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Steady-state Analysis of the SALUS IHTS using GAMMA+ code

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1. Introduction

The GAMMA+ (General Analyzer for Multi-component and Multi-dimensional Transient Application) [1] code is a development of the GAMMA (Gas Multi-component Mixture Analysis) code, which was developed to predict physical phenomena in accidents that can occur in high-temperature gas-cooled reactors. The code has been further developed and improved for the design and safety analysis of Very-high-temperature gas reactors. Recently, the applicability of the GAMMA+ code has been expanded to include small high-temperature gas reactors, liquid metal reactors, molten salt reactors, and space reactors, among others, through revisions aimed at broadening its scope. Accordingly, Korea Atomic Energy Research Institute (KAERI) is using the code for the design of an SFR reactor.

As part of the process [2] of creating input for a safety analysis code for SALUS reactor design, this study includes the development of Intermediate Heat Transport System (IHTS). The project, which includes this study, aims to construct and verify safety analysis input data for all systems by the end of the 2023.

2. Overview of IHTS used in SALUS

The SALUS (Small Advanced Long-cycled and Ultimate Safe SFR), currently being developed by KAERI, has the characteristic of being able to operate without the need for nuclear fuel replacement for about 20 years. One of the heat transfer systems in the SALUS, the intermediate heat transfer system, consists of two independent loops. Each loop is composed of pipes, an intermediate heat exchanger, a steam generator, an expansion tank, an electro-magnetic type pump, a steam trap, and valves as shown in Fig.1. For validation purposes, we plan to compare the results of the MARS-LMR code and GAMMA+ code using a nodalization (Fig.2).

2.1 Intermediate Heat Exchanger (IHX)

IHX is a shell-and-tube type heat exchanger. It is positioned vertically and the primary coolant enters the IHX through an inlet located at the top of the heat exchange section, flowing down through a total of five heat transfer tube supporters before exiting at the bottom outlet. IHX consists of four cylindrical heat exchangers, with one primary pump generating flow for two IHXs. The IHX design parameters were generated to comply with SALUS design requirements (100MWe). Common design requirements, such as temperature and flow rate, used for evaluating heat transfer area, were based on heat balance data (Table 1).

Table I: IHX design information

Shell-side (Sodium)	Flow rate (kg/sec)	341.4
	Inlet temperature (℃)	505.2
	Outlet temperature (℃)	357.6
Tube-side (Sodium)	Flow rate (kg/sec)	324.8
	Inlet temperature (℃)	322.7
	Outlet temperature (℃)	482.0

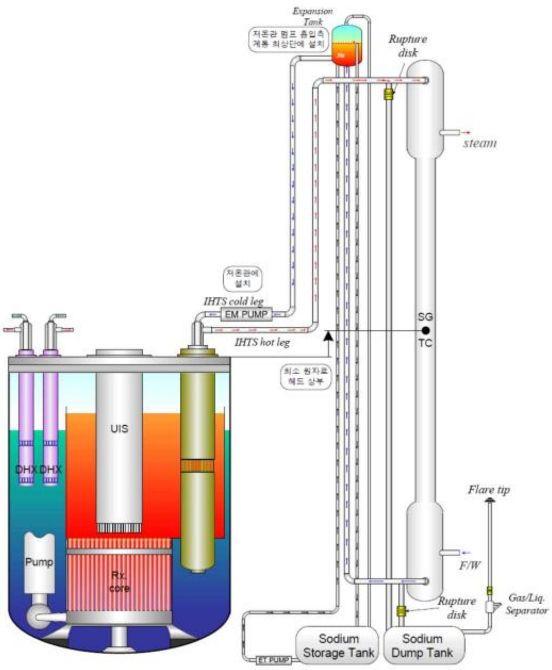

Fig. 1. IHTS arrangement requirements

2.2 Steam Generator (SG)

The steam generator is composed of the upper/lower outer cylinder, steam generator cylinder, cylinder bellows, feedwater head, steam head, steam generator support, heat exchange tubes and tube support plates, flow distributor, and orifice. Sodium introduced through the steam generator inlet nozzle flows upward through the annular space and then downward along the outside of the heat exchange tubes after passing through the upper inlet plenum.

2.3 Expansion Tank

To accommodate the volume change of the sodium in the intermediate heat transfer system during excessive operation, provide a uniform effective suction head to the intermediate heat transfer system pump, and continuously supply purified sodium to replace some of the contaminated sodium, an expansion tank is installed and connected to the intermediate sodium purification system.

2.4 EM Pump

The intermediate heat transfer system pump is an Annular Linear Induction Pump (ALIP), with one pump located on the cold inlet pipe per loop, for a total of two pumps. The pump suction pipe side is installed to be connected to the expansion tank.

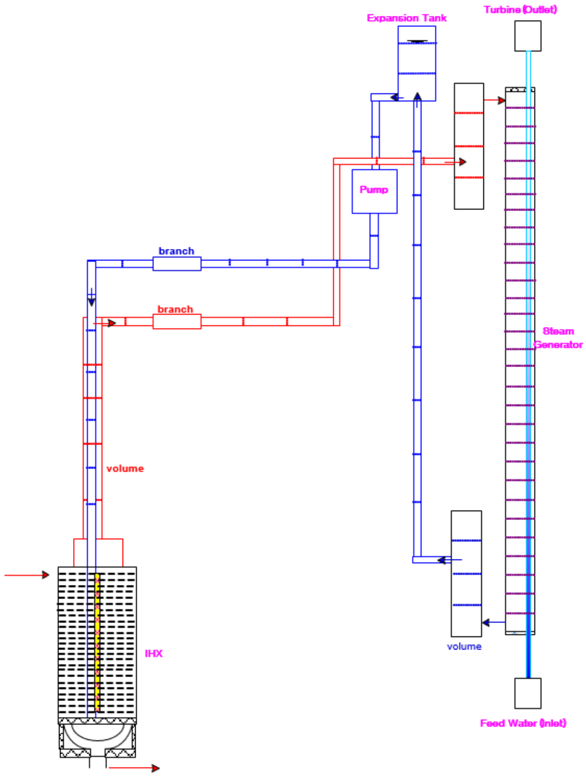

Fig. 2. IHTS nodalization

3. Preliminary Node Sensitivity Results

3.1 Intermediate Heat Exchanger (IHX)

Before making input for the IHTS system, it is necessary to evaluate the sensitivity of each device and node to input. First, for IHX, GAMMA+ input was tested for the heat transfer region. The sensitivity evaluation was performed for 20, 30, 50, 80, and 100 nodes. The results are shown in Table II.

Table II: Node sensitivity results of IHX heat transfer region

Case	N [#]	length/n [m]	time [sec]	Temperature [°C]		Q [MW]
				Shell	Tube	
1	20	0.200	43	368.0	470.9	61.8
2	30	0.133	96	366.2	472.8	62.6
3	50	0.080	176	364.7	474.5	63.3
4	80	0.050	269	363.8	475.4	63.7
5	100	0.040	384	363.5	475.7	63.8

3.2 Steam Generator (SG)

In the case of SG, it is relatively long and has a wider heat transfer area compared to IHX. When evaluating sensitivity, the entire device including semi-spherical supply headers on the tube (water) side and upper /lower heads on the shell (sodium) side were simulated. Node sensitivity evaluation was conducted for the heat transfer region. The results of 10e+3 iteration are shown in Table III.

Table III: Node sensitivity results of SG entire device

Case	N [#]	length/n [m]	time [sec]	Temperature [°C]		Q [MW]
				Shell	Tube	
1	10	2.380	1023	436.84	352.30	289.0
2	16	1.488	2026	445.51	352.31	254.7
3	20	1.190	2400	449.08	352.31	236.9
4	30	0.793	2688	454.80	352.32	204.2
5	40	0.595	2973	458.34	352.33	181.8

4. Results

In the analysis, a time step of 2.0e-2 was used, and the pressure and enthalpy errors were 5.7e-7 and 1.8e-7, respectively, after computing a total of 1000 steps to confirm the steady state.

Table IV: Analysis results with design values

		MARS-LMR		GAMMA+	
		Temp	flow	Temp	flow
IHX (Shell)	in	-3.1%	0.0%	0.0%	0.0%
	out	-1.2%	0.0%	1.3%	0.0%
IHX (Tube)	in	-0.2%	0.0%	-0.2%	0.0%
	out	-0.6%	0.0%	-0.2%	0.0%
SG (Shell)	in	-2.2%	0.0%	-0.8%	0.0%
	out	-0.1%	0.0%	0.0%	0.0%

The results of implementing IHTS using A are shown in Table 4 below. Each data point is expressed as an error relative to the design value and compared to the steady-state results of MARS-LMR. We confirmed that the heat capacity of IHX and SG were designed with a difference of -0.03% and -0.15%, respectively, compared to the design values. To ensure the convergence of each heat exchanger, 50 nodes were used, and the temperature changes within the device are shown in Figure 3.

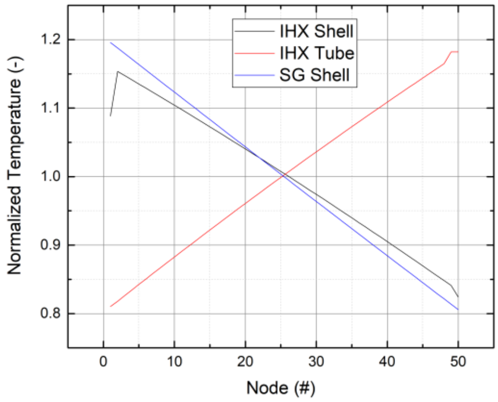

Fig. 3. Temperature change in IHX and SG

5. Conclusions

Starting from 2021, a validation project for the SFR system is underway using the expanded GAMMA+ code. Based on the validation of each device conducted in 2021-2022, validation of the system with the MARS-LMR code will be performed in 2023. It is expected that GAMMA+ will serve as a safety analysis tool for the development of SFR-type SMR projects.

REFERENCES

[1] H. S. Lim, GAMMA+ 2.0 Volume II: Theory Manual, KAERI/TR-8662/2021, Korea Atomic Energy Research Institute, 2021.
[2] J. Hong et al., 'Validation of GAMMA+ Code for SFR Application." Transactions of the Korean Nuclear Society Virtual Autumn Meeting, Oct. 21-22, 2021.