Hydrogen behaviour when released in confined atmospheres: experimental study and numerical simulations

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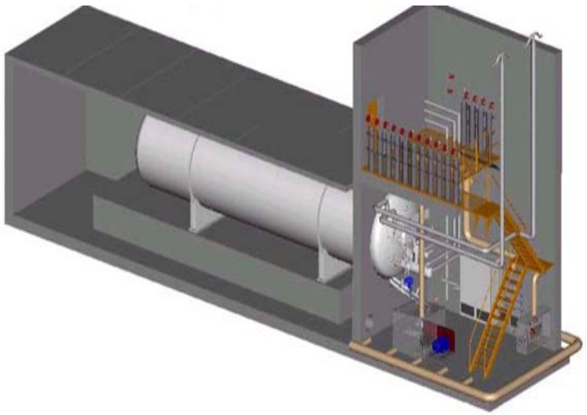
Outline

- Introduction – Motivations
- Focus of project
- Methodology
- Literature review:
  - Experiments
  - CFD simulations
- Planned experimental and simulation work
- Guidelines
- Conclusions and acknowledgements

Use of hydrogen systems in confined environments

garage

Electrolyser



Underground storage
(refuelling station)

H2 leaks for confined systems – scenarios 1/2

- Catastrophic release in confined spaces:
  - hazardous explosive atmosphere to be feared,
  - conventional mitigation systems (ventilation) inappropriate,
  - → Safety is handled by the system design itself (early detection and emergency shut-off, PRD routed outside...)

H2 leaks for confined systems – scenarios 2/2

- Accidental (pipe crack, gasket failure,...) / chronic (permeation) confined leaks,
  - more likely than catastrophic release,
  - some release rate are not detectable by integrated safety sensors,
  - such leaks can be handled by external safety systems (ventilation, emergency inerting, hydrogen removal systems,...)

→ Do hazardous explosive atmospheres (ATEX) form systematically?
→ Where would they preferably form?
→ What would be the best design for safety barriers (performance, optimisation)?

Project focus

- Concentrate on accidental releases (below 1g/s) rather than catastrophic releases.
- Explosive atmosphere (ATEX) will form systematically at release point. However, ATEX volume will be moderate for most release rate considered

→ Focus on H2 dispersion in confined atmosphere:

- How hydrogen will disperse inside the closed volume depending on the flow regime (jets, plume,…)?
- What is the effect of leak impingement and leak direction?
- Is hydrogen accumulating below the ceiling a relevant forecast for any leak?
- How quickly can an ATEX be formed?
- Effect of vent positioning on hydrogen removal?
- Where would hydrogen detectors be best located?
- Are existing guidelines appropriate?

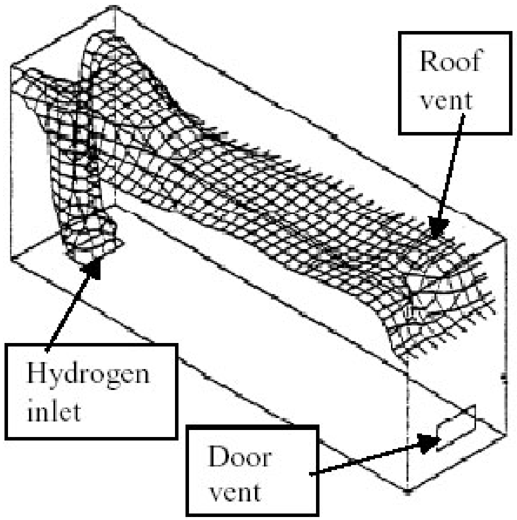
Project methodology and output

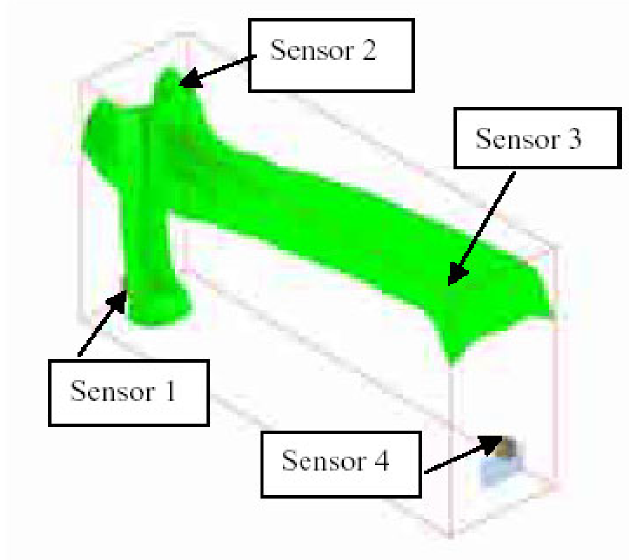
- Perform literature review (past experiments and modelling + existing guidelines on the safe use of H_2 systems),
- Perform new experiments to fill gaps,
- Perform CFD modelling (pre-calculation of tests, benchmarks for code validation),
- Results consolidation in a guidance report.

Literature review - experiments

Reference	Released substance	Year	Volumetric flow rate (lt/s)	H2 mass flow rate (g/s)	Exit velocity (m/s)	Emclosure volume (m3)	Objectives
Swain garage	He	1998	2.00	0.170	0.10	66.83	How should existing garages be modified to make them suitable for hydrogen fueled vehicle storage.
GEOMET tests	H2	1993	0.28	0.024		45.50	Gather data that could be used to determine the necessary vent size to keep hydrogen concentrations below 2% in a residential garage, during the charging cycle of an electric vehicle
Swain hallway	H2	1999	0.94	0.080	0.02	2.62	CFD Validation
JARI box	H2	2004	0.17	0.014	0.10	1.00	Examine the diffusion behaviour of hydrogen in an enclosed space with various rlease speed.
JARI box	H2	2004	0.17	0.014	0.20	1.00	Idem
JARI box	H2	2004	0.17	0.014	3.40	1.00	Idem
CEA-MH1	He	2004	5.88	0.500	1.33	100.00	Gather data for CFD validation
BMW test	H2	2004	0.187	0.017	Boil off	36.2	Validate that no hazardous ATEX could from with minimum ventilation
BMW test	H2	2004	0.0935	0.0085	Boil off	36.2	Idem

Literature review: Swain experiments



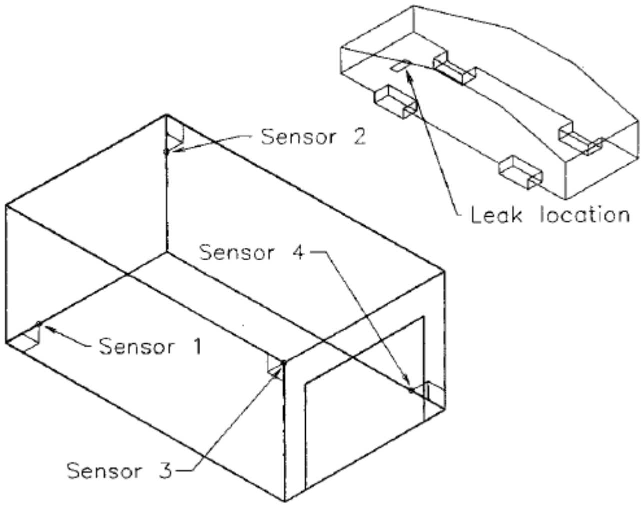


Release speed: **0.02m/s**

Release flow rate: **0.08g/s**

release diameter: **240mm**

Release duration: **1200s**



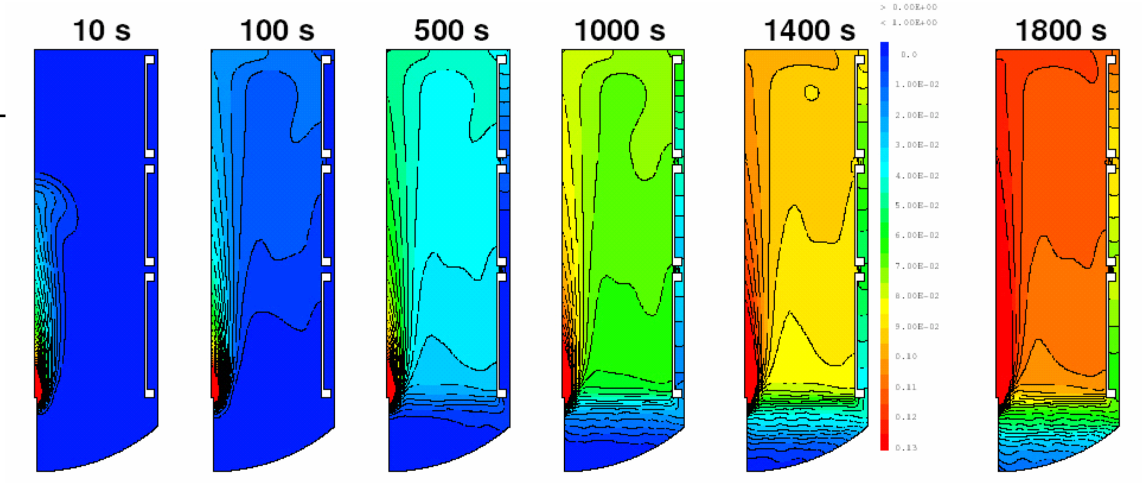
Release speed: **0.1m/s**

Release flow rate: **0.17g/s**

release diameter: **160mm**

Release duration: **7200s**

Literature review: CEA MISTRA experiments

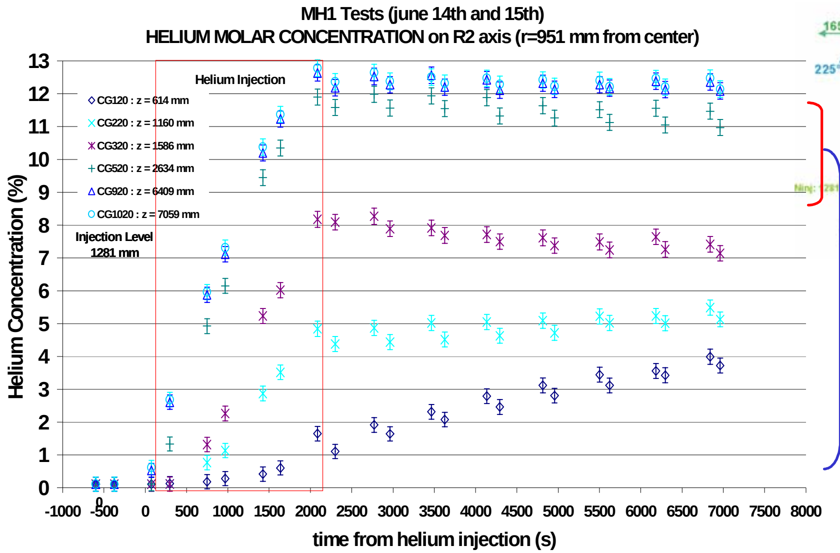


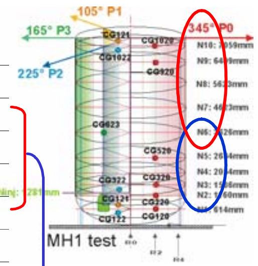
Release speed: **1.3m/s**

Release flow rate: **1g/s** (He)

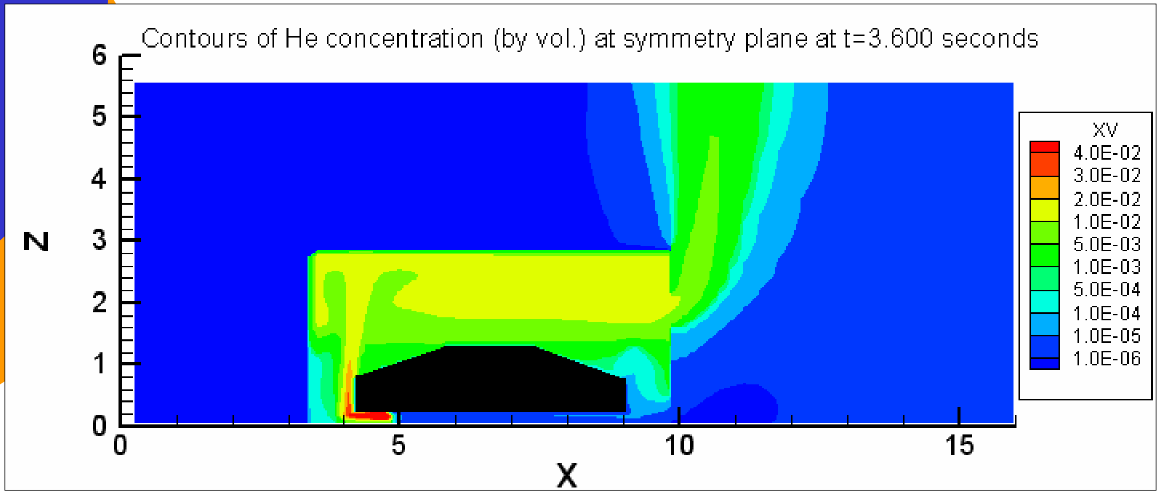
release diameter: **75mm**

Release duration: **1800s**

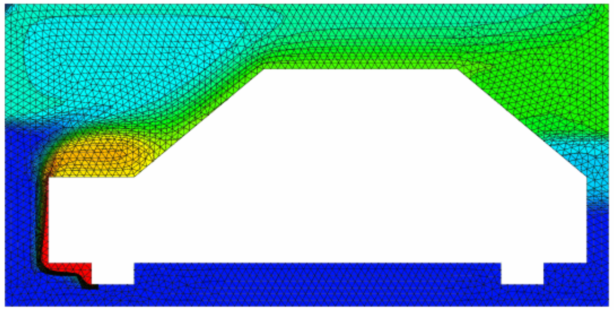




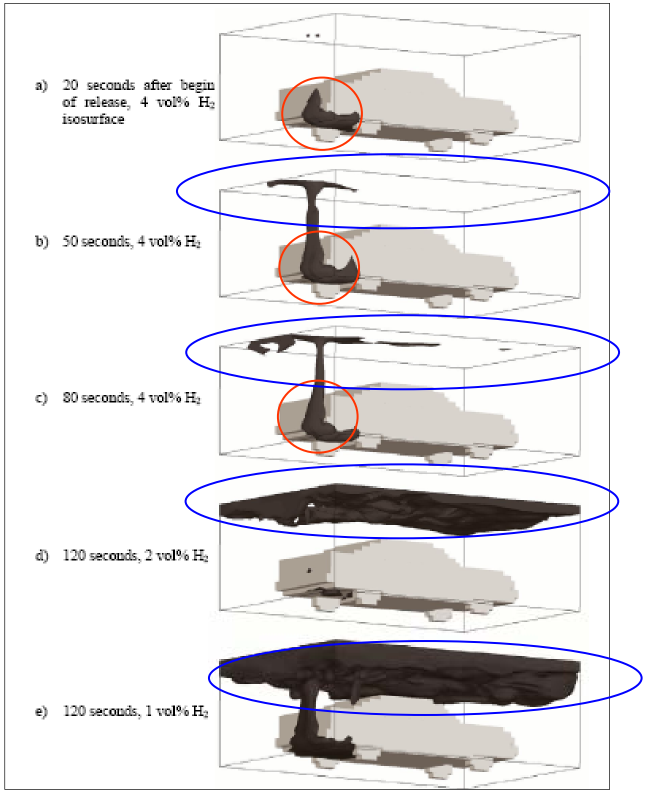
Literature review - CFD capabilities and needs



NCSRD simulation of Swain experiments (ADREA code)



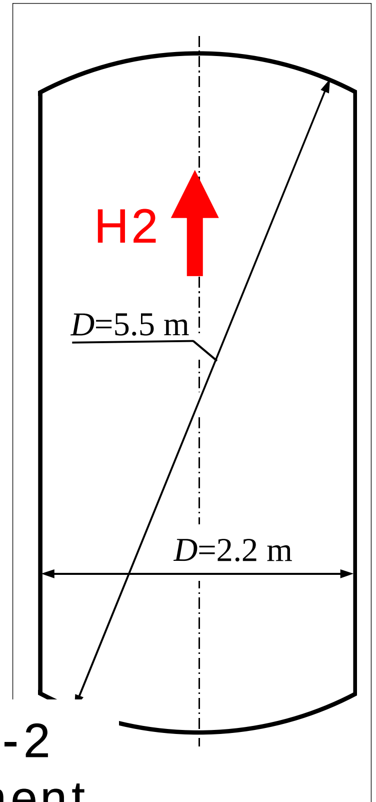
CEA simulations (CAST3M code)



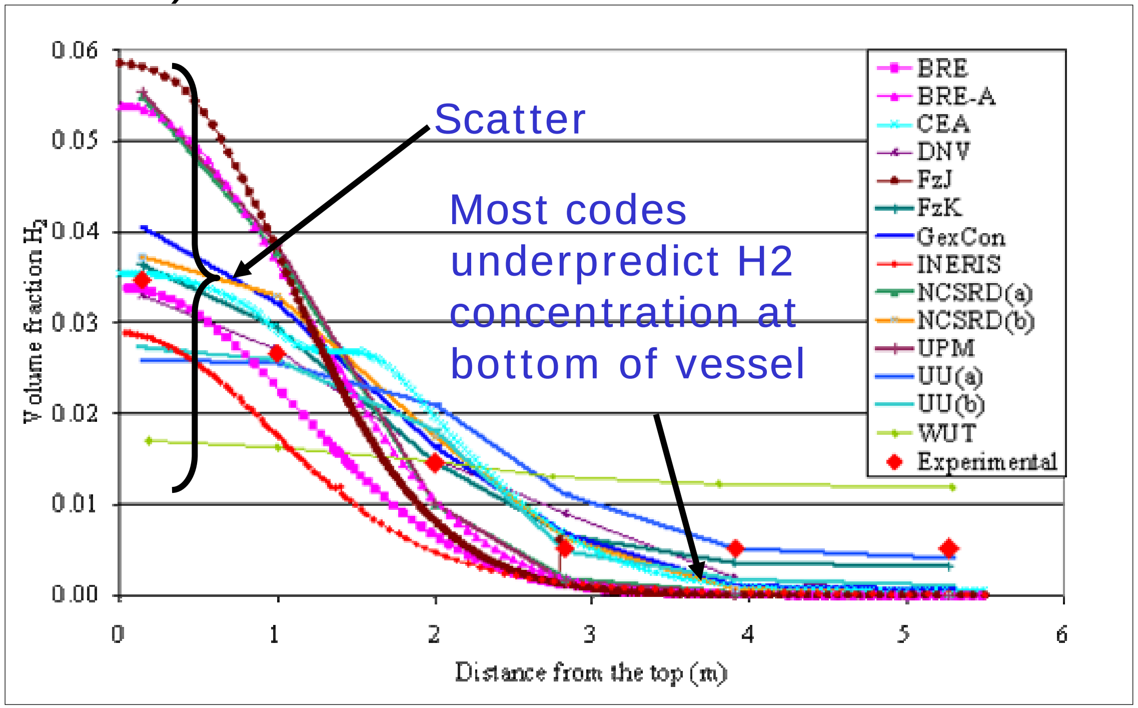
FZK simulations (GASFLOW code)

Literature review - CFD capabilities and needs

Open benchmark performed in HYSAFE: H2 injection followed by "diffusion" phase lasting 250min. Predict cloud formation & mixing (from E. Gallego et al., ICHS, 2005)



Russian-2 experiment



Also experimental data lacking

Conclusions from literature review 1/2

- Most experimental data related to garage safety
- Poor instrumentation generally used (4 sensors...),
- Issue of data confidentiality or accessibility
- Mainly used to validate safety concept and not to improve understanding of hydrogen dispersion and diffusion,
- Range of flow rate investigated are in line with what we consider as non-catastrophic release,

→ Some experimental data still needed

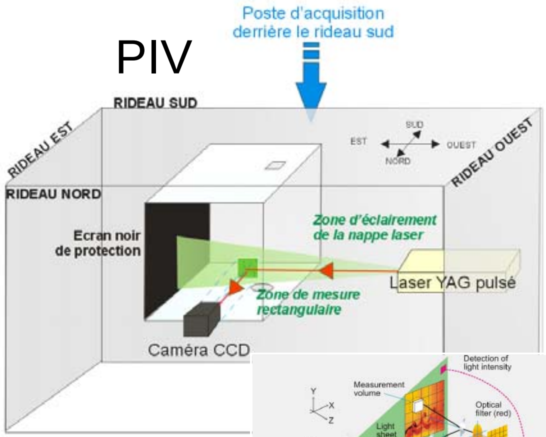
→ CFD deficiencies observed → validation needed

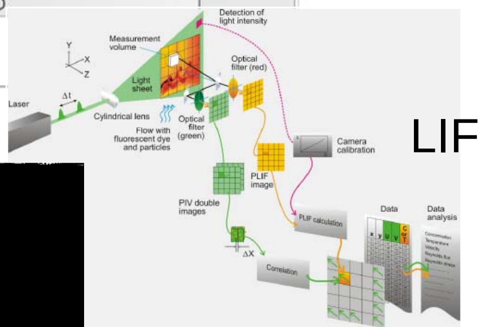
Conclusions from literature review 2/2

- Open questions on dispersion mechanisms: Provide phenomenological answers (detailed experimental data & improved CFD modelling), investigate release momentum effect,...
- Open questions on explosive atmosphere formation (size, delay): Provide answers for risk assessment (V_{ATEX} = f(release geometry, speed, ventilation),
- Test hydrogen detection techniques in real conditions
- Need to gain more practical experience for contribution to guidelines

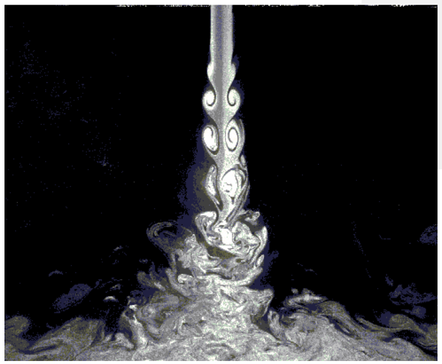
New experimental work: development/ application of new instrumentation techniques

PIV

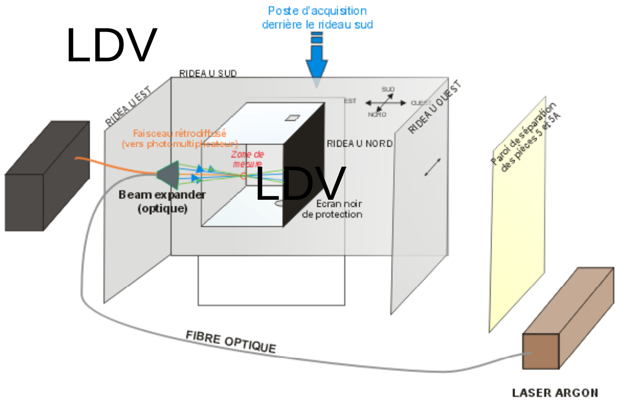


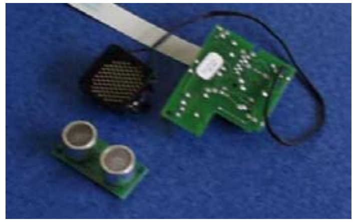


LIF

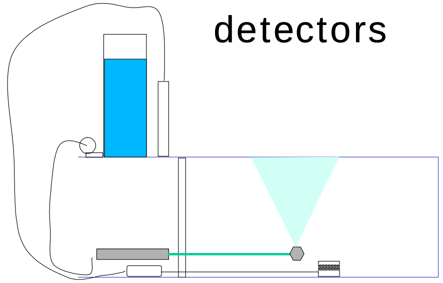


LDV





Ultrasound detectors



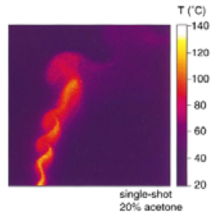


Fig. 1. Acetone PLIF temperature image obtained with 266-nm excitation and a flow field uniformly composed of 20% acetone in air. Instabilities are evident in this heated jet (Re = 100) in weak crossflow. The imaged region is 22 mm on a side.

NH3Cl seeding
+ visualisation
+ opacimetry

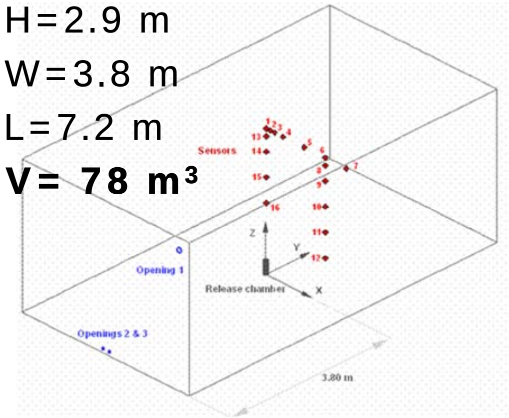
Mini-catherometers
(thermal-conductivity
sensors)

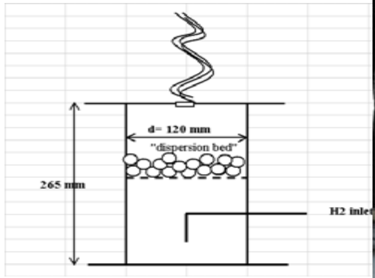
TCG-3880Pt

Mass spectro-metry

New experiments at INERIS: Gallery (2005)

H=2.9 m
W=3.8 m
L=7.2 m
V= 78 m³

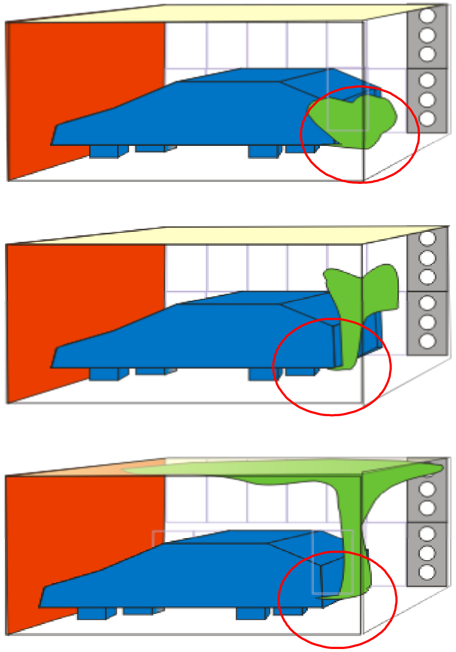


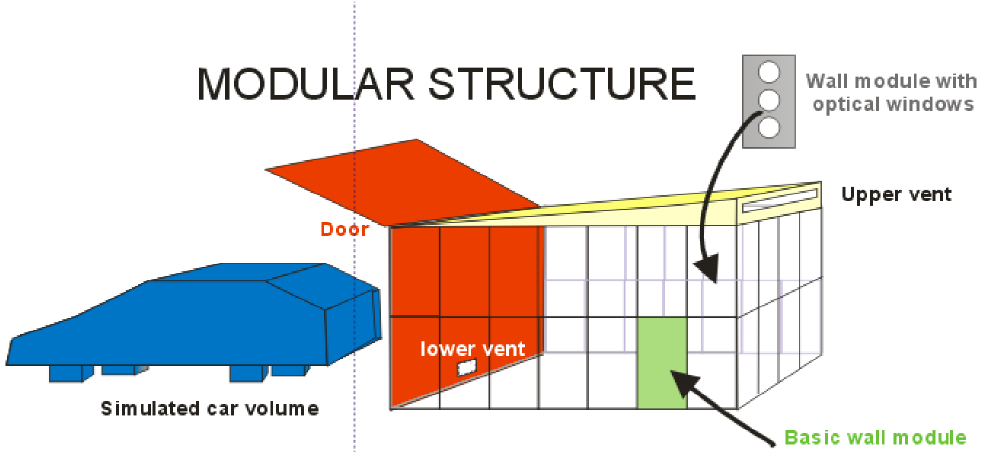


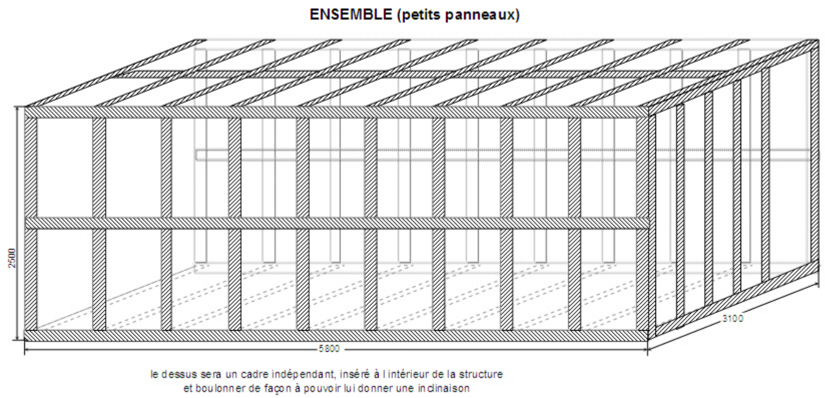
Material	Release direction	Filling temperature	Release mass flow rate	Release duration	Orifice diameter	Calculated exit velocity	Ventilation Flow rate	Trial N°
		[°C]	[mg/s]	[s]	[mm]	[m/s]	[m³/s]	
Hydrogen	Vertical upward	10	5	600	10	0.76	0	1
				600	20	0.19	0	2
			100	600	20	3.8	0	3
				600	20	3.8	240	4
			1000	240	4	950	0	5
				240	20	38.0	0	6

- Use of Hydrogen,
- Instrumentation : ammonium chlorine seeding + argon laser visualisation + opacimetry + catharometers,
- Output raw results: film of hydrogen release and dispersion, H_2 concentration versus time at 12 different locations.

New experiments at CEA: Garage (2006-08)







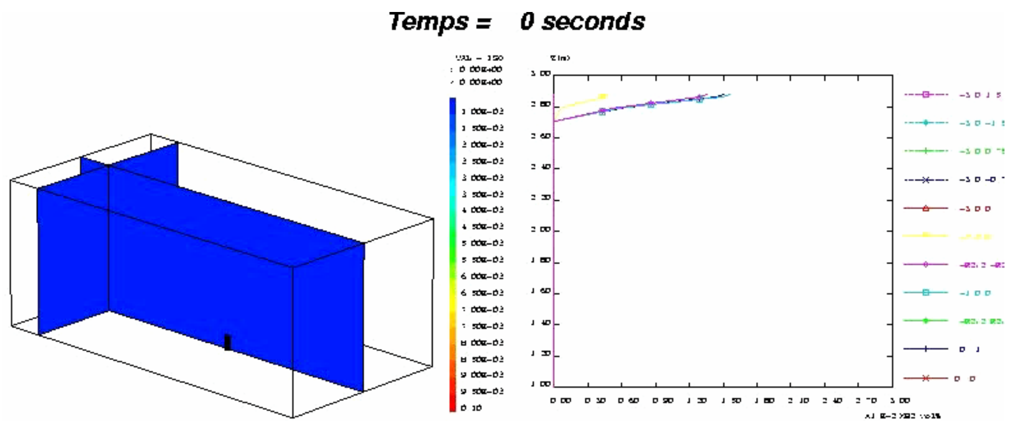
- Dense instrumentation
- Use of LDV, PIV

Test matrix

Phenomena which affect H_2 dispersion and ATEX formation	Gallery (H_2)	Garage (He & H_2)
Effect of release direction		Upward, downward, horizontal
Effect of release speed	Release speed from 0,2 to 1000 m/s	
Effect of impingement		Under plate releases
Effect of forced and natural ventilation	0 & 3 air change per hour	Various natural and forced ventilation
Effect of laminar diffusion	Hydrogen concentration measured once release has stopped	Hydrogen conctration measured once release has stopped
Effect of turbulence (natural convection,…)		Turbulence monitored

CFD Programme (1/2)

- Pre-test calculation undertaken (NCSRD, Gexcon, HSL, UU, CEA,...) to support sensor location, to choose most interesting experimental cases as well as to debug future CFD benchmark,



CEA calculations, CAST3M code

- Tests from each campaign chosen for blind CFD benchmark exercise (HySafe). Open to external participants.

CFD Programme (2/2)

- Expected output results: evolution of ATEX volume and mass versus time (can not be measured directly), H2 concentration versus time at each sensor location,... + description of the
- applied modeling methodology

Participation organisation	Used tool
CEA	CAST3M
DNV	tbd
FZJ	tbd
HSL	tbd
FZK	GASFLOW
Gexcon	FLACS
INERIS	PHOENICS
NCSRD	ADREA
UU	FLUENT
UPM	CFX

→ Recommended models and best practices guidelines.

→ Use of CFD to predict ATEX volume and location.

Review of Existing guidelines

Support Facilities for Hydrogen-Fueled Vehicles

Conceptual Design and Cost Analysis Study

July 2004

FM Global
Property Loss Prevention Data Sheets 7-14

March 1982
Revised May 2004
Page 1 of 9

FIRE & EXPLOSION PROTECTION
FOR
FLAMMABLE LIQUID, FLAMMABLE GAS, &
LIQUEFIED FLAMMABLE GAS PROCESSING EQUIPMENT
& SUPPORTING STRUCTURES

FM Global
Property Loss Prevention Data Sheets 7-91

June 1984
Revised September 2000
Page 1 of 13

NF EN 60079-10
Août 2003

AFNOR
Association Française de Normalisation

Electrical Apparatus for explosive gas atmosphere – Part 10 :Classification of hazardous areas

SAFETY STANDARD FOR HYDROGEN AND HYDROGEN SYSTEMS

Guidelines for Hydrogen System Design, Materials Selection, Operations, Storage, and Transportation

- Can we use existing examples from other gases?,
- We need recommendations to be harmonised & based on practical data.

Achievements so far…

- Review and study of available data,
- Development and use of innovative and extended instrumentation to further investigate accidental phenomena,
- Elaboration of a comprehensive and complementary experimental programme to cover 2005-2007 period,
- Initiation of a comprehensive CFD benchmarking effort,
- Critical review of existing guidelines for the safe use of systems in confined spaces.

Acknowledgements - Collaborations

- Part of this work performed in the framework of the HYSAFE Network of Excellence (2004-09)
- Also in the framework of future DRIVE project (French Research Programme PAN-H) (2006-08)
- Part of the project results to be included in IEA Task 19 Hydrogen Safety (2005-08)

Thank you for your attention!