FIRE Plasma Facing Component Design Studies

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Presented by

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The Boeing Company

Contributions from

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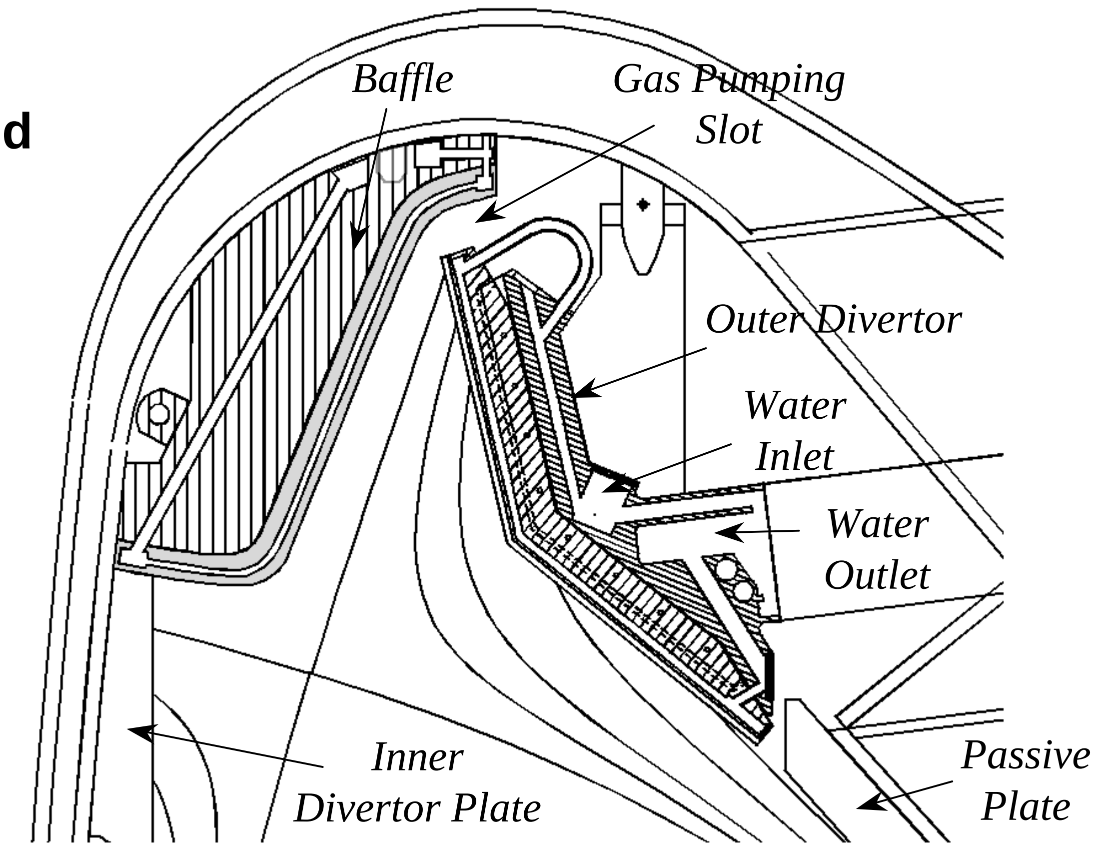
General Atomics

FIRE Divertor Components

U.S. Industrial Team

- Build on design/fabrication approaches developed during ITER-EDA
- W-brush armor for divertor and plasma-sprayed Be for first wall tiles
- Cu-alloy finger elements for high heat flux outer target
- Swirl tape or helical wire inserts for CHF enhancement
- Dome-like construction for lower heat flux baffle
- Passively-cooled W-Cu tiles for low heat flux inner target
- Modular units for remote maintenance during operation



Outer Divertor Design Concept

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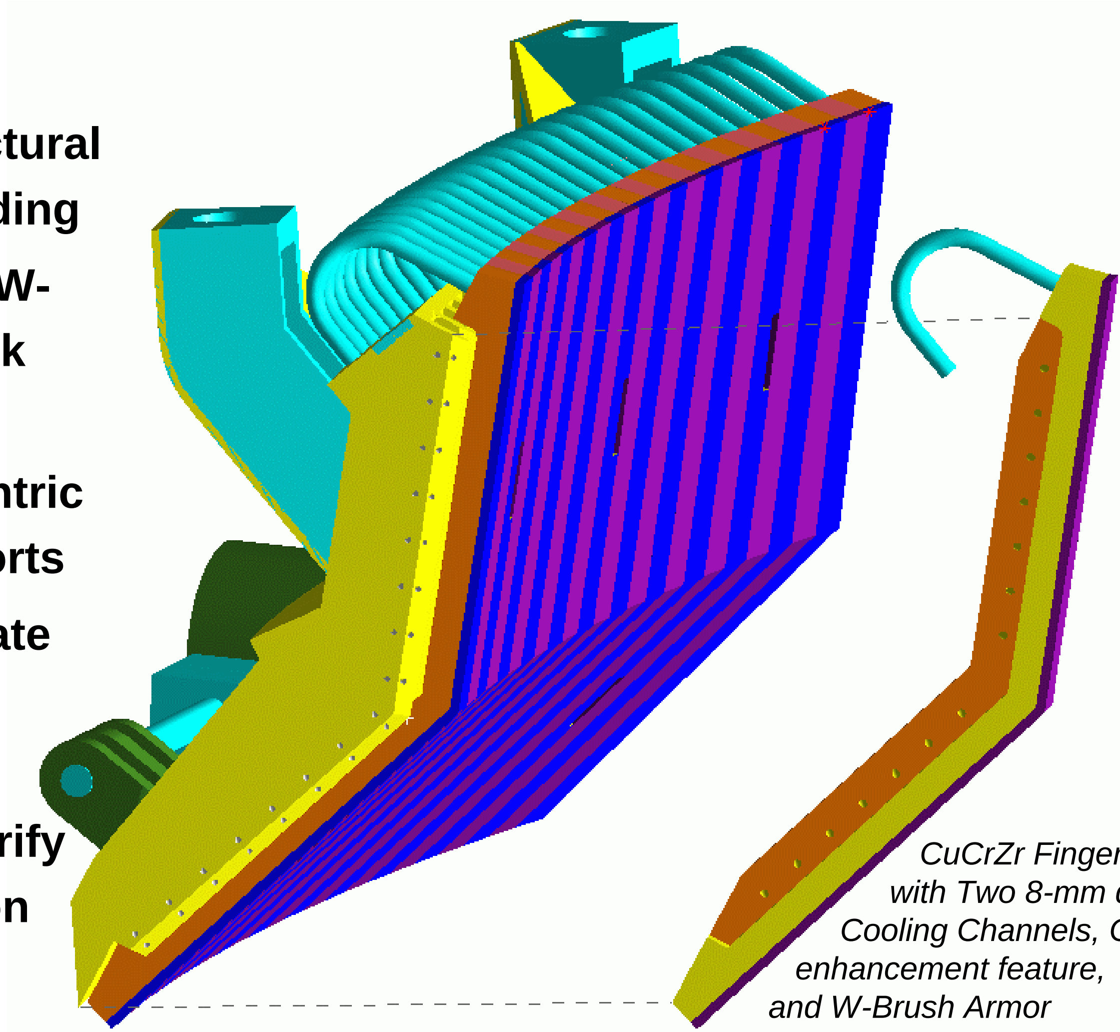
- SS316LN back plate for structural support and coolant manifolding
- 24 CuCrZr finger plates with W-brush armor, attached to back plate using pressed pins
- Actively cooled using concentric pipe feed through divertor ports
- HIP-bond armor using separate canister welds around each finger plate
- HHF cycle finger plates to verify armor joint prior to integration



CuCrZr Finger Plate with Two 8-mm dia Cooling Channels, CHF enhancement feature, and W-Brush Armor

Finger Element Attachment Concept

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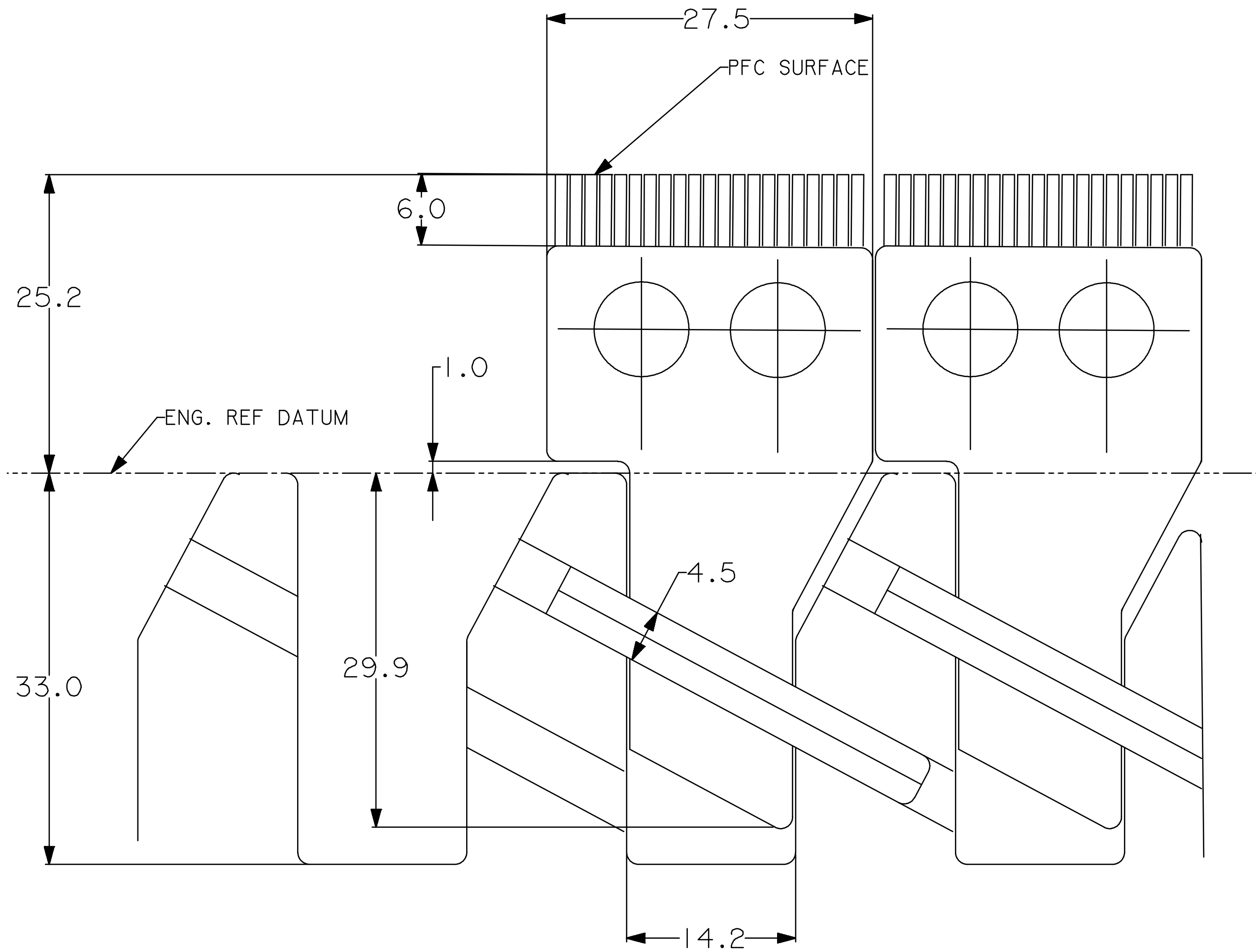

Component Cooling Assessment

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Parameter	Outer Divertor	Baffle
Total Power (MW)	34.3	10.7
Peak Power/module (MW)	2.32	0.58
Peak Heat Flux (MW/m^2)	20.0	6.0
Nuclear heating in W (W/cm^3)	42	34
Nuclear heating in Cu (W/cm^3)	16	13
Channel Diameter (mm)	8	10
Pitch (mm)	14	21
Number per module	48	30
Number in series	2	2
Enhancement	ST, t=1.5 mm Y= 2	None
Maximum PFC Temp (C)	1585	738
Maximum Copper Temp (C)	488	404
Flow velocity (m/s)	10	3
Flow/module (liter/s)	9	3.5
Exit coolant Temperature (C)	95	73.3
Exit Pressure (MPa)	1.06	1.48
Exit Subcooling (C)	87	120
Critical Heat Flux (MW/m^2)	44.	12.1
Maximum Wall Heat Flux (MW/m^2)	30.6	6.31

Unit Cell Geometry for Divertor and Baffle

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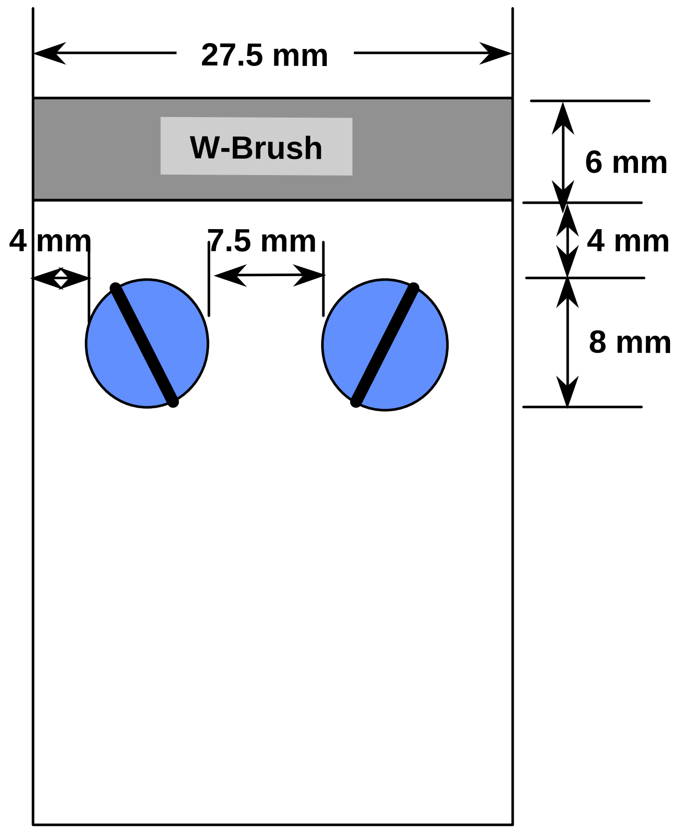
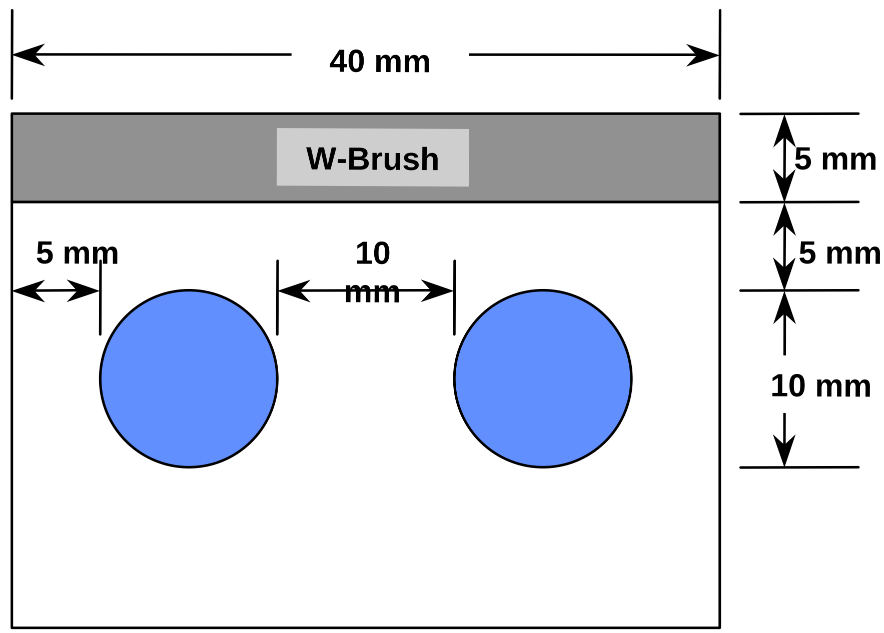
Divertor Unit Cell



Baffle Unit Cell



Outer Divertor Temperature Distribution

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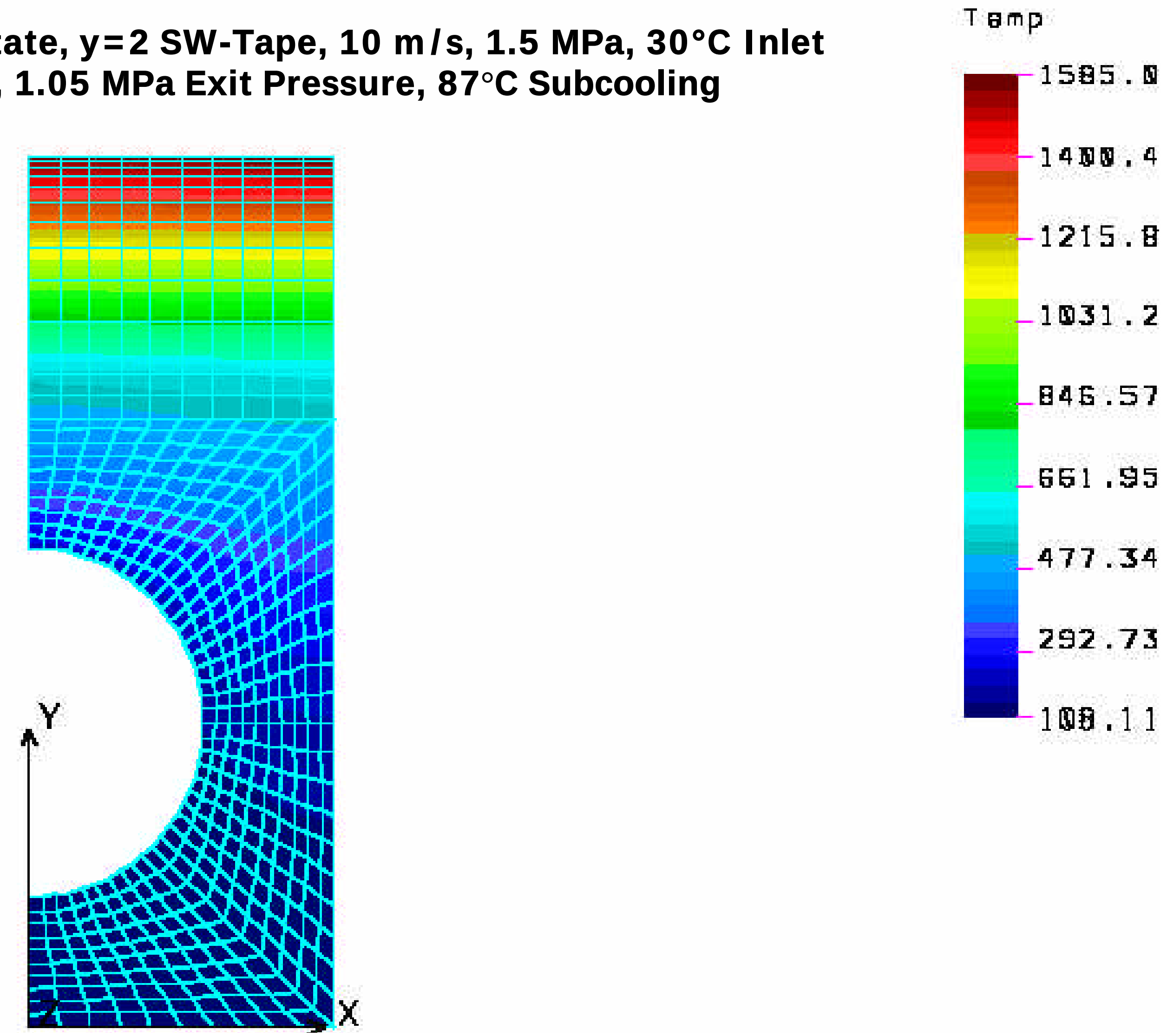
20 MW/m², Steady-State, y=2 SW-Tape, 10 m/s, 1.5 MPa, 30°C Inlet
95°C Exit Temp, 1.05 MPa Exit Pressure, 87°C Subcooling



Baffle Plate Design Concept

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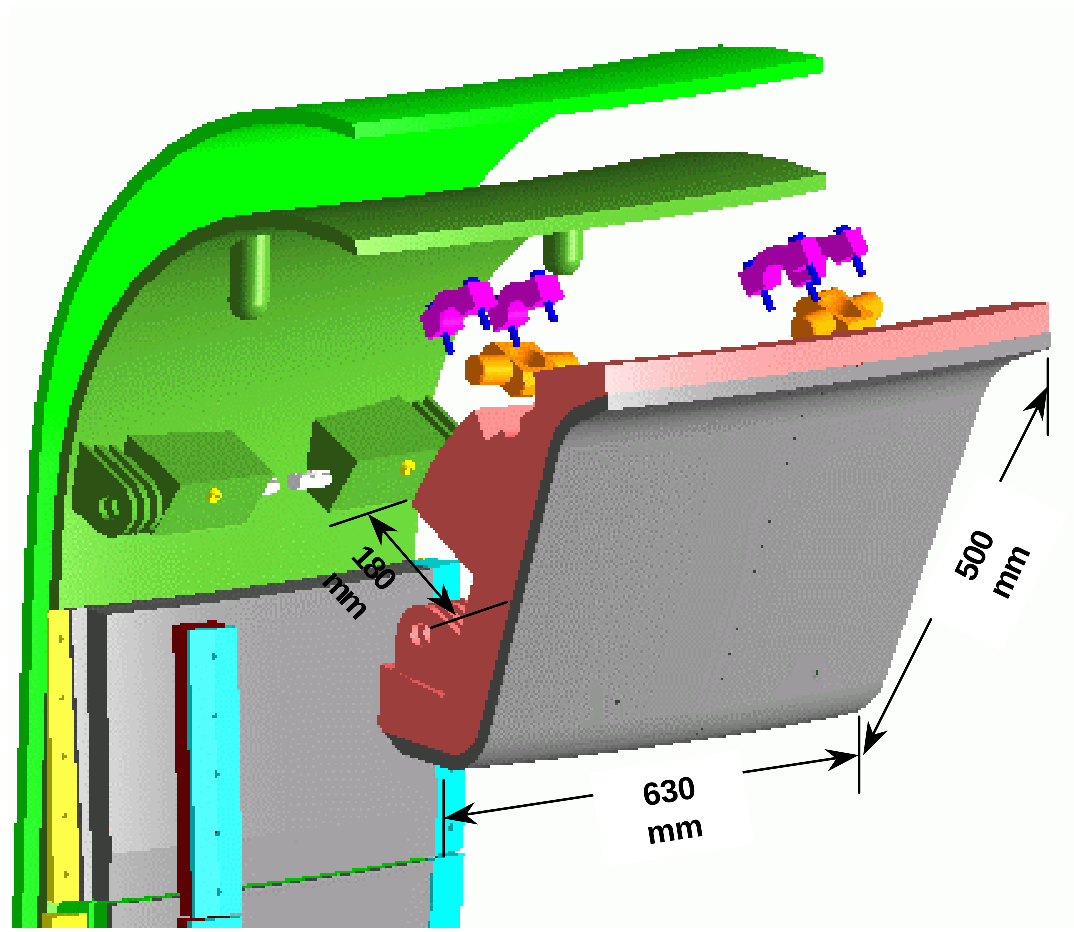
- Cooled CuCrZr forging with W-brush armor for erosion control
- Need to develop coolant supply/ return concepts for heat removal
- Integration with outer divertor module looks feasible, flow rates are low (3.5 l/s)
- Attached to vessel using upper pins/rotating sockets and lower shear plates/pins
- HIP-bond armor over entire baffle surface using single perimeter e-beam weld



Baffle Temperature Distribution

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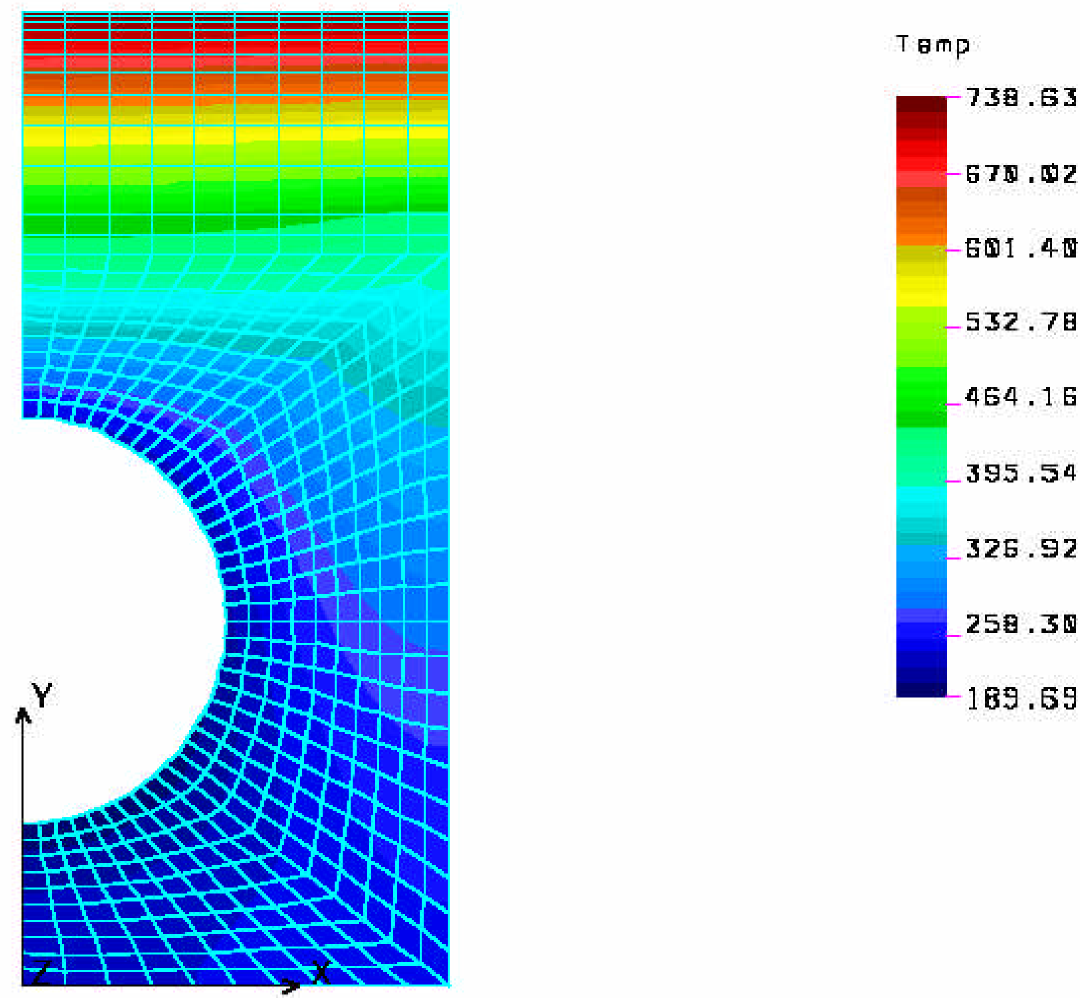
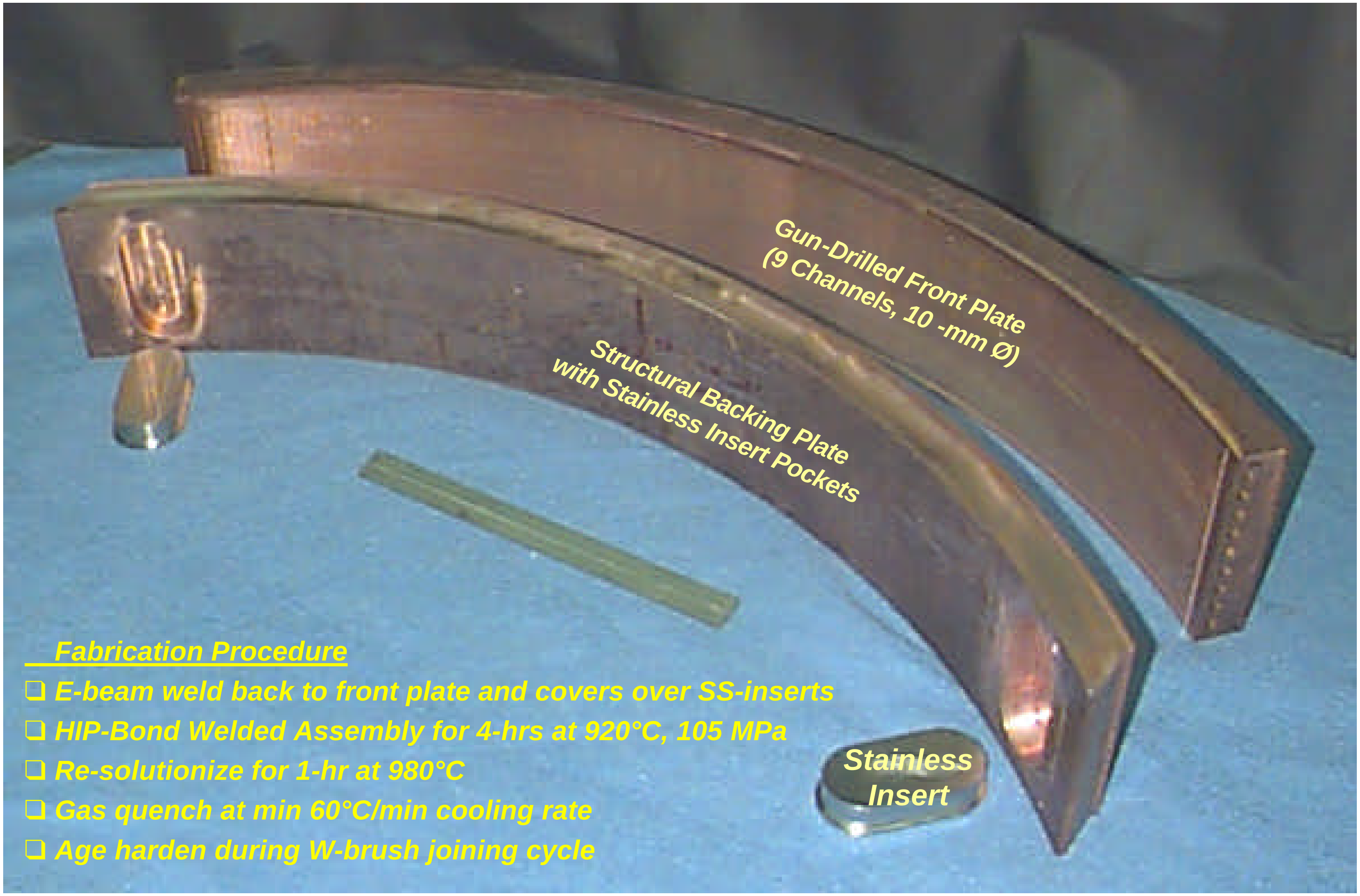
6 MW/m², Steady-State, Smooth Channels, 3 m/s, 1.5 Mpa, 30°C Inlet

73°C Exit Temp, 1.48 MPa Exit Pressure, 120°C Subcooling



ITER Dome Part Demonstrated Baffle Fabrication Process



Fabrication Procedure

- *E-beam weld back to front plate and covers over SS-inserts*
- *HIP-Bond Welded Assembly for 4-hrs at 920°C, 105 MPa*
- *Re-solutionize for 1-hr at 980°C*
- *Gas quench at min 60°C/min cooling rate*
- *Age harden during W-brush joining cycle*

Tensile Tests on Witness Part Bonds Confirmed Bond Quality

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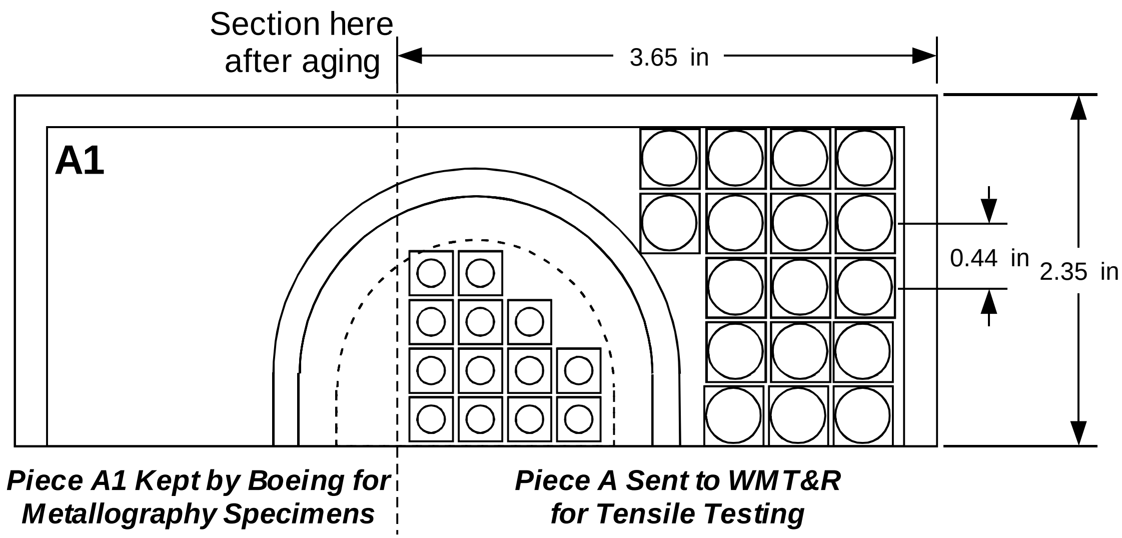

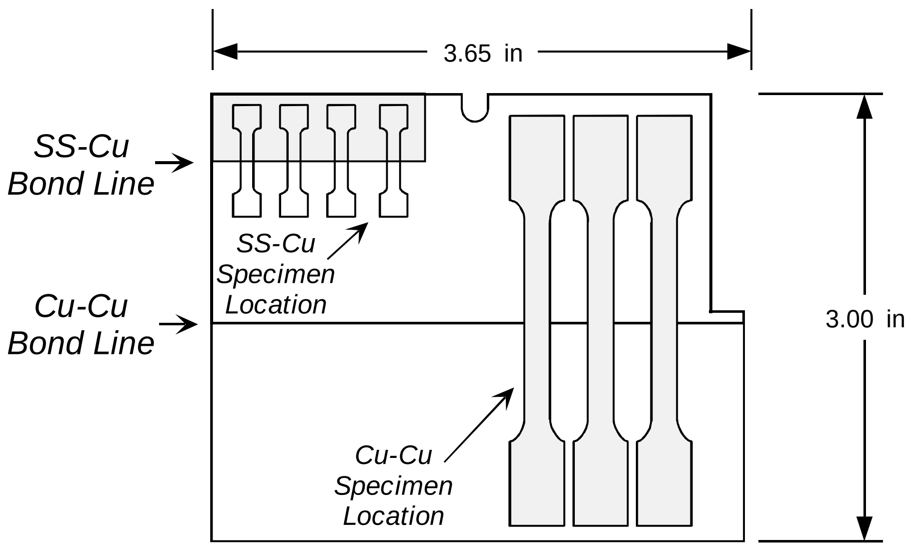

- Machine specimens from both Cu-Cu and SS-Cu interfaces
  - Cu-Cu Tests performed at RT, 150, 300, 450°C
  - SS-Cu tests performed at RT, 150, 300°C
  - Specimens taken from age-hardened material

- Summary of Cu-Cu Bonds

Temp	0.2%YS	%UE
RT	272	13.5
150	243	7.9
300	217	7.2
450	179	1.7

- Summary of Cu-SS Bonds

Temp	0.2%YS	%UE
RT	278	10.0
150	247	9.8
300	223	5.9

First Wall / Inner Divertor Tile Mounting Concept

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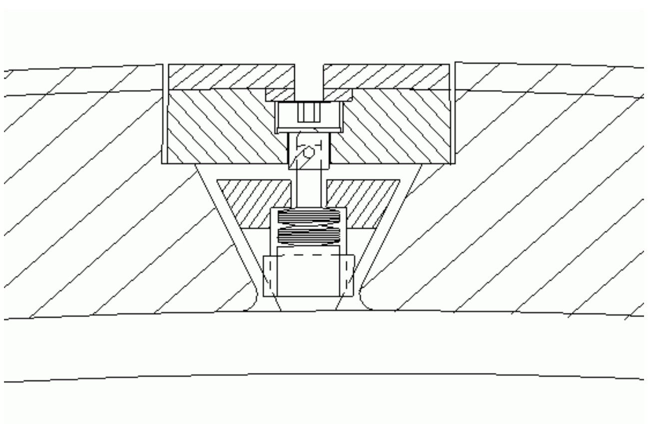
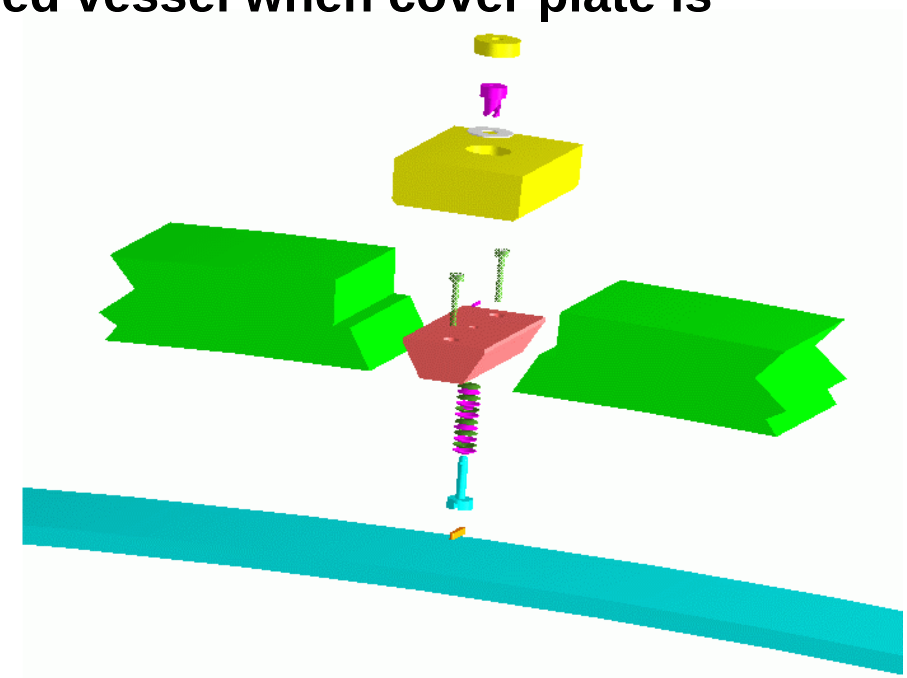
- 30-mm thick CuCrZr plates with 5-mm thick tungsten or plasma-sprayed beryllium armor
- Wedge-shaped SS316LN rails bolted to vessel, provide mechanical support
- Rails include captive fastener hardware for loading thermal interface contacts with cooled vessel when cover plate is installed





Inner Divertor Temperature Assessment

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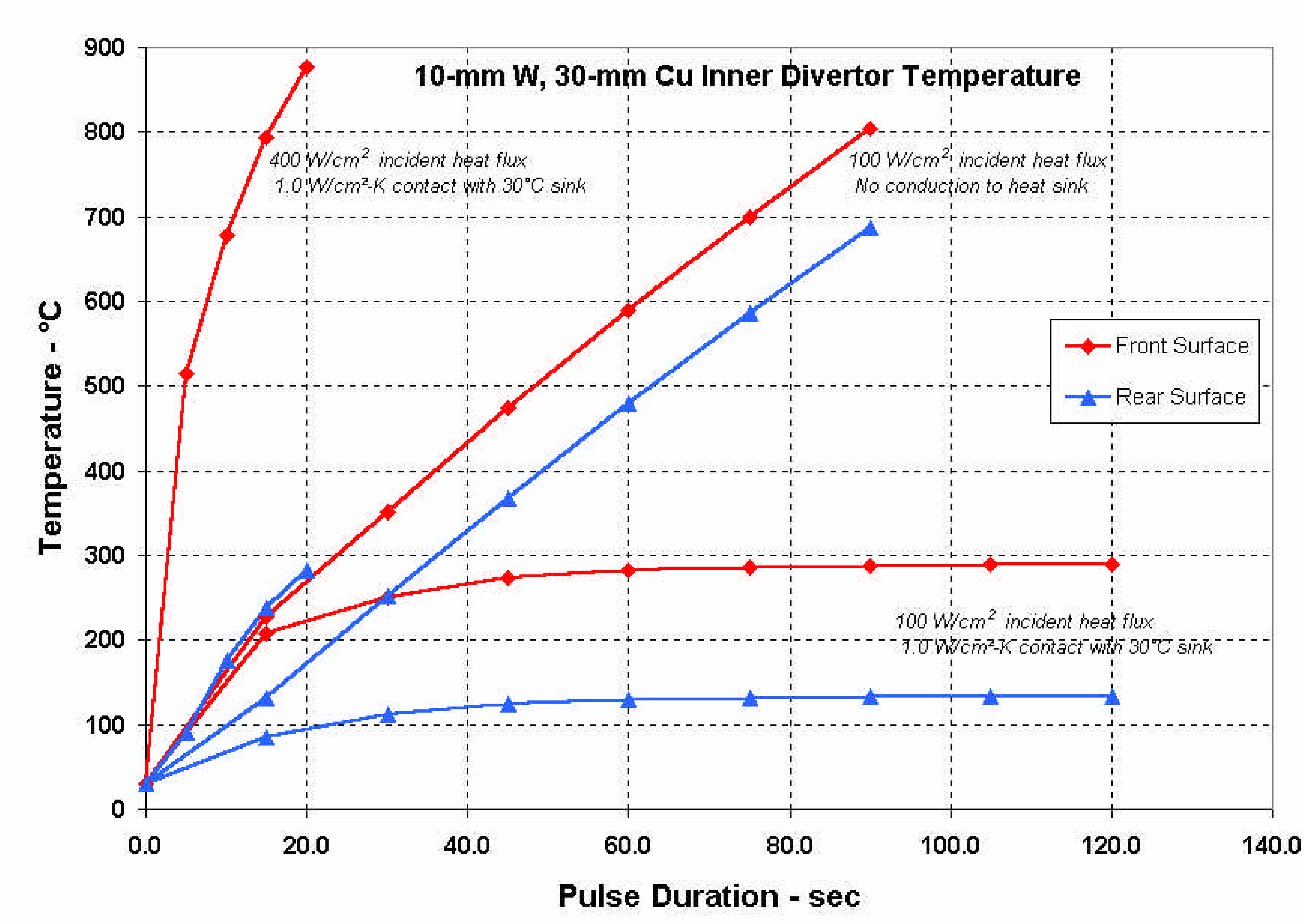

Halo Current / Disruption Load Assessment

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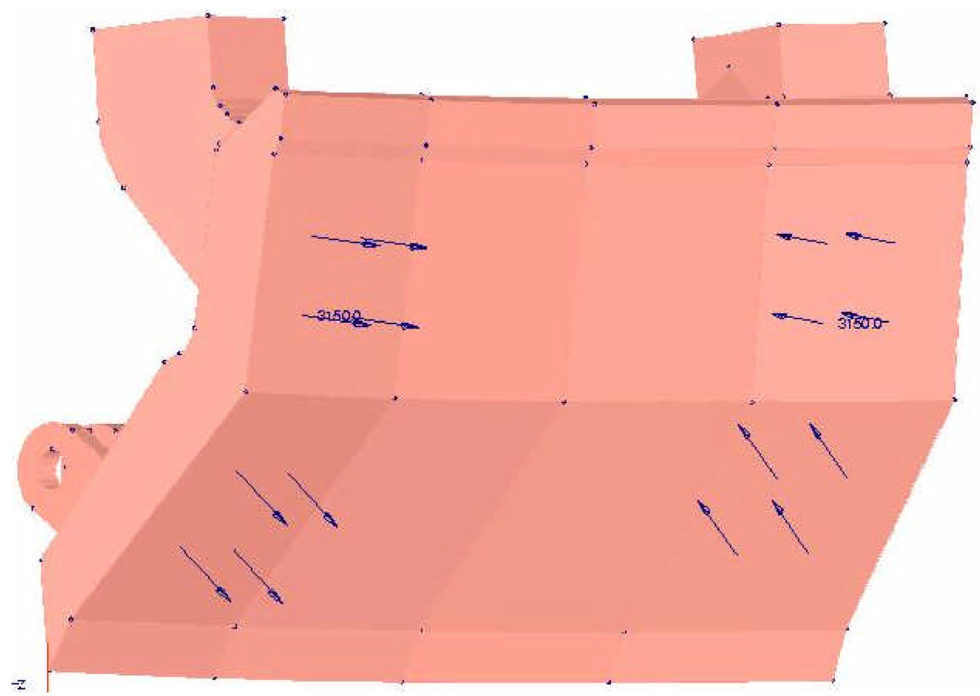
- 1.8 MN disruption loads applied as opposing 3150 lb/in^2 pressures over end quarter panels
- 0.8 MN halo current load applied as uniform 350 lb/in^2 pressure over entire plate surface
- Evaluate back plate response only, no credit taken for finger element load sharing
- Model pins as sliding contact interfaces fixed by springs to ground
- Include cross manifold channels in back plate and remove finger attach ribs from front surface



Initial Outer Divertor Configuration

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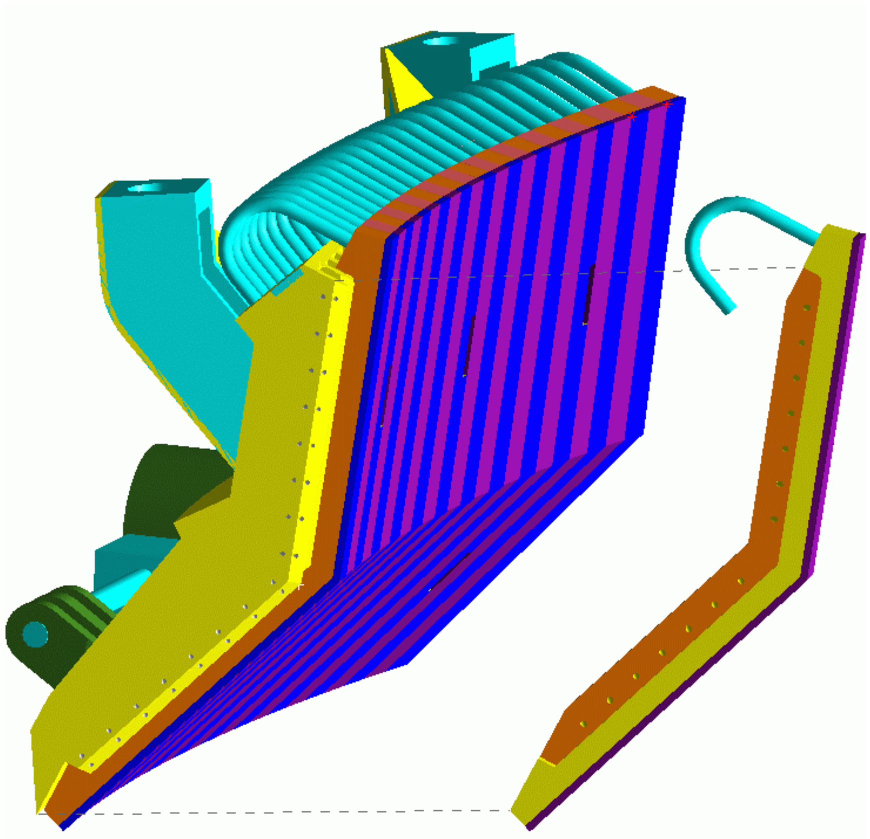
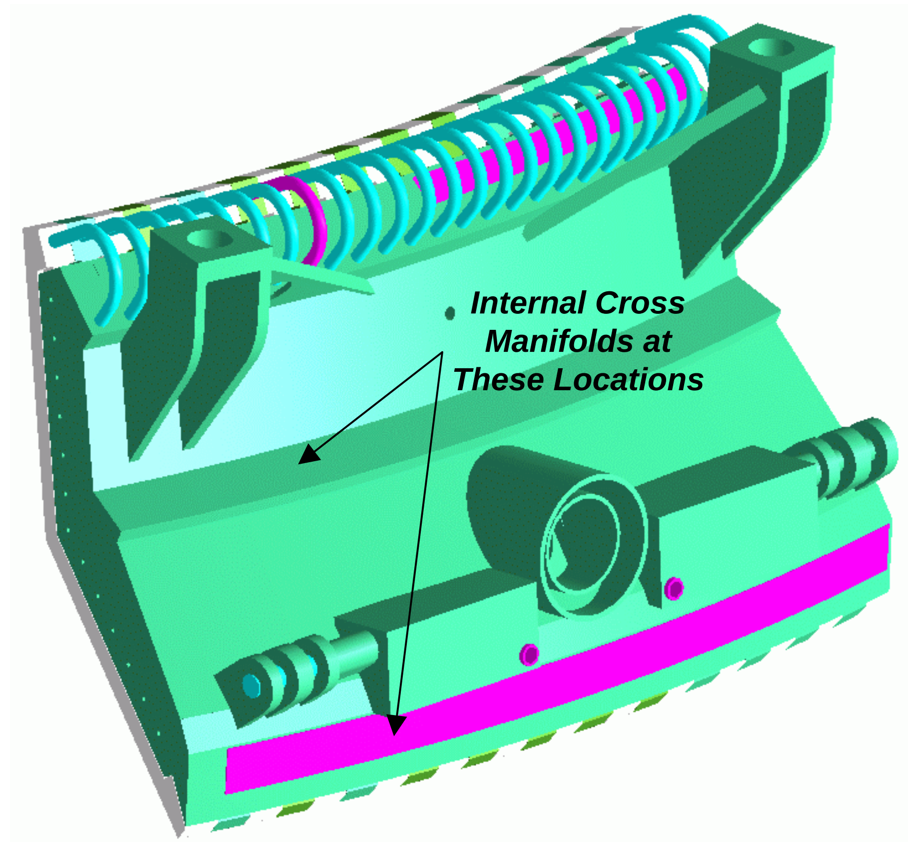
Front Surface View Showing Finger Elements



Rear Surface View Showing Vessel Attachment / Cooling Interface Features



Changes to Improve Disruption Load Handling Capability

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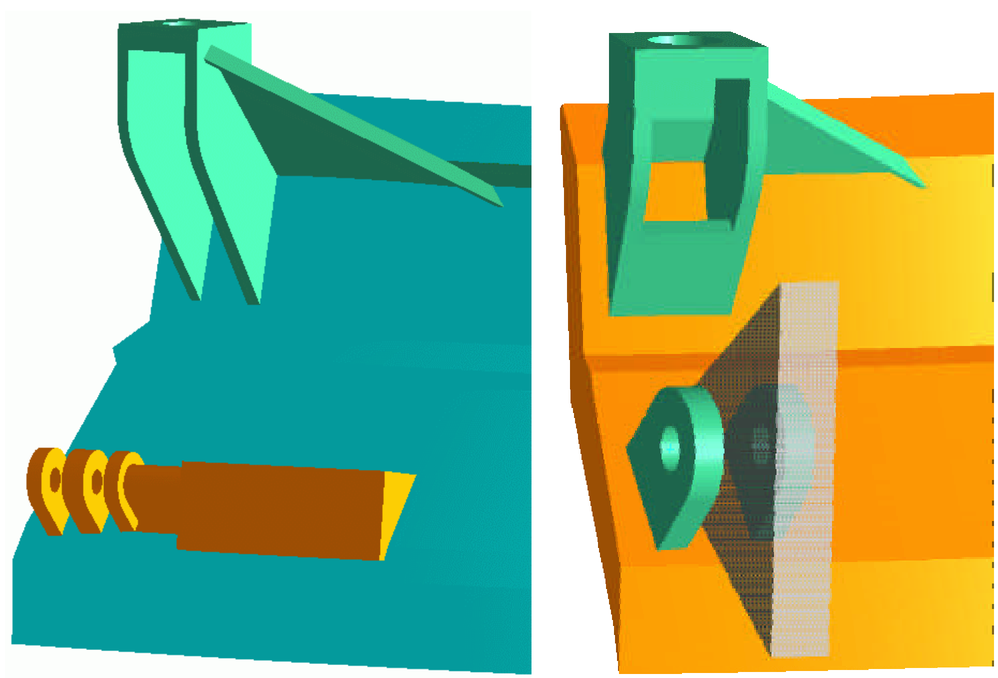
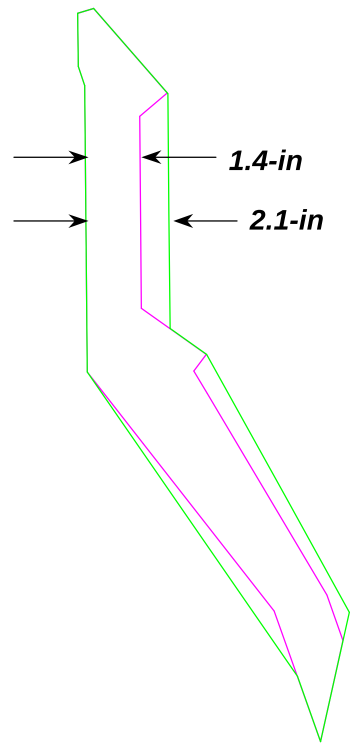
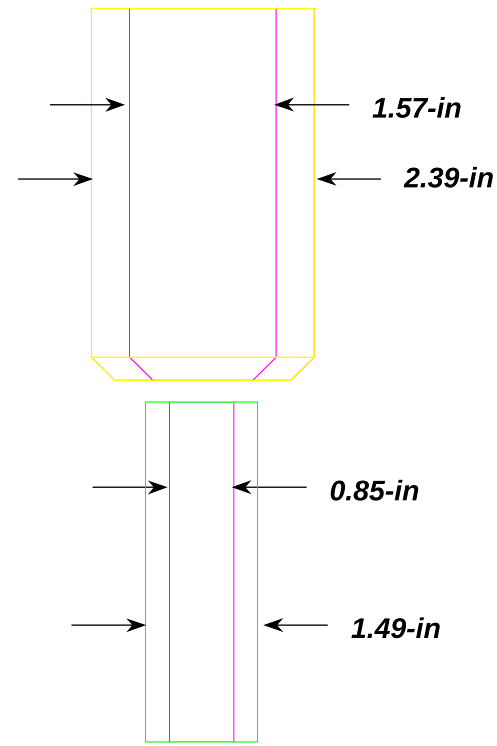
Lugs Enlarged, Single Vessel Support to Improve Load Distribution Tied Directly to Vessel Intershell Structure



Backplate Stiffened



Pin Sizes Increased



Halo Current Results Summary

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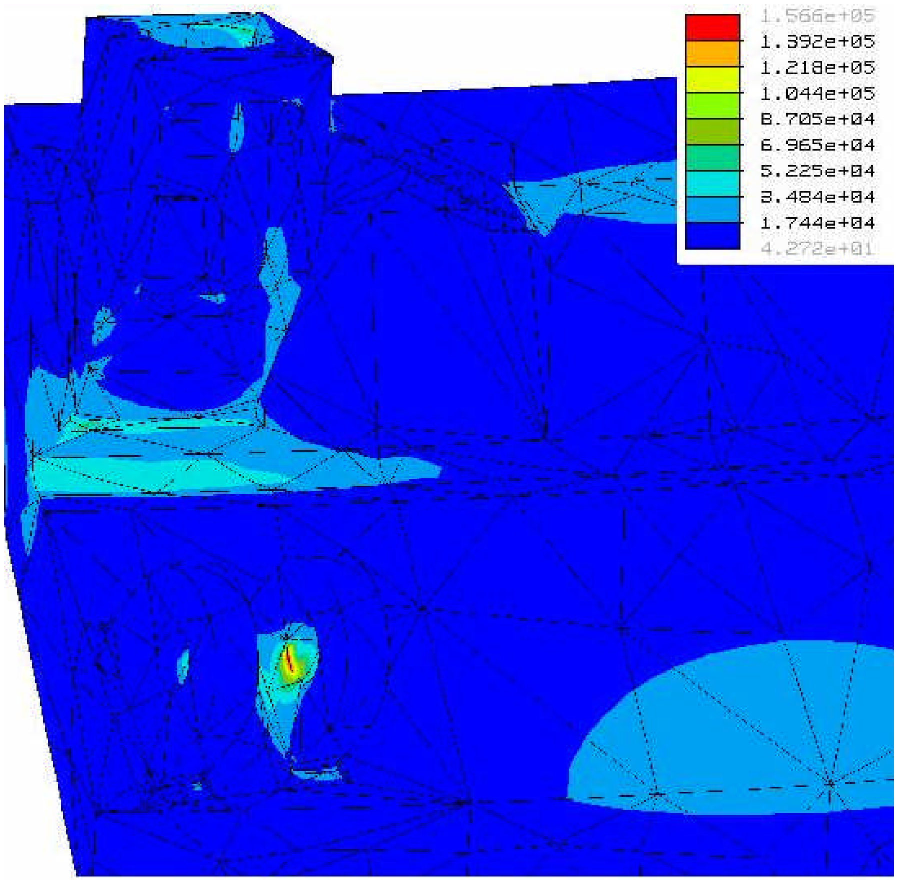
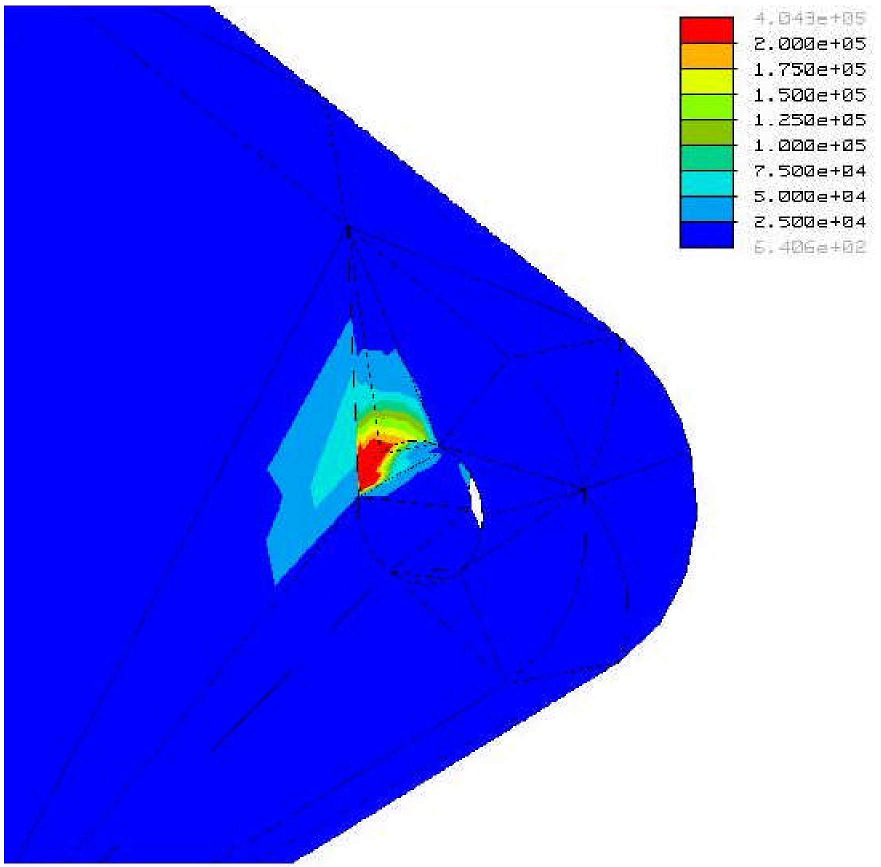
- Loads within 40 ksi allowable for SS316 in most areas
- Contact loads in lugs exceed bearing guideline of 1.5 yield





Disruption Eddy-Current Loads Require Inconel-718 Back Plate

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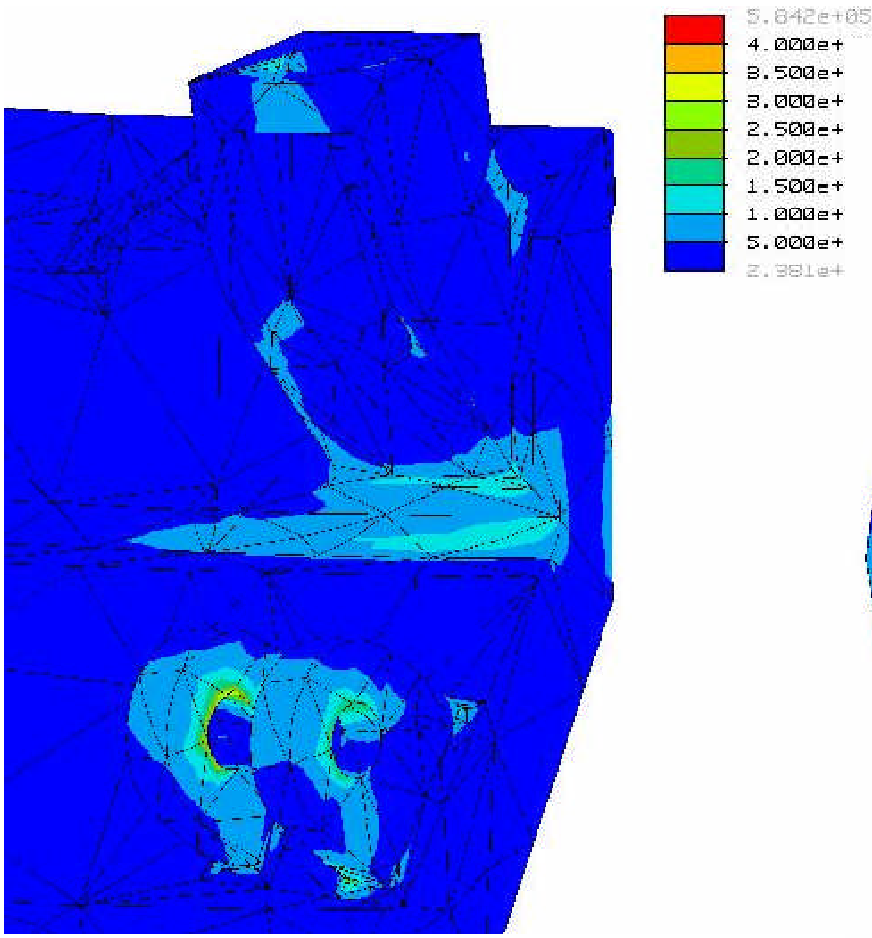
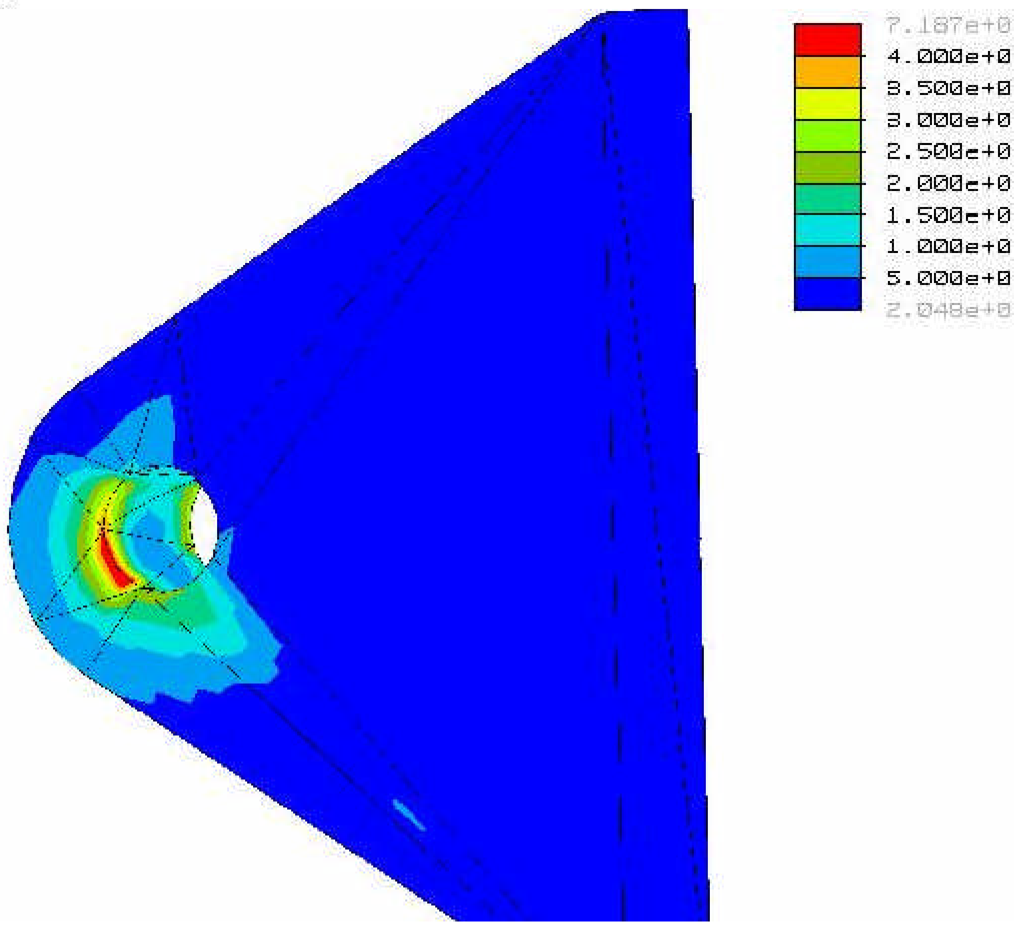
Backplate Loads Generally Below 150 ksi Yield for In-718



Some Plastic Deformation Expected Around Vessel Support Holes (0.1-in Chamfer)



Finger Plate Pull-Off Assessment

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Is pin attachment scheme adequate if disruption eddy current flows primarily in outer two Cu-finger elements?

- ❑ **Estimated load of 1.8 MN at each toroidal end of module, confined to 2 outer Cu-fingers**
- ❑ **Must react 0.9 MN pull-off load through attachment pins on single finger**
- ❑ **Requires minimum of 25 In-718 pins for baseline 4.5-mm diameter at backing plate interface**
- ❑ **Requires 40 pin holes in CuCrZr for bearing load maximum of 90 ksi assuming load reacted over ¼ hole circumference**

Toroidal Electrical Connectors

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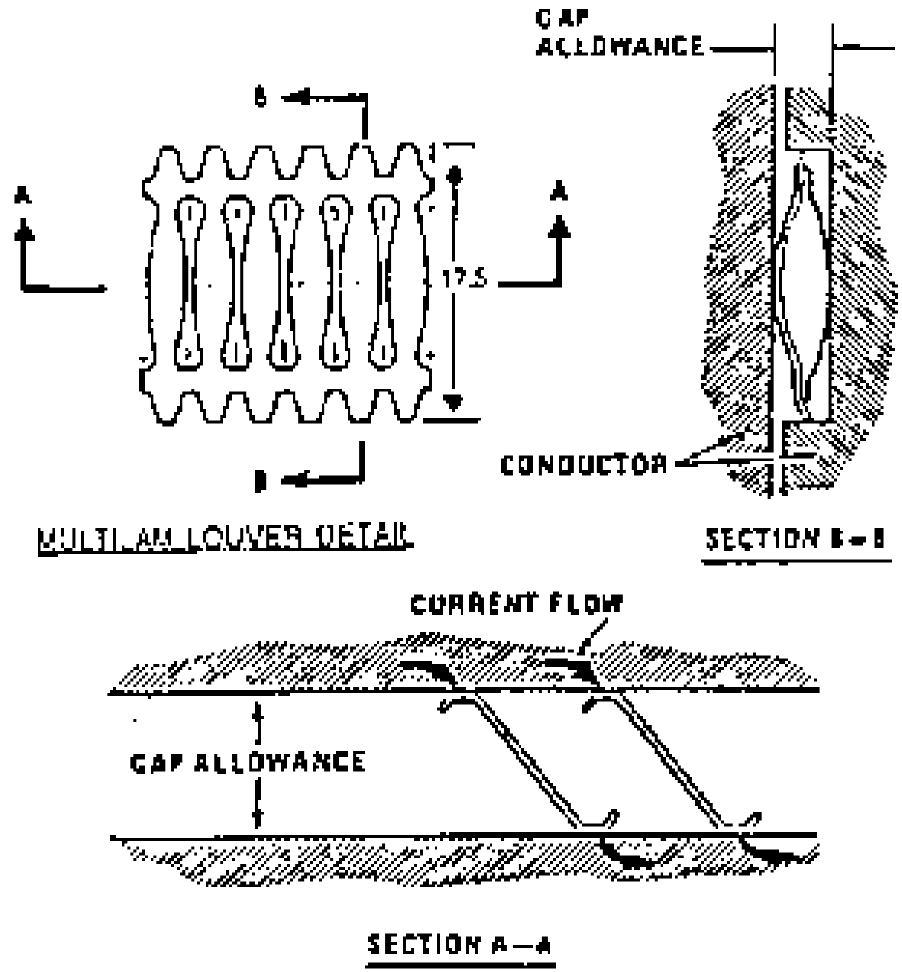
- ❑ Use Multilam® approach developed for ITER by General Atomics
- ❑ Assume type LAII/0.15 louver band with a width of 14-mm and a louver spacing of 1.5-mm
- ❑ Be-Cu material with good surface contact and spring capability
- ❑ Louvers will carry 750 A for a 1-sec duration short circuit condition with a surge capability (10-ms duration) of 3.5 kA
- ❑ Reference gap allowance is 0.5-mm for reliable contact force



Possible Connector Configuration

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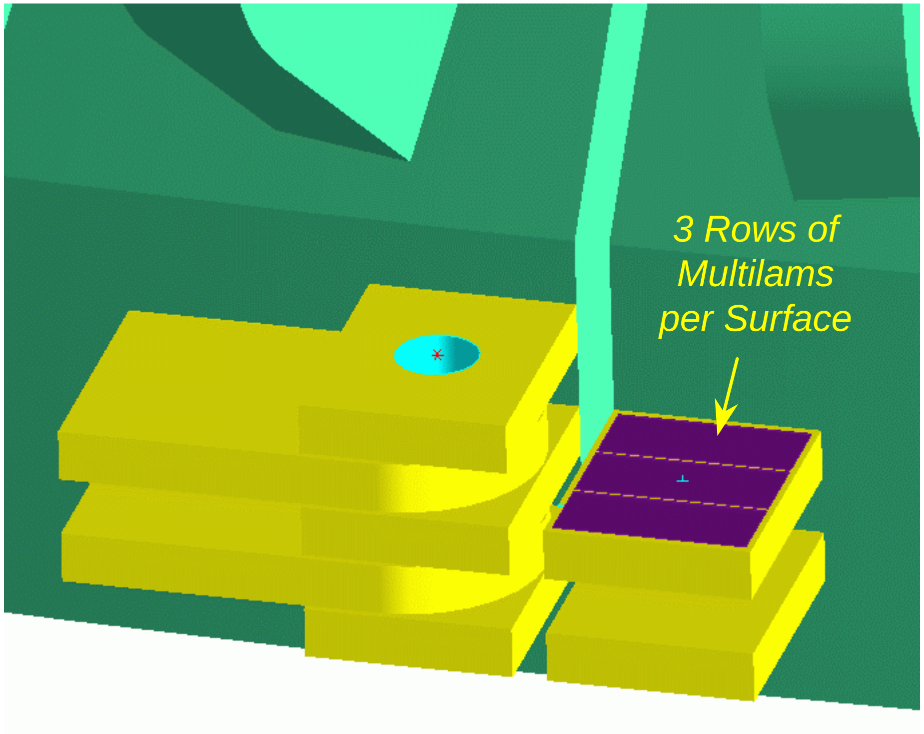
- **Estimated toroidal loop current of 400 kA during disruption**
- **Interweave louver strips to double contacts per unit length**
- **56 cm^2 (8.7 in^2) of area required to carry the 400 kA current**
- **Lugs retaining Multilam strips are 38-mm wide and contain 3 bands on each contact surface**
- **Rotating legs are ~82-mm long to bridge the gap between modules**
- **Plates are 10-mm thick to resist bending loads from the current flow**



Remaining Issues for FY'01

- Assess/update outer divertor module design based on new disruption conditions (in-place, VDE, and radial disruption). Determine whether toroidal electrical connectors are required.
- Refine toroidal electrical connector concepts including alignment and remote handling requirements
- Develop conceptual design for actively-cooled baffle
  - 2D & 3D thermal-structural analysis
  - Integration with vessel, primary cooling and remote handling systems
- Update conceptual design for passively-cooled inner-divertor plate based on new disruption conditions
  - 2D & 3D thermal-structural analysis
  - Integration with vessel and remote handling systems

Required R&D Tasks to Confirm Design

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- Continue W-brush fabrication process development / scale-up and HHF testing to validate performance and improve reliability / manufacturability
- Continue outer divertor fabrication process development / scale-up begun under ITER through prototype development and testing
  - Channels combining heat transfer enhancement (helical wire, swirl tape, etc.) with W-brush armor
  - Cu-finger element integration with SS back structure (pins, welds, alignment, etc.)
- Continue baffle fabrication process development / scale-up
  - Large-area HIP-diffusion bonding
  - End manifold closeout welds
  - Large-area W-armor integration
- Development of effective passive heat transfer layer for first wall and inner divertor tiles (copper foam metals, etc.)
- Fabricate and test electrical connectors to validate performance and in-service design guidelines
- Fabricate dummy elements/end effectors to use for validating remote handling interfaces and procedures
- Continue Be plasma spray process development begun under ITER for the first wall armor application

Divertor Piping Concept

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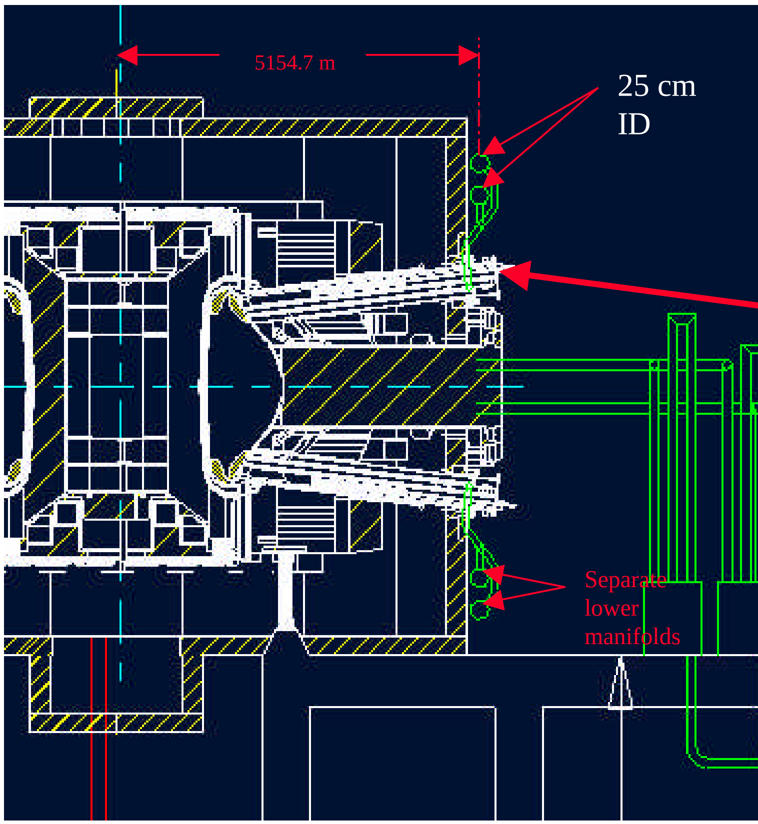

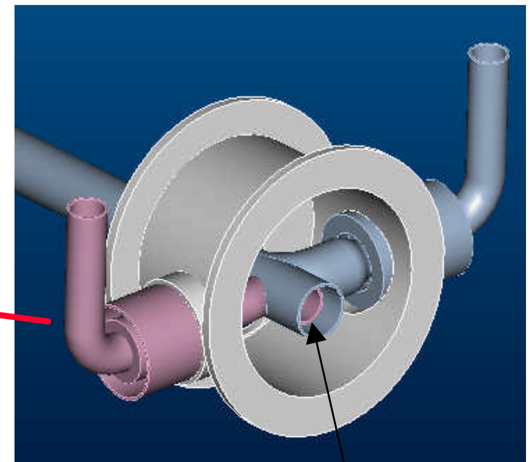

80 mm ID inner pipe

120 mm ID outer pipe

Separate upper and lower manifolds supply lines feed a 90° quadrant of the machine assembly.

Tensile Tests Confirmed Bond Quality

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HIP joint properties slightly lower than base metal due to gas quench