SIMULATION OF HYDROGEN MIXING AND PAR OPERATION DURING ACCIDENTAL RELEASE IN A LH_2 CARRIER ENGINE ROOM

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OUTLINE

- Introduction
- Modeling Approach
- Results
  - Unmitigated Scenario
  - Mitigated Scenario
- Summary and Conclusions

INTRODUCTION

Background

- Next-generation LH2 carriers may use the boil-off gas from the cargo tanks as additional fuel for the engine.
- Safety considerations were made for the a potential failure of the feed lines and release of GH2 into the room of the propulsion system.
- The worst-case scenario assumes a power blackout (failure of active ventilation systems) and an undetected leak.
- Hydrogen may accumulate locally and form a flammable mixture with air.

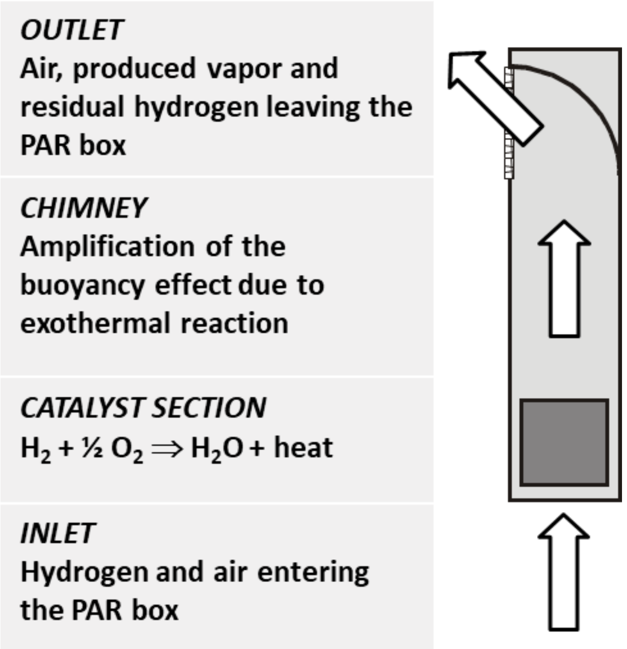
https://global.kawasaki.com/en/corp/newsroom/news/images/news_210506-2.jpg

➢ To prevent endangering the crew and the ship, the installation of passive auto-catalytic recombiners (PARs), was investigated in a collaboration between Forschungszentrum Jülich and Kawasaki Heavy Industries.

INTRODUCTION

Passive Auto-Catalytic Recombiners

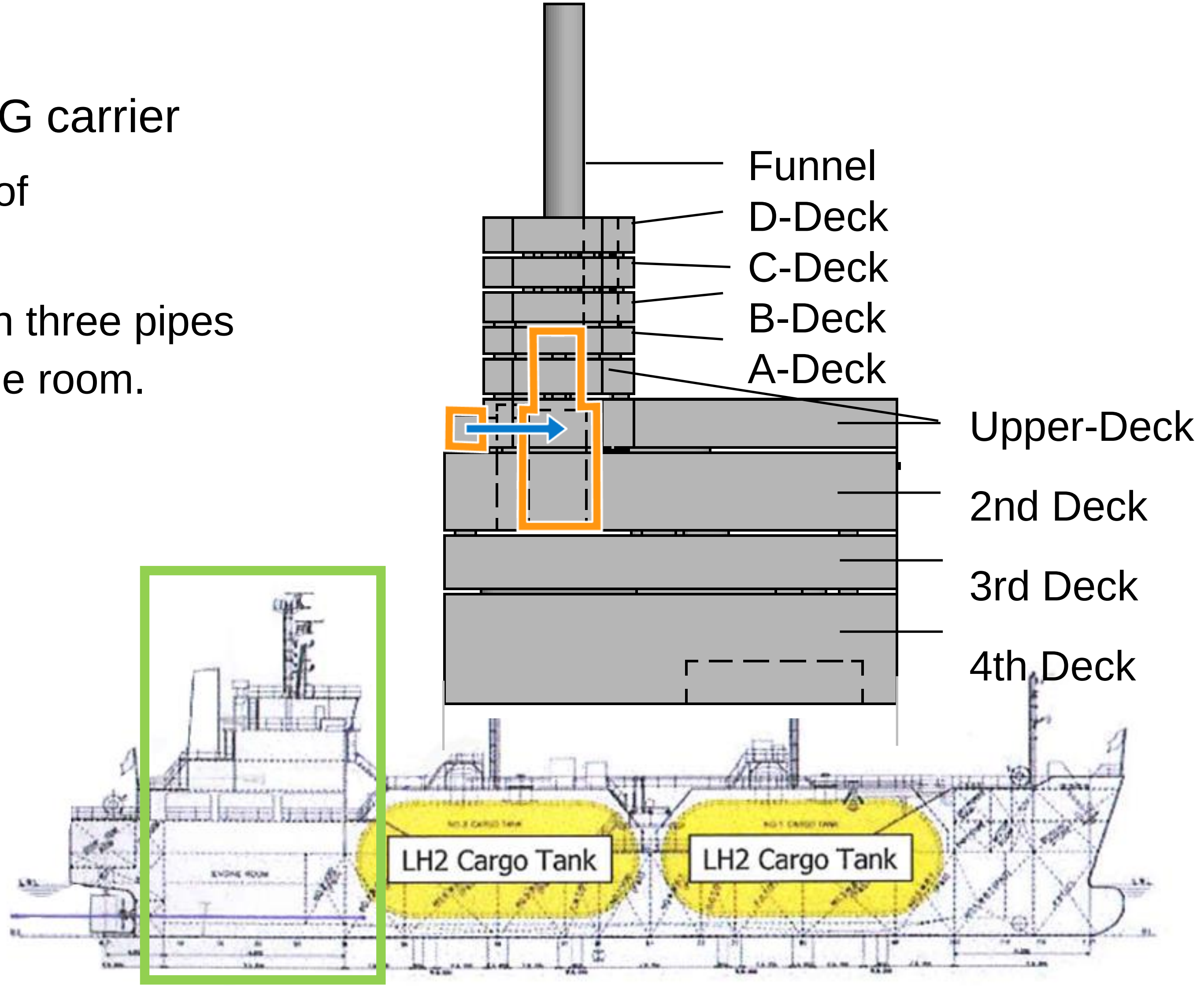
- PARs are qualified as safety systems under the conditions of nuclear power plant accidents and enable flameless conversion of Hydrogen to steam.
- Due to the exothermal reaction, a buoyancy-driven flow is induced through the chimney on top of the catalyst section.
- It inherently feeds the surrounding hydrogen/air mixture into the PAR.
- Being an entirely passive safety measure, PARs will operate even in case of blackout and without crew interaction.



MODELLING APPROACH

Geometry

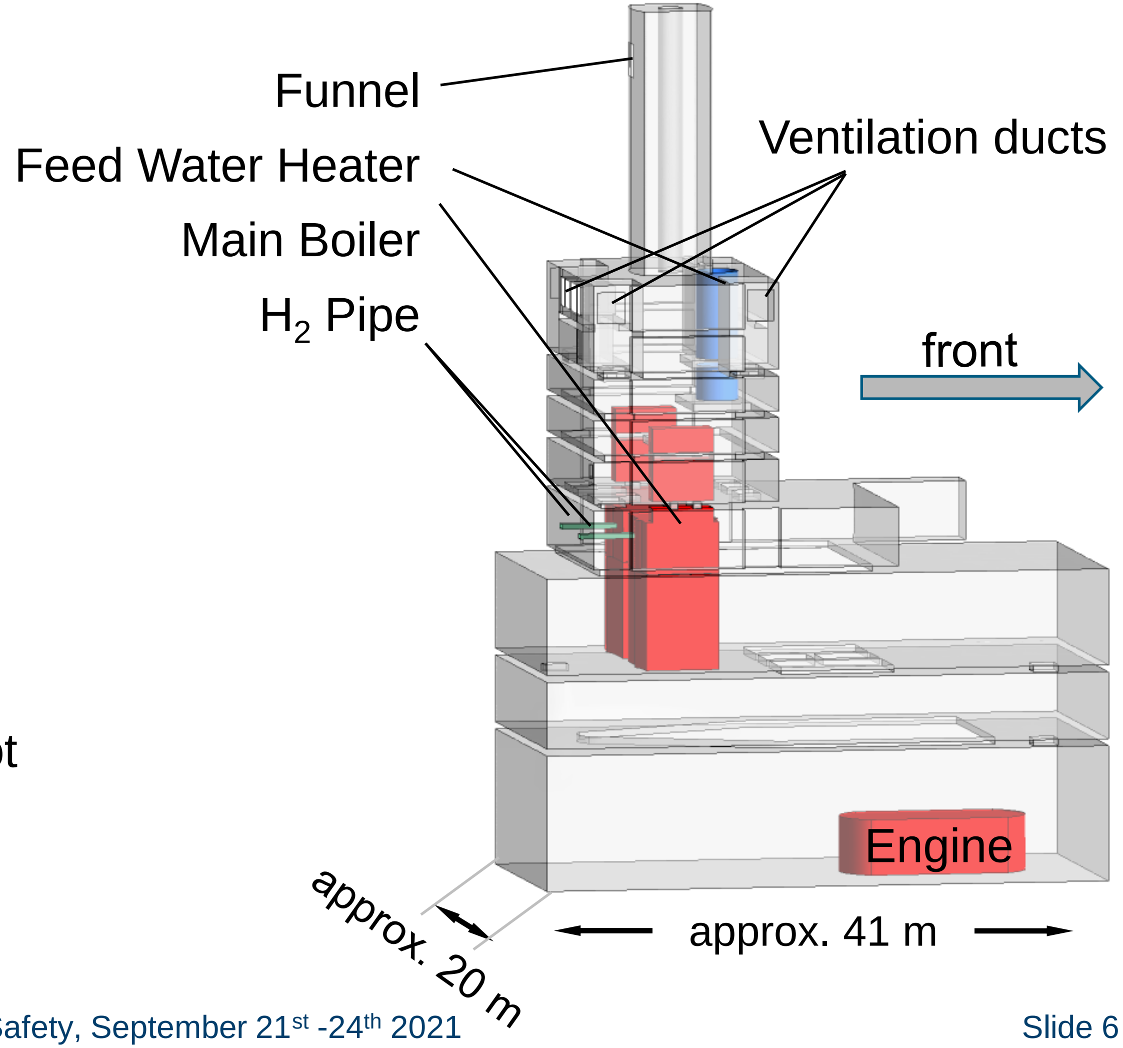
- The geometry is based on an existing LNG carrier
  - The engine room is located in the rear part of the hydrogen carrier.
  - The two main boilers are connected by each three pipes to the gas hood at the rear side of the engine room.
  - The pipes are housed in a rectangular, non-pressure-resistant protection tube.



MODELLING APPROACH

CFD domain

- The geometry is based on an existing LNG carrier
  - The engine room is located in the rear part of the hydrogen carrier.
  - The two main boilers are connected by each three pipes to the gas hood at the rear side of the engine room.
  - The pipes are housed in a rectangular, non-pressure-resistant protection tube.
  - The room of the propulsion system is connected to the environment by the ventilation ducts.
  - The simplified geometry resolves the large components as well as the open cross-sections in the ceilings, but not the small structures (piping, valves, walking grids etc.).



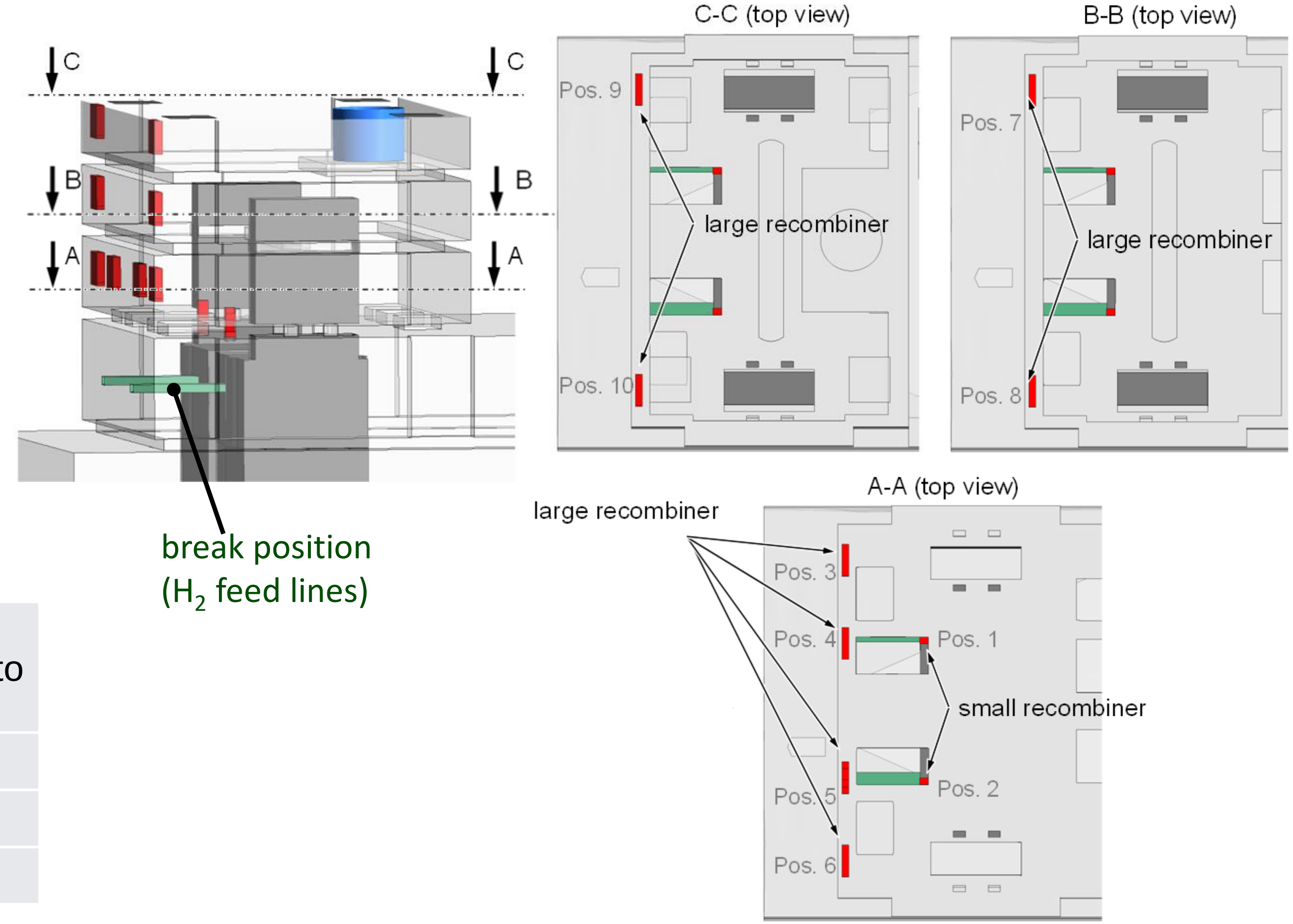
MODELLING APPROACH

PAR System

- 10 optimal PAR positions determined with ‚unmitigated reference case‘
  - In flow path of H2 plume (pos 1&2) opening in ceiling of upper deck.
  - Back wall of A-C decks, where H_2 accumulations were observed (pos 3-10).
  - Base concept (PAR-1).
  - Parametric study to asses impact of PAR size:

Recombiner system	PAR type at positions 1 and 2	PAR type at positions 3 to 10
PAR-1	**Small**	Large
PAR-2	**Large**	Large
PAR-3	Large	**Small**

(capacity of a large PAR ~ 5x of a small one)

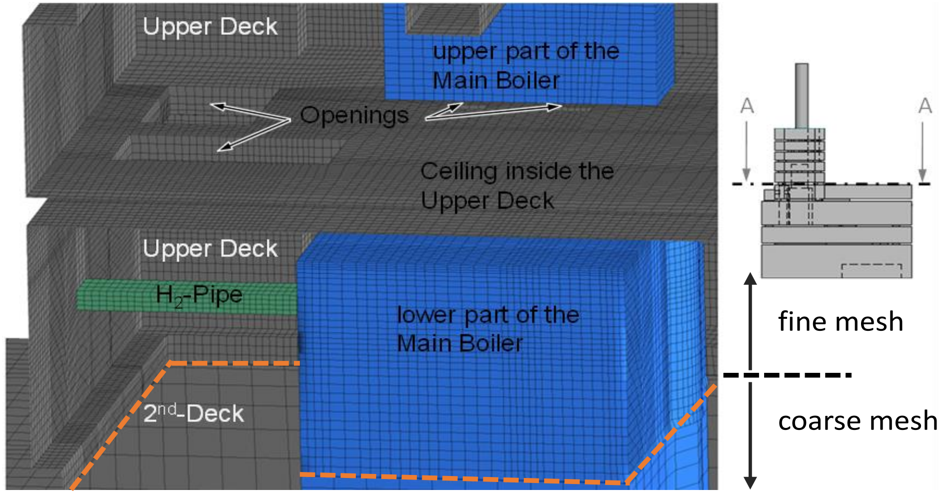


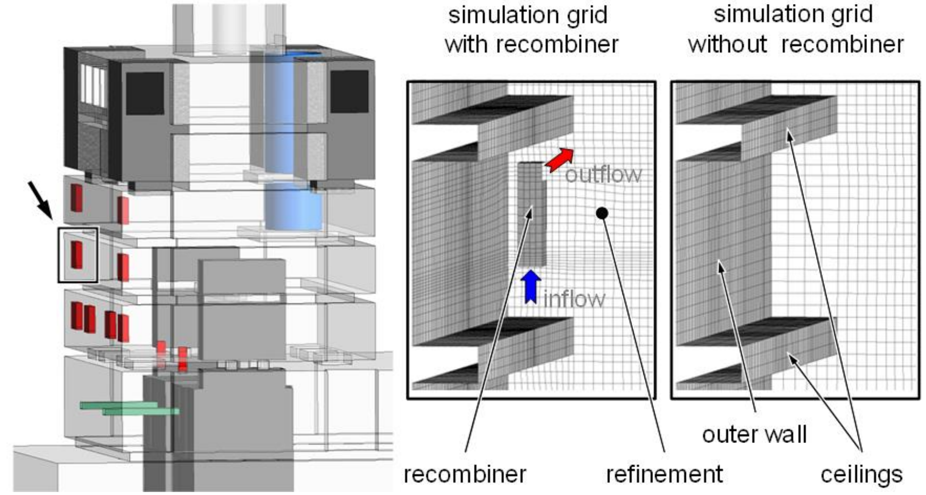
MODELLING APPROACH

Numerical Grid

- Multi-block structured mesh, generated with ANSYS ICEM CFD
  - 2x refined mesh resolution above 2nd deck.

Mesh statistics	without recombiners	with recombiners
Total number of fluid elements	~ 1,600,000	~ 2,800,000
Volume size of an average volume (m³)	~ 0.013	~ 0.008
Edge length of an average volume (m)	~ 0.24	~ 0.20
Grid Quality Metrics		
Aspect ratio	< 9	< 9
Cell volume ratio / growth rate	< 6.0	< 6.0
Minimum face angle (°)	> 27	> 27

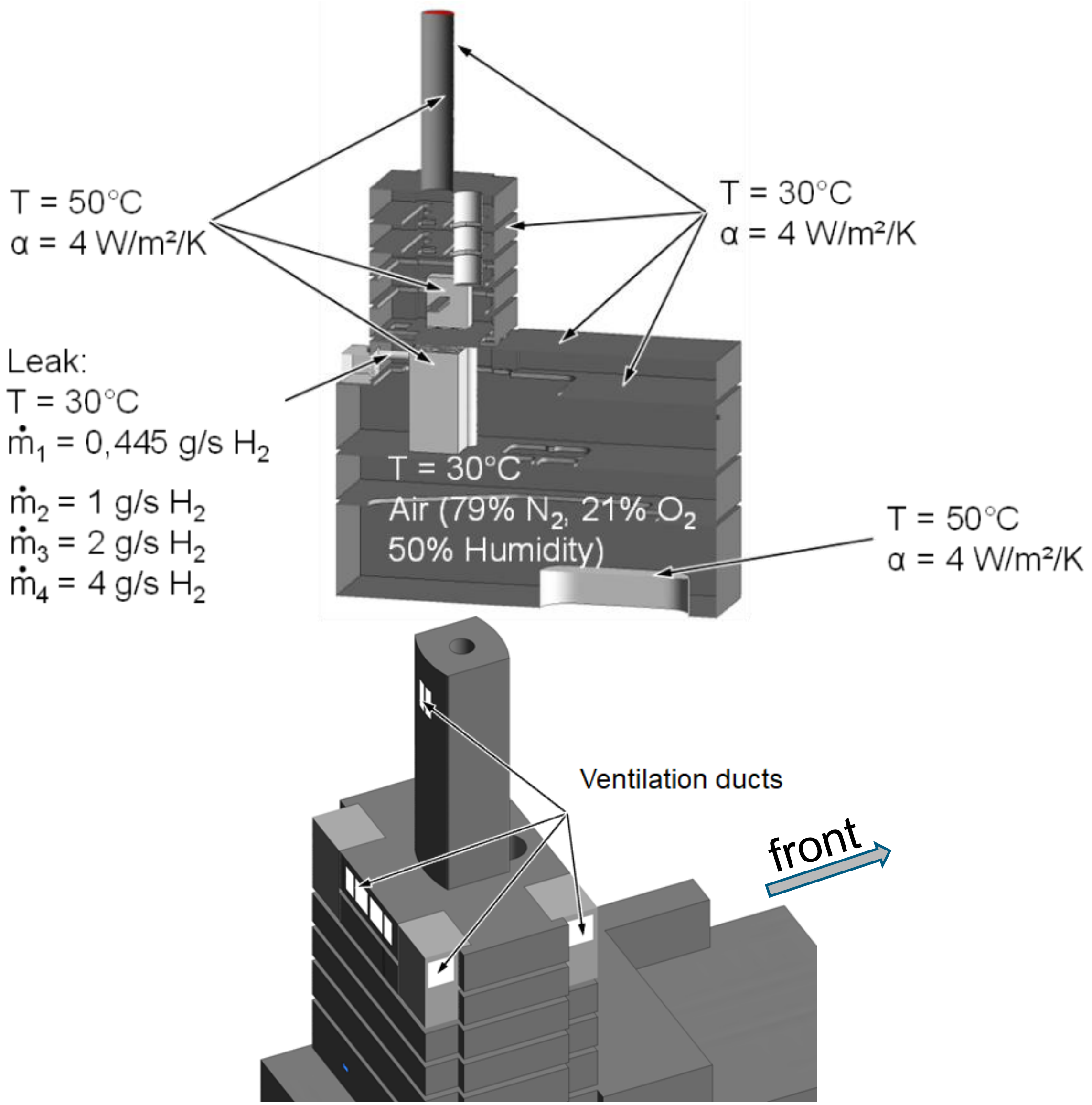




MODELLING APPROACH

Hydrogen Mixing and Transport Processes

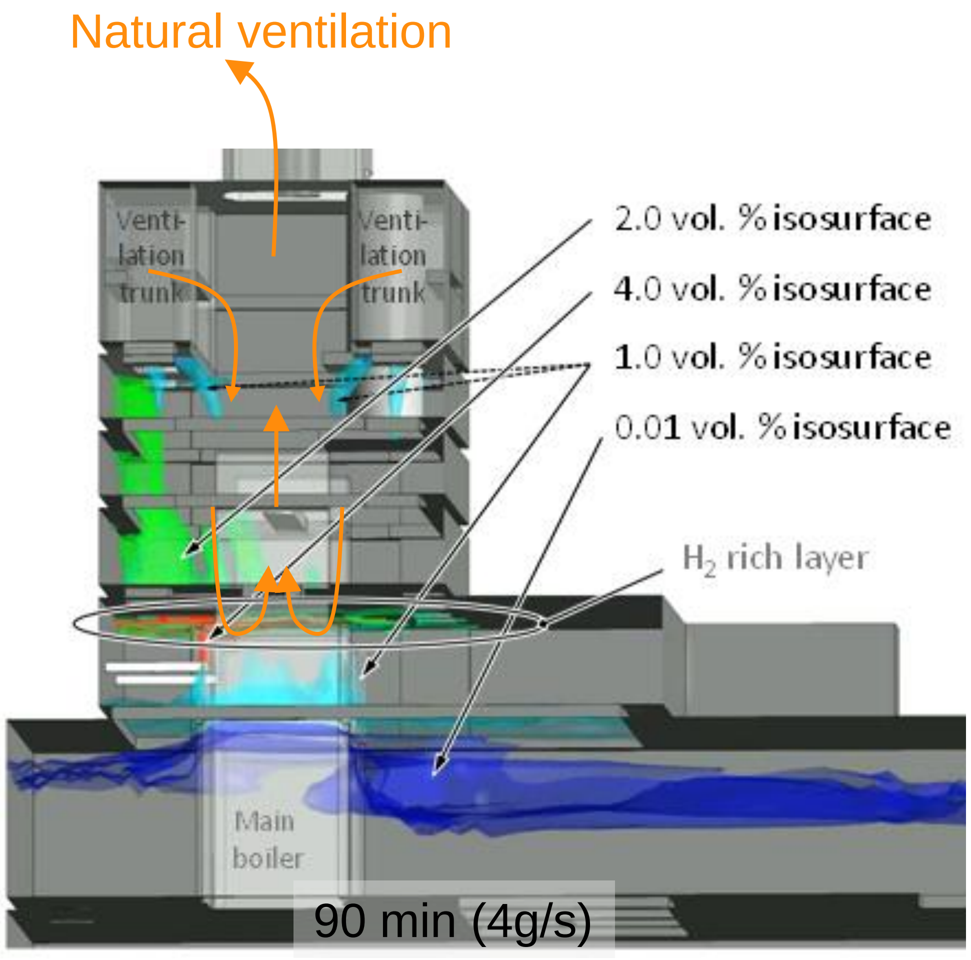
- Baseline model for hydrogen mixing and mitigation
  (comprehensively validated for nuclear reactor containment atmosphere mixing)
  - ANSYS CFX 14
  - URANS (k-ω SST model incl. full buoyancy effects)
  - Ideal gas equation of state
  - REKODIREKT PAR model
  - 2nd order discretization in time and space
  - Adaptive time stepping (ave. CFL ~ 1, Δt ~0.3s)
- Initial and boundary conditions:
  - Air @ 30°C and 50% rel. humidity
  - Free circulation through ventilation ducts (ξ=21.5)
  - Thermal buoyancy from hot engine / colder walls
  - H_2 release rates 0.445 - 5 g/s



RESULTS

Unmitigated Scenario

- The released hydrogen instantly forms a buoyant plume, which breaks up when passing through the ceilings.
- A natural circulation is formed as light H_2-rich gas is leaving the engine room through the upper vents and air (< 1 m³/s) enters at the lower vents (D-deck).
- Hydrogen disperses almost homogeneously throughout the upper decks above the injection elevation with concentration of < 1 vol.%.
- Considerable part of the released hydrogen is removed by the natural circulation.



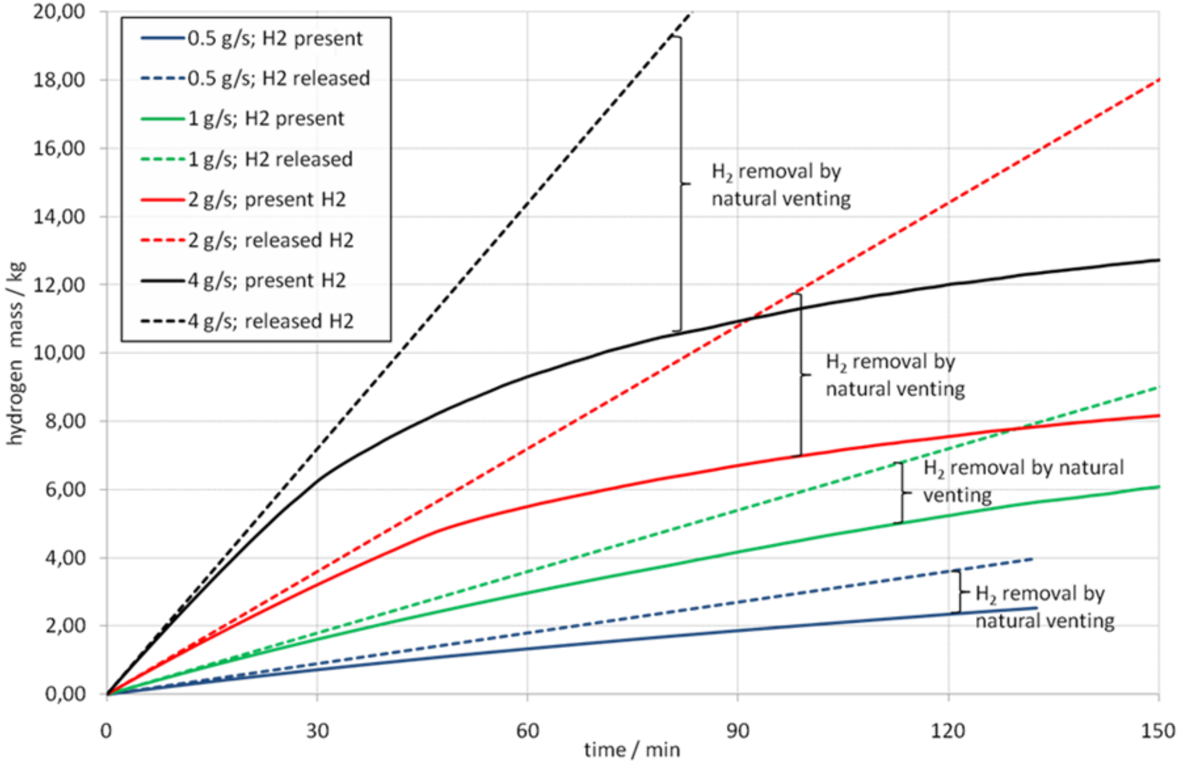
➢ Major source of uncertainty due to unresolved internal structures (piping, walking grids, small components etc.) and entrainment boundary condition.

RESULTS

Unmitigated Scenario

- Formation of a hydrogen-rich cloud depends on the release rate
  - No considerable flammable gas cloud (LFL 4 vol.%.) for release rates of 0.5 and 1 g/s.
  - Flammable clouds of ~8 m³ (2 g/s) and ~30 m³ (4 g/s) within the first 90 min primarily within ceiling layer above break location.
  - Hydrogen accumulation at the rear side of the engine room where flow is stagnating.

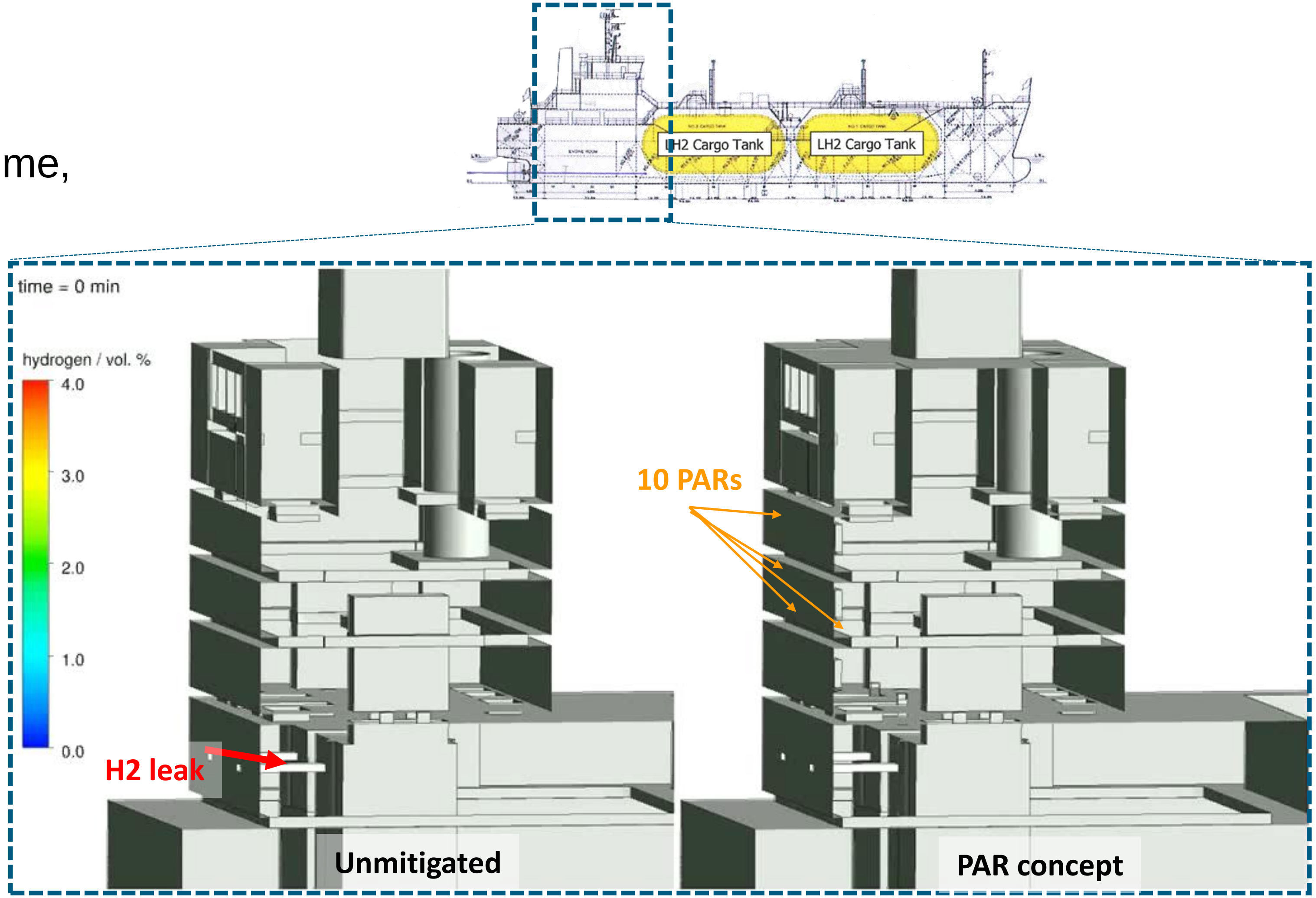
➢ PAR placed along flow path and positions with increased H_2 concentrations.



RESULTS

Mitigated Scenario

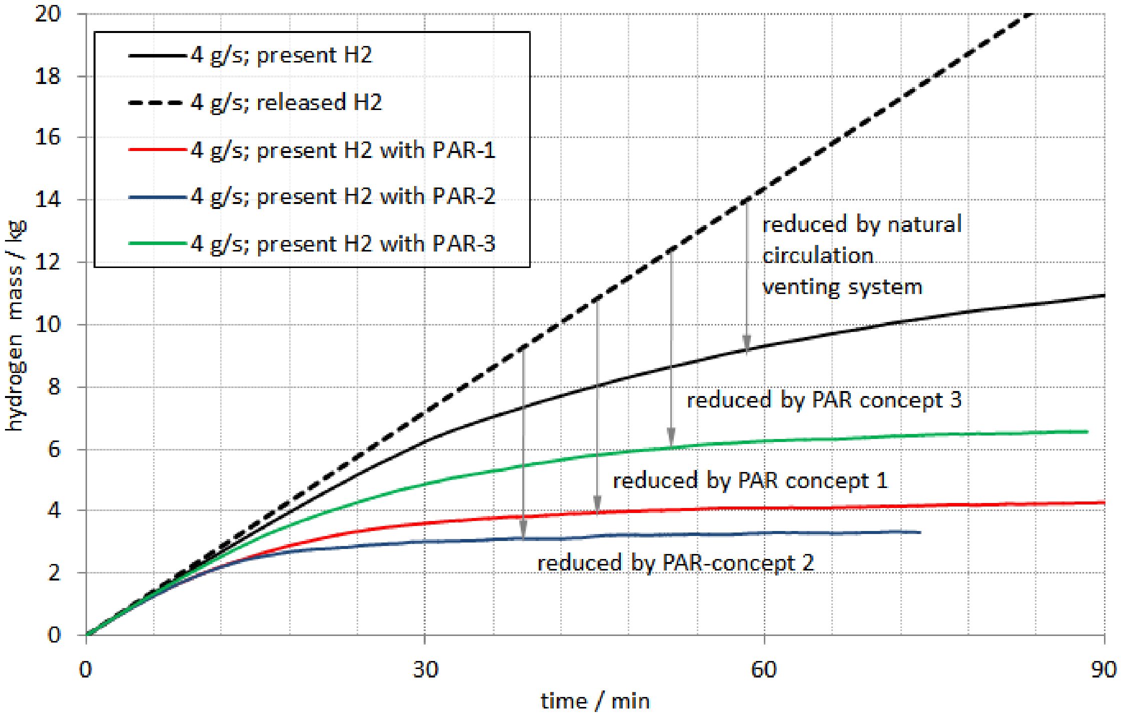
- The recombiners:
  - reduce H_2 concentration in the rising plume,
  - promote natural venting and mixing due to hot exhaust gas plume,
  - reduce H_2 accumulation in stagnation zones,
  - reduce the extent of the ceiling layer above the release location.



RESULTS

Mitigated Scenario

- Effect of PAR size
  - Similar effect on the formation of flammable clouds due to enhanced mixing, but different integral recombined mass for the three concepts.
  - PAR units 1 and 2 mounted in the flow path of the hydrogen plume significantly contribute to the reduction of hydrogen concentration and thus the overall risk.
  - The capacity of a large PAR units is not fully exploited.
  - ➢ An increased and more evenly distributed number of small PAR units may be more efficient in terms of hydrogen removal and mixing. Furthermore, the positioning of a small PAR unit is easier to realize and more flexible compared to a large one.



Recombiner system	PAR type at positions 1 and 2	PAR type at positions 3 to 10
PAR-1	**Small**	Large
PAR-2	**Large**	Large
PAR-3	Large	**Small**

SUMMARY AND CONCLUSIONS

- An accidental release of GH_2 into the room of the propulsion system of a LH_2 carrier was investigated.
- Full-scale CFD model for analysis of H2 mixing and mitigation by passive auto-catalytic recombiners was developed.
- A PAR concept was designed on basis of an unmitigated reference case: PARs were implemented along the flow path of the H_2 rich plume and in the stagnation zone where an accumulation could occur.
- PARs reduce risk considerably by converting H_2 and promoting mixing.
- For further system optimization, use of small and more evenly distribute units is suggested
- Future work should address the impact of ambient boundary conditions on the natural circulation mixing to support a generalization of conclusions.
- Ongoing work on model transfer to open-source CFD package containment∇FOAM