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Modeling human failure event of F&B operation in a PSA and its impact to the risk of a nuclear power plant

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1. Introduction

The expanded use of probabilistic safety assessment (PSA) in the risk-informed decision making process requires that PSA model should represent plant's configurations and operations as exactly as possible to ensure its technical adequacy. One of issues that need to be further investigated to improve the quality of PSA is the modeling of feed and bleed (F&B) operation [1].

This study represents (1) what is the difference between the modeling of F&B operation in a reference plant's PSA and its actual operational response characteristic, (2) what is its impact to the risk of the reference plant after revising the F&B modeling.

2. F&B Operation and PSA Modeling

F&B operation is an emergency response strategy for eliminating the residual core heat in case of total loss of all feedwater events. Under the loss of ultimate heat sink, residual heat can be removed by forcedly bleeding the RCS coolant into containment through the safety depressurization system (SDS) and injecting coolant of RWST into the RCS by the safety injection systems. According to the emergency operating procedure (EOP) of the reference plant [2], operators should open at least one SDS valve after confirming the open of the pressurizer safety valves (PSVs).

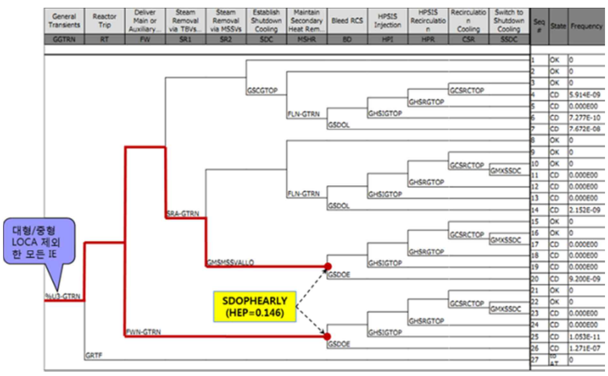

Fig. 1 F&B modeling of an ET for general transient

In PSA model of the reference plant which is a type of OPR1000, F&B operation is modeled in all event trees (ETs) except large or medium LOCAs [1]. Fig. 1 shows the ET for the initiating event of general transient. Red lines present the scenarios that F&B operation is required to prevent core damage in the early phase of scenario. In PSA of the reference plant, a human failure event (HFE), SDOPHEARLY, was defined for the failure of early F&B operation and used 0.146 as its human error probability (HEP). The HEP was generated by using K-HRA method [3] with the scenario of loss of condenser vacuum which was the most rigorous event from the viewpoint of RCS pressure control.

HEP of an emergency task is usually depends on the available time (AT) to complete the required task. AT of a HFE was defined as time duration from cue to the point that operation should finish a relevant emergency action of the HFE. In case of F&B operation in the reference PSA, AT was defined the duration from auxiliary feedwater actuation signal to PSV open. The AT for the F&B operation under loss of condenser vacuum was estimated as 16 minutes based on MAAP analysis. However, it was an arguable issue that the same HFE and HEP were used for the failure of F&B operation in other scenarios of total loss of all feedwater no matter which initiating event was.

3. Success Criteria for HFE of F&B Operation

For F&B operation, operators should open the valves of SDS to bleed RCS coolant forcedly to remove the residual heat. We defined the success criteria for the F&B operation like that operator must open at least one SDS valve just after opening of pressurizer safety valves (PSVs).

In order to eliminate uncertainty of the modeling of F&B operation in the PSA, we have analyzed the available time of F&B operation. First, we performed MAPP analysis to identify the allowable time for F&B operation, which are defined as the time to open pressurizer safety valve (PSV). Second, we estimated operators' action time to open SDS valves for F&B operation based on simulator records.

3.1 MAAP analysis

Thermal hydraulic analysis has been performed using MAAP code which is one of integrated severe accident analysis computer program. We run MAAP code for 9 different initiating events and checked the plant's parameters along with each initiating event [4]. Fig. 2 shows the result of MAAP code analysis for F&B operation.

초기사건	사건 발생시간 분석결과 (unit: seconds)					
	Rx trip	AFAS	SG dryout	PSV open	Core uncovery	RV failure
SLOCA-1 (0.38")	3,055	3,241	4,580	5,000	6,725	15,466
SLOCA-2 (1.0")	430	622	2,646	3.927	5,068	20,476
SLOCA-3 (1.91")	110	N/A	N/A	N/A	N/A	N/A
SGTR	865	1,060	N/A	N/A	N/A	N/A
LOFW	47	59	703	840	2,372	9,024
MSLB	24	36	61/830	1,053	2,448	9,143
MSSV	46	53	139/774	886	2,337	8,796
ADV	45	55	345/810	922	2,384	8,795
LOOP	0	1,915	5,336	3,302	7,002	15,742
SBO	0	1,915	5,336	3,302	7,002	15,742
GTRN,LOKV, LODC,LOCCW	0	1,911	5,338	3,258	7,006	14,809

Fig. 2. Analysis result of MAAP code for F&B operation

3.2 Operators' response analysis

For the operators' action time to open the SDS valve, we analyzed the simulator records obtained from training simulator in the reference plant. The task to be analyzed is 'the operator identifies the total loss of all feedwater, makes the decision of the bleed and feed operation, and then initiates the RCS bleeding by opening the SDS valves.' Fig. 3 shows the structure of EOPs and paths of operators' response for F&B operation in initiating events such as LOCA, SGTR, and a general transient. According to the result obtained from simulator records, the operators' action time to start F&B operation was much longer than 30 minutes after reactor trip.

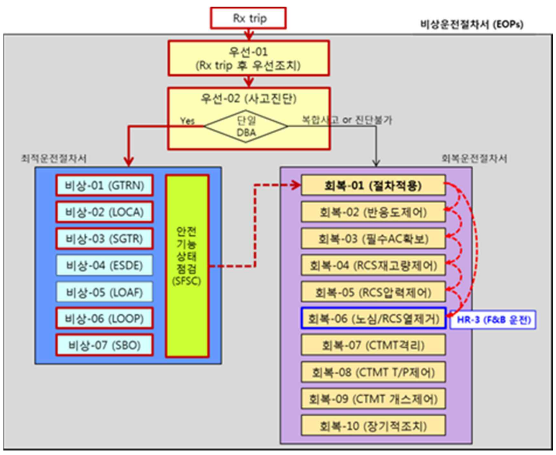

Fig. 3. A path of operators' response for F&B operation

4. Model changes and its impact to the risk

The modeling of F&B operation was revised based on the newly defined success criteria which were described in previous section. Table 1 summarizes the major changes in the PSA model of the reference plant. In case of SGTR initiating event, F&B operation cannot be credited anymore because the RCS pressure will not be higher than the set point of PSV open.

Fig. 4 shows the core damage frequencies of all initiating events comparatively in both original model and revised one. As shown in the figure, the risk was at least equal or increased in all initiating events.

Table I. Changes in modeling of F&B operation

초기사건	운전원 대응	F&B 모델 개정
LOFW, LOCV	우선02 -> 비상05 -> 회복06	현재 모델링 OK
ESDE	우선02 -> 회복01 -> 회복06	진단여유시간/수행시간 변화 (별도 HFE 정의)
SGTR	우선02 -> 비상03 -> 회복01 -> 회복06	F&B 운전조건 안됨 (모델 제외 or EOP 수정)
SLOCA	우선02 -> 비상02 -> 회복01 -> 회복06	진단여유시간/수행시간 변화 (별도 HFE 정의)
LOOP, SBO, GTRN, LOCCW, LOKV, LODC	우선02 -> 비상XX -> 회복01 -> 회복06	진단여유시간/수행시간 변화 (별도 HFE 정의)

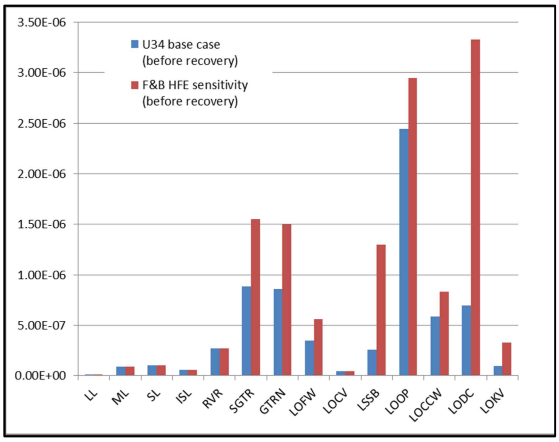

Fig. 4. Risk impact from the F&B model change

5. Conclusions

This paper summarized a study on modeling uncertainty of F&B operation and its impact to the risk of a nuclear power plant. It noticed that the model of F&B operation in the reference PSA did not reflect plant's behavior and operators' response exactly. The sensitivity analysis showed that the risk of the revised model was much higher than one of the original model. Now a PSA project has been undertaking to revise the original PSA model to improve its technical adequacy for risk informed application.

Acknowledgment

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