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Update on Sandia Hydrogen Releases Program

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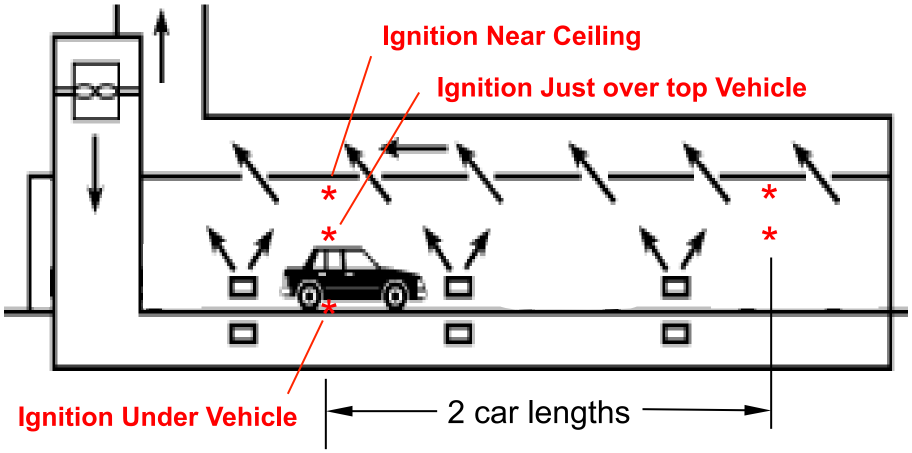
Effects of ignition location, time, and ventilation on resulting overpressure investigated

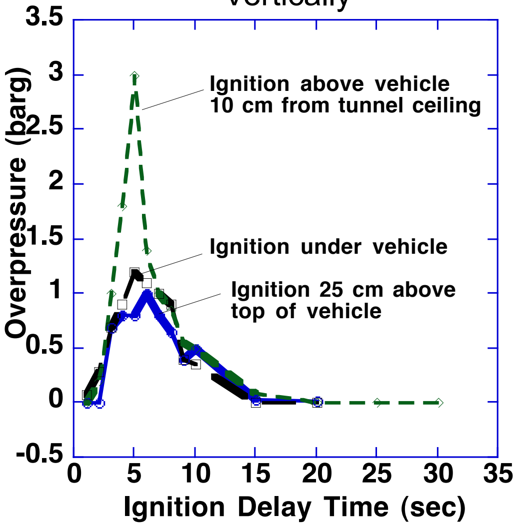
Transversely-Ventilated Tunnel



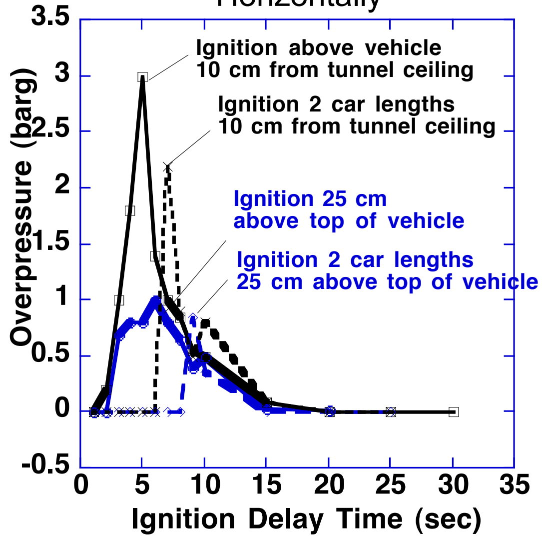
Results:

- Peak overpressure occurs about 5 sec after PRD release (near car ignition
- Overpressure greater for ignition near ceiling
- Ignition 2 car lengths away from release generates lower overpressure (peak at 8 sec)
- Overpressure highest for ignition at ceiling
- Overpressure lower with no tunnel ventilation

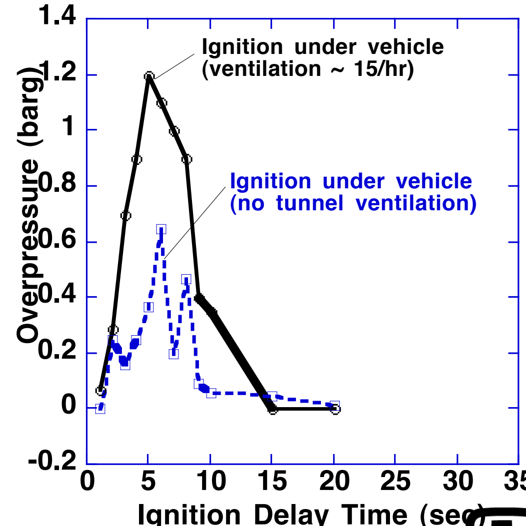
Effect of Moving Ignition Point Vertically



Effect of Moving Ignition Point Horizontally



Effect of Ventilation



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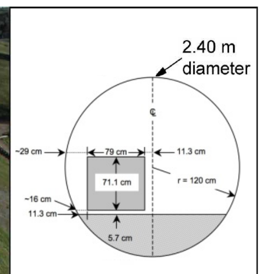
Model validation data produced from sub-scaled tunnels tests

- Froude scaling* used to resemble the full-scale tunnel simulations
- Scale factor (1/2.53) based on the ratio of the cross-sectional areas (0.3 Kg total GH2)
- CFD dispersion and deflagration simulations used to determine sensor placement



Tunnel cross-section

Time:

$$t_{SRI} = t_{FS}(SF)^{0.5}$$

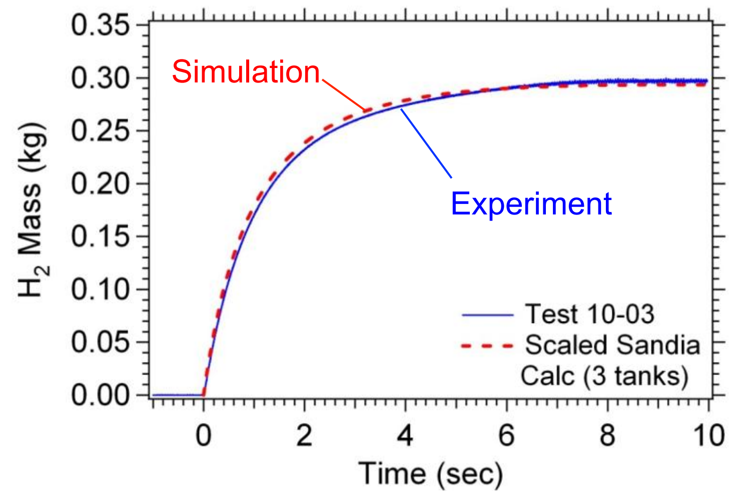
Mass release rate:

$$Q_{SRI} = Q_{FS}(SF)^{2.5}$$

Total mass released:

$$M_{SRI} = M_{FS}(SF)^{3}$$

Comparison of Simulations and Measurements for Vehicle H_2 Mass Release versus Time for Scaled Tunnel Tests

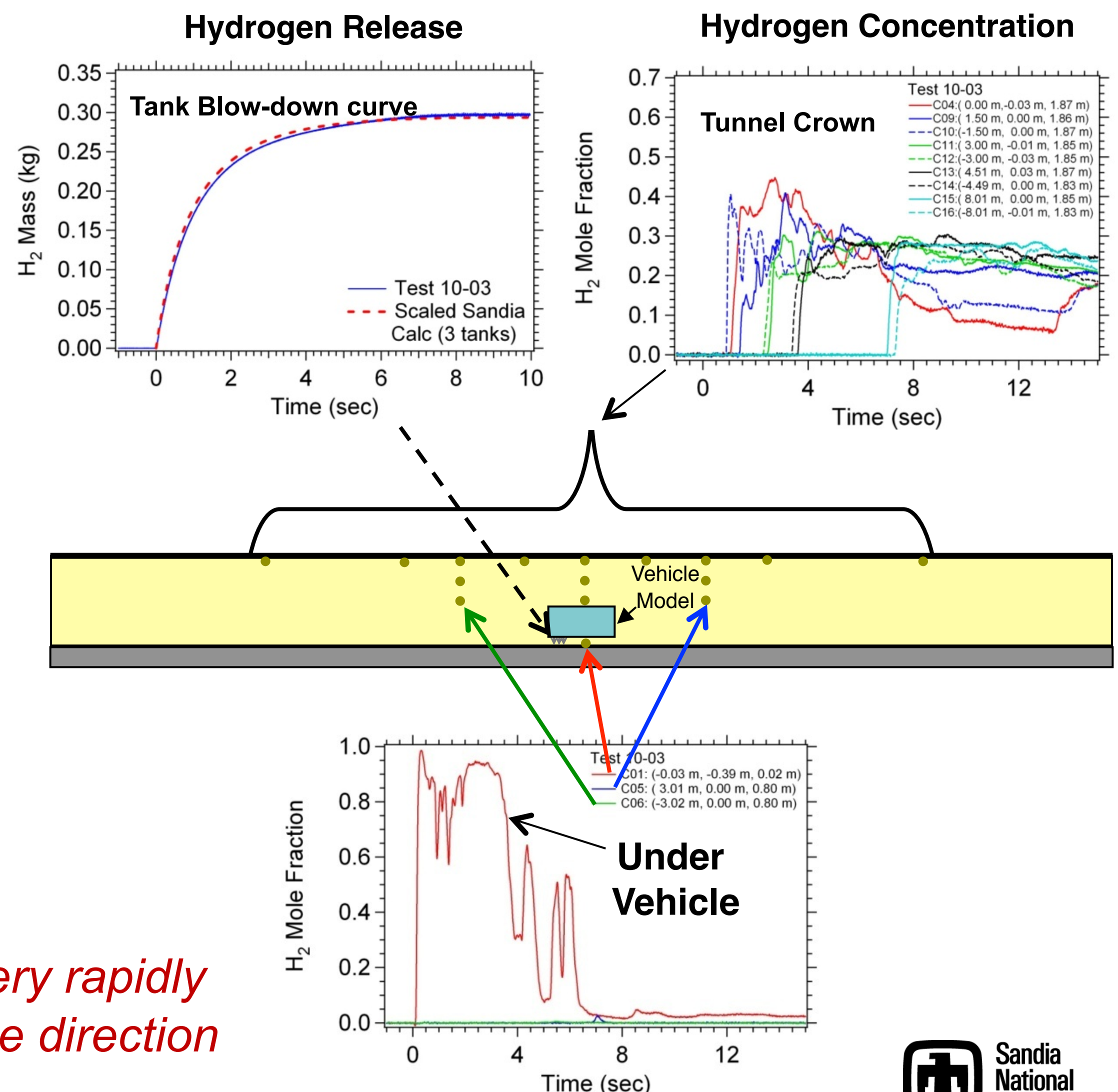


*D.J. Hall, S. Walker, "Scaling Rules for Reduced-Scale Field Releases of Hydrogen Fluoride," Jour. of Hazardous Materials, Vol. 54, pp. 89-111, 1997."

Experiments without ignition provide insight about the behavior of hydrogen

- Fast oxygen sensors were used to monitor hydrogen
  - Response time between 70 and 130 ms
- Underneath the vehicle the hydrogen concentration, rapidly approached 100%
- Hydrogen detected at the tunnel crown one second after the release

Dispersion in the tunnel occurs very rapidly and is highly influenced by release direction



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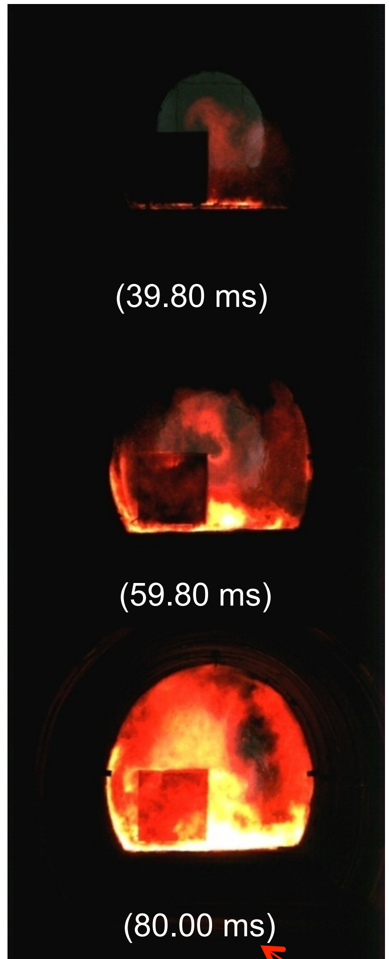
The ignition experiments provide overpressure data as a function of ignition time

- Average maximum overpressure was: 42 kPa (0.42 barg)
- The maximum overpressure measured: 63.4 kPa at 2.00 sec ignition
- As ignition delay time increased, the impulse also increased.

Quantification of overpressure allows for application of harm criteria

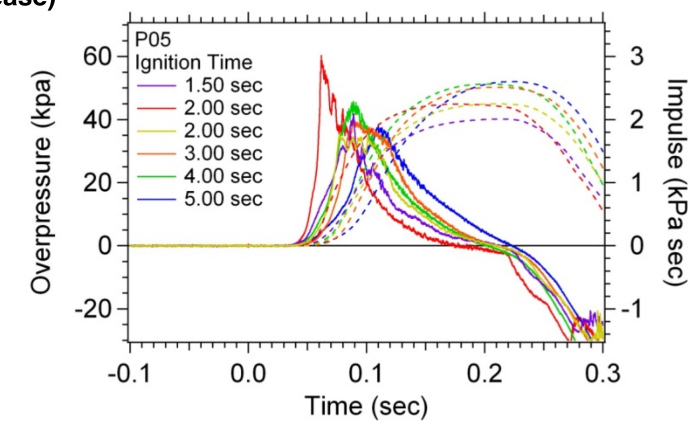
High-speed video frames

(Ignition 1.77 sec after beginning of release)

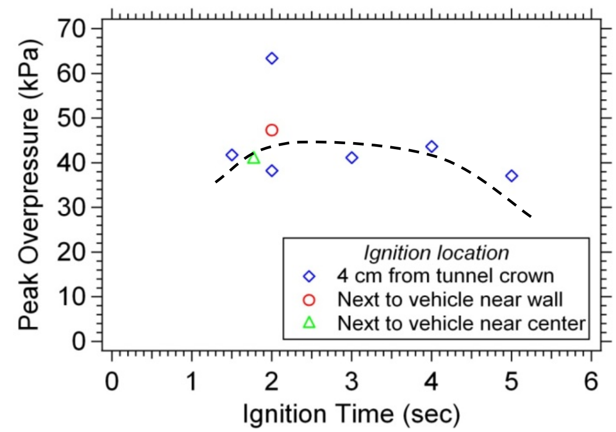


Time referenced to ignition

Transient Variation of Ignition Overpressure (P05 - located 10.60m from tunnel center)



Peak Ignition Overpressure Versus Ignition Delay Time



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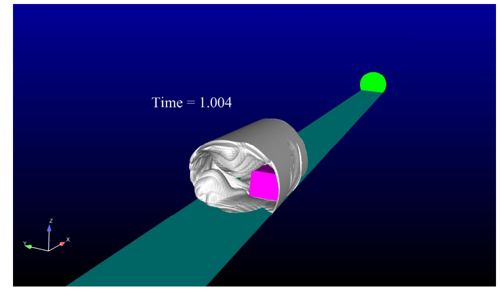
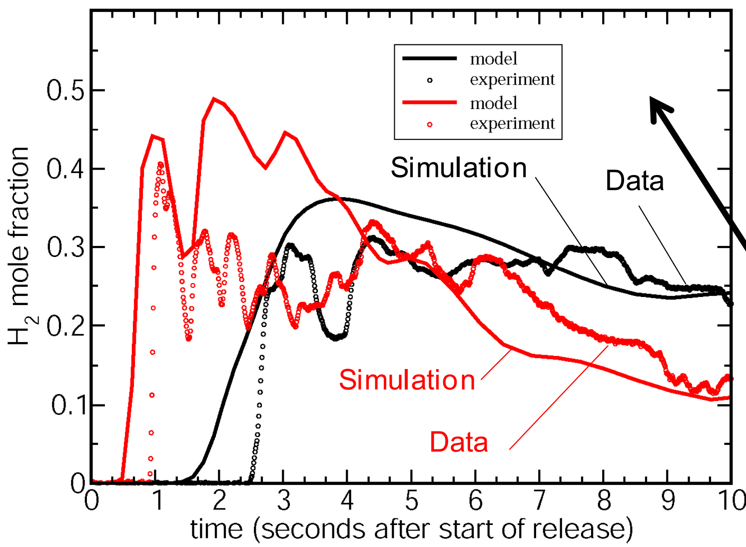
Accomplishment: Experimental results show good agreement with model

- Overpressures are in good agreement with the experimental data from the tests
- 3-D calculations
  - Transient hydrogen concentration using Sandia Fuego CFD code
  - Deflagration overpressure computed in FLACS

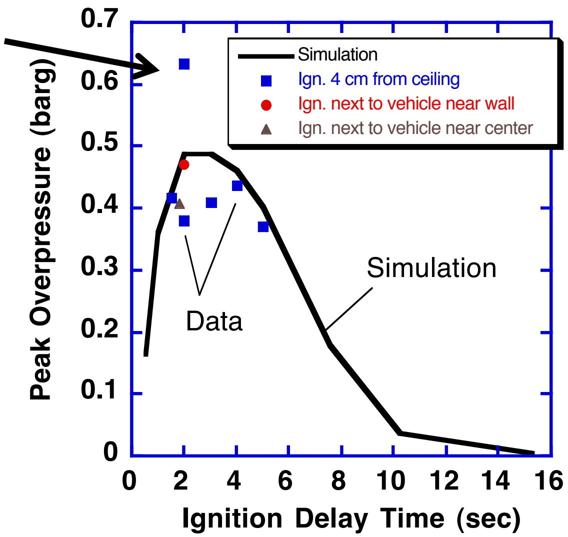


Simulation Showing Flammable H_2 Cloud (4%-75% m.f.) around vehicle in Test Tunnel (1 sec into the release)



H_2 mole fraction (near tunnel ceiling)

Peak Ignition Deflagration Overpressure



Validated model allows for parameter investigations of mitigation strategies

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We are developing a set of experiments and validated simulations to investigate releases from H2 fuel cell forklift vehicles in warehouses.

- We are using information from NFPA 52 and OEMs to define indoor release scenarios
- NFPA 52 - Indoor Refueling in Warehouses
  - Table 9.4.3.2.1 Min. Room Vol. for Max. Fueling Event
    - 0.8 Kg in room vol. of 1000 m^3 (without ventilation)
    - > 0.8 to 1.7 Kg in room vol. of 2000 m^3
  - Ceiling height not less than 8m (25 ft)
  - Ventilation rates of at least 0.3 m^3/min-m^2 (1ft^3/min-ft^2),

    but no less than 0.03 m^3/min-0.34m^3 (1ft^3/min-12ft^3)
- OEM specified leak size - dia. = 6.35 mm (0.25 in)

Indoor Refueling of an H2 Fuel Cell Forklift Vehicle

Courtesy of Nuvera Fuel Cells

Validated model allows for parameter investigations of mitigation strategies

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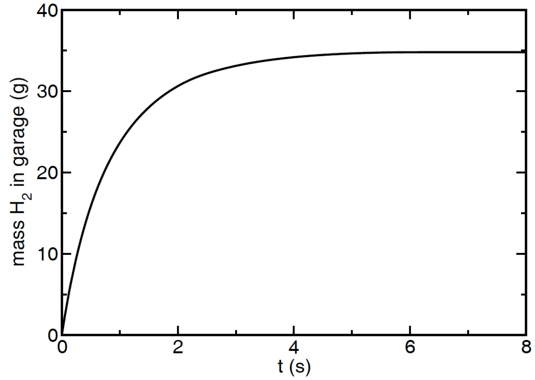
We have defined a set of indoor forklift release experiments to be performed in a sub-scale warehouse at SRI using the same scaling approach as applied in the vehicle tunnel release experiments.

Blast-hardened Sub-Scale Warehouse at SRI Test Site

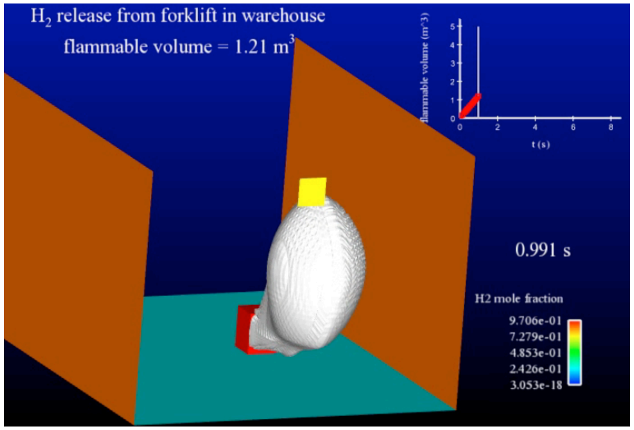
Scaled Mass Release Rate for the Experiment

(Based on 0.8 Kg H_2 released in 1000 m^3 room)

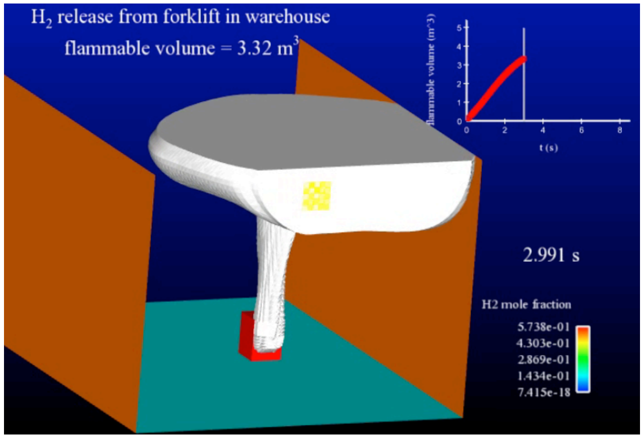


Fuego CFD Simulations of Forklift Vehicle H_2 Release in the Sub-Scale Warehouse Experiment

Flammable Volume 1 sec into Release



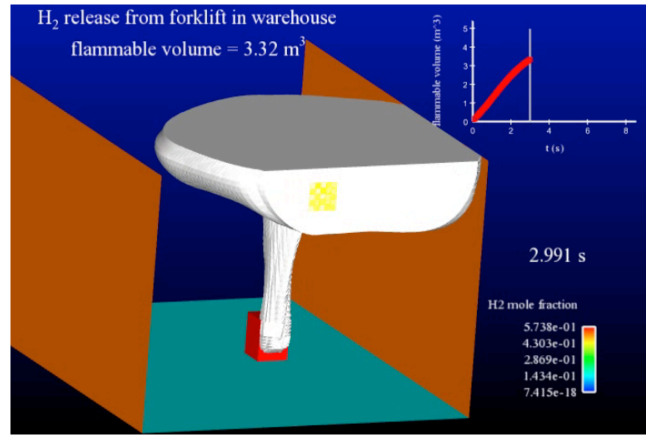
Flammable Volume 3 sec into Release



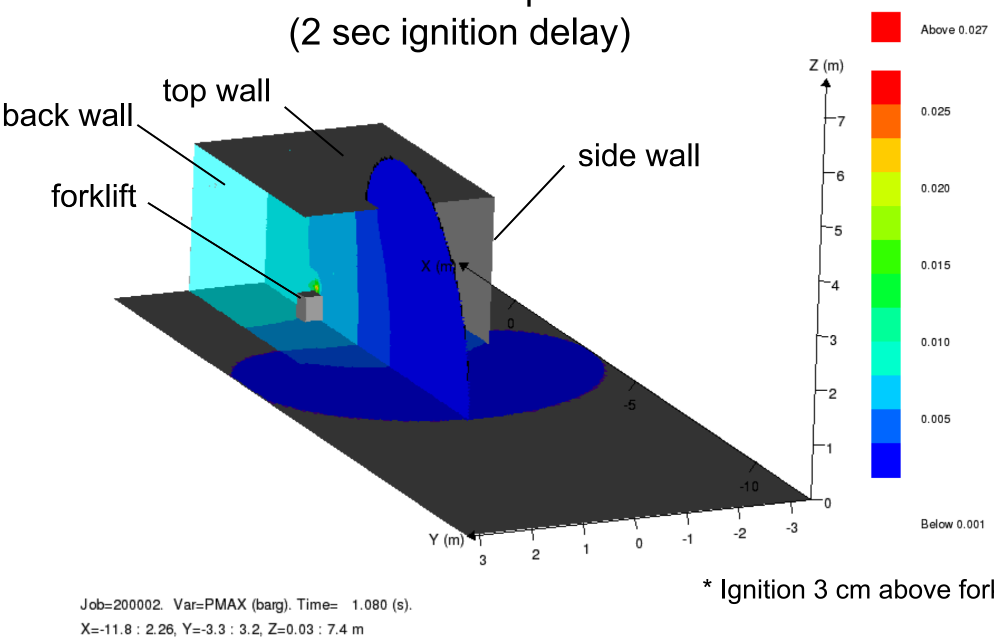
We have performed deflagration simulations of the sub-scale warehouse experiments with and without an open wall on the front.

Blast-hardened Sub-Scale Warehouse
at SRI Test Site

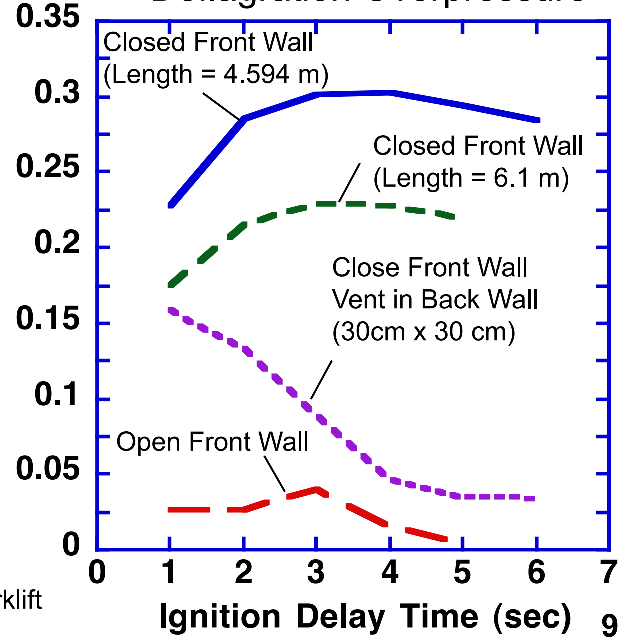
Flammable Volume 3 sec into Release



Maximum Overpressure
Sub-Scale Warehouse - Open Wall on Front
(2 sec ignition delay)



Deflagration Overpressure*



* Ignition 3 cm above forklift

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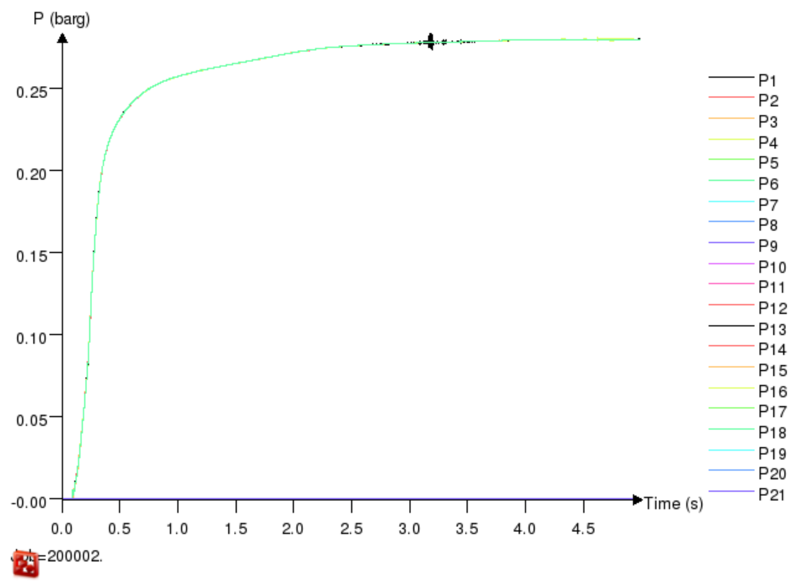
We have performed deflagration simulations of the sub-scale warehouse experiments with and without an open wall on the front.

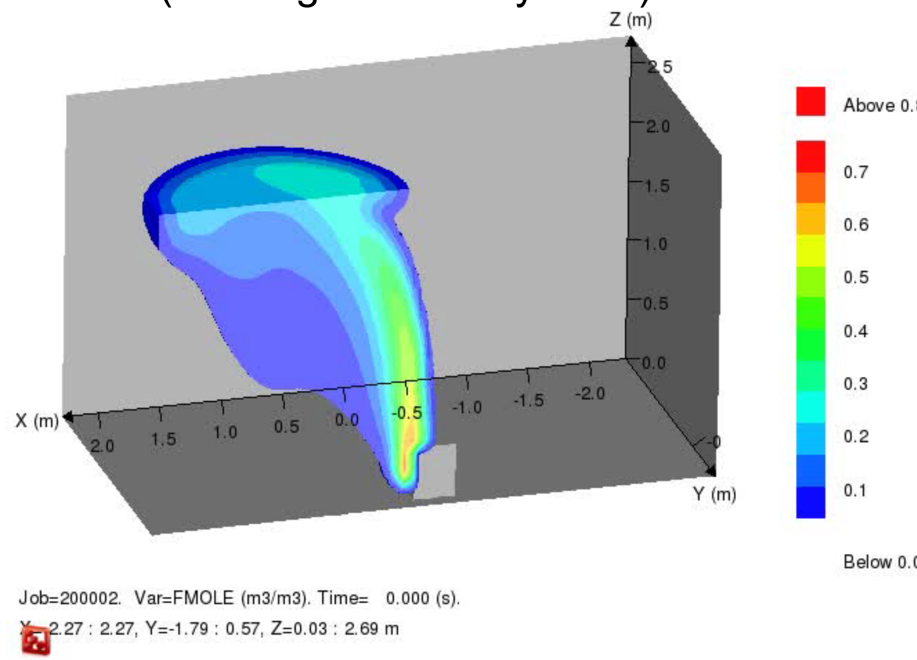
Blast-hardened Sub-Scale Warehouse at SRI Test Site

Deflagration Overpressure time Traces (2 sec ignition delay)



Closed garage case – no vents or openings
Length = 4.594 m

H_2 Mole Fraction (45-75%)
(2 sec ignition delay case)



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Test Objectives

Analyze capabilities to detect prescribed failure criteria:

> 118 SLPM hydrogen leakage rate
> 4% cabin/trunk hydrogen concentration for 1 hour

Investigate various leakage scenarios:

Rate (from creeping flow up to full-scale release)
Location (passenger cabin vs. trunk)
Type (buoyant or momentum dominant flows)

Evaluate experimental leakage detection methods:

Optimum sensor placement
Ideal sensor performance characteristics

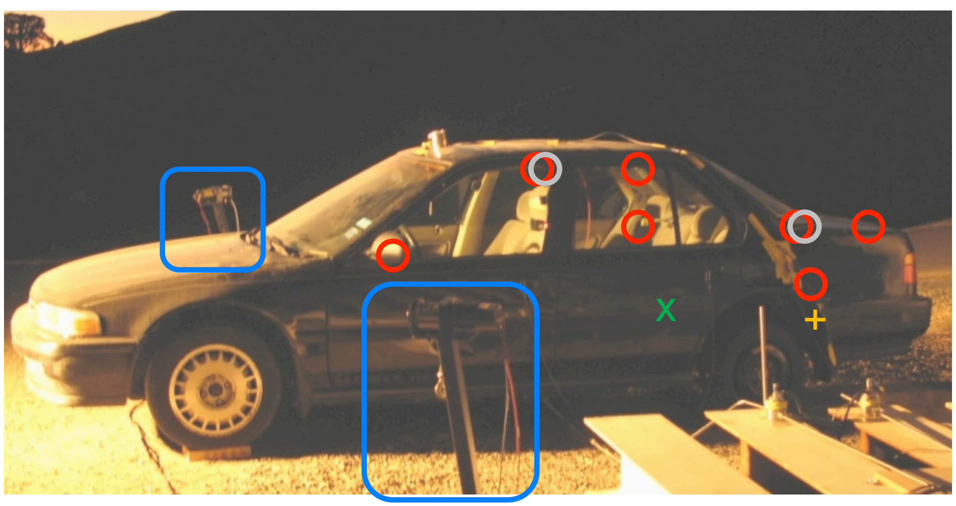
Feasibility of helium as a hydrogen surrogate

Test Vehicle

'95 Honda Accord

Cabin Volume: 2.61 m^3
Trunk Volume: 0.37 m^3

Door and trunk opened remotely



Sensors

9 O_2 Concentration
2 H_2 Concentration

Two H_2 release points

5–200 slpm flow controllers
Passenger cabin
Trunk

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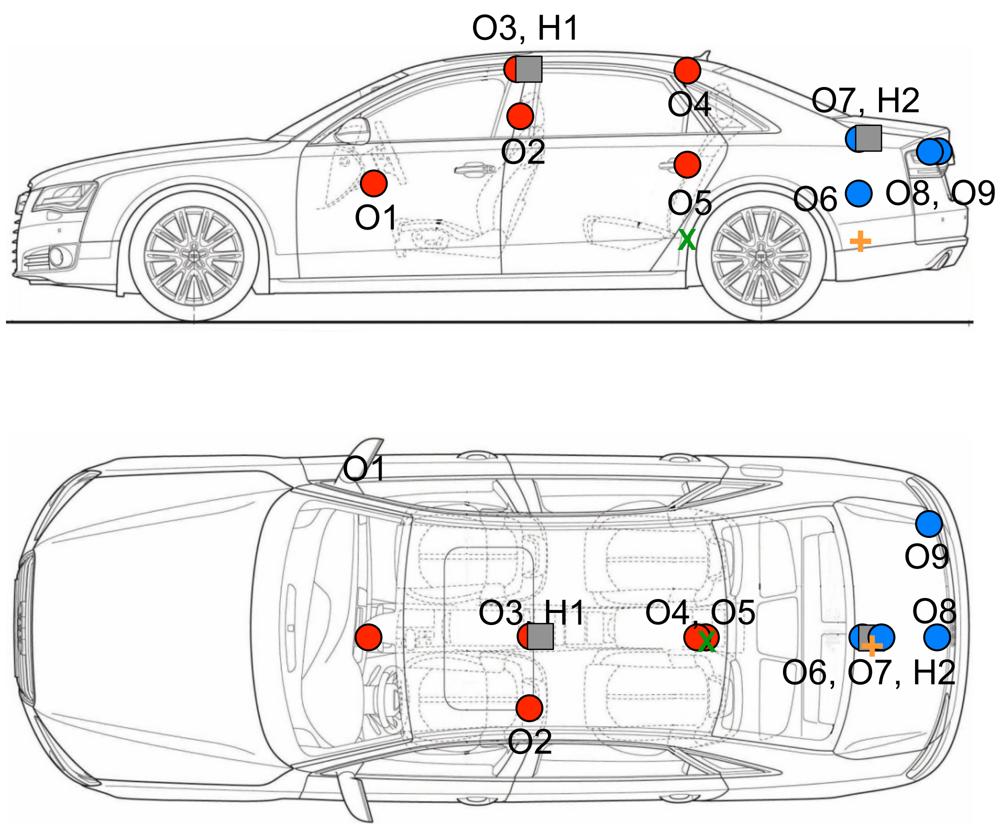
Vehicle Sensor Layout

O_2 sensors (4 trunk, 5 cab)

H2 sensors (1 trunk, 1 cab)

Trunk release

Cab release



O1:	Cigarette lighter
O2:	Driver's head
O3, H1:	Cab high point
O4:	High point above cab release
O5:	Directly above cab release
O6:	Directly above trunk release
O7, H2:	Trunk high point
O8:	Trunk rear
O9:	Tail light

Test Matrix developed to evaluate a variety of leakage scenarios

Test	Leak Diameter [mm]	Leak Rate [SLPM]	U_{exit} [m/s]	Leak Location	Gas
1	12.7	**118**	16.78	Passenger cabin	Hydrogen
2	12.7	**118**	16.78	Passenger cabin	**Helium**
3	12.7	25	3.55	Passenger cabin	Hydrogen
3 retest	12.7	25	3.55	Passenger cabin	Hydrogen
4	12.7	25	3.55	Passenger cabin	**Helium**
5	12.7	**5**	0.71	Passenger cabin	Hydrogen
6	12.7	**5**	0.71	Passenger cabin	**Helium**
7	**2**	25	**143.32**	Passenger cabin	Hydrogen
8	**2**	25	**143.32**	Passenger cabin	**Helium**
9	12.7	25	3.55	**Trunk**	Hydrogen
10	12.7	25	3.55	**Trunk**	**Helium**

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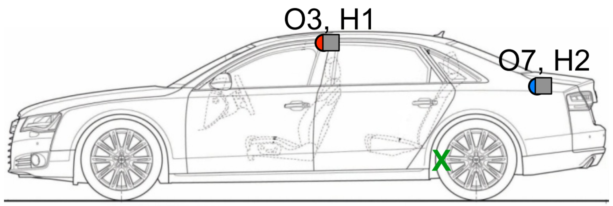
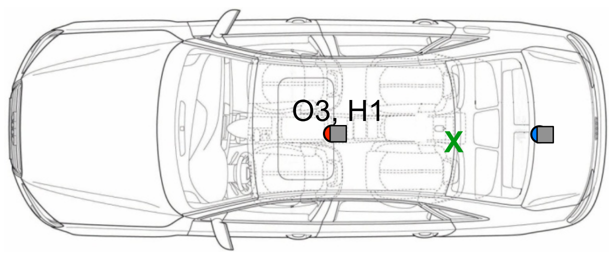
The baseline leak scenario indicates excellent agreement between the H_2 and O_2 sensor methods.



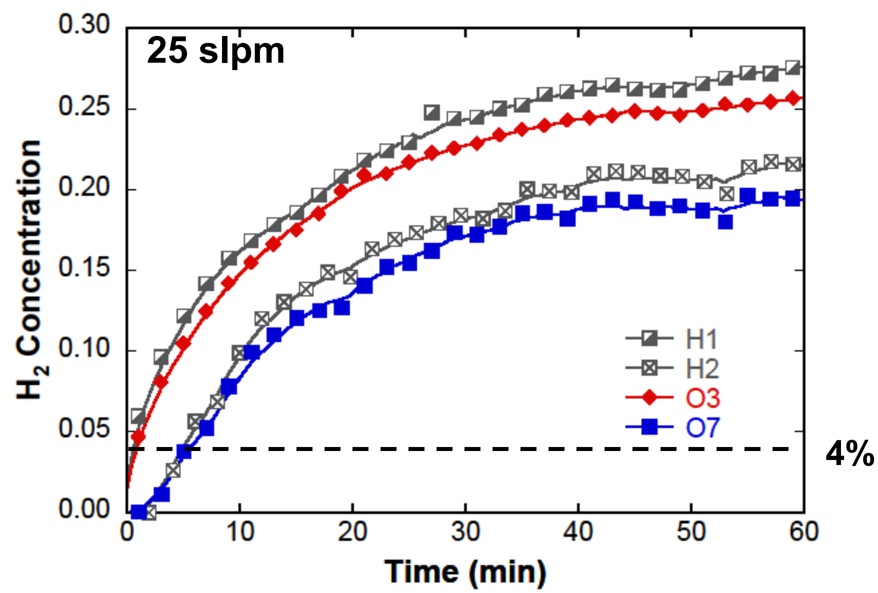


Conditions:

- Passenger cabin release
- H_2 gas
- 25 slpm release rate
- Buoyancy dominant flow (U_{exit} = 3.6 m/s)

Good agreement between O_2 and H_2 sensor measurements

O2 detection provides an accurate, species non-specific approach



Preliminary Conclusions

- O_2 sensors enable use of He or H_2 without species-specific sensors
- Repeatability between the tests is excellent
- Helium is an appropriate H_2 surrogate
- Leak rate and release characteristics has a large impact on detected hydrogen concentration gradients
  - Correlation to total flow may be challenging without understanding dispersion behavior in specific leak scenarios
  - Empirical correlation may be possible (more data needed)
- Any jet release into cabin is likely to result in a failure condition
  - Local concentrations in excess of 4% by volume
  - A leak rate of 150 slpm into cabin will quickly result in 50% concentrations
  - A pin hole leak (0.1 mm) from a 35 MPa tank = ~150 slpm
- Data can be referenced to help specify sensor performance and placement requirements
  - Understanding dispersion in a variety of vehicles for various leak characteristics may be necessary (eg. SUV vs sedan)

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Additional Slides