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Validation of MELCOR natural circulation and condensation based on PANDA experiments – preliminary results

15th EMUG, Rome, Italy, April 2024

COMPARE WP1 and WP2

WP1 (1 PM):

Review of MELCOR models for containment TH.

The primary objective here will be to gauge the state-of-knowledge regarding MELCOR capabilities for containment TH and to identify validation gaps that could be filled through PANDA experiments.

WP2 (2 PM):

Review of PANDA Experimental Database for MELCOR Validation.

The aim here will be to provide a comprehensive overview of all PANDA tests conducted so far of relevance for the validation of MELCOR containment TH and on this basis, select in collaboration with ENSI, the two first validation cases to be included in this project with focus on global- and regional predictions respectively with relevance to the Swiss reactors.

Deliverable

Technical report on WP-1 and WP2

- Selection of Validation Cases 1 HYMERES HP6_2 and 2 HYMERES HP6_1 or ERCOSAM-SAMARA

COMPARE WP3 and WP4

WP3 (6 PM), WP4 (6 PM):[1] Modelling and Analysis of PANDA Validation Case 1 & 2 ✓

- Development of Model and Base Validation against measurements
- Sensitivity studies for spatial/temporal convergence and bias/accuracy quantification
  - Code Version/Regression
  - System Representation
    - Nodalization scheme ✓
    - Mapping of multidimensional effects and flow paths
    - Input data related a) to system characteristics and components (e.g. geometries, heat structures and losses, form and friction losses etc.); b) to initial and boundary conditions

WORK IN PROGRESS

HYMERES project

PANDA HP6 natural circulation flow induced by opening hatches series [2] [3]

The objective for the HP6 series was to investigate gas flow transport in a multi-compartment containment for conditions which may lead to global natural circulations and homogenization of the gas mixture composition.

The experiments HP6_1 and **HP6_2** were performed with the same nominal initial conditions, i.e. all four vessels filled with 100% air at room temperature.

Each experiment consisted of four main phases, according to Table 1.

Phase 1, a high steam flow rate was injected in vessel 4.

Phase 2, no injection

Phase 3, helium was injected in Vessel 4

Phase 4 no fluid was added to the system until the end of the test.

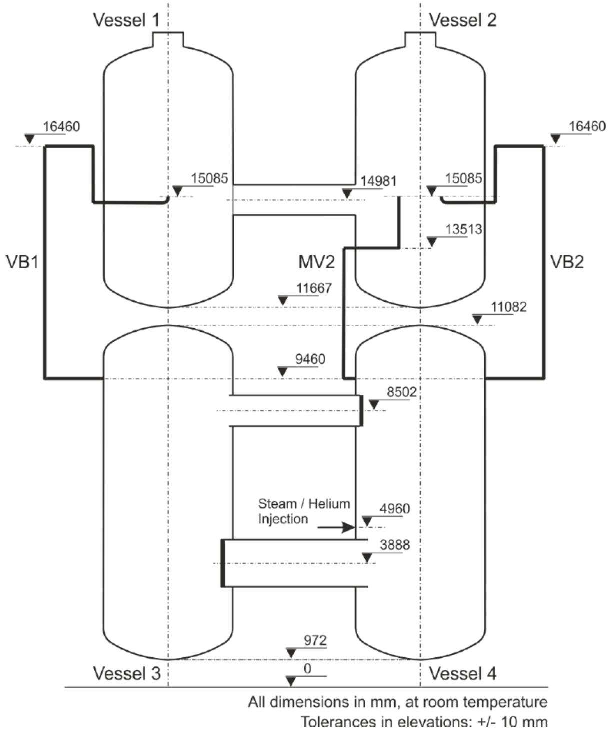
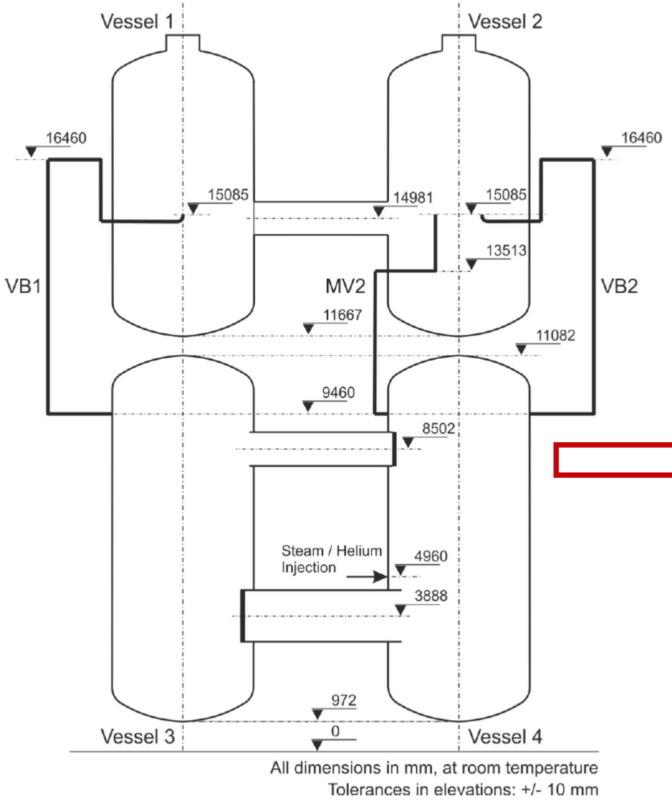


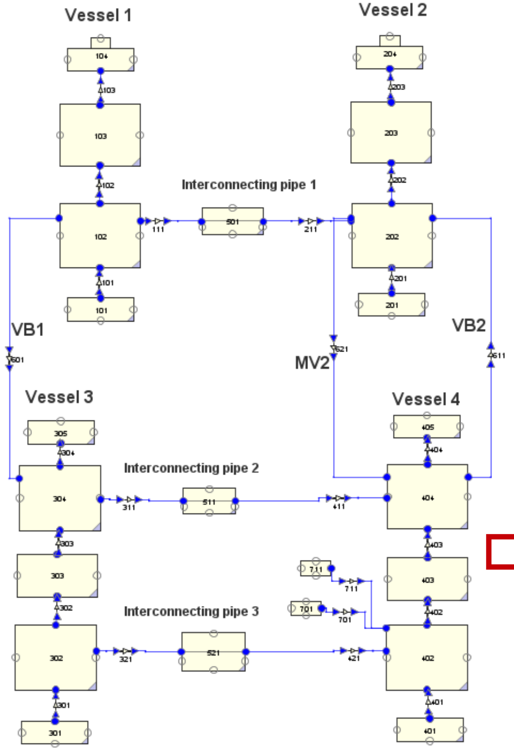
Table 1 HYMERES HP6 Phases

		HP6_1		HP6_2	
Phase name	Boundary condition	Start time [s]	duration [s]	Start time [s]	duration [s]
Phase 1	steam injection	0	5100	0	5106
Phase 2	no injection	5100	3000	5106	2994
Phase 3	helium injection	8100	576	8100	580
Phase 4	no injection	8676	6824	8680	7320
	Total time		15500 [s]		16000 [s]

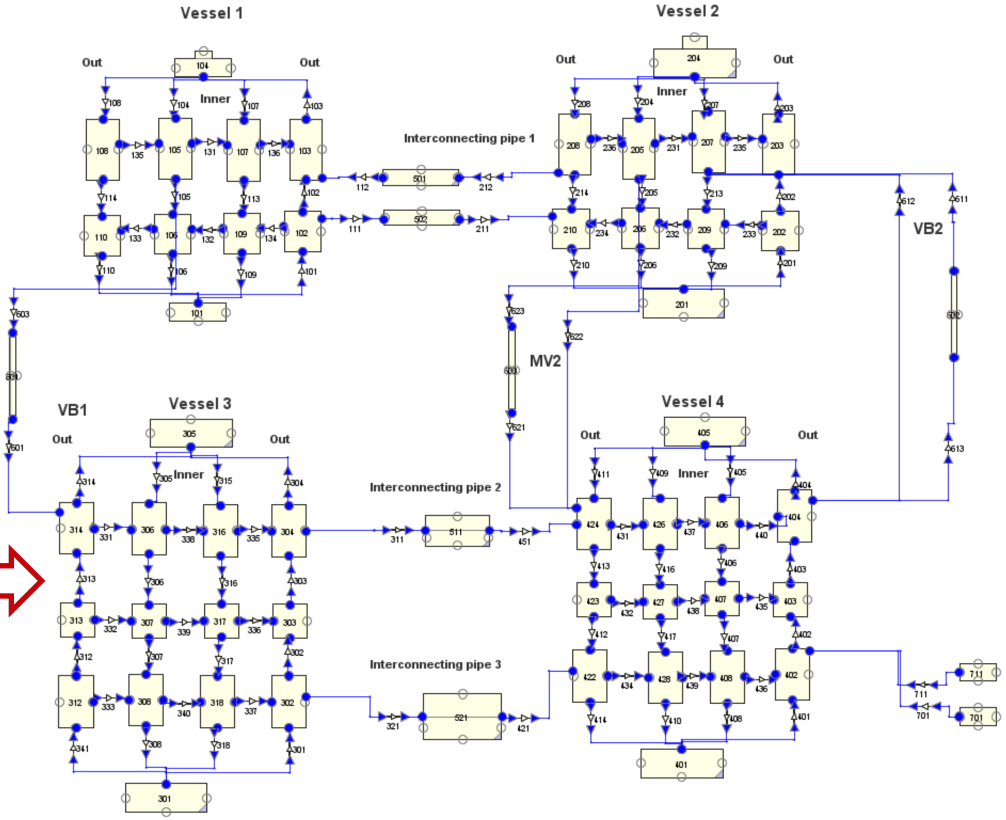
COMPARE WP3 - MELCOR model and nodalization

One of the first undertaken actions was to conduct a sensitivity study upon nodalization (70+ input decks were analyzed).





v5



V18_6_2

COMPARE WP3 - MELCOR model and nodalization

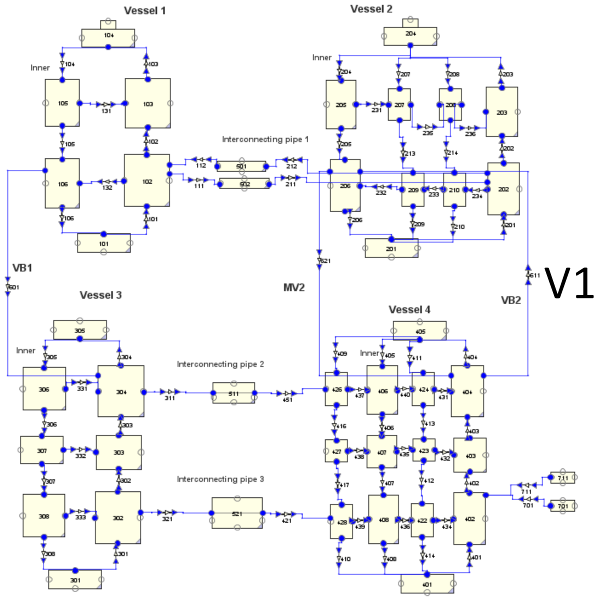
Based on input deck analyses few general remarks could be listed:

1. The pipes like VB1, VB2, MV2 and interconnecting pipes needs to be modelled not only by a flow paths but also as volumes (include CVH). Modelling convection or natural circulation in pipes by using CVH not only FLs gives results more accurate compared to the experimental data.

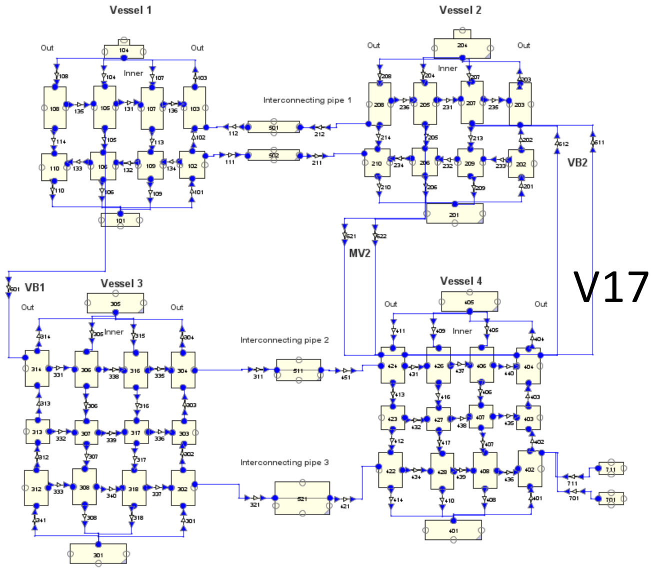
2. The horizontal pipes where gas and temperature stratification is expected e.g. interconnecting pipes provide better results if they are vertically divided.

3. Dividing volumes of the vessels into inner and outer regions seems to be essential for mixing. The outer CVHs are connected with separate HSs and to the inner CVHs by FLs, which improve mixing and condensation providing results closure to the experiment.

Input deck label	Short description
V5	Simplest input deck, all vessels divided only vertically
v10	Vessels divided also horizontally, interconnecting pipe 1 split to top and bottom part
v15_4_2	improved nodalization in Vessel 2 and Vessel 4 and only one CVH per level connected to HS
v16_5	improved nodalization and uniformed CVH volumes in all vessels, HS divided and connected to two CVHs per level
v17_6	CVHs and FL arranged to improved circulation (outer regions connected only to inner regions)
v18_6_2	Final input deck, additional CVHs added to flow paths VB1, VB2 and MV2.



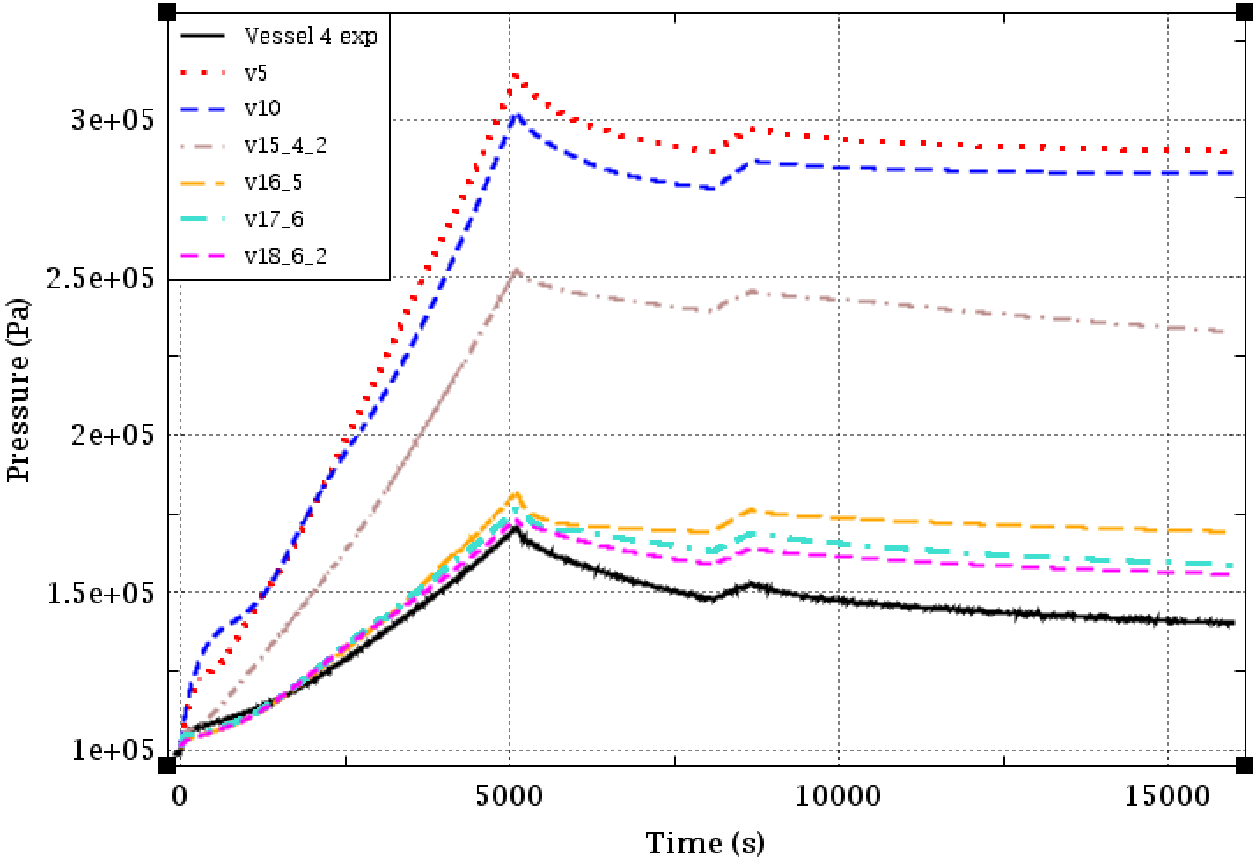
V16_5

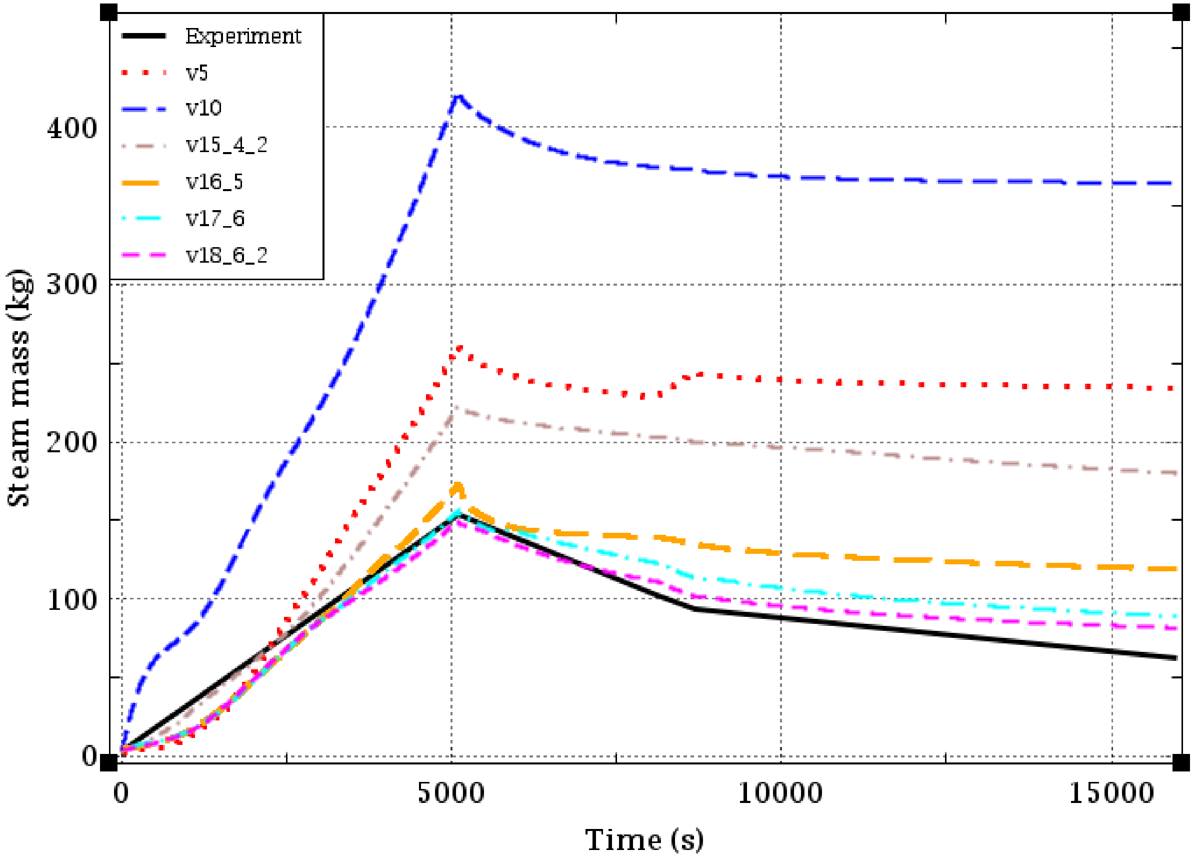


V17_6

COMPARE WP3 - MELCOR model and nodalization

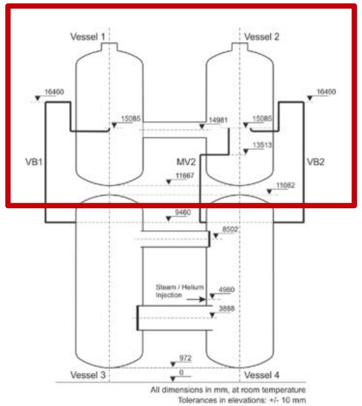
- Comparing evolution of the pressure and total steam mass (in the whole facility) between selected cases and experiment it is clear how big effect nodalization could have.
- Despite significant improvements the difference between the best results and experiment is not negligible

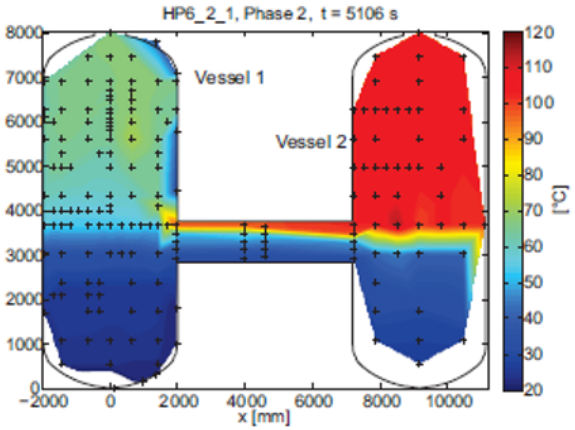


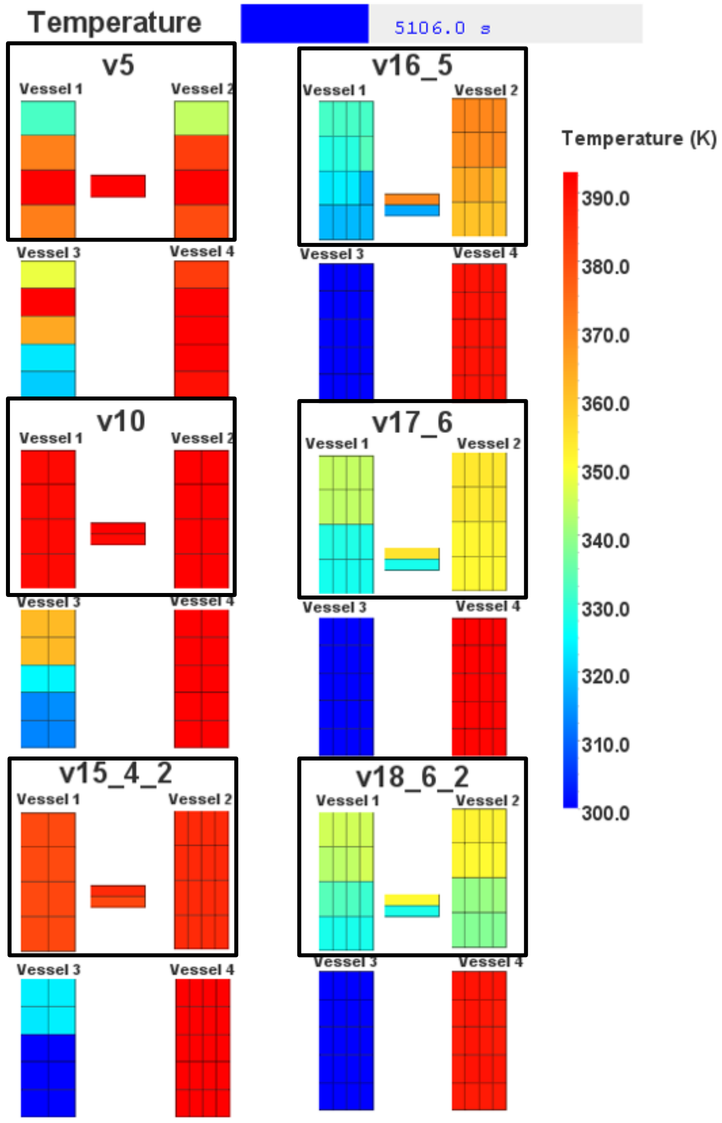


COMPARE WP3 - MELCOR model and nodalization

- HP6_2 provides also temperature mapping for vessel 1 and vessel 2 (top vessels)
- At the end of the Phase 1 (5106 s, steam injection) strong stratification is visible in both vessels .
- In Vessel 2, temperature at the top is around ~110 C (~383 K) when at the bottom ~25 C (~300 K).
- Case v18_6_2 is closest to the experiment; however, even there, the temperature difference is visible.
- The interconnecting pipe and Vessel 1 temperature stratification is also strong. In Vessel 1 top temperature is ~70 C (~ 345 K) which is close to case v18_6_2 but bottom is ~20 C (~ 295 K) while in the best calculated case is around ~50 C (~ 325 K)

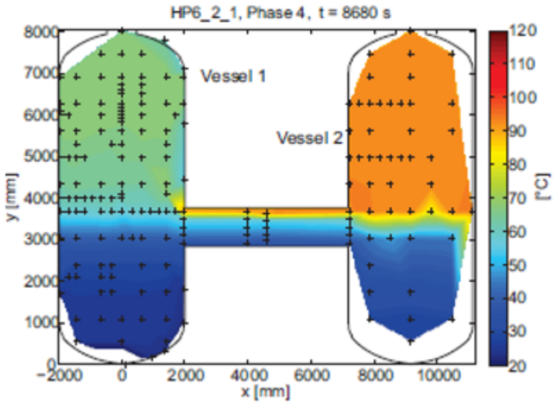


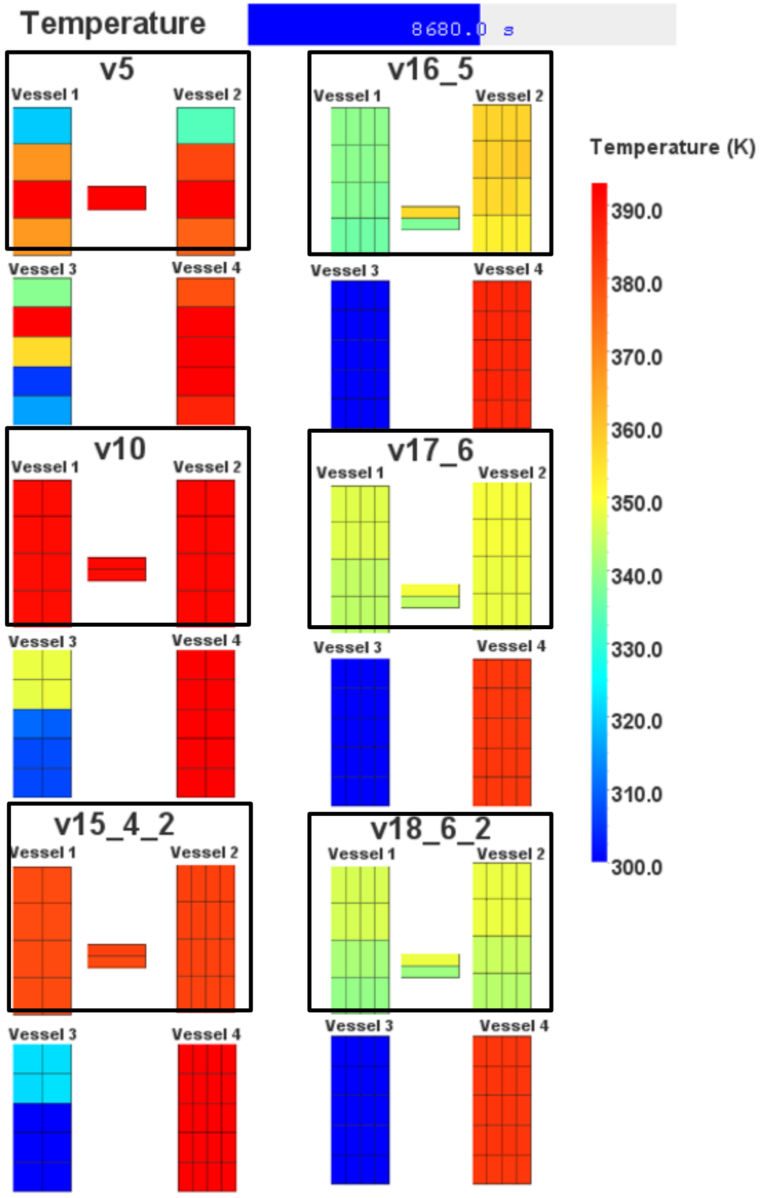




COMPARE WP3 - MELCOR model and nodalization

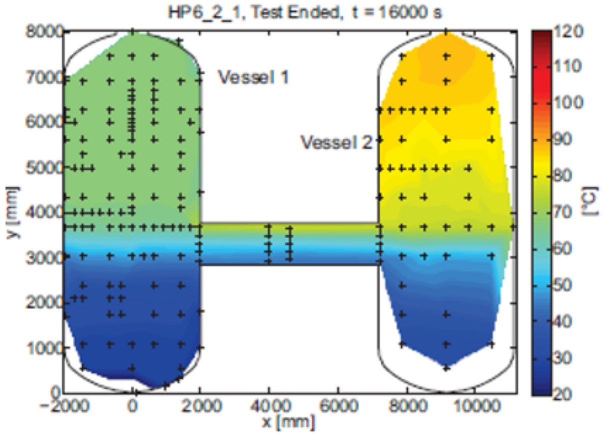
- At the end of the Phase 3 (8680 s, helium injection) a strong stratification is visible in both vessels
- In vessel 2 temperature at the top is visibly lower then in Phase 1 ~90 C (~ 365 K).
- Bottom temperature in both vessels is still around 25 C (300 K).
- Vessel 2 temperature seems to agree best with v16_5 analysis (temperature closure to the experiment). However, overall v18_6_2 provide better stratification in both analyzed vessels.

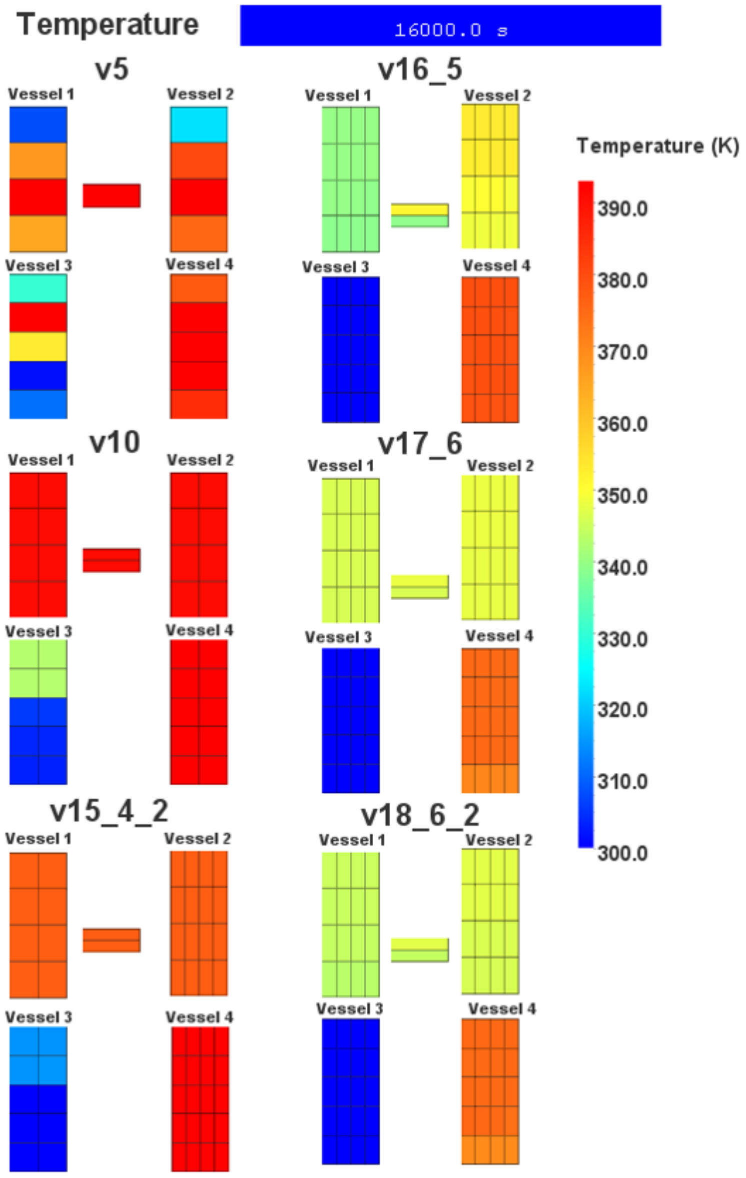




COMPARE WP3 - MELCOR model and nodalization

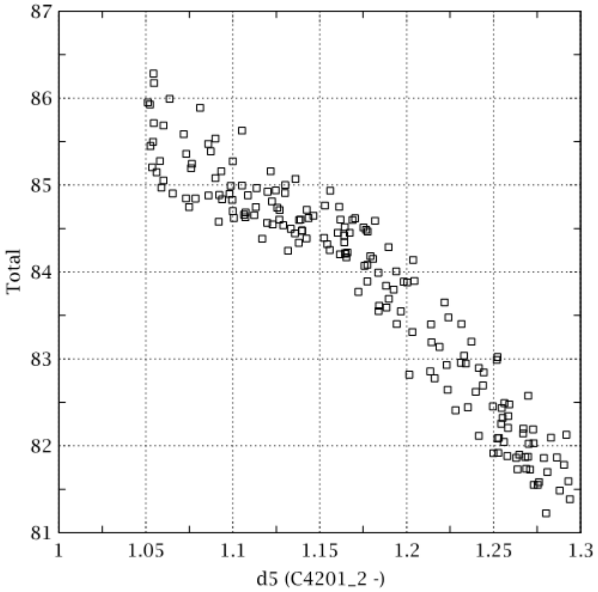
- At the end of the Phase 4 (16000 s) a strong stratification is visible in both vessels but again in vessel 2 temperature at the top is visibly lower ~80 C (~ 355 K).
- Bottom temperature in both vessels is still around 25 C (300 K) confirming that stratification maintained for the whole test which is not the case in MELCOR where almost all calculations provide uniform temperature distribution.
- Again, the case~~s~~ v16_5 seems to be slightly better in case of Vessel 2 (temperature and stratification closure to the experiment).

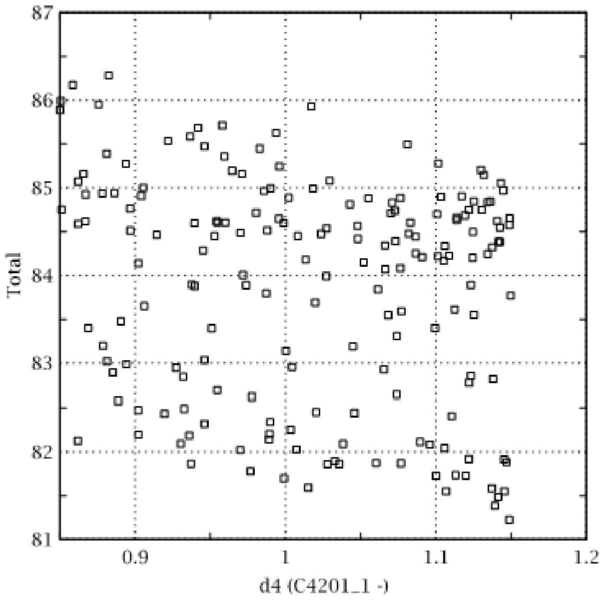




COMPARE WP3 - MELCOR UQ

- The next step of the study was to perform Uncertainty Quantification analyses to highlight the most impacting parameters
- The table below presents the list of parameters selected for the study based on previous work and literature study.
- The figures presents examples of weak and strong correlation





Correlation coefficients calculated for all uncertain parameters in calculation v18_6_2_UQ5

COMPARE WP3 - MELCOR UQ

	Default	Distribution Parameters	Model Variables	Model	parameter
d1	0.9995	a:0.9, b:0.9999	C4200_1	Mass Transfer Flux Model Transition Parameter	Ratio of steam partial pressure to total pressure in bulk atmosphere.
d2	0.023	a:0.0184, b:0.0276	C4117_1	Atmosphere Forced Convection / 17 for turbulent correlations for cylindrical geometries in internal flow	Constant multiplicator
d3	0.8	a:0.78, b:0.85	C4117_2	Atmosphere Forced Convection / 17 for turbulent correlations for cylindrical geometries in internal flow	Ra exponent
d4	1.0	a:0.85, b:1.15	C4201_1	Sherwood Number for Diffusion Mass Transfer	Constant multiplicator
d5	1.0	a:1.05, b:1.3	C4201_2	Sherwood Number for Diffusion Mass Transfer	Nu exponent
d6	4.363	a:3.9267, b:4.7993	C4114	Atmosphere Forced Convection / 14 for laminar correlations for cylindrical geometries in internal flow	Constant multiplicator
d7	0.046	a:0.414, b:0.506	C4102_1	Atmosphere Natural Convection / 02 for laminar correlations for cylindrical geometries in internal flow	Constant multiplicator
d8	0.333	a:0.2997, b:0.3663	C4102_2	Atmosphere Natural Convection / 02 for laminar correlations for cylindrical geometries in internal flow	Ra exponent
d9	0.046	a:0.414, b:0.506	C4105_1	Atmosphere Natural Convection / 05 for turbulent correlations for cylindrical geometries in internal flow	Constant multiplicator
d10	0.333	a:0.2997, b:0.3663	C4105_2	Atmosphere Natural Convection / 05 for turbulent correlations for cylindrical geometries in internal flow	Ra exponent
d11	0.333	a:0.2997, b:0.3663	C4117_3	Atmosphere Forced Convection / 17 for turbulent correlations for cylindrical geometries in internal flow	Pr exponent
d12	0.333	a:0.2997, b:0.3663	C4201_3	Sherwood Number for Diffusion Mass Transfer	Sc exponent
d13	-0.333	a-0.3663, b:-0.2997	C4201_4	Sherwood Number for Diffusion Mass Transfer	Pr exponent
d14	2000.0	a:2000.0, b:3000.0	C4085_1	Pool Laminar and Turbulent Forced Convection Ranges	Cylindrical geometry / Reynolds number upper limit for pool laminar forced convection
d15	10000	a9000.0,b:11000.0	C4085_2	Pool Laminar and Turbulent Forced Convection Ranges	Cylindrical geometry / Reynolds number lower limit for pool turbulent forced convection
d16	1	a:0.9, b:1.1	C4060_1	Atmosphere Natural and Forced Convection Ranges	Constant coefficient
d17	10	a:9.0, b:11.0	C4060_2	Atmosphere Natural and Forced Convection Ranges	Constant coefficient
d18	1.0E10	a:9.0E9, b:1.1E10	C4062_1	Atmosphere Laminar and Turbulent Natural Convection Ranges	Cylindrical geometry / Rayleigh number upper limit for atmosphere laminar natural convection
d19	1.0E11	a:9.0E10, b:1.1E11	C4062_2	Atmosphere Laminar and Turbulent Natural Convection Ranges	Cylindrical geometry / Rayleigh number lower limit for atmosphere turbulent natural convection
d20	2000.0	a:2000.0, b:3000.0	C4065_1	Atmosphere Laminar and Turbulent Forced Convection Ranges	Cylindrical geometry / Reynolds number upper limit for atmosphere laminar forced convection
d21	1.0E5	a:90000.0, b:1.1E5	C4065_2	Atmosphere Laminar and Turbulent Forced Convection Ranges	Cylindrical geometry / Reynolds number lower limit for atmosphere turbulent forced convection
d22	1	a:0.5, b:3.5	Loss	Reverse and forward los coeffciant on all flow paths	

COMPARE WP3 - MELCOR UQ

- From the preliminary UQ study we saw that one parameter is strongly correlated with the steam mass, namely d5 (SC4201_2) and potentially d4 (SC4201_1).

4201 – Sherwood Number for Diffusion Mass Transfer

A Sherwood Number Correlation calculates a diffusion mass transfer coefficient. The correlation has the following form:

$$Sh = C4201(1) x Nu^{C4201(2)} x Sc^{C4201(3)} x \, Pr^{C4201(4)}$$

Where:

Nu = Nusselt number Sc = Schmidt number Pr = Prandtl number.

C4201(1) Constant coefficient.

(default = 1.0, units = none, equiv = none)

C4201(2) Nusselt number exponent.

(default = 1.0, units = none, equiv = none)

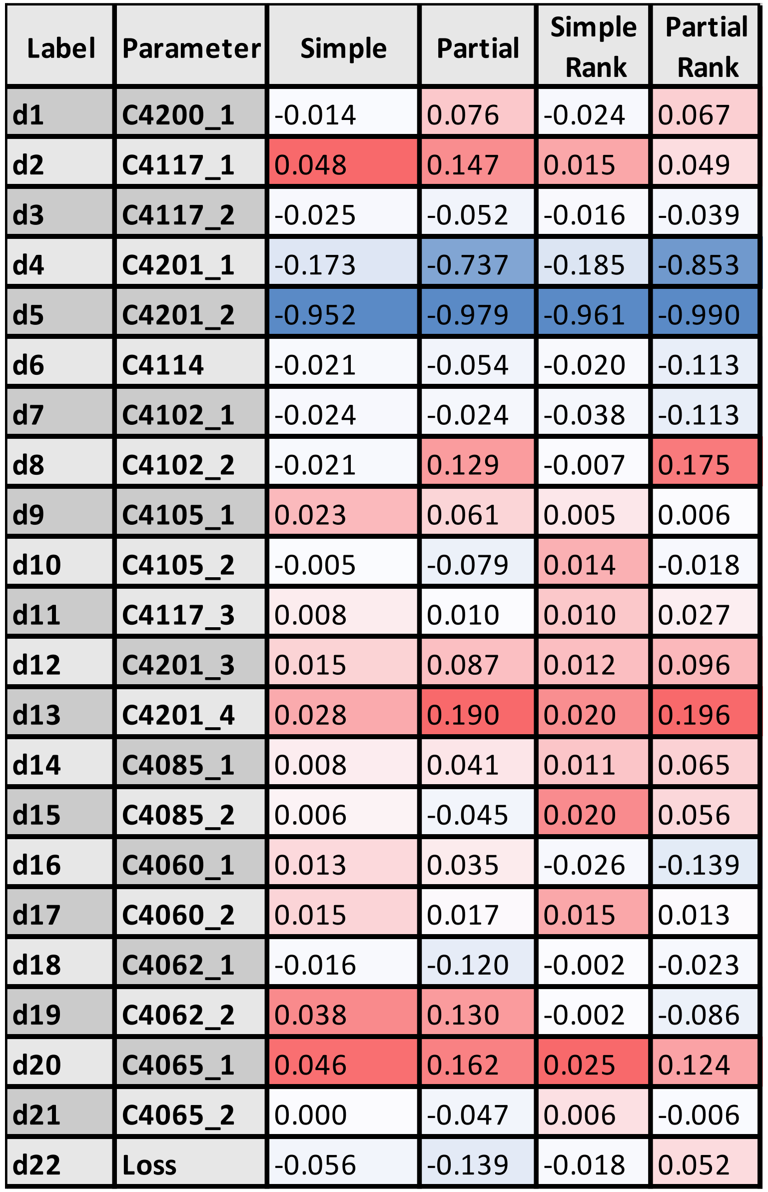
C4201(3) Schmidt number exponent.

(default = 1/3, unit = none, equiv = none)

C4201(4) Prandtl number exponent.

(default = -1/3, units = none, equiv = none)

Corelation coefficients calculated for all uncertain parameters in calculation v18_6_2_UQ5

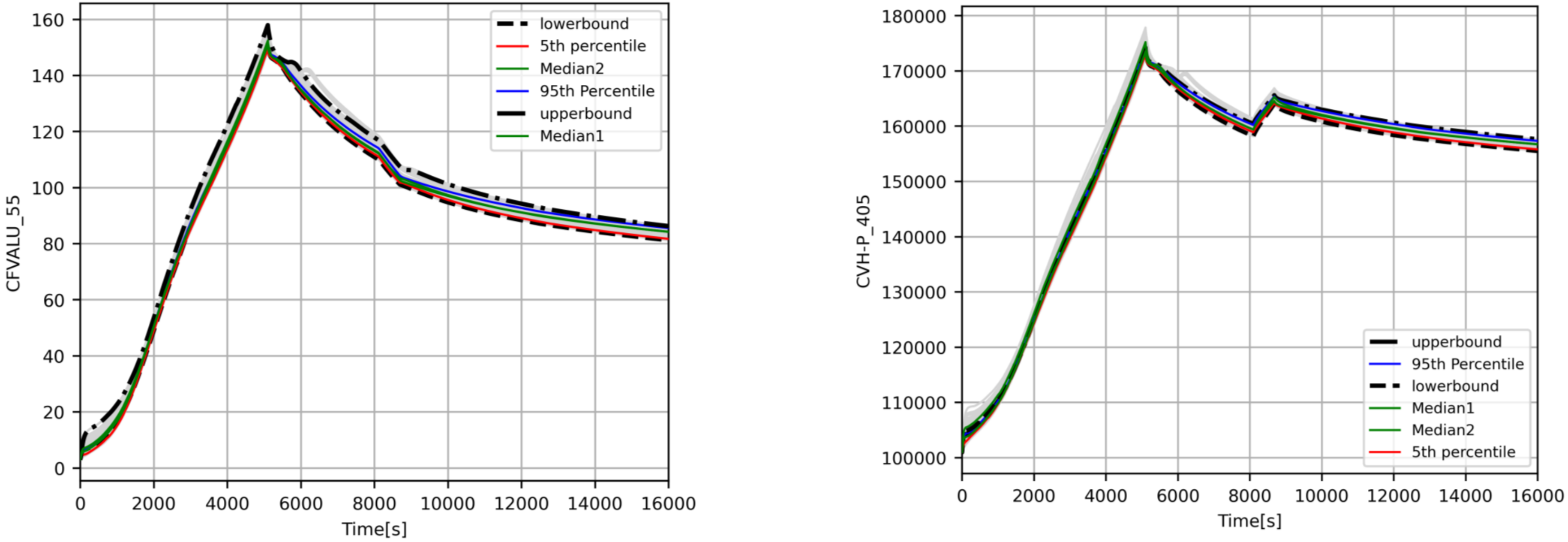


Label	Parameter	Simple	Partial	Simple Rank	Partial Rank
d1	**C4200_1**	-0.014	0.076	-0.024	0.067
d2	**C4117_1**	0.048	0.147	0.015	0.049
d3	**C4117_2**	-0.025	-0.052	-0.016	-0.039
d4	**C4201_1**	-0.173	-0.737	-0.185	-0.853
d5	**C4201_2**	-0.952	-0.979	-0.961	-0.990
d6	**C4114**	-0.021	-0.054	-0.020	-0.113
d7	**C4102_1**	-0.024	-0.024	-0.038	-0.113
d8	**C4102_2**	-0.021	0.129	-0.007	0.175
d9	**C4105_1**	0.023	0.061	0.005	0.006
d10	**C4105_2**	-0.005	-0.079	0.014	-0.018
d11	**C4117_3**	0.008	0.010	0.010	0.027
d12	**C4201_3**	0.015	0.087	0.012	0.096
d13	**C4201_4**	0.028	0.190	0.020	0.196
d14	**C4085_1**	0.008	0.041	0.011	0.065
d15	**C4085_2**	0.006	-0.045	0.020	0.056
d16	**C4060_1**	0.013	0.035	-0.026	-0.139
d17	**C4060_2**	0.015	0.017	0.015	0.013
d18	**C4062_1**	-0.016	-0.120	-0.002	-0.023
d19	**C4062_2**	0.038	0.130	-0.002	-0.086
d20	**C4065_1**	0.046	0.162	0.025	0.124
d21	**C4065_2**	0.000	-0.047	0.006	-0.006
d22	**Loss**	-0.056	-0.139	-0.018	0.052

COMPARE WP3 - MELCOR UQ example of preliminary results

Basic statistics from v18_6_2_UQ5 calculation for total steam mass.

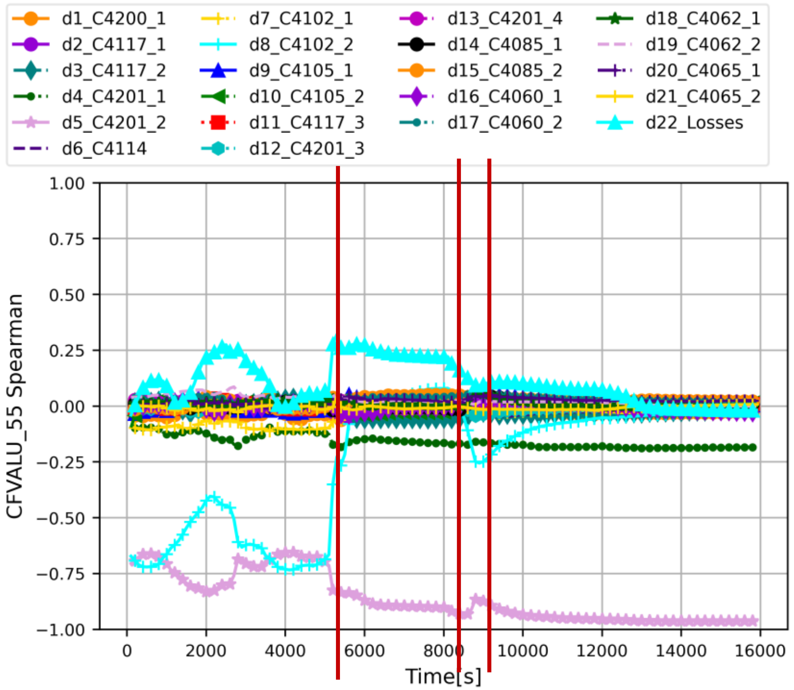
Summary	Value	Task #
Min Value	81.2217	26
Max Value	86.28165	141
Mean	83.8495	-
Median	84.24734	average of 157 and 126
Standard Deviation	1.27	-
Coefficient of Variance	-0.38766	-

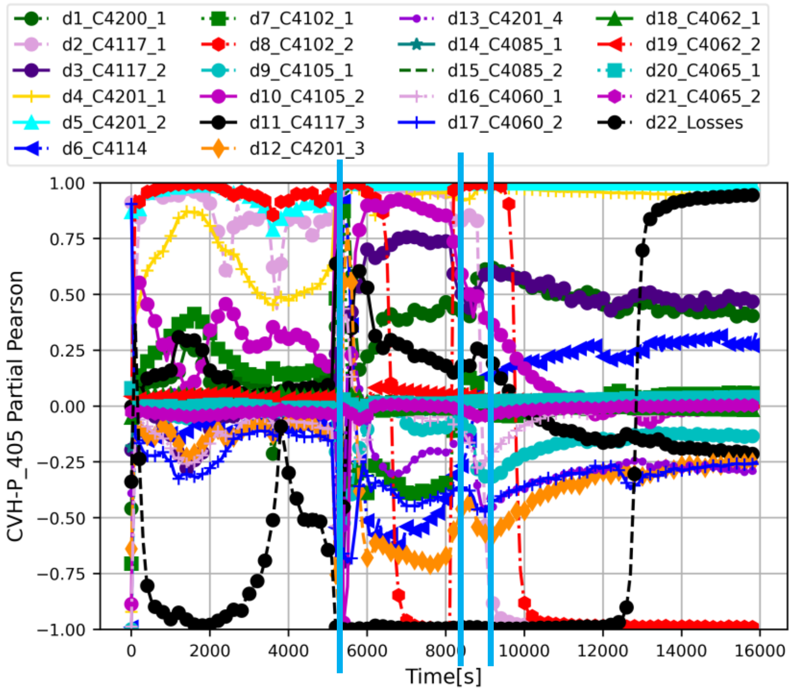


Dispersion figures of total steam mass evolution on the left and pressure on the right.

COMPARE WP3 - MELCOR UQ example of preliminary results

- Correlation are changing dependently on the test phase and analyses of those behaviours could be essantial for further code improvments





Corelation coeficients for totall steam mass (CFVALUE_55) and Pressure (CVH-P_405)

SUMMARY

- The MELCOR input deck sensitivity study of HYMERES HP6_2 was conducted
- The input deck analyses will be continued depending on the future findings
- Preliminary results show:
  - Strong impact of the nodalization and flow paths on the obtained results
  - Despite significant improvements of the calculations, discrepancies compared to the experiment are still not negligible
  - Preliminary UQ analyses show limited impact on the results and highlight only one influential parameter (further analyses is needed)

- As the project is ongoing and presented discrepancies reflect only a preliminary findings no conclusions should be made at that stage of the study.

Acknowlagement

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Eidgenössisches Nuklearsicherheitsinspektorat ENSI
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Wir schaffen Wissen – heute für morgen

Thank you for your attention