



Consequence analysis for selected LH₂ transfer operations

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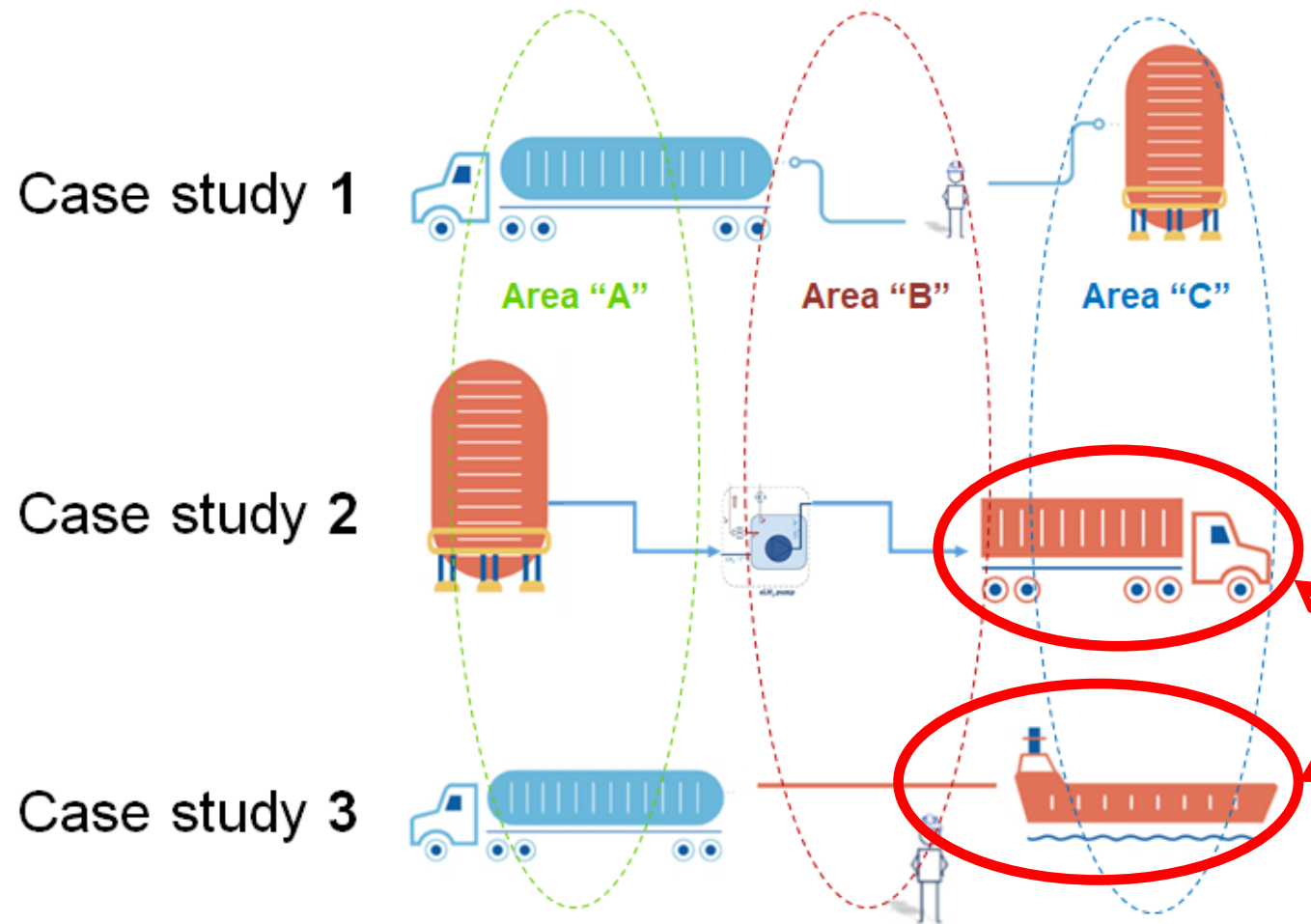
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Case studies examined at ELVHYS

Phenomena examined at this presentation:

1. Dispersion (flash fire risk)
2. Radiation (jet fire)
3. Combustion / explosion (delayed ignition overpressure)



Focus of current presentation
(releases relevant to the tanks of the truck and of the ship)

Cases to be presented

Truck tank rupture /risk examined	No wind	Wind 5m/s
Side 6mm /dispersion	Yes	N, S, W
Side 6mm /radiation	Yes	North
Side 6mm /combustion	Yes	North
Bottom 18mm /disp.	Yes	North
Bottom 18mm /comb.	Yes	North



Ship release scenario /risk examined	No wind	Wind 5m/s
Tower top 50mm /disp.	Yes	Yes
Tower top 50mm /rad.	Yes	No
Tower top 50mm /comb.	Yes	No
Bottom 20cm /disp.	Yes	Yes
Bottom 20cm /comb.	Yes	Yes



Tools used:

- DISCHA (for fictitious nozzle data)
- ADREA-HF (for CFD simulations)
 - RANS (steady state or transient)
 - $k-\epsilon$ turbulence model
 - MUSCL numerical scheme
 - Jet flame: Eddy dissipation/
P1 radiation model
 - Premixed combustion : Turbulent
burning velocity/ flame instabilities

Truck side release (6 mm)

New tanks: 16 bar subcooled LH2 (28 K)

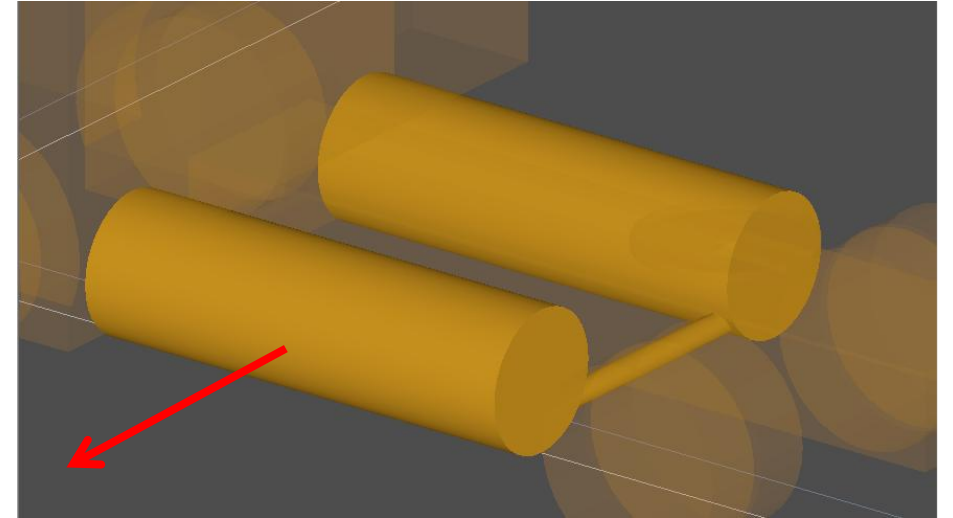
40 kg of hydrogen each tank

Ext. length 2.4 m, diameter 0.72 m

Distance from ground 0.26 m

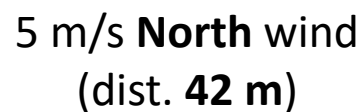
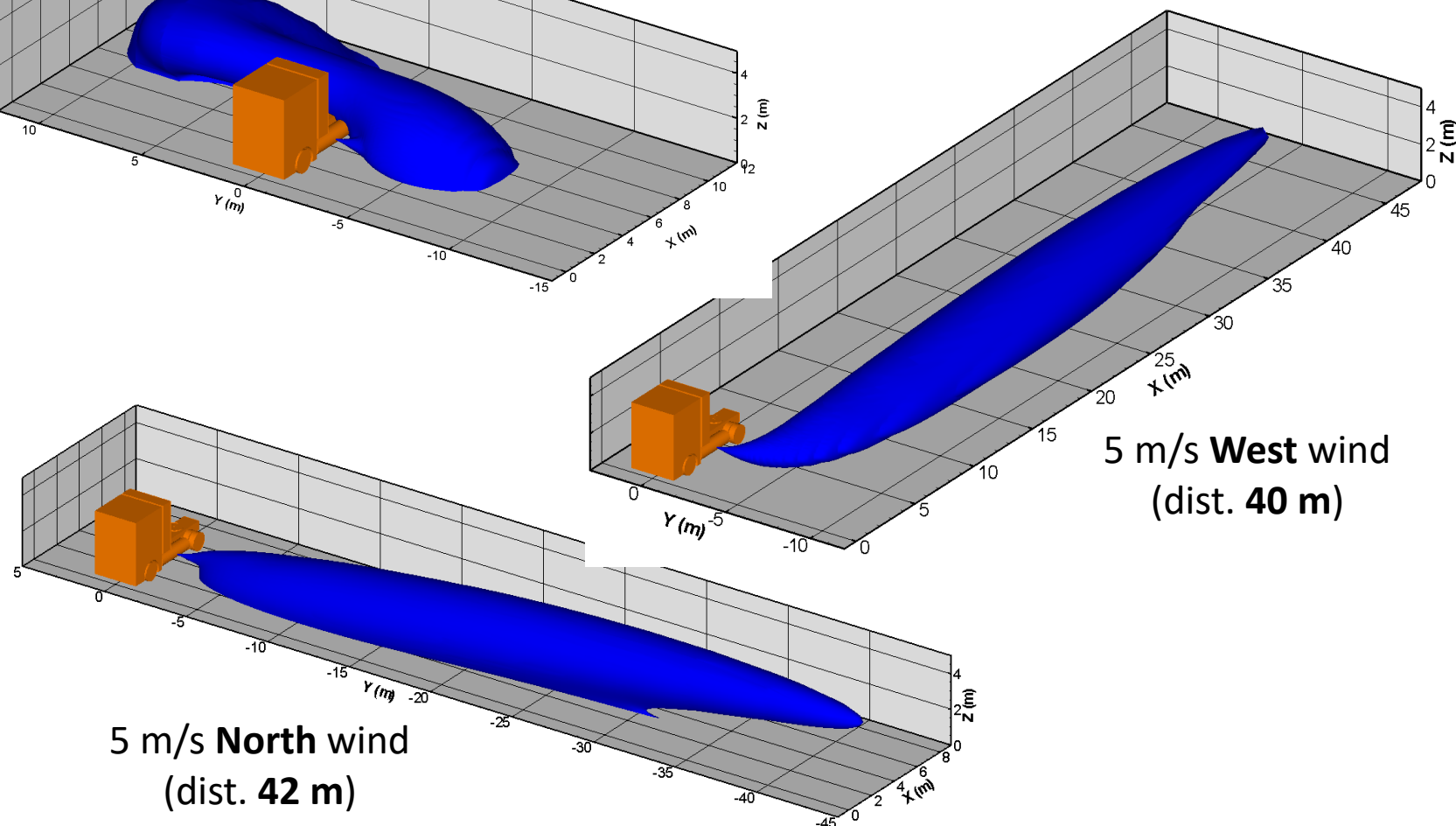
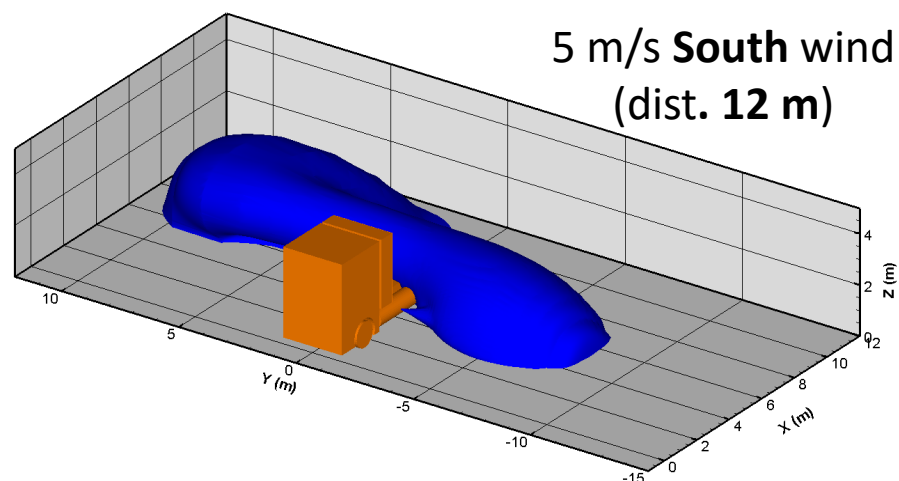
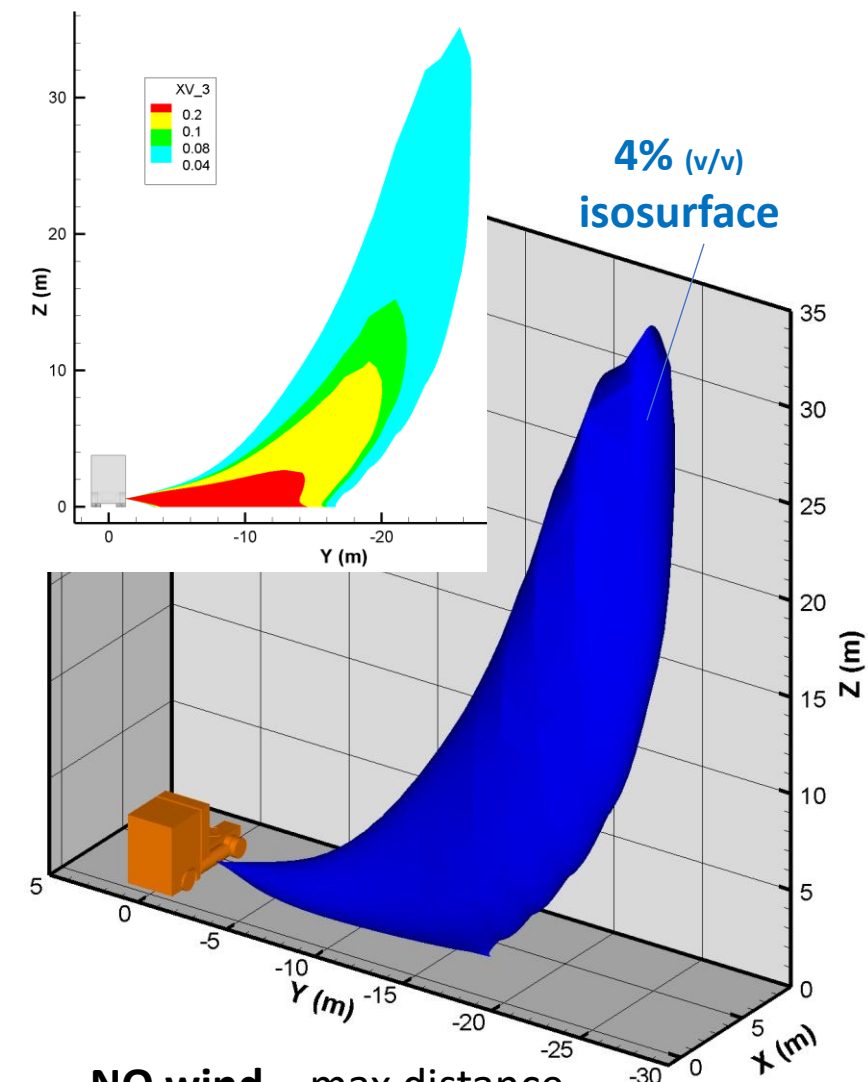
Connection pipe of 18 mm diameter

Side release: 6 mm, at $Z = 0.62$ m, steady state



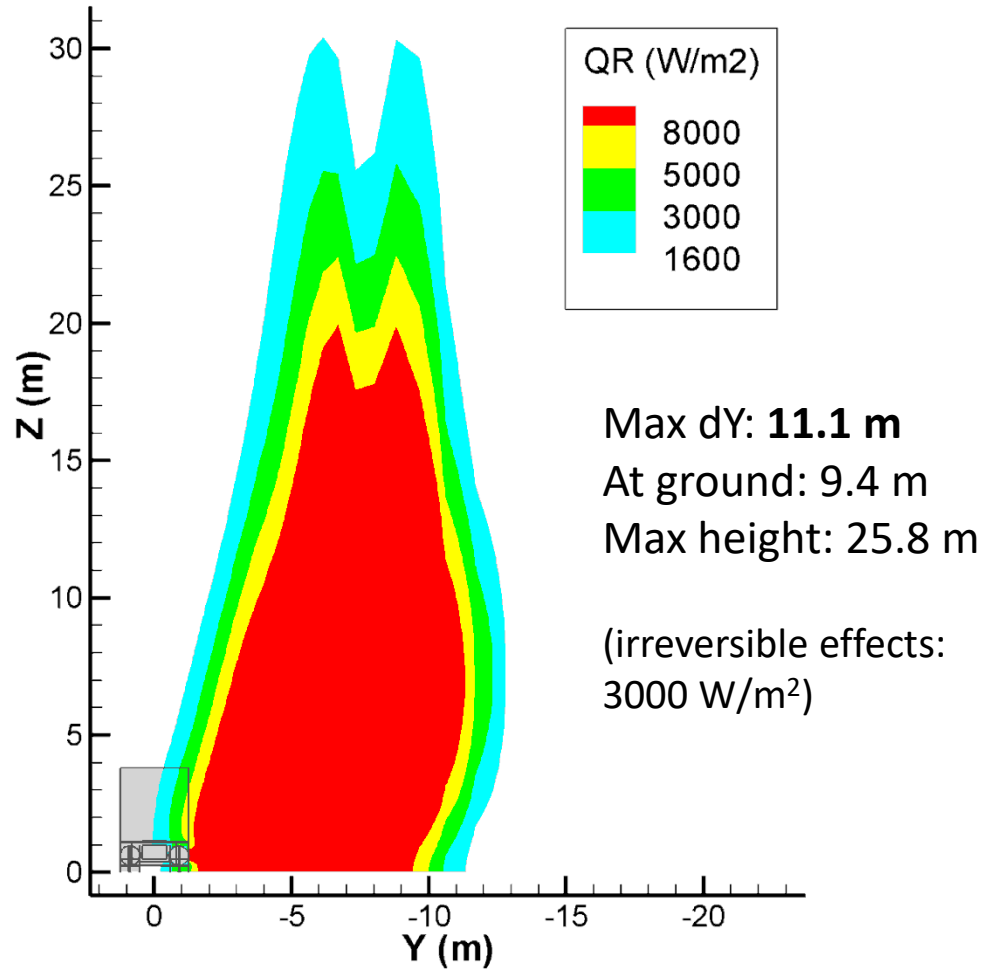
Tank P0 (bar)	Tank T0 (K)	Nozzle Diam. (mm)	Mass fl. rate (kg/s)	Fictit. Noz. T_2 (K)	Vap. qualit. X_2	Void fract. $VOID_2$	Fict. Dens. (kg/m ³)	Fict. Veloc. (m/s)	Fict. Diam. (mm)
16	28	6	0.330	20.37	0.207	0.933	6.01	131.45	23.07

Side 6 mm - Dispersion

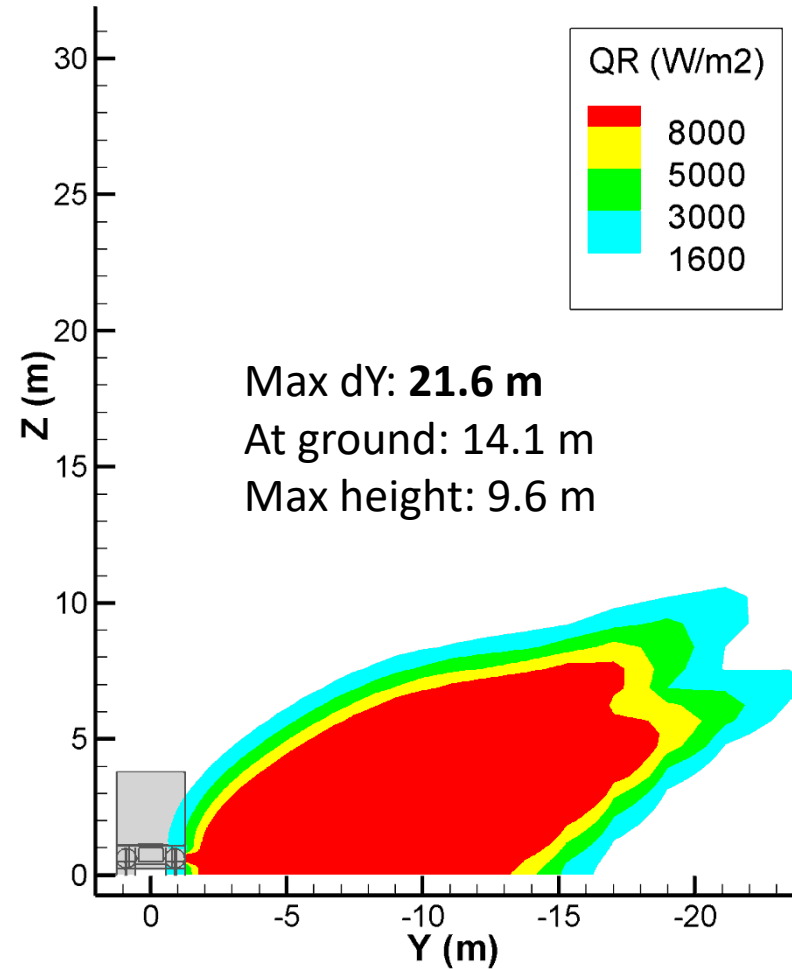


Side 6 mm - Radiation

No wind



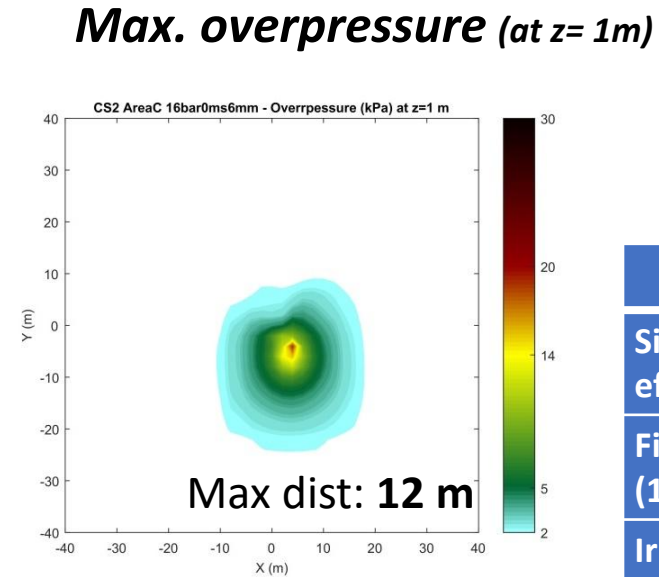
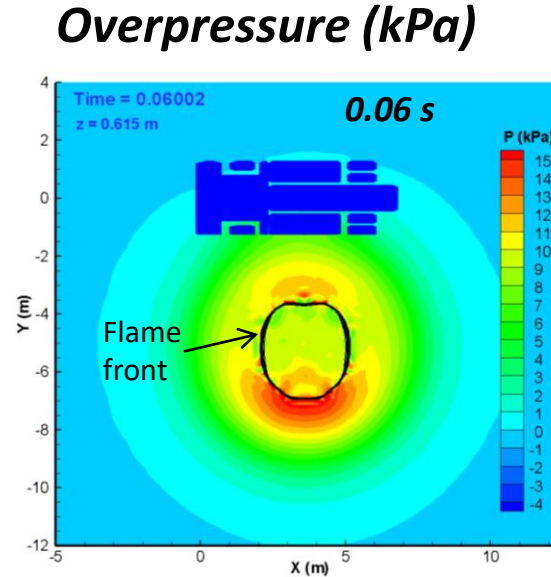
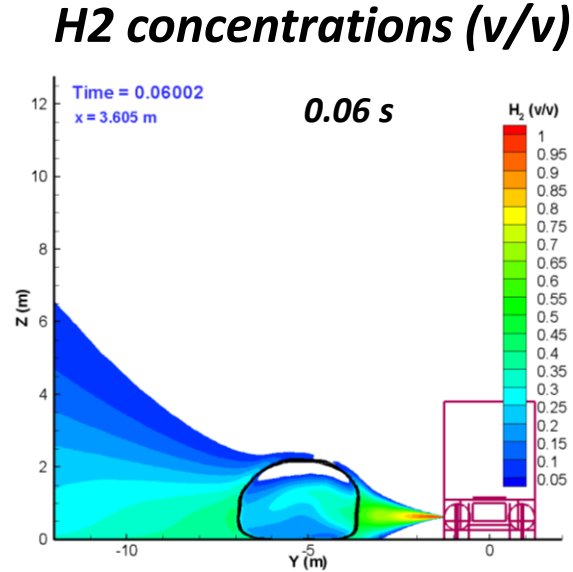
North wind 5 m/s



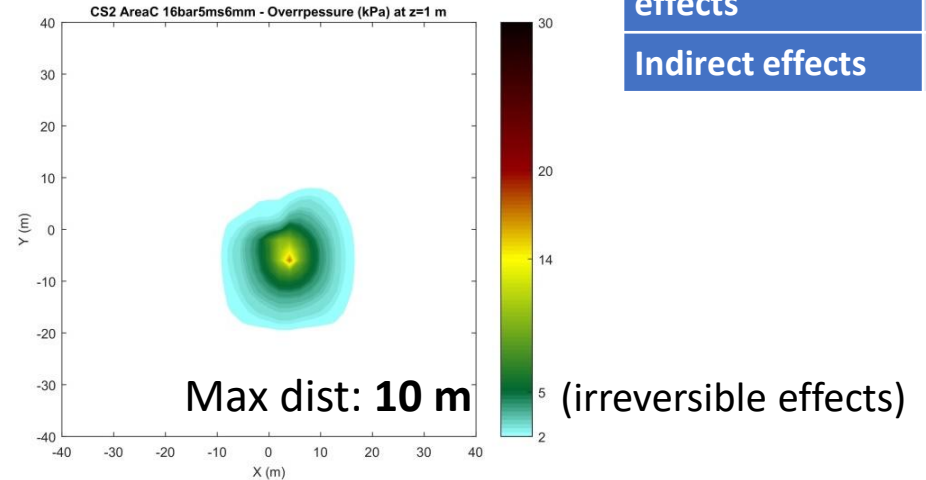
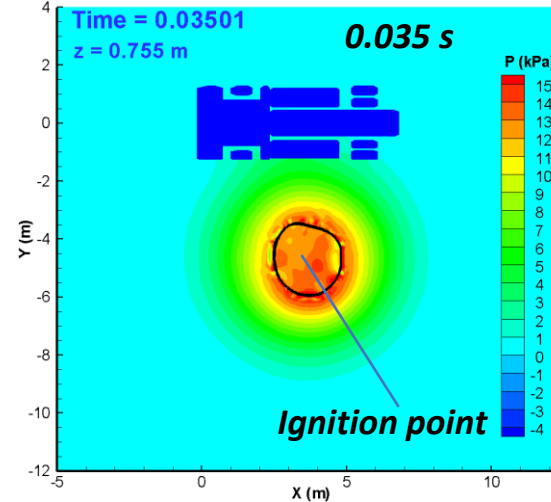
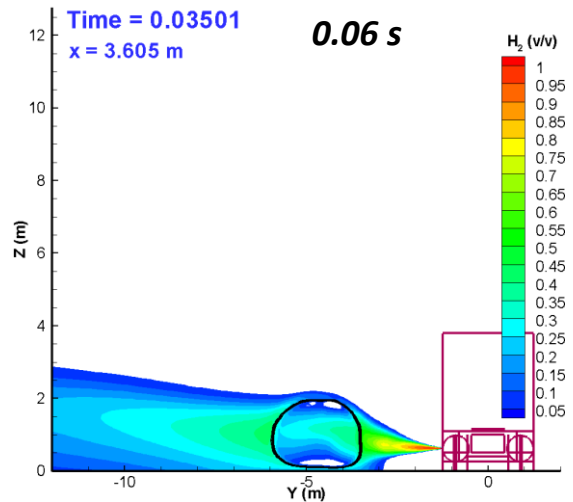
	QR
Significant lethal effects (5%)	8 kW·m ⁻²
First lethal effects (1%)	5 kW·m ⁻²
Irreversible effects	3 kW·m ⁻²
Indirect effects	1.6 kW·m ⁻²

Side 6 mm - Combustion

No wind

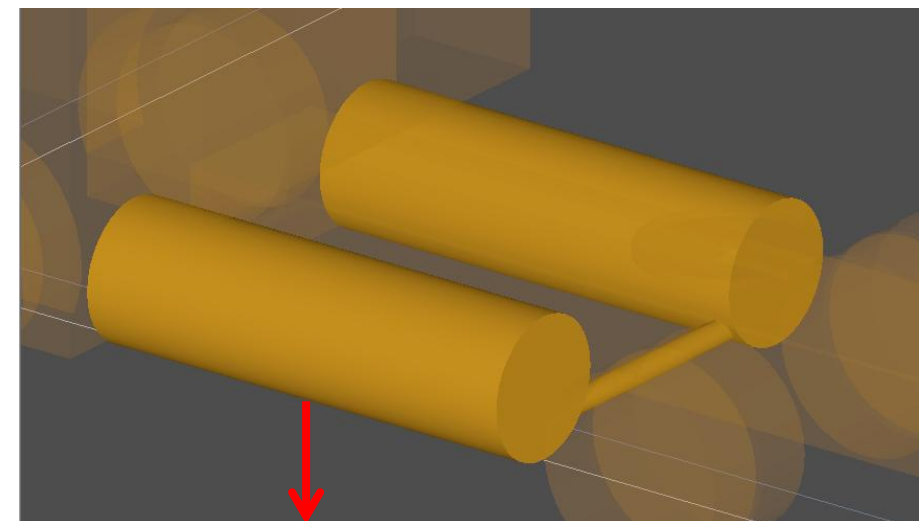


North wind 5 m/s

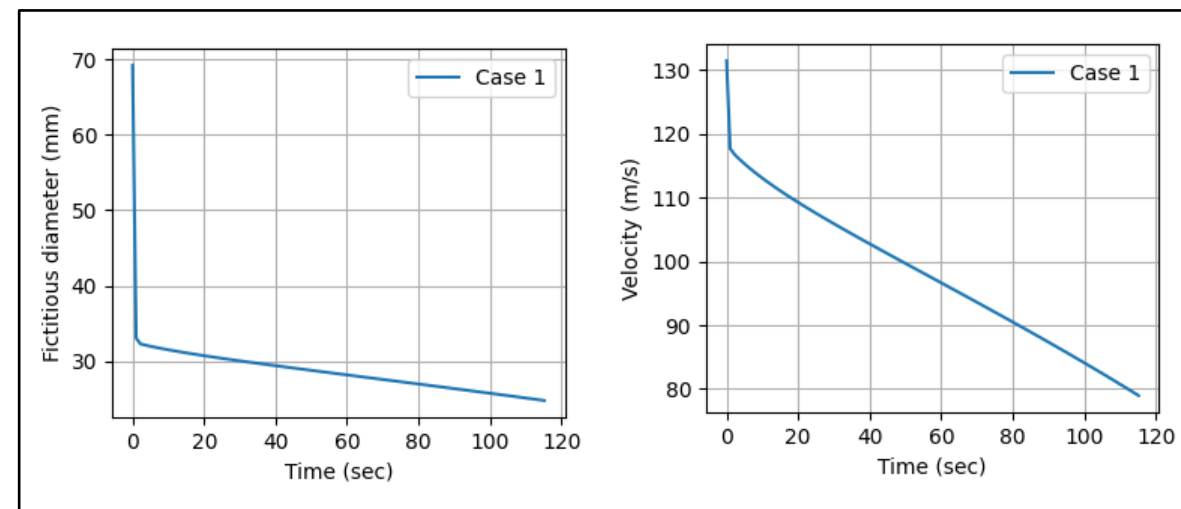


	OP
Significant lethal effects (5%)	20 kPa
First lethal effects (1%)	14 kPa
Irreversible effects	5 kPa
Indirect effects	2 kPa

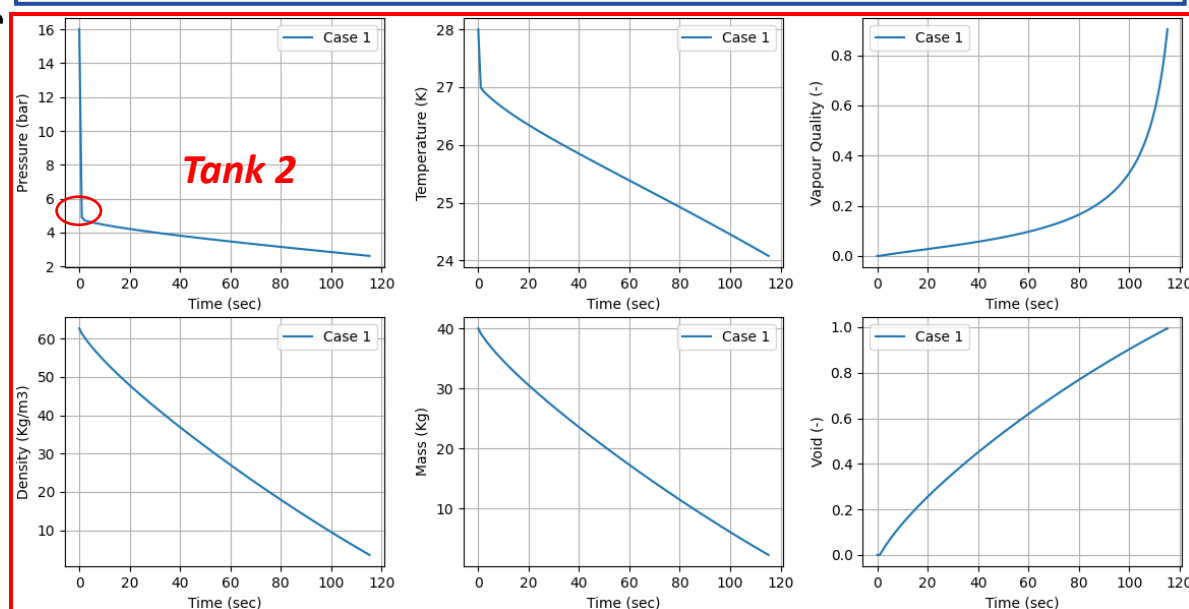
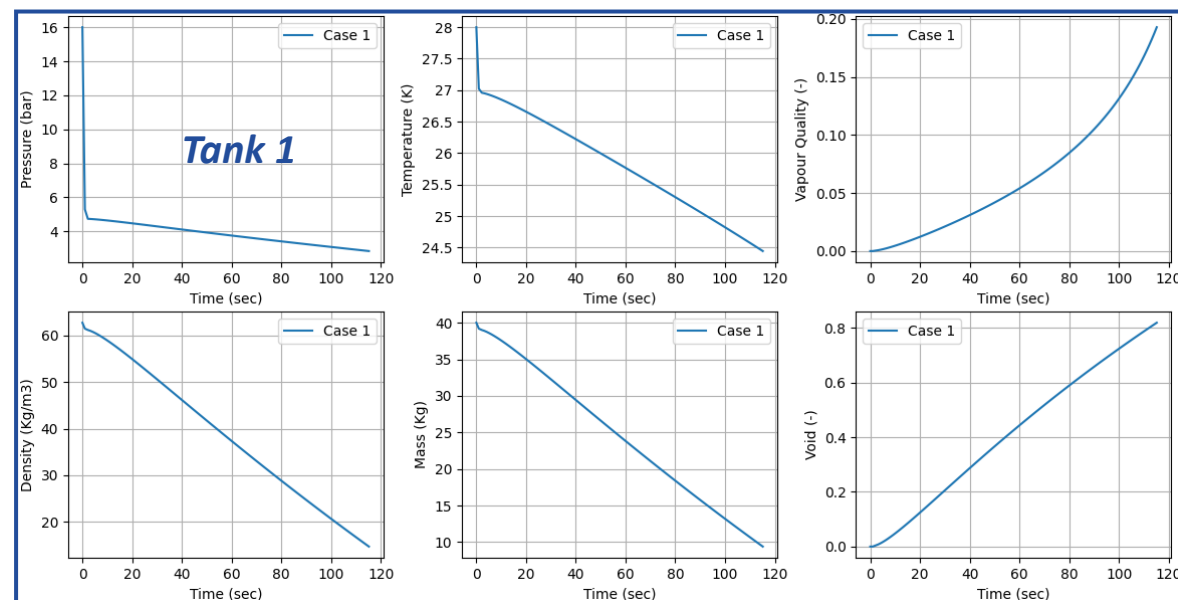
Truck bottom release (18 mm)



Fictitious nozzle



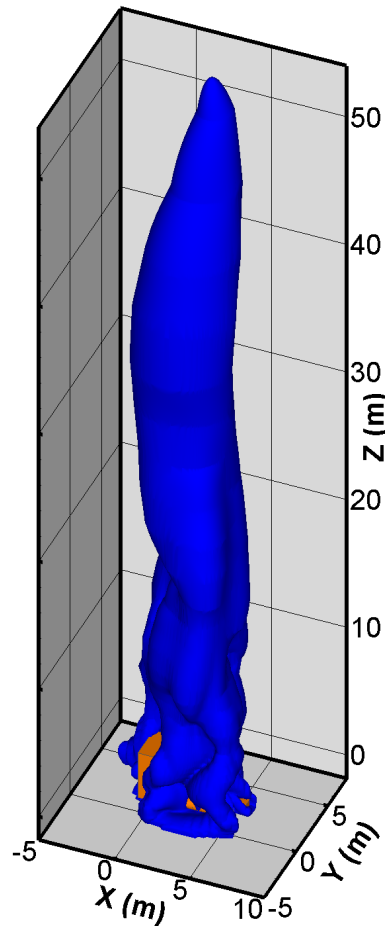
DISCHA calculations of release conditions



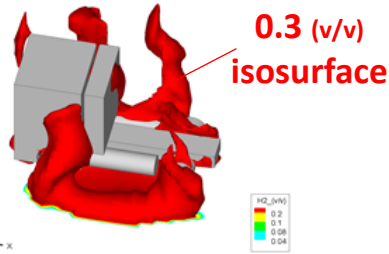
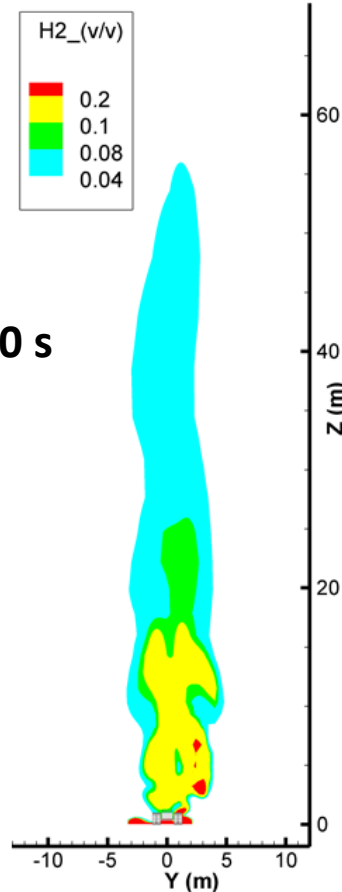
Bottom 18 mm - Dispersion

NO wind

max dX or dY **9 m** (at 20 s)

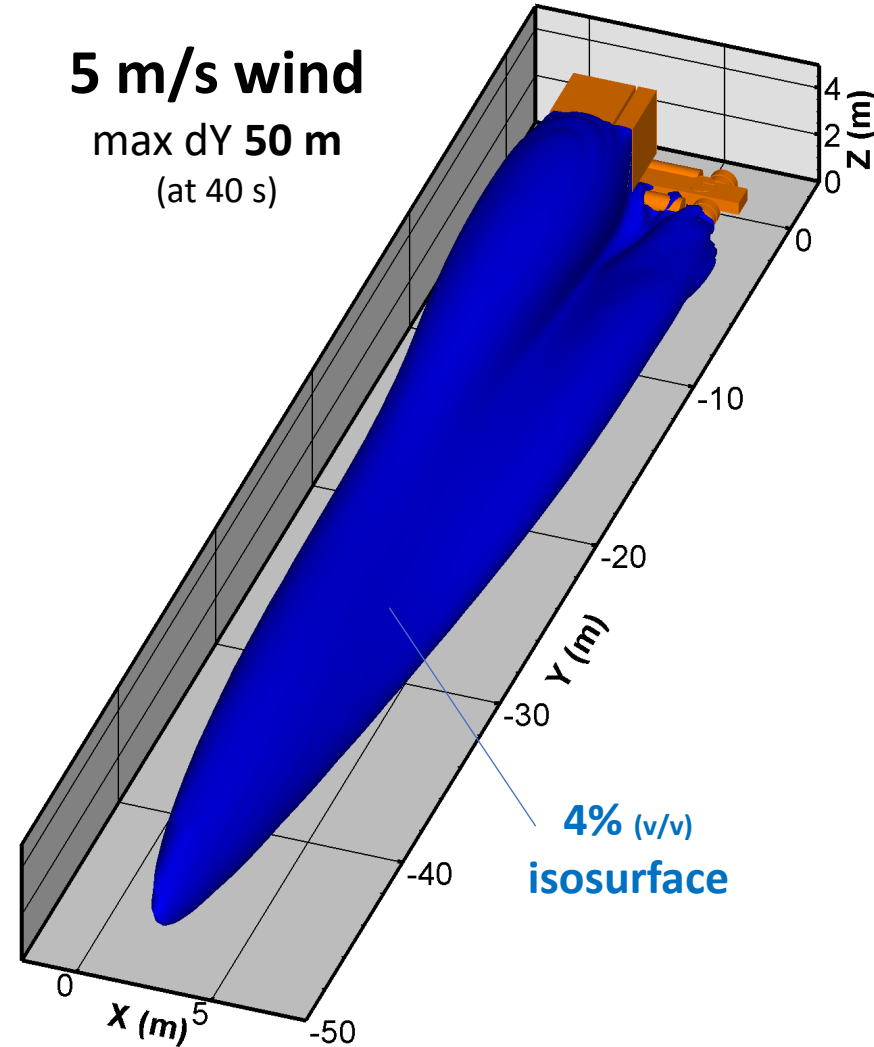


t = 80 s

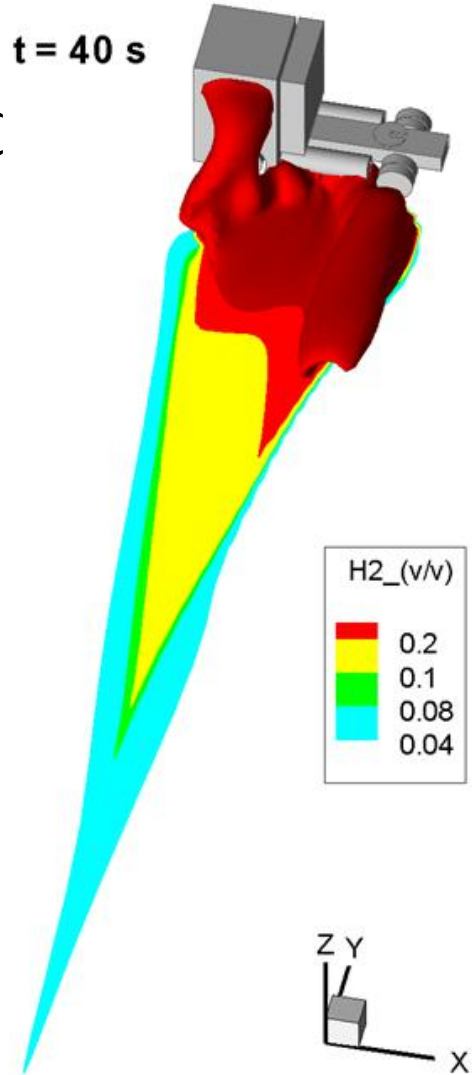


5 m/s wind

max dY **50 m**
(at 40 s)



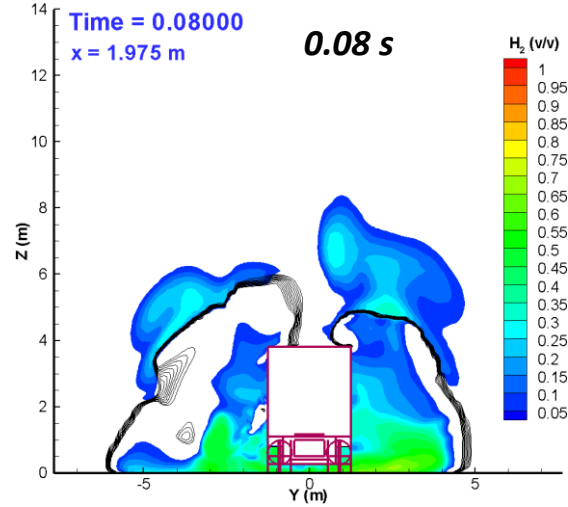
t = 40 s



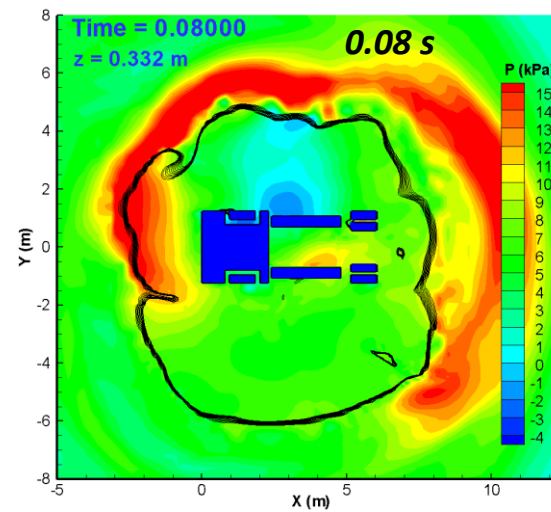
Bottom 18 mm - Combustion

No wind

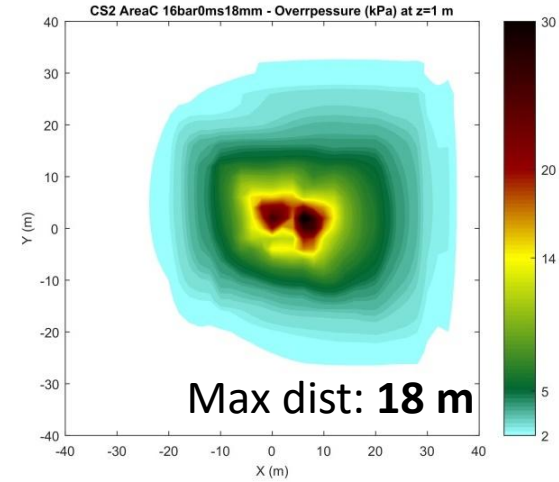
H₂ concentrations (v/v)



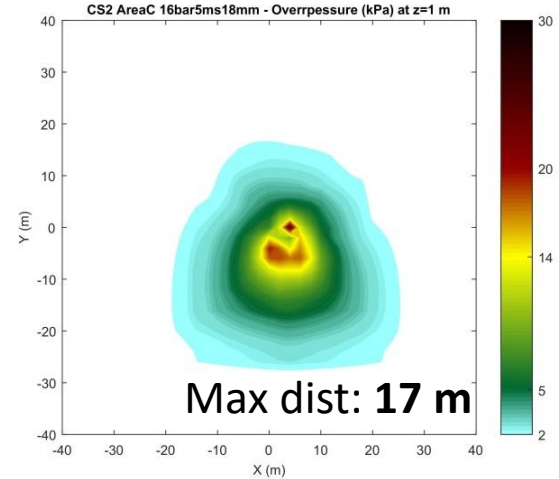
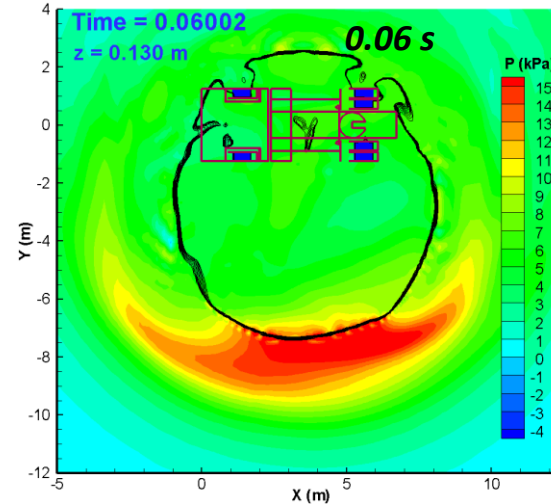
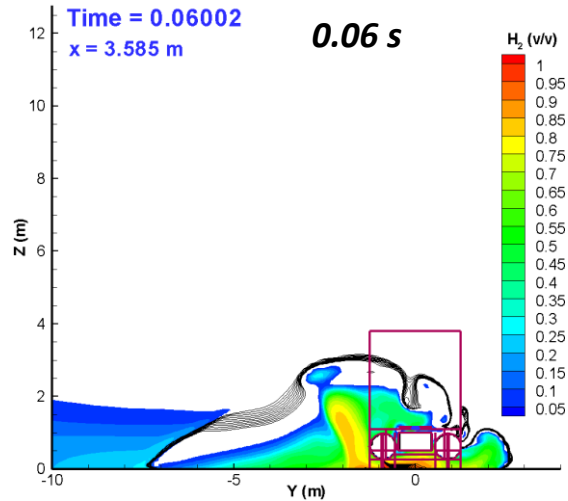
Overpressure (kPa)



Max. overpressure (at z=1 m)



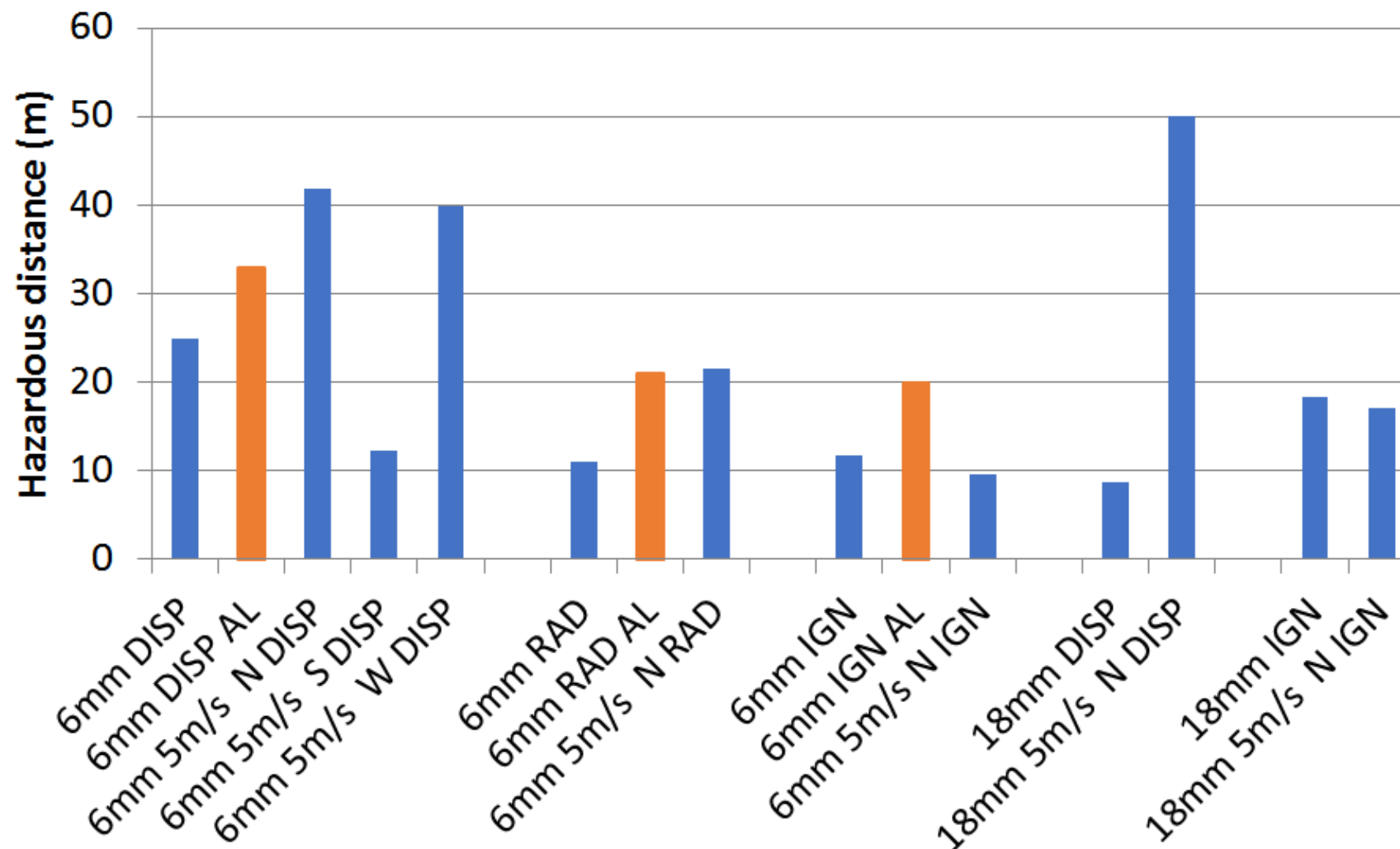
North wind 5 m/s



	OP
Significant lethal effects (5%)	20 kPa
First lethal effects (1%)	14 kPa
Irreversible effects	5 kPa
Indirect effects	2 kPa

(irreversible effects)

Truck scenarios – hazardous distances



Ship - full hose rupture at top of tower

50 mm hose (10 bar) at bunkering tower arm

Downwards release

Source details using the DISCHA tool

Fictitious nozzle area 0.0121 m^2

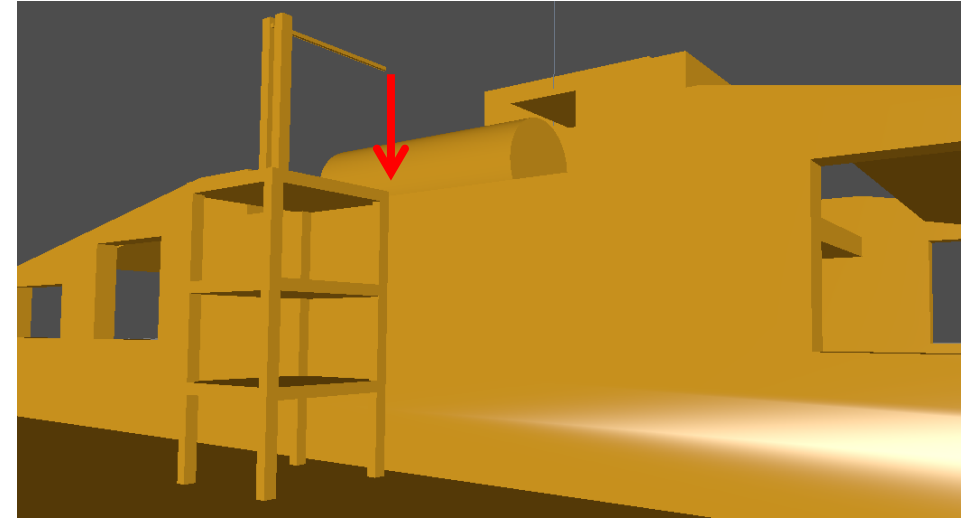
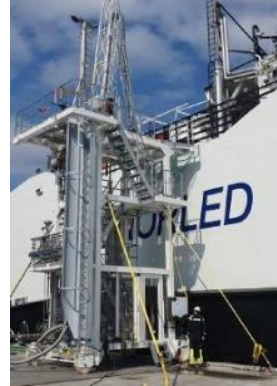
Exit velocity 179 m/s

Tank deck at 9.5 m from sea

Dispenser tower of three $3.5 \times 3.5 \text{ m}$ decks

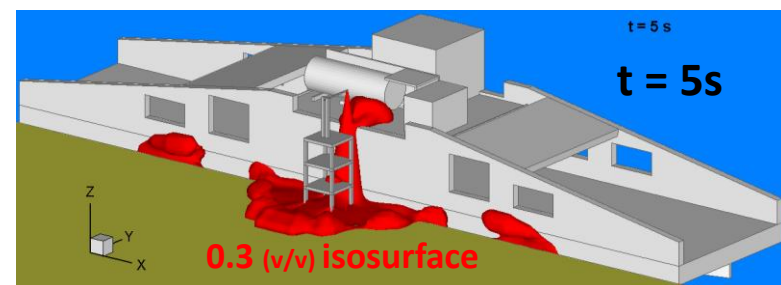
Pier height 1.9 m – distance from ship 0.6 m

Release at $Z=13.5 \text{ m}$ between pier and ship

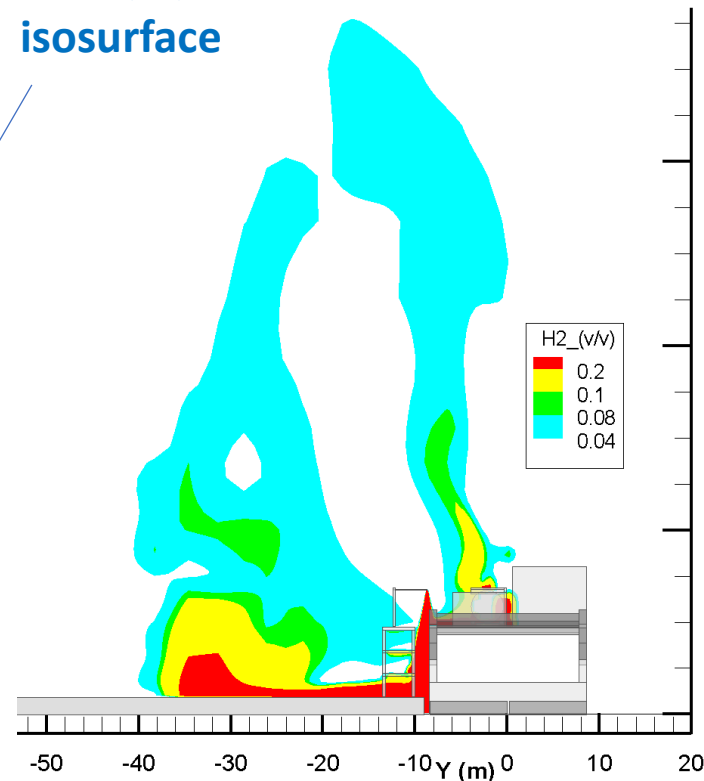
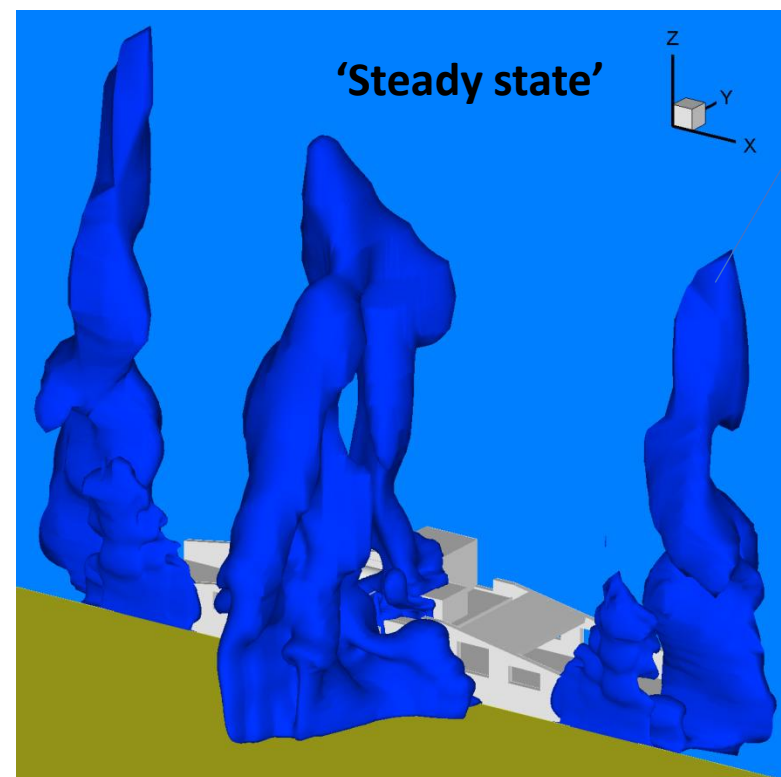


Top of tower 50 mm - Dispersion

NO wind

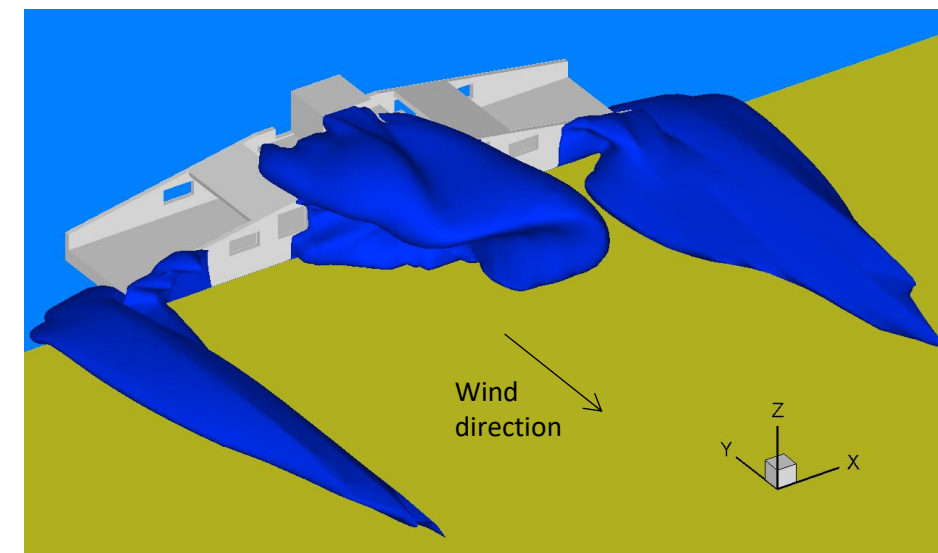


4% (v/v)
isosurface

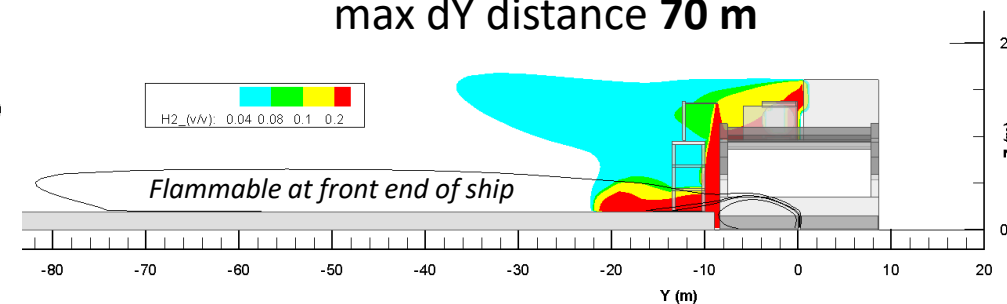


max distance dY of flammable cloud at 1 m height from pier: **29 m**

5 m/s wind

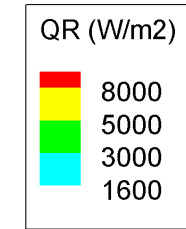
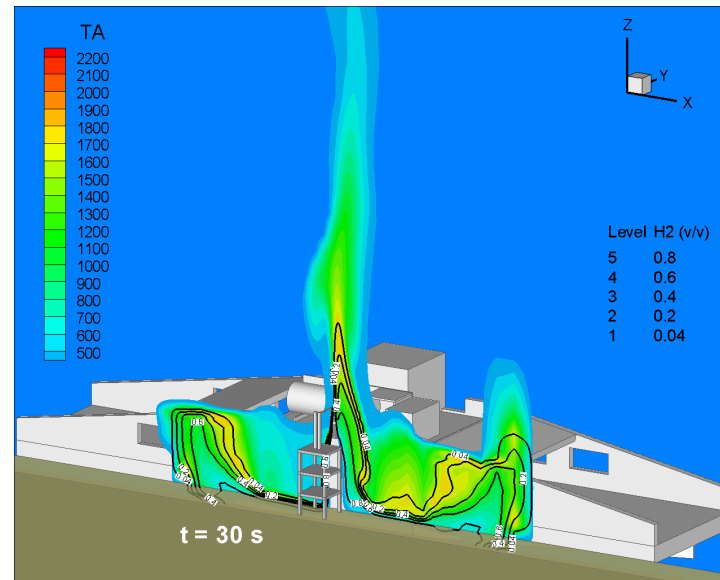
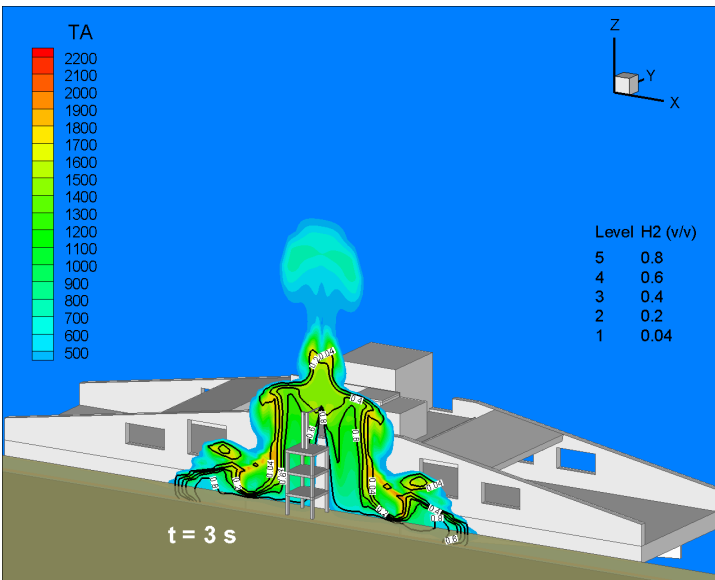
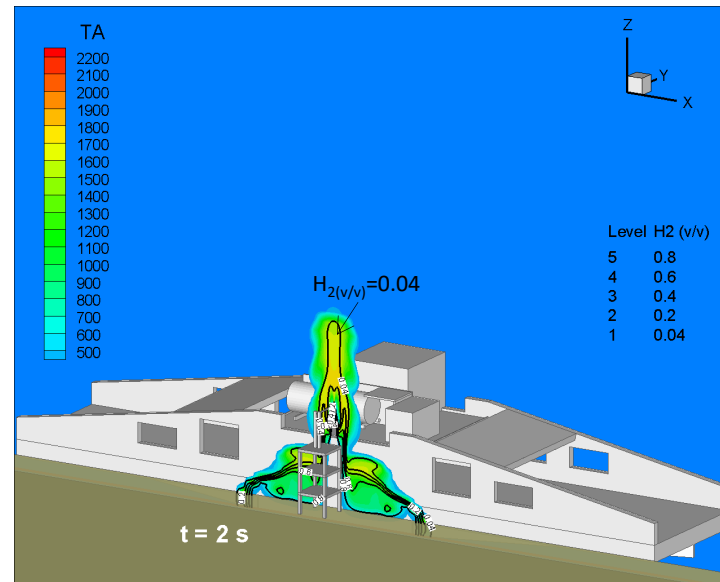
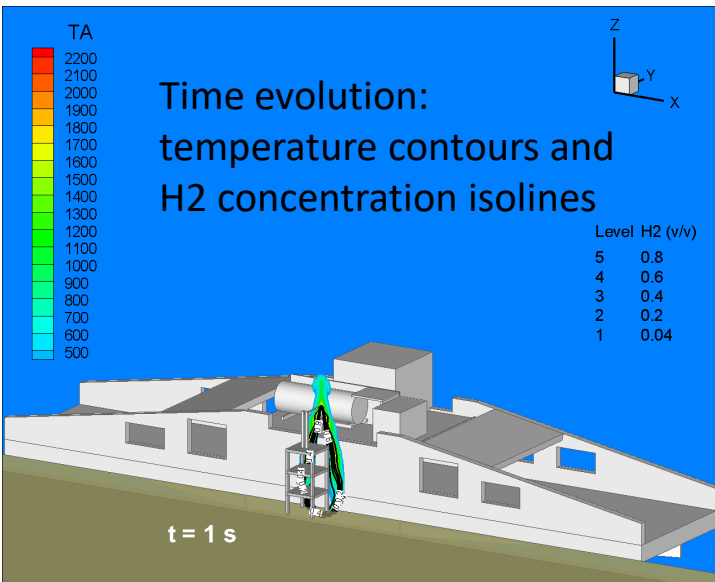


max dY distance **70 m**

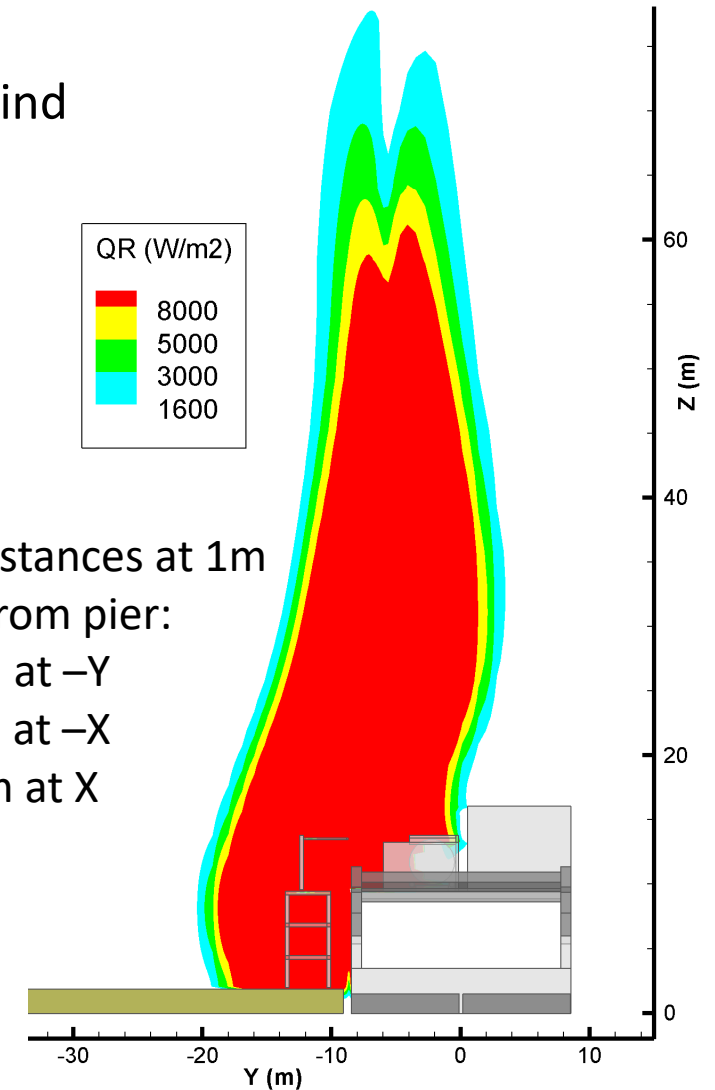


Top of tower 50 mm - Radiation

NO wind



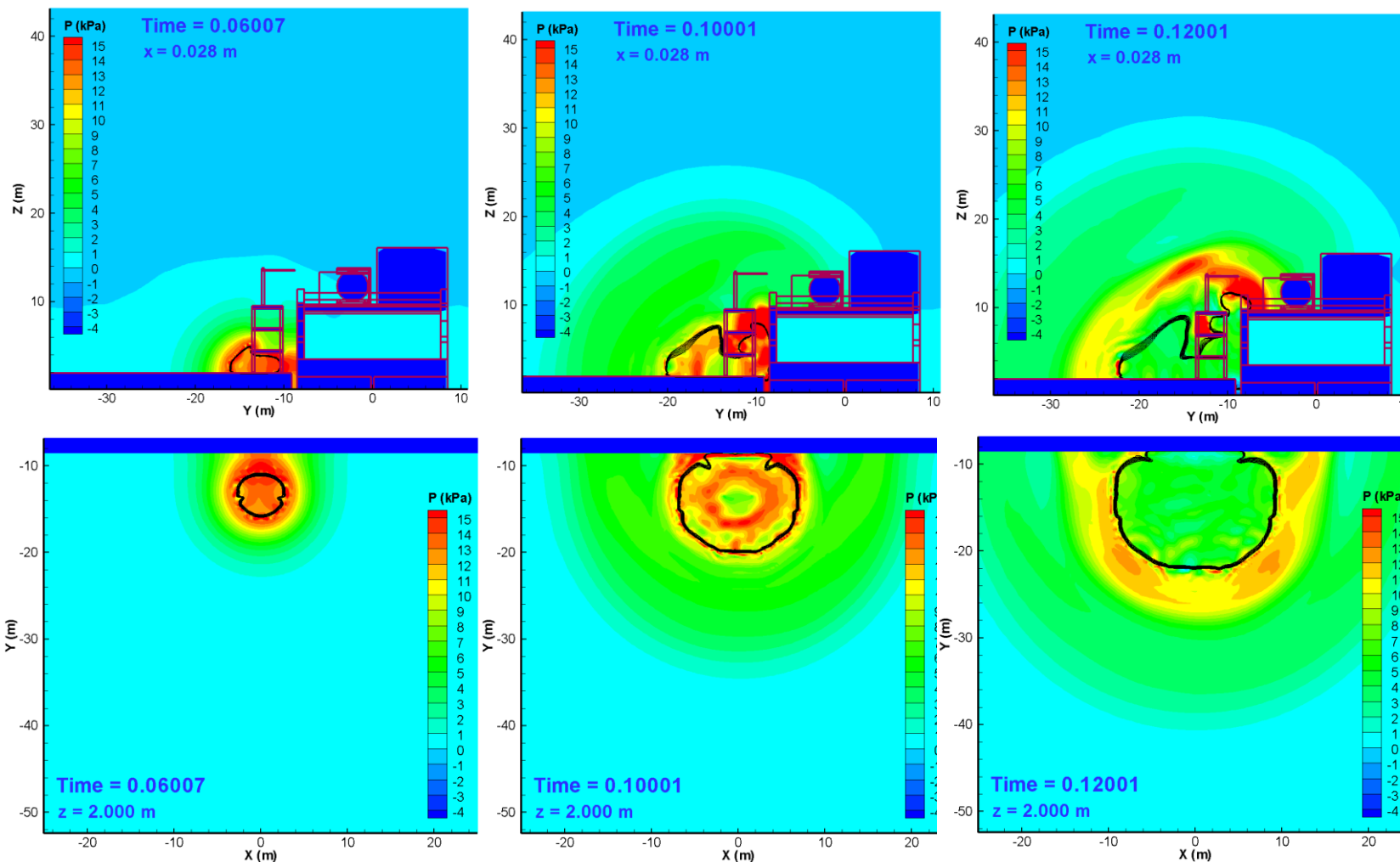
Hazardous distances at 1m
height from pier:
10 m at -Y
28 m at -X
31 m at X



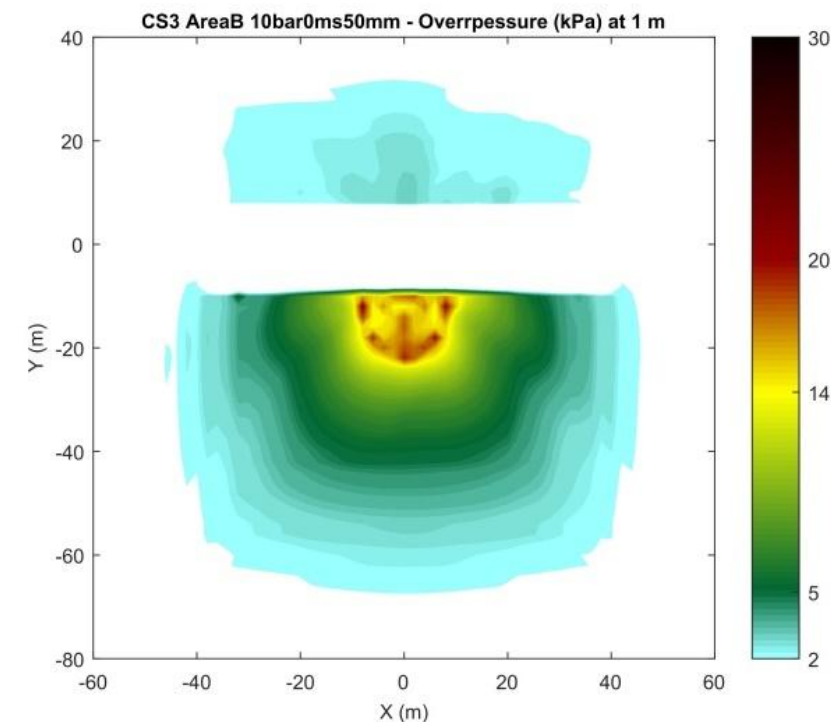
Top of tower 50 mm - Combustion

Time evolution: overpressure contours

NO wind



Maximum overpressure



Hazardous distance: **33 m**

0.06 s

0.1 s

0.12 s

Ship - big tank bottom release

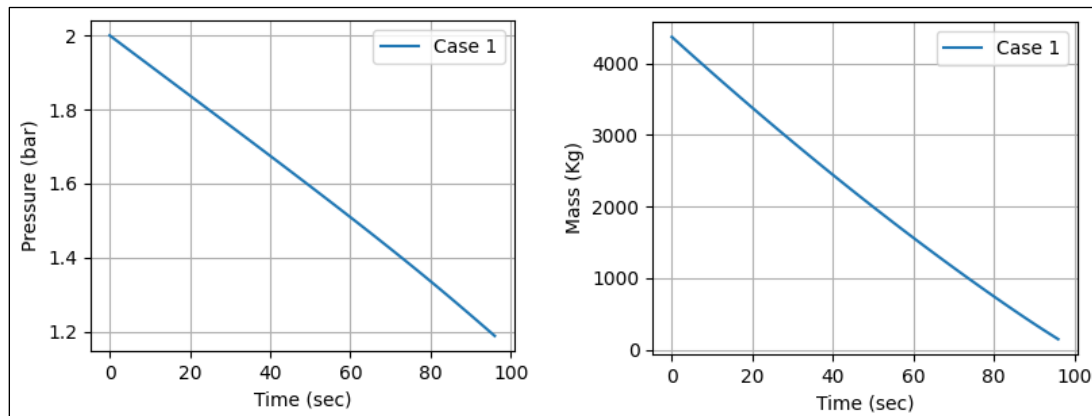
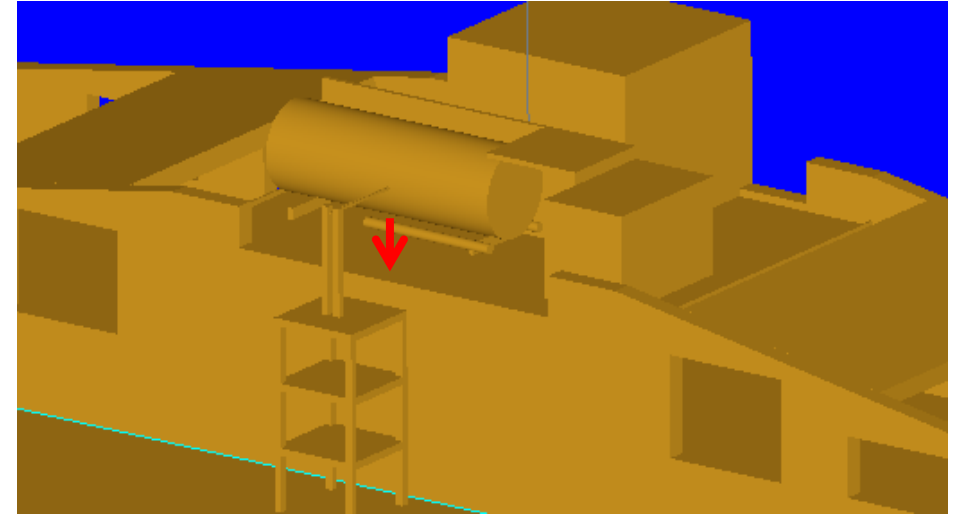
20 cm hole at bottom of tank

Tank 80 m³ - external L=10 m, D=3.5 m

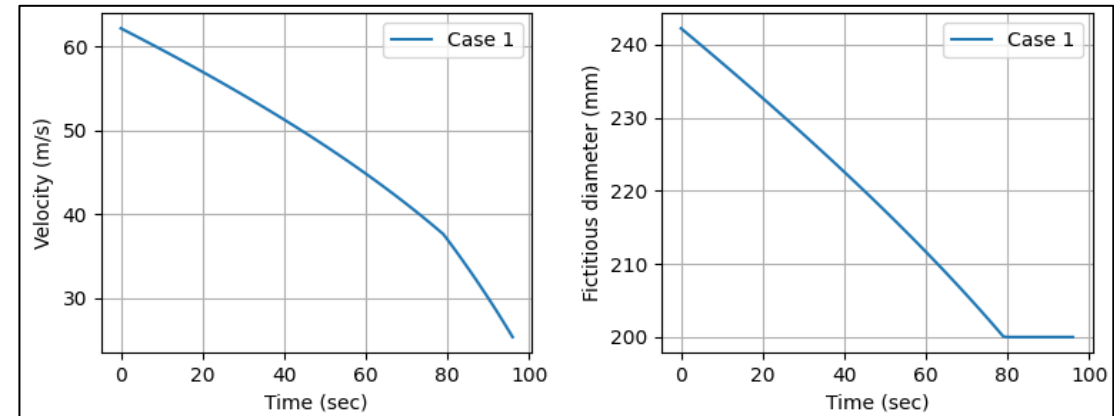
Initial tank conditions: 2 bar, 4373 kg of H₂

Transient release

Source details using the DISCHA tool

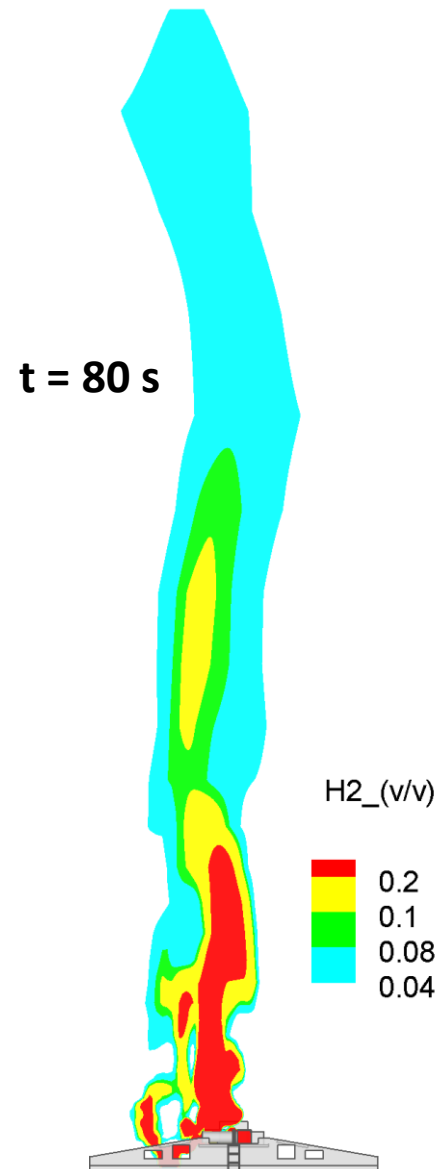
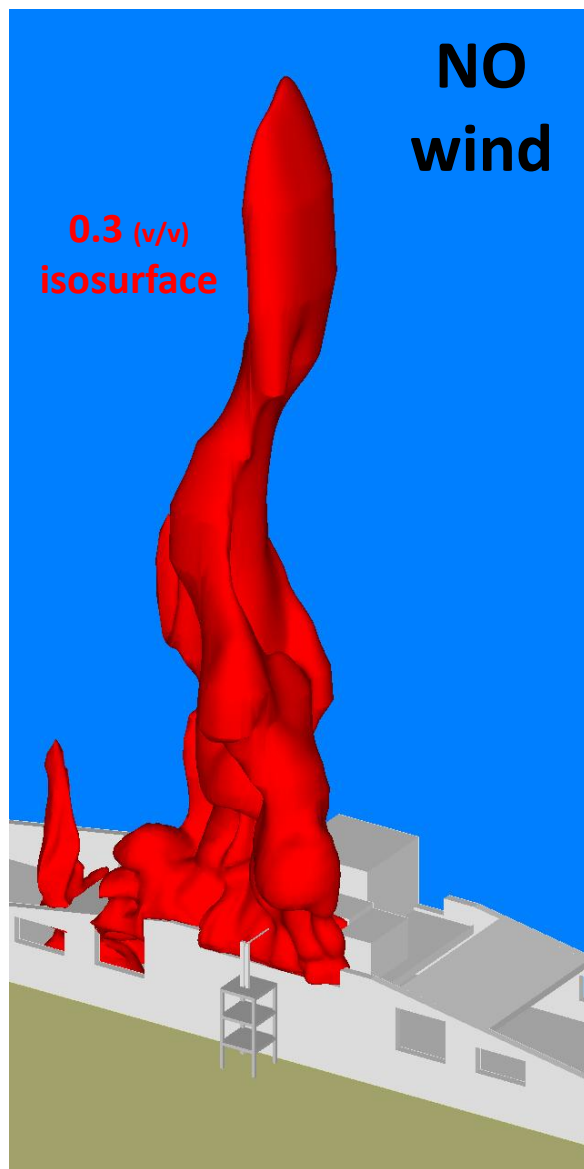


Tank

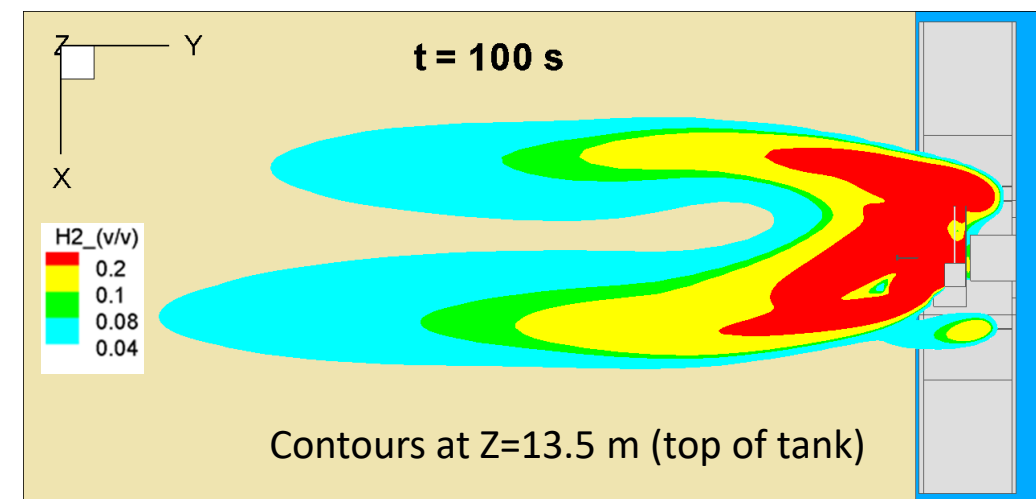
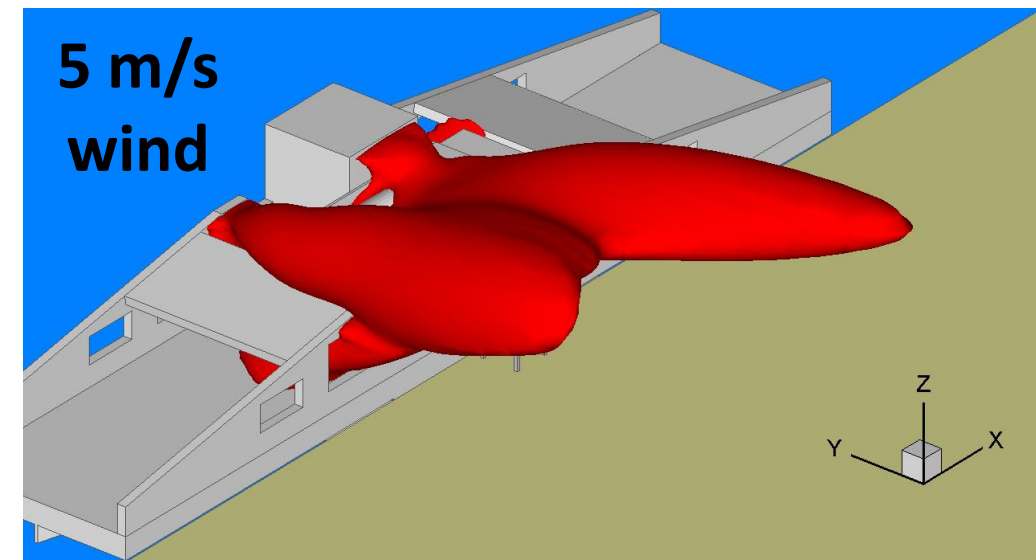


Fictitious nozzle

Bottom of tank 20 cm - Dispersion



No flammable at pier level
in either case

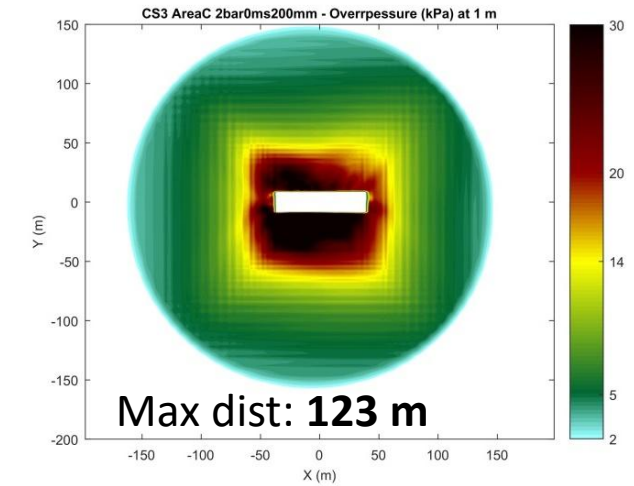
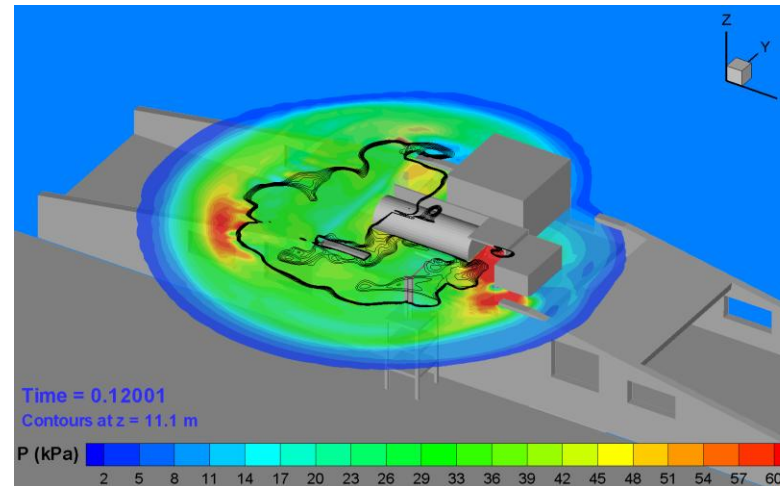
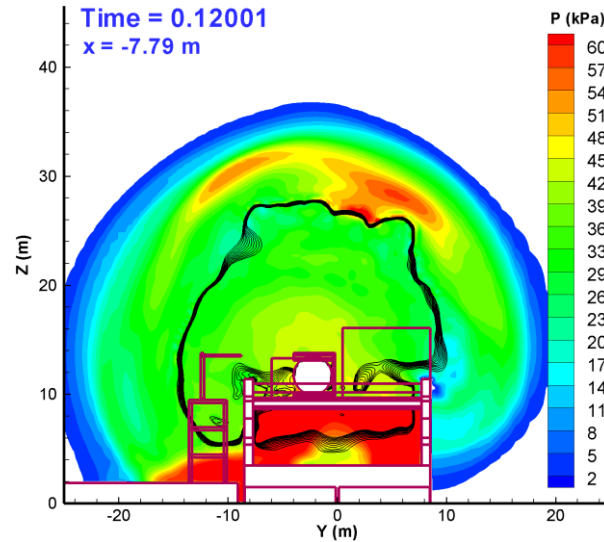


Bottom of tank 20 cm - Combustion

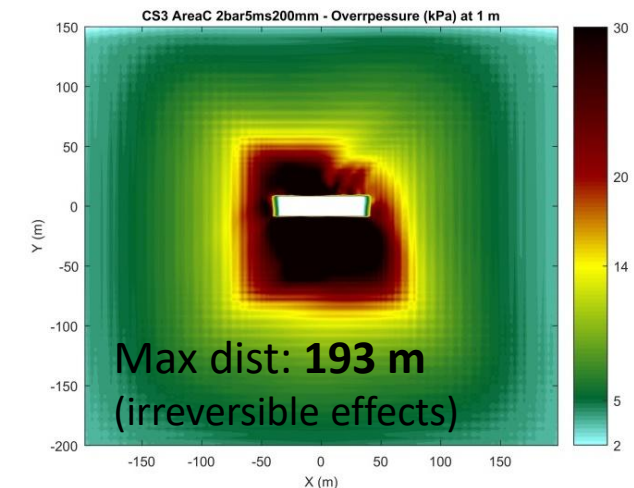
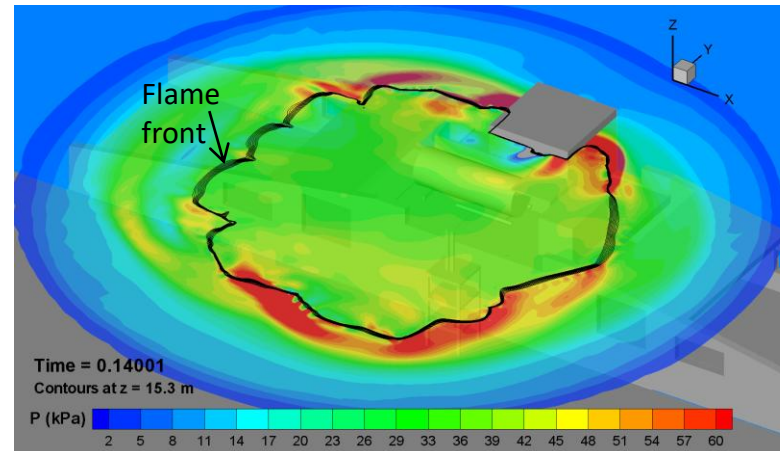
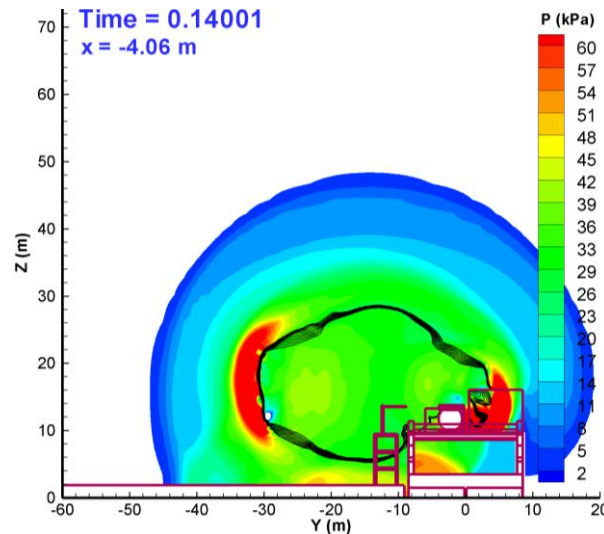
Overpressure contours at ignition planes at specific times (kPa)

Max. overpressure (at $z = 1\text{ m}$)

No wind



5 m/s wind



Conclusions

CFD suitable for detailed consequence assessment in complex geometries

Cryogenic, multi-component, multiphase flow and dispersion simulated including combustion, radiation and interaction with the geometry

Rare, worst-case scenarios examined around a truck and a ship

Truck side release 6 mm: up to about **40 m** hazardous distance

Truck bottom release 18 mm: up to **50 m** hazardous distance

Ship downwards 50 mm release from top of tower: complex physics

If channeled between pier and ship: **70 m** hazardous distance at pier level

Ship big 20 cm hole at bottom of tank: improbable, but interesting

Hazardous distances may reach **200 m** at pier level in case of explosion

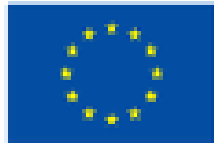


Thank you for your attention



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