LH2 release experiments to support large scale Shell projects

Steven Betteridge
Major Hazards group - shell

Agenda

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05 Dispersion

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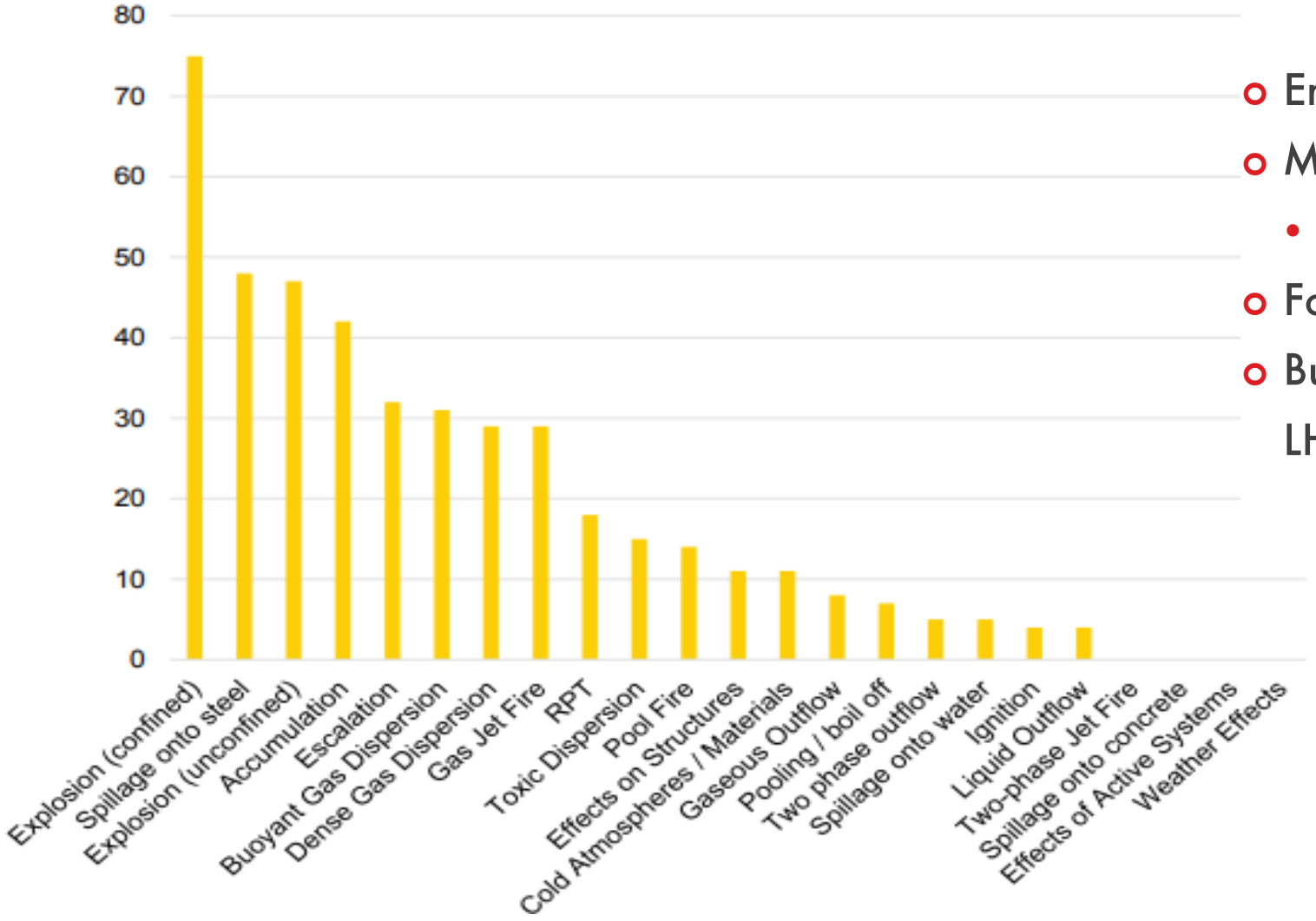
Background

Further quantification of major hazards required



- Energy transition is driving rapid change
- Many questions raised across industry
  - Especially for Liquid H_2 (LH2)
- Focussed assessment by Shell marine business
- But also unknowns for electrolyser plants, LH2 processing and LH2 storage

Shell H2 experimental programmes

- Urgent demand – especially to develop standards
- JIPs very important – but can they answer all the questions ?
  - Can be slow to start and generate results
  - Programme is usually a compromise

⇨Develop dedicated Shell programmes to resolve these urgent questions

- Is a sustained LH2 pool a credible scenario?
- Quantify material properties at LH2 temperatures
  - Collaboration with AkzoNobel to test CSP system exposed to LH2
- Generate dispersion data to confirm predictions for buoyancy
- Obtain good quality jet fire results
- Investigate H2 detector performance

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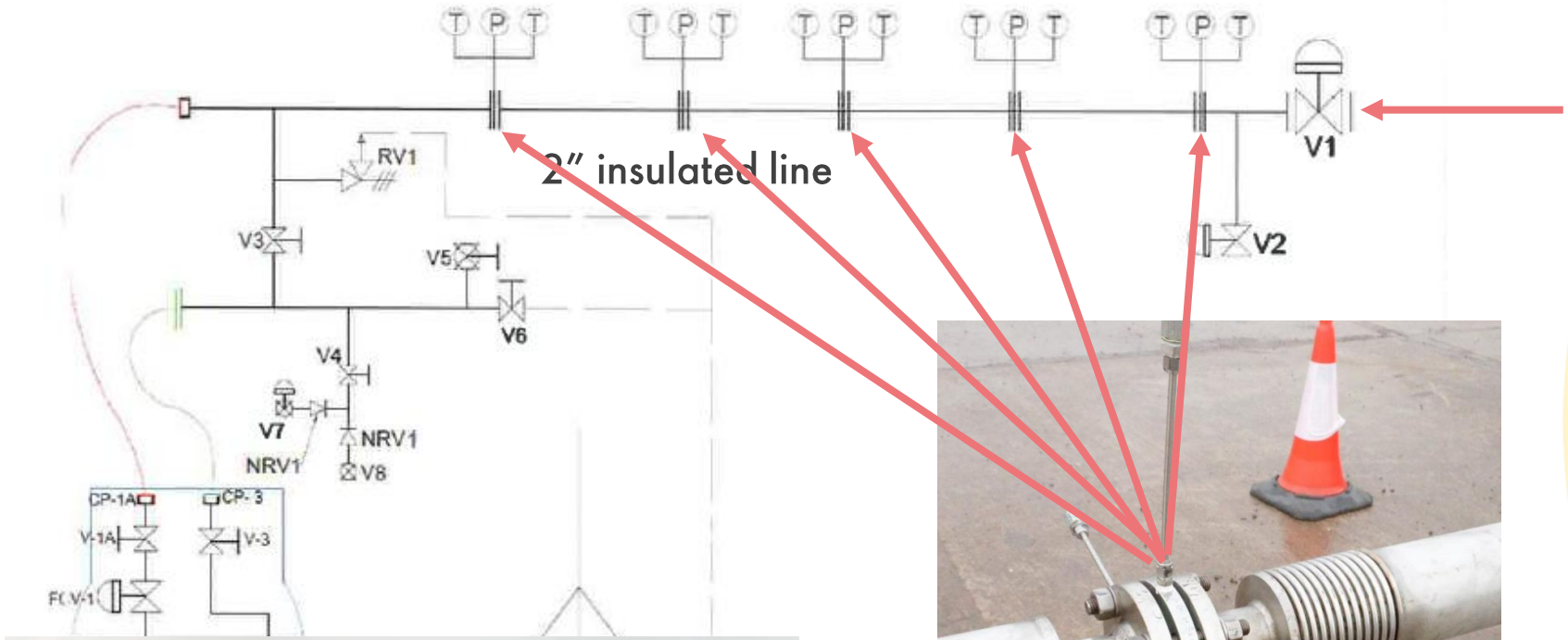
Experimental programme

LH_2 Supply / Pipe Schematic

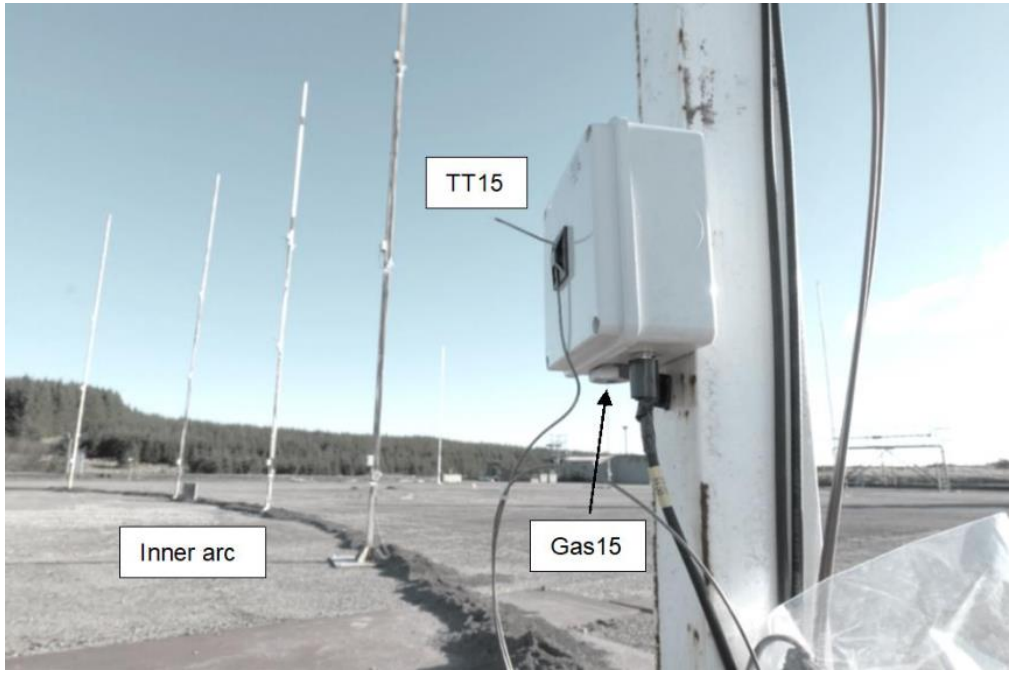


Instrument Array – Near Field

- 4 arrays of thermocouples – jet impingement measurements
  - 5 Type T thermocouples in each array (cross arrangement)
- 4 Radiometers
  - 30° to horizontal / 120° field of view
  - Positioned 5 m downwind distance and at ±8 and ±12 m perpendicular to release direction
- 8 dynamic pressure transducers (PCB Piezotronics)
  - Similar distance to radiometers

Instrument array – far field

- Two arrays of sensors at 25 and 50 m
- Oxygen depletion and thermocouples at 3 heights – up to 8 m
- Ultrasonic detector + five dedicated H_2 detectors



Experiments

- Approximately 25 releases
  - Each releases about 2-3 mins long
  - Flow rates approximately 0.06 – 0.91 kg/s
- Range of conditions
  - Orifice size from 5 mm – 50 mm
  - Tanker pressure 0.35 – 3.5 barg
- Environment
  - Ambient wind speed 1.5 – 6 m/s
  - Humidity 50 – 100%
  - Wind direction ±20° along release
- Dispersion
  - Horizontal releases (2 release heights)
  - Pool releases
- 6 ignited tests with radiometer measurements
- 4 tests filling bunded area
  - Concrete + PFP
  - Different pressure / filling rate
- Jet impingement on I-beam

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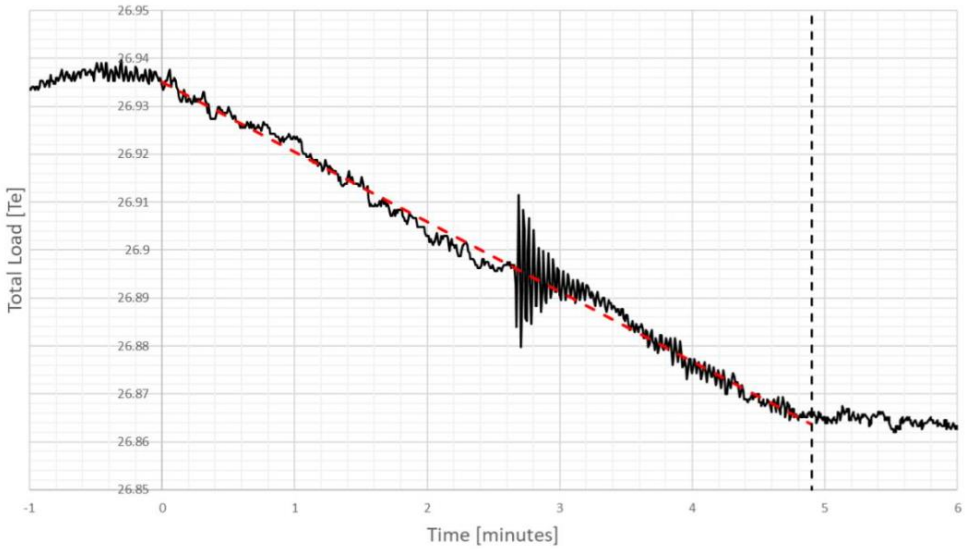
Process conditions

Defining the source term

What is coming out of the orifice ?



Source (°C)	Type N (°C)	Type T (°C)
LIN (-195.95)	-195.95	–196.82
LHe (-268.95)	-301.02	-252.72

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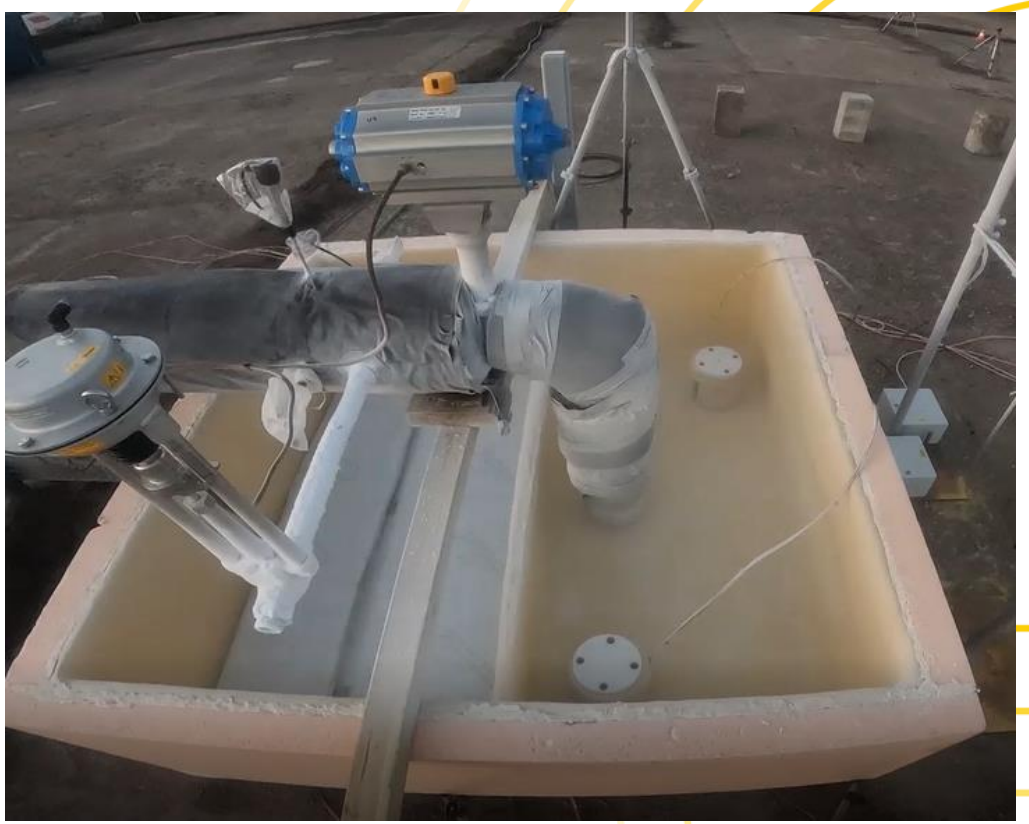
Pool Formation

Setup of Pool Bund

- Collaboration with AkzoNobel
  - Resilience of Cryogenic Spill Protection (CSP) to LH2
- Bunded area based upon ISO22899-1 / ISO20088-1
  - Fill one side with LH2
  - Filled area is 1.5 x 0.75 m = 1.11 m^2
  - Max liquid height 250 mm
- Concrete bund (C40)
  - Same bund dimensions
  - Determine boil off rates
- Source for passive dispersion



Liquid H2 pool on Cold Spill Protection

Integrity of CSP System

- No disbondment or visible defects immediately after LH2 testing
- Jet fire testing of this CSP system showed no adverse properties
- Similar results when box protected with reduced thickness CSP
- AkzoNobel verified that overall response similar to LIN (for same CSP)

Concrete Bund Test

- Sustained pool formed at
  - Raised pressure 1.0 barg saturation (estimated 0.5 kg/s)
  - 25 mm orifice 570 mm above surface

Bund	Pressure (barg)	Nozzle Height (mm)	Regression rate (kg/m²/s)
Thick CSP	0.3	20	0.014
Thin CSP	0.3	20	0.021
Concrete	0.3	20	0.064
Concrete	1.0	570	Unknown

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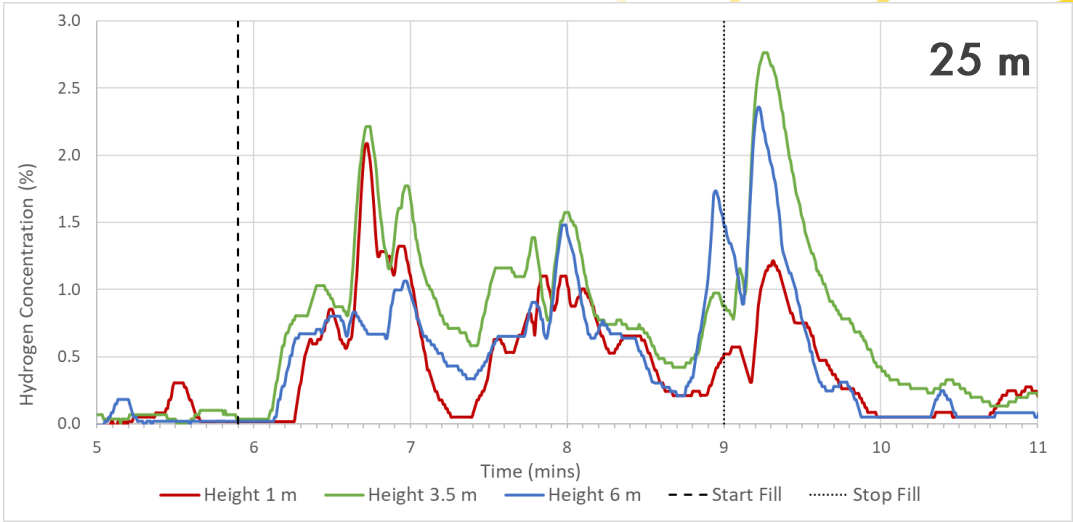
Dispersion

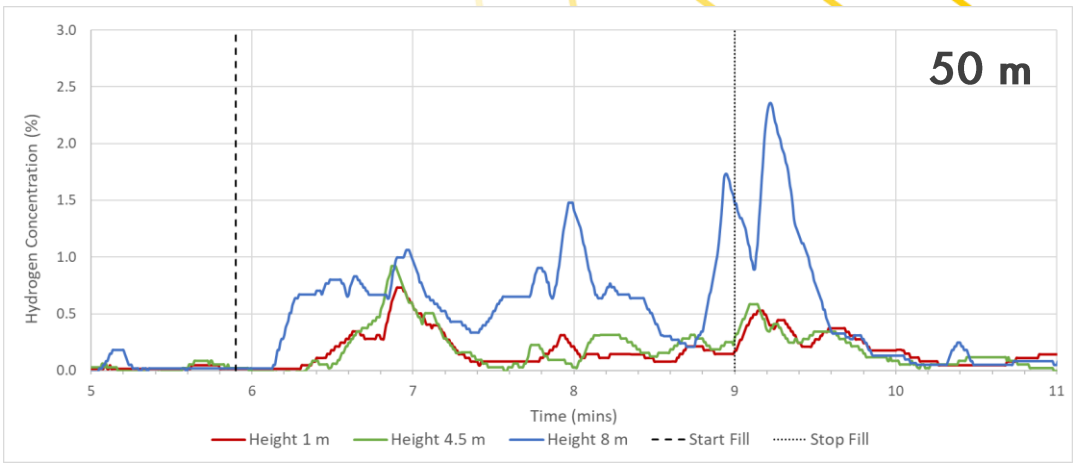
Dispersion From Concrete Bund

Dispersion Results - Concrete Bund @ 1 barg

- Concentration is max value across 5 stands
  - Account for plume meander
  - Concentration peak detected after filling stopped
- Results @ 25 m
  - Average plume height approximately 3.5 m
- Results @ 50 m
  - Majority of cloud at 8 m

- Concentrations for pool tests below LFL (4%)
  - At 25 and 50 m





Jet Dispersion

- Results still being analysed
- Some trends on buoyancy

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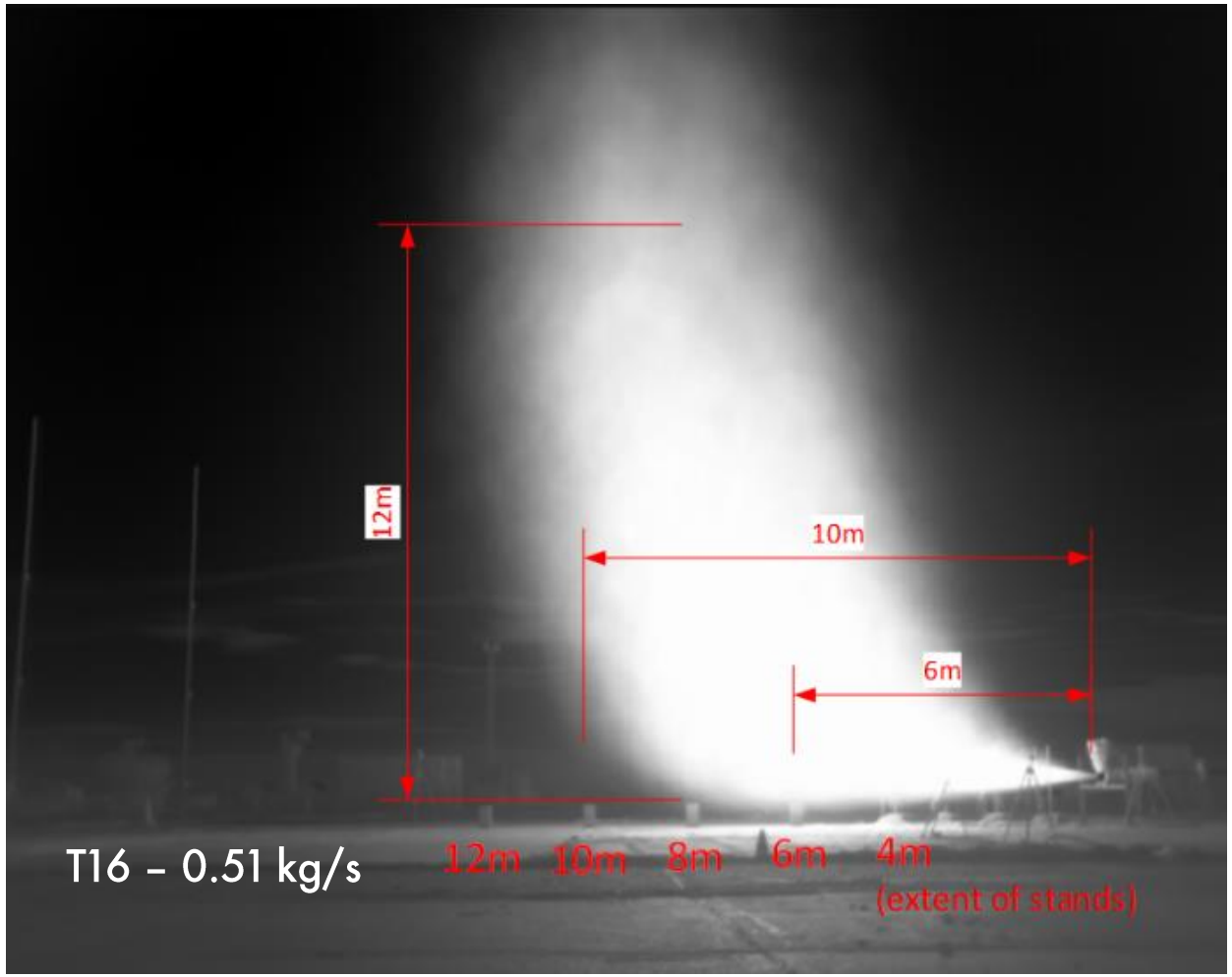
Jet Fires

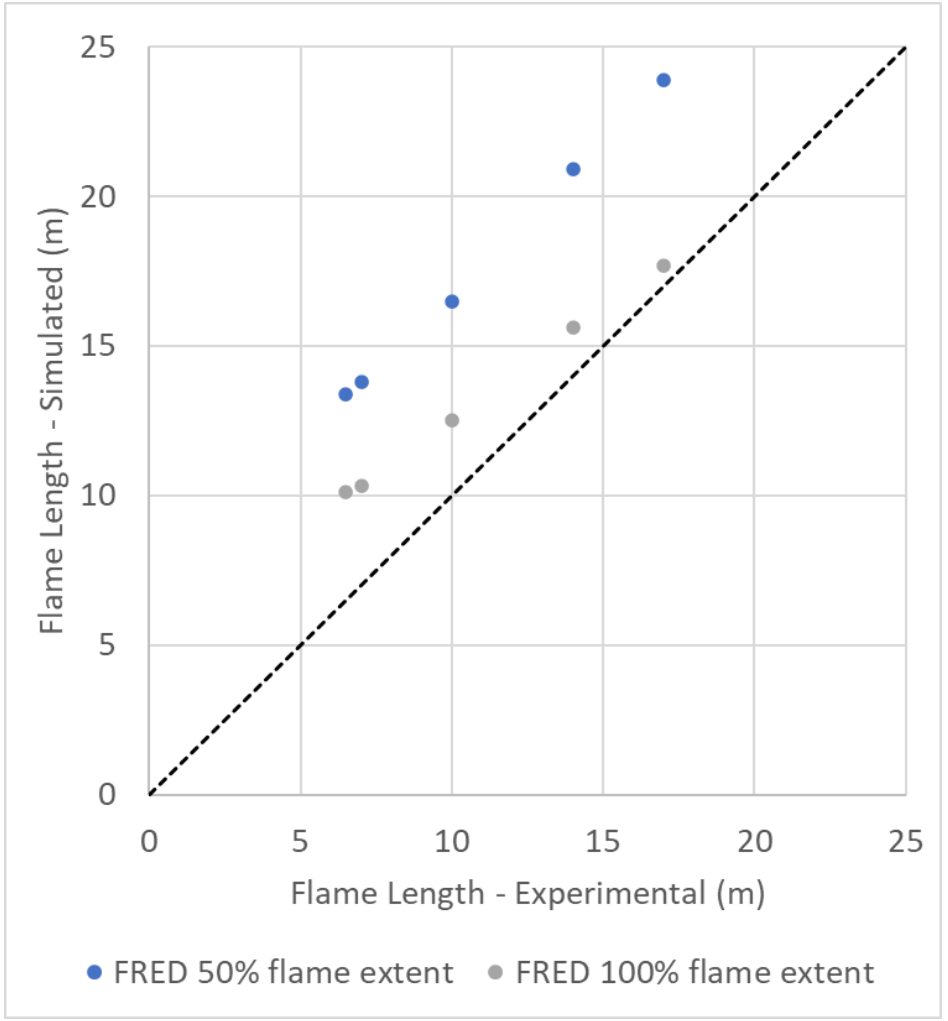
Example of Jet Fire result

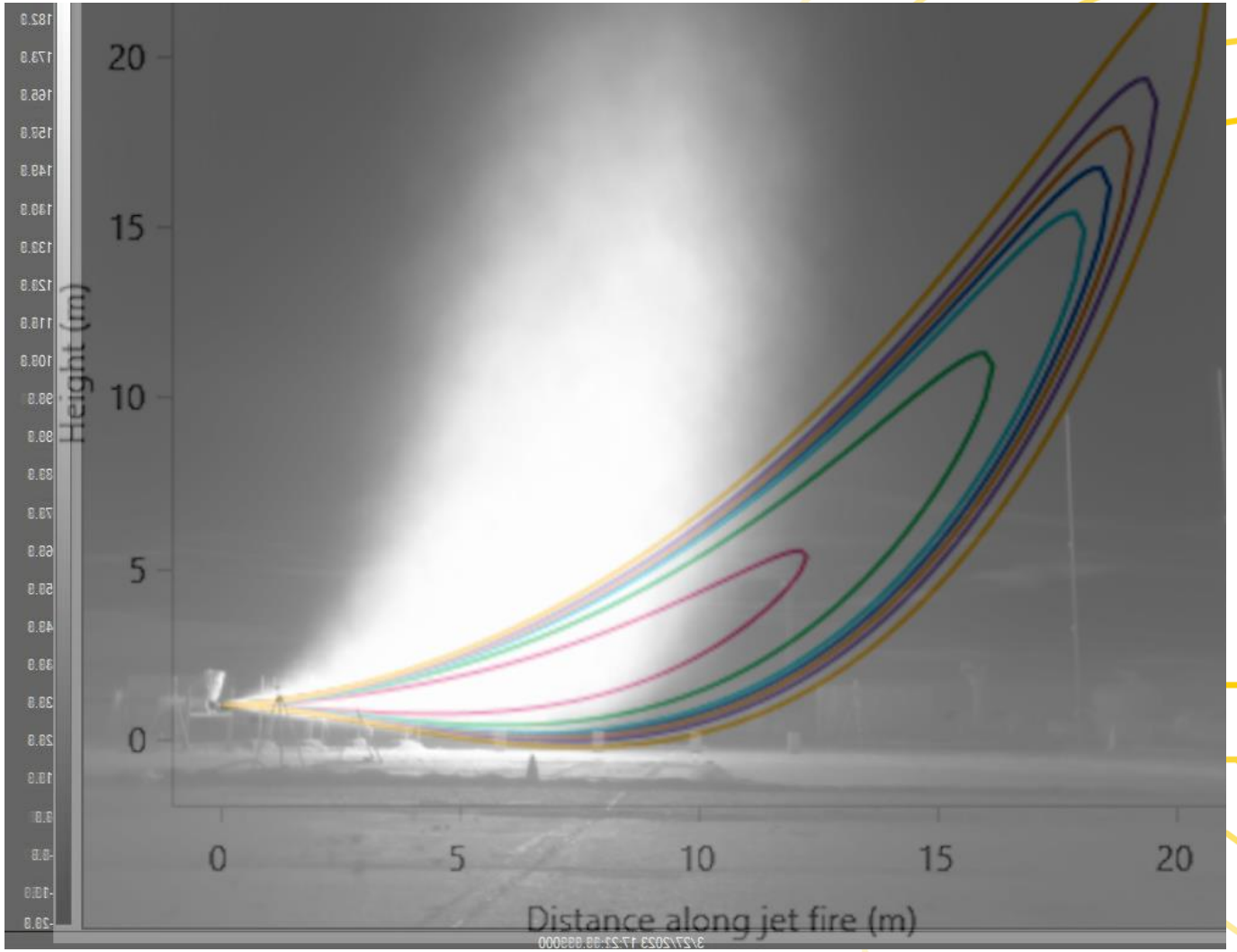
Quantification of Jet Fire Size



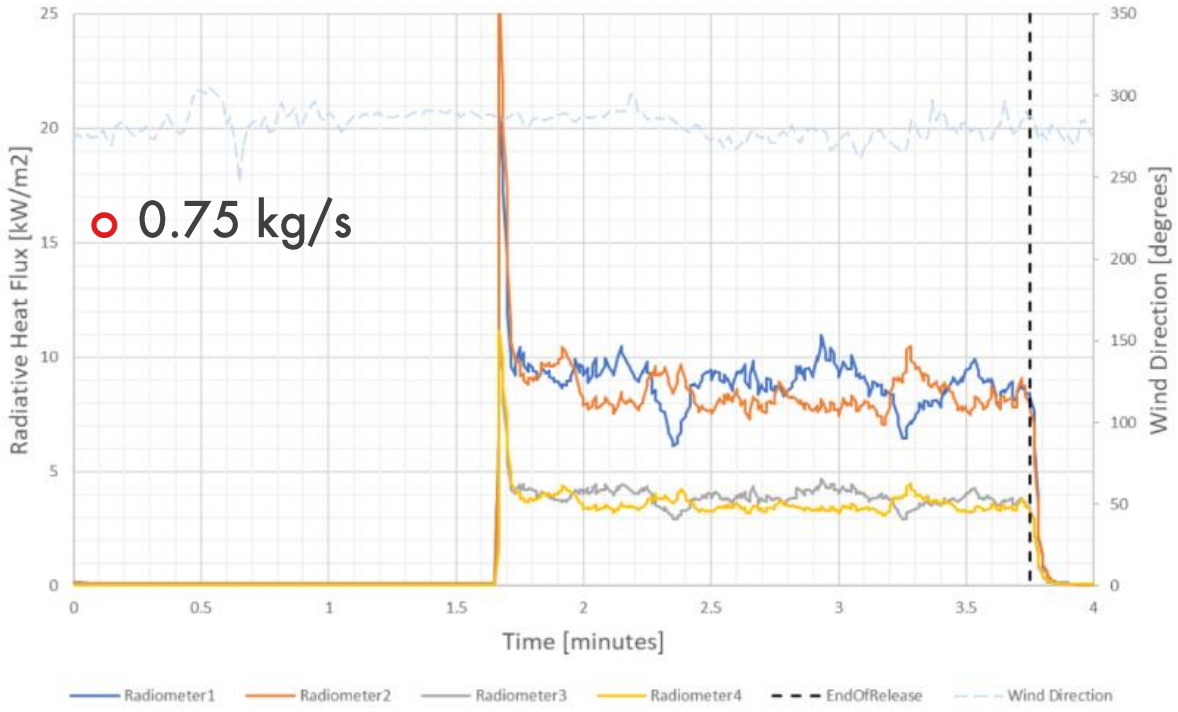
Test ID	Flow Rate	Length (m)	Height (m)
T11	0.24	6.5	6.5
T12	0.27	7	6.5
T16	0.51	10	10
T18	0.75	14	12.5
T21	0.91	17	13

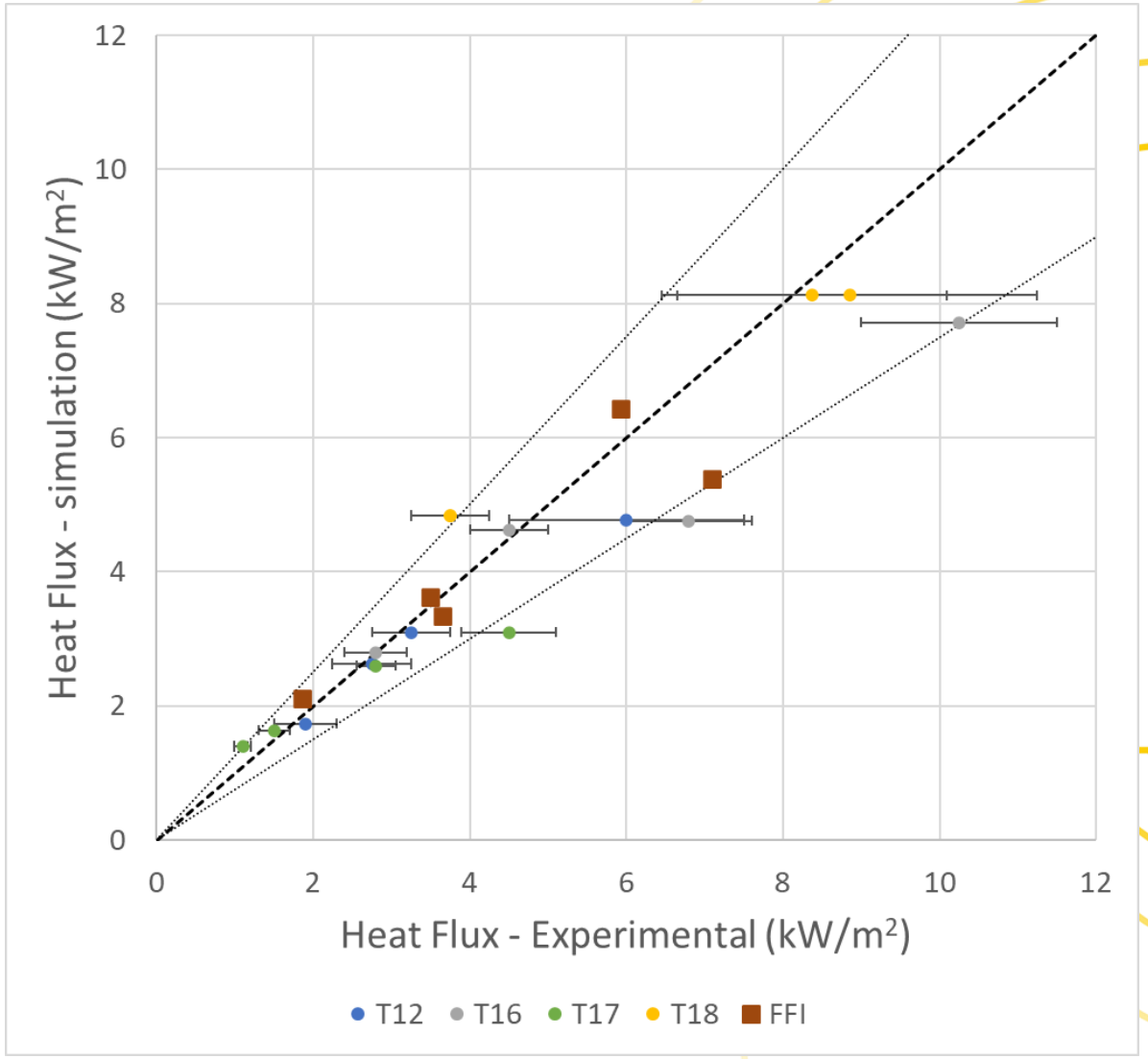
Validation of Jet Fire Model





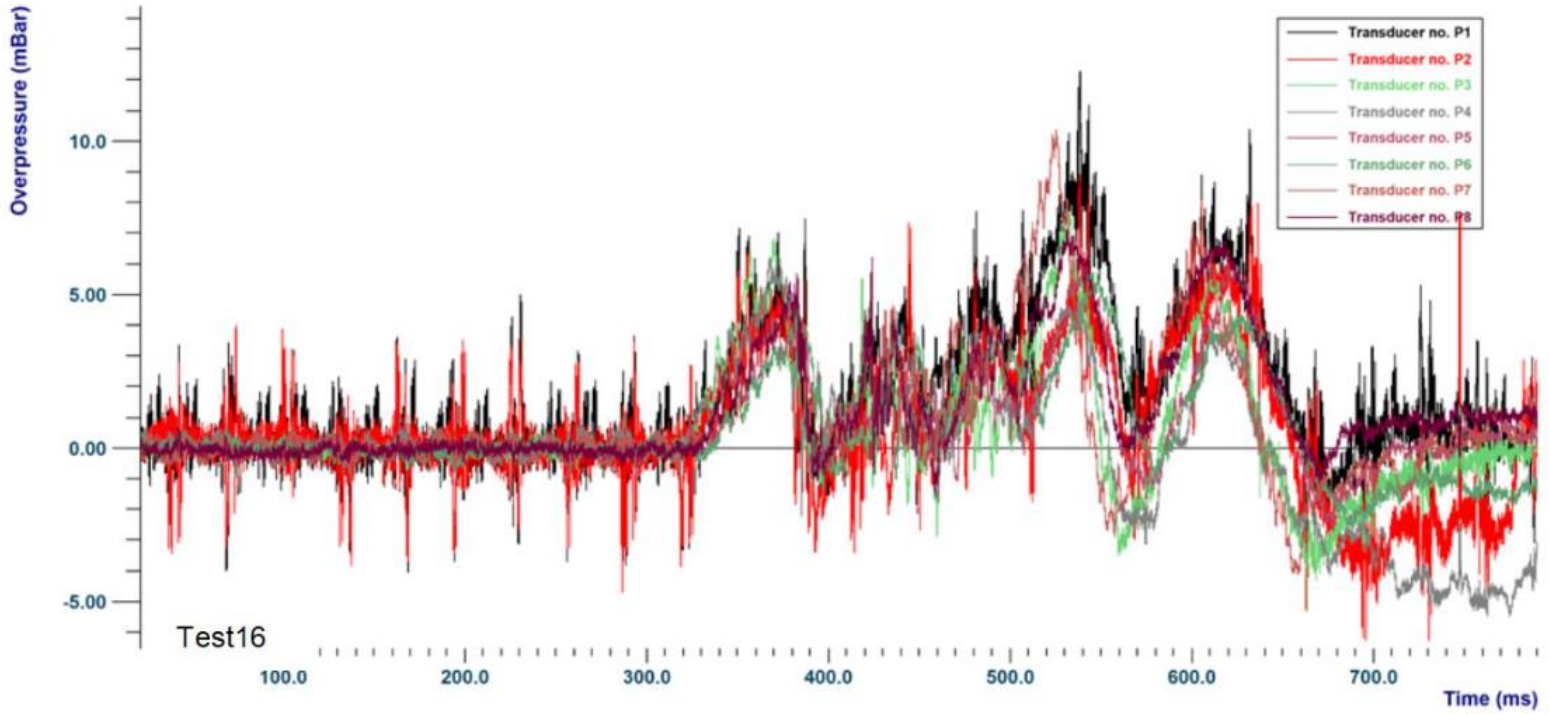
Thermal Radiation



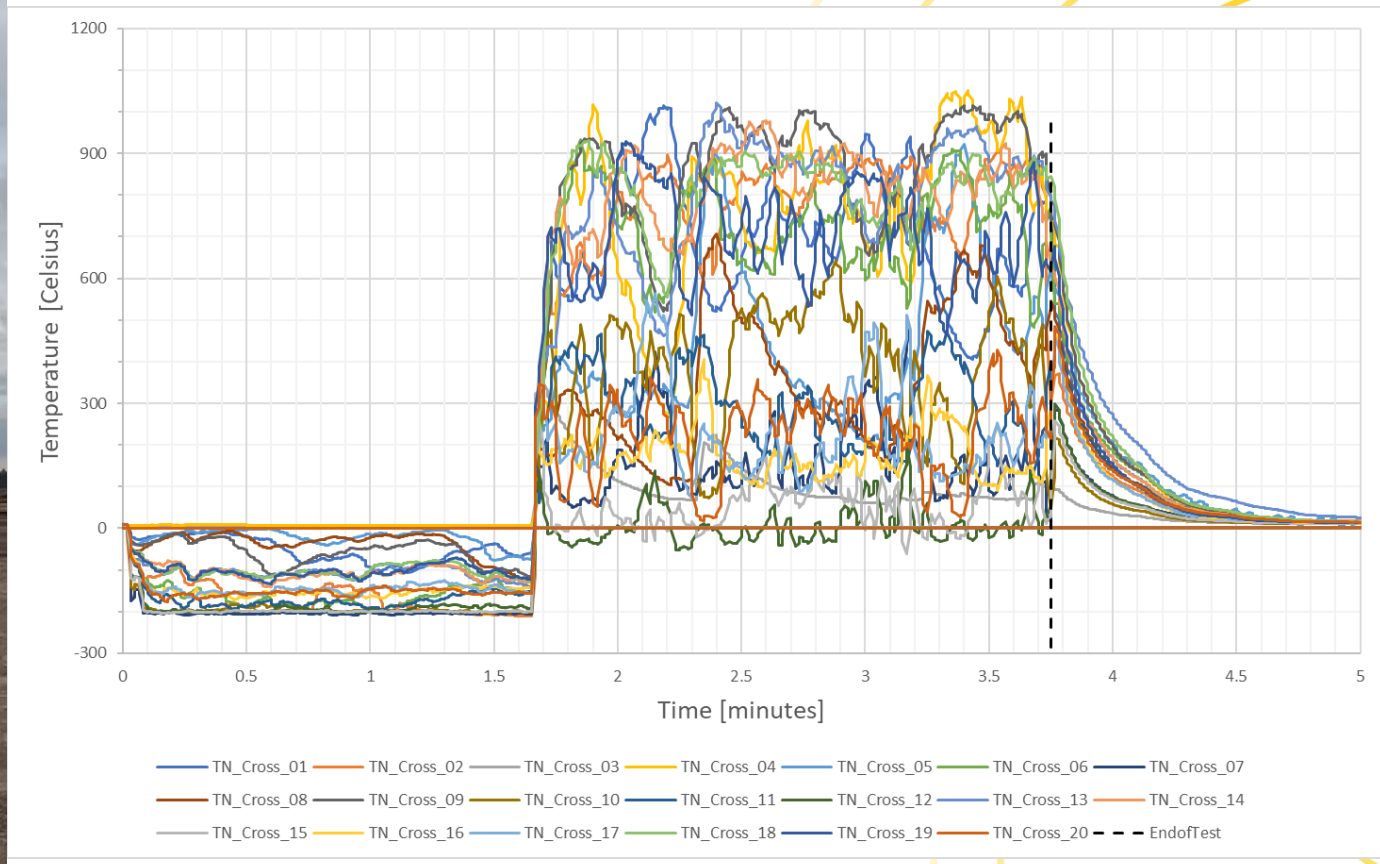


Overpressure

- Overpressure occurred for all ignited jets
  - Max overpressure 4-10 mbar
  - Multiple peaks



Flame Impingement



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Summary

Summary

- A dedicated experimental programme on large LH_2 releases has started
- A sustained LH2 pool was generated and regression rates calculated
- An AkzoNobel CSP coating used for marine / offshore deck applications showed no adverse effects
- Dispersion measurements indicate a transition from dense to buoyant behaviour
- The overpressure following ignition resulted in an OP ≤ 10 mbar
- Jet Fire results for LH_2 have been quantified (0.25 kg/s to 1 kg/s)
  - LH_2 jet fires have significant buoyancy and standard jet fire models overpredict flame length
  - FRED gives good prediction of overall thermal radiation
- Ongoing work to complete dispersion analysis
- Future work in 2024 is being planned

Q&A