IGNITED RELEASES OF LIQUID HYDROGEN: SAFETY CONSIDERATIONS OF THERMAL AND OVERPRESSURE EFFECTS

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Background

- HSE funded research program
- If hydrogen economy takes off there will be an increase in LH2 road tanker traffic in UK
- Increase in refuelling operations
- Therefore a need to assess the risk from a delivery hose failure in standard operation

Background

- Commissioned as four programs of work:
  - Positions paper: Hazards of LH2 (RR769)
  - Un-ignited releases
  - Computational modelling of the releases (un-ignited)
  - Ignited releases

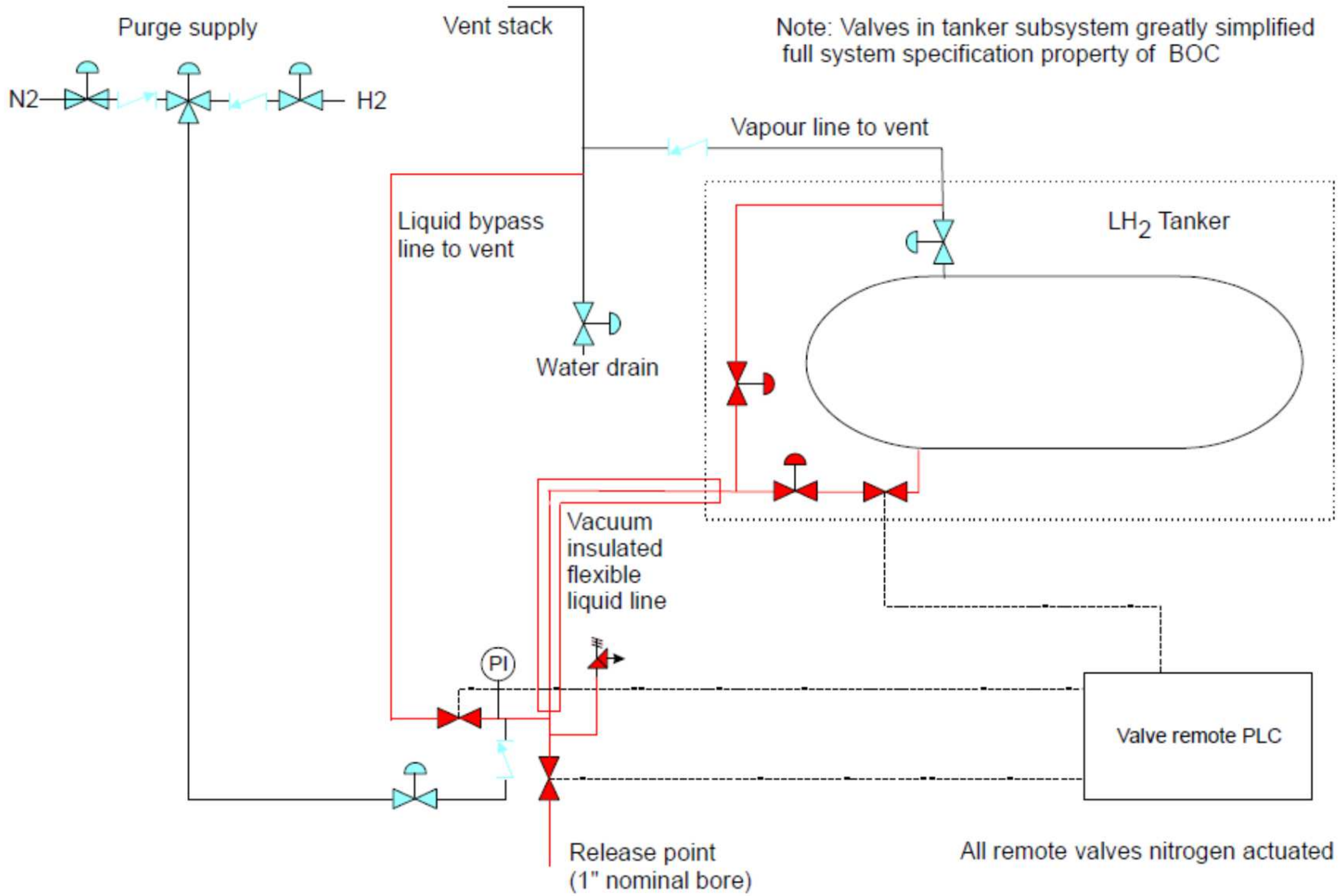
Project aims

- Flammable extent of a vapour cloud
- Flame speeds through a vapour cloud
- Radiative heat levels generated during ignition

Experimental set-up

Experimental set-up

- P&ID of release system



Experimental set-up

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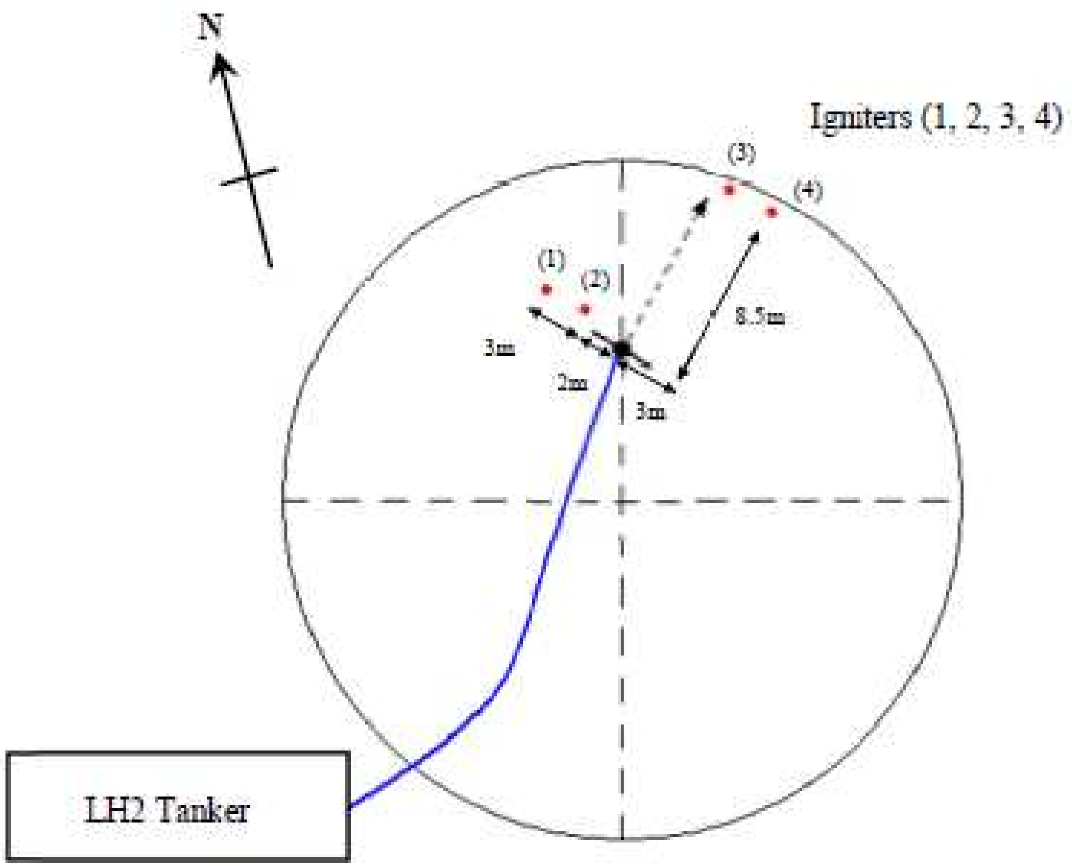
- LH2 tanker containing 2.5 tonnes
- 1” n.b. horizontal release line
- Release pressure of 1barg
- Flow rate measured to be ≈ 60 litres per minute
- Ignition system:
  - 1kJ chemical igniters in four locations due to variability in cloud direction
  - Ignition positions close and far from release

Experimental set-up

- Igniter positions

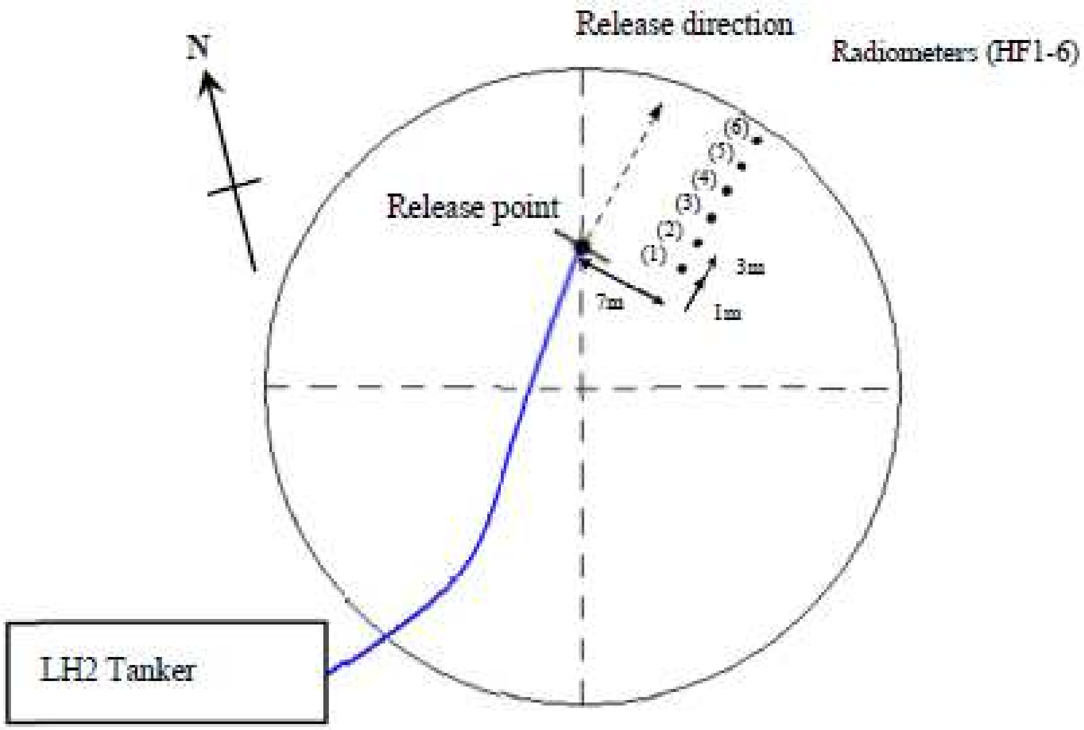


Experimental set-up

- Instrumentation:
  - Flammable extent and flame speed
    - Standard and IR video at 50fps
    - Some high speed video at 500fps
  - Radiative heat
    - Ellipsoidal radiometers, range: 110kW/m^2, 160º field of view
  - Meteorological measurement
    - Temperature, humidity, wind speed and direction

Experimental set-up

- Radiometer positions



Experimental releases

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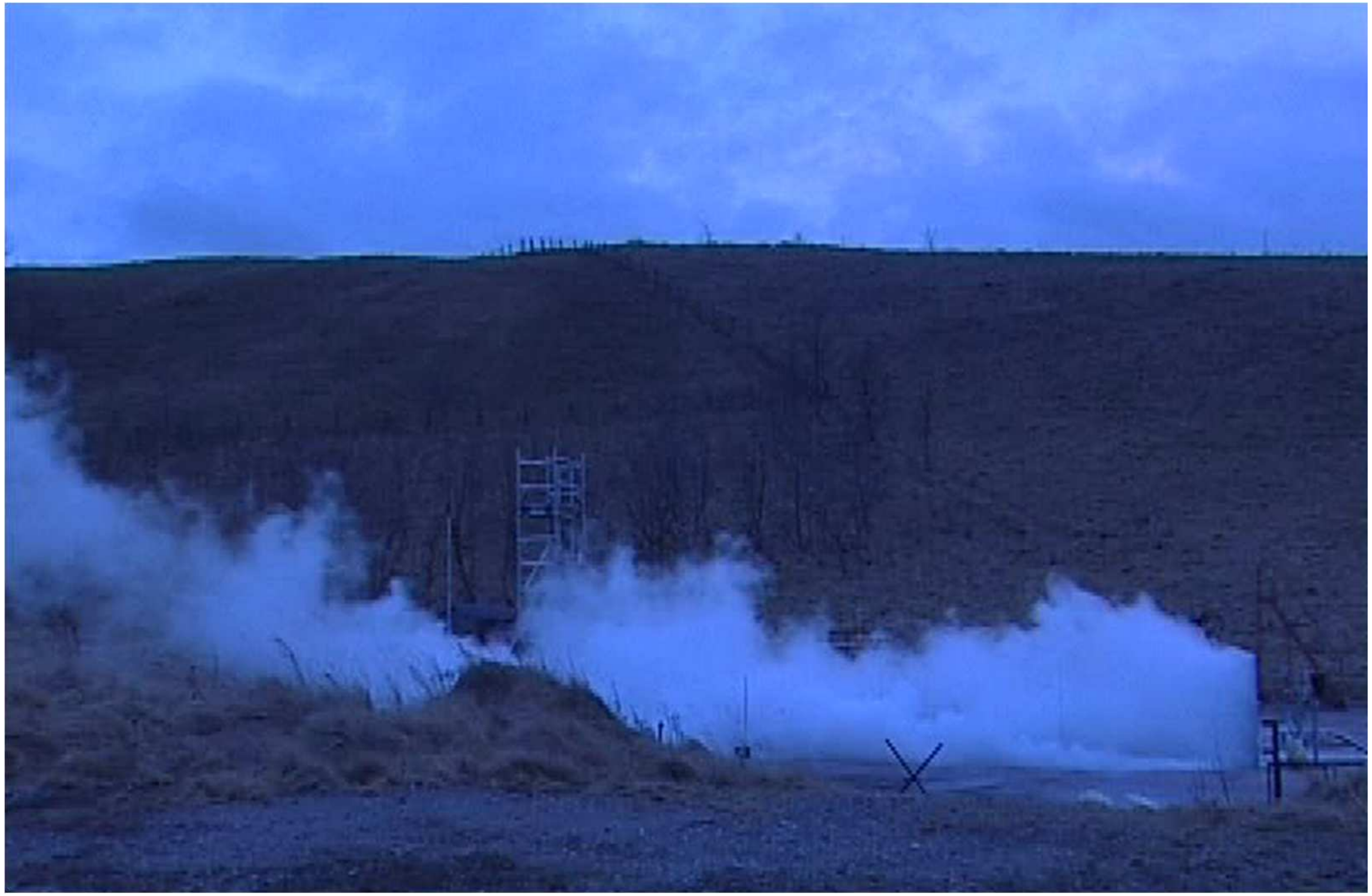
- 14 tests performed, of which 10 ignited
- Variables:
  - Release duration
  - Weather conditions (wind direction/speed)
  - Ignition position

Experimental releases

- Video of test 2

Experimental releases

- Video of test 3

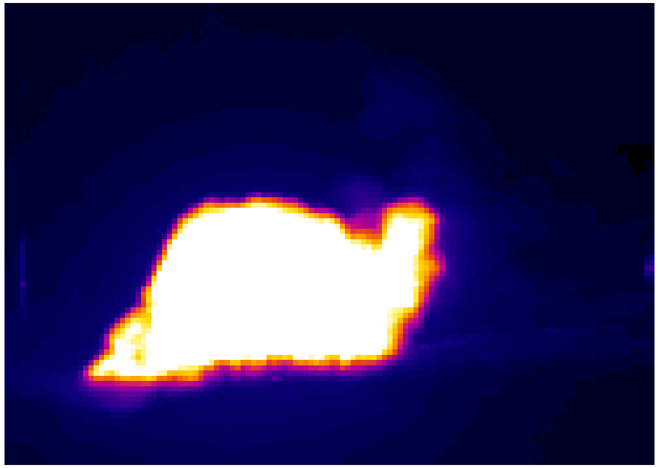


Experimental releases

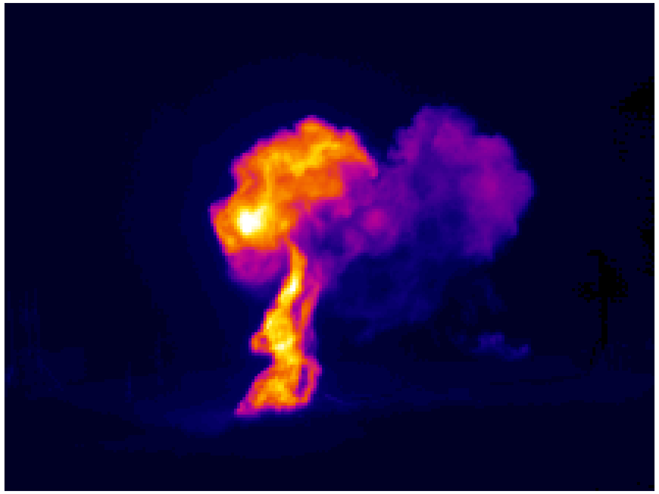
- High speed video of test 7

Experimental releases

- IR stills of test 11

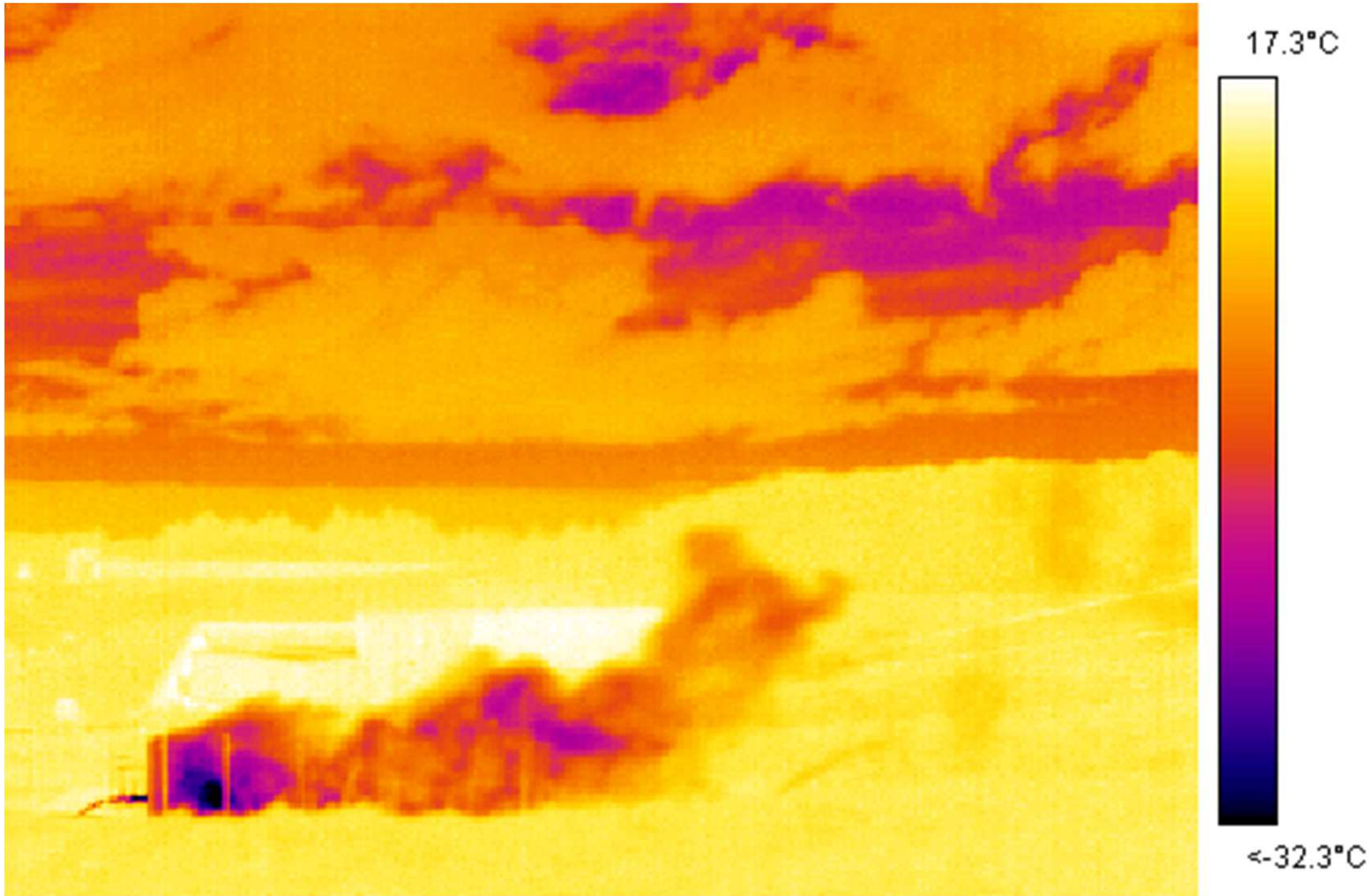
300ms post ignition

2000ms post ignition

Experimental releases

- Test 6



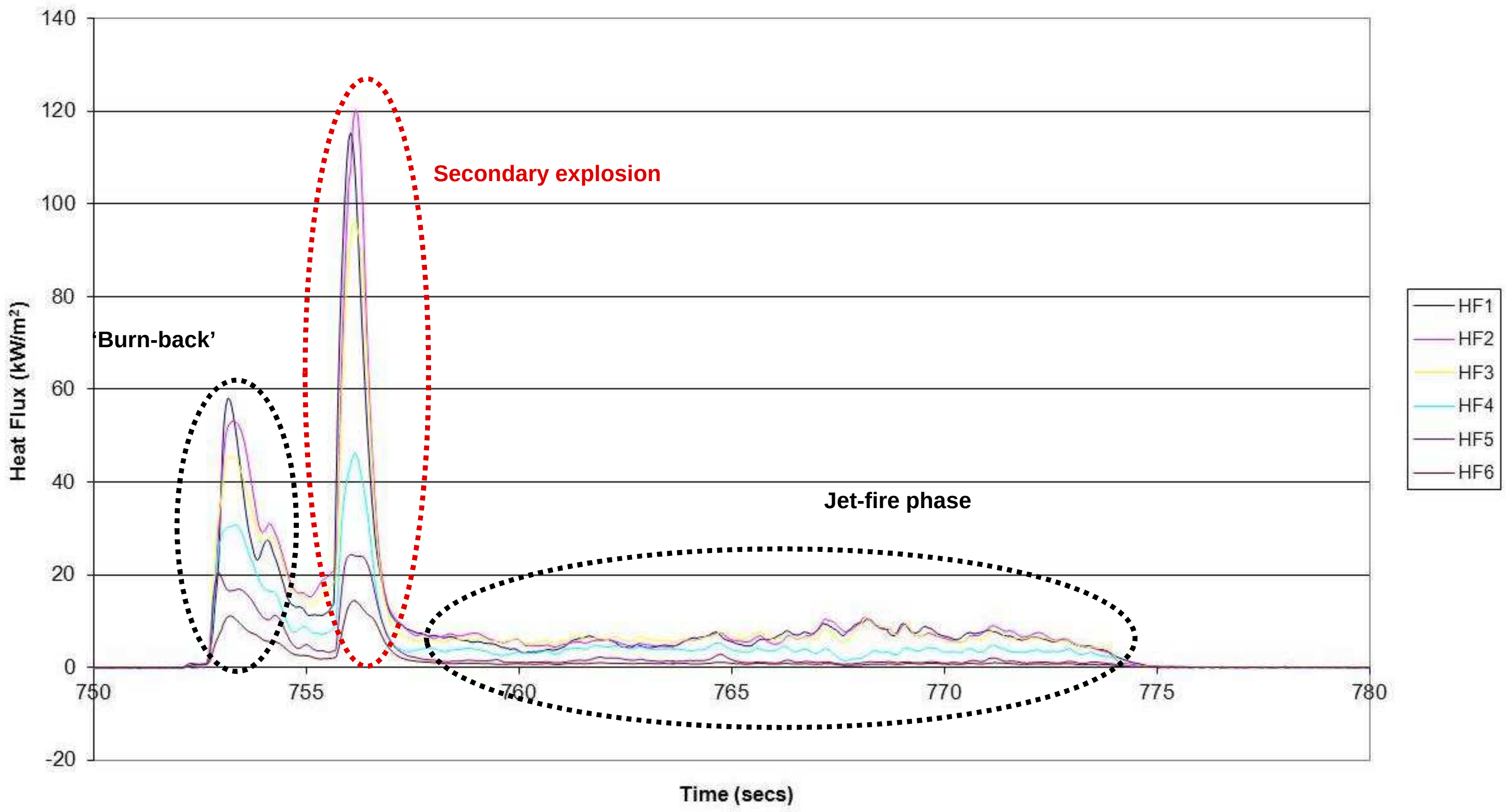
Experimental releases

- ‘Snow’ formation prior to ignition on long releases

- Secondary explosion appears to emanate from this location

Experimental releases

- Radiometer trace of test 6



Overpressure estimation

- During test 6 a one off secondary explosion occurred
- ≈ 260 second release
- Secondary explosion occurred ≈ 3 seconds after ignition
- Produced an 8m hemispherical fireball emanating 2.5m in line with release
- No pressure measurements at time of explosion, only standard video and radiometers

Overpressure estimation

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Two methods used:

1. Pressure Effects

- Perspex windows in small cabin 20m away failed to break, therefore a maximum can be deduced
- This is modelled in Hazl©, however, nearest material available is Polycarbonate (stronger than Perspex)
- TNT equivalent calculated to be < 4kg
- If the H_2 were act like a condensed phase explosive (i.e. all H_2 used to generate blast wave) then this equates to < 150g H_2 yielding 18MJ

Overpressure estimation

Two methods used:

2. Radiative Fraction

- Use radiometer data and relate to the radiative fraction
- Jet-fire phase used for estimate of radiative fraction

$$Q_r = \chi M \Delta H_c$$

where Q_r - heat radiated, kW; χ - radiative fraction (between 0 and 1); M - mass rate of fuel combustion, kg/s; ΔH_c - heat of combustion of the fuel, kW/kg

- Normally radiative fraction based on significant distance from flame
- In this case the flame was elongated along the line of radiometers and close to the ground

Overpressure estimation

- Therefore a semi-cylindrical radiating heat source assumed:

$$Q_r = (1 + \alpha)\frac{\pi d L q}{2}$$

where Q_r - heat radiated, kW; d - distance to radiometer, m; L - length of flame, m; q - heat flux at radiometer, kW/m^2; α - reflection coefficient of concrete surface below the flame

- Reflection co-efficient taken as 0.55
- Giving radiative fraction of 0.054 for jet-fire phase
- Estimate is based on the furthest radiometer, a hemispherical heat flux and a similar radiative fraction as during jet-fire phase
- Gives 675g H2 yielding 82MJ, ≈ 18kg TNT equivalent!!
- Reported that H2 explosions of a particular energy would cause less damage at a given distance than a TNT explosion of same energy

Safety distances: thermal effects

- Levels of harm equated to thermal dose units (TDUs)

$$TDU = I^{\frac{4}{3}} \times \mathrm{t}$$

where TDU - thermal dose units; I - thermal radiation intensity, kW/m^2; t - duration for which the radiation is experienced, secs

- Using the radiometer data from the ignited tests and historical IR burn severity data an assessment of the thermal dose from LH2 spills can be made
- Four test regimes considered:
  - Steady state jet-fire during high wind speeds > 0.6m/s
  - Steady state jet-fire during low wind speeds < 0.6m/s
  - Initial deflagration or ‘burn back’ of the release cloud to source
  - Secondary explosion seen after the initial deflagration

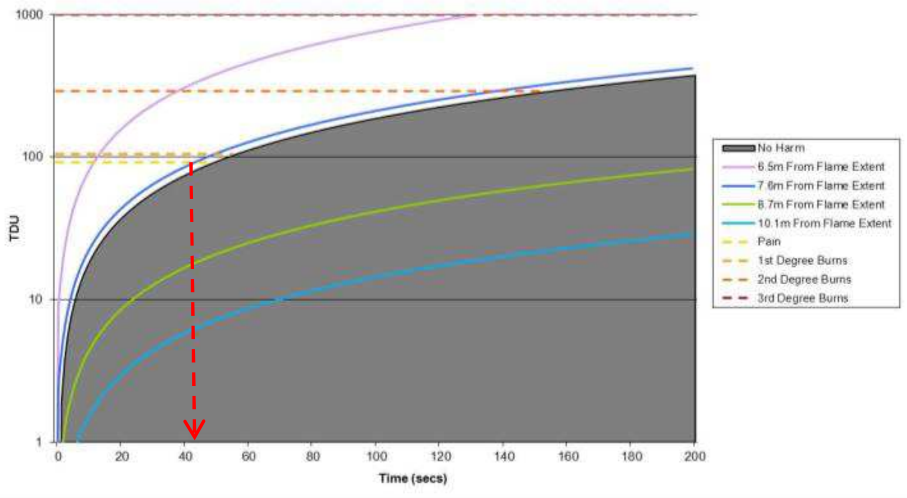
Continuous events

Instantaneous events

Safety distances: thermal effects

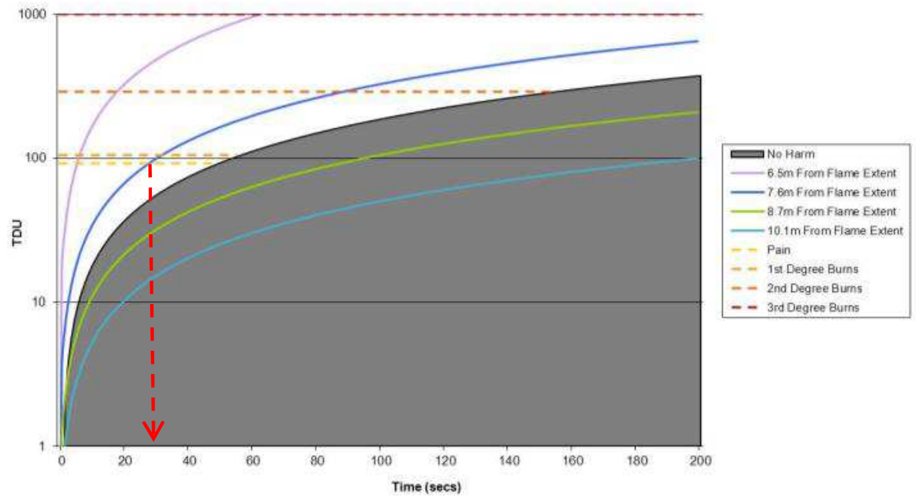
- Continuous jet-fires
  - No harm 1.6kW/m² (grey area)

Test 7
Wind speed: 0.59m/s



Time to 'pain' at 7.6m ≈ 44 seconds

Test 4
Wind speed: 2.15m/s



Time to 'pain' at 7.6m ≈ 28 seconds

Safety distances: thermal effects

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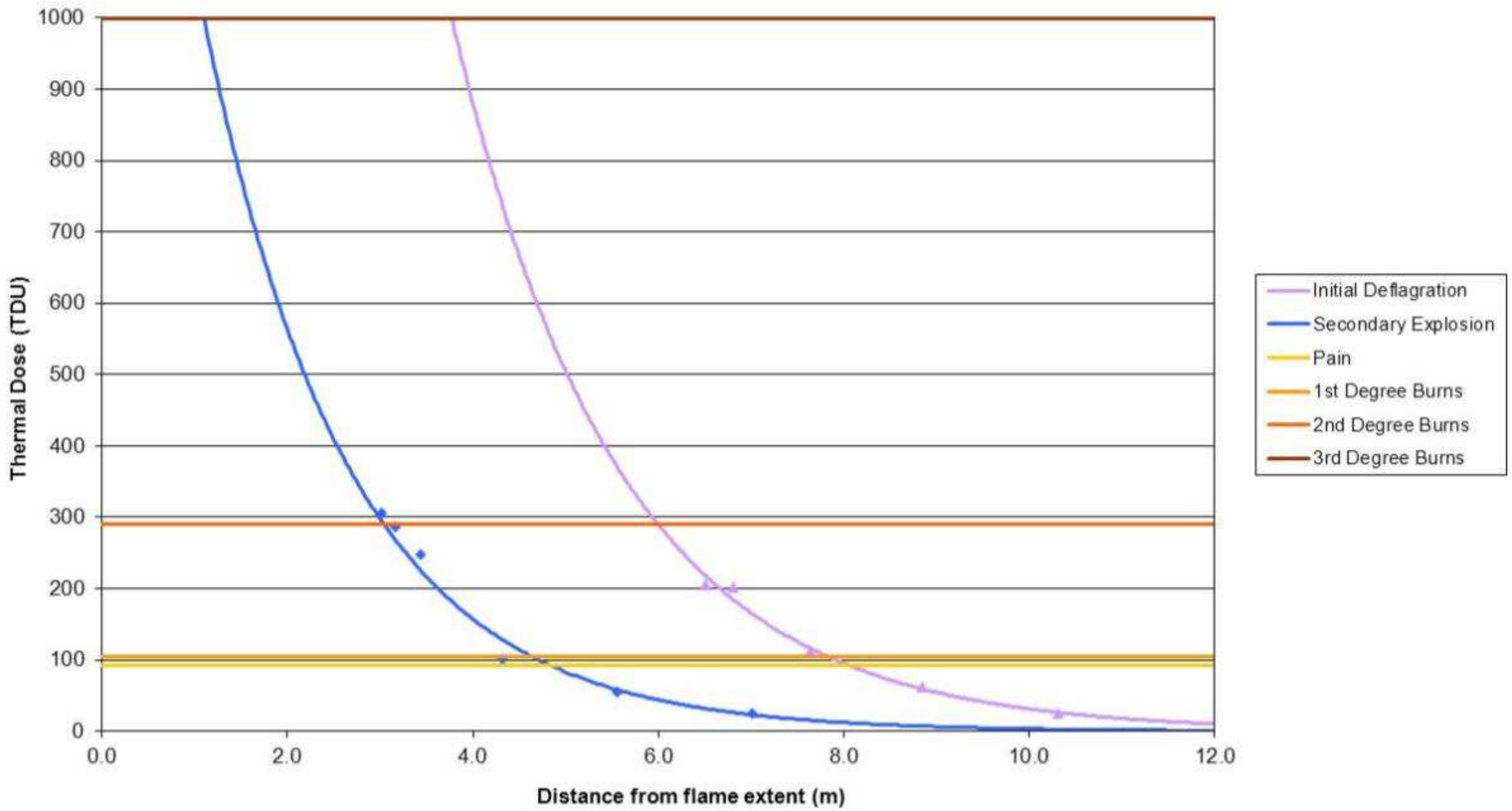
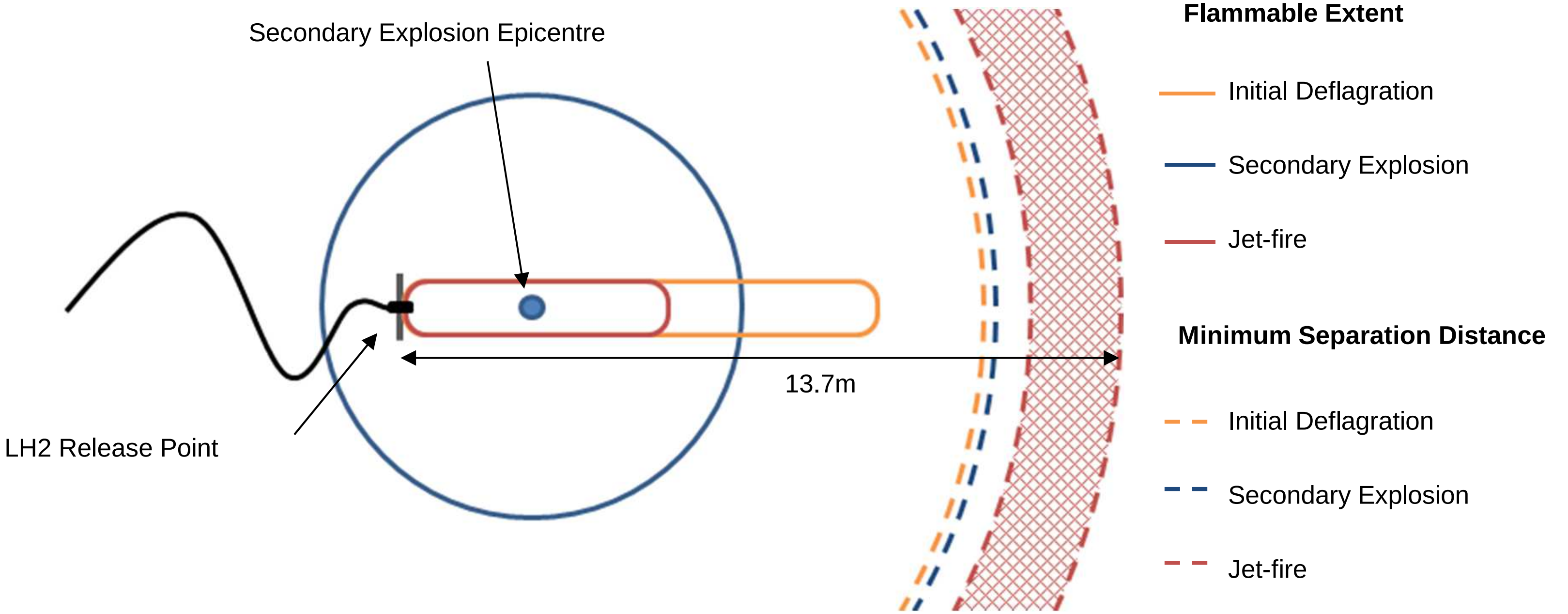
- Instantaneous deflagration and explosion
  - Test 6



Safety distances: thermal effects

- Approximate safety distances



	Initial cloud deflagration	Secondary explosion	Jet-fire (High wind)	Jet-fire (Low wind)
Minimum separation distance from source to avoid 'pain' (m)	> 11.1	> 11.3	12.6 > 13.7	12.6 > 13.7
Exposure time (secs)	0	0	∞	∞
Note: These values consider radiative heat only, not pressure effects				

Conclusions

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From experimentation, four separate regimes have been found to occur when a full bore failure of a 1” liquid (60 l/min) hydrogen tanker transfer hose is ignited:

- An initial deflagration of the cloud back to source, travelling at speeds up to 50 m/s
- A possible secondary explosion emanating from the solid deposit generated after the initial deflagration of the release cloud due to oxygen enrichment.
- A buoyancy driven jet-fire when wind conditions are minimal (wind speeds < 0.6 m/s), with flame speeds > 25 m/s
- A momentum dominated jet-fire when wind conditions are high (wind speeds > 0.6 m/s), with flame speeds > 50 m/s