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 technical & programmatic "lessons learned" in International Collaborative Fire Model Project (ICFMP)
- Capabilities & limitations of current fire models
- "Lessons learned" in the conduct of "blind" validation exercises in ICFMP
- Recommend international standard for fire model V&V

Reporting

- Detailed reports by Deytec, Inc., other participants of ICFMP, and panel reports available at www.deytecinc.com
- Report by Deytec, Inc. on "Lessons Learned in ICFMP Project" available at: http://www.deytecinc.com/FSA22.pdf
- Slides to be uploaded after meeting

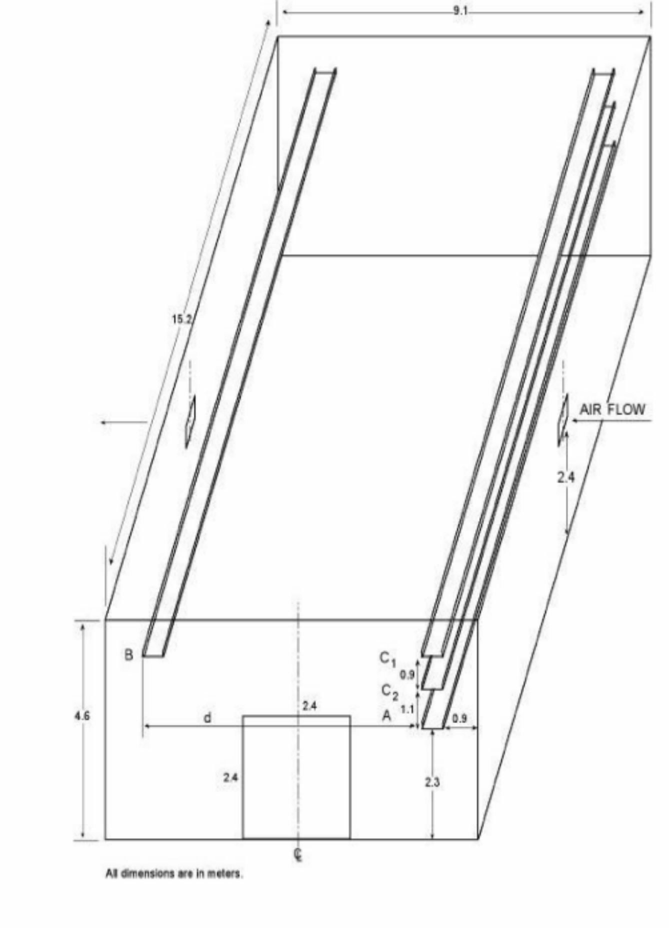
International Collaborative Fire Model Project (ICFMP)

- Conducted 1999-2008 by USNRC
- I Led project from 1999 to 2006
- Evaluate fire models for NPP applications through 5 benchmark exercises (BE)
  - Code to Code
  - Code to experimental data
  - Simple to challenging scenarios

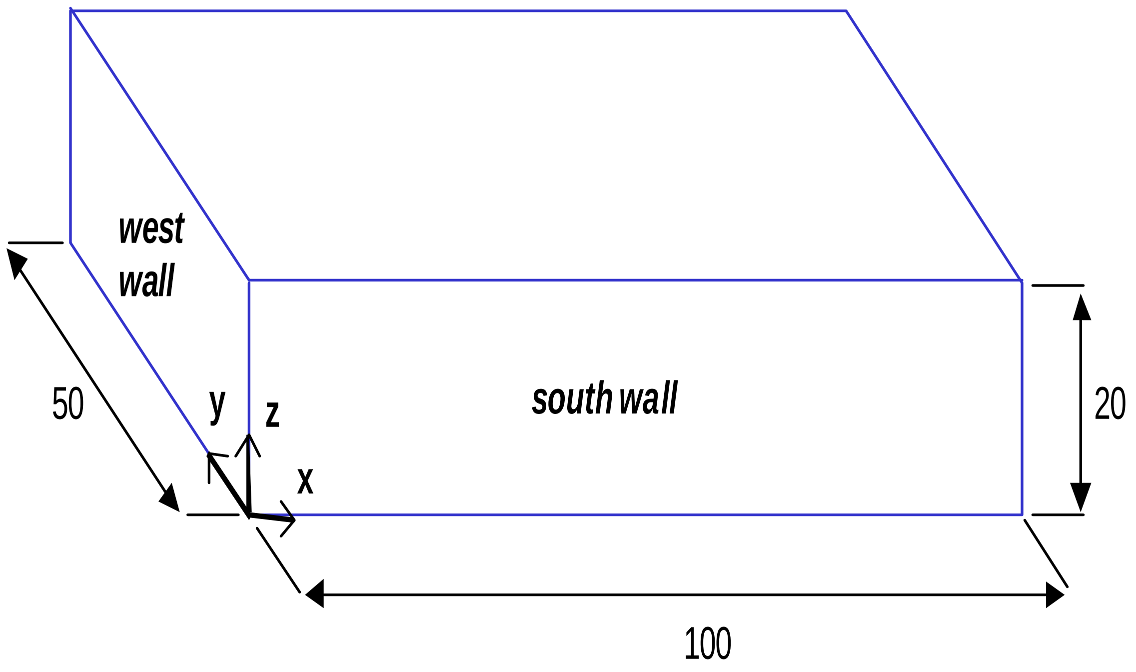
ICFMP Cont'd

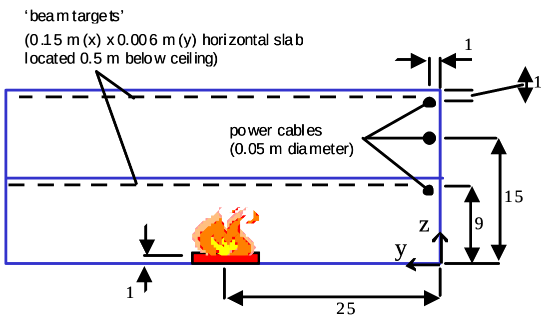
- Five countries participated, typically 7 organizations exercised fire models
  - **Germany – GRS, iBMB (COCOSYS, FDS, CFX, CFAST)**
  - **France – IRSN, EdF, CTICM (FLAMME-S, MAGIC)**
  - **UK – BRE (JASMINE, CFAST)**
  - **USA – NRC, NIST (CFAST, FDS, FDTs)**
    - **Assigned as guest researcher at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

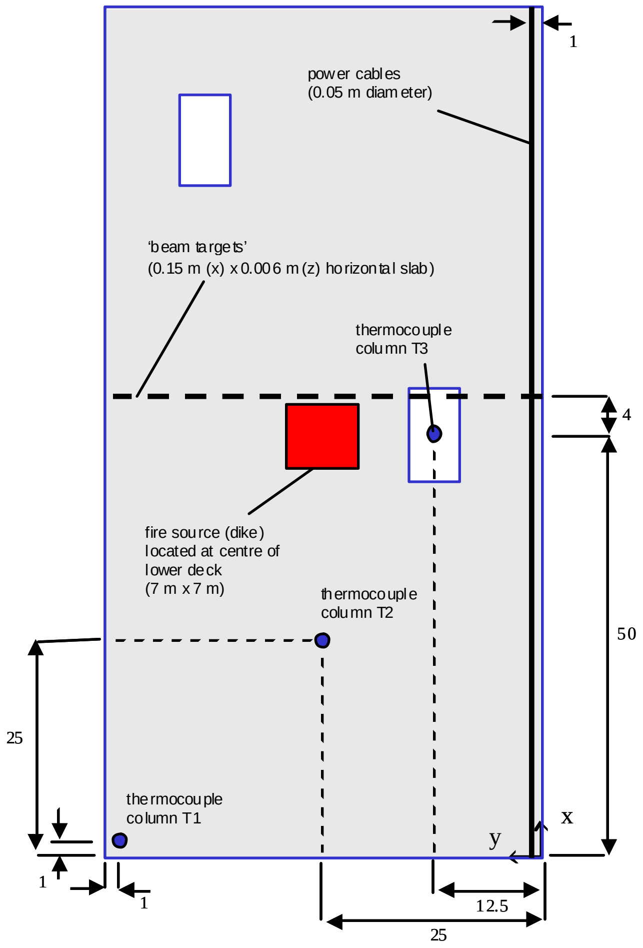
ICFMP Benchmark Exercise No. 1 – Cable Tray Fires



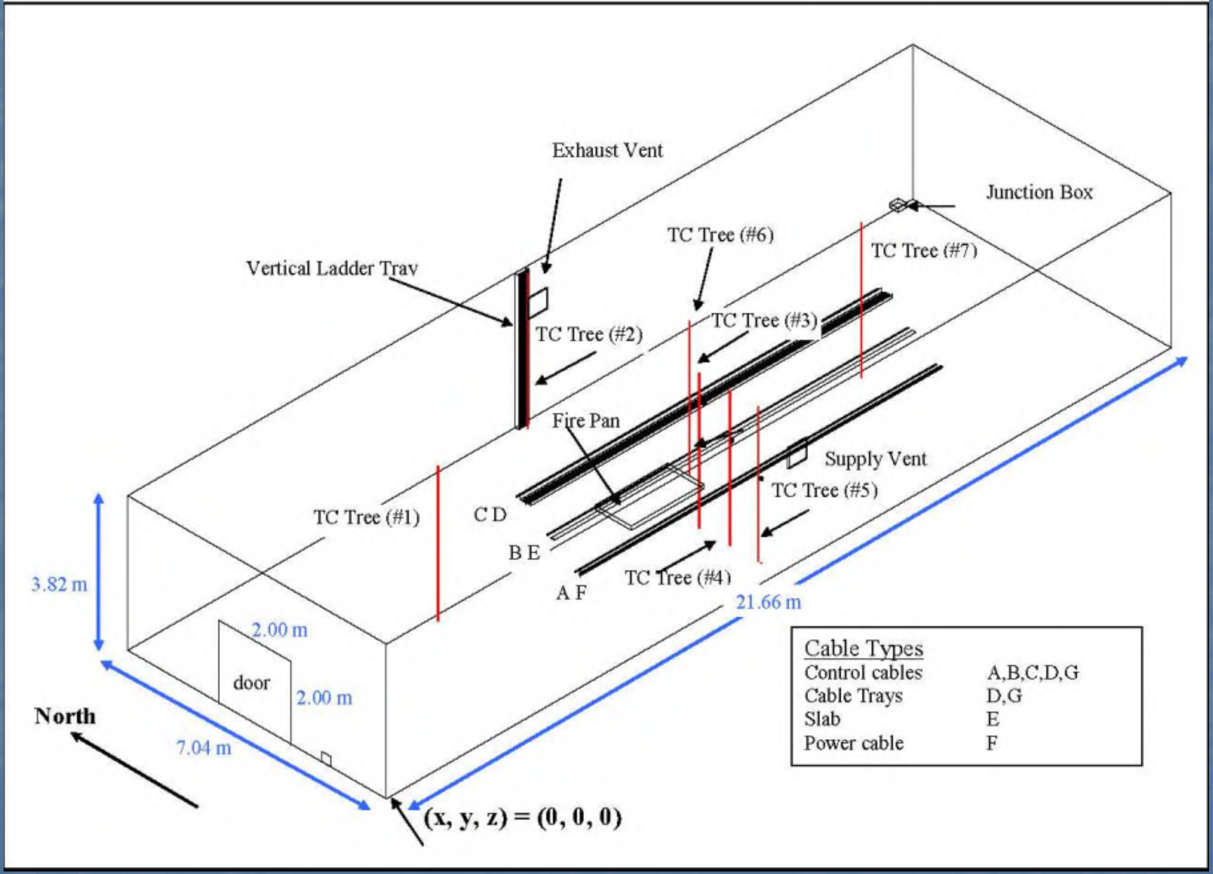
ICFMP Benchmark Exercise No. 2 – Pool Fires in Large Halls




'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

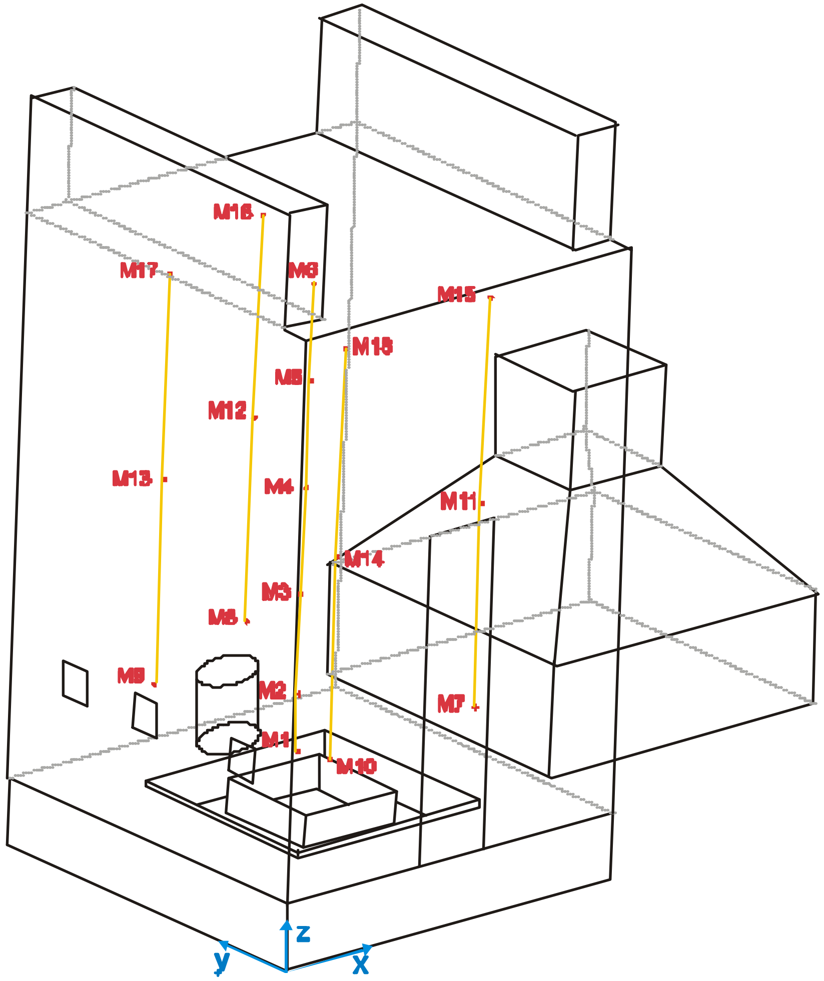

1
power cables
(0.05 m diameter)
'beam targets'
(0.15 m (x) x 0.006 m (z) horizontal slab)
thermocouple
column T3
4
fire source (dike)
located at centre of
lower deck
(7 m x 7 m)
thermocouple
column T2
50
25
thermocouple
column T1
x
y
1
1
12.5
25

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

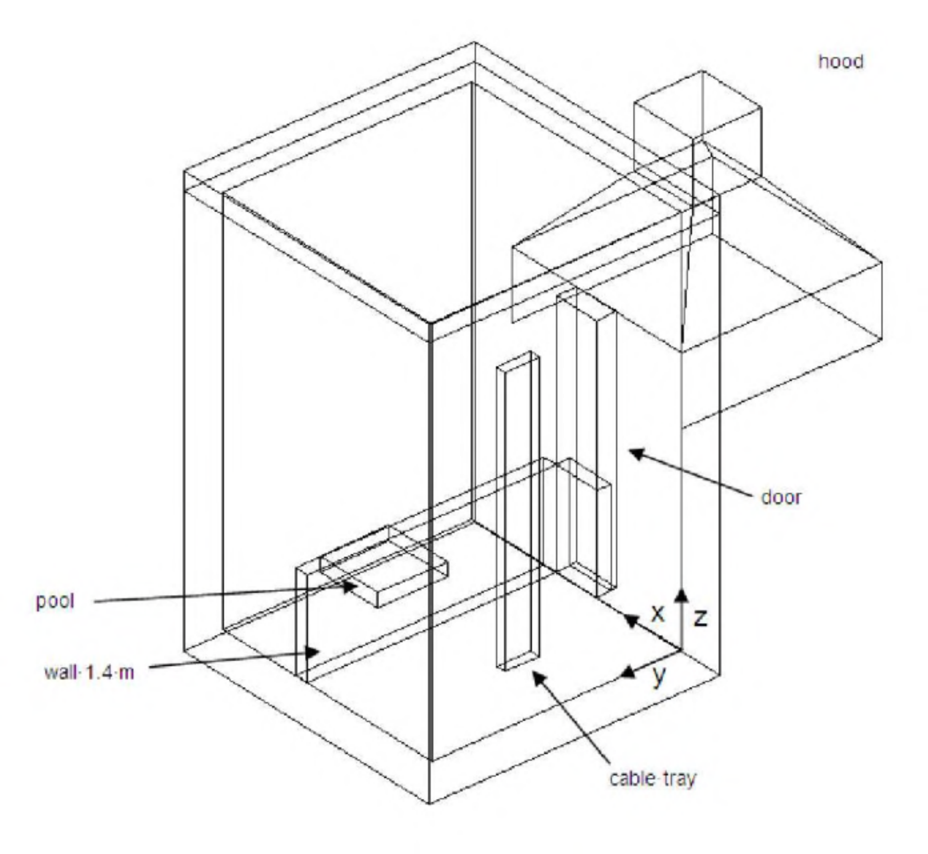


Cable Types	
Control cables	A,B,C,D,G
Cable Trays	D,G
Slab	E
Power cable	F

ICFMP Benchmark Exercise – No. 4
Large Fire Experiments



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



Ref. for Capabilities & Limitations

- Detailed discussion of capabilities & limitations presented at 2009 ANS Winter Meeting in Washington, DC
- Detailed discussion also contained in Deytec, Inc 2009-05 at: http://www.deytecinc.com/FSA17.pdf
- This presentation focused on programmatic "lessons learned"

Capabilities

- Combustion chemistry (O2, CO2) for ventilated conditions
- Plume flows
- Mass & energy balances
- Door mass & heat flows
- Hot gas interface height
- Hot gas temperature
- Local gas temperatures from CFD codes (FDS)

Limitations

- Movement & location of fire plume
- Under-ventilated conditions & fire extinction
- Heat flux from flame & hot gas
- Cable target modeling
- Intense fire conditions
- Fires in multi-level buildings
- Mechanical ventilation

Challenges for Nuclear Plant Applications

- Target heating, mainly cables
- Need to predict heat flux to targets
- Characterization of fire flame & plume
    - Under-ventilated fires
    - Effects of geometry
- Multi-level buildings

V&V Process to Determine Fire Model Predictive Errors

- ICFMP established to conduct “blind” benchmark exercises
- Need credibility of V&V process for establishing true predictive errors
- Detailed specification of benchmark exercises to minimize uncertainty

“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

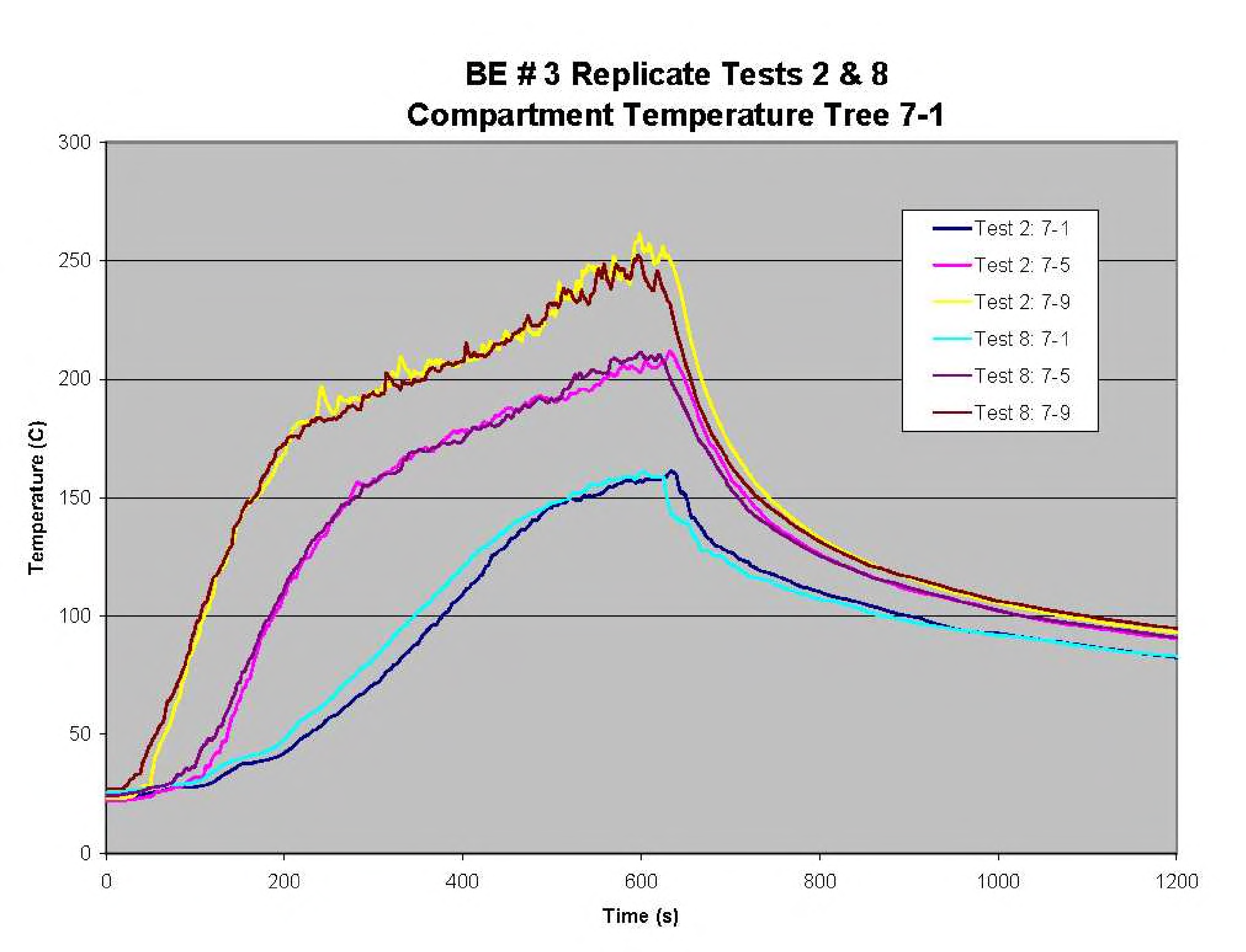
- Natural bias exists in *open* predictions
- Most fire model validations conducted a posteriori (*open*)
- Extent of bias presently unknown & currently being researched
- Need true predictive errors to establish safety margins
- “Real World” Fires

V&V Procedures in ICFMP

- Recognized need to conduct *blind* validations to determine “true” predictive errors needed to establish safety factors
- Minimize debate about input parameter values through detailed specifications
- Model assumptions, e.g. grid size
- Sensitivity analysis
- Need to establish “optimal” prediction is not inconsistent with sensitivity analysis

Challenges of *Blind* V&V Overcome in ICFMP

- Replication of experiments
- Conduct of tests according to test plan
- Uncertainty in model input data



BE # 3 Replicate Tests 2 & 8
Compartment Temperature Tree 7-1

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

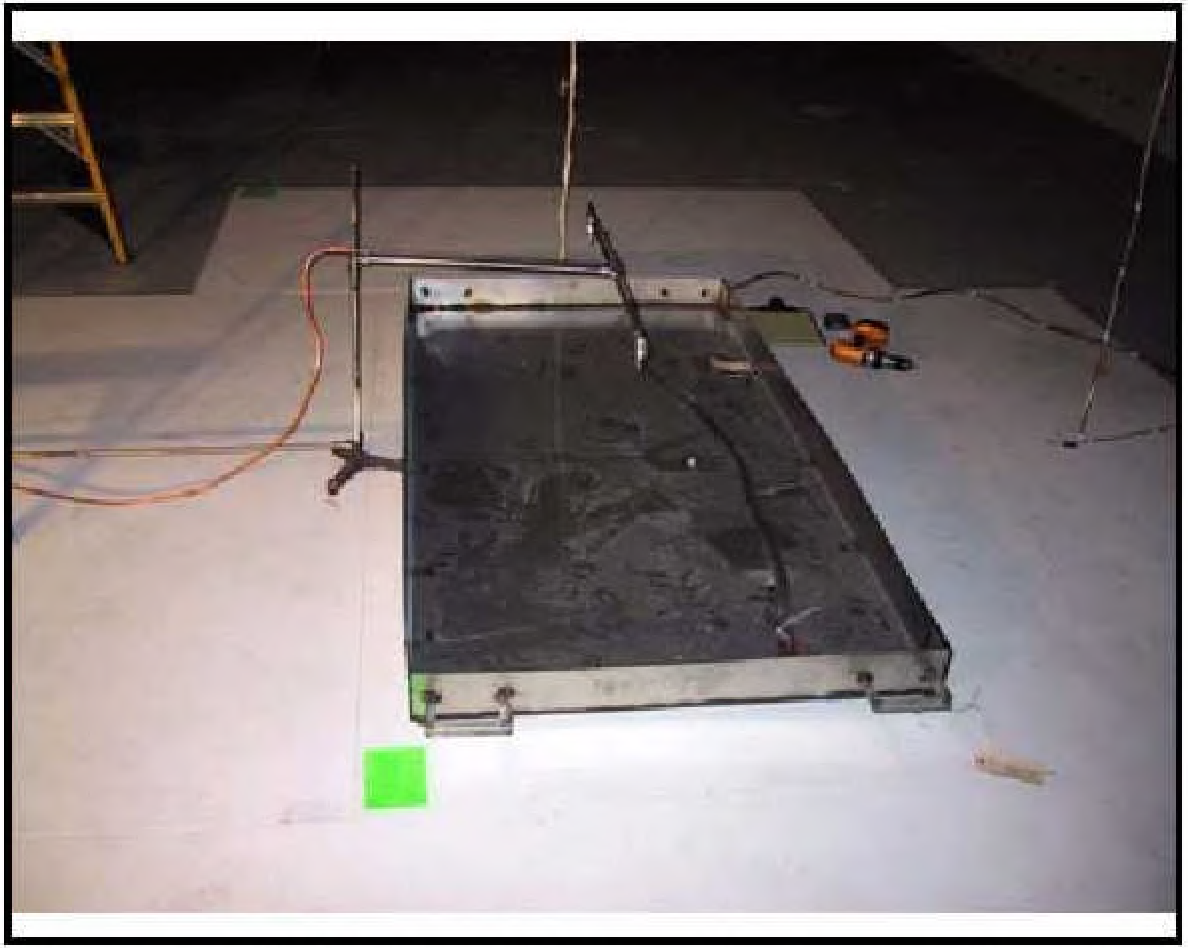


Figure 2.12 Fuel Pan with Spray Nozzle

Figure 3.3 Hot Gas Layer in Test 3

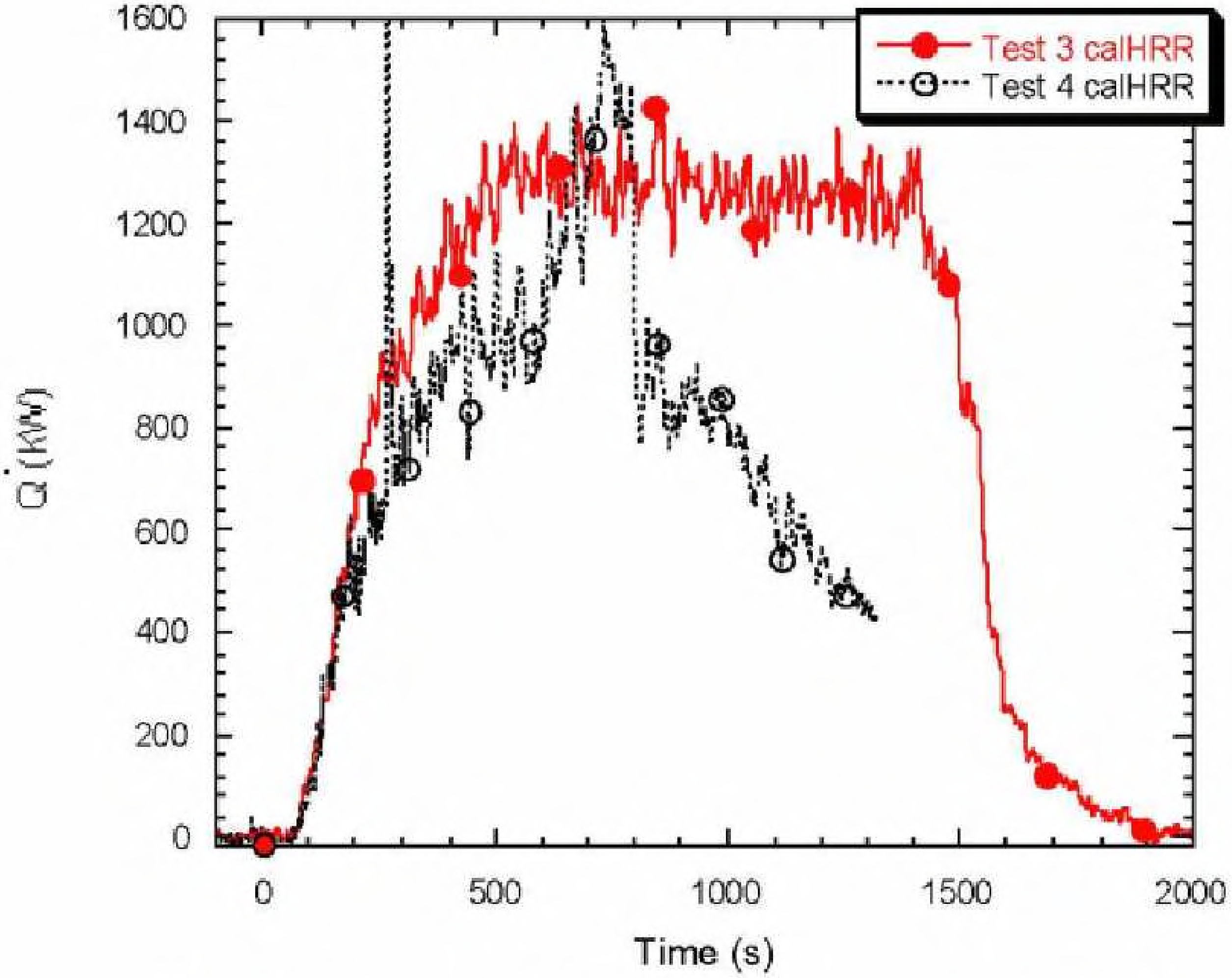


Figure 3-2 Typical Calorimetric Measurements of HRR

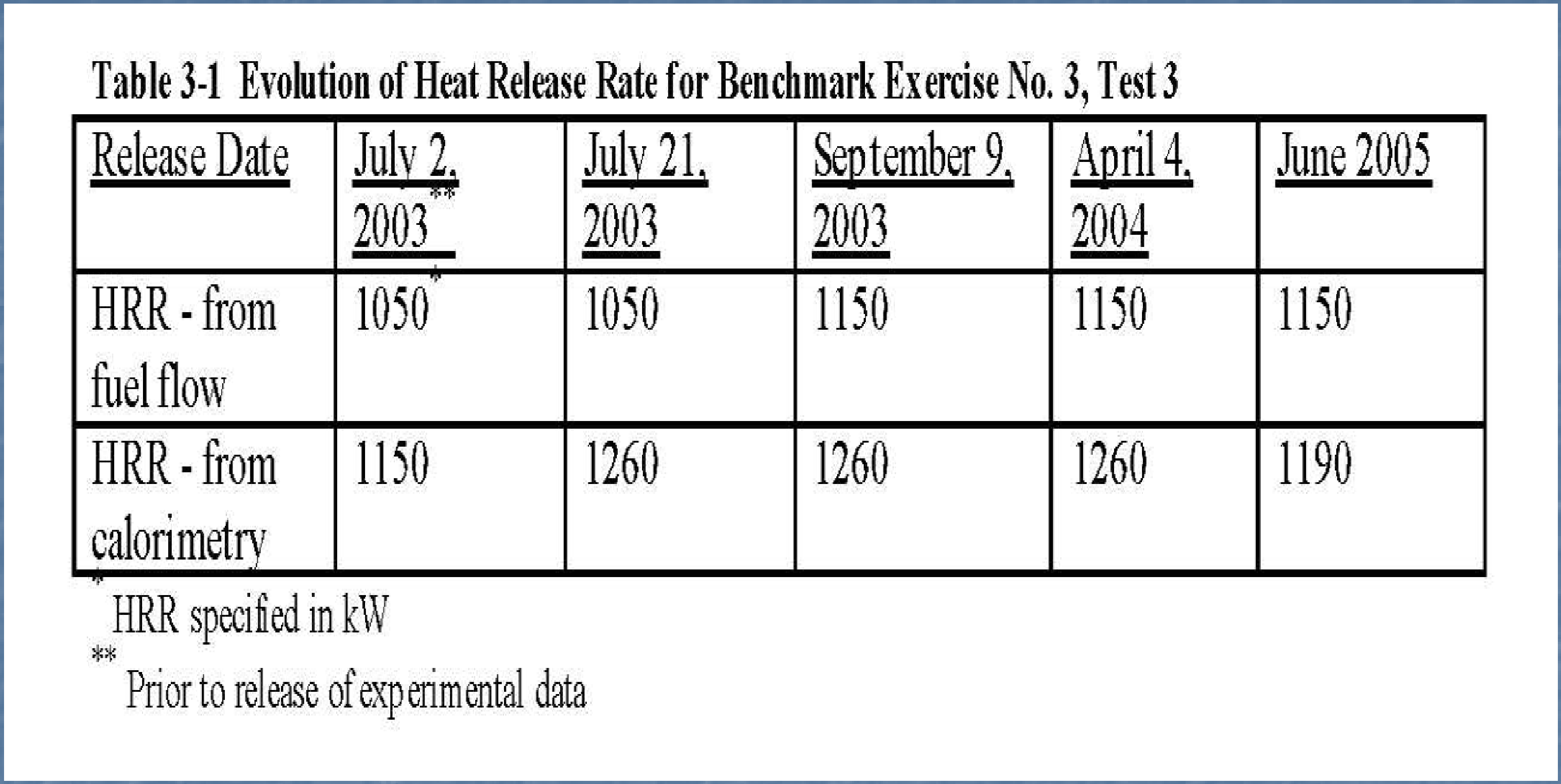


Table 3-1 Evolution of Heat Release Rate for Benchmark Exercise No. 3, Test 3

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

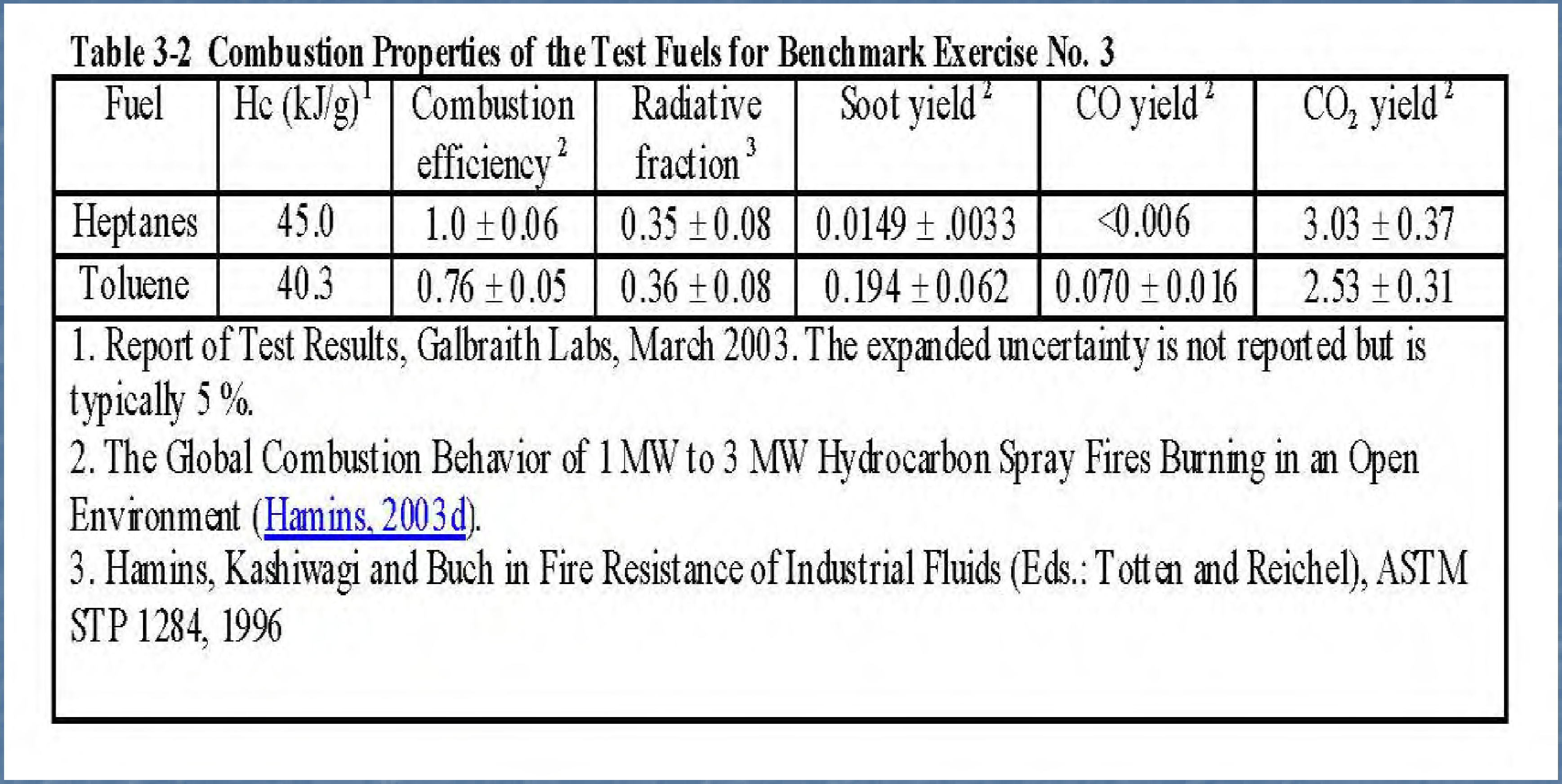


Table 3-2 Combustion Properties of the Test Fuels for Benchmark Exercise No. 3

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 ± .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

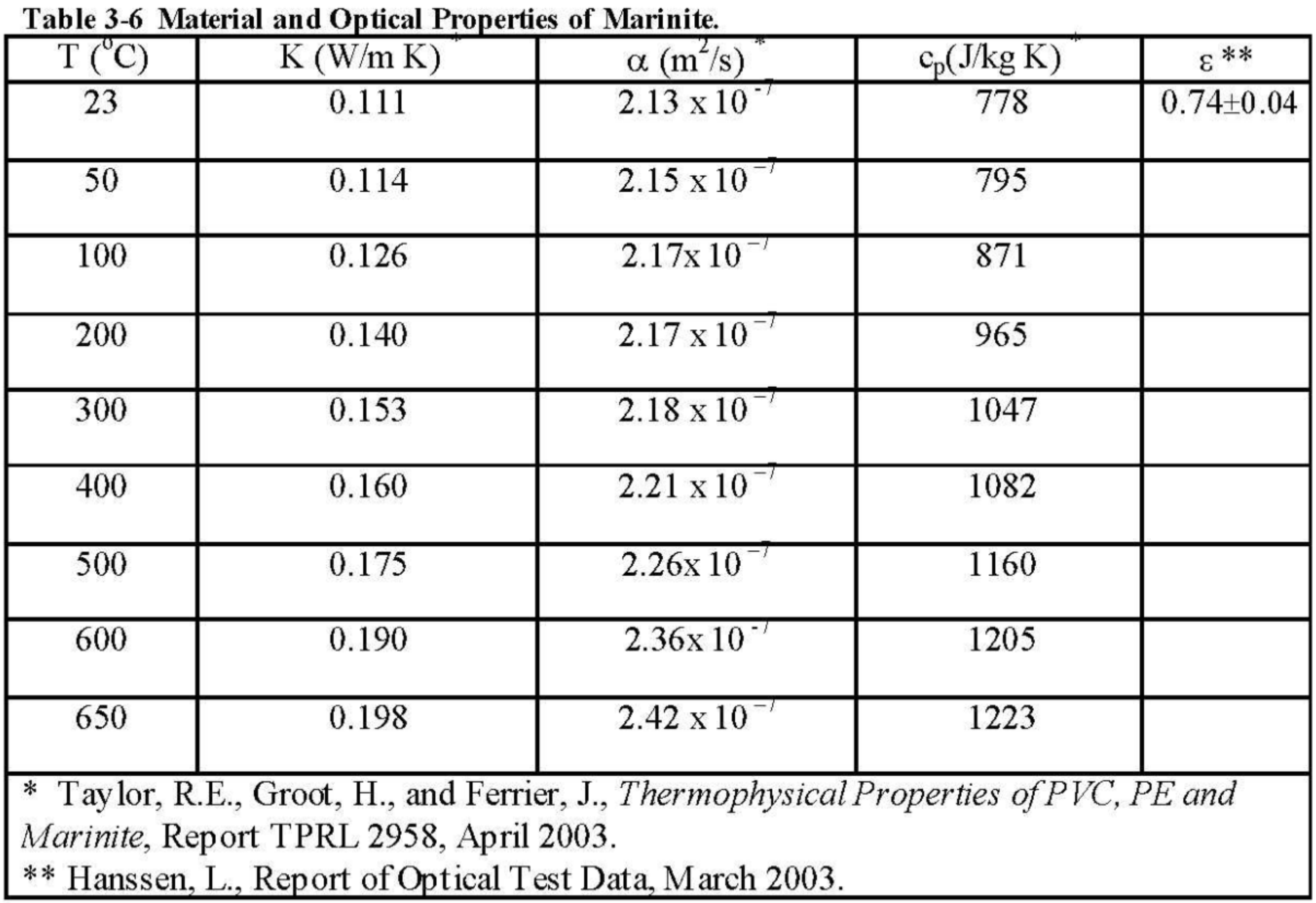


Table 3-6 Material and Optical Properties of Marinite.

T (°C)	K (W/m K)*	α (m²/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 was not conducted per an established international standard
- Informal due to collegial nature of collaborative project
- 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
- Some confusion on definition of "*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

Conclusions - Technical

- Erroneous decisions leading to unsafe nuclear plant conditions will result if limitations not considered
- Research and improvement programs should be developed to overcome limitations so that fire models become a reliable and useful tool
- Need to determine true model errors and establish safety margins in designs

Recommendation for International Standard for Fire Model V&V

- Establish consensus on measurement methods for parameters needed as input to fire models
- Develop consensus on values for parameters input to fire models
- Establish process 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

Conclusion

- V&V process in ICFMP project was very beneficial in many respects
- Benchmark exercises allowed different models to be analyzed & compared against each another & experimental data for a wide range of NPP fire scenarios
- Capabilities & limitations derived from such comparisons

Conclusion – Cont'd

- Development of V&V process provided experience in conduct of *blind* exercises & issues that provided a challenge.
- Experience in ICFMP has formed the basis of a V&V process
- ISO TC 92 examining ICFMP experience