Numerical Simulation Of A Compartment Fire In A Nuclear Power Plant Containment Building

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Overview

- Multi-block FDS
- HDR facility and the T52.14 oil pool fire test
- Results
FDS

- Fire Dynamics Simulator v2 (Dec. 2001)
- Computational fluid dynamics – LES/DNS
- Building and Fire Research Laboratory, NIST
- Submodels
  - Mixture fraction combustion
  - Finite volume, gray gas radiation
  - 1D heat conduction
  - Pyrolysis (solid and liquid fuel)
  - Sprinkler dynamics and droplet evaporation

- Smokeview for data visualization
Multi-Block

• Single-block: One grid used to span computational domain

• Multi-block: Multiple grids used

• Multi-block can reduce the number of grid cells at the expense of more complex boundary conditions

• For some problems the grid cell time savings >> boundary condition time penalty
Multi-Block Example 1

- Resolution needed for the fire > resolution needed for smoke movement

10000 Cells

1400 Cells
Multi-Block Example 2

- Complex geometries may result in many dead cells

1600 Cells  1120 Cells
HDR Facility

- Decommissioned containment building in Karlsruhe, Germany
- 20 m diameter
- 60 m high
- 8 levels
- >60 compartments
- 11,000 m³
- 5 vertical flow paths
HDR Fire Testing Program

- 7 test groups
- 33 tests
- 4 fuels: propane, wood, oil, and cable
- 4 locations
- 230 kW to >10 MW
T52 Test Series

- Four tests (T52.11- T52.14)
- Liquid hydrocarbon fuel (Shellsol T)
- Level 1.9 (Below dome operating deck)
- 1 m x 1 m to 1 m x 3 m pools
- Measured temperature, velocity, CO₂ throughout facility
T52 Test Layout
Input Parameters

- Fire Power: 2.65 MW (Steady-state power)
- Fuel
  - \( \text{C}_{12}\text{H}_{26} \): 170 g/mol, 42500 kJ/kg
- Surface definitions
  - Fire room: firebrick
  - Walls of hatch area: fire resistant fiberboard
  - Remainder: concrete
FDS Model

- Fire room, hatch room, dome
- Steady state portion
- Three grids, 650,000 grid cells:
  - Fire room, 10 cm, 48x25x32 (38 knodes)
  - Hatch, 10 cm, 40x36x72 (104 knodes)
  - Dome, 25 cm, 80x80x80 (512 knodes)
- One grid, 10 cm, 1,216,000 grid cells
- Also ran ¾ linear resolution
FDS Model
Time Required

- 2.2 GHz Pentium IV, 1 Gb RAM, Linux
  - Full resolution case (654,080 grid cells)
    - 7.5 min CPU/s realtime
  - ¾ resolution case (275,292 grid cells)
    - 2.5 min CPU/s realtime
# Integral Fire Room Results

<table>
<thead>
<tr>
<th>Parameter</th>
<th>HDR</th>
<th>Hand*</th>
<th>FDS $\frac{3}{4}$</th>
<th>FDS</th>
</tr>
</thead>
<tbody>
<tr>
<td>$h_n$ (m)</td>
<td>1.4</td>
<td>1.0</td>
<td>1.2</td>
<td>1.2</td>
</tr>
<tr>
<td>$T_{out}$ (°C)</td>
<td>870</td>
<td>1210</td>
<td>793</td>
<td>827</td>
</tr>
<tr>
<td>(kg/s)</td>
<td>1.90</td>
<td>2.13</td>
<td>2.30</td>
<td>2.14</td>
</tr>
</tbody>
</table>

FDS Flame Surface
Fire Room Doorway
Plume Animation
Hatch Temperature Full Grid
Hatch Temperature $\frac{3}{4}$ Grid
Hatch Velocity

Full Grid

3/4 Grid
Dome Temperature Full Grid
Dome Temperature $\frac{3}{4}$ Grid
Dome Velocity Full Grid
Dome Velocity $\frac{3}{4}$ Grid
Dome W-velocity Animation
Concluding Remarks

- Multi-block FDS shows great promise in enabling a user to simulate fires in very large, multi-compartment structures.
- Mass flux across grids is well maintained
- Energy flux across gris is well maintained