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The consequences of releasing liquid hydrogen on and into water

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RPT (Rapid Phase Transition)

“Definition”

- Process that takes place when a liquid rapidly changes phase to vapour, whereby the large increase in volume (due to the vapour generation) causes a localized pressure increase which can give rise to an air or waterborne blast wave

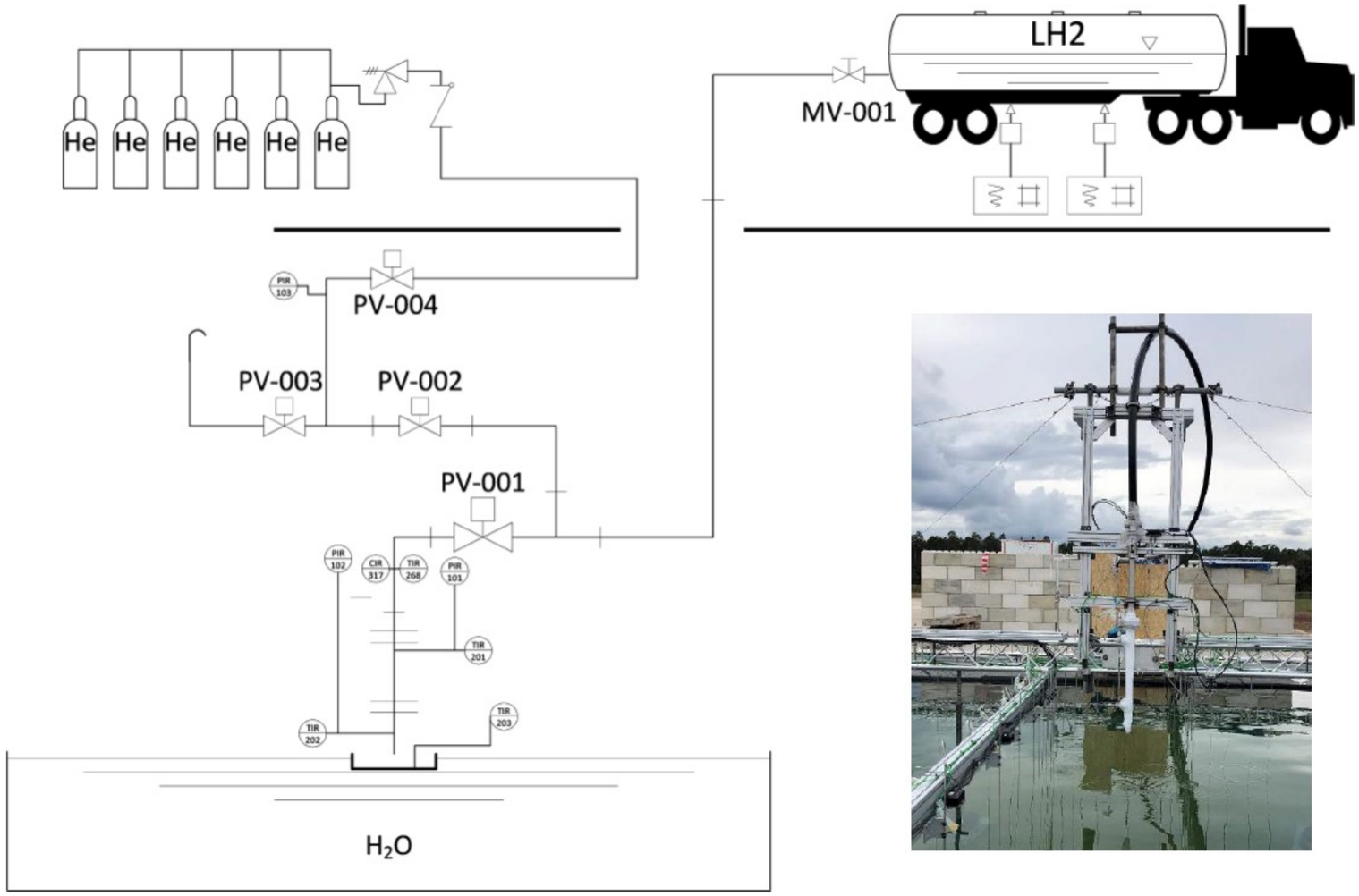
Discussion

- RPT is a complex phenomenon where the main mechanism causing direct contact between the hot and cold liquid is collapse of the insulating vapour film between the fluids. Upon collapse of the vapour film a chain reaction of rapid superheating of the cold liquid, homogeneous nucleation and explosive expansion is occurring.
- The low density of liquid hydrogen and a stable film-boiling (low Leidenfrost temperature) makes an early RPT unlikely

RPTs of LH2: previous work

- Releases of LH2 onto water were performed by Verfondern (2007) studying the result of a low-impulse spill. These authors tried to avoid RPTs (and succeeded)
- Atkinson (2020) investigated the effect of spraying water onto a pool of LH2. No RPT phenomenon was seen in these experiments either

Experimental set-up: release system



Experimental set-up

Experimental set-up: measurements

Item/Sensor	Number
Gas sensor for H2	10
Heat radiation sensor	At 70 m, 90 m and 110 m
Underwater pressure	2
Thermocouple	96
UAV	1
IR-Camera	1
Highspeed camera	1
Load cells	4
Blast sensors	2
Action cams	Up to 5
Ultrasonic anemometers	2

Test programme

- Variation of release rate (3 different rates)
- Variation of release point and direction
  - 50 cm over water surface pointing downwards
  - 30 cm under water surface pointing downwards
  - 30 cm under water surface pointing along water surface

Test programme

Trial	Type of Release	Number of successful releases	Number of rotations of the main valve (max. possible: 16)	Released mass flow (range)
RPT 001	A	1	10	**4 kg/s
RPT 002	A	8	10	0,3 – 1 kg/s
RPT 003	A	1	10	**0,1 kg/s
RPT 004	U	3	10	0,35 – 0,85 kg/s
RPT 005	A	2	10	**0,25 kg/s
RPT 006	U	4	10	0,5 – 1,1 kg/s
RPT 007	U	5	10	0,35 – 0,65 kg/s
RPT 008	U	3	10	0,55 – 0,62 kg/s
RPT 009	U	3	16	0,35 – 0,7 kg/s
RPT 010	U	3	16	0,35 – 0,45 kg/s
RPT 011	A	3	16	0,45 – 1,1 kg/s
RPT 012	A	3	16	0,32 – 0,58 kg/s
RPT 013	A	3	5	0,25 – 0,4 kg/s
RPT 014	U	2	5	0,3 – 0,5 kg/s
RPT 015	U	3	16	0,5 – 0,75 kg/s
RPT 016	U	1	16	0,8 kg/s
RPT 017	A	5	16	0,4 – **1,4 kg/s
RPT 019	A	2	16	0,8 kg/s
RPT 020	A	3	16	1,1 kg/s
RPT 021	U	4	16	0,25 – 0,76 kg/s
RPT 022	U	3	16	0,27 – 0,37 kg/s
RPT 023	UH	3	16	0,53 – 0,78 kg/s
RPT 024	UH	3	16	0,36 - 0,55 kg/s
RPT 025	UH	4	16	0,38 – **0,93 kg/s

Results

- Total of 75 releases
- High pressure in road tanker (typically 10 bar) caused high momentum releases
- LH2 jet penetrated deep into the water
- Evaporation mechanism different from seen for RPTs involving LNG and water. A traditional RPT is not taking place.
- Due to big difference in density break-up of large bubbles into smaller droplets occurs due to Taylor instability increasing evaporation rate
- Many of the releases resulted in a hydrogen cloud that was ignited

Interaction of hydrogen jet with water (RPT 001)

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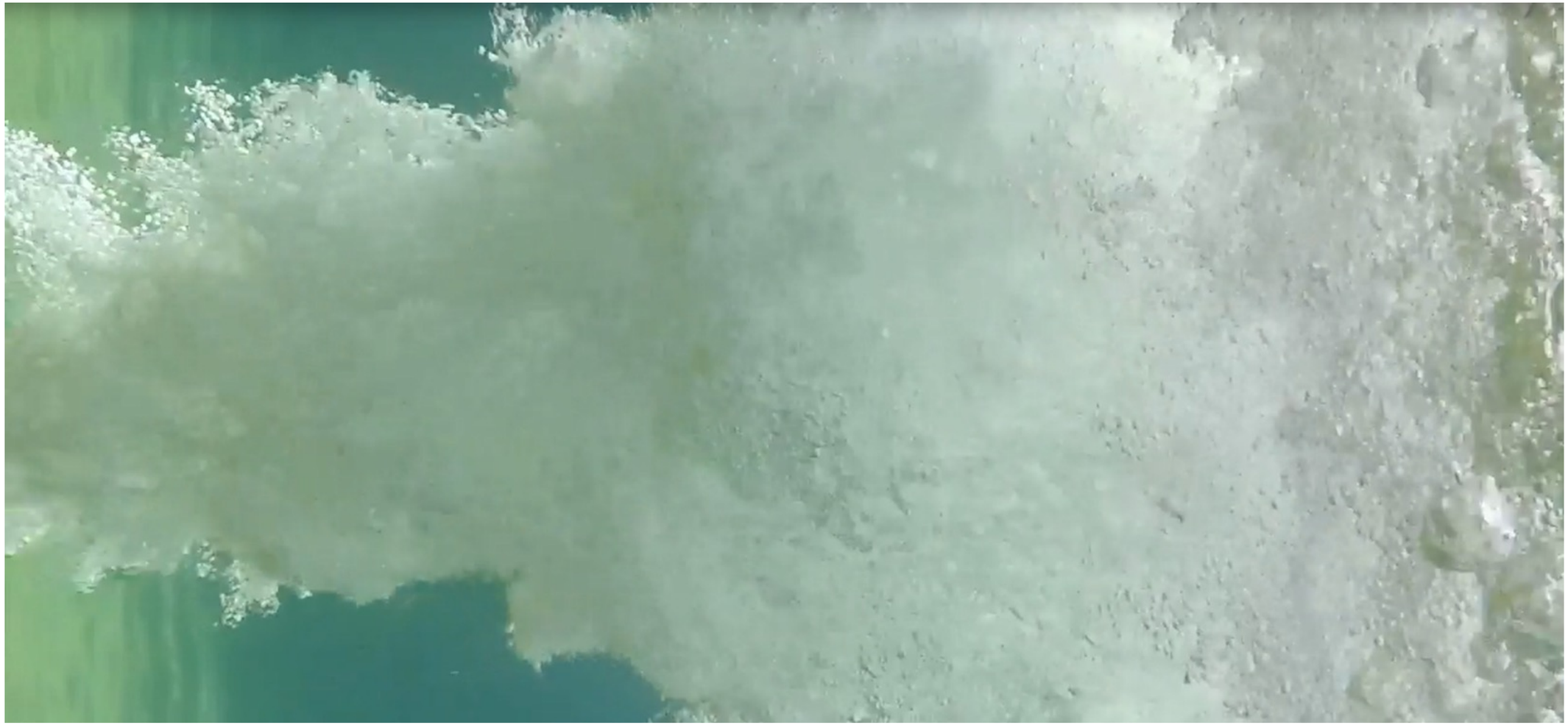
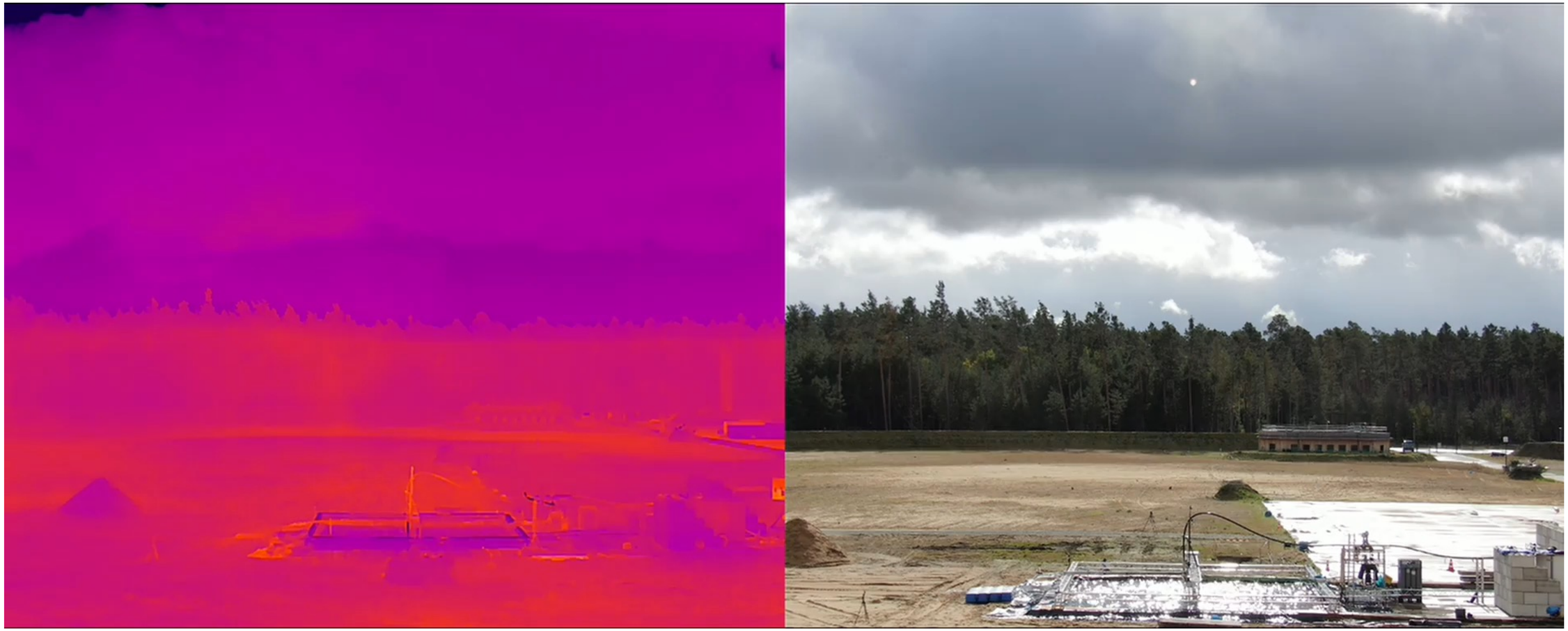


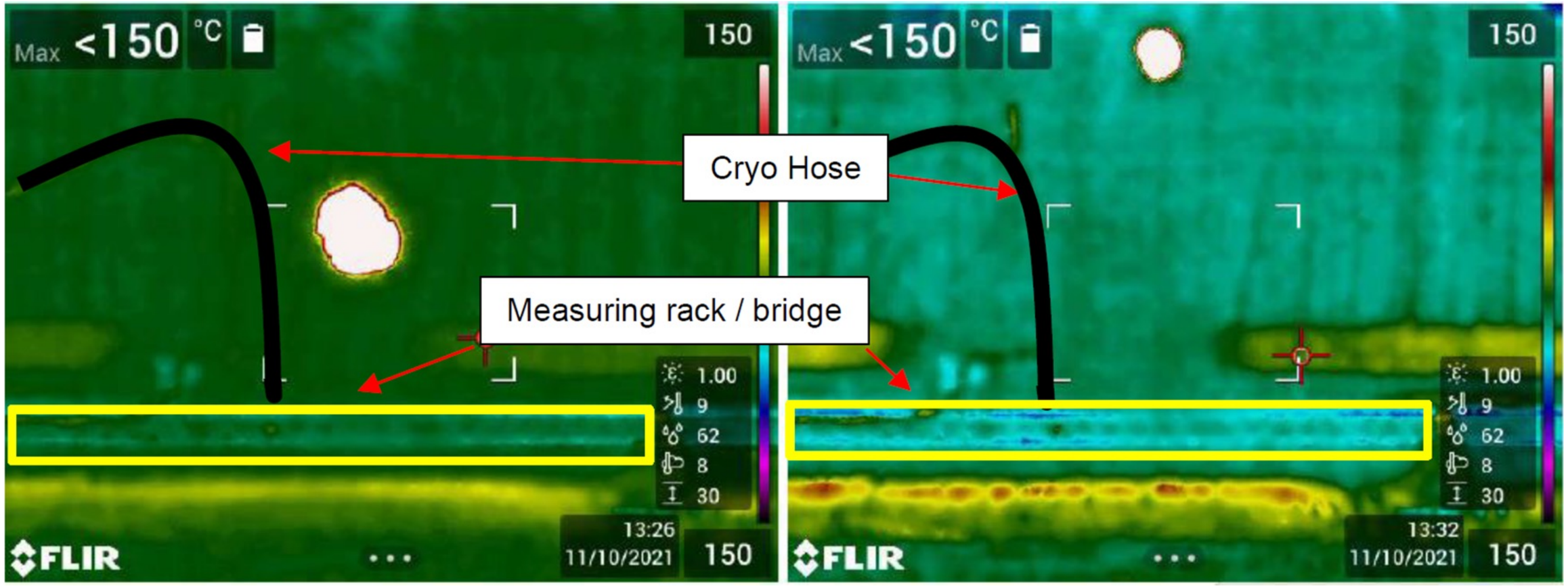
Release of LH2 onto water



Overall cases of ignition

Type of release	Total number of releases	Total Number of observed ignitions	Percent of releases with ignition
Above water pointing downwards	31	21	68
Under water pointing downwards	34	32	94
Under water pointing horizontal	10	7	70

Ignition location



Conclusions RPTs

- Pressure waves generated in air upon releasing high momentum LH2 jets into water either from a point above the water surface or under water due to the explosive evaporation are in the range of a few 10 of mbars
- The evaporation mechanism differs from that described for LNG and water. An RPT, in the traditional sense as seen for e.g. LNG, does not occur
- The majority of the releases showed an ignition of the generated gas cloud followed by an explosion producing overpressures of up to several 100 mbars in air
- The ignition itself took place in free air and the ignition mechanism is not identified yet.

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Thank you