Lessons Learned in ICFMP Project for Verification and Validation of Computer Models for Nuclear Plant Fire Safety Analysis

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Objective of Presentation

- Present "lessons learned" in International Collaborative Fire Model Project (ICFMP)
- Recommend the "way forward" for performance-based codes and fire safety design methods
- Details of technical findings presented elsewhere – e.g., *Deytec 2009-05, Deytec 2010-01*

Background

- Initiated performance-based (PB) fire safety codes & design in US in 1992
- Examination & development of new PB regulations & design methods
- Initiated & led the International Collaborative Fire Model Project from 1999-2006
- Deytec, Inc.– fire safety engineering consultancy
- United States delegate to ISO TC 92 Fire Safety Committee

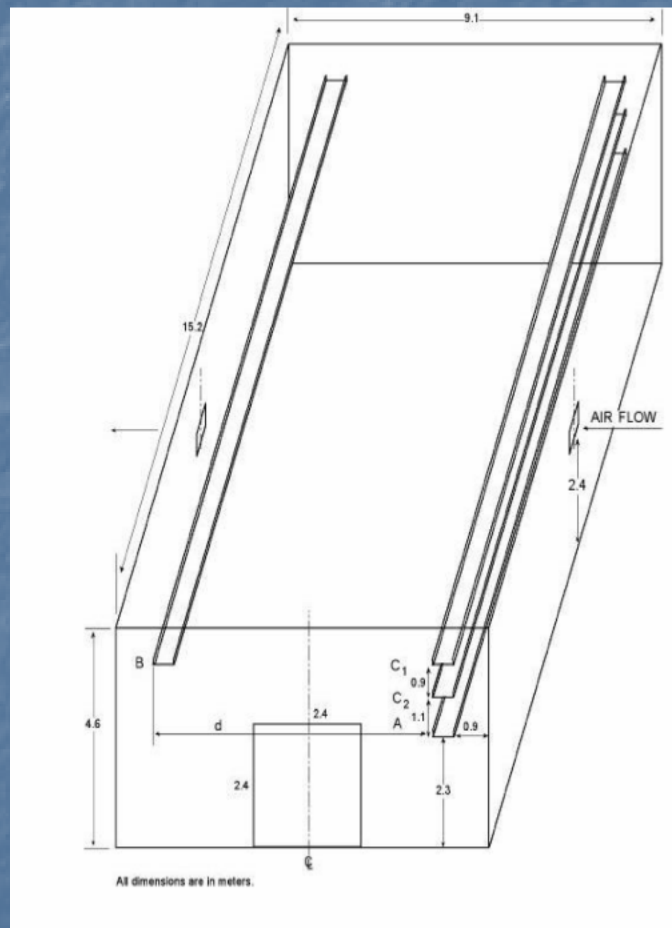
International Collaborative Fire Model Project (ICFMP)

- Conducted 1999-2008 by USNRC
- Evaluate fire models for nuclear plant applications through 5 benchmark exercises (BE)
  - Code to Code
  - Code to experimental data
  - Simple to challenging scenarios

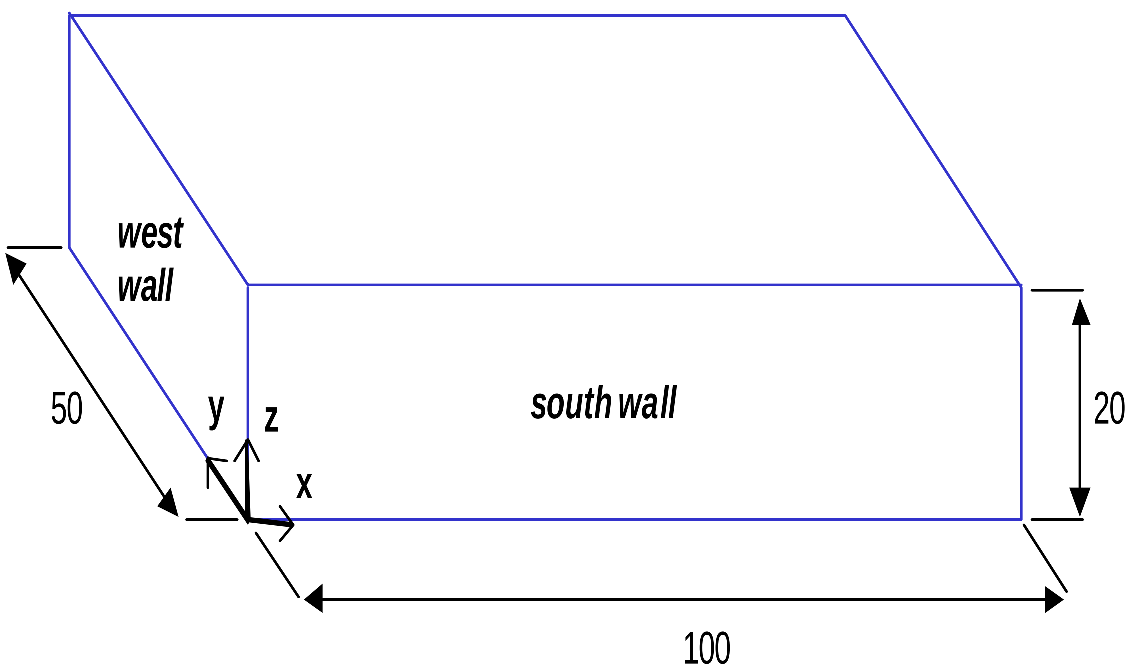
ICFMP Cont'd

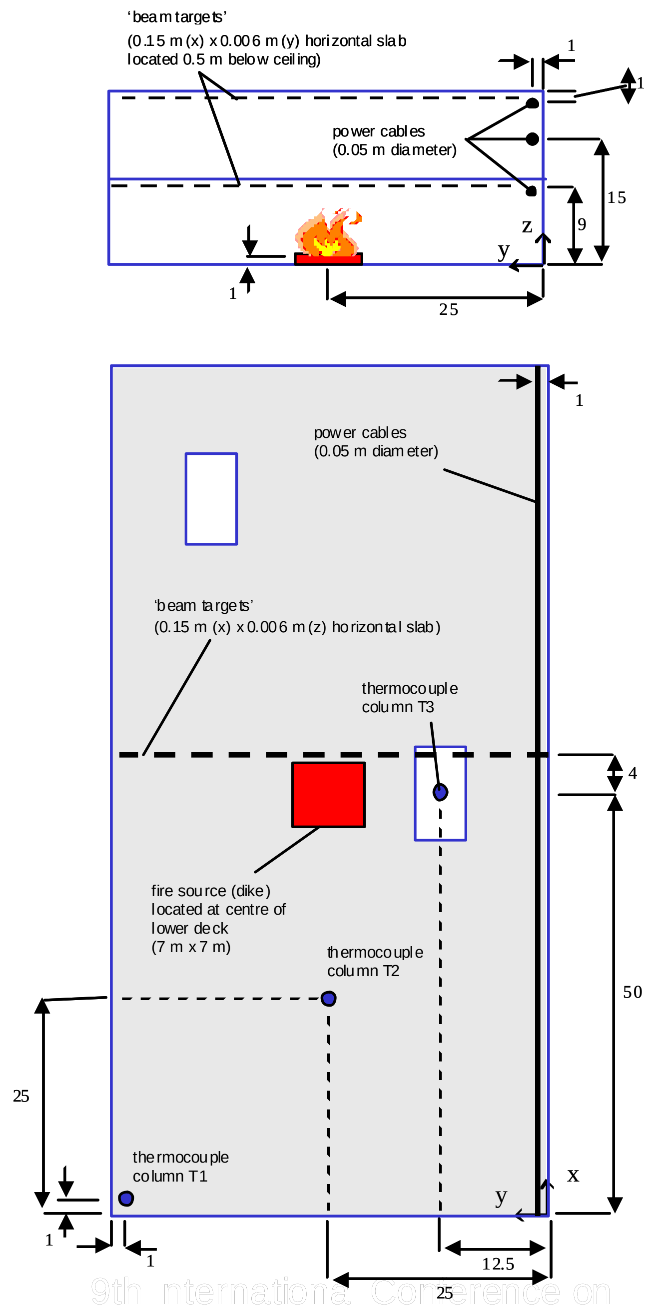
- Five countries participated, typically 7 organizations exercised fire models
  - **Germany – GRS, iBMB (COCOSYS, FDS, CFX, CFAST)**
  - **France – IRSN, EdF, CTICM (FLAMME-S, MAGIC)**
  - **UK – BRE (JASMINE, CFAST)**
  - **USA – NRC, NIST (CFAST, FDS, FDTs)**
    - **Assigned as guest researcher at NIST**
    - **Analyst for NRC**
- 10 organizations participated in peer review
- 12 international workshops over 10 years
- 5 ICFMP benchmark reports and summary report

ICFMP Benchmark Exercise No. 1 – Cable Tray Fires



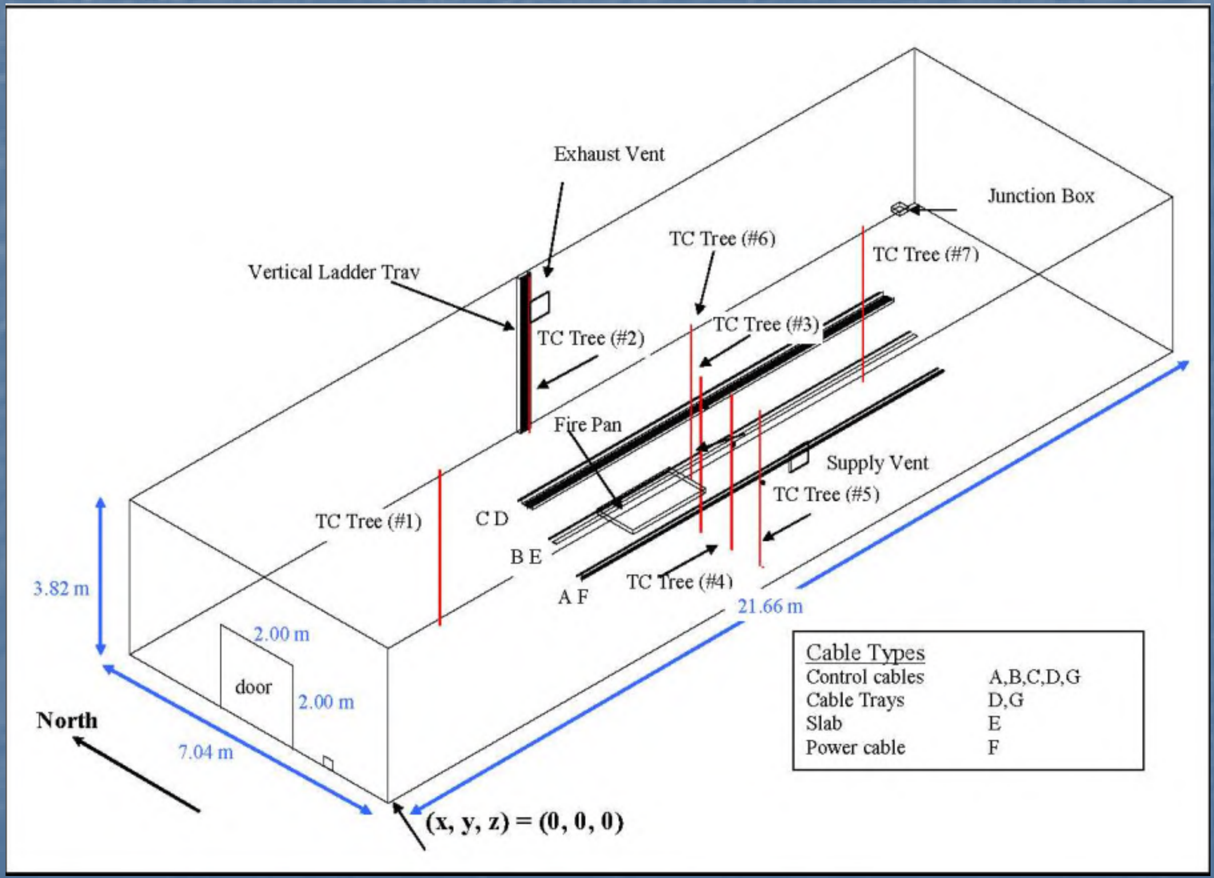
ICFMP Benchmark Exercise No. 2 – Pool Fires in Large Halls

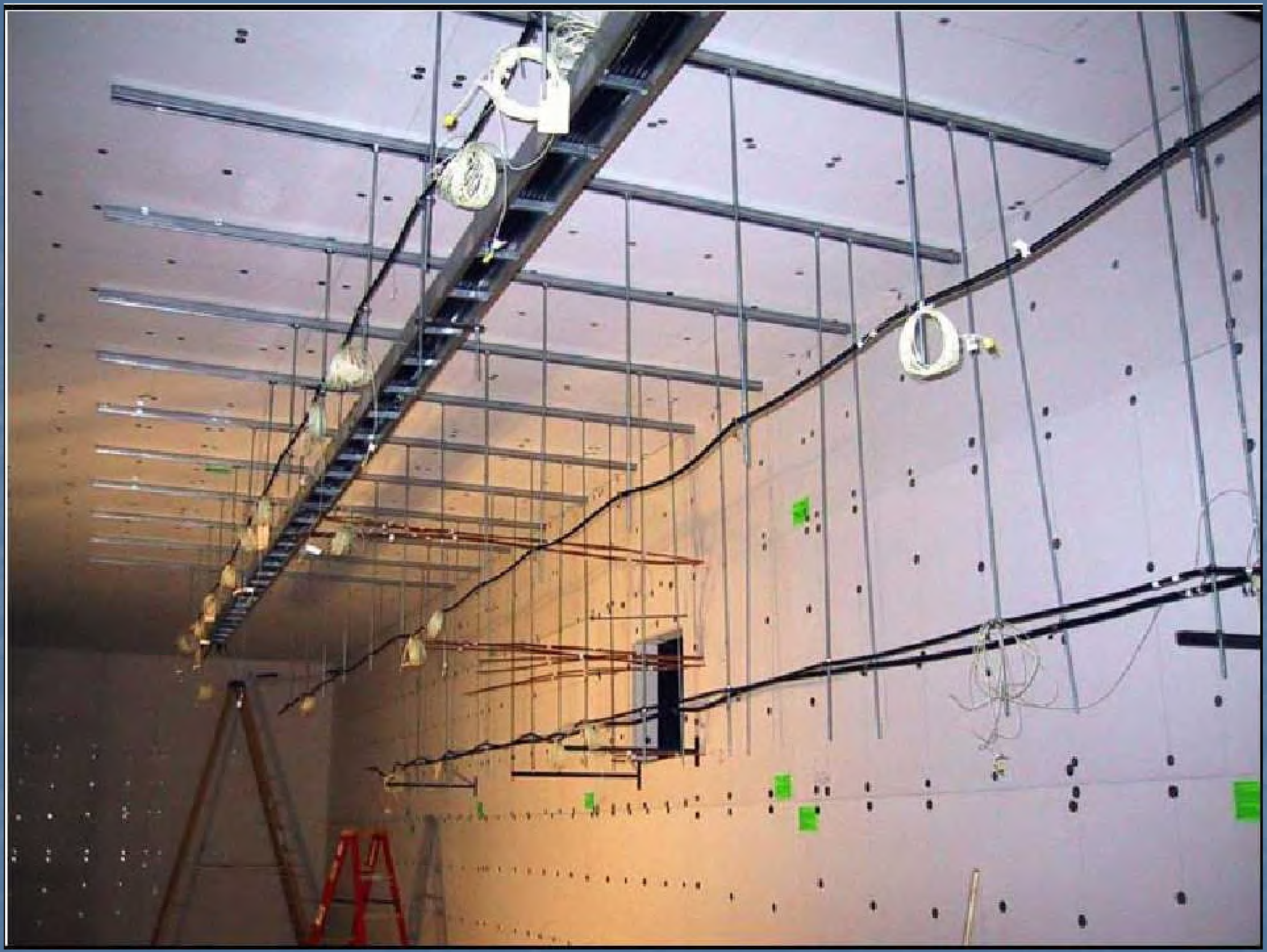




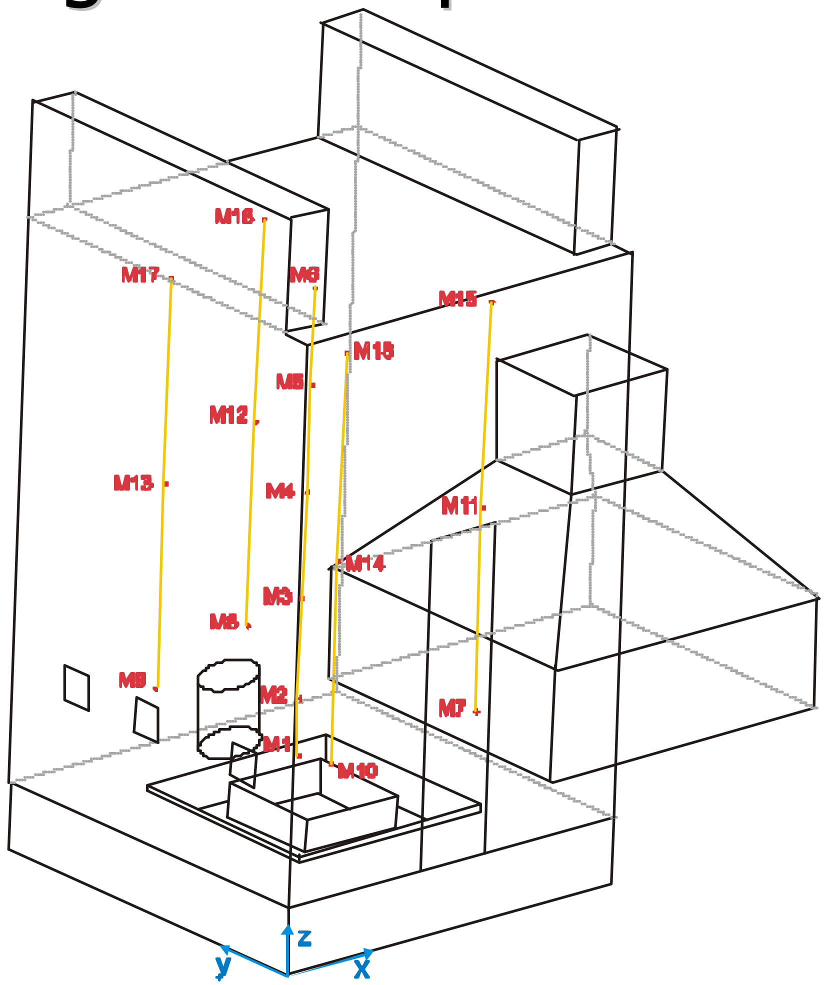
'beam targets'
(0.15 m (x) x 0.006 m (y) horizontal slab
located 0.5 m below ceiling)
power cables
(0.05 m diameter)
1
1
15
9
z
y
1
25
1
power cables
(0.05 m diameter)
'beam targets'
(0.15 m (x) x 0.006 m (z) horizontal slab)
thermocouple
column T3
4
fire source (dike)
located at centre of
lower deck
(7 m x 7 m)
thermocouple
column T2
50
25
thermocouple
column T1
x
y
1
1
12.5
25

ICFMP Benchmark Exercise No. 3 – Full Scale Compartment Fire Tests

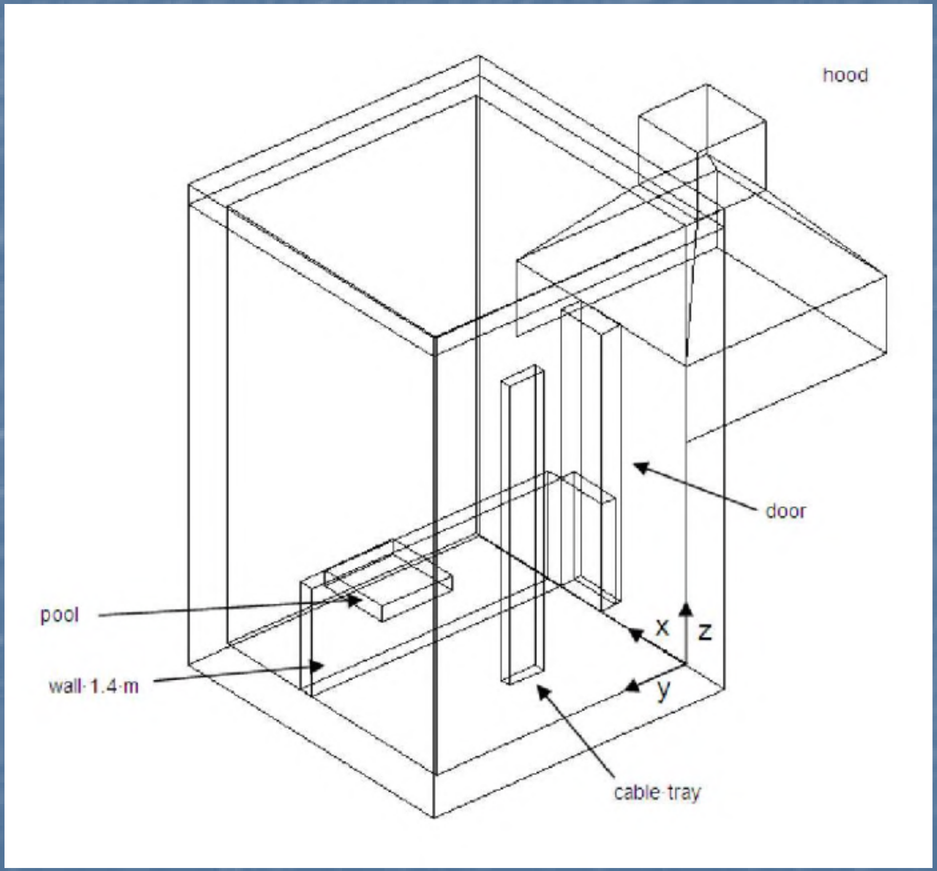




ICFMP Benchmark Exercise – No. 4
Large Fire Experiments



ICFMP Benchmark Exercise No. 5 – Pool Fires in a Trench



V&V Process to Determine Fire Model Predictive Errors

- ICFMP established to conduct "blind" benchmark exercises
- Need credibility of V&V process by determining true predictive errors
- Necessary to establish safety factors in performance-based designs

"Blind" vs "Open" Predictions

- In a priori (aka *blind)* modeler has no access to experimental data
- In a posteriori (aka *open*) modeler has access to the experimental data and measurements of predicted parameters
- Comparison of *blind* vs *open* calculations
  - Dalmarnock fire test project
  - Possible to match measured parameters by adjusting model input data

Bias in V&V Process

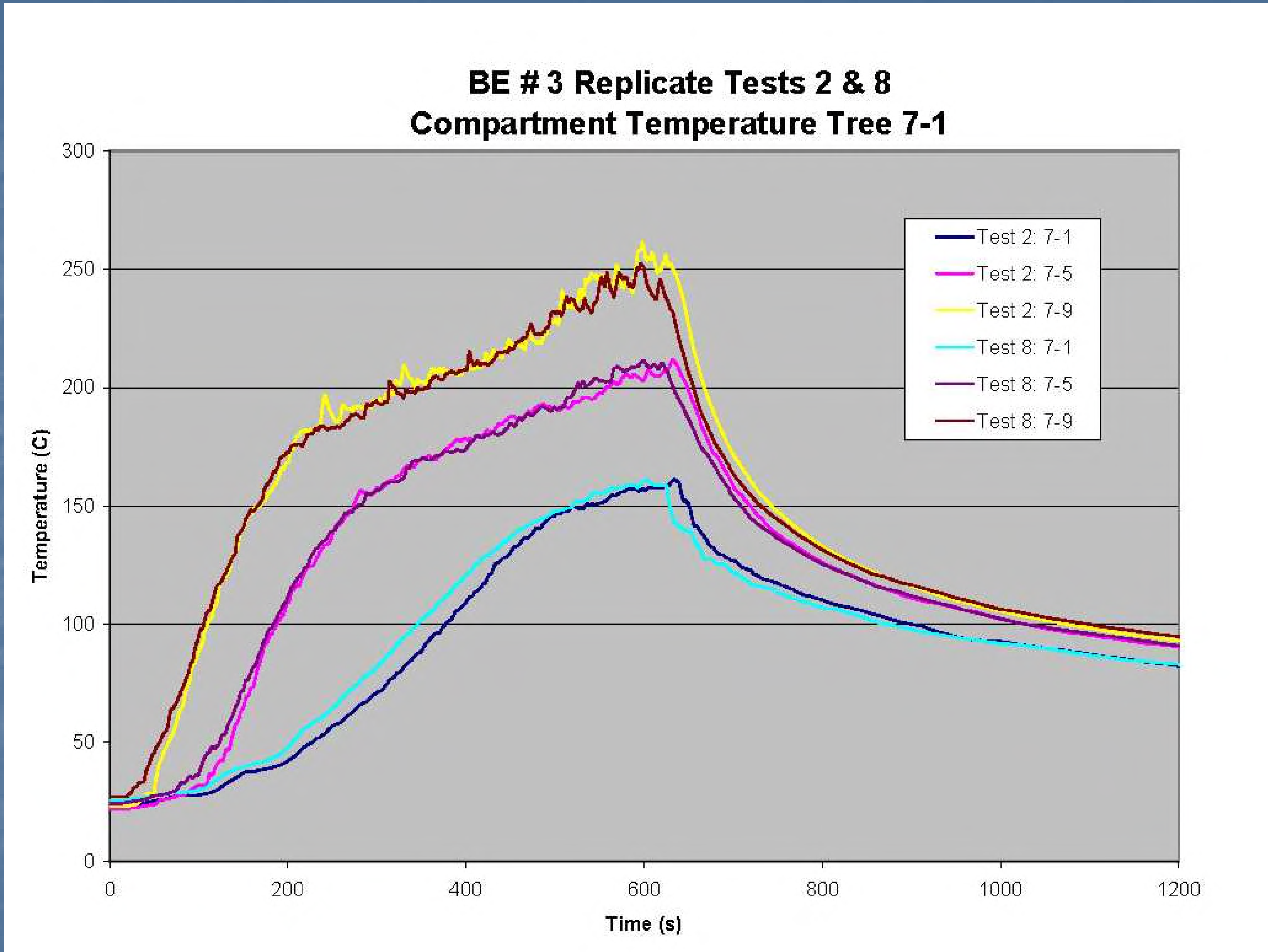
- Natural bias exists in *open* predictions
- Most fire model validations conducted a posteriori (*open*)
- Extent of bias presently unknown & currently being researched
- Need true predictive errors to establish safety factors in PB designs
- "Real World" fires – PB designs

V&V Procedures in ICFMP

- Recognized need to conduct *blind* validations to determine "true" predictive errors essential to establishing safety factors
- Minimize debate about input parameter values through detailed specifications of the benchmark exercises

Challenges of *Blind* V&V Overcome in ICFMP

- Replication of experiments
- Conduct of tests according to test plan
- Uncertainty in model input data
- Sensitivity & uncertainty analysis
- Need to establish “optimal” prediction


BE # 3 Replicate Tests 2 & 8
Compartment Temperature Tree 7-1
Temperature (C)
Time (s)
0
50
100
150
200
250
300
0
200
400
600
800
1000
1200
Test 2: 7-1
Test 2: 7-5
Test 2: 7-9
Test 8: 7-1
Test 8: 7-5
Test 8: 7-9

Issues Identified in V&V Process

- Lack of agreement among participants on measurements & data needed as input to fire models being exercised;
- Lack of established formal procedure for submission & collection of *blind* calculations from participants.

Parameter Issues

- Heat Release Rate (HRR)
- Radiative Fraction
- Thermal Parameters of Compartment Boundary

Heat Release Rate (HRR)

- Knowledge of combustion process/need to input parameter to models
- Predominantly determines magnitude of fire effects
- Major source of uncertainty

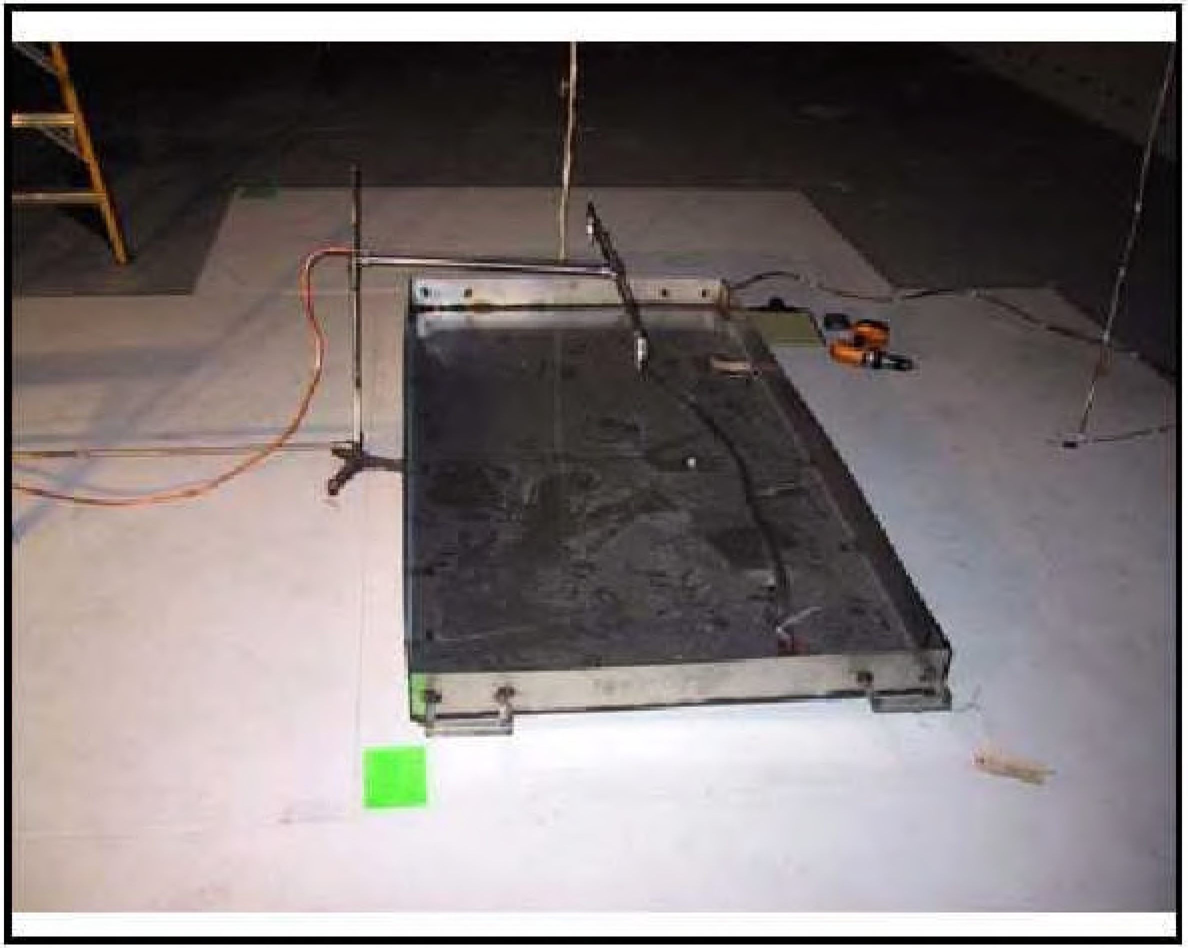


Figure 2.12 Fuel Pan with Spray Nozzle

Figure 3.3 Hot Gas Layer in Test 3

Table 3-1 Evolution of Heat Release Rate for Benchmark Exercise No. 3, Test 3

Release Date	July 2, 2003**	July 21, 2003	September 9, 2003	April 4, 2004	June 2005
HRR - from fuel flow	1050*	1050	1150	1150	1150
HRR - from calorimetry	1150	1260	1260	1260	1190

* HRR specified in kW

** Prior to release of experimental data

Radiative Fraction

- Radiative fraction of heat from fire must also be input to models
- Not measured for BE # 2, values of 0.4 used by some analysts (0.2 specified)
- Considerable effort made in BE # 3 to measure parameter but still disputed & adjusted by some analysts
- Similar issues in BE # 4 & 5

Table 3-2 Combustion Properties of the Test Fuels for Benchmark Exercise No. 3

Fuel	Hc (kJ/g)[1]	Combustion efficiency[2]	Radiative fraction[3]	Soot yield[2]	CO yield[2]	CO_2 yield[2]
Heptanes	45.0	1.0 ± 0.06	0.35 ± 0.08	$0.0149 \pm .0033$	<0.006	3.03 ± 0.37
Toluene	40.3	0.76 ± 0.05	0.36 ± 0.08	0.194 ± 0.062	0.070 ± 0.016	2.53 ± 0.31

1. Report of Test Results, Galbraith Labs, March 2003. The expanded uncertainty is not reported but is typically 5 %.
2. The Global Combustion Behavior of 1 MW to 3 MW Hydrocarbon Spray Fires Burning in an Open Environment (Hamins, 2003d).
3. Hamins, Kashiwagi and Buch in Fire Resistance of Industrial Fluids (Eds.: Totten and Reichel), ASTM STP 1284, 1996

Thermal Properties of Compartment Boundary

- Not measured & controversial for Benchmark Exercise No. 2
  - Properties adjusted to reduce thermal inertia by 50 % by some analysts
- Considerable effort made in BE # 3 to measure parameters but still disputed & adjusted by some analysts

Table 3-6 Material and Optical Properties of Marinite.

T (^oC)	K (W/m K)*	α (m^2/s)*	c_p(J/kg K)*	ε **
23	0.111	2.13×10^{-7}	778	0.74±0.04
50	0.114	2.15×10^{-7}	795	
100	0.126	2.17×10^{-7}	871	
200	0.140	2.17×10^{-7}	965	
300	0.153	2.18×10^{-7}	1047	
400	0.160	2.21×10^{-7}	1082	
500	0.175	2.26×10^{-7}	1160	
600	0.190	2.36×10^{-7}	1205	
650	0.198	2.42×10^{-7}	1223	

* Taylor, R.E., Groot, H., and Ferrier, J., *Thermophysical Properties of PVC, PE and Marinite*, Report TPRL 2958, April 2003.

** Hanssen, L., Report of Optical Test Data, March 2003.

Procedure Issues in ICFMP V&V

- Submission & collection of *blind* calculations were not conducted per an established formal procedure or standard
- Informal due to collegial nature of collaborative project & lack of standard
- Participants were permitted to categorize their calculations as *blind* or *open*.

Conclusion of *Blind* V&V

- Participants modified model input data based on their determination of the appropriate values
- Assumed this would still constitute as a *blind* calculation
- *Blind* & *Open* calculations could not be distinguished

Conclusion of *Blind* V&V – Cont'd

- Predictions by analysts differed:
  - Up to 45 % difference when same model used
  - Up to 40 % difference when models of same sophistication used
- ICFMP exercises failed as *blind* exercises

Recommendations for Fire Model V&V Standard

- Establish consensus on measurement methods for parameters needed as input to fire models
- Develop consensus on values for parameters input to fire models
- Establish procedure for conducting & ensuring that *blind* calculations are used to establish predictive model errors & safety margins
- Examine and include "third party validation" as an option for establishing true model errors

Performance-Based Codes: The Way Forward

- This forum shows PB design and codes being successfully deployed
- Caution needs to be exercised, and issues examined & addressed
- Distinguish sources of uncertainty
- Assembly of comments & current issues – *Deytec, Inc. 2011-01*
- Importance of applying reliable *safety factors*

Initiatives at ISO TC 92 Fire Safety Committee

- Presented work of ICFMP & Deytec, Inc. to ISO TC 92 in 2009 (Lancaster), 2010 (Paris), and 2011 (Ottawa)
- Presently serving as United States Delegate to ISO TC 92/SC4
- Revisions to fire safety engineering guidelines planned by ISO TC 92

Initiatives at ISO TC 92 Fire Safety Committee – Cont'd

- Issues being discussed:
  - V&V process improvement (ISO 16730:2007)
  - Safety factors
  - Design scenarios
  - Risk applications
  - Integration of fire safety engineering guidelines
- Recommend involvement in ISO through national bodies

Questions

- Questions and discussion welcome:
- deytec@frontiernet.net
- www.deytecinc.com
- Thank you.