Offsite Consequence Analyses to Support Level 3 PSA Event Tree Model for Alarm Time of Resident Evacuation

Sung-yeop Kim[a*], Kiwon Song[a]
[a]Korea Atomic Energy Research Institute, Daejeon, Republic of Korea

Abstract: In a radiation emergency, evacuation is one of the most important emergency responses. In addition to its importance in an actual emergency, timing the notification of resident evacuation when conducting a Level 3 PSA is important and can have a significant impact on the outcome of the assessment. The current Level 3 PSA codes define a single value from the start of the accident to when residents are instructed to evacuate. For example, MELCOR Accident Consequence Code System (MACCS) code defines this sequence of times with a single factor, OALARM. Historically, this value has been determined using very simple assumptions or a conservative approach, with large uncertainties. The offsite consequence results can be greatly affected by the timing of when residents are notified to evacuate. Therefore, a methodology is proposed to specify the timing of the notification of resident evacuation using an event tree approach. This study focuses on introducing how the offsite consequence analysis model was modeled and what results were derived from the analysis through the model. In this study, two representative scenarios of early release and late release were considered for model development. The developed model was used to analyze the offsite consequences during the emergency phase. Furthermore, it was investigated that how each determined notification time of resident evacuation can affect the offsite consequences.

Keywords: Level 3 PSA, Offsite Consequence Analysis, Emergency Response, Alarm Time

1. INTRODUCTION

Various uncertainties are inherent in a Level 3 probabilistic safety assessment (PSA) of a nuclear power plant (NPP), and there should be efforts to reduce uncertainty and increase the confidence of the analysis.

The time to notify the residents in the event of an NPP accident is one such uncertainty and is the focus of this study. Traditional Level 3 PSA analysis often uses a single value as the alarm time based on expert judgment or other approaches. MELCOR Accident Consequence Code System (MACCS), the Level 3 PSA code used in this study, requires the offsite alarm time variable (OALARM) to be entered as a single value. However, assuming a single value for alarm time has a large uncertainty and can lead to overly optimistic or conservative analysis results. The MACCS can account for uncertainty through Latin hypercube sampling (LHS) [1, 2], but it still has limitations, such as the choice of appropriate distribution functions. To overcome the limitation of the current method, this study and collaborative study [3] propose a solution to consider alarm time probabilistically by incorporating the Level 3 PSA event tree (Level 3 PSA ET) approach suggested by Song & Kim [4].

In the previous study [5], the concept of deriving the distribution of offsite alarm time by introducing the event tree approach was presented, and further study [3] attempts to calculate the alarm-time-frequency-weighted consequence by coupling the consequence result to each alarm time. For a comprehensive description of the overall methodology, it is recommended to refer to the paper of the collaborative study [3]. This paper rather focuses on introducing the development of an offsite consequence analysis model to provide consequence results corresponding to each alarm time.

2. METHODS

As aforementioned, MACCS Version 4.2 [6] was used in this study to perform offsite consequence analysis, but the methods presented in this study can be applied to any other offsite consequence analysis code. The radiological emergency planning zone in South Korea consists of precautionary action zone (PAZ) and urgent protective action planning zone (UPZ). The population in the PAZ is instructed to evacuate immediately after a red alert which is similar concept of general emergency (GE) is issued. While the population in the UPZ is determined to take protective actions based on the results of a radiation monitoring or computational simulation. The concept of PAZ and UPZ is depicted in Figure 1.

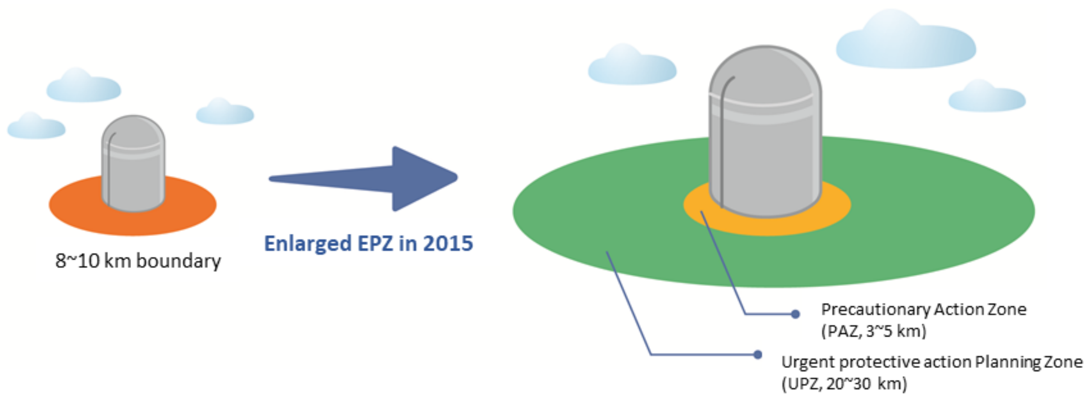

Figure 1. Concept of Radiological Emergency Planning Zone in Korea [7]

Because the time between the declaration of a general emergency and the instruction for residents to evacuate is much more critical within the PAZ, this study focuses on the emergency response of the population living within the PAZ. In addition, long-term countermeasures such as relocation and restriction of food consumption are not the scope of this study, so only the emergency phase is considered.

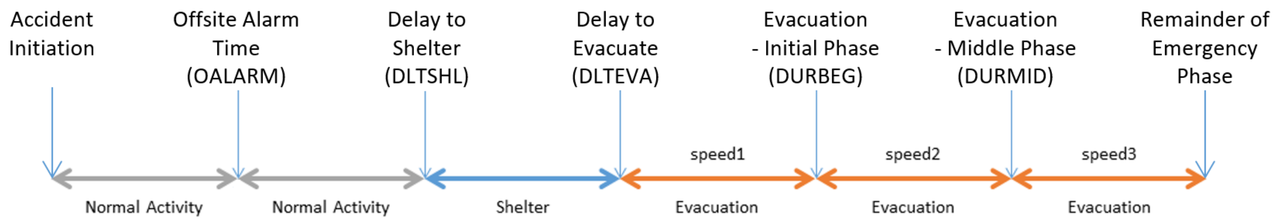

Figure 2. Time Steps of Emergency Phase and Relevant MACCS Input Parameters [6]

Figure 2 shows the time steps of emergency phase and relevant MACCS input parameters. The accident initiation of an NPP is regarded as a baseline with time zero. Offsite alarm time (OALARM), which is main focusing parameter in this study, incorporates the time for declaring an emergency and the time for notifying the residents.

$$OALARM = Declaration\ Time\ of\ General\ Emergency + Time\ to\ Notify\ Residents \quad (1)$$

Alarm time is the time when the emergency response of the population begins and is directly influential on the radiological consequences. If a late alarm time delays the evacuation of the population and the release of radioactive material occurs before that time, the impact of the accident on the population can be significantly increased.

Emergency phase includes two emergency response actions such as sheltering and evacuation and the delay time of each action is considered. Sheltering can be delayed and residents are expected to continue their normal activities during this time (DLTSHL). Time to prepare for evacuation which is delay time of evacuation (DLTEVA) is regarded as sheltering time.

2.1. Representative Accident Scenarios

For diversity in the analysis, two scenarios were considered named early and late initial source term categories (STCs). with early and late release of radioactive materials. Table 1 highlights the key times for both scenarios.

- Early Initial STC: Loss of offsite power (LOOP) → Entry into station black out (SBO) → Core damage (CD) after about 2 hours due to turbine driven auxiliary feed water (TD-AFW) pump initial startup failure → containment failure due to hydrogen explosion about 3 hours later (failure to operate all other safety systems). GE is declared when core exit temperature (CET) is reached to 354.4℃ and it takes about 120 minutes. Release starts from 445 minutes (7.4 hours) after the accident initiation.

- Late Initial STC: Loss of offsite power (LOOP) → Entry into station black out (SBO) → Operation of TD-AFW pump for 10 hours and battery discharges → containment failure due to containment pressure rise (failure to operate all other safety systems). The declaration of GE takes 720 minutes (12 hours), assuming that it takes as long as the TD-AFW pump operates (10 hours) than the Early Initial STC. Release starts from 2880 minutes (48 hours) after the accident initiation.

Table 1. Time of General Emergency and Release Start for Each Scenario

Scenario	**Declaration Time of General Emergency**	**Release Start Time**
Early Initial STC	120 minutes (2 hours)	445 minutes (7.4 hours)
Late Initial STC	720 minutes (12 hours)	2,880 minutes (48 hours)

2.2. Modeling of Emergency Response Action

Because not all populations can begin evacuation immediately, two cohorts named general public and tail were considered. General public begins evacuation 80 minutes after the GE, while the evacuation of the tail is delayed more 40 minutes than that of general public.

The evacuation speed under normal conditions was assumed to be 45 km/h and half that speed in traffic jams. The general public faces traffic jams in the middle phase of evacuation, and the tail faces traffic jams from the beginning of evacuation.

2.3. Sensitivity Analysis of Offsite Alarm Time to Radiological Consequence

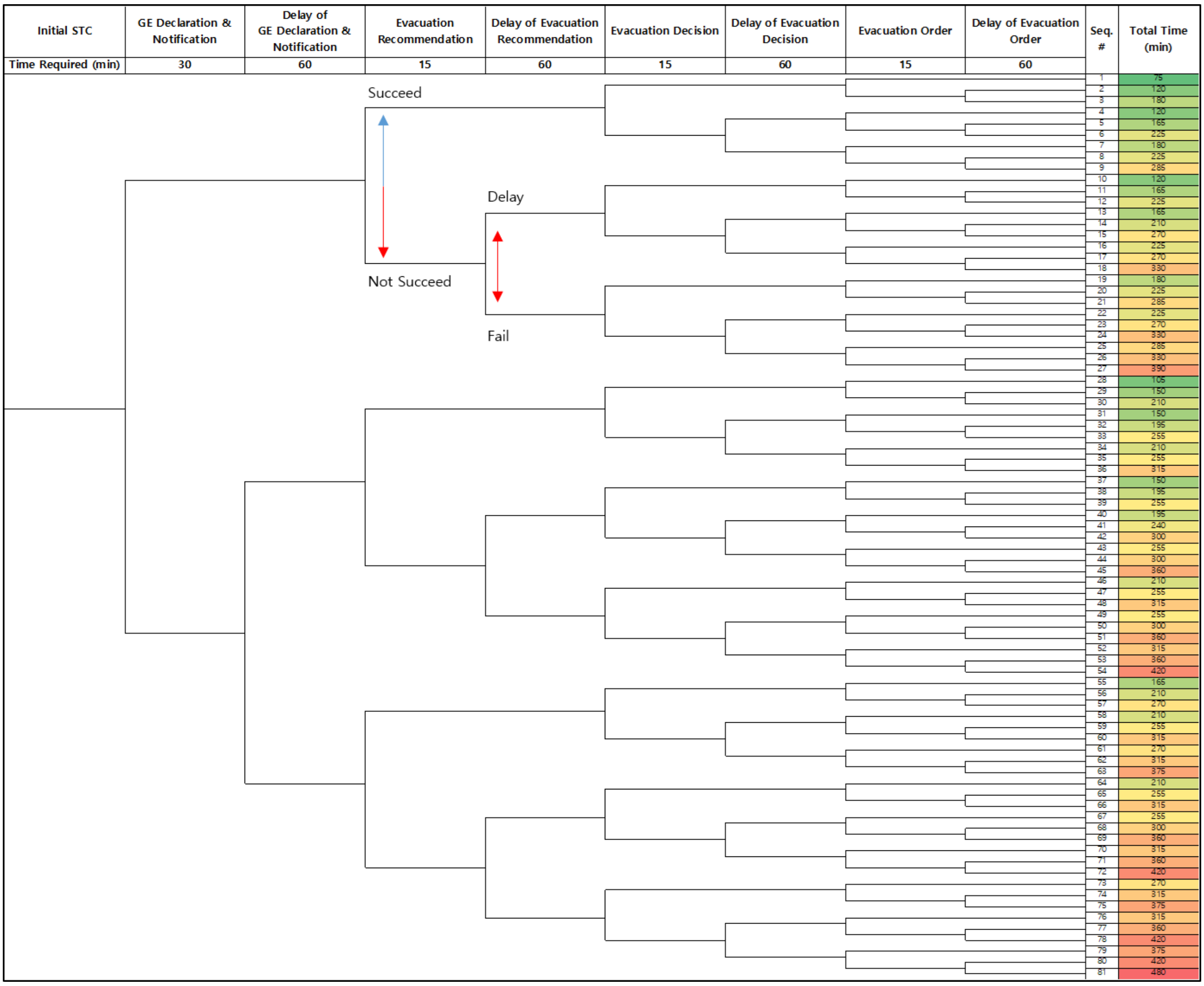

Figure 3. Designed Level 3 PSA Event Tree for Offsite Alarm Time [3]

Figure 3 presents the developed event tree for offsite alarm time and total time in the figure indicate the distribution of time to notify residents in Eq. (1). Declaration time of GE in Eq. (1) is 120 minutes for Early Initial STC and 720 minutes for Late Initial STC.

In order to provide consequence result for each time in Figure 3 and to perform a sensitivity analysis of offsite alarm time to radiological consequence, offsite consequence analyses were performed every 15 minutes up to 14 hours and every hour up to 24 hours. Population-weighted individual risk (PWIR) of early fatality and cancer fatality are calculated as radiological consequence results.

3. RESULTS AND DISCUSSIONS

For Late Initial STC scenario, due to the large difference between the GE declaration time and the start of the release of radioactive material, both the general public and the tail are successfully evacuated before the release of radioactive material. Therefore, both the results of early fatality and cancer fatality are zero.

Even for Early Initial STC scenario, early fatality results are zero because the dose will not exceed the threshold dose, despite the delay in the offsite alarm time. Therefore, the only interest of this study became the results of cancer fatality in the Early Initial STC scenario.

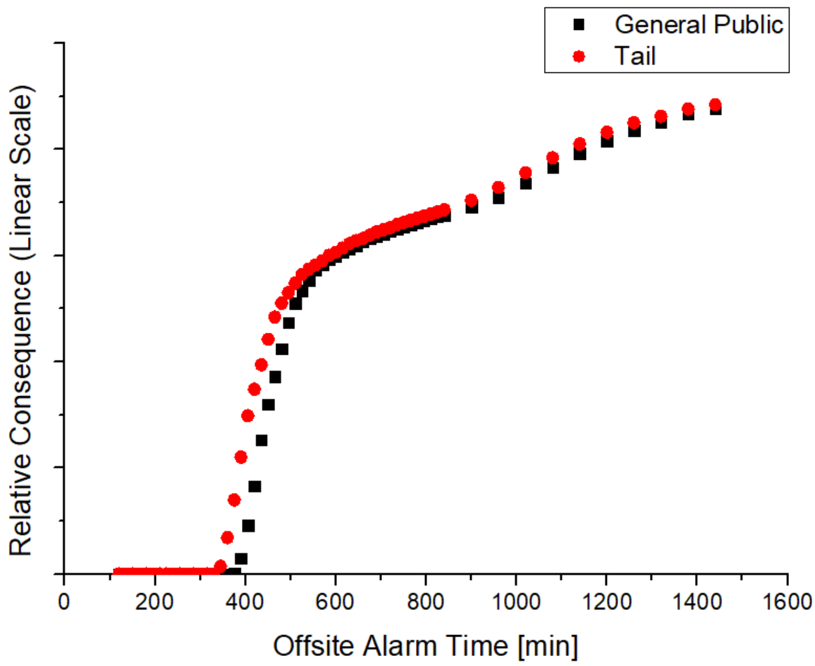

Figure 4. Relative Results of PWIR of Cancer Fatality in Early Initial STC Scenario

Figure 4 illustrates the relative results of PWIR of cancer fatality in Early Initial STC scenario. Only normalized relative results are provided since pilot study on a reference site is performed in this study and absolute values are meaningless in this stage. The main objective of this study is to investigate the feasibility and gain insight of the suggested method by conducting a pilot study on a reference site.

Offsite alarm time plus evacuation delay time (80 minutes for general public and 120 minutes for tail as introduced in Section 2.2) should be compared with the release start time (445 minutes). Therefore, consequence results become non-zero from 365 minutes for general public and 325 minutes for tail in Figure 4. The traditional method of assuming a single value for offsite alarm time has the potential to calculate offsite consequence as zero or much higher than practical situation. The calculation results in Figure 4 are provided to correspond to each event tree in order to consider the distribution of offsite alarm time comprehensively.

4. CONCLUSION

To overcome the limitation of existing studies that consider the offsite alarm time as a single value, Level 3 PSA ET method is proposed that can consider the offsite alarm time probabilistically. In this study, offsite consequence analyses were performed for early and late scenarios and general public and tail cohorts, to provide consequence results for each ET of offsite alarm time. By multiplying the frequency and consequence of each ET and adding them all together, offsite-alarm-time-frequency-weighted consequence can be estimated. This method comprehensively considers the distribution of offsite alarm time and is expected to be a solution to overcome the limitations of existing methods that assume a single value, which can lead to overly optimistic or conservative results.

Acknowledgements

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