Advanced Measurement & Predictive Methods Program

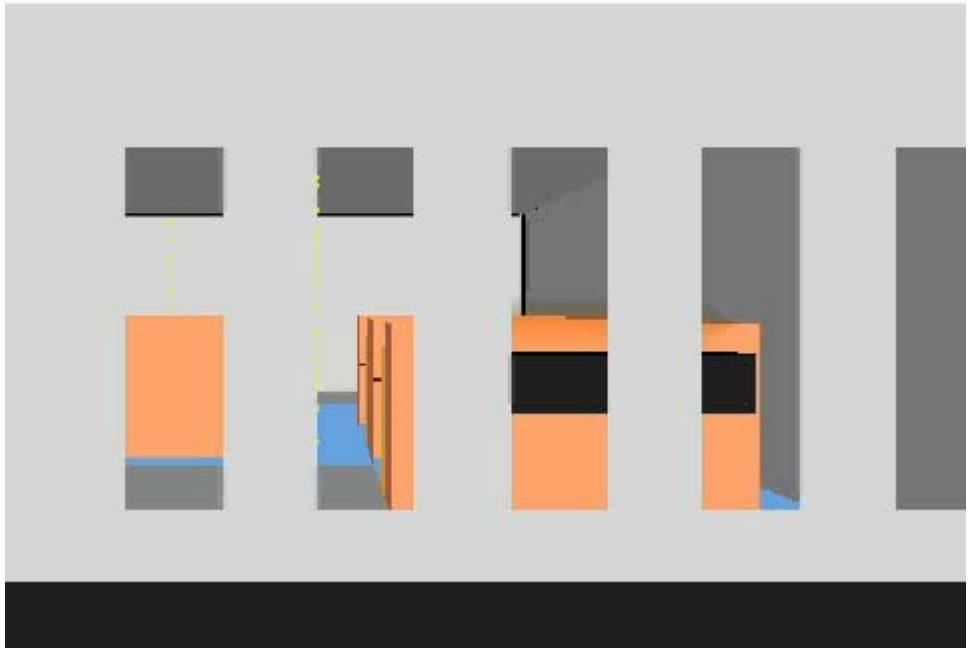
Program Manager: Greg Linteris / Anthony Hamins**;**

PIs: Bryant, Bundy. Forney, Gann, Grosshandler, Johnsson, Hamins, Linteris, Maranghides, McGrattan, Yang

Metrology and Modeling

Material decomposition
Gas flow
Heat transfer
Heat release
Soot
Toxic gases
Under-ventilated burning

LFL Full-Scale Burn



FDS Simulation

Program Goal

To produce accurate fire measurement data and techniques, and predictive methods, which enable engineered fire safety for people, products, facilities, and first responders.

Program Priorities

1. **Support** other BFRL programs and goals.

2. Be a recognized **source** of high quality:
   - fire measurements
   - fire predictions.

3. **Enhance** our specialized facilities:
   - establish a world-class Large Fire Laboratory (LFL) with advanced capabilities

4. **Transfer** BFRL research results to industry (such as fire testing labs) and to organizations that create standards and codes.

5. **Create** the fundamental tools and knowledge that:
   - enable the implementation of performance based fire codes
   - allow assessment of key test methods (ASTM cone calorimeter, ISO 9705 room fire, UL 94)
   - address international barriers to standards
   - support BFRL customers and stakeholders
   - maintain excellence in fundamental research capabilities.

Advanced Measurement & Predictive Methods

FY 06 Program Funding:

Advanced Measurements for Large Fires

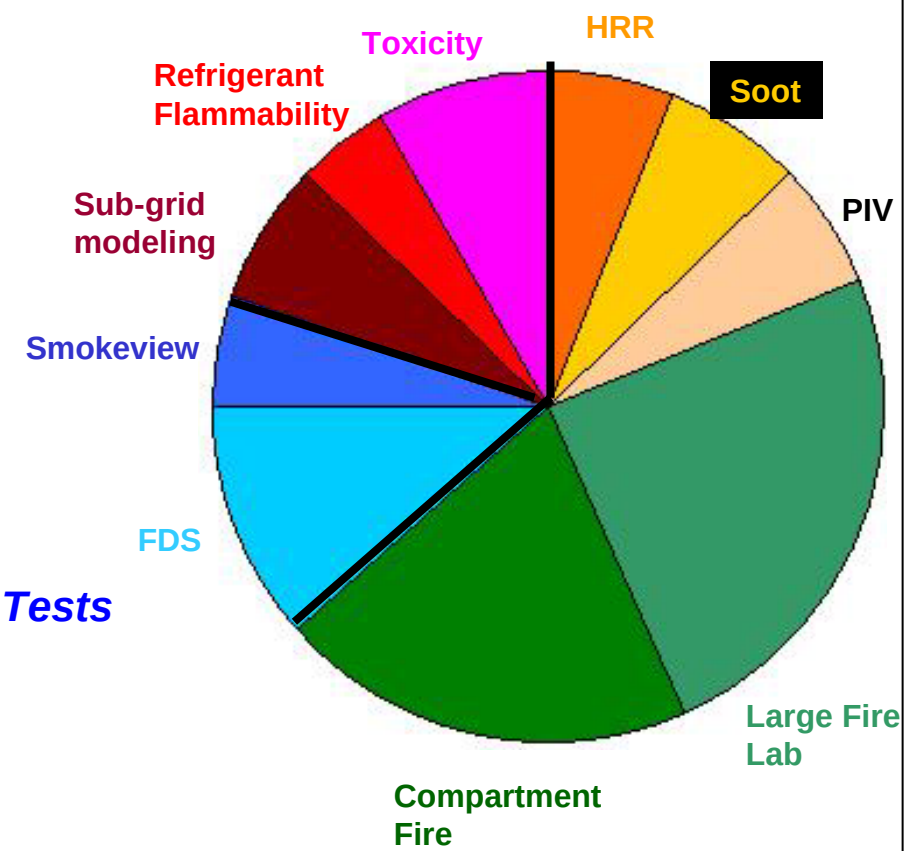
Heat Release in Large Fire Meas.
Soot Volume Fraction Measurements
Gas Velocity Measurements in LFL
Large Fire Laboratory Operations
Under-ventilated Compartment Fire Tests

Advanced Predictive Methods

FDS Development
Smokeview Development

Small-scale Tests in Support of Large-Scale Tests and Modeling

Experimental Data for Sub-Grid Modeling
Flame Speed as a Fundamental Metric
Toxicity Test Method Development

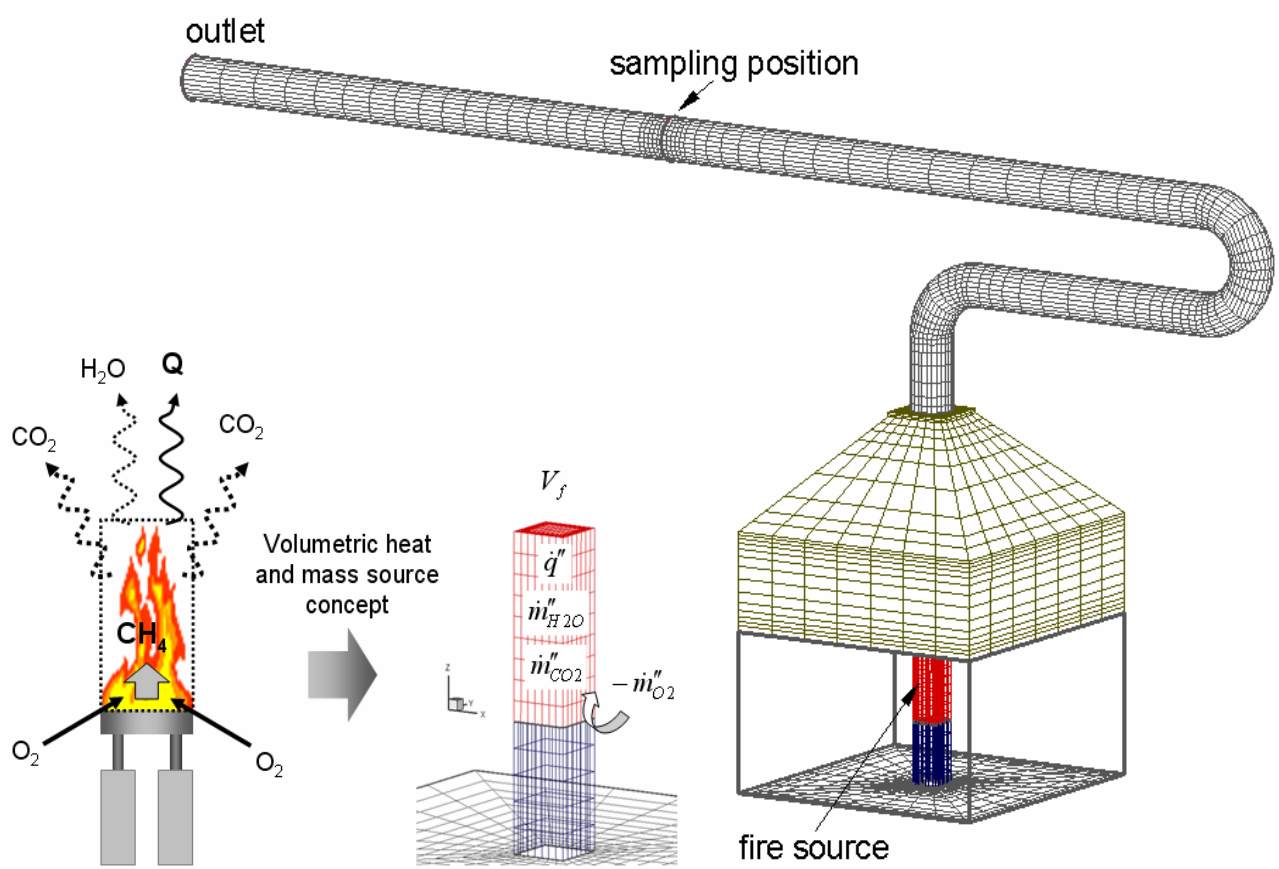


Recent Results

Heat Release in Large Fire Measurements PI: Matt Bundy

Recent Accomplishments:

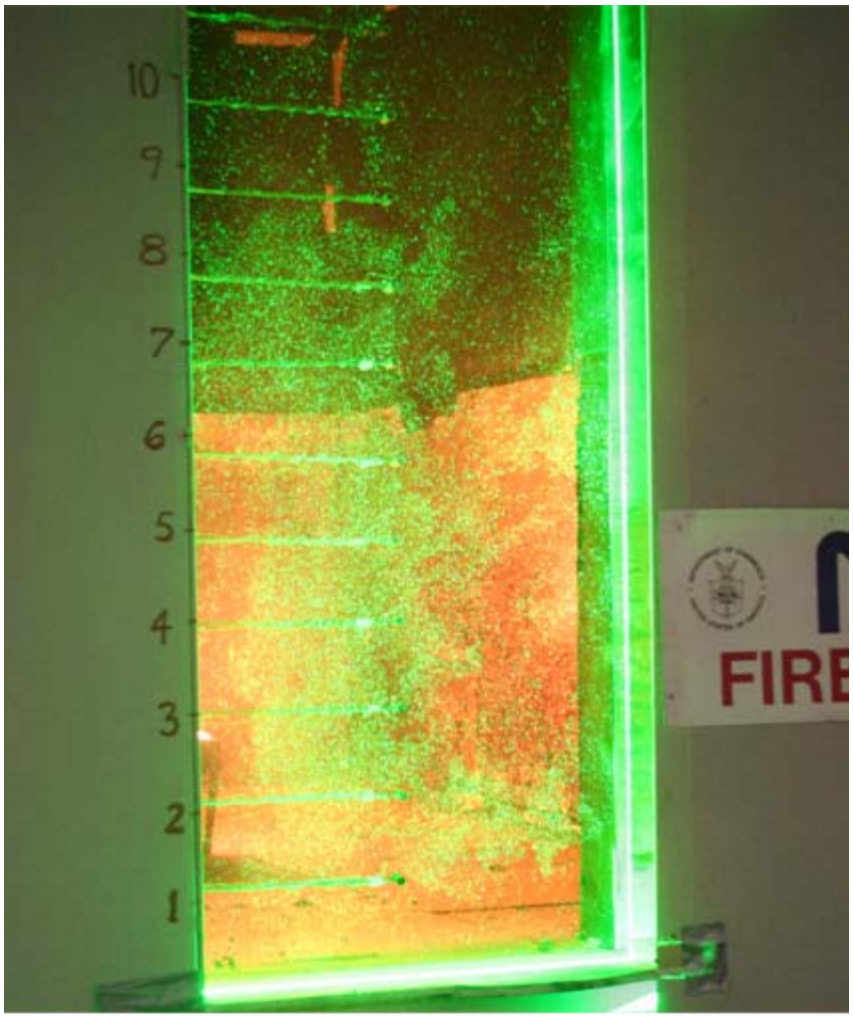
- Completed new design and installation of the 500 kW calorimeter (3 m x 3 m hood) exhaust duct
  - A new method for exhaust flow measurement has been implemented
  - The recent changes have resulted in more than a factor 2 reduction in the HRR uncertainty
- A plan for reducing the uncertainty in the 10 MW calorimeter (9 m x 12 m hood) has been developed

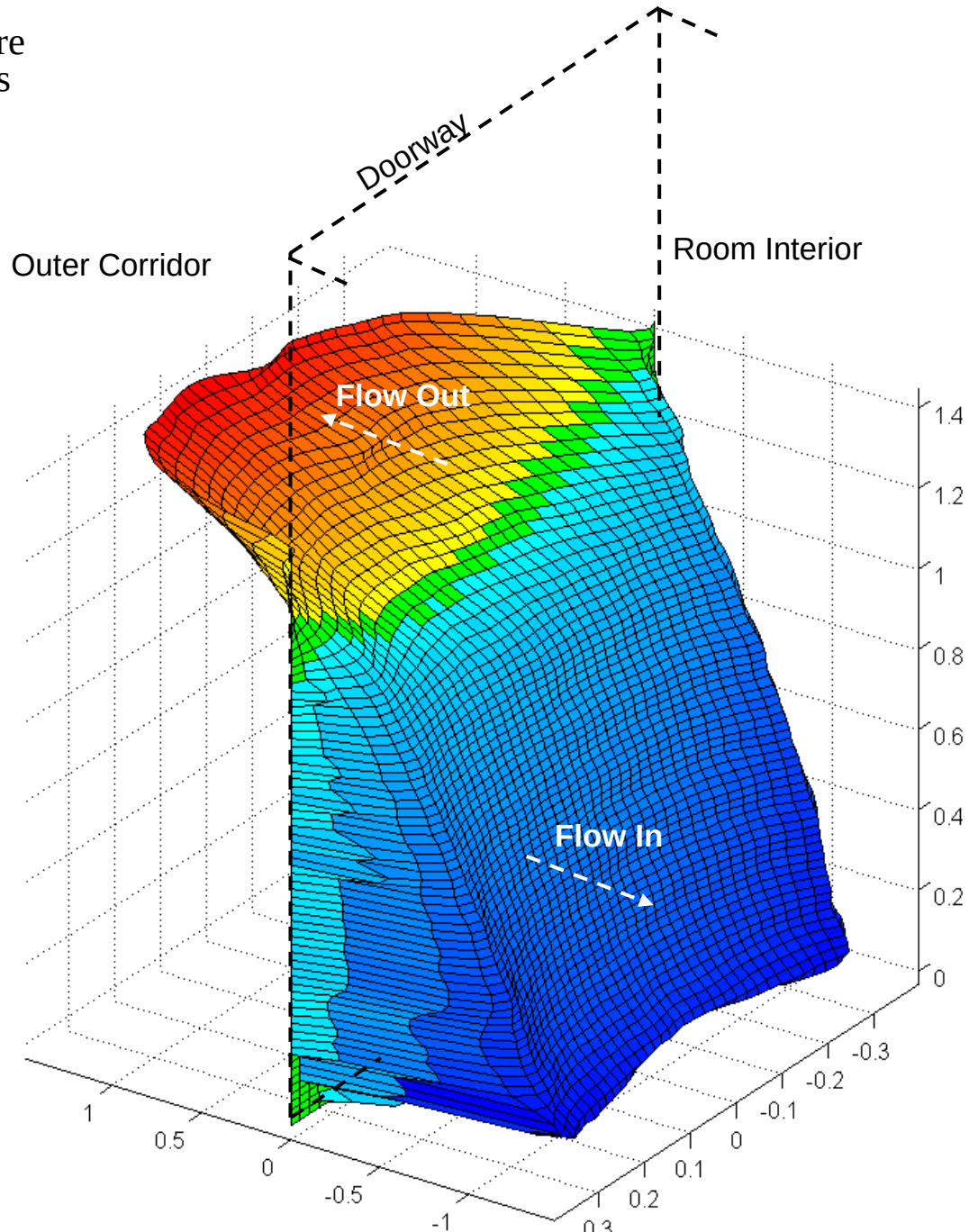


Numerical CFD model used to study and improve HRR measurement methods

Gas Velocity Measurements PI: Rodney Bryant

- Stereo Particle Image Velocimetry performed in a full-scale fire-induced doorway flow. Measures particle displacement and is totally independent of conventional physical probes for T and P.
- The flow <u>into</u> room was fully mapped (velocity component normal to the opening), improving computation of velocity flux.
- Added to the doorway flow measurement literature
  - Examined a large series of fire conditions
  - Fires closer to flashover conditions





Measurement of Soot Volume Fraction in Fires

PI: Jiann Yang

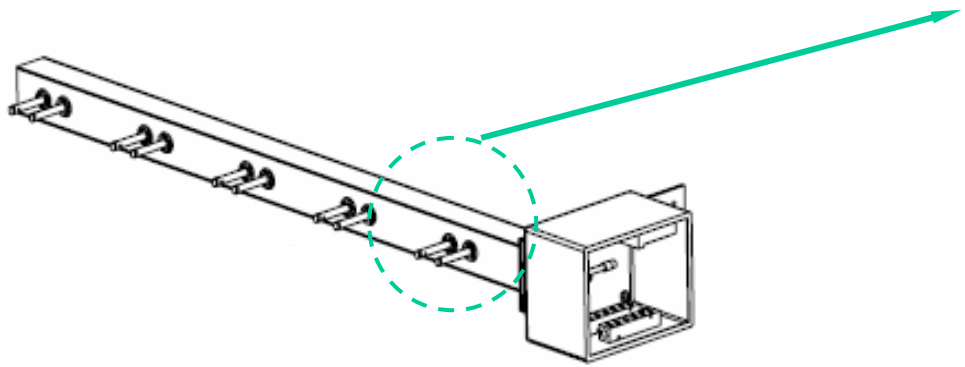
Test Conditions and Results:

1. Conducted tests in an enclosure filled with soot and smoke generated from various materials from a small pool fire placed at center of enclosure.

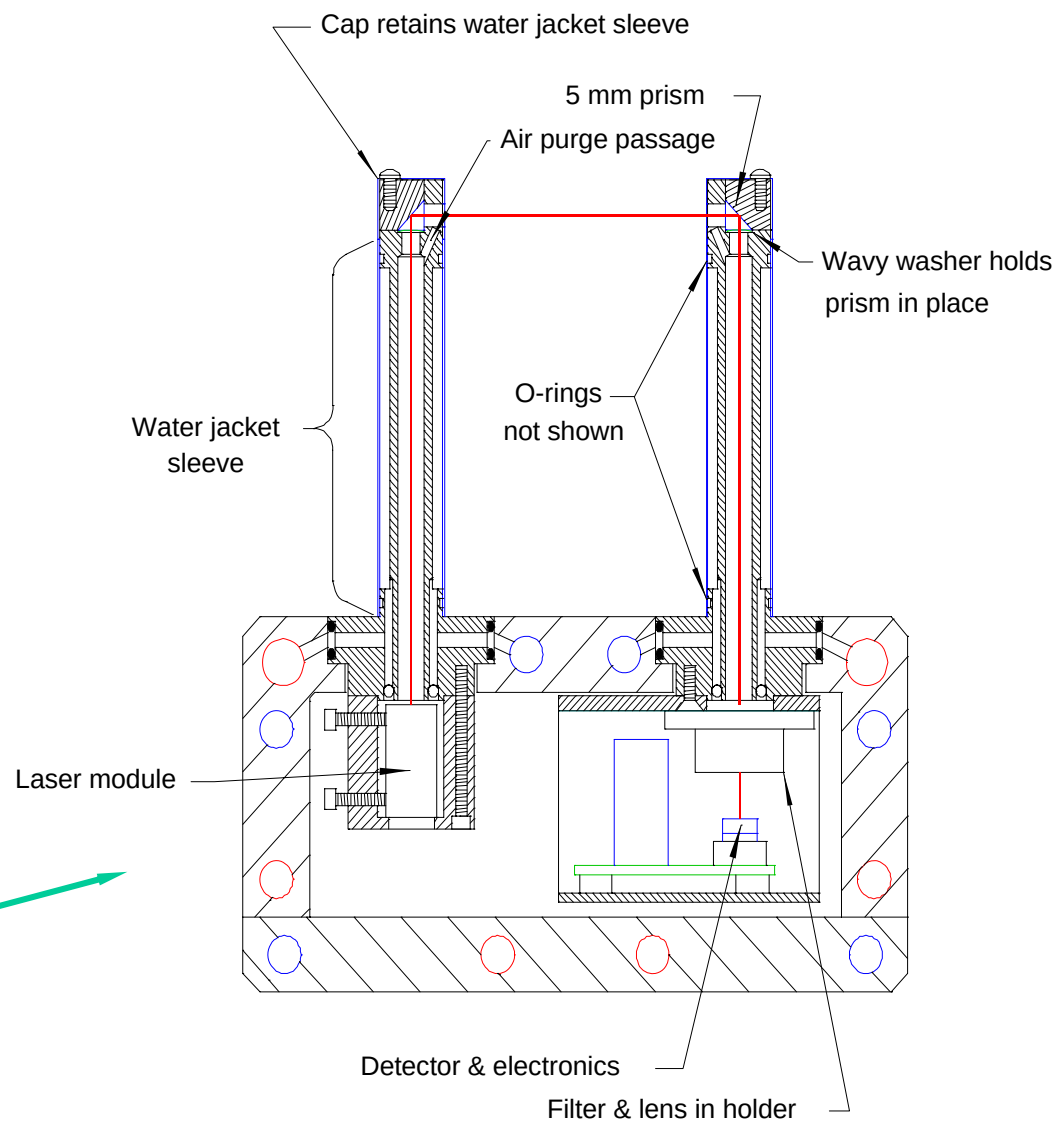
2. Probe failed in test series due to frequent software malfunction during tests and inadequate purging of probe which caused smoke deposition on the optics.

3. Software malfunction due to some built-in complex in situ data manipulation scheme, which was not really needed. (This problem has recently been fixed)

Multi-Point Device (1st generation)



Multi-Point Device (2nd generation)



Outbound water passages in blue

Return passages in red

Under-ventilated Compartment Fire Measurement

PI: Rik Johnsson

Co-Investigators: Matt Bundy, Anthony Hamins,
Sung Chan Kim, Gwon Hyun Ko, Andrew Lock

Objectives:

1. To provide improved understanding of the physics, chemistry, and structure of underventilated compartment fires.

2. To provide experimental measurements to guide the development of chemistry sub-models for field model improvement and to validate model predictions for under-ventilated burning in an enclosure.

Recent Accomplishments

- Conducted reduced-scale (2/5) enclosure experiments, varying:
  - fire conditions (56 quasi-steady conditions)
  - fuel: natural gas, heptane, toluene, methanol, ethanol, polystyrene
  - doorway width, full- and ½-width (heptane and natural gas)

- Measured:
  - O_2, CO_2, CO, THC, soot and temperature in the upper layer and exhaust stack, heat release rate
  - Composition of hydrocarbons (up to C_6) in upper layer using GC
  - Surface heat fluxes and temperatures
  - Doorway temperatures and velocities

- Documented work via:
  - NIST technical note
  - Presentation at FIRENET workshop in Ulster

328 kW Ethanol

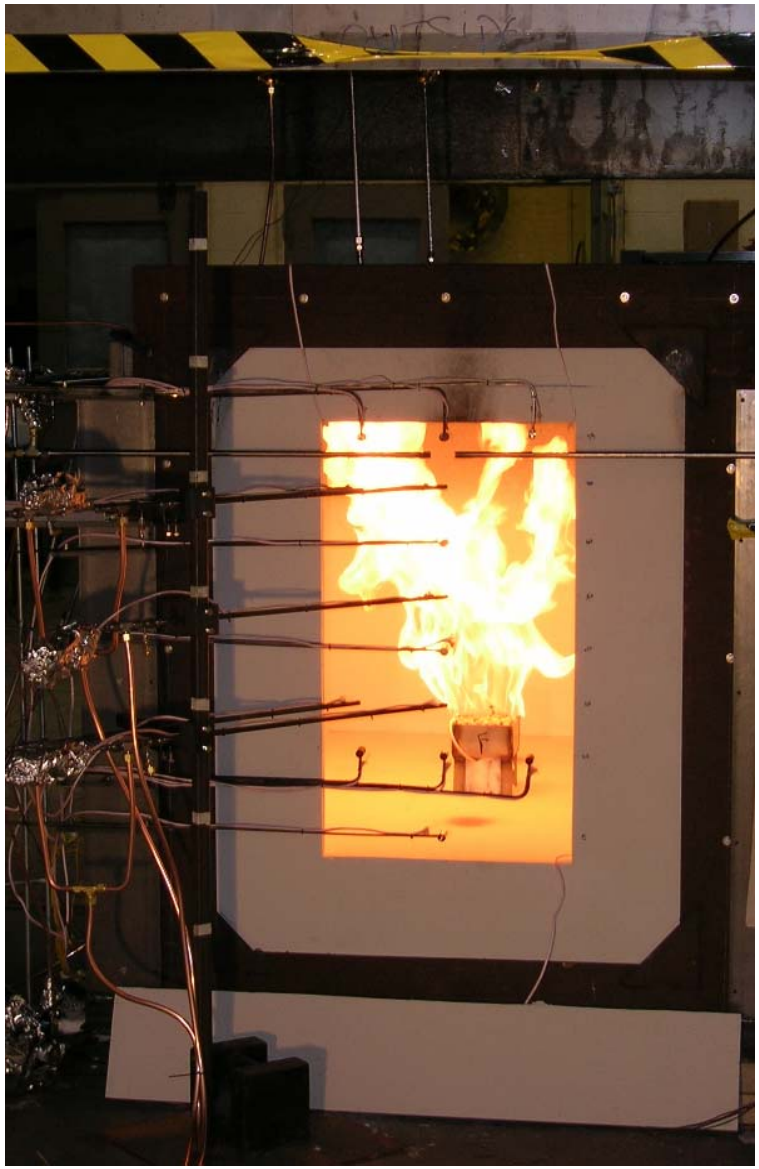
370 kW Heptanes

200 kW Toluene

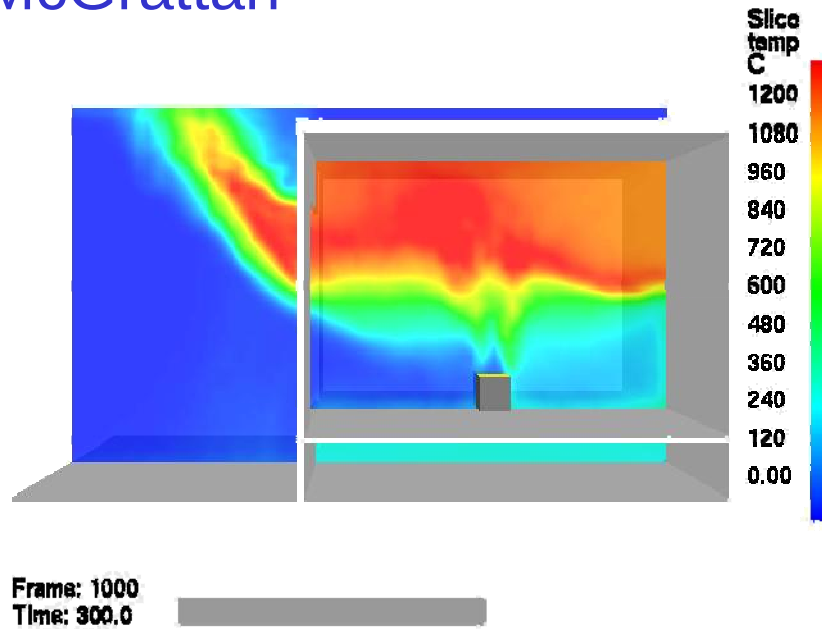
340 kW Polystyrene

Fire Dynamics Simulator (FDS) Development

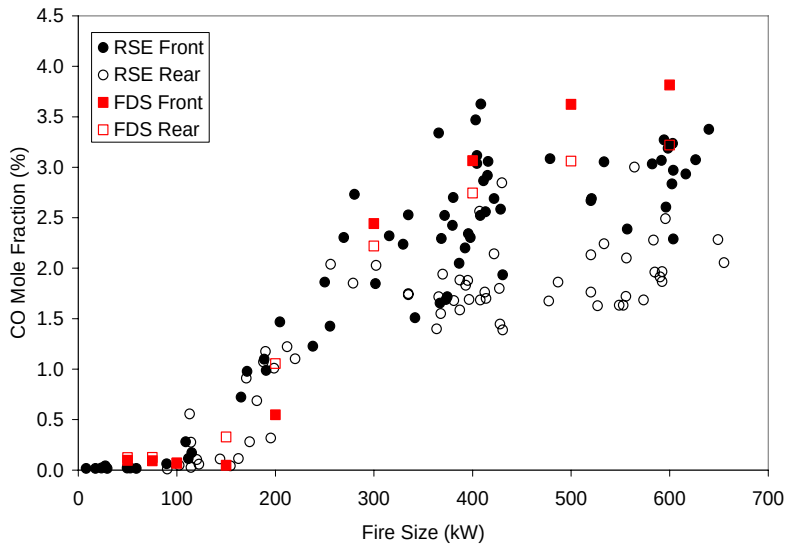
PI: Kevin McGrattan



Recent Reduced Scale Experiments
Johnsson, Bundy, Hamins



FDS Calculations by Floyd, McGrattan



CO Production, Pitts et al.

Smokeview Development PI: Glenn Forney

Investigating Lighting Algorithms for More Correct Smoke Visualization

Opacity Model

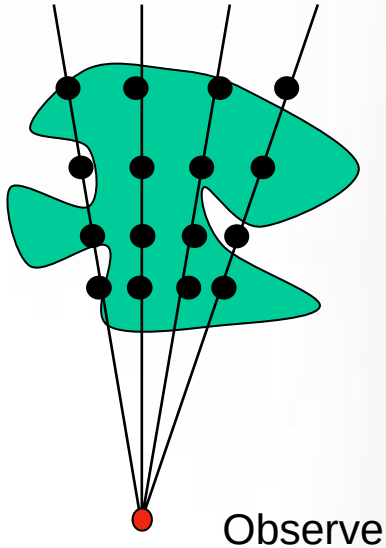
Use Beer's law to calculate obscuration given soot density

Lighting and Opacity Model

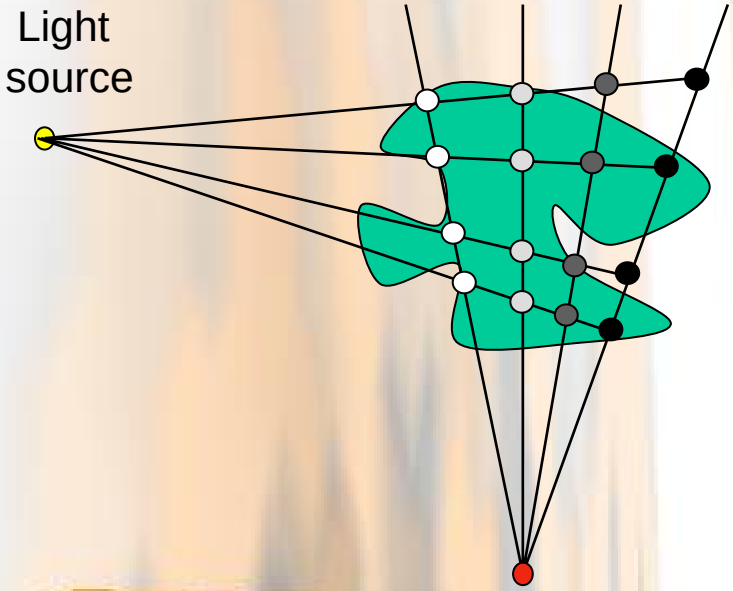
Use Beer's law to calculate both **obscuration** and **lighting** given soot density

Diffuse lighting

Back lighting



"Top" lighting



Beer's Law

Opacity=1-Exp(-$K_m m \Delta X$)

Beer's law calculation implemented on the video card (GPU) resulting in more effcient drawing (enabling more Physics for the same cost)

Smokeview Development PI: Glenn Forney

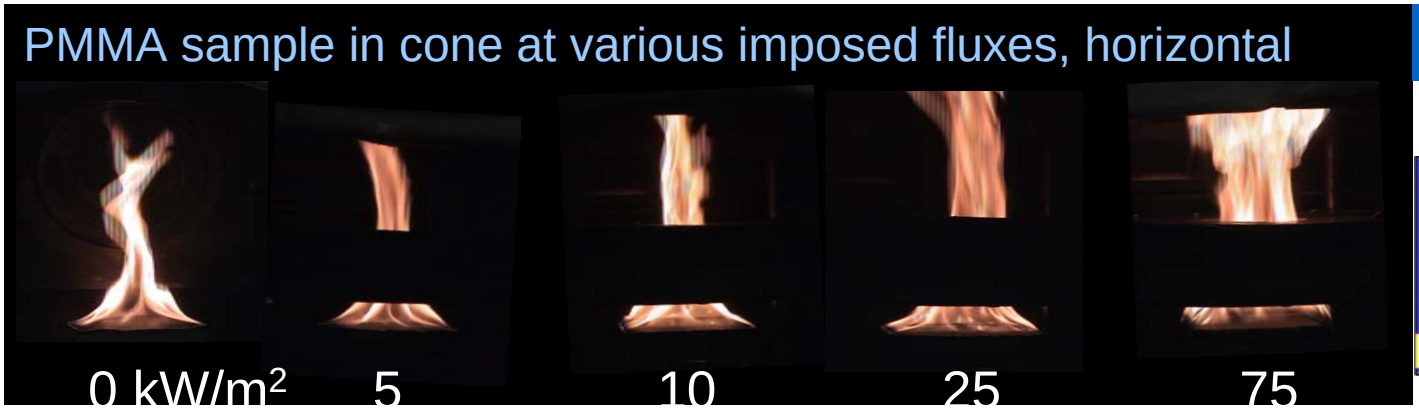
Smoke visualization without a lighting model at 90 s

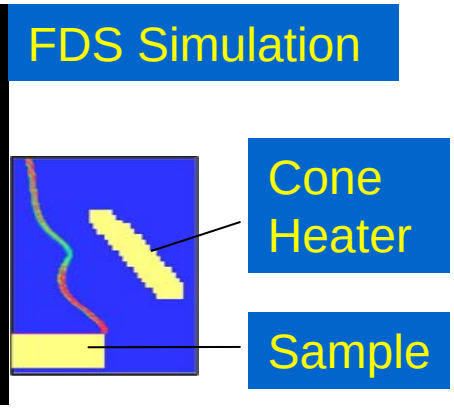
Smoke visualization with a simple lighting model at 90 s

Experiment – 20KW propene burner at 90 s

Experimental Data for Sub-grid Modeling

PI: Greg Linteris





Need:
An ability to describe the growth and spread of flames on burning objects (e.g. in FDS).

Objective:
To evaluate the capabilities, limitations, physical basis and required parameter input for sub-grid scale models of the fire growth and spread as used in FDS.

Approach:
Assess the ability of our state-of-the-art FDS to predict the behavior of burning solid fuels in the cone calorimeter.

Basic Idea:
If we can't predict the burning of an object in the cone, we probably can't predict it in a burning room either. So, check how well we can predict mass loss rate and heat release in the cone; doing so will teach us about the accuracy of the sub-grid-scale models in FDS that will be helpful as we make the next improvements.

Experimental Data for Sub-grid Modeling

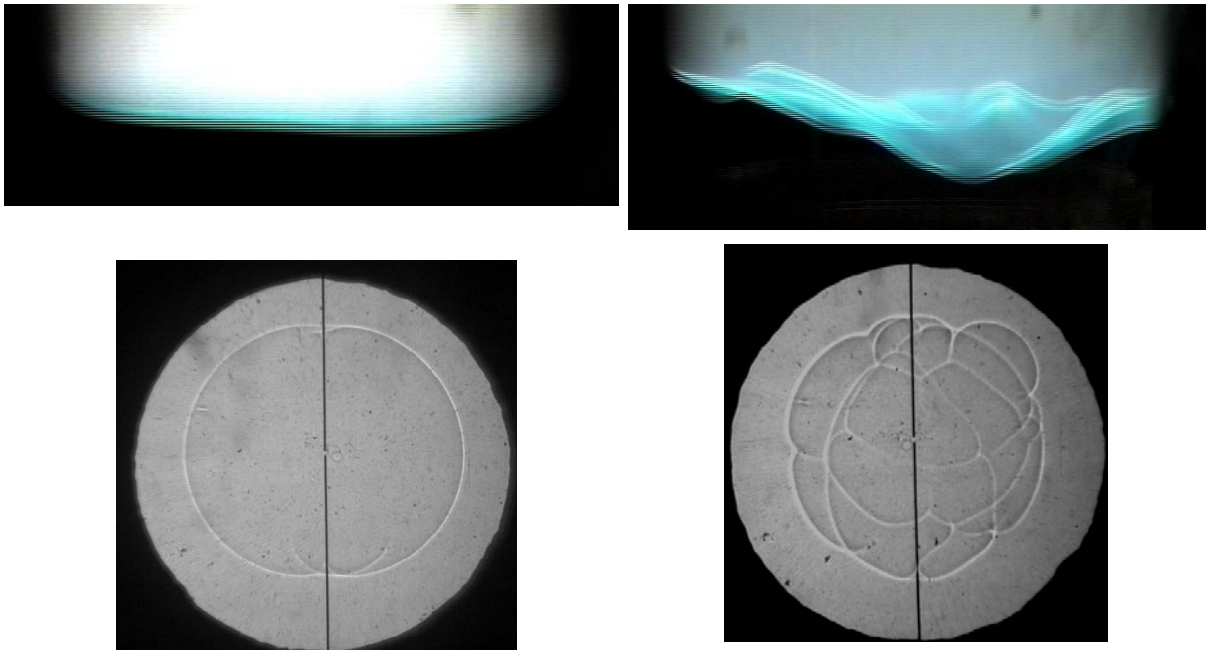
PI: Greg Linteris

	Effective Heat of Gasification H_g kJ/g		
Polymer	Literature Value	Extracted from Cone Mass Loss Data	Adjusted to fit FDS Cone HRR Prediction
PMMA	0.8 [1], 1.6 – 2.8[2]	3.7 [3] 2.7 [4] 2.6 [5]	0.8 – 0.84 1.3-1.5 1.6
ABS	2.6 [6] – 3.2 [7]	5.0 [3] 2.9-3.1 [5]	1.6 1.6
PE	1.8 - 3.6 [2]	7.5 [3]	4.6

1. Stoliarov, S.I., Walters, R.N., and Lyon, R.E., "Determination of Heats of Gasification of Polymers Using Differential Scanning Calorimetry," *SAMPE*, 2007.
2. Quintiere, J.G., Principles of Fire Behavior, Delmar, Albany, NY, 98.
3. Mulholland, G.W., Janssens, M., Yusa, S., Twilley, W., and Babrauskas, V., "The Effect of Oxygen Concentration on CO and Smoke Produced by Flames," *Fire Safety Science--Proceedings of the Third International Symposium*, 585-594,
4. Hshieh, F.Y., Motto, S.E., Hirsch, D.B., and Beeson, H.D., "Flammability Testing Using a Controlled-Atmosphere Cone Calorimeter," *International Conference on Fire Safety, 18th*, 299-325, Product Safety Corp., Sunnyvale, CA, 1993.
5. Linteris, G.T., unpublished data, 2006
6. Tewarson, A., "Generation of Heat and Chemical Compounds in Fires," in P.J. DiNenno, Ed., *SFPE Handbook of Fire Protection Engineering* National Fire Protection Association, Quincy, MA, 1995.
7. Tewarson, A., *"Experimental Evaluation of Flammability Parameters of Polymeric Materials,"* FMRC J.I. 1A6R1.RC, Factory Mutual Research Corp., Norwood, MA, (1979).

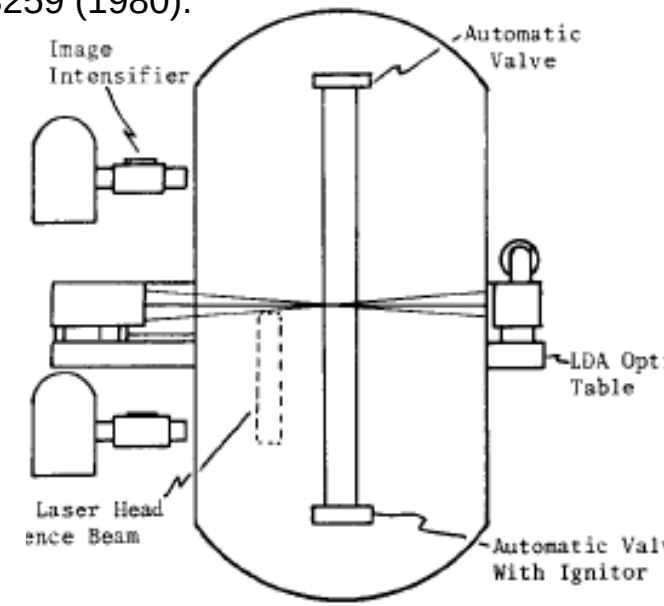
Flame Speed of Marginally Flammable Compounds

PI: Greg Linteris

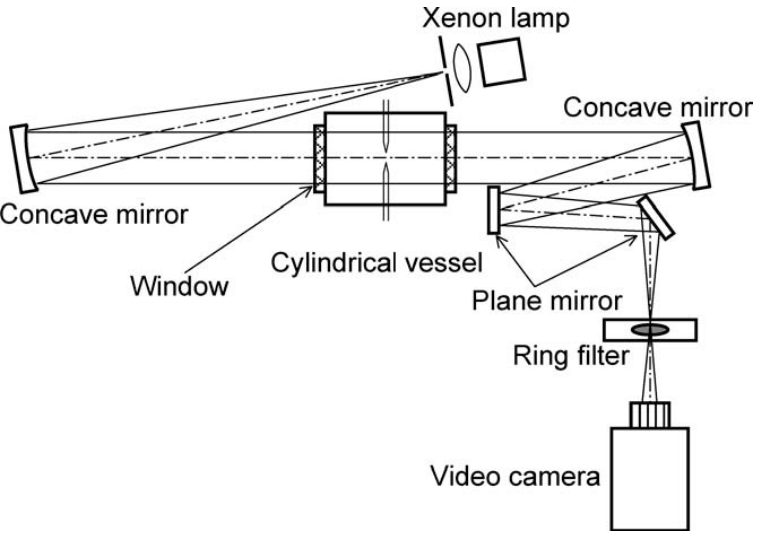


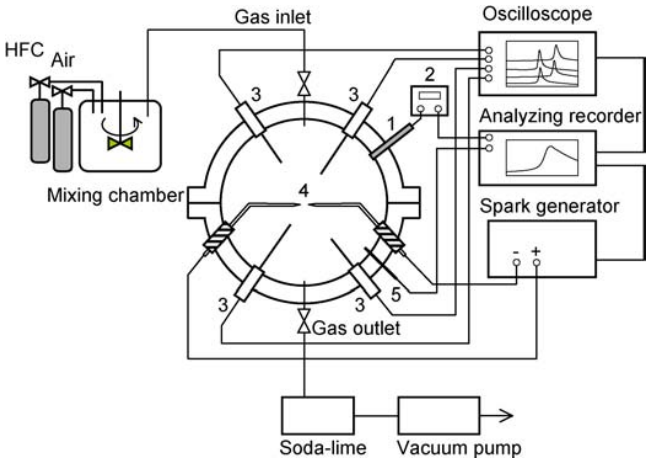
Johnston and Farrell, Proc. Combust. Inst. 30:217-224 (2005)

Strehlow and Reuss, NASA Report No. 3259 (1980).



Takizawa et al. Combust. Flame141:298-307(2005)





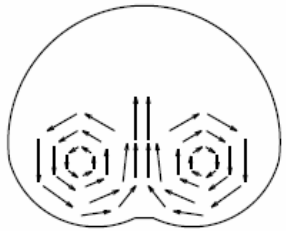


Figure 18: Vortex pair caused by the gravitational field.

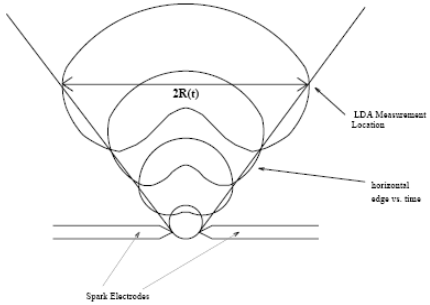


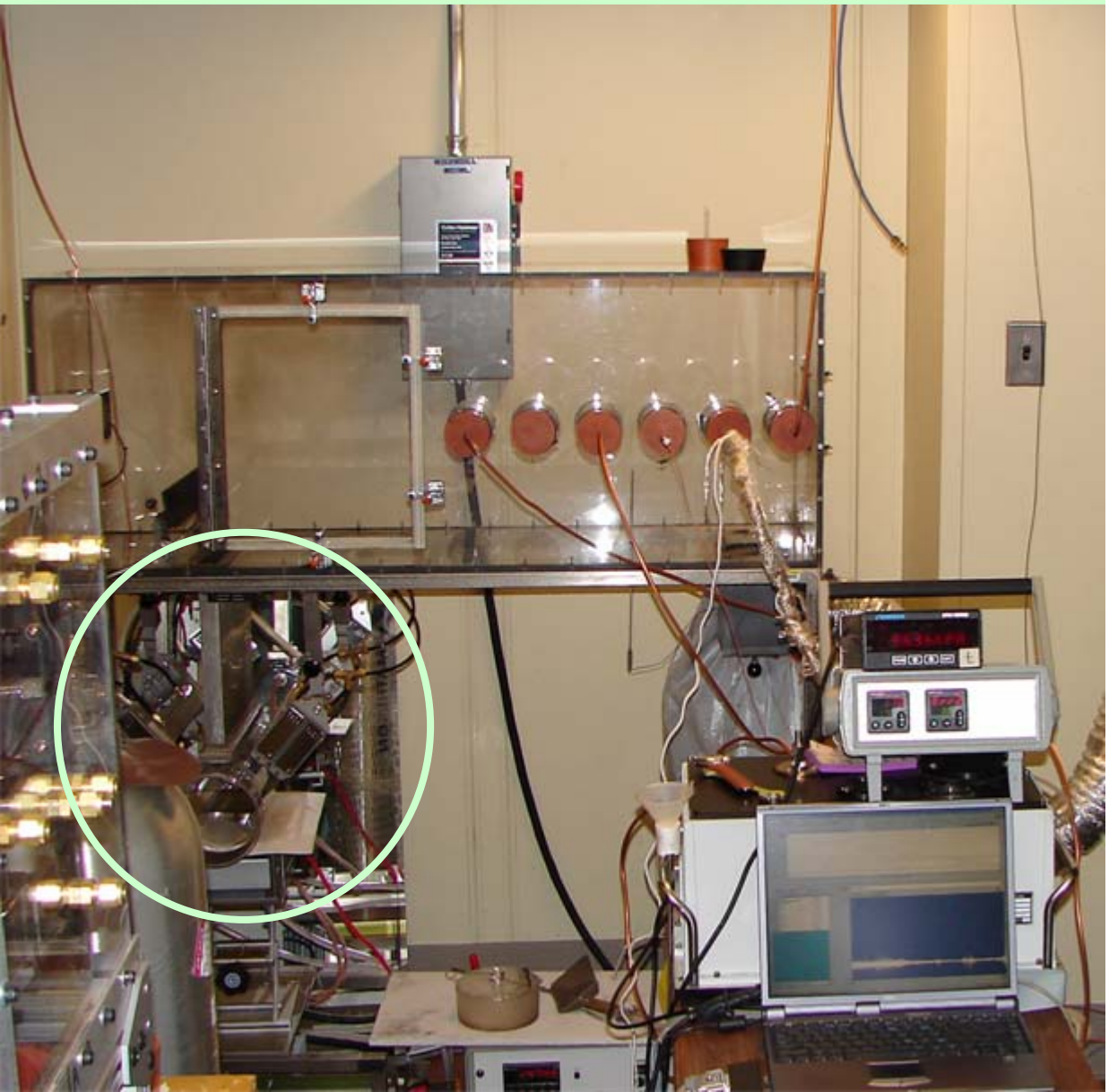
Figure 24: Suggested improved burning velocity measurement technique.

Toxicity Test Method Development

PI: Dick Gann

Co-Investigators: Jason Averill, Nathan Marsh, Marc Nyden

NFPA 269/ASTM E1678 Radiant apparatus



Objective: To establish the accuracy of smoke component yields from several generic bench-scale combustors

Recent Accomplishments:

1. Completed measurements and analyzing data for toxic gases from three combustibles: upholstered furniture, laminated particle board bookcase, and household power cable.

2. Shake-down tests of ISO tube furnace (ISO/TS 19700) is in-work.

3. ISO smoke toxicity standards and documents are being developed.

Enhanced Capabilities in Numerical Codes

Improved numerical algorithims

- improved smoke visualization algorithm in Smokeview
- implementation of parallelization

Improved treatment of fundamental fire physics

- gas-phase/condensed-phase interaction
- improved turbulence model for LES
- state relations for soot and CO in under-ventilated fires
- soot formation model, extinction, inhibition.

Accomplishments

1. Heat Release in Large Fire Meas.

- Intermediate-scale tests to provide input to WTC calculations.
- Multiple large-scale tests for WTC, NRC, RI, and Chicago fire investigations.
- 6x6 and 9x12 m HRR validation tests.

Accomplishments

2. LFL Measurement Uncertainty Projects

- 3 MW HRR report published.
- 10 MW HRR facility completed and used.
- Spray burner developed for validation tests.
- Tests conducted in WTC, Chicago, mattress, NRC, and RI fire tests.

- Report published on effect of global equivalence ratio on the specific mass extinction coefficient.
- Contract for large-fire laser extinction soot measurement written.

- PIV measurements made of simulated gas flow in an intermediate scale doorway.

Accomplishments

3. Predictive Methods

- Parallel code implemented and applied to WTC.
- Validation calculations for LFL burns in WTC, NRC, RI, and Chicago studies.
- Sub-grid validation studies for cone tests.
- Improvements in Smokeview treatment of visibility in smoky rooms.

Major Activities

-*Quantitative Measurements for Large Fire Applications*

- *Enhanced Capabilities in Numerical Codes and model Validation*

- *Development of Improved Understanding of Physical Phenomena from Bench-Scale Tests*