Fire Modeling at NIST

McGrattan, Forney, McDermott, Peacock, Baum, Rehm

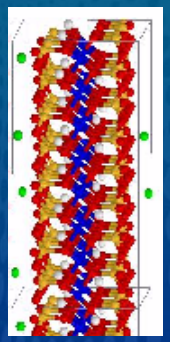
Federal Fire Working Group Meeting

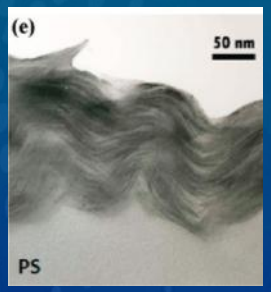
December 5, 2012

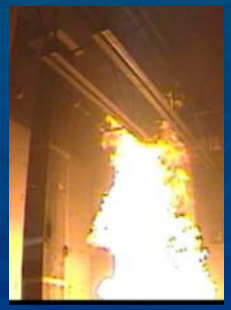
Anthony Hamins, Chief
Fire Research Division
Engineering Laboratory
National institute of Standards and Technology

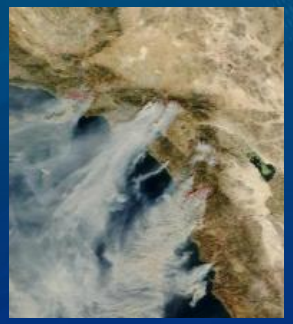
Why is the Problem Hard?

Technical Challenge: Understand, predict, control fire behavior over 16 orders of magnitude in length and time scales









10^{-10} 10^{-8} 10^{-6} 10^{-4} 10^{-2} 10^{0} 10^{2} 10^{4} 10^{6} (m)

computational domain meter-stick, yr 2012

Technical barriers:

- multiplicity of time and length scales
- complexity of inadequately understood inter-acting processes (multi-phase chemistry, heat & mass transfer, thermophysical properties,…)
- real-scale measurements are challenging
- solutions are multi-disciplinary

Non-technical barriers:

- education and training
- aging infrastructure & demographics
- human behavior
- public policy issues
- initial cost
- deliberate standards/codes process

Basic Conservation Equations for Single Species

Conservation of Mass

$$\frac{\partial \rho}{\partial t} + \nabla \cdot \rho \mathbf{u} = 0$$

Turbulence
Large Eddy Simulation

Conservation of Momentum

$$\frac{\partial (\rho \mathbf{u})}{\partial t} + \nabla \cdot \rho \mathbf{u}\mathbf{u} = -\nabla p + \rho \mathbf{g} + \nabla \cdot \tau$$

Conservation of Energy

$$\frac{\partial (\rho h)}{\partial t} + \nabla \cdot \rho h \mathbf{u} = \frac{Dp}{Dt} + \dot{q}''' + \nabla \cdot k \nabla T$$

Equation of State

$$p = \mathcal{R} \rho T$$

What are the unknowns? Density ρ; Velocity Components u, v, w; Enthalpy h, Pressure p

What needs to be provided? $\dot{q}'''$, the fire; τ, the (turbulent) viscous stresses, $\nabla \cdot k \nabla T$, thermal conductivity

Start with a very simple form of the energy transport equation:

$$\rho c_p \frac{DT}{Dt} = \dot{q}''' + k\nabla^2 T$$

Write it in non-dimensional form:

$$\rho^* \frac{DT^*}{Dt^*} = \left(\frac{L}{\rho_\infty c_p T_\infty U}\right)\dot{q}''' + \frac{1}{\mathrm{Re\ Pr}}\nabla^2 T^*$$

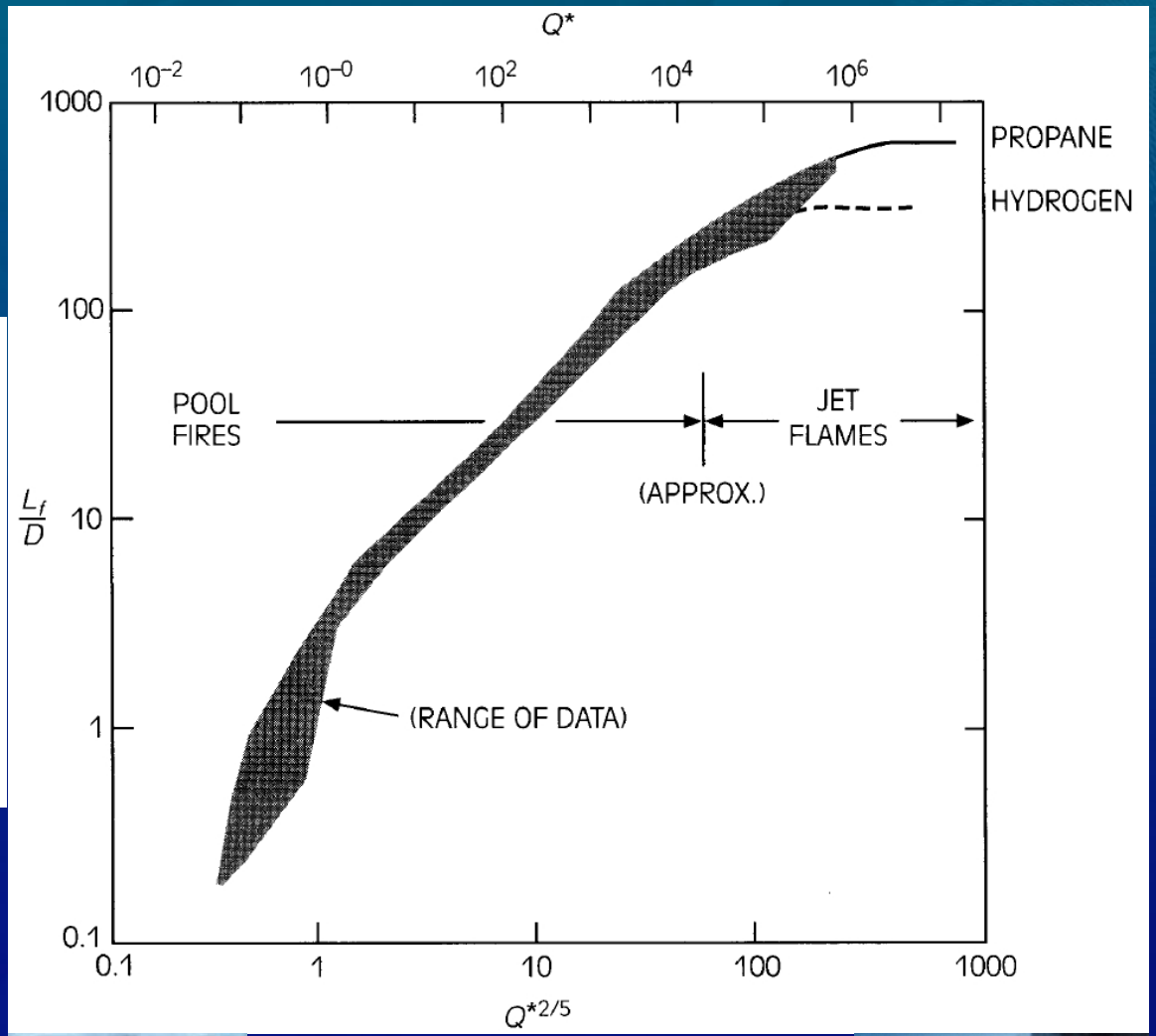
Define the Froude number:

$$\mathrm{Fr} = \frac{U}{\sqrt{gL}} \equiv \dot{Q}^* = \frac{\dot{Q}}{\rho_\infty c_p T_\infty \sqrt{g} D^{5/2}}$$

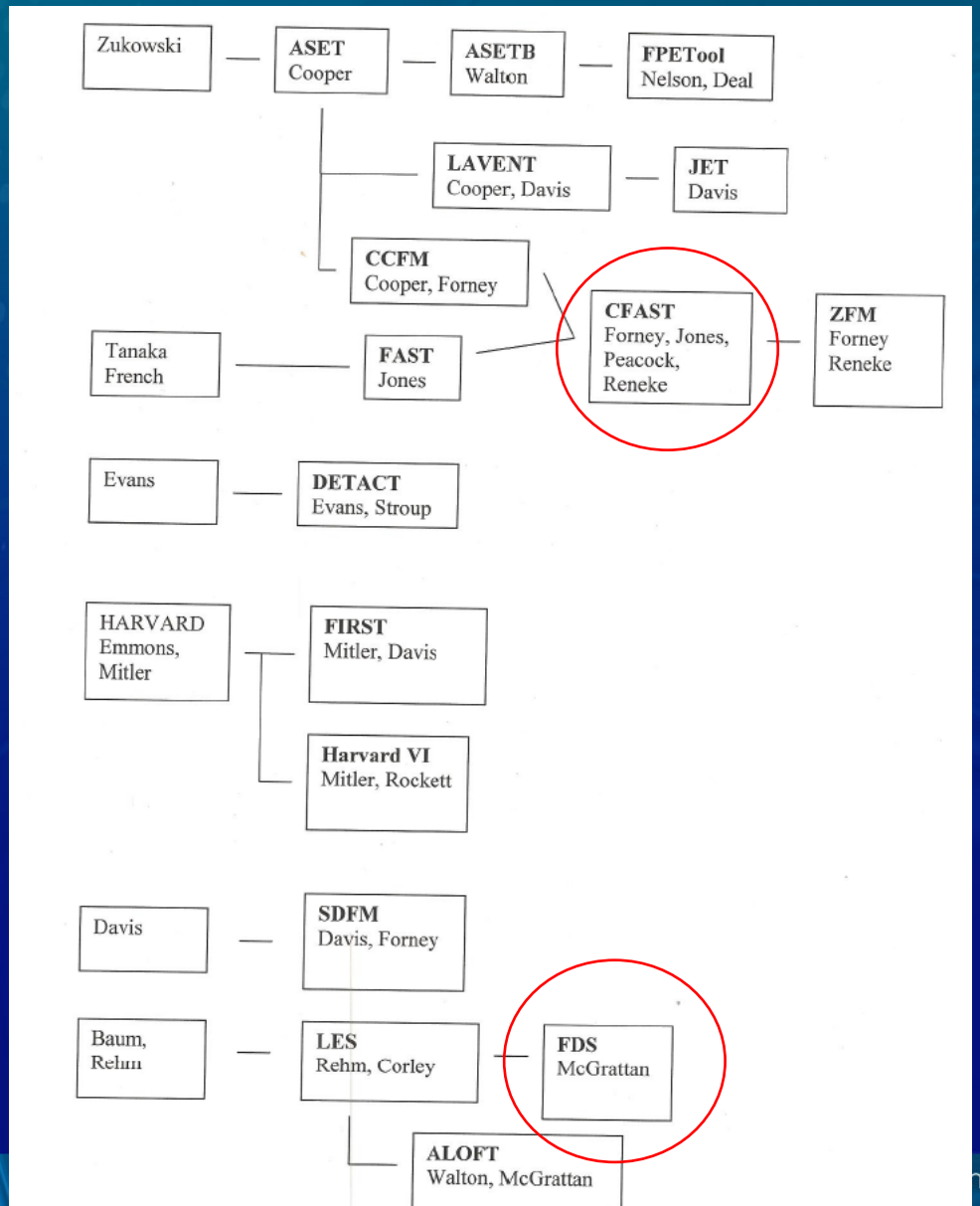
Heskestad Flame Height Correlation

$$\frac{L_f}{D} = 3.7\,(Q^*)^{2/5} - 1.02$$

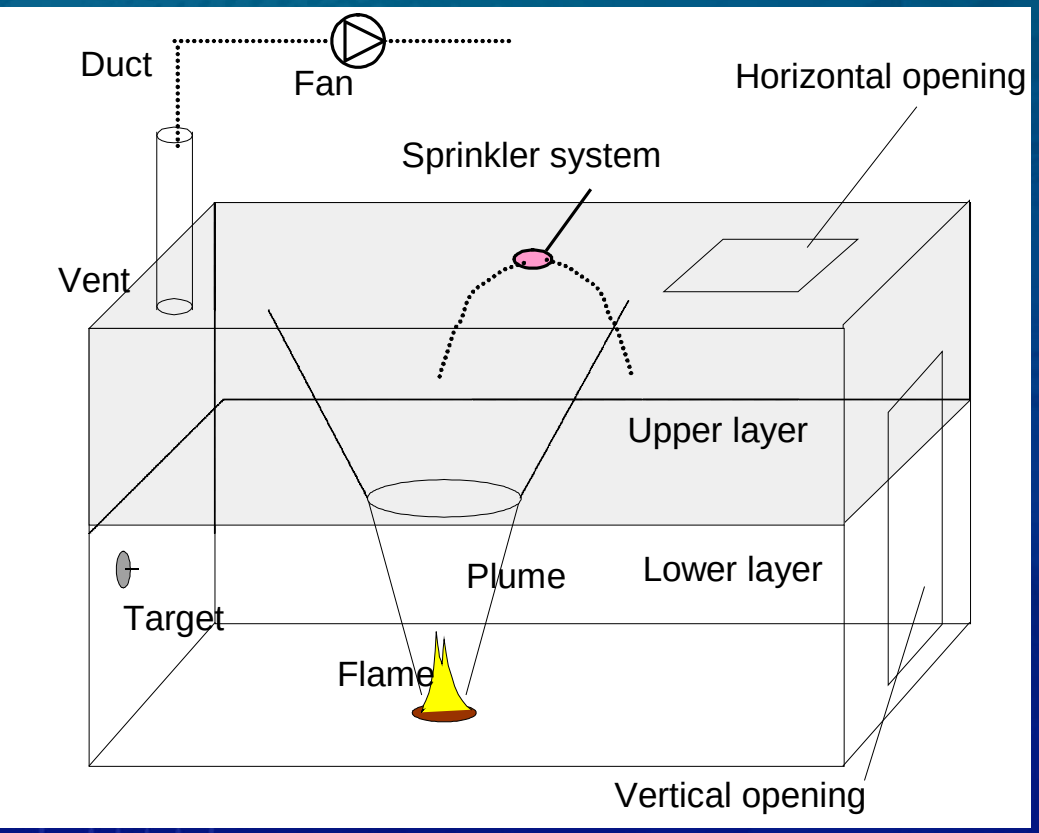
$$Q^* = \frac{\dot{Q}}{\rho_\infty c_p T_\infty \sqrt{g}\, D^{5/2}}$$



Evolutionary Tree of Several Fire Modeling Branches

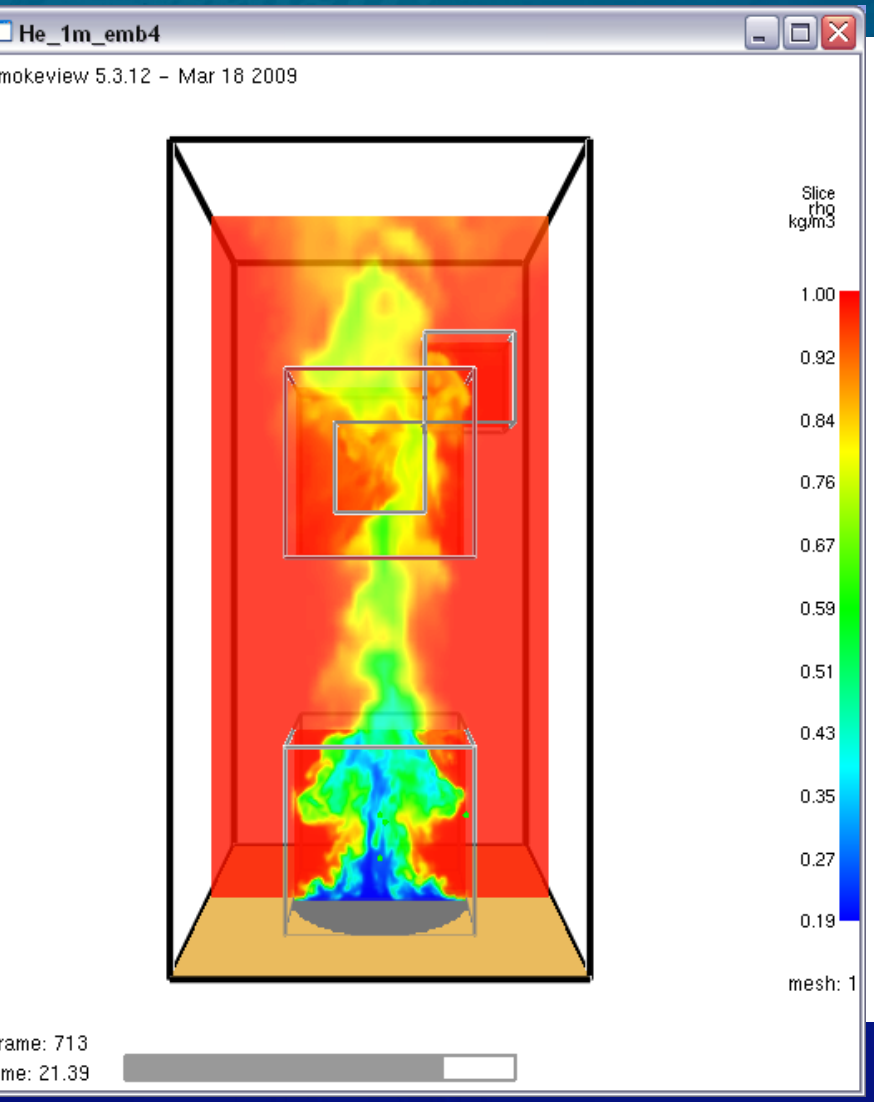


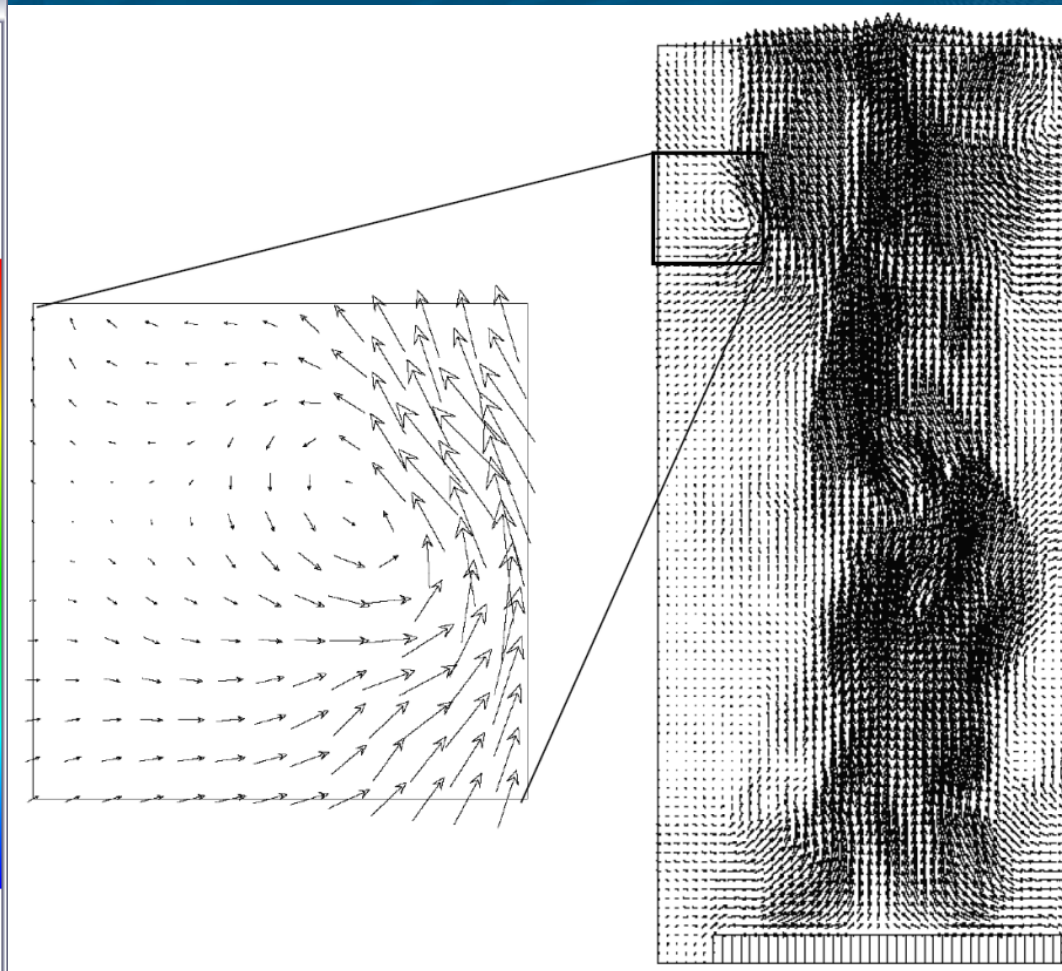
What is CFAST?

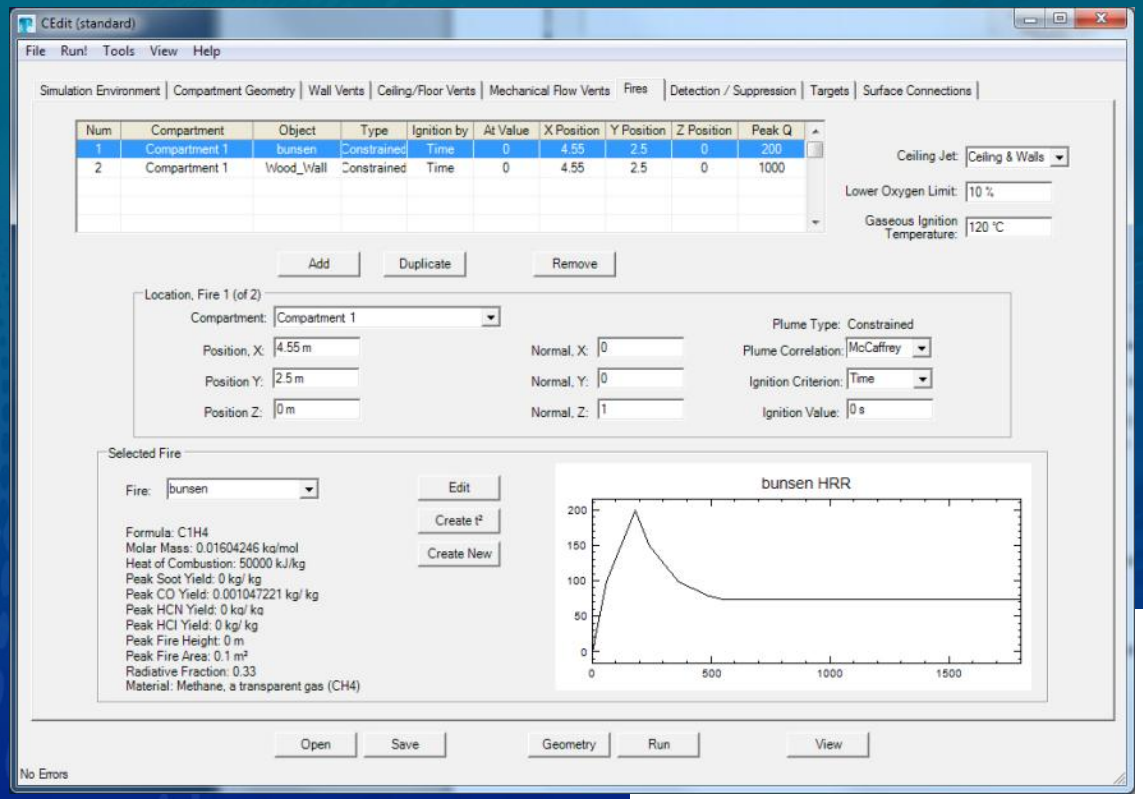


- CFAST is a two-zone fire model to calculate the distribution of smoke, fire gases and temperature
- The software solves the conservation equations for mass and energy in two control volumes

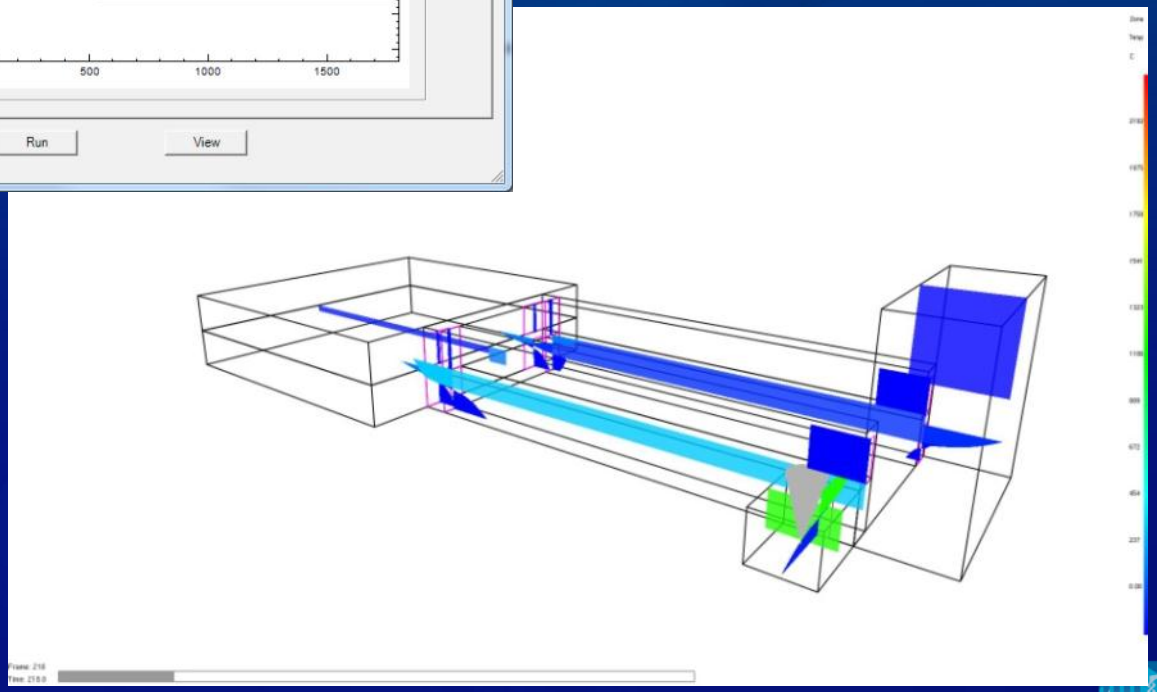
What is FDS?


He_1m_emb4
mokeview 5.3.12 – Mar 18 2009
Slice
rho
kg/m3
1.00
0.92
0.84
0.76
0.67
0.59
0.51
0.43
0.35
0.27
0.19
mesh: 1
rame: 713
me: 21.39





CFAST



W. Jones
R. Peacock
P. Reneke
G. Forney

CFAST Interface

Tabs group model inputs into several categories

Inputs grouped by function with units displayed

Save, view geometry, or run simulation

CEdit (standard)

File Run! Tools View Help

Simulation Environment | Compartment Geometry | Wall Vents | Ceiling/Floor Vents | Mechanical Flow Vents | Fires | Detection / Suppression | Targets | Surface Connections

Num	Compartment	Object	Type	Ignition by	At Value	X Position	Y Position	Z Position	Peak Q
1	Compartment 1	bunsen	Constrained	Time	0	4.55	2.5	0	200
2	Compartment 1	Wood_Wall	Constrained	Time	0	4.55	2.5	0	1000

Ceiling Jet: Ceiling & Walls

Lower Oxygen Limit: 10 %

Gaseous Ignition Temperature: 120 °C

Add | Duplicate | Remove

on, Fire 1 (of 2)

Compartment: Compartment 1

ion, X: 4.55 m

Position Y: 2.5 m

Position Z: 0 m

Normal, X: 0

Normal, Y: 0

Normal, Z: 1

Plume Type: Constrained

Plume Correlation: McCaffrey

Ignition Criterion: Time

Ignition Value: 0 s

Selected Fire

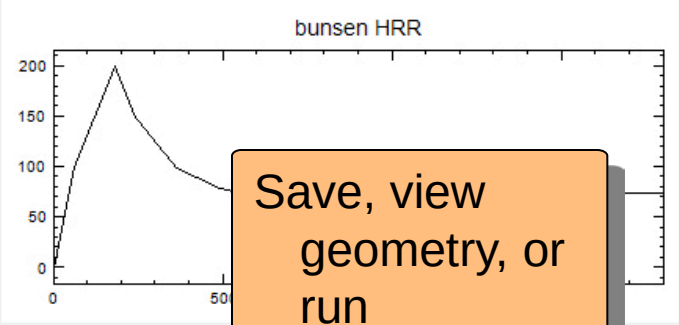
Fire: bunsen

Edit

Create t²

Create New

Formula: C1H4
Molar Mass: 0.01604246 kg/mol
Heat of Combustion: 50000 kJ/kg
Peak Soot Yield: 0 kg/ kg
Peak CO Yield: 0.001047221 kg/ kg
Peak HCN Yield: 0 kg/ kg
Peak HCl Yield: 0 kg/ kg
Peak Fire Height: 0 m
Peak Fire Area: 0.1 m²
Radiative Fraction: 0.33
Material: Methane, a transparent gas (CH4)



Open | Save | Geometry | Run | View

No Errors

Exploiting Social Media for FDS

Firefox

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fds-smv

Fire Dynamics Simulator (FDS) and Smokeview (SMV)

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International_Resources_and_Translators
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Smokeview_Release_Notes
Third_party_Tools
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Fire Dynamics Simulator (FDS) is a large-eddy simulation (LES) code for low-speed flows, with an emphasis on smoke and heat transport from fires.

Smokeview (SMV) is a visualization program used to display the output of FDS and CFAST simulations.

FDS+Evac is the evacuation simulation module for FDS.

Download FDS-SMV for Windows, Mac, and Linux

Download FDS and Smokeview

Documentation and Support

FDS-SMV Manuals	FDS and Smokeview User, Technical, Verification, and Validation Guides.
Discussion Group	Mailing list for general discussion, questions, and feedback.
Issue Tracker	Submit cases to the Issue Tracker to report specific bugs or problems.
Wiki Pages	Information on FDS-SMV development, third-party tools, and other resources.

Firefox

FDS6 - Humidity - FDS and ... | grass fire - Google Search | Issue 1788 - fds-smv - SMV ... | Issues - fds-smv - Fire Dyna... | Q&A: How to print a XP wi...

code.google.com/p/fds-smv/issues/list

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fds-smv

Fire Dynamics Simulator (FDS) and Smokeview (SMV)

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ID	Type	Status	Priority	Milestone	Owner	Summary + Labels
1773	Defect	New	Medium	----	CraigWeinschenk	Smyth Slot Burner validation file outdated
1779	Defect	Accepted	Medium	----	CraigWeinschenk	Unspecified Product Species Properties
885	Defect	MoreInfo	Medium	----	crogsch	Differences in results using the mpi- and openMP-versions
1045	Defect	Fixed	Medium	----	crogsch	OpenMP FDS 5.4.3. Mass fraction problem, no reaction occurs
1171	Defect	MoreInfo	Medium	----	crogsch	Different results for Interface boudanry manipulation for OpenMP
1196	Defect	MoreInfo	Medium	----	crogsch	2D axisymmetric case and OpenMP
1254	Defect	Started	Medium	----	crogsch	OpenMP in mass.f90
1319	Defect	MoreInfo	Medium	----	crogsch	Errors while building openmp_intel_linux_32 target
1440	Defect	Accepted	Medium	----	crogsch	FDS with OpenMP
1605	Defect	Accepted	Medium	----	crogsch	OpenMp Makefile
1702	Defect	Accepted	Medium	----	crogsch	Compilation of 64 bit linux version of openmp fds with intel compiler
132	Defect	OnHold	Low	----	drjfloyd	TRANSPARENCY Usability
166	Enhancement	OnHold	Low	----	drjfloyd	fds2ascii
427	Defect	OnHold	Medium	----	drjfloyd	Problem with function BLACKBODY_FRACTION
497	Defect	Fixed	Medium	FDS_6.0	drjfloyd	Control and removing of obstructions Usability
908	Enhancement	OnHold	Low	----	drjfloyd	User defined, spatially dependent velocity profile at vent inlet??
1003	Defect	Accepted	Medium	FDS_6.0	drjfloyd	pointer intialization
1347	Defect	Accepted	Medium	----	drjfloyd	Creation of mass
1734	Defect	Fixed	Medium	FDS_6.0	drjfloyd	Leakage case causes floating point exception in wall.f90, MPI only
1737	Other	Fixed	Medium	FDS_6.0	drjfloyd	HVAC damper don't close

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https://groups.google.com/forum/?fromgroups#!forum/fds-smv

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FDS and Smokeview Discussions

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Evac in FDS6 (5)	5	25	» fire...@optusnet.com.au +3	6:31 AM
Evac 2.4.1 download (4)	4	24	» fire...@optusnet.com.au +3	6:07 AM
Is there a way to use EVAC without CFD portion of FDS (fully render...	4	17	» DP +2	6:01 AM
kolmogorov lenth scale (5)	5	42	» yamina +1	Nov 30
FDS6 - Humidity (3)	3	18	» albrecht +2	Nov 26
problem with HRRPUA (8)	10	56	» Roman +4	Nov 23
Pool Ignition (3)	5	30	» silvi +3	Nov 22
t^2-function plus ramp-down (3)	3	33	» Martin +2	Nov 20
Computer power (7)	7	208	» Luke +5	Nov 19
BlenderFDS 2.0.0 released (2)	2	121	» Emanuele Gissi +1	Nov 18
vertical flame length (4)	4	37	» Jin +1	Nov 16
Benefits of Running FDS model in LINUX (3)	3	41	» Nat Ong +2	Nov 15
Random initial position? (5)	5	41	» ely +2	Nov 14

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FDS-SMV Manuals

- FDS Technic...ical Model.pdf
- FDS Technic...tion Guide.pdf
- FDS Technic...tion Guide.pdf
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FDS-SMV Manuals

8 items

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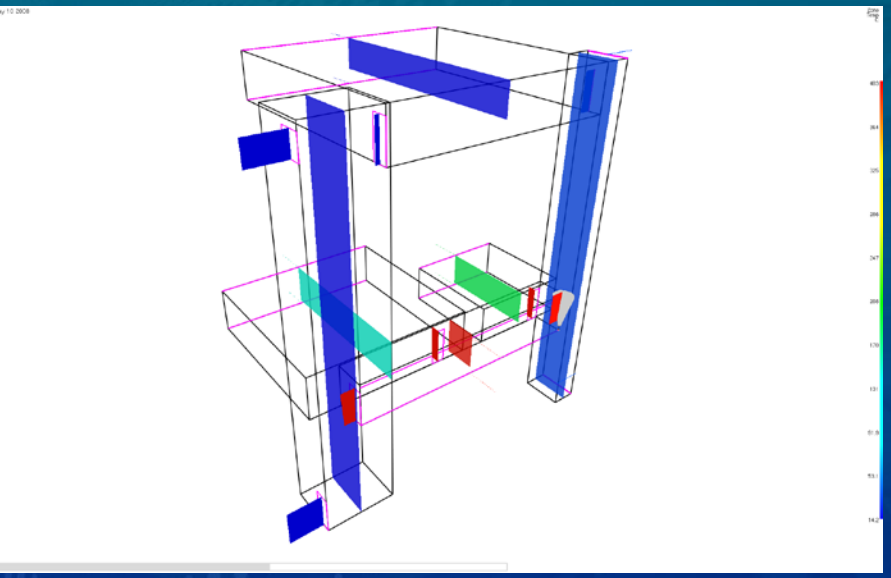
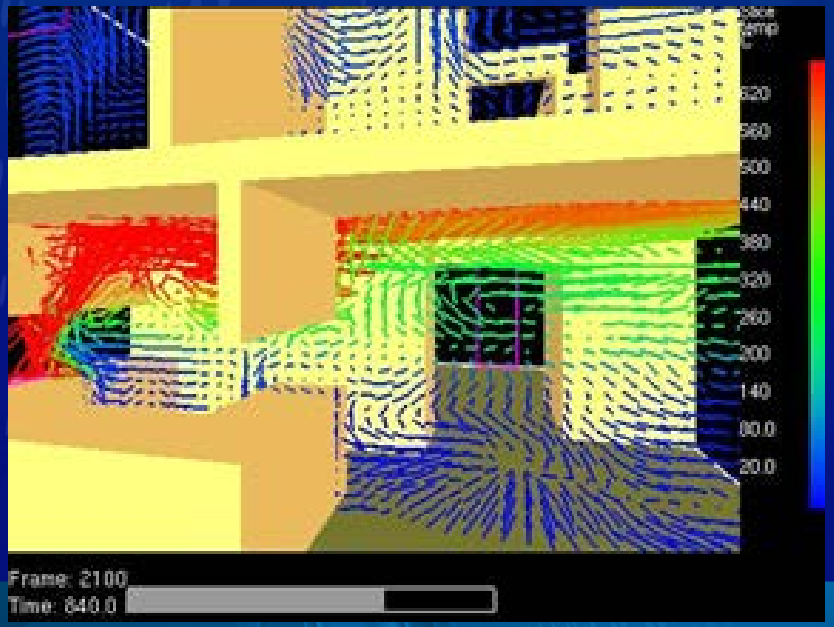
FDS Technical Reference Guide Volume 4: Configuration Management Plan.pdf

Scientific Visualization

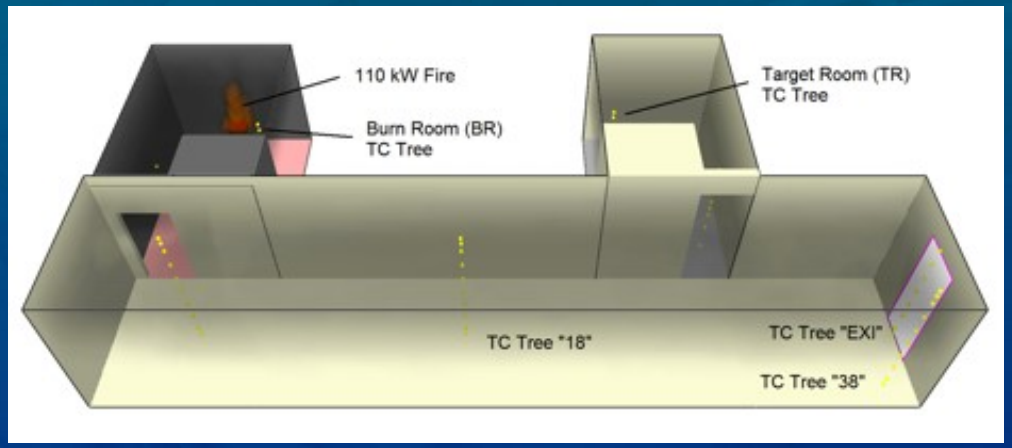


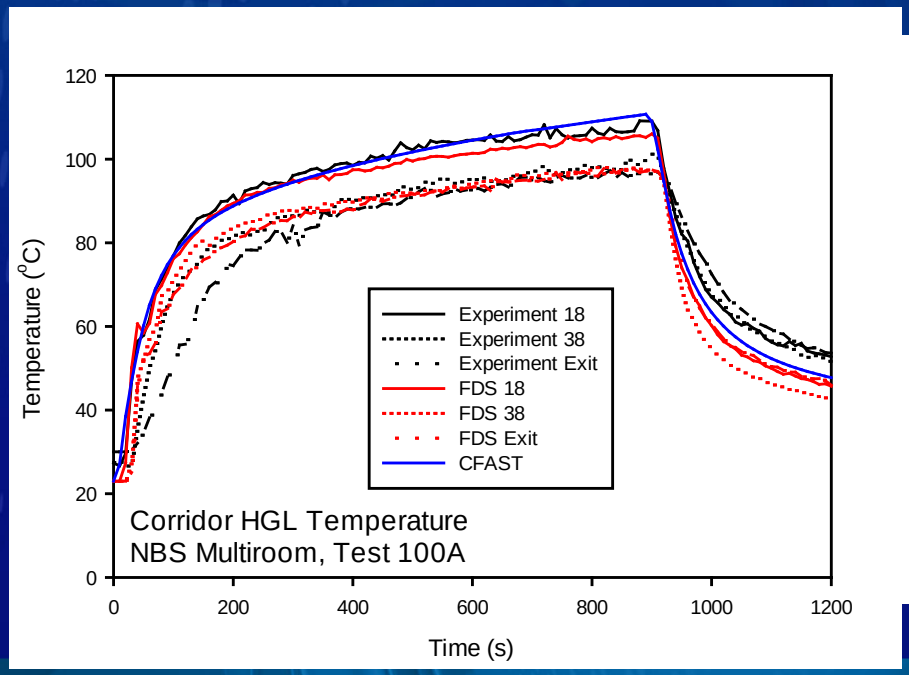
- CFAST use Smokeview to visualize the scenario geometry, vents, fires, and targets.

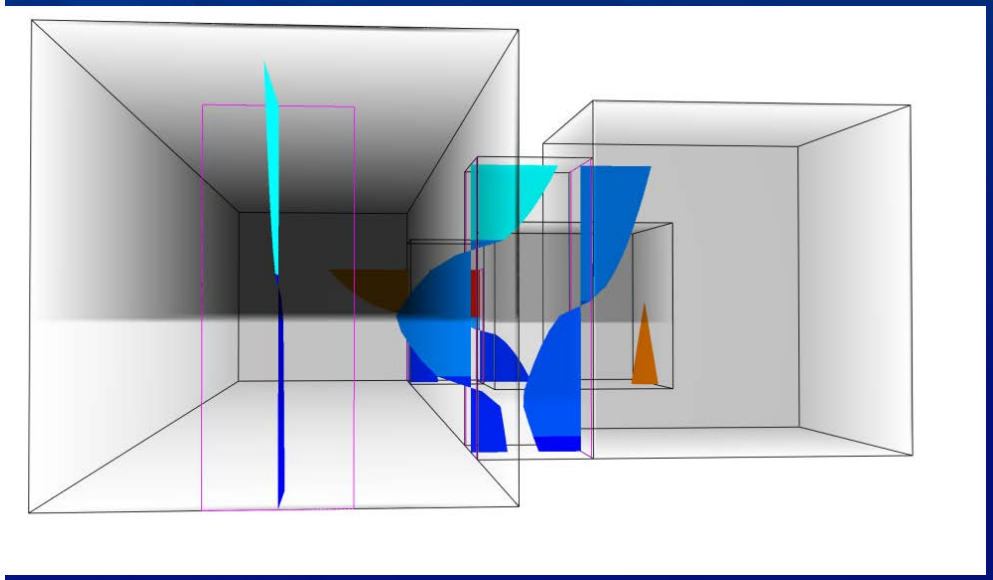


- FDS use Smokeview to visualize the evolving scenario geometry, fire, and fields of velocity vectors, temperature field, heat flux, species concentrations.

Smokeview: Scientific Visualization of CFAST and FDS







Smokeview and the Radiation Transport Equation

absorption | out-scattering | emission | in-scattering

$$(\omega\cdot\nabla)L(x,\omega) = -\sigma_a(x)L - \sigma_s(x)L + \sigma_a(x)L_e + \sigma_s(x)\int_{4\pi} p(x,\omega,\omega')L_i(x,\omega')d\omega'$$

$$\frac{dL(x)}{dx} = -\sigma_t(x)L(x) \Longrightarrow L(x) = L_0\, e^{-\sigma_t x}$$

Beer's law

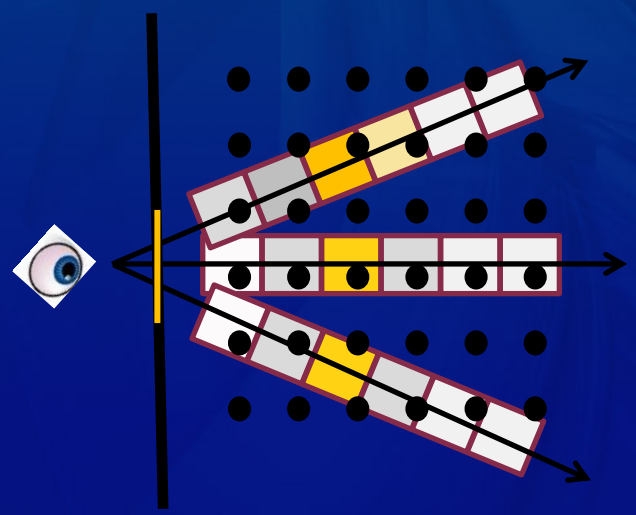


Image plane

ASTM E 1355, *Standard Guide for Evaluating the Predictive Capability of Deterministic Fire Models*

Verification: the process of determining that the implementation of a calculation method accurately represents the developer's conceptual description of the calculation method and the solution to the calculation method. Is the Math right?

Validation: the process of determining the degree to which a calculation method is an accurate representation of the real world from the perspective of the intended uses of the calculation method. Are the Physics right?

NUREG-1824
Draft for Comment

EPRI 1011999
Preliminary Report

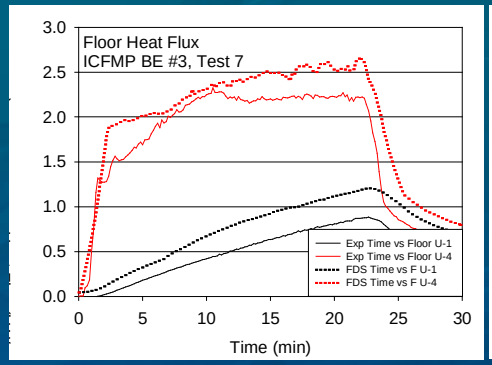
Verification and Validation of Selected Fire Models for Nuclear Power Plant Applications

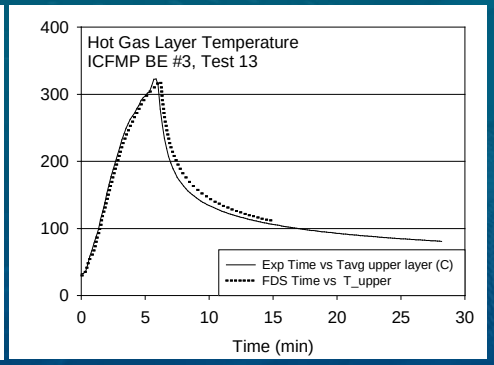
Volume 1: Main Report

December 2005

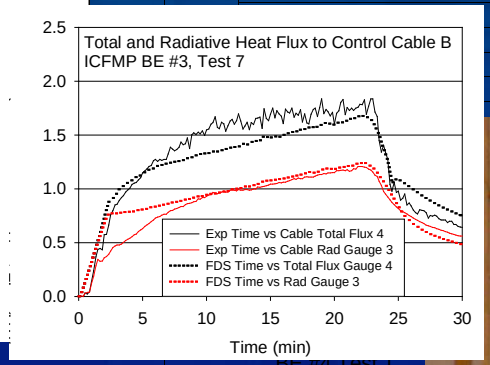
U.S. Nuclear Regulatory Commission
Office of Nuclear Regulatory Research
Washington, DC 20555-0001

Electric Power Research Institute
3412 Hillview Avenue
Palo Alto, CA 94303



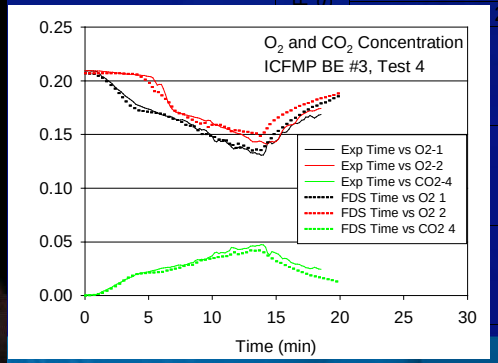


		HGL Temperature Rise			HGL Depth		
		Exp. (°C)	FDS (°C)	Rel. Diff. (%)	Exp. (m)	FDS (m)	Rel. Diff. (%)
BE #2	Case1	55	66	21	14.6	14.9	3
	Case2	86	102	18	14.8	15.3	4
	Case3	83	101	23	13.9	14.1	2
	Test 1	123	125	2	3.0	3.0	-1
		117	122	5	3.1	3.0	-1
		229	220	-4	3.0	2.9	-3
		218	220	1	3.0	2.9	-2
		204	214	5	3.0	2.9	-2
		198	212	7	3.2	2.9	-9
	BE #4 Test 1						
	BE #5 Test 4						
FM/SNL	Test 4						
	Test 5						
		21					
	EXI	--	92	--	2.2	2.1	-4
	BR	260	234	-10	1.2	1.1	-2
	18	65	75	16	1.2	1.2	-1
	38	67	68	2	1.2	1.4	13
	TR	35	40	14	1.5	1.5	-1

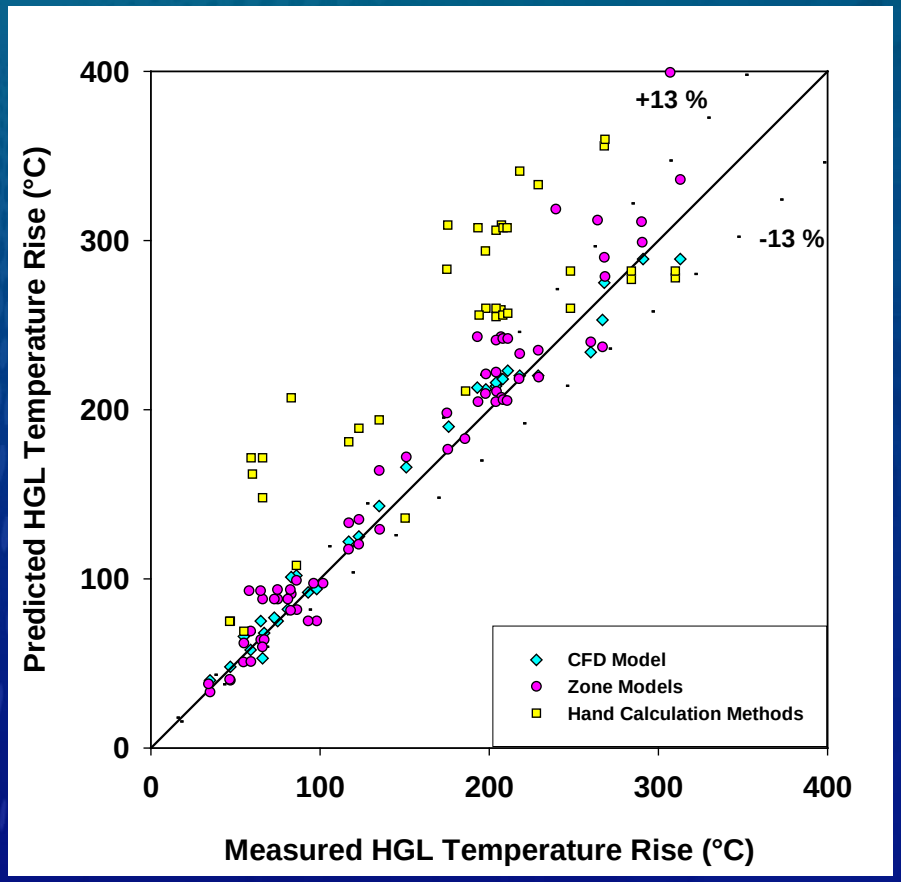


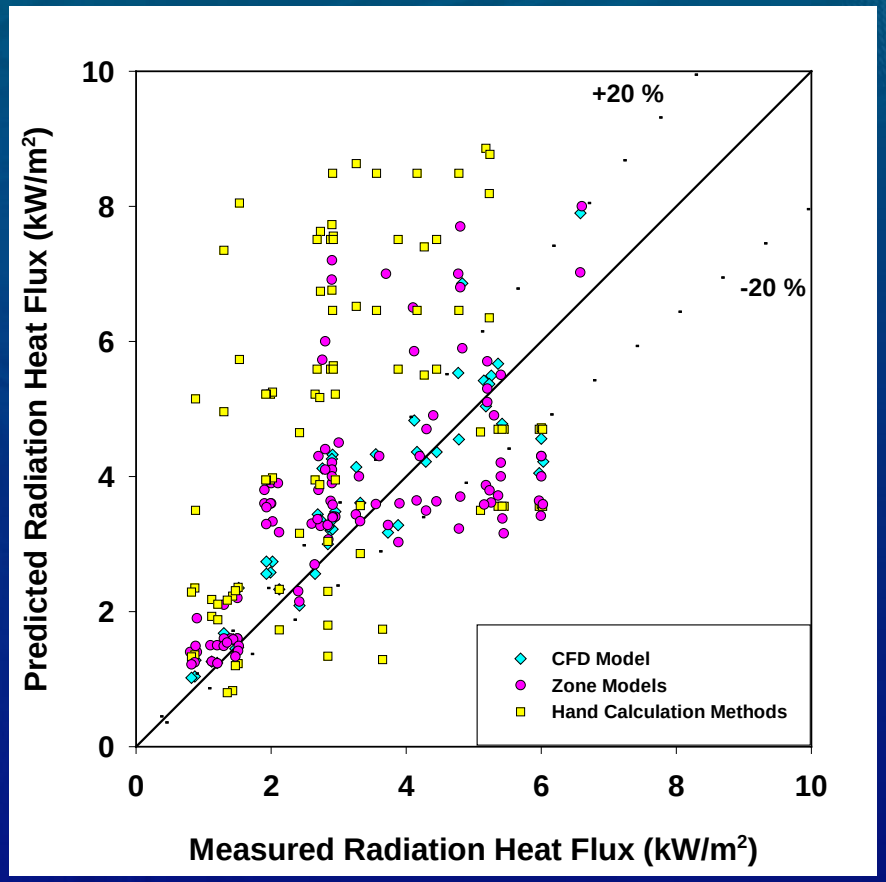
Courtesy, A Maranghides, NIST

Courtesy, S Hostikka, VTT



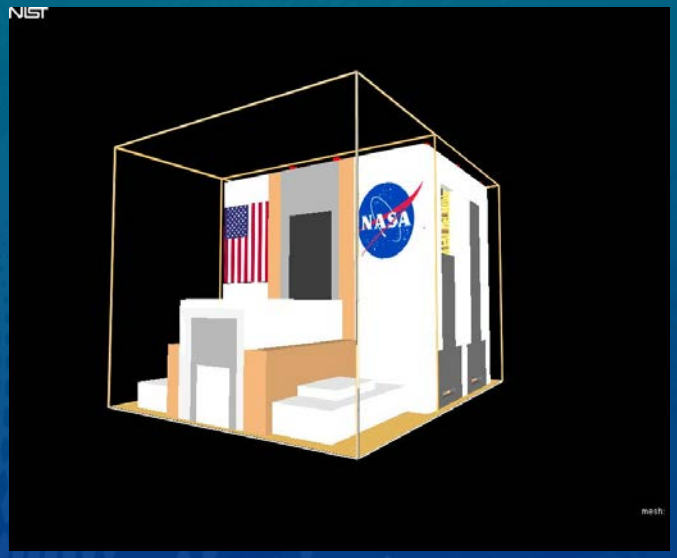
Results of NRC V&V (NUREG 1824)



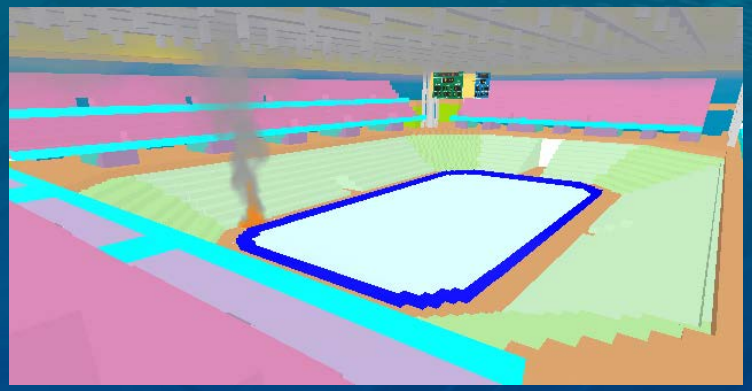


From *Fire Protection Engineering*, Spring 2007

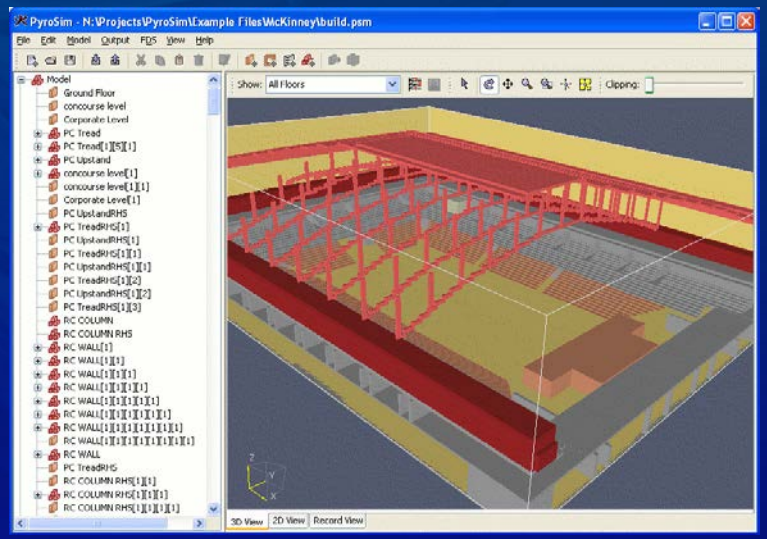
FPE Applications



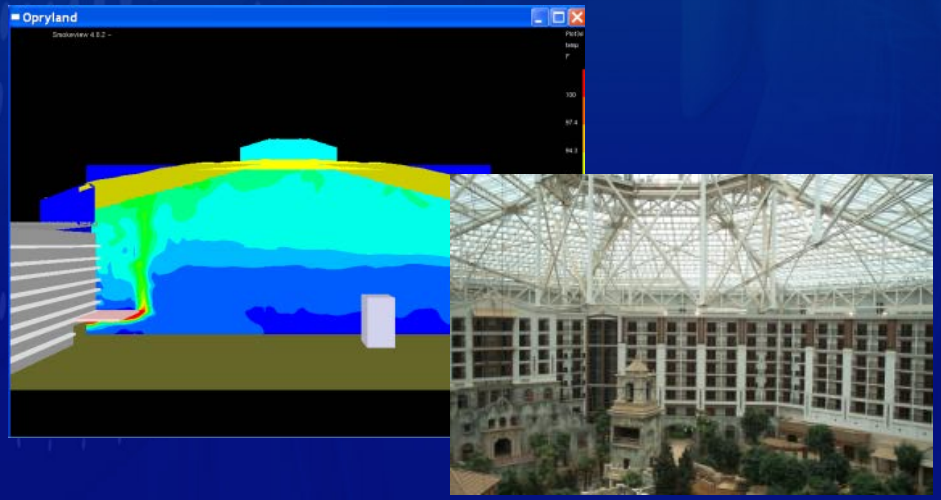
NASA Vehicle Assembly Building
Kennedy Space Center
courtesy Rolf Jensen



2006 Olympic Ice Hockey Stadium,
Turin, Italy, courtesy ArupFire, London

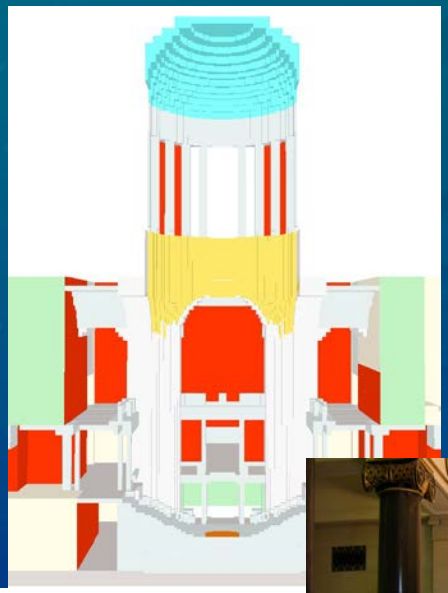


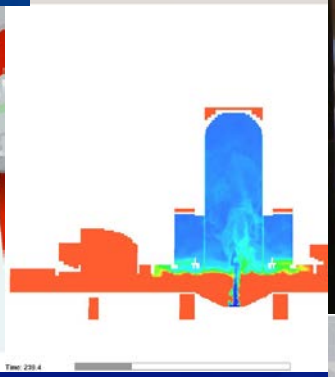
PyroSim, courtesy Thunderhead
Engineering Consultants,
Manhattan, Kansas



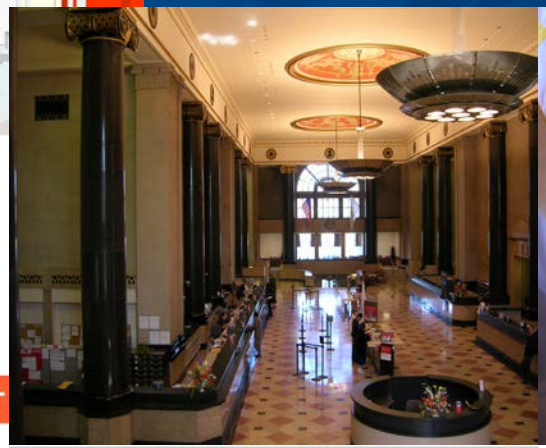
Opryland USA, Nashville, TN
Courtesy, Schirmer Engineering

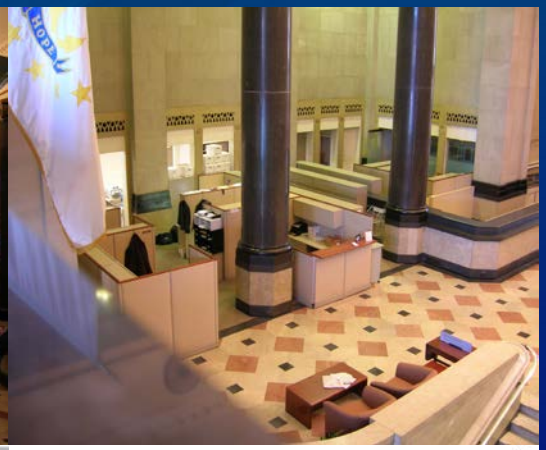
RI Statehouse

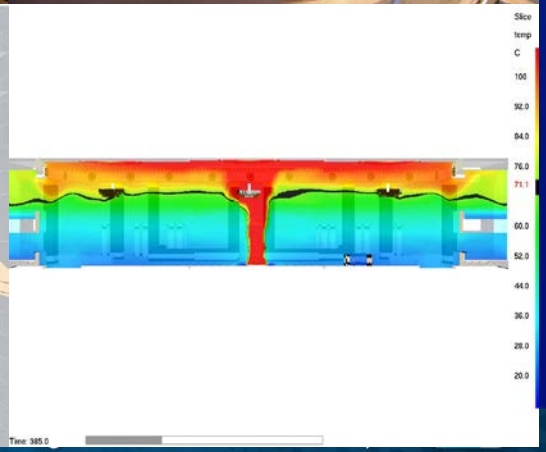




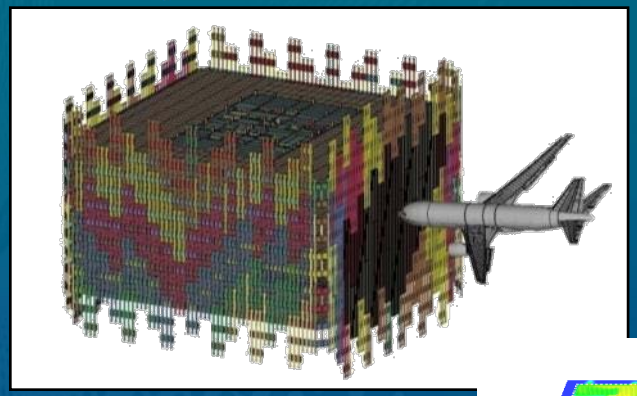
Bank of America Building, Providence



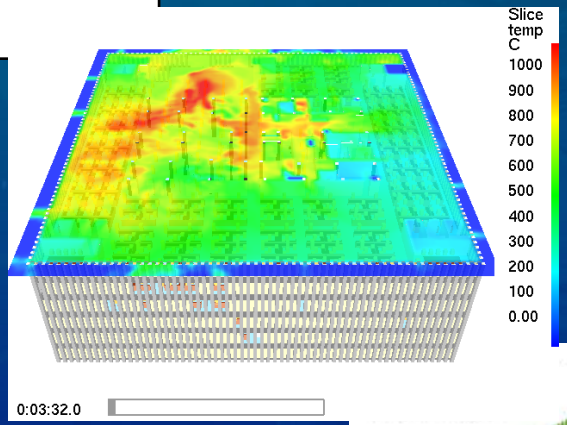




Fire Reconstruction: WTC

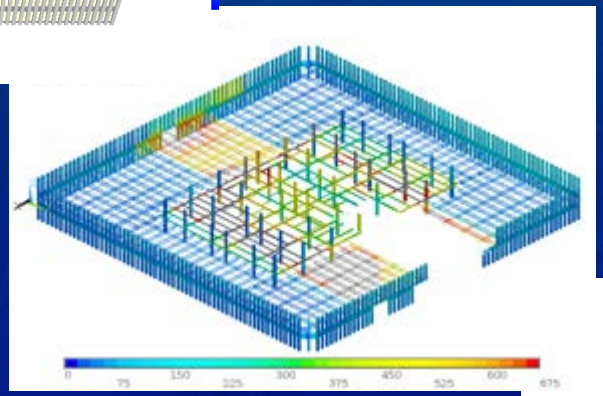


Aircraft Impact Analysis
Program: LS-DYNA

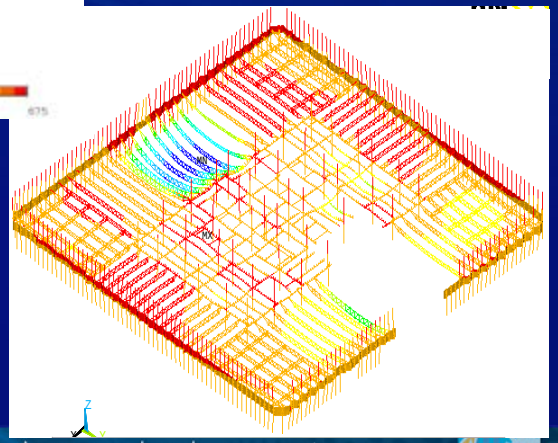


Fire Analysis
Program: Fire Dynamics Simulator

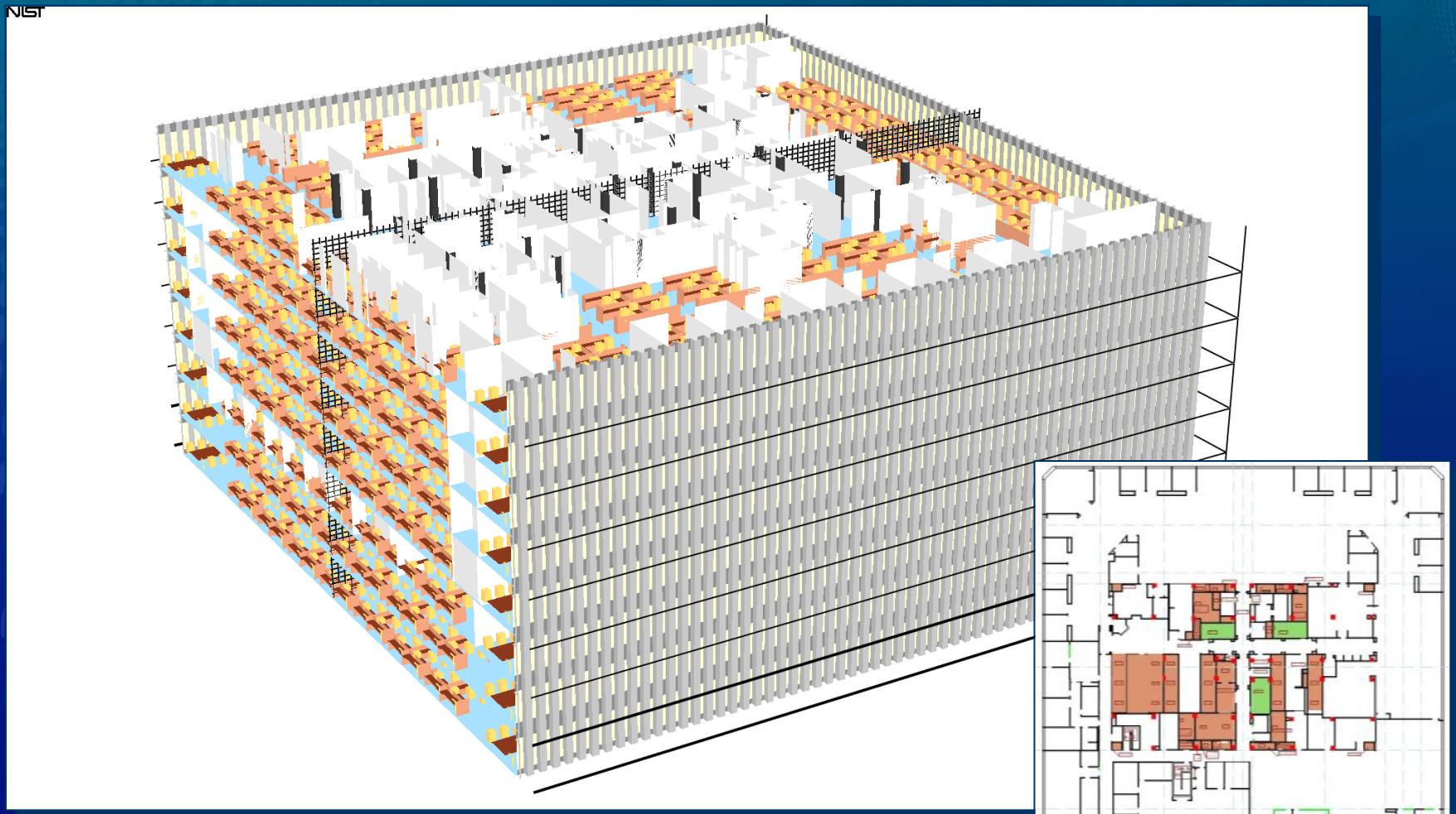
Thermal Analysis
Program: ANSYS



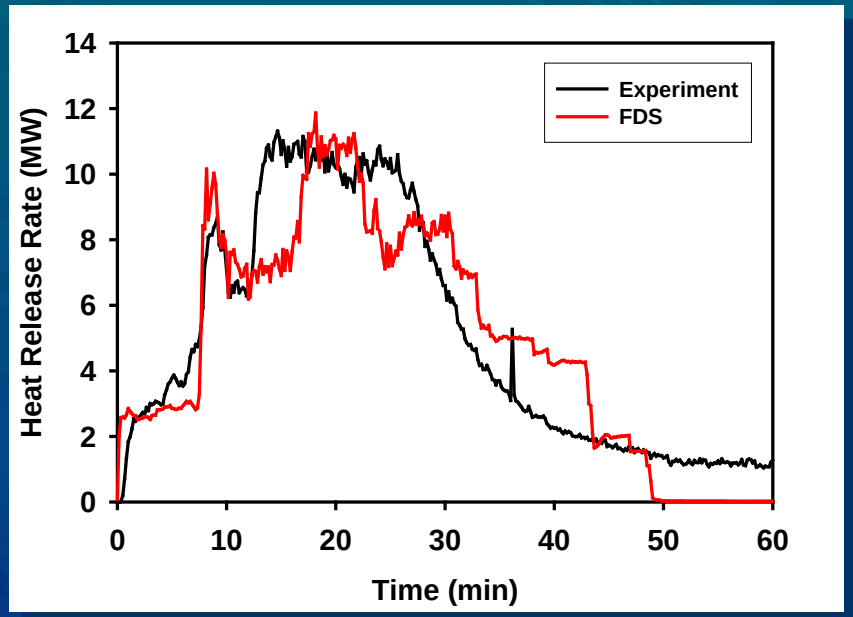
Structural Analysis
Program: ANSYS



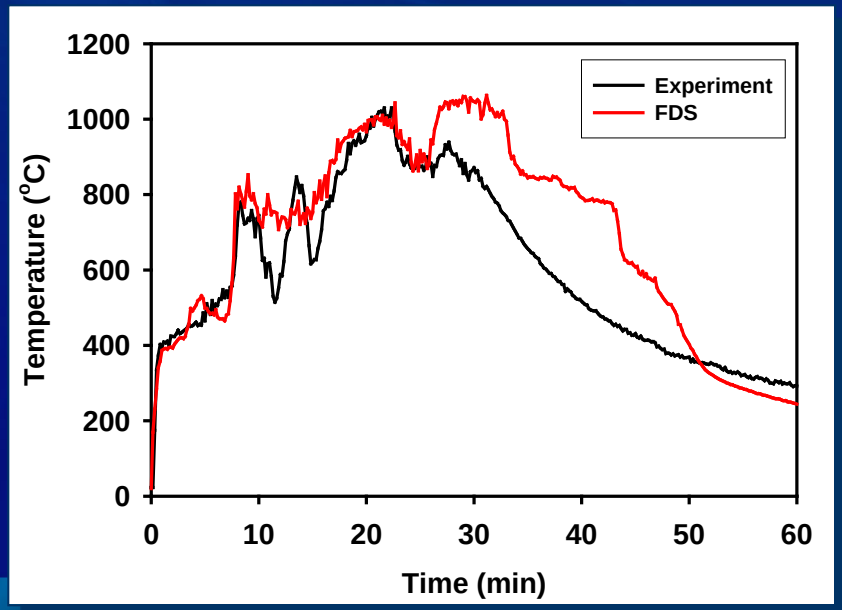
Multi-Floor WTC Geometry



Heat Release Rate



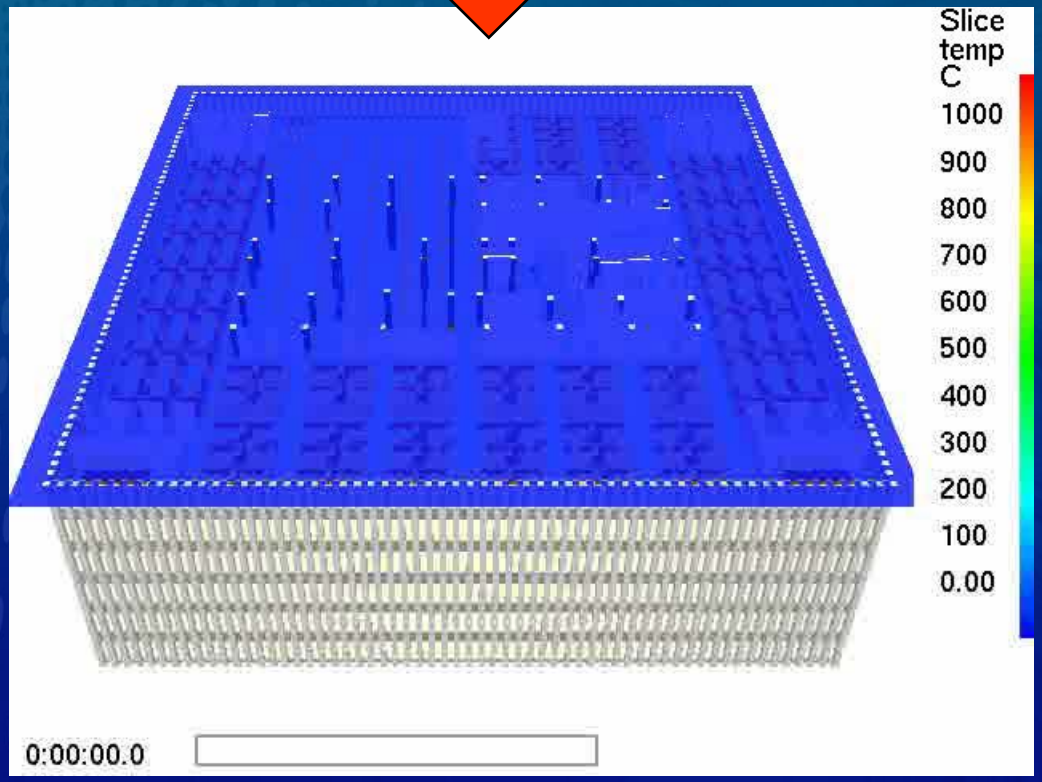
Temperature

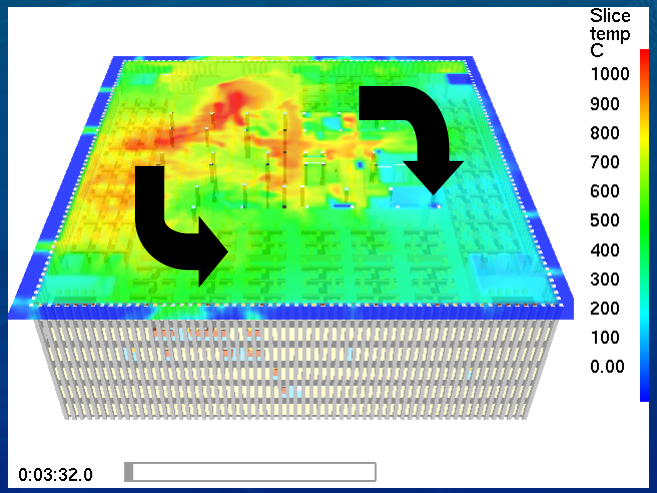


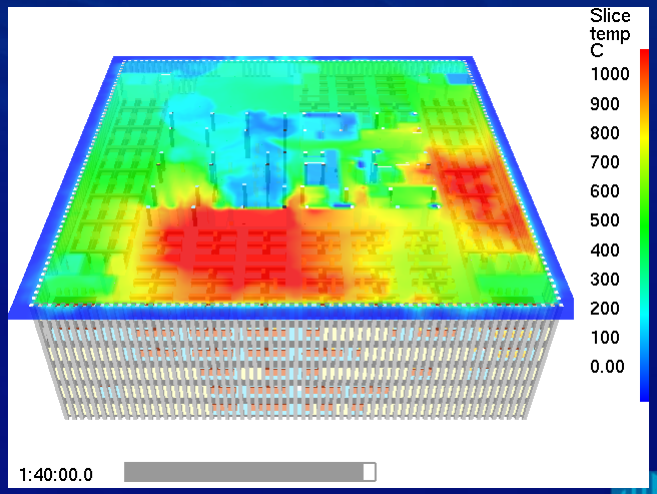
Video courtesy of Alex Maranghides, Anthony Hamins, NIST

Upper Layer Gas Temperatures

WTC 1 - Floor 97

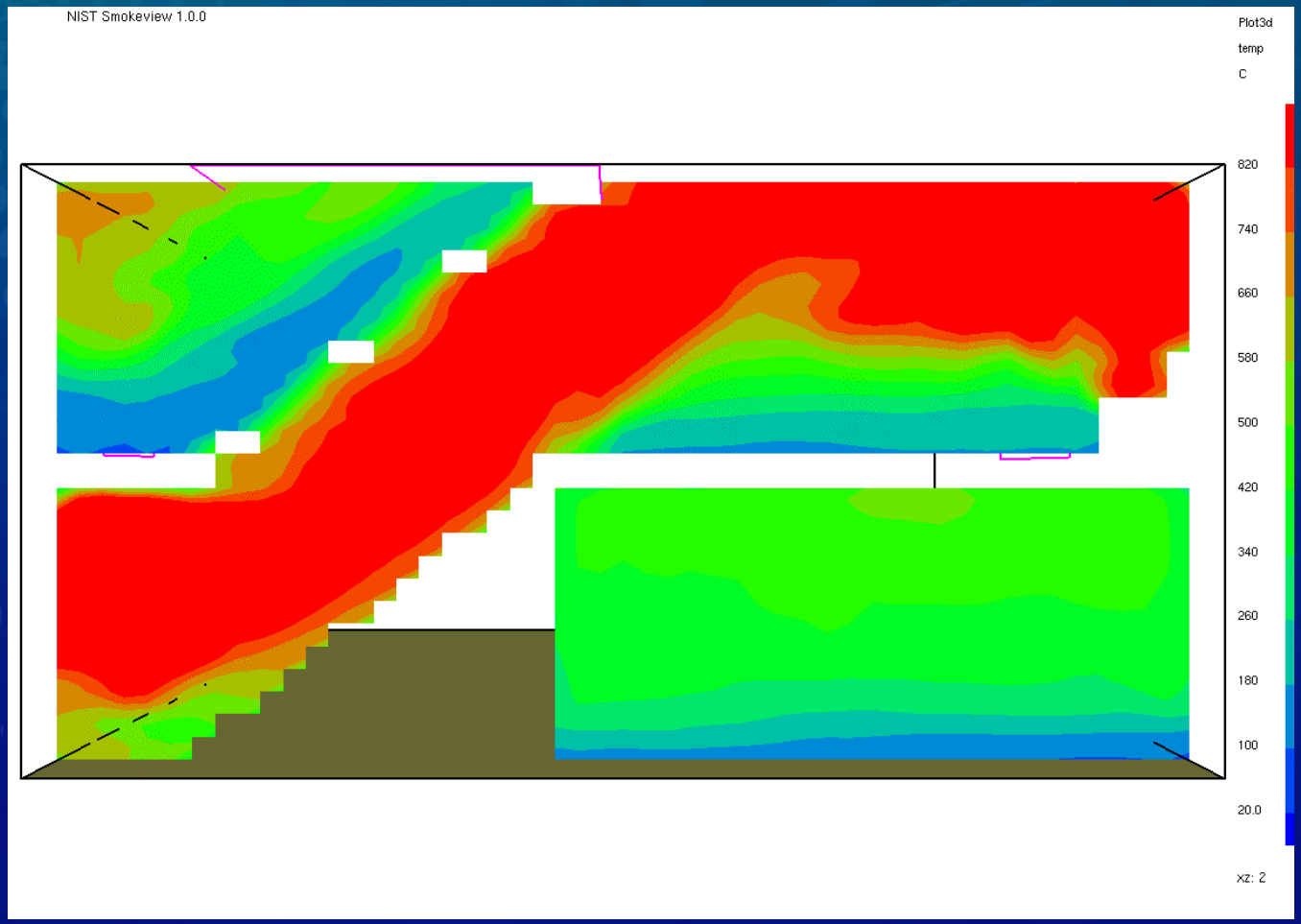






Graphics courtesy of Glenn Forney, NIST

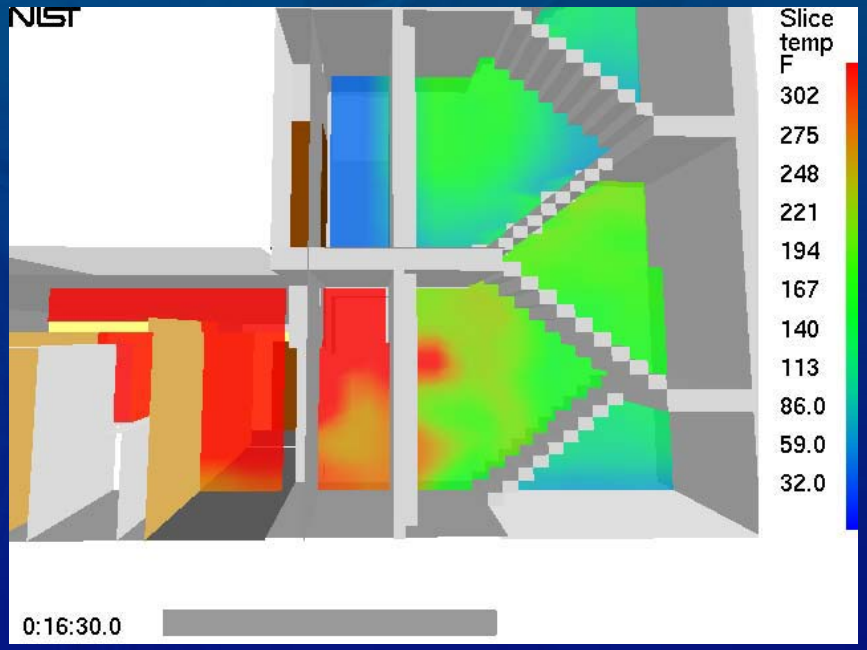
Simulation of the Dynamics of the Fire at 3146 Cherry Road NE, Washington D.C., May 30, 1999
NISTIR 6510, April 2000, Madrzykowski & Vettori



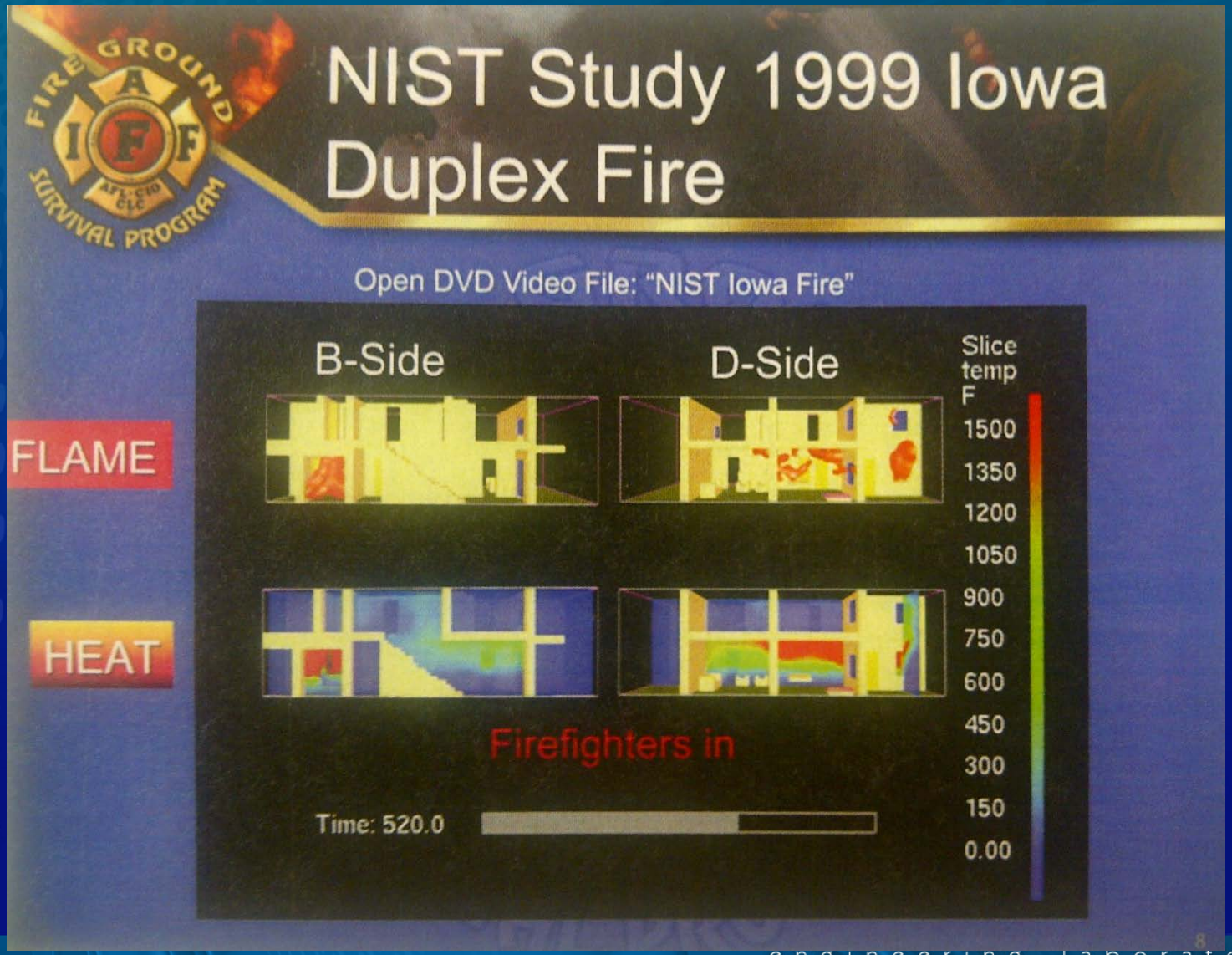
Station Nightclub Fire
FDS vs. Experiment 60 s after ignition

Report of the Technical Investigation of The Station Nightclub Fire (NIST NCSTAR 2), June 2005
William L. Grosshandler; Nelson P. Bryner; Daniel N. Madrzykowski; K Kuntz

Cook County Administration Building Fire, Chicago, Madrzykowski & Walton, NIST Report SP-1021, 2004

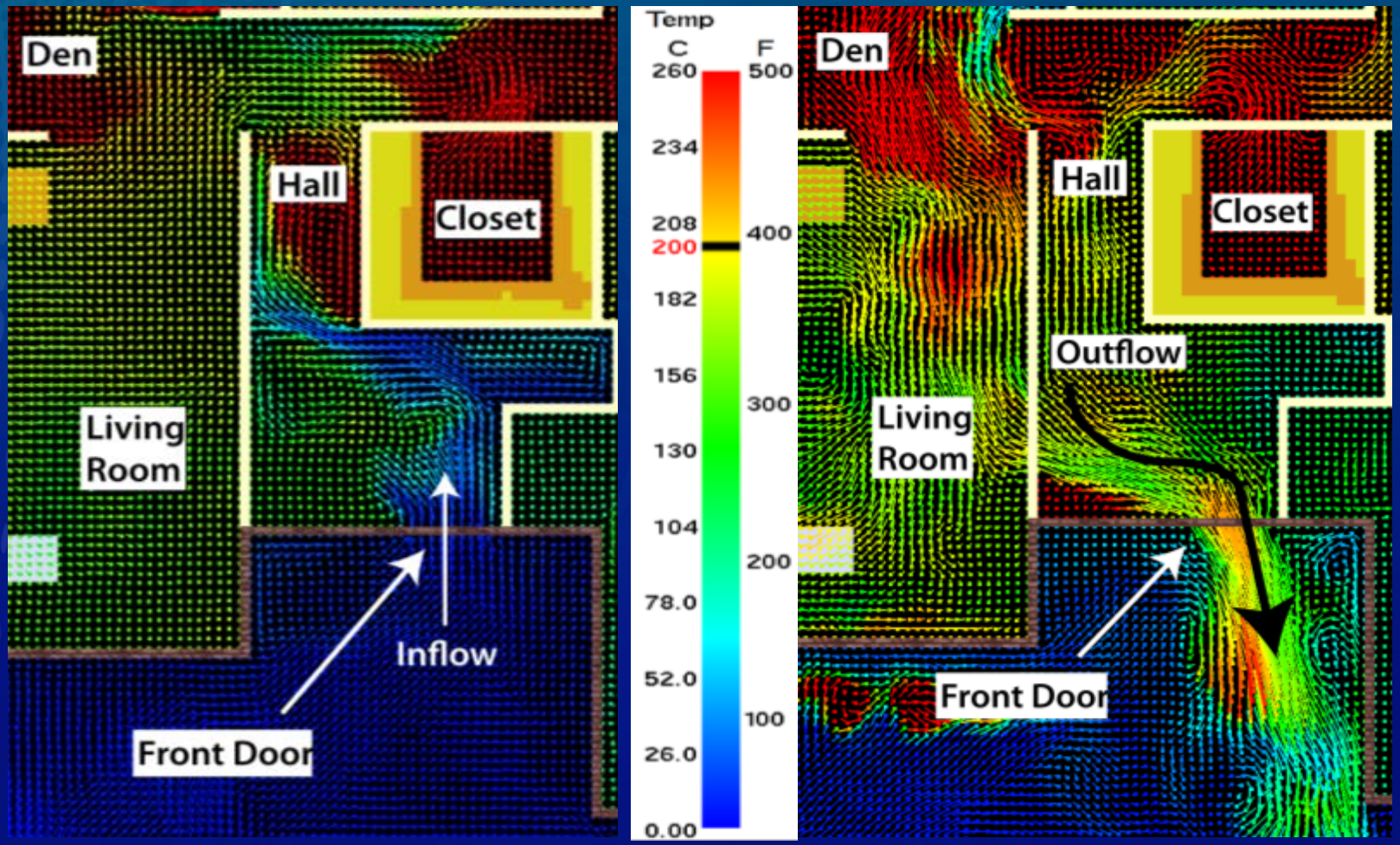


Two-Story Duplex Fire, Iowa, December 22, 1999, Madrzykowski et al, NISTIR 6854, January 2002



Houston – Wind Drive Fire
Flow reversal at the front door

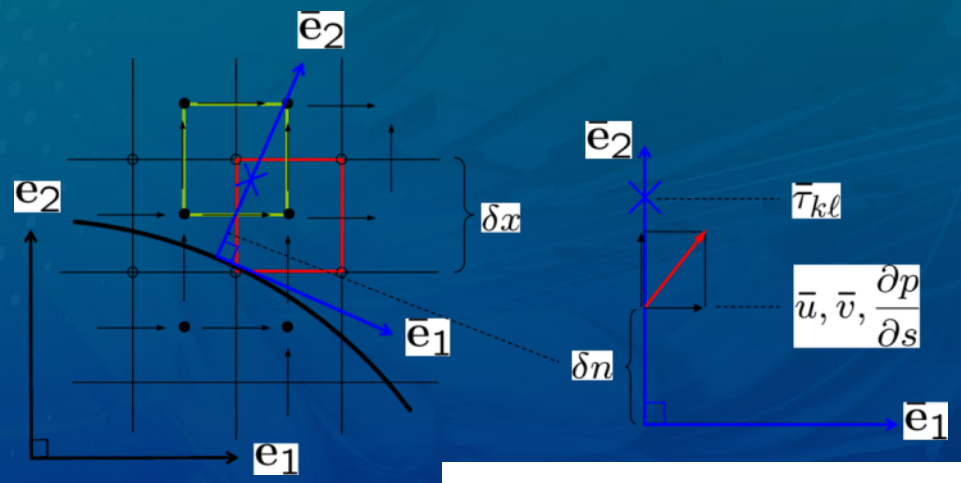
10 s before glass failure **10 s after glass failure**

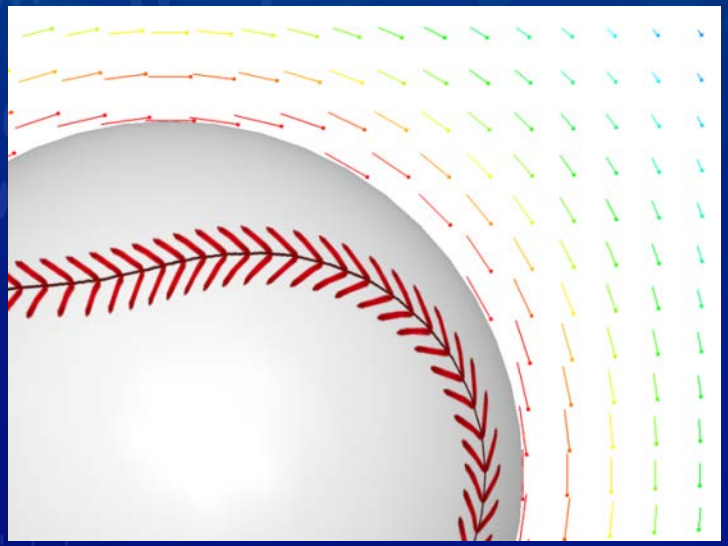


Future Challenges

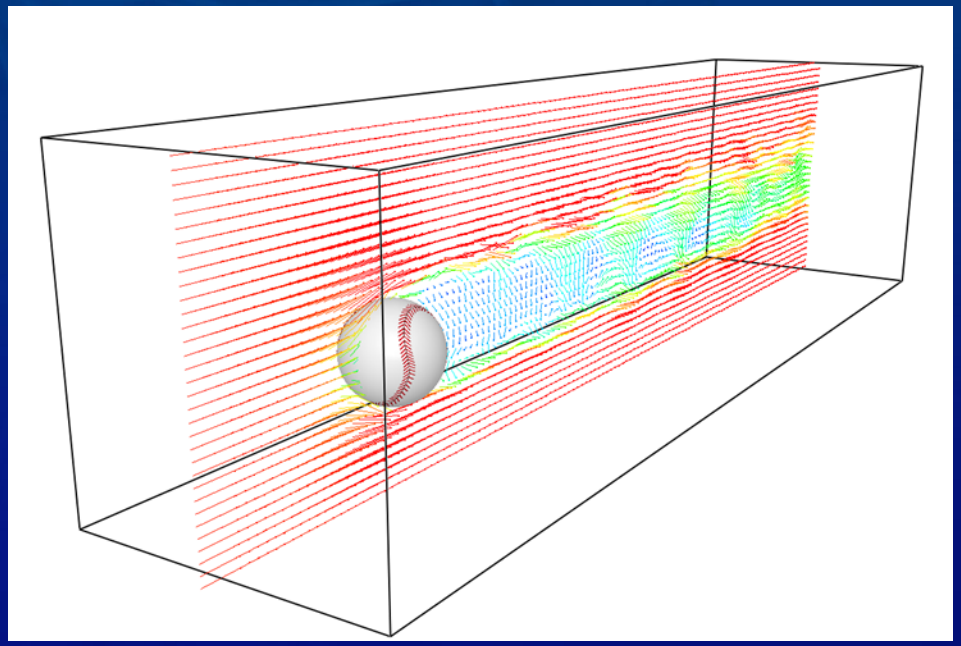
Pyrolysis
Chemistry
Complex Geometry (Immersed Boundary Methods)
Efficiency (Adaptive Mesh Refinement)

Immersed Boundary Methods (IBM)



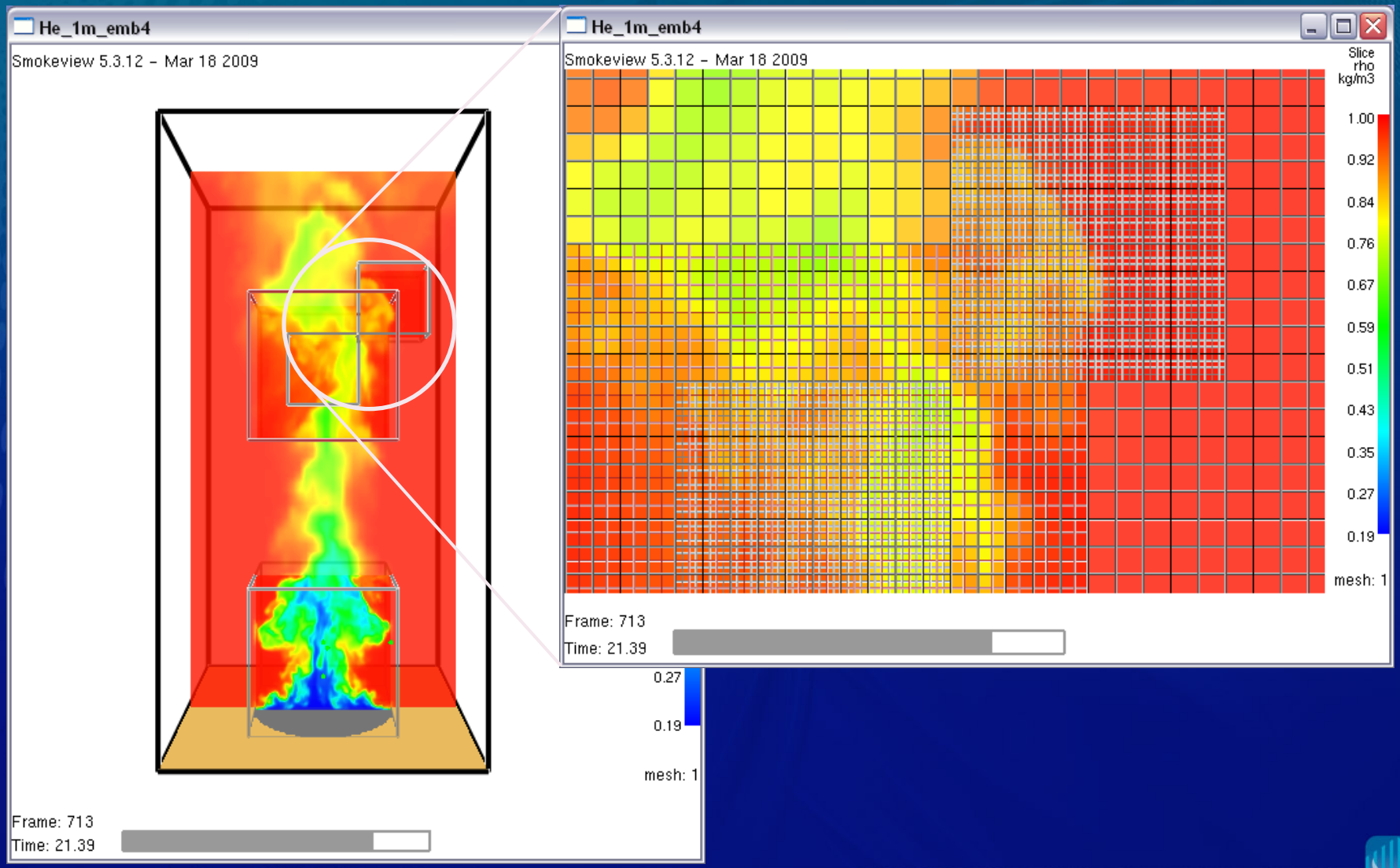


DNS, Re=4



LES, Re=2x10^5

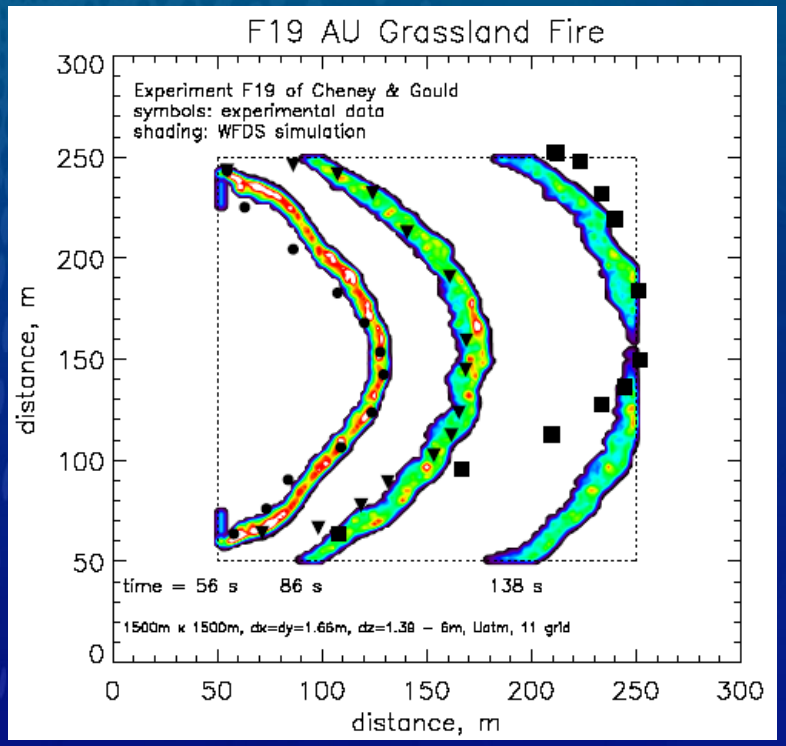
Embedded Mesh Method



New Applications: Outdoor Fires

Simulations of Australian Grassland Fires

Mell, Cheney and Gould, 2007



Grass Height: 51 cm
Mass Load: 0.31 kg/m^2
Moisture: 4.8%
Wind Speed: 4.8 m/s
Surface/Volume: 12200 m^{-1}