Development of the Standardized Level 2 PSA Model Structure for the MPAS

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1. Introduction

WASH-1400, the world's first probabilistic risk assessment (PRA) report in the United States in 1972, quantitatively evaluated the risk of nuclear power plants and it provides a perspective through comparison with non-nuclear risk [1]. In the Republic of Korea, a Probabilistic Safety Assessment (PSA) has been introduced and implemented to evaluate the integrated safety of NPPs since the late 1980s after the Three Mile Island Unit-2 (TMI-2) accident.

Korea Institute of Nuclear Safety (KINS), a regulatory agency, developed the Multi-purpose Probabilistic Analysis of Safety (MPAS) Level 1 PSA model for risk-informed regulation in cooperation with Korea Atomic Energy Research Institute (KAERI) from 2007 to 2018. However, a Level 1 PSA conducts only evaluation related to core damage scenarios. It means the MPAS Level 1 PSA model cannot evaluate the integrity of containment buildings and radiation materials behavior. Therefore, it is necessary to develop a Level 2 PSA model for risk-informed regulation.

In this study, a Plant Damage State Logic Diagram (PDSLD), a Containment Event Tree (CET), Decomposition Event Trees (DETs), and a Source Term Category Logic Diagram (STCLD) are developed that can evaluate MACST. These are the main part of a Level 2 PSA model that evaluates the behavior of a containment and radiation source in the event of severe accidents.

2. Methods and Results

When developing the MPAS Level 2 PSA model, the following key points were considered.

-Have a conservative and simple structure for general usage.

-Reflect accident mitigation strategies recently developed by the nuclear industry (e.g. Multi-barrier Accident Copying Strategy (MACST)).

-Adopt the applicable state-of-art research.

Level 2 PSA begins with expanding the core damaged scenarios defined as the result of the Level 1 PSA. Consider accident mitigation strategies that can prevent containment failure when expanding an accident scenario. There are generally more than hundreds of extended accident scenarios, so it is difficult to analyze all. So before analyzing accident progression using the CET and DETs, PDSLD is used to gather accident scenarios that have similar characteristics aspects of an accident progression to be analyzed.

The Level 2 PSA conducted in the Republic of Korea, a method of organizing and evaluating the CET and DETs to determine the accident progression in a containment building is commonly used [2]. The CET is developed to analyze the containment failure mode according to the progress of the accident. In general, since it is difficult to reflect all detailed accident progression in the CET, DETs are used as a means to assist this.

The STCLD is used to gather similar containment failure scenarios that are defined through the CET and DETs in aspects of the behavior of radioactive materials.

2.1 Development of the Plant Damage State Logic Diagram

The purpose of the development of the PDSLD is to gather accident scenarios with similar accident conditions and/or mitigation system behavior prior to perform an evaluation of phenomena that threaten the integrity of the containment building. To this end, in this study, the PDSLD has been developed using a total of 10 headings as follows

-BYPASS: Containment Bypass Accident
-CONISOL: Containment Isolation Failure
-PRCSCD: RCS Pressure at Core Damage
-RCPSINT: Status of RCP Seal Integrity
-AFW: Status of Auxiliary Feedwater System
-INVINJ: Status of In-vessel Injection
-CSS: Status of Containment Spray System
-HMS: Status of Hydrogen Mitigation System
-CAVCOND: Status of Containment Cavity
-RSGCON: Ruptured SG Condition

After the Fukushima Daiichi accident, Korea Hydrogen and Nuclear Power (KHNP) developed MACST, an accident mitigation strategy mainly composed of the use of mobile facilities. When developing the PDSLD, the operation time of the MACST strategy should be considered, not only the success or failure of the system operation as traditional PSA models. For example, headings related to the containment spray system can be divided into Early CS (CSE) and Late CS (CSL) to take into account cases where they are not available at the beginning of an accident like a portable containment spray pump.

The standardized PDSLD developed in this study is shown in Figure 1 and Figure 2.

Figure 1 and Figure 2 suggest the standardized PDSLD for OPR1000. In the case of APR1400, it is necessary to additionally consider changing the discharge flow path using a 3-way valve, or in the case of Westinghouse type plant, heat removal of the containment building using RCFC should be considered.

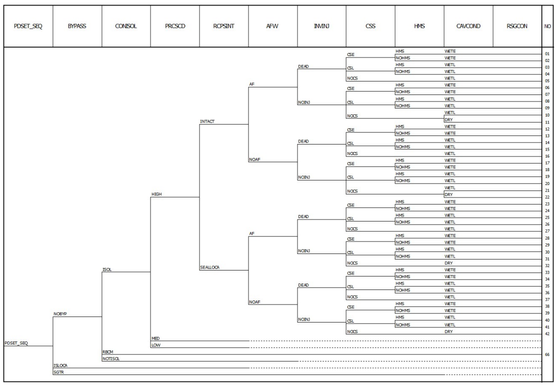

Fig. 1 Standardized PDSLD (1/2)

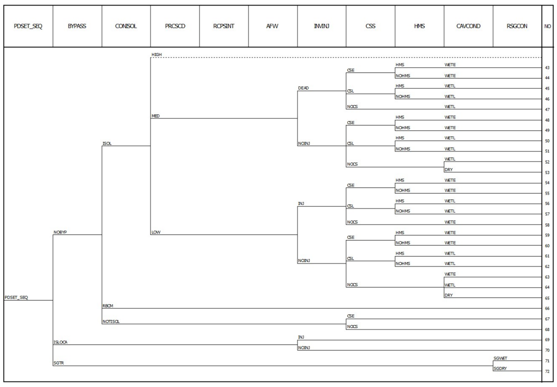

Fig. 2 Standardized PDSLD (2/2)

2.2 Development of the Containment Event Tree

In the case of a domestic Level 2 PSA, both the method of configuring individual CETs for each containment failure mode and the method of configuring all containment failure modes with one CET are used. This study uses a later one. This is because it is easy to manage the CET and track the cause of the results.

When developing the CET, a total of 10 headings have been used to determine the damage mode of the containment building as follows.

-BYPASS: Containment Bypass Accident
-CONISOL: Containment Isolation Failure
-RCSFAIL: Reactor Coolant System Status
-MELTSTOP: Core Melt Arrested
-DCF: Dynamic Containment Failure
-ECF: Early Containment Failure
-CSLATE: Status of Late Containment Spray System
-LCF: Late Containment Failure
-BMT: Containment Basemat Melt Through
-SCRUB: Status of Fission Pruduct Scrubbing

The standardized CET developed in this study is shown in Figure 3 and Figure 4.

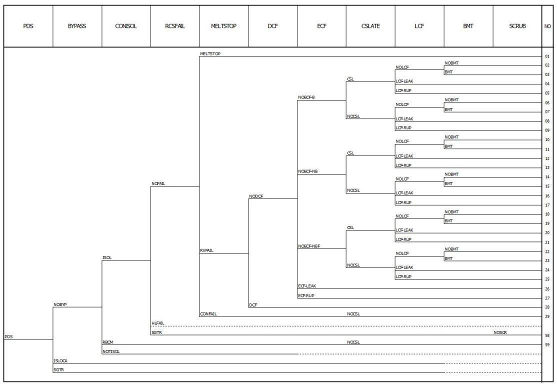

Fig. 3 Standardized CET (1/2)

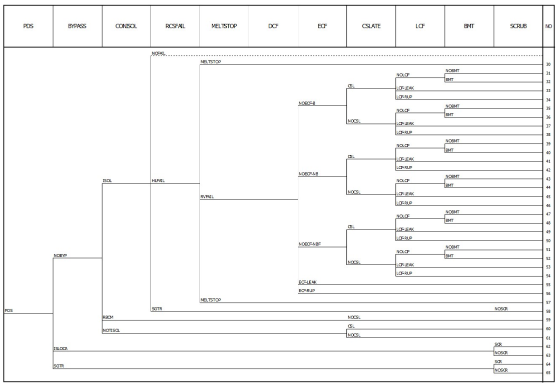

Fig. 4 Standardized CET (2/2)

2.3 Development of the Decomposition Event Tree

Each heading constituting the CET is assisted by the DET that can be judged more reasonably and in detail when the heading is branched.

The headings and branches for determining the accident progress in the containment building in each DET refer to the methodology generally used in the Republic of Korea. However, among the existing methods, the parts that were deemed necessary to reflect the latest domestic/foreign research results were revised. Also, each DET has been developed in consideration of the reflection of the MACST.

For example, in the case of RCSFAIL DET, the existing model evaluated the probability of a Thermal-Induced Steam Generator Tube Rupture (TI-SGTR) or a hot-leg/surge-line breakage based on only pressure at the time of reactor vessel rupture and these probabilities were determined regarding NUREG-1150 [3].

However, in the standardized RCSFAIL DET developed in this study, the steam generator status and loop seal clearing have been additionally considered as TI-SGTR occurrence conditions by referring to NUREG-2195, RASP Handbook, etc. [4, 5].

The standardized RCSFAIL DET developed in this study is shown in Figure 5.

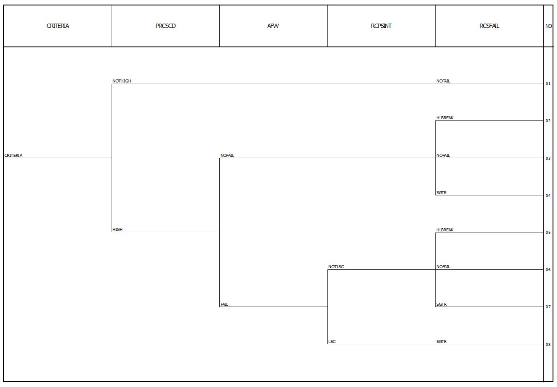

Fig. 5 Standardized RCSFAIL DET

2.4 Development of the Source Term Category Logic Diagram

Since the purpose of the STCLD is to gather containment failure scenarios that are expected to similar radiation material emission behavior, it should be composed with appropriate consideration of factors that will affect radioactive material behavior. To this end, in this study, the standardized STCLD has composed using a total of eight headings as follows.

-BYPASS: Containment Bypass Accident
-CONISOL: Containment Isolation Failure
-MELTSTOP: In-Vessel Core Melt Arrest
-TIMECF: Time of Containment Failure
-MODECF: Mode of Containment Failure
-CSLATE: Status of Late Containment Spray System
-CAVCON: Containment Cavity Condition
-SCRUB: Status of Fission Product Scrubbing

The standardized STCLD developed in this study is shown in Figure 6.

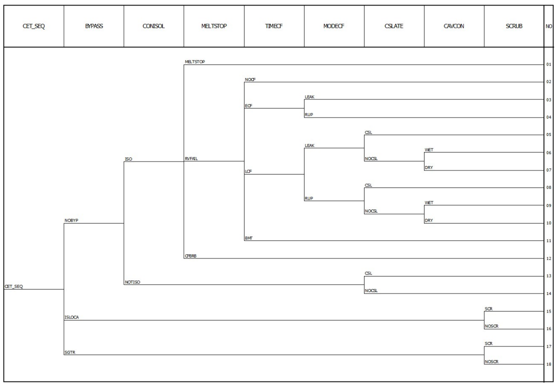

Fig. 6 Standardized STCLD DET

3. Conclusions

As safety regulation of nuclear power plants becomes more important, the regulatory agency is trying to prepare a Risk-Informed Decision Making (RIDM) system through a PSA. However, the MPAS PSA model currently held by the regulatory agency is limited to the Level 1 PSA model, so it is not possible to conduct the assessment of other risks other than Core Damage Frequency (CDF). Therefore, it is necessary to develop an MPAS Level 2 PSA model. And this model should be able to evaluate the latest accident mitigation strategies.

In this study, the standardized PDSLD, CET, DET, and STCLD have been developed to reflect the MACST in the Level 2 PSA model. It is planned to evaluate the effectiveness of the strategy by applying the developed standardized model when performing level 2 PSA for the MACST.

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