BRE

Development and validation of a comprehensive model for flame spread and toxic products in full-scale scenarios

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Topics

- Introduction
- Fundamentally-based flame spread model
  - finite thickness and finite rate
  - concurrent spread over PMMA in wind tunnel
- Simple flame spread model
  - critical net accumulated flux
  - model validation exercises
    - *plume studies*
    - *half-scale ISO room*
    - *five large-scale test scenarios with 10 materials*
      - *plastic/cellulosic*
      - *with and without flame retardant*

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Introduction (1)

- Prediction of fire growth and flame spread
  - Goal: “Time to flashover”
  - Realistic scenarios
- Simple models
  - few empirical parameters
  - bridge between small-scale tests and room predictions
    - *which tests for these parameters?*

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Introduction (2)

- CFD based studies
  - comprehensive
    - *fluid flow, turbulence, combustion, radiation and heat transfer*
  - what level of detail is required in each sub-model?
  - appropriate balance of our effort
    - *gas phase chemistry*
    - *solid phase pyrolysis*
    - *radiation*
    - *smoke*
  - critical model components
  - “consistent level of crudeness”

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Fundamentally-based flame spread model

- Implemented in SOFIE CFD code
  - Dr Xi Jiang (1999)
- Finite-thickness ablating solids
  - in-depth heat transfer
  - fuel consumption
- Volatilisation rate
  - surface vaporisation
  - in-depth solid pyrolysis

$$\dot{m}''' = A_s \rho_s e^{-E_s/(RT_s)} / L_s$$

  - Di Blasi et al - 2nd IAFSS,1989

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Model details

- Physical models
  - Transpiring wall functions
  - Low Reynolds number turbulence model (Lam and Bremhorst)
  - Eddy breakup combustion
  - Tesner soot model
  - Discrete transfer radiation model
- 2D simulations
  - 280 x 36 = 10k cells
  - 2 x 8 = 16 DT rays
  - 1 second timestep
  - 2 days run-time on 600 MHz machine

Model validation

- Chao & Fernandez-Pello - CST,1983
  - wind-aided spread over PMMA
  - 0.6m x 0.076m
- 20 experiments
  - inflow turbulence
  - inflow velocity
  - inflow oxygen mass fraction
  - geometry (floor/ceiling)

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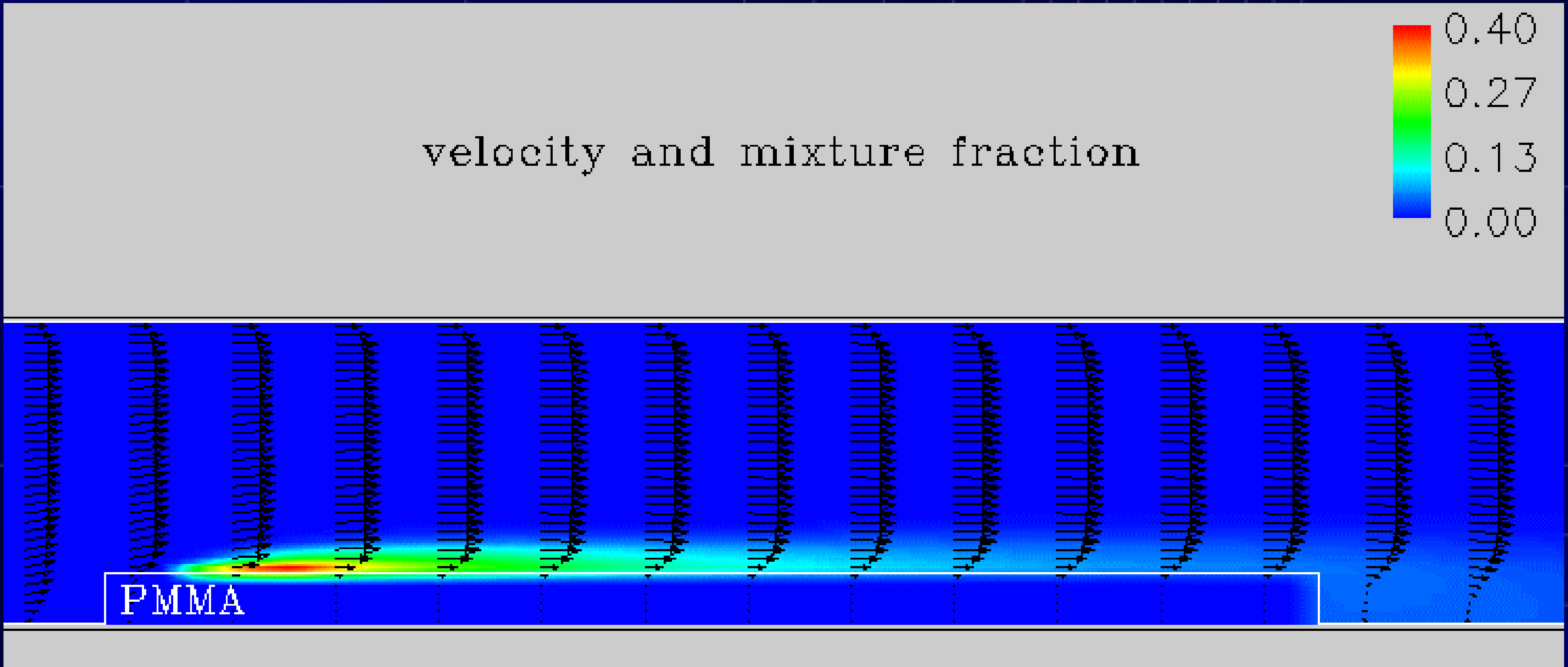
u'/U=10%, m_{ox}=0.5, U=1.0m/s, floor



(a)

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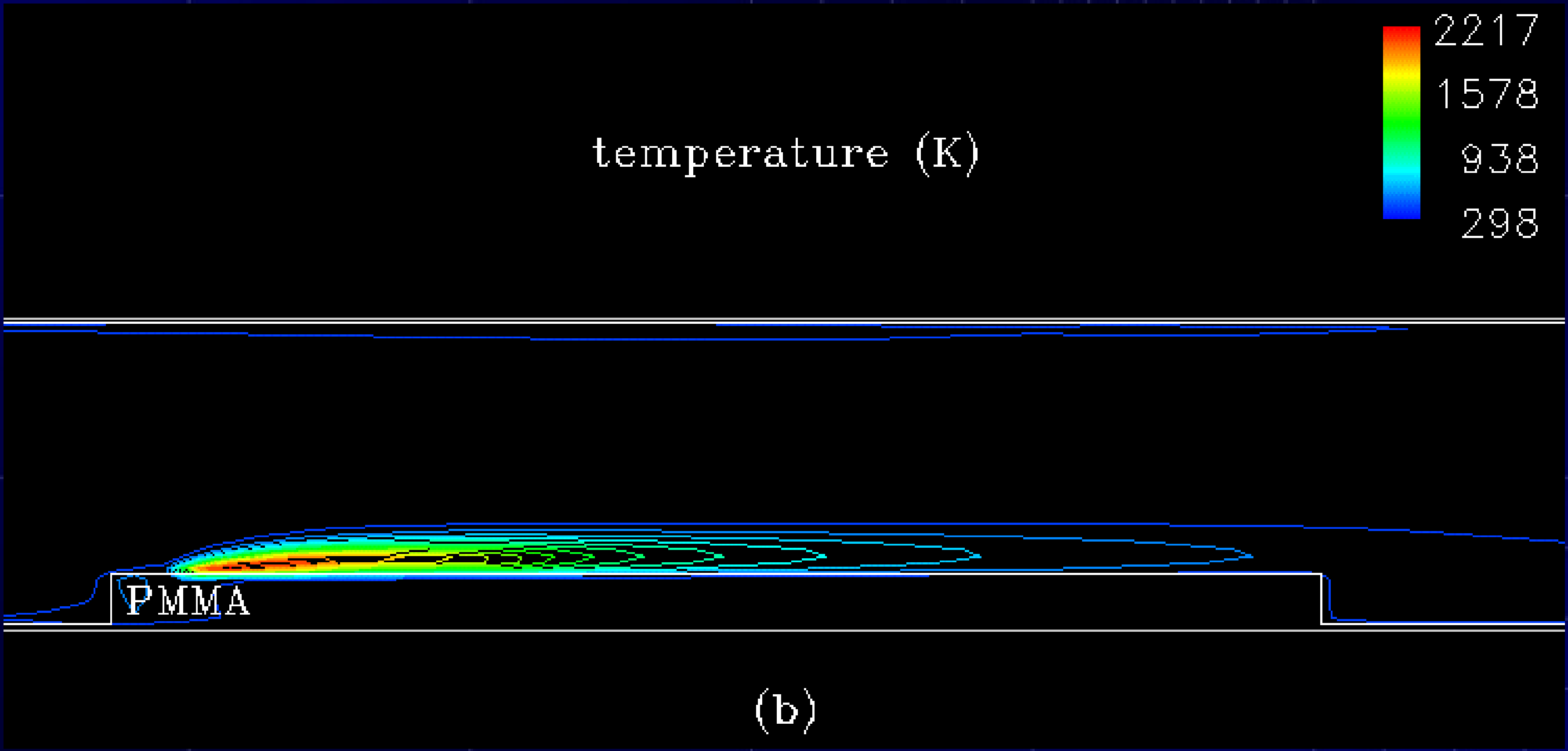
u'/U=10%, m_{ox}=0.5, U=1.0m/s, floor



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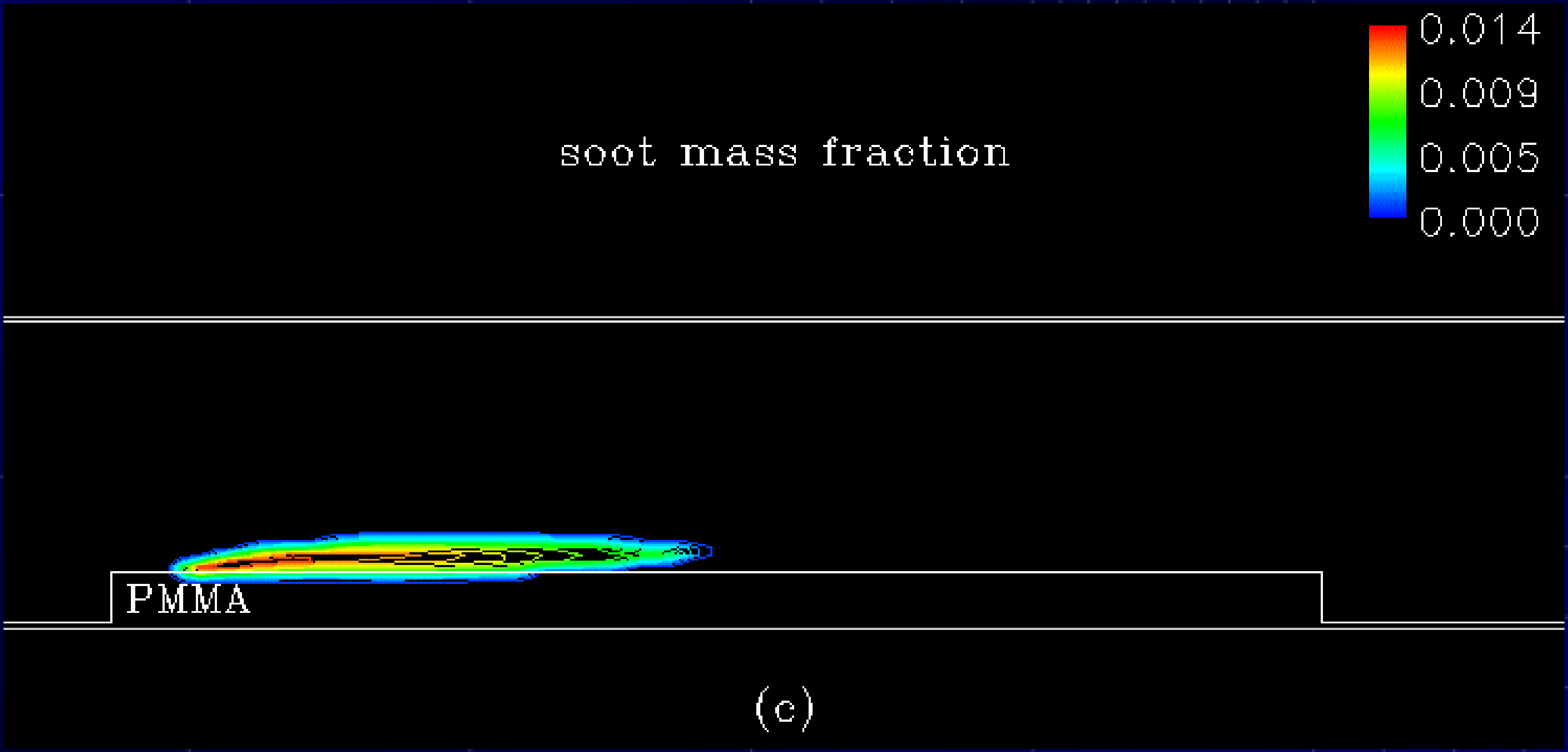
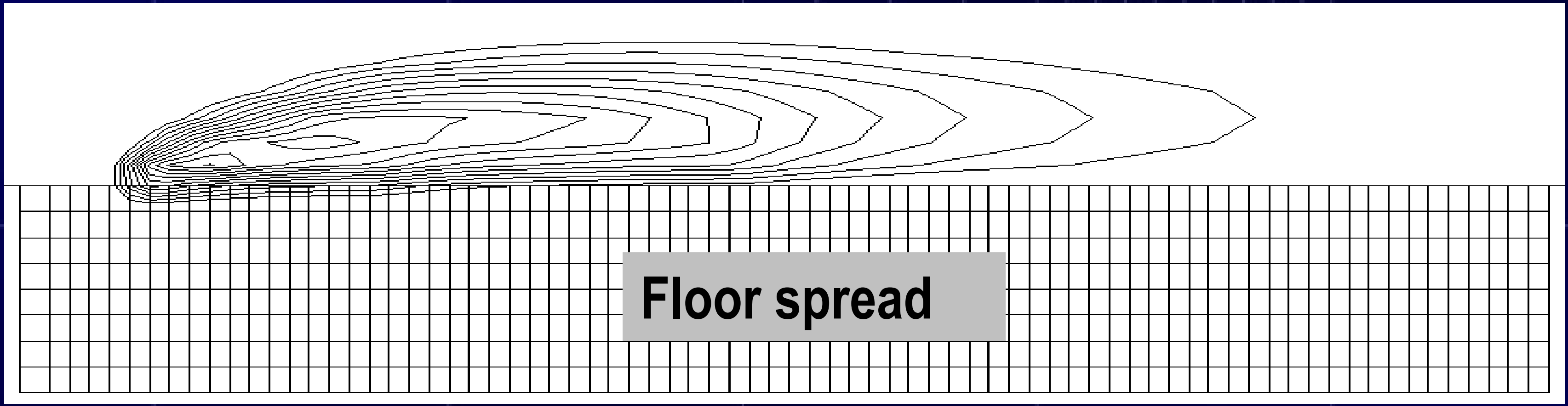
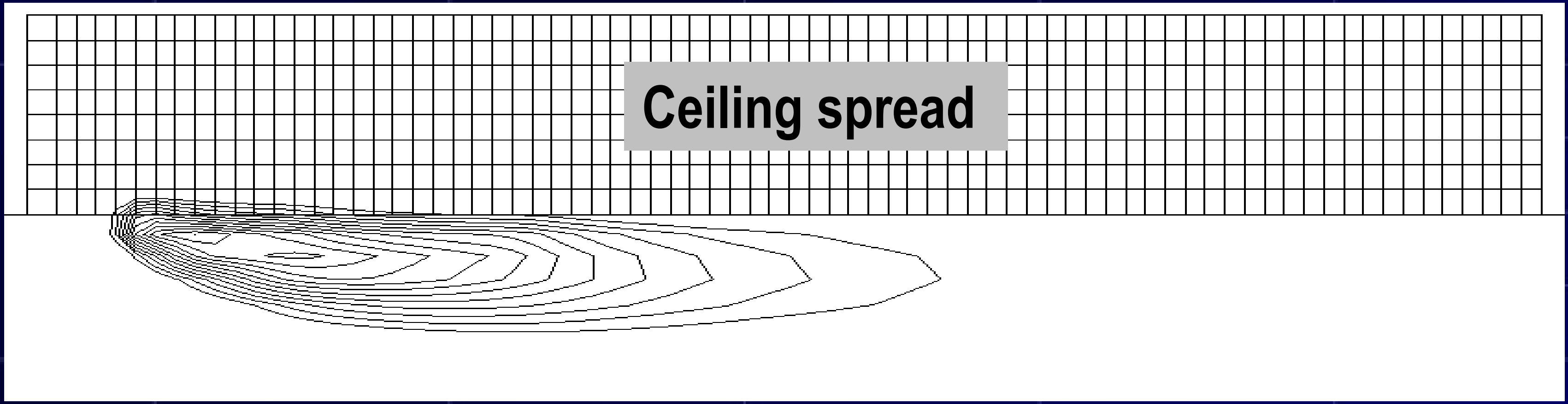
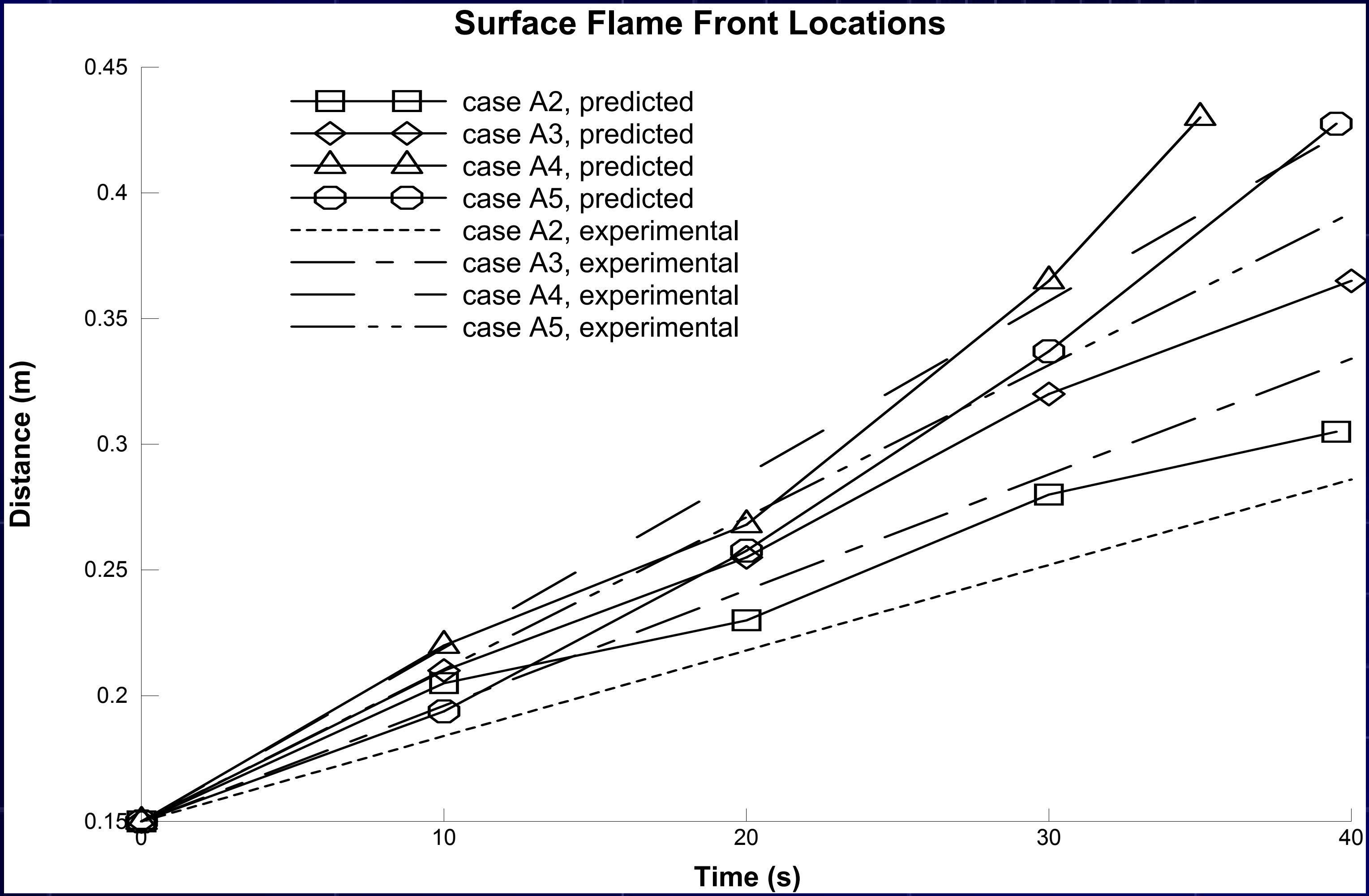


Effect of orientation





u'/U=5-20%, m_{ox}=0.5, U=1.0m/s, floor



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Flame spread model for building fires

- "Department for Transport, Local Government & the Regions"
  - 1997-2001 project
- Large-scale scenarios
  - rooms
  - façades
  - whole buildings
- Realistic building products
  - with and without fire retardant
  - plastic and cellulosic
- Life safety
  - time to incapacitation (includes carbon monoxide, smoke)

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Simple flame spread model

- Implemented in SOFIE CFD code
  - Dr I Aksit [Aksit et al - 3rd FEH,2000]
- Time to ignition
  - critical accumulated net incident heat flux:

$$E_{critical} = \sum_{0}^{t_{ignition}} \max(\dot{q}_{net} - \dot{q}_{net}, 0)\Delta t$$

- Volatilisation rate
  - heat of gasification
    - *function of the accumulated mass loss (hg1, hg2 parameters)*
- Includes burnout but neglects deformation
- Applied "macroscopically" in large cells

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Physical and numerical models

- Physical models
  - Flamelet combustion model
    - *multiple radiative loss libraries*
    - *carbon monoxide*
  - Flamelet soot model (Moss et al - 22nd CS,1988)
  - Discrete transfer radiation model
- Numerical simulations (deliberately “coarse”!)
  - 20 x 20 x 15 = 60k cells
  - 2 x 4 = 8 DT rays
  - 1 second timestep
  - 2 hour run-time on 600 MHz machine

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Non-adiabatic flamelets

- Flamelets
  - various fuels
    - *methane, ethylene, MMA, heptane*
  - Soot flamelet generated
    - *constants from Moss & Stewart - FSJ,1998*
    - *surface growth term scaled by soot yield [Tewarson - SFPE,1995]*
  - Kinetic mechanism
    - *Held et al - CST,1997 41 species / 274 reactions*
    - *Seiser et al - 28th CS,2000 160 species / 1540 reactions*

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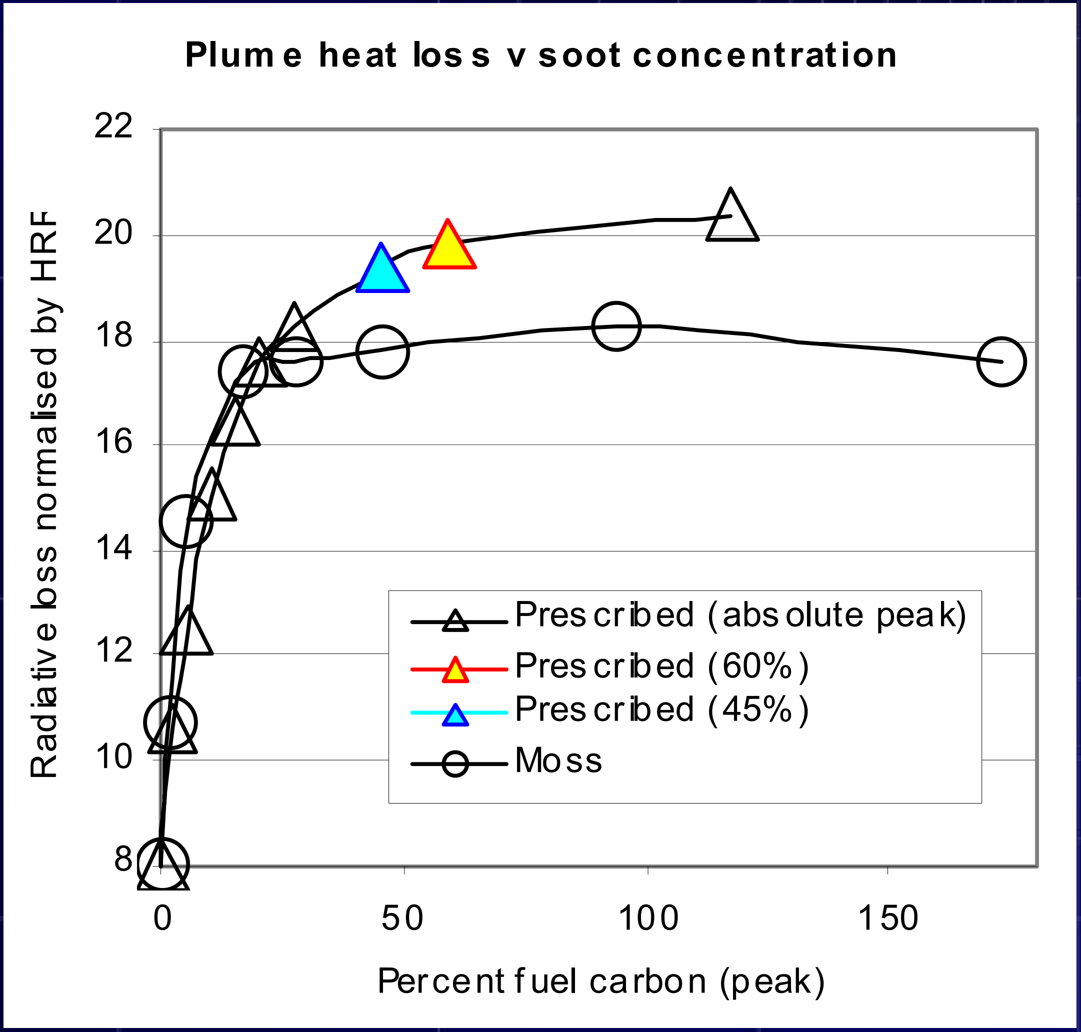
Model validation

- Plume heat loss study
  - empirical correlations for plume growth
  - empirical heat loss measurements
- Half-scale ISO room
  - Pierce & Moss - 3rd FEH, 2000
  - Toxic product predictions (CO and smoke)
- Large-scale tests on building materials
  - Smith et al - Interflam, 2000
  - detailed measurements flame spread (TC's, video)
  - duct measurements of HRR, temperature and toxic products
  - heat flux measurements

Plume heat loss



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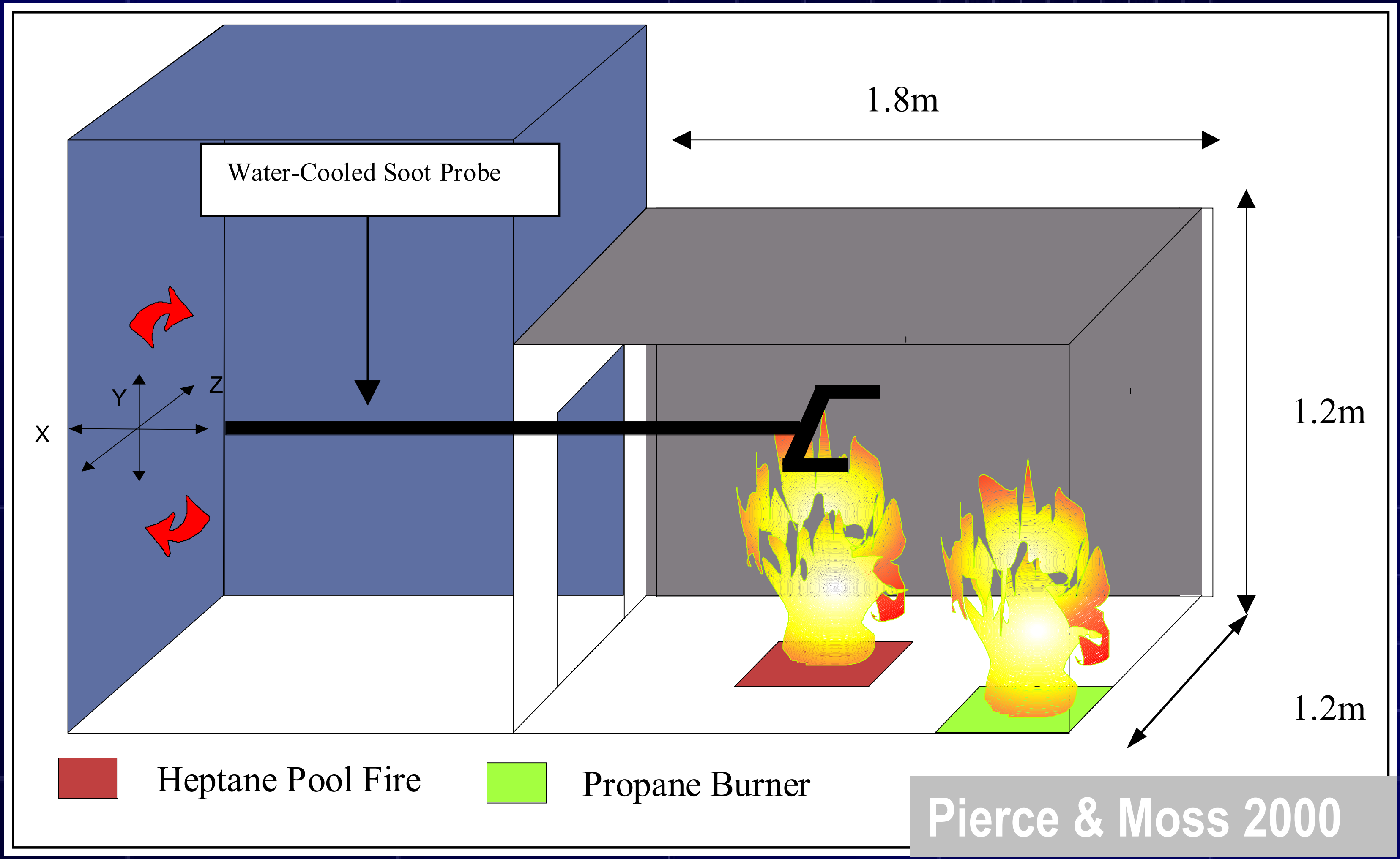
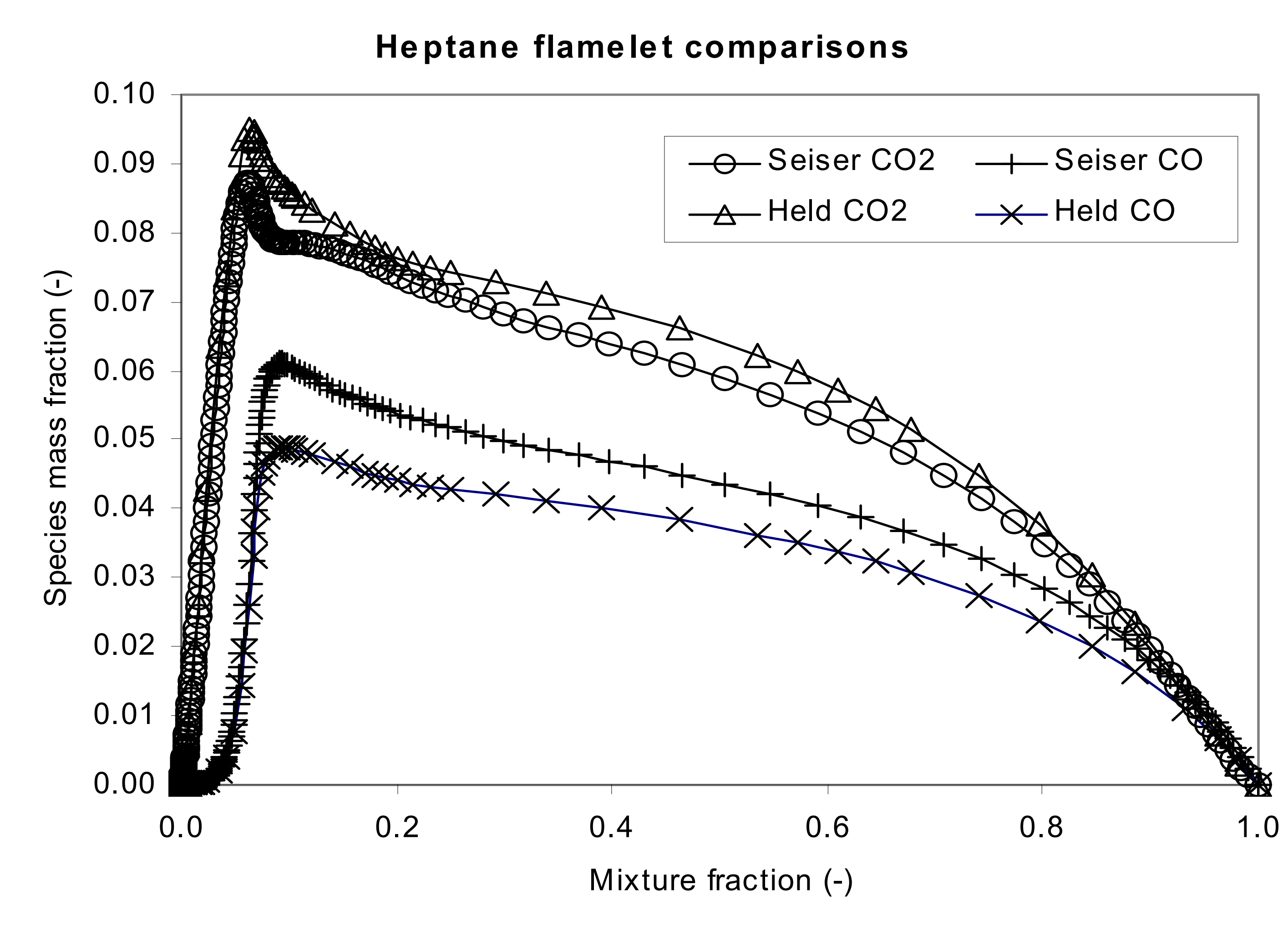
Half-scale ISO room



Pierce & Moss 2000

Flamelet sensitivities



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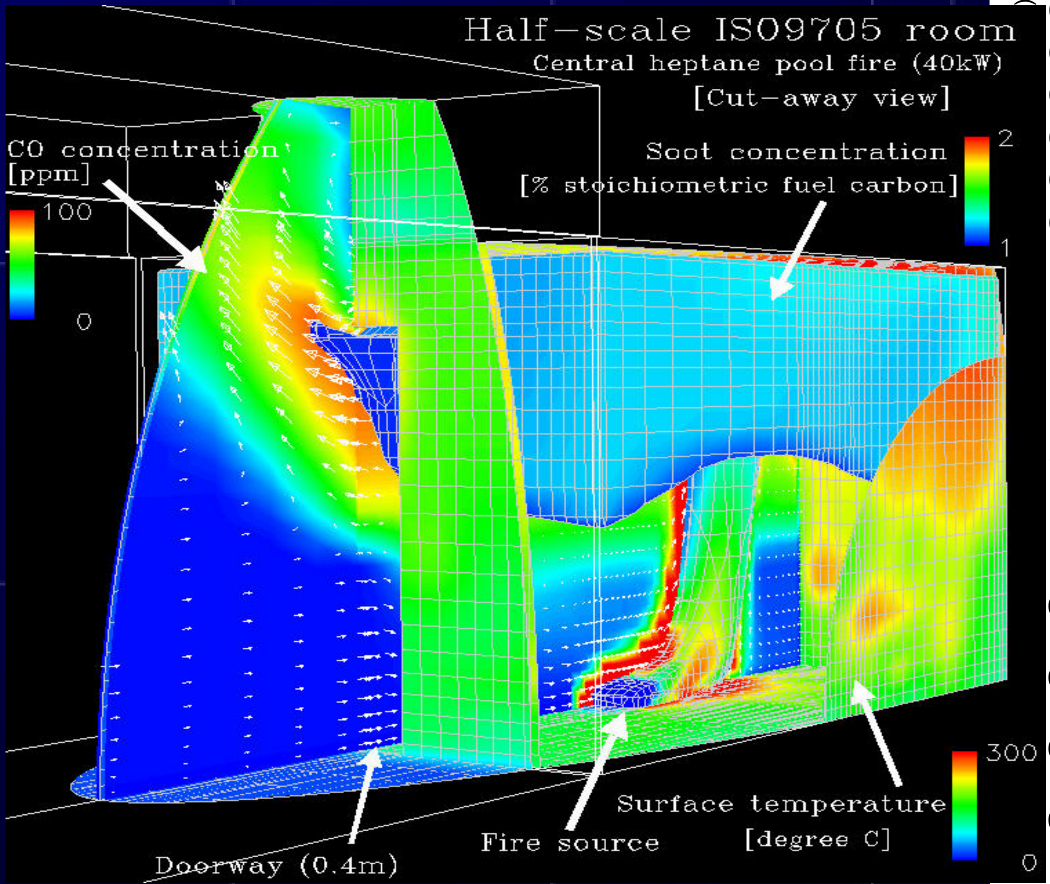
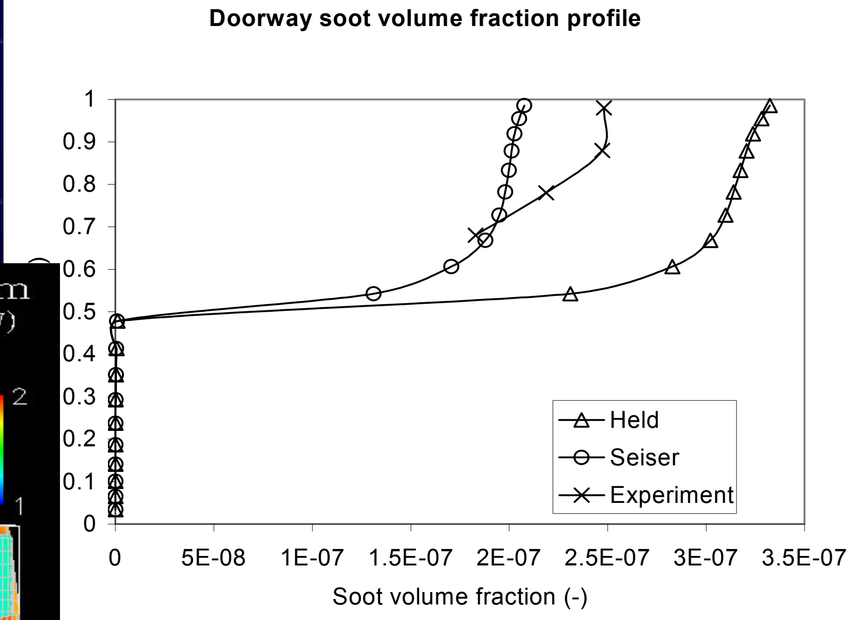
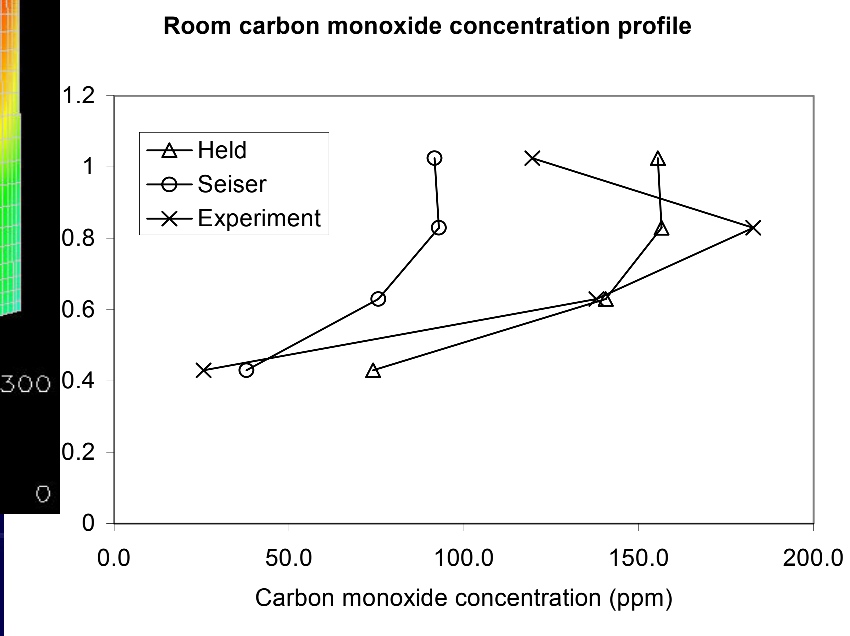
Toxic products







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Calibration/validation of flame spread model

- Full-scale tests
  - Corner façade 7.2 x 3.6 x 2.4 m, 500kW
  - Shaft 2.2 x 3.5 x 4.9 m, 500kW
  - Duct 7.2 x 1.2 x 0.3 m, 300kW
  - Corridor 7.2 x 1.2 x 2.4 m, 300kW
  - Room 3.6 x 2.4 x 2.4 m, 100-300kW
- 10 materials

	"Cellulosic"	"Plastic"
Non-fire retarded	Ordinary particleboard Ordinary plywood (birch) Low density fibreboard	PUR foam panels with Al foil faces (Steel-clad EPS sandwich panel)
Fire-retarded	FR chipboard	FR extruded polystyrene boards FR PVC

- Paper-faced gypsum plasterboard
- Acoustic mineral fibre tiles

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Calibration/validation of flame spread model

- Flame spread model parameters calibrated for corner façade
  - critical net accumulated heat flux
  - minimum flux
  - heat of gasification
    - *scaling factors (function of accumulated mass loss)*
  - material and char densities
  - char thickness
- Model applied “predictively” to other scenarios
  - *without changing any of the model constants!!!*

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Corner façade: particleboard

Corner façade: particleboard

Corner façade: particleboard

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Corner façade: particleboard

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Corner façade: FR-EPS

Corner façade: FR-EPS

Corner façade: FR-EPS

BRE

Corner façade: FR-EPS

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Corner façade: PVC

Corner façade: Sandwich Panel

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Duct

Duct: transition to external flaming

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Shaft: EPS

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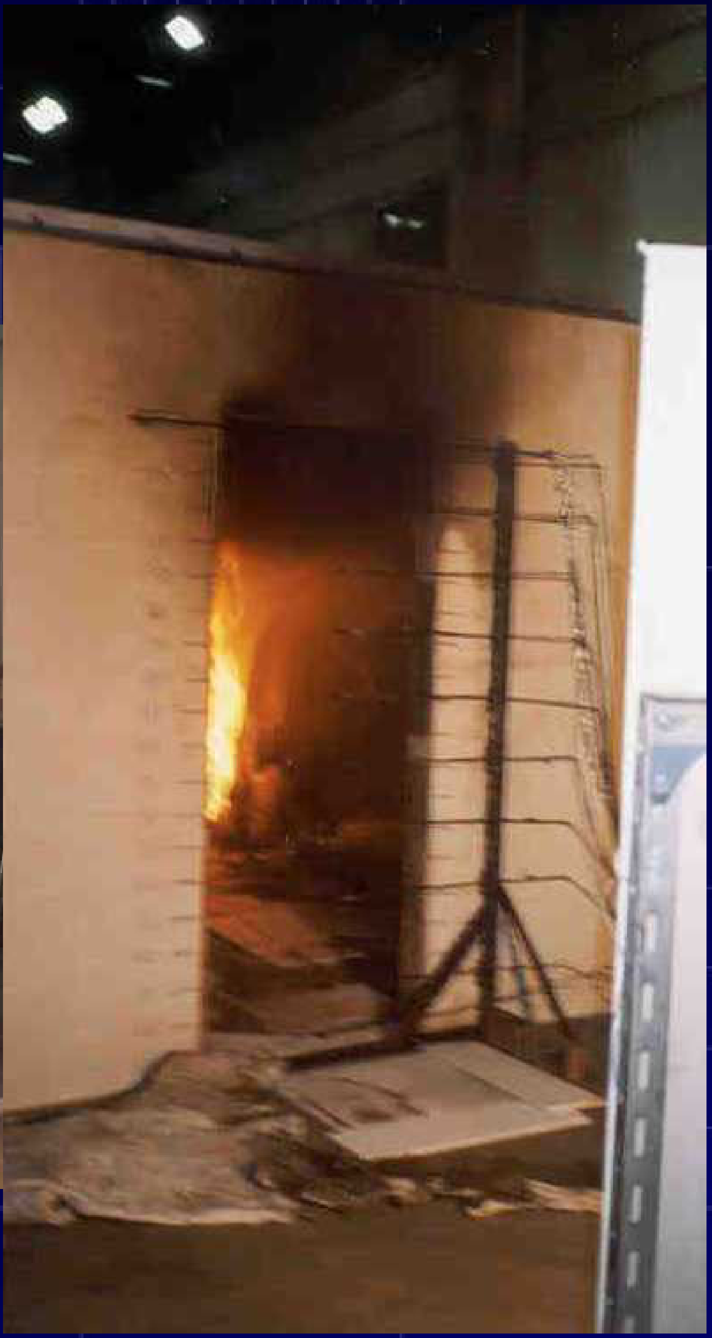
Room



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Room:
PIR post-test

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Corridor: EPS

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Corridor: EPS

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Corridor: EPS

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Corridor: EPS

Corridor: EPS

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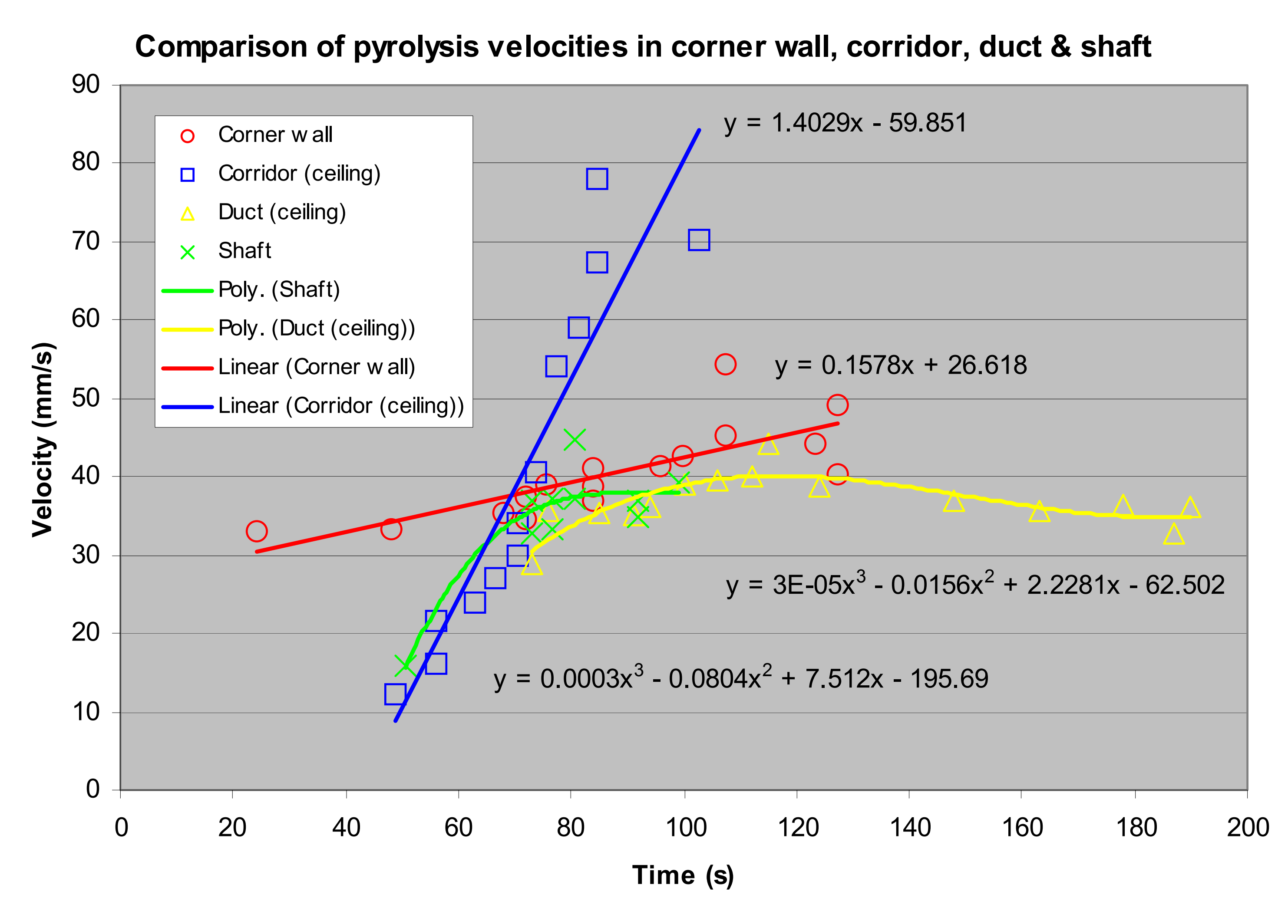
Full-scale tests



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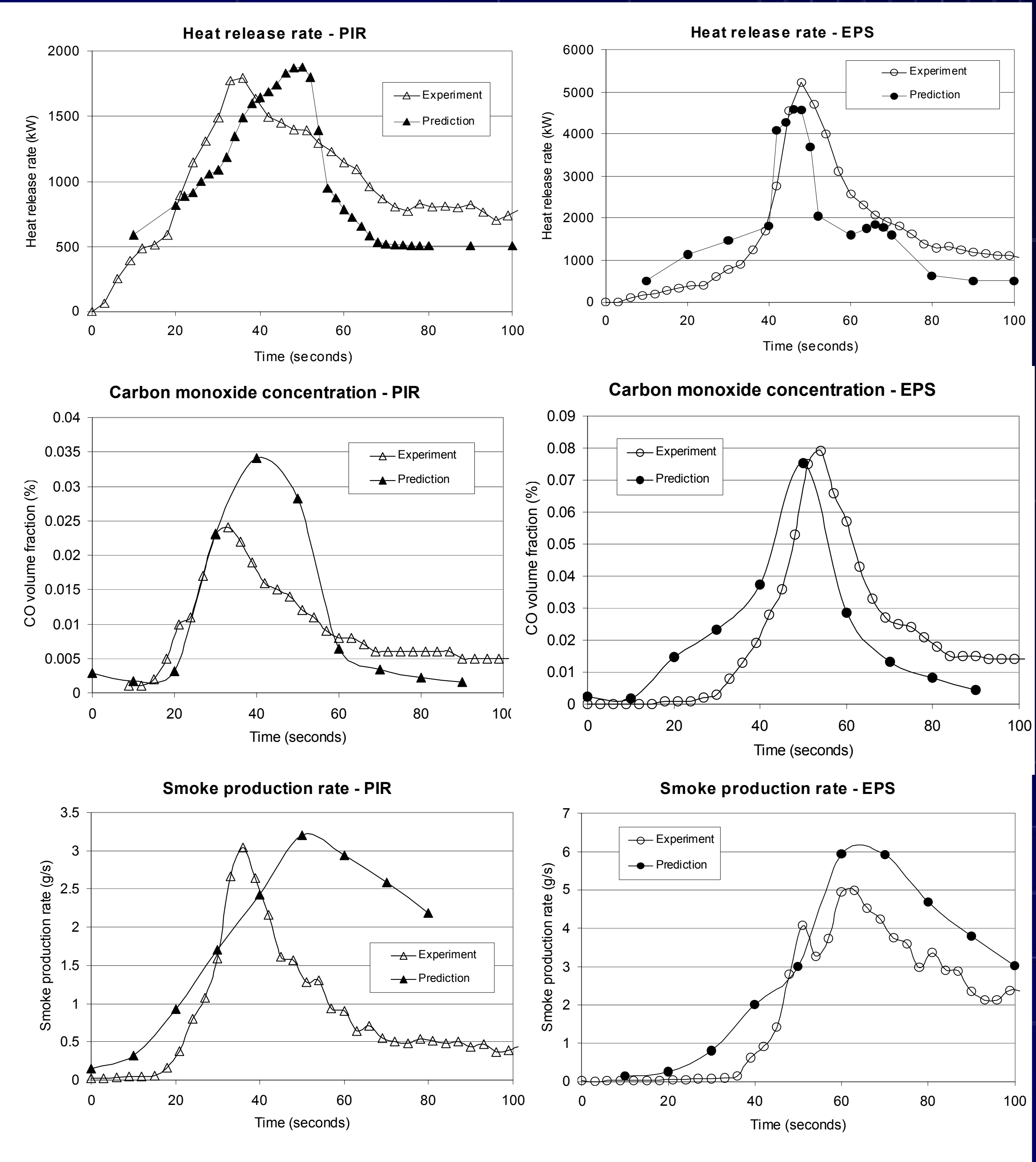
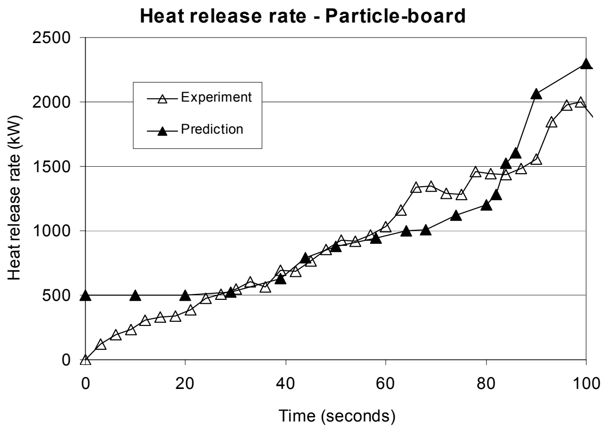
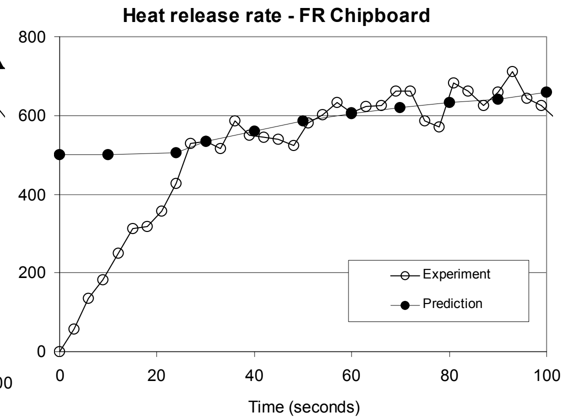


Heat release rate - PIR
Heat release rate (kW)
Time (seconds)
Experiment
Prediction
Heat release rate - EPS
Heat release rate (kW)
Time (seconds)
Experiment
Prediction
Carbon monoxide concentration - PIR
CO volume fraction (%)
Time (seconds)
Experiment
Prediction
Carbon monoxide concentration - EPS
CO volume fraction (%)
Time (seconds)
Experiment
Prediction
Smoke production rate - PIR
Smoke production rate (g/s)
Time (seconds)
Experiment
Prediction
Smoke production rate - EPS
Smoke production rate (g/s)
Time (seconds)
Experiment
Prediction

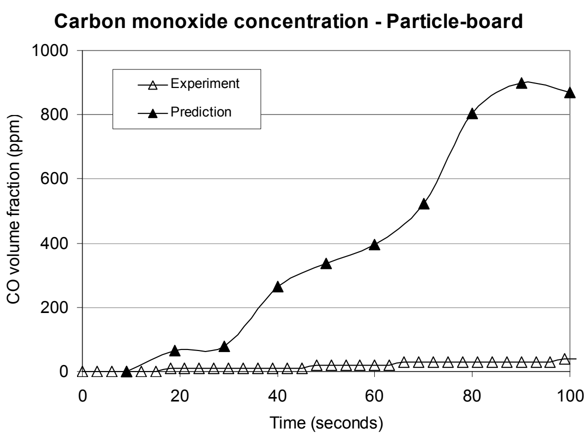
BRE



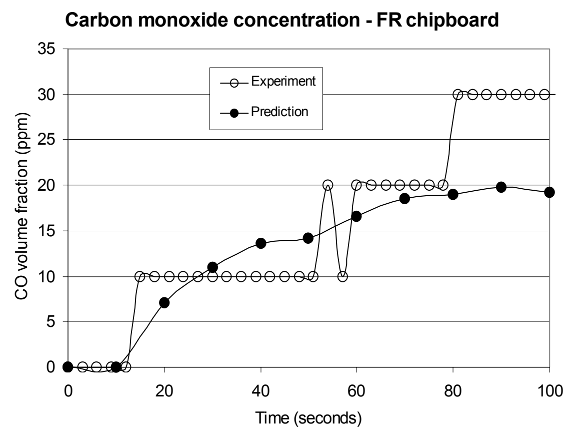
Heat release rate - Particle-board
Experiment
Prediction
Heat release rate (kW)
Time (seconds)



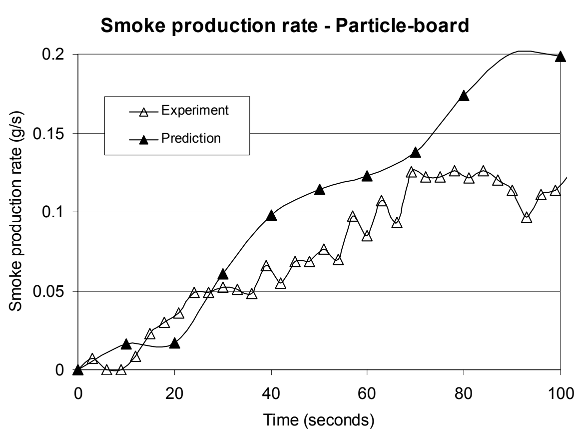
Heat release rate - FR Chipboard
Experiment
Prediction
Time (seconds)



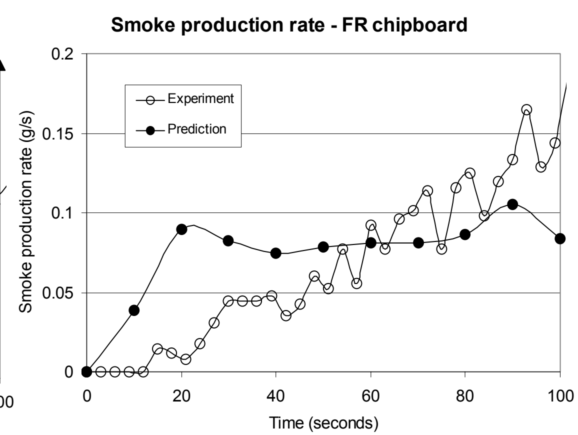
Carbon monoxide concentration - Particle-board
Experiment
Prediction
CO volume fraction (ppm)
Time (seconds)



Carbon monoxide concentration - FR chipboard
Experiment
Prediction
CO volume fraction (ppm)
Time (seconds)



Smoke production rate - Particle-board
Experiment
Prediction
Smoke production rate (g/s)
Time (seconds)



Smoke production rate - FR chipboard
Experiment
Prediction
Smoke production rate (g/s)
Time (seconds)

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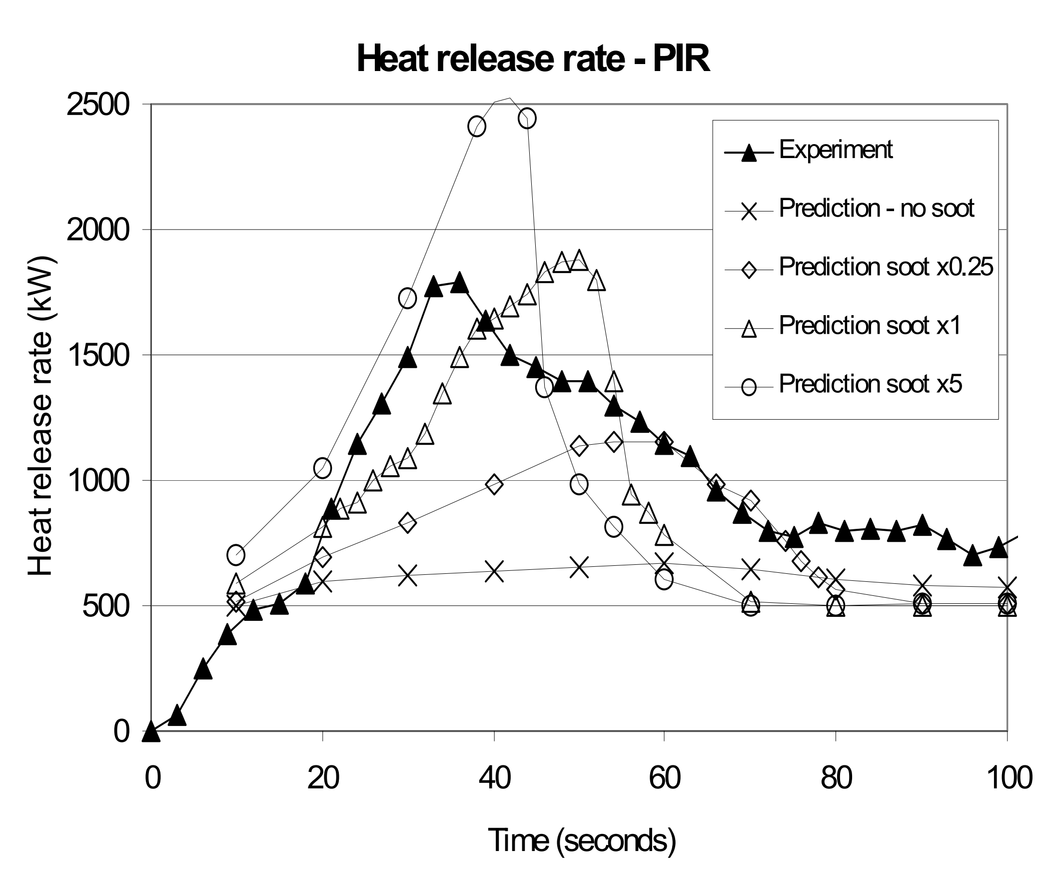
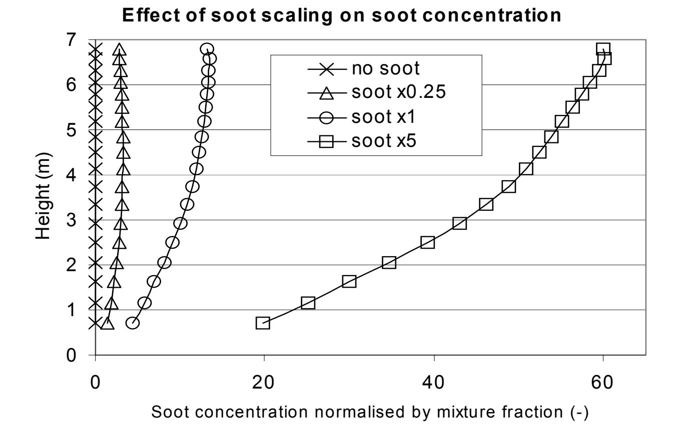
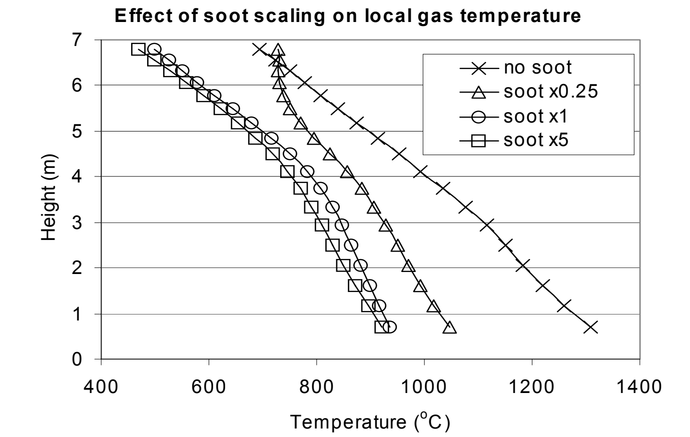
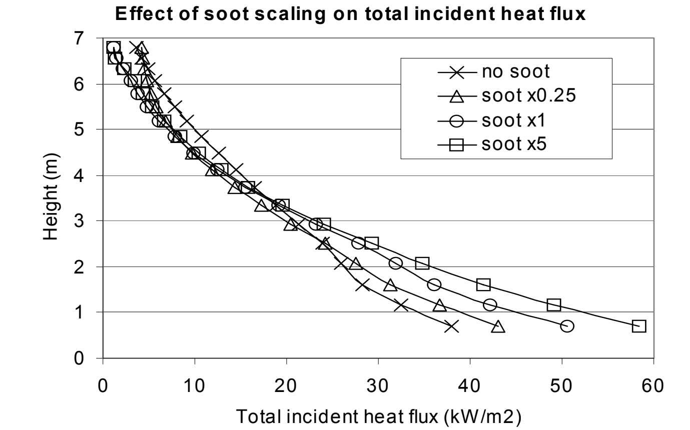
Soot effects









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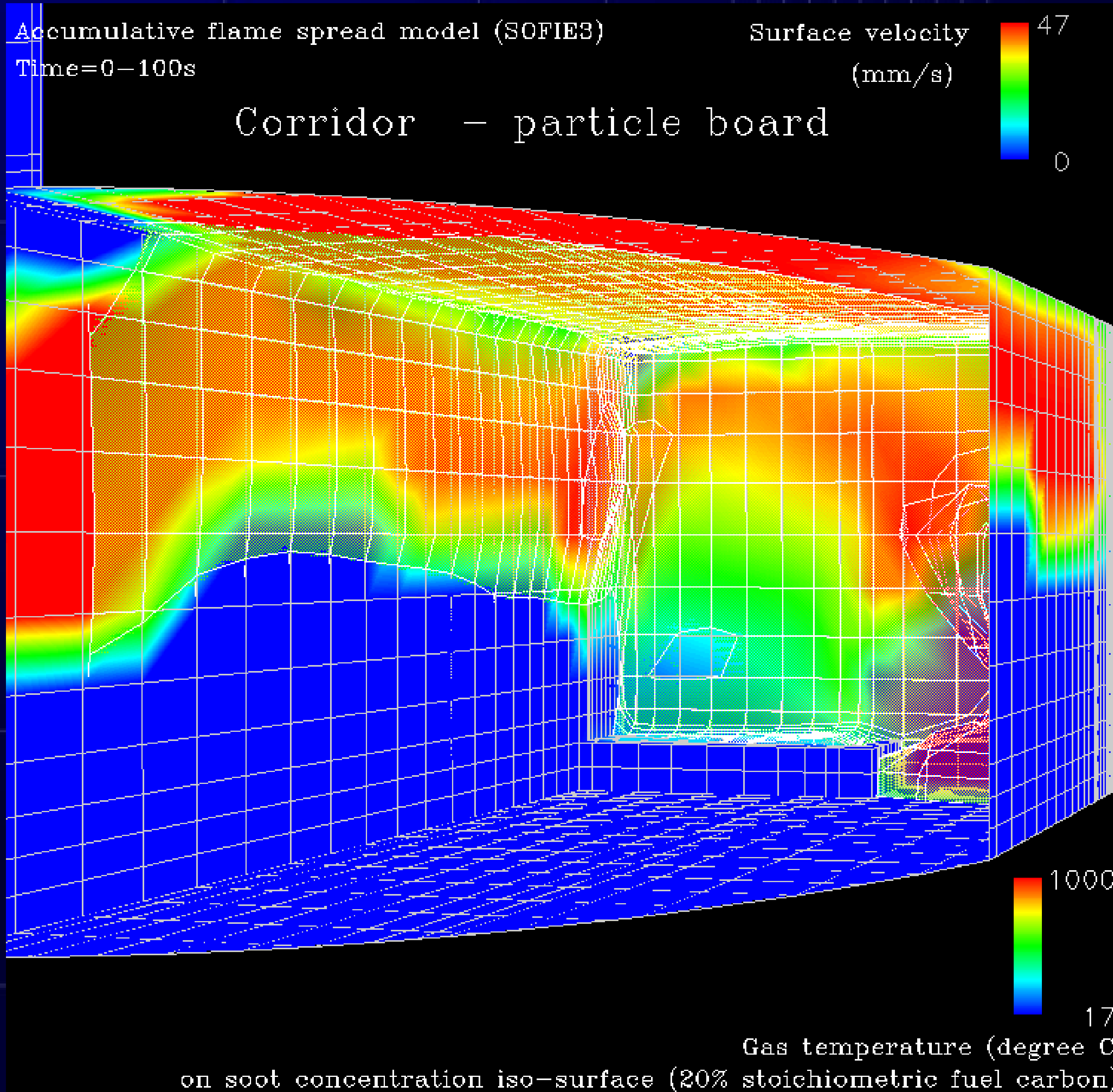
Accumulative flame spread model (SOFIE3)
Time=0–100s
Surface velocity
(mm/s)
47
0
Corridor – particle board
1000
17
Gas temperature (degree C)
on soot concentration iso-surface (20% stoichiometric fuel carbon)

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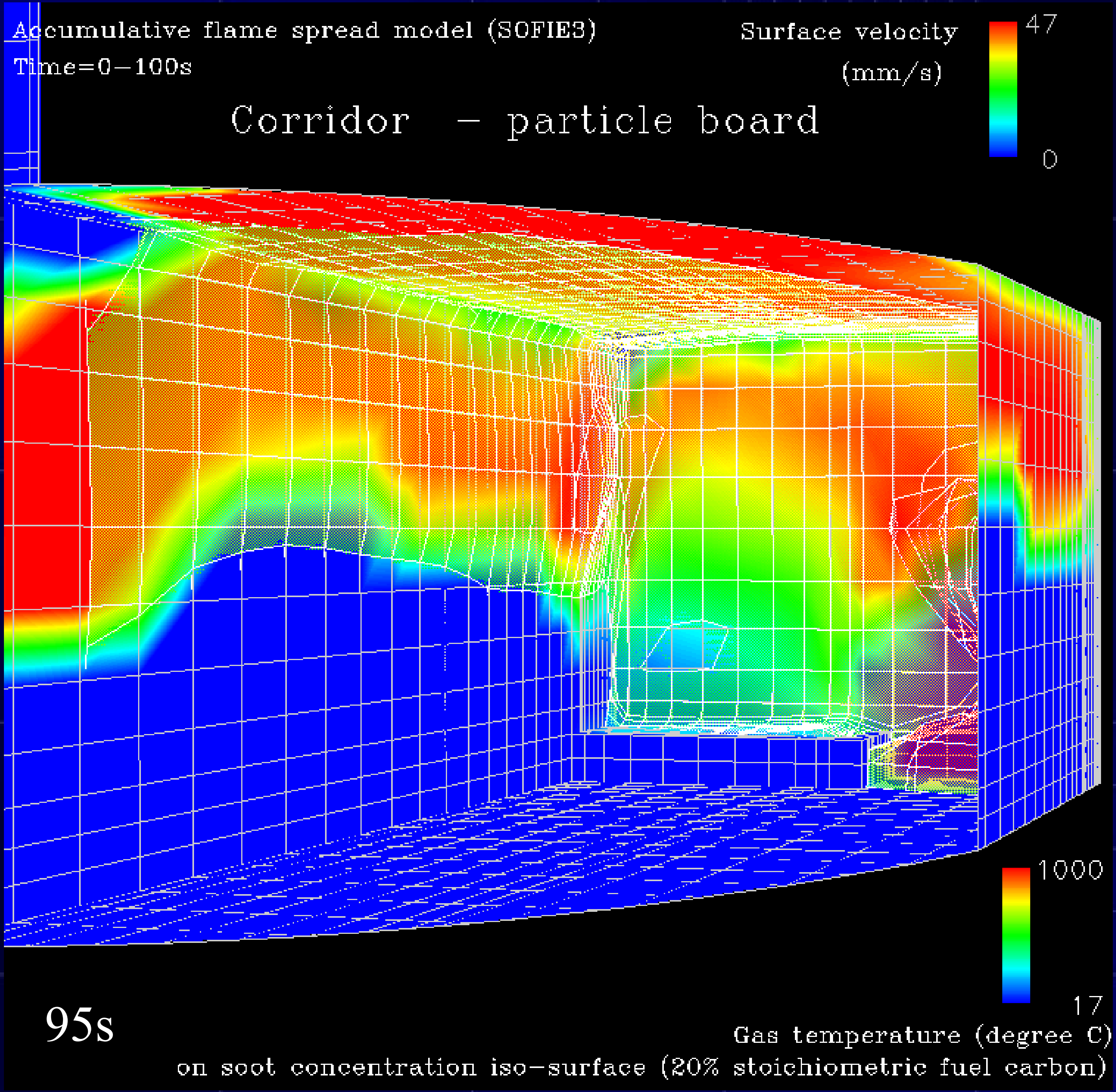


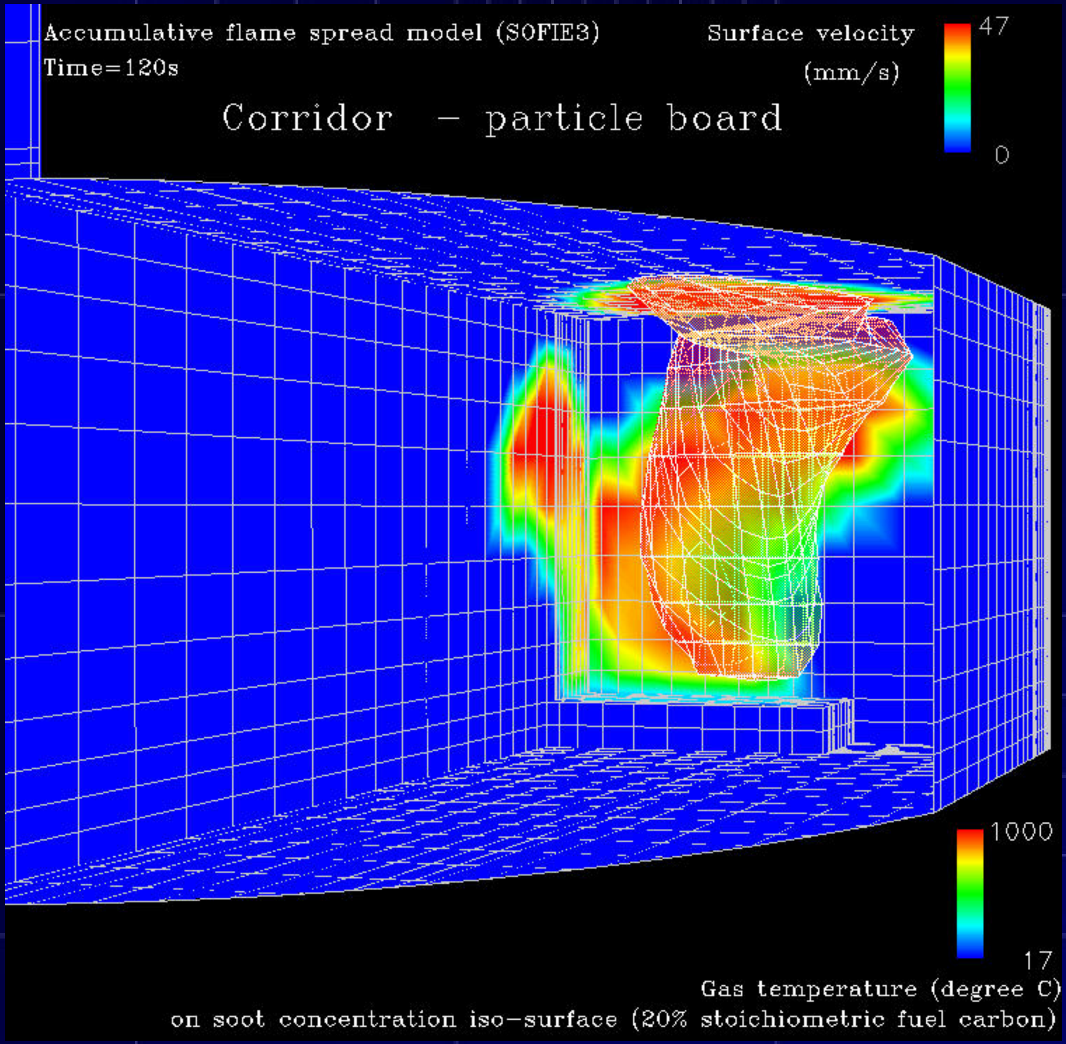
Accumulative flame spread model (SOFIE3)
Time=0–100s
Surface velocity
(mm/s)
47
0
Corridor – particle board
1000
17
95s
Gas temperature (degree C)
on soot concentration iso-surface (20% stoichiometric fuel carbon)

Predictive use of model - corridor

Time of ceiling spread:

Experiment: c. 35s

Prediction: c. 40s



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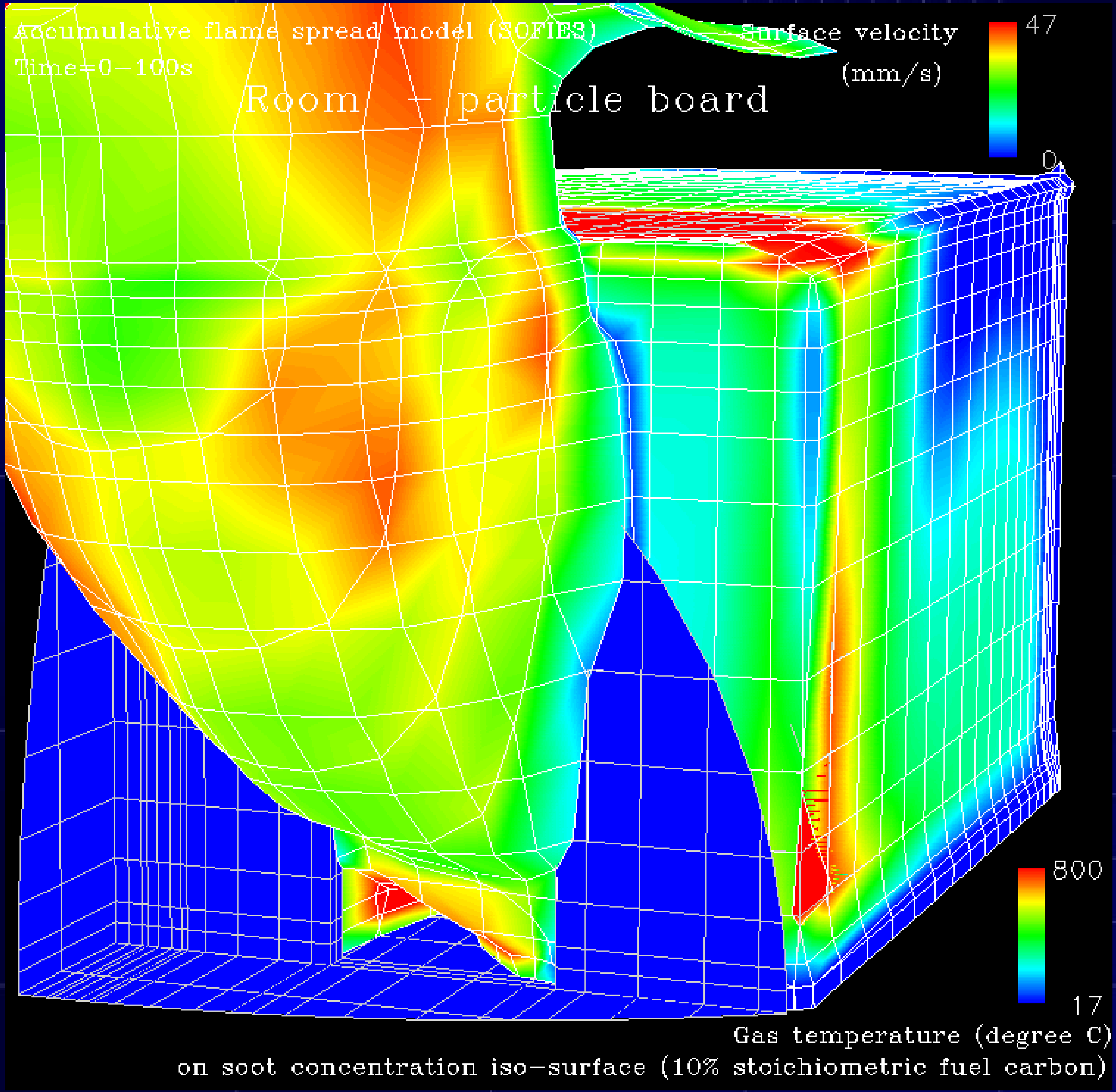
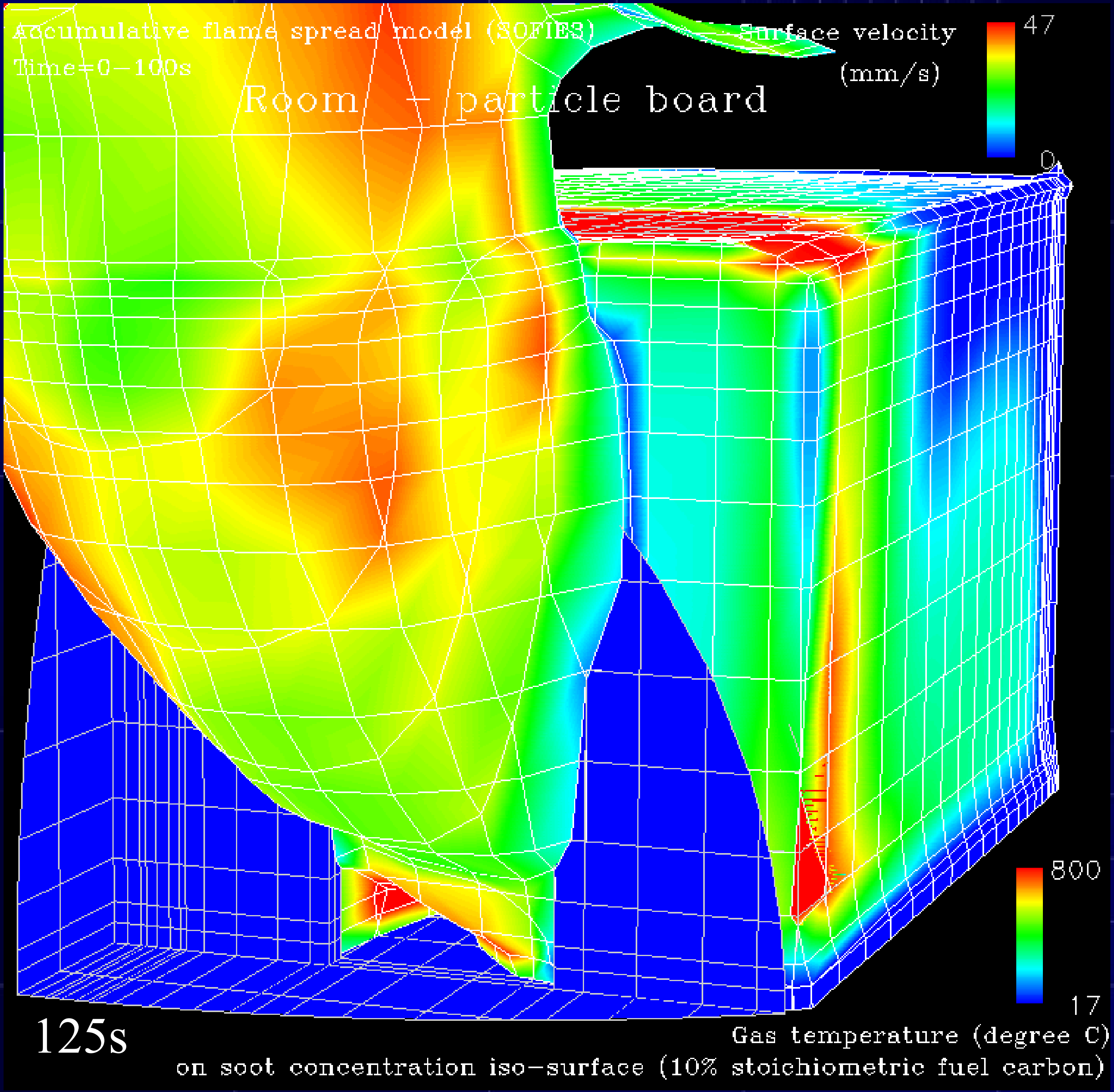

Accumulative flame spread model (SOFIE3)
Time=0-100s
Room - particle board
Surface velocity
(mm/s)
47
0
800
17
Gas temperature (degree C)
on soot concentration iso-surface (10% stoichiometric fuel carbon)

BRE


Accumulative flame spread model (SOFIE3)
Time=0-100s
Room - particle board
Surface velocity
(mm/s)
47
0
800
17
125s
Gas temperature (degree C)
on soot concentration iso-surface (10% stoichiometric fuel carbon)

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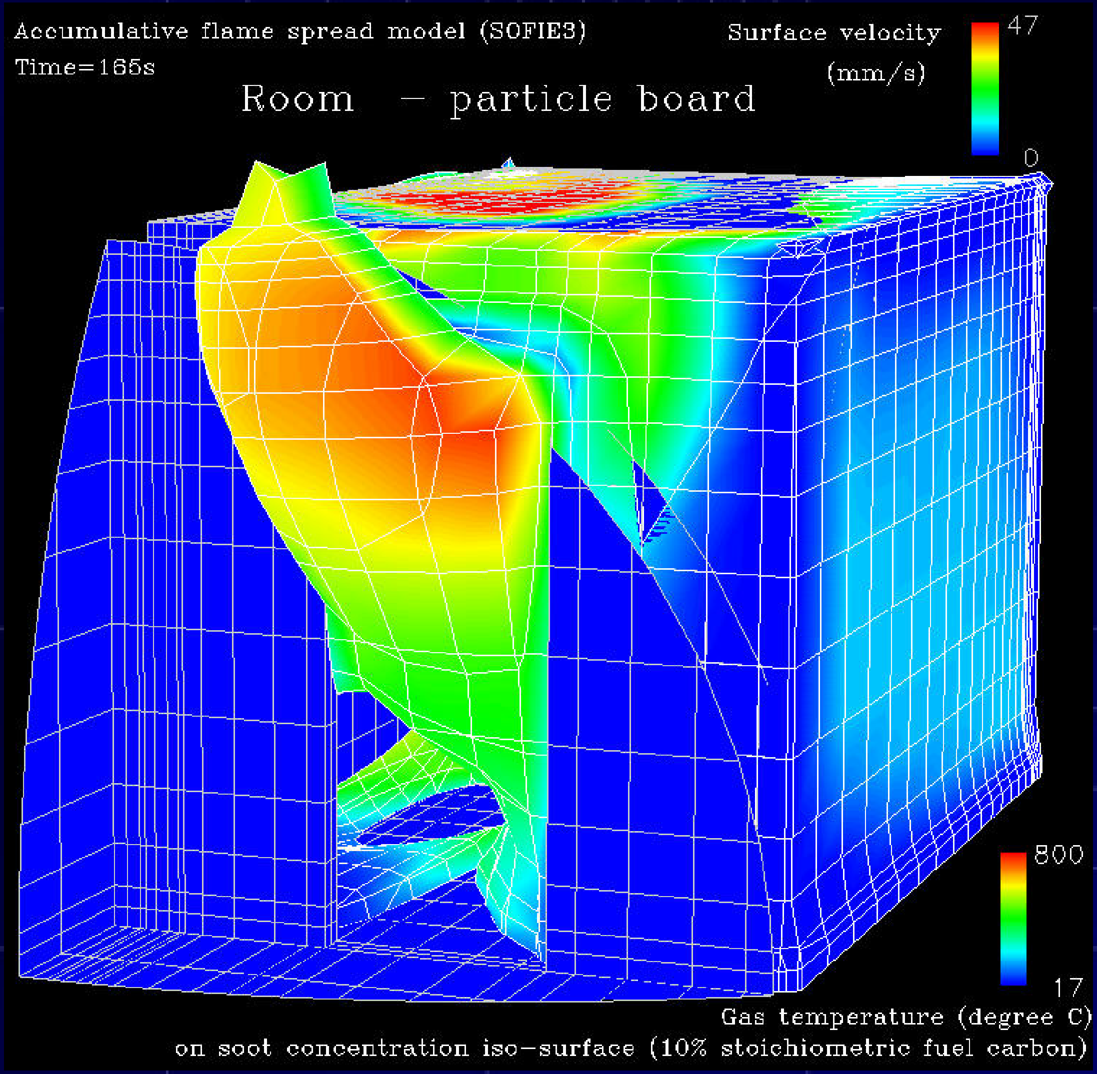
Predictive use of model - room

Time of ceiling spread:

Experiment: c. 105s

Prediction: c. 80s



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Further work

- Careful validation for whole set of tests
  - special consideration of more vitiated cases
- Sensitivity studies on numerical parameters (e.g. grid!)
- Need good representation of wood chemistry
  - would like to generate a new flamelet
- Development of a CFD treatment for multi-fuel problems!
  - currently treat everything as a single pure fuel

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Conclusions (1)

- Comprehensive fire growth and toxic products model
  - predictive capability depends on comprehensive nature
    - *simple flame spread model capitalises on detailed gas-phase info*
    - *fire growth behaviour intimately linked to gas-phase chemistry*
      - *strong sensitivity to soot predictions*
- Flame spread model
  - very crude
  - but reproduces fire growth phenomena sufficiently accurately in some cases
- Flamelet model
  - can reproduce smoke concentrations in these cases
    - *scale soot surface growth by measured yields*
  - can reproduce carbon monoxide concentration for plastics in these cases
    - *need another flamelet representing a typical "wood chemistry"*

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Conclusions (2)

- Requires material properties from tests
  - critical net accumulated heat flux
  - minimum flux
  - heat of gasification
    - *scaling factors (function of accumulated mass loss)*
  - material and char densities
  - char thickness
- We don't really mind which tests you do!