NSTX

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NSTX-U Centerstack Plasma Facing Components

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NSTX Center Stack Upgrade Peer Review
LSB B318
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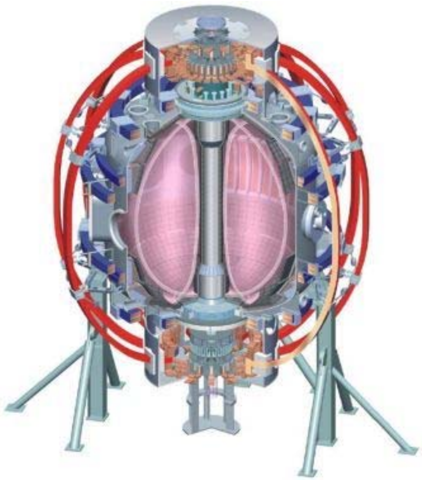

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Slide title

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Design Specifications

- This job covers the replacement, upgrade, and reinstallation of the carbon Plasma-Facing Components on the Centerstack Upgrade.
  - In accordance to the NSTX Centerstack Upgrade General Design Requirements (GRD) document.
    - Tiles shall be radially curved, with overlapping edges, ATJ Graphite, and designed for the upgrade heat loading and increased magnetic fields
    - Heat Flux Loading on the tiles shall be mitigated via advanced divertor operations and held to material (ATJ) allowables
    - Pulse length: 1 to 5 seconds, rep rate 1200 sec
    - 350 C bakeout temp
  - Other (non GRD) considerations:
    - Tiles will have diagnostic slotting and appropriate wire channels
      - » Passages for Gas Injection System
    - Tile thicknesses increase to .75”, 1” and 2” for the CSVS, IBD AS and VS, and the IBDHS, respectively.
    - Effort to reduce installation/re-installation problems
      - » Re-usability, anti-galling

Design Specifications

- Review-based Chits: All closed

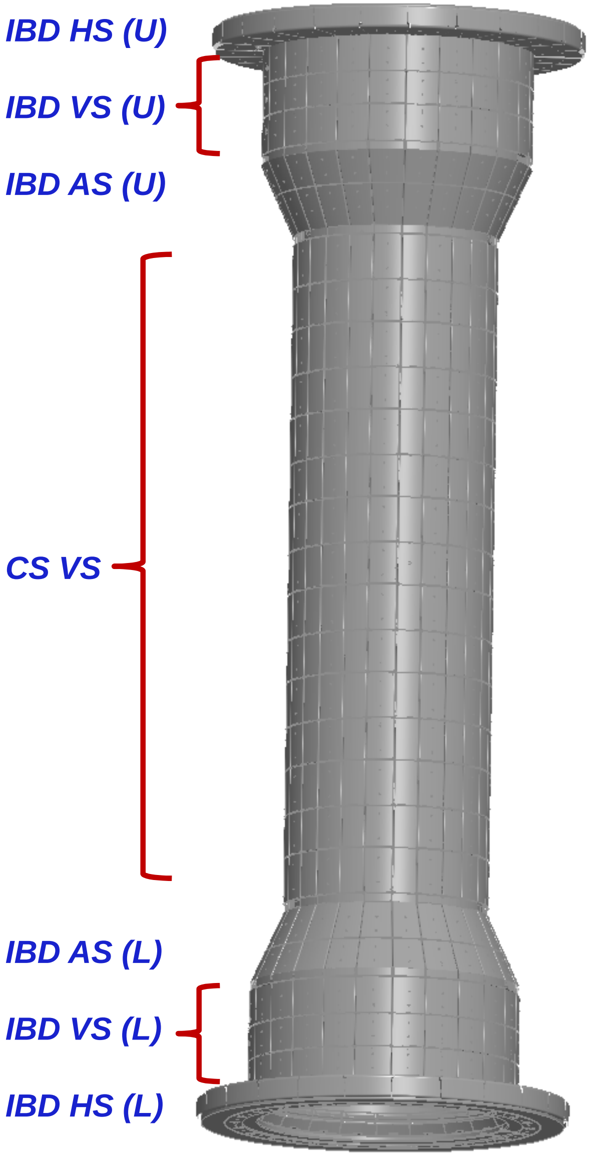
201004-03	April 2010 Peer Rvw	Peer-03	Make sure surface area of contact between tiles and backing surface is sufficient for disruption current and heat loads	Completed. Disruption current analyses was completed. All forces are inward. Grafoil is being reintroduced. Analysis confirms heat transfer is adequate and stresses are within limits.
201006-06	June 2010 PDR	Chit-06	Consider using graphite tiles for centre tub even if it needs increasing the centre column radius by a few mm to save cost (and time)	Concur. Will be using ATJ graphite on the CS column at GRD specified thicknesses.
201006-11	June 2010 PDR	Chit-11	At each review, a new tile connection scheme is shown. This latest one has not been used in other fusion machines. May present some R&D. Perhaps going with another fusion experiment's method should be considered.	The design is being changed to welded studs and threaded caps. (the proven existing NSTX design) Only exception is the use of Spiralock threads to prevent galling and allow reuse.
201006-19	June 2010 PDR	Chit-19	The definition of the CFC linked to requirements. Density, weave, graphitization temperature all need to be fed back to the design.	All tiles are now ATJ graphite. CFCs are not required.
201008-04	Lehman Aug 2010 CD-2	2.1-4	MAGNETS & CORE(Brad Nelson): Refrain from placing contracts for the PFC tiles until after the prototyping of the tiles and mechanical testing of the fastening scheme is completed.	CFC's were eliminated. ATJ graphite properties are well known. Loading is much lower and stresses are no longer a concern. Most stresses in the divertor tiles are thermally (internally) induced.

Tile Design

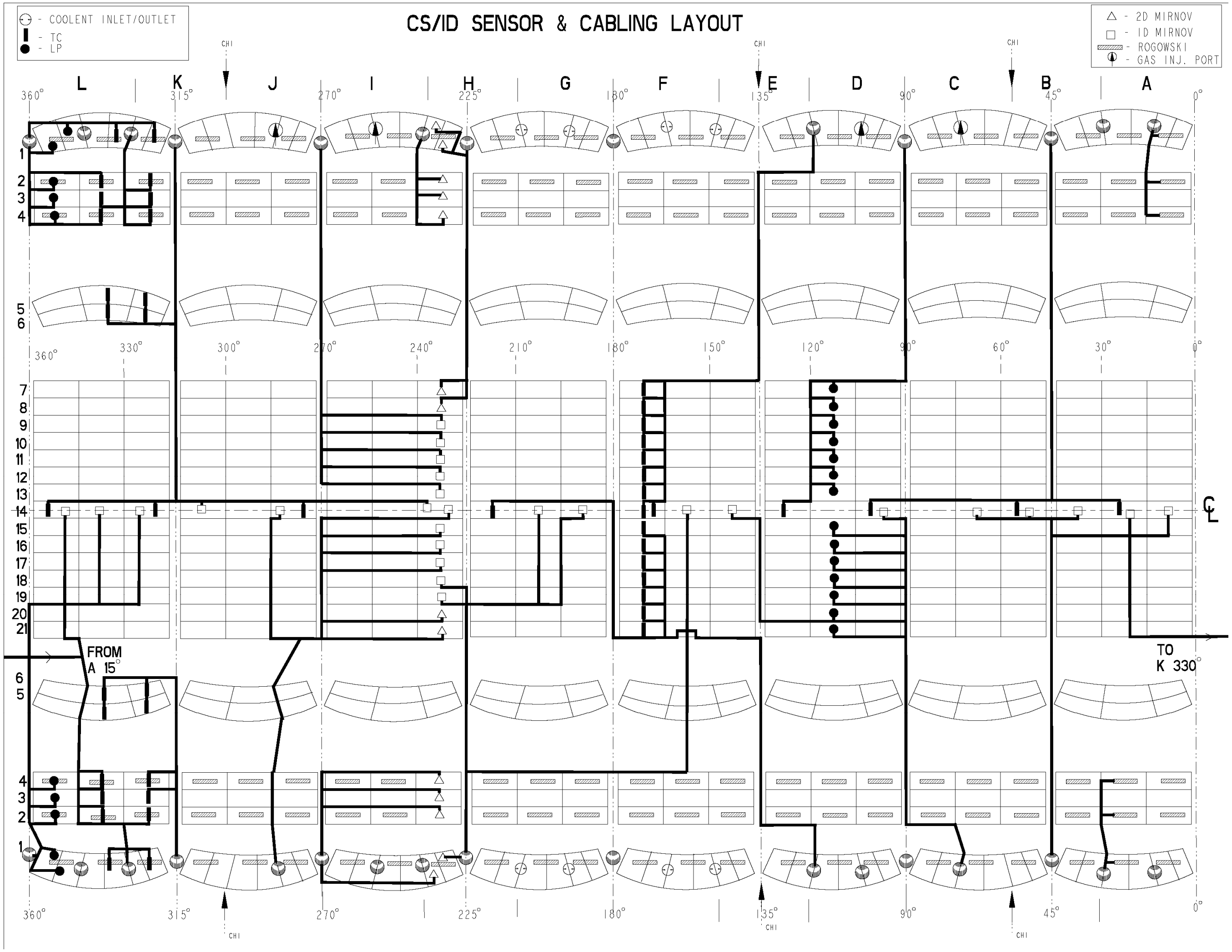
- Tile layout
  - Reduced overall tile number, increased size where possible
    - ~900 → ~700 tiles
      - IBD HS Tiles the same size due to thermal constraints

  - Designed diagnostic slots and wire channels
    - Mirnov, Rogowski, Langmuir, Thermocouple



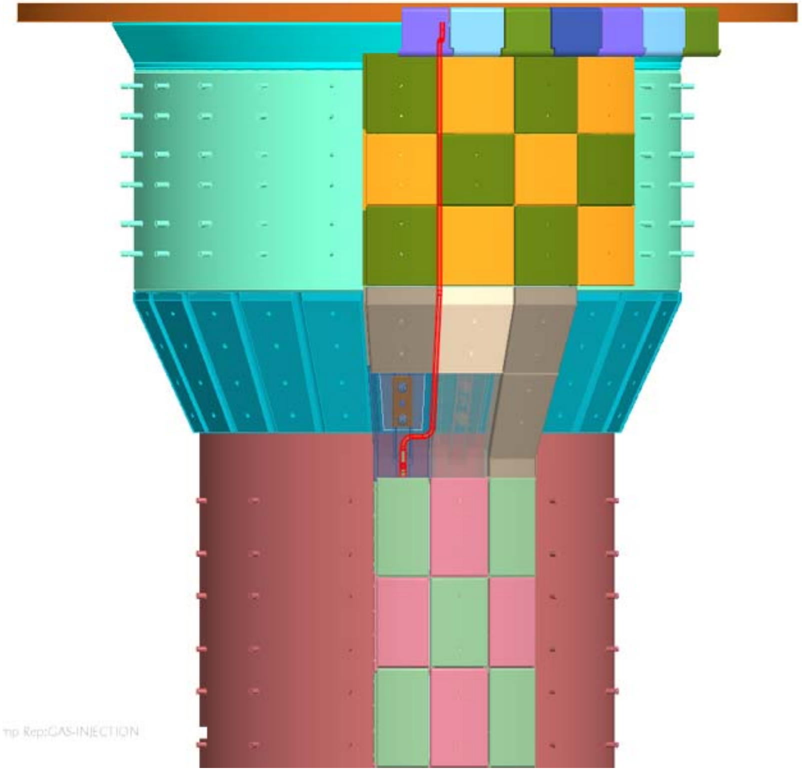
Tile Design

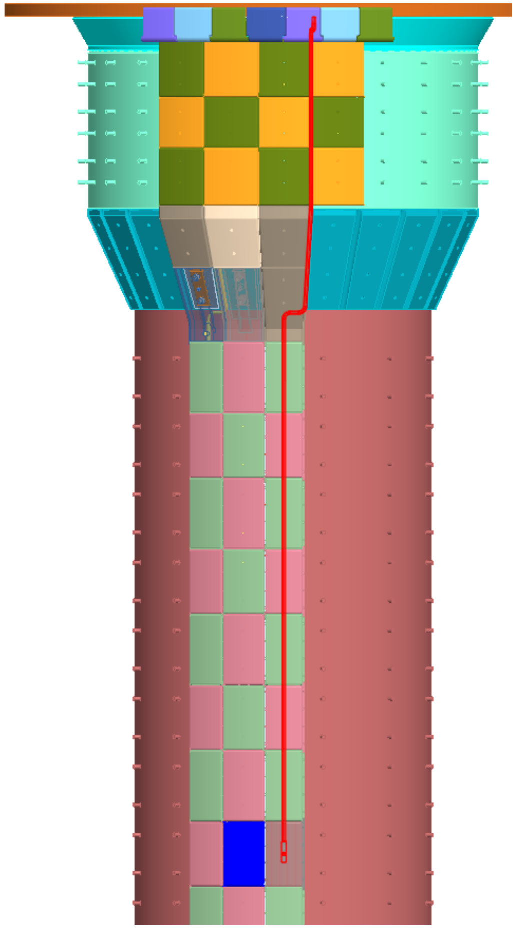


CS/ID SENSOR & CABLING LAYOUT
- COOLENT INLET/OUTLET
- TC
- LP
- 2D MIRNOV
- 1D MIRNOV
- ROGOWSKI
- GAS INJ. PORT
L
K
J
I
H
G
F
E
D
C
B
A
CHI
FROM A 15°
TO K 330°

Tile Design

- Tile layout
  - Collaborated to include Gas Injection System passages
    - Shoulder and Mid-plane





Tile Loading: Thermal

- GRD constraint: Use ATJ Graphite and

GRD Requirements – Heat Flux

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

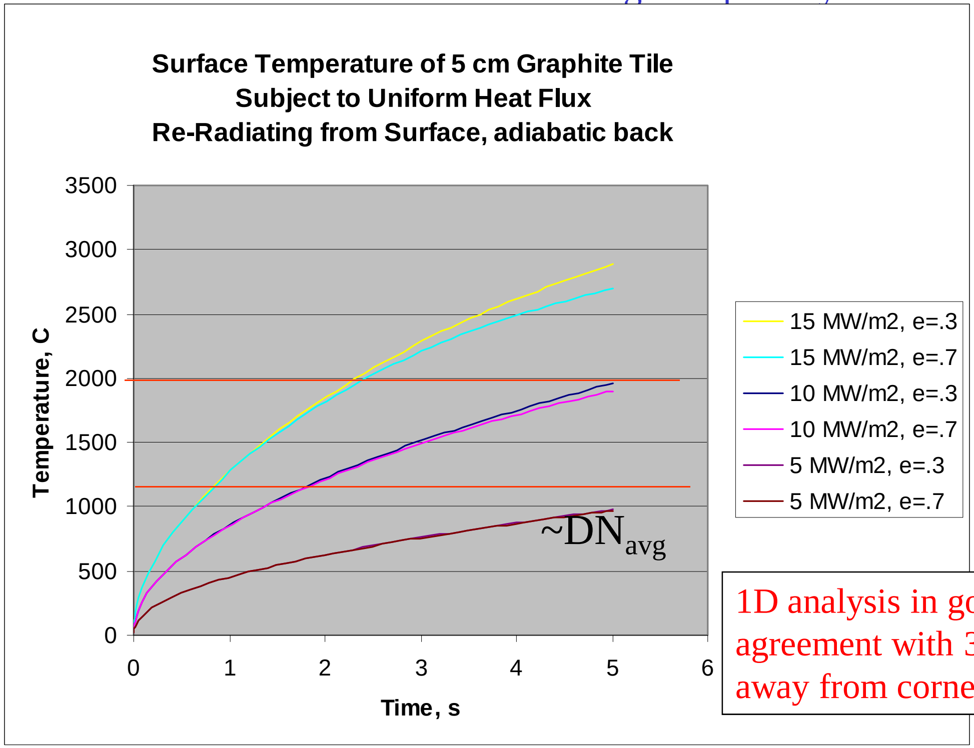
	CSFW	IBDAS, IBDVS	IBDHS
Single Null Divertor, T_{pulse}= as determined to be allowable			
Average Heat Flux q_{avg} [MW/m^2]	0.1	4.0	9.8
Peak Heat Flux q_{peak} [MW/m^2]	0.2	6.3	15.5
Power Flux Width λ [m]	n.a.	0.3	0.3
Double Null Divertor, T_{pulse}=5.0s			
Average Heat Flux q_{avg} [MW/m^2]	0.1	1.6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

- The thermal analysis is done using the average heat fluxes associated with a 14 MW plasma of 5 second duration pulse with 1200 second rep rate. (DN loading)
  - Heat Flux applied to Plasma Facing Surface of Tiles. For IBDhs this includes vertical surface

Tile Loading: Thermal

- Results
  - 1D results show that SN (15 MW/m2) will probably be limited to 1s if heat flux magnitude is not reduced via operations

1st Pulse Heat Flux/Pulse Length Capability

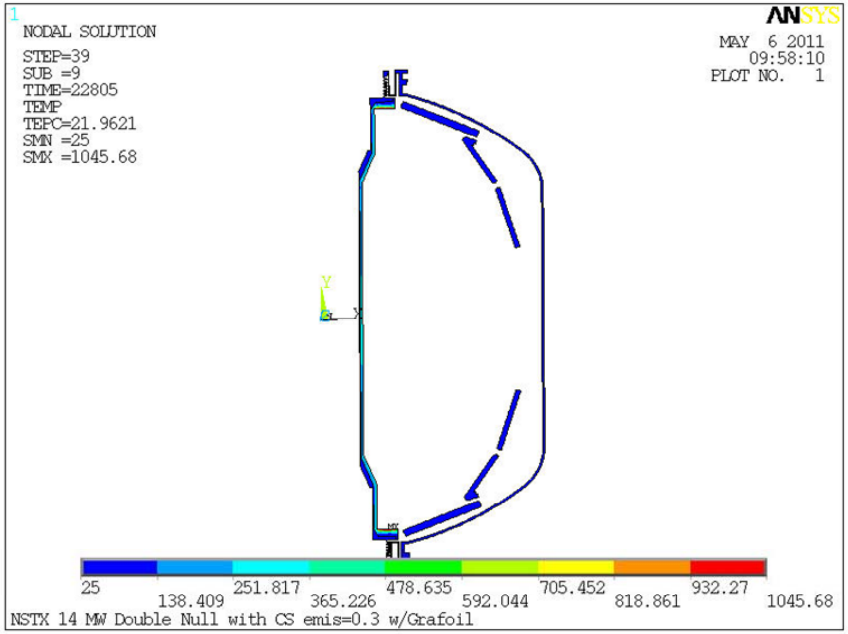


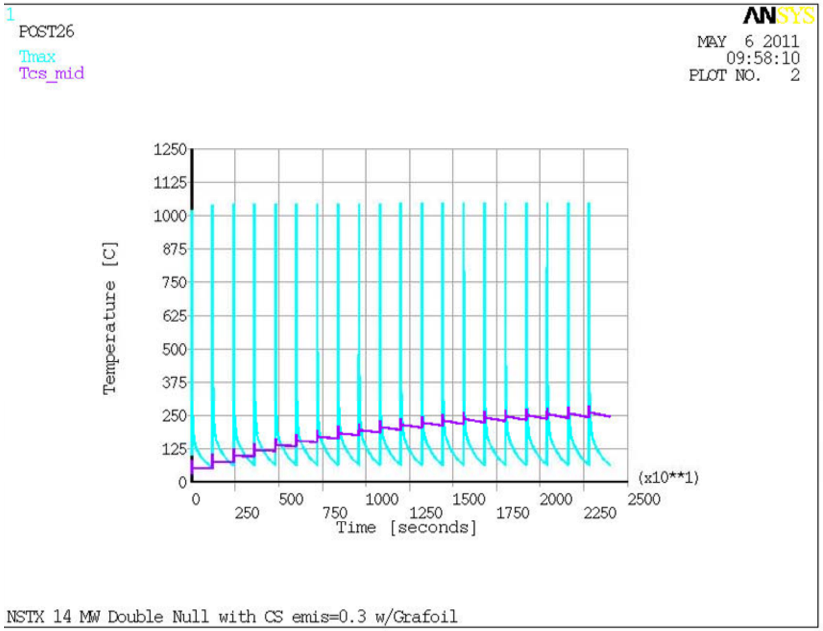
1D analysis in good agreement with 3D away from corner

Single pulse without ratcheting with ATJ Graphite

Tile Loading: Thermal

- Results
  - 2D analysis, with Grafoil, with water flow
    - Water lowers temp ratcheting while not exceeding own limits

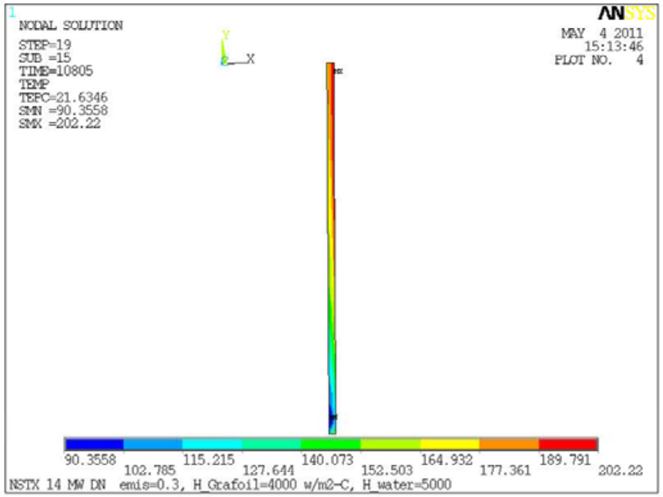


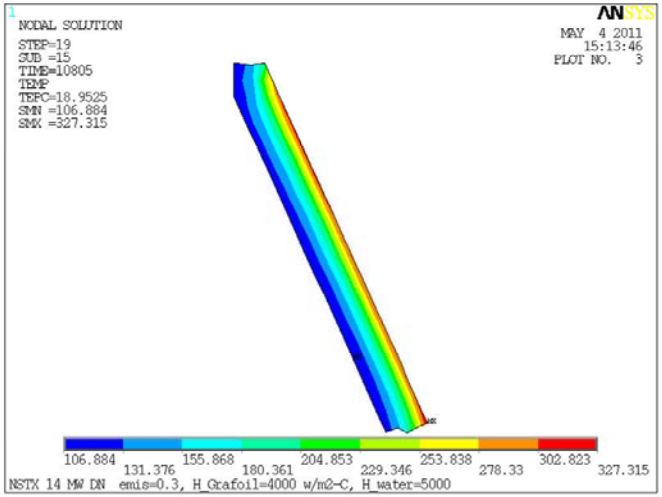


Tile Loading: Thermal

Tile SurfaceTemperatures

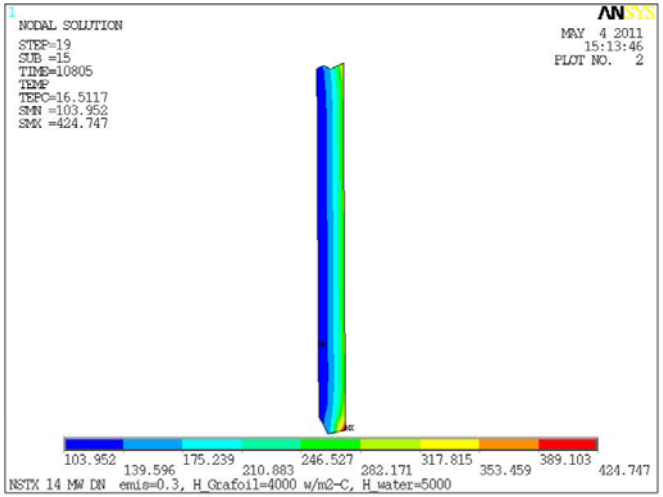
Max: 202 ℃

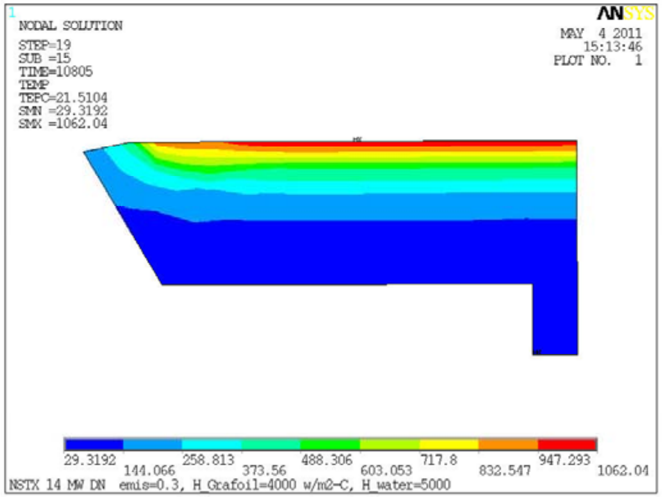




Max: 327 ℃

Max: 425 ℃

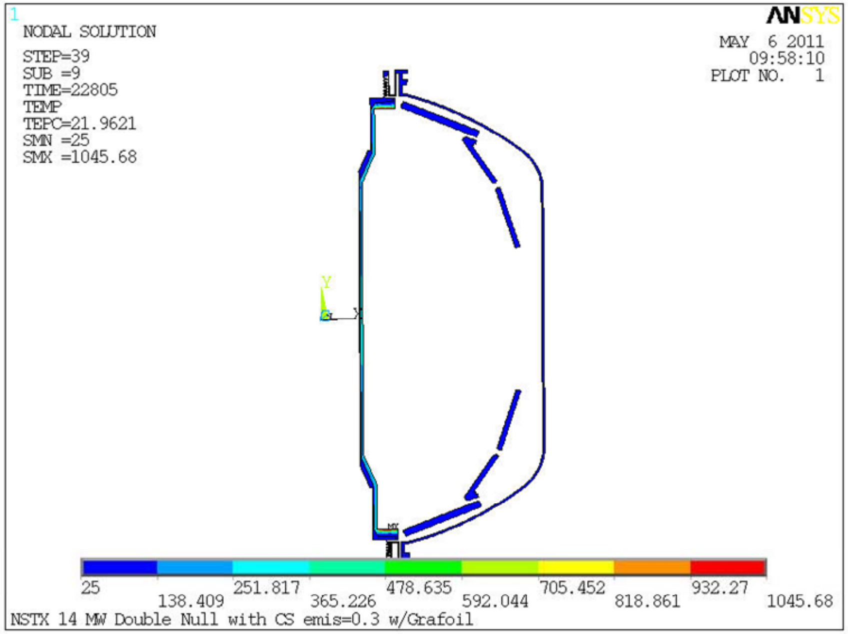


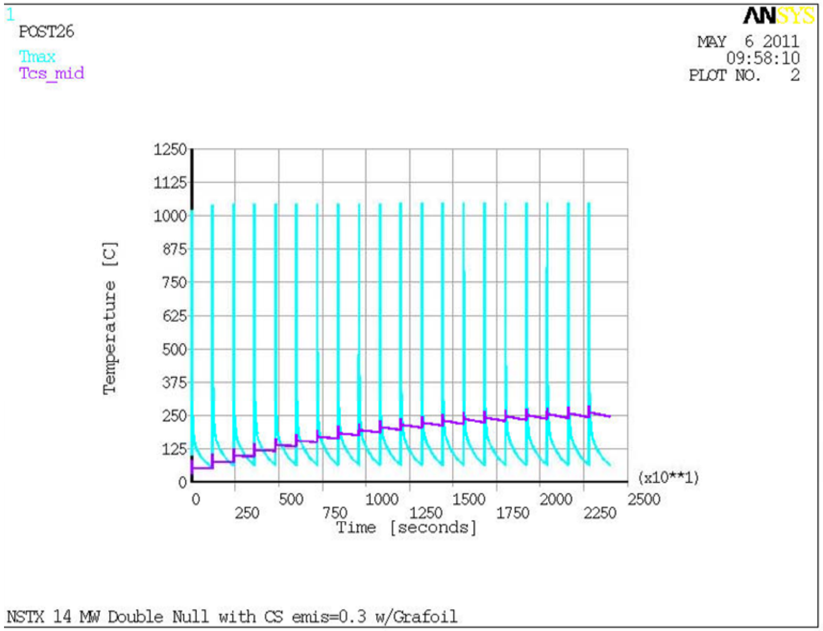


Max: 1062 ℃

Tile Loading: Thermal

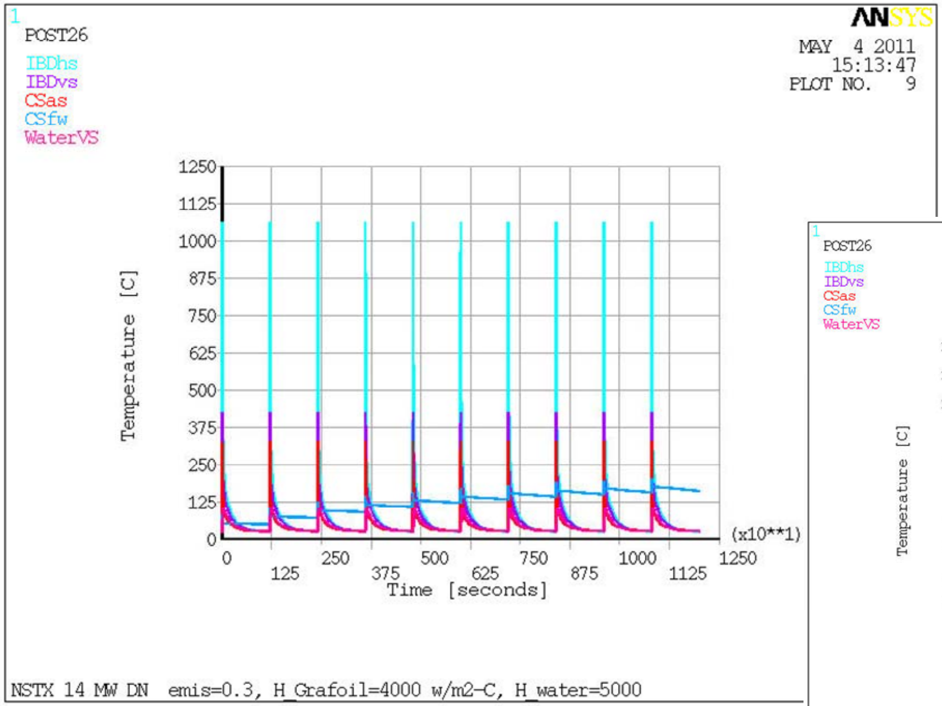
- Results
  - 2D analysis, with Grafoil, with water flow
    - Water eliminates tile-temp ratcheting while not exceeding 100 °C

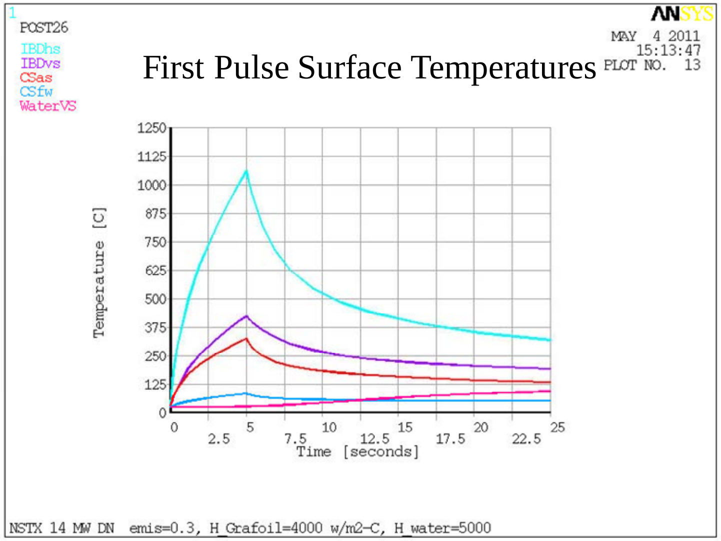




Tile Loading: Thermal

No Ratcheting on Water Cooled Tiles
Only on Radiation Cooled CSFW





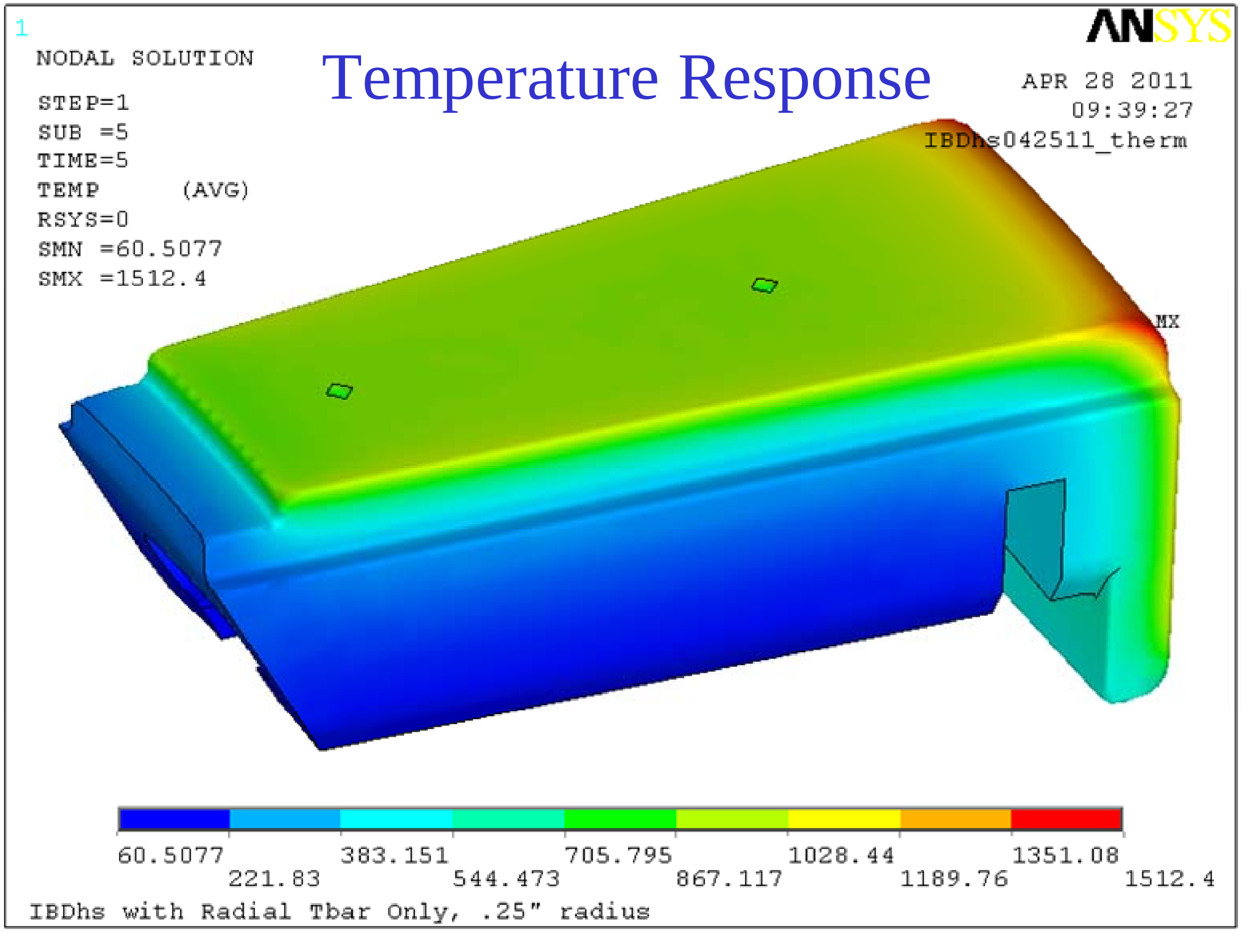
Tile Loading: Thermal Stress

- Results
  - All thermal stresses are well within limits of ATJ
    - Exception on edge of IBDHS tile, where heating could be on two faces, but not likely…

	Summary of Tile Thermal Structural Response				
	Heat Flux for 5s	Ratcheted Temperature	Peak Tensile Principal Stress, S1	Peak Compress Principal Stress, S3	Max Deflection
	mw/m2	C	MPa		mm
IBDhs, surface	5.0	1062	15.6	-58.0	0.6
Hot Spot at Corner		1512			
IBDvs, surface	1.6	425	7.0	-16.3	0.1
Hot Spot at Hole		560			
CSAS, surface	1.6	327	8.2	-10.7	0.2
Hot Spot at Hole		417			
CSFW	0.2	260	1.6	-6.5	0.01

Tile Loading: Thermal Stress

- IBDHS



Tile Loading: E-Mag

- The halo currents and associated Lorentz forces & directions are based on the following:
  - Halo Currents are resistively distributed & predominantly poloidal
    - Studies show this to be true even with large toroidal peaking (TPF) with in and out strike points at different toroidal angles
    - The exception is near the strike points where current quickly redistributes
  - The tiles are assumed shorted to each other (at least locally) by plasma filling the gaps
    - It is estimated that at a temperature of 10ev, the plasma electrical resistivity is very close to ATJ graphite (thou it may not penetrate very deep into the gap)
  - As a result of the above, there is current sharing between the tiles and CS casing based on the relative resistance
- Per Stefan Gerhardt, the interaction of the halo currents with the TF is always such as to press tiles toward VV wall or CS Casing
  - This is this is true even when the TF direction is opposite the plasma current.

Tile Loading: E-Mag

Current Sharing and Tile Forces

- Tiles share less than 30% of Halo currents based on relative resistance
- Forces due to the toroidal flow of halo currents are small compared to the poloidal component.
- Net Forces will remain into the VV/CS

Relative Resitivity and Halo Current Sharing in CS Tiles/Case

Res_inc	1.3	microOhm-m		Iplas	2	Ma
Res_atj	11.7	microOhm-m		HCF	0.35	
				TPF	1.2	
	CSFW	CSAS	IBDvs	IBDhs		
ntiles tor	24	24	24	24		
t_inc	0.25	1.27	0.25	1.00	in	
t_atj	0.67	0.85	0.94	2.00	in	
I_atj/I_tot	0.23	0.07	0.29	0.18		
I_tot, KA	35	35	35	35		
I_atj, KA	8.01	2.43	10.31	6.36		

Force Estimate Per Tile (Ipol x Btor, into VV)

	CSFW	CSAS	IBDvs	IBDhs	
Ipol	8.01	2.43	10.31	6.36	kA
Btf	2.97	2.61	2.34	1.92	T
tile pol len	0.15	0.29	0.15	0.17	m
F	3565.3	1841.3	3613.8	2081.7	N
	801.5	413.9	812.4	468.0	lbs
Surf Area	0.0123622	0.027134	0.015708	0.021612	m2
Equiv Pres	288405.28	67858.61	230064.4	96319.05	Pa

Force Estimate Per Tile (Itor x Bpol, into or out of VV)

	CSFW	CSAS	IBDvs	IBDhs	
Itor, model	11.50	10.00	3.00	27.30	
Itor, tile	2.63	0.69	0.88	4.96	kA
Bpf	0.57	0.57	0.57	0.50	T
tile tor len	0.082	0.094	0.105	0.127	m
F	123.6	37.0	52.8	315.5	N
	27.8	8.3	11.9	70.9	lbs

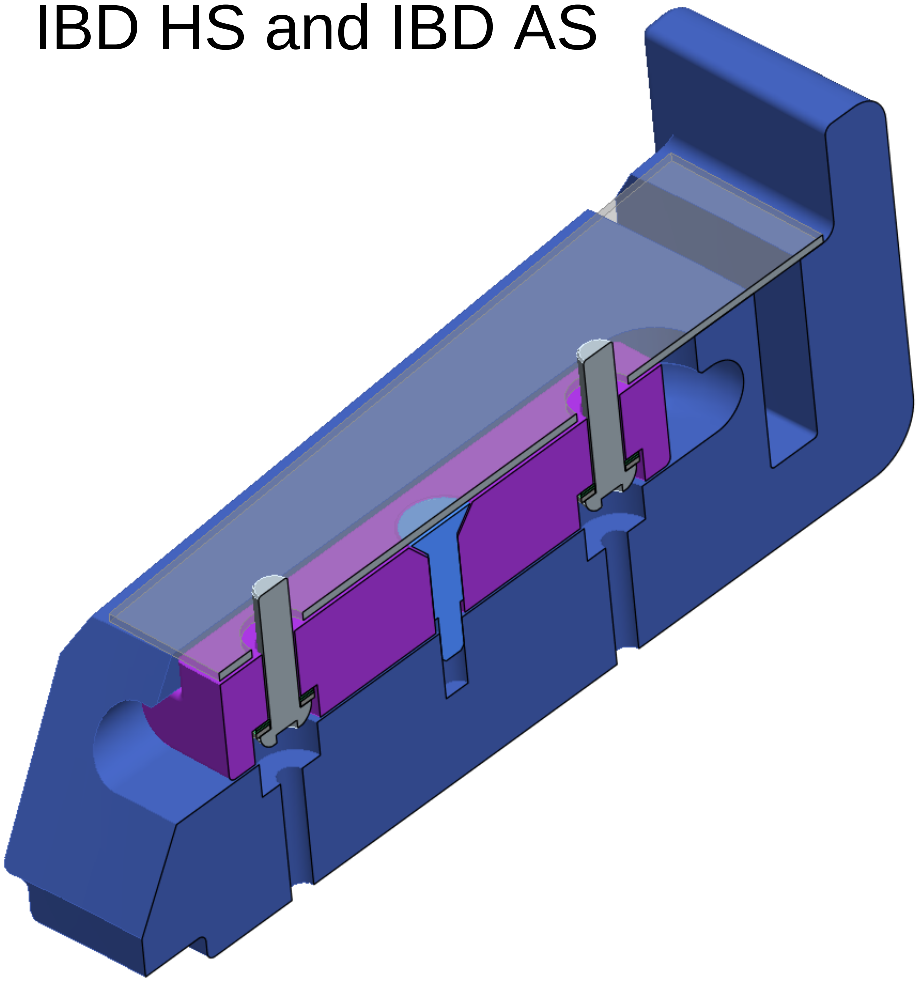
Fastening Scheme

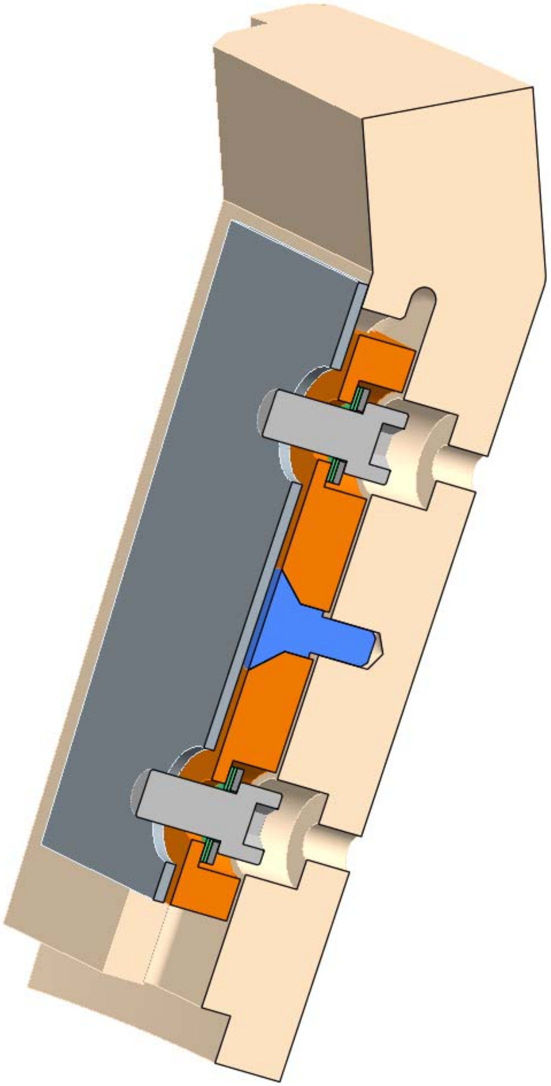
- Due to design flaws in previous proposals, reverting to present NSTX configuration
  - Weld Studs and nut caps in CSVS and IBDVS
    - With Spiralock threads
  - Bellevilles and socket cap screws in IBDAS and IBDHS
  - Grafoil!

- Redesign for steel to steel connections
  - ATJ tiles are passively held, allowed thermal freedom
    - Grafoil is minimally compressed via installation
    - Socket cap screws have low preload (112 lbs)
    - Spiralock tiles need high tolerances to maintain higher preloads w/o compressing ATJ or Grafoil

Fastening Scheme

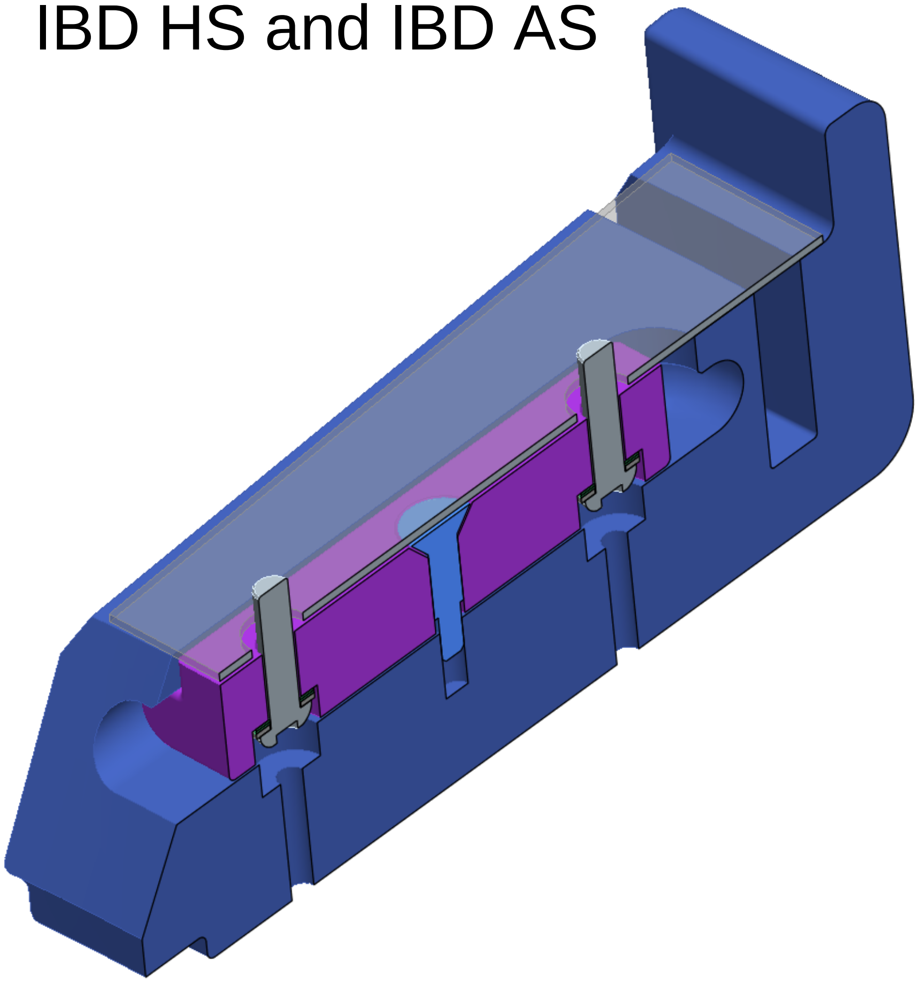
- IBD HS and IBD AS





Fastening Scheme

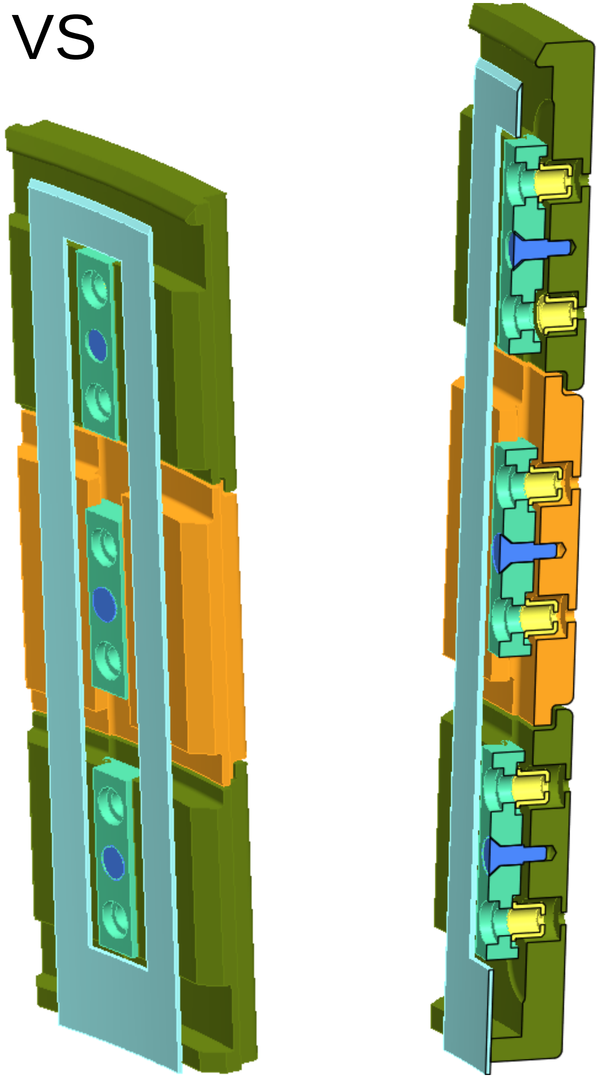
- IBD HS and IBD AS



- T-bar and cap screws
  - Light preload (112 lbs)
  - Bellevilles
  - Grafoil is lightly compressed by T-bar
  - Locating pin

Fastening Scheme

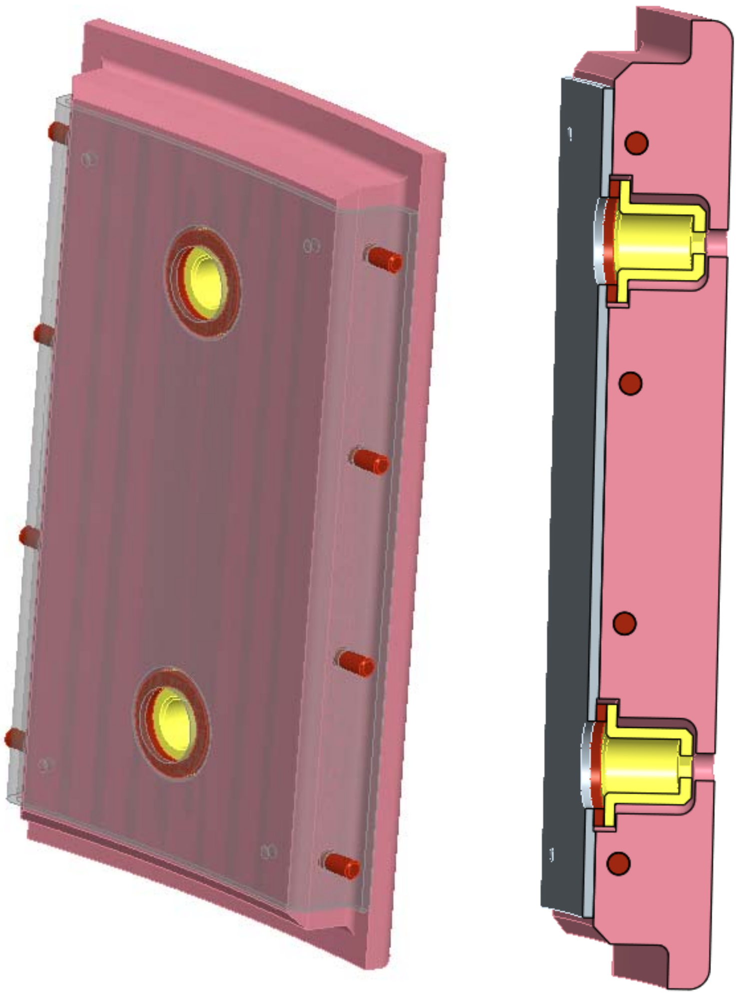
- IBD VS



- T-bar and Spiralock nutcaps
  - Large pre-load (75% of Sp)
  - Hard joint, steel to steel, high tolerances
  - Grafoil is BARELY compressed by tile, only to provide compliant surface for tile's thermal expansion.
  - Locating pin

Fastening Scheme

- IBD VS and CS VS



- Inconel Rail and Spiralock nutcaps
  - Large pre-load (75% of Sp)
  - Hard joint, steel to steel
  - Fastening columns hold adjacent tiles for economy.
  - Grafoil not needed, forces within limits, thermal heating almost none

Summary

- Design is adequate to handle GRD loading (thermal and E-Mag), provided certain assumptions hold:
  - Heat Flux for a SN **CAN** be controlled by operations (Strike point sweeping and Snowflake) to lower the magnitude
    - Will extend the pulse length
  - The directionality of the Halo force is **ALWAYS** away from plasma despite the direction of current flow
  - Heating to the IBD HS is **NOT** on both the tile's top surface AND the CHI gap surface at the same time.
- Other design components have been integrated into design without major issues
  - Design is solid, mature, and meets NSTX-U requirements
  - Analysis has been documented and checked
  - Chits have been addressed and closed

Summary Continued

- Left to do…
  - Cost and Scheduling needs to be updated in light of recent analysis
    - WAF need updating
  - Risks need to be updated
    - No “show stoppers” as of now
  - Final design needs prototyping (in progress)
  - Documentation
    - Procedures
    - Update SRD
    - Drawings
- FDR