PRESLHY

Release & Distribution

LH2 Safety Workshop, 6 March 2019, Bergen

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Pre-normative REsearch for Safe use of Liquid HYdrogen

Karlsruher Institut für Technologie

Air Liquide

HEALTH & SAFETY LABORATORY

hySafe
INTERNATIONAL ASSOCIATION FOR HYDROGEN SAFETY

INERIS

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Pro-Science

Ulster University

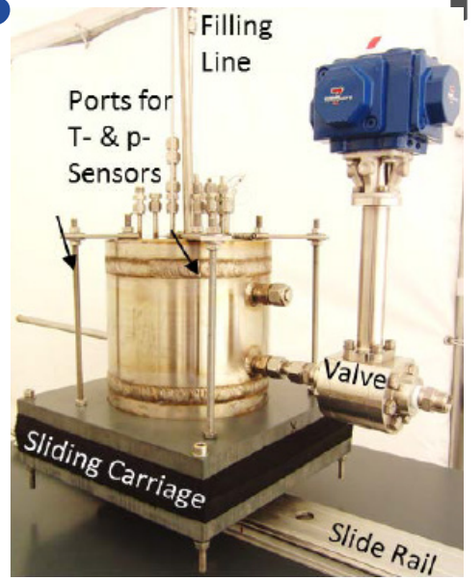
WARWICK
THE UNIVERSITY OF WARWICK

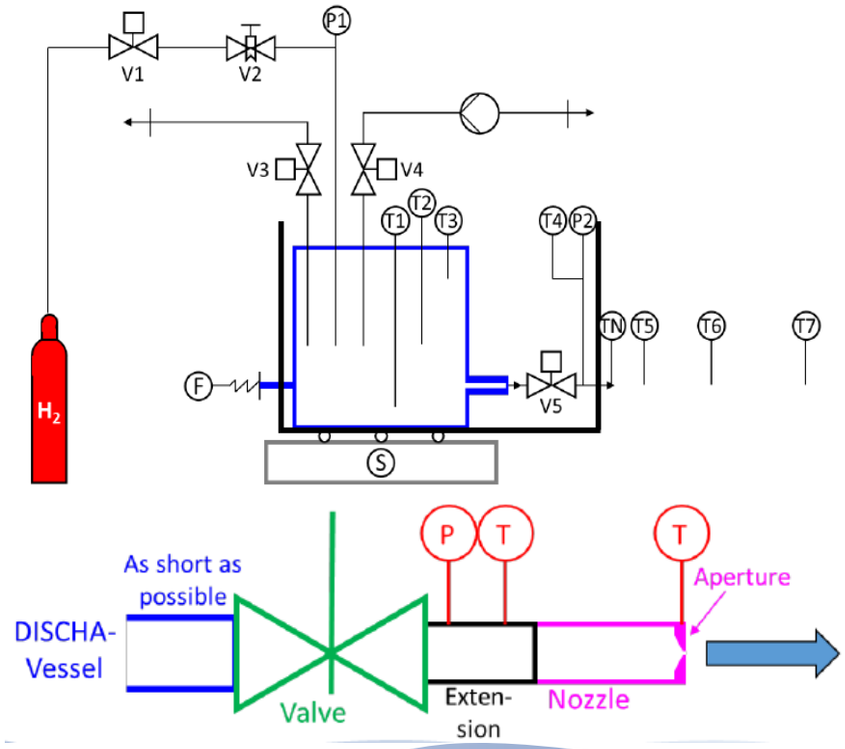
WP3 / Overview of Activities

- Experiments (KIT, PS)
  - GH2 and LN2 blowdown tests at DisCha facility, V ≈ 2,81 L
    - $T_{stag,min}$ ≈ 80K, up to 200 bar
  - LH2 steady releases at Cryostat facility, V ≈ 225 L
    - T_{stag}≈ 20K, up to 5 bar
  - Pool facility
    - Basin with size 50 x 50 cm filled with ground material
- Experiments (HSL)
  - HSL test site
  - Steady LH2 releases (T_{stag}≈ 20K, 1 barg)
- Modeling and Simulations (NCSRD, KIT, UU, UWAR, AL)
  - Validation against existing experiments
  - Simulations of PRESLHY experiments
  - Engineering tools

DisCha-Facility experiments

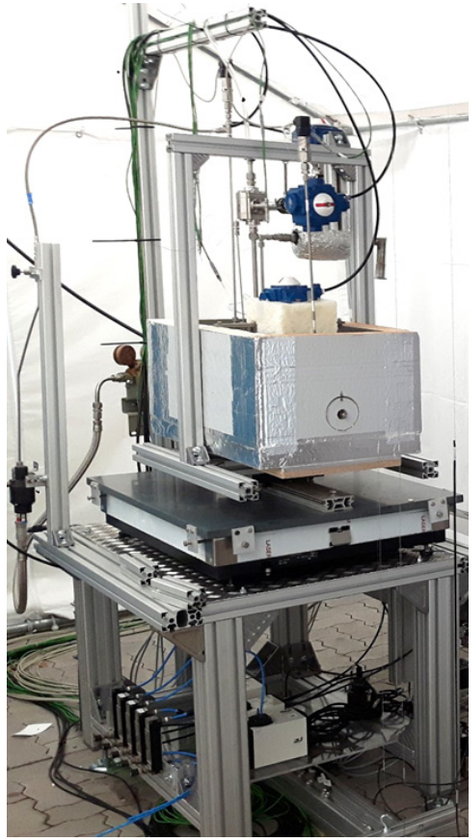
- Instrumentation
  - Inside Vessel:
    - 1 pressure sensor,
    - 3 closed and 3 open thermocouples
  - In release line:
    - 1 thermocouple in flow and
    - 1 pressure sensor in flow.
  - Nozzle
    - 1 thermocouple in nozzle material
  - Outside vessel
    - 1 force sensor and 1 scale
    - 5 thermocouples
    - 5 H2-concentration sensors
    - 3 cameras for BOS photography





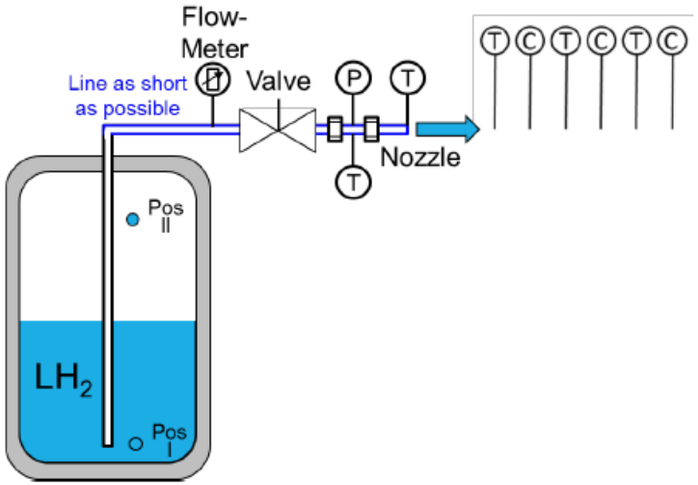
DisCha-Facility experiments

- DisCha-Facility put into operation,
- Few “Warm” (ambient temperature) tests performed with N_2 to check functionality,
- “Warm” (ambient temperature) test series with H_2 completed,
  - Only Blowdown tests,
  - Nozzle diameters: 0.5, 1.0, 2.0, 4.0 mm,
  - Initial pressures: 5, 10, 50, 100, 150, 200 bar,
  - Numerous BOS-Photos to visualize shape of Jet
  - In total > 50 experiments (at least one repetition/experiment),
- “Warm” experiments used to identify improvement potential of set-up:
  - 3 Open thermocouples added to vessel for faster T-measurement,
  - Measuring frequency of thermocouples increased to 100 Hz,
  - Measuring frequency of pressure sensors increased to 2 kHz,
  - Response-time of concentration measurements reduced to approx. 2 s,
  - Force and weight-sensors still problematic (torques during release).
- Facility already prepared to perform “Cold” Tests (LN_2-temperature).



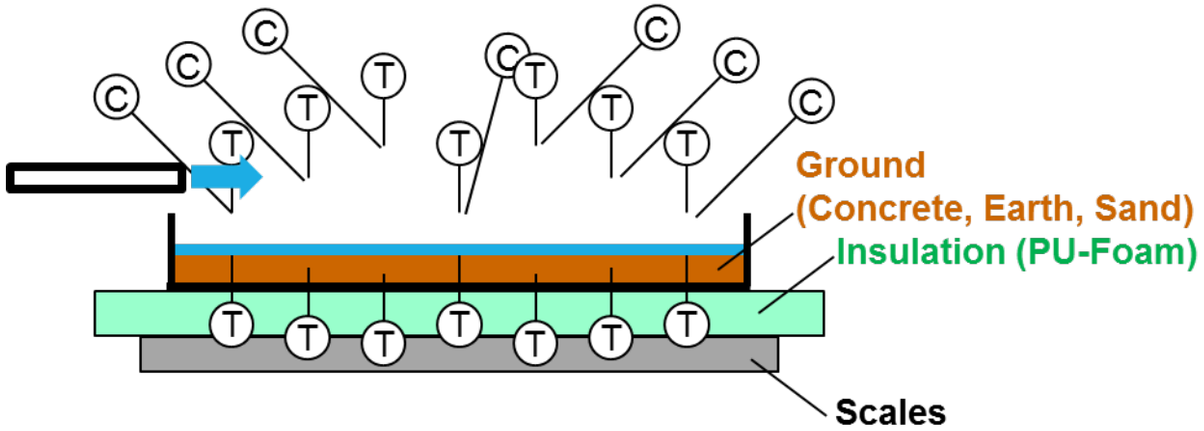
Cryostat-Facility Experiments

- Cryostat-Facility still under construction (top flange missing),
- Design of missing top flange is almost complete,
- Safety valve for LN_2-shield already available,
- Important expensive infrastructure and technical support will be provided by other KIT-Institute,
- Remote test-site for experiments found close to KIT,
- Amount of LH_2 to be released has to be carefully estimated.



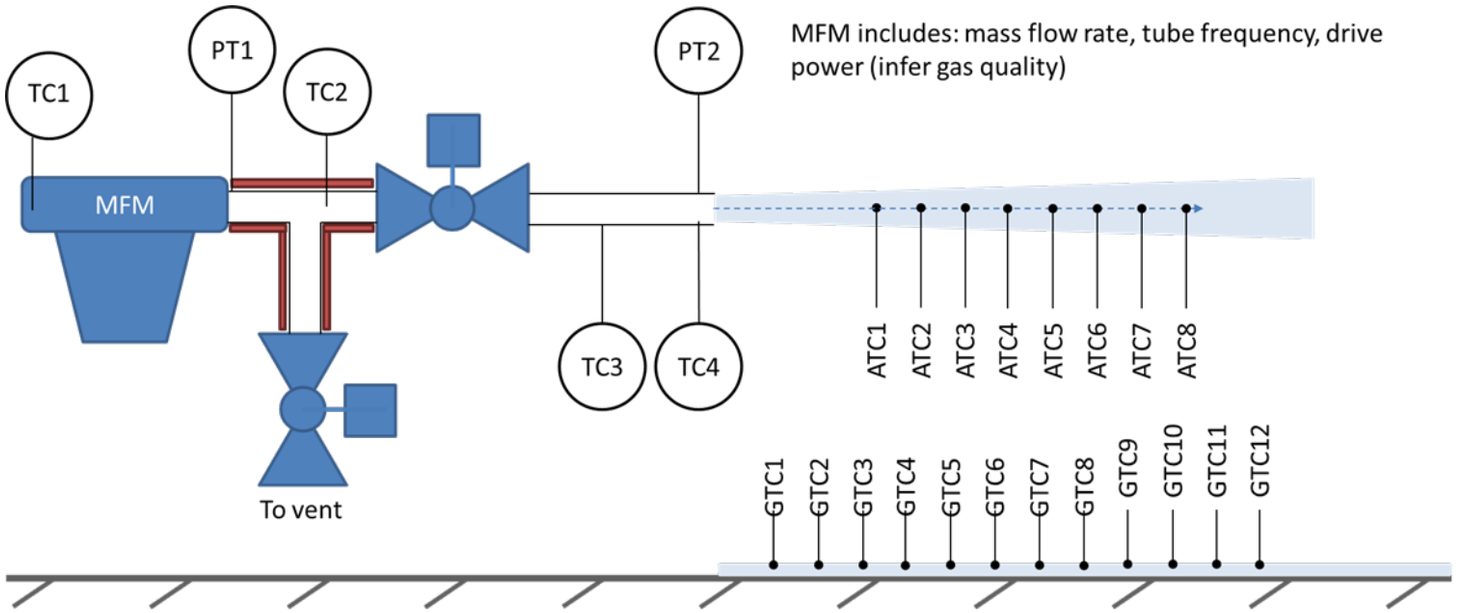
Pool-Facility Experiments

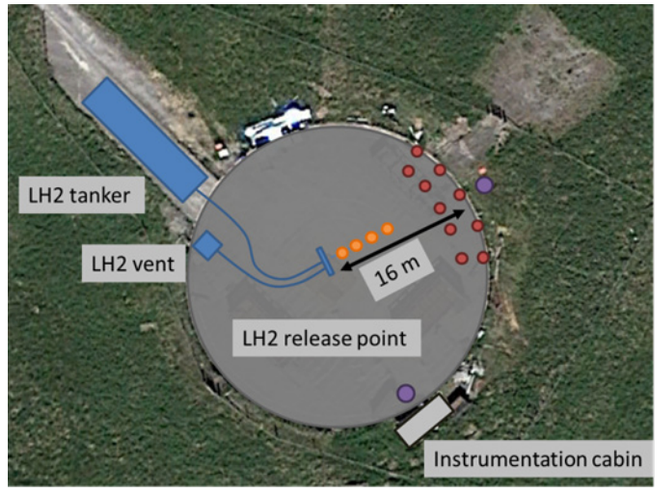
- Suitable test-site for experiments found close to KIT,
- Test-site is owned by institute of KIT-Campus South which has no obligations against use for the experiments,
- Test-site is remote and surrounded by woods and thus allows release of large amounts of H2,
- Even ignition of released H2 is possible,
- Test site is connected to electricity and water supply,
- Site visit planned for March.



WP3 HSL experiments

- WP3: Unignited releases focussing on dispersion / source term
- Main objective is to investigate LH_2 vaporization / pool formation for elevated release points.





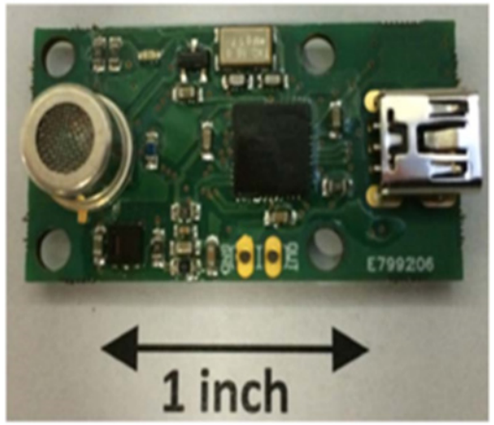
Instrumentation

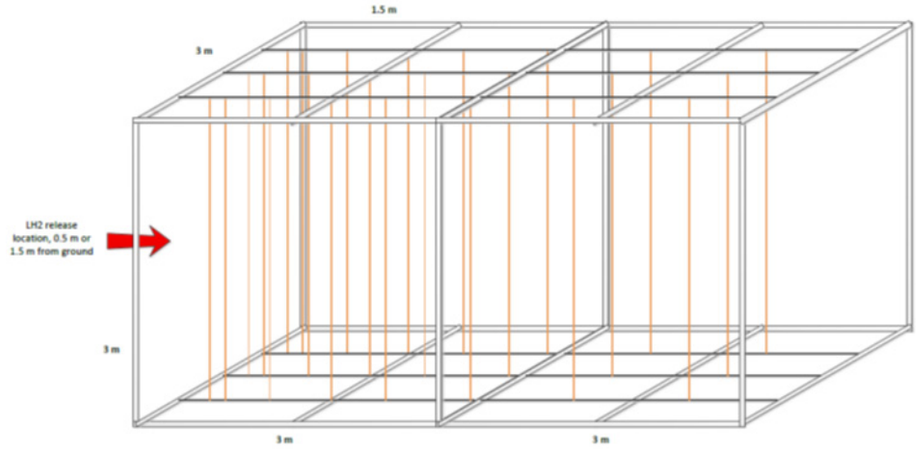
Release measurements will include:

- Pressure inside the tanker (visual)
- Pressure and temperature along the release pipe (PT1, TC1, TC2)
- Pressure and temperature at the exit nozzle (PT2, TC3 ,TC4)
- Mass flow meter (flow rate, drive gain (vapour quality) and infer density)
- Exit velocity and exit vapour quality will be derived from flow and density (see flow meter above)
- Spray vaporization/rainout (optical techniques i.e. 4k video, IR camera and thermocouples)
- Pool formation (thermocouple rake on ground, thermocouples in ground, 4k video and IR camera)
- Gas concentration through temperature and thermal conductivity (HYWAM vol% system, Draeger PPM, LEL, O_2 and co-located thermocouples)
- Ambient atmospheric conditions: temperature, pressure, humidity, wind speed and direction (two positions, site and release point)

Near-field concentration measurements

- Collaboration with National Renewable Energy Laboratory (NREL) for near-field concentration measurements
  - System of pumped sampling tubes and remote sensors
- Up to 32 detectors based on thermal conductivity
- Up to 12 co-located TC's
- Deployment of NREL's system for measurements in the jet
- Collaborative paper going in to ICHS 2019





Far-field concentration measurements

- 30 Draeger X-am 5000 units mounted at three heights on stands in the far field, 0.5, 1.5 and 2.5 m
- Each instrument contains:
  - PPM H_2 sensor
  - LEL H_2 sensor
  - O_2 sensor
- Each instrument co-located with a TC

Test matrix

Work Package	Experimental Subtask	Test No.	Experiment Title	Release Orientation	Release Height	Orifice/Nozzle Diameter
3	3.5	3.5.1	Rainout experiments	Horizontal	0.50 m	1”
3	3.5	3.5.2	Rainout experiments	Horizontal	0.50 m	½”
3	3.5	3.5.3	Rainout experiments	Horizontal	0.50 m	¼”
3	3.5	3.5.4	Rainout experiments	Horizontal	1.50 m	1”
3	3.5	3.5.5	Rainout experiments	Horizontal	1.50 m	½”
3	3.5	3.5.6	Rainout experiments	Horizontal	1.50 m	¼”
3	3.5	3.5.7	Rainout experiments	Vertically upward	NA	½”
3	3.5	3.5.8	Rainout experiments	Vertically downward	0.50 m	½”
3	3.5	3.5.9	Rainout experiments	Horizontal into baffle	0.50 m	½”

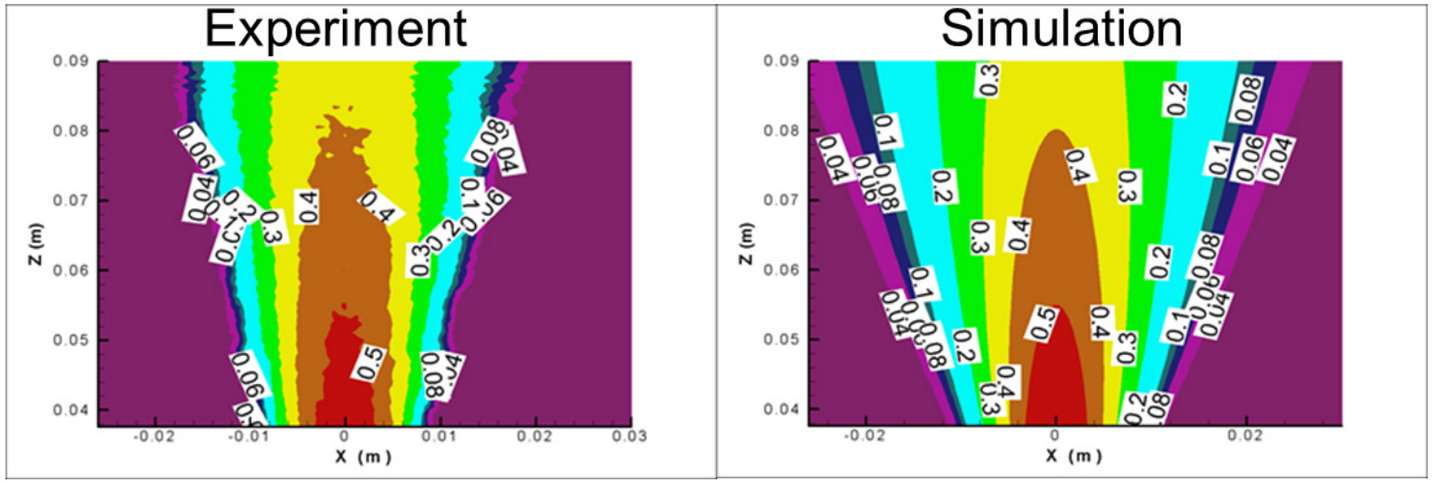
CFD validation

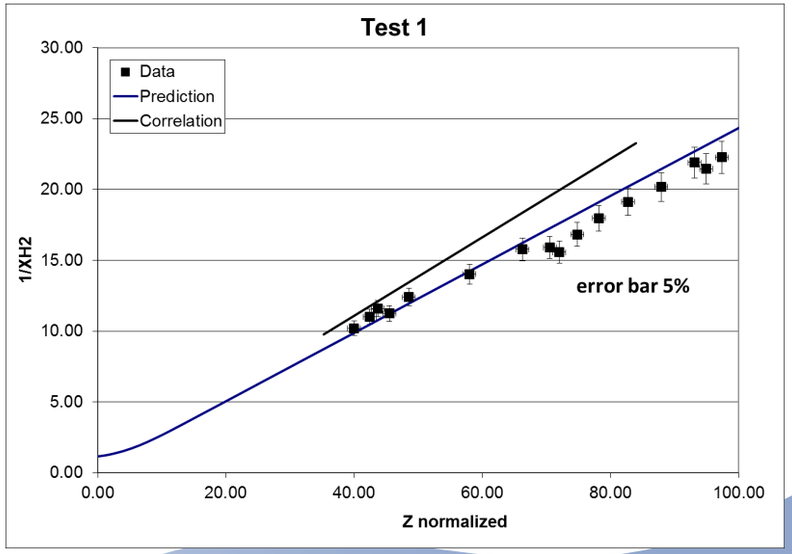
- SANDIA cryogenic h2 releases (Hecht and Panda IJHE, 2018)
  - Tests shared within PRESLHY for benchmarking

Table 1 – Experimental conditions in this work.

T_{noz} (K)	P_{noz} (bar_{abs})	d_{noz} (mm)	$n_{heights}$	T_{throat} (K)	P_{throat} (bar_{abs})	ρ_{throat}	v_{throat} (m/s)
58	2.0	1.0	4	43.5	0.972	0.55	544.5
56	3.0	1.0	4	41.9	1.457	0.86	533.3
53	4.0	1.0	4	39.6	1.940	1.22	516.4
50	5.0	1.0	5	37.4	2.422	1.65	498.2
61	2.0	1.25	6	45.7	0.973	0.52	558.9
51	2.5	1.25	2	38.2	1.215	0.79	508.4
51	3.0	1.25	6	38.2	1.457	0.95	507.5
55	3.5	1.25	3	41.2	1.699	1.03	527.6
54	4.0	1.25	2	40.4	1.940	1.20	521.6

  - Preliminary CFD results NCSRD for test1: (58K, 2 bar, 1mm)



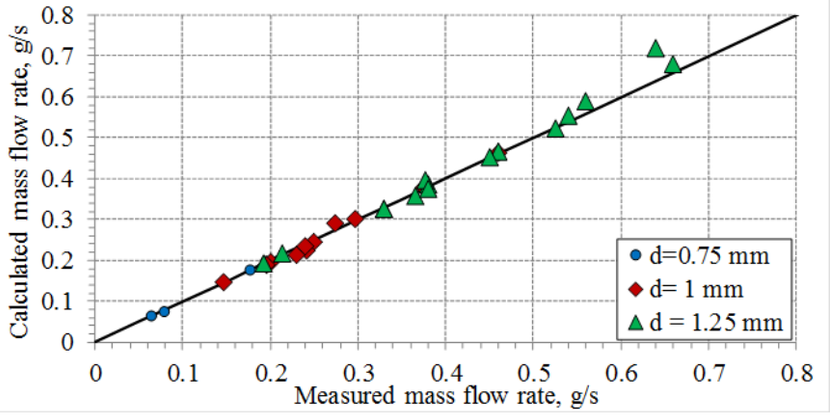


Analytical and CFD studies

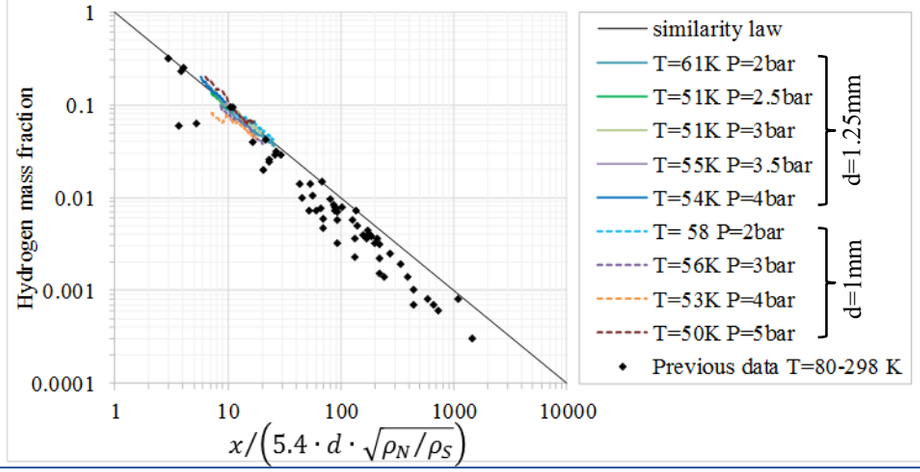
UU research on cryogenic unignited releases: SNL tests

Release source modelling

30 tests with T=46-295K and P=2-6bar

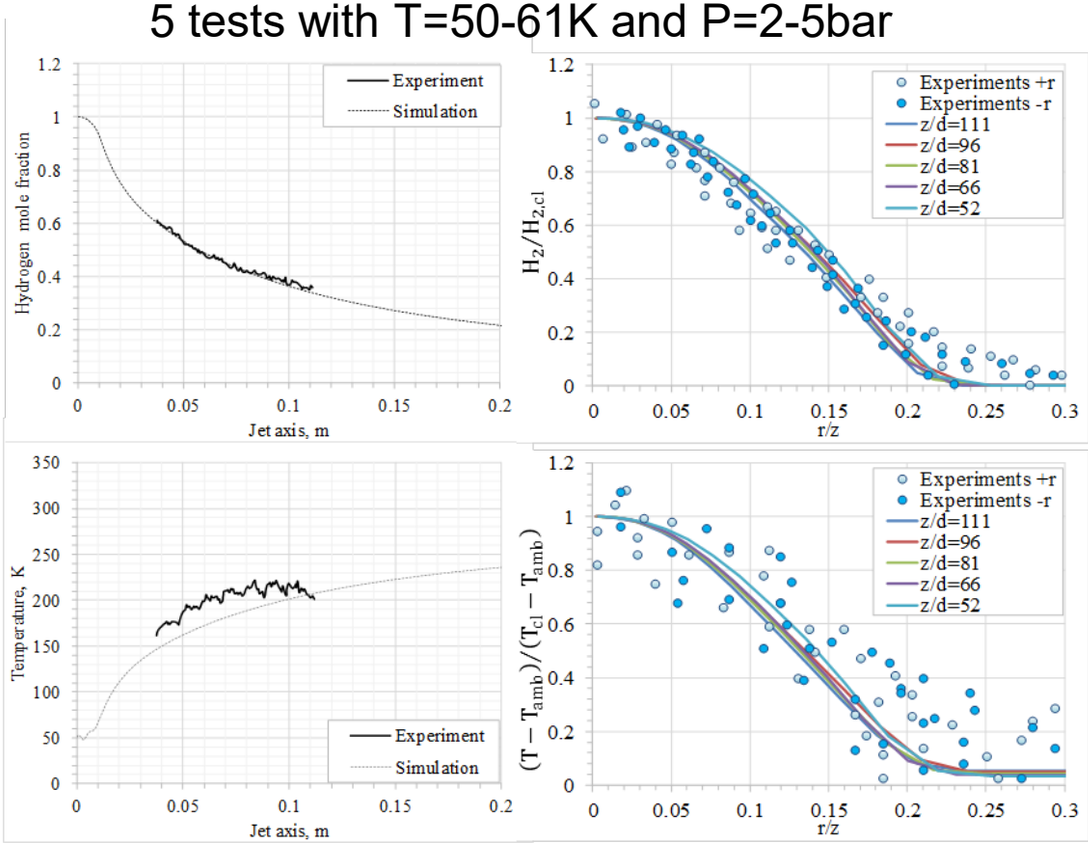


Similarity law for concentration decay



CFD modelling

5 tests with T=50-61K and P=2-5bar



Results for test P=2bar T=61K d=1.25mm

Sources for experimental data:
Panda and Hecht, 2016 - Hecht and Panda, 2018

CFD validation

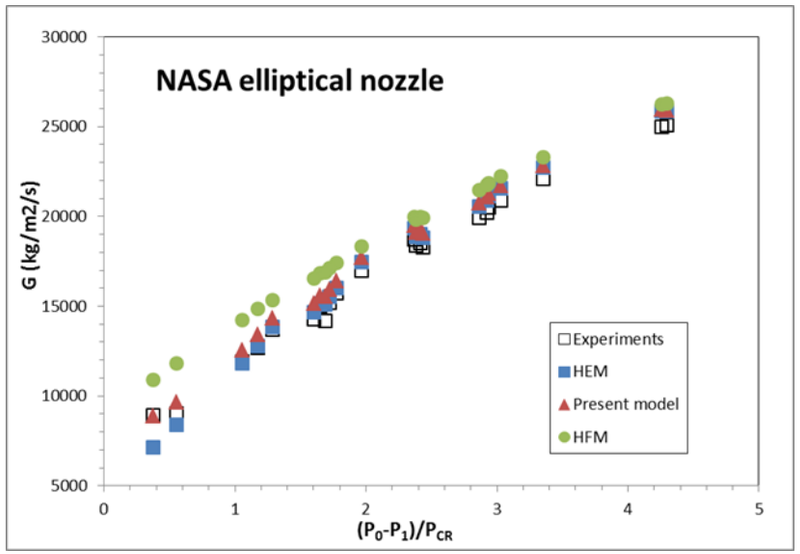
- INERIS large scale LHe releases on flat ground (Proust et. al 2001)
  - Tests 1 and 3 shared within PRESLHY for benchmarking.
  - Simulations by NCSRD on-going

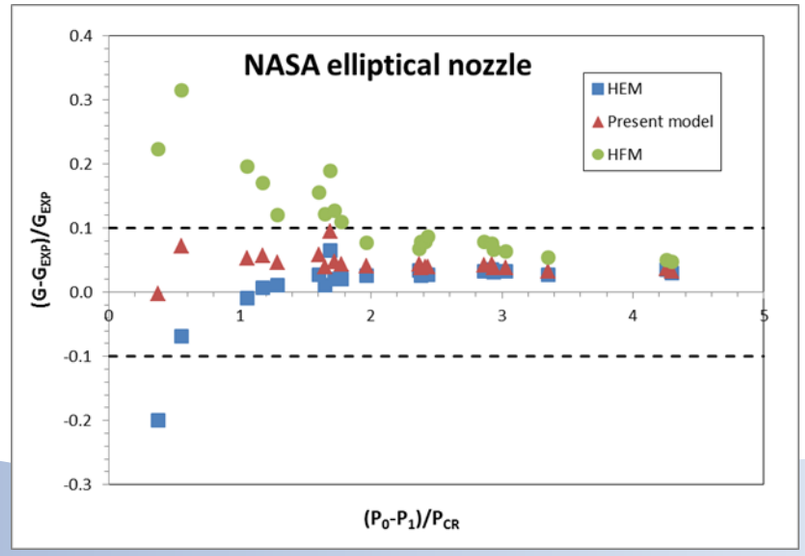
Issue n°	duration (s)	Mass flow rate (kg/s)	Wind speed (m/s) at 3 m height	Humidity (%)	Temp (°C)	H1 (m)	H2 (m)	L (m)
0	60	1,5	6	/	16	3	5	20
1	50	1,4	4,0±1,0	86	17	5	17	50
2	52	1,4	5,2±1,0	90	17	5	17	50
3	52	2,1	3,0±0,5	84	12	12	32	80
4	43	2,1	4,0±0,5	84	12	7	35	75
5	34	2,1	5,5±0,5	88	12	7	30	70
6	43	2,1	4,5±0,5	88	11	7	30	70
7	63	1,2	2,0±0,5	85	12			
8	65	1,2	2,0±0,5	85	12			
9	71	2,2	2,0±0,5	85	12			

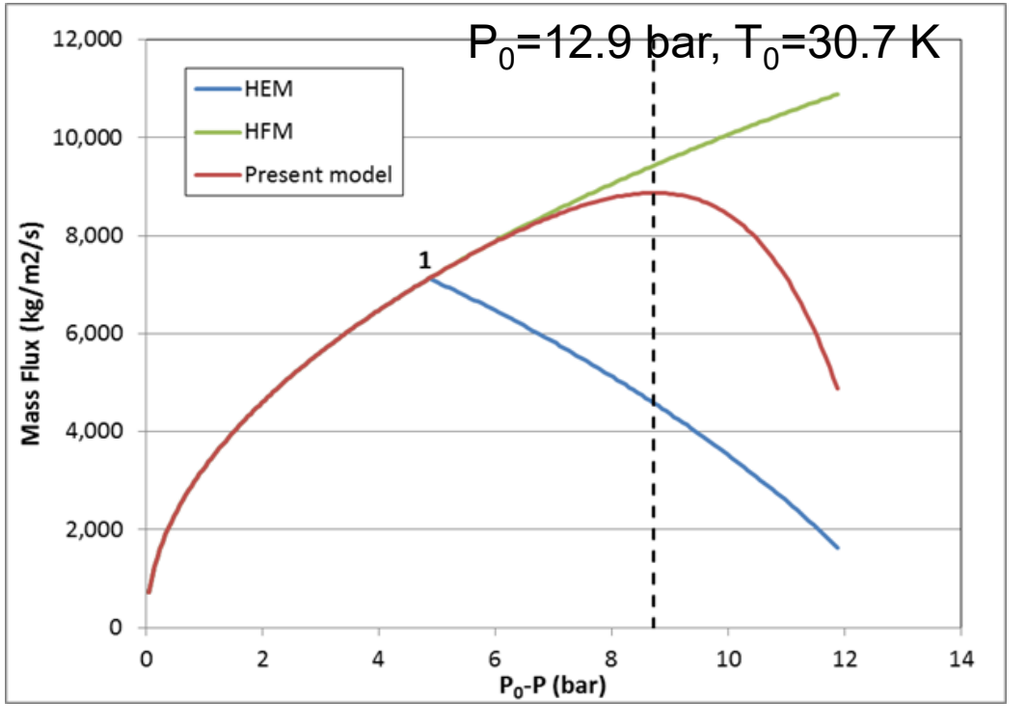
L the length of the cloud on the ground
H_1 the height of the base of the cloud
H_2 the height at the top of the cloud.

Engineering tools

- HNEM model for two-phase choked flow (Venetsanos, IJHE 2018)
  - Short pipe lengths)
  - Validation against Simoneau and Hendricks (1979) tests

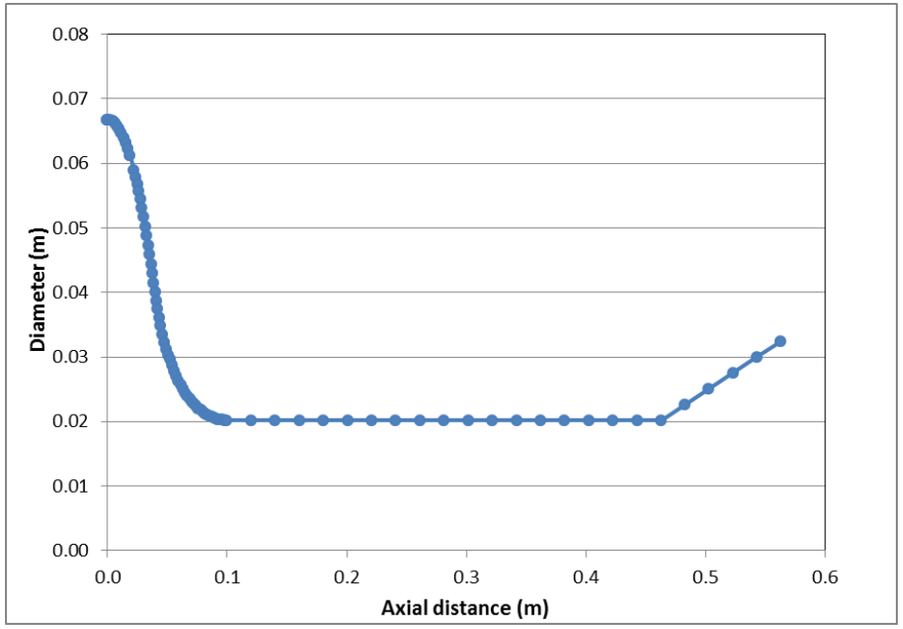


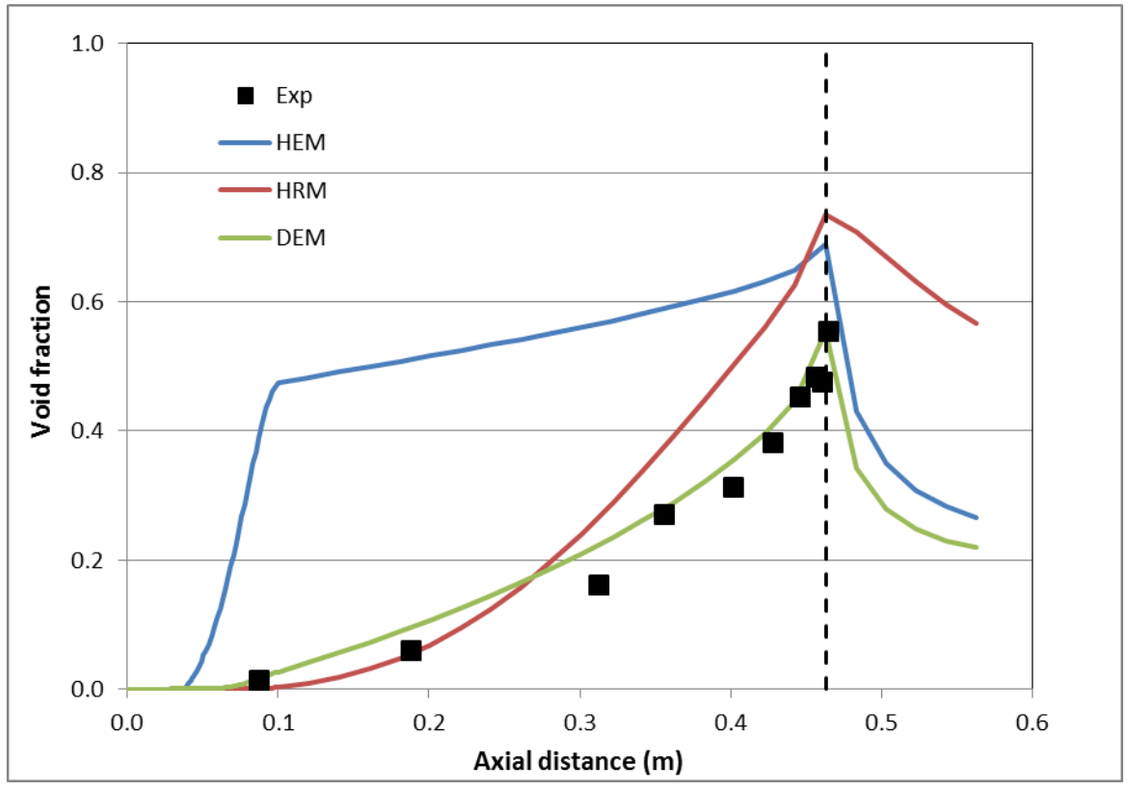




Engineering tools (2)

- Two-phase choked flow with large pipe length effects
  - Solve 1d steady state pipe mass, momentum and energy equations using PIF algo
  - EoS based on free energy formulation. Heat transfer effects ignored.
  - Preliminary results against Super Moby Dick data (liquid water, 20bar, 212.3 C)
  - Models compared: HEM, HRM (Homogeneous Relaxation) and DEM (Delayed Equilibrium).





Acknowledgments

Ευχαριστώ!

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