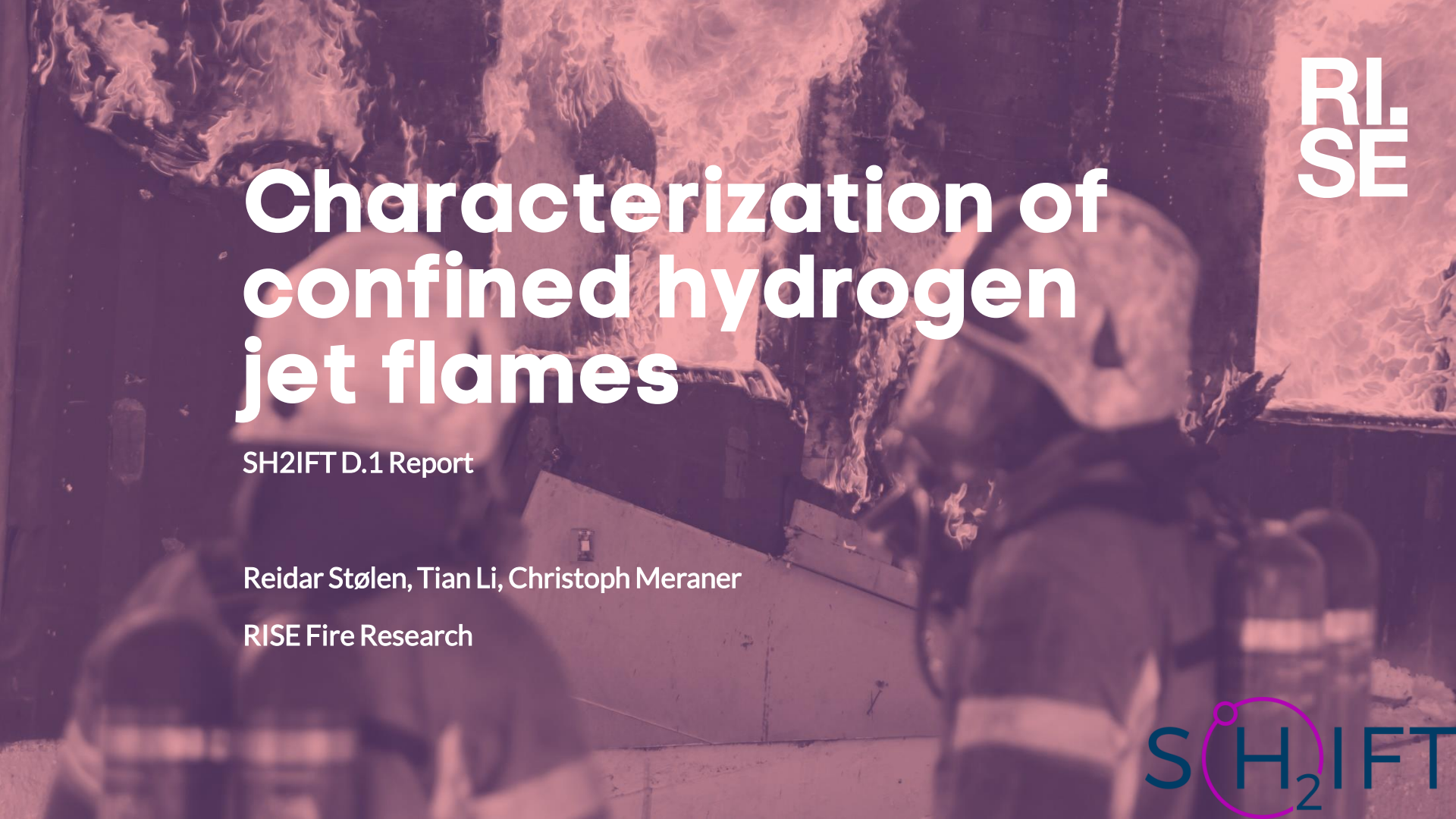


Characterization of confined hydrogen jet flames

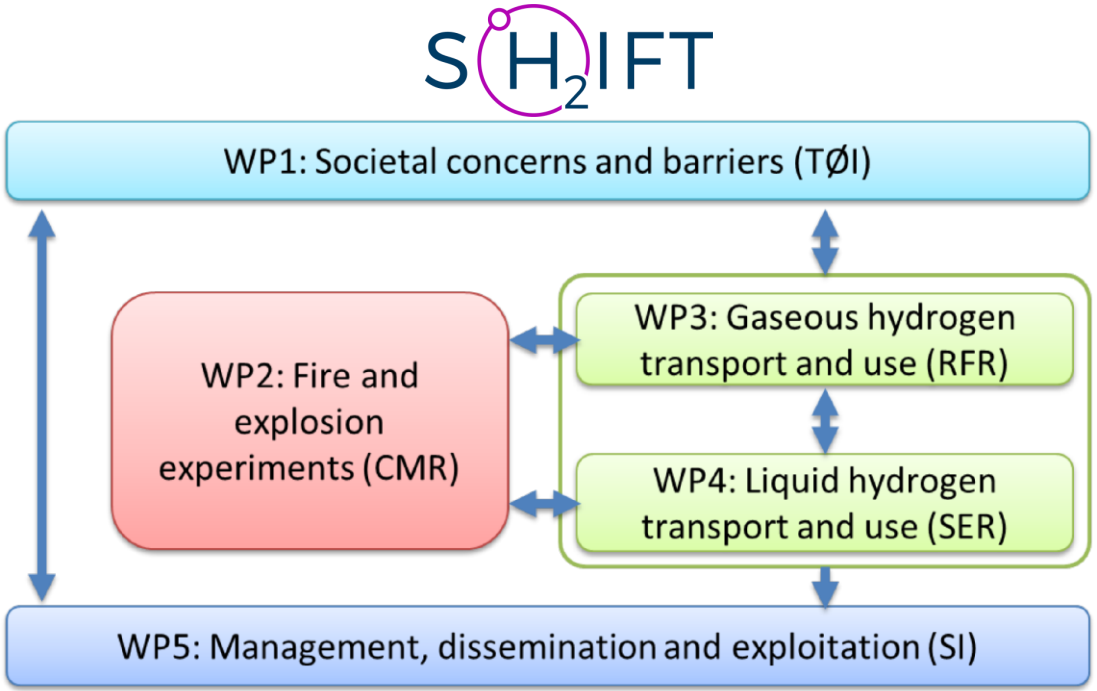
SH2IFT D.1 Report

Reidar Stølen, Tian Li, Christoph Meraner

RISE Fire Research

SH2IFT

- Increase competence within safety of hydrogen technology
- Large volumes and within closed and semi-closed environments
- Funded by the Research Council of Norway and industry partners
- Six research partners, led by SINTEF



https://www.sintef.no/projectweb/sh2ift/

RISE Fire Research

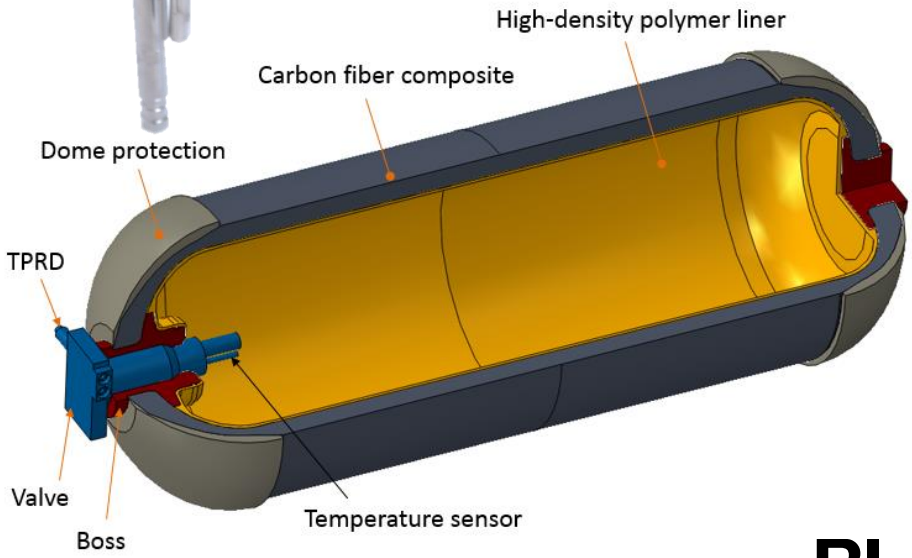
- Established in 1934 (earlier known as SINTEF NBL / SP Fire Research)
- RISE - Research Institutes of Sweden (70 %) and SINTEF (30 %)
- Accredited as test laboratory and inspection body
- Approved as a research organisation by the Research Council of Norway

Hydrogen release scenario

- Thermally activated pressure release device (TPRD)
- For a passenger car
  - 5 kg H_2 at 700 bar, 2 mm diameter for the TPRD vent
- For a bus
  - 30 – 50 kg H_2 at 350 bar, 4 – 5 mm diameter for the TPRD vent

Hydrogen tank value from OMB SALERI SPA (OTV 700)

Data sheet, OTV 700, OMB SALERI, available at https://omb-saleri.it/hydrogen-valves/



TPRD = Thermally Activated Pressure Relief Device

Credit: Process Modeling Group, Nuclear Engineering Division. Argonne National Laboratory (ANL)

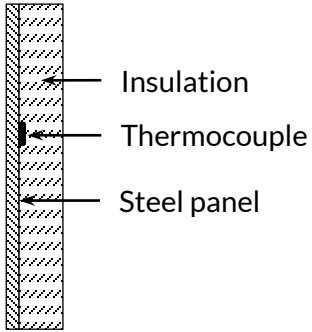
Retrived from https://www.energy.gov/eere/fuelcells/physical-hydrogen-storage on 27.01.2021

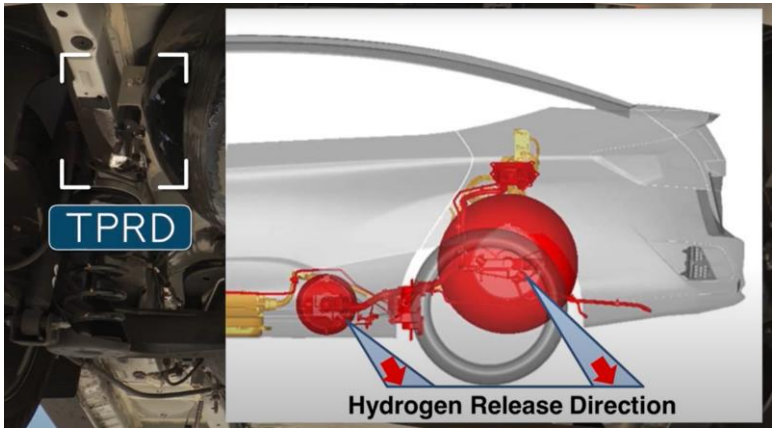
Test setup
Hydrogen supply system

- 5 x 50 liter H_2 at 300 barg (5.5 kg)
- 5 x hoses and bottle valves ID ~3mm
- Pipe ID 12 mm (6 m)
- Nozzle ID 6 mm

Test setup
Enclosure construction

- Fire involving a GH2 tank from a vehicle inside **an enclosed space** with a focus on the **thermal exposure on the surfaces**
- 3 m × 3 m steel panel with embedded thermocouples (25 mm AES wool insulation)





AIChE Academy
https://www.youtube.com/watch?v=-WyqLVOmaRU&ab_channel=AIChEAcademy
2017–18 Honda Clarity Fuel Cell Emergency Response Guide
https://nfpa.org/-/media/Files/Training/AFV/Emergency-Response-Guides/Honda/Honda-Clarity-FCV-2017-2018-ERG.ashx

5 panels

2 panels

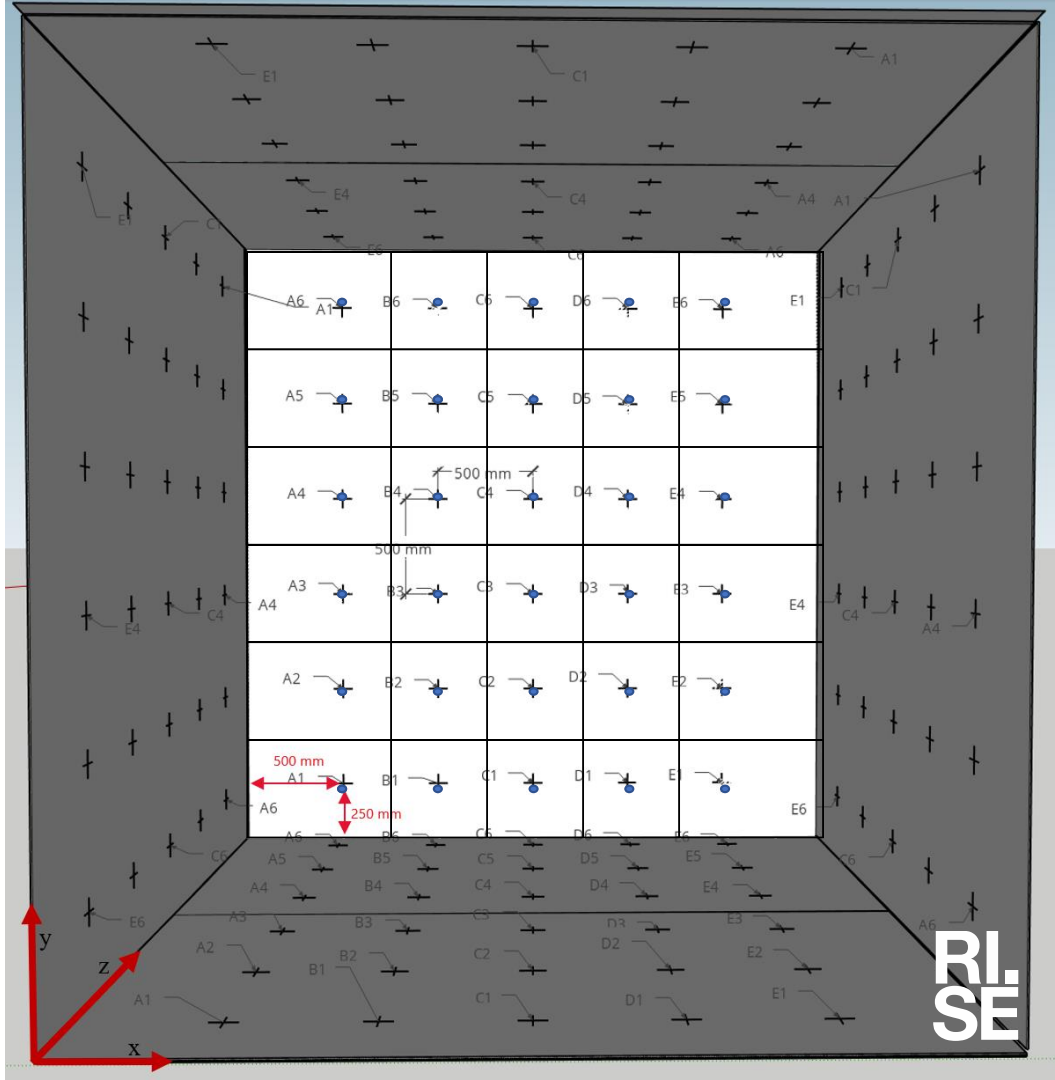
1 panel

Instrumentation

Measuring	Type of instrument	Measuring range
Manifold pressure	Piezoresistive pressure transducer	0 – 1000 barg
Hydrogen flow	Coriolis mass flow meter	0.5 – 25 kg/min
Steel enclosure temperature	Type K thermocouples. Class 1 IEC 60584	-270 °C – 1373 °C
Heat flux	Total heat flux meter	0 – 100 kW/m^2
Heat flux	Ellipsoidal radiometer	0 – 200 kW/m^2
Heat flux	Glass faced flux meter	0 – 200 kW/m^2
Heat flux	Ellipsoidal radiometer	0 – 200 kW/m^2
Heat flux	Total heat flux meter	0 – 200 kW/m^2
Heat	Infrared camera Optris PI 450i	-20 – 900 °C
Heat	Infrared camera FLIR GF 309	-40 – 1500 °C

Plate thermometer[1]

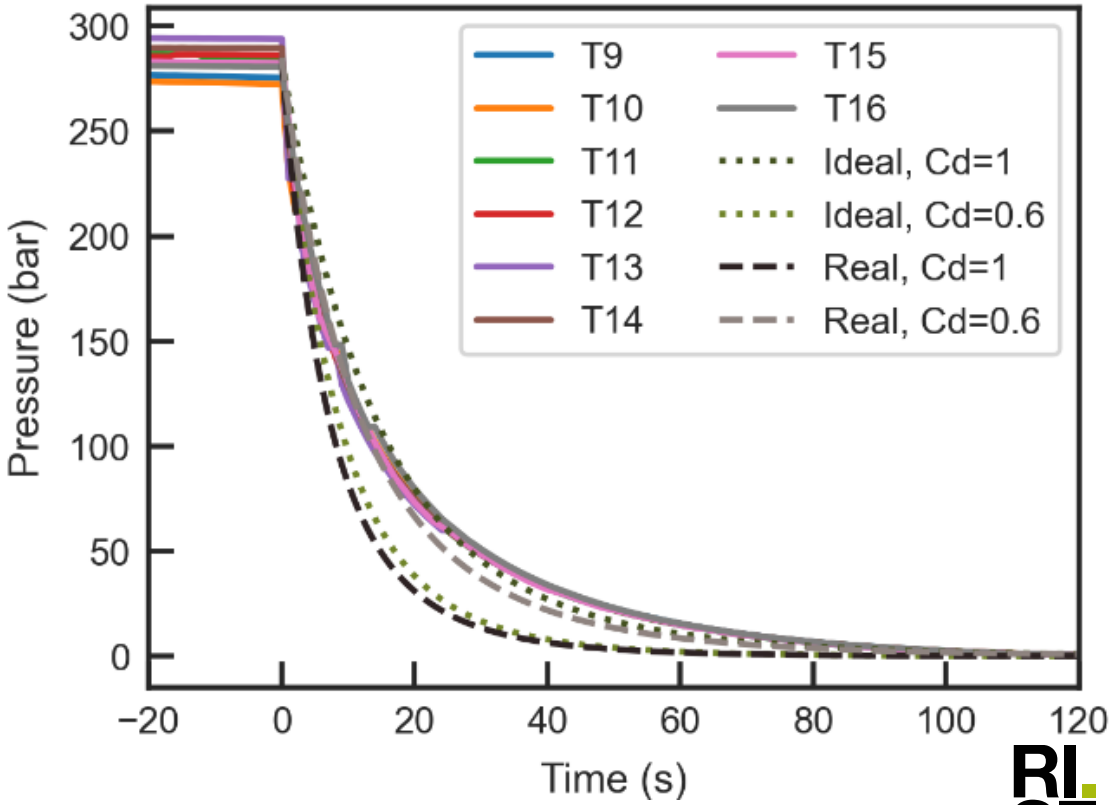
- Steel panel -> multiple connected small plate thermometers
- Negligible heat conduction within the steel plate
- Net heat flux = $C \frac{dT_p}{dt}$
- C ($Jm^{-2}K^{-1}$) is estimated based on 1.5 mm of steel panel



[1]Wickström et al., *Fire and Materials*, vol. 43, no. 1, pp. 51–56, 2019

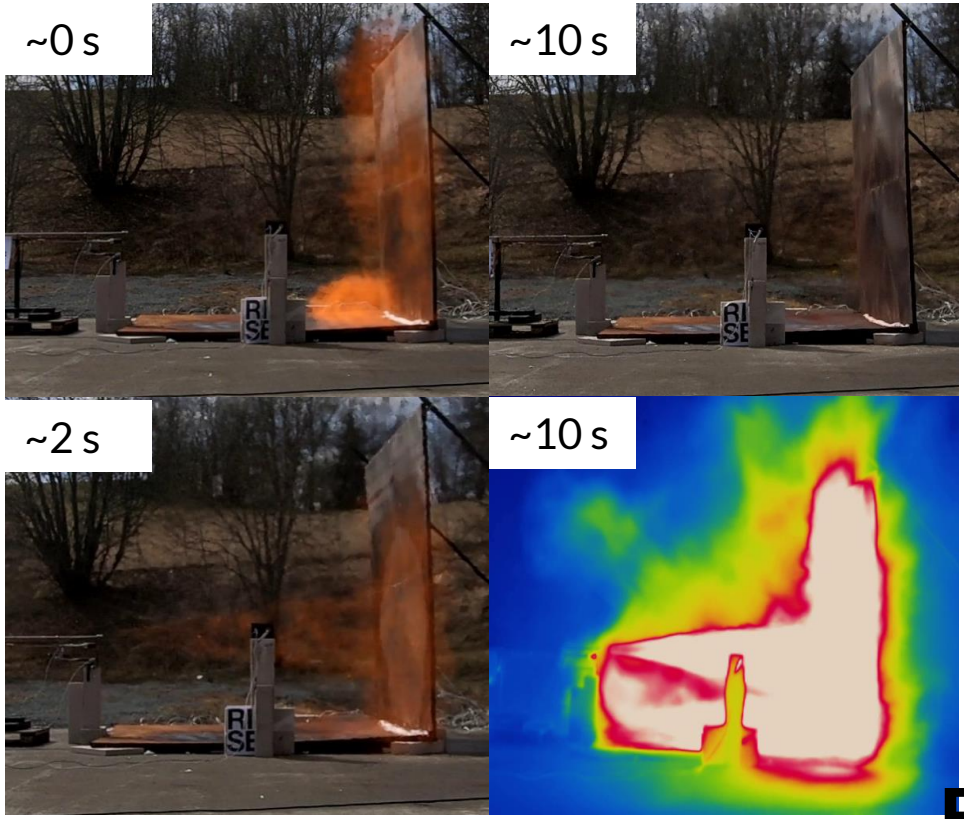
Hydrogen discharge history

- Similar pressure-time histories were recorded from all conducted tests
- Simplified tank blowdown model assuming chocked flow at the nozzle
- Peak release rate around 10 to 20 kg/min*



Flame characteristics

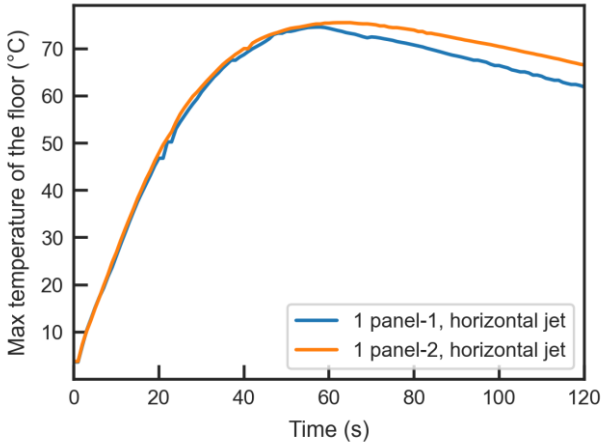
- Flame visibility varies
- Ambient light conditions and configurations
- Yellow/orange flames were observed occasionally
- Dust and salt in air
- Contamination of hydrogen
- H–α emission band

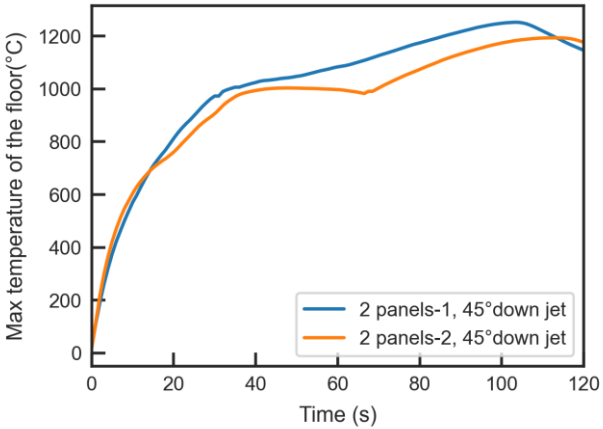


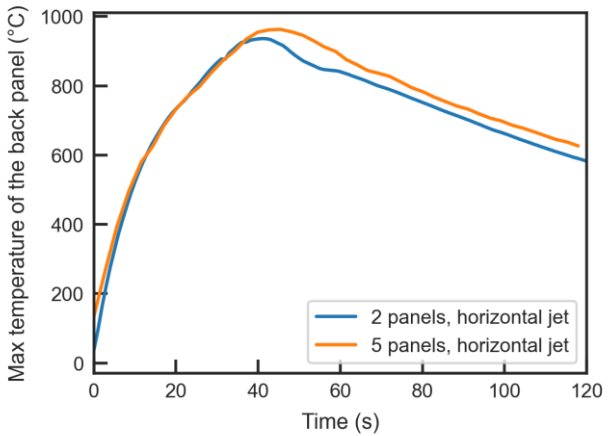
Test 9

Maximum surface temperature

- Maximum surface temperature under 100 °C for the one panel configuration (1 m above)
- Maximum surface temperature around 1200 °C (45° down, 0.4 m above)
- Similar maximum surface temperature between two-panel and five panel configurations

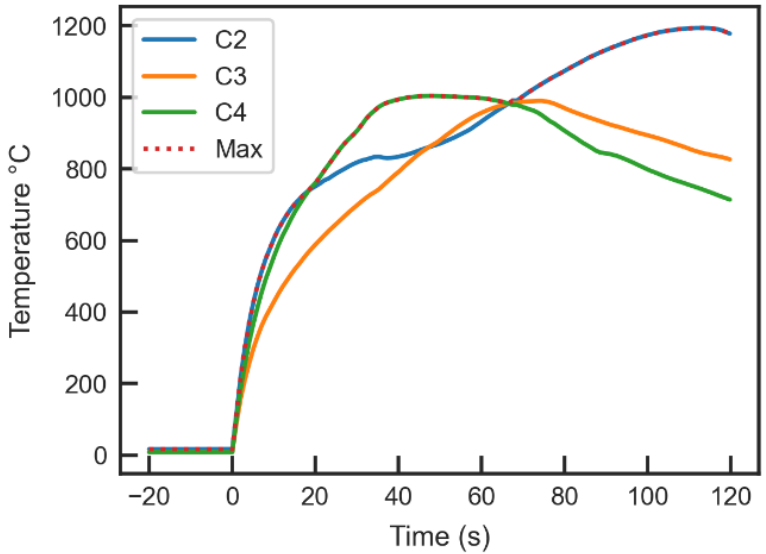


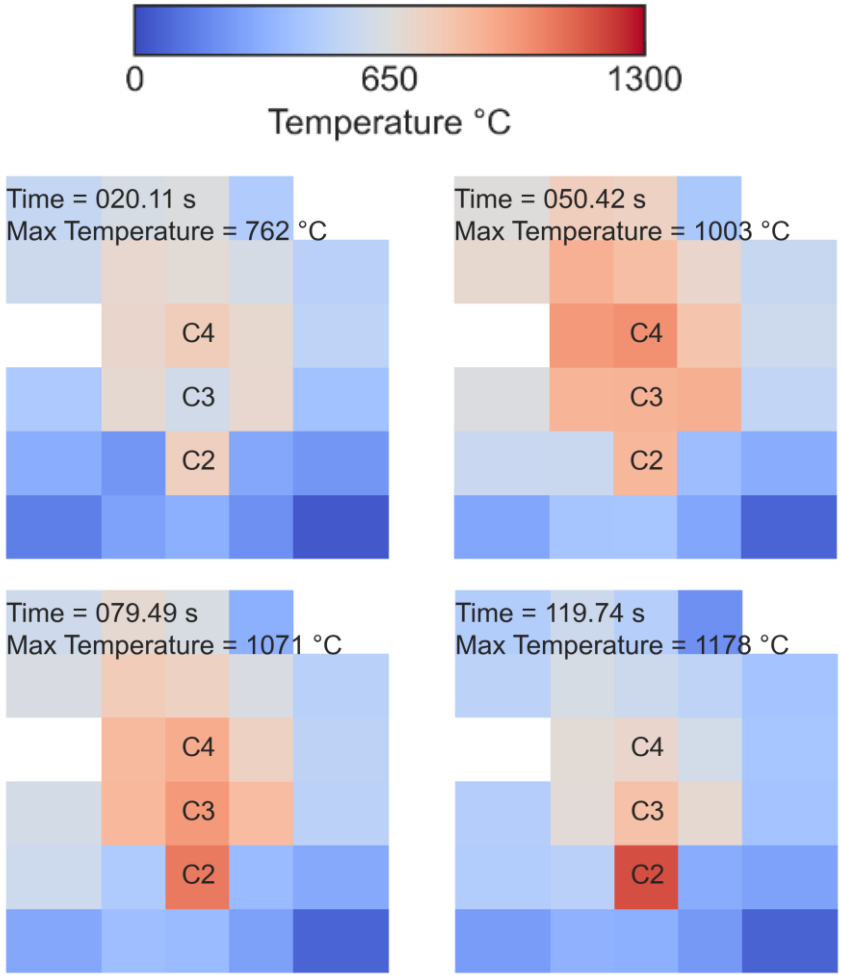




Surface temperature distribution

- 2-panel configuration
- 45 ° down jet (0.4 m above the floor)





Surface temperature distribution

- 2-panel configuration
- 45° down jet (0.4 m above the floor)

20 s

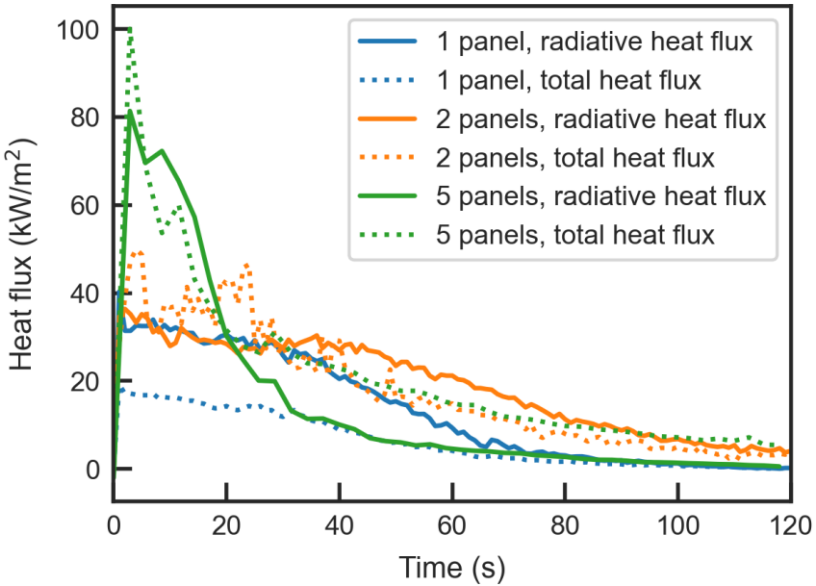
50 s

80 s

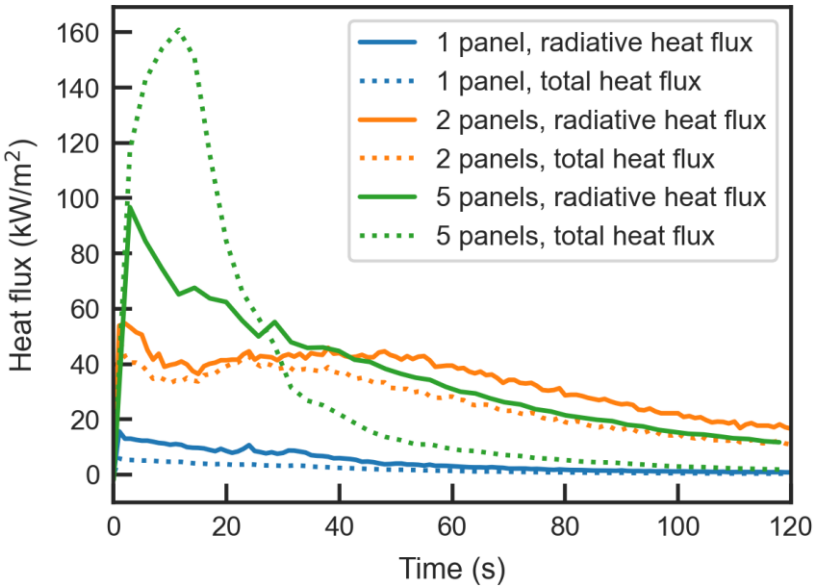
120 s

Heat flux horizontal jet

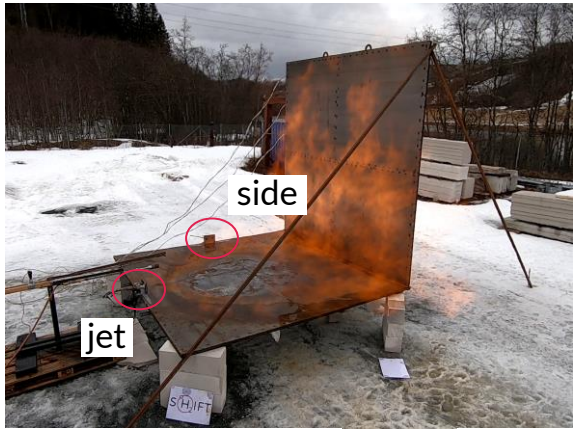
- Heat flux meters mounted at the side of the flame (1.5 m away)



- Heat flux meters at the center line of the jet facing the jet direction (0.4 m to 1 m away)



Heat flux 45° down jet



- Nozzle: 0.4 m above the panel
- Heat flux meter range 200 kW/m^2 (readings up to 400)

Flux meter

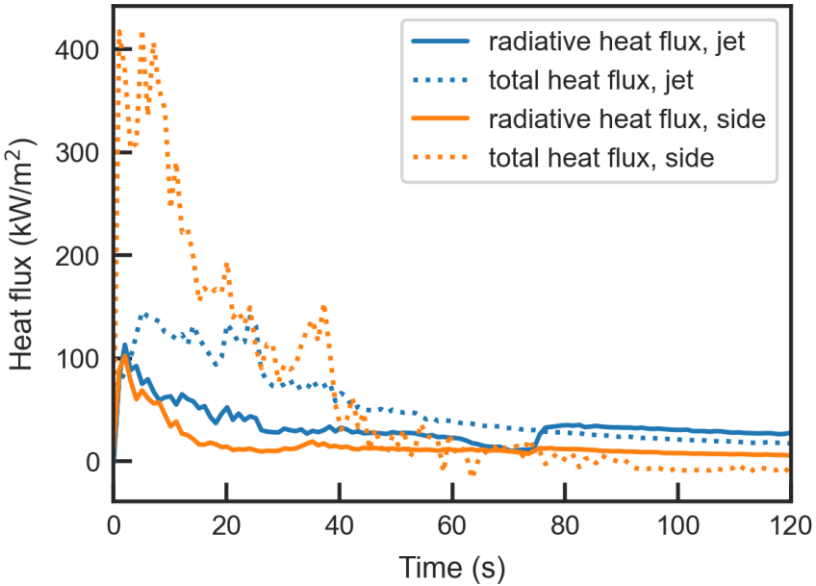
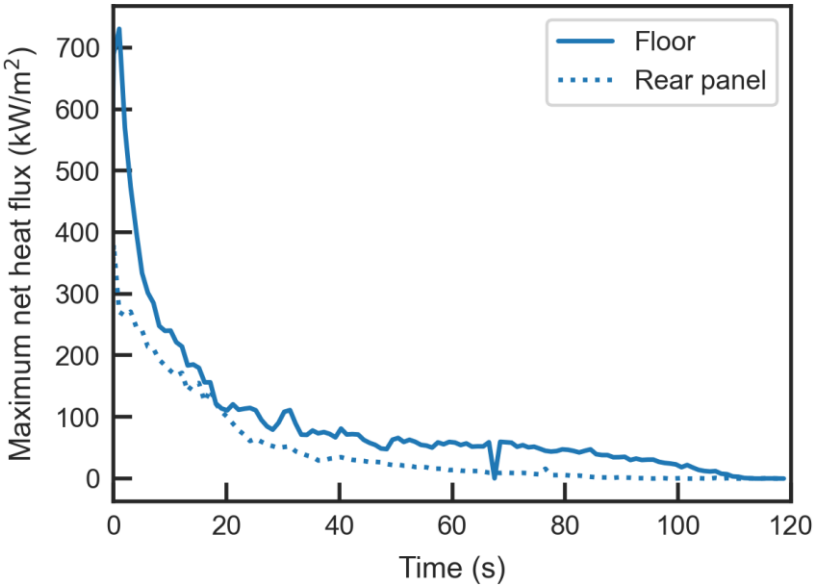
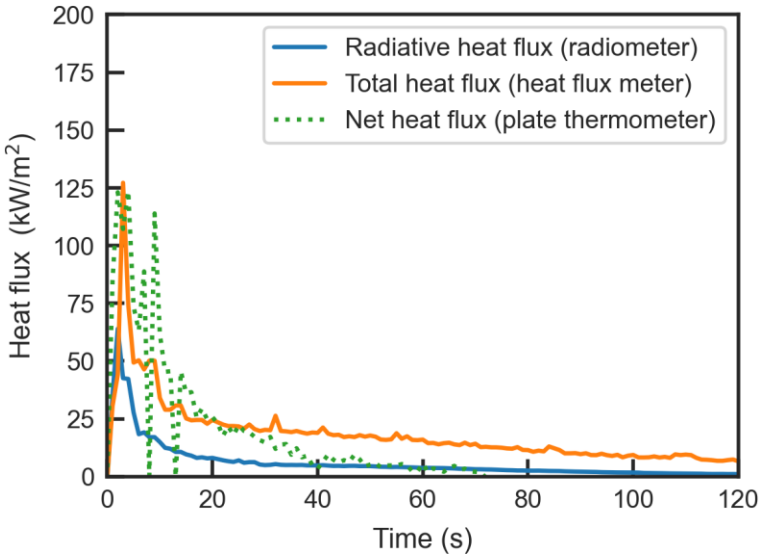


Plate thermometer



Heat flux

- Nozzle, 45° down, 1 m above the floor, 5 panels
- Heat flux at the right panel (1 m high and 1.5 m from the rear panel)
- Total heat flux meter measurements corresponds well with net heat flux calculated from plate thermometer



Conclusion and future work

- Large variation in flame visibility (ambient light, sodium, dust …)
- Very high heat flux levels where the jet impacts (over 700 kW/m^2 estimated by plate thermometers)
  - Mainly convective
  - Reduced with flow rate
- Lower heat flux on surfaces outside the jet flame (< 125 kW/m^2 estimated by plate thermometers and heat flux meters)
- Plate thermocouple net heat flux calculations corresponds well with total heat flux meters

- Repetition of selected experiments to increase the fidelity of the experimental campaign
- Variation of the leak position for selected scenarios
- Conduct reference experiments with hydrocarbon fuel

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Thank you!

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