CONSEQUENCE ANALYSIS BY CFD MODEL FOR LH_2 BUNKERING OF A HYDROGEN POWERED SHIP

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Introduction

- Studies roughly based on bunkering of “MF Hydra”, which is the only operational LH2 ship

80 vehicles

300 passengers

Bunkering tower

80 m^3 hydrogen tank

2 x 200 kW fuel cells

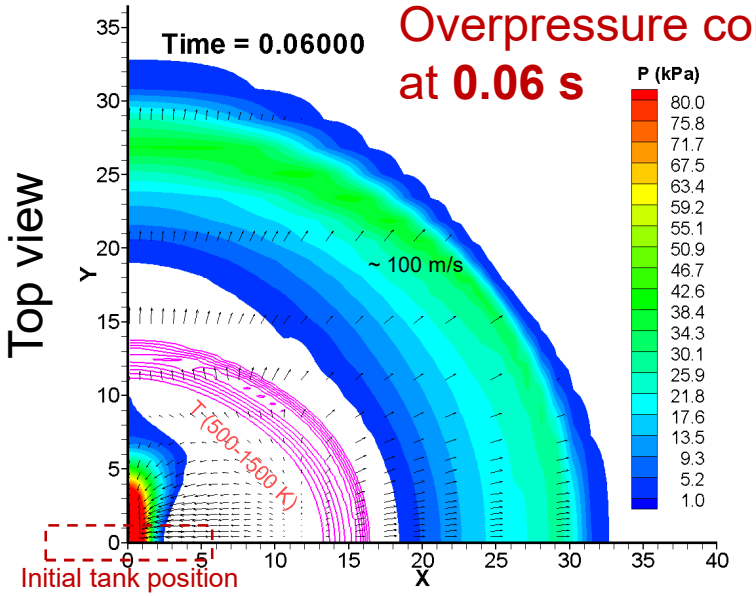
Introduction

- Consequence analysis: What will happen IF something goes wrong and it results in hydrogen release
  - Not all hazardous scenarios examined with CFD
  - Few scenarios will be presented
- Liquid hydrogen release may result in:
  - Dispersion (flammable cloud – flash fire)
  - Vapour Cloud Explosion (delayed ignition/ high overpressures)
  - Jet fire (immediate ignition resulting in high radiation)
- Abrupt tank rupture may result in:
  - BLEVE (Boiling Liquid Expanding Vapour Explosion)

Introduction

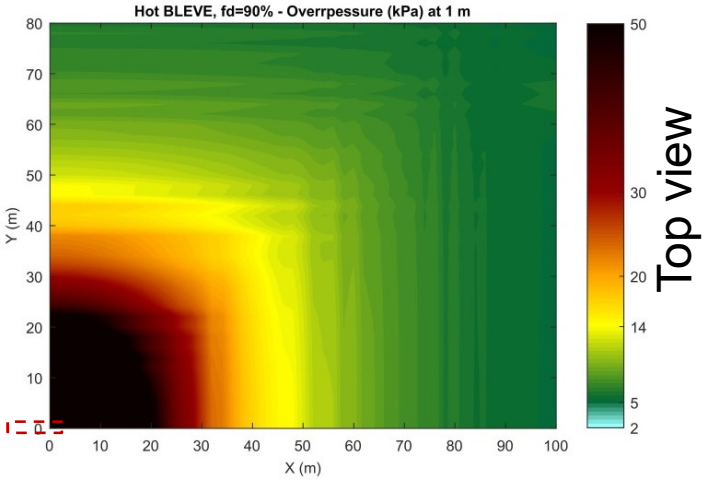
Indicative results/ BLEVE (trailer tank)

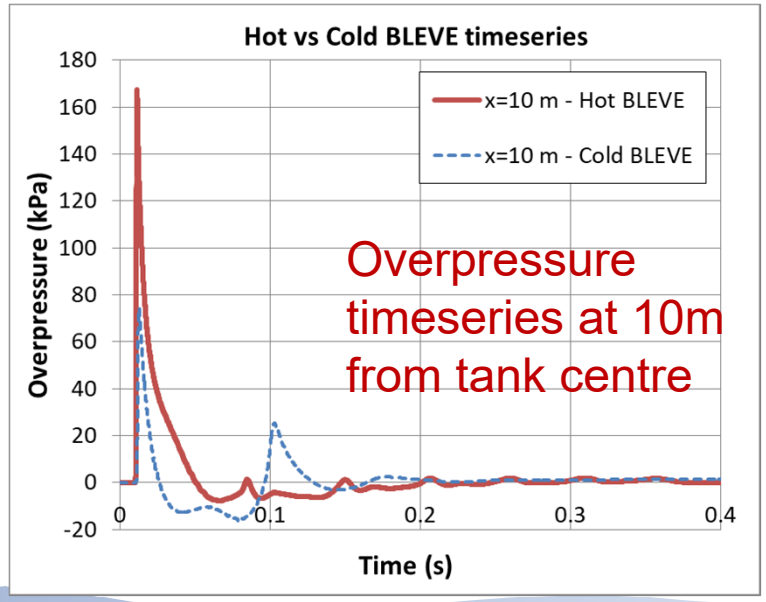
Overpressure contours at **0.06 s**



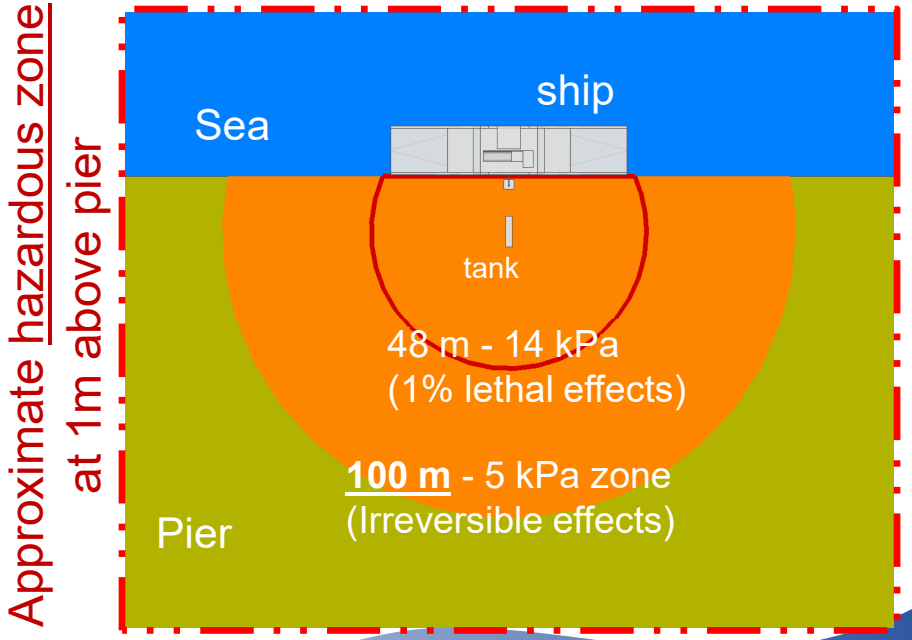
57 m^3 tank/ 10 bar
Filling degree 90%
Double symmetry
No obstacles

Maximum overpressure (regardless of time)





	Overpressure (1 kPa = 10 barg)
Significant lethal effects (5%)	20 kPa
First lethal effects (1%)	14 kPa
Irreversible effects	5 kPa
Indirect effects	2 kPa



Indicative results/ hose rupture

Dispersion

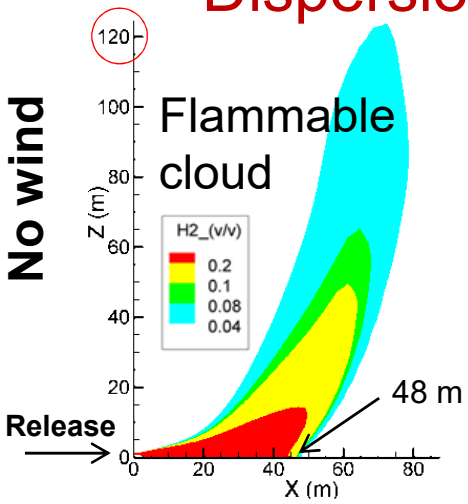
Jet fire

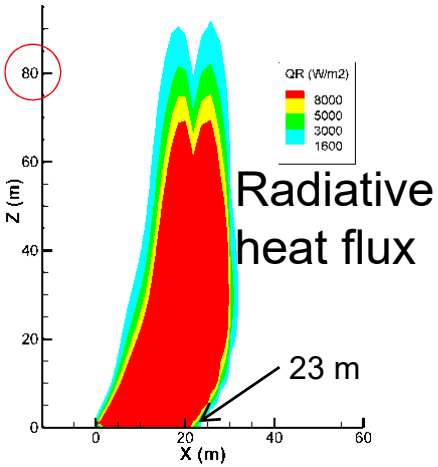
Explosion

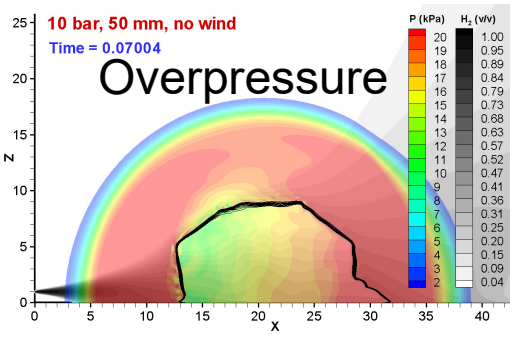
OP at indicative time

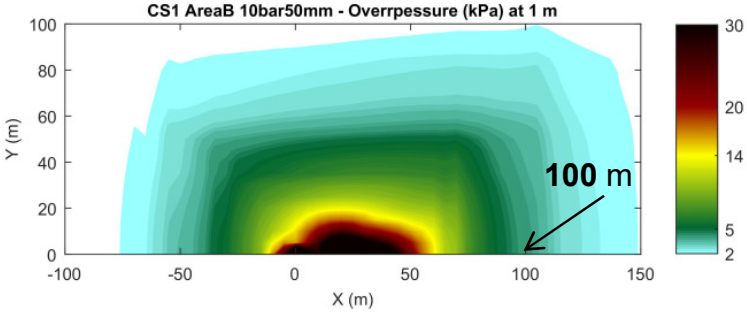
Maximum overpressure

No wind

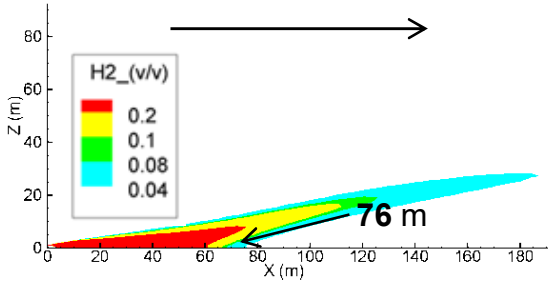


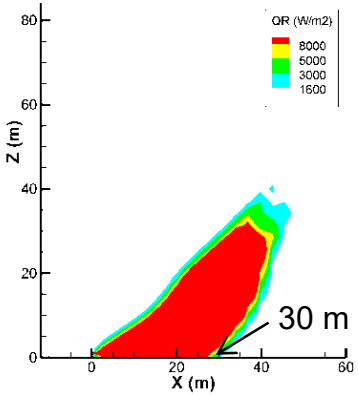


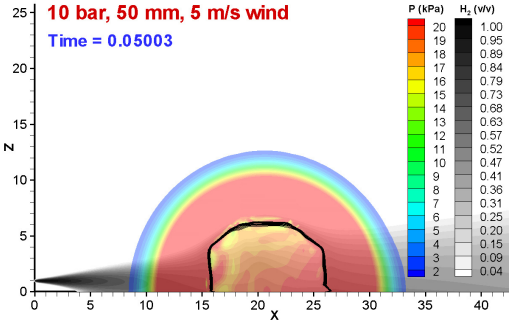


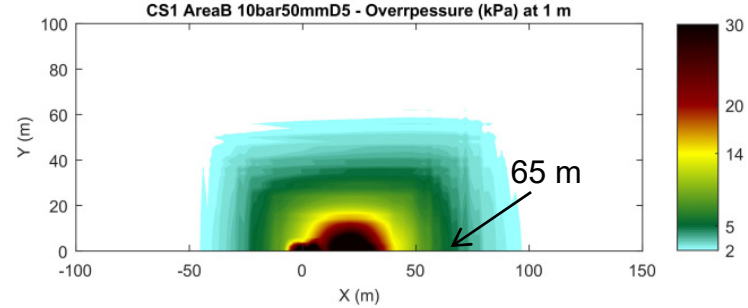


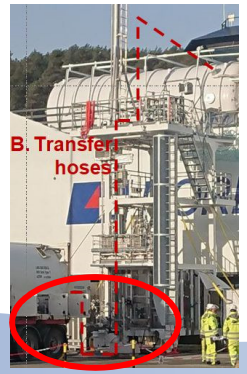
5 m/s wind



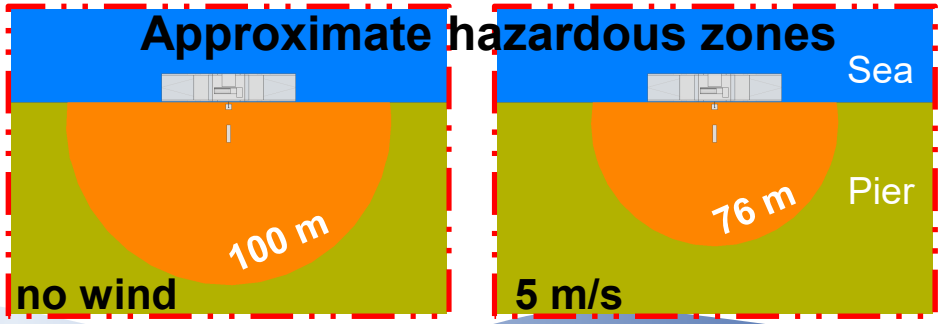






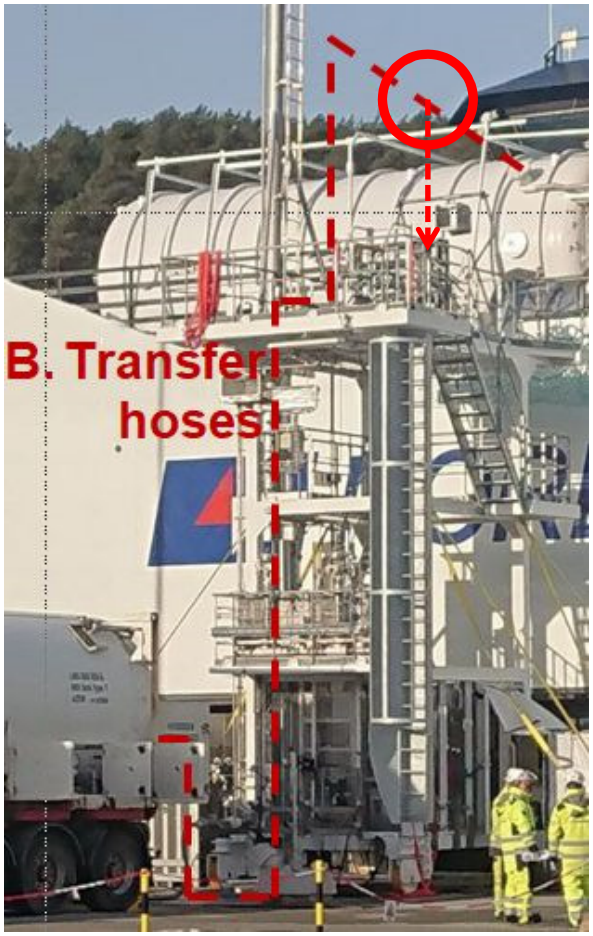


- 50 mm rupture (full bore)
- 10 bar
- No obstacles
- Horizontal release
  (Z=1m from ground)



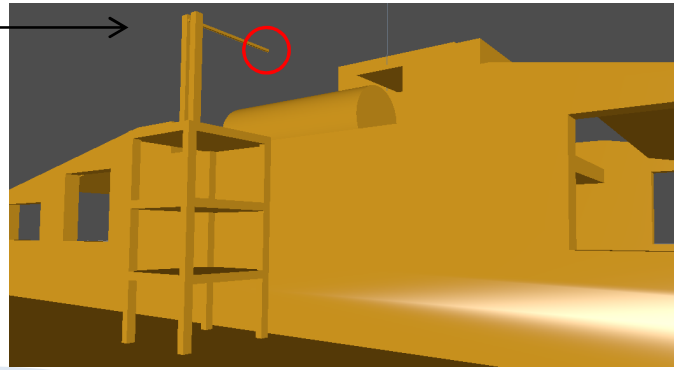
Hose rupture at top of bunkering tower

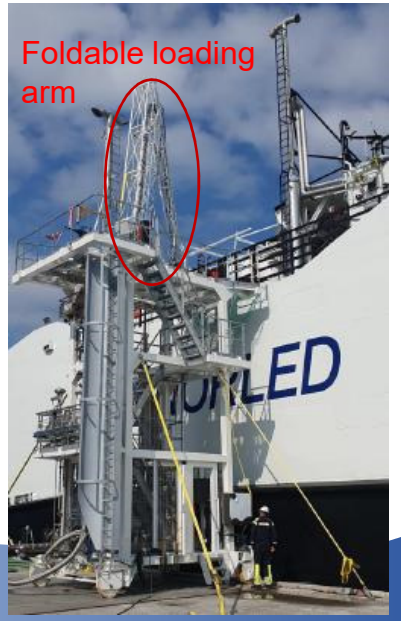
- 50 mm hose rupture, 10 bar, 50% R.H.
- Downwards release
- Source details using the DISCA tool
  - Fictitious nozzle
    - Total enthalpy=ct. Mach=1 (two phase conditions)
    - Fictitious nozzle area ~0.0121 m²
    - Exit velocity ~179 m/s
- ADREA-HF RANS CFD code used
  - Non-premixed combustion: Eddy dissipation
  - Radiation: P1 model
  - Premixed combustion : Turbulent burning velocity incorporating flame instabilities



Top of tower hose rupture - geometry

- Simplified geometry of “Hydra” vessel
  - 82.4 x 17 x 16.1 m (X, Y, Z)
  - Axis origin at ship centre (sea level)
  - Tank deck at 9.5 m from sea
  - Tank external L=10 m, D=3.5 m
  - Tank centre at (X, Y) = (-4, -2.25)
  - Dispenser tower of 3 3.5x3.5m decks
  - Pier height 1.9 m – distance from ship 0.6 m
  - Release at Z=13.5 m between pier and ship

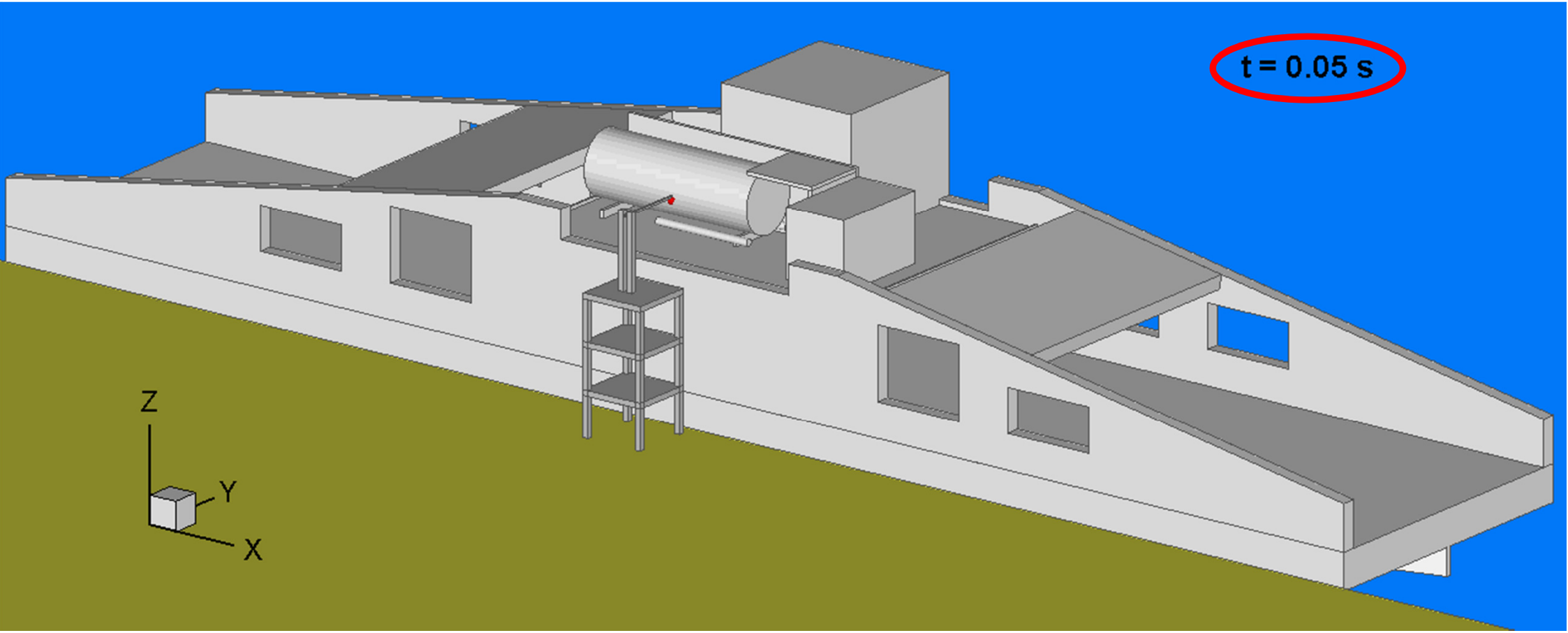


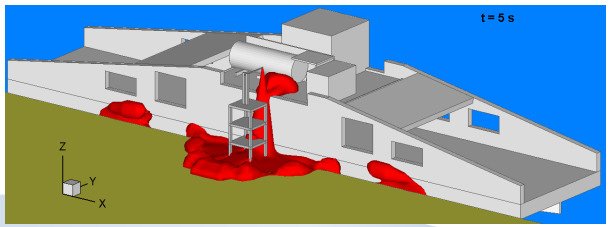


Top of tower hose rupture - results

Dispersion, **no wind**

Time evolution of $H_{2\ (v/v)}$ = 0.3 isosurface

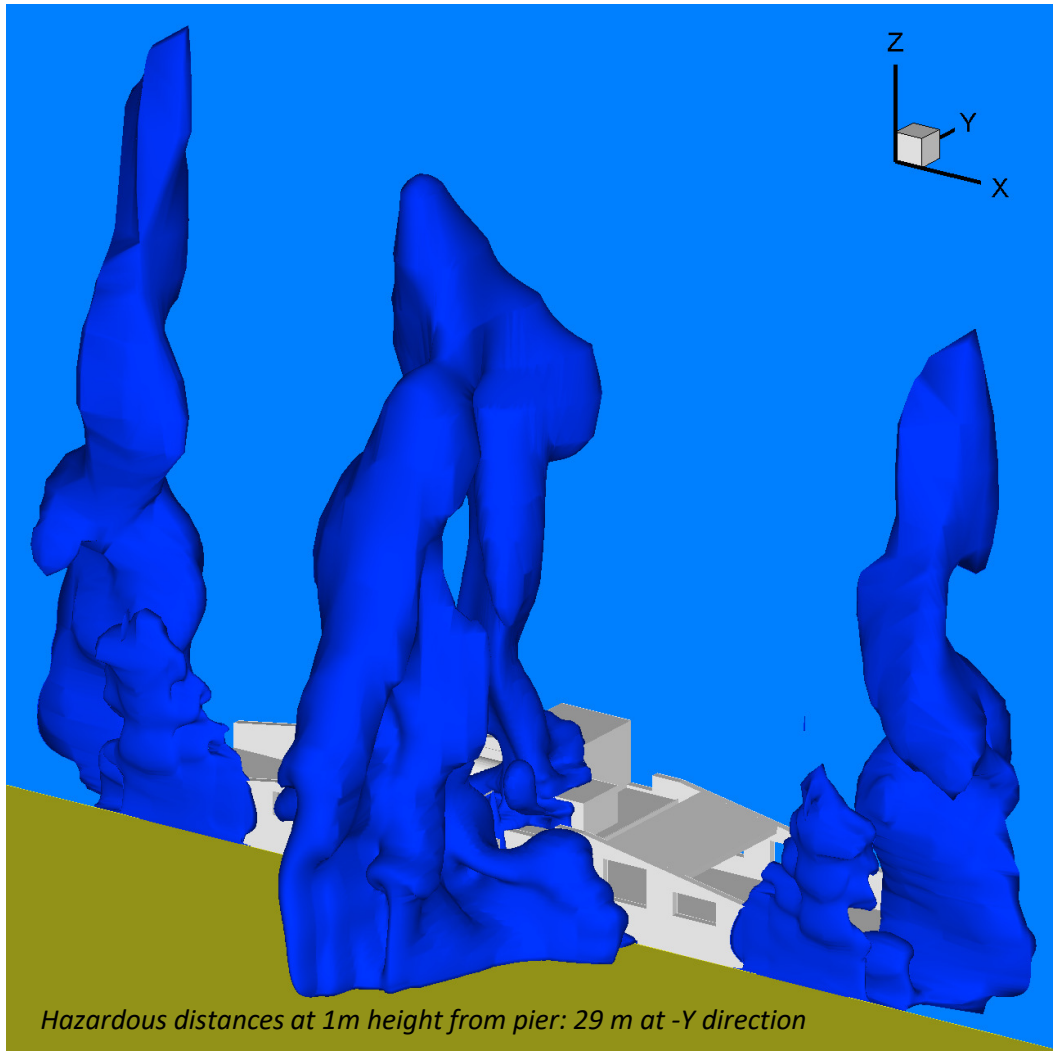




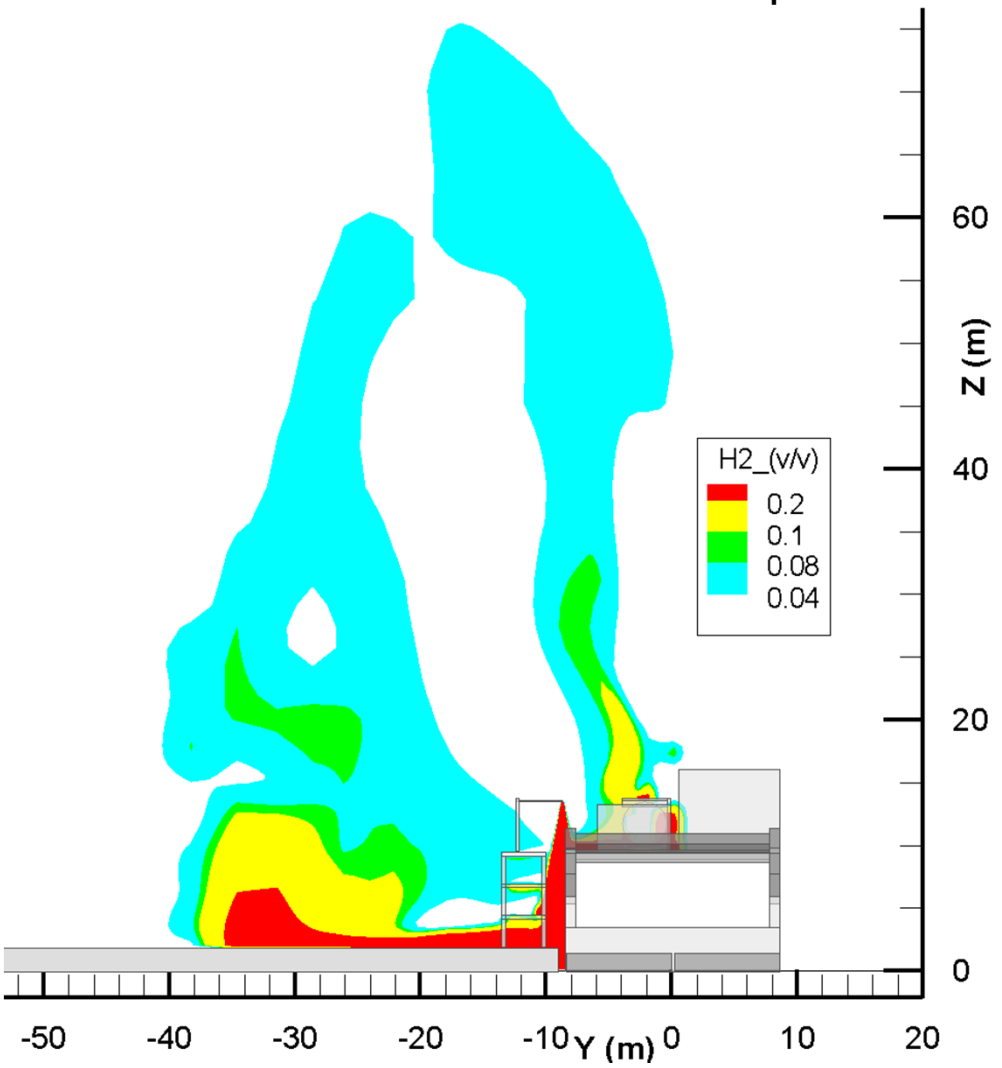
Top of tower hose rupture - results

Dispersion, no wind 'steady-state' results

Flammable isosurface ($H_{2\ (v/v)}$ = 0.04)



Concentration contours at X=0 plane

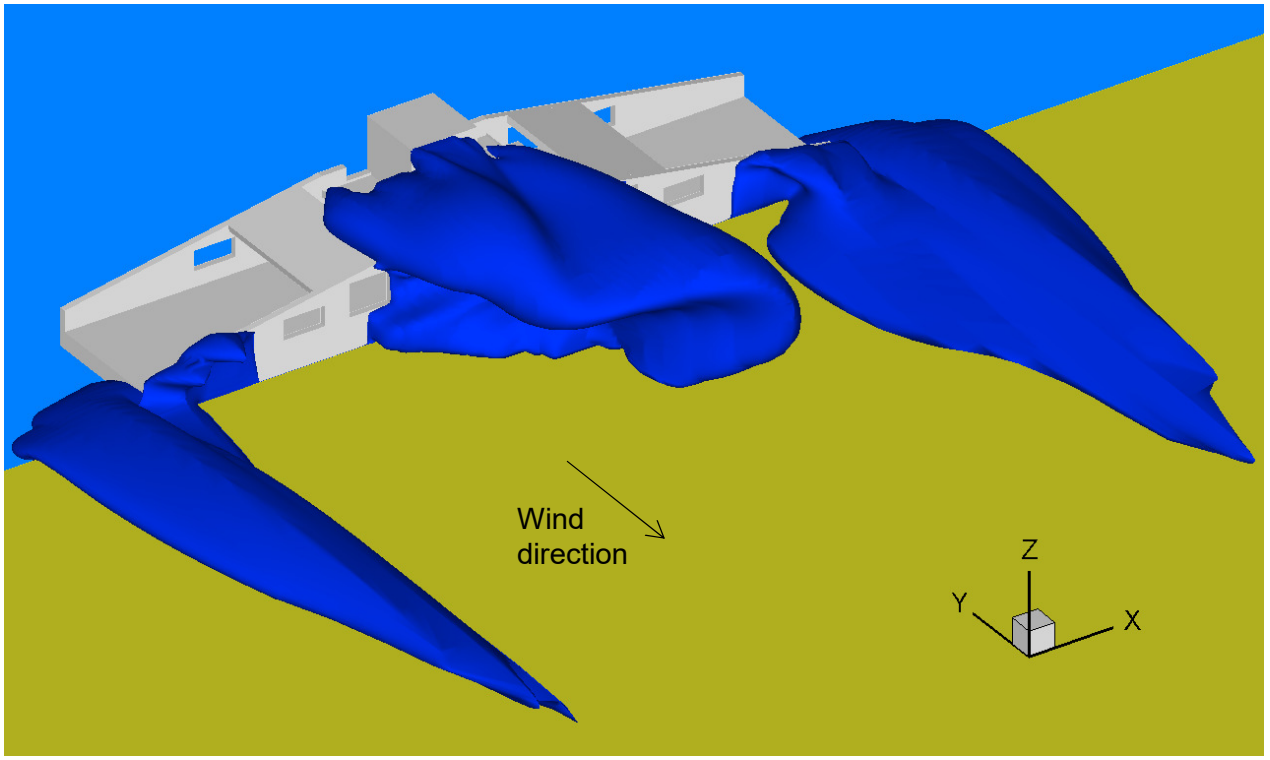


Top of tower hose rupture - results

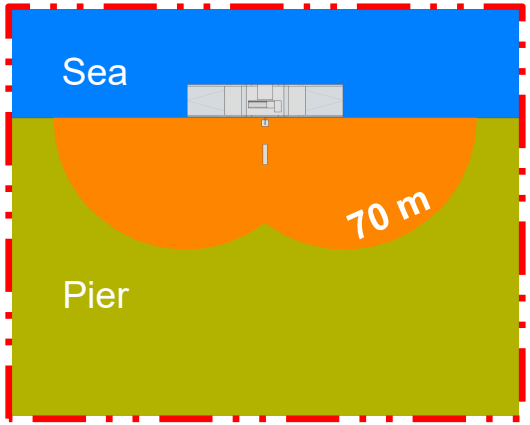
Dispersion

5 m/s wind

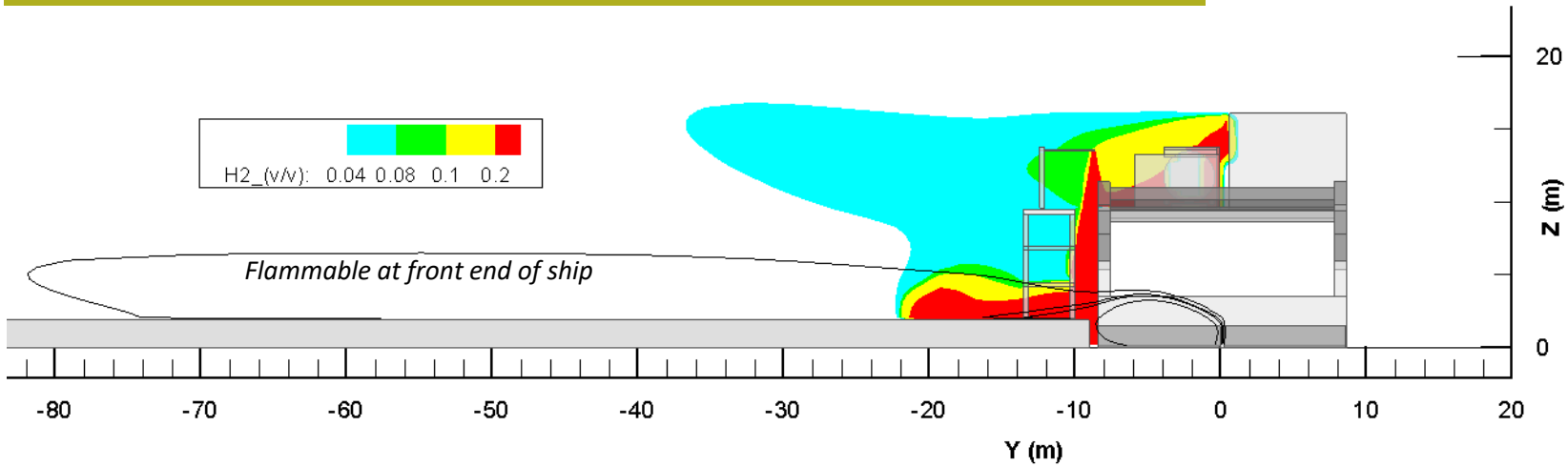
Flammable isosurface



Approximate hazardous zone



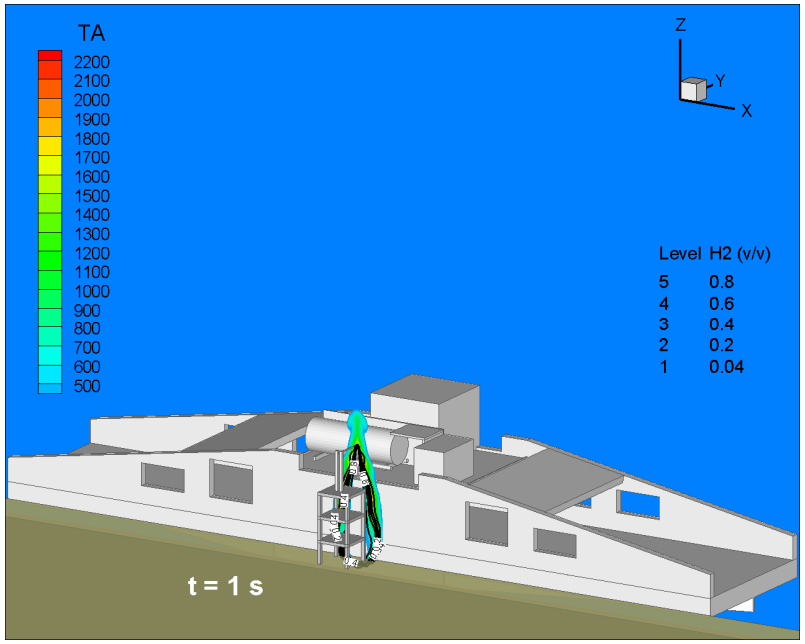
Concentration contours at X=0 plane

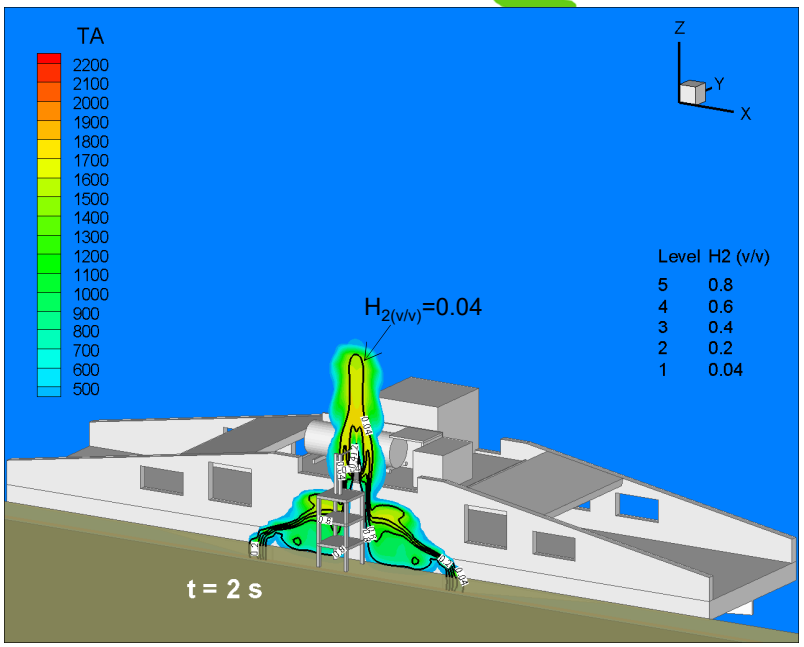


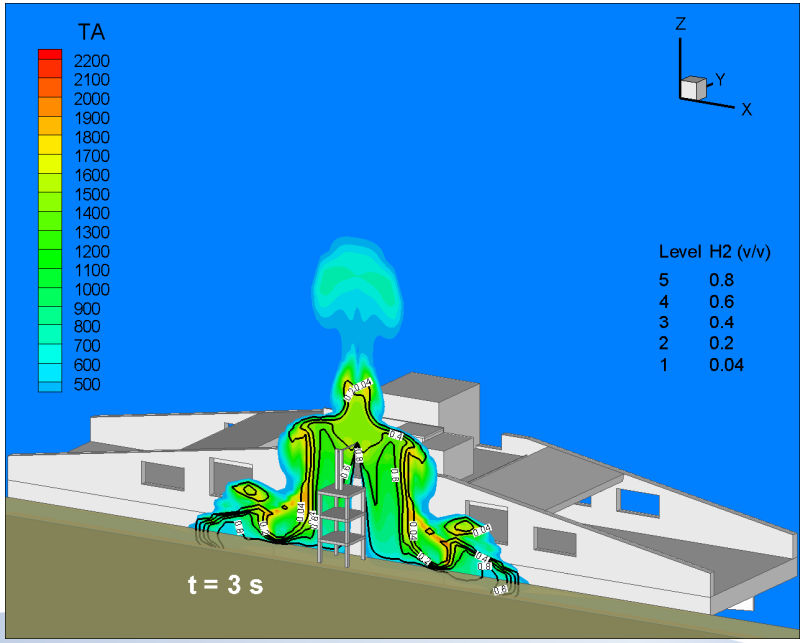
Top of tower hose rupture - results

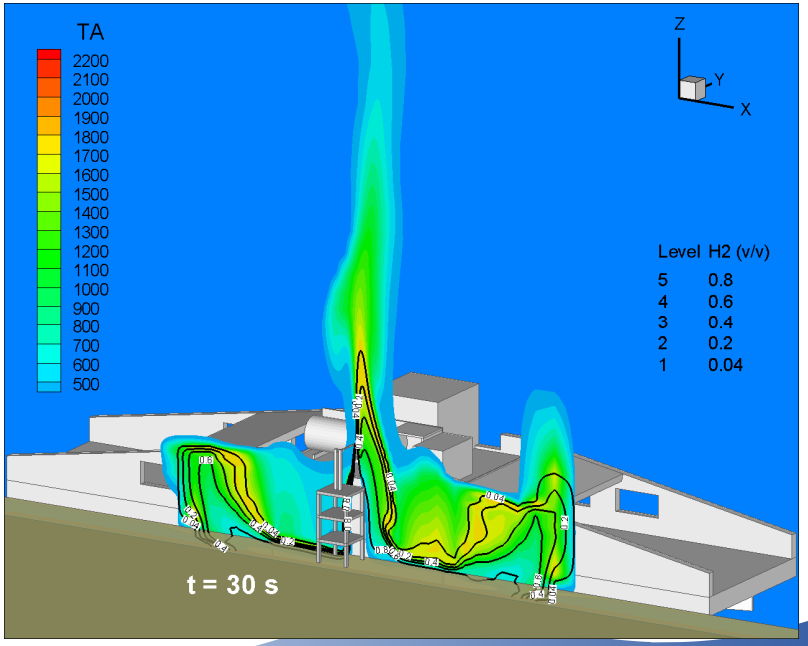
<u>Jet fire</u>,
no wind

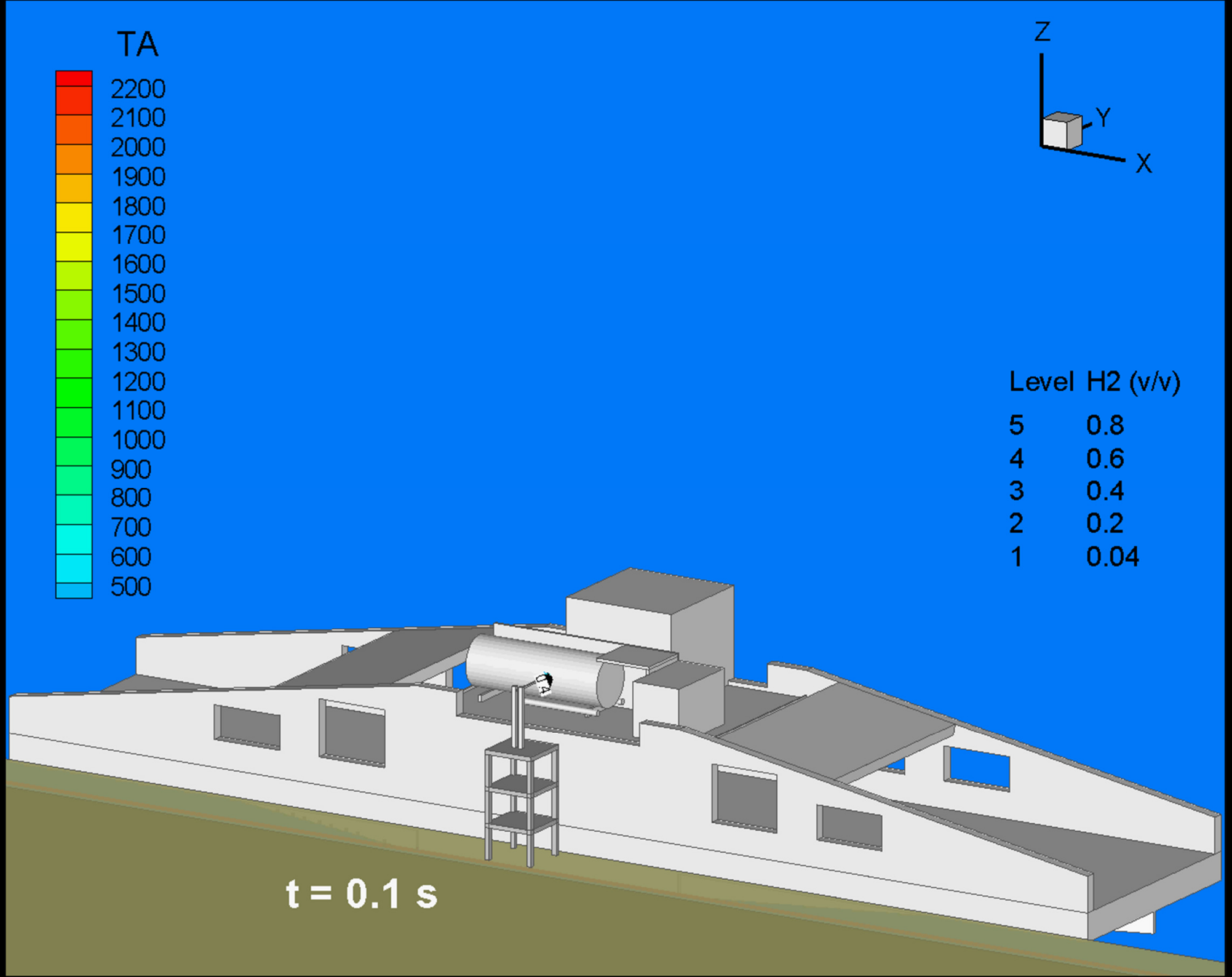
Time evolution: temperature contours and H_2 concentration isolines







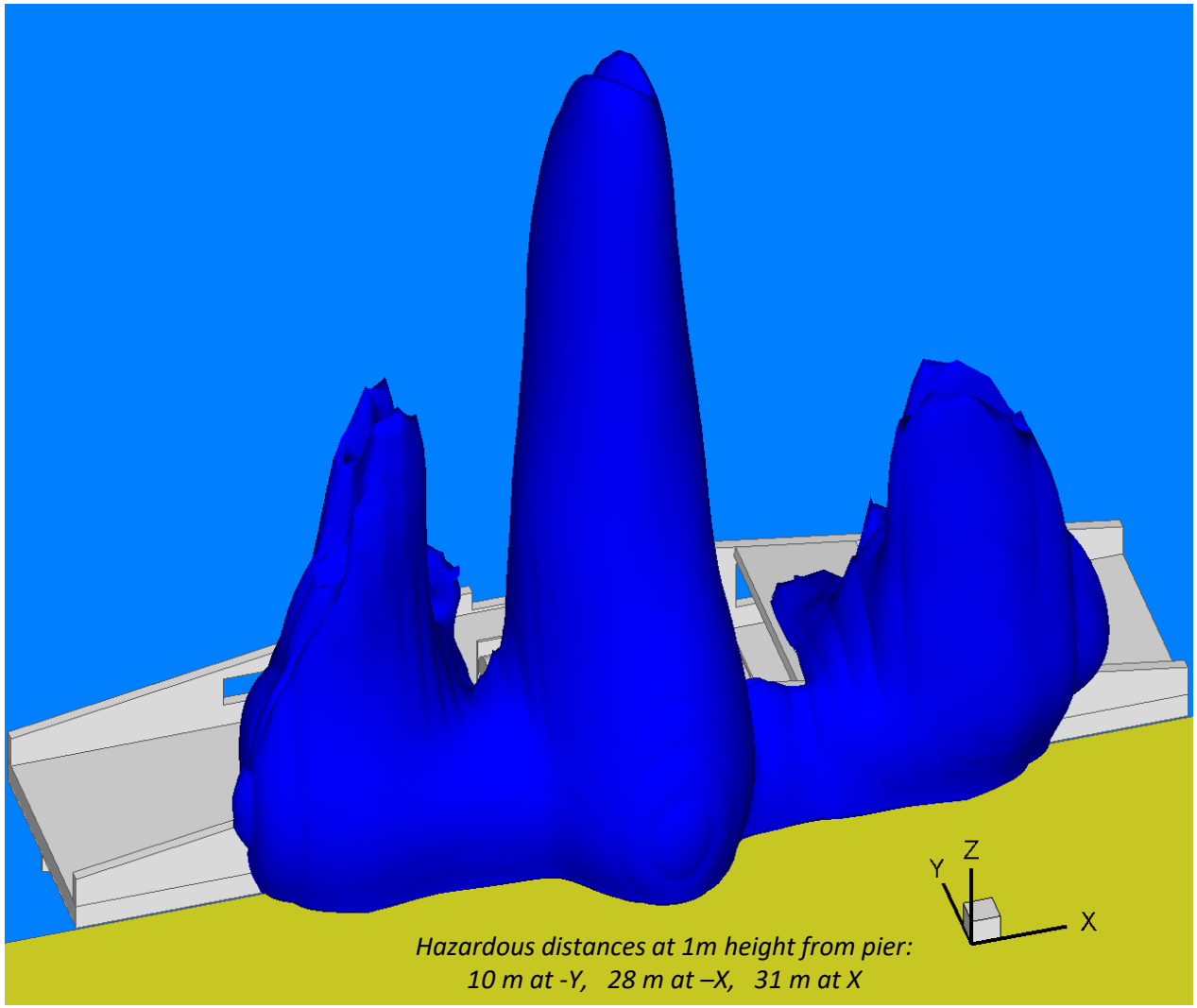



TA
2200
2100
2000
1900
1800
1700
1600
1500
1400
1300
1200
1100
1000
900
800
700
600
500
Z
Y
X
Level H2 (v/v)
5 0.8
4 0.6
3 0.4
2 0.2
1 0.04
t = 0.1 s

Top of tower hose rupture - results

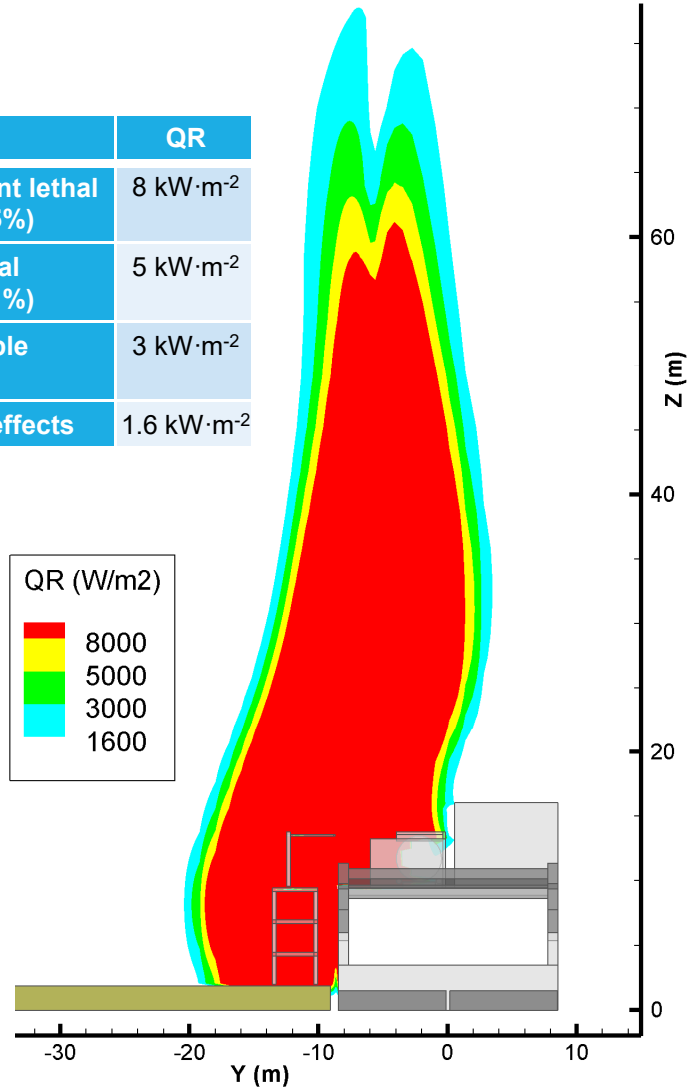
Jet fire, no wind 'steady state' results

QR=3000 W/m^2 isosurface



Radiative heat flux (QR) contours

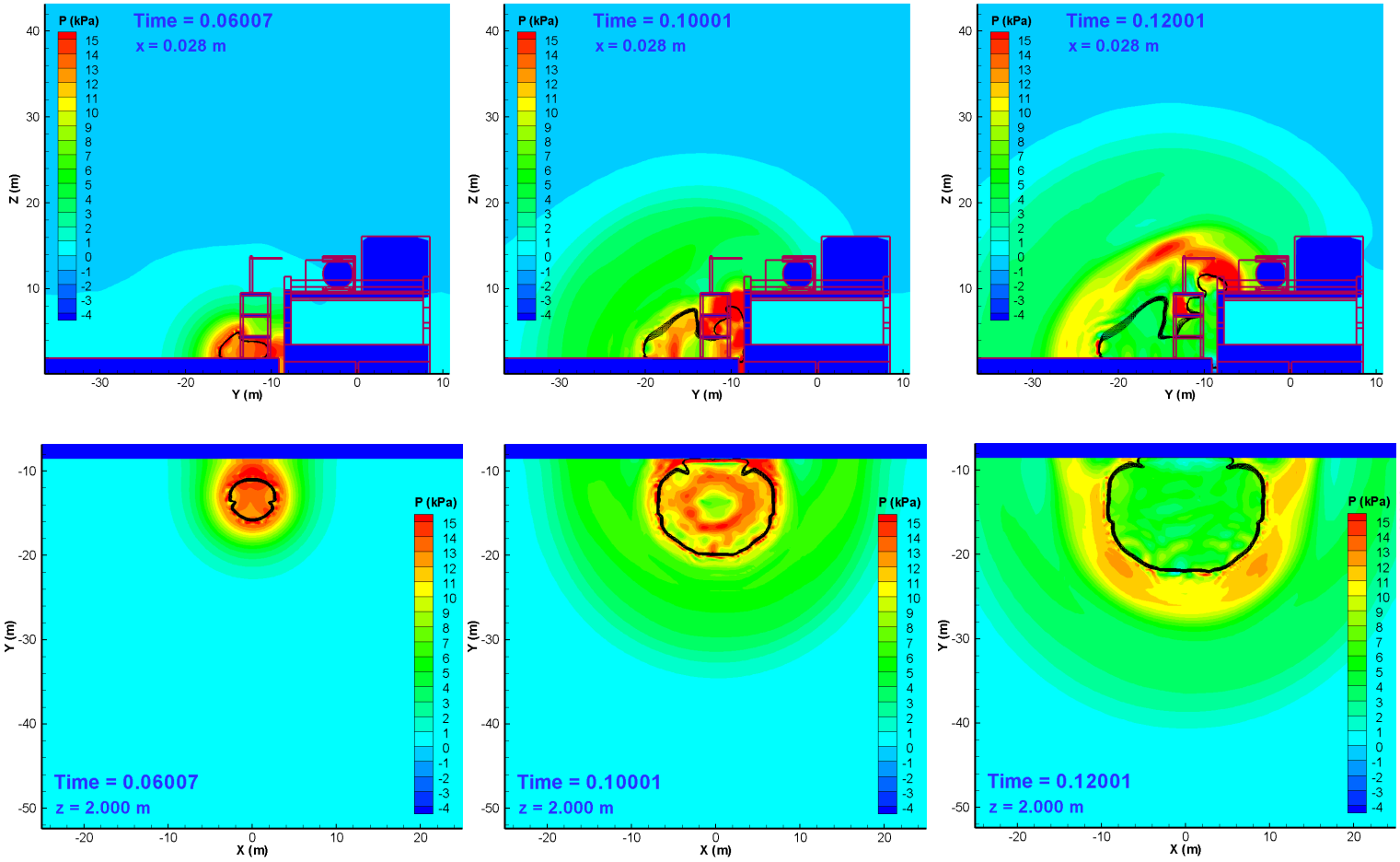
	QR
Significant lethal effects (5%)	8 kW·m^{-2}
First lethal effects (1%)	5 kW·m^{-2}
Irreversible effects	3 kW·m^{-2}
Indirect effects	1.6 kW·m^{-2}



Top of tower hose rupture - results

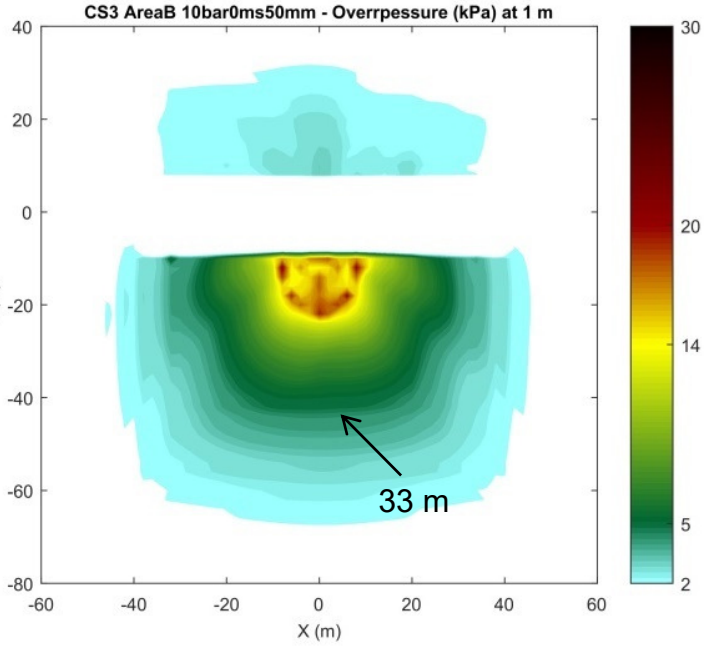
Explosion, no wind

Time evolution: overpressure contours



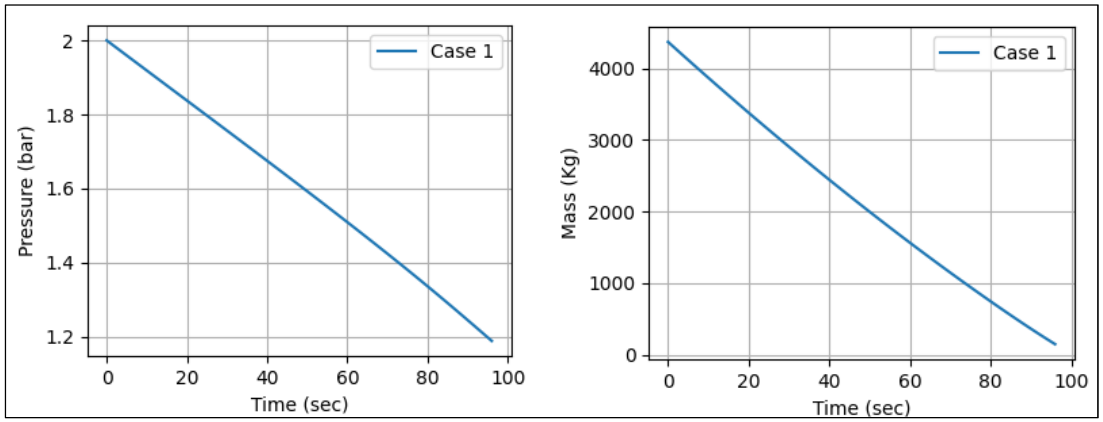
0.06 s 0.1 s 0.12 s

Maximum overpressure



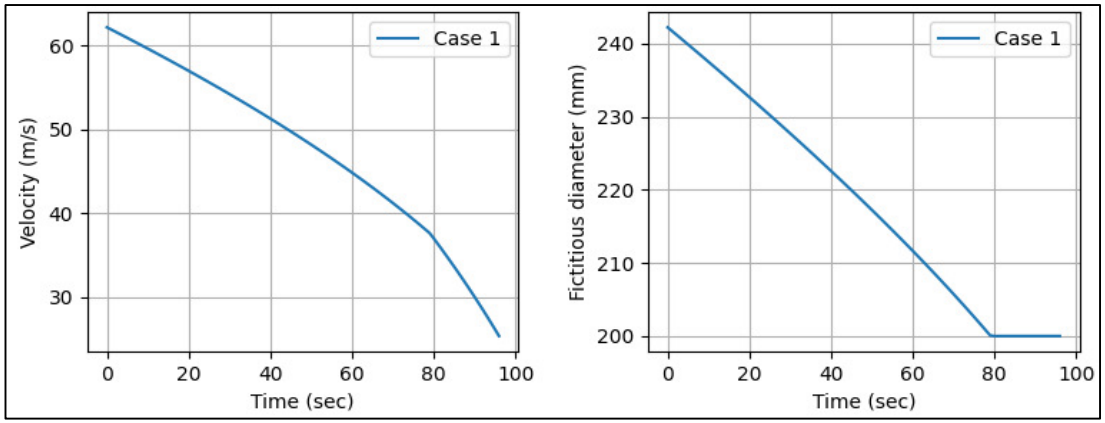
Indicative results/ big ship tank release

- A hypothetical scenario of a very large 20cm hole below the tank is considered
- Transient release (with DISCHA)



Tank

Highly improbable scenario

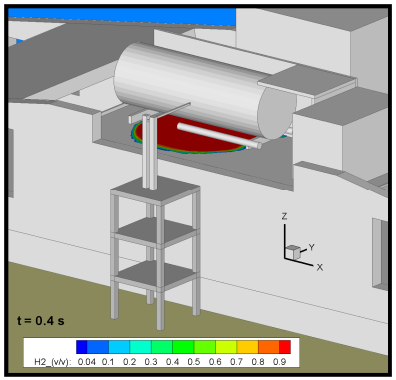


Fictitious nozzle

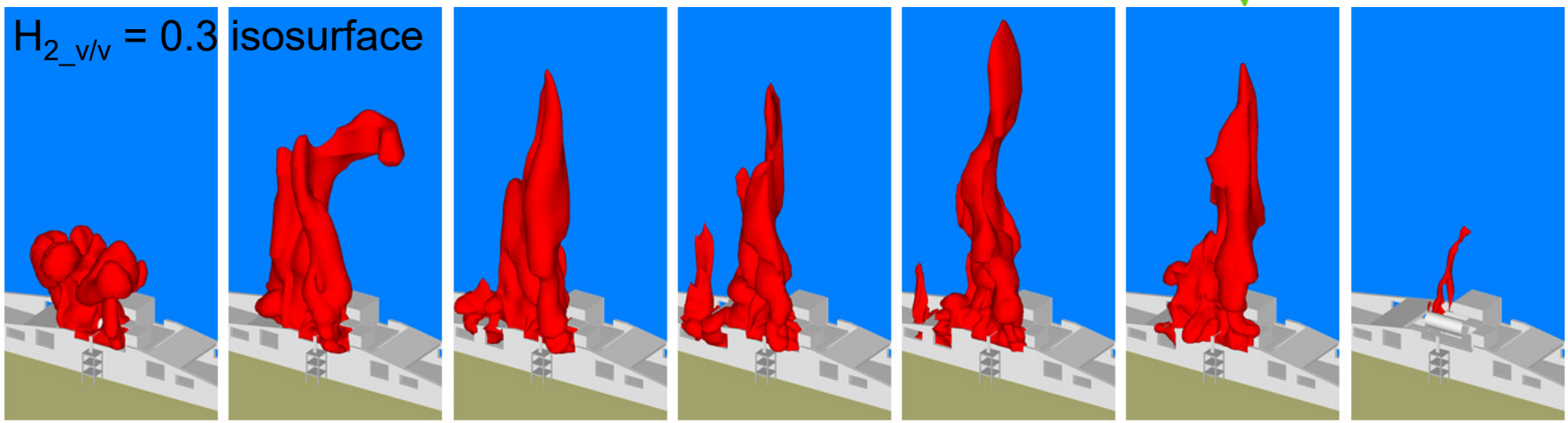
Indicative results/ big ship tank release

Dispersion

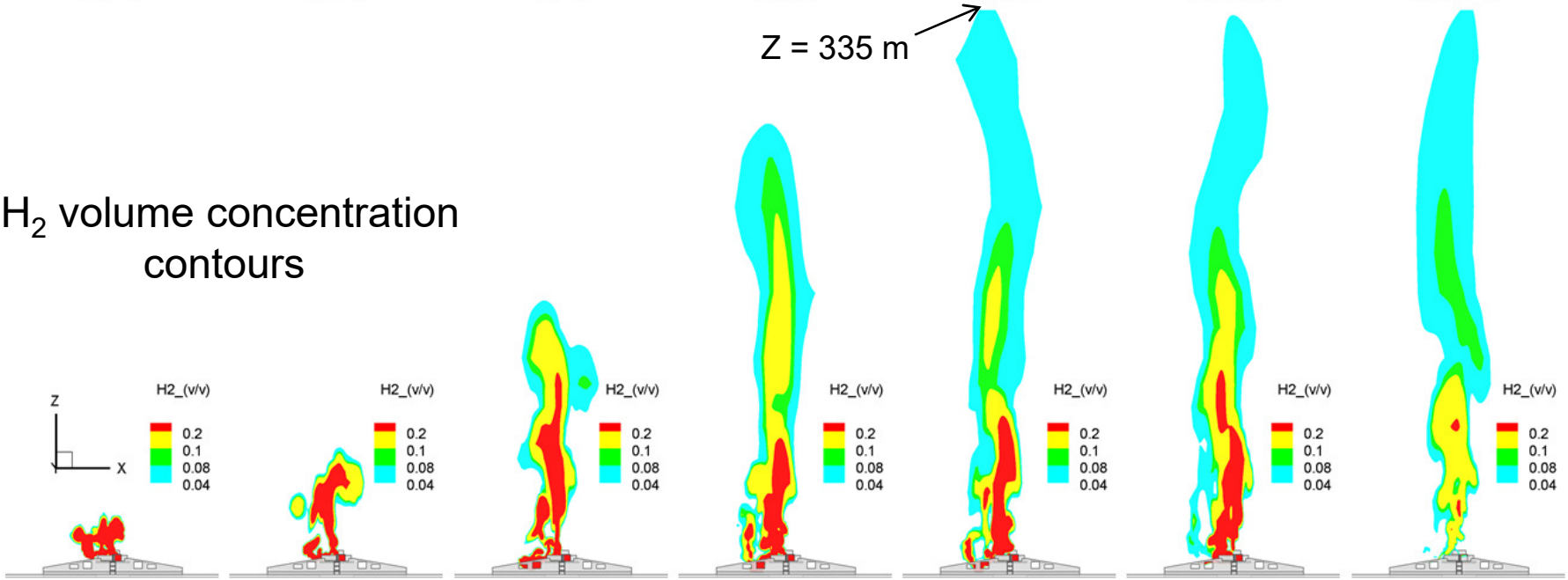
no wind



0.4 s



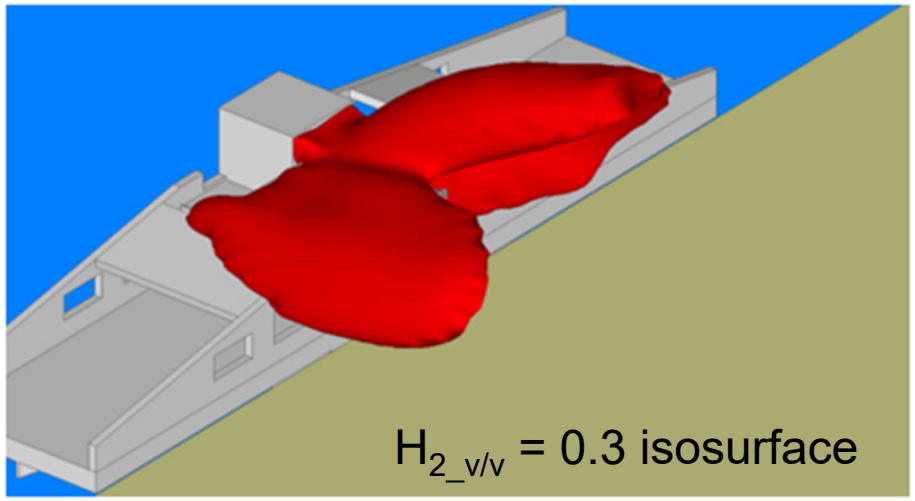
H_2 volume concentration contours



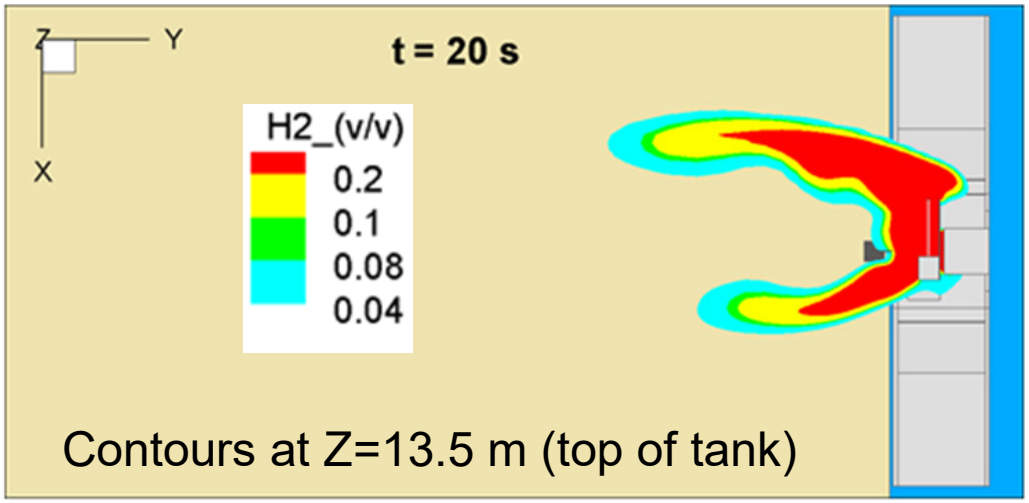
No flammable at pier level

Indicative results/ big ship tank release

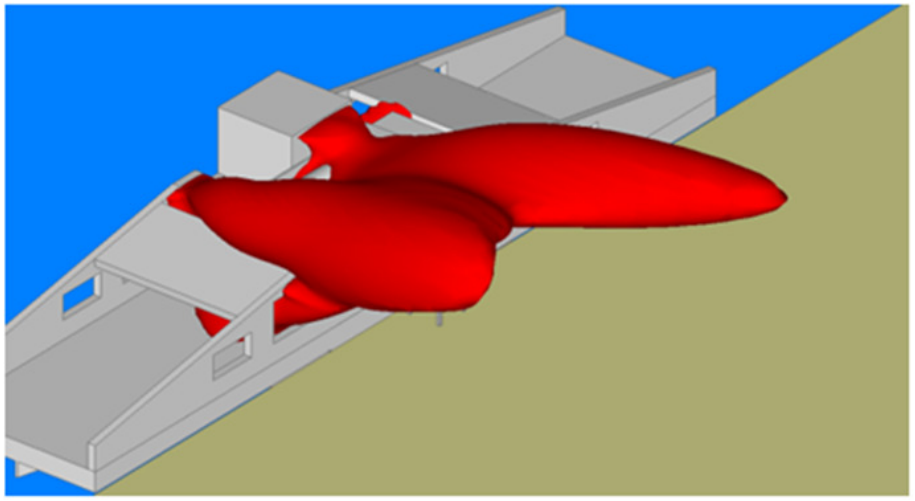
Dispersion, 5 m/s wind



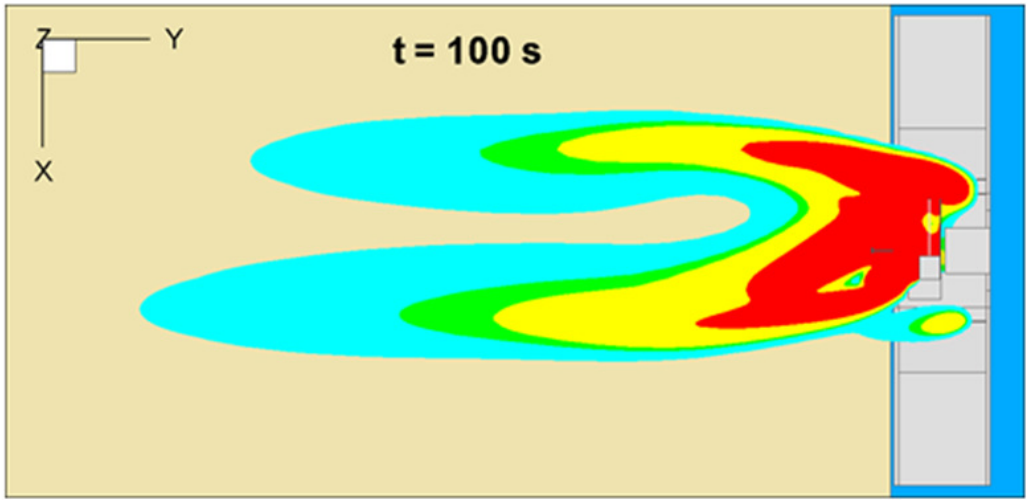
$H_{2\_v/v}$ = 0.3 isosurface



Contours at Z=13.5 m (top of tank)



No flammable at pier level



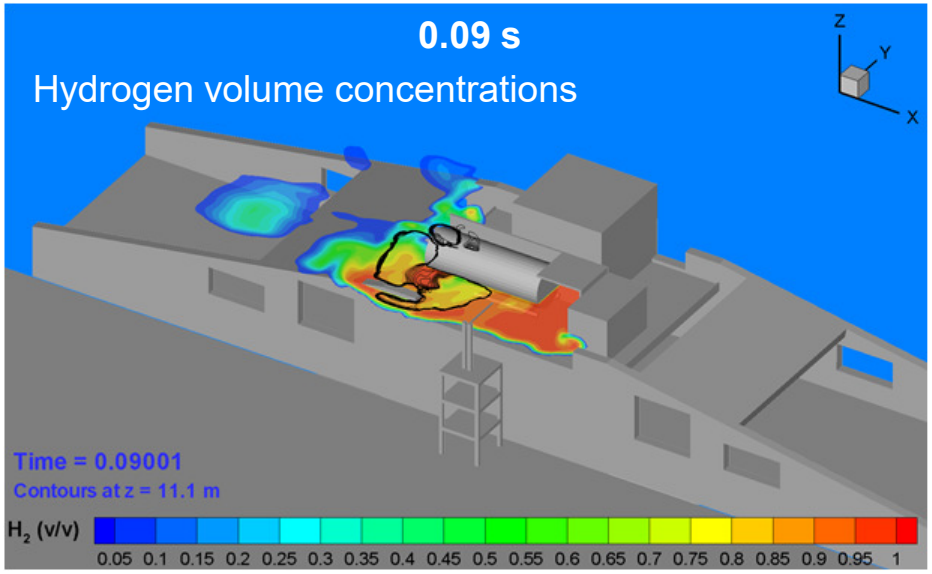
Maximum distance of flammable at big height > 264 m

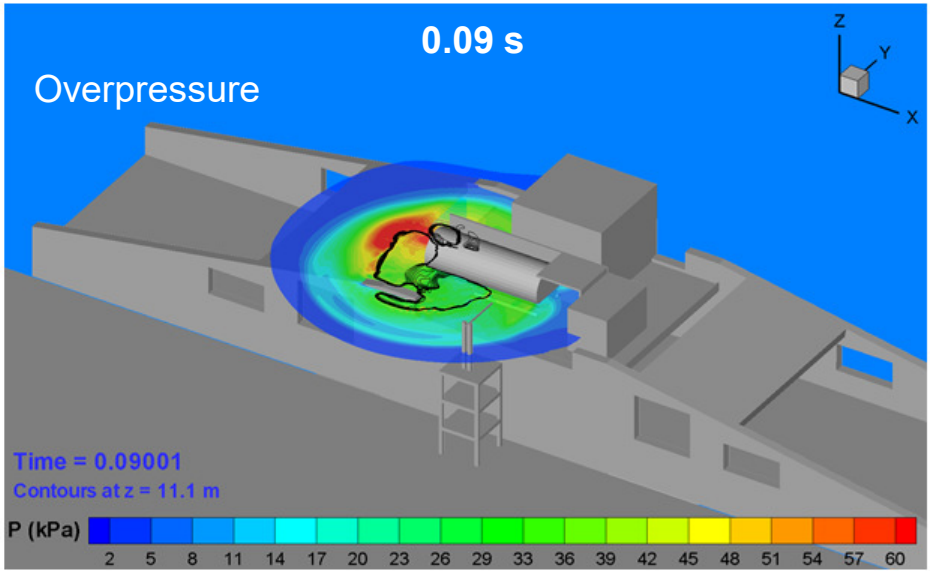
Indicative results/ big ship tank release

Explosion, no wind

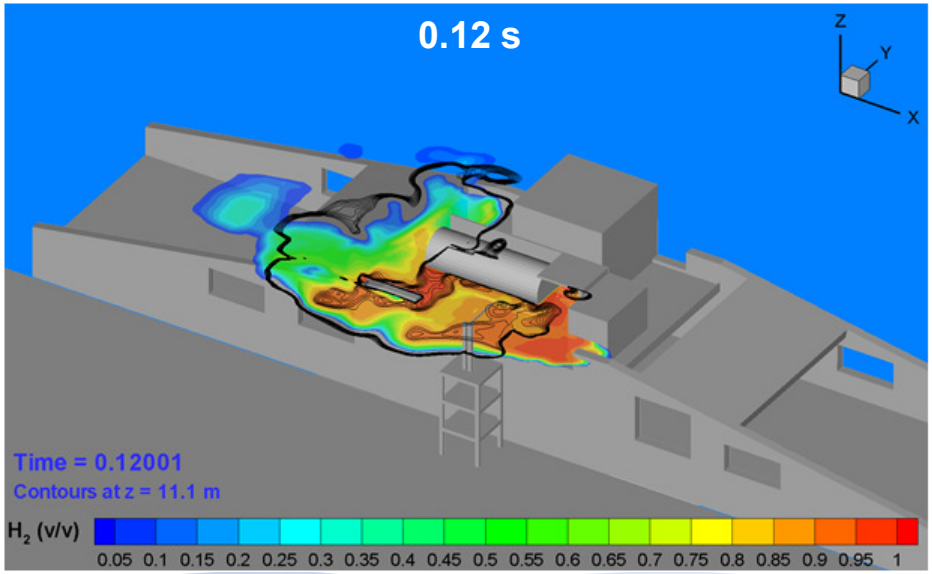
Ignition time:
80 s after release

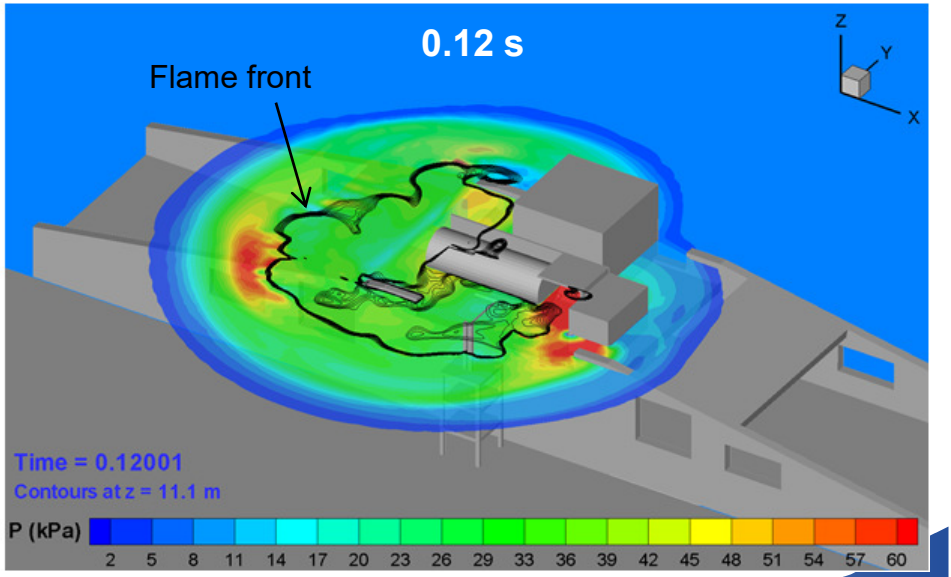
Ignition position (m):
x= -7.7 y= -2.3 z= 13.8





Hazardous distance at pier level: 123 m

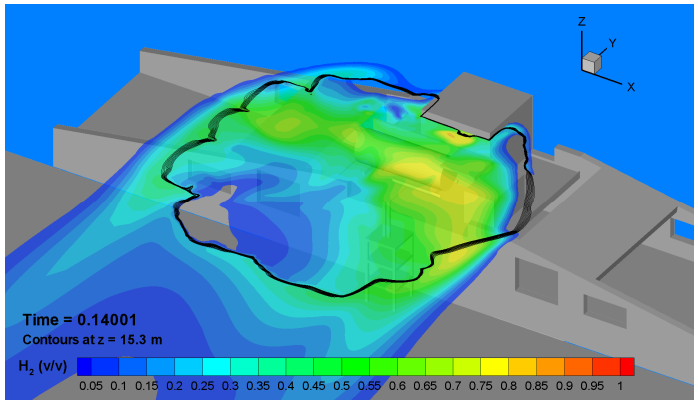


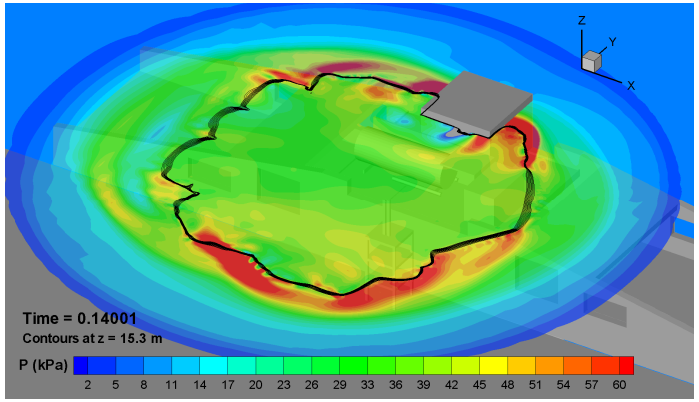


Indicative results/ big ship tank release

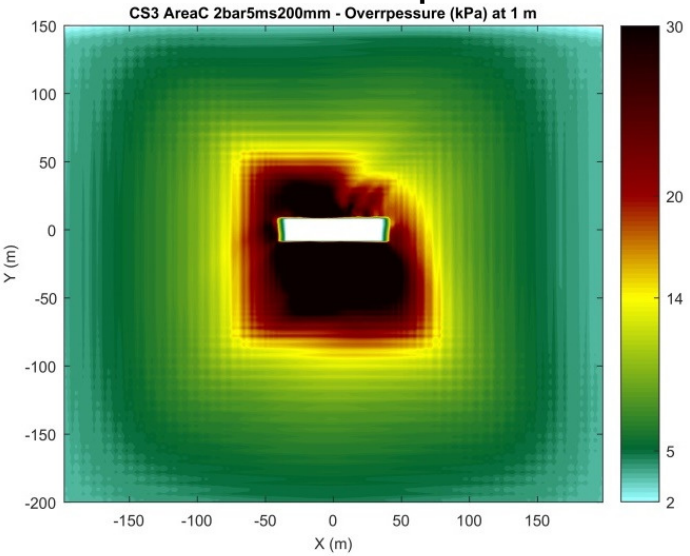
Explosion, **5 m/s wind**

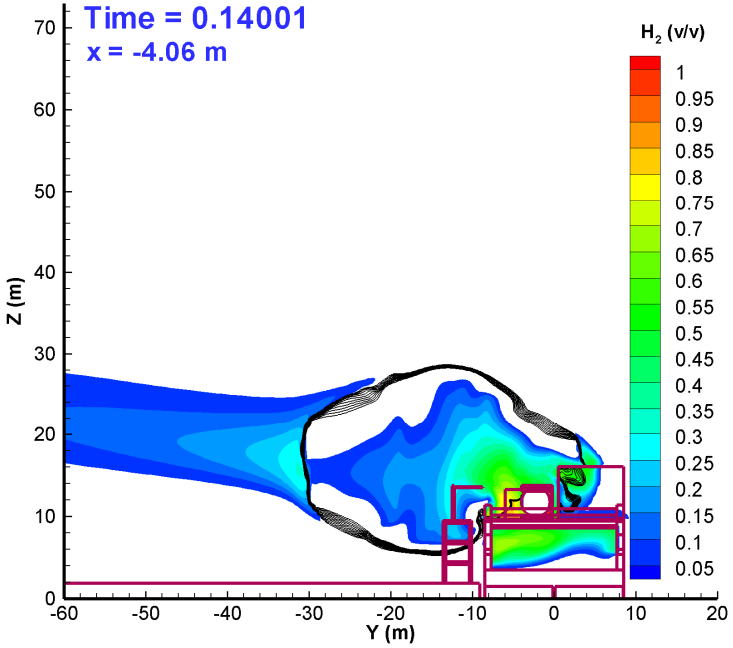
time = 0.14 s

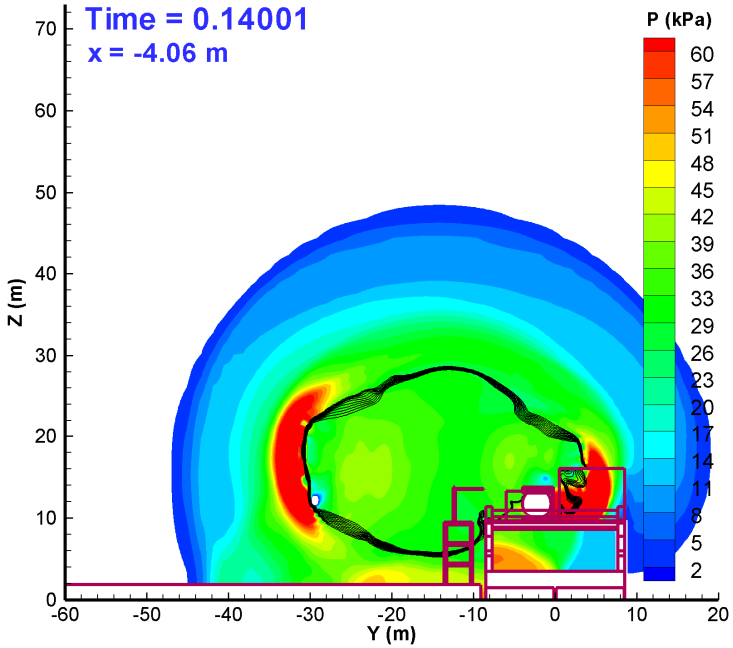




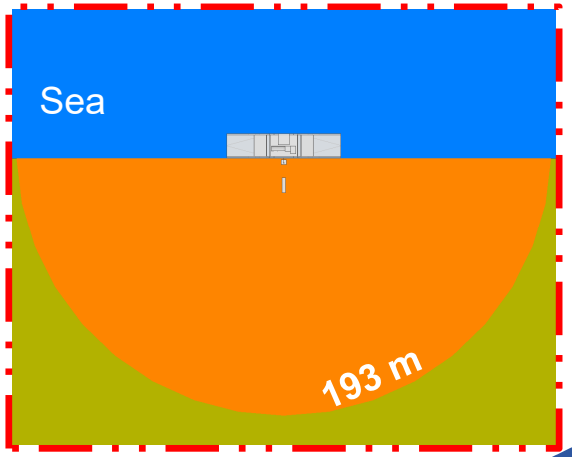
Maximum overpressure







Approximate hazardous zone



Conclusions

- CFD suitable for detailed consequence assessment
  - All physics simulated, including combustion, radiation, BLEVE
- Approximate maximum hazardous distances at z=1 m:
  - **100 m** for BLEVE of 57 m^3 tank
  - **100 m** for 50 mm/ 10 bar hose rupture
- Downwards release from top of tower: complex physics
  - If channeled between pier and ship: >70 m hazardous distance
- Fast release of whole ship tank containment: worst case
  - May result in hazardous distances of about 200 m

Thank you for your attention

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HPC ARIS

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