Application of SPAR-H Human Reliability Analysis Method to the use of Portable Equipment in Nuclear Power Plants

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1. Introduction

Since the Fukushima Nuclear Power Plant (NPP) accident, the safety of NPPs become a hot potato due to the possibility of natural disasters such as earthquakes or floods. The occurrence of such an accident can affect not only a single unit but also multiple units. The typical accidents in such events are Extended Loss of AC Power (ELAP) and Loss of Ultimate Heat Sink (LUHS). ELAP is an accident in which both the internal and external power sources are lost. LUHS is an accident in which the seawater cooling function, which is the final heat removal source of the NPP is lost.

NNPs are equipped with various operating guidelines related to various response equipment to mitigate this accident. The diverse and FLEXible coping strategies (FLEX) have been developed in the United States, while a Multiple barrier Accident Coping STrategy (MACST) was developed in Korea based on FLEX. The MACST has been added based on defense-in-depth strategies to mitigate severe accidents. Portable equipment components such as portable generators, portable pumps, and portable heat exchangers are being introduced into the NPP.

According to the recently revised Nuclear Safety Act in Korea, NPP companies must prove that their NPP meets deterministic and probabilistic safety standards by submitting an accident management plan. In particular, it is necessary to confirm whether the probabilistic safety objective has been achieved through a probabilistic safety assessment (PSA). The importance of Human Reliability Analysis (HRA) is being emphasized in PSA because the success or failure of portable equipment operation depends on the human actions of the NPP accident response organization, including the operator.

However, it is difficult to directly apply most of the existing HRA methods for the portable equipment HRA because they focus on the main control room operator actions or the local operator actions. To solve these problems, the Korea Atomic Energy Research Institute (KAERI) [1], the Nuclear Energy Institute (NEI) [2], and the Electric Power Research Institute (EPRI) [3] recommends a new approach for portable equipment HRA. This paper explores the application of the Standardized Plant Analysis Risk HRA (SPAR-H) [4] method to portable equipment HRA.

2. Approach of portable equipment HRA in existing method

This section describes the general processes of portable equipment HRA by reviewing existing methods. The portable equipment HRA processes are proposed by NEI in 2016, EPRI in 2018, and KAERI also published in 2018 [1,2,3].

2.1 Task analysis

The tasks for the operation of portable equipment were decomposed into sub-tasks. Considering the unique characteristics of the operator tasks while using portable equipment or additional operator tasks such as moving and installing portable equipment, it is not appropriate to perform the HRA in the same way as the existing internal event HRA. In the general HRA method applied to internal events, the tasks performed in the Main Control Room (MCR) (or local operators) are divided into "Diagnosis or Cognition" and "Execution" parts. The final HEP is the summation of the probability of each part.

In addition, in the existing general HRA, only MCR operators or local operators were considered, but in the use of portable equipment, the emergency Technical Support Center (TSC) that makes decisions, the Operational Support Center (OSC) that supports movement and installation, and subcontractors are involved. Organizations may differ from each other in terms of familiarity with work or level of training.

2.3 HEP quantification

Reviewing the existing portable equipment, HRA approaches confirmed that the general HRA method can be applied to the quantification of portable equipment HRA. In addition, it was confirmed that additional analysis was required for some tasks. When it was difficult to apply the general HRA methods directly, the following two approaches were adopted in the reviewed methods.

The first is to utilize other available data. For example, errors such as traffic accidents that may occur during the movement of mobile equipment are not analyzed in the general HRA methods. In the EPRI method, traffic accident probability data per mile in the Savannah River NPP site was used to evaluate human errors in portable equipment movement.

The second is to calculate the probability of error by applying the probability of the most similar task. For example, in the EPRI method, the case of field valve selection error in THERP [5] Table 20-13 was applied to the operation of connecting a hose to a mobile facility at a power plant.

3. Example of portable equipment HRA based on SPAR-H method

In this section, we will describe the portable equipment HRA based on the SPAR-H method. The SPAR-H method is also being applied in a current research project [5]. In this example, a 1MW portable generator is considered as the relevant portable equipment.

3.1 Base case of 1MW portable generator

- This task is required in ELAP when the off-site power is lost, the Emergency Diesel Generator (EDG) fails, and the alternate alternating current (AAC) DG fails.
- When all AC power in the site is lost, the operator declares ELAP and first instructs a request for the 1MW portable generator.
- It is assumed that the 1MW portable generator should be connected within 8 hours of the declaration of ELAP, which is the maximum battery life when unnecessary DC load is cut off (i.e. DC load shed).
- It is assumed that the cable is moved and installed as currently provided by the operating company.
- It is assumed that there is no influence of external events such as earthquakes or tsunamis.

3.2 Task analysis on the 1MW portable generator

The portable equipment tasks for the SPAR-H method application were divided into four types, as shown in Figure 1. The following is a description of each sub-task.
Subtask 1 – Decision making for portable equipment application; is the task of making a decision to apply portable equipment following the Emergency Operation Procedure (EOP) and Severe Accident Management Guide (SAMG) and instructing movement. If the decision to apply the portable equipment is directed at the procedural level close to the ELAP declaration, it may be substituted by analyzing the ELAP declaration. The MCR operator or the TSC performs the performance of this task. As this task has no execution, it can only be modeled for diagnostic or cognitive aspects.
Subtask 2 – Movement of portable equipment; involves the movement of the mobile generator from the storage area to the installation area. The 1MW portable generator requires one vehicle to carry both the generator and the connection cables. In Korean NPPs, employees of KEPCO KPS (Korea Electric Power Corporation Plant Service) are to perform this work. There is no important decision-making involved in this sub-task, and it mainly involves physical activity, so only the analysis of the execution aspect can be performed.

Subtask – 3 Installation of portable equipment; involves connecting the portable generator to the power plant connection point with a cable and connecting the hose for fuel supply to the mobile generator. In Korean NPPs, KEPCO KPS employees perform this work. There is no important decision-making involved in these sub-tasks, and mainly involves physical activity, so only the analysis of the execution aspect can be performed.

Subtask – 4 Start-up and supply of portable equipment; is the operation of starting portable equipment and performing lineup to the system required for the power supply or water supply. In this case, it is the operation of starting a portable generator by following the system procedure manual, EOP, and MACST operation guidelines (MOG). It also involves operating the circuit breakers in a lineup, which MCR operators and local operators perform. These actions are performed by referring to the procedures used in decision-making for mobile equipment application and other system

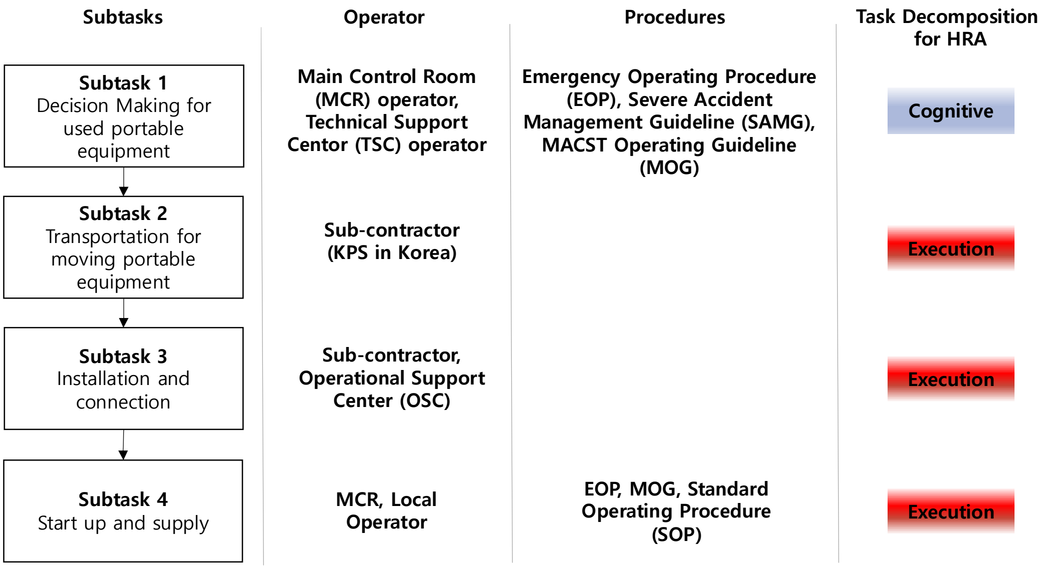

Fig. 1. Task analysis for portable equipment

procedures, but only the performance is modeled assuming that no major decision-making is necessary because the decision to apply the portable generator has been determined.

3.3 HEP quantification for 1MW portable generator

Table I shows the Performance Shaping Factor (PSF) evaluation and the evidence for the decision making for 1MW portable generator sub-task. This sub-task is a diagnostic action, and if calculated according to the formula suggested by SPAR-H, a HEP of 2.0E-04 will be obtained.

Table I: Decision making for 1MW portable generator

PSF	**Level**	**Multiplier**	**Evidence**
Available Time(min)	Time Aval.(340)/Time Req.(20)=18 (Expansive Time)	0.01	Timeline analysis
Stress	High	2	fixed equipment for the power supply is unavailable and multiple alarms are generated.
Complexity	Nominal	1	The necessity of portable power generation is clear.
Experience/ Training	Nominal	1	Sufficient training as decision-making is included in emergency procedures.
Procedure	Nominal	1	Included in emergency procedures
HMI	Nominal	1	MCR task
Fitness for Duty	Nominal	1	Each operator has his/her respective duties.
Work Process	Nominal	1	The work process is not affected
HEP	0.01(Basic HEP)*0.01*2*1*1*1*1*1*1 = 2.0E-04		

The movement of 1MW portable generator is a unique task compared to general HRA tasks. This sub-task is to move the 1MW portable generator from the storage point to the connection point. Statistical data is used to calculate the error probability of this sub-task. The probability of a commercial vehicle accident is 3.06E-07/km [6]. In addition, the error probability was calculated in the following way by applying the distance and the multiplier. The distance was assumed to be 5 km, which is the average distance of the on-site road, and a multiplier of 10 was applied assuming the road condition conservatively.

$$Movement\ HEP = 3.06 * 10^{-7}/km * 5km * 10 = 1.59*10^{-5}$$

Table II shows the PSF evaluation and the evidence for installation of portable equipment. If this sub-task is calculated according to the formula suggested by SPAR-H, a HEP of 3.0E-03 will be obtained.

Table II: Installation for 1MW portable generator

PSF	**Level**	**Multiplier**	**Evidence**
Available Time(min)	Time Aval. (370)/ Time Req. (30) =12	0.1	Timeline analysis
Stress	High	2	Accident in which the fixed equipment for power supply cannot be used
Complexity	Nominal	1	The complexity of the portable generator connection task is not high.
Experience / Training	Low	3	The training for the task is expected to be about once a year.
Procedure	Poor	5	KPS does not have its own procedure
HMI	Nominal	1	Labeling of the connection point is well done
Fitness for Duty	Nominal	1	Each operator has their respective duties.
Work Process	Nominal	1	The work process is not affected
HEP	0.001(Basic HEP)*0.1*2*1*3*5*1*1*1 = 3.0E-03		

Table III shows the PSF evaluation and the evidence for the start-up and supply of 1MW portable generator sub-task. If this sub-task is calculated according to the formula suggested by SPAR-H, a HEP of 3.0E-03 will be obtained.

Table III: Start-up and supply for 1MW portable generator

PSF	**Level**	**Multiplier**	**Evidence**
Available Time(min)	Time Required=15 Time Available=355 Time Aval./Time Req.=24	0.1	Timeline analysis
Stress	High	2	Fixed equipment for the power supply is unavailable and multiple alarms are generated.
Complexity	Moderately Complex	2	Several manipulations are required for starting and line-up of the portable generator.
Experience/ Training	Nominal	1	Sufficient training as decision-making is included in emergency procedures.

Procedure	Nominal	1	Included in emergency procedures
HMI	Nominal	1	Labeling is well done on the device to be operated.
Fitness for Duty	Nominal	1	Each operator has their respective duties.
Work Process	Nominal	1	The work process is not affected
HEP	0.001(Basic HEP)*0.1*2*2*1*1*1*1*1 = 4.0E-04		

HEP for using a 1MW portable generator in an emergency can be obtained by adding HEP for each sub-task. The calculated HEP for the 1MW portable equipment is 3.62E-03, as shown in Table IV.

Table IV: Total HEP of 1MW Portable Generator

Sub-task	HEP
Decision Making for Portable Equipment Application	2.00E-04
Movement of Portable Equipment	1.59E-05
Installing Portable Equipment	3.00E-03
Portable Equipment Start-up and Supply	4.00E-04
Total HEP	3.62E-03

3. Conclusions

This paper reviewed the mobile equipment HRA methodology and showed an example of performing portable equipment HRA based on the SPAR-H method. As the current research is still in progress, only the cases of operating portable equipment in the case of an internal event have been dealt with. Future studies will consider the occurrence of external or complex events. This is necessary to show how the HRA method for mobile equipment can consider environmental factors and resource management factors.

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