A Comparative Study on the Construction of a Loss of Component Cooling Water Initiating Event Fault Tree for Fire Events PSA

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1. Introduction

An internal fire event probabilistic safety assessment (PSA) model has generally been quantified by modifications of a pre-developed internal events PSA model. New accident sequence logic not covered in the internal events PSA model are separately developed to be incorporated into the fire PSA model. Recent studies [1,2] showed that the support system initiating event fault trees (SSIE FT) for fire events PSA could be constructed with the consideration of only initiating event initiators. However, their approaches for developing SSIE FTs with only initiating event initiators were not validated. Kang and Jung[3] performed a comparative analysis on the construction of SSIE FT model with only initiators, and the other with both initiators and enabling events. Enabling events are events that put the system in a critical state for the IE [4]. A critical state is a state that allows the system to transfer from an operating state to a failed state when the IE occurs. Their studies used the hypothetical internal accident scenarios for conducting the comparative study for different SSIE FT models with only initiators, and with initiators and enabling events.

In this study, we performed a comparative analysis on the construction of a loss of component cooling water initiating event fault tree (LOCCW IE FT) models with only initiators, and with initiators and enabling events. Hanul Unit 3 was selected as a reference NPP of this study. A LOCCW IE is defined as a loss of CCW train A. The fire induced LOCCW accident sequences with different LOCCW IE FT models were quantified to compare their quantification results.

2. Methods and Results

2.1 CDF equation and modification rules

The total core damage frequency (CDF) of a nuclear power plant from a fire can be represented by Eq. (1).

$$CDF=\sum_{k=l}^{m} CDF_k \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots(1)$$

In Eq. (1), CDF_k represents the CDF of each zoneor scenario. The CDF_k can be further represented as [3]

$$CDF_k=\%R_k*S\%R_k*N\%R_k*CCDP_k\ldots\ldots\ldots\ldots(2)$$

$\%R_k$= fire frequency of zone or scenario k
$S\%R_k$= severity factor of zone or scenario k
$N\%R_k$ = non-suppression probability of zone or scenario k
$CCDP_k$ = conditional core damage probability (CCDP) of zone or scenario k

The modification algorithm of an internal event PSA model into a fire event PSA model is as follows [3]:

- Internal PSA initiating event:
  $\%I => \%I + \Sigma\ \%R_k*S\%R_k*\ N\%R_k\ldots\ldots\ldots\ldots(3)$
- Internal PSA basic event for the component failure:
  $a => a + \sum\%R_k*S\%R_k*N\%R_k\ *P\%R_k\text{-}a\ \ldots\ldots(4)$

where,
%I: internal PSA initiating event or frequency
a: basic event for random component failure
$P\%R_k\text{-}a$: fire damage events for the basic events relating to the equipment or cables

Eq. (3) is used for internal IEs where there is no initiating event fault tree. Eq. (4) indicates that an internal basic event for a component failure is replaced by an ‘OR’ logic combination of the internal basic event itself and ‘AND’ logic combinations. For the case where there are initiating event fault trees for an internal event PSA, Eq. (4) is applied to those for the construction of IE fault tree for a fire PSA.

In this study, in place of the basic event for component failure, the zero fire damage events were used for the construction of a fire PSA model. In other words, the zero fire damage event was additionally modeled for the corresponding component failure events of active components in all FTs for the mitigating system including the supporting systems. Using information on the fire scenarios corresponding to the zero fire damage events, the right terms in Eq. (4) were modeled in the IE and mitigating system fault trees. In this study, the zero fire damage events have zero failure probabilities and they were used as the navigators for the construction of fire events PSA model.

2.2 Construction of a loss of component cooling water initiating event fault tree with only initiators

The LOCCW IE FT was constructed using the mitigating system FT of component cooling water system (CCWS) for the internal events PSA. First, we identified equipment affected by a fire. The identified equipment was active components such as pumps, motor operated valves, etc. Second, the zero damage events were modeled for the identified equipment. The other events except the zero damage events were deleted. Fig. 1 shows LOCCW IE FT with initiators before including the fire scenarios. Third, fire events PSA model were constructed using the mapping information for fire scenarios corresponding to the zero damage events.

During the construction of LOCCW IE FT, we used the same assumption applied to the mitigating system FT of CCWS. For an example, CCWS pump 1A was running and pump 2A was standby.

2.3 Construction of a loss of component cooling water initiating event fault tree with initiators and enabling events

The similar approach used in the sub-section 2.2 was used for the construction of the LOCCW IE FT with initiators and enabling events. The zero damage events were added to the affected equipment by a fire. All previous basic events modeled for the mitigating system FT for the internal events PSA remained. However, the mission time for the running failure events was changed from 24 hours to 72 hours. Fig. 2 shows LOCCW IE FT with initiators and enabling events before including the fire scenarios.

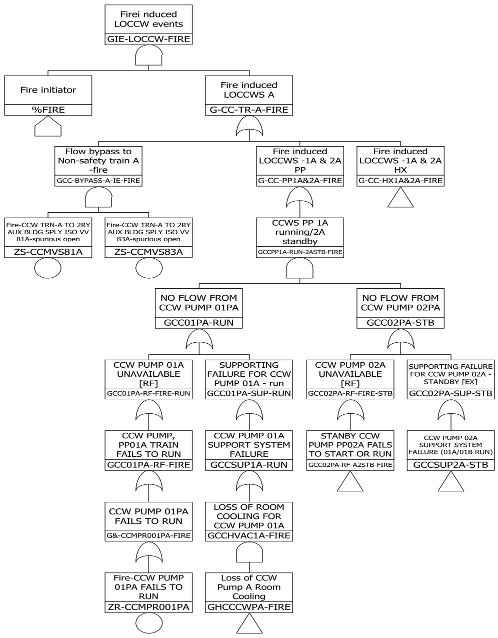

Fig. 1 LOCCW IE FT with only IE initiators

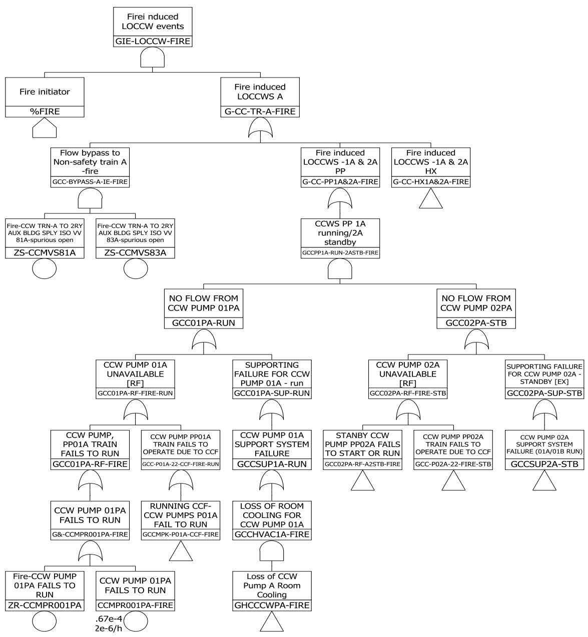

Fig. 2 LOCCW IE FT with IE initiators and enabling events

2.4 Quantification of LOCCW accident sequences

The fire induced LOCCW accident sequences with different LOCCW IE FT models were quantified to compare their quantification results. We assumed that a fire included in the fire event PSA is assumed to result in a reactor shutdown. The quantification results of LOCCW IE FT with only initiators are one half of those with initiators and enablers. We found that there were non-sense cut-sets in the quantification results of LOCCW IE FT with initiators and enablers. The identified nonsense cut-sets are 'AND' logic combination of enabling events for CCWS train 1A and 2A. Thus, we quantified again for the LOCCW accident sequences with LOCCW IE FT with initiators and enablers after deleting the logic for generating non-sense cut-sets. The quantification results of LOCCW IE FT with only initiators are almost the same as those with initiators and enablers. The minor quantification difference may come from the inherent PSA quantification approach such as rare event approximation. From this study results, we could confirm that the LOCCW IE FT for real fire events PSA model could be constructed with the consideration of only initiating event initiators.

3. Concluding remarks

In this paper, we performed a comparative analysis on the construction of LOCCW IE FT models with only initiators, and the other with both initiators and enabling events. Through the comparative study, we demonstrated that the LOCCW IE FT models for actual fire PSA model with initiating event initiators, in terms of quantifications of fire PSA models, were equivalent to those with initiating event initiators and enabling events.

Acknowledgments

This work was supported by Nuclear Research & Development Program of the National Research Foundation of Korea grant, funded by the Korean government, Ministry of Science and ICT (Grant number 2017M2A8A4016659).

REFERENCES

[1] Anoba, Richard C., 2011. MAPPING OF FIRE EVENTS TO MULTIPLE INTERNAL EVENTS PRA INITIATING EVENTS. International Topical Meeting on Probabilistic Safety Assessment and Analysis PSA 2011, March 13-17.
[2] Lovelace, N., Johnson, M., and Lloyd, M., 2014. Approach for Integration of Initiating Events into External Event Models. Probabilistic Safety Assessment and Management PSAM 12, June, Honolulu, Hawaii.

[3] Kang, Dae Il and Jung, Yong Hun, 2018. Comparative study on the construction of support system initiating event fault trees for a fire probabilistic safety assessment, Nuclear Engineering and Design 332 (2018) 345-356

[4] Schroeder, J., 2015. Support system initiating events modeling, Public presentation delivered on July 15, Rockville, MD, NRC ADAMS ML15189A444.