An Approach for Treating Non-Sense Minimum Cut Sets in Process of the Quantification of a One Top PSA Model for Fire Events

Dae Il Kang* and Yong Hun Jung
KAERI, 111 Daedeok-daero 989beon-gil, Yuseong-gu, Daejeon, 34057, Republic of Korea
**Corresponding author: dikang@kaeri.re.kr*

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. KAERI developed modification rules [1, 2, 3] 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 logics including all the event trees and fault trees for the core damage frequency (CDF) and large early release frequency (LERF) quantifications.

A fire PSA assumes that any fire included in the fire event PSA results in reactor shutdown [2, 4]. Therefore, the default initiating events (IEs) that can occur unconditionally should be assumed when constructing a fire PSA model. The IEs considered as the default IEs are general transient (GT), loss of main feed water (LOMF), or loss of condenser vacuum (LOCV). Non-sense cut sets may be generated if all fires are assumed to result in the default IEs. In this case, these non-sense cut sets should be eliminated. In addition, a single fire event can lead to multiple IEs, which can lead to duplicate non-sense cut sets. Such redundant cut sets should also be eliminated. This paper presents the cases of non-sense minimum cut sets generated in process of quantification of a one top fire PSA model and introduces the methods for treating them.

2. Methods and Results

2.1. Non-sense Cut Sets Generated from the Default IE

The assumption that the default IE occurs in the event of a fire can generate non-sense cut sets. Because one fire event can cause not only the default IE but also other IEs. The IE and mitigating system fault trees (FTs) for fire PSA are to be constructed for reasonably quantifying fire risk since a fire event can lead to multiple IEs and affect mitigating systems. Fig.1 is an example of non-sense cut sets generated when the default IE is assumed to be LOMF.

Fig. 1. represents the minimum cut sets for fire events, failure events of emergency diesel generators (EDGs) A and B, and accident sequence number of LOMF. The cut sets of Fig. 1 are non-sense because the reference nuclear power plant (NPP) has an alternate alternating current (AAC) EDG [3]. They must be deleted to reasonably estimate fire risk. The fire events that cause the default IE and other IEs must be modeled not to initiate the default IE. In terms of Boolean logic, default IE FT is to be represented as the product of a 'NOT' gate of other IE FTs. Fig. 2 illustrates an approach for treating non-sense cut sets caused by the default IE of LOMF[3].

2.2 Non-sense Cut Sets Generated from Multiple IEs

If non-sense cut sets caused by the default IE is eliminated, non-sense cut sets with the same fire event but different accident sequence numbers can be generated. Fig. 3 shows that the cut set number, 159 equals 164, 160 equals 163, and 161 equals 164, except for the accident sequence numbers #GIE-LOCCW-10! and #GIE-LOCKVA-10! located at the end [3]. Two different kinds of cut sets should be represented by single kind of cut sets. FTREX(Fault Tree Reliability Evaluation eXpert)'s command[5] can be used for handling the same cut sets with different accident sequences. If the order of deletion is to be determined for each fire-induced IE, change the flag events indicating accident sequences after making one top fire PSA model.

The following is an example of changing the flag events when the FTREX command, /F=# /FLAG_SORT=1, was used for quantification [3].

#G-GTRN ==>#G-ZGTRN
#G-LOMF ==> #G-YLOMF
#G-LOCCW ==> #G-XLOCCW (1)
#G-LOKVA ==> #G-WLOKVA
#G-LODCA ==> #G-VLODCA

where
⇒: change from the left event to the right event.

If changed and quantified as above, the non-sense cut sets are deleted in the order of GT, LOMF, LOCCW (loss of component cooling water), LOKVA (loss of 4.16 KV A), and LODCA (loss of direct current A) for the same cut sets with different accident sequence numbers. In the above example, the reasons for the determination of the deleting order are as follows. Two kinds of the default IEs, GT and LOMF, were considered and they were deleted first. LOCCW can be directly initiated by LOKVA or LODCA. However, LOCCW does not directly result in LOKVA or LODCA. LOKVA may be directly caused by the LODCA, but the LODCA is not directly initiated by the LOKVA. Fig. 4 shows the corrected cut sets after the application of Eq. (1) to Fig. 3.

3. Conclusions

This study is to present the cases of non-sense cut sets generated when a one top fire PSA model is quantified and to show an approach for resolving them. The non-sense cut sets may come from the default IEs. These kinds of non-sense cut sets were treated by the application of 'NOT' gate of IE FTs. Other kinds of non-sense cut sets can be generated from the multiple IEs except for the default IEs. These kinds of non-sense cut sets were resolved by using FTREX's command. More efforts are required for the quantification of one top fire PSA model to reasonably estimate fire risk.

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] 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 2009; 239: 2514–2520.
[2] Kang, Dae Il and Jung, Yong Hun, Comparative study on the construction of support system initiating event fault trees for a fire probabilistic safety assessment, Nuclear Engineering and Design 2018; 332: 345-356.
[3] Kang, Dae Il and Jung, Yong Hun, "User's Guide for ProFire-PSA(Program for Fire Probabilistic Safety Assessment)_Model", KAERI/TR-8701/2021. KAERI, 2021.
[4] S.P.Nowlen et al, "Fire PRA methodology for nuclear power facilities", NUREG/CR-6850, USNRC, 2005.
[5] "FTREX 2.0 User Manual", EPRI, Palo Alto, CA and KAERI, Daejeon, South Korea: 2020. 3002016047.

No	Value	F-V	Acc.	BE#1	BE#2	BE#3	BE#4	BE#5
1	7.041e-6	0.023127	0.023127	%F-100T01	EGDGR01A	EGDGR01B	/PSV	#GIE-LOFW-6!
2	7.041e-6	0.023127	0.046255	%F-100T01_135	EGDGR01A	EGDGR01B	/PSV	#GIE-LOFW-6!
3	7.041e-6	0.023127	0.069382	%F-100T01_073	EGDGR01A	EGDGR01B	/PSV	#GIE-LOFW-6!
4	7.041e-6	0.023127	0.092510	%F-100T01_073	EGDGR01A	EGDGR01B	/PSV	#GIE-LOFW-6!
5	4.804e-6	0.015781	0.108291	%F-073T07_056	EGDGR01A	EGDGR01B	/PSV	#GIE-LOFW-6!
6	4.804e-6	0.015781	0.124072	%F-073T07_100	EGDGR01A	EGDGR01B	/PSV	#GIE-LOFW-6!
7	4.804e-6	0.015781	0.139853	%F-073T07	EGDGR01A	EGDGR01B	/PSV	#GIE-LOFW-6!
8	3.368e-6	0.011062	0.150916	%F-100T01_073	EGDGR01A	EGDGS01B	/PSV	#GIE-LOFW-6!
9	3.368e-6	0.011062	0.161978	%F-100T01	EGDGR01A	EGDGS01B	/PSV	#GIE-LOFW-6!

Fig. 1. Example of non-sense cut sets generated when the default IE is LOMF.

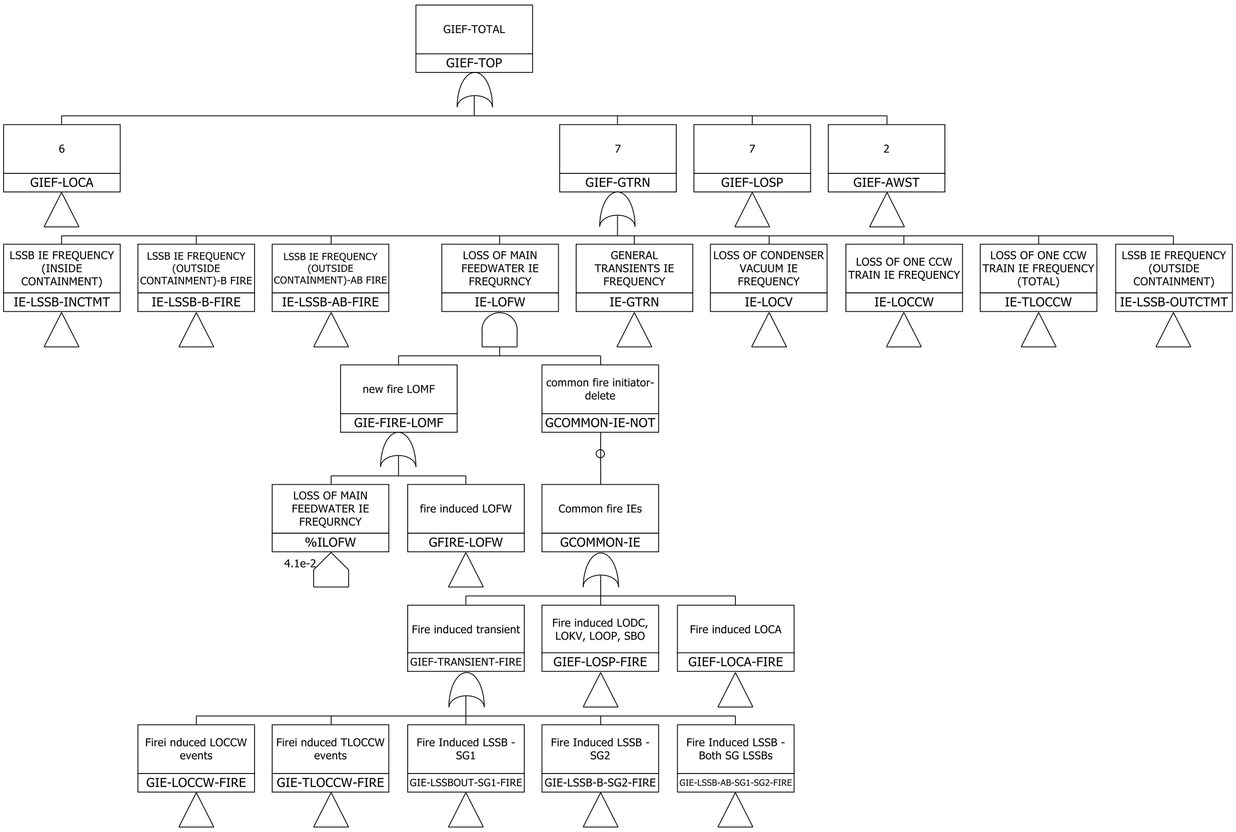

Fig. 2. Modeling approach of IE FT for treating non-sense cut sets generated when the default IE is LOMF.

159	5.243e-8	0.000725	0.520523	%F-100A06A_125A01A_AL	EGDGR01B	ZD%3821ETR01N%F-100A06A_125A0	ZD%3821ETR02N%F-100A06A_125A0	#GIE-LOCCW-10!
160	5.243e-8	0.000725	0.521247	%F-100A06A_125A01A_AL	EGDGR01B	ZD%3821ETR01M%F-100A06A_125A0	ZD%3821ETR02N%F-100A06A_125A0	#GIE-LOCCW-10!
161	5.243e-8	0.000725	0.521972	%F-100A06A_125A01A_AL	EGDGR01B	ZD%3811ETR01M%F-100A06A_125A0	ZD%3821ETR02N%F-100A06A_125A0	#GIE-LOCCW-10!
162	5.243e-8	0.000725	0.522697	%F-100A06A_125A01A_AL	EGDGR01B	ZA%0881E7722D3%F-100A06A_125A	ZD%3821ETR01N%F-100A06A_125A0	#GIE-LOKVA-10!
163	5.243e-8	0.000725	0.523421	%F-100A06A_125A01A_AL	EGDGR01B	ZD%3821ETR01M%F-100A06A_125A0	ZD%3821ETR02N%F-100A06A_125A0	#GIE-LOKVA-10!
164	5.243e-8	0.000725	0.524146	%F-100A06A_125A01A_AL	EGDGR01B	ZD%3811ETR01M%F-100A06A_125A0	ZD%3821ETR02N%F-100A06A_125A0	#GIE-LOKVA-10!
165	5.243e-8	0.000725	0.524871	%F-100A06A_125A01A_AL	EGDGR01B	ZA%0881E7722D3%F-100A06A_125A	ZD%3821ETR01M%F-100A06A_125A0	#GIE-LOKVA-10!
166	5.243e-8	0.000725	0.525595	%F-100A06A_125A01A_AL	EGDGR01B	ZA%0881E7522%F-100A06A_125A01	ZD%3821ETR02N%F-100A06A_125A0	#GIE-LOCCW-10!
167	5.243e-8	0.000725	0.526320	%F-100A06A_125A01A_AL	EGDGR01B	ZA%0881E7722D3%F-100A06A_125A	ZD%3811ETR01M%F-100A06A_125A0	#GIE-LOCCW-10!
168	5.243e-8	0.000725	0.527045	%F-100A06A_125A01A_AL	EGDGR01B	ZA%0881E7522%F-100A06A_125A01	ZA%0881E7722D3%F-100A06A_125A	#GIE-LOKVA-10!
169	5.243e-8	0.000725	0.527769	%F-100A06A_125A01A_AL	EGDGR01B	ZA%0881E7522%F-100A06A_125A01	ZA%0881E7722D3%F-100A06A_125A	#GIE-LOCCW-10!
170	5.243e-8	0.000725	0.528494	%F-100A06A_125A01A_AL	EGDGR01B	ZA%0881E7522%F-100A06A_125A01	ZD%3821ETR02N%F-100A06A_125A0	#GIE-LOKVA-10!
171	5.243e-8	0.000725	0.529219	%F-100A06A_125A01A_AL	EGDGR01B	ZA%0881E7722D3%F-100A06A_125A	ZD%3811ETR01M%F-100A06A_125A0	#GIE-LOKVA-10!
172	5.243e-8	0.000725	0.529943	%F-100A06A_125A01A_AL	EGDGR01B	ZA%0881E7722D3%F-100A06A_125A	ZD%3821ETR01M%F-100A06A_125A0	#GIE-LOCCW-10!
173	5.243e-8	0.000725	0.530668	%F-100A06A_125A01A_AL	EGDGR01B	ZA%0881E7722D3%F-100A06A_125A	ZD%3821ETR01N%F-100A06A_125A0	#GIE-LOCCW-10!
174	5.243e-8	0.000725	0.531393	%F-100A06A_125A01A_AL	EGDGR01B	ZD%3821ETR01N%F-100A06A_125A0	ZD%3821ETR02N%F-100A06A_125A0	#GIE-LOKVA-10!

Fig.3. Same non-sense cut sets having different accident sequences.

119	5.243e-8	0.001012	0.581791	%F-100A06A_125A01A_AL	EGDGR01B	ZA%0881E7722D3%F-100A06A_125A	ZD%3811ETR01M%F-100A06A_125A0	#GIE-WLOKVA-10!
120	5.243e-8	0.001012	0.582803	%F-100A06A_125A01A_AL	EGDGR01B	ZA%0881E7722D3%F-100A06A_125A	ZD%3821ETR01M%F-100A06A_125A0	#GIE-WLOKVA-10!
121	5.243e-8	0.001012	0.583814	%F-100A06A_125A01A_AL	EGDGR01B	ZA%0881E7522%F-100A06A_125A01	ZA%0881E7722D3%F-100A06A_125A	#GIE-WLOKVA-10!
122	5.243e-8	0.001012	0.584826	%F-100A06A_125A01A_AL	EGDGR01B	ZA%0881E7522%F-100A06A_125A01	ZD%3821ETR02N%F-100A06A_125A0	#GIE-WLOKVA-10!
123	5.243e-8	0.001012	0.585838	%F-100A06A_125A01A_AL	EGDGR01B	ZD%3821ETR01M%F-100A06A_125A0	ZD%3821ETR02N%F-100A06A_125A0	#GIE-WLOKVA-10!
124	5.243e-8	0.001012	0.586850	%F-100A06A_125A01A_AL	EGDGR01B	ZD%3821ETR01N%F-100A06A_125A0	ZD%3821ETR02N%F-100A06A_125A0	#GIE-WLOKVA-10!
125	5.243e-8	0.001012	0.587862	%F-100A06A_125A01A_AL	EGDGR01B	ZA%0881E7722D3%F-100A06A_125A	ZD%3821ETR01N%F-100A06A_125A0	#GIE-WLOKVA-10!
126	5.243e-8	0.001012	0.588874	%F-100A06A_125A01A_AL	EGDGR01B	ZD%3811ETR01M%F-100A06A_125A0	ZD%3821ETR02N%F-100A06A_125A0	#GIE-WLOKVA-10!

Fig. 4. Corrected cut sets having single accident sequence.