The Fluent RELAP5-3D Coupling

- Background
- What we’re doing
- Where we are at now
- Our future plans
Overall Perspective...

• **DOE’s Generation IV Roadmap effort is reaching completion. It is a part of national strategy to gain public acceptance of nuclear power, and to encourage vendors and utilities to consider nuclear power as an option again.**

• **Gen IV has identified 6 advanced concepts for further development; US will probably focus on half: Very High Temperature Reactor, Gas-Cooled Fast Reactor, & Supercritical Water Reactor. Others are the Pb-Bi, Na-cooled, and molten salt.**

• **In addition to Gen IV, there will also be Gen III advanced concepts to study, e.g., PBMR**
Very High-Temperature Reactor (VHTR)

Characteristics

- He coolant
- \(>1000^\circ C\) outlet temperature
- 600 MWe
- Solid graphite block core based on GT-MHR

Benefits

- High thermal efficiency
- Hydrogen production
- Process heat applications
- High degree of passive safety
Gas-Cooled Fast Reactor (GFR)

Characteristics

• He coolant
• 850°C outlet temperature
• direct gas-turbine conversion cycle – 48% efficiency
• 600 MW\(_{\text{th}}\)/288 MW\(_{\text{e}}\)
• Several fuel options and core configurations

Benefits

• Waste minimization and efficient use of uranium resources
Supercritical Water Reactor (SCWR)

Characteristics
- Water coolant at supercritical conditions
- 500°C outlet temperature
- 1700 MWe
- Simplified balance of plant

Benefits
- Efficiency near 45% with excellent economics
- Thermal or fast neutron spectrum
**Pb/Bi Reactor – Cartridge Core (Pb/Bi Battery)**

**Characteristics**
- Pb or Pb/Bi coolant
- 540°C to 750°C outlet temperature
- 120-400 MWe
- 15-30 year core life

**Benefits**
- Distributed electricity generation
- Hydrogen and potable water
- Cartridge core for regional fuel processing
- High degree of passive safety
- Proliferation resistance through long-life cartridge core
Sodium Liquid Metal-Cooled Reactor (Na LMR)

Characteristics
- Sodium coolant
- 150 to 500 MWe
- Metal fuel with pyro processing / MOX fuel with advanced aqueous

Benefits
- Consumption of LWR actinides
- Efficient fissile material generation
Molten Salt Reactor (MSR)

Characteristics
• Fuel: liquid Li, Be, Th and U fluorides
• 700°C outlet temperature
• 1000 MWe
• Low pressure (<0.5 MPa) & high temperature (>700°C)

Benefits
• Low source term due to online processing
• Waste minimization and efficient use of uranium resources
• Proliferation resistance through low fissile material inventory
Fluent & RELAP5-3D Are Being Coupled to...

- Develop tools to analyze advanced systems in the detail required—so:
- Enable an entire system to be modeled using 1-D features of RELAP5
- While modeling some sections of systems in great detail using Fluent
Development Underway Using Gas-Cooled Reactors as Basis

- PBMR is focus
- Working fluid: helium
- We’ll model input plenum, perhaps a portion of the core, and the outlet plenum.
International Community has also Recognized this need…

IAEA recently announced a meeting to discuss: “…interest in the application of 3-dimensional CFD software as a supplement to or in combination with system codes, which provide the boundary conditions for CFD codes.” Problems under discussion include:

- Evaluation of performance of passive safety features;
- Local phenomena leading to cladding ruptures;
- Multidimensional TH in various components;
- Liquid/gas stratification and interface tracking; and
- Bubble dynamics in suppression pools.”
We view Fluent RELAP5-3D coupling as applicable to...

- Most scenarios in VHTRs, gas-cooled fast reactors, Pb-Bi reactors, and liquid sodium reactors.

- Some specific phenomena in water-cooled systems such as supercritical water reactors.
Status

- Fluent and RELAP5-3D are coupled.
- Writing User Guidelines
- Will focus on latter part of V&V matrix over next year.
Blowup of Fluent model linked to RELAP5-3D model
**RELAP5-3D provides 1-D boundary conditions to Fluent**

- Fluent performs 3-D calculation
- *Inlet velocity profile, for example, is flat if not modified.*
- *Inlet profile can be modified to known condition if desired using Fluent user defined functions.*
- *Fluent 3-D output converted to 1-D for RELAP5-3D.*
## A Portion of V&V Matrix

<table>
<thead>
<tr>
<th>Experiment or Case</th>
<th>Working Fluid</th>
<th>Phenomena of Interest or Objective</th>
<th>PBMR Region of Interest</th>
<th>Reference</th>
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<tr>
<td>Turbulent flow in pipe section</td>
<td>Helium</td>
<td>Mesh coupling between Fluent &amp; RELAP5</td>
<td>PBMR inlet pipe</td>
<td>Streeter, V., 1961</td>
</tr>
</tbody>
</table>
| Turbulent flow in backward facing step with heat transfer | Air           | 1. Mesh coupling between Fluent & RELAP5  
2. Flow profile calculated by Fluent                                                              | PBMR inlet pipe and inlet plenum            | Baughn, J. W., et al, 1984                    |
| Neutronics-fluid Interaction in core region (LWR) | Water         | RELAP5/ATHENA neutronics coupling with Fluent mesh                                                  | Core; although this data set is for geometry unlike PBMR, | Bovalini, R., et al, 2001 (used by permission of Y. Hassan) |
| Countercurrent two-phase flow          | Water & SF₆   | 1. Mesh coupling between Fluent & RELAP5  
We’ll focus on PBMR…
Relevant V&V Cases…

• Turbulent pipe flow.

• Backward facing step

• Packed beds
Backward-Facing Step: Expanding Flow with Heat Transfer

- **Purpose:** Study coupling between Fluent—RELAP5/ATHENA and validate Fluent’s capability to model flow distribution downstream of step.

- **Region of applicability:** entrance flow into PBMR core.

![Diagram of Backward-Facing Step with Heat Transfer](image-url)
Backward-Facing Step (Cont-3)

Ratio of local $\text{Nu}$ to $\text{Nu}$ for fully-developed flow as function of length for various turbulence models in Fluent—compared to Baughn data.
Backward-Facing Step (Cont-4)

Typical velocity profiles calculated by Fluent.
Fluent Calculation of Flow Through Pebble Bed

- Calculation was performed using CFX5
- Agreement with data within 10%.
- Both laminar flow and turbulent flow were modeled.
V&V Packed Bed Data-CFX5
Comparison: Within 10%
Summary

• The Fluent-RELAP5 coupling is functional.

• First system case to be studied: PBMR.

• The V&V matrix problems are being used.

• User Guideline document is being written—expect first draft at year end.