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HEPs Calculation for MACST Equipment

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1. Introduction

1.1. Background

The primary lessons learned from the accident at Fukushima Daiichi was the significance of the challenge posed by a loss of safety-related systems following the occurrence of a beyond design-basis external event (BDBEE). Accordingly, the global nuclear industry has begun to discuss ways to respond to these extreme disasters, and also developed mitigating strategies for extreme damage to nuclear power plants. These strategies provide an additional layer of defense-in-depth, called diverse and flexible coping strategy (FLEX). FLEX introduced by the Nuclear Energy Institute (NEI) is a strategy to mitigate core damage by using permanently installed and portable equipment to restore or maintain various safety functions during beyond design basis conditions [2].

Korea nuclear power plants introduced various equipment such as potable pumps, mobile generators as part of the Post-Fukushima Countermeasures, which were established against extreme disasters after the Fukushima Nuclear Power Plant accident in 2011. These equipment are used to implement the basic concepts of FLEX. In addition, as the importance of severe accident management was raised in Korea after the Fukushima nuclear accident, the National Nuclear Safety Commission (NSSC) revised the Nuclear Safety Act in 2015, and required the utility to submit an accident management plan (AMP), including severe accident management. As a result, the Korea utility has begun developing a multi-barrier accident coping strategy (MACST) as part of AMP. MACST is based on the general understanding of FLEX as a strategy of coping with the multiple defense concept, which is a mixture of the European stress test and the US FLEX strategy.

The Nuclear Safety Act revised in 2015 introduced new deterministic and probabilistic safety performance goals, which can be confirmed by performing PRA on a variety of internal and external hazard sources [6].

Currently, PRA considers installed equipment mainly, but MCAST, which is mainly composed of potable equipment, has limitations to evaluating human error probability by existing HRA methodology. In particular, HRA is more important than MR because operator action greatly contributes to the core damage frequency (CDF) in the safety of NPP, and MACST equipment mainly considers operation characteristics outside the main control room (MCR). The Korea utilities are accumulating operating experiences through various training and tests in preparation for extreme conditions by utilizing the equipment used in MACST and the development Procedure.

1.2. Objective and Scope

The below table I shows the differences between the typical HRA and the MACST HRA.

Table I: Comparison between typical and MACST HRA

Type	Typical HRA	MACST HRA
Equipment	Installed	installed + portable
Task system	Series	parallel
Location	on-plant (MCR, Local)	on-site (MCR, Local, Site), off-site
Task Scope	Limited	Extensive
Task Complexity	Simple manipulation	Complex operation

Accordingly, this study would like to calculate and evaluate Human Error Probability (HEP) for MACST by using existing HRA methodology based on MACST training and operating experience. This study aims to suggest MACST HRA performance guidelines deviating from typical HRA through pilot HRA. In addition, in case of external events, there was no unique HRA methodology, so we simply applied 5 times or 10 times to internal event HEP. We intend to present seismic HRA methodology that can be used for MACST by reflecting the unique characteristics of earthquake.

The nuclear power plant to be used in this study is a pressurized water reactor, APR-1400, and the procedure is based on the actual test procedure according to the case scenario. Since the MACST procedure is currently in development, it will utilize existing available procedures such as abnormal operating procedure (AOP), emergency operating procedure (EOP), system operating procedure [1]. Since this study assumes the extended loss of ac power1 (ELAP) of beyond design basis accident (BDBA) situation, we will analyze the 3.2MW mobile generator corresponding to the various equipment of MACST.

2. MACST Statue

In Korea, before the accident at Fukushima Daiichi, the regulation on severe accident safety management was not clearly defined in the existing nuclear safety law, so the legal basis was poor. As a result, NSSC has clearly defined its accident management responsibilities and regulatory requirements, including severe accident management, in the Nuclear Safety Act. These regulations aim to promote public safety by minimizing the release of radioactive materials into or out of the nuclear power plant through accident management programs even in the event of severe accidents, and by restoring the plant to a safe state. Therefore, the utility satisfies the safety performance goal by implementing the accident management program, MACST.

2.1. MACST Equipment

Since 2011, Korea nuclear utility has introduced watertight doors, sea walls, potable pumps, PARs, and mobile generators as part of the Post-Fukushima Countermeasures. The equipment used in MACST is based on these equipment and aim to prevent the development of extreme disasters into severe accidents.

MACST also classifies equipment used in three phases like the FLEX of NEI 12-06.

- o Phase 1: Be dependent on installed plant equipment.
- o Phase 2: Shift from installed equipment to on-site FLEX equipment.
- o Phase 3: Involves using off-site equipment until power, water, and coolant injection systems are restored or commissioned.

2.2. MACST Procedure

Procedures used in the event of an accident at APR-1400 include AOP, EOP and SAMG (Severe Accident Management Guideline). In future procedural framework, new MACST Operating Guidelines (MOG) and Extensive Damage Management Guidelines (EDMG) are added. MOG aims to prevent severe accidents in extreme natural hazard such as earthquakes and fires, and EDMG aims to prevent core damage from artificial disasters such as aircraft impacts. Each procedure system would be closely linked to each other. In this study, we used preliminary MOG used in actual test and training in APR-1400 because the MACST procedural frame is still in development.

3. FLEX/MACST's HRA Method

The FLEX / MACST strategy, based on NEI 12-06, focuses on maintaining and restoring the plant's key safety functions in BDBA. It is expected that mobile equipment will be used more than fixed one in BDBA. To date, no systematic process and method exist to carry out detailed HRA for the operation of portable (or mobile) equipment. However, some research institutes have carried out HRA for the operation of mobile equipment.

Table II: FLEX/MACST's HRA

Study		Methodologies of cognition//execution	HFE analysis
NEI 16-06 [3]		CBDT // THERP	Load shed dc buses Deploy & install generator
EPRI 3002013018 [5]		CBDT, IDHEAS // THERP	Declare ELAP Perform deep dc load shed Deploy portable pump Implement portable pump Refuel portable generator
KAERI 2018	TR-7220 [6]	CBDT // THERP	Deploy & install generator
	TR-7432 [7]	K-HRA/P	

According to table II above, the HRA of mobile equipment using the FLEX/MACST equipment studied so far includes the following improvements.

1) Insufficient time window configuration including cue setting time
2) Use of facilities different from this research scope
3) Not considering HEP value for main task when using mobile generator
4) Calculation of HEP value without considering external events

Therefore, this study attempts to calculate the HEP value by applying the improved HRA methodology to the MACST mobile generator tested according to the actual procedure. This study assumes the ELAP situation due to the earthquake event. First, we calculate the HEP value by considering the internal event and then expand the external event to calculate the HEP value.

4. Calculation Method of HEPs

4.1. Construction of Integrated HFE

In constructing HFE, when ELAP is declared under the ELAP situation, subsequent tasks such as DC load shed and deploy generator proceed simultaneously, so HFEs are integrated as shown below figure 1. without considering HFEs individually.

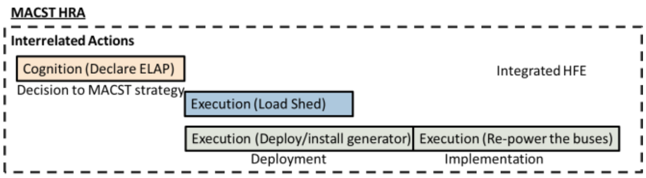

Fig. 1. MACST HRA

4.1.1. Suggestion about Calculating Method of Integrated HFE

As shown above, the operation of the equipment is not a HFE consisting of one cognition and one execution, but consists of several actions in one HFE. In addition, it is expected that the error probability values will be higher than those of the existing installed equipment as the mobile equipment which is not frequently operated is operated. Therefore, this study intends to apply integrated HEP calculation method as shown below figure 2., not simple addition method, referring to the issue of EPRI report [5] when considering the high error probability value of each individual action.

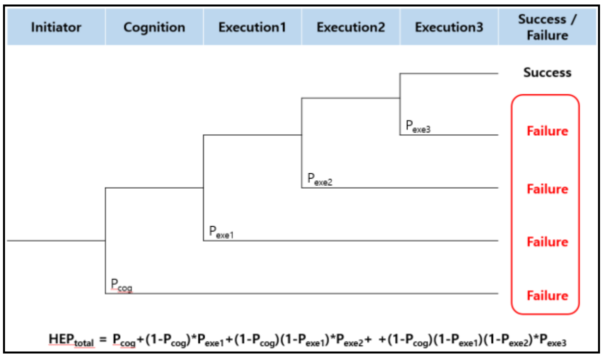

Fig. 2. Method for Determining the Final HEP

4.2. Operation of MACST Equipment

4.2.1. Staffing and Interrelated Action

The operation of the MACST facility is complex and extensively performed by numerous personnel in various locations. Thus, the interrelations between the actions that make up the integrated HFE should be considered and are different from the traditional dependency considered between each HFE.

4.2.2. Procedure

The below table III shows the procedure for using a mobile power plant and the test time for each step of the test performed accordingly. This was used to construct the time window and critical step.

Table III: Procedure of mobile generator operation; system-3593-01, rev. 4

Step	**Contents of Procedure**	**Time (Start/Finish)**	
6.1.1	Move mobile GTG to plant site	10:15	10:38
6.1.2 ~ 6.1.7	Disconnect unused cable and set up cable of mobile GTG to safety bus	10:38	10:51
6.1.8 ~ 6.1.14	Set fuel supply system of mobile GTG	10:51	11:02
6.1.15 ~ 6.1.22	Starts no-load operation of mobile GTG	11:02	11:28
6.2.1 ~ 6.2.7	Connect power to safety bus and	11:28	11:30
6.2.8 ~ 6.2.11	Restore power to individual load	11:30	11:48

4.2.3. Design Information

o Load shed must be completed within 2hours of the loss of all AC power (FSAR)

o 125V DC batteries can last their life by 8hours of the loss of all AC power after completing load shed

Thus, mobile generator must be deployed and supply the power within 8hours of the loss of all AC power (battery life)

4.2.4. Assumption

o Sufficient manpower outside the power plant arrives at the appointed location within the specified time

o Consider the PGA(g) up to 0.3g because of the seismic design of APR1400 NPP including the MACST storage facility

o The HEP value of cognition for DC load shed is calculated only by SPAR-H method, and the HEP value by THERP method is referred to the value of ERPI report. This is because the procedure for DC load shed is procedural as a single step in the EOP, so the procedure is not specific for obtaining the HEP value using the THERP methodology.

o In the near future, due to changes in the RCP seal design, the RCP seal integrity is to maintain in the event of any AC power loss.

o It should be successful for cleaning the debris such as slope collapse after large earthquake

4.3. HRA Method for Calculating the HEPs

The HEP calculation was divided into internal and external events. After time analysis, cognition was calculated using the HRA methodology of CBDTM and SPAR-H, and execution was calculated using THERP and SPAR-H. The criteria for judging all the HRA methodologies used in this paper are based on operator interviews and experience. In addition, the HRA methodology of external events, including earthquake events, has been applied to 10 times multiple HEP values calculated as internal events. Therefore, this study intends to apply the external HRA methodology considering the seismic natural characteristics to the operational tasks of mobile equipment.

4.4. External Event for MACST

In the EPRI report [4], the damage state is classified by considering the strength level in relation to the external event HRA methodology. After analyzing and evaluating factors that may affect human reliability according to the area, a qualitative methodology for calculating HEP values is presented. Therefore, in this study, we want to classify damage state area into two stages so that HEP value can be calculated.

- o Damage State 1; 0~0.14g
- o Damage State 2; 0.14g ~ 0.30g

First, the reason for considering only 0.30g is that the peak ground acceleration, which is the seismic design of the nuclear power plant targeted in this study, is 0.3g, and the seismic design of the storage facility that stores mobile generator also has a peak ground acceleration of 0.3g. In other words, the mobile generator cannot be used for more than 0.3g, so it is not possible to give credit to the mobile generator for an earthquake of more than 0.3g. Next, the reason for dividing the damage state based on 0.14g is that it is expected to affect the travel time of the mobile generator by falling down the roadside or slope collapse in the movement path of the mobile generator above 0.14g.

5. Result and Discussion

The following table IV, V summarizes the calculated HEPs and previous studies.

Table IV: Total HEPs comparison between previous and current study on internal event

Internal		
NEI 16-06	CBDTM+THERP	2.49E-02
EPRI 3002013018	CBDTM/IDHDAS+THERP	1.55E-01
current study	CBDTM+ THERP	1.59E-01
	SPAR-H	1.51E-01

Table V: Total HEPs of current study on external event

External		
DS 1; 0 ~ 0.14g	CBDTM+THERP	1.60E-01
	SPAR-H	1.78E-01
DS 2; 0.14 ~ 0.30g	CBDTM+ THERP	4.92E-01
	SPAR-H	8.15E-01

As shown in the table, the case of internal case shows that the results of this study and the results of ERPI are in good agreement. However, it is somewhat different from the result of NEI 16-06, which is due to the difference in HEP value according to the number of critical steps of the load shed. Therefore, considering these differences, the results of this study are in good agreement with the results of previous studies. In addition, the HEPs of the Damage State 2 external events were calculated 3-4 times larger than the internal events, which seem to overcome the limitations of the traditional external HRA methodology. This is because the traditional external event HEP value is multiplied by 10 times for the internal event. If the 10 times the internal event with a large HEP value such as the MACST facility, the HEP value is over 1 and it is meaningless.

6. Conclusion with Suggestion

This paper analyzes the human reliability of the tasks using the MACST equipment considering the large-scale earthquake. Unlike when considering only the internal event, when considering the earthquake event, which is an external event, very high HEPs were obtained. However, by changing some of the serial procedures in parallel, the priority of the procedures will be improved, and lower HEPs will be obtained by operating the MACST operating organization on-plant. In addition, HEPs calculated in this paper is obtained by using the currently available procedures and test results. If there is any improvement in future procedures or changes in contexts, the HEPs value should be recalculated.

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