A Study of Hybrid SIT Operation Strategy in Nuclear Power Plant

I. Seop Jeon & H. Gook Kang

INTRODUCTION

After Fukushima accident, safety of nuclear power plant (NPP) become the most important issue in nuclear field. People also want NPP to keep safe forever. For these reasons, passive system is suggested as an alternative way for active system because passive system is suitable for handling Station Black Out (SBO) accident but Probabilistic Safety Analysis (PSA) show that passive NPP which is consist of only passive system for safety systems is not safer than active NPP because passive NPP has similar amount of CDF compare with active NPP. In order to enhance reliability of NPP, many experts suggest to use active and passive system together. It should improve variety of safety systems of NPP and also improve diversity of it.

Hybrid SIT (H-SIT) is the accident mitigating system which is used for injecting coolant to Reactor Coolant System (RCS) and also it is passive system. H-SIT has a similar function with Safety Injection Pump (SIP) which is active system. As I mention above, if we have SIP and H-SIT in a one NPP, we can enhance reliability of NPP. However, in nuclear field, there is no information of parallel operation using combination of passive and active systems. Even if we install both systems in a one NPP, we can't operate those systems effectively. This study focus on H-SIT, therefore it suggest that what is the effective H-SIT operation strategy in NPP which is composed active systems and how we make that strategy logically.

BODY

Hybrid SIT

New design concept of a hybrid SIT both for safety injections at a low pressure and high pressure accidents was introduced [1,2].

Figure 1 shows the design concept of the hybrid SIT. For the low pressure accident such as LBLOCA, the ECC water of SIT is injected by the nitrogen gas while it is injected by a gravitational force for a high RCS pressure

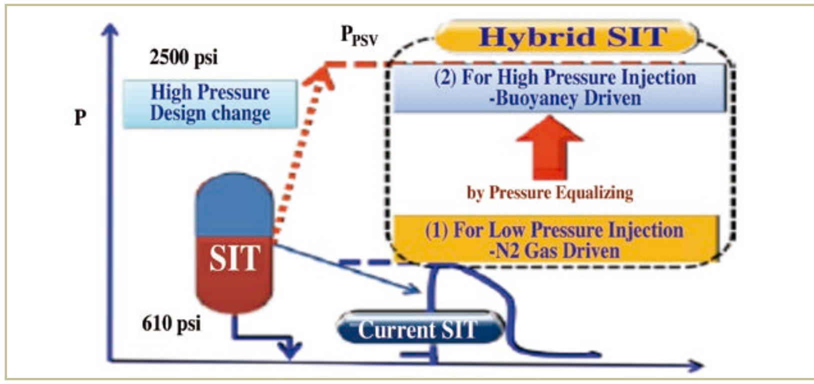

Figure 1. Design concept of hybrid SIT.

Order of PSA Event tree		Order of EOG
#	Head name	Number of EOG
1	Deliver aux feedwater using TDP	ORG #4,6,7
2	RCP seal failure	ORG #5
3	Recover AC Power	ORG #8~13
4	Deliver aux feedwater using MDP	ORG #14,15
5	Recover AC Power	ORG #18~20
6	Establish shutdown cooling	ORG #25~44

Table I. Compare the order between PSA and org.

accident such as SBO accident or small size SBLOCA. To drive a hybrid SIT, battery driven isolation valves for SBO condition and a pressure equalizing line between the SIT and pressurizer, hot leg, or reactor vessel is needed.

New methodology for making H-SIT operation strategy

Emergency Recovery Guidelines (EOG) is typical operation strategy procedure which give information of optimized mitigating way to operator in accident situations. What's interesting is that order of PSA event tree and EOG have many similarities and fault tree is also closely related to operation strategy because they have same purpose which is to mitigate accident of NPP and use same logic. Table 1 shows similarity of order of PSA and EOG.

Considering this similarity, technique of PSA will be a good reference for making operation methodology. Therefore, this study suggest new methodology for making effective H-SIT operation strategy using technique of PSA. New methodology contains situation decision analysis which are composed of the ways for categorizing operation cases and finding dominant parameters and it also contain timing analysis which is the way for finding suitable timing of H-SIT operation.

Situation decision analysis

In accident situations, there are lots of thermodynamic phases and recognizing phenomena in NPP. Thus, finding important parameters which are connected with H-SIT operation strategy closely is very essential part in this study. For perfect analyzing, at first, accident situations which need H-SIT operation are found and categorize those situations into some cases using new methodology. In this study, situation is categorized into 2 cases first and then each situations is categorized once more. Figure 2 show the logic diagram for categorizing cases

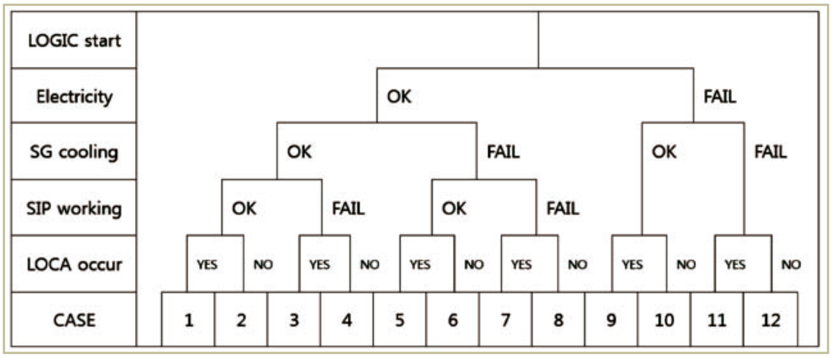

Figure 2. Logic diagram for catgorizing cases.

<table>
<tr><th rowspan="2"></th><th rowspan="2">RCS PRESSURE</th><th rowspan="2">DE-PRESS</th><th rowspan="2">LOCA LOCATION</th><th rowspan="2">2nd heat removal</th><th rowspan="2">SCP</th><th colspan="2">CHOOSE SYSTEM</th></tr>
<tr><th>H-SIT</th><th>SIP</th></tr>
<tr><td rowspan="10">L O C A</td><td rowspan="10">Above SIP injection pressure ~ PSV open pressure</td><td rowspan="5">ok</td><td>POSRV STUCK OPEN</td><td>n/a</td><td>n/a</td><td>impossible</td><td>use</td></tr>
<tr><td rowspan="2">Hot leg & DVI LOCA</td><td rowspan="2">H-SIT better</td><td>ok</td><td>Use first</td><td>Use later</td></tr>
<tr><td>fail</td><td>impossible</td><td>use</td></tr>
<tr><td rowspan="2">Etc</td><td rowspan="2">H-SIT better</td><td>ok</td><td>Use first</td><td>Use later</td></tr>
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<tr><td>fail</td><td>use</td><td>impossible</td></tr>
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Table II. Situation decision making logic table in case 3.

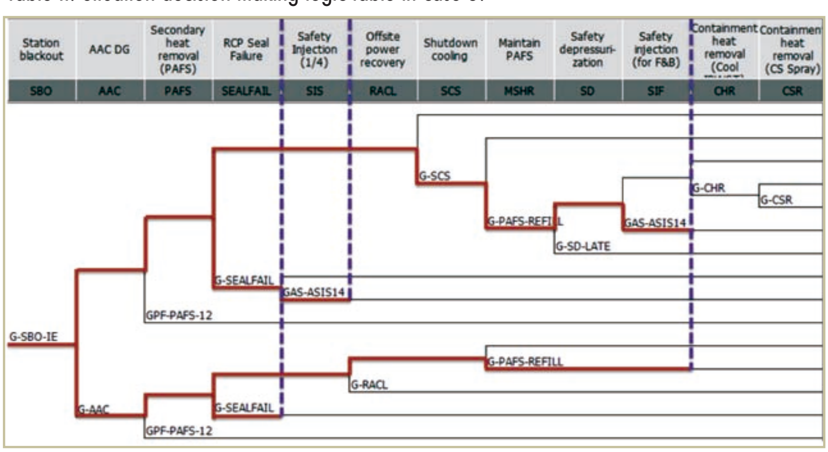

Figure 3. Timing analysis for H-SIT operation in SBO.

After categorizing cases, finding parameters which is affect H-SIT and active system operation is performed in each case. In order to do that, analysis of differences between active system such as SIP and H-SIT is carried out because even if H-SIT and SIP perform similar function in accident situations, conditions of operation are different. Dominant parameters is decided base on these differences. Then, logic for deciding situation to use H-SIT is made by using dominant parameters. Table 2 show situation decision making logic table in case 3.

Timing analysis

After deciding detail situation to use H-SIT, deciding appropriate operation order of it is essential. Because there are many safety mitigation system in NPP so it is very complicate process to decide order of H-SIT and other safety systems and also appropriate operation time of H-SIT make operation strategy effectively. In this study, PSA initiating events and event tree are used for deciding operation timing. As I mention chapter B, PSA event tree and operation strategy(or mitigation order) have same purpose. Therefore analyzing and reflecting PSA event tree help to find the best operation timing of H-SIT. This study use initiating event tree of APR+. Figure 3 show the example way of timing analysis for H-SIT operation in SBO.

Code analysis

Accident situation which need H-SIT and operation timing can be decided through new methodology but some decision need more detail analysis because it is performed under situation which have very complicate and changeable thermodynamic phases depend on time and degree of accidents so additional code analysis is needed for making clear decision in special point. In this study, MARS code is used as an analysis tool.

RESULT

In this study, new methodology which is decide operation strategy between H-SIT and active safety systems is suggested. It help plant operator to use both system effectively and also it can be used for making EOG or operation strategy for advanced NPP. Nowadays, passive system is drawing attention as a future safety system of NPP. In this situation, making methodology of parallel operation between passive and active system is essential and it have to be improved continuously.

ACKNOWLEDGMENT

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Dry process research about UO_2 powder production with GFX-200 devices

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INTRODUCTION

In order to meet the requirements of rapid increasing demands of domestic nuclear fuel markets, and keep in step with the developing situation of chemical conversion in the world, CNNC Jianzhong Nuclear fuel Co., Ltd. has launched the expanding strategy which mainly aims to develop dry process to improve capacity of its kiln from 90tU/y to 200tU/y.

CHARACTERISTICS OF GFX-200 DEVICES

A. Autoclaves

Autoclaves are horizontal and electric heating. Its safety and stability has greatly improved.

B. Kiln

The diameter and length of kiln have been enlarged in order to be suitable for larger capacity.

C. Nozzle

The diameters of inner pipe and out pipe, inner pipe guiding van, the taper angle have been changed to increase reaction efficiency.

EXPERIMENTS

A. Purpose and methods

- To research influences of different process parameters (temperature, flow) upon performances of UO_2 powder which produced by GFX-200 devices.
- Orthogonal experiment has been applied in the research in order to find the most optimized parameters.

B. Process principle

The following process is the main reaction occurred during the conversion.UF_6 gas reacts with steam and then the reaction product UO_2F_2 is reduced and defluorinated by steam and H_2.

$$UF_6(g) \rightarrow UO_2F_2(S) \rightarrow UO_2(S)$$

C. Devices

GFX-200 Devices: Autoclaves, nozzle, kiln, hopper, mixer, filter, graphite heat exchanger.

D. Experiment parameters

There are fixed and flexible parameters in the experiment; flexible parameters include kiln temperatures, flow ratio of UF_6 gas to steam from the nozzle, defluorination steam flow and H_2 flow. Four factor and three level orthogonal [$L_9(3^4)$]

Experiment has been designed.

Serial No	Kiln Temperatures (A)	Flow Ratio of UF6 Gas to Steam From the Nozzle (B)	Defluorination Steam Flow (C)	H_2 Flow (D)
1	A1	B1	C1	D1
2	A2	B1	C2	D3
3	A3	B1	C3	D2
4	A1	B2	C2	D2
5	A2	B2	C3	D1
6	A3	B2	C1	D3
7	A1	B3	C3	D3
8	A2	B3	C1	D2
9	A3	B3	C2	D1

Table I. Orthogonal experiment flexible parameters list.

Serial No	H_2O %wt	U %wt	F μg/gUO_2	O/U	ρa g/cm³	ρt g/cm³	SSA m²/g	d μm	Matrix Density %T.D.
	≤0.4	≥87.00	≤100	2.02~2.05	0.80~1.30	1.50~2.50	2.0~3.0	/	≥96.5[a]
1	0.2	87.7	11	2.15	1.01	1.50	2.4	13.9	97.8
2	0.3	87.2	13	2.10	0.88	1.39	2.1	11.5	98.1
3	0.3	87.4	9	2.13	0.99	1.26	3.8	12.3	98.4
4	0.3	87.6	7	2.14	1.05	1.50	2.3	13.2	98.4
5	0.2	87.4	5	2.13	0.96	1.44	2.5	21.4	98.5
6	0.3	87.3	17	2.12	0.95	1.37	3.1	10.6	98.4
7	0.2	87.7	17	2.14	1.09	1.58	2.6	12.6	98.2
8	0.3	87.7	6	2.14	1.15	1.62	2.1	11.6	98.2
9	0.3	86.1	416	2.28	0.89	1.29	3.1	10.0	/

a. Technical Requirments for UO_2 performances

Table II. Orthogonal experiments UO_2 performances.

E. Experiment Results

- Experiments have been done under the sequence illustrated in Table I. Experiment results data is listed in Table II.
- According Table II, orthogonal analysis for Matrix density results

Serial No.	Experiment Parameters				Matrix Density %T.D.
	A	B	C	D	
1	A1	B1	C1	A1	97.8
2	A2	B1	C2	A2	98.1
3	A3	B1	C3	A3	98.4
4	A1	B2	C2	A1	98.4
5	A2	B2	C3	A2	98.5
6	A3	B2	C1	A3	98.4
7	A1	B3	C3	A1	98.2
8	A2	B3	C1	A2	98.2
9	A3	B3	C2	A3	/
I	98.13	98.10	98.13	98.15	I+II+III=786
II	98.27	98.43	98.25	98.33	/
III	98.40	98.20	98.37	98.23	/
Range	0.27	0.33	0.24	0.17	/

Table III. Orthogonal analysis for matrix density results.

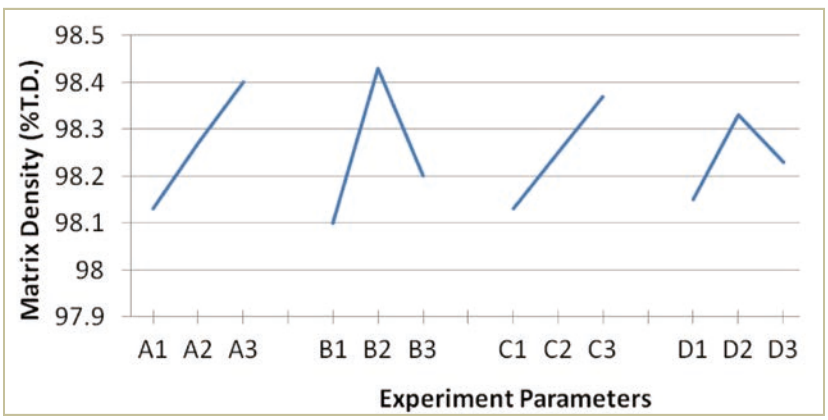

Figure 1. Influences of different parameters upon matrix density of UO_2

Parameters	H_2O %wt	U %wt	F μg/gUO_2	O/U	ρ_a g/cm³	ρ_t g/cm³	SSA m²/g	d μm	Matrix Density %T.D.
	≤0.4	≥87.00	≤100	2.02~2.05	0.80~1.30	1.50~2.50	2.0~3.0	/	≥96.5
A1 B3 C3 D2	0.10	87.62	<3	2.08	1.0	1.6	2.2	12.1	98.1

Table IV. Verification test UO_2 powder performances

Parameters	U %wt	O/U	Total Hydrogen μg/gUO_2	Impurities	Metallograph μm	Thermo-stability %T.D.
A1 B3 C3 D2	88.14	1.998	0.16	OK	9.4	0.34

Table V. Corresponding UO_2 pellets performaces.

could be done. And Figure 1 shows the influences of different parameters upon matrix density of UO_2 powder.

1) *Kiln Temperature*: UO_2F_2 reduction occurs normally under 600~700°C [1,2], with the rising of kiln temperature,matrix density of UO_2 powder decreases,because partial sinterization become easier to happen under higer temperature;
2) *Flow Ratio of UF_6 Gas to Steam From the Nozzle*: with the flow ratio rising, matrix density of UO_2 powder increases firstly and after reaching one balance point, matrix density decreases;
3) *Defluorination Steam Flow*: matrix density increases with flow of deflurination steam increasing;
4) *H_2 Flow*: with H_2 flow rising, matrix density of UO_2 powder increases firstly and then decrease after another balance point.
5) *Optimised parameters group*: As the most important performance of UO_2 powder, Matrix density indicates sintering ablity of UO_2, higher matrix density means higher sintering activity[3]. According the experiment results the optimised parameters group is A3, B2, C3 and D2 .

VERIFICATION TEST

In order to choose verification test parameters, two factors should be concerned, one is about capacity, and another is UO_2 performance, so the optimized parameter is amended to A3, B3, C3 and D2, because UF_6 gas flows in B2 parameter is lower than capacity's need.

According to the experiences of manufacturing UO_2 pellets and test date, corresponding UO_2 pellets have good performances in next processes in manufacturing of nuclear fuel elements.

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