NSTX-U

NSTX-U is sponsored by the
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Status and Plans for NSTX-U Recovery

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NSTX-U PAC-39
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B-318, PPPL

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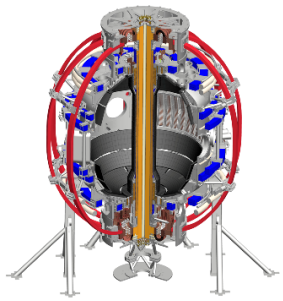
PPPL



Outline

- Overview of Recovery & Extent of Condition
- Technical Content and Impact of Recovery
- Extent of Cause Review & ASO

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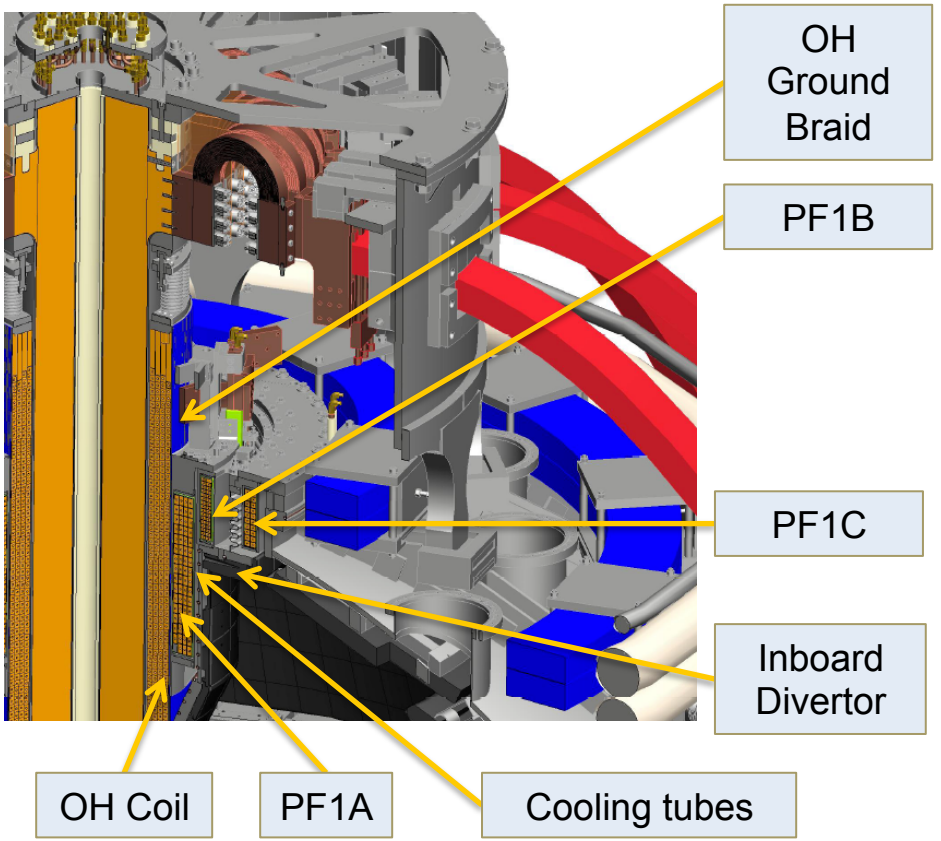
What is NSTX-U "Recovery"?

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



17 Reviews in FY2017 Enabled Us to Determine the Path Forward

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

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

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

→ 346 page report submitted: Recovery scope + CAP

Recommendations adopted after careful & in-depth deliberations between NSTX-U, EoC Committee, PU, & DoE

6 Major Scope Areas Define Recovery

Improved Reliability **Safety and Compliance**

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

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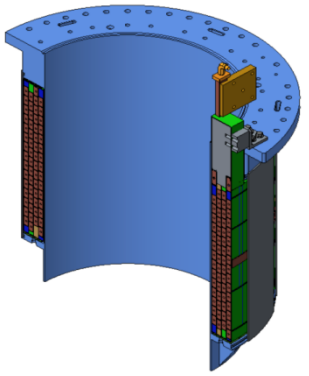
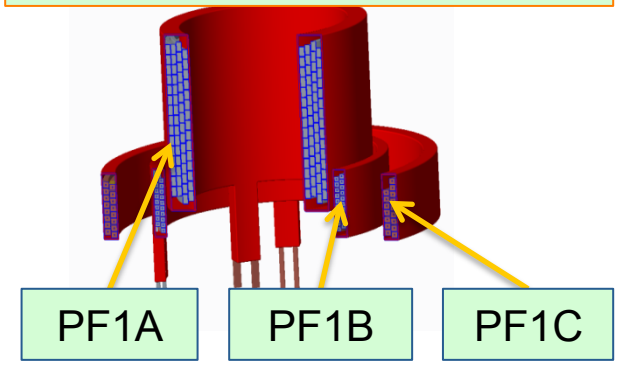
New Inner PF Coils
Designed to Improve Testability and Manufacturability

- EoCondition Recommendations
  - Retail all PF-1a/1b/1c coils
  - Use designs that facilitate turn-to-turn testing
- Previous coils fabricated on permanent mandrels
  - Advantages: Precision winding surface, VPI mold, intrinsic structural support
  - Disadvantages: mandrel is passive conductor
    - Impacts turn-to-turn acceptance tests
    - Deemed unacceptable during extent of condition review
- New coils: removable mandrels
  - Required new winding methods, tooling
  - Major schedule impact: had been intending to use permanent mandrels until mid-May 2017
- New coil design simplifies fabrication



Original PF1A Coil with Mandrel

Three Mandrel-Free Coils

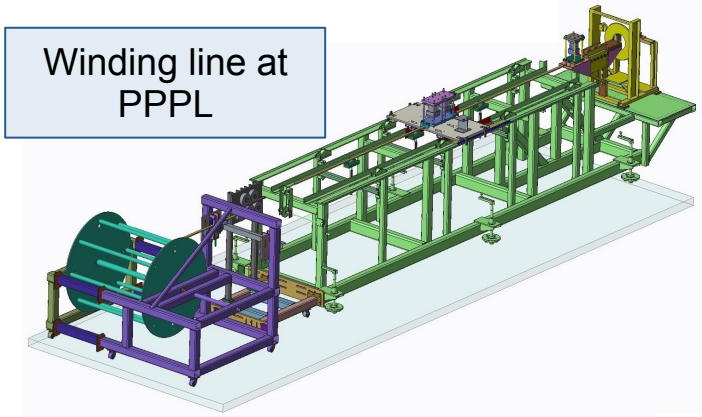


New Inner PF Coils
Fabrication Strategy Devised to Ensure Quality

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

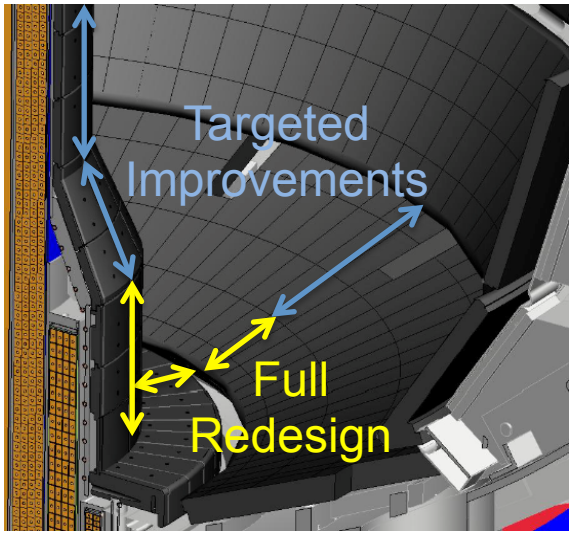
Portable Clean Room at PPPL

Winding line at PPPL



Improved PFC Designs

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



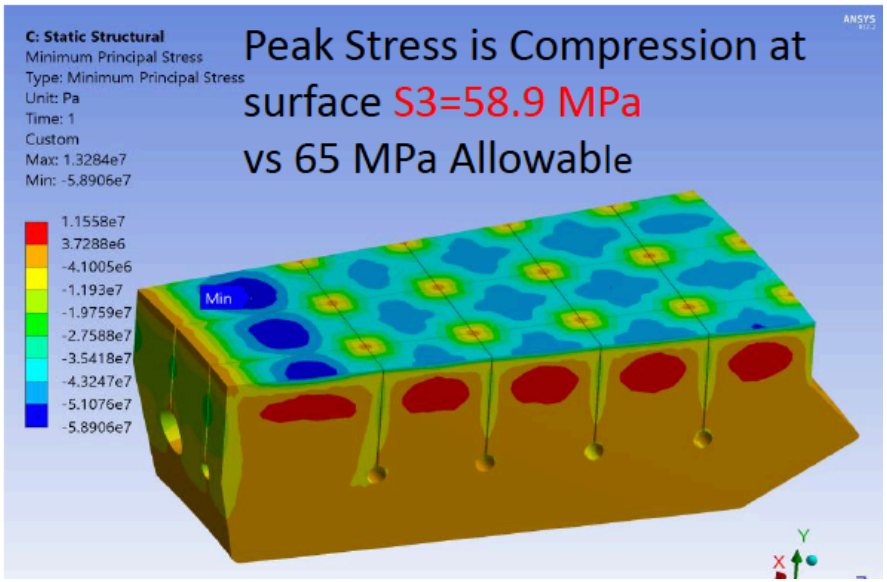
Path Forward

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

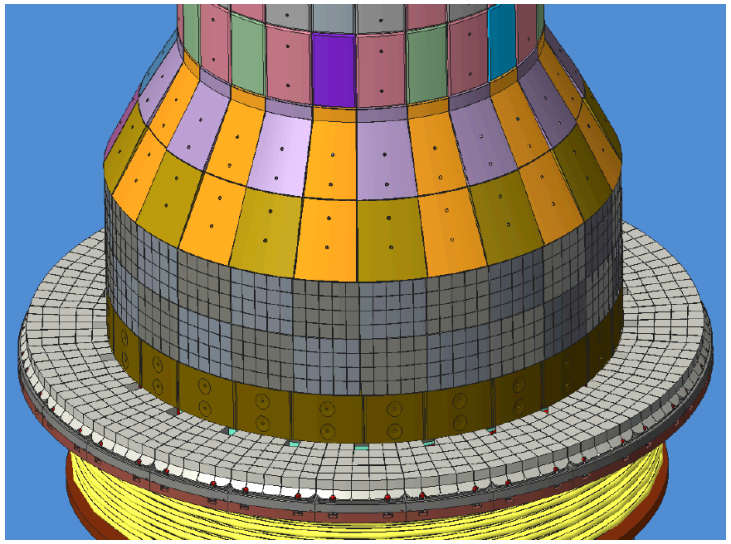
Castellated Tiles Maximize the Allowable Heat Flux

Castellations minimize the surface compressive stresses for a given surface temperature

End of pulse thermal stresses for a castellated tile



Deployment of castellated tiles on the inner targets

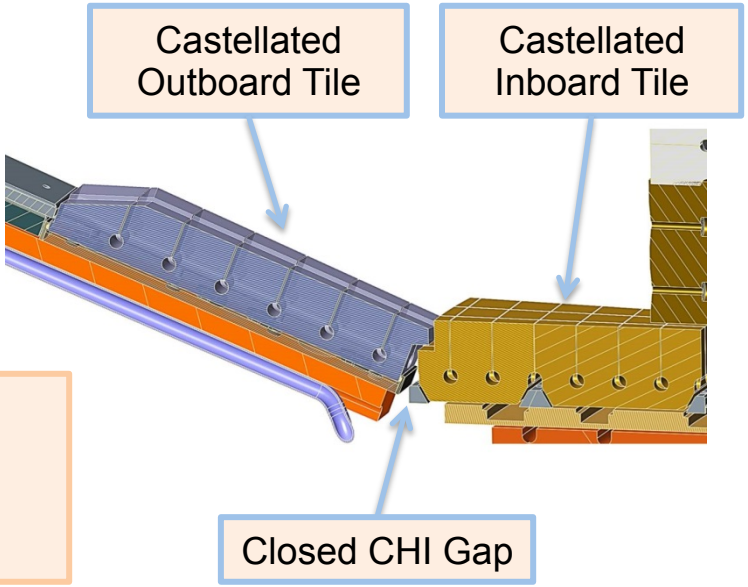


Testing material and component samples at Penn State high heat flux test facility (ORNL, PPPL)

Improving Design of Polar Regions
to Ensure High Performance and Reliability

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

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



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

Key Research Impacts of Recovery Redesign

- 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
    - Retained 2 kV power supply capability and commensurate coil design for all inner-PF coils with the express goal of allowing rapid field changes for CHI.
- 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

- All inner-PF coils retained.
- Bakeout system will be significantly improved, in both safety and functionality.
- 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.
- RF and NB systems maintained as before.
- Core machine reliability should be significantly improved via numerous targeted improvements.

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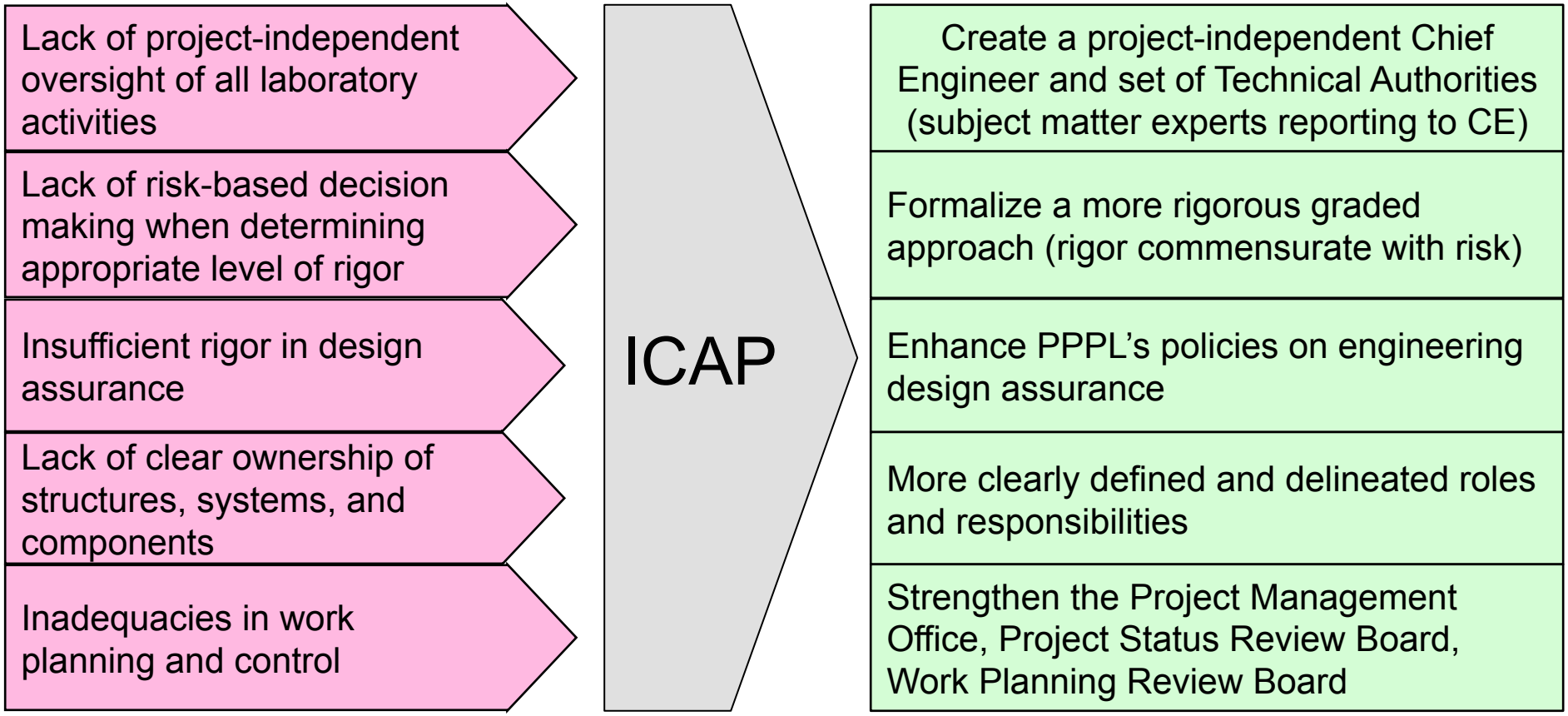
Extend of Cause Review Thoroughly Examined the Processes Used for Work at PPPL

- Team of independent experts
  - DoE Chicago ISC, ORNL, FNL, BNL, PNNL, MIT, expert consultants
- Reviewed previous incident reports and CAPs dating back to NCSX, reviewed PPPL procedures, interviewed >20% of staff
  - And issued reports, with Judgments of Need
- In response, PPPL developed the Integrated Corrective Action Plan (**ICAP**), providing corrective actions across all of the laboratories management systems.
  - QA/QC, Training & Qualifications, Engineering Design, Project Management, Configuration Management, Work Planning and Control, Contractor Assurance, Performance Management

ICAP will Bring PPPL Management Systems Inline with Complex-Wide Standards



Summary

- Reviews have determined what needs to be repaired / replaced
- We have developed new designs to repair and improve components
- Upgrades to laboratory processes will improve rigor of work at PPPL
- Recovery will significantly enhance NSTX-U reliability & safety, provide highest-performance ST device as a robust user facility

Backup

NSTX-U is Now Required to Operate Under the Accelerator Safety Order

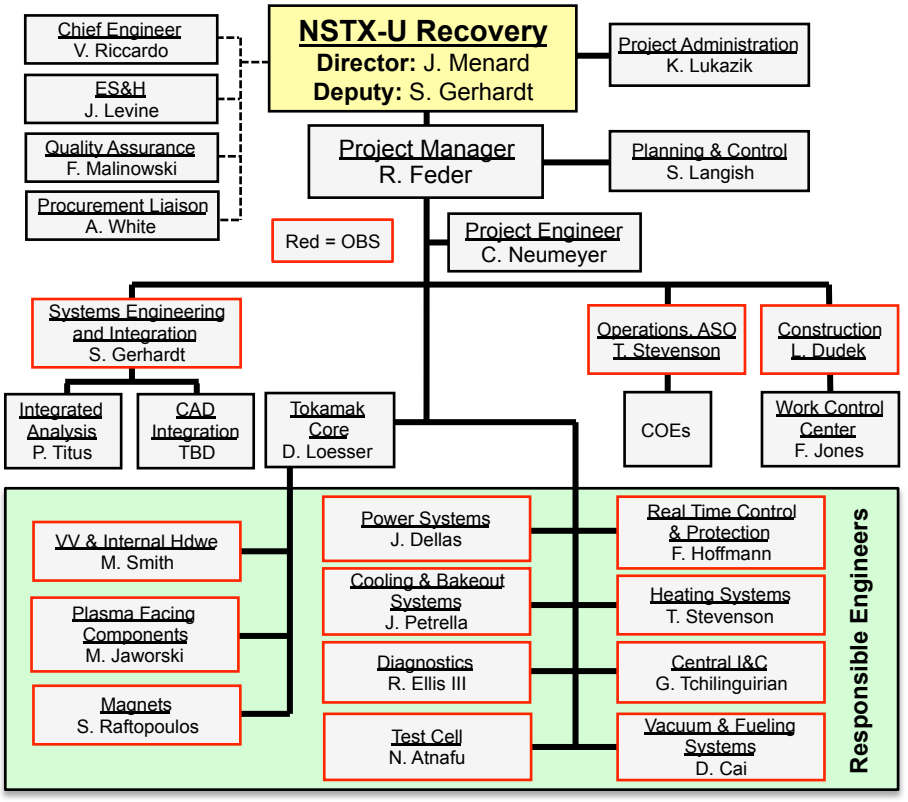
- Accelerator = Device that can accelerate charge particles and create a radiation area
- DOE Order 420.2 mandates a greater level of rigor in processes related to safety of employees, the public, and the environment
- Initiating upgrades to our safety documentation, project training and qualification, project configuration management,…
- One or more Accelerator Readiness Reviews will be required, leading to DoE site office permission to operate

The NSTX-U Recovery Project Taking Specific ICAP Actions to Improve Performance

- Hire a project manager
  - Done: R. Feder has extensive experience fusion facilities
- Complete a Preliminary Project Execution Plan
  - Iterating with DoE
- Set up an Interim Project Document Management System
  - Done: Chit resolution system and interim DMS functioning
- Stand up an Independent Advisor Board for Recovery
  - In progress: Board formed and charter written
- Update the project QA plan
  - Rev. 0 of the QA plan is being revised given new lab-wide procedures
- Enhance QA/QC and testing for critical component
  - Continuous effort, e.g. enhanced magnet testing

New Organization Created to Support Recovery

- Shown is the present organization
  - Has been considerable evolution in details over the year.
- Responsible Engineer roles cover the technical scope of the project.
- Project manager added in November.



DVVR Process Identified the Issues with NSTX-U

- Conducted 12 DVVRs between Jan. 18th and April 20th
- 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 I&C	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 days 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		

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