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Development of Operation Strategy for Hybrid-SIT in SBO Accident

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1. Introduction

The Fukushima accident was not managed properly due to a lack of effective mitigation systems against Station Black Out (SBO) accident [1]. For this reason, passive system is suggested as an alternative way for active system because passive system doesn't need external energy source and passive system can also increase the diversity of mitigation technique of Nuclear Power Plant (NPP).

A hybrid safety injection tank (H-SIT) is a passive injection system that adjusts to the APR+ [2]. This system is developed for mitigation of SBO scenarios. Main function of this system is injection of coolant to the Reactor Coolant System (RCS) in a passive way. The H-SIT system can inject water using the pressure from nitrogen gas as a normal SIT in low-pressure accidents such as large and medium break loss-of-coolant accidents. Additionally, the H-SIT system can inject water using the gravitational force in over-pressure accidents, which means that the pressure is higher than the safety injection pump (SIP) injection pressure. Figure 1 presents the outline of the H-SIT system.

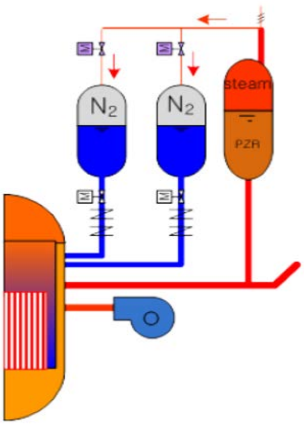

Fig. 1 Outline of H-SIT system [2]

A conventional NPP is mainly composed of active systems; thus, a conventional operating procedure or strategy of SBO are developed to focus on the restoration of electricity. Thus, in order to use the H-SIT system effectively, a new operation procedure is needed. Hence, this study focuses on developing an operation strategy for H-SIT in SBO situation.

2. Methodology

2.1 analysis of SBO accident

The SBO accident is the one initiated by a total loss of both offside and onsite AC power. Following this accident, the reactor is tripped, main feed water system is terminated, and charging pump is stopped. The RCP seals are damaged due to hot coolant thus Loss of Coolant Accident is occur through break part of RCP seal. On the other hand, Passive Auxiliary Feedwater System (PAFS) is still working because it is passive system. Those phenomena are important to analyze overall transients of SBO.

According to the characteristic of SBO accident, analysis of this accident can be focused on typical three phases: the SG's secondary fluid loss phase, the natural circulation phase, and the primary coolant loss phase. Those three phases are greatly affected by soundness of PAFS and occurrence of seal LOCA. Thus, in this study, those two standards are considered as a major factors to make operation strategy in SBO accident.

2.2 Application of H-SIT in SBO

The main function of H-SIT is RCS inventory make up. Thus, H-SIT can be used in many ways by using its function. In SBO situation, H-SIT is used for three purposes: Increase efficiency of natural circulation when seal LOCA occur, Increase of core coolant level when seal LOCA occur, extension time of cladding failure when PAFS fail.

Operation strategy of H-SIT is made by checking typical three phases of SBO accident and considering of proper use of H-SIT. , concept flow chart of H-SIT operation is presented in figure 2

To make proper operation strategy of H-SIT, the best operation timing of H-SIT have to be found. That means, proper indication in concept flow chart have to be identified. Thus, in this study, analysis for finding the best timing of H-SIT operation is performed.

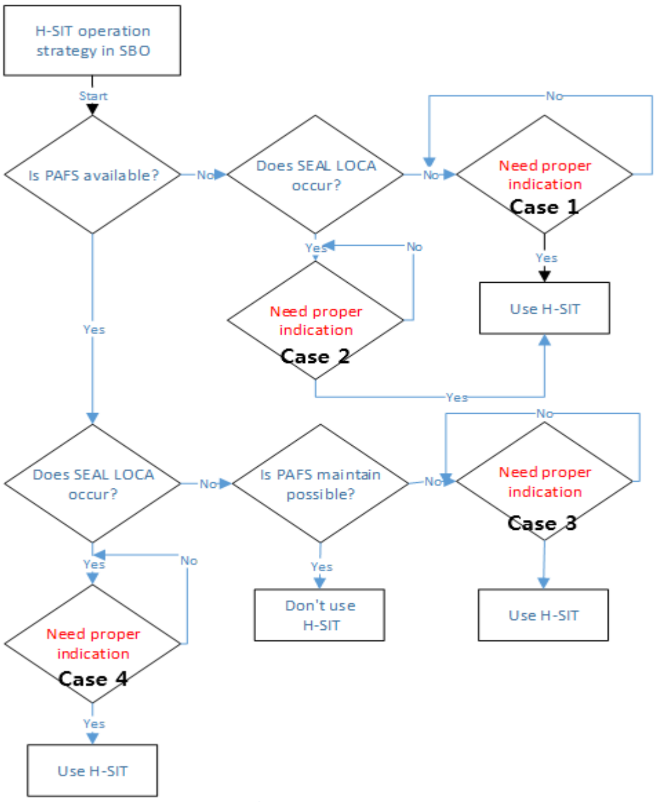

Fig. 2 Concept flow chart of H-SIT operation strategy

2.3 Initial condition and assumption of study

In concept flow chart, four cases for analyzing operation timing of H-SIT are indicated by using two major factors such as soundness of PAFS and occurrence of seal LOCA. Size of LOCA is assumed $0.5ft^2$ and RCP seals generally can maintain function for a maximum of 30 min [3]. Thus, this study also assume that time of seal failure is 1800s and PAFS is assumed that it lose its function 8hours after the SBO happen [4] and code calculation is stopped when temperature of cladding exceed cladding failure temperature, 1203°C [5]. In this study, all calculations are conducted by using the thermo-hydraulic code, MARS KS ver.

For finding the best timing of H-SIT operation, four timings are selected. Those are time of SG water level is 50% of its normal level, seal LOCA occur, POSRV open, core level is 50% of its normal level.

2.3.1. Case 1

In accident of Case 1, SBO, PAFS fail, seal LOCA does not occur. Pressurizer pressure of case 1 is presented in figure 2. In this case, fuel cladding is failed about 4040s after the SBO happen.

For finding the best timing of H-SIT operation, four timings are decided as an analysis points. Detail information of those are presented in table 1.

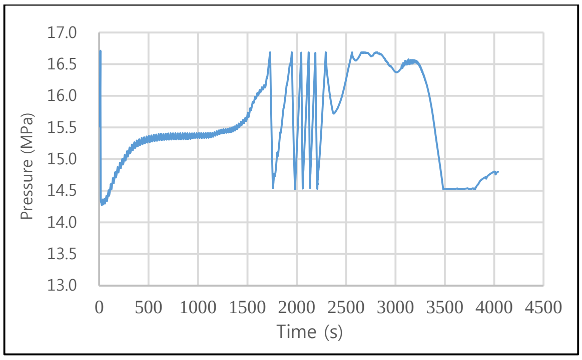

Fig. 3 PZR pressure during a transient in case 1 without H-SIT operation

Table 1 Operation timing of H-SIT in case 1

Operation timing	Time
When SG water level is 50% of its level in normal operation	577s
Seal LOCA occur	N/A
When POSRV open	1730s
When core level is 50% of its level in normal operation	3560s

2.3.2. Case 2

In accident of Case 2, SBO, PAFS fail, seal LOCA occur. Pressurizer pressure of case 2 is presented in figure 3. In this case, fuel cladding is failed about

3900s after the SBO happen. In case 2, Analysis points are also decided for finding the best timing of H-SIT operation as a case 1. Those are presented in table 2.

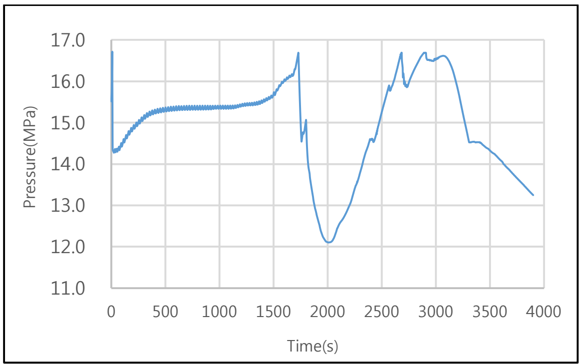

Fig. 4 PZR pressure during a transient in case 2 without H-SIT operation

Table 2 Operation timing of H-SIT in case 2

Operation timing	Time
When SG water level is 50% of its level in normal operation	N/A (577s)
Seal LOCA occur	1800s
When POSRV open	2683s
When core level is 50% of its level in normal operation	3457s

In this case, occurrence of seal LOCA is added for analysis point of operation timing of H-SIT, because lose the coolant through the break part of RCP seal can have an effect to natural circulation of primary side. Making up the coolant by using H-SIT can help primary side to circulate naturally.

2.3.3. Case 3

In accident of Case 3, SBO, PAFS is sound. Pressurizer pressure of case 3 is presented in figure 4. In this case, fuel cladding is failed about 43413s after the SBO happen. In case 2, Analysis points are also decided for finding the best timing of H-SIT operation as other cases. Those are presented in table 3.

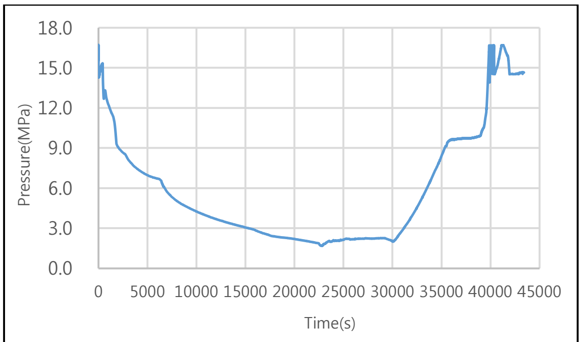

Fig. 5 PZR pressure during a transient in case 3 without H-SIT operation

Table 3 Operation timing of H-SIT in case 3

Operation timing	Time
When SG water level is 50% of its level in normal operation	36275s
Seal LOCA occur	N/A
When POSRV open	40024s
When core level is 50% of its level in normal operation	42577s

2.3.4. Case 4

In accident of Case 4, SBO, PAFS is sound, seal LOCA occur. Pressurizer pressure of case 4 is presented in figure 5. In this case, fuel cladding is failed about 34424s after the SBO happen. In case 4, Analysis points are also decided for finding the best timing of H-SIT operation as other cases. Those are presented in table 4.

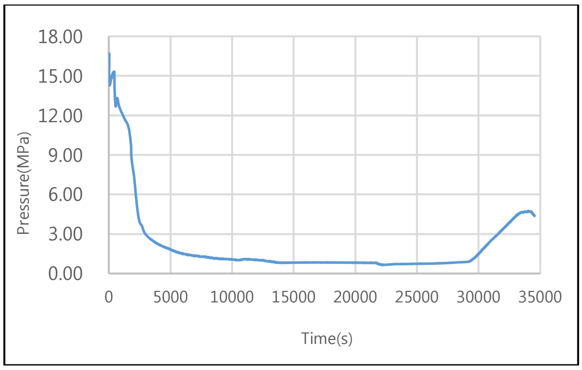

Fig. 6 PZR pressure during a transient in case 4 without H-SIT operation

Table 4 Operation timing of H-SIT in case 4

Operation timing	Time
When SG water level is 50% of its level in normal operation	N/A
Seal LOCA occur	1800s
When POSRV open	N/A
When core level is 50% of its level in normal operation	33810s

In this case, SG level don't decrease below than 50% of its normal level because heat transfer from primary side to secondary side have a low performance in this case. Lack of coolant of primary side which is caused by seal LOCA is the main reason of low heat transfer rate. Moreover, pressurizer pressure also don't increase over POSRV open pressure because of the same reason. Therefore, time of SG water level is 50% of its normal level and POSRV open are not considered in this case.

3. Result

3.1. Operation timing of H-SIT

Analysis by using MARS code is performed based on initial conditions which is set in previous section case by case. These results shows what is the best timing for H-SIT operation in each case.

3.1.1 Case 1

Based on the results of code, use of H-SIT can extend cladding failure time effectively. In case 1, especially, if H-SIT is operated at time when core level is 50% of its level in normal operation, core has the highest time extension rate among all timings because H-SIT dry out the latest due to the latest start time of H-SIT operation. It means that core can be cooled for the longest time by injecting water using H-SIT. Therefore, the later H-SIT is operated, extension time of cladding failure increase. However, after the time when core level is 50% of its level in normal operation, temperature of core is increasing, thus it is dangerous to use H-SIT too late. Margin which is for operator's reaction is needed. Therefore, in this case, core level is 50% of its level in normal operation is considered as a best timing of H-SIT operation, thus when SBO occur without PAFS operation and seal LOCA is not occur, H-SIT should be operated when core level is 50% of its level in normal operation. Cladding failure time of each case are presented in table 5 and Pressurizer pressure for each case is presented in figure 7.

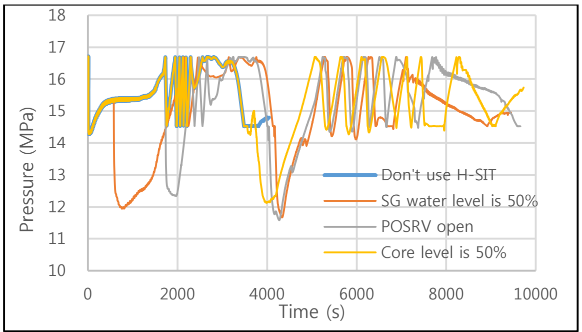

Fig. 7 PZR pressure during a transient in case 1 for various H-SIT initiation times

Table 5 Efficiency of the H-SIT based on the operation timing in case 1

Operation timing	Cladding failure time (Extension time)
Don't use H-SIT	4040s (0s)
When SG water level is 50% of its level in normal operation	9446s (+5406s)
When POSRV open	9654s (+5614s)
When core level is 50% of its level in normal operation	9726s (+5686s)

3.1.2 Case 2

In this case, if H-SIT is operated at time when seal LOCA occur, core has the highest time extension rate among all timings because early supply of coolant by using H-SIT help to stimulate the natural circulation in RCS system and to make flow from pressurizer to SIT tank because when early state, POSRV is not open. Good efficiency of natural circulation affect heat removal from primary side to secondary side and decrease of RCS pressure. This decrease of RCS pressure decrease amount of water which leak through break part of seal and accelerate water flow from pressurizer to SIT tank. This accelerated flow fill the SIT tank more, thus H-SIT dry out the latest even if H-SIT is operated early. It means that H-SIT can inject water to core for a longest time. That is reason why cladding failure occur the latest when H-SIT is operated at the timing when seal LOCA occur. Therefore, in this case, timing of seal LOCA is considered as a best timing of H-SIT operation, thus when SBO occur, seal LOCA occur and PAFS is not sound, H-SIT should be operated when seal LOCA occur. Cladding failure time of each case are presented in table 6 and Pressurizer pressure for each case is presented in figure 8.

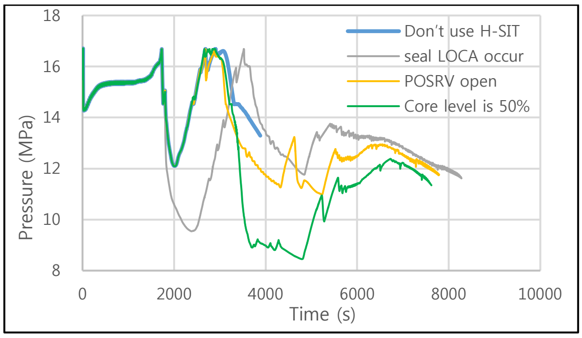

Fig. 8 PZR pressure during a transient in case 2 for various H-SIT initiation times

Table 6 Efficiency of the H-SIT based on the operation timing in case 2

Operation timing	Cladding failure time (Extension time)
Don't use H-SIT	3882s (0s)
Seal LOCA occur	8280s (+4398s)
When POSRV open	7791s (+3909s)
When core level is 50% of its level in normal operation	7622s (+3740s)

3.1.3 Case 3

In this case, if H-SIT is operated when SG water level is 50% of its level in normal operation, core has the highest time extension rate among all timings because when H-SIT is operated early, dry out time of

SG is late because core is cooled down by using H-SIT at the same time so heat transfer rate primary side to secondary side is relatively low compare with late operation of H-SIT. It means that core is cooled for a longest time through SG. And H-SIT is operated when POSRV not open, a lot of water flow from pressurizer to SIT tank is existed. For this reason, even if H-SIT is operated early, H-SIT dry out late. Therefore, in this case, SG level is 50% of its level in normal operation is considered as a best timing of H-SIT operation, thus when SBO occur and seal LOCA not occur and PAFS maintain fail, H-SIT should be operated when SG level is 50% of its level in normal operation. Cladding failure time of each case are presented in table 7 and Pressurizer pressure for each case is presented in figure 9.

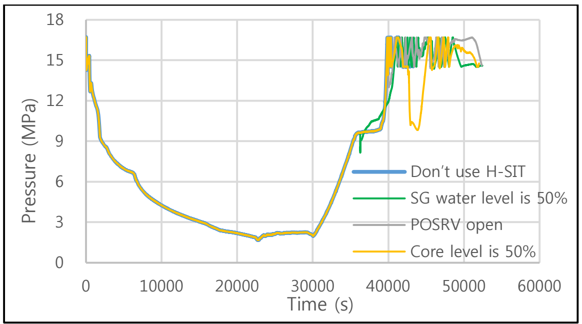

Fig. 9 PZR pressure during a transient in case 3 for various H-SIT initiation times

Table 7 Efficiency of the H-SIT based on the operation timing in case 3

Operation timing	Cladding failure time (Extension time)
Don't use H-SIT	43410s (0s)
When SG water level is 50% of its level in normal operation	52442s (+9032s)
When POSRV open	52364s (+8954s)
When core level is 50% of its level in normal operation	51997s (+8587s)

3.1.4 Case 4

In this case, if H-SIT is operated when core level is 50% of its level in normal operation, core has higher time extension rate compare with timing of seal LOCA because when H-SIT is operated in early phase, water which leak through break part of seal increase. It is known by checking amount of water flow of break part, this amount of flow presented in figure 9. For this reason, H-SIT cannot perform its function. That's why cladding failure time when seal LOCA occur is little different compare with when H-SIT is not operated. . Therefore, in this case, core level is 50% of its level in normal operation is considered as a best timing of H-SIT operation, thus when SBO occur and seal LOCA occur and PAFS maintain fail, H-SIT should be operated when core level is 50% of its level in normal operation. Cladding failure time of each case are presented in table 8 and Pressurizer pressure for each case is presented in figure 10.

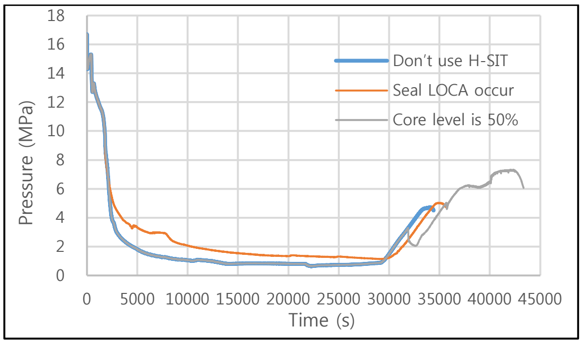

Fig. 10 PZR pressure during a transient in case 4 for various H-SIT initiation times

Table 8 Efficiency of the H-SIT based on the operation timing in case 4

Operation timing	Cladding failure time (Extension time)
Don't use H-SIT	34424s (0s)
Seal LOCA occur	35630s (+1206s)
When core level is 50% of its level in normal operation	43351s (+8927s)

3.2. Summary

Operation strategy of H-SIT can be divided into four case in SBO accident and each case has a deferent strategy of H-SIT operation. In case1, timing of H-SIT operation has the best efficiency when core level is 50% of its level in normal operation. H-SIT extend failure time of cladding up to 5686s. In case 2, timing of H-SIT operation has the best efficiency when seal LOCA occur. H-SIT extend failure time of cladding up to 4398s. In case 3, timing of H-SIT operation has the best efficiency when SG water level is 50% of its level in normal operation. H-SIT extend failure time of cladding up to 9032s. In case 4, timing of H-SIT operation has the best efficiency when core level is 50% of its level in normal operation. H-SIT extend failure time of cladding up to 8927s.

4. Operation strategy of H-SIT

Base on the results of timings, proper indications of flow chart are defined so finally flow chart of H-SIT operation strategy is completed. This final flow chart is presented in figure 11. This operation strategy is focused for proper mitigation of SBO accident by using H-SIT effectively. Use of this strategy increase capability of plant safety functions.

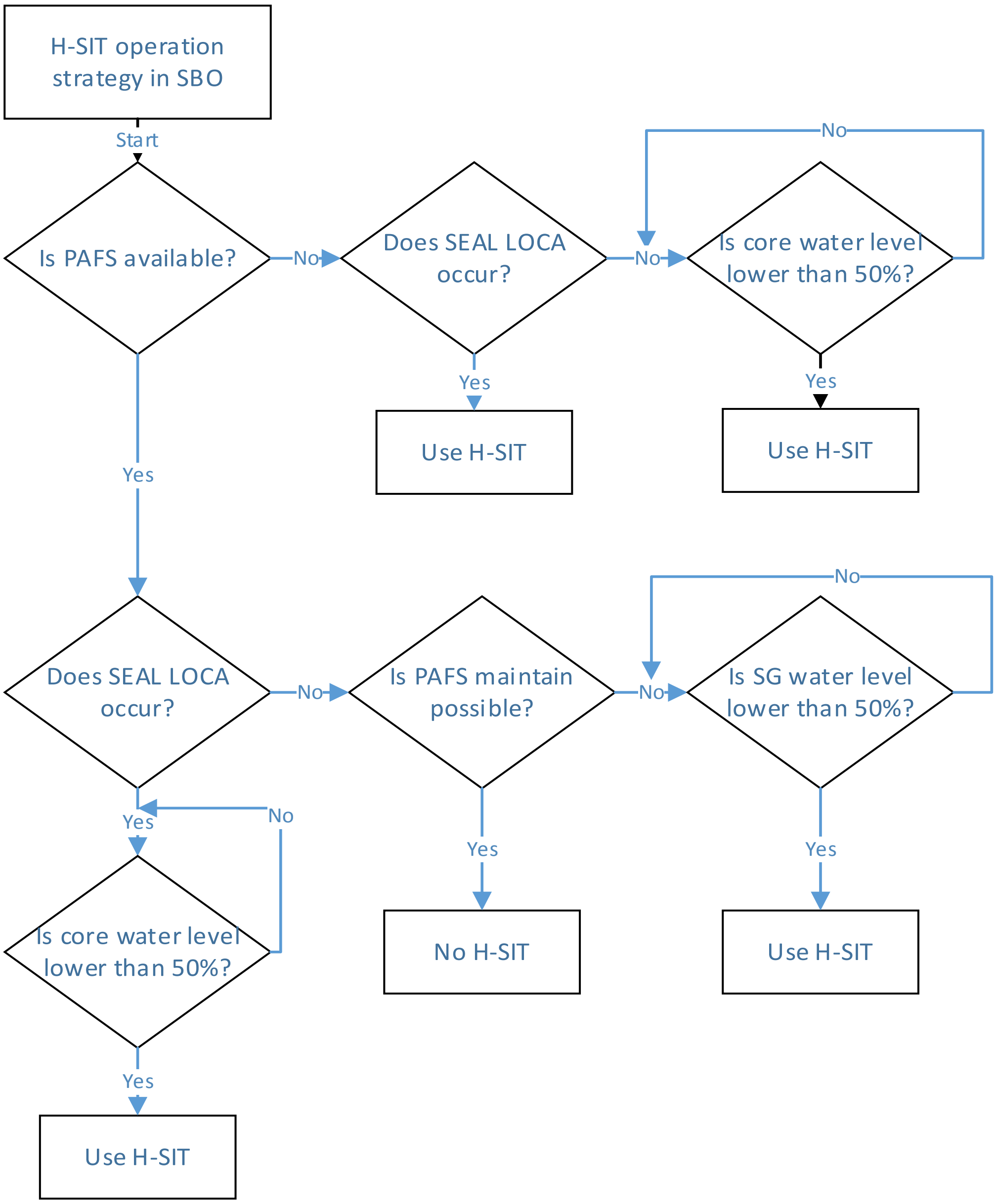

Fig. 11 Flow chart of H-SIT operation strategy

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