EPRG-PRCI-APGA
23rd Joint Technical Meeting
Edinburgh, Scotland • 6–10 June 2022

Paper 12: Numerical investigation of risks associated with decompression and atmospheric expansion of hydrogen

28 July 2022

Overview

- Background
- Hydrogen decompression tube test
- CFD model for atmospheric expansion of H_2 / CH_4
- Simulation results
- Risk mitigation
- Conclusions

Background

- Application of renewable H_2 is an important part of CO_2 emission mitigation efforts.
- Transmission pipelines are the most appropriate long-term choice for H_2 distribution… If there is large and sustained demand.
- To facilitate the transport via pipelines, an accurate understanding of the decompression characteristics of H_2 is essential to control running ductile fracture.
- Limited experimental or numerical programs have been conducted with decompression of H_2 or NG+H_2 blends.

Background

- Future Fuels CRC engaged NOVA Chemicals to conduct a decompression tube test program.

- The first test, conducted at TC Energy's Gas Dynamics Test Facility in Didsbury, Alberta, Canada, investigated the decompression of pure H_2 from approx. 17 MPa.

- The test indicated noise levels in excess of that witnessed at the site with NG and CO_2 mixtures. Ignition qualitatively witnessed 'immediately' after the onset of the rupture disc.

  - **Possible reasons:**
    - Higher release velocity of H_2 (in the order of 1,000 m/s);
    - Greater volumetric expansion (released volume over 2 times of that of NG).

Background

- Risks from overpressure wave, noise level, and ignition influence
  - The risk assessment of H_2 pipelines following an accidental release
  - The safety of controlled releases such as venting, blowdowns.
- A better understanding of the risks associated with high-pressure H_2 releases and their atmospheric expansion is warranted.
- Objective of this work:
  - Report the outcomes of the first pure H_2 decompression test;
  - CFD study to replicate the conditions of the decompression test on pure H_2;
  - Compare the risks from the decompression and expansion of pure CH_4 and H_2;
  - Discuss potential methods for risk mitigation.

Hydrogen decompression tube test

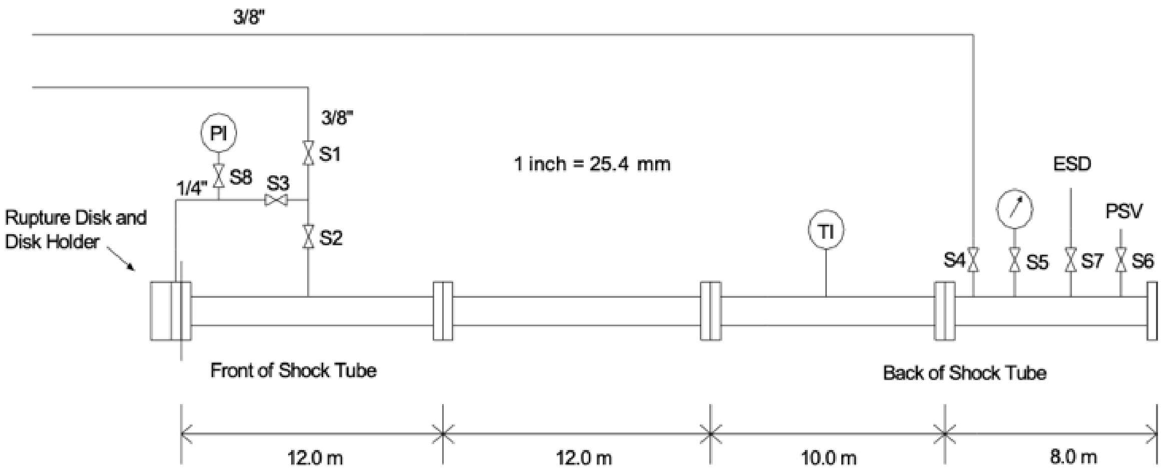
Hydrogen decompression tube test

Decompression tube at TCE

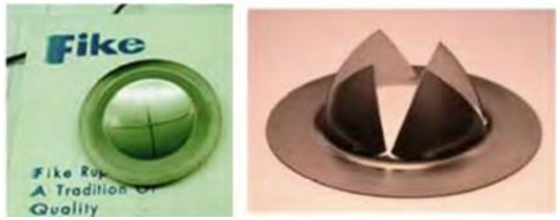
- 42 m long
- 38.1 mm internal diameter
- 14 pressure transducers (11 of which within the first spool)

First test

- Hydrogen (99.999% purity)
- Pressure: 16.62 MPa(a)
- Temperature: -1.5 °C



Schematic the decompression tube available at TCE



X-scored rupture disk

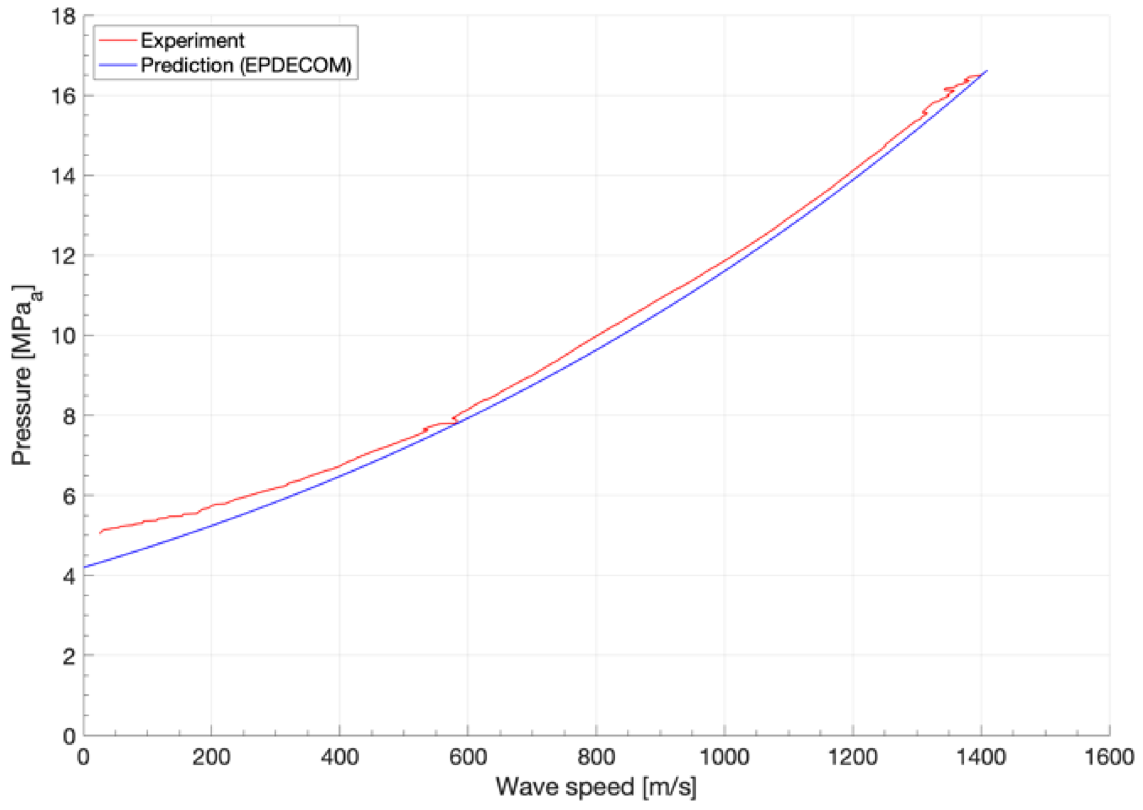
O-scored rupture disk

Hydrogen decompression tube test

Decompression wave speed

- Prediction using EPDECOM with GERG 2008 EOS
- Overall good agreement against measurements
- Minor difference at velocities above 600 m/s
- According to BTCM, the prediction produces a degree of non-conservatism
- Further work required to understand the role of friction and other factors

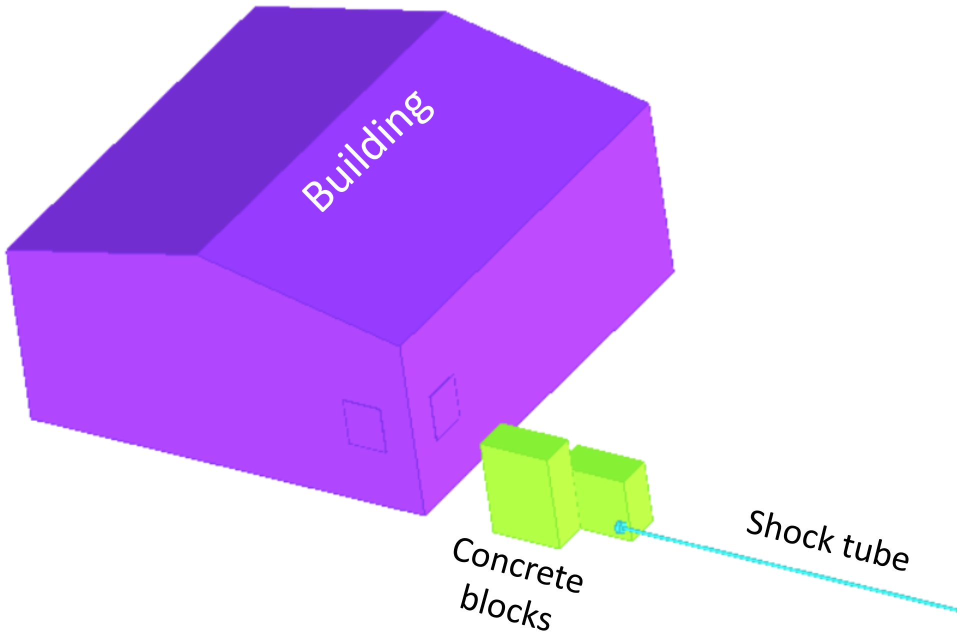
Decompression wave speed: measured vs predicted



Hydrogen decompression tube test

Other experimental observations

- Level of noise considered louder than experienced from previous tests (NG, CO_2) at same initial P and T.
- Front window located behind the blocks experienced some damage; a situation which had not been witnessed in previous tests.
- The outflow of hydrogen constrained between the exit of the tube and the concrete blocks ignited "immediately" according to witnesses.



CFD simulations proposed to highlight the differences between H_2 and CH_4, and to explain the mechanisms supporting the experimental observations.

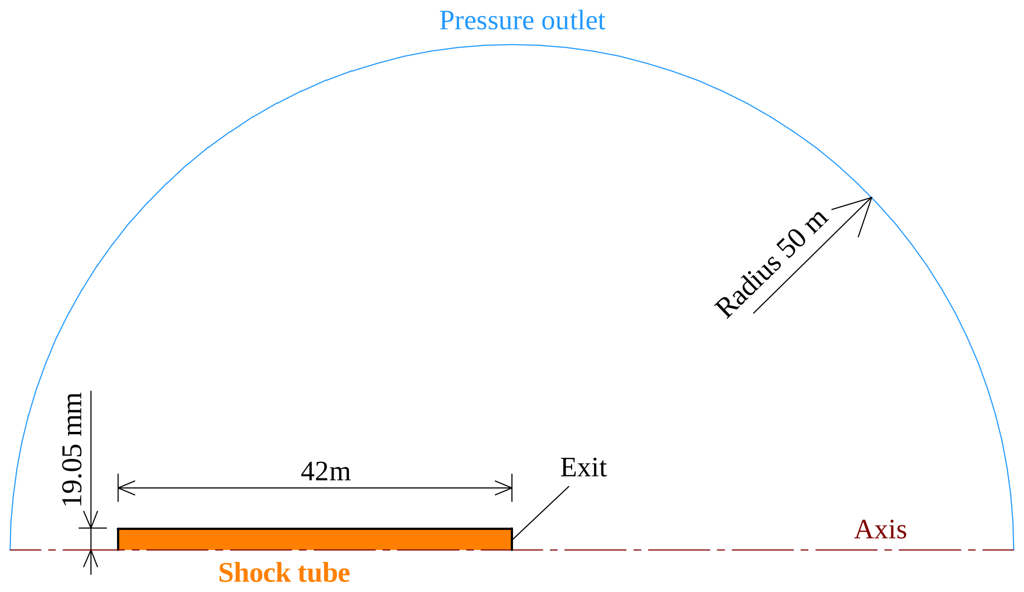
CFD model for atmospheric expansion of H_2 / CH_4

CFD model for atmospheric expansion of H_2 / CH_4

CFD model

- Replicates environment at TCE site
- Evaluate risks associated with H_2/CH_4 releases and atmospheric expansion:
  - Two-dimensional axisymmetric domain
  - Peng-Robinson EOS implemented for thermodynamics properties of H_2/Air or CH_4/Air mixtures
  - Realisable k-ε model for turbulence modelling
  - Density-based solver
  - Initial P: 17 MPa
  - Initial T: 0 °C

Computational domain



Simulation results

Simulation results
Overpressure

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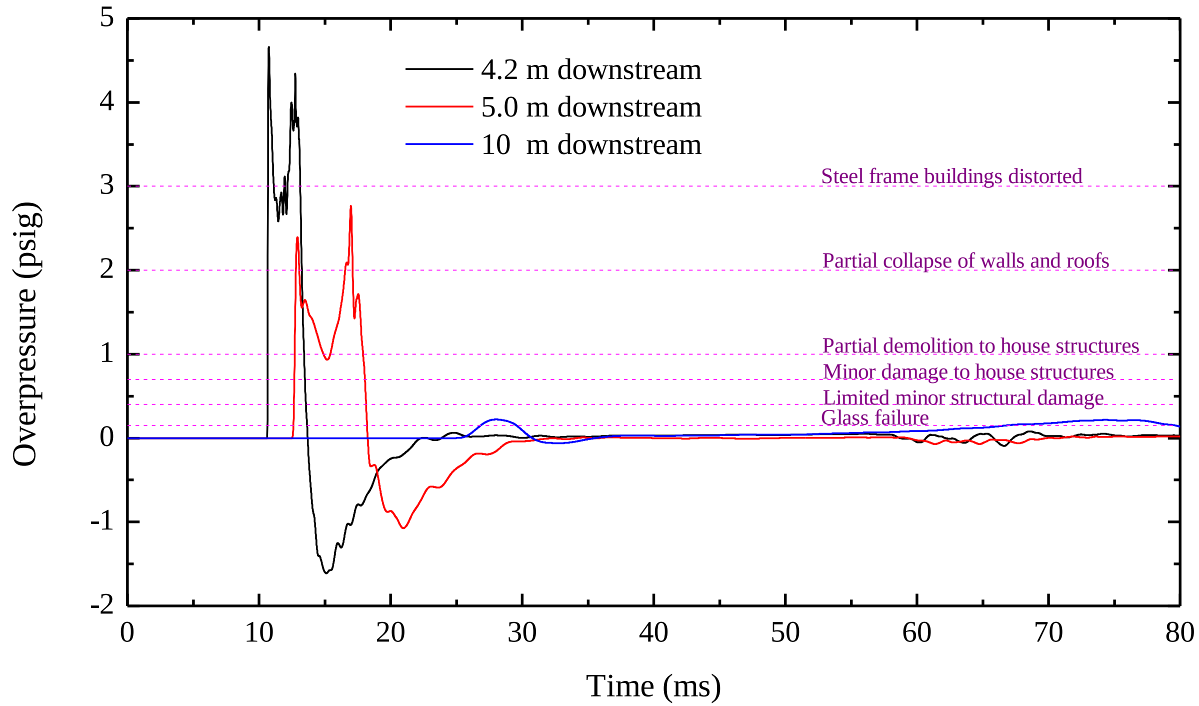
Damage expected at specific overpressure values

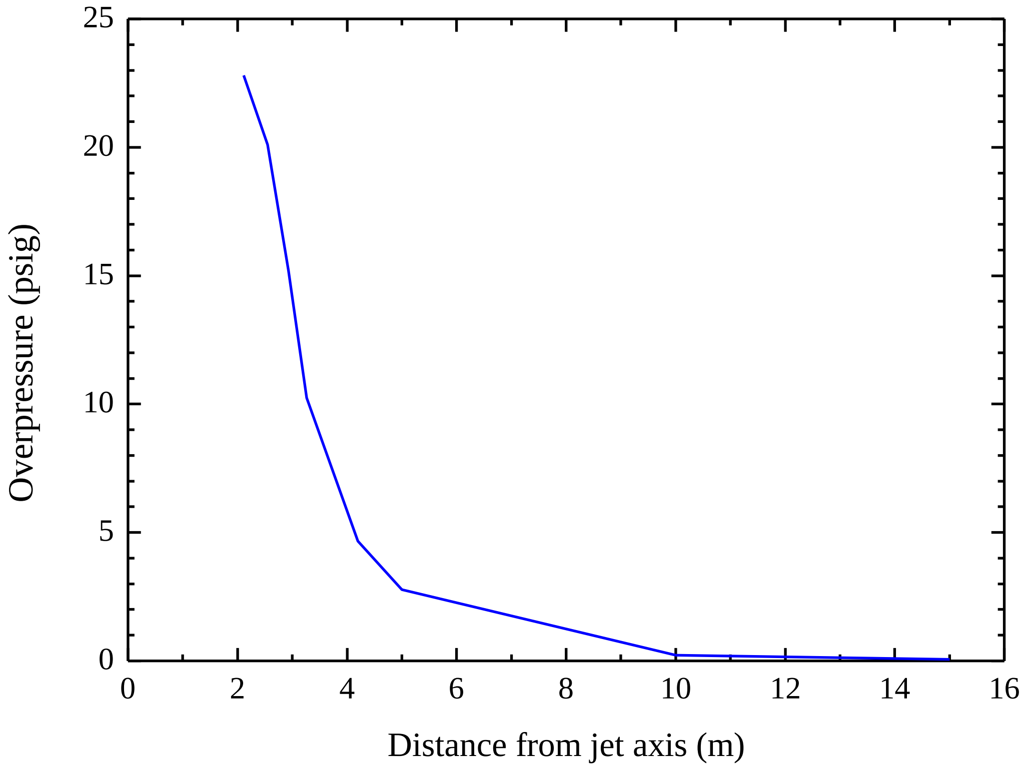
Overpressure (psig)	Expected damage
0.15	Typical pressure for glass failure.
0.40	Limited minor structural damage.
0.70	Minor damage to house structures.
1.0	Partial demolition of houses; made uninhabitable.
2.0	Partial collapse of walls and roofs of houses.
2.0-3.0	Non-reinforced concrete or cinder block walls shattered.
2.4-12.2	Range for 1-90% eardrum rupture among exposed populations.
3.0	Steel frame buildings distorted and pulled away from foundation.
5.0	Wooden utility poles snapped.
5.0-7.0	Nearly complete destruction of houses.
7.0	Loaded train cars overturned.
9.0	Loaded train box cars demolished.
10.0	Probable total building destruction.

Overpressure histories predicted for H_2 at 17 MPa

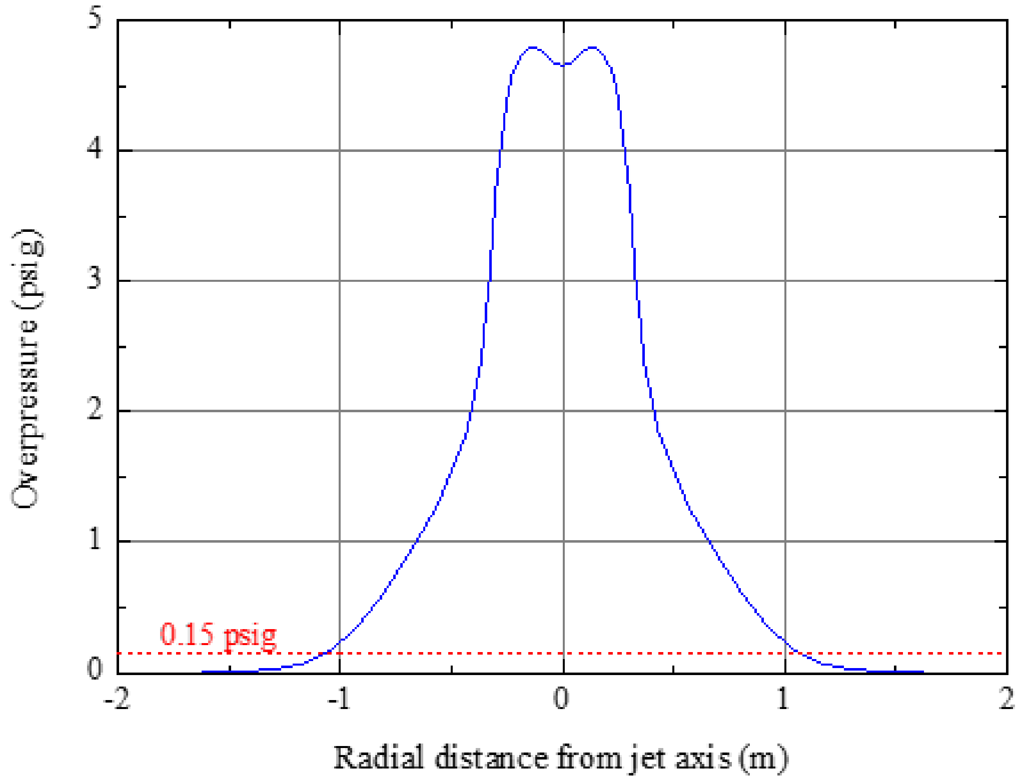


Simulation results:
Overpressure

Decay of maximum overpressure along the axis

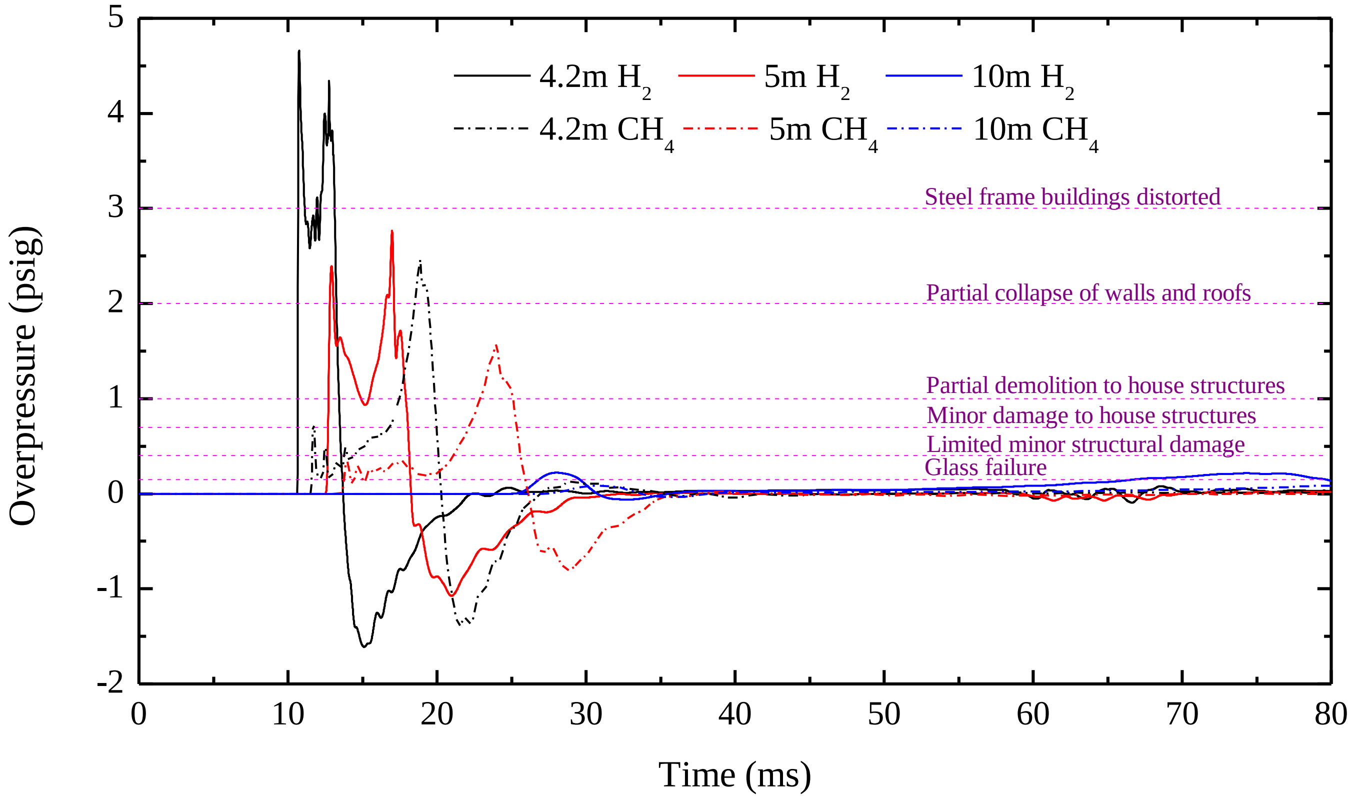


Overpressure profile on the jet cross section at 4.2m (on the building wall at 10.7 ms)



Simulation results: Overpressure

Overpressure histories: H_2 vs CH_4



Comparison between H_2 and CH_4 releases at 17 MPa:

- Shock wave produced by CH_4 travels slower than that produced by H_2
- CH_4 shock wave features initially a small peak
- Pressure wave produced by CH_4 is weaker than that produced by H_2
- Overpressures produced by CH_4 are half those produced by H_2

Simulation results: Overpressure

Quantification of the blast energy using scaled distance concept:

- Equivalent blast energy of H_2 is five times that of CH_4
- The ratio of the equivalent blast energy to the product *u·P* (or A.u.P) is constant
- Equivalent blast energy scaled with the product of *u·P* (or A.u.P) can be used to estimate the relative values of the levels of overpressure for future tests involving various blends of NG+H_2

Calculation of equivalent blast energies

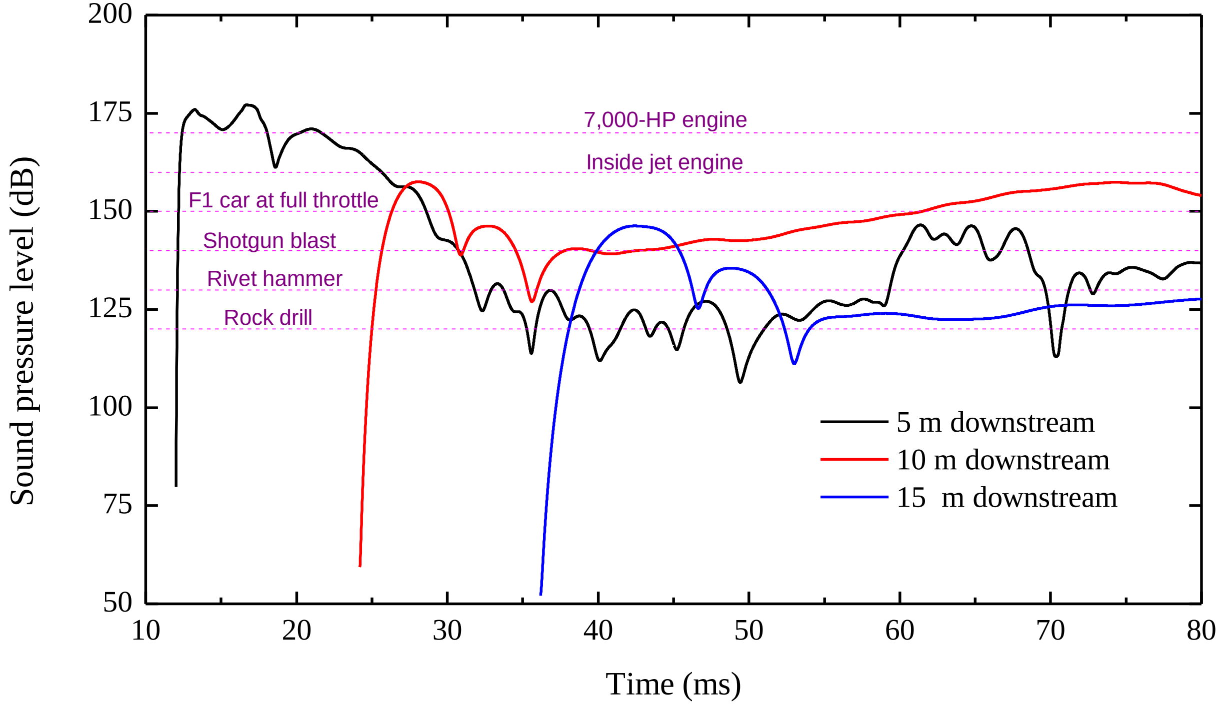
Distance (m)	4.2		5.0	
	H2	**NG**	**H2**	**NG**
Overpressure (psi)	4.7	2.46	2.8	1.58
Ambient Pressure (psi-a)	13.2	13.2	13.2	13.2
Normalized Overpressure	0.356	0.186	0.212	0.120
Scaled Distance*	5.3	8.6	6.3	10.2
Equivalent Blast Energy, TNT (kg)	0.498	0.116	0.500	0.118
Exit Velocity, u (m/s)	1083	228	1083	228
Exit Pressure, P (MPa-a)	4.199	4.647	4.199	4.647
Ratio of TNT/(u*P) x 1000	0.109	0.110	0.110	0.111

Simulation results:
Noise level

Noise levels with common noise sources and exposure time

Noise level (dB)	Sound source	Exposure time
85	Front-end loader	8 hr
100	Sheet-metal workshop	15 min
120	Rock drill	8.8 s
130	Rivet hammer (pain can be felt)	0.9 s
140	Shotgun blast directly beside ear	0.09 s
150	Formula One car at full throttle	N/A
160	Inside jet engine	N/A
170	7,000-HP engine	N/A
180	1 pound of TNT detonating 4.5 m away (15 ft)	N/A

Sound pressure level histories predicted for H_2



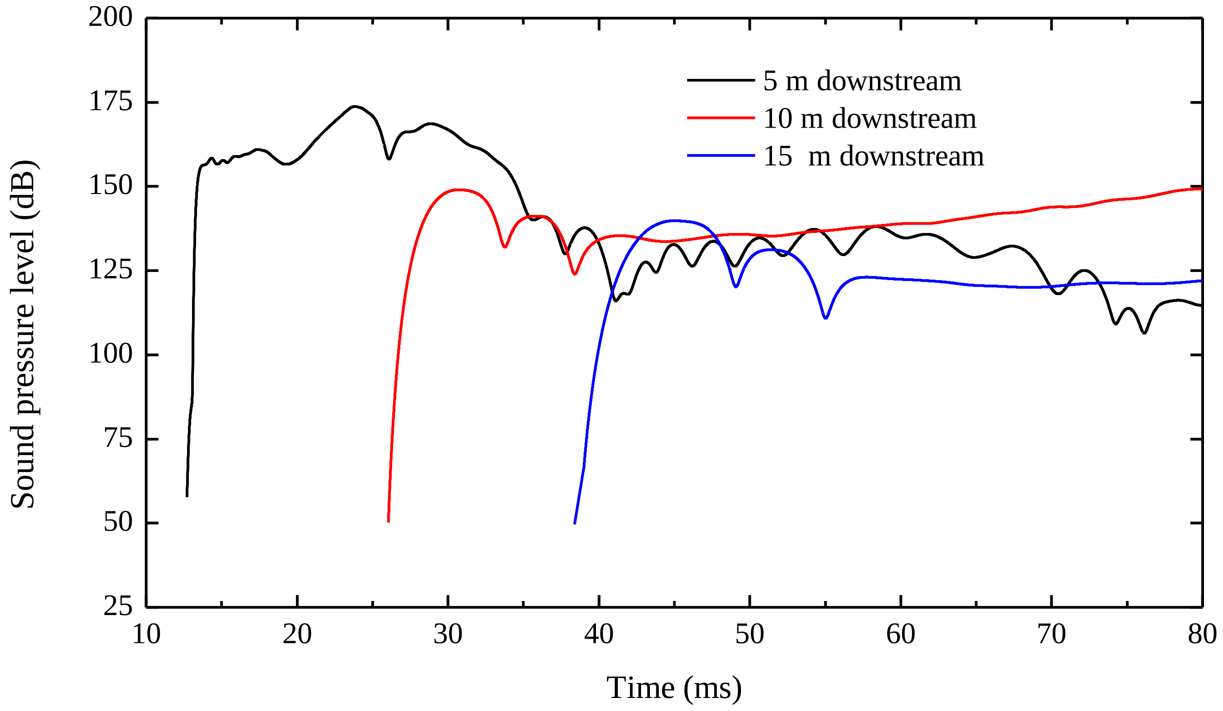
Simulation results:
Noise level

Noise levels* produced by CH_4 expansion:

- Evolution of noise level with time is similar to that of the H_2 expansion
- The maximum noise level from the expansion of H_2 is higher by 3 to 17 dB relative to CH_4
- During the H_2 release compared to CH_4, there would be a perceived 25% increase in loudness at 5 m distance and about 50% increase in loudness at 10 and 15 m

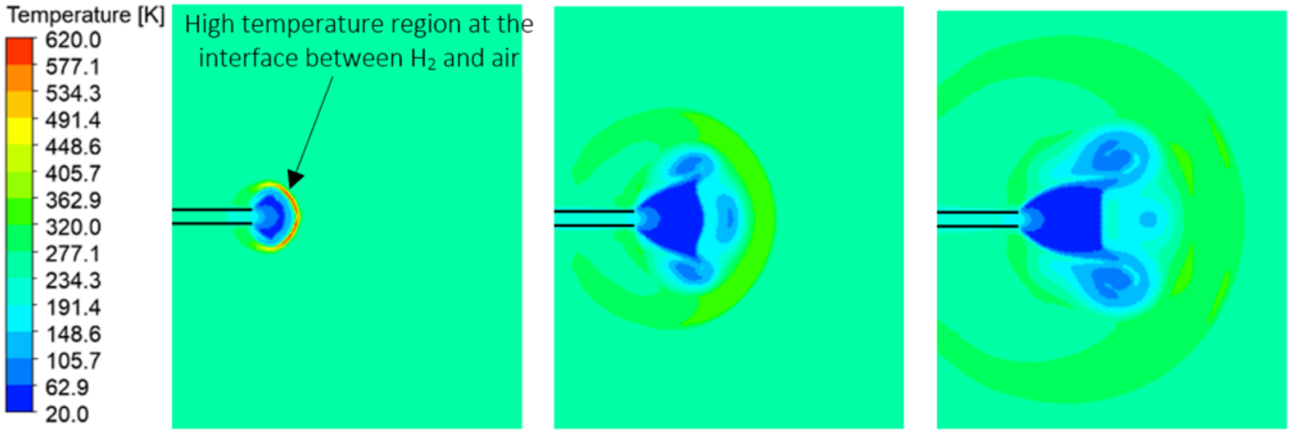
** An increase of 3 dB in sound pressure level yields an increase in loudness of about 25%.*

Sound pressure level histories predicted for CH_4



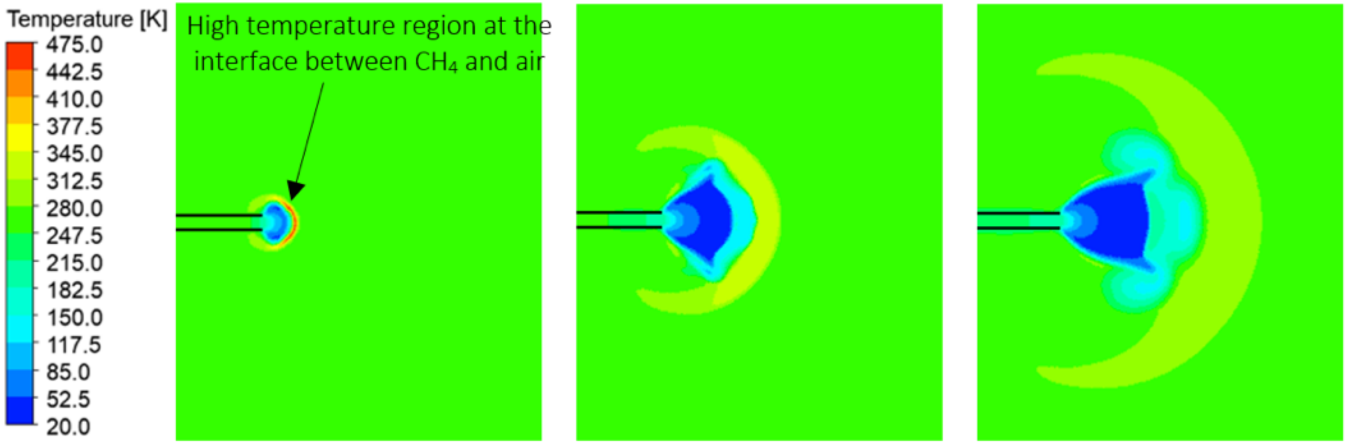
Simulation results:
Downstream temperature

Temperature contours near the jet exit: H_2



a. 0.1 ms b. 0.5 ms c. 1 ms

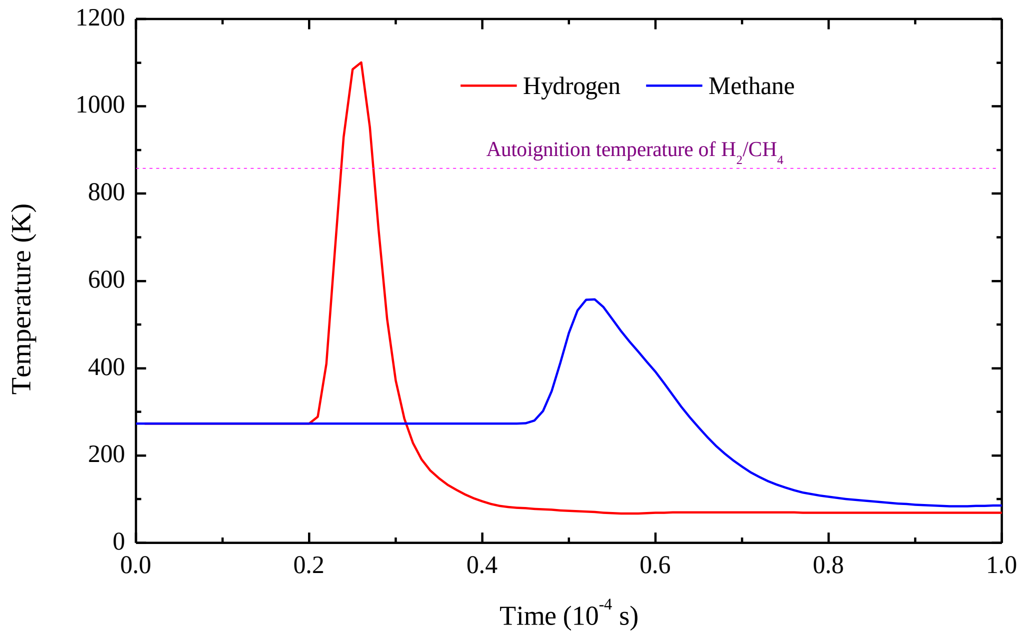
Temperature contours near the jet exit: CH_4



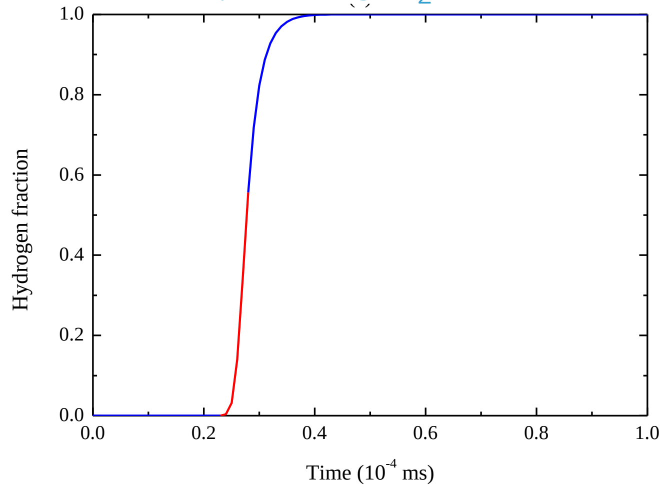
a. 0.1 ms b. 0.5 ms c. 1 ms

Simulation results:
Downstream temperature

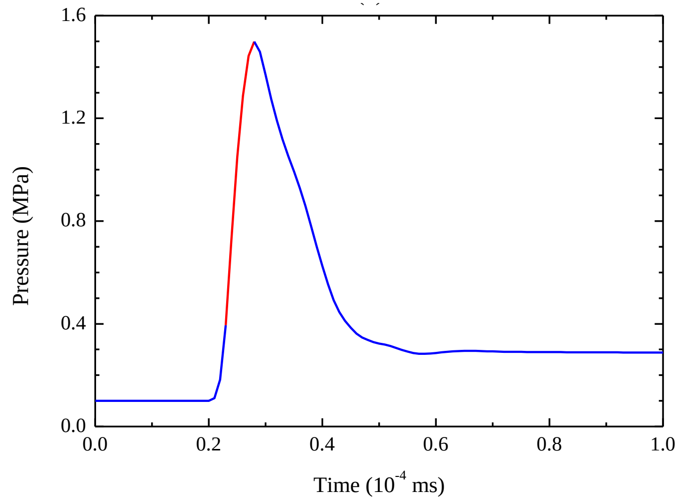
Temperature evolution before 0.1 ms at where the highest temperature occurs



Corresponding H_2 fraction



Corresponding pressure

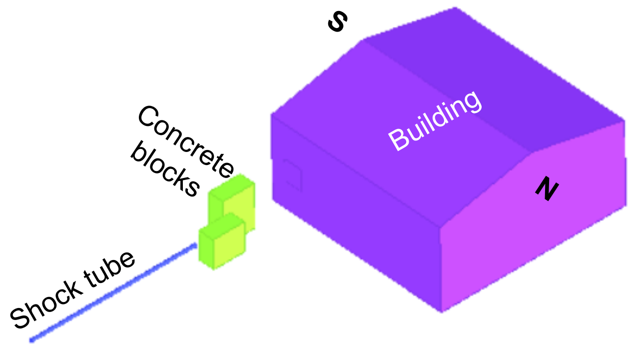


Risk mitigation

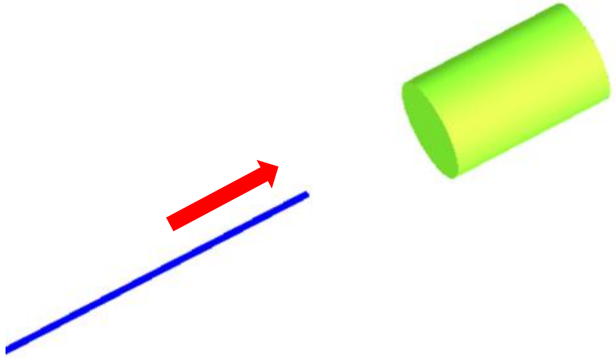
Risk mitigation

New cases simulated

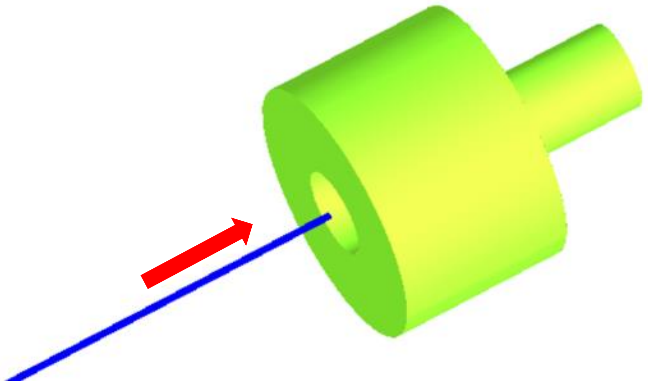
Main components at the test site



Case 1



Case 2



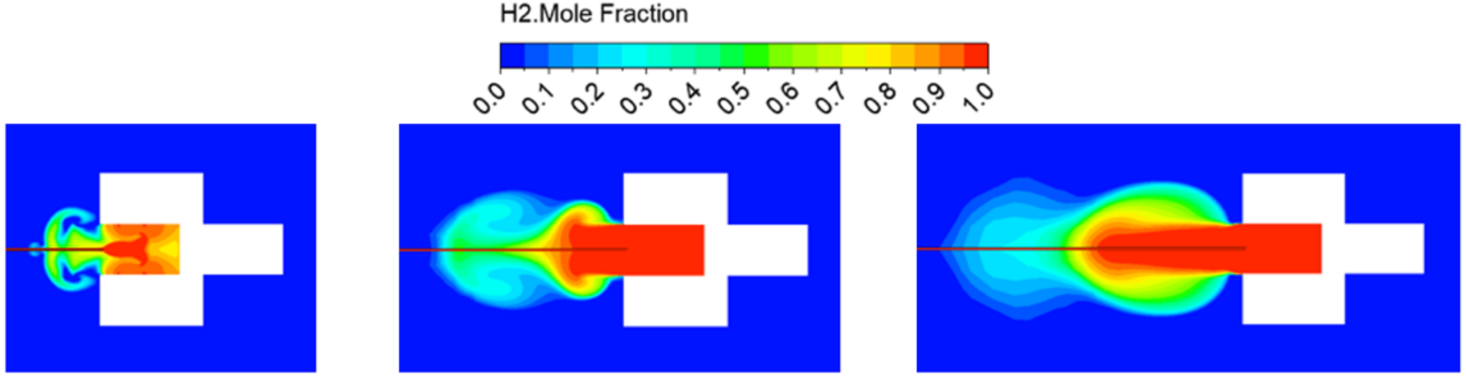
Two cases simulated to evaluate the effect of concrete blocks for risk mitigation purpose:

- Case 1 to account for the effect of shock wave bypassing the concrete block on the south side
- Case 2 impedes the jet flow in all lateral directions

Risk mitigation: Combustion

- Concrete blocks are not able to prevent the development of the initial high temperature crown.
- Objects present in the H_2 stream can promote the chance of ignition.
- Prior work found that the overpressures due to a NG pipeline rupture are about twice those produced by the combustion of the gas.
  - Assuming ignition of H_2-O_2 produced an equivalent overpressure half that of the H_2 release, then temperature and overpressures associated to combustion may need to be considered in more details in the future.

H_2 concentration contours predicted in Case 2



(a) 10 ms (b) 30 ms (c) 60 ms

Conclusions

Conclusions

- A shock tube test with pure H_2 was conducted at TCE Gas Dynamics Facility in Didsbury, Alberta, Canada.
  - Decompression wave speed successfully measured.
  - Good agreement between model and experiment observed.
- CFD models to better understand risks from overpressure wave, noise levels and ignition associated with H_2 decompression and expansion.
- Overpressure strength generated by H_2 release twice that of a CH_4 release.
- H_2 equivalent blast energy, expressed in kg of TNT, is about 5 times that of CH_4.
  - Without mitigations, damage may be caused to nearby building with both H_2 and CH_4 releases; the damage due to a H_2 release will be more severe.

Conclusions

- A decompression tube test with H_2 is about 6 dB higher than a CH_4 release, subjectively this is about 50% louder.

- High temperatures above the auto-ignition temperature are generated in a H_2 release.
  - It is highly possible that auto-ignition would take place within the first instants of the release.

- As done with previous releases, risk mitigation is to place concrete blocks between the shock tube exit and the downstream facilities
  - The jet flow propagation should be impeded over a wider surface area, in both the downstream and lateral directions.

- **Dedicated 3D simulations are being conducted**
  - Purpose is to draw correlations between location downstream of different block configurations and test conditions (mixture, operating (P,T).

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  The shock tube facility is part of a high-pressure natural gas test facility located in Didsbury, Alberta, Canada and is owned by TC Energy. Permission to use the shock tube and associated auxiliary system, unique instrumentation features and accurate data acquisition and processing schemes are greatly appreciated.

Thank you