FIRE Plasma Facing Component Design Activities

NSO Physics Validation Review Meeting

Mar, 2004

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The Boeing Company

Contributions from
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General Atomics

Presentation Outline

- Component sizing and thermal performance assessments
- Divertor component redesign into single module
  - New outer divertor configuration
  - New baffle configuration (actively-cooled)
  - Inner-divertor configuration (actively cooled)
- Halo-current / Disruption loading assessments
- Remote handling assessments
- Remaining conceptual design issues

Current FIRE Divertor Configuration

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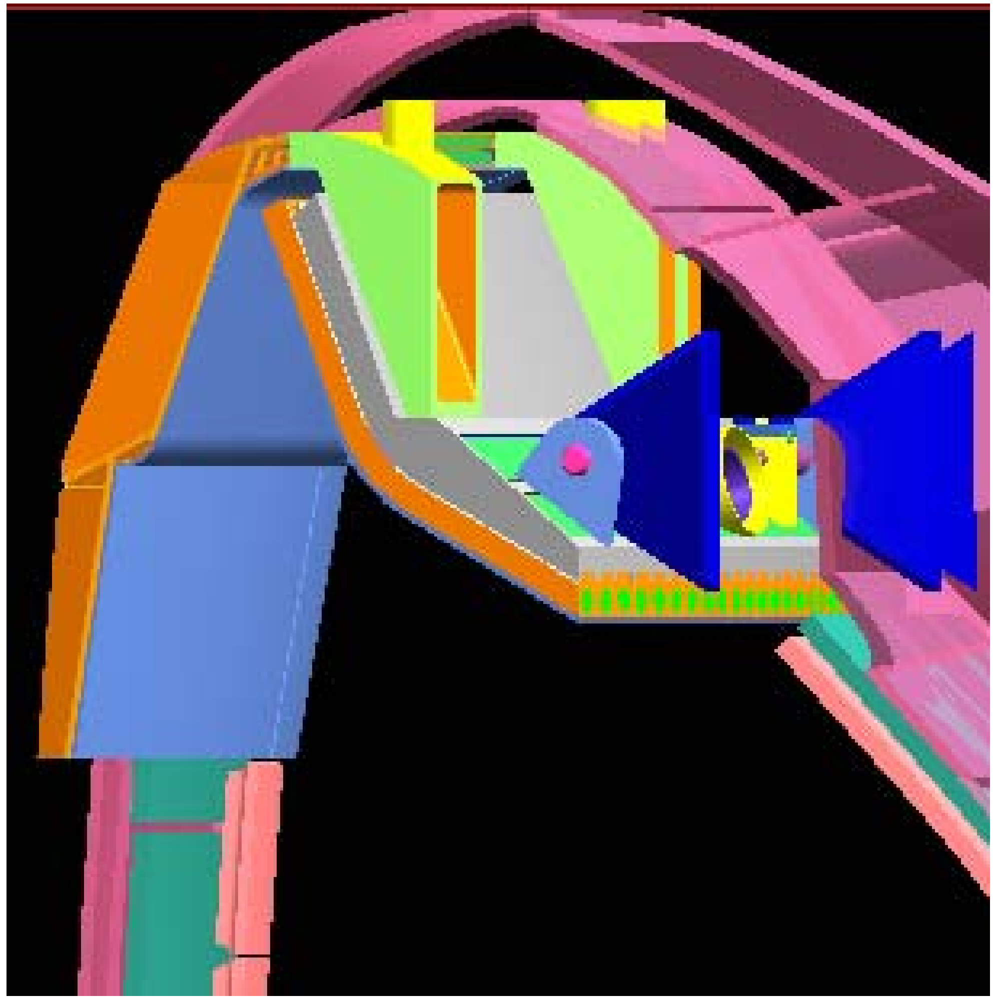
- 16 upper and lower modules combining inner divertor, outer divertor and baffle into single unit
- Build on design/fabrication approaches developed during ITER-EDA
- W-brush armor on divertor components and plasma-sprayed Be for first wall tiles
- Individually-tested Cu-alloy finger elements for high heat flux outer target
- Concentric cooling channel arrangement in outer divertor fingers eliminates water pipe loops at upper pumping slot end
- Gun-drilled channels in formed CuCrZr plate construction for lower heat flux baffle and inner divertor
- Combined modular unit for simple in-vessel remote handling operations during maintenance



All Components Actively Cooled by Horizontal Port Concentric Pipe Feed

Revised Divertor Design Improves Remote Handling and Vacuum Pumping

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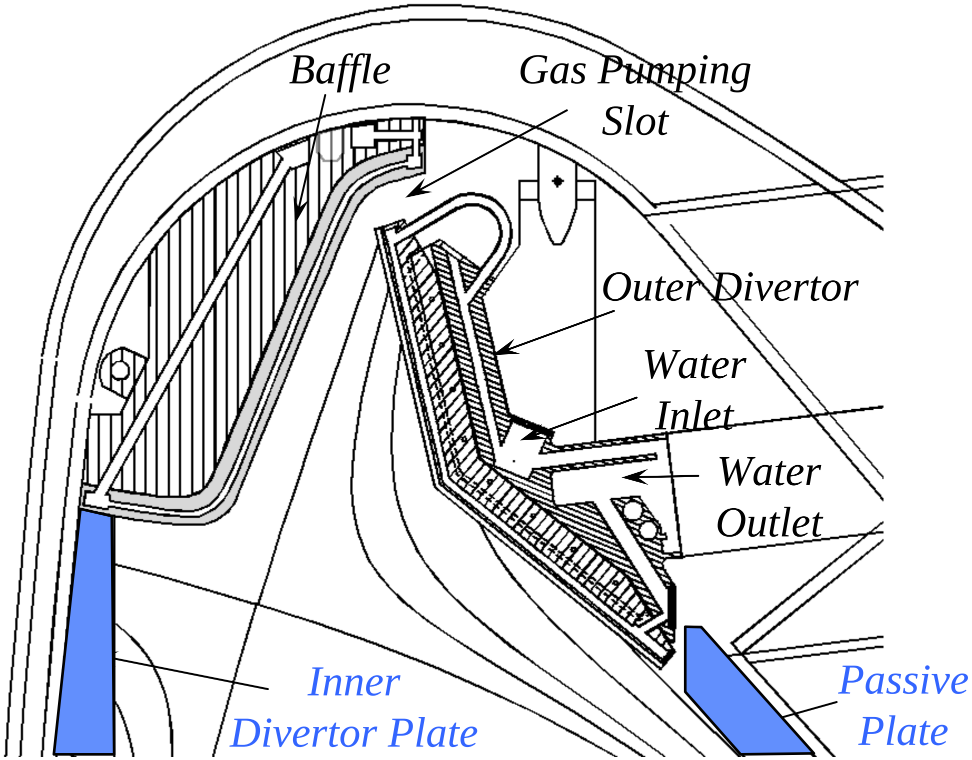
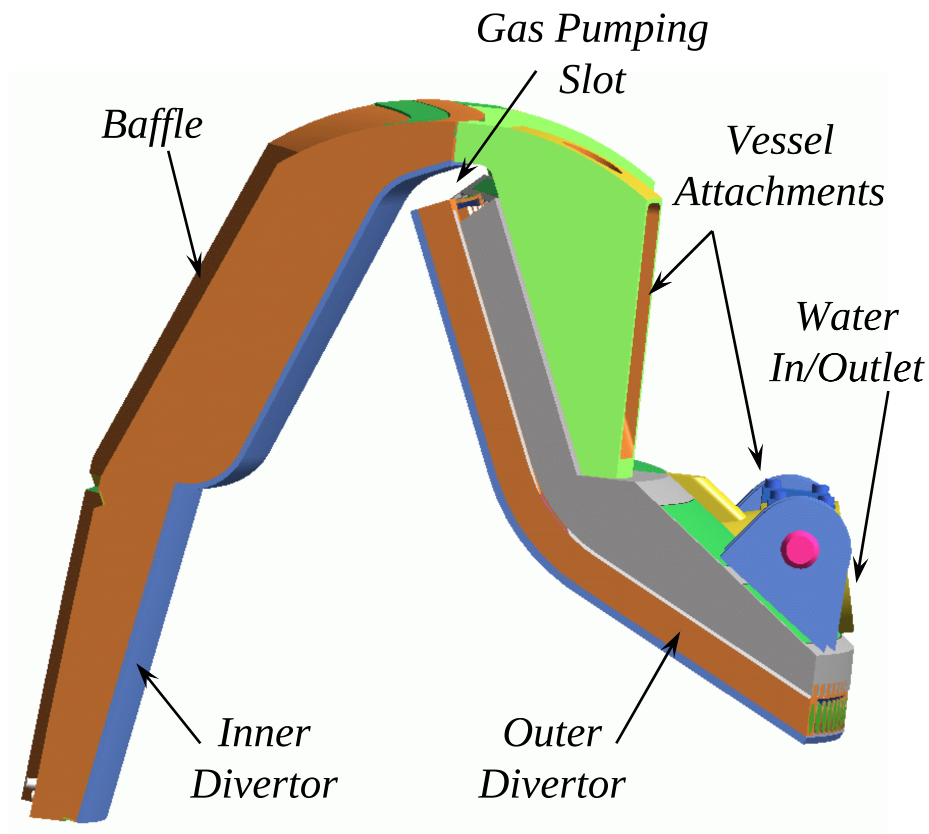
CY'01 Configuration

(Three Separate Components)



CY'03 Configuration

(Single Combined Module)



New Outer Divertor Design Concept

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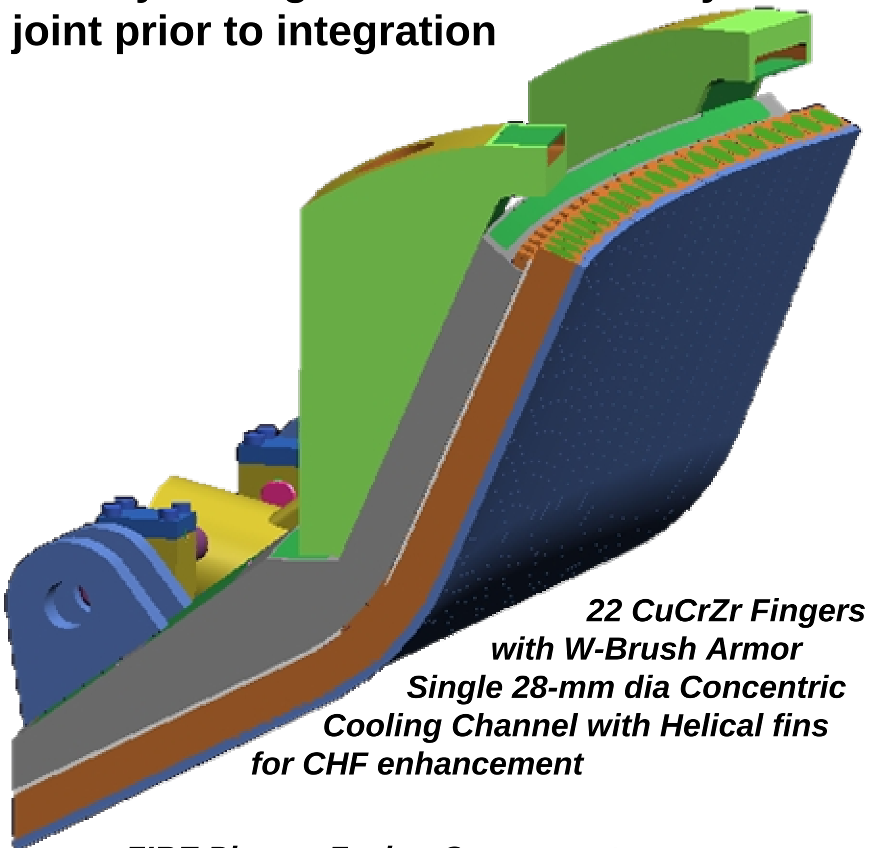
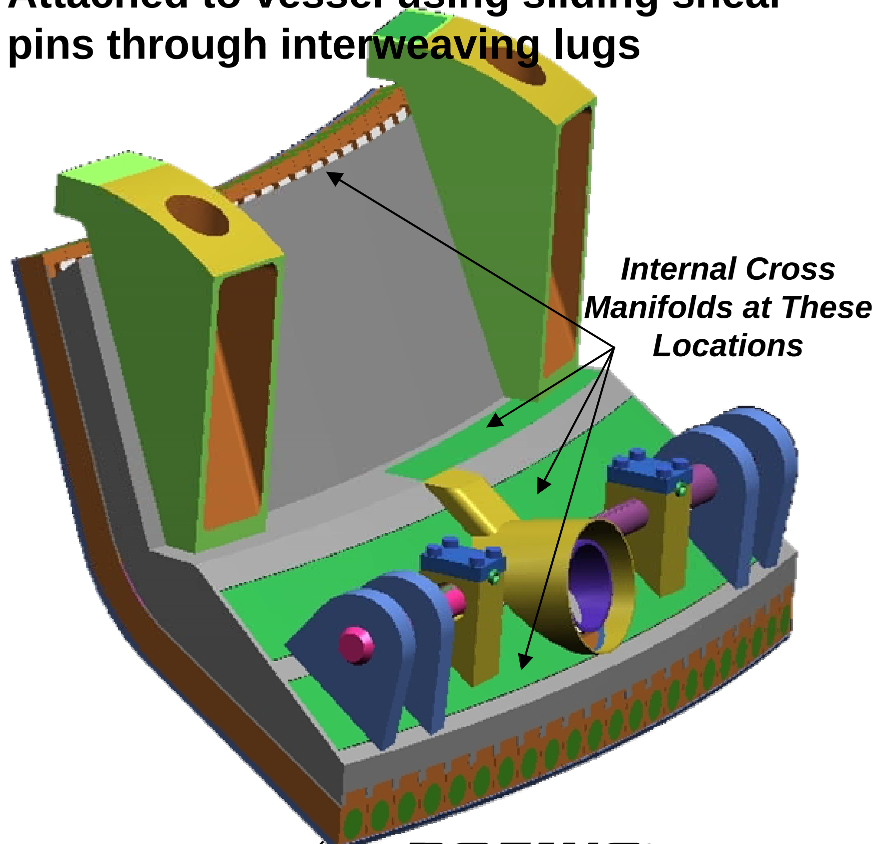
- ❑ 22 CuCrZr finger elements with W-brush armor, attached to back plate using sliding U-channel and laser welds
- ❑ Direct HIP-bond fixtured W-rods or EB-weld prefab brush with PS-Cu layer
- ❑ HHF cycle finger elements to verify armor joint prior to integration
- ❑ SS316LN back plate for structural support with machined/gun-drilled channels for cooling / manifolding
- ❑ Coolant supplied using concentric pipe feed down divertor ports
- ❑ Attached to vessel using sliding shear pins through interweaving lugs





Details of Backplate Design

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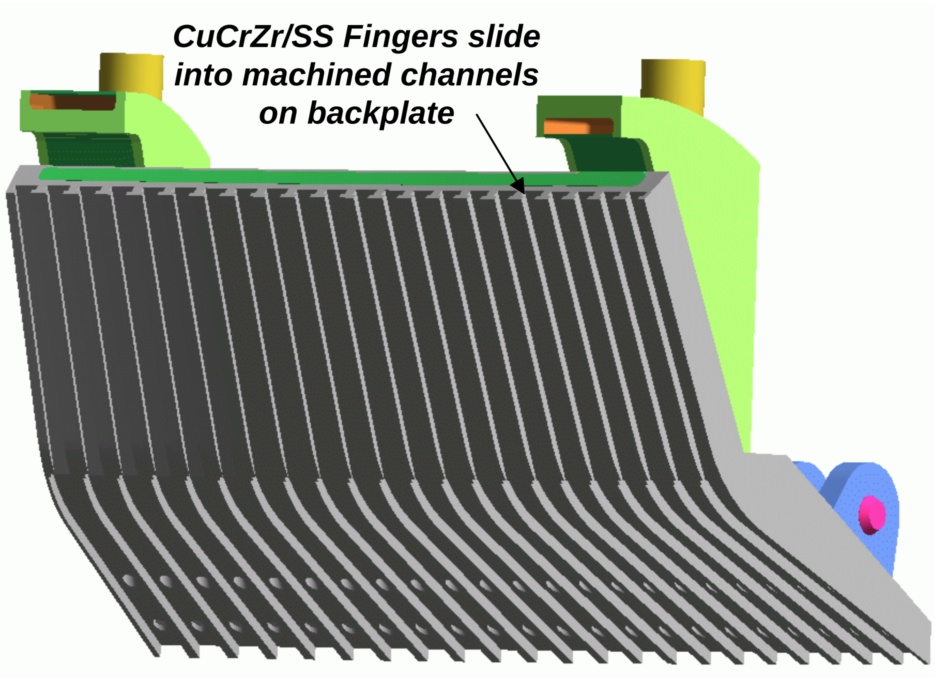
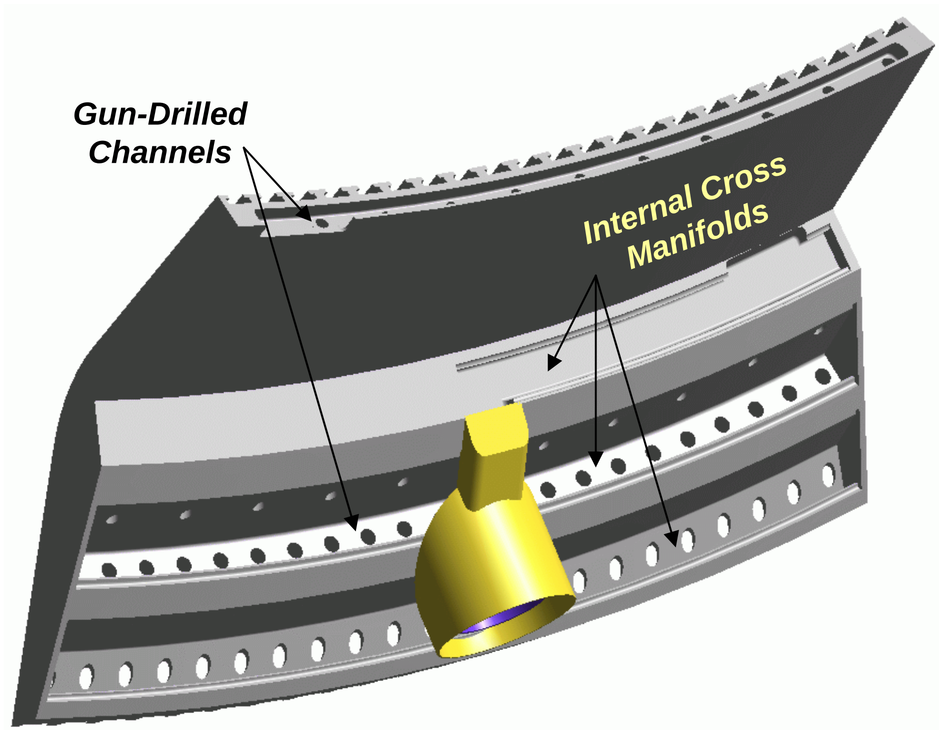
- Finger elements slide into machined U-channels on upper section of back plate
- Cooling connections welded after tube stubs engage machined holes on lower section of plate
- Laser weld lower section structural attachments after cooling welds verified
- Machined and gun-drilled channels for cooling / manifolding
- Welded cover plates close out machined cross channels
- Weld final vessel attach features in-place after cover plate welding





3D Views of New Outer Divertor Finger Plate Configuration

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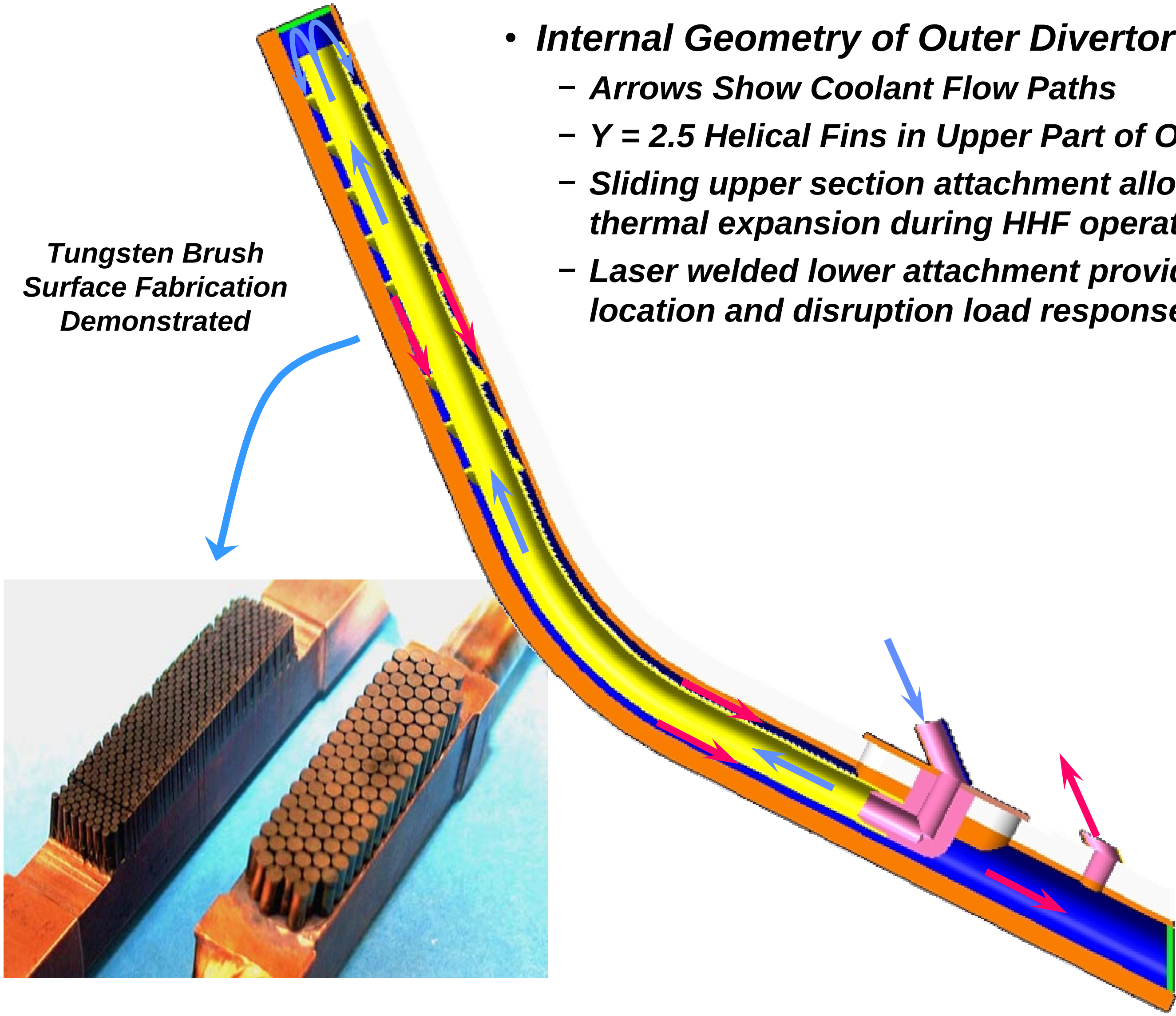
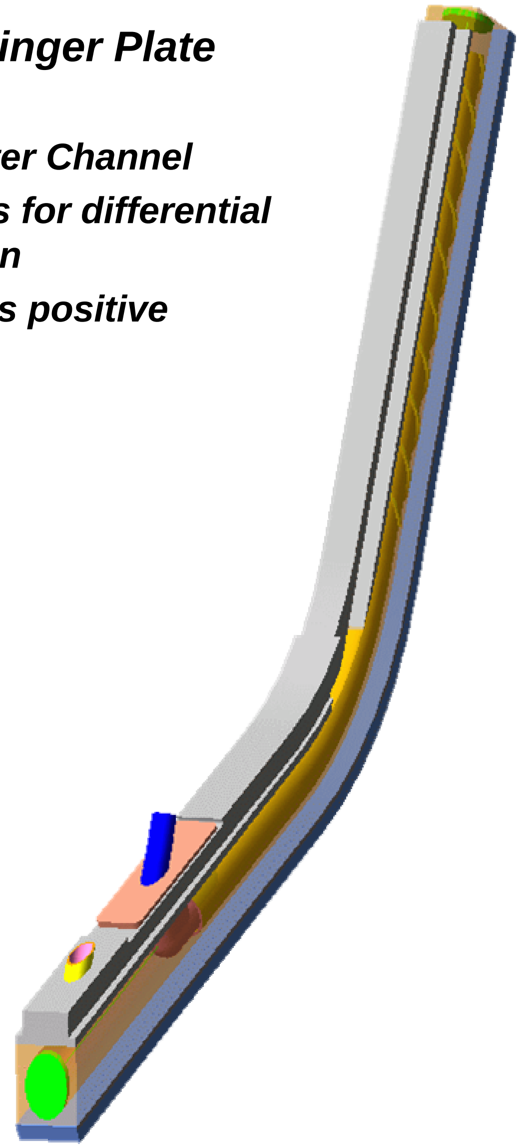
- ***Internal Geometry of Outer Divertor Finger Plate***
  - ***Arrows Show Coolant Flow Paths***
  - ***Y = 2.5 Helical Fins in Upper Part of Outer Channel***
  - ***Sliding upper section attachment allows for differential thermal expansion during HHF operation***
  - ***Laser welded lower attachment provides positive location and disruption load response***

Tungsten Brush Surface Fabrication Demonstrated





Typical Configuration for Actively-Cooled Finger Elements

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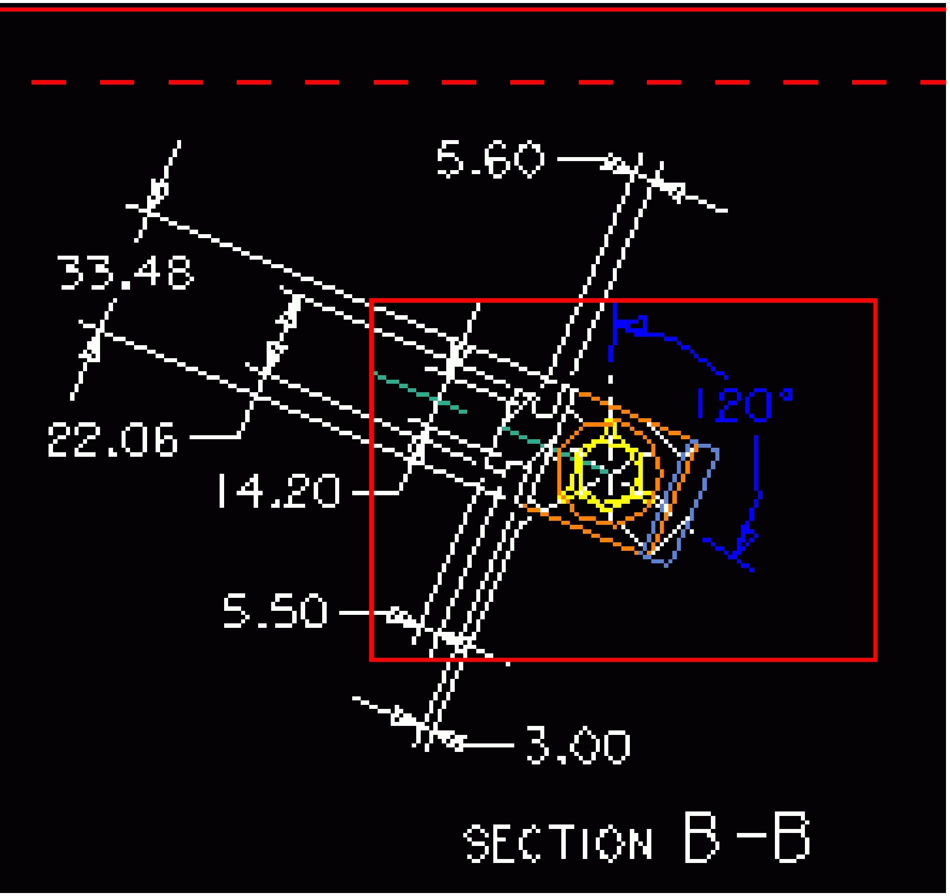
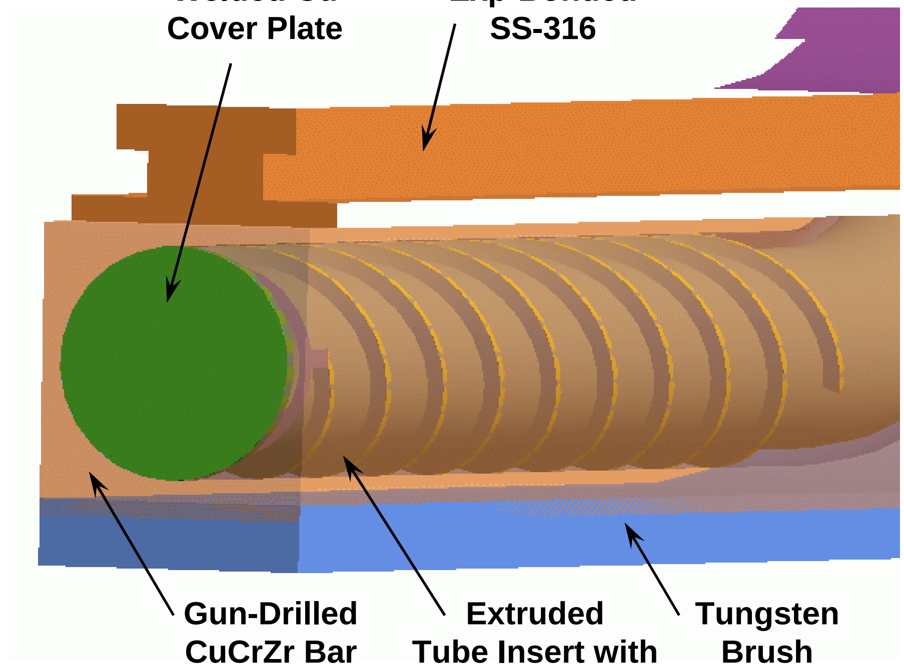
Outer Divertor Unit Cell
9 MW/m²

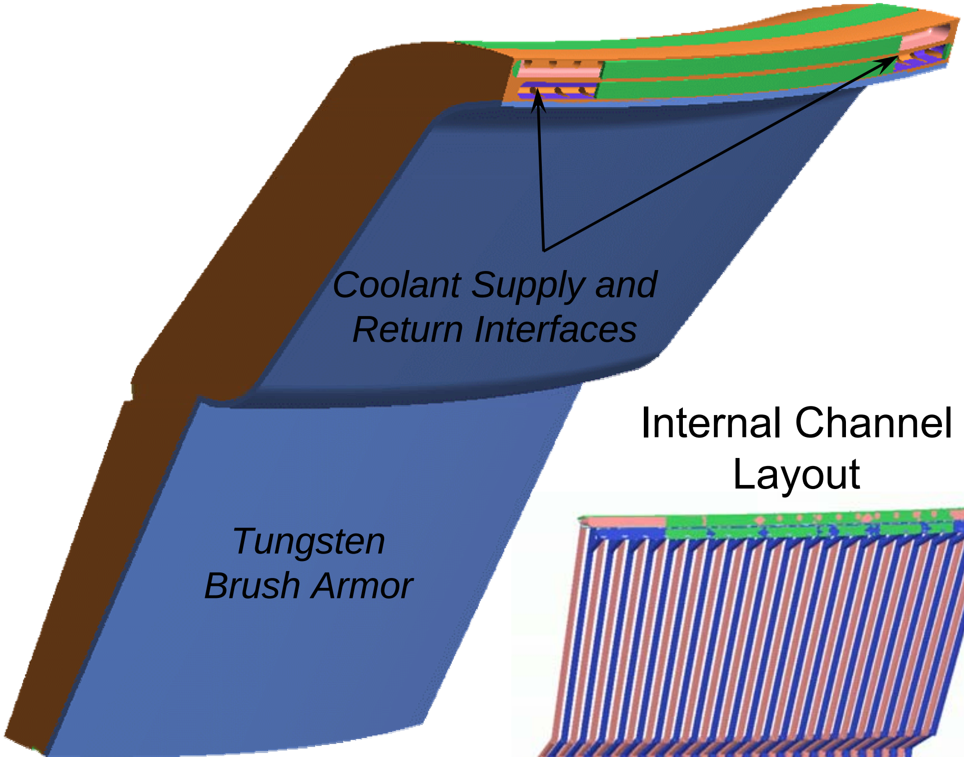


Gundrilled CuCrZr Finger Plate
y=2.5 Helical Fins
5 m/s, 30°C, 1.5 MPa

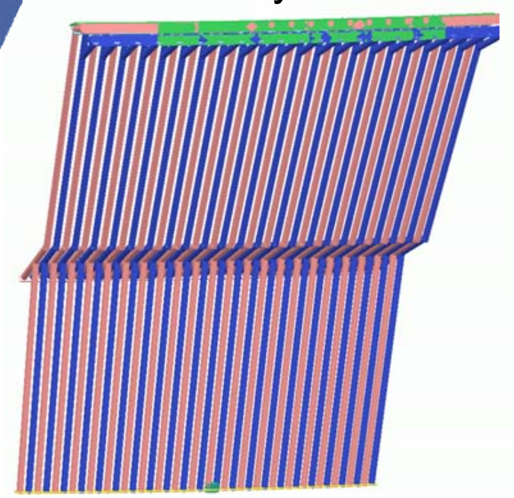


Baffle and Inner Divertor Component

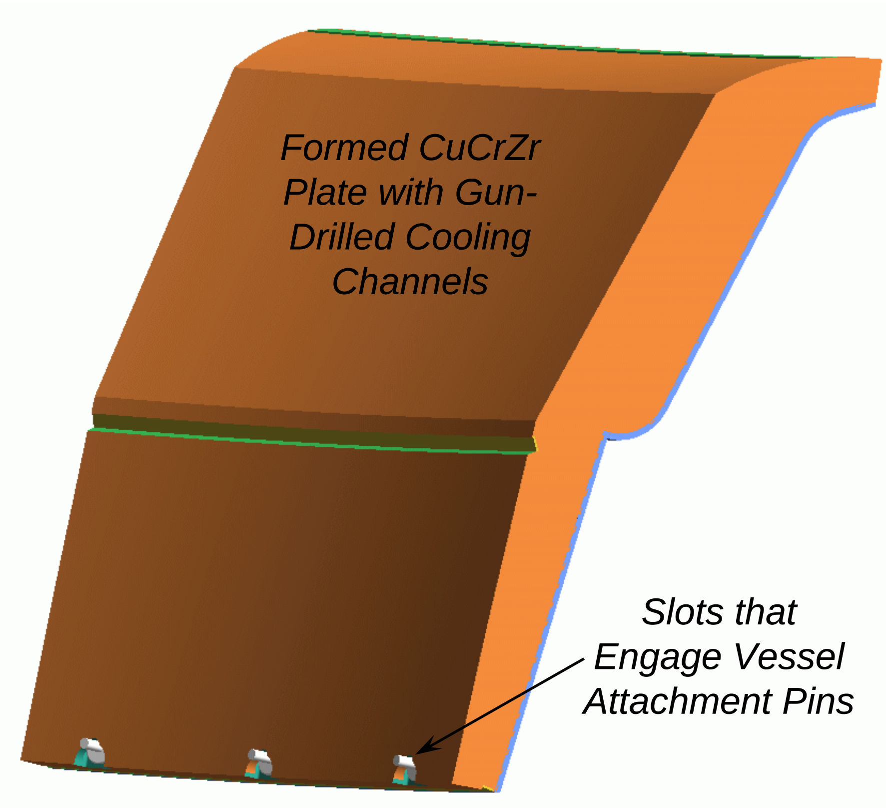
Front View



Internal Channel Layout



Rear View



Unit Cell Sizing for Actively-Cooled Outer Divertor and Baffle

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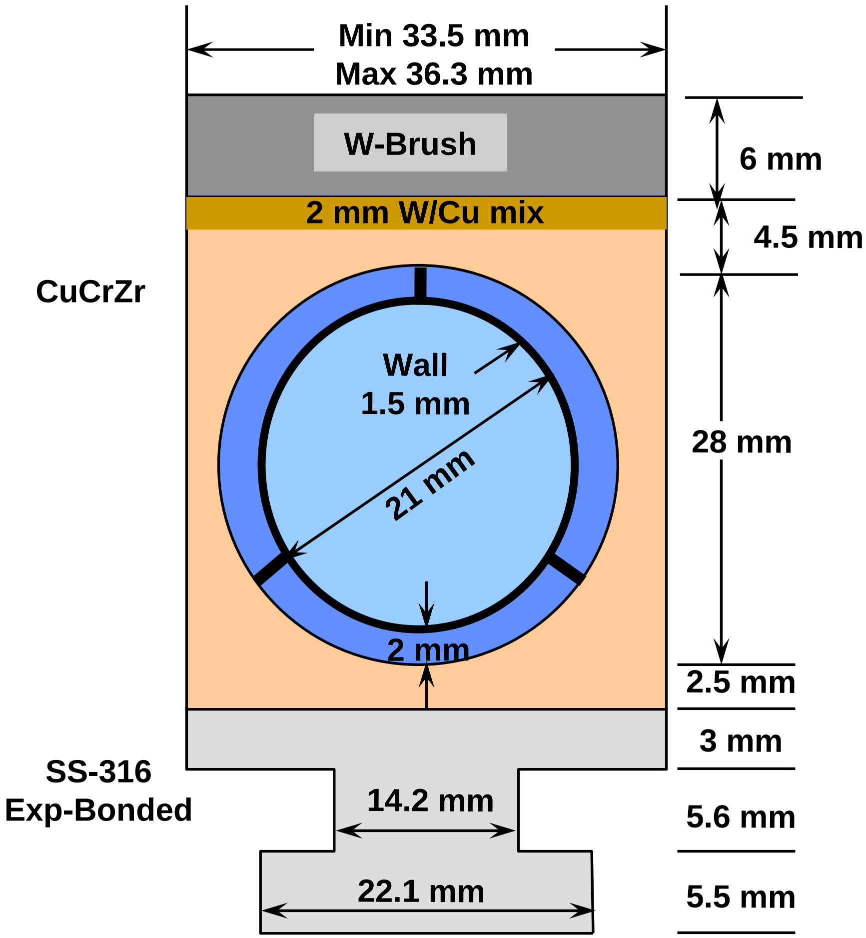
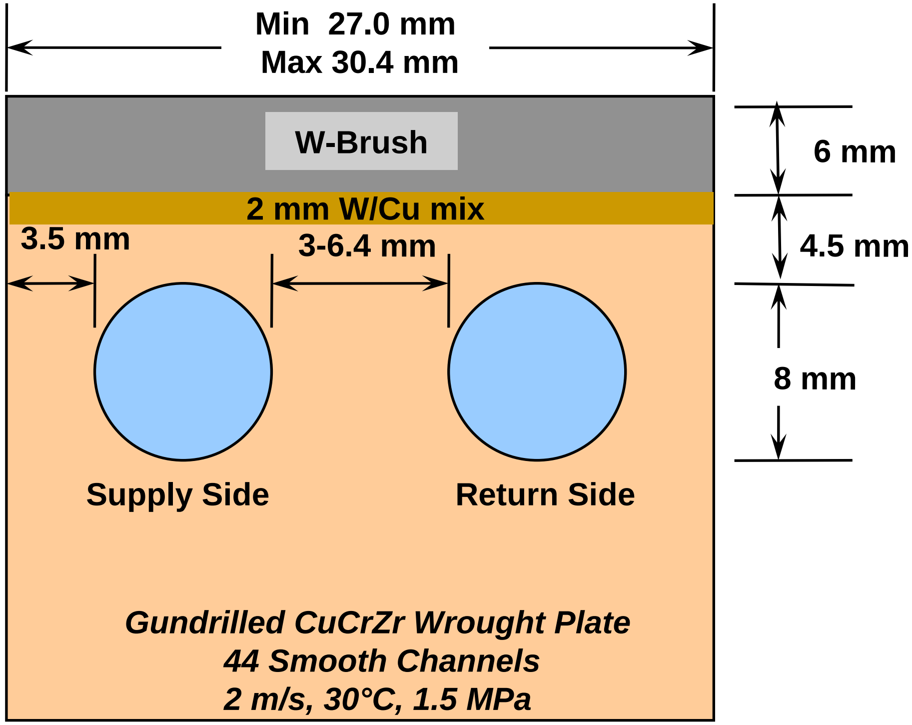
Outer Divertor Unit Cell
9 MW/m²



22 Gundrilled CuCrZr Finger Plates
y=2.5 Helical Fins
5 m/s, 30°C, 1.5 MPa

Baffle Unit Cell
3.4 MW/m²



Gundrilled CuCrZr Wrought Plate
44 Smooth Channels
2 m/s, 30°C, 1.5 MPa

Coolant Flow Paths and Manifolding in Backplate and Baffle Structures

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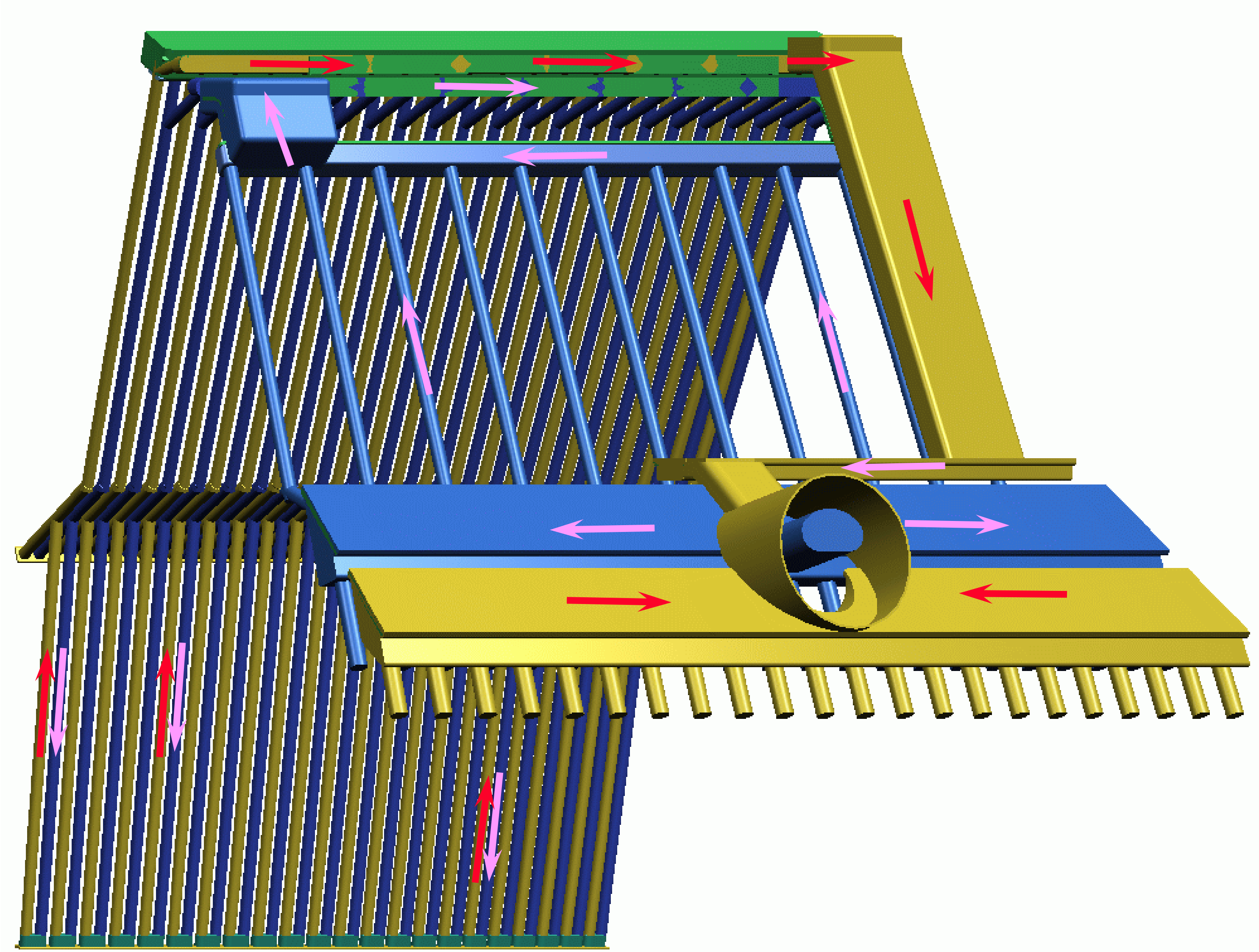
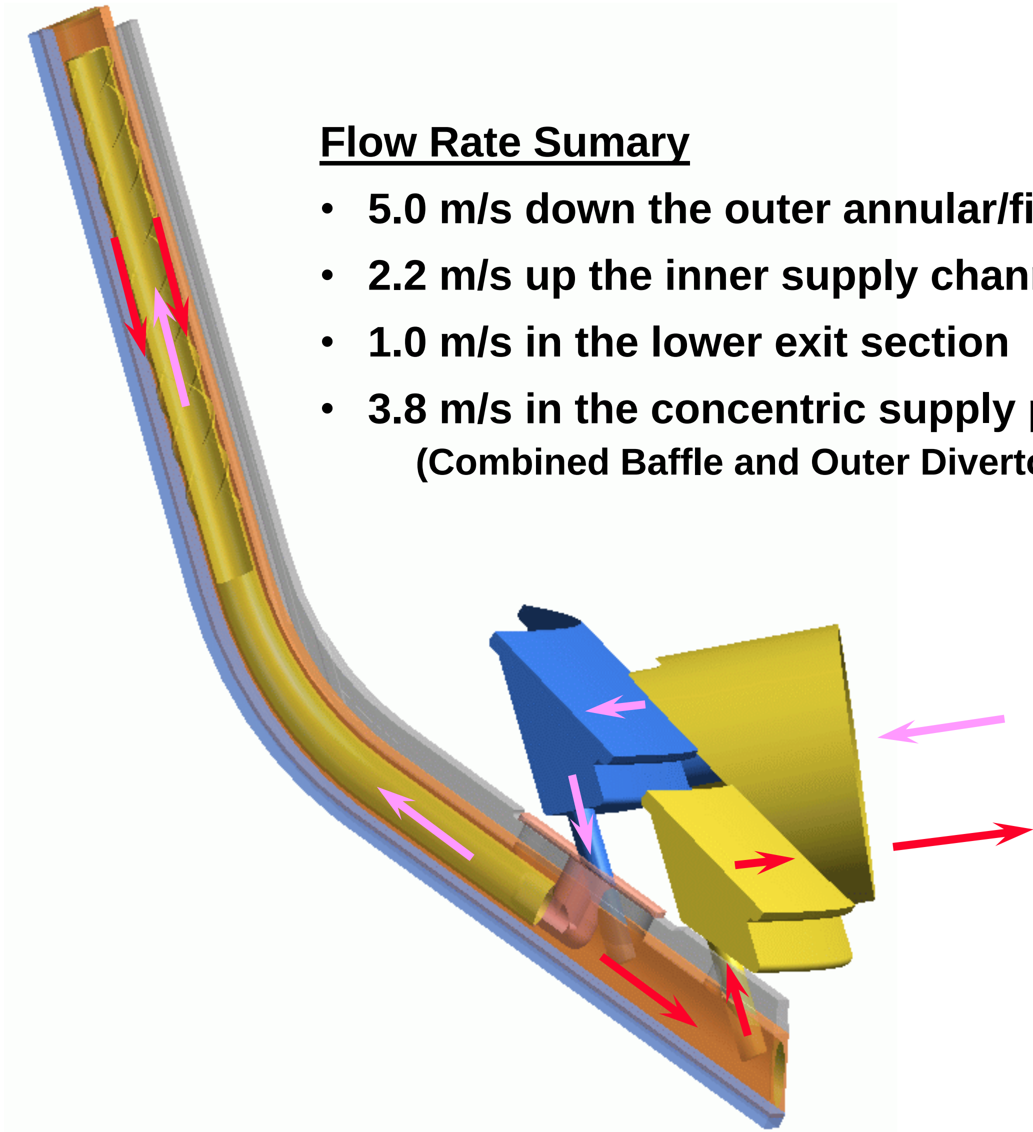


Finger Element Coolant Supply Path



Flow Rate Sumary

- **5.0 m/s down the outer annular/finned region**
- **2.2 m/s up the inner supply channel**
- **1.0 m/s in the lower exit section**
- **3.8 m/s in the concentric supply piping**
  (Combined Baffle and Outer Divertor Flow)

Outer Divertor Flow Parameter Summary

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Outer Divertor Power Balance and Flow Parameters for FIRE

Overall Power Balance

Fusion Alpha Power	30	MW
Auxiliary Heating Power	30	MW
Total Plasma Power	60	MW
Power Fraction Radiated	33%	
Power Fraction to Inner Divertor	20%	
Power Fraction Radiated in SOL	20%	
Power to Inner Divertor	6.4	MW
Power to Outer Divertor	25.6	MW
Power to Baffle	8.0	MW
Number Modules (Upper & Lower)	32	
Channel Flow Rate	5.0	m/s
Single Pass Mass Flow Rate	16.6	kg/s
Calculated Pressure Drop (Darcy)	0.156	MPa
L/D Equivalent for U-bend	100	

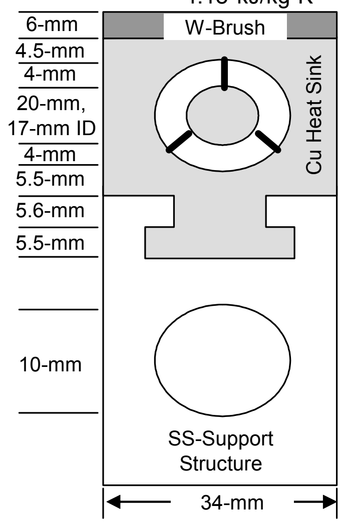
Channel Length (50% with Fins)		700.00	mm
Annular Flow Area (Fin Reduction)		151.36	mm2
Total Fusion Power		180.00	MW
Nominal Pressure Drop (Half ITER VT)		0.09	MPa
Number Channels per Finger		1.00	
Fingers in Divertor Module		22.00	
Density		1.00	kg/liter
Viscosity		0.0010	kg/m-s
Specific Heat		4.17	kJ/kg-K
Inlet Saturation Temp	Tsat	197.8	°C
Reynolds Number	Re	6,375	
Equivalent Channel Diam	De	1.22	mm
Wetted Flow Perimeter	Pe	496.1	mm
Friction Factor (Darcy)		0.0319	

1.5 MPa Inlet Pressure Case

	1	2
Divertor Module Parameter	**Pass**	**Passes**
Avg Power to Module (MW)	0.80	0.80
Peak Power to Module (MW)	1.73	1.73
Number Cooling Channels	22	22
Cooling Channel Dia (mm)	28.0	28.0
Flow Area, 3 fins, 2-mm (mm²)	151.4	151.4
Water Flow Velocity (m/s)	5.0	5.0
Module Flow Rate (liter/s)	16.6	8.3
Water Inlet Temperature (°C)	30	30
Inlet Pressure (MPa)	1.5	1.5
Pressure Drop (MPa)	0.156	0.31
Exit Pressure (MPa)	1.34	1.19
Exit Saturation Temp (°C)	192.1	186.3
Nominal Temp Rise (°C)	11.5	23.0
Nominal Exit Temp (°C)	41.5	53.0
Nominal Exit Subcooling (°C)	150.6	133.3
Maximum Temp Rise (°C)	24.9	49.7
Maximum Exit Temp (°C)	54.9	79.7
Min Exit Subcooling (°C)	137.3	106.6
Combined Inlet flow velocity (m/s)	3.8	2.1
Inlet pipe ID (mm)	80.0	80.0
Coaxial pipe OD (mm)	124.8	124.8

Worst Case Exit Check

T_{exit}	54.9	°C
T_{sub}	137.3	°C
	0.99	kg/liter
	4.18	kJ/kg-K



Concentric Channel Info

28.0	OID
24.0	IOD
21.0	IID
346.4	Inner Area
151.4	Annular Flow Area
	Includes 3-2mm fins
2.2	m/s Inner Flow Velocity
1.2	m/s Exit Section Velocity

Coolant Supply Flow Areas

5026.5	Inner Area
5277.9	Outer Area

Component Cooling Assessment Summary

Not Fully Updated

Parameter	Outer Divertor	Baffle
Total Power (MW)	25.6	3.4
Peak Power/module (MW)	1.73	0.54
Peak Heat Flux (MW/m^2)	9.0	4.0
Nuclear heating in W (W/cm^3)	42	34
Nuclear heating in Cu (W/cm^3)	16	13
Channel Diameter (mm)	2 Annular	8
Pitch (mm)	35	14
Channels per module	22	44
Channels in series	1	2
Enhancement	Fin 2 mm, Y=2.5	None
Maximum PFC Temp (C)	tbd	tbd
Maximum Copper Temp (C)	tbd	tbd
Flow velocity (m/s)	5	2
Flow/module (liter/s)	16.6	2.2
Inlet/Max Exit Temperature (C)	30/55	30/32
Pressure Drop (MPa)	0.2	0.02
Exit Pressure (MPa)	1.3	1.48
Exit Subcooling (C)	137	165
Critical Heat Flux (MW/m^2)	tbd	tbd
Maximum Wall Heat Flux (MW/m^2)	tbd	tbd

Many Elements of FIRE Divertor Fabrication Demonstrated on ITER

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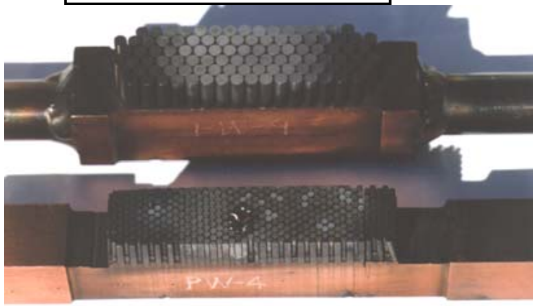
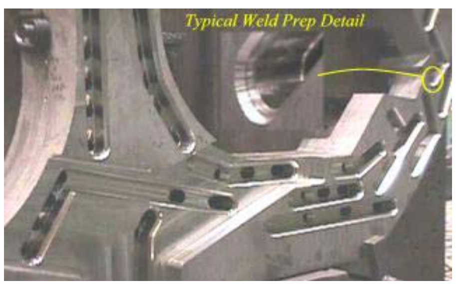
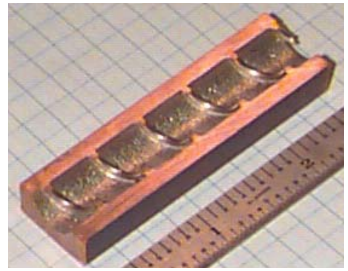
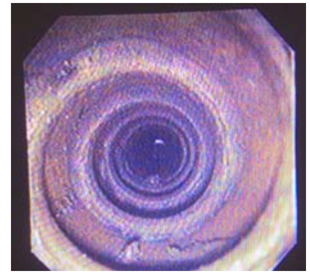
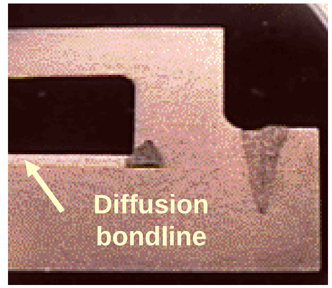


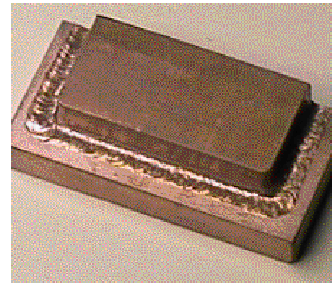


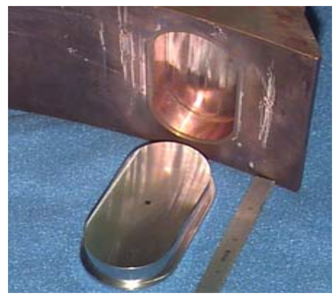
- **W-brush joining and helical wire integration for CHF enhancement**
- **Cu-alloy gundrilling, machining, and EB-welding for HIPping and coolant manifold closeout operations**
- **Cu-SS transition joints using inertial welding or HIP bonding**
- **SS back plate machining and automated closeout welding procedures using PE-flux**

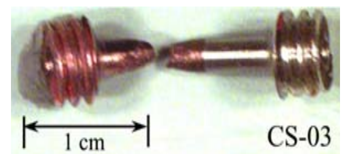












BOEING

Divertor Module Removal Sequence

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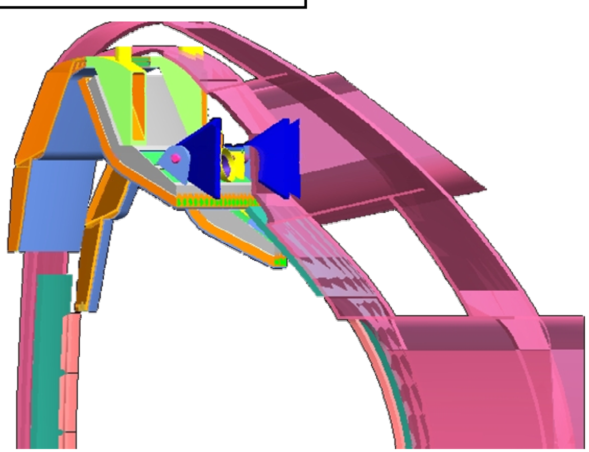
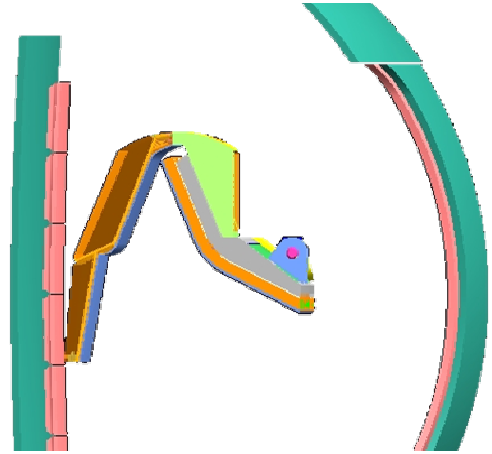
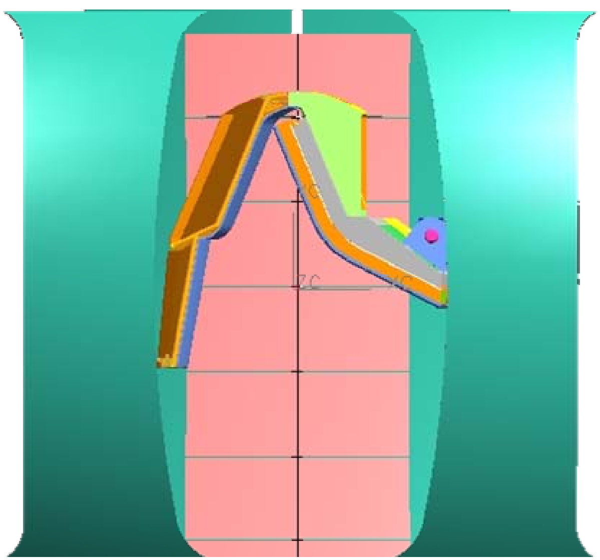


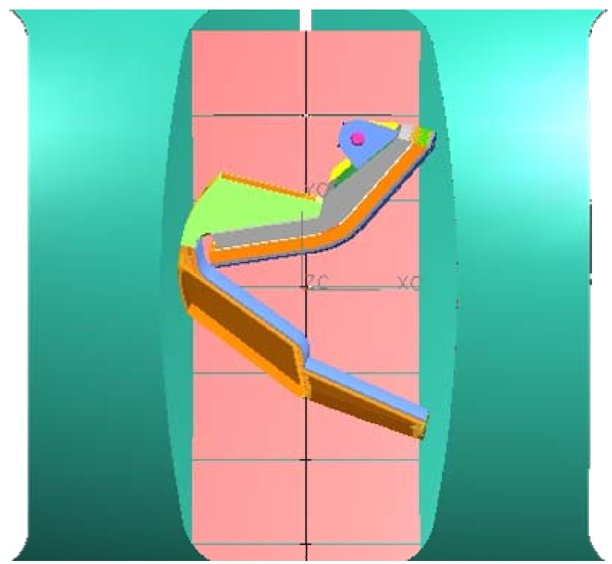
1. Cut concentric cooling pipes, Remove upper inboard FW tiles, Disengage outer pins



2. Raise module to disengage inner wall stubs, Rotate slightly to clear stubs and lower



3. Pivot to align vee side with midplane port opening



4. Rotate to clear midplane opening and remove