RELAP5-3D Development Status

Presented by
Gary W. Johnsen

Idaho National Engineering & Environmental Laboratory
Idaho Falls, Idaho 83415

2000 RELAP5 International User’s Seminar
September 12-14, 2000
Jackson Hole, WY
Outline

• Overview of development activities
• Selected reviews
  – Parallel computation
  – 3D downcomer model
  – Improved fuel deformation model
  – 1994 Decay heat model
  – 1995 Water properties
• Ongoing development
• Future work
## Development Highlights

<table>
<thead>
<tr>
<th>Item</th>
<th>Objective</th>
</tr>
</thead>
<tbody>
<tr>
<td>Precompiler for Parallel Processing</td>
<td>Clean up coding for parallel processing on multiple CPU’s</td>
</tr>
<tr>
<td>Semi-implicit Coupling*</td>
<td>Allow RELAP5-3D to couple to other codes semi-implicitly</td>
</tr>
<tr>
<td>Improved Matrix Solution of the Field Equations*</td>
<td>Reduce time step reductions caused by ill-conditioned matrices</td>
</tr>
<tr>
<td>Downcomer Pressure Drop</td>
<td>Allow single radial ring downcomer in 3D component</td>
</tr>
<tr>
<td>RELAP5 Graphical User Interface (RGUI)*</td>
<td>Further enhancements</td>
</tr>
<tr>
<td>Fuel Deformation Model</td>
<td>Cause flow area and volume to reduce due to fuel swelling</td>
</tr>
<tr>
<td>1994 ANS Decay Heat</td>
<td>Implement 1994 standard</td>
</tr>
<tr>
<td>1995 Water Properties</td>
<td>Implement IAPWS-95 standard for water properties</td>
</tr>
<tr>
<td>PYGMALION</td>
<td>Restore functionality</td>
</tr>
</tbody>
</table>

* Presentation in seminar
Other Activities

• ATHENA Development
  – Pb/Bi wall heat transfer and void model
  – ITER heat transfer option

• RELAP5/RT Support
  – Installed at Palo Verde, Comanche Peak, Salem, Hope Creek

• INER Support
  – Appendix K version of RELAP5-3D

• INSP Support

• Non-nuclear Applications
Pre-compiler for Parallel Processing

- Objective: Render parallel coding easier to read and maintain
- Method: Achieve parallel execution capability solely through the use of precompiler directives
Example Speed-Up from Parallel Execution

Problem: AP600 model (620 volumes)

<table>
<thead>
<tr>
<th></th>
<th>Single Thread</th>
<th>Two Threads</th>
<th>% Change</th>
</tr>
</thead>
<tbody>
<tr>
<td>CPU time (sec)</td>
<td>26115.33</td>
<td>36073.22</td>
<td>+38.1</td>
</tr>
<tr>
<td>Wall clock time (sec)</td>
<td>26416.78</td>
<td>18344.03</td>
<td>-30.6</td>
</tr>
</tbody>
</table>
Downcomer Pressure Drop Model

Problem: Original implementation of 3D component model required at least two radial nodes to properly compute the pressure change due to momentum flux from a one-dimensional pipe to a multidimensional downcomer.

\[ \Delta P_{MF} = \rho \left( v_r \frac{\partial v_r}{\partial r} + \frac{v_\theta}{r} \frac{\partial v_r}{\partial \theta} + v_z \frac{\partial v_r}{\partial z} - \frac{v_\theta^2}{r} \right) \]

Cross derivative terms ill-defined for one radial ring
The last term is computed assuming $v_\theta$ is constant in the radial direction:

\[
\int_{P}^{Q} \frac{v_\theta^2}{r} dr = v_\theta^2 \log \left( \frac{r_Q}{r_P} \right)
\]

The momentum flux pressure change is then given by:

\[
\Delta P = -\rho \left[ v_r \Delta v_r - v_\theta^2 \log \left( \frac{r_Q}{r_P} \right) \right]
\]
Improved Fuel Deformation Model

The existing fuel swelling and rupture model was improved to account for the effects on control volume flow area, volume, and hydraulic diameter.

\[
A^{n+1} = A^n - \Delta A \\
\Delta A = \left[ \pi \left( (R_o^{n+1})^2 - (R_o^n)^2 \right) \right] \frac{L_h}{L_v} \\
V^{n+1} = V^n \frac{A^{n+1}}{A^n} \\
D_{h}^{n+1} = D_{h}^n \frac{A^{n+1}}{A^n}
\]

\(L_h = \text{heat slab length}, \ L_v = \text{volume length}\)
Improved Fuel Deformation Model (cont’d)

Sample problem: Burst of low and high power fuel rods

Change in fuel rod radius

![Graph showing change in fuel rod radius over time for low and high power rods. The graph plots radius against time with markers indicating different time points. The legend shows symbols for low power rod (blue) and high power rod (pink).]
Improved Fuel Deformation Model (cont’d)

Effect on volume flow area

Change in Volume Flow Area

Time (s)

Flow Area (m²)
1994 Decay Heat Standard

The ANS94-4 Standard produces slightly higher decay heat than the ANS79-3 Standard
New Water Properties

- Implemented IAPWS-95 Formulation
- New tables built from calls to NIST STEAM routines from new ‘stgh2o95’ program in environmental library
- Transport property tables also built from NIST routines: thermal conductivity, dynamic viscosity, and surface tension
Ongoing Development

Advancing the code coupling capability:

- Executive for code coupling
- Kinetics coupling
Executive for Code Coupling

Executive

PVM

RELAP5-3D

Code 1

Code 2
Functions of the Executive

- Start the codes to be coupled
- Coordinate choice of time step size
- Control code output (plot/print frequencies)
  - Each code maintains its own output files
- Explicit or semi-implicit coupling
Kinetics Coupling

Objective: Transmit Kinetics-related data between RELAP5-3D and a coupled code

RELAP5-3D  PVM  Coupled code

Power data

Thermal and hydraulic data
Future Development

- Coupling follow-on tasks
- Further parallelization
- Convert bit-packing to FORTRAN 90
- Remedy code problems:
  - Oscillations in default critical flow model
  - Oscillations from flow regime transitions
  - Unphysical temperatures when filling a vertical stack