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Current Status of Modeling Portable Equipment in PSA

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1. Introduction

After the accident at Fukushima Daiichi, domestic and foreign regulatory bodies have requested to enhance their capabilities of accident mitigation for beyond–design-basis external event (BDBEE).

As a response to this, licensees have prepared portable equipment other than installed equipment and established accident mitigation strategies using it.

Development of the Probabilistic Safety Assessment (PSA) model with portable equipment was required to evaluate its impact according to the newly established accident mitigation strategies. However, there are some issues related to Human Reliability Analysis (HRA) and reliability data that should be addressed.

This study collects and reviews the technical reports that are recently published to address those issues and investigate to modeling portable equipment in PSA.

2. Portable Equipment

The U.S Nuclear Regulatory Commission (NRC) established a senior-level task force referred to as the Near-Term Task Force (NTTF) after the accident at Fukushima Daiichi. The NTTF issued SECY-11-0093 [1], SECY-11-0124 [2], and SECY-11-0134 [3], which included safety improvement measures for nuclear power plants, and suggested recommendations.

As a follow-up to reviewing the NTTF's recommendations, the NRC issued EA-12-049 [4] and required nuclear power reactor licensees to establish a mitigation strategy to withstand BDBEE.

The licensees developed Diverse and Flexible coping strategies (FLEX) in reference to NEI 12-06 [5] and proposed it to the NRC. The key strategy to the FLEX is to maintain and restore core cooling and make-up, containment cooling, and spent fuel cooling when Extended Loss of AC Power (ELAP) or Loss of Ultimate Heat Sink (LUHS) occur due to BDBEE.

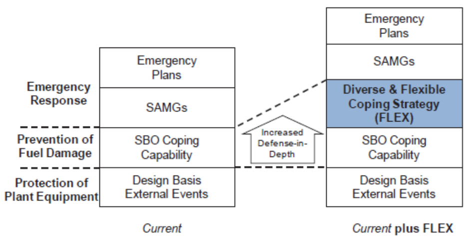

Fig. 1. Increase of Depend-in-Depth through FLEX

Portable equipment used in the FLEX is largely divided into three groups: a portable pump that replenishes cooling water or performs water supply directly for cooling, a portable generator to restore essential power, and auxiliary equipment to facilitate accident response.

Portable pump and portable generator have various features depending on the purpose and are shown in the table below.

Table I: Portable Equipment for Accident Mitigation

Group	Feature	Purpose
Portable Pump	Low Head, High Volume	SG Make-up
		Containment Spray
		Cooling water Make-up
	High Head, Low Volume	Reactor Make-up
Portable Generator	Low Capacity	120V AC, 125V DC Restore
	Medium Capacity	480V AC Restore
	High Capacity	4.16kV AC Restore

PSA is considering various strategies for mitigating accidents when they occur. Portable equipment included in FLEX can also be considered in PSA as a means of mitigation accidents. However, in order to incorporate portable equipment to PSA, it must not deviate from its own purpose and properly consider characteristics different from installed equipment.

3. Human Reliability Assessment

The existing HRA methods have limitations in quantifying Human Error Probability (HEP) for actions performed such as the transportation, placement, connection, or local control of portable pumps and generators. Therefore, HRA method and guideline are needed that can include feature of portable equipment to incorporate the mitigation strategies utilizing portable equipment.

The status of the recent HRA methods for portable equipment that was investigated and analyzed through a review of the technical reports are described the following.

NEI 16-06 [6] addresses an example of performing HRA for portable equipment using EPRI HRA Calculator [7, 8] to estimate or quantify human error probabilities that can be used in a PSA. The EPRI HRA

Calculator provides options to assess a potential failure probability or a specific action. But, there are no directly applicable options to cover actions like transportation of equipment or installation of portable hoses. Until new guidance on these issues is developed, engineering judgement is required to assess the probability of a human error for portable equipment. In these cases, a sensitivity study should be performed to evaluate the impact of these estimates on the PSA results.

EPRI-3002013018 [9] report provides example-based guidance for modeling deployment and use of portable equipment using EPRI HRA Calculator and identifies areas where EPRI HRA methods are inadequate and require additional research. It also addresses the comments on the HRA example of portable equipment presented in NEI 16-06. EPRI HRA methods are typically sufficient to model actions associated with portable equipment and flexible mitigation strategies. However, there are some areas where existing EPRI HRA methods continue to be insufficient and further research is required.

In the Applying HRA to FLEX - Expert Elicitation (RIL 2020-13 Vol.1) [10] report, the HRA expert elicitation project used an expert panel to estimate HEPs for portable equipment under given scenarios and identify the factors impacting the HEPs.

The expert elicitation process used the NRC's expert elicitation guidance documented in an NRC white paper [11].

The expert judgments of the HEPs for the portable equipment were derived through formal and structured processes. However, the expert elicitation was that the HEPs are very sensitive to changes in scenario context or action specifications. Therefore, the HEPs estimated in the expert elicitation is only applicable to the actions and scenarios defined in this project.

In the Applying HRA to FLEX - Using IDHEAS-ECA (RIL 2020-13 Vol. 2) [12] report, the HRA of scenarios involving FLEX and associated equipment are described. The HRA was performed using the NRC's new HRA method, the IDHEAS-ECA (Integrated Human Event Analysis System for Event and Condition Assessment) guidance [13], and its associated software tool [14].

Overall, the HEP results analyzed using IDHEAS-ECA guidelines and software is reliable and reasonable. However, for some HFE, there was a difference in the overall HEP value. Therefore, testing on IDHEAS-ECA should be continuously conducted to investigate why analyst-to-analyst variations in using IDHEAS-ECA occur.

4. Reliability Data

To incorporate FLEX equipment into PSA models, reliability data should be addressed. However, the operating experience to develop failure rates data, maintenance unavailability, and common cause failure (CCF) probability in use at PSA is not sufficient. Thus, in this section, some of the technical reports reviewed about the reliability data for portable equipment are described.

Section 7.6 in NEI 16-06 provides that the following guidelines could be used to develop failure rates for portable equipment until enough operating experience is available to calculate failure rates:

- Assume a bounding failure rate based on multiple (e.g., 2 to 10 times) of the failure rate of similar permanently-installed equipment based on engineering judgement.
- Assume an equivalent failure rate as that of similar permanently-installed plant equipment and perform sensitivity studies to determine the impact of that assumption on the PRA results.
- PWROG-14003 [15], presents an approach for assessing the probability of failure of portable equipment .
- Common cause data may not be available, initially, and the generic common cause factors in NUREG/CR-5496 [16], or WCAP-16672-P [17] can be used until such data becomes available.

Section 2.5 in PWROG-14003 provides the methods to develop component failure data for portable equipment using adjustment factors, common cause failure factors, test and maintenance unavailability.

The failure rates for portable equipment using adjustment factor are calculated the following steps:

- Select generic data to identify the installed equipment that is similar to portable equipment. Generic data can be used NUREG/CR-6928 [18], etc.,
- Select failure mode and failure rate data of the similar installed equipment. For example, failure modes of the gas turbine-driven portable generator are CTG-FTS, CTG-FTLR, CTG-FTR in NUREG/CR-6928.
- Identify four adjustment factors using the criteria in Table II.

Table II: Adjustment Factors for Portable Equipment

Adjustment Factors	Value
Deployment Factor(F_{DPM})	• 1.0: FLEX equipment is pre-staged, additional equipment is needed to support the active component. • 1.5: FLEX equipment is pre-staged, but requires additional support equipment to be functional. • 2.0: FLEX equipment must be deployed with

	additional support equipment, but without any significant challenges due to environmental conditions. • 4.0 to 10.0: FLEX equipment must be deployed with challenging environmental conditions that require debris removal (e.g., following a severe seismic event).
Location Factor(F_{LOC})	• 1.0: FLEX equipment is deployed to a protected area (e.g., turbine building) or is designed to function in nominal outside environmental conditions. • 2.0: FLEX equipment is deployed outside, in challenging environmental conditions (e.g., high winds). • 4.0: FLEX equipment is deployed outside, in some exceptionally challenging environment (e.g., aftershocks from a major seismic event).
Water Quality Factor(F_{WQ})	• 1.0: FLEX system fluid is "high quality" raw water (e.g., portable water) or the pump and system are designed for raw water (e.g., Service Water system). • 2.0: FLEX system fluid is "good quality" river, lake or ocean water, but below the nominal water quality for the system. • 4.0 to 10.0: FLEX system fluid is "poor quality" river, lake or ocean water (e.g., debris-laden water from a severe storm).
Test/Maintenance Factor(F_{TM})	• Test Interval(FLEX equipment) / [2 * Test Interval(similar installed equipment)] • This factor is never less than 1.0

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- Calculate failure rate(λ) as follows:

(a) Demand Failure:

$$\lambda_{Demand} = F_{DPM} * F_{TM} * \lambda_{demand\ failure/installed}$$

(b) Running Failure:

$$\lambda_{Running} = F_{LOC} * F_{WQ} * \lambda_{Running\ Failure\ /installed}$$

Common cause factor should be used generic CCF factors considering the boundary of portable equipment. The generic CCF data can be used the latest update of NUREG/CR-5497 [19] or WCAP-16672-P. The CCF group should be distinguished from the portable equipment and the similar installed equipment because portable equipment is physically diverse, different function and operate different environment.

The data of test and maintenance unavailability can be used as generic data because the operating experience is not enough to develop plant-specific data.

INL-EXT-20-58327 [20] provides that the review of the methodology which is used PWROG-18043-P [21] to develop the data of portable equipment from operating experience. The failure rates are calculated the following steps:

The data are collected and reviewed whether the data are representative of the nuclear power plant industry.

Select generic data to identify the installed equipment that is similar to portable equipment.

Select failure mode and failure rate and failure rate data of the similar installed equipment. Generic data can be used NUREG/CR-6928.

If the data are fewer than 50 demands or 100 hours of operating experience, weakly informed prior that is suggested by PWROG-18043-P is used to estimate failure rate. The detailed method is not open to the public. Otherwise, the Jeffreys non-informative prior, the empirical Bayes method could be used and the detailed methods are described in NUREG/CR-6823 [23].

If it is necessary to use weakly informed prior, scaling factor and variance factor are considered adjustment factor. The scaling factor is 4 to multiply the mean and standard deviation selected failure mode. This value is determined from engineering judgement. The variance factor is determined from the range factor as the square root of the ratio of the 95^{th} percentile and 5^{th} percentile. The range factor has a value from 5 to 10.

5. Conclusions

To incorporate accident mitigation strategies using portable equipment into PSA models, current status of portable equipment, recent technical reports related to HRA and reliability data analysis methodology in the United States were reviewed.

In the United States., FLEX was established to strengthen the NPP's accident coping capability in BDBEE. FLEX includes strategies for maintaining and restoring core cooling and make-up, containment cooling using portable equipment. When developing PSA models, these strategies can be applied with appropriate HRA and reliability data analysis for portable equipment.

As a result of reviewing several technical reports on recent HRA methods, when performing HRA for portable equipment, the HRA method using IDHEAS-ECA is considered appropriate. Although HRA results may vary depending on the analyst's comprehension and interpretation of the event and scenarios, overall HEP results analyzed using IDHEAS-ECA are reliable and reasonable.

Also, several technical reports on recent reliability data analysis methodology were reviewed. As a result, it appears that assume a bounding failure rate based on multiple (e.g., 2 to 10 times) of the failure rate of similar permanently-installed equipment based on engineering judgement is appropriate among the methods proposed in NEI 16-06. This is because portable equipment and related procedures are under development in Korea. Furthermore, the operating experience is insufficient.

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