Safe Use of LH2 in Non-industrial Settings

Contributions of the FCH JU project PRESLHY

Thomas Jordan, KIT

13th plenary SFEM Working Group HYDROGEN, 28 January 2020, Brussels, Belgium

Pre-normative REsearch for Safe use of Liquid HYdrogen

Outline

- Motivation
- PRESLHY Overview
- WP3 Release
- WP4 Ignition
- WP5 Combustion
- Exploitation
- Closure

Motivation

!




- Scale-up of existing and new applications increase H2 demand.
- Liquid hydrogen (LH2) provides **larger densities** and gains in **efficiency** and **potentially reduces risks** compared to compressed gaseous transport and storage
- Many **knowledge gaps** wrt accidental behavior of LH2 and **inconsistent** and **potentially over-conservative RCS** (e.g. NFPA 2 and EIGA)

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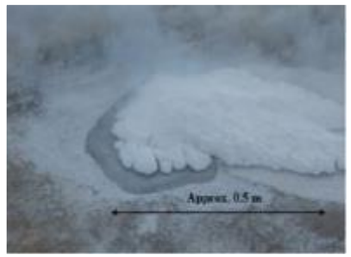
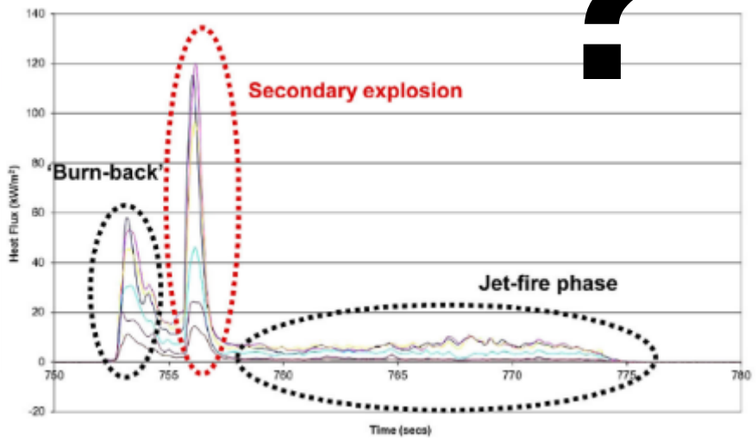
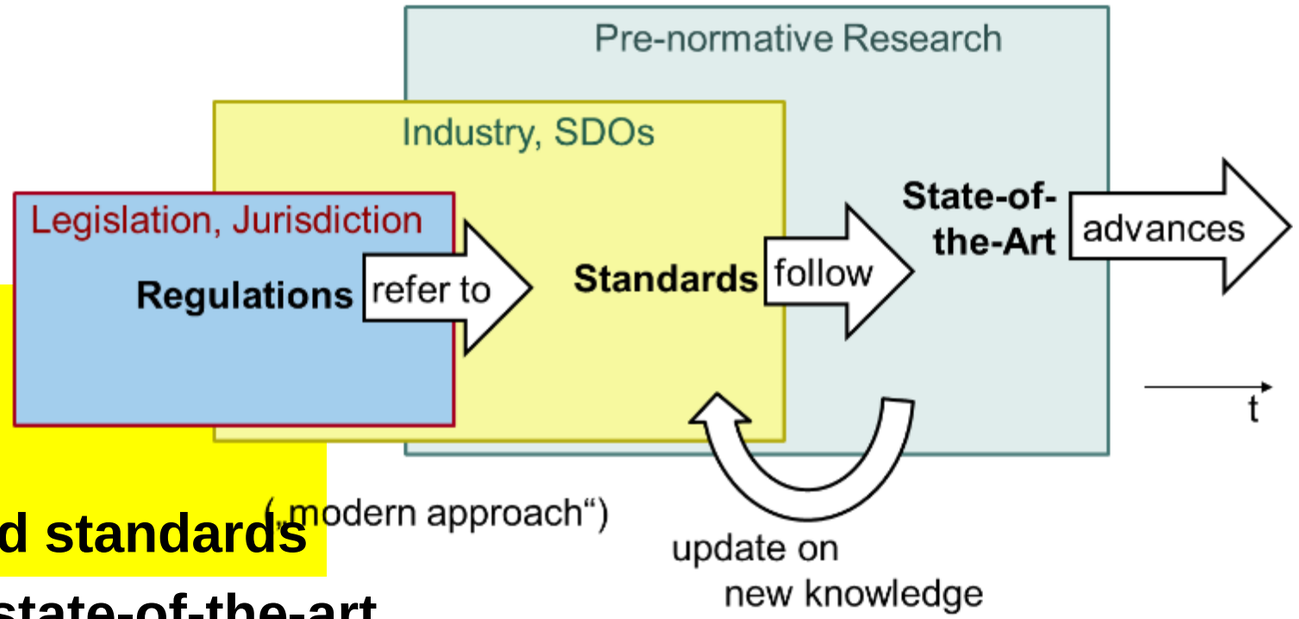


PRESLHY Objectives

- Report **initial state-of-the-art and knowledge gaps** with priorities wrt intended use of LH2
- Execute adjusted **experimental program** addressing release, ignition and combustion phenomena with highest priorities
- Document and publish detailed, aggregated and interpreted data in a FAIR way
- Develop **suitable models and engineering correlations** and integrate them in a suitable open risk assessment toolkit
- Provide **enhanced recommendations for safe design and operations** of LH2 technologies
- **Support international SDOs** in
  - **updating of existing standards** or
  - developing of **new international performance based and risk informed standards**
- Document and disseminate the **enhanced state-of-the-art**



External Networking / Dissemination

HySafe (+ Hydrogen Safety Pa

RCS SCG

JRC (HIA

ISO TC 197

IEA Hydrogen Task

US DOE

Presentation planned for next meeting

ISO/PWI 24077: „Safe Use of LH2 in Non-Industrial Settings“ established on 6.12.2018

Presentation on 19.10.2018

WP1 – Manage-ment (KIT)

WP2 - Strategy (AL)

WP3 – Release & Mixing (NCSRD)

WP4 – Ignition (HSL)

WP5 – Combus-tion (KIT)

WP6 – Implementation (UU)

PRESLHY Advisory Board

H2@Scale U.S. Department of Energy SNL

SH2IFT GexCon, IFE, Equinor

KHI, Toyota

Shell

General Approach

WP1 – Management

WP2 - Technical Strategy & Evaluation

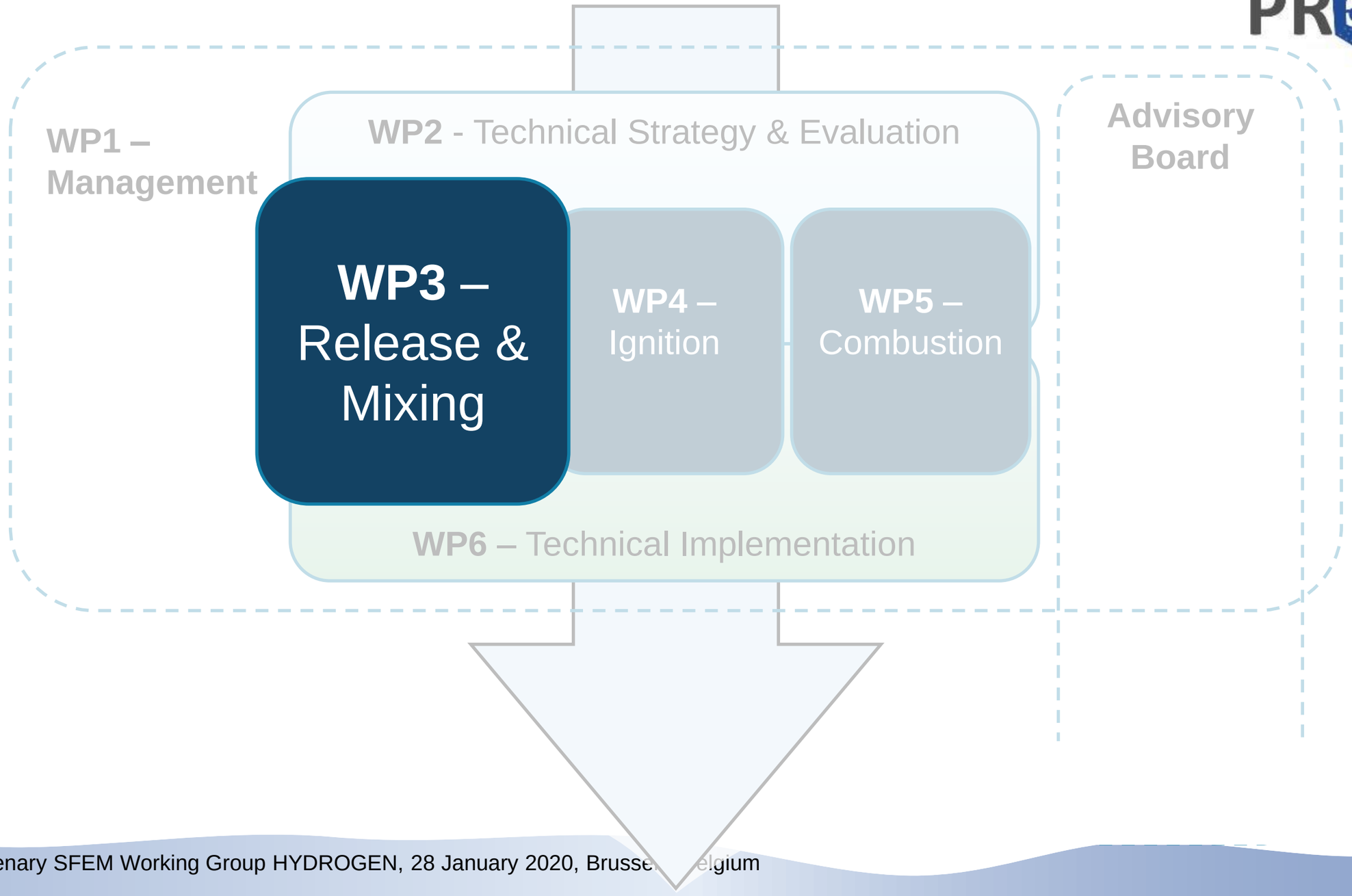
WP3 – Release & Mixing

WP4 – Ignition

WP5 – Combustion

WP6 – Technical Implementation

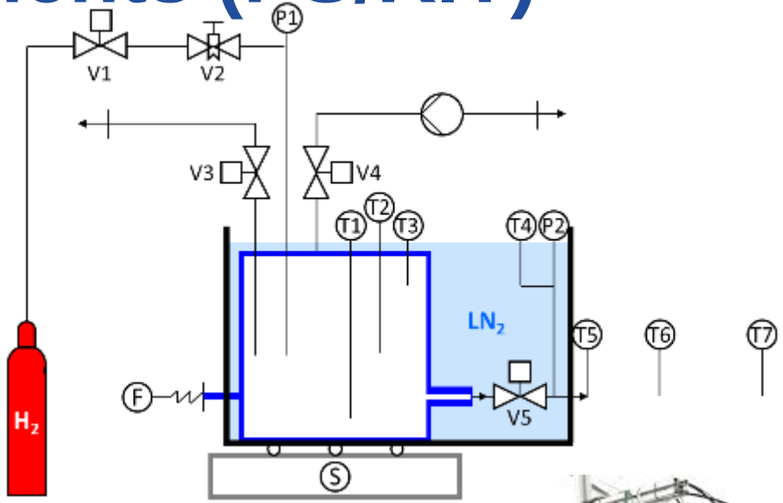
Advisory Board

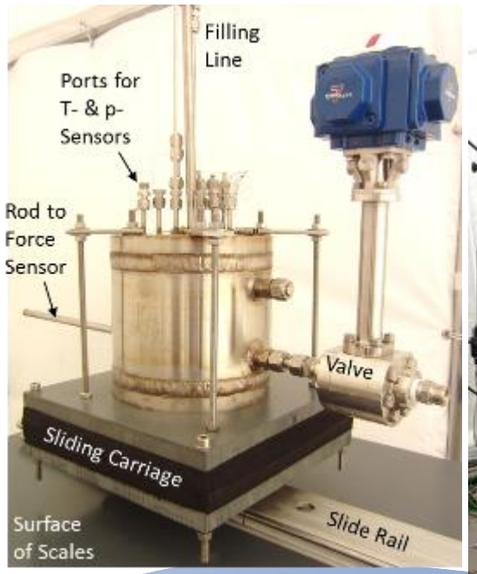

WP1 – Management
WP2 - Technical Strategy & Evaluation
Advisory Board
WP3 – Release & Mixing
WP4 – Ignition
WP5 – Combustion
WP6 – Technical Implementation

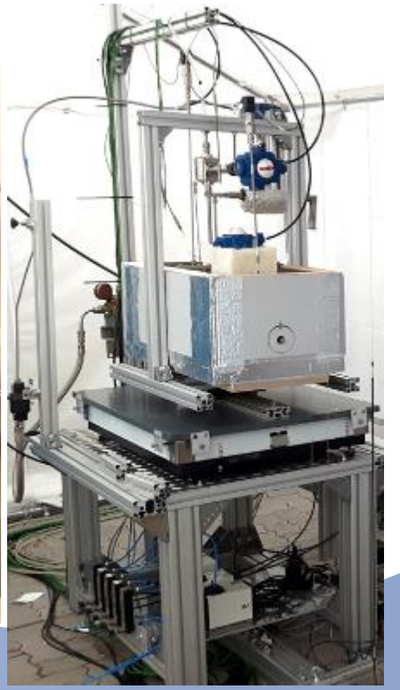
Experimental series E3.1a

Small Scale Multiphase Release experiments (PS/KIT)

- > 200 tests performed at DISCHA facility at HYKA / KIT
- Warm tests (ambient temp) and cold tests (77 K $T_{sat,LN2}$) where 2.81 L stainless steel vessel and release line cooled by bath of LN_2
- 4 nozzle diameters (0.5, 1, 2, 4 mm)
- 7 initial vessel pressures (5, 10, 20, 50, 100, 150, 200 bar)
- Every experiment was repeated at least 2 times (> 100 warm and ≈ 100 cold tests in total)
- **Only single (gaseous) phase conditions at nozzle were achieved**

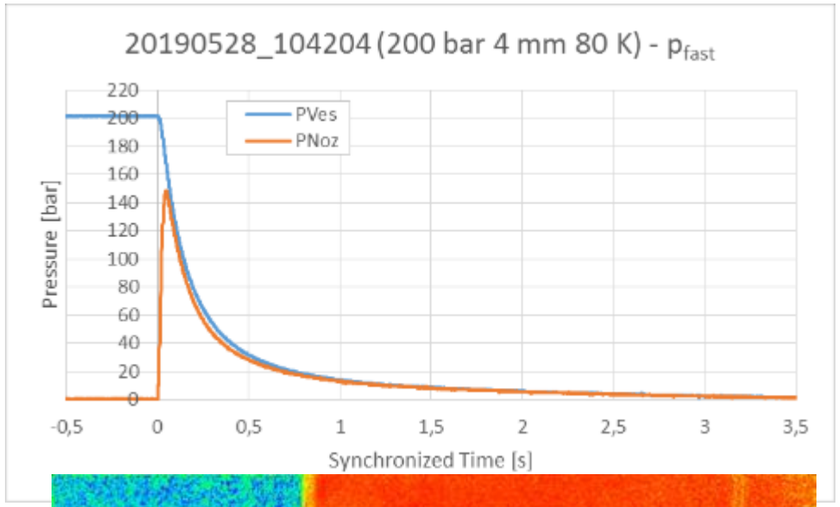


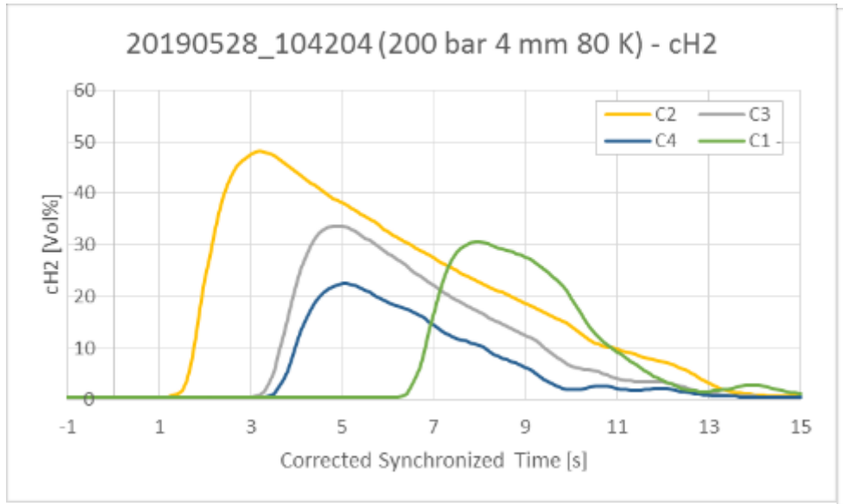


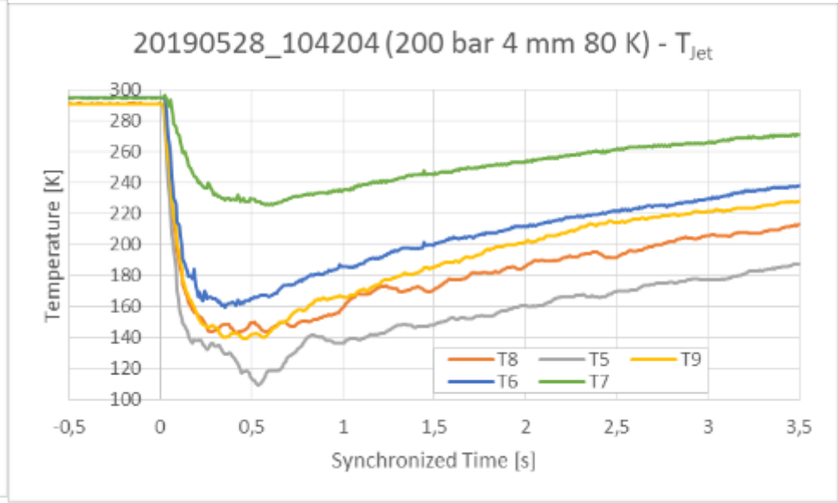


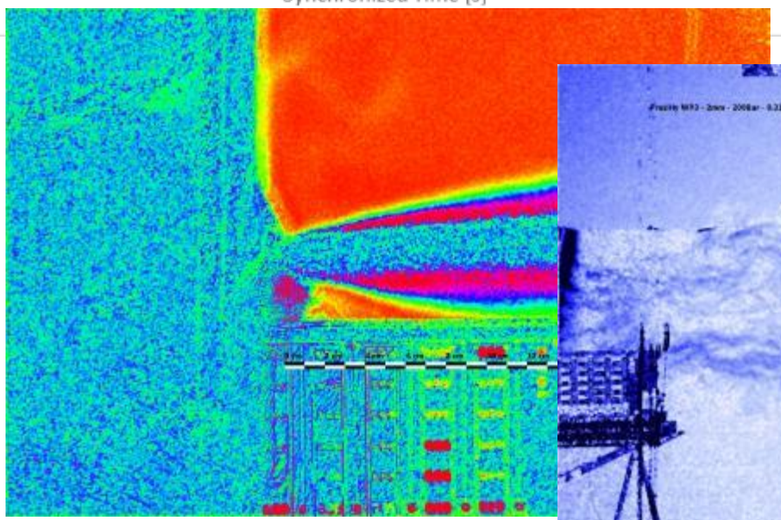
E3.1a: Validation Data

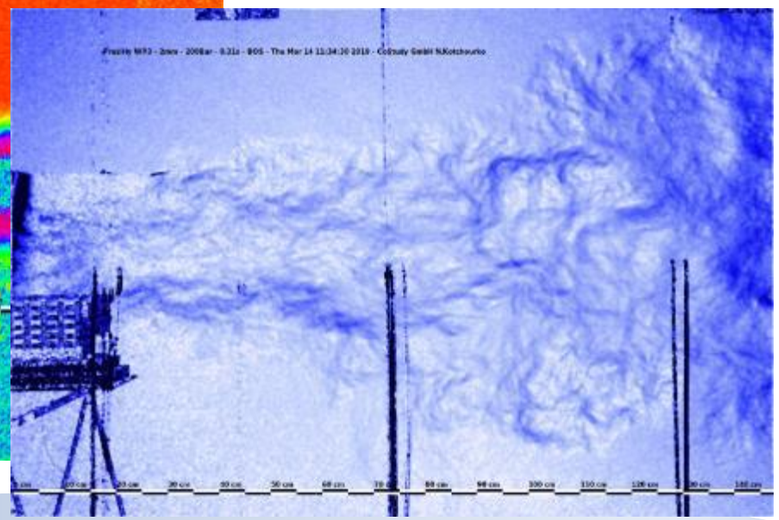
from ~200 tests in- and ex-vessel (jet) p, T, cH2, photography







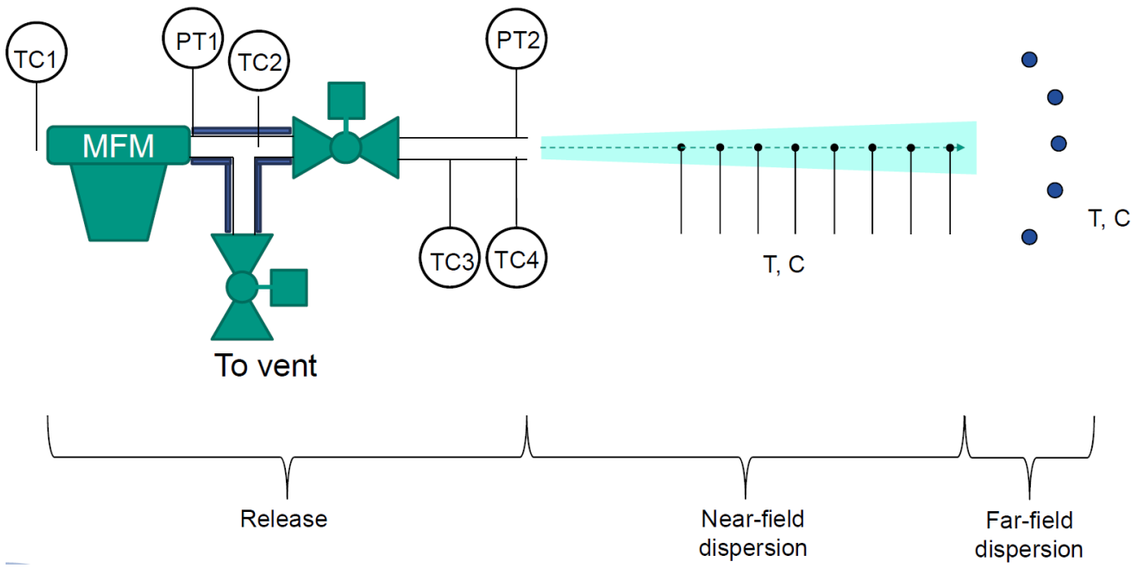


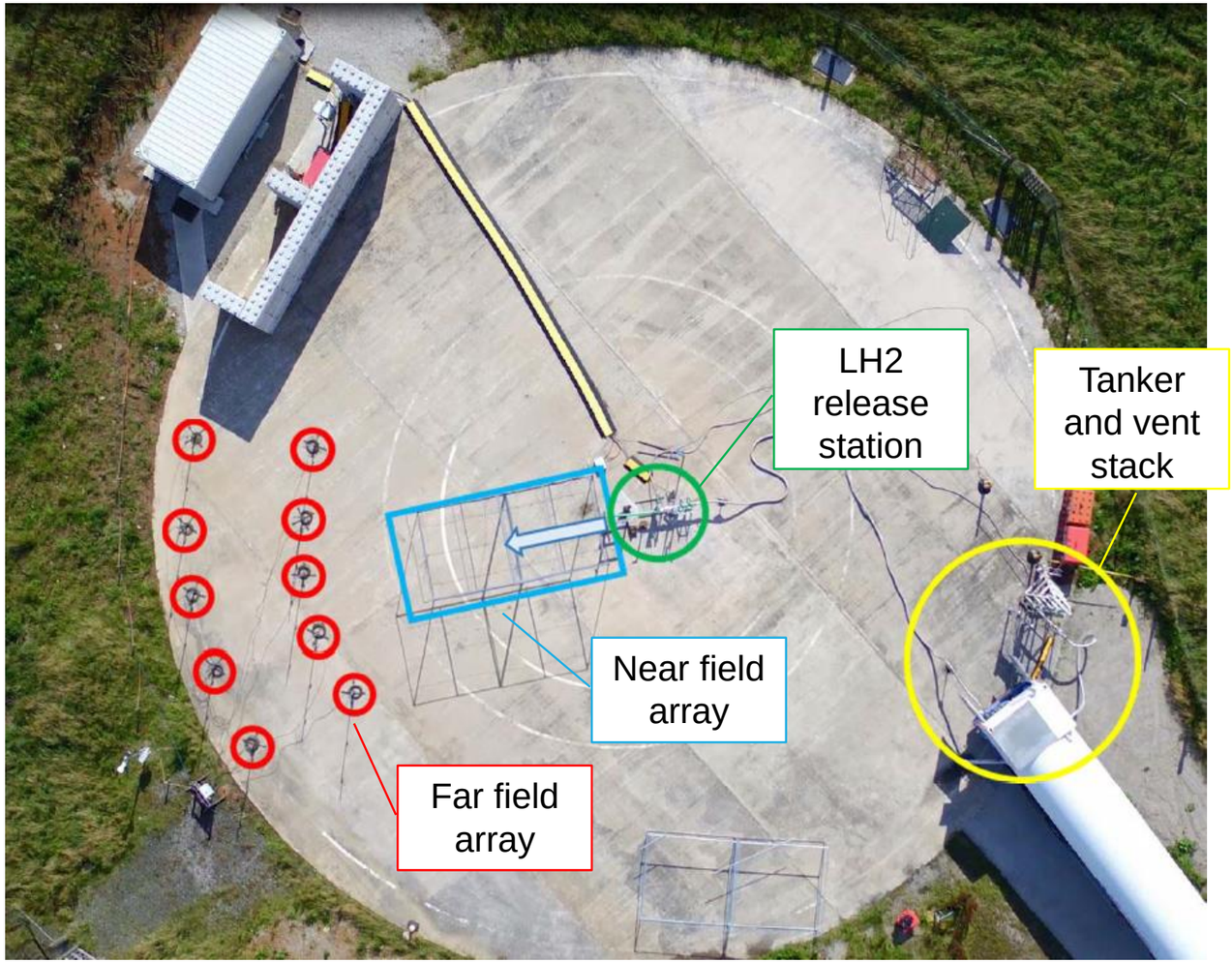


see https://doi.org/10.5445/IR/1000096833.

Experimental series E3.5

"Rain Out Tests" (HSE)

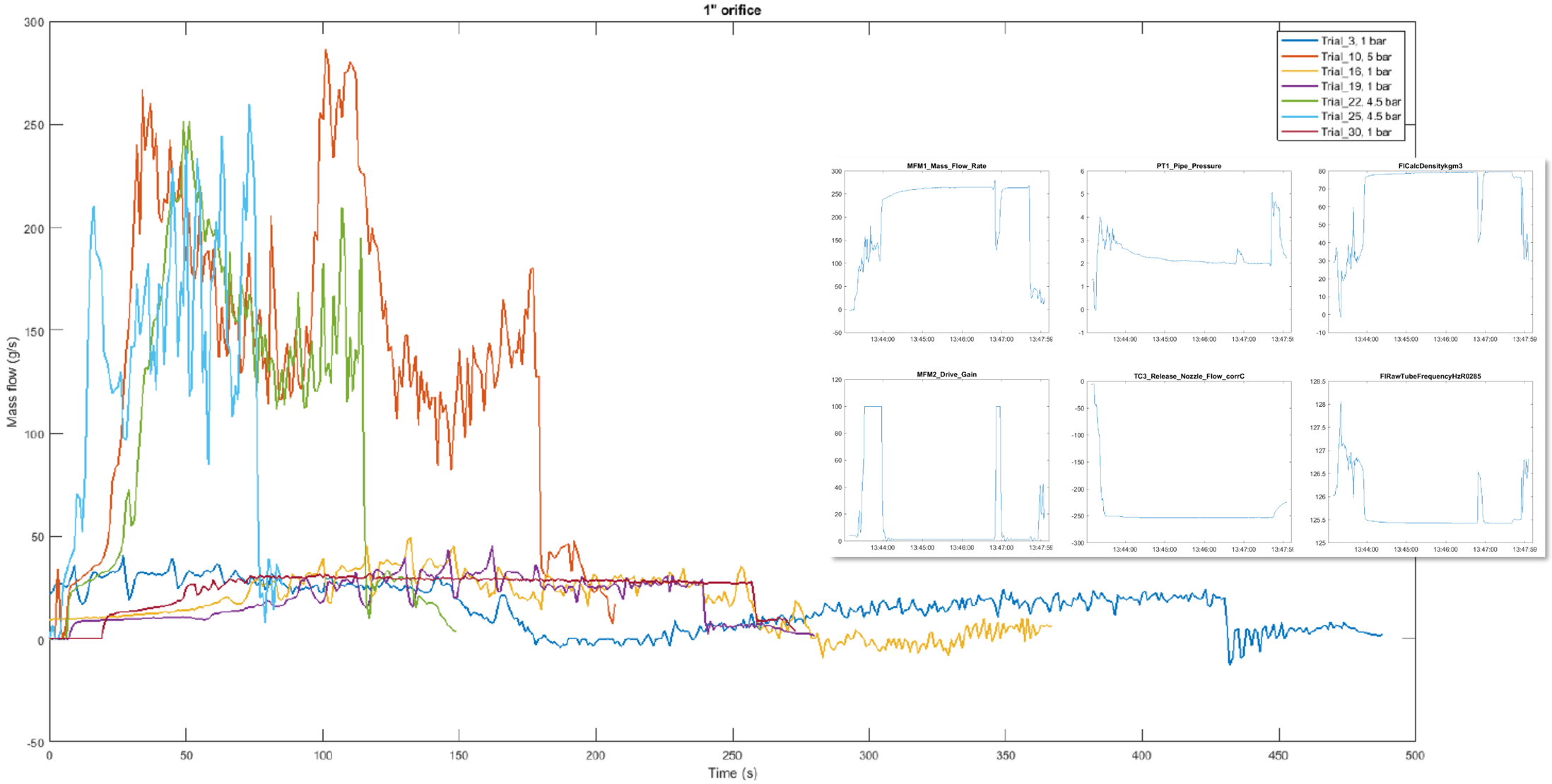




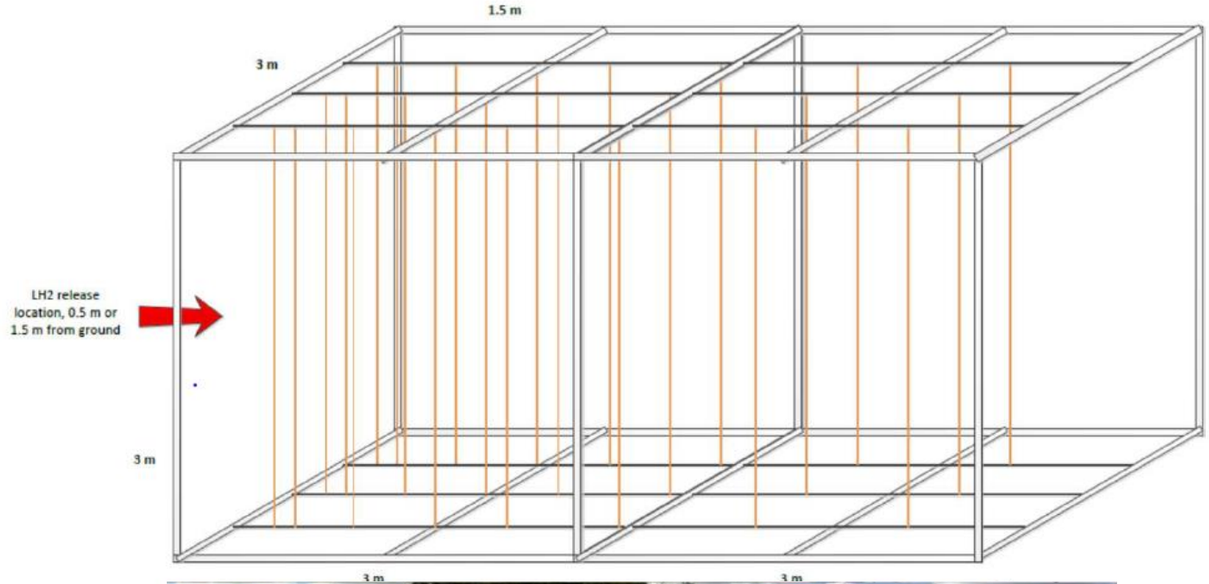
E3.5: Test Matrix

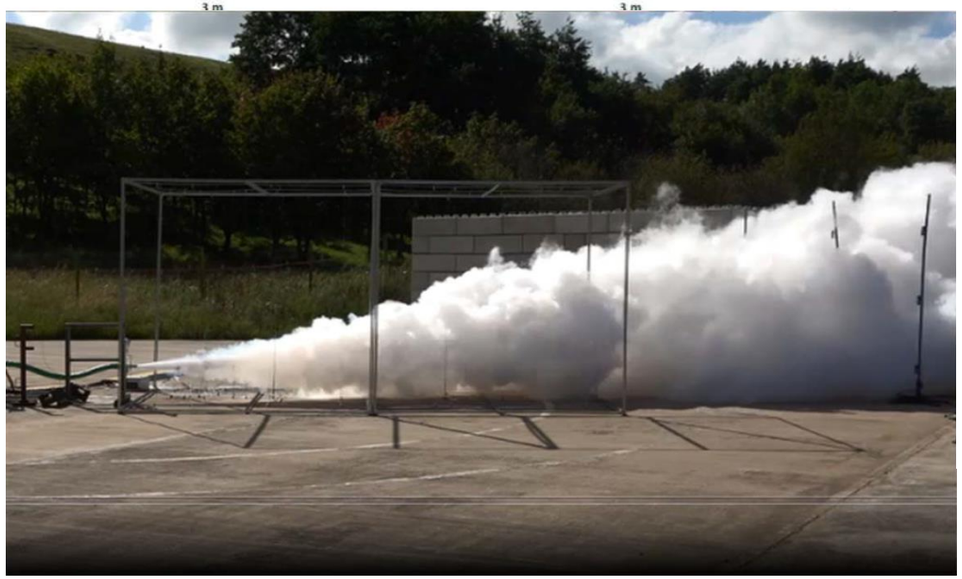
Trial No	Test No	Date	Time of start	Array location	Far Field sensor location	Additional Notes	Resistance
1	3.5.3	11/09/2019	15:16:54	Standard	Option 2a	Commissioning test.	$1.42x10^6\ \Omega^2$
2	3.5.1	11/09/2019	15:58:09	Standard	Option 2a	Commissioning test.	$1.06x10^7\ \Omega^2$
3	3.5.1	12/09/2019	11:45:31	Standard	Option 2a	Good conditions.	$1.02x10^6\ \Omega^2$
4	3.5.2	12/09/2019	12:08:57	Standard	Option 2a	Fist footage of solid air around nozzle.	$1.06x10^7\ \Omega^2$
5	3.5.3	12/09/2019	14:34:20	Standard	Option 2a		$2.48x10^6\ \Omega^2$
6	3.5.7	12/09/2019	15:35:30	250mm offset	Option 2a		
7	3.5.8	12/09/2019	16:10:18	250mm offset	Option 2a	0.7m radius pool formed with solid deposit.	
8	3.5.8	13/09/2019	10:32:55	250mm offset	Option 2a		$2.07x10^7\ \Omega^2$
9	3.5.9	13/09/2019	11:11:19	350mm offset	Option 2a	Baffle 160mm from release.	$2.72x10^4\ \Omega^2$
10	3.5.10	13/09/2019	13:25:06	50mm offset	Option 2a		$2.67x10^4\ \Omega^2$
11	3.5.11	13/09/2019	13:43:17	50mm offset	Option 2a		
12	3.5.12	13/09/2019	14:08:44	50mm offset	Option 2a		$2.67x10^4\ \Omega^2$
13	3.5.17	13/09/2019	14:33:43	250mm offset	Option 2a	1.2m radius pool formed.	
14	3.5.16	13/09/2019	14:57:14	250mm offset	Option 2a		
15	3.5.18	13/09/2019	15:23:26	250mm offset	Option 2a	Baffle 180mm from release.	
16	3.5.4	17/09/2019	11:02:07	Standard	Option 2b		$3.14x10^4\ \Omega^2$
17	3.5.5	17/09/2019	11:24:11	Standard	Option 2b		
18	3.5.6	17/09/2019	11:41:45	Standard	Option 2b		
19	3.5.4	18/09/2019	10:57:26	Standard	Option 2a		$1.03x10^7\ \Omega^2$
20	3.5.5	18/09/2019	11:18:55	Standard	Option 2a		
21	3.5.6	18/09/2019	11:40:06	Standard	Option 2a		
22	3.5.13	18/09/2019	14:57:25	Standard	Option 2a	Releases carried out at 4.5 bar.	
23	3.5.14	18/09/2019	15:14:47	Standard	Option 2a	Releases carried out at 4.5 bar.	
24	3.5.15	18/09/2019	15:29:36	Standard	Option 2a	Releases carried out at 4.5 bar.	
25	3.5.13	18/09/2019	15:47:58	Standard	Option 2a	Releases carried out at 4.5 bar.	$1.03x10^7\ \Omega^2$

E3.5: Mass Flow Measured

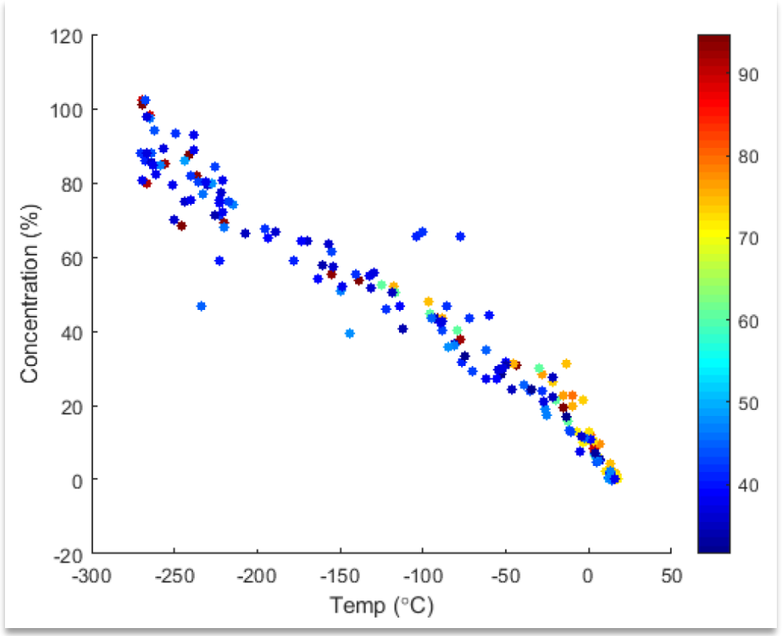


E3.5: Near Field Dispersion





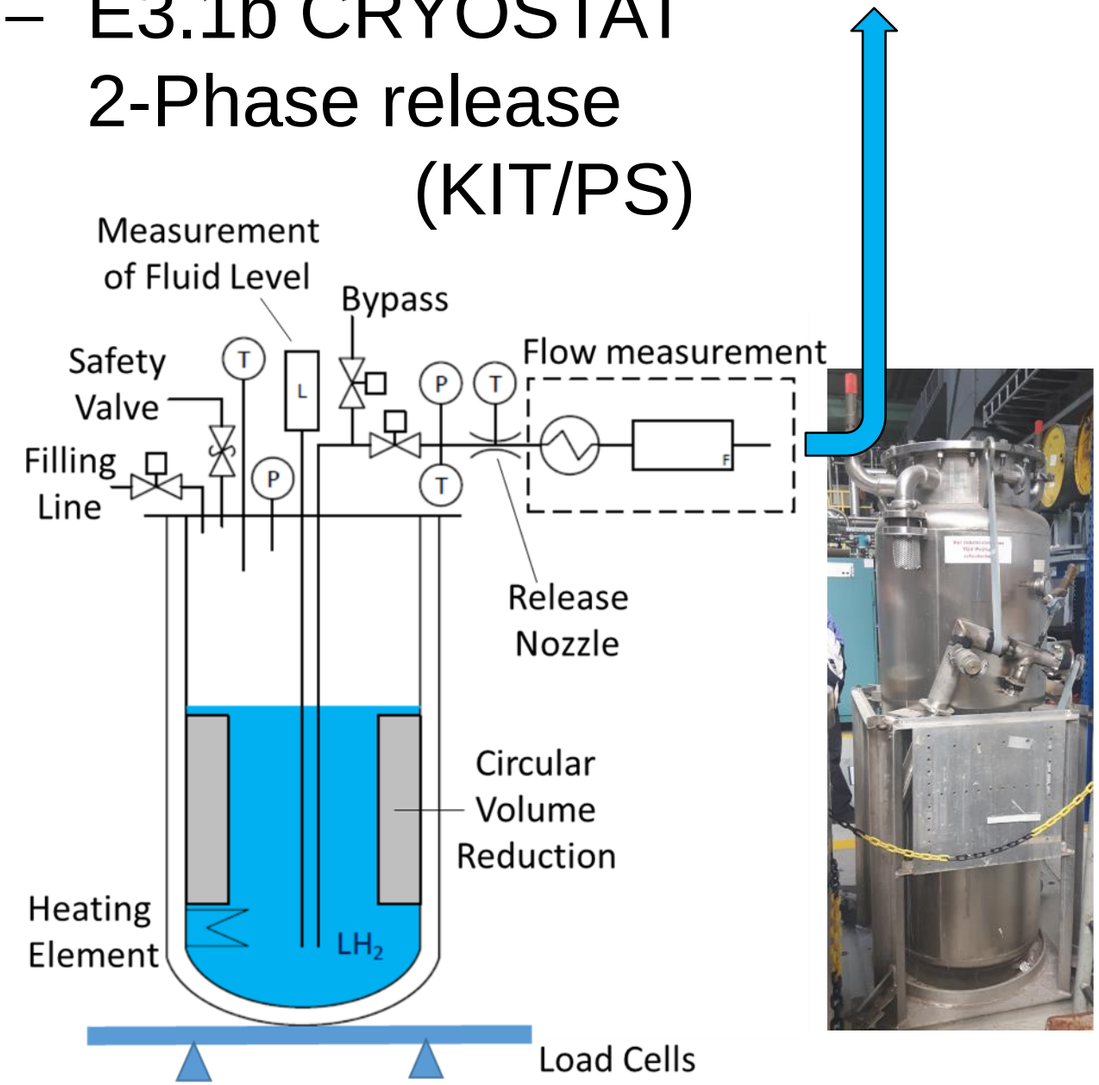
Some „solid material“ partially blocked sampling positions



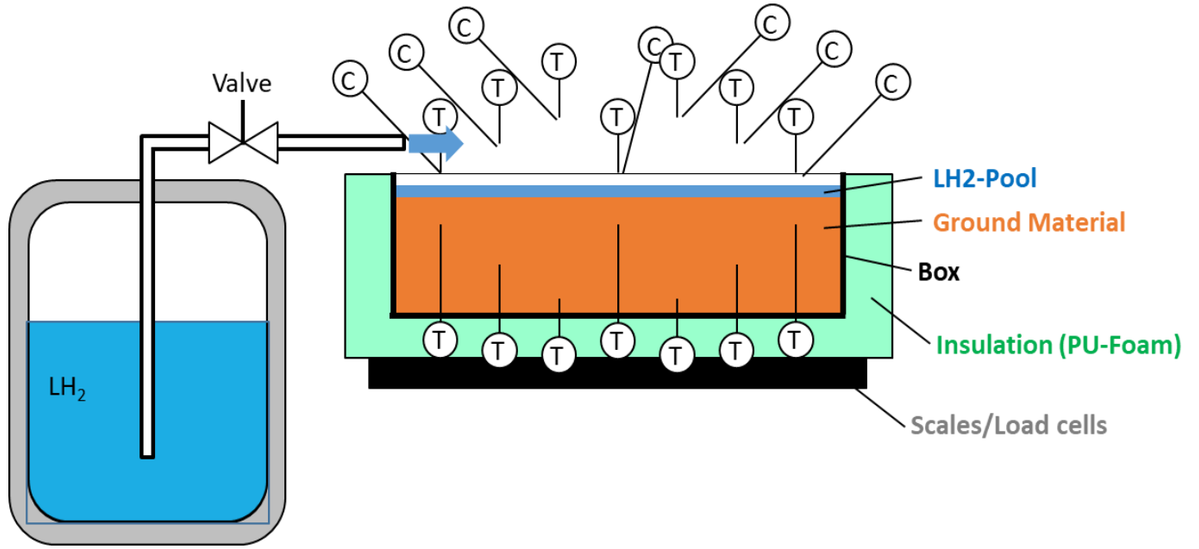
Correlation of T and H2 concentration with little influence of humidity in far field

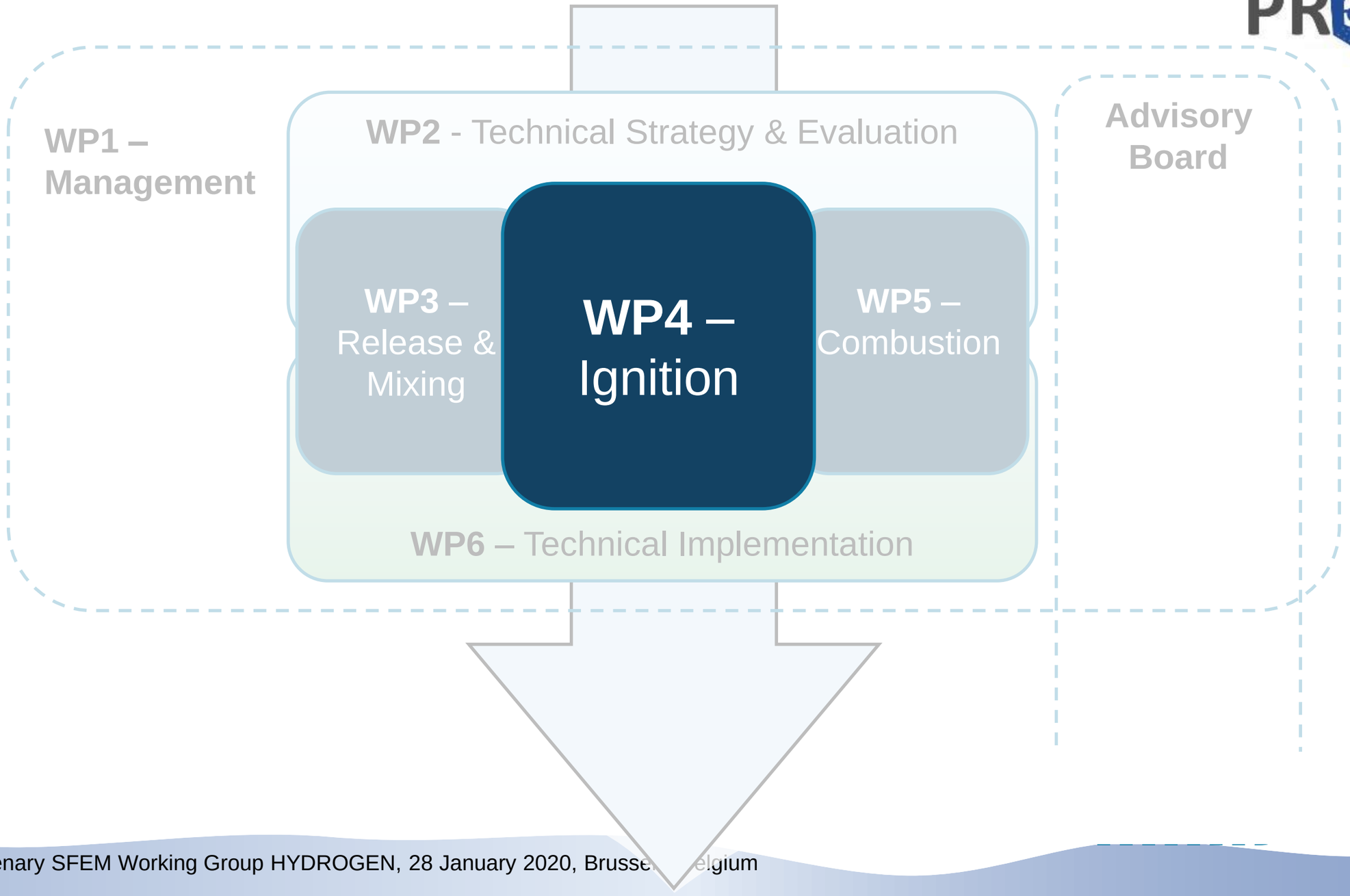
Next Release & Mixing Experiments

- E3.1b CRYOSTAT
  2-Phase release
  (KIT/PS)



- E3.4 Pool
  Release and evaporation
  (KIT/PS)

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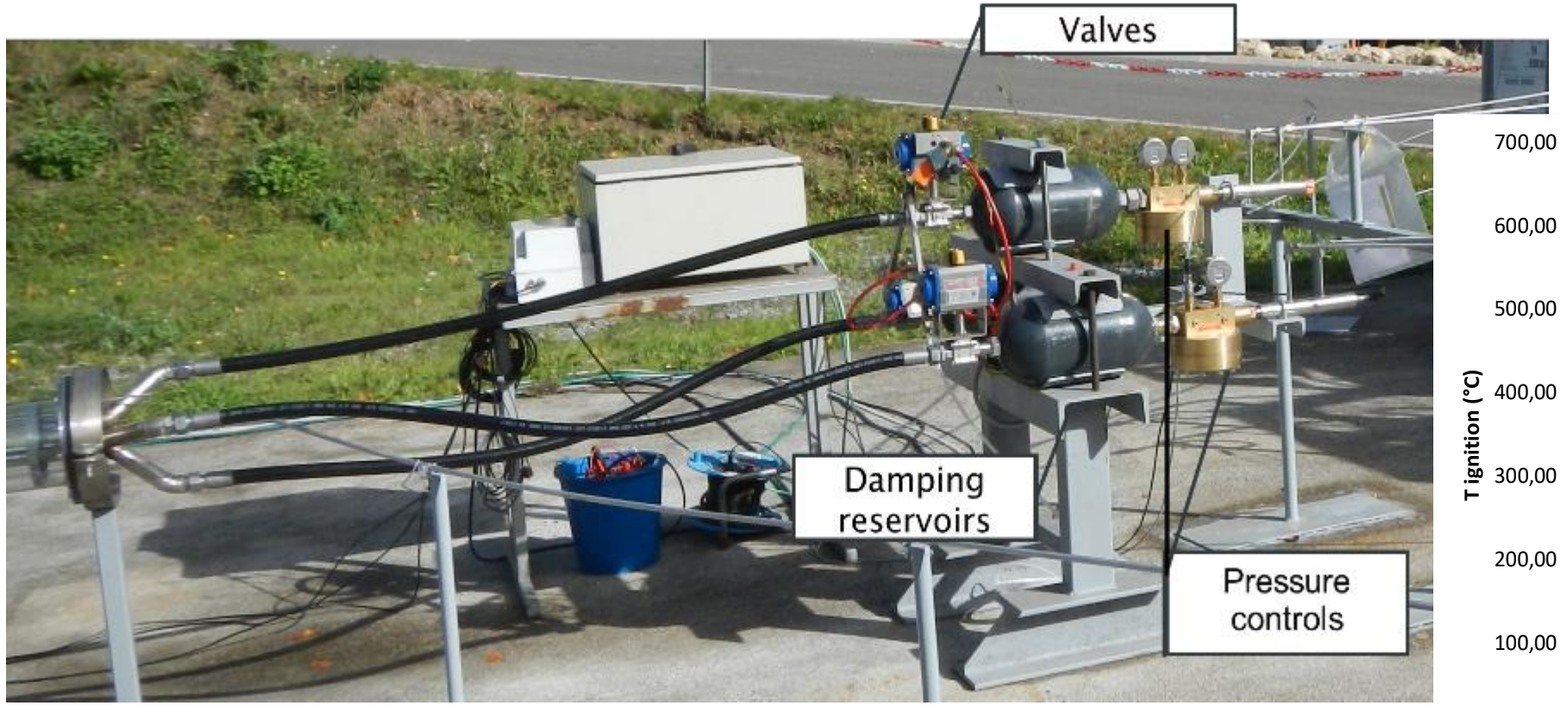
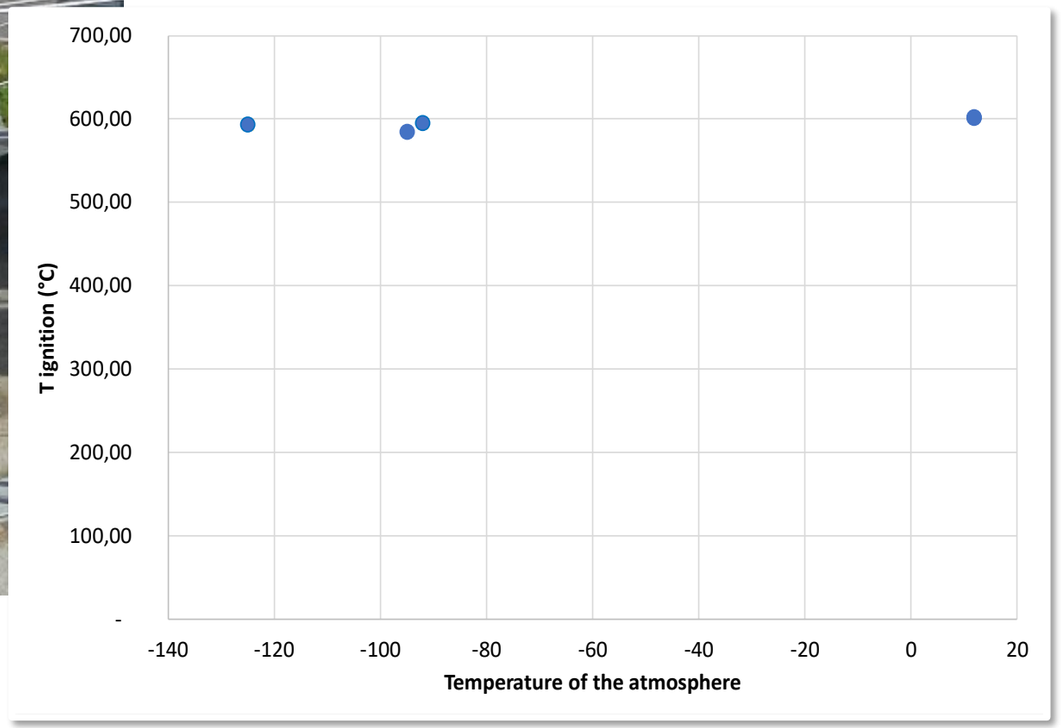
E4.1: Ignition by hot surfaces/power (INERIS)





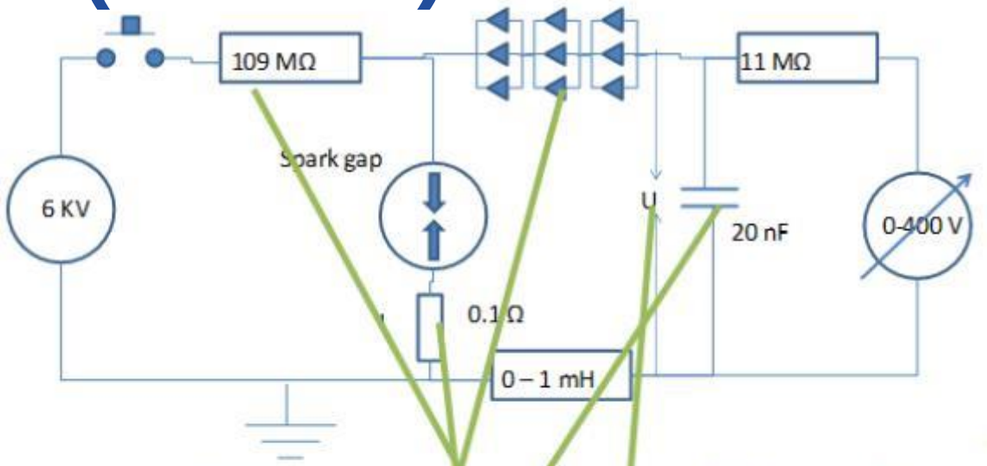
First conclusions:

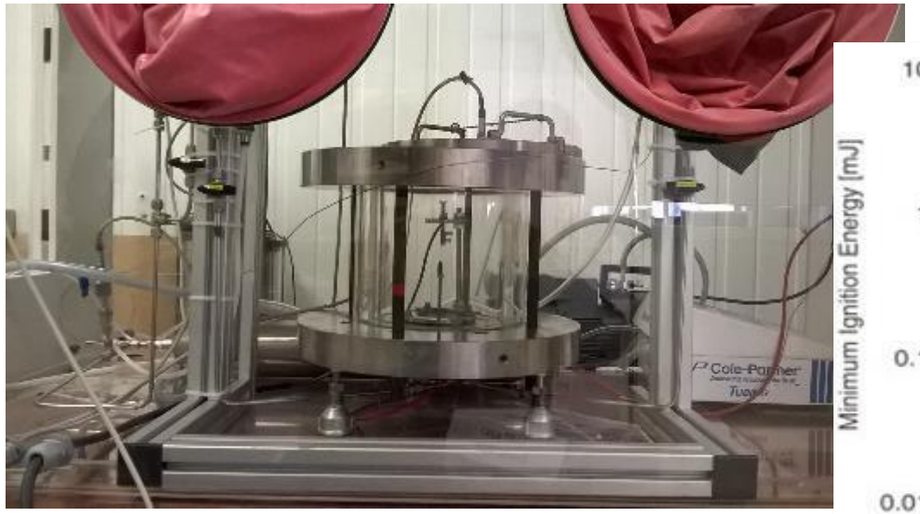
- Ignition on hot surface independent on T of surface
- Stoichiometry and flow velocity marginal influence

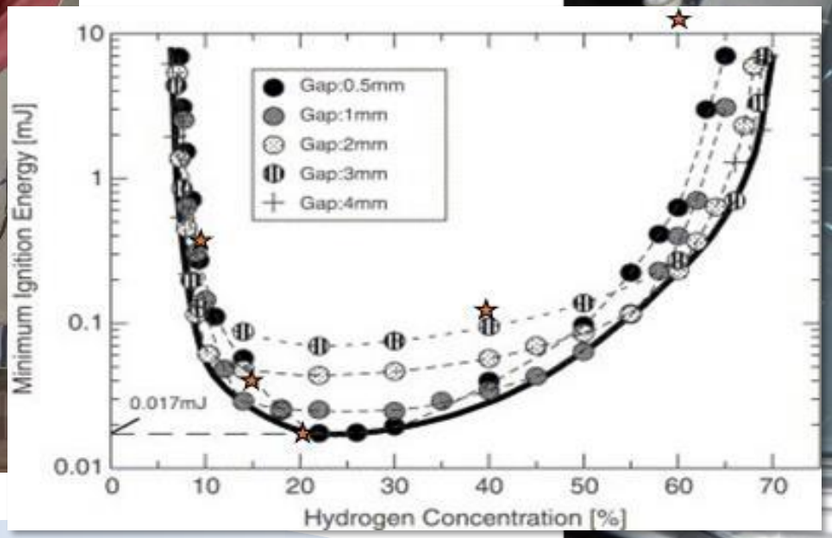
E4.1: Minimum Ignition Energy MIE (INERIS)

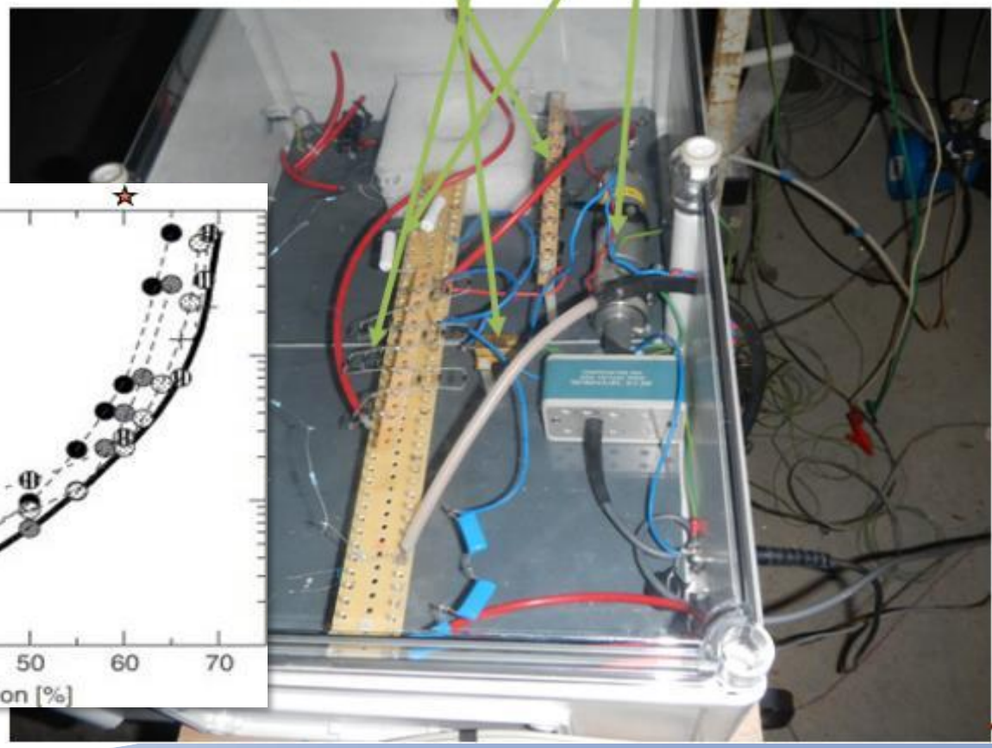
New device constructed:

- Triggered spark
- Current and voltage measured in the spark gap
- Inductance = 1 mH or zero
- Capacitance : variable
- From a few microjoules to 1 joule
- Ambient reference tests successful
- 80K tests under preparation



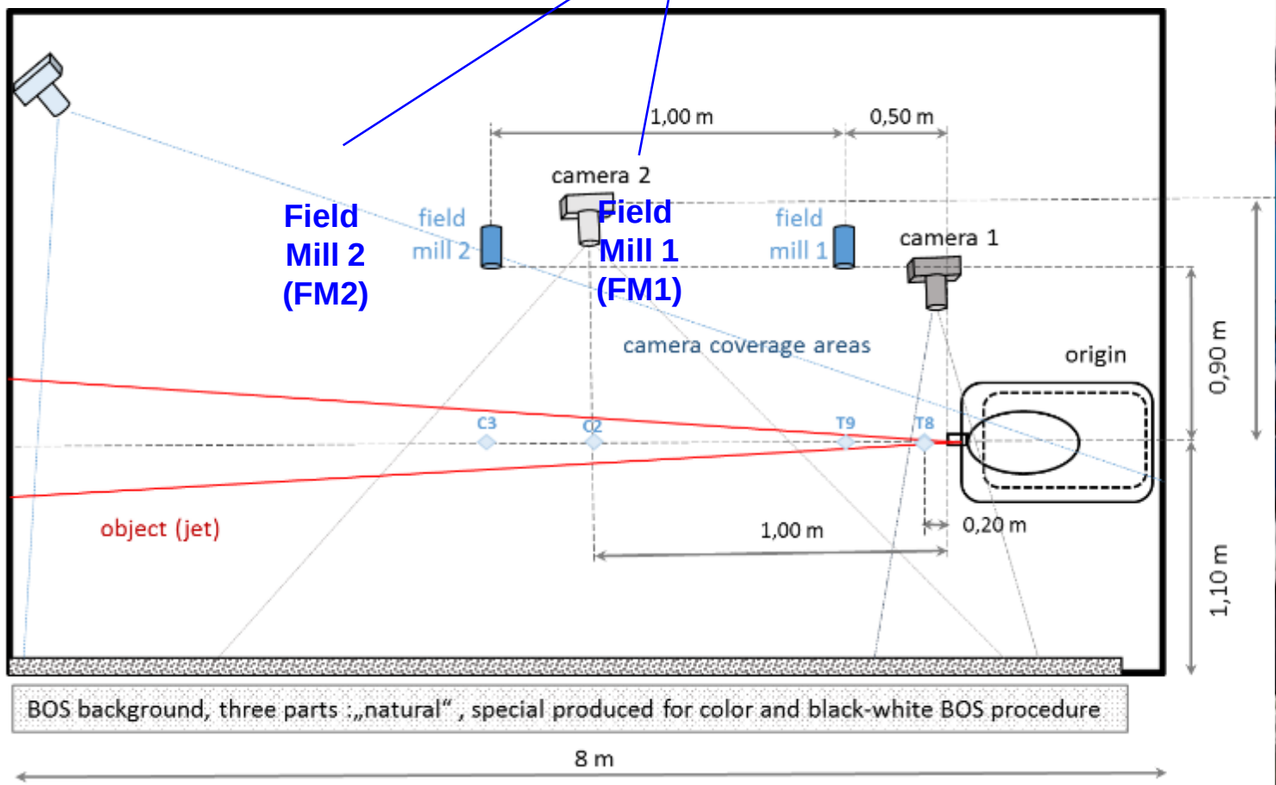






E4.2: Electrostatic Ignition in cold jet (KIT)

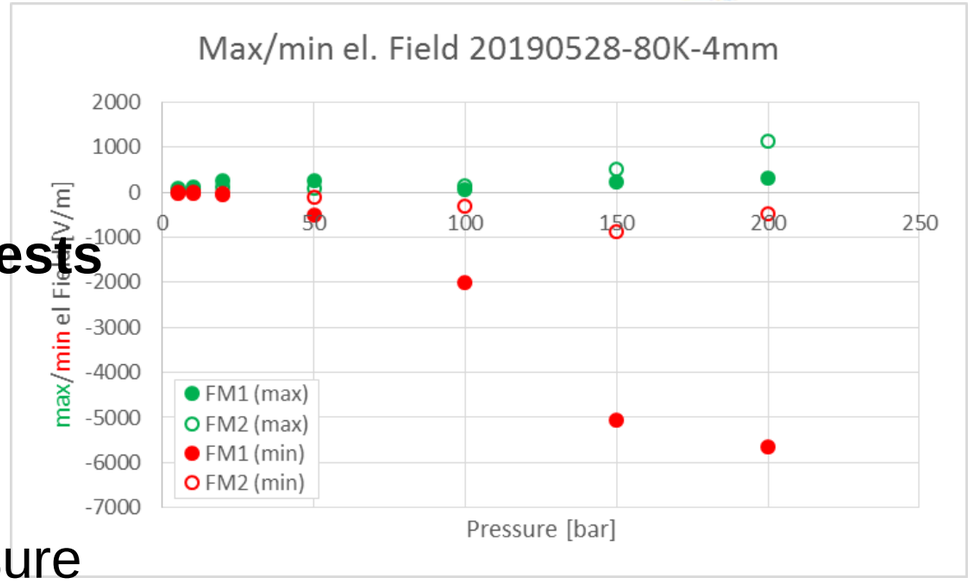
- Electrostatic field measurements with 2 field mills FM (field meters) were performed in more than 100 DisCha-experiments (see E3.1a)

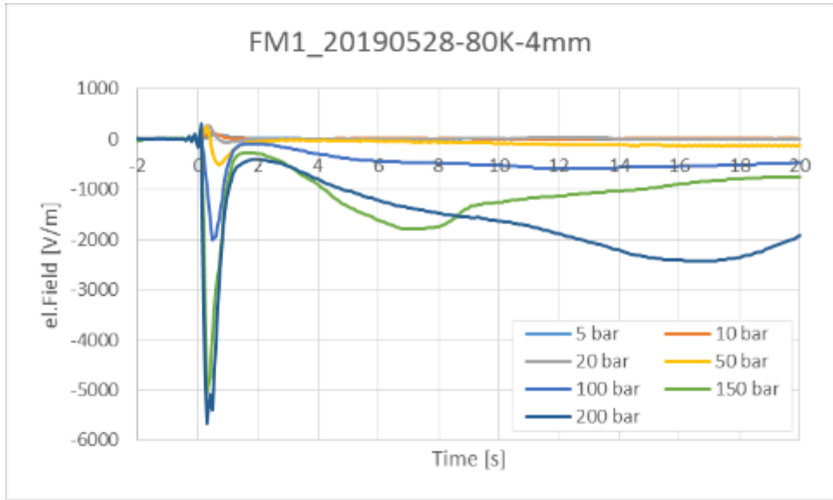


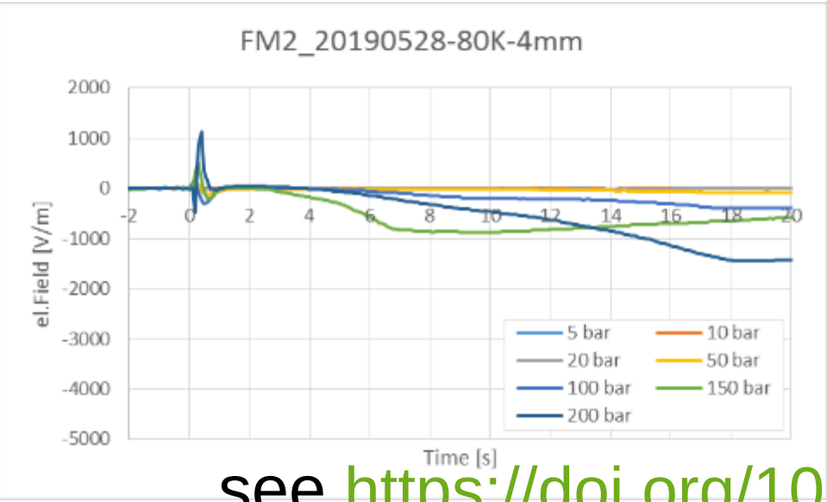
E4.2: Electrostatic Ignition in cold jet (KIT)

Initial conclusions:

- Strong electrostatic fields (~6000 V/m) observed for 80 K releases (~ factor 100 larger than at ambient T)
- **No spontenous ignition in more than 200 discharge tests**
- Positive as well as negative values
- Larger electrostatic fields close to nozzle (field mill FM1) than at farther position (FM2)
- Increasing electrostatic field values with increasing pressure

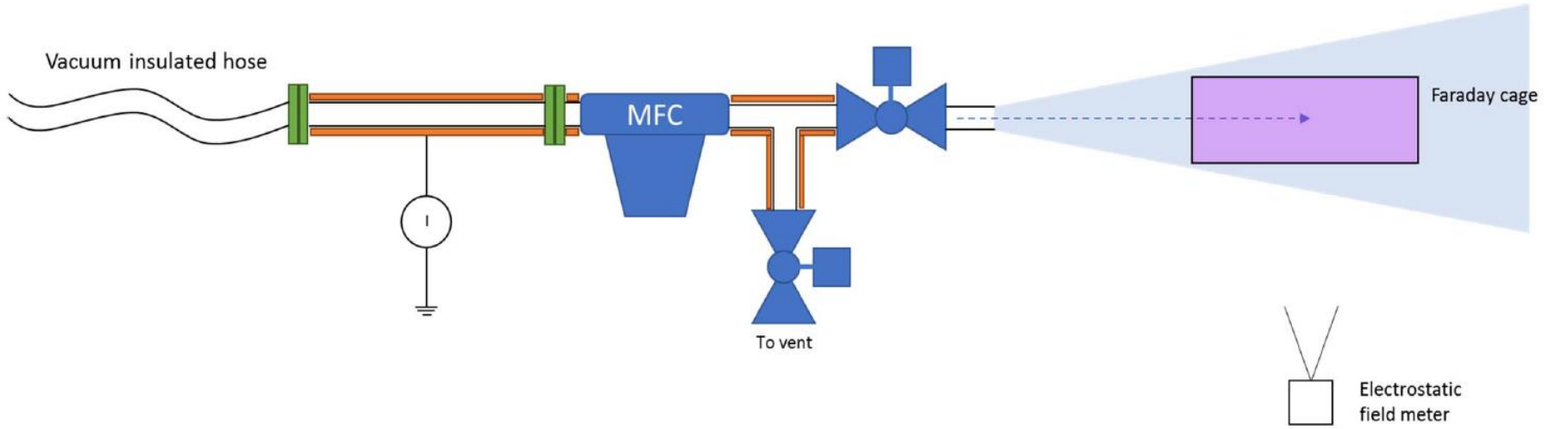






see https://doi.org/10.5445/IR/1000096833.

E4.3: Electrostatic Ignition in cold plume (HSE)



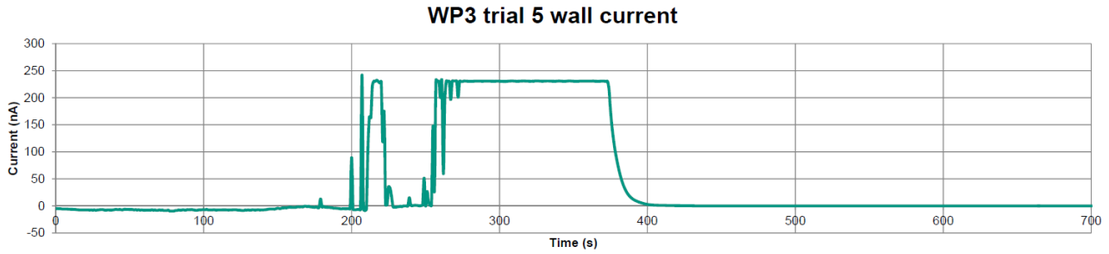
Intrumentation:

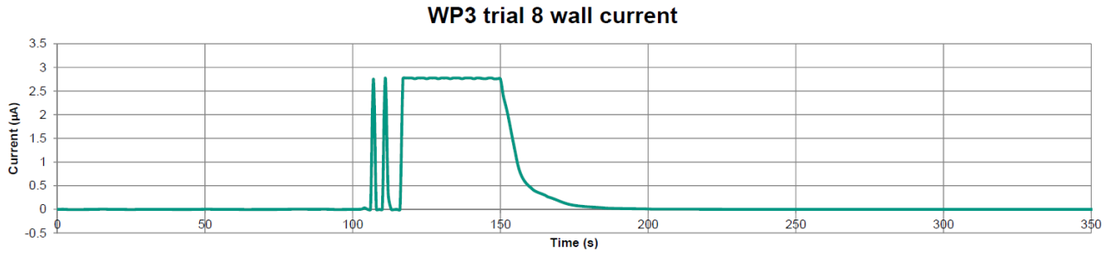
- Wall current:
  Isolated pipe section + electrometer
- Plume electrostatics measurement:
  Field meter + Faraday cage

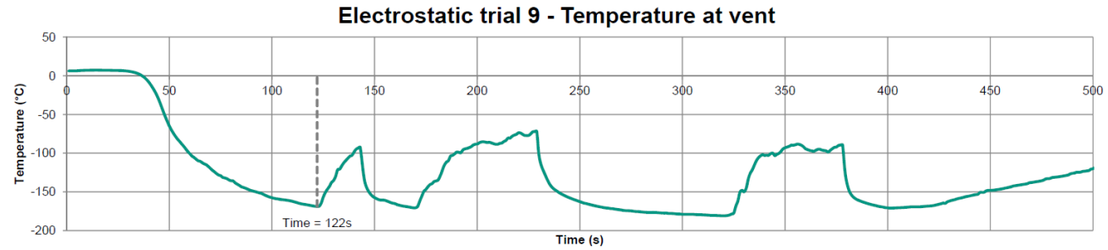
Isolated pipework

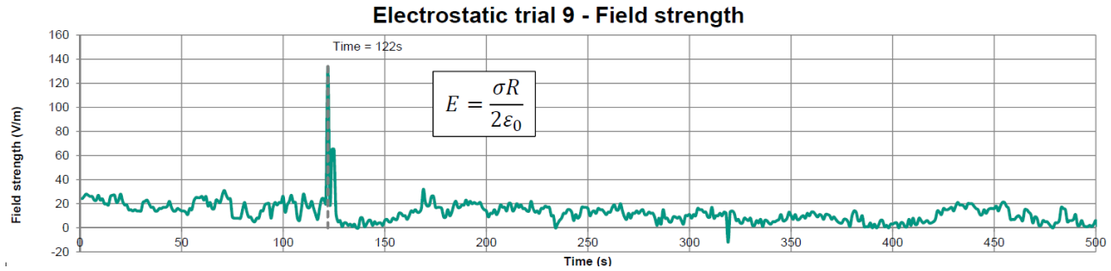
Faraday cage and field meter

E4.3: Electrostatic Ignition in cold plume





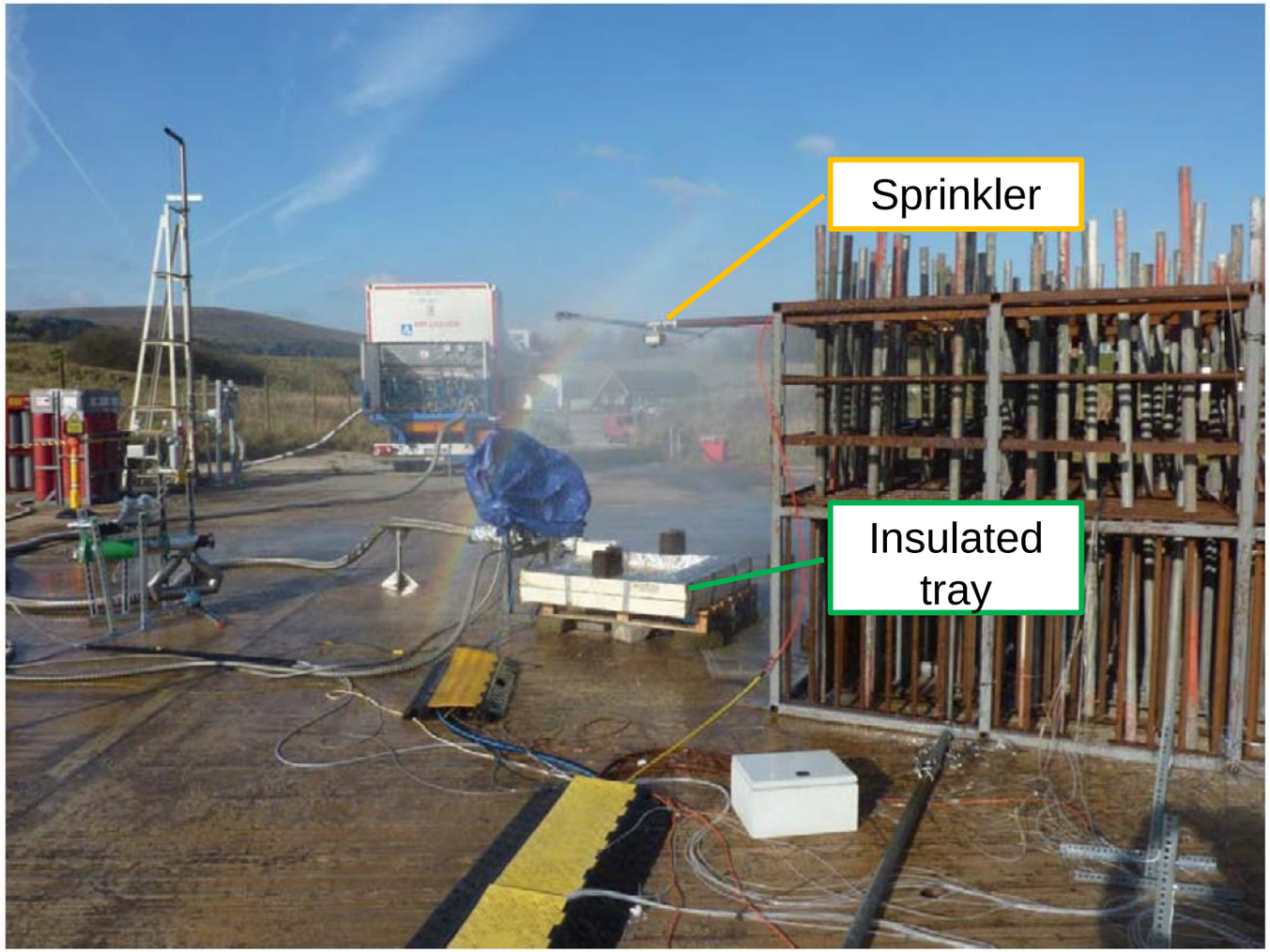




Initial conclusions:

- H2 did not hold a significant charge
- Multiphase H2 flow can generate a current in isolated pipework
- Occasional charge spikes have been identified, possibly cause by ice breaking off the nozzle or air being ejected from un-purged pipework

E4.X: Rapid Phase Transition RPT Tests



Sprinkler system test

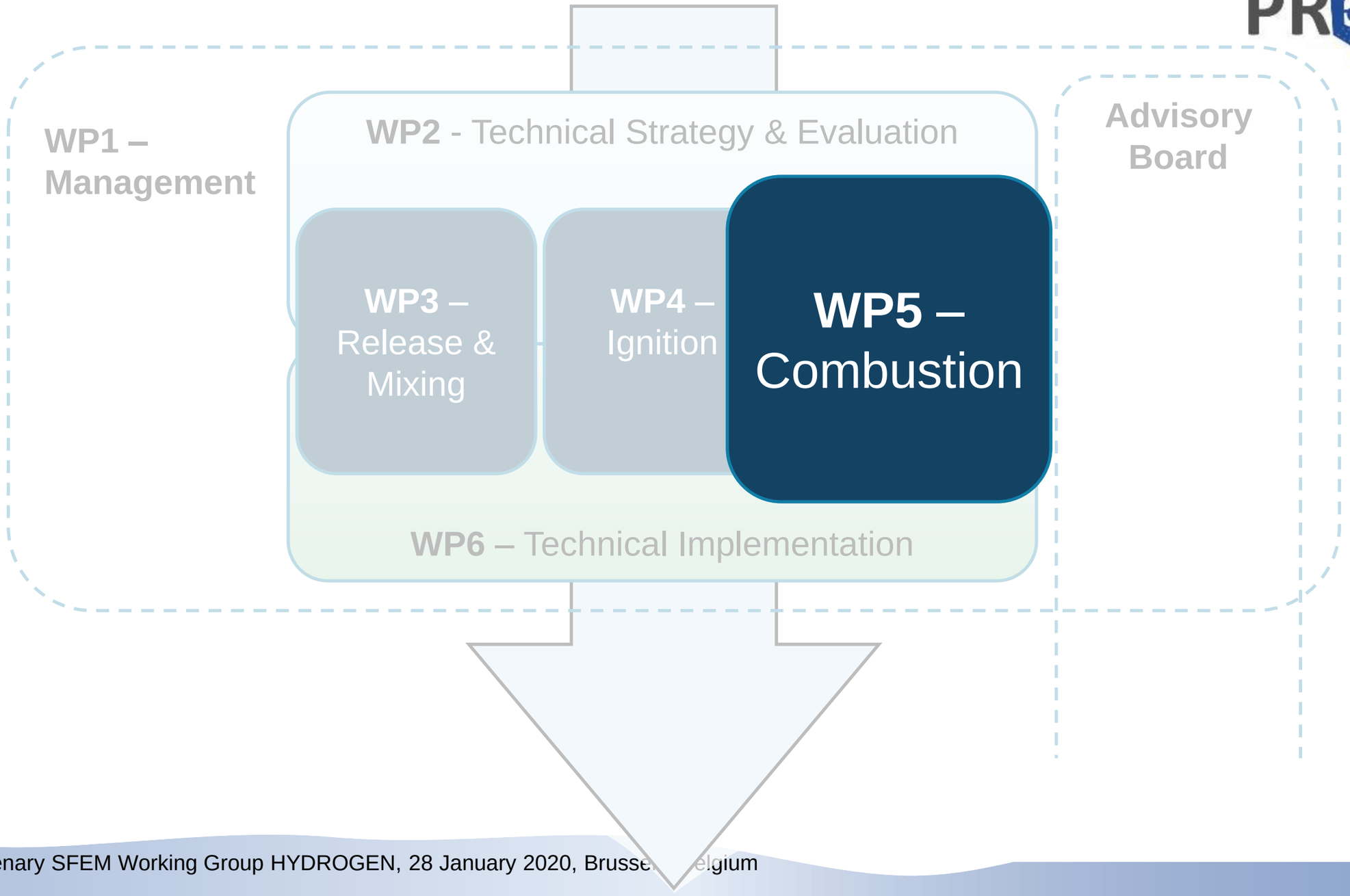
- Insulated tray to collect fluid
- Thermocouples arranged to indicate pool depth
- Water release system with sprinkler and hose attachment

Initial conclusions:

- Sprinkler system did not cause RPTs, when interacting with LH2 pool
- Fire hose deluge increased the evaporation rate of the LH2 pool

Next Ignition Experiments

- E4.1b Cold MIE (INERIS)
- E4.4 Ignition above pool (KIT)
- E4.5 Condensed phase ignition (HSL)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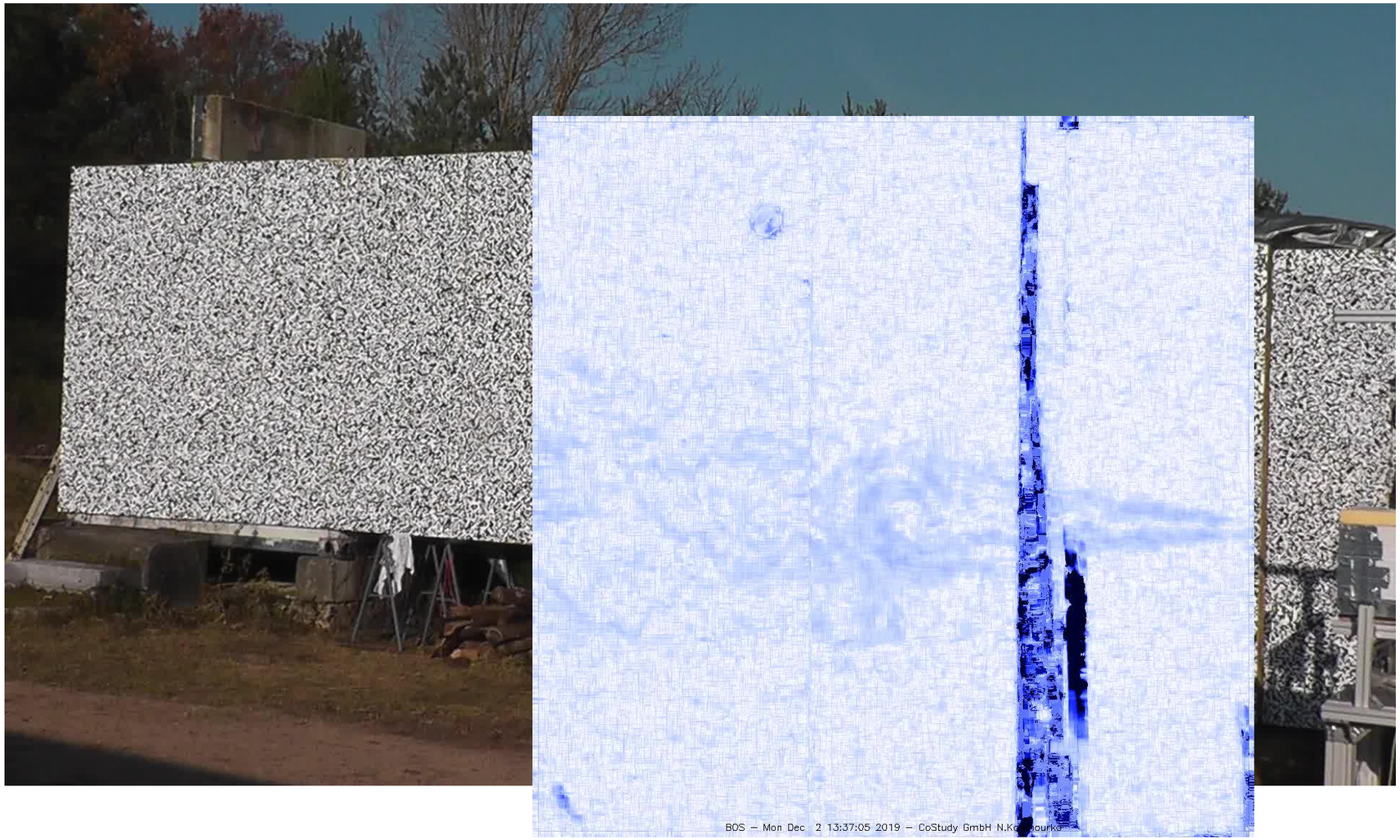
E5.1: Ignited Jet (“Jetfire DISCHA”)

Variation of ignition time and position

DisCha facility had to be transported to the free field test site

E5.1: Ignited Jet

Variation of ignition time and position



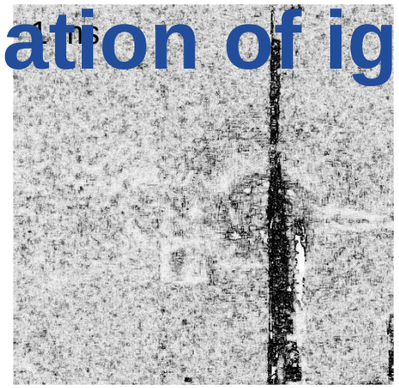
Experiments based on unignited discharge tests E3.1 with reduced parameters variation:
T = 80K, ~285K
p = 5, 100, 200 bar
D_{nozzle}= 1, 2, 4mm

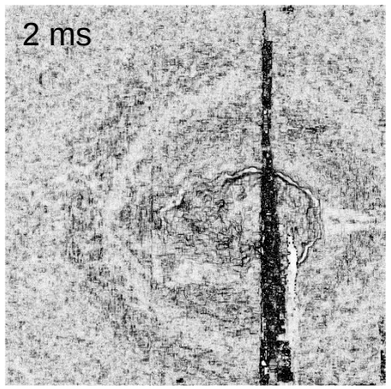
Iterative procedure
for identifying most critical ignition point and location

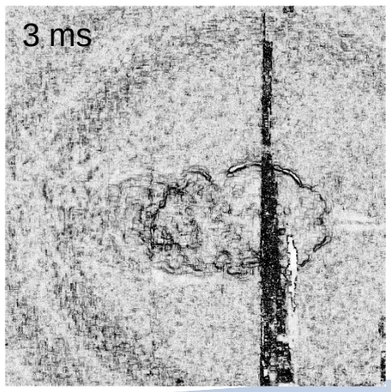
(> 90 tests
done by 10.12.2019)

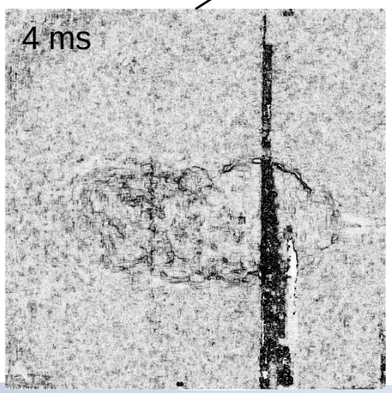
E5.1: Ignited Jet

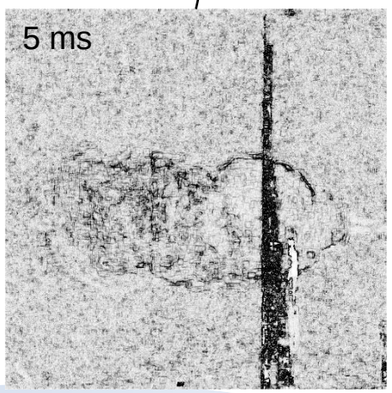
Variation of ignition time and position

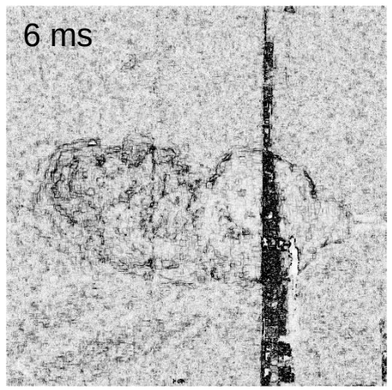


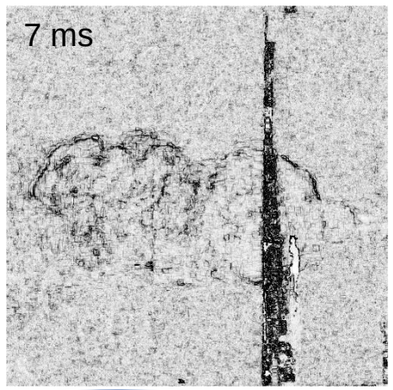


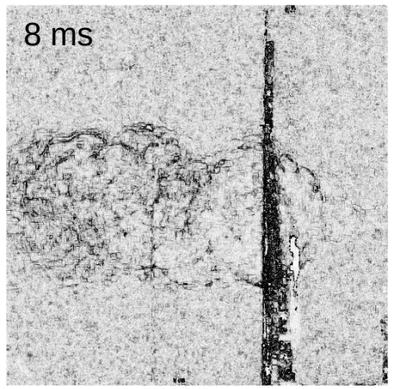


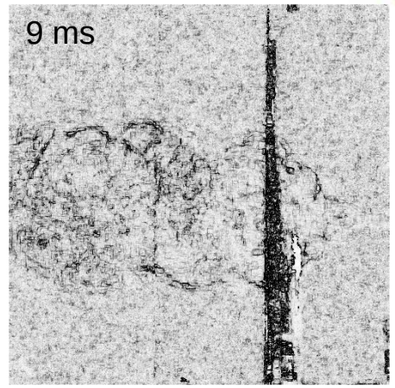


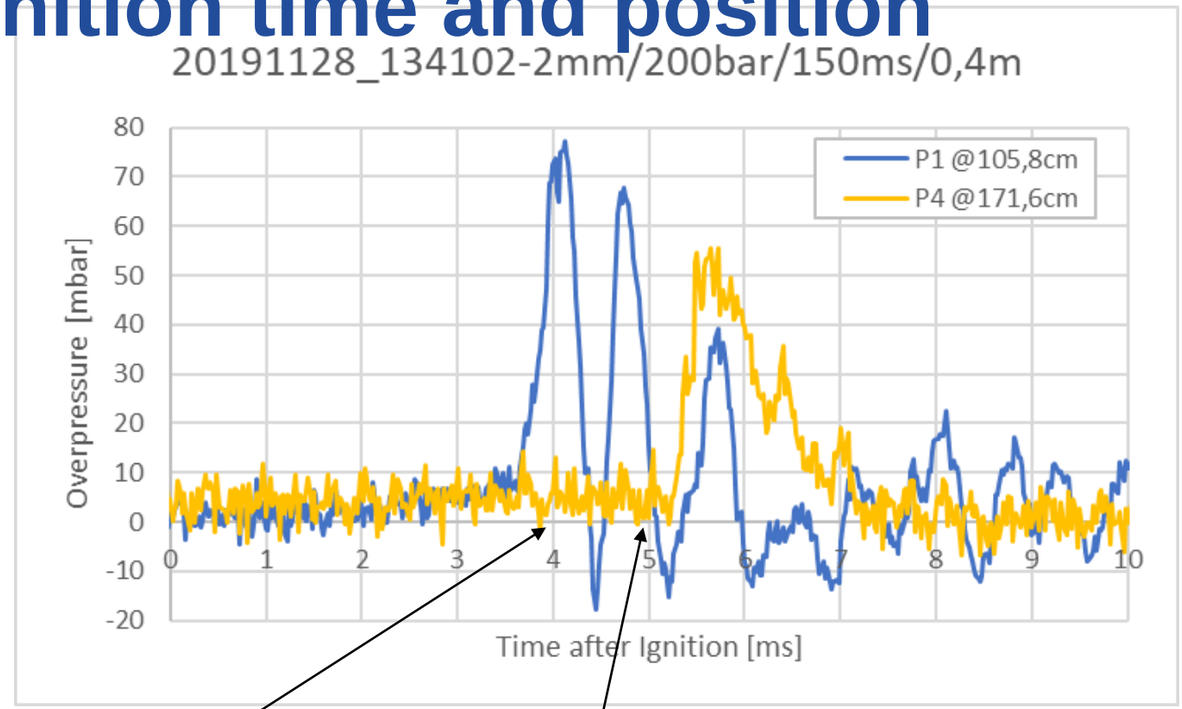






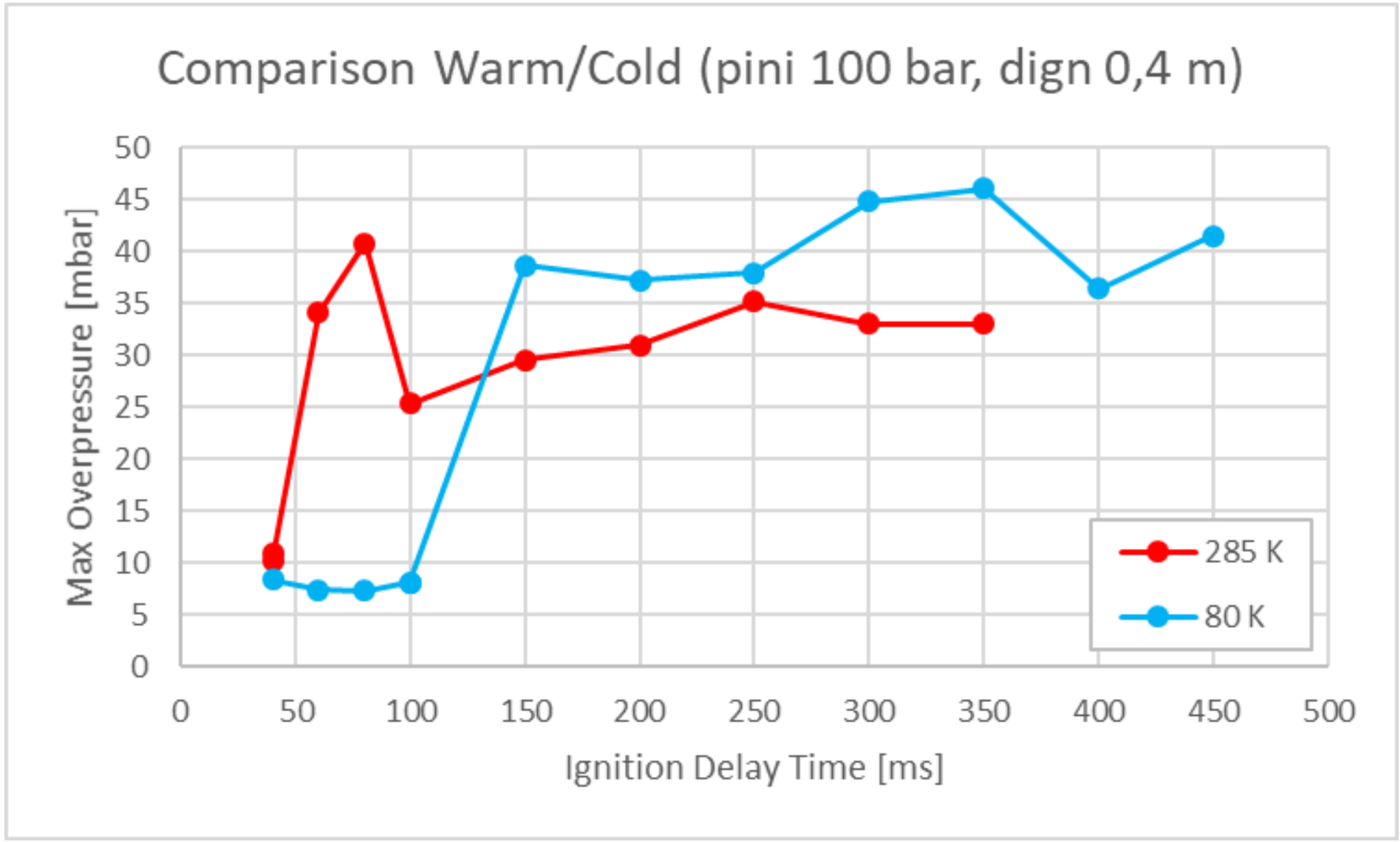






E5.1: Ignited Jet – Examplary Result

Variation of ignition time (fixed ignition position)

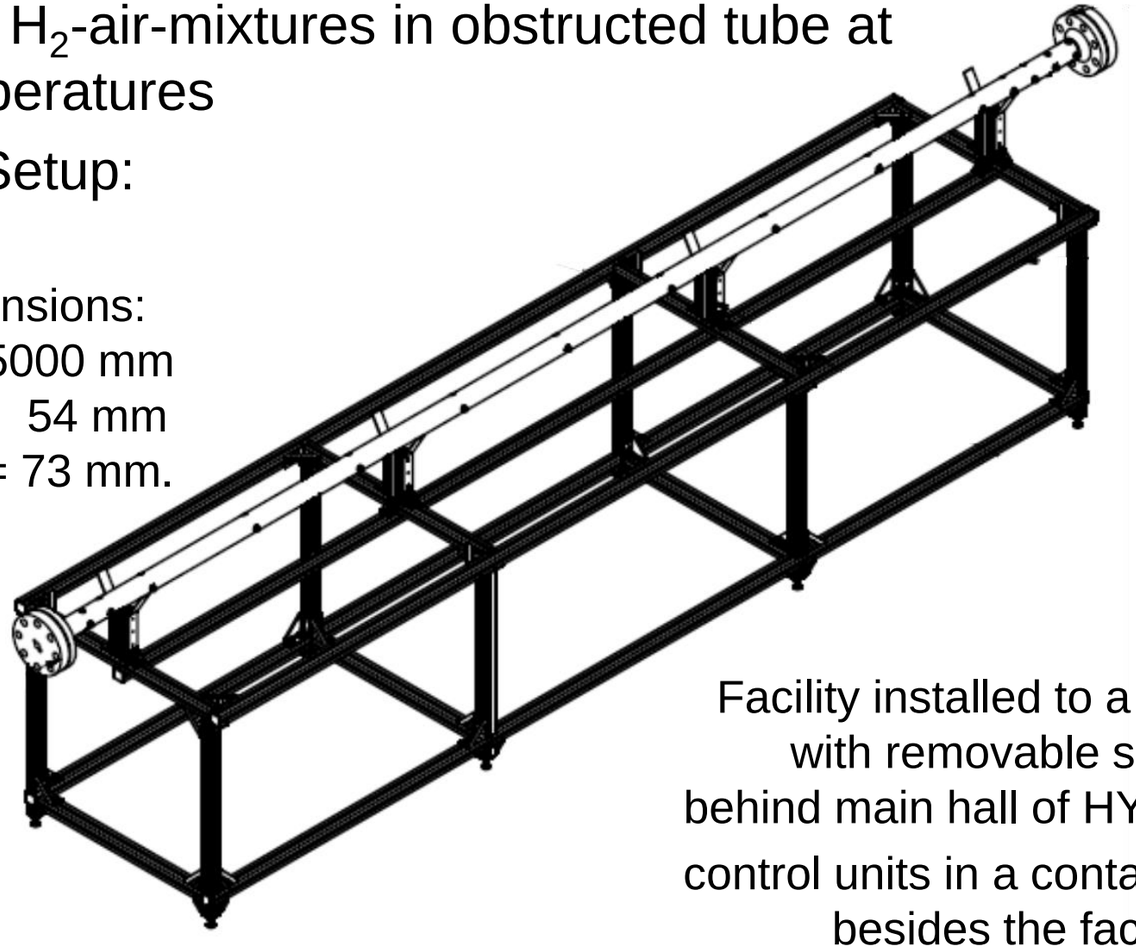


p = 100 Mpa
D_{nozzle} = 2mm
d_{ign} = 0.4m

E5.2: FA and DDT at cryogenic T ("Tube experiments")

- Combustion of H_2-air-mixtures in obstructed tube at cryogenic temperatures
- Experimental Setup:

Dimensions:
L = 5000 mm
D_{in} = 54 mm
D_{out} = 73 mm.



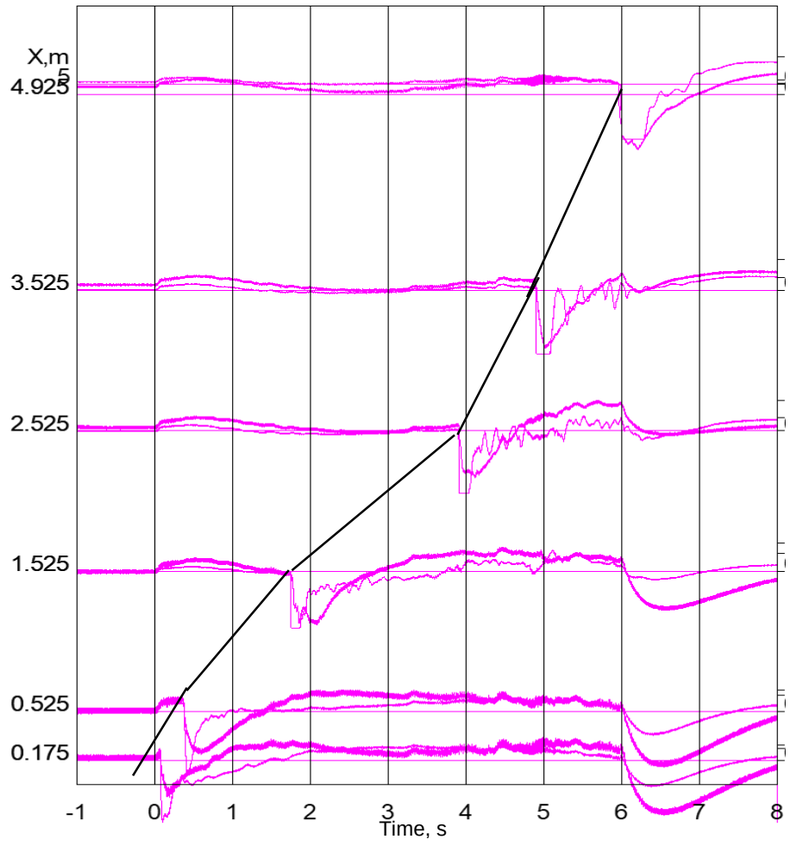
Facility installed to a tent with removable sides behind main hall of HYKA, control units in a container besides the facility.

E5.2: Reference tests

Several tests at ambient T have been conducted to check the facility

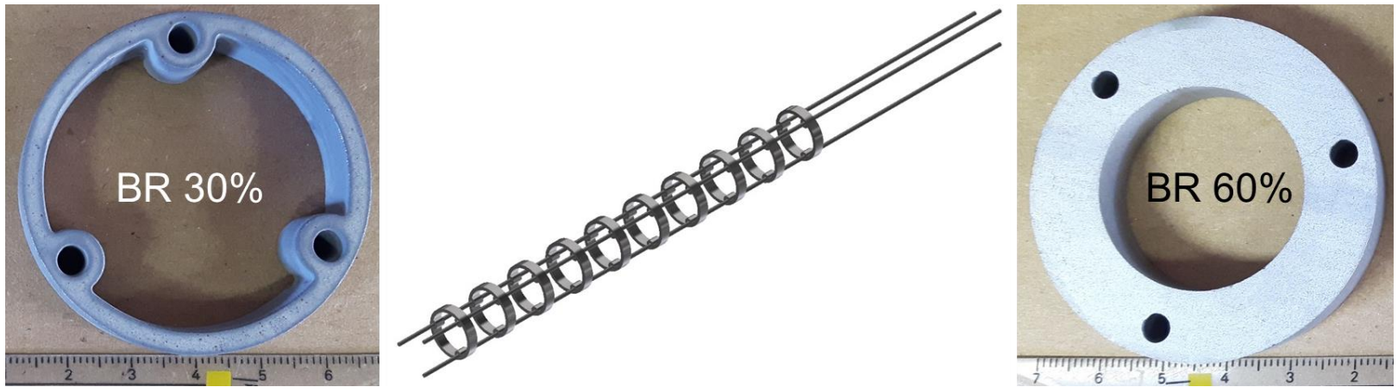
- Tests without obstacles
- Hydrogen-concentrations investigated in the warm tests are:
  cH_2 = 10, 11, 12, 15, 20, 30, 45, 60 vol%

x-t Diagram: Pressure signals along tube
10,6 Vol% H2, no obstacles



E5.2: Test Parameters for 80K Tests

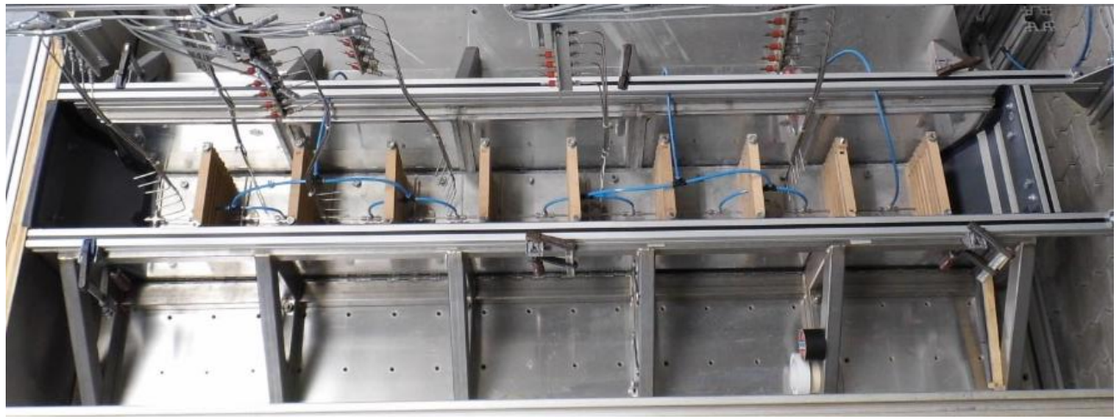
- 2 blockage ratios (30% and 60%)



- 10 H2-concentrations from within the ranges
  - 6 to 12 Vol.% H2
  - 15 to 20 Vol.% H2
  - 30 Vol.% H2
  - 60 to 75 Vol.% H2

Next Combustion Experiments

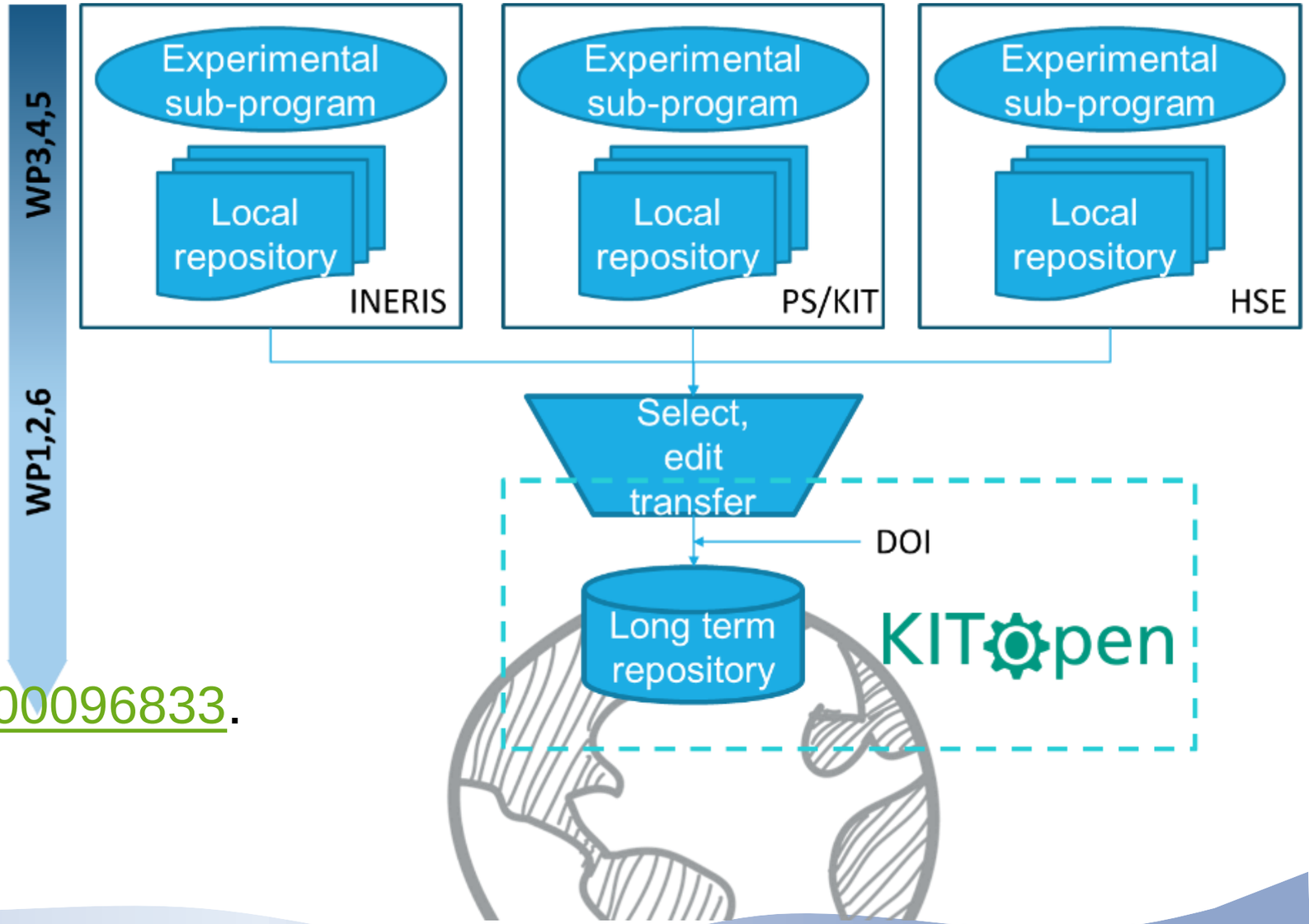
– E5.3 Flame propagation above LH2 pool (KIT/PS)



– E5.5 Flame propagation in confined /obstructed cold cloud (HSE)
(done – first report expected within 12/2019)

FAIR Data Management

- Development of the Data Management Plan
- Comparison and final selection of KITopen for the project Open Scientific Data Repository
- First prototypical data published for WP3 experimental series E3.1 https://doi.org/10.5445/IR/1000096833.



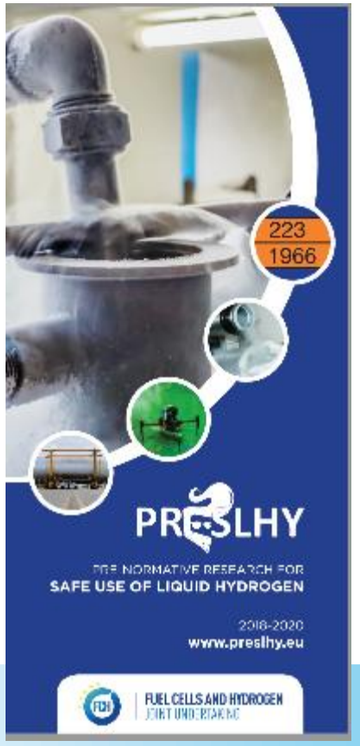
Outreach

www.preslhy.eu

PRESLHY Exploitation & Dissemination Activities

Management (WP1)

Implementation (WP6)



Task 1.3 Website

Data Manage ment

Engineering tools

Handbook

Guidelines

RCS Recom- mendations

White Paper

Task 6.6 Dissemina- tion Conference

Summary

- First results and initial conclusions generated in PRESLHY.
- Main part of experimental program just being executed.
- Data has to be transformed into knowledge, models and engineering correlations (main activity for second half 2020).
- Learnings from the other associated projects (SH2IFT, etc…) to be included → for a draft revision of ISO/TR 15916:2015 “Basic considerations for the safety of hydrogen” (by ISO PWI24077 or NWI)

Acknowledgement

The PRESLHY project has received funding from the Fuel Cells and Hydrogen 2 Joint Undertaking under the European Union's Horizon 2020 research and innovation program under the grant agreement No 779613.

… and many thanks to all contributors
(e.g. Equinor, SHELL, …)