Liquid Fuel Fire Hazard Characterization

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Background

- Liquid Fuel 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 / Pool (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, $\dot{Q}$
- Based on physical fire size or $\dot{Q}$, 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 Fuel Release

- A is known via physical constraints

  or

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

$$A = V / \delta$$

Estimate of Spill Depth

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

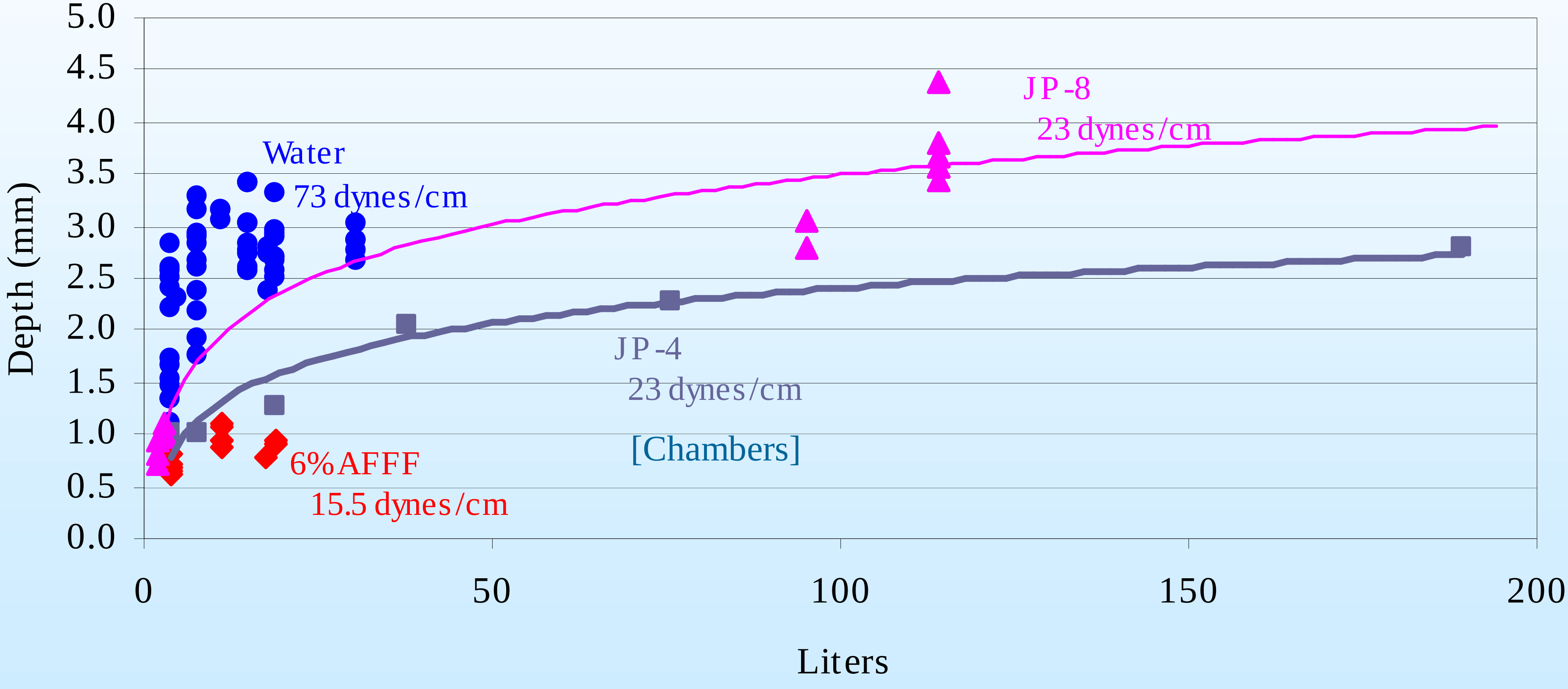
  No flame spread for Depths < 1.5 mm

- Experimental data for JP-8 and JP-4 fuels indicate depths as low as 0.7 mm

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

$$\dot{Q} = \dot{m}'' \cdot A \cdot \Delta h_c = \dot{m}'' \cdot V/\delta \cdot \Delta h_c$$

Liquid Spill Depths on Concrete



Estimated Minimum Spill Depths

Spill < 95 L (25 gal)	Depth = 0.7 mm
Spill $\geq$ 95 L (25 gal)	Depth = 2.8 mm

Alternately, express as the spill area per volume of fuel:

Spill < 95 L (25 gal)	A/V = 1.4 m^2/L (57 ft^2/gal)
Spill $\geq$ 95 L (25 gal)	A/V = 0.36 m^2/L (15 ft^2/gal)

Area of Continuously Flowing Unconfined Spill Fire

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

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

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 $\pm$20%

Typical Calculations

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

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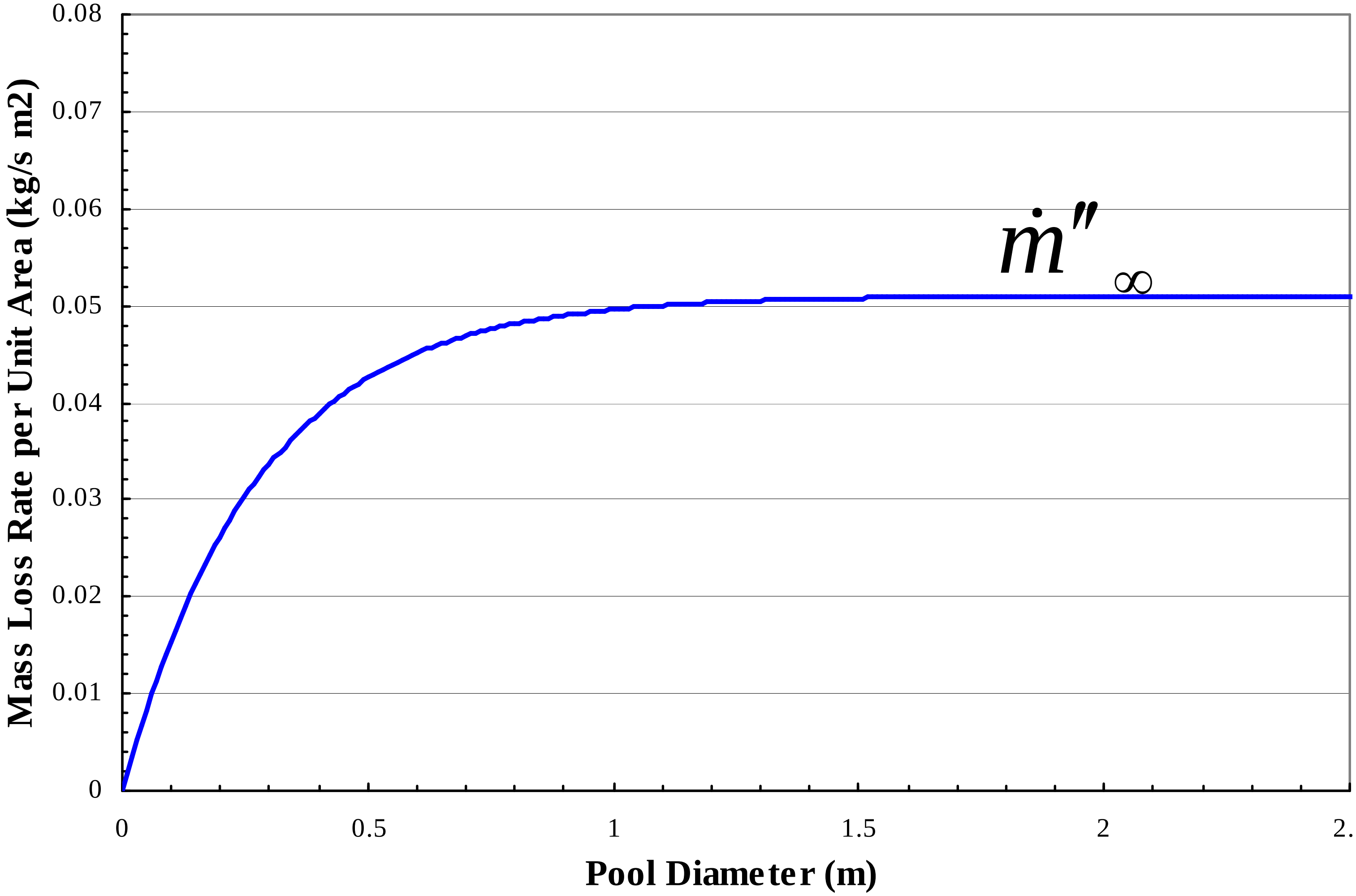
Flame Spread Rate

- Temperature of liquid most important factor
- Gas-phase (20 C > T_{FP})
  - 130 to 220 cm/s
- Liquid-phase
  - 1 to 12 cm/s
- Spread on porous surfaces
  - cm/min

Pool Correlation

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



Issues

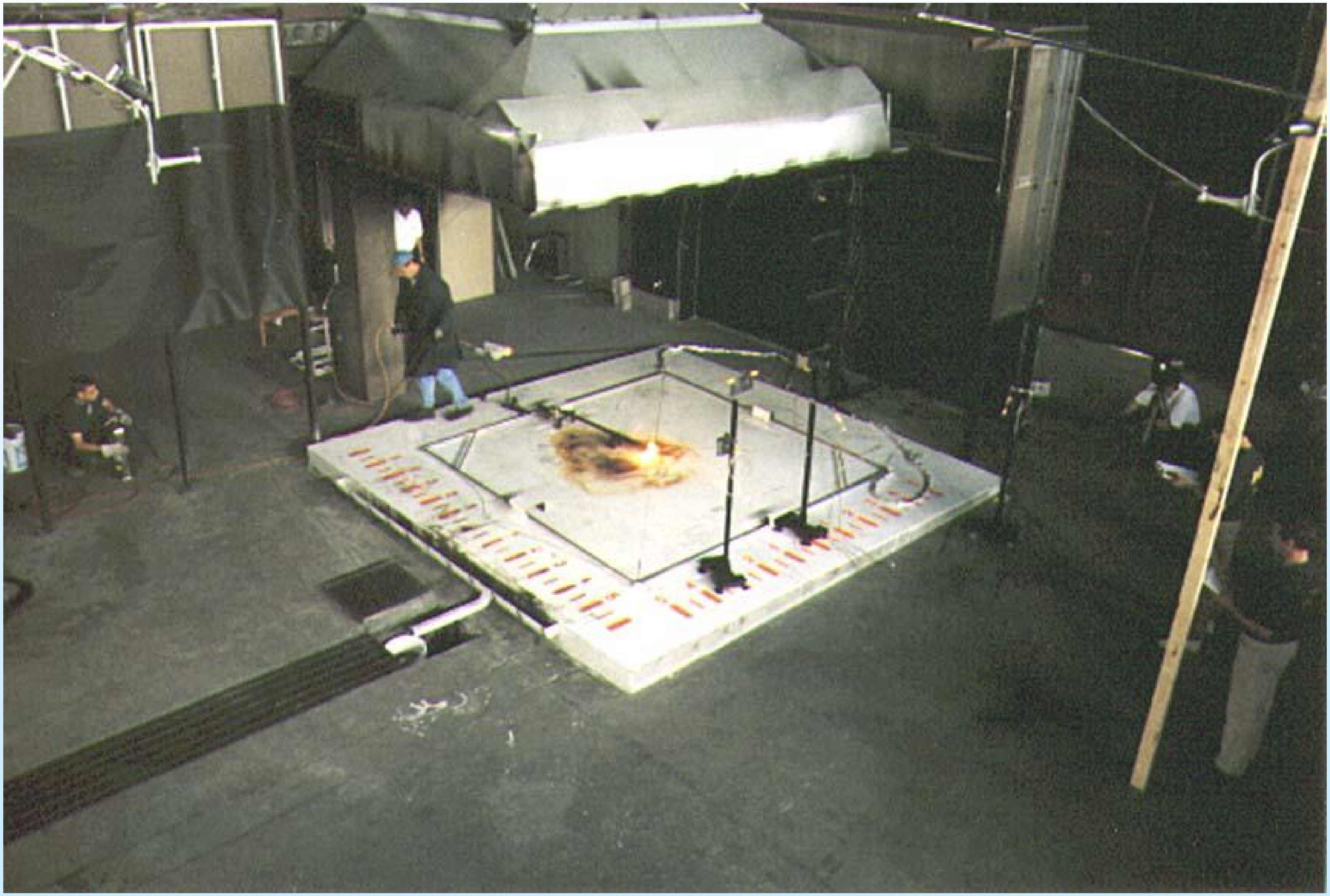
- Most published data is for confined fires (pan or diked pools)
- Pool depths typically greater than spill depths
- Will the pool fire correlation (or available regression rate data) accurately predict spill fire burning rates?
- How well can we estimate spill fire heat release rates and flame heights?

Experimental Program

- Measured pool size and HRR of JP-8 and JP-5 spill fires → calculated burning rate

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

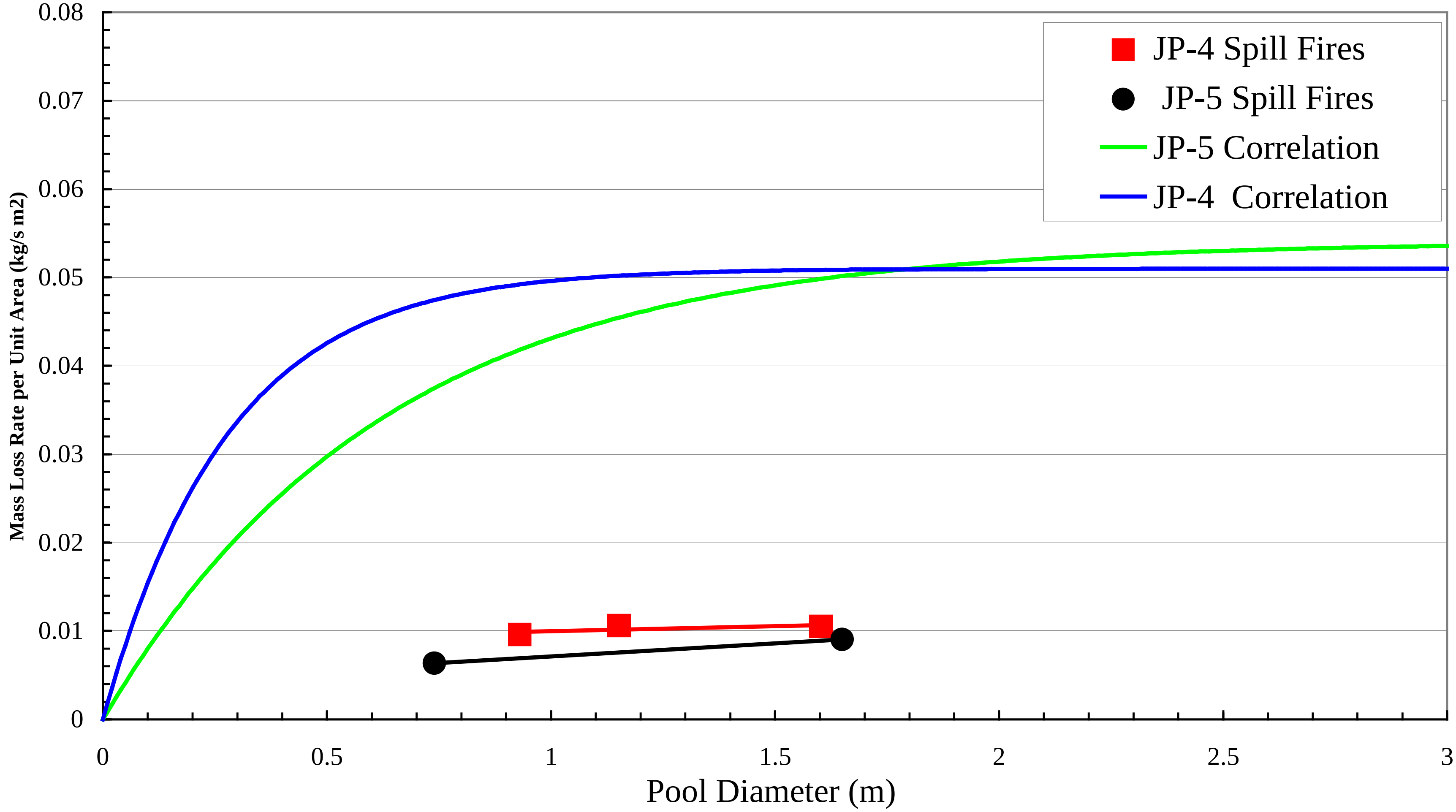
Experimental Setup



Typical Unconfined Spill Fire

Fixed Quantity Spill Fire

Experimental Fuel Spill Fire Results compared to Pool Fire Correlation



Findings

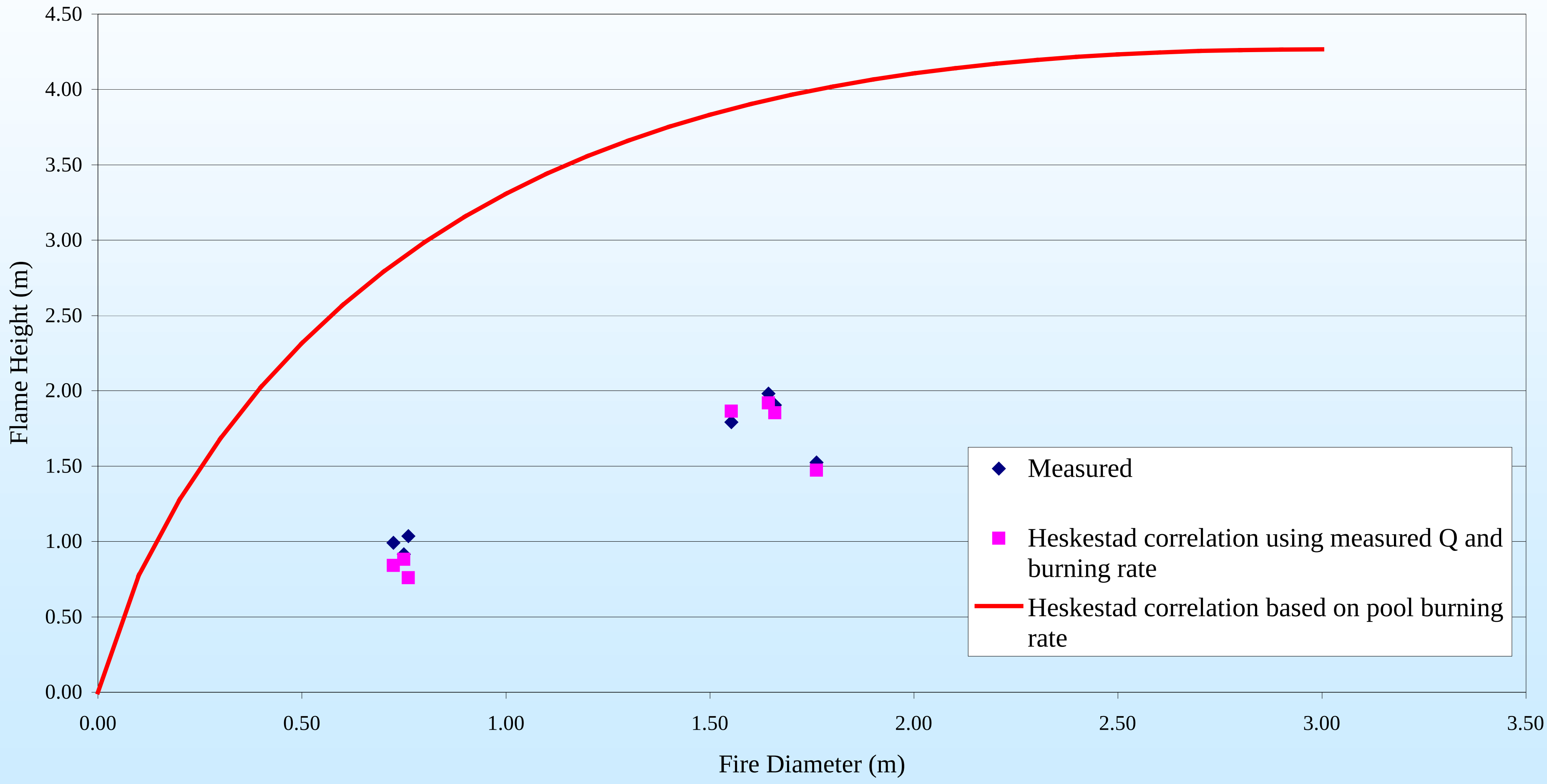
- Spill $\dot{m}''$ approximately 20-25% of the frequently used pool fire data:
  - Navy data
  - Putorti [2000]
- Lower spill fire burning rate correlates to spill diameters ~ twice as large as would be estimated using pool fire data

Flame Height

- Heskestad correlation for intermittent flame height, L_f:

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

Flame Height for JP-5 Spill Fires



Radiant Heating of Targets

- Shokri and Beyler Method

$$q'' = E \cdot F_{1-2}$$

$$E = 58(10^{-0.00823 \cdot D}) = [kW / m^2]$$

Conclusions

- Experiments demonstrated that commonly used pool fire data is not accurate for predicting fuel spill fire dynamics
- Average depths for spills can be as small as 0.7 to 1.1 mm

Conclusions

- Spill $\dot{m}''$ approximately 20-25% of the frequently used pool fire data
- Use of lower spill fire burning rates results in spill diameters ~ twice as large as would be estimated using pool fire data

Conclusions

- The Heskestad intermittent flame height correlation accurately predicts L_f when using the correct spill or pool fire burning rate