Applications of Hybrid Fire PSA Approaches to the SMART

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1. Introduction

A fire PSA shall be performed for new reactors according to policy set by KINS. Fire PRA Implementation Guide [1] has been used for performing fire PSA for NPPs in Korea. However, RG 1.189 [2] requires that the fire PSA for existing NPPs adopting NFPA 805 or new reactors be performed in accordance with NUREG/CR-6850 [3]. As the SMART is in a design stage and there is no previous mother plant for it, NUREG/CR-6850 cannot be fully applied to the SMART fire PSA. Because there is no information on circuit design for equipment, cable routing, position of equipment in fire areas, etc. Hybrid PSA approaches, using NUREG/CR-6850 [3] and the Fire PRA Implementation Guide [2], were applied to perform the SMART fire PSA. In this paper, the overall approaches and results of the SMART fire PSA are introduced and discussed.

2. Fire PSA methodologies of the SMART fire PSA

2.1 CDF equation due to a fire

The CDF due to a fire can be represented by the following equation:

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

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*,
$CCDP_k$ = conditional core damage probability of fire scenario *k*

In NUREG/CR-6850, the severity factors are estimated by using fire modeling. On the other hand, the Fire PRA Implementation Guide determines the severity factors according to the characteristics of ignition sources. NUREG/CR-6850 requires that the circuit analysis be performed or the conservative value be used to estimate fire-induced spurious operation probabilities of equipment. For the case of domestic NPPs having used the Fire PRA Implementation Guide, 0.1 was assumed as the probabilities for fire-induced spurious operation of equipment.

2.2 Overall approach of the SMART fire PSA

In the SMART fire PSA, calculations of fire frequencies, and estimations of fire-induced spurious operation probability of equipment and non-suppression probabilities were performed according to NUREG/CR-6850. Calculations of severity factors were performed by using the Fire PRA Implementation Guide because there is no design information on equipment layout and cable routing. Fire modeling analysis of the main control room was performed by NUREG/CR-6850.

Different approaches of the SMART fire PSA from the previous domestic fire PSA method are as follows:

- Use of one top fire event PSA model [4] in the quantitative screening and detailed analysis
- Modeling of additional equipment affected by a fire
- Re-evaluation of post-accident human error events modeled in internal event PSA
  - Five times of execution errors for ex-control room actions
  - Two times of execution errors for control room actions
- Estimation of fire frequencies accordance with NUREG/CR-6850
- Estimation of fire-induced equipment spurious operation probabilities based on NUREG/CR-6850
  - Standby equipment other than valves-1
  - Running equipment other than valves – 0.39
  - Motor operated valves – 0.17
  - Other valves – 0.25
- Use of fire modeling for main control room analysis

3. Results of the SMART fire PSA

Qualitative analysis of 242 fire areas showed that 145 fire areas including 725 fire scenarios with fire propagation were required for quantitative analysis. From the quantitative analysis of 145 fire areas, 23 fire areas were identified for the detailed quantitative analysis. All quantitative screening and detailed analysis were performed by using one top fire event PSA model based on an internal event one top PSA model. The cut-off value of 1.0E-13/yr was used for the quantification and the screening value of 7.0E-9/yr was used for the detailed analysis.

The detailed analysis results showed that the CDF due to an internal fire event of the SMART was quantified as 1.035E-6/yr. The CDF for each fire area is presented in Table 1. The main control room fire is identified as a major contributor to the CDF and its contribution to the CDF is 90.44%. The next contributor is identified as A5GC fire and its contribution is 3.93%. Contributions of the other fire area to the CDF are identified as less than 2%. The reason for a relatively high contribution of the SMART main control room fire to the CDF is thought to be a relatively small CDF for internal events of the SMART comparing to CDFs for those of the domestic NPPs.

4. Concluding remarks

As the SMART is in the design stage, hybrid approaches, using NUREG/CR-6850 and Fire PRA Implementation Guide, were used for performing the SMART fire PSA. For the SMART fire PSA, conservative generic values for fire-induced spurious operation probabilities of equipment were used because there is no design information on equipment circuit, and layouts of cables and equipment in fire areas. The internal fire CDF of the SMART will decrease if the detailed circuit analysis is performed to estimate fire-induced spurious operation probabilities of equipment.

More efforts are needed for the detailed circuit analysis and estimations of severity factors by using fire modeling if the design for the SMART is completed. The fire PSA results of the SMART could be used for preparations of abnormal fire operation procedures, fire protection procedures, and severe accident management procedures.

References

[1]. EPRI, "Fire PRA Implementation Guide", EPRI TR-105928 Dec. 1995
[2]. Regulatory Guide 1.189(Rev.2), "Fire Protection for Nuclear Power Plants", 2009
[3]. EPRI/NRC-RES "Fire PRA Methodology for Nuclear Power Facilities", EPRI 1011989, NUREG/CR-6850 Final Report, Sep. 2005
[4]. Dae Il Kang et al., "An approach to the construction of a one top fire event PSA model", Nuclear Engineering and Design 239, 2514-2520,2009

Table 1 Detailed quantification results of the SMART fire PSA

Fire Area	Name	CDF	% CDF
A208C	CLASS 1E LOAD CENTER 02A RM	1.58E-09	0.15
A2GC	GENERAL ACCESS AREA C(-6.0m)	1.40E-09	0.14
A2GD	GENERAL ACCESS AREA D(-6.0m)	1.04E-08	1.00
A3GD	GENERAL ACCESS AREA D(0.0m)	2.61E-09	0.25
A407C	ELEC. PENETRATION AREA A	5.15E-10	0.05
A407D	ELEC. PENETRATION AREA B	8.47E-10	0.08
A412D	ECT VALVE RM & PIPE WAY B	4.34E-09	0.42
A4GC	GENERAL ACCESS AREA C(6.0m)	9.26E-11	0.01
A4GD	GENERAL ACCESS AREA D(6.0m)	5.42E-10	0.05
A505C	I & C EQUIP. RM-CH A	1.95E-10	0.02
A505D	I & C EQUIP. RM-CH B	2.05E-10	0.02
A507C	I & C EQUIP. RM-CH C	3.00E-12	0.00
A507D	I & C EQUIP. RM-CH D	3.63E-12	0.00
A511C	TSC OFFICE	2.86E-11	0.00
G5C1	MAIN CONTROL ROOM	9.36E-07	90.44
A5G2	COMPUTER ROOM AREA	3.06E-10	0.03
A5GC	GENERAL ACCESS AREA C(12.6m)	4.07E-08	3.93
A5GD	GENERAL ACCESS AREA D(12.6m)	1.63E-08	1.57
A618D	ELECTRICAL EQUIP. RM B	1.60E-10	0.02
A619D	REMOTE SHUTDOWN RM	3.67E-09	0.35
A621D	CONTROL RM AREA SUPPLY AHU RM B	5.54E-11	0.01
A624C	CONTROL RM AREA SUPPLY AHU RM A	7.17E-11	0.01
T0G0	TURBINE	1.50E-08	1.45
Sum		1.04E-06	100.00