



Modelling of consequences from loss of containment of LH2 equipment

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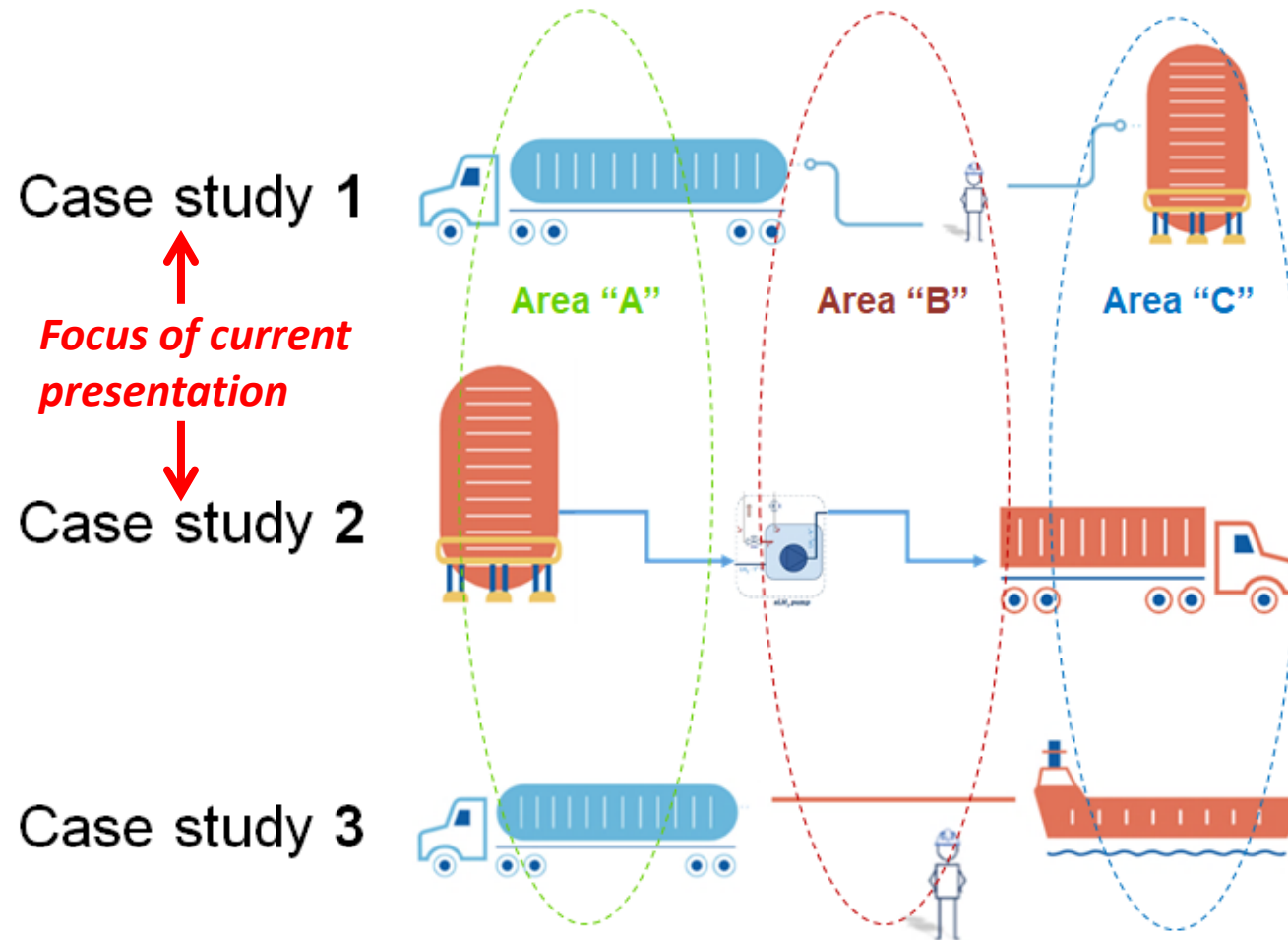
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Case studies examined at ELVHYS



Case study 1: Hose raptures during LH_2 transfer from a trailer towards stationary tank

Case study 2 : Hose raptures during filling of a mobile heavy duty truck from a stationary tank (pump driven transfer)

Phenomena examined:

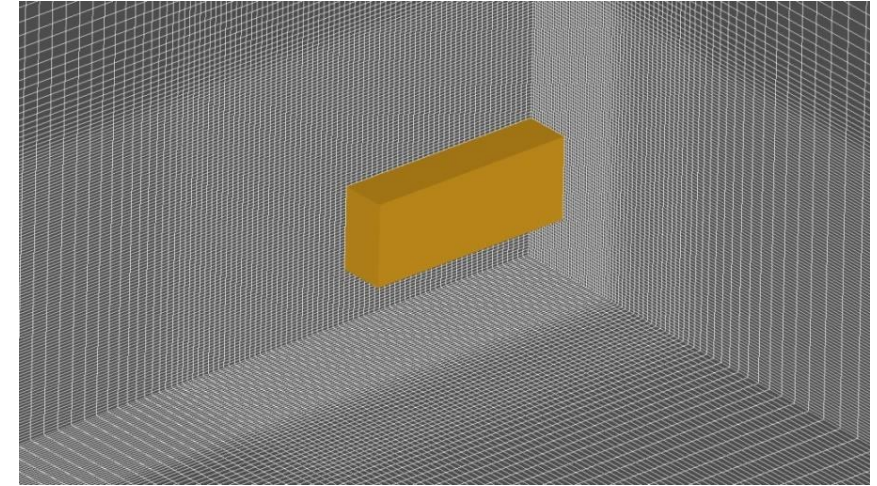
1. BLEVE
2. Dispersion (flash fire hazards)
3. Jet fire (radiation hazards)
4. Delayed ignition (overpressure hazards)

CFD modelling

- **ADREA-HF in-house CFD code**
 - RANS (steady state or transient)
 - k - ϵ turbulence model
 - MUSCL numerical scheme
 - Phase change: Raoult's law (local equilibrium conditions)
 - Notional nozzle approach for the release: DISCHA tool
 - Helmholtz free energy EoS
 - Constant total enthalpy and Mach = 1.0 at fictitious nozzle
 - Jet flame: Eddy dissipation/P1 radiation model
 - Premixed combustion: Turbulent burning velocity/ flame instabilities

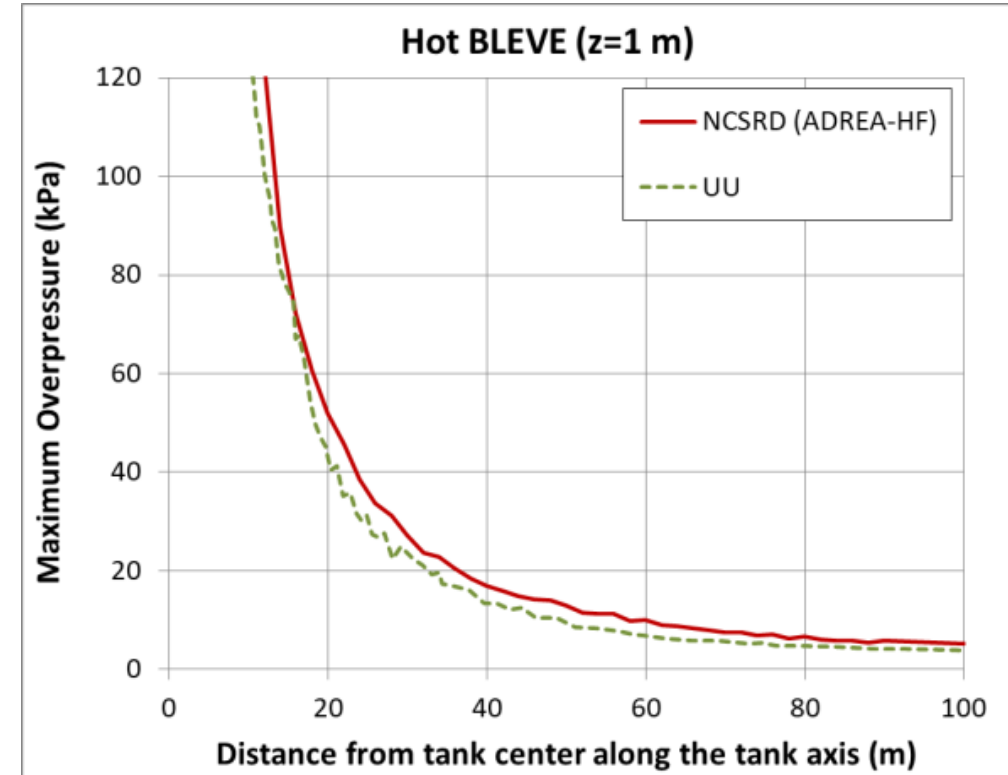
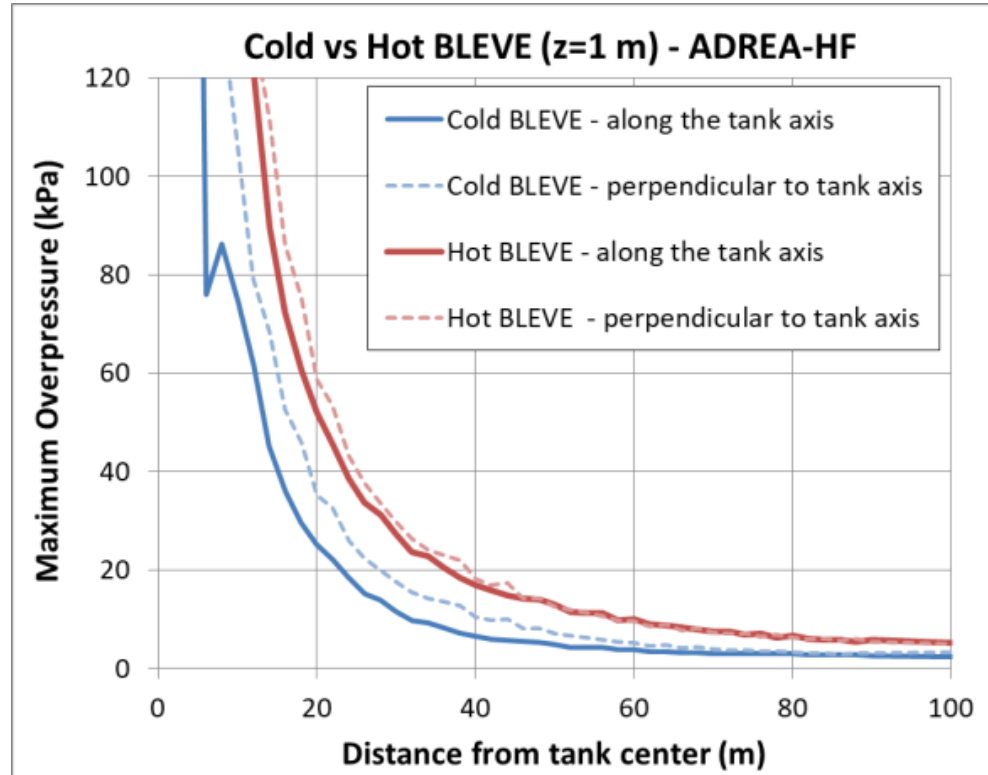
BLEVE modelling

- Trailer's tank volume: 57 m³
- Base case: 10 bar , 31.4 K, 90% filling, 2639.2 kg
- Rectangular parallelepiped tank
 - Square size 2.3 m, Length 10.7359 m, centre @ z=2.5m
- Double symmetry (x & y axis)/ 2.3 million cells
 - Cell size inside tank and around it: 0.15, 0.077 and 0.075 m in x, y and z
 - Cells inside tank: 36·15·27= 14,580
- Domain 150 x 120 x 80 m
- **Combustion:** Eddy Dissipation Concept (Magnussen et al., 1977)
 - The term in the model associated with products is omitted
 - No need for ignition modelling (Combustion occurs as soon as hydrogen and air are mixed)
- **EoS:** Peng-Robinson



$$\overline{\dot{\omega}_F} = \rho \frac{1}{\tau_t} \min \left(Y_F, \frac{Y_O}{s} \right)$$

BLEVE results

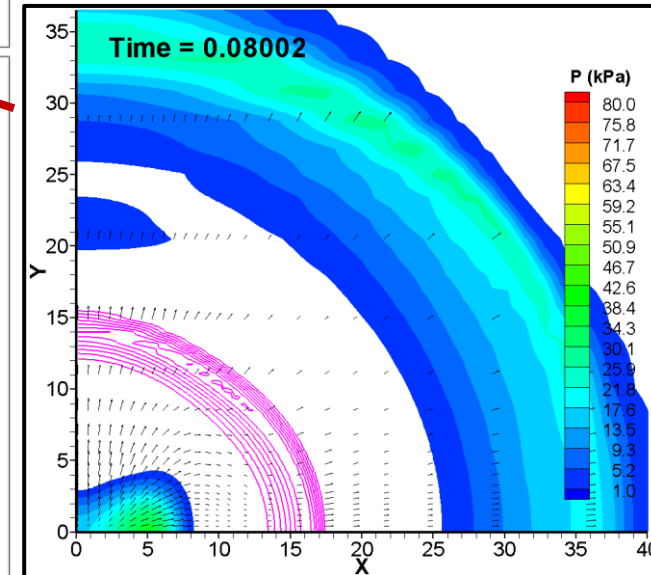
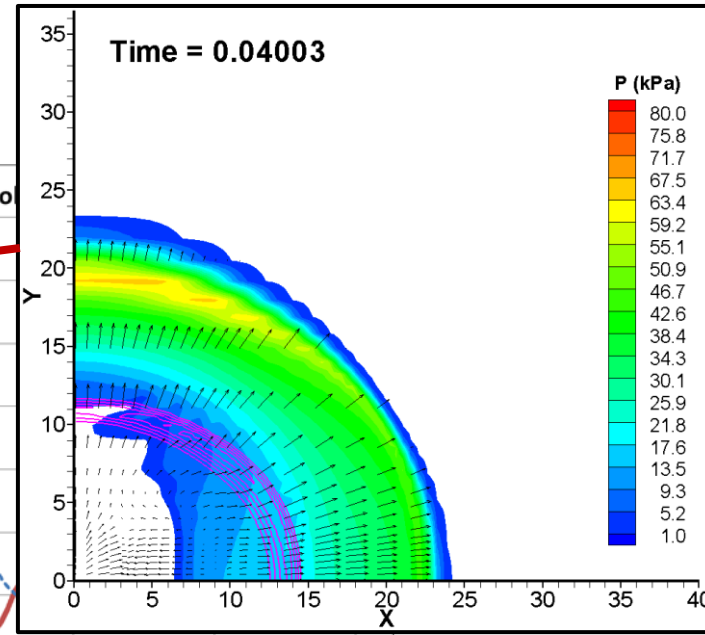
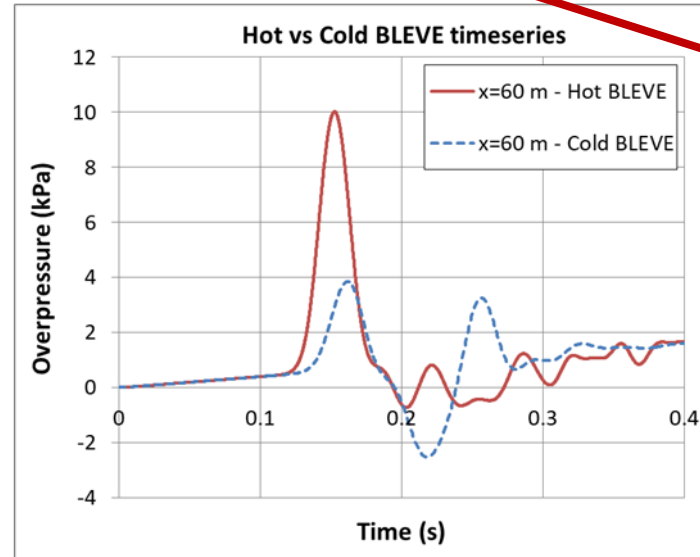
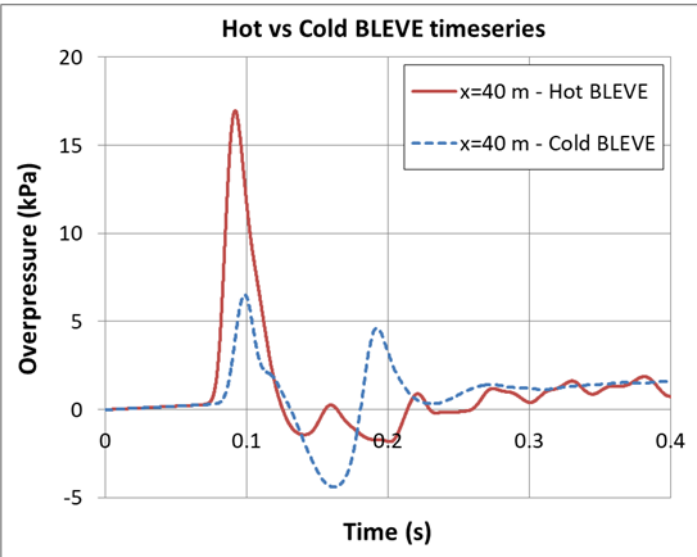
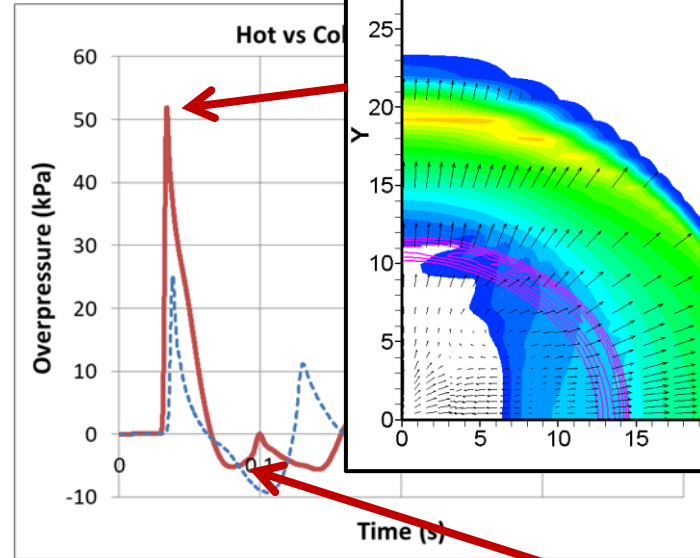
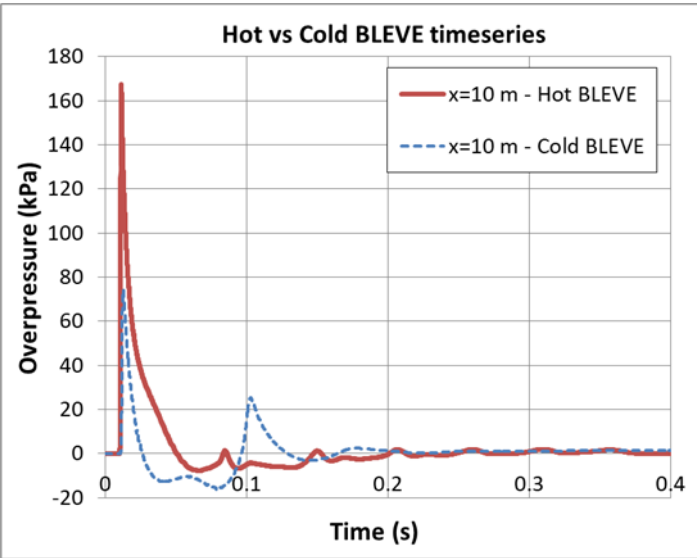


- Overpressure can be up to 2.7 times higher in hot BLEVE (this maximum difference is observed at 50 m distance)
- Overpressures perpendicular to tank are higher, especially in cold BLEVE case



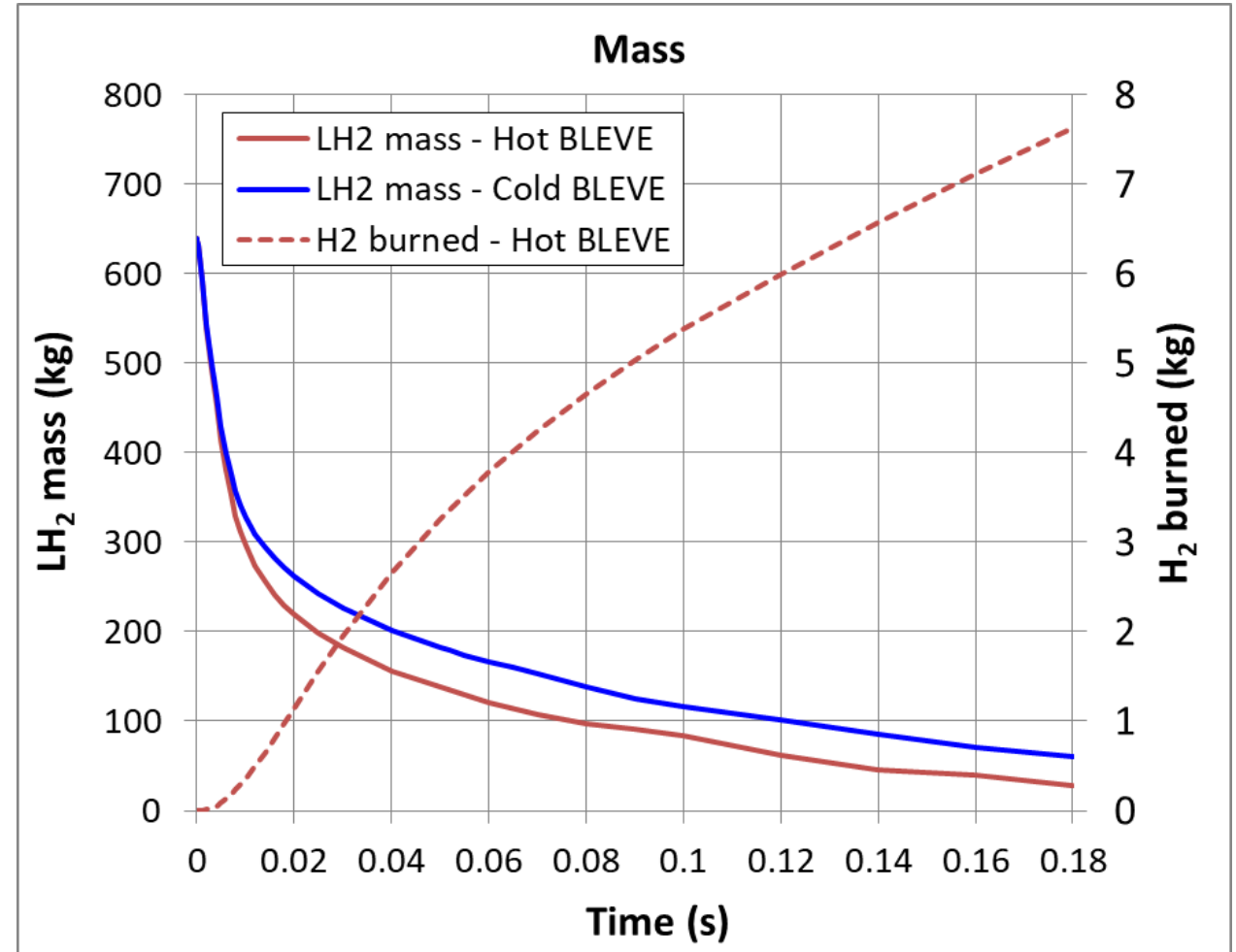
BLEVE results

**Hot BLEVE
Overpressure
contours
(pink lines:
flame front)**



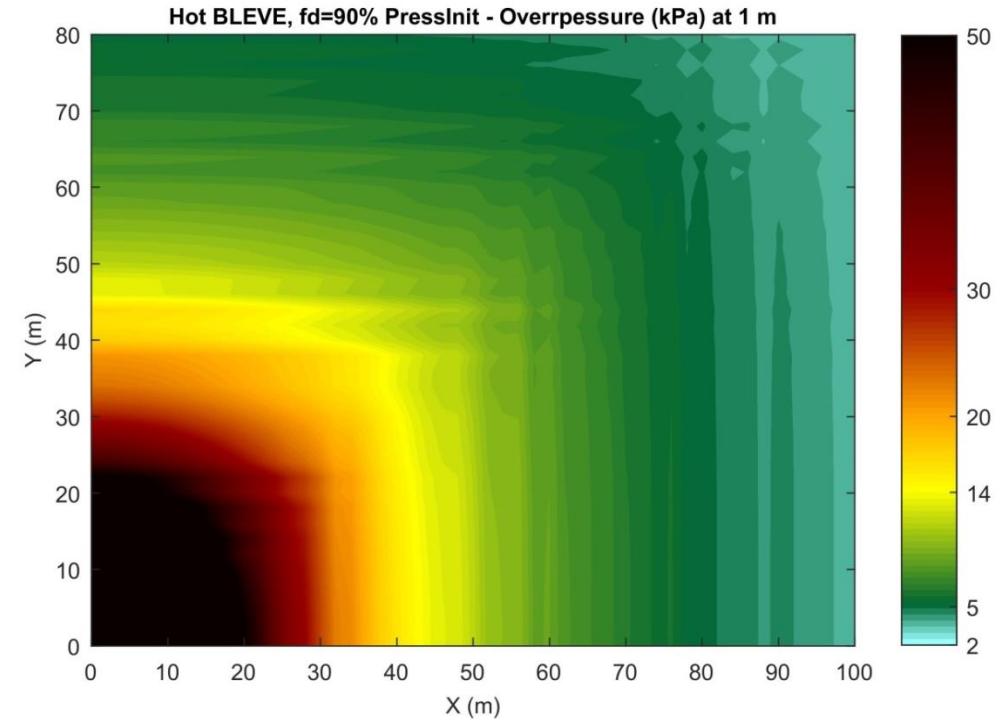
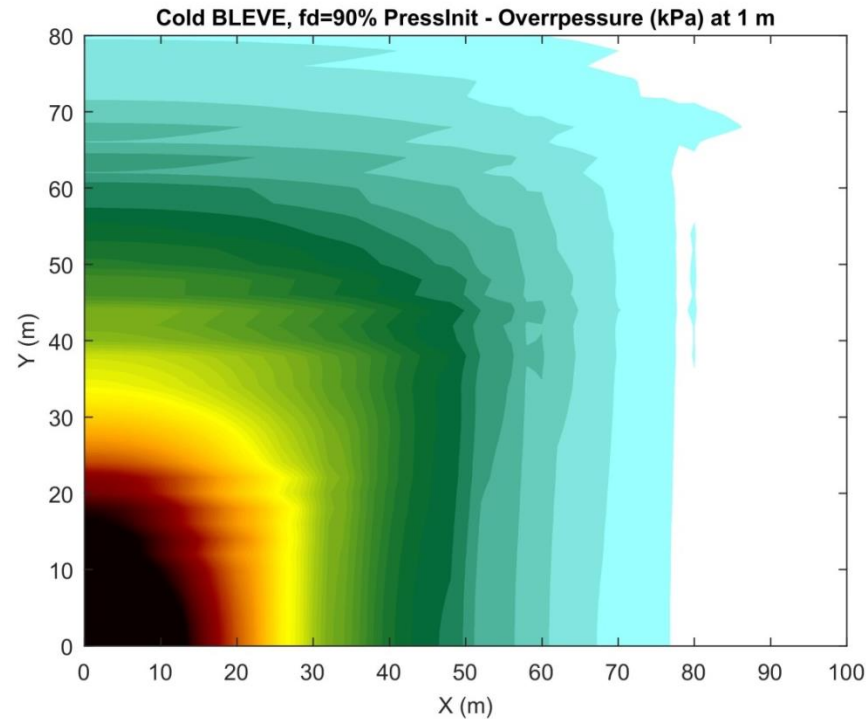
BLEVE results

- LH_2 mass and H_2 burned
- At 0.01 s half of mass has been evaporated
- More mass is evaporated in Hot BLEVE case
- Hot BLEVE:
 - At 0.04 s pressure wave separates from the F.F.
 - Only 2.6 kg of H_2 has been consumed
 - Only this small amount contributes to pressure increase compared to Cold BLEVE

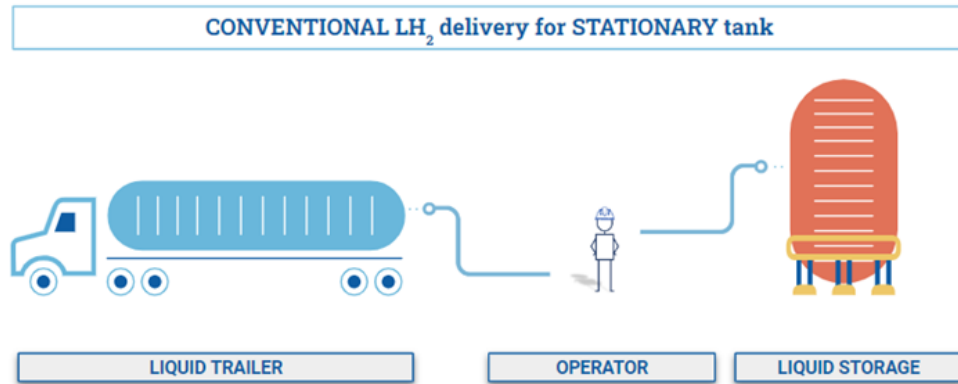


BLEVE results

- Maximum overpressure contours at $z=1$ m
 - Cold BLEVE vs. Hot BLEVE
 - Irreversible effects distance (5kPa): 60 m for Cold Bleve, more than 100 m for Hot Bleve



Hose raptures / Case study 1

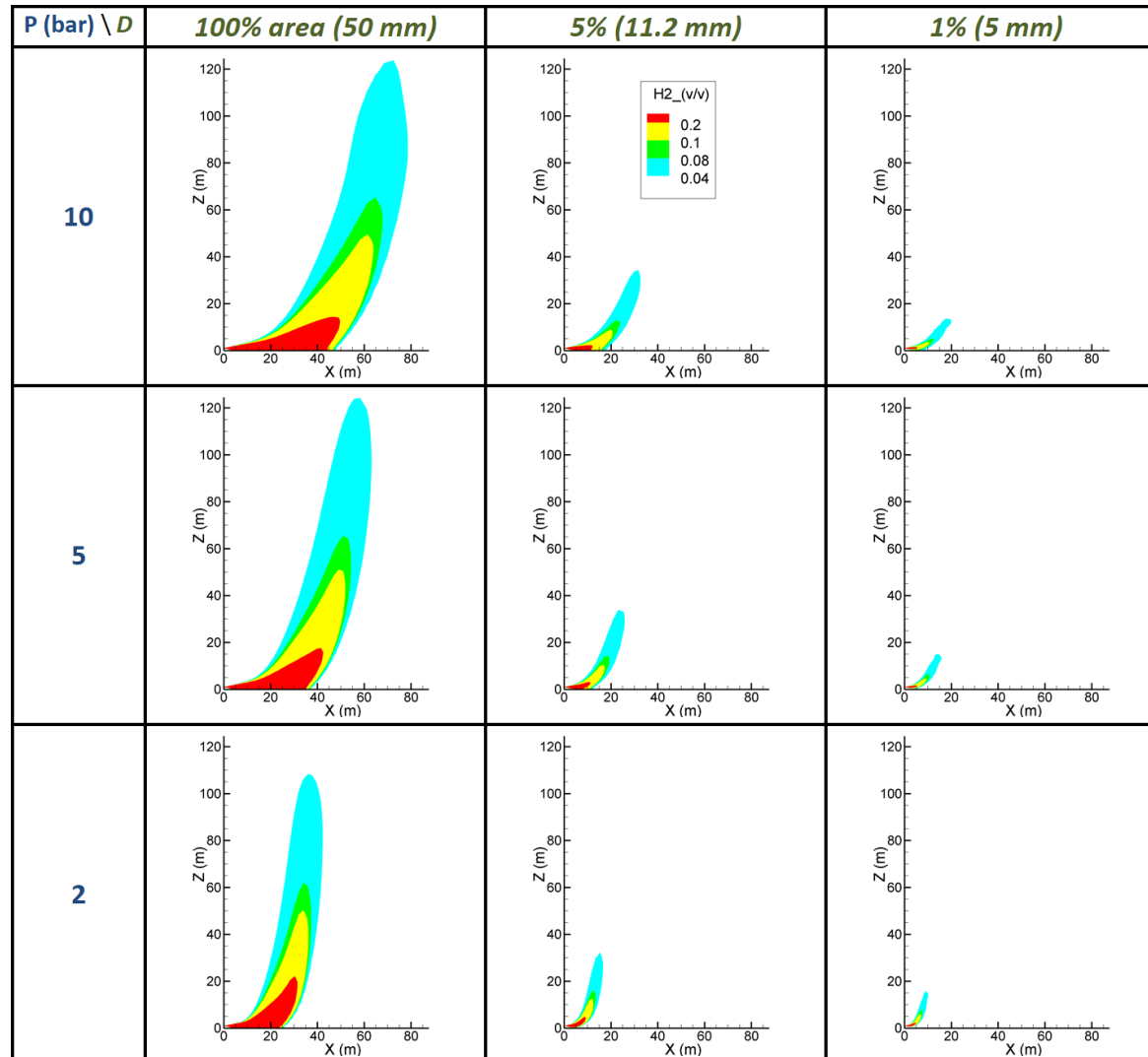


- **Case study 1:** Hose raptures during LH₂ transfer from a trailer towards stationary tank (pressure driven transfer)
- **Storage pressures:** 2, 5, 10 bars
- **Rapture diameter:** 5, 11.2, 50 mm
- **Wind speed:** 0, 3, 5 m/s
- **Phenomena:** Dispersion, Jet fire, Delayed ignition

	Pressure (bar)	Rapture diameter (mm)	Wind (m/s)	Dispersion	Jet fire	Deflagration
Case study 1	10	50	0	✓	✓	✓
	10	11.2	0	✓	✓	✓
	10	5	0	✓	✓	✓
	5	50	0	✓	✓	
	5	11.2	0	✓		
	5	5	0	✓		
	2	50	0	✓	✓	✓
	2	11.2	0	✓		
	2	5	0	✓	✓	✓
	10	50	3	✓	✓	
	10	11.2	3	✓		
	10	5	3	✓		
	5	50	3	✓		
	5	11.2	3	✓		
	5	5	3	✓		
	2	50	3	✓		
	2	11.2	3	✓		
	2	5	3	✓		
	10	50	5	✓	✓	✓
	10	11.2	5	✓		
	10	5	5	✓	✓	✓
	5	50	5	✓		
	5	11.2	5	✓		
	5	5	5	✓		
	2	50	5	✓	✓	✓
	2	11.2	5	✓		
	2	5	5	✓	✓	✓

Hose raptures / Case study 1

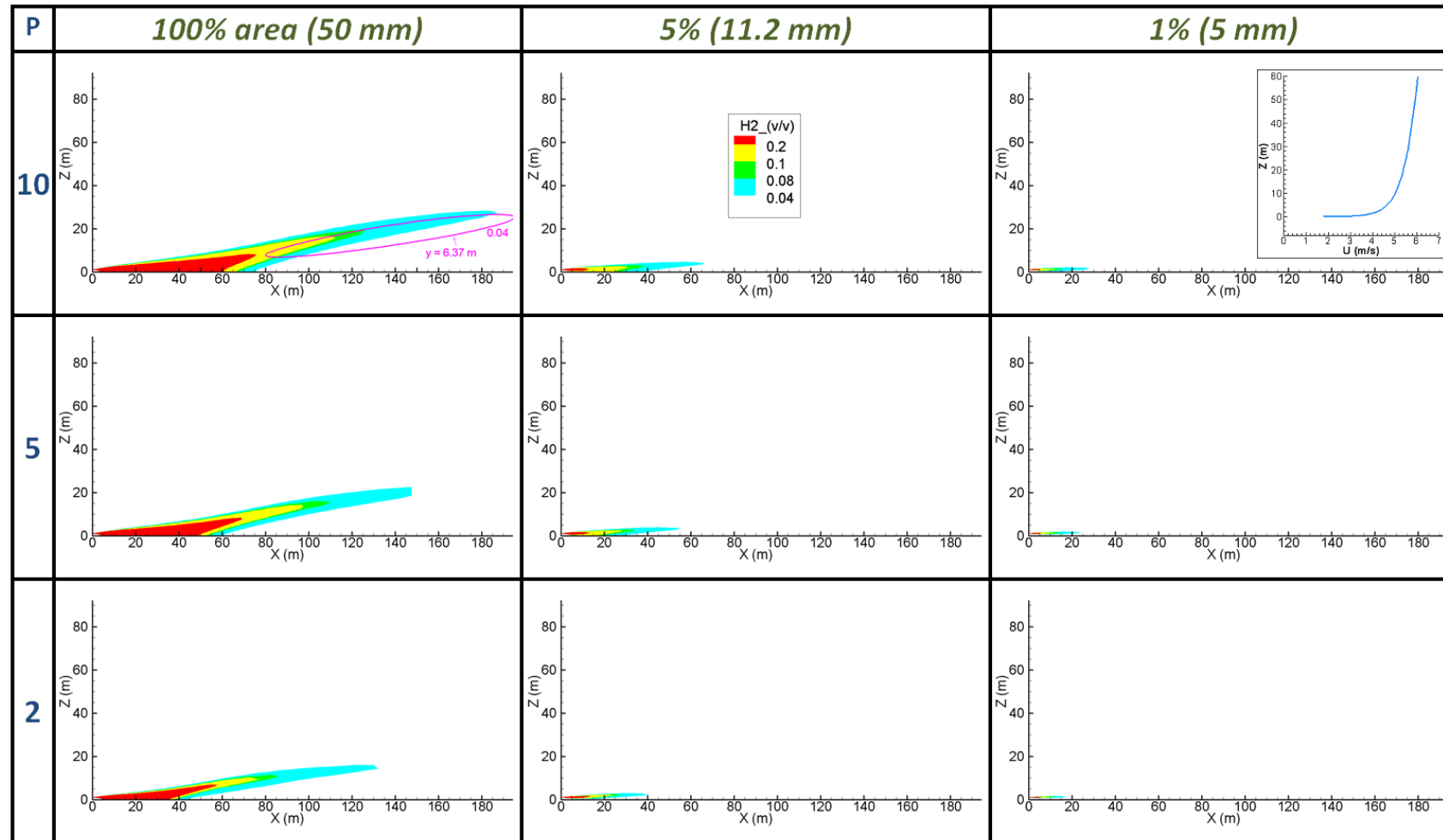
• Dispersion results, no-wind



- **Pressure decrease effect:**
 - Hazardous distance decreases
 - Slope of the cloud increases
 - Similar max. height
- **Diameter decrease effect:**
 - Hazardous distance significantly decreases
 - Slope of the cloud decreases
 - Significant decrease of max. height

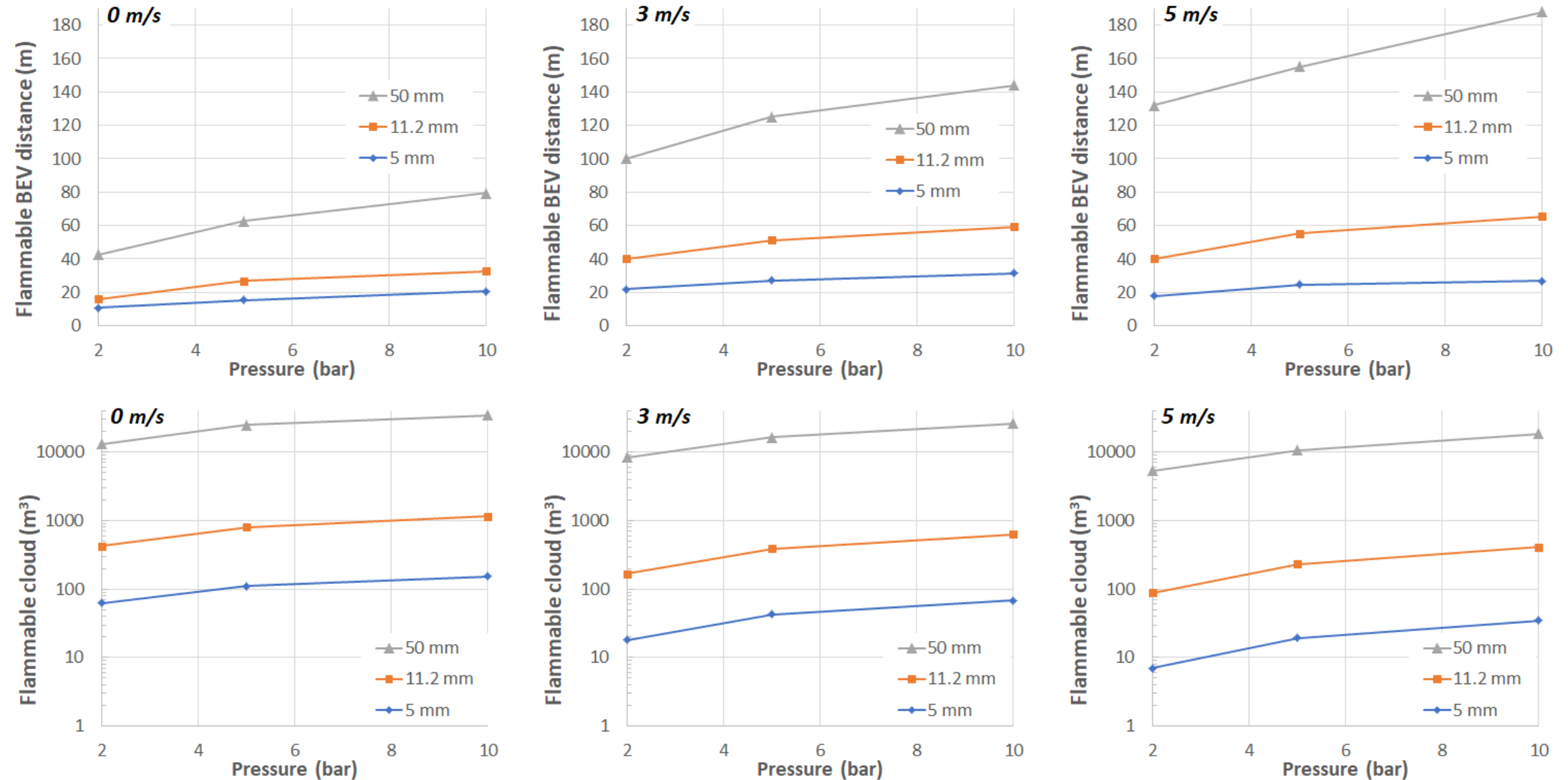
Hose raptures / Case study 1

• Dispersion results, 5 m/s wind



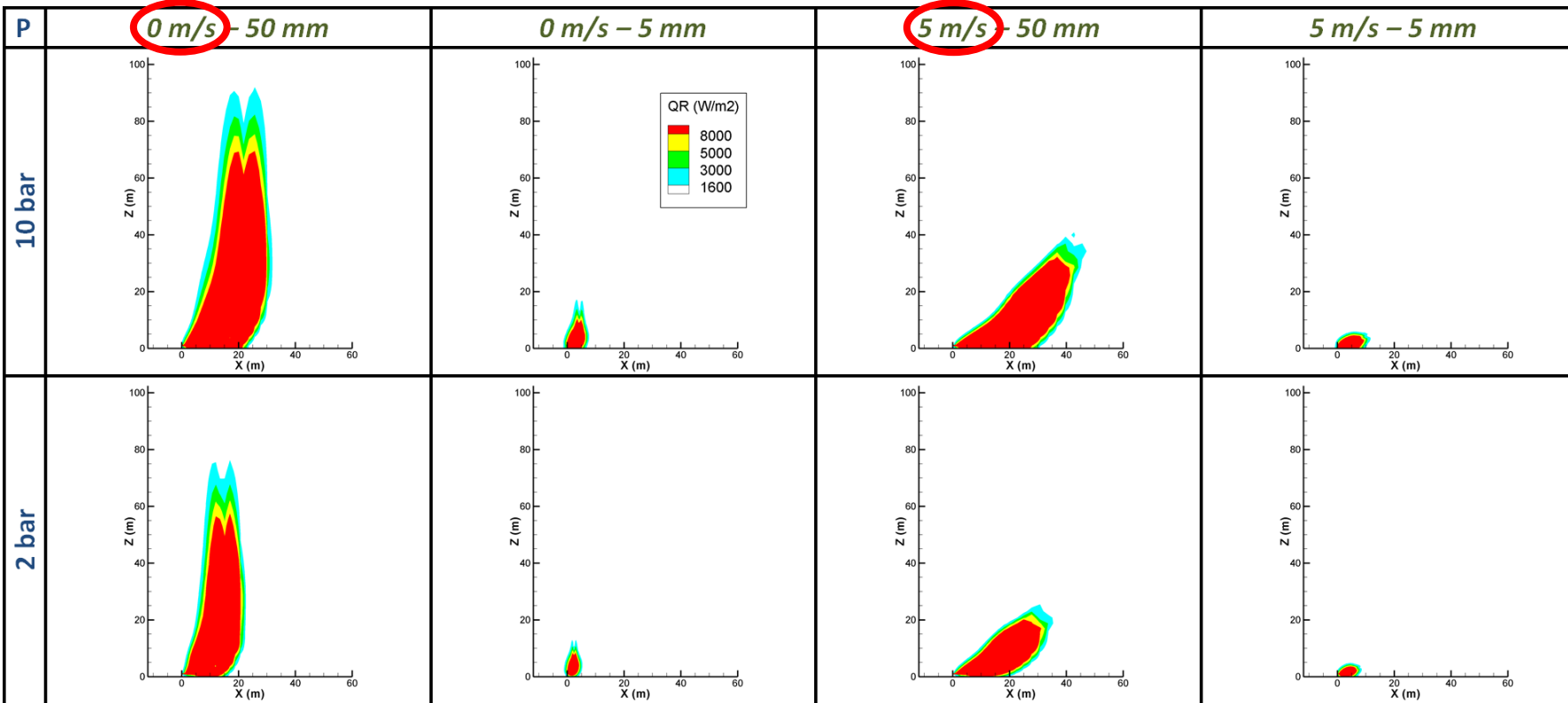
- Completely different cloud shape
 - Smaller height
- BEV distances increase (e.g. 185 vs. 80 m)
 - Max. BEV distance may be outside symmetry plane
- Cloud volume decreases
- Diameter is again critical

Case study 1 – dispersion summary



Hose raptures / Case study 1

• Jet fire results



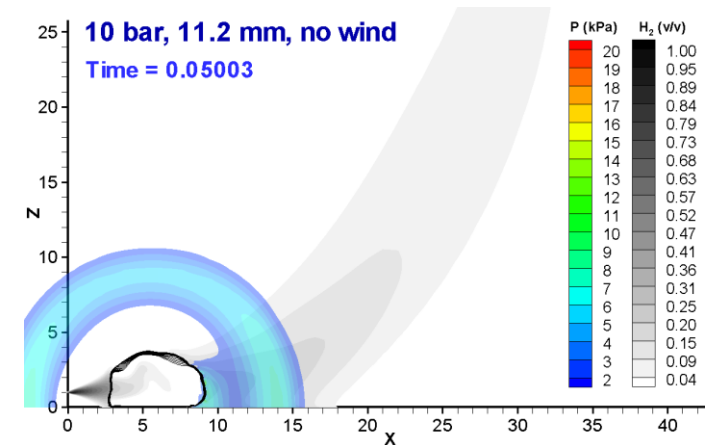
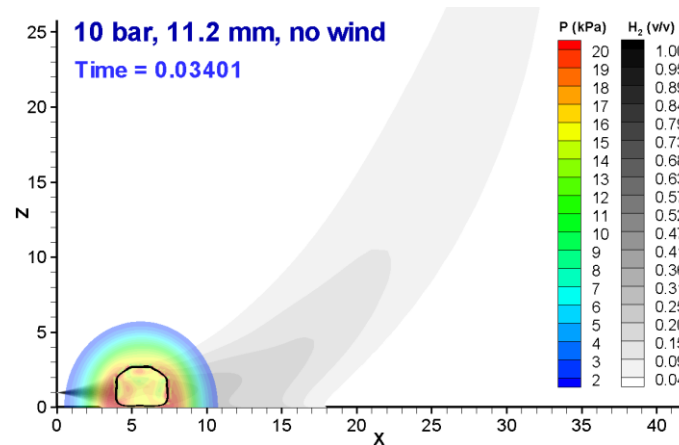
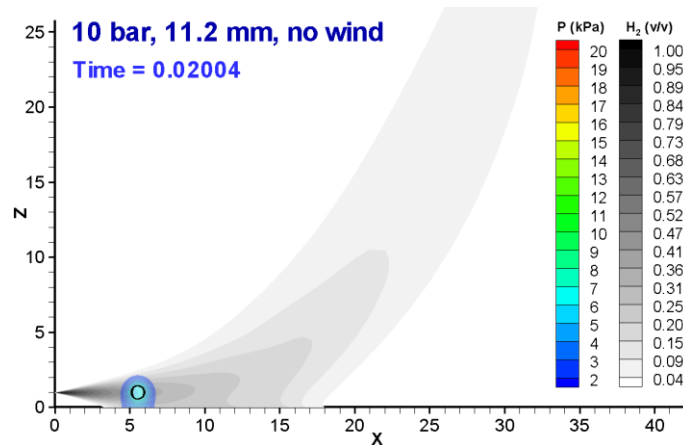
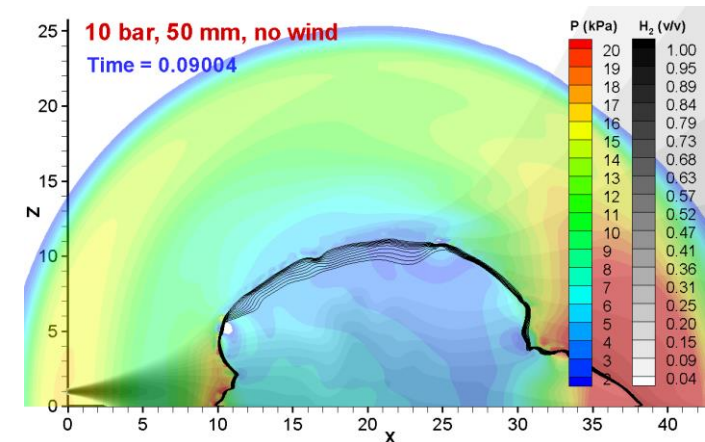
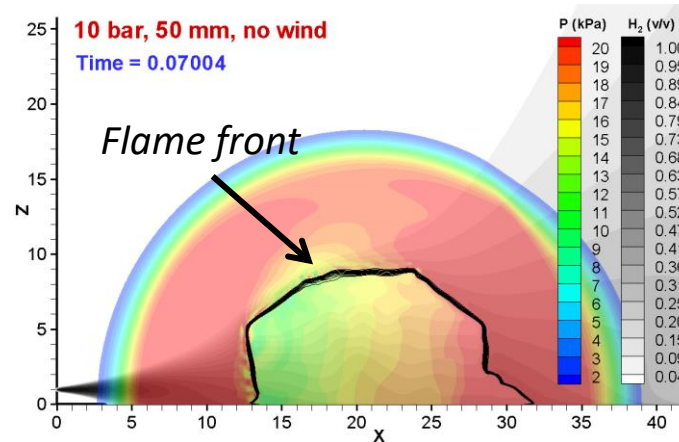
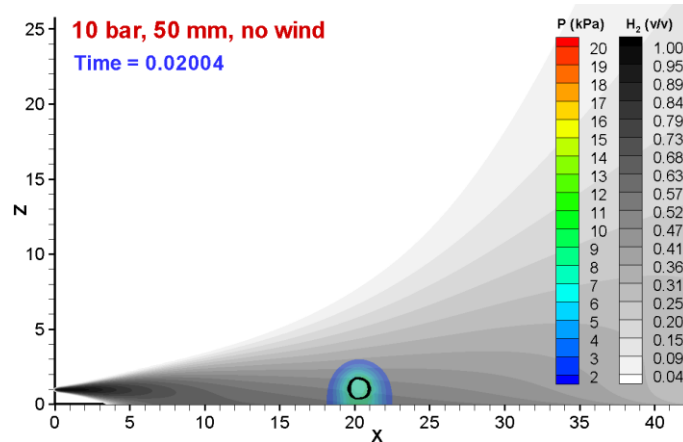
Indirect effects: 1600 W/m²
Irreversible effects: 3000 W/m²
First lethal effects: 5000 W/m²
Significant lethal effects: 8000 W/m²

- Similar shapes in **10 and 2 bar** cases
- The effect of **release diameter** is large, both under windy and stagnant conditions
- The **effect of wind** is the tilting of the plume axis
 - indirect-effects distance increases in x-axis and decreases in z-axis compared to the no wind case

Hose raptures / Case study 1

- Delayed ignition results

Indirect effects: 2 kPa
 Irreversible effects: 5 kPa
 First lethal effects: 14 kPa
 Lethal effects: 20 kPa



- Release diameter reduction, severely decreases max. overpressure and hazardous distances

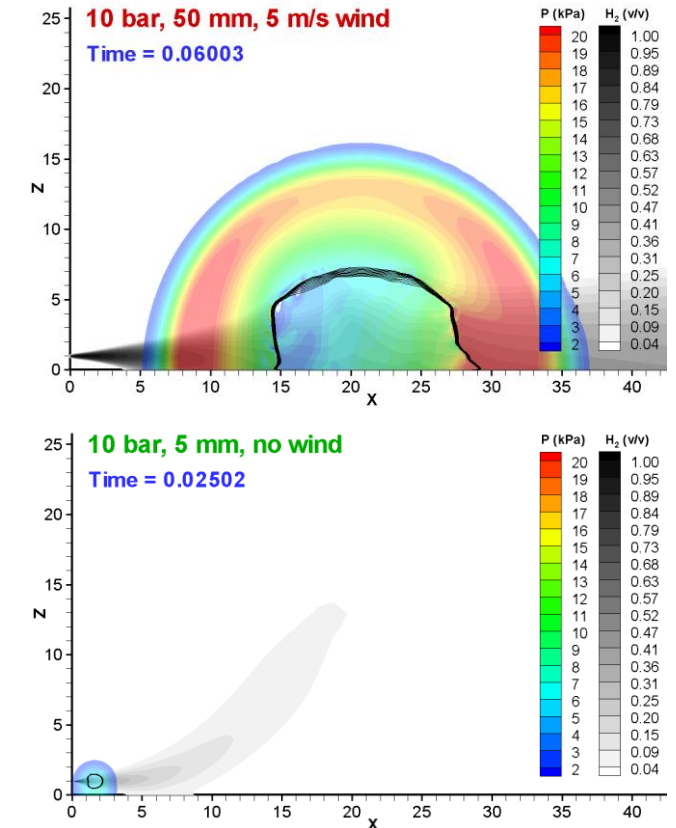
Hose raptures / Case study 1

- Delayed ignition results

Hazardous distances at z=1 m for all examined scenarios

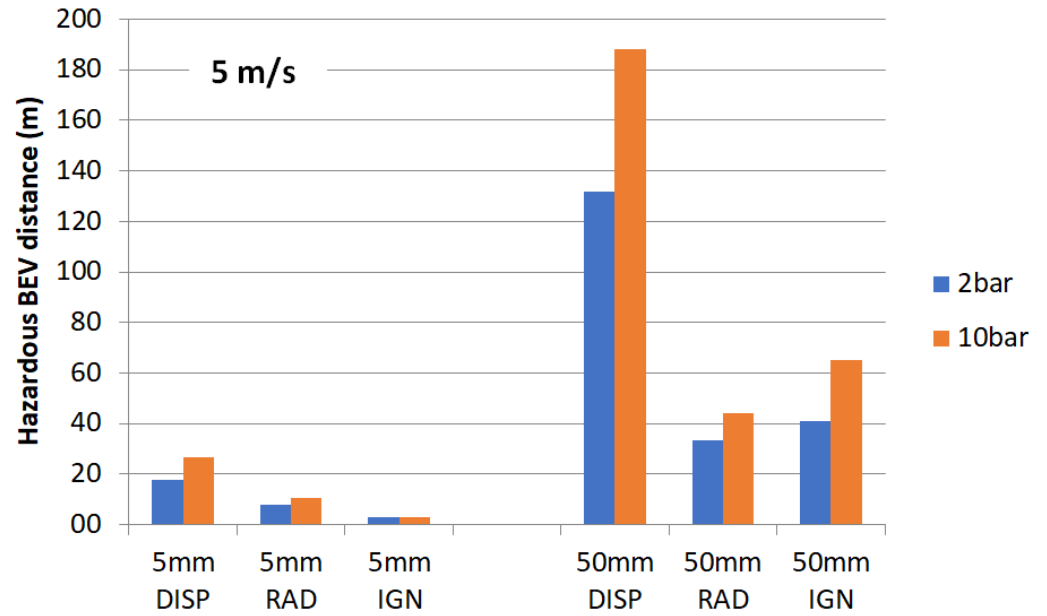
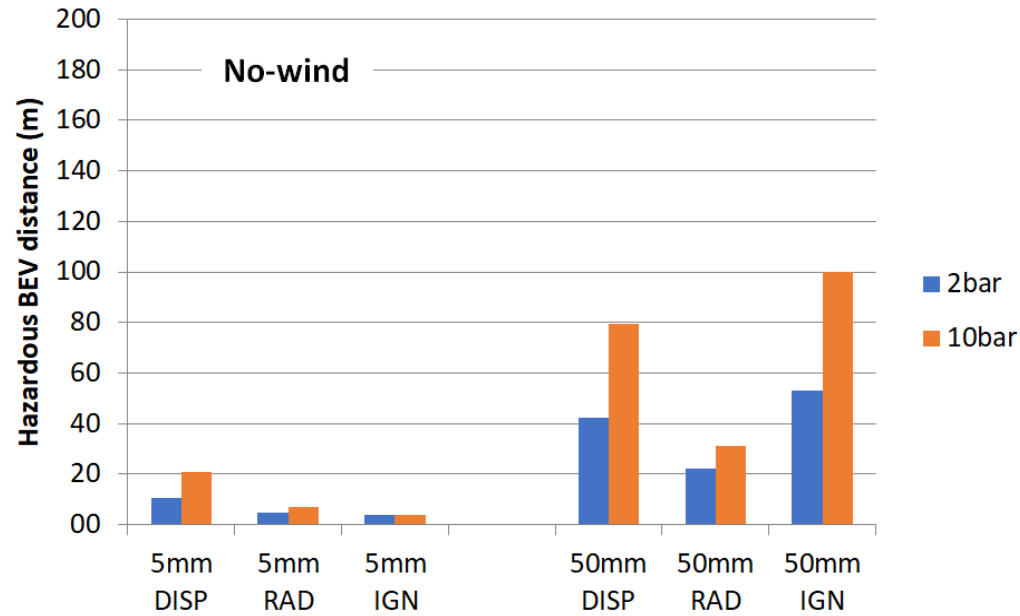
Deflagration overpressures	2 kPa	5 kPa	14 kPa	20 kPa
10 bar, 50 mm, no wind	160 m	100 m	62 m	53 m
2 bar, 50 mm, no wind	136 m	82 m	53 m	48 m
10 bar, 11.2 mm, no wind	30 m	18 m	10 m	8 m
10 bar, 5 mm, no wind	6 m	3 m	-	-
2 bar, 5 mm, no wind	5.5 m	3 m	-	-
10 bar, 50 mm, 5 m/s wind	96 m	65 m	41 m	36 m
2 bar, 50 mm, 5 m/s wind	57 m	41 m	27 m	25 m
10 bar, 5 mm, 5 m/s wind	6 m	3 m	-	-
2 bar, 5 mm, 5 m/s wind	5.5 m	3 m	-	-

- Wind reduces the overpressure (different initial cloud)
- Small leaks (5 mm) result in extremely smaller hazardous distances



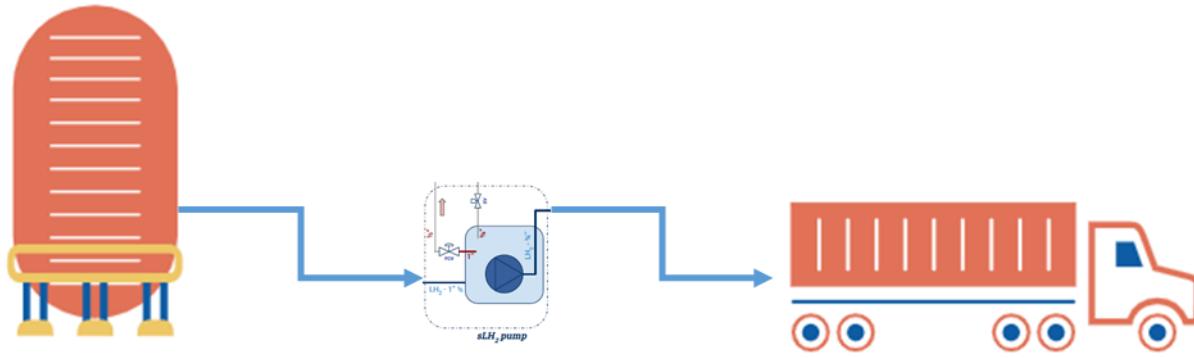
Hose raptures / Case study 1

- Comparison of hazardous distances for all phenomena (*distances for irreversible effects*)



- Release diameter the most critical parameter
- Existence of wind also critical
- Longer hazardous distances those of dispersion, except of the 10 bar 50 mm no-wind case
- Longer hazardous distance values
 - No-wind: 100 m
 - Wind: 185 m

Hose raptures / Case study 2

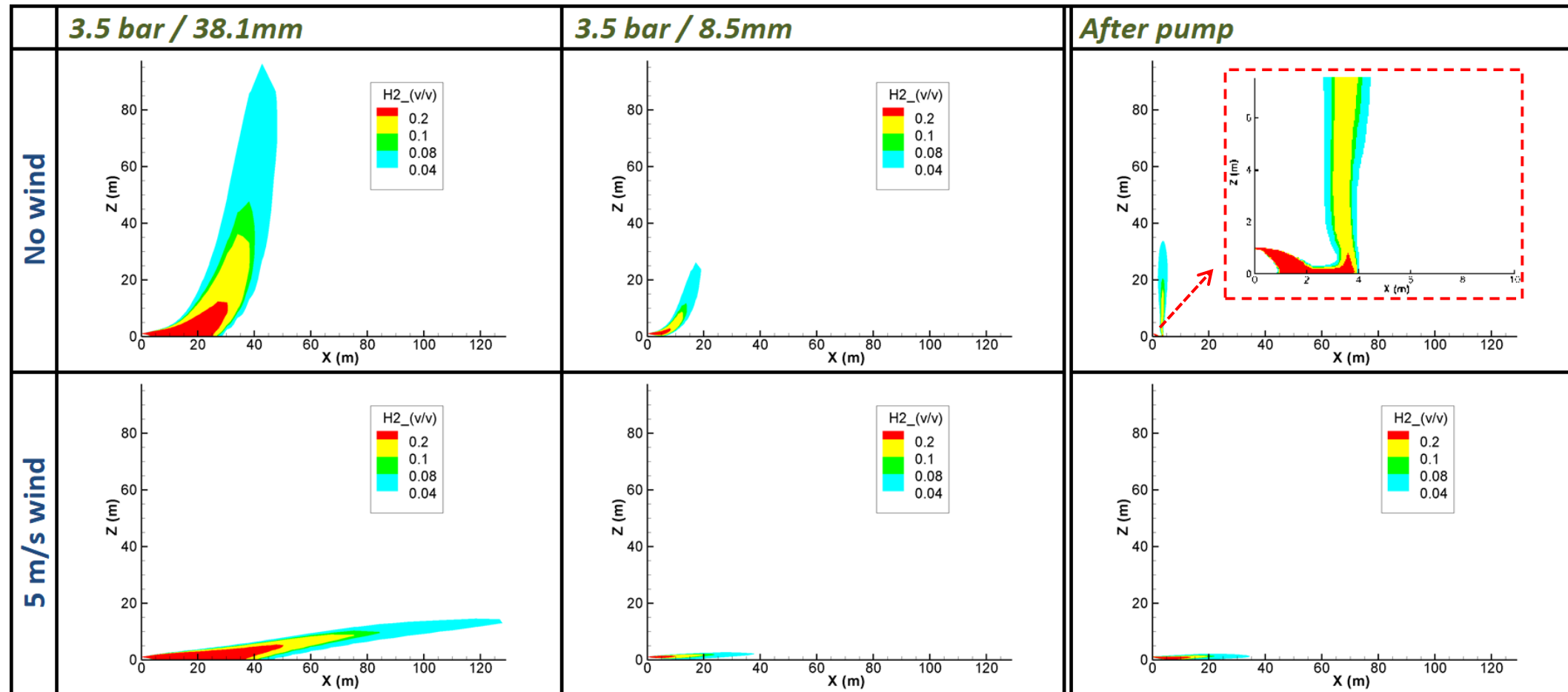


- **Case study 2:** Hose raptures during filling of a mobile heavy duty truck from a stationary tank (pump driven transfer)
- **Before pump:** 3.5 bars, 8.5 mm or 38.1 mm
- **After pump:** 20 bar, 25.4 mm
- **Wind conditions:** 0, 5 m/s
- **Phenomena:** Dispersion, Jet fire, Delayed ignition

	Pressure (bar)	Rapture diameter (mm)	Wind (m/s)	Dispersion	Jet fire	Deflagration
Case study 2	3.5 (before pump)	38.1	0	✓	✓	✓
	3.5 (before pump)	8.5	0	✓	✓	✓
	3.5 (before pump)	38.1	5	✓	✓	✓
	3.5 (before pump)	8.5	5	✓	✓	✓
	20 (after pump)	25.4	0	✓	✓	✓
	20 (after pump)	25.4	5	✓	✓	✓

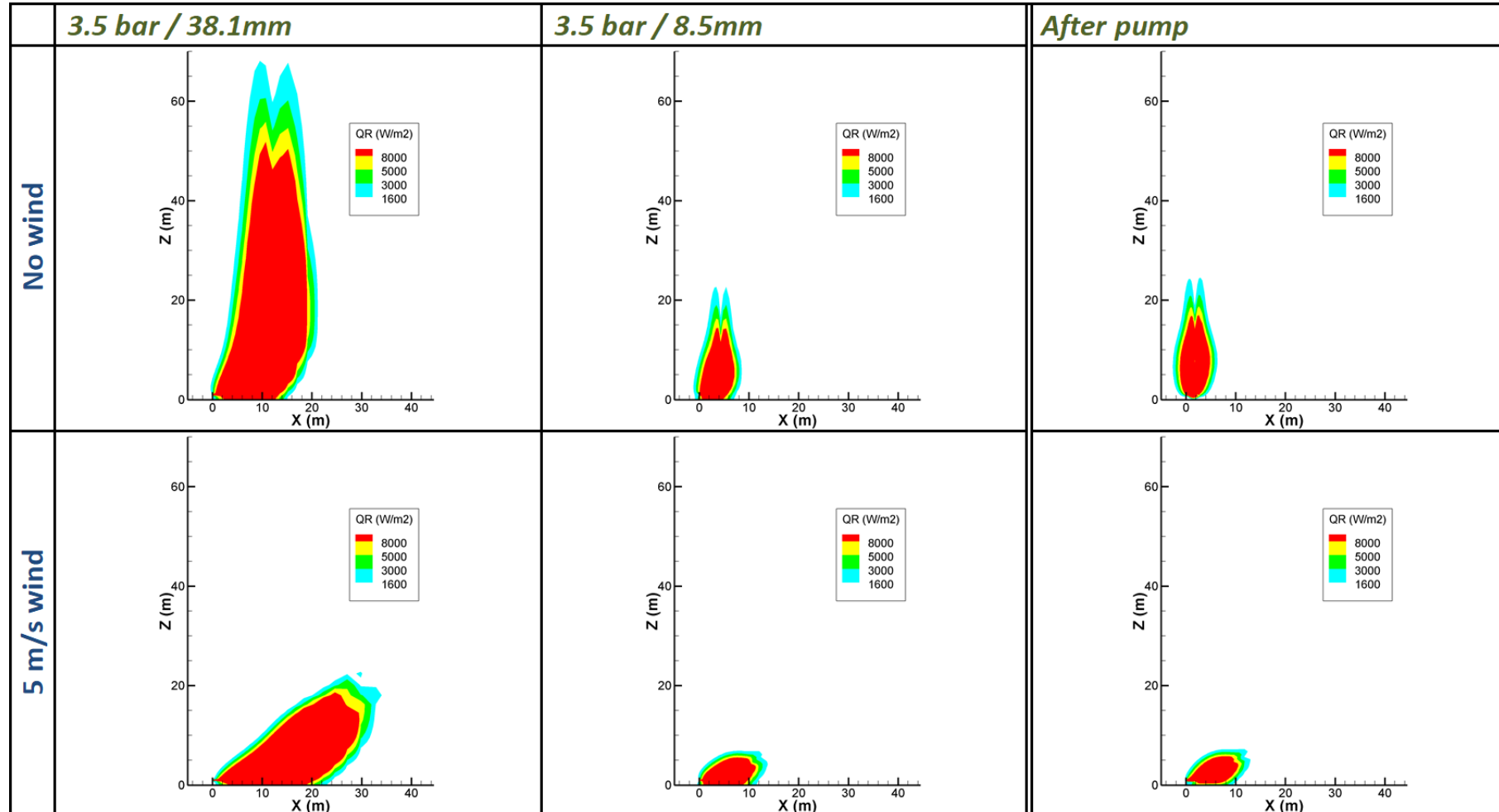
Hose raptures / Case study 2

- Dispersion results



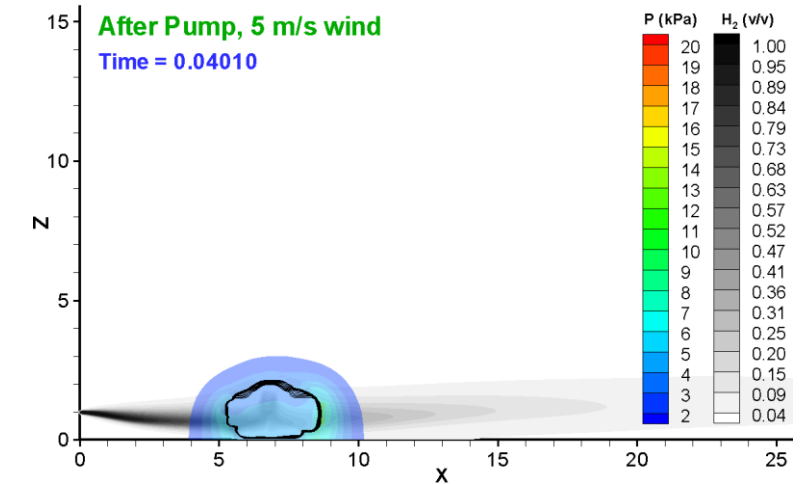
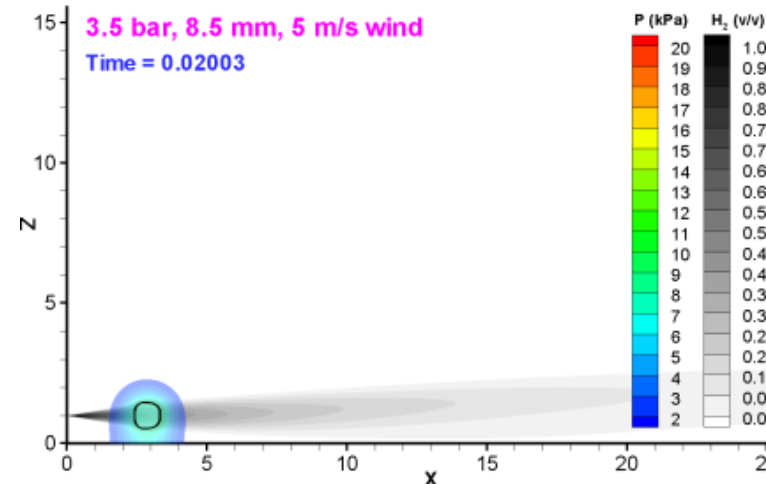
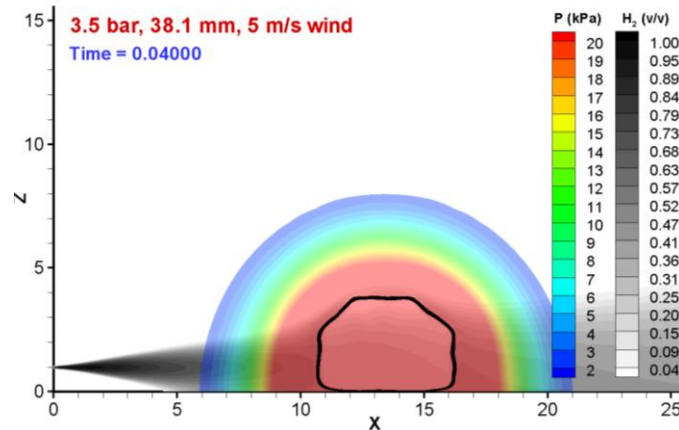
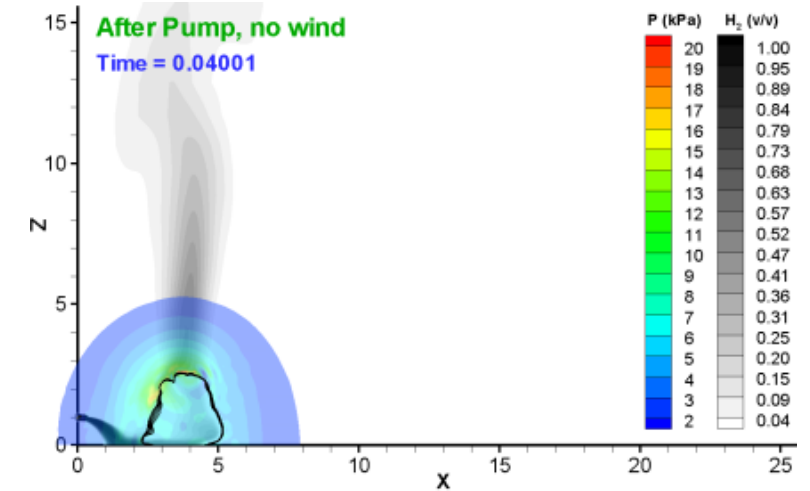
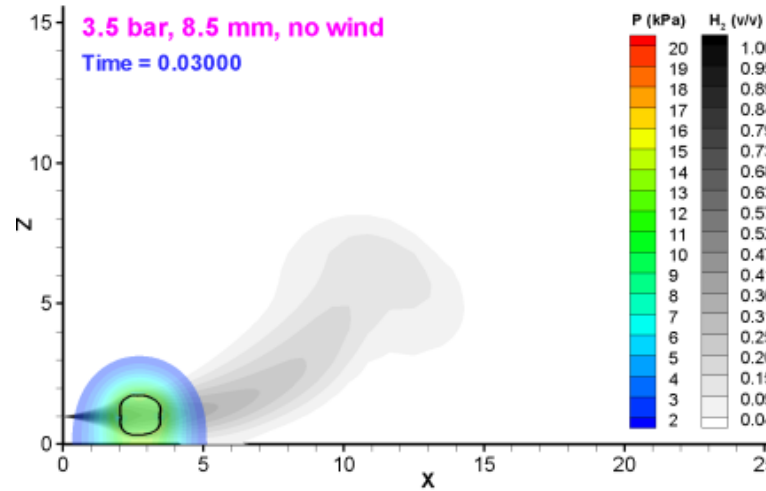
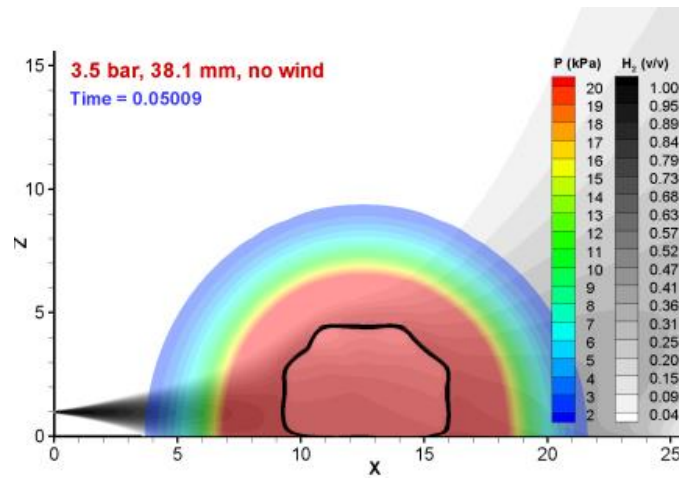
Hose raptures / Case study 2

- Jet fire results



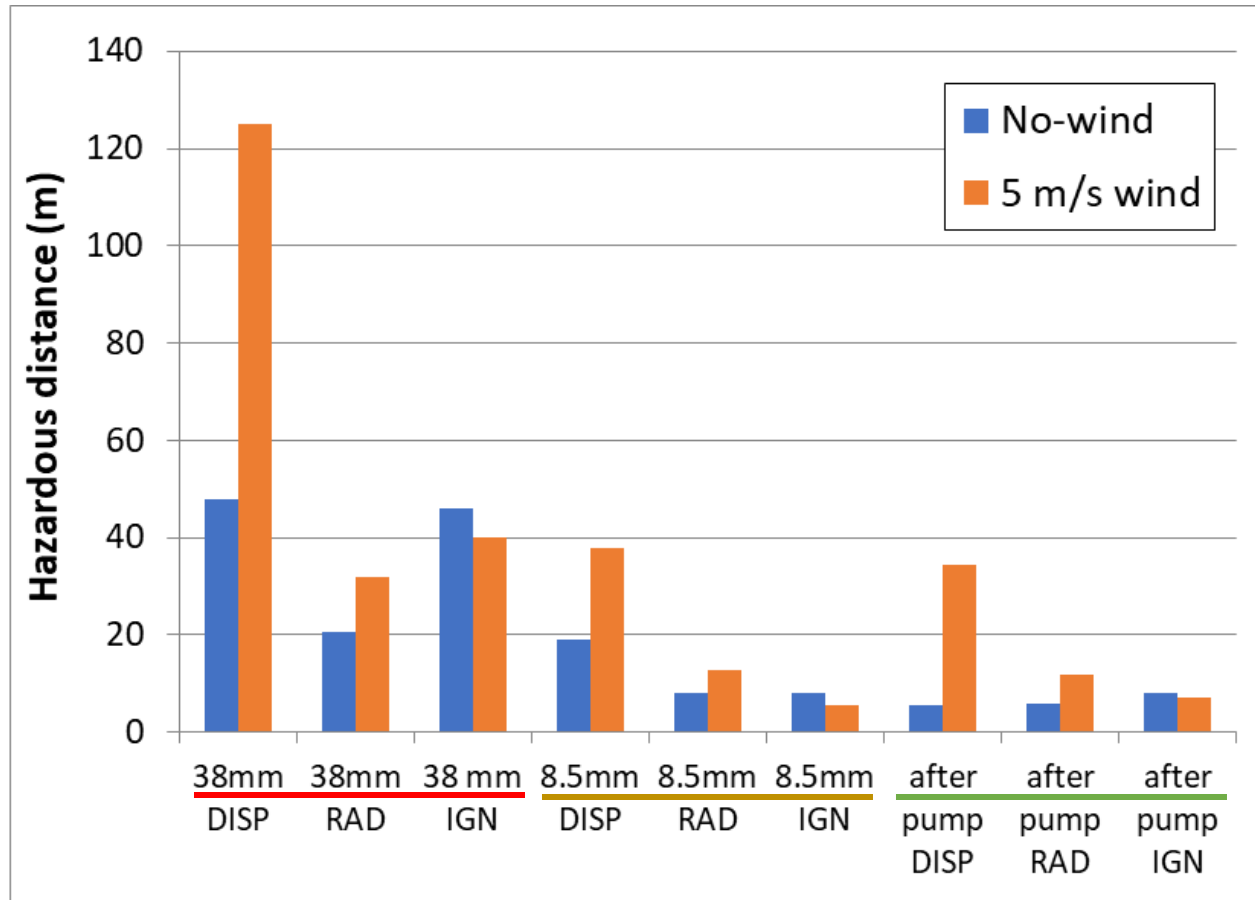
Hose raptures / Case study 2

- Delayed ignition results



Hose raptures / Case study 2

- Comparison of hazardous distances for all phenomena (*distances for irreversible effects*)



- Release diameter the most critical parameter
- Existence of wind also critical
- Longer hazardous distances those of dispersion
 - Up to about 3 times longer in case of wind
- After pump similar results to small rupture (except of dispersion due to less horizontal spreading)

Conclusions

- **BLEVE**

- Overpressure can be up to 2.7 times higher in Hot BLEVE compared to Cold
- Only a small amount of hydrogen contributes to this significant increase
- Hazardous distances (5 kPa): 60 m (Cold BLEVE), 100 m (Hot BLEVE)

- **Hose raptures**

- The release diameter the most critical parameter
- Hose pressure less critical
- Wind severely changed the dispersion field but was beneficial in case of ignition
- Maximum hazardous distances (D=50 mm): 100 m (no wind)/ 185 m (5 m/s)
- Radiation hazard was never worst than both dispersion and delayed ignition
- Dispersion the most critical to examine in most cases

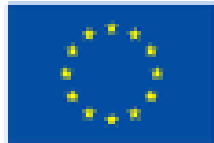


Thank you for your attention



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