Recent CFD-Related Activities at the High Flux Isotope Reactor of ORNL

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Invited Presentation to:
UT CFD Laboratory Colloquium,
University of Tennessee, Knoxville

In Honor of the Retirement of:
Professor A. J. Baker
May 18, 2010
Outline of this Presentation

• a brief history of how I got here

• early CFD activities at HFIR

• cold-source (and other upgrades) CFD activities at HFIR

• LEU Conversion Project CFD activities
The Brief History

• MSNE-1979 - computer simulation was my interest

• excellent mentoring brought strong desire for a “better way”

• early 1980s, started pursuing PhD

• 1st class from AJ at OR campus by video tape ~ 1980 ?

• a couple of years later we met and started our journey ~ 1982-1983 ?
The Goal

• to learn how to do it right from the best
• show others in the nuclear industry how it should be done
• where better to do this then at a research reactor?
• 1991 started at HFIR
• 1992 graduation
• ~ 2003 COMSOL becomes the tool of choice
Early CFD Activities at HFIR

• spent fuel re-racking project
• CFX used to analyze dropped element (Giles, Williams, Kirkpatrick)
• HEATING with user-supplied routines to establish the design basis (Williams)
• conservatively-developed code became the safety basis (Freels)
Upgrade of the HFIR: CFD Plays a Major Role

- permanent Be replacement (CFX)
- beam tube upgrades (CFX)
- cold source moderator vessel (CFX, PICMSS, FLUENT)
- cold source pressurizer (NASTRAN, HEATING, FEMLAB)
- cold source test heater (COMSOL)
### Table 6: Summary of results for H2 Production mode

<table>
<thead>
<tr>
<th>Variables</th>
<th>FLUENT UDF</th>
<th>CORRECTED UDF</th>
<th>CFX*</th>
</tr>
</thead>
<tbody>
<tr>
<td>Inlet Temperature (K)</td>
<td>H2</td>
<td>H2</td>
<td>H2</td>
</tr>
<tr>
<td>Outlet Temperature (K)</td>
<td>18</td>
<td>18</td>
<td>18</td>
</tr>
<tr>
<td>Heat Load (W)</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Total</td>
<td>2302</td>
<td>2402</td>
<td>2781</td>
</tr>
<tr>
<td>Fluid / Solid</td>
<td>463.6</td>
<td>1838</td>
<td>541.6</td>
</tr>
<tr>
<td>Heat Load – MCNP (W)</td>
<td></td>
<td></td>
<td>2361</td>
</tr>
<tr>
<td>Maximum Wall Surface Temperature (K)</td>
<td>44.0</td>
<td>42.3</td>
<td>42.5</td>
</tr>
<tr>
<td>Pressure drop (Pa)</td>
<td>1887</td>
<td>1477</td>
<td>1880</td>
</tr>
</tbody>
</table>

* report C-HFIR-2004-059/R0
# HFIR Cold Source Moderator Vessel Analysis

## Table 8: Hydrogen parameters in Standby mode

<table>
<thead>
<tr>
<th>Variables</th>
<th>FLUENT UDF</th>
<th>CORRECTED UDF</th>
<th>CFX*</th>
</tr>
</thead>
<tbody>
<tr>
<td>Inlet Temperature (K)</td>
<td>H2</td>
<td>H2</td>
<td>H2</td>
</tr>
<tr>
<td>Outlet Temperature (K)</td>
<td>80</td>
<td>80</td>
<td>80</td>
</tr>
<tr>
<td>Heat Load (W)</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Total</td>
<td>1873</td>
<td>1891</td>
<td>na</td>
</tr>
<tr>
<td>Fluid / Solid</td>
<td>35</td>
<td>1838</td>
<td>31</td>
</tr>
<tr>
<td>Maximum Wall Surface Temperature (K)</td>
<td>136.6</td>
<td>137.2</td>
<td>160</td>
</tr>
<tr>
<td>Pressure drop (Pa)</td>
<td>782</td>
<td>874</td>
<td>918</td>
</tr>
</tbody>
</table>

* report C-HFIR-2004-059/R0
Figure 14: Hydrogen Production mode wall temperatures, K
Upgrade of the HFIR: CFD Plays a Major Role

HFIR cold source pressurizer design calculations

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Upgrade of the HFIR: CFD Plays a Major Role

examine internal natural circulation flow at cryogenic temperature
Upgrade of the HFIR: CFD Plays a Major Role
Major Design Challenge for HFIR: Convert to LEU Fuel
COMSOL Models in 2D Provide Guidance for 3D Decisions
COMSOL Tools Provide Methods to Reproduce Current Safety Basis
A Consistent Set of Inputs and Assumptions Allow COMSOL to Reproduce the Current Safety Basis (part 1 of 2)
A Consistent Set of Inputs and Assumptions Allow COMSOL to Reproduce the Current Safety Basis (part 2 of 2)
COMSOL 2D Development of Fluid-Structure Interaction with HFIR Fuel Plates (part 1 of 4)

start with laminar flow – see movie of results
COMSOL 2D Development of Fluid-Structure Interaction with HFIR Fuel Plates (part 2 of 4)

extension to turbulent flow – entrance region
extension to turbulent flow – exit region
COMSOL 2D Development of Fluid-Structure Interaction with HFIR Fuel Plates (part 4 of 4)

extension to turbulent flow – dramatic interaction for settings used in 2D
Typical 3D result: metal surface temperature

shown is the clad surface temperature adjacent to the turbulent-wall of the coolant

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Typical 3D issue: creating accurate geometry
COMSOL CAD Tools have Limited Versatility

all geometry parts shown
remove side plates from view
COMSOL CAD Tools have Limited Versatility

remove coolant from view
COMSOL CAD Tools have Limited Versatility

remove clad top and bottom from view
COMSOL CAD Tools have Limited Versatility

fuel details top view
COMSOL Meshing Tools Yield High Quality

coolant and fuel region meshing top view
COMSOL Meshing Tools Yield High Quality

coolant and fuel region meshing top view magnified
COMSOL V4 – Beta2
Distributed Parallel Processing performance

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COMSOL V4 – Beta2
Distributed Parallel Processing performance

memory usage
this beta version is limited to isothermal flows for the low Rey extension
COMSOL T-H Summary for HFIR

- COMSOL is providing a modern simulation tool for the design of LEU fuel and analysis of present HEU fuel.

- The COMSOL analysis provides details and accuracy heretofore not possible, and allows for precise margin estimates.

- The 2D analysis provides a test bed for the 3D analysis to establish consistent parameter set (wall offset, mesh density, solution procedure, etc.)

- 2D results demonstrate methods that yield accurate benchmarks with established data base.

- 3D computational requirements have been demonstrated on a representative model. Model development to address axial grading requirements for HFIR LEU fuel are expected in FY10.