Human Reliability Analysis of the FLEX/MACST Actions deploying Portable Equipment

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1. Introduction

After the Fukushima Daiichi accident, new safety measures and equipment have been installed and are being prepared in order to increase the defense-in-depth capability of nuclear power plants. In those safety measures and equipment, it includes portable equipment such as portable pumps and hoses for injecting into the reactor coolant system (RCS) or the steam generator (SG), and portable generators for supplying essential AC and DC powers [1]. In addition, new legislation on nuclear safety has been promulgated in 2015, which defines probabilistic safety goal in terms of 'risk' that the licensees should meet. Therefore, there is a necessity to incorporate aforementioned new measures and equipment into the probabilistic safety assessment (PSA) models. Among the technical elements of the PSA technology, human reliability analysis (HRA) is required to adequately model and quantify the mitigation strategies using portable equipment from the U.S. diverse and flexible coping strategies (FLEX) or the Korean multi-barrier accident coping strategies (MACST).

In order to provide technical basis for HRA of the mitigation strategy using portable equipment, this study performed a preliminary human reliability analysis including detailed task analysis, qualitative analysis of error modes and performance shaping factors (PSFs) with recovery potentials, and estimation of human error probabilities (HEPs), in association with deploying portable equipment [2].

2. Mitigation Strategy and Timeline Analysis

A flow of mitigative actions required to cope with an extended loss of AC power (ELAP) event is provided in Fig. 1. ELAP is declared when the AC power is not restored within an allowed time. The initially required ELAP mitigation action is to shed non-essential DC loads from the safety-grade DC battery to extend the lifetime of the DC power. The RCS cooldown is conducted using the turbine-driven auxiliary feedwater (TDAFW) system and the atmospheric dump valves (ADVs). The essential AC and DC power is continuously supplied by deploying the 4.16kVAC/480VAC portable generator and connecting to a required AC bus. For long-term RCS cooling, the condensate storage tank (CST), or the auxiliary feedwater storage tank (AFST), which contains the water feeding the SG, should be refilled from any available water sources [3,4].

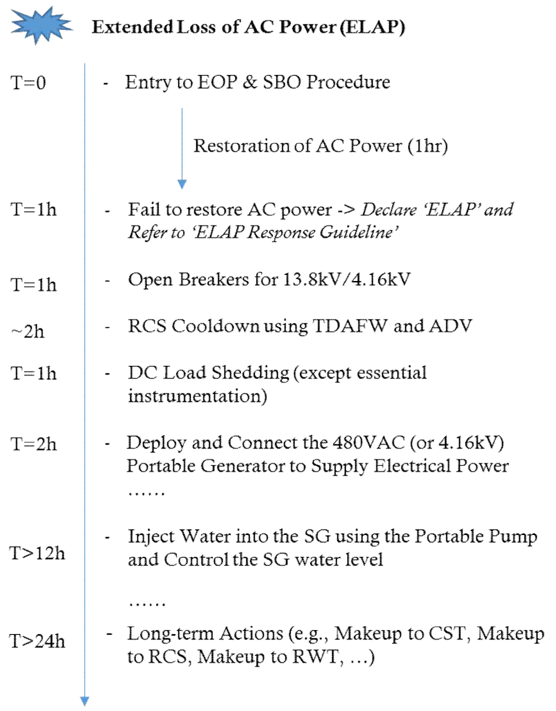


Fig. 1. ELAP mitigation strategy with rough timeline

In this study, a case study for an HRA has been performed for the task of supplying the 4.16kVAC or 480VAC power by deploying a portable generator. Three ways of using the portable equipment are investigated to assess their feasibility and to perform human reliability assessment based on detailed task analysis and qualitative error analysis. Classification of the three deployment methods are as follows.

- Case-1: pre-staging of portable equipment (connection and startup required)
  - Direction to responsible personnel (using communication equipment or direct oral instruction)
  - Move to the pre-staged location and connect/startup the equipment (coordination with MCR may be required)
- Case 2: deploying the equipment by the initial emergency response team
  - Direction to responsible personnel (using communication equipment or direct oral instruction)
  - Deployment/Installation/Connection of the portable equipment (coordination between work personnel, field lighting required, …)

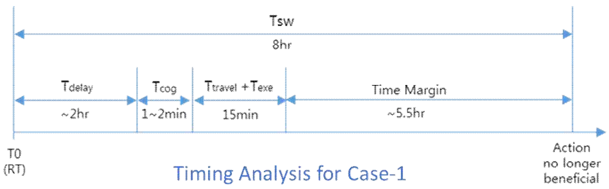
- Startup of the equipment (coordination with MCR may be required)

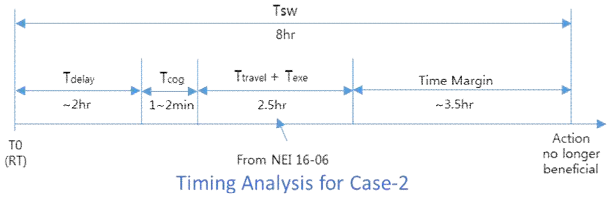
• Case 3: deploying the equipment by the off-site emergency response team (called from off-site)

- Notification to offsite emergency response team (via communication system)
- Direction to the responsible team (using communication equipment or direct oral instruction)
- Deployment/Installation/Connection of the portable equipment (coordination between work personnel, field lighting required, …)
- Startup of the equipment (coordination with MCR may be required)

3. Task Analysis and Qualitative Error Analysis

For the task of supplying the 4.16kVAC or 480VAC power by deploying a portable generator, detailed task analysis, timeline analysis, identification of preliminary error modes, performance shaping factors (PSFs), and error recovery potentials has been performed. The results from timeline analysis of individual methods of deployment are given in Fig. 2. The summary of results from the qualitative analysis on potential error modes and PSFs based on a detailed task analysis for the Case 2 of deployment methods are provided in Table I.





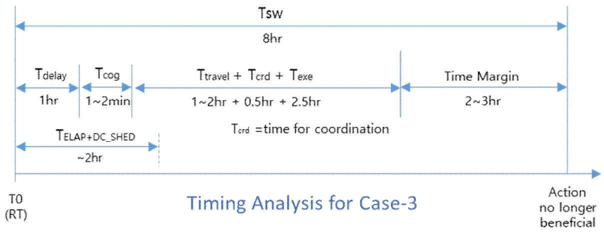


Fig. 2. Timeline analysis for deploying and installing the portable generator

4. Estimation of Human Error Probability

A preliminary estimation of HEP for the task of deploying a portable generator has been done using the EPRI external event HRA method [5]. The method provides how to conduct qualitative and quantitative HRA process for candidate human failure events (HFEs) for external events PSA with a focus on a seismic event, but does not provide specific guidance on a task that deploys portable equipment. Therefore, the aim of application of the method to the case study is not to gain a delicate HEP but a rough estimate of probability in association with use of portable equipment. The existing HRA method does not provide adequate HEP values for some actions or activities in association with use of portable equipment. Such actions/activities include transportation, load/unload, and/or connection of the portable equipment. Surrogate HEP values for such actions/activities were used temporarily until more appropriate values can be obtained. Table I provides preliminary estimates of HEP for each of sub-activities and a total HEP value for the Case 2 of deployment method using the portable generator.

Table I: Task analysis, error analysis, and estimation of error probability associated with the use of portable generator

Work Flow / Activity	Error Modes	PSFs	HEP Estimation
• Task Order to Local emergency response team (via communication system or direct oral communication)	• Omission of Task Initiation • Error in Delivery of Task Order (wrong communication)	• Procedure: transparency/multiple procedures/tasks • Training • Availability/Reliability of the communication system (under internal/external events)	• Initial HEP * recovery error prob. = 6.0E-3 (CBDT Pce) * 5.0E-2 (assuming LD between SS and TSC) = 3.0E-4
• Preparation of essential equipment/tools/ components	• Omission of preparing essential tools/components	• Status of preparation of essential tools/components for each of equipment	• Initial HEP * 'High' stress level * recovery error prob. = 4.2E-3 (Mean) x 5 x

			(1+19*2.1E-2)/20 = 1.47E-3
• Selection and Loading of the equipment	• Selection/loading of wrong equipment from the storage facility	• Transparency of equipment and labeling • Training	• 1.3E-3 x 5 x 3.2E-1 = 2.08E-3
• Transportation and Unloading of the equipment	• Damage to the equipment during transportation /unloading • Debris/Obstruction may be intervened on the road in external events	• Road status • Effect of weather or external events	• HEP = E_{trans}.
• Installation/Connection of the portable equipment (i.e., cables and buses)	• Inadequate/loose connection • connection to wrong object (bus)	• Working environment: lighting, narrowness, etc. • Clearness of labeling, similar object in neighborhood	• EOM: omission of connection - 4.2E-3 (Mean) x 5 x 1.3E-2 = 2.73E-4 • EOC: Inadequate/loose connection - 1.3E-2 x 5 x 1.3E-2 = 8.45E-4 • EOC: connection to wrong object (bus) - 3.8E-3 x 5 x 1.3E-2 = 2.47E-4 • Sum of HEPs = 2.73E-4 + 8.45E-4 + 2.47E-4 = 1.37E-3
• Report to the MCR on the completion of installation /connection, and Startup of the equipment (i.e., startup of the generator and put circuit breaker in)	• Omission of report on completion of connection work • Omission of the generator startup • Section of wrong circuit breaker • Failure of coordination with MCR	• Procedure for local operators • Training • Availability/Reliability of the communication system (under internal/external events) • Quality of MMI of the portable generator	• EOM: Omission of report - 2.60E-3 x 5 = 1.3E-2 • EOM: Omission of the generator startup - 4.2E-3 x 5 x 1.30E-2 = **2**.73E-4 • EOC: commission of the generator startup - 3.8E-3 x 5 x 1.30E-2 = 2.47E-4 • EOM: Omission of putting circuit breaker in - 1.25E-3 x 5 x 1.30E-2 = 8.13E-5 • EOC: Commission of putting circuit breaker in - 6.3E-3 x 5 x 1.30E-2 = 4.10E-4 • Sum of HEPs = 2.73E-4 + 2.47E-4 + 8.13E-5 + 4.10E-4 = 1.01E-3
Refueling task is required for long-term operation, but it is not included in this study			
			Final HEP = **6.23E-3**

5. Conclusion

This paper provided a preliminary human reliability analysis, which includes detailed task analysis, qualitative analysis of error modes and performance shaping factors (PSFs) with recovery potentials, and estimation of human error probabilities (HEPs) in association with deploying portable equipment. The results and conclusions gained from this study can be used as technical basis for further development of an HRA method and guideline for the FLEX or MACST mitigation actions using portable equipment.

Acknowledgement

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