A Method of Fire Scenarios Identification in a Consolidated Fire Risk Analysis

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1. Introduction

Conventional fire PSA consider only two cases of fire scenarios, that is one for fire without propagation and the other for single propagation to neighboring compartment [1]. Recently, a consolidated fire risk analysis using single fault tree (FT) was developed [2]. However, the fire scenario identification in the new method is similar to conventional fire analysis method. The present study develops a new method of fire scenario identification in a consolidated fire risk analysis method. An equation for fire propagation is developed to identify fire scenario and a mapping method of fire scenarios into internal event risk model is discussed. Finally, an algorithm for automatic program is suggested.

2. Fire Propagation Equation and Fire Event Model

A consolidated fire risk analysis is performed by generating a single FT, in which fire events are transplanted into an internal risk model. A mapping method of fire event to a failure of component in the system is used. To model a failure of a component by fire, fire event scenario should be identified. To search these fire event scenarios, a fire propagation equation is developed

2.1 Definition of Terms

The following terms are defined to develop the fire propagation equation.

(a) *FE(i)* : Total fire events in ith compartment including a fire event initiated at ith compartment and propagated fire event into ith compartment.
(b) F_i : a fire event initiated in ith compartment
(c) F_{ji} : a fire event initiated at jth compartment and propagated to ith compartment.
(d) X_{ji} : a fire event propagated from jth compartment to ith compartment. It includes a fire initiated at jth compartment and a fire event propagated to jth compartment.
(e) $F_{ij\ldots n}$: a fire event initiated at ith compartment and propagated to nth compartment through intermediate compartment j and etc.
(f) $X_{ij\ldots n}$: a sum of fire events initiated at and propagated to ith compartment and propagated to nth compartment through intermediate compartment

2.2 Development of Fire Propagation Equation

Five events in ith compartment is a sum of event which is propagated from other compartment and initiated at ith compartment as shown in Eq. (1)

$$FE(i) = F_i + \sum_{j\neq i}^{a_i} X_{ji} \quad (1)$$

A repetitive relation can be obtained for the X_{ji} if we consider a fire event propagated from neighboring compartment as follows:

$$X_{ji} = F_{ji} + \sum_{k\neq j}^{a_j} X_{kji} \quad (2)$$

Eq. (2) can be expressed by recursion relation as shown Eq. (3) if a propagation probability can be equally defined with a fire initiated at jth compartment and a fire propagated to jth compartment.

$$X_{ji} = T_{ji}\left(F_j + \sum_{k\neq j}^{a_j} X_{kj}\right) \quad (3)$$

Using Eq. (2), Eq. (1) can be further expanded by considering second propagation in Eq. (4).

$$\begin{aligned} FE(i) &= F_i + \sum_{j\neq i}^{a_i}\left(F_{ji} + \sum_{k\neq j,i}^{a_j} X_{kji}\right) \\ &= F_i + \sum_{j\neq i}^{a_i} F_{ji} + \sum_{j\neq i}^{a_i}\sum_{k\neq j,i}^{a_j} X_{kji} \end{aligned} \quad (4)$$

Repeating the process in Eq. (4), one can find the following fire propagation equation..

$$FE(i) = F_i + \sum_{j\neq i}^{a_i} F_{ji} + \cdots + \sum_{j\neq i}^{a_i}\sum_{k\neq j,i}^{a_j}\cdots\sum_{n\neq m,\cdots,i}^{a_m} F_{n\cdots ji} \quad (5)$$

By Eq. (5), one can identify all possible fire event scenarios at ith compartment.

2.3 Mapping of the Fire Scenario

To obtain a fire risk model in terms of FT, fire event scenarios should be transplanted to a component of a system of a nuclear power plant. It is assumed that the internal event PSA model has sufficient details to model fire risk. It is not the cases, fire risk model should be constructed independently.

To perform mapping the fire event information to internal event PSA model, several preliminary conditions should be given as follows.

(a) There is no simultaneous independent fire event, that is,

$$F_i \cdot F_j = 0 \qquad (6)$$

(b) The following absorption rule is valid (see Eq. 2)

$$f_{ij} + f_{ijk} = f_{ij} \qquad (7)$$

(c) When a fire event propagated to multiple compartments, this fire event can invoke more than two initiating events. In this case, the initiating event is considered to be the first visiting compartment. Fires in other compartments are assumed to induce a compartment unavailable.

The mapping of the conventional consolidated fire risk analysis can be categorized with the following three cases.

(a) Identical initiating events and failures of components in the same minimal cut-set (MCS).

$$\left(f_i + f_j\right)\left(C_i + f_i\right)\left(C_j + f_j\right)\left(C_{ij} + f_i + f_j\right)\cdot RCS \qquad (8)$$
$$= \left(f_i C_j + f_j C_i\right) RCS$$

(b) Identical Initiating events and single failure of component.

$$\left(f_i + f_j\right)\left(C_i + f_i\right)\cdot RCS = \left(f_i + f_j C_i\right)\cdot RCS \qquad (9)$$

(c) Identical initiating events and no component failure in the same cutest.

$$\left(f_i + f_j\right)\cdot RCS \qquad (10)$$

As shown in the above three case, it is shown from the three cases that the conventional mapping method is valid in all cases.

The fire event scenarios developed by present study can be mapped as follows:

(a) Initiating events:

$$IE_k \rightarrow \left(\sum_{j\in\varepsilon_k}\hat{F}(j)\right) \qquad (11)$$

Where

$$\hat{F}(i) = F_i + \sum_{j\neq i,\, j\notin(E-\varepsilon_k)} F_{ji} + \cdots + \sum_{j\neq i}\cdots\sum_{n\neq m} F_{n\cdots ji}, \quad i\in\varepsilon_k$$

(b) Failure of component:

$$C_i \rightarrow \left(C_i + F(i)\right) \qquad (12)$$

2.4 Example Calculation

Using the method developed from the present study, we performed example calculation for simple fire geometry. Let's suppose the following fire area

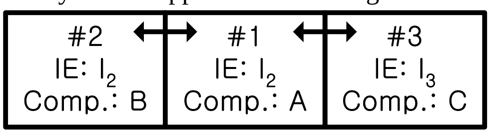

Fig. 1. Fire Area of an artificial NPP

For the fire area as shown in Fig. 1, the following MCS is assumed to be given from the internal event PSA model.

$$MCS = IE_2 BCD + IE_2 AE \qquad (13)$$

The initiating events and components failures are mapped as follows:

$$IE_2 \Rightarrow \left(f_1 + f_{21} + f_2 + f_{12}\right) = f_1 + f_2 \qquad (14)$$
$$IE_3 \Rightarrow \left(f_3 + f_{13}\right) = f_3 \qquad (15)$$
$$B \Rightarrow \left(B + f_2 + f_{12} + f_{312}\right) \qquad (16)$$
$$A \Rightarrow \left(A + f_1 + f_{21} + f_{31}\right) \qquad (17)$$
$$C \Rightarrow \left(C + f_3 + f_{13} + f_{213}\right) \qquad (18)$$

Inserting the equations from (14) and to (18), the following MCS are obtained.

$$MCS = f_1 BCD + f_{12} CD + f_{13} BD + f_{12} f_{13} D + f_2 CD + f_{213} D + f_3 AE + f_{31} E \qquad (19)$$

Inspecting Eq. (19), one can easily find that Eq. (19) has a MCS by simultaneous fire events and multiple fire propagation..

2.4Algorithm

The present method can be automated by using the following consecutive steps.

(a) Search of fire event in ith compartment and neighboring compartments
(b) Search of X_{ji} and F_{ji} in the neighboring compartment a_i
(c) Repetition of (b) until there is no compartment to be propagated. If tolerance limit is set based on propagation probability, the propagation stop when tolerance limit exceeds.
(d) Mapping the fire event information to internal event FT

3. Conclusions

The present study developed new fire event scenario identification methods for consolidated fire risk analysis. To identify the scenarios, a fire propagation equation was developed. A mapping methodology was discussed to confirm the applicability of the present method with a simple example calculation. Finally, an algorithm for the implementation of the present method was suggested.

REFERENCES

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