The fire scenario study for the Multiple Spurious Operation via BWR

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Abstract: The approach in this study is based on the fire PRA methodology issued by the USNRC, i.e. NUREG/CR-6850, complemented by the experiences gained from the past fire PRAs. It is aimed at upgrading the current fire PRA models of Kuosheng nuclear power plant. The fire PRA adopts a progressive screening process in terms of realisticity, screening qualitatively and quantitatively by fire compartment, then by fire scenario, until the most realistic scenario-based fire risk model is developed and quantified as possible. To quantify the fire risk, the failure modes and associated probabilities of fire damaged equipment and cables are also investigated. High risk cables also identified and need to analysis hot short and multiple spurious operations (MSOs). The percentage of MSOs remains at 57.75 %. Thus, MSOs occupied larger proportions of the total fire risk. The compartment ID:30 was chosen as case study. We discuss the procedure for the development of MSO fire scenarios in this study.

1. INTRODUCTION

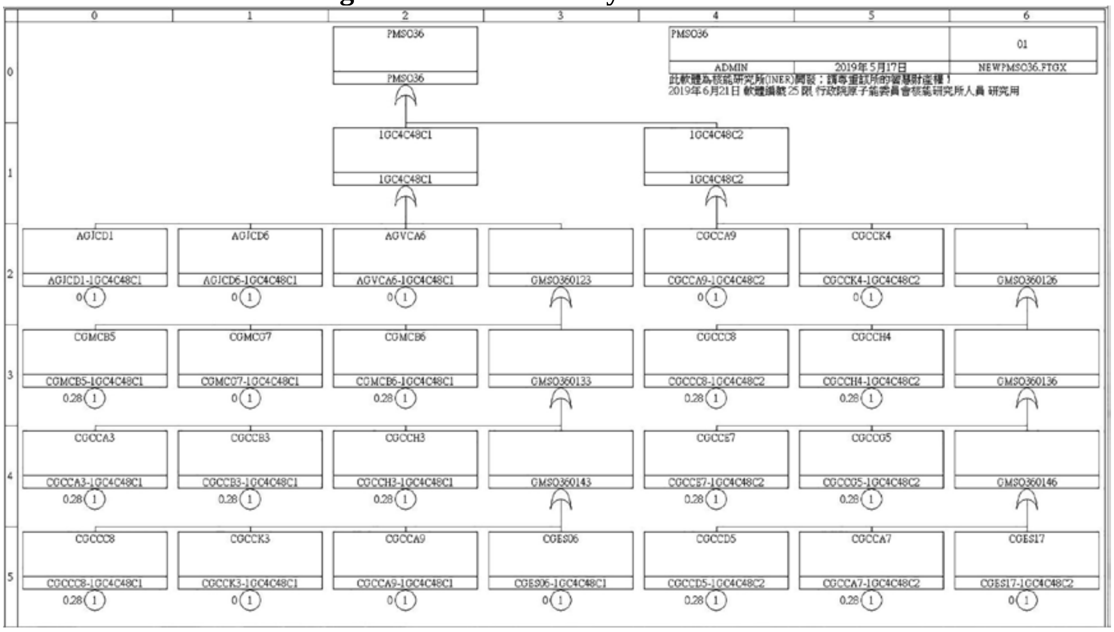
NUREG/CR-6850[1][2] Fire PRA methodology is developed by USNRC and Electric Power Research Institute (EPRI). It is the framework of the overall analysis process and the primary guidelines for the fire PRA development in the nuclear power plants. To determine the fire risk of the core damage frequency (CDF) of the nuclear power plant, it starts with identifying fire compartments, cables, followed by initial quantitative screening analysis, and iterative quantitative assessment.
In this study, we focus on systematic procedure for the development of multiple spurious operations (MSO) fire scenario. According to NUREG/CR-7150[3], it define electric circuit failure mode and given the failure probability. The electric circuit analysis tables are documented help us to further discuss in detail. As result of every compartment fire scenario, it rely on different equipment and cables generate various hot short failure and then apply fault tree analysis. It can ensure we don't miss any MSO scenarios.

2. Systematic procedure for the development of MSO fire scenarios

MSO caused by equipment or cables damaged when either of equipment, cables, transients (including Induced Transient, IT) or Induced Cable (IC) fires are discussed. If the fire compartment contains a cable tray that may have MSO scenarios, it is necessary to consider whether the damaged equipment included itself cable tray and the probability of an MSO scenario for equipment, cables, transients and IC. To simplify the quantification process for systematic procedures, there are some assumptions below:
Assumption 1: When there are multiple MSO scenarios in a single tray, the CCDP and failure probability can't be given separately. To simplify the analysis, the CCDP is calculated by unavailable equipment of all the MSO scenarios in the tray, and the failure probability is given by the highest failure probability of a single hot short circuit scenario.
Assumption 2: When multiple MSO scenarios are in the same fire compartment, the CCDP and failure probability can't be given separately. To simplify the analysis, the CCDP is calculated by unavailable equipment of all MSO scenarios in the fire compartment. Failure probability is given by the highest failure probability of a single hot short circuit scenario.
Since the fire scenario in each compartment will cause hot short circuit failure with respect to different equipment (ignition sources) and cables (target), fault tree analysis is applied in this study to ensure that none of the MSO scenario is missed. Taking the scenario of MSO 36 as an example, manual valve EJ-

HV-223 in Residual Heat Removal (RHR) system is closed because of hot short circuit malfunction, thereby disabling Low Pressure Cooling Injection (LPCI) system of train B. The fault tree of MSO 36, as illustrated in Fig. 1, describes the failure probability of MSO scenario of a single cable tray resulting from the failure of either cable IGC4C48C1 or IGC4C48C2.

Fig. 1. Fault Tree Analysis of MSO 36.



The fire scenario relating to the circuit analysis includes single cable self-ignition, cable tray self-ignition, fire spread to cable tray, fire spread to nearby cable tray, and fire compartment burnout, as explained below. Since the MSO scenario is developed from equipment, cables, transients and IC fire scenarios, the risk caused by either one of them needs to be deducted using the risk increment.

2.1 Single cable self-ignition

Although thermoset (TS) wrapped cables are sources of ignition, they are not liable for fire spreading when self-igniting because of the properties of the material. The probability of the occurrence of such cable fire is the probability of hot short circuit failure of the cable itself.

2.2 Single cable tray with single hot short circuit fire scenario

Thermoplastic (TP) wrapped cables are sources of ignition. Considering the properties of the TP material, TP-wrapped cables are easy to fire spreading. The possible combination of fire scenarios includes spreading from the list below:
(a) the burning single cable to the cable tray,
(b) burning equipment to a single cable tray, and
(c) transient fire to a single cable tray.
The hot short circuit cable on the cable tray should be considered as a single cable tray with single hot short circuit fire scenario.

2.3 Single cable tray with multiple hot short circuit fire scenario

Regarding the calculation of the probability of such MSO scenarios, the equation is rather complicated. For example, when there are N numbers of MSOs in the cable tray, including MSO A, MSO B, ..., MSO N, the probability of MSOs is PA, PB, .. , PN, respectively, and the CCDP is CCDPA, CCDPB, .. ., CCDPN, individually, as given by the quantification Eq. (1).

$$(P_A - P_A P_B - P_A P_C - \ldots - P_A P_N + P_A P_B P_C + P_A P_B P_D + \ldots + P_A P_M P_N - \ldots) \times CCDP_A + (P_B - P_B P_A - P_B P_C - \ldots - P_B P_N + P_B P_A P_C + P_B P_A P_D + \ldots + P_B P_M P_N - \ldots) \times CCDP_B + \ldots + P_A P_B \ldots P_N \times CCDP_{AB\ldots N} \qquad (1)$$

In order to simplify the calculation of MSO scenario in this study, the MSO of the same CCDP is classified first, and then the respective probabilities of MSOs are $P_A \geq P_B \geq P_C \geq \cdots \geq P_N$. Eq. (2) is adopted only if the MSO scenario is simple; otherwise, Eq (3) is adopted for segment quantification of severe scenarios.

$$P_A \times CCDP_{AB\ldots N} \qquad (2)$$

Eq. 3 is adopted for segment quantification of severe scenario.

$$\begin{gathered} (P_A - P_B) \times CCDP_A \\ (P_B - P_C) \times CCDP_{AB} \\ \ldots\ldots \\ P_N \times CCDP_{AB\ldots N} \qquad (3) \end{gathered}$$

It may be segmented again to simplify the calculation when numerous MSO scenarios in the cable tray are considered. For example, in any scenario when MSO C is the initial event change, Eq. (4) is adopted by divided into two segments and quantified.

$$\begin{gathered} (P_A - P_C) \times CCDP_{AB} \\ P_C \times CCDP_{AB\ldots N} \qquad (4) \end{gathered}$$

2.4 Multiple hot short circuit fire scenario with respect to train-level cable tray

This kind of fire scenario refers to burning by trains resulted from ignition sources such as equipment, transient fire and cable itself, thereby simplifying quantitative analysis. Considering the number of the cable scenarios, the zone of Influence (ZOI) of respective ignition sources are difficult to determine. For example, if a single cable tray is an ignition source, itself ZOI cannot be analyzed by an individual cable tray. To resolve this problem, all of the cable trays in the compartment are determined by train in advance, after which the obtained trains are classified into MSO scenarios. In addition, trains of the same MSO scenario are quantified.

Considering that trains' MSO scenario have been involved MSO scenarios resulted from multiple cable trays, the number of scenarios of a train-level cable tray is more than single cable tray. Although the quantification of the MSO scenario of a train- level cable tray is similar to that of a single tray with multiple hot short circuit, the fire propagation time from the ignited cable tray to the different cable trays need to consider. Conservatively, it is estimated that spreading of fire to the above cable tray takes 4 minutes, which is combined with NUREG/CR-7150 [] for estimation of the duration of the hot short circuit and revision of the probability of the previously obtained MSO.

3. Results

The MSO scenario is developed from the above four types of fire scenarios. The quantified results need to be deducted from the risk caused by the above four types of fires, after which the results are displayed in terms of risk increments. Therefore, this study establishes an MSO scenario quantification spreadsheet with respect to the fire compartment, providing follow-up integrated risk assessment of the plant. There are 2,918 MSO scenarios, including 217 equipment types, 2,140 cable types (including 424 cables; 1,716 trays), 139 temporary ignition sources (including IT), and 422 ICs. As an example, the high risk quantification results of the MSO scenario of the fire compartments are shown in Table 3-1 and 3-2. The linkage and the formula setting among cells of spreadsheets are as follows.

- λ_{is}* SF*P_{ns} : Refers to equipment ignition frequency, which is then multiplied by the severity factor and the probability of non-suppression.
- P_{MSO} : The probability of MSO scenario is calculated by fault tree.
- IE_{ori} : Initial events of MSO have not been included in.
- $CCDP_{ori}$: CCDP of MSO scenarios have not been included in.
- $CLERP_{ori}$: CLERP of MSO scenarios have not been included in.
- $CCDP_{MSO}$: CCDP of MSO scenario of fire.
- $CLERP_{MSO}$: CLERP of MSO scenarios of fire.
- ΔCDF_{MSO}: [λ_{is}* SF*P_{ns}]*P_{MSO}*($CCDP_{MSO}$ - $CCDP_{ori}$)
- $\Delta LERF_{MSO}$: [λ_{is}* SF*P_{ns}] *P_{MSO}* ($CLERP_{MSO}$ - $CLERP_{ori}$)

Table3-1 high risk MSO Scenario

Compartment No.	MSO Scenario ID	λ_{is} x SF x P_{ns}	MSO Item	P_{MSO}	IE_{ori}	$CCDP_{ori}$
30	30-321-T1-MSO	7.52E-05	57,90	8.61E-01	AAA-T2	2.03E-04
30	30-322-T1-MSO	2.33E-05	57,90	8.61E-01	AAA-T2	2.03E-04
30	30-8002-T1-MSO	1.87E-05	57,90	8.61E-01	AAA-T2	2.03E-04
30	30-8003-T1-MSO	1.88E-05	57,90	8.61E-01	AAA-T2	2.03E-04
54	54-8012-T1-MSO	3.56E-05	80	3.14E-01	AAA-T5	3.39E-03

Continued Table3-1 high risk MSO Scenario

Compartment No.	$CLERP_{ori}$	IE_{MSO}	$CCDP_{MSO}$	$CLERP_{MSO}$	ΔCDF_{MSO}	$\Delta LERF_{MSO}$
30	3.64E-06	AAA-T2	3.56E-02	3.66E-04	2.29E-06	2.35E-08
30	3.64E-06	AAA-T2	3.56E-02	3.66E-04	7.10E-07	7.27E-09
30	3.64E-06	AAA-T2	3.56E-02	3.66E-04	5.70E-07	5.83E-09
30	3.64E-06	AAA-T2	3.56E-02	3.66E-04	5.74E-07	5.87E-09
54	1.22E-05	AAA-T5	5.06E-02	1.34E-04	5.26E-07	1.35E-09

Table3-2 MSO Item descriptions

MSO Item	MSO descriptions
57	F010 and F011 valve opened by error single. It result in the water from suppression pool to condensate storage tank (CST). HPCS has no function.
90	F012 valve opened by error single. It result in the water from CST to suppression pool through minimum flow path. The water level of CST and suppression pool decrease or increase rapidly.
80	F013 and F045 valve opened by error single. It result in Reactor Core Isolation Cooling (RCIC) started.

3.1. MSO Scenario: 30-321-T1-MSO

The MSO ID : 30-321-T1-MSO is caused by 1A5 4.16KV Switchgear and considered an equipment fire. It burned and extend to cable tray (BOUCK3, BOUCM3). The ignition source is bin 16a : 480V~1000V HEAF Electrical enclosures. Ten minutes later the fire spreads to the compartment 30. The likelihood of MSO scenario is 57 and 90. While they include in risk mode, the PMSO and CCDP is 8.61E-01 and 3.56E-02 respectively (table 3-1). Finally, the risk increment is 2.29E-06/y.

3.2. MSO Scenario: 30-322-T1-MSO

The MSO ID : 30-322-T1-MSO is caused by 345 kV ST bus duct and considered an equipment fire. The ignition source is bin 16a : 480V~1000V HEAF. It burned and extend to other equipment by cables. 30 minutes later the fire spreads to the compartment 30. The likelihood of MSO scenario is 57 and 90. While they include in risk mode, the PMSO and CCDP is 8.61E-01 and 3.56E-02 respectively (table 3-1). Finally, the risk increment is 7.10E-07/y.

3.3. MSO Scenario: 30-8002-T1-MSO

The MSO ID : 30-8002-T1-MSO is caused by 1A5 4.16 kV Switchgear and considered an equipment fire. It burned and extend to cable tray (BOUCK3, BOUCM3). The ignition source is bin 15 : Electrical enclosures. 10 minutes later the fire spreads to the compartment 30. The likelihood of MSO scenario is 57 and 90. While they include in risk mode, the PMSO and CCDP is 8.61E-01 and 3.56E-02 respectively (table 3-1). Finally, the risk increment is 5.70E-07/y.

3.4 MSO Scenario: 30-8003-T1-MSO

The MSO ID : 30-8003-T1-MSO is caused by 345 kV ST bus duct and considered an equipment fire. The ignition source is bin 15 : Electrical enclosures. It burned and extend to other equipment by cables. 30 minutes later the fire spreads to the compartment 30. The likelihood of MSO scenario is 57 and 90. While they include in risk mode, the PMSO and CCDP is 8.61E-01 and 3.56E-02 respectively (table 3-1). Finally, the risk increment is 5.74E-07/y.

3.5 MSO Scenario: 54-8012-T1-MSO

The MSO ID : 30-8012-T1-MSO is caused by 480V Motor Control Center (MCC) BUS 1C1D(600A) and considered an equipment fire. It burned and extend to cable tray ANVCFE3, ANVCB2, ANVMA6, ANVCC1, ANVCD3, respectively. Within moment the fire spreads to the compartment 30. The likelihood of MSO scenario is 80. While they include in risk mode, the PMSO and CCDP is 3.14E-01 and 5.06E-02 respectively (table 3-1). Finally, the risk increment is 5.26E-07/y.

4. CONCLUSION

The major source of MSO fire risks is from compartment 30. The ignition sources and important equipment are 1C5A 480V MCC, 1A5 4.16 kV, Switchgear, 1A506X HPCS transformer, 345 kV ST bus duct, 69 kV EST bus duct and DG DIV III bus duct etc. The compartment 30 is a busbar and MCC rom. Many cables route in and power many MOVs (Motor Operated Valve). However, it is noteworthy that the calculation of MSO presented in the present study is relatively conservative, resulting in high CDF values and large contribution to the overall fire risk. Therefore, it is worthwhile to investigate MSO scenarios development further for a more realistic FPRA result if analytical resources allow.

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