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An Approach to the Construction of a Single Top PSA Model for Fire Events

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1. Introduction

An internal fire event PSA model is generally constructed by modifications of the pre-developed internal events PSA model. New fire-induced accident sequences, not modeled with the existing internal events PSA model, are developed separately. In this paper, we propose an approach to the construction of a single top PSA model for fire events by using the pre-developed single top internal events PSA model. The single top PSA model made by the proposed approach in this paper can be used for performing the core damage frequency (CDF) based screening analysis in the internal fire and flooding events PSA.

2. Fire PSA

2.1 CDF equations due to a fire

The CDF due to a fire can be represented by the following [1]

$$CDF = \sum_{j=1}^{m} \lambda_j SF_j NS_j CCDP_j \qquad (1)$$

λ_j = fire frequency of compartment j,
SF_j =severity factor of compartment j,
NS_j= non-suppression probability of compartment j
$CCDP_j$ = conditional core damage probability (CCDP) of compartment j

If specific fire scenarios within the compartment are considered, the CDF due to the specific fire scenario *k* could be expressed as [1]

$$CDF = \sum_{k=1}^{n} \lambda_k SF_k NS_k CCDP_k \qquad (2)$$

λ_k= fire frequency of fire scenario *k*,
SF_k= severity factor of fire scenario *k*,
NS_k= non-suppression probability of fire scenario *k*,
$CCDP_k$ = CCDP of fire scenario *k*

2.2 Screening analysis

Qualitative and quantitative analyses for a fire PSA are performed in a conservative way to reduce the number of fire compartments for the detailed analysis. Qualitative screening analysis identifies fire compartments that can be shown to have little or no risk significance without a quantitative analysis.

As shown in Eqs (1) and (2), quantitative screening analysis can be performed in two ways [1]. One way is to use the CDF and other is to use the fire occurrence frequency. Recommended quantitative screening criterion for the CDF and the fire occurrence frequency is 1.0E-7/yr [1]. The fire occurrence frequency for each compartment is estimated with the consideration of a severity factor, a non-suppression probability, and a barrier failure probability. The CDF based screening analysis is generally performed under the assumption that all the equipments within compartments including the cables are damaged. And, for the CDF quantification, the related parameters such as the probabilities of the fire-induced component failure events and the human failure events, a severity factor, a non-suppression probability, and a barrier failure probability, are estimated conservatively. For the case where the CDF for a multi-compartment fire is quantified, equipments in the exposing and exposed compartments are assumed to be damaged [1].

Detailed analysis is performed for the unscreened fire compartments. In this stage, specific fire scenarios within a compartment may be considered. Then, Eq.(2) is used for quantifying the CDF due to a fire. Qualitative and quantitative screening analysis can also be performed for each fire scenario.

3. An approach to the construction of a single top PSA Model

In Eq.(2), if $\% R_k$ is a fire frequency for fire scenario k and $S\%R_k$ is the severity for $\%R_k$ representing both the severity factor and non-suppression probability, then, Eq (2) can be represented as Eq.(3):

$$CDF = \sum_{k=1}^{n} \%R_k S\%R_k CCDP_k \qquad (3)$$

3.1 Modification rules

The following rules are suggested for the modification of an internal event PSA model into an internal fire event PSA model:

- Initiating events: If an initiating event occurs due to a specific fire scenario, then replace the initiating event by the specific fire scenario occurrence events including the severities.
- Basic events for the components: If the equipment or cable is damaged by a specific fire scenario, then replace the basic event by the basic event itself and AND logic combinations of the failure events for the components related to the damaged equipments including the cables due to a fire and of the specific fire scenario occurrence events including severities.

Fire-induced equipment or cable failures may result in failures and spurious operations of components, a prevention of the operators from performing a credited action, or an inducement to the operators to perform an inappropriate action. Thus, the modification rules mentioned above can be applied to only the failures and spurious operations of components because fire-induced human failure events may impact many components, systems, trains, or functions. Furthermore, the proposed modification rules are based on the following assumptions:

- All equipments and cables in the exposing and exposed compartments are damaged due to a fire. Equipments and cables considered in this study are active components and their power/control cables except for instrumentations.
- The probabilities of the failure modes for the components related to the damaged equipments or cables in each compartment are constant irrespective of the types of fire occurrence events.
- Any AND logic combinations of the fire occurrence events is deleted.

3.2 Application

Figure 1 of Reference [2] was used for the demonstration of the application of the proposed modification rules with small changes. Let us assume that an internal event PSA has the following two minimal cutsets (MCS):

$$\{IE_1bcd,\ IE_2ae\} \quad (4)$$

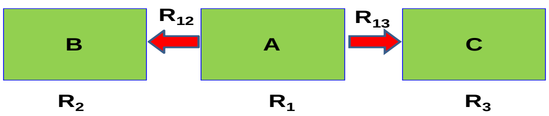

Fig. 1 Compartments of hypothetical plant

The hypothetical plant, as shown Fig.1, has three fire compartments R_1, R_2, and R_3 that have equipments or cables A, B, and C, respectively. The $\%R_{12}$ and $\%R_{13}$ denote a multi-compartments fire. It is assumed that if the fire event $\%R_1$, $\%R_2$, or $\%R_{12}$ occurs, then an internal initiating event IE_1 occurs, and that if the fire event $\%R_3$ or $\%R_{13}$ occur, then an internal initiating event IE_2 occurs. The probabilities of the failure modes, including spurious operations, for the components related to the equipments or cables A, B, and C are assumed to be a_f, b_f, and c_f, respectively. The definitions of the other events for the application of the modification rules are presented in Table1.

With the information in Table 1, the proposed modification rules were applied to two MCS in Eq.(4). The events IE1, IE2, a, b, and c in Eq.(4) were replaced by the right side Boolean formulas as follows:

$$IE_1 => \%R_1*S\%R_1 + \%R_2*S\%R_2 + \%R_{12}*S\%R_{12}$$

$$IE_2 => \%R_3*S\%R_3 + \%R_{13}*S\%R_{13}$$

$$a => a + \%R_1*S\%R_1*a_f + \%R_{12}*S\%R_{12}*a_f + \%R_{13}*S\%R_{13}*a_f$$

$$b => b + \%R_2*S\%R_2*b_f + \%R_{12}*S\%R_{12}*b_f$$

$$c => c + \%R_3*S\%R_3*c_f + \%R_{13}*S\%R_{13}*c_f$$

Consequently, the following fire PSA MCS were obtained:

$$\{\%R_1*S\%R_1*bcd,\ \%R_2*S\%R_2*bcd,\ \%R_2**S\%R_2*b_fcd,\ \%R_3*S\%R_3*ae,\ \%R_{12}*S\%R_{12}*bcd,\ \%R_{12}*S\%R_{12}*b_fcd,\ \%R_{13}*S\%R_{13}*ae, \%R_{13}*S\%R_{13}*a_fe\} \quad (5)$$

The appropriateness of Eq.(5) can be demonstrated easily by using the previous fire PSA method [3]. Failure probabilities of the components related to the damaged equipments or cables are 0, value between 0 and 1, or 1. They can be estimated from a detailed circuit analysis of the equipments due to a fire [1].

Table 1. Event descriptions

Event name	Event description
$\%R_1$	Fire occurrence event in compartment 1
$\%R_2$	Fire occurrence event in compartment 2
$\%R_3$	Fire occurrence event in compartment 3
$\%R_{12}$	Fire occurrence event in multi-compartments 1&2
$\%R_{13}$	Fire occurrence event in multi-compartments 1&3
$S\%R_1$	Severity for $\%R_1$
$S\%R_2$	Severity for $\%R_2$
$S\%R_3$	Severity for $\%R_3$
$S\%R_{12}$	Severity for $\%R_{12}$
$S\%R_{13}$	Severity for $\%R_{13}$
a	Component A failure due to a random failure
b	Component B failure due to a random failure
c	Component C failure due to a random failure
d	Component D failure due to a random failure
e	Component E failure due to a random failure
a_f	Component A failure due to a fire in compartment 1
b_f	Component B failure due to a fire in compartment 2
c_f	Component C failure due to a fire in compartment 3

4. Concluding remarks

The use of the modification rules suggested in this study will facilitate in the construction of a single top PSA model for fire and flooding events and the quantitative screening analysis for them. Detailed analysis in the fire and flooding events PSA could be performed with the modification of the single top PSA model made by the proposed approach. More studies are needed for handling the fire-induced equipment and cable failures affecting the operator actions.

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References

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