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Erosion of tunnel materials by hydrogen jets

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Clean Hydrogen Partnership

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Overview

Outline of presentation

- Aims of testing
- Experimental setup
- Tunnel materials
- Test programme
- Results
- Discussion
- Recommendations

Overview

Aims of testing

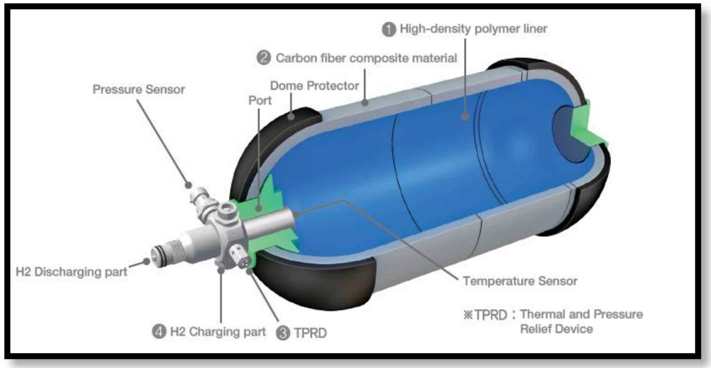
- Understand the characteristics of the jet itself e.g. expected temperatures and pressures when impinging onto tunnel materials
- Investigate the effects of the jet flame on tunnel materials e.g. explosive spalling, thermal effects, structural degradation
- Ultimate aim to define elements that could form part of a standard materials test

Experimental setup

Scenario: Impingement on a tunnel, car tank

- Tank volumes (can be up to 200L), 700bar
- TPRD typically 2mm diameter, angled downwards
- Would not expect direct jet impingement on tunnel wall unless car overturns

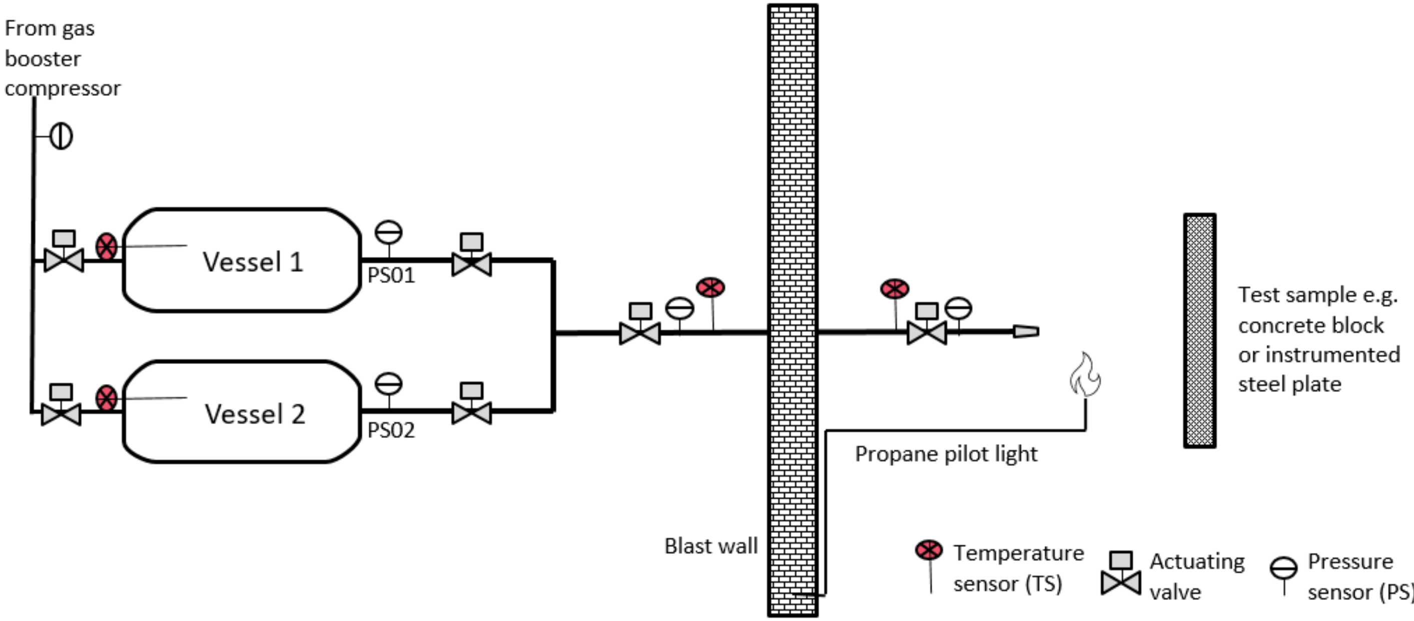
Toyota Mirai hydrogen fuel tank (www.car.nulisen.com)



Experimental setup

High Pressure Hydrogen rig (HPHR)

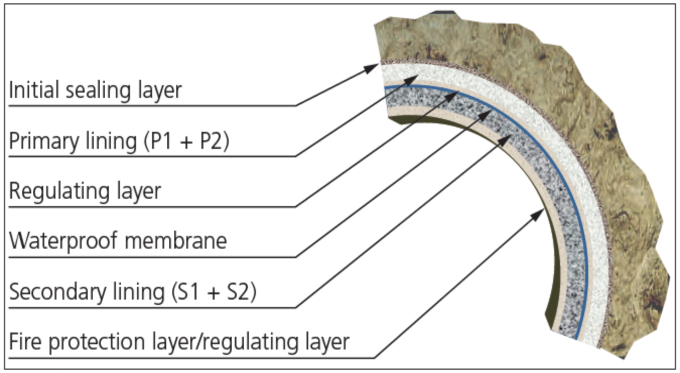
- Using both vessels (98L volume), 700bar
- Nozzle, to mimic TPRD, 2mm (and 0.5mm)
- Horizontal releases, standoff distance 1m



Tunnel materials

Factors affecting erosion/spalling

- Concrete strength >60MPa compressive strength
- Moisture content >3% by weight
- Addition of polypropylene fibres
- Permeability
- Loading



Tunnel design for the London Elizabeth east-west railway line

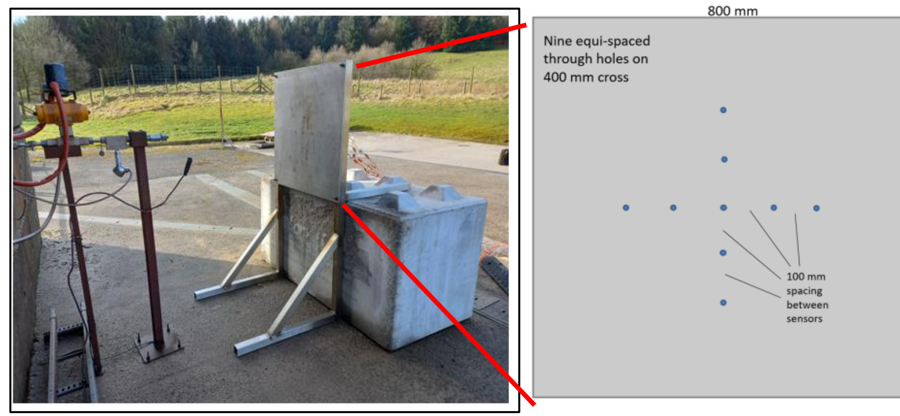
Concrete Grade	≈50 MPa)
water/cement (w/c) ratio	0.45
Microsilica	No
Fly ash (cement sub)	Improve strength, reduce porosity
Plasticiser	Water reducing admixture used
PP fibres	Yes (12 mm)
Aggregates	Land (0-20 mm)

- One road material tested (asphalt based with hot cure bitumen)

Test programme

Release scenarios

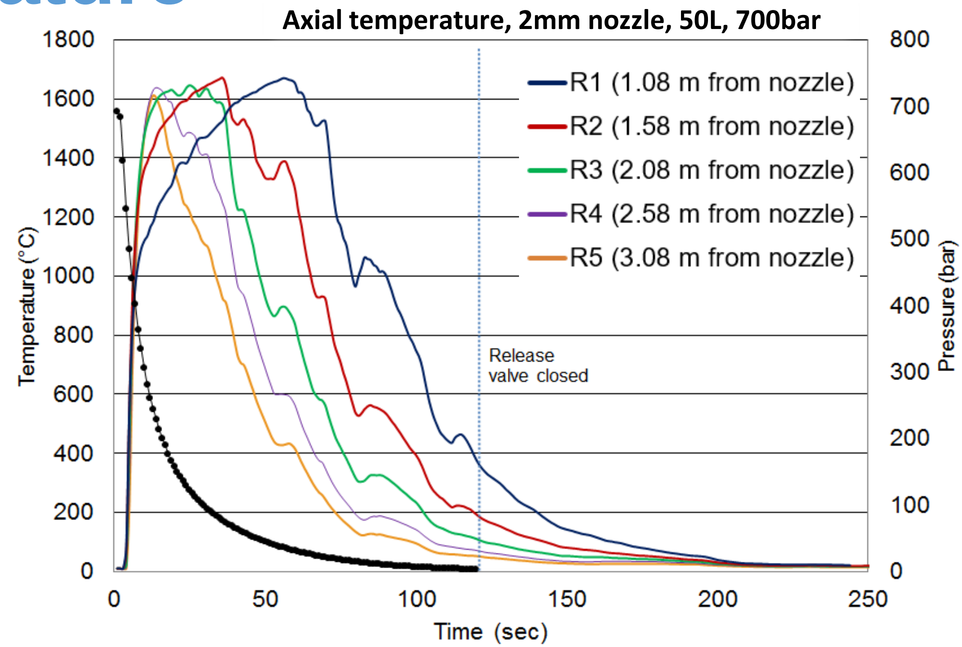
- Free jet release – temperature measurements made along the axial length of an unimpeded jet.
- Impeded jet release – sensor plates; instrumented with pressure and temperature sensors
- Impeded jet release – structural samples. Erosive effects investigated using imaging and post-test material analysis

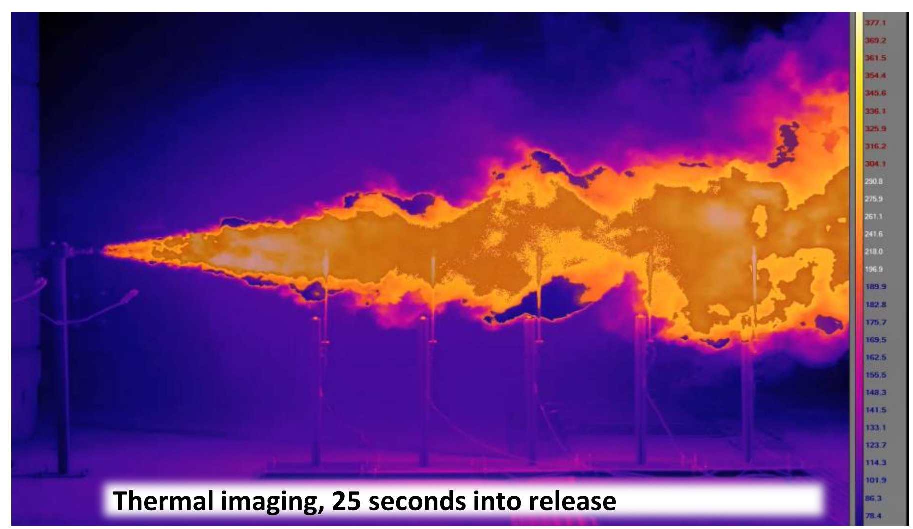


Results

Free jet – axial temperature

- Test: 49L, 2mm nozzle
- Temperatures up to 1650 °C at all thermocouple positions i.e. up to distance of 3m (likely up to 4m)
- Note: for 0.5mm nozzle, maximum temperature of 1650 °C at 0.5m from release point only. Lower temperatures at further distances





Thermal imaging, 25 seconds into release

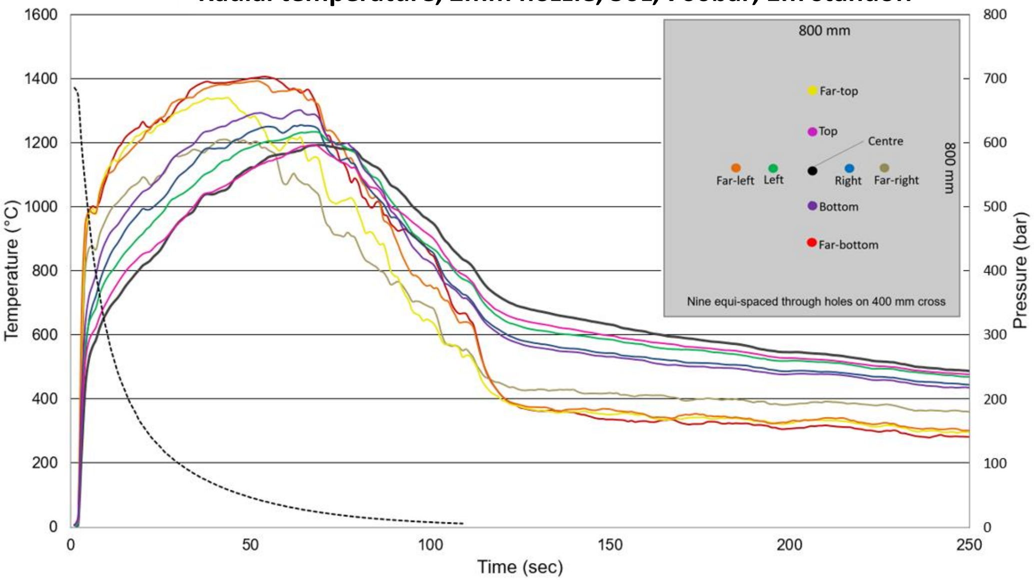
Results

Impeded jet – sensor plates (temperature and pressure)

- Test: 49L, 2mm nozzle, standoff 1m approx.
- Max. temperature for 2mm nozzle 1400°C on outer TCs
- Max. pressure magnitude for 2mm nozzle 92mbar at centre sensor
- Max. temperature for 0.5mm nozzle 1200°C
- No pressure readings above background for 0.5mm nozzle.

Temperature sensing plate. Note: outer thermocouple ends glowing

Radial temperature, 2mm nozzle, 50L, 700bar, 1m standoff



Results

Impeded jet – concrete samples

- Test: 98L, 2mm nozzle, 1m standoff, 3-4 minute impingement
- Sample with no PP fibres spalled
- Sample with PP fibres scorched but did not spall. This was also the case for 0.5mm nozzle, where jet impinged for up to 40 minutes

Sample with no polypropylene (PP) fibres (3-4 min impingement)

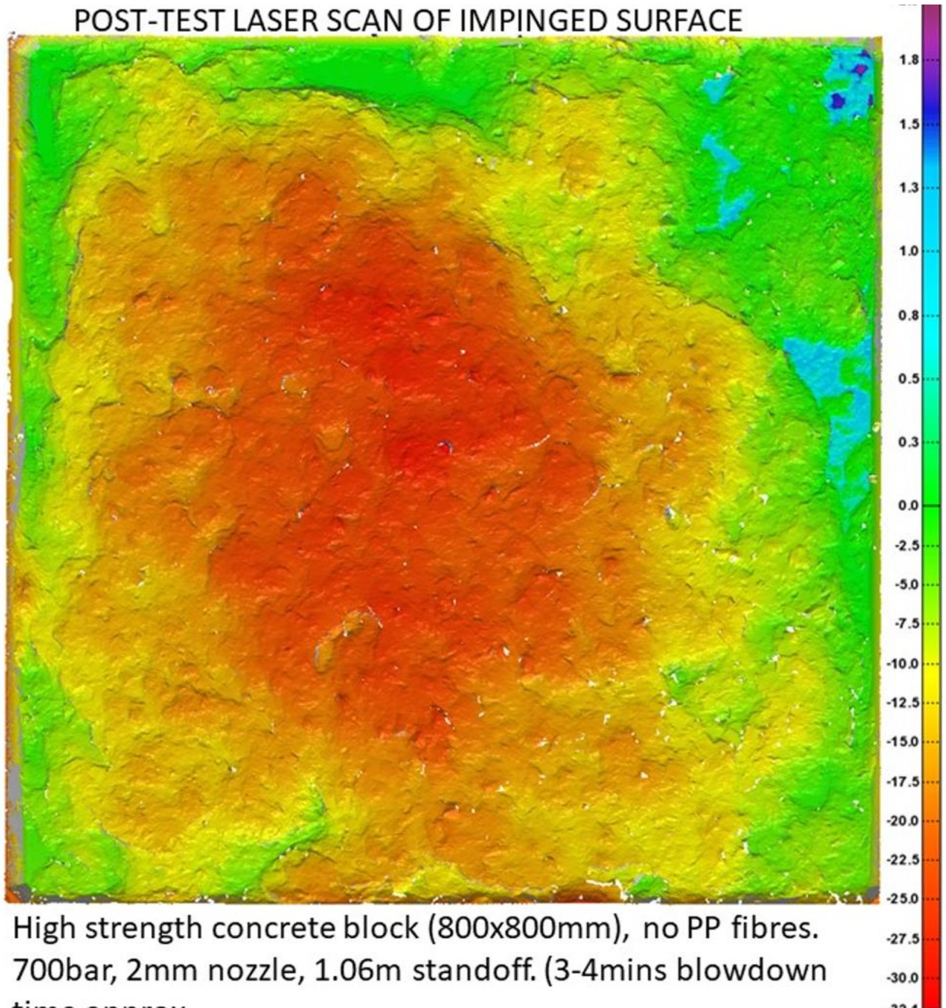
Sample with no polypropylene (PP) fibres (3-4 min impingement)

Sample with polypropylene (PP) fibres (3-4 min impingement)

Results

Post test – laser surface scan

POST-TEST LASER SCAN OF IMPINGED SURFACE



High strength concrete block (800x800mm), no PP fibres. 700bar, 2mm nozzle, 1.06m standoff. (3-4mins blowdown time approx.

POST-TEST VISIBLE IMAGE OF IMPINGED SURFACE

Results

Post test – structural tests (jet impinged vs. not)

- Compressive strength measured on 150mm diameter and length core
- Thermal conductivity measured to a depth of 45mm. Potential moisture loss reducing thermal conductivity
- Ultrasonic testing measured to a depth of 190mm. >4 km/s indicates good uniform structure

Example of extracted cores

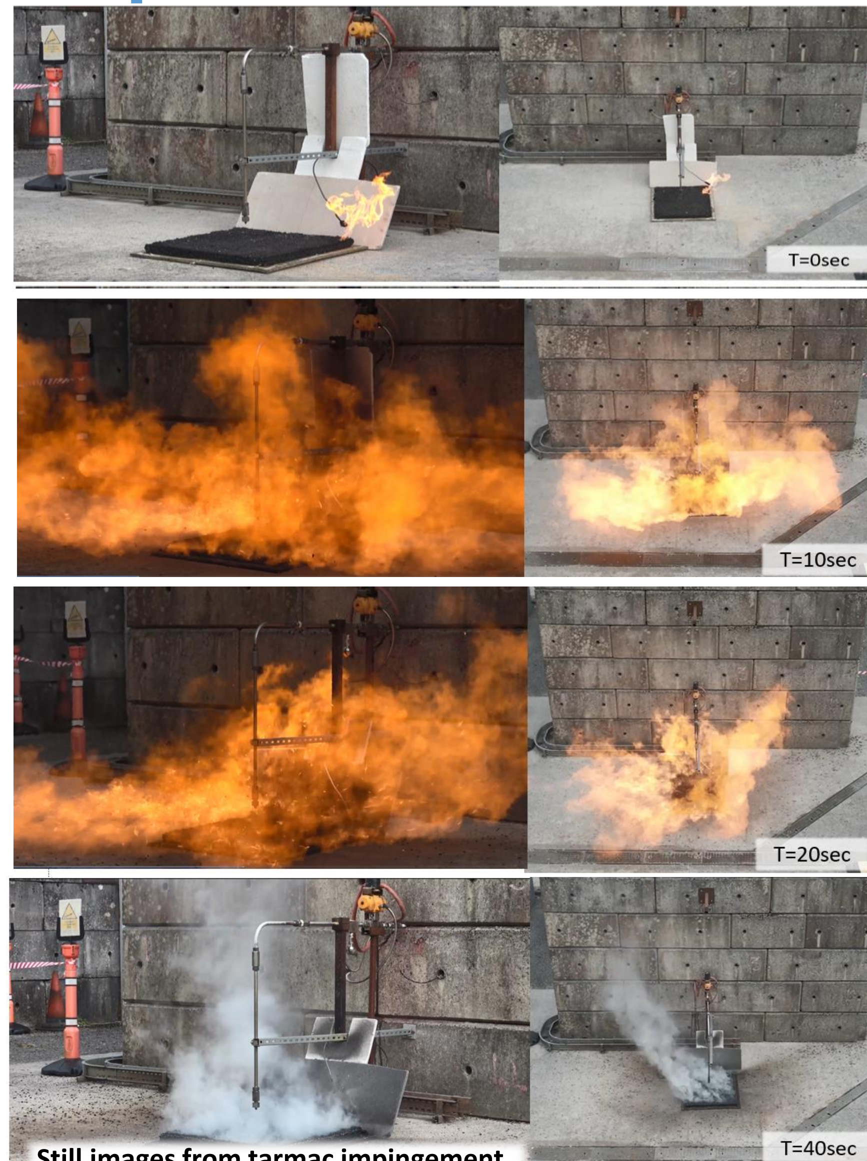
	Non-jet	Jet impinged
Compressive strength (N/mm^2)	55.3	54.9
Thermal conductivity ($W \cdot m^{-1} \cdot K^{-1}$)	0.792	0.649
Pulse velocity (km/s)	4.65	4.79

tunnel HP

Results

Impeded jet – tarmac sample

- Expecting a lot of black smoke potentially
- During jet release, appeared that hydrogen was the main fuel burning
- Jet very visible and audible



Still images from tarmac impingement

Discussion (Aim 1 and 2)

Safety aspects relating to hydrogen jet

Aim 1: Jet release characteristics

- Temperatures up to 1650°C with good air entrainment, 1400 °C with obstruction*
- Hazard distances reduced if using smaller nozzle i.e. max temperature measured at 0.5m from release point vs. over 3m

Aim 2: Erosive effects on tunnel materials

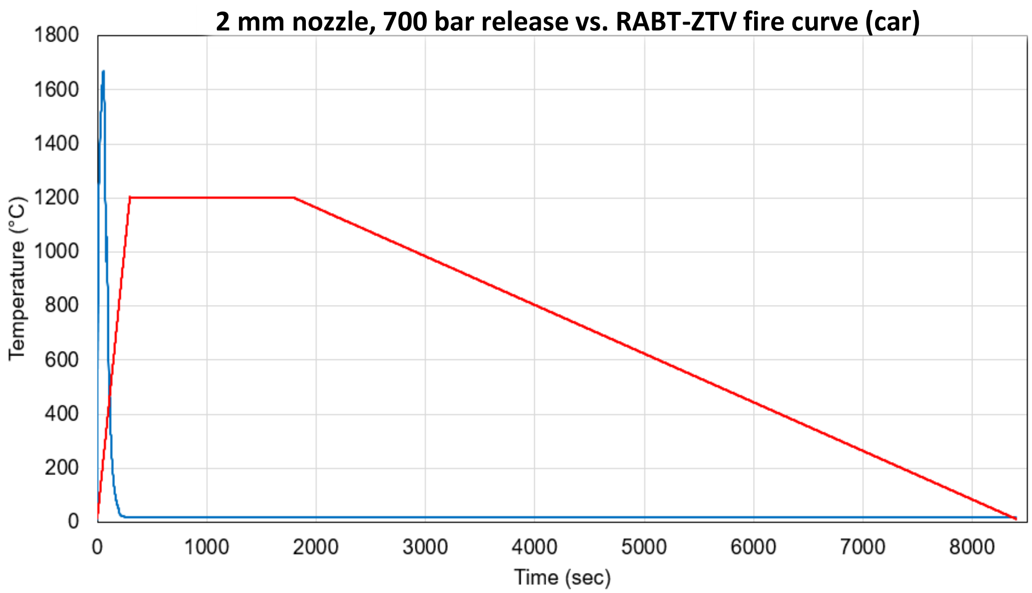
- Appear to be fairly superficial i.e. within the sacrificial layers considered in tunnel design*
- Polypropylene fibres effective against hydrogen jets, even with longer impingement duration (up to 40 minutes)

*based on these parameters and test method

Recommendations (Aim 3)

Materials test for hydrogen jets

- Create fire curve to account for hydrogen temperature profile i.e. short duration but rapid temperature increase (consider other fuel inventory)
- Could possibly use furnace setup rather than high pressure jet as temperature a greater contributory factor than pressure (dependent on time of ignition)



Recommendations (Aim 3)
Fire safety for first responders

- Hydrogen jet itself not visible however turbulence, poor air entrainment/fuel rich jet portion, interaction with other surfaces gives bright orange flame
- Jet, whether ignited or unignited gives loud "whooshing" noise

Jet blowdown, 350bar, 3.3m standoff distance, 5mm nozzle. Still of visible recording (5 secs approx. into release)

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