Transactions of the Korean Nuclear Society Spring Meeting
Gyeongju, Korea, October 27-28, 2016

Transient Analysis of STELLA-2 using MARS-LMR

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1. Introduction

The development of Prototype Gen IV Sodium-cooled Fast Reactor (PGSFR) is on-going and various experimental activities are scheduled to support the design verification and validation (V&V) of PGSFR. The Sodium Integral Effect Test Loop for Safety Simulation and Assessment (STELLA) program is one of the key activities and the basic design of STELLA-2 facility has been completed in 2015[1][2]. The STELLA-2 is a scaled facility including all the major components of PGSFR and is able to simulate the transient behavior. For STELLA-2 design evaluation, the representative design basis event (DBE) analysis was conducted by MARS-LMR with the same assumption and same approach used in PGSFR analysis. In this paper, the method and result of MARS-LMR transient analysis are described and also the comparison result with the PGSFR is illustrated. Among three representative DBEs, the Transient Over-Power (TOP) is not included in this study owing to its exclusion from the STELLA-2 test scope[3].

2. Design Basis Event

2.1 Loss of Flow (LOF)

Major accidents include the single/double failure of pump, the pump discharge pipe break, the pump rotor lock, and the pump shaft break. Major causes are the loss of offsite power (LOOP) or earthquake, the malfunction of pump control system or human error, and the pipe stress or welding defect.

The LOF occurs when all the power supplied to the pump is lost and it results in the immediate temperature rise of the coolant.

2.2 Loss of Heat Sink (LOHS)

Major accidents are the SG isolation, and the IHTS isolation. Major causes are the feedwater pipe break, the IHTS pipe break, the loss of offsite power, the SBO, sodium leak in SG, and etc.

In the case of LOOP condition, the transient behavior of LOF and LOHS are same and the initiating events are also considered to be same.

3. MARS-LMR Analysis

The node diagram for the input is illustrated in Fig. 1. The basic composition and layout is similar to the PGSFR. However the difference is in (1) core, (2) PHTS pump (3) SG, and (4) DHRS. In STELLA-2, the core heat is simulated by electric heater, and the pump is replaced by the electromagnetic pump loops. Furthermore, SG is simulated by the sodium-to-air heat exchanger named UHX. Finally, all 4 DHRS loops are modeled in STELLA-2 to observe the various transient behaviors including asymmetry DHRS operation.

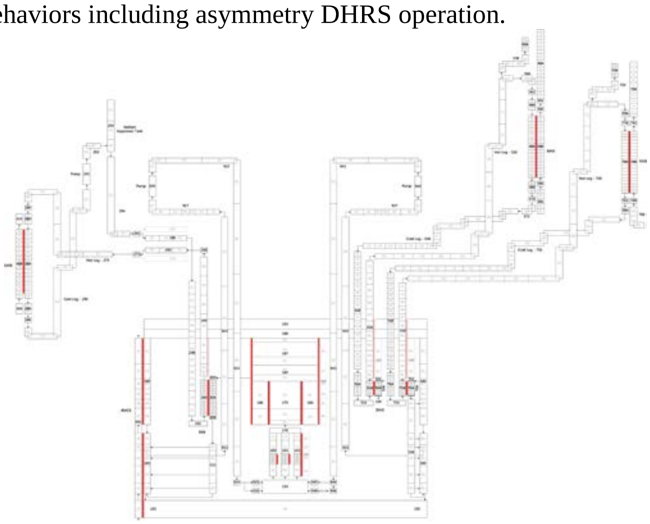

Fig. 1 STELLA-2 input node diagram

3.1 Steady-state

The main results of steady-state condition is summarized in the following tables. The target values are the data from the PGSFR heat balance during normal operation and the ST2 values are the result of MARS-LMR calculation. The temperature distribution is conserved to be 1/1 in STELLA-2 design, whereas the flowrate and power scale is 1/55.9[1]. Therefore the target value in Table 2 and 3 is the scaled value of PGSFR data.

The time to reach the steady-state was approximately 800 seconds and the analysis time was set to be 1,000 secs.

Table 1 Steady-state result (Temperature)

Variables	Temp (℃)		Description
	Target	ST2	
Inlet Plenum	390	391.7	
Core Out	545	546.7	
Hot Pool	545	544.8	IHX shell inlet
Cold Pool	390	462.1	DHX shell inlet
	390	389.5	PSLS intake
IHX	545	544.7	IHX shell inlet
	390	389.3	IHX shell outlet
DHX (Passive)	390	460.2	DHX shell inlet
	353.04	411.3	DHX shell outlet
DHX (Active)	390	460.1	DHX shell inlet
	353.04	414.4	DHX shell outlet
AHX	379.6	444.5	AHX tube inlet

	352.2	409.8	AHX tube outlet
FHX	379.6	445.6	FHX tube inlet
	352.2	412.5	FHX tube outlet
UHX	528	525.4	UHX tube inlet
	322	318.8	UHX tube outlet
Air (Out)	376.47	443.1	AHX shell outlet
	342.91	400.4	FHX shell outlet
	162.04	163.8	UHX shell outlet
Air (In)	20		AHX & FHX shell
	20		UHX shell

Table 2 Steady-state result (Flowrate)

Variables	Flow (kg/s)		Description
	Target	ST2	
PSLS	17.80	17.80	Intake 1
	8.899	8.898	Discharge 1
	8.899	8.898	Discharge 2
	8.899	8.898	Discharge 3
	8.899	8.898	Discharge 4
IHX	8.899	8.906	Shell
DHX	0.1123	0.1377	Shell (Passive)
	0.1123	0.1249	Shell (Active)
AHX	0.1512	0.1769	Tube
FHX	0.1512	0.1660	Tube
UHX	13.4	13.389	Tube
Air	0.01503		AHX shell
	0.01682		FHX shell
	25.75	24.181	UHX shell

Table 3 Steady-state result (Heat transfer)

Variables	Power (kW)	
	Target	ST2
Core	7016.1	7016.1
IHX	1752.70	1759.00
DHX (Passive)	5.35	8.60
DHX (Active)	5.35	7.28
AHX	5.35	7.84
FHX	5.35	7.00
UHX	3527.37	3536.24

The discrepancy on the temperature of DHX shell side comes from the design assumption. DHX is designed to operate at the temperature of cold pool, but in actual condition, the temperature inevitably rises due to thermal stratification at the top of the cold pool. The CFD analysis on the reactor pool concludes the similar result. Therefore, the inlet temperature of DHX shell side is much higher than the target value.

The flowrate and power difference of DHX, AHX, and FHX is due to the extra heat loss of RVCS. In PGSFR, there is slight heat loss through RVCS during normal operation. In STELLA-2, the corresponding scaled heat loss is too small to simulate with actual hardware, such as a blower and a damper. Therefore DHRS heat removal was slightly increased to cover the heat loss through RVCS.

3.2 Transient

The LOF + LOOP case was analyzed and the main results are illustrated in the following figures.

The main events and the corresponding time is as follows.

(1) PHTS pumps stop and coastdown starts : 4.47 sec
(2) IHTS pumps stop : 4.47 sec
(3) UHX air blow stops : 4.47 sec
(4) Core heater starts to decay : 6.7 sec
(5) Damper (AHX & FHX) opens : 8.94 sec

The time of events are scaled down from the PGSFR. The analysis time was set to 22,000 seconds which approximately corresponds to 50,000 seconds in PGSFR. However, the data up to 5,000 s are illustrated in the above graphs.

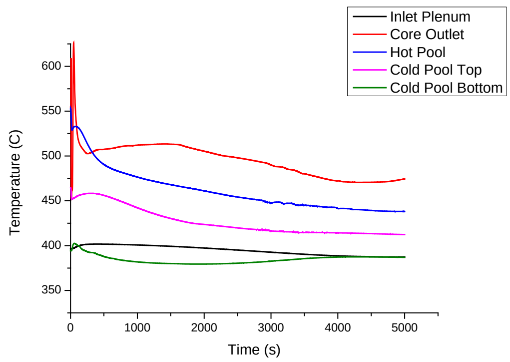

Fig. 2 PHTS temperature trend

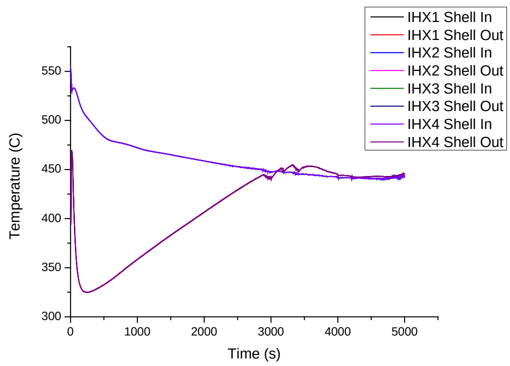

Fig. 3 IHX shell temperature trend

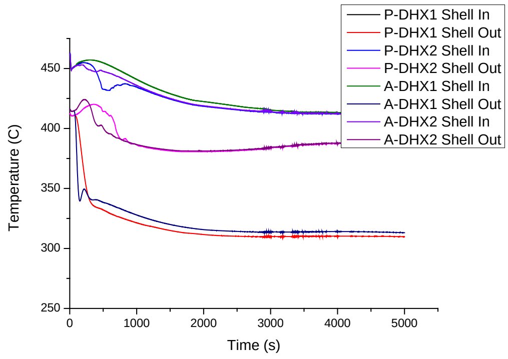

Fig. 4 DHX shell temperature trend

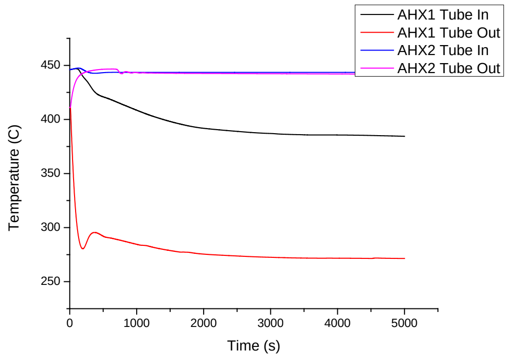

Fig. 5 AHX tube temperature trend

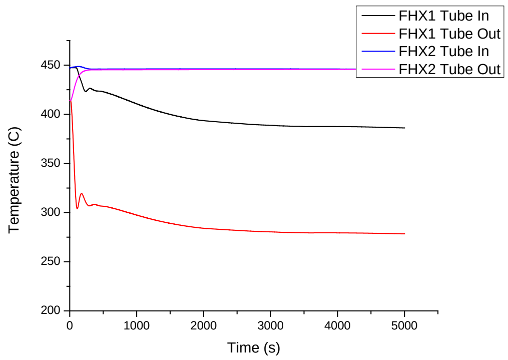

Fig. 6 FHX tube temperature trend

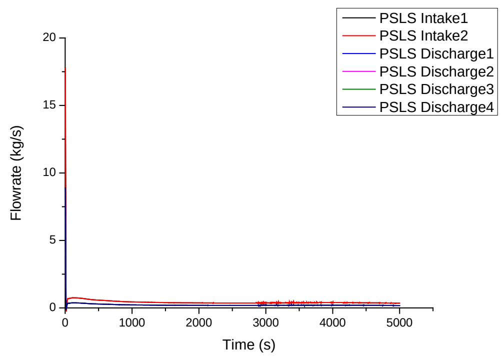

Fig. 7 PHTS flow trend

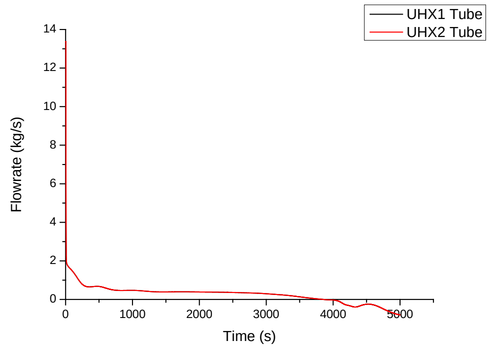

Fig. 8 IHTS flow trend

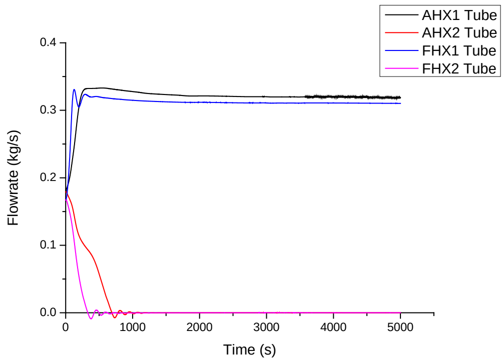

Fig. 9 DHRS loop flow trend

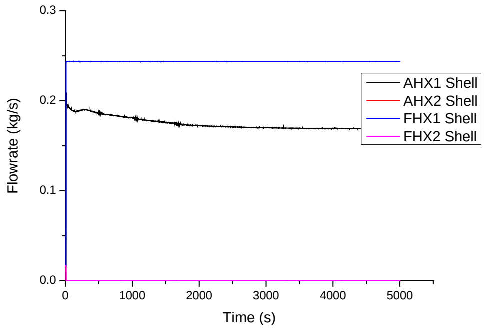

Fig. 10 DHRS HXs air flow trend

4. Comparison with PGSFR

4.1 Temperature

The comparison results are shown in the following figures. The general trends are consistent with the PGSFR but difference in temperature range was observed.

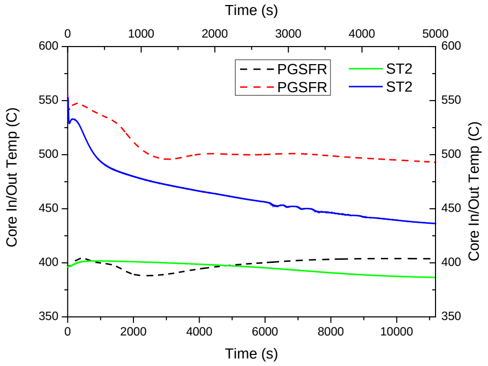

Fig. 11 Core in/out temperature comparison

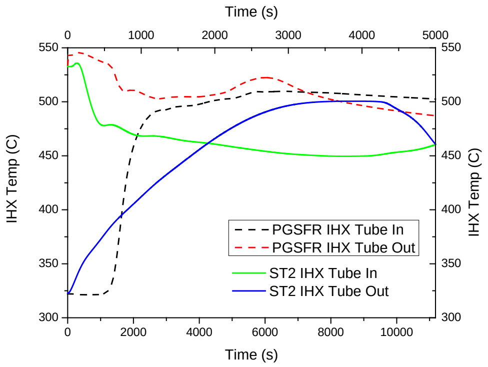

Fig. 12 IHTS temperature comparison

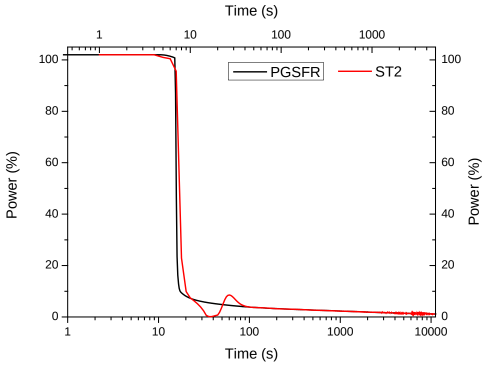

Fig. 13 Core power change comparison (Log scale)

The main reason of difference in temperature is due to the relatively large surface area to volume ratio compared to the PGSFR. STELLA-2 is a scaled-down model and the heat loss from hot pool to the cold pool via redan was found to be significantly influential factor. The CFD analysis result indicates that the heat transfer to the cold pool is about 6.45% in STELLA-2 (1.26% in PGSFR).

The IHTS temperature difference mainly comes from the UHX, which is a replacement of SG. During the transient in PGSFR, SG contributes as a small, but not zero, heat sink for some time in early period. Whereas, in STELLA-2, the UHX air blower was turned off during the transient. Therefore the temperature cross point comes earlier than the PGSFR.

4.2 Flow

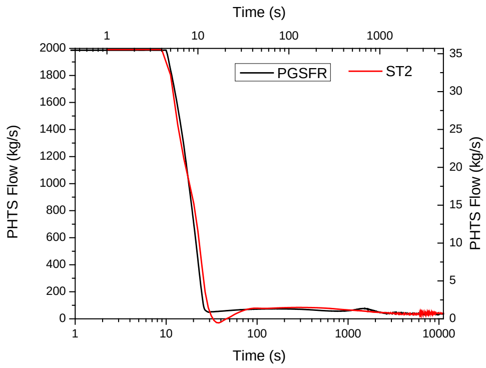

Fig. 14 PHTS flow change comparison (Log scale)

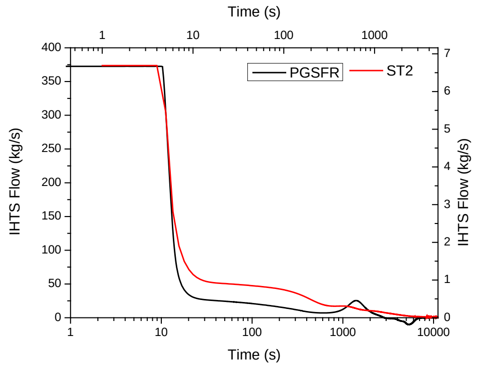

Fig. 15 IHTS flow change comparison (Log scale)

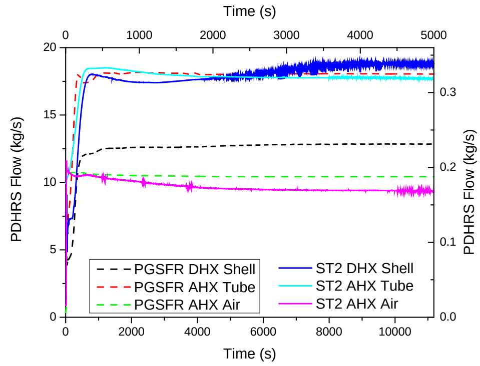

Fig. 16 PDHRS flow trend comparison

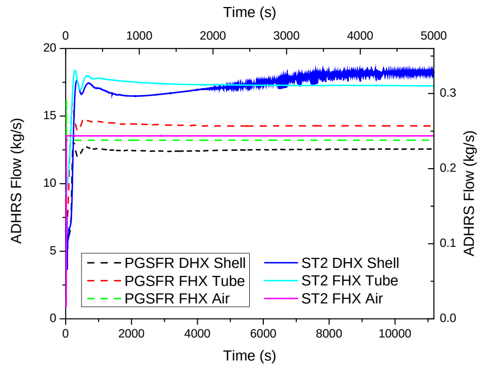

Fig. 17 ADHRS flow trend comparison

The main flow in PHTS and IHTS well follows the PGSFR result, but the only difference can be observed in the DHX shell flow of both PDHRS and ADHRS. For PGSFR input, the K factors for pressure drop calculation in DHX shell side were set to ensure the conservative result. However in STELLA-2 input, the K factors were determined based on the actual geometry. Therefore, the result of STELLA-2 is more realistic.

5. Conclusion

As a part of STELLA-2 design evaluation, MARS-LMR input was prepared to analyze the steady-state and transient behavior. The LOF condition with LOOP assumption was selected for the representative DBE and the result was compared with PGSFR analysis. Some of the values were inconsistent with PGSFR and the reason of difference was also discussed. For further study, various sensitivity test on each variable is planned.

Acknowledgement

This work was supported by the National Research Foundation of Korea (NRF) grant funded by the Korea government (MEST). (No. 2012M2A8A2025635)

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