Transactions of the Korean Nuclear Society Autumn Meeting
Gyeongju, Korea, October 25-27, 2017

Incorporating MACST Mitigation Strategies into PSA Models: HRA and Data Issues

Inn Seock Kim[a], Byung Gon Kim[a], Dae In Choi[a], Eun-Chan Lee[b]
[a]*Nuclear Engineering Service & Solution Co. (NESS), 96 Gajeongbukro, Yuseong-gu, Daejeon, Korea*
[b]*Korea Hydro & Nuclear Power Co., Ltd., 1312 Yuseongdaero,Yuseong-Gu, Daejeon, Republic of Korea*
[*]*Corresponding author: iskim@ness.re.kr*

1. Introduction

The Fukushima accident indicates, among others, that flexible and diverse mitigation strategies are needed to cope with a variety of unforeseen accident conditions that may be brought about by occurrence of beyond design basis accidents (BDBAs). These mitigation strategies will be typically implemented in Phase 2 or 3 when the evolving accident cannot be properly coped with by use of installed equipment alone [1]. There is world-wide effort to implement the accident mitigation strategies at nuclear power plants to further strengthen defense in depth. In the USA, the portable equipment that will be used to implement the mitigation strategies is called FLEX equipment. In Korea, the accident mitigation strategies will be carried out by so-called MACST (Multi-barrier Accident Coping Strategy) equipment, consisting of portable diesel generators, portable pumps, and so on.

In this paper, we discuss the issues associated with crediting MACST equipment and relevant mitigation strategies in Probabilistic Safety Assessment (PSA), focusing on Human Reliability Analysis (HRA) and data issues.

2. Crediting Portable Equipment in PSA

Since employment of mitigation strategies during accident conditions will help to avoid occurrence of core damage or failure of containment integrity, and to reduce release of radioactive materials to the environment, safety of nuclear power plants must be improved accordingly. As a result, MACST mitigation strategies are being incorporated into existing PSA models for more realistic estimation of plant risk by taking credit for portable equipment.

The PWROG Risk Management Committee identified ten PSA-related issues that should be explored to provide guidance to PSA analysts if FLEX equipment is incorporated into a PSA model [2]. They include issues with crediting FLEX equipment in a PSA, equipment routing, extended use of an alternate water supply in a clean water system, human reliability analysis, failure data, component mission time, component exposure time, model quantification, the range of the assessment of uncertainty and sensitivity runs, and crediting FLEX equipment in the significance determination process. Of these ten issues, HRA and data analysis for portable FLEX-like equipment were also identified as prominent issues in the studies performed by the Electric Power Research Institute (EPRI) [3] and the Nuclear Energy Institute (NEI) [4]. The HRA and failure data issues are discussed herein, primarily based on the PWROG report [2].

3. HRA Issues

Human reliability analysis (HRA) is one of the most important elements that need to be performed in a PSA. In general, human failure events (HFEs) are included in dominant accident sequences, making a significant contribution to the risk metrics such as core damage frequency (CDF) or large early release frequency (LERF). The HRA issues associated with incorporating FLEX-like equipment into a PSA model were addressed in the research performed by EPRI, NEI and PWROG.

The EPRI first points out, among others, that a critical weakness of current HRA methodologies is the lack of capability for modeling execution errors for non-control room equipment and actions. This is because FLEX-like activities involve various atypical actions which are not addressed in the existing HRA methodology such as THERP. Second, obtaining timing information is a significant challenge for modeling FLEX-like activities. A guidance needs to be developed with regard to how to construct a timeline for modeling these activities and how to collect timing data for the associated components of the actions (for instance, in connection with on-site equipment alignments, cues from offsite sources, and arrival of offsite staff).

According to the NEI study [4], some of the actions that may not be explicitly addressed in existing guidance or provided in HRA tools include: 1) making decisions to enter a procedure using judgment based on a belief in a future event (e.g., the expectation that offsite power will not be restored in a certain time frame); 2) actions to transport and install portable equipment; and 3) actions that require many people working in coordination to complete a single task. Potential avenues to address these issues are addressed through an example of load-shedding DC buses in the situation of an extended loss of AC power (ELAP). Other difficulties encountered in performing HRA for

FLEX-like activities include: time margin evaluation, command and control evaluation, and addressing complex actions in mitigating strategies. For instance, the following needs to be accounted for in analyzing the time margin: 1) diagnosis time associated with entering procedures to use portable equipment; 2) potential for debris removal for external events; 3) transportation and staging of portable equipment; 4) installation of hoses or cables; and 5) pre-operational checks, electrical rotation checks, and/or alignments. Finally, a couple of human failure events (i.e., "Operators fail to load shed DC buses" and "Operators fail to deploy and install FLEX generator") were evaluated using CBDTM and THERP methodologies to illustrate how HRA can be performed in FLEX PSA. The human error probabilities estimated for these human failure events by the EPRI HRA Calculator are $1.9\text{x}10^{-2}$ and $5.49\text{x}10^{-3}$, respectively.

4. Data Issues

While there are adequate sources of generic failure rates for permanently-installed equipment at nuclear power plants, there is limited failure data available for portable equipment. Hence, data analysis of portable equipment poses another big issue in crediting such equipment in PSA. The NEI states that, until sufficient industry data is compiled to estimate generic industry failure rates for the portable equipment in use at nuclear power plants, each site including portable equipment in their PSA models will have to use engineering judgments regarding the failure rates [4].

The PWROG provides an interim solution to the data analysis issue for FLEX PSA in terms of adjustment factors [2]. The conceptual approach is depicted in Fig. 1, and the key idea and relevant assumptions are as follows:

1. The failure data for portable equipment can be estimated from the failure data for similar installed equipment, if the expected service use and environment of the portable equipment as compared to the similar installed equipment are adequately identified and accounted for by means of adjustment factors.

2. The demand failure probability for portable equipment can be adjusted by considering the potential failure mechanisms associated with deployment (e.g., wear and tear from transport and setup), and the potential impact of extended test/maintenance period on equipment reliability. The deployment factor (F_{DPM}) includes three impacts: (a) impact on the portable equipment due to being moved from its storage location to the location where it will be used; (b) The reliability of equipment needed to move the FLEX equipment (e.g., trailer, truck/tractor) and potentially remove debris to clear a transit path; and the reliability of passive components (e.g., cables, hoses) used in conjunction with the deployment of FLEX equipment. The test/maintenance factor (F_{TM}) is applied under the assumption that the Technical Specification test intervals are conservative with regard to impact on component reliability, and increasing the test interval by a factor of two would not appreciably affect FLEX component reliability. Beyond a factor of two, it is assumed that the FLEX equipment failure rate would increase as the test interval is increased.

3. The operational failure rate for portable equipment can be adjusted by taking into account the specific location where the portable equipment will be used for accident mitigation, and also the condition of the water delivered by the portable pump. The location factor (F_{DPM}) addresses, for instance: the potential long-term impact of environmental conditions such as extreme temperatures that the FLEX equipment may be subject to when deployed outside; challenging environmental conditions due to high winds; and aftershocks from a major seismic event. The water quality factor addresses the potential long-term impact of raw water used for the system fluid, when the nominal fluid conditions are clean and chemistry-controlled (e.g., water injected into the steam generators).

The FLEX equipment failure-on-demand (FOD) is calculated as follows:

$$\lambda_{FOD/FLEX} = F_{DPM} * F_{TM} * \lambda_{FOD/INSTALLED},$$

and the FLEX equipment failure-to-operate (FTO) is calculated as follows:

$$\lambda_{FTO/FLEX} = F_{LOC} * F_{WQ} * \lambda_{FTO/INSTALLED},$$

where:

$\lambda_{FOD/INSTALLED}$ = demand failure rate for similar installed equipment (/demand), and
$\lambda_{FTO/INSTALLED}$ = operational failure rate for similar installed equipment (/hour).

5. Conclusions

There are a number of issues that need to be addressed in order to properly credit portable equipment and relevant mitigation strategies in PSA. The research performed by EPRI, NEI and PWROG in this regard sheds light on these issues, providing some interim solutions. In this paper we discussed a couple of prominent issues, namely HRA issues and data issues. Provide that more details become available regarding procedures for portable equipment and failure data for such equipment are compiled, these issues could be addressed more appropriately, enabling more realistic estimation of the plant risk with credit for portable equipment in accident scenarios for which they provide an alternate success path.

REFERENCES

[1] Nuclear Energy Institute, Diverse and Flexible Coping Strategies (FLEX) Implementation Guide, NEI-12-06, May 2012.
[2] Westinghouse Electric Company, Implementation of FLEX Equipment in Plant-Specific PRA Models, PWROG-14003-NP, August 2016.
[3] Electric Power Research Institute, Incorporating Flexible Mitigation Strategies into PRA Models, Phase 1: Gap Analysis and Early Lessons Learned, EPRI 3002003151, November 2014.
[4] Nuclear Energy Institute, Crediting Mitigating Strategies in Risk-Informed Decision Making, NEI-16-06, August 2016.

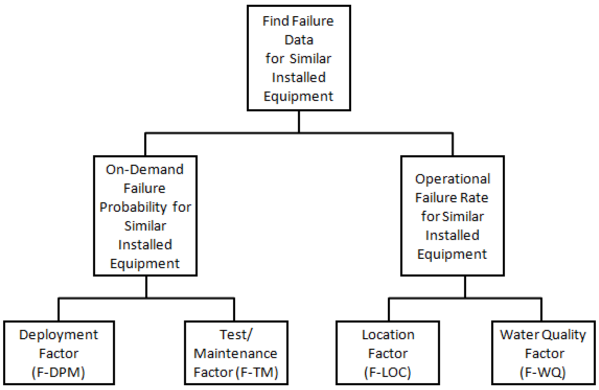

Fig. 1 Adjustment Factors for Portable Equipment