NSTX-U

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PFCR-WG Update

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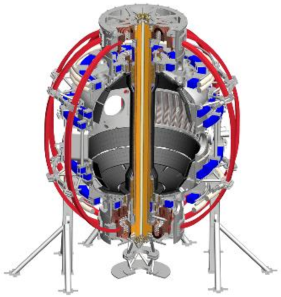
PFCR-WG Meeting
B-252
2/21/2018

PPPL



Goals of the Meeting

- discuss ongoing activities
  - MEMOs and ~~ACTION ITEMS~~ (need to update these)
- discussion of how to accommodate the impact of non-axisymmetric heat fluxes on PFC requirements
- discuss status of R18-1 Milestone Work
  - resources availability confirmed from PPPL and ORNL

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

Recent MEMO's Issued

- PFCR-MEMO-011: Modification of Heat Flux Requirements for OBD R3 and R4 Tiles
  - original requirement of estimate heat flux applied to full R3/R4 tiles, but this resulted in factor of two higher energy to tile, higher stress
- PFCR-MEMO-012: Impact of Small Gaps in Centerstack Tiles
  - ambiguous requirement of avoiding 'large gaps' to centerstack
  - suggested path to investigation 0.060" gaps in FY16 for more info
- PFCR-MEMO-013 (draft): Impact of Coil Alignment Tolerances on PFC Heat Flux Requirements
  - (to be discussed here)
- PFCR-MEMO-014 (draft): Goals for FY18 R18-1/PFCR-WG
  - (to be discussed here, if time)

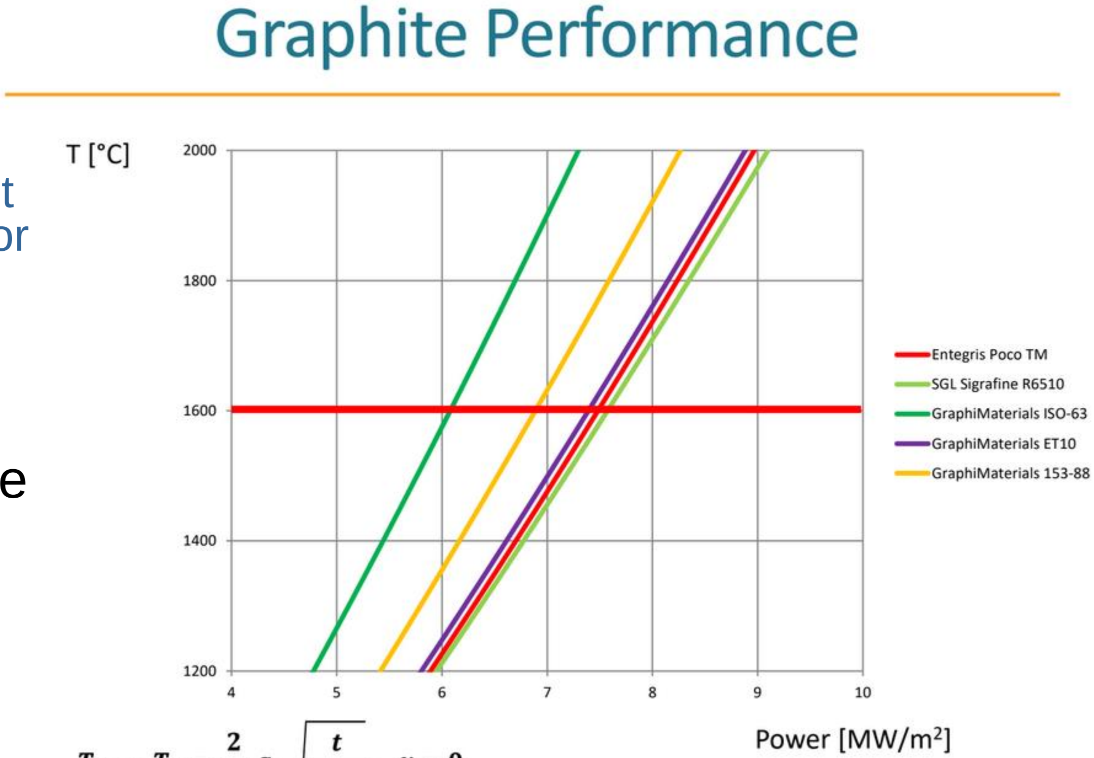
Analysis Completed to Estimate Impact of Possible Coil Misalignment on PFC Heat Flux

- shifts/tilts in the inner PF coil set produce vacuum fields which can locally increase angle of incidence
- derived from error fields calculations from linearized perturbations (A. Brooks)
  - outlined in NSTXU-CALC-11-09
- sensitivities of each PFC region were found for each coil (S. Gerhardt)
  - change in heat flux factor derived from change of angle of incidence for SRD-like cases
  - outlined in NSTX-U-DOC-101

Region	Impingement Angle degrees	Coil	Shift Sensitivity MW/m2 / mm	Tilt Sensitivity MW/m2 / mrad
IBDH	1	TF	0.00	0.36
		PF-1a	0.18	0.00
		PF-1b	0.06	0.04
		PF-1c	0.16	0.08
		PF-2	0.01	0.08
		OH	0.06	0.13
	2	TF	0.00	0.20
		PF-1a	0.10	0.00
		PF-1b	0.03	0.02
		PF-1c	0.09	0.04
		PF-2	0.01	0.06
		OH	0.03	0.07
IBDV	2	TF	0.41	0.66
		PF-1a	0.11	0.06
		PF-1b	0.00	0.00
		PF-1c	0.01	0.00
		PF-2	0.02	0.00
		OH	0.00	0.01
	4	TF	0.24	0.36
		PF-1a	0.06	0.03
		PF-1b	0.00	0.01
		PF-1c	0.01	0.00
		PF-2	0.01	0.00
		OH	0.00	0.00
OBDR1	1	TF	0.15	0.04
		PF-1a	0.07	0.01
		PF-1b	0.02	0.01
		PF-1c	0.02	0.05
		PF-2	0.17	0.10
		OH	0.03	0.07
	2	TF	0.09	0.03
		PF-1a	0.04	0.01
		PF-2b	0.01	0.01
		PF-1c	0.01	0.03
		PF-2	0.11	0.06
		OH	0.02	0.04

Analysis Completed to Estimate Impact of Possible Coil Misalignment on PFC Heat Flux

- a Monte-Carlo method randomly misaligned coils within tolerance limits
  - combined error field enhancement w/ fishscaling {1,2,1} & {5,5.5,5} for the {IBDH, IBDV, OBDR1}
  - reduce 'nominal' starting axisymmetric heat flux until mean + 1σ were below 8 MW/m^2
- 8 MW/m^2 chosen as an ultimate limit, consistent with a semi-infinite graphite plate reaching 1600 degC after 5 seconds



$$T_{1w} - T_0 = \frac{2}{\sqrt{\pi}} q_w \sqrt{\frac{t}{\lambda \rho c_p}}; \quad x = 0$$

A. Khodak

Analysis Completed to Estimate Impact of Possible Coil Misalignment on PFC Heat Flux

- a Monte-Carlo method randomly misaligned coils within tolerance limits
  - combined error field enhancement w/ fishscaling {1,2,1} & {5,5.5,5} for the {IBDH, IBDV, OBDR1}
  - reduce 'nominal' starting axisymmetric heat flux until mean + 1σ were below 8 MW/m^2
- 8 MW/m^2 chosen as an ultimate limit, consistent with a semi-infinite graphite plate reaching 1600 degC after 5 seconds
- completed for two different PFC positional tolerance limits
  - (not shown)

		1	2	3	4	5	6	7	8	9	Fishscale Only
PF-1a shift tolerance	mm	4.0	3.0	5.0	1.0	3.5	2.0	3.0	2.0	3.0	0
PF-1a tilt tolerance	mrad	3.0	2.0	3.0	1.0	2.0	1.0	2.0	1.5	2.0	0
PF-1b shift tolerance	mm	4.0	3.0	5.0	1.0	3.5	2.0	3.0	2.0	3.0	0
PF-1b tilt tolerance	mrad	3.0	2.0	3.0	1.0	2.0	1.0	2.0	1.5	2.0	0
PF-1c shift tolerance	mm	4.0	3.0	5.0	1.0	3.5	2.0	5.0	5.0	5.0	0
PF-1c tilt tolerance	mrad	3.0	2.0	3.0	1.0	2.0	1.0	4.0	4.0	4.0	0
PF-2 shift tolerance	mm	4.0	3.0	5.0	1.0	3.5	5.0	5.0	5.0	5.0	0
PF-2 tilt tolerance	mrad	3.0	2.0	3.0	1.0	5.0	5.0	5.0	5.0	5.0	0
TF shift tolerance	mm	4.0	3.0	5.0	1.0	2.0	3.0	2.0	2.0	4.0	0
TF tilt tolerance	mrad	0.5	0.5	1.3	0.4	0.4	1.3	0.4	0.4	1.4	0
MC on TF tilt?	0 or 1	0.0	0.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	0
PF ellipticity tolerance	mm	2.0	2.0	2.0	1.5	2.0	2.0	2.0	2.0	2.0	0
IBDH	MW/m^2	5.6	5.7	5.5	6.1	5.8	5.9	5.7	5.7	5.7	6.5
IBDV	MW/m^2	5.6	5.6	5.3	6.1	6.0	5.6	5.9	6.0	5.5	6.6
OBDR1	MW/m^2	4.7	4.7	4.5	5.0	4.8	4.7	4.7	4.7	4.6	5.3

Recommendations

- The heat flux requirements in NSTX-U-RQMT-SRD-003 should be based solely on assumptions of axisymmetric heat flux from the plasma
  - *e.g. judging PFC designs only needs to worry about the impact of fishscaling the tiles, not on peaking that could from coils*
- The impact of 3D fields on PFC heat flux limits should be evaluated using results from initial plasma operations.
  - A plan should be developed to that includes its evaluation, along with uncertain assumptions used in the PFC design to avoid delays in reaching high power operation post-Recovery.

Findings to Discuss

- Defining heat flux requirements based on coil alignment pre-assumes a design and decouples from PFC requirements from physics needs

- Present methods to define requirements for PFCs to support non-axisymmetric heat flux do not accurately specify the expected conditions.

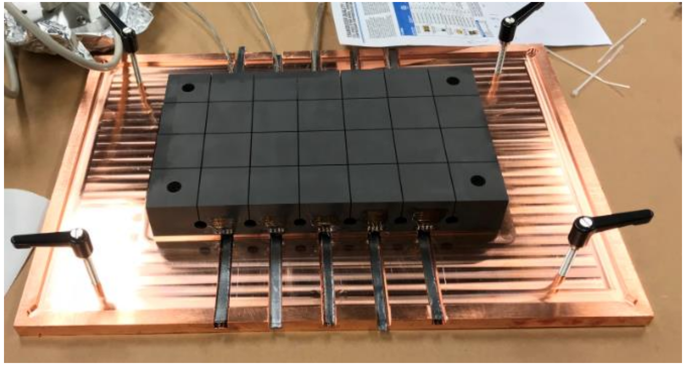
Findings to Discuss

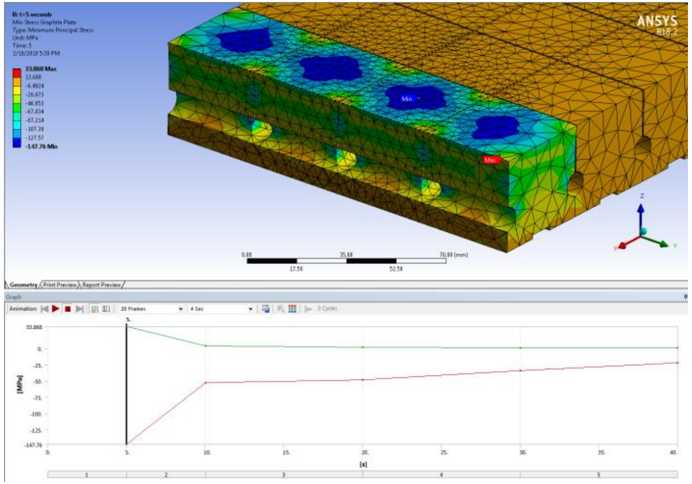
- If tiles are temperature limited, lowering the axisymmetric heat flux requirement is overly conservative if done to correct for non-axisymmetric PFC heat flux.

- The impact of heat flux enhancements from coil misalignments be accounted for when evaluating PFCs during initial, low power plasma operation.

R18-1 Milestone Planning

- recently, limited progress on milestone goals/WG activities
  - lot of focus on PFC Engineering activities
  - lot of focus on NSTX-U mission (PAC/OPA)
  - FY18-1 activities for PFC testing (Gray @ ARL this week) [images on right]
- Jan/Feb: discussions with PPPL (Menard) and ORNL (Canik) about resource needs
  - outlined a number of 'Goals', discussed at R18-1 milestone meeting
  - confirmed availability
- full list of goals in PFCR-MEMO-014





Outline of Goals from Expanded Team

- <u>R18-1/1-G1: Evaluate and demonstrate tools for efficiently computing heat flux from axisymmetric plasmas onto non-axisymmetric plasma facing components.</u>
  - looking at 'SMARDDA', 'PFC-Flux': assistance from Andreas Wingen (ORNL)
- <u>R18-1/1-G4: Determine feasibility of PCS control for dedicated heat flux application</u>
  - developing PCS algorithm and link to generation of g-files to test 'control' (R18-1/1-G2)
- <u>R18-1/1-G5: Determine necessary PCS enhancements for doing real-time control from imaging systems</u>
  - examining existing examples of PFC monitoring and report on PCS needs (Erickson)
- <u>R18-1/2-G4: Extend validated high heat flux (HHF) ANSYS simulation to allow for arbitrary surface heat flux as a function of space and time</u>
  - take what will be used to in the tile FDR and extent the model so that the research staff can program in examples of expected NSTX-U load conditions (Lumsdaine - ORNL)
  - help to start answering the question of how we operate NSTX-U to be within PFC limits
- <u>R18-1/3-G3: Demonstrate pathway for sub-surface, temperature measurements to validate heat flux model</u>
  - numerically evaluate the feasibility of a using only thermocouples to validate and a series of NSTX-U plasma to validate the heat flux model assumptions (Looby – UT/K, visiting week of 3/12)

Extra Slides

The Purpose of Having a SRD

- The purpose of the System Requirements Document, per ENG-050, is to “contain the engineering requirements that must be met for the system to function in accordance with the GRD [General Requirements Document]”,

(Relevant) GRD for PFCs

6.1.1.1.1 Performance

- a. The Plasma Facing Component (PFC) tiles shall consist of carbon-based materials designed to absorb the heat, particle, and photon flux from the plasma and heating systems, to minimize the influx of impurities to the plasma, and to withstand the electromagnetic forces associated with plasma disruption.

6.1.1.1.2 Engineering Requirements

- b. Tile surfaces may be designed to be non-axisymmetric (e.g. shaped in the toroidal direction) to avoid leading edges to meet heat flux requirements. Shaping shall be in accordance with the field polarities listed in Section 4.1.1.
- c. PFC tiles shall be classified as "critical components" for design evaluation per the definition given in the Structural Design Criteria [19].
- d. Tile design shall be based on accommodation of 10 MW input power for 5 seconds duration with a 2400 second repetition rate and the baseline cooling methods (radiation, conduction, and baseline levels of heat extraction with ex-vessel water or He).
- h. Sufficient number of tiles shall be instrumented with thermocouples to confidently assess their temperature during plasma and bakeout modes of operations.

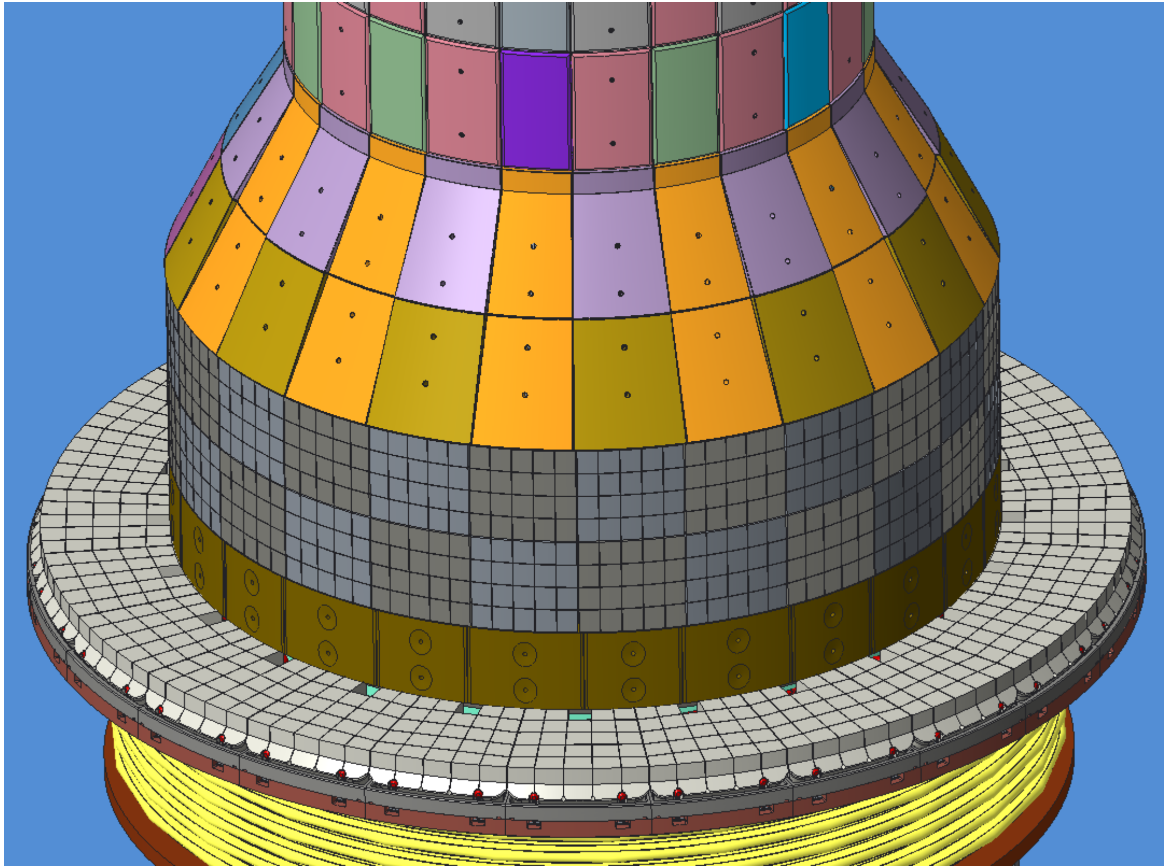
R18-1 Executed Within the PFCR-WG

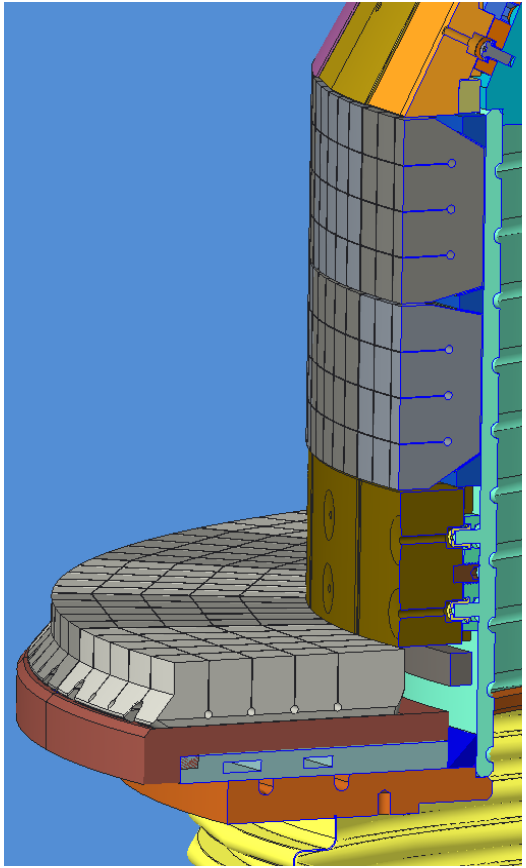
R(18-1): Develop and Benchmark Operations-Focused Reduced Heat Flux and Thermo-Mechanical Models for use in PFC Monitoring

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

Present, In-Progress HHF PFC Layout





Outer Divertor Interface