



Predictive tool to estimate the performance of LH2 components in a fire

ELVHYS Dissemination Conference

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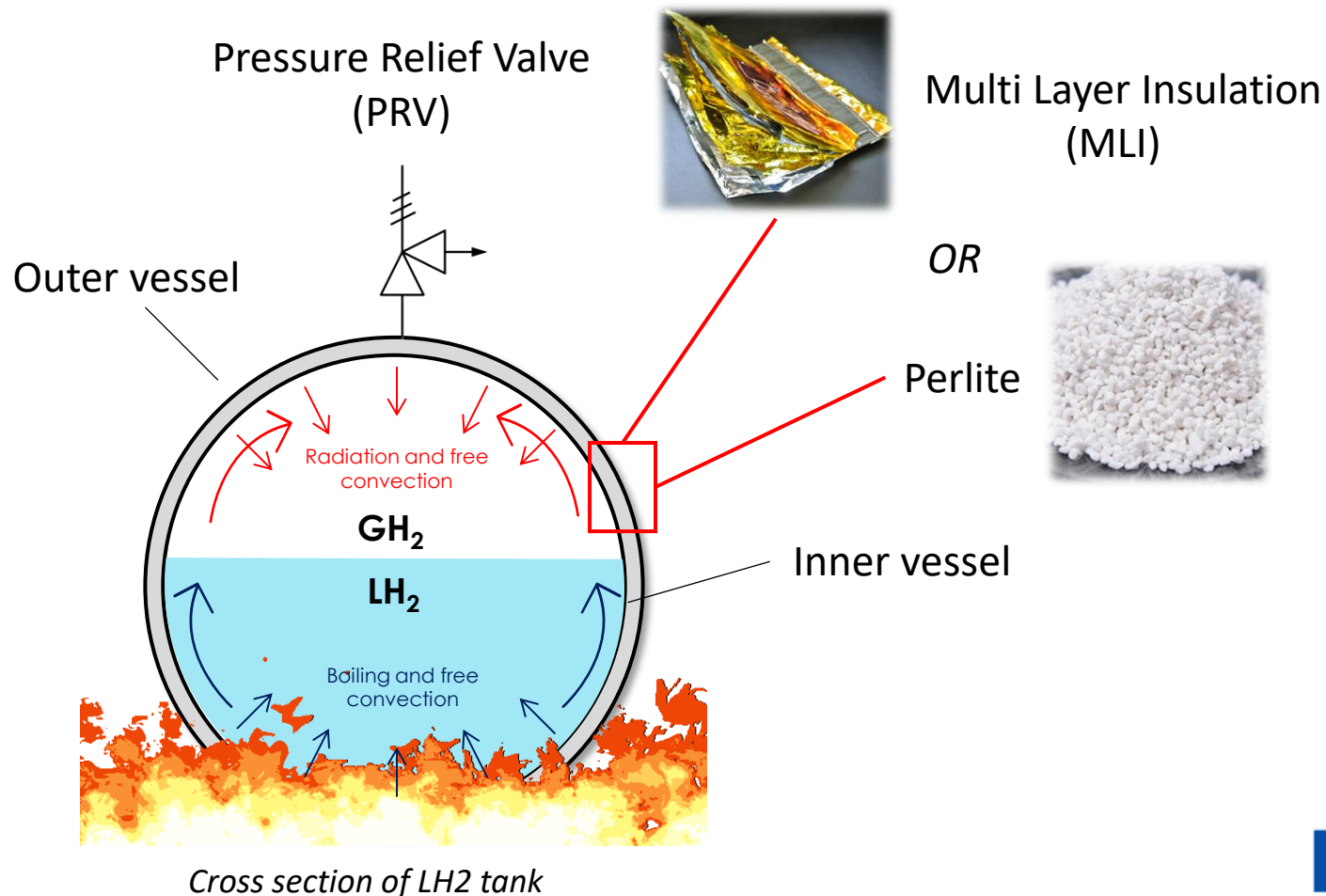
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LH2 tanks exposed to fire

The exposure of a cryogenic storage component to an external fire is one of the **worst-case accident scenarios**.



Inside the tank:

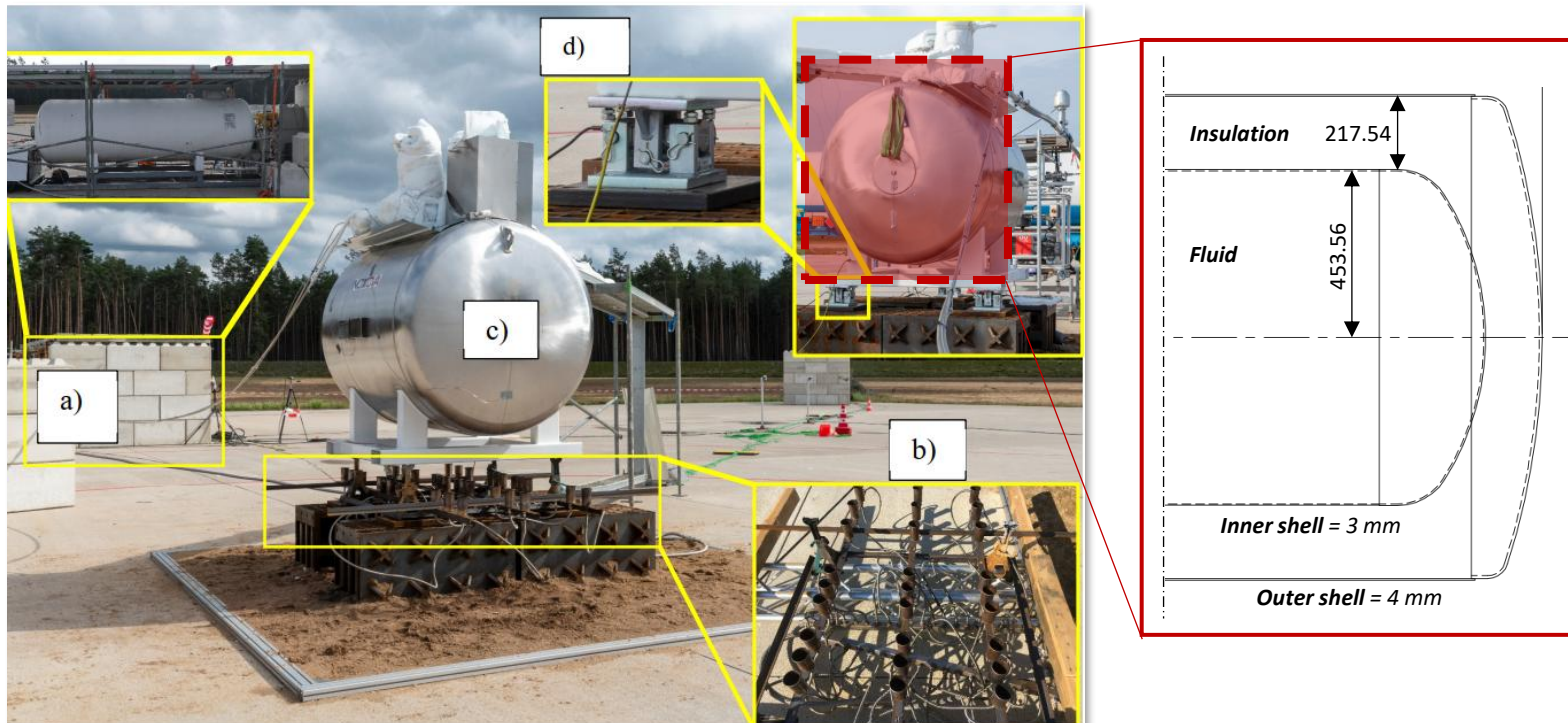
- ☐ Self-pressurization
- ☐ Temperature stratification
- ☐ Insulation degradation
- ☐ Supercritical conditions



Reference fire test

SH2IFT project fire tests

One of the three SH2IFT project fire tests on LH2 storage tanks was selected for the study.



Experimental setup

- ☐ Tank volume: 1 m³
- ☐ Initial tank pressure: ~ 4 bar
- ☐ Initial vacuum pressure: 0.3 mbar
- ☐ Filling tank degree: ~ 40%
- ☐ LH2 mass: ~30 kg

Experimental setup of the SH2IFT fire test carried out at the Federal Institute for Materials Research and Testing (BAM) in 2021

Goal

Models should estimate:

- ☐ Tank pressurization
- ☐ Temperature stratification
- ☐ Boil-off gas formation
- ☐ Time to Failure



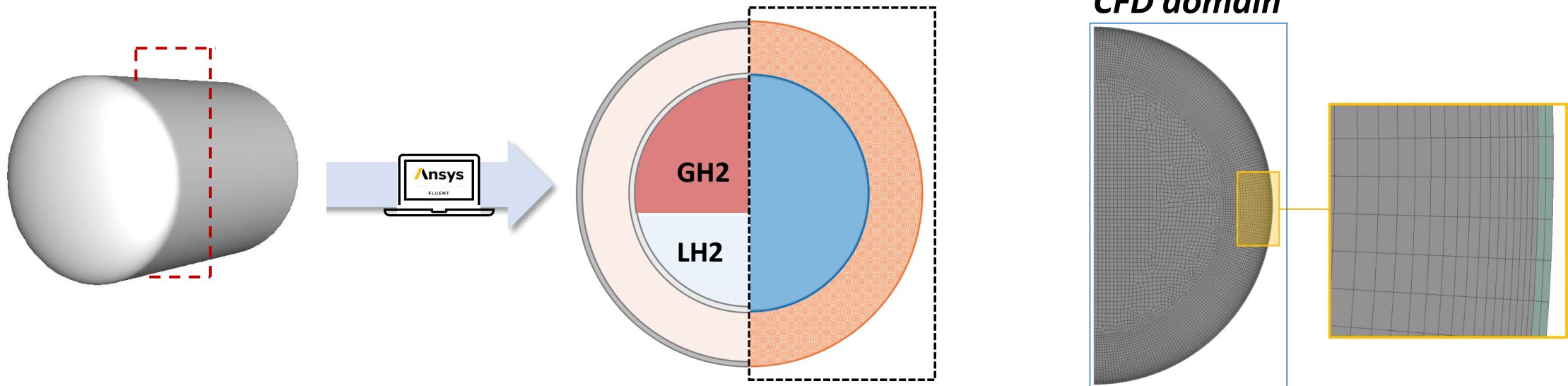
SH2IFT project fire test carried out at the Federal Institute for Materials Research and Testing (BAM) in 2021

CFD model

Computational domain: half of tank cross-section (symmetry) □

The computational domain is further divided into:

- **CFD domain** = fluid + tank inner shell ■ (element size = 1cm, 30 inflation layers, 10,625 cells)
- **Insulation model domain** = insulation + tank outer shell ■■ Camplese et al. (2024), <https://doi.org/10.1016/j.psep.2024.04.061>



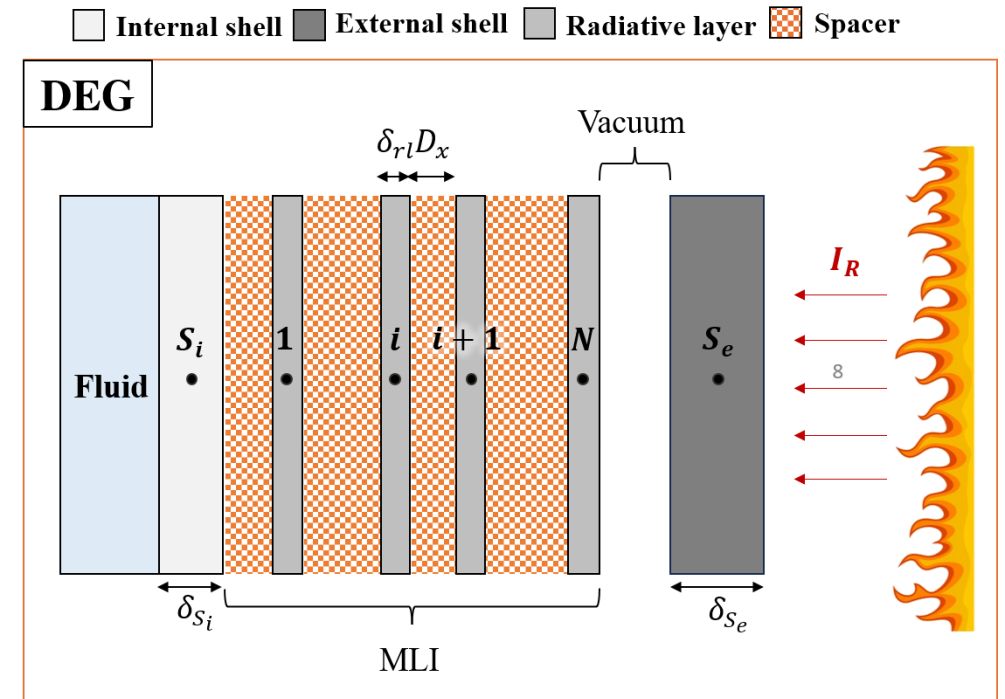
CFD model

Submodels

- **Multiphase** model: Volume of Fluid
- **Turbulence** model: $k-\omega$ SST
- **Evaporation-condensation** model: Lee (default coefficients: 0.1)

Material properties

- **Hydrogen**: piecewise linear functions of temperature
- **Steel**: default Ansys values
- **Insulation**: degradation model (Camplese et al., 2024)

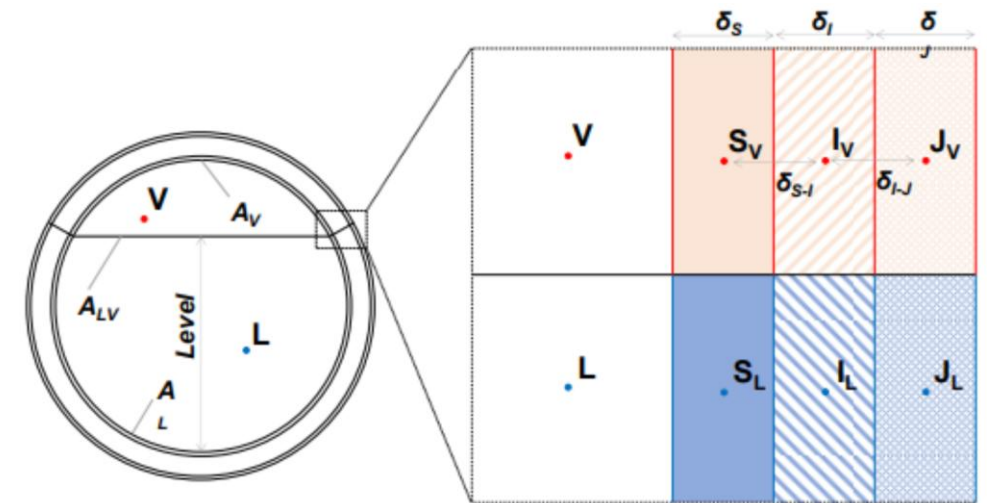


Schematization of the domain of the insulation model according to the MLI degradation model

Lumped model

Lumped model based on the thermal nodes approach developed by Ustolin et al. (2021) was further improved:

1. Addition of **interface node**.
2. Inclusion of the **compressed-liquid regime**.
3. More realistic **boundary conditions** (fire temperature and partial engulfment).
4. Refined modelling of the **MLI** and **perlite thermal conductivity**.



Eight thermal nodes included in the original model developed by Scarponi et al. (2016) <https://doi.org/10.3303/CET1653052>

Case study 1 (SH2IFT fire test)

Geometry & initial conditions

- **Tank volume:** 1 m³
- **Tank pressure:** initial experimental pressure
- **H2 temperature:** saturation + equilibrium

Assumptions

- **Pressure relief valve** not working
- **Inner shell:** 5083 Al alloy ($\max \sigma_{amm} = 112.5$ MPa)
- **Flame temperature:** 1,000 and 1,100 K (CFD), approx. 720 K (lumped model)
- **Fire engulfment:** full engulfment in CFD, partial engulfment in lumped

Case study 2 (ELVHYS; only lumped model)

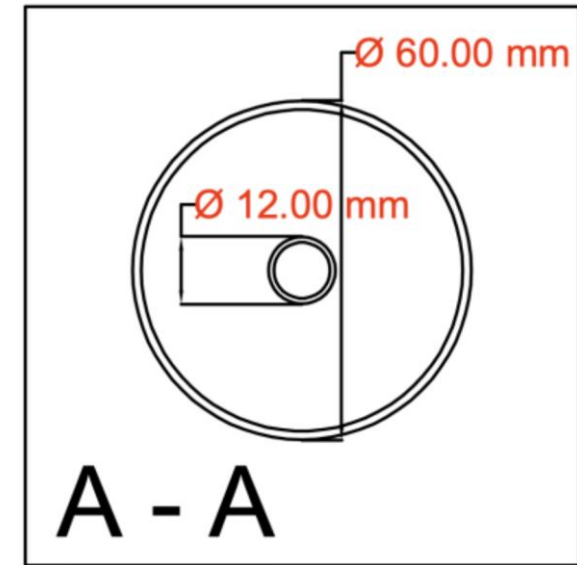


Geometry & initial conditions

- Inner diameter: 10 mm
- Pipe length: 1.926 m
- Initial LH2 mass: 5.5 g

Assumptions

- Pressure relief valve not working
- Insulation: MLI & vacuum, or only vacuum
- Flame temperature: approx. 720 K



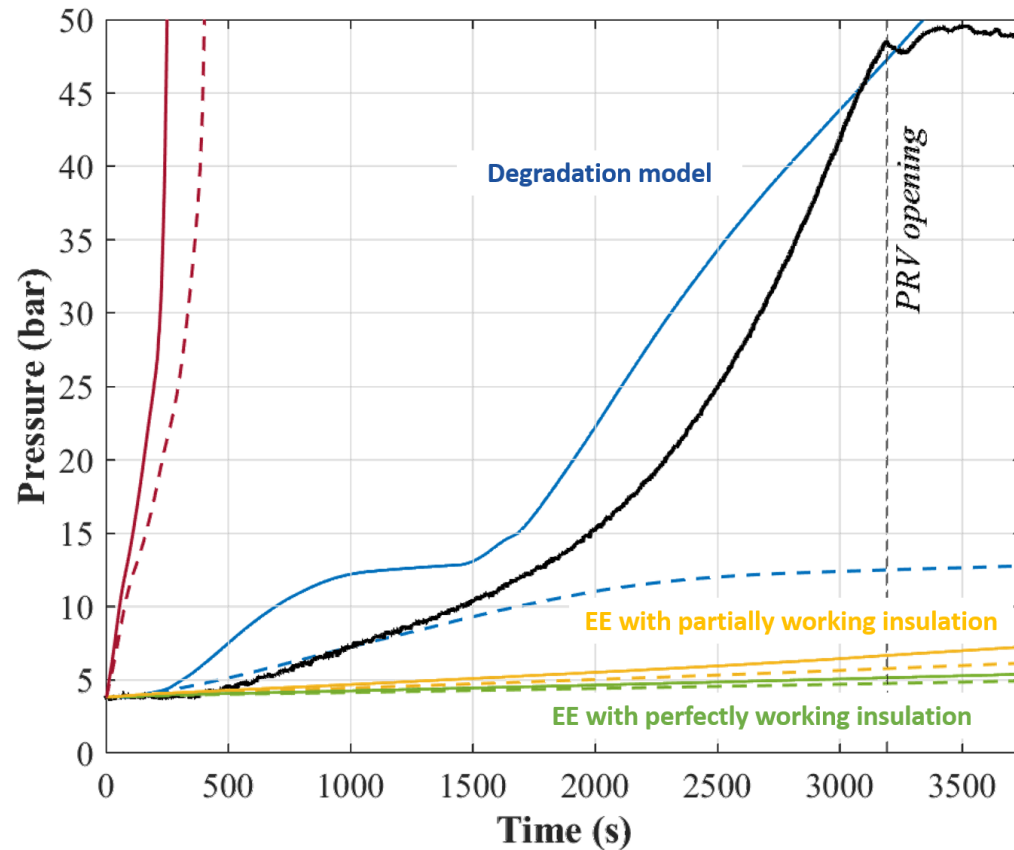
*Cross section of the rigid LH2 line
tested by KIT in ELVHYS WP4*

Main outcomes

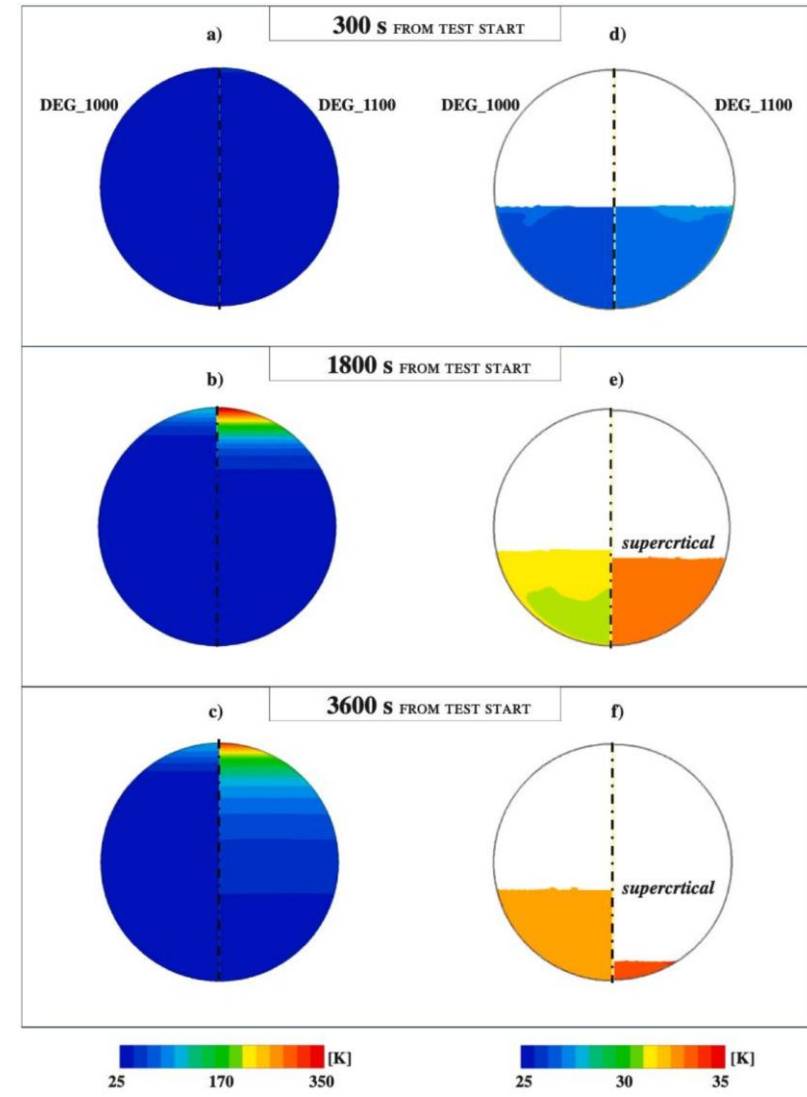
CFD model vs state-of-the-art (EE)

--- 1,000 K — 1,100 K

EE with completely degraded insulation



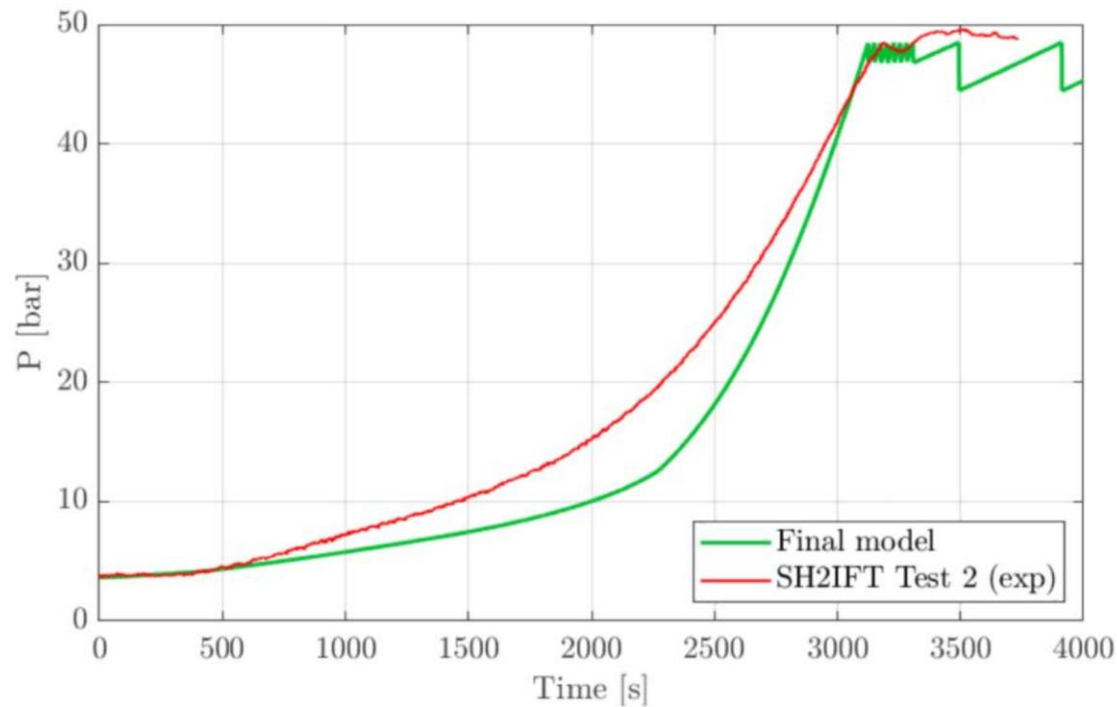
Tank pressure evolution (EE: effective emissivity)



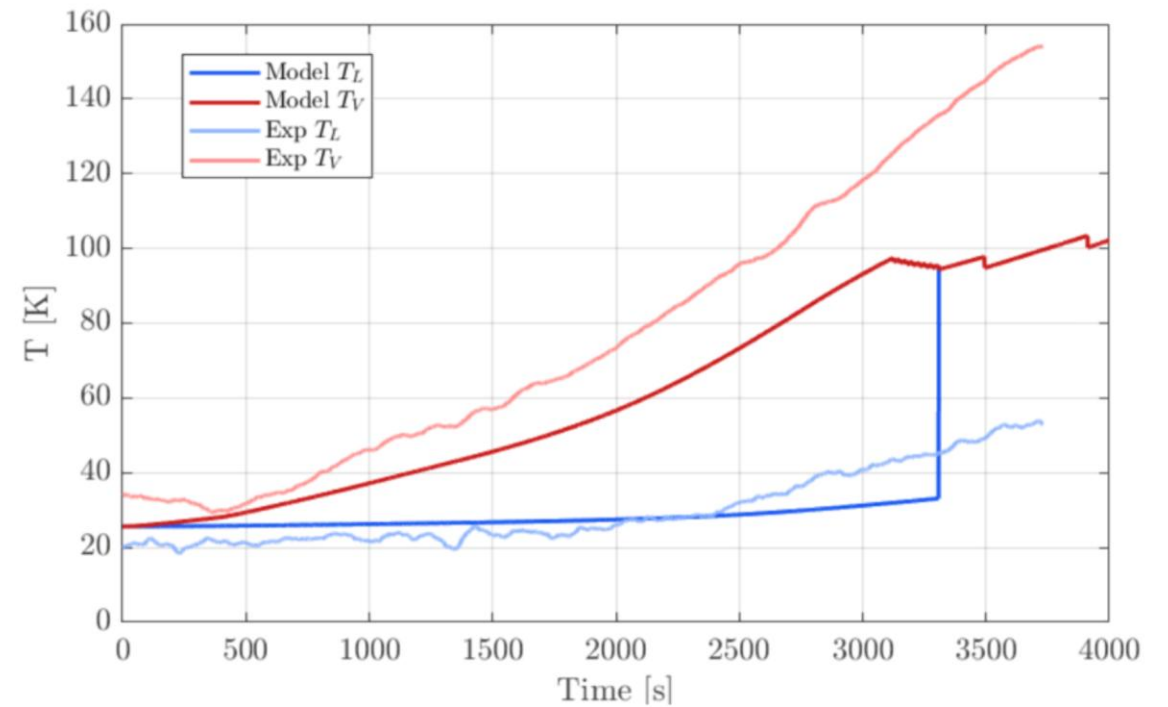
GH2 and LH2 temperature evolution

Main outcomes

Lumped model (case study 1)



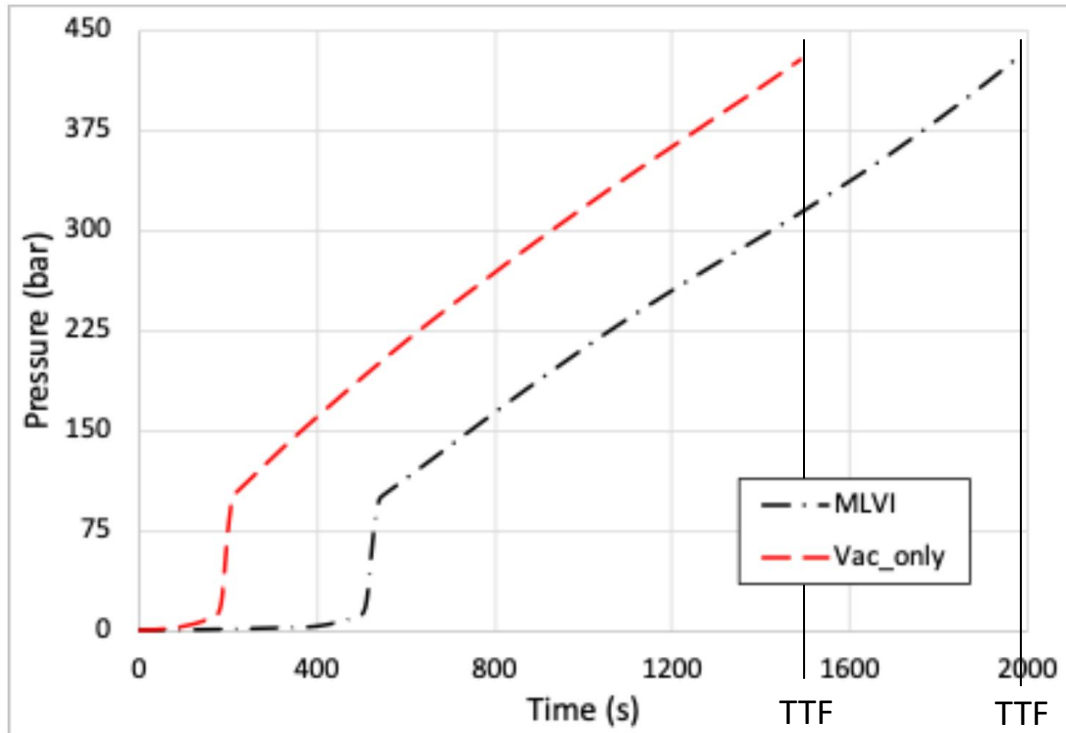
Tank pressure evolution



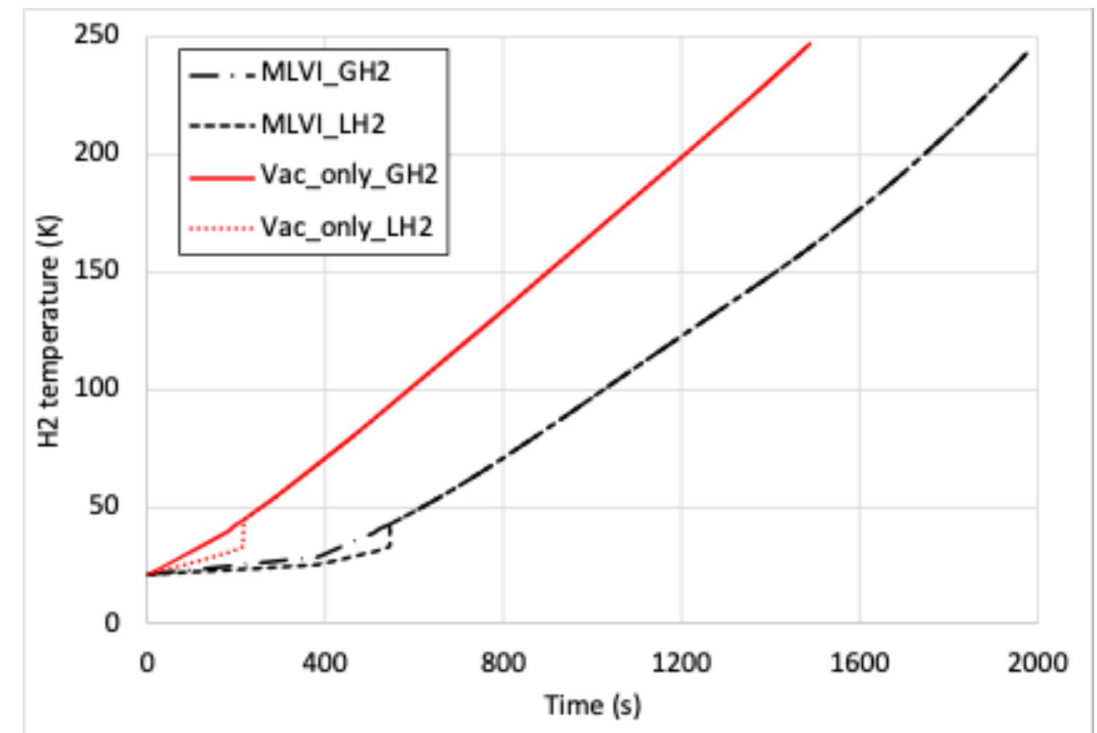
GH2 and LH2 temperature evolution

Main outcomes

Lumped model (case study 2)



Tank pressure evolution (TTF: time to failure)

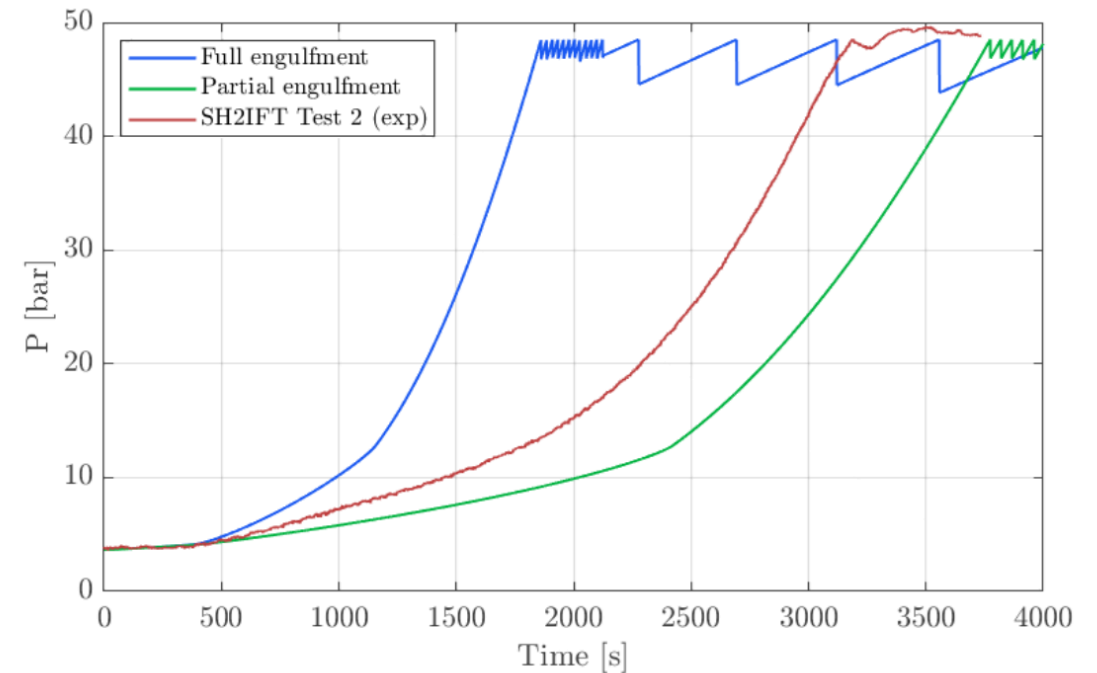


GH2 and LH2 temperature evolution (TTF: time to failure)

Results must still be compared with ELVHYS experiments

Conclusions and recommendations

- Accurate simulation of the **insulation performance** is crucial.
- **Number of layers** and **emissivity** of the insulation are the most crucial parameters.
- **Simplified approaches** where the insulation performance is oversimplified (e.g., static performance) may lead to misleading results.
- External **fire temperature** and **flame coverage** plays a significant role on the degradation of the insulation.
- **Further validation** of the models is needed, especially for larger scale.



Reference study

Additional details on the CFD model can be found here:

<https://www.sciencedirect.com/science/article/pii/S0957582025015861>

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Modelling the behaviour of cryogenic liquid hydrogen tanks engulfed in fire

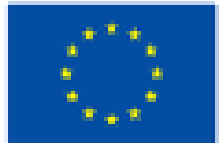
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Thank you for your attention

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