MOVING TOWARDS RISK ANALYSIS FOR LH2 TRANSFER OPERATIONS:

A CONSEQUENCE ASSESSMENT FOR LH_2 TRANSFER OPERATIONS

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UK Research and Innovation

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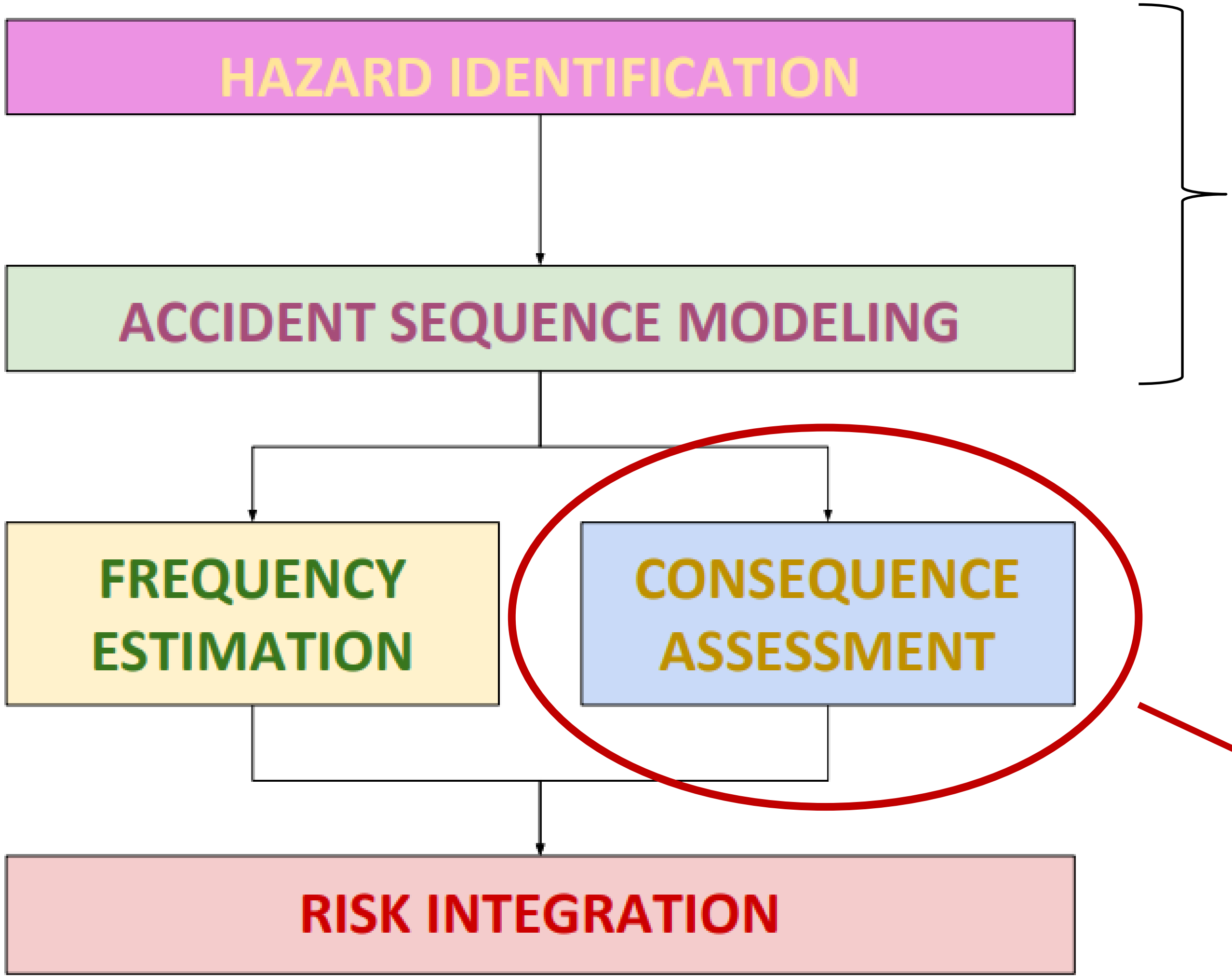
Quantitative risk assessment steps

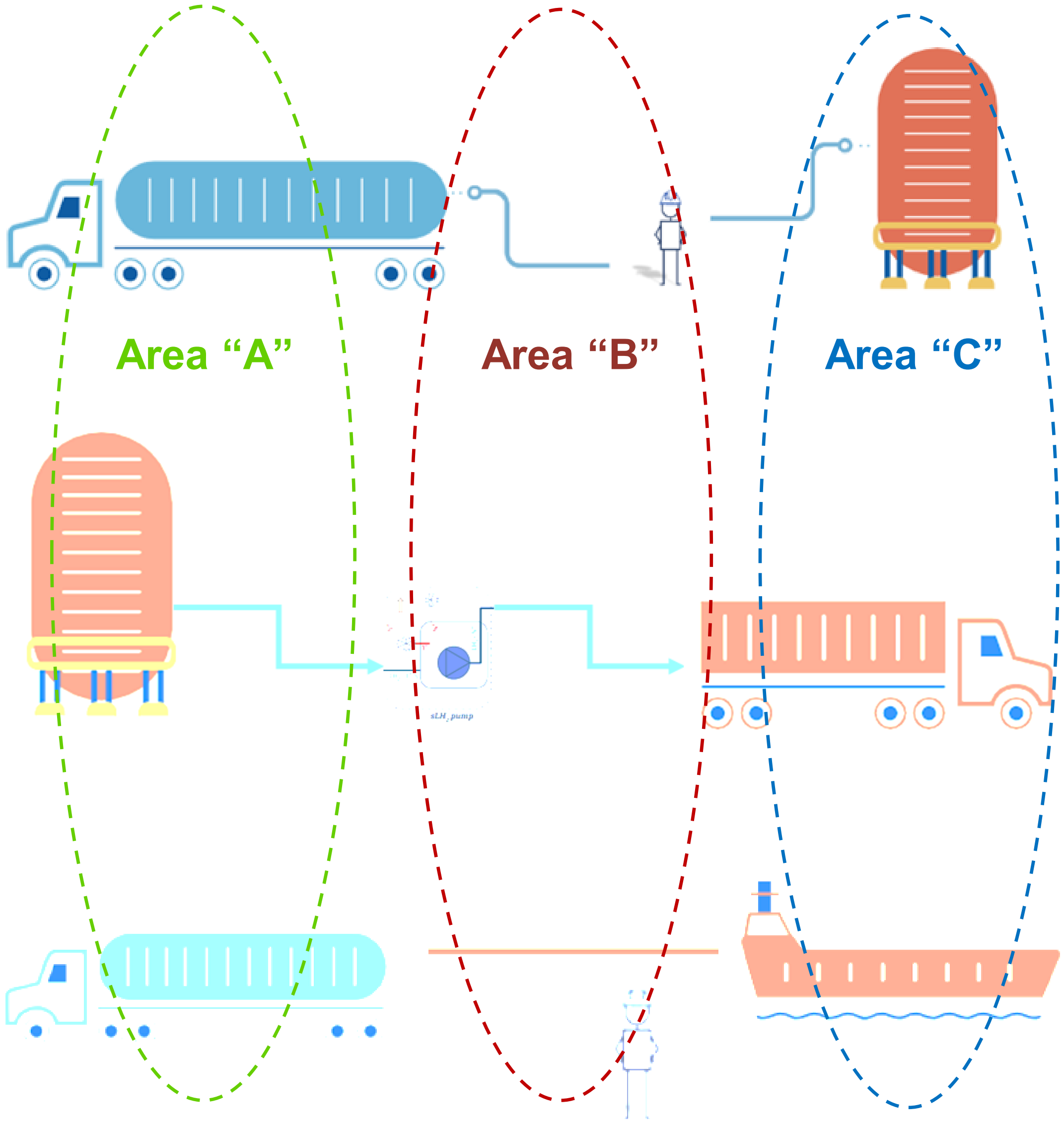


These steps helped in defining the <u>scenarios</u> to be studied for the case studies that the ELVHYS project needs to examine

Rest of the presentation

Case studies

- Case study **1**: Transfer of LH2 from a **trailer** to a **stationary tank**
- Case study **2**: Transfer of LH2 from stationary **tank** to an LH2 heavy duty **truck**
- Case study **3**: Transfer of LH2 from a **trailer** to an LH2 **vessel** (ship)



Case study 1-scenarios to be presented

AREA B

Pressure	Hose area	Wind speed	Geometry
10 bar	100%	0 m/s	no obstacles
5 bar	5%	5 m/s stab. D	
2 bar	1%	3 m/s stab. F	

Phenomena examined

Unignited dispersion (in order to assess the flammability limits)
Jet fire (ignited jet in order to assess the radiation effects)
Deflagration (delayed ignition in order to assess the overpressure)

AREA C

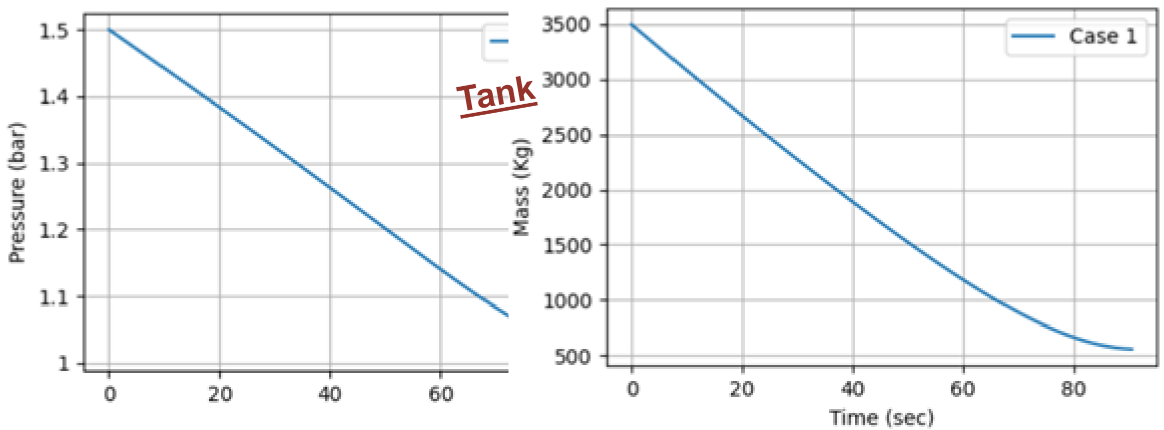
Unignited dispersion (in order to assess the flammability limits)

Case study 1 – release conditions

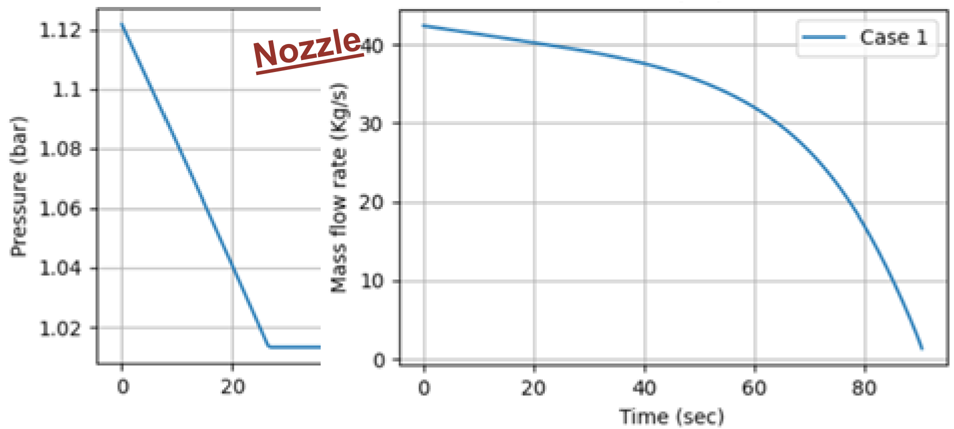
- Release conditions calculated with DISCHA tool

Area B

Stagnation conditions			Nozzle exit conditions								Fictitious nozzle conditions (Ma = 1, Total enthalpy = ct)						
P0 (bar)	T0 (K)	Vapor quality X0	Mass flux (kg/m2/s) G1	P1 (bar)	T1 (K)	X1	RHO1 (kg/m3)	Vel (m/s)	Diam (mm)	mfr (kg/s)	P2 (bar)	T2 (K)	X2	VOID2	RHO2	Vel (m/s)	Diam (mm)
10	31.39	0.00	3973.33	6.33	28.57	1.625E-01	28.511	139.360	50.0	7.802	1.013	20.369	3.57E-01	9.67E-01	3.61	179.31	123.91
									11.2	0.390							27.71
									5.0	0.078							12.39
5	27.24	0.00	2805.26	3.39	25.27	6.467E-02	33.028	84.935	50.0	5.508	1.013	20.369	1.79E-01	9.21E-01	6.85	120.94	92.02
									11.2	0.275							20.58
									5.0	0.055							9.20
2	22.91	0.00	1618.68	1.46	21.68	2.894E-02	33.825	47.855	50.0	3.178	1.013	20.369	5.73E-02	7.64E-01	17.75	62.20	60.55
									11.2	0.159							13.54
									5.0	0.032							6.05



Area C

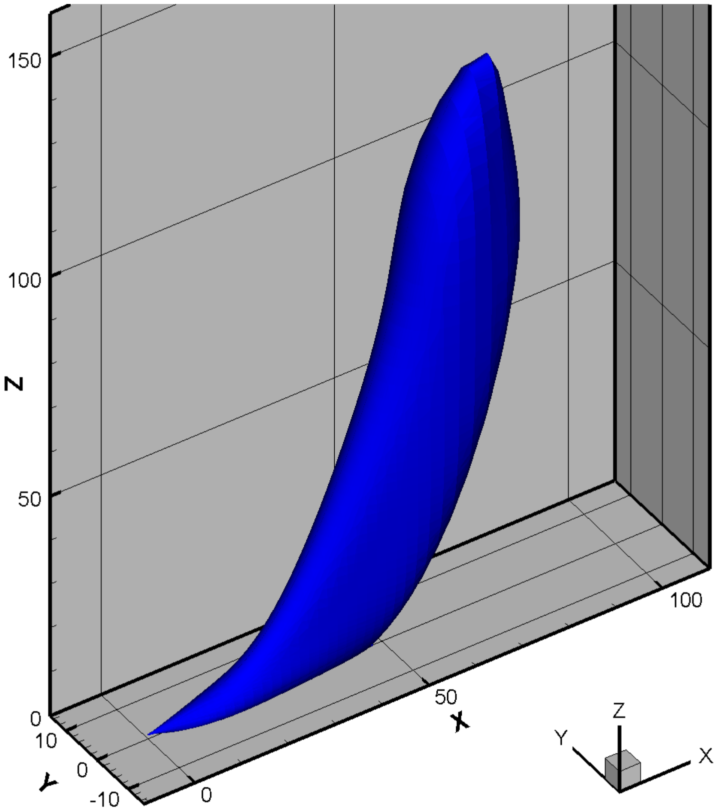


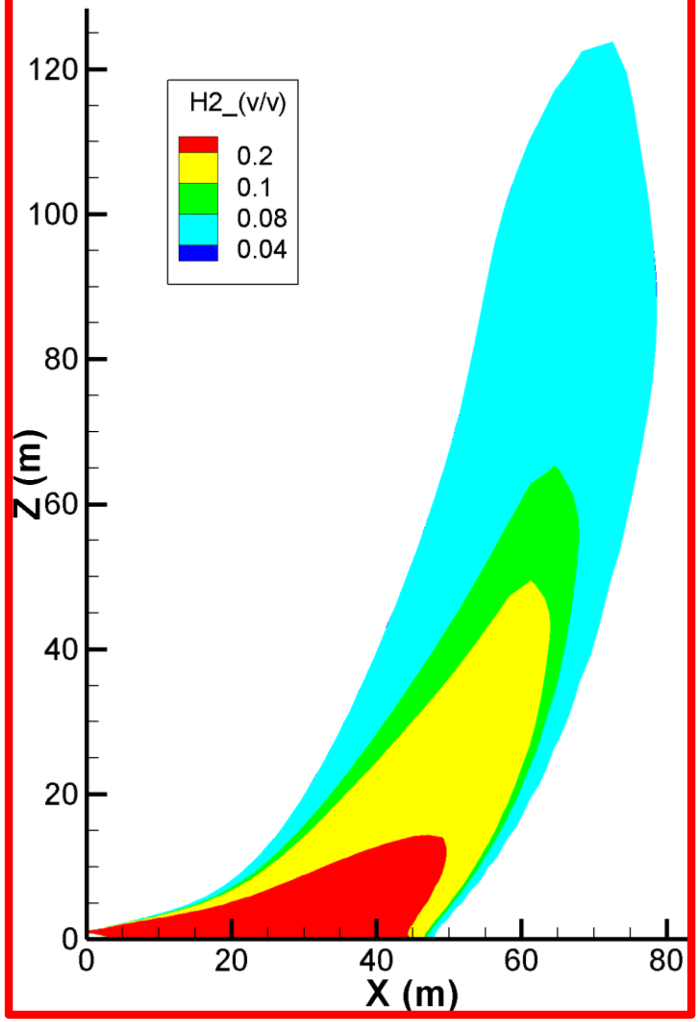
AREA B – ADREA-HF setup

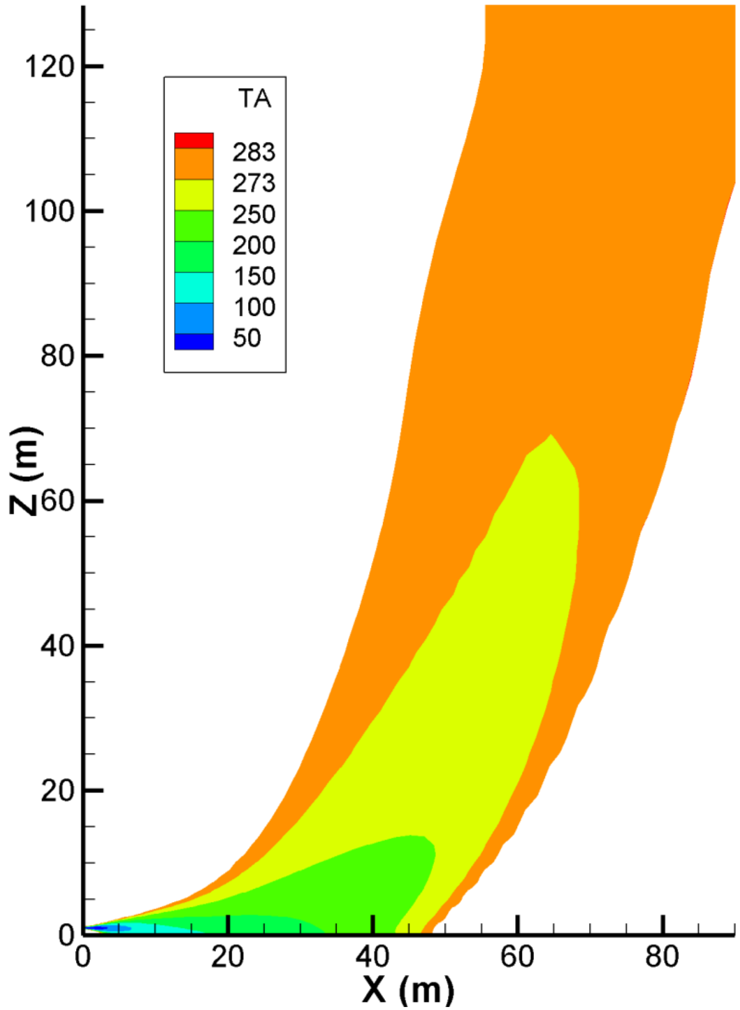
- Base case (10 bar, 50 mm hose rupture, 0 m/s wind)
  - 50% relative humidity
  - Horizontal release from z=1 m
  - Steady state RANS run
    - Symmetry
    - ~300 000 cells of half domain
    - Initial *k* 0.01 m^2/s^2
    - Heat transfer within ground (concrete, z_0=0.001 m)
    - 4 cells discretization of source
  - Source details from DISCHA
    - Fictitious nozzle model: Total enthalpy constant and Mach=1 (two phase conditions)
    - Fictitious nozzle area ~0.0121 m^2
    - Exit velocity ~179 m/s
    - Void fraction ~0.965

Dispersion – base case (10 bar, 50 mm)

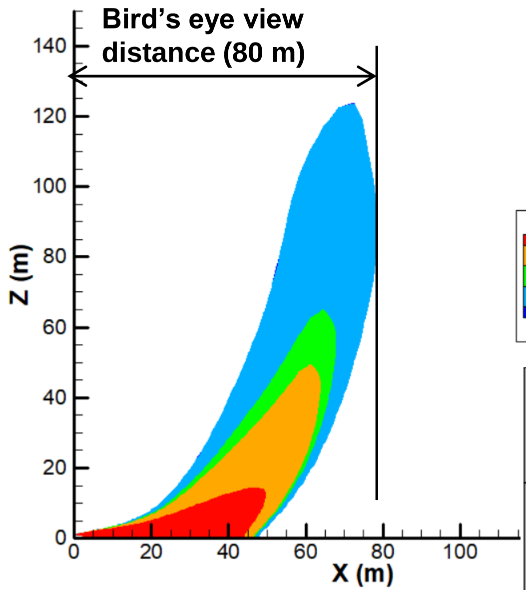
Flammable isosurface
123 kg, 17000 m³

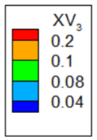




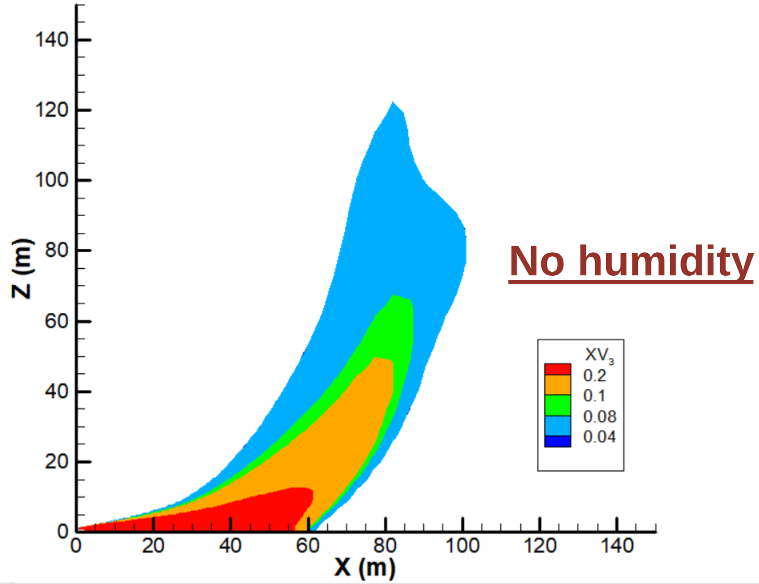


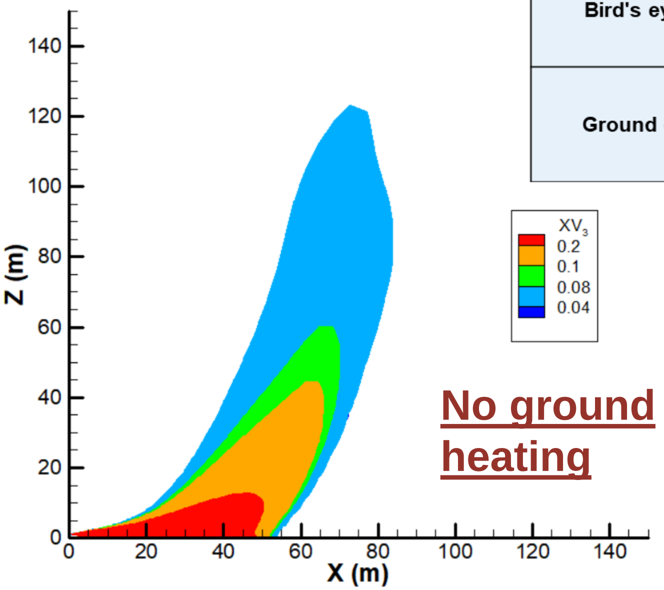
Base case results (10 bar, 50 mm)

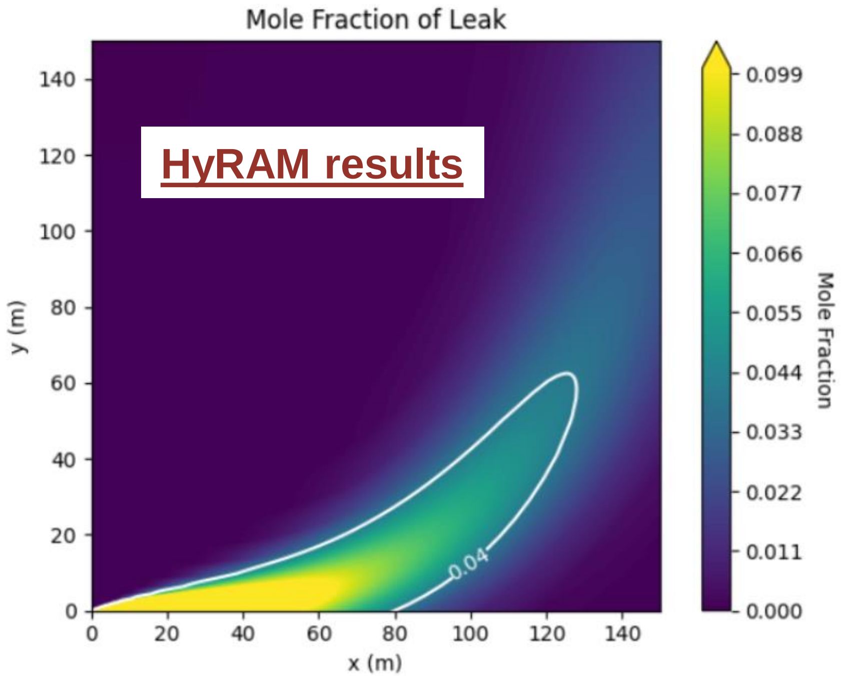




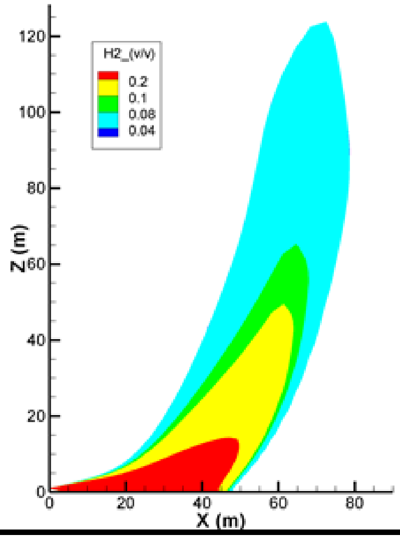
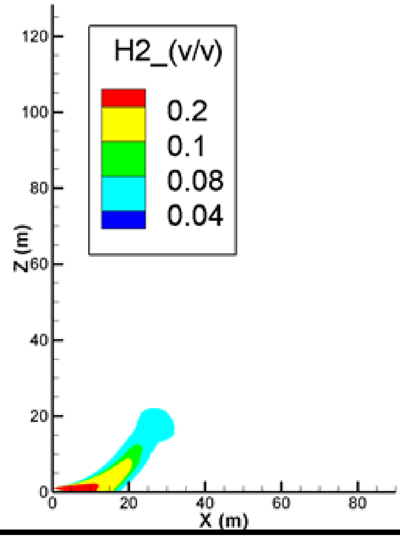
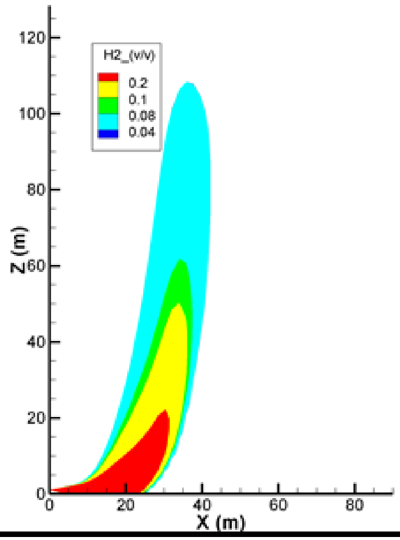
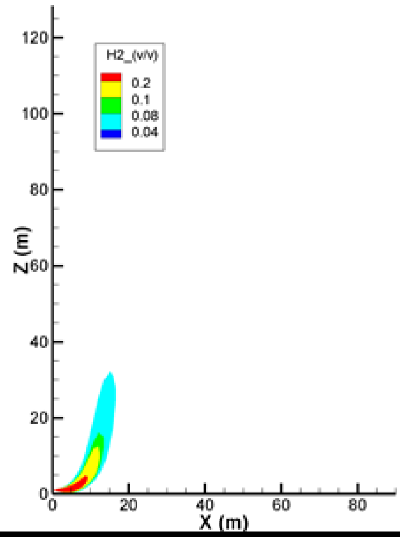
Horizontal hazardous distances (m)	ADREA	ADREA-dry	AL	HyRAM
Bird's eye view to 4% v/v H2	80	101	130	128
Bird's eye view to 10%	64	82	52	66
Ground distance to 4%	48	62		80





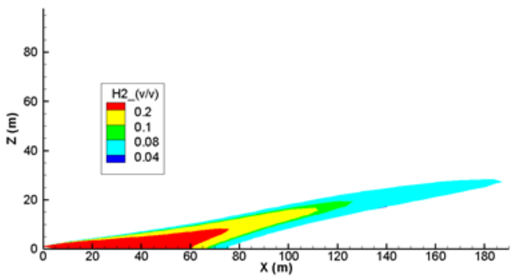
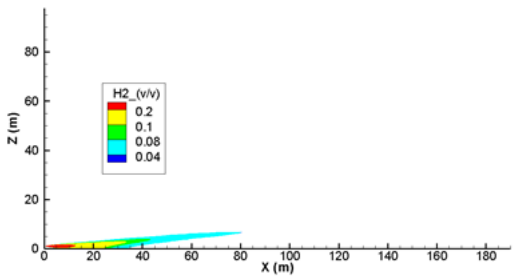
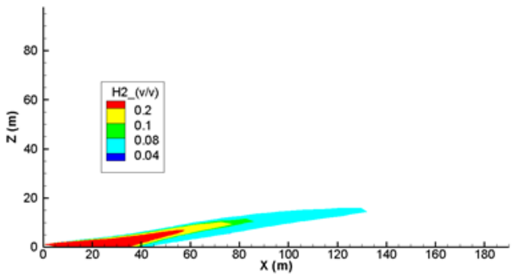
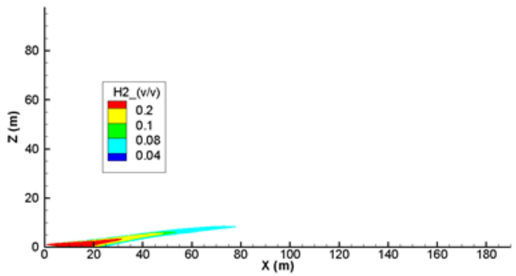


No-wind results – examples

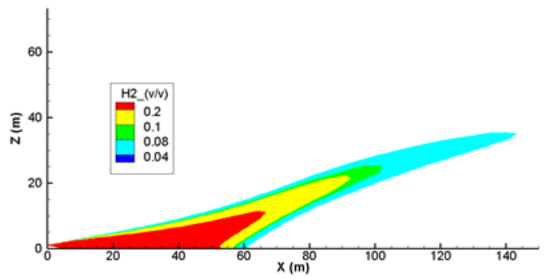
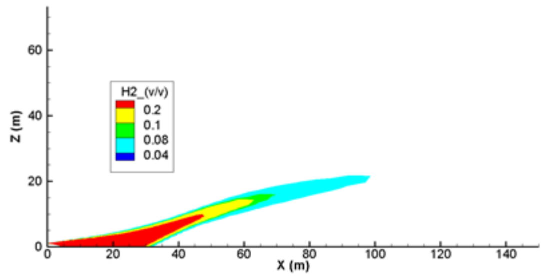
P (bar) \ *D*	*100% area (50mm)*	*5% (11.2mm)*
10		
2		

With wind results – examples

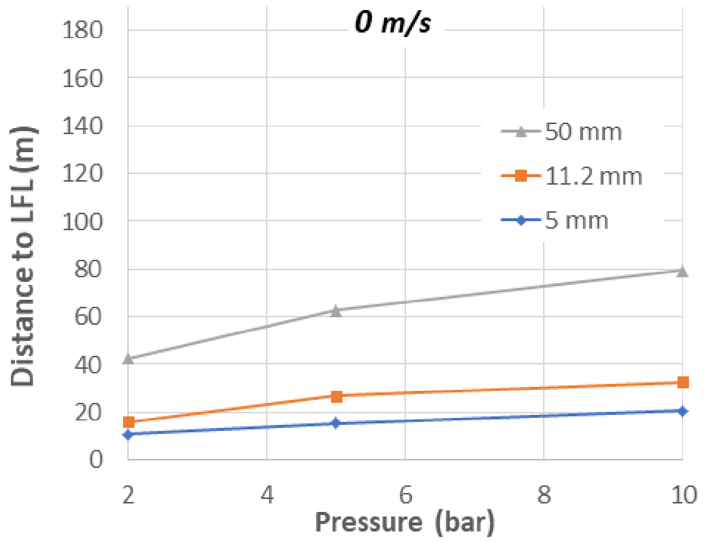
5 m/s wind - stability D

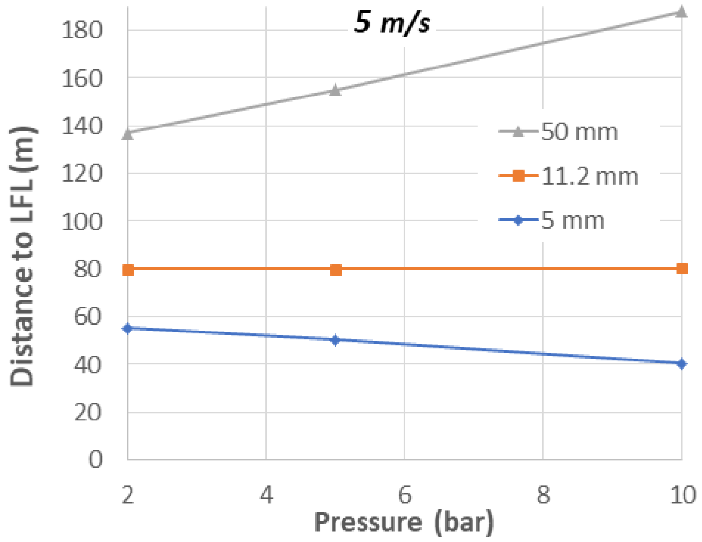
P (bar) \ *D*	*100% area (50mm)*	*5% (11.2mm)*
10		
2		

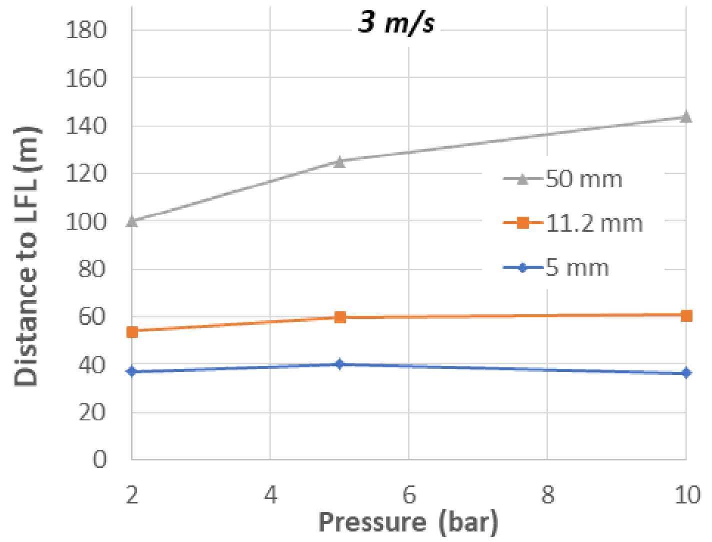
3 m/s wind - stability F

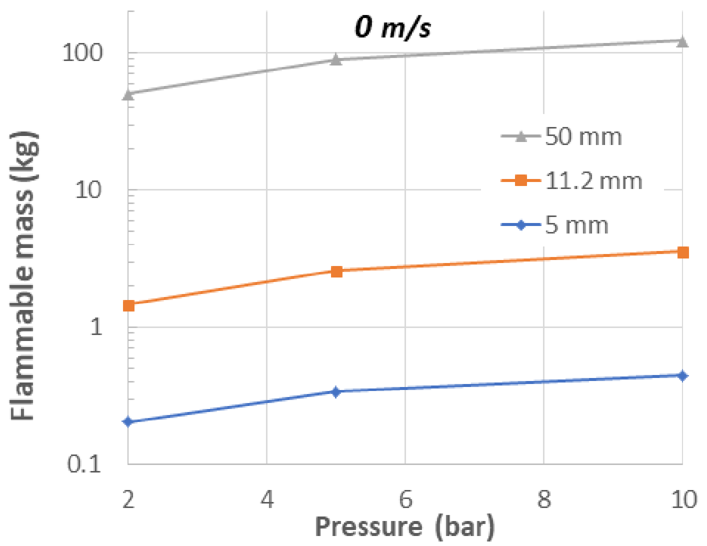
P (bar) \ *D*	*100% area (50mm)*
10	
2	

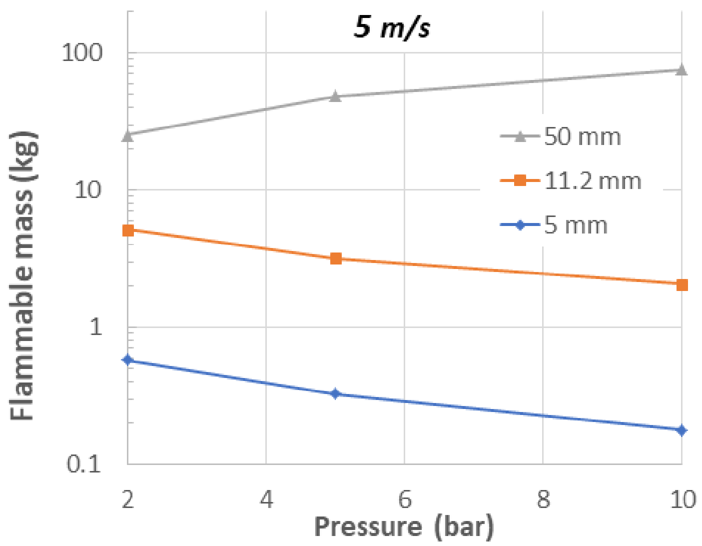
Results for all winds (area B)

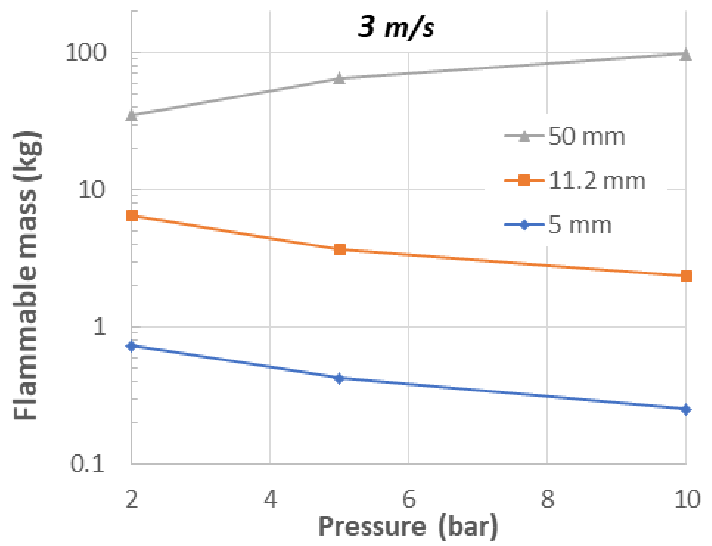




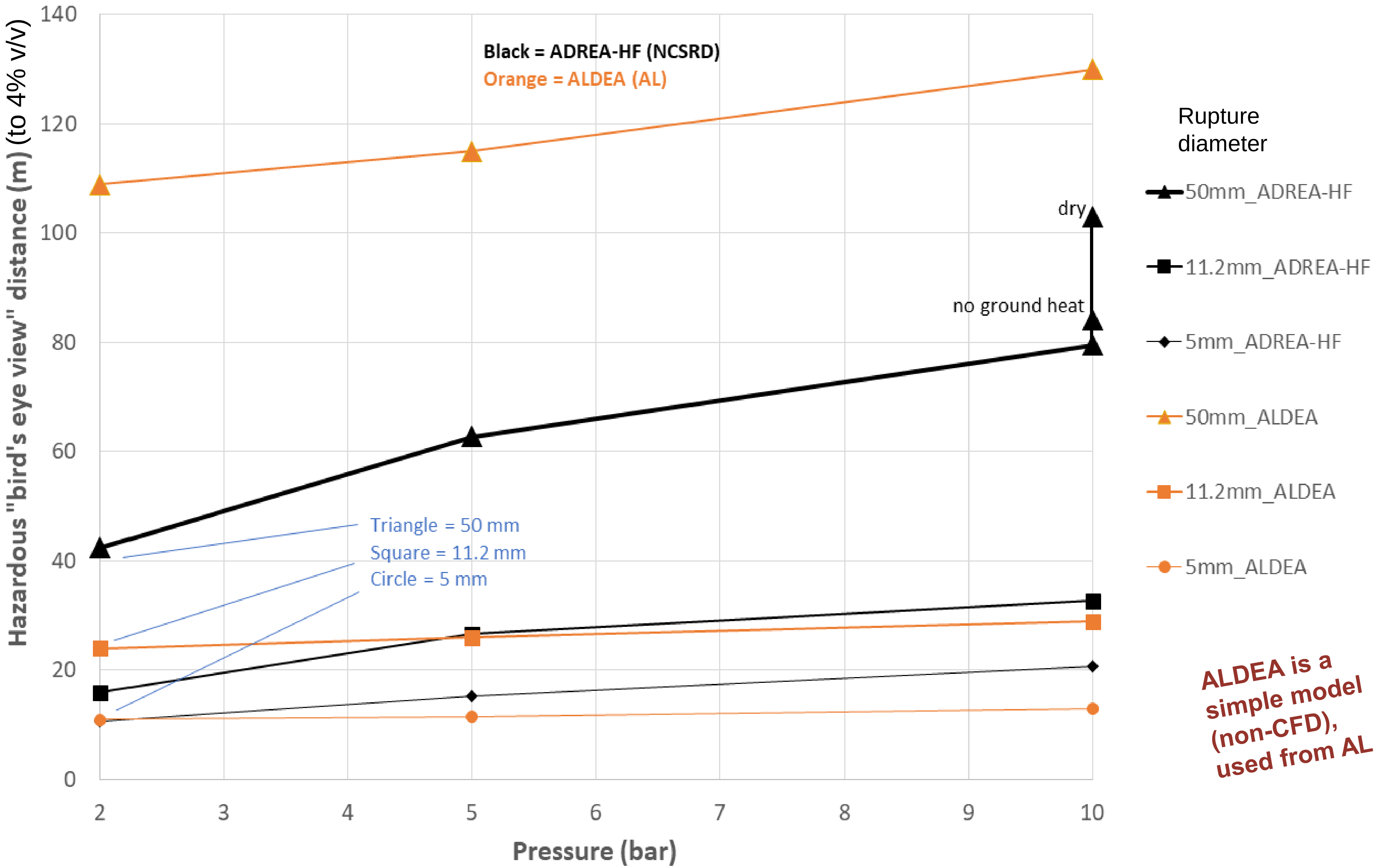








ADREA-HF vs. ALDEA (dispersion)



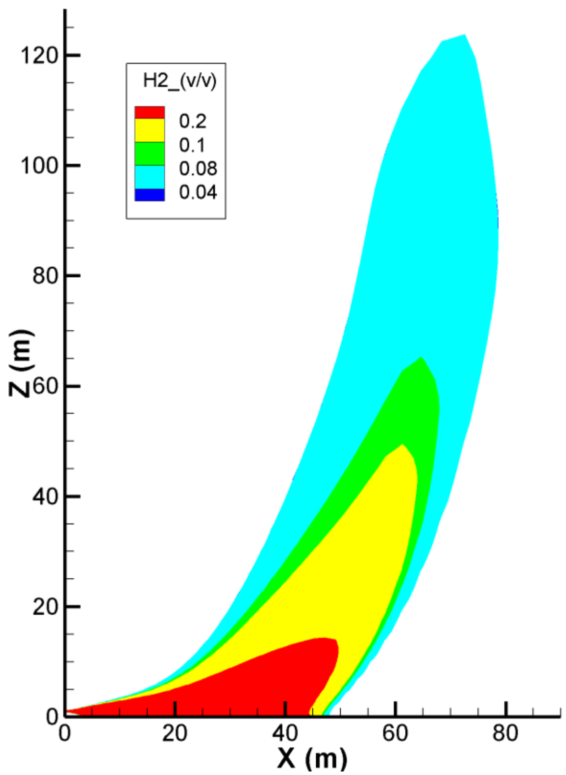
ALDEA is a simple model (non-CFD), used from AL

Jet fires setup – Radiation

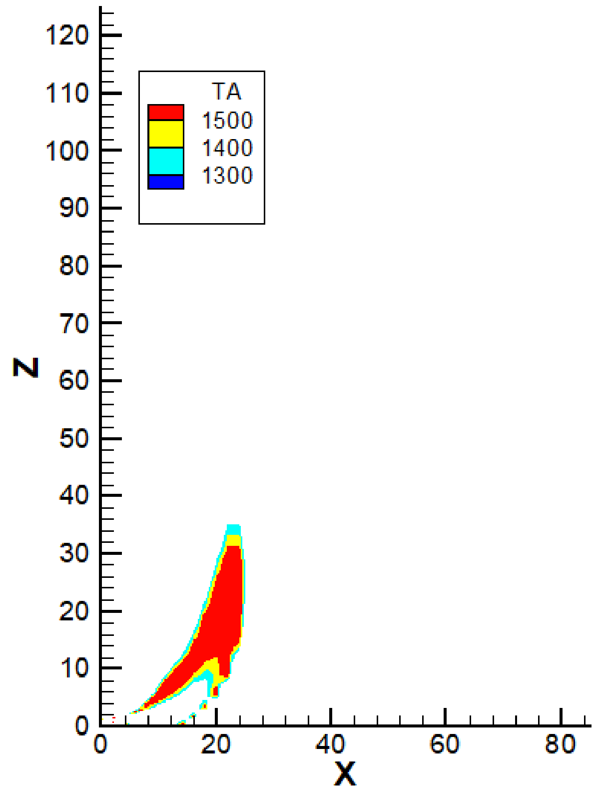
- A total of 15 scenarios simulated (area B)
- CFD parameters remain identical with dispersion cases
- Non-premixed combustion: Eddy dissipation model
- Radiation: P1 model
- Absorption coefficient: Planck-mean approximation (i.e. no spectral dependence)
- Coupled thermal boundary condition on the ground

Jet fires – base case (10 bar, 50 mm)

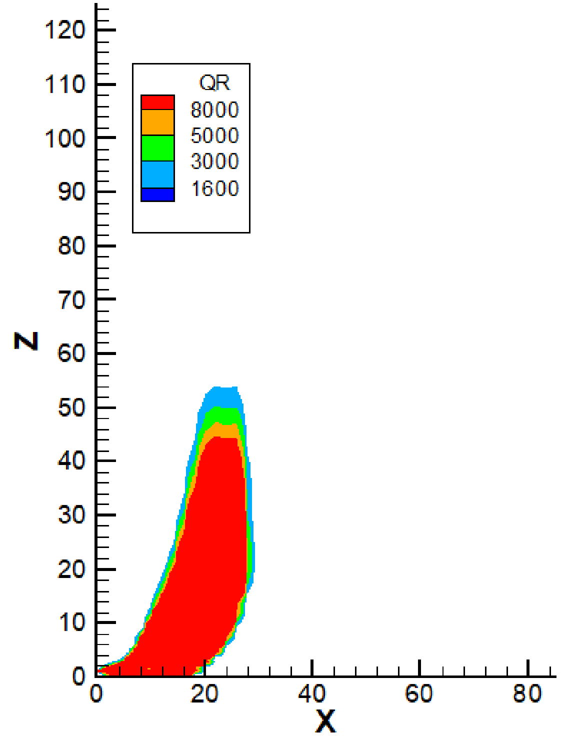
Flammability (dispersion simulation)



Visible flame

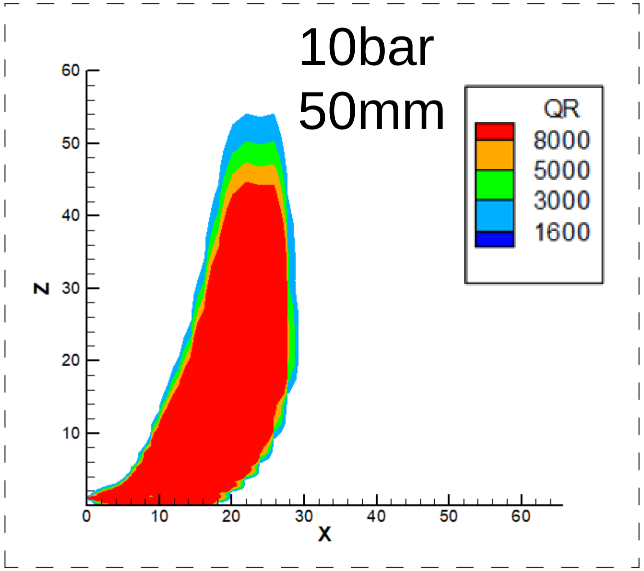


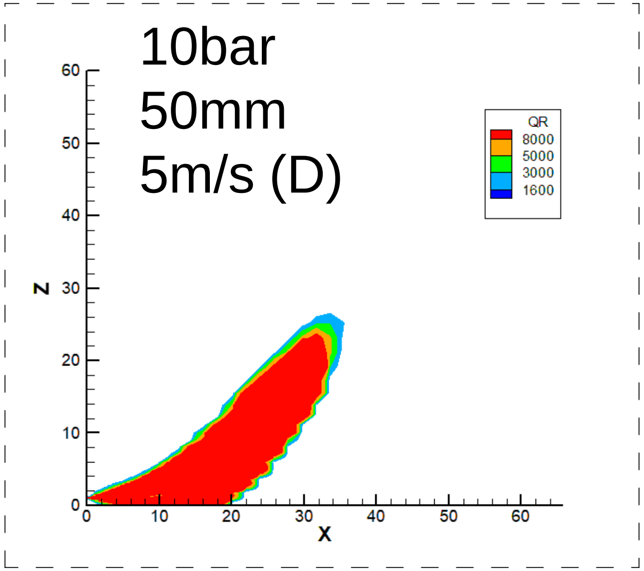
Radiative heat flux

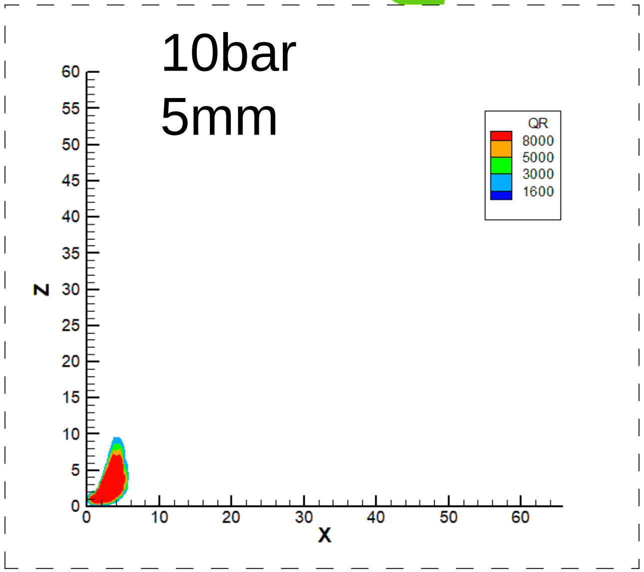


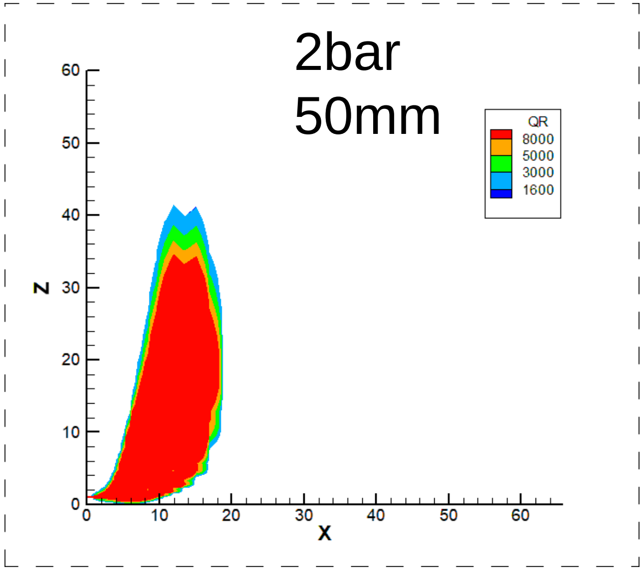
Indirect effects: 1.6kW/m^2
Irreversible effects: 3.0kW/m^2
First lethal effects: 5.0kW/m^2
Significant lethal effects: 8.0kW/m^2

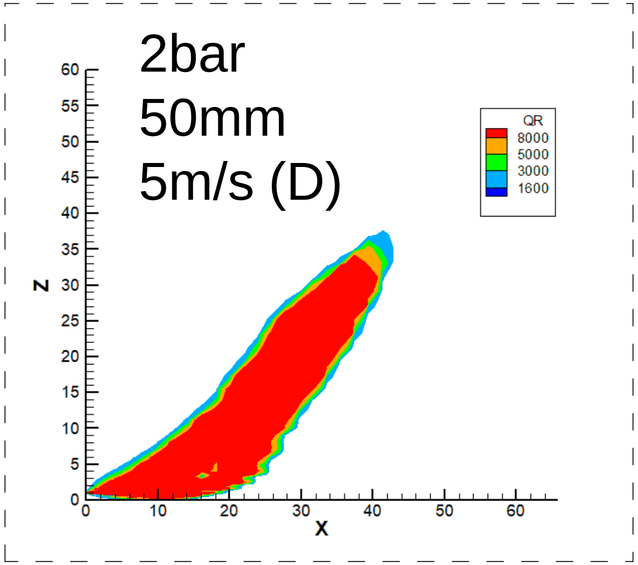
Jet fires – examples

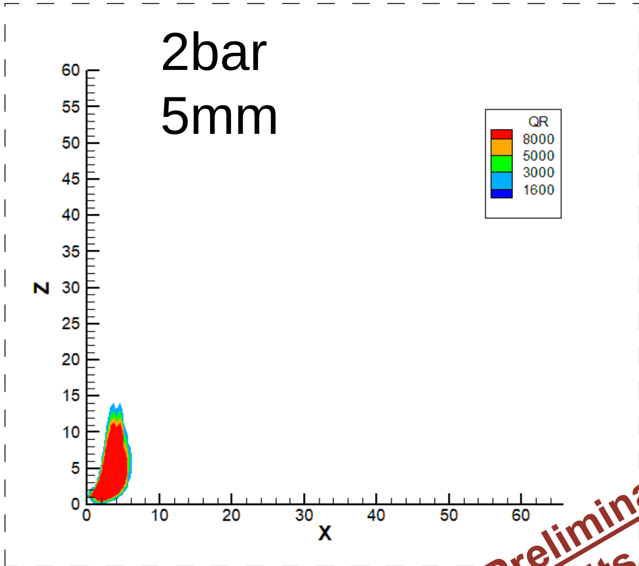












Preliminary results

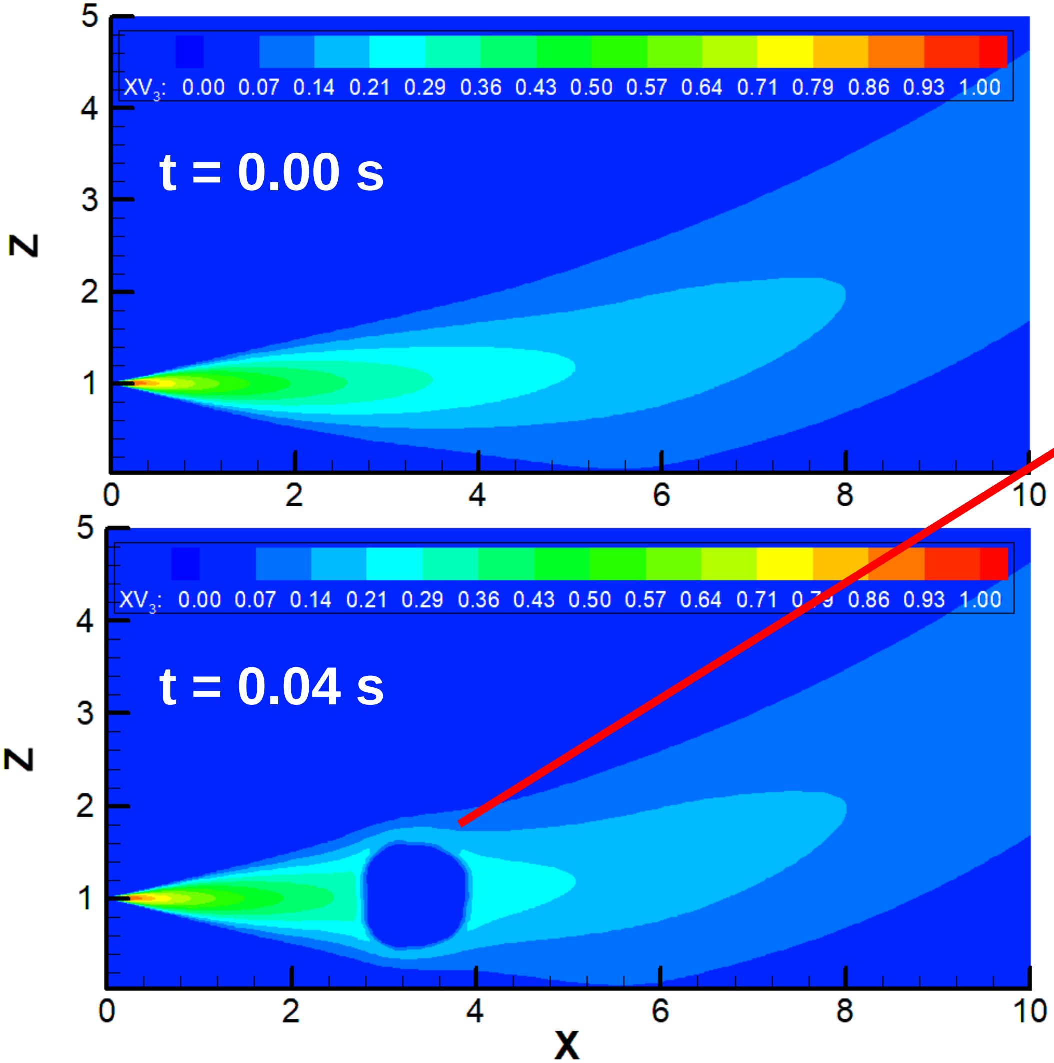
Deflagration simulations setup

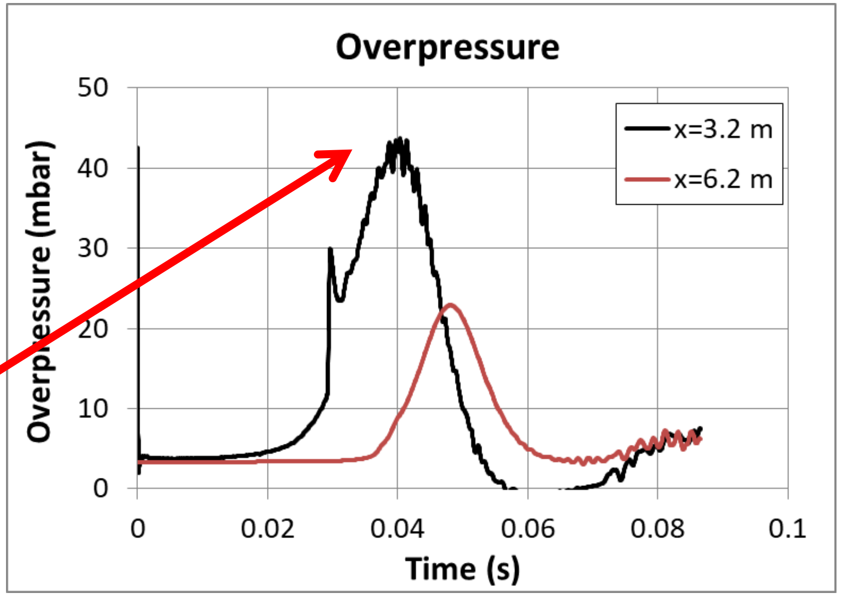
- The area B (hose) **10 bar** case was investigated
- 3 source diameters were simulated: **5**, **11.2**, **50** mm
- Main CFD parameters remain identical with dispersion cases
  - Premixed combustion model: Turbulent burning velocity model incorporating flame instabilities[1]
- Grid:
  - 1.8 million for 5, 11.2 mm cases
  - 4.7 million for 50 mm case
- Ignition at the centre line
  - The effect of ignition distance from the source is also studied

[1] Tolias I.C., Venetsanos A.G. 2018, An improved CFD model for vented deflagration simulations - Analysis of a medium-scale hydrogen experiment, IJHE, 43, 23568-84

Deflagration simulations – examples

- **5 mm case: Ignition point at x=3.2 m**

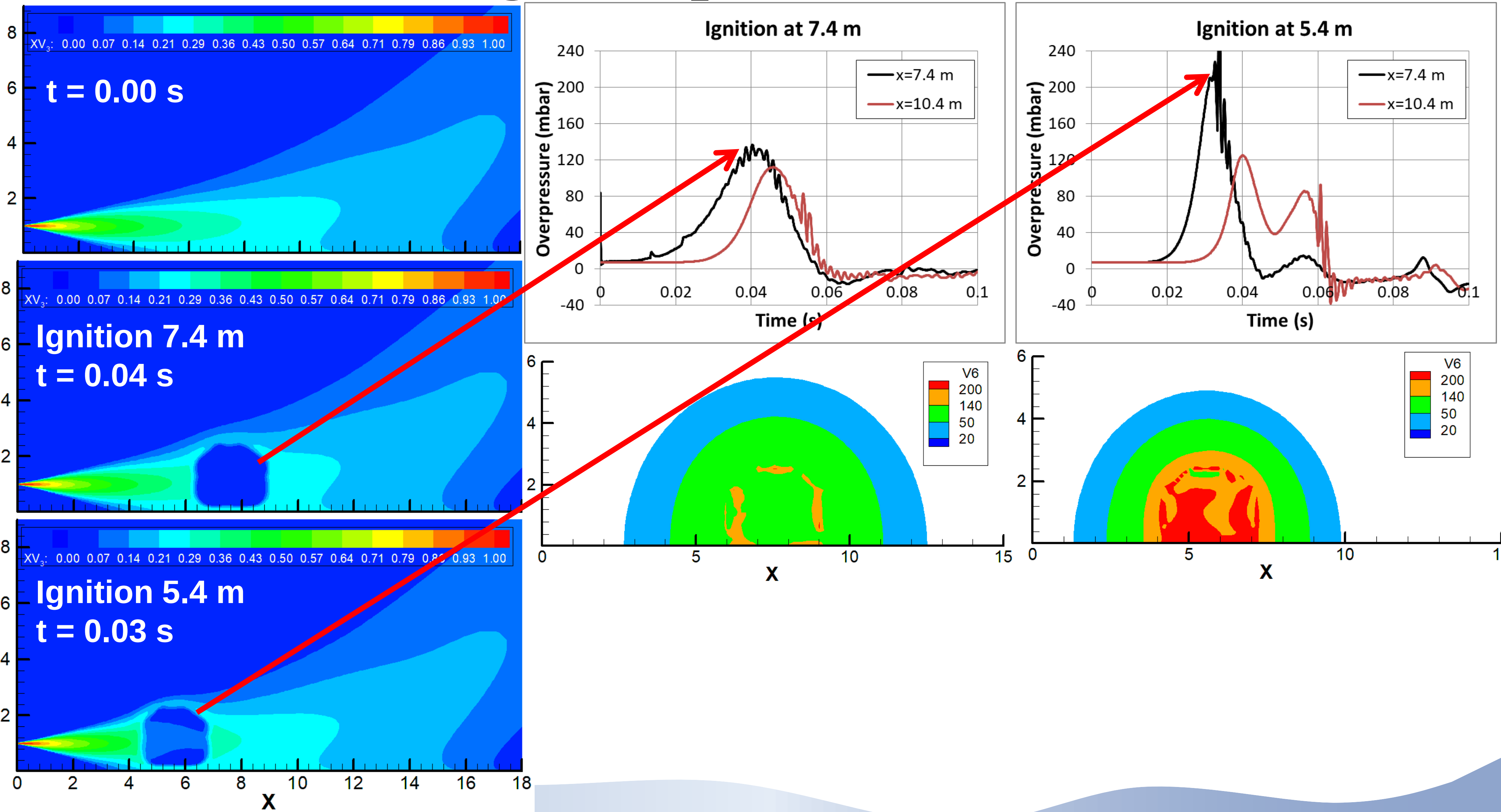




	Hazardous distances (from ignition point)			
Cases	20 mbar	50 mbar	140 mbar	200 mbar
Ignition at 3.2 m	3.6 m	0.8 m	-	-

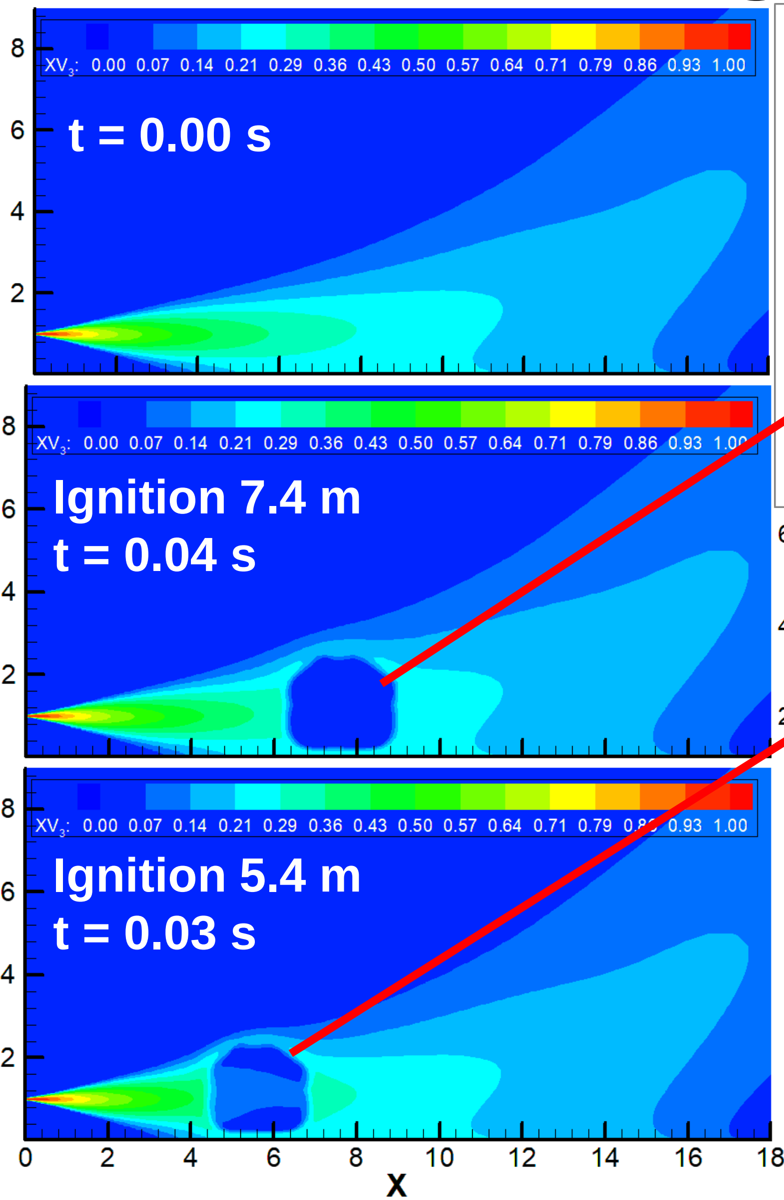
Deflagration simulations – examples

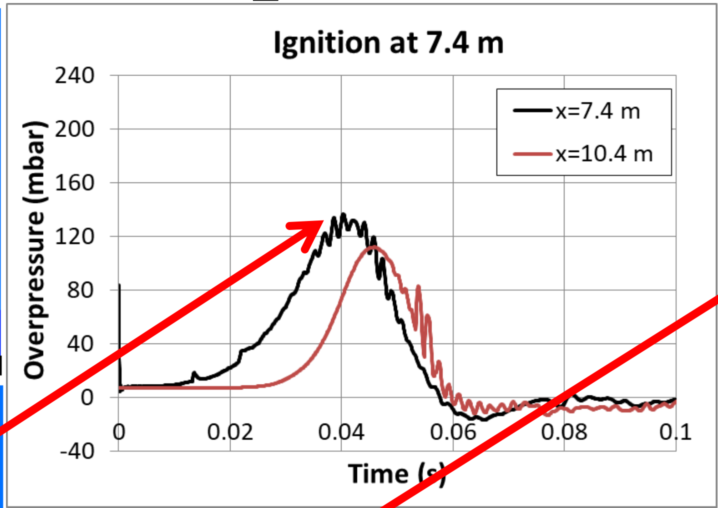
- **11.2 mm case: Ignition point at x=7.4 and 5.4 m**

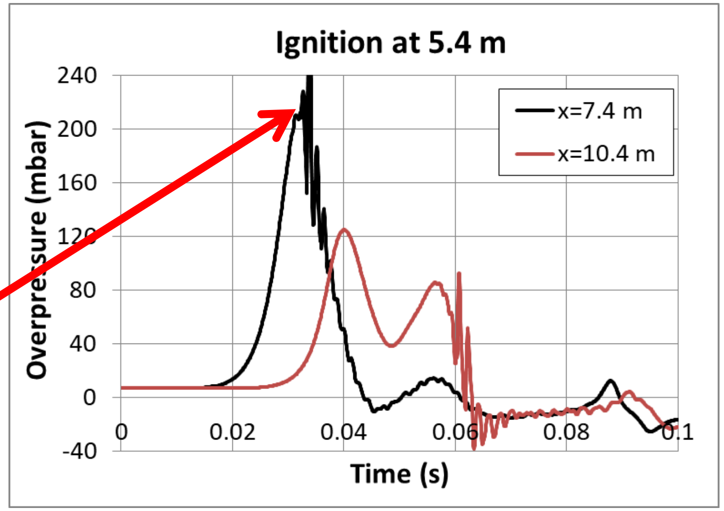


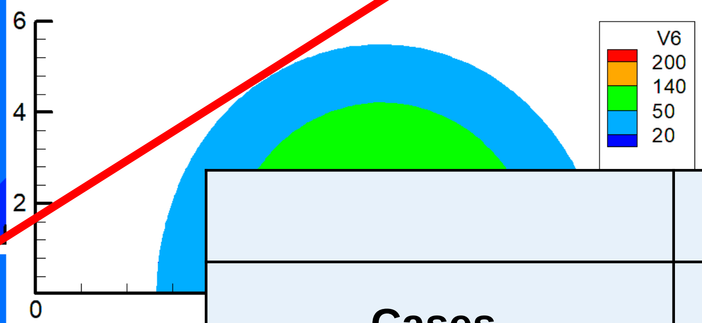
Deflagration simulations – examples

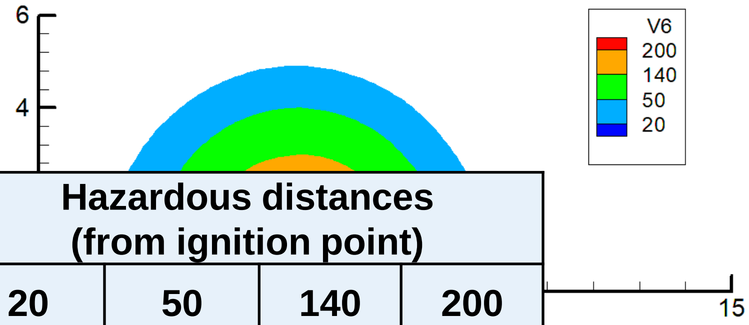
- **11.2 mm case: Ignition point at x=7.4 and 5.4 m**







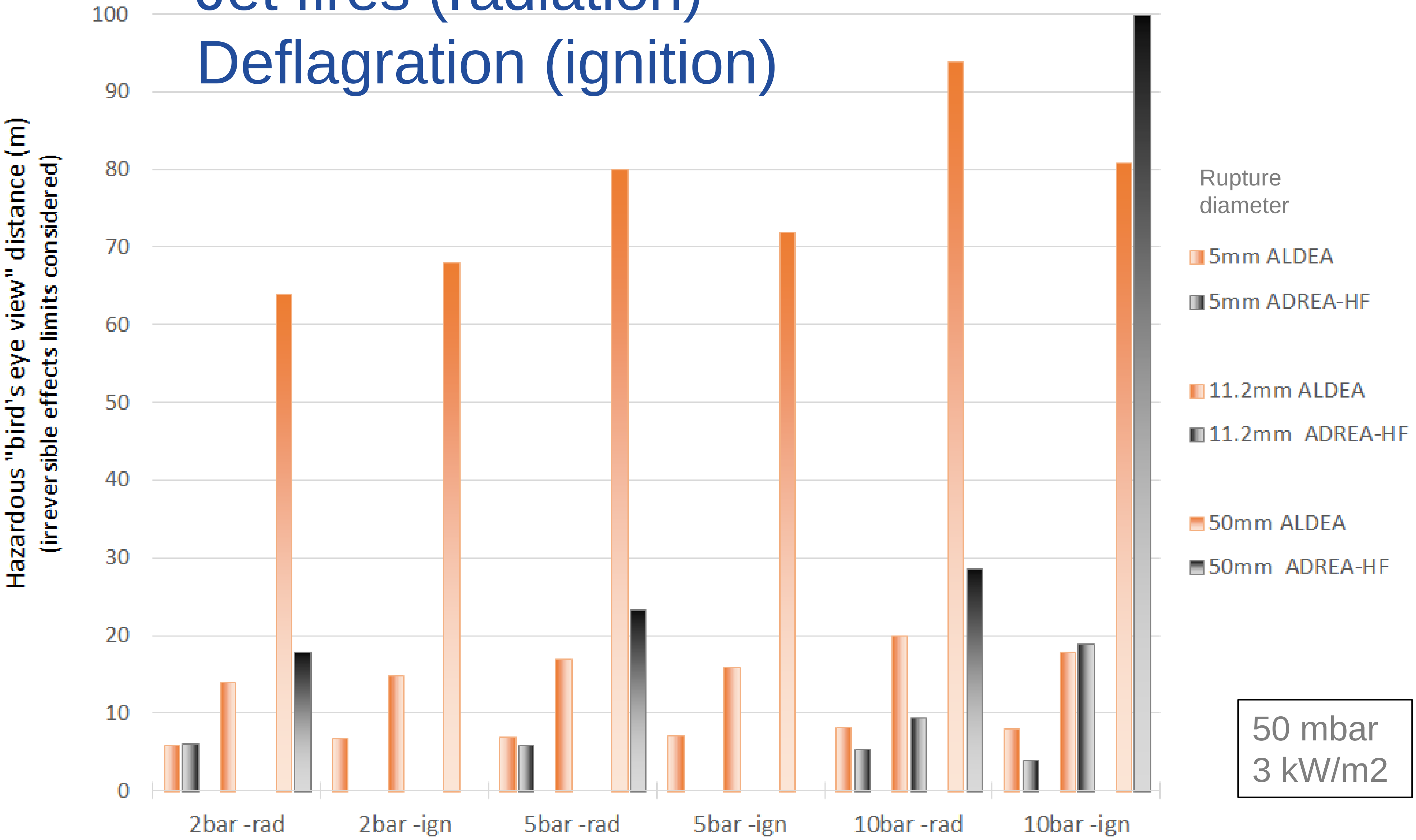




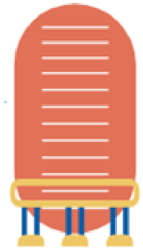
	Hazardous distances (from ignition point)			
Cases	**20 mbar**	**50 mbar**	**140 mbar**	**200 mbar**
Ignition at 7.4 m	23 m	8.6 m	2.1 m	-
Ignition at 5.4 m	27 m	14 m	4.4 m	2.5 m

ADREA-HF vs. ALDEA

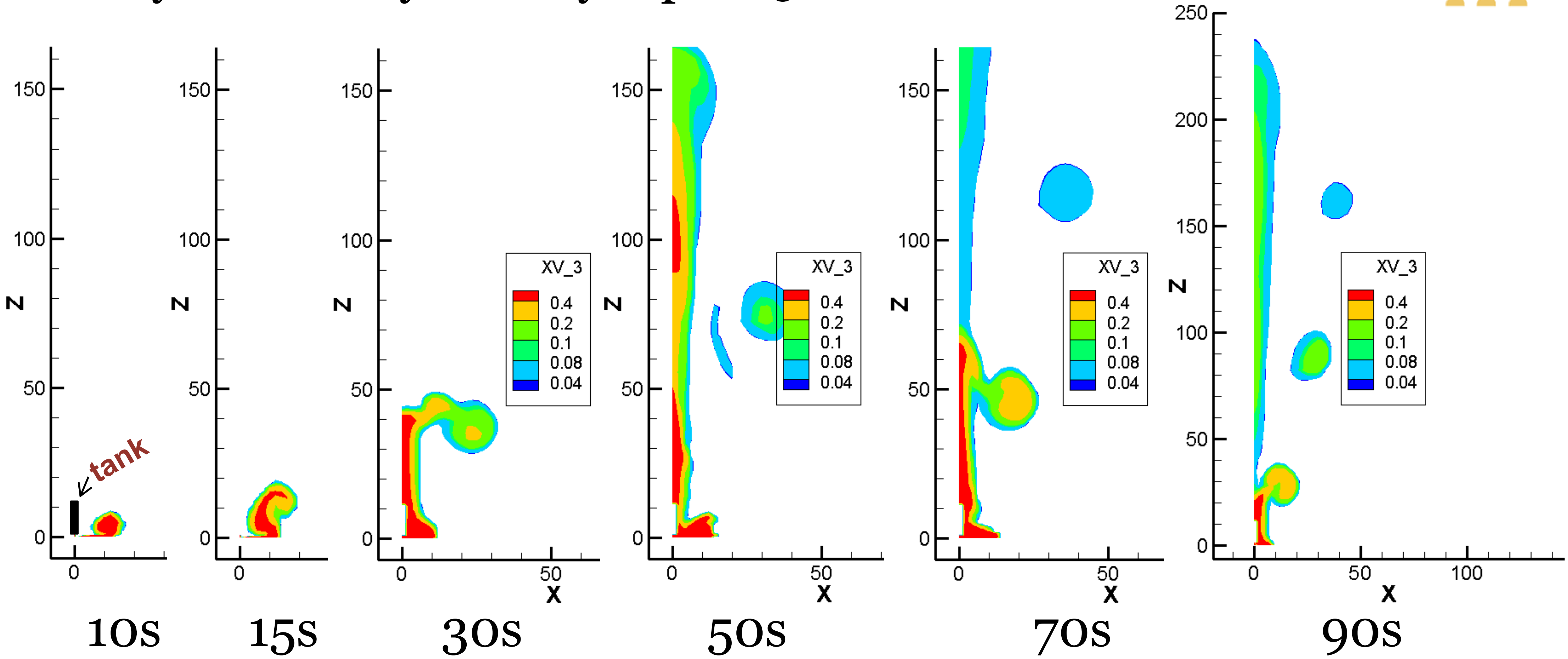
Jet fires (radiation)
Deflagration (ignition)



AREA C – Dispersion results



- Vertical tank of 56 m³ – Bottom rupture of d = 20 cm
- Cylindrical symmetry – p =1.5 bar



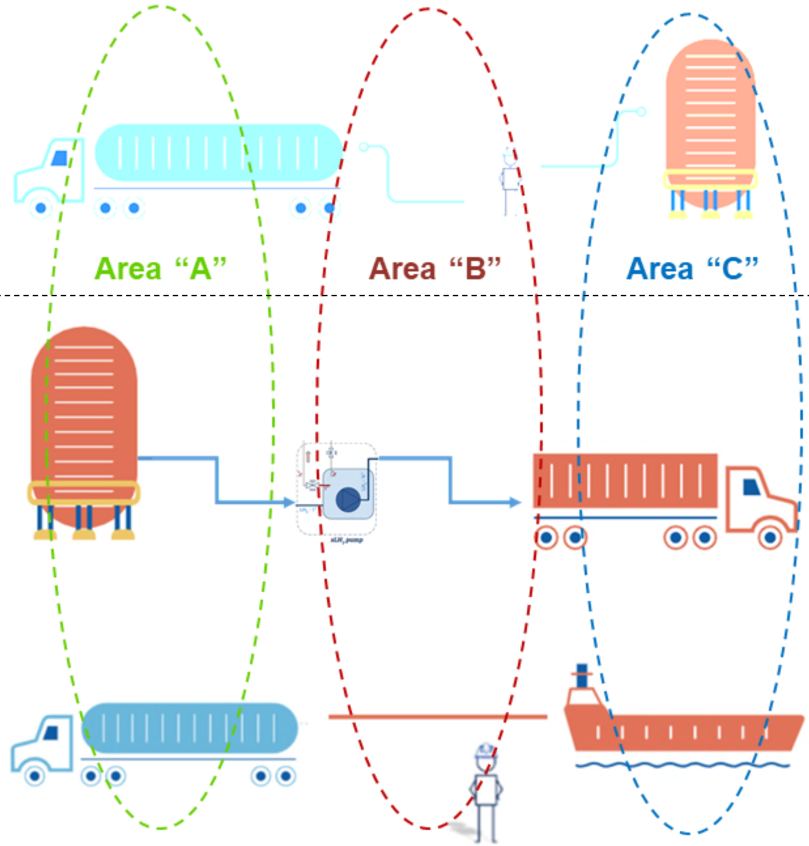
"Take-home" conclusions

- Reduced models are good, given their simplicity
  - Need to know their limitations
- Hose ruptures (area B): Release diameter very critical
  - Pressure not that critical
- Windy cases completely different
  - Distances up to 6 times higher
- Distances resulting from jet fires or deflagration are generally smaller than those of dispersion/flammability limit
- Big tank rupture (area C) very interesting

Future work within WP5 of ELVHYS

- Case study 1: Area A (BLEVE)
- Case study 1: Area C (large release from tank: wind, ignition)
- **Case studies 2 and 3**: Areas B and C

- Case study **1**: Transfer of LH2 from a **trailer** to a **stationary tank**
- Case study **2**: Transfer of LH2 from stationary **tank** to an LH2 heavy duty **truck**
- Case study **3**: Transfer of LH2 from a **trailer** to an LH2 **vessel** (ship)



Thank you for your attention

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HPC ARIS

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