An overview of Integrated CAE activities for an effective design of ITER TBM

(Integrated multi-physics analysis in a multi-code environment)

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The US HCCB concept for ITER testing

• To demonstrate that the HCCB blanket is capable of:
  – Withstanding cyclic surface heat flux:
    • of up to 0.5 MW/m², and a neutron wall load of 0.78 MW/m² with accumulated fluence of 0.1 MW·y/m²;
  – Operating for extended periods:
    • Up to 3 years and for significant thermal cycles (9,000 cycles) at ferritic steel temperatures in the range of 300-550°C
    • Ceramic breeder in the range of 375-900°C and beryllium in the range of 375-600°C; (establishing lower- and higher temperature limits, i.e. temperature window for ceramic breeders operation)
  – Effectively transferring heat between breeder and multiplier and cooling plates:
    • within aforementioned material temperature windows;
  – Generating high grade heat:
    • With a helium outlet temperature of 500°C with simultaneous release and control of tritium;
  – Generating tritium:
    • At a rate that extrapolates to tritium self-sufficiency in future facilities.
Helium cooling schemes for US HCCB ITER sub-module design

- Allows double snake design to occur
  - Green diverts flow from top & bottom caps
  - Orange transfers flow from one pass to the next
  - Blue is outlet collector
  - Tan tubes distribute flow poloidally to all parallel channels
- Uneven coolant flow will make manifold design challenging
EM module design starts with thermofluid analysis for manifold design to ensure uniform flow distribution

Four sequential sub-modules for different ITER operating phases minimizes technical risks

<table>
<thead>
<tr>
<th>Year of ITER operation</th>
<th>1</th>
<th>2</th>
<th>3</th>
<th>4</th>
<th>5</th>
<th>6</th>
<th>7</th>
<th>8</th>
<th>9</th>
<th>10</th>
</tr>
</thead>
<tbody>
<tr>
<td>Plasma phase</td>
<td>H-H</td>
<td>D-D</td>
<td>Low Duty D-T Cycle</td>
<td>High Duty D-T Cycle</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>HCCB</td>
<td>EM Module</td>
<td>NT Module</td>
<td>TM Module</td>
<td>Integrated Module</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
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Objectives and characteristics of the H-H sub-module

• The first sub-module of a series

  A design that **embodies the general geometrical architecture** of the D-T test sub-modules.

• Addresses one of the most critical engineering feasibility issues concerning blanket structure thermomechanics and response to off-normal operations.

• Provides fusion-relevant testing data to verify the design approach, fabrication technique and structural support of the TBM,

• Supports subsequent nuclear-grade test sub-module designs and **ITER D-T licensing**.
An exhaustive integrated CAE effort is an indispensable part of the EDA for the TBM

**Basic Analysis Platforms for H-H sub-module:**
- CAD/Thermo-fluid /structural thermo-mechanics
- CAD/Electro-magnetism/structural analysis
- Neutronics

CAD/CAE flow diagram for an integrated design analysis
Validation study for Thermo-fluid analysis using SC/Tetra

Average $h$ from Dittus Boelter correlation: 2779 W/m²K

Validity range of log law: $30 \leq y^+ \leq 1000$

<table>
<thead>
<tr>
<th>Resolution (mm)</th>
<th>Average heat transfer coeff. (W/m²K)</th>
<th>$y^+$</th>
<th>Pressure drop (MPa)</th>
<th>Max. Temp (Beryllium, K)</th>
</tr>
</thead>
<tbody>
<tr>
<td>0.1</td>
<td>4200</td>
<td>5-30</td>
<td>0.023</td>
<td>755</td>
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<tr>
<td>0.5</td>
<td>3100</td>
<td>30-300</td>
<td>0.028</td>
<td>765</td>
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<tr>
<td>1.0</td>
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<td>100-300</td>
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<td>300-1000</td>
<td>0.032</td>
<td>761</td>
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<tr>
<td>2.0</td>
<td>2900</td>
<td>300-1000</td>
<td>0.037</td>
<td>760</td>
</tr>
</tbody>
</table>

Effect of mesh resolution at the flow channel walls on numerical results

Two layers of prismatic elements were placed in the fluid domain at the fluid-solid interface. The mesh resolution in the table corresponds to the size of the wall prismatic elements. The logarithmic law of the wall was used to calculate turbulent heat transfer at the walls.
SC/Tetra thermo-fluid analysis for Inlet/FW collection manifold design: Design A

Flow vectors in the inlet manifold

Helium temperature distribution
Inlet/FW collection manifold design B

Velocity distribution in the inlet manifold

Helium temperature distribution
The coolant temperature in the bottom leg is higher than in the other ‘hot’ legs in this cooling scheme.
Even though, design B is an improvement over design A, the three channels in the middle of the first wall remain underfed and require some further modifications to the inlet manifold design.
Be layer and First wall structure temperature distribution from SC/Tetra

Temperature variation on the Be first wall. A hot spot forms at the bottom of the wall in the current cooling scheme. The hot and cold temperature bands correspond to the hot and cold legs of the three pass Helium cooling loop in the first wall.
First simulation of one fifth scale of FW cooling channels followed by coolant flow in 16 parallel channels in the breeder zone demonstrates that the software can handle extremely complex flow geometry involving numerous channels and distribution manifolds.
Example breeding zone He flow and thermal characteristics

Helium flow velocity distribution at a middle cross section

Helium coolant temperature at a middle cross section
Integrated thermo-fluid/thermal stress analysis through mesh based code coupling

- SC/Tetra is used to calculate the temperature field in the fluid and solid parts of the domain.
- SC/Tetra mesh is optimized towards a reliable calculation of helium flow distribution as well as conjugate heat transfer from the solid structure to the helium coolant.
- The thermal stress analysis in the solid structure is done by using ANSYS.
- The ANSYS mesh is tailored towards an effective calculation of thermal stresses in the solid structures and is different from the SC/Tetra mesh used to obtain the temperature field in the solid.
- Temperature data exchange across the meshes is undertaken by a special utility FLDUTIL from CRADLE
The temperature field in the solid domain of the SC/Tetra mesh is mapped onto the ANSYS structural mesh for thermal stress analysis. The temperature field acts as a body load for the thermal stress calculation.
From temperature field in SC/Tetra

To Von-Mises stress field and deformation in ANSYS

SC/Tetra temperature field provides the body load, which is mapped onto the ANSYS mesh using FLDUTIL
Tungsten Experiment

(Attila’s Model and Calculation under benchmarking)

**Tungsten Mock-up Configuration**

- **Solid Work Model**
- **Air**
- **Tungsten (DENSIMET-176)**
- **Tungsten (DENSIMET-180)**

Locations for multi-foils

1/4 of the Mock-up

**Tungsten Mock-up Configuration**

From SINBAD 2000 Archive Data Base

**Cells and three iso-surfaces are shown**

From Youssef’s presentation on 8-23-2006 at UCLA
Final comments

• The design of a complex system like the ITER TBM requires an exhaustive CAE effort encompassing multiple simulation codes supporting multi-physics modeling.

• The integration of multiple codes for TBM design can be viewed as a precursor to a larger effort towards developing VTBM.

• Integrated Data/multi-code multi-physics modeling activities, or Virtual TBM, is key for ITER TBM R&D activity.
  – As an efficient design tool: A platform for fast, streamlined and optimized TBM design effort through identification and isolation of potential design flaws.
  – As an effective operations aide: Facilitate simulation of normal and off normal operational scenarios. A tool for use to design the CODAS system