Fire Safety Engineering Workshop Session II B: Technical Methods for Fire Safety

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Quality Fire Safety Management

Presented at the Fire Safety Engineering Workshop at Sichuan Fire Research Institute, May 26-27, 2015, Chengdu, China

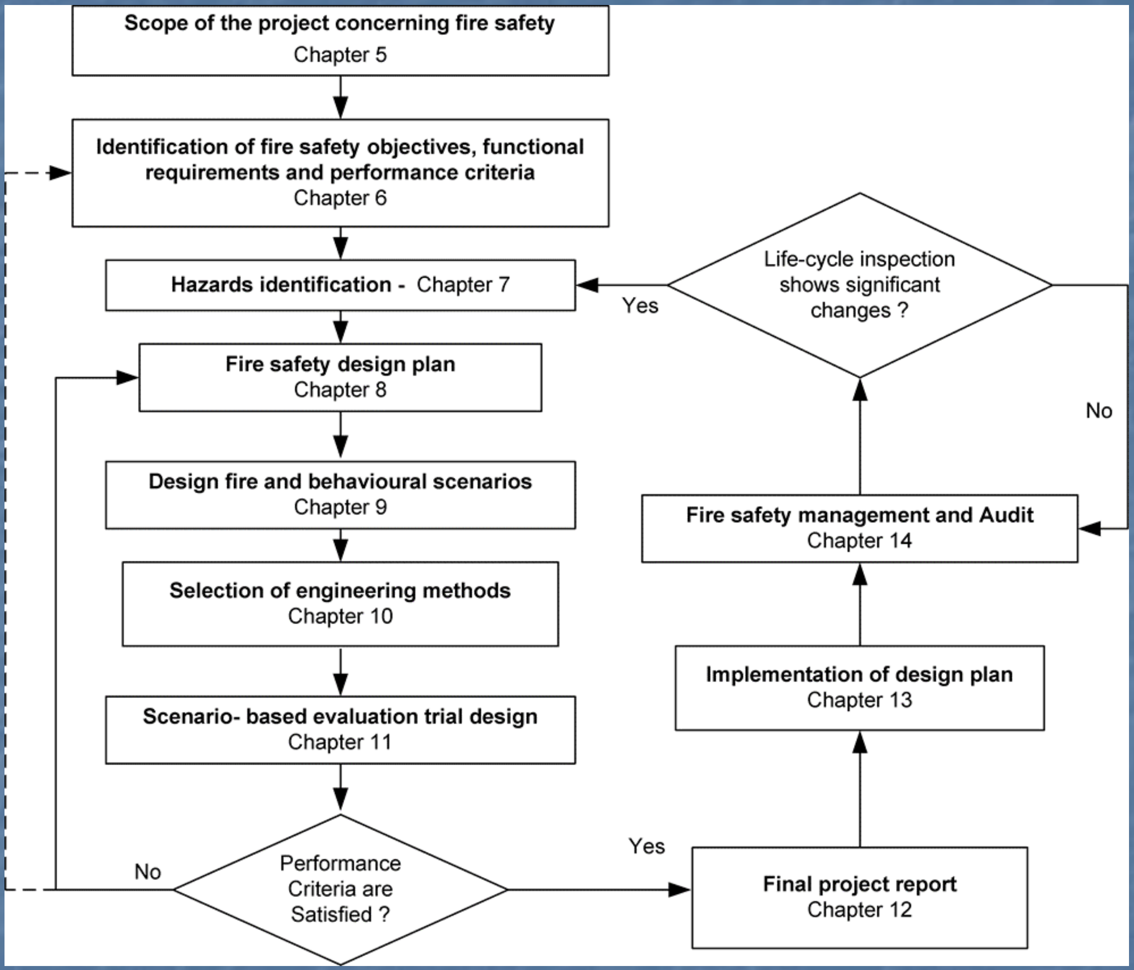
Plan for Session on Technical Methods

- General procedures for fire safety engineering
- Design fire scenarios and design fires
- Structural response and fire spread beyond the enclosure of origin
- Fire calculation methods for fire initiation, movement, and impact on structures

Plan for Session – Cont'd

- Methods for assessing the suitability of calculation methods for specific applications
- Verification & validation of fire calculation methods

Fire Safety Engineering Process



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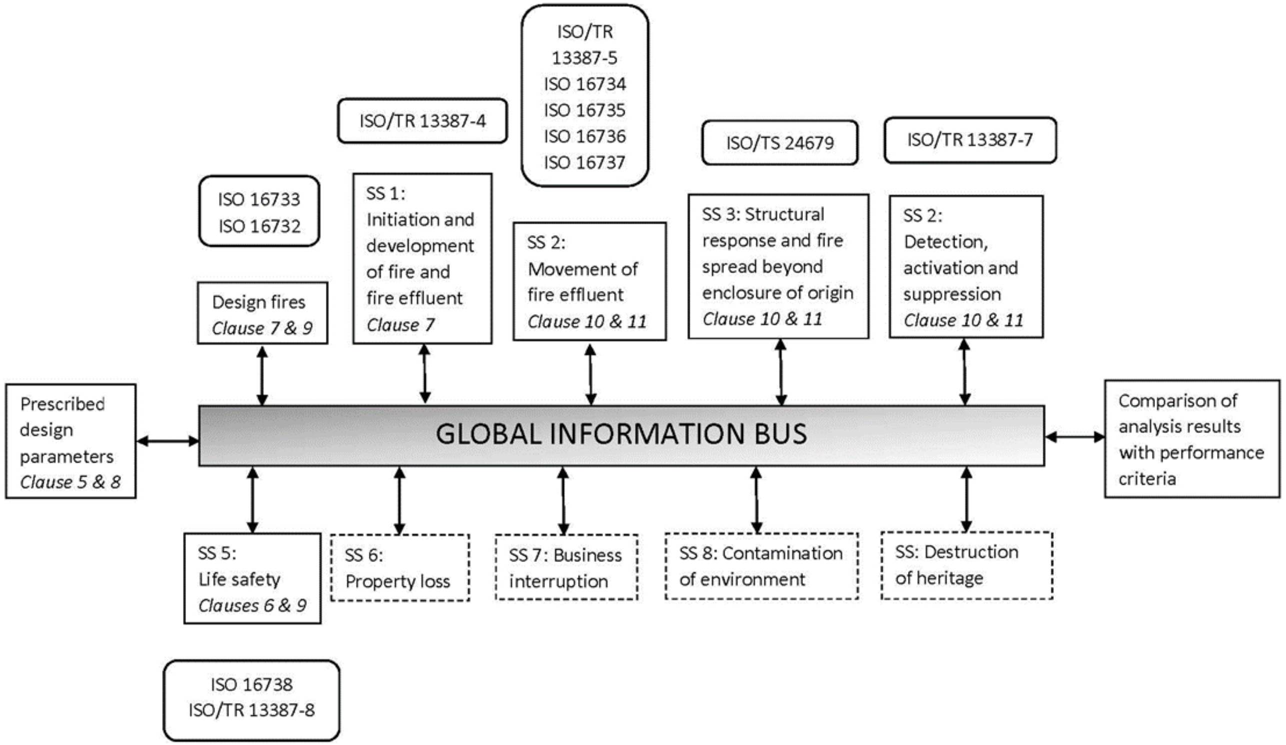
Global Information Bus



Global Fire Safety Engineering Analysis and Information System

Fire Calculation Methods

- Algebraic equations
- Two-zone models
- Computational fluid dynamic models
- One-zone models

Algebraic Equations

- ISO 16734 - Fire plumes
- ISO 16735 - Smoke layers
- ISO 16736 - Ceiling jet flows
- ISO 16737 - Vent flows
- New ISO standard under development to include above & full set of algebraic equations with ASTM & AIJ collaboration

Algebraic Equations

- Useful in quantification of design fire scenarios
- Quickly determine if fire safety design will meet performance criteria (PR)
- Can also check comprehensiveness of complex numerical models

Algebraic Equations

- Important considerations for use covered in ISO documents:
  - Physical phenomena & basis of formulation of governing equations
  - Limitations of equations
  - Input parameters
  - Domain of applicability

Algebraic Equations

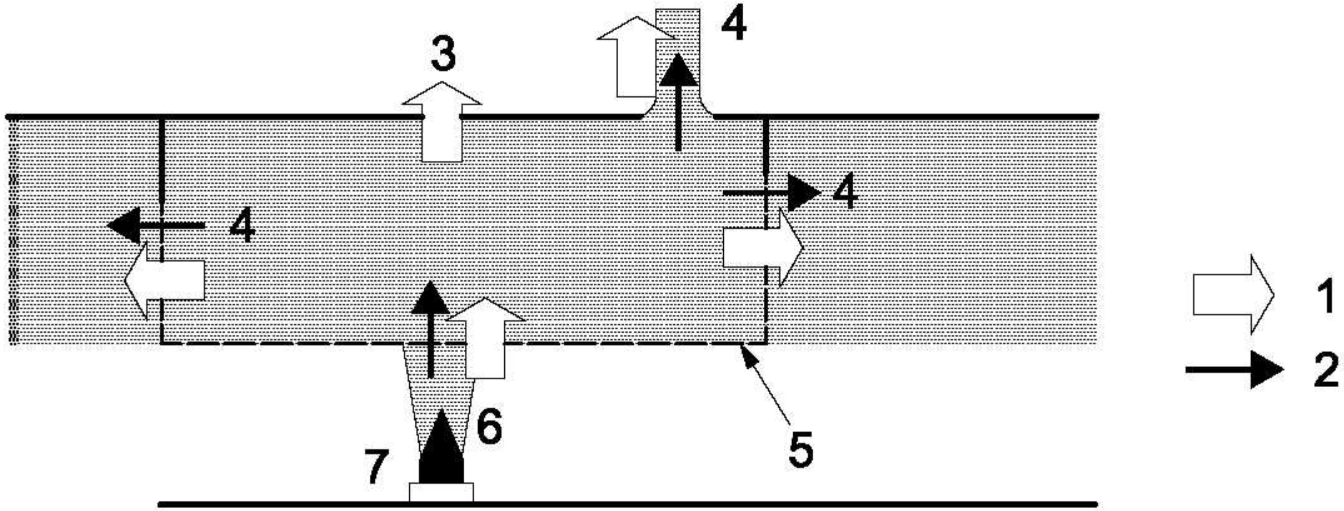
- Areas of application include:
  - Determination of convective & radiant heat transfer from fire plumes
  - Detector response times with ceiling jet flow
  - Smoke transport through vent openings
  - Smoke filling of rooms
  - Flame dimensions and flame spread

Algebraic Equations

- Fire Plume:
  - Quasi-steady state, axisymmetric fire plumes
  - Mean flame height
  - Mean center-line temperature rise
  - Mean centerline gas velocity

Algebraic Equations

- Smoke layers:
  - Interface position & time to fill room
  - Average temperature of smoke
  - Average concentration of smoke
  - Average concentration of chemical species
  - Smoke control by mechanical ventilation
  - Smoke control by horizontal vent



Key

1 heat flow
2 mass flow
3 wall heat absorption
4 vent flow
5 control volume
6 plume flow
7 fire source

From ISO 16735

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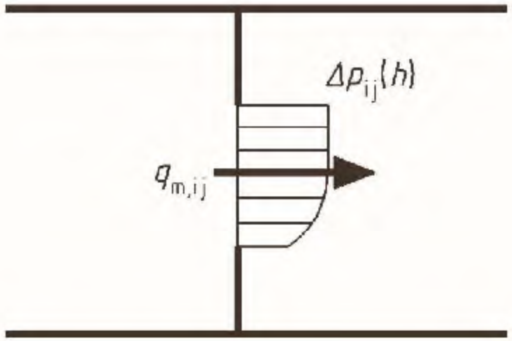
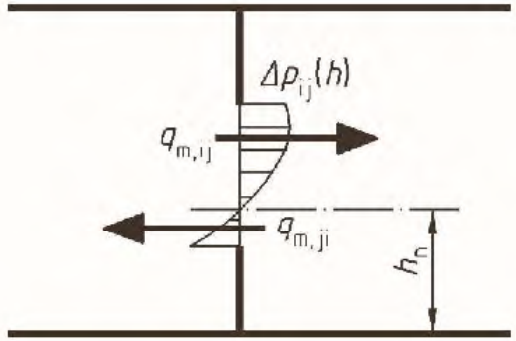
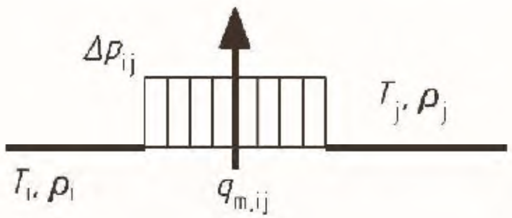
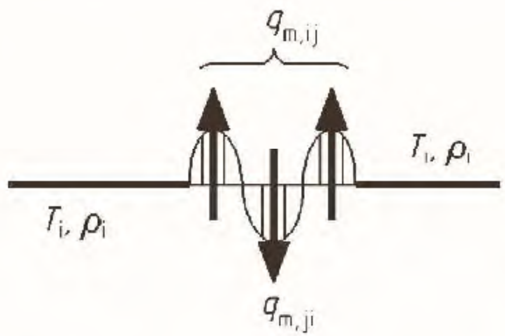
Algebraic Equations

- Ceiling jet flows
  - Response time of fire detectors & first activated sprinklers
  - Time to damage for some structural elements
  - Maximum gas temperature
  - Maximum ceiling jet velocity
  - Quasi-steady state, axisymmetric ceiling jet

Algebraic Equations

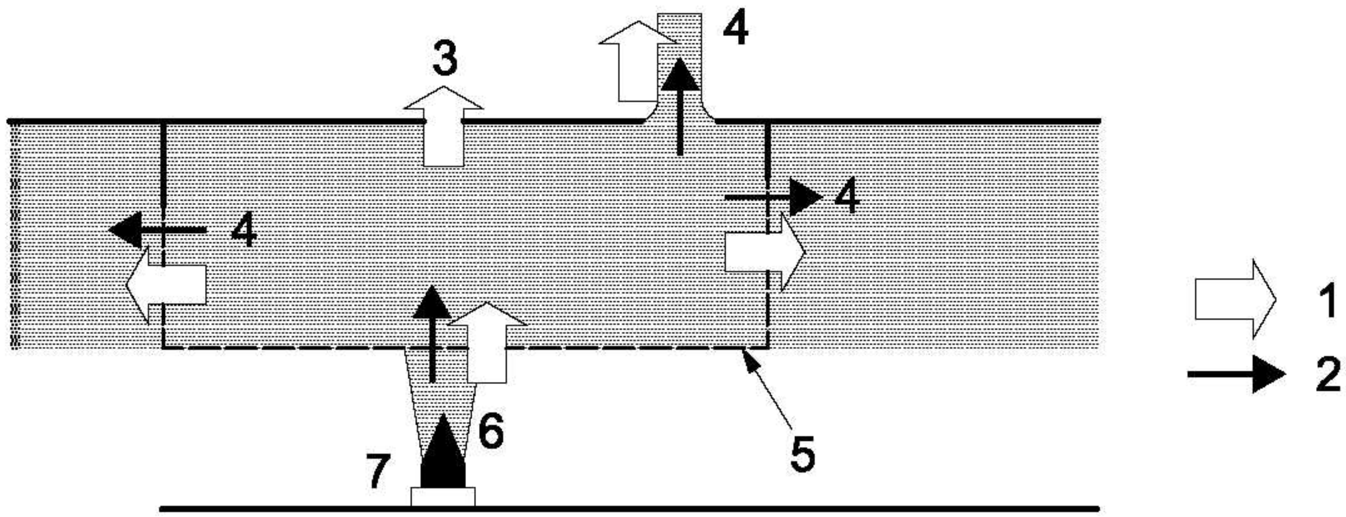
- Vent Flows
  - Orifice flow theory
  - Bi-directional for vertical vents & uni-directional for horizontal vents
  - Used to calculate movement of fire effluent through built environment

	uni-directional flow	bi-directional flow
vertical vent		
horizontal vent		 Flow is unstable. No explicit formula is available at present.

From ISO 16737

Zone Models

- ISO/TS Guidance for use of fire zone models
- Mass & energy conservation in control vol.
- Plume flow model
- Vent flow models
- Species concentration
- Time dependent numerical calculations



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Zone Models

- Applications:
  - predicting compartment smoke-filling time
  - evaluating tenability conditions for life safety
  - reconstructing past fire events
  - determining time of sprinkler operation
  - determining smoke extract capacity for naturally or mechanically ventilated spaces
  - Impact on equipment

Zone Models

- Limitations:
  - No solution of momentum equation, instantaneous rise & movement of gases
  - Lumped calculation results in average values
  - Suited for rectangular geometry
  - Idealized plume flow
  - No heat or mass transfer between zones
  - Modeling of vents

Zone Models

- Advantages:
  - Computationally less demanding than CFD models
  - Allows large number of simulations for sensitivity analysis
  - Allows analysis of transient effects compared to static algebraic equations
  - Accurate predictions of hot gas temperature
  - Accurate prediction of O2, CO2, CO, soot for ventilated conditions

CFD Models

- Solution of momentum equation provides flow patterns for complex geometries
- Modeling of flow turbulence
- High resolution provides detailed localized distributions
- Includes better modeling of fire source
- Development of ISO standard on use of CFD models planned

CFD Models

- Limitations:
  - Prediction of conditions at or near flame
  - Movement & location of flaming region
  - Prediction of flow for certain vent conditions
  - Modeling of under-ventilated conditions
  - Accurate prediction of heat flux from flaming region & hot gas
  - Computationally intensive
  - Large resolution leads to exhaustive data

Recommended Approach for Selecting Calculation Method

- Most fire safety designs can be completed with quick algebraic equations
  - Less costly
  - Generally conservative
  - Provides users knowledge of calculations
  - Transparent to authorities

Recommended Approach for Selecting Calculation Method

- In some cases use of zone models is useful to analyze transient behavior & to decrease conservatism
  - Easy to use
  - Limited input data
  - Can be used to provide conservative results for most problems

Recommended Approach for Selecting Calculation Method

- In rare cases, CFD models can useful for fire safety design:
  - Useful where details of flow distribution is valuable for safety design
  - Accurate local temperature distributions are predicted which can be useful for design
  - Use caution & acknowledge limitations: radiant flux, vitiated conditions, etc.

Comparison of Calculation Methods with Experiment

- Algebraic equations in the Fire Dynamics Tools (FDTs) compilations
- Consolidated Fire and Smoke Transport (CFAST) zone model
- Fire Dynamics Simulator (FDS)

Figure 3.9 Partially Under Ventilated Fire in Test 13 (2 MW)

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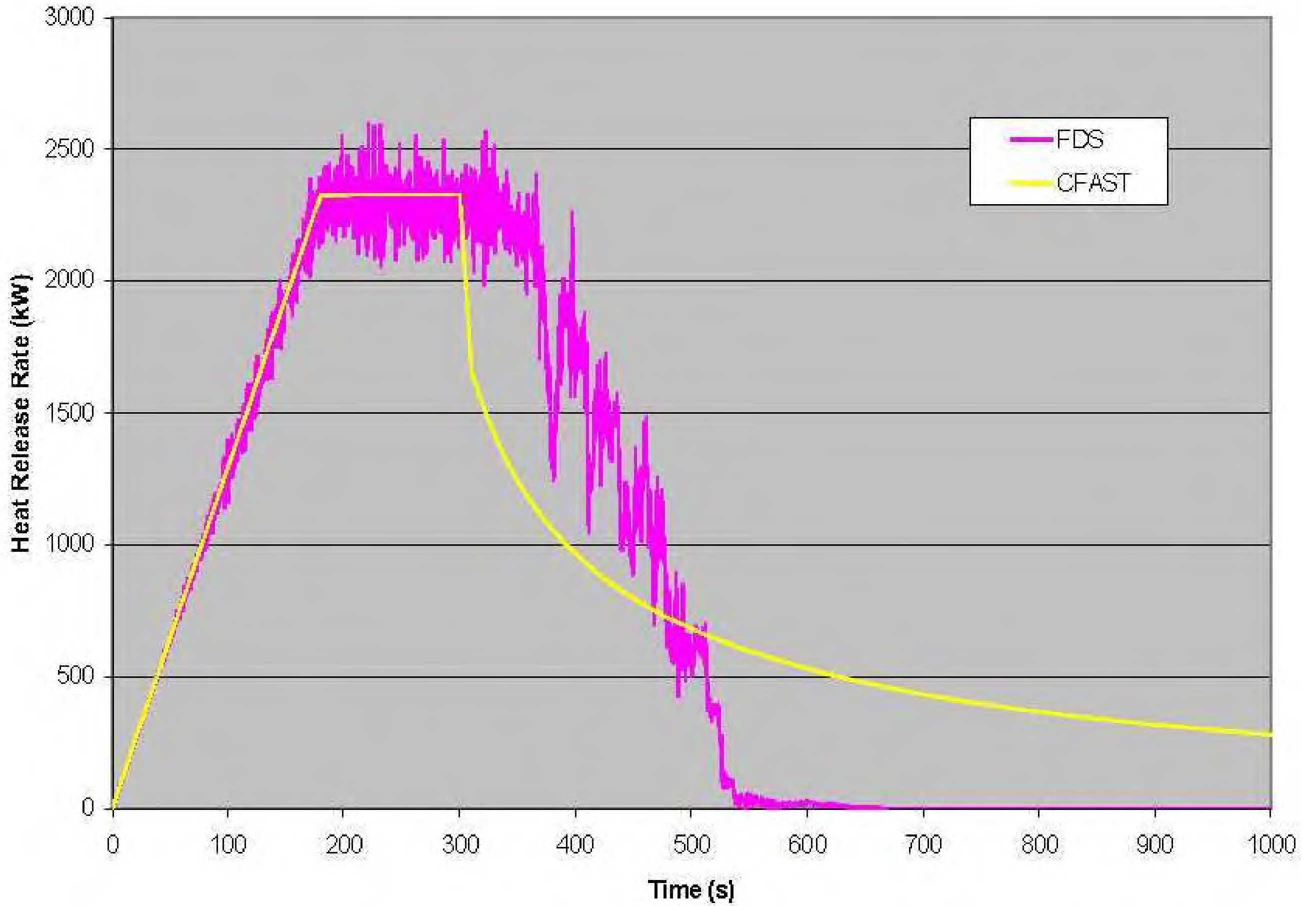

Figure 5.7.1 Heat Release Rate - Test 13

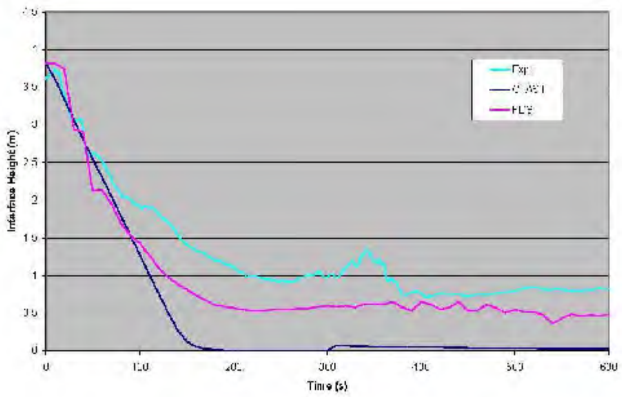

Figure 5.7.3 Hot Gas Layer Development - Test 13

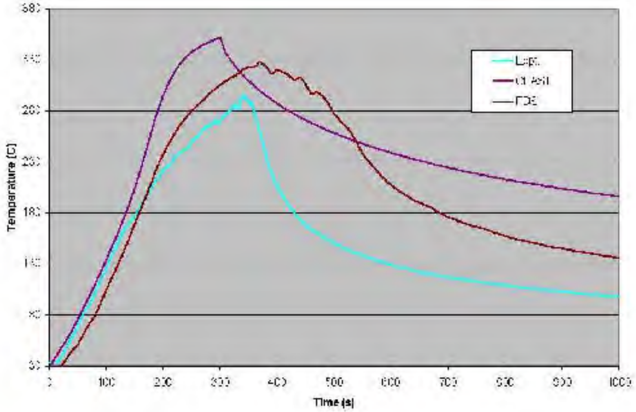

Figure 5.7.4 Hot Gas Layer Temperature - Test 13

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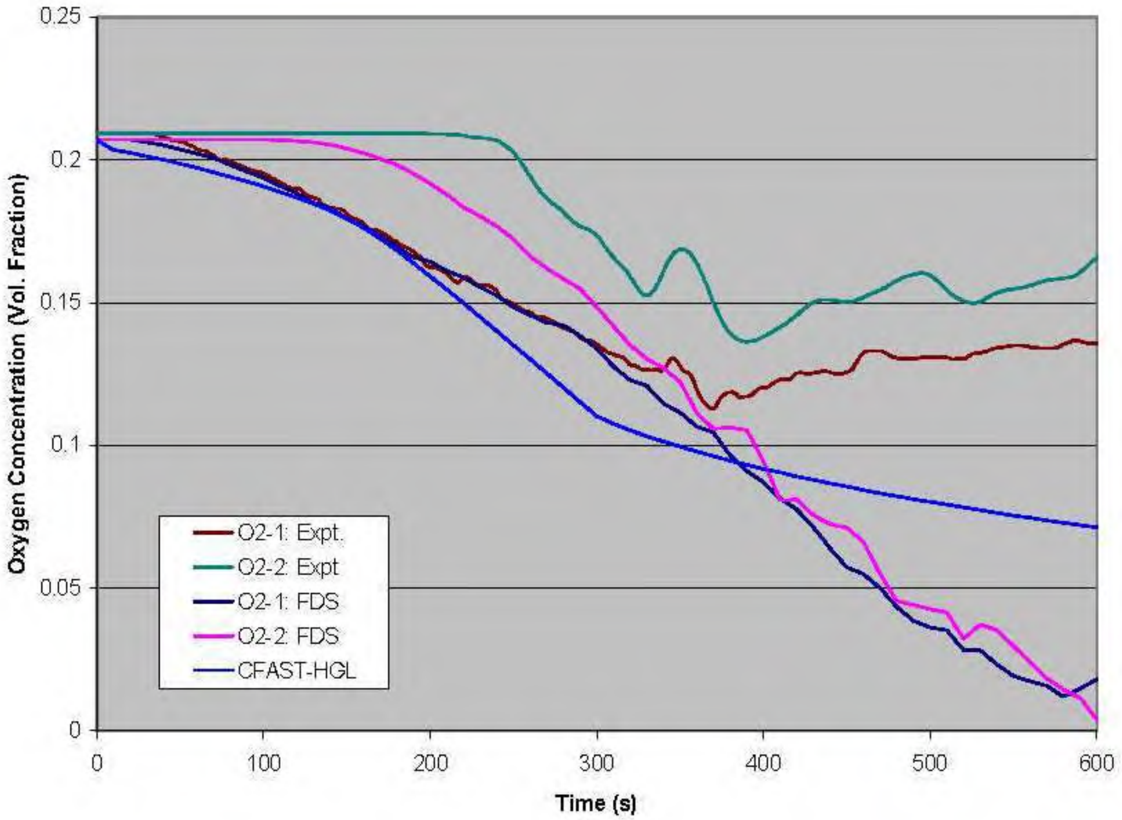

Figure 5.7.5 Oxygen Depletion - Test 13

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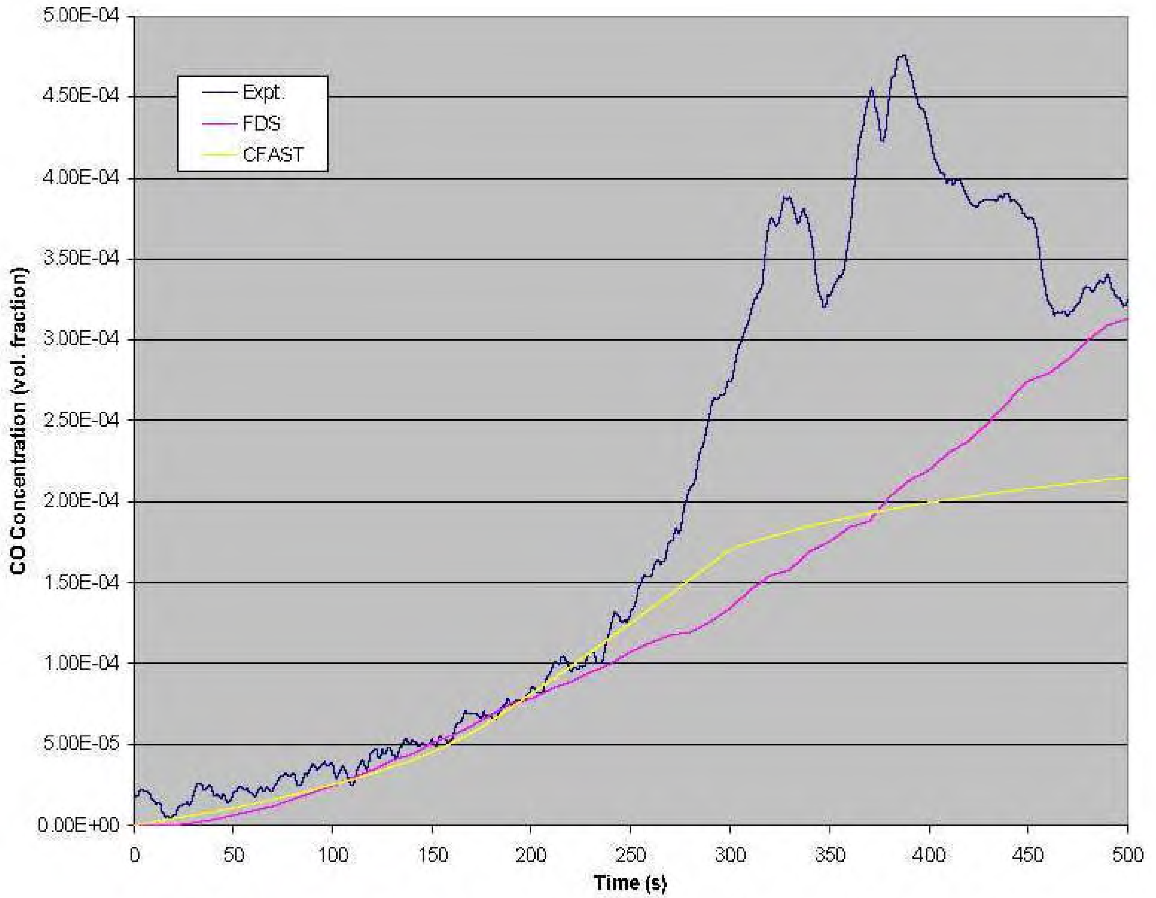

Figure 5.7.7 CO Concentration - Test 13

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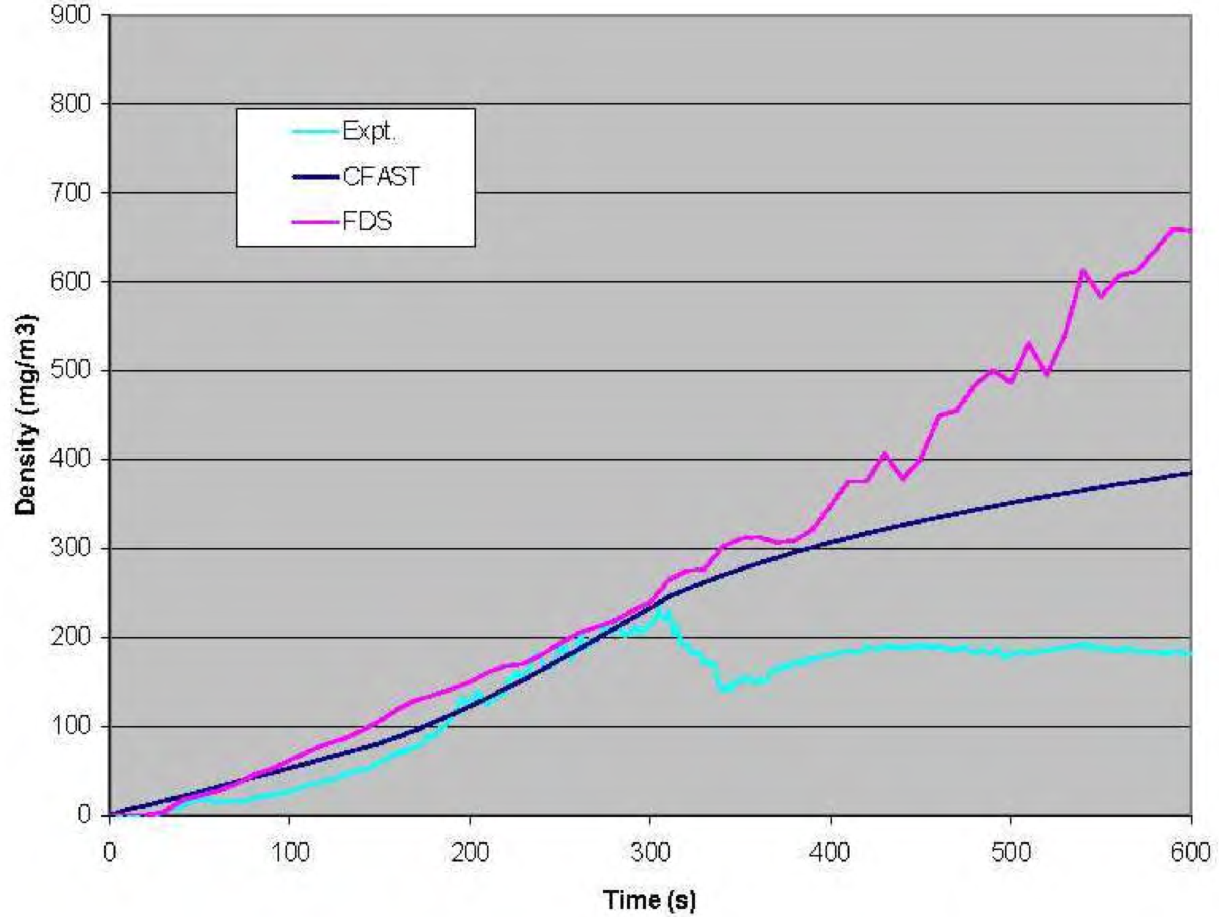

Figure 5.7.8 Smoke Density - Test 13

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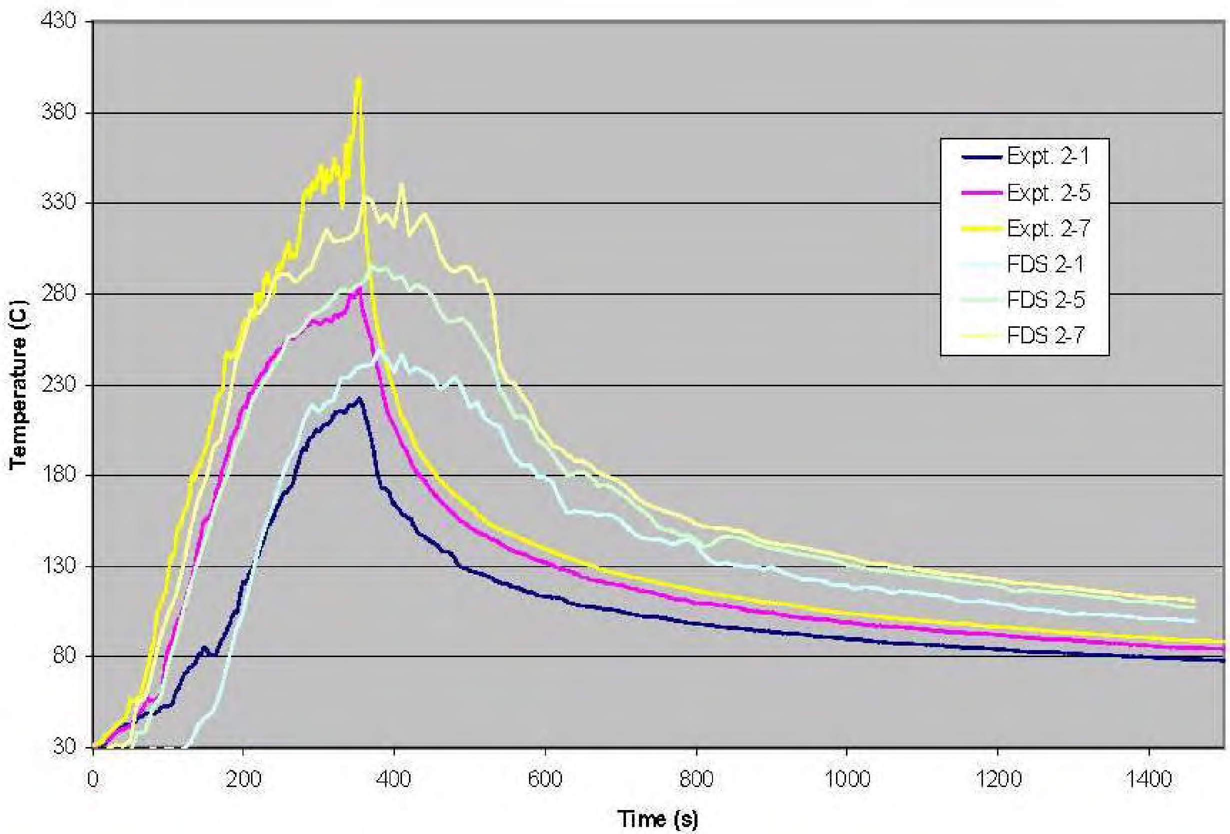

Figure 5.7.9 TC Tree 2 - Test 13

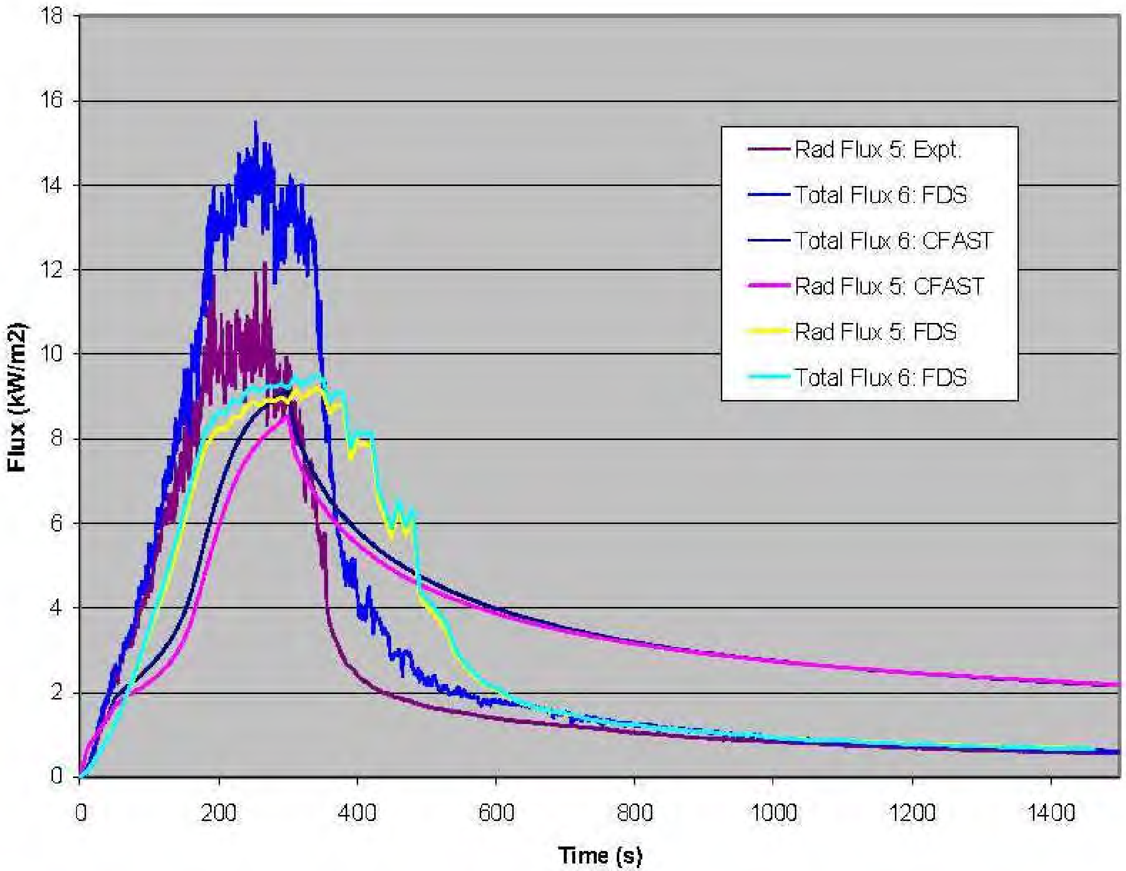

Figure 5.7.14 Heat Flux to Cables (5 & 6) - Test 13

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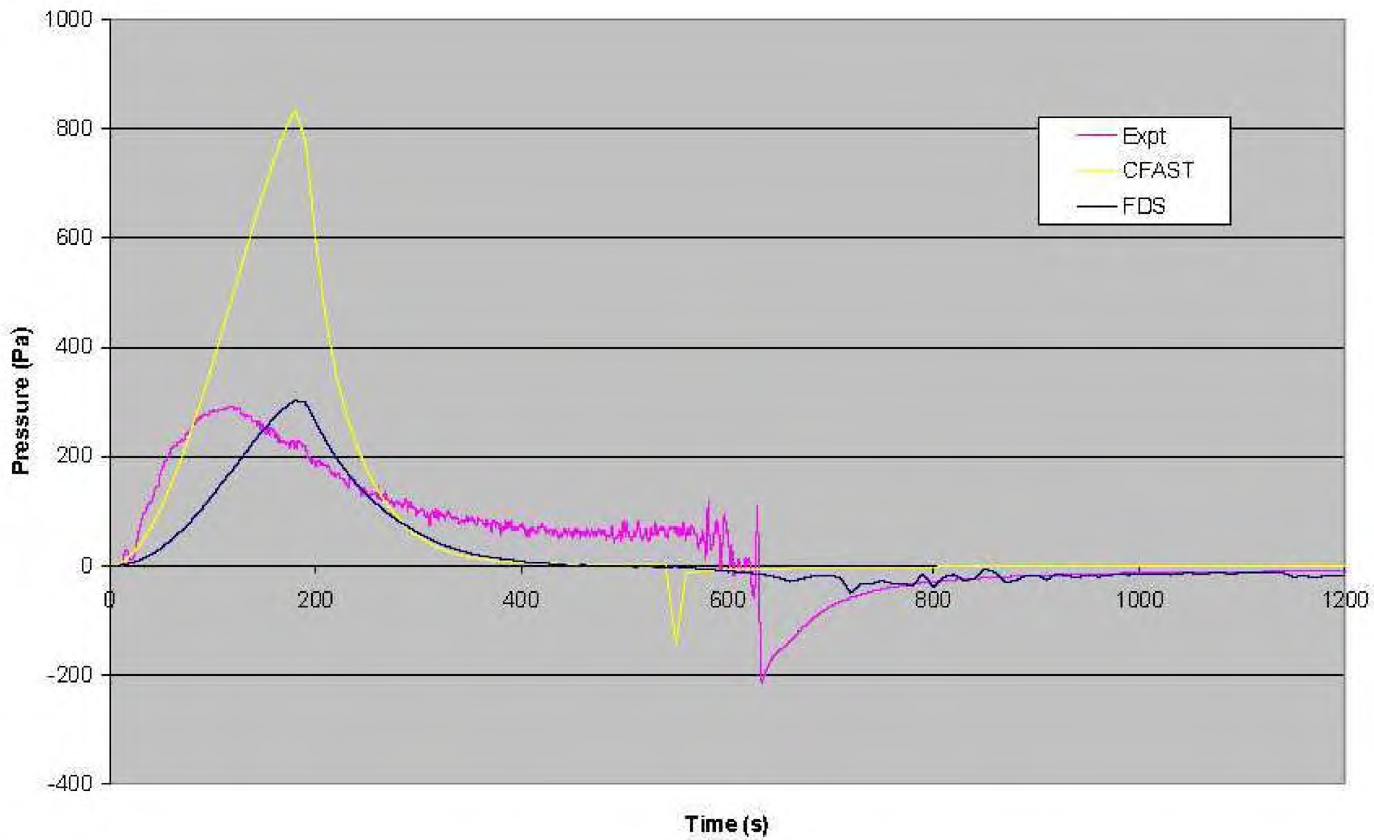

Figure 5.2.2 Compartment Pressure - Test 2

Recommended Approach to SCFRI

- Best method to select calculation is:
  - Understand the mathematical formulations of the calculation method
  - Assess the predictive capability of the methods through V&V studies for wide range of fire scenarios
  - Apply appropriate calculation methods based on above knowledge & problem to be solved

Recommended Approach to SCFRI

- Conduct experiments to cover wide range of fire scenarios for typical applications
- Conduct V&V exercises against these experiments
- Develop match of calculation method best suited for range of applications

Questions

- Comments and discussion
- Thank you

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