Transactions of the Korean Nuclear Society Autumn Meeting
Changwon, Korea, October 20-21, 2022

A Study on the Current State-of-the-Art for Decomposition Event Tree in Level 2 PSA

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1. Introduction

After the amendment of Nuclear Safety Act in 2015, licensee submitted accident management plans (AMPs) for all operating nuclear power plants (NPPs) as well as plants which are under regulatory reviews for operating license. According to the Article 85-22 (Assessment of accident management capabilities) in Regulation on Technical Standards for Nuclear Reactor, etc., the assessment results of accident management capabilities using probabilistic method should be included in the AMPs.

Hence, licensee performs probabilistic safety assessments (PSAs) and shows whether the PSA results meets the risk targets suggested in the Article 9 (risk evaluation) in NSSC (Nuclear Safety and Security Commission) rules 2017-34.

However, technical issues are raised due to the phenomenal uncertainties of severe accident which would be considered in the branch probabilities in decomposition event tree (DET) of Level 2 PSA [1].

This study aims to review the current status-of-the-art for key DETs of Level 2 PSA and explain the insights.

2. Brief Overview of Level 2 PSA

Plant damage state (PDS) event tree (ET) is developed by considering additional headings related to the plant conditions after the core damage, which affect severe accident progression and mitigation. PDS ET sequences having a similar behavior and characteristics are grouped into several PDSs using PDS logic diagrams. For each PDS, severe accident progression and subsequent containment failure are analyzed by CET analysis. A number of headings which describe possible containment failure modes and mechanism by severe accident progression and mitigation functions are used. For each CET headings, DET is developed for detailed modeling and quantification of severe accident progression.

3. Current Status-of-the-Art for DET Headings and its Branch Probability

In this study, the composition and branch probabilities of each DET were examined for the 9 headings of CET considered in Level 2 PSA for domestic NPPs. This section will deal with cases in which the analysis methodology of DET or the composition, conditions, and probabilities of DET branches are significantly different for each NPP type.

3 DETs such as ‘RCSFAIL’, ‘MELTSTOP’ and ‘BMT’ are selected and the brief explanation and the current status of the DETs are as follows.

3.1 RCSFAIL

DET-RCSFAIL determines whether the reactor coolant system (RCS) pressure boundary is intact under high RCS temperature and pressure during core damage and before the breach of lower head of the reactor vessel.

In RCSFAIL, the branch probability of ‘HOT LEG BREAK’ and ‘SGTR’ is determined based on generic data such as NUREG/CR-4551. However, significant difference was shown in the branch probability of ‘HOT LEG BREAK’ and ‘SGTR’ even the same generic data is referenced.

For example, Type A NPP uses 0.72 and 0.018 as branch probability for ‘HOT LEG BREAK’ and ‘SGTR’ based on NUREG/CR-4551 [2]. However, Type B NPP uses 0.1 and 0.01 whereas Type C NPP uses 0.35 and 0.018 respectively.

It was revealed that the effects of RCS depressurization was considered in the branch probability of Type B NPP and high pressure melt ejection and direct containment heating in case of reactor vessel breach was assumed for Type C NPP branch probability.

3.2 MELTSTOP

DET-MELTSTOP determines the integrity of reactor vessel considering the in-vessel injection. Type A, B and C NPPs used branch probability of DET-MELTSTOP based on NUREG/CR-4551.

Since 9 different cases were classified as MELTSTOP in NUREG/CR-4551, analysts selected different values based on their engineering judgment.

For the case where in-vessel injection is possible, 3 types of NPPs used branch probability of MELTSTOP provided in the NUREG/CR-4551.

However, it was shown that Type A NPP used the branch probability considering the timing of water injection. For example, if the RCS depressurization is delayed after an accident or the in-vessel injection is delayed, the probability of 0.9 is used based on the case 3 in NUREG/CR-4551.

For the case where in-vessel injection fails due to RCS pressure, the branch probability of 0 is used based on case 4 in NUREG/CR-4551.

For the case where RCS breaks, a situation that the RCS pressure decreases rapidly and the core cooling is successful as water is injected into the vessel is considered. In this case Type A NPP used branch probability of 0.5 based on case 7 in NUREG/CR-4551, whereas Type B NPP used branch probability of 0.9 based on the case 8 in NUREG/CR-4551 and NUREG-1150 [3].

Moreover, it was shown that there is an additional branch 'CTMNT FAIL' in heading ‘MELTSTOP’ considered for Type B and C NPPs. If the heat removal of the containment is successful, the branch is divided into 'MELTSTOP' and 'RV RUPTURE'. However, if the heat removal is failed, the branch is divided into 'CTMNT FAIL' and 'RV RUPTURE'. The branch probability of 'MELTSTOP' and 'CTMNT FAIL' is same.

3.3 BMT

BMT determines the containment integrity since the MCCI can penetrate the basemat in the reactor cavity. For Type A and C NPPs, the probability of occurrence of BMT is determined by the heading ‘LHTX’ that determines the heat transfer rates of the core material and coolant [4].

For ‘LHTX’, Type A and Type C NPPs used the branch probability of 0.01 according to the engineering judgment referring to the System 80+ and etc.

However, Type B NPP used the branch probability considering several conditions provided in NUREG/CR-4551. If the core material is cooled successfully or if large amount of core materials is released outside the reactor cavity, the branch probability of the BMT is assigned as 0. If the core material is not cooled and if small amount of core material is released outside the reactor cavity, there are four different BMT branch probabilities based on case 3, 4, 5, and 6 in NUREG/CR-4551.

4. Discussion

This section further discusses the DET-BMT. For Type B NPP, DET-BMT used the NUREG/CR-4551. The BMT occurrence probability is determined considering the situation whether the core is cooling, whether the cavity is flooded, and whether the amount of core material exists in the cavity (CR-EJECT). The heading such as ‘CR-EJECT’ is only considered in Type B NPP and its branch probability is based on NIREG/CR-4551. When MCCI is progressed, the probability of occurrence of BMT is assigned as 0.25 if a cavity is flooded and 0.4 if not flooded.

If less than 40% and more than 20% of the molten corium are released outside the reactor cavity and the cavity is flooded, a branch probability of 0.05 is assigned and 0.2 is assigned if not flooded. When MCCI proceeds with a small amount of core material, it is assumed that BMT does not occur.

For Type A and C NPPs, the BMT occurrence probability is determined by the heat transfer rate from the core materials to the coolant. Type A assumed the occurrence of BMT when the heat transfer coefficient between the core material and the coolant is very low. Referring to System 80+, the probability of molten corium penetration within 72 hours after the accident was evaluated as 0.01 [5].

Type C was analyzed using various deterministic model. Even in the analysis with the conservative heat transfer rate applied, the maximum erosion depth of the basemat did not exceed the criteria and still have margin for BMT. Therefore, BMT was judged to be difficult to occur within 3 days after the accident under any conditions, and the branch probability was designated as 0.01 which corresponds to ‘very unlikely’. The probability of the heat transfer rate was 0.01 with reference to CESSAR DC and System 80+.

Type A and C NPPs can be considered more conservative than Type B NPP, since the occurrence of BMT is assumed in case where cavity is not flooded. However, if the cavity is flooded, Type A and C have a heat transfer probability and BMT probability of 0.01, whereas Type B NPP has probability of 0.25 and 0.05 depending on the amount of core material. As it is shown, a branch probability of Type B NPP is conservative compared to Type A and C NPPs in case of cavity flooding. However, it is difficult to accurately compare the conservatism because the assumptions and considerations are different. For an additional explanation, the methodology referenced in Type B was published in the 1990s and since it is analyzed for five U.S. NPPs, situations may differ from domestic NPPs. Moreover, analysis using the MELCOR code has been continuously improved, which reduces the uncertainty of severe accidents and reasonable conservatism can be expected in terms of the safety of NPPs. Therefore, Type A and C NPPs are expected to be more suitable for the situation of domestic NPPs as they can simplify the number of headings through ‘LHTX’ and specify probability values applied with deterministic analysis model results and recent PSA results.

In addition, when comparing Type A and C, their electric power and construction date are quite different. However, it is not considered reasonable to have the same probability in the branch of the heat transfer rate. The System 80+ document referenced is more recently written than construction of Type A, and it is judged that there will be a problem to apply it equally to Type A and C NPPs. Therefore, a new standard needs to be applied to Type A NPP.

5. Conclusion

Through this study, the technology status considered in the three major DETs was identified. The results of this study are expected to be useful in reducing DET uncertainty. In the future, further studies such as the validity of the reference used in MELTSTOP will be needed.

Acknowledgements

This study was supported by the Nuclear Safety Research Program through the Korea Foundation of Nuclear Safety (KoFONS), granted financial resource from the Nuclear Safety and Security Commission (NSSC), Republic of Korea

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