Transactions of the Korean Nuclear Society Spring Meeting
Jeju, Korea, May 18-19, 2023

Preliminary GAMMA+ Modeling on Passive Decay Heat Removal System of SALUS

Hyun-Sik Park*, Sun-Rock Choi, Seung-Hyun Yoon, Nam-Il Tak, Byung-Ha Park, Jung Yoon, and Jonggan Hong
Korea Atomic Energy Research Institute, 989-111 Daedeokdaero, Yuseong, Daejeon, 305-353, Korea
**Corresponding author: hspark@kaeri.re.kr*

1. Introduction

Pool-type sodium-cooled fast reactors (SFR) were investigated by Korea Atomic Energy Research Institute (KAERI) since 1990's, and based on the accumulated SFR technology the Specific Design Safety Analysis Report (SDSAR) had been issued according to the specific design of Proto-type Gen-IV SFR (PGSFR) in 2017 [1]. Currently long-term sustainable small modular reactors are attracting attentions worldwide, which are designed to maximize the utilization of uranium resources using fast neutrons. Now KAERI is carrying out a conceptual design of SALUS (Small, Advanced, Long-cycled and Ultimate Safe SFR) under the PGSFR design experience.

Previously a preliminary analysis of the performance of the PDHRS loop was performed using the MARS-LMR code [2] to analyze the design value of the DHX and AHX heat exchanger and to support its basic design with the STELLA-2 facility. The code calculation results for DHX were in good agreement with the design values, however, the code calculation results for AHX show under-prediction compared with the design values [3]. Also it is noted that the GAMMA+ code [4] is validated using sodium thermal-hydraulic separate effect test data [5] including AHX and DHX.

In this paper, a preliminary modeling on passive decay heat removal system (PDHRS) of SALUS was performed using the GAMMA+ code to analyze the design values of the DHX and AHX heat exchangers.

2. Design Features of SALUS PDHRS

2.1 Conceptual Design of SALUS

The SALUS core is being designed with a cycle length of 20 years with 100 MWe power. The key design limit of the fuel rod is determined by the Cumulative Damage Fraction (CDF), which should be kept less than 0.05 as PGSFR. Since CDF is a function of cladding temperature, fuel rod internal pressure, and burn-up, in order to ensure the fuel rod integrity for extended cycle length, the coolant inlet/outlet temperatures were set lower than those of PSGFR. The long cycle length can be achieved by lowered power density, and the conversion of isotopes, fertile to fissile, through high neutron economy. Some of major design parameters and characteristics can be found in Table 1.

Table 1 Major Design Parameters of PGSFR and SALUS

Design Parameters	PGSFR	SALUS
Thermal power	392.2 MWth (150 MWe)	268 MWth (100 MWe)
Design limit	CDF < 0.05	CDF < 0.05
Coolant Inlet/Outlet Temperature	390 / 545 °C	360 / 510 °C
SG Inlet/Outlet Temperature	230 / 503 °C	240 / 454 °C
EFPDs	290 days	7300 days
Fuel type	U-10Zr	U-10Zr
Active core height	90 cm	150 cm
Avg. Discharge Burnup	65.941 GWd/MT	75.019 GWd/MT
Avg. power density (Active core region)	211.503 W/cm^3	50.537 W/cm^3

2.2 SALUS PDHRS

The fluid system of SALUS Nuclear Steam Supply System (NSSS), as shown in Fig. 1, is consisted of Primary Heat Transfer System (PHTS), Intermediate Heat Transfer System (IHTS), Decay Heat Removal System (DHRS) and sodium-Water Reaction Pressure Relief System (SWRPRS). Among them the DHRS has two kinds of decay heat removal types. The one is passive type called a passive decay heat removal system (PDHRS) and the other is an active decay heat removal system (ADHRS). There are two loops of passive and active DHRSs, respectively. The PDHRS has two kinds of heat exchangers which are sodium-to-sodium decay heat exchanger (DHX) and helical-type sodium-to-air heat exchanger (AHX), respectively. The PDHRS performs decay heat removal of cold pool in reactor vessel after shutdown [6].

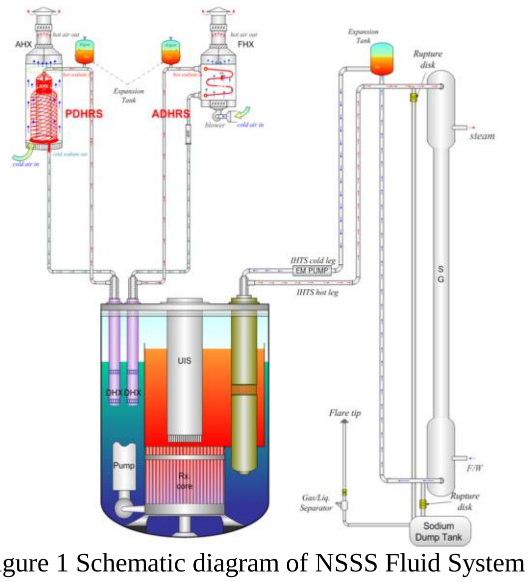


Figure 1 Schematic diagram of NSSS Fluid System of SALUS.

3. GAMMA+ Modeling on SALUS PDHRS

The GAMMA (Gas Multi-component Mixture Analysis) code has been developed to predict the physical phenomena expected following the anticipated as well as postulated accidents in a High Temperature Gas Cooled Reactor (HTGR). The GAMMA+ (General Analyzer for Multi-component and Multi-dimensional Transient Application) 1.0 version has been further updated from the original GAMMA code and the GAMMA+ 2.0 version is that extended to Micro Gas-Cooled Reactor (MMR), Liquid-Metal Reactor (LMR), Moten-Salt Reactor (MSR) and Space Power Reactor (SPR) [4]. Using the GAMMA+ code, the preliminary analysis of heat exchangers in SALUS PDHRS is performed. In the first step the AHX is modeled and then the whole PDHRS is modeled together with DHX.

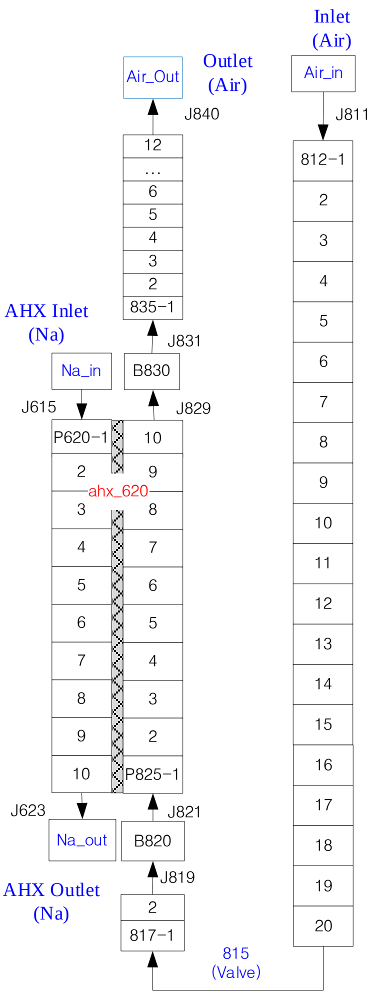


Figure 2 GAMMA+ nodalization scheme for the SLAUS AHX.

3.1 Preliminary GAMMA+ Results on SALUS AHX

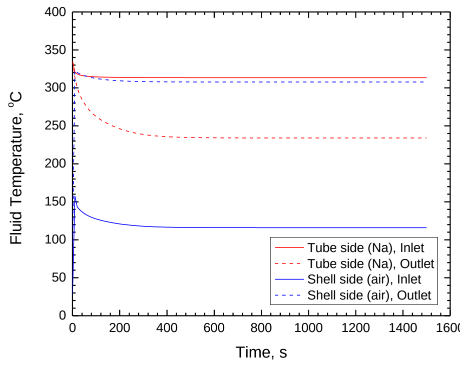
SALUS AHX was modeled for the GAMMA+ code using the design information. Fig. 2 shows the GAMMA+ nodalization scheme for the SALUS AHX.

Using the GAMMA+ code, the preliminary analysis on SALUS AHX is performed. The input and selected results from the GAMMA+ steady-state simulation for the SALUS AHX is listed in Table 2. The values are arbitrary and not design values. The present results are preliminary calculation results and further simulation will be done for the design of SALUS in the near future.

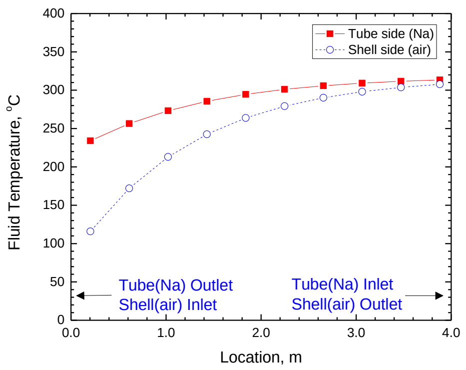
Table 2 GAMMA+ Simulation for the SALUS AHX

Parameters	Tube side (Na)	Shell side (air)
Flowrate (kg/s)	18.16	6.96
Pressure (MPa)	0.3	0.2
Inlet temperature (℃)	314.7	40.0
Outlet temperature (℃)	234.05	307.74

The temporal and axial temperature profiles are shown in Fig. 3. The steady states were well achieved and the local temperature profiles show reasonable results.



(a) Temporal variation of fluid temperatures



(b) Variation of fluid temperatures along the AHX

Figure 3 Steady-state calculation results on SALUS AHX.

From the node sensitivity calculation on the STELLA-1 AHX test, it was shown that the fluid temperatures were converged when the node number is more than 30 [5]. It is necessary to increase the node number from the present 10 to more than 30 during the detailed modeling of SALUS AHX.

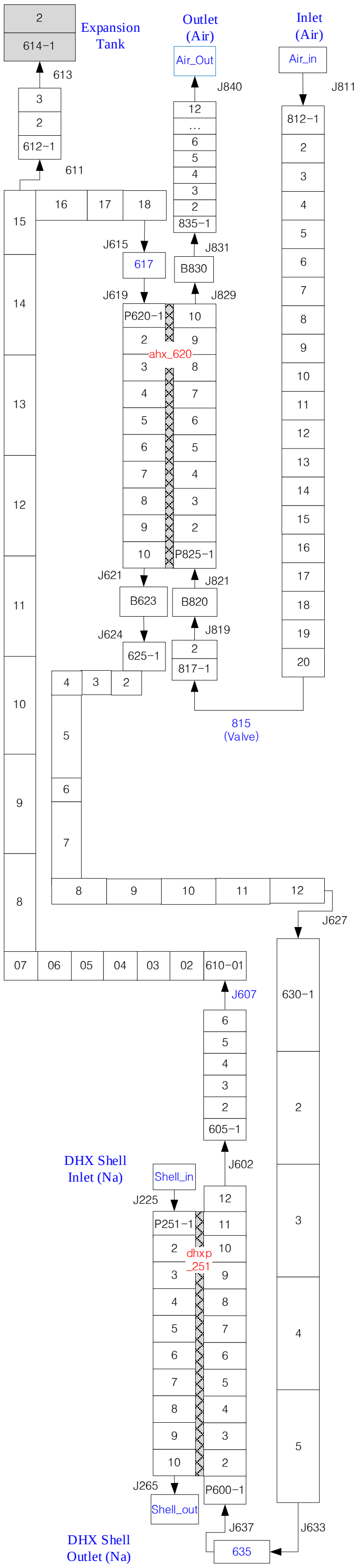


Figure 4 GAMMA+ nodalization scheme for the SALUS PDHRS.

3.2 Preliminary GAMMA+ Results on SALUS PDHRS

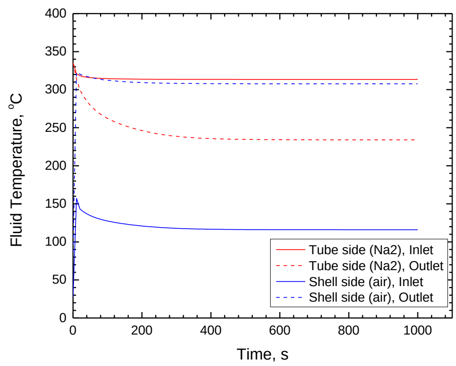
Using the GAMMA+ code, preliminary analysis on heat exchanger in SALUS PDHRS is performed. The PDHRS was modeled for the GAMMA+ code using the design information. Fig. 4 shows the GAMMA+ nodalization scheme for the SALUS PDHRS, which includes the DHX, hot-leg pipe, cold-leg pipe, a sodium expansion tank, and AHX.

The input and selected results from the GAMMA+ steady-state simulation for the SALUS PDHRS are listed in Table 3. The values are arbitrary and not design values. The present results are preliminary calculation results and further simulation will be done for the design of SALUS in the near future.

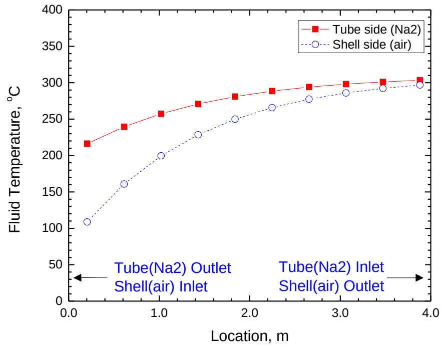
Table 3 GAMMA+ Simulation for the SALUS PDHRS

Parameters	Shell side (Primary Na)	Tube side (Secondary Na)	Shell side (air)
Flowrate (kg/s)	11.73	15.77	6.96
Pressure (MPa)	0.1225	0.466	0.2
Inlet temperature (℃)	360.0	244.7	40.0
Outlet temperature (℃)	239.8	-	296.9

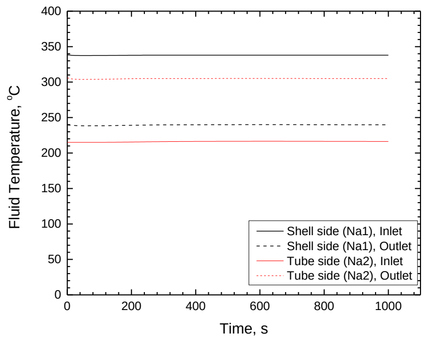
The temporal and axial temperature profiles are shown in Fig. 5. The steady states were well achieved both in AHX and DHX, and the local temperature profiles show reasonable results. When the flowrates from both shells of the primary sodium and air are given as boundary conditions, the flowrate in the secondary sodium loop is well stabilized within 200 seconds.



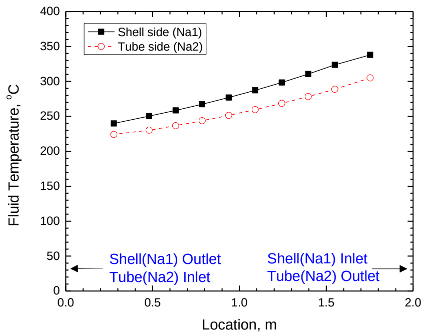
(a) Temporal variation of AHX fluid temperatures



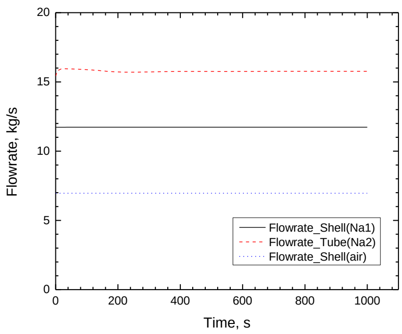
(b) Variation of fluid temperatures along the AHX



(c) Temporal variation of DHX fluid temperatures



(d) Variation of fluid temperatures along the DHX



(e) Variation of flow rates of primary/secondary sodium and air

Figure 5 Steady-state calculation results on SALUS PDHRS.

4. Conclusions

Preliminary analyses of the performance of both the AHX only and the whole PDHRS loop including AHX and DHX were performed using the GAMMA+ code. The temporal and local heat transfer characteristics were investigated to analyze the design value of the AHX and DHX heat exchangers. The detailed analysis based on these results will be done for design confirmation of SALUS as a future work.

ACKNOWLEDGEMENT

This work was supported by the National Research Foundation of Korea (NRF) grant funded by the Korean government (MSIT) [grant numbers 2021M2E2A2081061].

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