NSTX-U

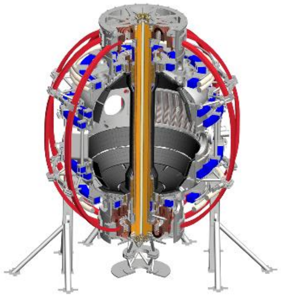
NSTX-U is sponsored by the
U.S. Department of Energy Office of Science
Fusion Energy Sciences

PFC Performance and Monitoring Requirements Working Group

M.L. Reinke

Kickoff Meeting
B-252
3/29/2017

PPPL

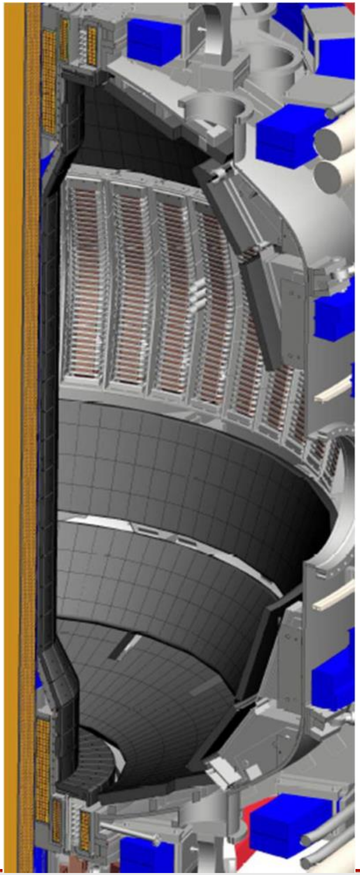


Goals of this Meeting

- brief background and status of NSTX-U Recovery Project activities related to the PFCs
  - outline of how NSTX/NSTX-U heat loads were specified
  - recent extension of this methodology
- introduction of the mission of the working group
  - (alarmingly) near term needs
  - longer term goals
- suggested org. structure and communication methods
- (if time) get started, and assign homework

PFCs & NSTX-U Recovery Project

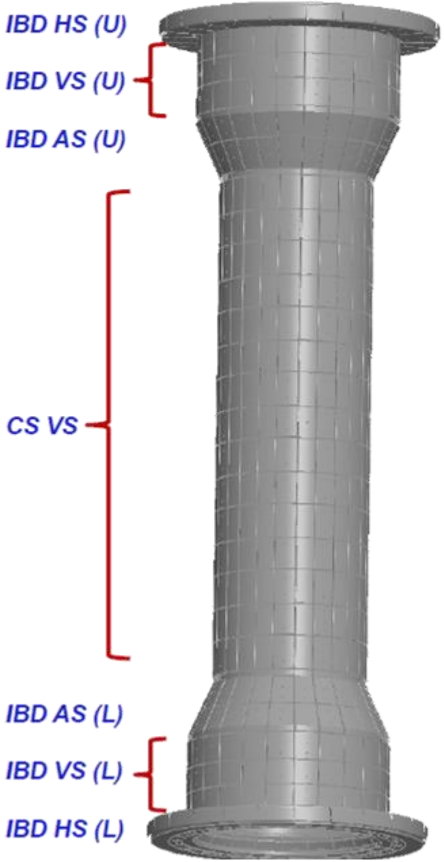
- see recent Team Meeting slides on status of the Recovery Project
- two DVVRs on Integrated Systems and the VV+PFCs identified range of **‘necessary for startup’** corrective actions
  - update heat flux requirements for: inner horizonal target, inner vertical target, outer divertor
  - evaluate what scenarios (i.e. the ‘96’) can plausibly reach 2 MA, 5 seconds w/r/t PFC heating
- other strongly recommended for startup or added to operations plan
  - centerstack first wall, outboard limiter



Portion of PFCs Do Not Meet Specifications

- IBDhs limited by thermal stress inherited by NSTX mounting scheme and material choice
  - PFCs are now critical components due to impact of failure
  - what was 5.2 MW/m^2 $\rightarrow$ 3.7 MW/m^2

Issue	GRD Spec	Achieved?
Heat Flux to IBDhs	5.2 MW/m2 avg 8.3 MW/m2 peak	No – limited to 3.7 MW/m2 avg
Heat Flux to OBD row1	5.2 MW/m2 avg 8.3 MW/m2 peak	No – limited to 4.2 MW/m2 avg
Heat Flux to IBDvs & IBDas	1.6 MW/m2 avg 2.5 MW/m2 peak	Yes
Heat Flux to CSFW	0.1 MW/m2 avg 0.2 MW/m2 peak	Yes



- NOTE: we are not here to try and redesign the tiles, but we may be asked for input on diagnostics

NSTX/NSTX-U Design Basis

- design point spreadsheet: description and tables
  - based on a 1996 memo
  - single points for SND, DND
  - *italic: assumed values*
  - DND @ 5 sec, SND @ as determined to be allowable
- NSTX-U GRD "The heat flux deposited on the PFCs will be controlled by the NSTX physics program (e.g., advanced divertor operations) and will be maintained within allowables based on the choice of materials, geometry, and cooling. Allowables resulting from the design will be provided. Nominal heat and power flux widths on the PFCs, in the absence of advanced divertor operations, are shown in Table 3-2."
  - implies a flow direction ENG to PHYS

	SND	DND	
Total Heating power (nbi+rf+ohmic) [Pheat]	*14.00*	*14.00*	MW
Power fraction radiated from core [frad_core]	*0.125*	*0.125*	
Total Power in SOL [Psol]	12.25	12.25	MW
Center Stack...			
SOL Power fraction to Center Stack [fcs]	*0*	*0*	
Total Power to Center Stack [Pcs]	0	0	MW
Power Dissipation Area [Acs]	*3.91*	*3.91*	m^2
Average Loss Power Flux [qcs]	0	0	MW/n^2
Outboard Divertor			
SOL Power fraction to divertor [fdiv]	*0.75*	*0.8*	
Power fraction radiated at divertor [frad,div]	0	0	
Up/down asymmetry [Ku/l]	*1*	*1*	
Power flux width at midplane [mp]	*0.01*	*0.01*	m
Flux expansion factor [fflux]	*20*	*20*	
Private flux region additional area factor [fpfr]	*0.33*	*0.33*	
Incidence angle [alpha]	*60*	*60*	degress
Radius to strike point [Rsp]	*0.49*	*0.49*	m
Power flux width at divertor [Δdiv]	0.31	0.31	m
Divertor target area	0.95	0.95	m^2
Power to divertor [Pdiv]	9.19	4.9	MW
Average power flux [qavg]	9.65	5.15	MW/m^2
Peak power flux [qpeak]	15.27	8.14	MW/m^2
Total Power in Outboard Divertors [Pobd]	9.19	9.8	MW
Inboard Divertor....			
Total Power in Inboard Divertors [Pibd]	3.06	2.45	MW
First Wall...			
Total Power to First Wall [Pfw]	1.75	1.75	MW
TOTAL POWER	14.00	14.00	MW

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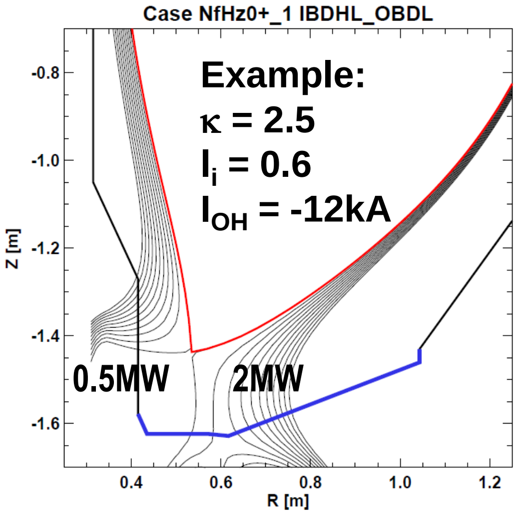
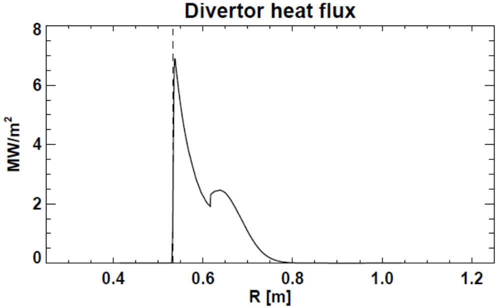
Table 3-2 - Heat Flux and Power Flux Width on PFCs

	CSFW	IBDAS, IBDVS	IBDHS
Single Null Divertor, T_{pulse}= as determined to be allowable			
Average Heat Flux q_{avg} [MW/m^2]	0.1	4.0	9.8
Peak Heat Flux q_{peak} [MW/m^2]	0.2	6.3	15.5
Power Flux Width λ [m]	n.a.	0.3	0.3
Double Null Divertor, T_{pulse}=5.0s			
Average Heat Flux q_{avg} [MW/m^2]	0.1	1.6	5.2
Peak Heat Flux q_{peak} [MW/m^2]	0.2	2.5	8.3
Power Flux Width λ [m]	n.a.	0.3	0.3

Recent Effort Expand Specification (Menard)

- Goal: P_{NBI} = 10MW, I_P = 2MA, B_T = 1T, Δt_{flat} = 5s
  - up/down symmetric (UDS) divertor as baseline
    - Mitigation: PF1C / PF1B for flux expansion and/or strike-point sweeping
- f_{rad} (core + divertor) = 0.5, $f_{outboard\text{-}legs}$ = 0.8, N_{div} = 2
  - 2MW onto each outboard leg, 0.5MW to each inboard leg
  - Eich/Goldston SOL heat-flux width for outer and inner legs
    - Note: Outer leg q_{peak} and widths compare favorably to NSTX data
- Confinement: H_{98} to H_{ST} (H_{98}~1.6)→ β_N = 3 to 5
- κ = 2.4-2.7, l_i = 0.5-0.7 → NSTX-U γ_{vert} ~ NSTX γ_{vert}
  - Consider open-loop vertical instability index f_d:
    - $f_d < 0$ stable, $0 \leq f_d < 1$ resistively unstable, $f_d \geq 1$ ideally unstable
  - $f_d \leq 0.5$ from NSTX/NSTX-U flat-top VDE thresholds (Boyer)
  - Need to confirm/determine if PF3 power supply has sufficient bandwidth (4× control power) at I_P = 2MA, 2× I_{PF3} (Boyer)





Open, On-Going Questions

- are the changes to the specifications correct?
  - do they capture a modern physics basis for heat loads?
- what else is missing from the design basis that could impact the heat loading? (i.e. 3D fields)
- what are the cascaded requirements of using various mitigation strategies
  - strike point sweeping impacts PF coils, number/location/current
  - high f_{RAD} impacts bolometry diagnostics and gas fueling systems
- what aspects of the heat loading influence the 'hands and feet' of the engineering/design team?
- what is the impact of a reduced NSTX-U operating space?

PFC Requirements Working Group Charges

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

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

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Can we make near-term progress by April 7th in time to inform IBDhs CDR?

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

Suggested Group Structure

ENGINEERING AND DESIGN

EMPIRICAL AND REDUCED MODELS

PLASMA CONTROL AND PFC MONITORING

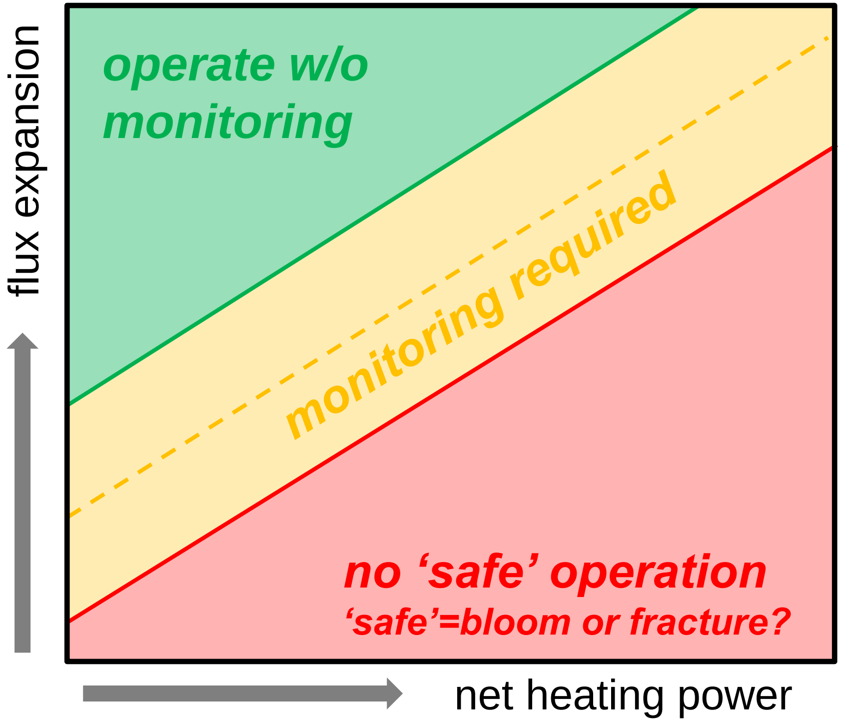
2D/3D BOUNDARY PHYSICS SIMULATIONS

welcome a formation of a 'core' team that can spend non-negligible time on this

- initial focus on working group is serving the needs of the PFC design engineers
  - is there anything holding up their work?
    - ex: maximum allowable temp.
  - how can input from physics be vetted and data be structured to best serve their needs?
- both phys + engineers need to update the basic structure of heat load specifications
  - what values need to be added?
  - what point values need to become 'ranges'?
  - (phys) how to generate heat load spec. from scenario?
- delegate work to responsible person(s) in physics to provide numbers/ranges and give provenance
  - literature/data review of experimental basis
  - engage and interpret boundary modeling

NSTX-U Would Benefit from Intra/Inter-shot Monitoring

- some NSTX-U configurations will likely exceed *any* PFC design
- presently we don't have
  - understanding of 'rough' boundaries of safe/unsafe regions (tiles + physics)
  - no operations pre-flight checkout
  - no reliable means of intra-shot or post-shot monitoring
- tools would assist new tile designs and serve upcoming commissioning
  - need to balance immediate benefit versus cost of other CAP work
- can we decouple monitoring system from PFC design?



example third access is time

Communication Methods

- try to avoid ‘overburden’ of e-mails and meetings sent to everyone yet avoid siloed, untracked discussions
- email: for meeting announcements, general inquiries
  - nstxu_pfcr_wg@pppl.gov (e-mail me or contact Helpdesk)
- Slack: for topical discussions, results communication
  - https://nstxu-pfcr.slack.com (free web-based service)
  - ‘opt-in’ to discussions, allow for searchable history
- document storage (for now) via Drag’n’Drop or Slack
  - future work may require a /p drive location, etc.

New Things to Update in Requirements

- field line angle at the tiles
  - poloidal angle of incidence specified
- upper/lower, inner/outer sharing derived from magnetic balance
  - variation of heat flux with topology
  - vertical growth of centerstack PFCs during the pulse
- ST heat flux width scaling with Ip
  - Scaling in H-mode vs L-mode?
- inner divertor heat flux width
- inner limiter heat flux width
- credible ‘S’ parameter in Eich parameterization
- radial convected power (blobs, ELMs, etc)
- radiation (core vs. boundary)
  - does core radiation help if you need P_{SOL} to get H_{98}?
  - at high radiation fraction, is the general heat flux load (0.13 MW/m2) violated?
- max surface temperature of tiles
  - when will carbon bloom get so bad operations will be repeatedly impacted
- strike point sweeping
  - influence of lambda_q and control system on the ability to be in DND
  - sweeping rate and direction (back and forth or just one way) extent vs. present gaps?
    - What kind of gap between IBDhs vs OBD do we need
- diagnostic systems for monitoring heat flux/surface temperature and to what accuracy.
- impact of 3D fields (error fields, externally applied)
  - can we ‘rotate’ the 3D fields – if so, what frequency?
- shape of tiles due to orbit loss effects (recent monoblock challenge)
- impact of ELM heat loading
- impact of disruption heat loads
  - do we need to worry about disruption specifics (i.e. add MGI into PCS?)
- Impact of heat loads on ratcheting, thus impacting the reprate
- Impact of sensor removal from tiles if going to smaller tile designs