Experimental Study of Natural Circulation in CLOF (Complete Loss Of RCS Flow rate) Accident with SMART-ITL

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- Experiment: CLOF Test
- Results & Analysis
- Conclusion & Further Study

1. INTRODUCTION: SMATR-ITL & PRHRS

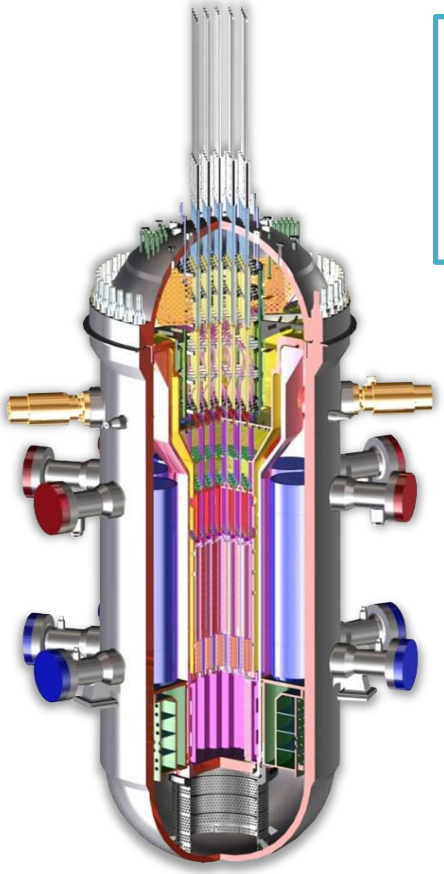
2. Experiment: CLOF Test

3. Results & Analysis

4. Conclusion & Further Study

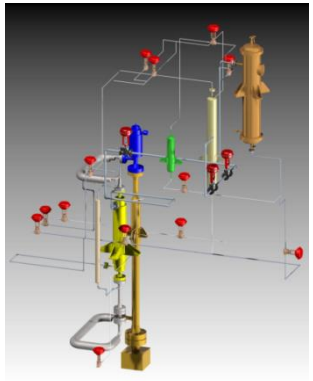
SMART-ITL (Integral Test Loop)

❖ Scaling Methods

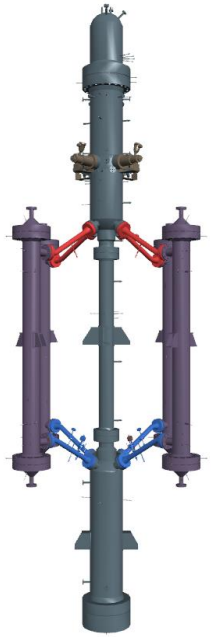


SMART

Volume scaling
(main components)
+
Three-level scaling
(partially)



*VISTA-ITL



SMART-ITL
(**FESTA)

Parameters	Scale Ratio	**FESTA	*VISTA-ITL
Length, l_{0R}	l_{0R}	1/1	1/2.77
Diameter, d_{0R}	d_{0R}	1/7	1/21.75
Area, a_{0R}	d_{0R}^2	1/49	1/472.9
Volume, V_{0R}	$d_{0R}^2 \cdot l_{0R}$	1/49	1/1310
Time scale	$l_{0R}^{1/2}$	1/1	1/1.664
Velocity	$l_{0R}^{1/2}$	1/1	1/1.664
Power/Volume	$l_{0R}^{-1/2}$	1/1	1.664
Heat flux	$l_{0R}^{-1/2}$	1/1	1.664
Core power	$a_{0R} \cdot l_{0R}^{1/2}$	1/49	1/787
Flow rate	$a_{0R} \cdot l_{0R}^{1/2}$	1/49	1/787
Pump head	l_{0R}	1/1	1/2.77
Pressure drop	l_{0R}	1/1	1/2.77

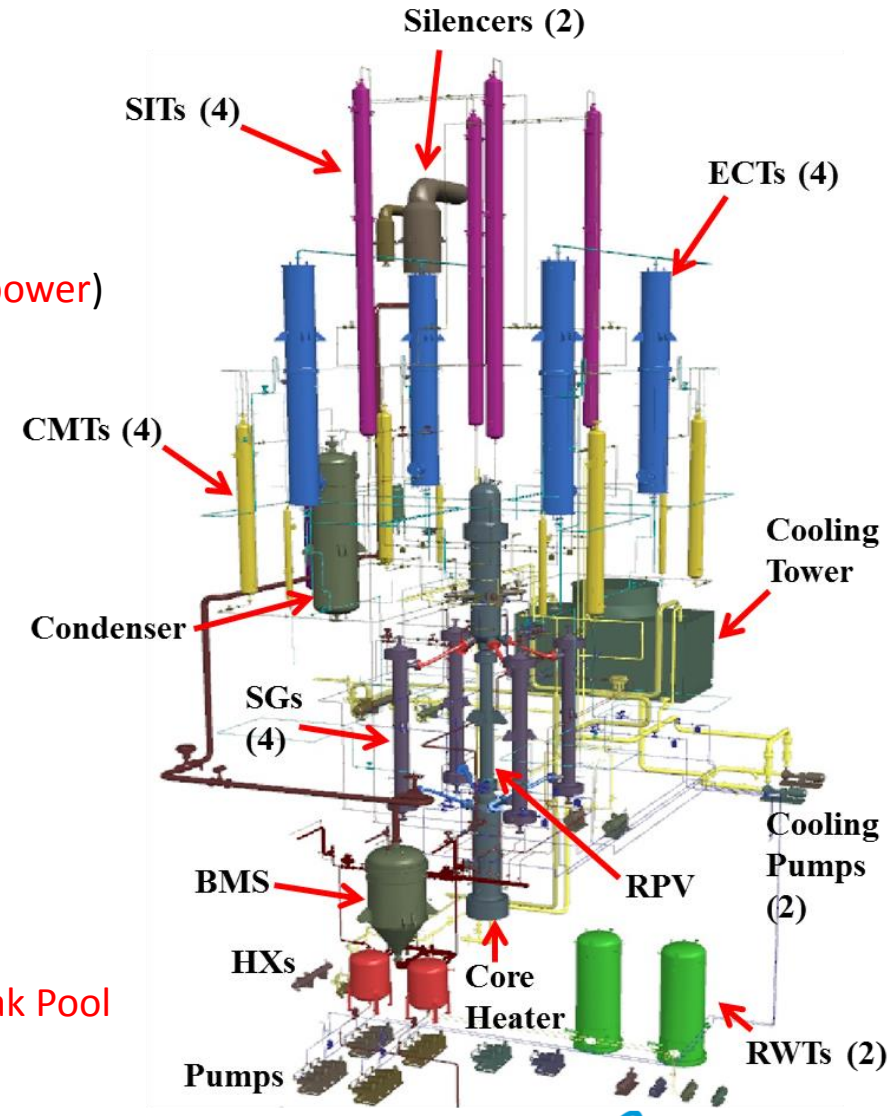
*Experimental Verification by
Integral Simulation of Transient and Accident

**Facility for Experimental Simulation
of Transients and Accidents

SMART-ITL (Integral Test Loop)

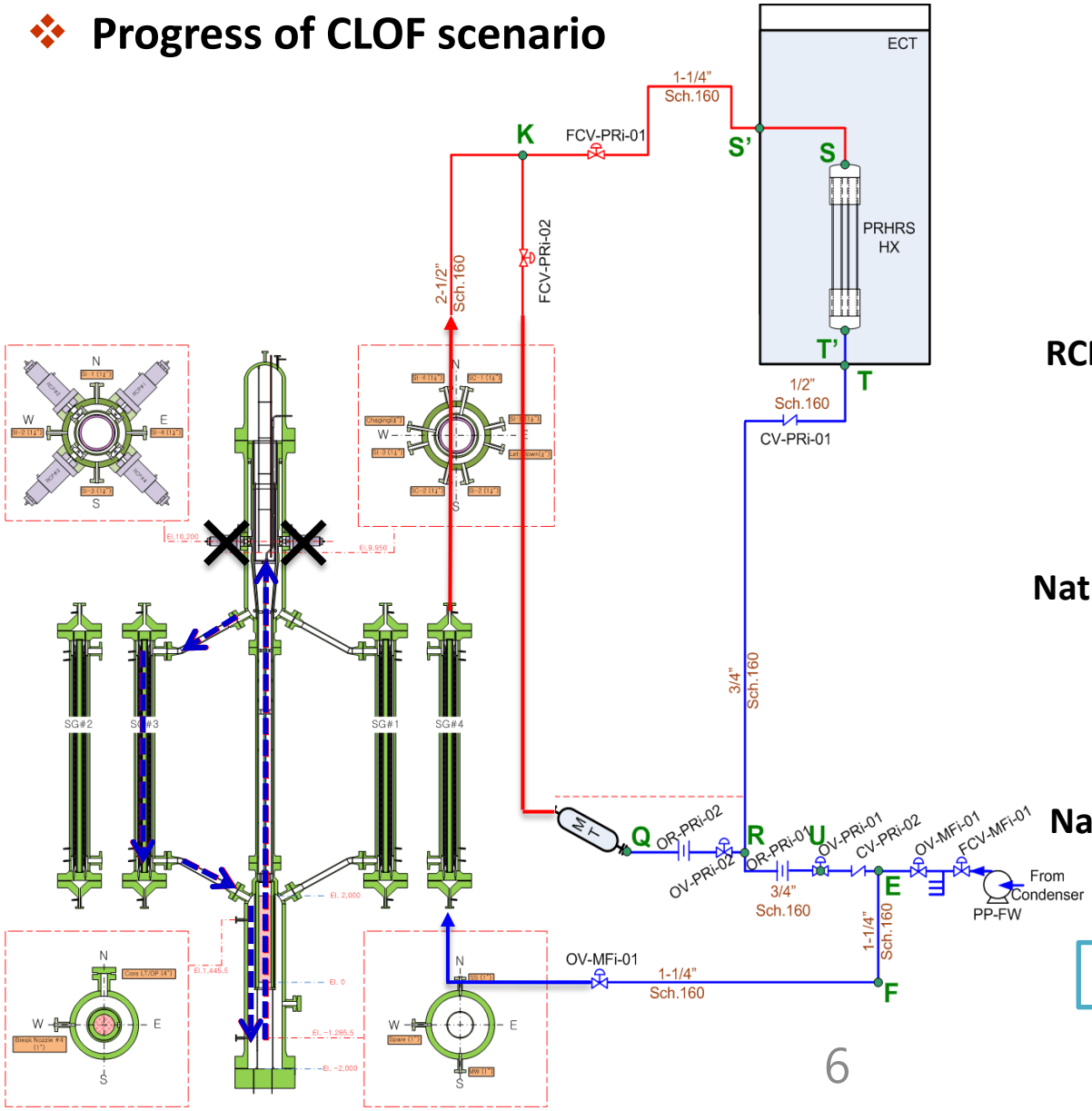
Design Figures

- Design pressure & temp.:
  - 180 bar, 370 ℃
- Core heater power:
  - Maximum: 2.0 MW (30% of scaled full power)
  - Operation: 1.5 MW (20%) + heat loss
- External SGs
  - Proper instr. and easy maintenance
- SG & PRHRS: 4 Trains
- PSIS (CMT & SIT): 4 Trains
- ADS: 2 Trains
- Major components
  - Reactor Coolant/Secondary systems
  - PRHRS, ASIS/PSIS
  - Auxiliary systems
  - Break system, Break meas. System, Break Pool
- Instruments : ~ 1,344
  - P, T, flow rates, mass, power, etc.



CLOF (Complete Loss Of RCS Flow rate)

❖ Progress of CLOF scenario



Steady-state operation

RCPs stop due to emergency power loss.

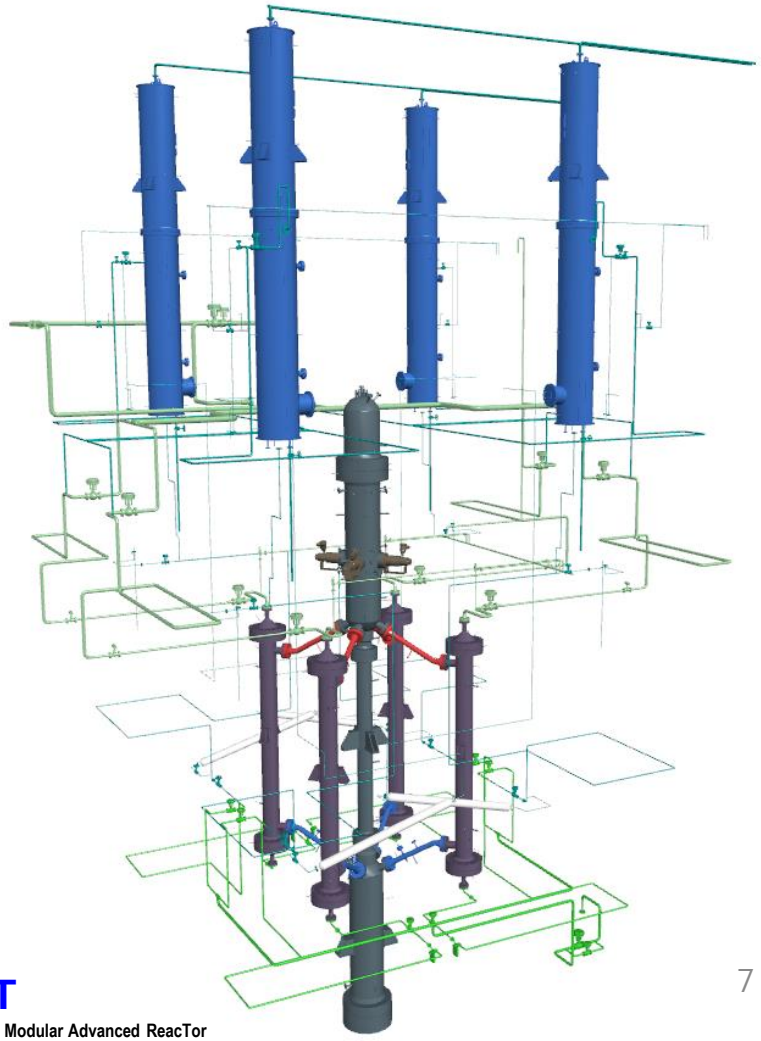
Natural Circulation occurs in primary loop.

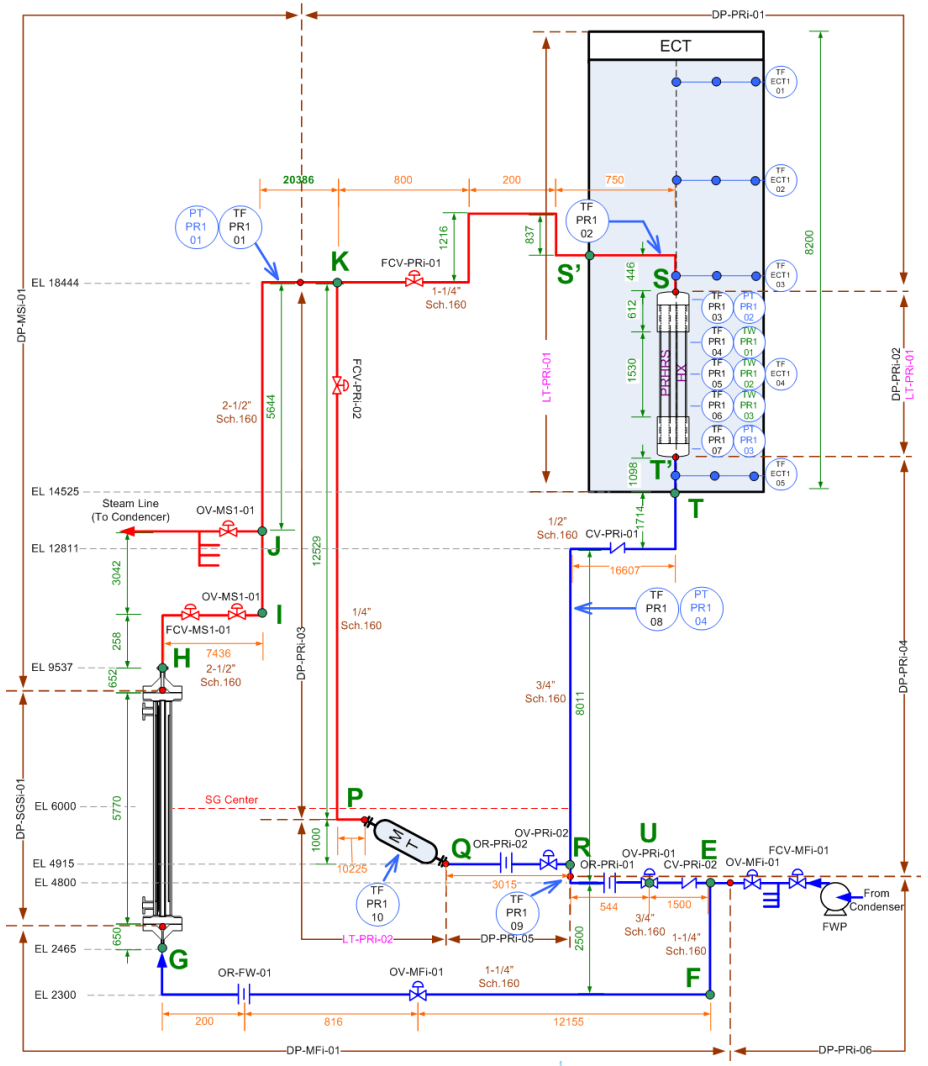
Natural Circulations in PRHRS also start.

Single phase NC vs. Two-phase NC

❖ Passive Residual Heat Removal System (PRHRS)

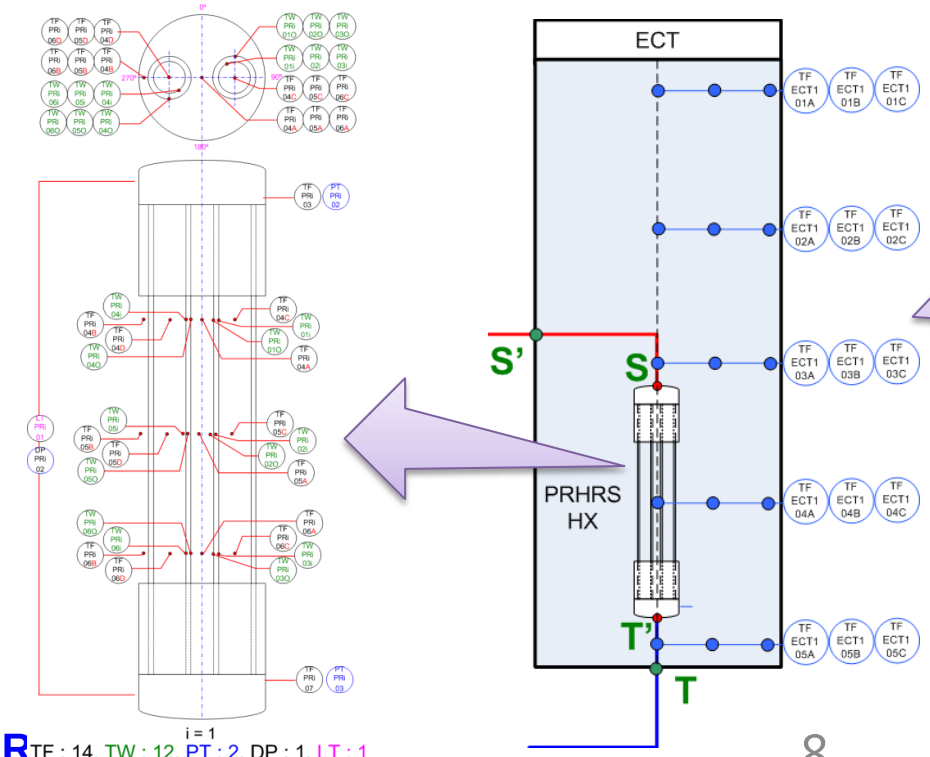
- Heat exchanger (Hx) + Emergency Cooldown Tank (ECT) + Makeup tank (MT): 4 trains

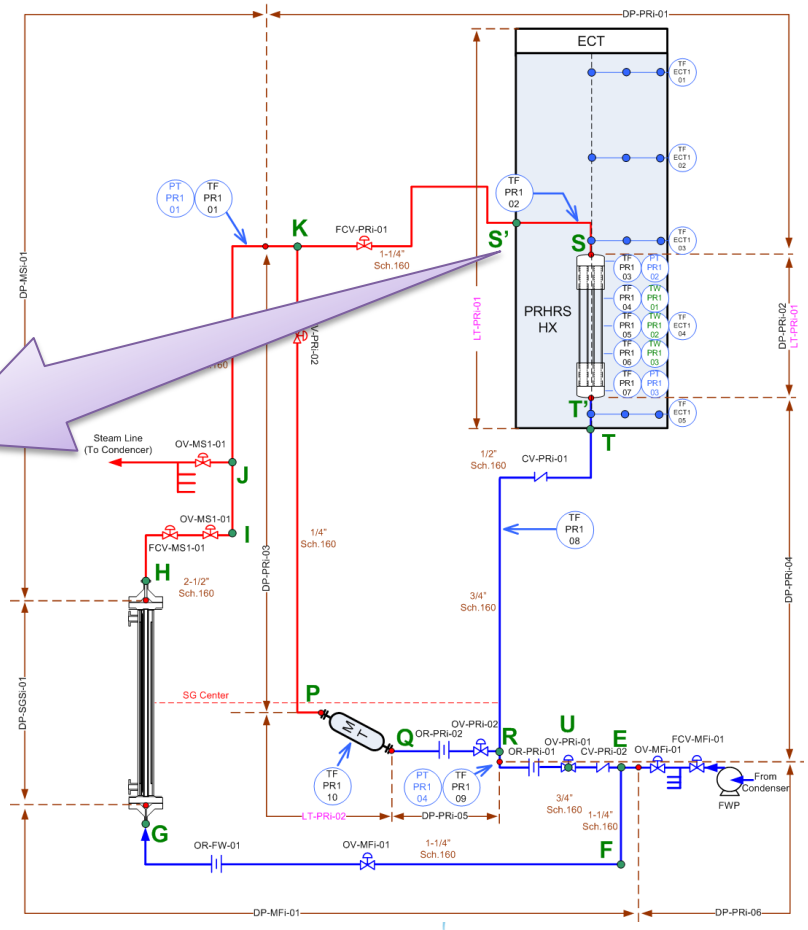




Passive Residual Heat Removal System (PRHRS)

- Heat removal by two-phase natural circulation
  - < safety shutdown temperature (176℃) in 36 hrs
  - Maintain < SST during 72 hrs without MT.
- Heat capacity of ECT is oversized for safety margin.





SMART TF : 14, TW : 12, PT : 2, DP : 1, LT : 1
System integrated Modular Advanced ReacTor

1. Introduction: SMATR-ITL & PRHRS

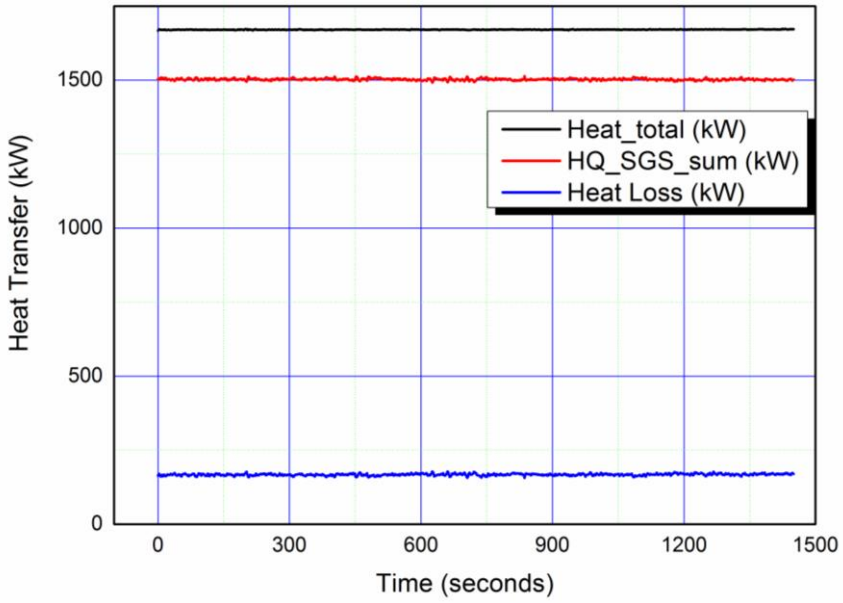
2. EXPERIMENT: CLOF TEST

3. Results & Analysis

4. Conclusion & Further Study

Steady State Operation

Parameter	Target Value	Measured Value
Core Power (MW)	1.50	1.67 (Heat Loss 0.17)
Core Coolant Temperatures (In / Out) (℃)	295.5 / 320.9	295.5 / 320.6
S/G Coolant Temperatures (In / Out) (℃)	320.9 / 295.5	320.6 / 298.1
Mass Flow Rate of Primary Coolant, kg/s	10.23	10.26
Pressure of PZR, MPa	15.00	15.05
Coolant Temp. of PZR, (℃)	342.1	342.1
Volume of Coolant in PZR, % (m)	70 (3.12)	70.6 (3.14)



Heat Balance (Avg.)

Heat source from core	1670kW
Heat sink of SG	1502kW
Heat loss	168kW

Sequence of Event

Event	Trip signal and set-point	Operation
Transient occurs **Ex.) Station black-out**	RCP stop & RCP coast-down FW pump stop Turbine stop	PP-RC01 ~ 04 STOP PP-MF-01 STOP
RCP Pump Signal (RPS) set-point	RCP stop + 0.37 s	RPM = 0.9×RPM_{normal}
Reactor trip signal **PRHRS actuation signal (PRHRAS)** **CMT actuation signal (CMTAS)** **MSIV/FIV close start** **PRHRS IV open start**	RPS + 1.1 s	PRHRSAS, CMTAS due to low feed water flow rate
Control rod insert	RPS + 1.6 s	Decay heat (residual heat) table
4 trains of CMT injection start	RPS + 2.2 s (CMTAS + 1.1 s)	OV-IL1,2,3,4-101 OPEN
MSIV/FIV close completed **PRHRS IV open completed**	RPS + 6.1 s (PRHRAS + 5.0 s)	OV-PR 1,2,3,4-03 OPEN OV-MS 1,2,3,4-01 CLOSE OV-MF 1,2,3,4-01 CLOSE
End of event	PRHRAS + 36 hr (Temp. of coolant < 215 ℃)	After safety shut down condition

1. Introduction: SMATR-ITL & PRHRS
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3. RESULT & ANALYSIS

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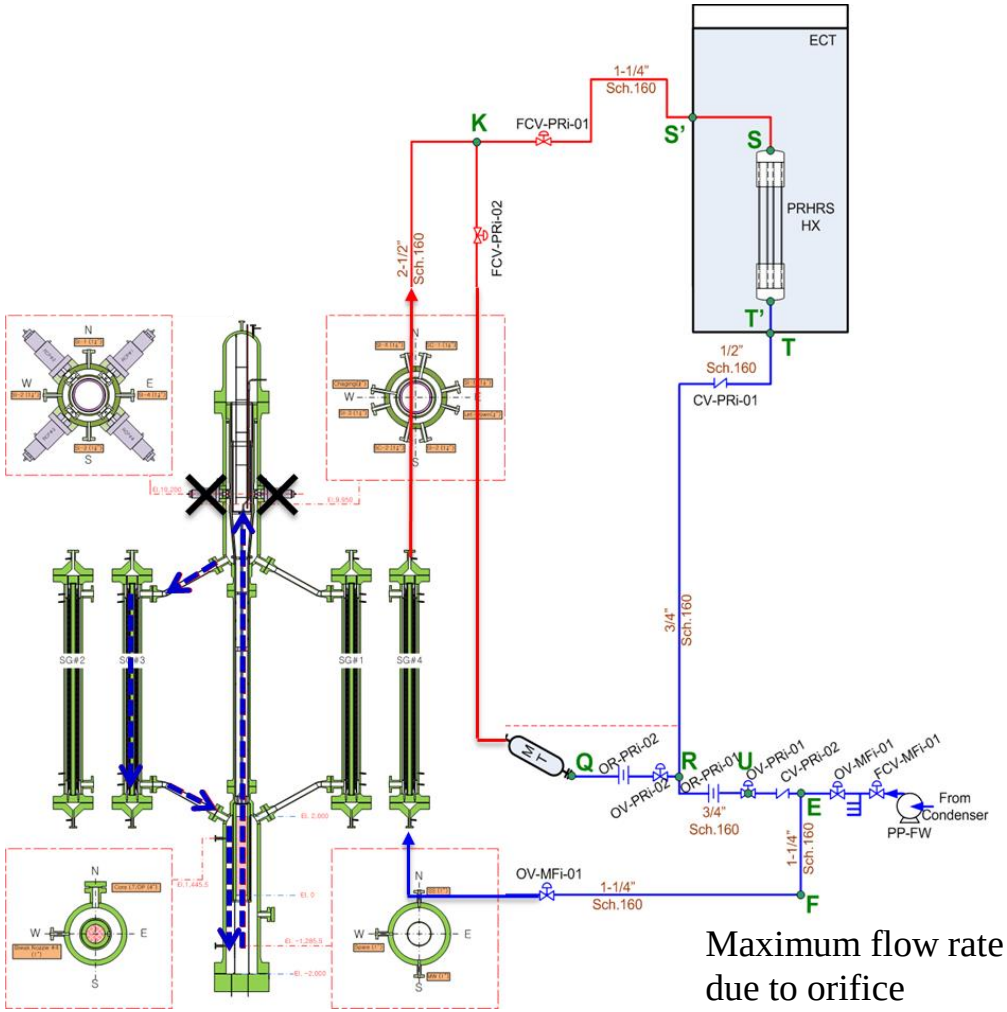
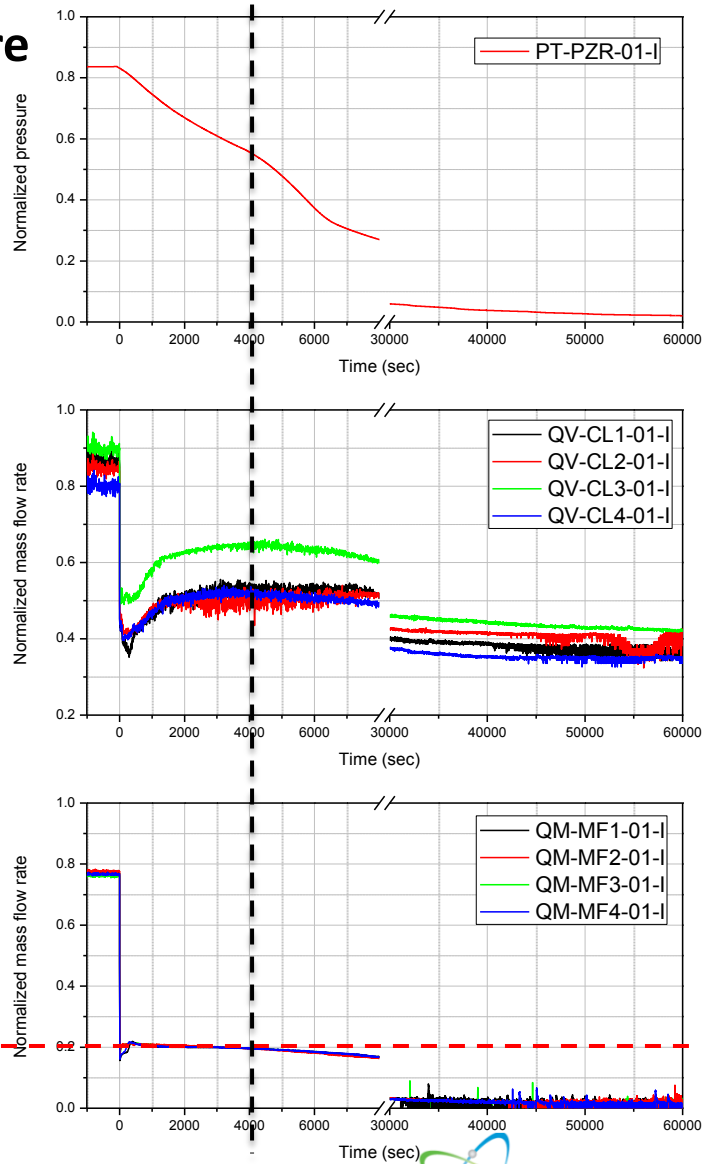
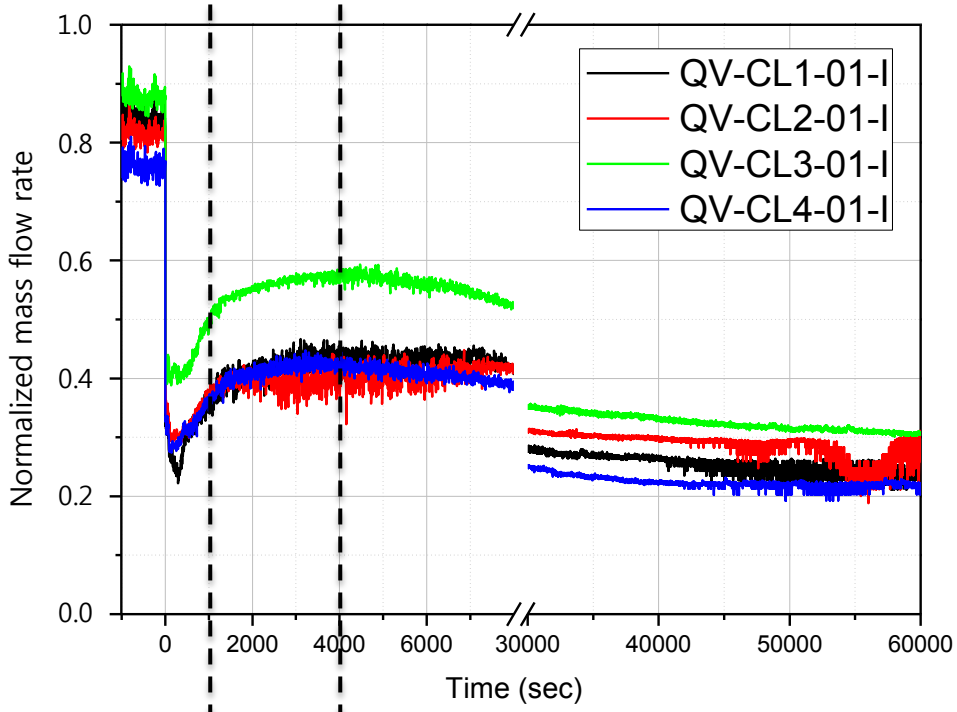
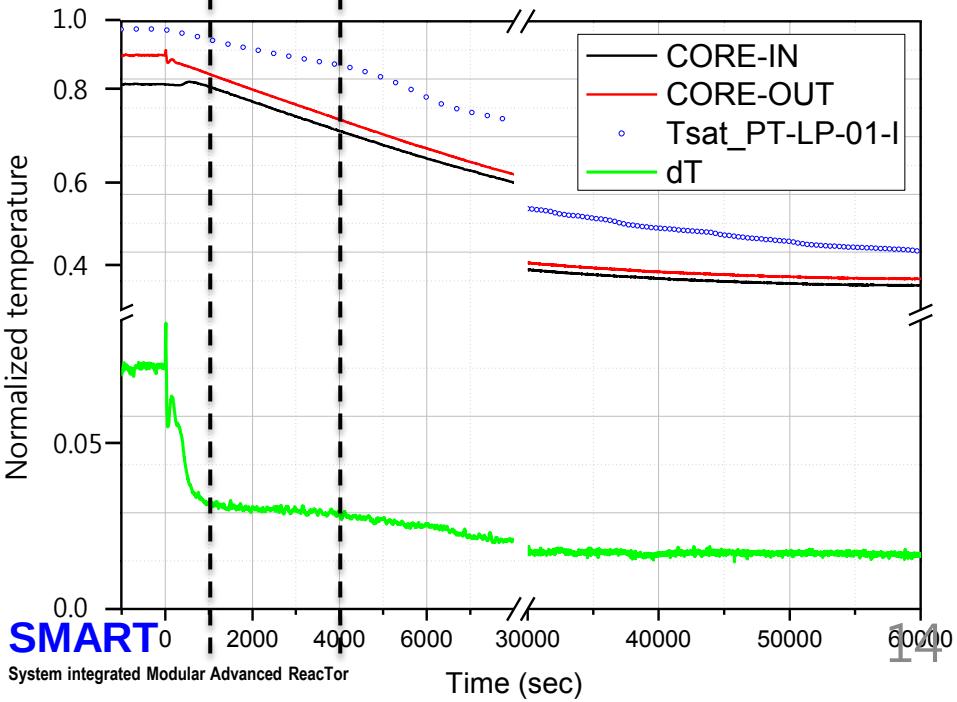
❖ Transient Simulation: Decay Power & Pressure



Maximum flow rate due to orifice







Results & Analysis

❖ Mass Flow Rate & Temp. (1ry)

$$\mathrm{Ra_L} = \mathrm{Gr_L}\,\mathrm{Pr} = \frac{(\beta \Delta T)\, g L^3}{\nu^2}\,\mathrm{Pr}$$

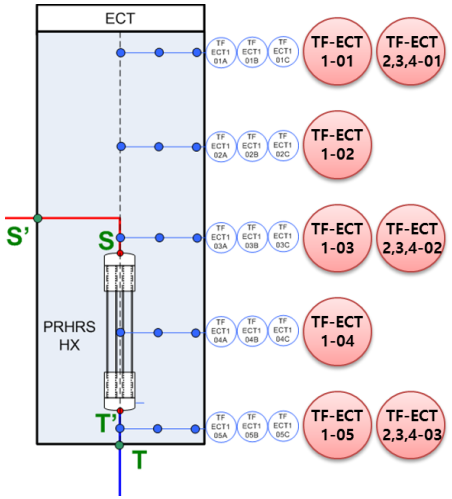
< 4000 s : NC mass flow in primary increases.

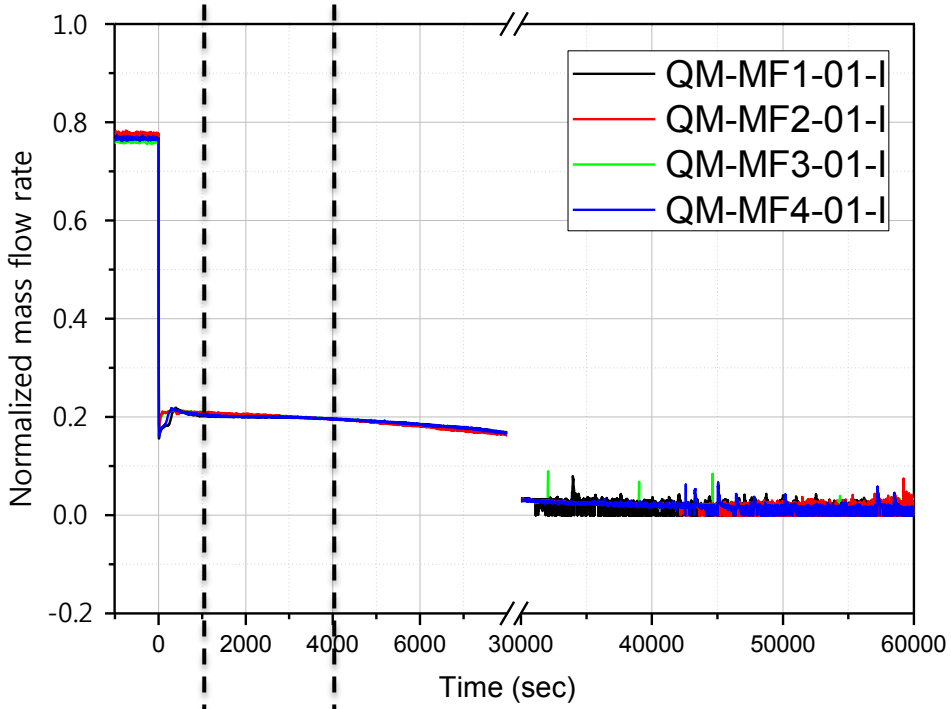
> 4000 s : NC mass flow in primary decreases.

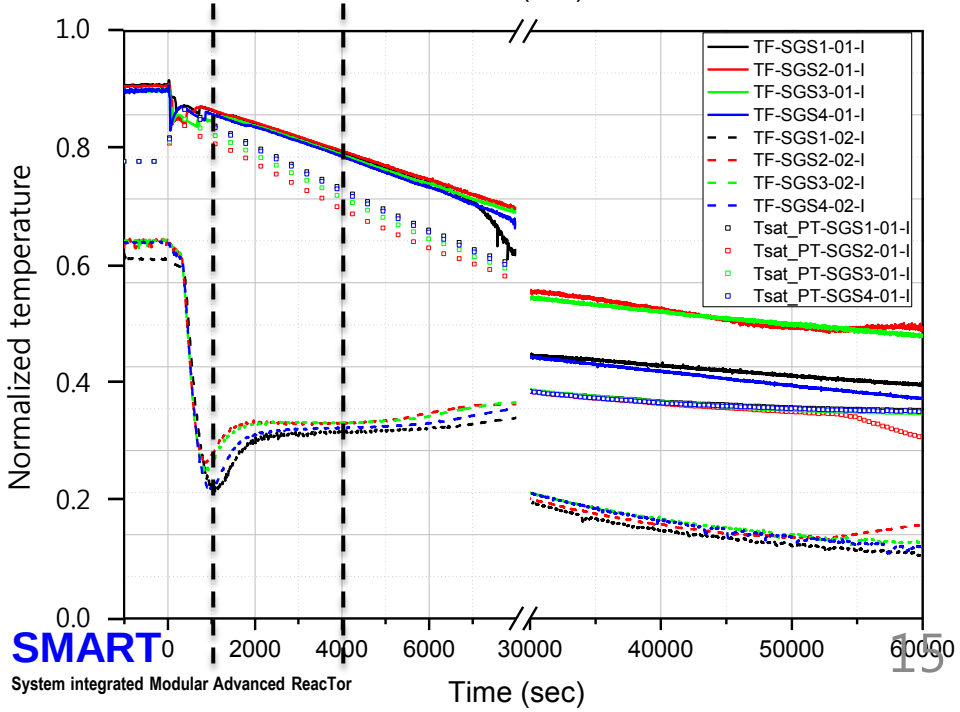
➡ Temperature potential affects NC flow rate.

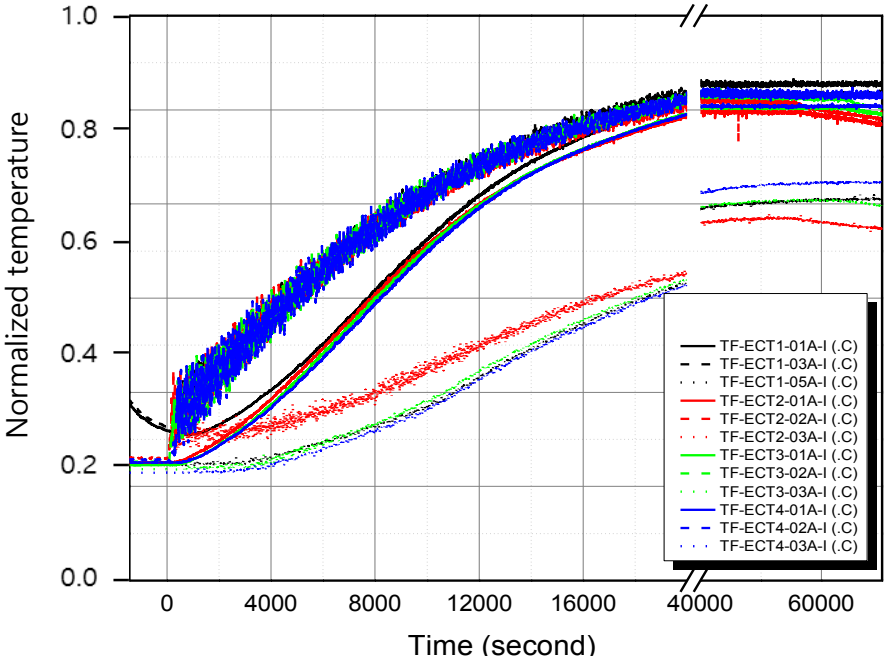
Results & Analysis

❖ Mass Flow Rate & Temp. (2ry)



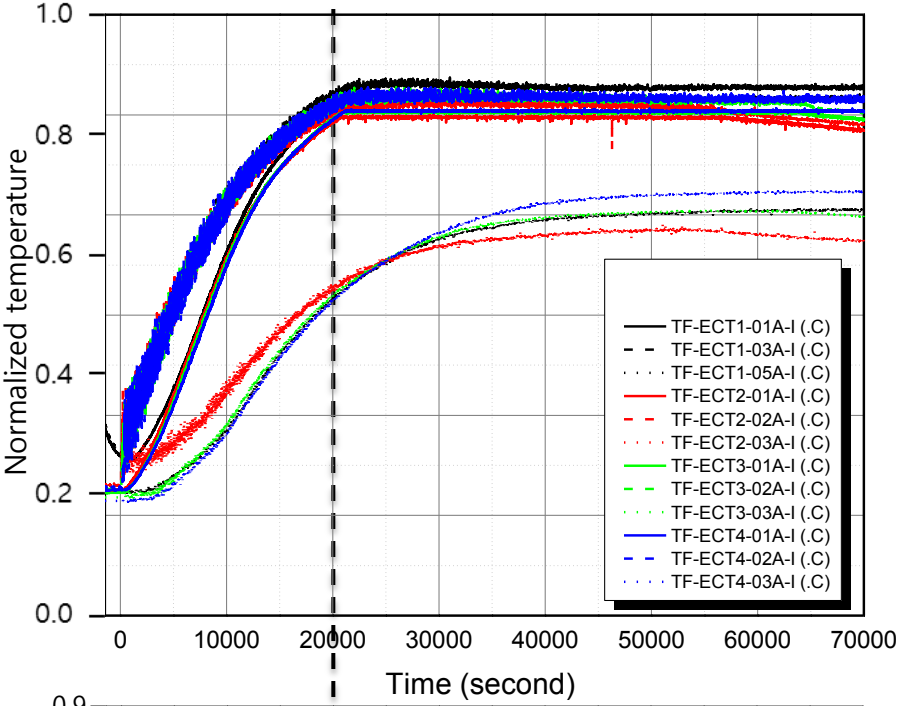


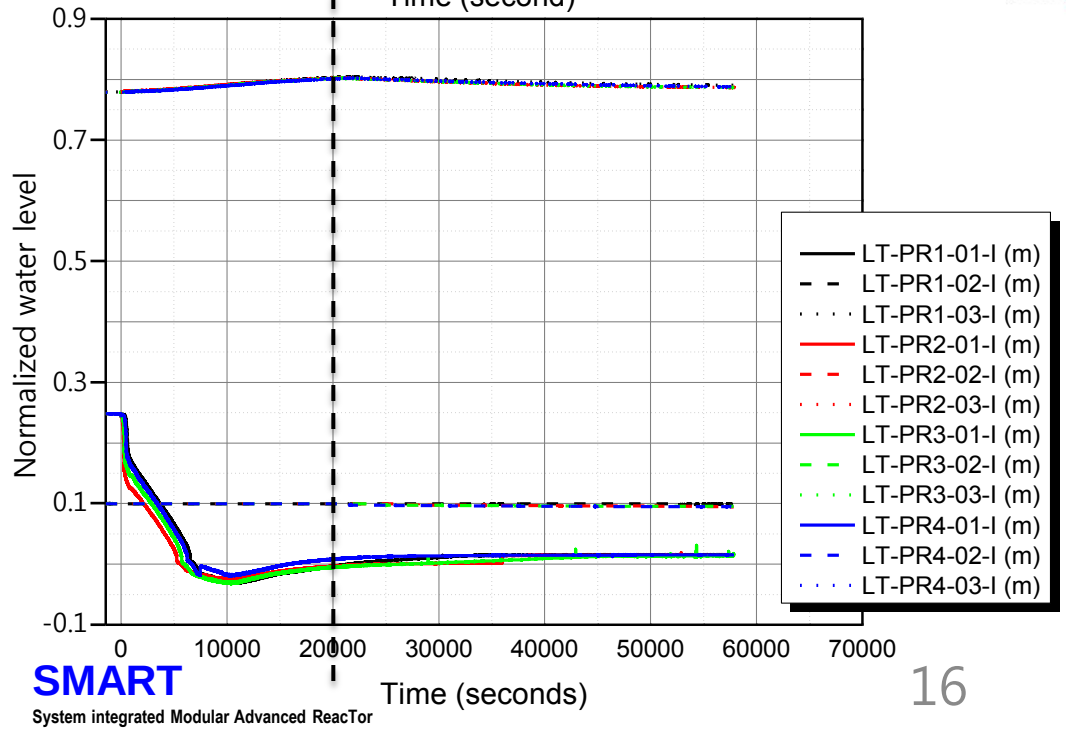


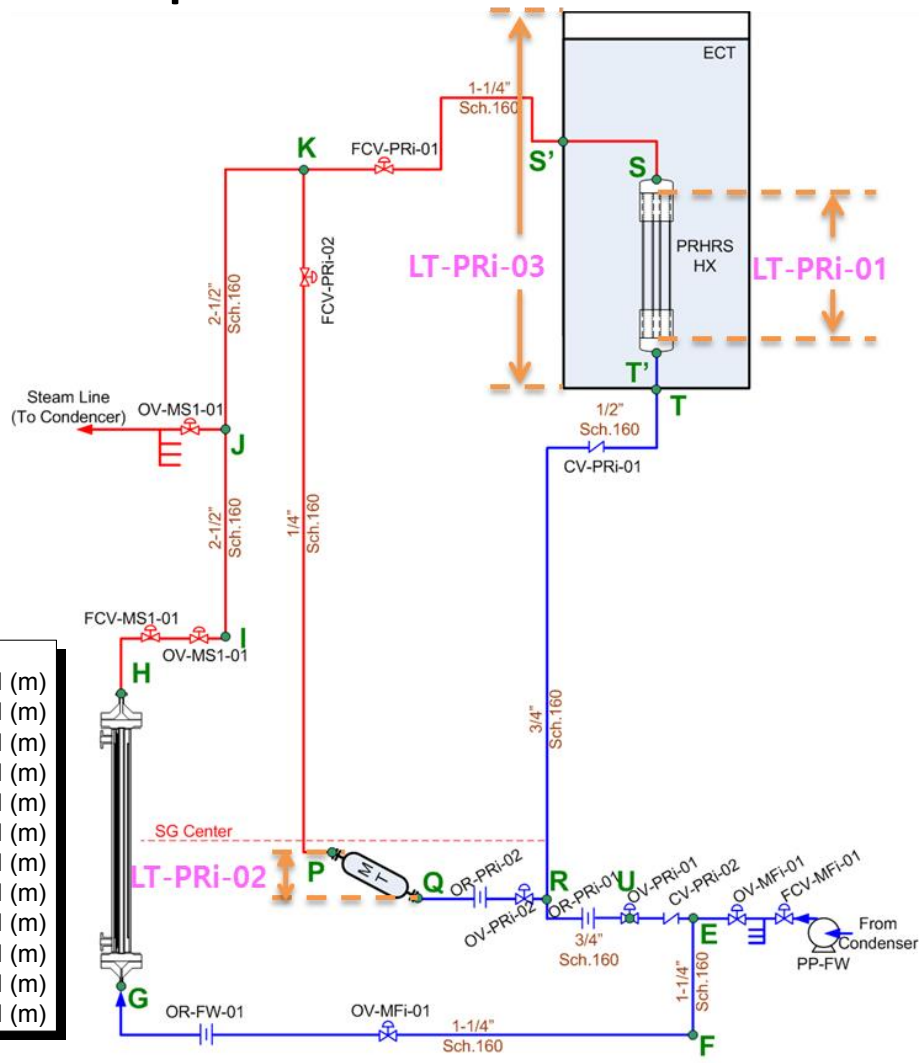


Results & Analysis

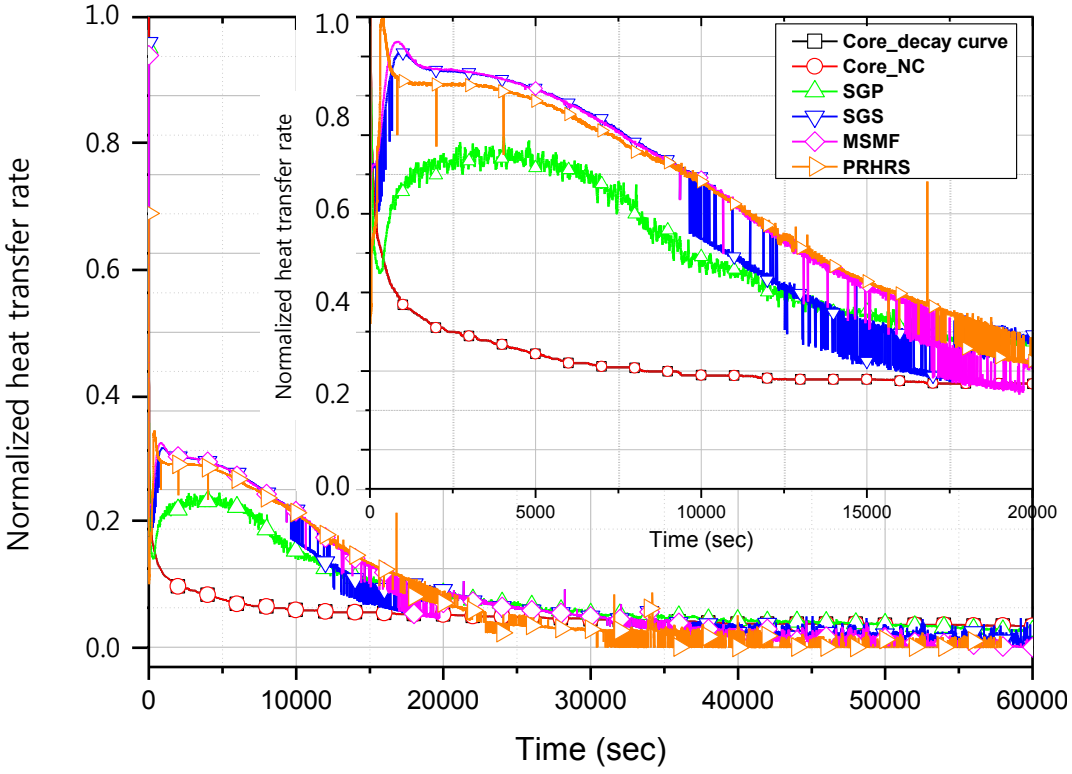
❖ Temp. & Water Level of PRHRS

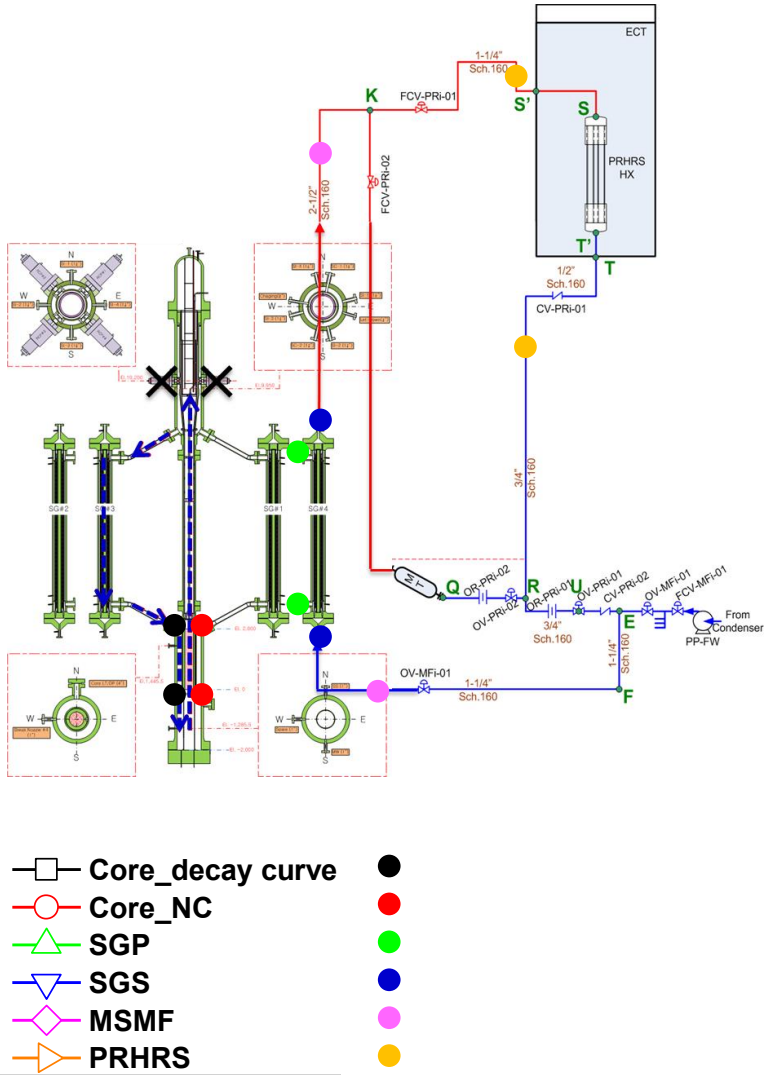




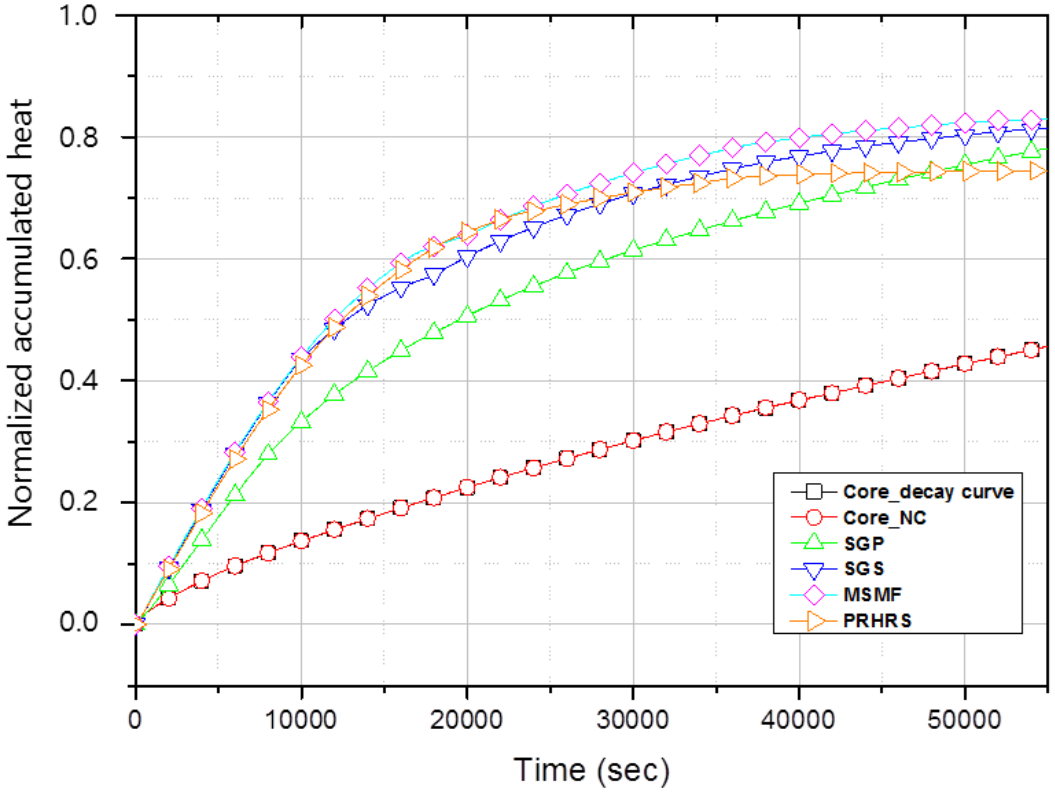


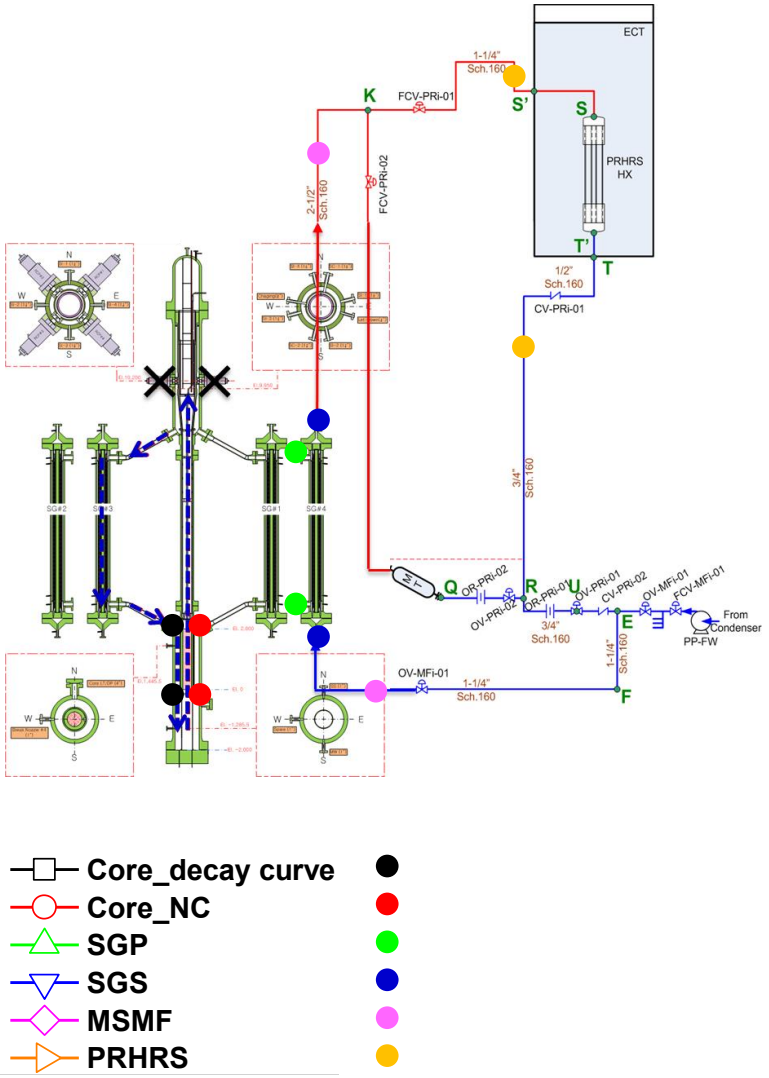
❖ Heat Balance between 1ry & 2ry systems



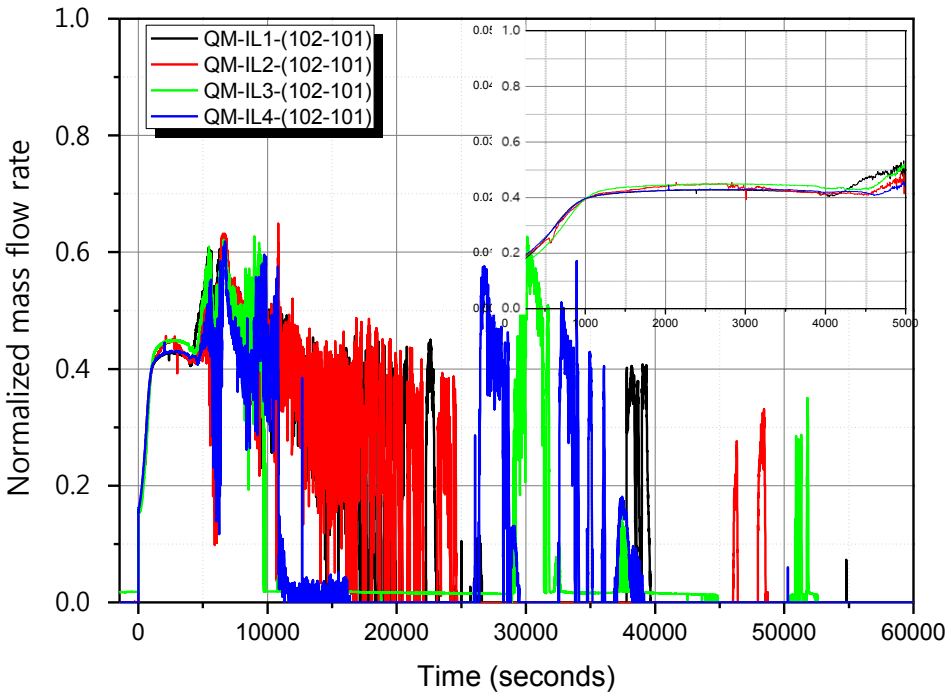


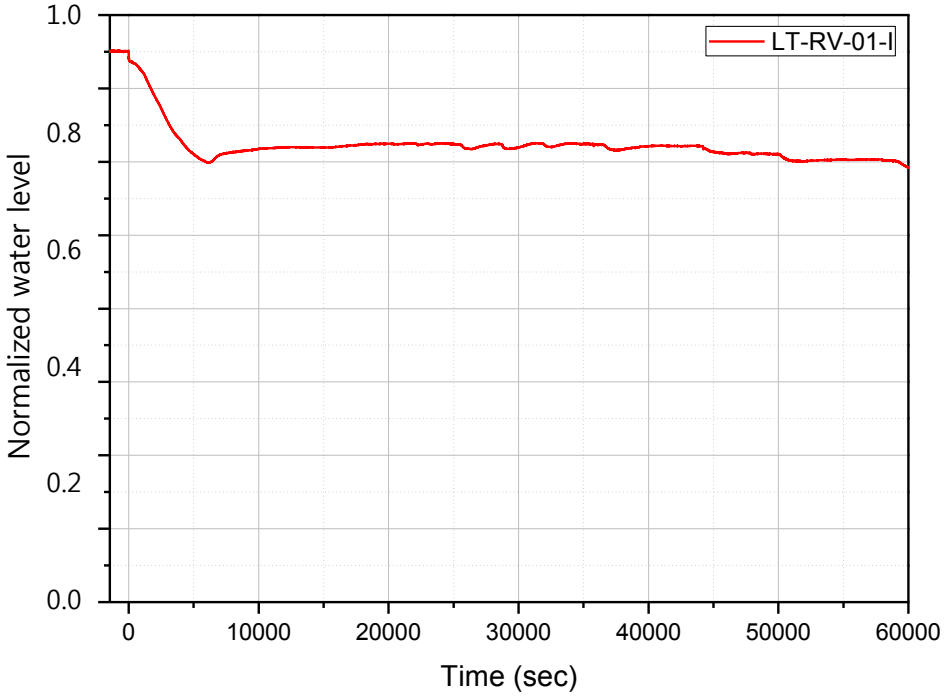
❖ Heat Balance between 1ry & 2ry systems



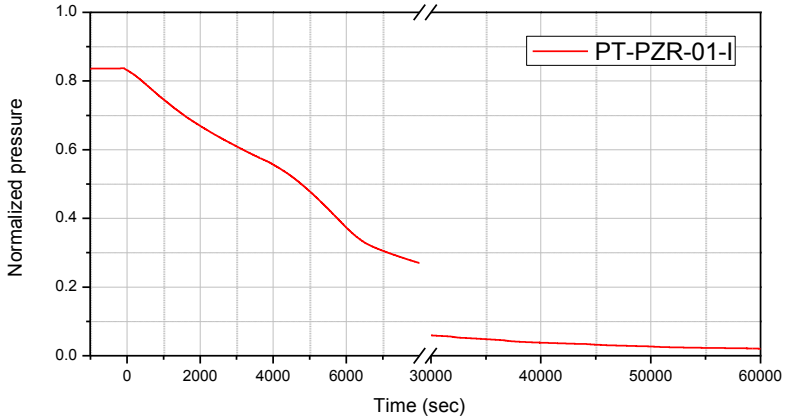


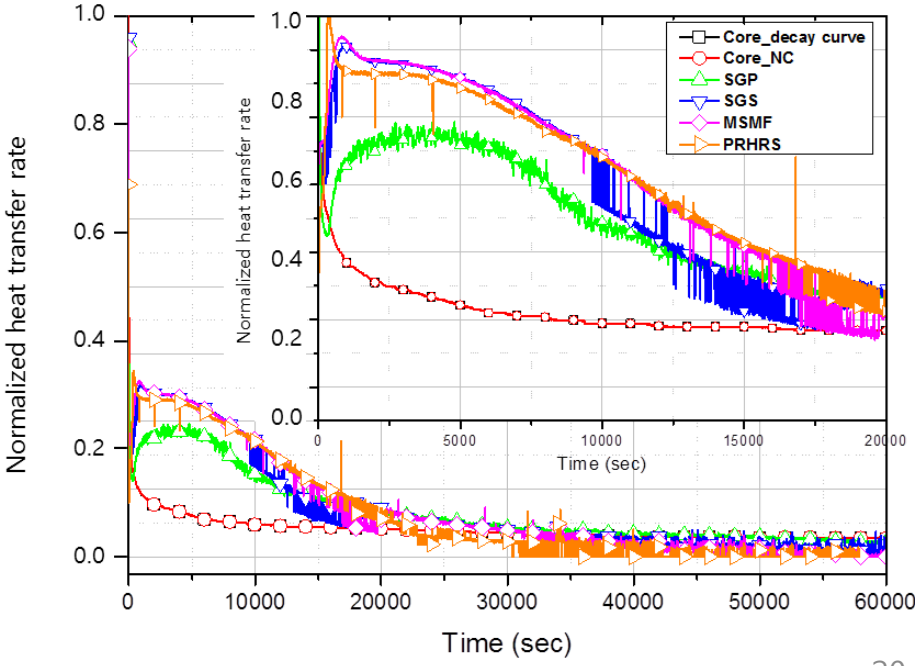
❖ Characteristic of CMT Injection

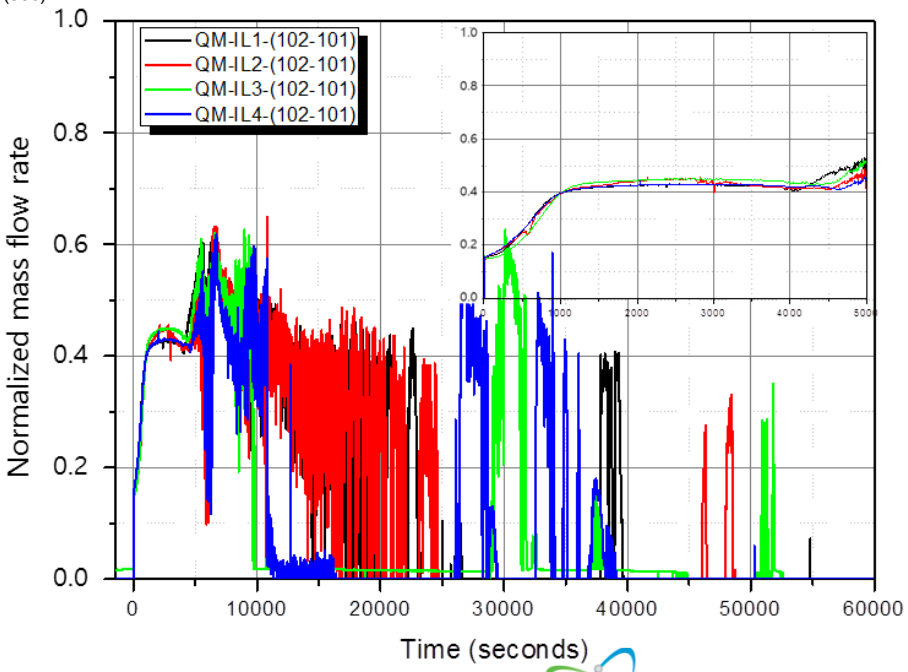




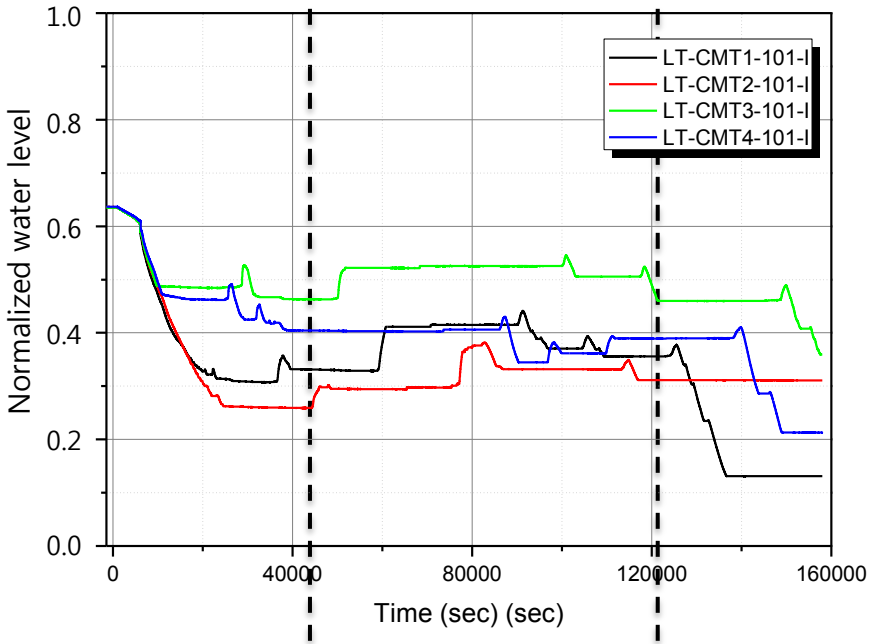
❖ Physical Basis of Pressure Gradient Change

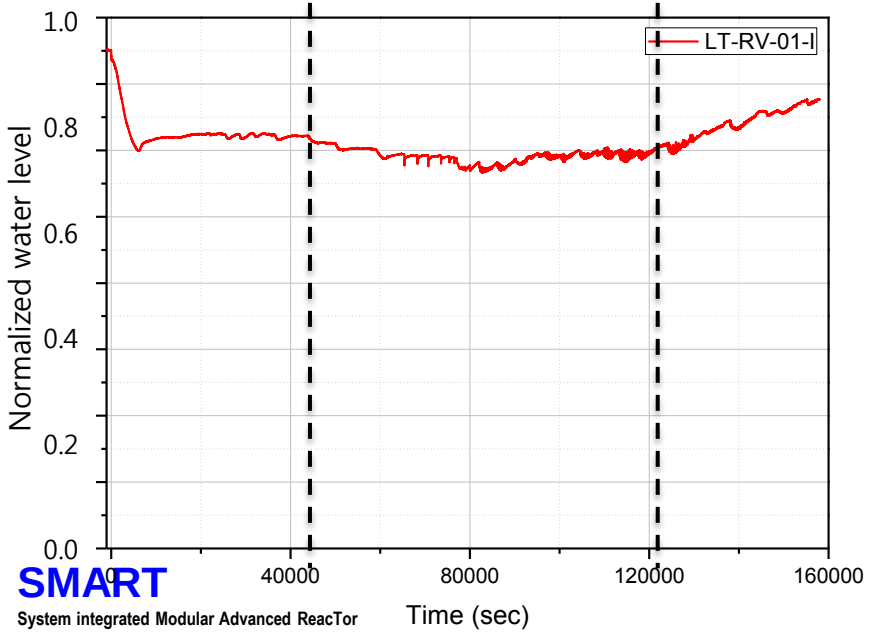


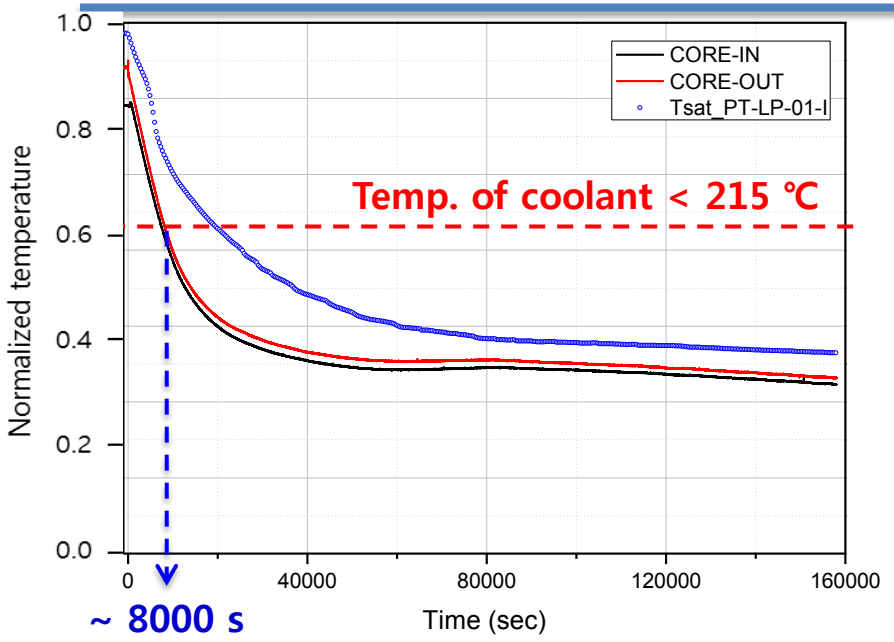




Results & Analysis







Safety criteria were satisfied!!

1) Core was not exposed during 36 hrs with PRHRS.

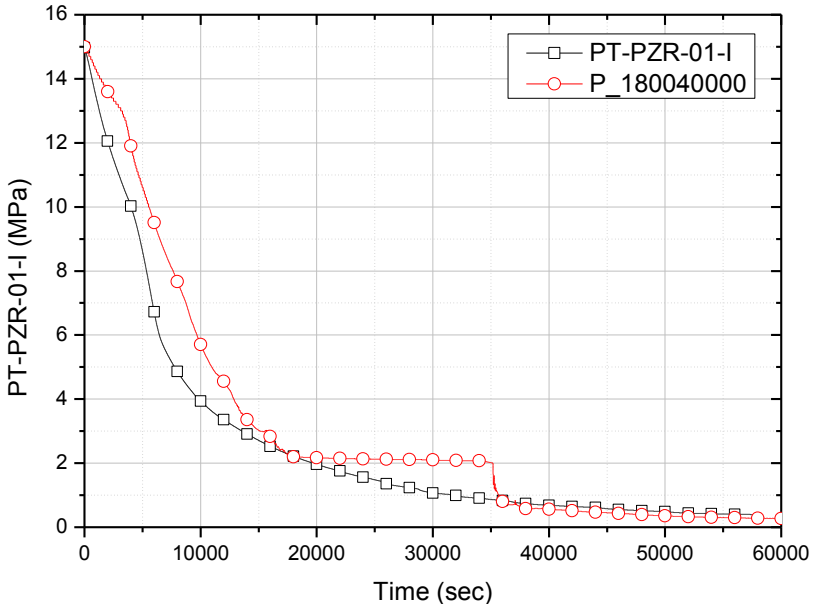
2) Temperature of primary coolant was sustained under safety shut down temperature (< 215 ℃).

4. CONCLUSION & FURTHER STUDY

Conclusion

- CLOF accident was simulated with SMART-ITL.
- Natural circulations in the 1ry & 2ry system were analyzed with trend of pressure gradient.
- Heat balance from core (heat source) to ECT of PRHRS (heat sink) was quantified by experimental results and it was helpful to understand about progress of CLOF accident.
- Effect of CMT injection couldn't be quantified independently, but it was an important factor to remain the water level of RCS.
- If CLOF occurred in the SMART, the passive safety systems (4 trains of PRHRS & CMT) were enough to ensure safety of nuclear reactor.

- Simulation with system analysis code (MARS)



- Study about local phenomena
  - Subcooled boiling after CLOF accident
  - Heat transfer in the ECT