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Study of the FLEX Effectiveness of Strategies Under the Long-Term SBO by PRA

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***Abstract* - Beyond Design Basis Accident (DBA) can make a big impact on nuclear power plant like the Fukushima-Daiichi accident. In particular, if long-term Station Black Out (SBO) occurs, the probability of core damage increases, and there is a possibility that the radiation may leak to the outside when reactor core is uncovered. During long-term SBO, all of the power is not available except batteries and the period of SBO is longer than the battery capacity. In order to prevent this situation, Nuclear Energy Institute (NEI) has created a measure called diverse and flexible coping strategies (FLEX). The objective of FLEX is to prevent damage to the fuel in the reactor and to maintain the containment function by using FLEX. The underlying FLEX strategies for coping with a Beyond Design Basis External Event (BDBEE) involve a three-phase approach. The first phase relies initially on installed plant equipment. The second is transition from installed plant equipment to on-site FLEX equipment. The third is to obtain additional capability and redundancy by using off-site equipment until power, water, and coolant injection systems are restored or commissioned.**

BDBEE occurs outside the plant and affects plant operation. It also make an initiating event. Then, the effectiveness of the proposed FLEX in reducing the plant vulnerabilities is analyzed by Level 1 Probabilistic Risk Assessment (PRA). In order to verify the efficiency of FLEX, SBO model and applied FLEX in the SBO model are needed. By comparing the results of the two models, the efficiency of the FLEX can be verified. The FLEX application to the PRA model shows that additional mitigation systems decrease Core Damage Frequency (CDF) and improve safety for the nuclear power plant.

Keywords* – E*nergy, nuclear, long term, mixture, MESSAGE, South Korea

I. INTRODUCTION

SBO means the complete loss of alternating current (AC) electric power to class 1E and non-class 1E switchgear buses [1]. The SBO scenario involves the loss of offsite power (LOOP) concurrent with a turbine trip and failure of the onsite emergency diesel generators (EDGs) [2]. During an SBO, non-class 1E alternate AC diesel generator (AAC DG) and batteries will provide power for the set of required shutdown loads to bring the plant to safe shutdown. An AAC DG power is provided for the operation of the motor-driven auxiliary feed water pump (MDAFP) lines during an SBO. If AAC DG is not available, the turbine driven auxiliary feed water pump (TDAFP) will be provided with battery backed power which are capable of providing auxiliary feedwater to the steam generators (SGs) coincident with a single failure for 8 hours. Battery-backed power is also available to the turbine governor speed control [3]. Electrical systems that are necessary to support systems in an SBO have sufficient capability and capacity to provide that core cooling and containment integrity are maintained.

However over the 8hours, the loss of the TDAFP may occur due to the battery depletion or deletion of the water source. If TDAFW pumps fail to start and deliver feedwater to the steam generators, secondary steam removal through the secondary safety valves or atmospheric dump valves will continue until the steam generator boils dry. Primary pressure will rapidly rise and the pilot operated safety relief valves (POSRVs) will open. Core uncover and, thus, core damage will occur rapidly unless power is restored and auxiliary feed water flow is established. This situation is called long-term SBO that can occur if BDBEE exceeds the assumptions used in the design and licensing of a plant.

In order to prevent or mitigate this situation, NEI has established a FLEX implementation guide [4]. According to FLEX implementation guide, FLEX could be used to enhance the ability to cope with conditions. In addition FLEX would enhance safety at each site that will increase defense-in-depth for beyond-design-basis scenarios [4].

Although this guidance addresses events caused by a BDBEE, the strategies may be applied for the identified set of plant conditions regardless of whether they resulted from a BDBEE or other causes [4]. Under the long-term SBO, FLEX is an efficient method to protect or mitigate accident that the effectiveness of the proposed FLEX in reducing the plant vulnerabilities can be quantified by CDF using PRA. In developing the current PRA model, the reference plant is APR1400 and the scope of analysis is limited to level 1 PRA. The result of PRA will be utilized for long-term SBO and can find vulnerability of plant.

II. METHODOLOGY

The design and operation of the plant are analyzed in order to identify the sequences of events that can lead to core damage and the CDF is estimated through PRA. In order to verify the efficiency of FLEX, a long-term SBO scenario and the plant's response with the proposed FLEX needs to be modeled using PRA.

To develop the PRA model, the accident scenario is identified and accordingly, an event tree with success criteria is developed. The information needed to model the accident scenario can be collected through the APR1400 safety analysis report (SAR) and system description. Based on this

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information, the accident scenario is developed using SAREX software. SAREX is a computer program for performing reliability analysis or PRA analysis in areas such as nuclear power plants and aviation industry. The success criteria is determined by thermal hydraulic analysis or related studies. Next, a fault tree is developed by identifying key systems and combination of equipment failure that affect core damage. When developing a fault tree, equipment failure probability, and human reliability analysis (HRA) have to be included in the system model. The failure probability of each component is estimated based on engineering experience data or data analysis. If an operator action is required, the HRA should also be analyzed. After developing the event tree and fault tree for the chosen accident scenario, it can be quantified and the result will be used to assess the plant vulnerability to extreme conditions and the effect of each equipment on CDF.

Ⅲ. DEVELOPMENT OF PRA MODEL

A. ACCIDENT SCENARIO FOR SBO

As previously indicated, SBO is the complete loss of alternating current (ac) electric power to the Class 1E and non-Class 1E switchgear buses [2]. During an SBO, a non-Class 1E AAC diesel generator (DG) provides power for the set of required shutdown loads to bring the plant to safe shutdown. The AAC DG is started and manually connected to the set of required shutdown equipment within 10 minutes [2]. However, under the long term SBO, it is assumed that AAC DG is not available and that only direct currency (DC) battery is available via batteries. DC battery provides power for secondary heat removal system (SHR) and vital equipment that is composed of TDAFP, main steam safety valve (MSSV) and atmospheric dump valve (ADV). If secondary heat removal (SHR) is not available, it is assumed that core damage will occur within 1 hour. However battery capacity is 8 hours, therefore, SHR can be operated for 8 hours. During SBO, reactor coolant pump (RCP) seal also can occur. When reactor coolant system (RCS) pressure is decreased, then SIT or SIP are operated to makeup RCS. In addition, if offsite power is recovered within 8 hours, it can provide power for MDAFP, feed & bleed operation and containment heat removal. Based on these scenarios, event tree is made as shown in Fig. 1.

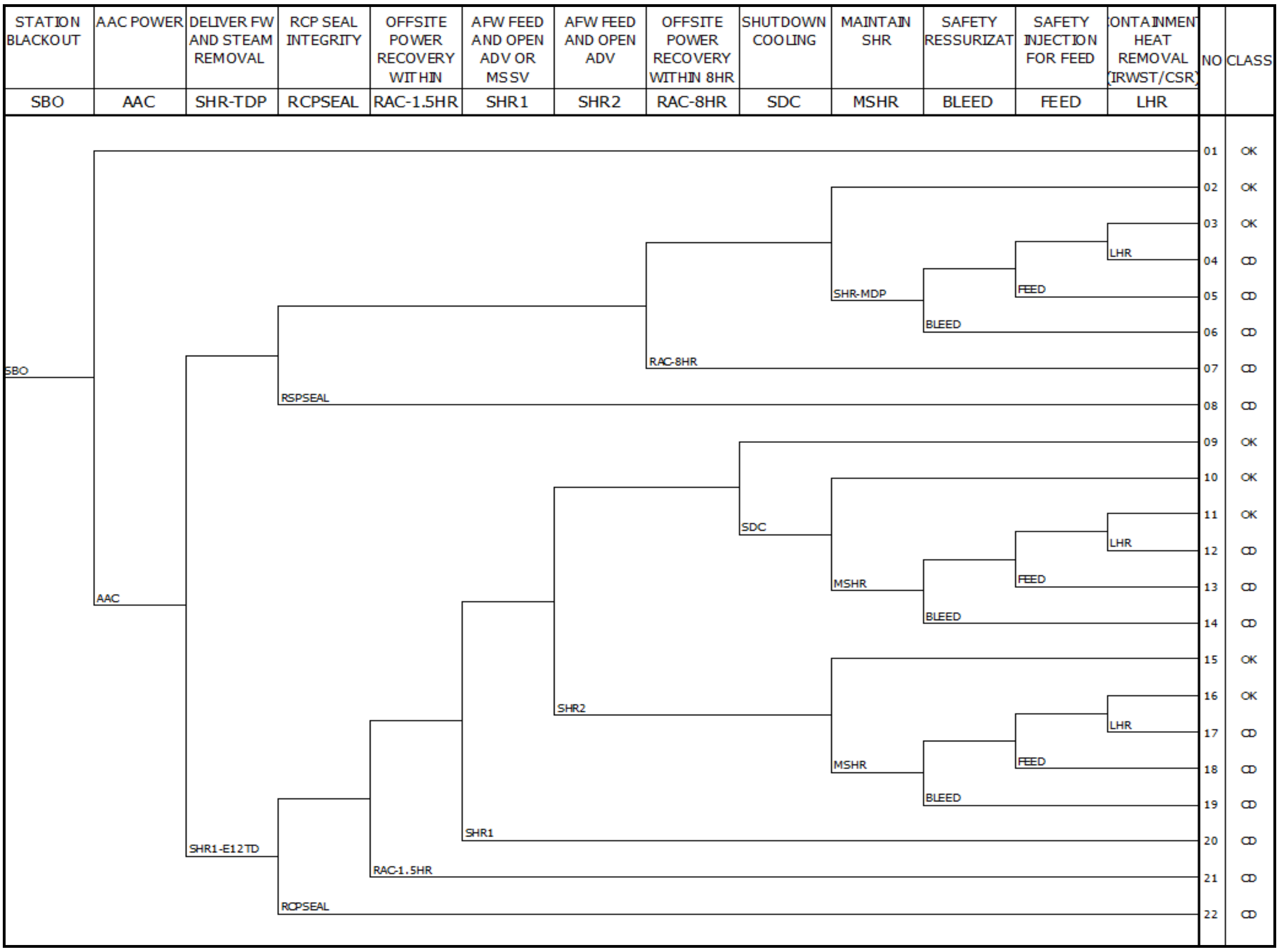

Fig. 1, Event tree for SBO

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B. SUCCESS CRITERIA

Success criteria based on the Shin-Kori Unit 3 & 4 FSAR and APR1400 DCD was considered for main system safety functions and corresponding components set to mitigate the accident. The success criteria were determined in terms of initiating event for APR1400 under SBO scenario as shown in Table 1.

TABLE 1. SUCCESS CRITERIA FOR SBO

No	Event Name	Description
1	AAC	AAC DG power source aligned to one Class 1E 4.16 kV ac bus
2	SHR-TDP	1 of TDAFPs supply feedwater to SG
3	RCPSEAL	RCP seal remains intact given RCP seal injection
4	RAC-1.5HR	Offsite power restored within 1.5 hour following a LOOP event
5	SHR1	1 of TDAFPs to associated SG and 1 MSADV or 1 MSSV on associated SG
6	SHR2	1 of TDAFPs to associated SG and 1 MSADV on associated SG
7	RAC-8HR	Offsite power restored within 8 hours following a LOOP event
8	SDC	1 of SC pump provides cooling water to RCS
9	MSHR	1 of MDAFPs to associated SG and 1 MSADV or 1 MSSV on associated SG
10	BLEED	2 of 4 POSRVs need to open
11	FEED	1 of 4 SI pumps provides DVI injection.
12	LHR	1 of CS (containment spray) pumps to associated CS nozzle and 1 of SC (shutdown cooling) pumps to associated IRWST cooling

C. FAULT TREE FOR SBO

The Level 1 PRA uses a small event tree and large fault tree method that are linked to each other. A fault tree is used to calculate component failure probability and can easily be used to identify scenarios that affect other systems if the required mitigation function is not available. Thus, fault tree can identify combinations of equipment failures that may result to failure of system function. The process of constructing a fault tree consist of accident sequence analysis, system model, data analysis, HRA, and quantification.

Fault tree was analyzed according to NUREG-0492 [5], and all of the failure data, unavailability data and frequency of initiating event is taken from NUREG/CR-6928[6]. In NUREG/CR-6928, parameter estimations, component reliability, and component/train unavailability are used in the data analysis. Available generic data sources are compiled and reviewed to guide the selection of the failure parameters associated with components modeled in the system fault trees. NUREG/CR-6928 data was collected for 103 power plant in United States of America and that have a component unreliability, component/train unavailability, system special event and initiating event. It also represents current industry performance.

In the fault tree development, HRA analysis has to be performed in fault tree development before quantifying fault tree model. If operator behavior related to basic event is not important, it can be screened out qualitatively. Quantification should be performed operator action that are not screened out. All of the human operator actions in fault tree model are post-initiators and technique for human error rate prediction (THERP) is used to analyze post-initiators [7]. THERP is a widely technique for HRA. THERP can also consider errors of omission and errors of commission with performance shaping factors (PSF). PSF involves timing, cues, procedure, training and environment that should be considered for operator action. Estimates of failure probabilities consider dependency on prior human failures in the scenario. The human failure event (HFE) related to SBO are shown in Table 2.

TABLE 2. OPERATOR ACTION IN SBO

Event Name	Description
DAOPH-S-AACDG	Operator fail to start AAC DG
MSOPH-S-SGADV-HW	Operator fail to open ADV by handheel
SIOPH-S-SPRAYBACK	Operator fail to start SC pump for containment spray
SIOPH-S-IRWSTCOOL	Operator fail to IRWST cooling
AFOPH-S-ALT-LT	Operator fail to change water source

After developing event tree and fault tree, quantification is performed by the SAREX software with FORTE engine. SAREX deal with event tree, fault tree, database analysis, cutset, Recovery and etc. The results are reviewed and significant cutsets and basic events are identified. The result of SBO quantification are provided in section III-D.

D. RESULT OF SBO

The developed model estimates the total CDF resulting from an SBO scenario to be 3.13×10^{-7}/year. The main sequence is occurrence of SBO, loss of AAC DG, and failure to recover offsite power within 8 hours. The most important pieces of equipment are AAC DG and TDAFP. Their high probability can be explained by their high reliability and by a high consequence of their failures. If power source and water source are not available, then core damage will occur rapidly. However, proposed strategies by NEI can provide power source and water source that will be utilized for long term SBO. The significant accident sequences are shown in table 3.

TABLE 3. TOP ACCIDENT SEQUENCE IN SBO

No	Sequence No.	Freq.	Cum.	Sequence Description
1	SBO_007	2.66e-07	85%	SBO*Fail of AAC DG* Fail of offsite power recovery within 8hours
2	SBO_021	2.77e-08	8.9%	SBO*Fail of AAC DG* Fail of TDAFP*Fail of Offsite power recovery with 1.5 hours
3	SBO_008	1.93e-08	6.2%	SBO*Fail of AAC DG* Fail of RCP seal
4	SBO_022	6.34e-10	0.2%	SBO*Fail of AAC DG* Fail of TDAFP*RCP seal
5	SBO_006	1.18e-10	0.04%	SBO*Fail of AAC DG* Fail of maintain SHR* Fail of safety depressurization

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Ⅳ. FLEX SYSTEM

A. Strategies of FLEX

The objective of FLEX is to prevent damage to the fuel in the reactor and to maintain the containment function by using FLEX. Therefore, equipment of FLEX are focused on maintaining or restoring key plant safety functions. FLEX equipment will be used until power, water, and coolant injection systems are restored or commissioned [4].

B. Portable Equipment in FLEX

In the FLEX, there are some structure and equipment examples: waterproof door, sea wall, and portable equipment. Among them, portable equipment is a last resort that provides power and water to maintain or restore safety functions for a nuclear power plant. In addition, portable equipment is a vehicle so it can be moved from one place to another to supply power or water. Mobility of portable equipment is important that can flexibly cope with accident mitigation and reduce frequency of core damage. These portable equipment are included in third phase of FLEX strategies. Thus, portable equipment are selected to apply in PRA model. Representative portable equipment are mobile gas turbine generator and portable pump for external injection. Detailed description for mobile gas turbine generator and portable pump are given in section Ⅳ-C and Ⅳ-D.

C. Mobile Gas Turbine Generator

There are two type of mobile generators that is gas turbine and diesel generators. Compared with diesel generator, mobile gas turbine generator (GTG) can supply high quality power and correspond to overload. In addition, it will reach to rated load rapidly and very safely to earthquake because it has less piping line than diesel generator [8]. Therefore, this machine is suitable to FLEX and it is already prepared in APR1400. Most of mobile gas turbine generator consists of turbine, generator, electrical panel and fuel tank. A gas turbine is a type of internal combustion engine. It has an upstream rotating compressor coupled to a downstream turbine. The basic operation of the gas turbine is similar to that of the steam power plant except that the working fluid is air instead of water. Fresh atmospheric air flows through a compressor that brings it to higher pressure. Energy is then added by spraying fuel into the air and igniting it so the combustion generates a high-temperature flow. This high-temperature high-pressure gas enters a turbine, where it expands down to the exhaust pressure, producing a shaft work output in the process. The turbine shaft work is used to drive the compressor and other devices such as an electric generator that may be coupled to the shaft. The energy that is not used for shaft work comes out in the exhaust gases, so these have either a high temperature or a high velocity [9].

The turbine generator will make electricity which is supplied to safety load. Voltage is 4.16kV and capacity is 3,520 kW. It will supply power to one of safety 4.16kV switchgear and power will be used for feed and bleed operation or secondary heat removal. Operation time of 3,520kW mobile GTG is 200 hours [10].

An electrical panel (also known as panelboard, breaker panel, or electric panel) is a component of an electricity supply system that divides an electrical power feed into subsidiary circuits, while providing a protective fuse or circuit breaker for each circuit in a common enclosure. Also control overall system of mobile turbine generator included battery and charger for starting power.

Gas turbine generator`s main fuel is diesel. During long term SBO, the fuel will be supplied from EDG diesel fuel oil tank. Capacity of diesel fuel oil tank is approximately 7days [11] that it is sufficient to operate for long term SBO.

There are two types of cooler, air and water. In mobile gas turbine generator, air cooler will be used for heat removal in equipment. Air cooling is a method of dissipating heat. It works by expanding the surface area of or increasing the flow of air over the object to be cooled, or both. Air is mainly used for air-cooled internal combustion engines (ICE), because it is a readily available fluid and is often at a suitable temperature to be used efficiently. In addition, there is no piping to cool which is seismic strength. The configuration of the mobile GTG is shown in Fig. 2.

In normal operation mode, mobile gas turbine generator is not operated that will only be used for accident. Under the long term SBO, if AAC DG and battery will not be operated, then operators prepare mobile gas turbine generator. However, this system was prepared recently and detailed information is not available. Therefore, operation procedure is assumed as follows. 1) Operators of main control room (MCR) direct to prepare to two standby operators for mobile gas turbine generator, 2) The mobile gas turbine generator will be moved in front of EDG room, 3) Operator will connect cable reel from mobile GTG to connection line of emergency power in EDG room, 4) Operator will connect portable fuel transfer pump from mobile GTG to fuel oil tank, 5) To operate small pump, cable reel for power will be connected from vehicle to small pump, and 6) Mobile GTG will be operated.

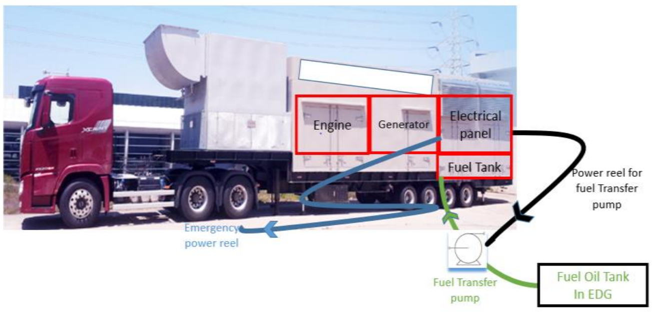

Fig. 2. Mobile GTG

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D. Portable Pump

When the TDAFWPs are unavailable after depletion of battery and fail of mobile GTG, an external portable pump of secondary side can provide feedwater to SG. A portable pump is connected to the SG auxiliary feedwater (AFW) supply line and it can remove heat from SG. However, using portable pump for external injection to SG is not set up to in a nuclear power plant. Therefore, according to NEI 12-06 [4], using portable equipment and detailed information was assumed as follows. To inject external injection, the capacity of portable pump is the same as TDAFWP. According to APR 1400 DCD [12], each AFW pump is capable of providing the required minimum flow of 2,461 L/min (650 gpm) with 1,240 psia and 176.67 °C which accounts for the SG design pressure, safety valve uncertainty, and feed nozzle losses from the downcomer nozzle to the SG steam space. The portable pump is equipped in vehicle and it will inject feedwater from AFWST to SG that are shown in Fig. 3.

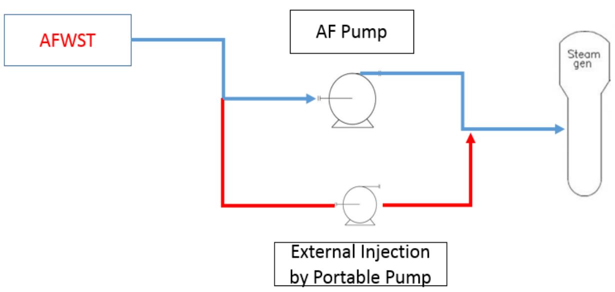

Fig. 3. Portable Pump Flow Path

The fuel for pump operation is supplied from the EDG fuel oil tank, and the place for external injection should be close to the EDG room. Fuel oil tanks can supply fuel for 7 days, so it is sufficient for external injection during long-term SBO. A small pump is needed for fuel supply and power can be supplied from the vehicle. The panel consists of a battery, a charger for starting the vehicle, and control devices for pump operation. The pump hose must be able to withstand heat and pressure, and more than 50 meters for external injection. The pump water source is an AFWST, and a non-safety-related backup water source by gravity feed to AFW pump suction is also available from the condensate storage tank and raw water storage tank [12].

The operating procedure is assumed as follows: 1) Operators of MCR direct to prepare portable pump, 2) The portable pump will be moved in front of EDG room, 3) Operator will connect small pump from vehicle to fuel oil tank in EDG room to supply fuel, 4) to operate small pump, cable reel for power will be connected from vehicle to small pump, 5) Operator will connect pump hose from portable pump to water source and AF line, 6) Operator will connect power reel from portable pump to SG instrument, and 7) Portable pump will be operated. The configuration of portable pump for external injection that are shown in Fig.4.

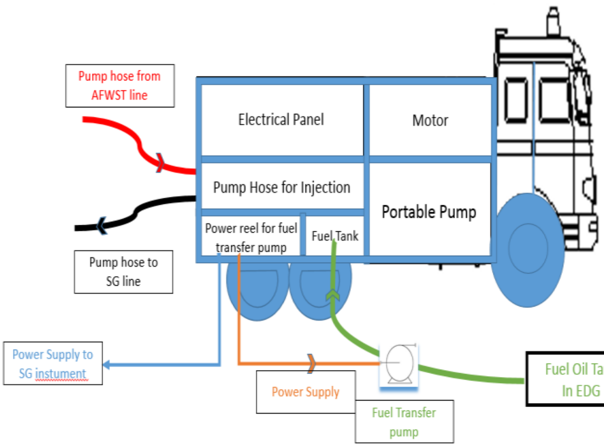

Fig. 4. Vehicle with Portable Pump

Ⅴ. INCLUSION OF FLEX EQUIPMENT IN PRA MODEL

Modeling of portable equipment in FLEX can be used to estimate the magnitude of the expected benefit from including the equipment in the PRA. The portable equipment is used for long-term SBO, would decrease CDF significantly. The modeling of portable equipment in a PRA model is very similar to modeling of installed equipment.

A. Accident Scenario of portable equipment in PRA model

Portable equipment are mobile GTG and portable pump for external injection. Under the long-term SBO, after depletion of battery with failure of AAC DG and offsite power recovery, mobile GTG will supply power for MDAFP of SHR, safety injection pump of feed & bleed operation and CS or SC pump of containment heat removal system. Mobile GTG can provide power to reach safe shutdown. If one of these systems are not available, portable pump can maintain SHR. Developed event tree is shown in Fig. 5.

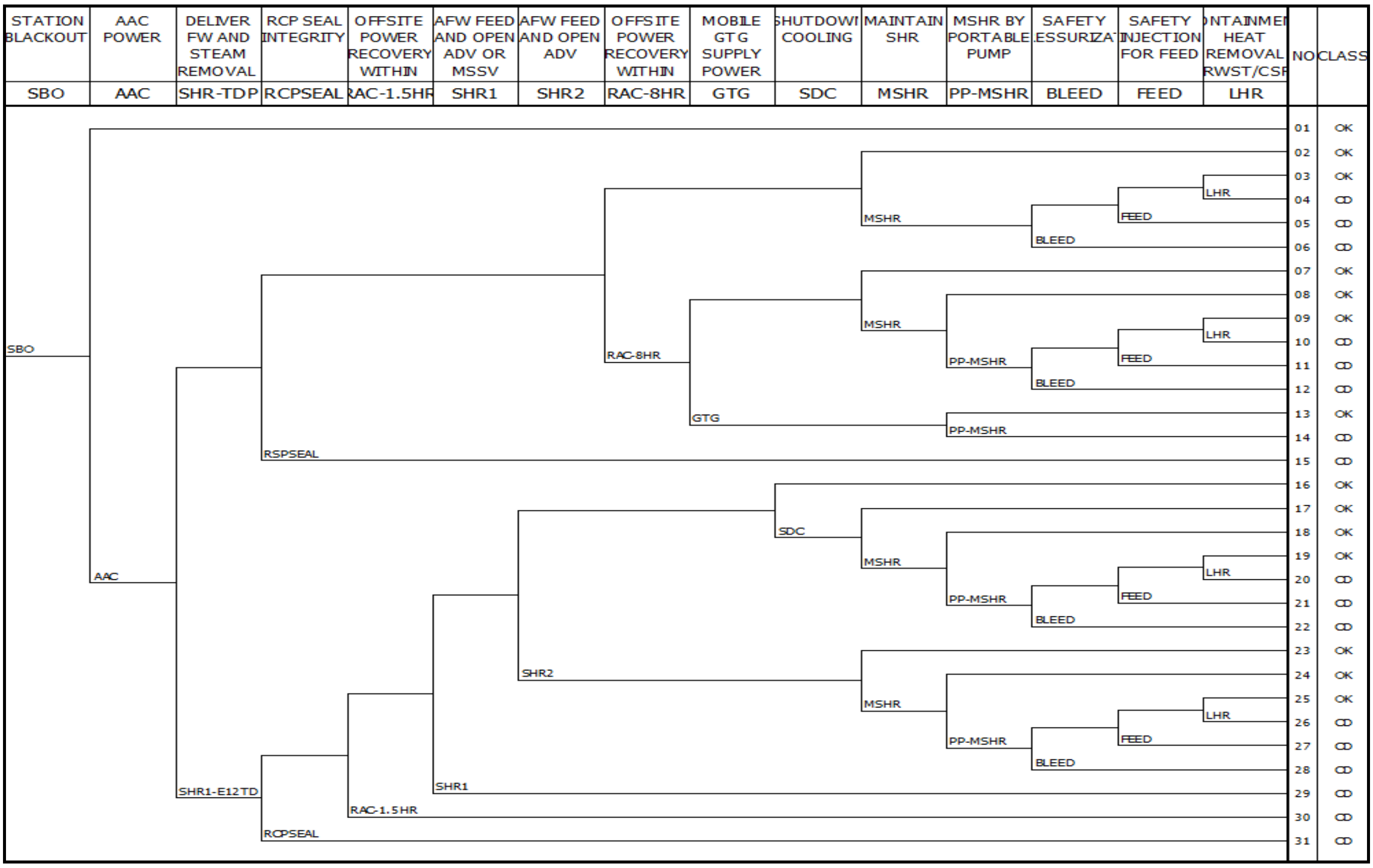

Fig. 5. Event Tree of FLEX

B. SUCCESS CRITERIA

The success criteria for the portable pump should be to prevent core damage and mitigate accidents. The success criteria were determined for each sequence of initiating event modeled for the APR1400 [13]. Success criteria for portable pumps is confirmed by thermal hydraulic analysis. Compare with section III-B, the success criteria is the same and added success criteria for the portable equipment are: 1) GTG – mobile GTG provide power for one of safety switchgears, and 2) PP-MSHR – Portable pump supply feedwater to SG and 1 MSADV or 1 MSSV on associated SG.

C. FAULT TREE OF PORTABLE EQUIPMENT

The system model of portable pump was developed in the same way with section III-C. Fault tree of portable equipment include random failure of equipment, fail of maintenance and HRA. In the case of portable pump, the following items are modeled: Failure of pump, power connection reel, water tank, fuel transfer pump, and electrical supporting system. Portable pump is not set up to nuclear power plant and there is no experience data. But there is data on the same type equipment in NUREG/CR-6928. For example, the frequency of pump is applied to the frequency of engine driven pump. The frequency of the power connection reel is applied to the NUREG / CR-3263[14]. This document describe for the degradation of cable. Related to vehicle, the vehicle can be faulty due to mechanical faults during the move and about this data was referred from SAND2006-7723[15]. The used data related to portable equipment are shown in Table 4.

TABLE 4. COMPONENT FAILURE DATA

Basie Event	Description	Prob.	Data Source
GTTGL-S-GTG	GTG fail to run for less 1hour	5.79E-03	NUREG/CR-6928
GTTGM-S-GTG	GTG unavailable due to maintenance	5.00e-02	NUREG/CR-6928
GTTGR-S-GTG	GTG fail to run for more 1hour	1.78e-01	NUREG/CR-6928
GTTGS-S-GTG	GTG fail to start	5.12e-02	NUREG/CR-6928
GT-GTG-REEL	Fail of GTG reel	1.12e-06	NUREG/CR-3263
GT-GTG-MOVING	Fail of GTG during move	2.97e-02	SAND2006-7723
GT-GTG-REEL	Fail of GTG reel	1.2e-06	NUREG/CR-3263
EIEPL-S-PP01	PP fail to run for less 1hour	9.8e-04	NUREG/CR-6928
EIEPM-S-PP01	PP unavailable due to maintenance	3.34e-03	NUREG/CR-6928
EIEPR-S-PP01	PP fail to run	4.45e-02	NUREG/CR-6928
EIEPS-S-PP01	PP fail to start	2.17e-03	NUREG/CR-6928
EIMP-PP01-HOSE	Fail of PP hose	5.89e-06	EPRI 3002000079
EI-PP01-MOVING	Fail of GTG during move	2.97e-02	SAND2006-7723

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Operator action is essential and important that are post-initiators for long-term SBO. These actions are modeled in fault tree and analyzed by cause-based decision tree methodology (CBDTM) and THERP [16]. These method are suggested by NEI. The advantage of using these methods is that evaluate fundamental aspects and factors affecting human performance and are capable of addressing the detailed analyses needed for the scenarios considered. In case of CBDTM, decision tree is very simple to use and provides an initial set of failure mechanism and influencing factors to be considered. Also, THERP has a detailed task analysis with five level dependency model that can help develop valuable insight operator action. Hence, CBDTM is applied for cognitive error of operator action, and THERP is applied for execution error. These method could contribute to better assessment of human error probability. The items used in the analysis are as shown in Table 5 follows.

TABLE 5, OPERATOR ACTION OF PORTABLE EQUIPMENT IN SBO

Event Name	Description	Prob.
EIOPH-S-PP	Operators fails to provide external injection by portable pump	6.16e-02
GTOPH-S-GTG	Operators fails to provide 1E 4.16KV switchgear 01A, B, C, D	1.73e-02

D. Result of Portable Equipment in PRA

The total CDF from the investigated long-term SBO with applied FLEX is 7.12×10-8/year. The highest sequence frequency (See Table 6) is 2.77×10-8/year that is not applied FLEX strategies. When compare with SBO model, the frequency of sequence with applied FLEX are decreased very low. For example, the highest sequence frequency (SBO_007) in SBO model (See Table 3) is 2.66×10-7/year. This sequence is related to SBO_014 of applied FLEX equipment that values is 2.33×10-8/year. Therefore, FLEX equipment contributes greatly to reducing frequency. The significant accident sequences are shown in Table 6.

TABLE 6. TOP ACCIDENT SEQUENCE WITH APPLIED FLEX EQUIPMENT

No	Sequence No.	Freq.	Cum.	Sequence Description
1	SBO_030	2.77e-08	38.9%	SBO*Fail of AAC DG* Fail of TDAFP*Fail of Offsite power recovery within 1.5 hours
2	SBO_014	2.33e-08	32.7%	SBO*Fail of AAC DG* Fail of TDAFP*Fail of GTG*Fail of Secondaryside injection
3	SBO_015	1.91e-08	26.8%	SBO*Fail of AAC DG* RCP seal
4	SBO_031	6.34e-10	0.9%	SBO*Fail of AAC DG* Fail of TDAFP*RCP seal
5	SBO_006	1.18e-10	0.2%	SBO*Fail of AAC DG* Fail of maintain SHR* Fail of safety depressurization

VI. SENSITIVITY ANALYSIS

Mobile GTG was recently installed and external injection is not yet running. So, there is no experience data for flex and that means to need of sensitivity analysis. In this sensitivity analysis for flex, other type of data were applied. For Mobile GTG, failure data of diesel generator was applied instead of gas turbine generator. Also, for external injection, failure data of motor driven pump was applied instead of engine driven pump. For the case of mobile GTG with applied diesel generator data, the CDF was changed from 7.12×10^{-8}/year to 5.72×10^{-8}/year and for the case of external injection, the CDF was changed 7.12×10^{-8}/year to 6.04×10^{-8}/year. These results show that gas turbine generator and engine driven pump have a high failure probability. When both failure data of diesel generator and motor driven pump are applied to mobile GTG and external injection, the CDF was changed 7.12×10^{-8}/year to 5.22×10^{-8}/year. Also considering long-term SBO, when the mission time is 72 hours, the CDF is estimated as 1.46×10^{-7}/year. According to the above results, range of CDF for FLEX is 1.46×10^{-7}/year to 5.22×10^{-8}/year.

VII. CONCLUSION

As a result of comparing SBO model and applied portable equipment in PRA, portable equipment was effective. The CDF is decreased from 3.13E-10^{-7}/year to 7.12×10^{-8}/year. According to the analysis, even if an accident exceeding the DBA occurs, core damage can be prevented by the mobile GTG and secondary side injection. The cause of the decrease in CDF is the improvement of coping ability. In the long-term SBO, mobile GTG is a power source that replaces AC and DC power. In addition, secondary side injection through portable pump can provide heat removal for SG. In addition, this coping can be effective means of defense in depth and multi defense. However, frequency of sequence for SBO_030 and SBO_015 are more than 1.0×10^{-8}/year (See Table 6). These are not applied for FLEX strategies. If there are mitigation system for RCP seal and offsite power recovery within 1.5hours, safety for plant will be increased more. Additional mitigation systems decrease core damage frequency and improve safety for the nuclear power plant. Therefore, strategies of FLEX is essential in case of a nuclear power plant accident. Also, FLEX strategies for RCP seal and offsite power recovery within 1.5 hours will have to be discussed in depth in the future.

VIII. ACKNOWLEDGEMENT

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REFERENCES

[1] NUREG-0800, Section 8.4, "Station Blackout", Rev. 1
[2] APR1400 DCD, Section 8, "Electric Power", Rev. 0 (2014)
[3] Shin Kori Unit 3&4, Final Safety Assessment Report", Section 8, "Electric Power",
[4] NEI 12-06, "Diverse and Flexible Coping Strategies (FLEX) Implementation Guide", Rev.1 (2015)

International Journal of Engineering Research & Technology (IJERT)
ISSN: 2278-0181
Vol. 6 Issue 10, October - 2017

[5] NUREG-0492, “Fault Tree Handbook”, (1981)
[6] NUREG/CR-6928, “Industry-Average Performance for Components and Initiating Events at U.S. Commercial Nuclear Power Plants”, (2007)
[7] NUREG/CR-1278, “Handbook of Human Reliability Analysis with Emphasis on Nuclear Power Plant Applications”,
[8] https://www.wartsila.com/energy/learning-center/technical-comparisons/gas-turbine-for-power-generation-introduction
[9] https://en.wikipedia.org/wiki/Gas_turbine
[10] http://www.ecomedia.co.kr/news/newsview.php?ncode=1065544970692303
[11] APR1400 DCD, Section 9, "Auxiliary Systems", Rev. 0 (2014)
[12] APR 1400 DCD, Section 10, “Steam and Power Conversion System”, Rev. 0 (2014)
[13] APR 1400 DCD chapter 19, “Probabilistic Risk Assessment and Severe Accident Evaluation”, Rev 0 (2014)
[14] NUREG / CR-3263, “Correlation of Electrical Cable Failure with Mechanical Degradation”, (1984)
[15] SAND 2006-7723 “Tractor/Trailer Accident Statistics”, SNL, (2006)
[16] Evaluation of Human Reliability Analysis Methods Against Good Practices (NUREG-1842), (2006)