SAND2019-6026C

MELCOR V2.2 PERSEO Experiment 7.1 Benchmark Results

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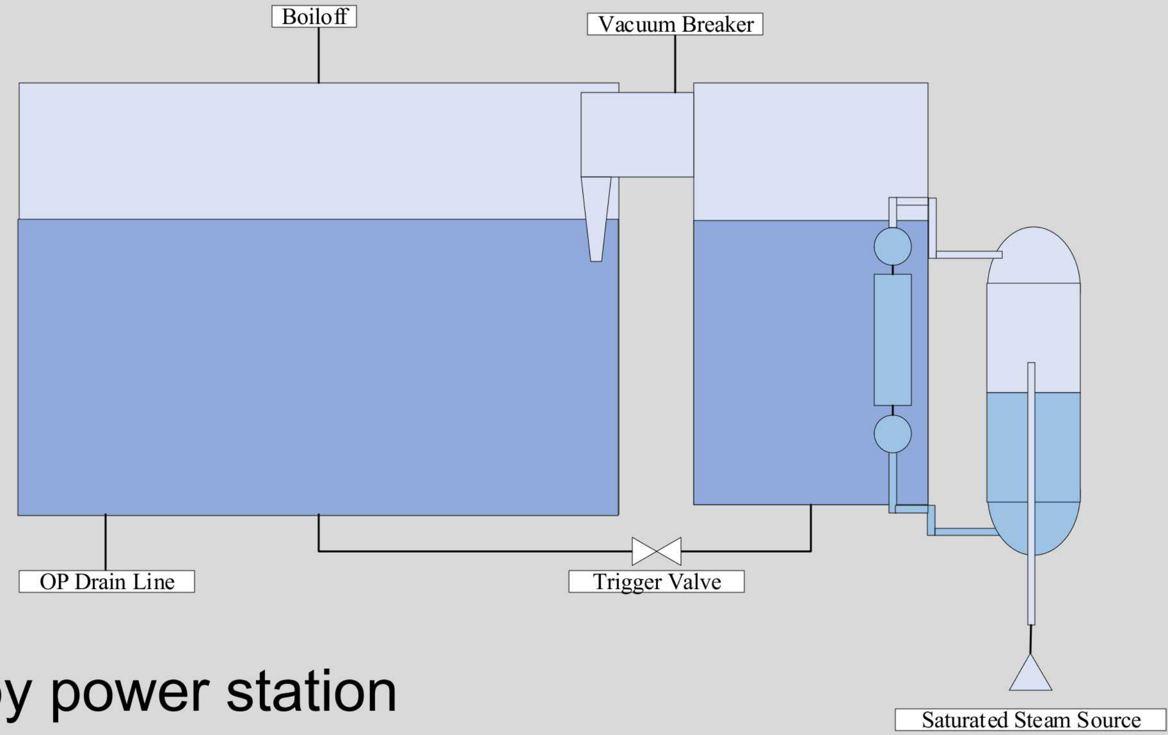
In-Pool Energy Removal System for Emergency Operation (**PERSEO**) Facility Description

- Primary Side
  - RPV (with vertical riser, steam separator, and dryer)
  - Steam Line
  - Heat Exchanger
  - Drain Line
- Secondary Side
  - Overall Pool
  - Steam Duct
  - Injector nozzle
  - Heat Exchanger Pool
  - Liquid Line
- Steam supplied by nearby power station



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Overview

- Goals
  - Benchmark MELCOR against PERSEO experiment
  - Report on the current status of MELCOR modelling capabilities relevant to phenomena observed at PERSEO facility
  - Identify potential improvements to heat transfer and natural circulation modelling capabilities in MELCOR
- Motivation
- PERSEO Model Description
  - Nodalization
  - Initial and boundary conditions
- PERSEO Test 7 Part I
  - Test description
  - Results
- Summary
- Future Work

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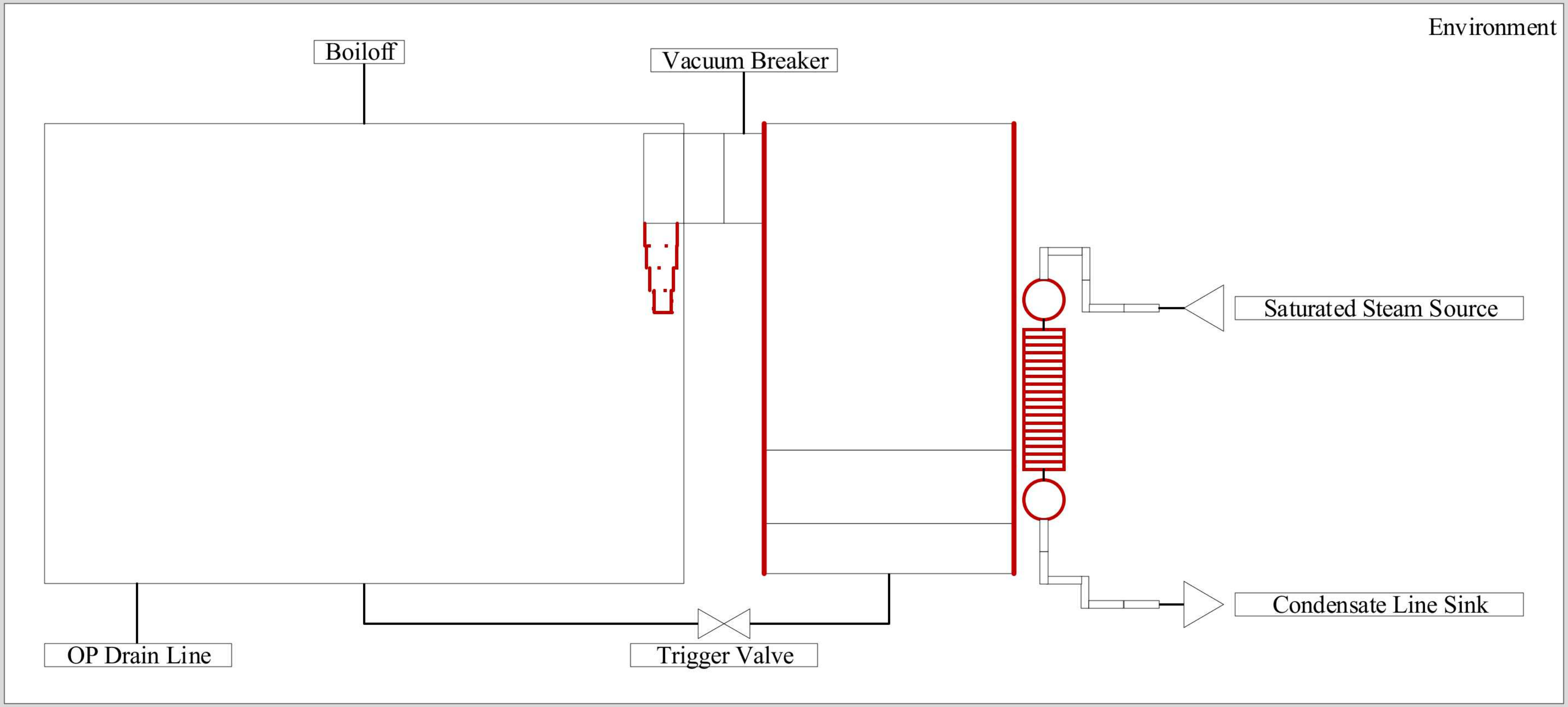
Motivation

- Natural convection is essential to the safe operation of Gen III+ and Gen IV reactor design components – including safety systems
  - Small modular reactors (SMRs), GE ESBWR, Westinghouse AP-600, Lead-cooled fast reactor (LFR)
- MELCOR does not currently treat natural convection explicitly

- Benchmark MELCOR V2.2 against the PERSEO facility experiments (ENEA)
  - Heat transfer in a full scale heat exchanger submerged in a liquid pool, the coupling process between two pools connected through a natural circulation circuit, and pool phenomena

PERSEO Model Nodalization



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PERSEO Test I Description

Relevant Thermal Hydraulic aspects	Experiment Time(s)	Experiment Quantity	MELCOR Time(s)	MELCOR Quantity
Triggering valve (F045) opening and closure	10475 - 10608	-	10471 s – 10601 s	-
Triggering valve (F045) re-opening and re-closure	10621 - 10655	-	10622 s – 10649 s	-
Maximum level in the HX Pool for the first filling step	10683	1.41 m	10649 s	1.41 m
Small Heat removal from the primary side	10600 – 11000	3.5 MW	10630 s – 11056 s	~ 1.9 MW
Slow water consumption in the HX Pool	11049	From 1.41 m to 1.4 m	Not observed	Not observed
Instabilities for steam condensation in the Injector	10930 - 11290	Negative HXP relative pressure	Not observed	Not observed
Triggering valve (F045) opening and closure	11039 - 11260	-	11039 - 11264 s	-
Maximum level in the HX Pool	11050	3.4 m	11260 s	3.4 m
Maximum exchanged power	11260 – 11845	21.5 MW	11263 s	21 MW
HX Pool minimum level	14800	1.25 m	14784 s	1.13 m
OP average temperature	13000	around 55 °C	13000 s	59 C

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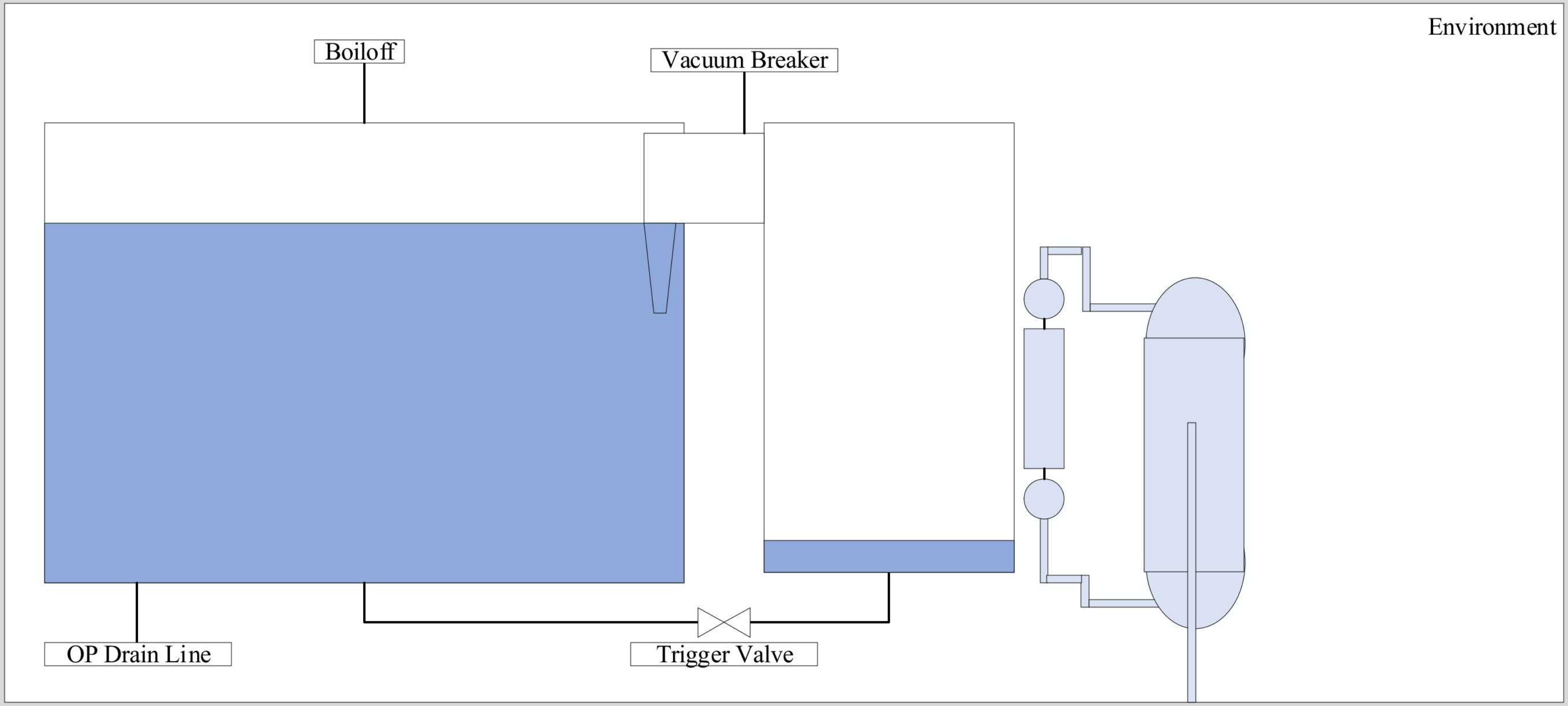
Test 7 Part I Description



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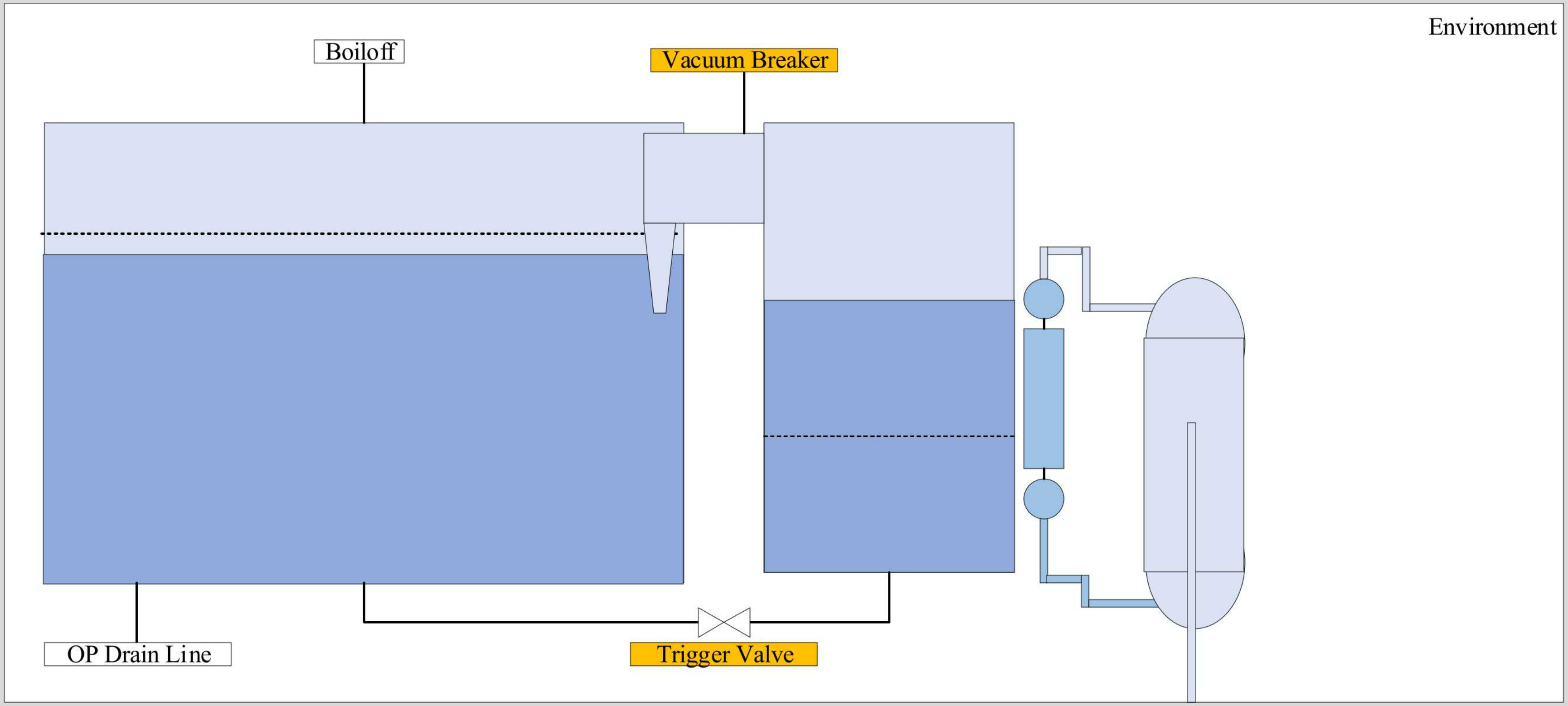

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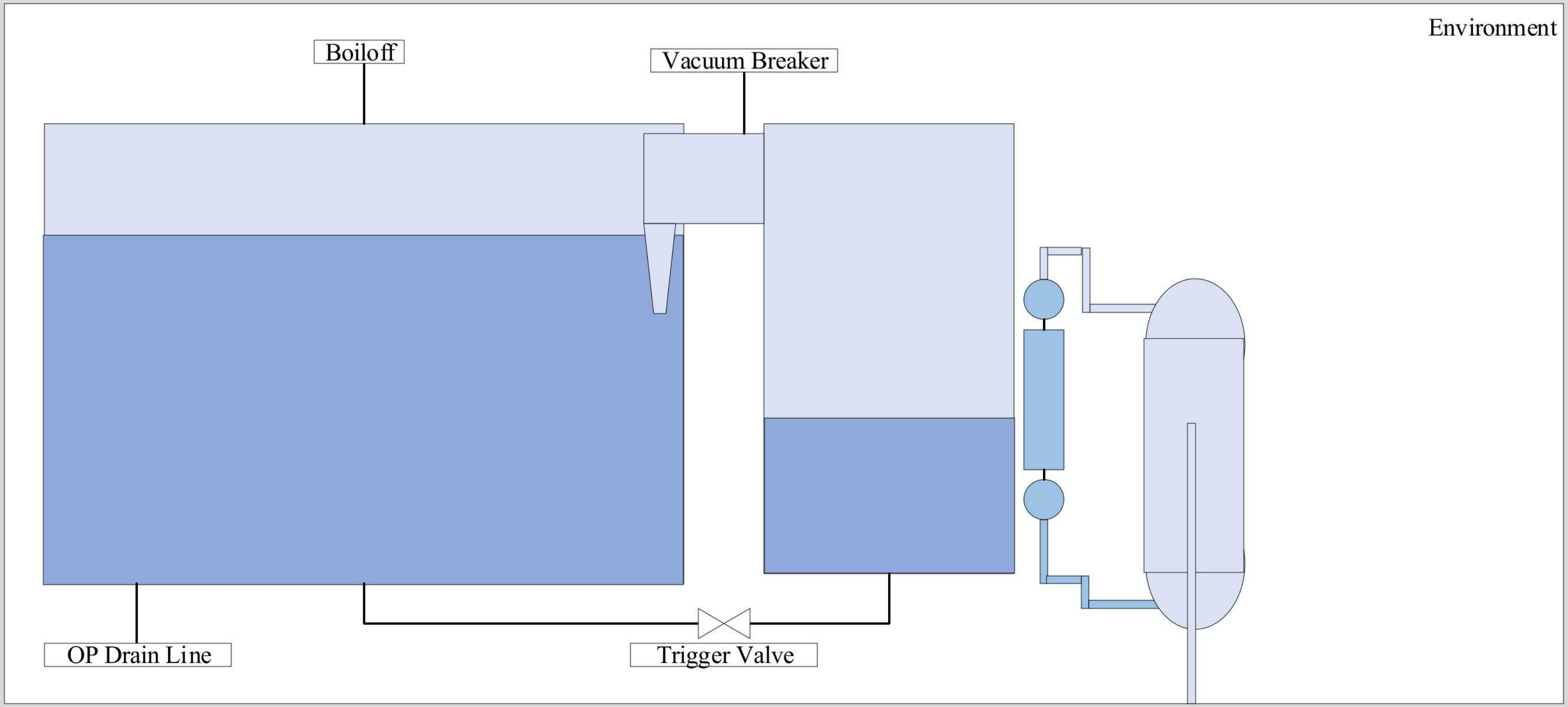
Lucas Albright I University of Utah Nuclear Engineering Program I www.nuclear.utah.edu

Test 7 Part I Description



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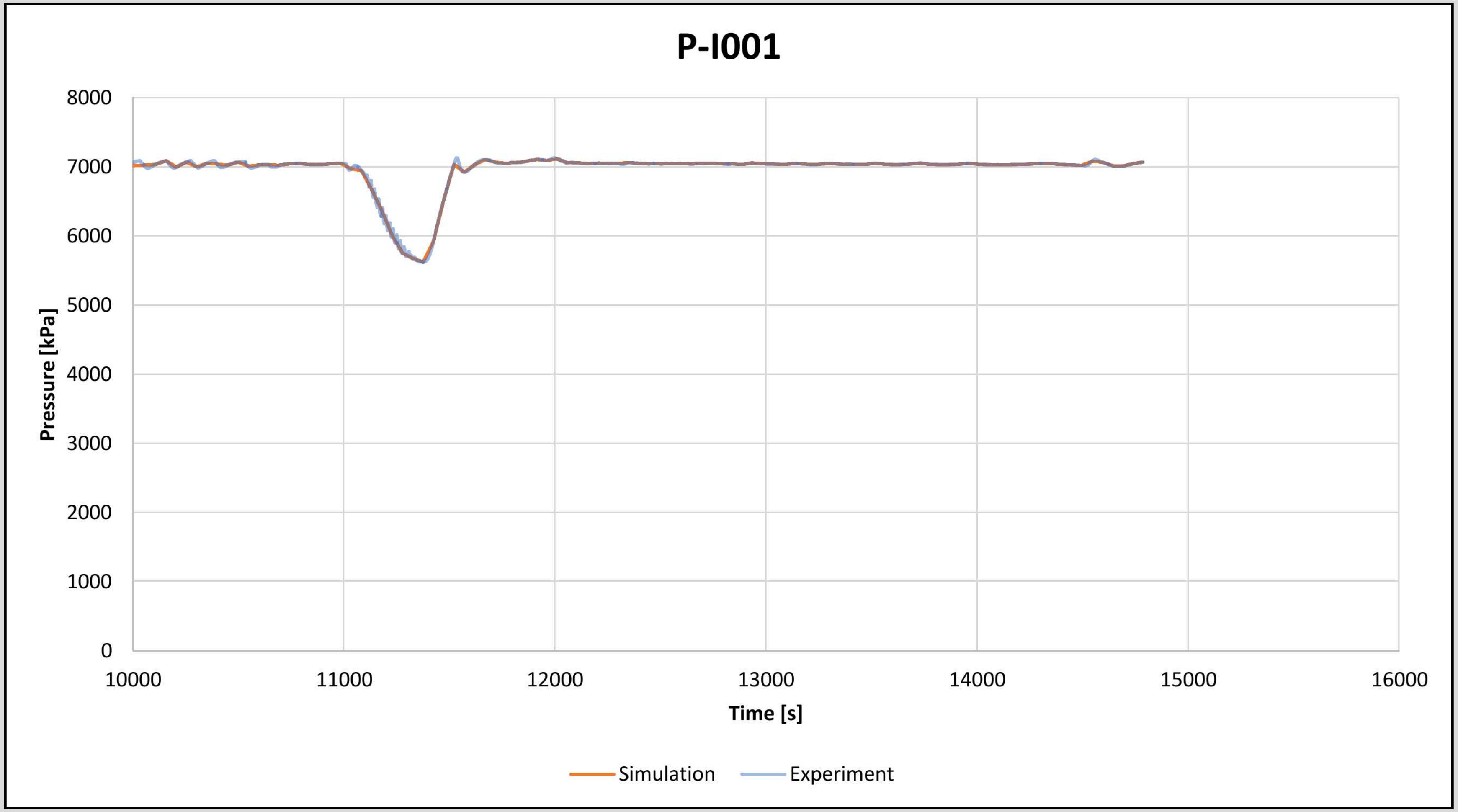
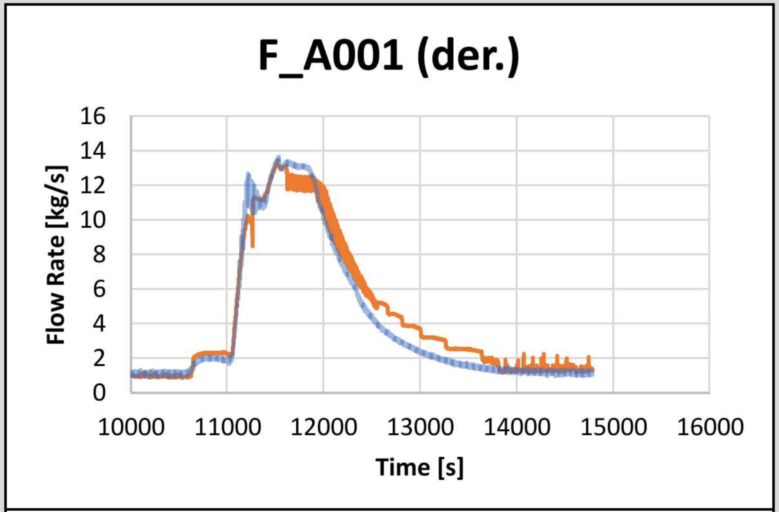
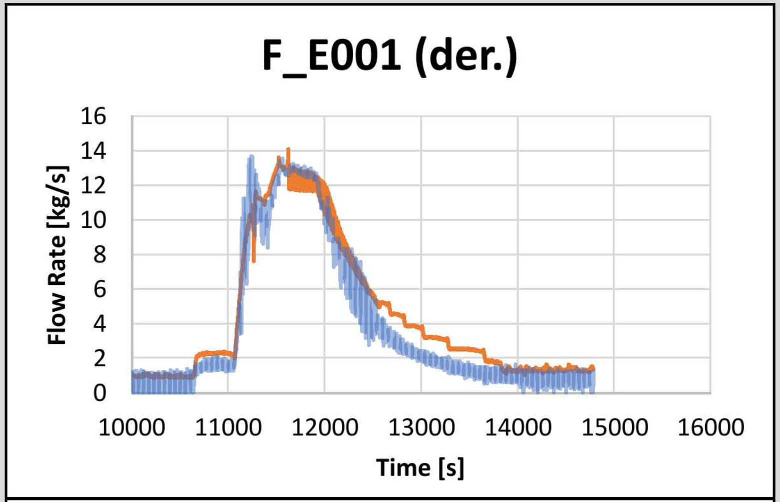
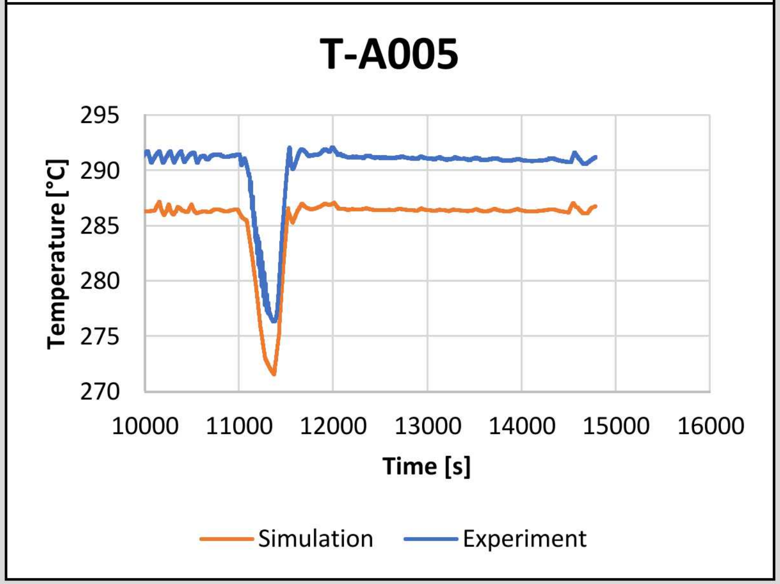
Test 7 Part I: Primary Pressure

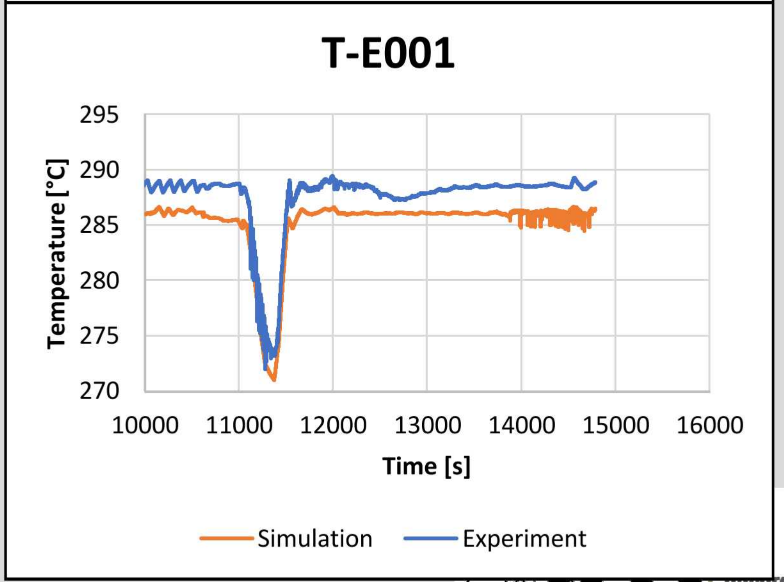


Test 7 Part I: Primary Flow

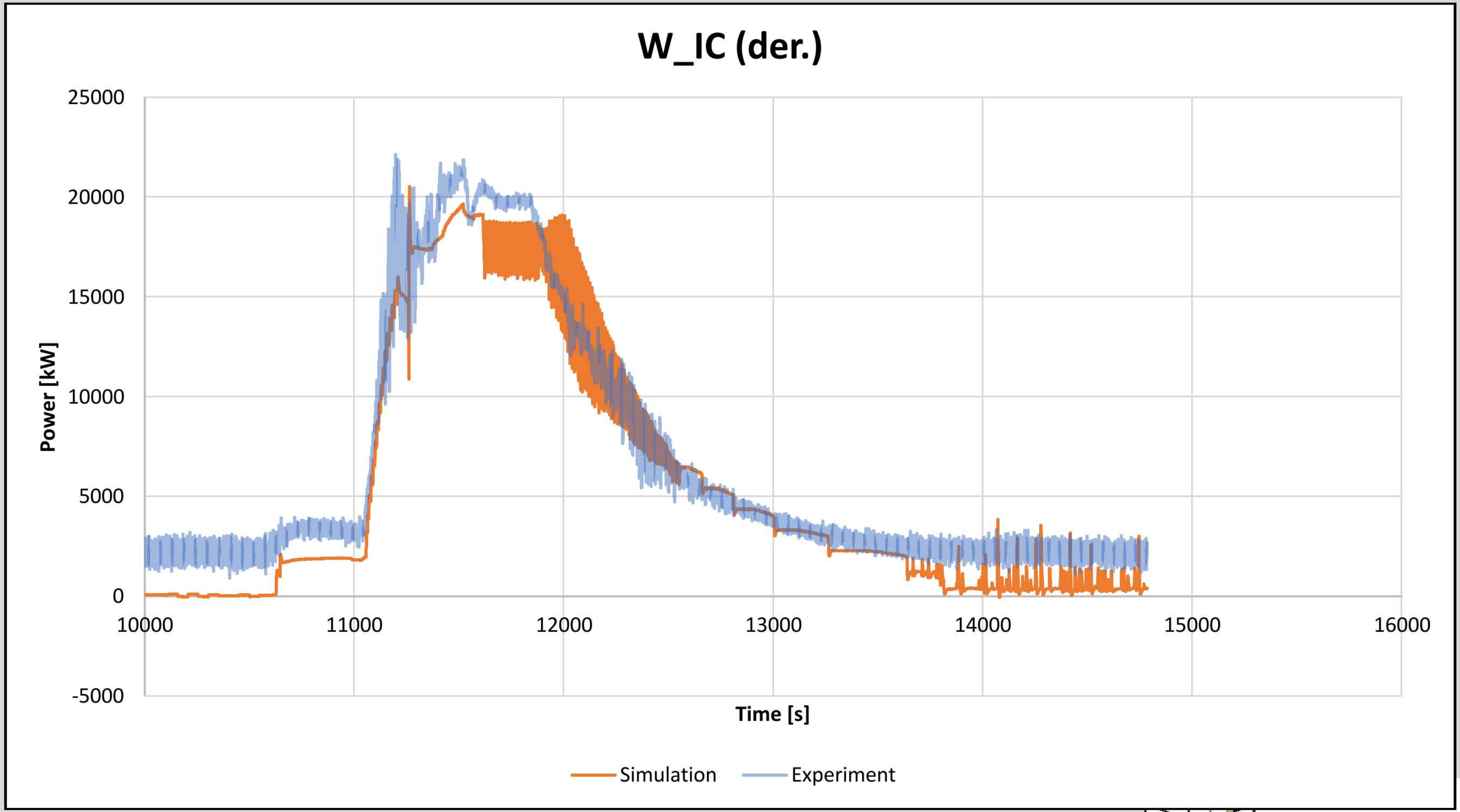








Test 7 Part I: Exchanged Power



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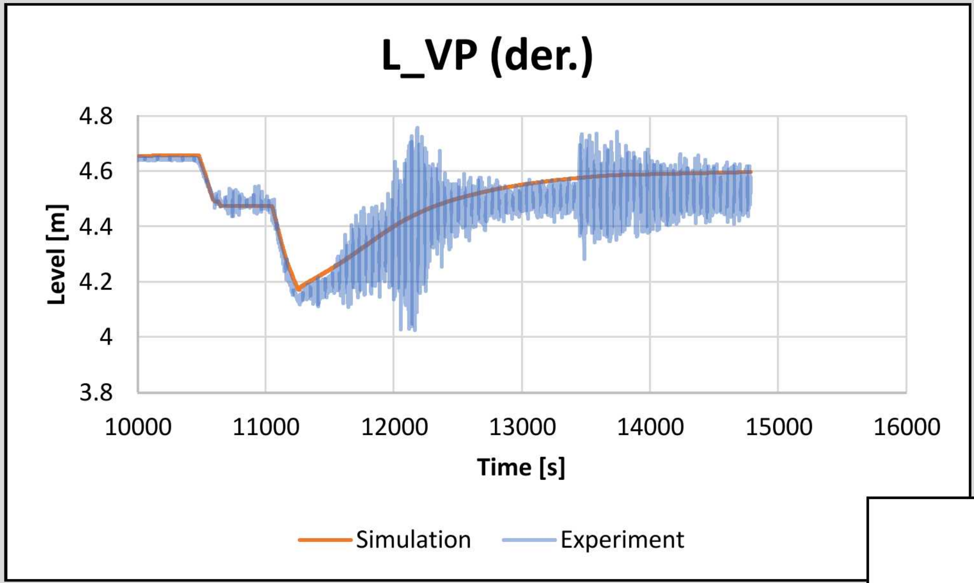
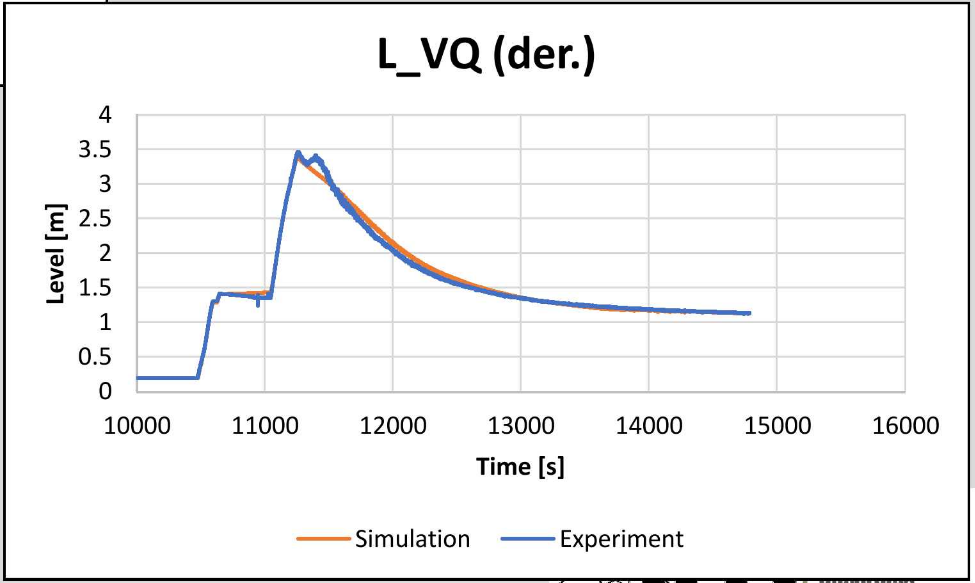
Test 7 Part I: Secondary Water Levels





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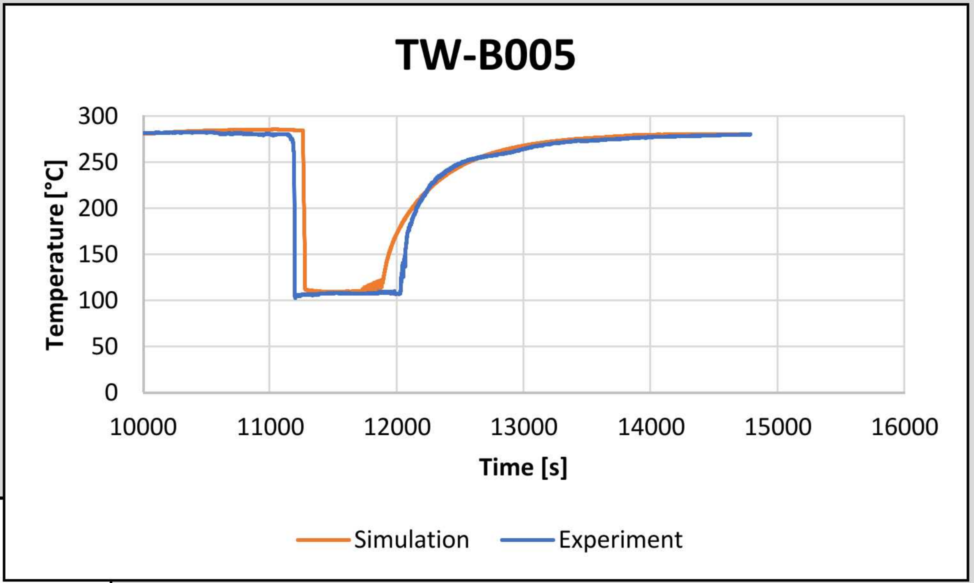
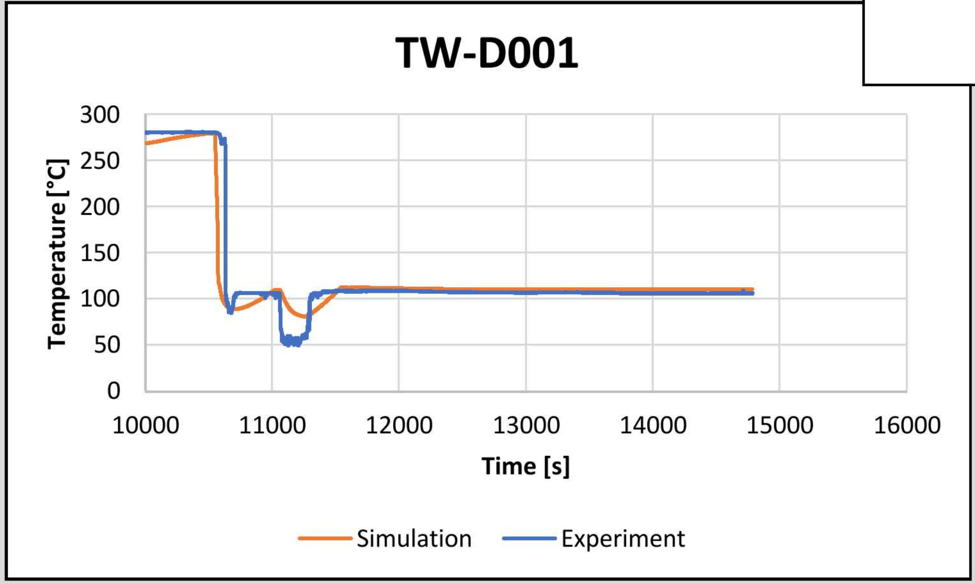
Test 7 Part I: Heat Exchanger Temperatures





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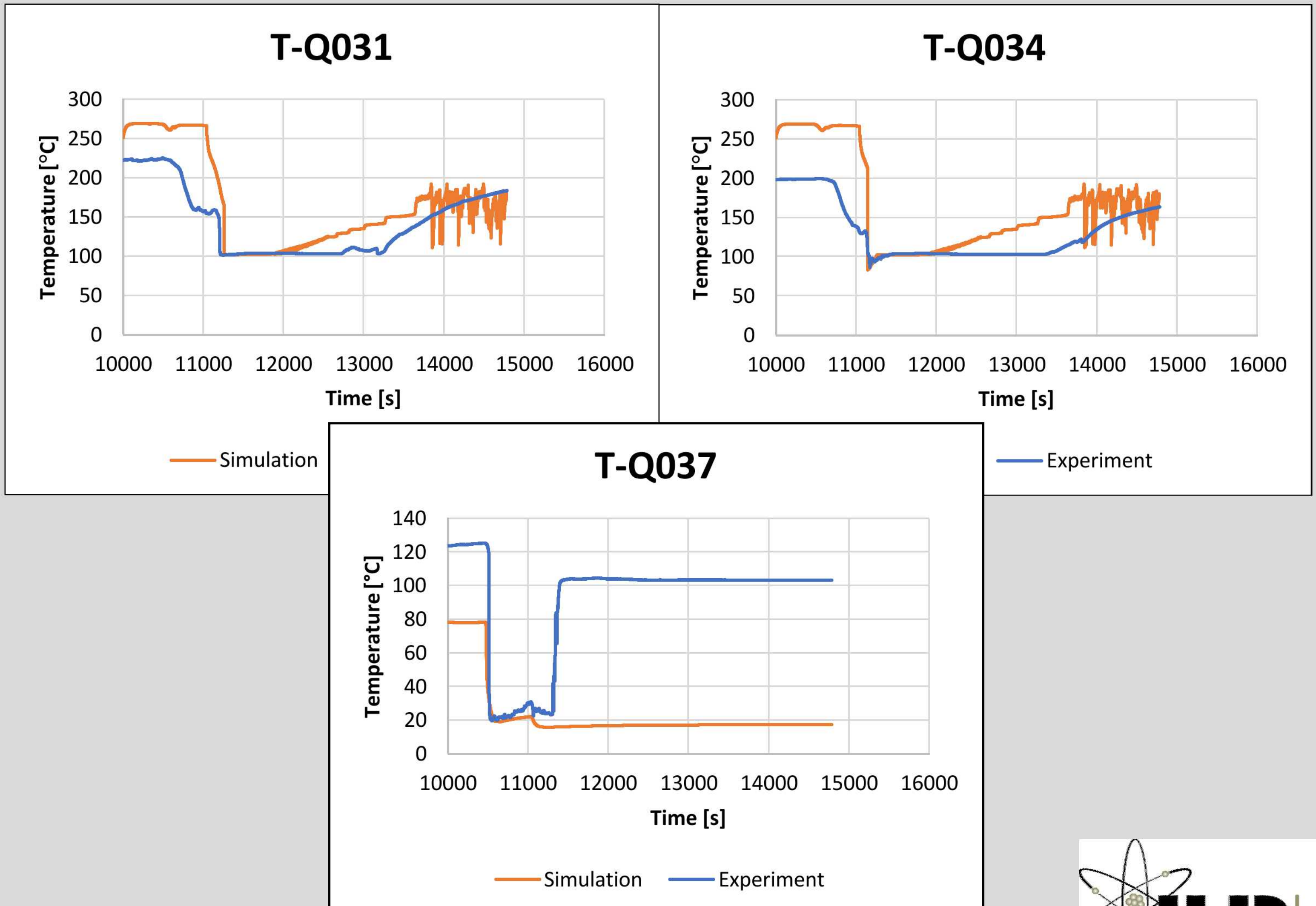
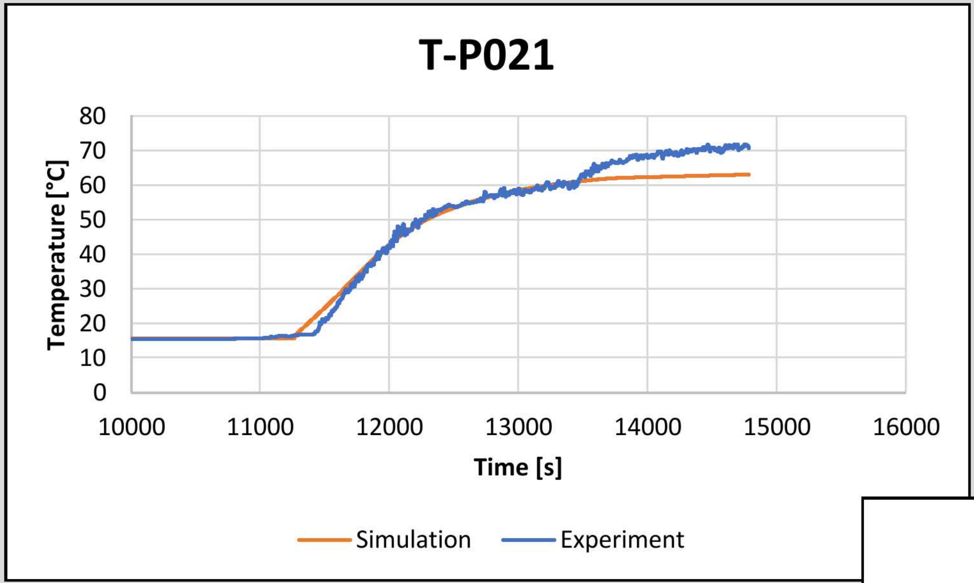
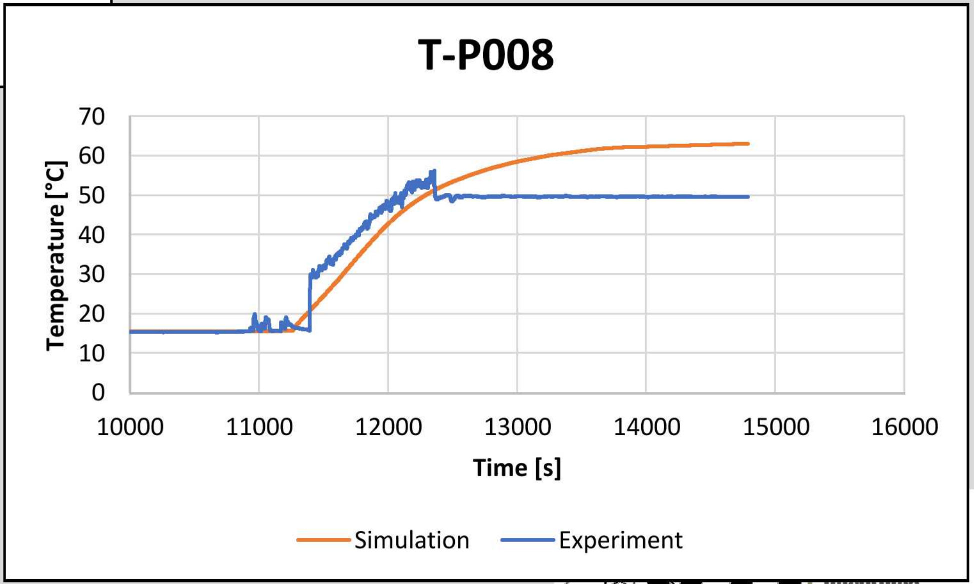
Test 7 Part I: Heat Exchanger Pool Temperatures



Test 7 Part I: Overall Pool Temperatures





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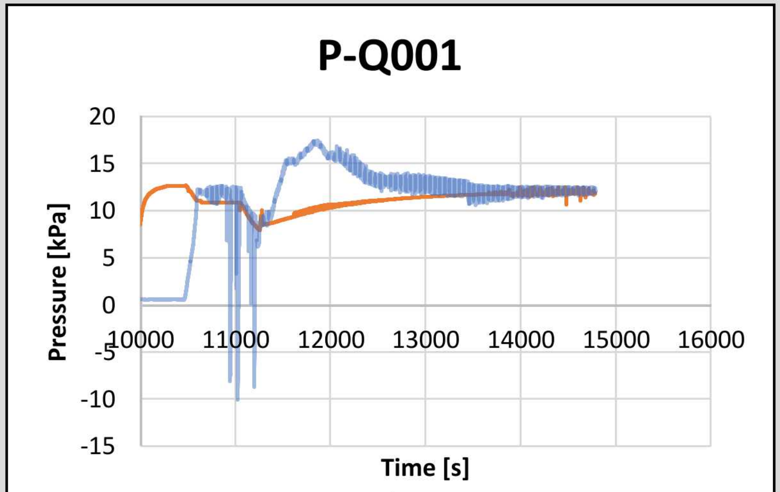
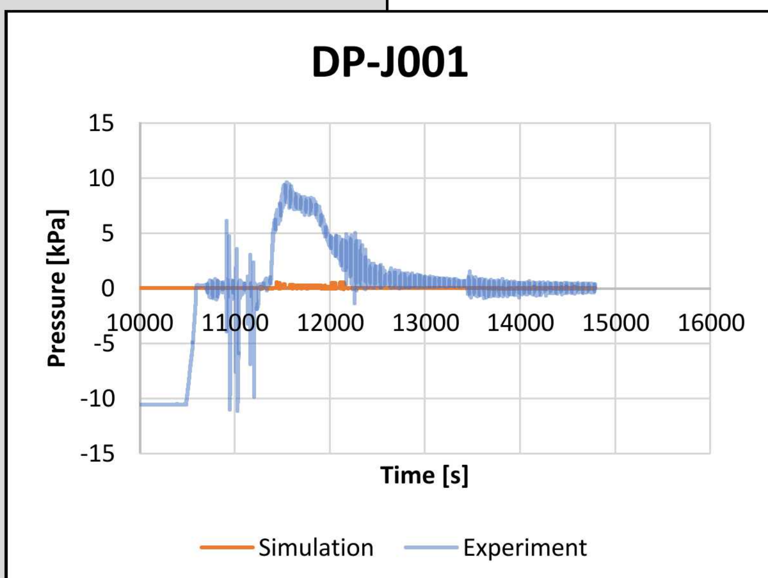
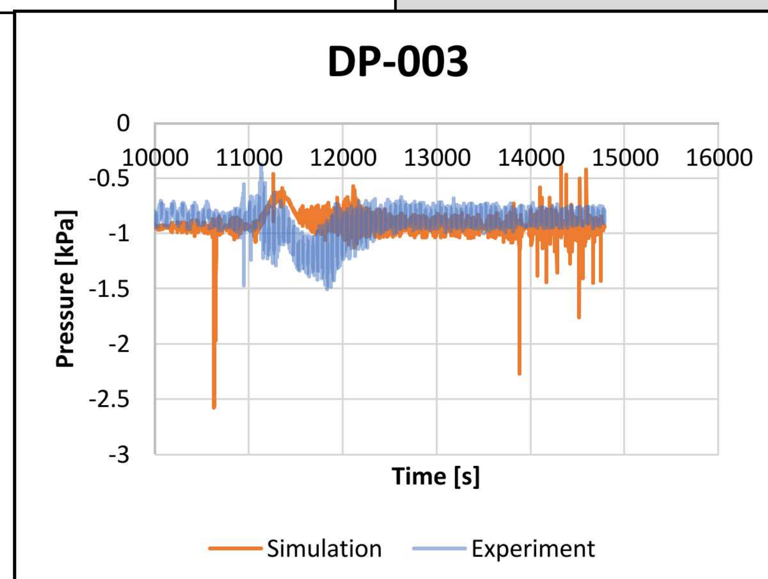
Test 7 Part I: Secondary Pressures







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Summary

- Without tuning by the user, the MELCOR model underestimates heat transfer through the heat exchanger tubes
  - Identified modeling gaps include the absence of axial conduction between heat structures modeling the heat exchanger tubes and a subcooled pool boiling correlation
- To correct this underestimation the number of heat exchanger tubes was increased from 120 to 180
- Key experimental results were reproduced with good agreement after tuning by the user
- Difficulty replicating differential pressures through the nozzle, and relative pressures in the heat exchanger pool remained even after model tuning

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Summary

- MELCOR has no dedicated models to capture the behavior of the injector component
- The injector is modeled as concentric cylinders of decreasing radii
- In the absence of such models, flow through the injector nozzle and related pressures could not be captured accurately

- The nodalization scheme adopted for this analysis underlines the importance of not defining artificial, non-physical natural circulation loops in MELCOR, which uses the control volume approach to capture “average” behaviors. It also recognized the possibility of the existence of “floating pools” if axial control volumes are improperly applied under boiling conditions.

Future Work

- Leverage current MELCOR modelling developments to improve the PERSEO benchmark case
  - Axial conduction between heat structures
- Identify and test appropriate subcooled pool boiling correlation

Acknowledgments

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- This material is based upon work supported under an Integrated University Program Graduate Fellowship. Any opinions, findings, conclusions or recommendations expressed in this publication are those of the author(s) and do not necessarily reflect the views of the Department of Energy Office of Nuclear Energy
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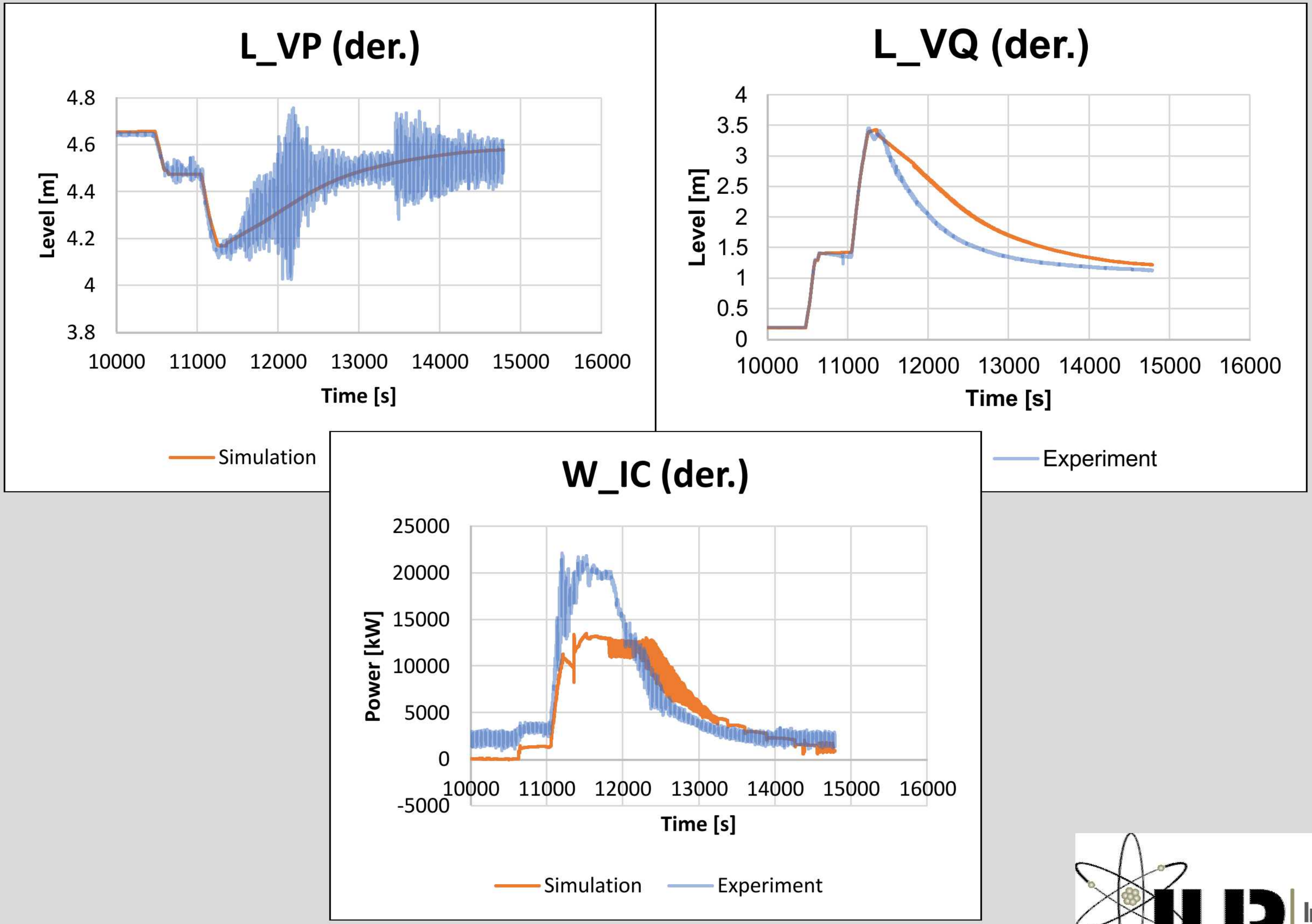
Thank you for your attention

Underestimated Heat Transfer: 120 HX Tubes



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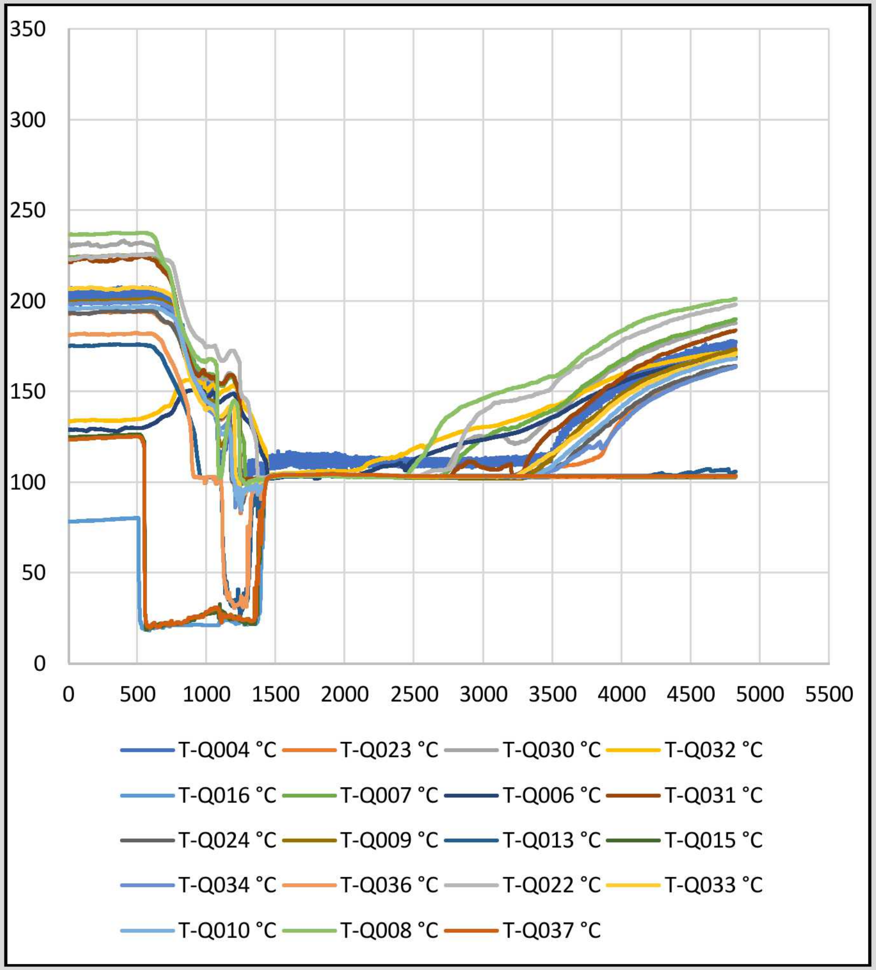
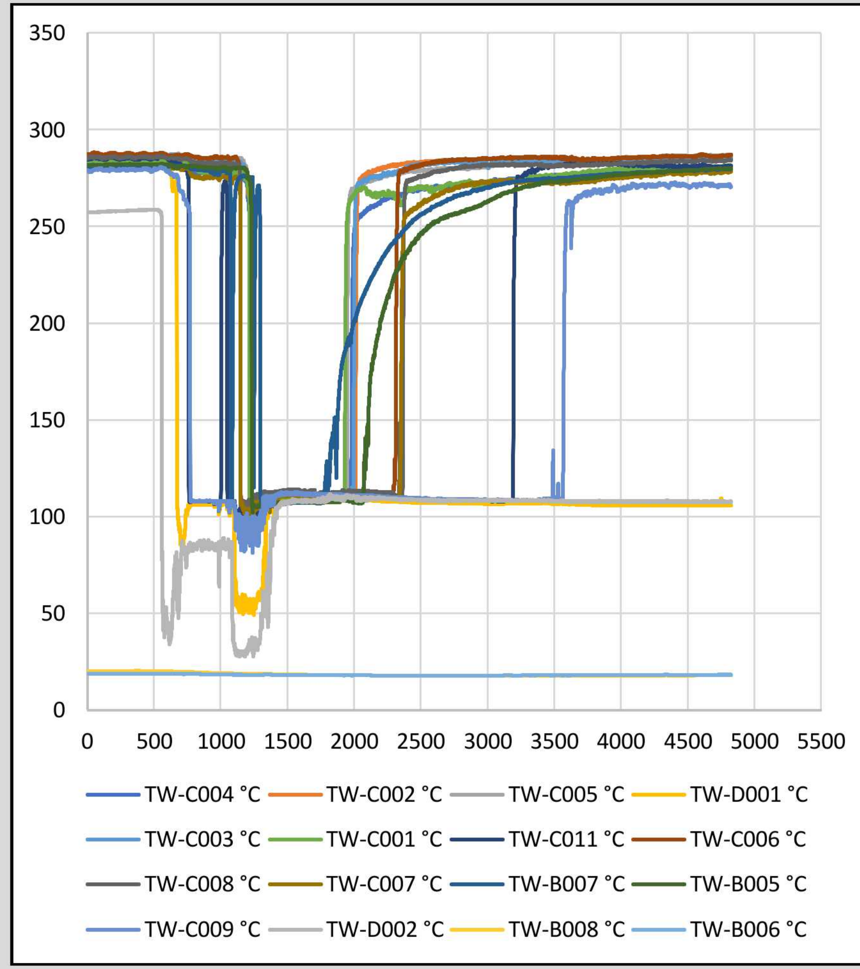
Heat Exchanger

Internal Heat Transfer Area HX (m2)	12.571 (total) 6.155 (upper header) 47.012 (HX tubes) 6.155 (lower header)
External Heat Transfer Area HX (m2)	15.507 (total) 7.610 (upper header) 51.710 (HX tubes) 7.610 (lower header)
HX heat structure axial nodes number	1 (upper header) 18 (HX tubes) 1 (lower header)
HX heat structure radial nodes number	4

Heat Exchanger Pool and Wall Temperatures





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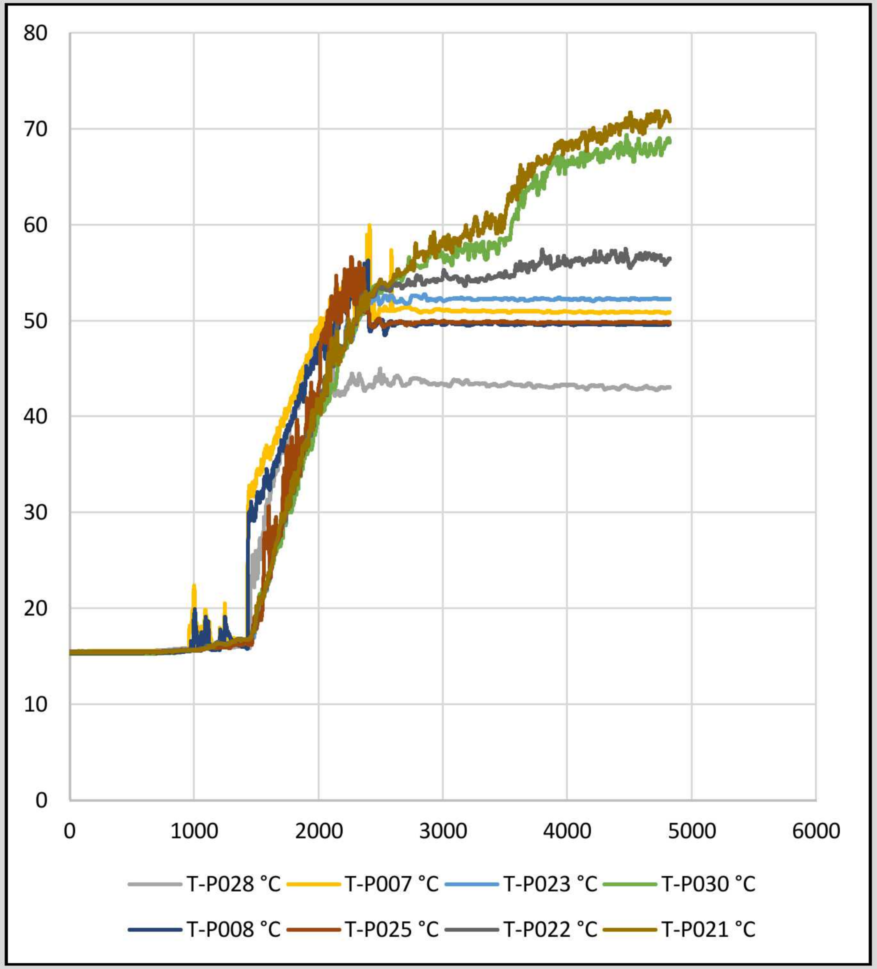
Overall Pool Temperatures



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MELCOR Model of the PERSEO Facility

	Number of hydraulic volumes	Number of junctions	Number of heat structures	Overall Volume (m3)
Vessel	Not modeled			
Steam Supply Line	1	1	0	0.32
Steam Line	6	6	0	1.4331
HX	20	20	22	1.83984
Condensate line	6	6	0	0.4947
HXP	3	3	3	26.55564
Steam duct	3	3	0	12.22198
Nozzle	1	1	4	0.41
OP	1	3	0	172.91

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MELCOR "Tuning"

Parameter	MELCOR SC ID	Parameter Value	Description
Atmosphere Natural and Forced Convection Ranges	4060	-1.0	Convection heat transfer to the atmosphere is assumed to be given by the greater of the values defined by the natural and forced convection correlations.
Pool Natural and Forced Convection Ranges	4080	-1.0	Convection heat transfer to the pool is assumed to be given by the greater of the values defined by the natural and forced convection correlations.
Pool Laminar and Turbulent Natural Convection Ranges	4082	-1.0	Natural convection heat transfer to the pool is assumed to be given by the greater of the values defined by the laminar and turbulent natural convection correlations.
Pool Laminar and Turbulent Forced Convection Ranges	4085	-1.0	Forced convection heat transfer to the pool is assumed to be given by the greater of the values defined by the laminar and turbulent forced convection correlations.

MELCOR "Tuning"

Parameter	MELCOR SC ID	Parameter Value	Description
Minimum Boiling Heat Flux Coefficient	4182	0.177	Minimum boiling heat flux coefficient (default = 0.09)
Pool Natural Convection Coefficient	4161	0.15	Pool natural convection heat transfer correlation coefficient, C, for turbulent natural convection external to a cylindrical surface. (default = 0.10)
Atmospheric Natural Convection Coefficient	4111	0.15	Atmospheric natural convection heat transfer correlation coefficient, C, for turbulent natural convection external to a cylindrical surface. (default = 0.10)
Heat exchanger tube multiplier	-	180.0	To increase heat transfer along the heat exchanger tubes, the number of heat exchanger was artificially increased from 120 to 180.

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Test 7 Part I Initial Conditions

Parameter	Initial Condition
Primary	
Control volume pressure	Approximated based on the available PERSEO data
Control volume state	All primary side CVs filled with saturated steam
Flow between control volumes	Assumed no flow
Secondary	
Control volume temperature and pressure	Approximated based on the available PERSEO data
Control volume state	All primary side CVs filled with dry air
Control volume pool levels	Approximated based on the available PERSEO data
Flow between control volumes	Assumed no flow
Heat exchanger wall temperatures	Approximated based on the available PERSEO data
Heat exchanger pool wall temperatures	Assumed to be near ‘Environment’ CV temperature (25 °C)
Nozzle wall temperatures	Assumed to be near overall pool water temperature

Test 7 Part I Boundary Conditions

Parameter	Boundary Condition
	Primary
Steam Supply	A time-specified control volume was used to represent primary-side steam supply. Control volume pressure was defined by a control function to match measured primary pressures (P-I001). The control volume was filled with saturated steam.
Condensate Line Sink	The condensate line sink was defined by a separate control volume with a time-specified pressure defined to account for the change in measured water level in the RPV.
	Secondary
Environment	Time-independent control volume (10000 m^3) filled with dry air; P = 100 kPa, T = 25 °C
OP Drain Line	Closed for the duration of test 7 part I
Vacuum Breaker	One-way valve that opens when pressure in steam duct drops below atmospheric pressure in the environment
Triggering Valve Operation	Due to the unavailability of data for the operation of the triggering valve, a control function was used to define triggering valve operation. The control function used approximate flow rates (FPOOL) and valve opening times to simulate valve operation approximate valve operation; it was also tuned to match the maximum heat exchanger pool height reported during each period of triggering valve operation.

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