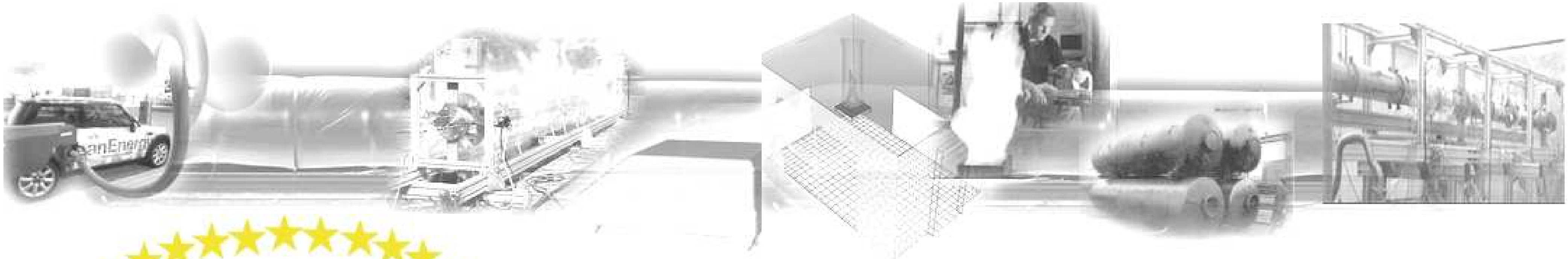

The European Network of Excellence for Hydrogen Safety

On the use of hydrogen in confined spaces: Results from the internal project InsHyde

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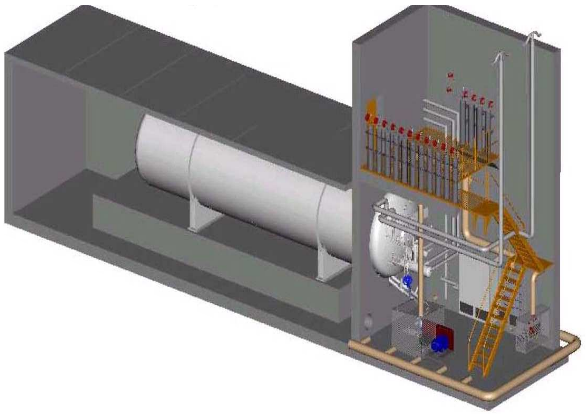
3rd International Conference on Hydrogen Safety
Ajaccio, Corsica (FR), 16-18 Sept. 2009

Use of hydrogen in confined spaces

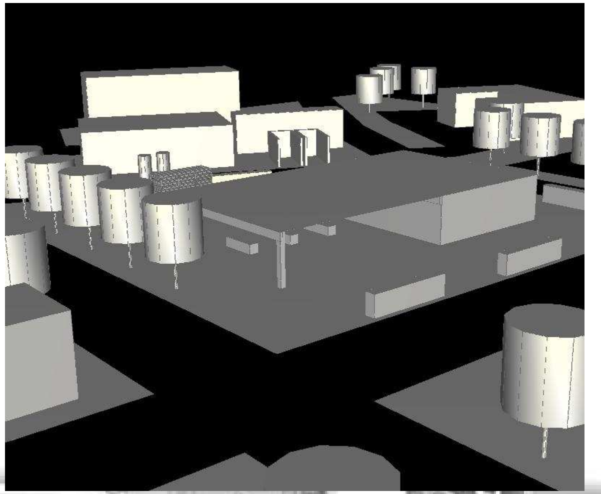
Spaces containing parts where hydrogen can accumulate

garage

Electrolyser



Underground storage



Refuelling station

InsHyde IP

Internal project within HySafe NoE

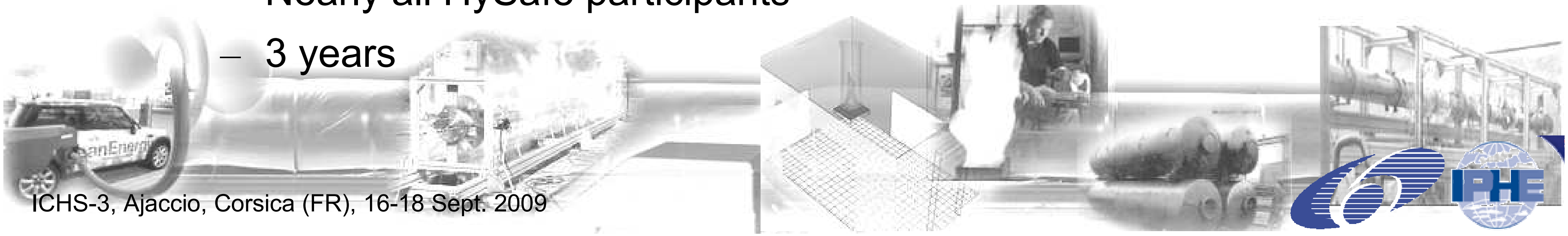
– http://www.hysafe.net/InsHyde

Scope

– To investigate realistic small-medium indoor leaks and provide recommendations for the safe use/storage of indoor hydrogen systems
– To pull together work packages proposals and existing research projects toward a common goal and a useful contribution to the society for the safe implementation of hydrogen technologies.

Participation/Duration

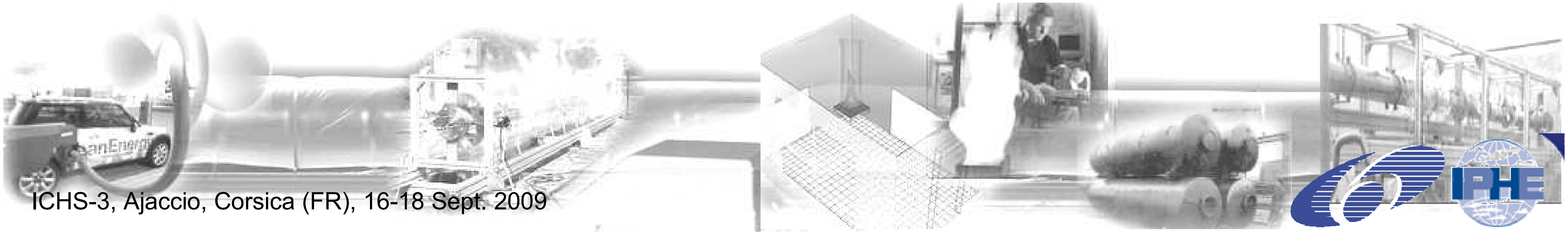
– Nearly all HySafe participants
– 3 years



InsHyde structure

Work packages (wp-leaders):

1. Review (DNV)
2. Hydrogen Detection experiments (JRC)
3. Study of permeation (VOLVO)
4. Dispersion experiments (CEA)
5. Explosion experiments (FZK)
6. Ignition (HSL)
7. CFD modelling (GEXCON)
8. Scaling methodology (FZK)
9. Recommendations (NCSRD, INERIS)
10. Dissemination (NCSRD, INERIS)



Hydrogen detection experiments

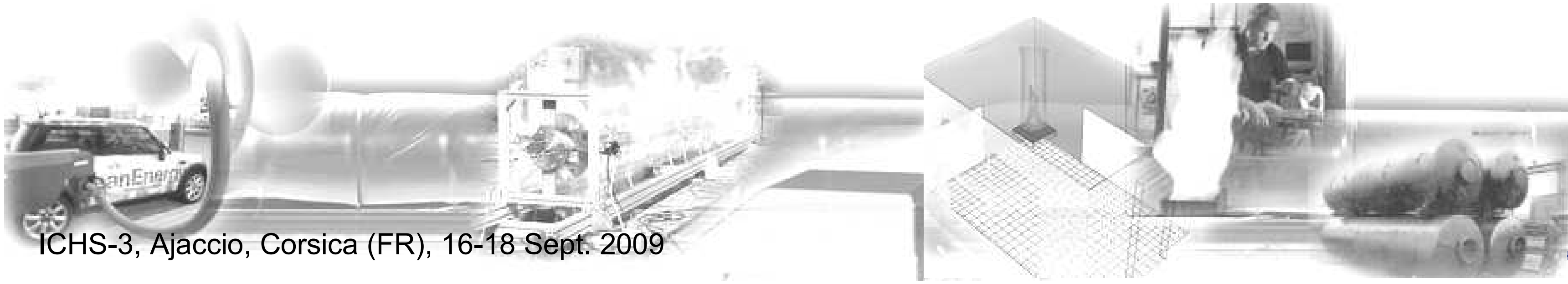
- Scope
  - Assessment of the performance of commercially available hydrogen detectors (JRC and INERIS)
  - Inter-laboratory comparison on calibration-type tests on selected sensor types (JRC and BAM)
- Methodology
  - Test program based on IEC 61779-1 & 4
  - 9 detectors were tested from different manufacturers (electrochemical and catalytic)
  - Acquisition of calibration curves, measuring the response and recovery time during an instantaneous variation of the hydrogen concentrations
  - Response to variation in environmental temperature, humidity and pressure
  - Cross-sensitivity in the case of CO

Hydrogen detection experiments

- Some Results
  - Tests have shown that the electrochemical technology allows to detect hydrogen concentration lower than in the case of catalytic technology, whose detection threshold is around 500 ppm (~1.25 % of hydrogen LFL)
  - A new “continuous calibration” concept has been tested. The results compare well with those obtained by the standardised technique.
  - The response time (t90) of catalytic detectors, with a gas test concentration of 50 % of hydrogen LFL, was less than 10 seconds. Response time was moderately influenced by temperature.
  - Humidity had a greater impact on response time. Increased humidity leads to higher response time value.
  - CO sensitivity was high for catalytic combustion sensors (approximately 1/3 of that to hydrogen).
  - In comparison to the humidity and cross-sensitivity effects, temperature and pressure variation induce a more limited signal deviation.

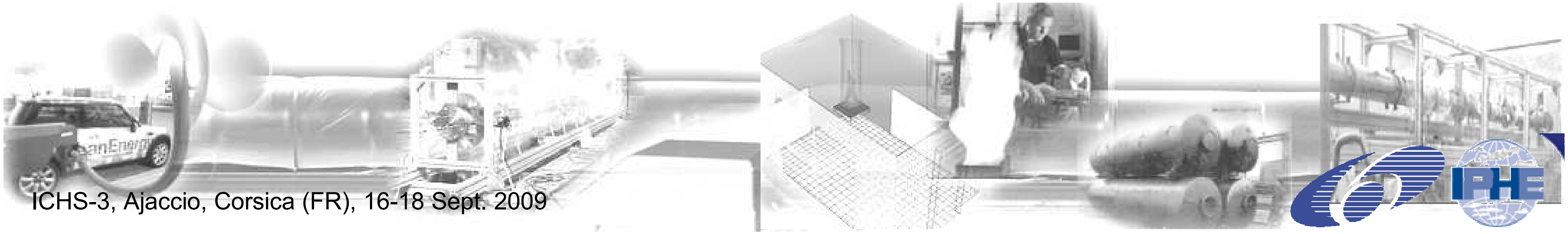
Study of permeation

- Scope:
  - Examine whether existing allowable permeation rates could relaxed
  - Examine whether permeation type releases lead to stratification or to homogeneous distribution
- Methodology
  - Review of previous pre-normative work and results (VOLVO)
  - Review of garage sizes/natural ventilation rates (VOLVO, BRE)
  - CFD simulations (NCSRD, UU)
  - Helium dispersion Experiments (CEA)
  - Theoretical considerations (VOLVO and all)



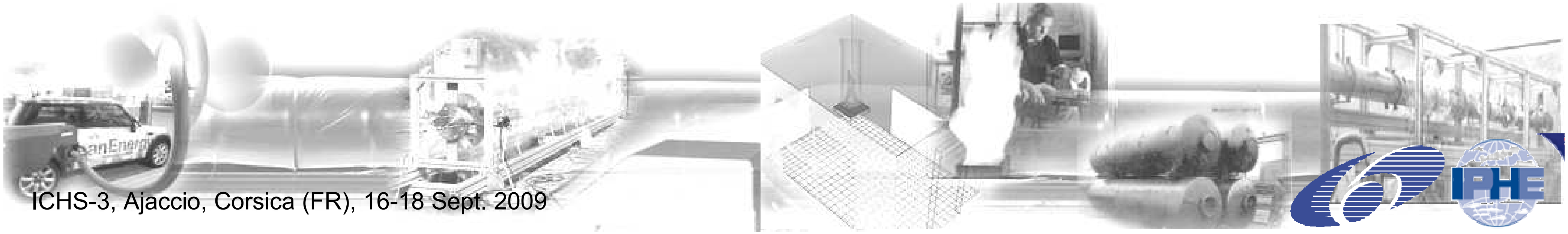
Study of permeation

- Previous allowable permeation values:
  - 1.0 NmL/hr/L water capacity @ SoL and AT (ECE draft)
  - 2.0 NmL/hr/L water capacity @ 350MPa, SoL and AT (ISO draft)
  - 2.8 NmL/hr/L water capacity @ 700MPa, SoL and AT (ISO draft)
  - 75 NmL/min (SAE draft)
- HySafe proposal:
  - 6.0 NmL/hr/L water capacity @ SoL and 15 °C or
  - 8.0 NmL/hr/L water capacity @ SoL and 20 °C
  - Proposed figures are not applicable for permeation into vehicle compartments



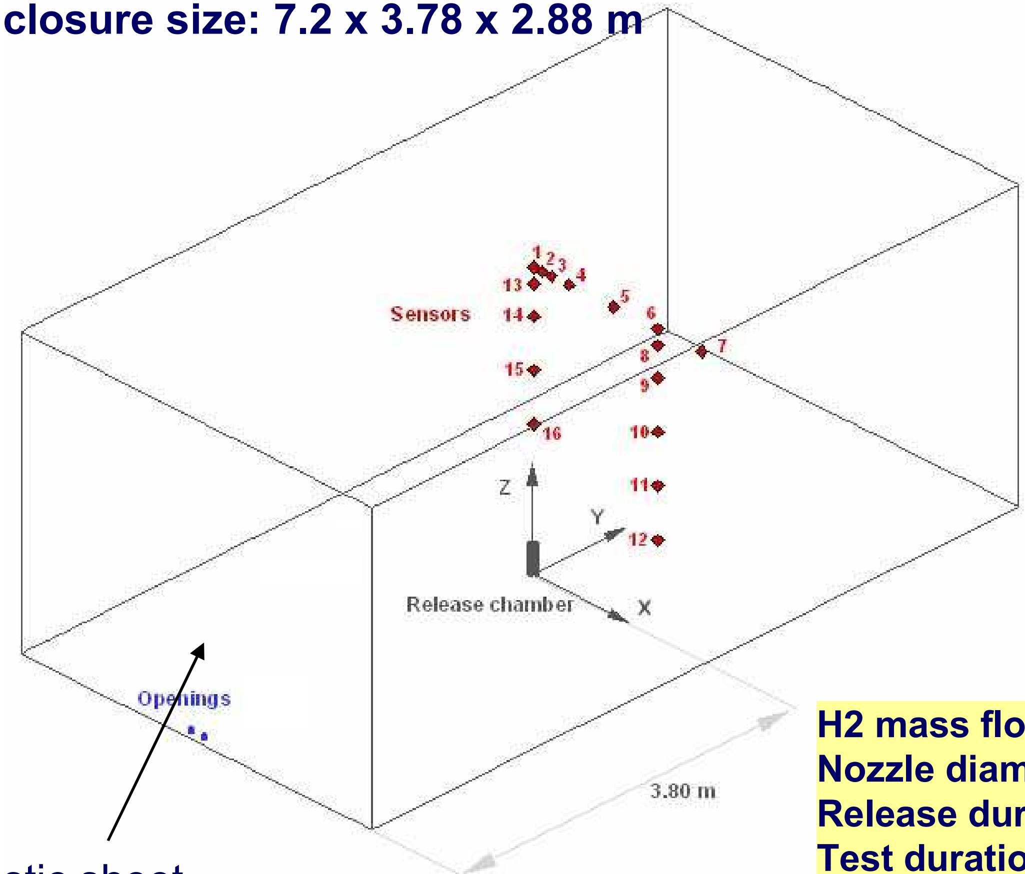
Dispersion tests

- Scope
  - Study of hydrogen accumulation in garage
  - Effect of source strength, source momentum, ventilation
  - Generation of new data sets for CFD validation
- Experimental program
  - INERIS tests, using H2
  - CEA tests, using He



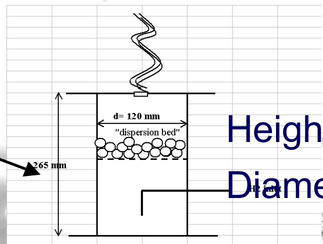
H2 dispersion test INERIS-6C

Enclosure size: 7.2 x 3.78 x 2.88 m



Plastic sheet

Release chamber



Height 265mm

Diameter: 120mm

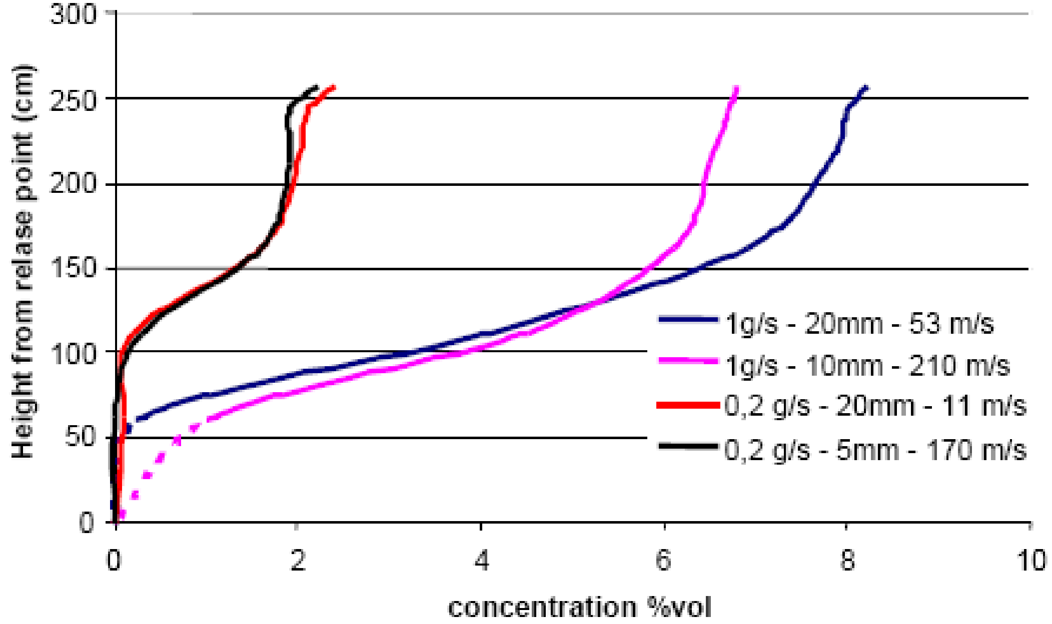
Sensor	X (cm)	Y (cm)	Z (cm)
1	0	0	283
4	40	0	283
6	140	0	283
7	1.84	0	283
8	140	0	268
9	140	0	238
10	140	0	188
11	140	0	138
12	140	0	88
13	0	0	268
14	0	0	238
16	0	0	138

H2 mass flow rate: 1 g/s
Nozzle diameter: 20 mm
Release duration: 240 s
Test duration: 5400 s
Ambient temperature: 10 °C
Target concentration: 3.53%

Lacome et al., Large scale hydrogen release in an isothermal confined area, ICHS-2, 2007

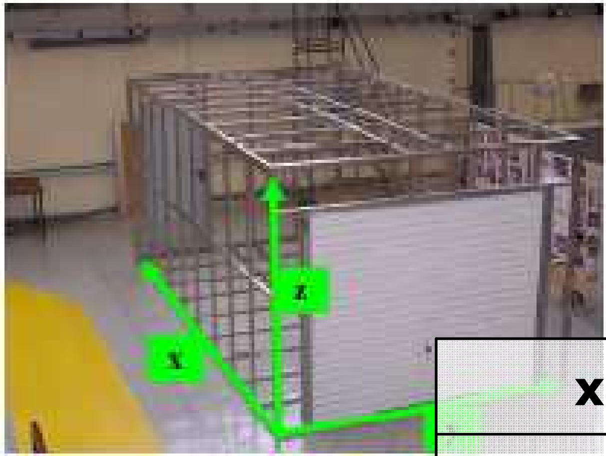
H2 dispersion test INERIS-6C

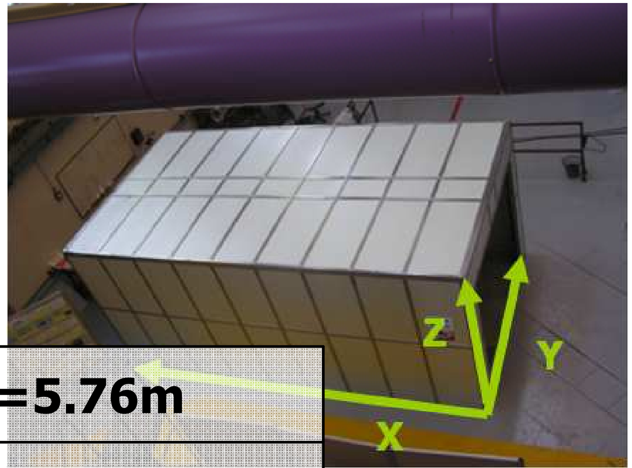
Filling temperature	Flow rate (g/s)	Release diameter (mm)	Release direction	Exit velocity (m/s)	Release duration (s)	Opening status (open/closed)	Observation Time (s)
15 °C	0,7	20	Vertical upwind	38	240	closed	7200
	0,7	20		38	240	open	7200
	1	20		53	240	closed	7200
	1	10		210	240	closed	7200
	0,2	20		11	240	closed	7200
	0,2	5		170	240	closed	7200



He dispersion tests by CEA

Garage facility at CEA





x_i=5.76m
y_i=2.96m
z_i= 2.42m
V_i= 40.92 m^3

- ✓ Stainless steel skeleton
- ✓ Replaceable wall modules
- ✓ Commercial tilting door in the front side (not completely sealed)
- ✓ Technical access door in the back (sealed)
- ✓ Laser based measurements possible

Gupta et al. Hydrogen related risks within a private garage: Concentration measurements in a realistic full scale experimental facility, ICHS-2, 2007

He dispersion tests by CEA

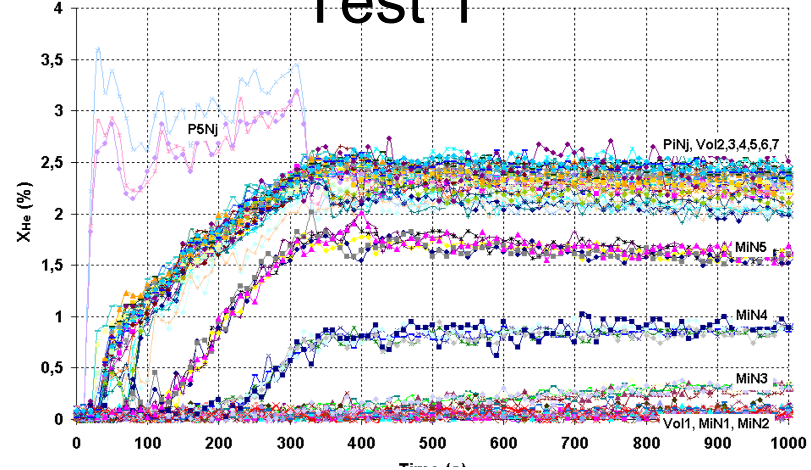
Test matrix (free volume - no ventilation)

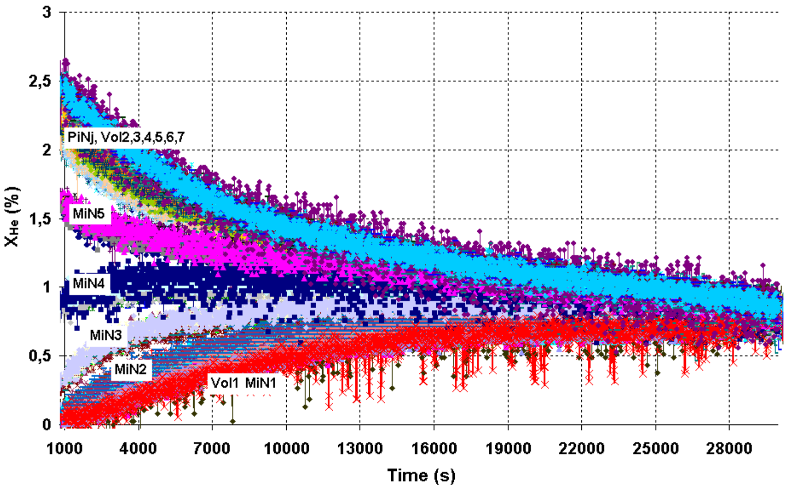
	GAR_FV_nV-TEST1	GAR_FV_nV-TEST2	GAR_FV_nV-TEST3	GAR_FV_nV_TEST4	GAR_FV_nV-TEST5
Volumetric flow rate – STP ($NL.min^{-1}$)	668	66.8	668	18	18
Helium mass flow rate ($g.s^{-1}$)	1.99	0.2	1.99	0.05	0.05
Release diameter (mm)	20.7	20.7	20.7	5	30
Release duration (s)	121	300	500	3740	3740
Release Direction	Upward	Upward	Upward	Upward	Upward
Release Type	Continue	Continue	Continue	Continue	Continue
Release period – if pulsed	-	-	-	-	-
x release (m)	2.88	2.88	2.88	2.88	2.88
y release (m)	1.48	1.48	1.48	1.48	1.48
z release (m)	0.22	0.22	0.22	0.22	0.22
Garage temperature T_{moy} (°C)	20	20	20	20	20
Released volume – STP (Nm^3)	1.35	0.33	5.57	1.12	1.12
Released volume - T_{moy} (m^3)	1.45	0.36	5.97	1.2	1.2
Released mass (g)	240	60	994	200	200
Concentration T_{moy} (%)	3.5	0.9	14.5	2.9	2.9
Exit velocity - 20°C ($m.s^{-1}$)	35.50	3.55	35.50	16.40	0.46
Re_0 - 20°C	6150	615	6150	686	114
Ri_0 - 20°C	9.9E-04	9.9E-02	9.9E-04	1.1E-03	8.7E+00
	turbulent jet	laminar jet-plume transition	turbulent jet	laminar jet	Laminar plume

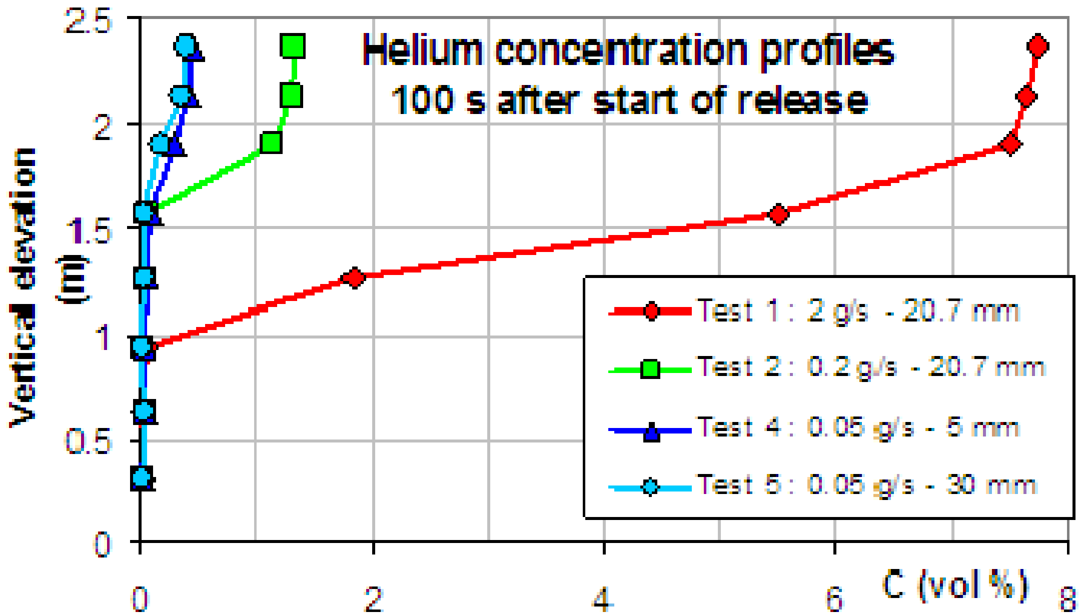
Gupta et al. Hydrogen related risks within a private garage: Concentration measurements in a realistic full scale experimental facility, ICHS-2, 2007

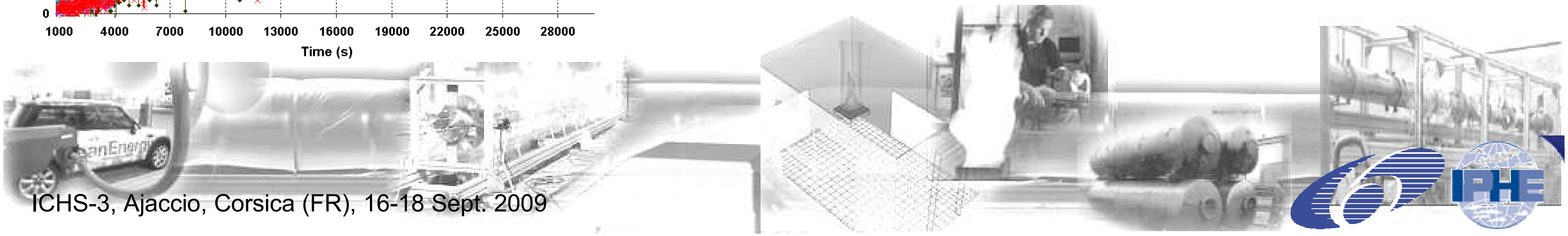
He dispersion tests by CEA

Test 1









Hydrogen explosion tests

- Scope
  - What is the maximum amount of hydrogen that can be released and "safely" exploded?
  - Effects of obstacles (blockage)
  - Generation of new data sets for CFD validation
- Experimental program
  - FZK tests (up to 10gr)
  - KI tests (0.1 to 1 kg)

H2 explosion tests by FZK

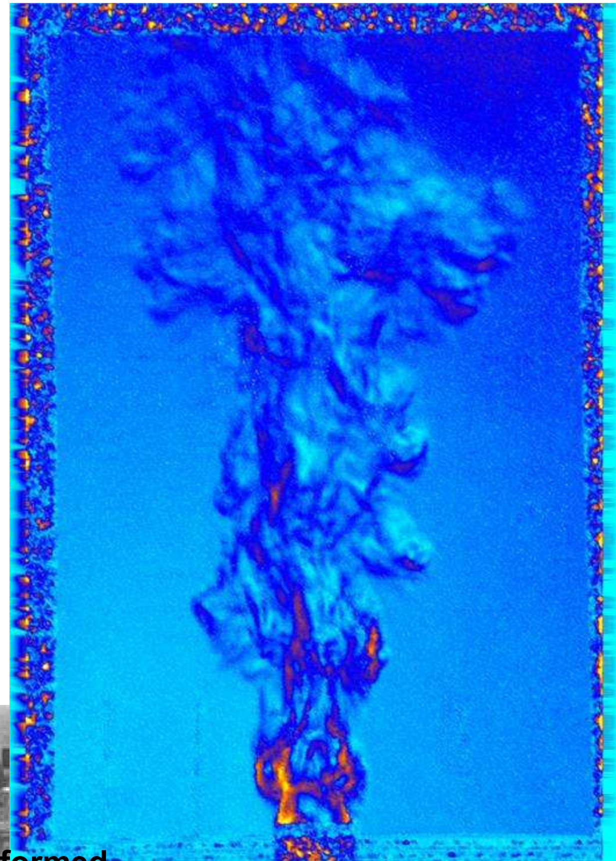
Explosion tests facility at FZK

Confinement

Sound speed measurements:
- Concentration
- Gas velocity

Injection

BOS visualization. Test w/o ignition.
Flat enclosure. No obstruction.



Friedrich et al. Experimental study of jet-formed hydrogen-air mixtures and pressure loads from their deflagrations in low confined surroundings, ICHS-2, 2007

H2 explosion tests by FZK

Explosion tests matrix

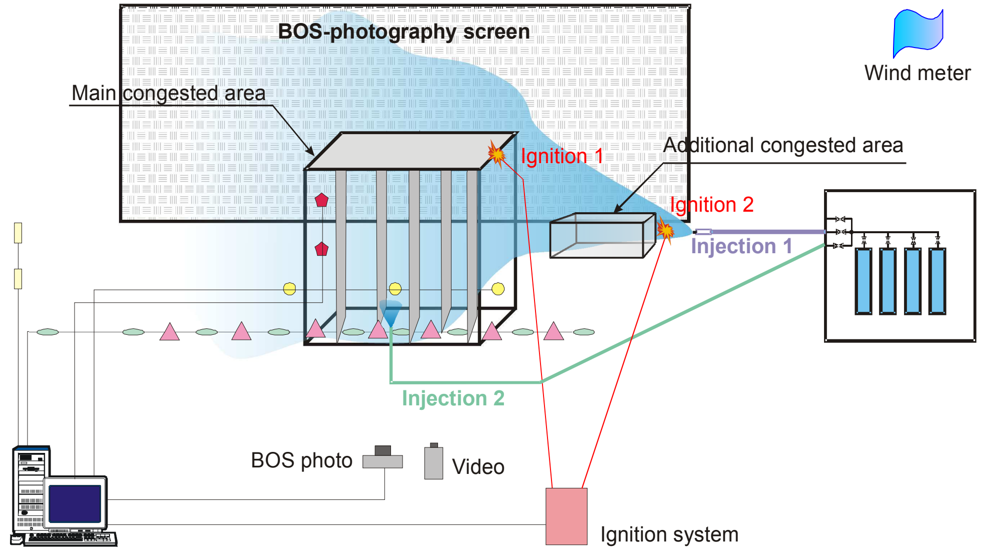
Release duration (s) for H_2 Inventory: 1g			
Exit velocity; m/s	Nozzle d= 100mm	Nozzle d= 21mm	Nozzle d= 4mm
0,2	**7,13 s**		
1	**1,43 s**		
5	**0,29 s**	**6,47 s**	
100		**0,32 s**	**7,00 s**
200		**0,16 s**	**3,50 s**
400			**1,75 s**

Release duration (s) for H_2 Inventory: 3g			
Exit velocity; m/s	**Nozzle d= 100mm**	**Nozzle d= 21mm**	**Nozzle d= 4mm**
0,2	**21,39 s**		
1	**4,28 s**		
5	**0,86 s**	**19,40 s**	
100		**0,97 s**	**21,00 s**
200		**0,49 s**	**10,50 s**
400			**5,25 s**

Release duration (s) for H_2 Inventory: 10g			
Exit velocity; m/s	**Nozzle d= 100mm**	**Nozzle d= 21mm**	**Nozzle d= 4mm**
0,2	**71,30 s**		
1	**14,26 s**		
5	**2,85 s**	**64,67 s**	
100		**3,23 s**	**70,00 s**
200		**1,62 s**	**35,00 s**
400			**17,50 s**

Friedrich et al. Experimental study of jet-formed hydrogen-air mixtures and pressure loads from their deflagrations in low confined surroundings, ICHS-2, 2007

H2 explosion tests by KI



- H_2 concentration gauges - 14
- Pressure gauges - 20
- Convective integral heat flux transducers - 10
- Radiative integral heat flux transducers - 2
- Collimated photodiodes - 10
- BOS photo - 1
- Video - 1
- Wind meter - 1

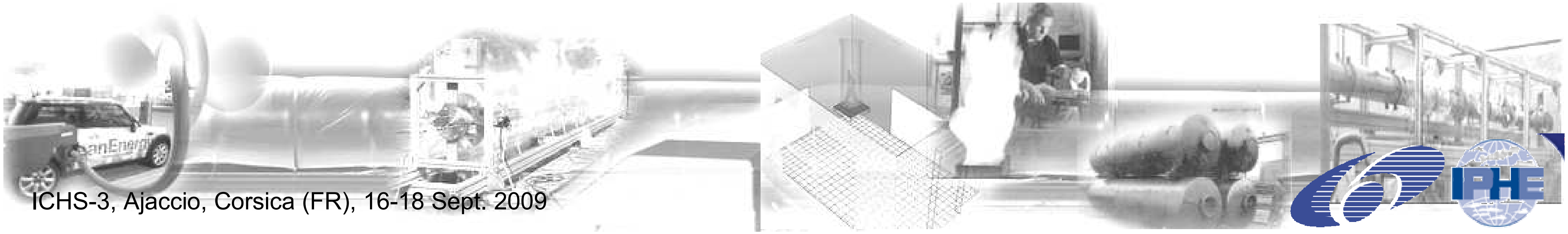
H2 explosion tests

Some results:

- FZK tests
  - Undisturbed free jet a maximum overpressure of 11.1 mbar at distance 0.403 m from the ignition source
  - Hydrogen accumulation in a hood a maximum overpressure of 53.2 mbar at the highest position inside the hood at a distance of 0.78 m from the ignition
  - Grid net layer structures for flame acceleration a maximum overpressure of 9176 mbar and 410 mbar at distance 0.345 and 1.945 m from the ignition
- KI tests
  - For congested area (BR= 0.3 and 0.54) slow combustion took place with maximum overpressure lower than 60 mbar. With additional congestion maximum overpressure reaches 400 mbar.
  - Special geometry was found that results in fast deflagration with overpressure more than 10 atm.

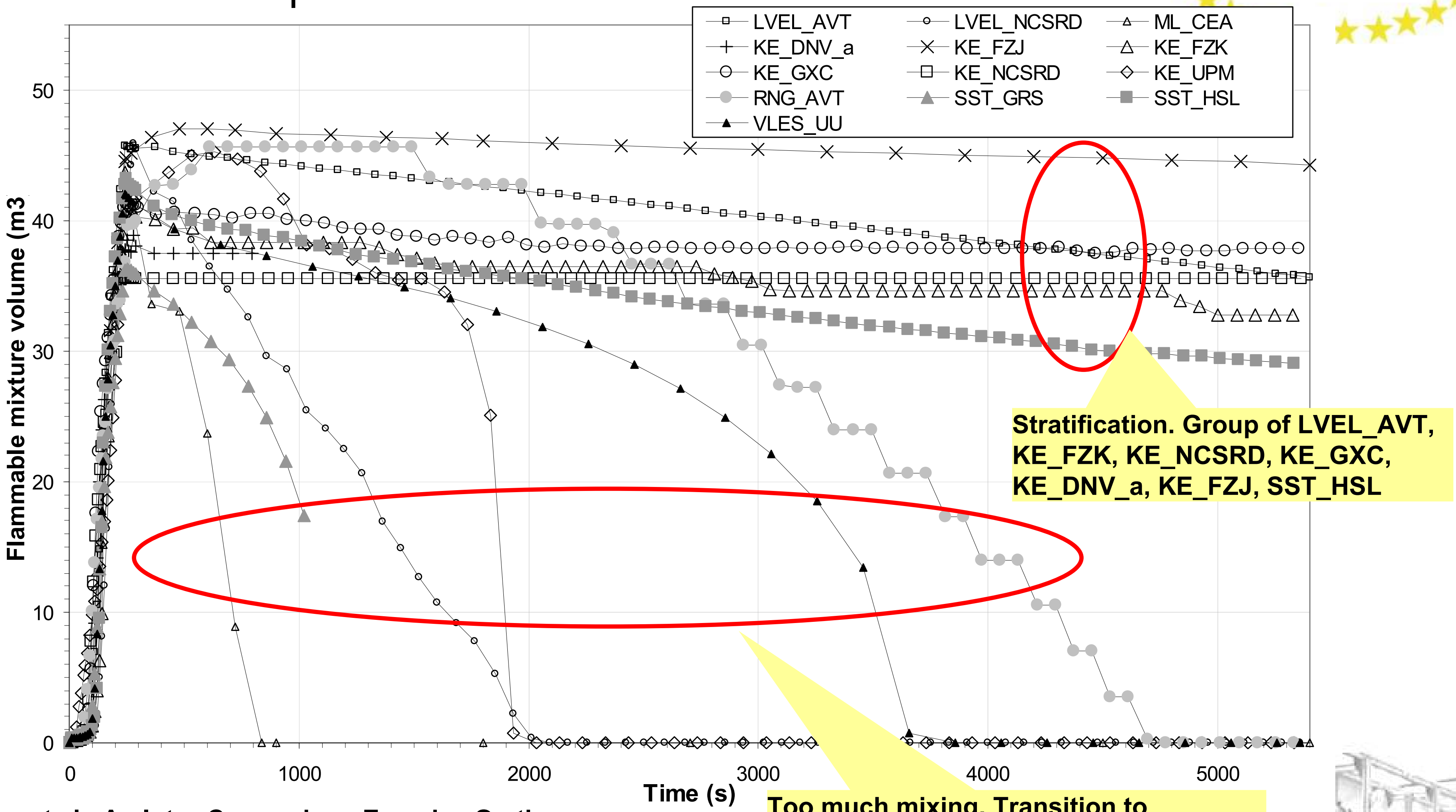
CFD modelling

- Scope
  - Support of experimental activities by performing pre-test calculations
  - CFD validation against existing and newly obtained experimental data
  - CFD applications



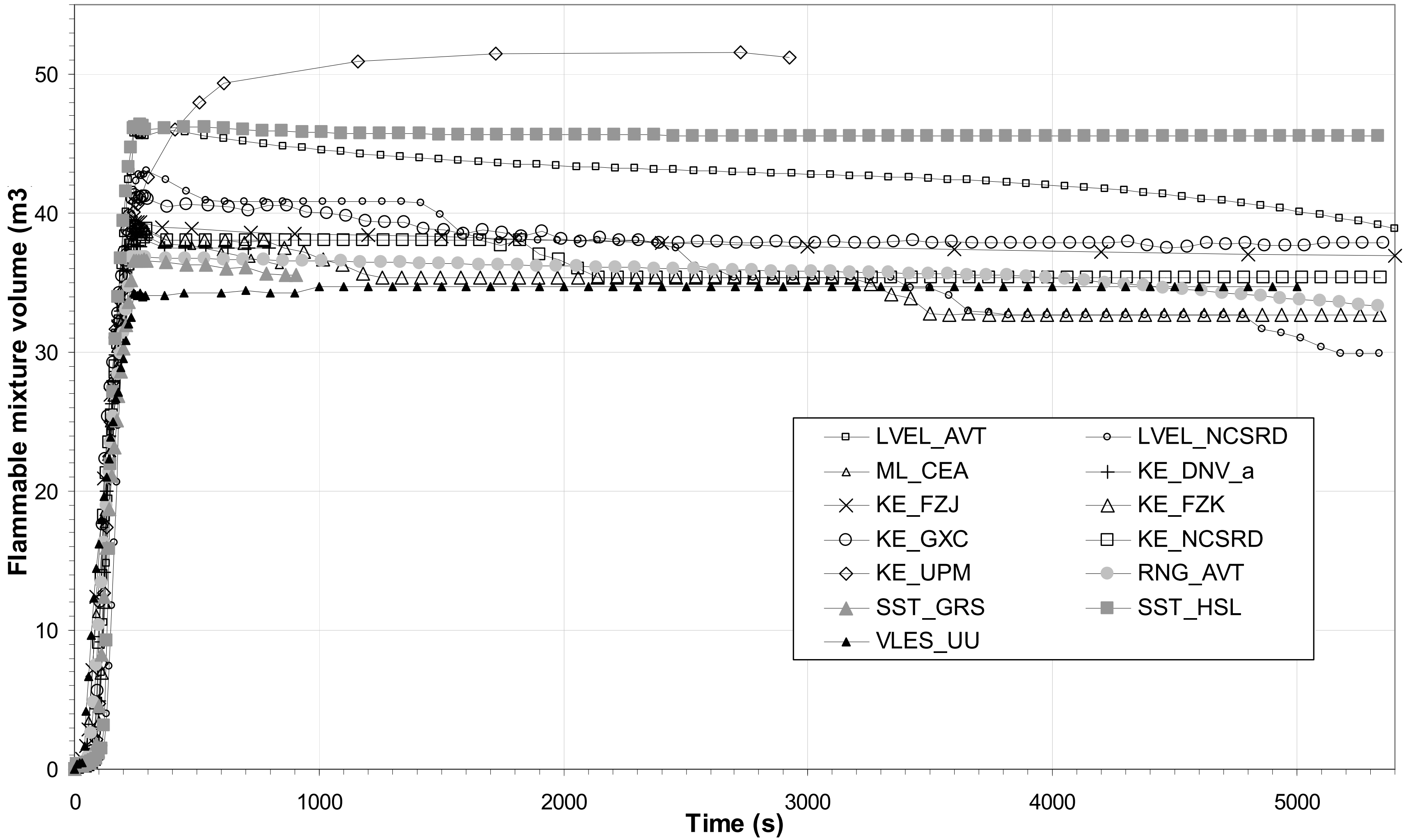
Blind CFD modelling of INERIS-6C

Risk assessment parameters



Venetsanos et al., An Inter-Comparison Exercise On the Capabilities of CFD Models to Predict the Short and Long Term Distribution and Mixing of Hydrogen in a Garage, IJHE, 2009

Post CFD modelling of INERIS-6C



Venetsanos et al., An Inter-Comparison Exercise On the Capabilities of CFD Models to Predict the Short and Long Term Distribution and Mixing of Hydrogen in a Garage, IJHE, 2009

Recommendations

Deliverable D113

- Initial guidance for using hydrogen in confined spaces - Results from InsHyde (90 pp.)

Scope

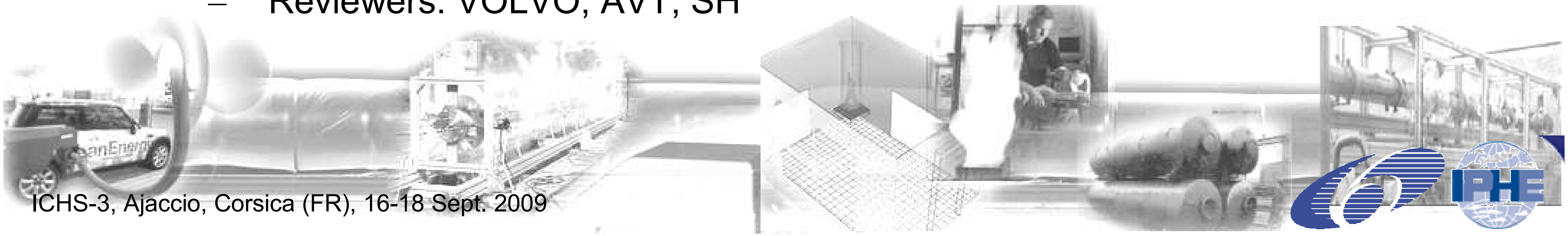
- To provide general guidance on the use of hydrogen in confined spaces
- To summarize results obtained during InsHyde

Concerned public

- Research, industry and general public

Contributions

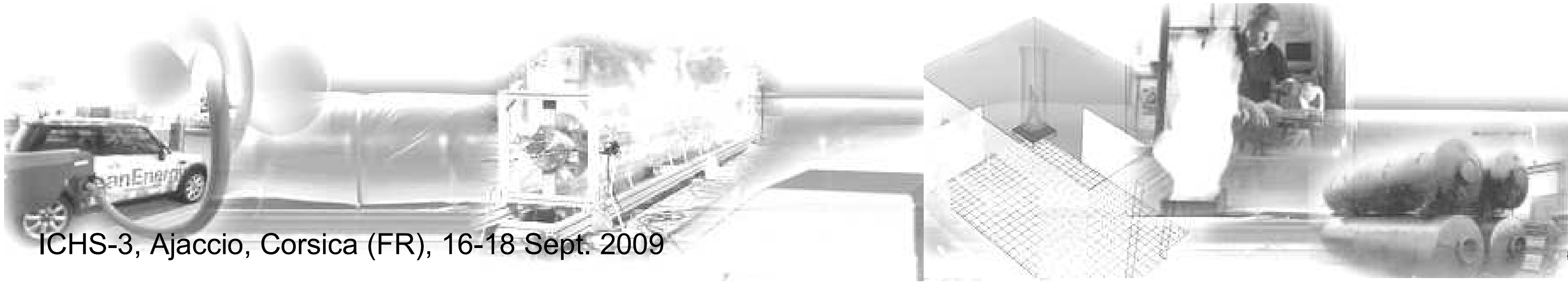
- Coordination: NCSRD and INERIS
- Authors (alphabetically): BMW, BRE, FH-ICT, FZJ, FZK, GEXCON, HSL, INASMET, INERIS JRC, KI, NCSRD, STATOIL/HYDRO, UNIPI, UU
- Reviewers: VOLVO, AVT, SH



Recommendations

Deliverable 113 structure

1. Introduction
2. Risk control measures when using hydrogen indoors
3. Hydrogen behaviour in accidental situations
4. Risk assessment recommendations
5. Experiences from HYSAFE members



Dissemination

- Scientific papers
  - Conferences: ICHS-2 and ICHS-3
  - Journals: IJHE
- InsHyde Website (http://www.hysafe.net/InsHyde)
  - Public deliverables
    - D113 (Guidance)
    - D54 (detectors)
    - D74 (permeation)
- Direct contacts
  - Presentation of Guidance document (D113) to the members of the HySafe database of hydrogen safety related organizations
  - Presentations of HySafe permeation proposal (D74) to EC, ISO, SAE and other regulatory/standardization organizations

Future work

- Further pre-normative work is needed:
  - To formulate the requirements for permitting the use of hydrogen systems (vehicles, hydrogen storage and delivery systems, fuel cells) in confined spaces both from the perspective of the hydrogen systems and of the buildings
  - To increase our understanding on hydrogen behaviour in confined spaces
  - To be jointly undertaken by research + industry + regulatory bodies

Thank you!!