Scoping Analysis of STELLA-2 using MARS-LMR

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Abstract. To support the development of Prototype Gen IV Sodium-cooled Fast Reactor (PGSFR), the Sodium Integral Effect Test Loop for Safety Simulation and Assessment (STELLA) program has been launched and the basic design of STELLA-2 facility was completed in 2015. The STELLA-2 is a down-scaled facility including all the major systems and components in PGSFR and is able to simulate the transient behavior. For the scoping analysis of STELLA-2, the representative design basis event (DBE) analysis was conducted and evaluated by using MARS-LMR code with the same assumption and approach used for PGSFR. The Loss of Flow (LOF) accidents with the Loss of Offsite Power (LOOP) was the target event and the result of PGSFR and STELLA-2 were compared. In general, the flow trend well-followed the PGSFR behavior whereas the temperature trend slightly deviated from the PGSFR result. The design issue was investigated and the solution for the problem is also suggested. After the improvement/modification of the STELLA-2 input, it was verified that the both flow and temperature trend well-follows the PGSFR transient behavior. This issue is expected to be managed in the installation and manufacturing stage of STELLA-2. For further study, various sensitivity tests on key factors will be needed. Furthermore, more DBEs are under consideration to be analyzed and evaluated.

Key Words: STELLA-2 Scoping Analysis, STELLA-2 DBE Analysis, STELLA-2 Evaluation

1. Introduction

The development of Prototype Gen IV Sodium-cooled Fast Reactor (PGSFR) is on-going and various experimental activities are followed by many researchers 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 1/5 sized system of PGSFR including all the major components such as key heat exchangers, pump systems, reactor internals, core systems, and etc. The distinctive feature of STELLA-2 is its capability to simulate the transient behaviour of PGSFR under various accident scenarios and the integral effect can be observed.

For the scoping analysis of STELLA-2 design, the representative design basis event (DBE) was determined and evaluated using MARS-LMR with the same assumption and same approach used for PGSFR. For the safety analysis of PGSFR, the Loss of Offsite Power (LOOP) is assumed and it results in same scenario for the Loss Of Flow (LOF) and Loss Of Heat Sink (LOHS). In this paper, the LOF with LOOP was selected as a reference transient and the evaluation results are described in next sections.

The methodology and preliminary transient analysis[3] was conducted to verify the procedure and results. The updates on this established methodology are summarized in this paper and this includes the comparison with the PGSFR safety analysis data.

2. MARS-LMR Analysis

2.1. Input Preparation

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) mechanical pump (3) steam generator, and (4) Decay heat removal system (DHRS). In STELLA-2, the core heat is simulated by the electric heater, and the pump is replaced by the electromagnetic pump loops. Moreover, the steam generator is simulated by a sodium-to-air heat exchanger named Ultimate Heat eXchanger (UHX). Finally, all 4 DHRS loops are modeled in STELLA-2 to observe the various transient behaviors.

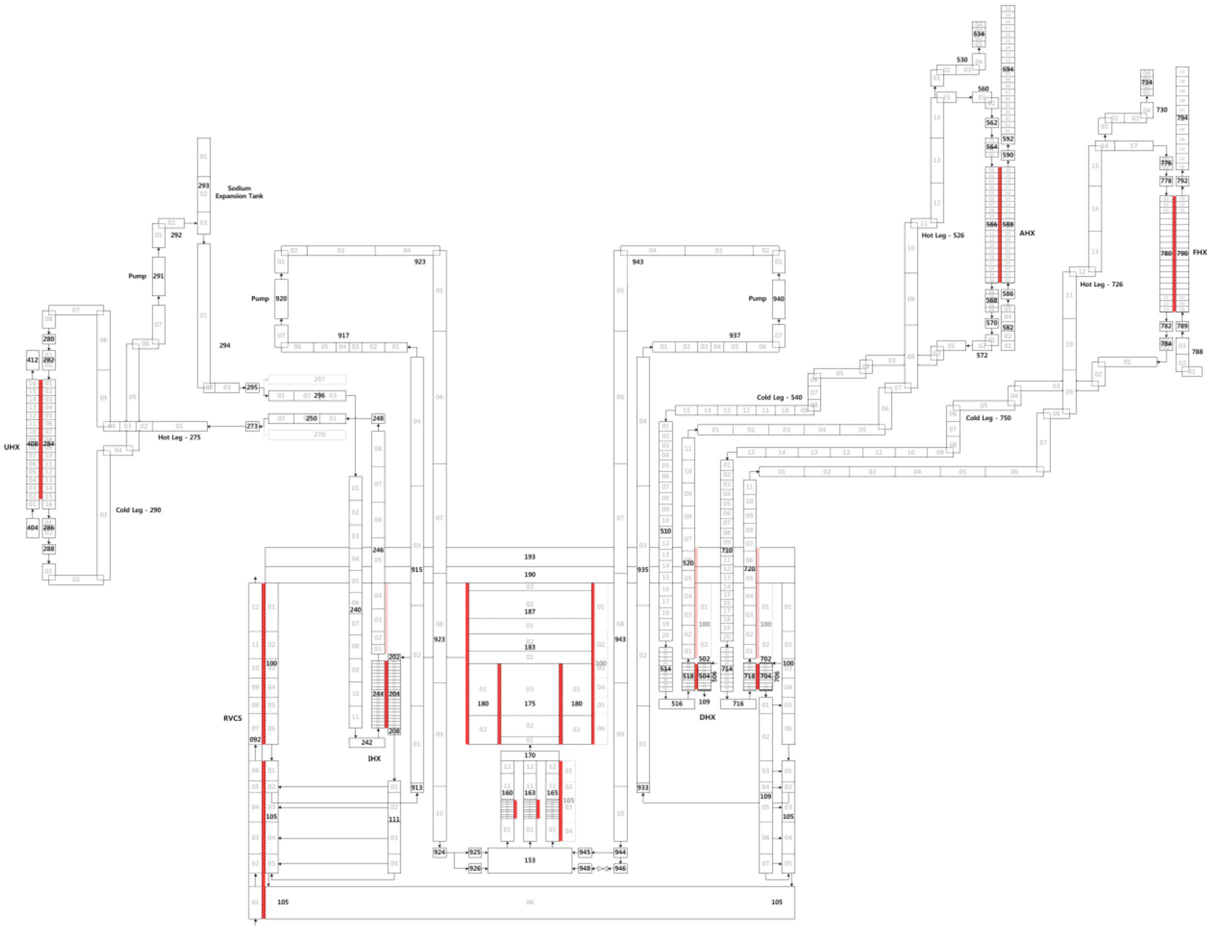

FIG. 1 STELLA-2 Input Node Structure

2.2.Steady-state Analysis

The main results of steady-state condition is summarized in the following tables (TABLE 1 and 2). The target values are the data from the PGSFR during normal operation and the ST2 values are the result of MARS-LMR steady-state analysis. 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 values in TABLE 2 are scaled data. The time to reach the steady-state was approximately 1,000 seconds and the analysis time was set to be 2,000 secs.

In general, the temperature distribution well meets the target value as shown in TABLE 1. The difference on the temperature of DHX shell outlet is linked with AHX tube outlet temperature and this discrepancy is due to the different heat transfer calculation in design code and MARS-LMR. Similarly, the discrepancy in FHX side can also be observed. However, the temperature difference range is within acceptable range.

In TABLE 2, the flowrate data of ST2 is in accordance with the target value. The air flowrate of UHX was manually controlled to discharge the required heat. The steady-state comparison is illustrated in FIG. 2.

TABLE 1 STEADY-STATE ANALYSIS RESULT (TEMPERATURE)

Variables	**Temp (℃)**		**MARS Component**	**Description**
	Target	**ST2**		
Inlet Plenum	390	390.0	153	
Core Out	545	544.4	170	
Hot Pool	545	542.9	183	IHX shell inlet
Cold Pool	448	455.1	100	DHX shell inlet
	390	388.6	105	PSLS intake
IHX	545	542.8	202	IHX shell inlet
	390	388.5	206	IHX shell outlet
DHX (Passive)	448	452.7	502	DHX shell inlet
	426	406.7	506	DHX shell outlet
DHX (Active)	448	453.0	702	DHX shell inlet
	426	413.0	706	DHX shell outlet
AHX	441	444.5	564	AHX tube inlet
	423	404.7	568	AHX tube outlet
FHX	435	446.2	778	FHX tube inlet
	402	411.5	782	FHX tube outlet
UHX	528	523.5	282	UHX tube inlet
	322	317.9	286	UHX tube outlet
Air	442	443.0	590	AHX shell outlet
	418	399.2	792	FHX shell outlet
	162.04	163.3	408	UHX shell outlet
Fixed Value				
Air	40		582	AHX & FHX shell
	20		404	UHX shell

TABLE 2 STEADY-STATE ANALYSIS RESULT (FLOWRATE)

Variables	**Flow (kg/s)**		**MARS Component**	**Description**
	Taget	**ST2**		
PSLS	17.80	17.80	914	Intake 1
	8.899	8.901	925	Discharge 1
	8.899	8.901	926	Discharge 2
	8.899	8.901	945	Discharge 3
	8.899	8.901	946	Discharge 4
IHX	8.899	8.900	203	Shell
DHX	0.1123	0.1130	503	Shell (Passive)
	0.1123	0.1125	703	Shell (Active)
AHX	0.1512	0.1520	565	Tube
FHX	0.1512	0.1516	777	Tube

UHX	13.4	13.405	281	Tube
Fixed Value				
Air	0.01503		595	AHX shell
	0.01682		795	FHX shell
	24.182		414	UHX shell

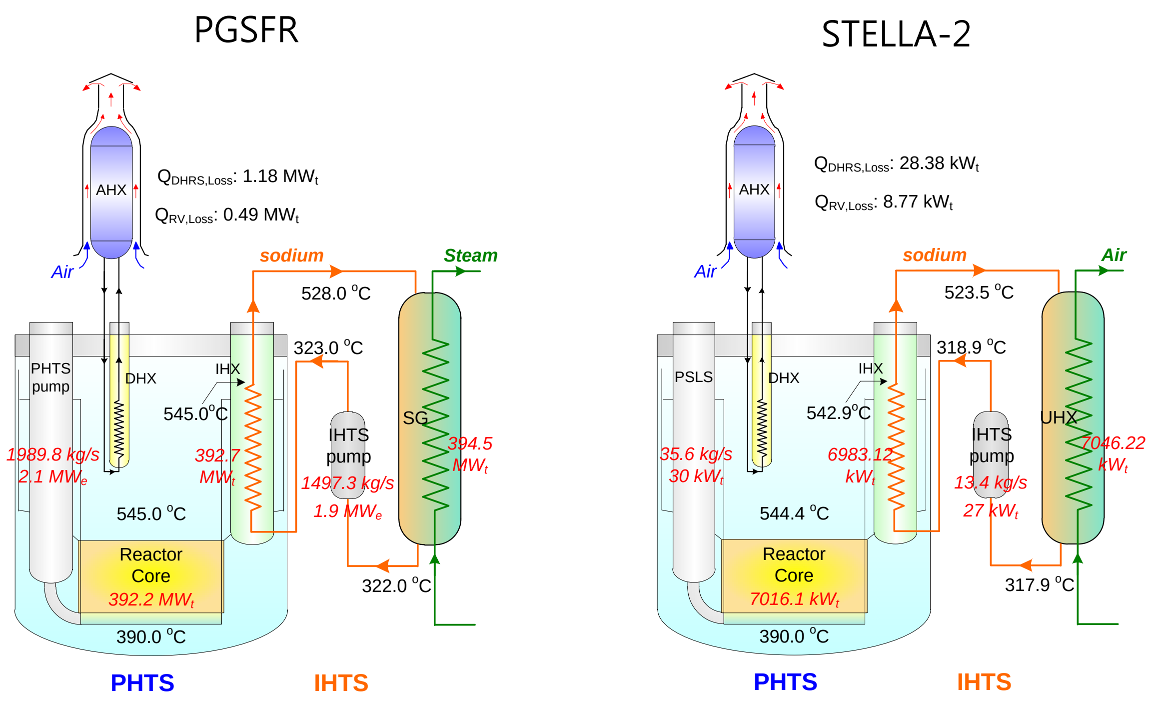

FIG. 2 Comparison of Steady-state Analysis Result

2.3. Transient Analysis

The LOF + LOOP case was analyzed and the main results are illustrated in FIG. 3 ~ 9. In the analysis, 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 each event is scaled-down with the factor of 1/2.24 (time scale of STELLA-2 design). The calculation was done up 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 following figures.

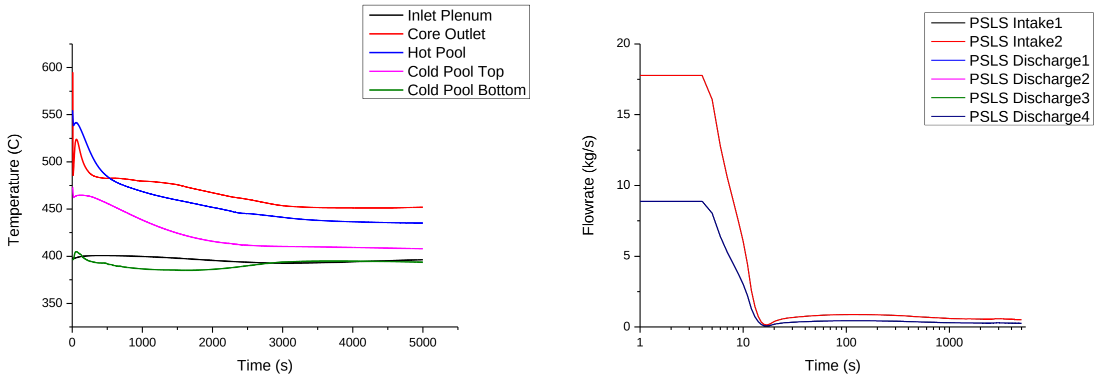

FIG. 3 PHTS Temperature and Flow (log scale)

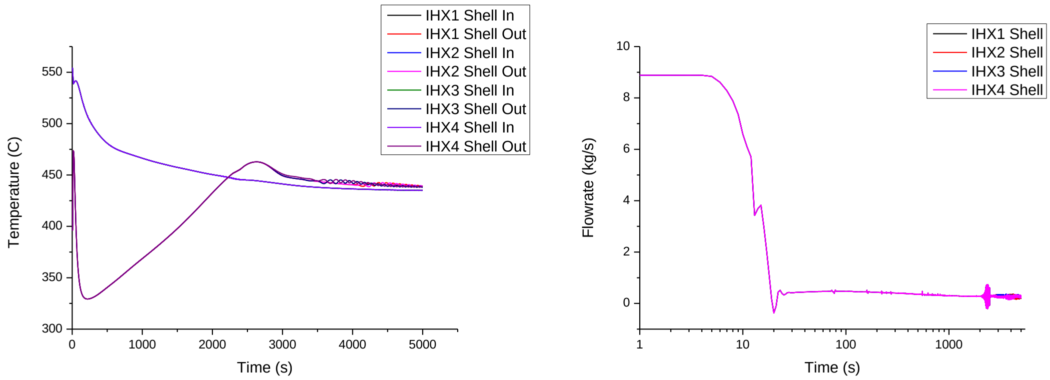

FIG. 4 IHX Shell Temperature and Flow (log scale)

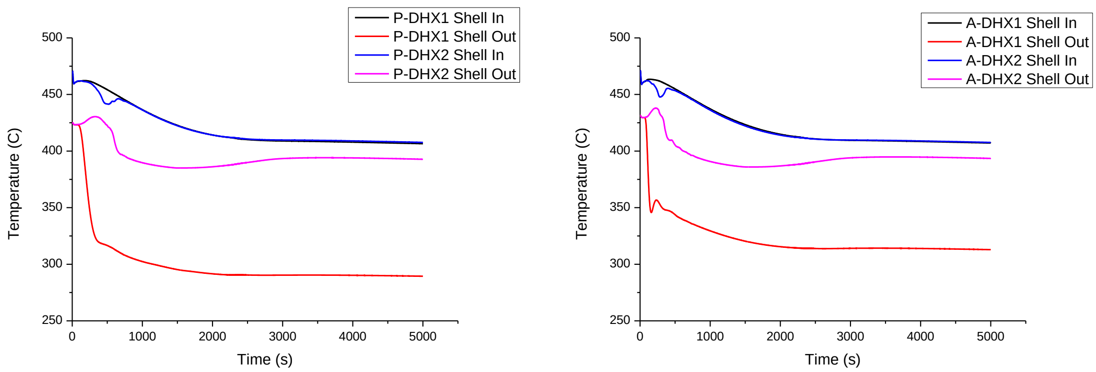

FIG. 5 Passive and Active DHX Shell Temperature

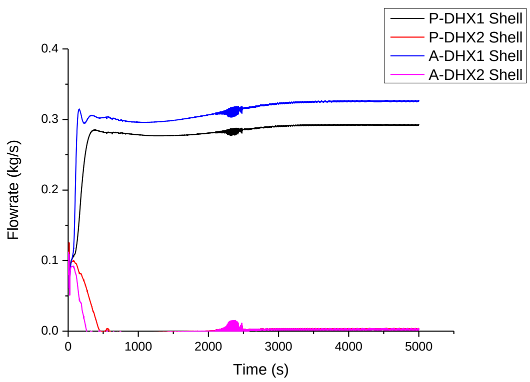

FIG. 6 DHX Shell Flow

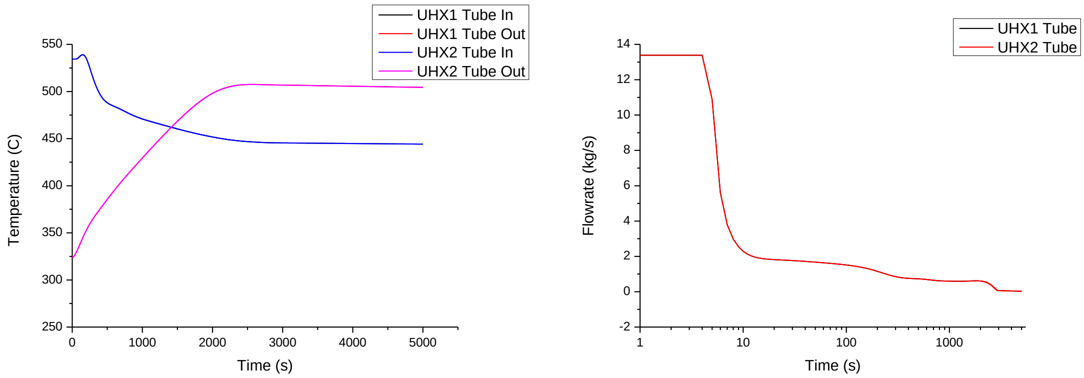

FIG. 7 IHTS Temperature and Flow (log scale)

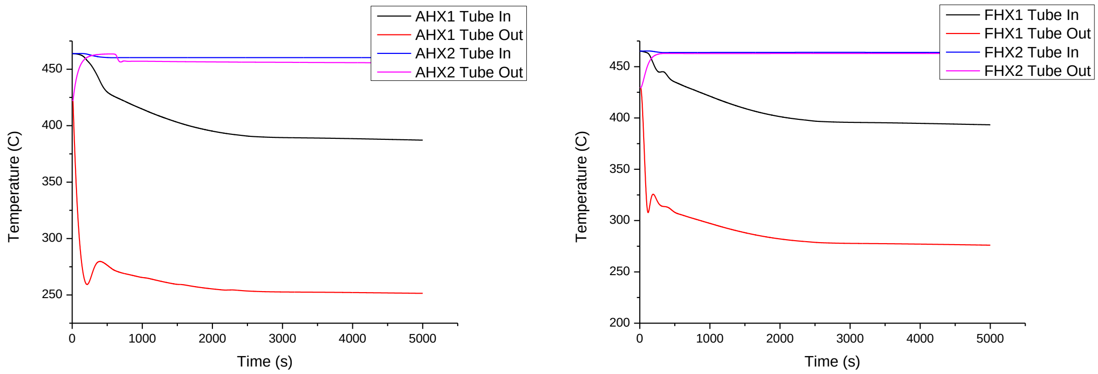

FIG. 8 AHX and FHX Tube Temperature

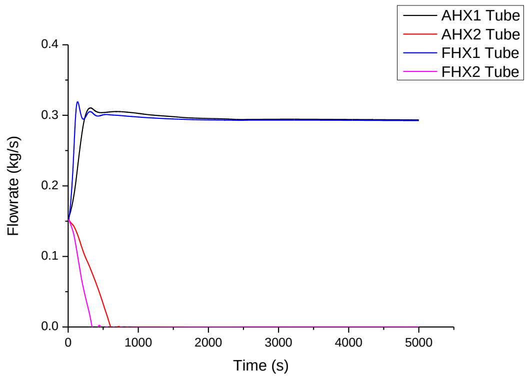

FIG. 9 DHRS Flow

3. Comparison with PGSFR

The comparison results are shown in FIG. 10 ~ 14. The overall trend is consistent with the PGSFR but difference in temperature was observed. 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 is very important. The CFD analysis result indicates that the heat transfer to the cold pool is about 6.45% in STELLA-2 (1.26% in PGSFR)[4].

The IHTS temperature difference mainly comes from the UHX, which is a replacement of SG. During the transient in PGSFR, SG contributes as a very small, but not zero, heat sink. Whereas, in STELLA-2, the UHX air blower is turned off during the transient.

The main flow including the natural circulation in PHTS and IHTS well follows the PGSFR result, but the difference can be observed in the DHX shell flow of both PDHRS and ADHRS. Because of difference in temperature change in DHRS loop and DHX shell in/out, the influence appears mostly on the DHX shell flow. Therefore, more investigation on heat transfer calculation used in the design code and MARS-LMR will be needed.

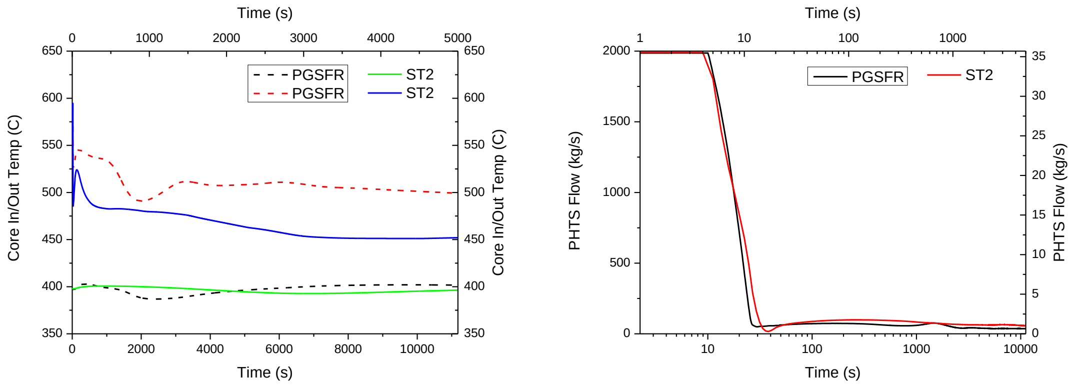

FIG. 10 Core In/Out Temperature and PHTS Flow Comparison

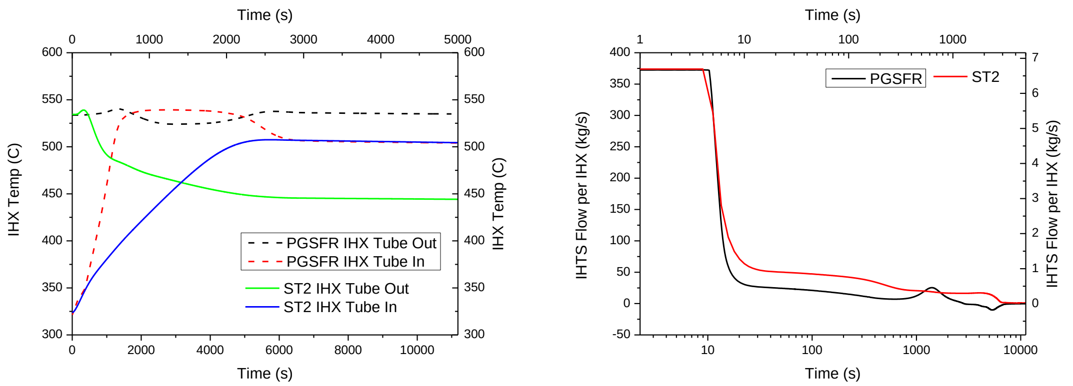

FIG. 11 IHTS Temperature and Flow Comparison

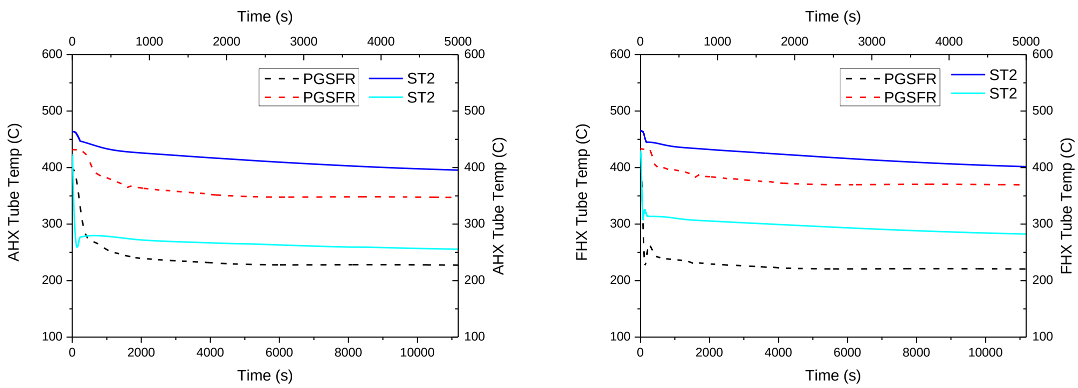

FIG. 12 DHRS Hot/Cold Temperature Comparison

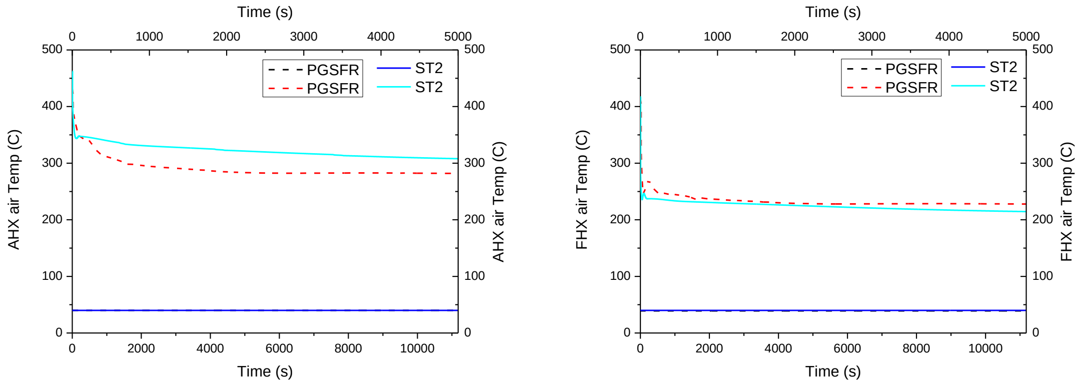

FIG. 13 AHX and FHX Air Temperature Comparison

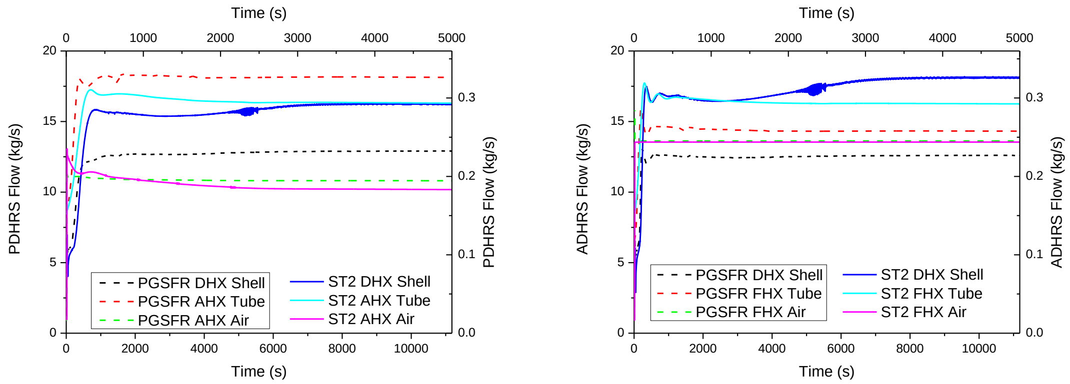

FIG. 14 DHRS Flow Comparison

4. 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 was selected for the representative DBE and the result was compared with PGSFR. Some of the values were inconsistent with PGSFR and the reason of difference was also discussed. For further study, various sensitivity test as well as the comparison of heat transfer correlation will be needed.

5. Reference

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