SUPDET 2010 Conference
High Challenge Warehouse Workshop

Redefining Suppression

Photo: Tupperware Storage Warehouse Fire, Georgetown Country Fire Dept. Hemingway, SC

Collaboration

Assistant Professor Ali Rangwala
Fire Protection Engineering
Worcester Polytechnic Institute

Jonathan Perricone, P.E.
Creative FPE Solutions, Inc.

Professor José Torero
BRE/RAE Chair in Fire Safety Engineering
University of Edinburgh

Michael Gollner, E.I.T.
UC San Diego

Professor Forman Williams
UC San Diego

The University of Edinburgh

Worcester Polytechnic Institute 1865 WPI

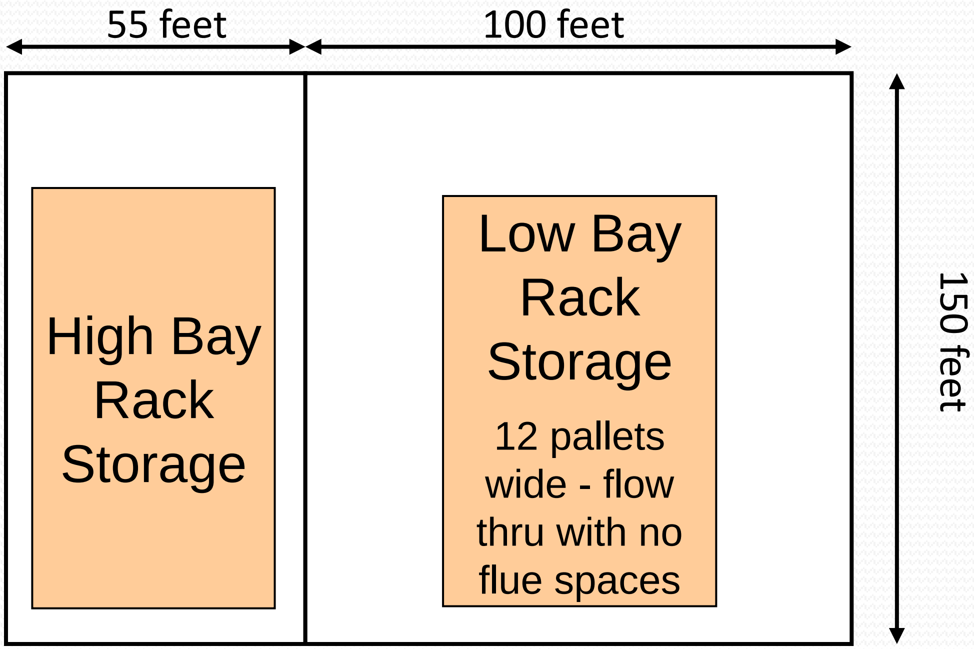
UCSD Jacobs | Mechanical and Aerospace Engineering

Creative FPE Solutions, Inc.

Warehouse Design Problem

- Automatic suppression system design for High Bay section of new warehouse facility
- 65' high
- 8,200 ft^2 Area
- Limited Water Supply
  - 60 psi static
  - 20 psi residual, 80 gpm
- ***Final fire extinguishment is necessary***

Top-View



Guidance from NFPA 13 (2010)

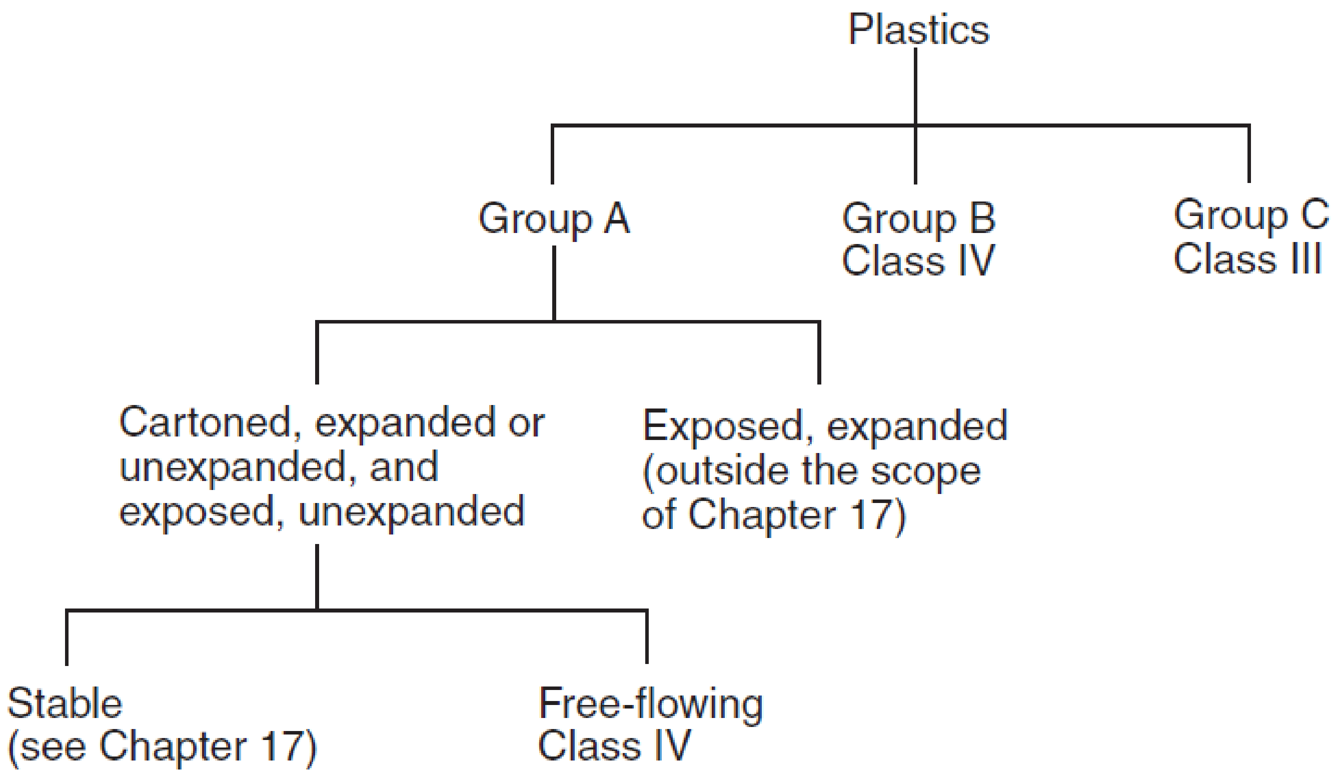


FIGURE 17.1.2.1 Decision Tree.

Control Mode Protection

Table 17.3.2.1 CMSA Sprinkler Design Criteria for Single-, Double-, and Multiple-Row Racks Without Solid Shelves of Plastics Commodities Stored Over 25 ft (7.6 m) in Height

Storage Arrangement	Commodity Class	Maximum Storage Height		Maximum Ceiling/Roof Height		K-Factor/ Orientation	Type of System	Number of Design Sprinklers	Minimum Operating Pressure	Hose Stream Allowance	Water Supply Duration (hours)
		ft	m	ft	m						
Single-, double-, and multiple-row racks without solid shelves (no open-top containers)	Cartoned unexpanded plastics	30	9.1	35	10.6	19.6 (280) Pendent	Wet	15	25 psi (1.7 bar)	500 gpm (1900 L/min)	1½
		35	10.6	40	12.1	19.6 (280) Pendent	Wet	15	30 psi (2.1 bar)	500 gpm (1900 L/min)	1½

Suppression Mode (ESFR)

Table 17.3.3.1 ESFR Protection of Rack Storage Without Solid Shelves of Plastics Commodities Stored Over 25 ft (7.6 m) in Height

Storage Arrangement	Commodity	Maximum Storage Height ft	Maximum Storage Height m	Maximum Ceiling/Roof Height ft	Maximum Ceiling/Roof Height m	Nominal K-Factor	Orientation	Minimum Operating Pressure psi	Minimum Operating Pressure bar	In-Rack Sprinkler Requirements	Hose Stream Allowance gpm	Hose Stream Allowance L/min
						22.4 (320)	Pendent	40	2.8	No		
Single-row, double-row, and multiple-row rack (no open-top containers)	Cartoned unexpanded					25.2 (360)	Pendent	40	2.8	No	250	946
						14.0 (200)	Pendent	75	5.2	No		
				40	12.2	16.8 (240)	Pendent	52	3.6	No		
						25.2 (360)	Pendent	25	1.7	No		
		35	10.7			14.0 (200)	Pendent	90	6.2	Yes		
				45	13.7	16.8 (240)	Pendent	63	4.3	Yes		
						22.4 (320)	Pendent	40	2.8	No		
						25.2 (320)	Pendent	40	2.8	No		
						14.0 (200)	Pendent	90	6.2	Yes		
		40	12.2	45	13.7	16.8 (240)	Pendent	63	4.3	Yes		
						22.4 (320)	Pendent	40	2.8	No		
						25.2 (320)	Pendent	40	2.8	No		

FM Global (Control Mode)

<table>
<tr><th rowspan="3">Maximum Storage Height, ft (m)</th><th rowspan="3">Maximum Building Height, ft (m)</th><th colspan="6">Cartoned Unexpanded Plastic and Cartoned Expanded Plastic in SRR, DRR and MRR</th></tr>
<tr><th colspan="3">K-factor 11.2 (160) A.S., 280°F (140°C) on a Dry-System, No. A.S. Pressure, psi (bar)</th><th colspan="3">K-factor 16.8 (240) A.S., 280°F (140°C) on a Dry-System, No. A.S. Pressure, psi (bar)</th></tr>
<tr><th>None/Open/ Less than 20 ft² (2.0 m²)</th><th>Solid Shelves 20 to 64 ft² (2.0 to 6.0 m²)</th><th>Solid Shelves Greater than 64 ft² (6.0 m²)</th><th>None/Open/ Less than 20 ft² (2.0 m²)</th><th>Solid Shelves 20 to 64 ft² (2.0 to 6.0 m²)</th><th>Solid Shelves Greater than 64 ft² (6.0 m²)</th></tr>
<tr><td rowspan="6">25 (7.5)</td><td rowspan="3">30 (9.0)</td><td>25 @ 50 (3.5) & IRAS(EO)</td><td>25 @ 50 (3.5) & IRAS(E)</td><td rowspan="3">25 @ 25 (1.7) & IRAS(ETL)</td><td>40 @ 22 (1.5)</td><td>25 @ 22 (1.5) & IRAS(E)</td><td rowspan="3">25 @ 15 (1.0) & IRAS(ETL)</td></tr>
<tr><td rowspan="2">25 @ 25 (1.7) & IRAS(E)</td><td rowspan="2">25 @ 25 (1.7) & 2 IRAS(E)</td><td>25 @ 22 (1.5) & IRAS(EO)</td><td rowspan="2">25 @ 15 (1.0) & 2 IRAS(E)</td></tr>
<tr><td>25 @ 15 (1.0) & IRAS(E)</td></tr>
<tr><td rowspan="3">45 (13.5)</td><td>40 @ 50 (3.5) & IRAS(EO)</td><td>25 @ 50 (3.5) & IRAS(E)</td><td rowspan="3">25 @ 25 (1.7) & IRAS(ETL)</td><td>40 @ 22 (1.5) & IRAS(EO)</td><td>25 @ 22 (1.5) & IRAS(E)</td><td rowspan="3">25 @ 15 (1.0) & IRAS(ETL)</td></tr>
<tr><td>25 @ 50 (3.5) & IRAS(E)</td><td rowspan="2">25 @ 25 (1.7) & 2 IRAS(E)</td><td>25 @ 22 (1.5) & IRAS(E)</td><td rowspan="2">25 @ 15 (1.0) & 2 IRAS(E)</td></tr>
<tr><td>25 @ 25 (1.7) & 2 IRAS(E)</td><td>25 @ 15 (1.0) & 2 IRAS(E)</td></tr>
</table>

FM Global (Suppression Mode)

Commodity	*Plastics Type/ Packaging*	*Maximum Storage Height, ft (m)*	*Maximum Building Height, ft (m)*	*Class 1, Class 2, Class 3, Class 4, Cartoned Unexpanded Plastics, Cartoned Expanded Plastics, Uncartoned Unexpanded Plastics, and Uncartoned Expanded Plastics in SRR, DRR and MRR*					
				Wet-Pipe, No. A.S. @ Pressure, psi (bar)					
				K-factor 14.0 (200), 160°F (70°C) Upright	K-factor 14.0 (200), 160°F (70°C) Pendent	K-factor 16.8 (240), 160°F (70°C) Upright	K-factor 16.8 (240), 160°F (70°C) Pendent	K-factor 22.4 (320), 160°F (70°C) Pendent	K-factor 25.2 (360), 160°F (70°C) Pendent
Class 1, 2, 3, 4, Plastics	Cartoned Unexpanded	25 (7.5)	30 (9.0)	12 @ 50 (3.5)	12 @ 50 (3.5)	12 @ 35 (2.4)	12 @ 35 (2.4)	12 @ 25 (1.7)	12 @ 20 (1.4)
			35 (10.5)	12 @ 75 (5.2)	12 @ 75 (5.2)	12 @ 52 (3.6)	12 @ 52 (3.6)	12 @ 35 (2.4)	12 @ 30 (2.1)
			40 (12.0)	DNA	12 @ 75 (5.2)	DNA	12 @ 52 (3.6)	12 @ 45 (3.1)	12 @ 40 (2.7)
			45 (13.5)	DNA	12 @ 90 (6.2) & IRAS(E)	DNA	12 @ 63 (4.3) & IRAS(E)	12 @ 50 (3.5)	12 @ 50 (3.5)
		30 (9.0)	35 (10.5)	12 @ 75 (5.2)	12 @ 75 (5.2)	12 @ 52 (3.6)	12 @ 52 (3.6)	12 @ 35 (2.4)	12 @ 30 (2.1)
			40 (12.0)	DNA	12 @ 75 (5.2)	DNA	12 @ 52 (3.6)	12 @ 45 (3.1)	12 @ 40 (2.7)
			45 (13.5)	DNA	12 @ 90 (6.2) & IRAS(E)	DNA	12 @ 63 (4.3) & IRAS(E)	12 @ 50 (3.5)	12 @ 50 (3.5)
		35 (10.5)	40 (12.0)	DNA	12 @ 75 (5.2)	DNA	12 @ 52 (3.6)	12 @ 45 (3.1)	12 @ 40 (2.7)
			45 (13.5)	DNA	12 @ 90 (6.2) & IRAS(E)	DNA	12 @ 63 (4.3) & IRAS(E)	12 @ 50 (3.5)	12 @ 50 (3.5)
		40 (12.0)	45 (13.5)	DNA	12 @ 90 (6.2) & IRAS(E)	DNA	12 @ 63 (4.3) & IRAS(E)	12 @ 50 (3.5)	12 @ 50 (3.5)

Guidance from Experience

- Fire severity is a strongly influenced by storage height
  - HRR for standard plastic commodity is directly proportional to number of storage tiers ($\leq$ 6) in first stage (2-3 min)[a]
- In-rack sprinkler protection is always required for storage over 25 feet high
- Plastic commodity storage heights above 35 feet are almost exclusively dependent on in-rack protection[b]
- In-rack sprinkler placement highly specific to fuel type, configuration
- Ceiling sprinkler densities influenced by storage clearance

---

[a,b]: *Zalosh, R. Industrial Fire Protection Engineering. Wiley & Sons, 2003. pp.157.*

How to Proceed

- Designs become solutions through validation
- Validation is optimized when experiments are designed based on verifiable theory
- Full-scale fire testing of a 65-foot tall facility is too costly to proceed by guess and check methods

Problems with Design

- ***"Final fire extinguishment is necessary"***
- Current standards dictate "control" of a warehouse fire
  - Fire is not supposed to spread beyond some limit.
  - Thus, spread rate is less than a defined value.
  - What is this value? Tests do not quantify this.
- *Extinction* is the point at which combustion ceases
- *There are **no methods**, currently, to **quantify** warehouse fire control, suppression or extinguishment.*

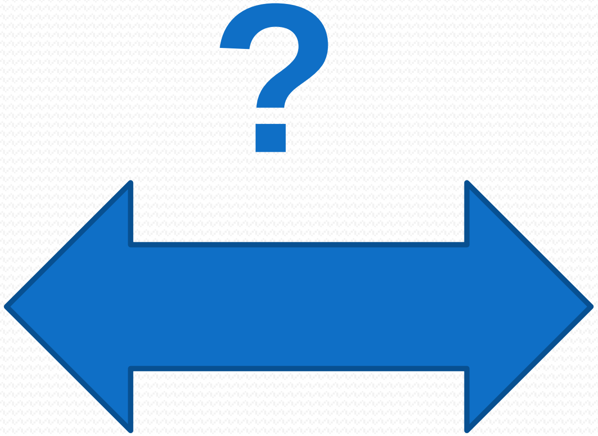
Options to Design Extinguishment

- Full-Scale tests
  - Must test all materials and configurations
  - Prohibitively expensive (only check once, no repeatability)
- Numerical modeling of potential suppression systems
  - CFD codes cannot resolve boundary-layer effects (small-scale) necessary to model the impact of suppressants.
  - Burning rate must be a known input to the model
- Scale Modeling
  - Disconnect between large-scale tests and laboratory setups
  - Laboratory tests ignore important physics occurring at large scales

Experimental Testing

Full-Scale Tests

Intermediate-Scale Tests (FPC)

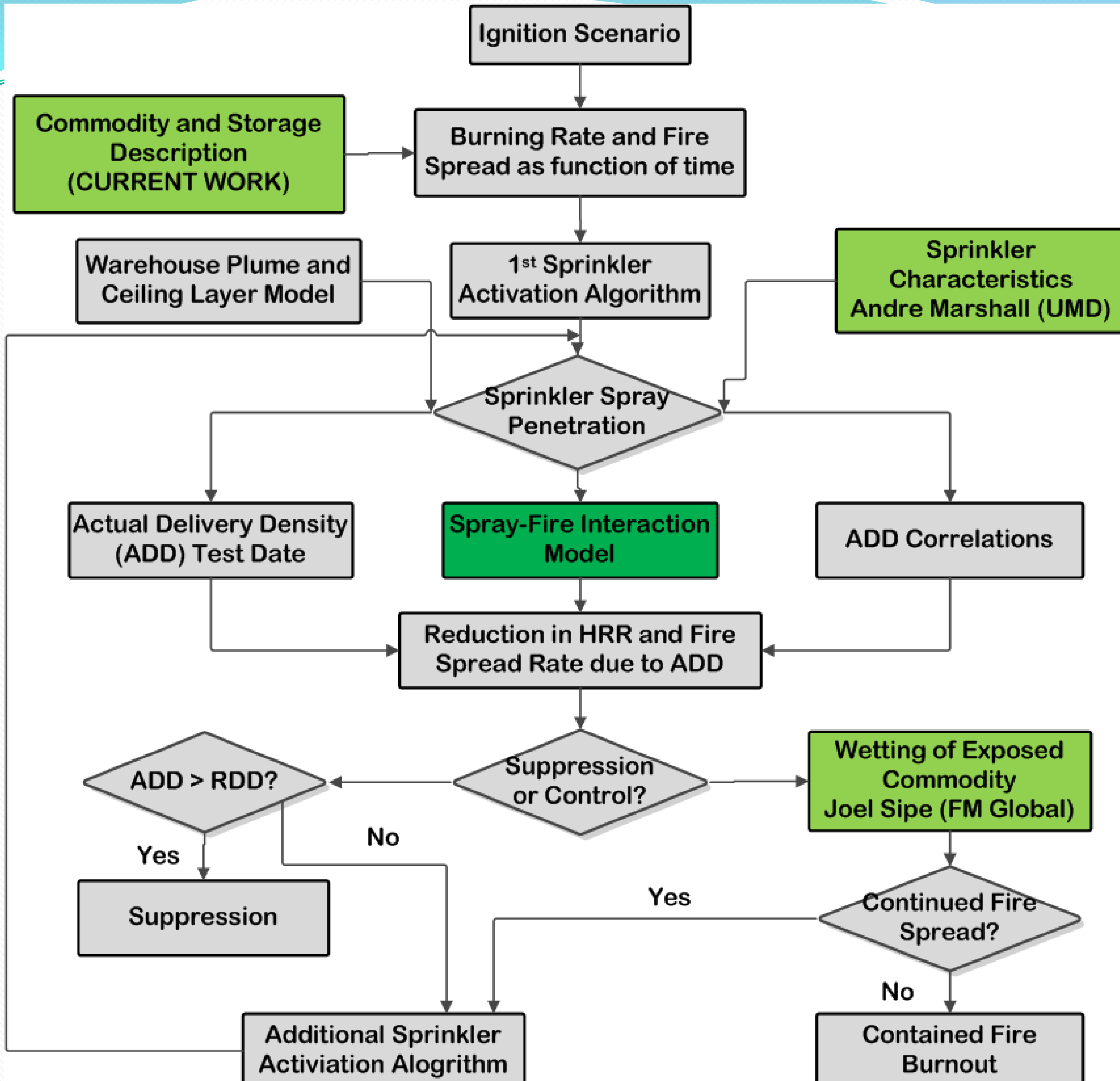


Cup Burner (Co-Flow):

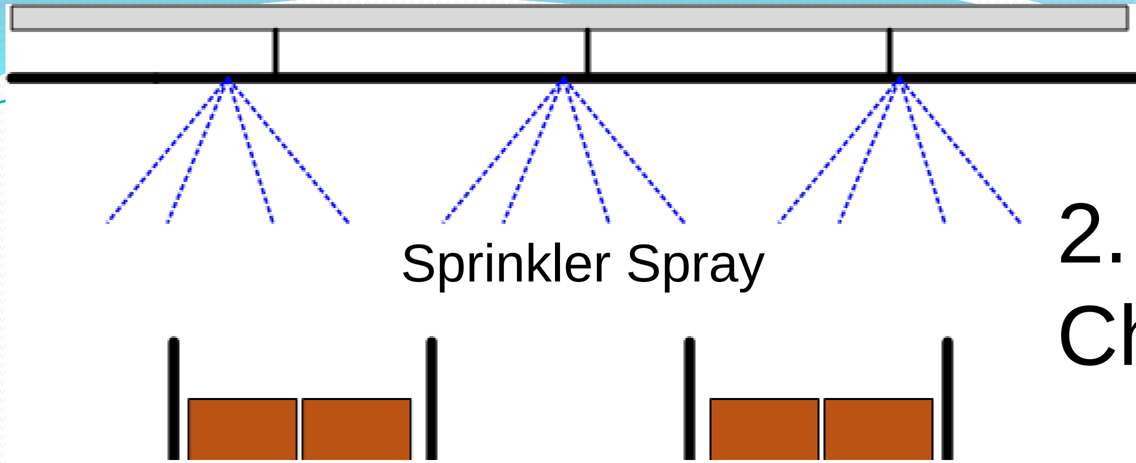
Counter-Flow Burner

(top) UL/Schirmer Engineering HVLS Fan Test Report. (Bottom) FM Global.

(top) Pro. Comb. Inst. (31) 2. 2007. pp. 2731-2739
(bottom) Pro. Comb. Inst. (32) 1, 2009, pp. 1067-1074



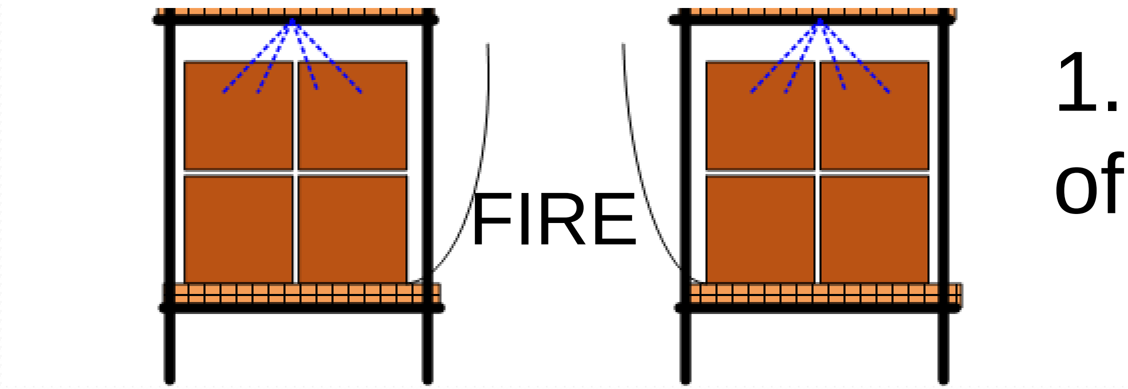
Zalosh, Industrial Fire Protection Engineering, pg 159



2. Sprinkler Flow Characterization

Large Scale Solution!

action



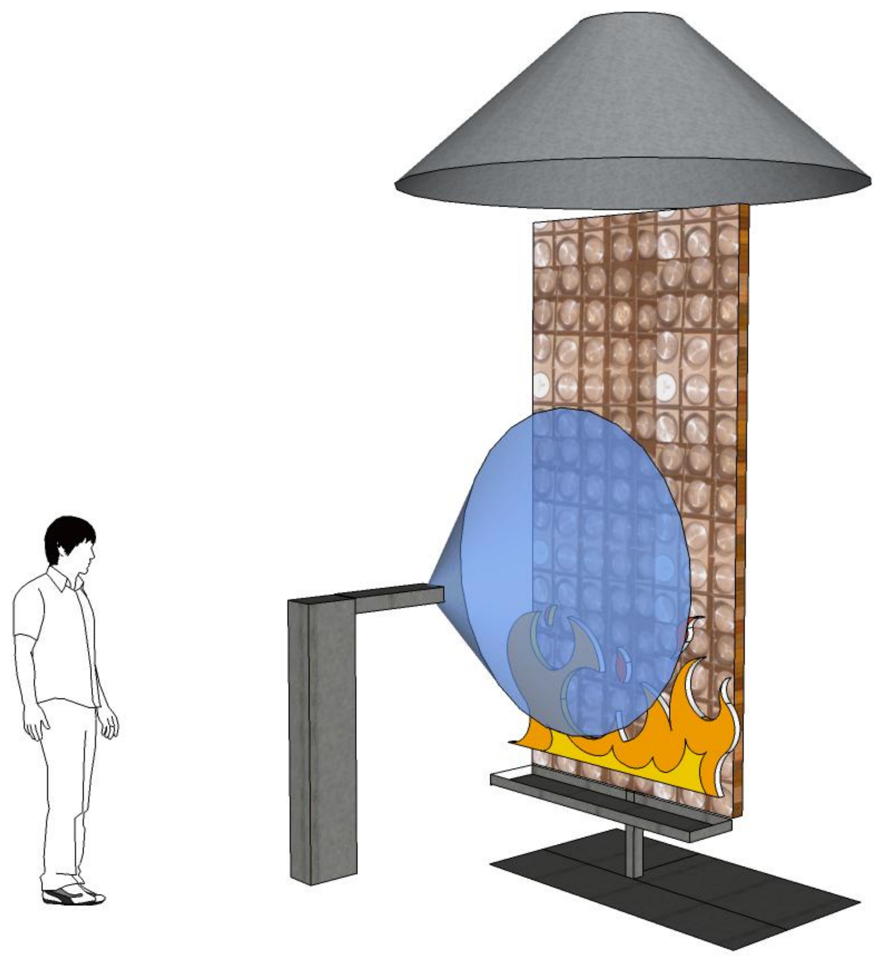
1. Classification of Commodity

1. New Intermediate-Scale Test

•Mixed-material mesh of materials on upright wall

•Water suppression spray with same droplet characteristics as sprinkler

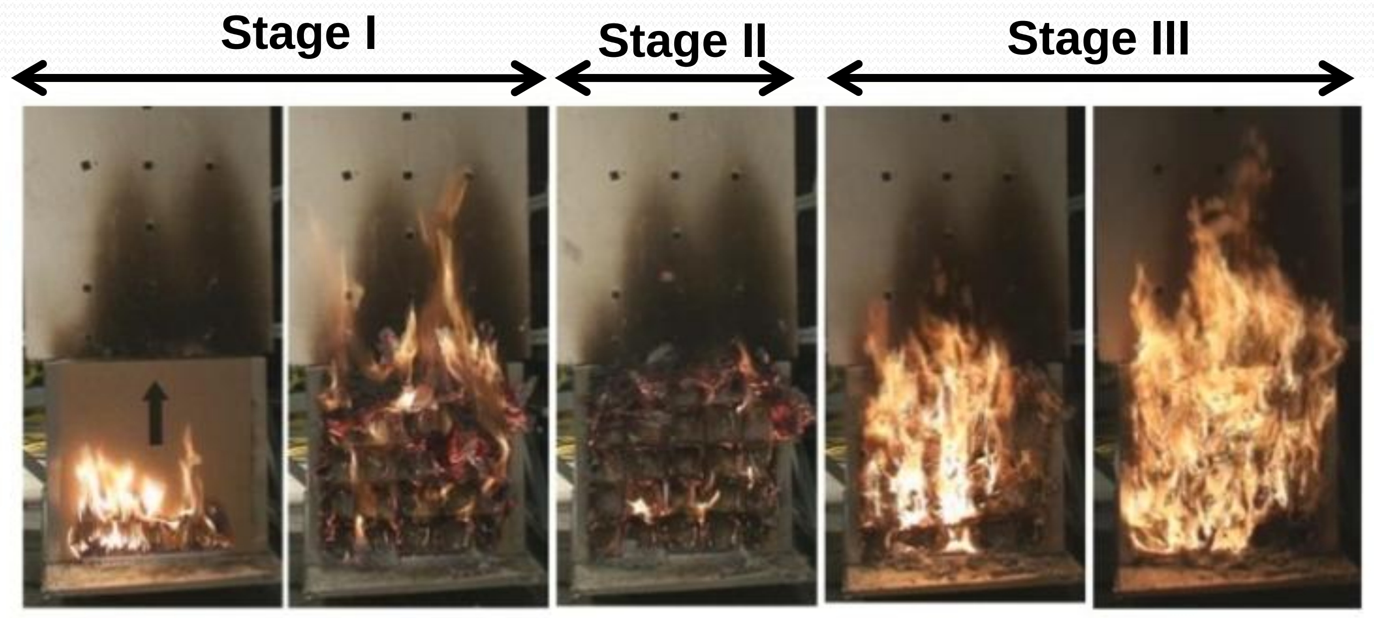
•Single layer of Group A, Class II commodities can be tested. Also test new plastics, wood, etc.



1. New Intermediate-Scale Test

- Quantitatively determine water application rate necessary to achieve suppression
  - Suppression defined by: **spread rate = 0**
- Upward spread test over common mixed-materials will simulate interaction of water droplets through a boundary layer and onto a burning solid.
- Actual commodity is used, so soaking, bouncing of water droplets off surface, and flow is accurately modeled.
- Water density required for suppression versus a commodity parameter will be determined.
- Droplet distribution will be same as actual sprinklers.

1. Mixed Materials Modeling



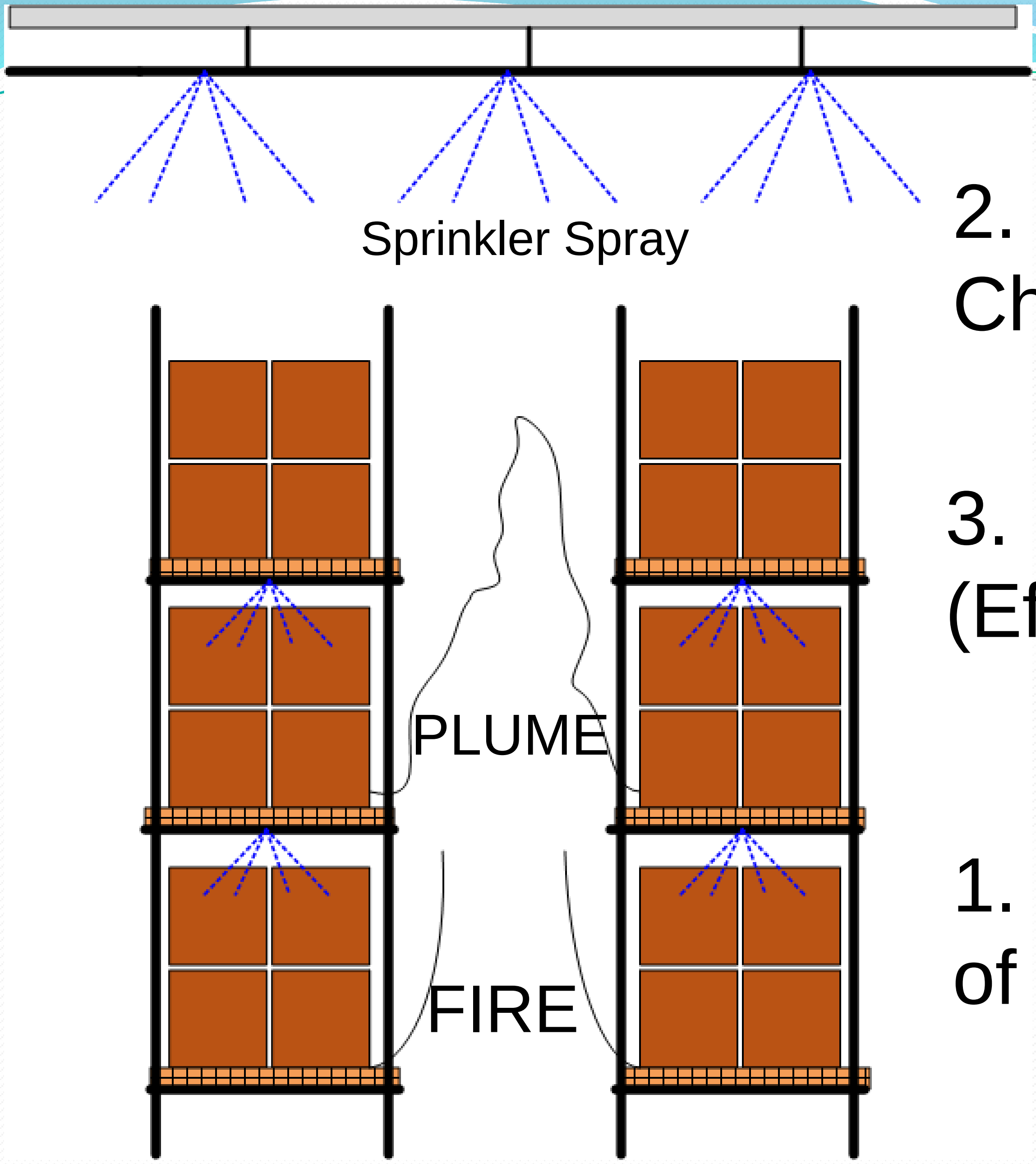
- Interaction of different materials over time must be taken into account
- Stage I can be modeled just by corrugated cardboard
- Stage II and III can be modeled by corrugated cardboard and polystyrene cups in single layer
- Allows for classification of commodity with inclusion for volume ratio and mass ratio

2. Sprinkler Flow Characterization

- Research currently performed (Andre Marshall, UMD) has characterized the spray coming out of various sprinkler heads
- CFD can reproduce droplet trajectories after the discharge pattern has been well characterized and serves as input to the models (i.e. FDS).

3. Flow Interaction with Geometry & Fire Plumes

- This information will be used as an input to a numerical model to determine “efficiency factors,” the percentage of droplets which reach the surface of the burning commodity.
- This is where CFD can be very useful, between exit from the sprinkler spray and before entrance into the thermal and fluid boundary layer.
  - Droplet losses by geometry
  - Droplet losses by radiation
  - Momentum change of droplets before reaching surface



2. Sprinkler Flow Characterization

3. Flow Interaction (Efficiency)

1. Classification of Commodity

Large-Scale Relationship

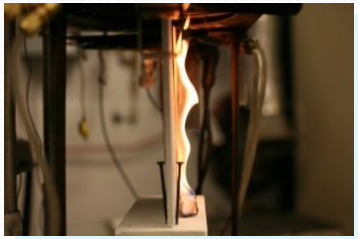
- Large-scale testing necessary to determine losses, or "efficiency factors" that effect droplet flow between sprinklers and burning commodity.
- Relationship between Area Density (# Sprinklers) and Design Area (Thermal load from fire) from Scale testing (step 1)
- A combined relationship (table) will incorporate efficiency factors[1]
  - *Following method by Quintiere (Fundamentals of Fire Phenomena)*

---

[1] *Following method by Quintiere (Fundamentals of Fire Phenomena)*

Why Invest in Such an Approach?

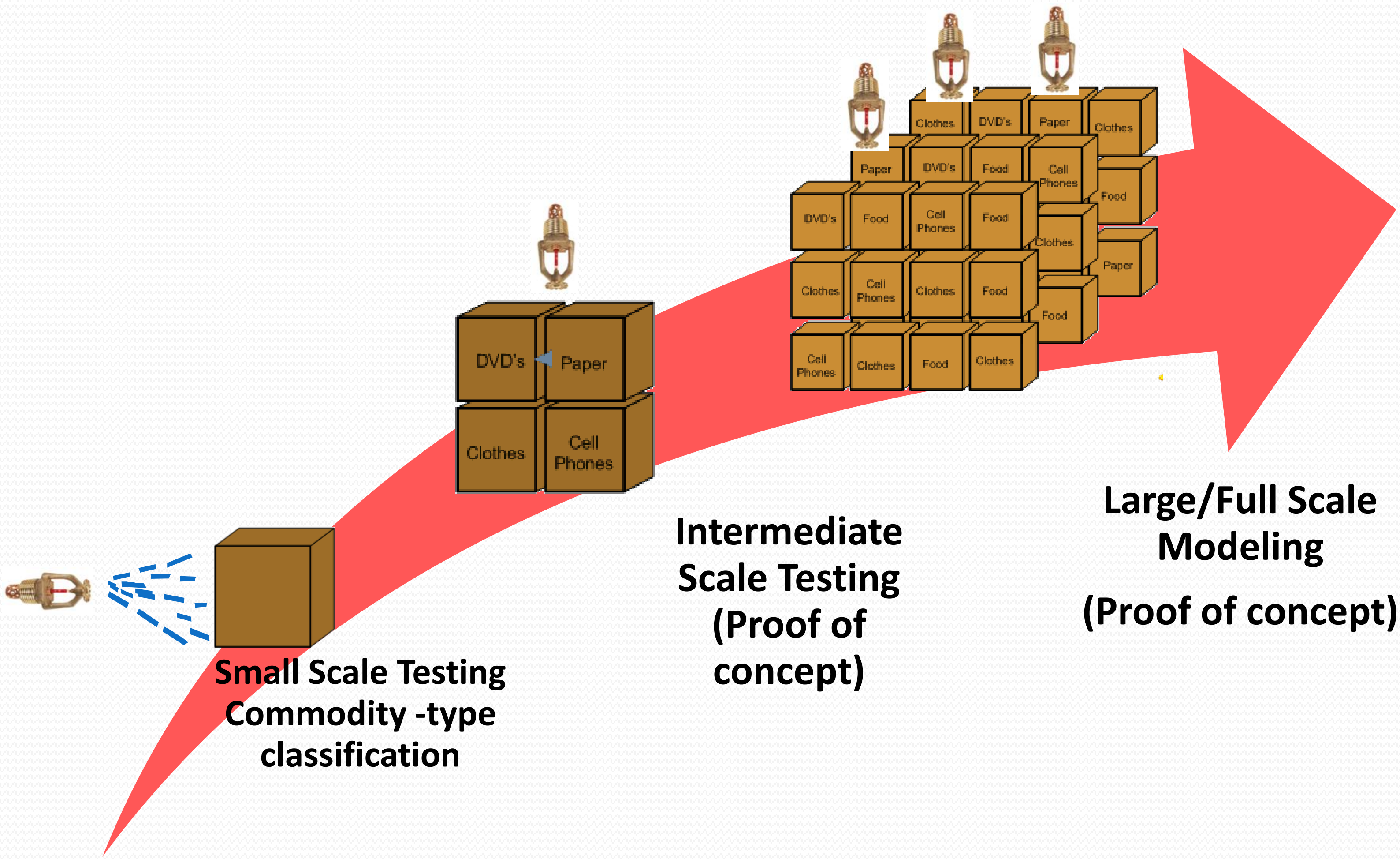
Increasing Costs →



Bench Scale Tests → **Small Scale Tests** → **Intermediate Scale Tests** → **Large Scale Tests**

Bench Scale Tests	Small Scale Tests	Intermediate Scale Tests	Large Scale Tests
Material Properties	Suppression	Efficiency factors & Validation	Efficiency factors & Validation

Engineering Approach to Warehouse Fire Protection Design



Conclusion

- A fundamental basis for suppression design can be achieved
  - Separately study controlling factors
  - Classification becomes truly predictive
- Materials that typically fall out of classification tests and are “exceptions” can be classified
  - E.g. Tupperware, Meat Trays
- Error bounds for worst and best case scenarios are defined
- Long-term cost savings for the entire industry.

Work to Date

1. Gollner, M.J., *A Fundamental Approach to Commodity Classification,* Masters Thesis. 2010, University of California, San Diego.
2. Overholt, K., *Characterizing the Flammability of Storage Commodities Using an Experimentally Determined B-number.* 2010, Worcester Polytechnic Institute.
3. Gollner, M.J., Overholt, K., Rangwala, A.S., Perricone, J., Williams, F.A., *Warehouse Commodity Classification from Fundamental Principles. Part I: Commodity & Burning Rates.* Fire Safety Journal, 2009. Under Review.
4. Overholt, K., Gollner, M.J., Rangwala, A.S., Perricone, J. and Williams, F.A., *Warehouse Commodity Classification from Fundamental Principles. Part II: Flame Heights and Flame Spread,* Fire Safety Journal, 2009. In Preparation.
5. Gollner, M.J., Overholt, K., Rangwala, A.S., Williams, F.A., and Perricone, J., The B-number as a Criterion for Commodity Classification. Combustion Institute Western States Fall Meeting, Irvine, CA, October 2009.
6. Gollner, M.J., Hetrick, T., Rangwala, A. S., Perricone, J., Williams, F. A., , *Controlling parameters involved in the burning of standard storage commodities: A fundamental approach towards fire hazard classification,* 6th U.S. National Combustion Meeting. 2009: Ann Arbor, Michigan.
7. Overholt, K., Gollner, M., Rangwala, A. S.,, *Characterizing the Flammability of Corrugated Cardboard Using a Cone Calorimeter,* 6th U.S. National Combustion Meeting. 2009: Ann Arbor, Michigan.
8. Gollner, M.J., Overholt, K., Rangwala, A.S., Williams, F.A., and Perricone, J., A Fundamental Approach towards Storage Commodity Classification*,* Society of Fire Protection Engineers Annual Engineering Technology Conference, Scottsdale*, AZ,* October, 2009.