Experimental and Numerical Investigations on Depressurization Process in a Large Liquefied Hydrogen Tank

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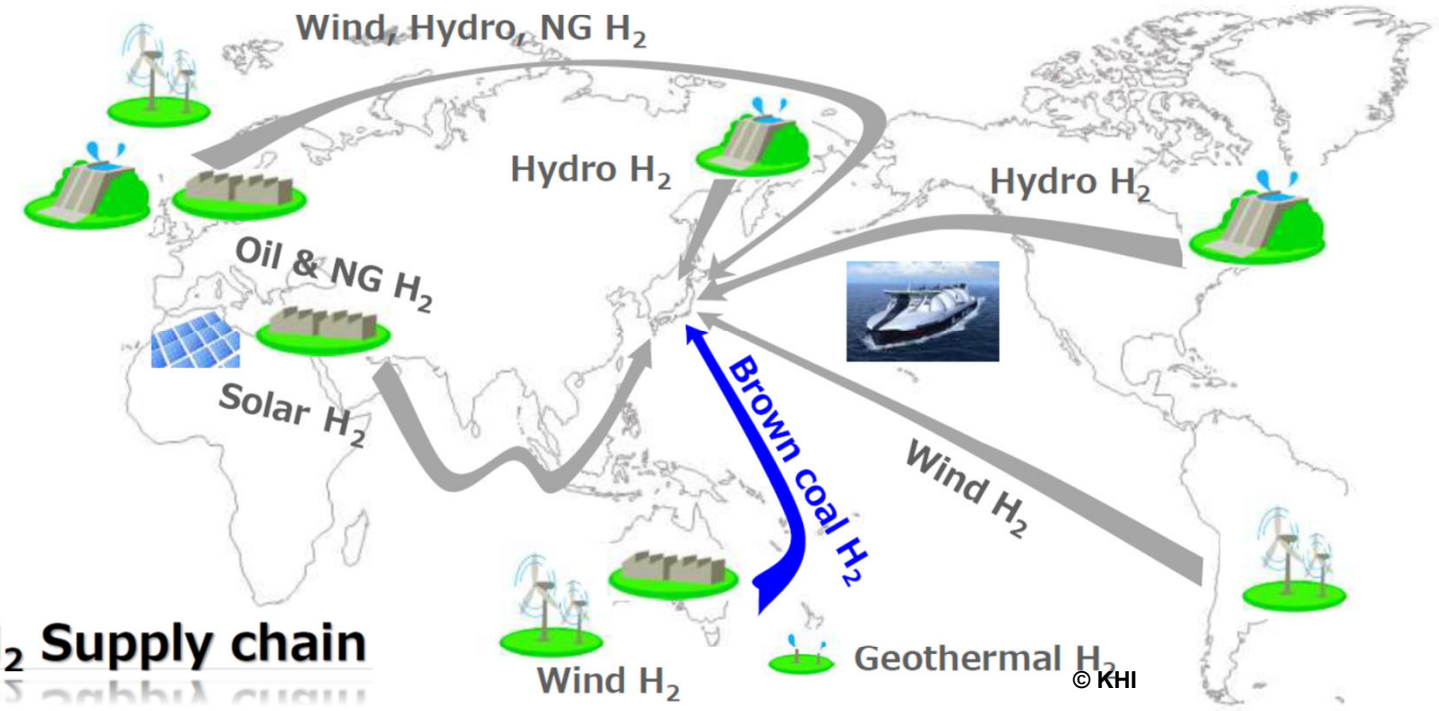
International liquefied hydrogen supply chain
Japan and Australia governments' promotion

In order to establish a "hydrogen-based society" in pursuit of carbon-neutrality goals, …



Expected CO_2-free H_2 Supply chain

Consortiums of Japanese and Australian companies join the Project.

<Members of Australian portion>
J-Power, Iwatani Corporation, Kawasaki, Marubeni and AGL(Australian company)

Australian portion: consisting of gas refining and loading terminal in Australia supported by Australian Governments, coordinated by HEA, Kawasaki's subsidiary.

NEDO portion: consisting of gasification in Australia, H_2 carrier and unloading terminal in Japan supported by NEDO, performed by HySTRA

<Members of HySTRA>
J-Power, Iwatani Corporation, Shell Japan, Kawasaki, Marubeni and JXTG Nippon Oil & Energy

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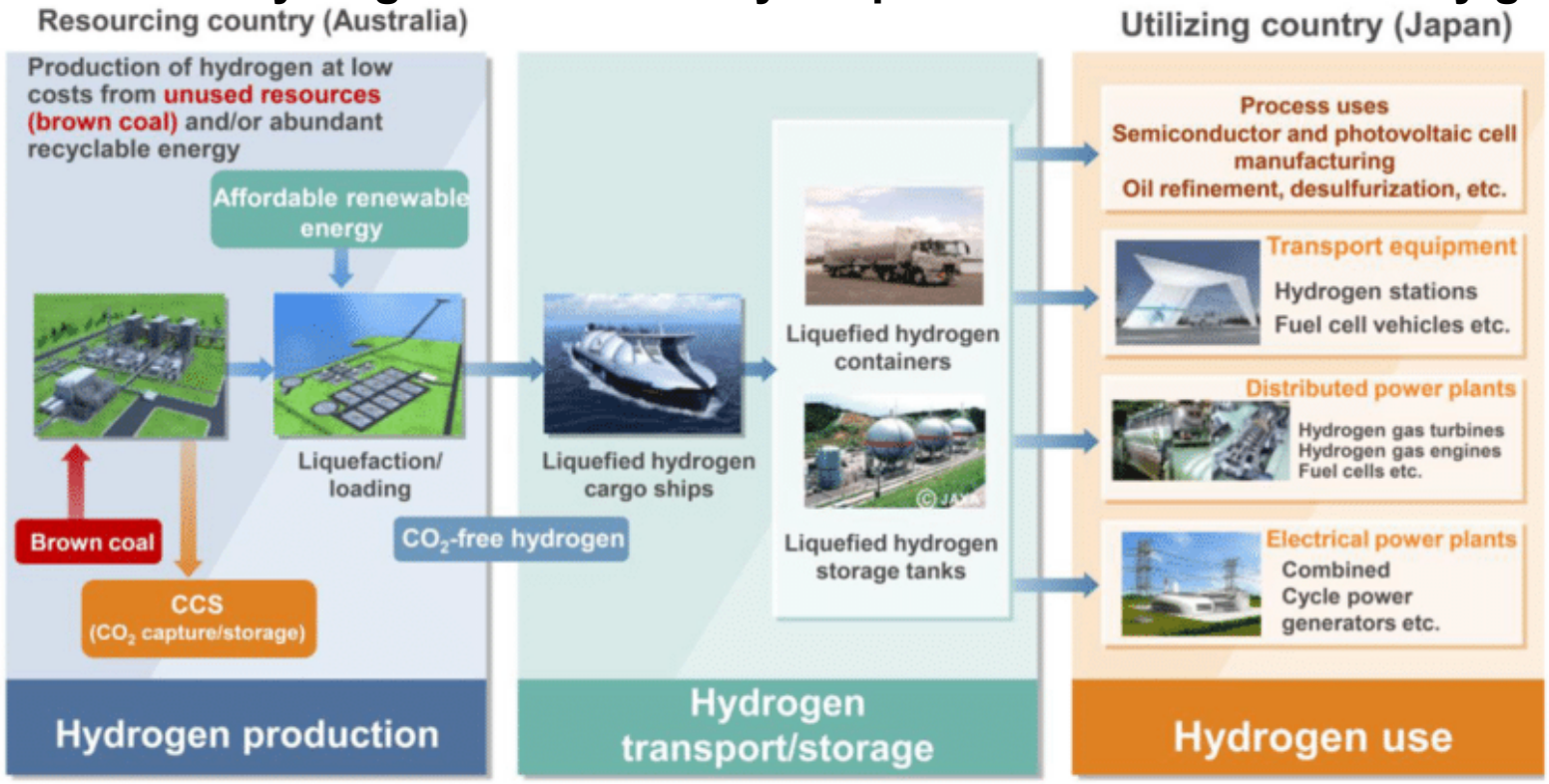

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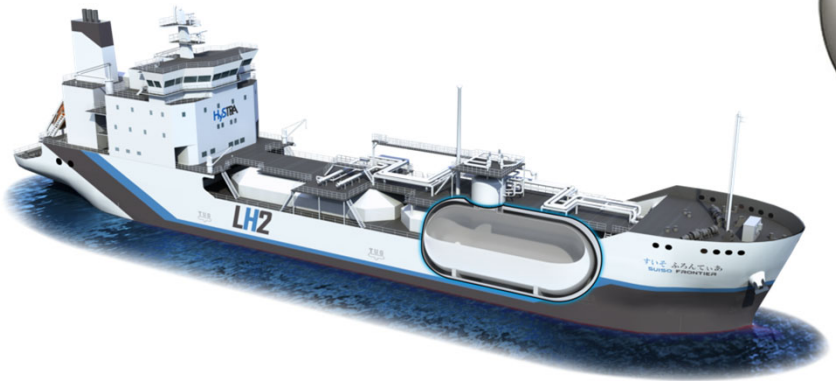
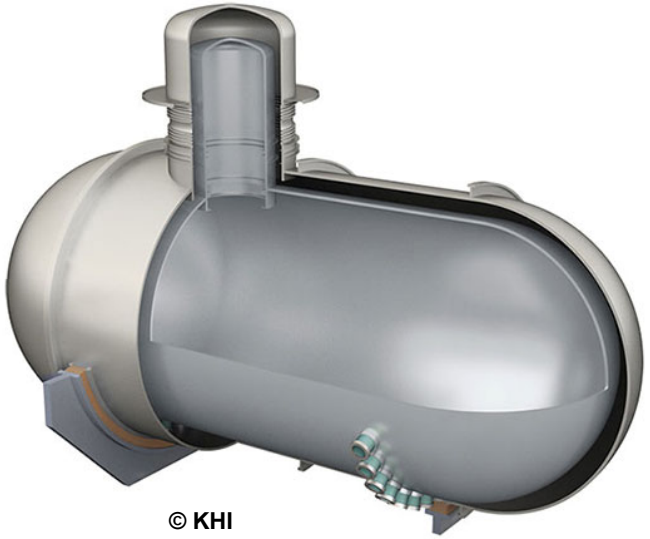
International liquefied hydrogen supply chain
the world's first LH2 tanker, "Suiso Frontier"

As a pilot project, the world's first LH2 tanker, "Suiso Frontier" was developed and successfully transported LH2 from Australia to Japan in 2022.

Suiso Frontier was developed in Japan, primary by Kawasaki Heavy Industries, departed from the port of Kobe on December 24, 2021 and arrived in Port Hastings in Victoria, Australia on January 20 in 2022. The vessel containing LH2 returned safely to Kobe on February 25.





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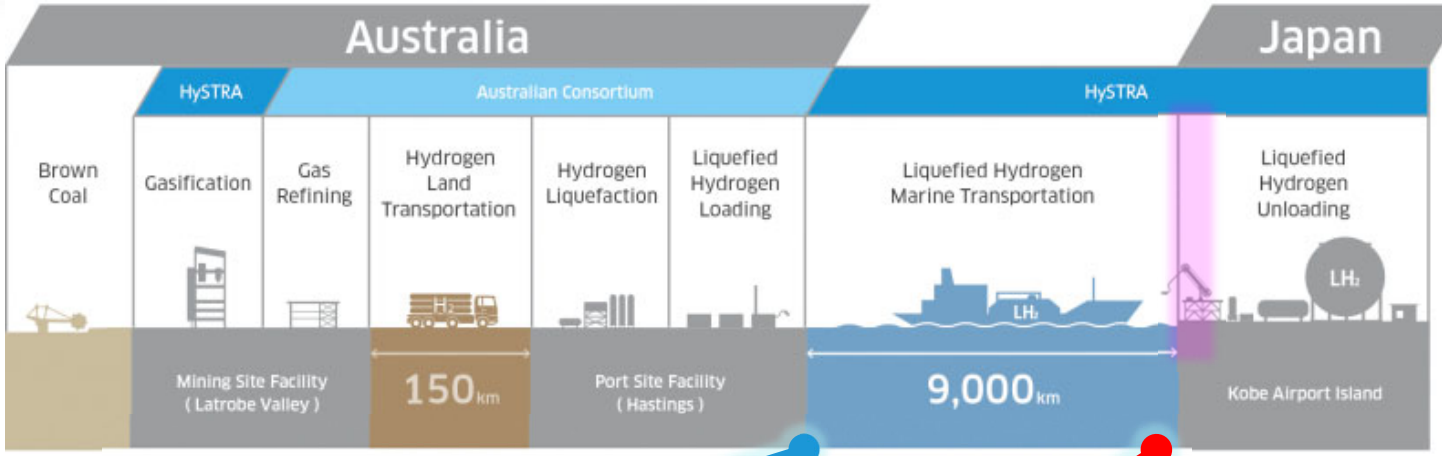
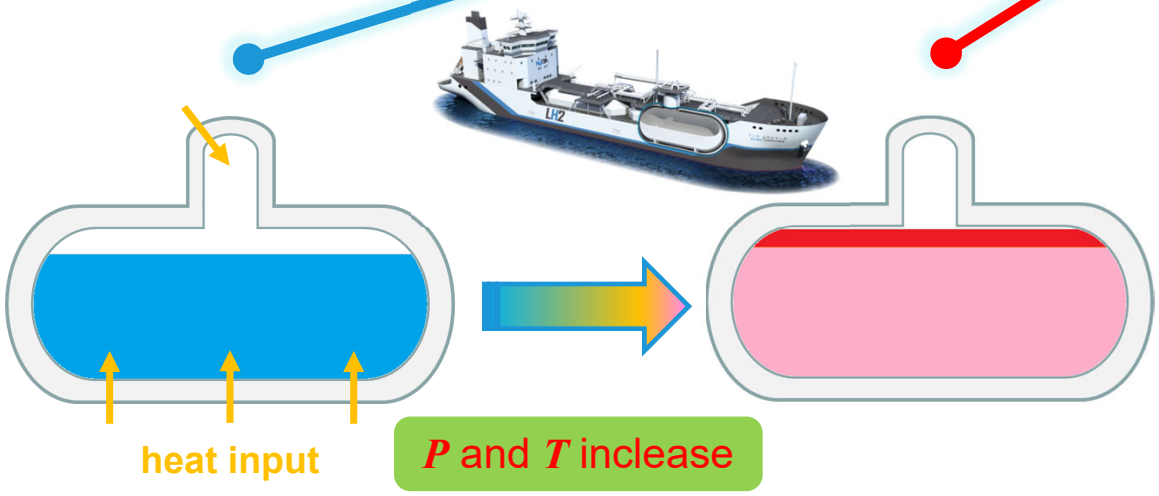
LH2 vessel
- + Diameter : 9m
- + Length : 18m
- + Volume : 1250 m3
- + Super-insulated by vacuum double structure with MLIs
- + Pressure accumulation type

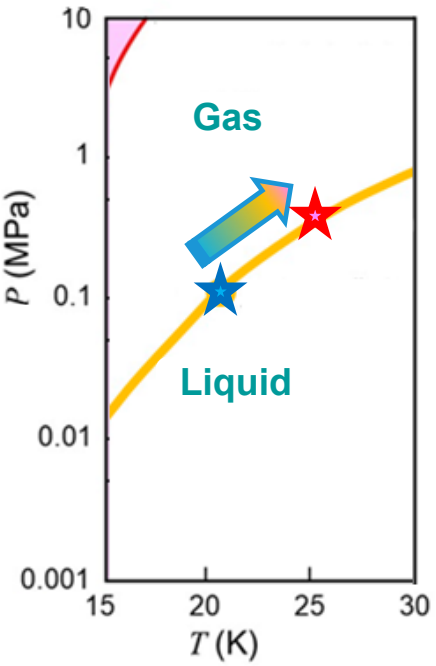
A technical problem regarding LH2 vessel

Depressurization prior to unloading





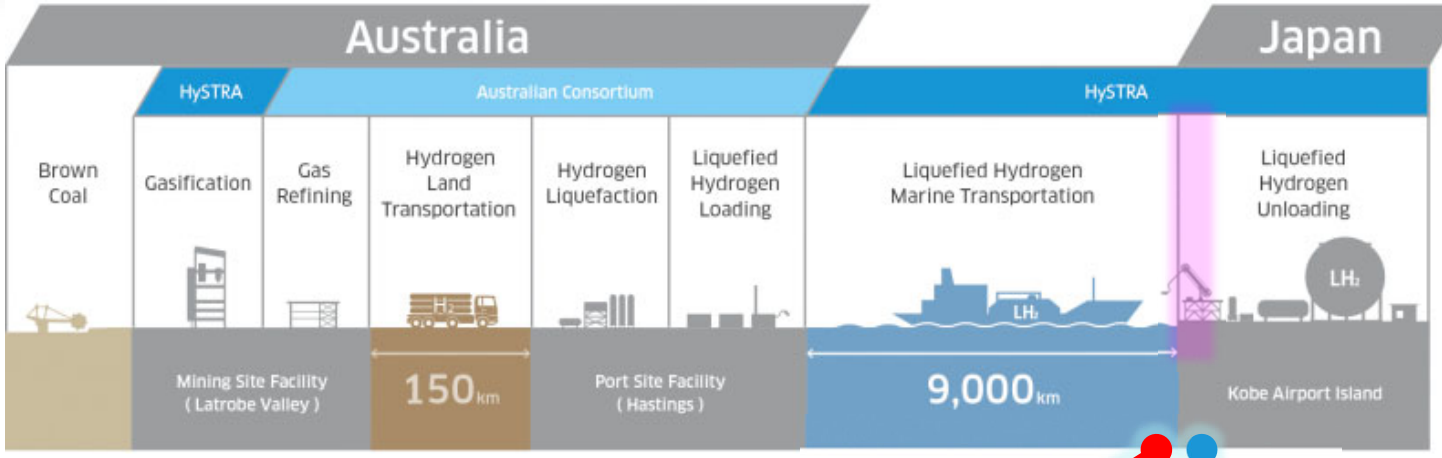
saturated vapor pressure curve for para-H2.



LH2 is pressurized by GH2, that is,
a gas-liquid two-phase system of single specie,
where (P, T) state tends to
obey Clausius–Clapeyron equation
move on the saturated vapor pressure curve.

A technical problem regarding LH2 vessel

Depressurization prior to unloading



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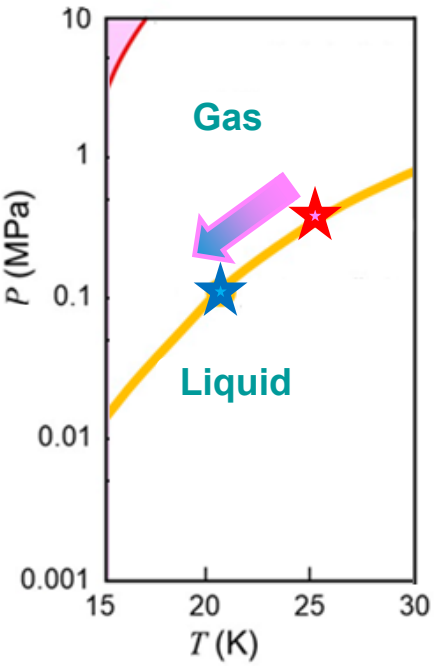
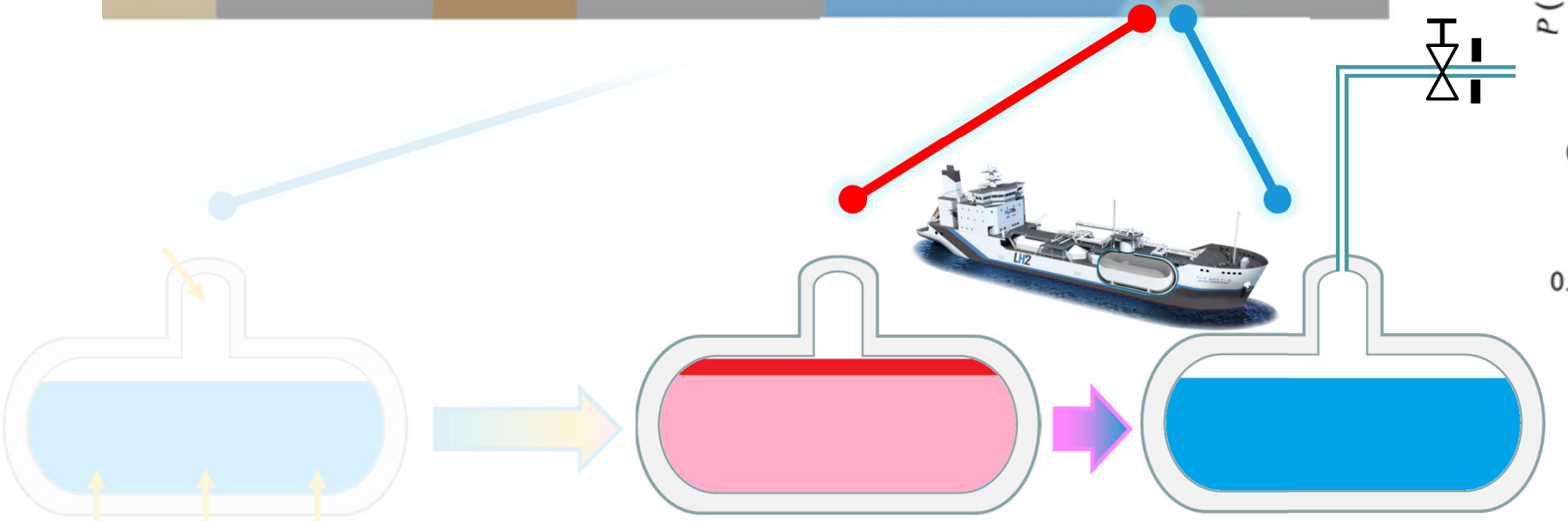




heat input

P and T inclease

P must be decreased

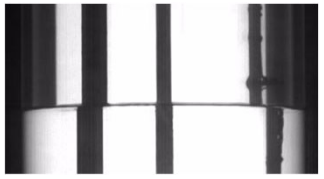
7

A technical problem regarding LH2 vessel
Depressurization prior to unloading

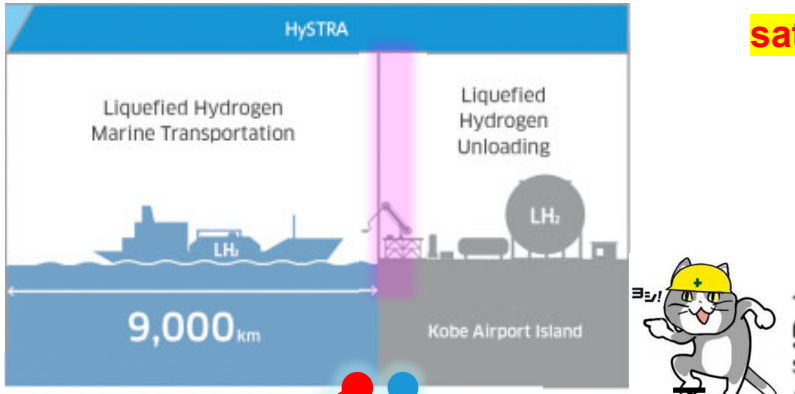
The rate of depessurization dP/dt is important.

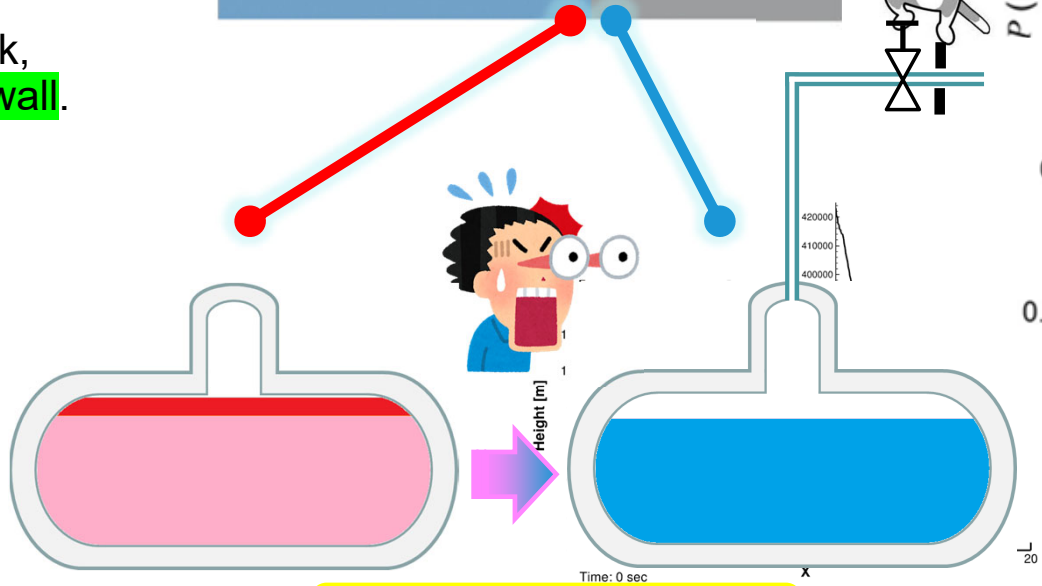
If the dP/dt is too rapid,
due to a wrong operation or
in case of emergency release of P,

there exists a concern that
an explosive boiling or
a geysering phenomenon
should take place in the tank,
lifting up the liquid to the top wall.



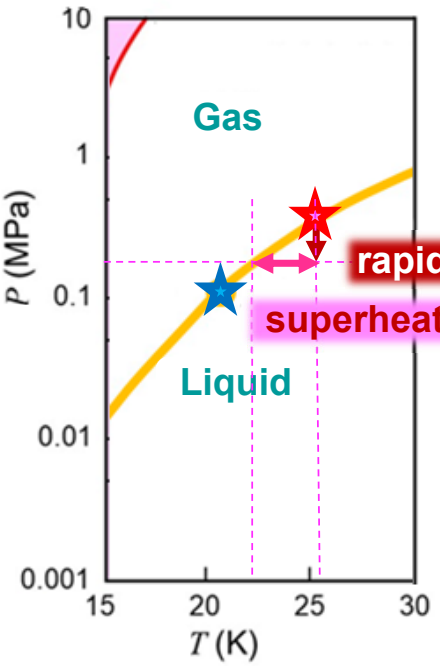
There are not so many
technical knowledge
about rapid depressurization
especially,
about LH2 in large vessel.





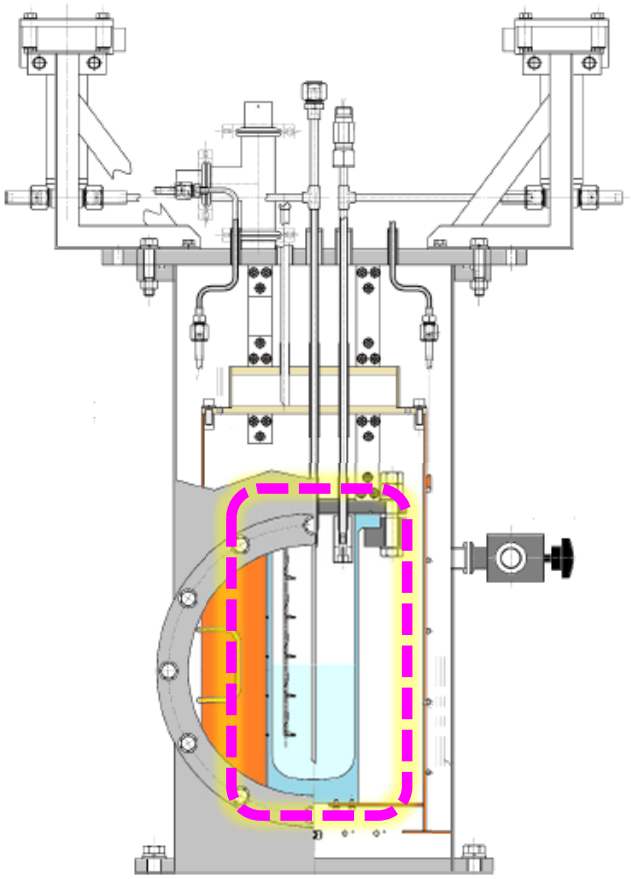
P must be decreased

saturated vapor pressure curve
for para-H2.

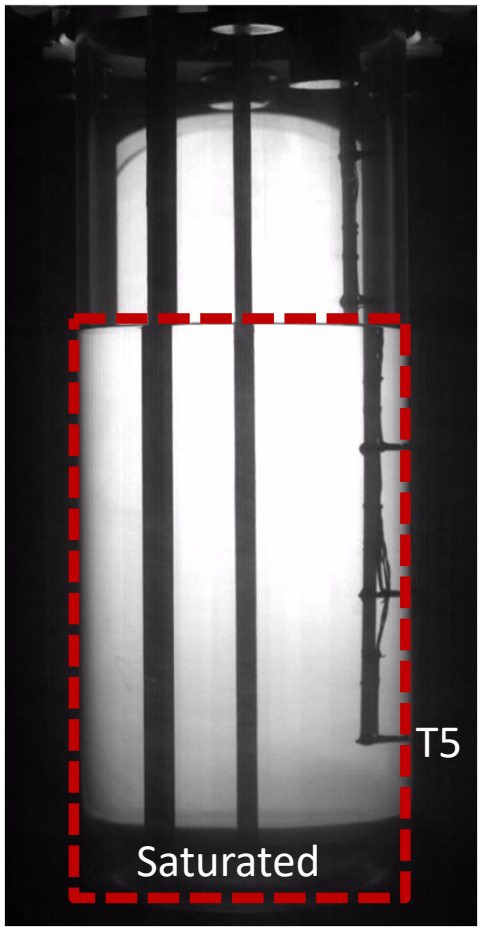


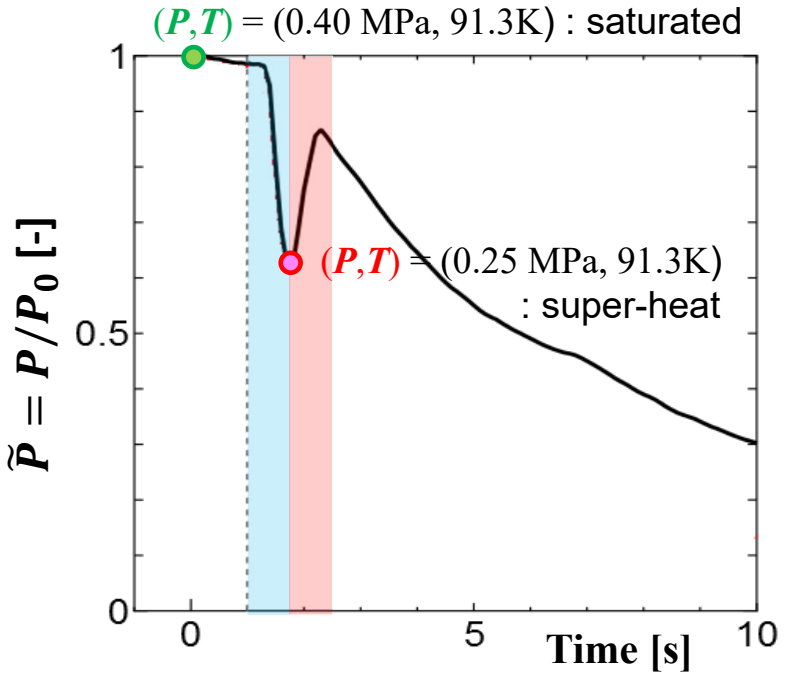
Fundamental experiment to grasp at thermo-fluid behavior

Depressurization in a small vessel with LN2



+ Diameter : 100 mm
+ Height : 250 mm



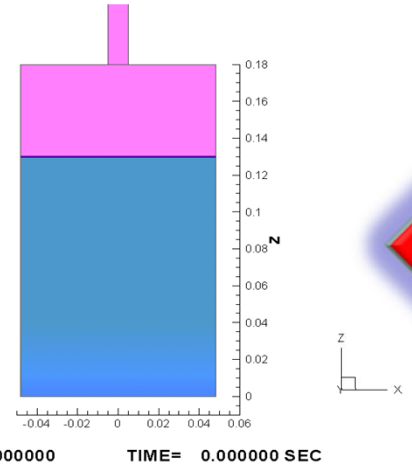


Adiabatic depressurization w/o boiling
followed by
explosive boiling in super-heated liquid
and pressure recovering

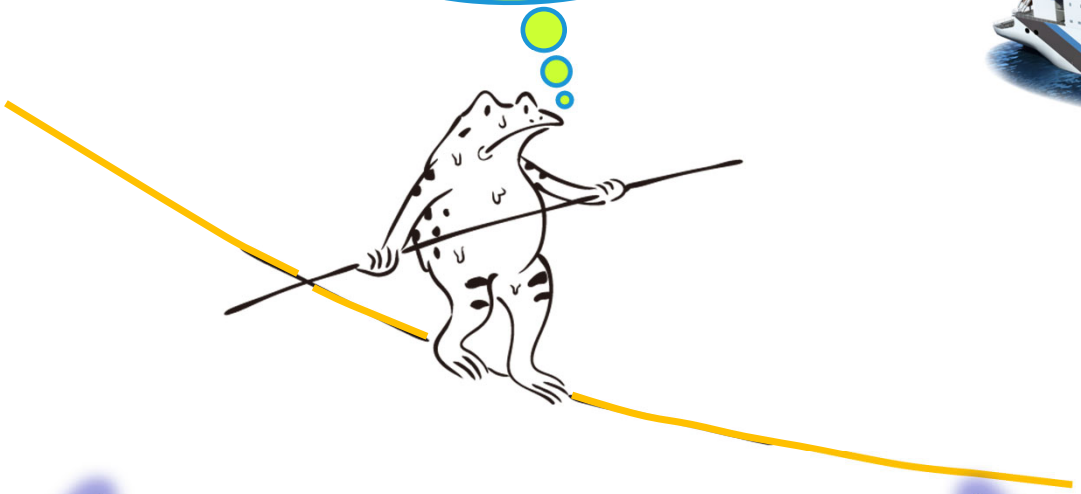
Fundamental experiment to grasp at thermo-fluid behavior

Depressurization in a large vessel with LH2

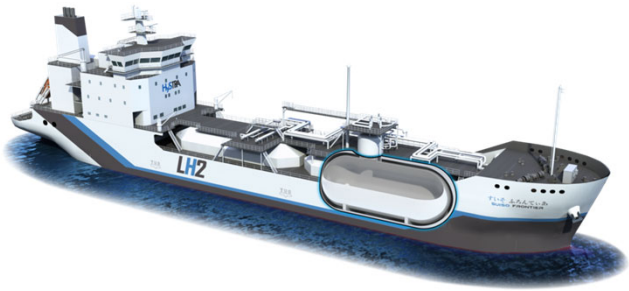
0.001m³
LN2, Visualized

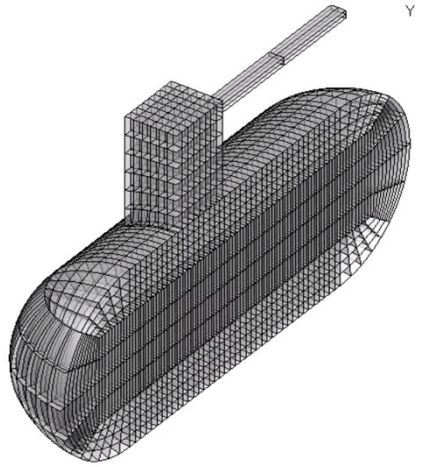


Are our knowledge and predictive method based on small scale experiment applicable to large scale phenomena ?



1250 m³ or larger
LH2, ~~Visualized~~





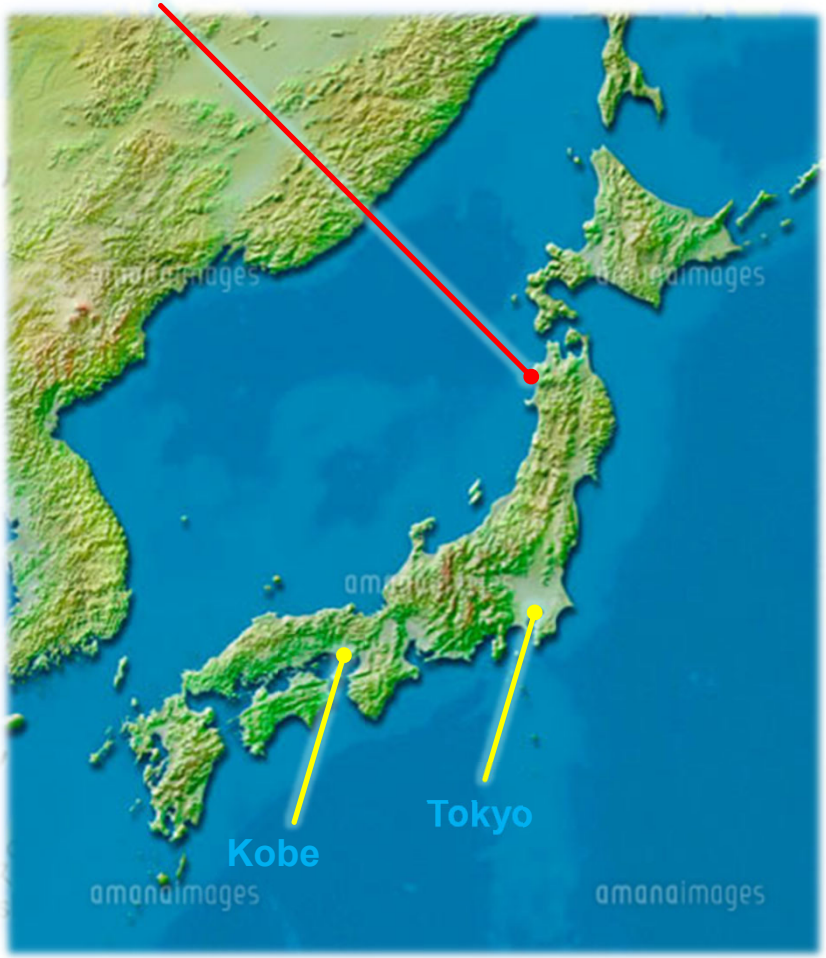
PHYSICAL GAP

To establish the predictive methodology, thermo-fluid characteristics in large scale tank, at least middle scale tank, are strongly desired.

Fundamental experiment to grasp at thermo-fluid behavior
Depressurization in a large vessel with LH2

UT-KHI-JAXA Collaboration

Noshiro Testing Center of JAXA



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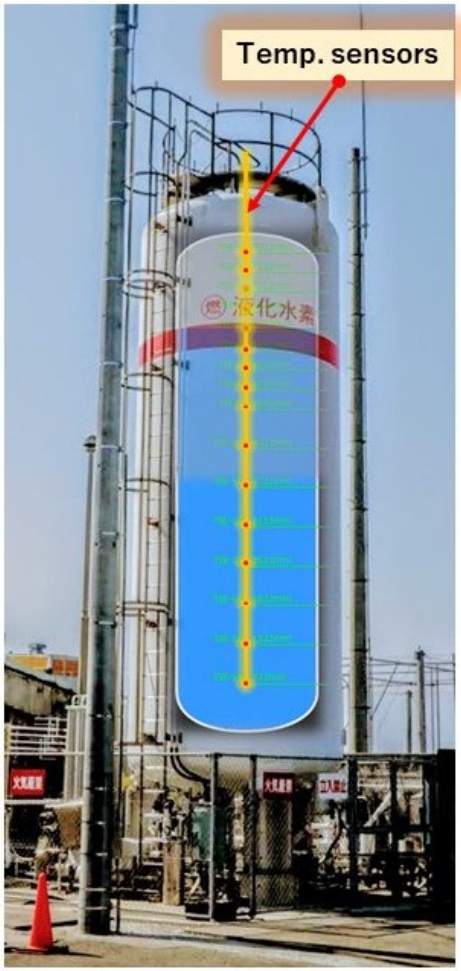
Fundamental experiment to grasp at thermo-fluid behavior

Depressurization in a large vessel with LH2

UT-KHI-JAXA Collaboration

DT sensors Flowmeters

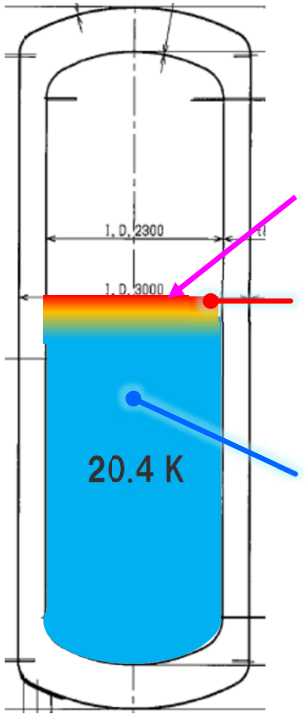
An infrastructure of LH2 supply became our test vessel.



30 m^3 LH_2 Tank

Fundamental experiment to grasp at thermo-fluid behavior
Depressurization in a large vessel with LH2

UT-KHI-JAXA Collaboration



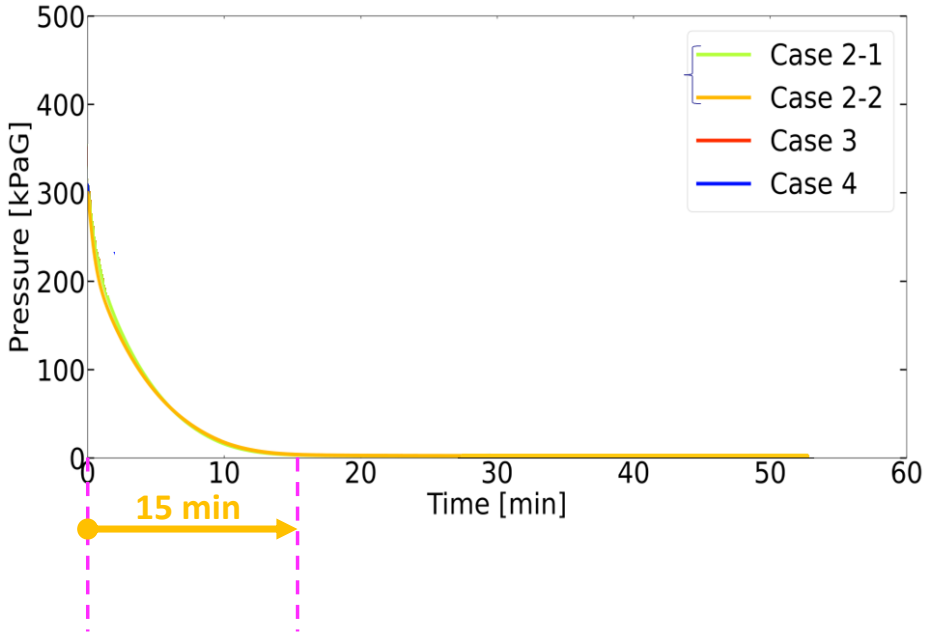
$T = T_{sat}$ as a function of P on liquid surface

Thermal stratification = Saturated (Hot) LH2

Sub-cooled (cold) LH2

Case2

w/o boiling



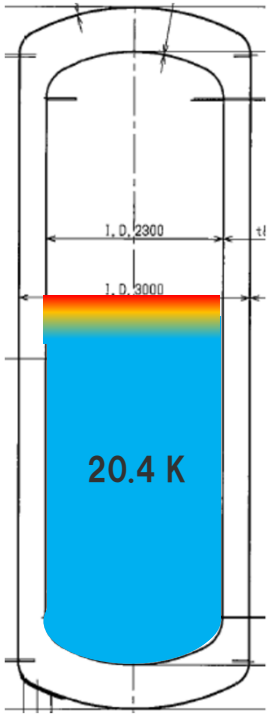
Owing to heat exchanger and valves connected to the LH2 tank, various condition in T distribution could be obtained.

When the liquid was occupied by sub-cooled LH2, the P would decrease adiabatically and rapidly w/o boiling.

Fundamental experiment to grasp at thermo-fluid behavior

Depressurization in a large vessel with LH2

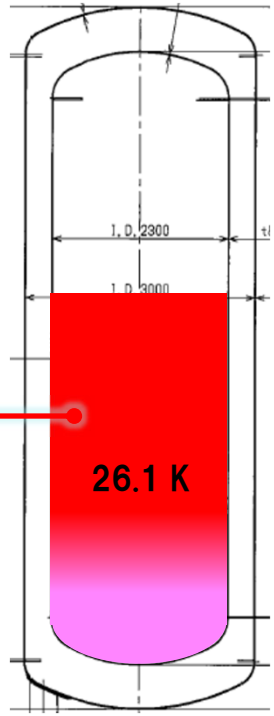
UT-KHI-JAXA Collaboration



Case2

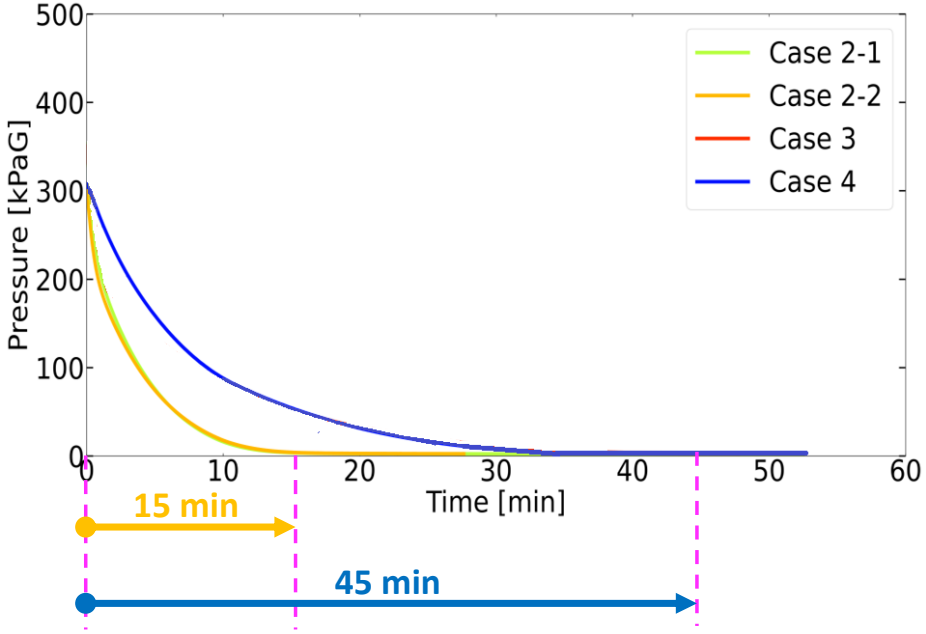
w/o boiling

Saturated LH2



Case4

w boiling

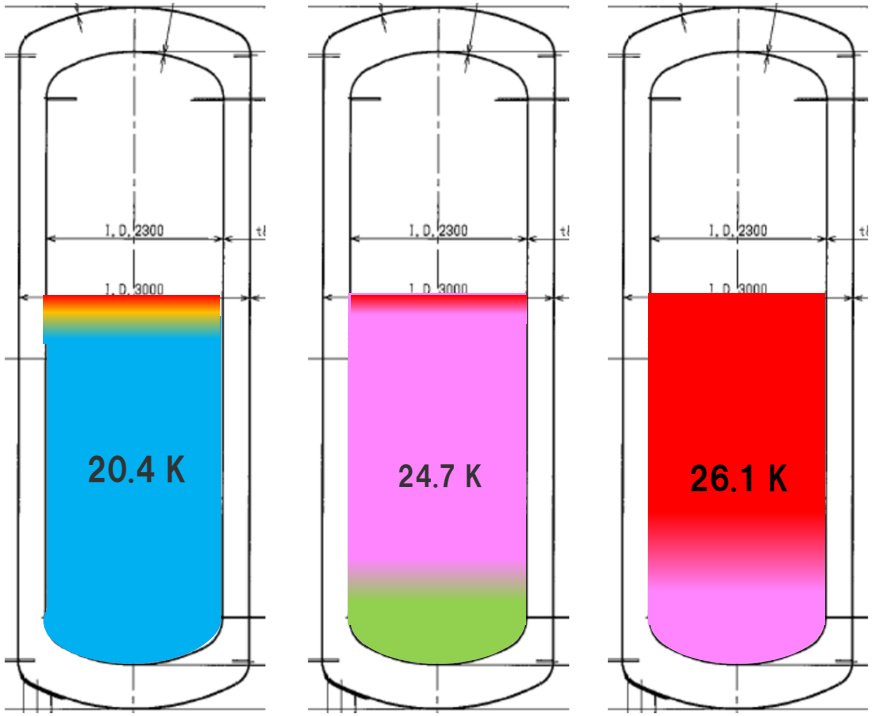


When the liquid was occupied by saturated LH2,
the P would decrease slowly with boiling.
This was because of the balance of exhaust and boiling flow rate.
It took 3 times longer than sub-cooled case to settle the P.

Fundamental experiment to grasp at thermo-fluid behavior

Depressurization in a large vessel with LH2

UT-KHI-JAXA Collaboration



Case2

w/o boiling

Case3

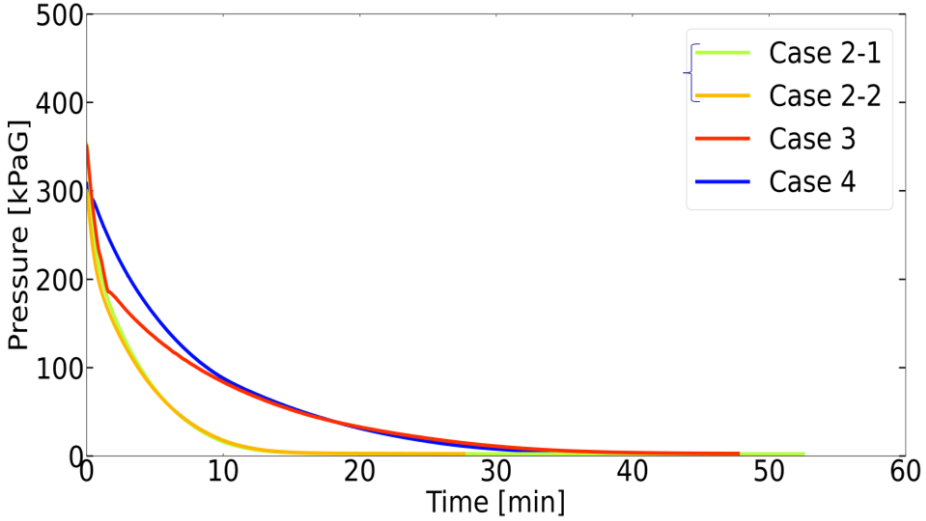
w/o boiling

↓

w boiling

Case4

w boiling



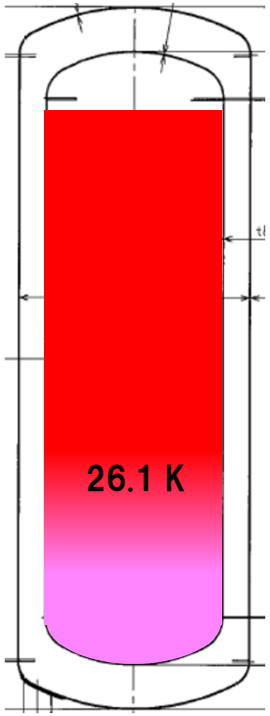
In the case with LH2 of T_{sat} corresponding to lower P than initial P, rapid decrease in P w/o boiling was found to be followed by slow decrease with boiling.

These phenomenon were well explained by equilibrium theory.

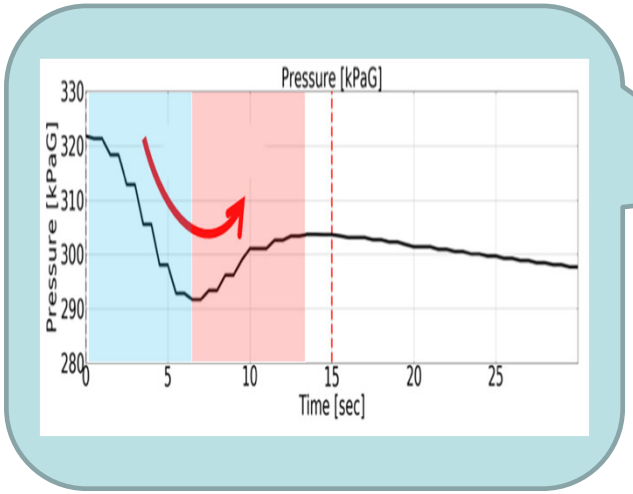
Fundamental experiment to grasp at thermo-fluid behavior

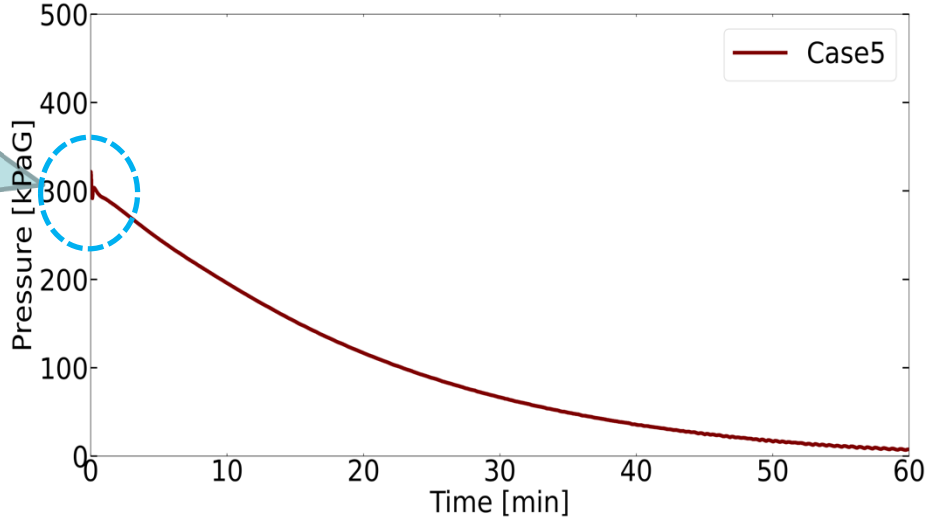
Depressurization in a large vessel with LH2

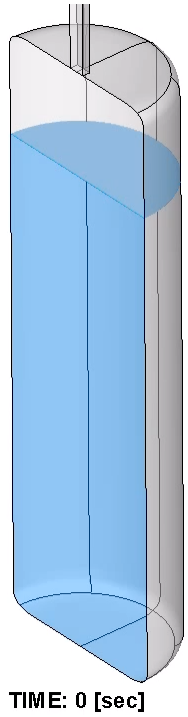
UT-KHI-JAXA Collaboration



Case5







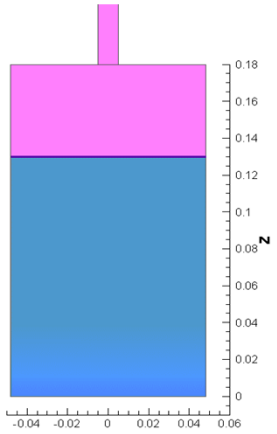
In the cases with saturated LH2 with higher liquid level,
the non-equilibrium phenomena,
adiabatic depressurization followed by pressure recovering was observed.

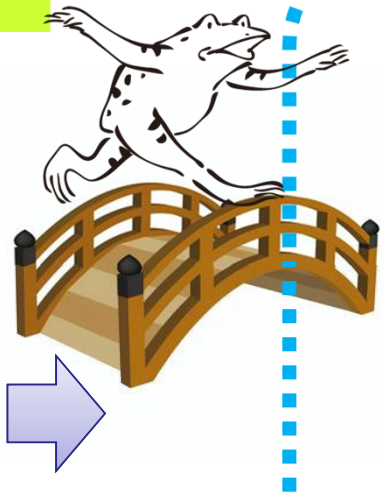
The flow field inside the tank could not be visualized,
explosive boiling in super-heated liquid was seemed to be induced.

Fundamental experiment to grasp at thermo-fluid behavior

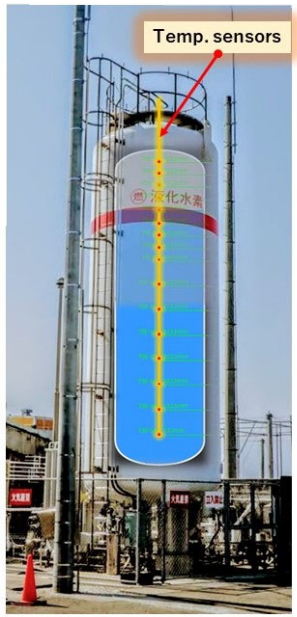
Depressurization in a large vessel with LH2

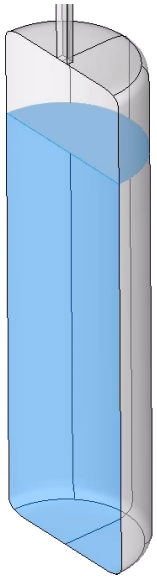
0.001m³
LN2, Visualized





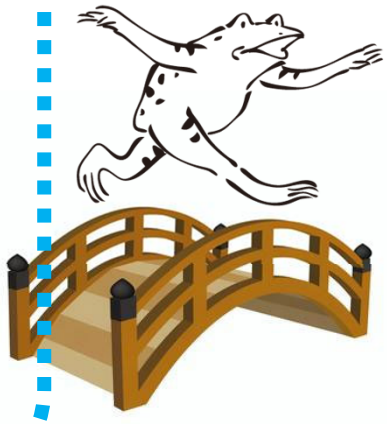
30 m³
LH2, ~~Visualized~~

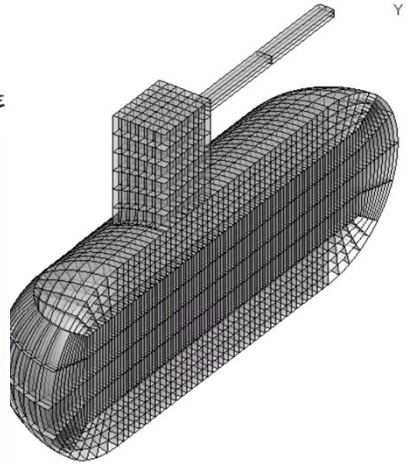




We came to accumulate technical knowledge and rich imagination on LH2 in large tanks.

1250 m³ or larger
LH2, ~~Visualized~~

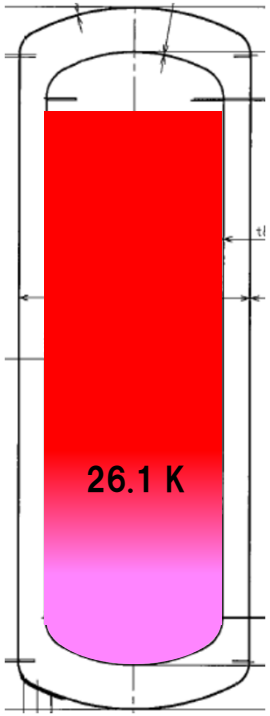




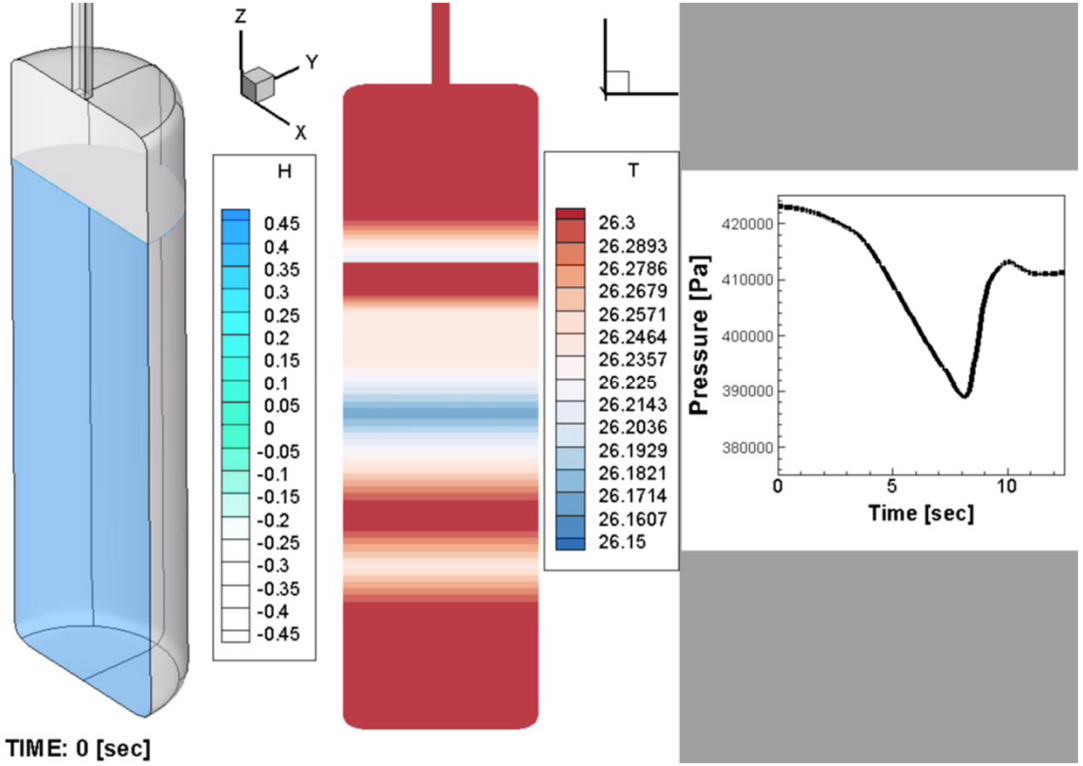
Numerical simulation to grasp at thermo-fluid behavior

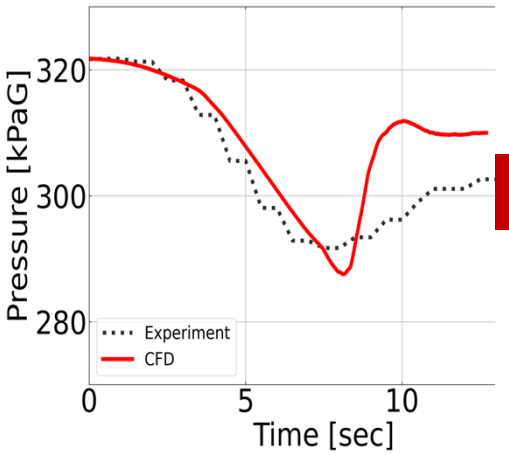
Depressurization in a large vessel with LH2

Experimental data were utilized for the validation of CFD and the phase change models employed in our CFD code were modified.



Case5

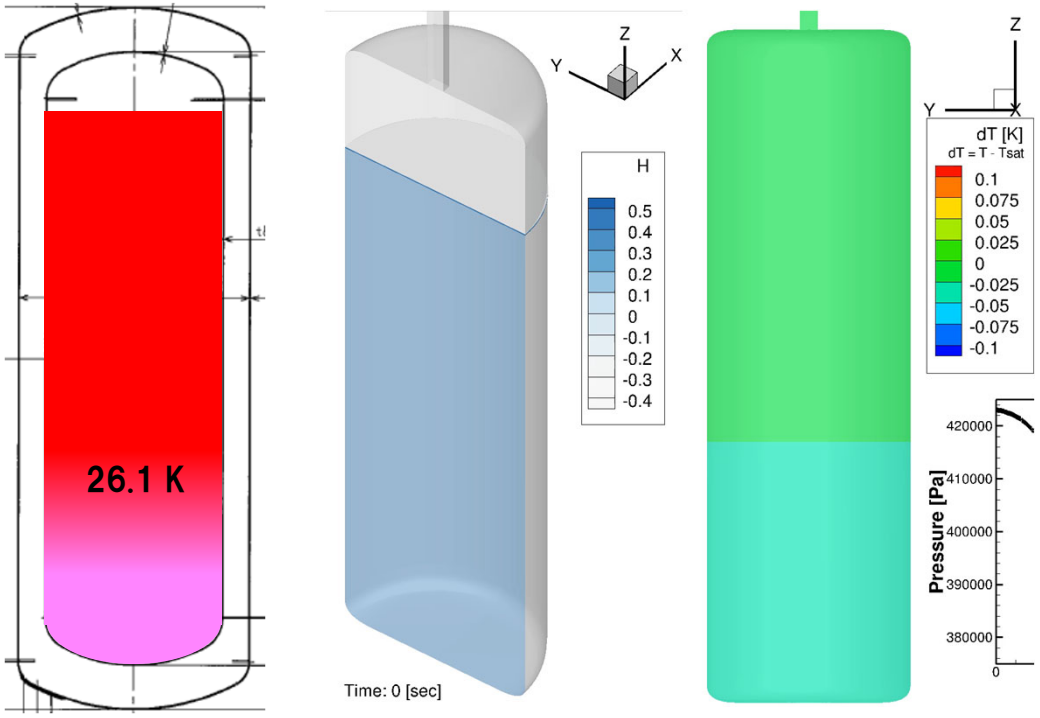




Case5

Numerical simulation to grasp at thermo-fluid behavior

Depressurization in a large vessel with LH2



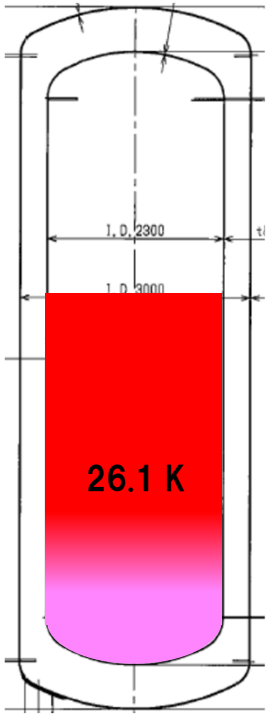
Case5H

The exhaust flow rate was set to be
10 times as much as that in the experiment.

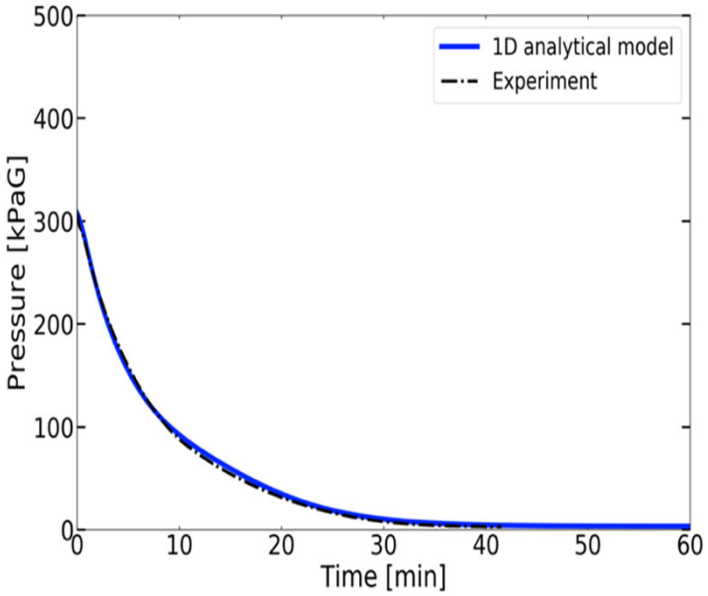
In numerical simulations
such a hazardous conditions could be imposed.

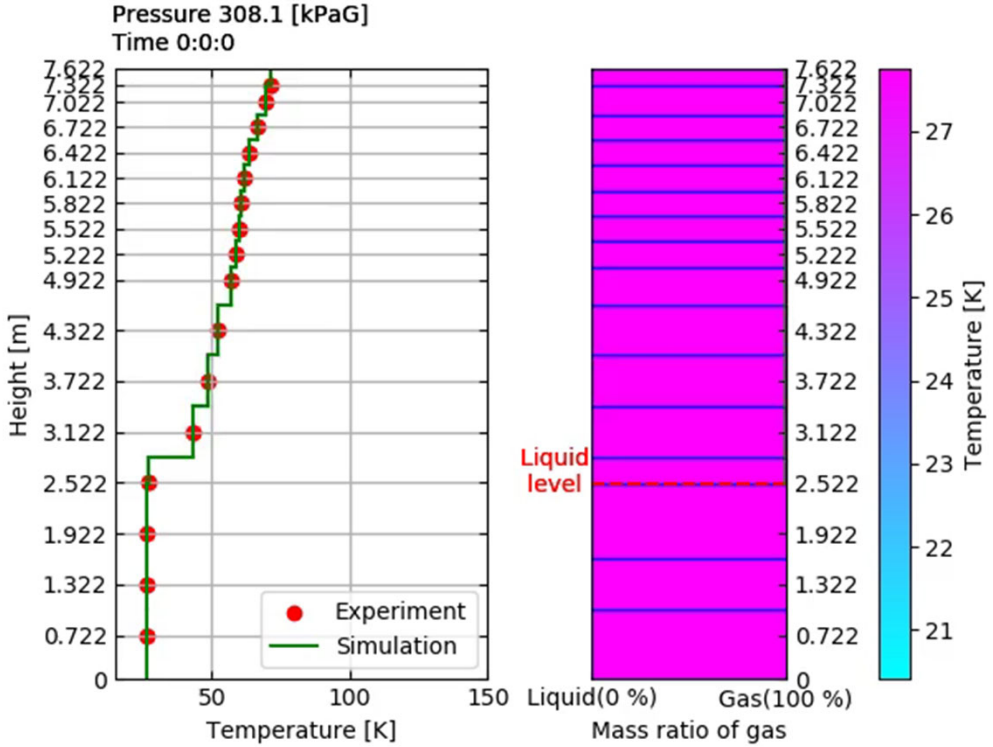
Numerical simulation to grasp at thermo-fluid behavior

Depressurization in a large vessel with LH2



Case4





CFD analysis should be apply ONLY for understanding complicated phenomena.

1-dimensional reduced model for depressurization was also proposed.
Time history of pressure and amount of flush-loss could be well predicted.

w boiling

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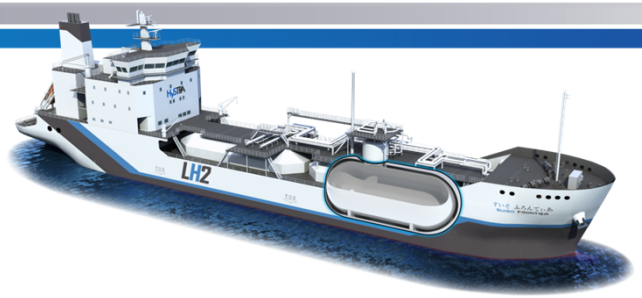
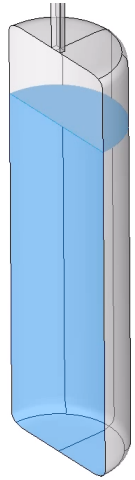
On-going and future works

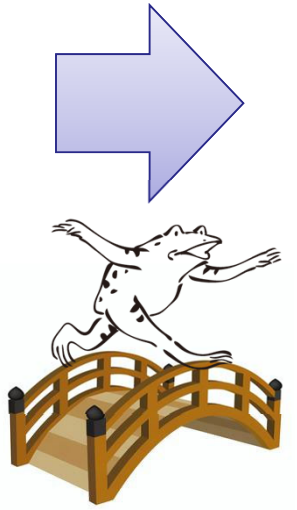
UT JET PROPULSION LABORATORY

Numerical simulation to grasp at thermo-fluid behavior

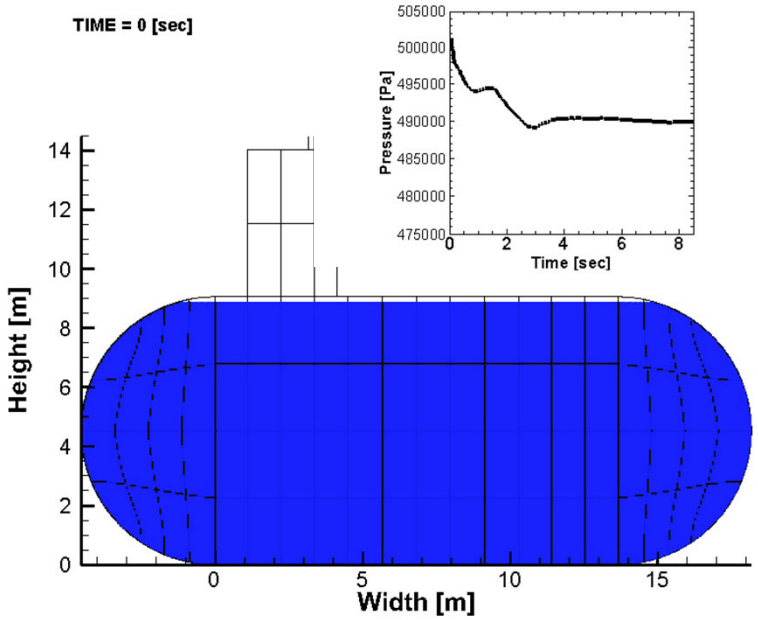
Depressurization in a real vessel with LH2



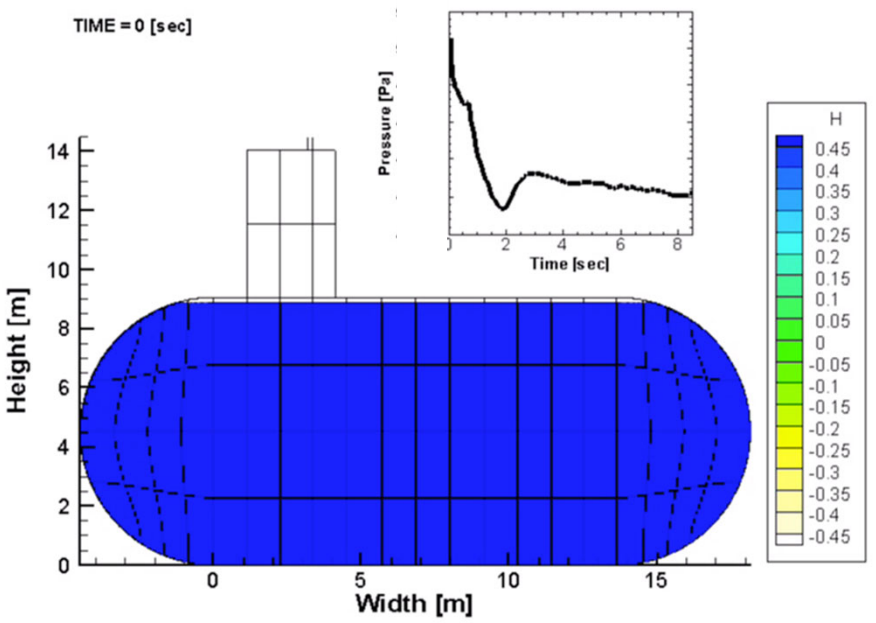




Nominal operation



Wrong operation of valve opening



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Summary

UT JET PROPULSION LABORATORY

Summary

Cryogenic Fluid Management (CFM) technologies ;
control of the motion and thermal behavior of cryogenic fluids in containers on the ground and moving tanks on vehicles.

To establish the technology for Cryogenic Fluid Management,
it is essential to accumulate technical knowledge and obtain rich imagination on dynamic behavior of liquid under various conditions.

The numerical investigation,
as well as theoretical and experimental approach,
is also desired for the more precise assessment.

UTokyo makes intensive effort to establish the fundamental technology accelerating ourselves toward “hydrogen-based society” through close collaboration with industries.

Thank you for your kind attentions.