NSTX-U

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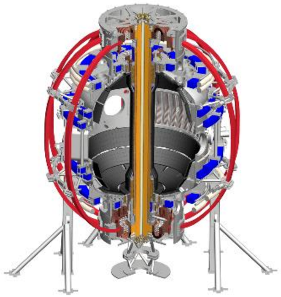
Fusion Energy Sciences

Plans for FY18 PFCR Working Group Activities

M.L. Reinke

PFCR-WG Meeting
B-252
9/13/17



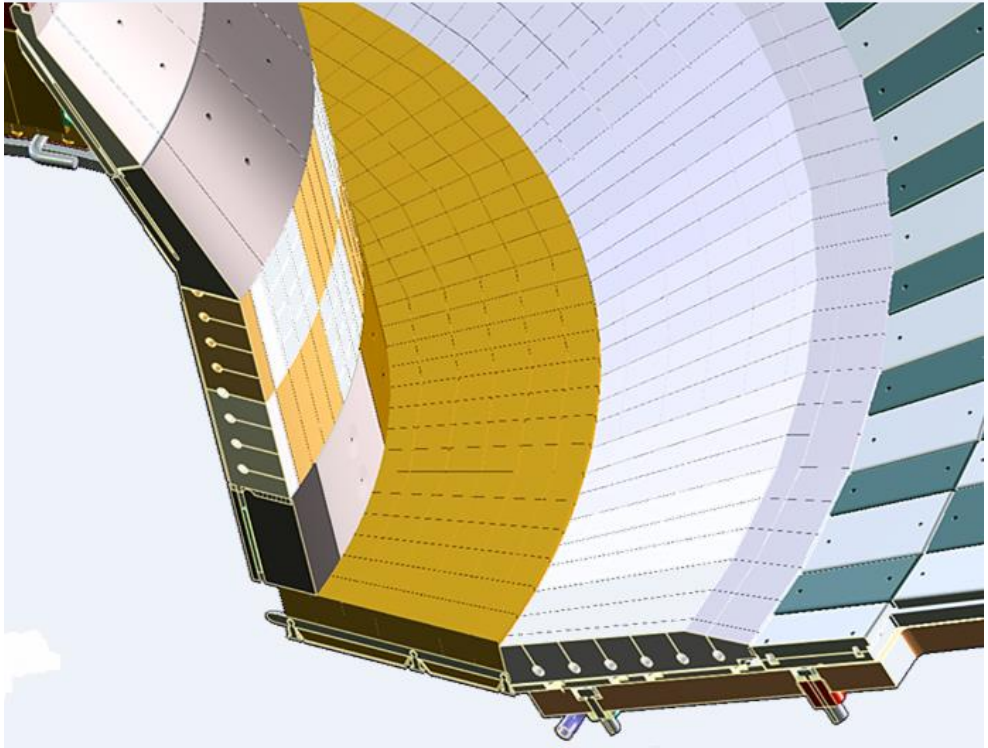
PPPL

Goals of the Meeting

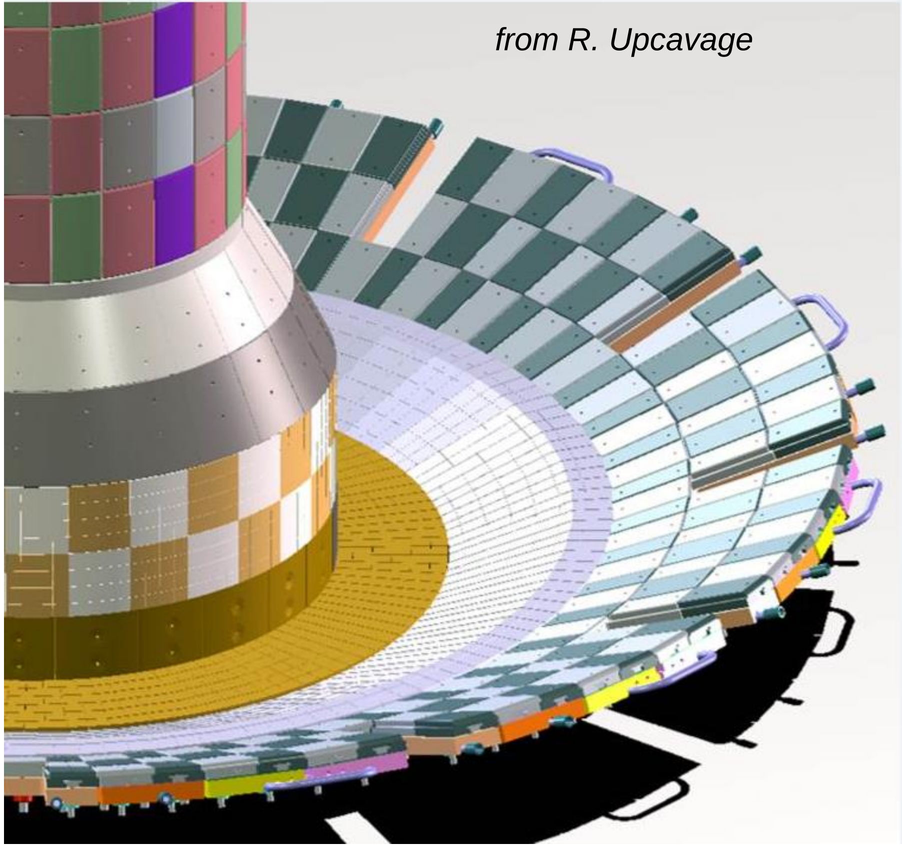
- discuss open ACTIONS & MEMOs
  - MEMOs and ACTION ITEMS
- discuss goals and approach to FY18 activities
  - continued support of Recovery Project needs
    - design/engineering team and further scenario compatibility guidance
  - activities under R(18-1)
    - (1) develop and (2) benchmark improved reduced models for heat flux and PFC engineering limits for OPS/real-time use
    - (3) scope PFC monitoring

http://nstx-u.pppl.gov/program/working-groups/pfc-requirements-working-group

Present, In-Progress HHF PFC Layout



castellated tiles chosen for HHF areas



Present, In-Progress HHF PFC Layout

castellated tiles chosen for HHF areas

from R. Upcavage

Designs are informed by PFC Requirements but a much harder job is figuring out how we operate NSTX-U to be within those requirements!

Continuous WG Activities

- be responsive to Recovery Project requests
  - falling a bit behind in some Action Item requests and MEMOs
  - may have requests to look at PFC requirements (lower I_pB_T)
- expand and continue scenario exploration started by Menard/Gerhardt for TSG input (Battaglia?, Boyer?)
  - maintain connection between PFC design and science goals
    - presently no infrastructure to go from ‘scenario’ to W_PFC input
  - finer selection of ‘flat-top’ scenarios needed to get from end of FY16 to key performance metric(s) (e.g. 2 MA, 1 T, 10 MW)
  - time-evolving cases that include ramp-up, flat-top and ramp-down to better estimate realistic load cases
    - are we missing something? KNOWN: CSFW ramp-down, LFS limiter

R(18-1) Goals Map to PFCR-WG Charges

R(18-1): Develop and Benchmark Operations-Focused Reduced Heat Flux and Thermo-Mechanical Models for use in PFC Monitoring

The NSTX-U Recovery Project will deploy new plasma facing components (PFCs) to meet updated heat exhaust requirements driven by narrower scrape-off-layer widths, increased heating power, and longer pulse durations relative to NSTX. Inter-shot monitoring or intra-shot control of heat flux to PFCs is anticipated for a range NSTX-U operating space, necessitating reduced models that can be run between shots or even in real-time. Monitoring requires a reliable instrumentation suite which can support or contradict model predictions and confirm PFC integrity. The goals of this milestone are three-fold: 1) Develop tools for pre-shot planning and confirmation of post-shot PFC thermal observations which use reduced models to predict time-evolving heat fluxes to shaped PFCs and estimate distances from engineering limits. Assess additional effort needed for implementation of reduced models in PCS. 2) Where feasible, benchmark reduced models against boundary physics (e.g. SOLPS, UEDGE) and finite element analysis (e.g. ANSYS) tools, and validate using experimental data from relevant tokamaks and results from Facility Milestone F(18-1). 3) Evaluate examples of discrete monitoring systems that are sufficient to capture the evolution of the PFCs relative to engineering limits. Compare the ability for different techniques (e.g. thermocouples vs. imaging) and technologies (e.g. near vs. long-wave infrared cameras) to achieve NSTX-U PFC monitoring objectives.

1. ~~define which (additional) parameters need to be specified in an updated requirements document for the NSTX-U PFCs~~
2. facilitate generation of updated requirements utilizing:
   a) available reduced models, empirical scalings, boundary simulations
   b) ultimately, a validated model for specifying heat loads to all plasma facing components for arbitrary NSTX-U scenarios
3. in preparation for operations, develop:
   a) instrumentation plan for intra and inter-shot PFC monitoring
   b) a reduced model for heat loading for pre-shot planning
   c) guidance on how to best integrate monitoring with operations
   d) control, diagnostic requirements for real-time heat-flux control
4. work closely with engineers and analysts to develop and implement requirements

Pathways to Support WG Contributions

- University 'NSTX-U Diagnostics' collaborators can discuss contributions w/ J. King but those on 'NSTX-U Physics' may have trouble contributing after early CY18
- PPPL staff can consider contributions and make suggestions in yearly goals
- limited subset of Lab collaborators can propose Recovery activities
  - draft ORNL milestones for revised Recovery FWP
    - ~~Establish NSTX-U PFC Working Group to tackle issues related to heat loading of plasma facing components (6/2017)~~
    - Establish capability for high-heat flux testing of PFCs at an electron beam facility (9/2017)
    - Participate in high heat flux testing of prototype and/or final designs of a NSTX-U high heat flux tile(s) (12/2017)
    - Lead the PFCR Working Group to provide supporting information to Recovery/Operations to outline PFC monitoring approaches (2/2018)
    - Demonstrate reduced PFC heat flux modeling tools capable of capturing impacts of 3D PFC shaping (6/2018)
    - Lead the PFCR Working Group to deliver an instrumentation and operations support plan for PFC monitoring (10/2018)
    - Complete changes to IR thermography and resistive bolometer diagnostics necessary to be compatible with new PFCs designs (5/2019)
  - draft LLNL milestones (TBD)

Improve Physics Tools to Define PFC Heat Flux

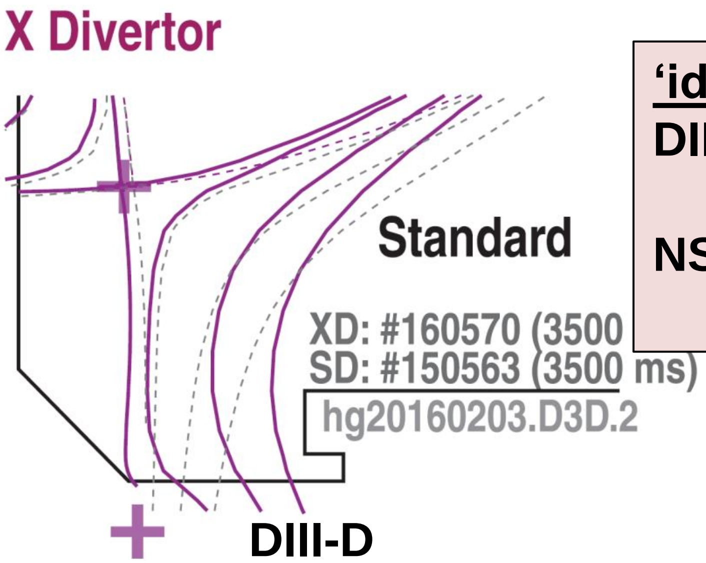
- progression of complexity expect for heat flux models
  - STEP 0: axisymmetric PFCs, axisymmetric plasma (present)
  - STEP 1: non-axisymmetric PFCs, axisymmetric plasma (FY18)
  - STEP 2: non-axisymmetric PFCs, non-axisymmetric plasma (TBD)
- multiple tools to explore for STEP 1 (personnel?)
  - PFCFlux (CEA): requires a collaboration w/ CEA
  - SMARDDA (CCFE): available now for any MAST collaborators
  - DIV3D (ORNL): available now, but needs dusting off (Lore)
  - EMC3 (various): have talent within our group (Lore, Waters)
  - custom (?): advantage to developing something locally?
- eventual need for fast (< 5 min per shot) tools to be used for pre-shot planning and inter-shot analysis (reduced models?)

Integrate Eng. Tools to Define PFC Limits

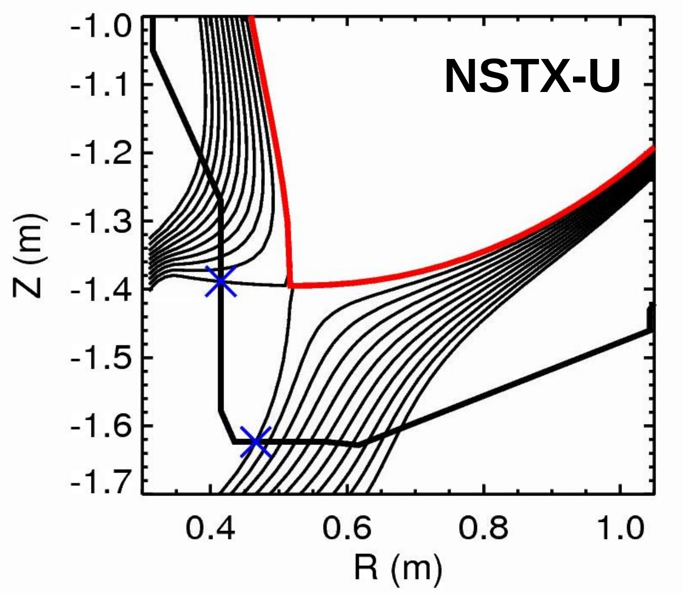
- progression of complexity expected for PFC limits
  - STEP 0: simple semi-infinite model w/ $T < T_{crit}$?, $\sigma < E\alpha\Delta T$
  - STEP 1: finite-element (ANSYS) of castellation to $q_{||}(\mathbf{r},t)$ (FY18)
  - STEP 2: interpolation of full ANSYS simulations (TBD)
- should have resources to explore STEP 1 (Reinke)
  - work with Analysis (Brooks? Mardenfeld?) to setup a scriptable ANSYS run to find peak stress to arbitrary heating time histories
  - expectation of non-linearity as material properties are f(T)
  - determine if workflow could be done inter-shot
- connect with the F(18-1) HHF testing of PFCs to connect to validation of tile failure limits

Validating Heat Flux Models

- common question: *“if Machine X were to use our model, would they predict a PFC problem?”* <u>we should look into this, but…</u>
  - ex: DIII-D (LSN): 27 MJ over 10 s to ODIV (shelf) 1.15 < R < 1.37 ~ 1.74 m^2
  - ex: NSTX-U (DN): 14 MJ over 5 s to ODIV (IBDH) 0.45 < R < 0.60 ~ 0.50 m^2



<u>‘ideal’ spread evenly</u>
DIIID: 16 MJ/m^2
1.5 MW/m^2
NSTX-U: 28 MJ/m^2
5.7 MW/m^2



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- present modeling (W_PFC) can be adapted to other devices
  - INPUTS: g-file, P_{HEAT}, P_{RAD}
  - OUTPUTS: q_{surf} at the various divertors
  - should compare to few machine with near-DN examples
    - as long as we're not proposing/running new experiments, but comparing results
  - NSTX (Gray?), C-Mod (Reinke), MAST/MAST-U (?), DIII-D (?)

Scope Breakdown for NSTX-U Activities

Recovery Scope	Maintenance and Run Preparation	Operations Enhancements for Improved Reliability
Scope to address DVVR issues or EoC recommendations related to design, fabrication, or installation that remedies severe design deficiencies or performance limitations	Scope to address reliability of critical components in supporting infrastructure outside tokamak core; need not be a DVVR issue but could have been identified in the DVVR or EOC recommendations	Deferrable scope that addresses reliability of less critical components; need not be a DVVR issue
Scope to address DVVR issues related to reliability of the tokamak core (PFCs, magnets, vessel, etc.)	Routine maintenance and repair tasks; need not be a DVVR issue but could have been identified in the DVVR or EOC recommendations	Desirable but not essential enhancements
Scope to address any known safety issue; need not be a DVVR issue	Critical scope that was planned before the start of the Recovery activities	
	Operations support functions (minimal staff to support operations, allocations, energy consumption, etc.)	

r defining scope in the Corrective Action Spreadsheet and for the remainder of this report

Scope Covered at Recent Cost & Schedule Review

No Completion Date, Not Required for Restart of NSTX-U

Draft Corrective Action Plan

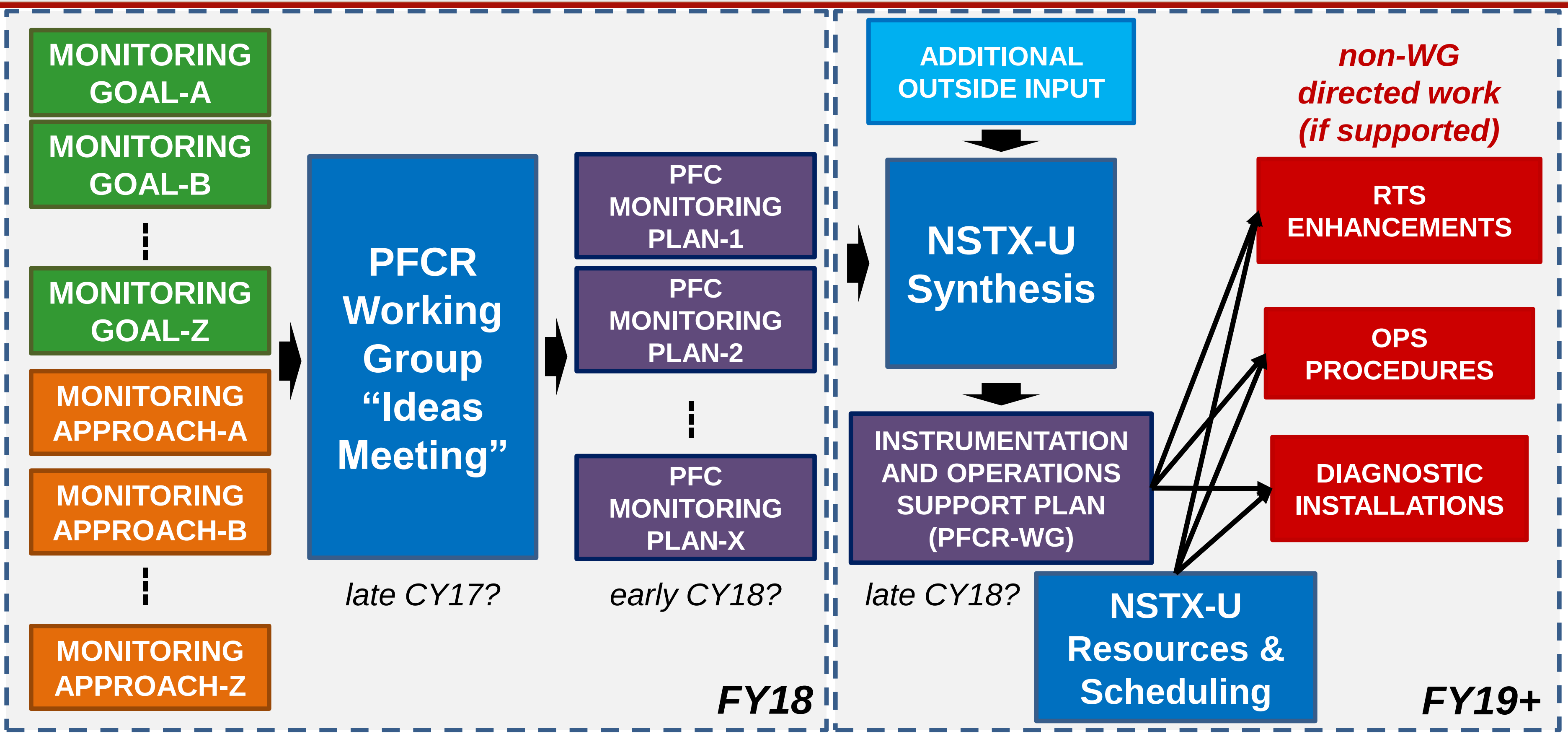
PFC Monitoring is "Operations Enhancements"

- scope is in Sec 14: Integrated Design (RE: Gerhardt)
  - cost estimate below 2 M$ listed based on prior Working Group contribution
  - 'enhancements' possible in parallel w/ recovery, but must avoid key resources
- work covers DVVR Issue ID10-5: *"Consider developing a scheme for realtime PFC and machine protection from thermal issues"* (excerpts)
  - "pre-conceptual designs for such PFC monitoring systems are being done, in case we find that the PFC are stress limited and wish to implement such a system" (Section 14.4.2)
  - "[monitoring] design choices will be addressed in future conceptual design activities if it is deemed prudent to implement such a system" (Section 14.4.2)
- example "Recovery Scope": DVVR Issue ID12-3: "*Implement comprehensive measurement system to characterize mechanical/structural behavior of critical machine components"*
  - coil mounts, vessel structure: much larger impact of system failure NSTX-U

PFC Monitoring Scope for FY18

- deliver the concept and design information to project to be able to quickly make future decisions
  - improve cost estimates ($, port space, time) based on vetted techniques
  - reasonable expectation of monitoring capabilities as PFC designs mature and limitations are better understood (or budget tradeoffs made)
- R(18-1) follows conventional technology
  - thermocouples, surface imaging (MWIR vs. NIR), bolometry
  - how do we combine proven discrete sensors & deliver monitoring goals?
- additional work under F(18-1) to consider new alternatives or techniques which haven't been previously shown to work
  - strain sensing to avoid inferring from temperature, new temp. sensors
  - surface monitoring in a Li coated environment (Magnum?)

Draft Flowchart to Develop PFC Monitoring



Summary

- multiple WG activities to contribute to in FY18
  - ownership of various topics welcome (see Reinke)
  - details and amount of support need to be confirmed
- effort directly benefits on-going Recovery Project and will help prepare NSTX-U for success post-Recovery
- scope and concepts for PFC monitoring evaluated in FY18 will provide input for FY19+ decisions
  - organize a longer ‘Ideas Meeting’ this fall to coordinate