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Developing a Methodology of MELCOR Uncertainty Analysis Considering Mobile Equipment for Accident Management

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1. Introduction

Since the Fukushima accident, Korea has established and is promoting the Multi-barrier Accident Coping Strategy (MACST), a strategy that blends/compromises the U.S. FLEX strategy and the European Severe Accident Prevention and Mitigation Strategy. MACST improve the response capability of nuclear power plants to Beyond Design Basis External Events (BDBEE). MACST has developed as a strategy to prevent and mitigate severe accidents.

In this study, an uncertainty analysis methodology for the main branch probabilities was established for the WH600 model by referring to the latest study, State-of-the-Art Reactor Consequence Analyses (SOARCA), which faithfully reflects the realistic accident response facilities and procedures of nuclear power plants, and considering mobile equipment to improve the safety of nuclear power plants against extreme and severe accidents..

2. Domestic and International Mobile Equipment Technology Status

The U.S. NRC issued the Near-Term Task Force (NTTF) recommendations (SECY-11-0093) immediately after the Fukushima accident, and the nuclear power industry proposed Diverse and Flexible Coping Strategies (FLEX) through NEI 12-06 to improve the ability to maintain and recover reactor cooling capacity, containment building integrity, and spent fuel cooling capacity in response external beyond design basis accident. In accordance with the FLEX strategy, nuclear power plant operators have prepared various mobile equipment and established procedures for the operation of mobile equipment. Subsequently, the nuclear power plant operator decided that the FLEX facility would be useful for risk reduction and wanted to reflect the FLEX facility in the probabilistic safety assessment (PSA) model for risk information utilization [1].

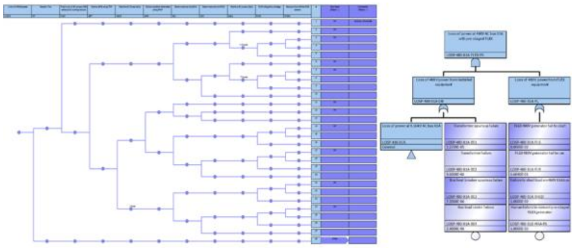

Fig. 1. FLEX Facility PSA Application Example

In Korea, immediately after the Fukushima accident, safety inspections were conducted for all nuclear power plants in Korea and follow-up measures were established based on safety confirmations. As part of the follow-up measures, a PSA was conducted for all operating nuclear power plants in 2015 as part of the development of guidelines for managing major accidents during low power and shutdown operation. Since then, PSA have been conducted as a legal requirement, as they were included as a new factor in the Periodic Safety Review (PSR) in 2014. In addition, in 2015, PSA was enacted into law, and as part of the PSA, PSA were conducted for all operating nuclear power plants in 2019 and submitted to the regulator, and the licensing process is currently underway.

As part of the PSA, the NPP operator conducted a PSA for all of its operating units and considered the MACST facility in the PSA. The PSA currently submitted to the regulator reflects the results of the MACST conceptual design, and any changes resulting from the detailed design and equipping of the MACST will be reflected in the PSA model revision during the licensing process. The MACST facility was considered for accident mitigation in accordance with the Multi-Defense Operating Guideline, which is the operating guideline for the MACST facility, and the latest US research (NEI 16-06, PWROG-14003-NP) was utilized and applied to the PSA [2][3].

3. Mobile Equipment PSA and MELCOR Application Methodology

Since the PSA model methodology for mobile equipment is not yet established, it is necessary to derive a methodology for applying mobile facilities to the PSA model in order to reflect mobile equipment in the PSA model.

Phase 1 and Phase 2 of the incident management strategy consider turbine-driven auxiliary water pumps, which require 125 V DC power for control. Therefore, the 1 MW mobile generating unit should be modeled to provide emergency power to the battery charger to maintain continuous secondary heat removal operation with the turbine-driven auxiliary feedwater pump. This assumption applies to the scenarios of successful secondary heat removal to the turbine-driven auxiliary feedwater pump in a station black out (SBO-R/S), failure of the alternating-current emergency diesel generator, and failure to restore marginal power, and is reflected in the model by adding a heading that considers the mobile generator as an event. Low-pressure mobile pump trucks contribute to secondary heat removal (SHR) and maintain SHR for the supply of alternative water supply on the secondary side.

They are used after 8 hours according to the operator's multi-barrier accident coping strategy (MACST) strategy and should be reflected in the model.

In this study, the MELCOR code Version 2.2 was used to perform the mobile unit critical accident analysis, and the WH600 reactor type was selected as the reference reactor and the MELCOR input model was developed.

To develop a methodology for the application of mobile equipment, it is important to evaluate not only the effectiveness but also the feasibility and side effects in the evaluation of incident management strategies. However, utilizing the MELCOR code inevitably involves uncertainty, so this study developed an uncertainty analysis methodology for important phenomena.

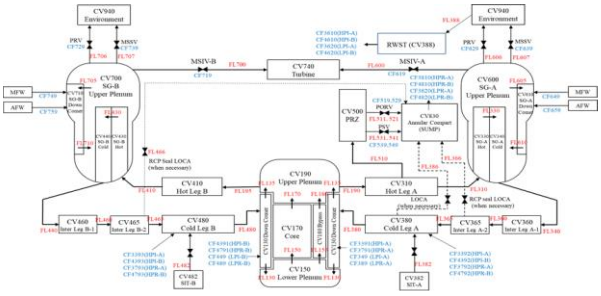

Fig. 2. Part of the developed MELCOR model nodalization

4. Uncertainty Analysis Methodology

This study examines the feasibility and effectiveness of the strategy of utilizing mobile units and develops an uncertainty analysis methodology for the key phenomena MELTSTOP (Core Damage Arrested without Vessel Breach) by referring to SOARCA, a recent study that faithfully reflects realistic accident response facilities and procedures in power plants [4]. MELTSTOP is determined based on recent relevant studies and the unique design characteristics of the plant.

The uncertainty analysis parameters were selected as follows. For the distribution information of each uncertainty parameters, the results of SOARCA study are cited [4].

Table 1. Uncertainty analysis parameters of MELTSTOP

Parameter	**MELCOR Input Record**	**Range**	**Distribution Type**
Zircaloy melt breakout temperature	SC1131 (2)	2100 ~ 2540	Triangular (mode = 2400)
Molten clad drainage rate	SC1141 (2)	0.1 ~ 2.0	Triangular (mode = 1.0)
Radial molten debris relocation time constant (molten / solid)	SC1020 (1) / (2)	100 ~ 1000 / 10~100	Uniform
Multiplier of ANS Decay Heat	SC3200(1)	0.9~1.1	Uniform
Effective temperature at which the eutectic formed from UO2 and ZrO2 melt	SC1132(1)	-	Normal, Mean : 2479 σ : 83
Oxidation Kinetics Model	COR_OX	Model Selection (#3)	Discrete

For uncertainty analysis, we use Sandia Lab's Uncertainty Helper program and MERTAG that developed by and previous research [5]. MERTAG is a program that performs the uncertainty analysis more conveniently. Uncertainty analysis is based on sufficient samples. Due to the huge amount of sample data necessary to obtain meaningful results considerable manpower and time are required. To carry out this process more simply and quickly, the MERTAG program has been developed to analyze the results of uncertainty

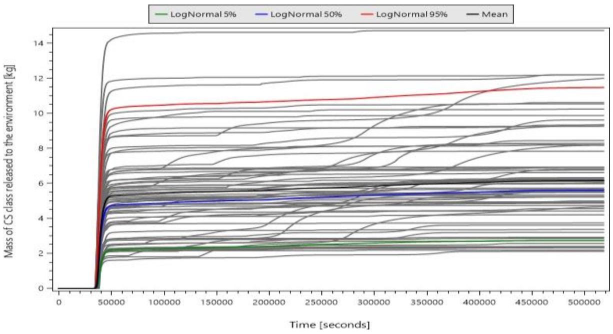

Fig. 3. Example result of uncertainty analysis with MERTAG

Using MERTAG, you can see the lognormal distribution of all the samples, as shown in the figure, as well as the 5%, 50%, and 9% distributions and the mean distribution.

5. Conclusion

In this study, we developed a methodology for applying MELCOR to mobile equipment for the WH600 and developed an uncertainty analysis methodology for the key phenomena, MELTSTOP. The uncertainty analysis methodology was established using the uncertainty analysis program MERTAG.

Since the PSA model methodology for mobile facilities has not yet been established internationally, to reflect mobile facilities in the PSA model for regulatory verification, an appropriate application method was derived through a review of the currently available domestic and foreign PSA model methodologies for mobile facilities, and the main phenomenological results should be determined by reflecting recent relevant research and the unique design characteristics of the power plant.

Acknowledgments

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