WHEN TRUST MATTERS

LH_2 Releases at Large Scale

Associated with Norwegian Ferry Application

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Full Reports and Dataset:

https://www.vegvesen.no/fag/trafikk/ferje/gronn-ferjedrift/testing/

Introduction

- Project executed by FFI Forsvarets forskningsinstitutt Norwegian Defence Research Establishment and relating to LH_2 bunkering
- Funding provided by Statens vegvesen (Norwegian Public Roads Administration)
- Need for large scale data on LH2 release phenomena for model development and validation
  - 'Outdoor Releases'
    - Including preliminary modelling exercise (Ann and Jan)
  - 'Closed Room Releases'
- Today:
  - Experimental Arrangements and methods used
  - Programme Details
  - Results by phenomenon

https://www.norled.no/en/news/the-mf-hydra-first-in-the-world/ © NORLED

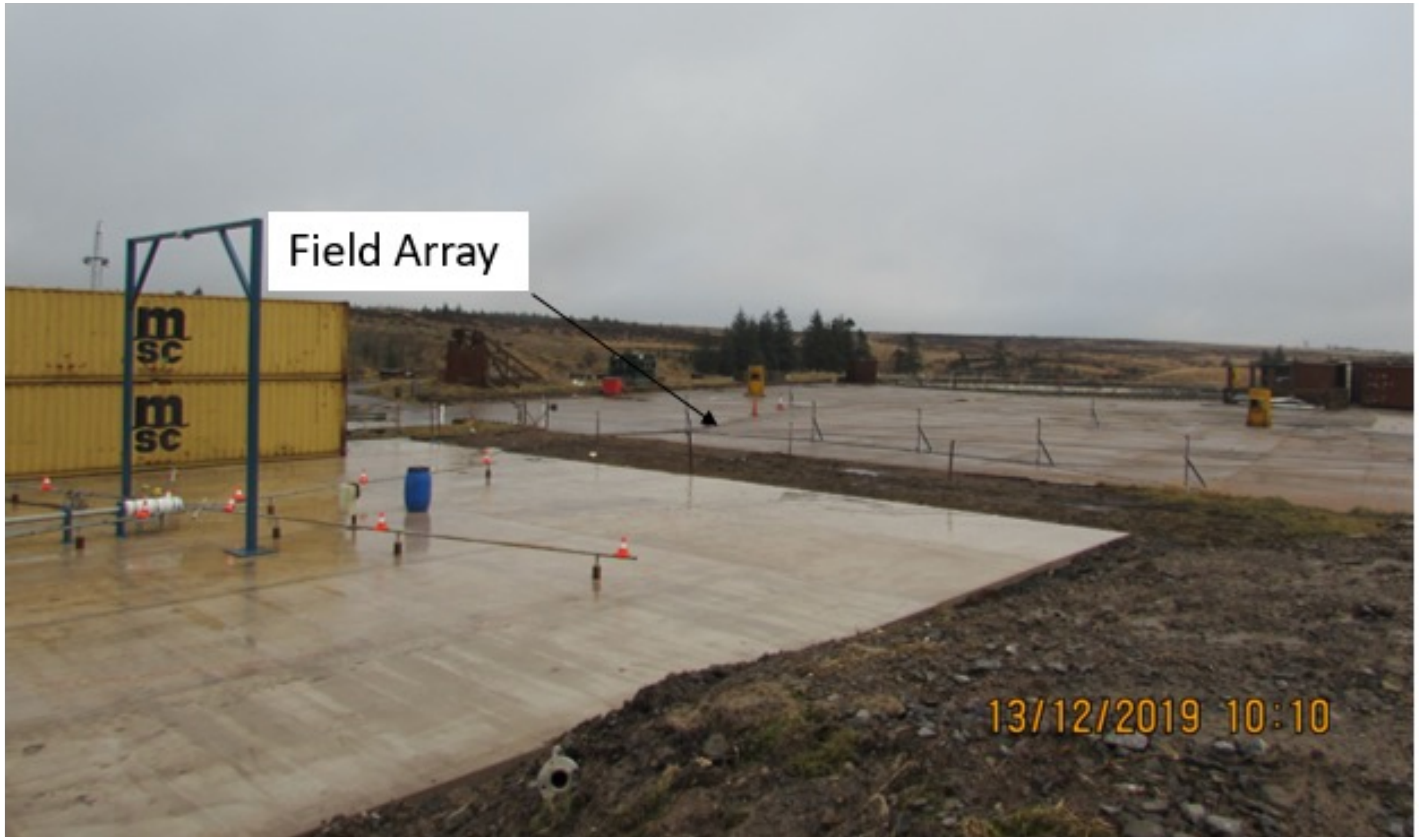
Experimental Arrangement

Experimental Arrangements: Bulk LH_2 Delivery

Experimental Arrangements: LH_2 Supply Pipework

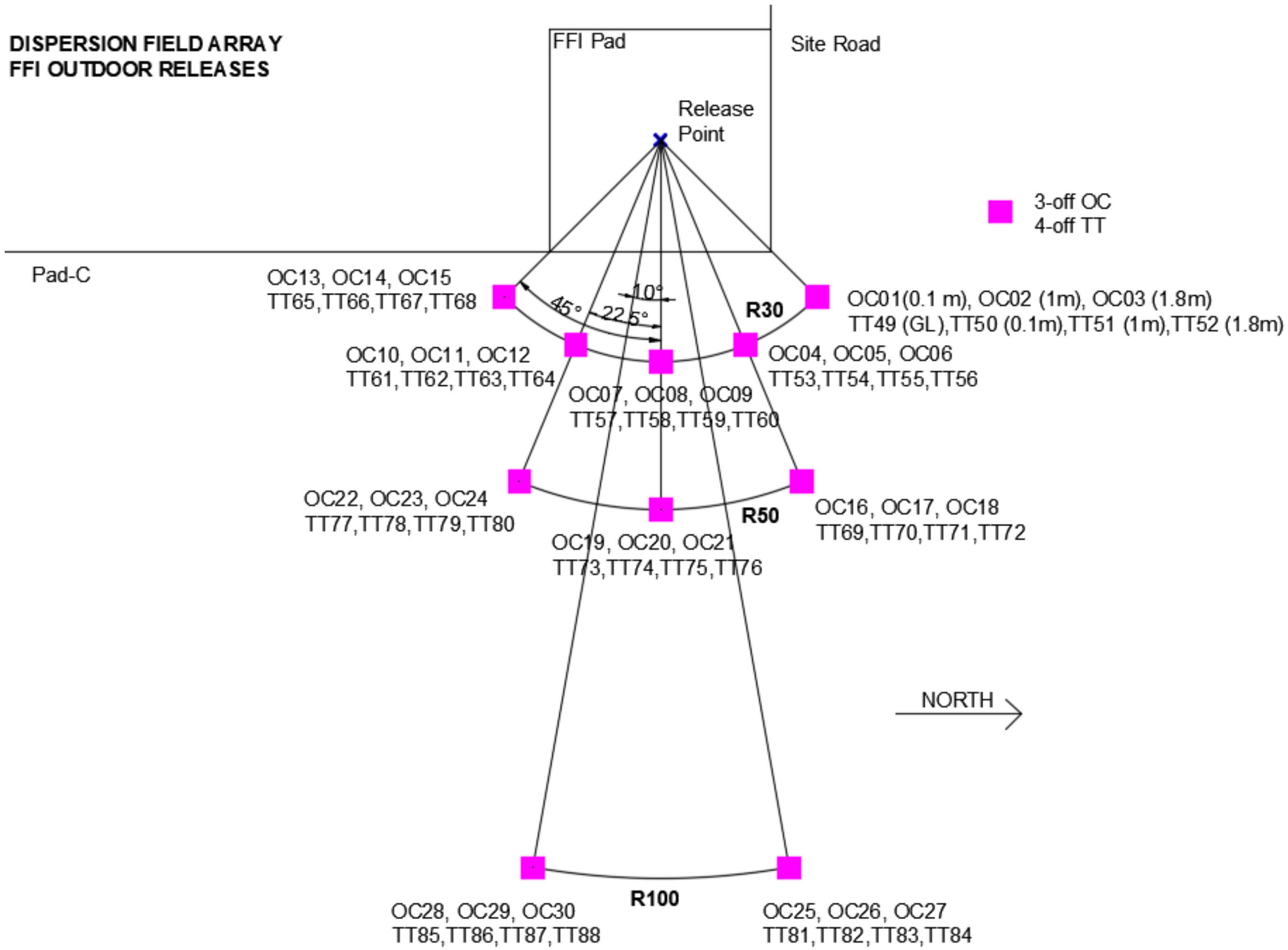
Experimental Arrangements: Open Releases, Near-Field Array

Experimental Arrangements: Open Releases, Field Array



Experimental Arrangements: Open Releases, Field Array

- E.g. Test01



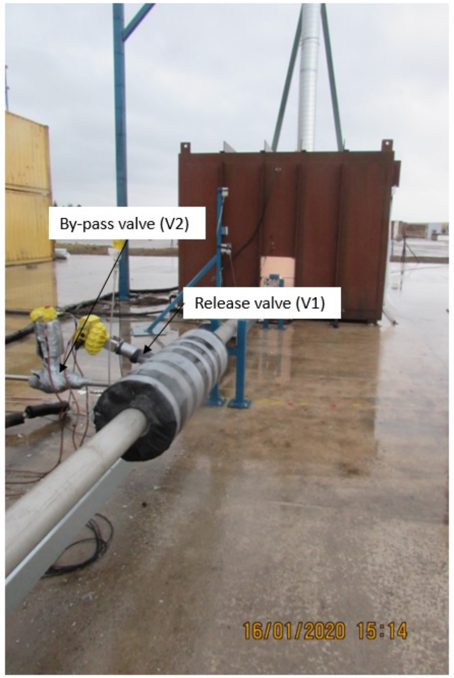
Outdoor Programme

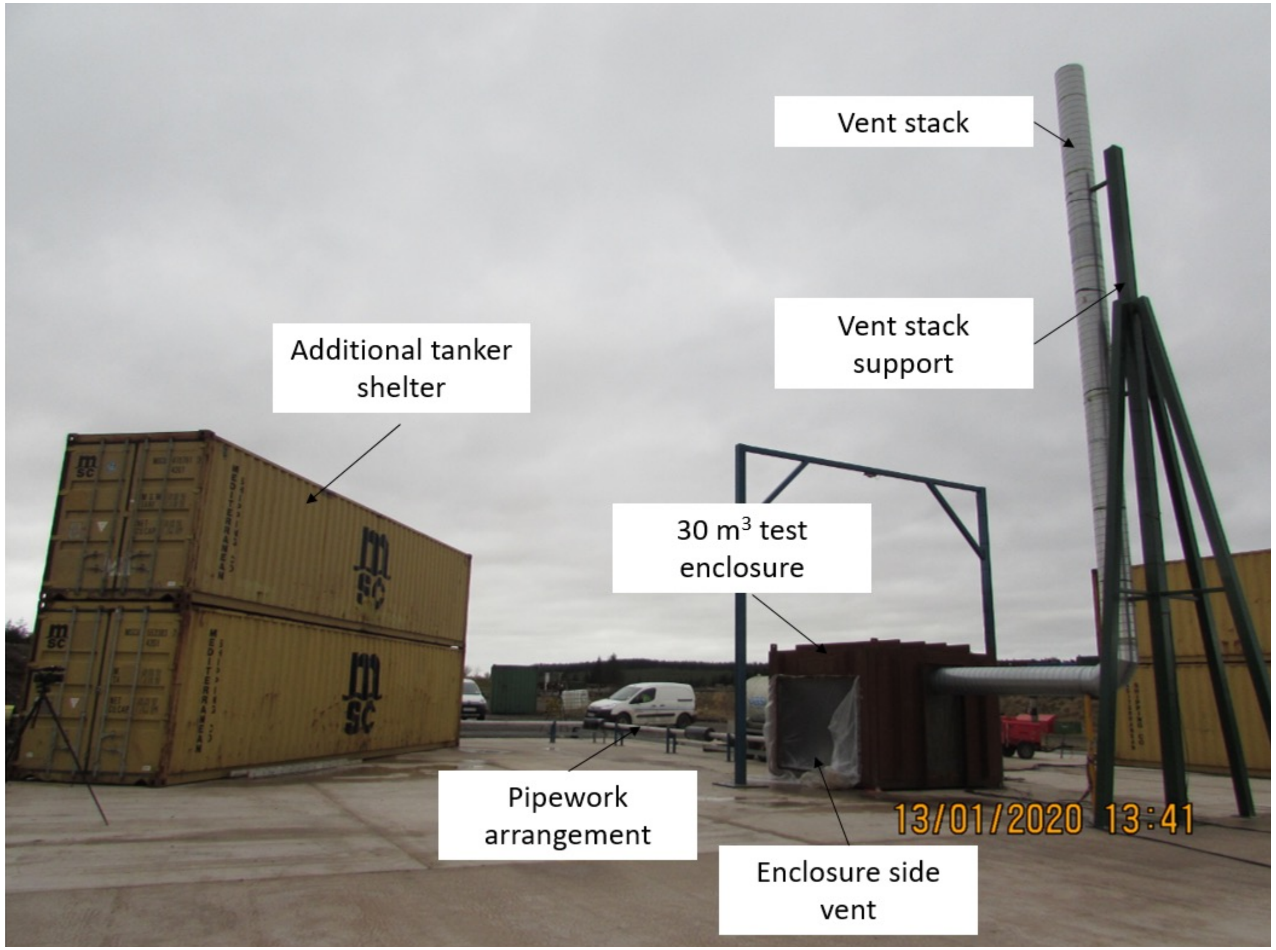
- Variants in:
  - Orientation
  - Ignition Yes/No
  - Initial Tanker Pressure
  - Run Time
  - Wind Speed / Direction

Test No	Release Orientation	Ignition	Initial Tanker Pressure (barg)	Outflow (kg/min)	Run time (min)	Wind Direction	Observations
1	Vertical Downwards	No	2	13.5	13	W-WSW	• First test performed at pressure as received. • All instrumentation in original positions
2	Vertical Downwards	No	6	28.2	8	E-ENE	• Easterly wind present, field array stands re-positioned to the West and to front of ISO container. • Tanker initial pressure increased to achieve higher flow rate (6 barg on tanker prior to release)
3	Vertical Downwards	No	10	43.8	15	W-WSW	• Increase tanker initial pressure to 10 barg to achieve higher flow rates • Back on Westerly wind, instrument stands on West re-positioned to R100 m on East.
4	Horizontal	No	10	49.7	6	W-WSW	• Repeat of Test03 but with a horizontal orientation, co-flowing with wind
5	Vertical Downwards	Yes	10	42.9	6	W-WSW	• Repeat of Test02 but ignited • Suspected voltage interaction between ignitors and release valve. Release had to be re-initiated and left to run again for 2 minutes before ignition at 18m downwind.
6	Horizontal	Yes	10	49.9	3	W-WSW	• Repeat of Test04 but ignited • Ignited on first firework (30 m downwind of release point)
7	Vertical Downwards	No	0.8	9.7	8	W-WSW	• Final release to empty tanker at saturation pressure • Heavy rain present

Experimental Arrangements: Closed Room

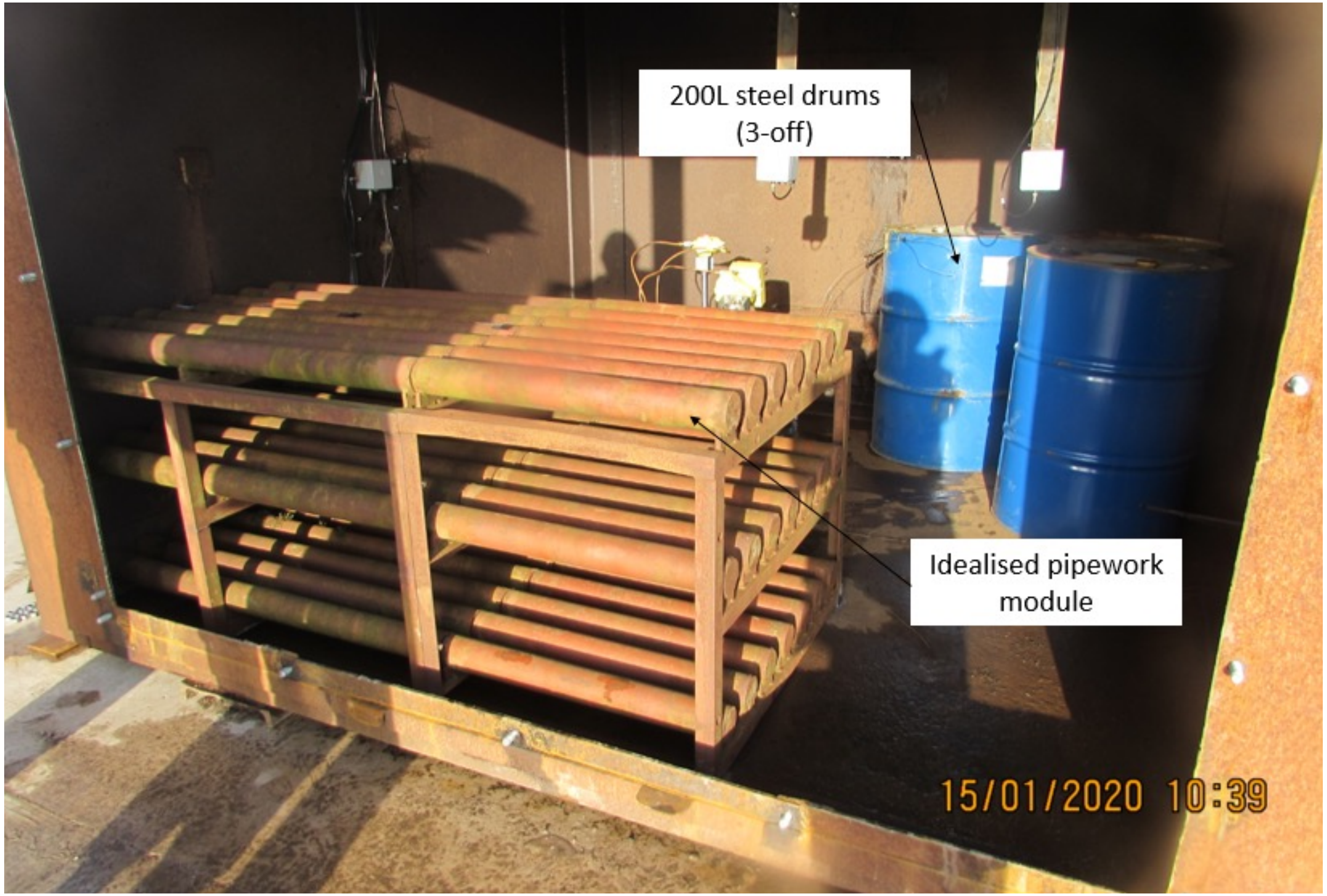
- Same as Open Releases but:
  - Included ~30m^3 'Closed Room'
  - Included 13m high vent stack





DNV

Experimental Arrangements: Closed Room



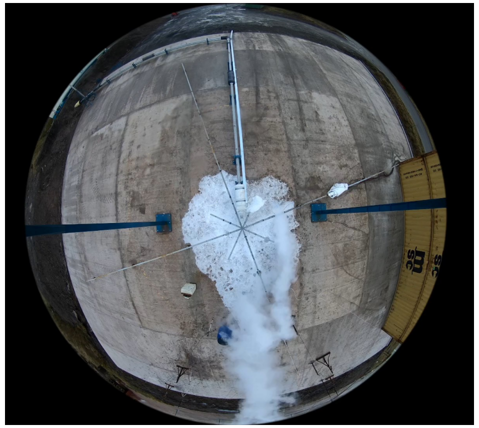
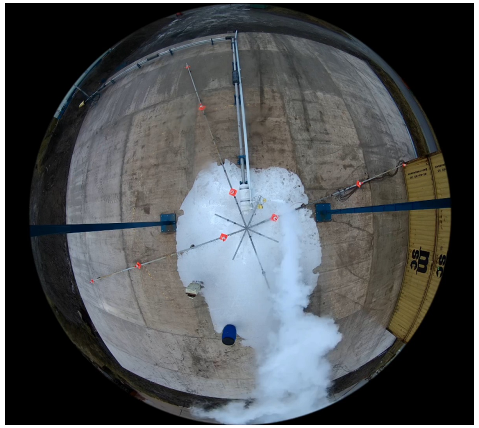
Experimental Arrangements: Closed Room

Closed Room Programme

- Variants in:
  - Orifice size
  - Ignition Yes/No
  - Initial Tanker Pressure
  - Run Time
  - Purge
  - Ventilation mast isolation
  - Wind Speed / Direction

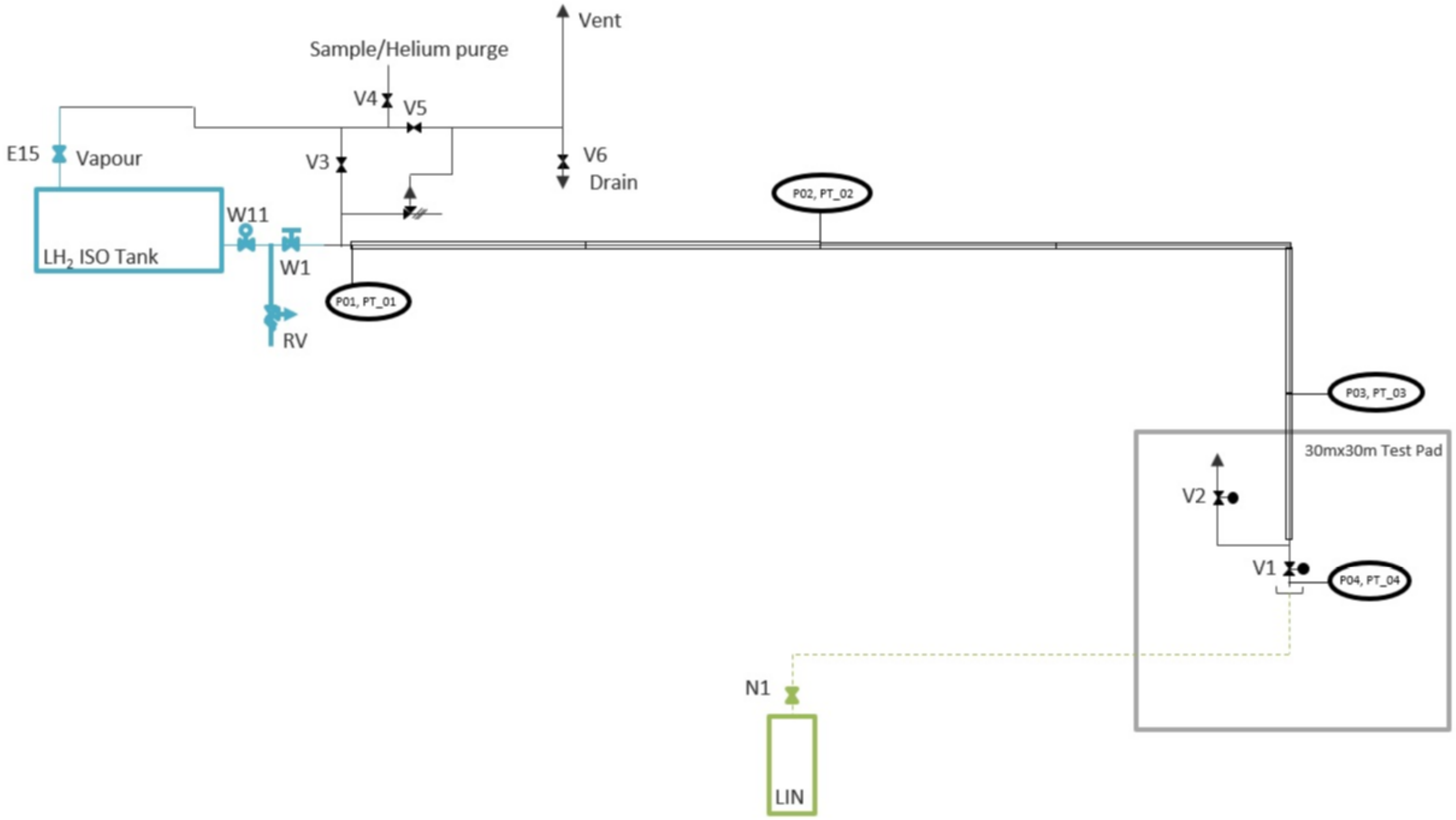
Test No	Release Size	Ignition	Initial Tanker Pressure (barg)	Outflow (kg/min)	Run time (min)	Observations
8	1”	No	1.5	11.0	11	• First test performed at pressure as received. • All instrumentation in original positions
9	1”	No	10	32.6	11	• Field array stands re-positioned to the top of the ISO container. • Tanker initial pressure increased to achieve higher flow rate (10 barg on tanker prior to release)
10	½”	No	10	28.6	10	• Release nozzle size decreased to ½”NB to achieve single phase and higher outflow. • Obstacles introduced inside closed room including 3-off water-filled drums and idealised pipe array. • Data on H2 decay in ventilated closed room collected.
11	½”	No	10	31.3	9	• Nitrogen purge prior to release achieved. • Nitrogen purge re-started once release stopped, however, vent had ripped during release due to cold temperatures.
12	½”	No	10	35.5	5	• Repeat of Test11 but with initial air purge. Plastic vent doubled in attempt to avoid tearing due to cold temperatures. • Nitrogen purge introduced after release to collect hydrogen decay data. • Plastic vent tore due to cold temperatures hence limited hydrogen decay data collected.
13	½”	Yes	10	40.1	3	• Sealed closed room and air atmosphere prior to start of the release. Thin polystyrene sheet installed between plastic vent sheets to avoid tearing due to cold temperature in closed room. • Ignited test (ignition at top of vent stack). • Temperatures increased in stack over time for around 30 minutes when second event occurred, a low pressure explosion in the TCS
14	½”	Yes	10	22.2	2	• Ventilation increased by removing sealing of low-level vent. Thin polystyrene sheet installed between plastic vent sheets to avoid tearing due to cold temperature in closed room. • Ignited test (ignition at top of vent stack). Ignition achieved on first firework. • Temperatures rapidly increased in stack (1-2 minutes) when second event occurred, a significant explosion in the TCS. • Vent stack and TCS floor suffered significant damage.
15	½”	Yes	10	24.6	3 (unignited) then 3 (ignited)	• Vent stack outlet in box sealed. • 10 barg release onto closed box. • Ignitor to be activated when concentration in box decayed to highly reactive mixture levels (~30%vol). • Two releases were performed, after first release data on gas concentration decay at different location within the closed room was collected. Following the second release, concentration level near ignitor location was monitored. As concentration decay was slow it was agreed to ignite mixture when concentration fell to 50%vol.

Videos

	Above	Ground Level	Ignited
Downwards			
Horizontal			
Confined			

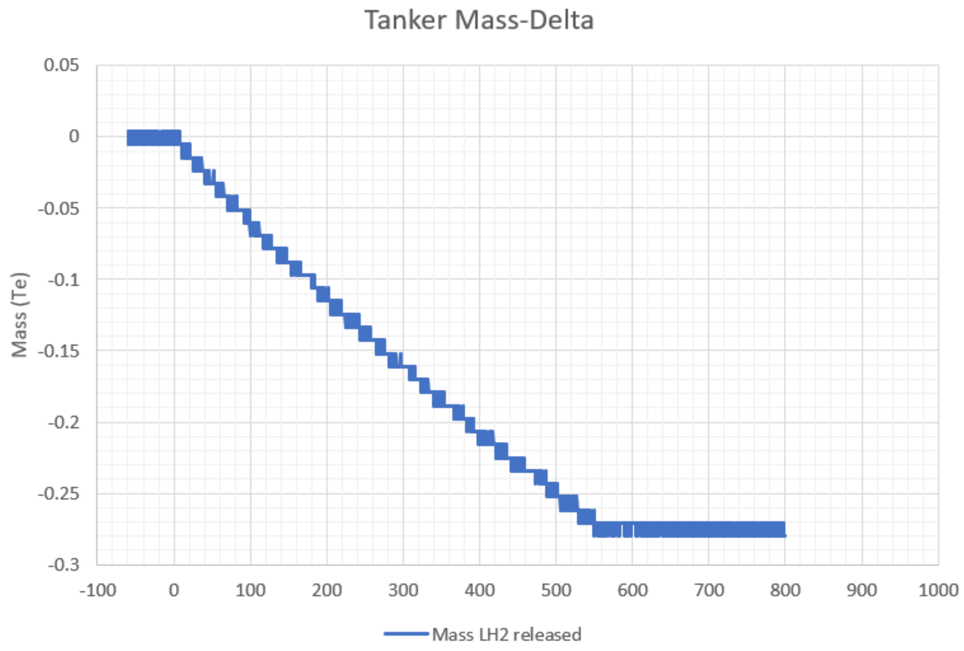
Outflow / Flashing

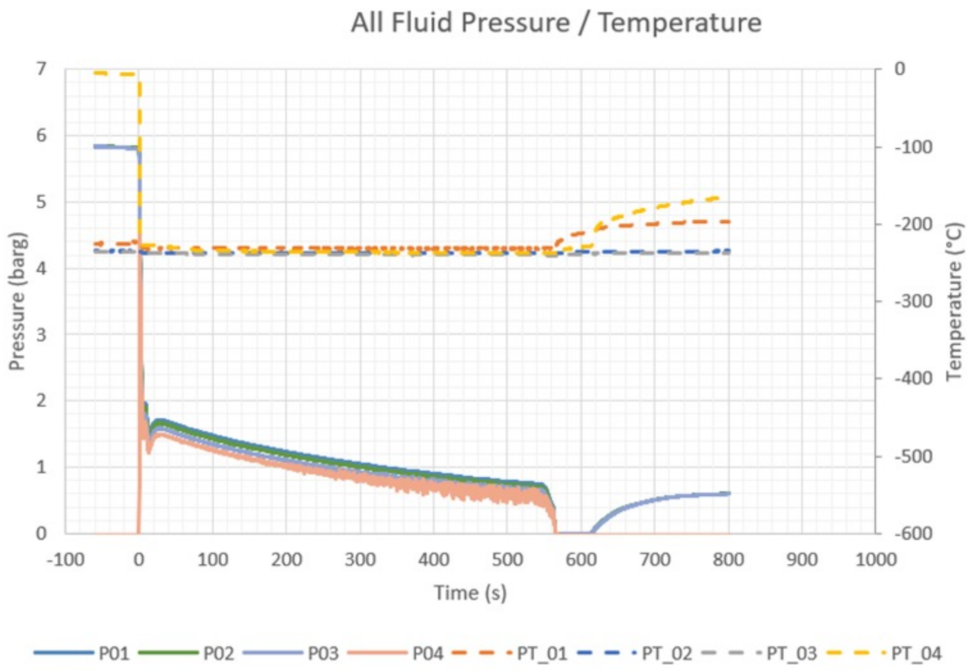
Schematic experimental set up: overview



From Experiment: Outflow

- Pick averaging period
- 100-500 seconds here





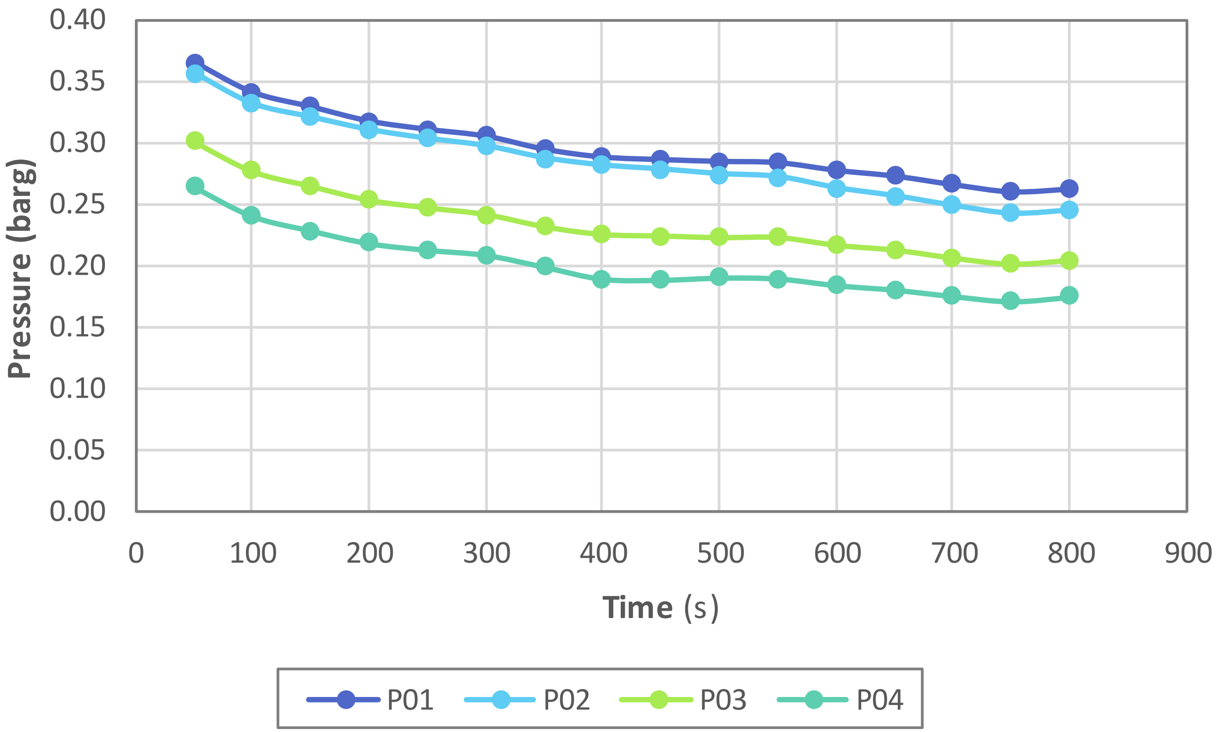
Sensor	Average	Max	Min	STDEV	units
Mass LH2 released	-	-0.060	-0.253	-	Te
P01	1.07	1.48	0.78	0.20	Barg
P02	1.03	1.43	0.73	0.20	Barg
P03	0.95	1.35	0.61	0.19	Barg
P04	0.87	1.27	0.48	0.19	Barg
PT_01	-231.3	-230.5	-232.3	0.3	°C
PT_02	-237.8	-237.5	-238.1	0.2	°C
PT_03	-239.3	-238.5	-239.9	0.3	°C
PT_04	-236.0	-233.8	-238.1	0.9	°C
MassFlow	0.473				kg/s
Wind_Direction_High	81.9	112.8	41.9	10.4	0.0
Wind_Direction_Low	82.7	118.6	46.1	12.2	Deg
Wind_Speed_High	4.1	6.2	2.4	0.8	m/s
Wind_Speed_Low	3.9	7.7	1.6	1.0	m/s

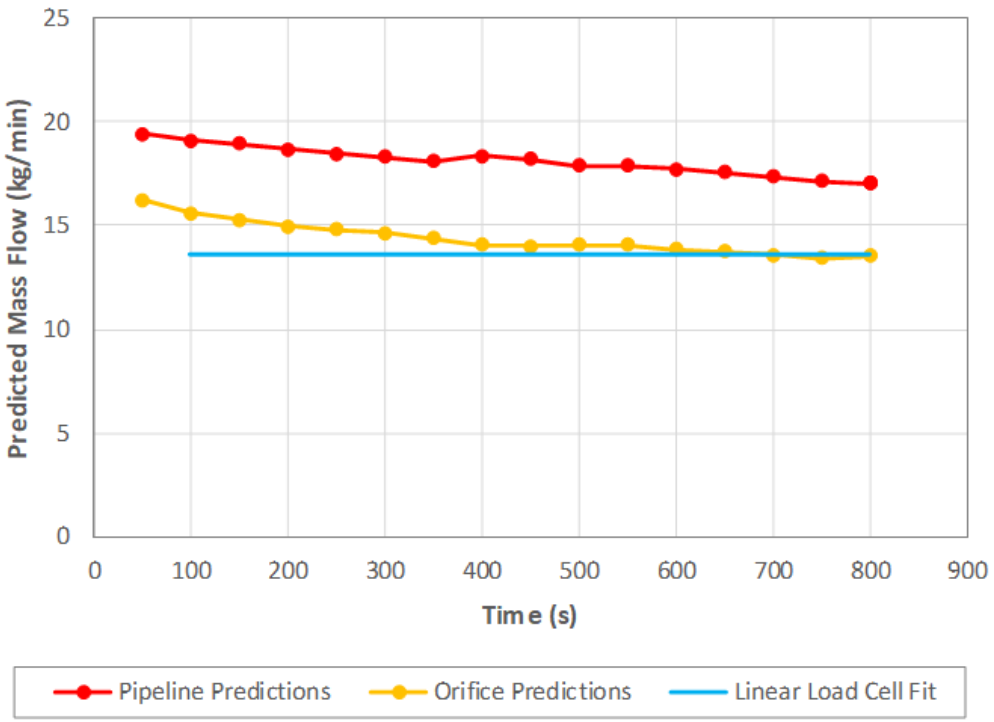
Outflow: FROST

- Using pressure drop along pipeline

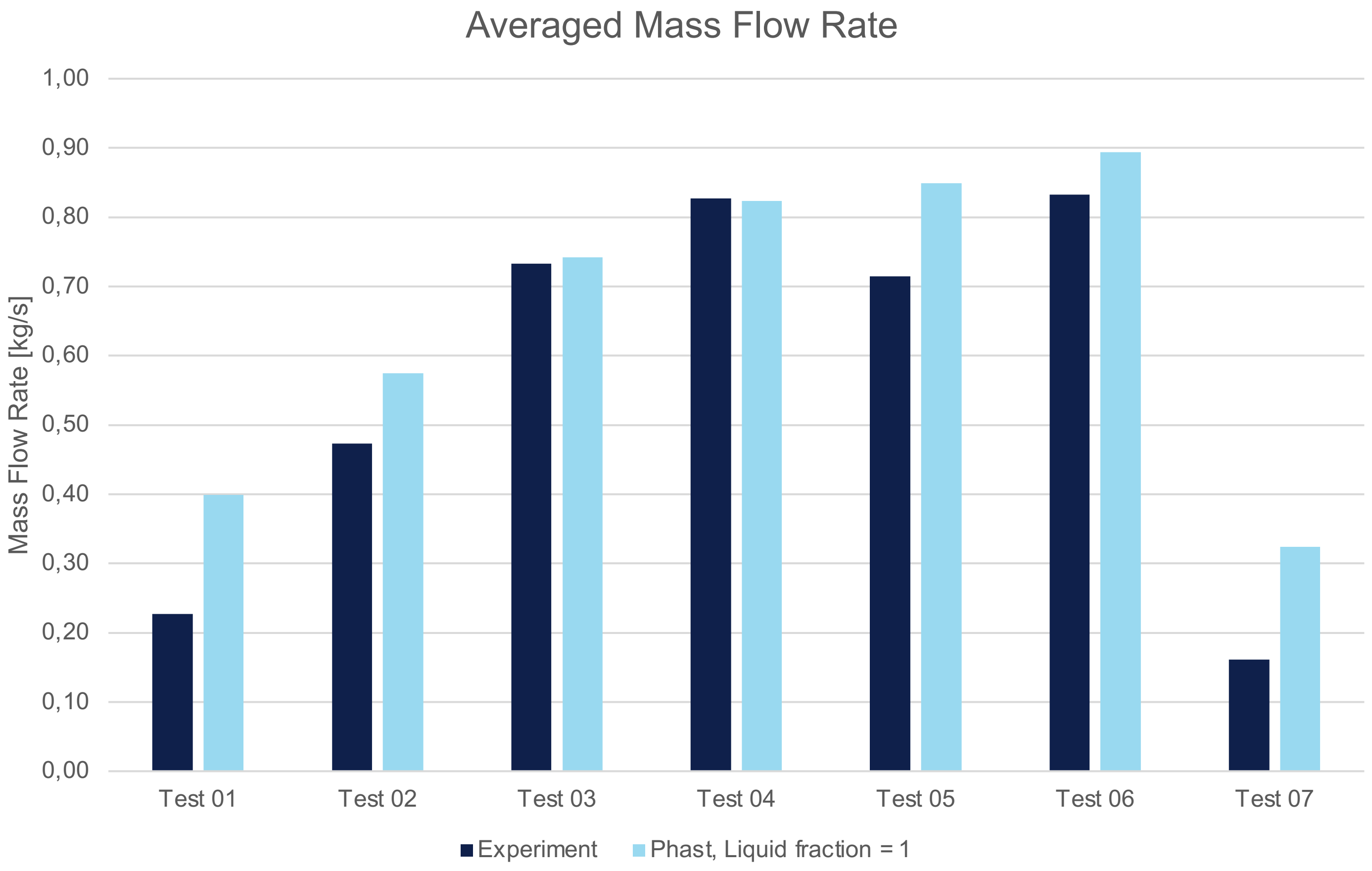
OR

- Orifice calculation





Flow rates: experiments vs Phast predictions

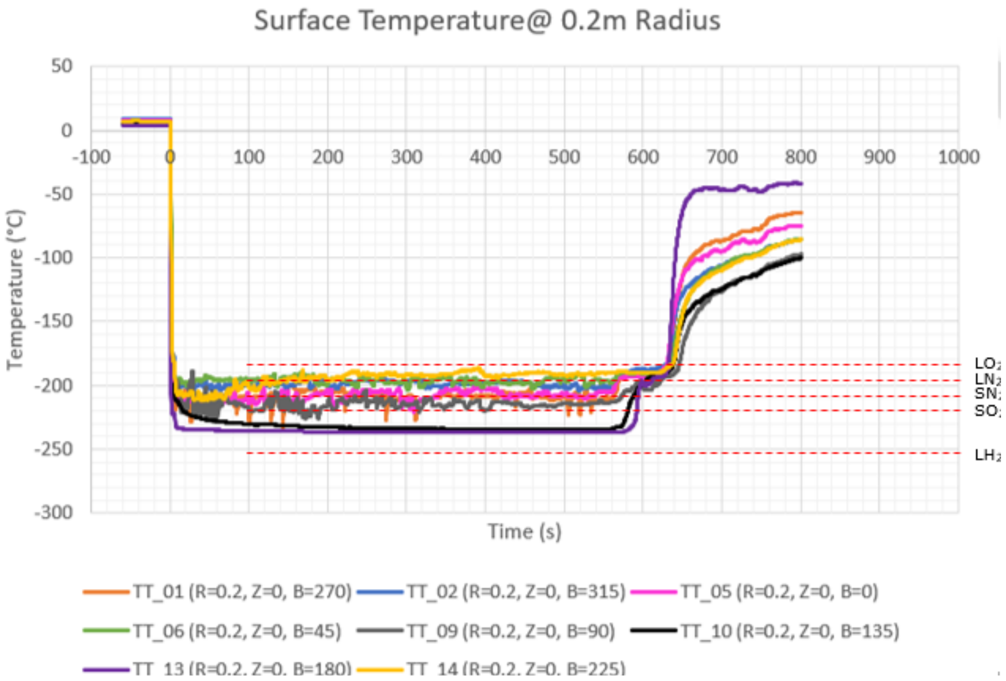


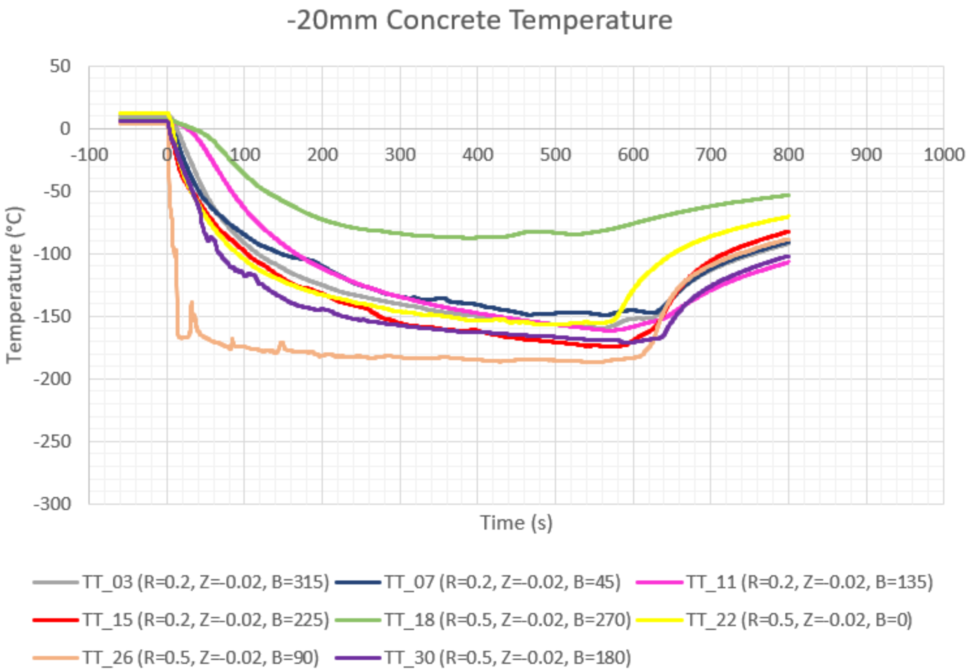
- Standard Phast leak model
- Averaged pressure at P04
- Saturation temperature
- Assume liquid fraction 1.0
- Flow rate predictions: Generally good agreement

Pooling / Rainout

From experiment
Pooling / Rainout

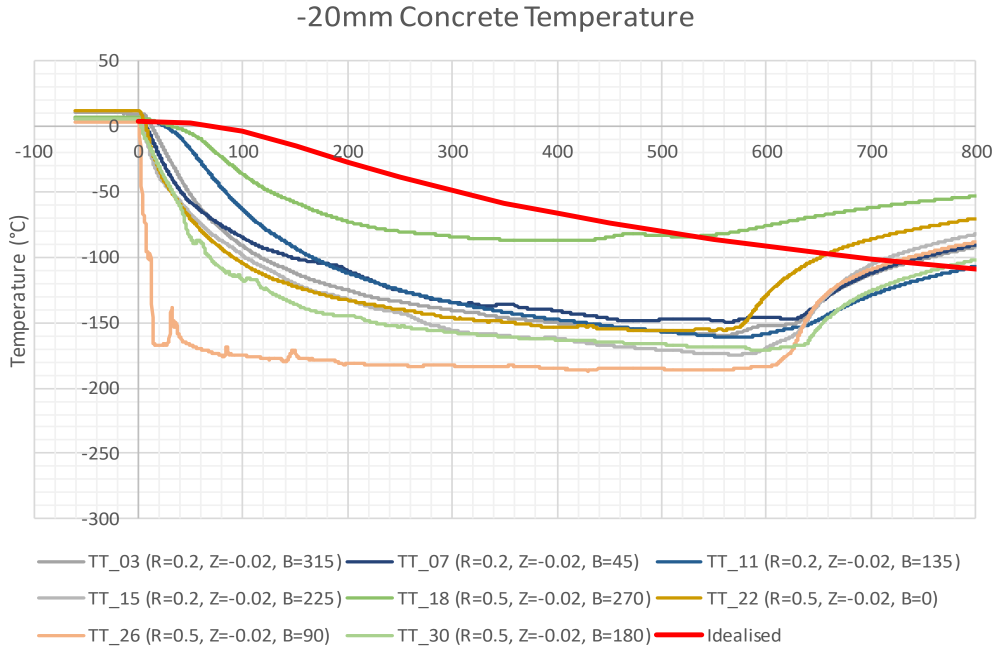
- Surface temperature measurements show evidence of LH_2
  - Difficult to distinguish between 2-phase and actual pool
  - Release in this example (Test02) stops circa 560 seconds
    - Enduring L-Air components ~80 seconds after release
  - No LH_2 evidence beyond 0.5m from release
- No evidence of rainout in horizontal releases

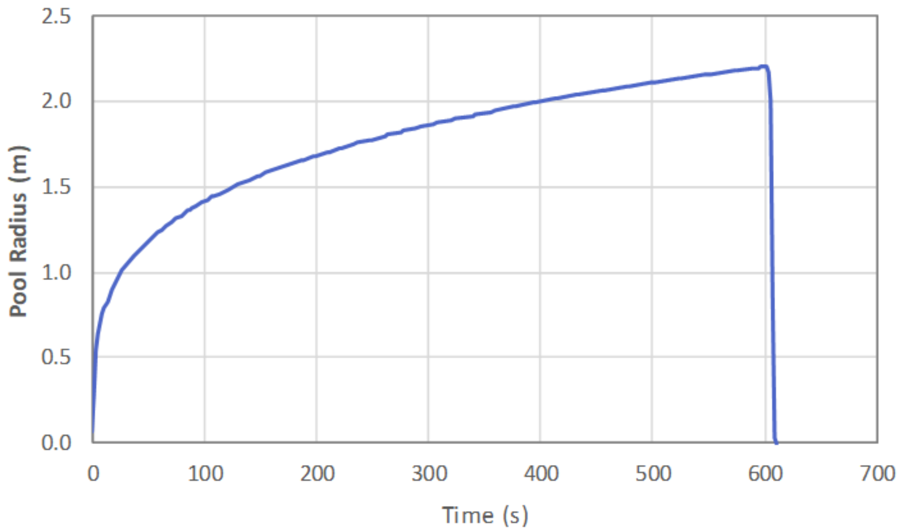


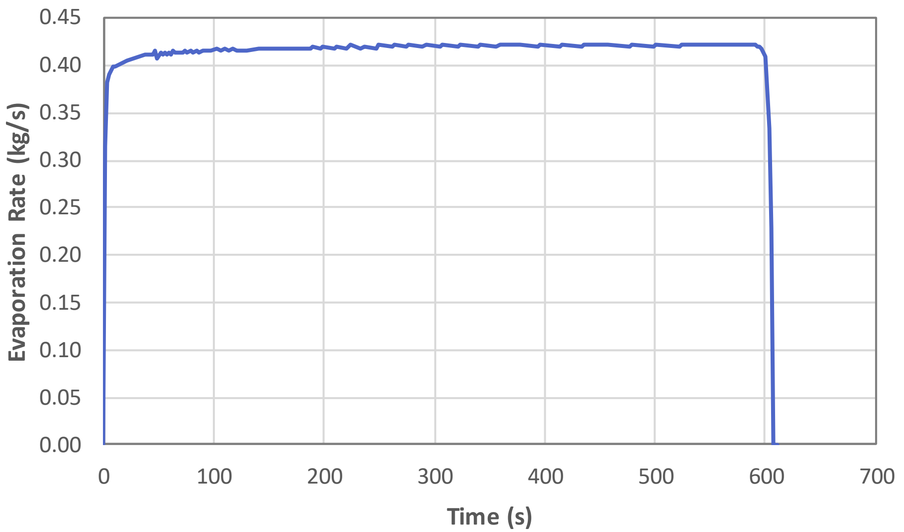


From FROST Pooling / Rainout

- Higher predicted LH_2 pool radius than observed
- Assume 85% by mass hitting ground
- Concrete responding slower in model than experiment

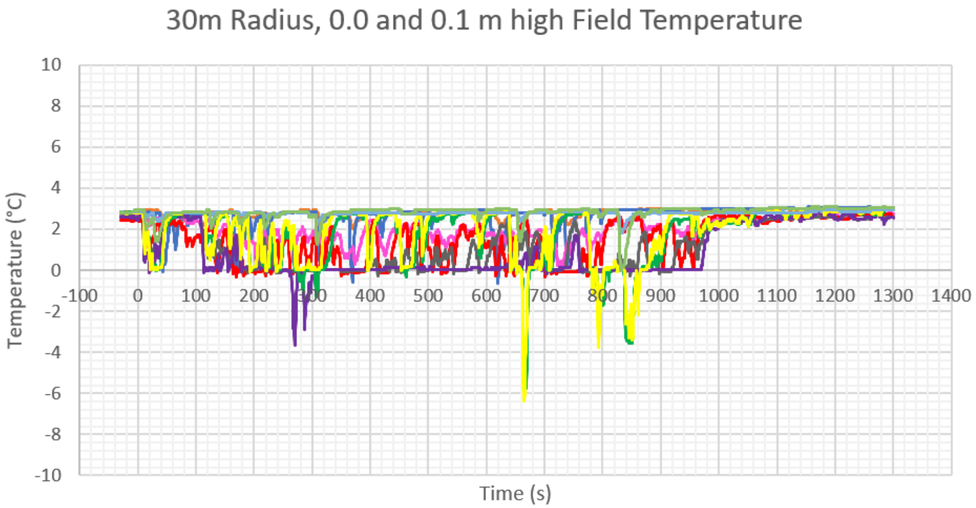


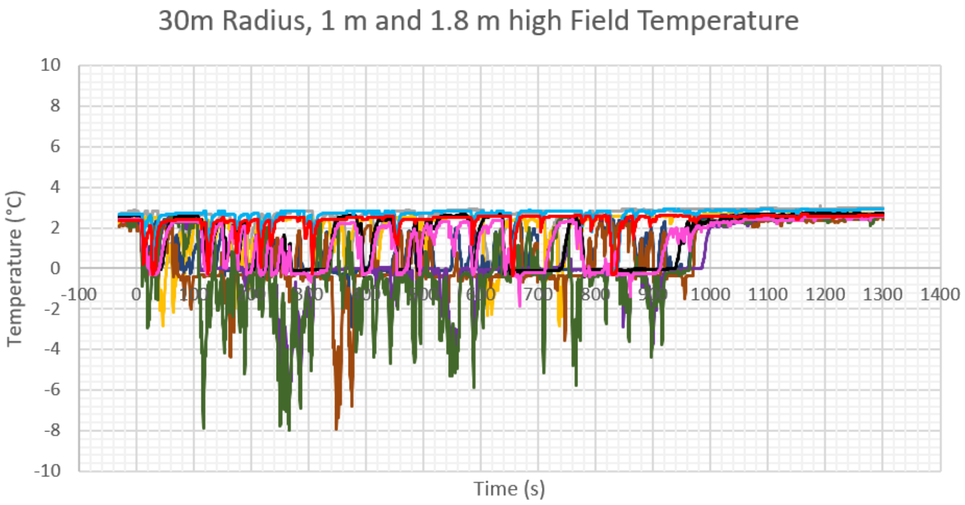


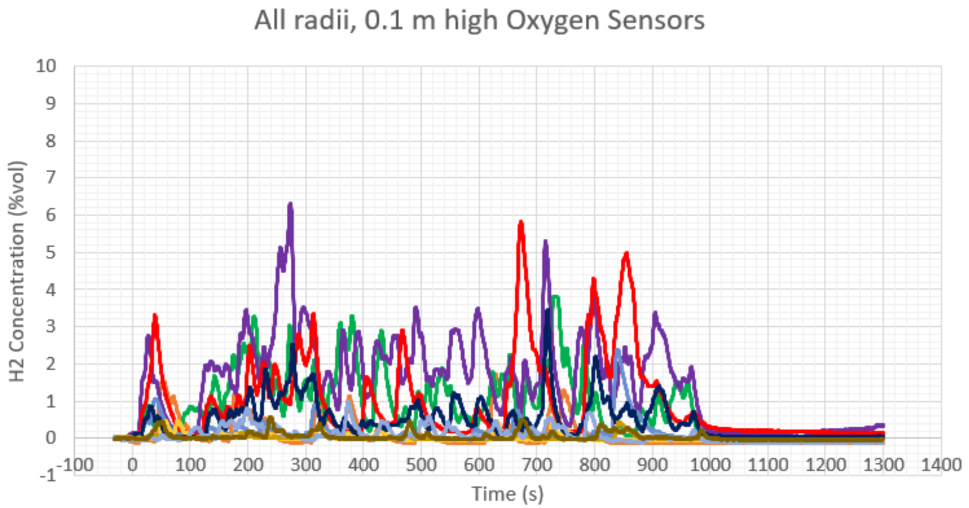


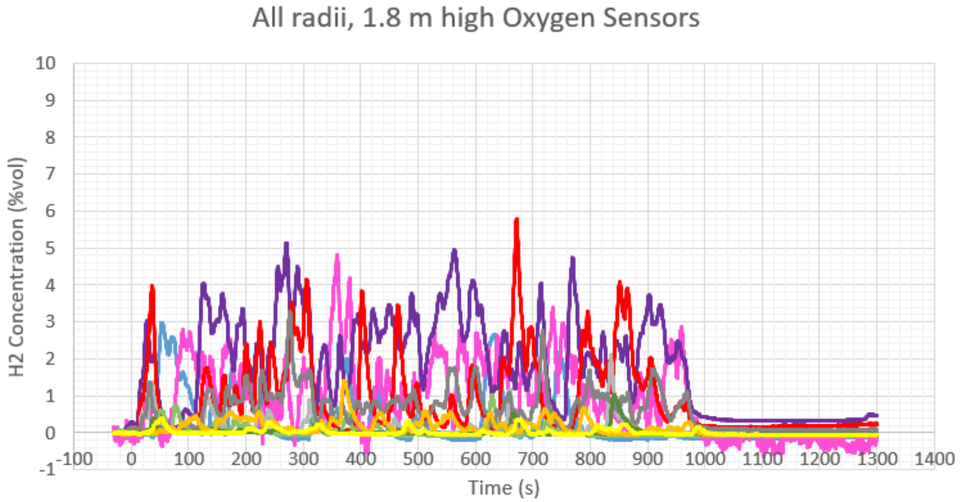
Dispersion / LFL limits

From experiment: Dispersion, LFL Limits

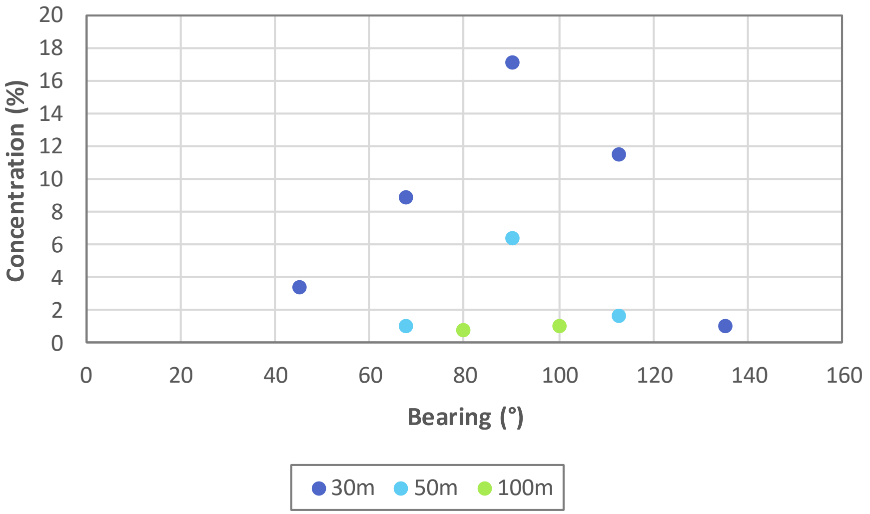


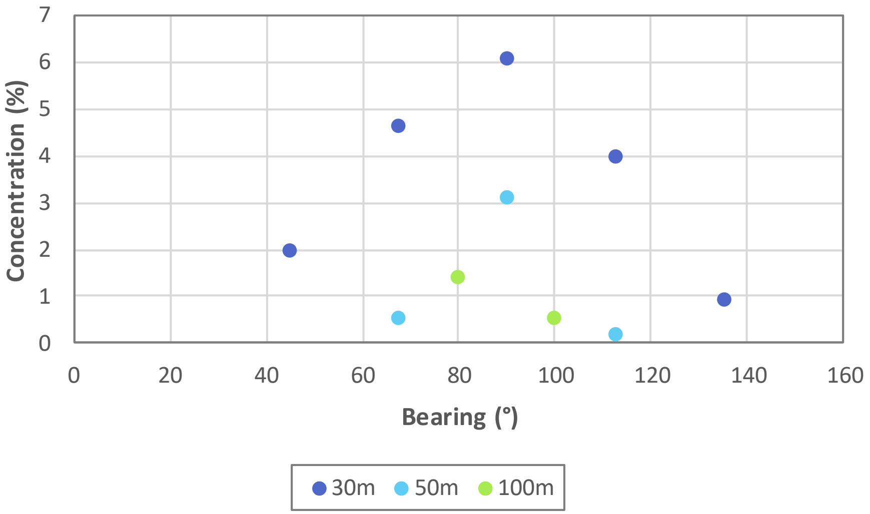






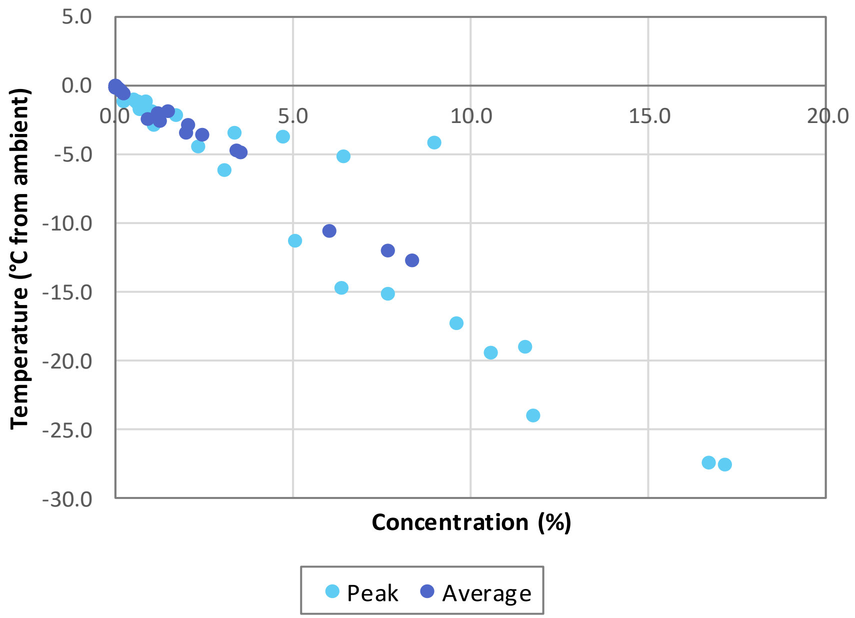
From experiment: Dispersion, LFL Limits

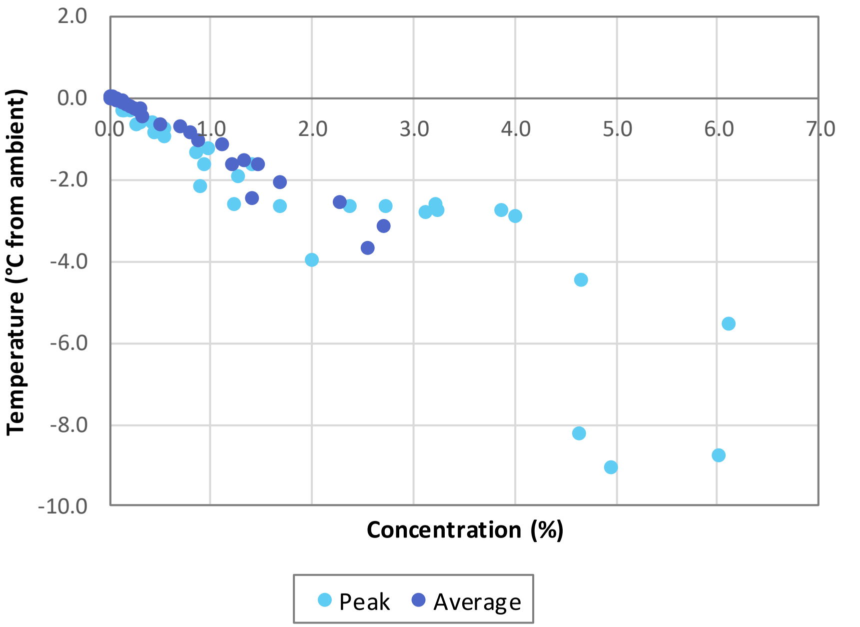




Horizontal: Peak concentration

Downwards: Peak concentration

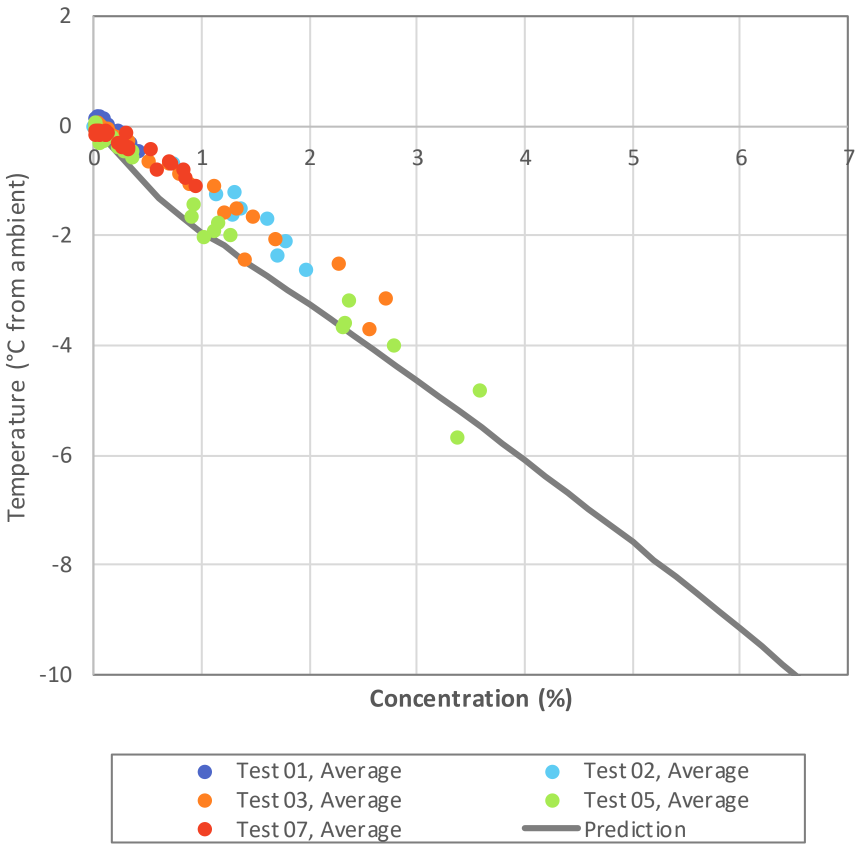




- Generally:
  - Increased concentration → decreased temperature
  - LFL not exceeded in downward past 30m, ~50m in horizontal

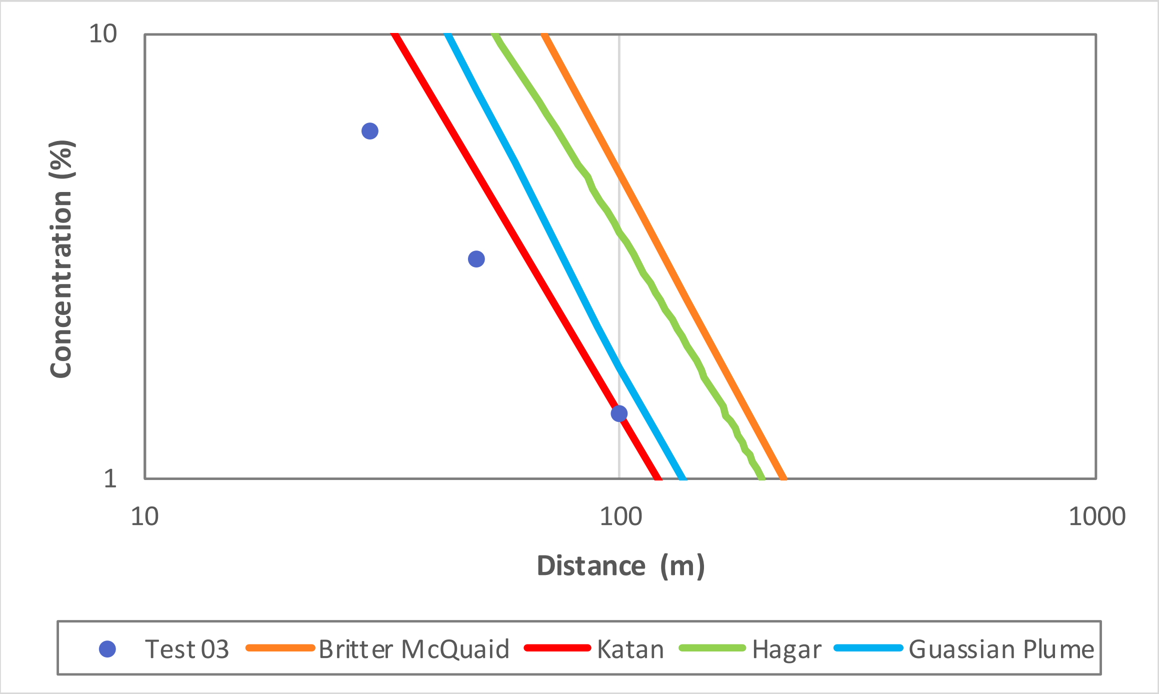
DNV

From GasVLE: Dispersion, LFL Limits



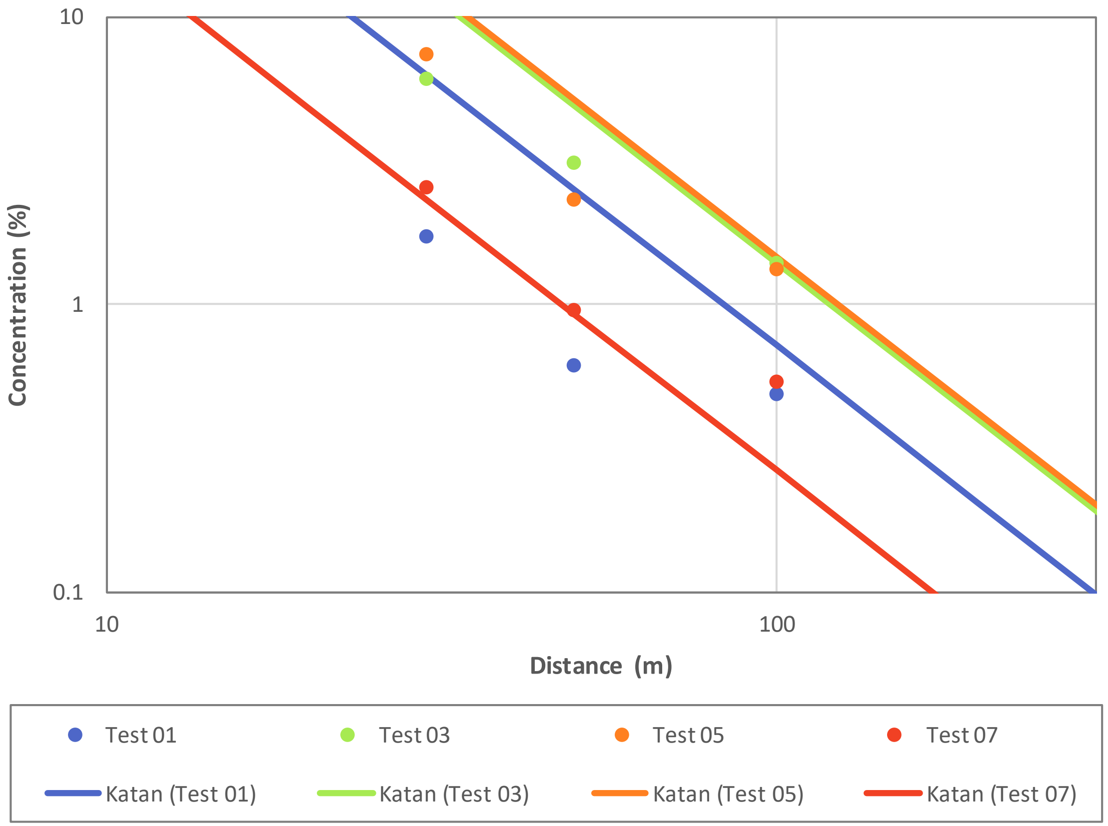
- GasVLE prediction
  - Does not allow for heat transfer from the ground

From FROST:



- Test03 vs various models / correlations

- Various tests versus Katan corellation



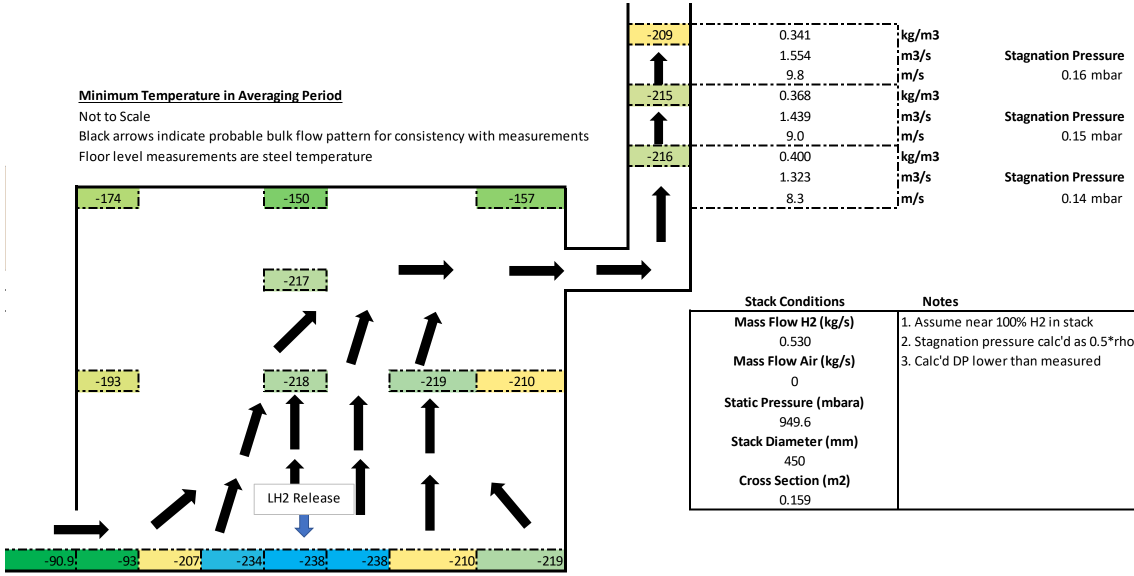
Accumulation, ventilation

Minimum Temperature in Averaging Period

Not to Scale

Black arrows indicate probable bulk flow pattern for consistency with measurements

Floor level measurements are steel temperature

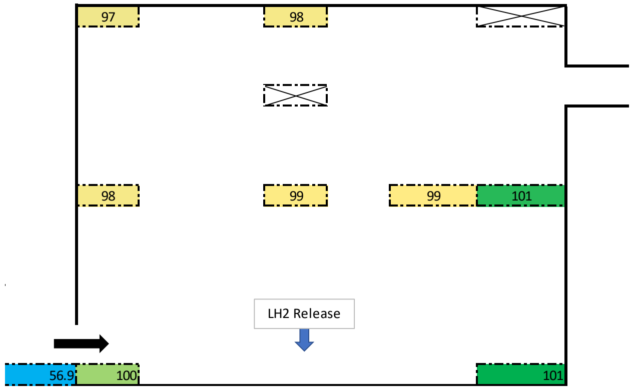


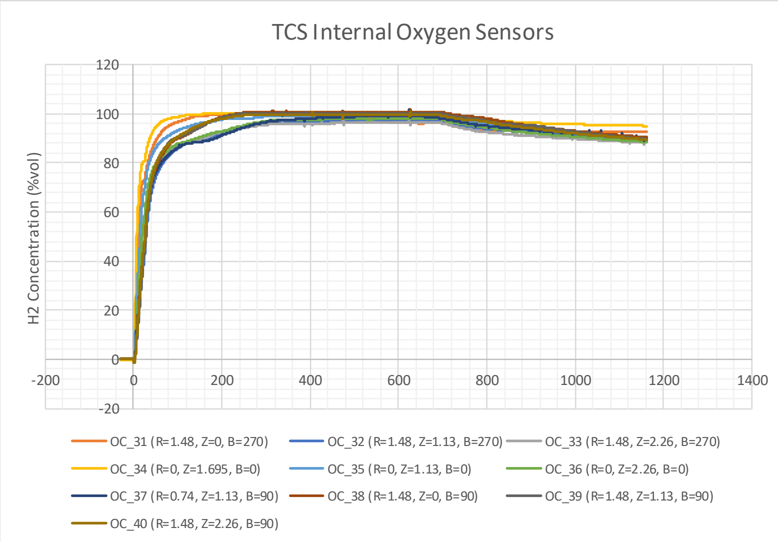
Stack Conditions	Notes
Mass Flow H2 (kg/s)	1. Assume near 100% H2 in stack
0.530	2. Stagnation pressure calc'd as 0.5*rho*v^2
Mass Flow Air (kg/s)	3. Calc'd DP lower than measured
0	
Static Pressure (mbara)	
949.6	
Stack Diameter (mm)	
450	
Cross Section (m2)	
0.159	

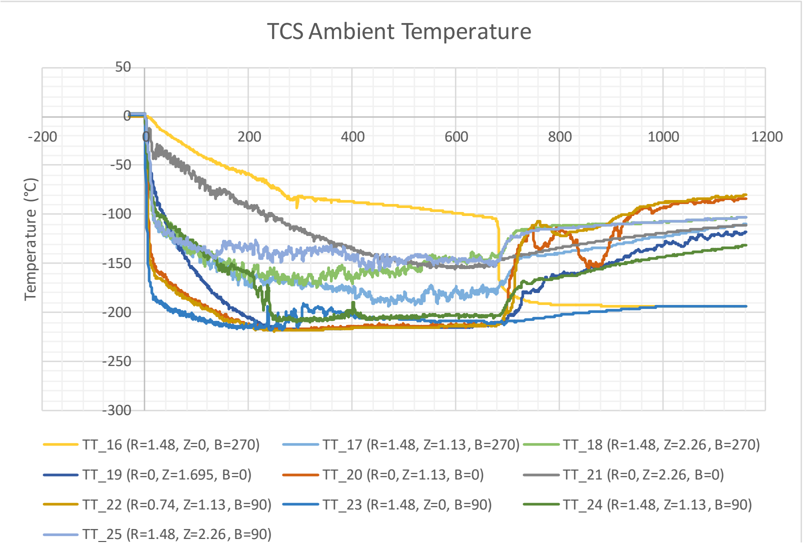
Hydrogen Concentration

Not to Scale

Uses maximum value before trace truncated for temperature effects

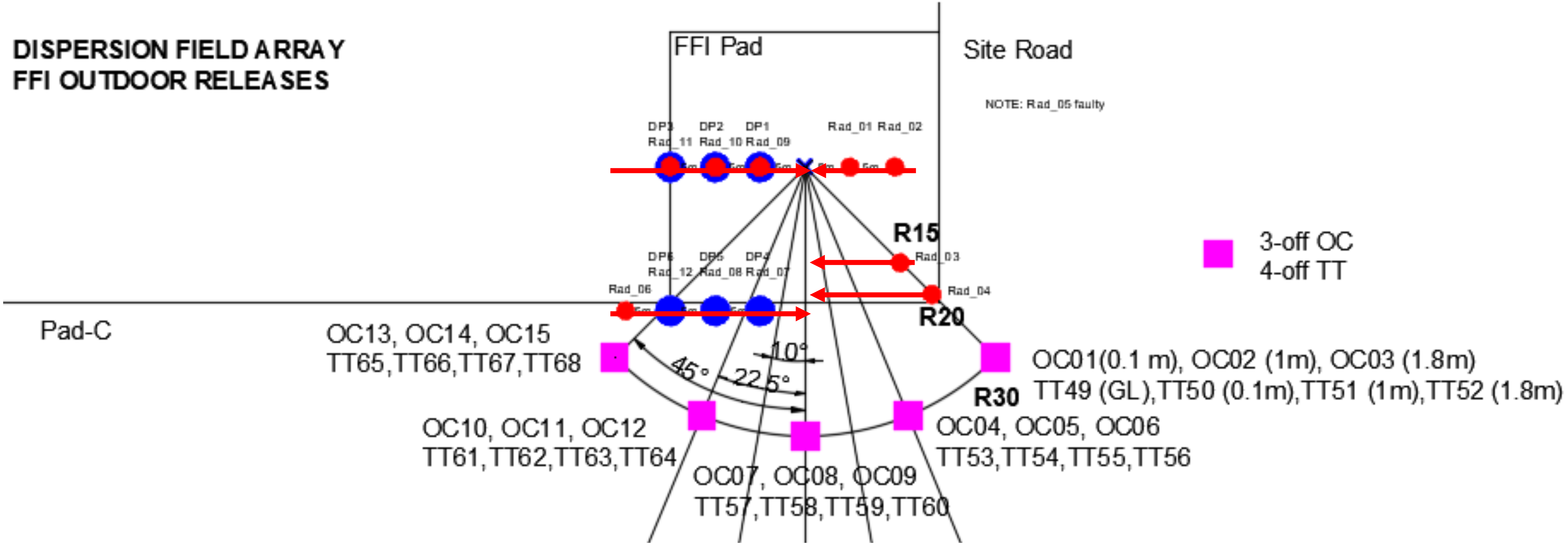






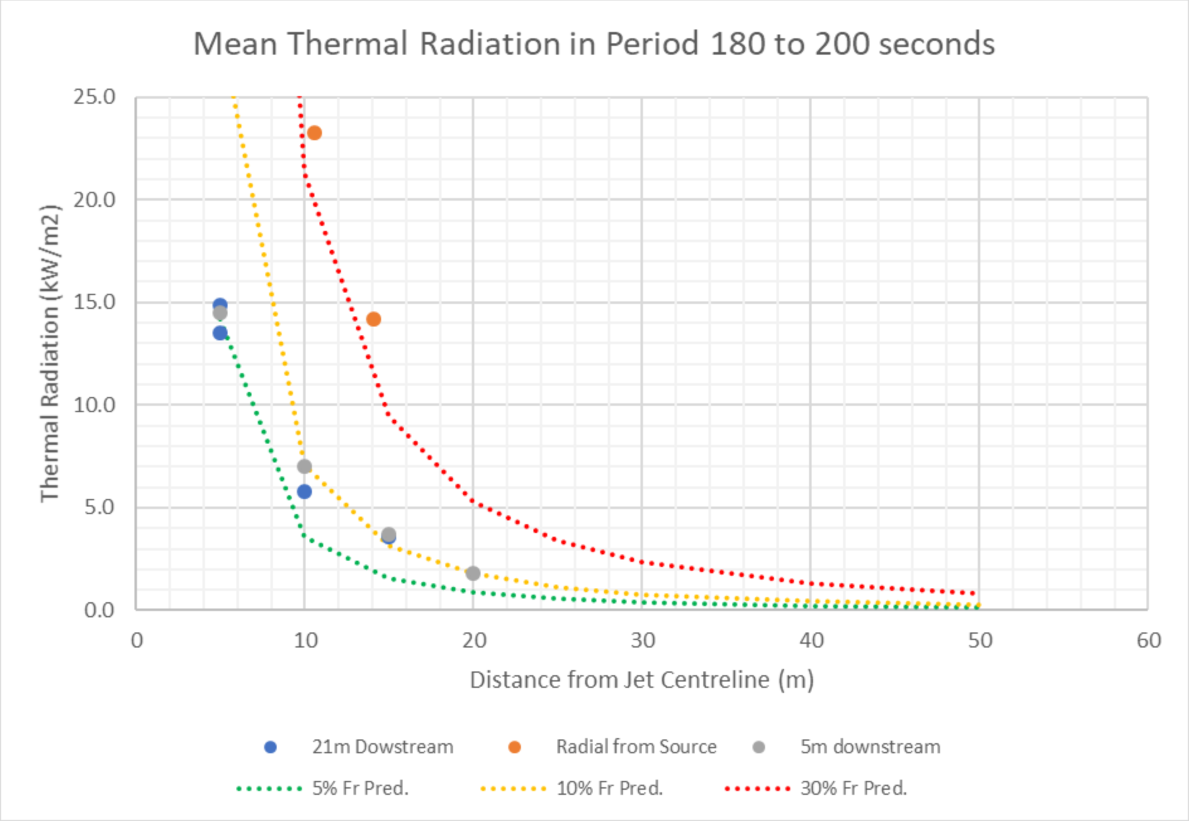
Thermal Radiation

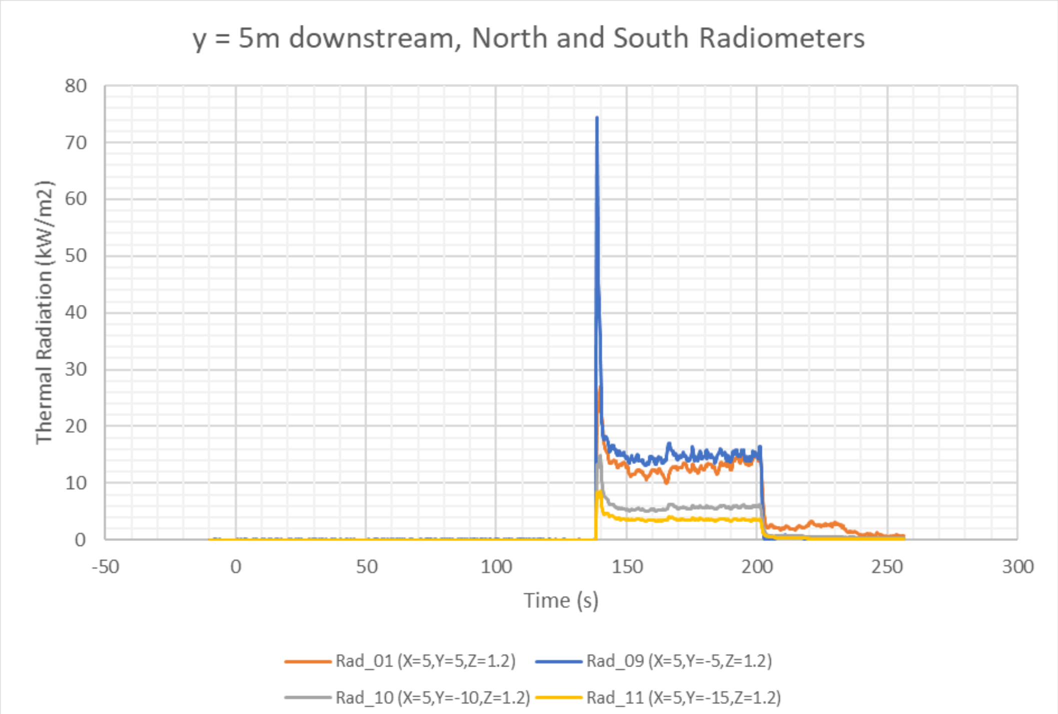
Thermal Radiation

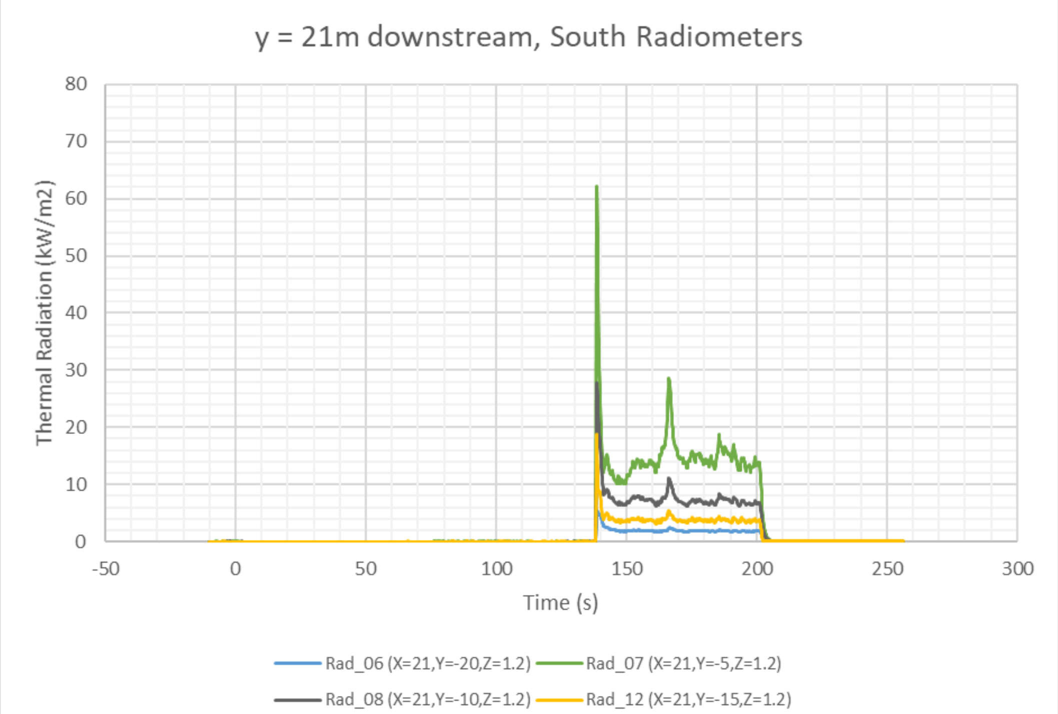


Thermal Radiation

- Seems to fall with r^{-2}
- Initial fireball ~4-5 times higher flux than steady state
- Curious that radial sensors higher than normal sensors



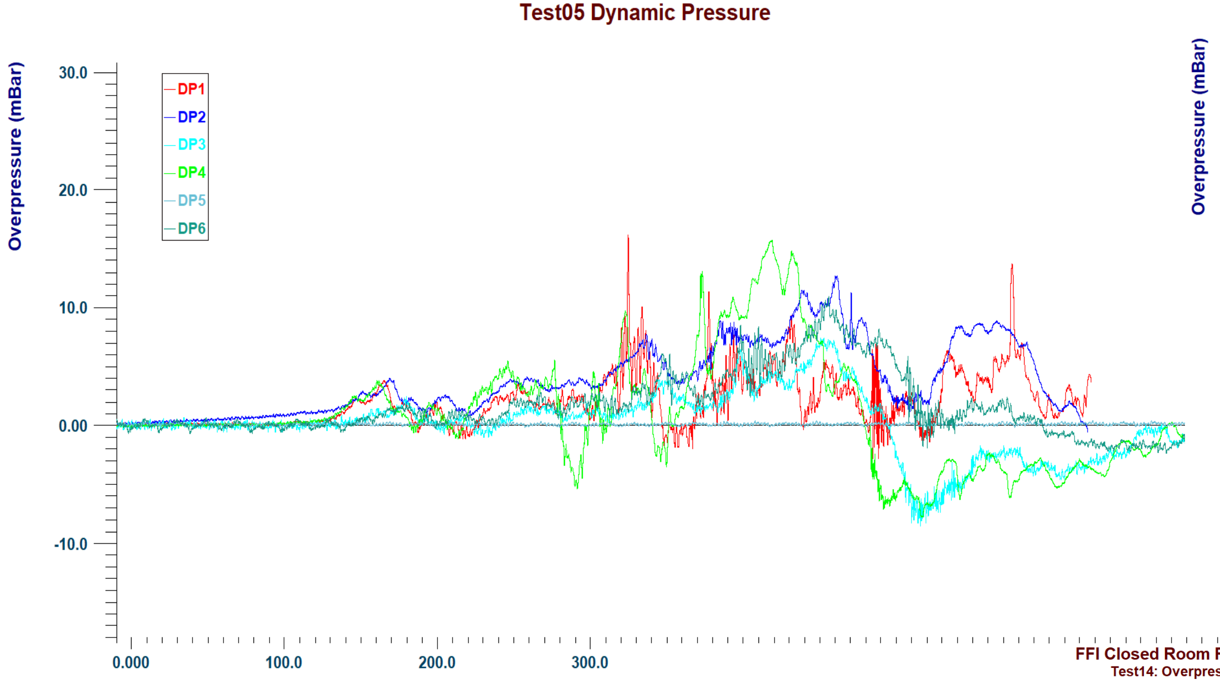




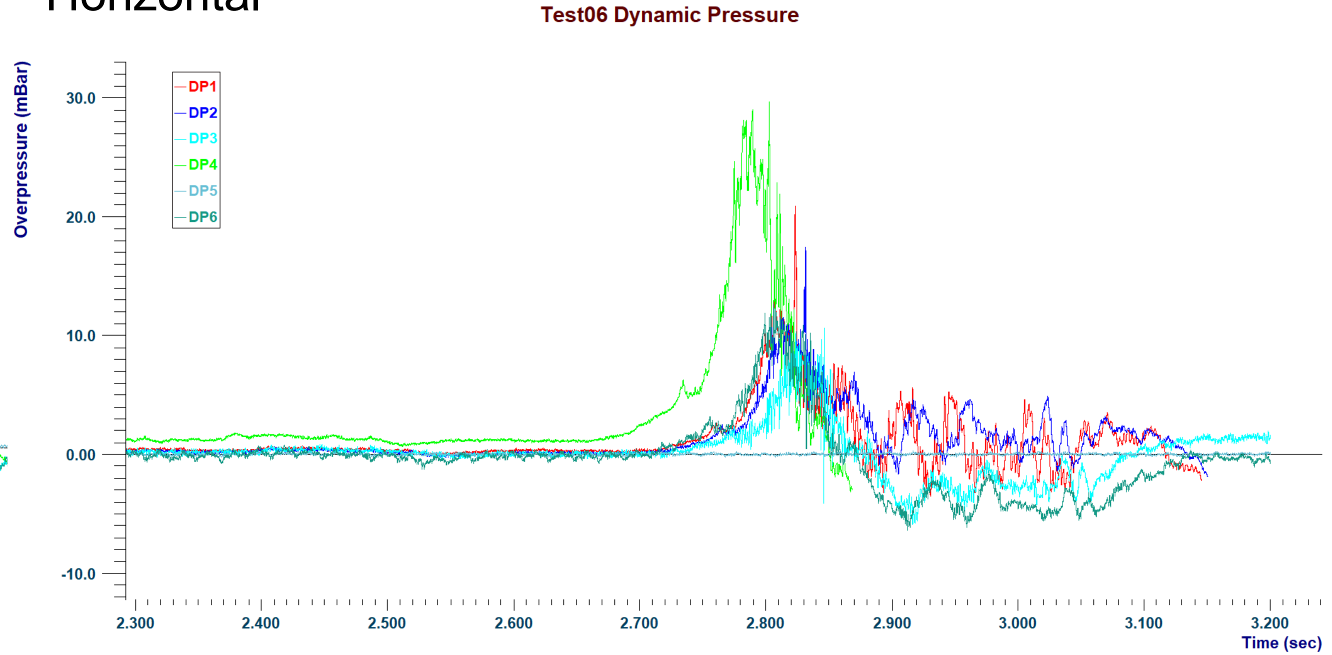
Explosion Effects

Explosion Effects

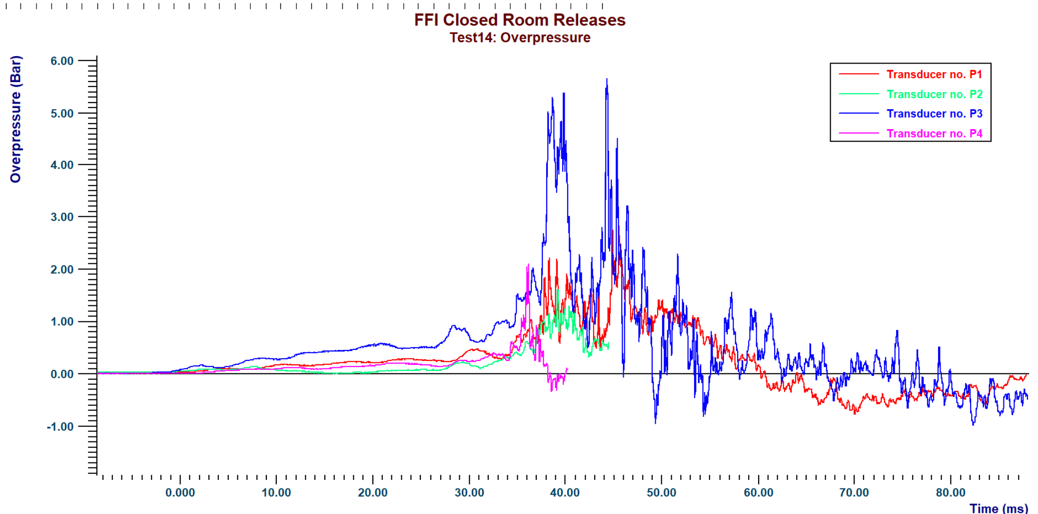
- Downwards



- Horizontal



- Closed Room (severe)



Questions?

Thanks for your attention

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