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Modeling strategies for the construction of a one top fire event PSA model

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1. Introduction

Kang et al.[1] developed an approach for the construction of a one top fire event PSA model by modifications of the pre-developed internal events PSA model. They suggested the use of a unified core damage frequency (CDF) equation to represent the compartment-level and scenario-level CDF equations presented in NUREG/CR-6850 [2]. Meanwhile, Han [3] proposed the use of the SIMA rule to develop a one top fire, flood, seismic, or shutdown event PSA model with the AIMS-PSA. In this paper, we propose the modeling strategies for the construction of a one top fire event PSA model according to the estimated value for the variables constituting the unified CDF equation.

2. Unified CDF Equation and SIMA Rule

2.1 CDF equations due to a fire

The CDF due to a fire can be represented by the following [2]

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

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 [2]

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

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 Unified CDF equation

Kang et al.[1] suggested the use of a unified CDF equation to represent the compartment-level and scenario-level CDF equations presented in NUREG/CR-6850 [2] as follows:

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

In Eq.(3), $\% R_k$ is a fire frequency of compartment k or fire scenario k without consideration severity factor. $S\%R_k$ is the severity for $\%R_k$ representing both the severity factor and non-suppression probability. $CCDP_k$ is the CCDP of compartment k or fire scenario k. For the case of the multi-compartment fire, $\%R_k$ is the compartment-level fire frequency of compartment k with the consideration of the failure probability of a barrier. Thus, Eq.(3) can be used for compartment-level and scenario-level CDF quantifications for single and multi-compartment fires.

2.3 SIMA rule

The SIMA [3] is the interface program used in the AIMS-PSA for the construction of fire, flood, seismic, and shutdown event PSA model with a one top internal event PSA model. In other words, AIMS-PSA read input file for fire event PSA model represented by the SIMA rule and convert it a one top fire event PSA model. Table 1 shows examples of the SIMA rule.

Table 1. Examples of the SIMA rule

Case	Example	Remark
Add+	Add+ A B	Add B to A
Value	Value B 0.1	Set B 0.1
Set	Set A C	Change A to C
	Set A True, Set E False	

3. Modeling strategies

3.1 General strategy

Initiating events and component failure events in the internal PSA model affected by a fire are modified to build a one top fire event PSA model by incorporating fire events into a one top internal event PSA model. According to the suggestions of Kang et al., Eq.(3), and the SIMA rule, initiating events and component failure events in the internal PSA model are changed as follows [4]:

Initiating event: $\%I ==> \sum \%R_k * S\%R_k \qquad (4)$

Component failure event: $a ==> a + \sum \%R_k * S\%R_k * P\%R_k\text{-}a \qquad (5)$

where, %I: initiating event in internal PSA model
a: basic event of component failure in internal PSA model
$P\%R_k\text{-}a$: failure probability or event of component ‘a’ due to $\%R_k$ fire

Eq. (4) is to change %I to $\%R_k*S\%R_k$ if any fire event $\%R_k$ occurs and it triggered initiating event %I considered in the internal event PSA model. In the same manner, Eq.(5) is to change component basic event ‘a’ to ‘a’ + $\sum \%R_k*S\%R_k*P\%R_k\text{-}a$. There are several basic events representing component failures such as demand failure event, running failure event, common cause failure events, etc. In general, one of them is selected as a representative event to model fire occurrence events.

3.2 Screening analysis

For the case where screening analysis is performed, severity factor and non-suppression probability are generally estimated at one. Consequently, severity, $S\%R_k$, of Eq.(3) is also estimated at one. Thus, the CDF equation of compartment k is represented as follows:

$$CDF_k = \%R_k * CCDP_k \quad (6)$$

As mentioned in references [1, 4], modeling strategies are dependent on the fire induced component failure probability. Initiating events and component failure events in the internal PSA model are changed as follows:

- Fire induced component failure probability= 1
  - ✓ Initiating event: $\%I ==> \sum\%R_k$
  - ✓ Component failure event : $a ==> a + \sum\%R_k$
- Fire induced component failure probability $\fallingdotseq$ 1
  - ✓ Initiating event: $\%I ==> \sum \%R_k$
  - ✓ Component failure event: $a ==> a + \sum \%R_k * P\%R_k - a$

3.3 Detailed analysis

For the case where detailed analysis is performed, modeling strategies are dependent on the severity and fire induced component failure probability. If severity, $S\%R_k$, is estimated at one, then the modeling strategy is the same as the case of screening analysis. If severity is not equal to one, the modeling strategies are as follows:

- Fire induced component failure probability= 1
  - ✓ Initiating event: $\%I ==> \sum\%R_k * S\%R_k$
  - ✓ Component failure event : $a ==> a + \sum\%R_k * S\%R_k$
- Fire induced component failure probability $\fallingdotseq$ 1
  - ✓ Initiating event: $\%I ==> \sum \%R_k * S\%R_k$
  - ✓ Component failure event: $a ==> a + \sum \%R_k * S\%R_k * P\%R_k - a$

3.4 Applications

Modeling strategies proposed in this study were applied to the screening analysis and detailed analysis of specific fire compartments considered in the previous fire PSA of Ulchin Unit 3 & 4[4]. That the modeling strategies were well applicable to the construction of a one top fire event PSA model was confirmed. Figure 1 shows the quantification results of diesel generator room DG A fire event by using the previous domestic fire PSA quantification method. Figure 2 shows the quantification results of diesel generator room DG A fire event with a one top fire event PSA model developed by using the suggested modeling strategies. As shown in Figure 1 and 2, the two quantification results are the same.

4. Concluding remarks

In this paper, the modeling strategies for the construction of a one top fire event PSA model according to the estimated value for the variables constituting the unified CDF equation have been proposed. That the modeling strategies were well applicable to the construction of a one top fire event PSA model was confirmed. The suggested modeling strategies are being programmed in the IPRO-ZONE, which selects basic events corresponding to component failures affected by fire occurrence events and produces input file for fire events PSA model.

Acknowledgements
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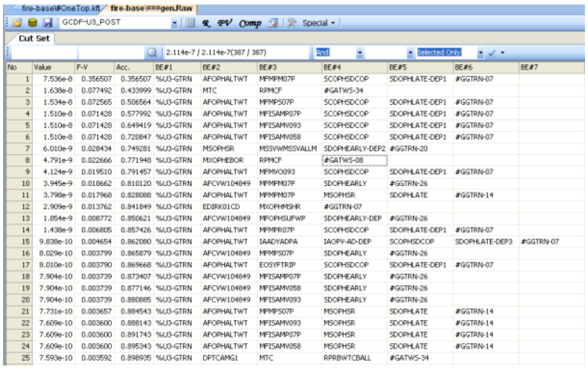
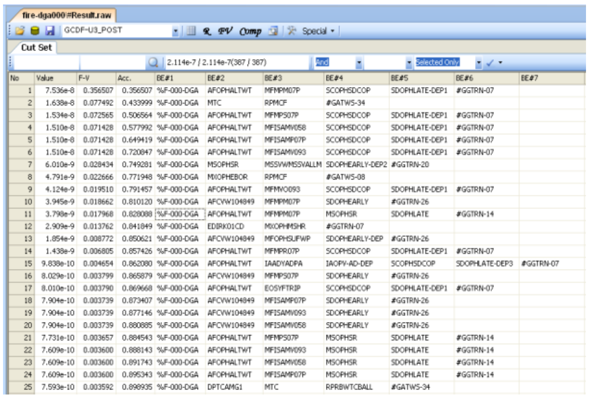


2.114e-7 / 2.114e-7(387 / 387)

No	Value	F-V	Acc.	BE#1	BE#2	BE#3	BE#4	BE#5	BE#6	BE#7
1	7.536e-8	0.356507	0.356507	%U3-GTRN	AFOPHALTWT	MFMPM07P	SCOPHSDCOP	SDOPHLATE-DEP1	#GGTRN-07	
2	1.638e-8	0.077492	0.433999	%U3-GTRN	MTC	RPMCF	#GATWS-34			
3	1.534e-8	0.072565	0.506564	%U3-GTRN	AFOPHALTWT	MFMPS07P	SCOPHSDCOP	SDOPHLATE-DEP1	#GGTRN-07	
4	1.510e-8	0.071428	0.577992	%U3-GTRN	AFOPHALTWT	MFISAMP07P	SCOPHSDCOP	SDOPHLATE-DEP1	#GGTRN-07	
5	1.510e-8	0.071428	0.649419	%U3-GTRN	AFOPHALTWT	MFISAMV093	SCOPHSDCOP	SDOPHLATE-DEP1	#GGTRN-07	
6	1.510e-8	0.071428	0.720847	%U3-GTRN	AFOPHALTWT	MFISAMV058	SCOPHSDCOP	SDOPHLATE-DEP1	#GGTRN-07	
7	6.010e-9	0.028434	0.749281	%U3-GTRN	MSOPHSR	MSSVWMSSVALLM	SDOPHEARLY-DEP2	#GGTRN-20		
8	4.791e-9	0.022666	0.771948	%U3-GTRN	MXOPHEBOR	RPMCF	#GATWS-08			
9	4.124e-9	0.019510	0.791457	%U3-GTRN	AFOPHALTWT	MFMVO093	SCOPHSDCOP	SDOPHLATE-DEP1	#GGTRN-07	
10	3.945e-9	0.018662	0.810120	%U3-GTRN	AFCVW104849	MFMPM07P	SDOPHEARLY	#GGTRN-26		
11	3.798e-9	0.017968	0.828088	%U3-GTRN	AFOPHALTWT	MFMPM07P	MSOPHSR	SDOPHLATE	#GGTRN-14	
12	2.909e-9	0.013762	0.841849	%U3-GTRN	EDIRK01CD	MXOPHMSHR	#GGTRN-07			
13	1.854e-9	0.008772	0.850621	%U3-GTRN	AFCVW104849	MFOPHSUFWP	SDOPHEARLY-DEP	#GGTRN-26		
14	1.438e-9	0.006805	0.857426	%U3-GTRN	AFOPHALTWT	MFMPR07P	SCOPHSDCOP	SDOPHLATE-DEP1	#GGTRN-07	
15	9.838e-10	0.004654	0.862080	%U3-GTRN	AFOPHALTWT	IAADYADPA	IAOPV-AD-DEP	SCOPHSDCOP	SDOPHLATE-DEP3	#GGTRN-07
16	8.029e-10	0.003799	0.865879	%U3-GTRN	AFCVW104849	MFMPS07P	SDOPHEARLY	#GGTRN-26		
17	8.010e-10	0.003790	0.869668	%U3-GTRN	AFOPHALTWT	EOSYFTRIP	SCOPHSDCOP	SDOPHLATE-DEP1	#GGTRN-07	
18	7.904e-10	0.003739	0.873407	%U3-GTRN	AFCVW104849	MFISAMP07P	SDOPHEARLY	#GGTRN-26		
19	7.904e-10	0.003739	0.877146	%U3-GTRN	AFCVW104849	MFISAMV058	SDOPHEARLY	#GGTRN-26		
20	7.904e-10	0.003739	0.880885	%U3-GTRN	AFCVW104849	MFISAMV093	SDOPHEARLY	#GGTRN-26		
21	7.731e-10	0.003657	0.884543	%U3-GTRN	AFOPHALTWT	MFMPS07P	MSOPHSR	SDOPHLATE	#GGTRN-14	
22	7.609e-10	0.003600	0.888143	%U3-GTRN	AFOPHALTWT	MFISAMV093	MSOPHSR	SDOPHLATE	#GGTRN-14	
23	7.609e-10	0.003600	0.891743	%U3-GTRN	AFOPHALTWT	MFISAMP07P	MSOPHSR	SDOPHLATE	#GGTRN-14	
24	7.609e-10	0.003600	0.895343	%U3-GTRN	AFOPHALTWT	MFISAMV058	MSOPHSR	SDOPHLATE	#GGTRN-14	
25	7.593e-10	0.003592	0.898935	%U3-GTRN	DPTCAMG1	MTC	RPRBWTCBALL	#GATWS-34		

Figure 1. Quantification results by the previous method



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4	1.510e-8	0.071428	0.577992	%F-000-DGA	AFOPHALTWT	MFISAMV058	SCOPHSDCOP	SDOPHLATE-DEP1	#GGTRN-07	
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25	7.593e-10	0.003592	0.898935	%F-000-DGA	DPTCAMG1	MTC	RPRBWTCBALL	#GATWS-34		

Figure 2. Quantification results by the suggested method