

# **Development of a Water Mist Protection for Flammable Liquid Use Occupancy Using Physical Scaling Approach**

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# Outline

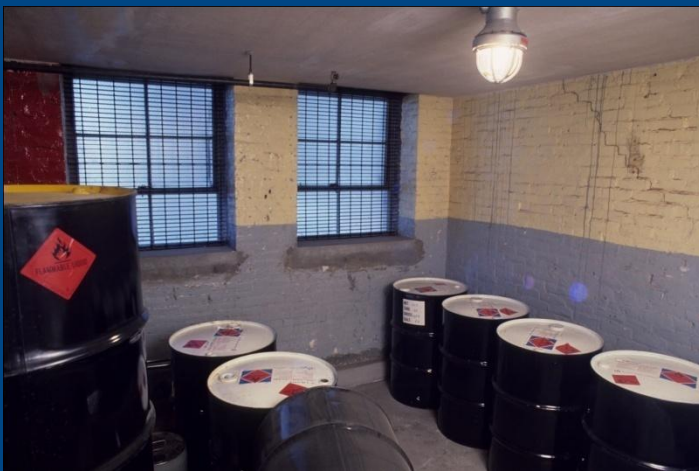
- Flammable liquid use occupancy
- Review of Froude-based scaling laws
- Fire extinguishing requirements in a 1/2-scale enclosure
- Determination of fire extinguishing requirements for a full-scale enclosure of 7.47x7.47x7.47 m
- Full-scale fire test validation
  - *Spill fire + pool fire*
- Summary

# Flammable-Liquid Cut-Off Rooms

- Dispensing (Use) occupancy



- Storage occupancy



# Challenges for Water Mist Protection

- Low flash point liquids
- Large door openings
- High ceilings
- Ceiling nozzles only
- Obstructed fires

# Protection Objective and Development Approach



- **Protection Objective**

A total flooding water mist system to extinguish flammable liquid fires in a 7.47x7.47x7.47-m use occupancy, with door openings ranging from 1.83x3.73 m high to 3.73x3.73 m.

- **Approach for Water Mist Protection Development**

Conduct fire suppression/extinguishment tests in a 1/2-scale enclosure, and then scale-up the protection requirements.

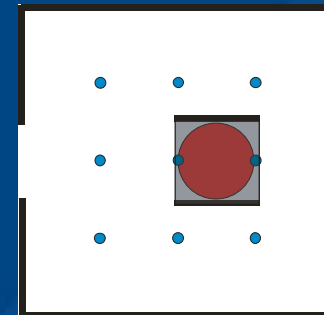
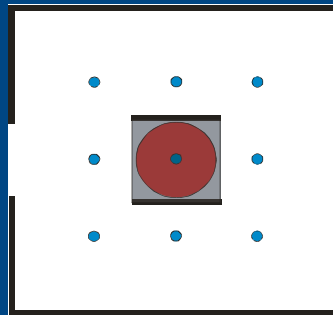
# Scaling Relationships

$$Re_d = \frac{d|\bar{u}_d - \bar{u}_g|}{\nu_g}$$

Applications	Water Mist	Sprinkler
Reynolds Number Regime	$Re_d \leq 1$	$10 \leq Re_d \leq 500$
Drag Coefficient	$\sim Re_d^{-1}$	$\sim Re_d^{-1/2}$
Scale Ratio $S=L_2/L_1$	$S^1$	$S^1$
Time	$S^{1/2}$	$S^{1/2}$
Scalar Quantities	$S^0$	$S^0$
Velocity	$S^{1/2}$	$S^{1/2}$
Ventilation Rate	$S^{5/2}$	$S^{5/2}$
Fire Convective Heat Release Rate	$S^{5/2}$	$S^{5/2}$
Total Water Discharge Rate	$S^{5/2}$	$S^{5/2}$
Water Flux	$S^{1/2}$	$S^{1/2}$
Total Cooling Rate	$S^{5/2}$	$S^{5/2}$
Drop Diameter	$S^{1/4}$	$S^{1/2}$

# 1/2-Scale Test Conditions – 1

- 1/2-scale enclosure: 3.66x3.66x3.66 m
- Door opening: 0.91x1.83 m high (1.83x3.73 m in full scale)
- Fire Sizes:
  - Propane fires – 155 , 330, 470, 685 kW (920, 1960, 2790, 4070 kW in full scale)
  - Heptane pool fires – 265 kW, 470 kW (1575, 2790 kW in full scale)
- Fire shield dimensions: 1.23 x 1.23 x 1.83 m high
- Shield orientation: Openings facing the enclosure opening
- Fire locations:



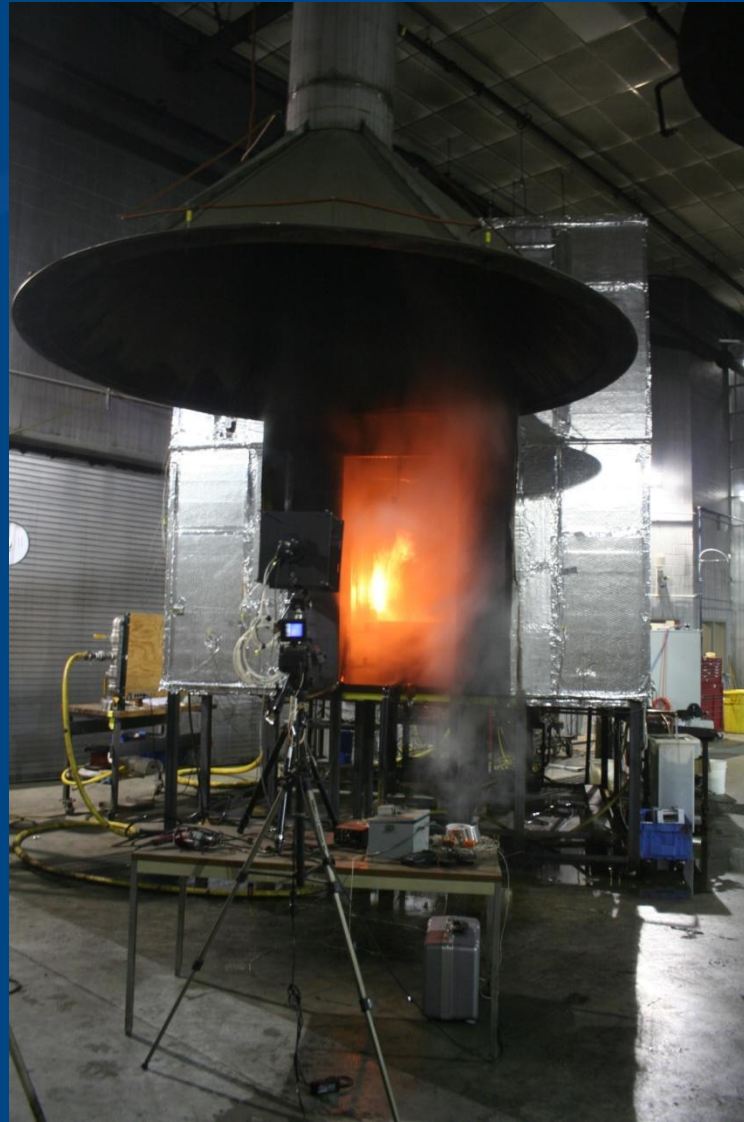
# 1/2-Scale Test Conditions – 2

- Deploy 9 nozzles at ceiling level in 3x3 matrix with nozzle spacing of 0.91 x 0.91 m (1.83x1.83 m in full scale)
- 1/2-scale water mist spray conditions

Scale	Discharge Pressure	Spray Angle	Drop Size $d_{v0.5}$	Total Discharge Rate
	(bar)	(deg)	( $\mu\text{m}$ )	(liter/min)
1/2	43.7	60	88	25.7



# 1/2-Scale Tests



# 1/2-SCALE TEST RESULTS



<b>Starting Fire Heat Release Rate (kW)</b>	<b>Fire at Center</b>		<b>Fire Off-Center</b>	
	<b>1/2-Scale Propane Fire</b>	<b>1/2-Scale Heptane Pool Fire</b>	<b>1/2-Scale Propane Fire</b>	<b>1/2-Scale Heptane Pool Fire</b>
<b>155</b>	<b>No</b>	<b>-</b>	<b>Yes</b>	<b>-</b>
<b>265</b>	<b>-</b>	<b>No</b>	<b>-</b>	<b>Yes</b>
<b>330</b>	<b>Yes</b>	<b>-</b>	<b>Yes</b>	<b>-</b>
<b>470</b>	<b>Yes</b>	<b>Yes</b>	<b>Yes</b>	<b>Yes</b>
<b>685</b>	<b>Yes</b>	<b>-</b>	<b>Yes</b>	<b>-</b>

# Water Mist Sprays for the 7.47x7.47x7.47-m Enclosure (Full Scale)



## Projected Water Mist Requirements

Ceiling Nozzle Layout	Nozzle Spacing	Discharge Pressure	Spray Angle	Drop Size $d_{v0.5}$	Total Water Mist Discharge Rate From Nine Nozzles
$S^0$	(m) $S^1$	(bar) $S^1$	(°) $S^0$	( $\mu\text{m}$ ) $S^{1/4}$	(liter/min) $S^{5/2}$
3x3	1.87	89	60	105	153

## Water Mist Discharge Properties of Two Candidate Nozzles

Nozzle ID	Discharge Pressure	Spray Angle	Drop Size $D_{v0.5}$	Total Water Mist Discharge Rate From Nine Nozzles
	(bar)	(°)	( $\mu\text{m}$ )	(liter/min)
A	90	180	96	220
B	90	100	115	254

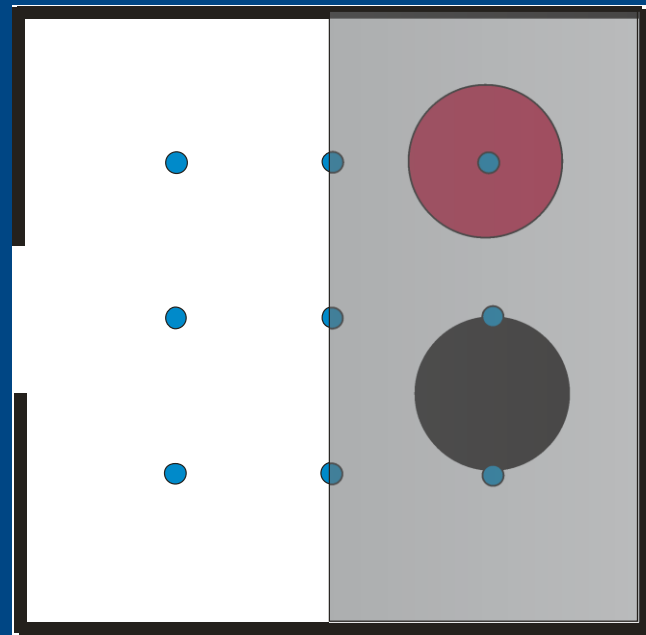
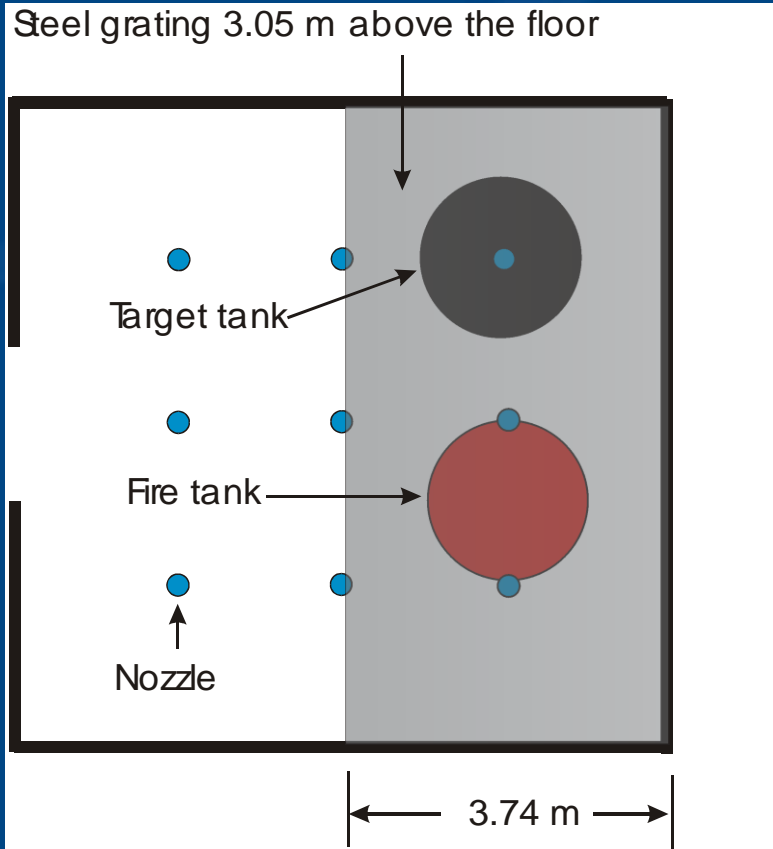
# Use Occupancy Test Conditions

- Enclosure: 7.47x7.47x7.47 m high
- Door opening: 1.83x3.73 m high to 3.73x3.73 m
- Simulated fuel tanks: two 1.83 m diameter x 2.74 m high tanks, 0.91 m apart, and 0.91 m above floor
- Mezzanine obstruction: 70%-opening, perforated steel grating 3.05 m above the floor
- Fire scenario: cascading heptane fire spilling from the top of one tank at 38 liter/min

# Use Occupancy Mock-up



# Tank Mock-up Locations



# Use Occupancy Test Procedure



# Test Results for the Use Occupancy



Door Opening (m x m high)	Fire Tank Location	Nozzle Configuration		
		Ceiling – Nozzle A Door - None	Ceiling – Nozzle B Door - None	Ceiling –Nozzle A Door – Nozzle B
1.83 x 3.73	Near-Center	Yes	Yes	-
	Near-Corner	No	Yes	-
2.44 x 3.05	Near-Center	Yes	Yes	-
	Near-Corner	No	-	-
2.44 x 3.73	Near-Center	Yes	No	-
	Near-Corner	-	-	-
3.05 x 2.74	Near-Center	-	-	-
	Near-Corner	No	-	-
3.05 x 3.05	Near-Center	Yes	Yes	-
	Near-Corner	No	Yes	Yes
3.73 x 3.05	Near-Center	-	-	-
	Near-Corner	-	-	Yes
3.73 x 3.73	Near-Center	-	-	-
	Near-Corner	-	-	Yes



# Door Nozzles

## Door nozzle layout:

- Spaced with half the door opening width
- Symmetrical to the opening centerline
- 0.15 m above the door opening
- 0.20 m away from wall



- Demonstrate the development of a water mist fire protection for a representative flammable-liquid use occupancy, based on the Froude-modeling-based scaling methodology and the fire extinguishment requirements for a 1/2-scale enclosure.
- Verify the water mist protection projected for a 7.47x7.47x7.47 m flammable liquid use occupancy with door openings up to 3.73x3.73 m.
- Provide a benchmark for the water mist spray characteristics required for the intended protection. The benchmark consists of water mist discharge rate, drop size, downward spray momentum, spray angle and nozzle spacing.