Experimental Investigation of Hydrogen Jet Fire Mitigation by Barrier Walls

Robert Schefer and William Houf
Sandia National Laboratories
Livermore, CA USA

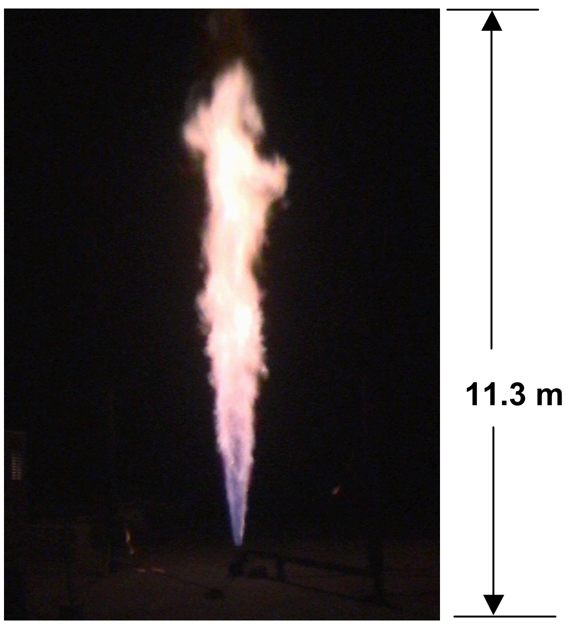
Erik Merilo and Mark Groethe
SRI International
Menlo Park, CA USA

3rd International Conference on Hydrogen Safety
Ajaccio, Corsica
September 16-18, 2009

Session 13
Paper Reference Number: 178

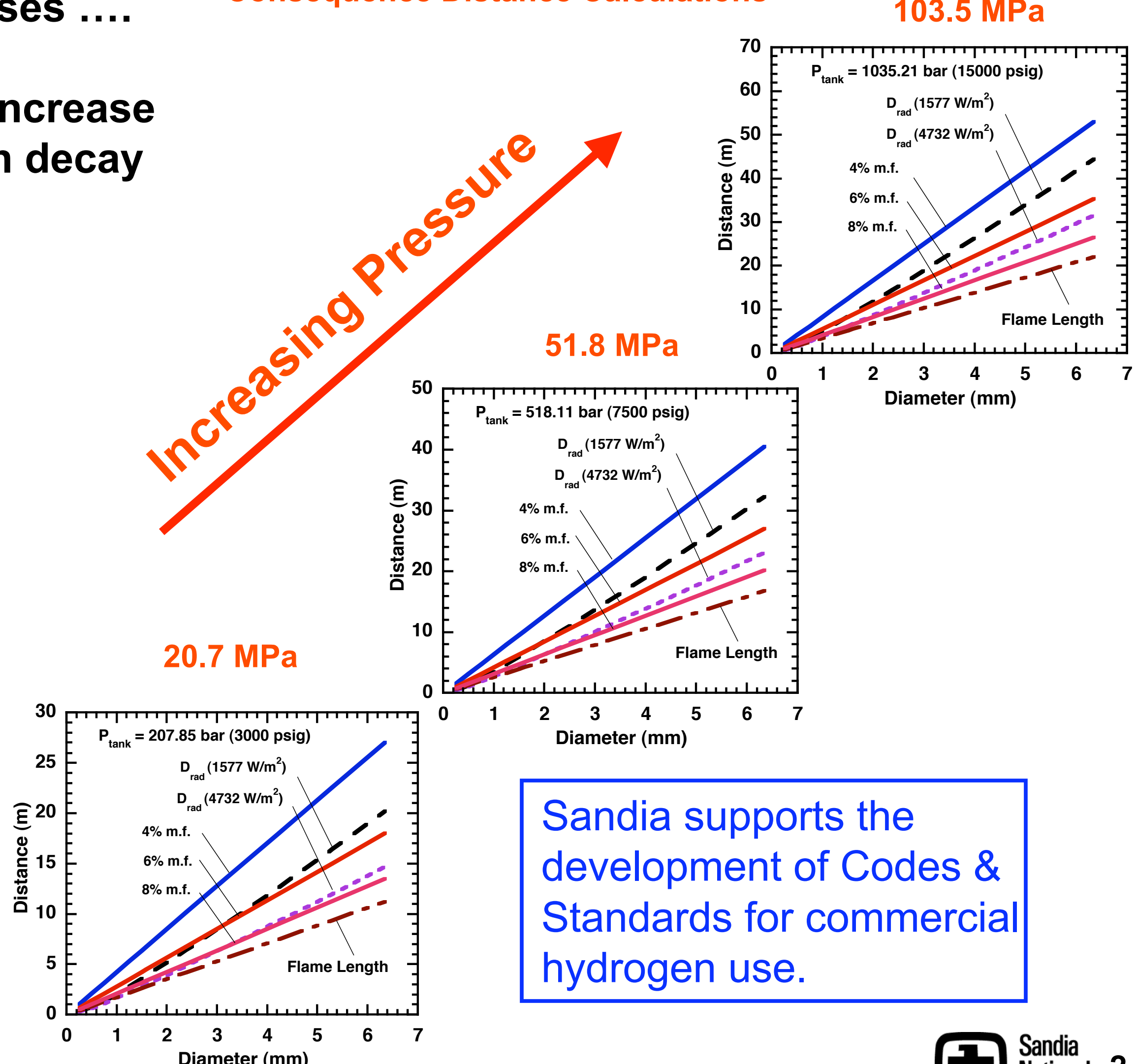
Experiments and calculations have shown that consequence distances increase as refueling pressure increases.

- As leak source pressure increases ….
  - Jet flame lengths increase
  - Radiation heat flux levels increase
  - Unignited jet concentration decay distance to LFL increases



Nighttime Photo of H_2 Jet Flame Test
Source Press. = 41.3 MPa (6000 psig)
Dia. = 5.08 mm
L_{vis} = 10.6 m

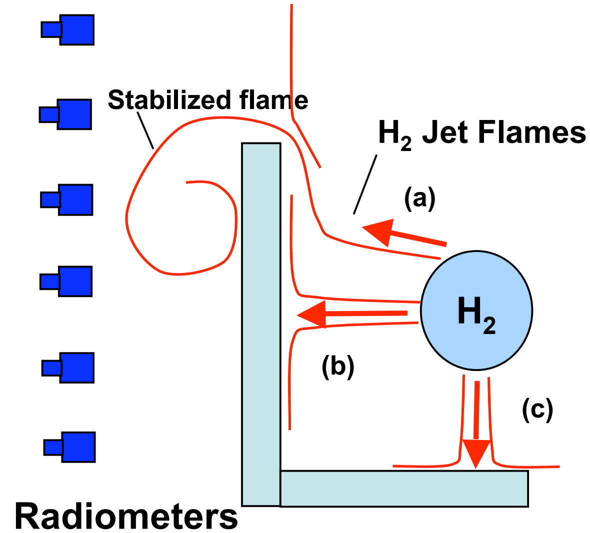
Consequence Distance Calculations



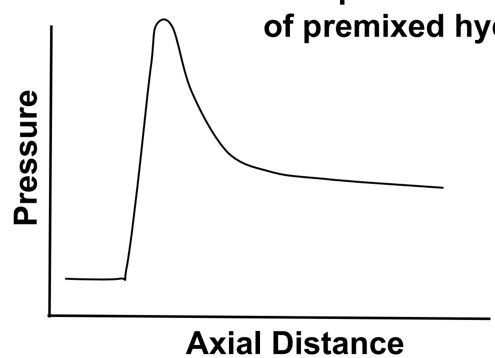
Sandia supports the development of Codes & Standards for commercial hydrogen use.

We have performed a study of barriers to determine if they are an effective mitigation strategy to reduce safety distances.

- **Goal: Determine if barriers are an effective jet flame mitigation technique for reducing safety distances**
- **Combined experimental and modeling approach**
- **Issues of importance:**
  - **Jet flame deflection and protection from impingement**
  - **Reduction of thermal radiation exposure**
  - **Reduction of unignited jet flammability envelope**
  - **Ignition overpressure and attenuation by barrier**
- **Collaborating with the HYPER project in Europe on barriers**
- **Experimental data shared with HYSAFE for modeling**
- ***Combine data and analysis with quantitative risk assessment for barrier configuration guidance.***

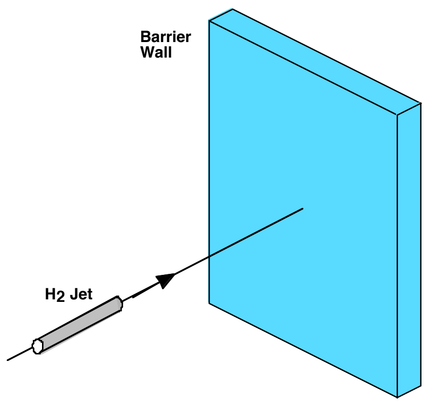


Sandia/SRI H_2 Jet Flame Barrier Test

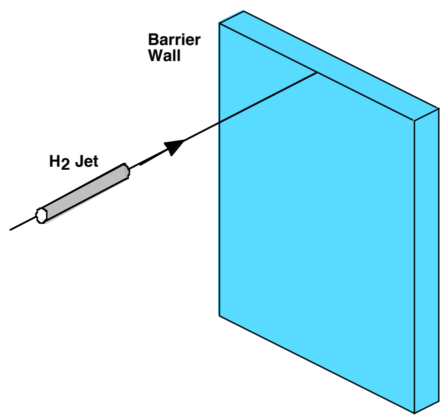


Initially we identified several barrier configurations for evaluation with experiments and modeling.

1-Wall Vertical Barrier (Jet at Wall Center)

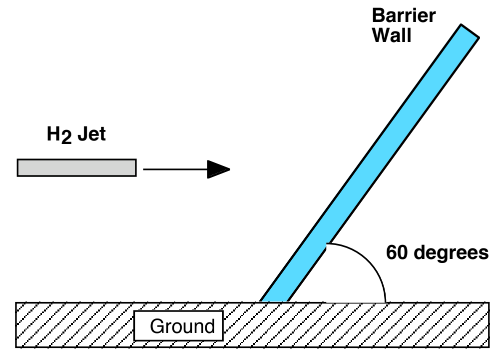


1-Wall Vertical Barrier (Jet at Wall Top)



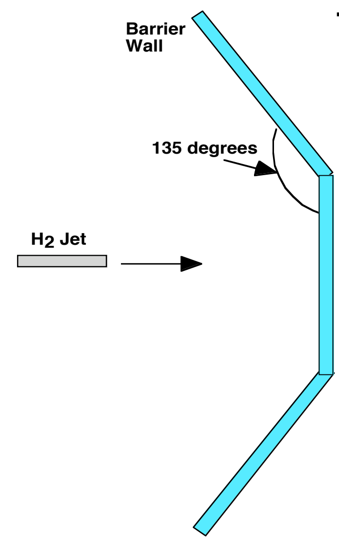
1-Wall Tilted Barrier[1]

Side View



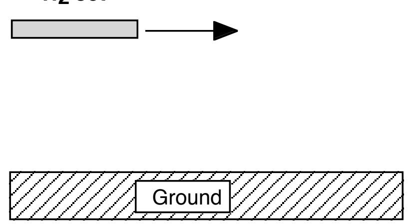
3-Wall Barrier[2]

Top View



Free Jet

Side View



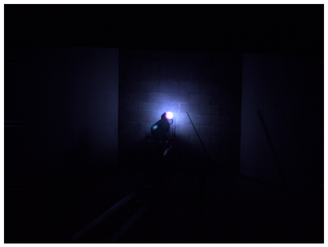
[1] Based of NFPA 68 guidelines for barrier walls.
[2] Recommended by IFC 2006.

Sandia National Laboratories

Initial experiments focused primarily on jet flame impingement on barriers with limited ignition overpressure measurements.

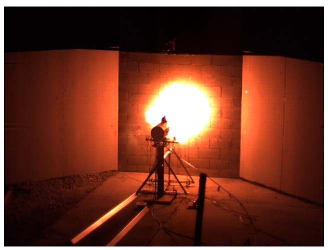
High-speed movie frames of H_2 ignition near barrier wall

Frame 1 (t = 137 msec)
Spark ignition

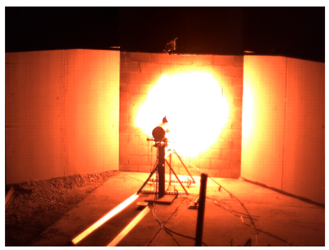


Frame 5 (t = 145 msec)

Frame 10 (t = 155 msec)

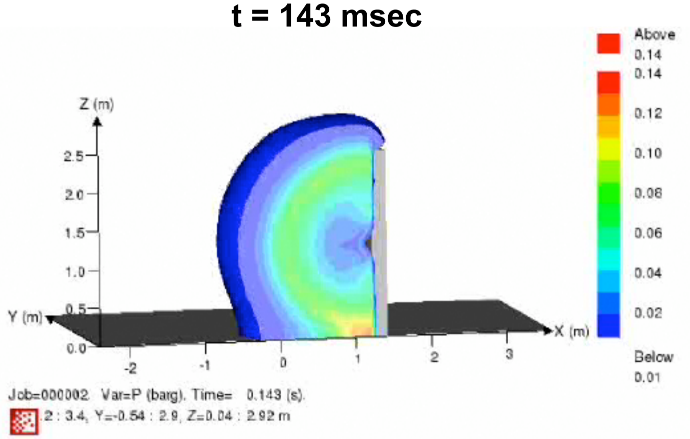


Frame 15 (t = 165 msec)

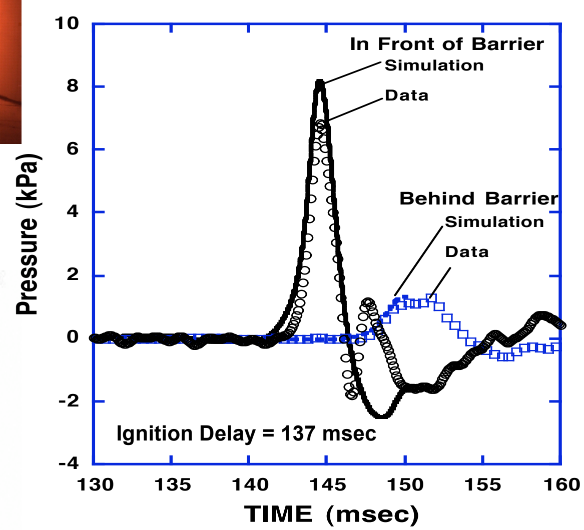


- We have investigated overpressure around barriers from H_2 ignition
  - Measurements of overpressure on front and back of barrier
  - Different barrier configurations
  - Time of release before ignition
  - Point of ignition
- Combined experimental and modeling approach
- Simulations are used to guide large-scale experiments

Single Wall Test
Simulation - Overpressure (barg)
t = 143 msec

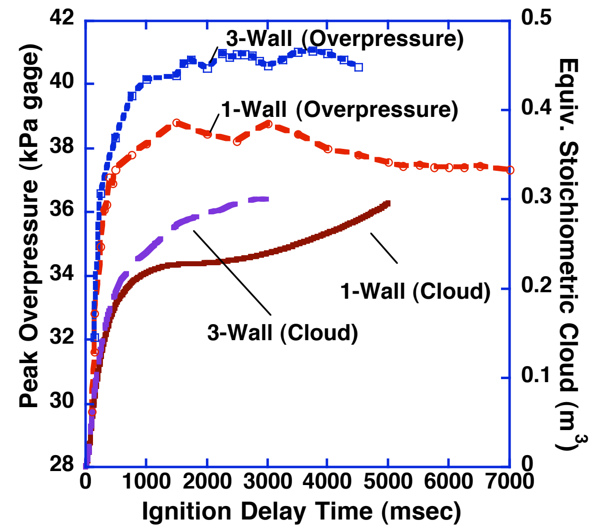


Comparison of Simulation and Experiment for Overpressure Sandia/SRI 1-Wall Test



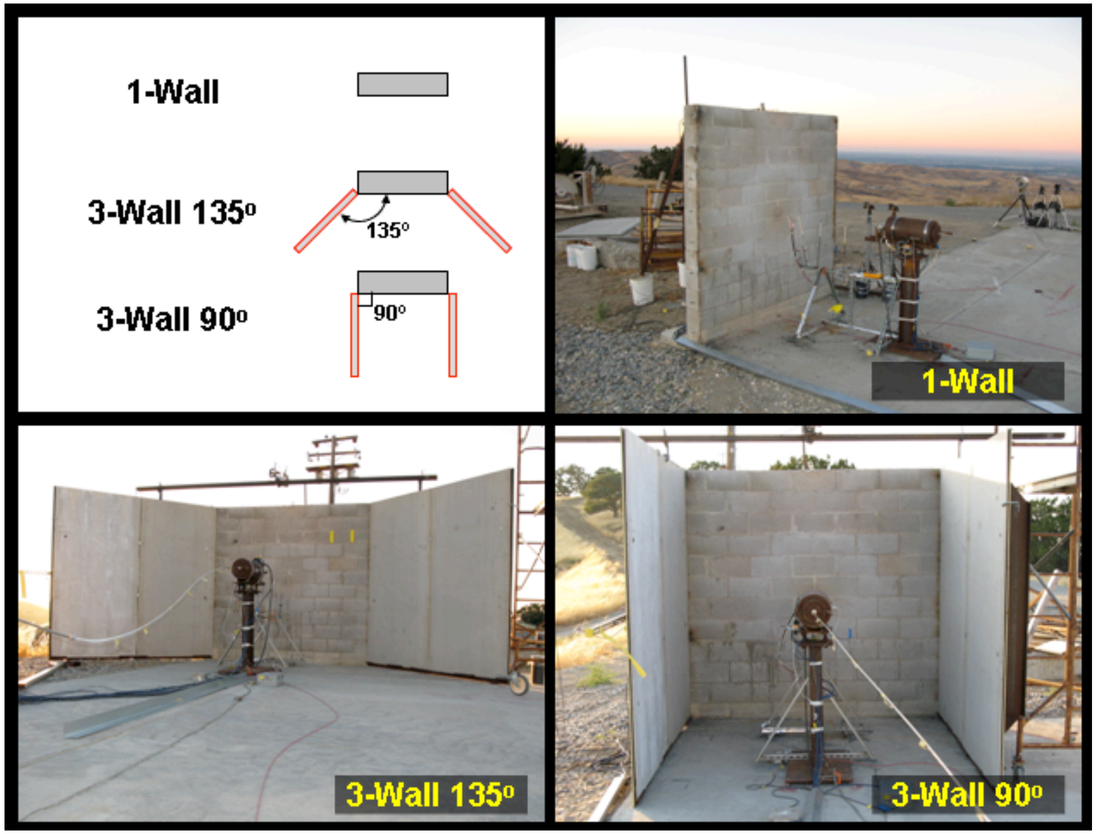
- Tests performed at SRI Corral Hollow test site

Simulation of Peak Overpressures For Different Ignition Times 1-Wall and 3-Wall



We have performed additional barrier tests to look at the effect of ignition delay time, confinement, and ignition location on overpressure.

Barrier Wall Configurations*



- **Long duration jet flame releases**
- **Ignition delay tests**
- **Spark location varied (40 Joules)**

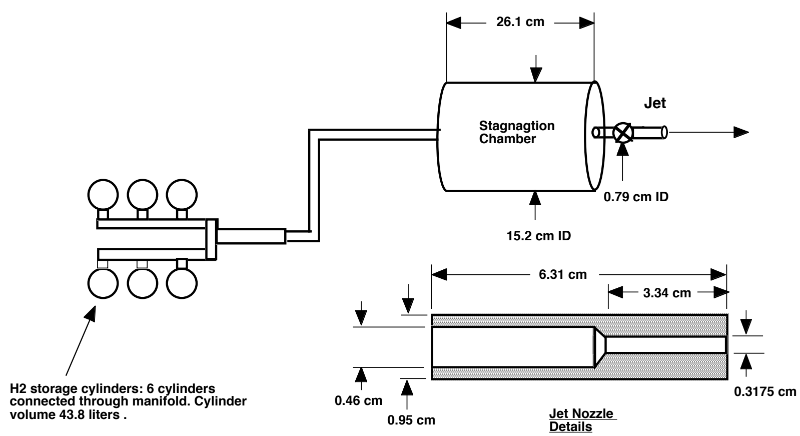
- **Central cinderblock wall with rebar - 2.4m x 2.4 m x 0.197m**
- **Side walls (2.4m x 2.4m) steel plate covered with cement backer board (12.7 mm thick steel with steel I-beams on back)**

* Tests performed at SRI Corral Hollow Test Site

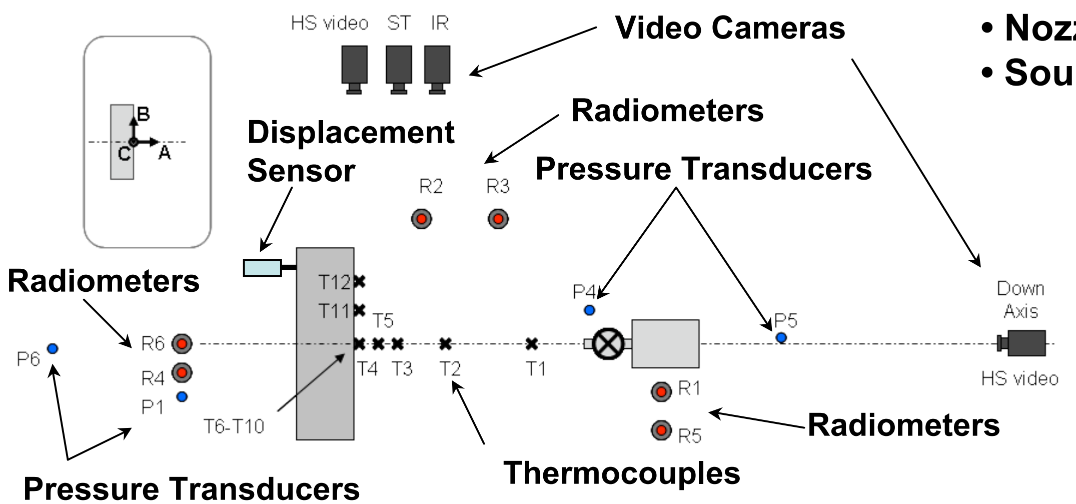
Schematic of flow delivery system and detector layout for single wall test.

filename: SRI_Barrier_setup6.clar

Gas Delivery System for Barrier Wall Tests



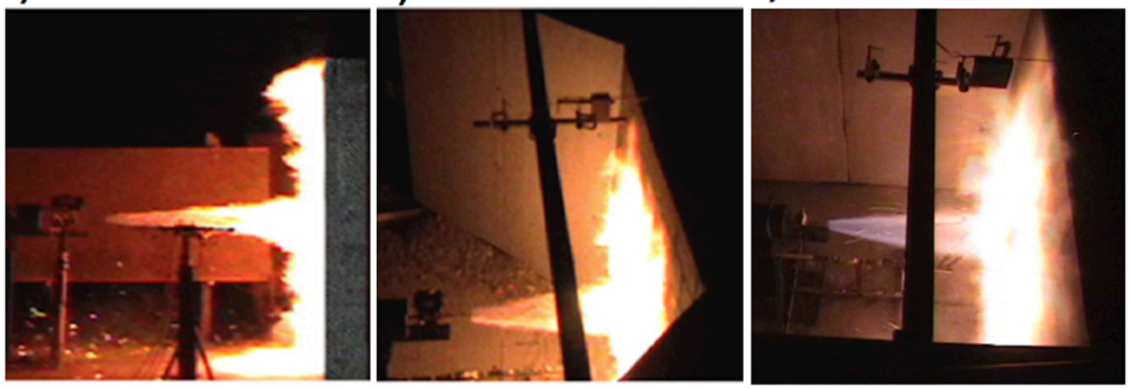
Top View



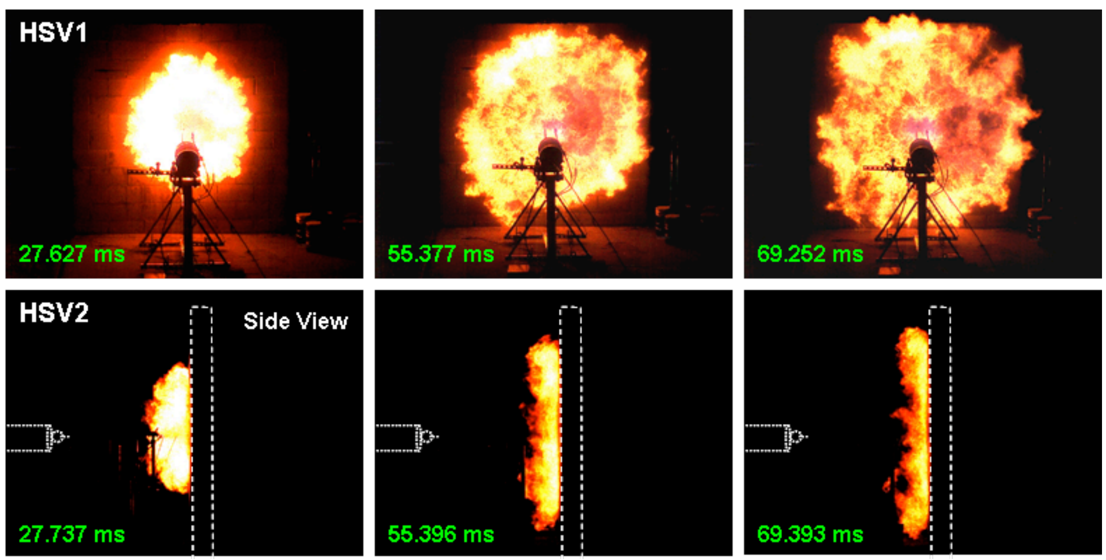
- Nozzle Diameter - 3.175 mm
- Source Pressure - 136 barg (2000 psig)

Hydrogen jet flame barrier wall impingement tests have been completed and used to assess the effectiveness of barriers.

a) 1-Wall   b) 3-Wall 135º   c) 3-Wall 90º

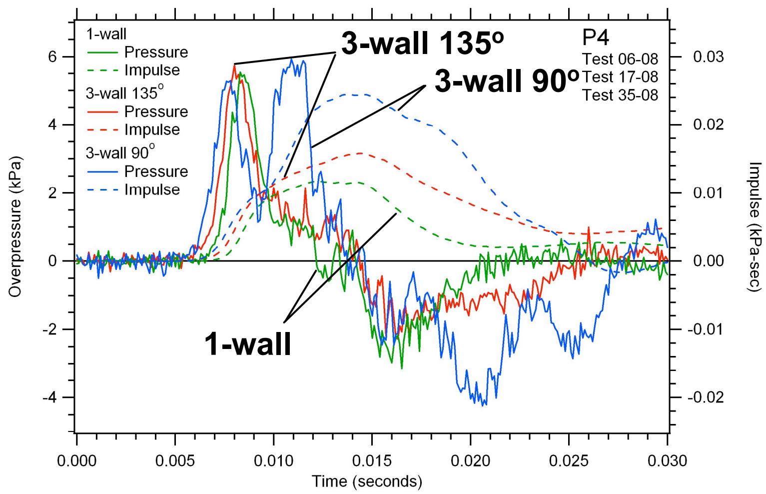


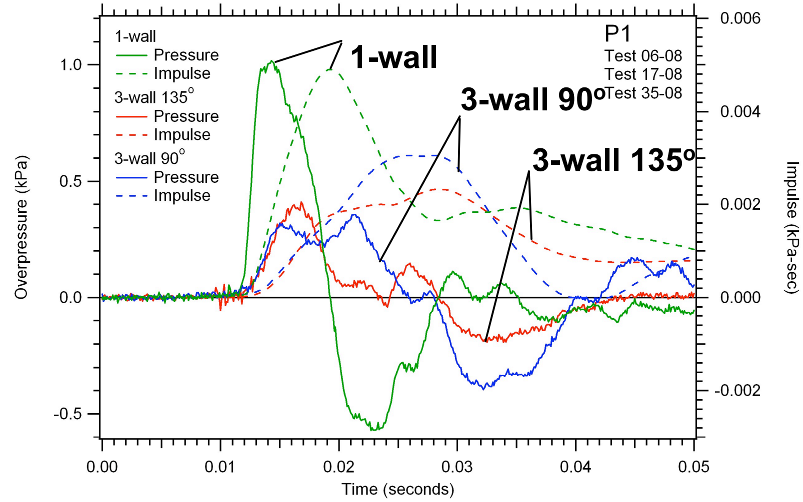
High-Speed Video of Ignition for 1-Wall Configuration



Barrier Wall Tests: Effect on Overpressure

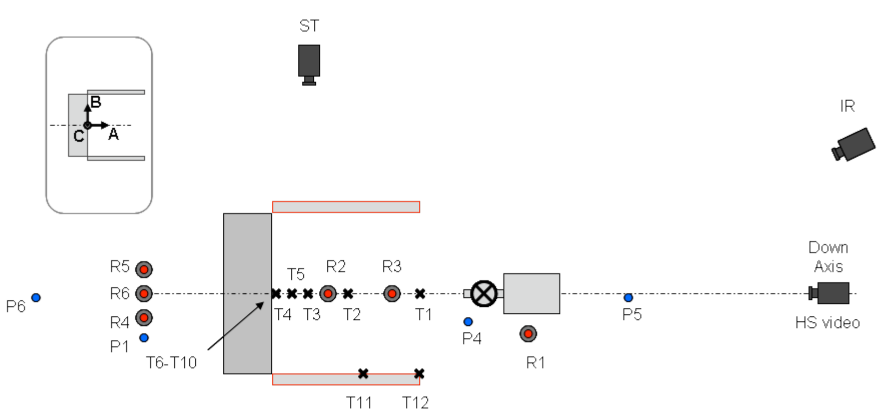
Comparison of Overpressure and Impulse Time-Traces for Different Barrier Configurations



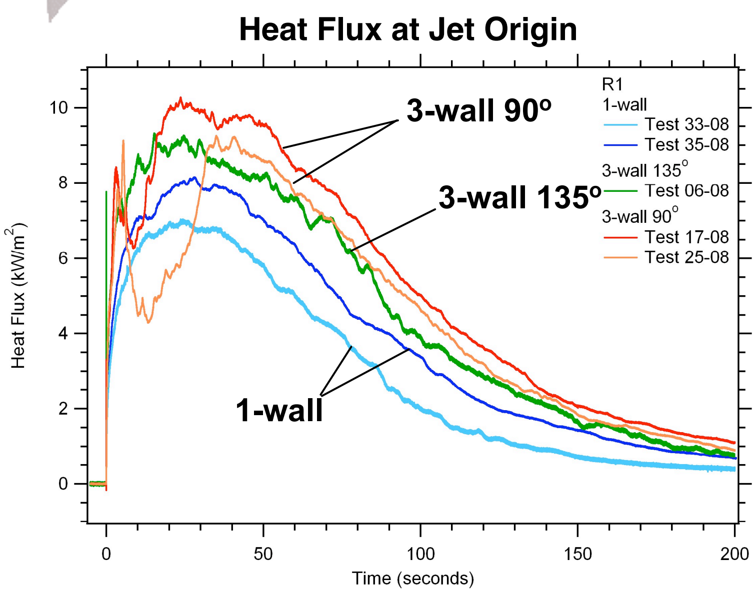


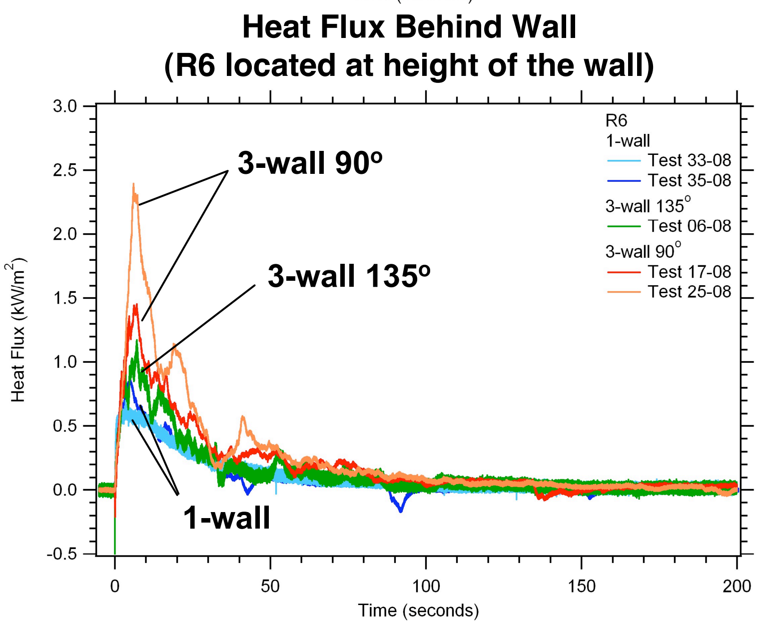
- Overpressure behind barrier significantly higher for 1-wall barrier versus either 3-wall configuration
- Pressure waveforms similar for 1-wall and 3-wall 135° configurations
- Pressure waveform for 1-wall 90° has two peaks
  - 2nd peak caused by reflection off side walls
  - Peak pressure and impulse greater than 3-wall 135°
  - Increased potential for damage at leak source

3-Wall 90° (Top View)



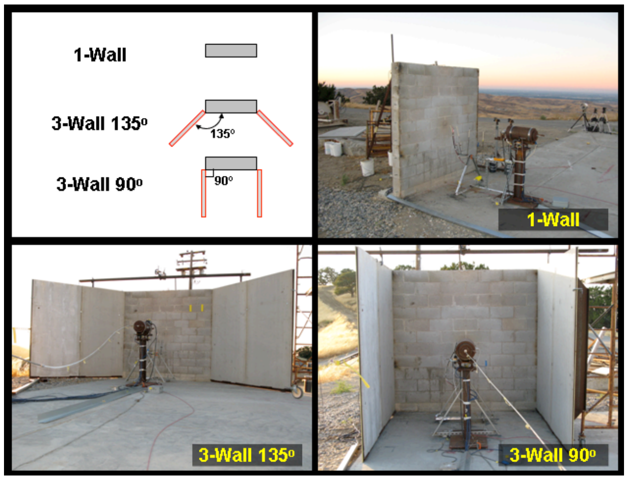
Barrier Wall Tests: Effect on Radiative Heat flux





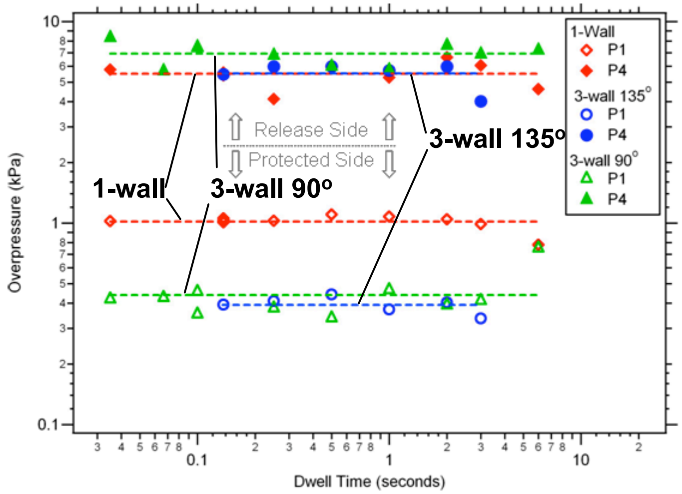
- Maximum radiative heat flux behind wall occurs for 3-wall 90º barrier
  - Side-walls cause hot gases to be vented over top of the wall
- Heat flux for all barrier configurations are well below harmful levels behind wall.
- Walls are an effective mitigation strategy for radiative heat flux hazards as long as flame is confined by wall.
- Walls significantly increase heat flux levels at leak origin as compared to free jet flame.

Barrier Wall Configurations

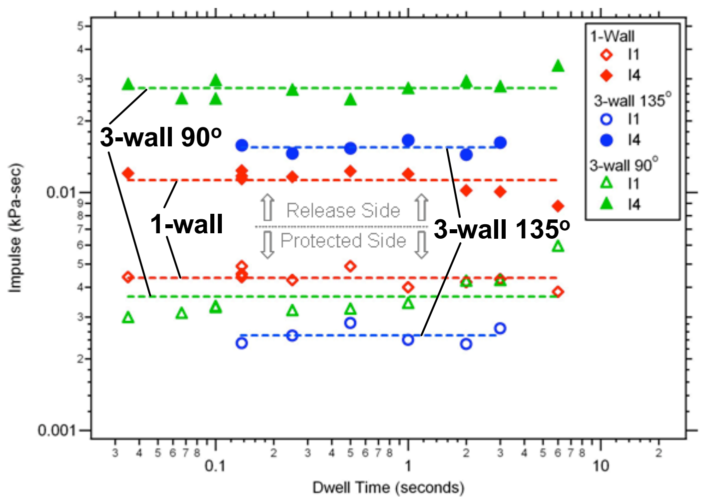


Barrier Wall Tests: Effect of ignition delay time on peak overpressure and impulse.

Comparison of Avg. Peak Overpressure On Front and Backside of Barriers

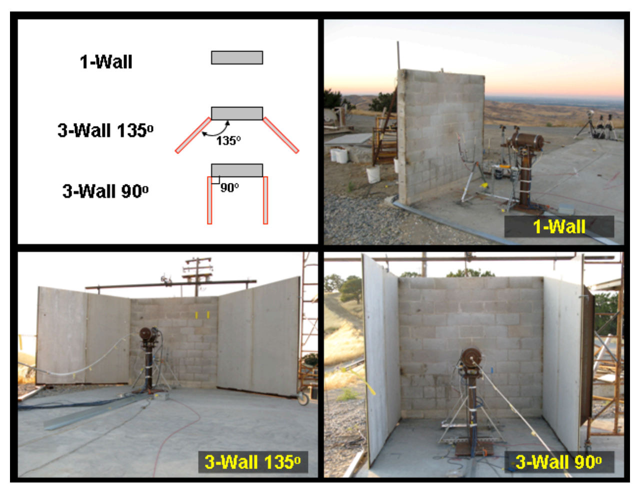


Comparison of Impulse on Front and Backside of Barriers



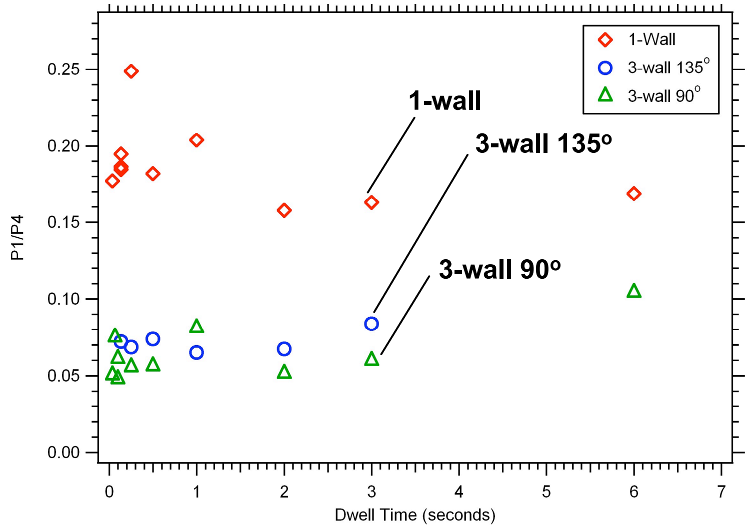
- Ignition delay time varied from 0.04 sec to 6.0 sec
- Peak overpressure and impulse relatively constant with ignition delay time
- 3-wall 135° configuration produced best combination of low peak overpressure and low impulse in front of and behind barrier
- 3-wall 135° configuration produced peak overpressures near release point approx. the same as 1-wall barrier
- Backside overpressures for 3-wall 135° configuration approx. the same as 3-wall 90° configuration
- 3-wall 135° configuration produced slightly higher impulse than 1-wall configuration
- Backside impulse for 3-wall 135° configuration the lowest

Barrier Wall Configurations

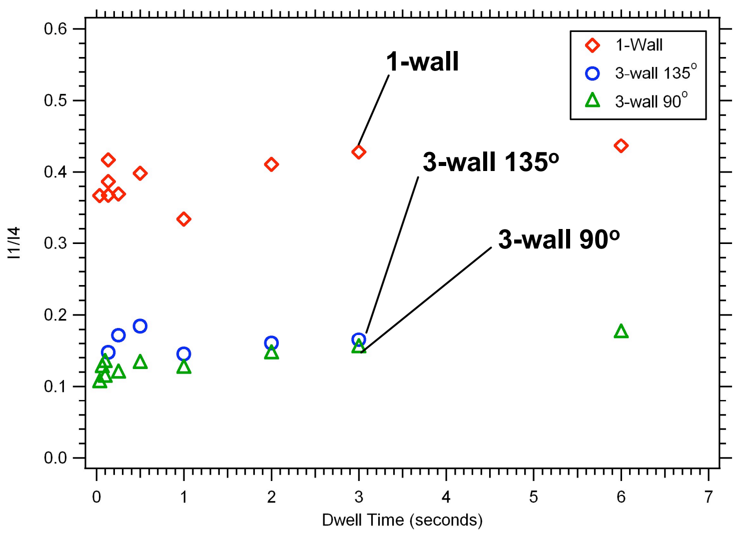


Barrier Wall Tests: Effect of ignition delay time on mitigation of overpressure and impulse.

Ratio of Overpressure Behind Barrier to Overpressure in Front of Barrier

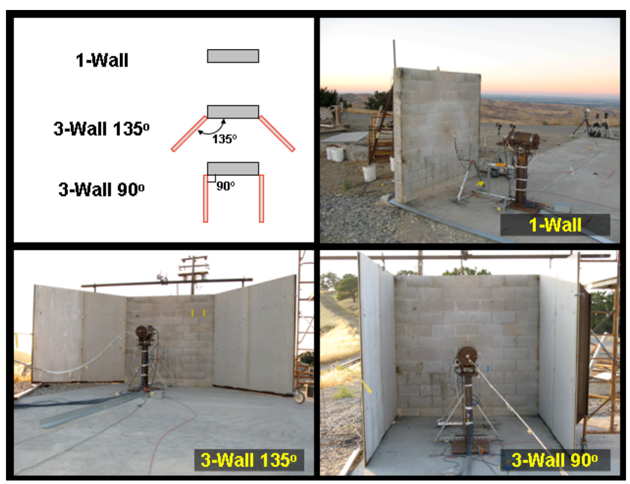


Ratio of Impulse Behind Barrier to Impulse in Front of Barrier



- Ignition delay time varied from 0.04 sec to 6.0 sec
- Ratio of peak overpressure and impulse behind wall (P1, I1) to peak overpressure and impulse in front of wall (P4, I4) computed
- Effectiveness of barriers at reducing overpressure and impulse relatively constant with ignition delay time
- Reduction of overpressure and impulse by 3-wall 135° nearly identical to 3-wall 90° barrier (both better than 1-wall barrier)
  - 3-wall 135° barrier exhibits better overall performance because overpressure and impulse are lower on both front and back of barrier (see previous slide)

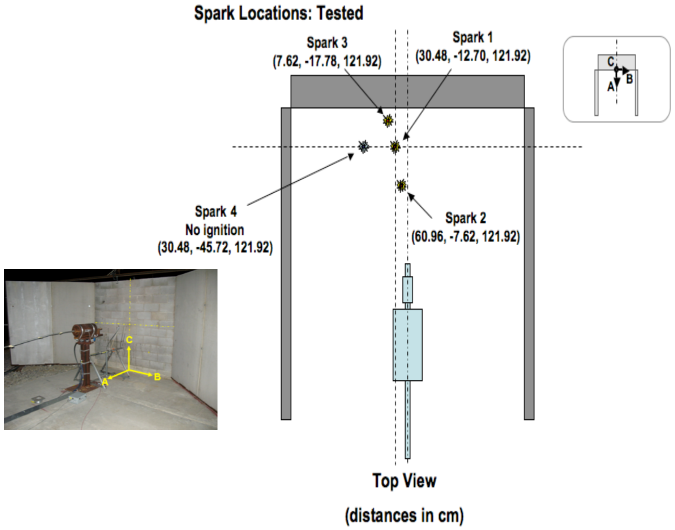
Barrier Wall Configurations



Sandia National Laboratories

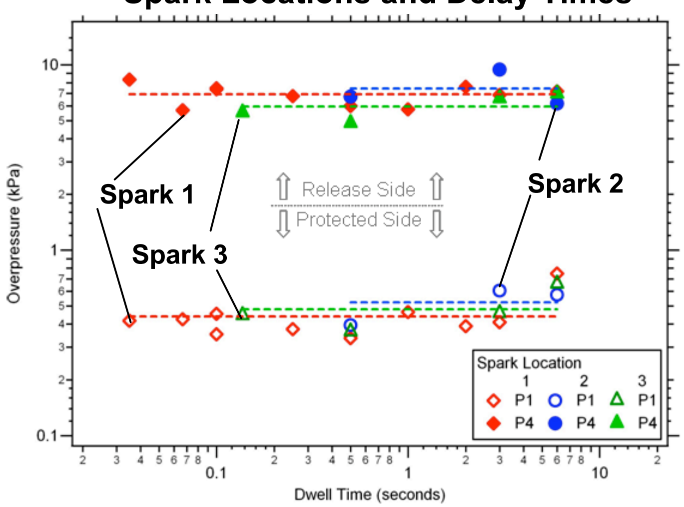
Barrier Wall Tests: Effect of ignition location on overpressure and impulse.

Spark Locations for 3-wall 90° Barrier (Top View)

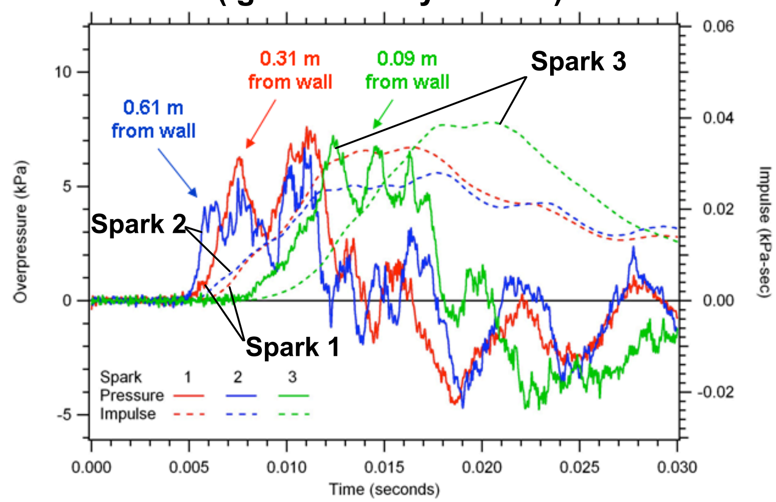


- Altering spark location <u>did not</u> have an effect on magnitude of peak overpressure and impulse
- Altering spark location <u>did</u> effect overpressure and impulse waveforms
  - Distance pressure wave must travel to reflect off walls and reach detector changes
- No ignition obtained at spark location 4 (agrees with FLACS)

Front and Back Peak Overpressure for Different Spark Locations and Delay Times

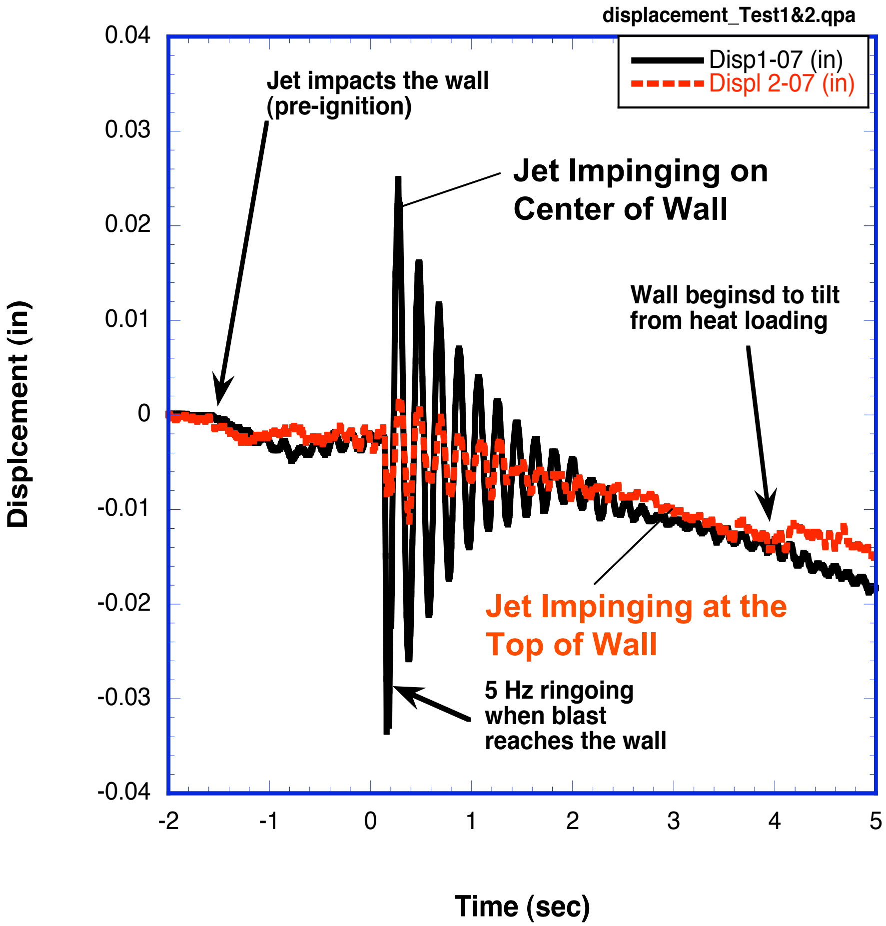


Overpressure and Impulse Waveforms in Front of the Wall for Different Spark Locations (Ignition Delay = 6 sec)



Structural response of reinforced cinder-block wall.

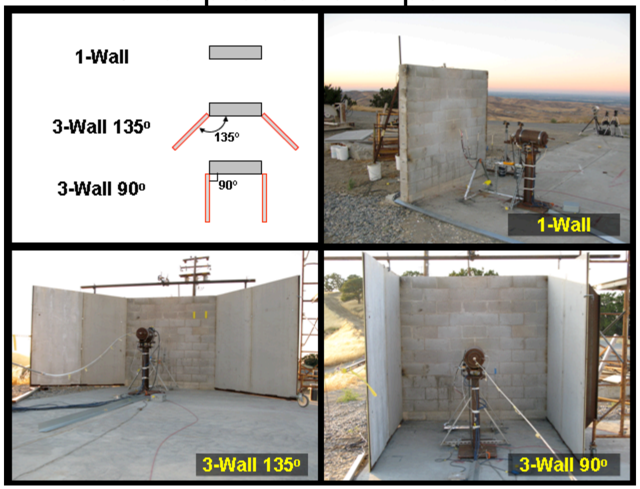
Wall Displacement



Wall Structural Damage (Jet Centered at Top of Wall)

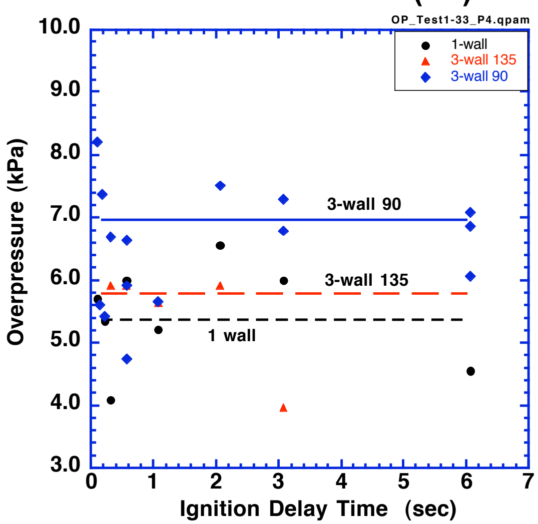
Summary and Conclusions.

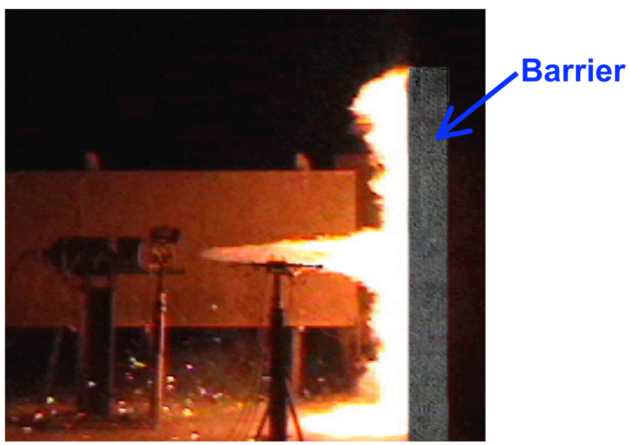
Barrier Wall Configurations for Over-pressure Experiments



- 3-wall 135° barrier most effective overall
  - Overpressures at release point the same as 1-wall
  - Attenuated overpressure the same as 3-wall 90°
  - Radiative flux at release point lower than 3-wall 90° but not quite as low as 1-wall
  - Radiative flux on backside of barrier only slightly higher than 1-wall (both less than 1.5 kW/m^2)
- Some parameters are insensitive to wall configuration
  - Over-pressure is approximately constant with respect to ignition delay time (> 100 msec)
  - Overpressure is not sensitive to ignition location

Overpressure Measured Near Jet Release Point (P4)





Sandia/SRI H_2 Jet Flame Barrier Test

Publications & Presentations

1. W. Houf, G. Evans, and R. Schefer, "Evaluation of Barrier Walls for Mitigation of Unintended Releases of Hydrogen", 2009 NHA Conference and Hydrogen Expo, Columbia, SC, March 30 - April 3, 2009.
2. R. Schefer, W. Houf, M. Groethe, G. Evans, M. Royle, D. Willoughby, "HYPER Report 5.4 - Report on Experimental Evaluation of Barrier Walls for Risk Reduction of Unintended Releases of Hydrogen," Sept. 30, 2008.
3. W. Houf, G. Evans, R. Schefer, "HYPER Report 4.3 - Releases, Fires, and Explosions Final Modelling Report, Chapter 6 - Effects of Barriers and Walls", Aug. 31, 2008.
4. W. Houf, G. Evans, R. Schefer, "Analysis of Jet Flames and Unignited Jets from Unintended Releases of Hydrogen," *International Journal of Hydrogen Energy*, in press February 24, 2009.
5. R. Schefer, M. Groethe, W. Houf, G. Evans, "Experimental Evaluation of Barrier Walls for Risk Reduction of Unintended Hydrogen Releases," *International Journal of Hydrogen Energy*, Volume 34, Issue 3, February 2009, pp. 1590—1606.
6. Schefer, R.W., Groethe, M., Houf, W.G. and Evans, G., "Experimental Evaluation of Barrier Walls for Risk Reduction of Unintended Hydrogen Releases," Sandia Report SAND2008-41411, October, 2008.
7. R.W. Schefer, W.G. Houf, T.C. Williams , "Investigation of small-scale unintended releases of hydrogen: momentum-dominated regime", *International Journal of Hydrogen Energy*, *Volume 33, Issue 21*, *November 2008*, *pp. 6373-6384*.
8. R.W. Schefer, W.G. Houf, T.C. Williams, "Investigation of small-scale unintended releases of hydrogen: Buoyancy effects", *International Journal of Hydrogen Energy*, *Volume 33, Issue 17*, *September 2008*, *pp.4702-4712*.
9. J. LaChance, W. Houf, B. Middleton, L. Fluer, "Analyses to Support Development of Risk-Informed Separation Distances for Hydrogen Codes and Standards," Technical Report SAND2009-0874, March 2009.
10. W. S. Winters and W. G. Houf, "Results from an Analytical Investigation of Small-Scale Releases from Liquid Hydrogen Storage Systems", 2009 NHA Conference and Hydrogen Expo, Columbia, SC, March 30 - April 3, 2009.