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Development of Safety Evaluation Methodology for Beyond Design Basis Accident

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1. Introduction

Although the deterministic and probabilistic approaches seem to be different and have no relationship, they are somewhat complementary to each other. The limitation of deterministic approach is mainly caused by considering only design basis accident scenario which has unrealistic assumptions. On the contrary, in probabilistic approach, all possible and realistic sequences including operator action are taken into account. The probabilistic approach also has the limitation that there is not systematic assessment to classify the sequence as success or core damage and PSA has lack of acceptance criteria and concept of safety margin. On the other hand, in deterministic approach, there is systematic thermal-hydraulic calculation methodology called BEPU, and acceptance criteria and safety margin are very well defined and strictly applied.

The safety of nuclear power plant for beyond design basis accidents (BDBAs) has been evaluated by using the PSA results. In present PSA results, most of BDBAs have very low CDF values because the initiating event frequencies (IEFs) of that are extremely low as compared with those of DBAs. However, the conditional core damage probabilities (CCDPs, = CDF/IEF) for BDBAs are very high and that means if the accident occurs it can be aggravated to severe accident with high probability. Nevertheless, the nuclear power plants have been considered to be safe for BDBAs due to very low values of CDF. In addition, since the IEF included in CDF has large uncertainty, CDF is not enough to be only criterion to represent the nuclear safety for BDBAs.

In this study, the safety analysis method integrating the deterministic and probabilistic approach is reviewed, and based on this method the safety evaluation methodology for BDBA is developed.

2. Integrated Safety Analysis Method

Integrated safety analysis method has been developed in the way of quantifying functional failure by using BEPU analysis and including explicitly it into PSA. A functional failure is defined as the inability of a system to perform its mission due to deviations from its expected behavior [1]. Within a reliability physics framework, a functional failure occurs whenever the applied “load” exceeds the “capacity” [2, 3]. Practically, the probability density function of the load is determined directly by BEPU calculations and that of the capacity simply is replaced by safety limit which is expected to be set below actual capacity conservatively. Therefore the functional failure probability is defined as the probability that load exceeds the safety limit, and is also called exceedance probability [4]. Once the exceedance probability is calculated, it is implemented in PSA, and then the CDF values can be a final measure of the safety of system.

3. Safety Evaluation Methodology for BDBA

The safety objective for beyond design basis accident is to avoid core damage such as cladding embrittlement, etc. Level 1 PSA result can be utilized and the safety limits applied to calculate exceedance probability can be defined as requirements of 10CFR50.46 such as peak cladding temperature and cladding oxidation thickness, etc. Both core damage frequency and conditional core damage probability are the acceptance criteria determining whether nuclear plant is safe or not. The CDF and CCDP are set as comprehensive acceptance criterion for safety and acceptance criterion evaluating mitigation capability respectively.

A flow diagram of the methodology is shown in Fig. 1. The methodology is composed by the following 14 steps;

1. Select BDBA: the analyst selects the beyond design basis accident (initiating event) to be evaluated based on the design and operation experience information.
2. Determine target CDF & CCDP: the values of CDF and CCDP as acceptance criteria are determined for specific BDBA.
3. Determine IEF: initial event frequency is assessed based on operating experience database, etc.
4. Identify accident sequence: the progress of an accident with initiating event as a start point is predicted.
5. Quantify sequence probability & frequency: the sequence probabilities and sequence frequencies are quantified based on the unavailability of equipment.
6. Is sequence needed to calculate $P_{cond,exc}$: In this step, a preliminary estimate of the conditional exceedance probability is performed. Conservatively, the conditional exceedance probabilities can be calculated on only success paths in traditional PSA results.
7. Develop simulation model: In this step, the model used to simulate the evolution of the sequence is developed

or chosen among existing ones. The model should be a best estimate model, so that uncertainties in the parameters can be propagated.

8. Identify & quantify relevant uncertainties: In this step, the relevant uncertainties should be identified and quantified.

9. Calculate conditional exceedance probability: The probability density function of the load and probability that the load exceeds the capacity representing safety limit for a given sequence are calculated.

10. Return value of conditional exceedance probability: The conditional exceedance probability determined from step 6 or 9 for all sequence should be returned to calculate CDF & CCDP.

11. Calculate CDF & CCDP: In this step, core damage frequency and conditional core damage probability are calculated using the conditional exceedance probability.

12. CDF & CCDP < acceptance criteria: The calculated CDF and CCDP for the accident from step 11 should be compared with target CDF and CCDP from step 2, respectively.

13. Plant modification: If the calculated CDF and CCDP don't meet acceptance criteria, plant design should be modified or reliability of component utilized in the accident should be increased in order to improve the safety, and re-follow previous steps.

14. End of evaluation: If the calculated CDF and CCDP meet acceptance criteria, the evaluation of BDBA is terminated.

4. Conclusions

The safety evaluation methodology for beyond design basis accident is developed based on the safety analysis method integrating the deterministic and probabilistic approach to supplement the limitation. In this methodology, the conditional exceedance probability is quantified by using best-estimate plus uncertainty analysis and included explicitly into probabilistic safety assessment. Both core damage frequency and conditional core damage probability are the acceptance criteria.

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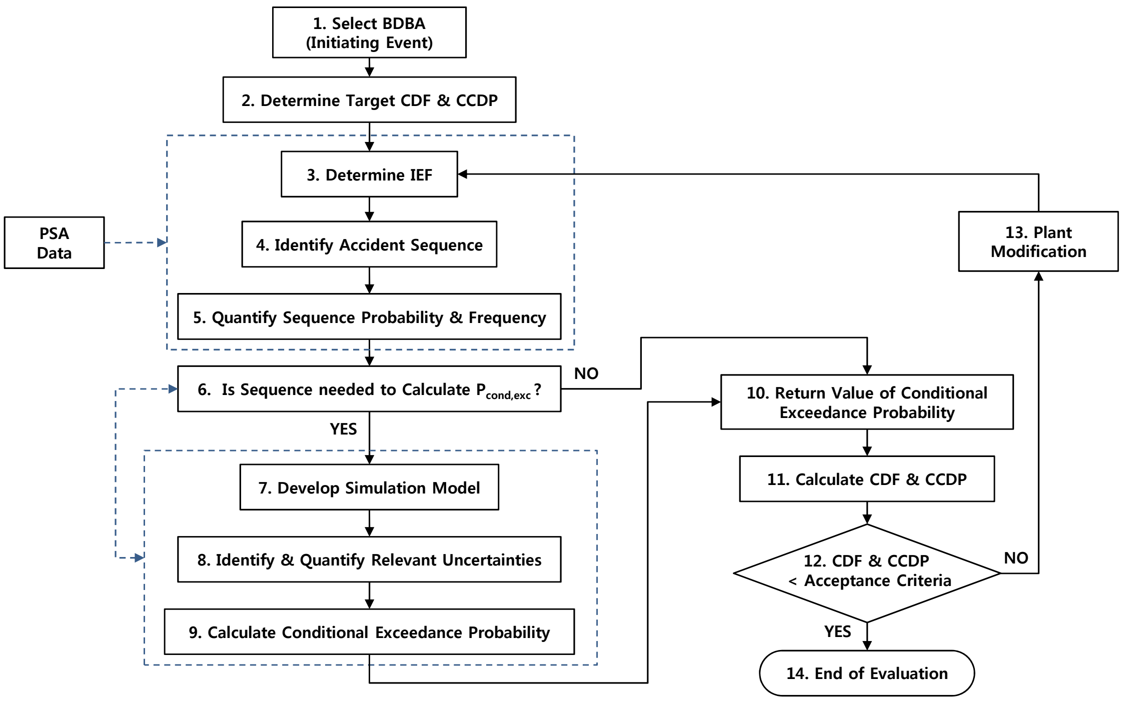

Fig. 1. Flow diagram of safety evaluation methodology for BDBA