Spray Characteristics of Fire Sprinklers

David T. Sheppard, Ph.D.
PhD Dissertation
Northwestern University
Evanston, IL

Funded By The Building And Fire Research Laboratory (BFRL)
of the National Institute of Standards and Technology (NIST)

Facilities Provided by Underwriters Laboratories, Inc.

Advisor : Dr. Richard Lueptow

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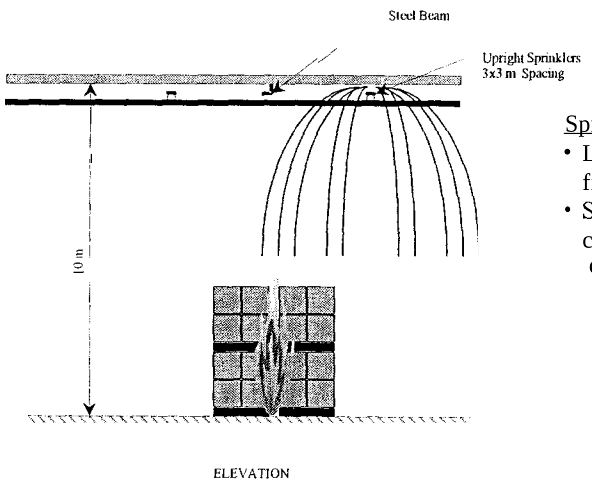
Sprinkler Design



Sprinkler Design Criteria

- Large Drops inust penetrate fire plume to control fire
- Small drops must evaporatively cool the air to limit the number of activated sprinklers

2

Non-Dimensionalize Velocity

Bernoulli $$U \propto \sqrt{\frac{P}{\rho}}$$

Non-Dimensionalization $$\bar{U}(\phi,\theta) = u_r(\phi,\theta)\sqrt{\frac{\rho}{P}}$$

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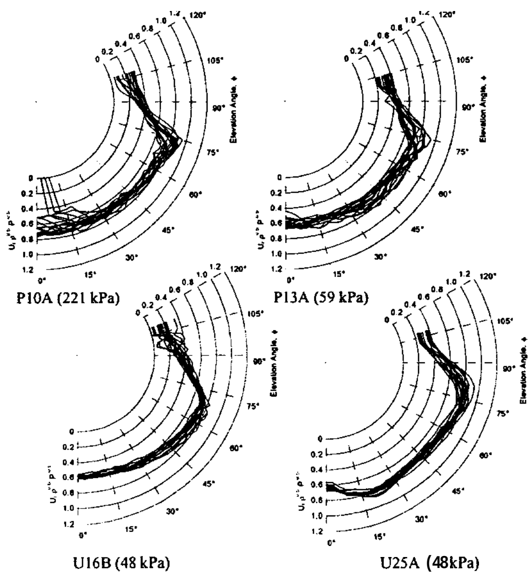
Dimensionless Radial Velocity



$$0.6 \leq \bar{U} \leq \ .0$$

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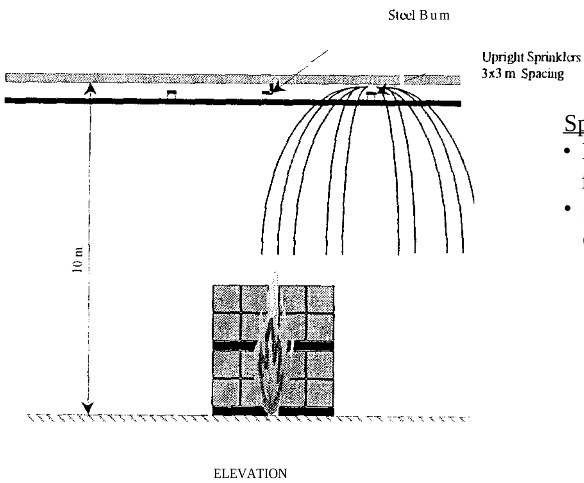

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- Large Drops must penetrate fire plume *to* control fire
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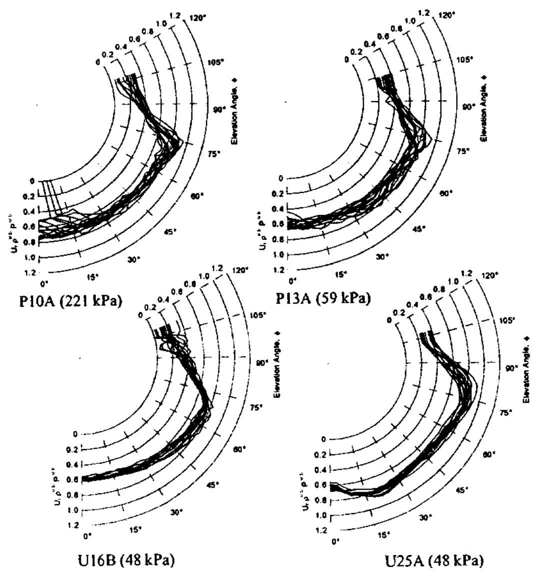
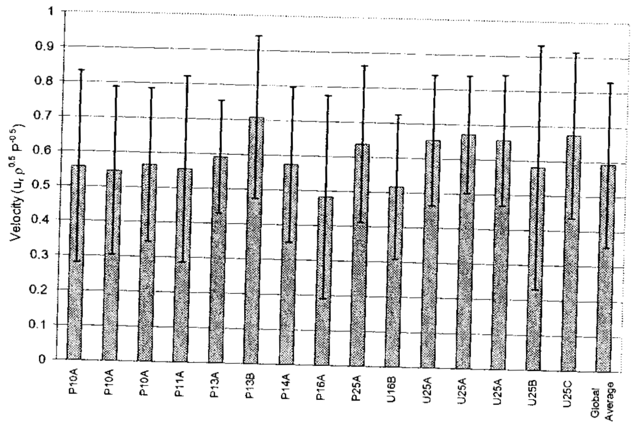
Dimensionless Radial Velocity



$$0.6 \le \bar{U} \le 1.0$$

Average Non-dimensional Velocity



$$\bar{U}_{avg} = 0.59\sqrt{P/\rho}$$

$$\sigma = 0.24$$

$$\bar{U}_{avg} \approx 0.6\sqrt{\frac{P}{\rho}}$$

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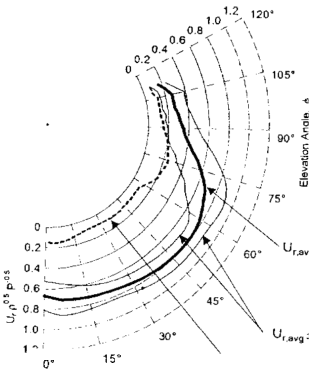
Average for All Sprinklers



average standard deviation = 26%

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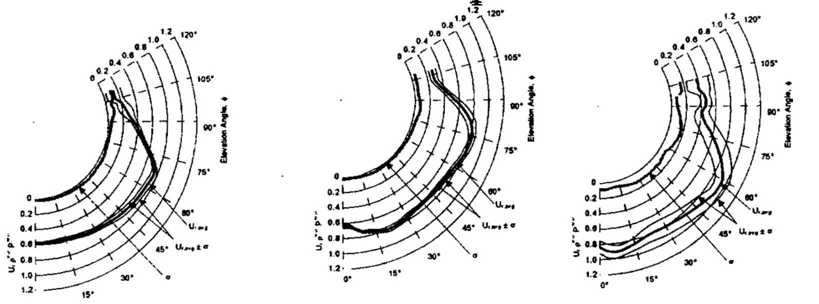
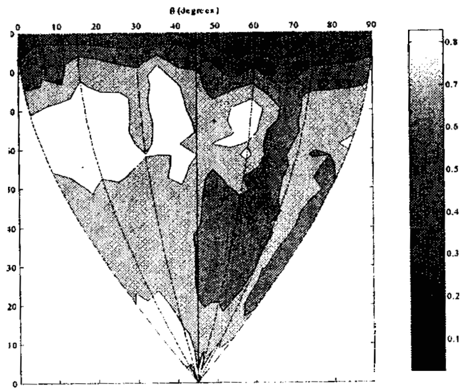
Azimuthal Dependence



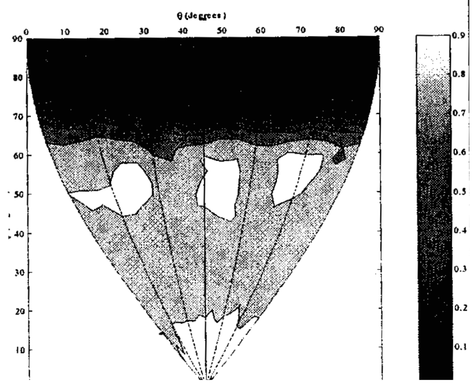
U16B (48 kPa) U25A (48 kPa) U25C (103 kPa)

5 of 12 sprinklers can be modeled as axisymmetric because the standard deviations (σ) are less than 5%. Depends on condition because changing pressure can increase σ > 5%

Velocity Contours



U25A



U25B

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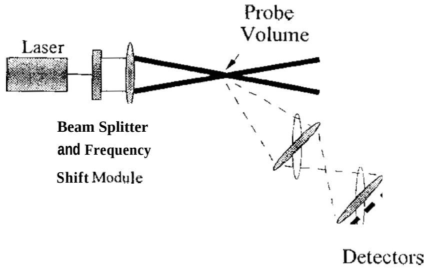
Droplet Sizes
Phase Doppler Interferometry (PDI)

Advantage

- Precise Measurement

Disadvantage

- Small Probe Volume



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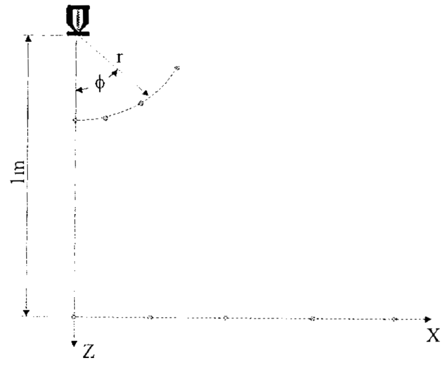
PDI Measurement Locations



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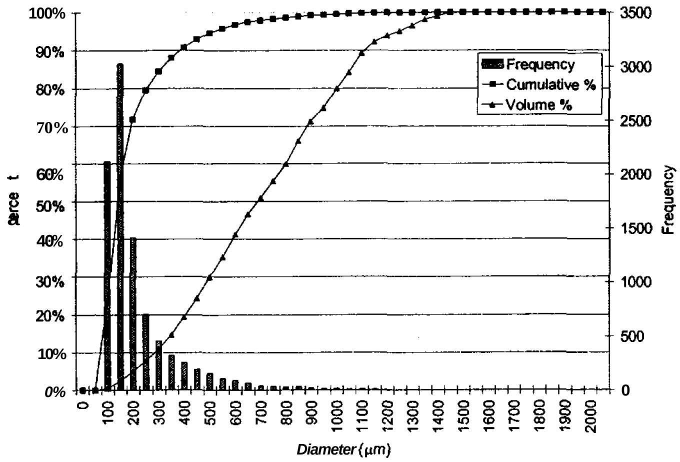
Typical PDI Result Near Sprinkler



P13B at 88kPa, $\phi = 0"$

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Equivalent Diameters

Symbol	Name	Definition	Formula
d_i	Diameter	Diameter of sphere	d
d_{32}	Surface Volume Diameter (Sauter Diameter)	Diameter of a sphere having the surface to volume ratio as a droplet.	$D_{32} = \frac{d^3}{d^2}$
DV50	Volume Median Diameter	Half of a given volume of water is contained in droplets greater than this diameter and the other half in droplets smaller than this diameter	

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PDI Results

- Average number of droplets : 10286
- Maximum number of droplets : 13028
- Minimum number of droplets : 6094

<u>Equivalent Diameters</u>

- 157 $\leq d_1 \leq$ 795 μm
- 252 ≤ DV50 I3393 μm
- 316 $\leq d_{32} \leq$ 5693 μm

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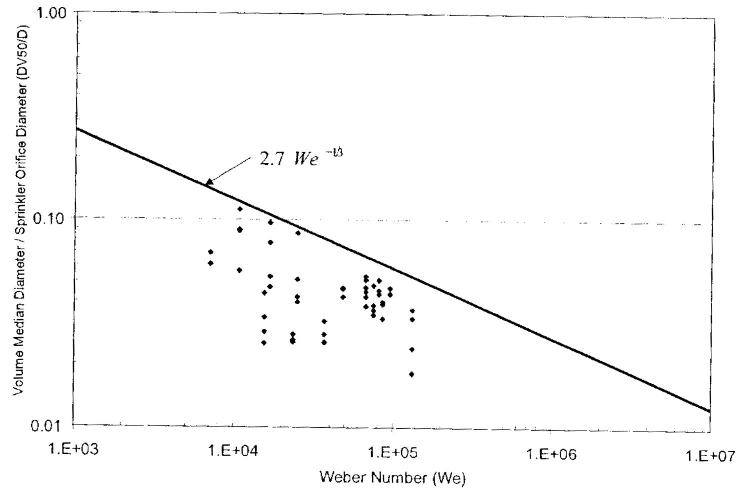
Droplet Size and Weber Number



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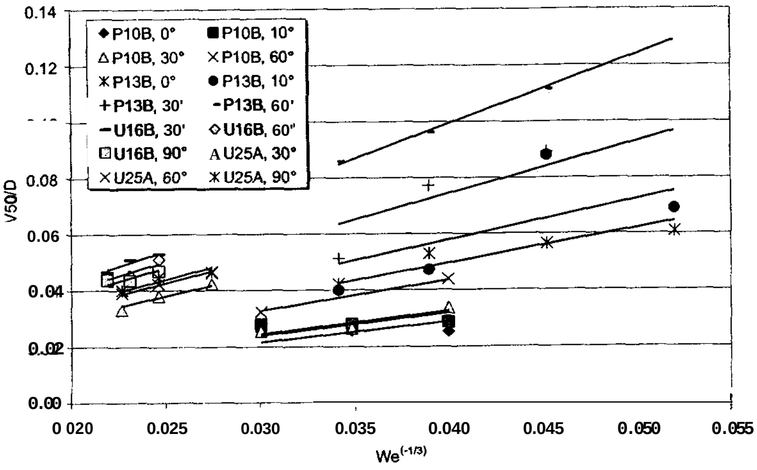
DV50 and Weber Number



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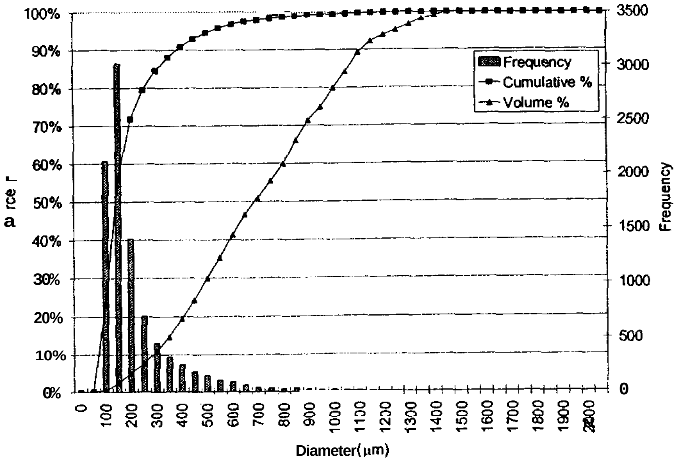
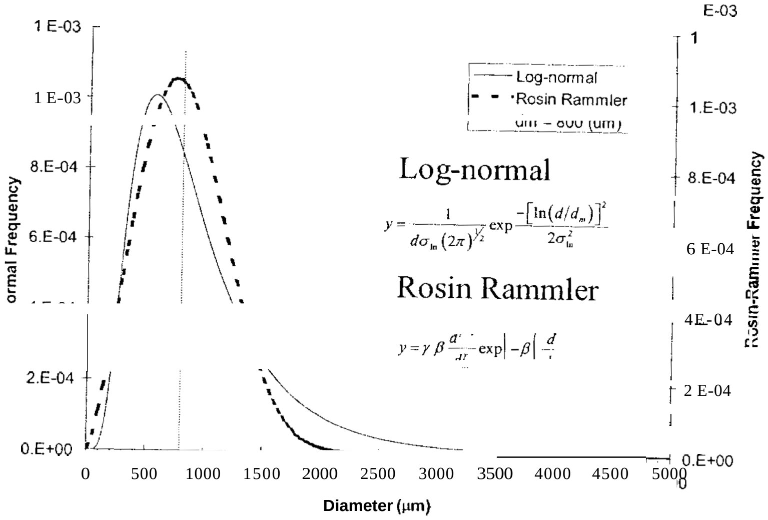
Typical PDI Result



P13B at 88kPa, 4 = 0"

Droplet Distribution Functions



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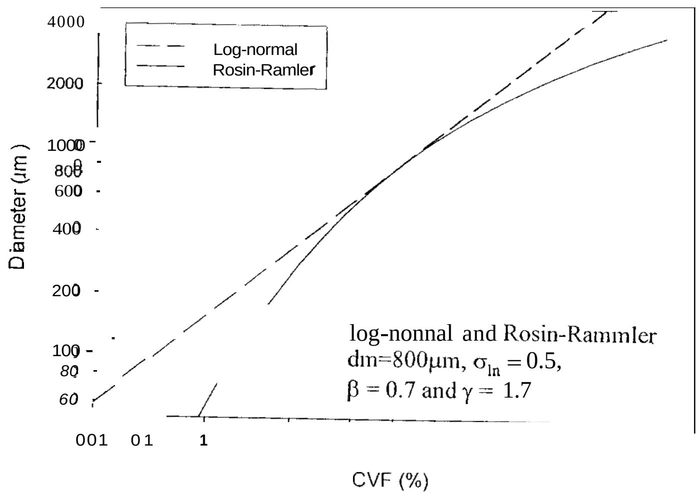
Cumulative Volume Fraction (CVF)



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Comparison of experimental CVF with log-normal and Rosin-Rammler distributions

Sprinkler	Pressure (kPa)	Elevation (degrees)	Distribution below DV50	Distribution above DV50	DV50 (μm)	β (μm)	γ (μm)	σ_{ln} (μm)
P10B	130	0	log-normal	above log-normal	252	0.63	3.20	0.36
P10B	130	10	log-normal	above log-normal	286	0.61	2.72	0.39
P10B	130	30	log-normal	above log-normal	337	0.62	2.06	0.48
P10B	130	60	below log-normal	below log-normal	439	0.68	1.73	0.68

$0.35 < \sigma_{ln} < 0.86$ average = 0.55, standard deviation = 0.14

$0.64 < \beta < 0.75$ average = 0.69, standard deviation = 0.026

$1.85 < \gamma < 2.57$ average = 2.19, standard deviation = 0.186

Γable 8

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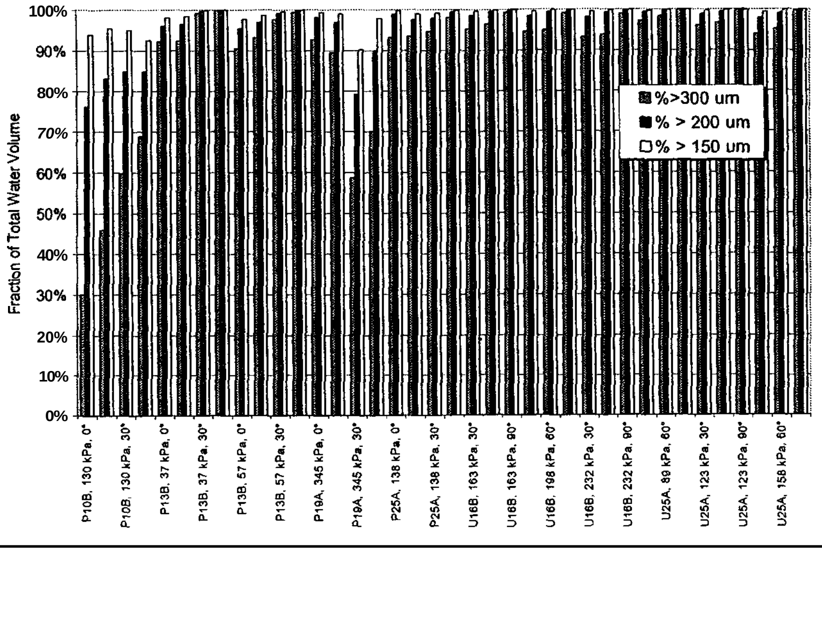
Fraction of Water Visible in PIV Images



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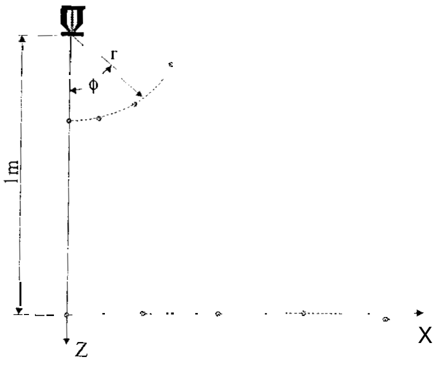
PDI 1m Below Sprinklers

- Droplet size increases with distance from sprinkler axis
- Bimodal shape observed



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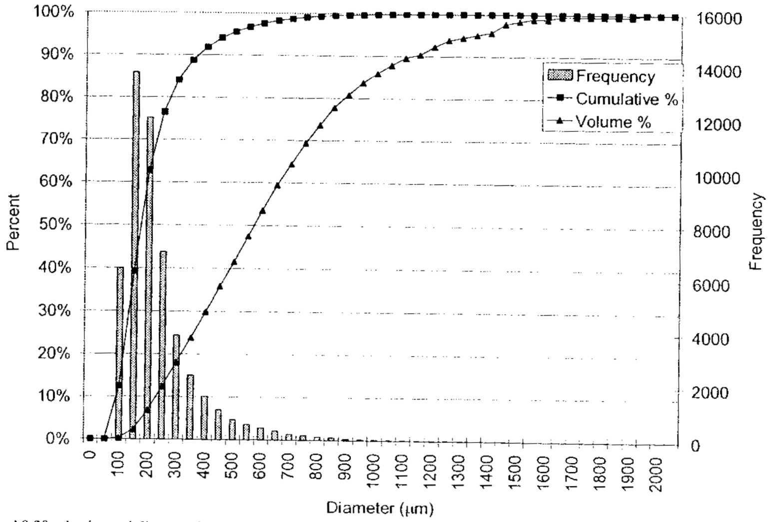
PDI Results Below Sprinkler



1m below and 0.29m horizontal distance from P19B

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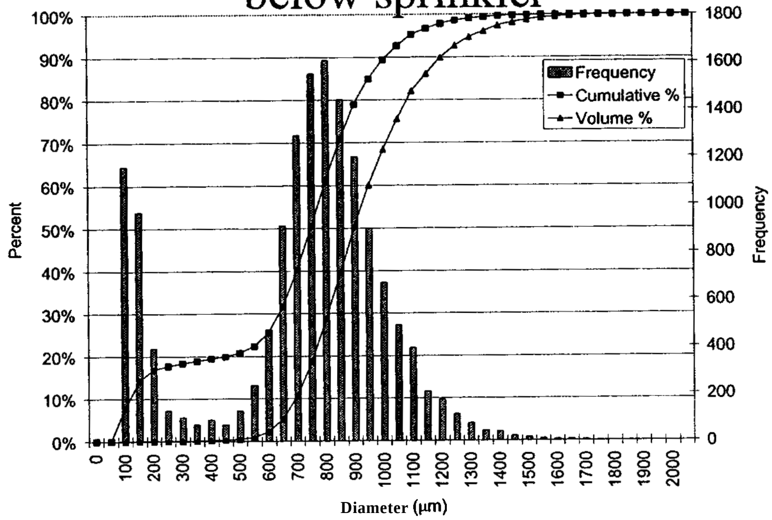
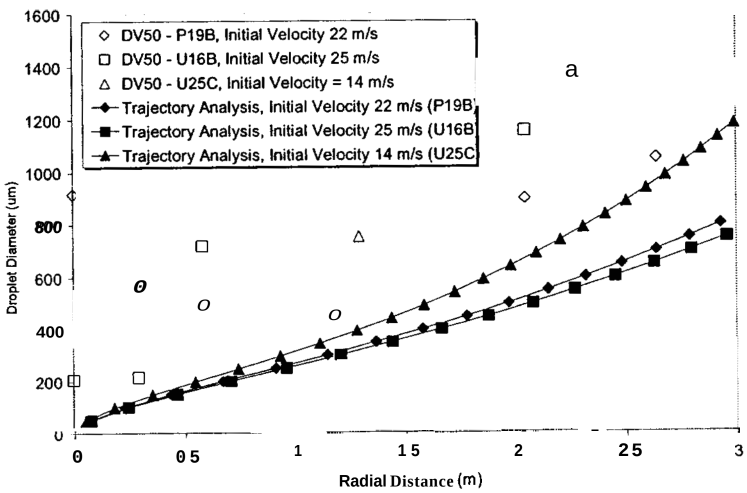
Bimodal shape in histograms 1m below sprinkler

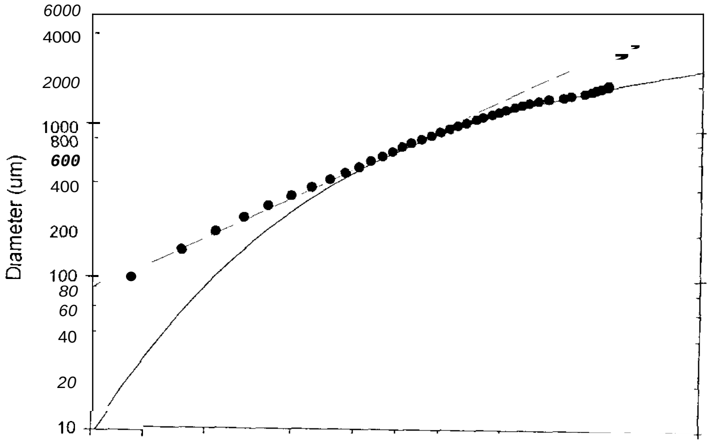


1m below and 2.04m horizontal distance from P19B

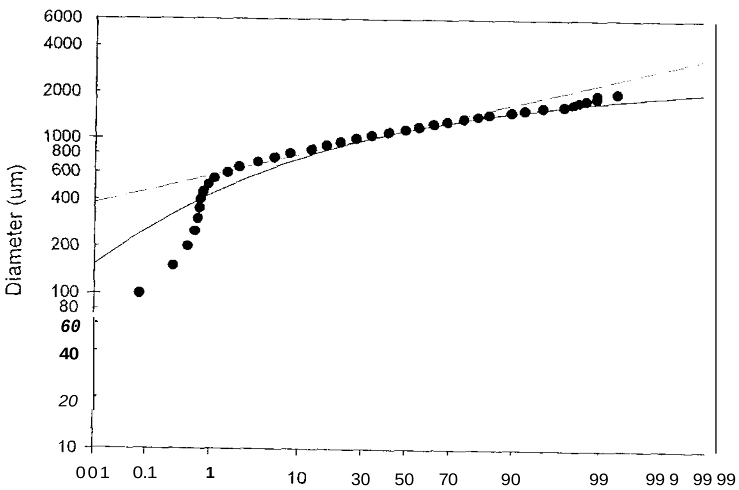
DV50 versus Horizontal Distance



CVF Combination log-normal Rosin-Rammler



CVF – Bimodal Histogram



16B sprinkler at X = 2.044m

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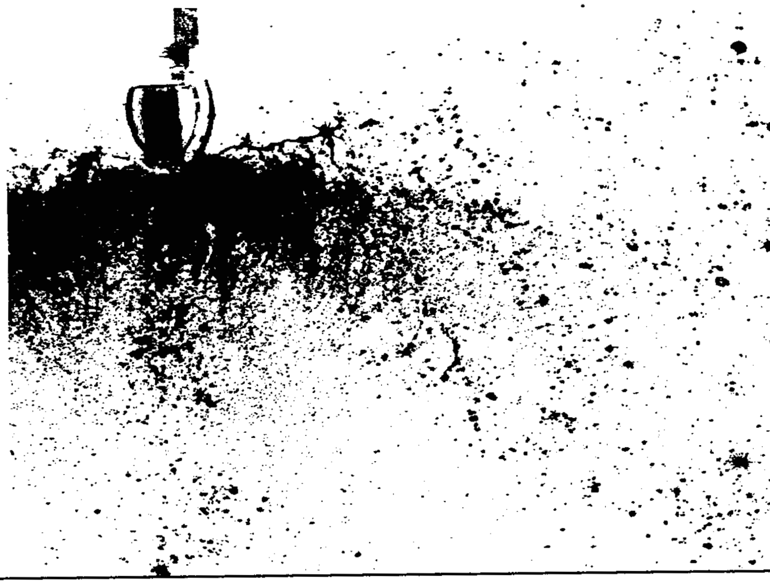
Water Flux



Water Flux

$$\textbf{Water}\ Flux = kg/\sec/m^2$$

$$q'' = \dot{q}/A$$

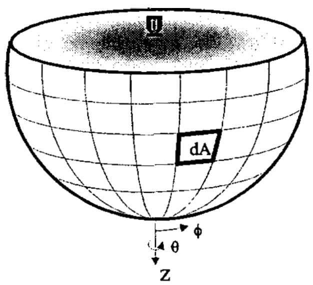
$$dA = r^2 \sin\phi \, d\theta \, d\phi$$

Assume number of visible droplets is proportional to volume of water

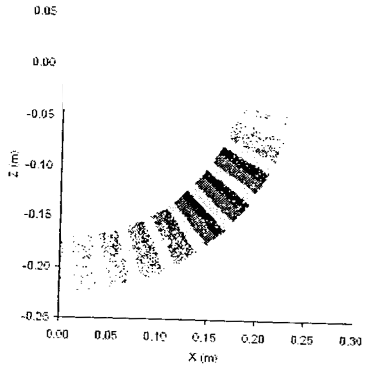
$$dq = \frac{\pi D^3}{6} \mathrm{N} \, dV$$

$$q'''(\phi,\theta) = \frac{q}{V} \equiv \frac{\pi D^3}{6} N(\phi,\theta)$$

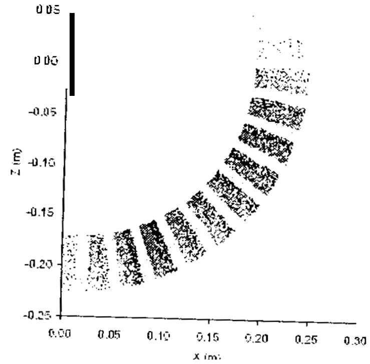
$$d\dot{q}(\phi,\theta) = q'''(\phi,\theta) \, u_r(\phi,\theta) \, dA$$



Droplet Count



P10A



U25A

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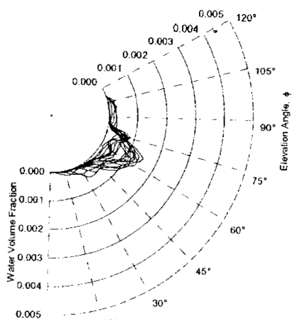
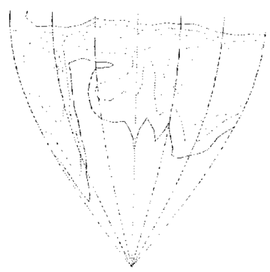
Volume Fraction





P10A sprinkler at 221 kPa

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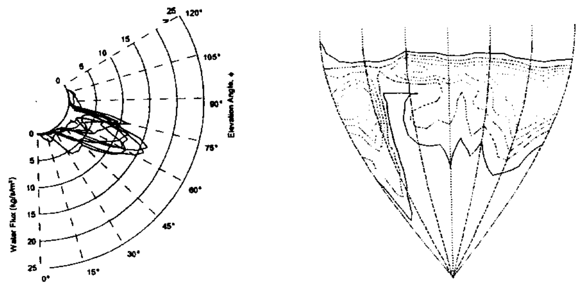
Water Flux



P10A **sprinkler** at 221 kPa

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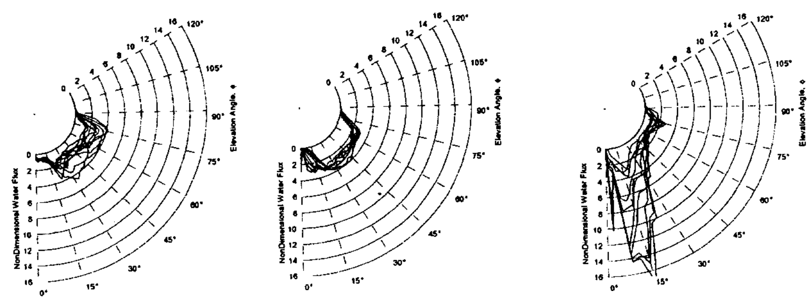
Non-dimensional flux

$$\bar{\dot{m}}'' = \dot{m}'' \frac{A}{\dot{m}_{sprinkler}}$$



48 kPa 76 kPa **103** kPa

U25A

Non-dimensional flux

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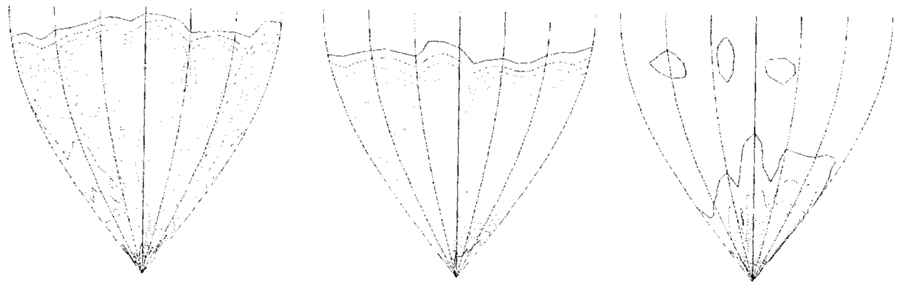

48 kPa 76 kPa 103 kPa

U25A

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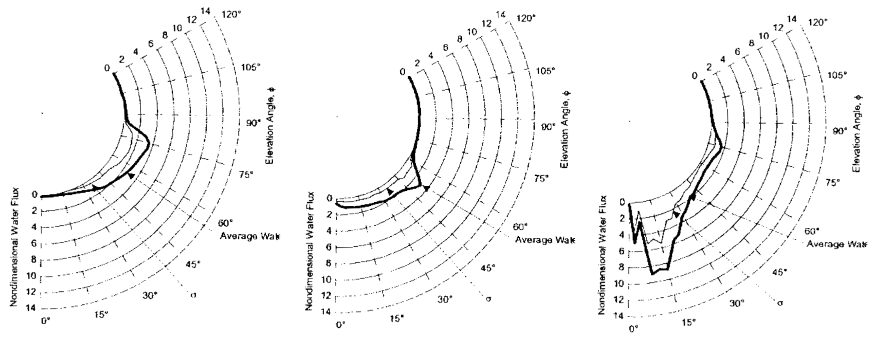
Azimuthal Dependence



P13B (131 kPa) P16A (48 kPa) U25A (103 kPa)

standard deviation was typically about *50%* of the axisymmetric flux at any location

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Summary

- The spray velocity radial.
- The velocity profile varies widely with no differentiation between upright and pendant sprinklers.
- The maximum radial velocities range from 5.8 to 14.1 $m \times s^{-1}$.
- The non-dimensionalized velocity, accounts for the effect of orifice pressure.

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Summary

- The velocity profiles for 5 of 12 sprinklers could be modeled as axisymmetric.
- Many variations in the velocity profile could be linked to sprinkler features
- **A** typical axisymmetric sprinkler velocity profile was created from all the velocity results.

5:

Summary

- The largest number of droplets are less than 250μm in diameter,
- The majority of water volume is carried by droplets with diameters greater than 300μm.
- Near the sprinklers more large droplets were present as the elevation angle increased.

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Summary

- The CVF was unique for each sprinkler and location.
- $DV50 \propto We^{-1/3}$
- Water flux can be calculated using PIV Images
- Maximum flux was 2.7 to 9.7 times the average.
- Changes in pressure alter the distribution of the water flux.

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Quick Response Sprinkler Sensitivity in Dry Pipe Sprinkler Systems

Victoria B. Valentine, E.I.T.
Manager of Product Standards
January 2003

1

Outline

- Problem Statement
- Background
- System Description
- Fire Modeling
- Experiments
- Results
- Conclusions

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