# Development of A Framework For Assessing Accident Sequence Precursor and Its Application

Sunghyun Park, Seunghyun Jang and Moosung Jae*
*Department of Nuclear Engineering, Hanyang University, Sungdong-gu, Seoul, 04763, Korea*
**Corresponding author: jae@hanyang.ac.kr*

## 1. Introduction

The purpose of ASP (Accident Sequence Precursor) analysis is to evaluate operational accidents in full power and low power operation by using PRA (Probabilistic Risk Assessment) technologies. In 1979, US performed ASP analysis for the first time in the world. They developed a model which covers limitations of existing PRA models. And, SPAR (Standardized Plant Analysis Risk) program has been developed to support ASP programs since 1992. 80 SPAR programs on behalf of 100 nuclear power plants in US has been developed by 2013 and they has expanded the research and development range.

Recently, the awareness of the importance of ASP analysis has been on rise. The methodology for ASP analysis has been developed in Korea, KINS (Korea Institute of Nuclear Safety) has managed KINS-ASP program since it was developed.[1] In this study, we applied ASP analysis into operational accidents in full power and low power operation to quantify CCDP (Conditional Core Damage Probability). To reflect these 2 cases into PRA model, we modified fault trees and event trees of the existing PRA model. Also, we suggest the ASP regulatory system in the conclusion.[2]

## 2. Methods and Results

The risk of operational accidents could be quantified by modified PRA models. The modified factors could be event trees, fault trees, frequency of initiating event, failure-rate of components, and probabilities of human error and recovery and uncertainty parameters.

### *2.1 A Methodology for ASP Analysis*

To apply the accident sequence into PRA model, we have to modify an existing PRA model.[3] In this study, we suggest 4 steps to analysis ASP.

1. To select precursor: it induces inadequate core cooling or core damage.
2. To be familiar with a sequence of accident: it needs to reflect a real accident data into PRA model.
3. To modify an existing PRA model: fault trees, event trees, frequency of IE, probabilities of human errors, etc.
4. To quantify a modified PRA model: it needs to get a CCDP.

### *2.2 Application and Results*

We performed ASP analysis in full power and low power operation. We select the LOKV in Hanbit and SGTR in Hanul. And, we used SAREX program to modify PRA model and quantify it.[4]

#### *2.2.1 Full Power*

The operational accident in full power operation is ‘Loss of a 4.16kV AC bus and running of EDG by running of a ground fault protection relay in Hanbit unit 4’. It is as below,

1. Running Start-Up Transformer (SUT) and a ground fault protection relay (251 GNA)
2. Opening of a switchyard circuit breaker (PCB 7900, 7971), a 4.16kV AC bus circuit breaker
3. Loss of Voltage (LOV)
4. Running Emergency Diesel Generator (EDG) and supplying power to 4.16kV AC bus

Full power PRA model of Hanbit nuclear power plant (unit 3, 4) was used as a base model. The event tree is shown in Fig. 1. And, 2 kinds of fault trees were changed due to unavailability of 01SA Fig. 2 and running of EDG shown in Fig. 3.

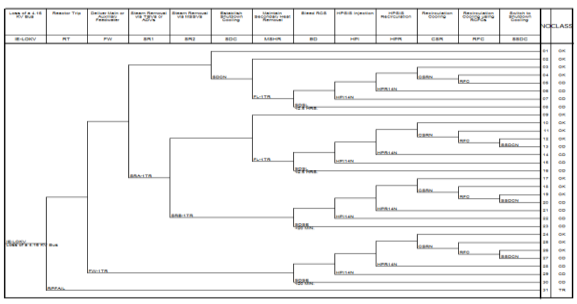

Fig. 1. Event Tree of LOKV

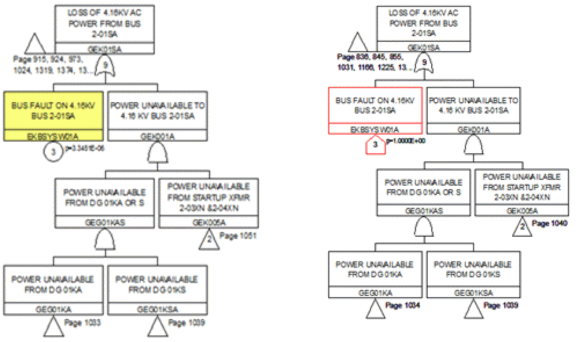

Fig. 2. Modified Fault Tree by unavailability of 01SA

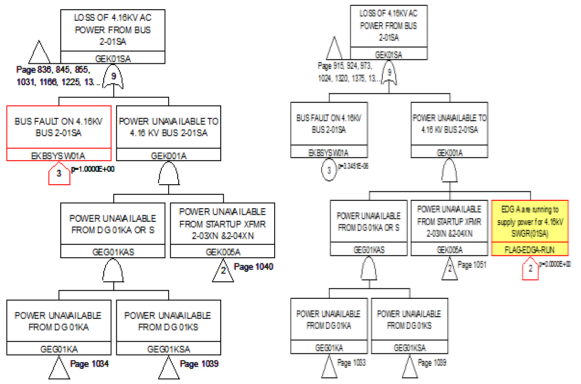

Fig. 3. Modified Fault Tree by running of EDG

The quantification results is shown in Table I. The net result of CCDP is 1.195E-06. It means a 'Precursor' and 'White' in color coding of NRC.[5]

Table I: Result of Case 1

| model | value | per (%) | cut-off |
|---|---|---|---|
| Base model | $2.267x10^{-9}$ | - | $1.0x10^{-12}$ |
| %IE = 1 | $1.195x10^{-6}$ | - | $1.0x10^{-9}$ |
| Current case 1 | $1.195x10^{-6}$ | 0(%) | $1.0x10^{-9}$ |
| Current case 2 | $1.195x10^{-6}$ | 0(%) | $1.0x10^{-9}$ |

### *2.2.2 Low Power and Shutdown*

The operational accident in low power operation is 'Safety injection by Steam Generator Tube rupture in Hanul unit 4'. It is as below,[6]

1. Shutdown for overhaul
2. Drawing-down of level during hot standby mode
3. An alarm for high reactivity in SG blow down line occurs.
4. Recognizing tube rupture in SG B
5. Isolating SG B
6. Pressure equilibrium by SG A

This accident occurred in POS (Plant Operational State) 2. Full power PRA model of Hanul nuclear power plant (unit 3, 4) was used as a base model. The event tree was changed by deleting the heading of RT (Reactor Trip), DPI (Depressurize RCS for LPSIS Injection) and LPI (LPSIS Injection) which is shown in Fig. 4.

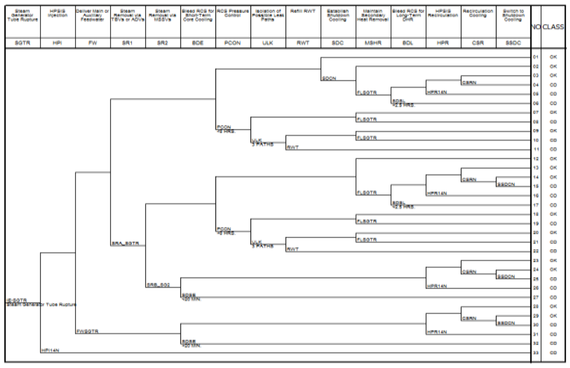

Fig. 4. Deletion headings of RT, DPI and LPI

There are 3 types of modified fault trees. These are due to a loss of electrical grid by turbine trip couldn't occur, delete of auto reset and human error that a manager, at that time, opened MSIBV to prevent leaking out of radioactive materials. These are shown in Fig. 5, Fig. 6 and Fig. 7.

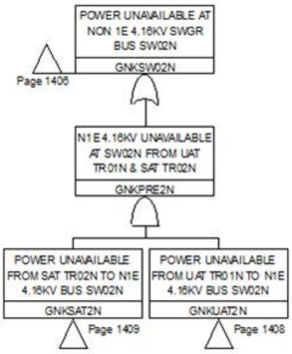


Fig. 5. Deletion of EOSYFTRIP

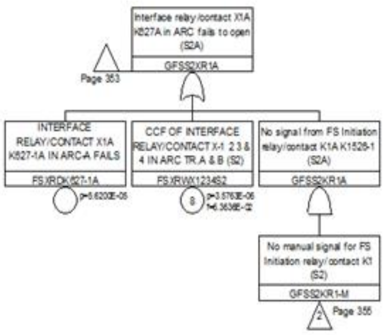

Fig. 6. Deletion of auto signal

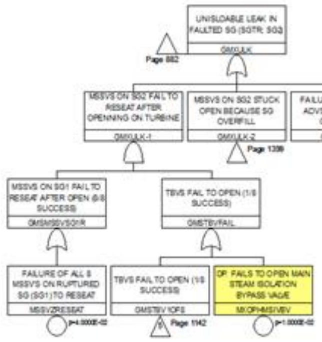

Fig. 7. Consideration of MSIVBV

The quantification results is shown in Table II. The net result of CCDP is 2.261E-03. It means a ‘Precursor’ and ‘RED’ in color coding of NRC.

Table II: Result of Case 2

| model | value | per (%) | cut-off |
|---|---|---|---|
| Base model | 50195x10$^{-7}$ | - | 1.0x10$^{-12}$ |
| %IE = 1 | 1.159x10$^{-4}$ | - | 1.0x10$^{-10}$ |
| Current case 1 | 1.134x10$^{-4}$ | -2 | 1.0x10$^{-10}$ |
| Current case 2 | 2.289 x10$^{-3}$ | 1875 | 1.0x10$^{-10}$ |
| Current case 3 | 2.261 x10$^{-3}$ | 1851 | 1.0x10$^{-10}$ |
| Current case 4 | 2.261 x10$^{-3}$ | 1851 | 1.0x10$^{-10}$ |

## 3. Conclusions

In this study, we reviewed previous studies for ASP analysis. Based on it, we applied it into operational accidents in full power and low power operation. CCDP of these 2 cases are 1.195E-06 and 2.261E-03.

Unlike other countries, there is no regulatory basis of ASP analysis in Korea. ASP analysis could detect the risk by assessing the existing operational accidents. ASP analysis can improve the safety of nuclear power plant by detecting, reviewing the operational accidents, and finally removing potential risk. In the future, this study might contribute to systematize a regulatory basis of ASP analysis in Korea. We suggest the regulatory system of ASP program in Fig. 8.

Operator have to notify regulatory institute of operational accident before operator takes recovery work for the accident. After follow-up accident, they have to check precursors in data base to find similar accident. And, probabilistic safety assessment and deterministic review of the accident are performed. Based on this information, regulatory institute takes appropriate actions to check and evaluating licensee for this precursor.

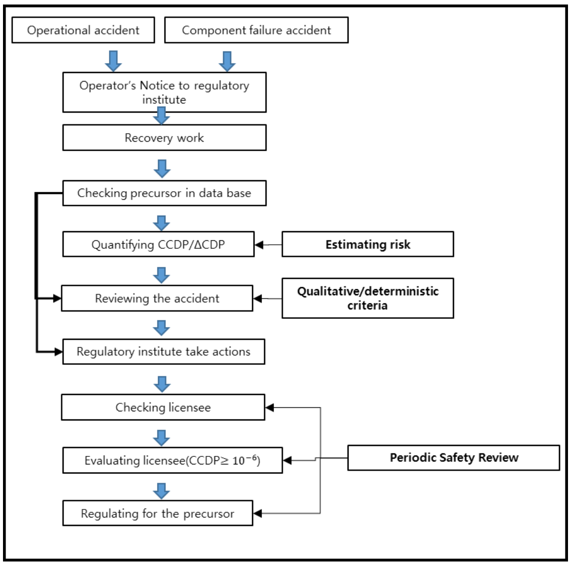


Fig. 8. Regulatory system of ASP

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