The Evaluation of PHTS Integrity by the SG SWR event in PGSFR

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1. Introduction

Korea Atomic Energy Research Institute(KAERI) has been developing the Prototype Generation IV Sodium Cooled Fast Reactor(PGSFR). In the PGSFR, it uses the sodium as a coolant to transfer heat produced from the core to the Intermediate Heat Transport System(IHTS). Comparing with the water, the sodium has a high heat transfer rate and below boiling temperature. While it has an excellent heat transfer characteristics, there are carefully treated things to design the sodium-cooled fast reactor. The one of those is a Sodium Water Reaction (SWR) event caused by rupturing of the steam generator tubes. This event derives to the failure of the IHTS heat removal function. For this reason, it is categorized to the loss of heat sink events, which are undercooling the Primary Heat Transfer System(PHTS). Also, this event has a potential possibility to release the radiological materials of the PHTS to the IHTS loop.

In this paper, it is assumed that IHTS heat removal function is failed along with SWR event occurs. The PHTS integrity is evaluated by MARS-LMR[1] as a safety analysis code in PGSFR. To the conservative evaluation, the failure of the 2 IHTS loop function is considered.

2. Analysis methods

The influences caused by the sodium-water reaction event in the SG should be analyzed to the two aspects. The one is the evaluation to the integrity of the IHX tube which is a barrier between IHTS and PHTS with a radiological material. The other is the evaluation of the PHTS cooling capability after the failure of the IHTS loop function. The former is evaluated by the specified code which could calculate the peak pressures produced by the SWR. In PGSFR, the Sodium Water Advanced Analysis Method(SWAAM-II) code which is developed by the ANL is used for the purpose of calculating the peak pressures. The purpose of this evaluation is that PHTS integrity to the cooling capability sufficiently maintains during the SWR event.

When the rupture of the steam generator tube occurs, instantaneously hydrogen bubble is generated by the sodium water reaction and abrupt high pressure pulse is produced within the IHTS including the steam generator. The sodium within the affected IHTS loop is discharged to the sodium dump tank by the rupture disks burst. The failure of the heat removal function of the one affected IHTS loop occurs. Thus, the SWR event in the steam generator is arranged into the loss of heat sink events.

2.1 Assumptions & Calculation

The IHTS consists of the four IHX and two closed loop which are filled with sodium as an intermediate heat transfer medium. The sodium in the cold leg is divided into the two pipe line before entering to the IHX tube inlet. The sodium leaved from the outlet of the two IHX tube is jointed together to the hot leg line. The IHTS in PGSFR is classified as the non-safety grade. The function of the IHTS including the steam generator is not considered in the integrity evaluation.

Fig. 1 presents the MARS-LMR code nodalization to the IHTS including an IHX. Based on the steady input deck[2], the steady state for relevant to this event is recalculated. The flow and pressure boundary condition are applied to the cold leg and hot leg, respectively. To simulate the IHTS function failure, the mass flow rate at the TMDP junctions(C391,C396,C491,C496) are set to zero.

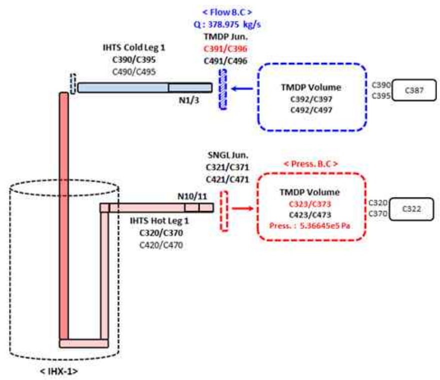

Fig. 1 MARS-LMR code Nodalization of the IHTS

This event is categorized into the design basis event which is required to apply the conservative method and assumption. A few assumptions for analysis as follows; 1) Single failure: One circuit of the two ADRC(Active Decay Removal Circuit) is failed. 2) LOOP(Loss Of Offsite Power) : The function of the two RCP is stopped. 3) The delay time for reactor trip is a 5(s). The reactor trip signal occurs through the detection of the rupture disk burst or the outlet temperature in the SG shell side.

It presents a null transient state from 0(s) to 10(s). The actuation time for the reactor trip signal and LOOP occur at 10(s). By the delay time of the reactor trip 5(s), reactor trip and IHTS loop failure occur at 15(s). The mass flow rate at the flow B.C is linearly decreased during the 5 seconds. The flow rate of the IHTS loop becomes a zero at 20(s). Fig. 2 presents the mass flow rate at the flow B.C to simulate the IHTS function failure. For the conservative evaluation, considered the case of the 2 IHTS loop function is failed together. The damper of the AHX and FHX are fully opened after the 20(s) elapsed time from the reactor trip occurs. From the calculation result, the damper operating time is not much influence on the PHTS integrity to the long term cooling.

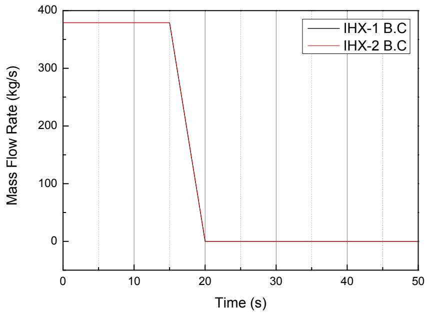

Fig. 2 The Mass flow rate at the flow B.C junction

2.2 Results

To evaluate the cooling capability of the PHTS, the transient calculation is performed during the 5000(s). Fig. 3 presents the coolant temperatures at the core inlet and outlet. The core outlet temperatures by generated decay heat gradually increase to the 1000(s). Due to the operation of the Decay Heat Removal System(DHRS) after the reactor trip, the core inlet temperatures are gradually decreased after the 500(s). Fig. 4 presents the temperature at the hot assembly of the core to the radial direction. The peak temperature occurs at the upper part to the axial direction. It is not excesses to the 900(K) and then gradually decreases following the 1000(s). From the respects of the thermal hydraulic integrity, the fuel is a within the range of the safety criteria. Fig. 5 presents the result of the comparison between core decay heat and heat removed by DHRS. The calculation of the 2 IHTS loop failure presents the result of the heat removal rate by the DHRS excess the core decay heat after the 500(s). From the respects of the long term cooling, the PHTS integrity is maintained after the SWR event occurs.

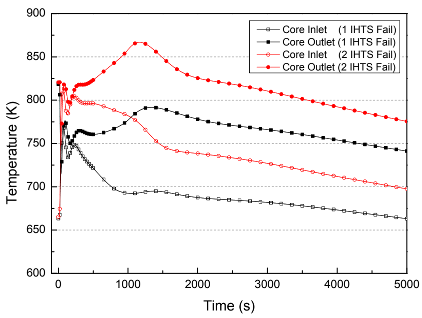

Fig. 3 Core Inlet and Outlet Temperature
(1 IHTS loop failure and 2 IHTS loop failure)

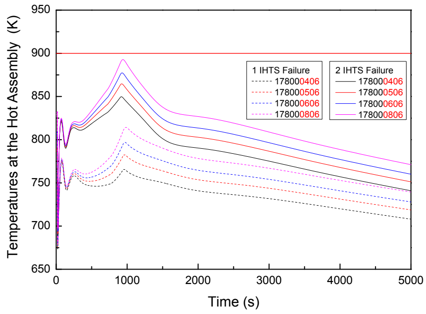

Fig. 4 Temperature at the Hot Assembly
(1 IHTS loop failure and 2 IHTS loop failure)

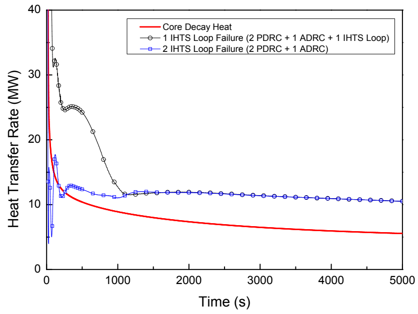

Fig. 5 Comparison between DHRS Heat and Core Decay Heat
(1 IHTS loop failure and 2 IHTS loop failure)

3. Conclusions

After the SWR event occurs inside of the steam generator in PGSFR, the PHTS integrity is evaluated by using the MARS-LMR code.

From the respects of the long term cooling capability, the temperature at the core outlet gradually decreases as preceding the event. Though the failure of 2 IHTS loop function occurs, the temperature at the hot assembly is a within the range of the safety criteria.

REFERENCES

[1] Ha, K.S., "Development of MARS-LMR and Steady-state Calculation for KALIMER-600,"(2007)

[2] Lee, K.L., "Analysis of design bases events in the conceptual design of a PGSFR using MARS-LMR,"(2013) KAERI/TR-4971/2013