Mapping Fire Events to Multiple Internal Events PSA Initiating Events for a One-Top Fire Event PSA Model

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1. Introduction

An internal fire event probabilistic safety assessment (PSA) model has been generally quantified by modifications of a pre-developed internal events PSA model [1, 2]. KAERI developed modification rules [3, 4] for the construction of a one-top PSA model for fire events by using a one-top PSA model for internal events. A one-top fault tree is a one fault tree representing the PSA logic including all the event trees and fault trees for the core damage frequency (CDF) and large early release frequency (LERF) quantifications. Equipment or cable affected by the fire may be damaged, resulting in multiple initiating events (IEs) of internal events PSA due to a single fire event [1,2]. Therefore, quantifying the fire PSA model may generate unrealistic minimal cut sets (MCs) [5~9]. In this paper, unrealistic MCs [9] are collectively referred to as duplicated, subsumed into other MCs, non-sense, or over-counted fire scenario frequency. These unrealistic MCs could be generated during the quantification process of fire event PSA model because a single fire event maps to multiple IEs of internal event PSA and the quantification of the PSA model is based on a rare event approximation [5, 7].

In the previous studies [5~8], Anova [5] and Lovelace et al. [7] proposed methods for addressing MCs that can be duplicated or subsumed into other MCs. Albinson et al. [6] suggested that the fire-initiating event decision tree (FIEDT) was used for ensuring that the overall scenario frequency was not over-counted. Risley et al. [8] suggested that the visual basic program was used to select the most serious IE in terms of conditional core damage probability and exclude other IEs for resolving the problem of over-counting fire scenario frequency.

Previous studies [5~8] refer to issues that may arise when mapping a single fire event to multiple internal events PSA IEs and suggest approaches for resolving them. However, they did not present actual examples of unrealistic MCs that appear when mapping fire events to multiple internal events PSA IEs. Without actual examples of unrealistic MCs, it may be difficult to understand the previous studies for fire PSA beginners or engineers who use PSA tools or procedure different from them. In addition, previous studies [5~8] did not discuss meaningless (non-sense) MCs that could occur if all fire events were quantified at once using the one-top fire event PSA model. Because the IEs can be modeled in the mitigating system of the one-top PSA model for convenience of modeling, specific events that can only be considered for specific IE accident sequences may appear in other IE accident sequences.

Therefore, this study showed real examples of unrealistic MCs generated from the quantification process of a one-top fire event PSA model. The hypothetical one-top fire event PSA model was constructed from the simple one-top internal event PSA model and used for generating unrealistic MCs. The resolving process for the issues of these unrealistic MCs was presented and discussed. The procedure of resolving the issues for the unrealistic MCs was also suggested.

2. Methods and Results

2.1 Simple one-top internal event PSA model

A simple one-top internal event fault tree (FT) was constructed to introduce the process of changing from an internal event PSA FT to a fire event PSA FT. The simple One-Top internal event FT made has the following characteristics [9]:

- Internal events PSA IEs considered are Loss of Main Feed-water (LOMF) event, loss of off-site power (LOOP) event, and small loss of coolant accident (SLOCA).
- System A has an electrical system, and when the LOOP occurs, the emergency power system, 'EAC-A', actuates.
- Operator action is required for the operation of system B. In the case of LOOP and LOMF IEs, the operator action, 'OPNOR-B', is modeled, and in the case of SLOCA, the operator action, 'OPABN-B', is modeled.

The internal event FT made using AIMS-PSA [10] is shown in Fig. 1. In Fig.1, #LOMF-SEQUENCE, #LOOP-SEQUENCE, and #SLOCA-SEQUENCE were used to represent PSA accident sequences as a kind of flag.

2. 2 Construction of the simple one-top fire event PSA model

We constructed a fire event FT using the internal event FT of Fig. 1. Assumptions for the construction of fire event FT are as follows [9]:

- The fire occurs in ROOM 1, 2, and 3.
- Both severity and non-suppression probability are 1.
- In the event of any ROOM fire, LOMF IE occurs.
- LOOP IEs occur in the event of ROOM 1 and 3 fires. In ROOM 1 fire, LOOP IE occurs only when EQ1 is damaged, but in the case of ROOM 3 fire, LOOP IE occurs without equipment damage.
- SLOCA IE occurs when EQ2 is damaged in ROOM 2 fire and when EQ3 is damaged in ROOM 3 fire.
- System C is unavailable if EQ2 is damaged in the event of ROOM 2 fire.
- Operator actions, 'OPNOR-B' and 'OPABN-B', could be differently quantified to address the fire conditions, but in this study, the same name and the same human error probabilities of those for the internal events PSA are also used in fire event PSA.

The fire event FT was constructed as shown in Fig. 2, using the internal event FT in Fig. 1 and fire event information in Table I.

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Table I: Fire event information

Events	Description	Mean	Remarks
%FIRE-INITIATOR	Fire initiator	0	Use for fire PSA quantification
%R1	Room 1 fire	5.0E-04/yr	Fire occurrence event or frequency
%R2	Room 2 fire	5.0E-04/yr	Fire occurrence event or frequency
%R3	Room 3 fire	5.0E-04/yr	Fire occurrence event or frequency
EQ1	Fire induced EQ1 failure	2.00E-01	Fire-induced equipment failure event or probability
EQ2	Fire induced EQ2 failure	3.00E-01	Fire-induced equipment failure event or probability
EQ3	Fire induced EQ3 failure	4.00E-01	Fire-induced equipment failure event or probability

2.3 Examples of Unrealistic MCs

Quantification of the fire event FT in Fig. 2 is performed by setting the internal events (%INT-LOOP, %INT-LOMF, %INT-SLOCA) to 'FALSE', and setting the %FIRE-INITIATOR to 'TRUE'. Fig. 3 shows the quantification results of Fig. 2. FTREX [11], quantification engine, and AIMS-PSA [10], quantification program, were used for the quantification of FT in Fig. 2. Fig. 3 shows that there are many MCs that are duplicated, subsumed with other MCs, non-sense, or over-counted frequency of fire scenarios. Examples of these unrealistic MCs in Fig. 3 are as follows [9]:

- Duplicated MCs: The fourth and fifth MCs are fire scenarios representing #SLOCA-SEQUENCE and #LOMF-SEQUENCE, respectively. They are the same MCs except for the flags representing the accident sequences of internal event PSA IEs.
- MC subsumed with other MCs: The thirty-second MC can be subsumed with the twenty-first or the twenty-second MCs unless a flag indicating the IE is taken into account.
- Meaningless MCs: The second and third MCs are scenarios for LOMF and SLOCA events, respectively, showing different operator actions than those used only for LOMF and SLOCA scenarios. These MCs should be corrected.
- MCs having over-counted fire scenario frequency: For the case of R1 fire, the twenty-seventh and twenty-eighth MCs are LOOP accident sequences caused by EQ1 damage. The success event of EQ1 is not modeled in the twentieth and twenty-sixth MCs.

2.4. Resolving the issues of unrealistic MCs

In this section, we did not address the unrealistic MCs with over-counting fire scenario frequency. Detailed discussions on over-counting frequency are presented in section 2.5.

When quantifying Fig. 2, the accident sequence designators (#LOMF-SEQUENCE, #LOOP-SEQUENCE, #SLOCA-SEQUENCE) were defined as a flag (FTREX command, /F=#). Its quantification results are shown in Fig. 4. The second MC of Fig. 4 is the SLOCA accident sequence and the wrong operator action, 'OPNOR-B', is modeled. This MC should be corrected. As discussed in the previous studies [5, 7], except for nonsense and over-counted MCs, the use of flags for IE accident sequence designators resolved the issues of unrealistic MCs which are duplicated or subsumed into other MCs.

Since meaningless MCs for operator action were generated, the FT of system B was modified. In Figs. 1 and 2, operator actions for system B were modeled by using IEs. The FT of mitigation system B, G-SYS-B-FIRE, was modified by excluding IEs from Fig. 2. Fig. 5 shows the modified simple one-top fire event FT. Quantification result of modified simple one-top fire event FT using FTREX command(/F=#) is presented in Fig.6. Unlike Figs. 3 and 4, there are no meaningless MCs related to operator actions.

2.5 Discussion and procedure for resolving the issues of unrealistic MCs

The requirements for multiple IEs in ASME PRA Standard shall consider all possible IEs in case of a fire event. If a particular IE is selected among the multiple IEs considered, it should encompass the risk contribution from all applicable IEs. It would be appropriate to ensure that any differences with respect to selecting a more specific initiating event are negligible [2]. With current fire PSA programs available, it is difficult to apply the previous studies [6, 8] for the over-counting of fire scenario frequency to the one-top fire event PSA model. Albinson's approach [6] may lead to the underestimation of the fire risk because the IE scenarios selected preferentially could remove the IE scenarios selected later [9]. Risley's method cannot meet the ASME PRA Standard requirement [2] because the fire risk for the excluded IE scenarios may not be negligible compared with that for the selected IE scenario. From Fig. 6, MCs with the over-counting frequency were corrected as shown in Fig.7. In Fig.7, ~EQ1, ~EQ2, and ~EQ3 represent the success events of EQ1, EQ2, and EQ3, respectively [9].

Based on this section and section 2.4, the procedure for resolving the issues of unrealistic MCs generated from the quantification of the one-top fire event PSA model is suggested as follows:

- Make the fire-induced IE FTs that include fire events and equipment spurious operations, and construct a one-top fire PSA event model. The IE accident sequences of the internal event PSA model are represented by flag events (e.g. #).
- Quantify the one-top fire event PSA model and review the MCs to determine if there are meaningless MCs.
- If the meaningless MCs are identified, decide whether to change the fire event PSA model or to apply post-process to it for correcting the meaningless MCs. If the PSA model is changed, quantification is performed after the change of the PSA model to reconfirm that no meaningless MCs have been generated.
- Flags for the accident sequence of internal events PSA IEs are used for resolving the problems of unrealistic MCs that are duplicated or that can be subsumed into other MCs.
- Determine whether the fire risk due to over-counting of fire scenario frequency contributes significantly to the overall fire risk (e.g. 1 percent or more) or not. If significant contributions are made, the fire risk is quantified again by evaluating in detail the probability of equipment spurious operation that causes the IE and considering additional IEs when the equipment spurious operations do not occur.

3. Conclusions

A single fire event can cause multiple internal events PSA IEs, which can lead to unrealistic MCs during the quantification process of fire event PSA models. This study introduced the process of constructing a one-top fire event PSA model using a simple one-top internal event PSA model. In addition, real examples of unrealistic MCs appearing when modeling fire PSA was shown. The results of this study are expected to contribute to the understanding and resolution of the unrealistic MCs that appear when quantifying the fire event PSA model.

Acknowledgments

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REFERENCES

[1]Nowlen, S.P. et al., “Fire PRA methodology for nuclear power facilities“, NUREG/CR-6850, USNRC, 2005.

[2] ASME/ANS, “Addenda to ASME/ANS RA-S-2008, Standard for Level 1/Large Early Release Frequency PRA for NPP Applications,” ASME/ANS RA-Sb-2013, ASME, New York, U.S., September 2013.

[3] Kang, D.I., Han, S.H., Kim, K.Y., An approach to the construction of a One-Top fire event PSA model, Nuclear Engineering and Design 239, 2514–2520, 2009.

[4] Kang, D.I and Jung, Y.H, Comparative study on the construction of support system initiating event fault trees for a fire PSA, Nuclear Engineering and Design 2018, 332, 345-356, 2018.

[5] Anoba, R.C., Mapping of fire events to multiple internal events PRA initiating events, ANS PSA 2011 International Topical Meeting on Probabilistic Safety Assessment and Analysis, Wilmington, NC, March 13-17, 2011.

[6] Albinson, B. T., Zucal, G.T, and Vanover, D.E, Integration of a Fire Initiating Event Decision Tree into a Fire PRA, ANS PSA 2013 International Topical Meeting on Probabilistic Safety Assessment and Analysis, Columbia, SC, September 22-26, 2013.

[7] Lovelace, N., Johnson, M., and Lloyd, M., Approach for Integration of Initiating Events into External Event Models, Probabilistic Safety Assessment and Management PSAM 12, Honolulu, Hawaii, 2014.

[8] Risley, P.E, Worrell, C., Christiansen, K., An Approach for Apportioning Fire Scenario Frequencies to Induced Initiating Events, PSA 2019 International Topical Meeting on Probabilistic Safety Assessment and Analysis, Charleston, SC, April 28-May 3, 2019.

[9 Kang, Dae Il and Jung, Yong Hun, “A Study on Mapping Fire Events to Multiple Initiating Events in a One-Top Fire Event PSA Model”, KAERI/TR-9200/2022, KAERI, 2022.

[10] Han, S.H, Lim, H.G., Yang, J.E, AIMS-PSA: A software for integrating various types of PSAs, 9th International Conference on Probabilistic Safety Assessment & Management, Hong Kong, China, 2008.

[11] EPRI, “FTREX 2.0 User Manual”, EPRI, Palo Alto, CA and KAERI, Daejeon, South Korea: 2020, 3002018234, 2020.

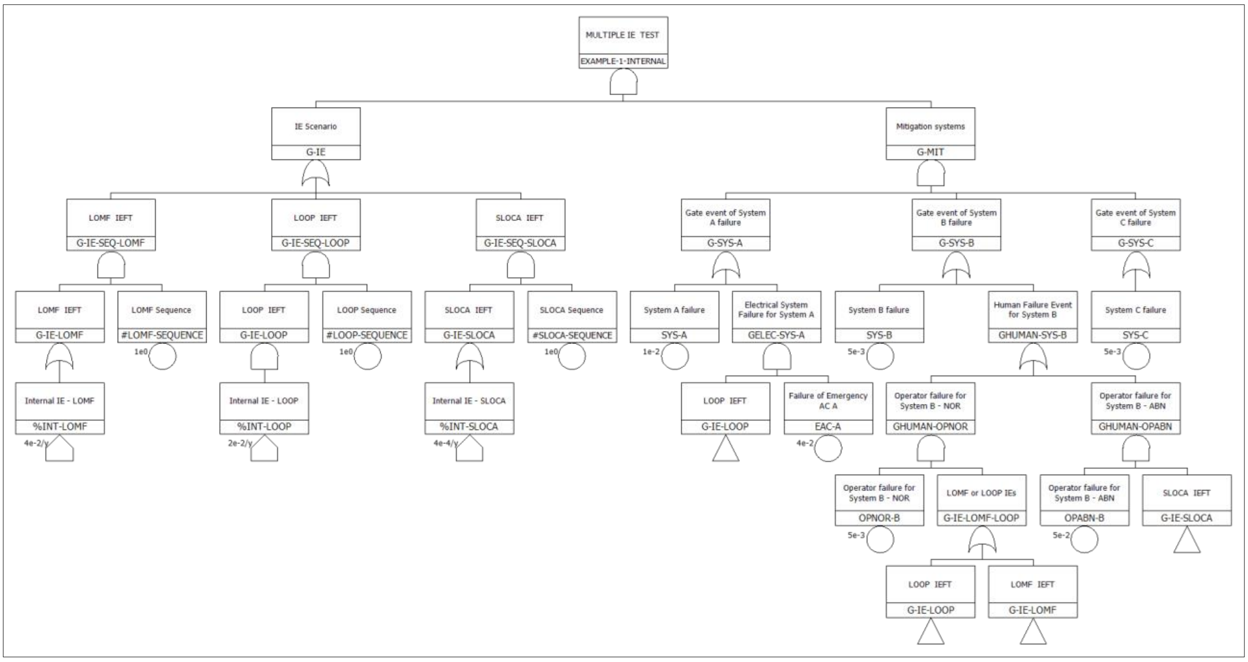

Fig. 1. Simple one-top internal event FT

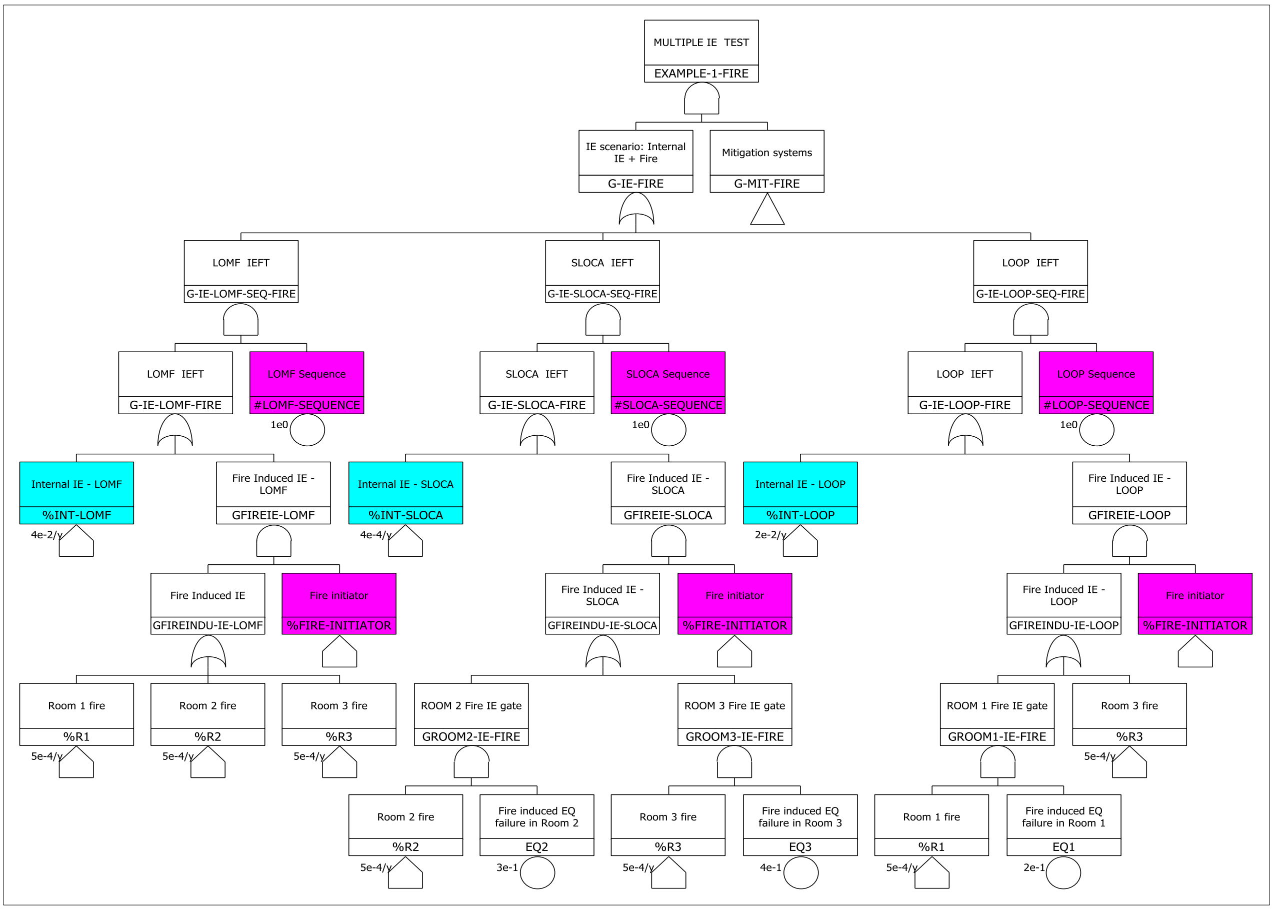

Fig. 2. Simple one-top fire event FT(1/2)

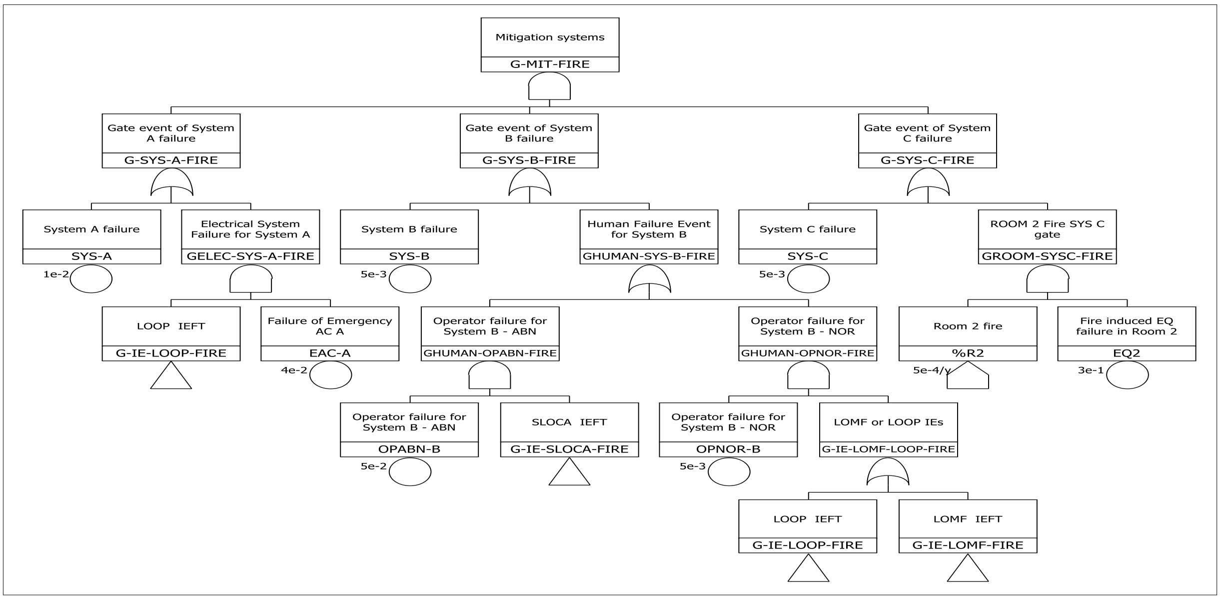

Fig. 2. Simple one-top fire event FT(2/2)

Cut Set — 1.915e-7 / 34 (1.915e-7 / 34) — And — Selected Only

No	Value	F-V	Acc.	BE#1	BE#2	BE#3	BE#4	BE#5	BE#6
1	7.500e-8	0.391747	0.391747	%R2	EQ2	OPABN-B	SYS-A	#SLOCA-SEQUENCE	
2	7.500e-8	0.391747	0.783494	%R2	EQ2	OPABN-B	SYS-A	#LOMF-SEQUENCE	
3	7.500e-9	0.039175	0.822669	%R2	EQ2	OPNOR-B	SYS-A	#SLOCA-SEQUENCE	
4	7.500e-9	0.039175	0.861844	%R2	EQ2	SYS-A	SYS-B	#SLOCA-SEQUENCE	
5	7.500e-9	0.039175	0.901019	%R2	EQ2	SYS-A	SYS-B	#LOMF-SEQUENCE	
6	7.500e-9	0.039175	0.940193	%R2	EQ2	OPNOR-B	SYS-A	#LOMF-SEQUENCE	
7	2.000e-9	0.010447	0.950640	%R3	EAC-A	EQ3	OPABN-B	SYS-C	#LOMF-SEQUENCE
8	2.000e-9	0.010447	0.961086	%R3	EAC-A	EQ3	OPABN-B	SYS-C	#SLOCA-SEQUENCE
9	2.000e-9	0.010447	0.971533	%R3	EAC-A	EQ3	OPABN-B	SYS-C	#LOOP-SEQUENCE
10	5.000e-10	0.002612	0.974145	%R3	EQ3	OPABN-B	SYS-A	SYS-C	#LOMF-SEQUENCE
11	5.000e-10	0.002612	0.976756	%R3	EQ3	OPABN-B	SYS-A	SYS-C	#SLOCA-SEQUENCE
12	5.000e-10	0.002612	0.979368	%R3	EQ3	OPABN-B	SYS-A	SYS-C	#LOOP-SEQUENCE
13	5.000e-10	0.002612	0.981980	%R3	EAC-A	SYS-B	SYS-C	#LOMF-SEQUENCE	
14	5.000e-10	0.002612	0.984591	%R3	EAC-A	SYS-B	SYS-C	#LOOP-SEQUENCE	
15	5.000e-10	0.002612	0.987203	%R3	EAC-A	OPNOR-B	SYS-C	#LOMF-SEQUENCE	
16	5.000e-10	0.002612	0.989815	%R3	EAC-A	OPNOR-B	SYS-C	#LOOP-SEQUENCE	
17	2.000e-10	0.001045	0.990859	%R3	EAC-A	EQ3	SYS-B	SYS-C	#SLOCA-SEQUENCE
18	2.000e-10	0.001045	0.991904	%R3	EAC-A	EQ3	OPNOR-B	SYS-C	#SLOCA-SEQUENCE
19	1.250e-10	0.000653	0.992557	%R3	OPNOR-B	SYS-A	SYS-C	#LOOP-SEQUENCE	
20	1.250e-10	0.000653	0.993210	%R1	OPNOR-B	SYS-A	SYS-C	#LOMF-SEQUENCE	
21	1.250e-10	0.000653	0.993863	%R3	SYS-A	SYS-B	SYS-C	#LOOP-SEQUENCE	
22	1.250e-10	0.000653	0.994516	%R3	SYS-A	SYS-B	SYS-C	#LOMF-SEQUENCE	
23	1.250e-10	0.000653	0.995168	%R3	OPNOR-B	SYS-A	SYS-C	#LOMF-SEQUENCE	
24	1.250e-10	0.000653	0.995821	%R2	OPNOR-B	SYS-A	SYS-C	#LOMF-SEQUENCE	
25	1.250e-10	0.000653	0.996474	%R2	SYS-A	SYS-B	SYS-C	#LOMF-SEQUENCE	
26	1.250e-10	0.000653	0.997127	%R1	SYS-A	SYS-B	SYS-C	#LOMF-SEQUENCE	
27	1.000e-10	0.000522	0.997650	%R1	EAC-A	EQ1	SYS-B	SYS-C	#LOOP-SEQUENCE
28	1.000e-10	0.000522	0.998172	%R1	EAC-A	EQ1	OPNOR-B	SYS-C	#LOOP-SEQUENCE
29	1.000e-10	0.000522	0.998694	%R1	EAC-A	EQ1	OPNOR-B	SYS-C	#LOMF-SEQUENCE
30	1.000e-10	0.000522	0.999217	%R1	EAC-A	EQ1	SYS-B	SYS-C	#LOMF-SEQUENCE
31	5.000e-11	0.000261	0.999478	%R3	EQ3	OPNOR-B	SYS-A	SYS-C	#SLOCA-SEQUENCE
32	5.000e-11	0.000261	0.999739	%R3	EQ3	SYS-A	SYS-B	SYS-C	#SLOCA-SEQUENCE
33	2.500e-11	0.000131	0.999869	%R1	EQ1	SYS-A	SYS-B	SYS-C	#LOOP-SEQUENCE
34	2.500e-11	0.000131	1.000000	%R1	EQ1	OPNOR-B	SYS-A	SYS-C	#LOOP-SEQUENCE

Fig. 3. Quantification result of simple one-top fire event FT

Cut Set — 9.445e-8 / 15 (9.445e-8 / 15) — And — Selected Only

No	Value	F-V	Acc.	BE#1	BE#2	BE#3	BE#4	BE#5	BE#6
1	7.500e-8	0.794071	0.794071	%R2	EQ2	OPABN-B	SYS-A	#SLOCA-SEQUENCE	
2	7.500e-9	0.079407	0.873478	%R2	EQ2	OPNOR-B	SYS-A	#SLOCA-SEQUENCE	
3	7.500e-9	0.079407	0.952885	%R2	EQ2	SYS-A	SYS-B	#SLOCA-SEQUENCE	
4	2.000e-9	0.021175	0.974060	%R3	EAC-A	EQ3	OPABN-B	SYS-C	#SLOCA-SEQUENCE
5	5.000e-10	0.005294	0.979354	%R3	EQ3	OPABN-B	SYS-A	SYS-C	#SLOCA-SEQUENCE
6	5.000e-10	0.005294	0.984648	%R3	EAC-A	SYS-B	SYS-C	#LOOP-SEQUENCE	
7	5.000e-10	0.005294	0.989942	%R3	EAC-A	OPNOR-B	SYS-C	#LOOP-SEQUENCE	
8	1.250e-10	0.001323	0.991265	%R3	OPNOR-B	SYS-A	SYS-C	#LOOP-SEQUENCE	
9	1.250e-10	0.001323	0.992589	%R3	SYS-A	SYS-B	SYS-C	#LOOP-SEQUENCE	
10	1.250e-10	0.001323	0.993912	%R1	SYS-A	SYS-B	SYS-C	#LOMF-SEQUENCE	
11	1.250e-10	0.001323	0.995236	%R1	OPNOR-B	SYS-A	SYS-C	#LOMF-SEQUENCE	
12	1.250e-10	0.001323	0.996559	%R2	SYS-A	SYS-B	SYS-C	#LOMF-SEQUENCE	
13	1.250e-10	0.001323	0.997882	%R2	OPNOR-B	SYS-A	SYS-C	#LOMF-SEQUENCE	
14	1.000e-10	0.001059	0.998941	%R1	EAC-A	EQ1	OPNOR-B	SYS-C	#LOOP-SEQUENCE
15	1.000e-10	0.001059	1.000000	%R1	EAC-A	EQ1	SYS-B	SYS-C	#LOOP-SEQUENCE

Fig. 4. Quantification result of simple one-top fire event FT using FTREX command(/F=#)

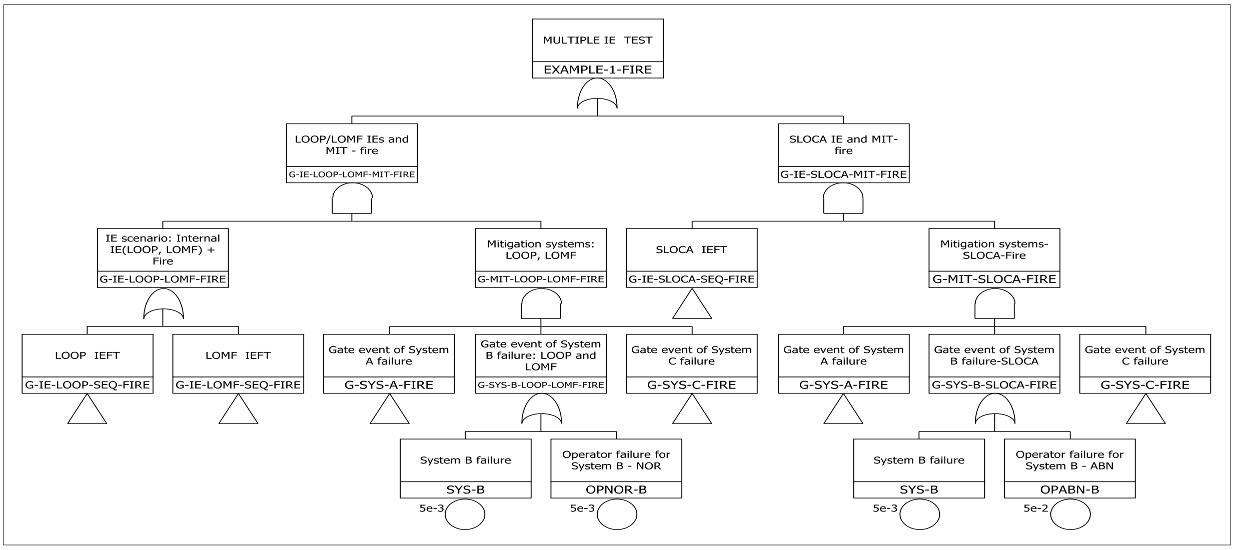

Fig.5. Modified simple one-top fire event FT (mitigating system)

Cut Set

9.445e-8 / 15 (9.445e-8 / 15) | And | Selected Only

No	Value	F-V	Acc.	BE#1	BE#2	BE#3	BE#4	BE#5	BE#6
1	7.500e-8	0.794071	0.794071	%R2	EQ2	OPABN-B	SYS-A	#SLOCA-SEQUENCE	
2	7.500e-9	0.079407	0.873478	%R2	EQ2	OPNOR-B	SYS-A	#LOMF-SEQUENCE	
3	7.500e-9	0.079407	0.952885	%R2	EQ2	SYS-A	SYS-B	#LOMF-SEQUENCE	
4	2.000e-9	0.021175	0.974060	%R3	EAC-A	EQ3	OPABN-B	SYS-C	#SLOCA-SEQUENCE
5	5.000e-10	0.005294	0.979354	%R3	EQ3	OPABN-B	SYS-A	SYS-C	#SLOCA-SEQUENCE
6	5.000e-10	0.005294	0.984648	%R3	EAC-A	OPNOR-B	SYS-C	#LOOP-SEQUENCE	
7	5.000e-10	0.005294	0.989942	%R3	EAC-A	SYS-B	SYS-C	#LOOP-SEQUENCE	
8	1.250e-10	0.001323	0.991265	%R3	OPNOR-B	SYS-A	SYS-C	#LOOP-SEQUENCE	
9	1.250e-10	0.001323	0.992589	%R3	SYS-A	SYS-B	SYS-C	#LOOP-SEQUENCE	
10	1.250e-10	0.001323	0.993912	%R1	SYS-A	SYS-B	SYS-C	#LOMF-SEQUENCE	
11	1.250e-10	0.001323	0.995236	%R1	OPNOR-B	SYS-A	SYS-C	#LOMF-SEQUENCE	
12	1.250e-10	0.001323	0.996559	%R2	SYS-A	SYS-B	SYS-C	#LOMF-SEQUENCE	
13	1.250e-10	0.001323	0.997882	%R2	OPNOR-B	SYS-A	SYS-C	#LOMF-SEQUENCE	
14	1.000e-10	0.001059	0.998941	%R1	EAC-A	EQ1	OPNOR-B	SYS-C	#LOOP-SEQUENCE
15	1.000e-10	0.001059	1.000000	%R1	EAC-A	EQ1	SYS-B	SYS-C	#LOOP-SEQUENCE

Fig. 6. Quantification result of modified simple one-top fire event FT (mitigating system) using FTREX command(/F=#)

Cut Set

9.383e-8 / 15 (9.383e-8 / 15) | And | Selected Only

No	Value	F-V	Acc.	BE#1	BE#2	BE#3	BE#4	BE#5	BE#6
1	7.500e-8	0.799361	0.799361	%R2	EQ2	OPABN-B	SYS-A	#SLOCA-SEQUENCE	
2	7.500e-9	0.079936	0.879297	%R2	EQ2	SYS-A	SYS-B	#SLOCA-SEQUENCE	
3	7.500e-9	0.079936	0.959233	%R2	EQ2	OPNOR-B	SYS-A	#LOMF-SEQUENCE	
4	2.000e-9	0.021316	0.980549	%R3	EAC-A	EQ3	OPABN-B	SYS-C	#SLOCA-SEQUENCE
5	5.000e-10	0.005329	0.985878	%R3	EQ3	OPABN-B	SYS-A	SYS-C	#SLOCA-SEQUENCE
6	3.000e-10	0.003197	0.989075	%R3	EAC-A	SYS-B	SYS-C	~EQ3	#LOOP-SEQUENCE
7	3.000e-10	0.003197	0.992273	%R3	EAC-A	OPNOR-B	SYS-C	~EQ3	#LOOP-SEQUENCE
8	1.000e-10	0.001066	0.993339	%R1	EAC-A	EQ1	SYS-B	SYS-C	#LOOP-SEQUENCE
9	1.000e-10	0.001066	0.994404	%R1	EAC-A	EQ1	OPNOR-B	SYS-C	#LOOP-SEQUENCE
10	1.000e-10	0.001066	0.995470	%R1	OPNOR-B	SYS-A	SYS-C	~EQ1	#LOMF-SEQUENCE
11	1.000e-10	0.001066	0.996536	%R1	SYS-A	SYS-B	SYS-C	~EQ1	#LOMF-SEQUENCE
12	8.750e-11	0.000933	0.997469	%R2	SYS-A	SYS-B	SYS-C	~EQ2	#LOMF-SEQUENCE
13	8.750e-11	0.000933	0.998401	%R2	OPNOR-B	SYS-A	SYS-C	~EQ2	#LOMF-SEQUENCE
14	7.500e-11	0.000799	0.999201	%R3	OPNOR-B	SYS-A	SYS-C	~EQ3	#LOOP-SEQUENCE
15	7.500e-11	0.000799	1.000000	%R3	SYS-A	SYS-B	SYS-C	~EQ3	#LOOP-SEQUENCE

Fig. 7. Quantification result of modified simple one-top fire event FT (mitigating system) without over-counted fire frequency