Construction of Support System Initiating Event Fault Trees for a Fire 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 logics 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 a fire PSA could be constructed with the consideration of only initiating event initiators. However, their approach for developing SSIE FTs with only initiating event initiators was not validated. Therefore, we performed a comparative analysis on the construction of SSIE FT model with only initiators, and with initiators and enabling events. In order to conduct the comparative study, the hypothetical internal accident scenarios were used for developing the fire PSA models having different SSIE FT models with only initiators, and with initiators and enabling events. The developed fire PSA 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).

$$CDF=\sum_{k=1}^{m} CDF_k \quad \text{.....(1)}$$

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

$$CDF_k=\%R_k*S\%R_k*N\%R_k*CCDP_k \quad \text{.....(2)}$$

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

where,
%I: internal PSA initiating event or frequency
a: basic event for random component failure
$P\%R_k$-*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 case, zero fire damage events can be used to represent fire-induced failure events of the active components owing to a fire. Using information on the fire scenarios corresponding to the zero fire damage events, the right terms in Eq. (4) are modeled in the IE and mitigating system fault trees. The zero fire damage events were deleted when the specific fire scenarios were applied to them.

2.2 hypothetical internal event accident scenarios

As shown in Fig. 1, the hypothetical internal event accident scenarios consist of initiating events (G-I) and failure events (G-X and G-Y) of system X and Y. Descriptions of basic events for Fig. 1 are presented in Table I. The initiating events (G-I) are represented by single events. Assumption that initiating event, %I-A1 or %I-A2, occurs if subsystem A1 or A2 fails is consistent with that any fire in NPP cause a reactor trip [1,2]. We further assume that the active components of Fig. 1 fail due to a fire. However, the passive components are not affected by a fire.

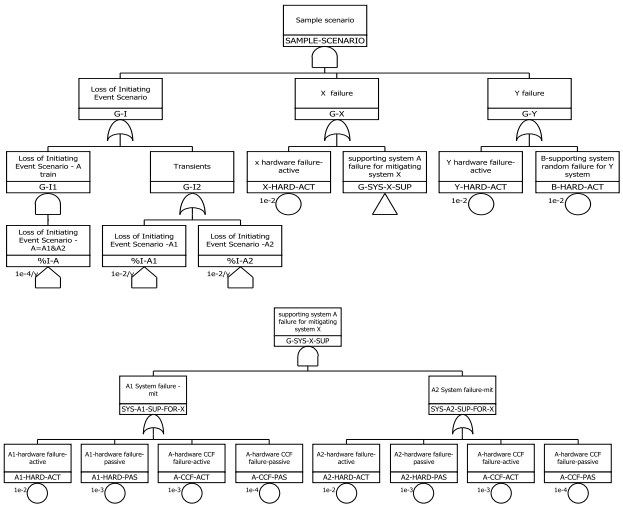

Fig. 1 Fault tree representing hypothetical internal event accident scenarios

2.3 Change of internal events PSA model to fire events PSA model

Table I: Descriptions of basic events for hypothetical internal event accident scenarios

Event name	Event descriptions
%I-A	Loss of Initiating Event Scenario A (A1 and A2) event or frequency due to a random failure
%I-A1	Loss of Initiating Event Scenario A1 event or frequency due to a random failure
%I-A2	Loss of Initiating Event Scenario A2 event or frequency due to a random failure
X-HARD-ACT	System X(active) failure event or probability due to a random failure
A1-HARD-ACT	Support system A1(active) failure event or probability of system X due to a random failure
A1-HARD-PAS	Support system A1(passive) failure event or probability of system X due to a random failure
A2-HARD-ACT	Support system A2 (active) failure event or probability of system X due to a random failure
A2-HARD-PAS	Support system A2 (passive) failure event or probability of system X due to a random failure
A-CCF-ACT	Common cause failure event or probability of support systems A1 and A2 (active) of system X du e to a random failure
A-CCF-PAS	Common cause failure event or probability of support systems A1 and A2 (passive) of system X d ue to a random failure
Y-HARD-ACT	System Y (active) failure event or probability due to a random failure
B-HARD-ACT	Support system B (active) failure event or probability of system Y due to a random failure

The initiating event fault tree of system with redundancy can be represented by the multiplication of initiating event initiators and enabling events [4]. Namely, initiating event fault tree of a system with redundancy can be represented as the multiplication of fire occurrence events (frequency) and unavailability (probability) of subsystem or components. The specific support system such as component cooling water system or electrical system may cause a reactor trip and be used for the mitigating system as supporting systems for the frontline systems. In this case, the specific SSIE FT can be constructed with only initiating event initiators [1,2].

Fire induced initiating event fault tree modeled with fire damage initiators is presented in Fig. 2 and that modeled with fire damage initiators and enabling events is presented in Fig. 3, respectively. As shown in Table II, the cutsets and frequencies resulting from the quantifications of Fig. 2 and Fig. 3 are the same. Using these results, we can conclude that the SSIE FT models with only initiators, in terms of quantifications of fire PSA models, are equivalent to those with initiators and enabling events.

Table II: Quantification results of fire induced accident scenarios with initiating event fault tree

	Value	F-V	Acc.	BE#1	BE#2	BE#4
1	1.00E-06	0.092251	0.092251	%Z-A-LA-FIRE	B-HARD-ACT	
2	1.00E-06	0.092251	0.184502	%Z-A-LA-FIRE	Y-HARD-ACT	
3	1.00E-06	0.092251	0.276753	%Z-A1-SM-FIRE	A2-HARD-ACT	B-HARD-ACT
4	1.00E-06	0.092251	0.369004	%Z-A2-SM-FIRE	X-HARD-ACT	Y-HARD-ACT
5	1.00E-06	0.092251	0.461255	%Z-A1-SM-FIRE	B-HARD-ACT	X-HARD-ACT
6	1.00E-06	0.092251	0.553506	%Z-A1-SM-FIRE	X-HARD-ACT	Y-HARD-ACT
7	1.00E-06	0.092251	0.645757	%Z-A1-SM-FIRE	A2-HARD-ACT	Y-HARD-ACT
8	1.00E-06	0.092251	0.738007	%Z-A2-SM-FIRE	A1-HARD-ACT	Y-HARD-ACT
9	1.00E-06	0.092251	0.830258	%Z-A2-SM-FIRE	B-HARD-ACT	X-HARD-ACT
10	1.00E-06	0.092251	0.922509	%Z-A2-SM-FIRE	A1-HARD-ACT	B-HARD-ACT
sum	1.084E-5					

3. Conclusions

In this paper, we performed the comparative analysis on the construction of SSIE FT models with initiating event initiators, and with initiating event initiators and enabling events. Through the comparative study, we demonstrated that the SSIE FT models with initiating event initiators , in terms of quantifications of fire PSA models, were equivalent to those with initiating event initiators and enabling events.

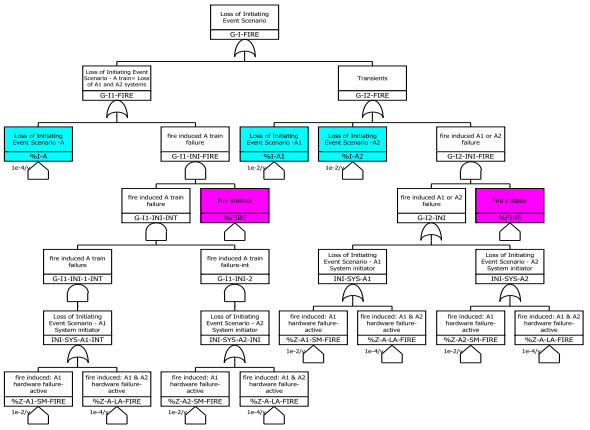

Fig. 2 Initiating event fault tree with fire damage initiators

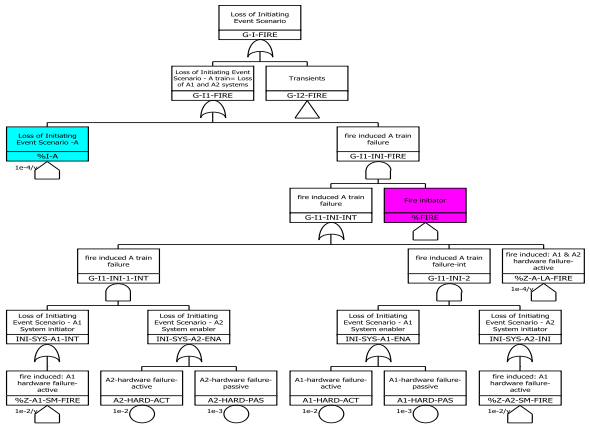

Fig. 3 Initiating event fault tree with fire damage initiators and enabling events

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