



LH2 release and dispersion from the 56 m³ storage tank: hazard distances by flammability and frostbite

ELVHYS Dissemination Conference

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17.09.2026



Co-funded by
the European Union

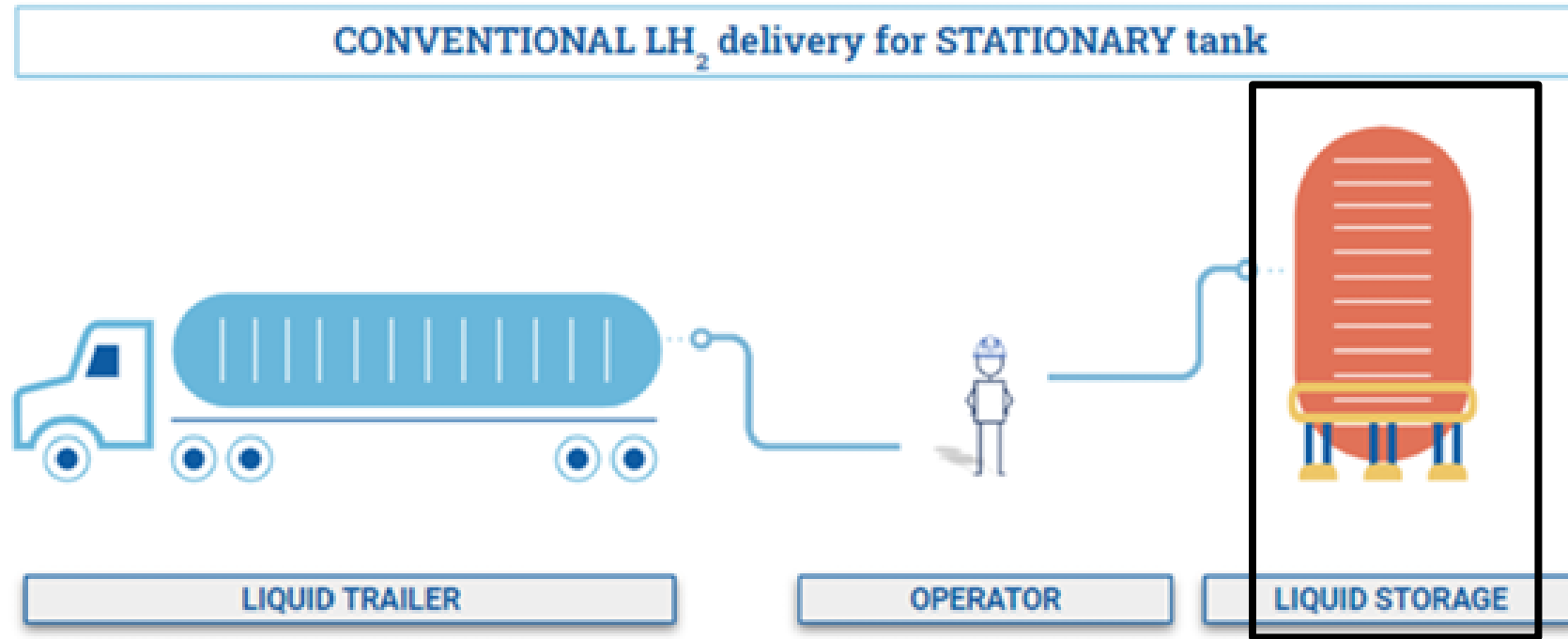


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ELVHYS project No. 101101381 is supported by the Clean Hydrogen Partnership and its members. UK participants in Horizon Europe Project ELVHYS are supported by UKRI grant numbers 10063519 (University of Ulster) and 10070592 (Health and Safety Executive)

Introduction

Transfer of LH₂ from a trailer to a stationary tank



- The critical areas of the specific case study are the following:
- A) Trailer area
- B) Transfer hose
- C) Stationary tank

Catastrophic release from 56m³ tank

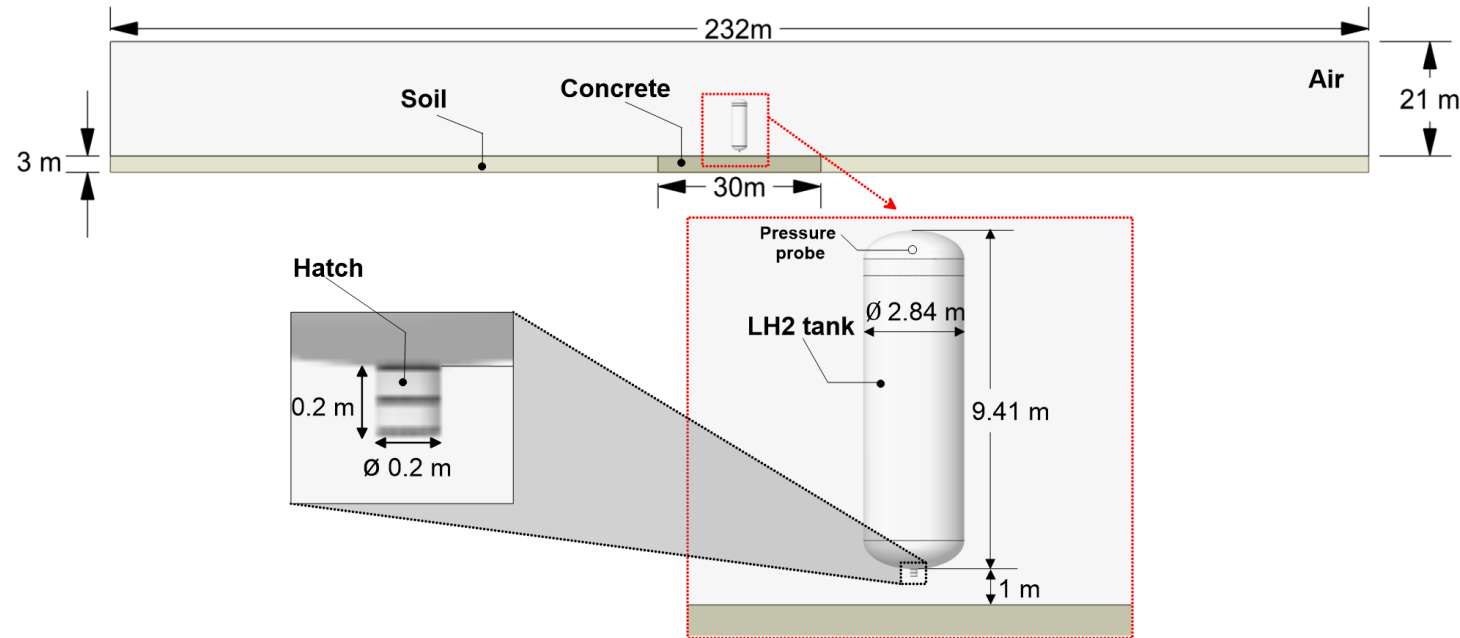
Scope of study

- Develop a numerical model for full loss of containment in a hydrogen tank
- Dynamic parameters of a catastrophic release from LH2 tank
- Simulate unignited release to assess hazard distances by flammability and frostbite
- Discovery of the “bubbling” phenomenon (oxygen ingress into LH2 storage tank)

CFD model

Geometry and computational domain

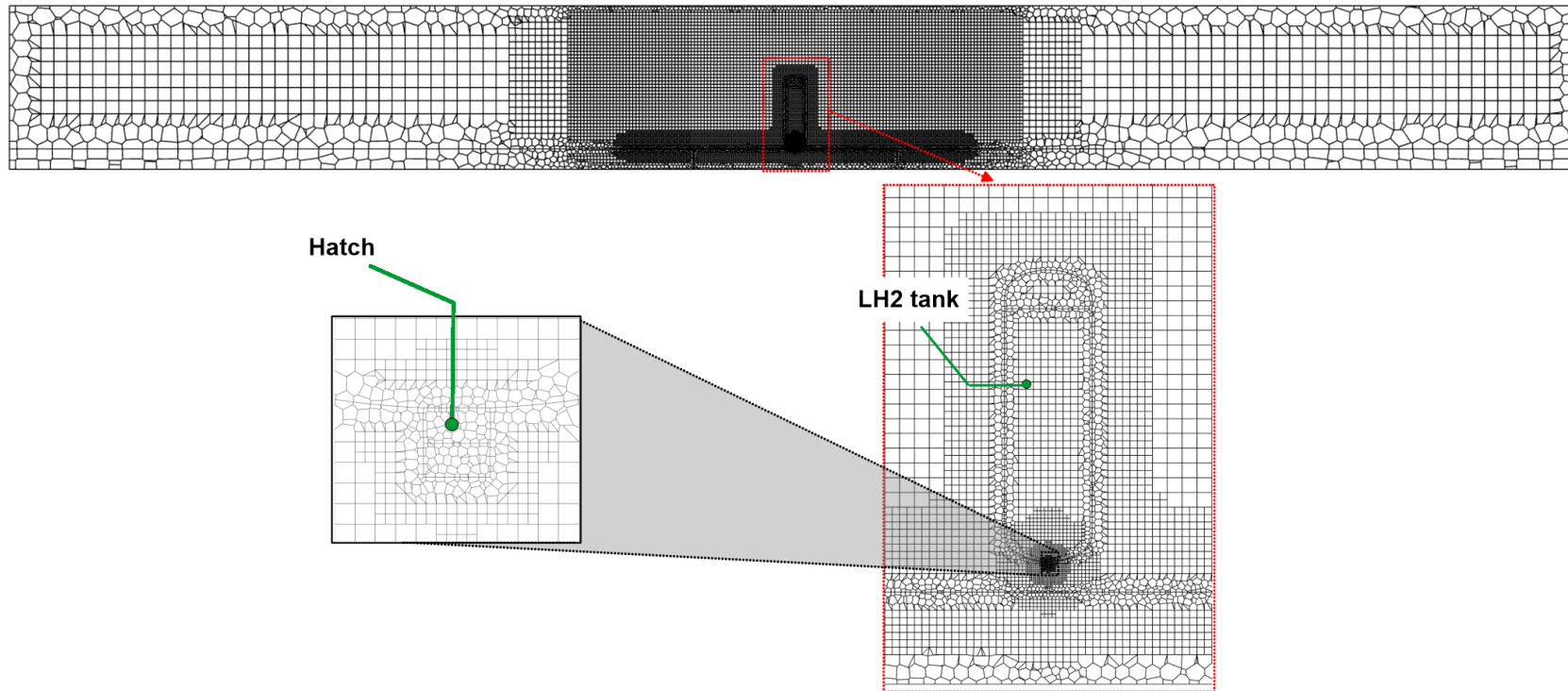
- Tank volume: 56 m³
- Internal diameter: 2.84 m
- Internal height: 9.41 m
- LH2 level: 90% of total volume
- Distance from the ground: 1 m
- Diameter of hole: 20 cm
- Ground thickness: 3 m
- Concrete dimensions: 30 m × 30 m × 3m
- Computational domain: 232 m × 232 m × 21 m



CFD model

Numerical mesh

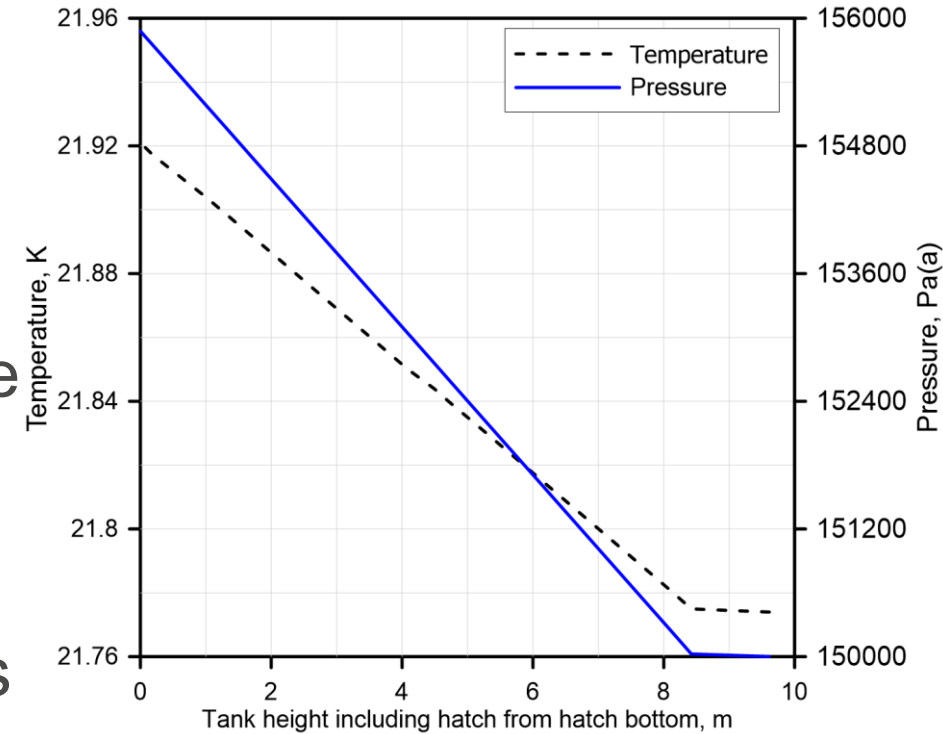
- Poly-hexahedral mesh
- 2,334,768 computational cells (CVs)



CFD model

Initial and boundary conditions

- Ambient temperature: 10.3°C
- Ambient pressure: 1.01325 bar (a)
- Relative humidity: 68%
- LH2 volume fraction: 1.0 in 90% of tank volume
- Heat flux for tank walls: 1.66 W/m²
- Outer domain: Pressure outlet
- Concrete and soil: No-slip impermeable walls



CFD model

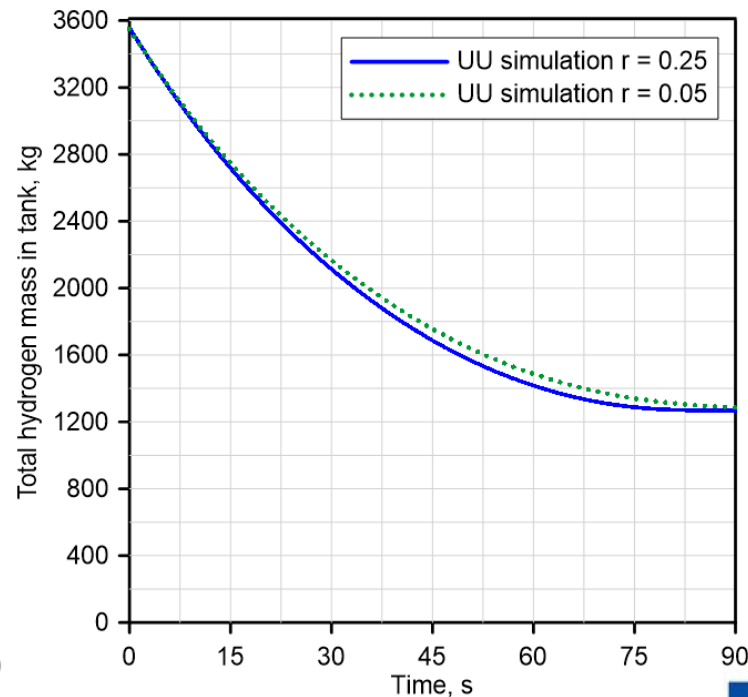
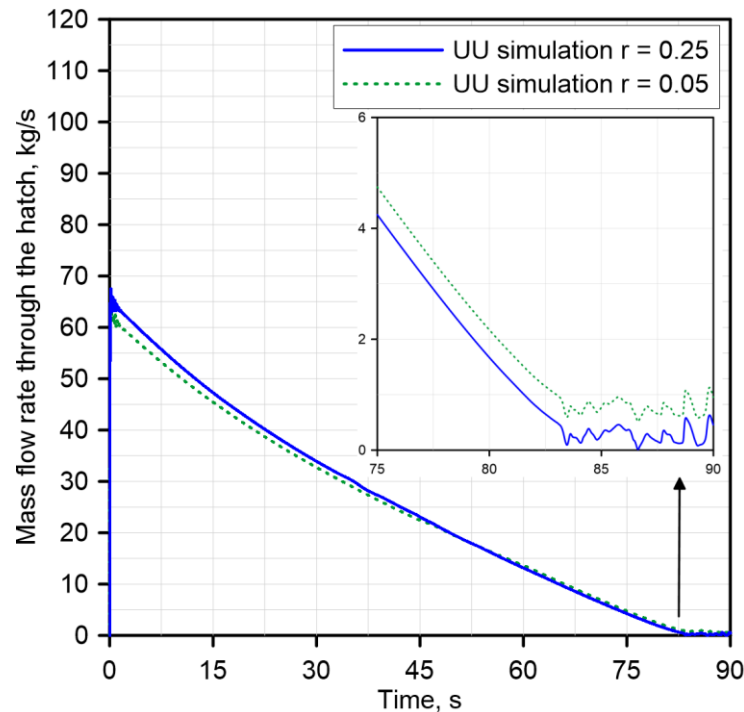
Simulation setup

- **Governing equations:** Conservation of mass, momentum and energy
- **Turbulence:** $k-\omega$ SST model
- **GH2 properties:** GH2 density is obtained from RGP tables
- **LH2 properties:** LH2 density is constant at 70.85 kg/m³
- **Numerical details:** PISO for pressure-velocity coupling, 2nd order upwind discretisation, implicit time stepping
- **Time step:** Initially set to 10^{-5} s, then gradually increased to maintain the simulations convergence
- **CFD engine:** ANSYS Fluent 2024R2

CFD model

Multiphase setup

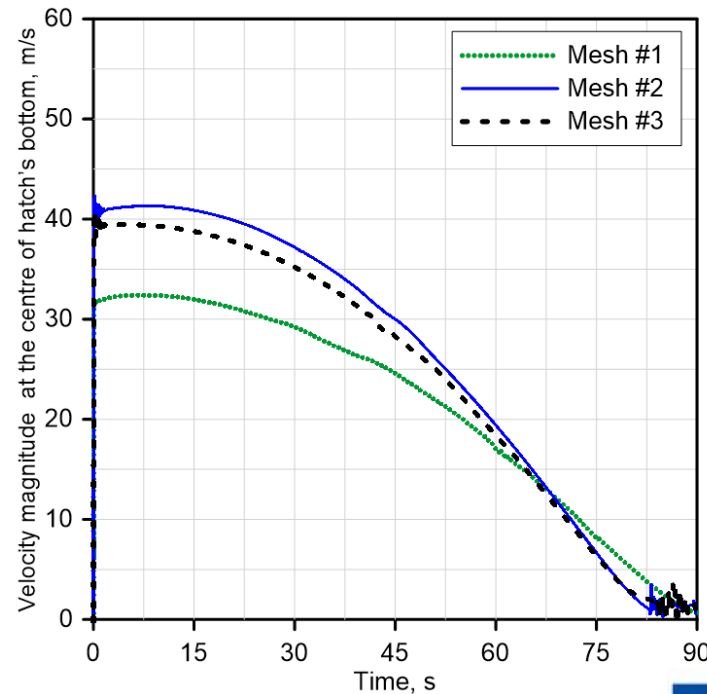
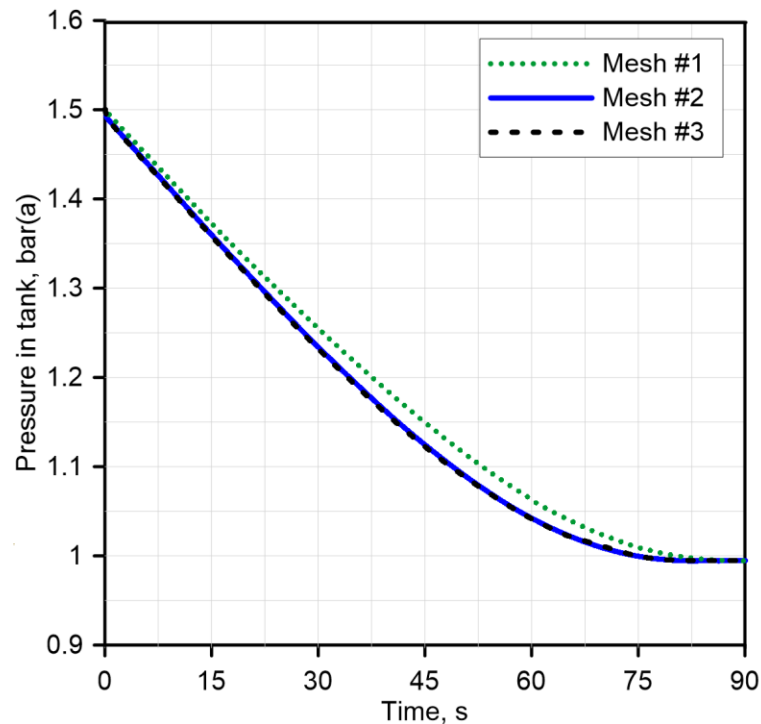
- **Multiphase model:** Volume of Fluid (VOF)
- **Air condensation modelling:** Three components of air
- **Interface modelling type:** Dispersed
- **Phase change model:** Lee's model for evaporation



Simulation result (1/15)

Grid sensitivity analysis

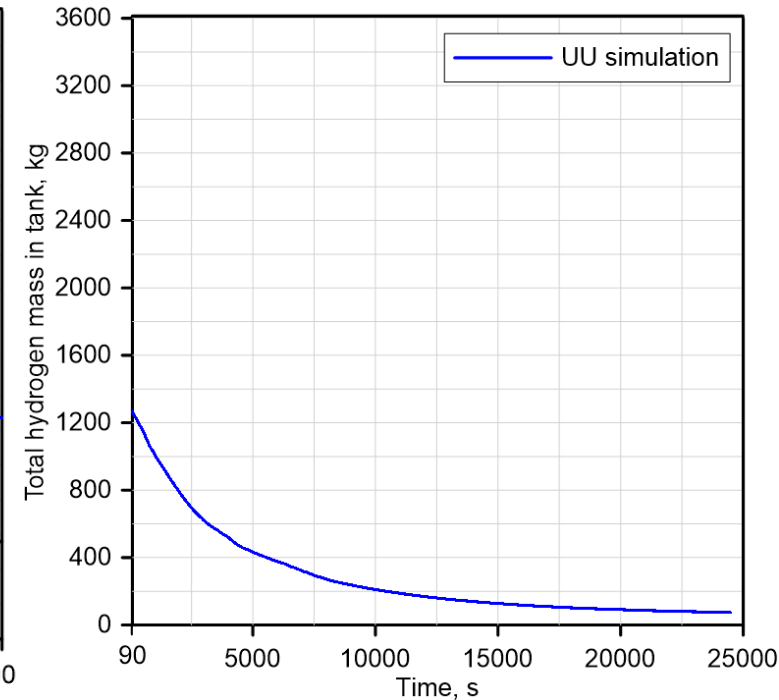
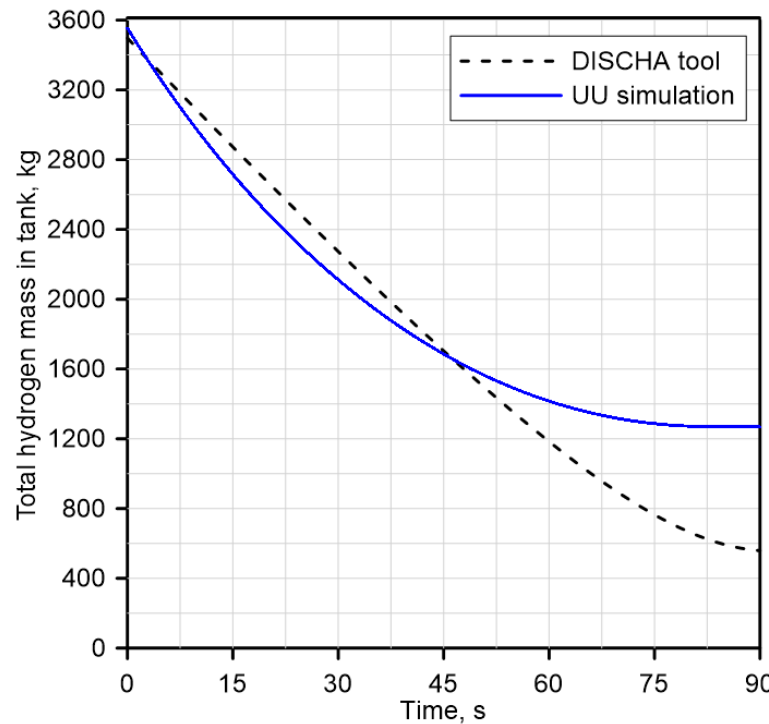
- Coarse Mesh #1: 506,582 CVs
- Medium Mesh #2: 2,334,768 CVs
- Fine Mesh #3: 9,090,030 CVs
- Mesh #2 was selected for subsequent simulations



Simulation result (2/15)

Comparison of UU simulation and DISCHA reduced tool

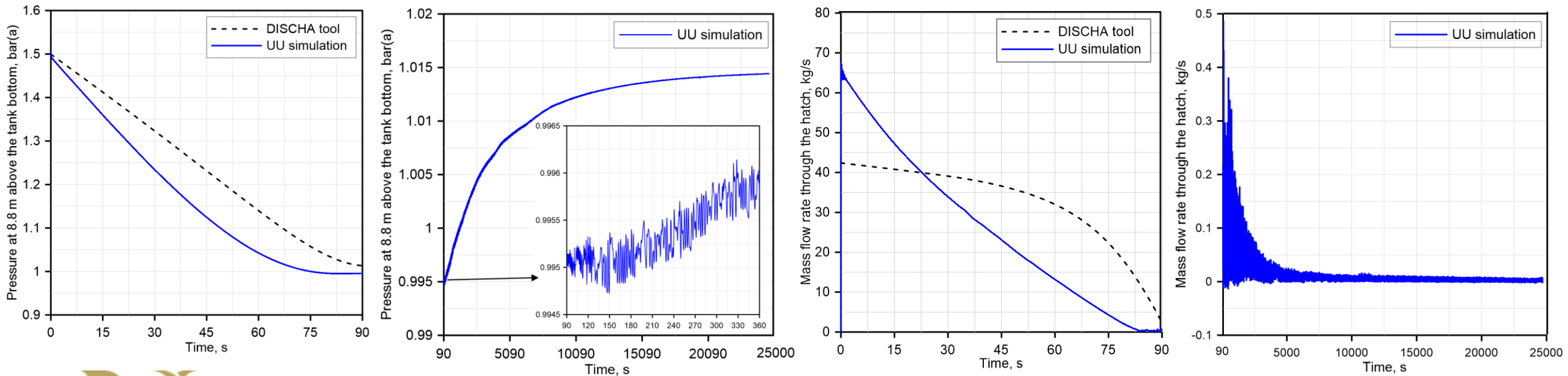
- DISCHA is an integral engineering tool for hydrogen discharge analysis
- CFD model captures long-term release behaviour
- The LH2 release predicted by the CFD model lasted 6.8 hours



Simulation result (3/15)

Comparison of UU simulation and DISCHA reduced tool

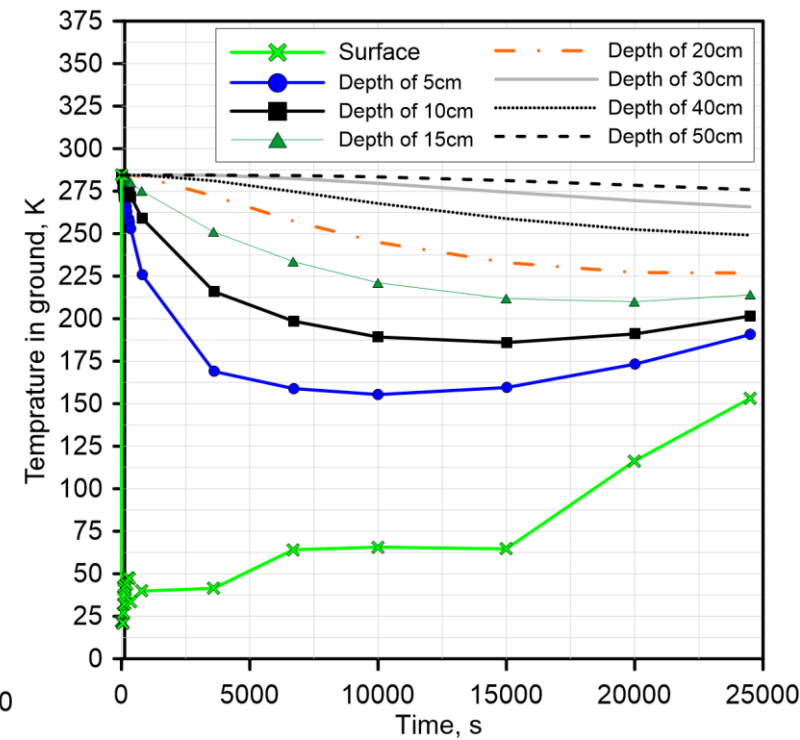
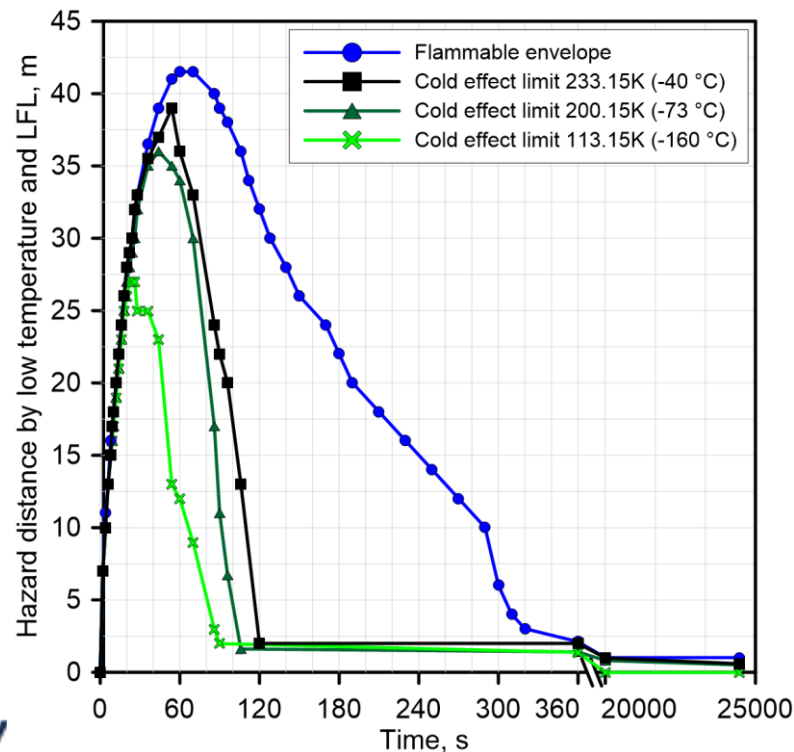
- A weak vacuum at the top of the tank acts as a counterpressure to the hydrostatic pressure
- This counterpressure reduces oscillations in the mass flow rate during the later stages of LH2 release



Simulation result (4/15)

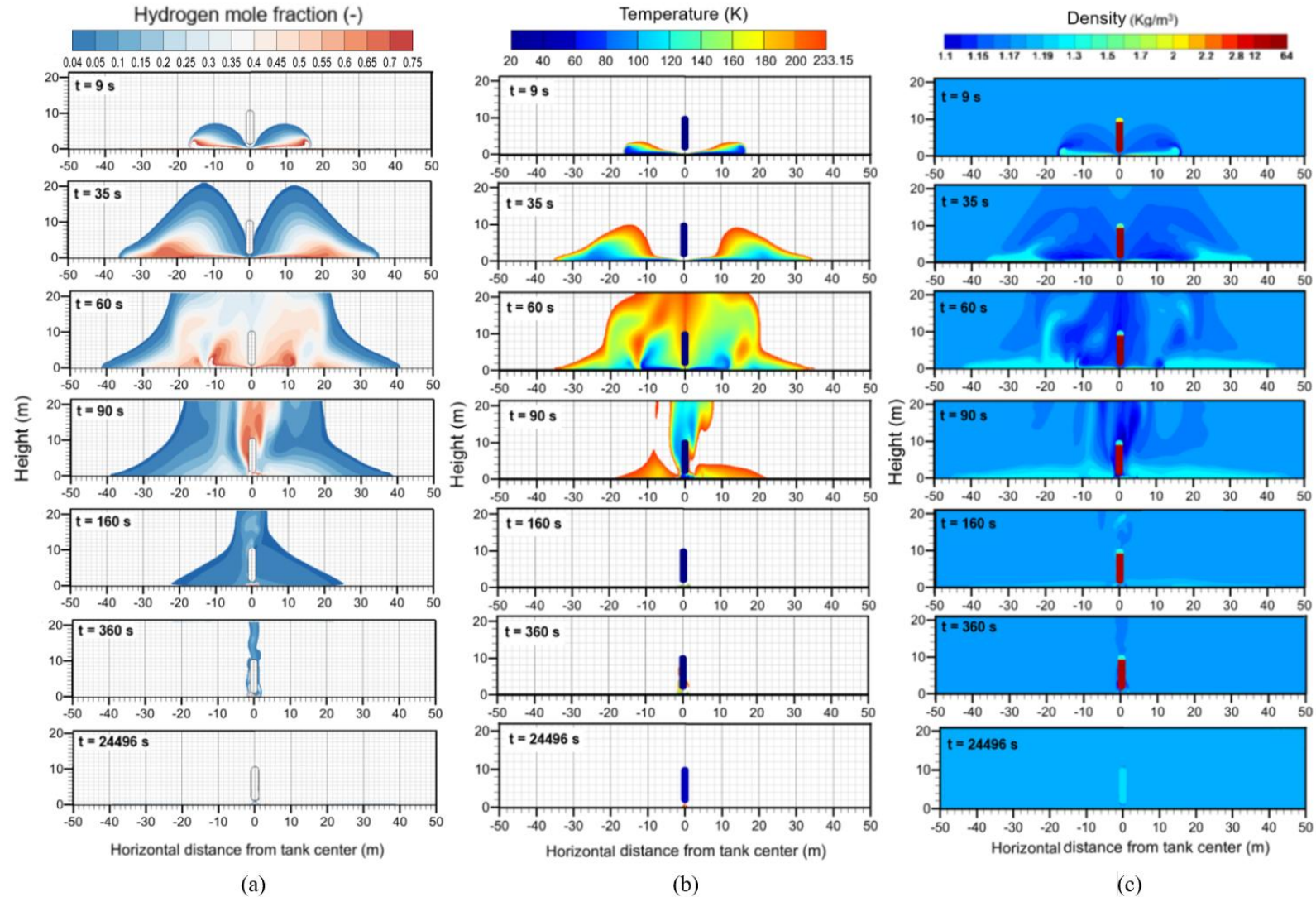
Evolution of hazard distances

- The horizontal span of the flammable hydrogen-air cloud is 41.5 m, while the frostbite hazard distance is 39 m
- Cooling effect in the ground is limited to a depth of 50 cm over 6.8 hours



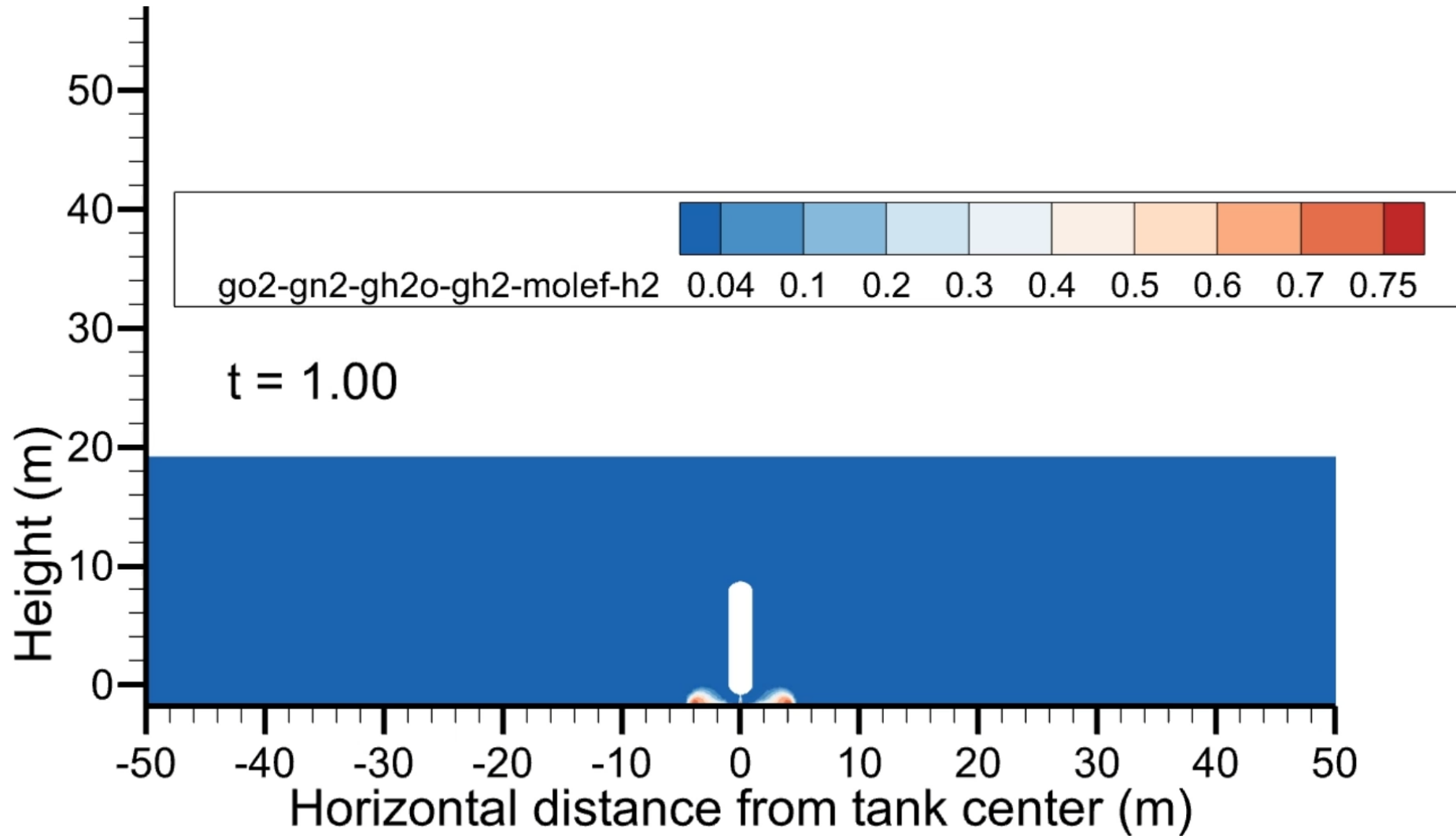
Simulation result (5/15)

Evolution of hazard distances



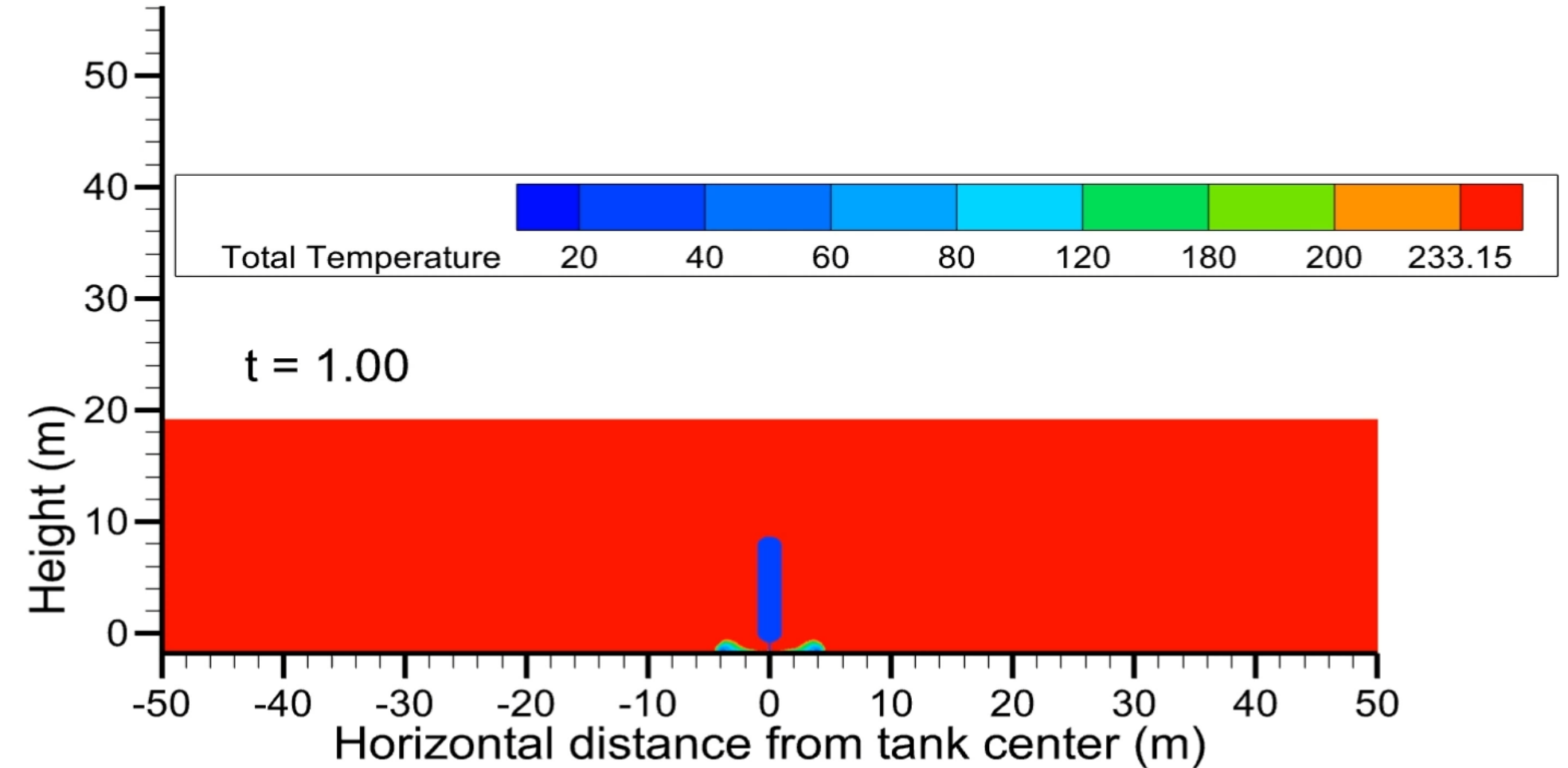
Simulation result (6/15)

Flammable cloud



Simulation result (7/15)

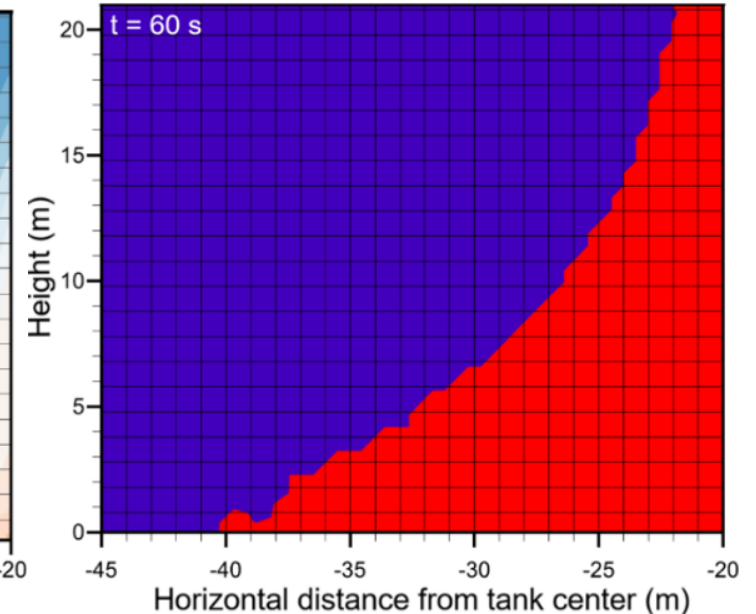
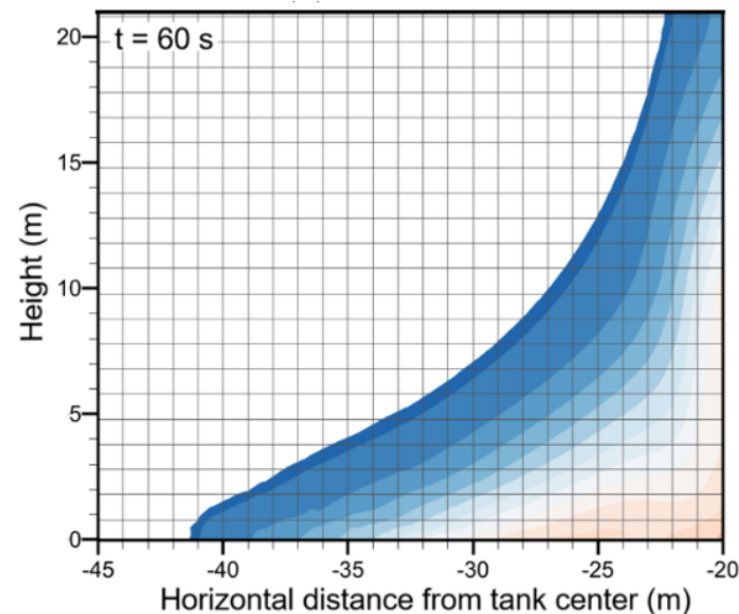
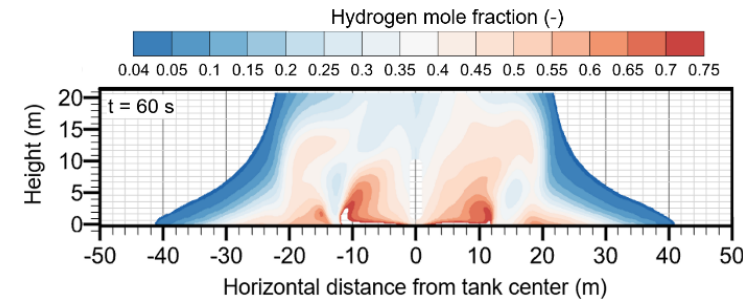
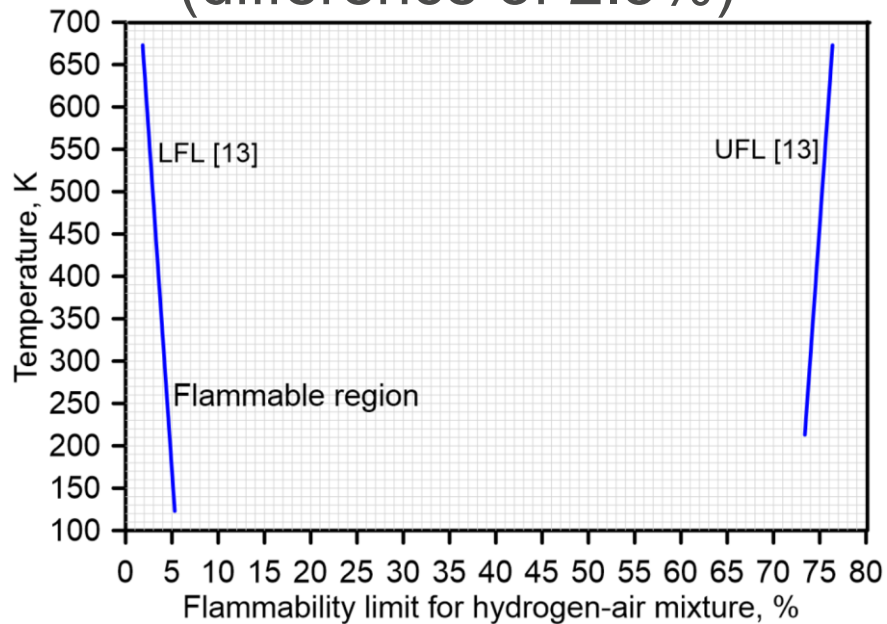
Temperature dynamics



Simulation result (8/15)

Standard and real LFL

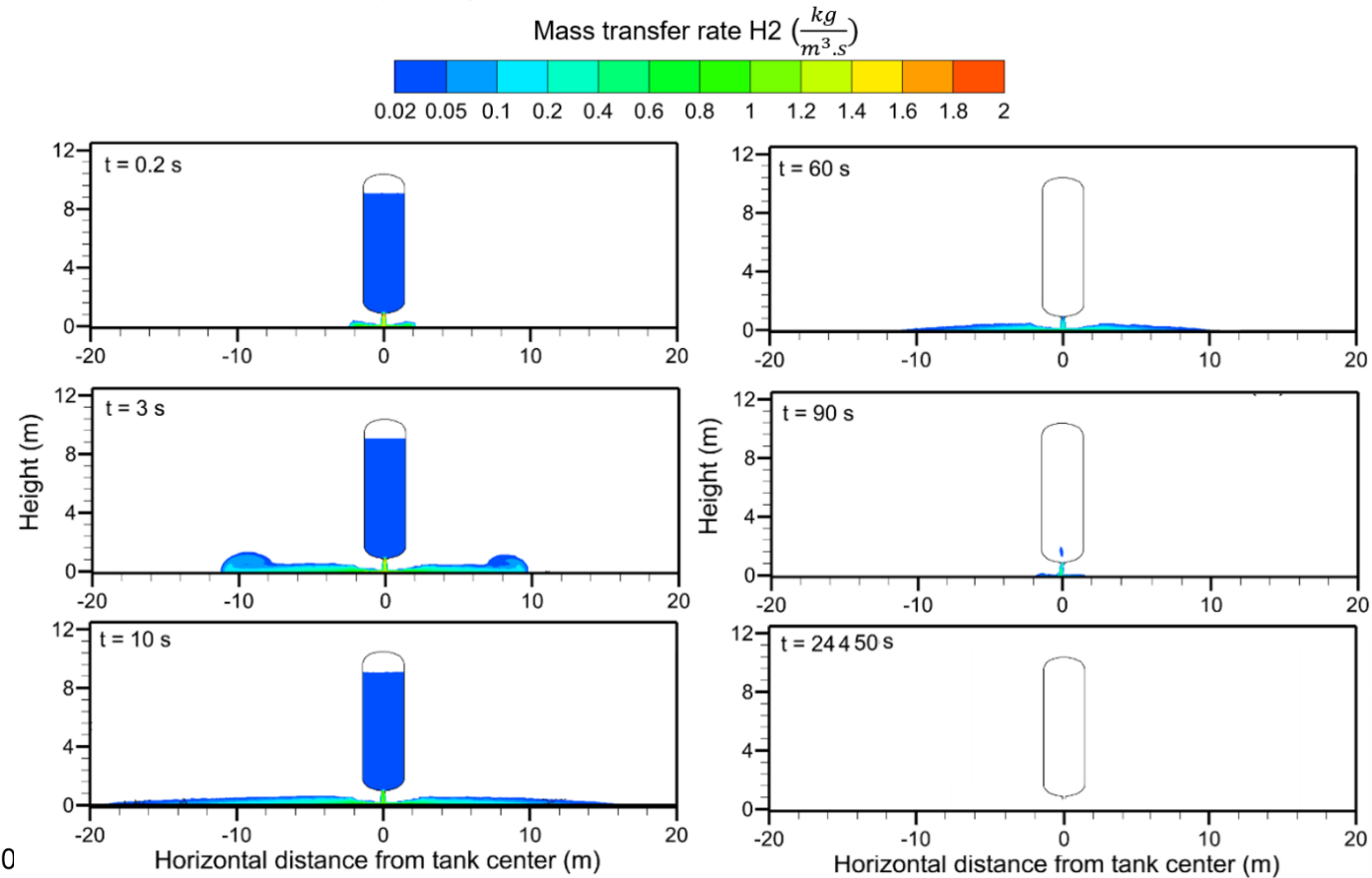
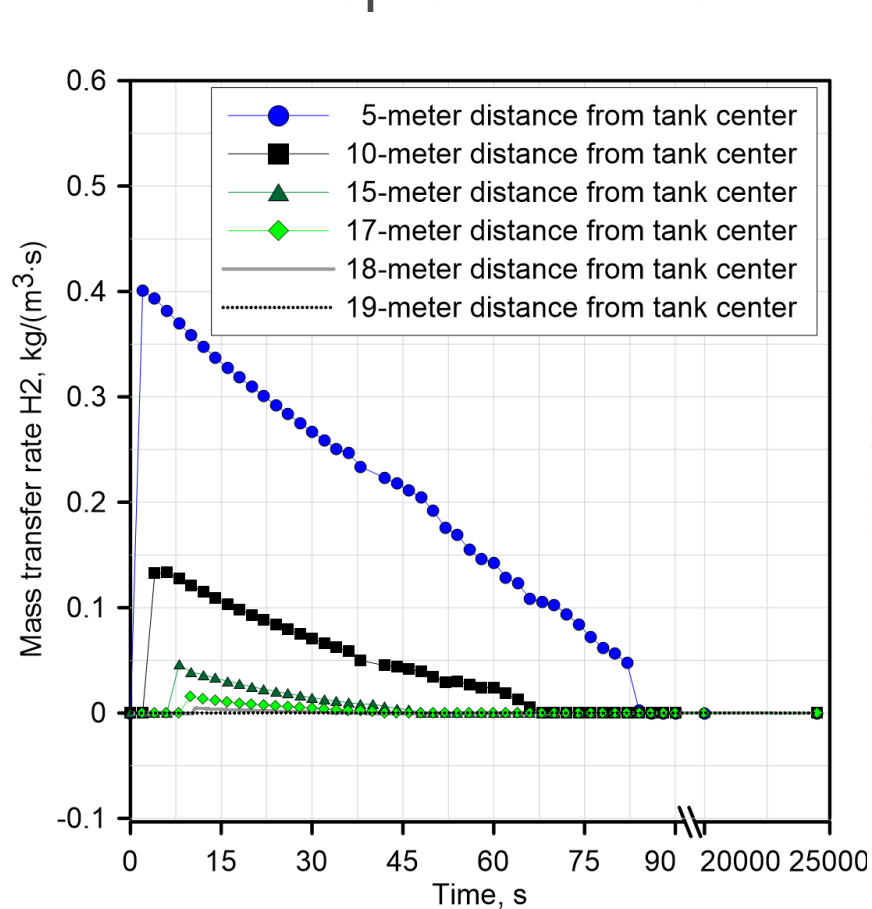
- LFL and UFL dependence on temperature
- Comparison of the standard LFL of 4% H₂ by volume against real LFL (difference of 2.5%)



Simulation result (9/15)

LH2 spread

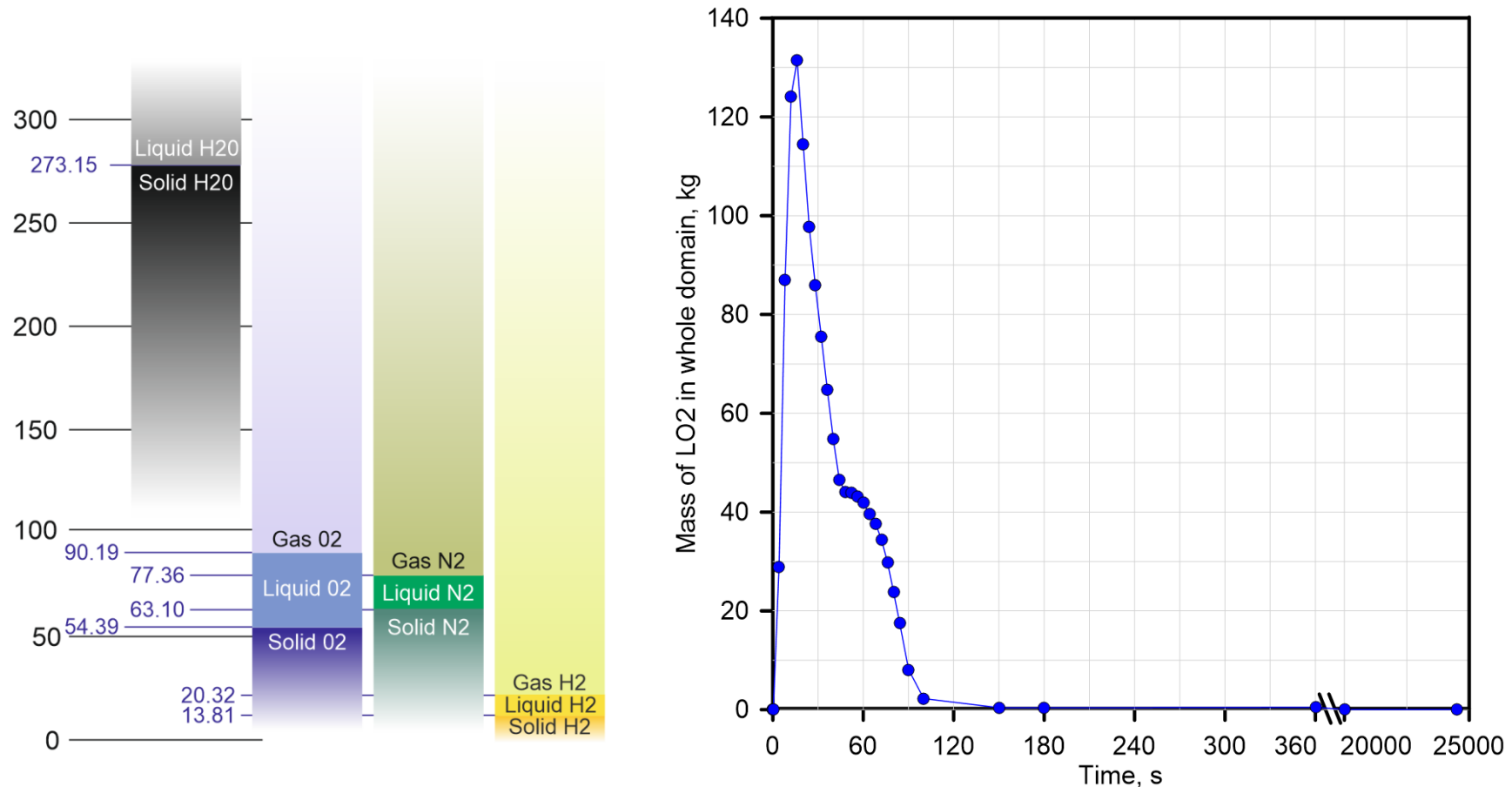
- Mass transfer rate of hydrogen at different distances from tank centre
- LH2 spread radius for this scenario is 18 m



Simulation result (10/15)

Evolution of LO2

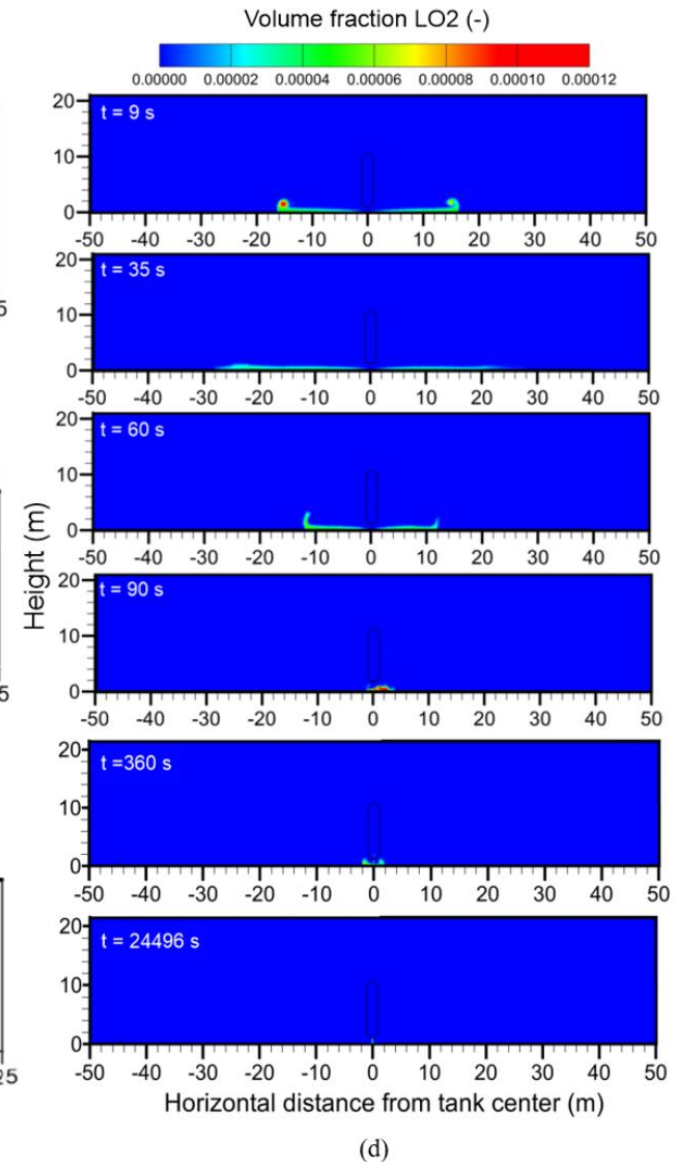
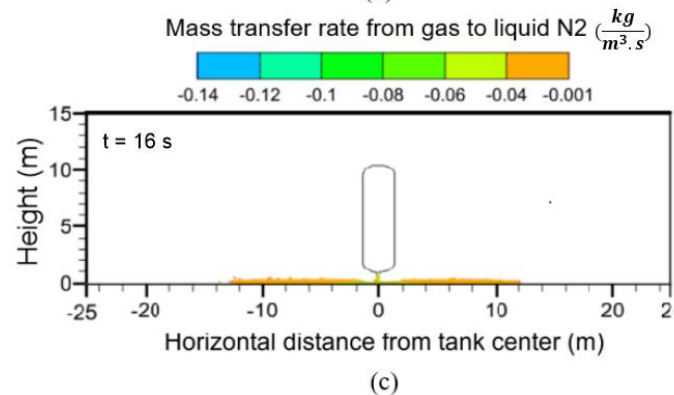
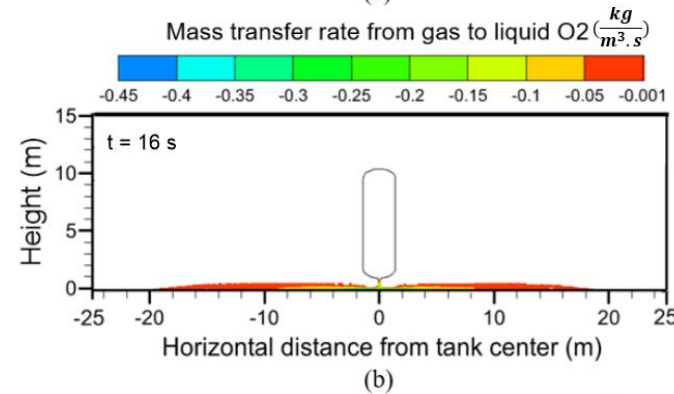
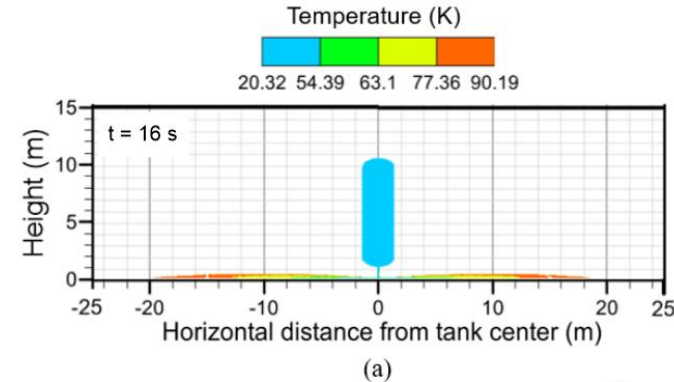
- The maximum LO2 mass in the atmosphere is 131 kg at 16 s



Simulation result (11/15)

Evolution of LO2 and LN2 formation

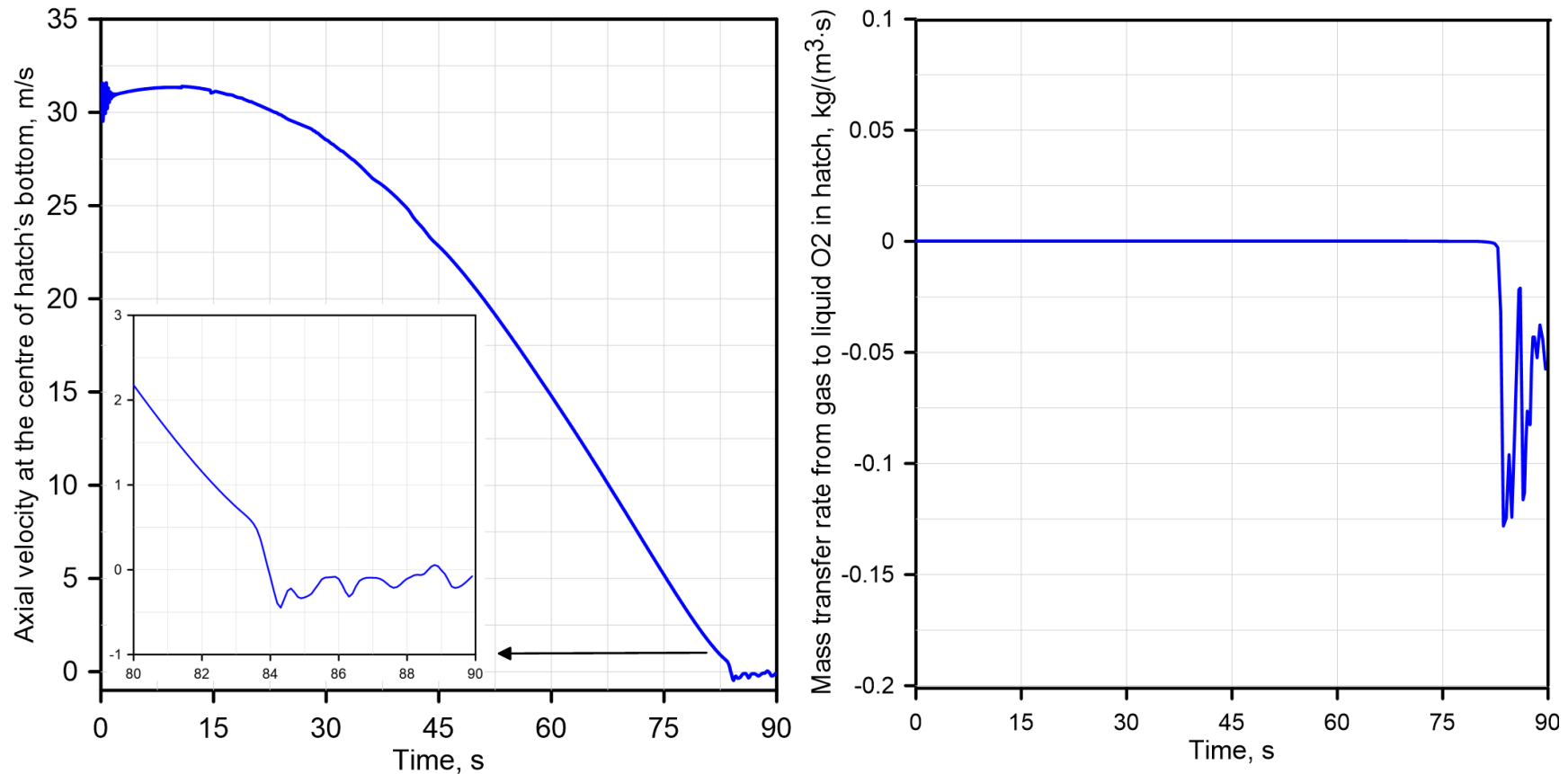
- Negative mass-transfer rates, confirming condensation from GO2 to LO2 and GN2 to LN2
- At 35 s, the LO2 spread reaches approximately 28 m



Simulation result (12/15)

Discovery of the “bubbling” phenomenon

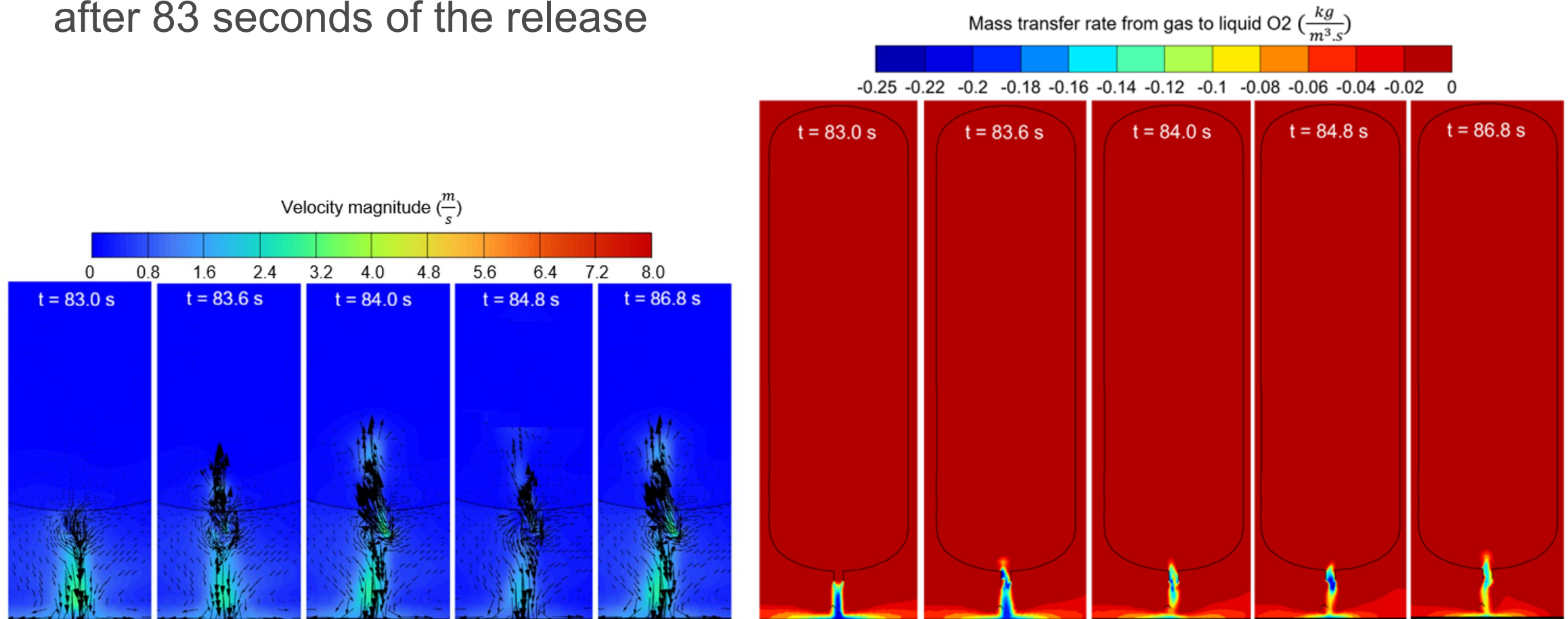
- Negative axial velocity is observed after 83 s
- The bubbling phenomenon is associated with air ingress into the tank



Simulation result (13/15)

Discovery of the “bubbling” phenomenon

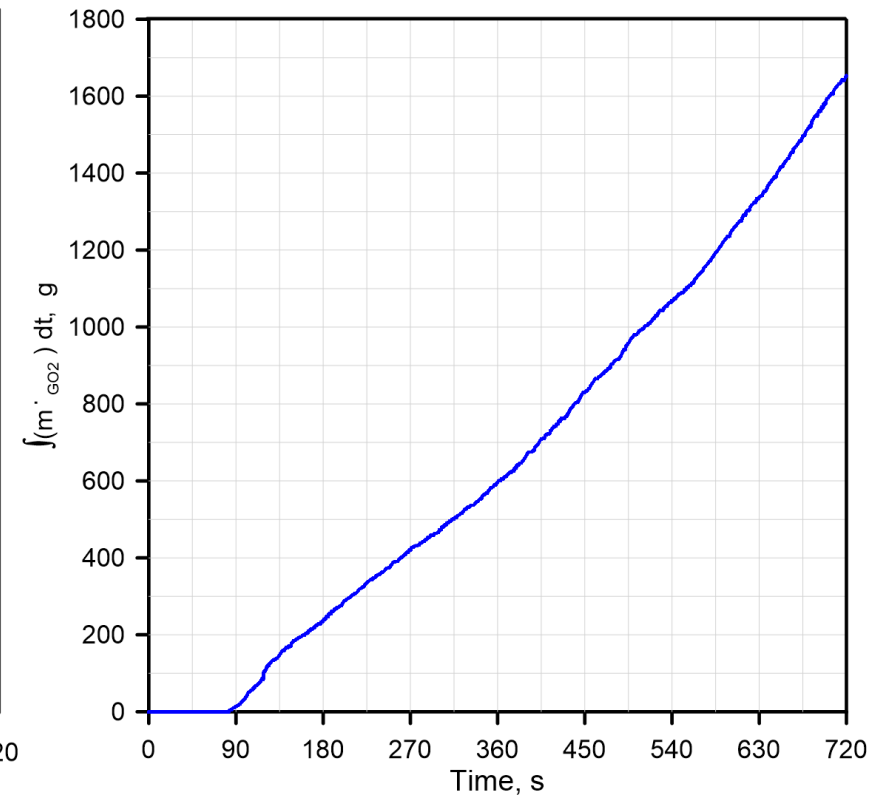
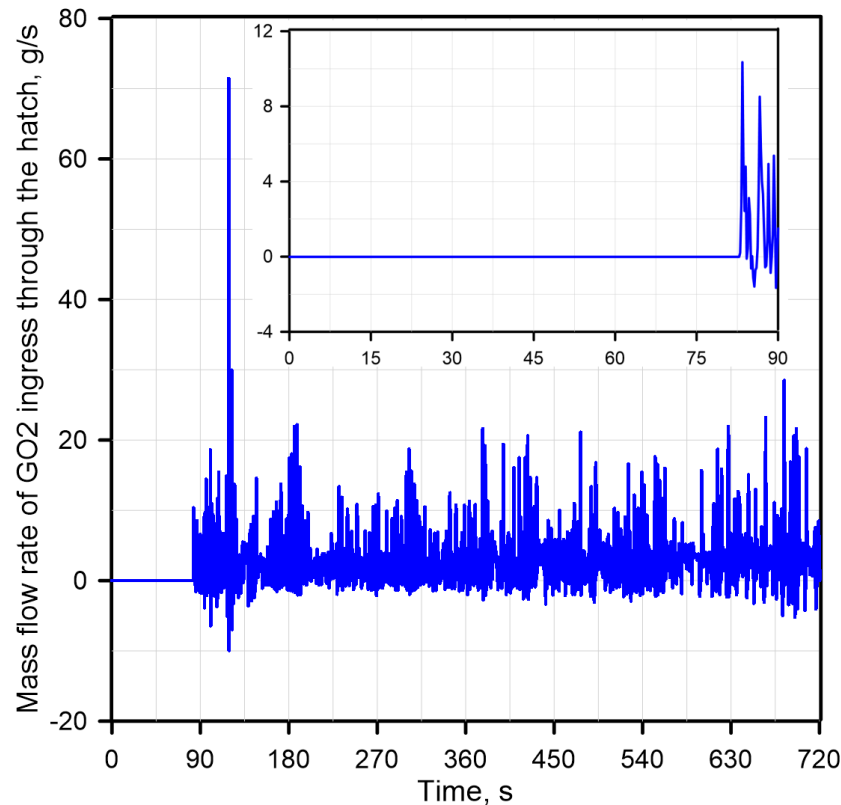
- Initial stage of air ingress through the hatch into the LH2 tank after 83 seconds of the release



Simulation result (14/15)

Discovery of the “bubbling” phenomenon

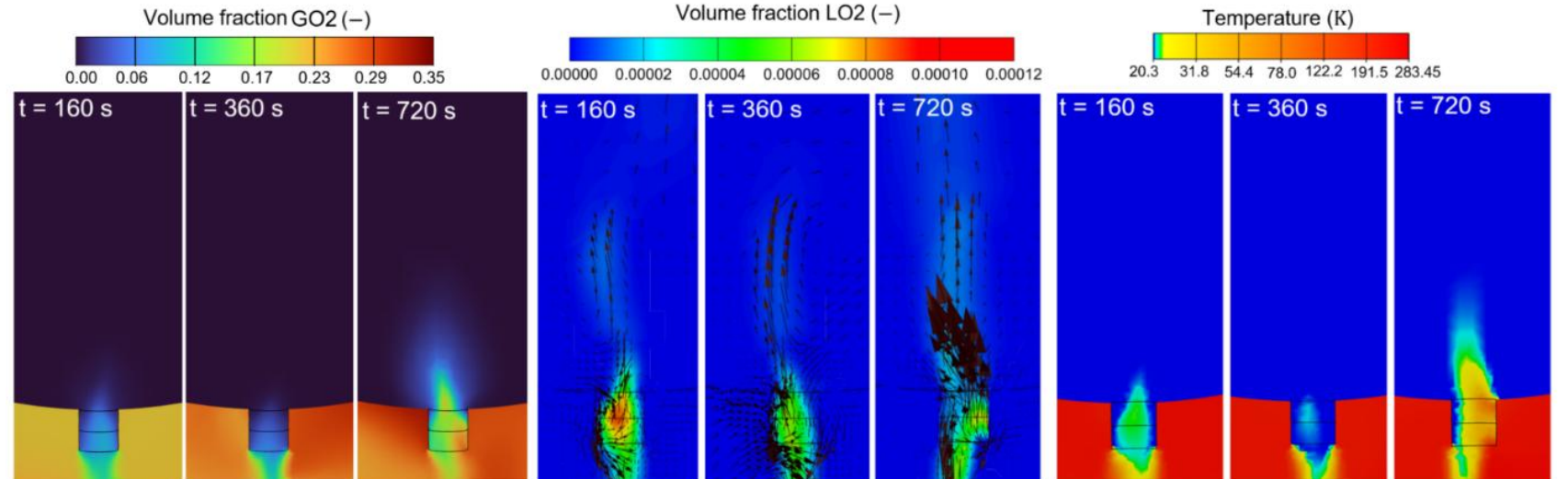
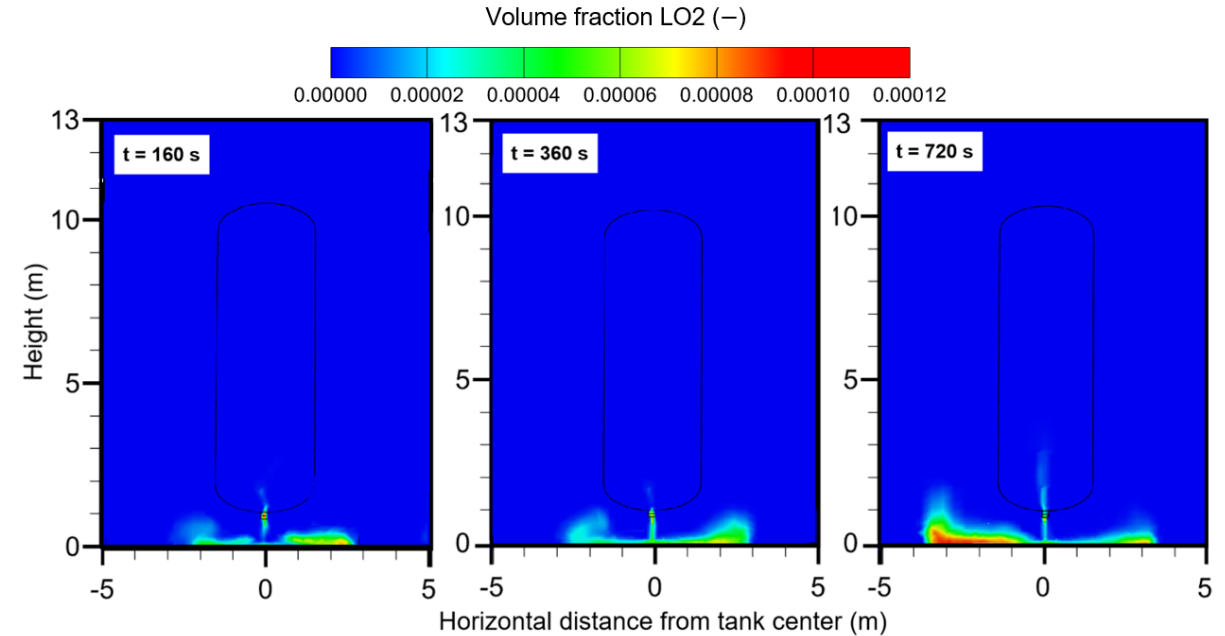
- The GO2 mass flow rate remains zero until approximately 83 s
- The total GO2 ingress is estimated to be about 63 kg at 24,450 s



Simulation result (15/15)

Discovery of the “bubbling” phenomenon

- Formation of liquid oxygen within the storage tank
- Hatch and zoomed-in views of the storage tank



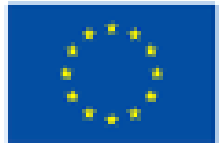
Concluding remarks

- As the pressure at the release location approaches atmospheric conditions, a weak vacuum at the top of the tank acts as a counter-pressure to the hydrostatic pressure, thereby reducing the oscillating mass flow rate, leading to a total duration of 6.8 hours
- Hazard distance by flammability (41.5 m) is larger than by frostbite (39 m)
- Cooling effect in the ground is limited to a depth of 50 cm over 6.8 hours
- LH2 spread radius for this scenario is 18 m.
- The bubbling phenomenon begins when the pressure inside the tank drops from the initial to atmospheric pressure



Thank you for your attention

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