Modeling and Analysis of a Hydrogen Release in a Large Scale Facility

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Overview

- Background
- Scale Model Simulations
- Full Scale Simulations
- Extending Results
- Additional Considerations
- Questions

Background

- Increasing use of hydrogen powered forklifts within warehouses
- Indoor refueling of forklifts presents possible release scenarios
- Consequence of accidental release needs to be assessed

Background

- Modeling Approach
  - FireFoam code used for CFD simulations
    - tracked transport of H_2 in warehouse
    - estimated overpressure from mass above LFL
  - Two sets of simulations
    - scale model
      - compared with experiments
    - full scale warehouse

Scale Model Simulation

- Experiments

  (Ekoto et al. 2012)

  – 2.7 x 4.6 x 3.6 m^3 enclosure

  – simulated release from a forklift

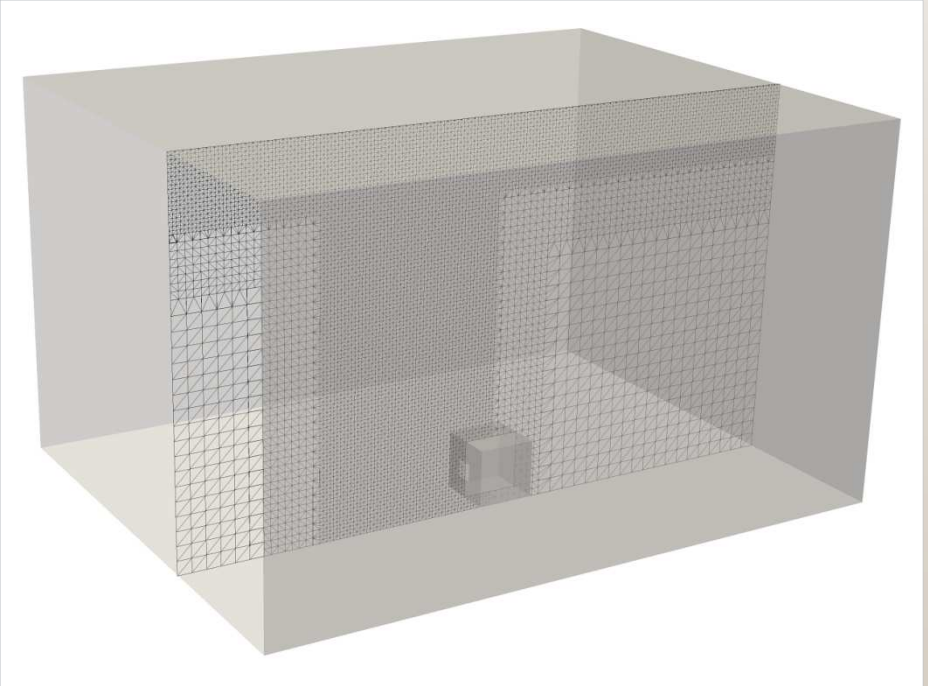
  – varying release rate

    - simulated H_2 tank release

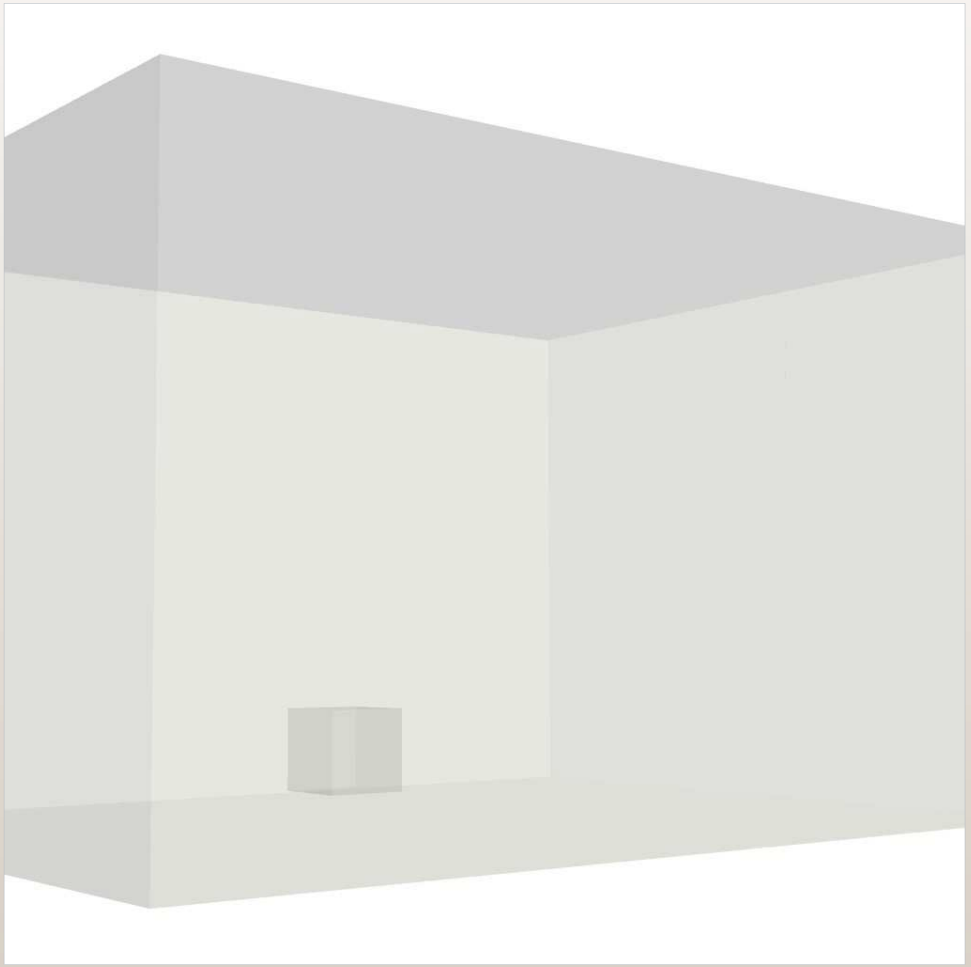
  – measured H_2 concentration, overpressure

Scale Model Simulation

- CFD Simulations
  - non-uniform mesh, refined mesh where H_2 is present
  - tested multiple mesh resolutions, from 2.5 -10 cm
    - 50,000 – 900,000 grid points

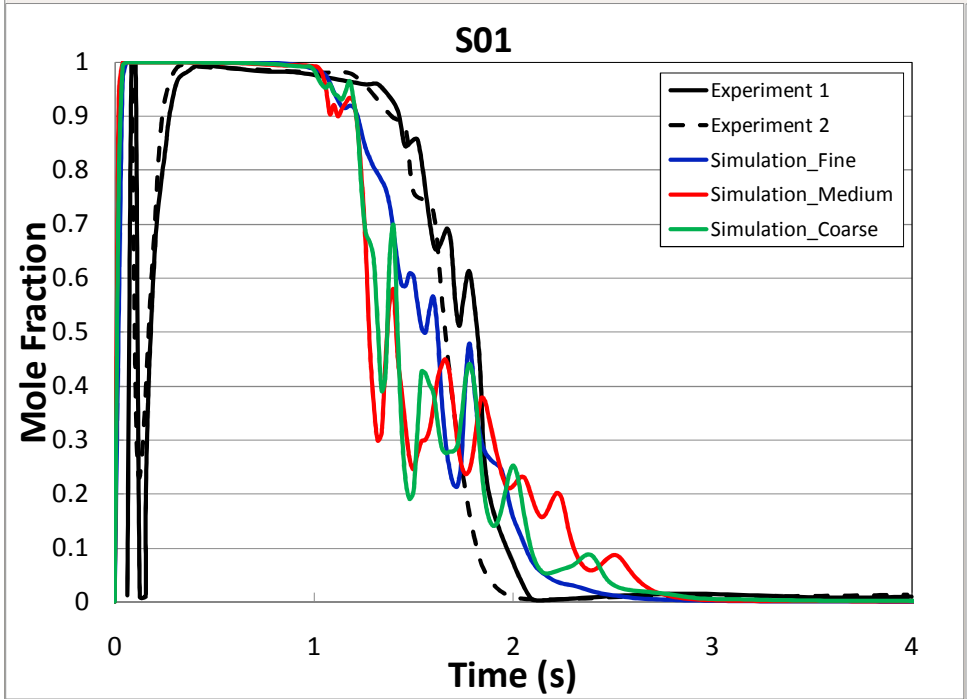


Scale Model Simulation

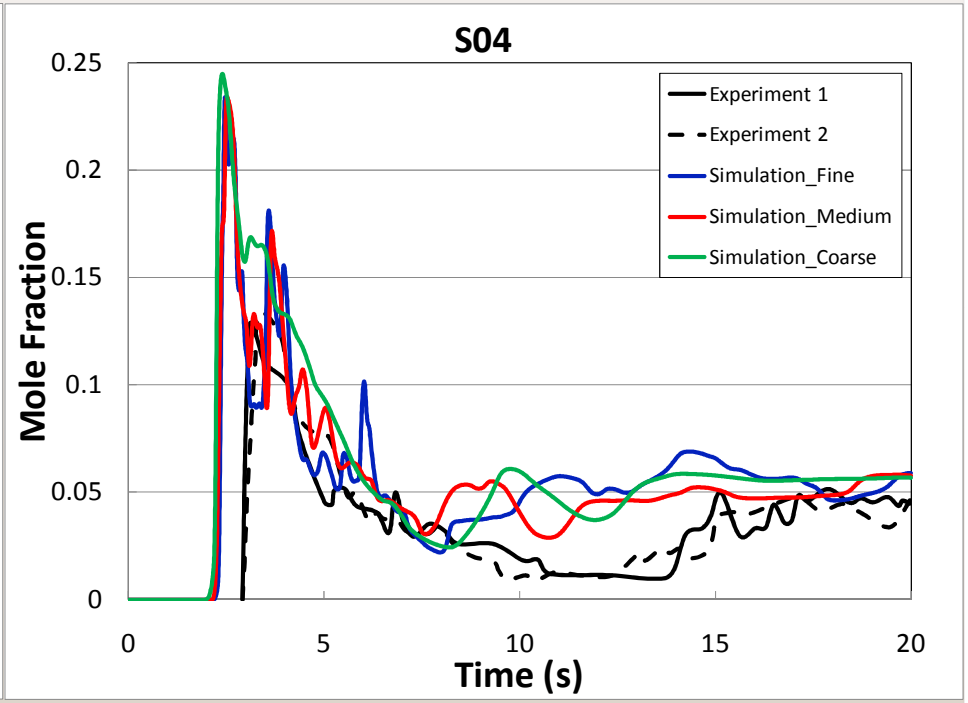


Scale Model Tests

- Concentration Results



near dispenser



at ceiling

– Total mass above LFL consistent across resolutions

Scale Model Tests

- Overpressure estimate
  - quasi-static pressure rise
    - pressure rises uniformly on all surfaces in warehouse
  - assumptions :
    - all H_2 above LFL consumed
    - well sealed enclosure

$$\Delta p = p_0 \left[\left(\left(\frac{V_T + V_{H_2}}{V_T} \right) \left(\frac{V_T + V_{Stoich}(\sigma - 1)}{V_T} \right) \right)^{\gamma} - 1 \right]$$

Scale Model Tests

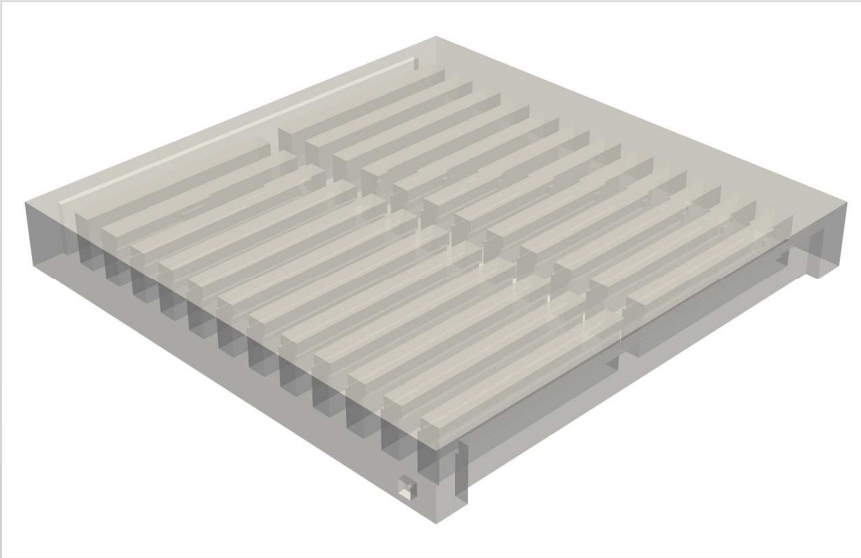
- Maximum Overpressure
  - Measured (Ekoto et al., 2012):
    - 0.19 bar ceiling ignition
    - 0.25 bar forklift ignition
  - Model results:
    - 0.24 bar

Scale Model Tests

- Summary
  - simulation results closely match experimental concentration measurements
  - grid independence found for mesh resolutions up to 10 cm
  - quasi-static pressure rise method produces reasonable estimate for overpressure

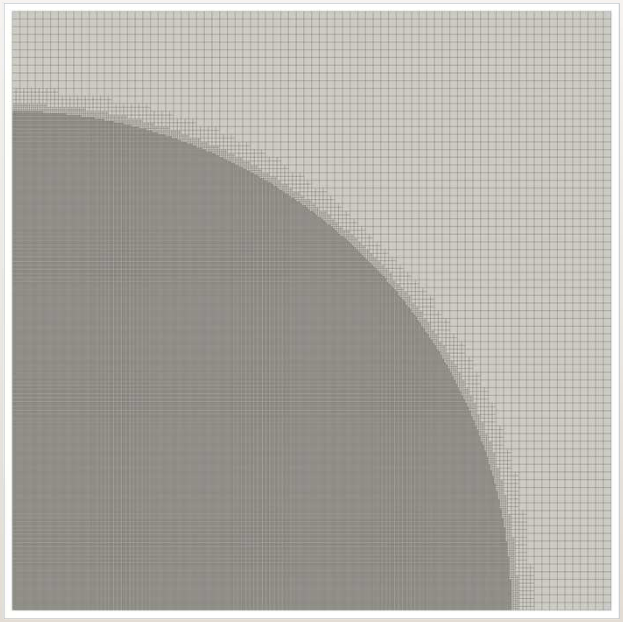
Full Warehouse Simulation

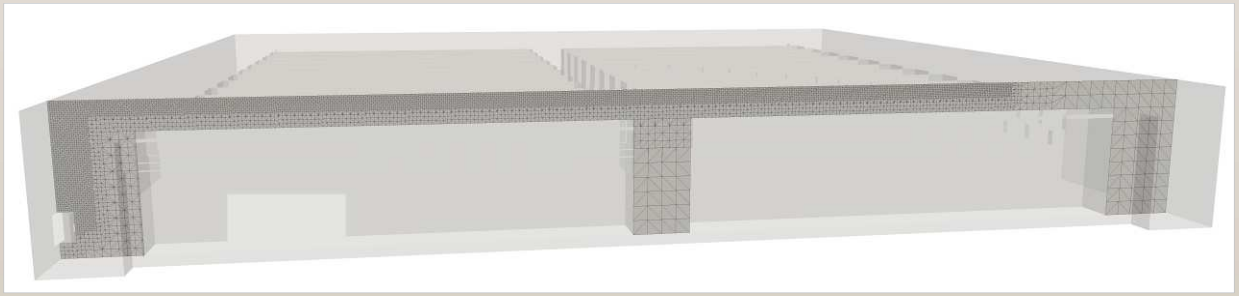
- 62 x 62 x 8 m warehouse (approx. 200x200x25 ft)
- steady 3 minute release
- 5 release rates used
  - 0.25, 0.5, 1.0, 2.0 and 4 kg/min



Full Warehouse Simulation

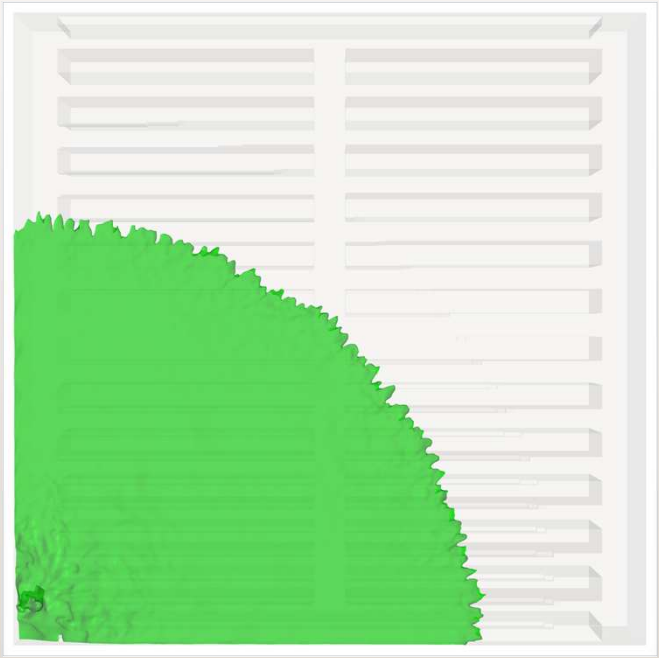
- Computational Mesh
  - non-uniform mesh
  - 10 cm grid resolution
  - 0.24 m^2 release outlet, low exit velocity, corner of warehouse

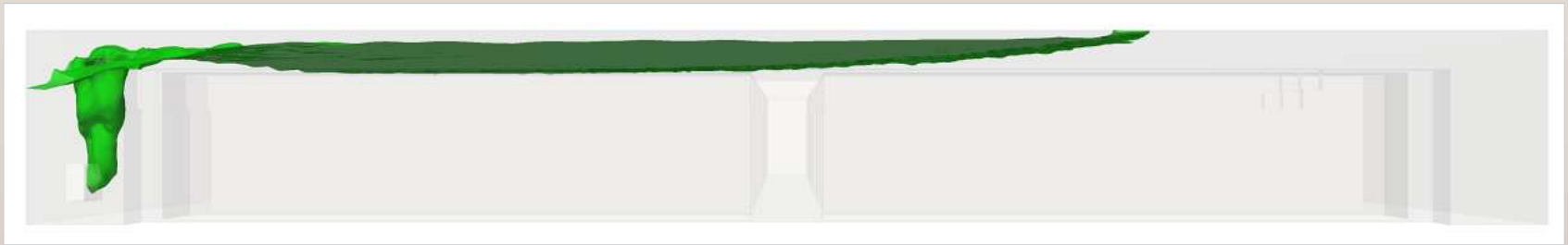




Full Warehouse Simulation

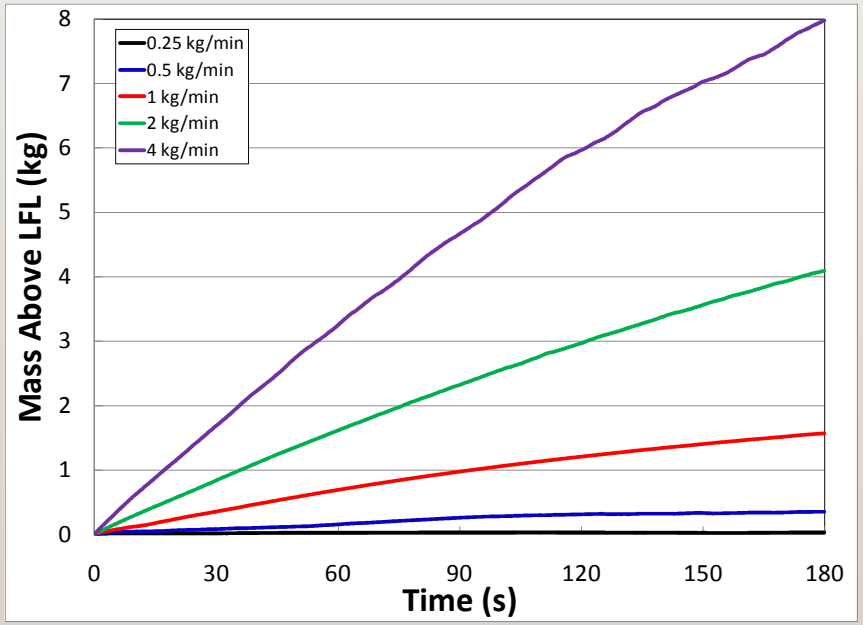
- Results
  - H_2 formed thin circular clouds below ceiling
  - cloud thickness varied with release rate

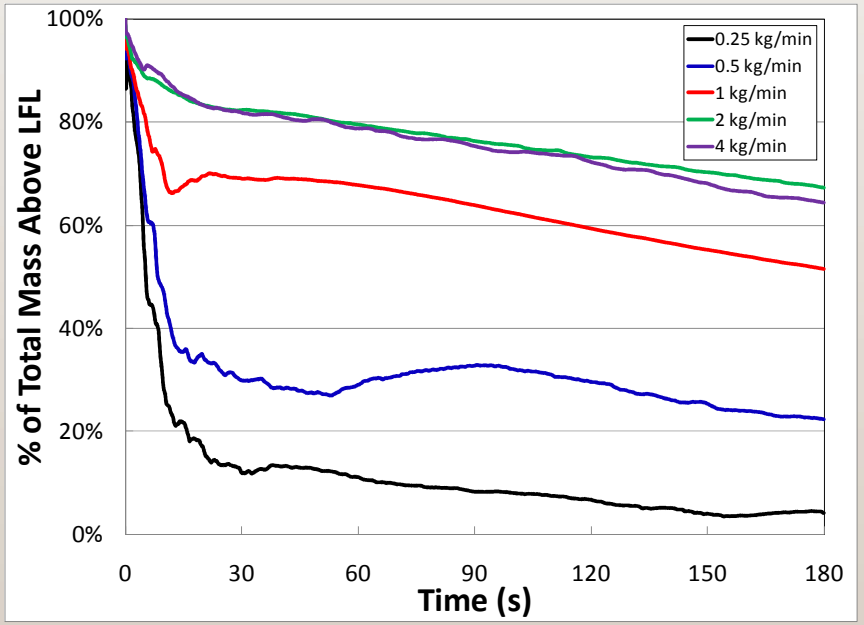




Full Warehouse Simulation

- Results
  - with lower release rates, proportionally less H_2 remained above LFL





Full Warehouse Simulation

- Summary of CFD Results
  - closed, unventilated warehouse

Release rate (kg/min)	Mass above LFL (kg)	P_{max} (bar)
0.25	0.03	-
0.5	0.34	0.01
1	1.6	0.02
2	4.1	0.06
4	8.0	0.12

> 0.02 bar light damage to roof/wall panels and broken windows expected

> 0.10 bar major structural damage expected

Extending Results

- Effect of Ventilation Systems
  - fully closed warehouse assumption overly conservative
  - ventilation systems can reduce pressure two ways
    - provides venting/pressure relief
    - removes hydrogen from warehouse
  - hydrogen removal neglected
    - highly dependent of vent placement

Extending Results

- Ventilation System Pressure Relief Estimate
  - estimate H_2 consumption time from cloud shape, size
  - compares ventilation with volume production rate

$$\Delta p = p_0 \left[V_T^{-\gamma} \left(V_T + \frac{\pi h(\sigma - 1)}{4} R^2 - \frac{R\dot{V}_{vent}}{\sqrt{\sigma} S_L} + \frac{\dot{V}_{vent}^2}{\pi h(\sigma - 1)\sigma S_L^{\,2}} \right)^{\gamma} - 1 \right]$$

- Extended warehouse sizes
  - assume cloud shape, mass above LFL unchanged
  - simply increase volume used in calculation

Extended Results

- Peak overpressure summary

  (Ventilated results assume 3 air changes/hour)

Volume (m^3)	1 kg/min		2 kg/min		4 kg/min	
	Closed (bar)	Ventilated (bar)	Closed (bar)	Ventilated (bar)	Closed (bar)	Ventilated (bar)
16,000	0.05	0.03	0.12	0.09	0.24	0.21
25,000	0.03	0.01	0.08	0.04	0.15	0.11
31,000	**0.02**	**0.01**	**0.06**	**0.02**	**0.12**	**0.08**
50,000	0.01	-	0.04	0.01	0.07	0.04
62,000	0.01	-	0.03	-	0.06	0.02
100,000	0.01	-	0.02	-	0.04	0.01

Additional Considerations

- Sprinkler Activation
  - hydrogen cloud accumulates at ceiling
    - sprinklers typically mounted within 18” of ceiling
  - high temperature combustion products
  - sprinkler activation can cause significant damage
    - water damage to commodities
    - impair fire protection of warehouse
  - sprinkler activation experimentally confirmed

Additional Considerations

- Sprinkler Activation
  - using CFD results for cloud size, area of sprinkler activation can be estimated

Release Rate (kg/min)	Cloud Radius (m)	Percentage of Warehouse* Area (%)
0.25	8	1.3
0.5	19	7.4
1	34	23
2	46	43
4	54	60

Summary

- Model approach produces results consistent with scale model experiments
- Maximum overpressure highly dependent on release rate, size of warehouse
- Damage associated with sprinkler activation must also be considered

Questions?