An Efficient Vital Area Identification Method

Woo Sik Jung
Sejong University, 209 Neungdong-Ro, Gwangjin-Gu, Seoul 143-747, South Korea
**Corresponding author: woosjung@sejong.ac.kr*

1. Introduction

A new Vital Area Identification (VAI) method was developed in this study for minimizing the burden of VAI procedure. It was accomplished by performing simplification of sabotage event trees or Probabilistic Safety Assessment (PSA) event trees at the very first stage of VAI procedure (see Section 3).

VAI is performed for the physical protection of nuclear facilities. Target sets and prevention sets are calculated from the sabotage fault tree. The rooms in the shortest (most economical) prevention set are selected and protected as vital areas. All physical protection is emphasized to protect these vital areas.

All rooms in the protected area, the sabotage of which could lead to core damage, should be incorporated into sabotage fault tree. So, sabotage fault tree development is a very difficult task that requires high engineering costs.

IAEA published INFCIRC/225/Rev.5 [1] in 2011 which includes principal international guidelines for the physical protection of nuclear material and nuclear installations. A vital area [2] is defined as "An area inside a protected area containing equipment, systems or devices, or nuclear materials, the sabotage of which could directly or indirectly lead to unacceptable radiological consequences."

US research institutes had been leading VAI method and requirements [3, 4]. They proposed and initiated the use of sabotage fault tree for the VAI. The sabotage fault tree can be directly developed [3, 4] or be converted from Probabilistic Safety Assessment (PSA) event trees and fault trees [5-7]. Korea Atomic Energy Research Institute (KAERI) has developed PSA-based VAI method [5-7] and software VIPEX [7]. KAERI method takes advantage of fire and flooding PSA results, since they have mapping information between components (basic events) and room failures.

Although sabotage fault tree can be derived from sabotage event trees or PSA event trees, it is well known that the development of sabotage fault tree from PSA results is more accurate and economical engineering procedure than the direct development of sabotage fault tree in absence of PSA results.

2. Current PSA-based VAI

For the explanation of current PSA-based VAI method, loss of main feedwater (%LOFW) event tree is selected. This event tree and its fault tree are depicted in Figs. 1 and 2. Here, the fault tree in Fig. 2 has failures of very simple safety systems.

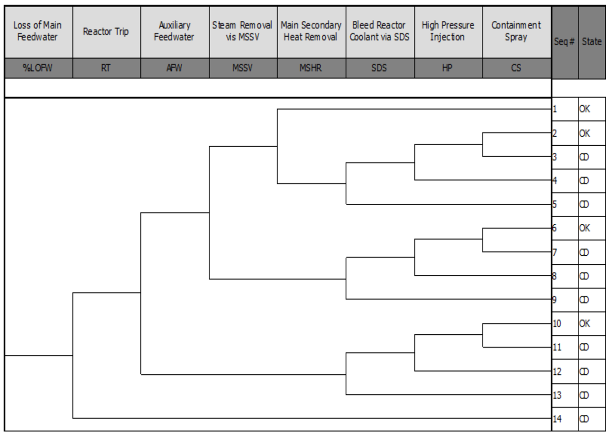

Fig. 1. Event tree for loss of main feedwater (LOFW)

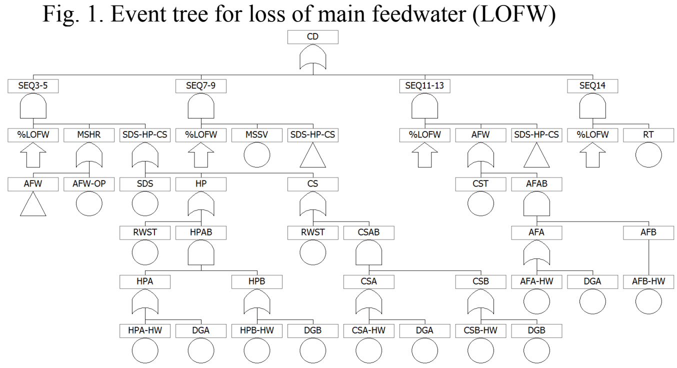

Fig. 2. Fault tree for loss of main feedwater (LOFW)

The current VAI procedure is as follows: (Step 1) Select PSA event trees for performing VAI analysis. (Step 2) Combine event trees into a single fault tree as in Fig. 2. (Step 3) Create sabotage fault tree by replacing each basic event in Fig. 2 with a room failure in Table I that has mapping information between rooms and basic events. Here, rooms are geographical areas that are surrounded by concrete walls. (Step 4) Calculate target sets and prevention sets as in Table II. (Step 5) Select the shortest (most economical) prevention set {R-CST, R-AFB-HW}, and announce these rooms in the selected prevention set as vital areas. All physical protection is designed to protect these vital areas.

$$\text{Vital areas} = \{\text{R-CST, R-AFB-HW}\} \quad (1)$$

Since complex combination of rooms are connected to %LOFW, it is not selected as the shortest one in Step 5.

When the sabotage fault tree is solved in Step 4, the following assumption is applied. Basic event, human error, common cause failure, and event tree heading that occur probabilistically even in the sabotage situation are ignored by setting them FASLE logic. With this assumption, the events RT, MSSV, and AFW-OP in Figs 1 and 2 are ignored by setting them FALSE logic.

Table I. Room to event mapping

Rooms	Initiator or basic events
Complex rooms	%LOFW
R-CSA-HW(a)	CSA-MOV1 CSA-CV1 CSA-PUMP CSA-CV2 CSA-MOV2
R-CSB-HW	CSB-MOV1 CSB-CV1 CSB-PUMP CSB-CV2 CSB-MOV2
R-HPA-HW	HPA-MOV1 HPA-CV1 HPA-PUMP HPA-CV2 HPA-MOV2
R-HPB-HW	HPB-MOV1 HPB-CV1 HPB-PUMP HPB-CV2 HPB-MOV2
R-AFA-HW	AFA-MOV1 AFA-CV1 AFA-PUMP AFA-CV2 AFA-MOV2
R-AFB-HW	AFB-MOV1 AFB-CV1 AFB-PUMP AFB-CV2
R-CST	CST
R-DGA	DGA
R-DGB	DGB
R-RWST	RWST
R-CONT	SDS

(a) CSA-MOV1, CSA-CV1, CSA-PUMP, CSA-CV2, and CSA-MOV2 are replaced with R-CSA-HW.

Table II. Prevention sets for LOFW

%LOFW					
R-CST(a)	R-AFB-HW(a)				
R-CST	R-DGA	R-AFA-HW			
R-DGA	R-RWST	R-CONT	R-HPA-HW	R-CSA-HW	
R-DGB	R-RWST	R-CONT	R-HPB-HW	R-CSB-HW	
R-DGA	R-DGB	R-RWST	R-CONT	R-CSB-HW	R-HPA-HW
R-DGA	R-DGB	R-RWST	R-CONT	R-HPB-HW	R-CSA-HW

(a) {R-CST, R-AFB-HW} are vital areas.

3. New Efficient VAI

A new VAI method was developed to minimize the burden of VAI procedure. It was accomplished by inserting PSA event tree simplification at the initial stage of VAI procedure. Event tree simplification is first performed, preliminary prevention sets are manually calculated with simplified event tree headings, a simplified fault tree is prepared from the shortest preliminary prevention set, simplified sabotage fault tree is derived from the simplified fault tree, final prevention sets are calculated from the simplified sabotage fault tree, the shortest prevention set is selected, and the rooms in the selected prevention set are protected as vital areas.

(Step 1) Simplify event trees by using the same assumption as in the previous Section. The events RT, MSSV, and AFW-OP are ignored by setting them FALSE logic. This assumption is applied to the event tree in Fig. 1, and the resultant event tree is depicted in Fig. 3. (Step 2) Calculate preliminary prevention sets with event tree headings as

$$CD = \%LOFW * AFW * (SDS + HP + CS) \quad (2)$$

$$/CD = /\%LOFW + /AFW + /SDS\, /HP\, /CS \quad (3)$$

It can be manually solved without fault tree solver. (Step 3) Select the shortest preliminary prevention set {AFW}. The fault tree AFW in Fig. 4 is used for VAI instead of the whole fault tree in Fig. 2. (Step 4) Create sabotage fault tree by replacing each basic event in Fig. 4 with a room failure in Table I that has mapping information between rooms and basic events. (Step 5) Calculate prevention sets as in Table III. (Step 6) Select the shortest (most economical) prevention set {R-CST, R-AFB-HW}, and announce the rooms in the selected prevention set as vital areas.

$$\text{Vital areas} = \{\text{R-CST, R-AFB-HW}\} \quad (4)$$

Please note that the vital areas in the current method and new efficient method are identical as shown in Eqs. (1) and (4).

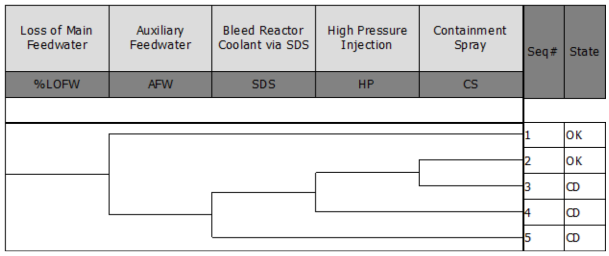

Fig. 3. Event tree for loss of main feedwater (LOFW)

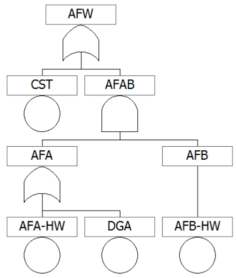

Fig. 4. Fault tree for AFW

Table III. Prevention sets for AFW

R-CST	R-AFB-HW	
R-CST	R-DGA	R-AFA-HW

4. Conclusions

A new efficient VAI method was developed and demonstrated in this study. Since this method drastically reduces VAI problem size, it provides very quick and economical VAI procedure. A consistent and integrated VAI procedure had been developed by taking advantage of PSA results [5-7], and more efficient VAI method was further developed in this study by inserting PSA event tree simplification at the initial stage of VAI procedure.

REFERENCES

[1] IAEA, Nuclear Security Series No. 13 - Nuclear Security Recommendations on Physical Protection of Nuclear Material and Nuclear Facilities, INFICRC 225/Rev. 5, 2011.

[2] IAEA, Nuclear Security Series No. 16 - Identification of Vital Areas at Nuclear Facilities, 2012.

[3] EPRI, Probabilistic Consequences Analysis of Security Threats – A Prototype Vulnerability Assessment Process for Nuclear Power Plants, 1007975, Final Report, 2004.

[4] G.B. Varnado and D.W. Whitehead, Vital Area Identification for U.S. Nuclear Regulatory Commission Nuclear Power Reactor Licensees and New Reactor Applicants, SAND-5644. Sandia National Laboratories, 2008.

[5] C.K. Park, W.S. Jung, J.E. Yang, H.G. Kang, "A PSA-based vital area identification methodology," Reliability Engineering & System Safety 2 (2), 133–140, 2003.

[6] J.J. Ha, W.S. Jung, C.K. Park, "The application of PSA techniques to the vital area identification of nuclear power plants," Nuclear Engineering and Technology 37 (3), 259–264, 2005.

[7] W.S. Jung, Y.H. Lee, J.E. Yang, "Development of a new quantification method for a fire PSA," Reliability Engineering & System Safety 94, 1650–1657, 2009.