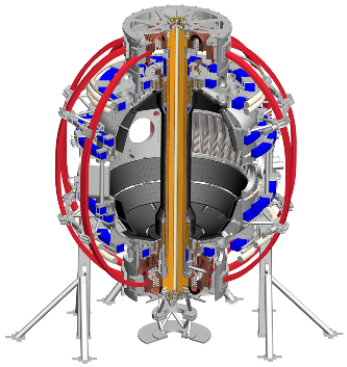
Highlights from DVVRs & Recent Recovery Project Engineering Activities

S.P. Gerhardt, R. Hawryluk and C. Neumeyer

NSTX-U Team Meeting
3/22/2017
MBG Auditorium



Outline

- Introduction (R. Hawryluk)
- DVVR Process (S. Gerhardt)
- Key DVVR Findings (S. Gerhardt)
- Overview of the Correction Action Plan and Extent of Condition Process (R. Hawryluk)
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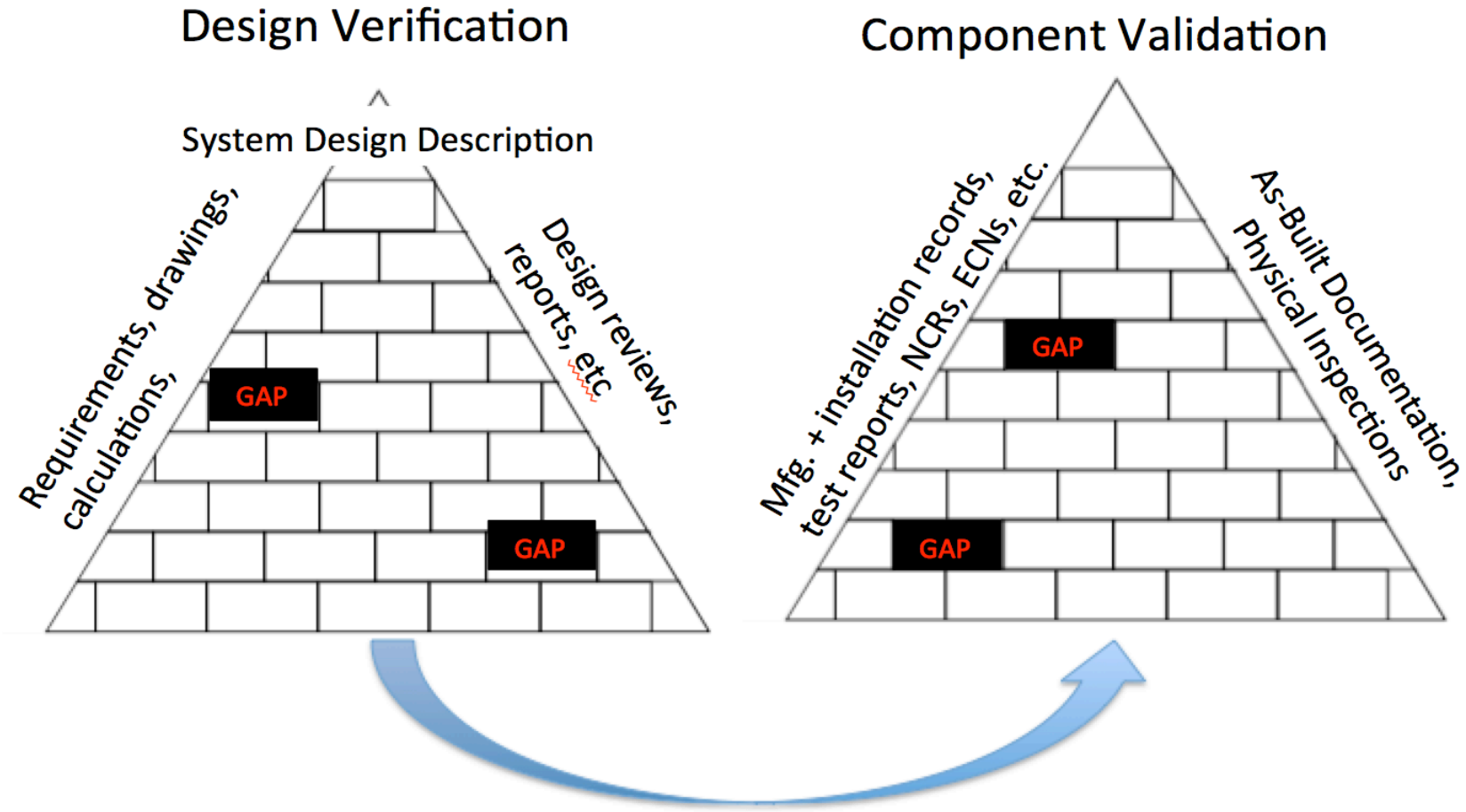
DOE Notable Outcomes Have Been the Near-term Focus

- *EXTENT OF CONDITION*
  - *FES: Complete an extensive extent-of-condition review of NSTX-U* ***to identify all design, construction, and operational issues. Prepare correction action plan (CAP) to include cost, schedule, scope, and technical specifications of actions****. Provide an interim progress report by March 31, 2017 and complete the CAP review and send the final report to DOE by September 30, 2017.*
- *EXTENT OF CAUSE*
  - *SC/PSO: Conduct a review of policies and procedures for design, construction, installation, commissioning and operations of NSTX-U and other construction activities and projects. Develop corrective actions to ensure the highest quality project management across the lab.*

Design Verification & Validation Review System Design Description (SDD) is Key



- DVVR looks for potential gaps in design basis or as-built configuration developed by Responsible Engineers
- Corrective Action Plan (CAP), derived from the DVVRs, determines path forward

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Practical Understanding of a DVVR

- Described in NSTX-U-GUIDE-001-01
- External and internal reviewers
  - External reviewers have been hugely valuable
- Review system to assess the suitability for use.
  - Look for issues in design, fabrication, installation, testing, operations.
- Examine (for instance):
  - Guiding requirements
  - The design + supporting analysis
  - Fabrication & test records and issues
  - Installation and operations records and issues
- When a "gap" or issue is potentially identified, it is recorded as a electronic chit.
- *All with a view of ensuring high reliability of NSTX-U of NSTX-U operations over the full parameter range.*

We have had 8 DVVRs to Date

	Date	# of Days	Responsible Engineer	# of Chits	Included in Interim CAP
Central I&C	1/18	1.5	Tchilinguirian	72	Yes
Integrated Design	1/24	1	Neumeyer	82	Yes
Heating Systems	1/30	2	Stevenson	98	Yes
Magnets	2/7	4	Raftopoulos	185	Yes
Vacuum Vessel and Internal Hardware	2/14	3	Sibilia	220	Yes
Cooling Systems	2/22	1	Atnafu	72	No
Power Systems	2/27	1.5	Dellas	84	No
Interim EoC Committee, 3.5 days					
Test Cell	3/16	1	Perry	25	No

This Presentation: Highest of Highlights

Total: ~920

You Have Access to All this Information!

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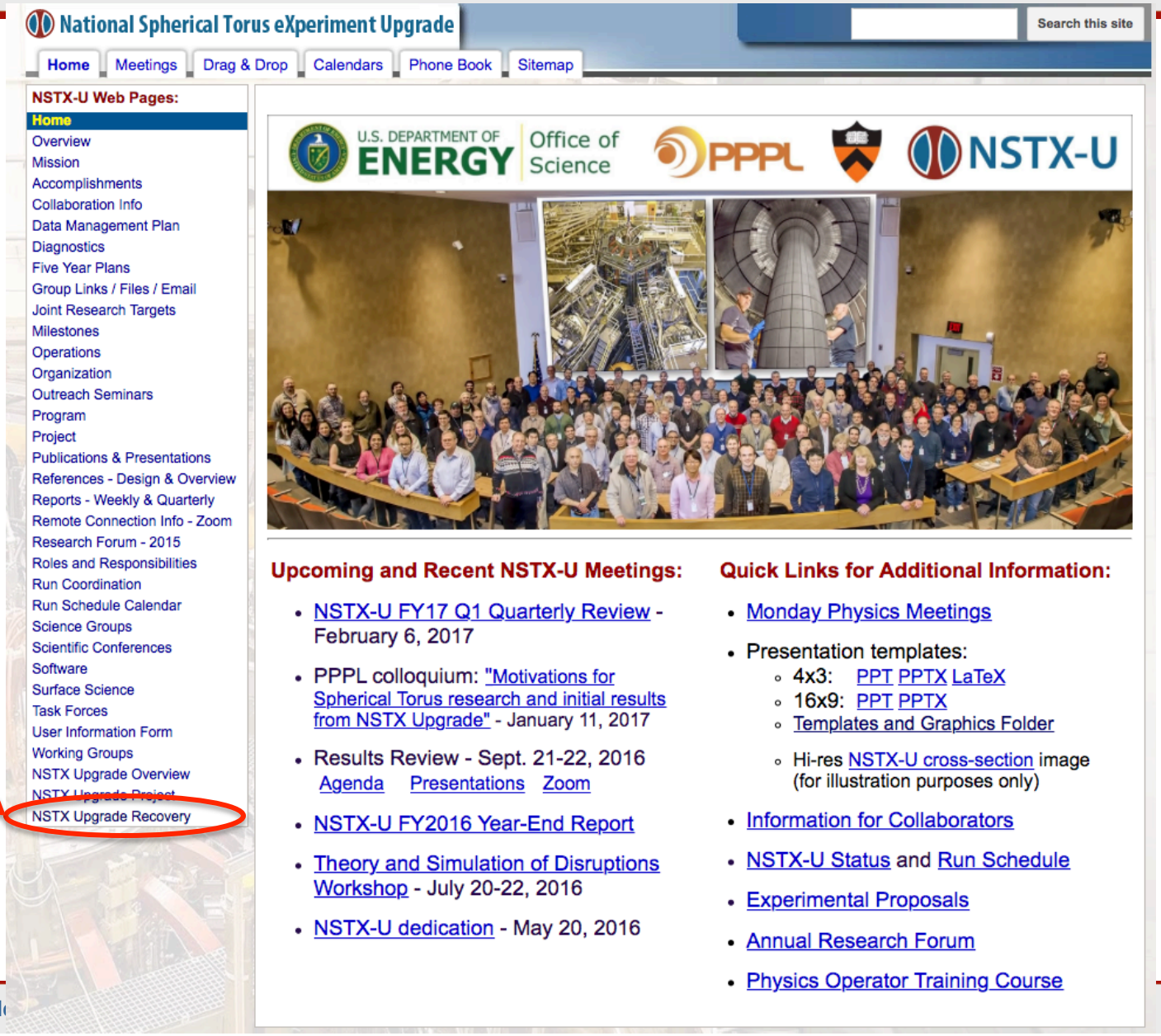

NSTXU Recovery Home Page

Everything About the Recovery Project

GENERAL

- ORGANIZATION CHART
- WBS/OBS
- NSTXU ENGINEERING MEETING FOLDER
- NSTXU DESIGN REVIEW MATRIX
- MISCELLANEOUS FOLDER
- NSTXU ENGINEERING GOOGLE DRIVE TOP LEVEL
- CONTROLLED DOCUMENTS
- CALCULATIONS
- DRAWINGS
- SYSTEM DESIGN DESCRIPTION TEMPLATE
- CURRENT ISSUES LOG
- MANAGEMENT ACTION ITEM LIST
- QA DATABASE
- NSTXU RECOVERY PROJECT REVIEW PLANNING
- NSTXU DOCUMENT GATHERING REPOSITORY
- NSTXU QA PLAN
- PLAN FOR ADDRESSING FY17 NOTABLE OUTCOME: EXTENT OF CONDITION
- REQUIREMENTS
  - NSTXU CS GENERAL REQUIREMENTS
  - NSTXU NB REQUIREMENTS
- FAULT REPORTS
  - ARC FAULT
  - PF1A FLEX BUS
  - PF1AU FORENSIC ANALYSIS
  - OH FAULT EXTENT OF CONDITION
- DVVR/EOC REVIEW INFORMATION
  - DVVR-EOC REVIEW GUIDE
  - DVVR TEMPLATE
  - DVVR CHIT FORM
  - DVVR AND EOC REVIEW SCHEDULE
  - EXTENT OF CONDITION REVIEW DASHBOARD

FILE ACCESS VIA WBS FOLDER (GOOGLE DRIVE)

- WBS 1.1 TORUS SYSTEMS
  - Systems Engineering and Integration - Neumeyer
  - Vacuum Vessel and Internal Hardware - Sibilia
    - Vacuum Vessel and Internal Hardware DVVR Dashboard
  - Magnet Systems- Raftopoulos
    - Magnet System DVVR Dashboard
    - PF1A PDR Dashboard
- WBS 1.2 PLASMA HEATING & CURRENT DRIVE SYSTEMS
  - Heating Systems-Stevenson
  - DVVR Dashboard
- WBS 1.3 AUXILIARY SYSTEMS
  - Bakeout System- Petrella
  - Cooling Systems - Atnafu
    - Cooling System DVVR Dashboard
  - Vacuum Systems and Fueling- Blanchard
    - Vacuum and Fueling DVVR Dashboard
- WBS 1.4 PLASMA DIAGNOSTICS
  - Diagnostic Systems- Ellis
- WBS 1.5 POWER SYSTEMS
  - Power Systems- Dellas
    - Power Systems DVVR Dashboard
  - Real Time Control & Protection - Hoffmann
- WBS 1.6 CENTRAL I&C
  - Central I&C - Tchilinguirian
- WBS 1.7 PROJECT SUPPORT AND INTEGRATION
  - Operations - von Halle
- WBS 1.8 SITE PREPARATION AND ASSEMBLY
  - NSTXU Test Cell - Perry
  - DVVR Dashboard

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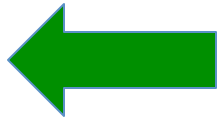

Findings: Central I&C

- Many issues of hardware obsolescence
  - –CAMAC in the data acquisition and clock
  - –Numerous older computers
- Need to incorporate more rigorous modern version & configuration control methods across the breadth of I&C software.
- Need to develop reliable bare metal restore capability for computers that operations relies on.

Heating Systems (NBI)

- Need to assemble more ion sources
  - And a new source isolation valve for 1A
- Needs to improve spare situation
  - Source isolation valves, autotransformers, grid modules, TIV, source Langmuir probes,…
- Refrigerator is a single point of failure for the full NB system
  - Should procure spare heat exchanger assembles, turbine controller.
- Recommendation to reconstitute species mix spectroscopic diagnostic

Heating Systems (HHFW+ECH)

- Numerous issues with availability of spares
  - Especially on RF sources 1 & 2: HVPS, FPA, LPAs, etc.
- RF PLC is very antiquated
- ECH-PI
  - Need to look at system refurbishment.
  - Is an 18 GHz system…assess if the frequency needs to change.
- Assess suitability of the present RF antenna guards as the sole outboard limiter.

Magnets

- Three days of reviews + a peer review of new PF-1a design.
- A range of opinions from the assembled experts regarding the remaining inner PF coils
- Much discussion, for example:
  - role of the insulation system in the carrying the inner-TF torsional shear
  - Role of the mechanical properties of the glass-kapton-resin insulation systems on the OH.
  - Recommended additional calculations, tests, and instrumentation.
- Discussion of the legacy NSTX coils, with support for instrumentation to monitor health.

Vacuum Vessel

- Review committee questioned the reliability of 5 single O-rings at each of the top and bottom of the machine.
- Need to repair failed or improper components
  - Water leak on the beam armor heating/cooling lines
  - Damaged copper cooling tubes
  - Poorly sealed O-rings on the bellows flange
  - Inner horizontal target PFCs
- Reassess the design of the PF-1c can, which is a vacuum boundary, can draw plasma heat flux and halo currents.
- Ensure high temperature bakeout capability.
- Assess outboard divertor for upgrade thermo-mechanical and electro-mechanical loads.
- Many many analysis and inspection related chits.

Water Cooling Systems

- Many comments & chits on modernizing the legacy controls.
- Many comments & chits on potential single point failures and the need for spares.
- Comments on need to improve the water systems procedures and documentation.

Power Systems

- Reviewed modernizations:
  - Cycloconvertor controls, fault detectors, HCS, XST-1 & XST-2 transformers, underground 13.8 kV cables, DCCTs, various switchgear
- Reviewed maintenance & repairs:
  - Repair the cracked welds on MG#2, MG thrust bearings, MG stators
- Discussion of reducing PF-1a/b/c current ripple via in-line inductors
- Infamous SPA noise

NSTX-U Test Cell

- Facility related issues:
  - HVAC controls, compressed air system, leaking roof
- E-Stops & Hardwired Interlock System
  - Extended discussion on whether an e-stop during the pulse would damage FCPC hardware.
- Health physics & radiation
  - Warning lights linked to gamma/neutron detectors
  - Need to improve shielding at various penetrations/ doors.

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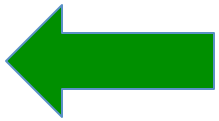

Issues Recorded as Chits

- Large number of chits were received to date
  - ~940 chits so far
- Very thoughtful chits enabling a comprehensive review of these systems
  - Thanks to PPPL staff and external reviewers

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Categorizing and Organizing the Chits

- Combined similar chits into an issue (super-chit)
  - Decrease duplication and provide clear tracking of all chits.
- System "Verification"
  - Design basis reviewed with respect to requirements in SDD
- Component "Validation"
  - Identified major components associated with issues
    - Example: Heating system: (EC, NBI: sources/beamlines, power train, cryogenics, HHFW: power train, in-vessel components
- Bin the issues into corrective action category
  - Examples: redesign and rebuild, analyze and test, maintenance/repair, modernize/replace, spares

Estimated Risk Reduction due to Corrective Action for **Each Issue**

System (OBS)	Issues	Applicable Chits	Affected Component	Issue to be Addressed (Event)	Unmitigated Event Duration	Unmitigated Event Impact	Unmitigated Event Likelihood
Magnets	Fabricate new PF1AU coil to replace failed coil	IPF1	PF1A-U	Coil has failed	Duration > 1 year	Dead Stop	Present State

Corrective action	CAP Category	Mitigated Residual Event Duration	Mitigated Residual Event Impact	Mitigated Residual Event Likelihood	Cost	Schedule	Proposed Action
Fabricate new PF1AU coil	Redesign and rebuild	Duration > 1 year	Dead Stop	Unlikely Event	$$	Y	Necessary for Start-Up

- The analysis is detailed in CAP spreadsheet.
  - Severity index is a qualitative assessment used as a guide.
    - Product of three variables representing the event duration, impact and likelihood, with a maximum value of 28665, weighted to emphasize major issues.
- The results are summarized in terms of CAP categories by component.

Status of Developing a Comprehensive Corrective Action Plan

- Current assessment is for the five systems that had a DVVR.
  - ~2 weeks since the end of the vacuum vessel DVVR and posting analysis, limiting the development of the CAP
- Seeking input from the Extent of Condition Review on whether corrective actions are: necessary for start-up, strongly recommended or recommended for start-up (integrated testing) or recommended future operations, investigate further or not endorsed.
- Actions have not been transformed into a detailed workplan.
- Output from this review will result in an interim report to FES to be submitted at the end of the month.

Panel Recommendations on Major Strategic Choices

- Panel strongly recommended replacing existing PF1 coils
  - Identified benefit of PF1B for flux expansion and operational flexibility
  - Benefit of deleting PF1B is 3-4 months schedule improvement, if CF(R)C tiles were not on the critical path and it reduces risk to the schedule
    - Tradeoff study for CFC vs graphite tiles recommended and is ongoing
- Recommended consideration of removable mandrels on PF1 coils to facilitate turn-to-turn acceptance testing
  - Note: we are exploring this on PF1B and PF1C for other reasons, but we are not pursuing this for PF1A.
  - We will respond to the input from the EOC review
- Retaining 300-350C bakeout strongly recommended
- Recommended "indefinite deferral" of CHI to allow modification and simplification of the end-flanges of the Vacuum Vessel to improve the reliability of the machine
  - Would eliminate ceramic insulator and a reduction/elimination of O-rings
  - Would reduce requirements on vacuum boundary around PF1C coil
  - Note: this is a new idea and cost and schedule implications are not yet understood

Subsequent Steps in Developing a Corrective Action Plan

- Need to complete the remaining DVVRs
- Need to categorize the new chits and address them
  - This provides the basis for developing a detailed workplan.
  - Focus of next EOC meeting
- Develop an agreed upon approach with FES
- Develop a detailed cost and schedule
  - Approach will enable a value engineering assessment to prioritize actions
  - Develop a re-commissioning plan leading to start of operations and qualification of the machine.

Reassigning Staff From DVVRs to Design

- Moving mechanical engineering staff to focus on the what are viewed as critical path activities
  - Increasing the staff assigned to work on magnets and vacuum vessel
- Developing WAFs with schedules and cost estimate
  - Resource loaded
- Aim to have a CDR in April to develop an integrated approach to the in-vessel and magnet issues.
  - Some options discussed in next part of this talk

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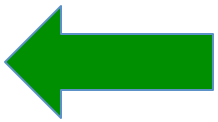
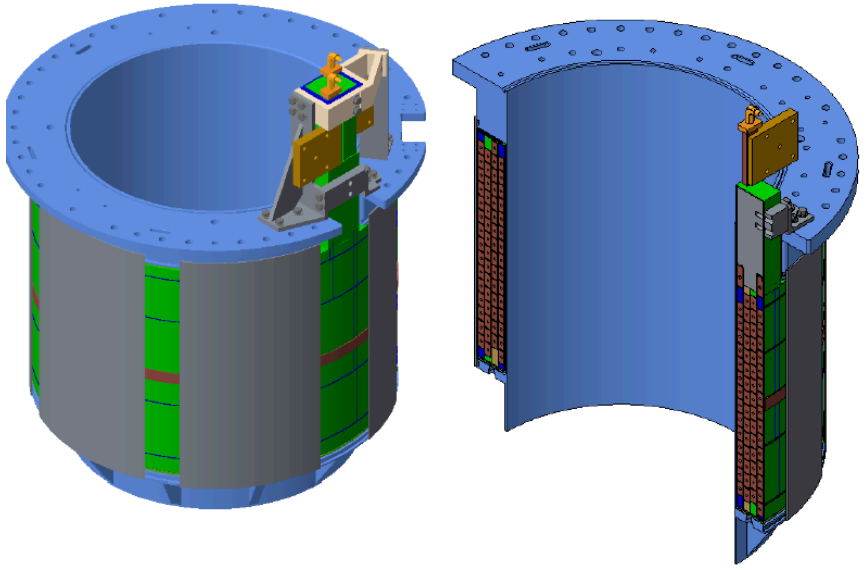
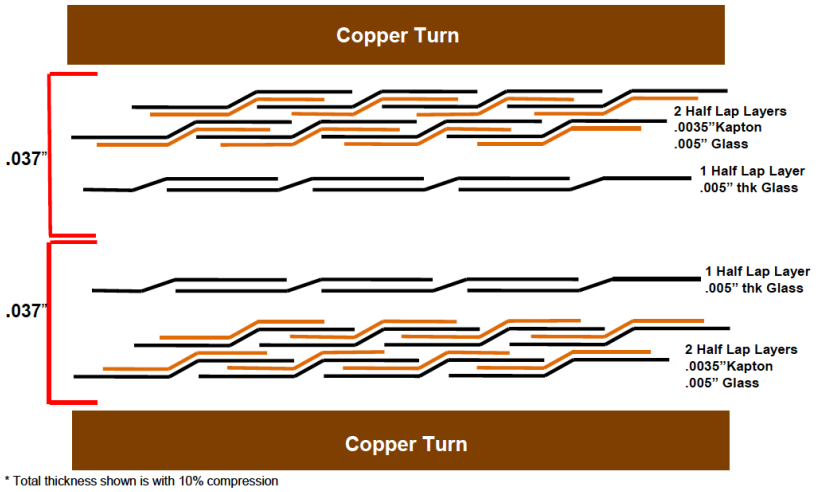


Preliminary Design Review for New PF-1a Coils Held on 3/17

- Three presentations:
  - Mechanical design
  - Electrical Insulation design and testing
  - Analysis
- Key design updates:
  - No joggles
  - More turn insulation compared to previous case
  - No in-line conductor brazes w/ softer copper
- Considerable discussion of thermal shock issues when cold water enters a hot coil.
  - Assessing the required I^2t for scenarios of interest.
- VPI cycles and manufacturing considerations not covered in this review and are planed for the next review.





We Have Been Examining Many Options For Coil Winding

- DoE National labs:
  - Extensive contacts, but no credible path forward established.
- Industry:
  - Pursuing many credible options, including in Europe
- PPPL:
  - Setting up a winding line in the C-site Test Cell

PPPL Winding Line is in the Shake-Down Phase

- On the verge of pulling some spare copper onto a mandrel as a test.
- Conductor is at vendor being grit blasted and primed.
- Intend to wind a prototype after:
  - Resolution of critical PDR chits.
  - Development of full manufacturing procedure & documentation system
  - Review of manufacturing.

4 DVVRs Yet to Complete

	Date	# of Days	Responsible Engineer
Vacuum and Fuelling	3/23/17	2	Blanchard
Bakeout	3/30/17	1	Petrella
Diagnostics	4/5/17	2	Ellis
Realtime Protection and Control	4/19/17	2	Hoffmann

Other Engineering Notes

- For those areas that have not yet had DVVRs, preparing for those DVVRs is the highest priority
- For others, key steps are refining cost/schedule via WAFs, then doing the work!
- A team of design and analysis engineers has been identified to resolve the outstanding conceptual design issues for the vessel:
  - How to thermally isolate the PF-1b coil while supporting the CS casing?
    - Casing support on large- or small-R side of coil?
  - How to define the vacuum boundary around the PF-1c?
    - Considering options that eliminate or retain the CHI insulators
  - What is the proper material and fixturing for the inner-target tiles?
    - And refining heat flux, halo current requirements.

NSTX-U Recovery is Moving Forward

- To ensure reliable and predictable operation in the future:
  - Addressing the issues comprehensively
  - Taking a deep dive into all systems
    - Applying a rigorous systems engineering approach.

- Thanks to those participating in the DVVRs and Extent of Condition Review

- A much better understanding of the issues that need to be addressed is being achieved.