令和4年度
原子力規制庁技術基盤グループ–原子力機構安全研究・防災支援部門
合同研究成果報告会

Numerical simulation on the effect of thermal radiation in the atmosphere mixing inside the CIGMA containment vessel

令和4年11月22日

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安全研究・防災支援部門　安全研究センター
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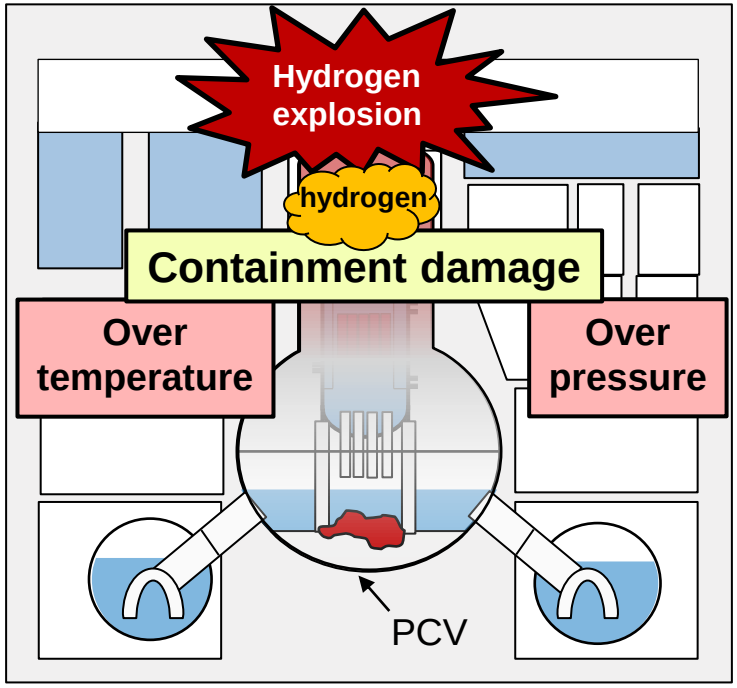
ハムダニ　アリ

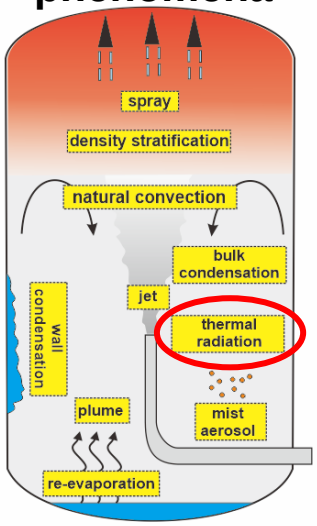
本研究（の一部）はNRA事業の成果である。

Introduction

It is important to know the hydrogen behavior for planning and implementing effective accident management measures. Even though several numerical safety analyses have been performed under the OECD/NEA international projects framework, there are many difficulties, mainly because the **hydrogen-related phenomena** are complex and evolve over a long transient time.



Hydrogen-related phenomena



Previous studies on **containment thermohydraulic** showed that neglecting the thermal radiation in the numerical model leads to temperature overestimation.

It is difficult to evaluate the thermal radiation heat transfer because the separated test on thermal radiation was not available

We need to perform a separate test on the thermal radiation in order to validate the computational fluid dynamics (**CFD**) code.

Objective

To investigate the effect of radiative heat transfer on the **thermal evolution** of a containment atmosphere.

Overview of HYMERES-2 Series H2P2 Thermal Radiation effects

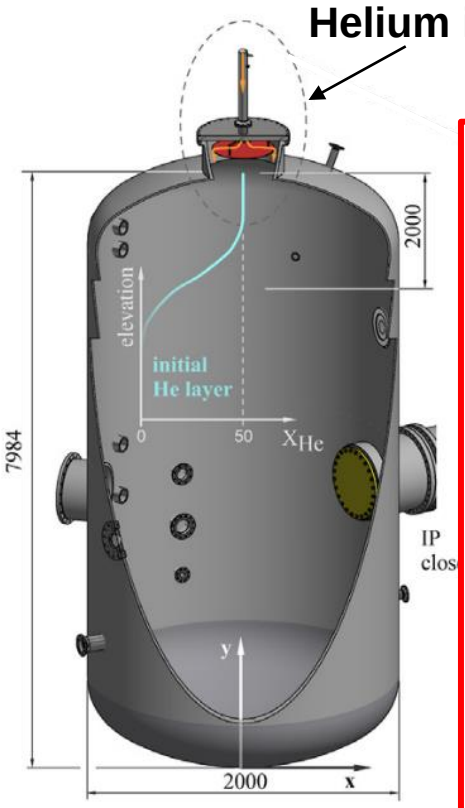
Objective

To create an **experimental database** valuable for the **validation** and improvement of advanced computational tools related to the effects of thermal radiation on large-scale containment atmospheres.

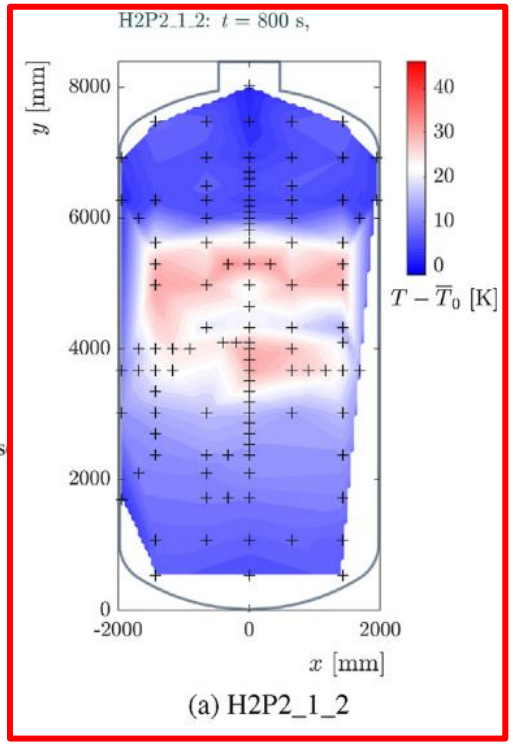
The **PANDA** experiments of the H2P2 series are characterized by the **injection of helium** at a high flow rate from the top of the vessel, which leads to an increase in the vessel pressure and a corresponding increase in the gas temperature.

Table 1
Test matrix for series H2P2. Depicted are the nominal conditions for the five experiments conducted. The important initial conditions are highlighted in **bold**.

Experiments	→	H2P2_1_2[a]	H2P2_2	H2P2_3	H2P2_4[b]	H2P2_5[c]
Parameters	Units	Start at room temperature		Start at elevated temperature		
Gas atmosphere	-	air	air	air	air	air
Initial temp.	-	T_r	T_r	T_{el}	T_{el}	T_{el}
Steam / Humidity	X_{st} %	**0.1**	2	2	2	**60**
Stratification	X_{He} %	50	50	50	50	50
He mass flow	g/s	10	10	10	10	10
Compression	s	1200	1200	1200	1200	1200
Decay phase	s	> 1200	> 1200	> 1200	> 1200	> 1200
Initial pressure	bar	1	1	1	**3**	1



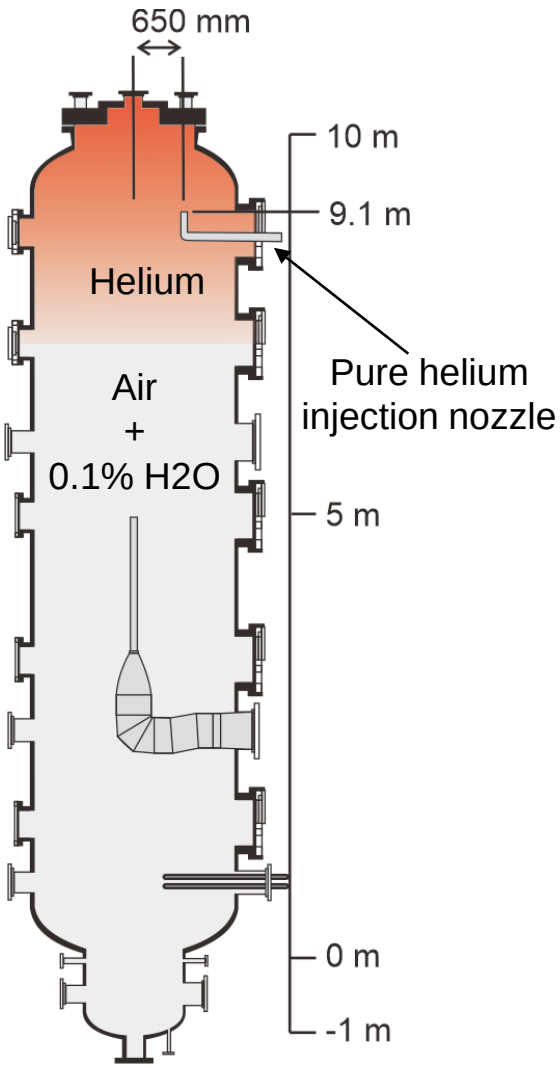
"thermal bubble"



(a) H2P2_1_2

Today Focus: Very low steam content

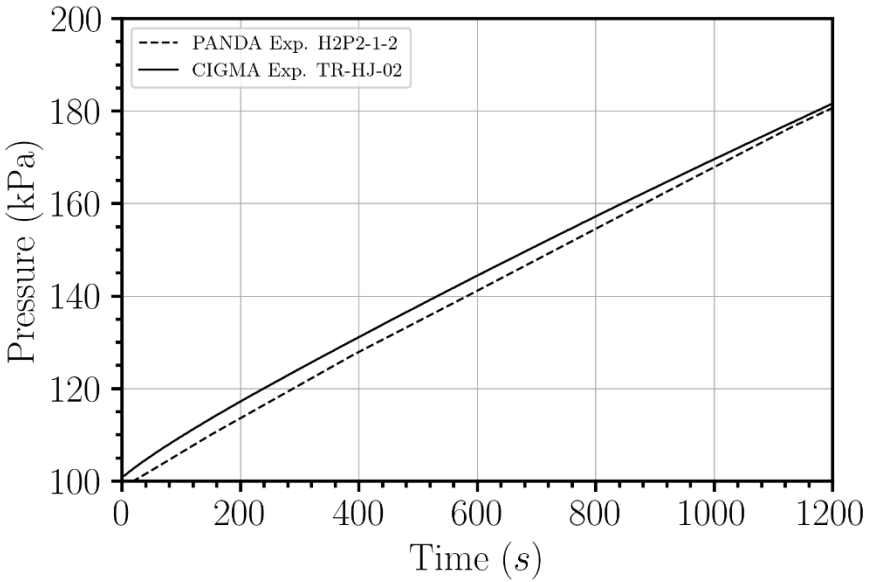
Thermal Radiation effects experiment in CIGMA vessel



Experimental conditions in **CIGMA** and **PANDA**.

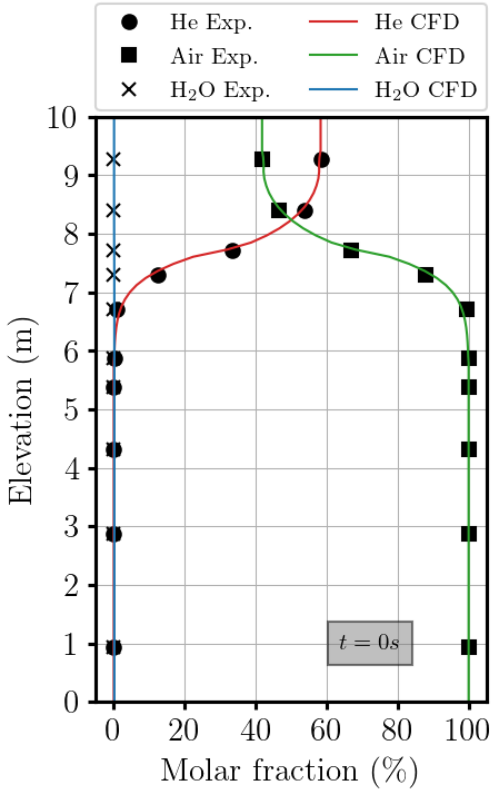
		CIGMA vessel ID: **TR-HJ-02**	PANDA vessel ID: **H2P2-1-2**
Initial condition before compression	Pressure (atm)	1	1
	Temperature (℃)	30	20
	Steam (%)	0.1	0.1
	He (%) (in the helium layer)	55	50
Compression	He gas injection (g/s)	5.6	10
	Time (s)	1200	1200

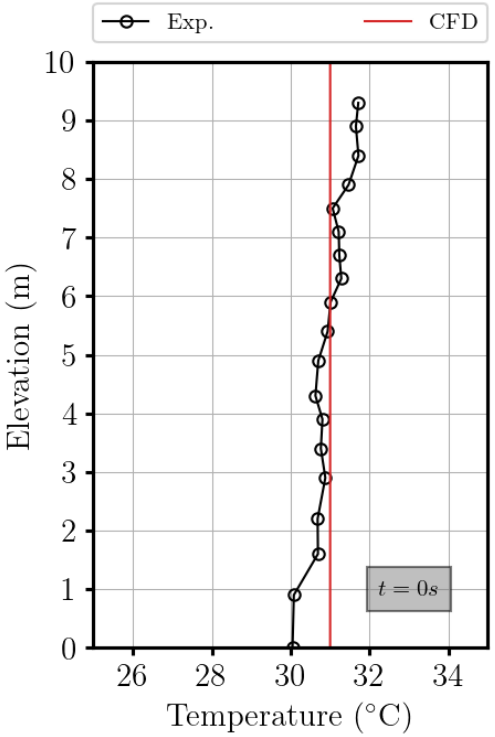
The injection rate in the **CIGMA** vessel was scaled in order to get a similar pressure increase in the **PANDA** vessel, as shown in the figure below.

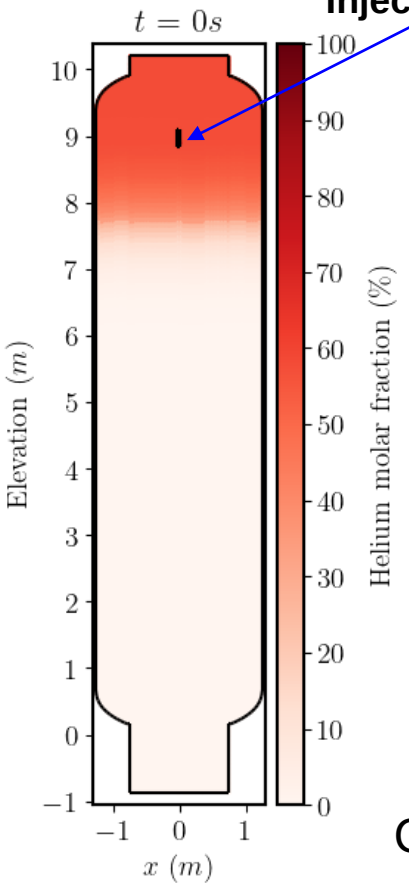


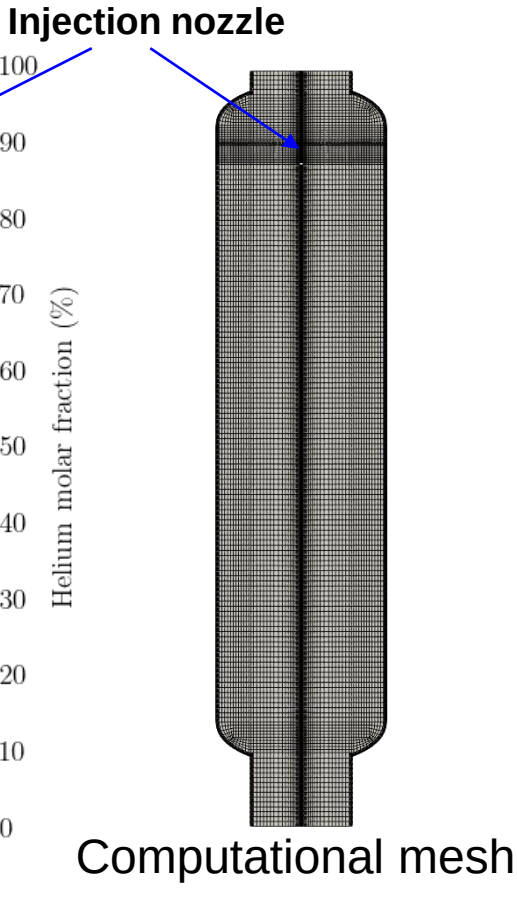
CFD simulation

Initial and boundary conditions







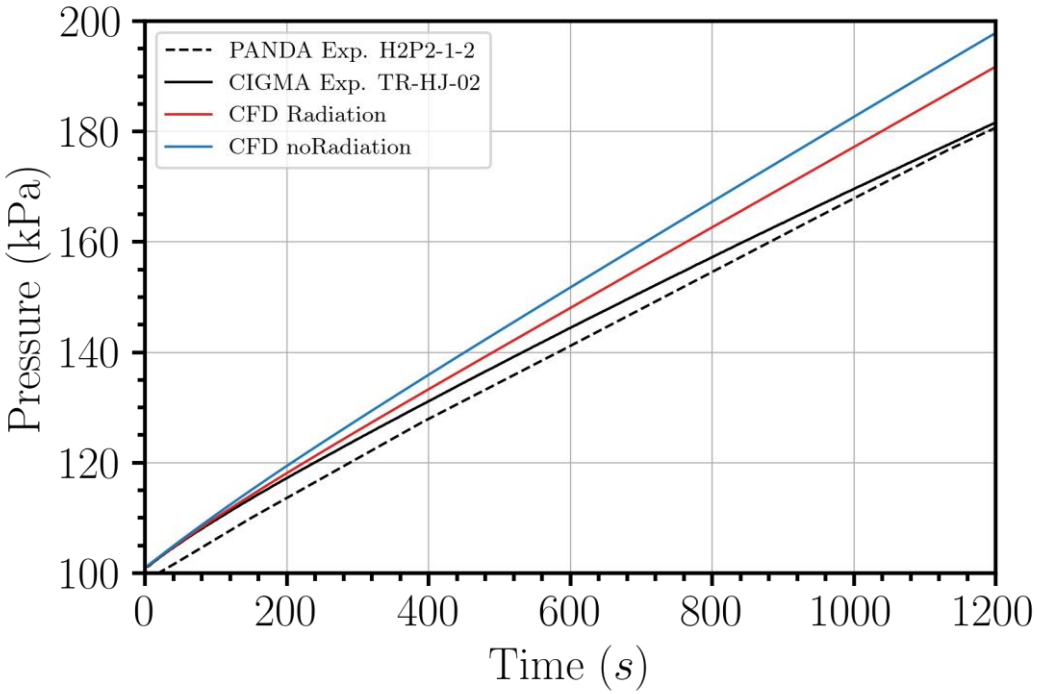


- He injection from t = 0s to 1200s
- Initial pressure = 1 bar
- $T_{inj} = T_{wall}$ = 31° C
- Mass flow rate = 5.6 g/s

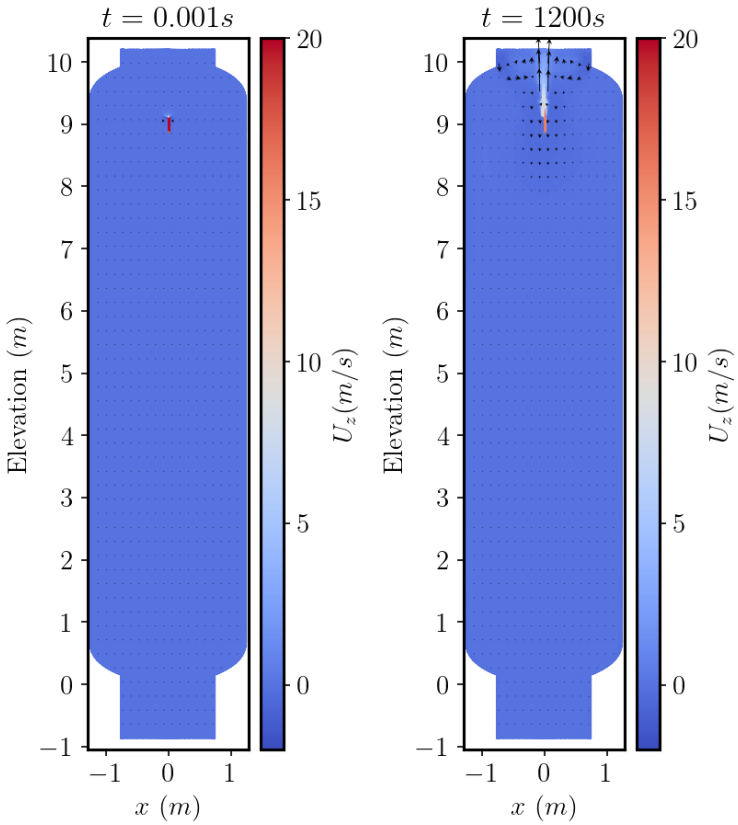
- CFD solver: OpenFOAM®
- 3D fully hexahedral mesh
- Radiation model: fvDOM

Results

Pressure history



Velocity contour

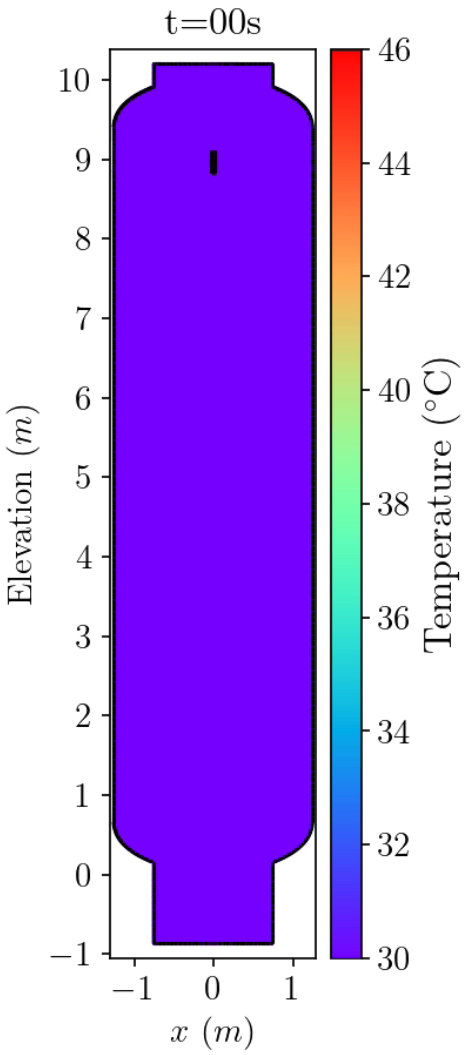


Generally, the pressure prediction by **CFD** is still overestimated. This overestimation might also affect the temperature evolution.

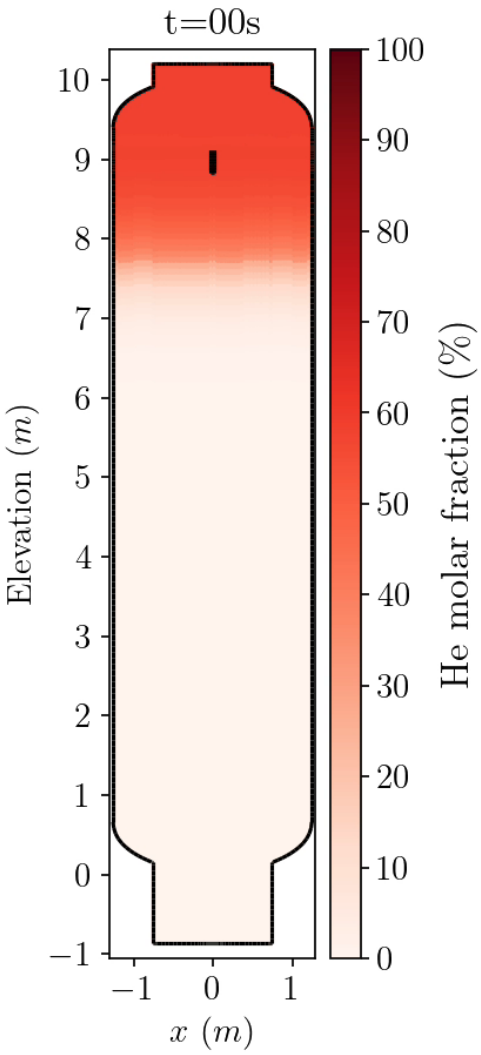
No flow is observed, therefore **heat transfer** by convection is minimized.

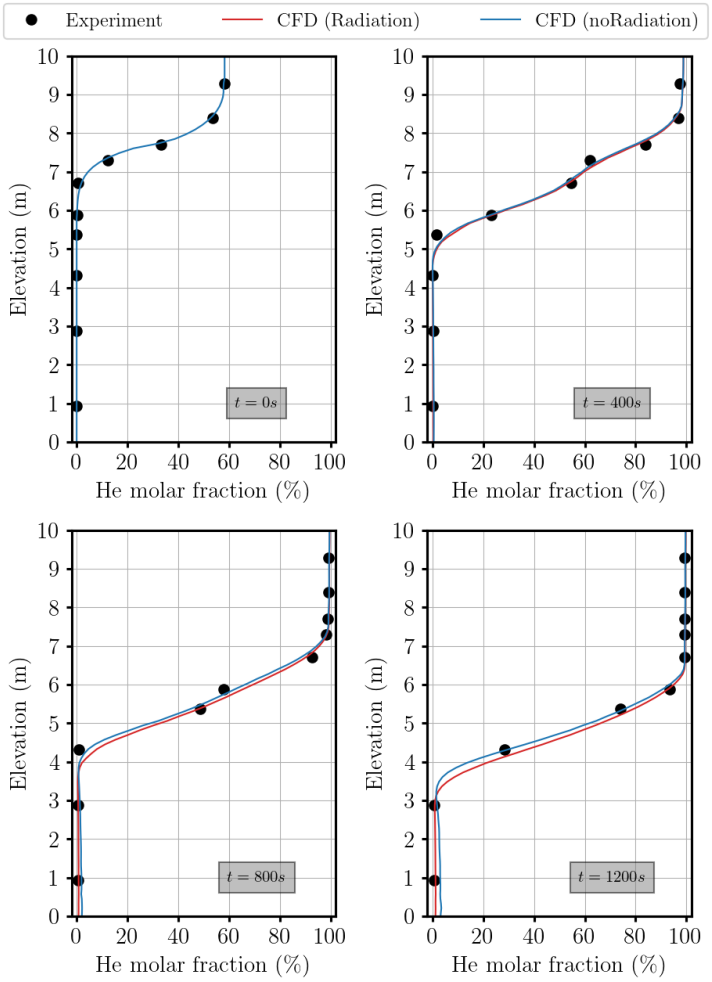
Helium profiles

Temperature



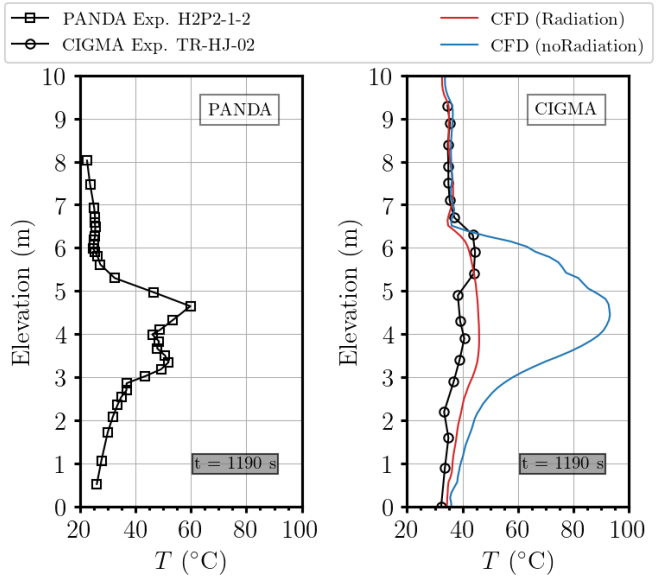
He molar fraction

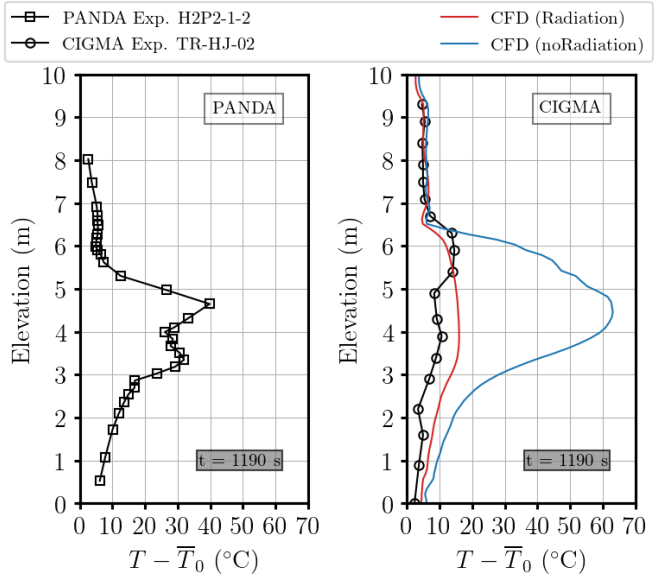


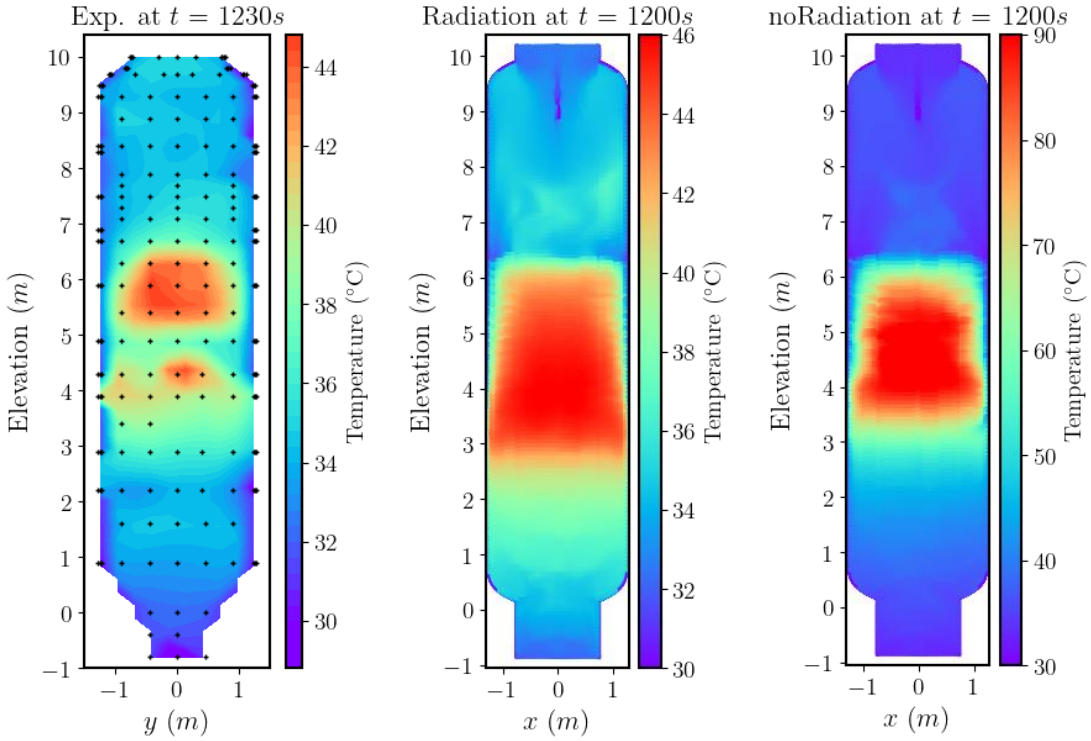


CFD results showed a good agreement with experimental data

Temperature profiles







- The **CFD** simulation without the thermal radiation model overestimates the temperature.
- The **CFD** simulation model with the thermal radiation showed better agreement with the experimental data.

Conclusions

- Separate effect tests for radiation modeling had successfully conducted in the **CIGMA** vessel.
- **CFD** results on the thermal radiation model showed a reasonable agreement with the experimental data.
- It is confirmed that neglecting radiation in gas mixtures results are significantly over-predicted gas temperatures.

Future work: Further investigation on the impact of steam concentration in the thermal radiation heat transfer.

Thank you for your kind attention