Calculation and Analysis of Redan Insulation Effect of STELLA-2 Test Facility using MARS-LMR

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1. Introduction

During normal operation, the high-temperature core exit sodium contacts only the inner surface of the redan structure, and the reactor vessel can be protected from the severe temperature gradient that may occur during transient operation by the redan structure. Thus, A study on the thermal insulation effect of redan was performed. Redan forms a boundary between the hot pool region and the cold pool region in connection with the shroud and the separating plate. As shown in Fig. 1, the four intermediate heat exchangers (IHXs) are located in the high temperature pool and the primary heat transfer system (PHTS) pump and four decay heat exchangers (DHXs) are located in the low temperature pool. Therefore, in Fig. 2, the plan view shape of the redan structure is a long peanut shape in the IHX direction and a short pump direction. [1]

In this study, the MARS-LMR code [2] was used to implement the thermal insulation effect of the STELLA-2 test facility using the MARS-LMR code to evaluate the heat loss in the steady state and heat exchange ability in the loss of flow(LOF).

2. Part of STELLA-2 facility

2.1. Decay Heat Removal System (DHRS)

The main purpose of the STELLA-2 facility is to evaluate the transient behavior of PGSFR under Design Basis Event (DBE) conditions and to verify and validate (V&V) the safety analysis code. The STELLA-2 facility is a down-scaled system the temperature and pressure are conserved to simulate the steady-state and transient behavior.

The DHRS consists of two passive loops and two active loops, which include a sodium-to-air heat exchanger (AHX) and a finned-tube sodium-to-air heat exchanger (FHX), respectively. Also, a sodium-to-sodium decay heat exchanger (DHX) is included in this system. In total, there are four DHXs, two AHXs, and two FHXs. Each model heat exchanger was designed to keep the scaling criteria and to satisfy the similarity requirements. [3]

2.2. Insulation (FLEXTHERM)

The FLEXTHERM [4] is new concept insulation material made of highly efficient microporous material with very high thermal conductivity in the form of lattice quit type blanket.

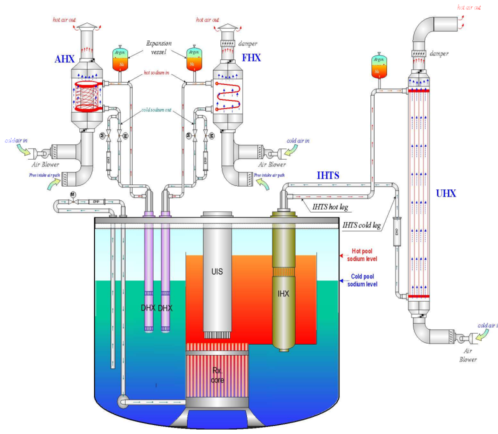


Fig. 1. STELLA-2 System Concept

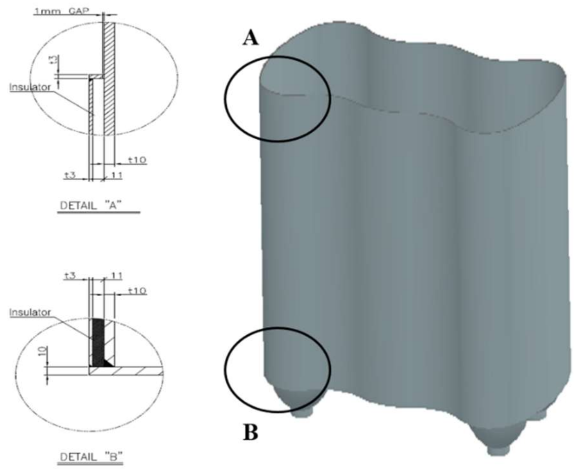
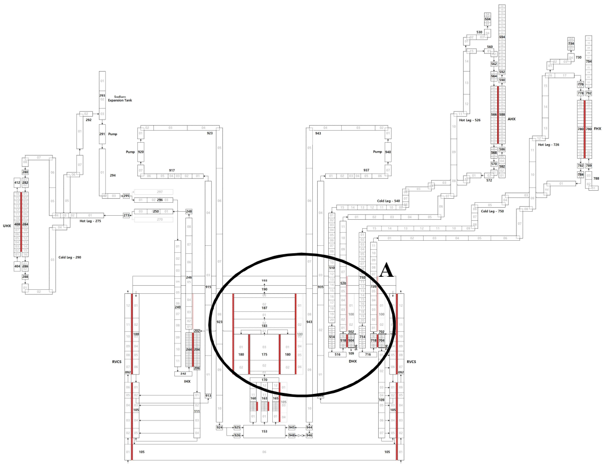


Fig. 2. Detailed Drawing of Redan Structure

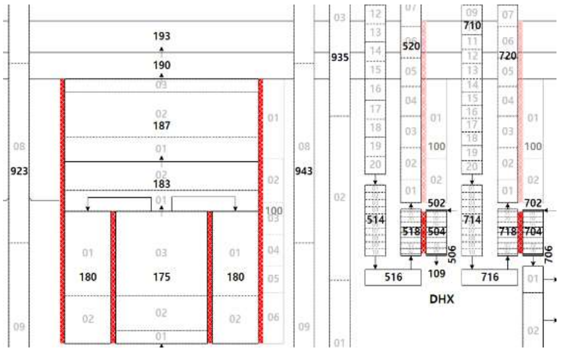
The thermal conductivity at 100℃ and 600℃ is less than 0.027 W/m-K and 0.045 W/m-K, respectively.

3. Analysis Methodology

Fig. 3 shows the safety analysis nodalization of the MARS-LMR based on the basic design of STELLA-2. The system calculation time was approximately 40,000s and it stopped after checking to see if all the variables reached the steady-state points. The four sodium-to-sodium DHXs (Decay Heat eXchangers) and two pumps are located in the cold pool, whereas four IHXs (Intermediate Heat eXchangers) are located in the hot



(a)



(b) DETAIL "A"

Fig. 3. Nodalization of MARS-LMR code for basic design of STELLA-2.

pool to transfer the reactor generated heat from PHTS to the SG (Steam Generators). In STELLA-2 input, all four DHRSs are modelled, and during the accident, only one AHX and one FHX are set to operate. DHX is located and submerged in the cold pool region and the sodium-to-air heat exchanger is located in the upper region of the reactor building. The air boundary regions are adopted with a pressure condition for simulating natural circulation phenomena.

This parameter, Q, denotes the heat transfer amount, the heat transfer coefficient (k), the total area of redan in contact with sodium in the cold pool (A), the temperature difference between the hot and cold pools (ΔT), and the thickness (L). Each variable used here is shown in Table I.

$$Q = kA\Delta T / L \qquad (1)$$

Table I: Parameter

	K (w/m℃)	L (m)	A_{total} (m^2)
Insulator redan	0.04	0.011	6.097
Stainless steel redan	20.3	0.024	6.097

4. Redan Insulation Effect in Steady State

4.1. Heat transfer amount and core inlet/outlet temperature

In steady state, direct heat flow from the hot pool to the cold pool has a large heat loss in terms of thermal efficiency.

In case of the Insulator redan, there is almost no change in heat transfer from the hot pool to the cold pool regardless of whether DHRS works, but when SS redan, the DHRS is turned on, so the heat transfer to the cold pool is much greater.

The heat transfer amount from the hot pool through the redan to the cold pool is shown in Table II, and compared with the Insulator redan, SS redan is about 19 times (DHRS on) / 11 times (DHRS off) the heat is transferred to the cold pool through the redan.

When the DHRS is operated, the temperature difference between the hot and cold pools increases, so the heat transfer through the redan becomes relatively large.

As shown in Fig. 5/6 and Table III, the core inlet / outlet temperature is higher in SS redan than the Insulator redan, so the core inlet / outlet temperature is formed in a steady state, indicating that it is disadvantageous in terms of thermal efficiency.

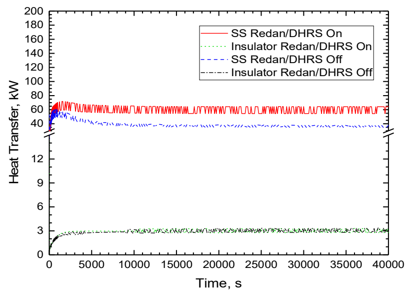


Fig. 4. Heat transfer from hot pool to cold pool through Redan in case of DHRS on or off

Table II: Heat transfer from hot pool to cold pool

	Q(kW) w/ DHRS On	Q(kW) w/ DHRS Off
Insulator redan	3.3	3.3
SS redan	64.3	37.8

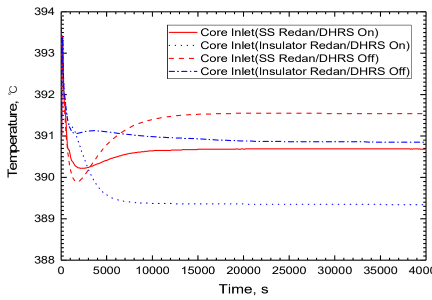


Fig. 5. Core Inlet Temperature

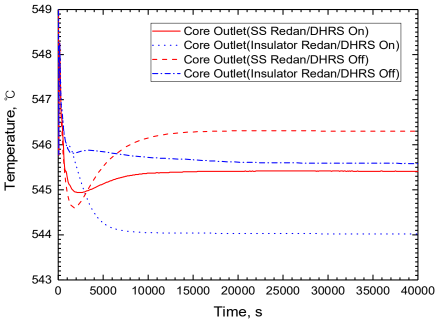


Fig. 6. Core Outlet Temperature

Table III: Core Inlet / Outlet Temperature

	DHRS On (℃)	DHRS Off (℃)
Insulator redan	389.3 / 544.0	390.9 / 545.6
SS redan	390.7 / 545.4	391.5 / 546.3

4.2. Heat Decay through AHX/FHX heat exchanger

Compared to the Insulator redan, in the case of SS redan, since the temperature of the cold pool in which decay heat removal system (DHRS) DHX is submerged is relatively high, the amount of heat removed by DHRS is about 26-38% larger.

Insulator redan is about 79.9℃ lower when DHRS On than SS redan, and about 121.2℃ lower when DHRS Off. That is, in the steady state, in the case of SS redan, since the heat transfer amount through redan is larger than that of the Insulator redan, the temperature of cold pool is relatively high and disadvantageous in terms of thermal efficiency.

However, in case of the LOF, the temperature of the cold pool is relatively high, and SS redan is more advantageous in terms of heat release to the atmosphere.

Table IV: Heat removal amount of AHX/FHX

DHRS		Insu. redan	SS redan
On	AHX(kW)	5.0	6.9
	FHX(kW)	5.4	6.8

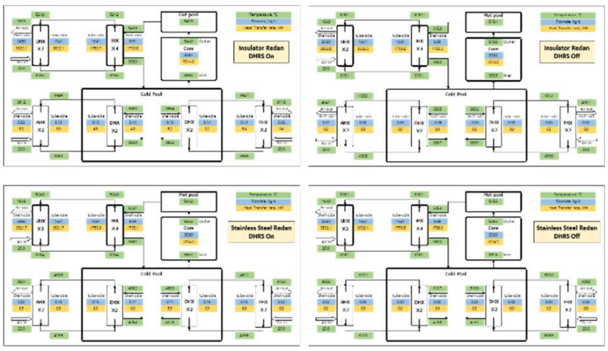


Fig. 7. Redan effect graphics DHRS on and off

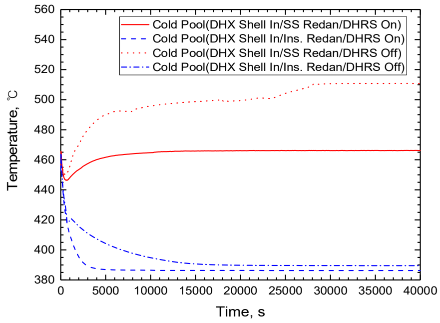


Fig. 8. Cold pool DHX shell temperature Stainless steel redan and Insulator redan in case of DHRS On or Off

As shown in Fig. 7, the heat removal amount through the UHX heat exchanger for DHRS On is 7044.2kW (= 3522.1 x 2) and 7043.4kW (= 3521.7 x 2) for Insulator redan and SS redan respectively, and 7065.0kW (= 3532.5 x 2) for DHRS Off , 7064.2kW (= 3532.1 x2).

5. Redan Insulation Effect in Loss of Flow

5.1. DHRS DHX inlet temperature of cold pool

In the early stage of LOF, the Insulator redan is about 79.9℃ lower when DHRS On than the SS redan, and about 121.2℃ lower when DHRS Off. As time goes by, the temperature difference decreases, and after 2,500 seconds, the Insulator redan is about 48.5℃ lower when DHRS On than SS redan, and about 49.5℃ when DHRS Off.

Table V: DHRS DHX inlet temperature of cold pool

	DHRS	Insu. Redan (℃)	SS redan (℃)	ΔT (℃)
Steady State	On	386.3	466.2	79.9
	Off	389.5	510.7	121.2
LOF	On	332.9	381.4	48.5
	Off	336.4	385.9	49.5

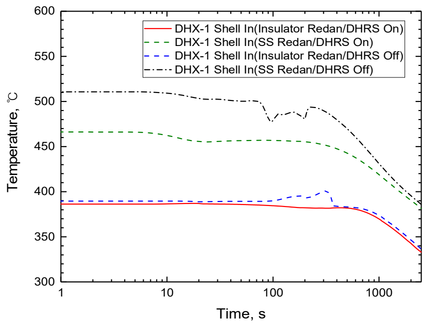


Fig. 9. DHRS DHX shell in cold pool temperature in case of LOF through DHRS on or off

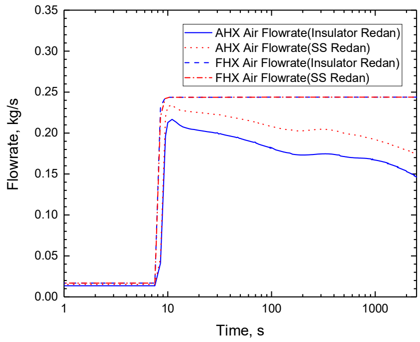


Fig. 10. Change of air flow in DHRS in case of LOF through redan effect

5.2. Amount of heat removal through DHRS

As shown in Fig. 10, in case of LOF in DHRS, the flow rate change after 8.26 seconds was increased from AHX air flow rate to 0.01526 → 0.23 kg / s, and FHX air flow rate increased from 0.01680 to 0.24 kg / s, respectively. In the case of the Insulator redan, AHX has a maximum heat removal amount of 69 kW after 11 seconds in the event of LOF, and then decreases to remove 34 kW of heat after 2,500 seconds. Through FHX, the heat removal amount is maximized to 49 kW after 9.5 seconds, and then to 34 kW after 2,500 seconds, which is equivalent to the heat removal amount of AHX. The case of SS redan is shown in Table VI. Here, as shown in Fig. 11, it can be seen that the temperature of the cold pool in case of an accident is relatively high for SS redan in terms of heat release to the atmosphere.

Table VI: Amount of heat removal DHRS in LOF

	After (Sec.)	Insu. Redan (kW)	SS redan (kW)
AHX	11	69	92
	2,500	34	46
FHX	9.5	49	61
	2,500	34	40

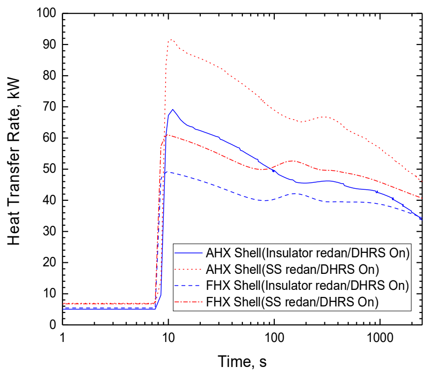


Fig. 11. Heat removal amount of AHX/FHX in case LOF through DHRS on

6. Conclusion

When the heat flow from the hot pool to the cold pool is small, the cold pool temperature is kept relatively low compared to the case where there are many heat flows. In addition, the DHRS DHX of the STELLA-2 is heat exchanged in a low-temperature pool.
In the steady state, in the case of SS redan, since the heat transfer amount through redan is larger than that of the Insulator redan, the temperature of the cold pool is relatively high and disadvantageous in terms of thermal efficiency.
However, in the event of an accident (LOF), SS redan, which has a relatively high temperature in the low-temperature pool, is more advantageous in terms of heat release to the atmosphere, so the size of the DHRS heat exchanger can be reduced.
Therefore, when designing a nuclear reactor, the design must be carried out in consideration of both heat loss in steady state and heat exchange capacity in LOF.

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