Hydrogen consequences

Delayed ignition

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Do not take this call while driving, even when using a headset or hands-free

Please ensure that discussions are not overheard

Know the name of the building, room and floor number

Phone number for emergency (often separate internal or external depending on seriousness)

Be familiar with sound of the fire alarm

Location of nearest fire alarm, fire extinguisher, emergency exits and muster points

When using a headset, ensure you are still able to hear the fire alarm

Location of first aid kit and/or first aider

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Keep your microphones on mute unless you would like to ask a question during the Q&A.

You may submit questions at any time by typing a question in the chat box.

Please close all other applications to maintain focus.

Introduction

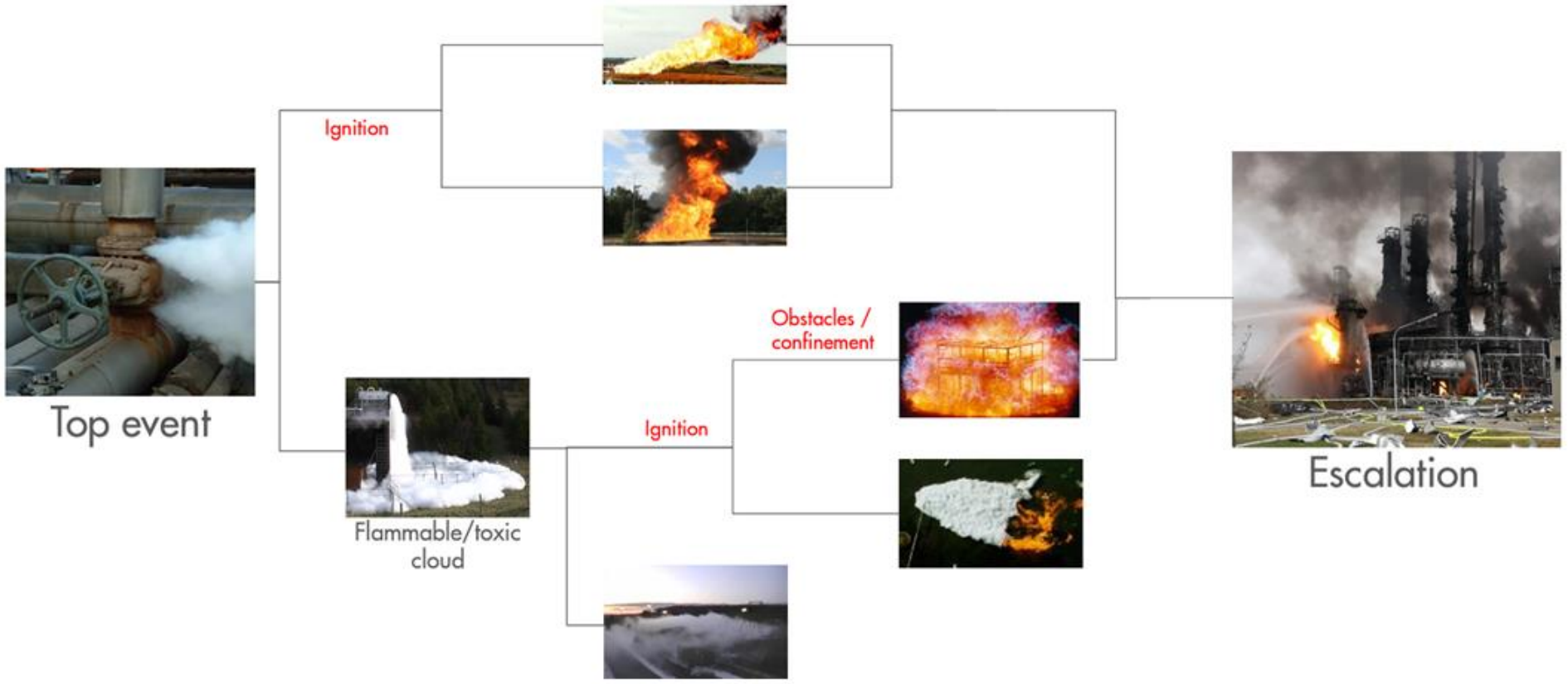
- Separation distances for Hydrogen Refuelling Stations are based on PGS35
  - Separation distances are provide between equipment (leak sources) and People inside buildings (shop) and outside within the premises
- In the Netherlands a QRA is used to determine safety distance outside the premises

- PGS35 and QRA only consider direct ignition scenarios for separation distances
- 100% direct ignition probability of hydrogen is sometimes seen as conservative and safe

- Is a 100% direct ignition probability credible?
- Difference in direct ignition and indirect ignition consequences

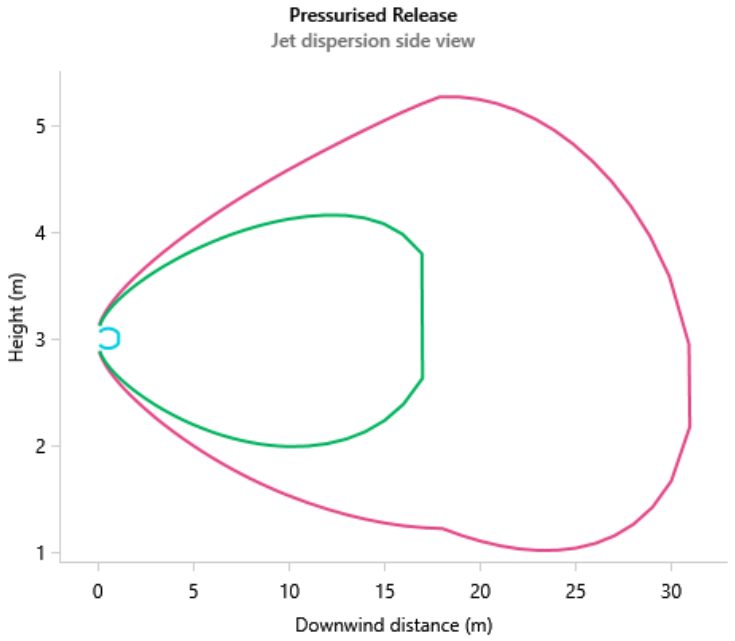
Delayed ignition for hydrogen

Consequence paths



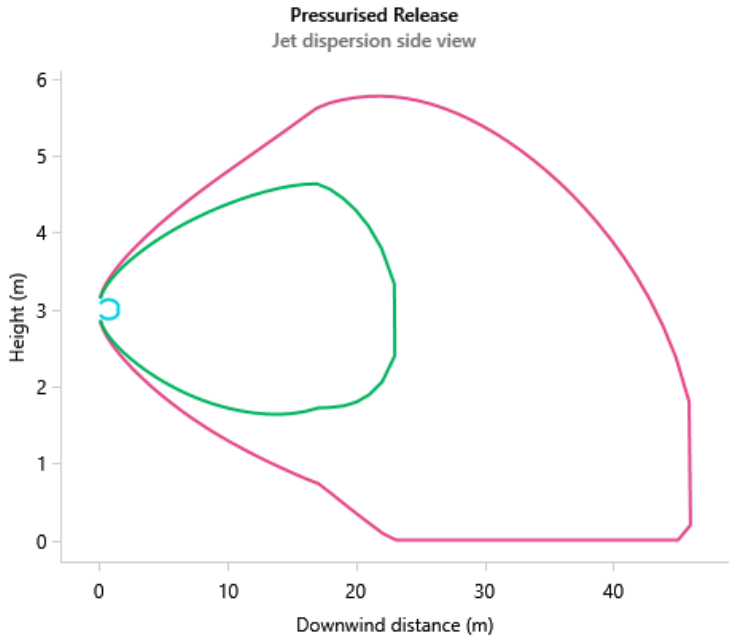
Hydrogen dispersion

- Hydrogen is 14 times lighter than air
- This does not mean flammable clouds do not form at ground level!
- Dispersion models for release at 3 meter height



Concentration contours (ppm)
40000
80000
760000

500 barg, 9mm diameter release



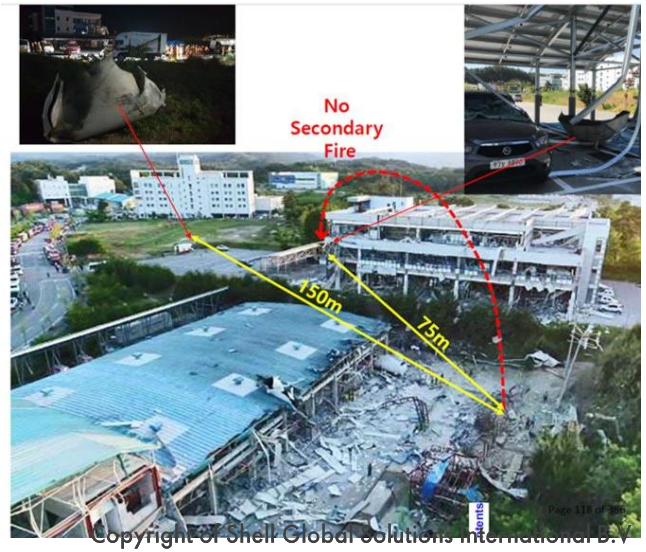
Concentration contours (ppm)
40000
80000
760000

Wind speed :- 5 m/s
Stability class :- D - Neutral
Mass flow rate :- 2.384 kg/s
Release Height :- 3 m

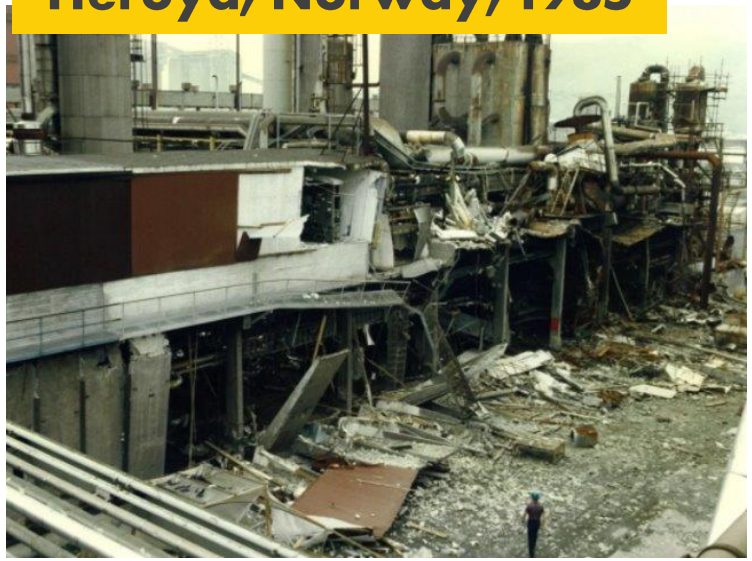
500 barg, 12mm diameter release

Incidents

Gangneung, South Korea, 2019

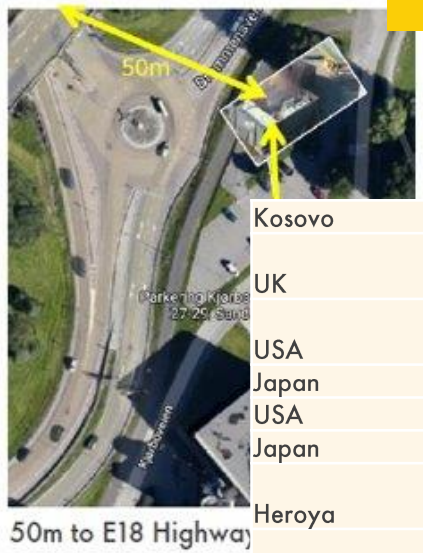


Heroya, Norway, 1985

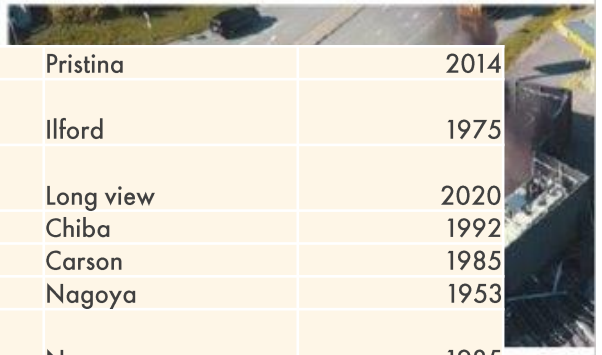


20-30 seconds delay before ignition, 10-20 kg release. Windows shattered 700m away.

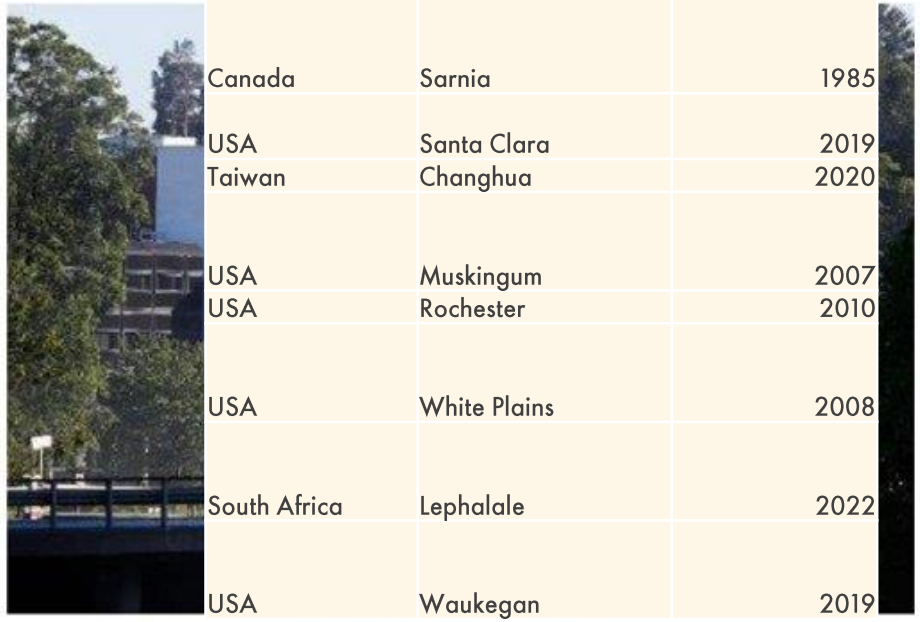
Kjørbo, Norway, 2019



50m to E18 Highway



Kosovo	Pristina	2014
UK	Ilford	1975
USA	Long view	2020
Japan	Chiba	1992
USA	Carson	1985
Japan	Nagoya	1953
Heroya	Norway	1985
Canada	Sarnia	1985
USA	Santa Clara	2019
Taiwan	Changhua	2020
USA	Muskingum	2007
USA	Rochester	2010
USA	White Plains	2008
South Africa	Lephalale	2022
USA	Waukegan	2019



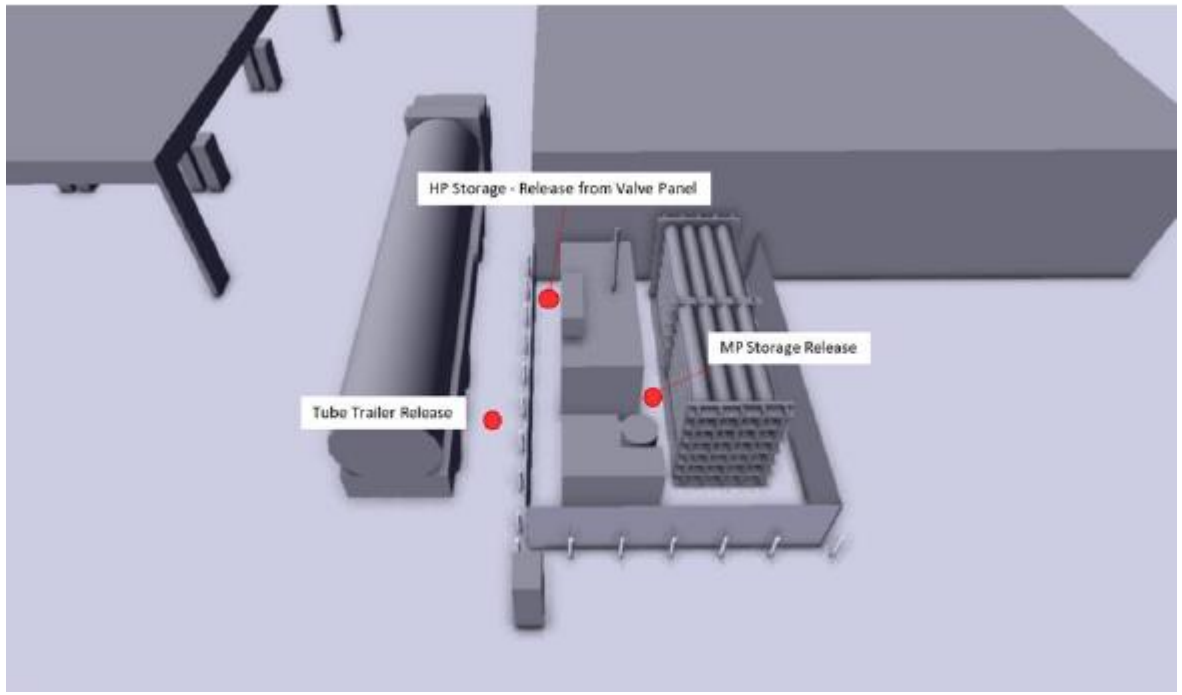
Shattered windows and damage to Office Building 65m away.

CFD modelling HRS large leaks

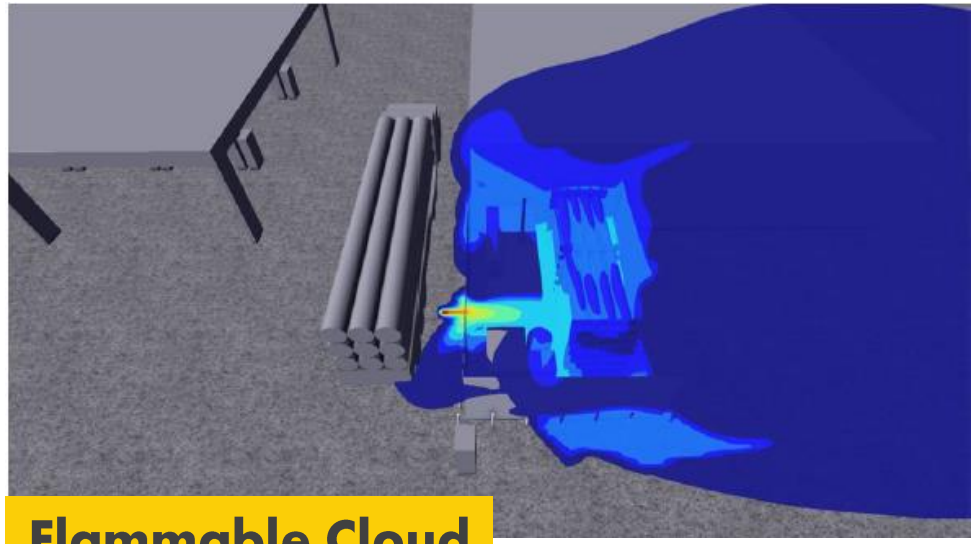
Large leak scenarios

Release rates

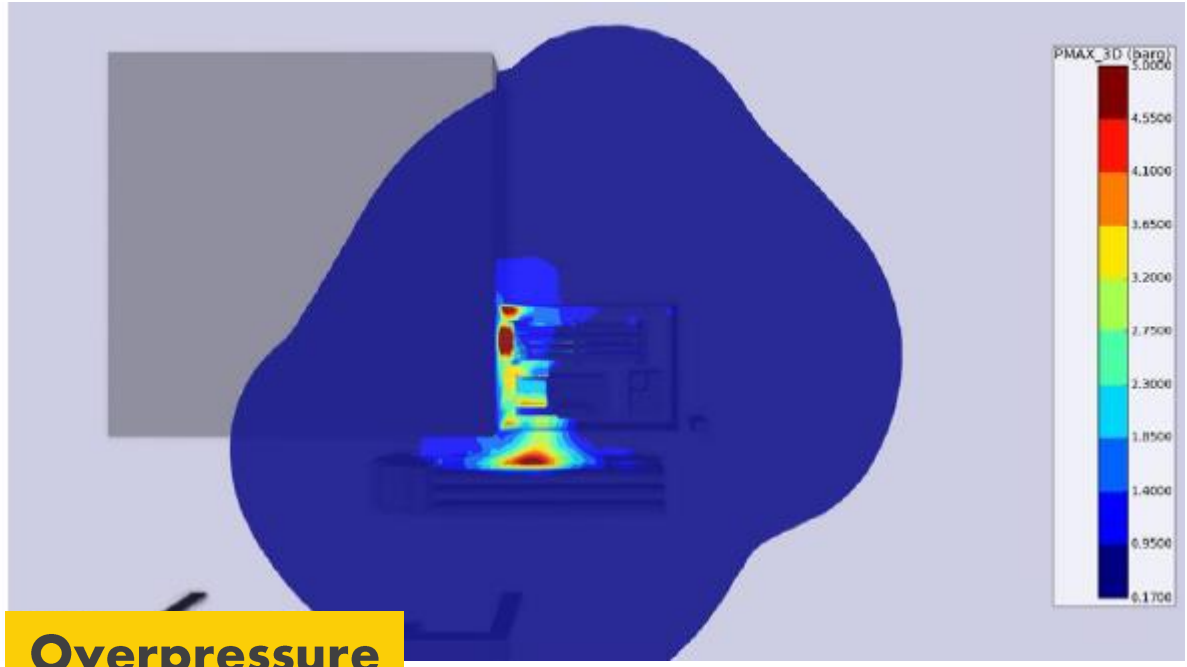
- Tube trailer 2.2 kg/s (500bar, 11mm)
- MP storage 0.5 kg/s (500bar, 6mm)
- HP storage 1.0 kg/s (950bar, 6mm)
- Storage area 2.2 kg/s (500bar, 11mm)



Trailer release ignited within equipment area



Flammable Cloud

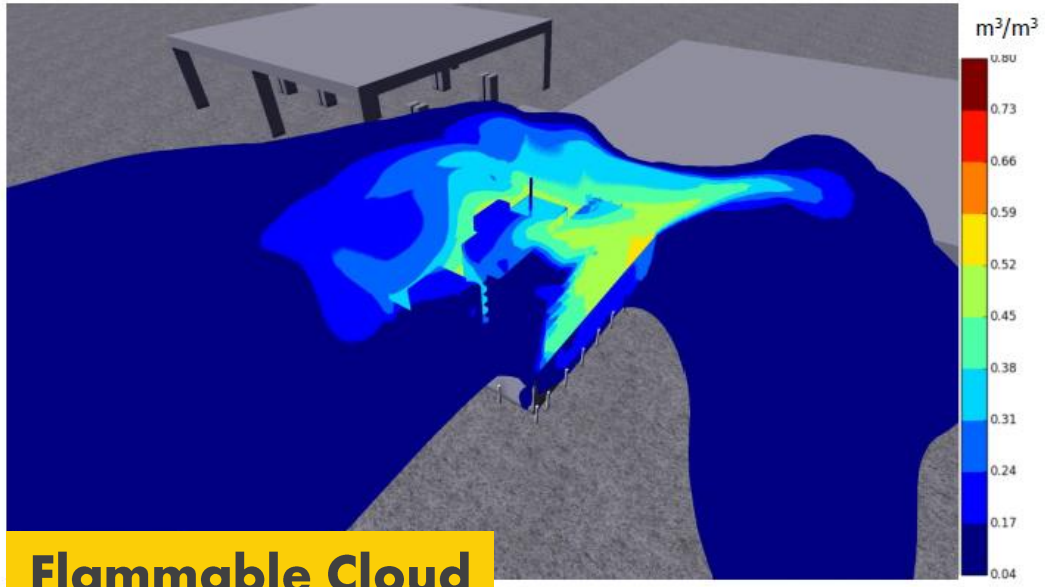


Overpressure

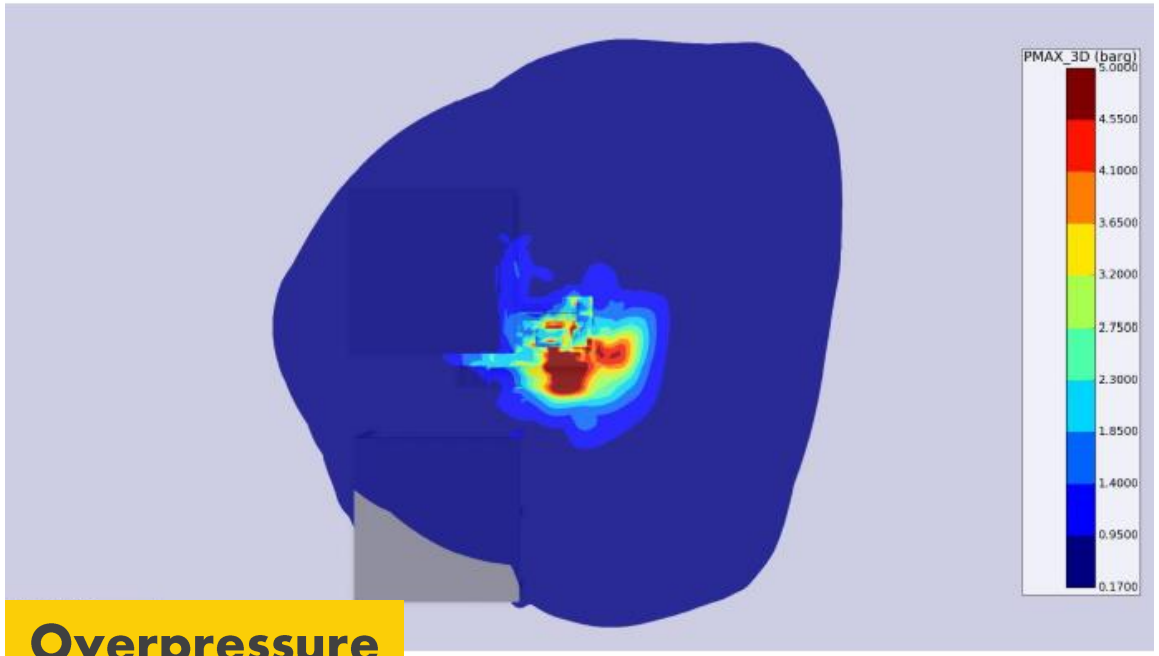
Flammable cloud 260m^3

170 mbar contour at 20 meters

Full bore rupture equipment area



Flammable Cloud



Overpressure

Flammable cloud 280m^3

170 mbar contour at 42meters

500 bar 10mm downward release

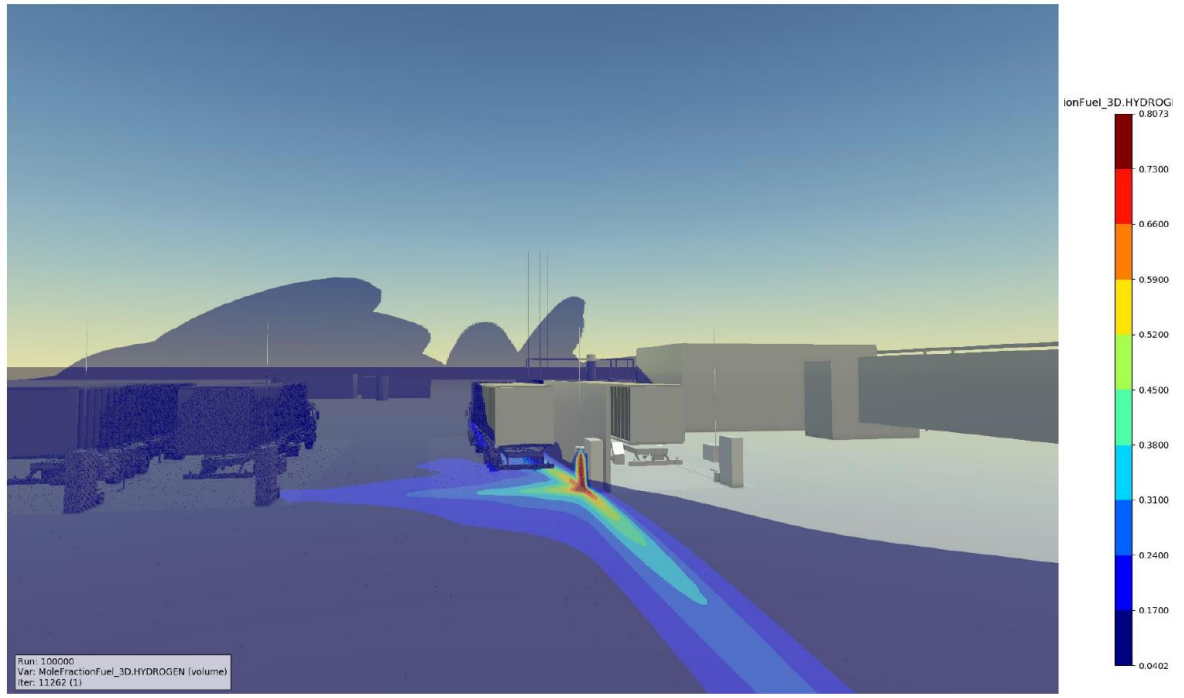
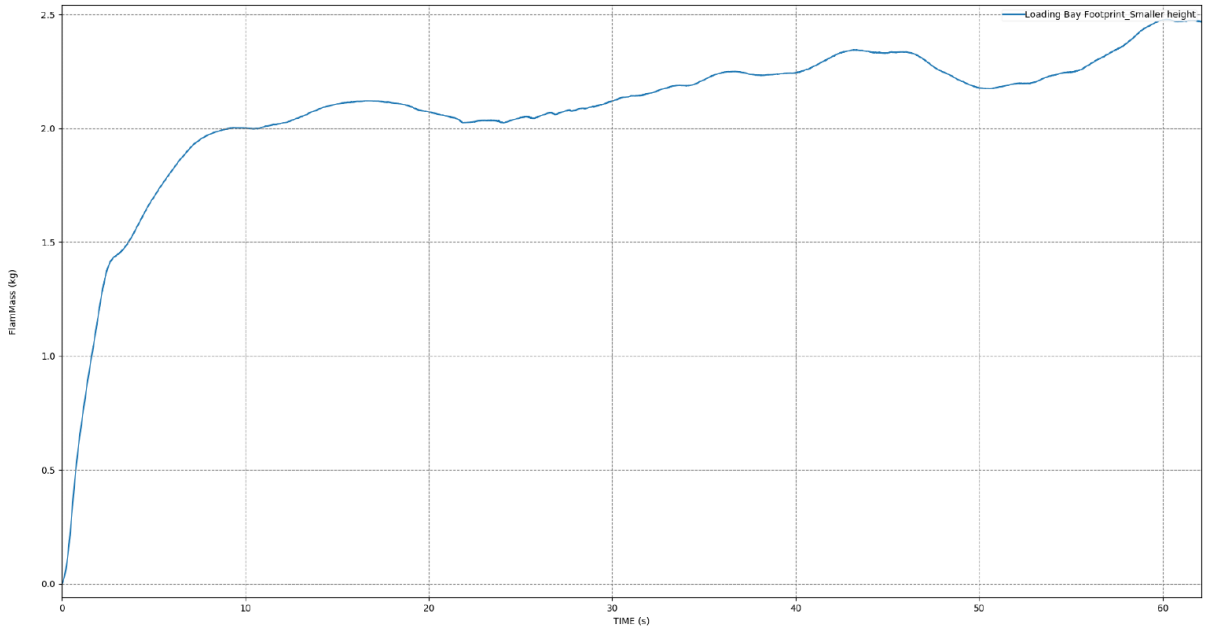


Figure 8-1: Steady state flammable gas cloud produced by a 10mm downward release from the loading area (south of fire wall)



Leak Size	FlamMass (kg)	FlamVol (m^3)	Q9 (m^3)	Maximum Calculated Stoichiometric Cloud Volume (m^3)
Prevailing Wind Direction				
10 mm	2.4	230	45	90
1 mm	0.005	1.05	0.014	0.2
Wind Direction Towards Buildings of Interest				
10 mm	2.4	230	49	90
1 mm	0.005	1.05	0.014	0.2

Comparing scenarios

Jet fires and Vapour Cloud Explosions

- Summary of results from these studies, which are highly dependent on specific layout and release conditions

Leak scenario for 500 bar	10 kW/m^2	100 mbar
1mm	3m	-
1.4mm	5m	20-25m
3.8mm	11m	16-29m
11mm	34m	29-63m
17mm	52m	100m

- Note: vapour cloud explosion modelling assumes a deflagration, although there were some high source overpressures and high levels of congestion meaning that detonation cannot be ruled out.

Design considerations

- Firewalls, trade-off between fire protection and increasing overpressure and decreasing ventilation
- Blast walls
- Equipment layout
- Storage banks setup
- Separation distances
- Natural / mechanical ventilation

- Safety Functions
  - SIL levels on instrumentation (LOPA driven)
  - Gas detection with automated or manual ESD
  - Gas tight compressor compartmentalization with gas detection
  - Restricting orifice/choke valve on trailer
  - ESD valve on trailer

Storage models

Conclusion

- Explosion scenarios are a credible scenario that should be considered for an HRS
- Explosion consequence is more difficult to predict than jet fire consequence due to
  - Equipment layout
  - Congestion
  - Confinement
  - Ignition timing
  - Direction of release and influence of ventilation
- Explosion consequences may have larger consequence contours than jet fires
- Not all leaks on site immediately ignite, delayed ignition may be possible prediction is more uncertain.
- Only considering jet fire scenarios may underestimate the safety risk for a HRS
  - Separation distances may be too short
  - Mitigations for jet fire may have adverse impact on explosion scenarios
  - Other safeguards and SIL levels are not appropriately considered to reduce probability

- Requires appropriate explosion modelling integrated into the risk based decision making process when considering internal separation distances within the premises and a QRA for outside the premises of the HRS.