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Original Article

Application of Dynamic Probabilistic Safety Assessment Approach for Accident Sequence Precursor Analysis: Case Study for Steam Generator Tube Rupture

Hansul Lee [a], *Taewan Kim* [b], *and Gyunyoung Heo* [a,*]

[a] *Kyung Hee University, 1732 Deogyeong-daero, Giheung-gu, Yongin-si, Gyeonggi-do, 17104, South Korea*
[b] *Incheon National University, 119 Academy-ro, Yeonsu-gu, Incheon, 22012, South Korea*

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ABSTRACT

The purpose of this research is to introduce the technical standard of accident sequence precursor (ASP) analysis, and to propose a case study using the dynamic-probabilistic safety assessment (D-PSA) approach. The D-PSA approach can aid in the determination of high-risk/low-frequency accident scenarios from all potential scenarios. It can also be used to investigate the dynamic interaction between the physical state and the actions of the operator in an accident situation for risk quantification. This approach lends significant potential for safety analysis. Furthermore, the D-PSA approach provides a more realistic risk assessment by minimizing assumptions used in the conventional PSA model so-called the static-PSA model, which are relatively static in comparison. We performed risk quantification of a steam generator tube rupture (SGTR) accident using the dynamic event tree (DET) methodology, which is the most widely used methodology in D-PSA. The risk quantification results of D-PSA and S-PSA are compared and evaluated. Suggestions and recommendations for using D-PSA are described in order to provide a technical perspective.

1. Introduction

The event-tree-based methodologies are extensively used to perform reliability and safety assessments of complex and critical engineering systems. One disadvantage of these methods is that the timing/sequencing of events and system dynamics is not explicitly accounted for in the analysis. Several techniques, such as dynamic-probabilistic safety assessment (D-PSA), have been developed in order to overcome these limitations. Monte Carlo simulation and dynamic event tree (DET) are two of the most widely used D-PSA methodologies for the safety assessment of nuclear power plants (NPPs) [1].

In the 1990s, the D-PSA was applied only in limited accident scenarios such as a steam generator tube rupture (SGTR) accident because of a lack of available computational power. In the 2000s, Monte Carlo or DET was used for the support of existing

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[*] *Corresponding author.*
E-mail address: gheo@khu.ac.kr (G. Heo).

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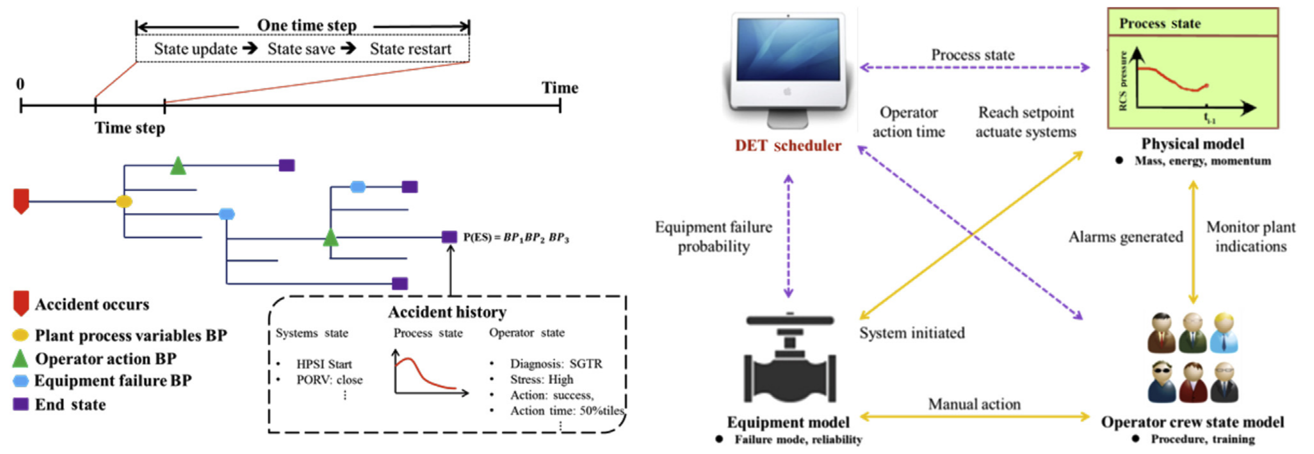

Fig. 1 – Schematic diagram of dynamic event tree and dynamic interactions in nuclear power plants. BP, branch probability; DET, dynamic event tree; HPSI, high-pressure safety injection; NPP, nuclear power plant; PORV, pilot operated relief valve; SGTR, steam generator tube rupture.

safety analysis. Several tools have been developed under the DET framework: Monte Carlo dynamic event tree (MCDET) [2], analysis of dynamic accident progression trees (ADAPT) [3], simulation code system for integrated safety assessment (SCAIS) [4], and reactor analysis and virtual control environment (RAVEN) [1]. Currently, RAVEN, accident dynamic simulator (ADS), and ADAPT codes are used for design basis accident (DBA) and severe accident analysis in the United States. By using the D-PSA approach, it is possible to derive high-risk/low-frequency accident scenarios through the derivation of all possible scenarios and to reflect the dynamic interaction between the physical state of the plant in the accident situation and the actions of the operator in the risk quantification.

In this paper, an SGTR accident in a Korean NPP was studied using the DET in the D-PSA to investigate the applicability of D-PSA for accident sequence precursor (ASP) analysis. The risk quantification results from the D-PSA and the conventional PSA, the so-called static PSA (S-PSA) due to its relatively fixed nature, were compared. The authors recommended application plans and described the expected outcomes of D-PSA.

2. Materials and methods

2.1. *ASP analysis*

The primary objective of the ASP program is to systematically evaluate operating experiences to identify, document, and rank those events in terms of the potential for inadequate core cooling and core damage. In addition, the program has the following secondary objectives: (1) to categorize the precursors for plant-specific and generic implications; (2) to provide a measure that can be used to trend nuclear plant core damage risk; and (3) to provide a partial check on PSA-predicted dominant core damage scenarios [5].

Events were selected and documented as precursors to potential severe core damage accidents (accident sequence precursors) if the conditional probability of subsequent core damage exceeds at least 1.0^{-6}.

2.2. *D-PSA approach*

The DET integrates the plant physical model, operator crew state model, and equipment model based on dynamic interactions in an accident situation. It conducts a new generation of branch points and analyzes potential accident sequences using the DET scheduler [6]. The DET has a function that is responsible for sharing and exchanging information between the models while reflecting dynamic interactions in an accident situation. Each model is briefly described as follows.

2.2.1. *Plant physical model*

This provides the NPP states and thermal hydraulic parameters by integrating information regarding operator action, the probability distribution from the operator/crew state model, and the equipment model.

2.2.2. *Operator crew state model*

This model calculates the probability of operator action failure and determines the probability of the samples assuming the distribution of operator actions. The probability of the samples is used for the calculation of core damage frequency (CDF).

2.2.3. *Equipment model*

The equipment model determines the reliability of automatic and manual operation of equipment. The reliability is used for the calculation of CDF. For realistic calculation, the reliability of the equipment model includes the aging effect and thermal hydraulic conditions in an accident situation.

2.2.4. *DET scheduler*

This provides new generation and analysis for branches of potential accident sequences. The DET scheduler performs the acquisition/distribution of information for each module at a specified time interval. In addition, it sets up the truncation criteria for determining the interruption of analysis and assigns the boundary condition of thermal–hydraulic analysis. The schematic diagram of the DET is shown in Fig. 1.

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