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Exhaustive Simulation Approach for Severe Accident Scenarios

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1. Introduction

Unlike Level 1 PSA which derives as many scenarios as possible, Level 2 PSA (Probabilistic Safety Assessment) uses a grouping feature to handle a tremendous of accident scenarios efficiently [1]. Level 2 PSA accident scenarios is logically much larger than Level 1 PSA accident scenarios because Level 2 PSA accident sequences were obtained by expanding the Level 1 PSA accident scenarios. Moreover, in terms of source term quantification for interface with Level 3 PSA, grouping a many accident scenario into much small groups can overcome small computational resources.

However, fourth industrial revolution accelerates increasing of computing power and current data science is pretty much ready to handle any shape of big data in many engineering fields. In this regard, it is persuasive to consider all of the Level 2 PSA accident scenarios. Exhaustive simulations of Level 2 PSA can improve the accuracy of Level 2 PSA results, and accordingly suggest many of decision-making based on the accurate Level 2 PSA results. Moreover, by comparing both approaches, it is possible to confirm the accuracy of current Level 2 PSA results.

The most challenge of the exhaustive simulation is to perform the computation code simulations for all of the accident scenarios. For the simulation of accident scenarios of NPPs (Nuclear Power Plants), integral severe accident computer code such as MAAP (Modular Accident Analysis Program), and MELCOR was used. It generally calculates mass, momentum, and energy conservation equations for water/steam behavior. Also, many phenomenological behaviors are predicted by empirical data. To simulate the specific accident scenario using these computer codes, input data which identifies several specifications of accident should be prepared. For simulations for a thousand accident scenarios, a thousand input data should be prepared that is practically impossible. To overcome this challenge, we developed a software that makes input data automatically.

The purpose of this paper is to suggest exhaustive simulation approach of Level 2 PSA for NPP, and to perform application study for the real NPP PSA models using developed approach. To this end, a software that helps to make a plenty sets of input files of severe accident computer code was developed. Using the developed software, exhaustive simulations for OPR-1000 (Optimized Power Reactor – 1000) full-power internal events were conducted.

2. *MESSAGE*: Module for Exhaustive Scenarios based Severe Accident Input Generation

For this study, MAAP code was selected as a simulation tool of severe accident scenarios because the MAAP code is a fast-running code that provides a flexible, efficient, integrated tool for evaluating the in-plant effects of a wide range of postulated accidents and for examining the impact of operator actions on accident progressions. MAAP is generally used for nuclear plant analysis including Level 1 PSA success criteria, evaluating potential severe accident mitigative actions, and analysis of a wide range of severe accident progression scenarios. In this application, we used MAAP 5.03 computer code.

MESSAGE (Module for Exhaustive Scenarios based Severe Accident Input Generation) have been developed on C# language for automatic MAAP input generation. As shown in Fig.1, the algorithm in MESSAGE combined sequence generation and MAAP input preparation. Combined sequences can be generated by combining core damage sequences and containment event sequences in Level 2 PSA. All Level 1 PSA sequences are directly connected to containment events and the resulting Level 2 PSA sequences are not grouped. The information on sequences of Level 1 PSA and Level 2 PSA is loaded by reading corresponding PSA result files. MAAP input files are prepared by adding or modifying lines in a reference input file according to the combined sequence headings. Firstly, the reference input file for each initiating event is prepared. In this reference input file, the initiating accident conditions (e.g., component/system malfunctions or pipe breaks) are defined. Secondly, the template files are prepared, in which the lines for defining the operator actions or major accident progression changes are included. Basically, a template file is prepared for each heading of plant damage state event trees and containment event trees. Thirdly, the input files are generated for all combined sequences. For each sequence, a proper reference input file is chosen, and then according to headings, the corresponding template files are added into the reference file.

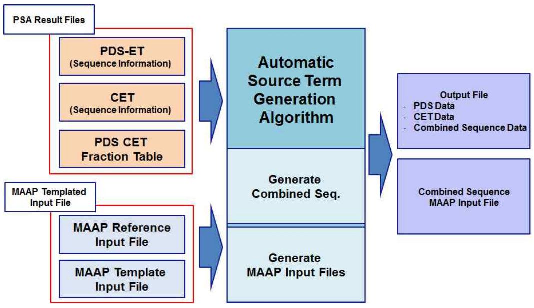

Fig.1 Schematic of MESSAGE Algorithm

3. Application results

Exhaustive simulation approach was applied into OPR-1000 full-power internal event. The number of core damage sequences and severe accident progression scenarios were 1,289 and 100, respectively. Accordingly, the number of all combination accidents scenarios were 128,900 (= 1,289 * 100). Among them, only 9,962 non-zero-frequency sequences was obtained through considering both non-zero-frequency core damage sequences and PDS-CET (Plant Damage State – Containment Event Tree) mapping fractions.

For this applications study and further studies in view of practicality, while analyzing as many numbers as possible to reduce information loss, reasonable time required for simulations should also be satisfied by analyzing the appropriate number. In this regard, this study considered top frequency 690 accident scenarios corresponding 99% cumulative frequency fractions.

Simulation results of Cs-137 and I-131 radioactivity released to environment for 690 accident scenarios were obtained as shown in Fig.2.

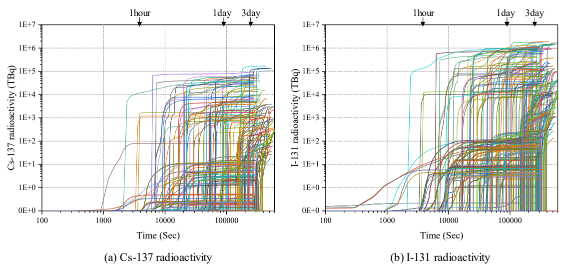

Fig.2 Simulation results of Cs-137, I-131 radioactivity released to environment (690 scenarios corresponding 99% cumulative frequency fraction)

To compare risk quantification results for both conventional grouping approach and exhaustive simulation approach, illustrating risk stairs was suggested as shown in Fig. 3. Each simulation result is expressed in a rectangle, with a width of frequency and a height of amount of Cs-137 release. Fig.3 (a), is comprised of 17 rectangles because grouping approach simulated only 17 accident scenarios for 17 STCs (Source Term Categories). On the other hand, Fig.3 (b) is comprised of 690 rectangles corresponding the exhaustive accident scenarios.

Fig.3 (c) shows two lines corresponding both approaches by extracting top line. Below area of the line means total risk index because it is equivalent to summation of the values multiplied by frequency and amount of Cs-137 release. It should be noted that, consequence analysis was not performed, so this study assumed amount of Cs-137 release as consequence index. Risk indexes were estimated 8.24E-2, and 3.69E-2 for conventional grouping approach and exhaustive simulation approach, respectively. Given that the risk estimation of exhaustive simulation approach is close to real value, conventional grouping approach may overestimate risk values by more than twice. This application study was performed using representative accident scenarios with the largest amount of Cs-137 within the specific group. It means the results considerably depend on how to determine the representative accident scenarios.

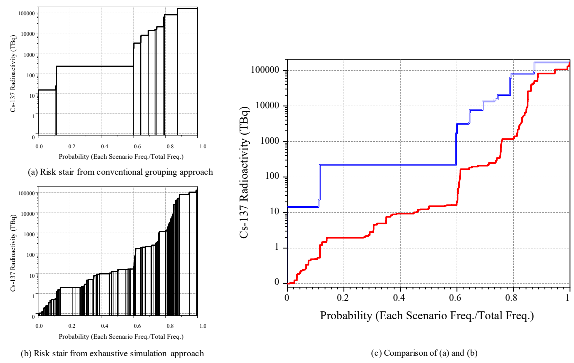

Fig.3 Risk stair results for (a) conventioanl grouping approach and (b) exhaustive simulation approach

4. Conclusion

This study suggested exhaustive simulation approach of Level 2 PSA accident scenarios with new software which is automatic input generator of MAAP code. The application results show that exhaustive simulation approach worked properly with an operating large-size NPP and its PSA model. Further studies are required to expand the exhaustive simulation approach to new Level 2 PSA method and risk-informed application.

ACKNOWLEDGEMENT

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REFERENCES

[1] Development and Application of Level 2 Probabilistic Safety Assessment for Nuclear Power Plant, Specific Safety Guide, No. SSG-4, IAEA, 2010.