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Safety Analysis for PHTS Integrity by the failure of the IHTS function 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). A sodium is used as a reactor coolant to transfer the core heat to the turbine. It rigorously reacts with a water or steam in chemical and generates the high pressure waves and high temperature reaction heat. While it has an excellent characteristics as a coolant, there is an event to be necessarily considered in the sodium cooled fast reactor design. The Sodium-Water Reaction(SWR) event can be occurred due to the rupture of steam generator tubes. This event threaten the integrity of the Primary Heat Transfer System(PHTS). It is categorized to the loss of heat sink events, which are undercooling the Primary Heat Transfer System(PHTS).

In this paper, the failure of the heat removal function of the IHTS by the SWR event is assumed. The integrity of the PHTS is analyzed by MARS-LMR[1] code.

2. Analysis methods

In PGSFR, the SWR event is classified as the AOO, DBA Class-I & II category based on the leak rate and occurrence frequency of the event. The analysis result must be satisfied with the safety acceptance criteria such as maximum temperature of the fuel, cladding and CDF (Cumulative Damage Fraction).

The effects and results of this event is analyzed to the core and cladding integrity point of view.

2.1 Assumption & Calculation

One IHTS loop consists of the two IHX, one IHTS EM pump, one expansion tank and one SG. These components are connected with a hot leg and cold leg pipe which are closed loop filled with a sodium coolant. The sodium of one cold leg pipe is divided into the two pipe line before entering to the IHX tube inlet. The sodium leaved from the two IHX are jointed together to the one hot leg pipe and then entered to the SG inlet.

Fig. 1 presents the MARS-LMR code nodalization to model the failure of heat removal function of one IHTS loop due to the SWR event. 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 model the failure of the IHTS function, the mass flow rate at the TMDP junctions(C391, C396,C491,C496) are set to zero. Total discharged time of the sodium of the affected IHTS is conservatively assumed to 5.0(s).

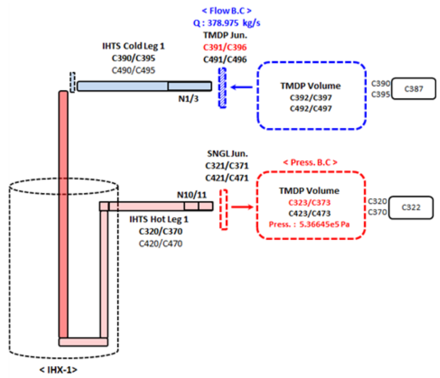

Fig. 1 MARS-LMR nodalization to model the affected IHTS

The analysis of the design basis event is required to be applied the conservative method and assumptions.

A few assumptions for analysis as follows; 1) Single failure: One of the two ADRC(Active Decay Removal Circuit) circuit is failed. And one of the two PDRC (Passive Decay Removal Circuit) circuit is assumed to be failed for maintenance. 2) LOOP(Loss Of Offsite Power) : The function of the two RCP and one IHTS EM pump are stopped. 3) The delay time for reactor trip signal is a 2.8(s). For this event, the reactor trip signal can be occurred through the detection of the ratio of the power to flow and the sodium outlet temperature in the SG.

To apply the conservative event conditions during the transient period, the sensitivity analysis is performed to the major variables such as core reactivity feedback coefficients, LOOP, control rod drop time considering the SSE.[3]

2.2 Results

Table. 1 presents a event scenario for transient period for this event. Depending on the mass flow rate of the affected IHTS sodium is reached to zero, the event is initiated and then high power to flow ratio trip variable is reached to the trip setpoint at 2.53(s). At 5.0 seconds, all the sodium inventory in the affected IHTS is totally discharged. After considering the signal delay time of 2.8 seconds, RPS and turbine trip signal are occurred at 5.53(s). Fig. 2 presents the mass flow rate at the two IHTS loop. The mass flow rate of the affected IHTS is linearly decreased during the 5 seconds. The mass flow rate of the affected IHTS loop becomes a zero at 5.0(s). Fig. 3 presents the ratio of the core power to the full power. In consideration the measurement uncertainty of the instrument, initial core power is assumed to 102 % of the full power.

Table. 1 SWR event scenario

Time(s)	Event	Value
0.0	SWR Event initiation & LOOP	
0.0	The discharge affected IHTS sodium is initiated	
2.53	High power to flow ratio value is reached	121.4%
5.00	The discharge affected IHTS sodium is stopped	
5.33	RPS signal and turbine trip are occurred	
5.40	Temperature of fuel and cladding are reached to the peak value	744.2℃, 691.6℃
7.33	Control rod drop is initiated	
10.33	DHRS damper open and reactor cooling is initiated	

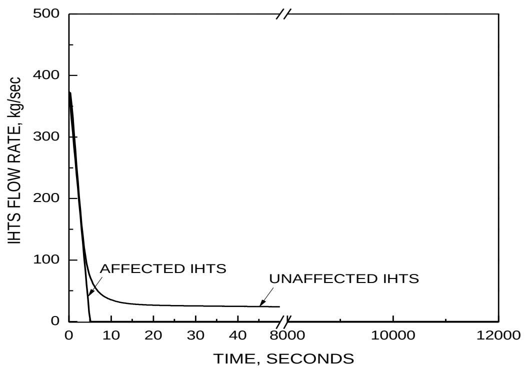

Fig. 2 The mass flow rate at the two IHTS loop

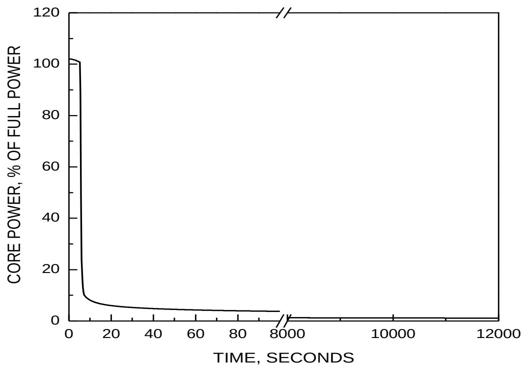

Fig. 3 The ratio of the core power to full power

To evaluate the cooling capability of the PHTS, the transient calculation is performed during the 12,000(s). Fig. 4 presents the comparison results of the core decay heat and heat removed by DHRS. After the 5,000(s), the heat removal rate by the DHRS excesses the decay heat generated from the core. From the respects of the long term cooling, the integrity of the fuel and cladding are well maintained during the transient period. Fig. 5 presents the result of the CDF which is a variable for the integrity of the cladding. This value has a sufficient margin to the safety analysis criteria 0.05.

Fig. 6 presents the result of the temperature behavior in the cladding. During 5.0(s), it is gradually increased due to the high temperature core inlet flow. At this time, heat transfer between the IHX shell and tube side is not occurred due to the discharge of the IHTS sodium. The peak temperature of the cladding is reached to the 691.6 ºC at 5.4(s). As a reactor is tripped, the temperature is decreased and then the temperature is increased due to the decay heat generated from the core. The temperature is a within the range of the safety criteria 1,075 ºC for cladding. Fig. 7 presents the peak temperature of the fuel. The result is a similar behavior to the cladding temperature. The peak temperature of the cladding is reached to the 744.2 ºC at 5.4(s). It has a sufficient margin the safety criteria 1,237 ºC for fuel temperature.

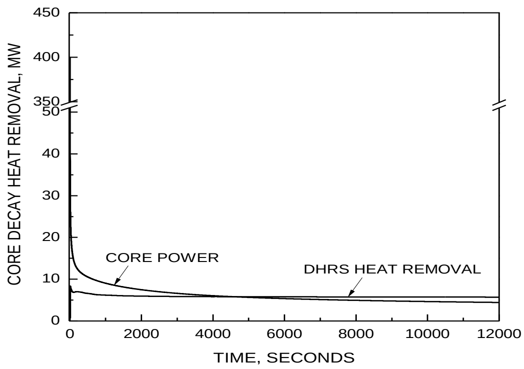

Fig. 4 Core decay heat and heat removal in DHRS

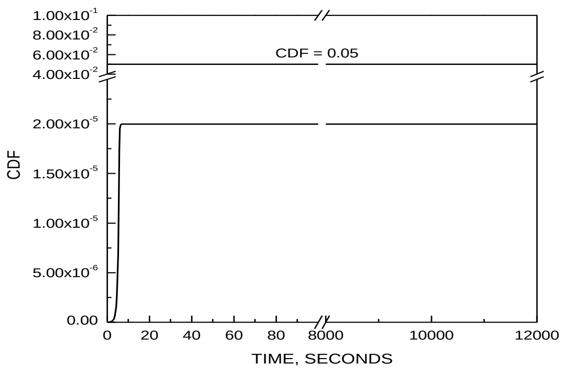

Fig. 5 Cumulative damage fraction

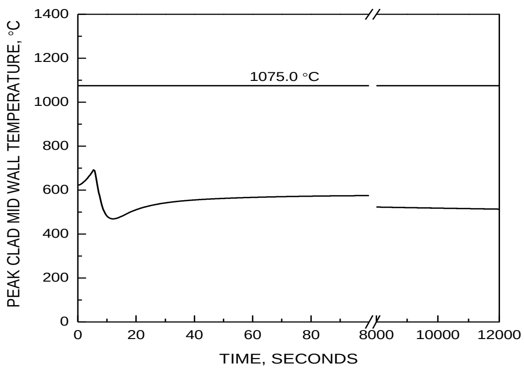

Fig. 6 The peak temperature in the cladding

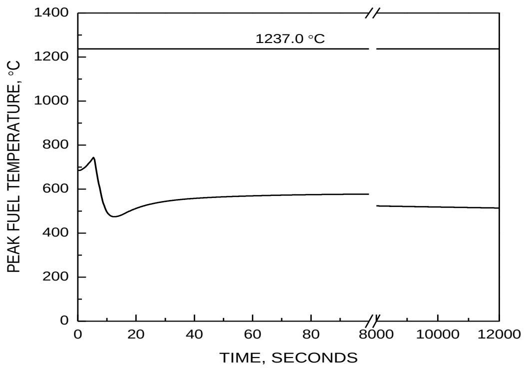

Fig. 7 The peak temperature in the fuel

3. Conclusions

In PGSFR, the SWR event can be occurred in the SG. The PHTS is analyzed to the respects of the integrity of the fuel and cladding using the MARS-LMR code.

From the analysis results, the peak temperature of the fuel and cladding have a sufficient margin to the safety acceptance criteria 1,237 ºC and 1,075 ºC, respectively. Also, the maximum CDF satisfies the value less than 0.05. From the view point of the long term cooling, the reactor is normally cooled by the DHRS.

REFERENCES

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