Development of Trend Map on the Plant Initial Condition Using Sensitivity Study in the Non-LOCAs

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1. Introduction

KINS (Korea Institute of Nuclear Safety) has been developing a Non-LOCA regulatory audit methodology, which consisted of advantages from both the conservative and BEPU approaches. It is essential to use the proper kind of nuclear codes to obtain the results reasonably such as core, fuel performance, thermal-dynamics and sub-channel analyzer. However, there have been numerical errors or biases between interconnection codes due to not only the lacks of experimental data or mathematics models but also user dependency. Sensitivity study has been one of the best ways how to deal with these errors and this method can be sufficiently compensated on non-conservative tendency [1].

Korea safety review guideline clearly describes that designer must analyze sensitivity study on the initial condition to ensure conservative results in the field of DBA. Thus, it must be confirmed in the safety review stage that the safety analysis performed by the designer fully assumed the status of the initial plant condition to be conservative.

There have been analyzing the sensitivity study using the nuclear codes. However, their trends were not consistent due to many design changes and unknown parameters to affect the safety results even though the same type of plants, for example of APR1400, have analyzed the same initial condition.

The main steam line break and seized reactor coolant pump rotor in this study were chosen for the analysis of sensitivity on the initial condition because they were representative transients with respect to fuel damage among the non-LOCA. This study's purpose is an assessment of acceptance criteria, which are critical heat flux, primary and secondary pressure, and development of trend map according to the variety of the initial plant condition on the above regulatory acceptance.

2. Modeling applied to multiple channel

Most of the DBA caused core asymmetry in terms of mass flow rate, core inlet temperature and pressure during its transient. For these reasons, core modeling is divided into multiple core channels to simulate core asymmetry phenomena. Two hot channels were consisted to analyzed the degree of asymmetric phenomena in the lower plenum. The core lower plenum was modeled as three-part not to mix coolant, which flows into the lower plenum from the downcomer.

Two hot channels and two average channels interconnect to simulate the cross flow, and coolant passing from the core region is modeled to flow forward to the hot plenum nozzle in the upper core [2].

It was revised to improve the secondary system in MARS-KS, in which the input model of U-tubes in the steam generator was modified based on the latest design data. In contrast to LOCA analysis, it has been necessary to model the secondary system in Non-LOCA analysis clearly. Thus U-tube in the steam generator is divided into three-part considering the length of U-tubes.

There was no significant deviation in the steady-state analysis after modifying the multiple cores and U-tubes model.

Figure 1 shows the nodalization of the reactor vessel and steam generator in the MARS-KS.

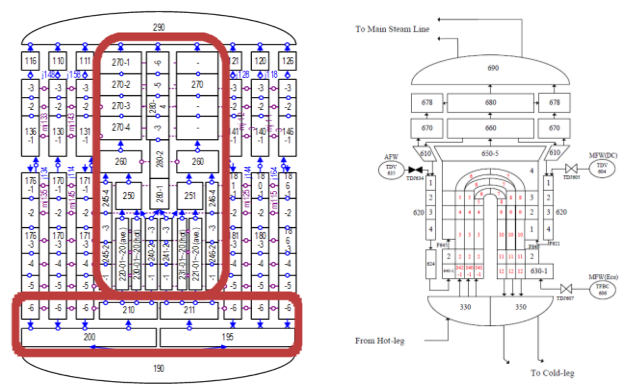

Fig. 1 The nodalization of RV and SG applied to multi-channel

3. Sensitivity parameters

A sensitivity study was performed to focus on the departure from nucleate boiling ratio in the range of limiting conditions for operation. Pressure, flow rate and temperature, reactor power and void fraction of coolant were known for influent operating parameters on the DNBR. In the case of MARS-KS, the correlation for critical heat flux equipped with MARS-KS was AECL CHF Look-up table, which was not precisely predicted sub-channel behavior, but we decided to be suitable to predict the trend on the sensitivity parameters from much experience for regulatory audit calculation.

Tables 1 and 2 show the most influential two parameters: mass flow rate and core inlet temperature to both MSLB and seized RCP rotor in this sensitivity study.

Table 1. sensitivity parameters in MSLB

Case no.	Parameter			Remark
	RCS flow (%)	Inlet Temp. (K)	FTC	
Base case	112.56	569.25	Most negative	Flow-hi Temp.-hi
1	112.56	569.25	Least negative	
2	95.0	569.25	Most negative	Flow-low
3	97.5	569.25		
4	100.0	569.25		Flow-nor.
5	102.5	569.25		
6	105.0	569.25		
7	108.0	569.25		Flow-hi
8	112.56	560.95		Temp.-low
9	112.56	562.0		
10	112.56	564.0		
11	112.56	566.0		
12	112.56	567.53		Temp.-nor.

Table 2. sensitivity parameters in seized RCP rotor

Case no.	Parameter			Remark
	RCS flow (%)	Inlet Temp. (K)	FTC	
Base case	92.0	561.24	Most negative	
1	95.0	561.47		Flow-low
2	97.5	561.66		
3	100.0	561.84		Flow-nor.
4	102.5	562.02		
5	105.0	562.19		
6	108.0	562.39		Flow-hi
7	92.0	560.95		Temp.-low
8	92.0	562.0		
9	92.0	564.0		
10	92.0	566.0		
11	92.0	567.53		Temp.-nor.

4. Results of sensitivity

As shown in Fig 2 simulating MSLB, the variation of RCS flow rate did not significantly influence the DNBR. However, the results of DNBR slightly decreased as the RCS flow rate was getting reduced. Fig. 3 presents the DNBR results according to the deviation of core inlet temperature. The degree of effect to the DNBR was largely observed on the core inlet temperature. In addition, both the beginning and end of the fuel cycle had a similar value of DNBR in the base case.

Figures 4 and 5 are results of seizure of RCP rotor, which is regarded as representative transient as core flow asymmetry. However, figure 4 does not show the asymmetry effect for DNBR on the coolant inlet flow rate. It is because MARS-KS is one of the system codes employing lumped nodes that cannot calculate detailed critical heat flux in sub-channels or complexed core regions [3]. Thus, it needs to use the sub-channel analyzer to precisely calculate the DNBR in the sub-channels. Figure 5 shows the results of DNBR on the core inlet temperature that the hotter coolant was, the faster DNBR occurred.

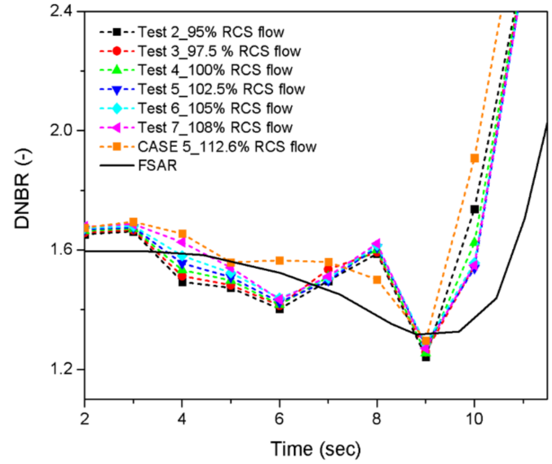

Fig. 2 Results of sensitivity study on the RCS flow (MSLB)

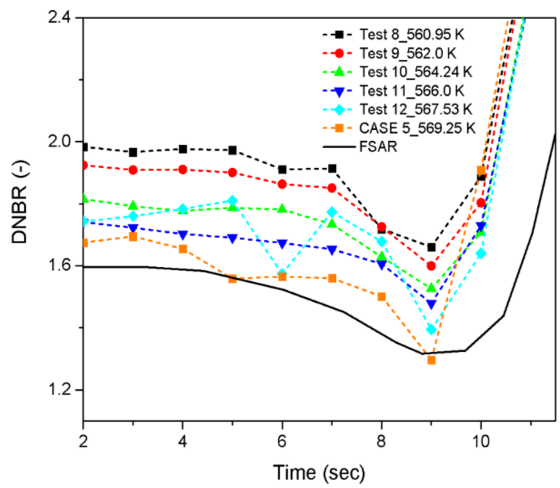

Fig. 3 Results of sensitivity study on the inlet temperature (MSLB)

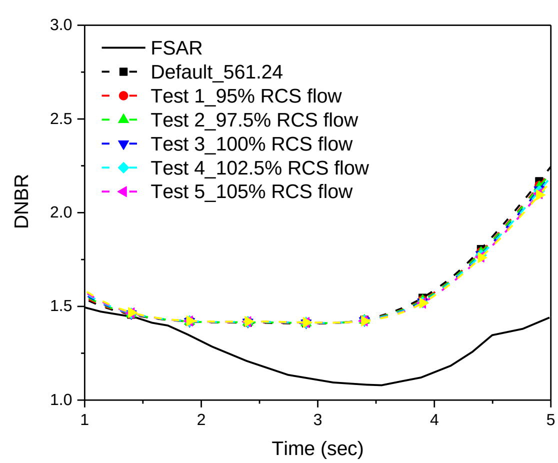

Fig. 4 Results of sensitivity on the RCS flow (LR)

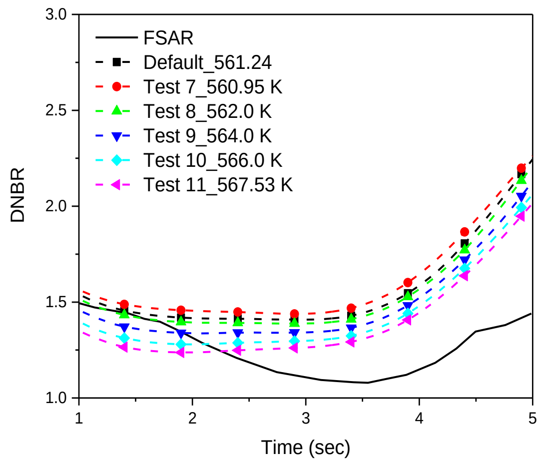

Fig. 5 Results of sensitivity on the inlet temperature (LR)

5. Development of trend map

Based on the sensitivity study results, a trend map was developed to give an insight into the conservatism of the initial condition in the range of LCO. Figures 6 and 7 illustrated the trend for DNBR during MSLB and seized RCP rotor transients, respectively, which predicted DNBR according to both RCS flow and core inlet temperature of initial conditions. This trend map is consistent with the results of sensitivity. This study needs to analyze more operating parameters in the initial conditions to finalize the trend map in the near future.

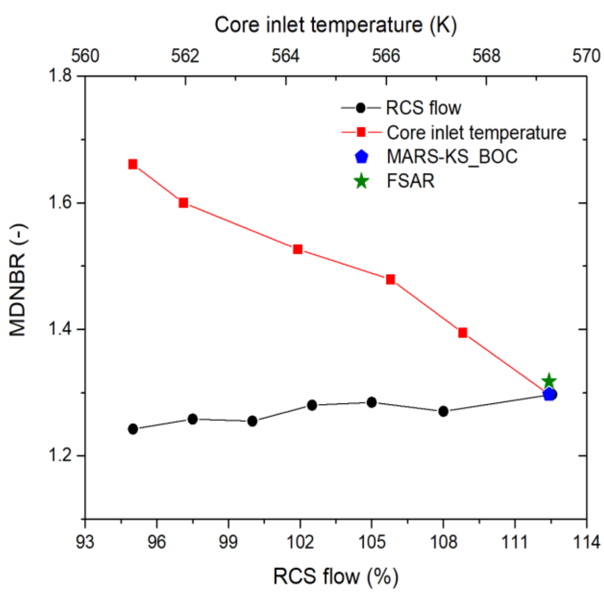

Fig. 6 The trend map on the initial condition during MSLB

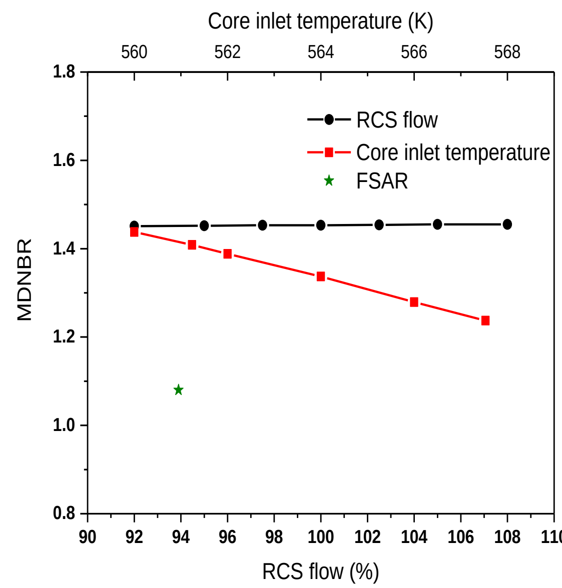

Fig. 7 The trend map on the initial condition during LR

6. Conclusions

This study presented sensitivity results on the initial condition in the range of LCO and developed the trend map based on the sensitivity study. It was found that system code was not partially suitable to calculate the DNBR on the core flow rate and another nuclear code could be needed.

It is crucial to make sure the conservative initial and assumption for a regulatory safety review. Thus, it needs to develop the whole trend map on the Non-LOCA continuously.

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