# Update on ISO PWI24077

## Safe Use of LH2 in Non-industrial Settings

## *Contributions of the FCH JU project PRESLHY*

Thomas Jordan, KIT

Plenary Meeting of the ISO TC 197, Grenoble France, 12/13 December 2019

**Pre-normative REsearch for Safe use of Liquid HYdrogen**

# Outline

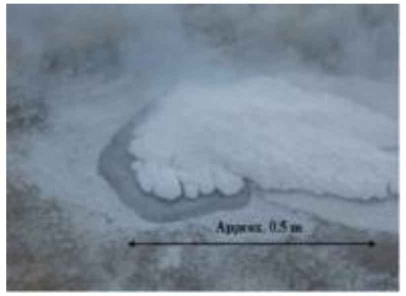
- Motivation
- PRESLHY Overview
- WP3 Release
- WP4 Ignition
- WP5 Combustion
- Exploitation
- Closure

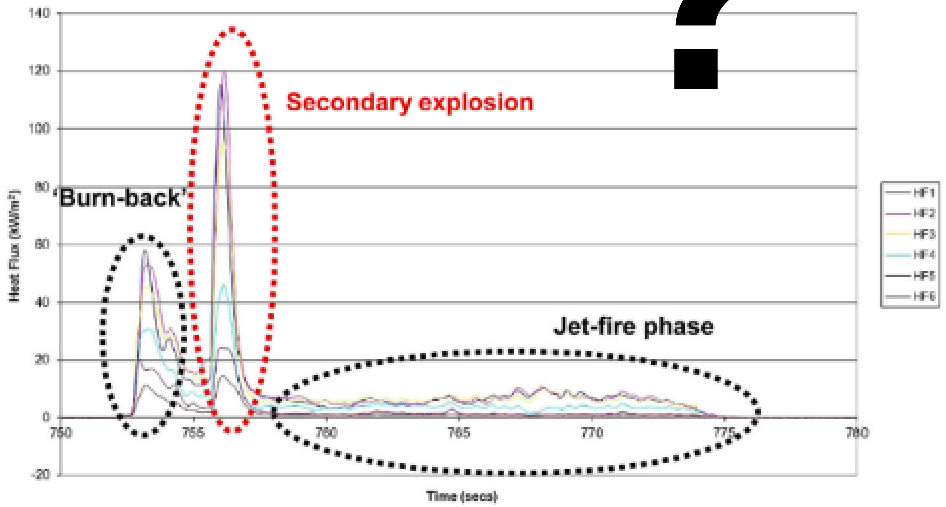
# Motivation

!

- 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)

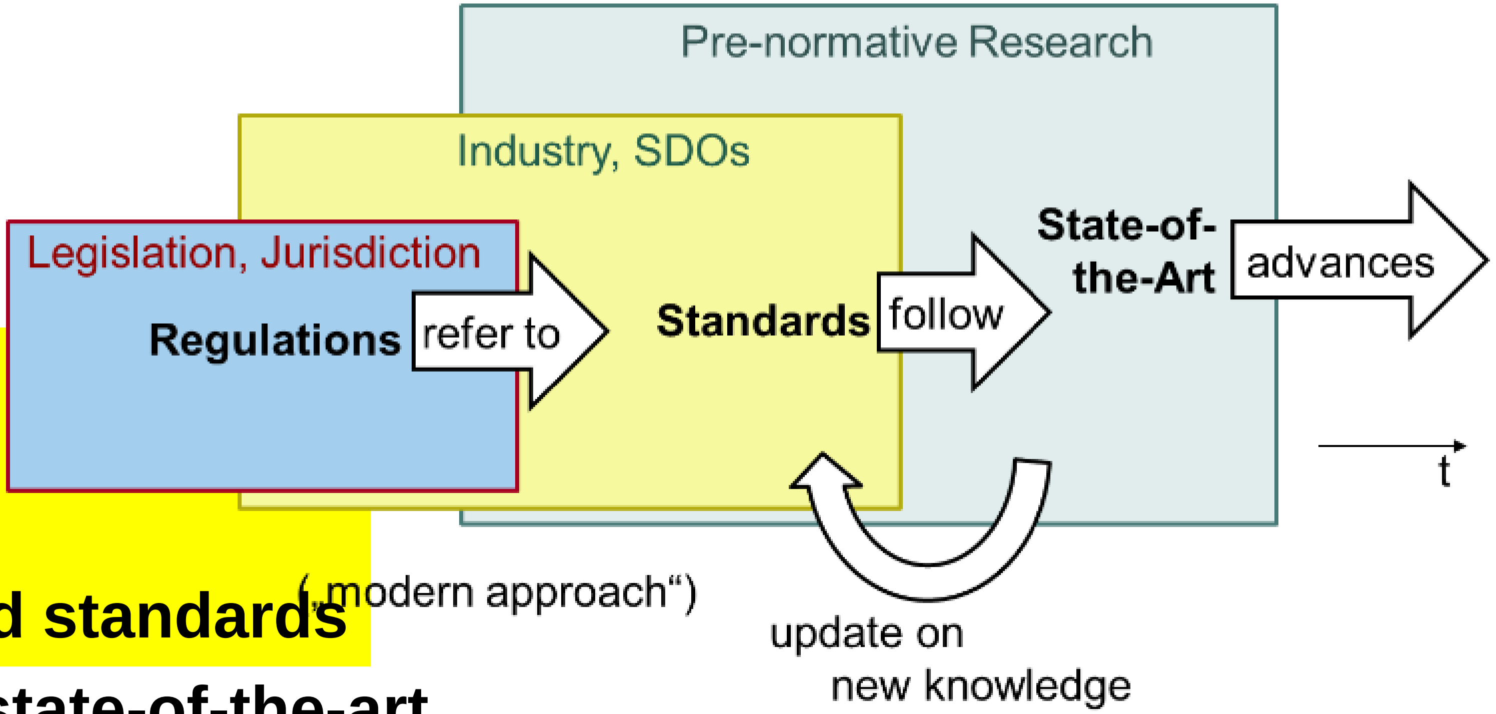
?





# 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

PRESLHY

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

ISO

Presentation on 19.10.2018

FCH – Fuel Cells and Hydrogen Joint Undertaking

**WP1** – Management (KIT)

**WP2** - Strategy (AL)

**WP3** – Release & Mixing (NCSRD)

**WP4** – Ignition (HSL)

**WP5** – Combustion (KIT)

**WP6** – Implementation (UU)

**PRESLHY Advisory Board**

H2@Scale U.S. Department of Energy – SNL

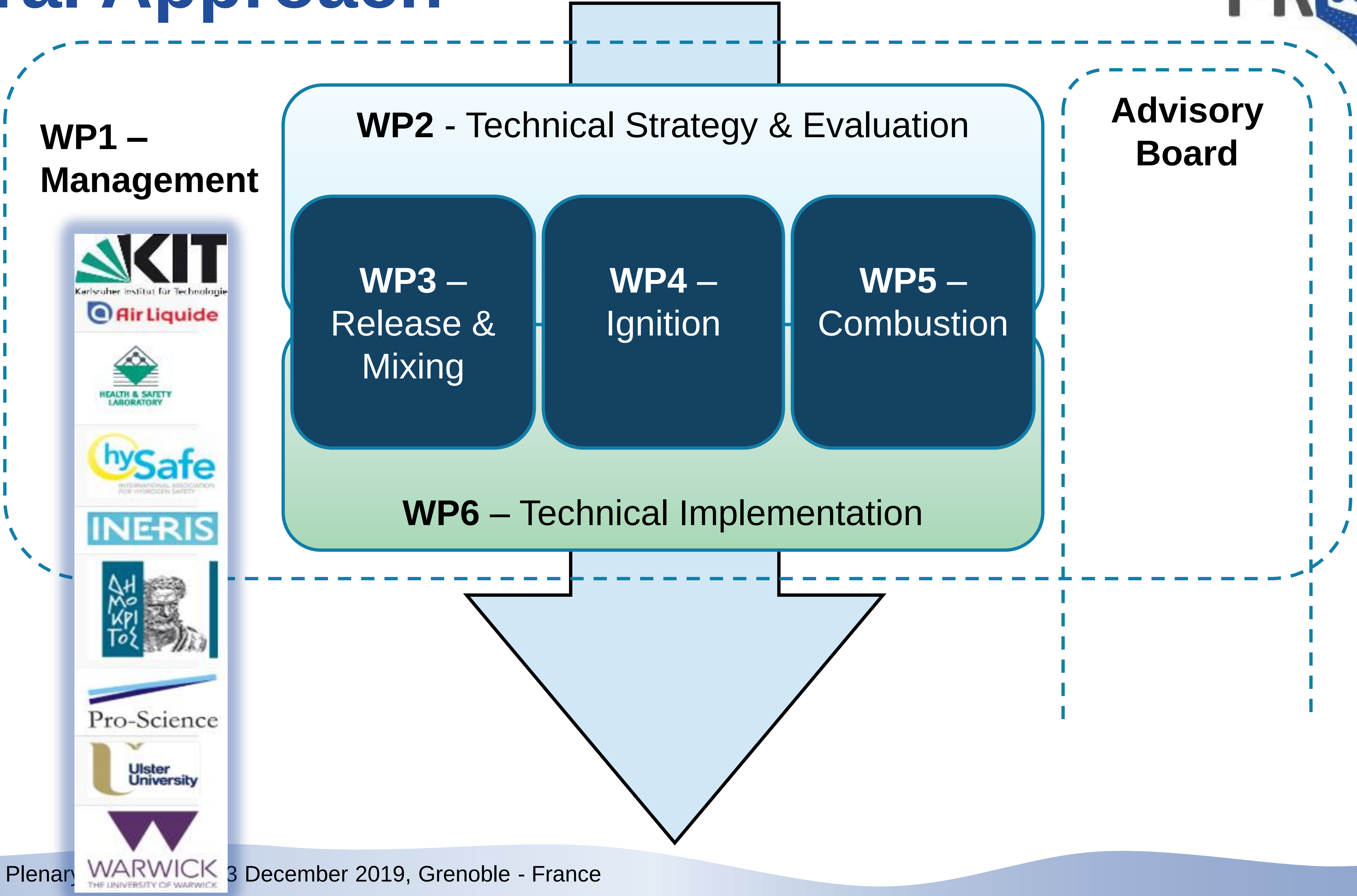
SH2IFT

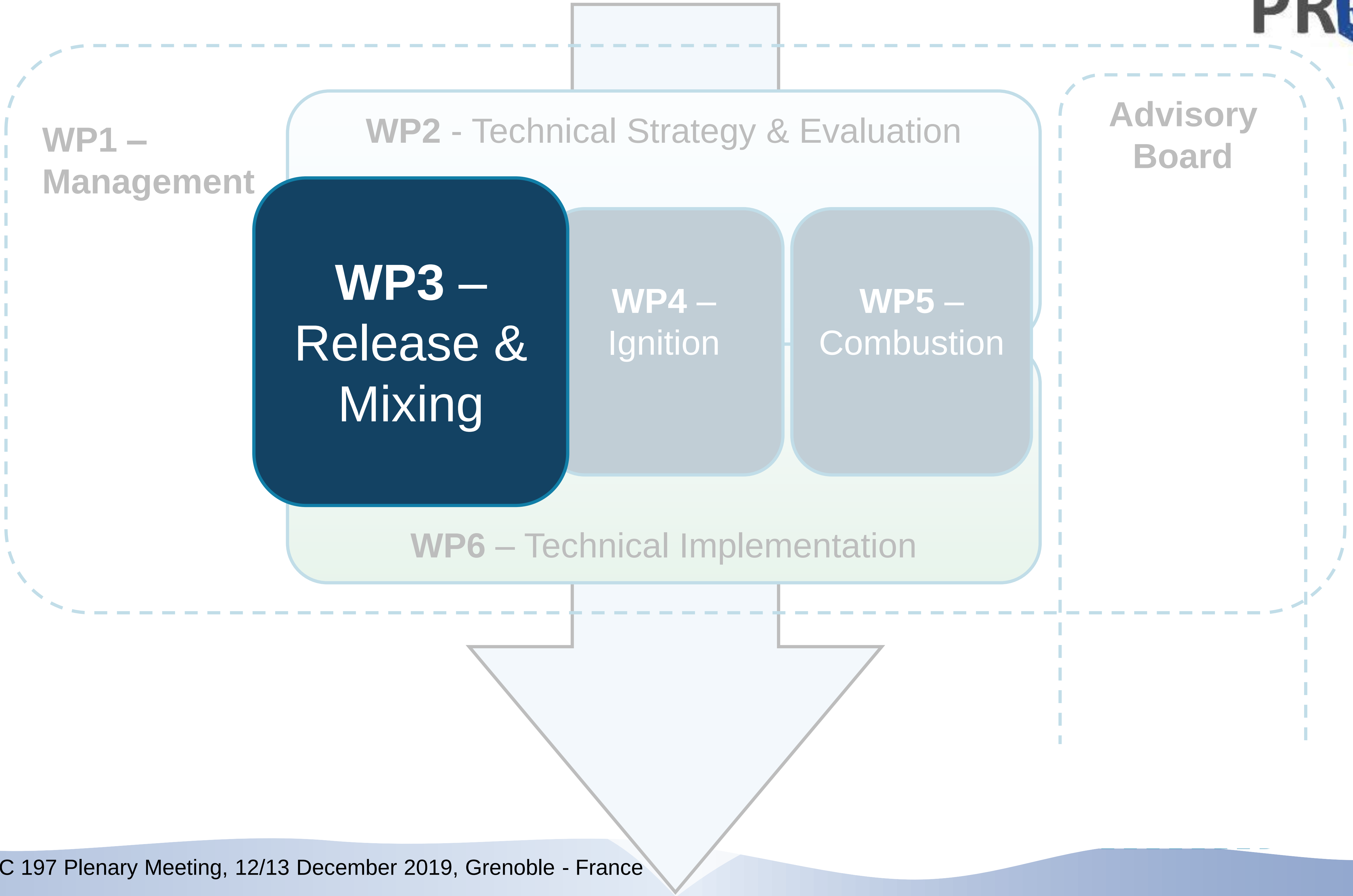
GexCon, IFE, Equinor

KHI, Toyota

Shell

# General Approach

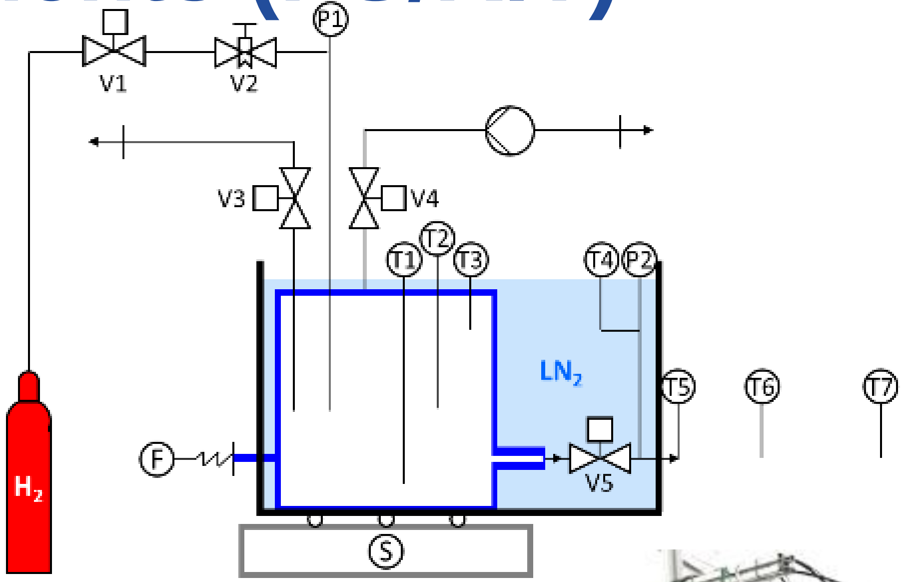


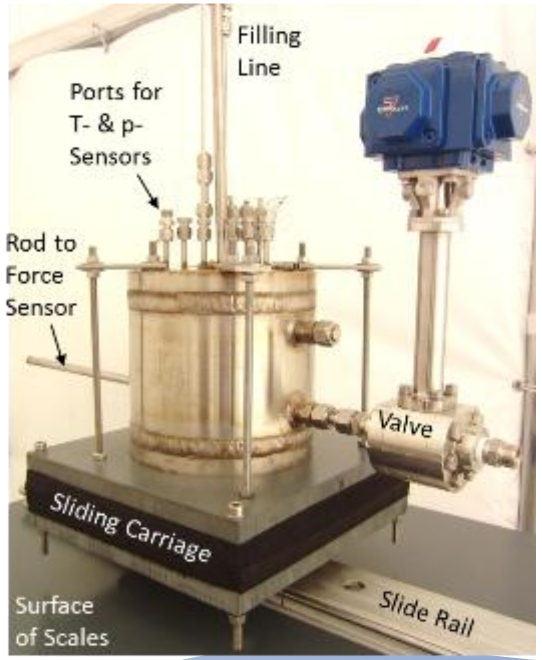

WP1 – Management
WP2 - Technical Strategy & Evaluation
Advisory Board
WP3 – Release & Mixing
WP4 – Ignition
WP5 – Combustion
WP6 – Technical Implementation

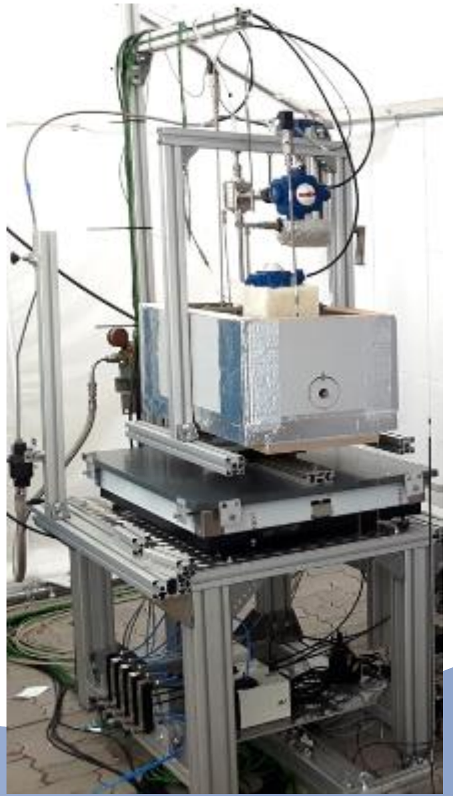
# Experimental series E3.1a

## 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**

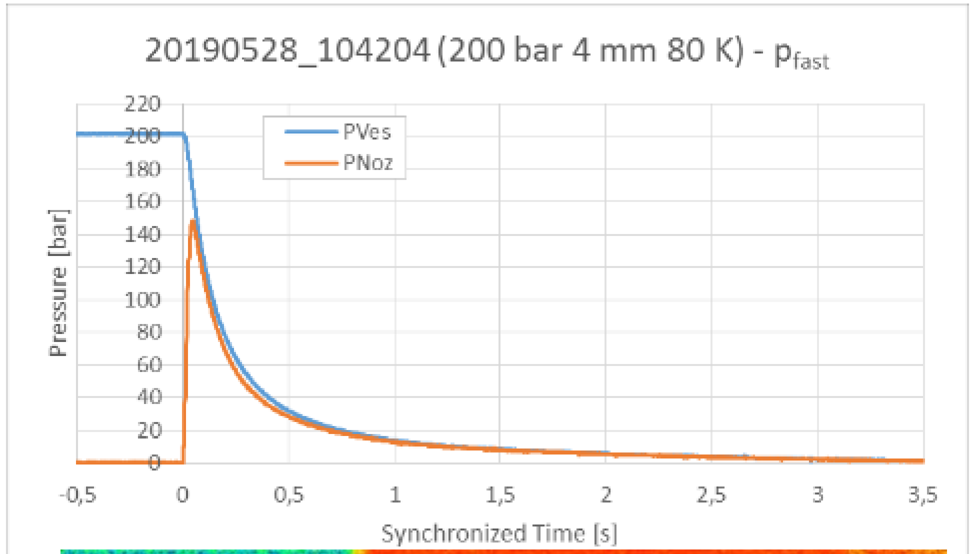


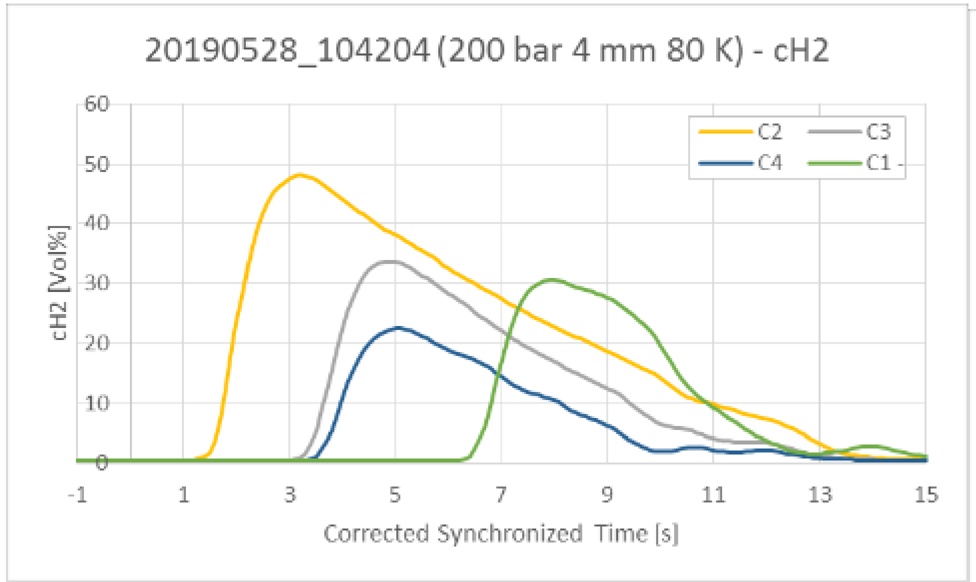



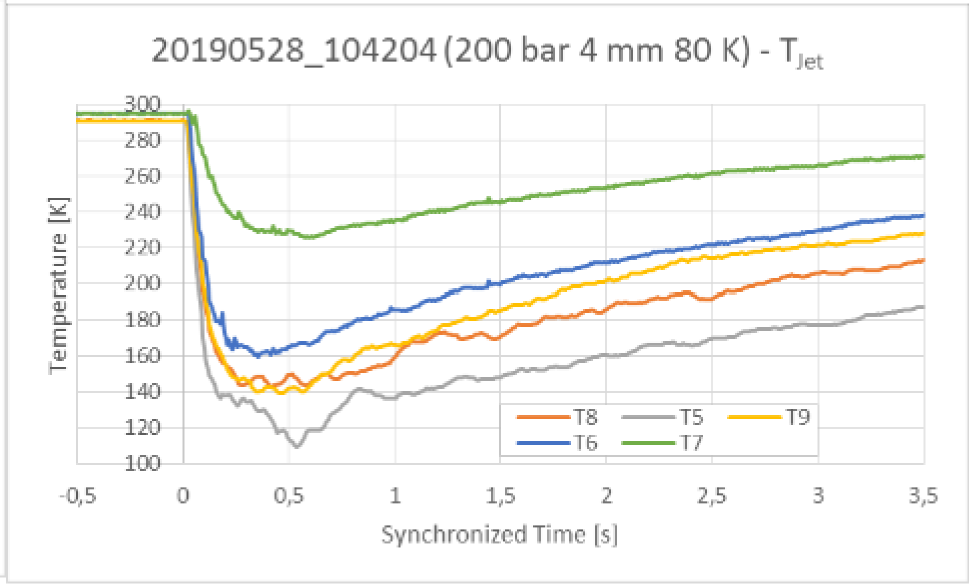



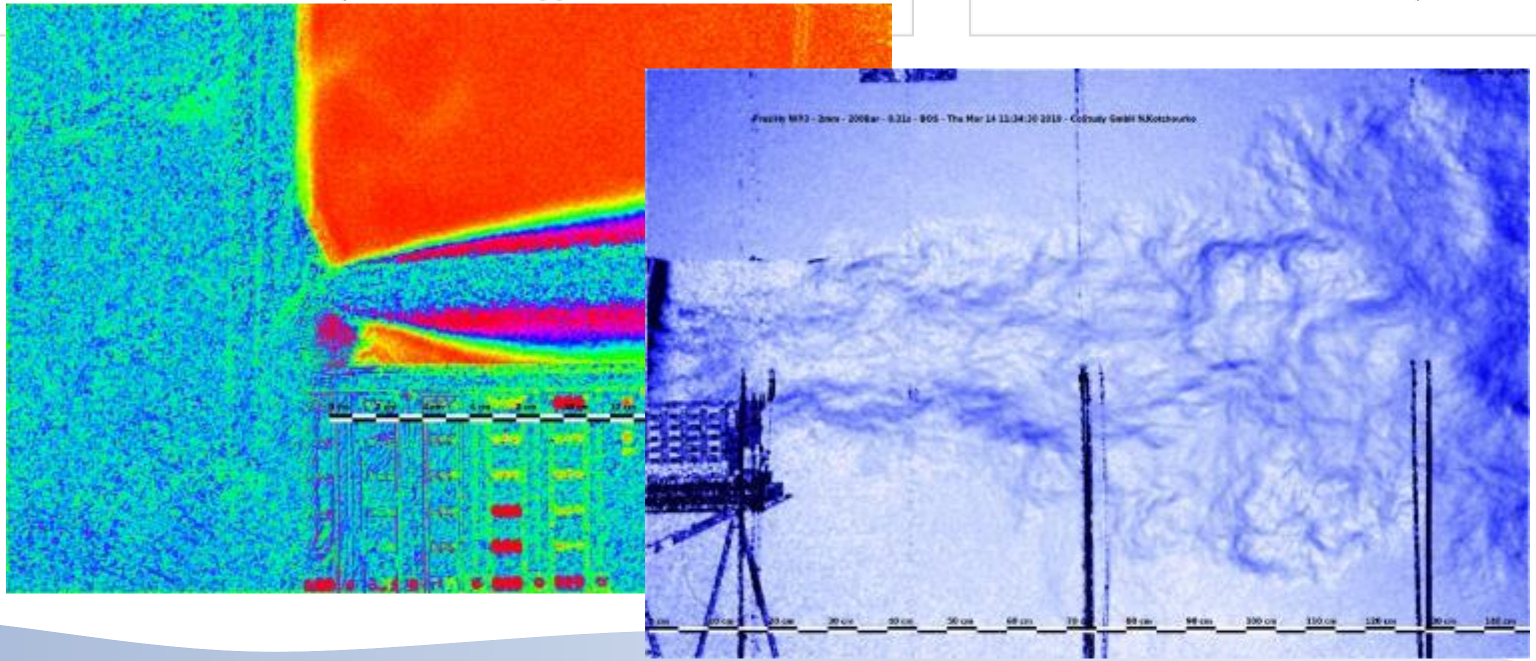
# E3.1a: Validation Data

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



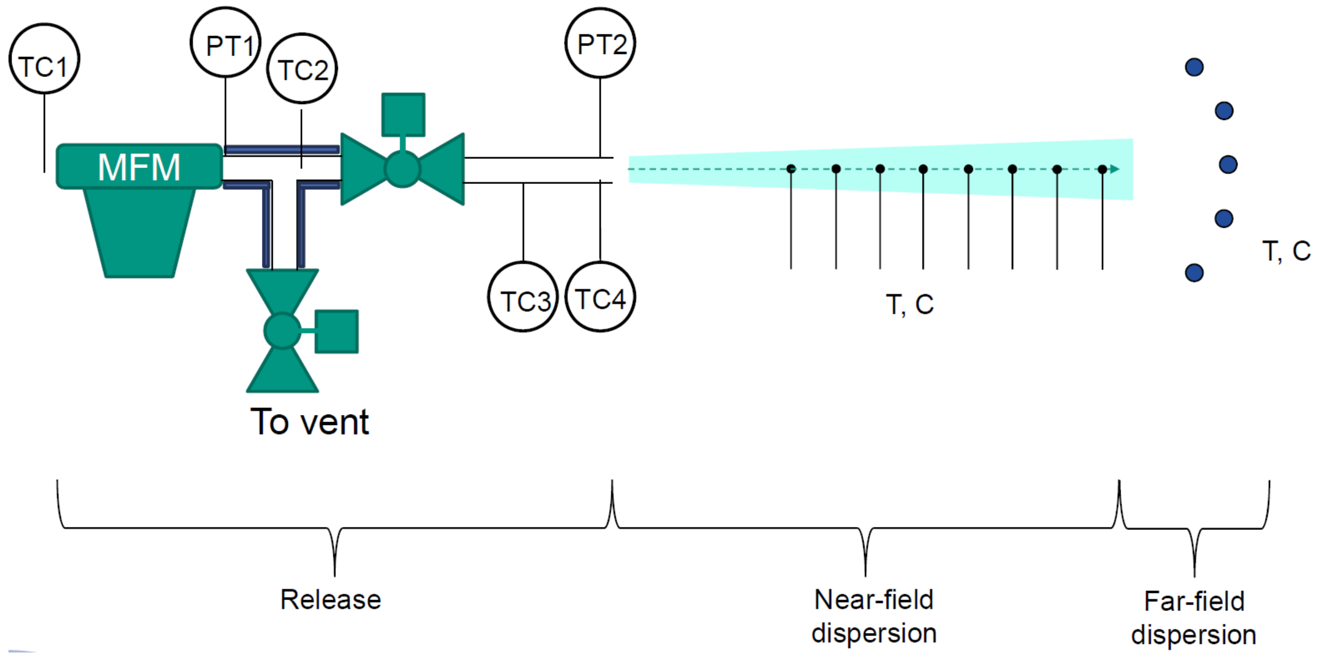



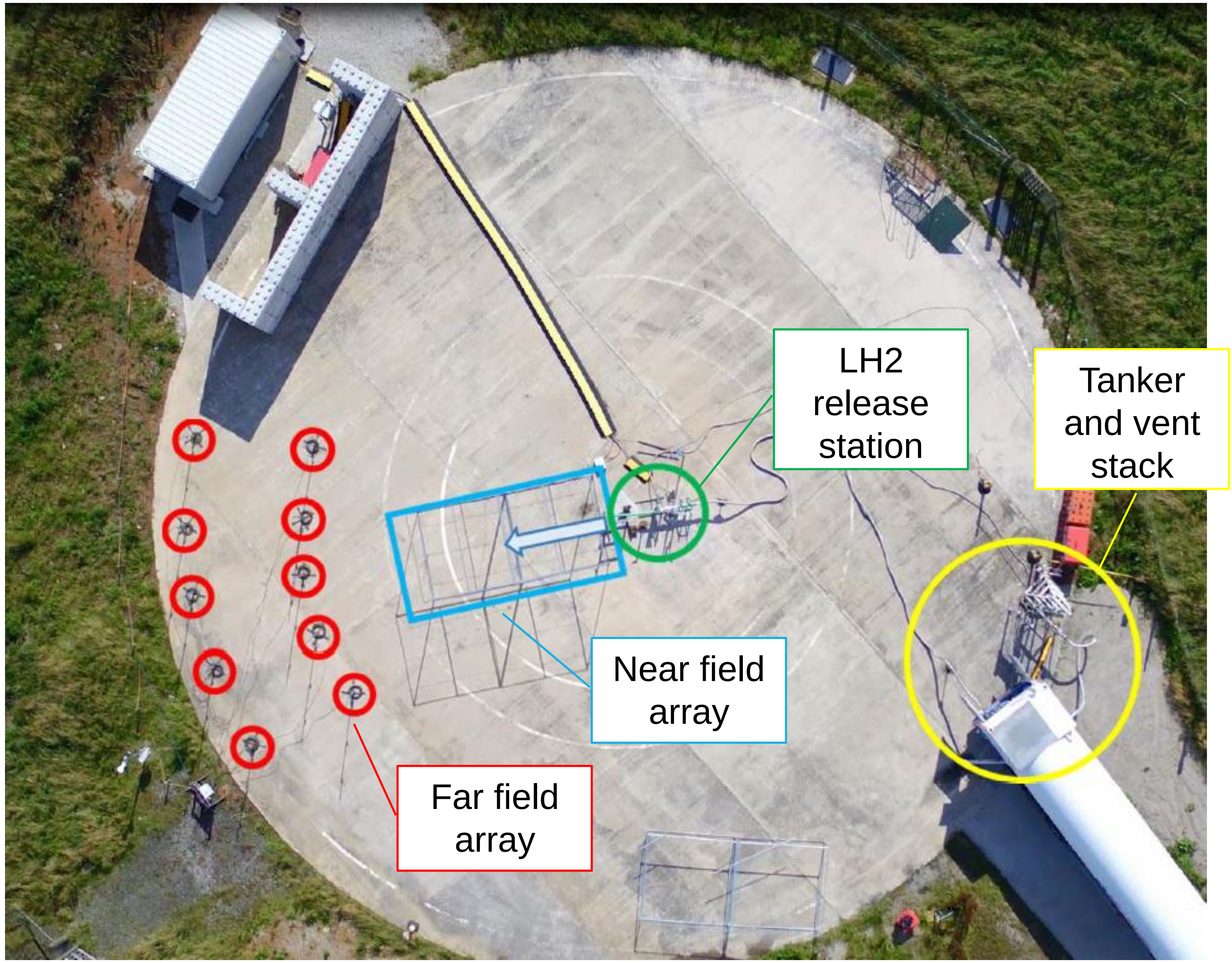



see https://doi.org/10.5445/IR/1000096833.

# Experimental series E3.5

## "Rain Out Tests" (HSE)



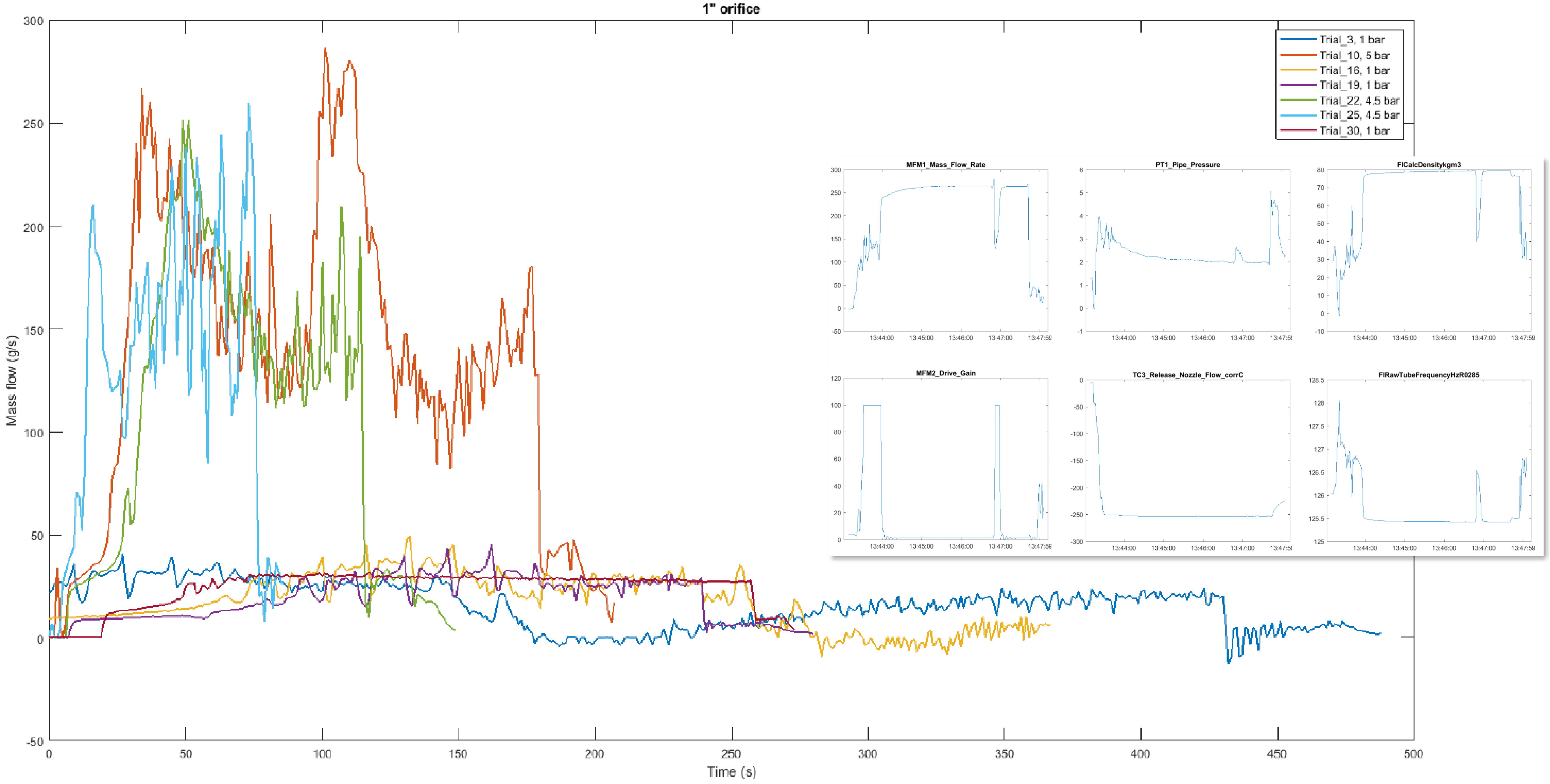



# E3.5: Test Matrix

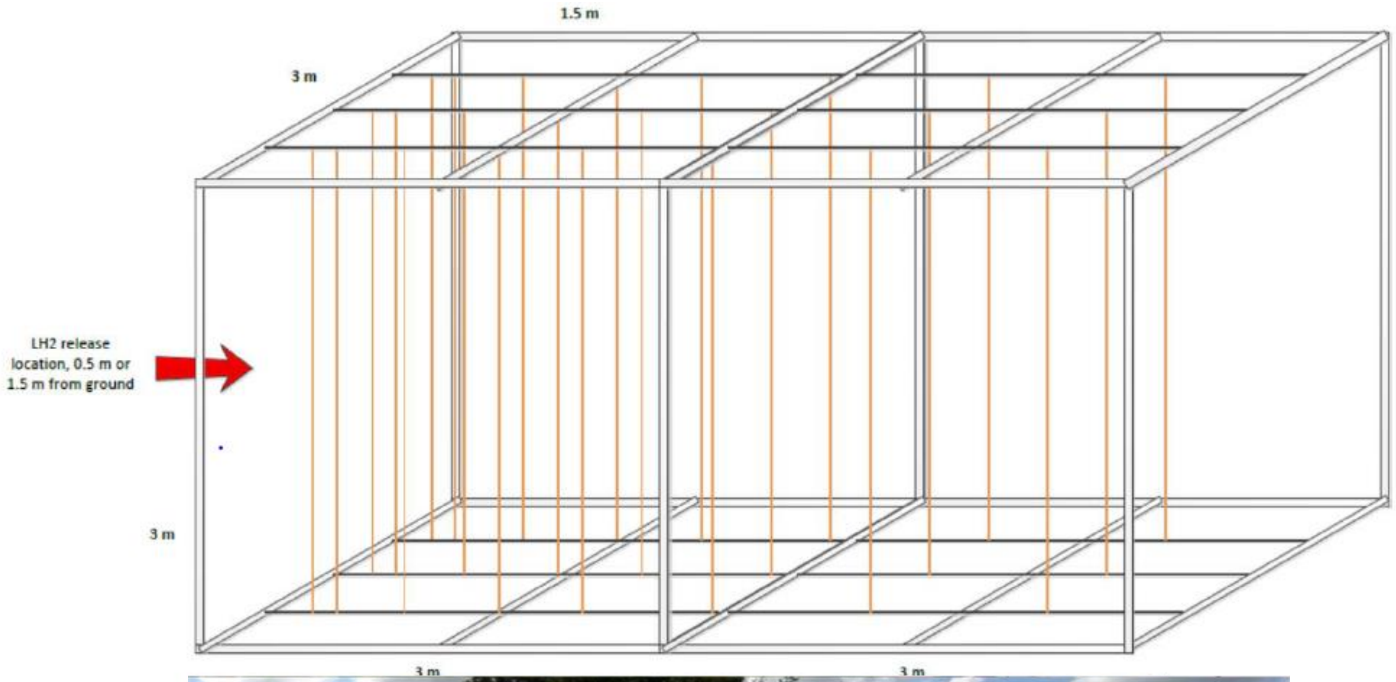
PRESLHY

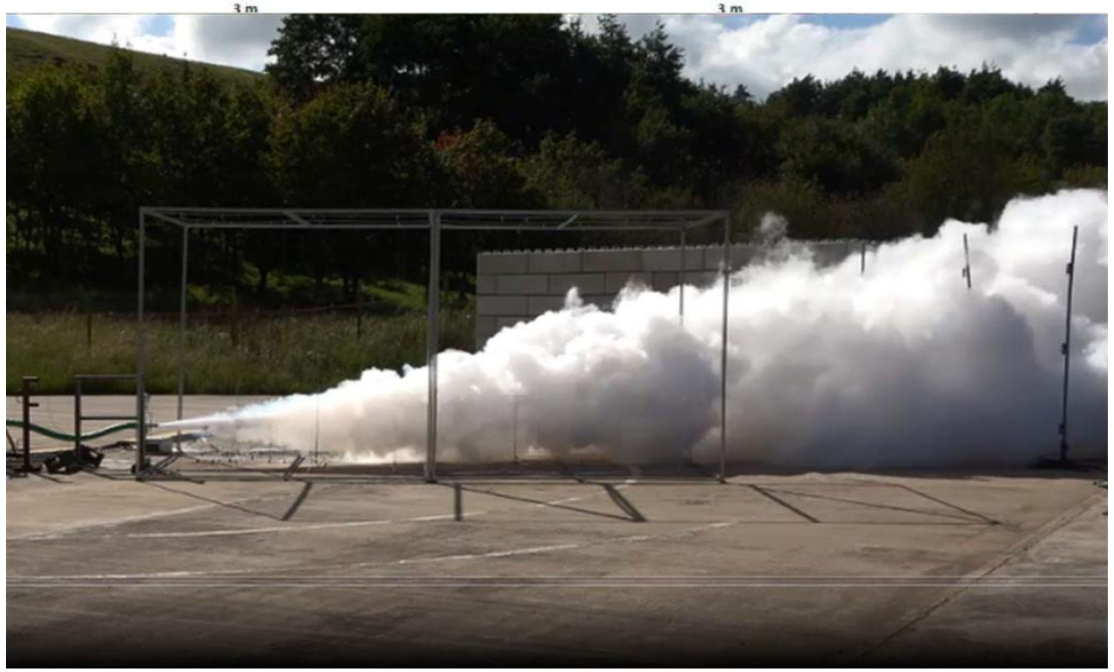
| Trial No | Test No | Date | Time of start | Array location | Far Field sensor location | Additional Notes | Resistance |
|---|---|---|---|---|---|---|---|
| 1 | 3.5.3 | 11/09/2019 | 15:16:54 | Standard | Option 2a | Commissioning test. | $1.42 \times 10^6\ \Omega^2$ |
| 2 | 3.5.1 | 11/09/2019 | 15:58:09 | Standard | Option 2a | Commissioning test. | $1.06 \times 10^7\ \Omega^2$ |
| 3 | 3.5.1 | 12/09/2019 | 11:45:31 | Standard | Option 2a | Good conditions. | $1.02 \times 10^6\ \Omega^2$ |
| 4 | 3.5.2 | 12/09/2019 | 12:08:57 | Standard | Option 2a | Fist footage of solid air around nozzle. | $1.06 \times 10^7\ \Omega^2$ |
| 5 | 3.5.3 | 12/09/2019 | 14:34:20 | Standard | Option 2a | | $2.48 \times 10^6\ \Omega^2$ |
| 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 | | $2.07 \times 10^7\ \Omega^2$ |
| 9 | 3.5.9 | 13/09/2019 | 11:11:19 | 350mm offset | Option 2a | Baffle 160mm from release. | $2.72 \times 10^4\ \Omega^2$ |
| 10 | 3.5.10 | 13/09/2019 | 13:25:06 | 50mm offset | Option 2a | | $2.67 \times 10^4\ \Omega^2$ |
| 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 | | $2.67 \times 10^4\ \Omega^2$ |
| 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 | | $3.14 \times 10^4\ \Omega^2$ |
| 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 | | $1.03 \times 10^7\ \Omega^2$ |
| 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. | $1.03 \times 10^7\ \Omega^2$ |

# E3.5: Mass Flow Measured

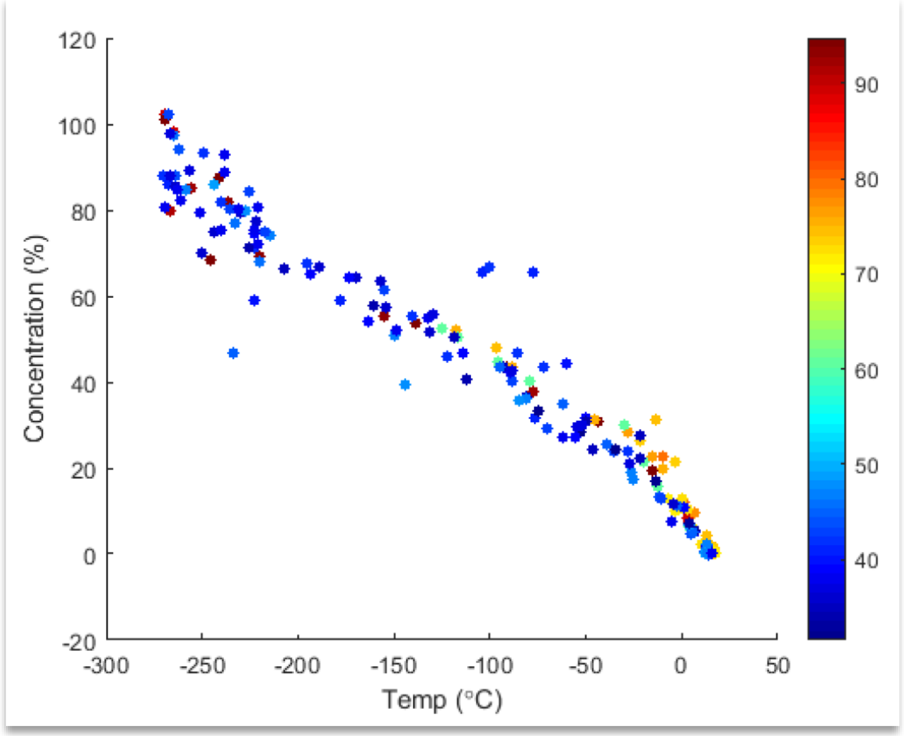


# E3.5: Near Field Dispersion



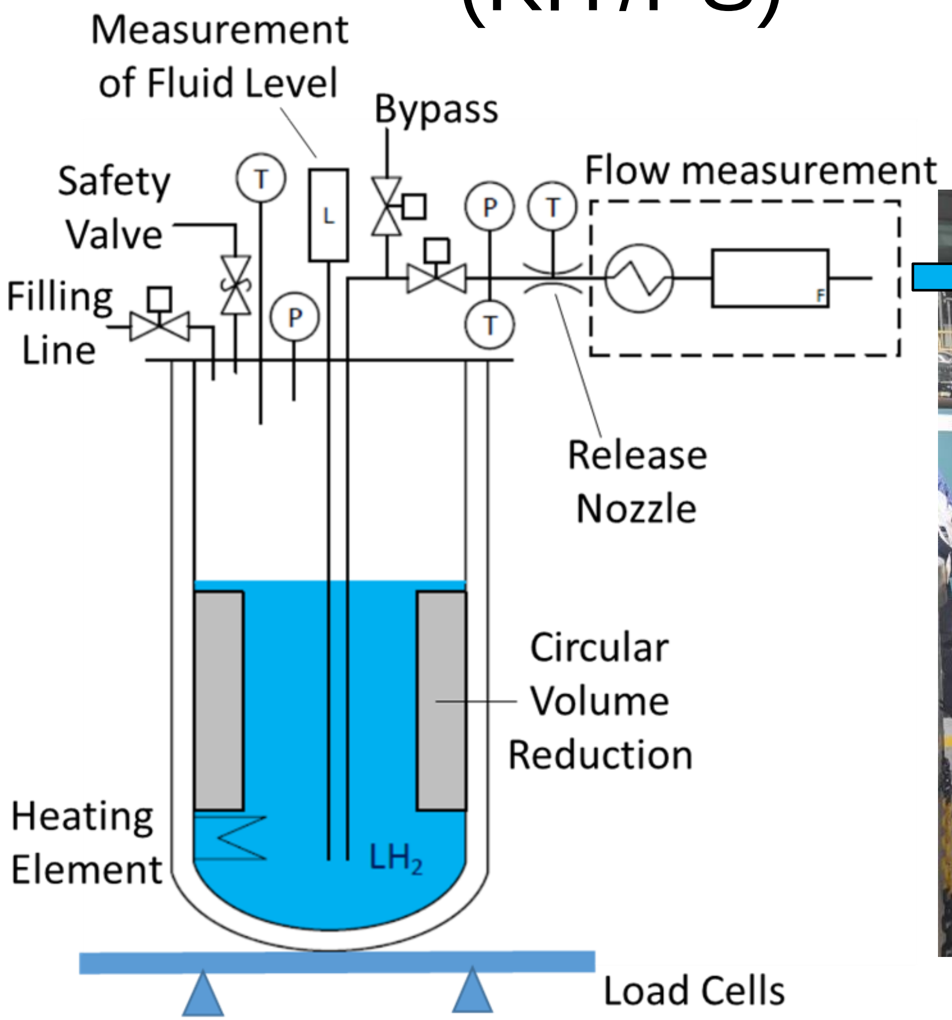
Some „solid material“ partially blocked sampling positions



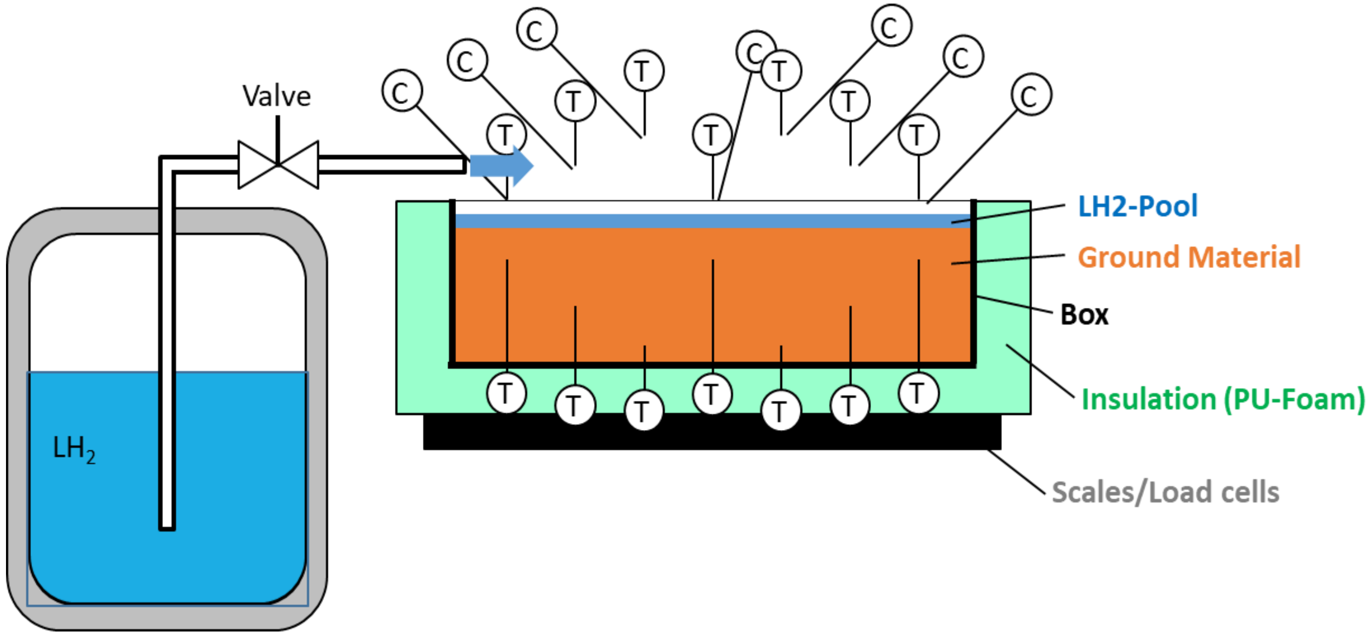

Correlation of T and H2 concentration with little influence of humidity in far field

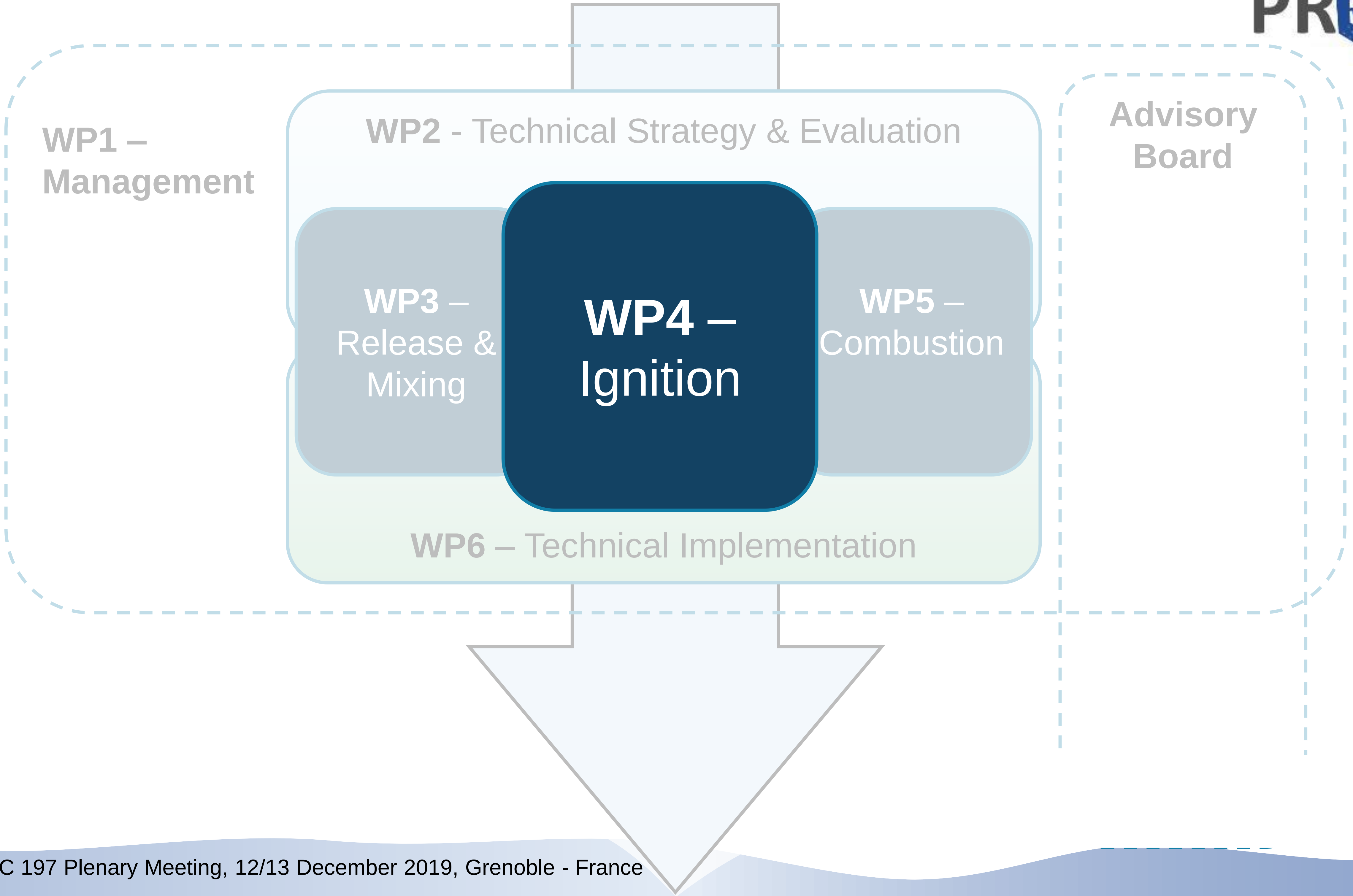
# Next Release & Mixing Experiments

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

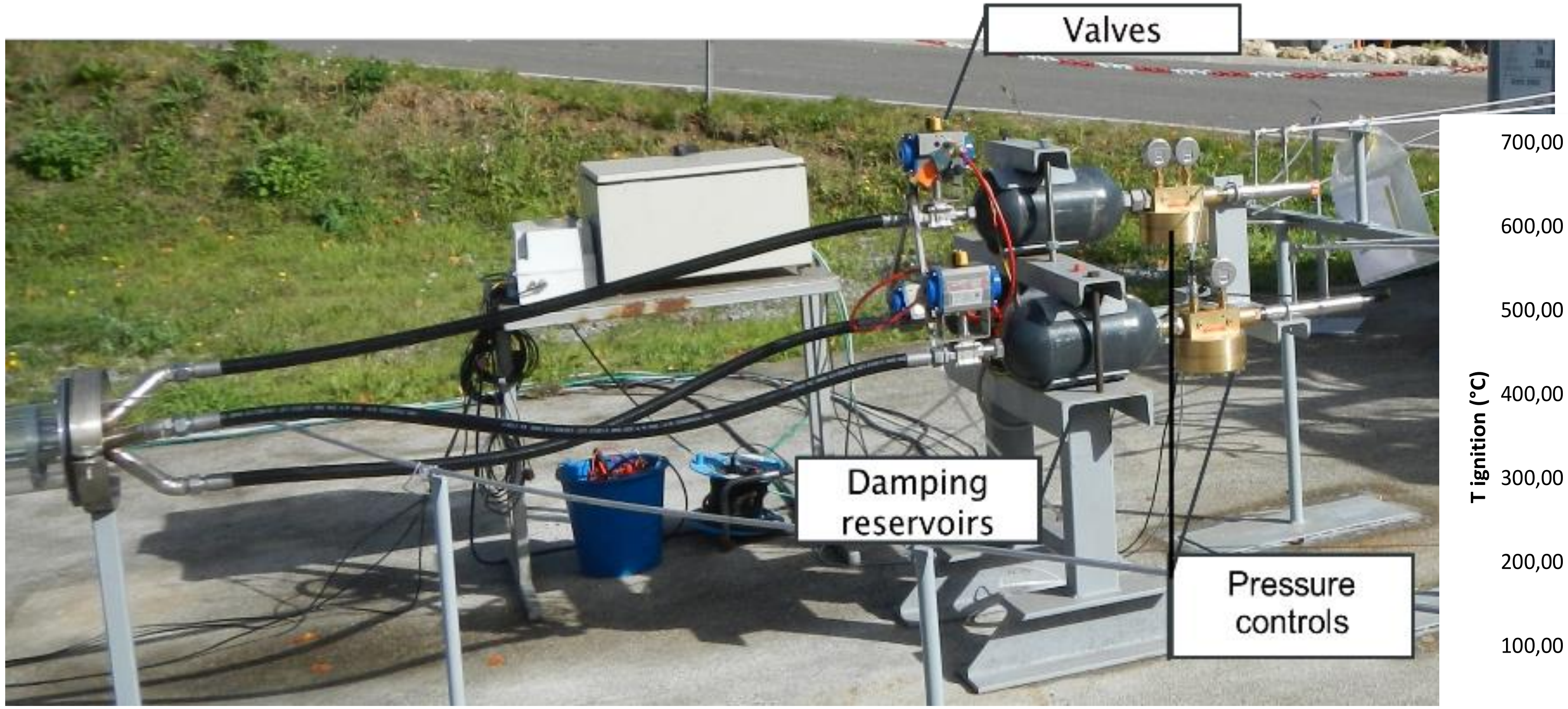


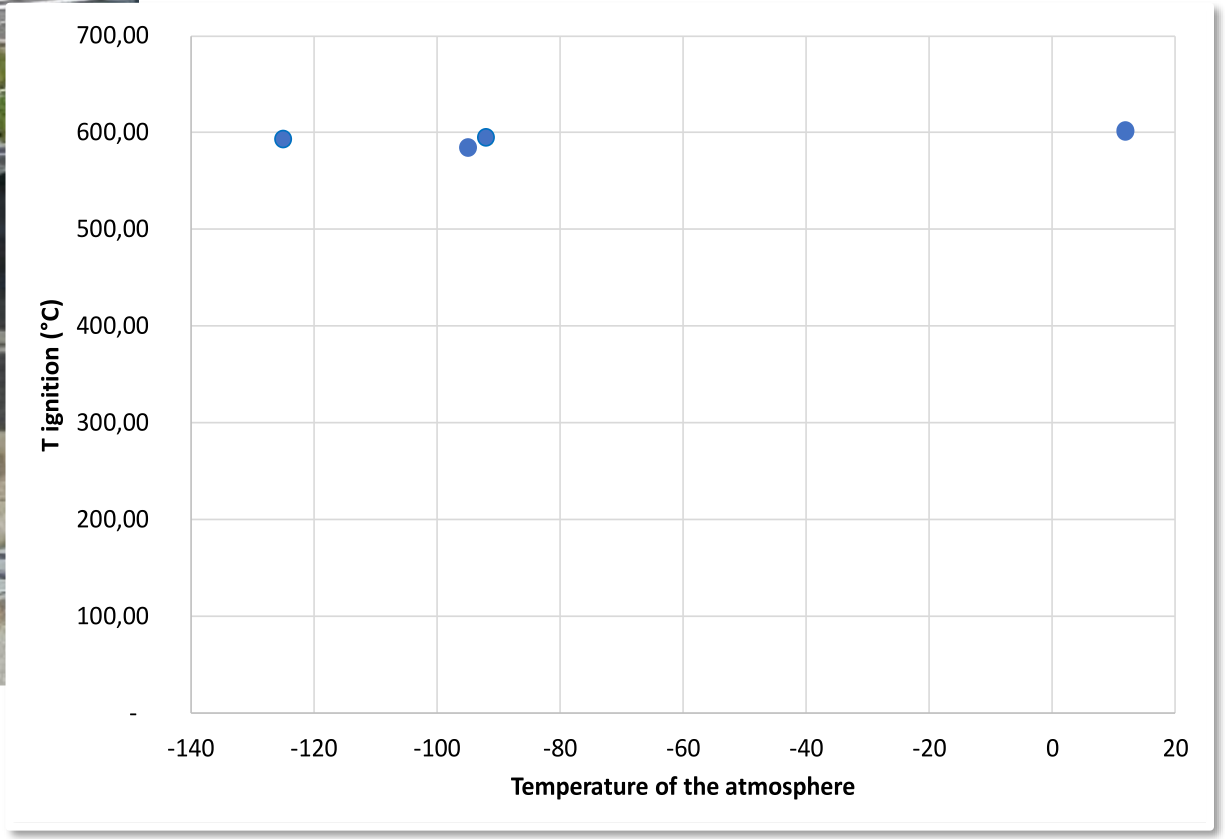

– E3.4 Pool
Release and evaporation
(KIT/PS)




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

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

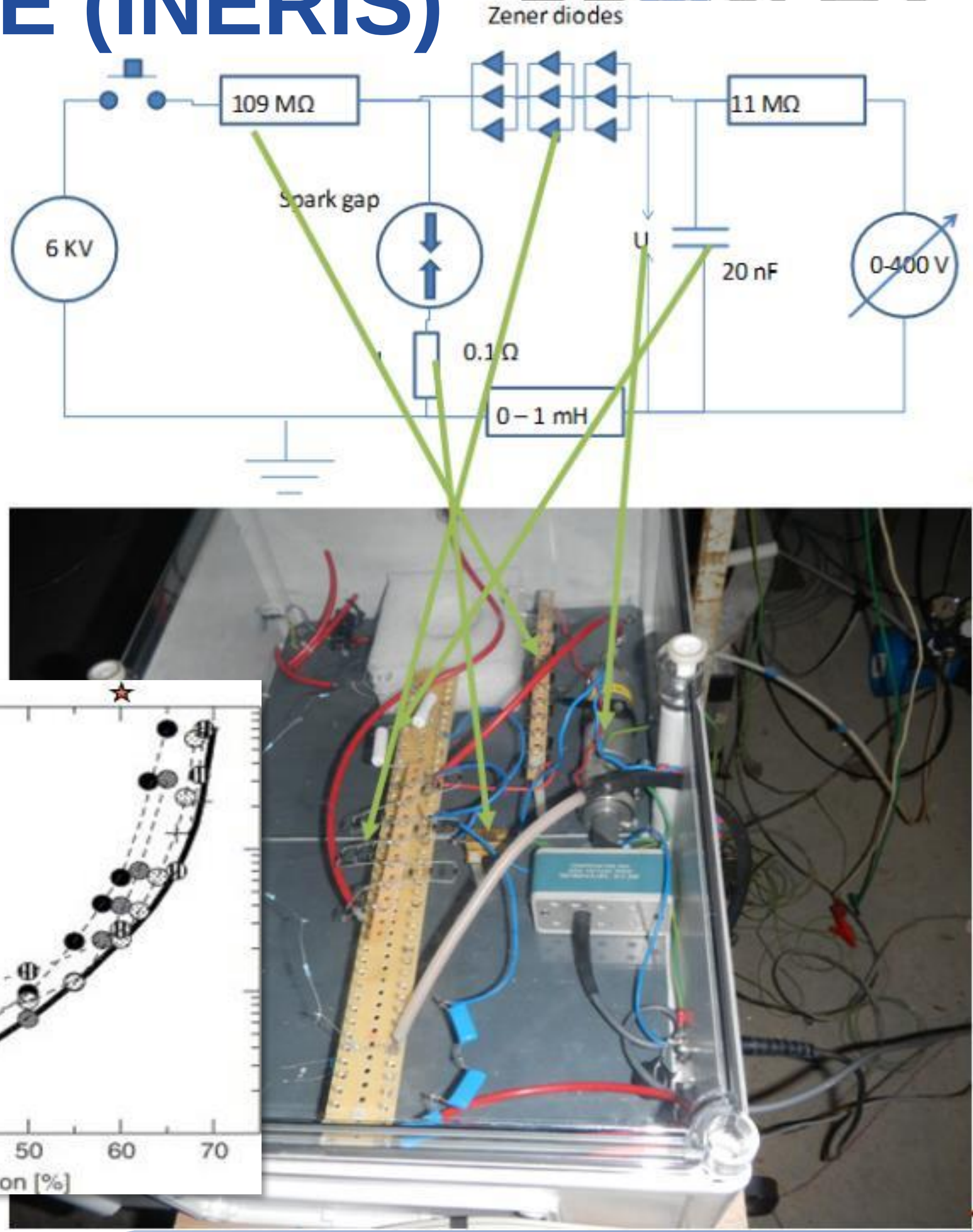



**First conclusions:**

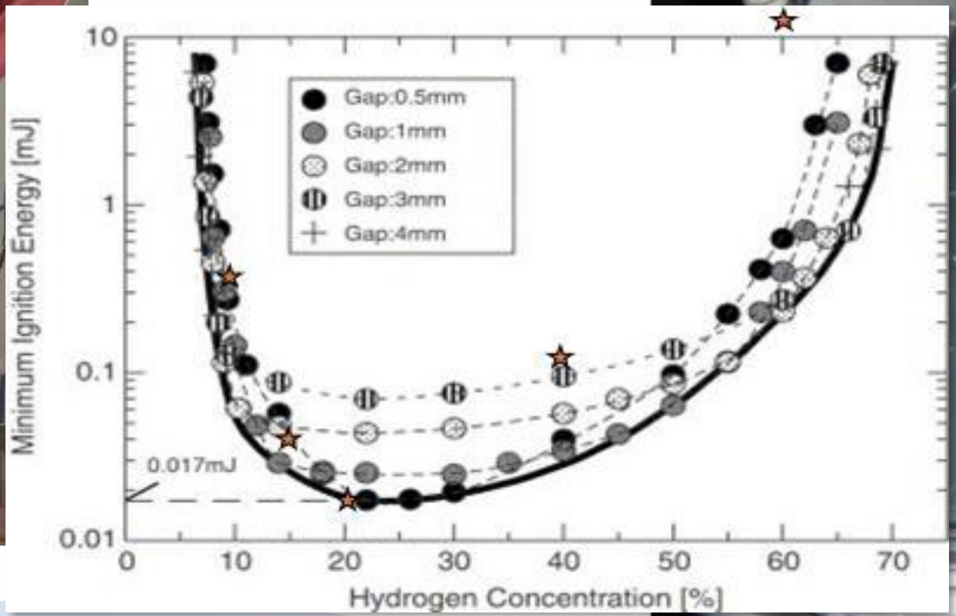
- Ignition on hot surface independent on T of surface
- Stoichiometry and flow velocity marginal influence

# E4.1: Minimum Ignition Energy MIE (INERIS)



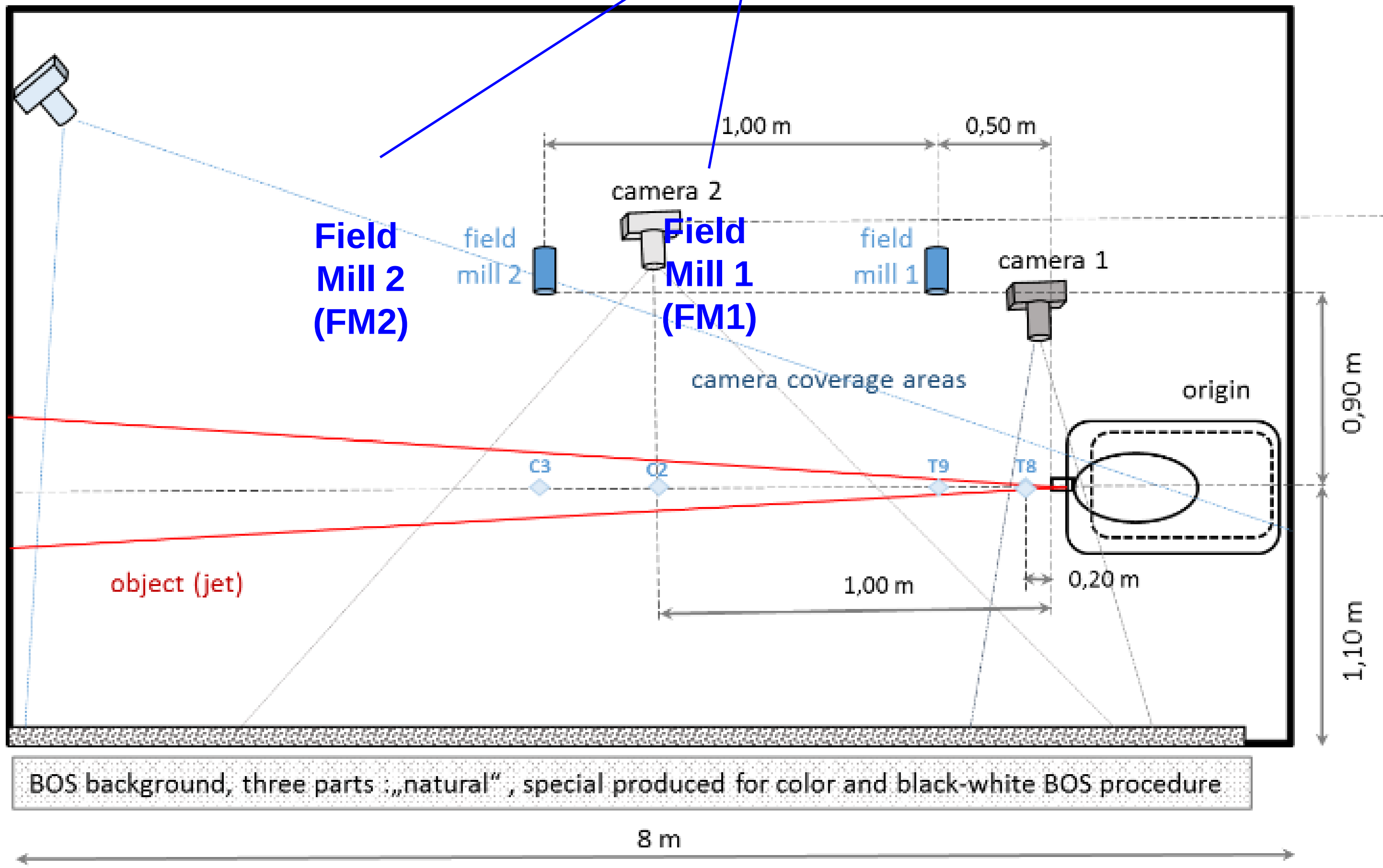

New device constructed:

- 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)

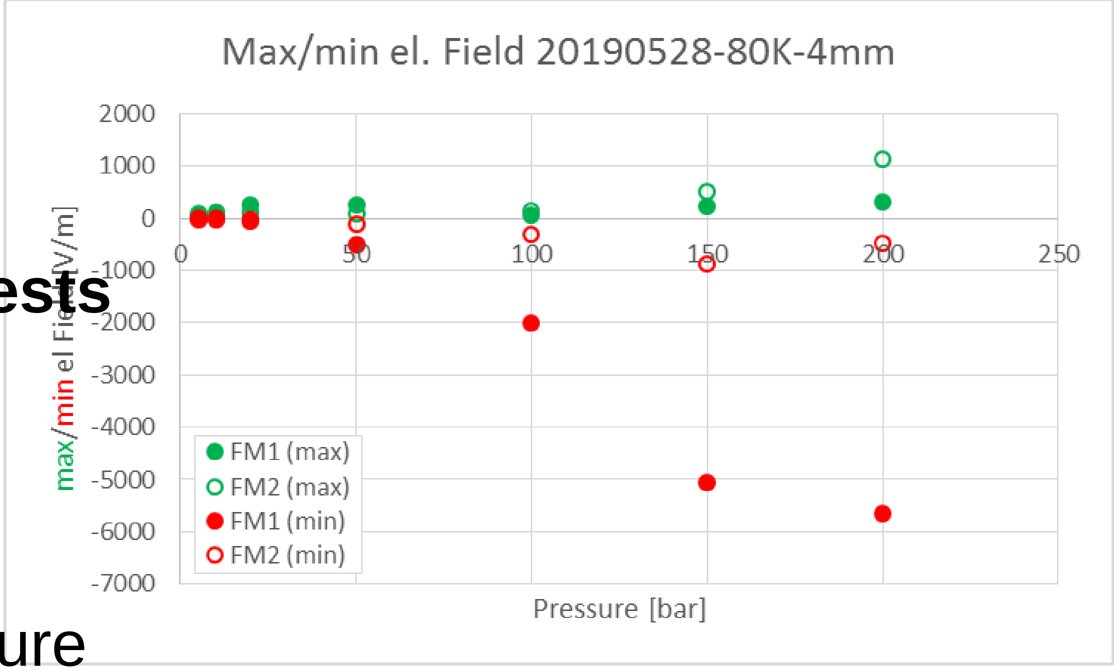



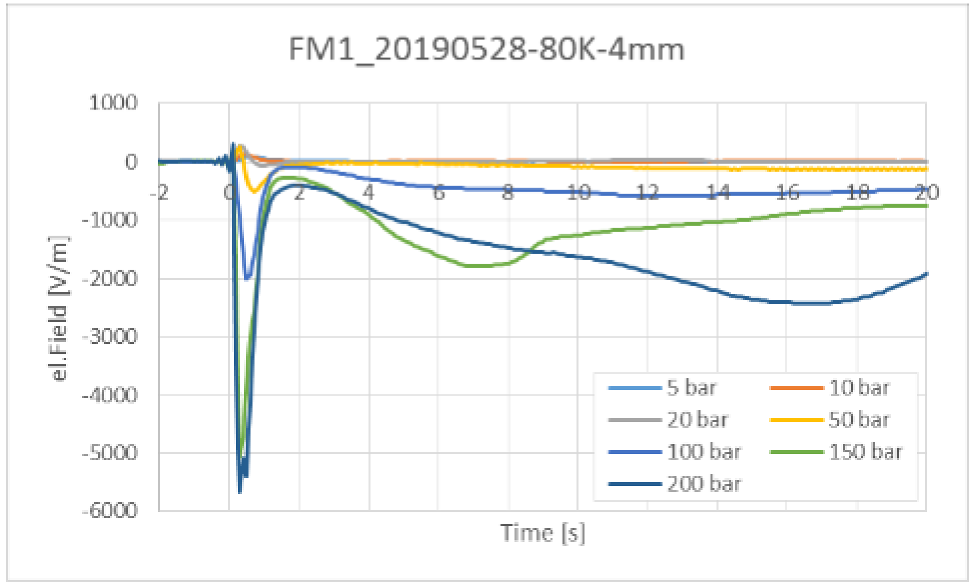

# E4.2: Electrostatic Ignition in cold jet (KIT)

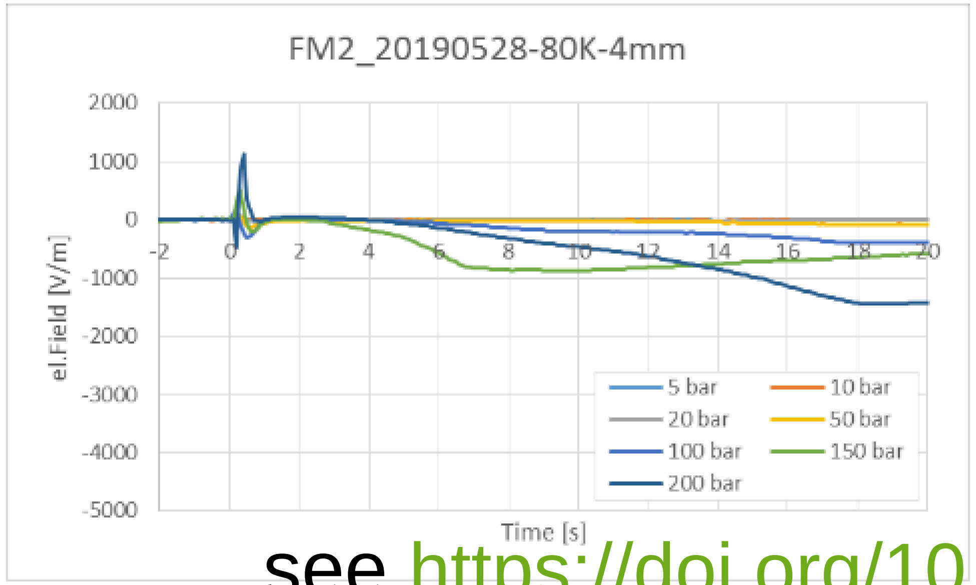
PRESLHY

**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

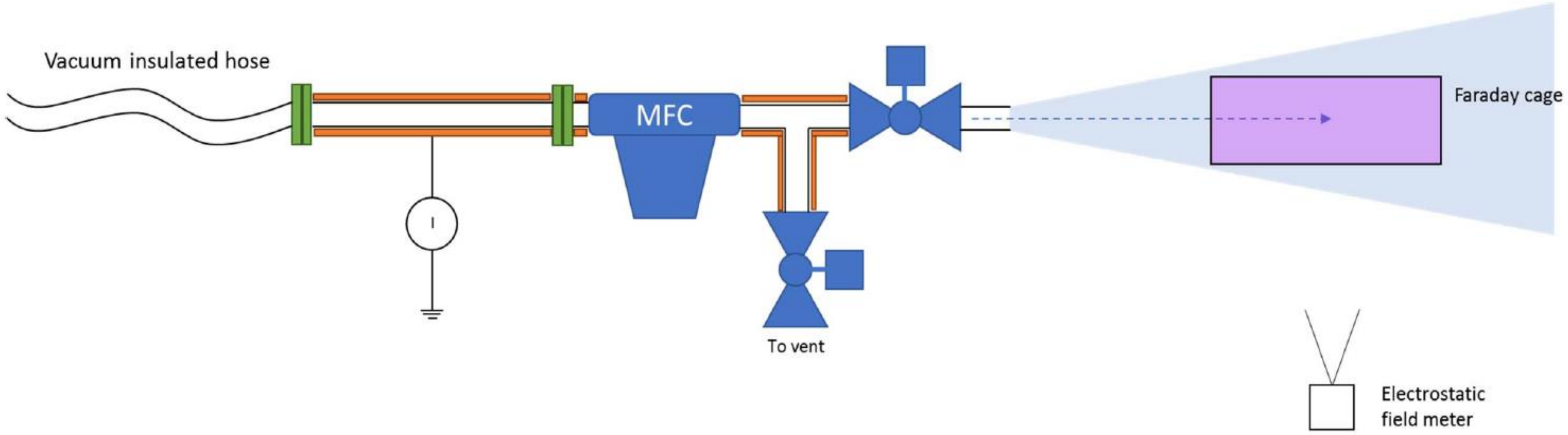


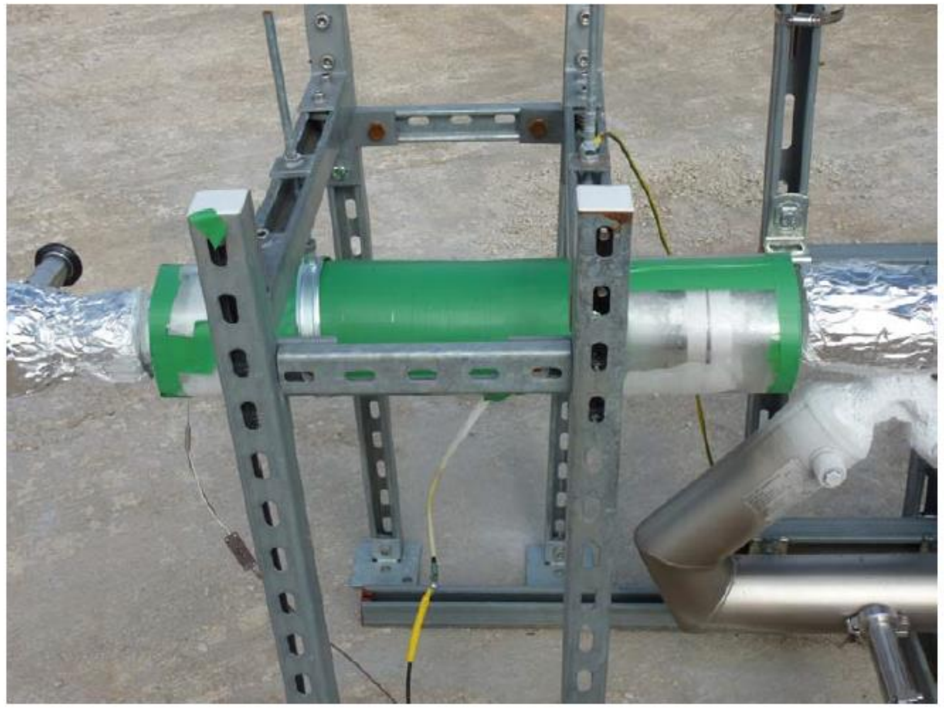

see https://doi.org/10.5445/IR/1000096833.

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




**Intrumentation:**

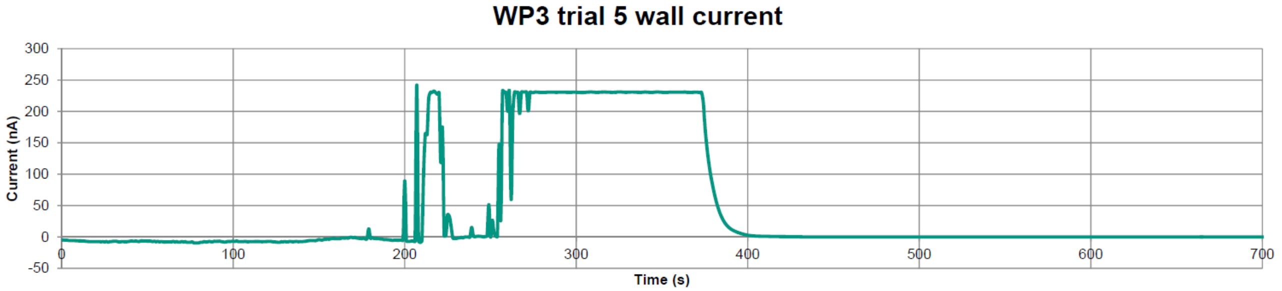
- Wall current:
  Isolated pipe section + electrometer
- Plume electrostatics measurement:
  Field meter + Faraday cage

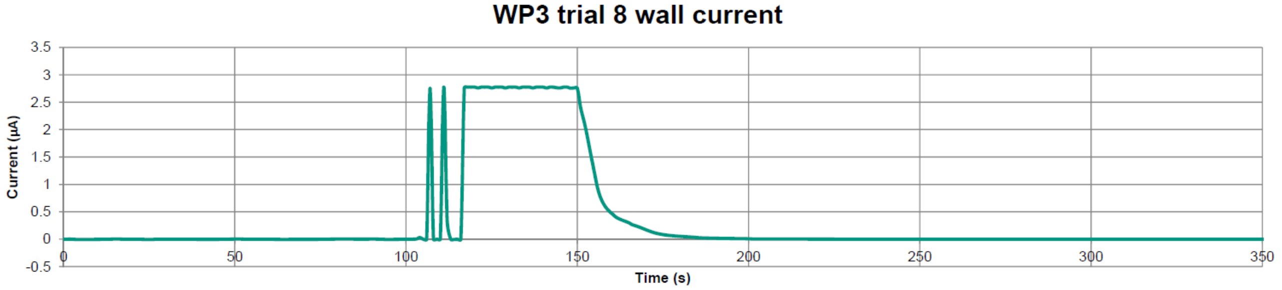


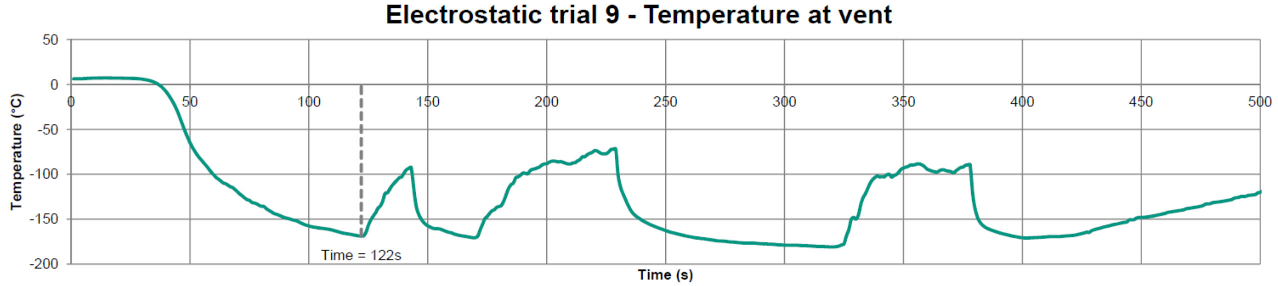
*Isolated pipework*

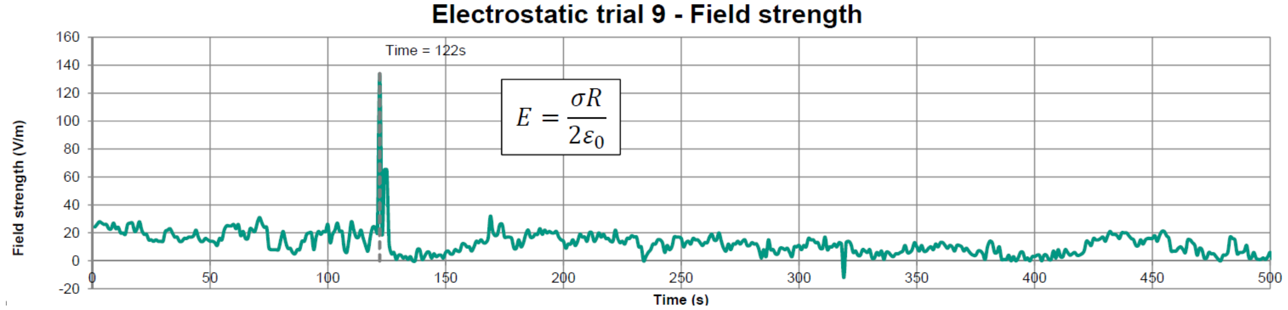
*Faraday cage and field meter*

# E4.3: Electrostatic Ignition in cold plume



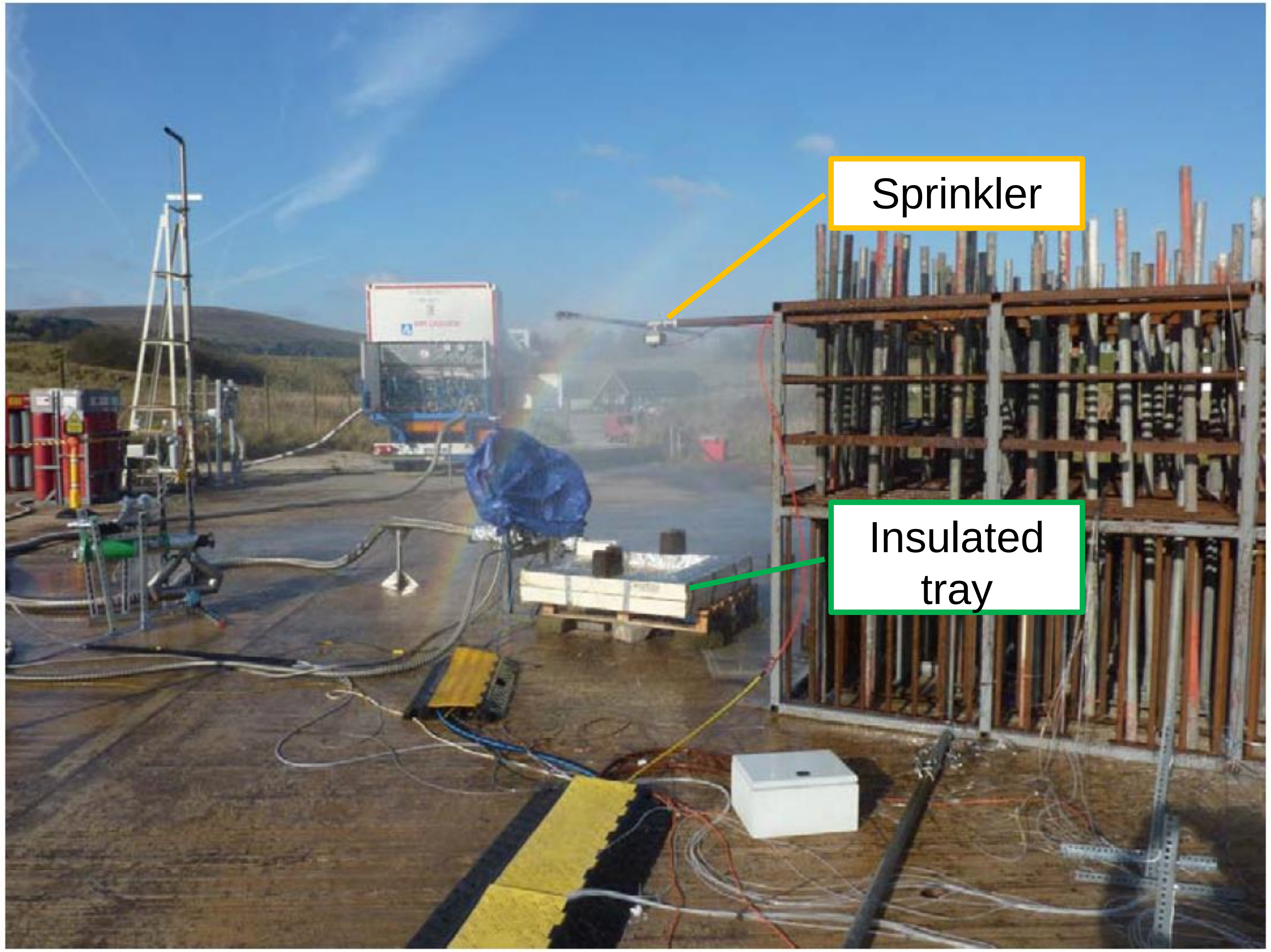




**Initial conclusions:**

- 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

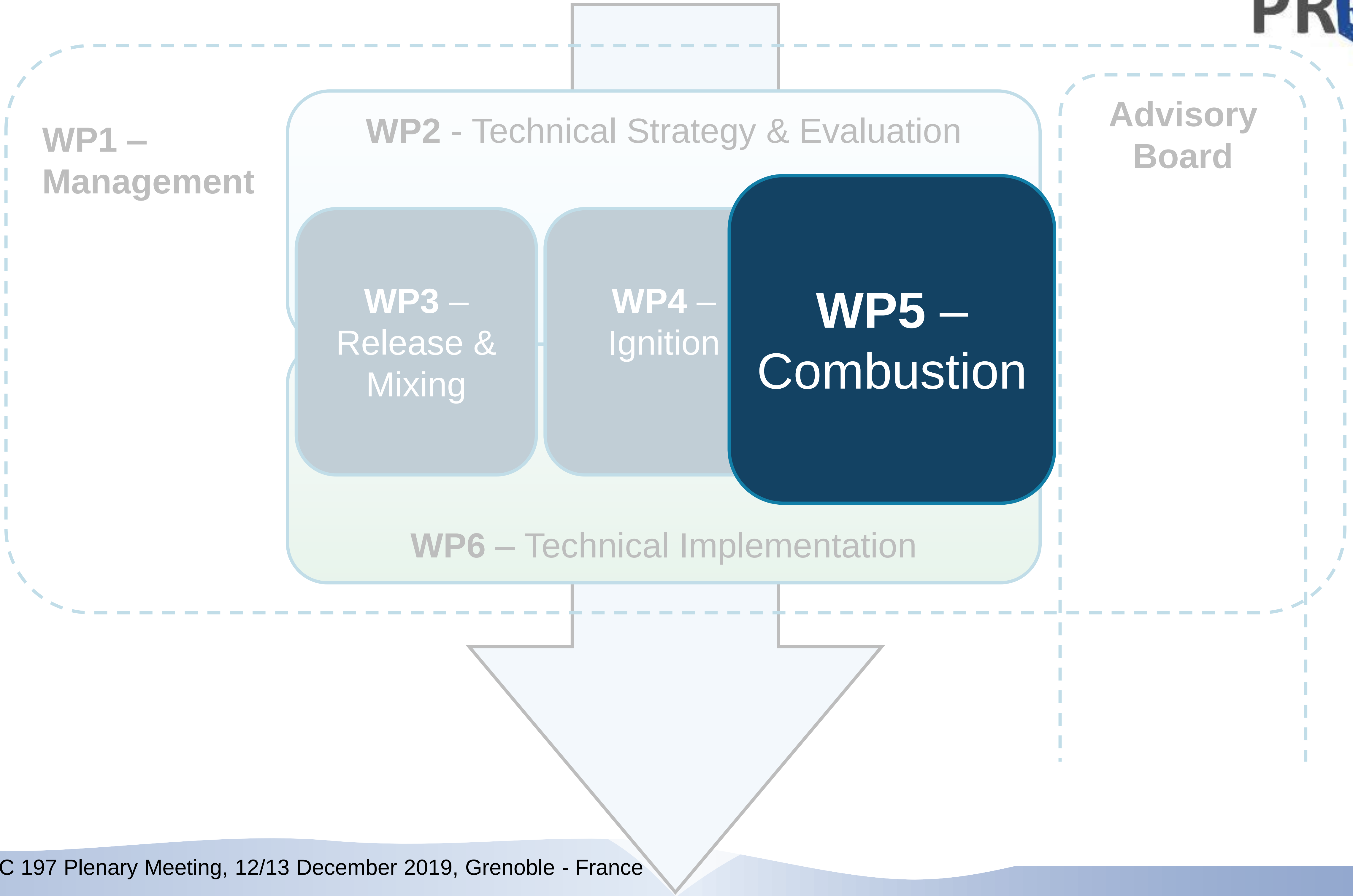
- Insulated tray to collect fluid
- Thermocouples arranged to indicate pool depth
- Water release system with sprinkler and hose attachment

**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)


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

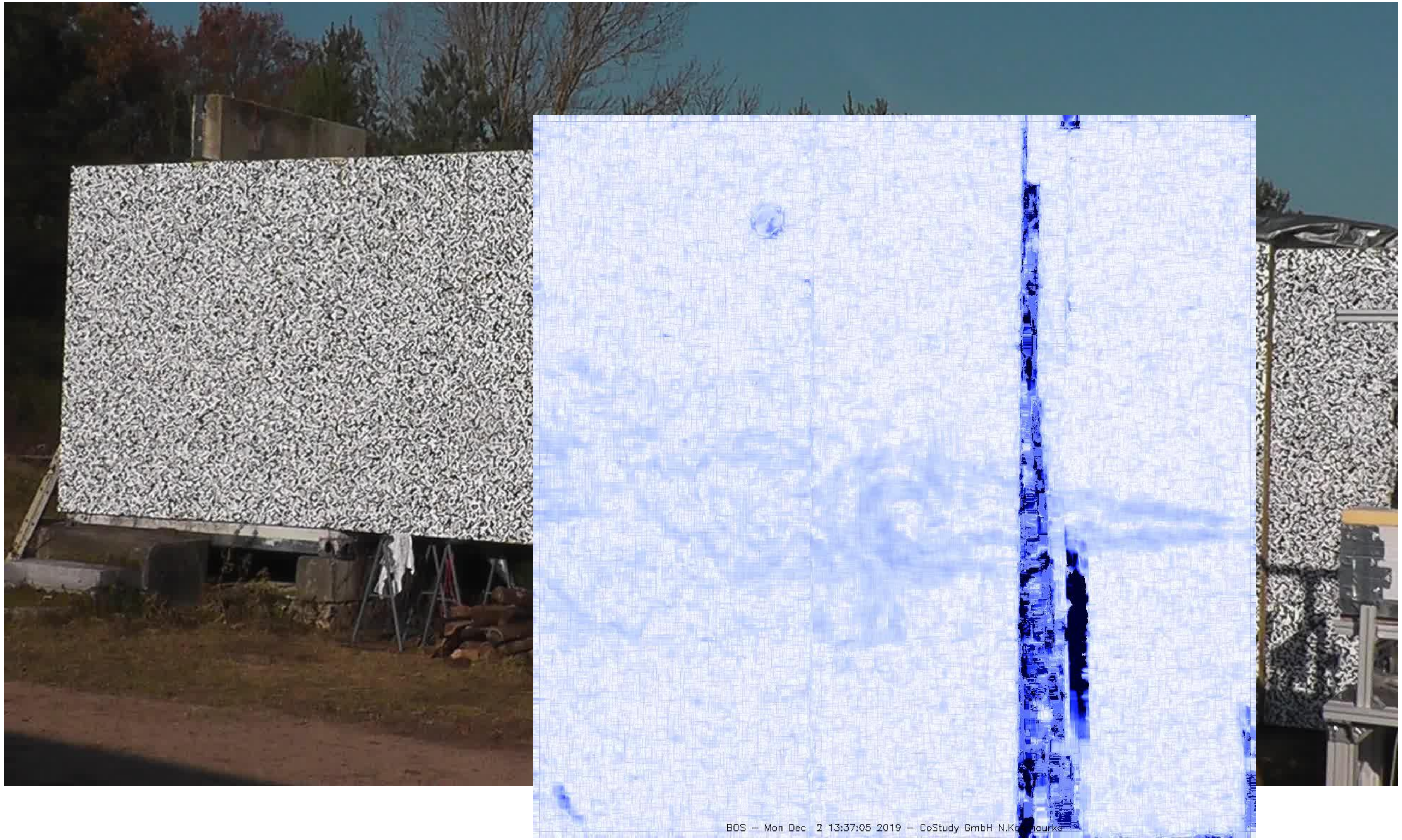
# E5.1: Ignited Jet ("Jetfire DISCHA")

## 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



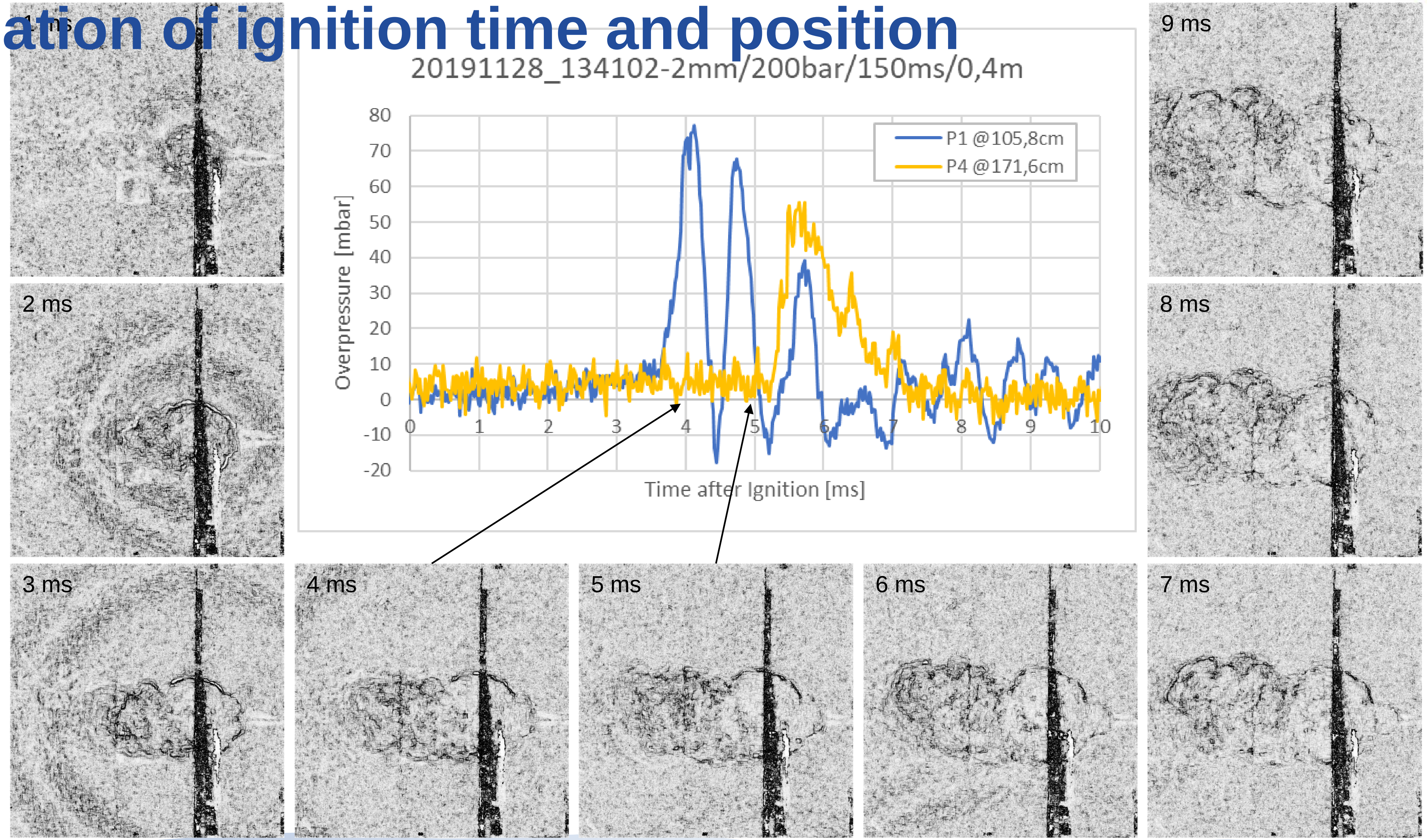

Experiments based on unignited discharge tests E3.1 with reduced parameters variation:
T = 80K, ~285K
p = 5, 100, 200 bar
$D_{nozzle}$= 1, 2, 4mm

Iterative procedure for identifying most critical ignition point and location

(> 90 tests
done by 10.12.2019)

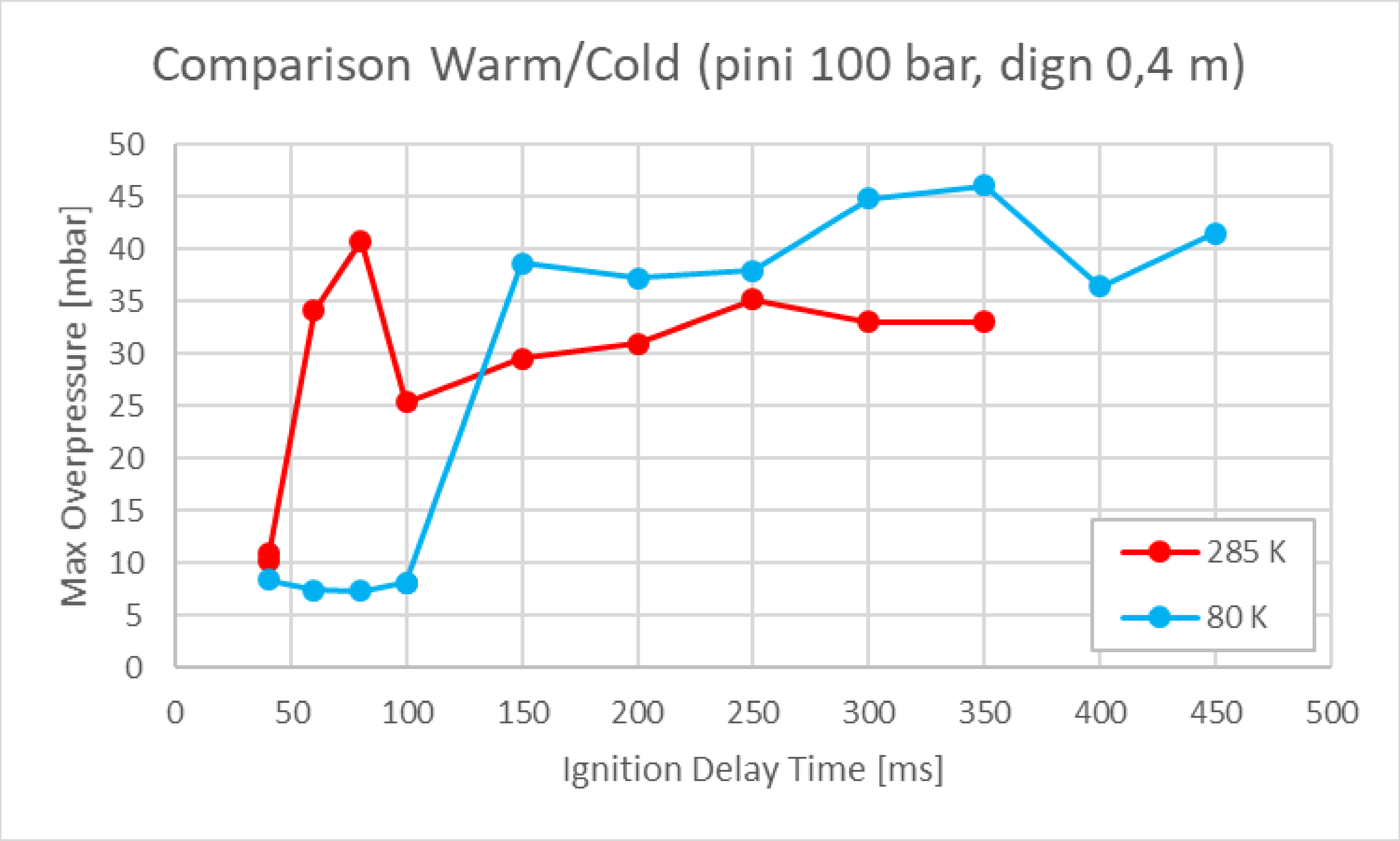
# E5.1: Ignited Jet

## Variation of ignition time and position



# E5.1: Ignited Jet – Examplary Result

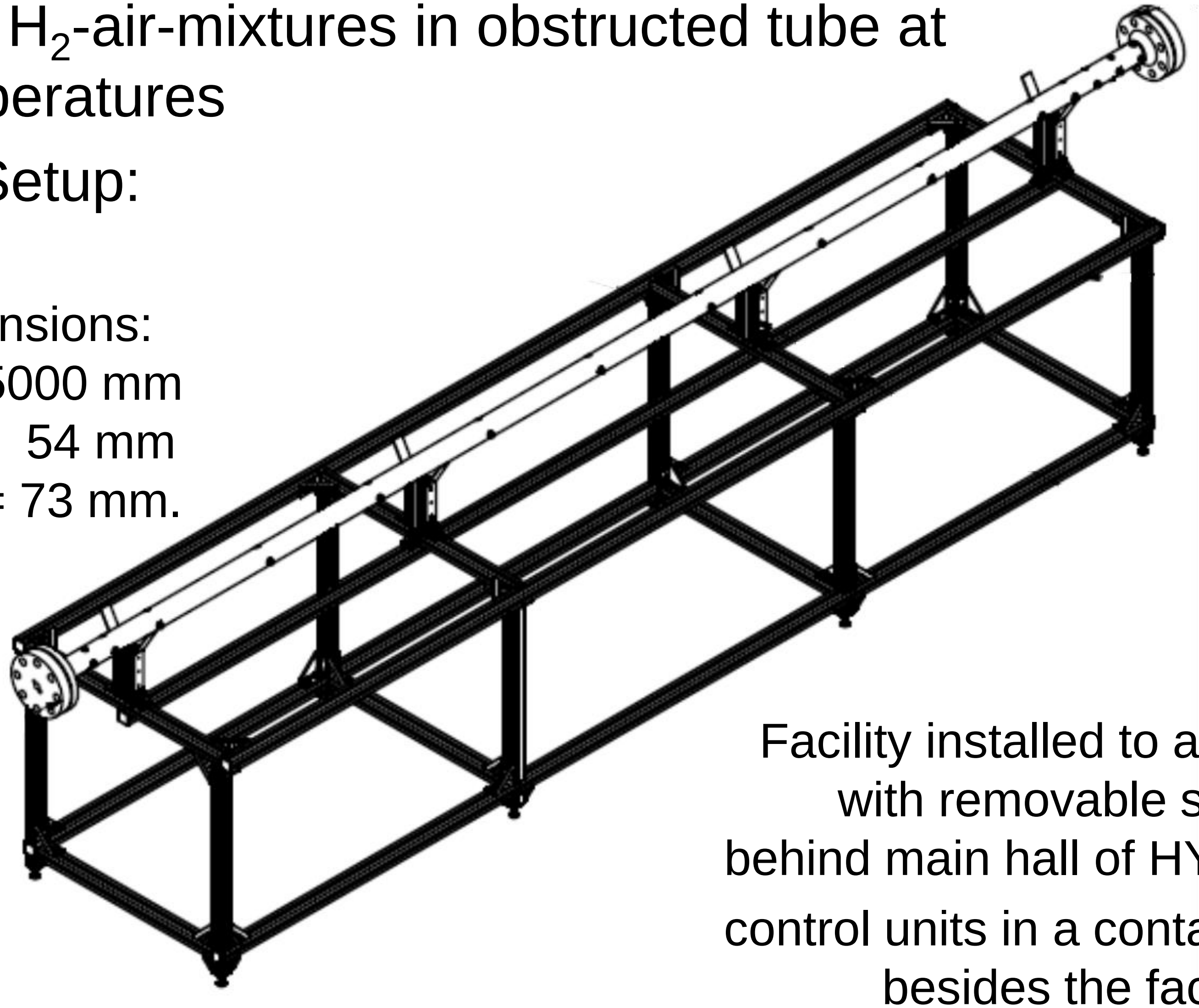
## Variation of ignition time (fixed ignition position)




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.

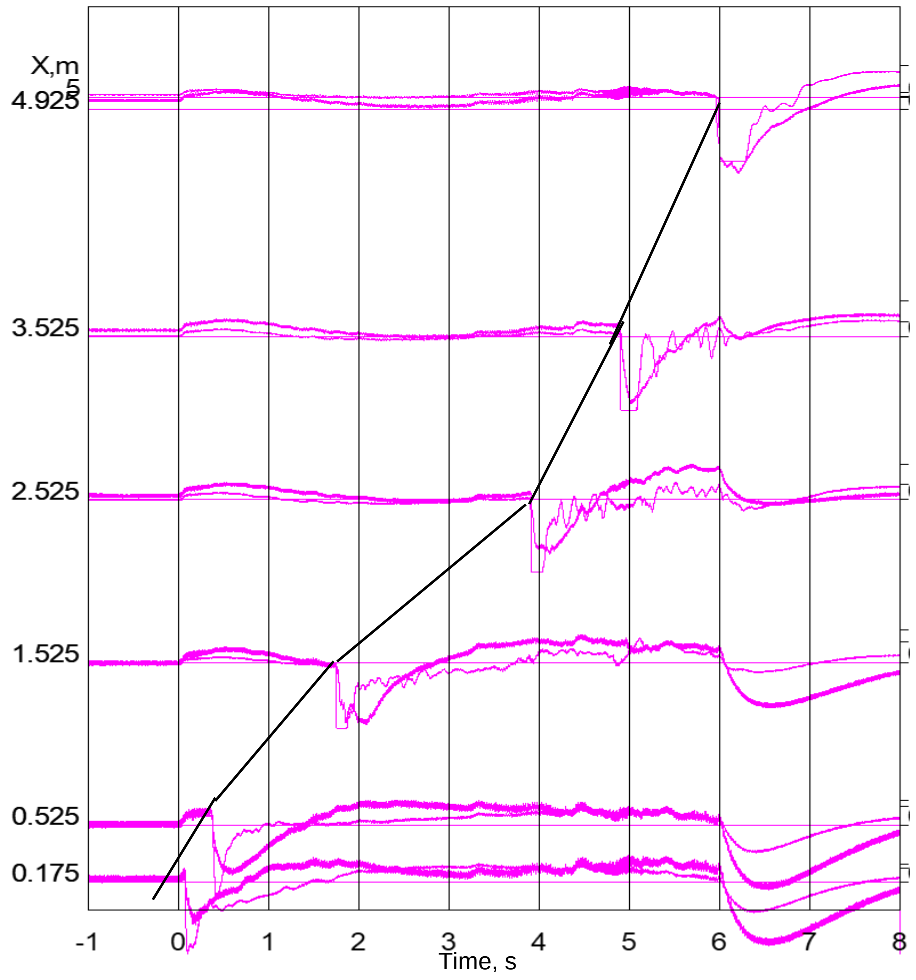
Facility installed to a tent with removable sides behind main hall of HYKA, control units in a container besides the facility.

# E5.2: Reference tests

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

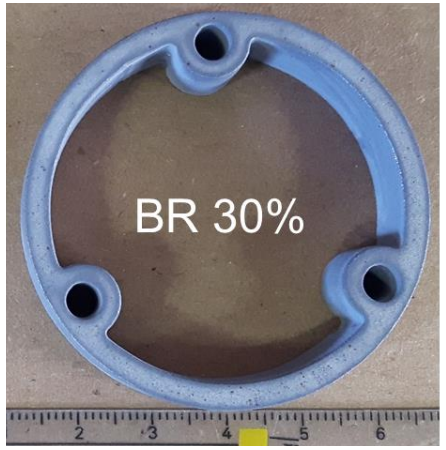
- Tests without obstacles
- Hydrogen-concentrations investigated in the warm tests are: $cH_2$ = 10, 11, 12, 15, 20, 30, 45, 60 vol%

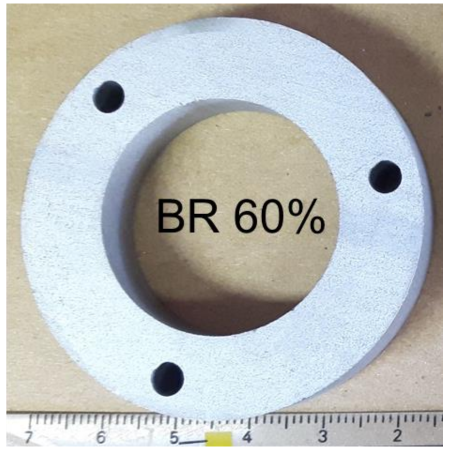
x-t Diagram: Pressure signals along tube
10,6 Vol% H2, no obstacles



# E5.2: Test Parameters for 80K Tests

- 2 blockage ratios (30% and 60%)

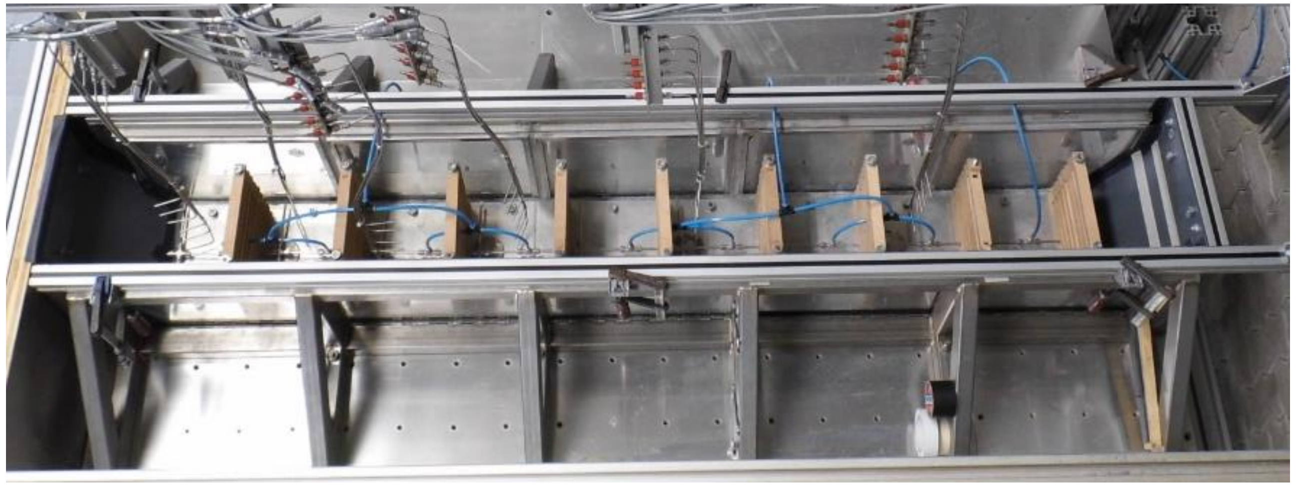



- 10 H2-concentrations from within the ranges
  - 6 to 12 Vol.% H2
  - 15 to 20 Vol.% H2
  - 30 Vol.% H2
  - 60 to 75 Vol.% H2

# Next Combustion Experiments

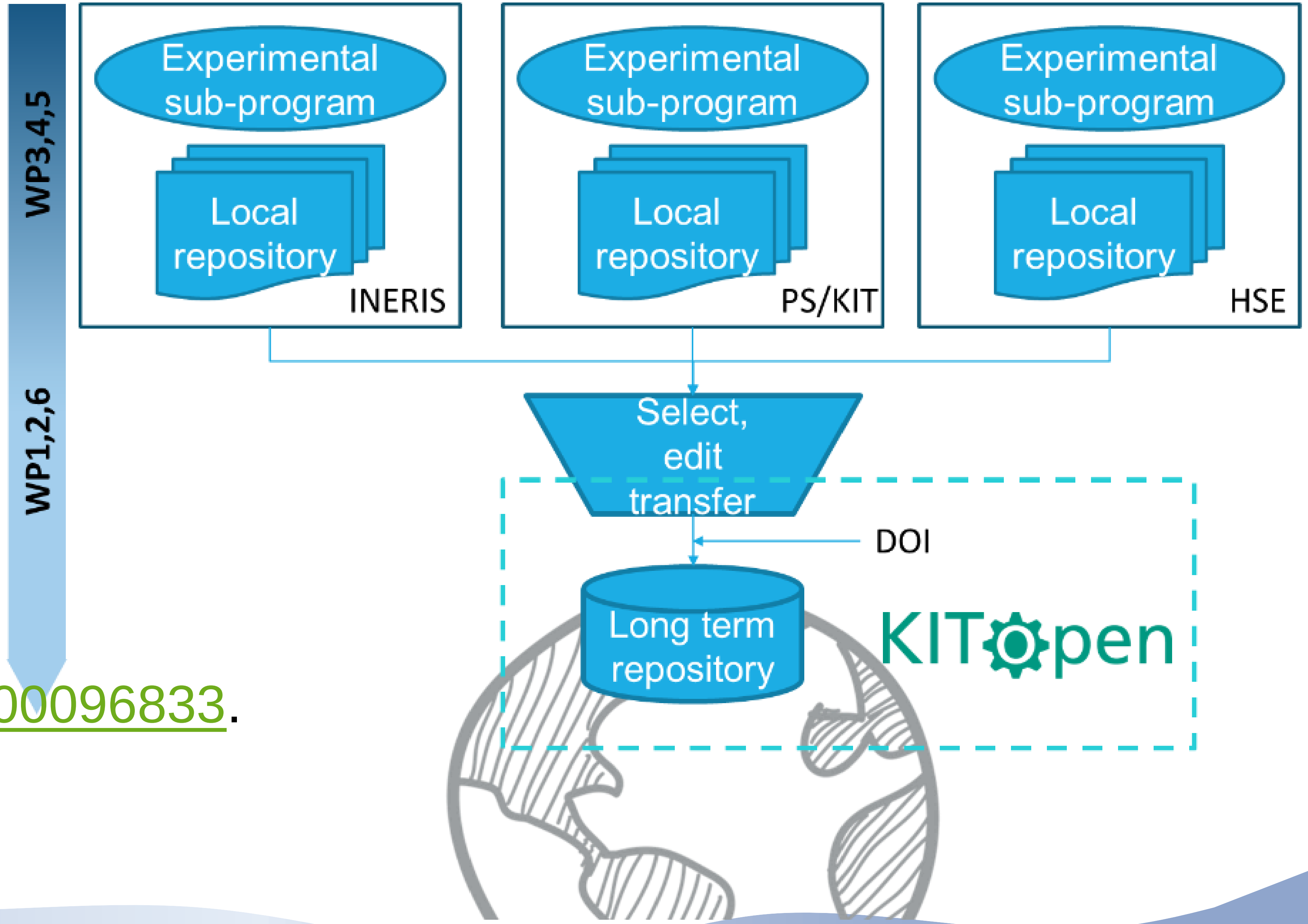
- E5.3 Flame propagation above LH2 pool (KIT/PS)



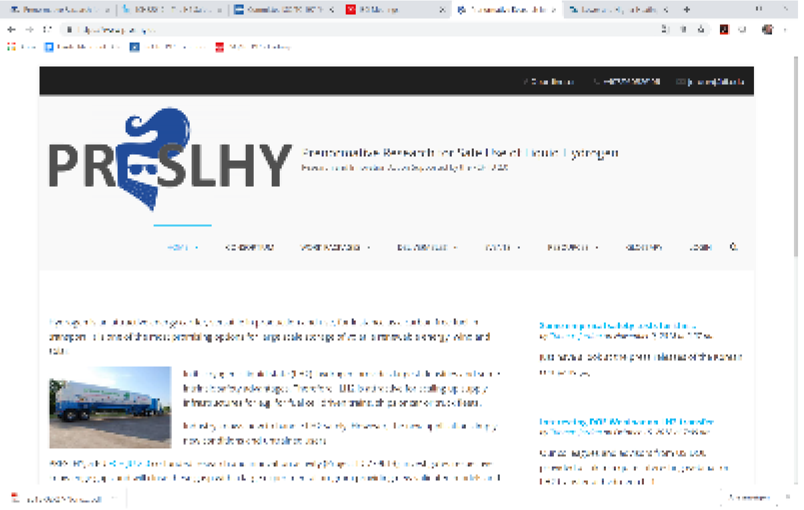
- E5.5 Flame propagation in confined /obstructed cold cloud (HSE)
  *(done – first report expected within 12/2019)*

# 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



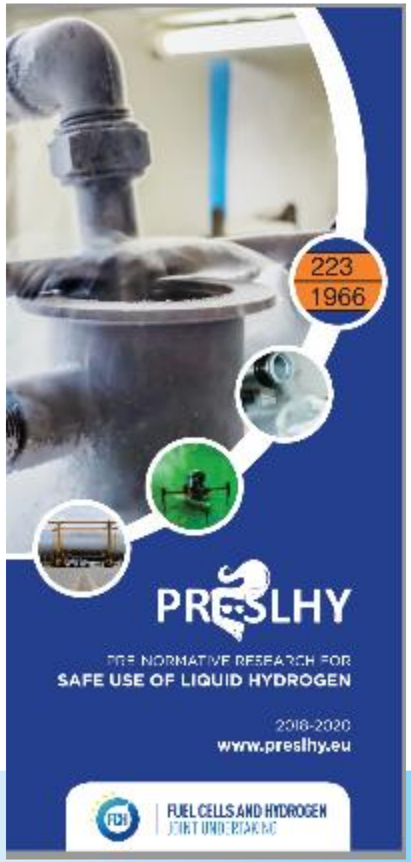

**www.preslhy.eu**

**PRESLHY Exploitation & Dissemination Activities**

**Management (WP1)**

**Implementation (WP6)**

- **Task 1.3 Website**
- **Data Management**
- **Engineering tools**
- **Handbook**
- **Guidelines**
- **RCS Recommendations**
- **White Paper**
- **Task 6.6 Dissemination 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.

FUEL CELLS AND HYDROGEN JOINT UNDERTAKING

European Commission | Horizon 2020 European Union funding for Research & Innovation

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