WHEN TRUST MATTERS

Explosions In Weak Structures

UKELG 63rd Discussion Meeting, HSE Buxton

23 October 2023

Motivation

Motivation

- Net Zero by 2050
- Policy decisions needed now if Gas Industry is to decarbonise
- Policy requires known (or best known) safety position

HOME › GENERAL › RECENT EXPLOSIONS SHUTDOWN HYDROGEN VEHICLE REFUELING IN NORCAL AND NORWAY

Recent explosions shutdown hydrogen vehicle refueling in NorCal and Norway

BY JEFF NISEWANGER on JUNE 11, 2019 · (1)

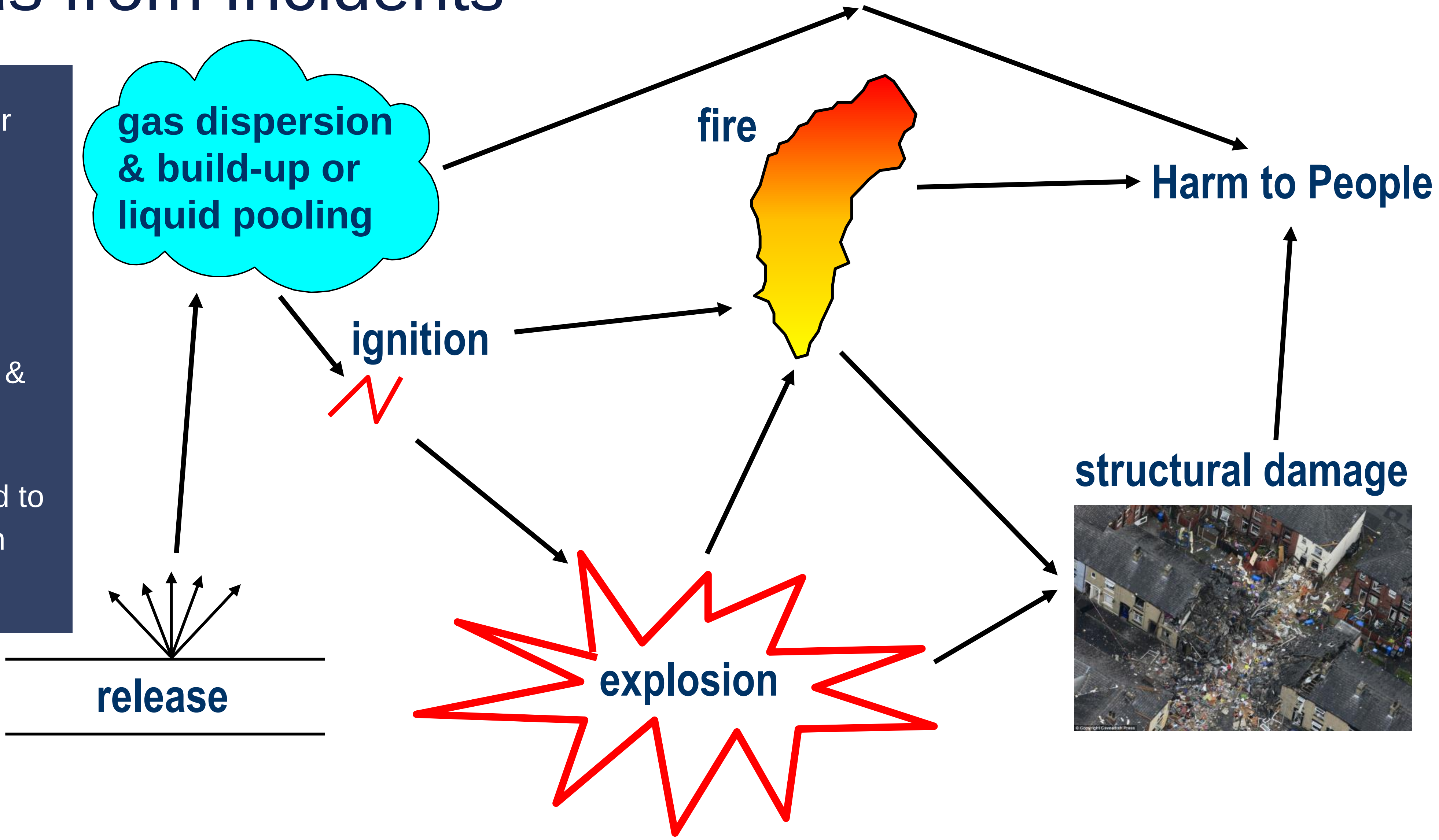
- No showstopping reasons from QRA style studies so far
- QRA doesn't take into account Public Perception
- All conclusions to date have been reached with no significant explosion research
- 40+ years of operating natural gas networks provides great statistical backup where research doesn't exist.
  - **Not the case for hydrogen network operation**

Hazards from Incidents

Design to prevent or break the chain of events

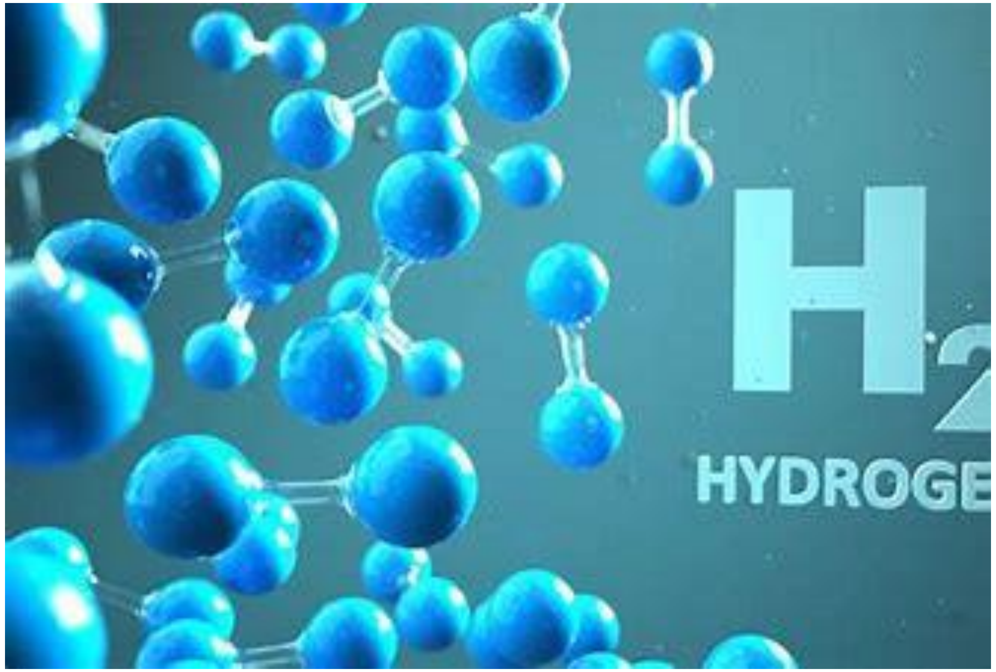
Techniques are nothing new – standard for any oil & gas project

Understanding used to predict → Research



Basic Hydrogen and Methane Properties

	Hydrogen	Methane	Unit
Density*	0.09	0.72	kg/m^3
Lower Heating Value	120	50	MJ/kg
	10.8*	36*	MJ/m^3
LFL$^+$	4	5	% (v/v)
UFL$^+$	75	15	% (v/v)
Min Ign Energy	0.02	0.30	mJ



To deliver the same energy flow through a pipe at the same pressure, hydrogen flow speeds need to be over 3 times that of methane

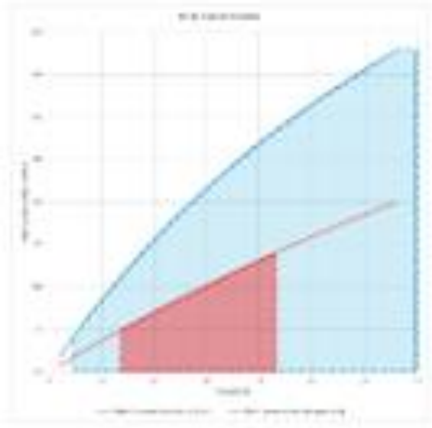
** @ STP, 0 deg C, 1 atm*

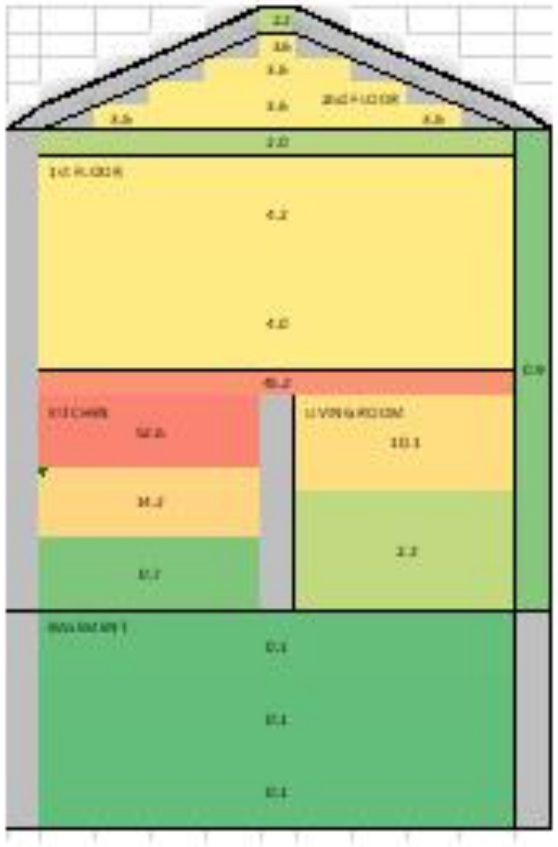
+ - Lower and Upper Flammable Limits

DNV

Pre-Explosion: Leakage, Accumulation and Ignition

- Up to 3 times the volume released from same hole / pressure combination
- Generally leads to higher concentrations – although added buoyancy aids ventilation
- Hy4Heat and H21 both investigated this
- Much higher UFL means that rich mixtures remain flammable with hydrogen where methane would be non-flammable.
- Ignition probability is difficult – lower ignition energy for hydrogen doesn't necessarily translate into more ignitions…



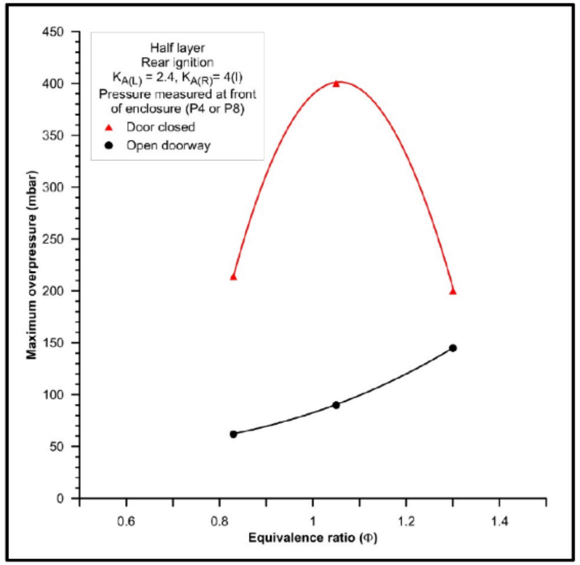


Explosion – factors enhancing explosions

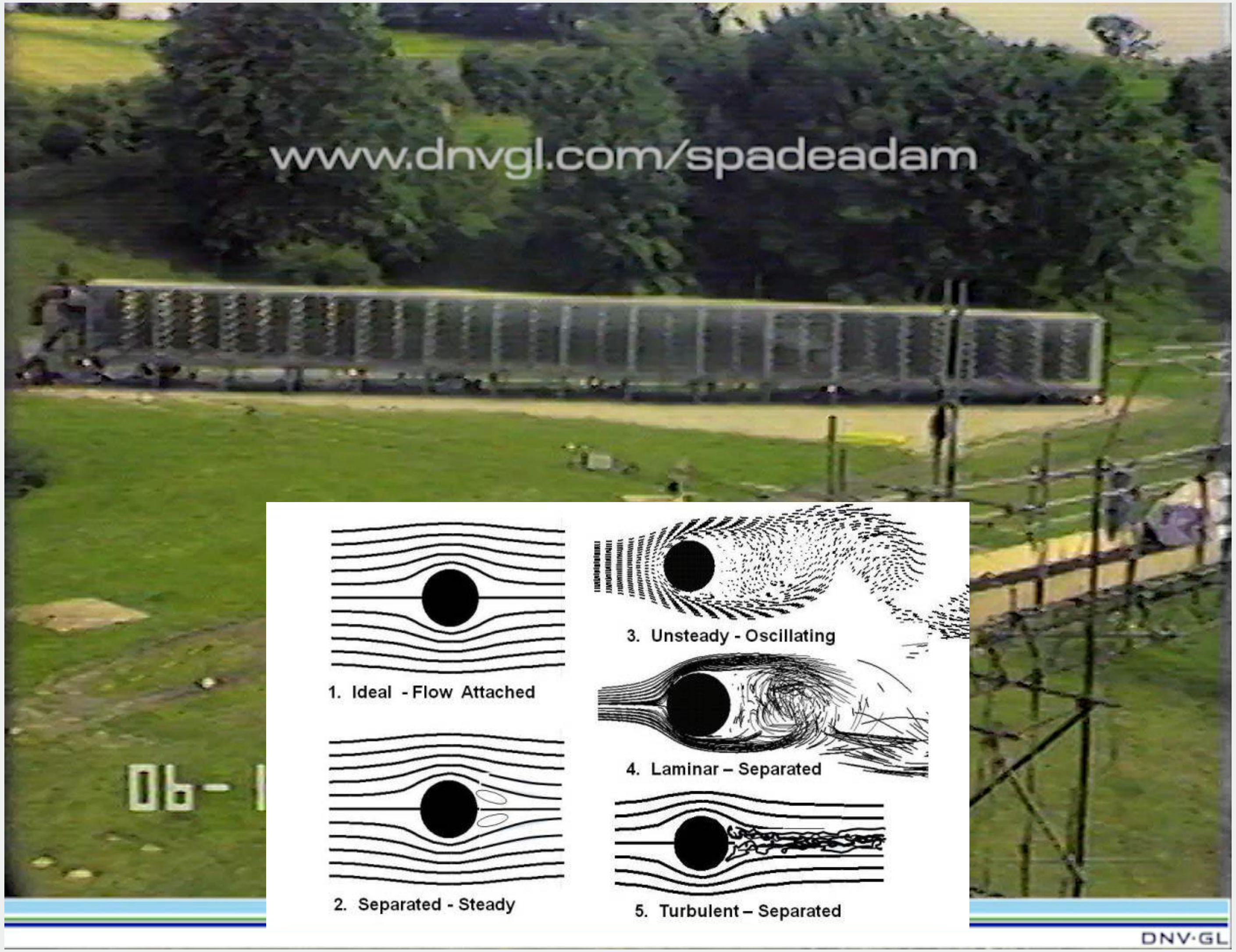
CONFINEMENT

- Hot combustion products want to expand
- Inhibit this with walls and borders → pressure generation
- Peak pressure limited by breakdown of confinement (venting and / or structural collapse)

→ Peak pressure and structure strength are coupled



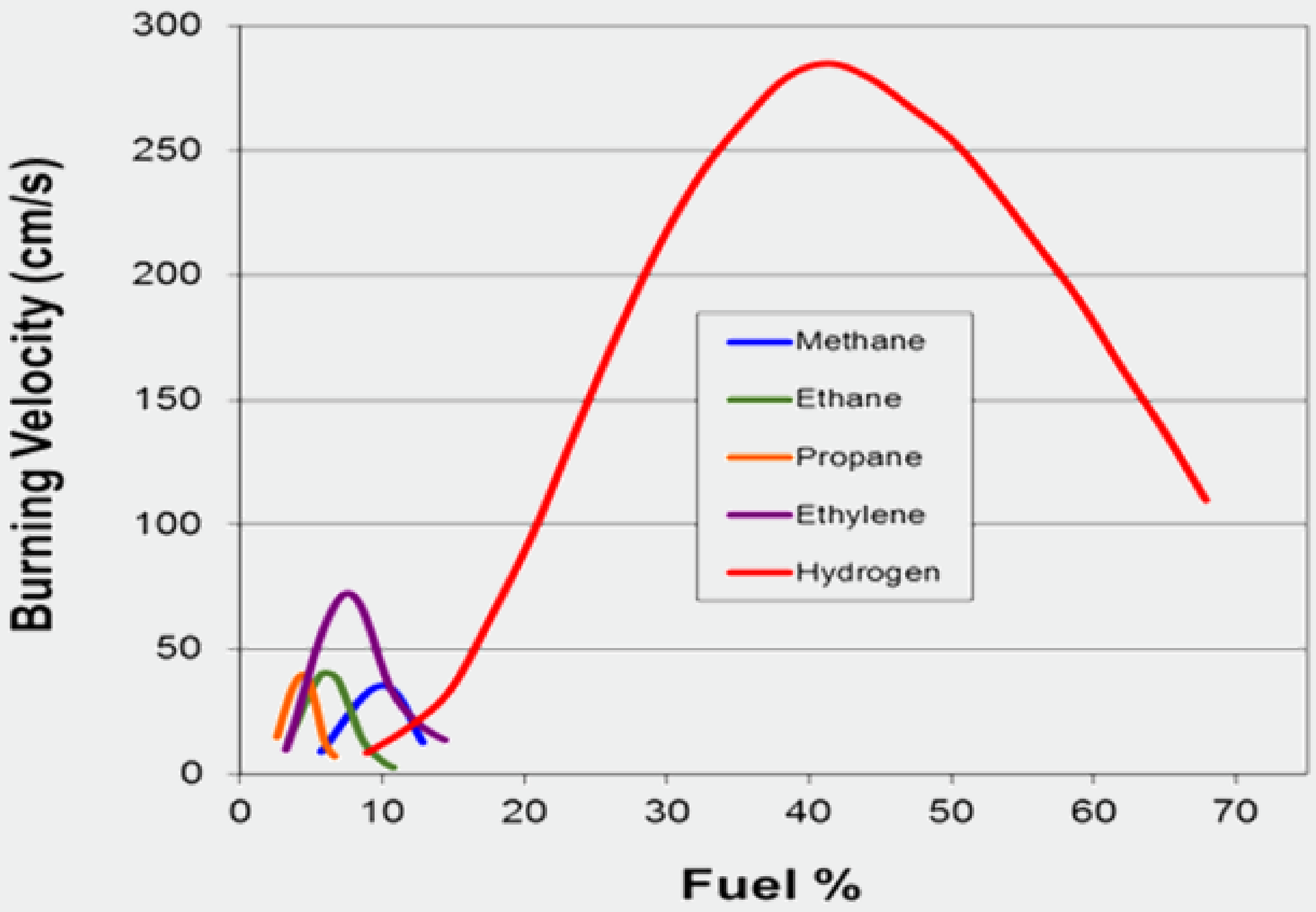
Explosion – factors enhancing explosions



CONGESTION

- Flow ahead of the flame interacts with obstacles
- Generates turbulence
- Increases rate of combustion (increased flame surface)
- Increases flow towards next obstacle

Explosion – factors enhancing explosions



Reactivity

- Varies with fuel : air concentration for all fuels
- Varies between fuels
- Significantly higher for hydrogen compared to even the ‘exciting’ hydrocarbons

Example: Filling Station Research

- Explosions range from benign to extreme for relatively minor changes in ventilation, outflow rate, confinement and congestion

8% H_2

26% H_2

Weak Structures Example: H21 Kiosks

MB = Meter Box

GKS = Governor Kiosk Small

TB = Telecoms Box

GKM = Governor Kiosk Medium

BK = Buried Kiosk

D = Duct

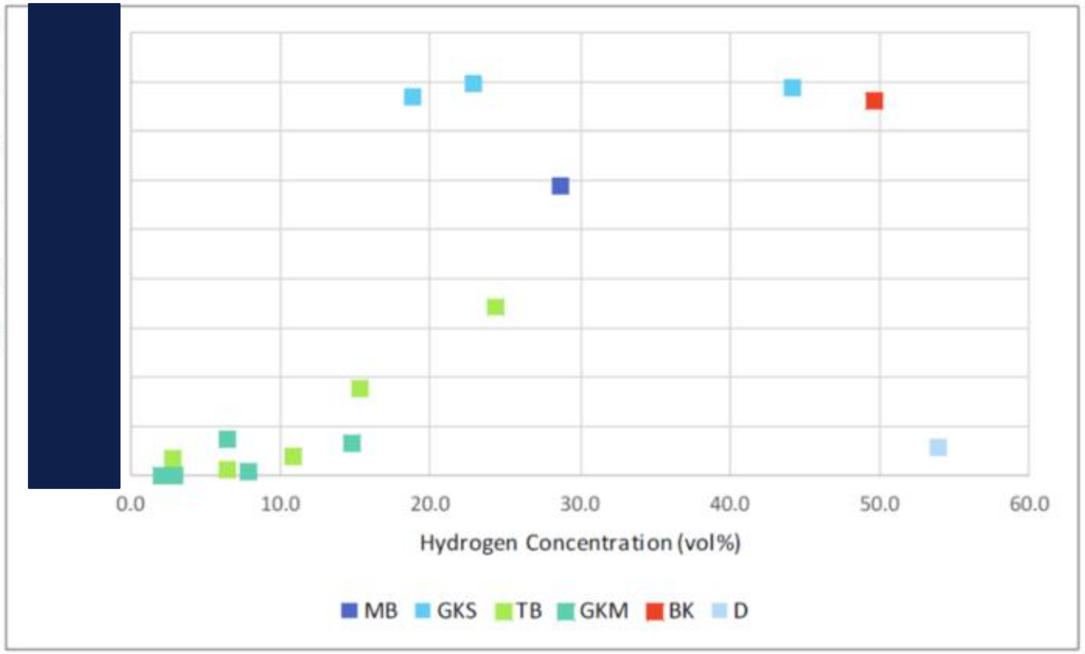
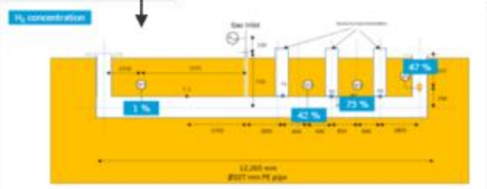


Figure 39: Variation of measured maximum internal overpressure with hydrogen concentration for all experimental enclosures

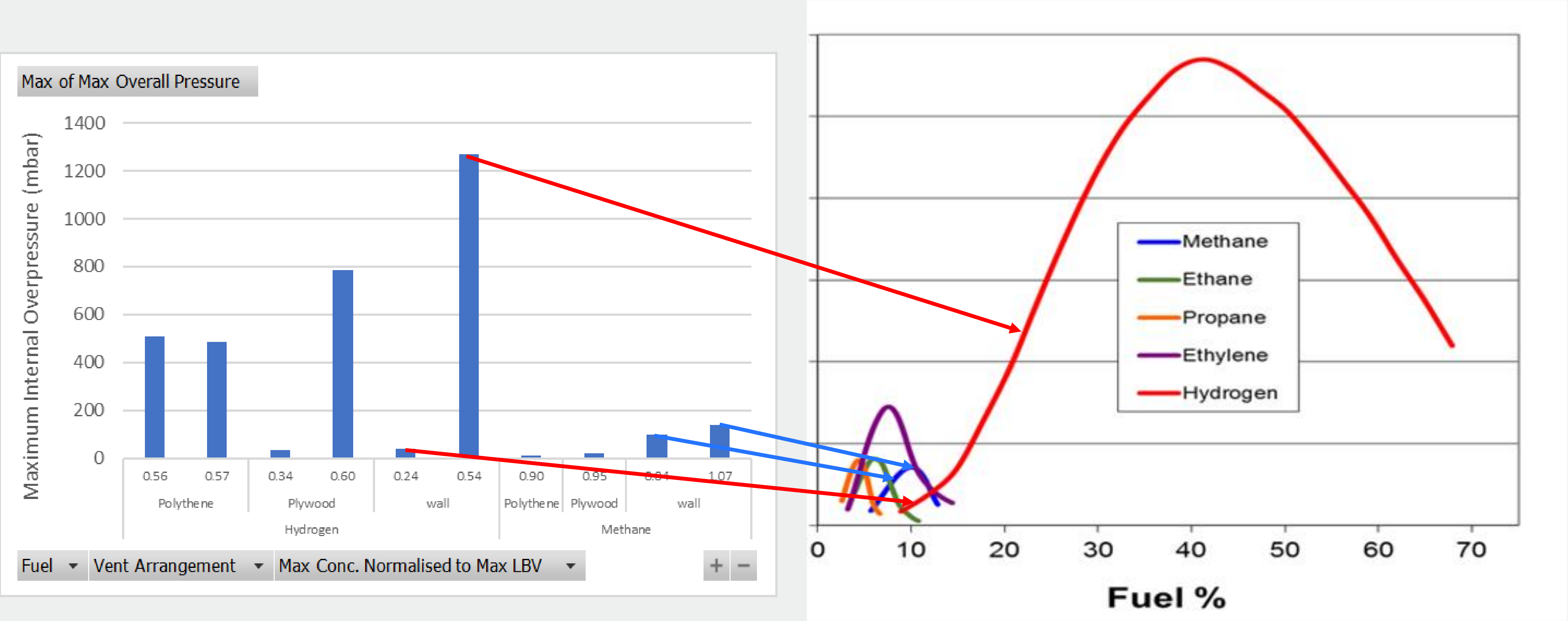


Weak Structures Example: DNV Preliminary Research

Hydrogen (20%vol layer)

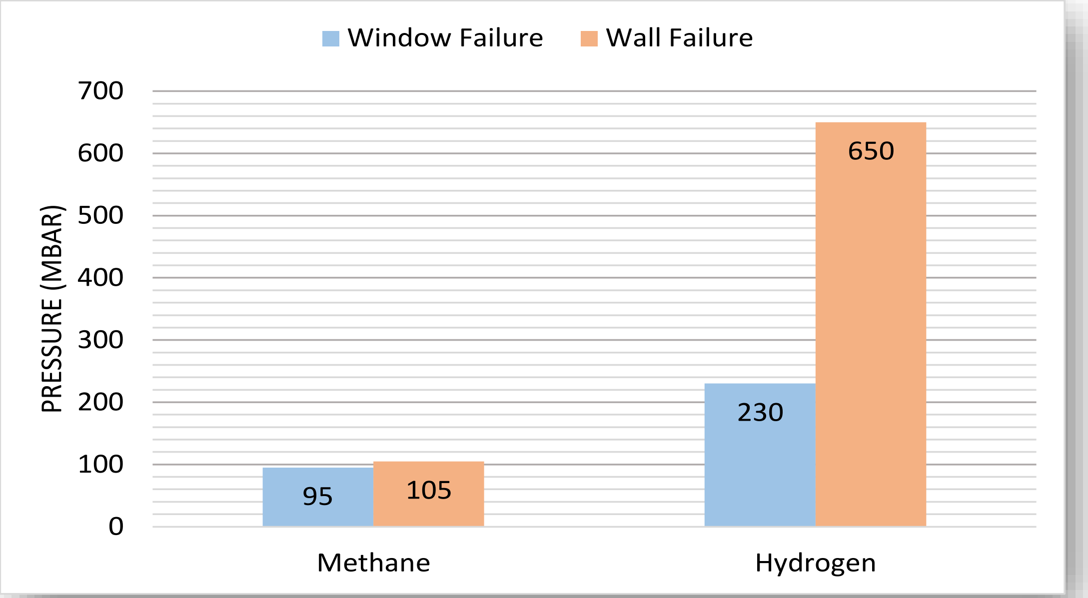
Methane (10%vol layer)

Weak Structures Example: DNV Preliminary Research



Weak Structures Example: DNV Preliminary Research

- Videos aligned to window failure but pressures very different



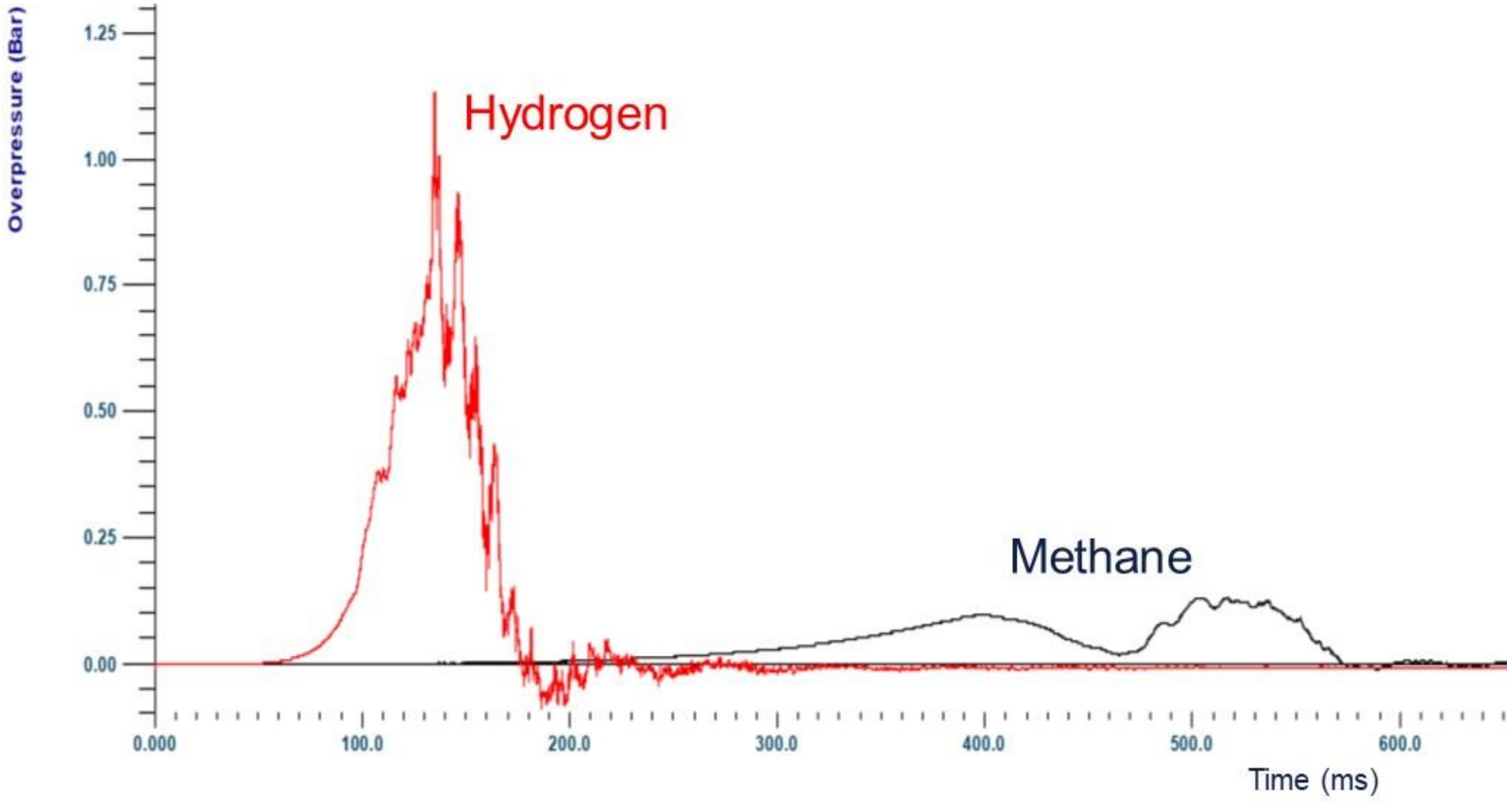
- Pressures in hydrogen experiment far exceeded the minimum required failure pressure of window and wall.
- Why?

DNV

Weak Structures Example: DNV Preliminary Research

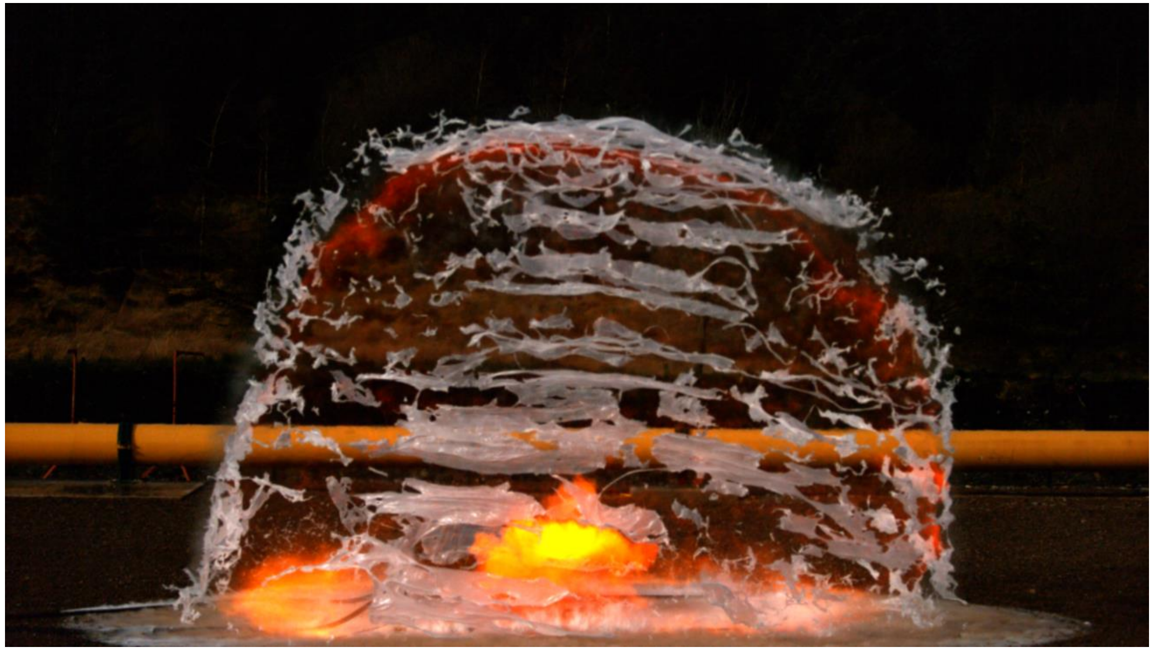
- Peak rate of pressure rise:
  - Hydrogen ~10 mbar/ms
  - Methane ~ 0.5 mbar/ms

- Time taken for structural failure is critical for hydrogen

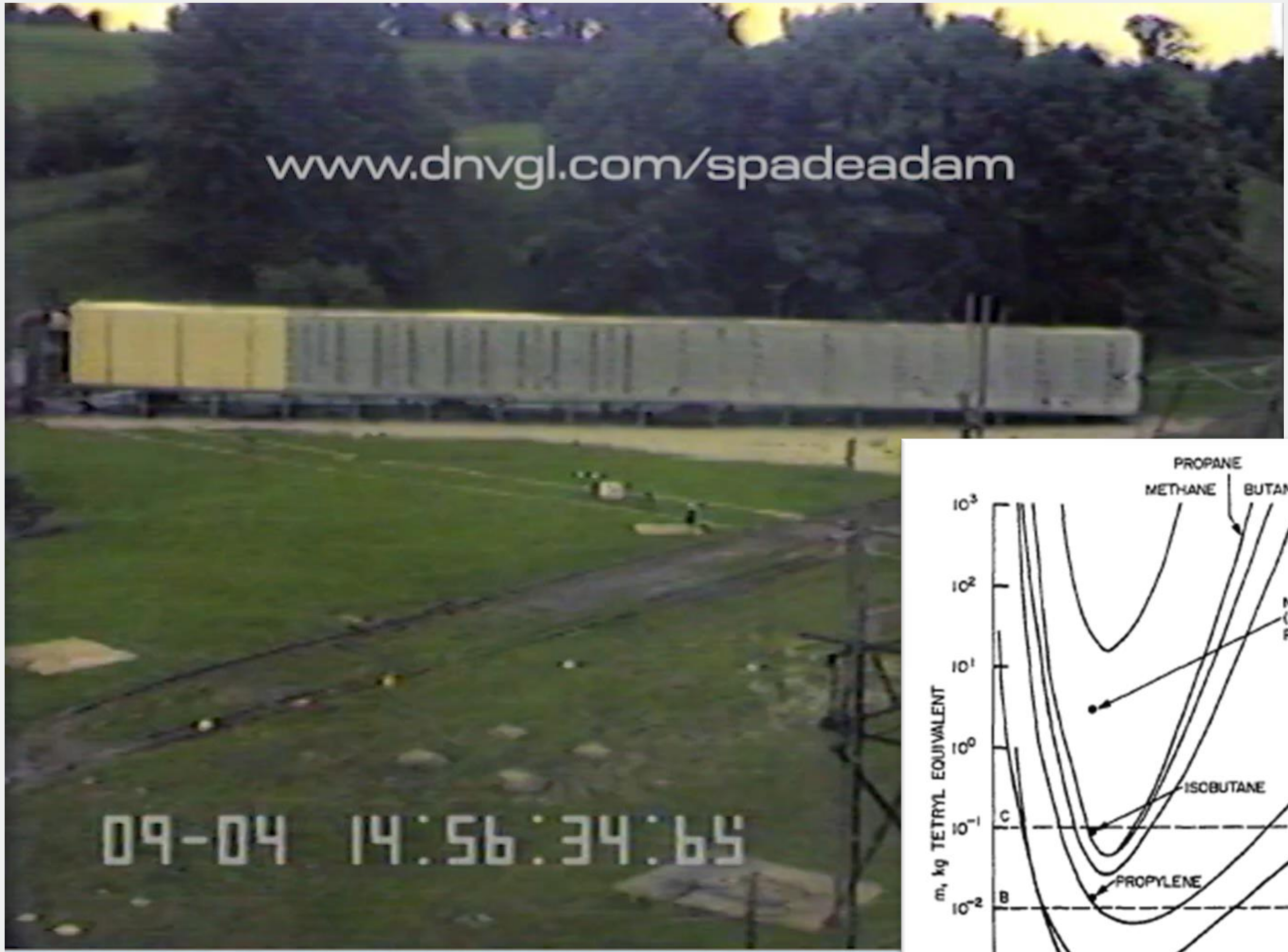


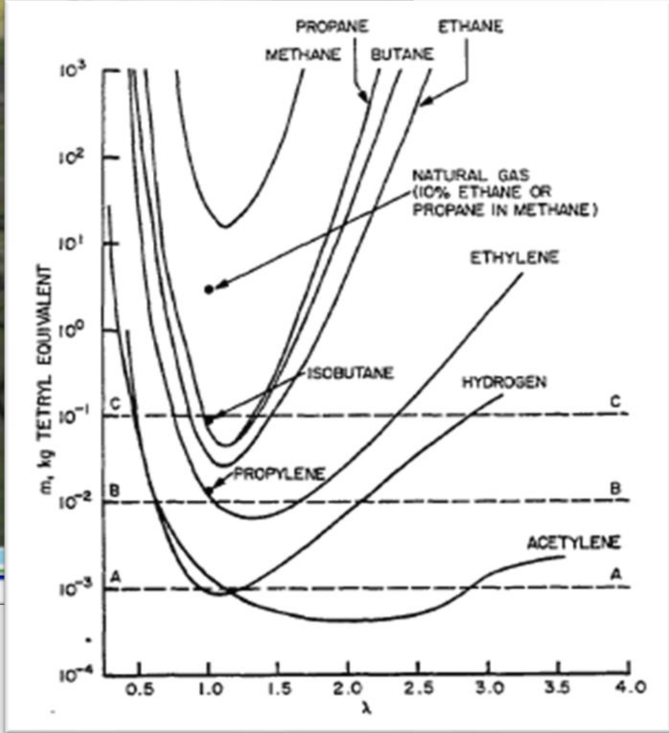
Detonation

- Shock wave of 20 bar compresses fuel mixture to auto-ignition temperature
- Immediate combustion of fuel provides energy to maintain the shock wave
- Self sustaining and will propagate through the flammable mixture at 1800 m/s



Explosion – factors enhancing explosions





Detonability

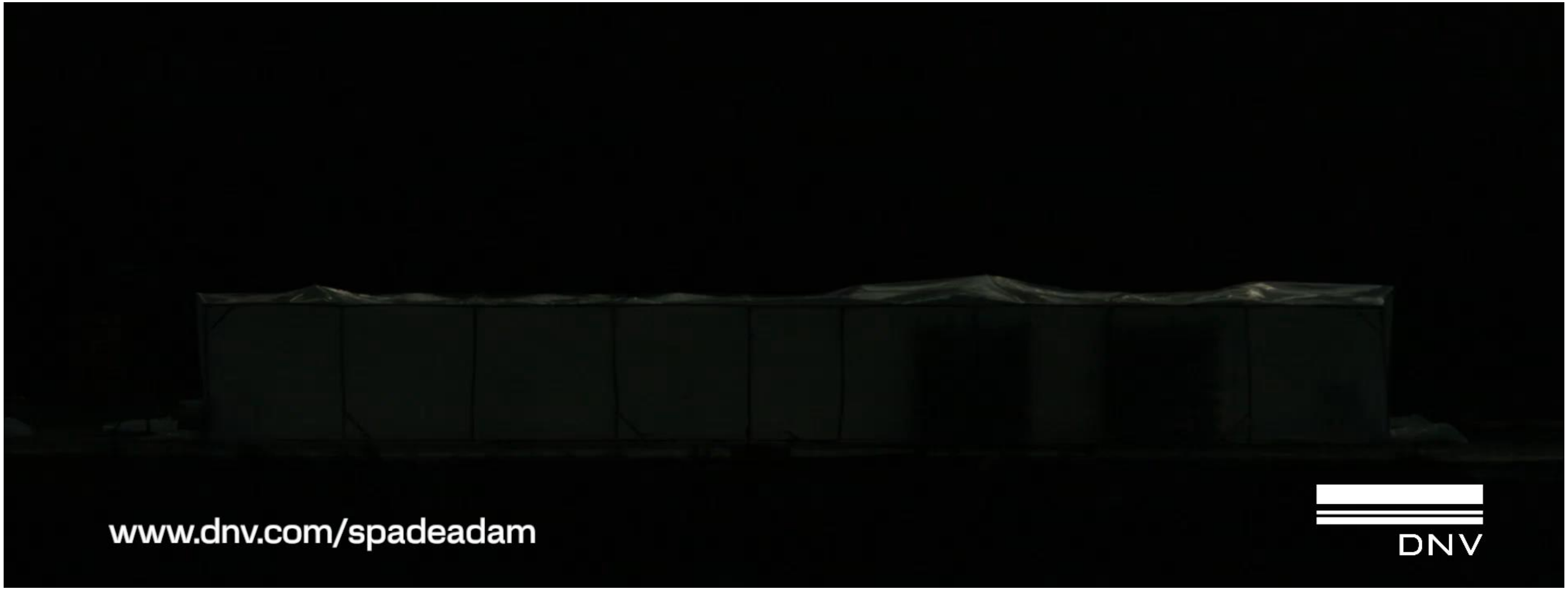
- Varies with fuel : air concentration for all fuels
- Varies between fuels
- Significantly lower initiation energy for hydrogen compared to even most of the ‘exciting’ hydrocarbons

DNV

Deflagration to Detonation Transition

Observed in major industrial explosions on process plant

Experiment involves flame accelerating in two congested pipework regions with DDT at the exit



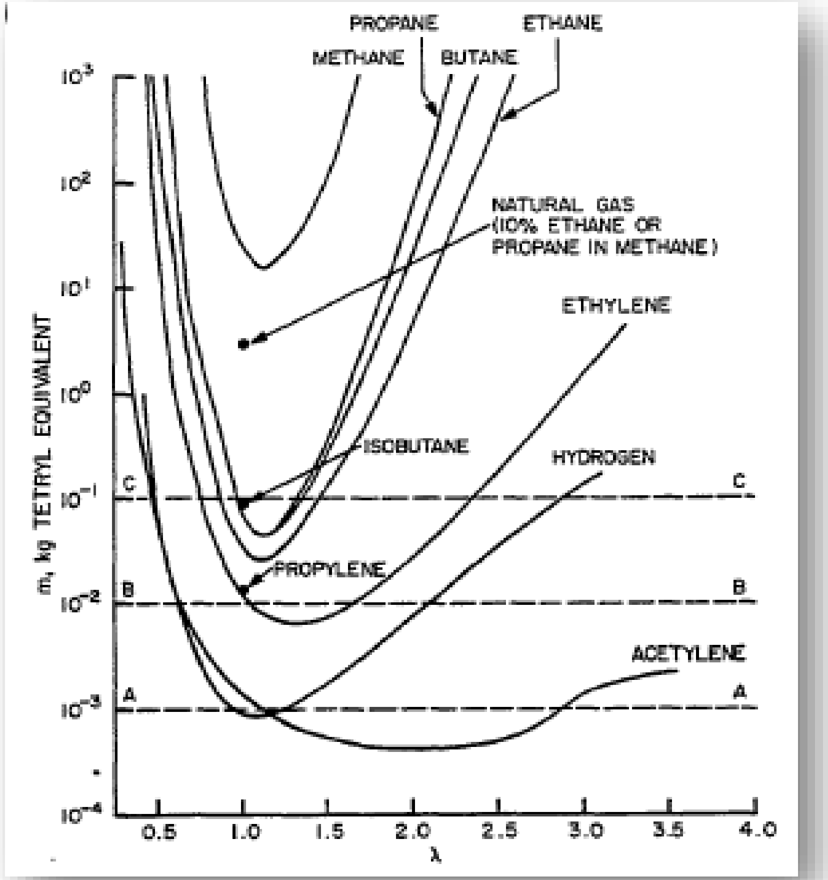
Lattice congestion with wall

Detonability

- Detonability varies with fuel type and fuel concentration
- Initiation of detonation quantified by explosive mass required to initiate a detonation

Fuel	Minimum Mass tetryl (g)
Hydrogen	**0.8**
Methane	16,000
Propane	37
Ethylene	5.2
Acetylene	0.4

- Natural Gas detonations ~*NEVER* happen
- Hydrogen detonations are entirely credible – but at what scale?



Concentration limits to the initiation of unconfined detonation in fuel/air mixtures, DC Bull, Transactions of the Institute of Chemical Engineers, Volume 57, Number 4, Pages 219-2271979 (λ indicates the concentration relative to stoichiometric)

H2 DDT in Small Scale Unconfined Explosions

Acceleration of Unconfined Flames in Congested Areas

J. Grune[1], A. Veser[1], G. Stern[1], W. Breitung[2], S. Dorofeev[2]
[1] ProScience GmbH, Parkstr. 9, 76275 Ettlingen, Germany
[2] Forschungszentrum Karlsruhe, P.O. Box 3640, 76021 Karlsruhe, Germany
email: dorofeev@iket.fzk.de

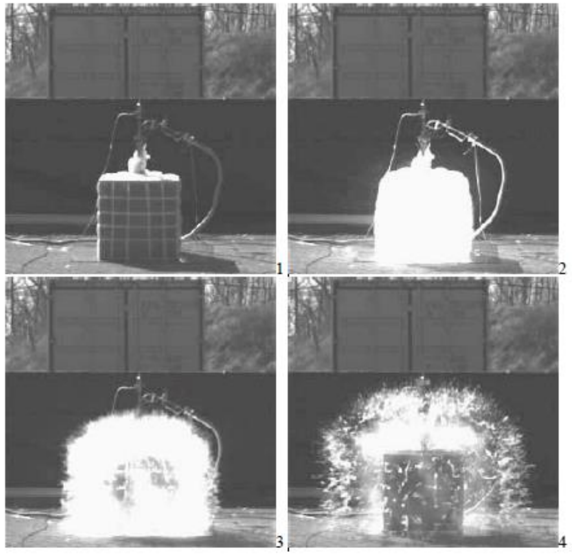


Figure 47. Images from high speed video showing initial setup (upper left frame); the moment of highest luminosity characteristic of onset of detonation (upper right frame); and flying fine strips of plastic bag (lower).

In the case of the finest grid with 48 layers the flame speed inside the cube reached the value of about 700 m/s as recorded by photodiodes. It is remarkable that the flame was able to accelerate from the laminar speed to 700 m/s after propagating just about 0.2 m. Moreover, flame evolution in this particular test resulted in the transition to detonation. Transition to detonation occurred outside the initial volume of the cube. During the subsonic stage

Figure 1: Assembly of the cube. System of grids 40 x 4 mm with 4 layers (left) and 12 layers (right)

Consequences are what matter

- Wide variation in consequences
- Worst case for hydrogen might not be *much* worse but is it more likely?
- DDT could show different picture

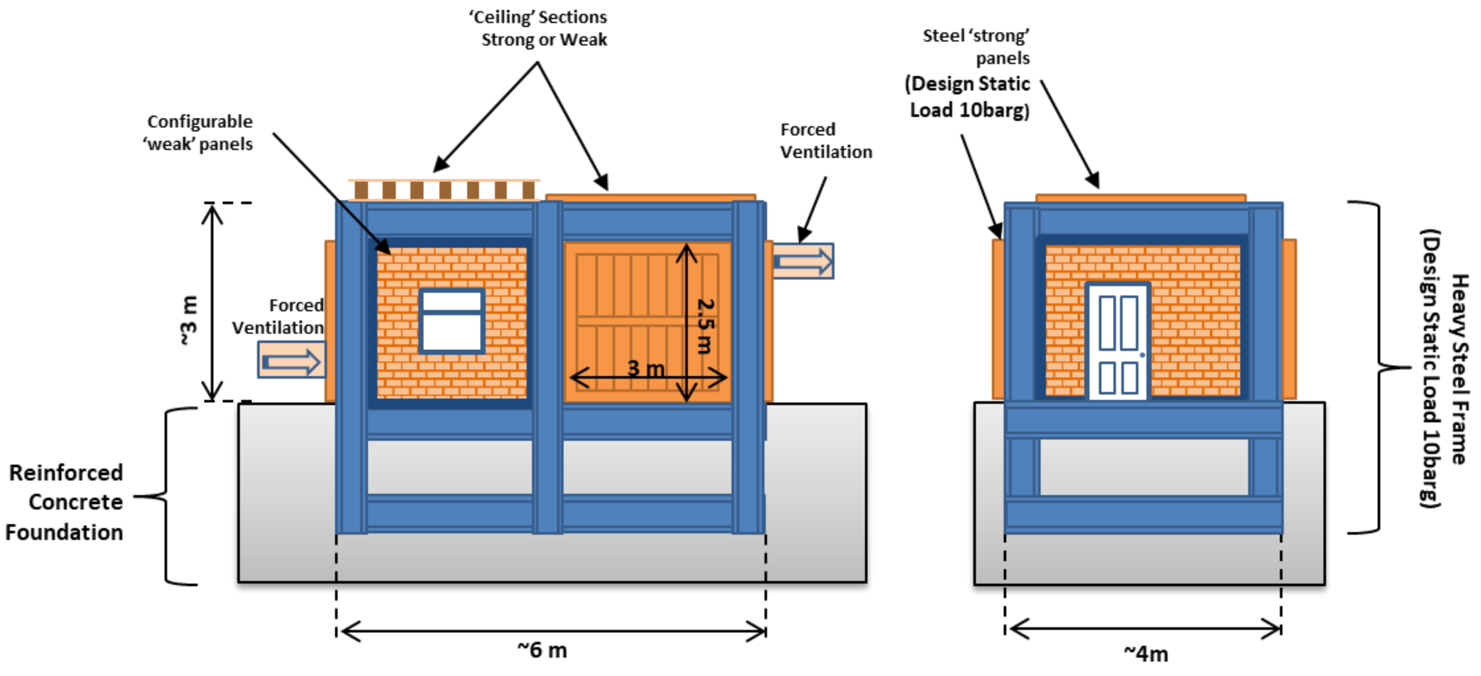
NIA 344 – Ignition Consequences

Scope Overview – Test Rig

- The explosion test facility will be constructed with a minimum of two ‘rooms’ capable of withstanding significant pressures (design will be for 10 barg static pressure loading).

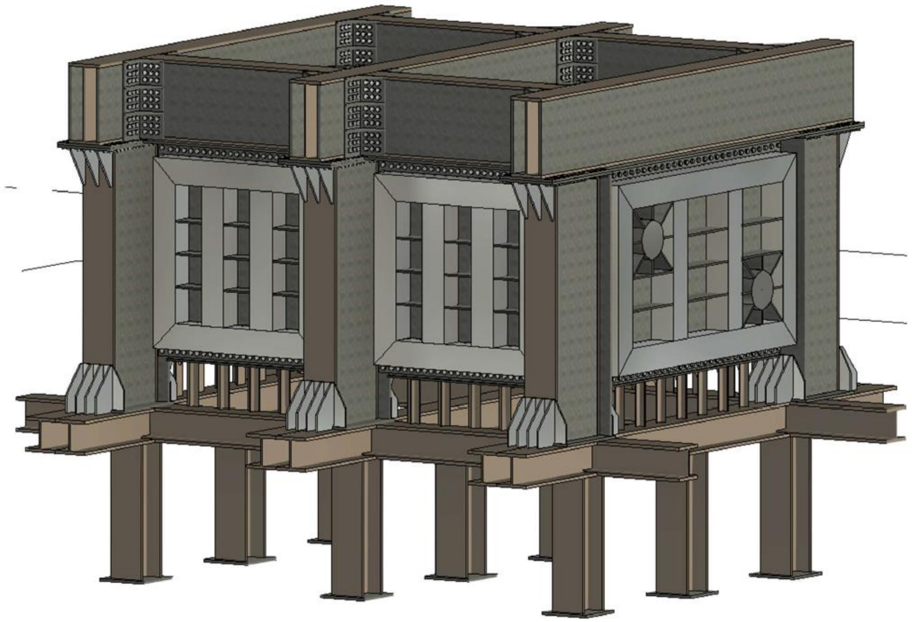
- The facility is proposed to be able to be configured to represent ground floor, upstairs or basement of a domestic property with a single frame which can be repeatedly used to best preserve budget for experimentation.

- A design pressure of 10 barg static loading is chosen in order to best match resistance to the potential detonation events (higher pressures possible but of very short duration).



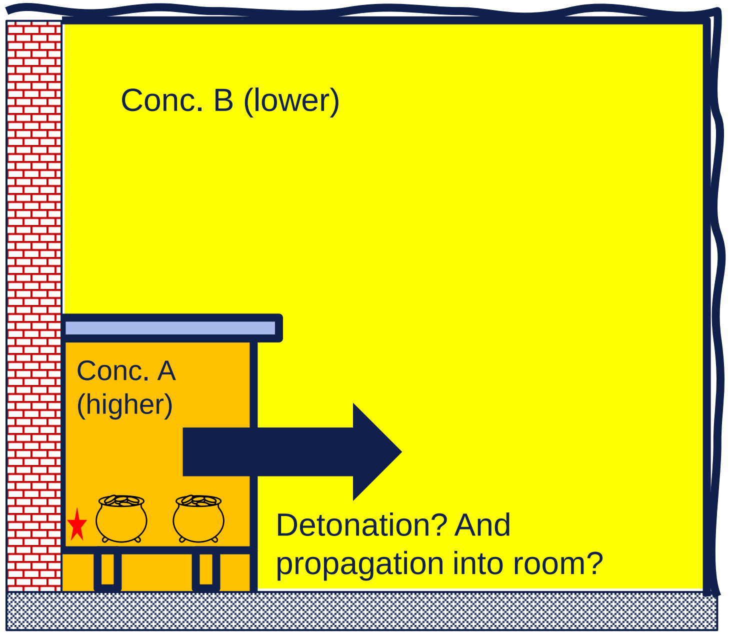
Side Elevation (example configuration)

Front Elevation (different example configuration)



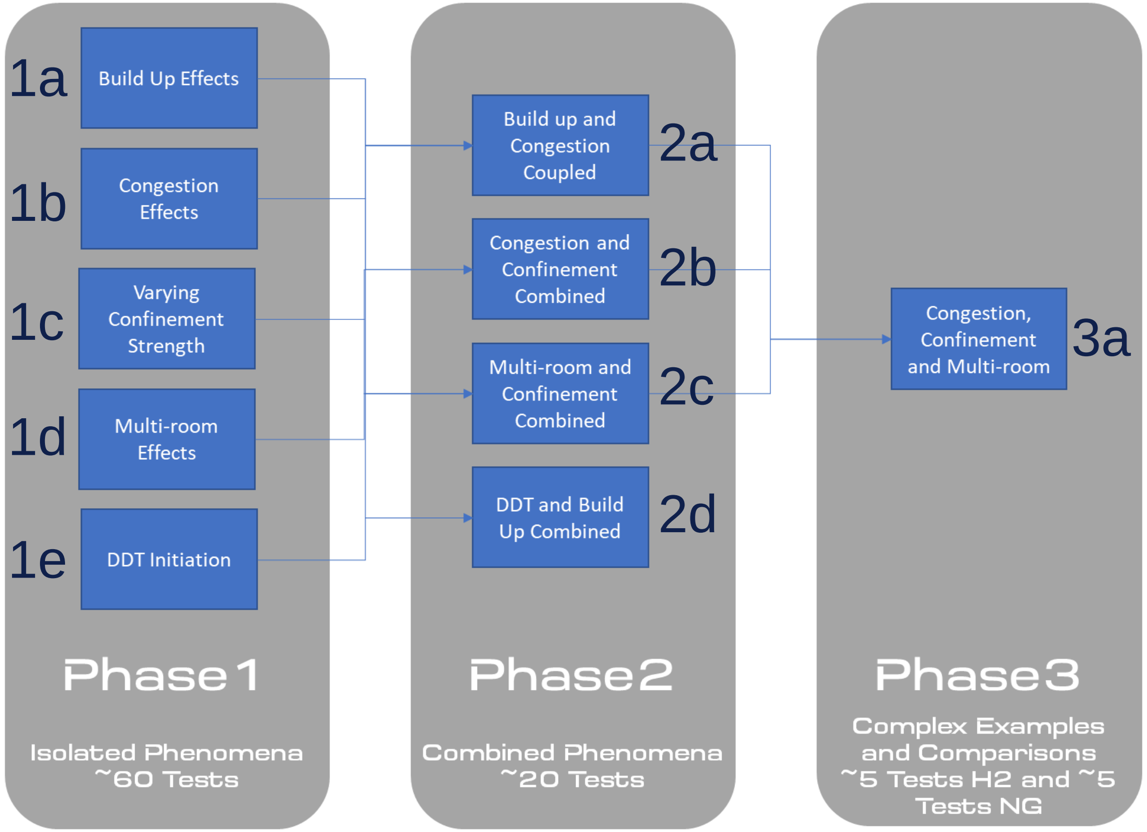
Detonation Initiation

1e – Detonation Initiation



Scope Overview – Experimental Phases

- The experimental programme in this project will focus on explosion phenomena.
- Using a phased approach the programme starts with isolated phenomena to achieve baseline data for each phenomenon in the experimental facility before moving onto coupled phenomena and more complex experiments.
- The high level programme approach is shown here:



Interested?

- Lead Gas Distribution Network is Northern Gas Networks (NGN) and the key contact is:
- Sam Stone, Project Manager
- sstone@northerngas.co.uk

Thank you

www.dnv.com

DNV