Transactions of the Korean Nuclear Society Spring Meeting
Jeju, Korea, May 18-19, 2023

Concept of Level 3 PSA Event Tree Model Considering Emergency Responses

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1. Introduction

Many researches on Level 3 probabilistic safety assessment (PSA) have been done to evaluate radiological consequences of hypothetical accident of the nuclear power plant [1]. Simulation codes are generally employed to calculate the effect to the public health and environment through estimation of the offsite atmospheric dispersion. Health effects are largely related to the weather condition and countermeasures such as sheltering and evacuation.

A research report from VTT performs ID-PSA (integrated deterministic and probabilistic safety assessment) as pilot study for Fukushima accident [2]. The goal of this report is to probabilistically analyze whether the low fatality from radiation in the Fukushima accident was a coincidence or not. The paper used deterministic methods for atmospheric dispersion and population dose analysis, while probabilistic methods are used for weather condition, and success rate of sheltering and/or evacuation. Average weather data in March and evacuation and/or sheltering probabilities based on expert judgment were developed as event tree, and the ARANO code [3] was used to analyze offsite consequence analysis. However, the report presents only indicative data with limitation in simple modeling of evacuation and/or sheltering probabilities.

In order to reflect the human responses to the emergency condition, this paper provides a Level 3 event tree concept considering emergency response plans. In this study, only internal events are included without considering natural disaster. The main purpose of this paper is to propose a new concept to analyze Level 3 PSA by event tree [4].

The results drawn by this concept can produce probabilistic consequence with reduced conservatism. In addition, it would be helpful to decision making in emergency response process by performing sensitivity analysis and evaluating important parameters.

2. Concept of Level 3 PSA Event Tree

Level 3 event tree heading should be determined carefully with a reference to radiological emergency plan guidelines. The probabilities of success and failure depends on the human responses in accordance with dynamic behavior of TSC (Technical Support Center), EOF (Emergency Operation Facility), and public. To use WinMACCS as a consequence analysis code, appropriate input model should be developed taking into account all the Level 3 event tree headings.

2.1 Level 3 PSA Event Tree Model

Fig. 1 illustrates the PSA methodology framework. In Fig. 1 top image, the quantities and probabilities of STCs (Source Term Categories) resulting from the Level 2 PSA are used as inputs to the Level 3 PSA analysis. At this point, Level 3 PSA performs a deterministic offsite consequence analysis for a representative scenario of each STCs, and the conditional consequence is multiplied by the STC probability to derive the risk. Statistical consideration which is incorporated in current Level 3 PSA studies was only about meteorological data. The Level 3 calculation codes generally take into account annual weather condition, cohort characteristics, and deterministic sheltering and/or evacuation times, etc. Fig. 1 bottom image shows the concept of Level 3 Event Tree model presented in this study. This concept performs a probabilistic analysis of offsite scenarios, similar to the Level 1 and Level 2 PSAs. After the accident initiation of a nuclear power plant, various scenarios may occur depending on the response of the licensee, government and the public.

2.2 Headings of Event Tree

When severe accident occurs, the licensee will evaluate the emergency situation in accordance with the Radiation Emergency Plan and the Implementation Procedures. After the public is made aware of the hazardous situation through an emergency declaration, the public is evacuated in accordance with the Radiation Emergency Plan Guidelines. Various factors such as decision support system and/or human error determine the probability of success and failure of sheltering and/or evacuation, which in turn determine offsite consequences.

Fig. 2 shows an example of a Level 3 event tree. The heading of the event tree should be determined by a variety of sources, including the radiological emergency plan and the emergency response guidelines for population protection. In this paper, the event tree of a Level 3 PSA is divided into four main parts: the first is the type of accident, which is the early and late release. The second is the timing of resident alerts for the emergency. This is divided into success, delay 1, delay

2, and failure, each of which means very quick, before source release, after source release, and too late alarm.

The third and fourth headings, sheltering and evacuation, are based on Emergency Response Guidelines and the human and social sciences. The probabilities can be calculated using reliable expert judgment, experiences, and simulations.

The probability of the second heading, Alarm, can be derived from an example DET (Decomposition Event Tree), as shown in the bottom image of Fig. 2. This DET method is commonly used in Level 2 PSA analysis to determine the probability of each branch of a large event tree [5]. This is just one hypothetical example, but various factors including instrumentations, simulator, human error, broadcast systems, etc. might be considered.

Each scenario obtained along the Level 3 Event Tree will be simulated using WinMACCS code. The risk can then be calculated from the consequence and frequency of each scenario.

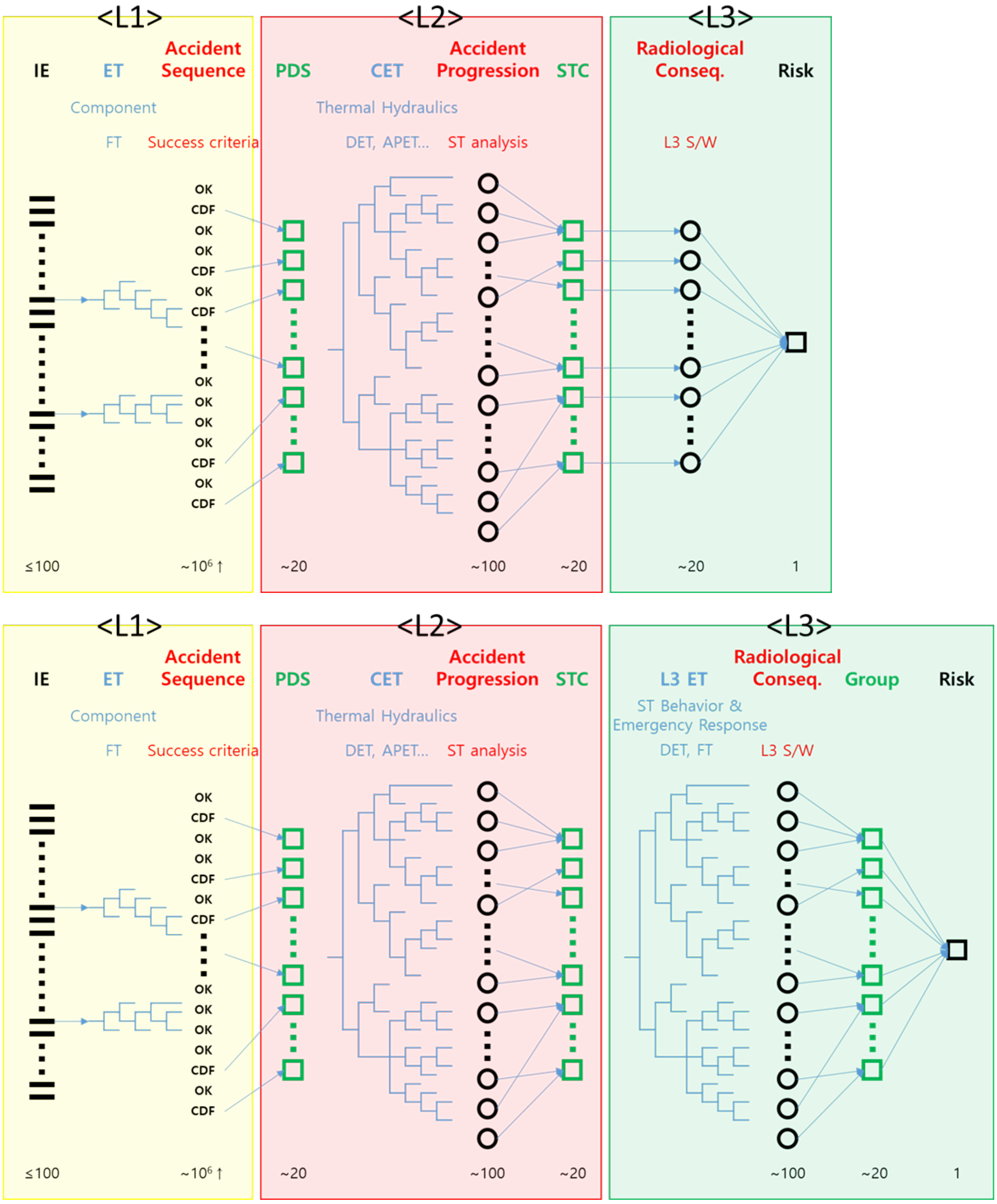

Fig. 1. A framework of PSA analysis procedure (Top - general method, and bottom - Level 3 event tree method)

Fig. 2. Example of Level 3 event tree (top – Level 3 event tree, and bottom - DET (Decomposition Event Tree) of Alarm Heading)

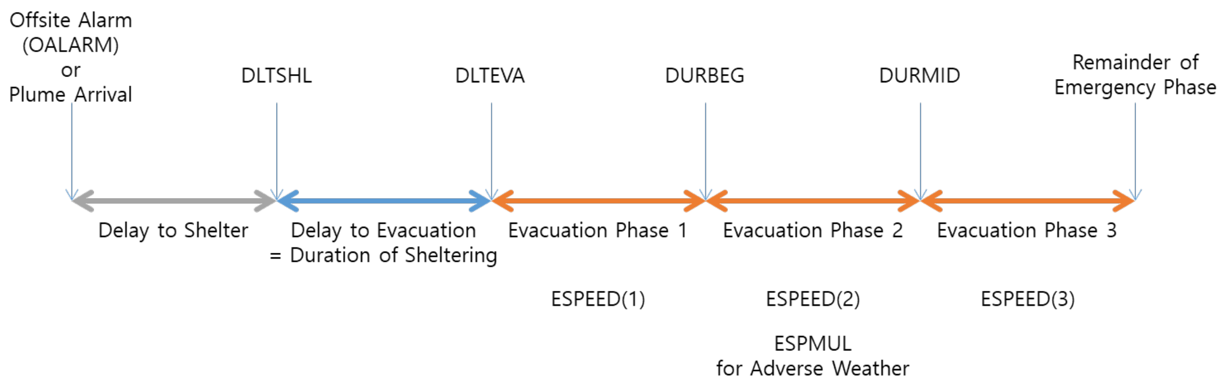

Fig. 3. Time steps of emergency response modeling using MACCS

2.3 Interfacing with Offsite Consequence Analysis Code

Level 3 PSA ET model should be appropriately interfaced with offsite consequence analysis code. In this study, MACCS code [6] is considered as an example of offsite consequence analysis code.

Important parameters of MACCS code for the modeling of emergency phase is presented in Table I and Fig. 3 shows time steps of emergency response modeling.

Table I: MACCS Parameters Related with Level 3 PSA ET Model

	MACCS Parameters	Description
Reference Time Point	OALARM ARRIVAL	Alarm Time Plume Arrival
Sheltering	DLTSHL DLTEVA	Delay to Shelter Delay to Evacuation (= Duration of Sheltering)
Evacuation	DURBEG DURMID ESPEED1 ESPEED2 ESPEED3 ESPMUL	Duration of Evacuation Phase 1 Duration of Evacuation Phase 2 Duration of Evacuation Phase 3 (Remainder of Emergency Phase) Evacuation Speed for Phase 1 Evacuation Speed for Phase 2 Evacuation Speed for Phase 3 Evacuation Speed Multiplier

3. Limitations and Further Work

The approach suggested in this study can reduce uncertainty and enhance the accuracy of Level 3 PSA. However, applying the approach can increase complexity and time of analysis. Therefore, the approach is desirable to apply the analysis which has limited number of scenarios such as single-unit PSA. It is not recommended to apply the approach to the analysis which has a large number of scenarios such as multi-unit PSA.

4. Conclusions

This paper presented the concept of a Level 3 PSA event tree. To overcome the limitations of the existing Level 3 PSA analysis methodology, a new method for applying probabilistic concepts to emergency response was presented. In the event of a severe accident, the paper presented various offsite scenarios and the main factors that determine them. An example of a Level 3 event tree with headings that take into account various factors was presented to concretize the new method. The establishment of an event tree and the selection of probability values based on concrete evidence are the most important for the realization of this concept in the future.

Further researches may have the following expected effect:

- Offsite risk assessment using probabilistic concepts
- Selection of key factors through sensitivity analysis and utilization in decision making

5. Acknowledgment

This work was supported by a National Research Foundation of Korea (NRF) grant funded by the Korean government (MSIT: Ministry of Science, ICT) (No. RS-2022-00144405).

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