Design of Automated Function for Safe Cooldown Using F&B Operation

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1. Introduction

Various safety systems have been placed in nuclear power plant (NPP) to protect integrity of reactor vessel and prevent radioactivity release when an accident occurs. However, since NPP has lots of functions and systems, operated procedure is much complicated and the chance of human error to operate the safety systems is quite high. Accordingly, human error has been handled as one of the main reasons of nuclear power plant (NPP) accidents, and people have made a lot of effort to reduce the human error in NPPs [1]. Automation has led to increased comfort, safety, quality control, efficiency, magnification and scale of work within the NPP industry [2]. The automation not only reduces the operator's workload, but also increases the accuracy of operation.

2. Automated Function for Safe Cooldown

To reduce the human error and operate the safety systems accurately, an automated function of safe cooldown (AFSC) is suggested. AFSC performs two roles. One is prediction of successful cooldown using the function; the other is operation of safety systems. AFSC can predict whether the plant will be safe after relevant safety systems are initiated, and perform the safety systems automatically.

2.1 Feed and bleed operation

A feed and bleed (F&B) operation is the process to cool the primary coolant in primary system directly and initiated by operator with high human failure probability. In conventional emergency operation procedure, the F&B operation can start, if secondary system is failed to remove heat from the primary coolant as shown in figure 1.

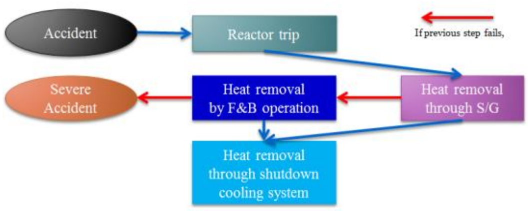

Fig. 1. Process of a cooling method of a conventional NPP.

This system can initiate the F&B operation when the system predict that the system to achieve safety goal. When operator imitates AFSC, reactor is cooled by F&B operation with possible methods which can be removed decay heat as shown in figure 2.

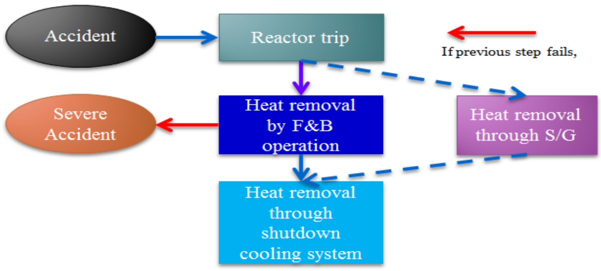

Fig. 2. Process of cooling method using the AFSC.

Relevant systems of F&B operation are safety depressurization system (SDS), and safety injection system (SIS).

2.2 Critical conditions to identification the success boundary

Expectation of success of AFSC means removal of the decay heat successful without fuel failure and making a shutdown cooling system operate. The F&B operation can be initiated, if a summation of heat energy which can transfer to secondary coolant, heat energy which is rejected by loss of water from primary system, heat energy which is rejected by injecting water from SIS before the F&B operation, and thermal margin of primary coolant between shutdown and F&B operation is more than decay heat. A summation of decay heat after the F&B operation, heat capacity of primary coolant from cold-shutdown to hot-shutdown, and thermal margin of primary coolant between shutdown and F&B operation should be removed by heat energy which is rejected by loss of vapor from SDS, heat energy which is rejected by injecting water from SIS, heat energy which can transfer to secondary coolant after the F&B operation, and heat energy which is rejected by loss of water from primary system. These principles are so complicated and time-dependent. Therefore, in this research, critical condition is identified to decide safety boundary for the expectation of success of AFSC as shown in figure 3 [3, 4].

S1	I1	L	M	V	I2	L	S2
Heat transfer to S/G	**Flow from SIS because of loss of coolant**	**Heat removal of liquid coolant**	**Thermal Margin**	**Heat removal though bleed**	**Sufficient flow from SIS**	**Heat removal by liquid coolant**	**Heat transfer to S/G**
Availability of components in secondary system	Availability of components in SIS			Availability of components in SDS	Availability of components in SIS		Availability of components in secondary system
Level of S/G	Pressure IRWST level Flow rate from SIS	Pressure	Core water level	Flow rate from SDS valves	Pressure IRWST level Flow rate from SIS	Pressure	Level of S/G
Forced/Natural circulation of primary coolant	Occurrence of LOCA	Break size	Degree of sub-cooling	containment spray for unlimited heat sink	Continuous flow rate	Break size	Natural circulation of primary coolant

Before operating the AFSC — After operating the AFSC

Fig. 3. Critical conditions for expectation of success of AFSC.

2.3 Identification of success boundary

As mentioned in previous sections, principle and expectation of success of heat removal are so complicated and time-dependent. To identify the success boundary according to the critical conditions, we analyzed using A MARS code (Multi-dimensional Analysis of Reactor Safety) modified for OPR1000.

Critical conditions are largely affected by LOCA (loss of coolant accident) or non-LOCA. In case of LOCA, core loses the primary coolant. Then, pressure decreases, and SIS is operated to make up the coolant and cool down the reactor. Secondary system may not be useful according to the amount of loss of primary coolant. In case of non-LOCA, there is no loss of primary coolant, and pressure and temperature increase when the secondary system failed.

Heat transfer from primary system to secondary system is possible when natural circulation maintains because break size is small [5]. Initiation of the F&B operation after the LOCA is same as increase of break size. Then, available range of natural circulation after the LOCA with the F&B operation decreases than the LOCA without the F&B operation.

In case of LOCA, according to break size with F&B operation, the effects of heat transfer by secondary system, F&B operation, and heat removal by the SIS can be identified. Sensitivity studies using the MARS code are performed according to break size with/without the F&B operation. Based on the results, the effects of availability of relevant components for success boundary of AFSC could be obtained.

In case of non-LOCA, the success boundary could be obtained when the secondary system failed. The boundary means the conditions for the maximum of thermal margin of primary coolant between shutdown and F&B operation without secondary system.

3. Conclusions

To reduce the operator's workload and perform the operation accurate after the accident, automated function for safe cooldown based on the F&B operation is suggested. The F&B operation is the process of primary cooling system and it is important because it is last resort if all other attempts failed. AFSC should be not only reflected the procedure of the F&B operation for the automation, but also considered the reactor condition including accident scenarios and possible components to expect the success of heat removal.

To expect the success of AFSC, success boundary should be identified according to the critical conditions. Critical conditions are largely affected whether LOCA or non-LOCA occurs. Moreover, the break size of LOCA is important to maintain the heat transfer from primary system to secondary system. Cases studies are performed for available range of natural circulation according to break size with/without the F&B operation. Based on these results, the effects of availability of relevant components for success boundary of AFSC could be obtained.

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