FIRE Plasma Facing Component Design Activities

NSO Physics Validation Review Meeting

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Contributions from
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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

- 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

CY’01 Configuration
(Three Separate Components)

CY’03 Configuration
(Single Combined Module)
New Outer Divertor Design Concept

- **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**

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**FIRE Plasma Facing Components**

- **22 CuCrZr Fingers with W-Brush Armor**
- **Single 28-mm dia Concentric Cooling Channel with Helical fins**
- **for CHF enhancement**

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**Internal Cross Manifolds at These Locations**
Details of Backplate Design

- 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

- **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

Outer Divertor Unit Cell
9 MW/m²

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

U.S. Industrial Team
Baffle and Inner Divertor Component

U.S. Industrial Team

Front View

- Coolant Supply and Return Interfaces
- Tungsten Brush Armor
- Internal Channel Layout

Rear View

- Formed CuCrZr Plate with Gun-Drilled Cooling Channels
- Slots that Engage Vessel Attachment Pins
Unit Cell Sizing for Actively-Cooled
Outer Divertor and Baffle

**Outer Divertor Unit Cell**

- **9 MW/m²**
- Min 33.5 mm
- Max 36.3 mm
- W-Brush
- CuCrZr
- 2 mm W/Cu mix
- SS-316 Exp-Bonded
- 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**
- Min 27.0 mm
- Max 30.4 mm
- W-Brush
- 2 mm W/Cu mix
- 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
**Flow Rate Summary**

- 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

### 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

**Pressure Drop**
- **Channel**: 0.09 MPa
- **Wetted Flow Perimeter**: 496.1 mm
- **Number Channels per Finger**: 1.00
- **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 Dia**: De 1.22 mm
- **Water Flow Velocity**: 5.0 m/s
- **Module Flow Rate**: 16.6 liter/s
- **Water Inlet Temperature**: 30 °C
- **Inlet Pressure**: 1.5 MPa
- **Pressure Drop**: 0.156 MPa
- **Exit Pressure**: 1.34 MPa
- **Exit Saturation Temp**: 192.1 °C
- **Nominal Temp Rise**: 11.5 °C
- **Nominal Exit Temp**: 41.5 °C
- **Nominal Exit Subcooling**: 150.8 °C
- **Maximum Temp Rise**: 24.9 °C
- **Maximum Exit Temp**: 54.9 °C
- **Minimum Subcooling**: 137.3 °C
- **Combined Inlet flow velocity**: 3.8 m/s
- **Inlet pipe ID**: 80.0 mm
- **Coaxial pipe OD**: 124.8 mm

**Worst Case Exit Check**
- **Texit**: 54.9 °C
- **Tsub**: 137.3 °C
- **Nominal Exit Subcooling**: 150.6 °C
- **Maximum Exit Temp**: 54.9 °C
- **Combined Inlet flow velocity**: 3.8 m/s
- **Inlet pipe ID**: 80.0 mm
- **Coaxial pipe OD**: 124.8 mm

**Concentric Channel Info**
- **W-Brush**: 6-mm, 4.5-mm, 4-mm, 20-mm, 17-mm ID, 5.5-mm, 5.6-mm, 5.5-mm
- **Cu Heat Sink**: 10-mm, 5.5-mm, 5.5-mm
- **SS-Support Structure**: 10-mm
- **Cylindrical Heat Sink**: 34-mm
- **Inlet pipe ID**: 80.0 mm
- **Coaxial pipe OD**: 124.8 mm
- **Inlet pipe**: 34-mm
- **W-Brush Size**: 6-mm
- **4.5-mm**: IOD
- **4-mm**: OID
- **20-mm**: IID
- **17-mm ID**: Inner Area
- **5.5-mm**: Inner Area
- **5.6-mm**: Inner Area
- **5.5-mm**: Outer Area
- **10-mm**: Inner Area
- **34-mm**: Inner Area

**Coolant Supply Flow Areas**
- **5026.5**: Inner Area
- **5277.9**: Outer Area
## Component Cooling Assessment Summary

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Outer Divertor</th>
<th>Baffle</th>
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</thead>
<tbody>
<tr>
<td>Total Power (MW)</td>
<td>25.6</td>
<td>3.4</td>
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<tr>
<td>Peak Power/module (MW)</td>
<td>1.73</td>
<td>0.54</td>
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<tr>
<td>Peak Heat Flux (MW/m²)</td>
<td>9.0</td>
<td>4.0</td>
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<tr>
<td>Nuclear heating in W (W/cm³)</td>
<td>42</td>
<td>34</td>
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<tr>
<td>Nuclear heating in Cu (W/cm³)</td>
<td>16</td>
<td>13</td>
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<tr>
<td>Channel Diameter (mm)</td>
<td>2 Annular</td>
<td>8</td>
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<tr>
<td>Pitch (mm)</td>
<td>35</td>
<td>14</td>
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<tr>
<td>Channels per module</td>
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<td>44</td>
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<tr>
<td>Channels in series</td>
<td>1</td>
<td>2</td>
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<tr>
<td>Enhancement</td>
<td>Fin</td>
<td>2 mm (Y=2.5)</td>
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<tr>
<td>Maximum PFC Temp (C)</td>
<td>tbd</td>
<td>tbd</td>
</tr>
<tr>
<td>Maximum Copper Temp (C)</td>
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<td>tbd</td>
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<tr>
<td>Flow velocity (m/s)</td>
<td>5</td>
<td>2</td>
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<tr>
<td>Flow/module (liter/s)</td>
<td>16.6</td>
<td>2.2</td>
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<tr>
<td>Inlet/Max Exit Temperature (C)</td>
<td>30/55</td>
<td>30/32</td>
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<tr>
<td>Pressure Drop (MPa)</td>
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<td>0.02</td>
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<tr>
<td>Exit Pressure (MPa)</td>
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<td>1.48</td>
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<td>Exit Subcooling (C)</td>
<td>137</td>
<td>165</td>
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<td>Critical Heat Flux (MW/m²)</td>
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<td>tbd</td>
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<tr>
<td>Maximum Wall Heat Flux (MW/m²)</td>
<td>tbd</td>
<td>tbd</td>
</tr>
</tbody>
</table>
Many Elements of FI RE Divertor Fabrication Demonstrated on ITER

- 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
Divertor Module Removal Sequence

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

FIRE Plasma Facing Components