Winkelman, M. Duco, M. Gomez, S. Gerhardt, C. Neumeyer, A. Khodak, A. Brooks, I. Zatz
- Comprehensive Review
  - 7 Presentations
  - 10 Calculations
  - https://sites.google.com/pppl.gov/pf-coils-fdr/home

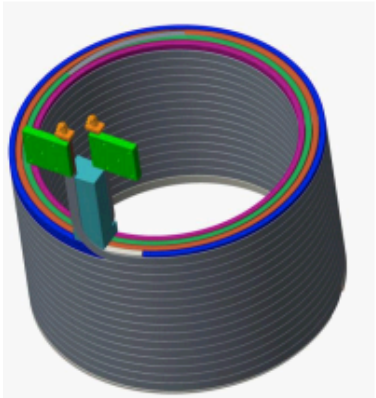
The Coils…

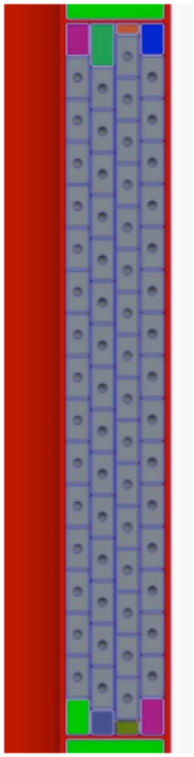
PF-1b

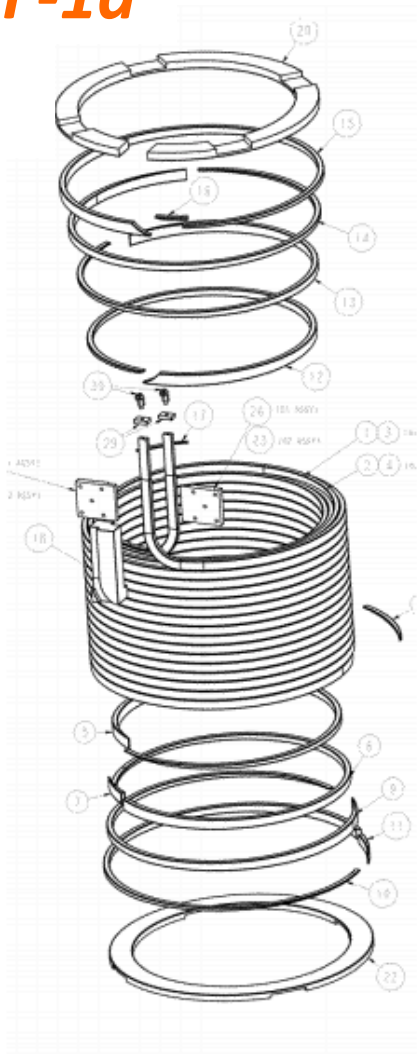


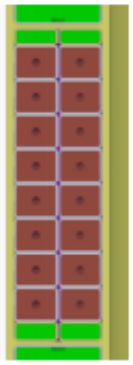


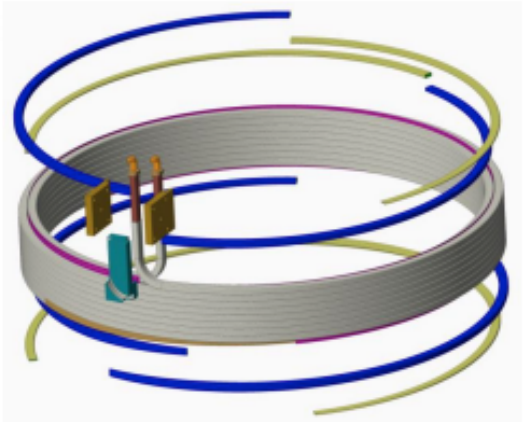
PF-1a

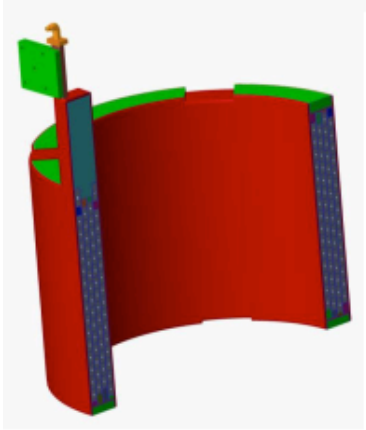












PF-1c

Key Engineering Details and Features

	Original NSTX-U	Recovery NSTX-U
PF-1a	64	61
PF-1b	32	20
PF-1c	20	16

- These coils will operate at higher supply current, though still within transrex 24 kA limit
- Physics studies validated that these amp-turns and cross-sections are sufficient for 2 MA / 5 second scenarios of interest

Design Feature	Consequence
Will be fabricated w/o permanent mandrel	Enhanced turn-to-turn testing fidelity
Will be fabricated from continuous Cu extrusion	Enhanced reliability by elimination of in-line braze joints
Two layers of glass-kapton for turn insulation	Factors of 40 to 80 safety factor on turn-to-turn dielectric strength (factor of ~30 on conductor-to-ground dielectric strength)
Require significant pre-load to mitigate thermal strain: • 100 klbs for PF-1a • 60 klbs for PF-1b	Support structures will need to provide and maintain that preload

Prototype Coil Fabrication is Well Underway

- Prototype coils are primarily designed to assess the ability of vendors to fabricate coils
  - Their QA/QC, safety practices
  - Their ability to do winding, Vacuum Pressure Impregnation (VPI)
  - Their ability to deliver on schedule
- On-site PPPL oversight
  - Technical → engineers or senior technicians full time
  - Quality → QA/QC representatives part time
- Four shops are making prototypes (PPPL + 3 external)
- Coil will be have numerous tests as part of vendor qualification.
  - Hydrostatic tests
  - electrical tests (hipot tests, surge tests)
  - Sectioning and inspection of insulation system
- One coil will be tested to full current and energy with FCPC rectifiers
  - This is a second Notable Outcome for PPPL

Inner PF Coil Prototype Fabrication External Vendors

- Tesla Engineering close to done.
  - On layer 4, of four total layers
- Everson-Tesla has completed winding
  - Preparing for vacuum pressure impregnation
- Sigma-Phi moving forward.
  - Now working on the 2nd layer

Tesla winding. On layer 4 –

Everson-Tesla completed last layer and have brazed outer flag

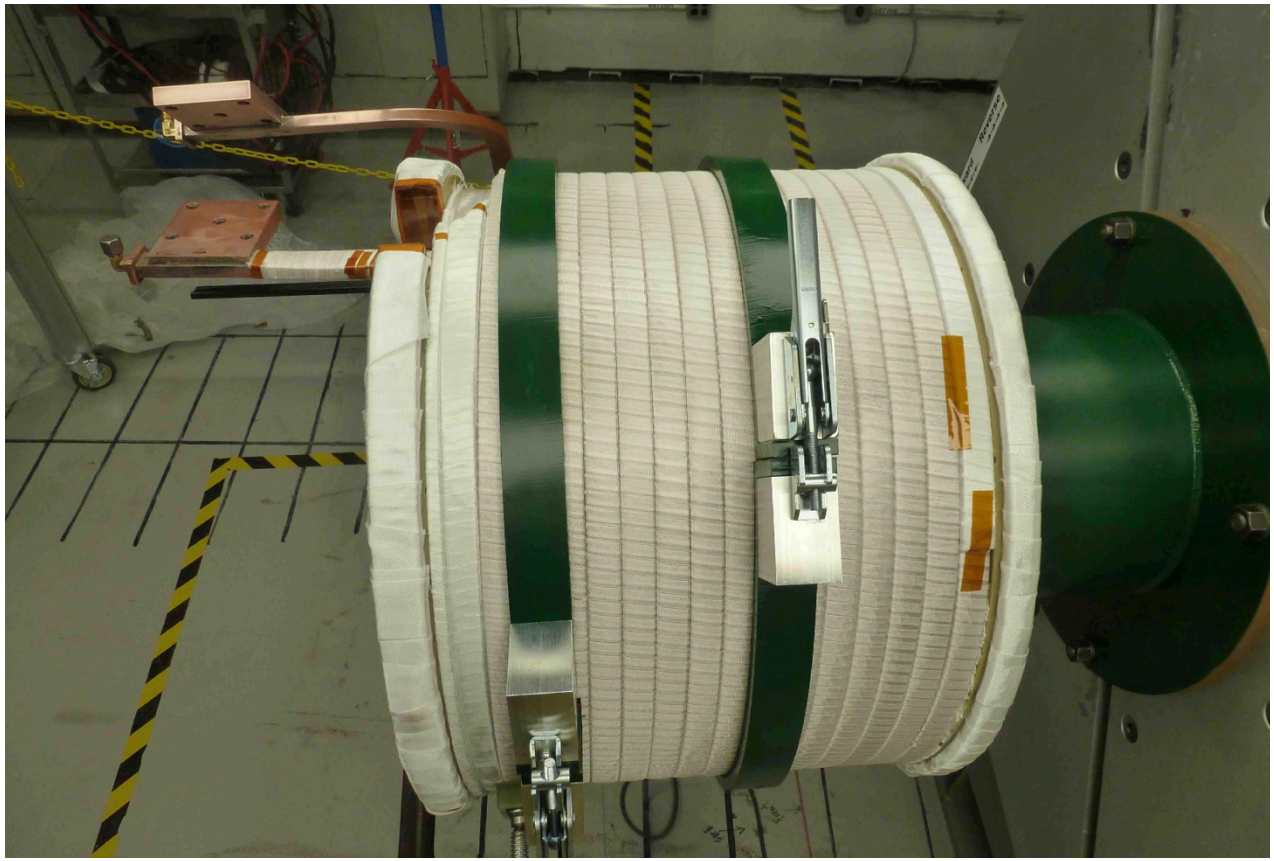
Sigma Phi working on the first layer

M. Kalish, C. Ciummo, D. Downing, R. Burke, S. DePasquale, J. Levine, J. Malo, F. Malinowski, A. Amaya,…

Inner PF Coil Prototype Fabrication

Internal (PPPL) Coil Fabrication

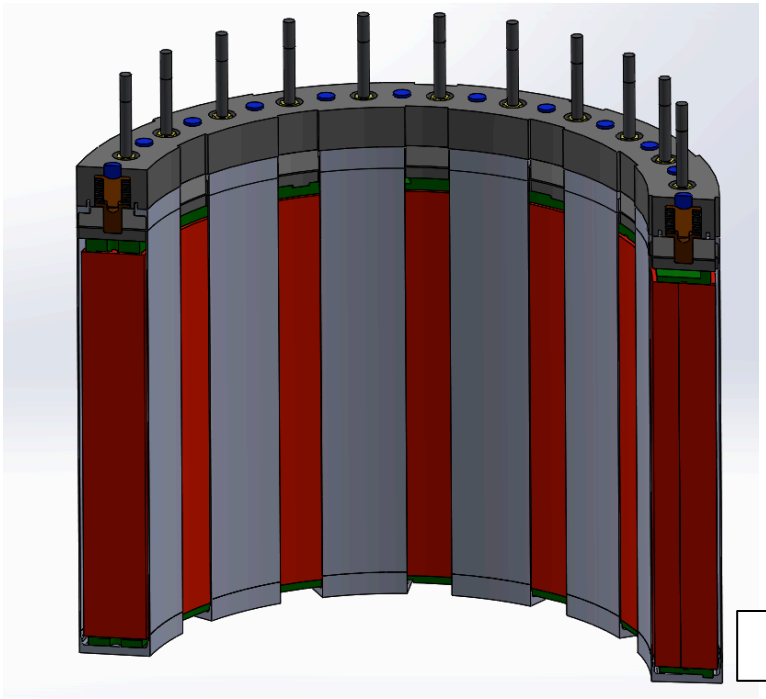
- All 4 layers completed
- Lead flag brazed
- VPI delivery plumbing being assembled

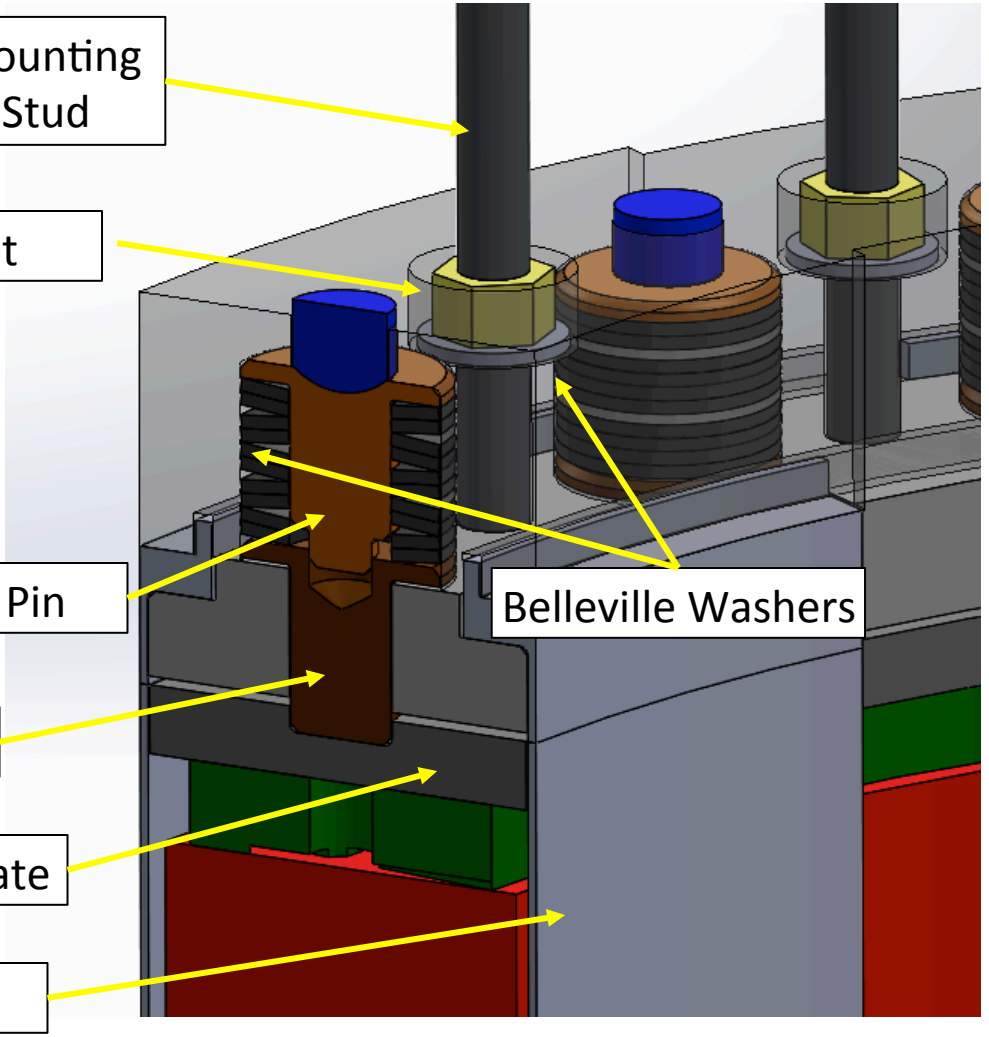


All 4 layers of copper conductor completed. Final G11 spacers are completed. Exit lead bent and flag brazed

M. Viola, S. Raftopoulos, M. Anderson, A. Amaya, many others on the coil winding crew…

Have Developed Preliminary Design for Coil Support Structures



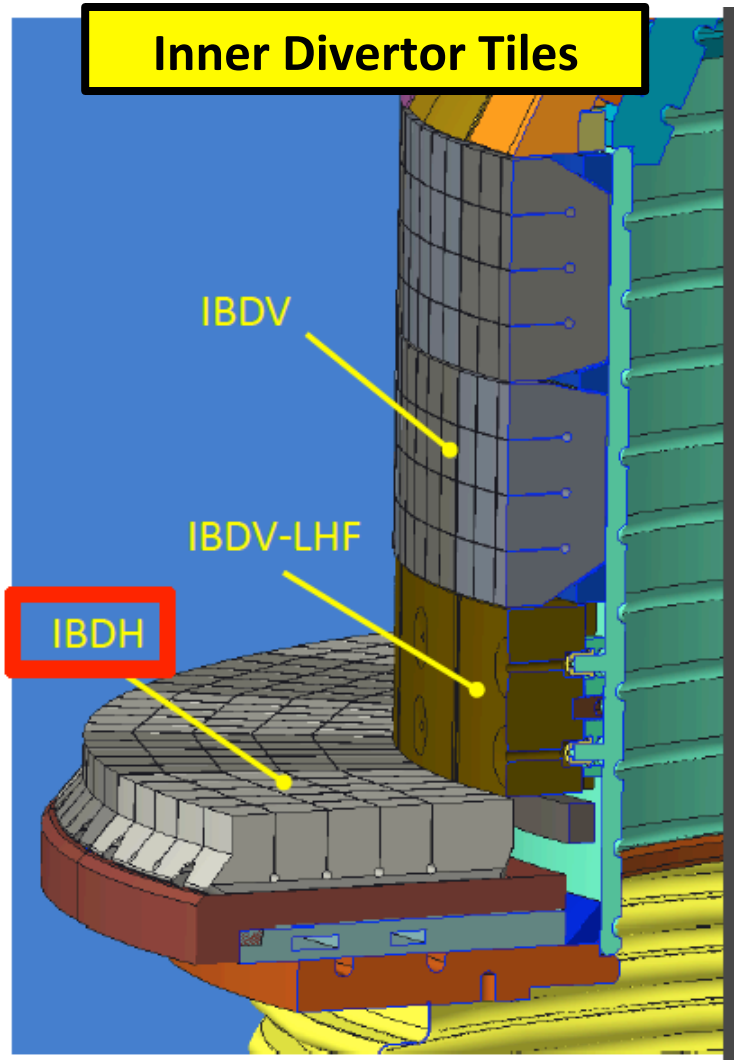


Pre-Load Accomplished by Belleville Stack and Sling Stretch

M. Smith, N. Dean, T. Willard, J. Hennessy

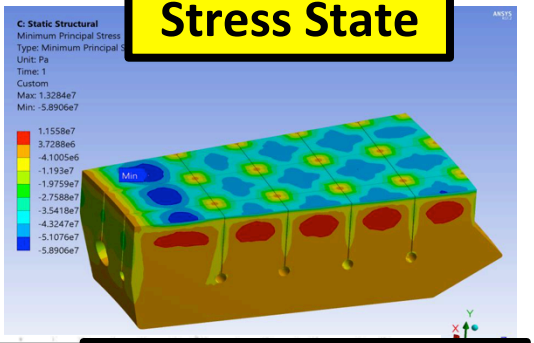
Tiles Will Use Castellations and Ramping to Optimize Heat Flux Handling

Inner Divertor Tiles

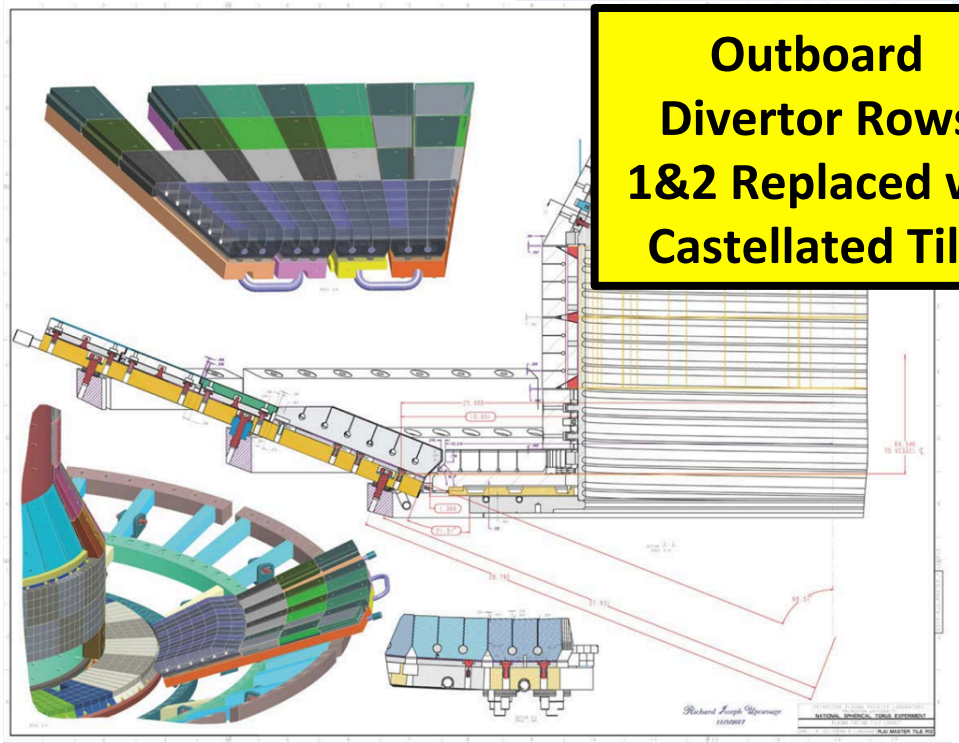


Castellated Prototype

End-of-Pulse Stress State



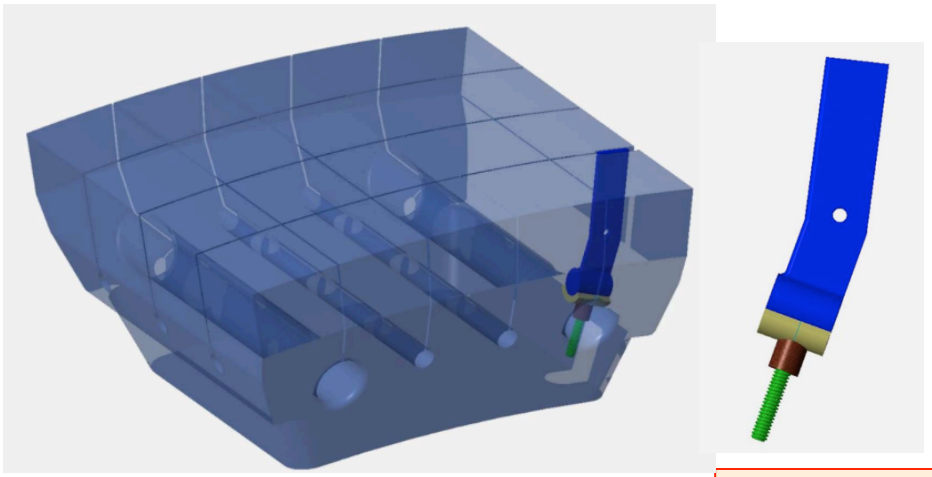
Outboard Divertor Rows 1&2 Replaced w/ Castellated Tile



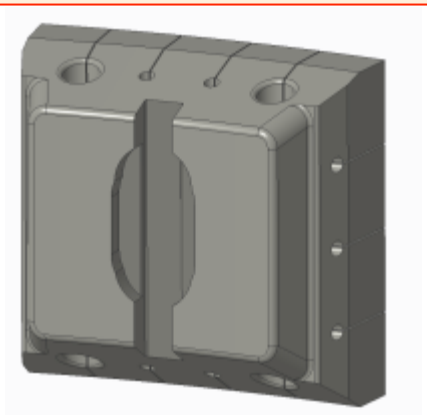
M. Jaworski, A. Khodak, R. Ellis, M. Messineo, M. Reinke, B. Linn, T. Gray, R. Upcavage, J. Klabacha, A. Brooks, J. Fang, D. Loesser, A. Jariwala, N. Allen, G. Smalley, J. Carbone

Tile Design and Analysis Team are Refining Features and Details

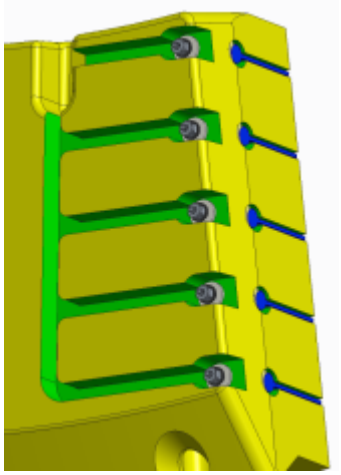
LPs on Vertical Target Tile



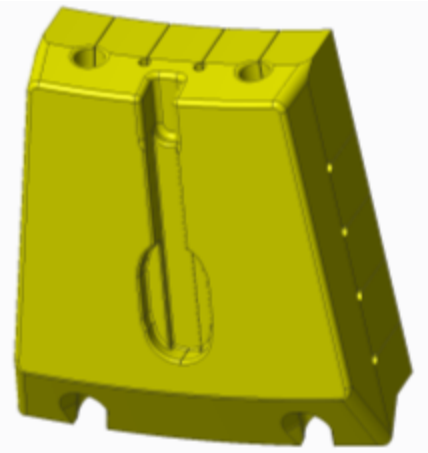
Mirnov Sensor on Vertical Target Tile



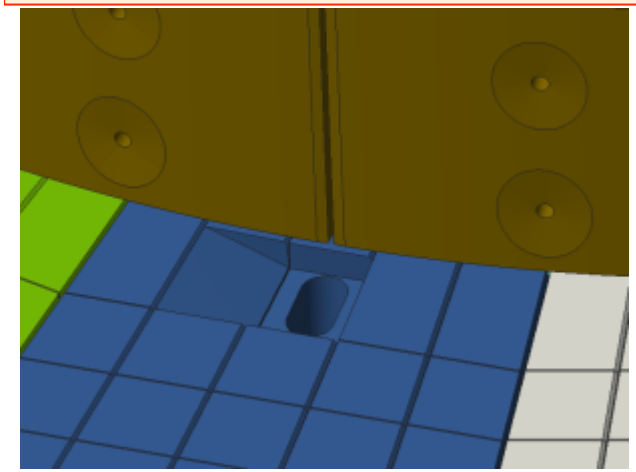
LPs on Horizontal Target Tile



Mirnov Sensor on Horizontal Target Tile

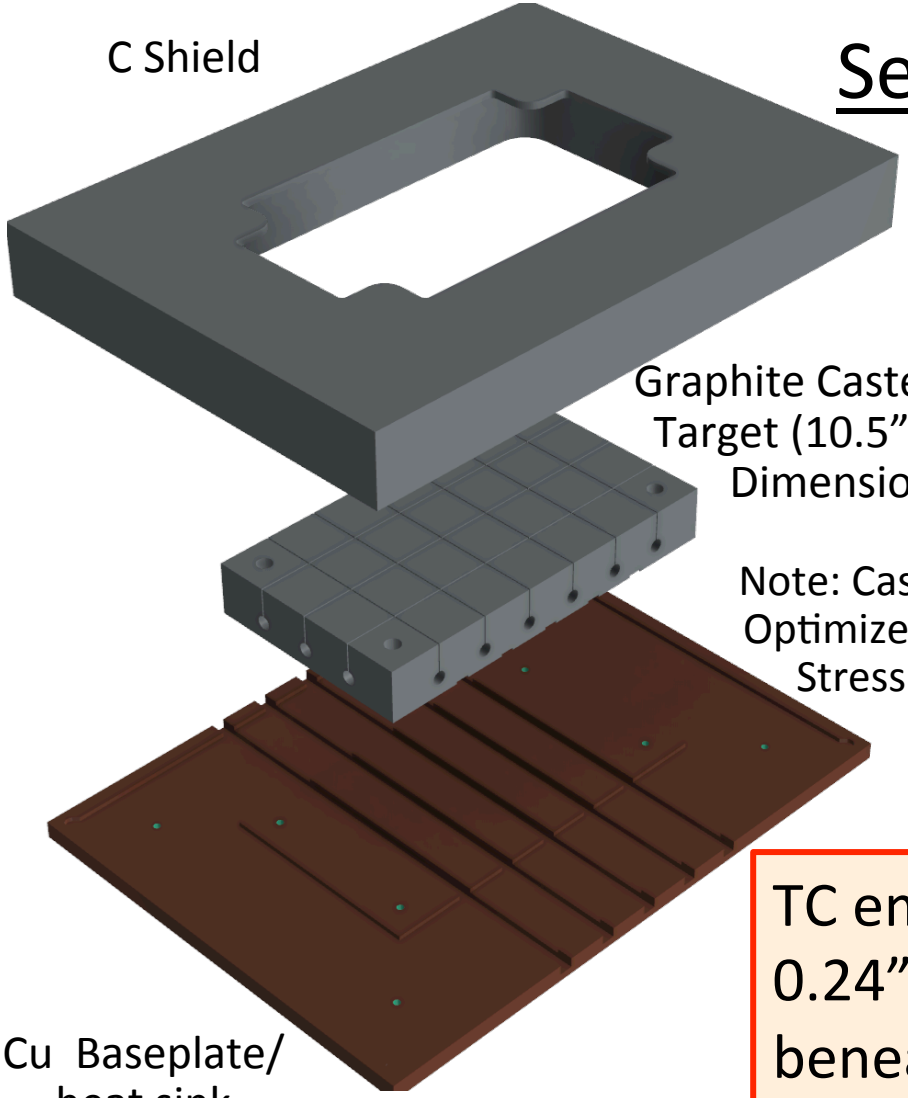


Access Hole above an Organ Pipe



ORNL-Led Activity Demonstrated ARL e-Beam as a *Quantitative* HHF Test Stand for PFCs

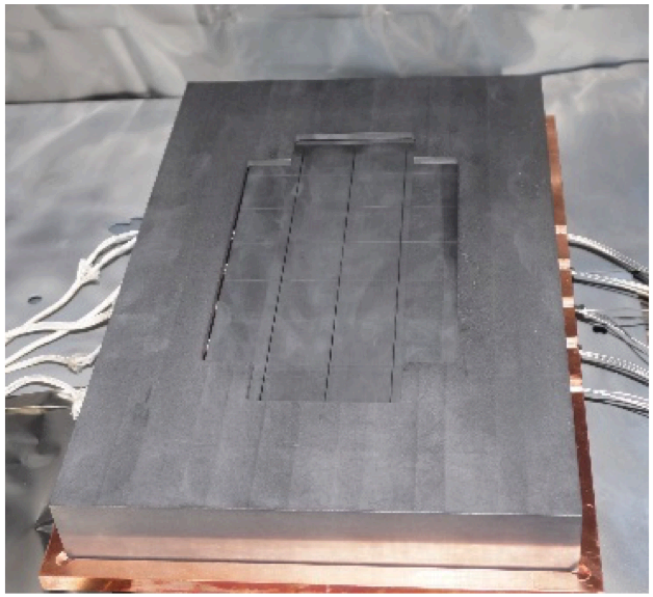
Setup



Note: Castellations Not Optimized for Thermal Stress Mitigation

See T. Gray HTPD Paper for more Details

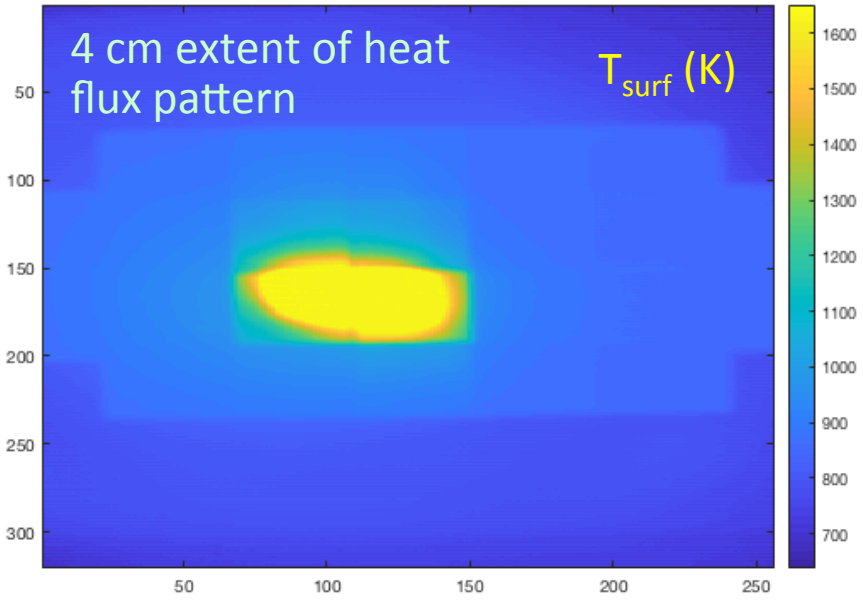
TC embedded 0.24” or 0.48” beneath surface in castellations



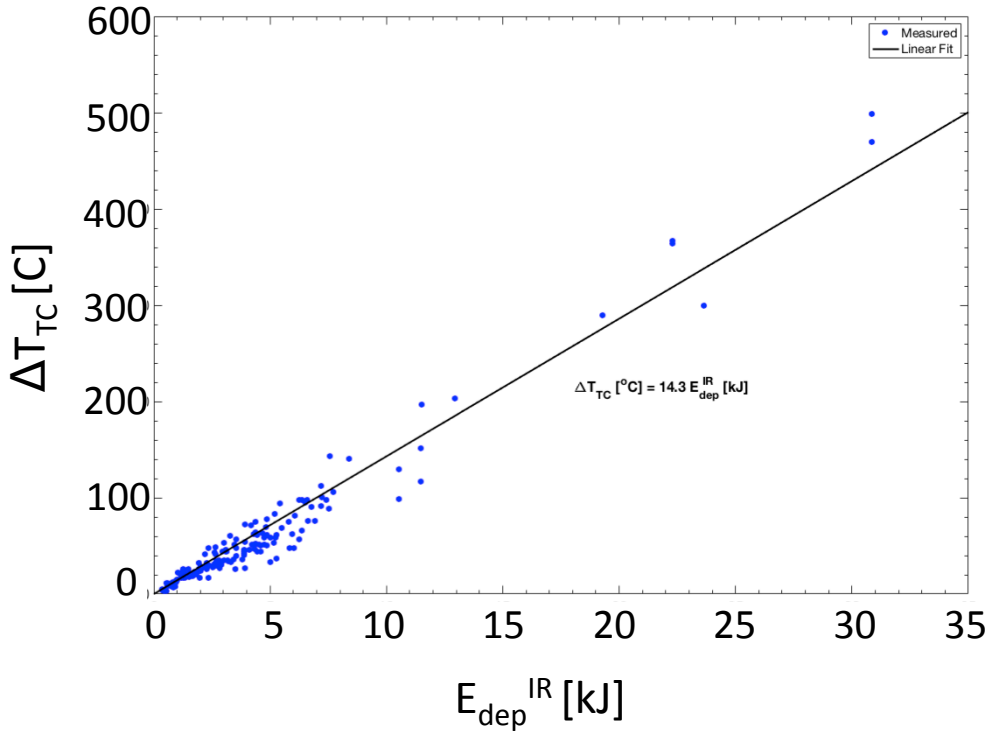
ORNL Activity Demonstrated Utility of Castellations as Calorimeters

Result

Surface Temperature as Measured by IR Camera



Thermocouple temperature rise vs. energy deposited



Side Observation: Tile Began to Ablate, but no Fracturing Observed
→ Suggests the castellations create a "T_{surf} limited" tile

See T. Gray HTPD Paper for more Details

The New CS Will Have a More Expansive Set of PFC Diagnostics

	2016 NSTX-U	Recovery	Diff.
CS Thermocouples, Vertical Array	15	15	0
CS Thermocouples, Horizontal Midplane Array	6	0	-6
Upper Vertical Target Thermocouples	4	13	9
Lower Vertical Target Thermocouples	4	14	10
Thermocouples on Angled Section, Upper	4	4	0
Thermocouples on Angled Section, Lower	4	4	0
Upper Horizontal Target Thermocouples	5	12	7
Lower Horizontal Target Thermocouples	5	11	6
Upper Horizontal Target Fast Thermocouples	1	0	-1
Lower Horizontal Target Fast Thermocouples	1	0	-1
1D Mirnov Coils on CS	18	18	0
2D Mirnov Coil on Upper CS	6	6	0
2D Mirnov Coil on Lower CS	4	4	0
2D Mirnov Coil on Upper Vertical Target	10	10	0
2D Mirnov Coil on Upper Lower Target	10	10	0
2D Mirnov Coil on Upper Horizontal Target	4	4	0
2D Mirnov Coil on Upper Horizontal Target	6	6	0
Center Stack 1D Midplane Mirnov Array	10	6	-4
Center Stack Midplane Tilted Mirnov Array	5	5	0
Langmuir Probes - Center Stack	7	6	-1
Langmuir Probes, Upper Vertical Target	3	7	4
Langmuir Probes, Lower Vertical Target	6	7	1
Langmuir Probes, Upper Horizontal Target	2	7	5
Langmuir Probes, Lower Horizontal Target	5	7	2
Segmented Rogowskis on Center Stack	3	0	-3
Continuous Rogowskis on Center Stack	3	4	1
Shunt Tiles - Center Stack	18	18	0
total ->	**169**	**198**	**29**

More TCs in Castellations on the Vertical Targets

More TCs in Castellations on the Horizontal Targets

Fast TCs are gone

Upshot:

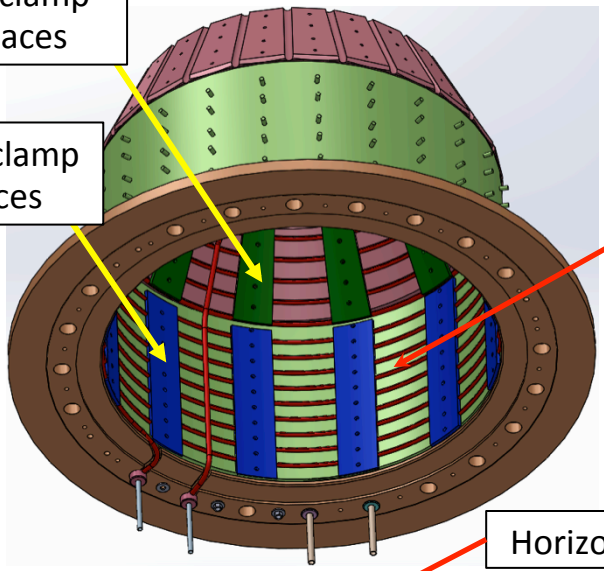
- Better operational reliability and redundancy
- Enhanced physics capability

More LPs in Castellations on both the Vertical and Horizontal Targets

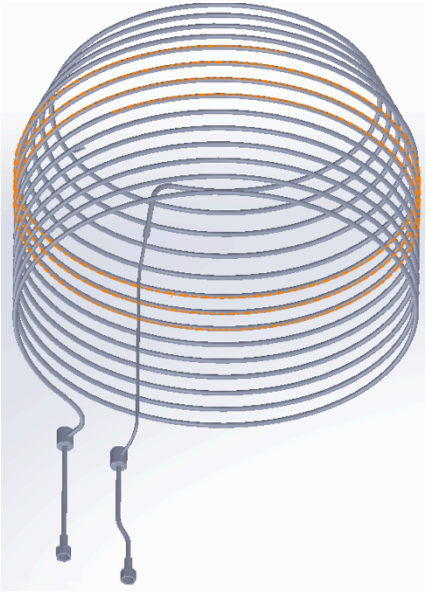
New Cooling Features to Remove Tile Heat Have Completed PDR

Angle clamp
12 places

Vertical clamp
12 places

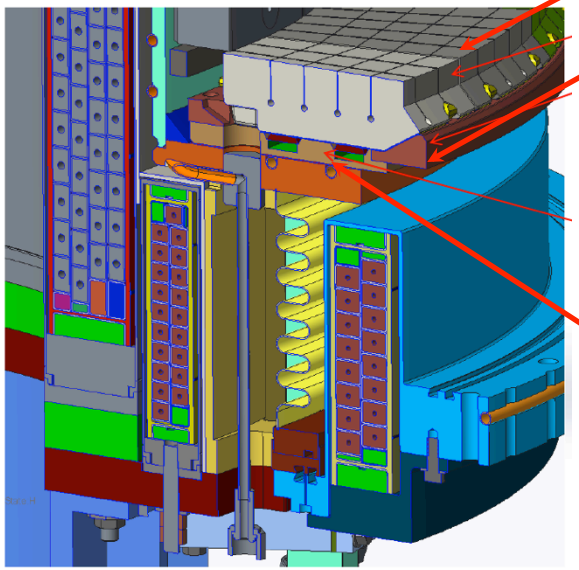


Heat Transfer Tubing
- Inconel 625 (resists corrosion, low J_{eddy})
- Compressed into grooves in CS for good thermal contact
- Will use water

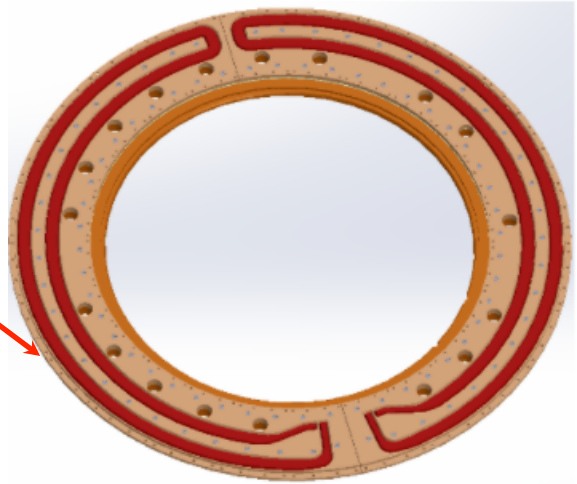


Horizontal Target Tiles

Tile Mounting Tray



Heat Transfer Plate
- Inconel 625
- Provides the mounting surface for tiles.
- Used in tile heating or cooling function
- He gas as the medium

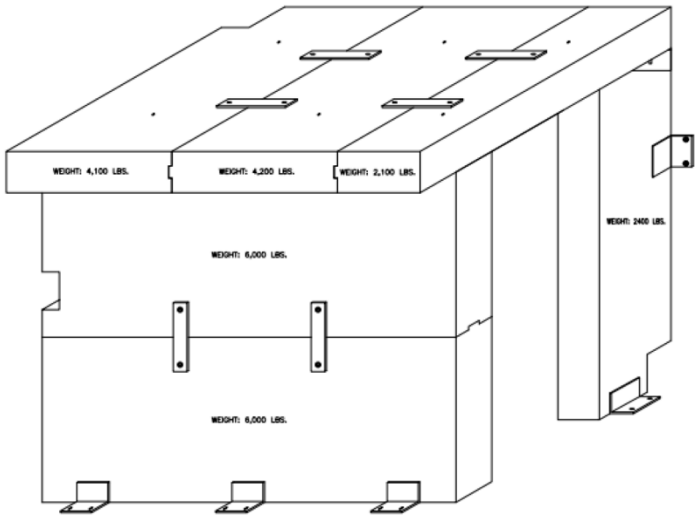


D. Cai, A. Finehart, H. Zhang, A .Brooks, J. Hennessy

Shielding PDR Refined Concepts from the CDR

New Shielding at the South Door
Mitigates the Primary Means for Neutrons to Exit the NTC

Close the North Door
During Operations

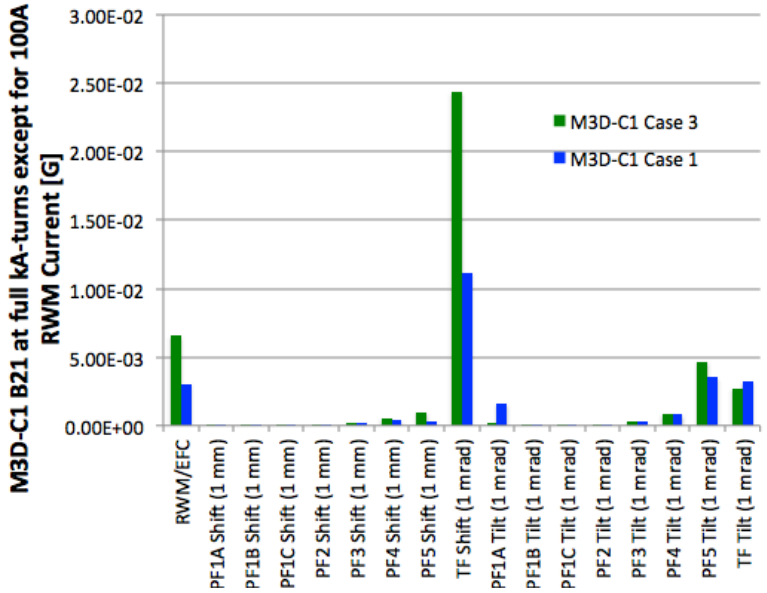


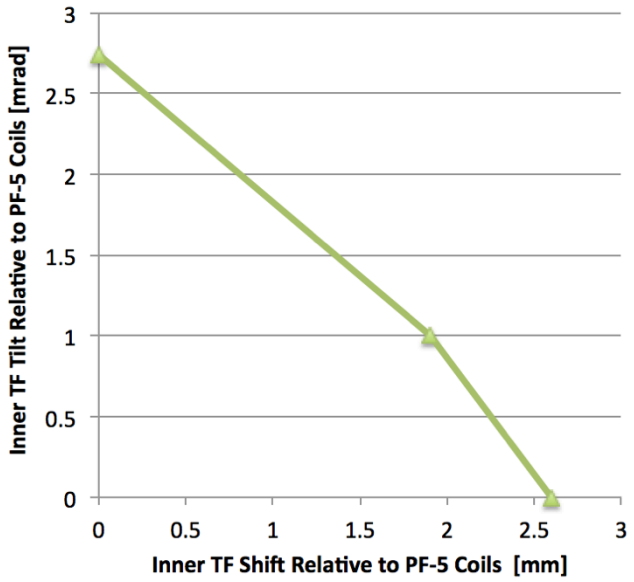
N. Atnafu, G. Ascionne, M. Cropper, M. Yavor, R. Kramer

- Will fill numerous empty windows and shield many penetrations in walls.
- Many penetrations in test cell floor are more difficult to shield
  →Plan to close the MER and MER Mezzanine during operations
- Once work starts, significant construction activities in & around the NTC

Global Alignment Tolerances Have Been Formulated

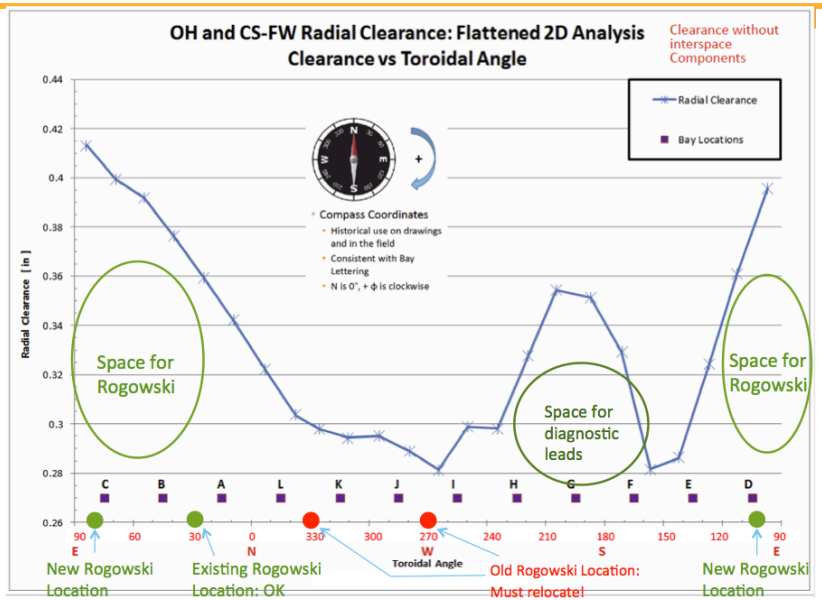
- Drivers for Global Coil Alignments
  - Desire to operate at least some scenarios w/o EFC for prevention of locking
  - Desire to limit the total NTV
  - Desire to not require too much error field correction current.
- These were assessed with MHD calculations
  - IPEC for locking, NTV, and EFC requirements
  - M3D-C1 for EFC requirements.
- Combined in aggregate to create a boundary on total relative shift/tilt of the TF relative to the outer-PF coils
  - Best captured in soon-to-be-released Rev. 1 of NSTX-U-DOC-101

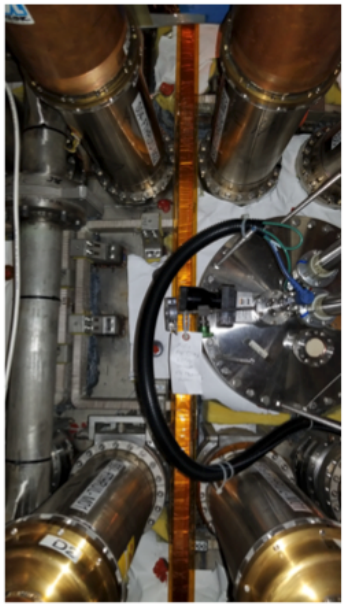


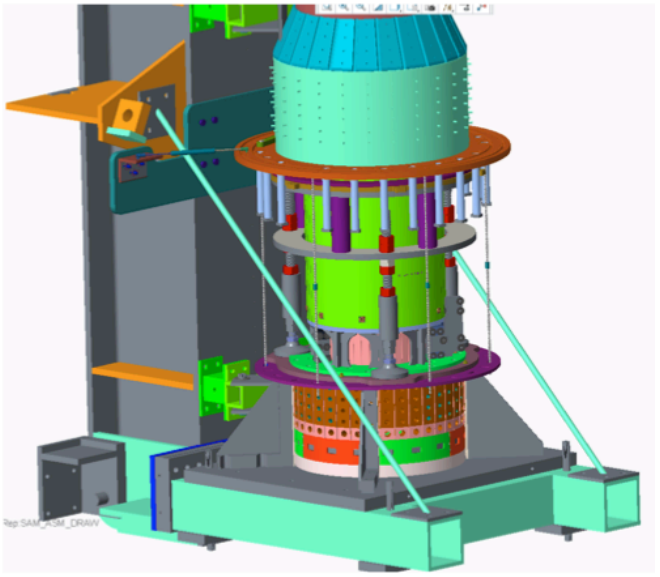


Engineers are Assessing the Clearance Between TF/OH and Casing as Part of Alignment Study

- Recall: significant tilt & shift between bundle and casing in 2016 run.
  - Interface between bundle and casing complicated by numerous as-built conditions of the components, requirement to run Rogowski sensors
- Detailed & sophisticated metrology effort has identified specific optimal toroidal angles for running Rogowskis.
- Trial fit with custom tooling will confirm the clearances identified by metrology
- Part of larger metrology effort







M. Mardenfeld, A. Brereton, S. Gifford, D. Stevens, J. Basler, A. Jariwala, S. Meytus, A. Basile, G. Smalley

Additional Key Design Reviews in the Coming Months

- Passive Plates PDR → Laboratory Notable
  - Assessing helium line support needs, plate fixturing to brackets
- Full Polar Region PDR
  - Assessing double O-ring seals, integration of inner-PF supports, ceramic break assembly, alignment capabilities.
- PF Bus Support PDR
- PFC FDR → Laboratory Notable
- Integration PDR
- Numerous other more modest scope PDRs
- Remainder of FDRs

Accelerator Safety Order

T. Stevenson, M. Cropper,
M. D'Agostino, R. Camp, J. Malo, J. Levine, W. Blanchard, C. Gentile
Consultant: Scott Davis

NSTX-U Will Operate Under the Accelerator Safety Order (DOE O 420.2c)

Why?

1: Because it represents DOEs standard for operational excellence for facilities of this nature

2: Because it is in the laboratory contract.

Definition per O 420.2c:

Accelerator: a device employing electrostatic or electromagnetic fields to impart kinetic energy to molecular, atomic or sub-atomic particles and capable of creating a radiological area.

On the Surface, ASO Has Only 5 Requirements

(1) an approved accelerator safety envelope (ASE);

(2) a safety assessment document (SAD);

(3) **clearly defined roles and responsibilities** for accelerator activities including those for training and procedures;

(4) **an unreviewed safety issue (USI) process**.

(5) an **accelerator readiness review (ARR) program**

Note: none specific to the technology of linear accelerators or storage rings or other conventional accelerators

(1) an approved accelerator safety envelope (ASE); (2) a safety assessment document (SAD);

- → Must update the Safety Analysis Document (SAD)
  - → Will be expanded from old SAD to include the "balance of plant"
  - → Will have revisions to more clearly identify the controls required for safe operations
- → Use the SAD to derive an Accelerator Safety Envelope (ASE)
  - → ASE defines the bounding conditions to ensure safety to workers, public, and the environment
  - → Also defines the systems required to ensure operation with the envelope.
    - →"Credited Controls"
  - → ASE is approved by DOE/PSO

(3) clearly defined roles and responsibilities for accelerator activities including those for training and procedures

- Improvements to operator training and qualifications on NSTX-U
  - COEs, neutral beam source operators, gas system operators, physics operators (?),…
  - And don't forget formal instructor qualifications
- Renewed focus on conduct of operations and chain-of-command considerations
- New ICAP focus on roles and responsibilities is beneficial

an unreviewed safety issue (USI) process.

"A USI process supports configuration management efforts that helps ensure the facility and supporting safety documentation are maintained current and periodically updated"

…let me translate…

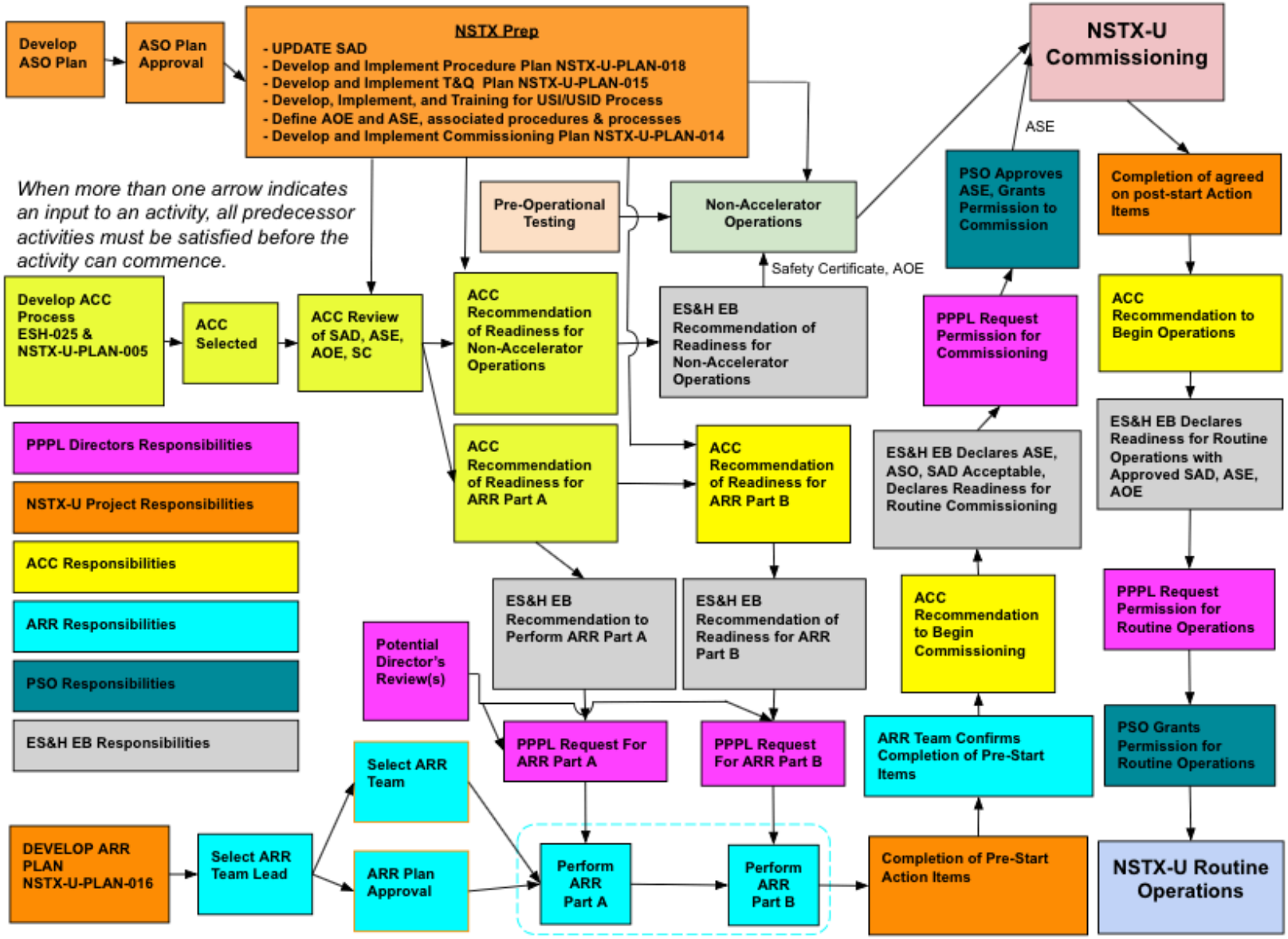
- If you:
  - Are making a change to the facility that may impact safety
  - Discover a condition in the facility that adversely impacts safety
- The USI process provides a structured means to:
  - Document the proposed change or "as-found condition"
  - Assess the implications against the existing hazard analysis
  - Make change/updates to hazard analysis & ASE, modify the proposed change, or remediate the as-found conditions
- Training to follow…USI process implemented via ESH-025 and D-NSTX-OP-AD-131.

accelerator readiness review (ARR) program

"an **accelerator readiness review (ARR) program** that ensures facilities are adequately prepared for safe commissioning and/or operations"

- Team of external experts
- Comprehensive look at all processes and procedures used to run the experiment
  - Conduct of operations,
  - Training and qualifications,
  - Configuration management,
  - Work control
  - Operations, maintenance, testing, & emergency response procedures,…
- Heavy field-observations…not a paper study.
- We are envisioning a two-part ARR process
  - the committee would convene twice, with charges addressing different aspects of the facility operations.

Draft Flow Chart for ASO Implementation



Summary

- Project is making pace through the required cycle of reviews
- Project is working towards the implementation of the accelerator safety order
- See presentation by Russ Feder for how this technical progress fits in a Project context.

National Spherical Torus eXperiment Upgrade

NSTX-U Team Meeting

Recovery Project Update

Russell Feder

April 27, 2018

Focus on CDE-2/3A

1. **CDE-1 ESAAB-E Meeting Scheduled for Late June**
    1. **This is good!!** → Due to successful Feb and March OPA Reviews
    2. PPEP Re-Draft in Progress
    3. Steve Binkley PME and new IPT leader Ethan Merrill

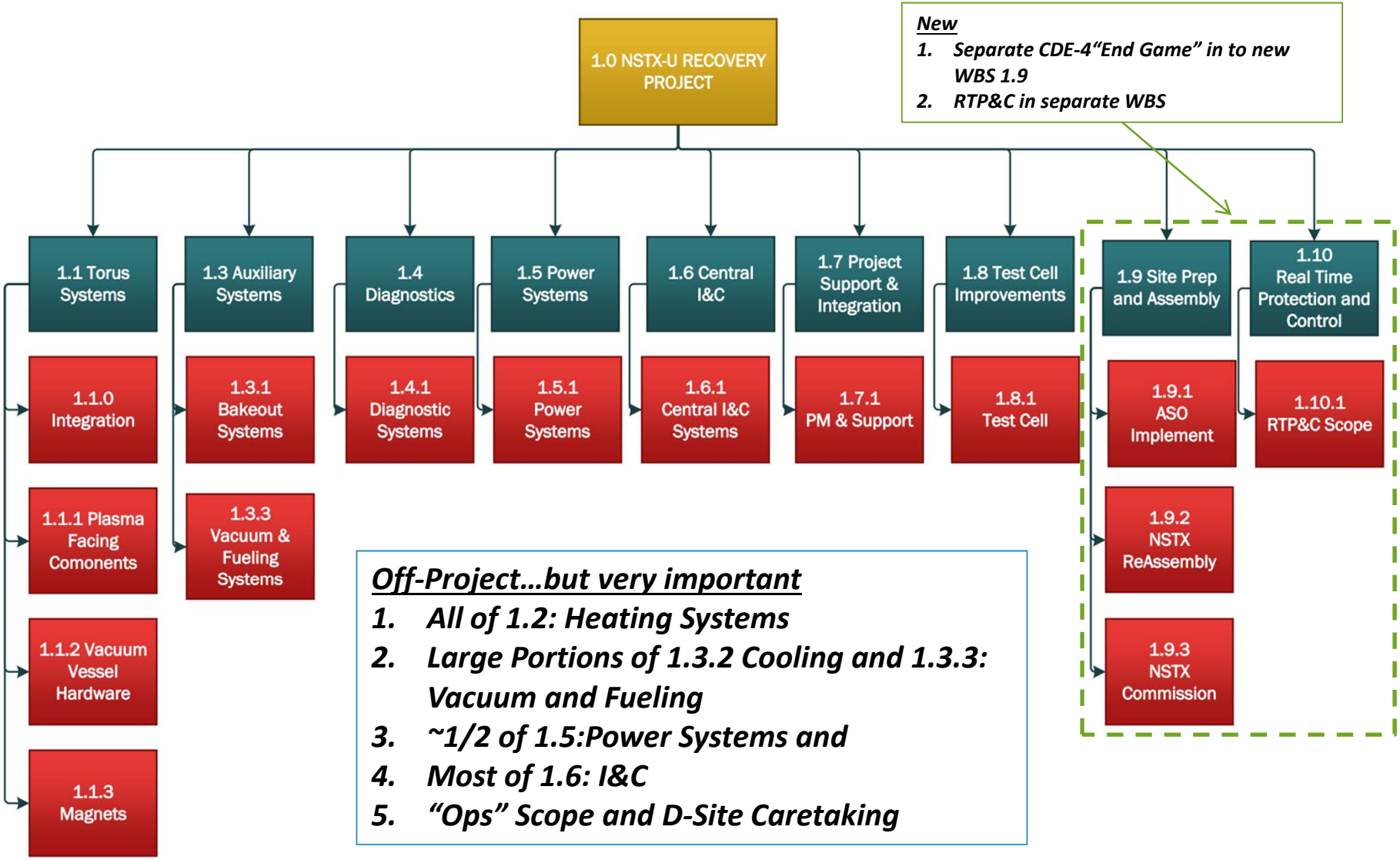
2. **Working through WAF Updates, PDRs and FDRs for CDE-2 and CDE-3A**
    1. Director's Review and mini-ICE in late August → CDE-2 Dress Rehearsal
    2. OPA CDE-2/3A ~ 6-8 weeks later

3. **Working to lock in remaining uncertainty in Recovery Project scope**
    1. Passive Plates
    2. Metrology, Machine Re-Assembly and TF/OH Alignment
    3. ASO Implementation
        1. Scott Davis new ASO implementation consultant
    4. Accounting for project impacts from
        1. ICAP, QAPD
        2. Resource Leveling and staff performance

FY18 PEMP Notable Status

PEMP Objective		Key Event	Late Finish	4/26/18 Status
Goal 2.0 - Design, Fabrication, Construction and Operation of Research Facilities				
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	ETI and PPPL will start VPI in early May. Tesla and SigmaPhi are 2-3 weeks behind that. PPPL staff preparing machine shop and high-voltage test areas for PT coil evaliuation.
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	Peer review in early May, PDR by mid to late July.
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 8/16. Mobilizing additional ME resources from subcontractors and ORNL
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	Coordinating with ICE, DR Panel and key PPPL staff to lock in review planning

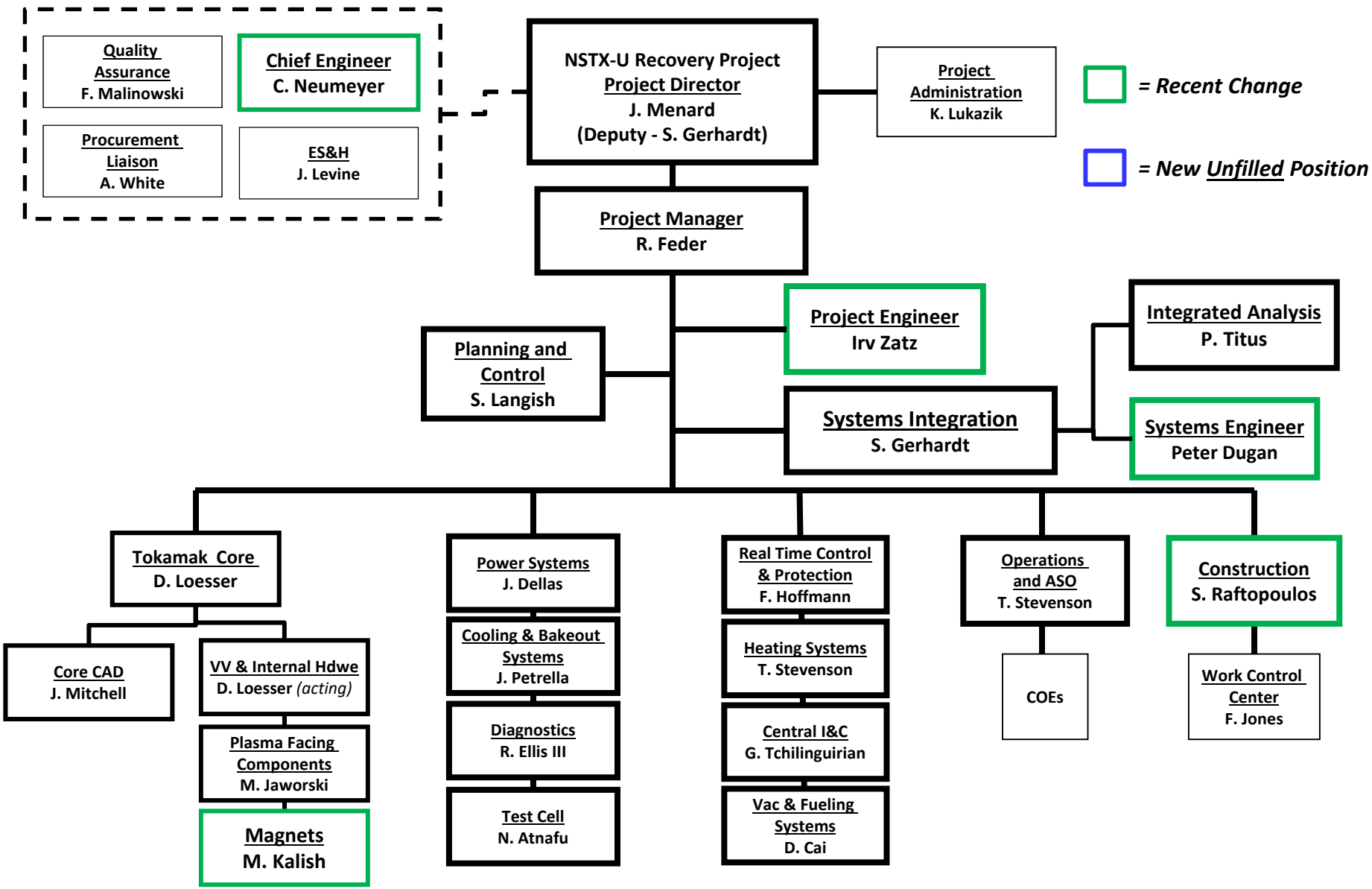
Recovery Project WBS



Off-Project…but very important

1. *All of 1.2: Heating Systems*
2. *Large Portions of 1.3.2 Cooling and 1.3.3: Vacuum and Fueling*
3. *~1/2 of 1.5:Power Systems and*
4. *Most of 1.6: I&C*
5. *"Ops" Scope and D-Site Caretaking*

Recovery Project Org Chart Updates



Building a team for success

1. **Mechanical Engineering**
   A. Building to ~40 FTEs of ME Design, Analysis and Project Engineering staff
   B. Subcontractors
   C. ORNL Engineering
   D. Physics staff acting in engineering roles (Gerhardt, Jaworski)
2. **Project Staff**
   A. Communications Specialist
   B. Project Management Assistant(s)
   C. Office Admin Assistant (*need to be careful of VSP rules*)
3. **ASO Implementation Specialist**
4. **We need more help** from PPPL Staff → Do you want to step up?
   A. Mechanical Engineering tasks help
   B. Project Help
      i. CHIT tracking, sorting and disposition
      ii. Risk management
      iii. Other? *Let me or Jon know how you can help*

CDE-2 and CDE-3A Design Reviews

WBS and Review	Schedule
1.1.1.1 Low Heat Flux PFCs	9/28/2017
1.1.1.1 High Heat Flux PFCs	11/15/2017
1.1.2.4 Cooling Tubes	11/30/2017
1.1.3.1 Inner PF Coils	12/14/2017
PF1A Conductor Size Peer Review	12/19/2017
Turn-to-Turn Testing Peer Review	12/21/2017
Alignment I Peer Review	1/18/2018
Alignment II Peer Review	2/1/2018
1.5.1.3 PF1B Bipolar Circuit	2/27/2018
1.1.2.1 Polar Region - Inner PF Coil Supports	3/27/2018
1.8.1.1 NTC Shielding	4/10/2018
ASO WAF Review	**6/8/2018**
1.1.2.1 Polar Region - CS Casing/Flanges/O-Rings/Insulators/Supports	**6/21/2018**
1.1.3.3 PF Bus Support	**7/10/2018**
1.1.2.2 Passive Plates + Helium Line Supports (PEMP NOTABLE)	**7/31/2018**
1.8.1.3 NSTXU Reassembly	**7/31/18**
1.1.0.1 Integration Scope	**8/1/18**

Required PDRs for CDE-2 (11 of 17)
→ Mandatory

WBS and Review	Schedule
1.1.3.1 Inner PF Coils	3/30/2018
CS Casing Trial Fit	5/17/18
1.5.1.3 PF1B Bipolar Circuit	**7/24/2018**
1.1.1 Plasma Facing Components	**8/16/18**
1.1.2.4 Cooling Tubes	**8/23/2018**

Planned FDRs for CDE-3A (2 of 5)
→ Strategic but Discretionary

CDE-2 and CDE-3A Design Reviews

CDE-3B PDRs (15 of 32)

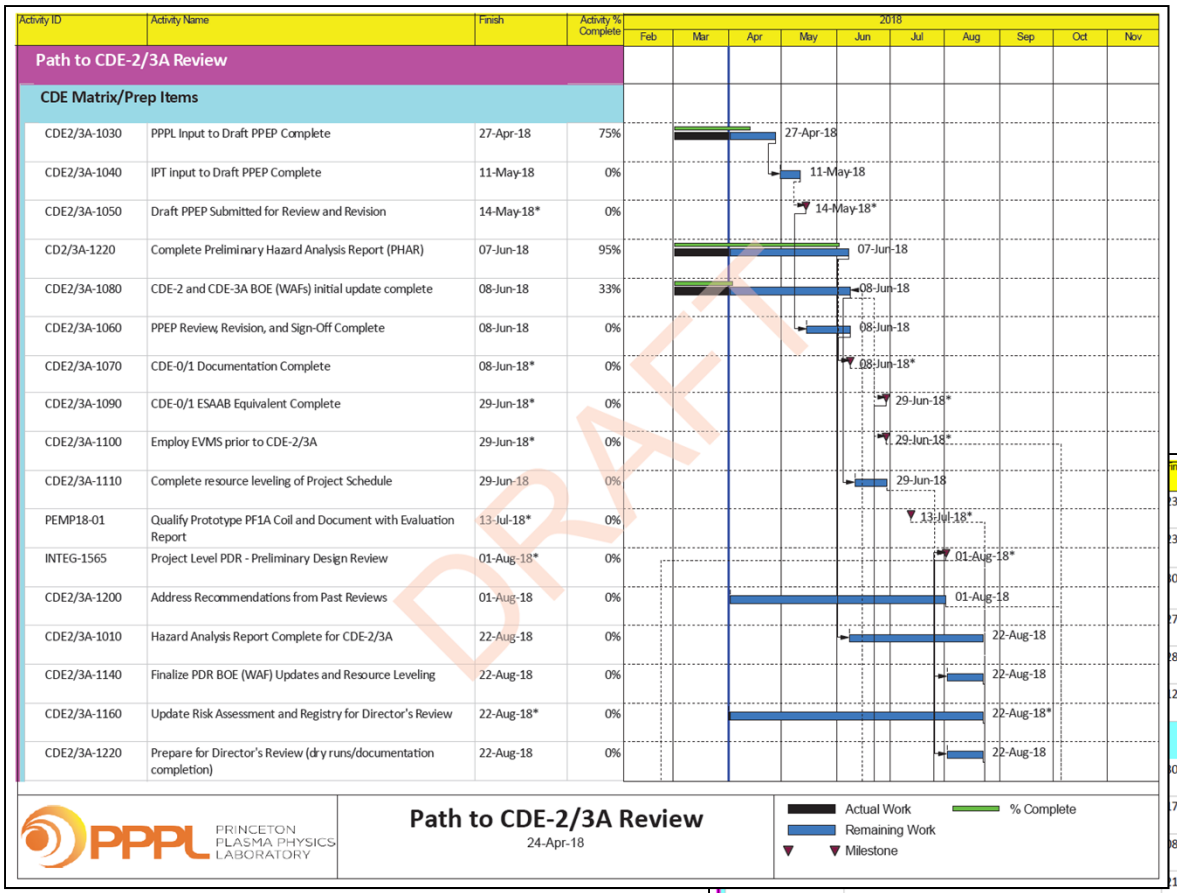
WBS and Review	Schedule	Actual
1.3.3.1 TVPS Backing Pump	9/29/2017	9/29/2017
1.6.1.4 Fiber Optic Networking	10/26/2017	10/26/2017
1.3.1.1 Helium Bake System - Feedthrough Re-Design	12/1/2017	12/1/2017
1.3.3.3 Interspace Pumping	12/20/2017	12/20/2017
1.4.1.2 PFC Diagnostics	1/4/2018	1/4/2018
1.3.1.1 Helium Bake System - Gas Piping	1/11/2018	1/11/2018
1.3.1.2 exVessel Heating System	2/1/2018	2/1/2018
1.6.1.1 CAMAC Replacment Plan - Phase 1 + 2	2/16/2018	2/16/2018
1.1.3.4 Magnet RP Scope - M6-2 Modify Cooling Water System	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	4/3/18	4/3/18
1.3.1.5 DC Current to Top NSTXU	4/5/2018	4/5/2018
1.3.3.2 Startup Tasks - GDC Anode	4/12/2018	4/12/2018
1.1.2.3 VVHW Field Scope - Part II		
1.8.1.2 NTC O2 Monitor		
1.4.1.3 Aerodag Replacment		
1.3.1.4 Bakeout PLC Upgrade	5/10/18	
1.6.1.4 Fiber Optic Networking		
1.4.1.7 BES Shutter		
1.8.1.3 NTC Door Rad Monitor		
1.7.2.1 Turn-to-Turn Fault Monitoring		
1.5.1.1 Power Sys Maint/Repair - Partial Discharge Monitoring		
1.7.2.1 PCS Enhancements		
1.6.1.1 CAMAC Replacment Plan - Phase 3		
1.7.2.2 RTPC Spares - FIMM-2		
1.3.2.2 I&C for CWS (not recovery scope)	10/18/2018	
1.3.3.5 Private Flux Region Fuelling	10/11/2018	
1.6.1.1 CAMAC Replacment Plan - Phase 1 + 2		
1.7.2.2 RTPC Spares - DITS-2		
1.3.3.2 Burst DIsk (not recovery scope)	5/29/18	

- ***Need to sort through all of this one more time to calibrate with latest Recovery Project vs. Ops Sort***

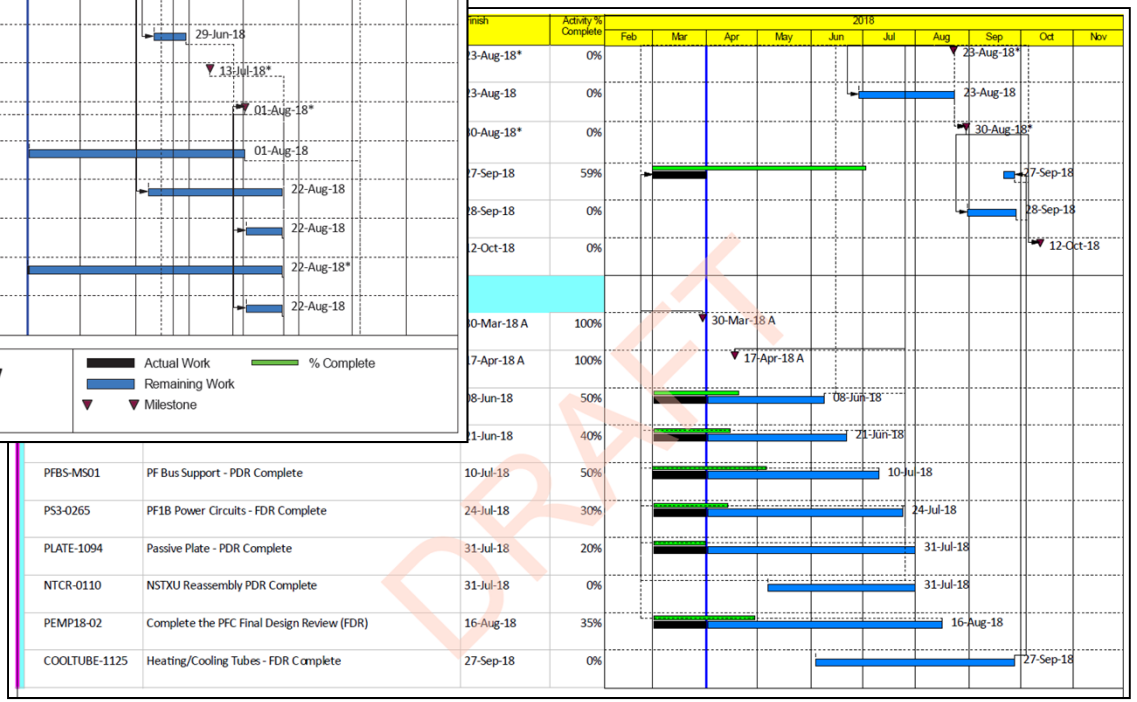
CDE-3B FDRs (4 of 35)

WBS and Review	Schedule	Actual
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
1.1.2.2 Passive Plates + Helium Line Supports	7/26/2018	
1.8.1.1 NTC Shielding	7/31/2018	
1.1.2.1 Polar Region - Inner PF Coil Supports	**9/21/2018**	
1.1.2.1 Polar Region - CS Casing/Flanges/O-Rings/Insulators/Supports		
1.1.3.3 PF Bus Support	*9/6/18*	
1.4.1.1 Vessel/Coil Instrumentation	9/20/18	
1.1.3.4 Magnet RP Scope - TF/OH Bundle Reliability M9-3,5,7,9	9/4/18	
1.6.1.3 EPICS Infra Upgrade	9/11/18	
1.3.1.1 Helium Bake System - Feedthrough Re-Design	9/13/18	
1.1.3.4 Magnet RP Scope - M9-1 Inspect Outer PF Coils/Repair	9/25/18	
1.3.3.3 Interspace Pumping	9/27/18	
1.1.2.3 VVHW Field Scope	10/2/18	
1.3.1.2 exVessel Heating System	10/4/18	
1.6.1.5 Network Segregation	10/15/18	
1.3.1.1 Helium Bake System - Gas Piping	11/1/18	
1.1.3.4 Magnet RP Scope - M6-2 Modify Cooling Water System (	11/6/18	
1.8.1.2 NTC O2 Monitor	11/8/2018	
1.8.1.3 NTC Door Rad Monitor	11/13/2018	
1.3.1.5 DC Current to Top NSTXU	11/15/18	
1.3.3.2 Startup Tasks - GDC Anode	11/27/18	
1.3.1.4 Bakeout PLC Upgrade	11/29/18	
1.7.2.1 Turn-to-Turn Fault Monitoring	12/4/18	
1.3.2.2 I&C for CWS	12/6/18	
1.5.1.1 Power Sys Maint/Repair - Partial Discharge Monitoring	12/11/18	
1.3.3.5 Private Flux Region Fuelling	12/13/2018	
1.8.1.3 NSTXU Reassembly	12/18/18	
1.1.0.1 Integration Scope	12/21/18	
1.7.2.2 RTPC Spares - TIMING MODULE	1/31/19	
1.1.3.5 Magnet RP Scope - M9-6 RWM Field Mods	2/1/19	
1.3.3.2 Startup Tasks - Ballast Tank Burst Disc	2/5/2019	
1.3.3.4 RGA data logging	2/12/19	

CDE-2/3A Roadmap



Activity ID	Activity Name	Finish	Activity % Complete
Path to CDE-2/3A Review			
CDE Matrix/Prep Items			
CDE2/3A-1030	PPPL Input to Draft PPEP Complete	27-Apr-18	75%
CDE2/3A-1040	IPT Input to Draft PPEP Complete	11-May-18	0%
CDE2/3A-1050	Draft PPEP Submitted for Review and Revision	14-May-18*	0%
CD2/3A-1220	Complete Preliminary Hazard Analysis Report (PHAR)	07-Jun-18	95%
CDE2/3A-1080	CDE-2 and CDE-3A BOE (WAFs) initial update complete	08-Jun-18	33%
CDE2/3A-1060	PPEP Review, Revision, and Sign-Off Complete	08-Jun-18	0%
CDE2/3A-1070	CDE-0/1 Documentation Complete	08-Jun-18*	0%
CDE2/3A-1090	CDE-0/1 ESAAB Equivalent Complete	29-Jun-18*	0%
CDE2/3A-1100	Employ EVMS prior to CDE-2/3A	29-Jun-18*	0%
CDE2/3A-1110	Complete resource leveling of Project Schedule	29-Jun-18	0%
PEMP18-01	Qualify Prototype PF1A Coil and Document with Evaluation Report	13-Jul-18*	0%
INTEG-1565	Project Level PDR - Preliminary Design Review	01-Aug-18*	0%
CDE2/3A-1200	Address Recommendations from Past Reviews	01-Aug-18	0%
CDE2/3A-1010	Hazard Analysis Report Complete for CDE-2/3A	22-Aug-18	0%
CDE2/3A-1140	Finalize PDR BOE (WAF) Updates and Resource Leveling	22-Aug-18	0%
CDE2/3A-1160	Update Risk Assessment and Registry for Director's Review	22-Aug-18*	0%
CDE2/3A-1220	Prepare for Director's Review (dry runs/documentation completion)	22-Aug-18	0%

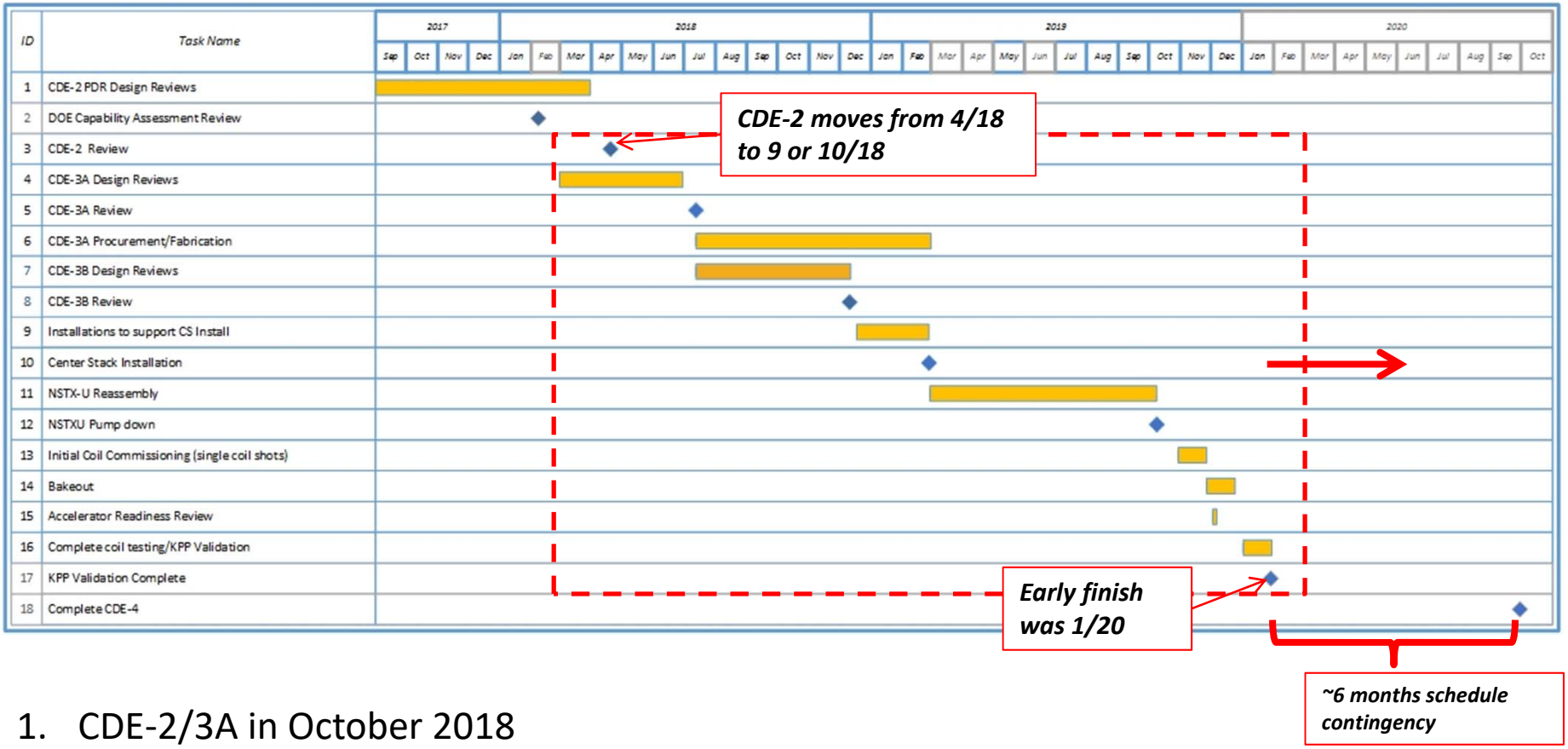


PFBS-MS01	PF Bus Support - PDR Complete	10-Jul-18	50%
PS3-0265	PF1B Power Circuits - FDR Complete	24-Jul-18	30%
PLATE-1094	Passive Plate - PDR Complete	31-Jul-18	20%
NTCR-0110	NSTXU Reassembly PDR Complete	31-Jul-18	0%
PEMP18-02	Complete the PFC Final Design Review (FDR)	16-Aug-18	35%
COOLTUBE-1125	Heating/Cooling Tubes - FDR Complete	27-Sep-18	0%

- See PDF file for closer look

CDE-4 Schedule is Under Construction

This was the plan at the end of 2017 calendar year



1. CDE-2/3A in October 2018
2. CDE-4 is very much dependent on how many FDRs we can squeeze into CDE-3A → Polar Region FDR is currently the critical path

Thank you for all your hard work!

- NSTX-U Recovery project is on track to enhance NSTX-U reliability and safety and provide the highest performance ST device as a robust user facility.
- Important progress is being made in all key technical areas
- Project plans for CDE-2/3A and beyond are being finalized through a strong partnership with FES

Members of the NSTX-U Recovery project team

EXTRA SLIDES

Main Project Assumptions

- The NSTX-U Recovery Project will follow a project management process equivalent to that of DOE Order 413.3B, “Program and Project Management for the Acquisition of Capital Assets”
- The NSTX-U Recovery Project and subsequent facility operations will follow DOE Order 420.2C, “Safety of Accelerator Facilities”.
- Recovery Project funding will be made available by DOE Fusion Energy Sciences through Operations funding in accordance with the profile which forms the basis for the baseline resource loaded schedule, as presented in the Project Execution Plan.
- There will be no changes to PPPL funding or programs that would have a major impact on the overhead rates upon which the baseline is based.
- Funding for maintenance, spares, facility caretaking and start-up, energy, consumables, and routine operations support costs will be made available by DOE Fusion Energy Sciences through Operations funding outside of the Recovery Project.

Sorting Scope Between Recovery and Ops/Maintenance/Caretaking

Recovery Project scope includes the following:

1. Direct specific support of a KPP, namely:
    1. New scope that if not completed would prevent completion of a KPP
    2. Redesigned components that if not completed would prevent completion of a KPP
2. Items integrated within the tokamak core and would require significant disassembly
    1. Anything inside the center-stack assembly and/or that requires toroidal field coil flex-link disassembly inside the umbrella structure(s)
    2. Items subject to electromagnetic loads – both static and dynamic including plasma disruptions
    3. Magnets
    4. Items associated with the bake-out system located directly on the NSTX-U tokamak core
3. Replacement of highly integrated core-tokamak components with severe design deficiencies as identified during the Design Verification and Validation Reviews (DVVRs) carried out as part of the 2017 NSTX-U Extent of Condition reviews.
4. Engineered Safety Systems identified during DVVRs
5. Accelerator Safety Order (ASO) implementation and activities directly supporting Accelerator Readiness Review(s) (ARR)
6. Non-maintenance activities that precede achievement of Recovery scope supporting KPPs (e.g. in-vessel diagnostics that must be installed before pump-down preceding the bake-out KPP)
7. Recovery Project management
8. Site-Preparation (e.g. test-cell shielding)

CDE-2/3A Roadmap: Project Planning Steps

CDE Matrix/Prep Items	Activity	Due	% Complete
CDE2/3A-1030	PPPL Input to Draft PPEP Complete	27-Apr-18	75%
CDE2/3A-1040	IPT input to Draft PPEP Complete	11-May-18	0%
CDE2/3A-1050	Draft PPEP Submitted for Review and Revision *Next Bi-Weekly Status*	14-May-18	0%
CD2/3A-1220	Complete Preliminary Hazard Analysis Report (PHAR)	7-Jun-18	95%
CDE2/3A-1080	CDE-2 and CDE-3A BOE (WAFs) initial update complete *1-month PPEP sign-off buffer*	8-Jun-18	33%
CDE2/3A-1060	PPEP Review, Revision, and Sign-Off Complete	8-Jun-18	0%
CDE2/3A-1070	CDE-0/1 Documentation Complete	08-Jun-18	0%
CDE2/3A-1090	CDE-0/1 ESAAB Equivalent Complete	29-Jun-18	0%
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CDE2/3A-1110	Complete resource leveling of Project Schedule	29-Jun-18	0%
PEMP18-01	Qualify Prototype PF1A Coil and Document with Evaluation Report *PEMP*	13-Jul-18	0%
INTEG-1565	Project Level PDR - Preliminary Design Review	01-Aug-18	0%
CDE2/3A-1200	Address Recommendations from Past Reviews	1-Aug-18	0%
CDE2/3A-1010	Hazard Analysis Report Complete for CDE-2/3A	22-Aug-18	0%
CDE2/3A-1140	Finalize PDR BOE (WAF) Updates and Resource Leveling	22-Aug-18	0%
CDE2/3A-1160	Update Risk Assessment and Registry for Director's Review	22-Aug-18	0%
CDE2/3A-1220	Prepare for Director's Review (dry runs/documentation completion)	22-Aug-18	0%
CDE2/3A-1170	All other documents required for CDE-2/3A complete	23-Aug-18	0%
CDE2/3A-1000	PEP Ready for CD-2/3A IPR	23-Aug-18	0%
CDE2/3A-1180	Director's Review for Baseline Validation - CDE-2/3A Prep and ICE Review *PEMP*	30-Aug-18	0%
RPMS-01	PDRs and FDRs to for CDE-2/3A complete	27-Sep-18	59%
CDE2/3A-1190	Address recommendations from Director's and ICE Review	28-Sep-18	
CDE2/3A-1210	Baseline Validation Review - CDE-2/3A and Long-lead procurements	12-Oct-18	

Needs some additional planning

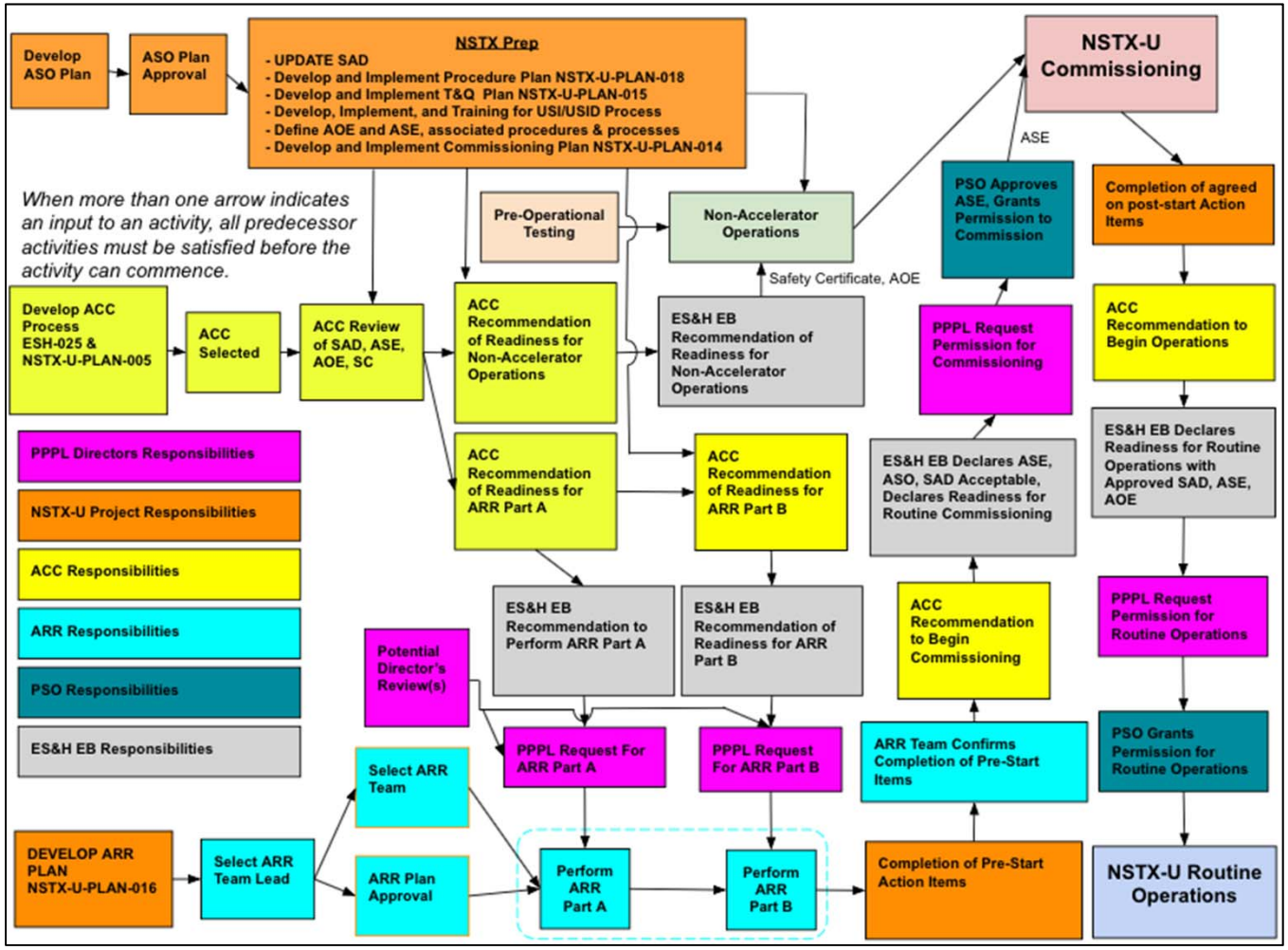
CDE-2/3A Roadmap: Key Reviews Progress

- Complete all BOE Updates and PDRs essential for Director's Review and CDE-2 approval
- Complete FDRs that are essential for CDE-3A approval

PDR/FDR/WAF Reviews				
MAGS-11770	Inner PF Coil FDR Complete	*PEMP Notable*	30-Mar-18	100%
POLAR-5221	CS Casing Trial Fit FDR		17-Apr-18	100%
ASO-001	ASO Implementation WAF Review		8-Jun-18	50%
POLAR-11335	Polar Region - PDR 2 Complete		21-Jun-18	40%
PFBS-MS01	PF Bus Support - PDR Complete		10-Jul-18	50%
PS3-0265	PF1B Power Circuits - FDR Complete		24-Jul-18	30%
PLATE-1094	Passive Plate - PDR Complete	*PEMP Notable*	31-Jul-18	20%
NTCR-0110	NSTXU Reassembly PDR Complete		31-Jul-18	0%
PEMP18-02	Complete the PFC Final Design Review (FDR)	*PEMP Notable*	16-Aug-18	35%
COOLTUBE-1125	Heating/Cooling Tubes - FDR Complete		27-Sep-18	0%

ASO Implementation

- ***Scott Davis under contract as ASO advisor, successful initial visit April 17-19***
- ***Draft ASO Implementation Plan shared with IPT and PSO 4/26***
- ***ASO cost and schedule estimate update, based on flow chart, underway (complete no later than June 8)***
- ***Working on new hire for ASO Implementation Specialist***



Five ASO Requirements

1. Approved Accelerator Safety Envelope (ASE)
2. Safety Assessment Document (SAD)
3. Clearly defined R2A2s
4. Unreviewed Safety Issue (USI) process
5. Accelerator Readiness Review (ARR) program