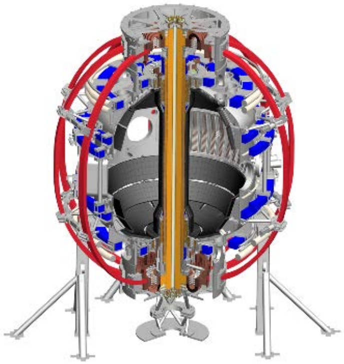
NSTX-U is sponsored by the
U.S. Department of Energy Office of Science
Fusion Energy Sciences

NSTX-U Team Meeting

R. Hawryluk, J. Menard,
S. Gerhardt, M. Reinke, R. Maingi

MBG Auditorium
April 28, 2017



Agenda

- FES perspective on Recovery / Research: Josh King
- Organizational Diagnosis Status / Next Steps: Rich and Jon
- Recovery:
  - DVVR / EoC status and next steps (Rich Hawryluk)
  - Updates on divertor heat flux and PF coil requirements (Jon Menard)
  - Recent engineering design activities in polar regions (Stefan Gerhardt)
- Research:
  - Status and plans for PFC Requirements working group (Matt Reinke)
  - Impact of polar region options on research ops flexibility (Matt/Jon/Stefan)
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Addressing the Concerns from the Organizational Diagnosis Review

	Leadership & Communications	Operational Improvements	Our People & their Jobs
Leadership Coordinators	Dave McComas, Andrew Zwicker, Mike Zarnstorff	Stacia Zelick, David Carle, Rich Hawryluk	Les Hill, Valeria Riccardo, Jon Menard
TIES THAT BIND			
MISSION	X		
NATURE OF THE WORK	X		
RELATIONSHIPS	X		
PRINCETON UNIVERSITY	X		
DIVISION WITHIN			
ISOLATION			X
LACK OF TEAMWORK			X
INTERGROUP TENSION & FRUSTRATION			X
Researchers /Indirects			X
Science/Engineering			X
Lab/DOE			X
Lab/Princeton University			X
Generational Divide			X
Gender Divide			X
THREATS AT THE BOUNDARIES			
POLITICAL ENVIRONMENT	X		
LOSS OF YOUNGER STAFF			X
EXISTENTIAL THREATS TO THE LAB	X		
UNCERTAINTY ON THE INSIDE			
RAPIDITY OF CHANGE	X		
JOB LOSS FEARS	X		
DECLINING MORALE			X
TENUOUS CORE			
UNFAMILIAR LEADERSHIP	X		
INCONSISTENT COMMUNICATION VEHICLES	X		
UNCLEAR VISION	X		
ANTIQUATED INFRASTRUCTURE		X	
INEFFECTIVE PROCESSES		X	

Responsible for engaging staff, identifying key issues, actions → recommendations

Need Your Participation

- Looking for volunteers in the three areas

- When the teams are formed, provide input to your colleagues on the teams

- The Laboratory will be responsive to the issues raised
  - Want to develop responses that solve long term issues

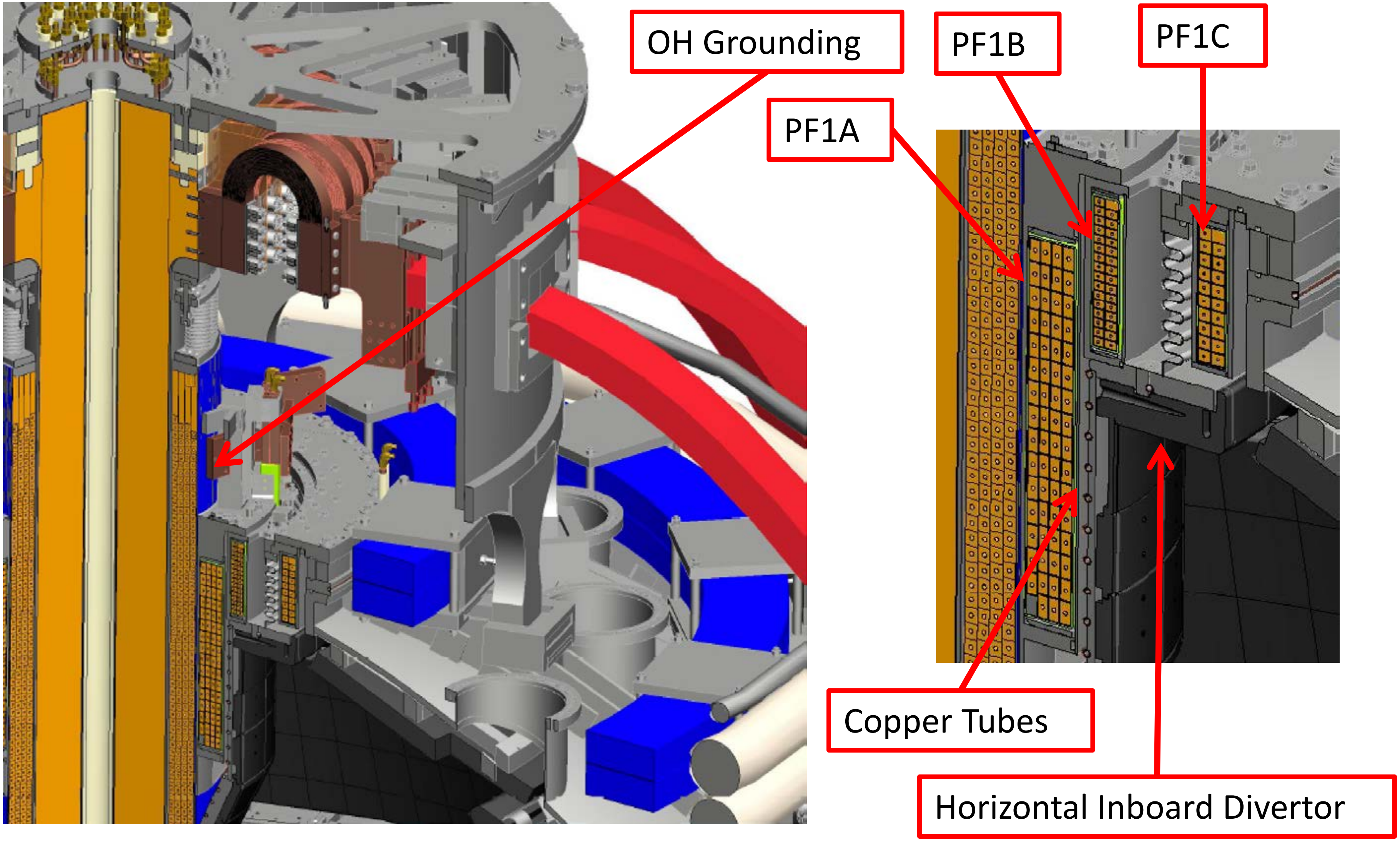
NSTX-U Recovery Project Update

R. J. Hawryluk

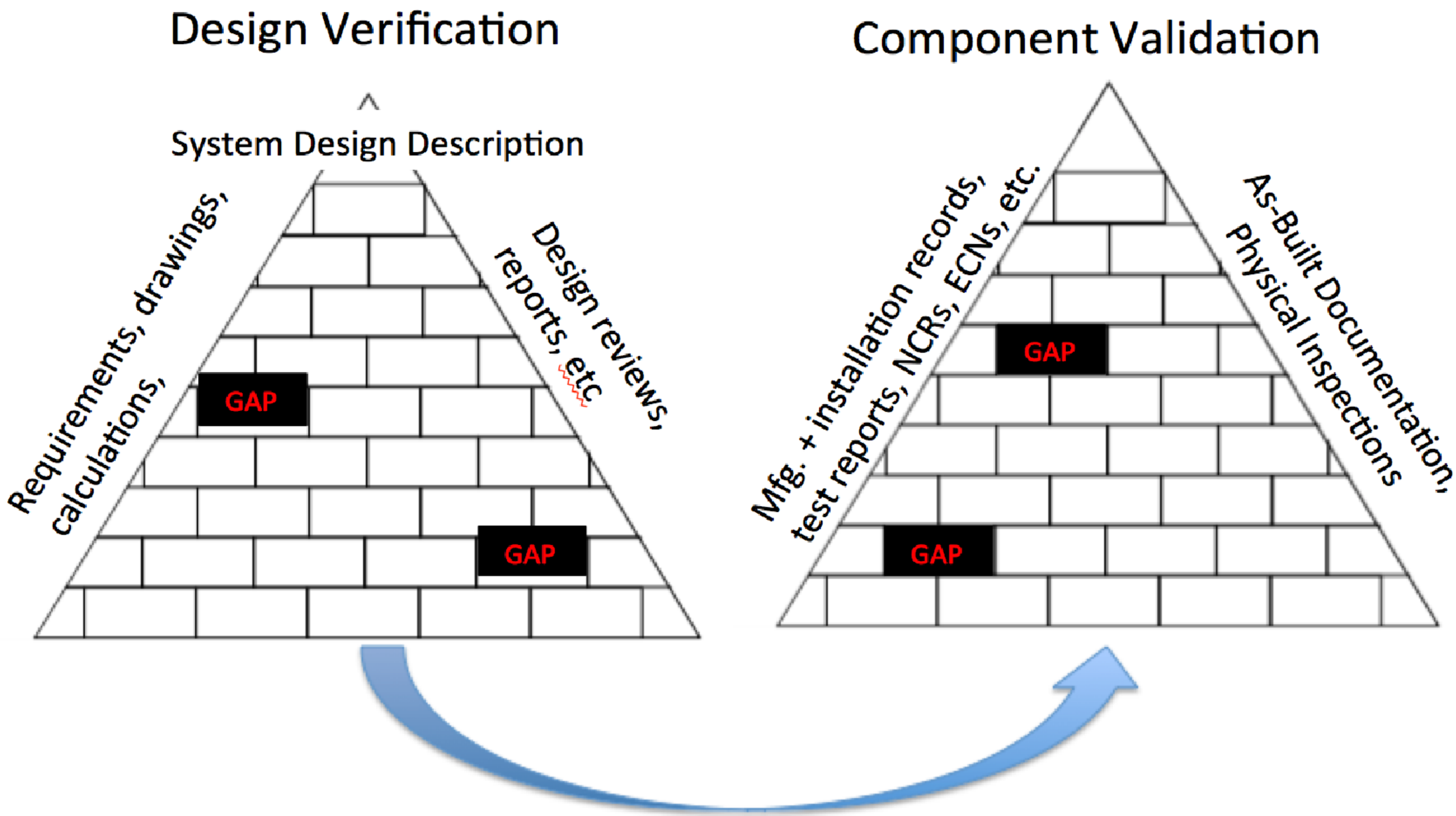
Presentation includes Preliminary Information

April 28, 2017

Region Where Problems Have Occurred



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



- DVVR looks for potential gaps in design basis or as-built configuration
  - Using an integrated systems approach
- Corrective Action Plan (CAP), derived from the DVVRs, determines path forward

Design Verification and Validation Reviews Form the Basis for the EOC Review

System	**Date**
Central I&C	*18-Jan*
Integrated Project Design	*24-Jan*
Heating Systems:	
HHFW	*30-Jan*
NBI	*31-Jan*
Magnets	*7-Feb*
VV & Int. Hdwe.	*14-Feb*
Cooling	*22-Feb*
Power Systems	*27-Feb*
EOC Review #1	*6-Mar*
Test Cell	*16-Mar*
Vacuum & Fueling	*23-Mar*
Bakeout	30-Mar
Submit Notable Interim Report	31-Mar
Diagnostics	5-Apr
Realtime Control & Protection	19-Apr
EOC Review #2	week of 15- May

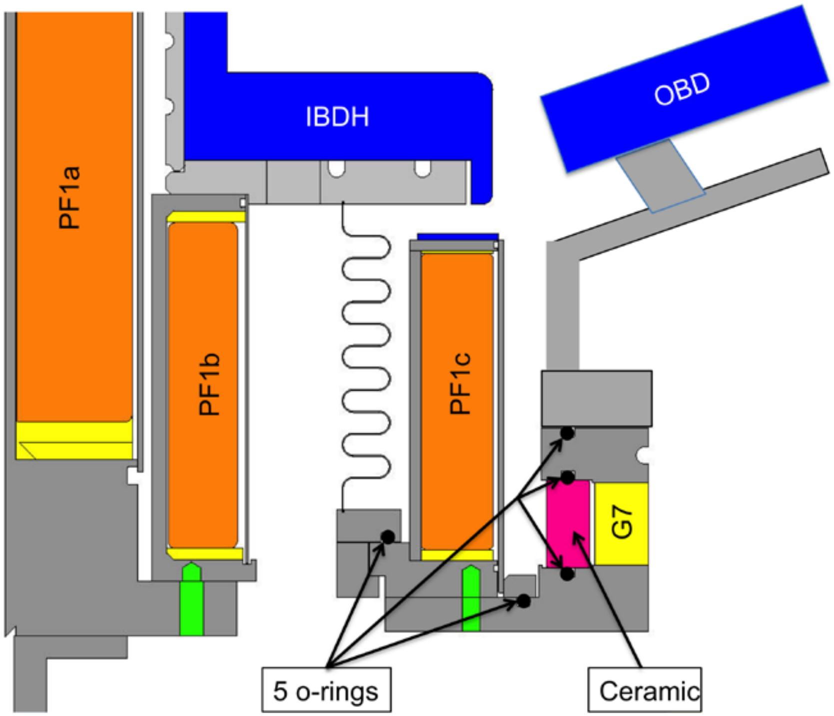
Scope of EOC Review #1 (18-Jan through 14-Feb)

- ***12 of 12 DVVRs are now complete***

Extent of Condition Panel Recommendations on Major Strategic Choices

- Panel strongly recommended replacing all existing PF1 coils
- Recommended consideration of removable mandrels on PF1 coils to facilitate turn-to-turn acceptance testing
- Retaining 300-350C bakeout strongly recommended
- Strongly recommended "indefinite deferral" of Co-Axial Helicity Injection to allow modification and simplification of the end-flanges of the Vacuum Vessel to improve the reliability of the machine

Design Integration Review of "Polar Regions"



Existing Design

- A Design Integration Review took place last Friday
  - Very productive in identifying issues with various approaches to define work that needs to be done prior to the EOC meeting.
- To be discussed further by S. Gerhardt

Highlights of Cooling System DVVR

- No major issues
- Useful suggestions regarding:
  - Spares
  - Operating and maintenance procedures
  - Technical improvements
  - Modernization

Highlights from Bakeout DVVR

- Potential safety issues identified:
  - Ex-VV water heating has a combination of pressure and temperature potentially unsafe
  - Helium pipework exceeds the max design temperature - needs requalification
- Documentation issues
  - Consistency of GRD, SAD and operation of system
    - Meet minimum temperature and address non-uniformities
  - Why gas distribution is uneven
- Obsolete equipment
  - Allen-Bradley PLC and Window XP no longer supported

Highlights from Diagnostic DVVR

- Effects of radiation in the test cell
- Are diagnostics designed and operated on NSTX compatible with NSTX-U requirements
  - Halo currents, bakeout
- Assess impact of changes to the tiles and polar region

Highlights from Vacuum Pumping and Fueling DVVR

- Identified the need to complete tasks that were largely in the pipeline:
- Pump Group PG02 has failed. It needs to be replaced.
- The HVAC cooling water does not supply the proper pressure and flow for the new pumps;
- Implementation of routine electronic archiving of the RGA data
- The RGA valve that tends to cycle with fields should be adjusted

Highlights of Test Cell DVVR

- Radiation monitoring data identified the need for additional shielding
- Modernize the HVAC control system
- Leaking roof over the Test Cell

Highlights from Power Supply DVVR

- Address the high harmonic current in the PF1 coils
- SPAs create EMI issues for diagnostics
- MG2 weld repairs and enable it to be a spare.
- Modernize the cycloconverter

Highlights of Realtime Control and Protection DVVR

- Improve air conditioning in Junction Area (where realtime computers reside)
- A large number of potential improvements to the coil protection system suggested.
- Need to develop our inventory of spare realtime data-link modules.
- Suggestion to form a machine protection committee.
- Suggestions to improve various status and annunciation capabilities on the realtime systems.

Where Do We Go From Here?

- The EOC review in May will be used to define the critical scope that needs to be addressed in the recovery project
  - Preparing a response to the previous recommendations from the first EOC meeting
  - Presentation will be given on the polar region
  - Presentations on the other seven DVVRs will be given
  - Updated spreadsheet for CAP will be distributed
- Next big task after the EoC review is to develop cost and schedules
- WAFs are the building block for that
  - Starting to develop WAFs

Subsequent Steps in Developing a Final Corrective Action Plan

- Develop a detailed cost and schedule
  - Perform risk analysis to evaluate contingency requirements
  - Use corrective action plan as part of a value engineering assessment to prioritize actions
  - Develop a re-commissioning plan leading to start of operations and qualification of the machine for research.
  - Conduct an external review of cost and schedule

- NSTX-U Recovery Project is transitioning from Discovery to Implementation

Thank You!

- The DVVRs and EOC reviews entailed an enormous effort
- The team pulled together and identified what needs to be done.
- Now, we need to finalize the plan and execute it!

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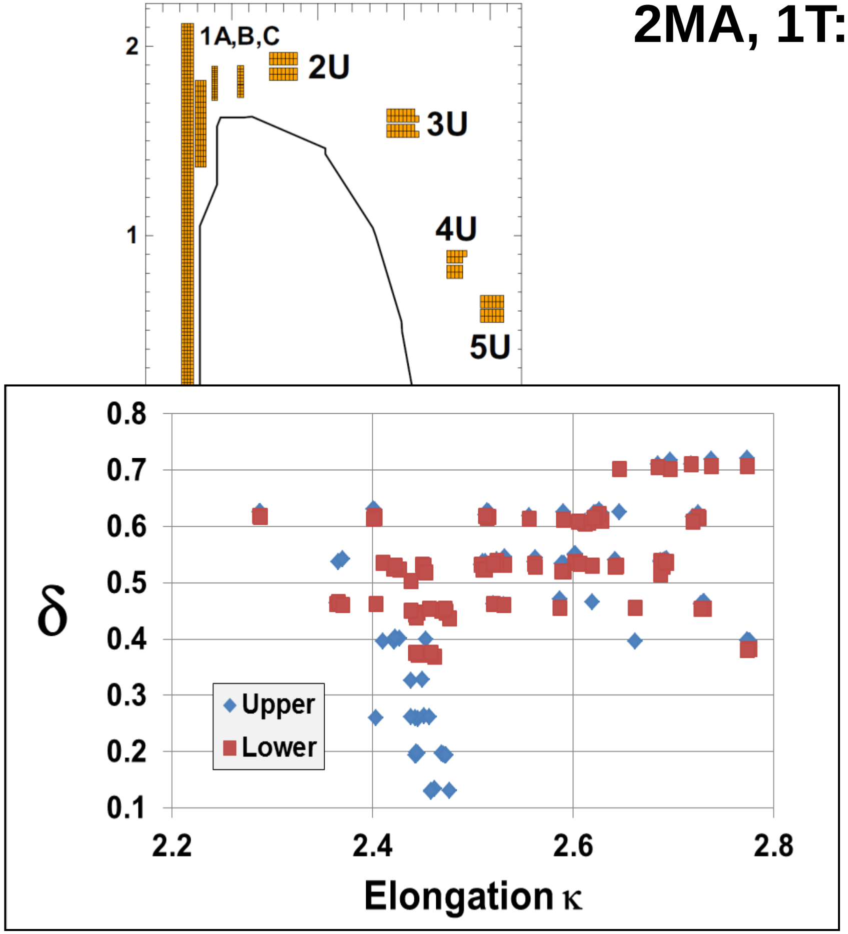
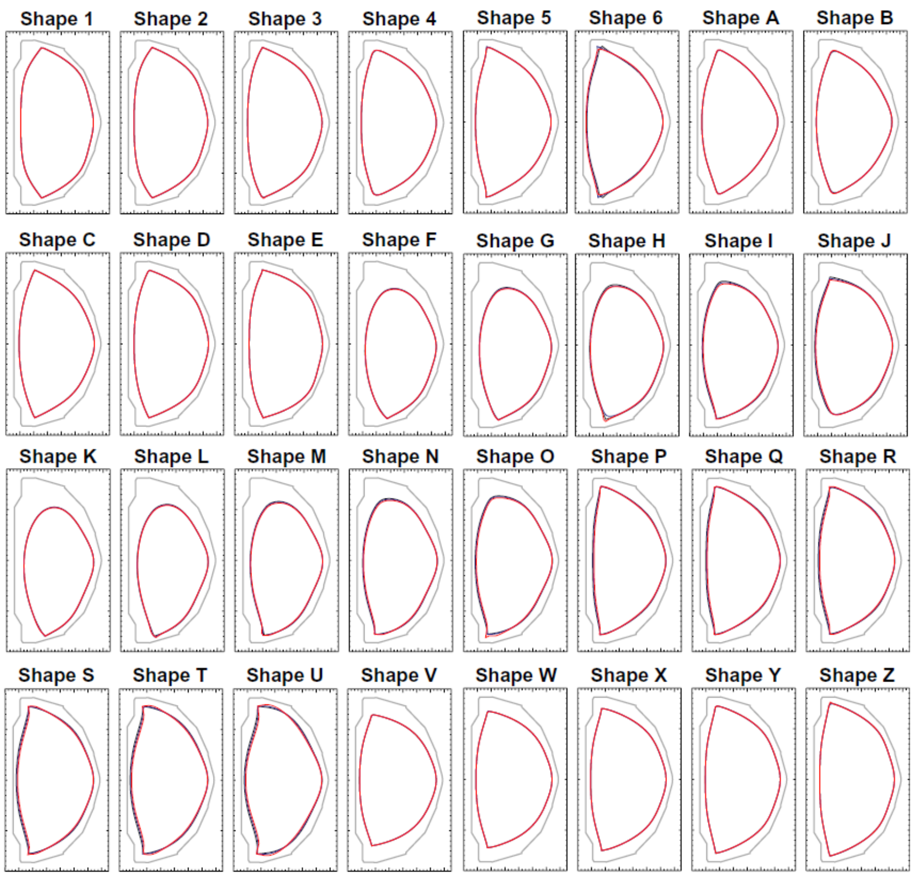
Boundary shaping flexibility drives PF coil and structural requirements for plasma operation



2MA, 1T: 32 shapes × 3 OH states = 96 equilibria



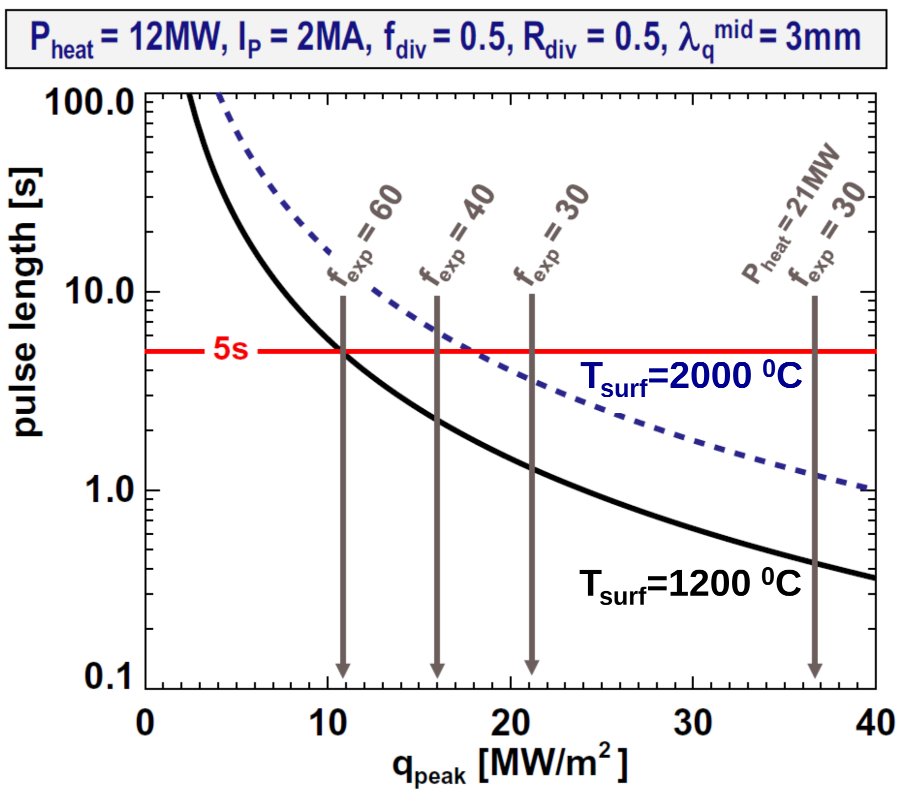
- Vary κ at fixed / high δ = 0.5 - 0.6
- Vary δ at fixed / high κ = 2.4 - 2.5
- Many other combos also possible

Role of the 96 scenarios

- Physics design computed 288 free-boundary equilibria
  - 3 x 96 = 288: β_N = 1, 5 (baseline), 8 to **quantify poloidal field requirements** for wide range of power / confinement states
- Heat fluxes at plasma facing components were not computed for most of these equilibria
  - Majority of outboard divertor (OBD) PFCs not in Upgrade scope → OBD plasmas constrained by NSTX tile capabilities
  - Time duration limits from plasma exhaust onto OBD were not computed, but in retrospect should have been in order to:
    - Explicitly document that not all 2MA plasma equilibria can operate for 5s
    - Inform operators, physicists, stakeholders about operational boundaries
- 2MA, 5s requires high enough confinement, high κ, δ → NSTX-U scenarios focus on inboard divertor target

Divertor power exhaust challenge motivated multiple PF coils to control flux expansion

Example tile surface temperature estimate, Nucl. Fusion 52 (2012) 083015



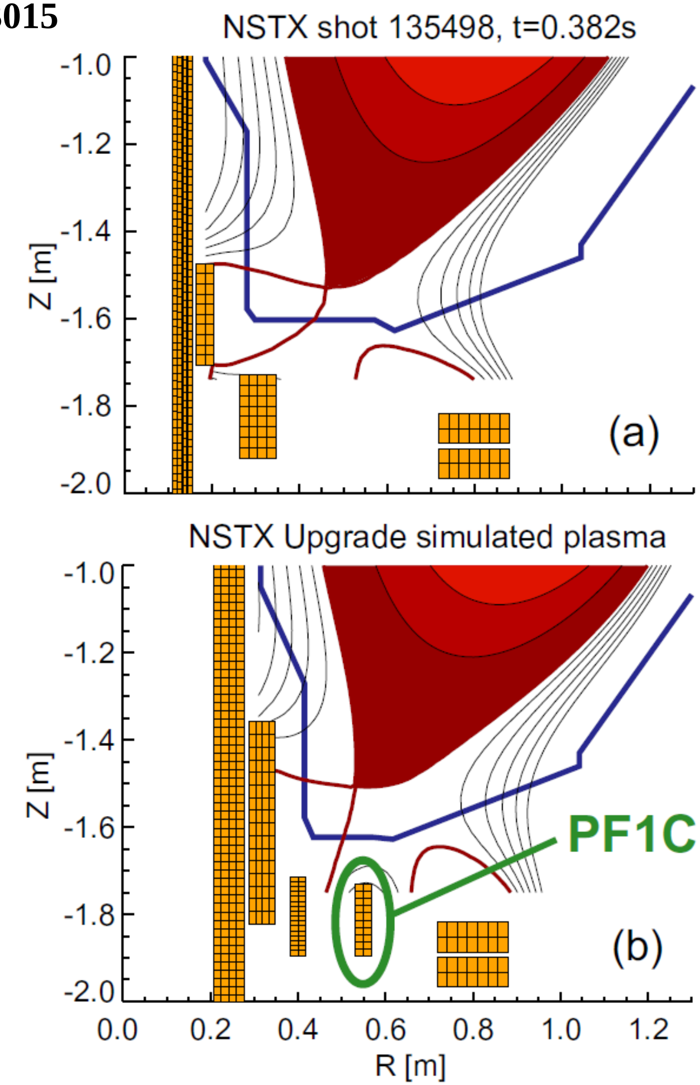


Figure 43. (*a*) Snowflake divertor in NSTX and (*b*) NSTX Upgrade.

- Goldston / Eich: Projected heat flux width has further narrowed to ~2mm
  - This heat flux scaling is at the forefront of fusion research, and is another motivation for choice of Upgrade parameters

Heat flux measurement vs. simple model:
NSTX example: high δ, I_P= 1.2MA

V.A. Soukhanovskii et al Nucl. Fusion 49 (2009) 095025

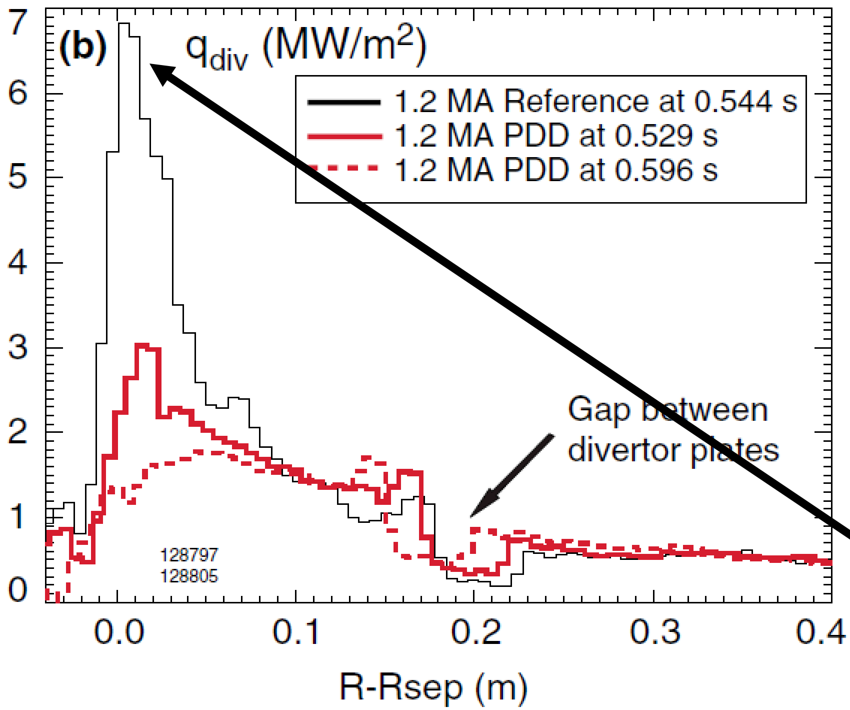
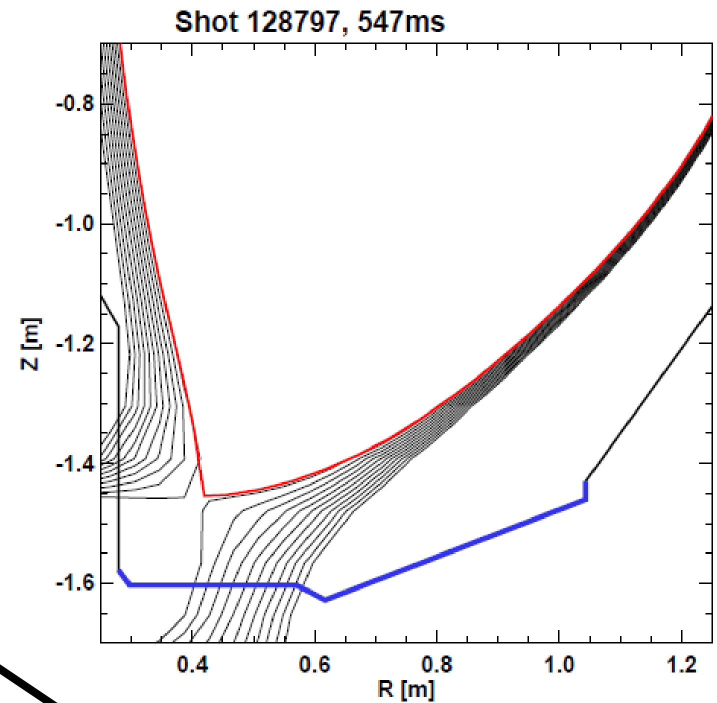
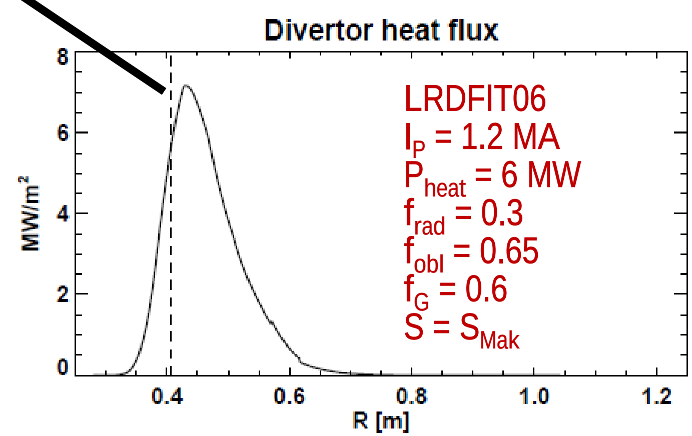


Figure 4. Divertor heat flux profiles in the reference and PDD discharges: (*a*) 1.0 MA and (*b*) 1.2 MA.





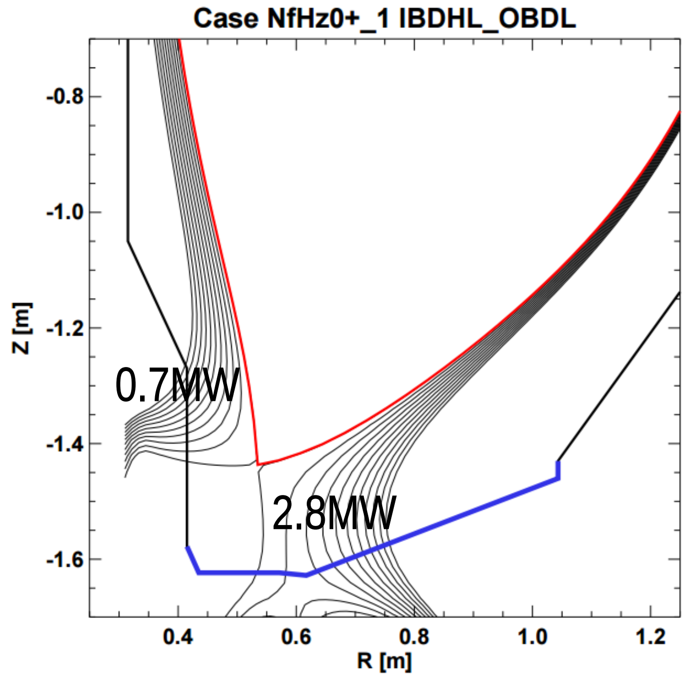
- **S = S_{Mak} may be reasonable approx. scaling assumption for NSTX/NSTX-U**
- **Detachment can reduce $q_\perp$ by ~50-70%**

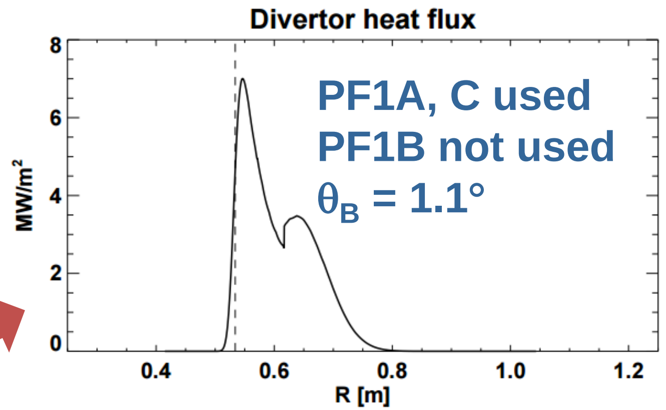
New scans since Integration DVVR

- Performed 3 systematic scans of projected power exhaust
  - Needed for PFC requirements update, tile redesign to meet original GRD
  - Also useful to determine required PF1 currents for high-flux-expansion
  - Results could influence PF1 $\int I^2 dt$ and ΔT requirement
  - **Scans have P_{NBI} = 10MW, I_P = 1-2MA, B_T = 1T, f_{rad} = 30%, $f_{OB\text{-}leg}$ = 0.8**
  - No partial detachment – could provide additional heat flux reduction
- Scan 1: No PF1B, use PF1C for high flux expansion (27 cases)
  - β_N = 4 (H_{98}~1.3) κ = 2.4, 2.55, 2.7 l_i = 0.5, 0.6, 0.7, I_{OH} = 0, -12, -24 kA
- Scan 2: w/ PF1B, vary I_P, I_{OH} to model time evolution (50 cases)
  - β_N = 4 κ = 2.4 – 2.9 l_i = 0.5-0.6 I_{OH} = 12, 6, 0, -12, -24 kA
- Scan 3: Up/down symmetric standard div. w/o PF1B (16 cases)
  - β_N = 3, 5 (H_{98}~1, 1.6) κ = 2.4, 2.7 l_i = 0.5, 0.7 I_{OH} = 0, -24 kA
    - Typically have high heat fluxes = 10-46MW/m^2 → need sweeping/radiation/short-duration
- Scan 4: Subset of original 96 scenarios: β_N=5, I_{OH}=0 (32 cases)
    - Wider range of heat fluxes = 4-46MW/m^2 → require sweeping/radiation/short-duration

Scan 1 example:
No PF1B, use PF1C for high flux expansion

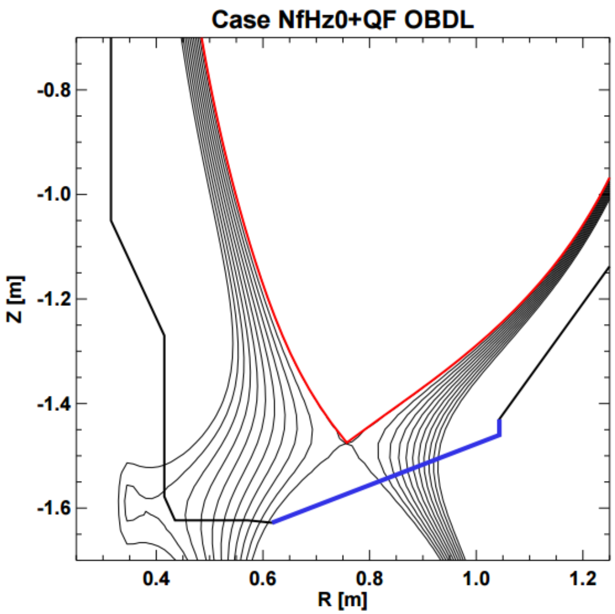
- Example case from scan:
  - $\kappa = 2.5$
  - $l_i = 0.6$
  - I_{OH} = -12kA (~mid/late flat-top)
- No PF1B, use PF1C for flux expansion → R_{strike} variation
  - **Need to narrow or close CHI gap**

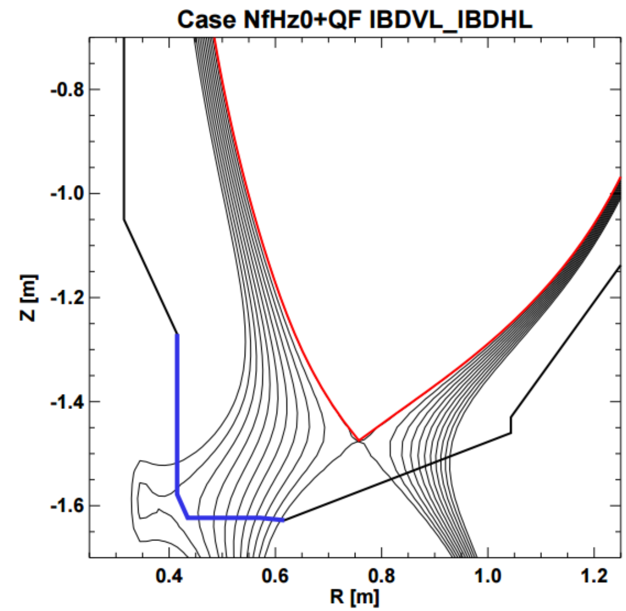


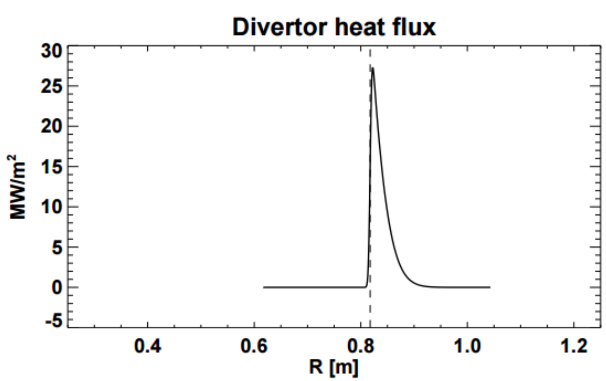


Example case from 96 with high I_{PF1A}

- **A=1.84, κ=2.5, $\delta_{U,\,L}$ = 0.193, 0.375, I_{OH}=0, $I_{PF1AU,L}$ = 15, 7kA**

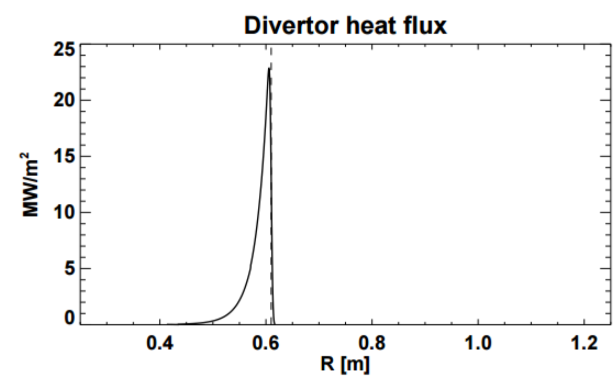






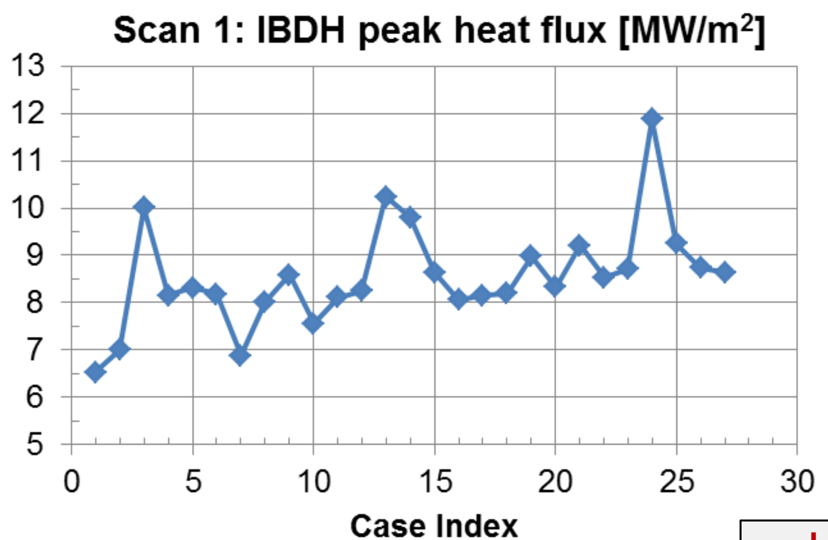
q_{peak} ~20-25MW/m²

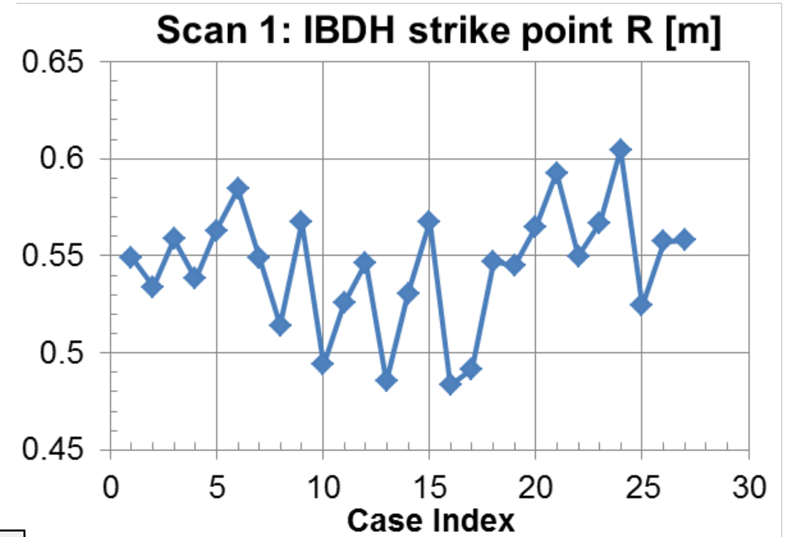
Δt_{flat} < 1s without sweeping or other mitigation



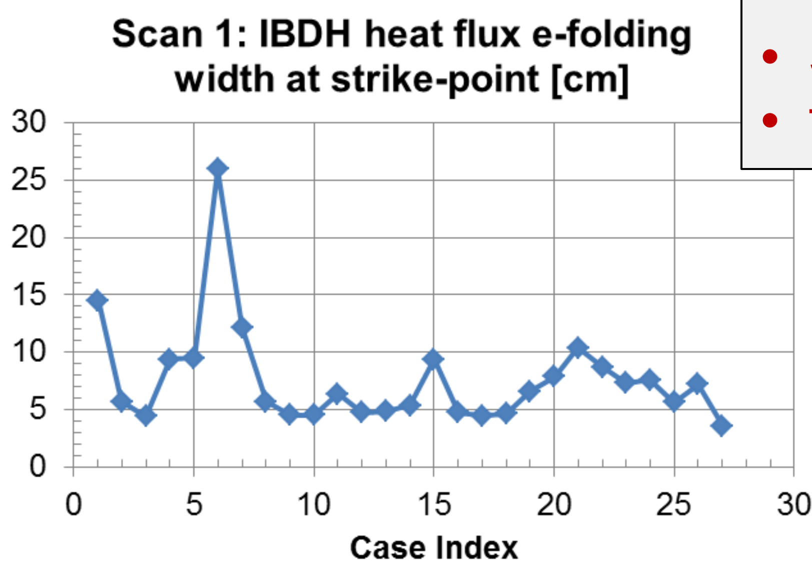
Scan 1: No PF1B, use PF1C for high flux expansion

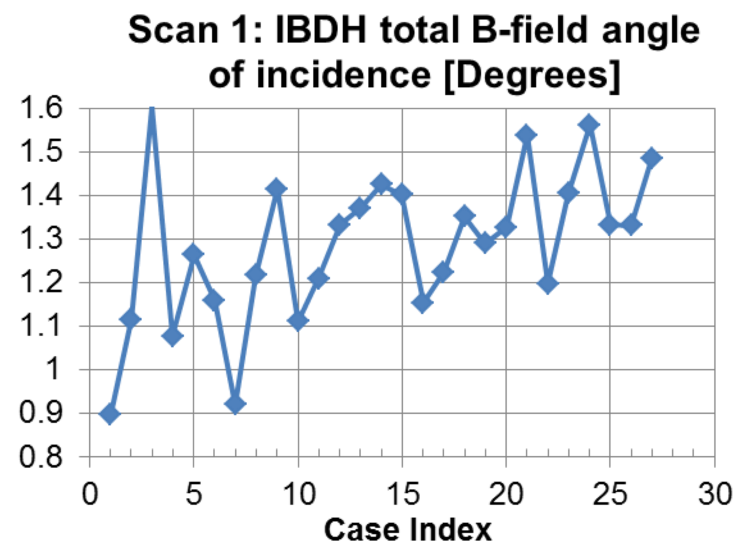
IBDH tile heat flux projections





- HD model λ_q
- $S / \lambda_q = 0.15$
- $f_{rad} = 0.3$





Additional scans improving quantification of 2MA/5s operating window, coil requirements

- Extrema of PF1 currents are largely for shapes that will be limited in pulse duration by PFC heat flux limits
  - Associated shapes are potentially important for boundary physics studies, less likely to be high-performance/long-pulse
- Heat flux mitigation using high flux expansion requires currents that are sufficiently below original GRD spec maxima that coil thermal requirements can be relaxed
- Proposal: Decouple PF1 maximum current requirements from maximum thermal requirements:
  - Retain GRD PF1 kA-turns to retain original shaping flexibility
  - Determine thermal requirements according to scenarios and PFC heat-flux limits rather than t_{flat} = 5.5s and T_{max} = 100C

Revised PF1 requirements under consideration

Original DPSS-GRD PF1 requirements

Coil	5.5s current normalized to maximum current	Action normalized to DPSS-GRD action	ΔT	Tmax
Units	none	none	deg C	deg C
PF1A	100%	100%	80	92
PF1B	62%	100%	88	100
PF1C	88%	100%	88	100

Updated PF1 requirements - 4/9/2017

Coil	5.5s current normalized to maximum current	Action normalized to DPSS-GRD action	ΔT	Tmax
Units	none	none	deg C	deg C
PF1A	62%	39%	31	43
PF1B	46%	54%	48	60
PF1C	52%	34%	30	42

- $T_{max} \leq$ ~60C instead of 100C sufficient in scans so far
- May mitigate cooling-wave / insulation issue for PF1s

Summary of updated requirements

- Extensive additional analysis performed coupling free-boundary equilibria and coil currents, projected heat-fluxes, and vertical stability (not shown)
- 2MA / 5s / 10MW operation requires operation of divertor legs on inboard horizontal/vertical tiles
- Heat fluxes from systematic scans used to inform / generate updated requirements for PFCs

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- Required PF1 coil currents for high-flux expansion or swept scenarios are significantly below GRD maxima
- Highest PF1 currents are set by scenarios that will be limited by PFC heat fluxes (or core stability)

- Next steps: Looking into PF4/5 current requirements

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Polar Region Overview

Stefan Gerhardt

Thanks to all the members of the engineering team who provided input…see their names on the slides

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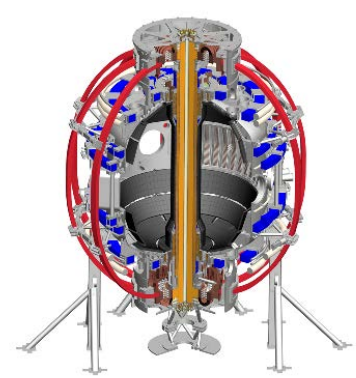
4/28/17

PPPL



This Talk

- What is the polar region?
- The review itself.
- What were some findings?

This Talk

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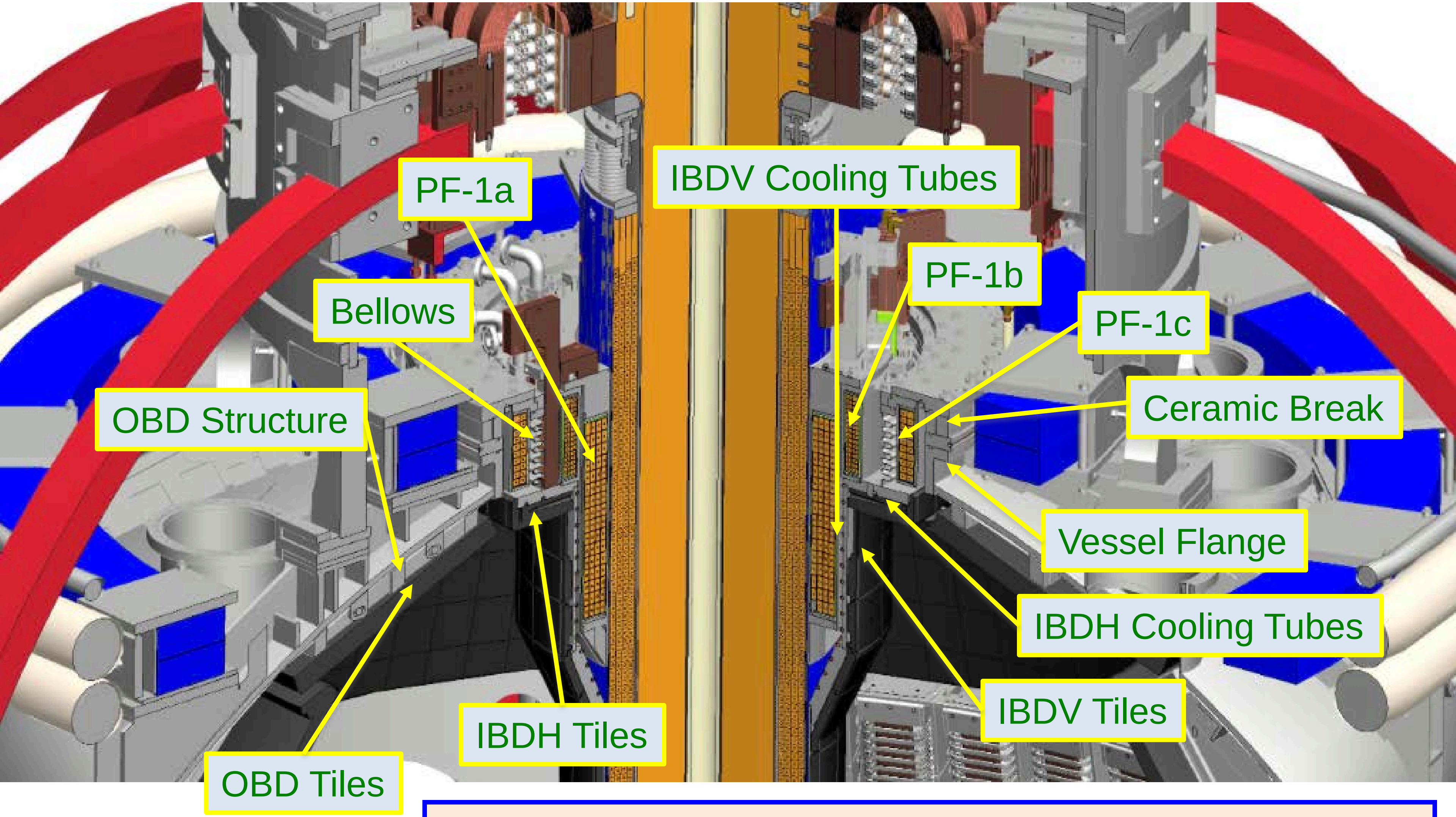
This is the Polar Region



This review dominantly about the vessel and PFCs, not coils

This Talk

- What is the polar region?
- The review itself.
- What were some findings?

Mechanics of the Review

- Held all day on 4/21/17
- Chaired by Valeria Riccardo
- Topics included both physics requirements and engineering design and analysis
- Both physics and engineering team members present as reviewers
- Numerous external reviewers
  - Brian LaBombard (MIT)
  - Dennis Youchison (ORNL)
  - Michel Huget (ITER, retired)
  - Tom Todd (CCFE, retired)

Warning on Images in this Talk

- In some cases, the components under consideration in a particular context may be in a CAD image where other components are old or incorrect.
- I'll show some CAD models, but also some analysis models.
- This is a work in progress!

This Talk

- What is the polar region?
- The review itself.
- What were some findings?

Review Goals: Bakeout and Vacuum

- From EoC: Machine reliability could be improved if the ceramic breaks were eliminated.
  - **Review Question**: Assess options for the vessel design and bakeout if the breaks are absent.
- From EoC: Machine reliability could be improved if the single O-rings were replaced by double O-rings or welded lip-seals
  - **Review Directive**: Assess options for double O-rings or welded lip seals, both with pumped interspaces.

First Technical Talk Discussed Options for Bakeout with Insulators Removed

- Reminder: CS is presently heated by DC current passed down CS.
  - If breaks are eliminated, then the outer vessel will shunt most of the DC current away from the CS.
- Options for Bakeout w/o Ceramic breaks

TF Current Oscillation

- Basic current path is similar to DC system
  - Global effect is to put power where we want it.
- Concerns
  - Heating in other smaller loops
  - Appropriate current shunts to bypass bellows
  - May need new power supply.

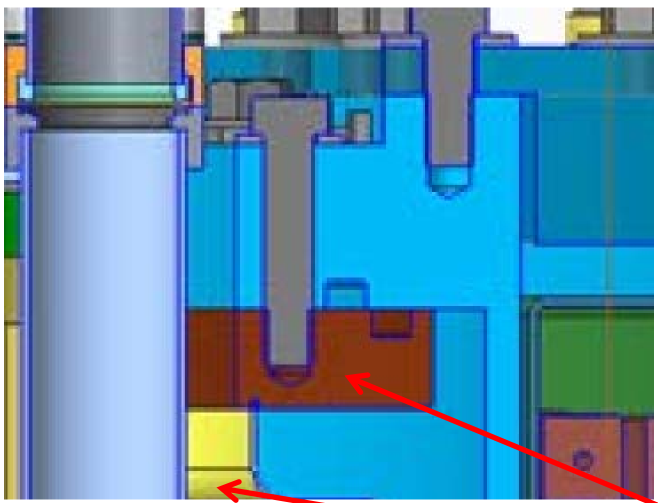
OH Current Oscillation

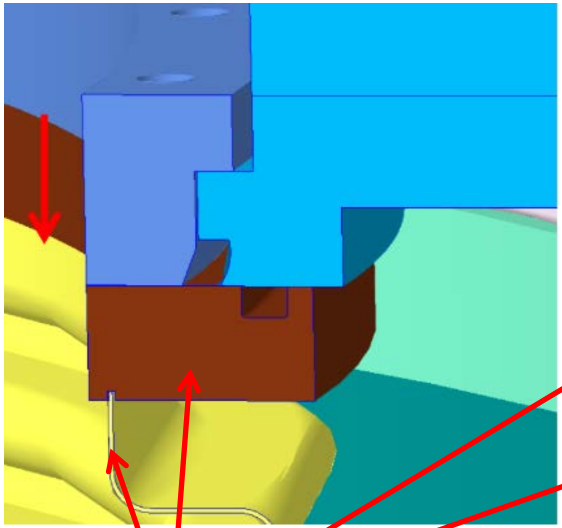
- Current can be more concentrated in CS (and vicinity) if the frequency is high enough (>~50 Hz)
- Concerns
  - Tendency to have large heating in other rings, such as PF-1a and PF-1b supporting structures
  - May need new power supply
  - OH fatigue life (very small stress for very many cycles)

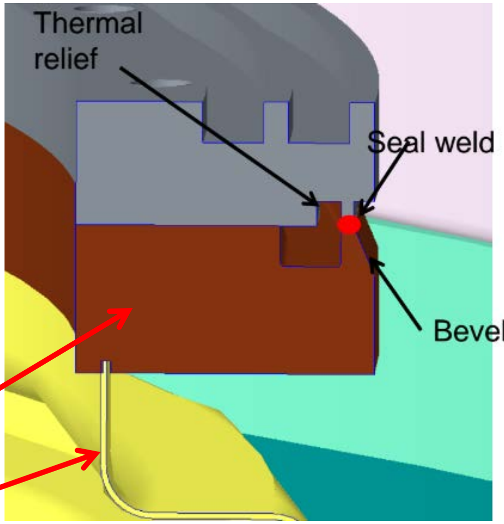
- Recommendation from C. Neumeyer was to retain the breaks
- Many chits in this area, and we continue to evaluate the best path
- A final decision has not been made.

C. Neumeyer

Assessed Various Geometries for Double O-Rings on Bellows Flange







Yellow Bellows and Brown Flange Welded to the Casing
Single O-ring Groove
Would Prefer Not to Remove These Parts from Casing

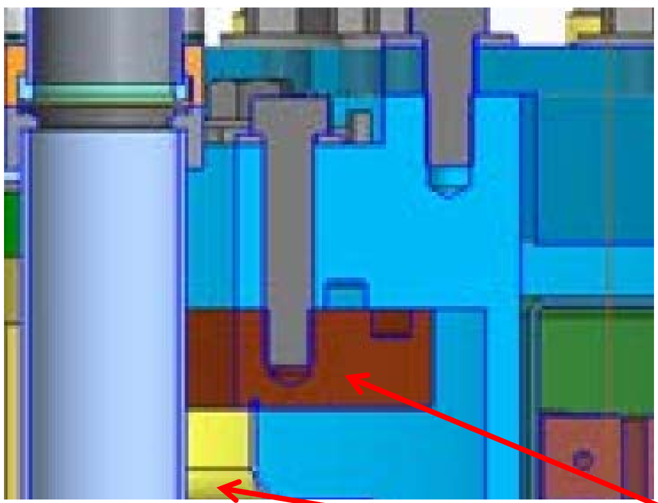
M. Sibilia,
J. Hennessy

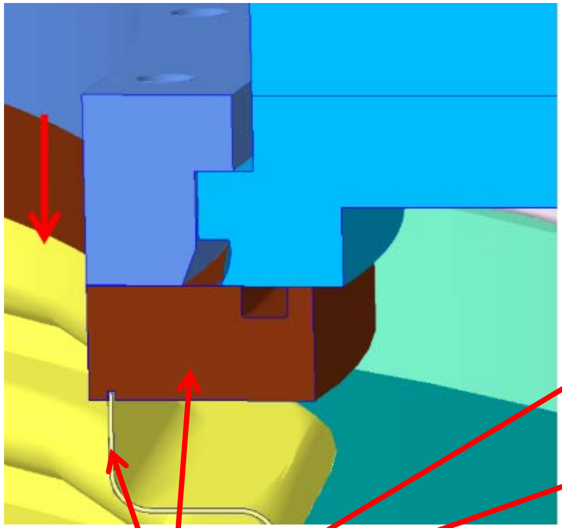
Assessed Various Geometries for Double O-Rings on Bellows Flange

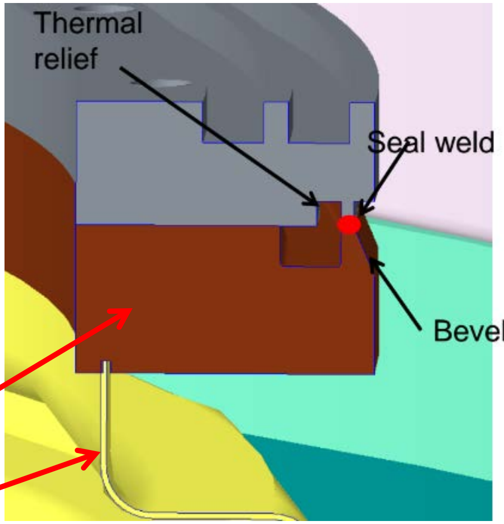
Option 1:
Put second O-ring on the PF-1c Flange

Option 2:
Embed the O-ring between parts

Option 3:
Weld new plate to bellows flange





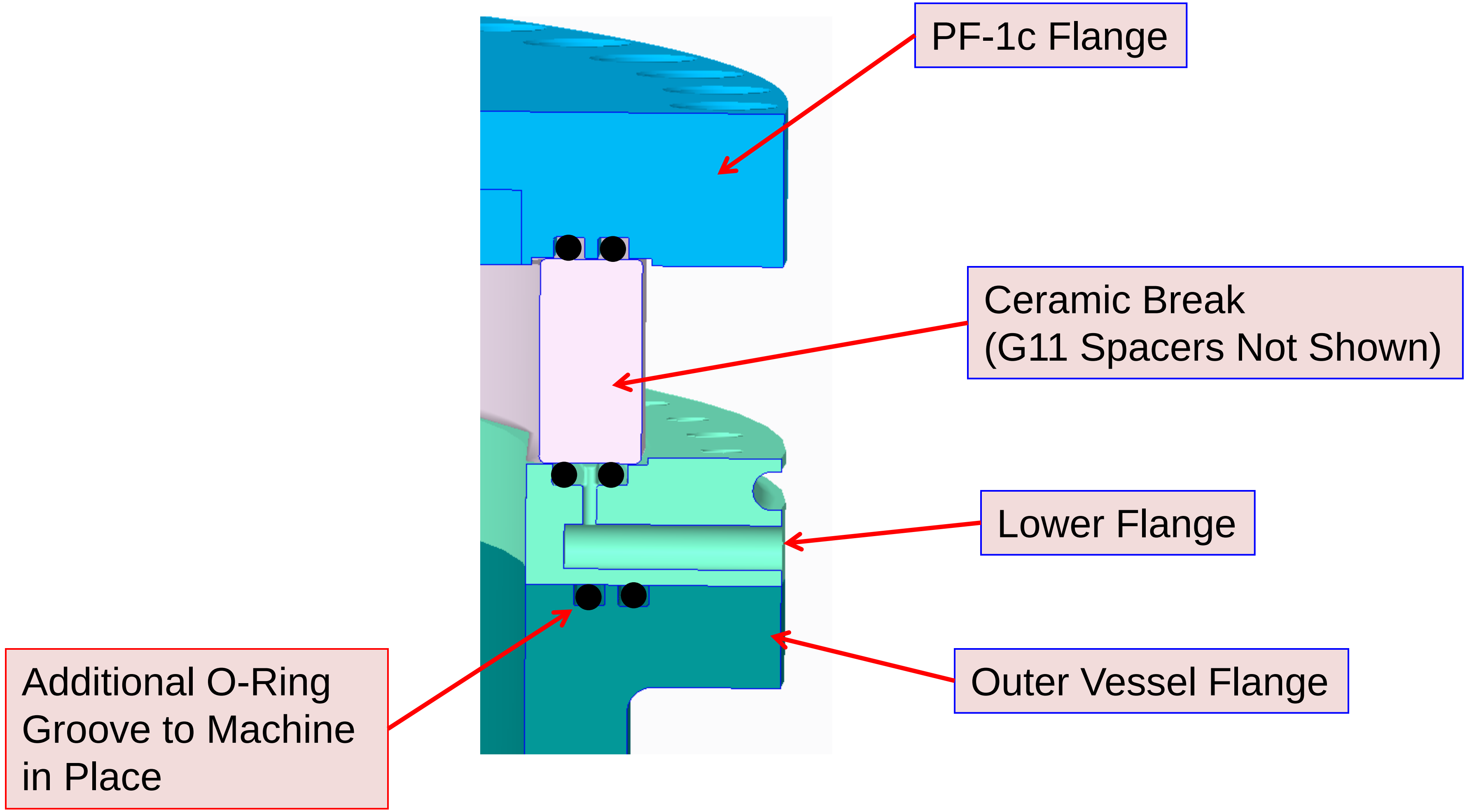


Yellow Bellows and Brown Flange Welded to the Casing
Single O-ring Groove
Would Prefer Not to Remove These Parts from Casing

Recommended for further evaluation

M. Sibilia,
J. Hennessy

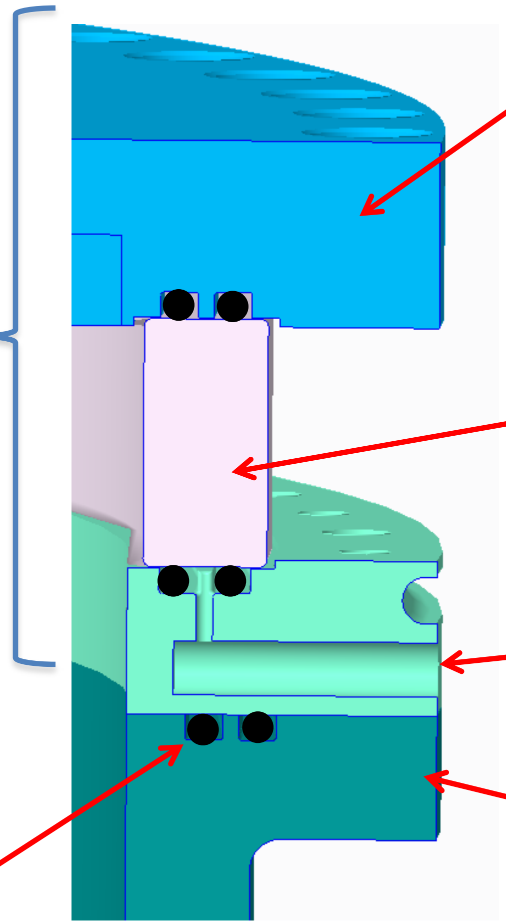
Have Reasonable Schemes for Providing Double O-Ring Seals on Break if it is Retained



M. Sibilia, J. Hennessy

Have Reasonable Schemes for Providing Double O-Ring Seals on Break if it is Retained

With Access to Interspace, the Ceramic Break Assembly Can be Fully Leak Checked Before Installation



Also looking at options for welded lip seals

M. Sibilia, J. Hennessy

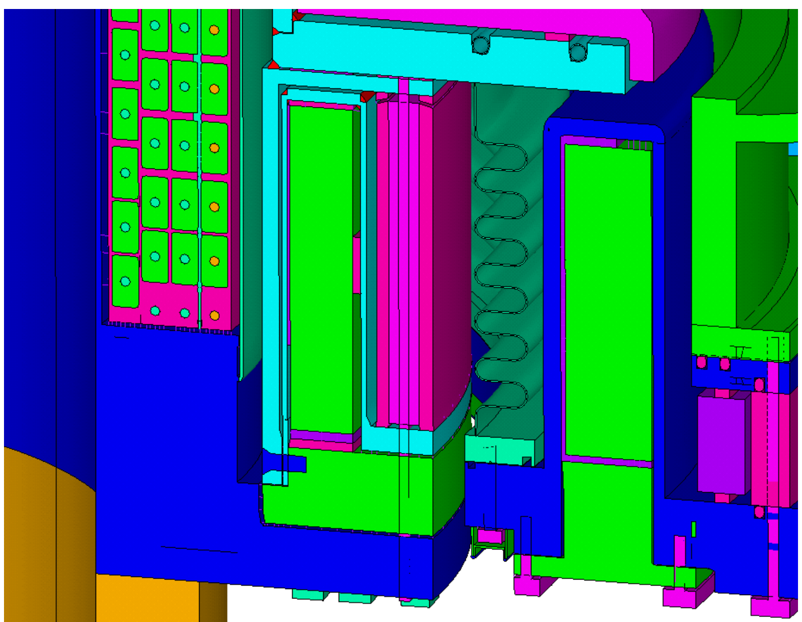
Review Goals: Coils Supports

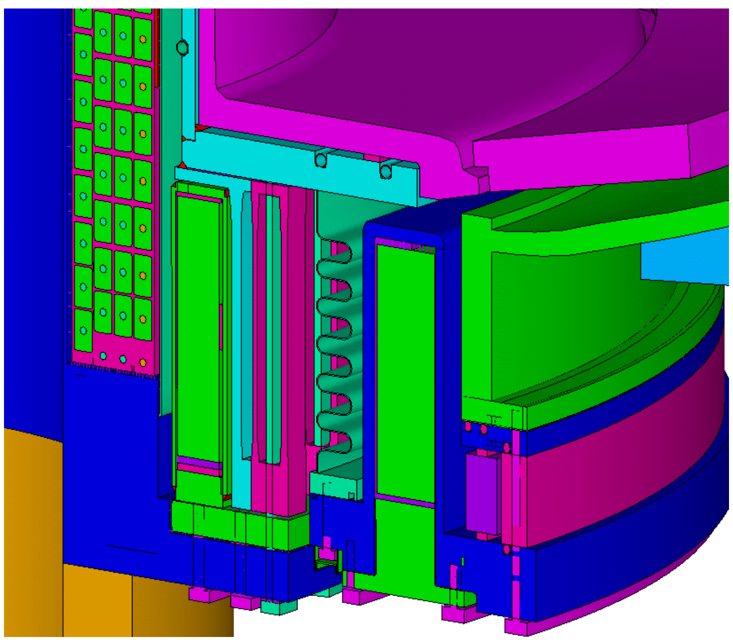
- From Operations: Bakeout constrained by heat leaks to the -1b coils due to their being tightly coupled to the casing.
  - **Review Directive**: Assess concept for the Casing and -1b supports that keep coil capability while allowing proper bake.
- EOC: A robust design for the PF-1c vacuum boundary must be developed
  - **Review Directive**: Assess options for the PF-1c design.
- EOC: Consider inner-PF coil designs that are free from mandrels
  - **Review Directive**: Assess the mounting schemes for those coils without mandrels

Assessed Various Geometries for the Casing Support and -1b Coil

Inner Support for Casing
- Direct Load Path
- PF-1b coil thermally isolated in a "sling"
- During bakeout, hot support piece between the cold PF-1a and PF-1b coils

Outer Support for Casing
- Offset Load Path
- Both cold coils adjacent, and separated from hot components

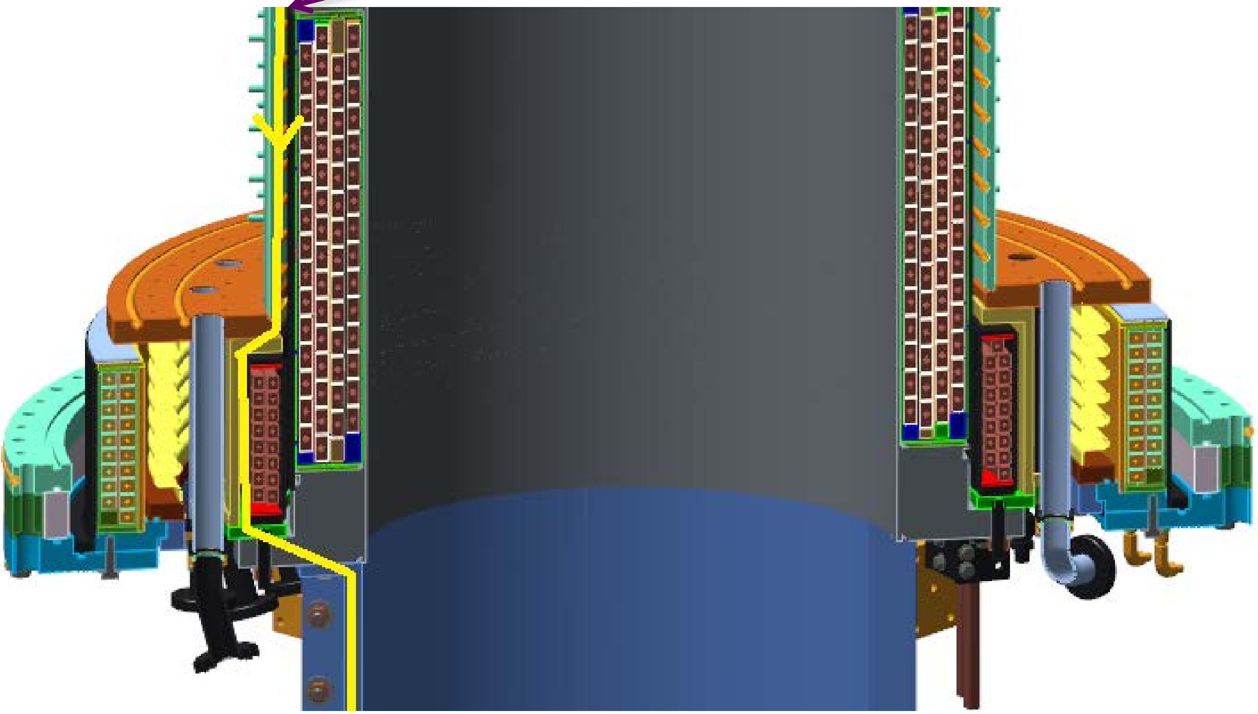


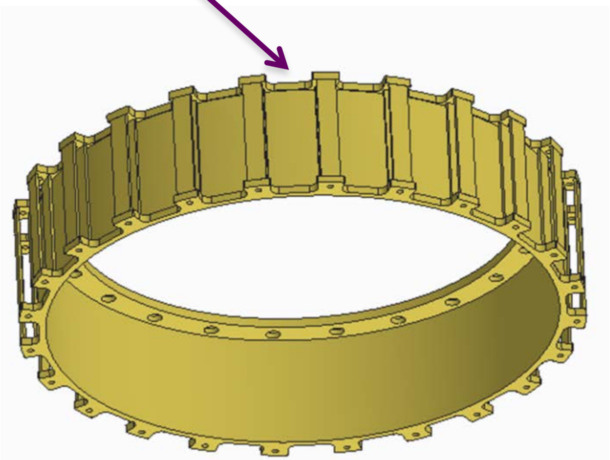


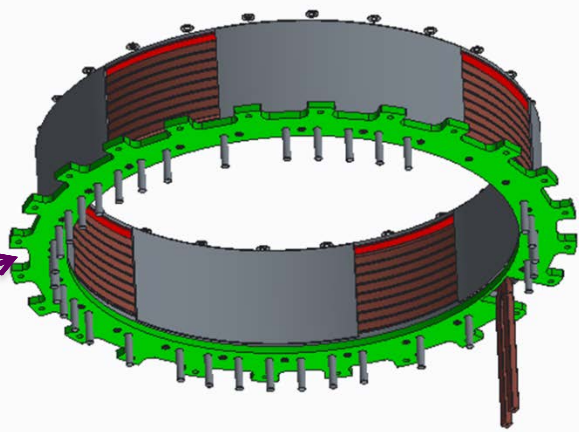
Favoring PF-1b Design With Support on Outboard Side

Indication of load path

Casing support structure accommodates radial growth from axial thermal gradients



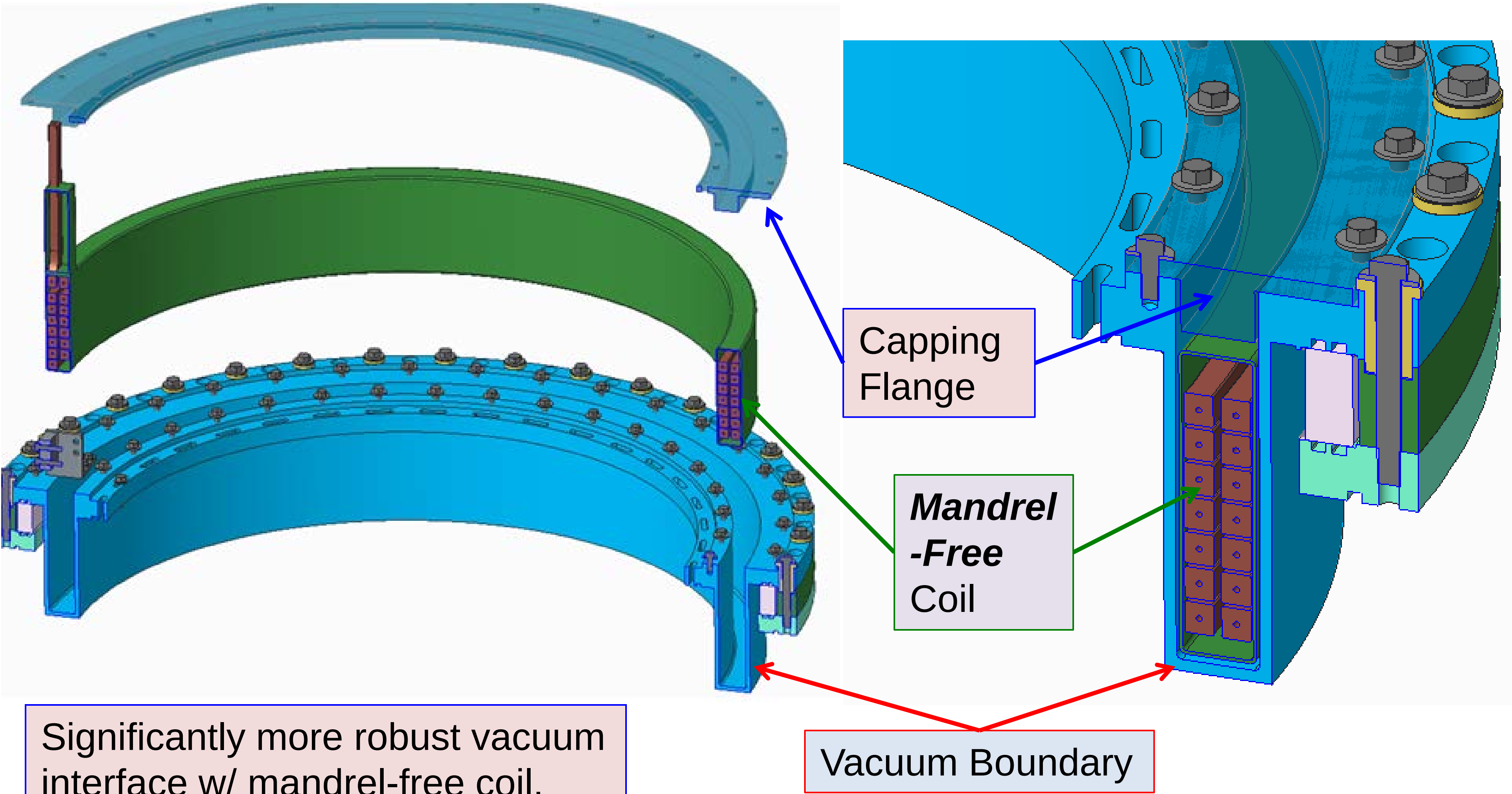




Mandrel-Free PF-1b Coil in "Sling"

P. Titus, M. Sibilia, J. Hennessy

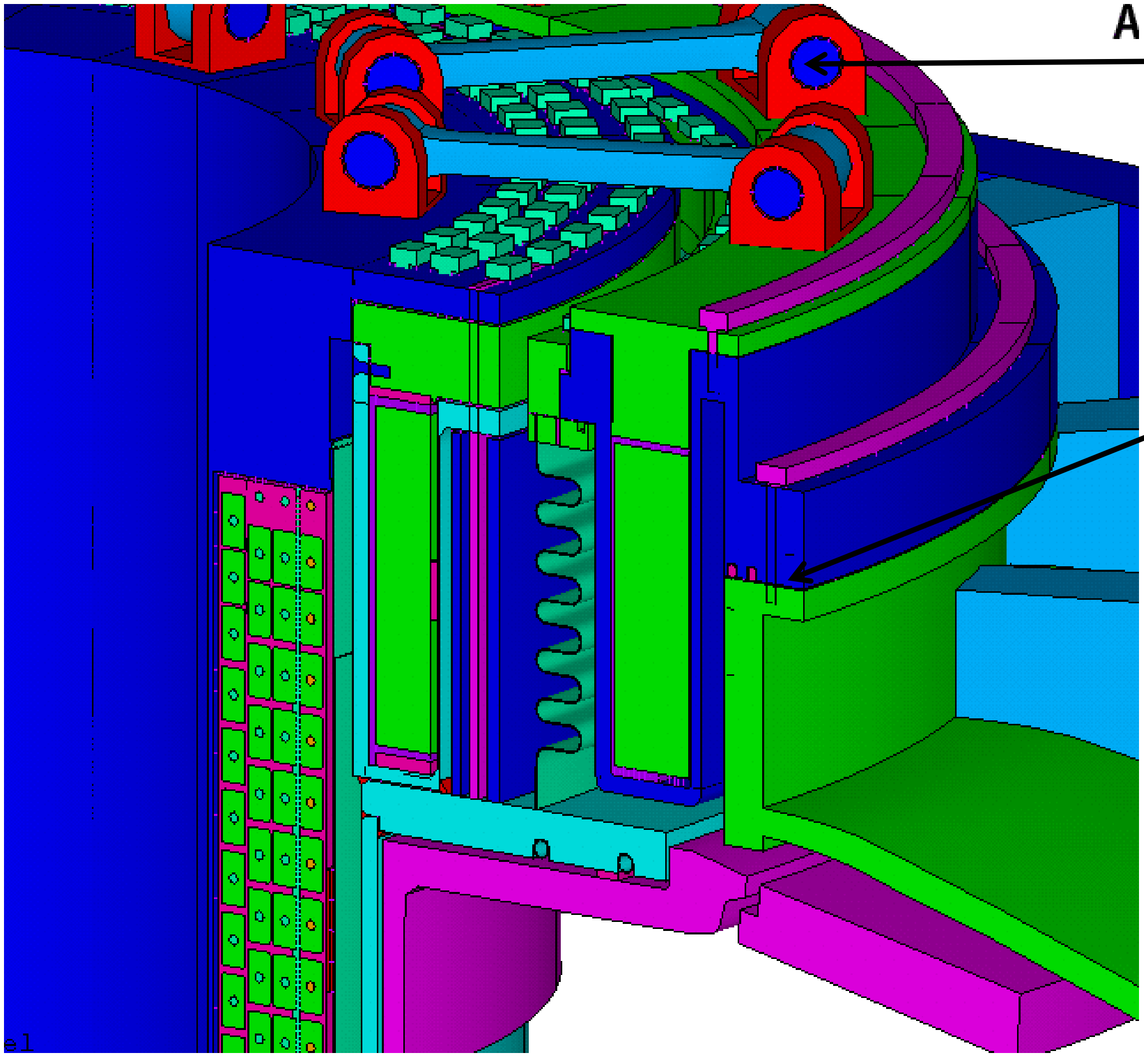
Settling Towards a Design of the -1c Coil Similar to That Proposed by EoC1



Significantly more robust vacuum interface w/ mandrel-free coil, robust 316SS vacuum housing and double O-ring seals

M. Sibilia, J. Hennessy

Nearby Designs for PF-1c Region are Consistent With the Elimination of the Insulator



Radius Rods (alternatively, trackbars)

No Ceramic Break

This design mandates one of the revised bakeout schemes.

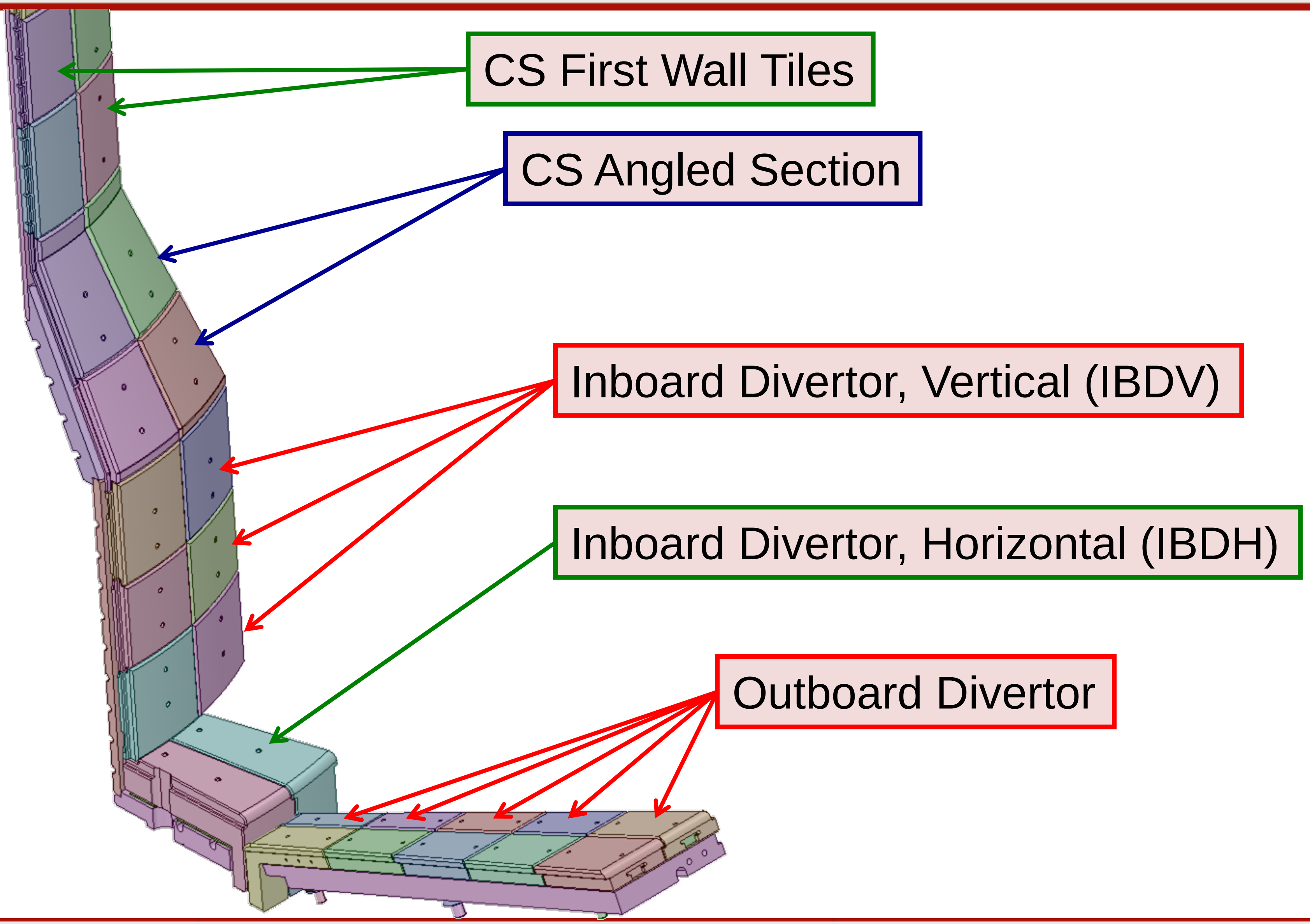
Ceramic Break may be retained in order preserve DC current bakeout

P. Titus

Review Goals: PFCs and Cooling

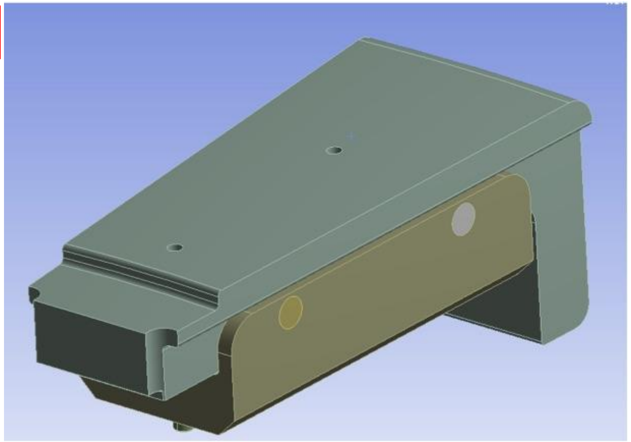
- DVVRs: Various tiles are not simultaneously qualified for disruption and thermal loads
  - **Review Directive**: Assess designs for the Horizontal Divertor tiles, including potential requirements for casing modifications.
  - **Review Directive**: Assess status of other CS tiles.
- Operations & DVVRs: Heating/Cooling lines on the inner vertical and horizontal targets have failed and/or may be inadequate.
  - **Review Directive**: Develop conceptual ideas for the replacement of those cooling lines.

These are the Polar Region Tiles

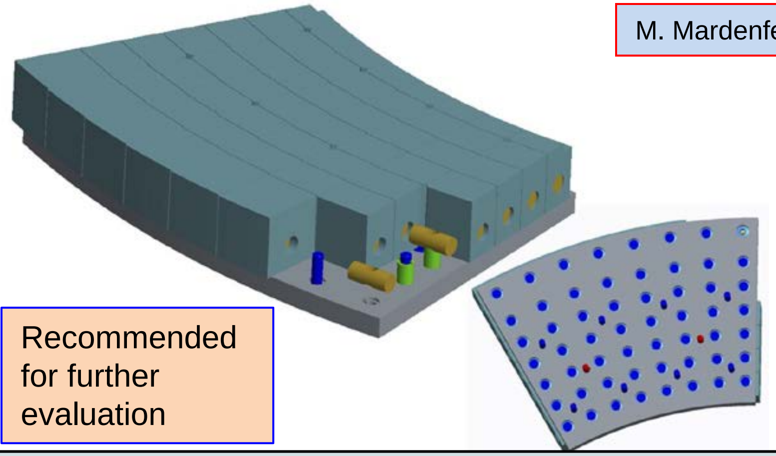


Assessed Two Concepts For New Inner Horizontal Target Tiles

A. Brooks



M. Mardenfeld

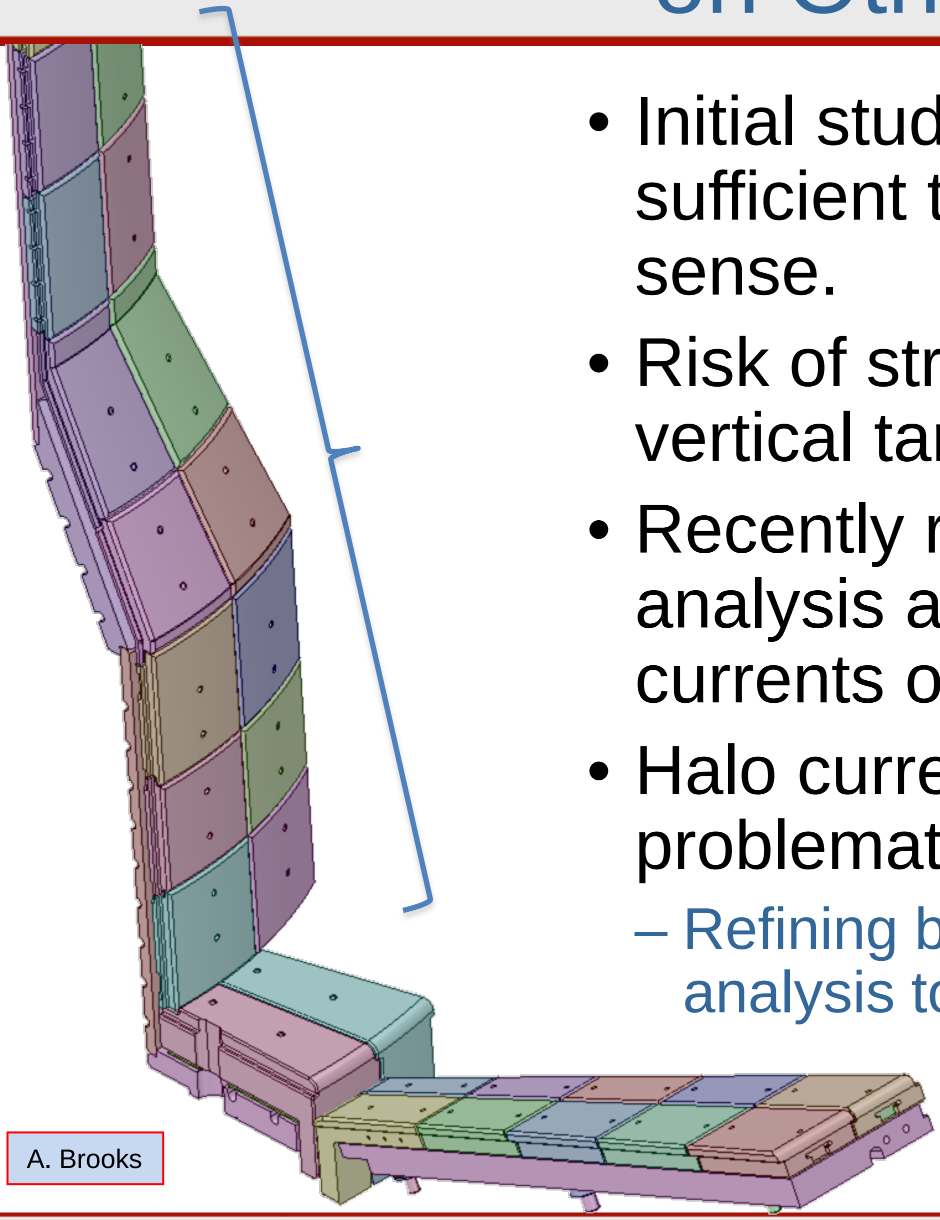


Recommended for further evaluation

Simple Cassette, Sigrafine, 1 or 2 sub-tiles		Fake Monoblock (Mardenblock)	
Advantage	**Disadvantage**	**Advantage**	**Disadvantage**
Meets GRD heat flux, especially with subdivided tiles	Will be thermal stress limited, likely less operating space	No surface features if fishscaled • No Leading Edges • No Stress Concentrators	Tends toward wanting fishscaling
Pins react radial halo currents force	Stress concentrations, surface features for bolt holes, diagnostic	Limited by max T Replace cubes to change helicity Halo Current Forces Smaller	Substantial diagnostic redesign

We continue to evaluate the optimal path forward, including optimal fish-scaling angles

Still Working to Resolve Our Final Position on Other Tiles

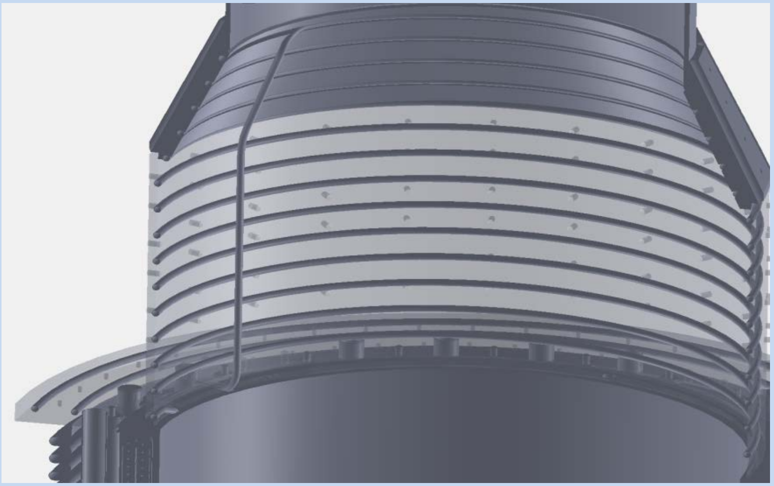


- Initial studies indicate that their may be sufficient thermal margin in an average sense.
- Risk of strong leading edge heating on vertical target
- Recently revised both physics and analysis assumptions regarding halo currents on the CS.
- Halo current loads are large and likely problematic
  - Refining both the requirements and the analysis to better assess this issue.

A. Brooks

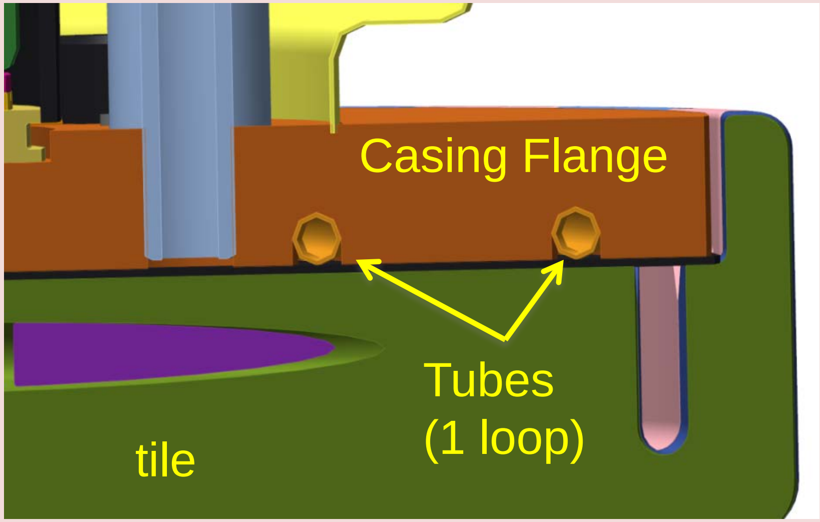
Vertical Cooling Tube is Straightforward, But Horizontal Flange Cooling Presents Challenges

Vertical Target Cooling



- Water cooling permitted since on air side
- Calculations show little apparent risk in removing the required heat provided appropriate thermal contact provided.
- Assessing means to best hold in place

Horizontal Target Heating/Cooling



- Recent requirement banning in-vessel water reduces cooling capability.
- Requires good thermal contact between tubes and flange, and between tiles and flange.
- Assessing whether we need to modify the geometry.

Summary

- Productive review addressed design options following from DVVR & Extent of Condition reviews.
- We have developed initial design concepts to address many of the identified issues in:
  - Vessel & Vacuum Boundary
  - Coil Supports
- We are actively working on many outstanding issues as discussed above.
- Will present our findings, options, and recommendations in 2nd EoC meeting and follow-on design reviews.

Agenda

- FES perspective on Recovery / Research: Josh King
- Organizational Diagnosis Status / Next Steps: Rich and Jon
- Recovery:
  – DVVR / EoC status and next steps (Rich Hawryluk)
  – Updates on divertor heat flux and PF coil requirements (Jon Menard)
  – Recent engineering design activities in polar regions (Stefan Gerhardt)
- Research:
  – Status and plans for PFC Requirements working group (Matt Reinke)
  – Impact of polar region options on research ops flexibility (Matt / Jon)
  – Overview of upcoming FESAC and NAS workshops (Rajesh Maingi + Jon)

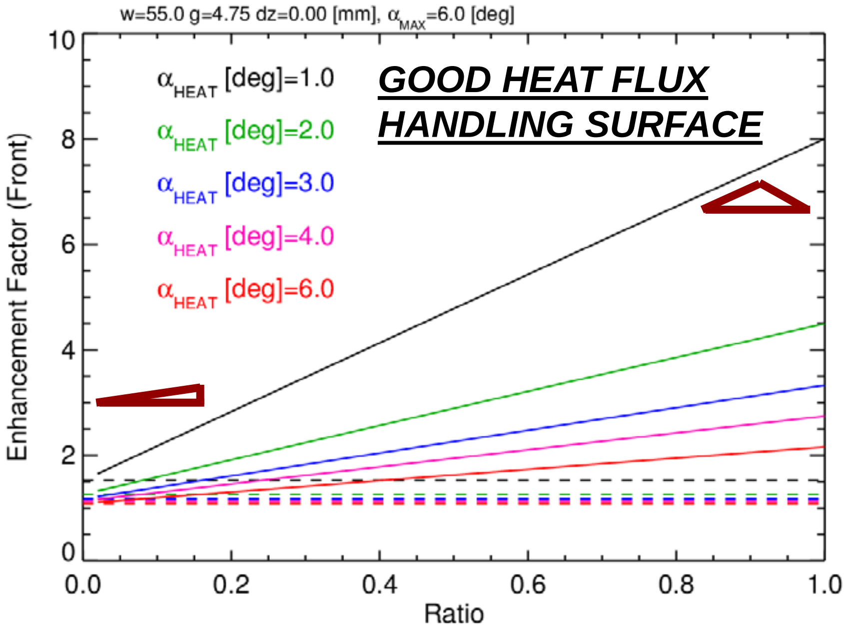
NSTX-U PFC Performance and Monitoring Requirements Working Group (PFCR-WG)

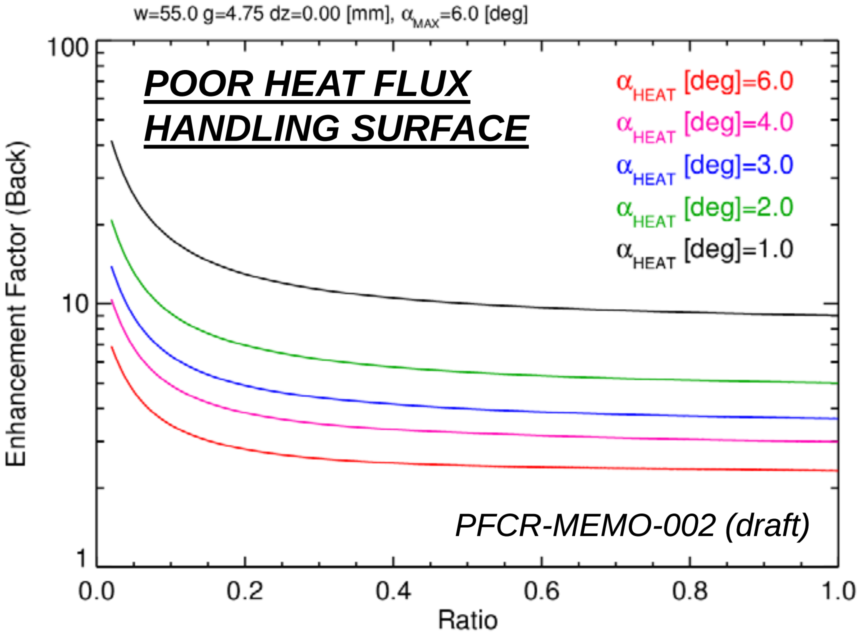
- Formed and charged by JEM after 3/22 Team Meeting:
  - 1. Define which (additional) parameters need to be specified in an updated requirements document for the NSTX-U PFCs
  - 2. Facilitate generation of updated requirements utilizing:
    - a. Available reduced models, empirical scalings, boundary simulations
    - b. Ultimately, a validated model for specifying heat loads to all plasma facing components for arbitrary NSTX-U scenarios
  - 3. Develop instrumentation plans and operational guidance
  - 4. Work closely with engineers and analysts to develop and implement requirements
- Kick-off meeting on 3/29 (Deputy: Mike Mardenfeld)
  - 38 members: theory, experiment and engineering participation
  - PPPL, ORNL, U. Wisconsin, U. Washington, UT-K, LLNL and CCFE
- Want to increase participation within the NSTX-U team
  - Many open questions that need physics input to guide engineering design and outline future operations guidance
  - See website for open ACTION ITEMS, please submit your own!
    - literature investigations, NSTX/NSTX-U data mining, interaction with other devices

Recent Work and Future Plans

- Directly contributed to the drafting of the requirements document which was reviewed at PFCR-WG meeting
  - charge 1, close to being complete (rev0 of requirements soon)
  - summarized evolution of requirements process on MAST-U
- In-progress/near complete contributions (MEMOS!)
  - guidance to Recovery Project on EoC recommendations for real-time protection of PFCs (needs further WG consensus)
  - guidance on reversed field requirements and tile shaping options (next slide)
  - impact of error fields like CS alignment on tile shaping (Ferraro)
  - review of literature/designs on carbon temperature limits (Raman)
- Need to start working on Charge 2 to help improve the accuracy in the heat loading data that is in the requirements (future meeting)
  - start from Menard model, check accuracy & question assumptions
    - examine uncertainties in the IBDV that could impact design decisions
    - respond to PFC Engineering team as they analyze other regions of the machine
    - try and bound physics uncertainty to ensure requirements are accurate
  - eventually move to proven community tools (PFCFlux, SMARDDA?) that can robustly handle shaped tiles
    - not the first facility to deal with this and should take advantage of existing knowledge

Challenge to Shape Tiles for Flexibility





- high heat flux divertors typically shape tiles toroidally to hide leading edges created by tooling gaps, diagnostics and installation/fabrication tolerance
  - necessarily give up heat flux handling to gain operational flexibility
  - 'fish-scaling' (uni-directional) or 'roof-top' (bi-directional)
- plotted 'enhancement factor' qualitatively means either dropping heat flux (proportionally) or operational time (squared) [it's really a bit more complicated than this]
- optimal tile shape driven by desired operational space
  - desired range of field line angles, expected heat flux on forward/rear surfaces
  - even if we decided on an optimized case, still need operational space to get to it!

Impact of polar region options on research flexibility

- No ceramic breaks would eliminate CHI capability
- Tile fish-scaling required in several regions to manage high heat fluxes of 2MA/10MW/5s → Eliminates reversed B_T
  - Langmuir probes, gas feeds / divertor MGI, other sensors in tiles will also need to be redesigned in concert with PFCs
- (Near) perfect snowflake divertors (SFDs), other advanced divertors will have reversed helicity for some tile regions
  - Need requested SFD equilibria ASAP to assess tile impact / options
  - Bi-directional tiles may be an option for lower $q_\perp$ divertor regions
- Pedestal/ELM/H-mode threshold studies - need additional specs of requested range of ΔR_{SEP}, duration, κ, δ, R_{strike}
  - Up/down asymmetric boundary increases q_{peak}, reduces Δt_{flat}
- BP SG/TT TSG charged to provide info to PFCR-WG/JEM

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National Academy of Science charged to assess importance of burning plasmas in future of US fusion energy development

- Also consider scientific & engineering challenges, opportunities on path toward fusion energy, scenarios to achieve that goal
- The NAS committee will prepare an interim report that will:
  - **I1.** Describe and assess the **current status of U.S. research that supports burning plasma science**, including current and planned participation in international activities, and describe international research activities broadly
  - **I2.** Assess **importance of US burning plasma research to development of fusion energy**, also plasma science, other science & engineering disciplines
- And will prepare a final report, building on interim report:
  - **F1.** Consider **scientific, engineering challenges and opportunities** associated with advancing **magnetic confinement fusion as energy source**, including scientific, technical developments since 2004 NAS study on burning plasmas
  - **F2. In two separate scenarios in which, after 2018, (1) the United States is a partner in ITER, and (2) the United States is not a partner in ITER: provide guidance on a long-term strategic plan (covering the next several decades)** for a national program of burning plasma science and technology research which includes supporting capabilities and which may include participation in international activities, **given the U.S. strategic interest in realizing economical fusion energy in the long term**

Goals of fusion community workshops:

1. Provide an open forum to hear community views on
   - Importance of burning plasma research (charge I2)
   - Key scientific and engineering opportunities (charge F1)
   - Impacts if US is/is not partner in ITER (charge F2)
   - ➢ And provide community feedback on these views

2. Identify key elements of a long-term U.S. fusion strategic plan - with/without U.S as partner in ITER
   - Including both domestic and international research
   - Identify points of community consensus on the most critical key elements of that plan

Community workshop dates and locations

- **Workshop 1**: July 24-28, 2017 - Madison, WI
- **Workshop 2**: Dec. 11-15, 2017 - Austin, TX (tentative)

- Exact dates of NAS meetings are not yet available
  - But approximate dates ranges have been provided by NAS

- Workshop 1 dates (July) chosen to:
  - Provide input to second NAS meeting, NAS interim report
- Workshop 2 dates (December) chosen to:
  - Provide time to assess and incorporate the NAS interim report (due October 31, 2017) in workshop discussions
  - Provide input to later 3rd / 4th NAS meeting, NAS final report

Community Input

- Input will be solicited in the form of 2 page whitepapers briefly summarizing a proposed strategic element
- Whitepapers due 11:59PM Eastern June 26, 2017
- Community input will also be sought in the form of brief presentations at workshop(s)
  - Whitepapers will be used by Program Committee to select and/or consolidate strategic elements or topics for oral presentation
- Workshop Website: https://sites.google.com/site/usmfrstrategicdirections
- Questions?
  - Contact co-chairs: David Maurer, Jon Menard, and Mickey Wade
    - maurer@physics.auburn.edu, jmenard@pppl.gov, wade@fusion.gat.com

Program Committee Membership for U.S. Fusion Community Workshops

Name	Affiliation	E-mail Address
Workshop Co-chairs		
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Jonathan Menard	Princeton Plasma Physics Laboratory	jmenard@pppl.gov
Mickey Wade	General Atomics	wade@fusion.gat.com
Program Committee Members		
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Francois Waelbroeck	University of Texas - Austin	flw@mail.utexas.edu
Steven Zinkle	University of Tennessee - Knoxville	szinkle@utk.edu

FESAC Transformative Enabling Capabilities (TEC) panel – request for community input

R. Maingi, A. Lumsdaine,
on behalf of the FESAC TEC panel

27-April-2017

FESAC TEC panel requests your input

- The FESAC was recently charged “*to identify the most promising transformative enabling capabilities (TEC) for the U.S. to pursue that could promote efficient advance toward fusion energy, building on burning plasma science and technology.*”
  - https://science.energy.gov/~/media/fes/fesac/pdf/2017/Charge_Letter_FESAC_Feb_2017.pdf

- The charge lists sample focus areas including *”liquid metals, additive manufacturing, high critical-temperature superconductors, exascale computing, materials by design, machine learning and artificial intelligence, and novel measurements.”* Other relevant areas considered!

- The committee will be accepting community input on any *”promising transformative enabling capabilities”* that promote efficient advance toward fusion energy.

FESAC TEC panel invites your input for white papers and talks to be presented at public meetings

Chair: R. Maingi, Vice-Chair: A. Lumsdaine

FESAC ex-officio: D. Rej, S. Knowlton; FES lead: S. Barish

Three sub-panels:

- Plasma Diagnostics, Actuators, and Control (lead: A. White)
- Plasma Materials Interaction (lead: J.P. Allain)
- Reactor and Balance of Plant (lead: C. Greenfield)

Physical meetings:

- **May 30-June 1, 2017 (Washington DC area)**: Community input meeting for Plasma Diagnostics, Actuators, and Control sub-panel, and also for Reactor and Balance of Plant sub-panel. **TALK REQUEST DEADLINE: MAY 16**
- **June 20-22, 2017 (Chicago or Washington DC area)**: Community input meeting for Plasma-Materials Interaction sub-panel. **TALK REQUEST DEADLINE: JUNE 6**
- **July 19-21, 2017 (PPPL, Princeton NJ)**: Final workshop for all three sub-panels. **TALK REQUEST DEADLINE: JULY 5**

Guidance for white papers and talks

- White papers limited to 4 pages
- Talk preliminary guidance: 15 min. talk, 15 min. of Q/A from the FESAC subcommittee
- Talk request should made to R. Maingi (rmaingi@pppl.gov) and A. Lumsdaine (lumsdainea@ornl.gov)
- Final talks and white papers can be submitted through the FESAC TEC home page; cc to Maingi & Lumsdaine

https://www.burningplasma.org/activities/?article=FESAC%20TEC%20Panel%20Public%20Info%20Home%20Page

White papers and talk content guidance

- Seven questions to address in white papers and talks
  - Description of the technology
  - Application of the technology for fusion energy, e.g. in a fusion power plant
  - Expected performance of the technology – what is the critical variable (or variables) that determines or controls the output of the technology?
  - Design variables – what are the parameters that can be controlled in order to optimize the performance of the technology?
  - Risks and uncertainties with the technology development and performance
  - Current maturity of the technology, using e.g. Technical Readiness Levels (TRL – see Appendix 2 for DoE TRL guidelines)
  - Required development for the technology

Thank you!

Any questions?