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

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May 2002

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

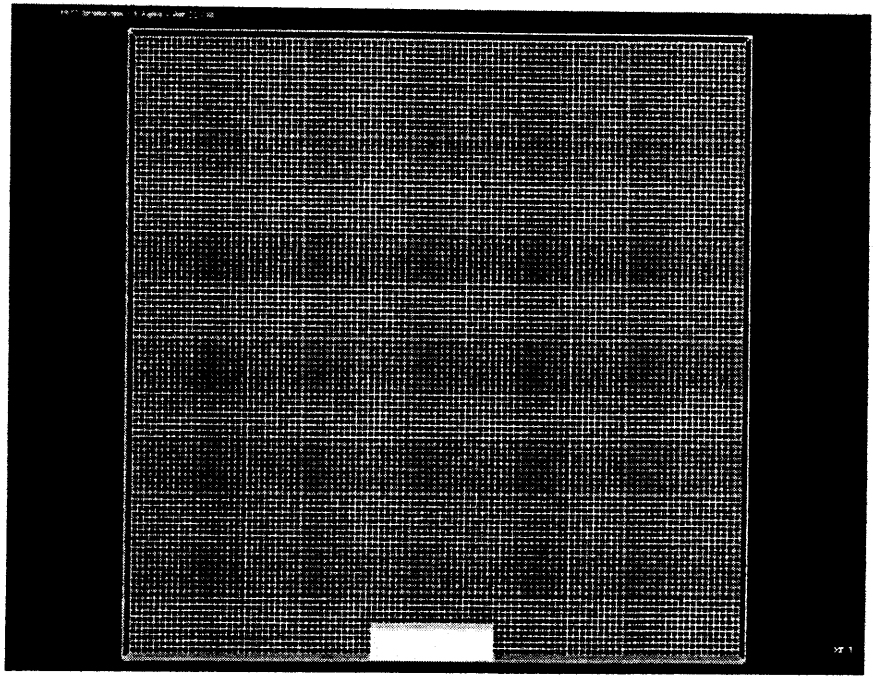
- Smokeview for data visualization

Multi-Block

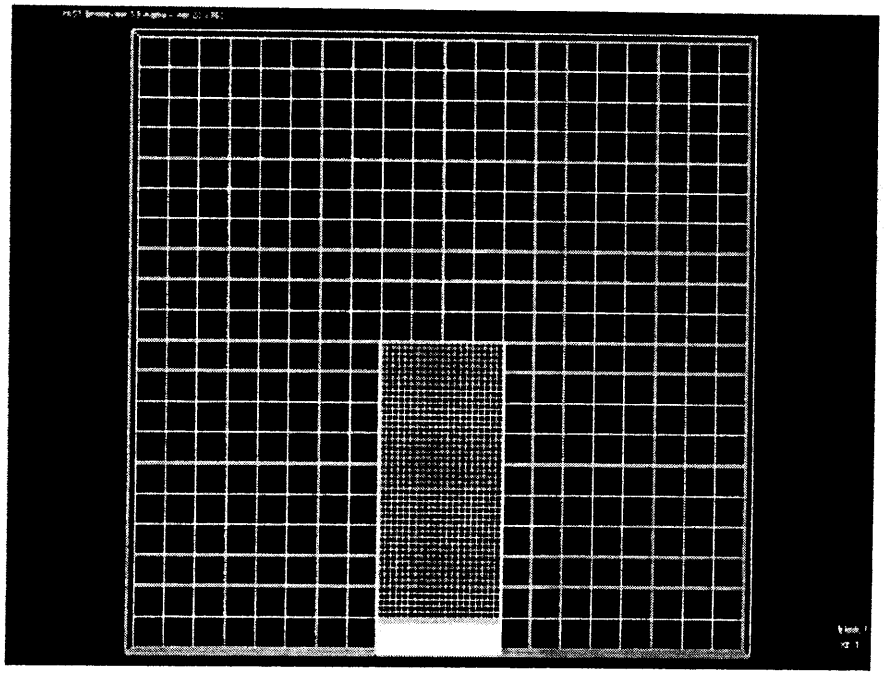
- Single-block: One grid used to span computational domain
- Multi-block: Multiple grids used
- Multi-block can reduce the number of grid cells at the expense of more complex boundary conditions
- For some problems the grid cell time savings >> boundary condition time penalty

Multi-Block Example 1

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



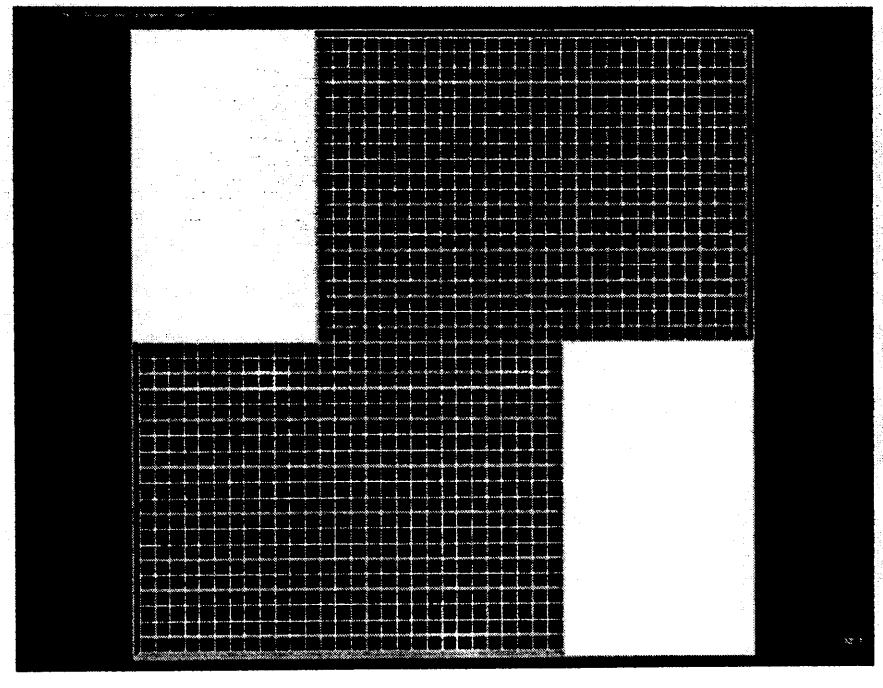
10000 Cells



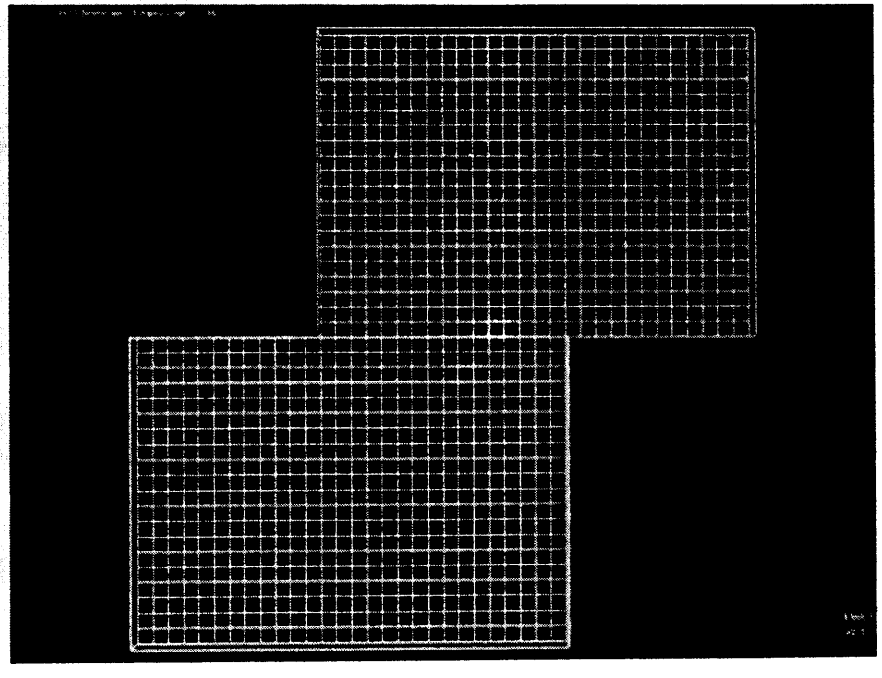
1400 Cells

Multi-Block Example 2

- Complex geometries may result in many dead cells



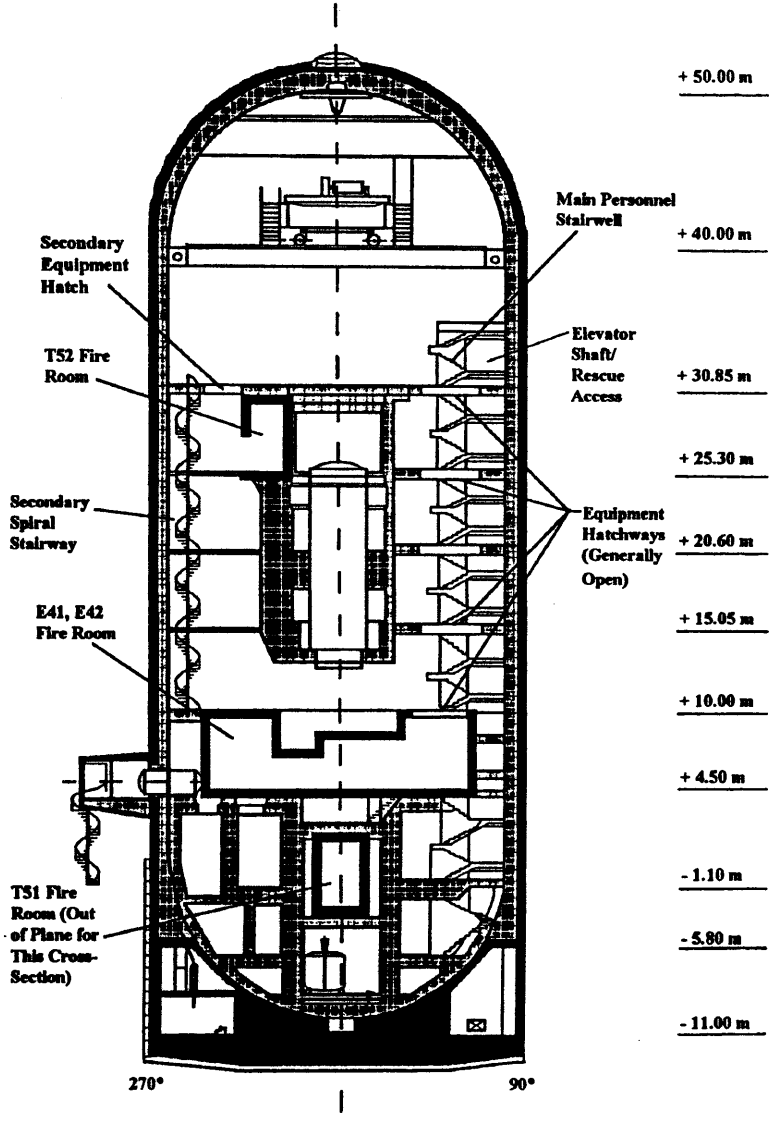
1600 Cells



1120 Cells

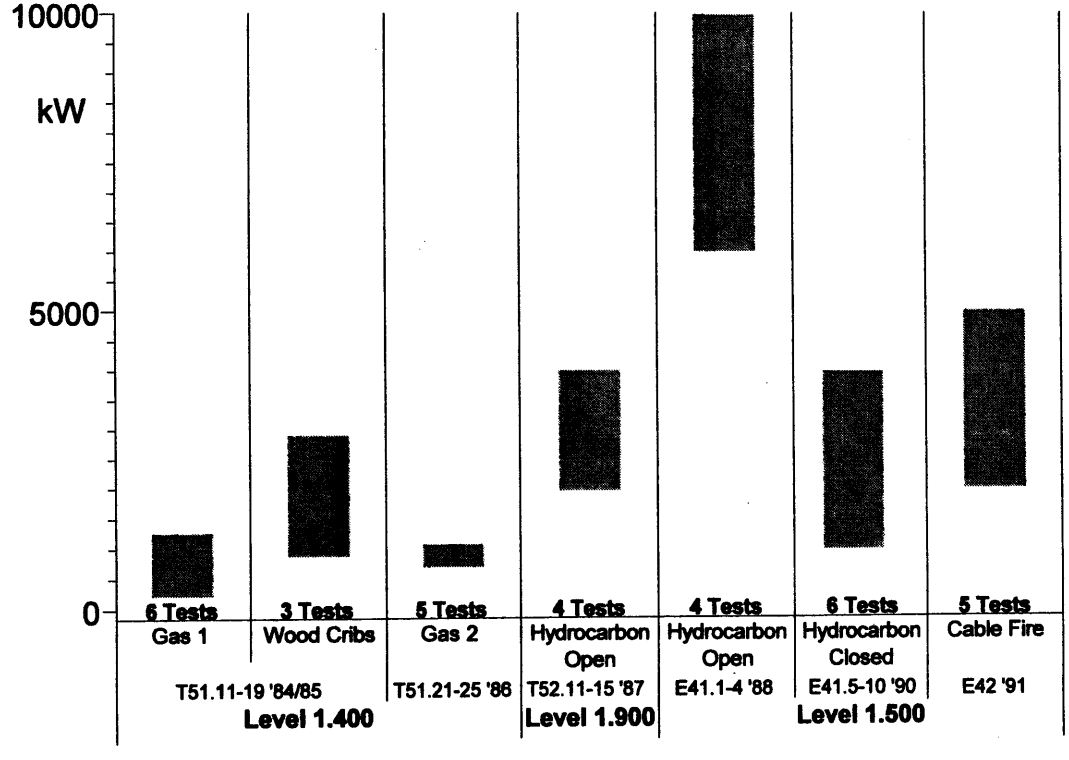
HDR Facility

- Decommissioned containment building in Karlsrhue, Germany
- 20 m diameter
- 60 m high
- 8 levels
- >60 compartments
- 11,000 m^3
- 5 vertical flow paths



HDR Fire Testing Program

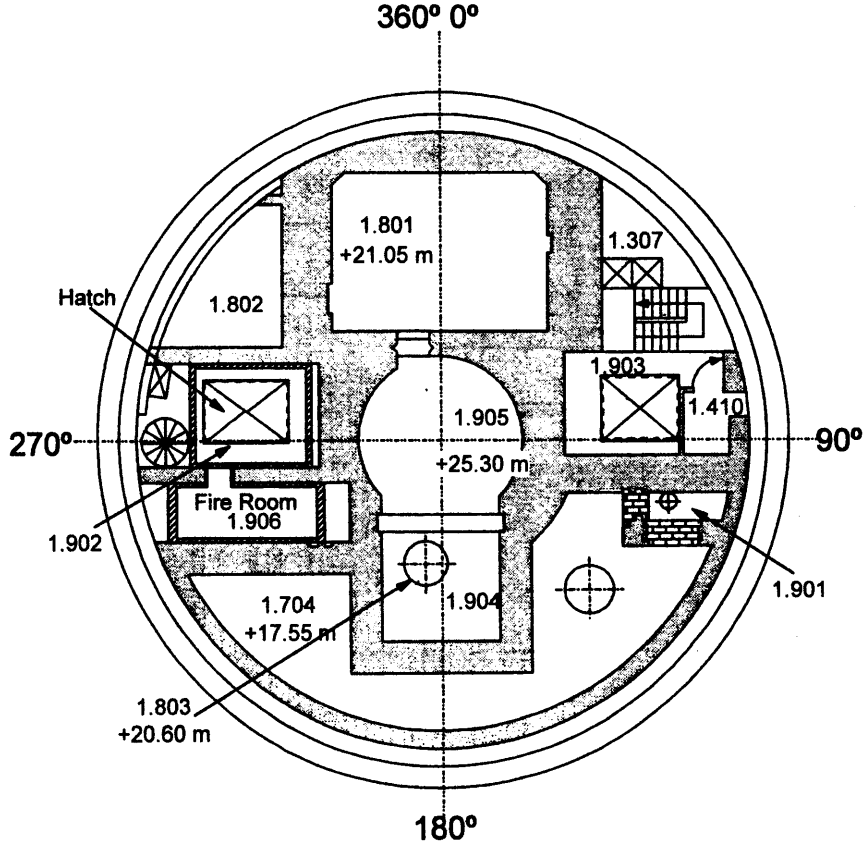
- 7 test groups
- 33 tests
- 4 fuels: propane, wood, oil, and cable
- 4 locations
- 230 kW to >10 MW

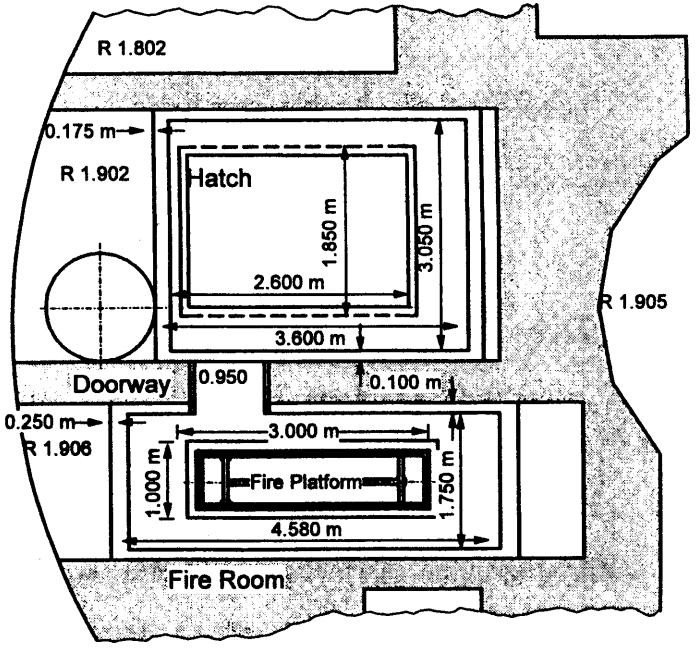


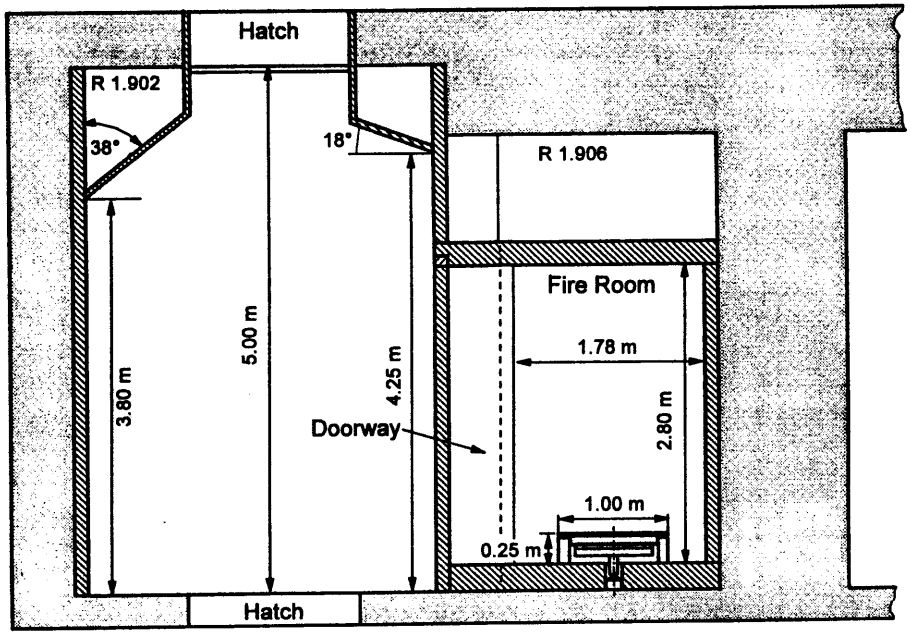
T52 Test Series

- 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, CO_2 throughout facility

T52 Test Layout

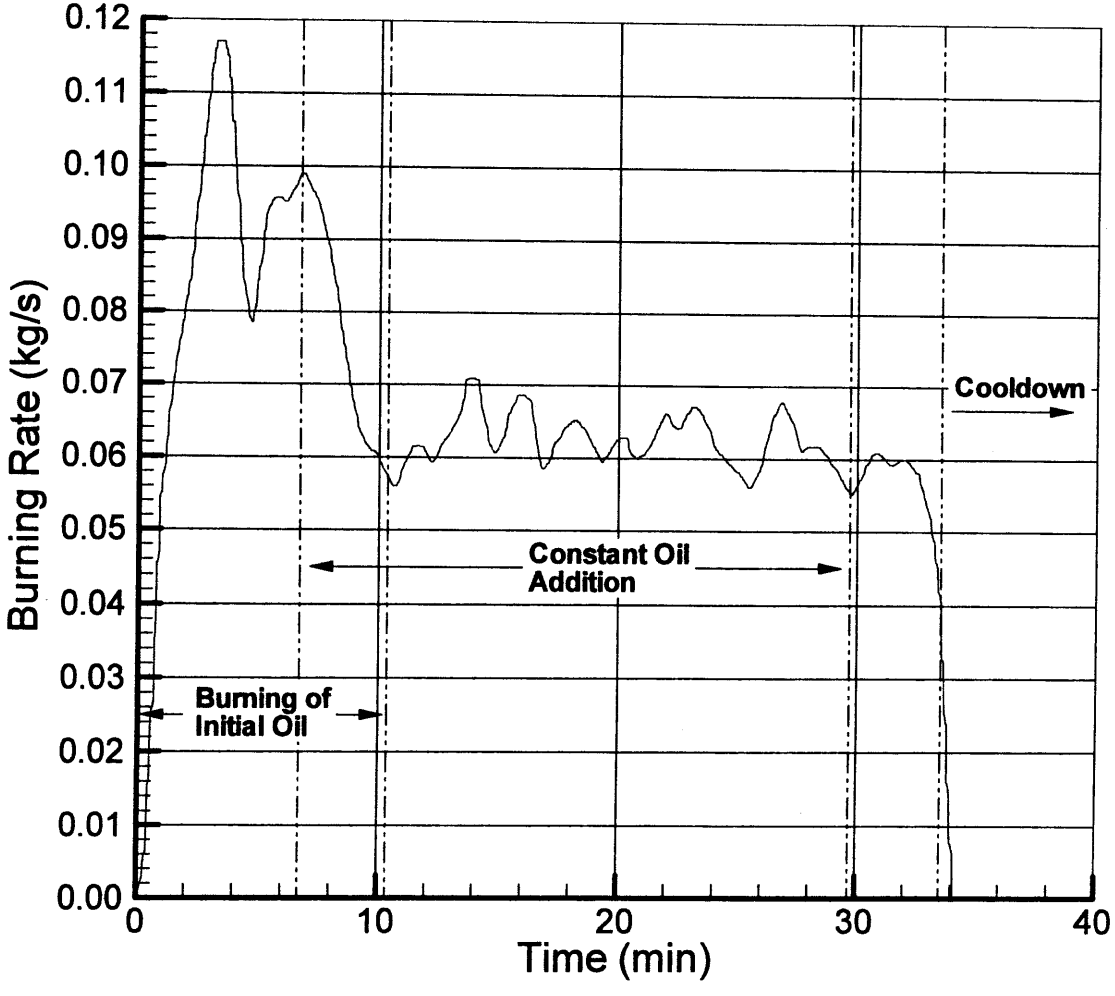






D-150

Test T52.14


Burning Rate (kg/s)
0.12
0.11
0.10
0.09
0.08
0.07
0.06
0.05
0.04
0.03
0.02
0.01
0.00
0
10
20
30
40
Time (min)
Burning of Initial Oil
Constant Oil Addition
Cooldown

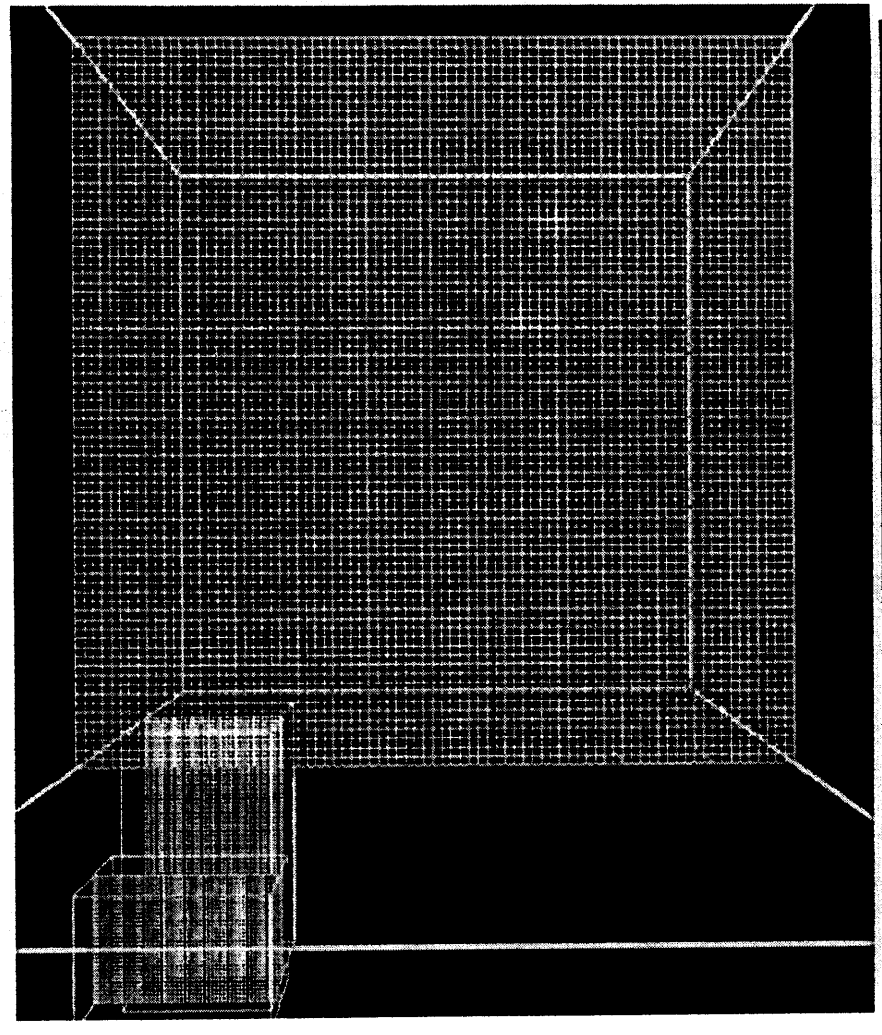
Input Parameters

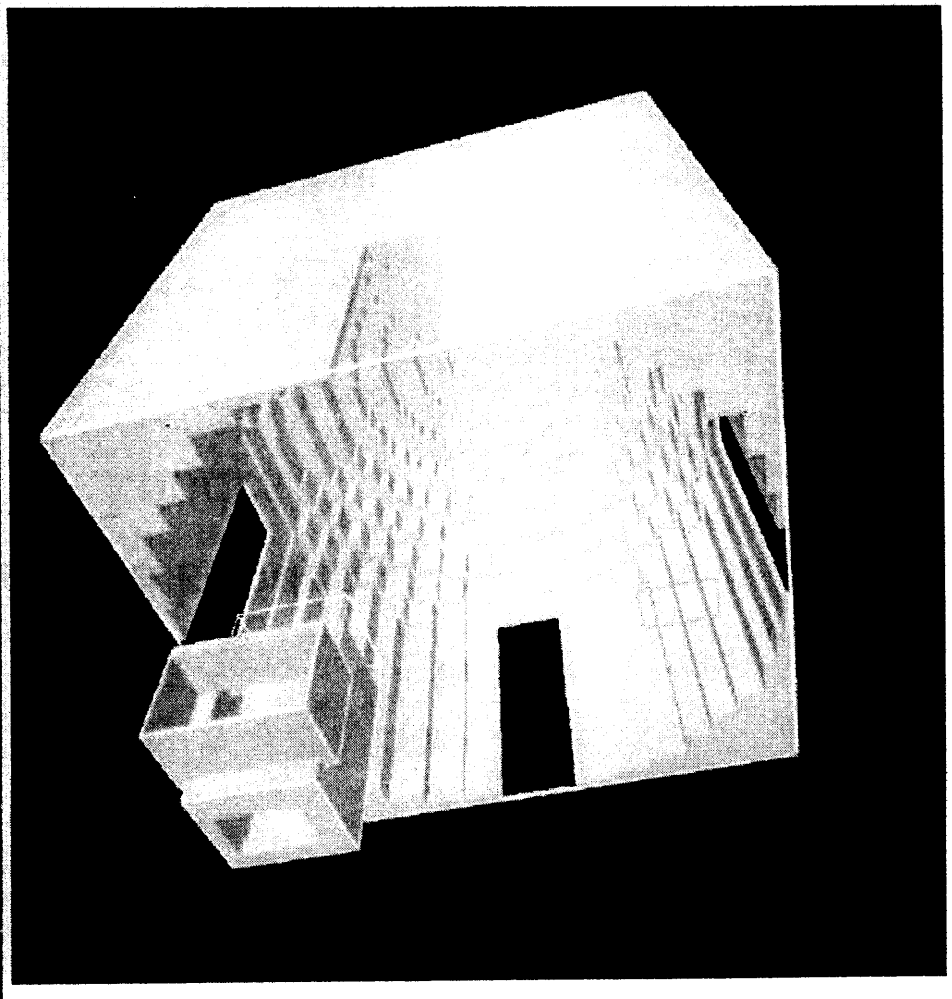
- Fire Power: 2.65 MW (Steady-state power)
- Fuel
  - $C_{12}H_{26}$: 170 g/mol, 42500 kJ/kg
- Surface definitions
  - Fire room: firebrick
  - Walls of hatch area: fire resistant fiberboard
  - Remainder: concrete

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

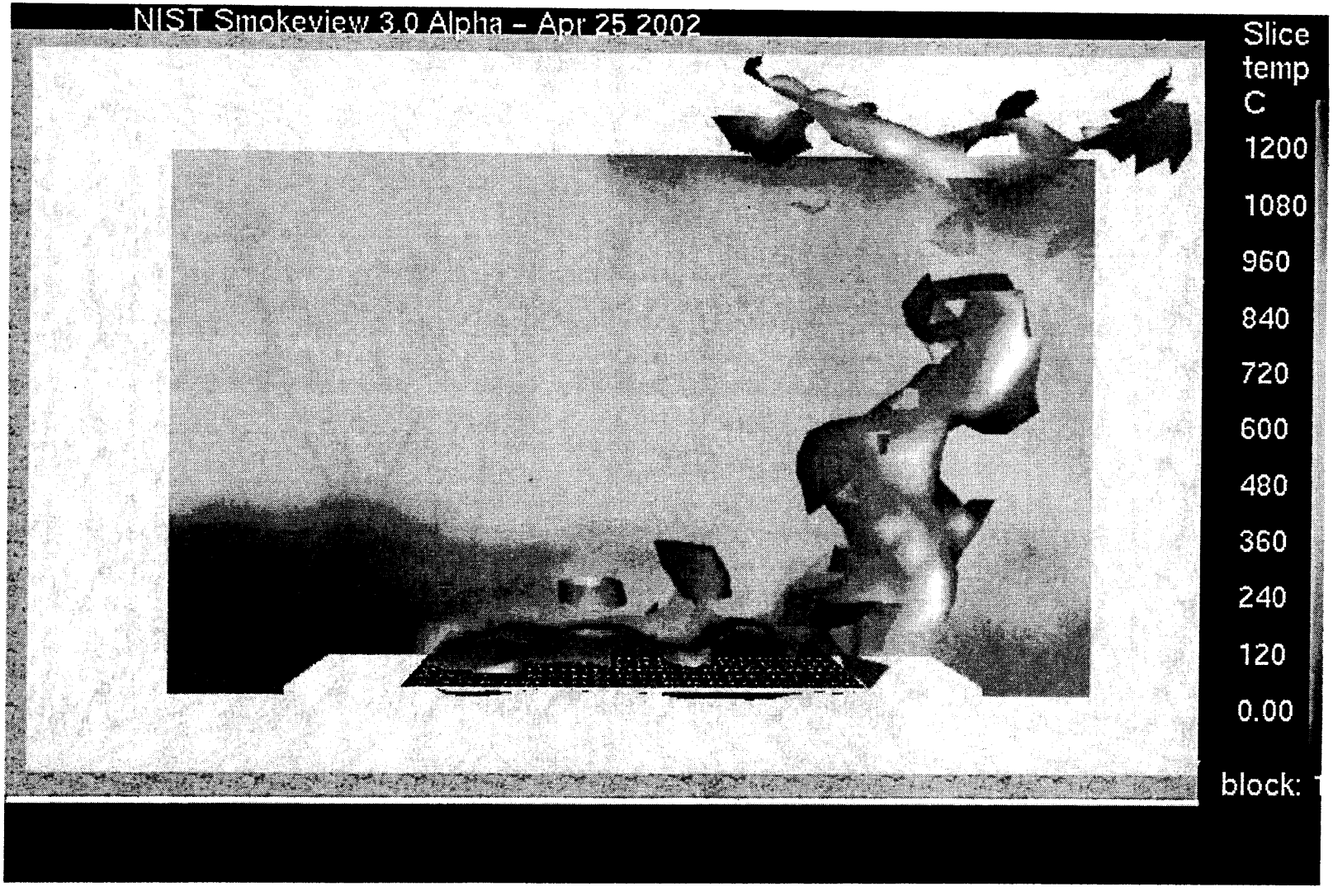
- 2.2 GHz Pentium IV, 1 Gb RAM, Linux
  - Full resolution case (654,080 grid cells)
    - 7.5 min CPU/s realtime
  - ¾ resolution case (275,292 grid cells)
    - 2.5 min CPU/s realtime

Integral Fire Room Results

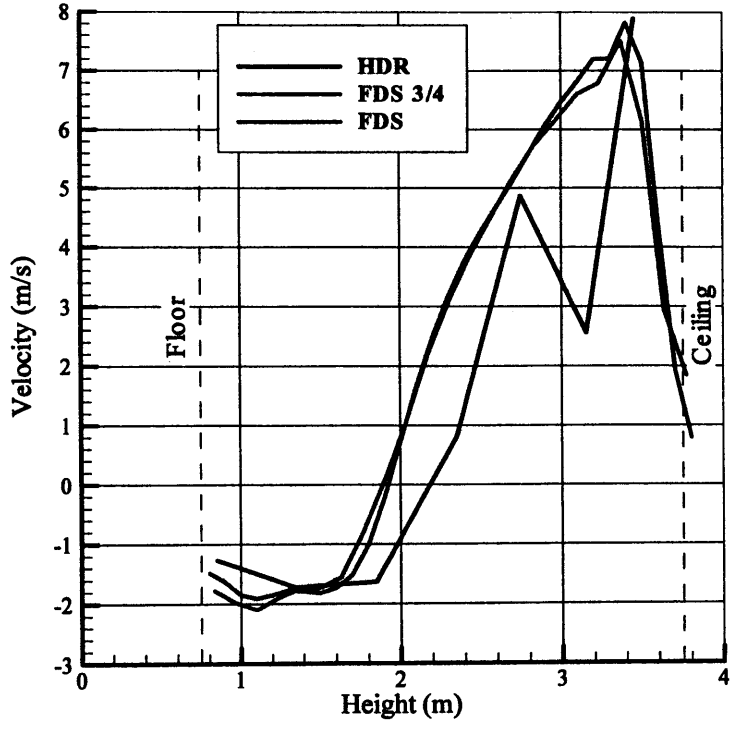
Parameter	HDR	Hand*	FDS ¾	FDS
h_n (m)	1.4	1.0	1.2	1.2
T_{out} (°C)	870	1210	793	827
(kg/s)	1.90	2.13	2.30	2.14

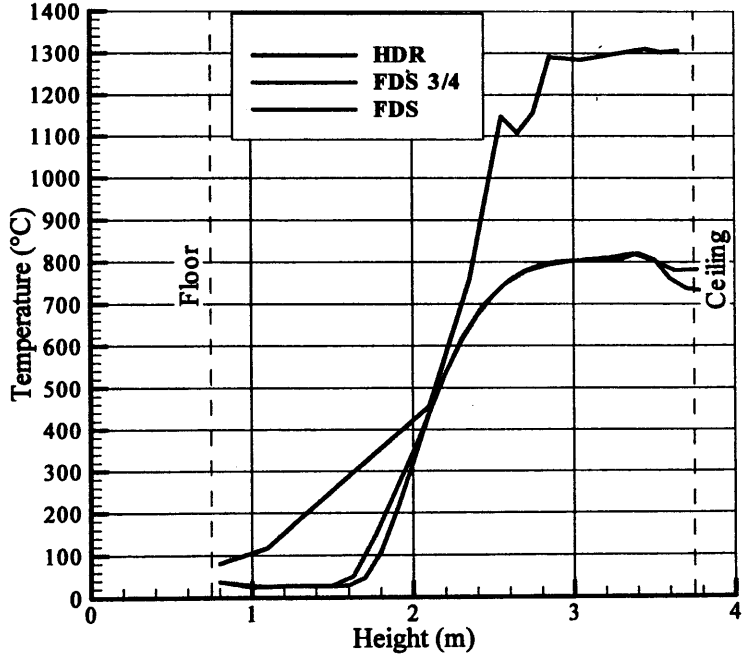
*Hand calculation following 1-layer method of Karlsson and Quintiere, 2000, Enclosure Fire Dynamics, CRC Press.

FDS Flame Surface

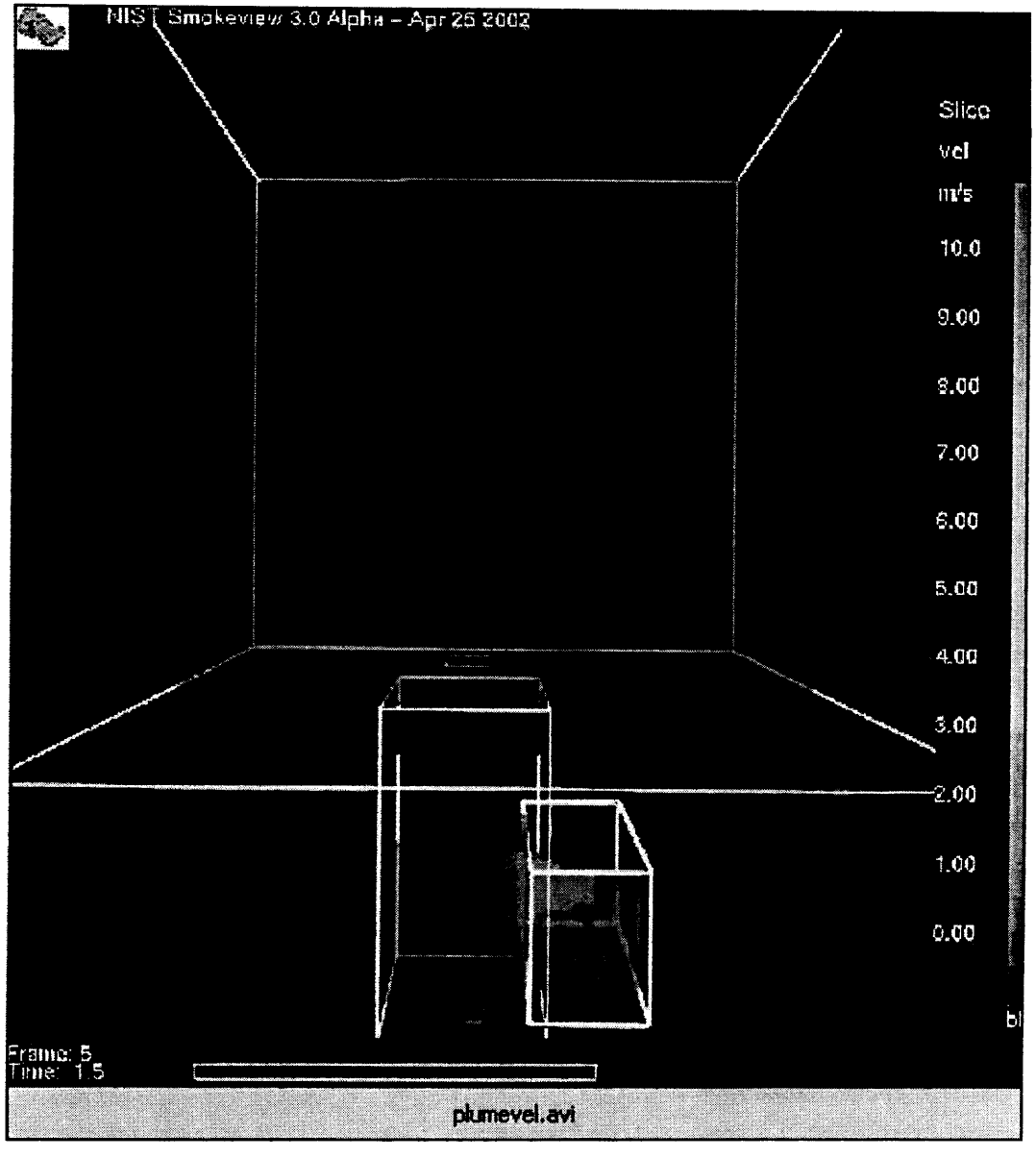


Fire Room Doorway

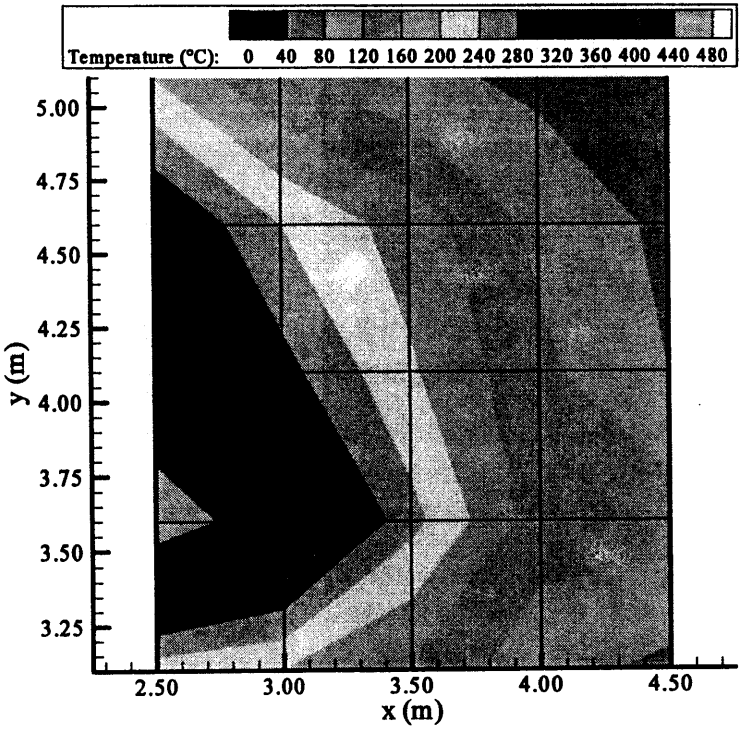


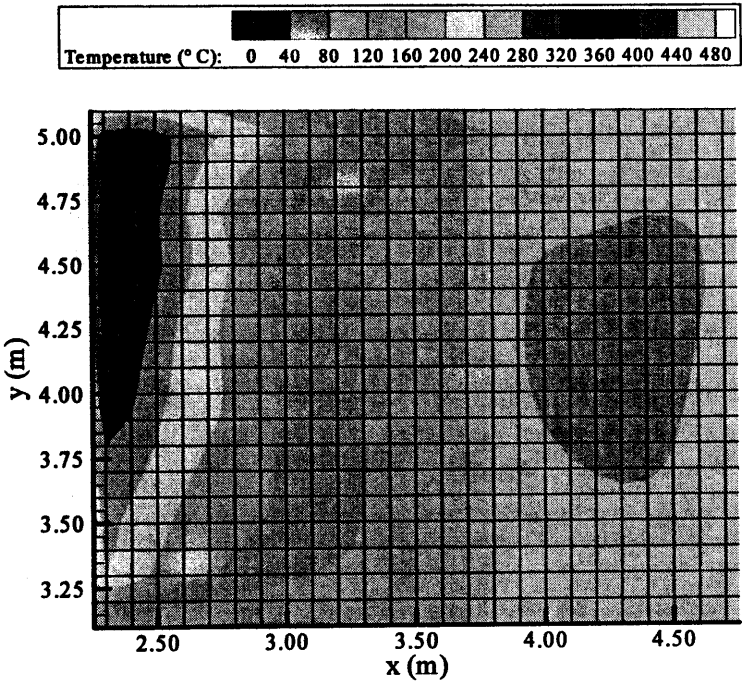


Plume Animation

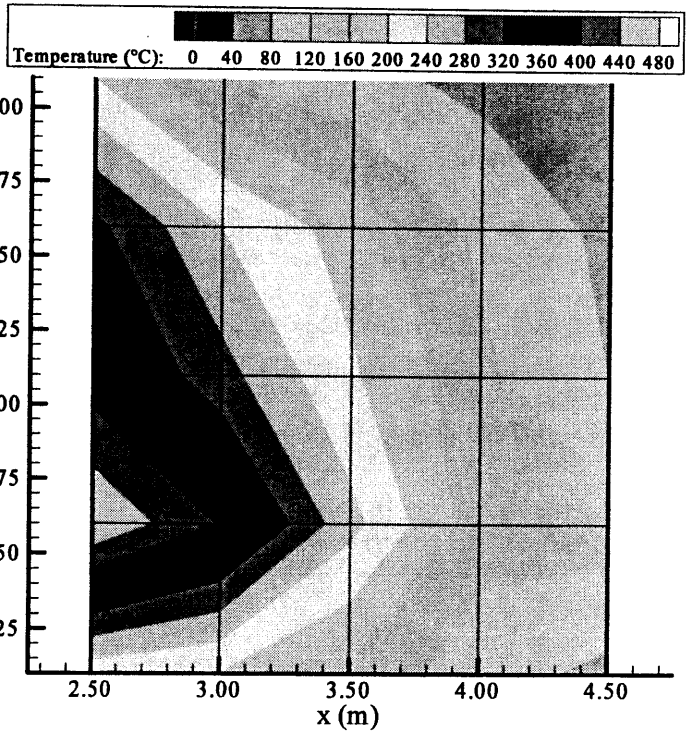


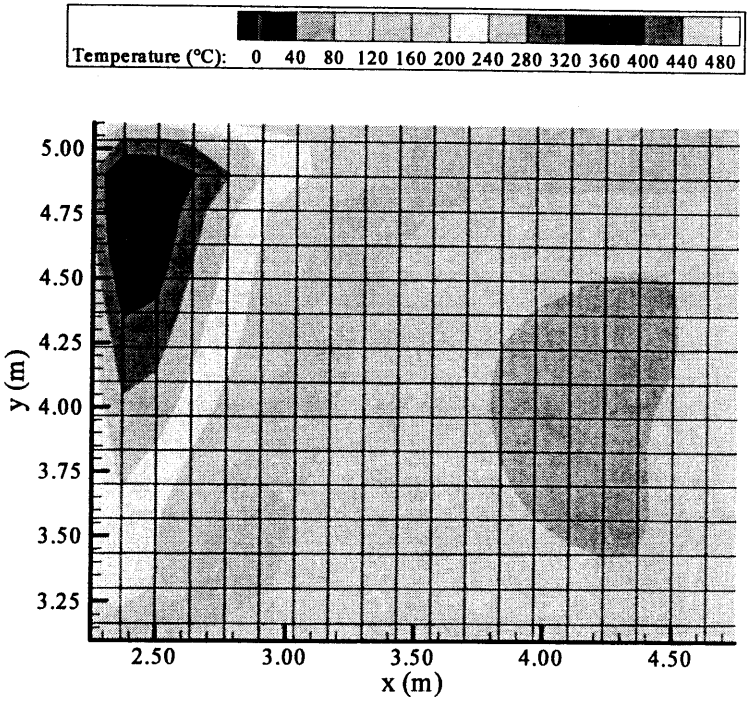
Hatch Temperature Full Grid





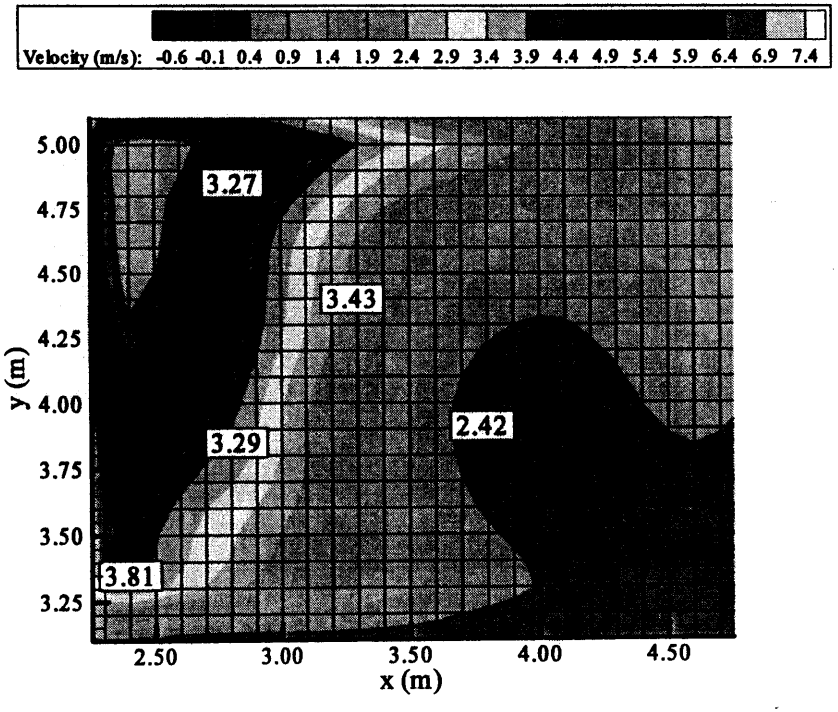
Hatch Temperature ¾ Grid



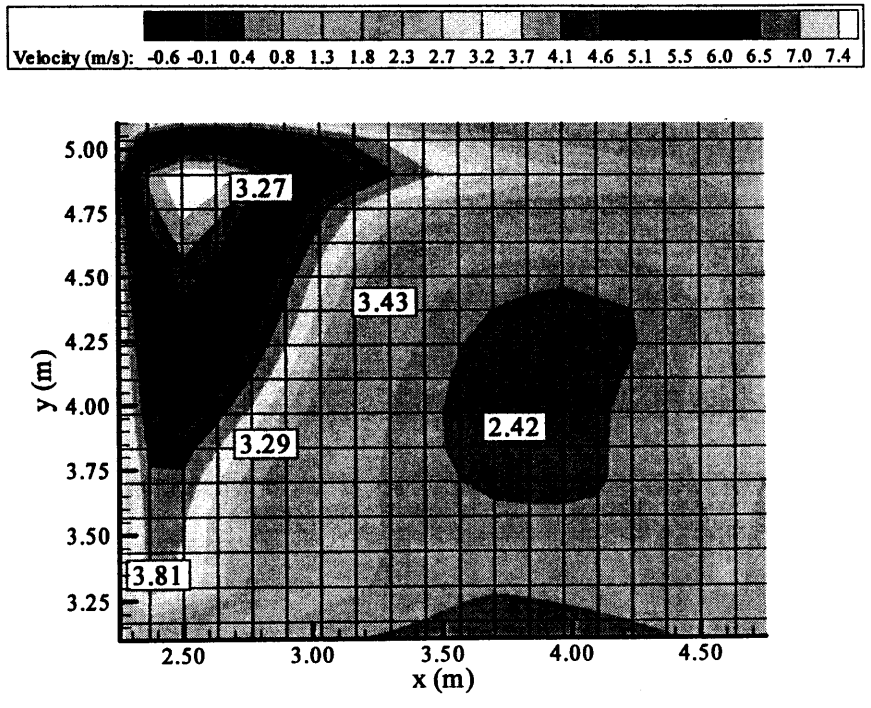


Hatch Velocity

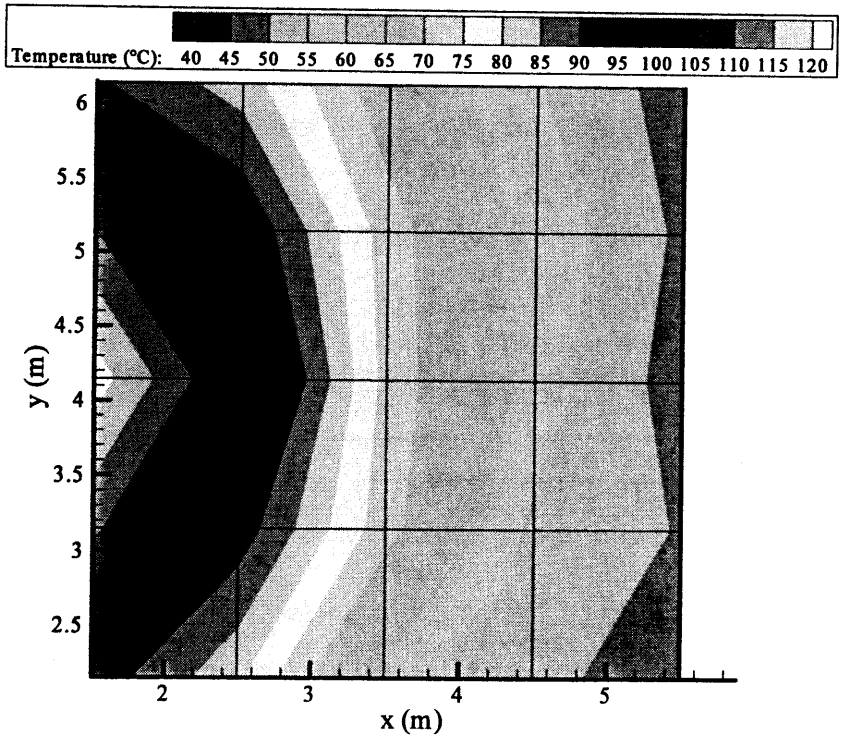
Full Grid

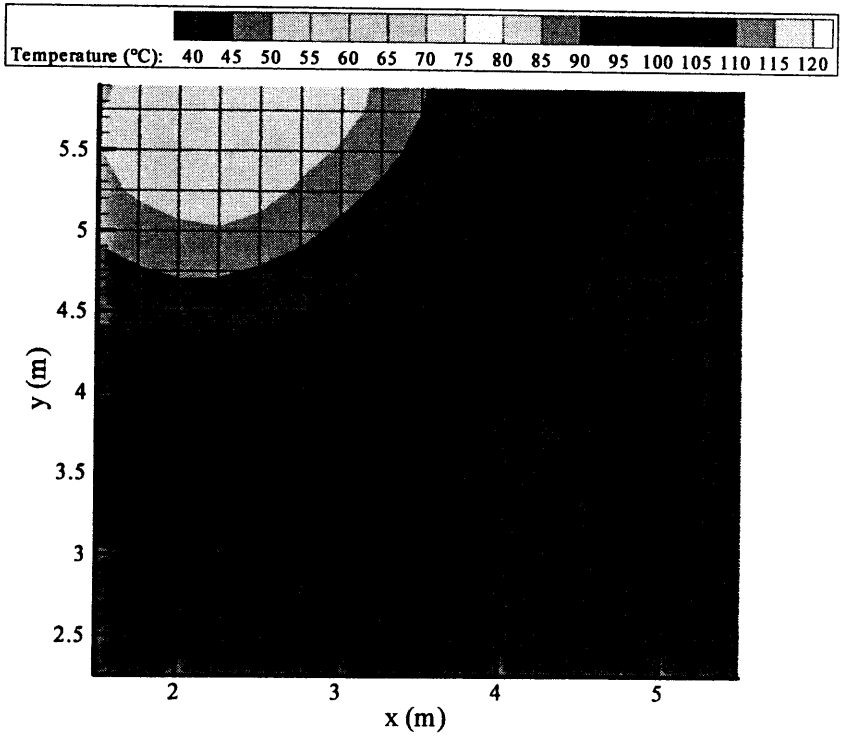


3/4 Grid

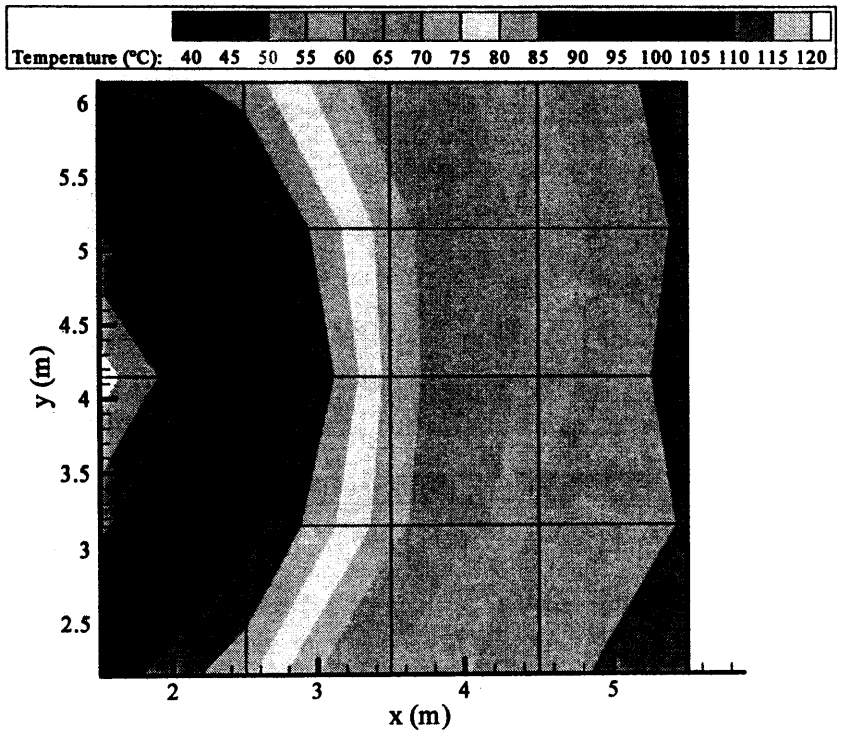


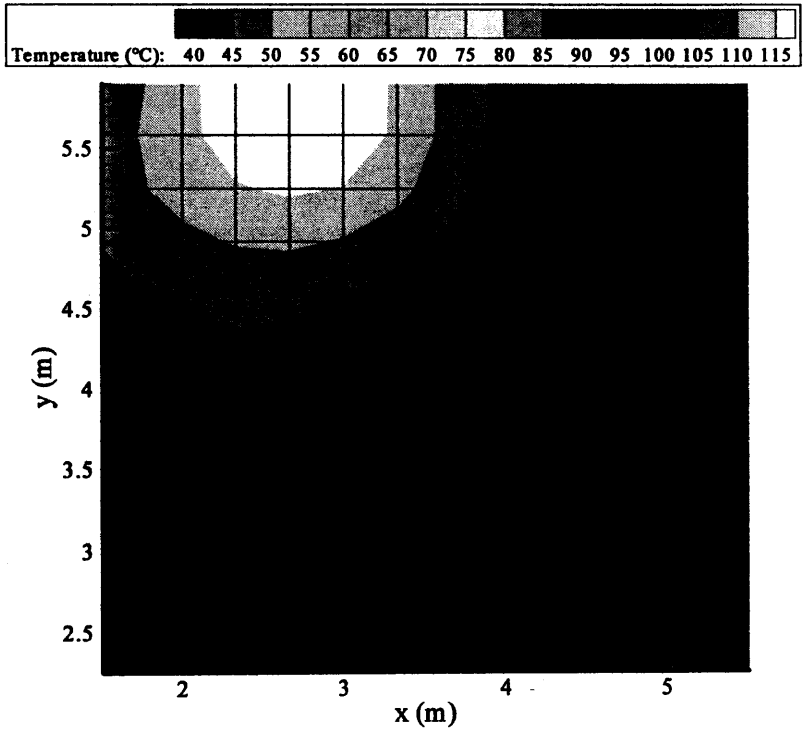
Dome Temperature Full Grid



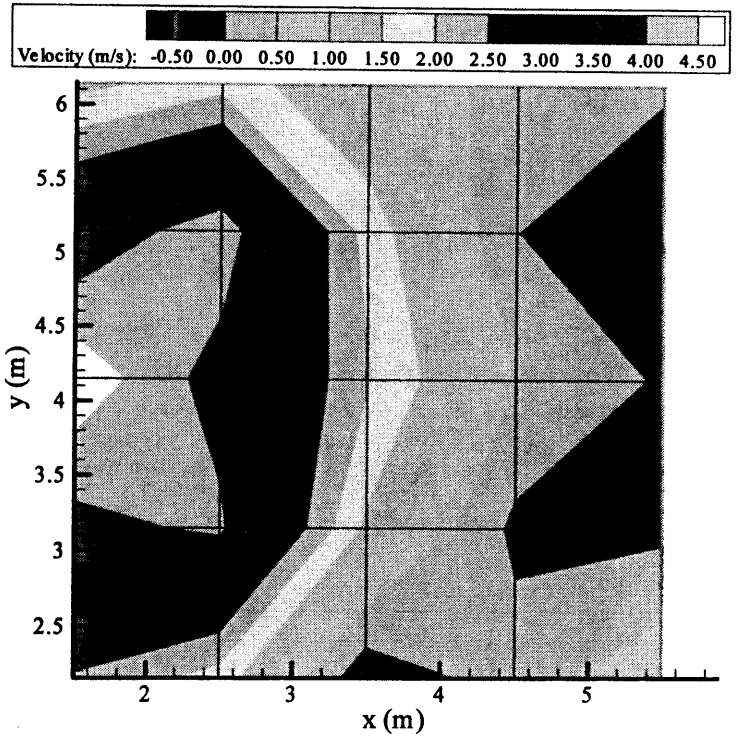


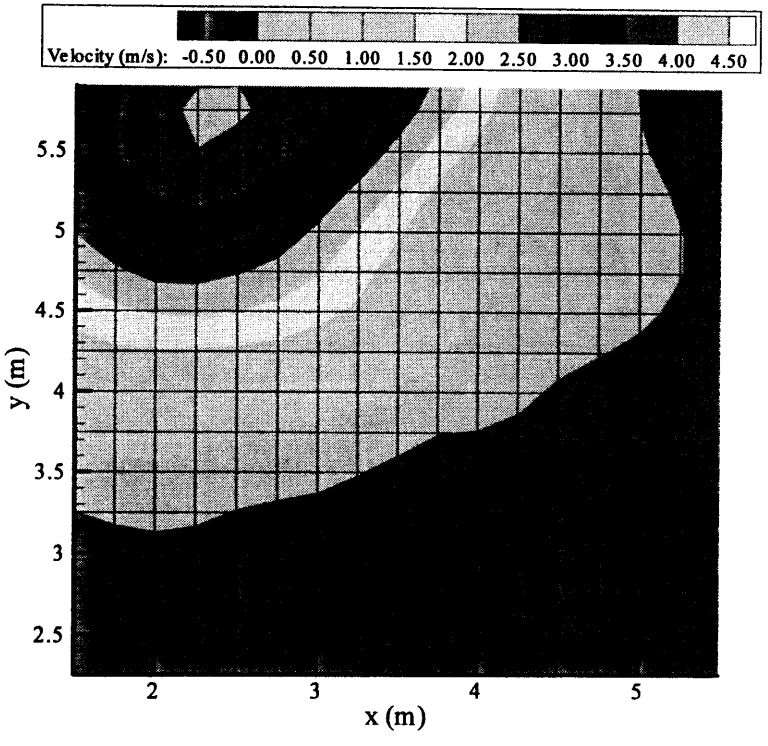
Dome Temperature ¾ Grid



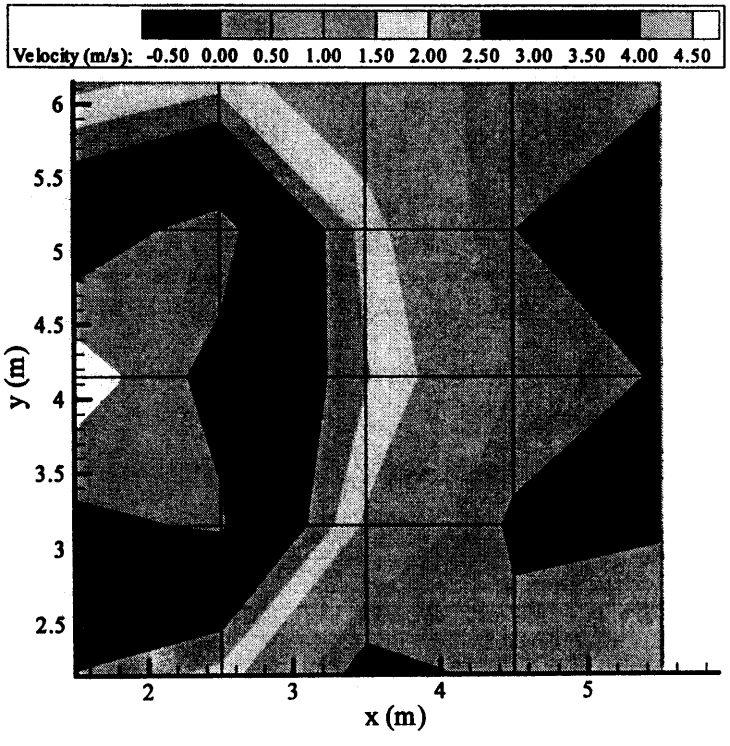


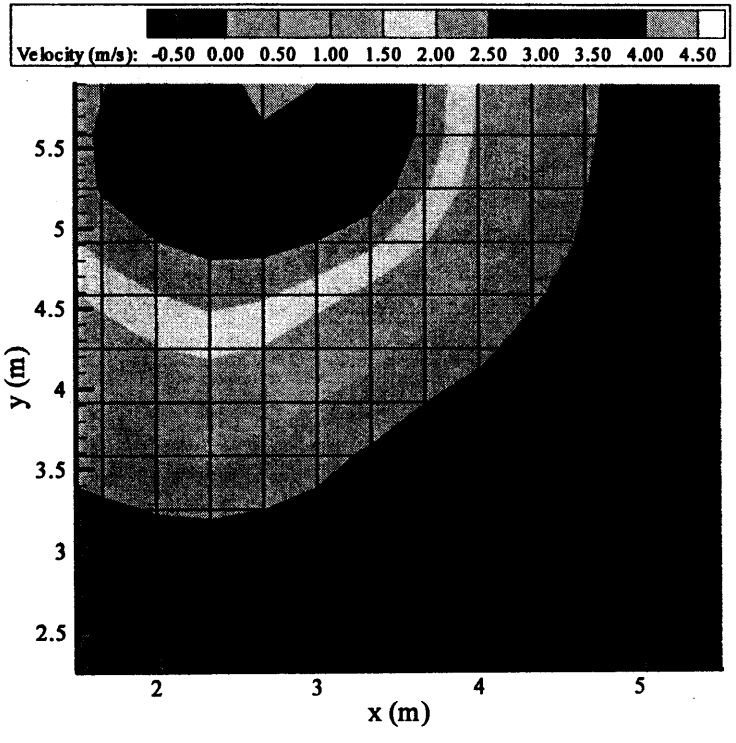
Dome Velocity Full Grid



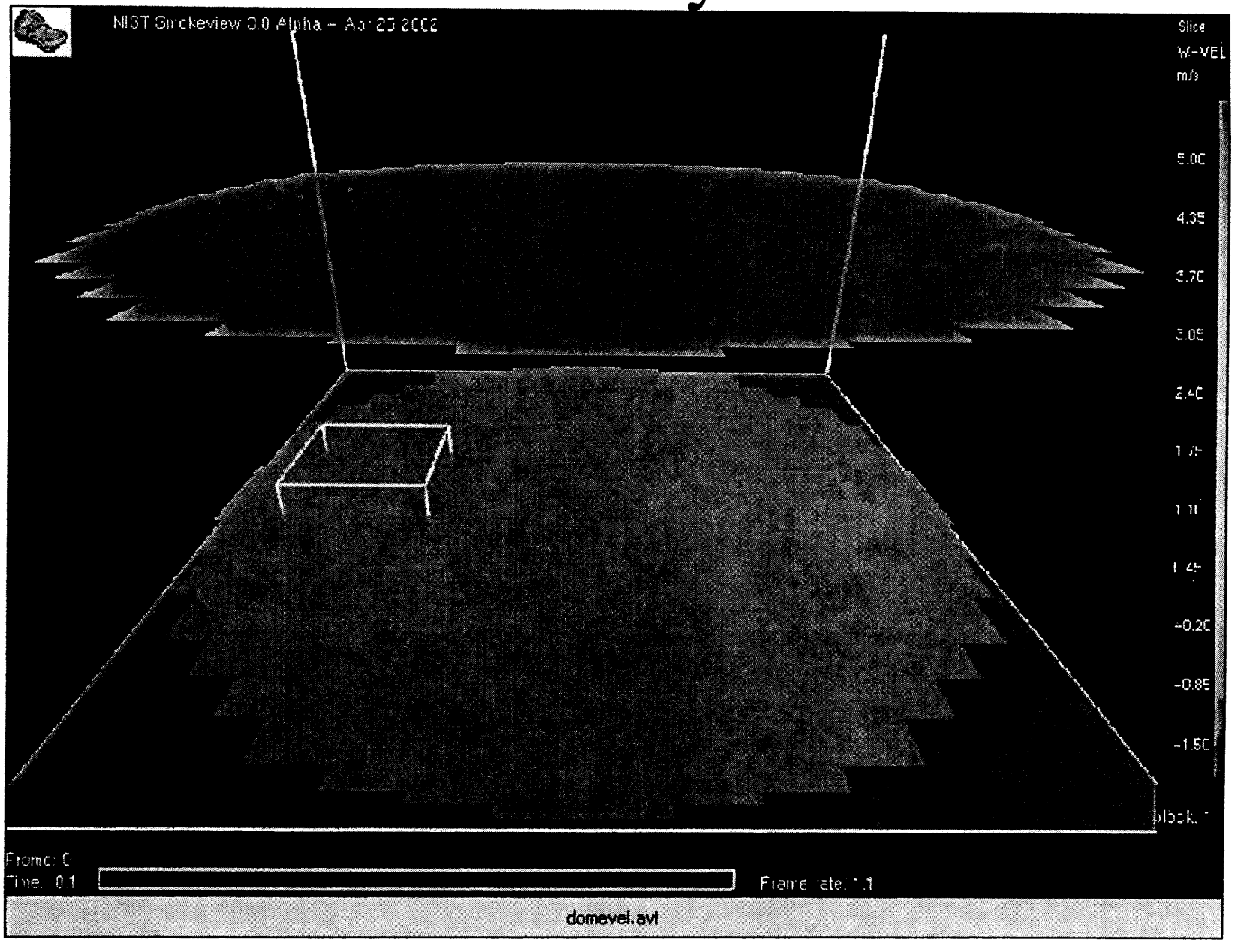


Dome Velocity ¾ Grid





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