



**SIXTH FRAMEWORK PROGRAMME
NETWORK OF EXCELLENCE**

HYSAFE

Safety of Hydrogen as an Energy Carrier



Contract no.: 502630

***Compilation of descriptions of experimental facilities
(WP 2)***

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Partner: *FZK*



- Facilities:**
- *A1 Vessel*
 - *A3 Vessel*
 - *A6 Vessel*
 - *A8 Vessel*
 - *12 m detonation tube (DT)*
 - *Flow Test Chamber (TC)*
 - *Partially Vented Explosion Tube (PET)*
 - *Explosion Bomb*
 - *HyJet (Hydrogen Jet)*

Overview

Name	A1 Vessel	
Type	<i>cylindrical vessel</i>	
Scale	<i>full or large scale</i>	
Experiments	<i>studies on turbulent combustion and detonations, vented explosions, hydrogen distribution, integrity of mechanical structures under high pressure load</i>	

Technical details

Dimensions	<i>98 m³ vessel, internal diameter 3.3 m, length 12 m</i>
Temperatures	<i>ambient</i>
Pressure	<i>up to 100 bar of static pressure</i>
Media	<i>hydrogen, air, nitrogen, oxygen.</i>
Special features	<i>full or large scale; licensed high static pressure 100 bar; multiple entries possible</i>
Further particulars	<i>several vents up to 800 mm in diameter; several windows for visual observations; internal volume can be divided on several joined rooms with different volume; regular grid with obstacles can be used inside the volume; A1 vessel can be connected with other large vessel (e.g. A3 vessel)</i>

Experiments – Equipment

Experiments	<ul style="list-style-type: none"> - <i>experiments on turbulent combustion in uniform and nonuniform gas mixtures at different initial pressure;</i> - <i>effect of obstacles and multi-compartment (room connections with different volumes) on flame acceleration and DDT;</i> - <i>effect of venting and pre-compression in connecting rooms on flame propagation regime;</i> - <i>jet initiation of detonation;</i> - <i>experiments on hydrogen distribution in closed volume</i>
Level of detail	<i>integral</i>

Instrumentation	<i>gas temperature</i> <i>pressure</i> <i>gas composition</i> <i>hydrogen distribution</i> <i>velocity</i> <i>deformations</i>	<i>thermocouples</i> <i>piezoelectric, piezoresistive gauges</i> <i>mass spectrometer, gas flow control</i> <i>sonic hydrogen sensors</i> <i>photodiodes, ion probes</i> <i>strain gauges</i>
Schedule	<i>preparatory work of experimental set-up to specific test series requires one month;</i> <i>1 – 2 days are needed for preparation and conduction of one experiment in the series;</i> <i>1 day is needed for processing of raw experimental data</i>	
Tools	<i>standard software required for data acquisition system to convert analogous signals to digital form (ASCII or binary format)</i>	
Further particulars	-	

Information for the preparation of integration

- **Exchange of instruments and personnel**

How many persons are needed to prepare/conduct experiments?

3-4 persons are needed to prepare/conduct experiments

What kind of movable equipment is available and could be shared?

Data acquisition system processed by accompanying service team (1-2 persons)

- **To prepare filling possible gaps**

What kind of experiments/tests could be performed in this facility after minor modifications and/or by applying additional instrumentation?

Experiments on integrity of mechanical structures under detonation pressure load could be done using A1 vessel as secure shell against missiles.

- **To prepare promotion and specialisation**

What features/possibilities would you like to promote?

Large and full scale experiments on turbulent combustion and detonation, experiments under elevated pressures and extremely high pressure load, hydrogen distribution in closed volume.

Which additional equipment could enhance the results of your experiments?

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Overview

Name	A3 Vessel
Type	<i>cylindrical vessel</i>
Scale	<i>full or large scale</i>
Experiments	<i>studies on turbulent combustion and detonations, vented explosions, hydrogen distribution</i>



Technical details

Dimensions	<i>33 m³ vessel, internal diameter 2.5 m, height 8 m</i>
Temperatures	<i>ambient</i>
Pressure	<i>up to 60 bar of static pressure</i>
Media	<i>hydrogen, air, nitrogen, oxygen</i>
Special features	<i>large scale; licensed high static pressure 60 bar, multiple entries possible</i>
Further particulars	<i>vessel has several vents of different sizes; internal volume can be divided on several joined rooms with different volume; regular grid with obstacles can be used inside the volume; A3 vessel can be connected with other large vessel (e.g. A1 vessel)</i>

Experiments – Equipment

Experiments	<ul style="list-style-type: none"> - <i>experiments on turbulent combustion in uniform and nonuniform gas mixtures at different initial pressure;</i> - <i>effect of obstacles and multi-compartment (room connections with different volumes) on flame acceleration and DDT;</i> - <i>effect of venting and pre-compression in connecting rooms on flame propagation regime;</i> - <i>experiments on hydrogen distribution in closed volume</i> 	
Level of detail	<i>integral</i>	
Instrumentation	<ul style="list-style-type: none"> <i>gas temperature</i> <i>pressure</i> <i>gas composition</i> <i>hydrogen distribution</i> <i>velocity</i> 	<ul style="list-style-type: none"> <i>thermocouples</i> <i>piezoelectric, piezoresistive</i> <i>mass spectrometer, gas flow control</i> <i>sonic hydrogen sensors</i> <i>photodiodes, ion probes</i>

Schedule	<i>preparatory work of experimental set-up to specific test series requires one month; 1 – 2 days are needed for preparation and conduction of one experiment in the series; 1 day is needed for processing of raw experimental data</i>
Tools	<i>standard software required for data acquisition system to convert analogous signals to digital form (ASCII or binary format)</i>
Further particulars	-

Information for the preparation of integration

- **Exchange of instruments and personnel**

How many persons are needed to prepare/conduct experiments?

3-4 persons are needed to prepare/conduct experiments

What kind of movable equipment is available and could be shared?

Data acquisition system processed by accompanying service team (1-2 persons)

- **To prepare filling possible gaps**

What kind of experiments/tests could be performed in this facility after minor modifications and/or by applying additional instrumentation?

Experiments on hydrogen distribution and hydrogen stratification effect on flame propagation.

- **To prepare promotion and specialisation**

What features/possibilities would you like to promote?

Large or full scale experiments on turbulent combustion and detonation, experiments under elevated pressures and extremely high pressure load, hydrogen distribution in closed volume.

Which additional equipment could enhance the results of your experiments?

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Overview

Name **A6 Vessel**

Type *cylindrical vessel*

Scale *large scale*

Experiments *studies on turbulent combustion and detonations, vented explosions, hydrogen distribution, integrity of mechanical structures under high pressure load*



Technical details

Dimensions *21 .5 m³ vessel, internal diameter 3.3 m, height 3.1 m*

Temperatures *ambient*

Pressure *up to 40 bar of static pressure*

Media *hydrogen, air, nitrogen, oxygen*

Special features *large scale; licensed high static pressure 40 bar, multiple entries possible*

Further particulars *vessel has two vents of 800 mm in diameter;
gas filling system;
data acquisition system;
spark/glow plug for mixture ignition*

Experiments – Equipment

Experiments *- experiments on turbulent combustion in uniform and nonuniform gas mixtures at different initial pressure;
- effect of venting and pre-compression in connecting rooms on flame propagation regime;
- experiments on hydrogen distribution in closed volume;
- integrity of mechanical structures under detonation pressure load*

Level of detail *integral*

Instrumentation *gas temperature thermocouples
pressure piezoelectric, piezoresistive gauges
gas composition mass spectrometer, gas flow control*

	<i>velocity</i>	<i>photodiodes, ion probes</i>
	<i>deformations</i>	<i>strain gauges</i>
Schedule	<i>preparatory work of experimental set-up to specific test series requires one month;</i> <i>1 day is needed for preparation and conduction of one experiment in the series;</i> <i>1 day is needed for processing of raw experimental data</i>	
Tools	<i>standard software required for data acquisition system to convert analogous signals to digital form (ASCII or binary format)</i>	
Further particulars	-	

Information for the preparation of integration

- **Exchange of instruments and personnel**

How many persons are needed to prepare/conduct experiments?

2-3 persons are needed to prepare/conduct experiments

What kind of movable equipment is available and could be shared?

Data acquisition system processed by accompanying service team (1-2 persons)

- **To prepare filling possible gaps**

What kind of experiments/tests could be performed in this facility after minor modifications and/or by applying additional instrumentation?

Experiments on integrity of mechanical structures under detonation pressure load could be done using A6 vessel as protection against missiles.

- **To prepare promotion and specialisation**

What features/possibilities would you like to promote?

Large scale experiments on turbulent combustion and detonation, experiments under elevated pressures and extremely high pressure load, hydrogen distribution in closed volume.

Which additional equipment could enhance the results of your experiments?

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A8 Vessel

Overview

Name A8 Vessel

Type *cylindrical vessel*

Scale *large and medium scale*



Experiments *studies on gas combustion and detonations, vented explosions, hydraulic and pneumatic equipment explosions, integrity and fracture of mechanical structures under high pressure load, blast vessels*

Application field within
the thematic structure of HySafe *H2-H5, V1-V3*

Technical details

Dimensions *8.8 m³ vessel, internal diameter 1.8 m, length 3.7 m*

Temperatures *ambient*

Pressure *up to 120 bar of static pressure*

Media *hydrogen, hydrocarbons, air, inert gases, pressurized gases themselves.*

Special features *large or medium scale; licensed static pressure limit 120 bar; multiple entries possible*

Further particulars *several vents up to 300 mm in diameter;
8 glass windows for visual observations Ø150 mm;
removable flange with opening of 1.8 m in diameter*

Experiments – Equipment

Experiments	<i>- experiments on turbulent combustion in uniform and nonuniform gas mixtures at different initial pressures ; - jet initiation of detonation; - blast vessels; - exploding pipes, valves; - bursting membranes</i>	
Level of detail	<i>integral</i>	
Instrumentation	<i>gas temperature pressure gas composition velocity deformations, fracture</i>	<i>thermocouples piezoelectric, piezoresistive transducers mass spectrometer, gas flow control; photodiodes, ion probes strain gauges, high speed camera</i>
Schedule	<i>preparatory work of experimental set-up to specific test series requires one month; 1 – 2 days are needed for preparation and conduction of one experiment in the series; 1 day is needed for processing of raw experimental data</i>	
Tools	<i>standard software (LabView) required for data acquisition system to convert analogous signals to digital ones (ASCII or binary format)</i>	
Further particulars		

Information for the preparation of integration

- **Exchange of instruments and personnel**

How many persons are needed to prepare/conduct experiments? - 2-3 persons are needed to prepare/conduct experiments

What kind of movable equipment is available and could be shared? - Data acquisition system processed by accompanying service team (1-2 persons)

- **To prepare filling possible gaps**

What kind of experiments/tests could be performed in this facility after minor modifications and/or by applying additional instrumentation? - Experiments on integrity and/or fracture of gas equipment (piping, valves, and membranes) either pressurized or under detonation pressure load could be done using A8 vessel as secure shell against missiles.

- **To prepare promotion and specialisation**

What features/possibilities would you like to promote? Large and medium scale experiments on turbulent combustion and detonation, experiments under elevated pressures and extremely high pressure load, testing of high pressure equipment.

What more/better results could you obtain if you had additional equipment?

Overview

Name **12 m detonation tube (DT)**

Type *cylindrical tube*

Scale *medium scale*

Experiments *studies on turbulent combustion, DDT and steady state detonations, heat transfer, ignition, flame propagation regimes, chemical kinetic.*



Technical details

Dimensions *internal diameter 350 mm, length 12 m*

Temperatures *ambient*

Pressure *up to 100 bar of static pressure*

Media *hydrogen, air, nitrogen, oxygen*

Special features *medium scale*

Further particulars *tube could be filled with regular ring shape obstacles grid spaced by tube diameter, blockage ratio BR = 0.3, 0.45, 0.6, 0.75, 0.9; tube is equipped with gas filling system and data acquisition system, spark/glow plug for ignition*

Experiments – Equipment

Experiments *- experiments on turbulent combustion in uniform and nonuniform gas mixtures at different initial pressure;
- experiments on flame acceleration, DDT and flammability limits;
hydrogen distribution in closed volume*

Level of detail *microscopic to integral*

Instrumentation	<i>gas temperature</i>	<i>thermocouples</i>
	<i>pressure</i>	<i>piezoelectric, piezoresistive gauges</i>
	<i>gas composition</i>	<i>mass spectrometer, gas flow control</i>
	<i>velocity</i>	<i>photodiodes, ion probes</i>

Schedule *preparatory work of experimental set-up to specific test series requires one week;
3 – 4 hours are needed for preparation and conduction of one*

	<i>experiment in the series;</i> <i>1 day is needed for processing of raw experimental data</i>
Tools	<i>standard software required for data acquisition system to convert analogous signals to digital form (ASCII or binary format)</i>
Further particulars	-

Information for the preparation of integration

- **Exchange of instruments and personnel**

How many persons are needed to prepare/conduct experiments?

2-3 persons are needed to prepare/conduct experiments

What kind of movable equipment is available and could be shared?

Data acquisition system processed by accompanying service team (1-2 persons)

- **To prepare filling possible gaps**

What kind of experiments/tests could be performed in this facility after minor modifications and/or by applying additional instrumentation?

Experiments on chemical kinetic and heat transfer.

- **To prepare promotion and specialisation**

What features/possibilities would you like to promote?

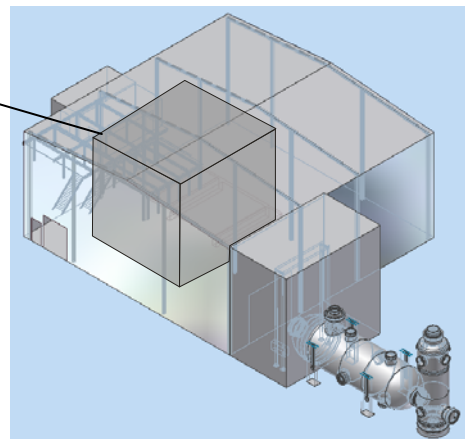
Medium scale experiments on turbulent combustion and detonation, experiments under elevated and reduced pressures, experiment on ignition and flame propagation limits.

Which additional equipment could enhance the results of your experiments?

-

Overview

Name	Flow Test Chamber (TC)
Type	<i>rectangular chamber</i>
Scale	<i>full or large scale</i>
Experiments	<i>studies on vented combustion and detonations (up to 16g of hydrogen); hydrogen distribution, testing of ventilation system; testing of automotive hydrogen engines</i>



Technical details

Dimensions	<i>160 m³ chamber, dimensions 8.53x5.5x3.3 m</i>
Temperatures	<i>ambient</i>
Pressure	<i>ambient</i>
Media	<i>hydrogen, air</i>
Special features	<i>full/large scale</i>
Further particulars	<i>chamber is equipped with ventilation system with variable exchange rate; possibility of hydrogen inlet with controlled flow rate; hydrogen engines can be tested inside of test chamber</i>

Experiments – Equipment

Experiments	<i>- experiments on vented combustion and detonations; - experiments on hydrogen distribution in closed volume - experiments on shock wave load under combustion and detonation</i>	
Level of detail	<i>integral (macroscopic)</i>	
Instrumentation	<i>gas temperature pressure gas composition hydrogen distribution velocity deformations</i>	<i>thermocouples piezoelectric, piezoresistive gauges mass spectrometer, gas flow control sonic hydrogen sensors photodiodes, ion probes, visual observations with high speed CCD camera strain gauges, displacement sensors (laser, mechanical and visual)</i>

Schedule	<i>preparatory work of experimental set-up to specific test series requires one month; 1 – 2 days are needed for preparation and conduction of one experiment in the series; 1 day is needed for processing of raw experimental data</i>
Tools	<i>standard software required for data acquisition system to convert analogous signals to digital form (ASCII or binary format)</i>
Further particulars	-

Information for the preparation of integration

- **Exchange of instruments and personnel**

How many persons are needed to prepare/conduct experiments?

3-4 persons are needed to prepare/conduct experiments

What kind of movable equipment is available and could be shared?

Data acquisition system processed by accompanying service team (1-2 persons)

- **To prepare filling possible gaps**

What kind of experiments/tests could be performed in this facility after minor modifications and/or by applying additional instrumentation?

Experiments on vented combustion and detonation could be done using test chamber as protection against shock wave and thermal load.

- **To prepare promotion and specialisation**

What features/possibilities would you like to promote?

Large and full scale experiments on hydrogen distribution in big closed volume, vented combustion and detonation (up to 16 g of hydrogen)

Which additional equipment could enhance the results of your experiments?

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Overview

Name	Partially Vented Explosion Tube PET
Type	<i>cylindrical tube with variable opening</i>
Scale	<i>medium scale</i>



Experiments	<i>studies on vented explosions, turbulent flame propagation, flame acceleration and DDT; jet initiation of detonation</i>
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Technical details

Dimensions	<i>55 dm³ vessel, internal diameter 0.1 m, length 7 m</i>
Temperatures	<i>ambient</i>
Pressure	<i>ambient</i>
Media	<i>hydrogen, air, nitrogen, oxygen</i>
Special features	<i>medium scale; controlled venting degree</i>
Further particulars	<i>tube could be filled with regular ring shape obstacles grid spaced by tube diameter, blockage ratio BR = 0.3, 0.6; variable transverse venting ratio (opening rate) from 0 to 40% tube is equipped with gas filling system and data acquisition system, spark/glow plug for ignition; PEV has possibility to make combustible surrounding atmosphere with thin polyethylene film around of the tube.</i>

Experiments – Equipment

Experiments	<i>- experiments on vented combustion in uniform and nonuniform gas mixtures; - experiments on flame acceleration and DDT under transverse venting conditions.</i>	
Level of detail	<i>integral</i>	
Instrumentation	<i>gas temperature pressure gas composition velocity</i>	<i>thermocouples piezoelectric, piezoresistive gauges mass spectrometer, gas flow control photodiodes, ion probes, visual observation with high speed CCD camera.</i>

Schedule	<i>preparatory work of experimental set-up to specific test series requires one week; 3 – 4 hours are needed for preparation and conduction of one experiment in the series; 1 day is needed for processing of raw experimental data</i>
Tools	<i>standard software required for data acquisition system to convert analogous signals to digital form (ASCII or binary format)</i>
Further particulars	-

Information for the preparation of integration

- **Exchange of instruments and personnel**

How many persons are needed to prepare/conduct experiments?

2-3 persons are needed to prepare/conduct experiments.

What kind of movable equipment is available and could be shared?

Experimental facility and data acquisition system processed by accompanying service team (2-3 persons)

- **To prepare filling possible gaps**

What kind of experiments/tests could be performed in this facility after minor modifications and/or by applying additional instrumentation?

Experiments on transient regimes of DDT at various degree of venting: from fully confined to unconfined gas mixture.

- **To prepare promotion and specialisation**

What features/possibilities would you like to promote?

Small scale experiments on turbulent combustion and DDT under transverse venting conditions.

Which additional equipment could enhance the results of your experiments?

Explosion bomb

Overview

Name	Explosion bomb
Type	<i>spherical vessel</i>
Scale	<i>laboratory scale (8.2 dm³)</i>
Experiments	<i>flammability limits, minimum ignition energy, laminar flame velocity, chemical kinetics, flame structure</i>



Application field within
the thematic structure of HySafe *H1-H6, V2, V4-V5*

Technical details

Dimensions	<i>8.2 dm³ vessel, internal diameter 25 cm, wall thickness >34 mm</i>
Temperatures	<i>20 – 300 °C</i>
Pressure	<i>up to 800 bar of static pressure</i>
Media	<i>hydrogen, hydrocarbons, oxygen, air, steam, inert gases</i>
Special features	<i>laboratory scale; licensed static pressure limit 800 bar; quartz windows for optical observations</i>
Further particulars	<i>2 quartz windows for optical observations Ø50 mm; blind flanges instead of windows</i>

Experiments – Equipment

Experiments	<i>- experiments on flammability limits at elevated initial pressures and temperatures;</i> <i>- minimum ignition energy at elevated initial pressures and temperatures;</i> <i>- laminar flame velocity at elevated initial pressures and temperatures</i>	
Level of detail	<i>integral</i>	
Instrumentation	<i>gas temperature</i> <i>pressure</i> <i>gas composition</i> <i>velocity</i>	<i>thermocouples</i> <i>piezoelectric, piezoresistive transducers</i> <i>mass spectrometer, gas flow control;</i> <i>high speed schlieren cinematography</i>
Schedule	<i>preparatory work of experimental set-up to specific test series requires one month;</i> <i>1 – 3 hours are needed for preparation and conduction of one experiment in the series (depending on an initial pressure);</i> <i>1-2 days are needed for processing of raw experimental data</i>	
Tools	<i>standard software (LabView) required for data acquisition system to convert analogous signals to digital ones (ASCII or binary format)</i>	
Further particulars		

Information for the preparation of integration

- **Exchange of instruments and personnel**

How many persons are needed to prepare/conduct experiments? - 1-2 persons are needed to prepare/conduct experiments

What kind of movable equipment is available and could be shared? - Data acquisition system processed by accompanying service team (1-2 persons)

- **To prepare filling possible gaps**

What kind of experiments/tests could be performed in this facility after minor modifications and/or by applying additional instrumentation? - Experiments on selfignition temperature, experiments on turbulent flames, and experiments on chemical kinetics and minimum ignition energy.

- **To prepare promotion and specialisation**

What features/possibilities would you like to promote?

What more/better results could you obtain if you had additional equipment? Detailed flame structure using laser techniques and high speed photo.

HyJet

Overview

Name HyJet

Type *horizontal/vertical hydrogen jet*

Scale *small and medium scale (up to 3 m)*



Experiments *studies on hydrogen release from pressurized vessel, dynamic hydrogen concentrations and flow velocity profiles, investigations on flammability of the turbulent hydrogen jet.*

Application field within the thematic structure of HySafe *H1-H6, V1, V3*

Technical details

Dimensions *0.16, 1, 5, 10 mm nozzle diameter, up to 10 g/s hydrogen mass flow (stationary) or up to 100 g/s (maximum, temporary)*

Temperatures *from cryogenic (20K) to ambient*

Pressure *up to 260 bar*

Media *pressurized hydrogen, air, inert gases, heterogeneous cryogenic gas release.*

Special features *small or medium scale; sub- or supersonic flow velocity, buoyant jet,*

Further particulars *jet interactions with obstacles grid, barriers, hood and so on.*

Experiments – Equipment

Experiments	<ul style="list-style-type: none">- spatial and temporal <i>hydrogen and velocity distribution in a jet</i>;- <i>vertical and horizontal free jets</i>;- <i>jet interaction with obstacles and barriers</i>;- <i>subsonic and supersonic jets, buoyant jets</i>- <i>ignition, combustion and explosion of hydrogen jets</i>;- <i>steady-state and non steady-state jets</i>	
Level of detail	<i>integral</i>	
Instrumentation	<i>gas temperature</i> <i>pressure</i> <i>heat radiation</i> <i>gas composition</i> <i>velocity</i> <i>noise level</i>	<i>thermocouples, infrared camera</i> <i>piezoelectric, piezoresistive transducers</i> <i>infrared camera, heat flux sensors</i> <i>mass spectrometer, ultrasonic Doppler velocimetry; Background Oriented Schlieren (BOS) method</i> <i>ultrasonic Doppler velocimetry; BOS method</i> <i>high speed camera</i> <i>microphone, piezoelectric sensors</i>
Schedule	<i>preparatory work of experimental set-up to specific test series requires 2 weeks;</i> <i>1 – 2 hours are needed for preparation and conduction of one experiment in the series;</i> <i>1-2 days are needed for processing of raw experimental data</i>	
Tools	<i>standard software (LabView) required for data acquisition system to convert analogous signals to digital ones (ASCII or binary format)</i>	
Further particulars		

Information for the preparation of integration

- **Exchange of instruments and personnel**

How many persons are needed to prepare/conduct experiments? - 2-3 persons are needed to prepare/conduct experiments

What kind of movable equipment is available and could be shared? - Data acquisition system processed by accompanying service team (1-2 persons)

- **To prepare filling possible gaps**

What kind of experiments/tests could be performed in this facility after minor modifications and/or by applying additional instrumentation? – Hydrogen and velocity distribution in a hydrogen jet using laser techniques (Mie and Rayleigh scattering, LDV)

- **To prepare promotion and specialisation**

What features/possibilities would you like to promote? Critical conditions for ignition, combustion and explosion of hydrogen jets.

What more/better results could you obtain if you had additional equipment?