FIRE DYNAMICS OF SPILL FIRES

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Background

- Fuel Spill Fires
  - Potential hazard in many applications
  - Nature of the accident is highly variable
    - Source of release
    - Surface features (e.g., concrete, ground, water)
    - Confinement of spill
    - Point of ignition

General Characterization

- Continuously Flowing Spill
- Instantaneous Spill (static)
  - Unconfined spill fire
  - Confined pool fire (typically greater fuel depth)

Hazard Analysis Objectives

- Determine impact of a fire on surroundings:

1. Does the fire directly impinge on objects (e.g., roof members, equipment, aircraft)?
2. What is the radiant heat transfer to targets?

Specific Goals

- Determine physical size of fire
  - Spill area (base of fire)
  - Flame height
- Determine heat release rate, Q
- Based on fire size and Q, estimate radiant flux to targets

Typical Calculations

Heat Release Rate (kW): $\dot{Q} = \dot{m} \cdot \Delta h_c$

Burning Rate (kg/m^{2}s): $\dot{m} = A \cdot \dot{m}''$

Mass burning rate per area is empirically based.

Burning Rate (kg/m^{2}s): $\dot{m} = A \cdot \dot{y} \cdot \rho$

Density, ρ, is known and
Regression rate is empirically based.

Area of Static Spill Fire

- A is known via physical constraints
- A is calculated based on an estimated spill depth, δ, and the initial volume, V, of fuel:

$$A = V/\delta$$

Estimate of Spill Depth

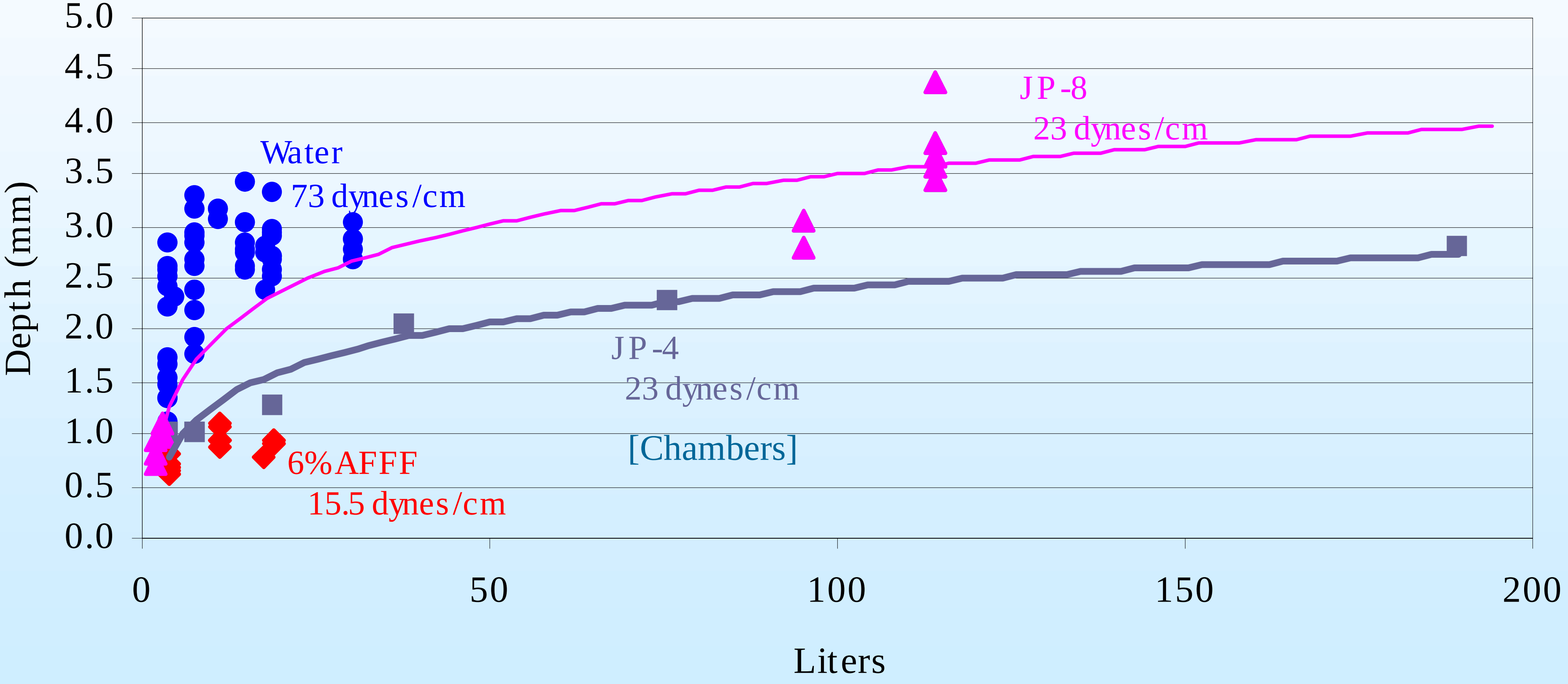
- MacKinven et al (1970) and Burgoyne and Roberts (1968) work indicate

  No flame spread for Depths < 1.5 mm

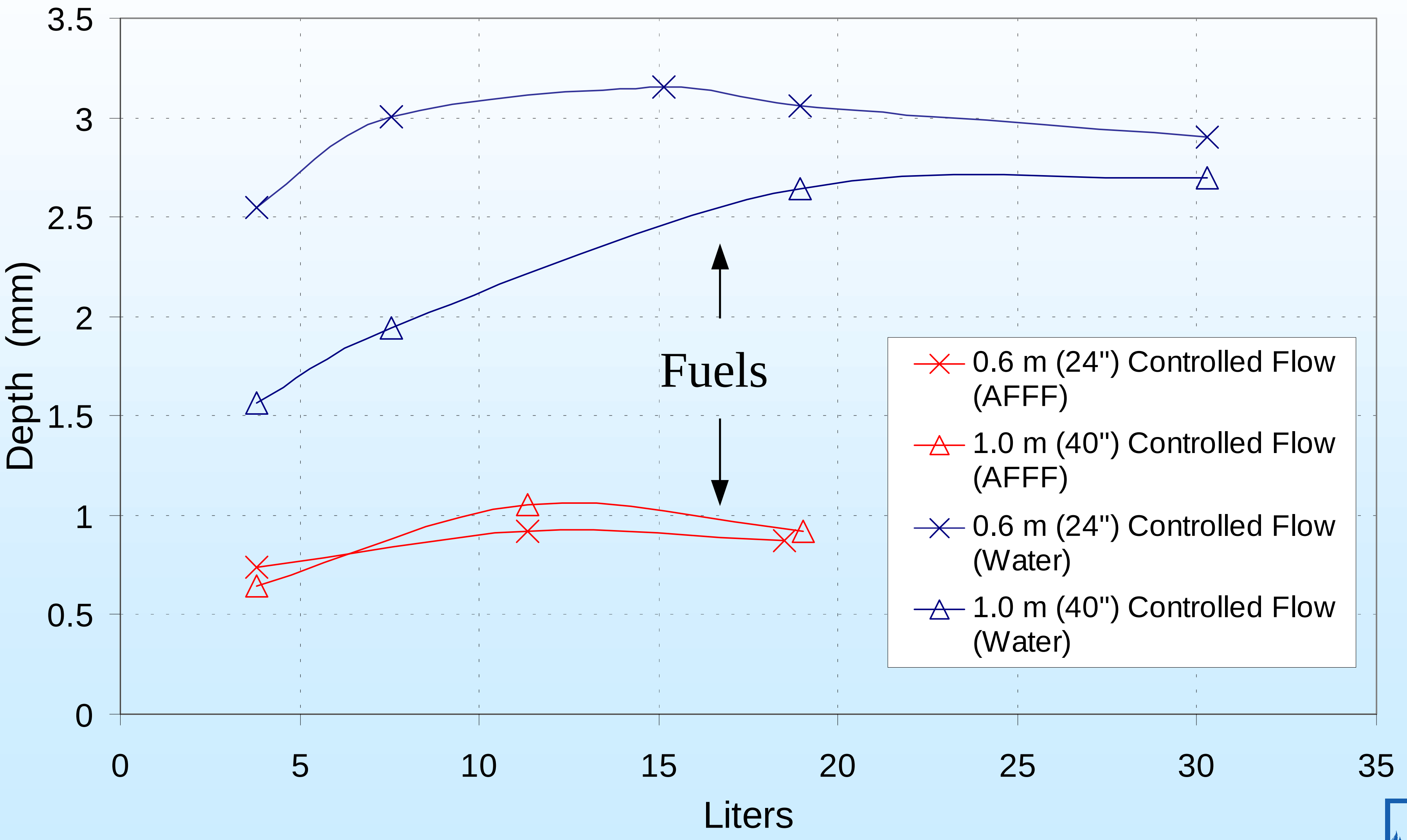
- More recent experimental data indicate depths as low as 0.7 mm

- Smaller depth -- larger spill area -- larger fire -- shorter duration (all other things constant)

Liquid Spill Depths on Concrete



Spill Depths vs Volume and Spill Height



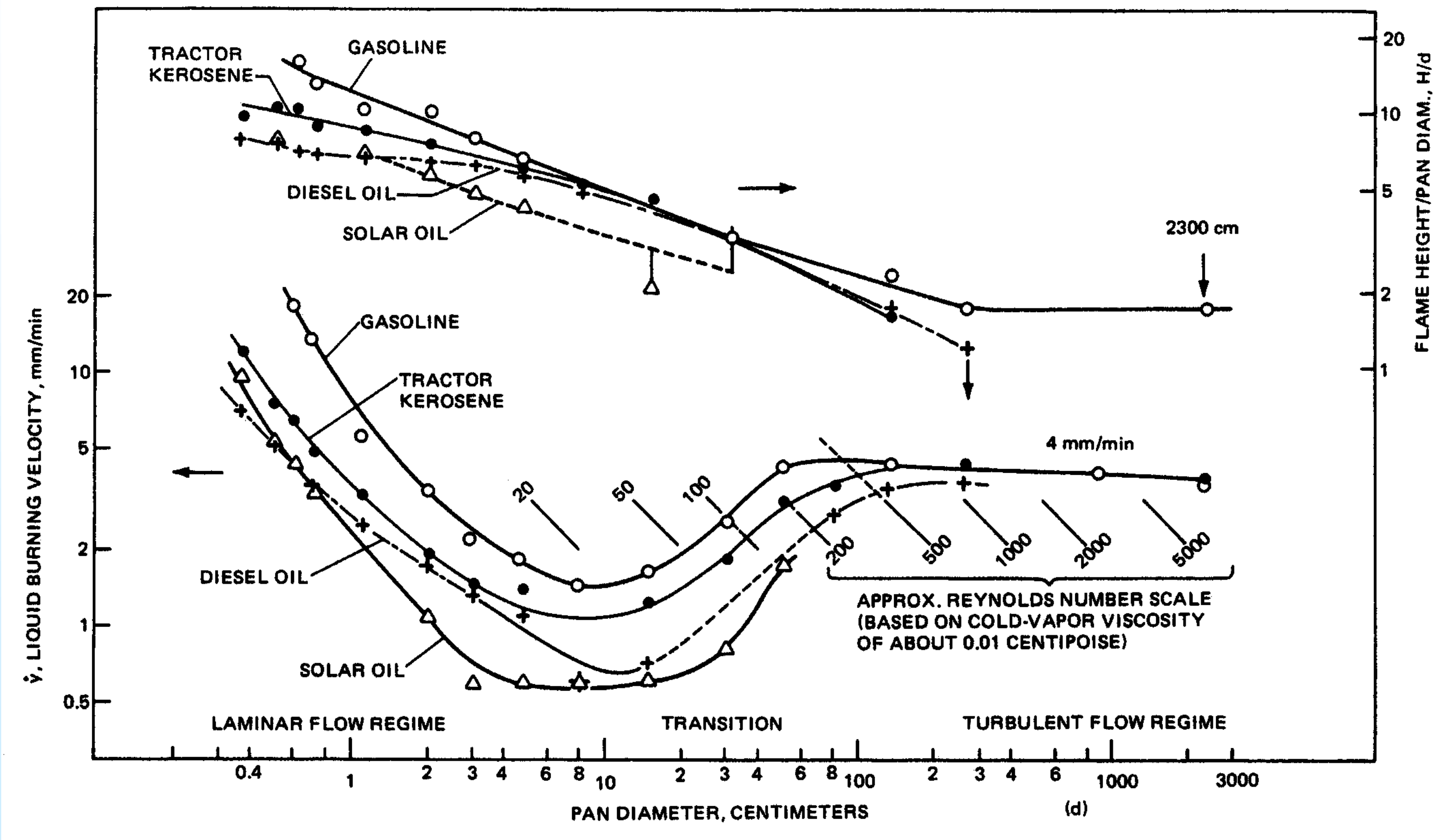
Continuously Flowing Unconfined Spill Fire

Maximum spill area based on balance between volumetric flow rate and volumetric burning rate of fuel:

$$\dot{V}_L = A \cdot \dot{y} = \frac{\Pi D^2}{4} \dot{y}$$

$$\dot{Q} = A \cdot \dot{y} \cdot \rho \cdot \Delta h_c$$

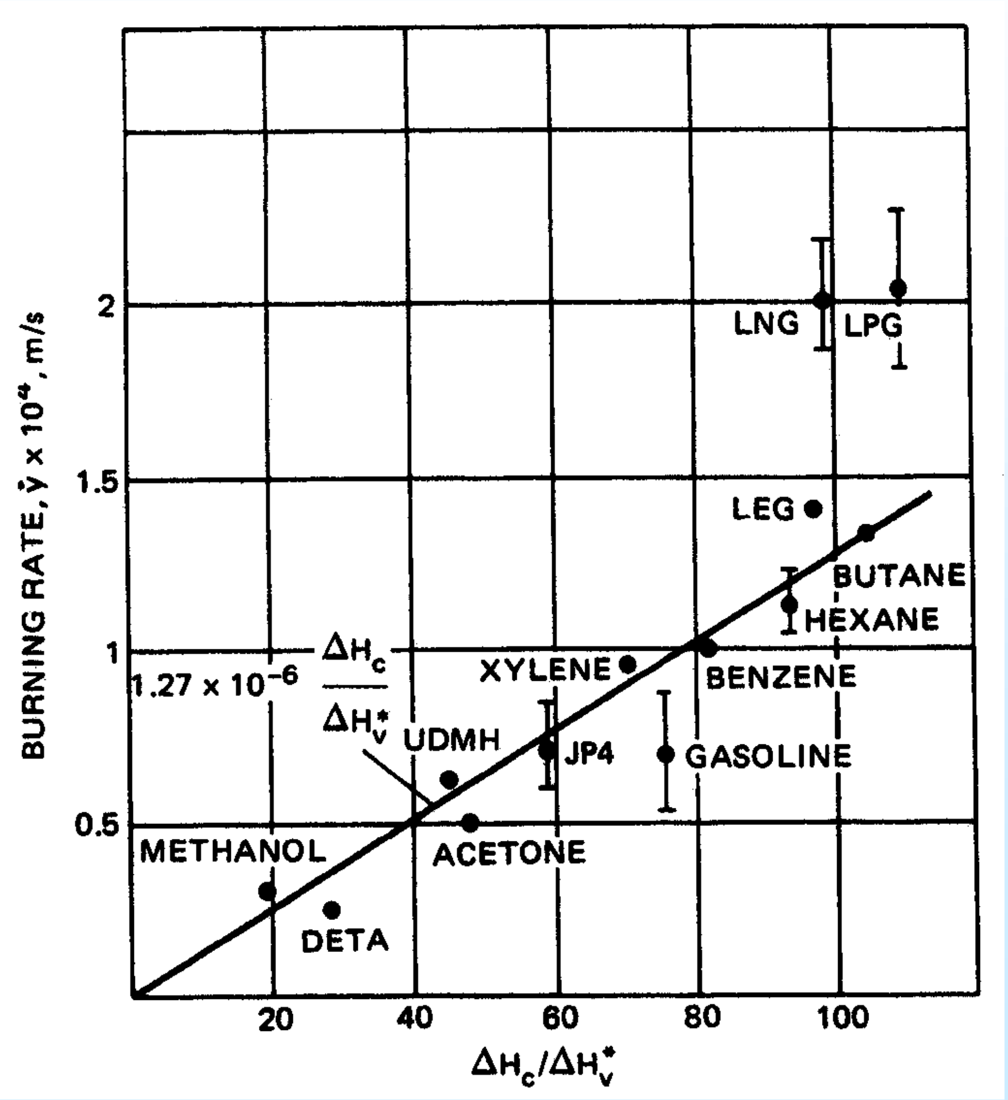
Regression Rate vs. Pool Dia.



Hottel (1959) taken from Mudan and Croce (1995)

Regression Rate Data

Mudan and Croce (1995)



ΔHc = net heat of combustion

ΔHv = net heat of vaporization

Continuously Flowing Unconfined Spill Fire

- Area also can be estimated using experimental correlations
- Mansfield and Linley [1991]:

$$D = 3.5\dot{V}^{1/2}$$

D = spill diameter (ft)
V = spill rate (gpm)
Correlation is best fit to 150 to 600 gpm spill data
Uncertainty estimated at ±20%

Typical Calculations

Heat Release Rate: $\dot{Q} = \dot{m} \cdot \Delta h_c$

Burning Rate (kg/m^{2}s): $\dot{m} = A \cdot \dot{m}''$

Mass burning rate per area empirically based.

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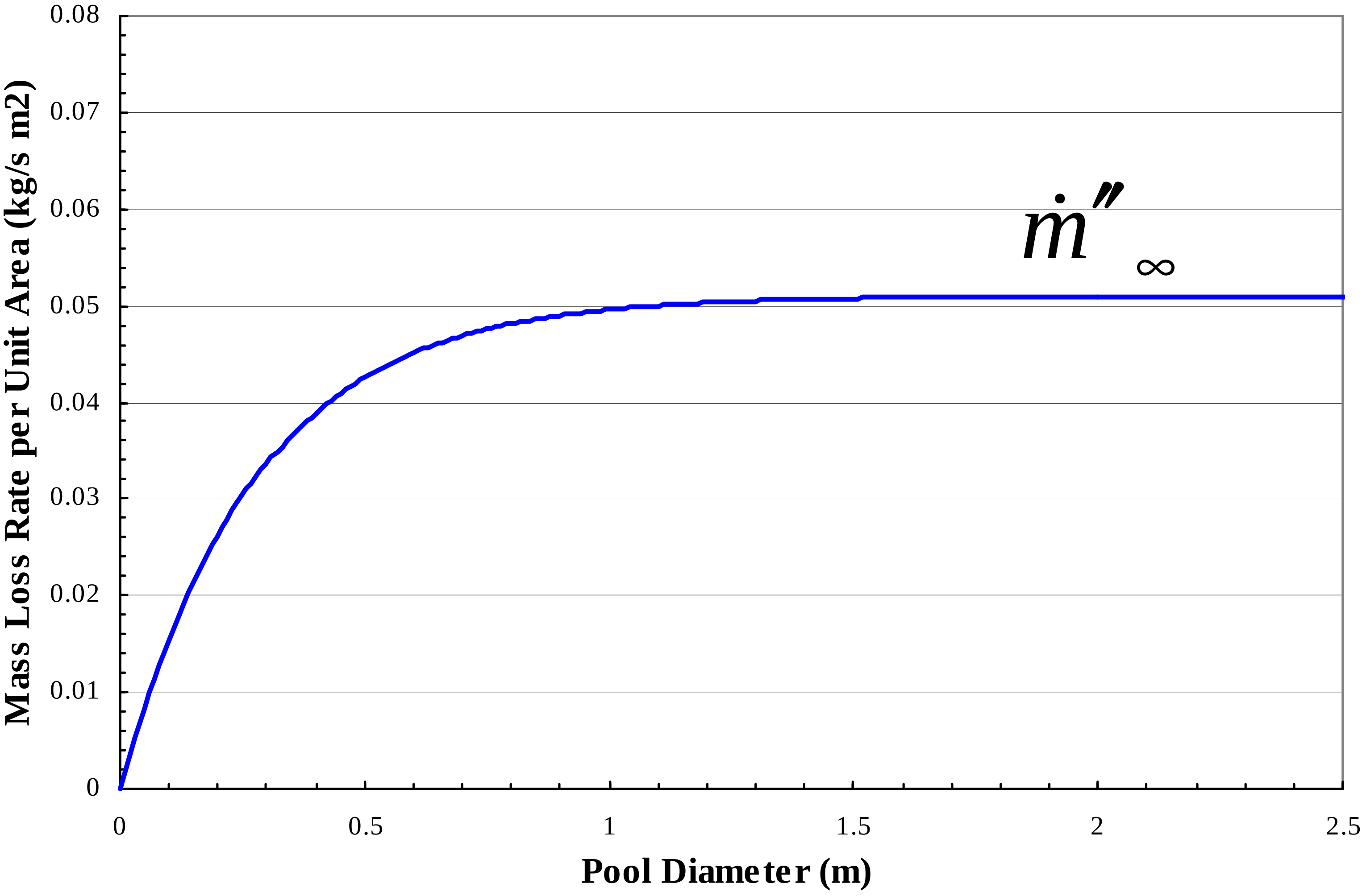
Babrauskas Correlation

$$\dot{m}'' = \dot{m}''_{\infty}\left(1 - e^{-k\beta D}\right)$$

k∃ = product of the extinction-absorption coefficient of the flame (k) and the mean-beam-length correction (∃)

$\dot{m}''_{\infty}$ approached for D > 1 to 2 m

0.051 and 0.054 kg/m^{2}s for JP-4 and JP-5 fuels


Mass Loss Rate per Unit Area (kg/s m2)
0.08
0.07
0.06
0.05
0.04
0.03
0.02
0.01
0
0
0.5
1
1.5
2
2.5
Pool Diameter (m)
$\dot{m}''_{\infty}$

Issues

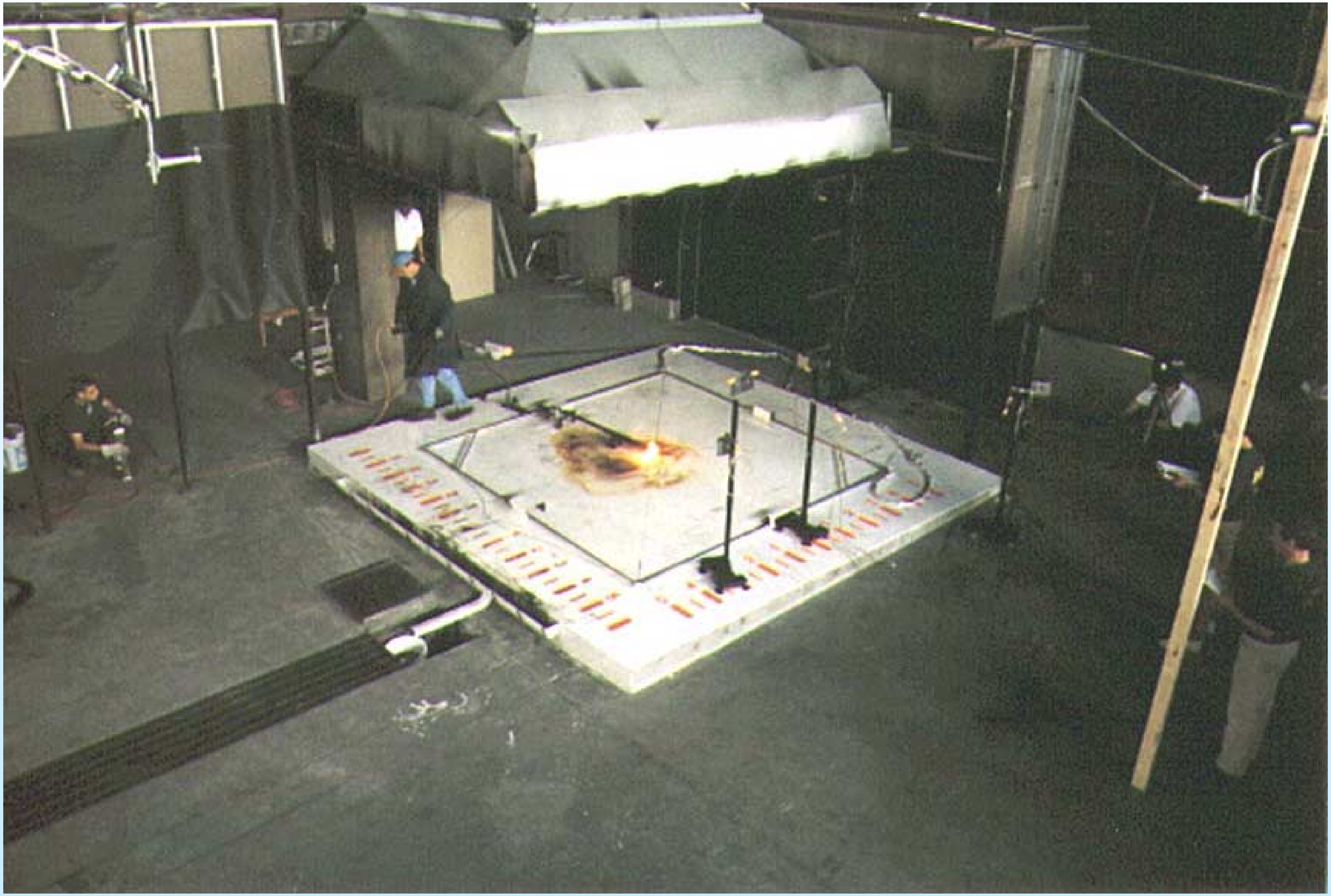
- Most published data is for confined fires (pan or dyked pools)
- Pool depths typically greater than spill depths
- Will the Babrauskas Correlation (or available regression rate data) accurately predict spill fire burning rates?
- How well can we estimate spill fire heat release rates and flame heights?

Experimental Program

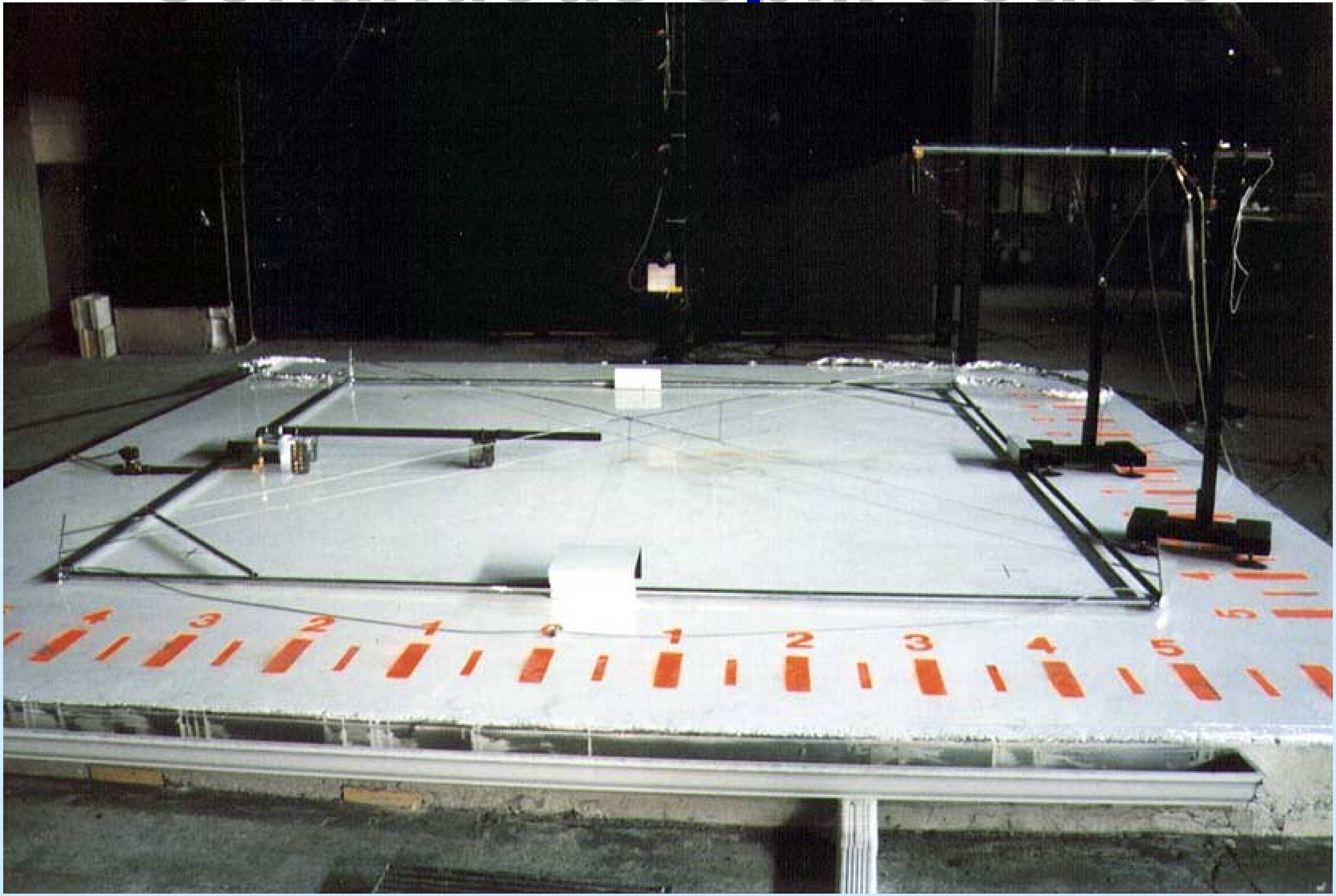
- Evaluated optical fire detectors using JP-8 and JP-5 fuel spill fires on concrete

- Scenarios
  - Unconfined continuous spill, ignition at source
  - Confined (channeled) continuous spill, ignition at source
  - Unconfined fixed quantity, ignition at edge of spill after static

Experimental Setup

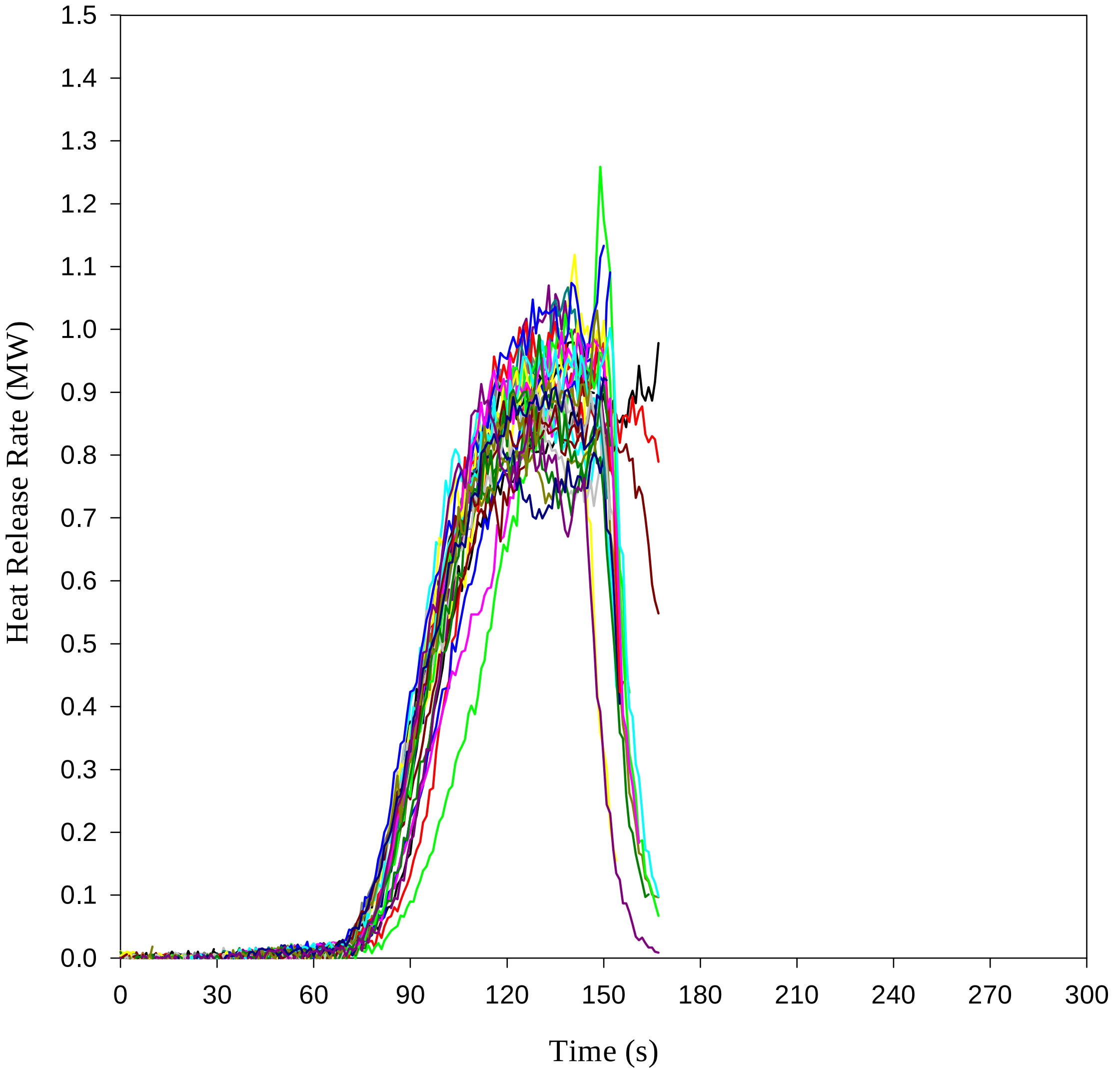


Concrete Pad with Continuous Spill Source



Typical Unconfined Spill Fire

1.7 Lpm JP-8 Tests

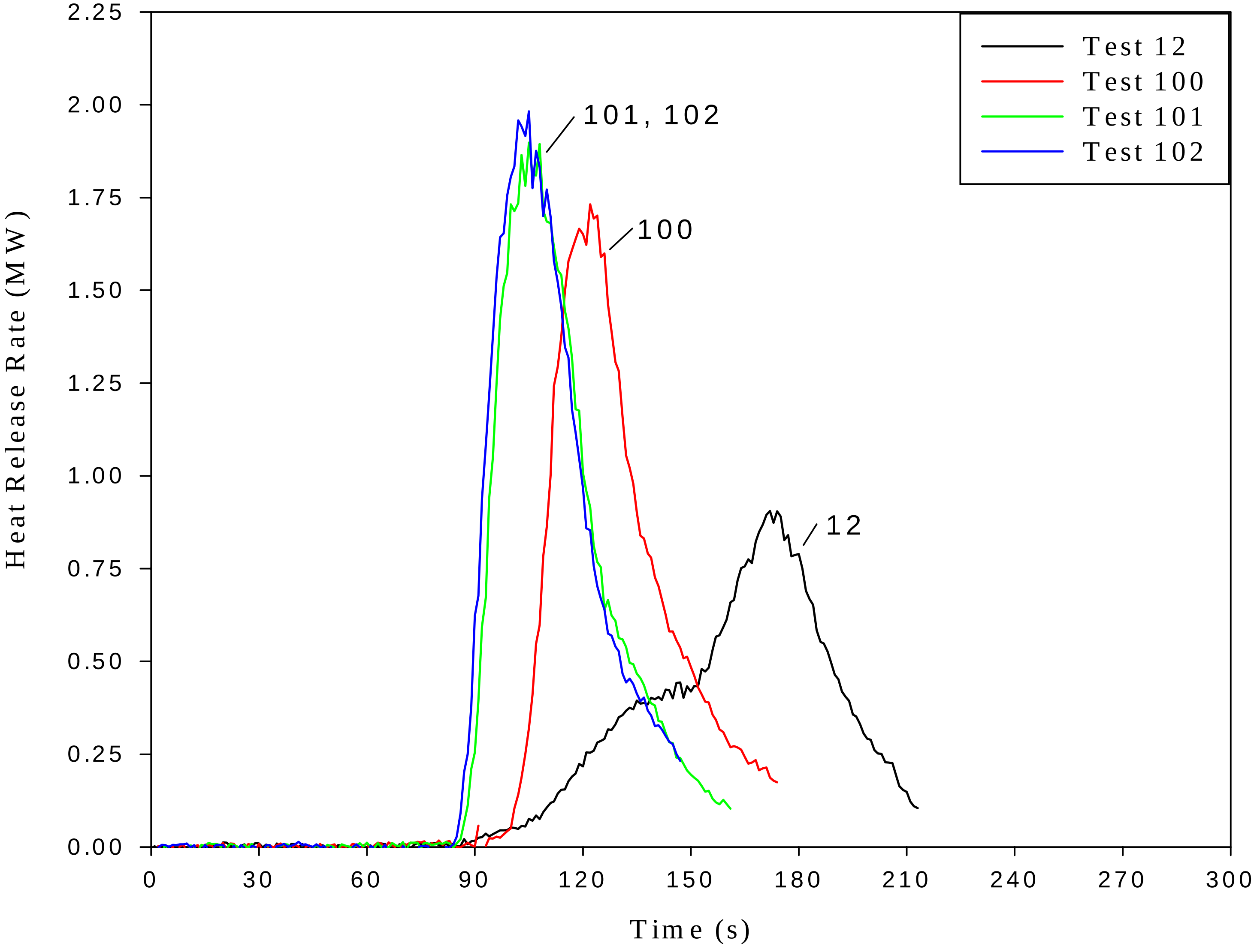


HRR for Continuously Flowing Spill Fires

- Primarily dependent on flow rate
- Second order effect due to concrete temperature
  - Peak HRR increased with increase in Temp ~15% for 25 C difference (1.7 Lpm fires)
  - Growth rate unchanged in 1.7 Lpm fires
  - Growth rate increased at lower flow rates (0.17 Lpm)

Fixed Quantity Spill Fire

3 L Fixed Quantity Spills



HRR for Fixed Quantity Spill Fires

- Peak HRR dependent on quantity of fuel
- Strong effect due to concrete temperature and surface features
  - Peak HRR and growth rate increased with increase in concrete and fuel temperature
  - Surface unevenness was a factor in fire growth compared to continuous spill fires

Experimental Mass Burning Rates

- Calculated using the time-averaged steady-state data from the 0.42, 0.85 and 1.7 Lpm continuous spill fire tests:

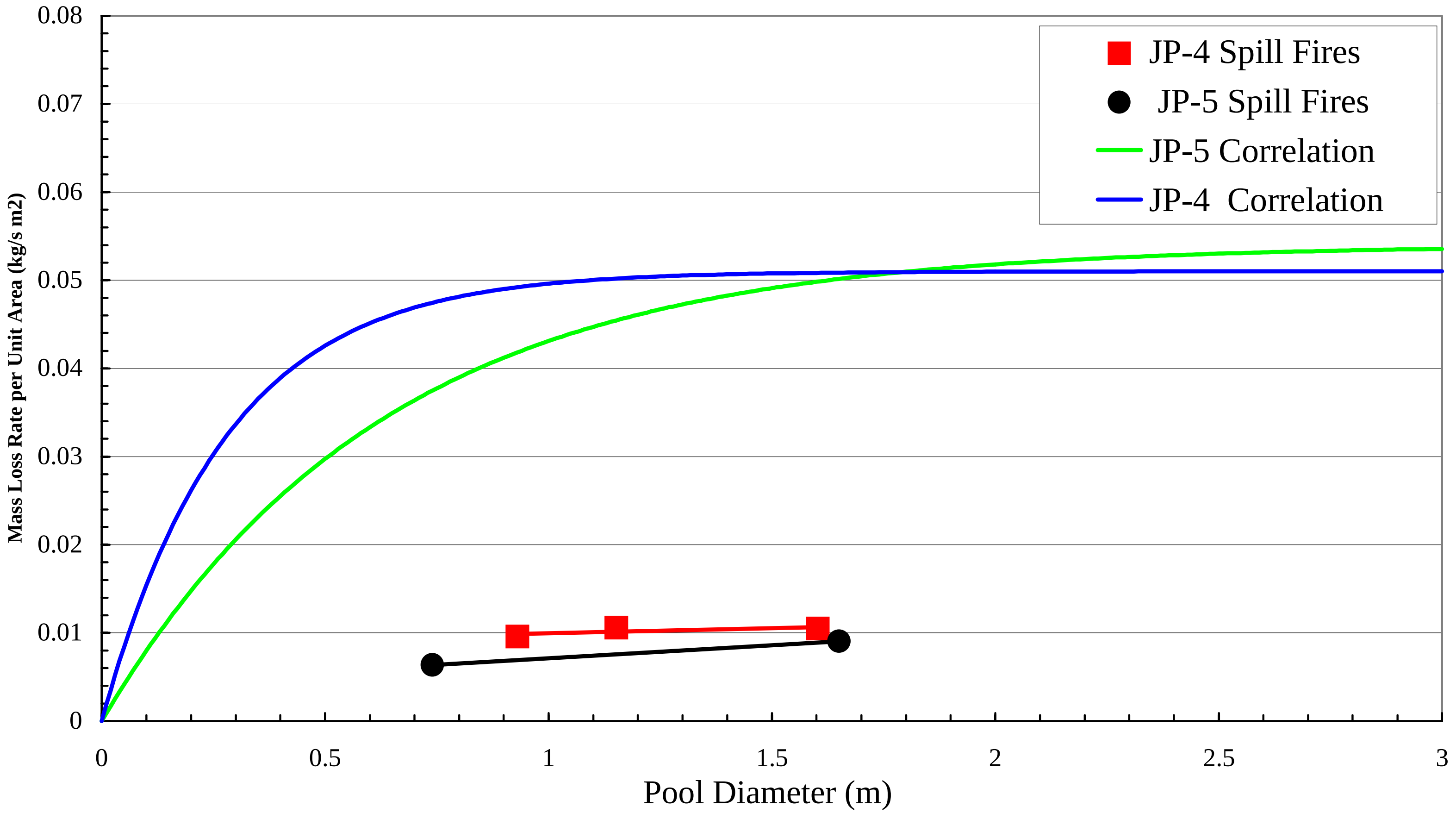
$$\dot{m}'' = \frac{\dot{Q}}{\Delta h_C \cdot A}$$

Babrauskas Correlation

$$\dot{m}'' = \dot{m}''_{\infty}\left(1 - e^{-k\beta D}\right)$$

- Used to calculate burning rate based on values in the literature
- Compared to the average experimental data from the spill fire tests

Experimental Results compared to Babrauskas Correlation

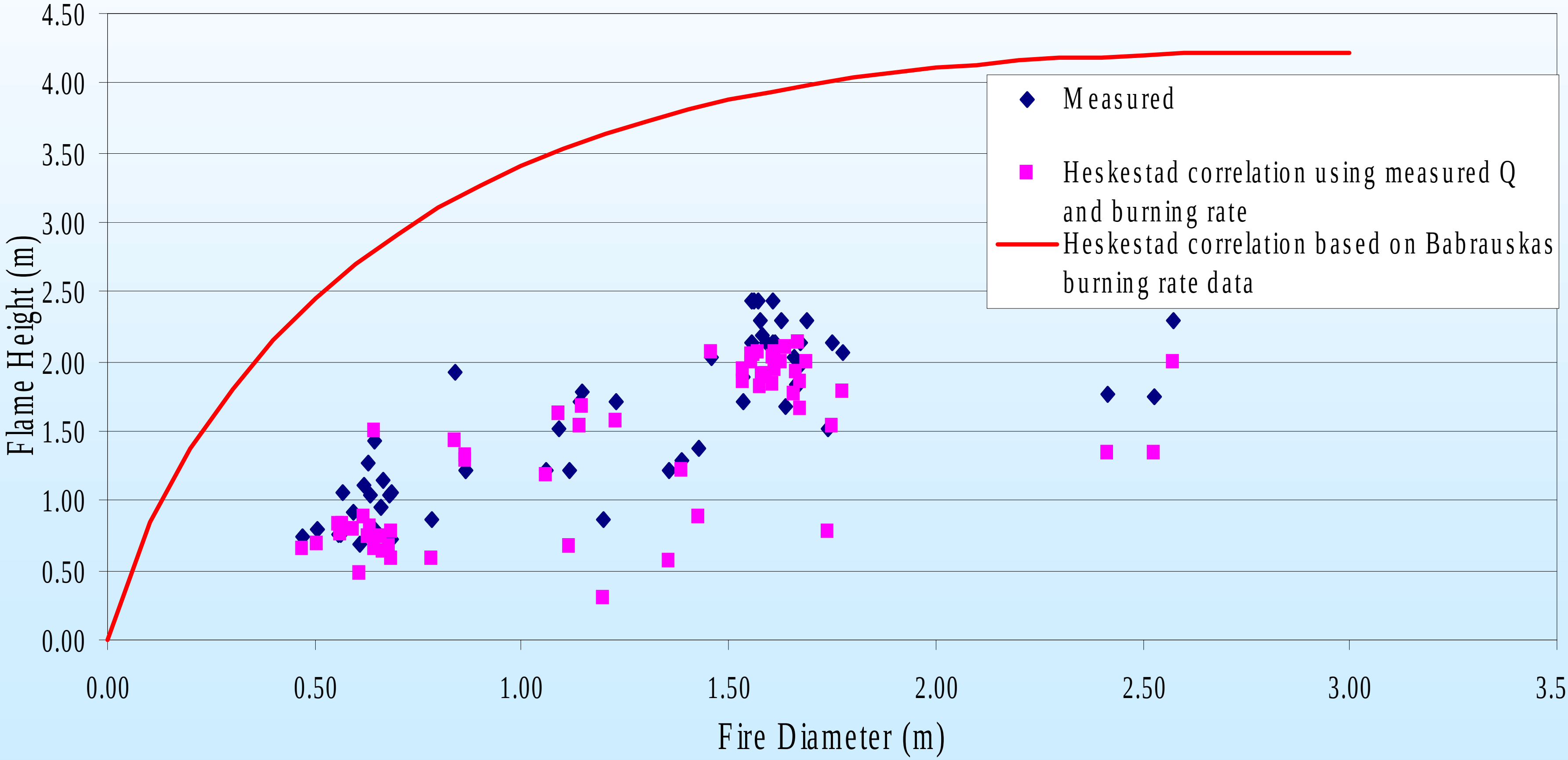


Flame Height

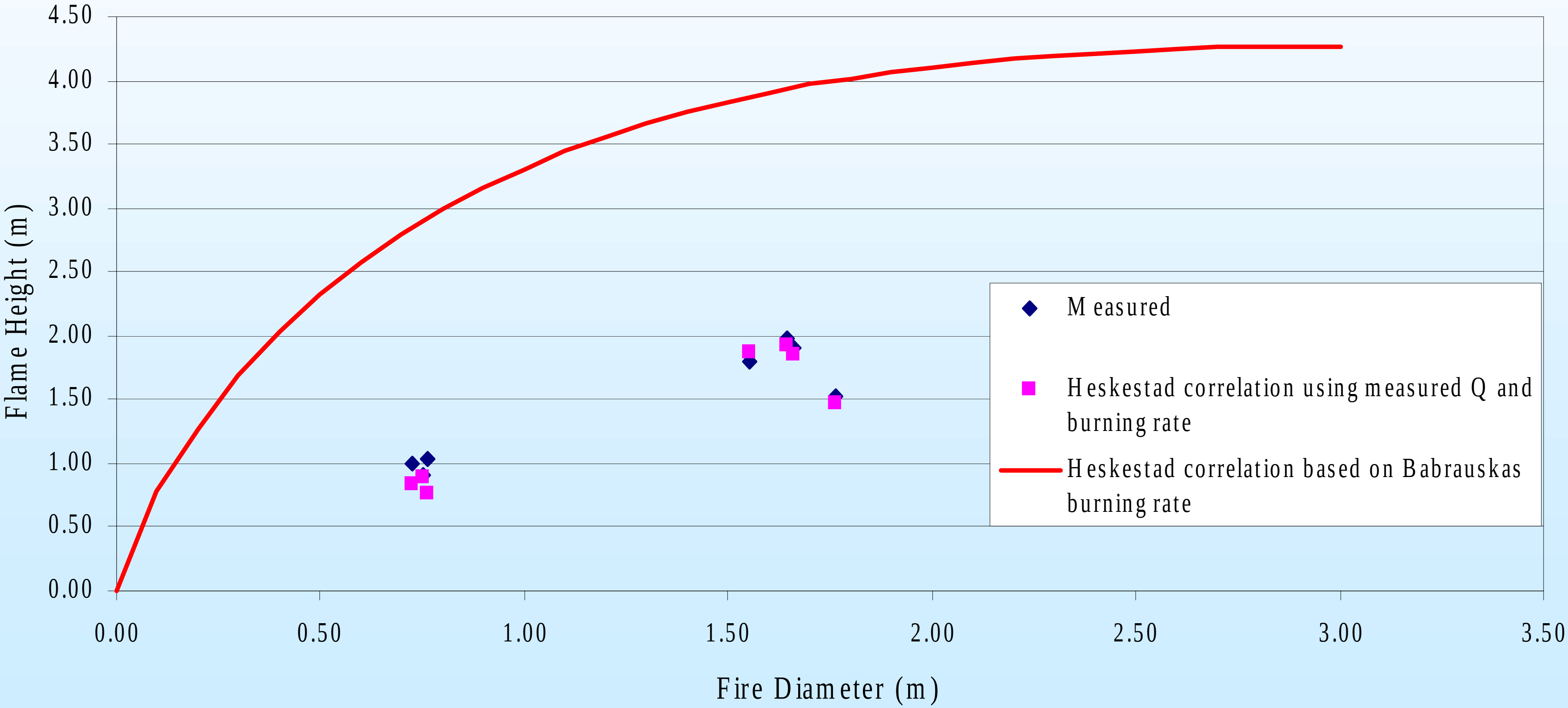
- Heskestad correlation for intermittent flame height, L_f:

$$L_f = 0.23\dot{Q}^{2/5} - 1.02D$$

Flame Height for JP-8 Fires



Flame Height for JP-5 Fires



Conclusions

- Experiments demonstrated that commonly used pool fire data is not accurate for predicting spill fire dynamics
- Average spill depths for 1 to 3 L spills of JP-8 ranged from 0.7 to 1.1 mm (literature indicated > 1.5 mm required)

Conclusions

- $\dot{m}''$ approximately 20-25% of the frequently used published data:
  - 0.01 kg/m^{2}s JP-8
  - 0.008 kg/m^{2}s JP-5 (0.051 - 0.054, JP-4 & JP-5)
- Lower burning rate results in spill diameters ~ twice as large as would be estimated using published data

Conclusions

- Calculated flame heights based on existing correlations and data are ~ 2 to 3 times larger than measured in these tests at a given spill diameter
- The Heskestad intermittent flame height correlation accurately predicts L_f when using the new experimental data