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Steady-state Analysis of the SALUS using GAMMA+ code

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1. Introduction

The GAMMA+ (General Analyzer for Multi-component and Multi-dimensional Transient Application) 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. [1]

As part of the process [2], the purpose of this study is to set the initial conditions with GAMMA+ code using design data obtained from the SALUS unprotected transient over power. The project, which includes this analysis, aims to construct and verify safety analysis system with GAMMA+ for all heat transfer systems by the end of the 2023.

2. Overview of PHTS 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 long-term. The designed thermal power of the SALUS is 268 MWth. Major components of the primary heat transport system (PHTS) consist of two primary pumps, four intermediate heat exchangers, four decay heat exchangers, hot/cold pools and core included in/outlet plenum. The components in PHTS are submerged in – sodium pools (hot and cold pools). The pools have no pressurized condition and there is a direct mixing of coolant before entering the next component as shown in Fig.1.

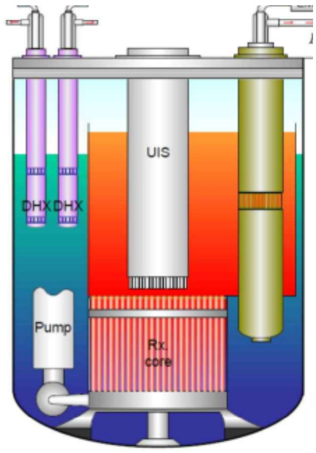

Fig. 1 PHTS arrangement

2.1 PHTS modeling

The core consists of 7 kinds of subassemblies including fuel (inner, outer and outmost), control rod (primary and secondary) reflector and B_4C shield (Fig.2). The total number of assemblies is 253 EA. After CDF flattening analysis, the flow groups of core assemblies are classified with 15. Each assembly has hexagonal duct and fuel assemble has 169 helical wire-wrapped pins. The B4C shields are also located in the axial direction.

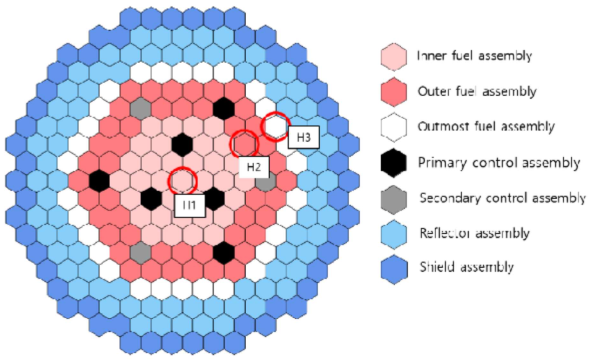

Fig. 2 Schematics of core configuration of the SALUS

The core modeling in the GAMMA+ is divided into 8 fluid channels as shown in Fig.3. The channels are modeled to hottest channel #1-3 (H1-H3 in Fig.1), average driver, reflector, shield, control rod and leakage as an assemble unit. Each fuel driver (CH-1 to CH-4) can classified with lower reflector, active core, sodium bonding region, gas plenum and upper reflector regions. Since the axial core power and length at BOC, MOC, and EOC is different, it was analyzed separately as the value at eh point representing each fuel cycle.

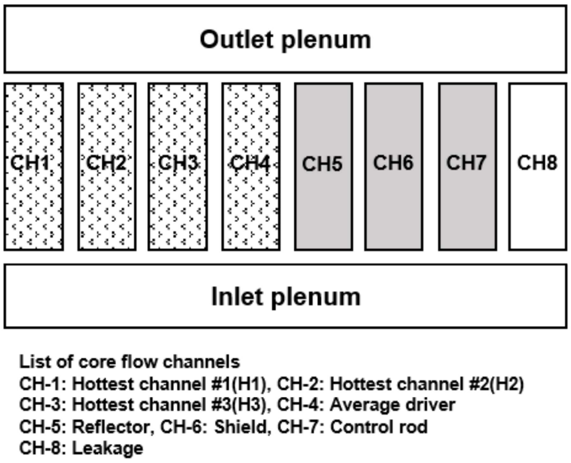

Fig. 3 SALUS core channel modeling in GAMMA+

The hot and cold pools were modeled with one-D hydraulic volume of 12 and 14 included bottom head. Four intermediate heat exchangers (IHXs) and decay heat exchangers (DHXs) are modeled with shell and tube type and heat structures. The EM-pump in the loop of IHTS is individually modeled with a mechanical pump having a zero coast-down time in the GAMMA+ to represent the inherent characteristics of EM pump.

The heat transfer correlation for the straight tube of the IHX and DHX is modeled with Dittus-Boelter correlation for forced convection and McAdams correlation for free convection. The normal operation condition of each DHRS is modeled based on the design condition. The boundary conditions used in the modeled PHTS are flow and temperature at the steam generator feedwater side, FHX air side and AHX air side.

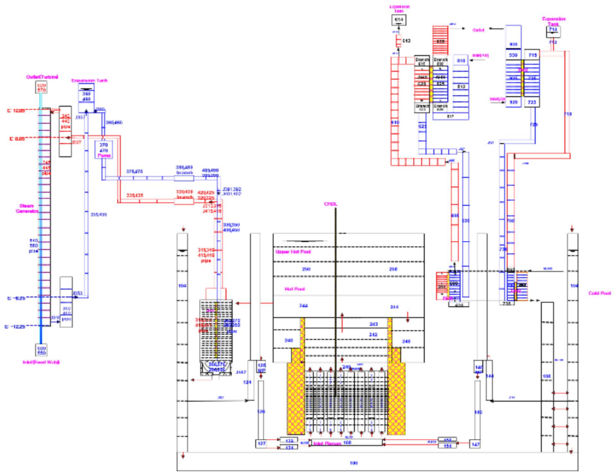

Fig. 4 SALUS PHTS nodalization

2.2 steady-state results

Each data was organized by considering the location of the node, and the analysis results were compared with design values and the MARS-LMR results, which is currently used as a safety analysis code.

Table 1-3 show the representative steady-state results obtained by the GAMMA+ and MARS-LMR calculation. Overall, it can be seen that the GAMMA+ code matches the design values well and agrees well with the modeled values of MARS-LMR. However, for the IHX inlet temperature, the mixing effect in the hot pool is not well simulated and the flow rate in the closed loop section of the DHRS is different from the design and MARS-LMR.

The flow rate in the closed-loop section of the DHRS can reduce the error depending on whether the modeling is based on normal or design operation condition. This study was conducted to more accurately simulate the design condition of the DHRS in a future works. (e.g. unprotected accidents etc.) It was determined that the difference in DHRS energy due to the difference in flow rate was negligible and therefore acceptable.

Table 1 Comparison of code temperature results with design values

		Design	GAMMA+		MARS-LMR	
		Temp(C)	Temp(C)	(%)	Temp(C)	(%)
Core	in	360.0	360.0	0.0%	360.0	0.0%
	out	510.0	510.0	0.0%	510.0	0.0%
IHX_HT	in	482.0	503.9	4.5%	498.0	3.3%
	out	360.0	360.0	0.0%	360.0	0.0%
ADHX_HT	in	360.0	360.0	0.0%	356.9	-0.9%
	out	324.9	325.2	0.1%	335.7	3.3%
PDHX_HT	in	360.0	360.0	0.0%	356.1	-1.1%
	out	324.9	316.3	-2.7%	331.7	2.1%
IHX_TB	in	322.7	323.2	0.2%	319.1	-1.1%
	out	482.0	483.4	0.3%	480.5	-0.3%
ADHX_TB	in	324.5	323.0	-0.5%	329.6	1.6%
	out	347.2	342.8	-1.3%	352.5	1.5%
PDHX_TB	in	324.5	314.3	-3.2%	331.8	2.2%
	out	347.2	337.3	-2.9%	354.1	2.0%
SG_HT	in	482.0	483.4	0.3%	469.3	-2.6%
	out	322.0	323.0	0.3%	318.5	-1.1%
SG_TB	in	240.0	248.6	3.6%	239.9	-0.1%
	out	454.0	462.8	1.9%	438.7	-3.4%
FHX_TB	in	347.2	342.5	-1.4%	353.7	1.9%
	out	324.5	323.0	-0.5%	331.8	2.2%
FHX_HT	in	20.0	20.0	0.1%	20.0	0.0%
	out	344.7	336.8	-2.3%	345.1	0.1%
AHX_TB	in	347.2	337.3	-2.9%	352.2	1.5%
	out	324.5	314.2	-3.2%	327.2	0.8%
AHX_HT	in	20.0	20.0	0.0%	20.0	0.0%
	out	347.5	337.1	-3.0%	348.0	0.1%

Table 2 Comparison of code flowrate results with design values

	Design	GAMMA+		MARS-LMR	
	flow(kg/s)	flow(kg/s)	(%)	flow(kg/s)	(%)
Core	1367.66	1395.01	2.0%	1399.90	2.4%
IHX_HT	341.91	348.75	2.0%	349.56	2.2%
ADHX_HT	7.31	5.50	-24.7%	8.26	13.0%
PDHX_HT	7.45	5.02	-32.6%	8.77	17.7%
IHX_TB	325.20	324.81	-0.1%	325.05	0.0%
ADHX_TB	9.94	9.95	0.1%	9.24	-7.1%
PDHX_TB	9.85	9.75	-1.1%	10.07	2.2%
SG_HT	650.50	649.63	-0.1%	650.15	-0.1%
SG_TB	62.70	62.35	-0.6%	65.70	4.8%
	62.86	62.38	-0.8%	65.70	4.5%
FHX_HT	0.78	0.78	0.0%	0.78	0.0%
AHX_HT	0.89	0.89	0.0%	0.96	7.3%

Table 3 Comparison of code energy results with design values

	Design	GAMMA+		MARS-LMR	
	Q(MW)	Q(MW)	(%)	Q(MW)	(%)
IHX_HT	66.37	66.75	0.6%	66.76	0.6%
ADHX_HT	0.28	0.26	-8.7%	0.26	-6.3%
PDHX_HT	0.28	0.29	4.3%	0.32	15.9%
SG_HT	133.3	133.71	0.3%	134.04	0.6%
FHX_TB	0.28	0.29	4.4%	0.26	-6.2%
AHX_TB	0.28	0.3	-8.7%	0.33	16.4%

3. Conclusions

GAMMA+ code was validated by MARS-LMR code, which is currently used as a safety analysis code as a steady-state analysis for SALUS PHTS application. The steady-state simulation results for each component seem to be in good agreement with the design values compared to the MARS-LMR code results. However, the error of the flow rate in DHXs show a large error compared to the design values because it was modeled based on the design operation condition. Although the flow rate difference is large, the resulting energy and temperature differences are similar to the design values, so it is not expected to have a significant impact on future accident simulation.

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