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# Pipe Break Accident Analysis of STELLA-2 using MARS-LMR

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## 1. Introduction

One of the Design Basis Events(DBE) of pool-type Sodium-cooled Fast Reactor (SFR) is "Pipe Break" and it is more precisely the primary pump discharge pipe connected to the inlet plenum where the core inlet starts. Unlike the LWR flow piping, the system is under atmospheric pressure and thus there is very little chance of guillotine break. However, for conservatism, the safety analysis assumes the total break of the discharge pipe and the coolant flows out to the cold pool.

In the case of pipe break accident, the appropriate flow path for natural circulation inside the pool cannot be set and due to leakage point and eventually the coolant flow rate cannot be developed enough to remove the core decay heat. Therefore, it must be addressed during the safety analysis with the consideration of various conditions.

In Korea Atomic Energy Research Institute (KAERI), there is a large-scale integral effect test facility to support the SFR development, namely the STELLA-2 facility established under the Sodium Integral Effect Test Loop for Safety Simulation and Assessment (STELLA) program[1] and it is capable of simulating the Pipe Break Accident. The facility has a dedicated sub-system consisting of a very special valve and flow path to simulate the Pipe Break.

In this study, various transient behavior under pipe break events with diverse decay heat removing combinations were analyzed using MARS-LMR. The scope of this analysis bounds within the preliminary code calculation results. The comparison with the experiment data and verification will be continued next year.

## 2. STELLA-2 Facility

The STELLA-2 is a down-scaled test facility to verify the performance of DHRS of the reference reactor. At the same time, the experiment database is used for V&V of safety analysis code[2,3].

The STELLA-2 includes all the major components of the reference reactor except the nuclear fuel core, the steam generator, and the mechanical pump. Instead, the electric core simulator[4], the straight tube-type sodium to air heat exchanger and the EMP replaces each component. In the STELLA-2, there are four lines of DHRS. Two loops are for the passive heat exchanger and the other two loops are for the active heat exchanger. All four heat exchangers are of same capacity.

The facility was designed to conserve the characteristic and transient behavior of the reference reactor and it was evaluated at several stages using various means and tools including CFD and system code.

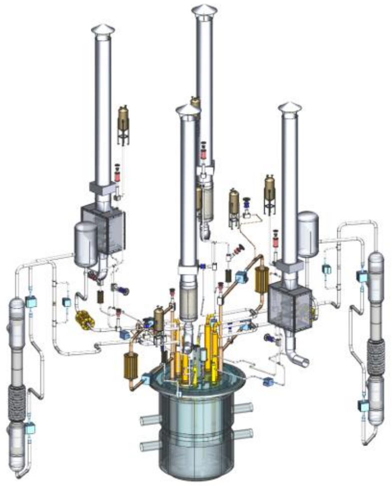

**Fig. 1 STELLA-2 Facility Layout**

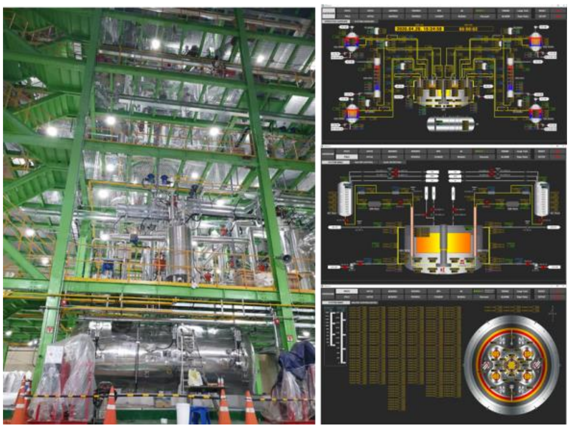

**Fig. 2 STELLA-2 Installation and Control System**

## 3. MARS-LMR Analysis

### *3.1 Pipe Break Accident*

The various conditions for the pipe break events are listed in Table 1 for STELLA-2 facility. Based on this test matrix the experiments are going to be conducted and will be compared with the preliminary analysis result.

For the MARS-LMR analysis, the event progress with time is as follows.

1. Pipe break valve open: 4.47s
2. Pump trip: 4.47s
3. UHX blower off: 4.47s
4. Rx trip: 5.81s
5. DHRS starts to operate: 8.26s

6. (1) 1 PDHRS + 1 ADHRS working
   (2) 2 PDHRS + 2 ADHRS working
   (3) 1 PDHRS + 2 ADHRS working
   (4) 2 PDHRS + 1 ADHRS working

The time is set to satisfy the time scale ratio between the reference reactor and the STELLA-2. Therefore, the assumption of the event start time in real scale is 10sec and this corresponds to 4.47sec in STELLA-2.

**Table 1 STELLA-2 Pipe Break Test Matrix**

| | | |
|---|---|---|
| PHTS Pump Discharge Pipe Break | - Rx Trip<br>- with LOOP<br>- 1 line Break<br>- IHTS Na is not considered | - PHTS pump 1&2 stops<br>- Break Simulation Valve On<br>- IHTS pump 1&2 stops<br>- DHRS working condition:<br>· 2 passive + 2 active |
| | - Rx Trip<br>- with LOOP<br>- 1 line Break<br>- IHTS Na is considered | - IHTS sodium inventory consideration:<br>· SG F/W drayout simulation using UHX blower |
| PHTS Pump Discharge Pipe Break + DHRS 1 loop fail | - Rx Trip<br>- with LOOP<br>- 1 line Break<br>- IHTS Na is not considered | - PHTS pump 1&2 stops<br>- Break Simulation Valve On<br>- IHTS pump 1&2 stops<br>- DHRS working condition:<br>· 2 passive + 1 active<br>· 1 passive + 2 active |
| | - Rx Trip<br>- with LOOP<br>- 1 line Break<br>- IHTS Na is considered | - IHTS sodium inventory consideration:<br>· SG F/W drayout simulation using UHX blower |
| PHTS Pump Discharge Pipe Break + DHRS 2 loops fail | - Rx Trip<br>- with LOOP<br>- 1 line Break<br>- IHTS Na is not considered | - PHTS pump 1&2 stops<br>- Break Simulation Valve On<br>- IHTS pump 1&2 stops<br>- DHRS working condition:<br>· 2 passive<br>· 2 active<br>· 1 passive + 1 active |
| | - Rx Trip<br>- with LOOP<br>- 1 line Break<br>- IHTS Na is considered | - IHTS sodium inventory consideration:<br>· SG F/W drayout simulation using UHX blower |

*3.2 Node layout and Assumptions*

The node layout is shown in Fig. 3. Based on the heat balance of the reference reactor design, the steady-state point was set to match the temperature distribution inside the pool and the transient started with the opening of the valve. The primary and intermediate loop pumps stop and the core heater starts to follow the decay heat curve.

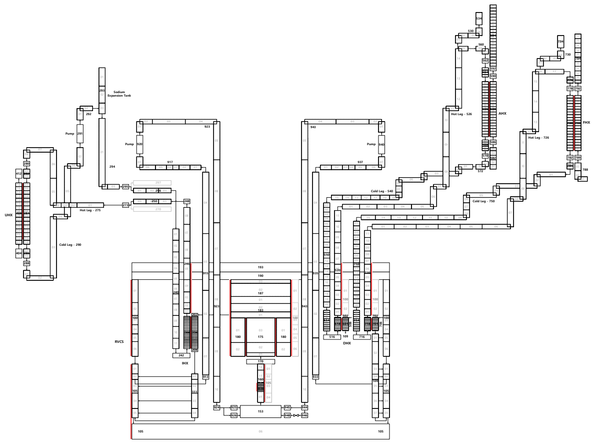

**Fig. 3 Node Diagram**

## 4. Results and Discussion

The representative case result of 1 passive + 1 active DHRS working condition is described as follows. This case is selected because this condition is the least heat removing condition and is the worst case for the core. The other cases are not included in this paper for it showed similar trend with small difference in heat removing capacity.
The pipe break occurs at the Pump Discharge line 4 and connects to the cold pool directly. The calculation time of analysis was upto 10,000 seconds.

*4.1 Flowrate Trend*

- PHTS Pump Inlet 1: 1.25kg/s (0.0s) → 0.053kg/s (200s, min flowrate at early stage) → 0.097kg/s (540s, max flowrate at early stage) → continuous decrease → small back flow starts at 890s → 1,380s flow recovers direction and increase → 0.29kg/s(3,190s, max flowrate and decrease) → 0.1kg/s(10,000s)
- PHTS Pump Inlet 2: 1.25kg/s (0.0s) → 0.043kg/s (190s, min flowrate at early stage) → 0.085kg/s (550s, max flowrate at early stage) → continuous decrease → small back flow starts at 880s → 1,280s flow recovers direction and increase → 0.29kg/s(3,160s, max flowrate and decrease) → 0.1kg/s(10,000s)
- Pump Discharge 1&2: the trend is same as the PHTS Pump Inlet 1 at the same timeline
- Pump Discharge 3: most of sodium back flow from Discharge line 4 goes through Discharge line 3 and to the Inlet Plenum(Core Inlet). The trend is symmetrical to Discharge line 4 (opposite direction and same flowrate).
- Pump Discharge 4: flowrate decreases rapidly after 19s → back flow from cold pool to inlet plenum starts at 23s → -0.64kg/s (44s max back flowrate at early stage) → -0.45kg/s (320s, min back flowrate at early stage) → -0.68kg/s (max back flowrate) → 1,890s flow recovers direction → 0.11kg/s (3,180s, max flowrate) → 0.00023kg/s (10,000s)

- Inlet Plenum to Cold Pool line: the trend is similar to that of Pump Discharge line 4 but with different flowrate.
- Through Core: flowrate decrease after 5s → 1.13kg/s (290s, min flowrate at early stage) → 1.69kg/s (640s, max flowrate) → 0.5kg/s (10,000s)
- Passive DHX shell side: sudden increase after 140s and the max flowrate(0.38kg/s) at 250s → 0.25kg/s (10,000s)
- Active DHX shell side: sudden increase after 110s and the max flowrate(0.41kg/s) at 140s → 0.22kg/s (10,000s)
- AHX tube side: starts to increase after 30s and 0.5kg/s of max flowrate at 210s → slowly decreases and 0.37kg/s at 10,000s
- FHX tube side: starts to increase after 30s and 0.51kg/s of max flowrate at 120s → slowly decreases and 0.32kg/s at 10,000s

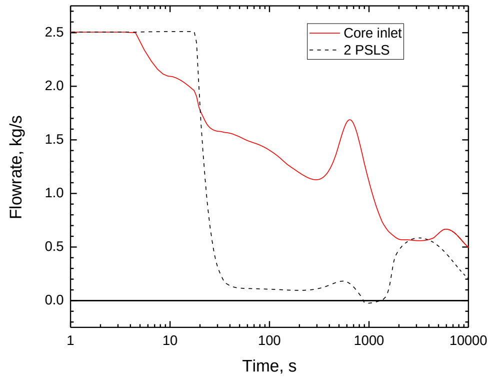


**Fig. 4 Core and Pump Inlet Sodium Flowrate**

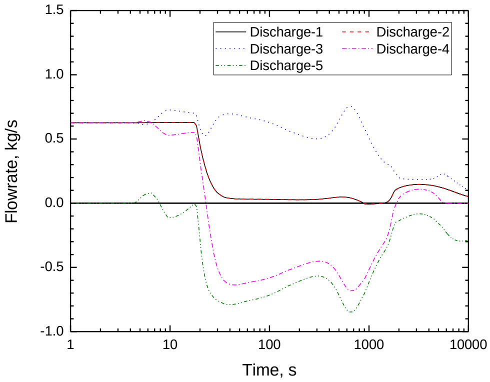


**Fig. 5 Pump Discharge Line Sodium Flowrate**

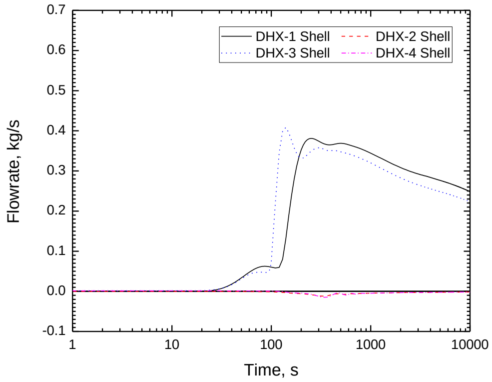


**Fig. 6 DHX Shell-side Sodium Flowrate**

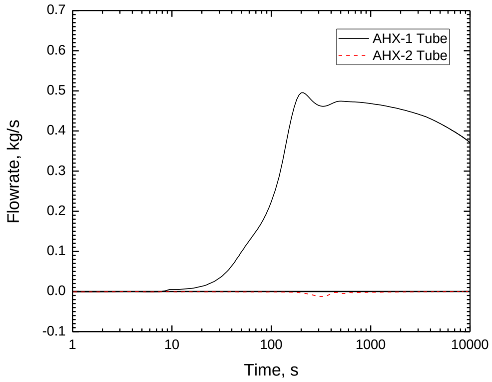


**Fig. 7 AHX Tube-side Sodium Flowrate**

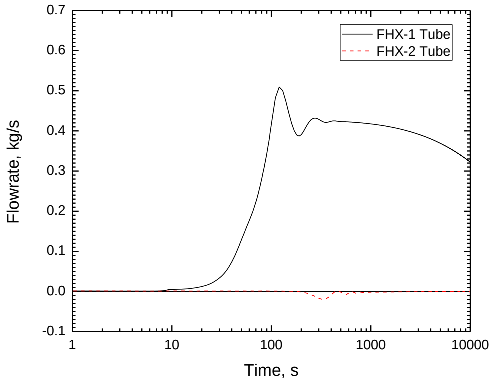


**Fig. 8 FHX Tube-side Sodium Flowrate**

### *4.2 Temperature Trend*

- In early stage, the natural circulation flow through the core develops sufficiently to decrease the core outlet temperature → the flowrate reaches the max at 640s and slowly decreases → the min core outlet temperature 443℃ at 680s → temperature slowly increases and reaches 506℃ at 10,000s

- Core inlet temperature starts to increase after 3,000s and reaches 430℃ at 10,000s
- AHX tube-side inlet sodium temperature maintains 497℃ upto 200s and starts to decrease to 238℃ at 10,000s. AHX tube-side outlet sodium temperature rapidly decreases until 140s to 304℃ and then increases to 360℃ at 290s. It reaches 165℃ at 10,000s
- FHX tube-side inlet sodium temperature maintains 499℃ upto 140s and starts to decrease to 243℃ at 10,000s. FHX tube-side outlet sodium temperature rapidly decreases until 110s to 315℃ and then increases to 379℃ at 170s. It reaches 174℃ at 10,000s

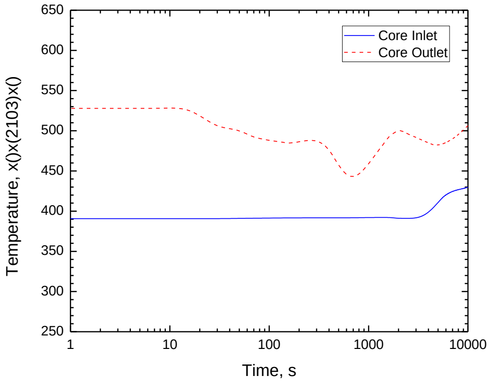


**Fig. 9 Core In/Out Sodium Temperature**

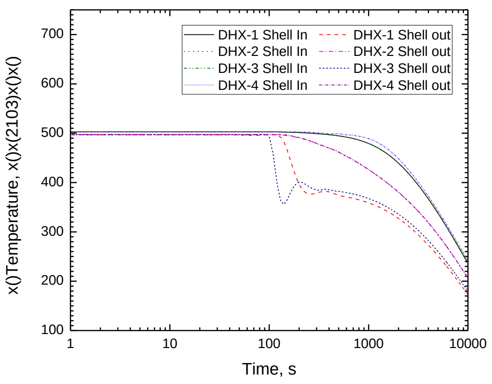


**Fig. 10 DHX Shell-side In/Out Sodium Temperature**

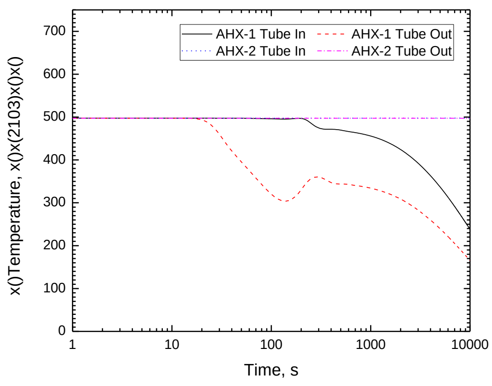


**Fig. 11 AHX Tube-side In/Out Sodium Temperature**

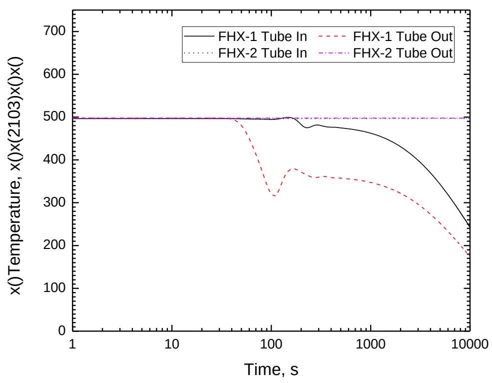


**Fig. 12 FHX Tube-side In/Out Sodium Temperature**

### *4.3 Heat Removal Trend*

- At the end of calculation time (10,000s), the core produces 48.4kW
- PDHRS and AHX removes 35.9kW
- ADHRS and FHX removes 29.0kW

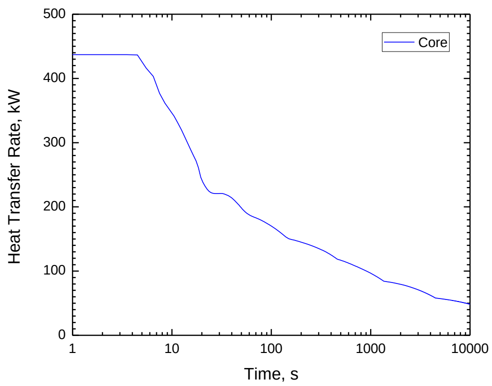


**Fig. 13 Core Heat Transfer Rate**

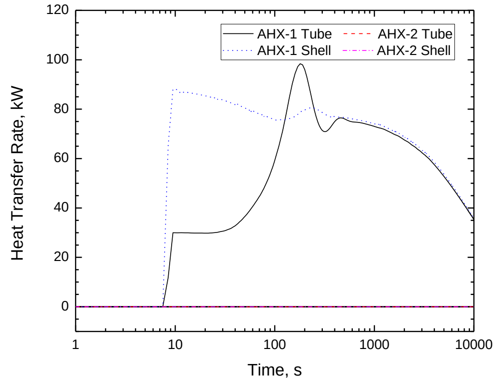


**Fig. 14 AHX Heat Removal Rate**

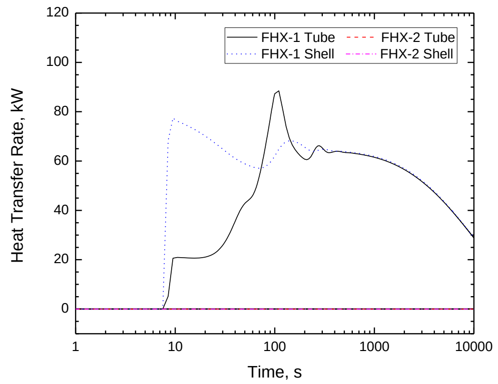


**Fig. 15 FHX Heat Removal Rate**

*4.4 Summary*

The developed natural circulation flow at 10,000 for

(1) Core: 0.5kg/s
(2) PDHX Shell-side: 0.25kg/s
(3) ADHX Shell-side: 0.22kg/s

The natural circulation flow through DHX shell-side is a local path flow developed within cold pool and is almost same as the main path(core–hot pool–cold pool–core) flow (Approximately 94%).
In early stage of the accident, the decay heat from the core is larger than the heat removed by 1 AHX and 1 FHX but it balances after 190s and reverses. At 1,360s, the difference is at max and the difference slowly decreases upto 10,000s.
The flow peak occurs at about 600s in Fig. 4 due to the incoming sodium flow from cold pool through the breakage point to the core. This flow develops because the pressure drop is smaller than the normal path.

## 5. Conclusion

In this study, the pipe break events of STELLA-2 facility with various conditions were analyzed with MARS-LMR. As expected, the back flow from cold pool to the inlet plenum occurs through the pump discharge pipe but the effect of decay heat removal was not significantly large at early stage of the event. However, the long-term behavior of heat removal is negative and there should be a technical solution to secure the long-term coolability of the core. The further study of comparison with experiment data will show more realistic analysis results and hopefully provide feedback to the safety design of the reference reactor.

## ACKNOWLEDGEMENT

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