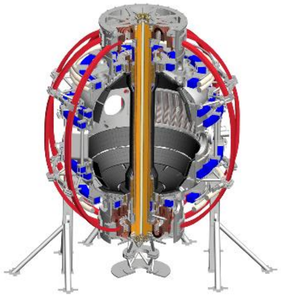
R18-1 Milestone Update

M.L. Reinke on behalf of the R18-1 Team

NSTX-U Milestone Update Meeting
B318
1/30/2018



Milestone Description

R18-1: Develop and benchmark reduced heat flux and thermo-mechanical models for 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.

R18-1 Executed Within the PFCR-WG

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

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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

Activities Under R18-1/1

R18-1/1: 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.

- GOAL 1: Evaluate and demonstrate tools for efficiently computing heat flux from axisymmetric plasmas onto non-axisymmetric plasma facing components
- GOAL 2: Develop and test an initial ‘pre-shot’ planning tool using existing PCS infrastructure*
- GOAL 3: Develop and test initial ‘post-shot’ heat flux summary tool
- GOAL 4: Determine necessary PCS enhancements for real time strike point and flux expansion control*
- GOAL 5: Determine necessary PCS enhancements for doing real-time control from imaging systems

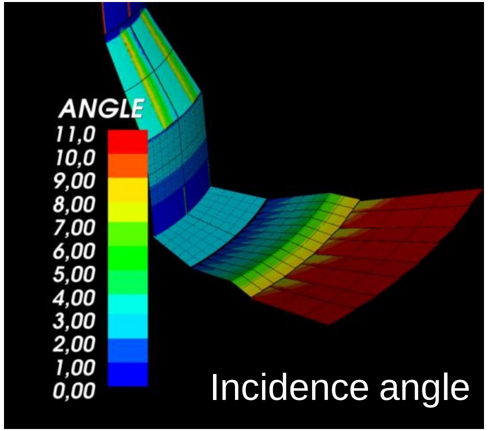
**dependent on PPPL resource decisions*

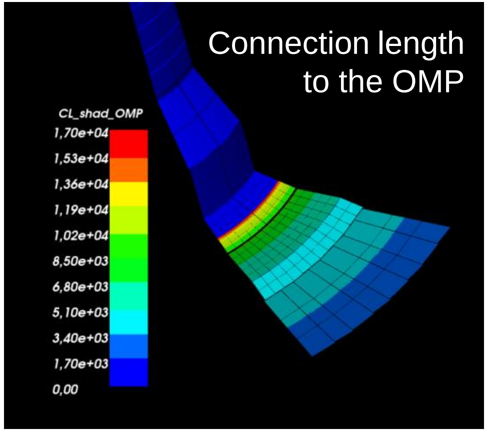
R18-1/1-G1: Evaluating Tools to Be Used for Modeling Heat Flux to Non-Axisymmetric PFCs

test runs of PFC Flux completed by CEA* (used on WEST, JET, EAST)

- interfaces field line tracing (gfile) with 3D PFC geometry (STEP)
- surface meshed, elements traced to common region where $q_{||}$ is defined (e.g. LFS midplane)
  - define $q_{||}\left(\hat{b}\cdot\hat{n}\right)$ and account for effects of ‘shadowing’ from PFC or mount shaping
- test case for NSTX-U ‘like’ heat flux to demonstrate utility and capability
  - 5 MW conducted power λ_q=5 mm, S=1 mm

*M. FIRDAOUSS & J. GERARDIN | CEA/IRFM | DECEMBER 2017





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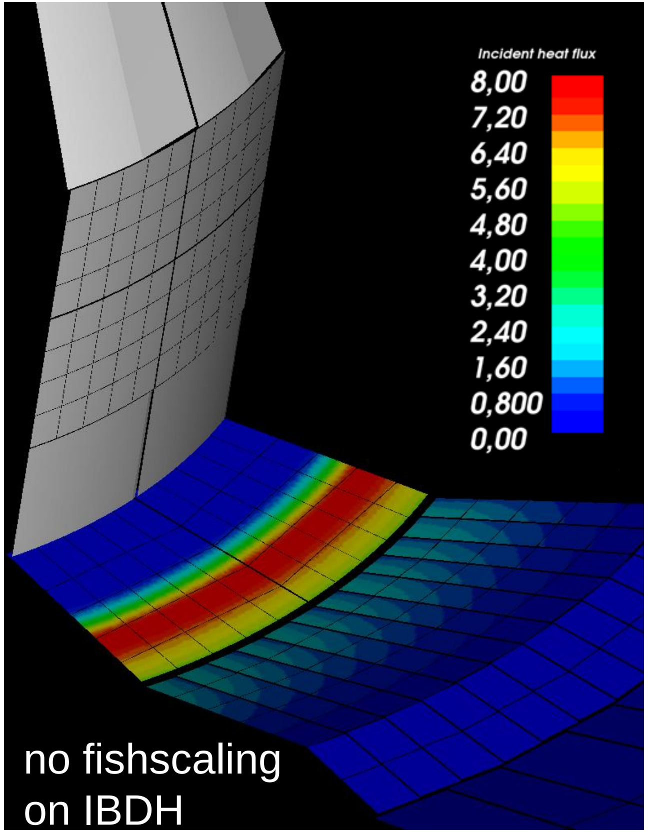

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R18-1/1-G1: Evaluating Tools to Be Used for Modeling Heat Flux to Non-Axisymmetric PFCs

evaluating other existing tools for this application

- Div3D[#] (ORNL), developed for design of W7-X PFCs
  - assigns power to field lines at LCFS, follows as diffused ⊥
    - (Lore) modification/adaptation required for use w/ Eich model tokamaks
  - allows for 3D plasma solutions (M3D-C^1), so would be useful for future application to understand impact of coil alignment
- SMARDDA* (CCFE), developed for MAST-U PFCs
  - similar in scope as PFC Flux, discussions w/ W. Arter
  - plans to test for NSTX-U on CCFE computer system (Reinke)
    - goal to complete evaluation prior to end of February visit to MAST-U

[#] J.D. Lore, *et al.* IEEE TPS 42, 539 (2014).   *W. Arter, *et al*. IEEE TPS 42, 1932 (2014)

Activities Under R18-1/2

R18-1/2: 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).

- GOAL-1: Export/Extend W_PFC to allow for comparisons to non NSTX/NSTX-U heat flux measurements
- GOAL 2: Compare W_PFC predictions to Alcator C-Mod measurements
- GOAL 3: Compare W_PFC predictions to (tokamak/ST to be determined) measurements
- GOAL 4: Extend validated high heat flux (HHF) ANSYS simulation to allow for arbitrary surface heat flux as a function of space and time#
- GOAL 5: Compare detailed ANSYS model against semi-infinite solid predictions and evaluate role of temperature dependent thermal properties#

#*work to be done following PFC final design review*

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- **GOAL 3: Compare W_PFC predictions to (tokamak/ST to be determined) measurements**

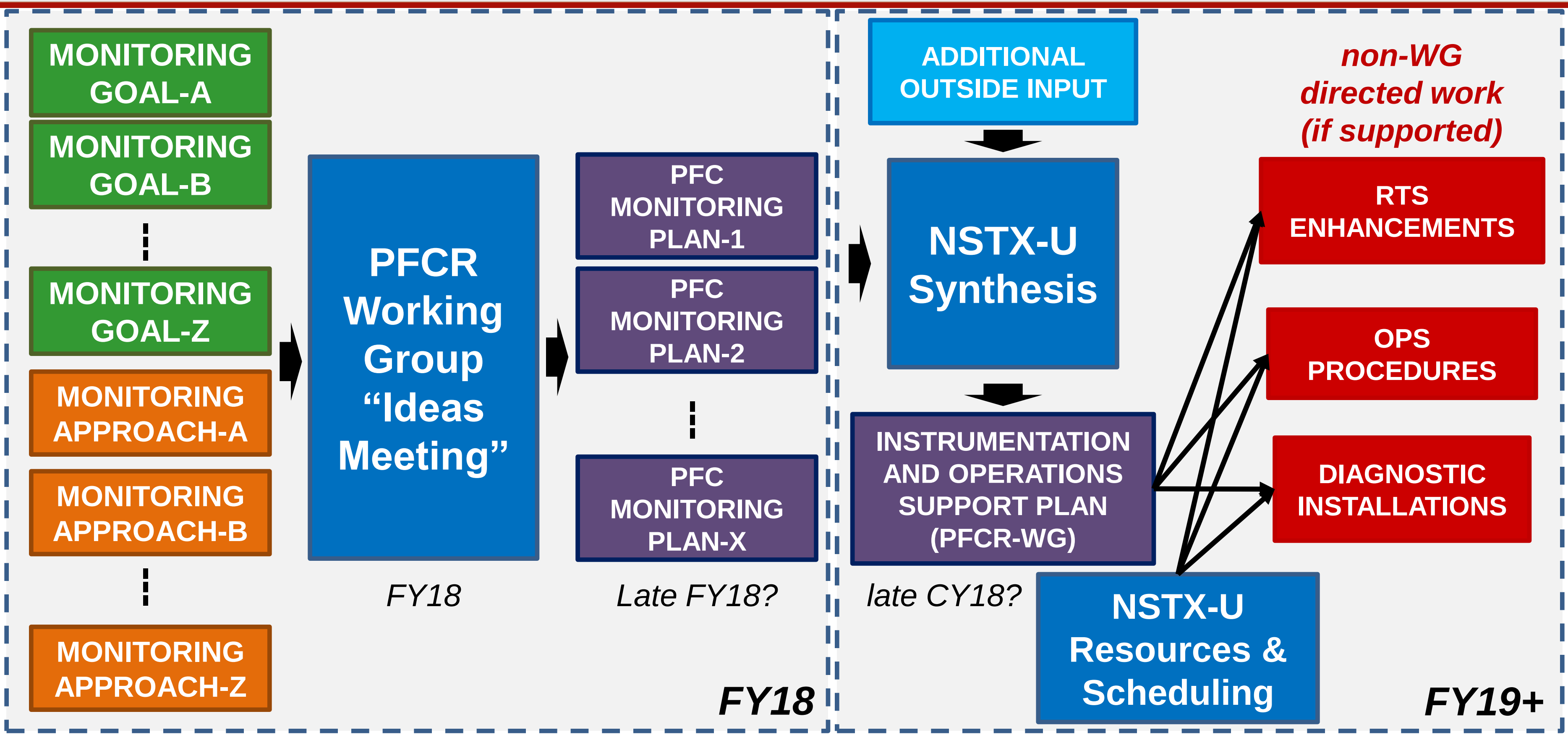
If through collaboration, people find machines/scenarios they want to test the heat flux modeling tools used for NSTX-U, let the R18-1 group know and we'll evaluate how best to try and accomplish it (e.g. deploy W_PFC tools to facility or import g-file/CAD)

Activities Under R18-1/3

R18-1/3: 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.

- GOAL-1: Describe monitoring approach that does not use optical measurements to determine if an NSTX-U discharge is approaching temperature limits
- GOAL-2: Describe monitoring approach that uses optical (NIR/IR) measurements to determine if an NSTX-U discharge is approaching temperature limits
- GOAL 3: Demonstrate pathway for sub-surface, temperature measurements to validate heat flux model

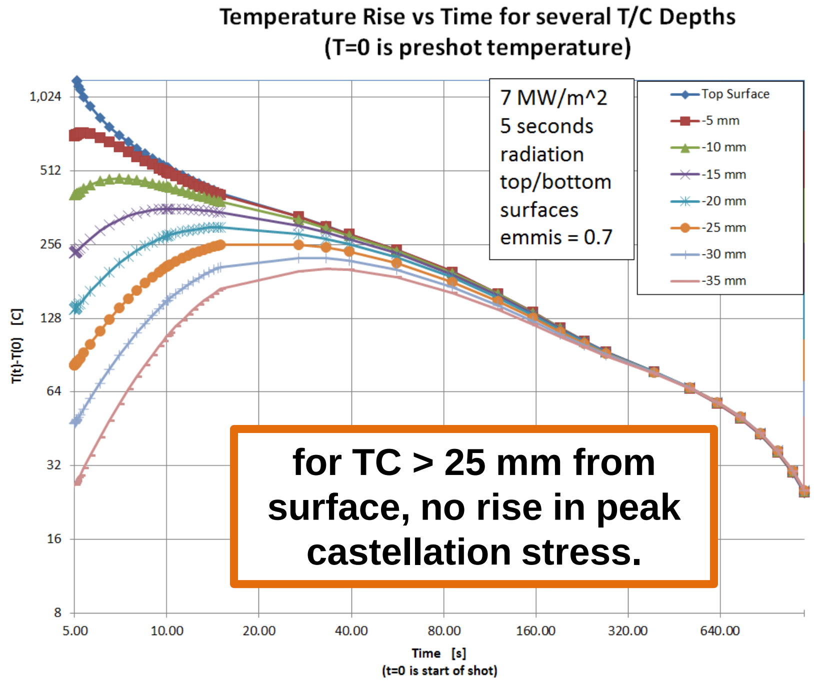
Draft Flowchart to Develop PFC Monitoring



Comparison of Monitoring Approaches

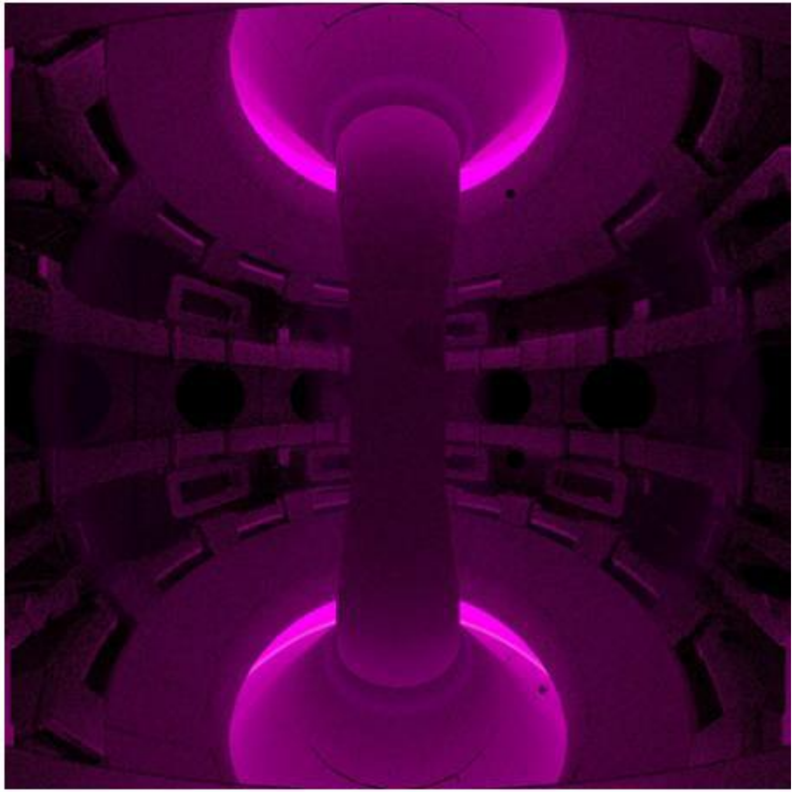
non-optical (Looby/Reinke)

- assume 0-D power balance and equilibrium known in real time
  - need to deploy ‘2π’ bolometry
  - PCS ‘knows’ surface temperature
- post-shot comparison of measured ΔT with predictions progressively validate/update PCS model
  - PlasmaTV used to ensure no gross-scale deviations/failures
- UT-K Masters thesis (Looby) to show model information (W_PFC) can be derived from limited, sub-surface TC data



M. Mardenfeld for PFC diagnostics

Comparison of Monitoring Approaches



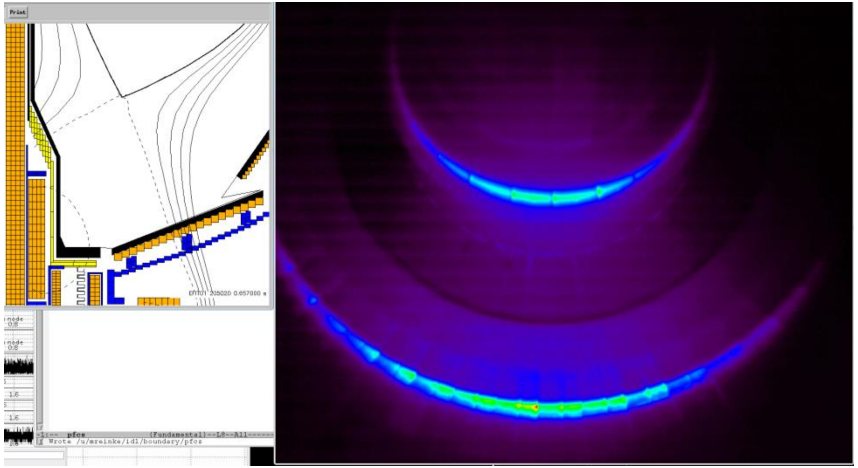
CHERAB simulation of MAST-U (Carr EPS 2017)

optical* (Gray)

- IR/NIR cameras for temperature monitoring
  - watch and control for hot-spots
- port CHERAB (CCFE) software used on MAST-U, JET and ASDEX-U
- preliminary check, FOV comparison to FY16 IR tools
- use to evaluate tools needed for post-Recovery monitoring

**pending resource availability*

Comparison of Monitoring Approaches



raw WIDE-IR data from 205020

optical* (Gray)

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  - – watch and control for hot-spots
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Summary

- mission and goals defined for R18-1 Milestone, work currently being executed in three areas
- resources and schedule to achieve these goals not yet certain, may need to down-scope next quarter
  - impact of staffing to ST Physics reorganization
  - needs/responsiveness of team to PFC Recovery jobs
  - needs of team to execute F18-1 (high heat flux testing)