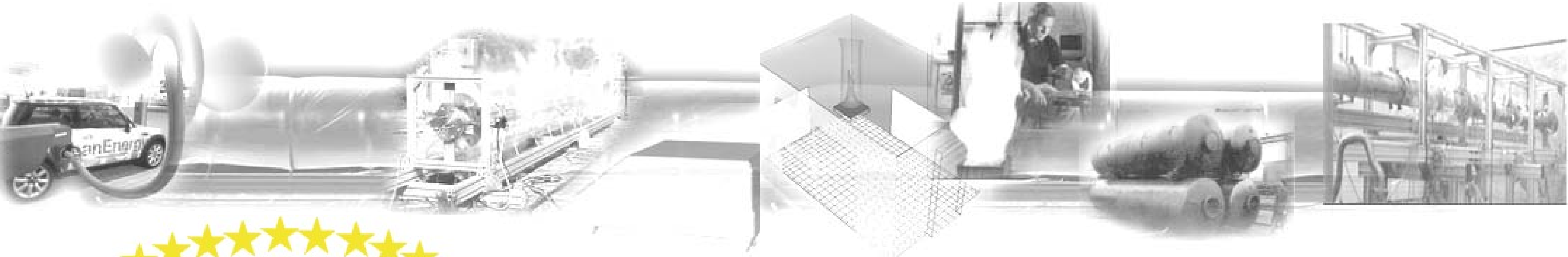

The European Network of Excellence for Hydrogen Safety

Guidance for using hydrogen in confined spaces
Results from InsHyde

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InsHyde coordination
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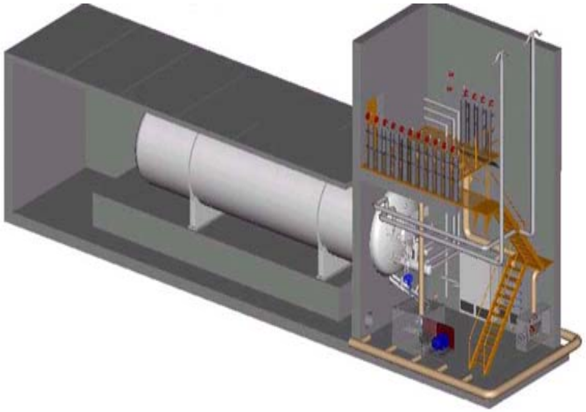
Workshop on New Energy Carriers in tunnels and underground installations,
Frankfurt Airport, 20 Nov 2008

Use of hydrogen in confined spaces

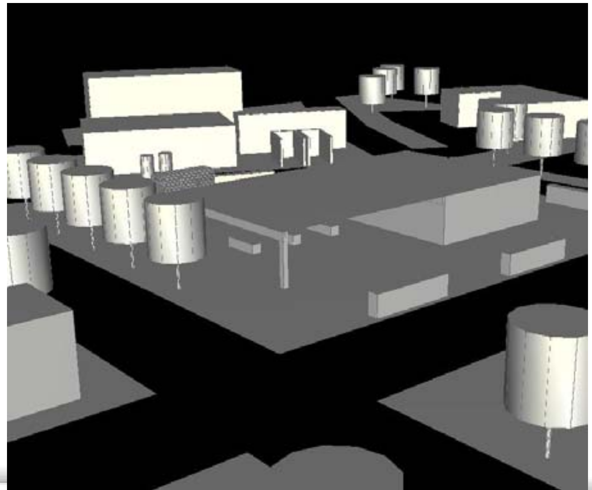
Spaces containing parts where hydrogen can accumulate

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
- Participation/Duration
  - Nearly all HYSAFE participants
  - 3 years

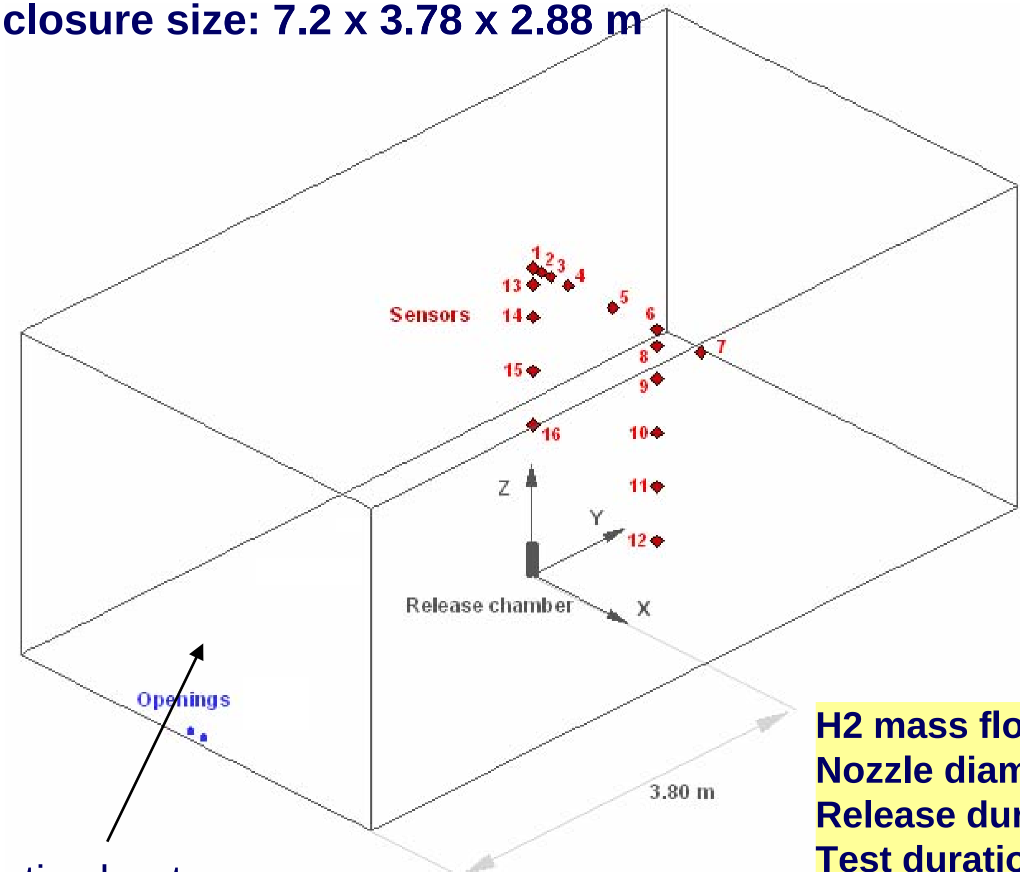
InsHyde structure

Work packages:

1. Review
2. Gas Detection experiments (public D54, see website)
3. Theoretical study of permeation
4. Dispersion experiments (see refs 1-3, ICHS-2)
5. Explosion experiments (see refs 4-5, ICHS-2)
6. Ignition
7. CFD modelling (see refs 2,6, ICHS-2)
8. Scaling methodology
9. Recommendations (D113 public by Dec 2008)
10. Dissemination (ICHS-2, ICHS-3, …)

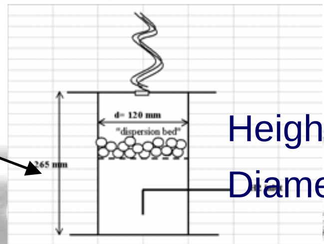
H2 dispersion test INERIS-6C (ref 1)

Enclosure size: 7.2 x 3.78 x 2.88 m



Plastic sheet

Release chamber



Height 265mm

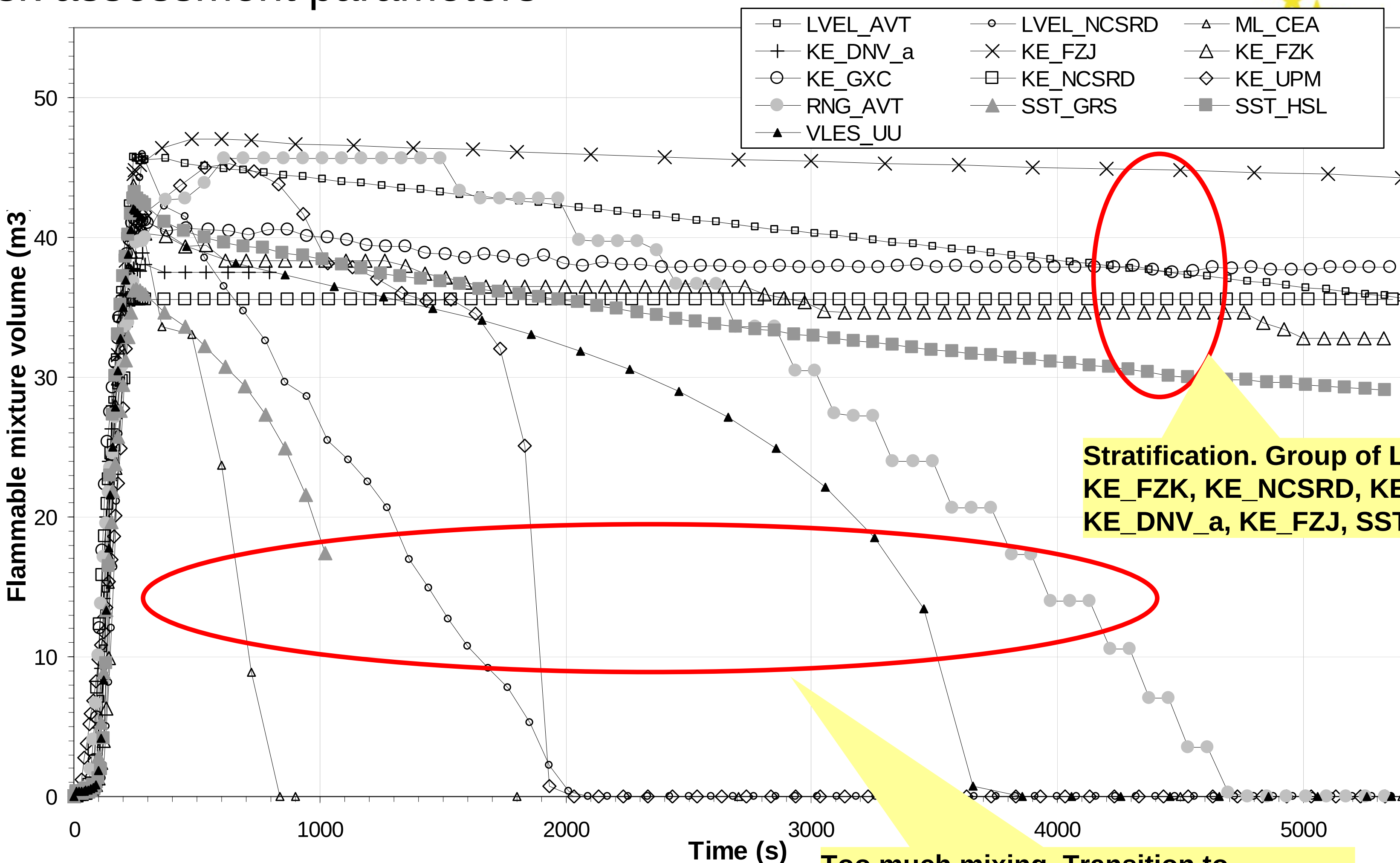
Diameter: 120mm

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%**

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

Blind CFD modelling of INERIS-6C (ref 2)

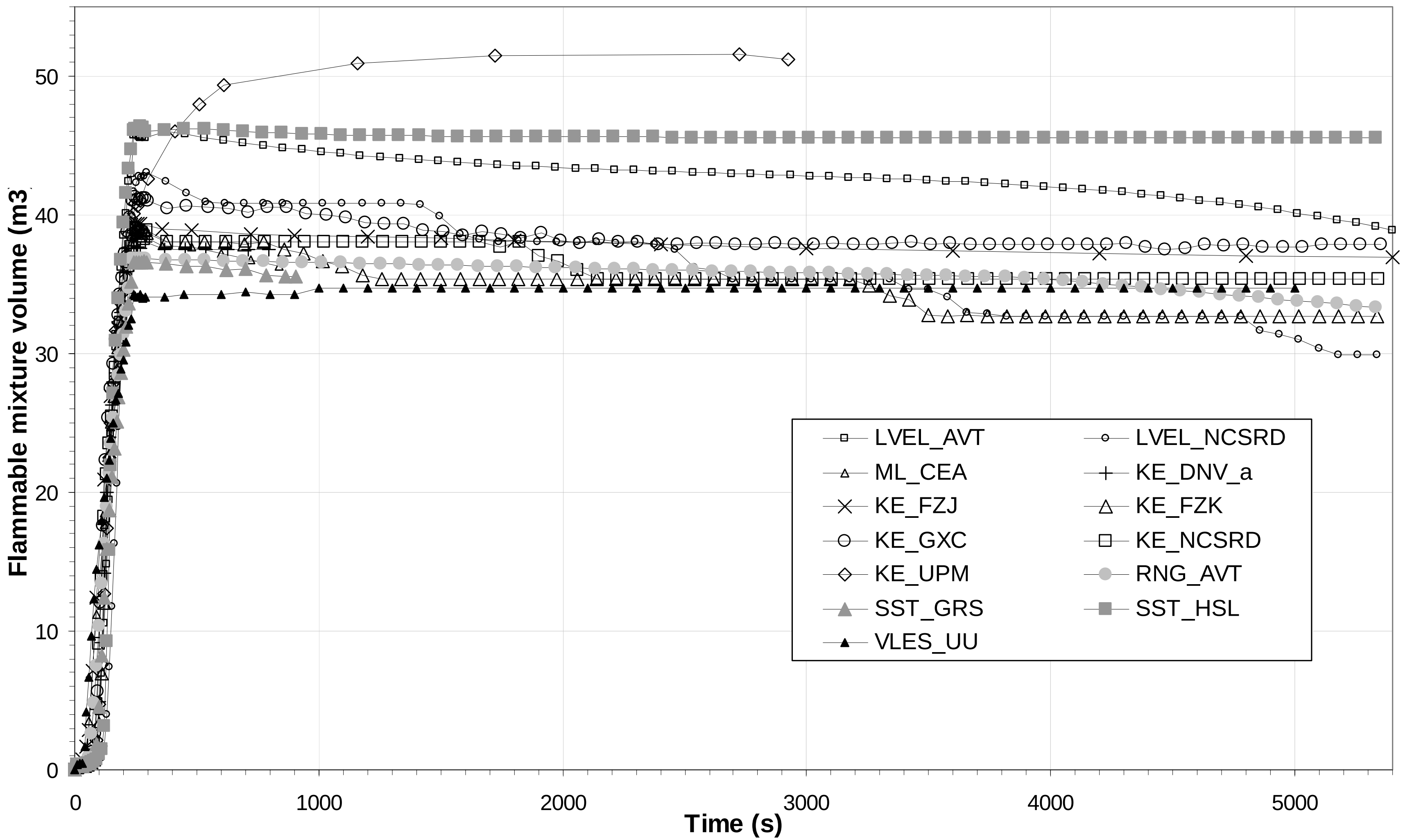
Risk assessment parameters



Stratification. Group of LVEL_AVT, KE_FZK, KE_NCSRD, KE_GXC, KE_DNV_a, KE_FZJ, SST_HSL

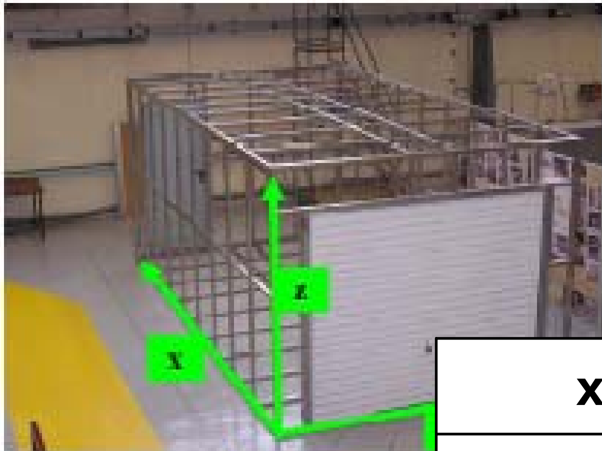
Too much mixing. Transition to homogeneous conditions. Group of LVEL_NCSRD, ML_CEA, KE_UPM, RNG_AVT, SST_GRS, VLES_UU

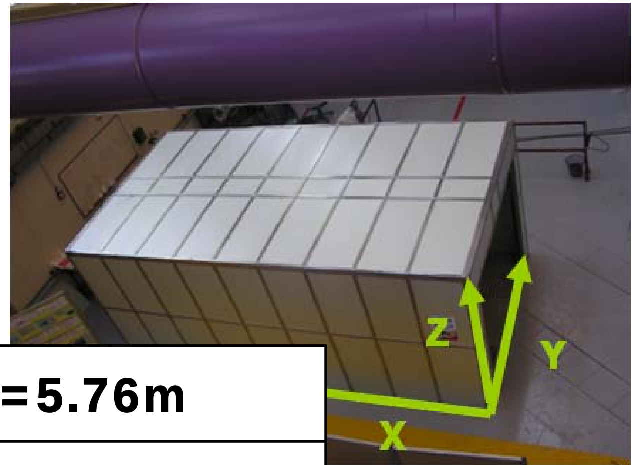
Post CFD modelling of INERIS-6C (ref 2)



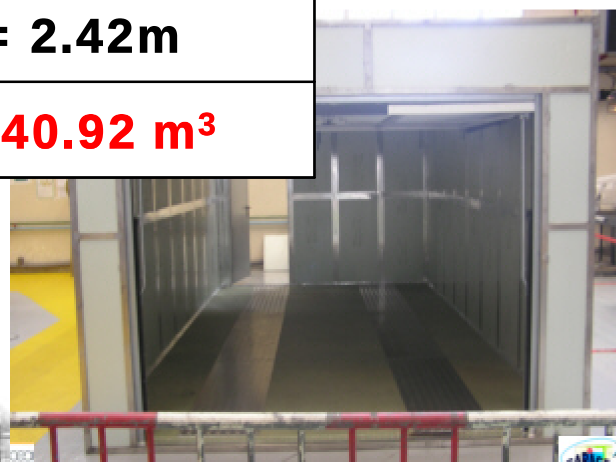
He dispersion tests by CEA (ref 3)

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**

He dispersion tests by CEA (ref 3)

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

H2 explosion tests by FZK (refs 4,5)

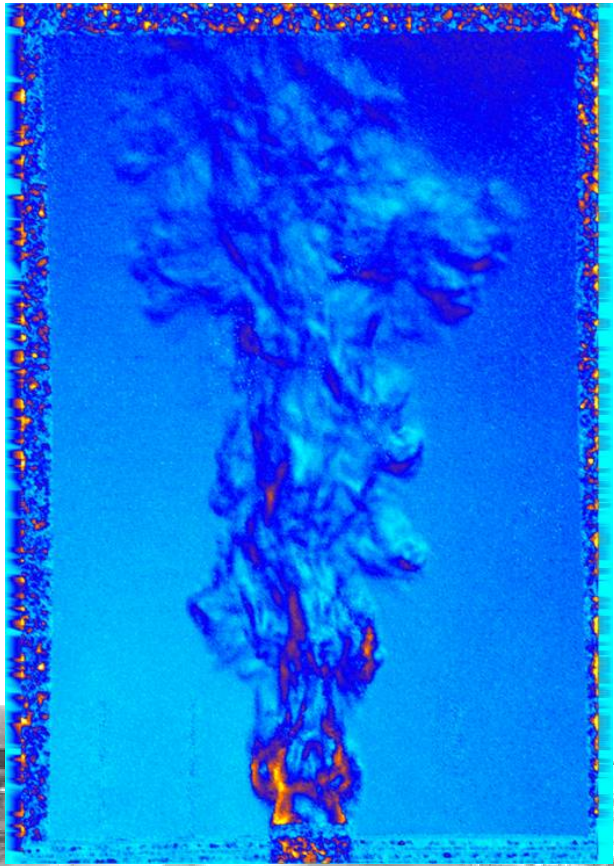
Explosion tests facility at FZK

Confinement

Sound speed measurements:
- Concentration
- Gas velocity

Injection

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



H2 explosion tests by FZK (refs 4,5)

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**

H2 explosion tests by FZK (refs 4,5)

Some results:

- 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 at distance 0.345 m from the ignition
  - a maximum overpressure of 410 mbar at distance 1.945 m from the ignition

InsHyde/ Document D113

Title:

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

Scope

- To provide general guidance on the use of h2 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

InsHyde/ Document D113

Document 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

InsHyde/ D113 structure

1. Introduction
   - Scope
   - Hydrogen basic properties
   - Confined spaces and hydrogen systems
   - Reference documentation
2. Risk control measures when using hydrogen indoors
   - Fuel supply and storage arrangement
   - Detection
   - Ventilation and exhaust
   - Fire and explosion safety
   - Commissioning, inspections, training and worker protection
   - Reference documentation

InsHyde/ D113

3. Hydrogen behaviour in accidental situations
   - Hydrogen release and dispersion
   - Hydrogen ignition
   - Hydrogen explosion
   - Hydrogen fire
   - Reference documentation
4. Risk assessment recommendations
   - Risk assessment methodology
   - Consequence assessment
   - Reference documentation

InsHyde/ D113

5. Experiences from HYSAFE members
   - Schematic for the assessment and prevention of explosive risks
   - Safety assessment for hydrogen laboratory at Forschungszentrum Juelich, Germany
   - Safety assessment for Statoil/Hydro 15 bar electrolyser
   - BMW (H2 research centre – 250 bar CGH2 and LH2)
   - Safety assessment of the PEMFC test laboratory at INASMET-Tecnalia, Spain
   - Safety assessment for explosion risks at Fraunhofer Solid Oxide Fuel Cell Laboratory
   - Safety assessment for hydrogen facilities at University of Pisa, Italy
   - Safety assessment for the Safety Vessel A1 on the hydrogen test site HYKA at Forschungszentrum Karlsruhe, Germany
   - Safety assessment for dispersion and explosion testing at INERIS, France
   - Safety assessment for the “Globus” facility at Russian Research Center Kurchatov Institute Moscow, Russia
   - HSL Risk assessment

Future work

Further pre-normative work is needed:

- To be funded by JTI +…
- To be jointly undertaken by research + industry + regulatory bodies
- To increase our understanding on hydrogen behaviour in confined spaces
- In order to formulate the requirements (at EC and global level) for permitting the use of hydrogen vehicles (cars and commercial vehicles) in confined spaces

Thank you!!

References

1. J.M. Lacome, Y. Dagba, L. Perrette, D. Jamois, Ch. Proust, Large scale hydrogen release in an isothermal confined area, ICHS-2, 2007
2. A.G. Venetsanos, E. Papanikolaou, M. Delichatsios, J. Garcia, O.R. Hansen, M. Heitsch, A. Huser, W. Jahn, T. Jordan, J-M. Lacome, H.S. Ledin, D. Makarov, P. Middha, E. Studer, A.V. Tchouvelev, A. Teodorczyk, F. Verbecke, M.M. van der Voort, 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, ICHS-2, 2007
3. S. Gupta, J. Brinster, E. Studer, I. Tkatschenko, Hydrogen related risks within a private garage: Concentration measurements in a realistic full scale experimental facility, ICHS-2, 2007
4. A. Friedrich, J. Grune, N. Kotchourko, A. Kotchourko, K. Sempert, G. Stern, M. Kuznetsov, Experimental study of jet-formed hydrogen-air mixtures and pressure loads from their deflagrations in low confined surroundings, ICHS-2, 2007
5. P. Middha, O.R. Hansen, J. Grune, A. Kotchourko, Validation of CFD calculations against ignited impinging jet experiments, ICHS-2, 2007
6. Papanikolaou E.A. and Venetsanos A.G., CFD simulations of hydrogen release and dispersion inside the storage room of a hydrogen refuelling station using the ADREA-HF code, ICHS-2, 2007