Center for Nuclear Engineering and Sciences

MELCOR validation of PANDA facility tests

TEMPEST 1.1 (T1.1) & HYMERES 4 (H1P4) experiments

Rainer Kelk
Brno, 11 April 2025

TEMPEST 1.1 (T1.1) test model

Main objectives:

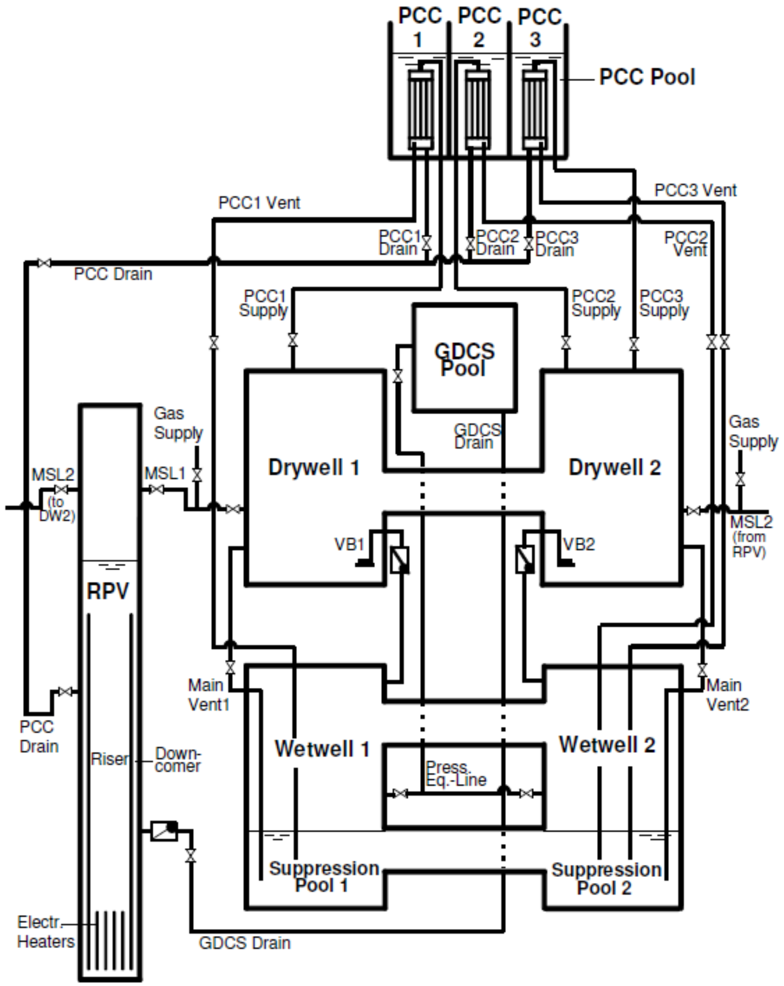
- Learn MELCOR
- Highlight key parameters to influence big-scale condensation

T1.1 test of TEMPEST project

- The main purpose of test T1.1 was to **investigate the long-term PCCS cooling phase** in **presence of NCGs** - air (heavier than steam) and helium (lighter than steam).

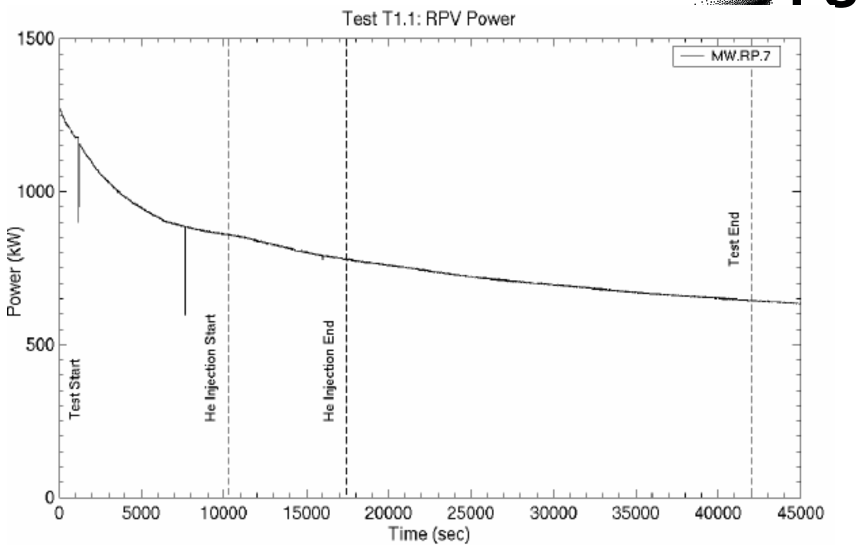
- Previous work has been done also with MELCOR
  - **Sevón, T. (2012). *MELCOR Modeling of a Passive Containment Cooling System*.**
  - Andreani, M. (2004). *EU 5th FWP Project TEMPEST, Deliverable D07: GOTHIC calculations for representative passive containment cooling system tests*.

- Integral test, all components of PANDA except IC are included
  - 1 RPV (electrical heaters), 2 DWs, 2 WWs, 1 GDCS, 3 PCCS

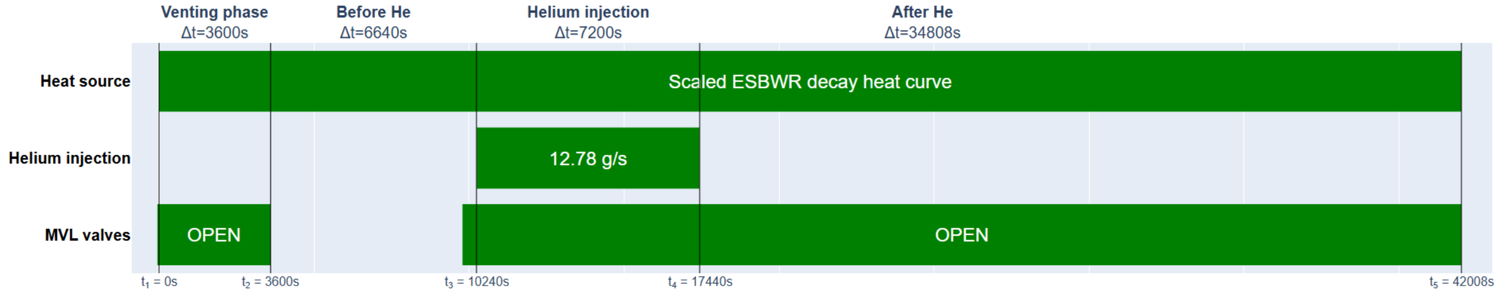


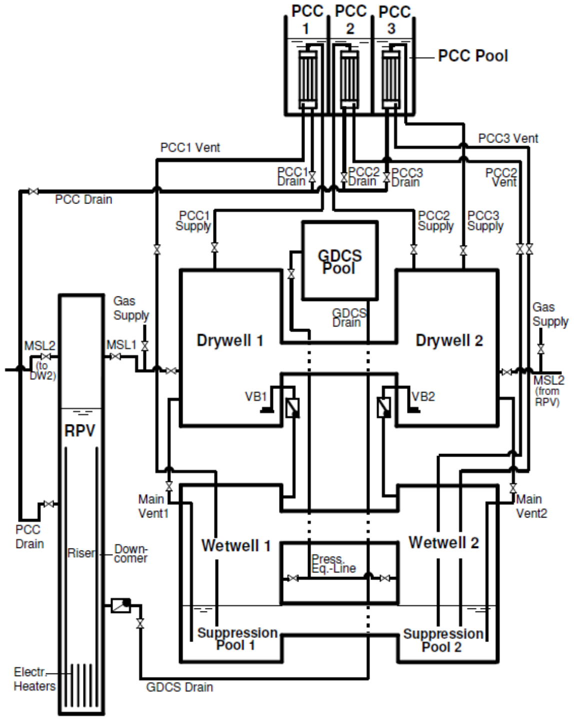
Test procedure

- Post-LOCA scenario – MSLB in a scaled ESBWR
  - Decay curve



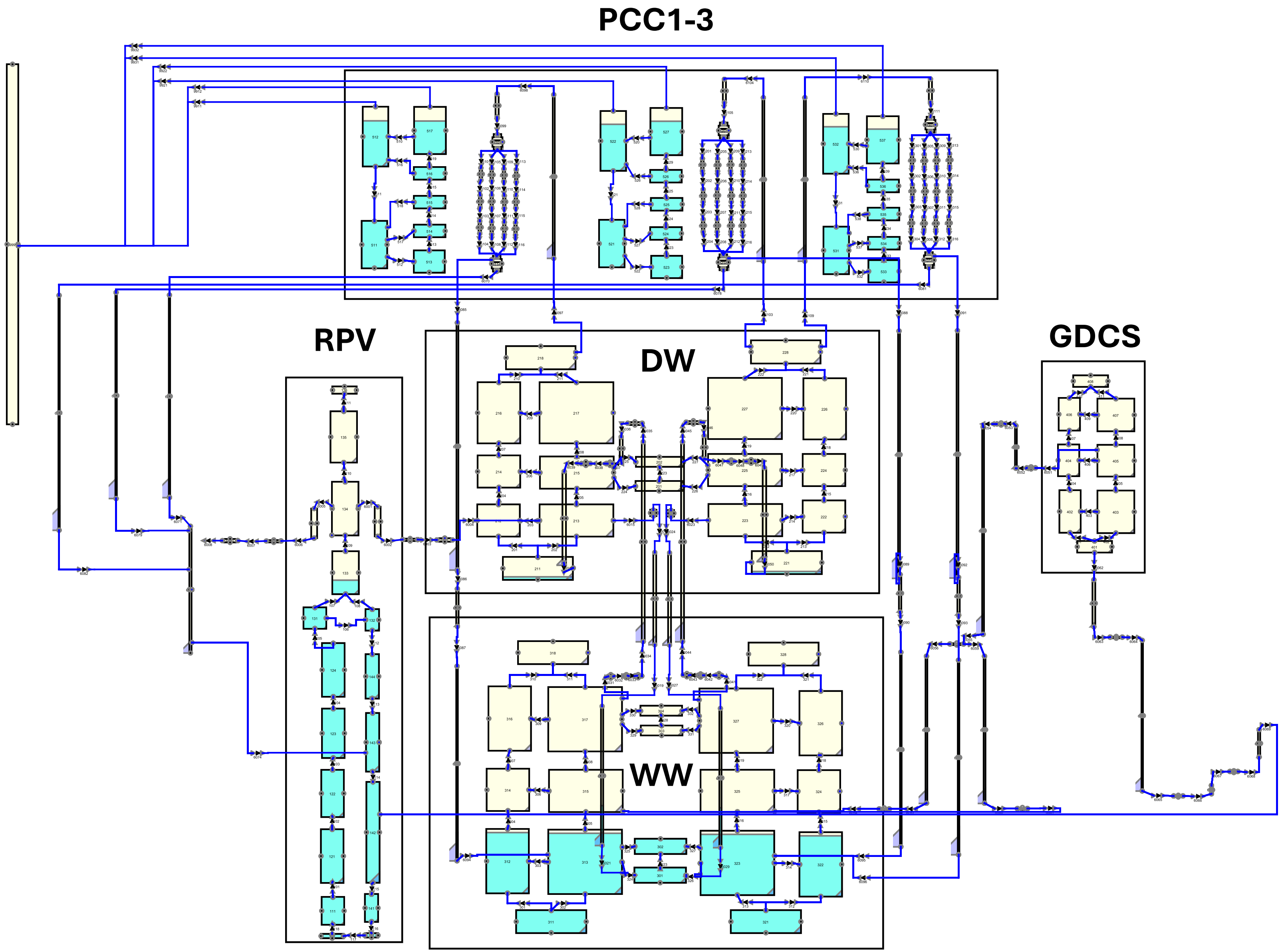
- Four phases:
  - **Venting phase** – MVL valves between DWs and WWs open
  - **Before He** – MVL valves closed, steam-air condensation
  - **He injection** – Steam-air-He condensation
  - **After He** – settling of the system, steam-air-He condensation





Nodalization – full system

- CVH 193
- FL 282
- HS 198
- CF 56



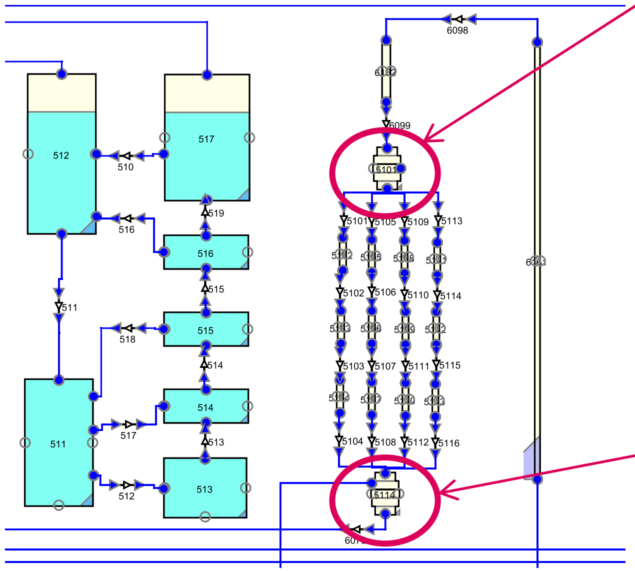
MELCOR model

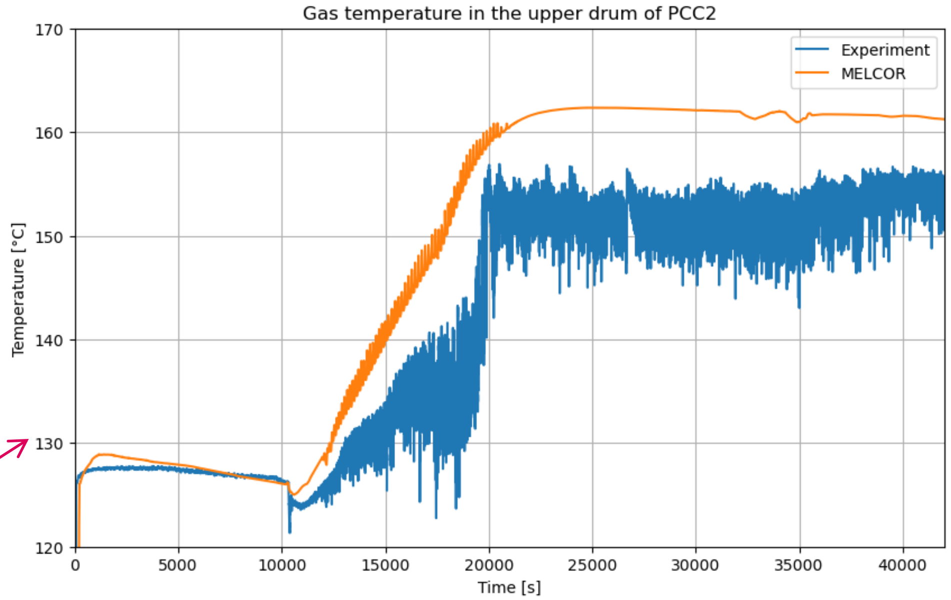
- No modified correlations, only SC altered were steady-state iteration parameters
- Library NCGs and materials were used. Defined insulation layer materials for vessels and lines
- Mass spectrometre gas consumption and leakage modelled
- Vertical surfaces – film tracking on
- Boundary conditions as-given
  - Except helium injection mass as deduced by Tuomo
    - 82% of the reported He mass
- MELCOR version 2024.0.3 is used together with SNAP

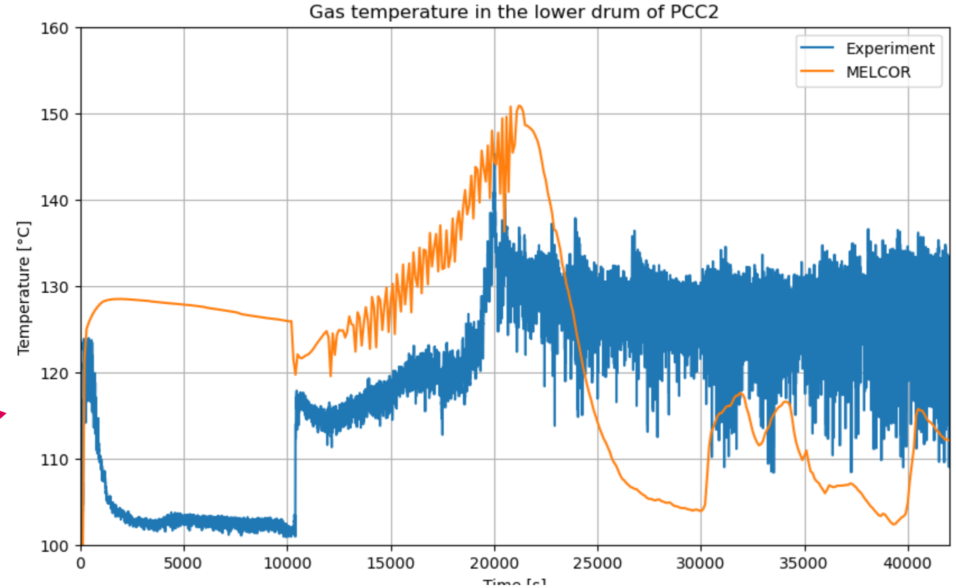
Variable	Unit	Experiment value	MELCOR value	Error
P_{env}	bar	0.98	0.98	0.00
T_{sat} at P_{env}	°C	99.1	99.1	0.0
RPV Total Pressure	bar	2.66	2.59	-0.07
RPV Fluid Temperature	°C	129.6	129.2	-0.4
RPV Water Level	m	12.7	12.5	-0.2
DW Total Pressure	bar	2.65	2.45	-0.20
DW Air Pressure	bar	0.04	0.05	+0.01
DW Gas Temperature	°C	127.0	126.2	-0.8
DW1 Water Level	m	0.14	0.14	0.00
DW2 Water Level	m	0.12	0.12	0.00
WW Total Pressure	bar	2.37	2.38	+0.01
WW Air Pressure	bar	2.02	2.01	-0.01
WW1 Fluid Temperature	°C	73.2	72.7	-0.5
WW1 Gas Temperature	°C	72.7	74.0	+1.3
WW2 Fluid Temperature	°C	72.9	72.7	-0.2
WW2 Gas Temperature	°C	72.4	74.0	+1.6
WW Water Level	m	3.9	3.9	0.0
GDCS Total Pressure	bar	2.37	2.38	+0.01
GDCS Fluid Temperature	°C	56.5	56.2	-0.3
GDCS Water Level	m	0.0	0.0	0.0
PCC1 Pool Temperature	°C	96.1	95.3	-0.8
PCC2 Pool Temperature	°C	96.5	95.7	-0.8
PCC3 Pool Temperature	°C	96.5	95.3	-1.2
PCC1 Pool Level	m	4.34	4.34	0.00
PCC2 Pool Level	m	4.36	4.36	0.00
PCC3 Pool Level	m	4.40	4.39	-0.01

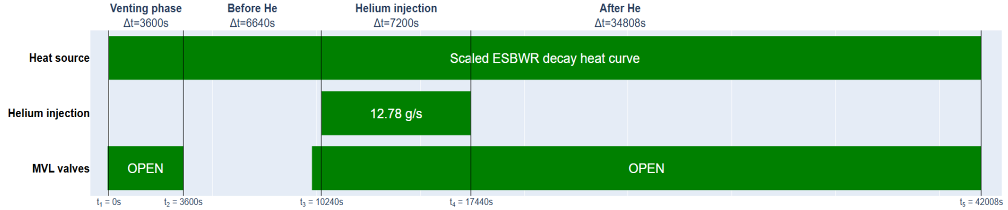
Key results

- PCC units do not behave as supposed – too small pressure drop induces close to no temperature drop which diminishes condensation and heat removal rate





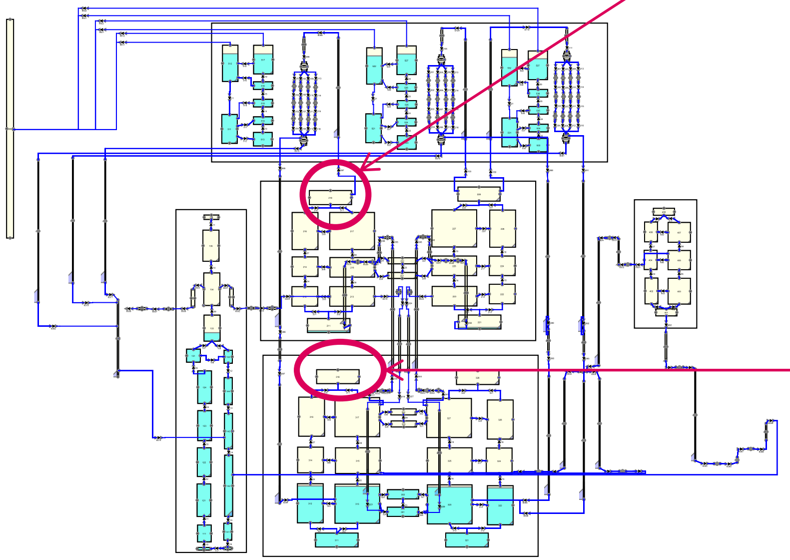


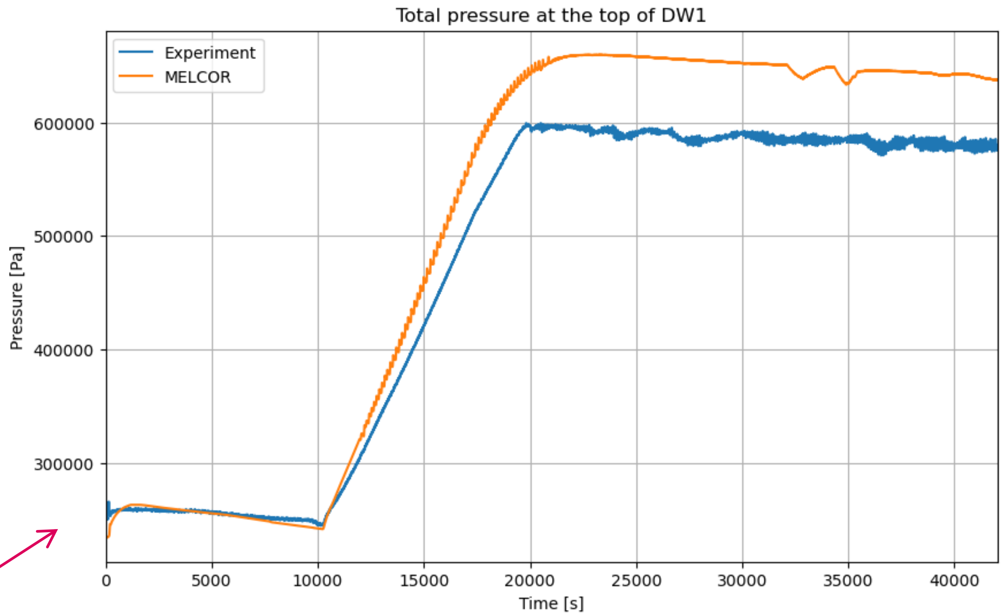


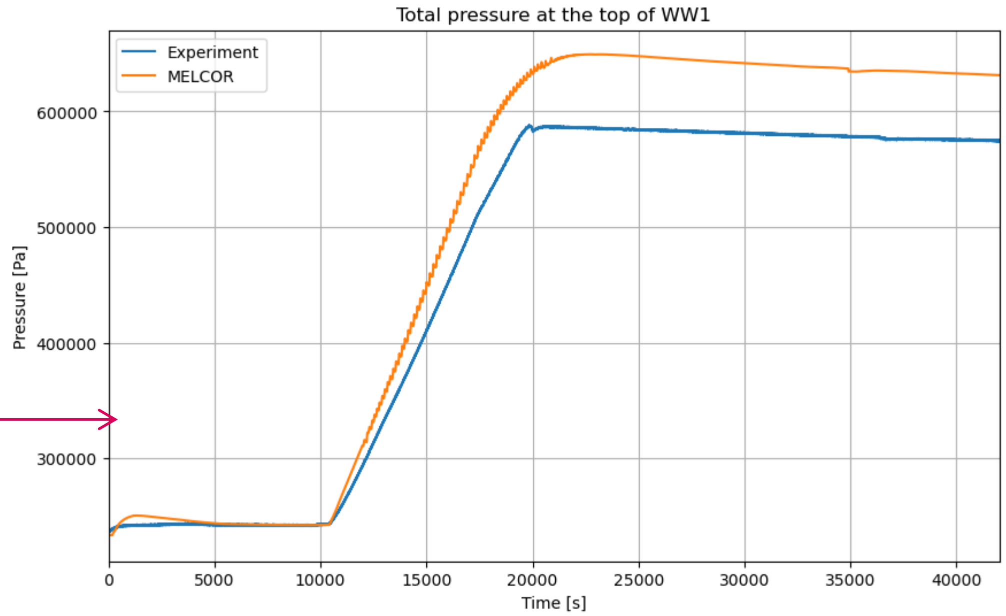
Key results

- PCC units do not behave as supposed – too small pressure drop induces close to no temperature drop which diminishes condensation and heat removal rate

- Pressure is too high





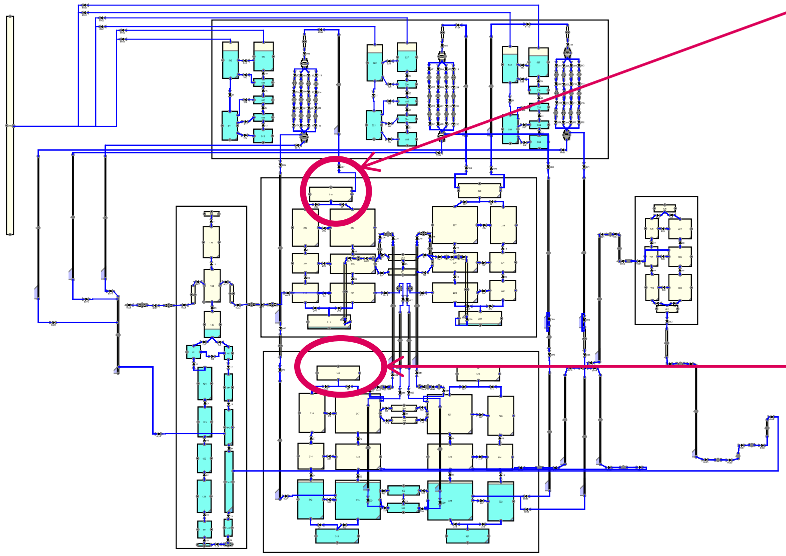


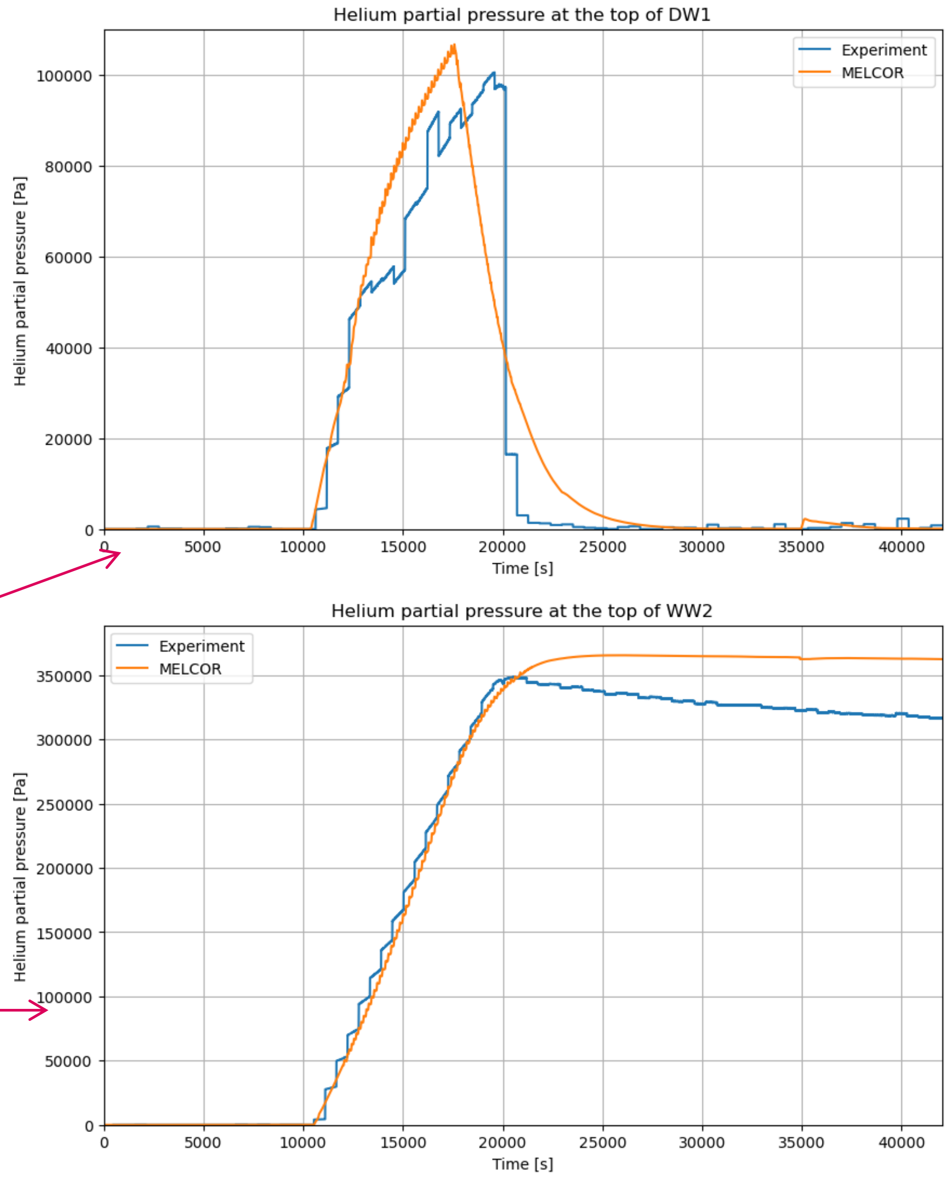
Key results

- PCC units do not behave as supposed – too small pressure drop induces close to no temperature drop which diminishes condensation and heat removal rate

- Pressure is too high

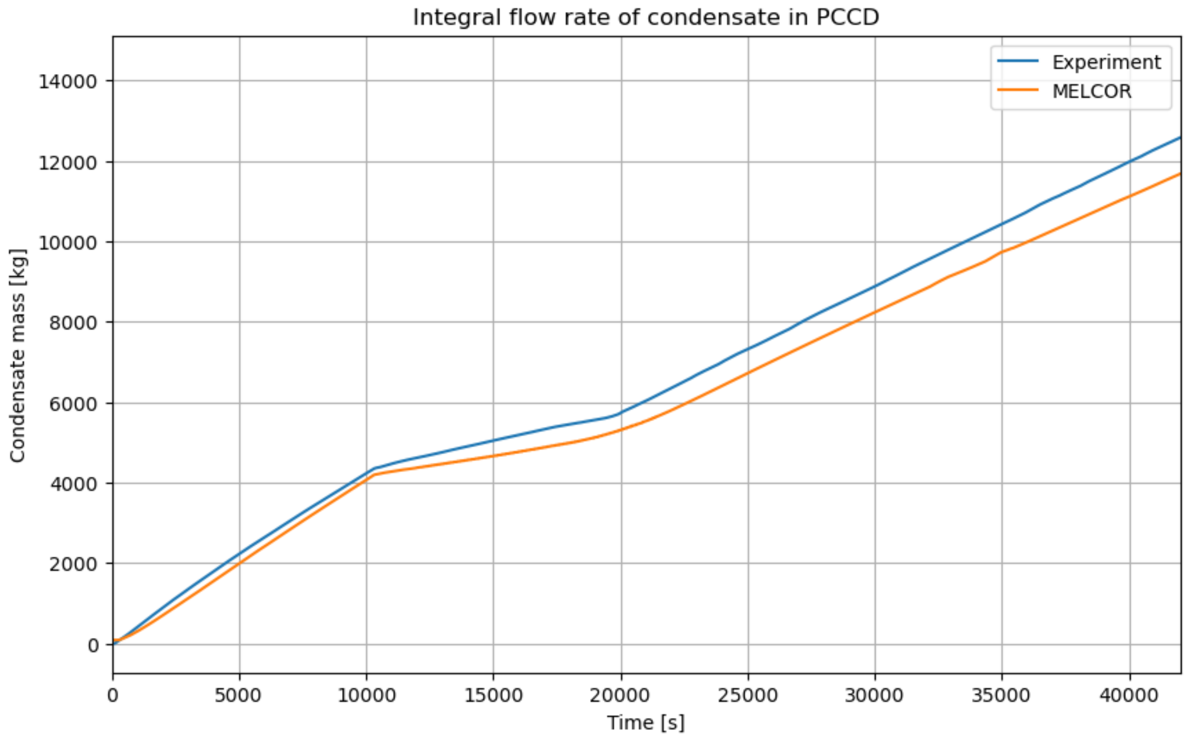
- Helium partial pressure is too high in DW and WW

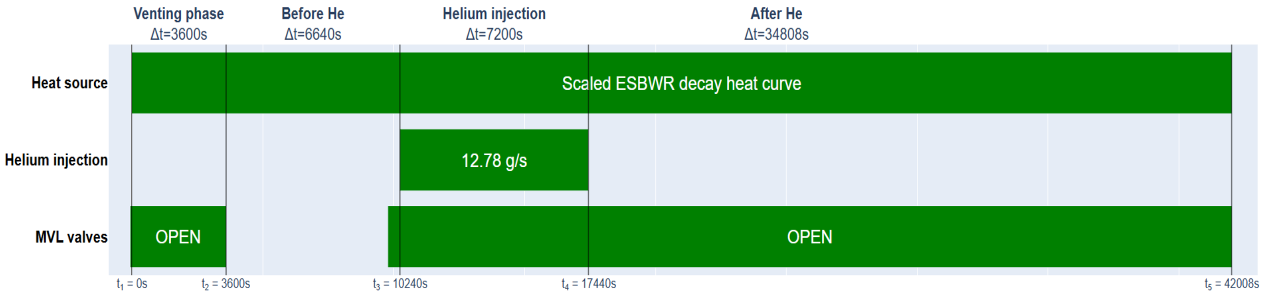




Key results

- PCC units do not behave as supposed – too small pressure drop induces close to no temperature drop which diminishes condensation and heat removal rate
- Pressure is too high
- Helium partial pressure is too high in DW and WW
- Amount of condensation in the system is less than the experimental values
  - Simulation condensation rate goes down in phase 3





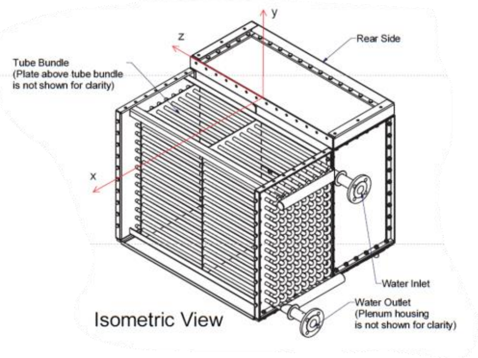
HYMERES 4 (H1P4) test model

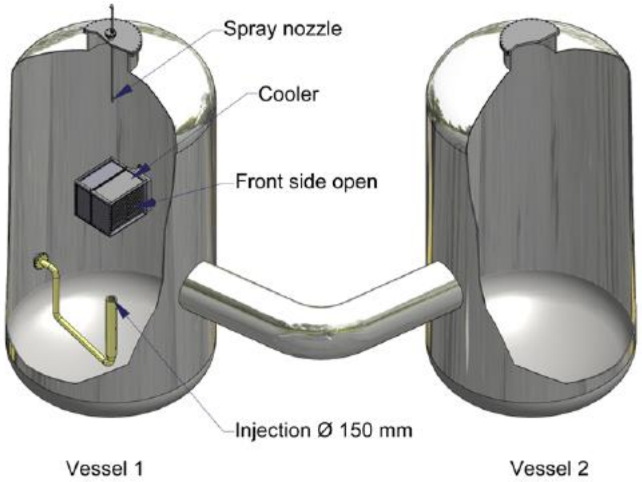
Main objectives:

- Study effects of cooler modelling choices on condensation
- Highlight key parameters to influence medium-scale condensation

HP4 test series of HYMERES project – „Spray and cooler“

- Assessment of the **combined effect of the cooler and spray** on the distribution of gas species (air, steam, helium) inside a containment
- The test HP4_0 serves as a “Base Case” for the test series.
  - **No spray actuation** in base case
- Carried out in large two vessels
  - Vessel 1 and 2 (DW1-2) for a volume of 180 m3
    - *Di* = 3.96 m, *H* = 8 m
  - Interconnecting pipe
    - *Di* = 0.928 m, *L* = 5.175 m





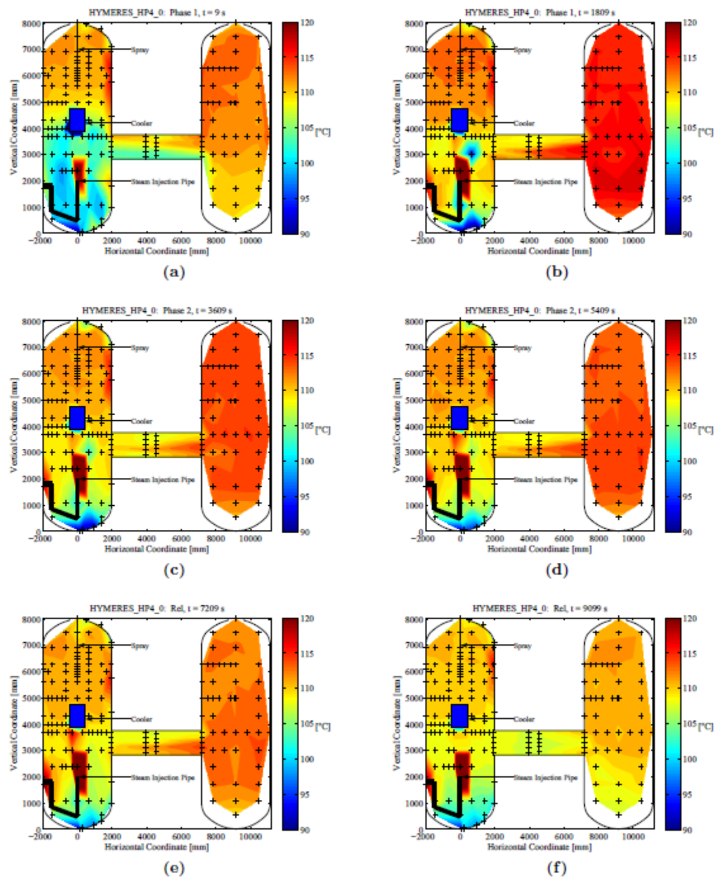
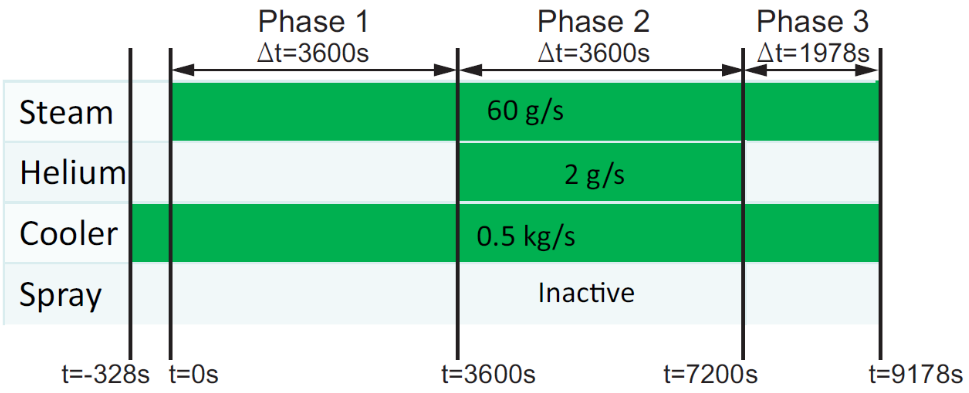
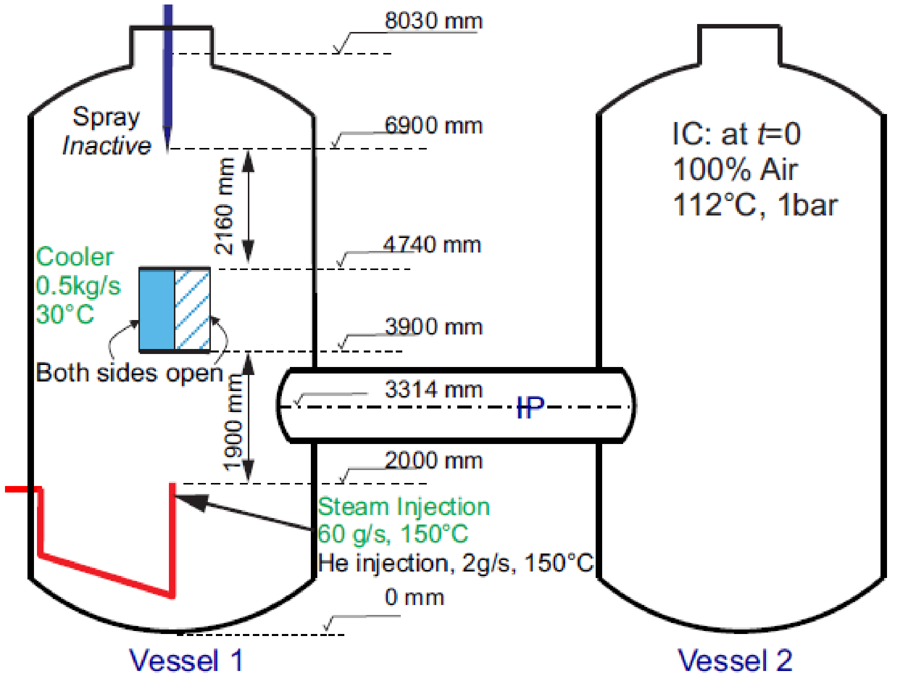
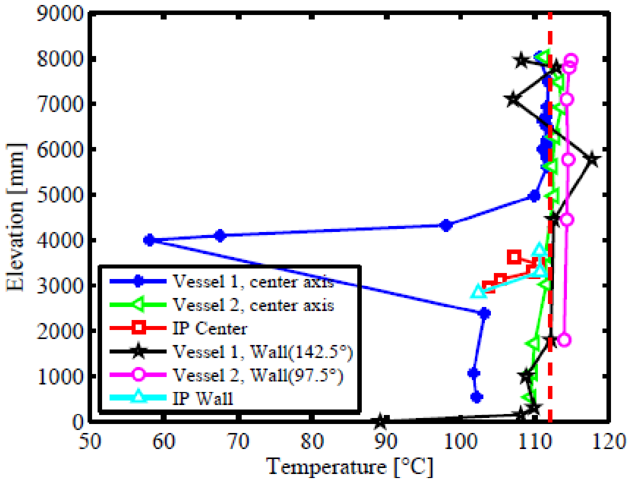


Figure 5.1: *Evolution of gas temperature distribution*

Test procedure and initial conditions







Initial Conditions	Nominal Value
Initial vessel pressure [bar]	1
Vessel 1 gas molar fractions	100% air
Vessels wall temperature [°C]	112
Vessels fluid temperature [°C]	112
Boundary Conditions	
Phase 1	
Cooler flow rate [kg/s]	0.5
Cooler injection temperature [°C]	30
Steam injection flow rate [g/s]	60
Steam injection temperature [°C]	150
Phase 2	
Cooler flow rate [kg/s]	0.5
Cooler injection temperature [°C]	30
Steam injection flow rate [g/s]	60
Steam injection temperature [°C]	150
Helium flow rate [g/s]	2
Phase 3	
Cooler flow rate [kg/s]	0.5
Cooler injection temperature [°C]	30
Steam injection flow rate [g/s]	60
Steam injection temperature [°C]	150

MELCOR model

Three main ways to model the cooler would be investigated:

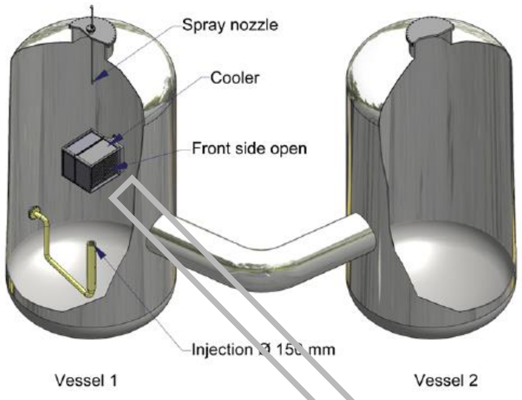
1. **Explicit, convective HS** – presented today
2. Explicit, Zukauskas HS
3. FCL package

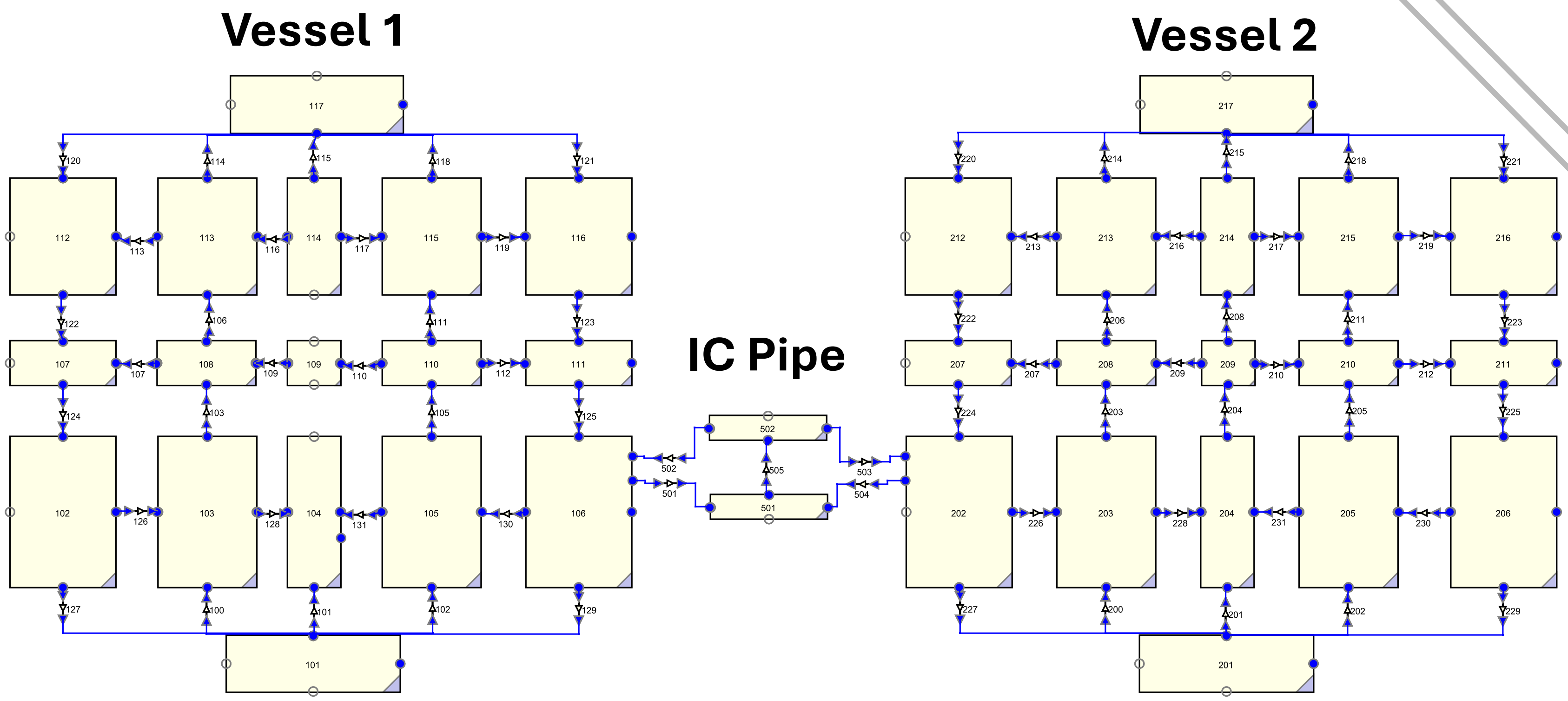
- Fine nodalization to study stratification
- Gas consumption via mass spectrometers + leakage is modelled
- All parameters values and boundary conditions modelled as reported by experiment

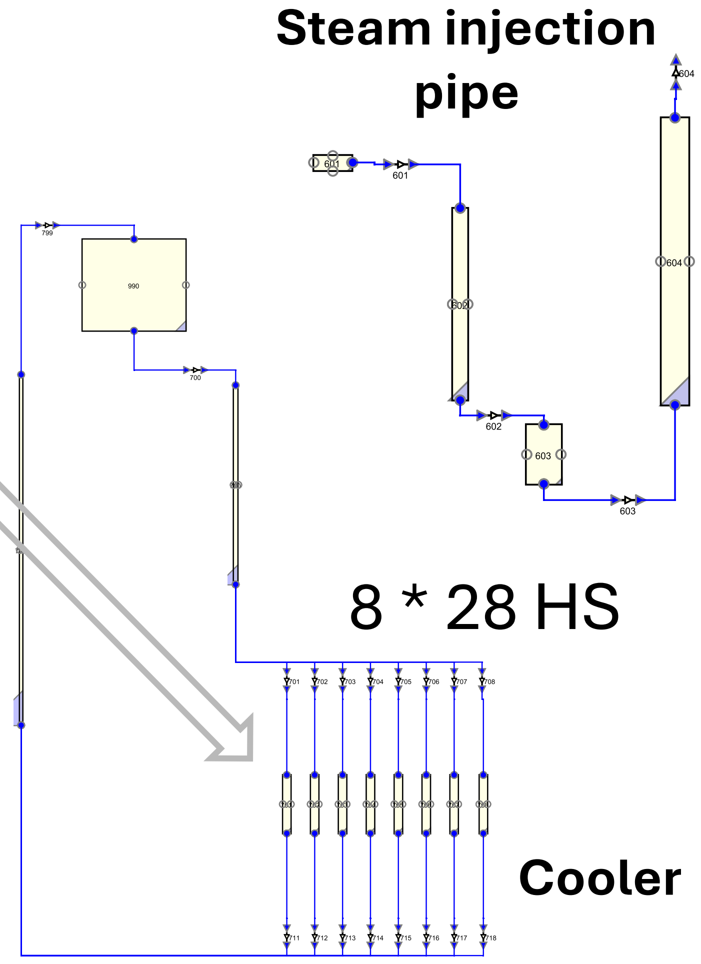
PARAMETER	MEASURED	MODEL	ERROR
Wall TEMP			
DW1 up	117.7°C	112.8°C	**-4.9°C**
DW1 low	112.2°C	112.8°C	**+0.6°C**
DW2 up	114.5°C	112.8°C	**-1.7°C**
DW2 low	114.0°C	112.8°C	**-1.2°C**
IC pipe	102.4°C	101.9°C	**-0.5°C**
Gas TEMP			
DW1 up	111.1°C	106.3°C	**-4.8°C**
DW1 low	102.7°C	105.1°C	**+2.4°C**
DW2 up	112.7°C	111.1°C	**-1.6°C**
DW2 low	110.0°C	110.7°C	**+0.7°C**
IC pipe	105.4°C	106.8°C	**+1.4°C**
Pressure			
P in DW2	1.015 bar	1.012 bar	**-0.003 bar**

Nodalization

52 CVH, 120 FL, 38 HS, 26 CF

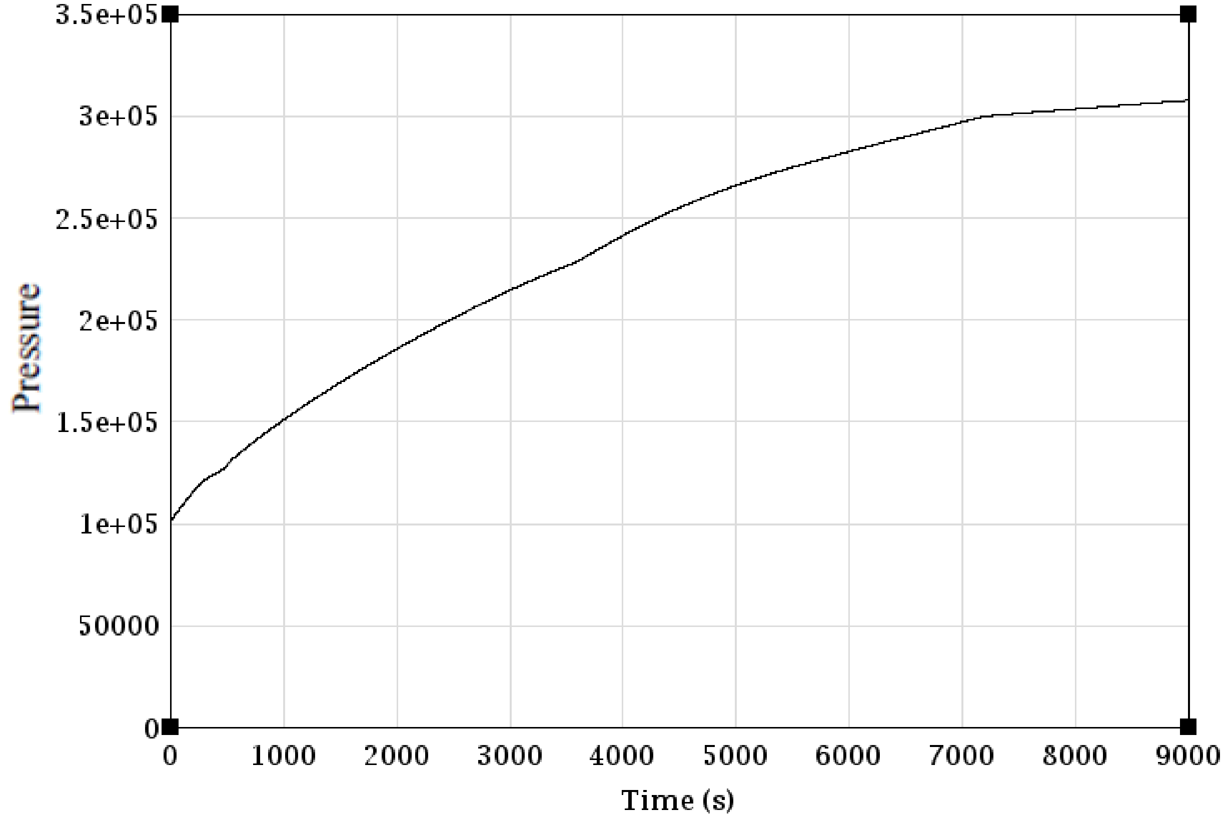






Key results

- Overestimation of pressure in the system in HP4_0 model



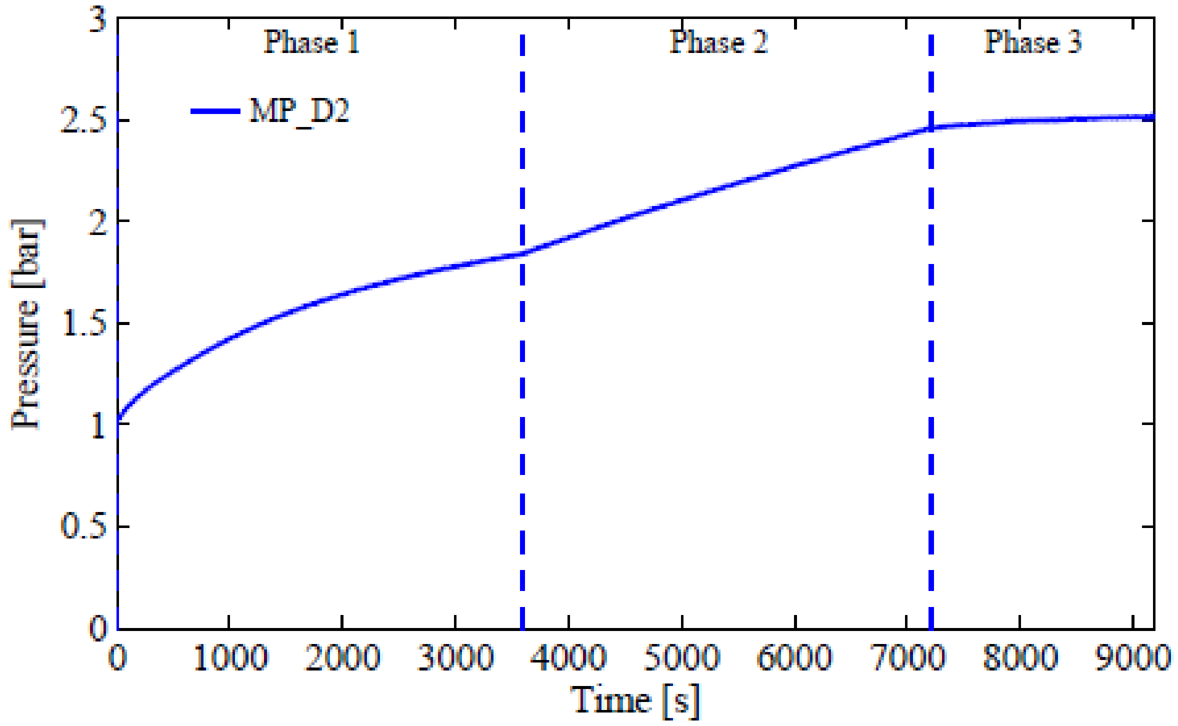
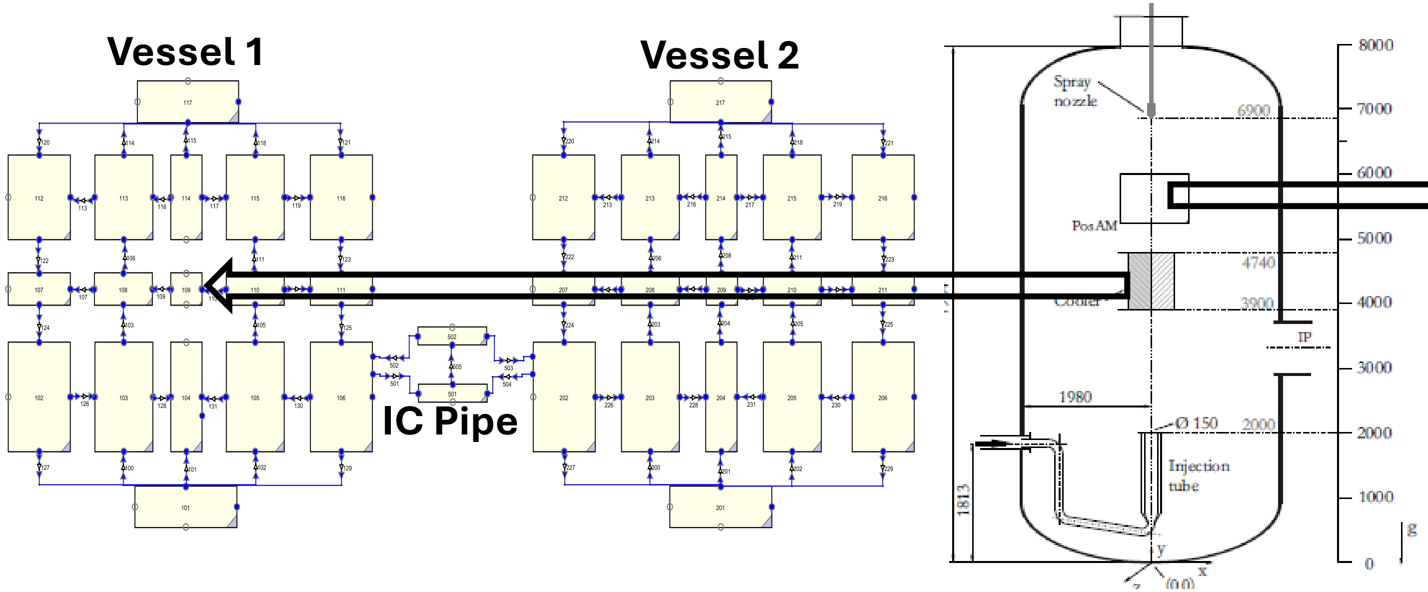


Figure 3.4: *Vessel pressure during the steam injection phase*

Troubleshooting of too high pressure



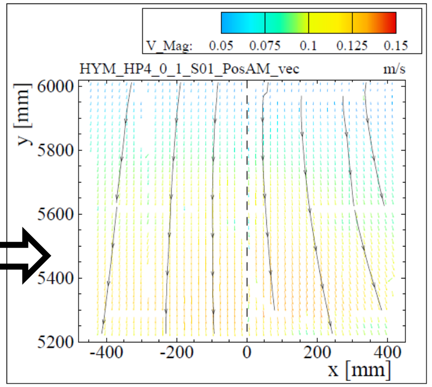
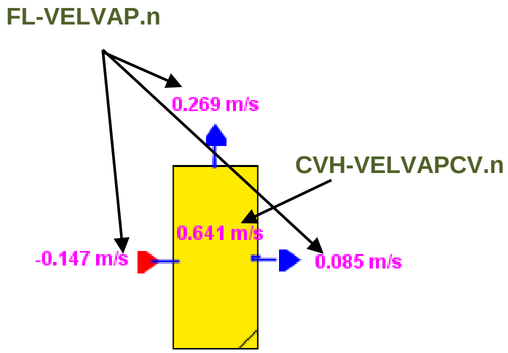


Figure 5.10: *Mean velocity field at t_c = 1840.4 s*

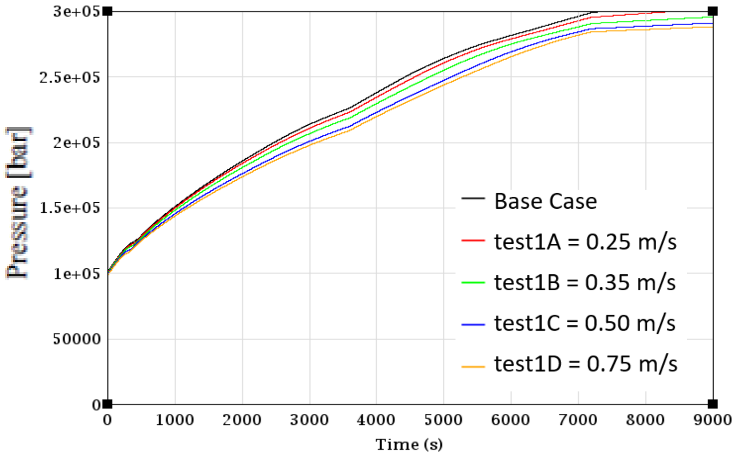


What brings down pressure?

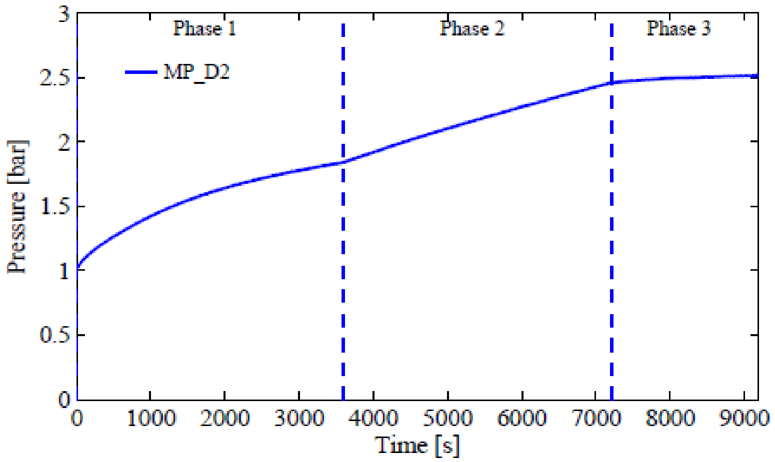
The most effective measure seems to be **time-independent airflow through the cooler element**

- No data on flow velocity from experiment

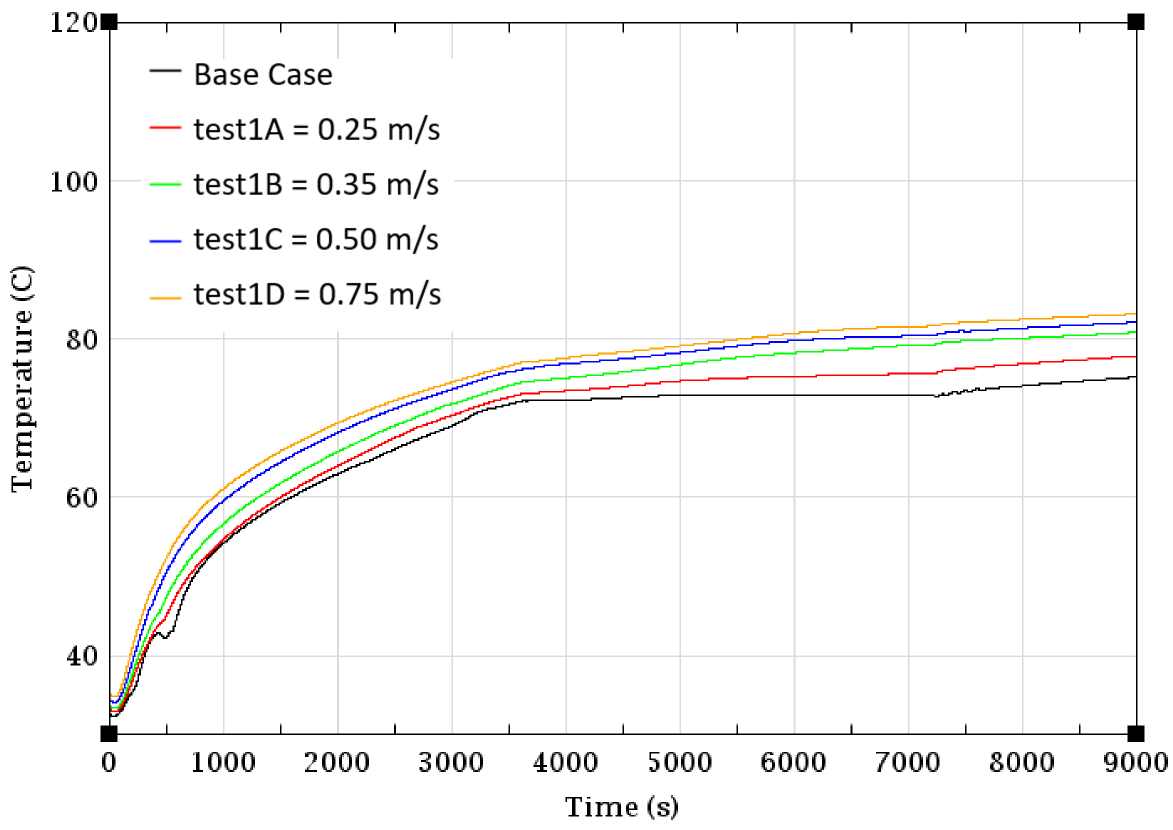
Forced airflow

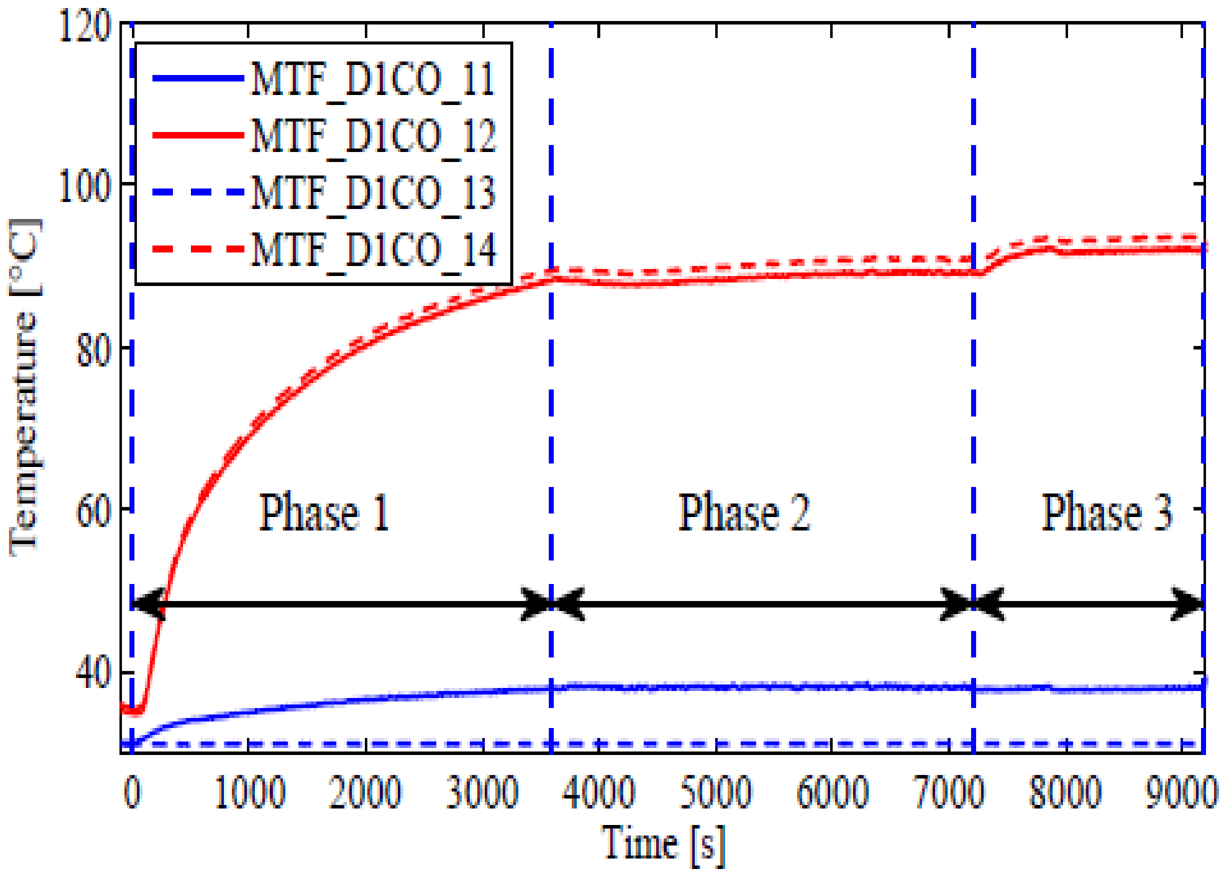


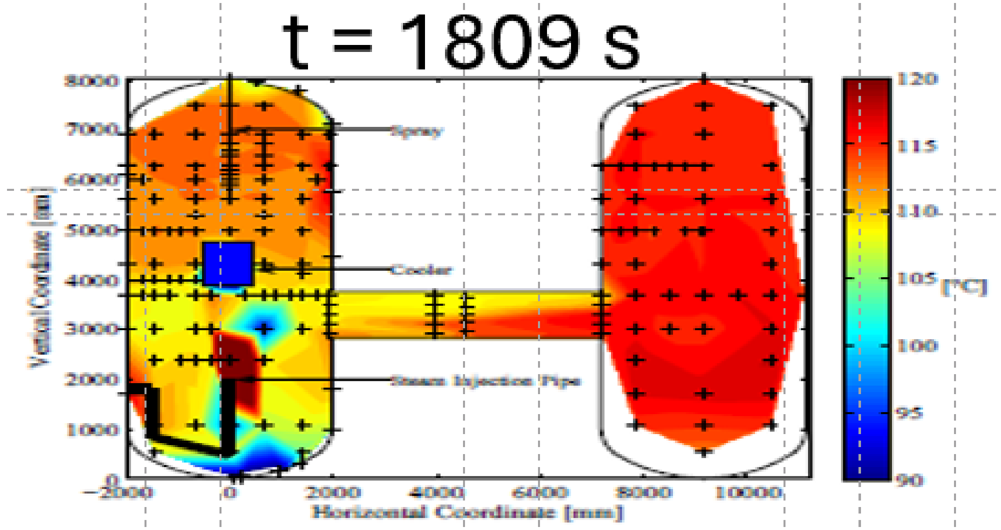
Experiment results

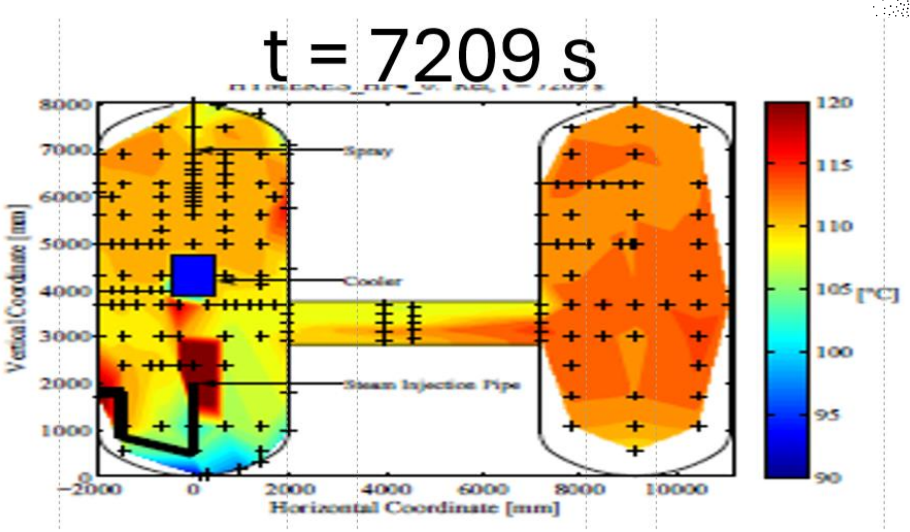


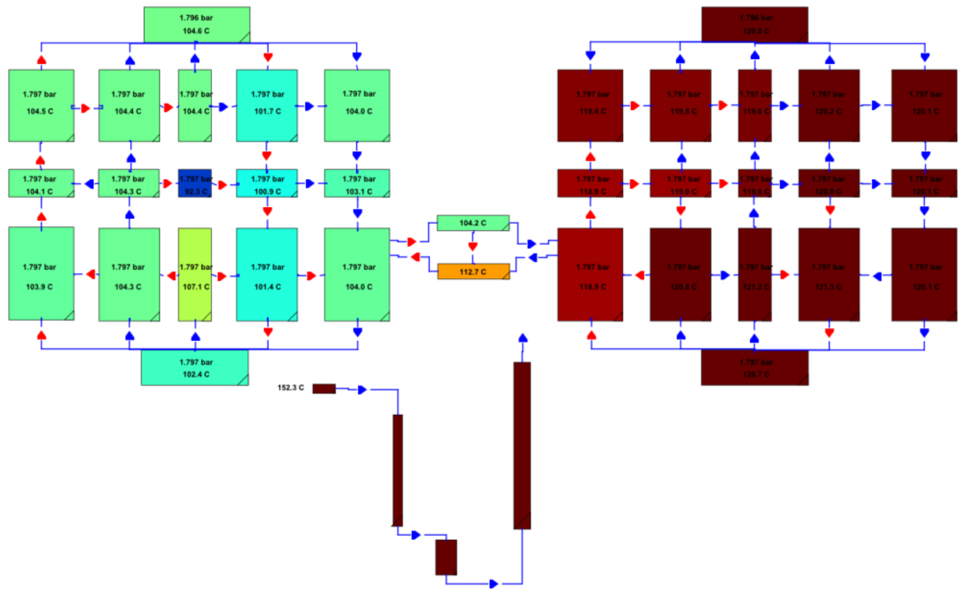
Cooler outlet temperature

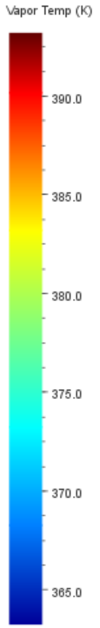


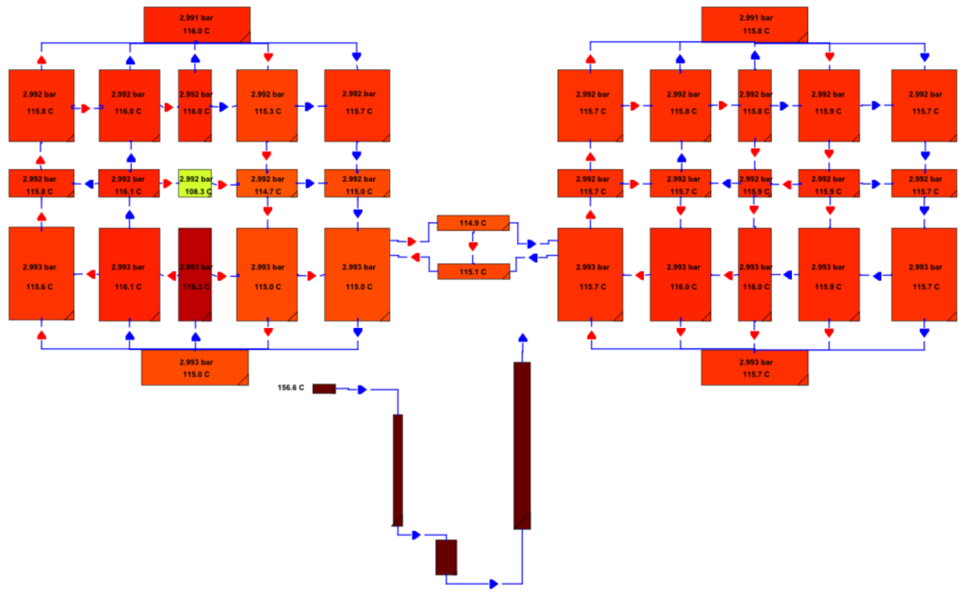



t = 1809 s
Spray
Cooler
Steam Injection Pipe
Vertical Coordinate [mm]
Horizontal Coordinate [mm]
[°C]
120
115
110
105
100
95
90


t = 7209 s
Spray
Cooler
Steam Injection Pipe
Vertical Coordinate [mm]
Horizontal Coordinate [mm]
[°C]
120
115
110
105
100
95
90




Vapor Temp (K)
390.0
385.0
380.0
375.0
370.0
365.0



Lessons learned & future work

Lessons learned:

- MELCOR is a feeling
- Nodalization on each level affects the end result
  - „More control volumes cause more problems“ – T. Sevon
  - Started off with too fine nodalization in my models
- Systems are often too big to point out exact reasons for discrepancies

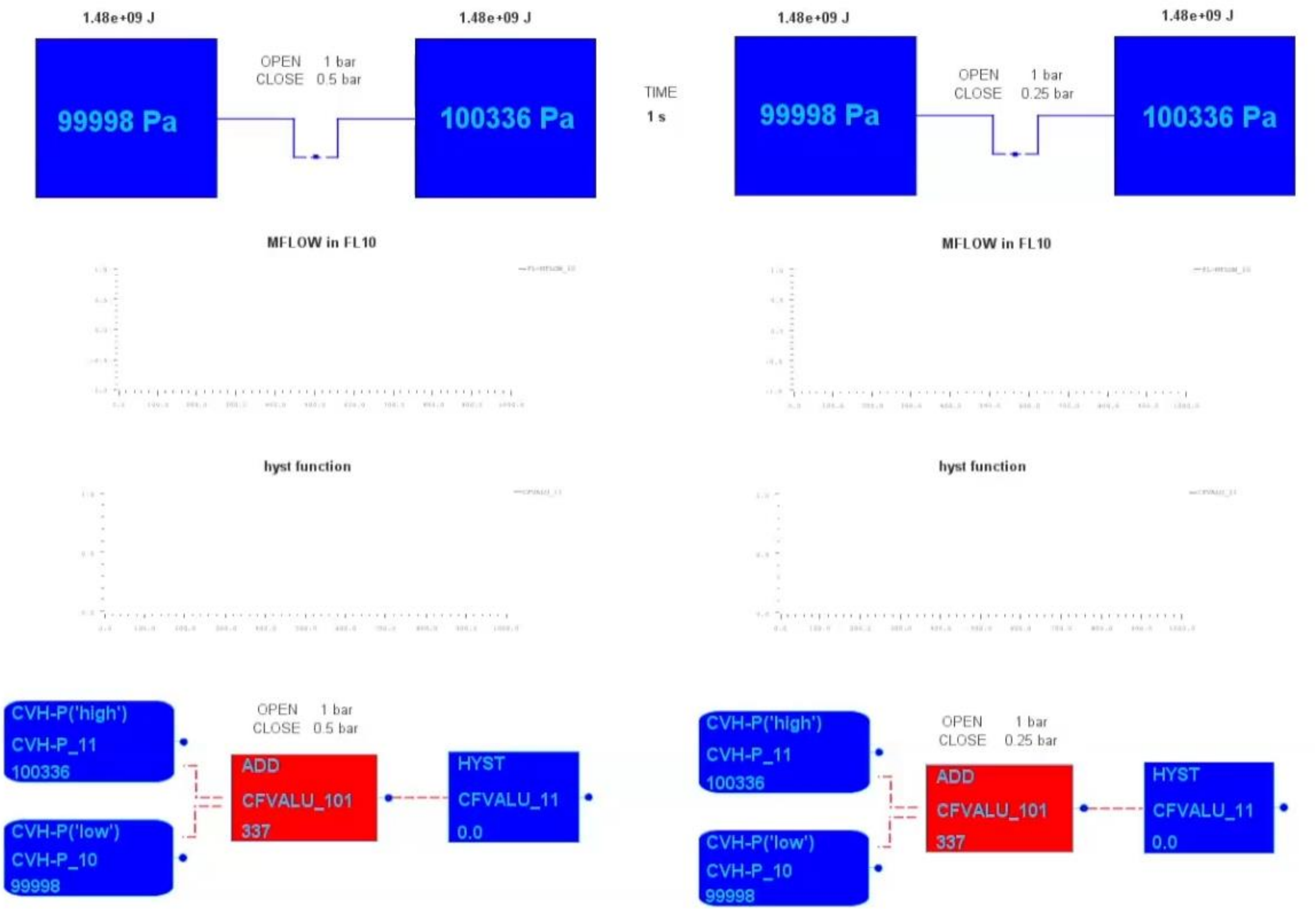
Next steps:

- H1P4 model development (Zukauskas, FCL)

Sensitivity analysis of all scales will be used in **model development phase** as knowledge foundation of the most influencial parameters to affect condensation.

- Formation of relevant experiment portfolio focusing on wall and on-tube condensation

valveTest


1.48e+09 J
99998 Pa
OPEN 1 bar
CLOSE 0.5 bar
1.48e+09 J
100336 Pa
TIME
1 s
1.48e+09 J
99998 Pa
OPEN 1 bar
CLOSE 0.25 bar
1.48e+09 J
100336 Pa
MFLOW in FL10
MFLOW in FL10
hyst function
hyst function
CVH-P('high')
CVH-P_11
100336
CVH-P('low')
CVH-P_10
99998
OPEN 1 bar
CLOSE 0.5 bar
ADD
CFVALU_101
337
HYST
CFVALU_11
0.0
CVH-P('high')
CVH-P_11
100336
CVH-P('low')
CVH-P_10
99998
OPEN 1 bar
CLOSE 0.25 bar
ADD
CFVALU_101
337
HYST
CFVALU_11
0.0

Encountered issues/questions

Hysteresis valve issue

- The same logic that works for 1/0.5 bar does not work for 1/0.25 bar

CVH vs FL flow velocity

- Inconsistency when observing CVH vs FL flow velocity as highlighted in Slide 15

No way to plot external sources

- Injected energy to CVH – cannot plot the value for double-checking

Thank you for paying attention!

Thank you for organizing EMUG!

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Brno, 11.04.2025, EMUG