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Approach for Risk Informed Circuit Analysis in Fire Hazard Analysis

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1. Introduction

In the fire hazard analysis for nuclear power plant, post-fire safe shutdown analysis is essential part to ensure that radioactive releases to the environment in the event of a fire will be minimized. Electrical circuit analysis for both safe shutdown circuit and associated circuits should be performed in safe shutdown analysis. The associated circuit is as important as safe shutdown circuit in safe shutdown analysis. An approach for risk informed circuit analysis is described in this paper.

2. Methods and Results

In this section circuit analysis structure and associated terms are described, and importance and approach to risk informed circuit analysis is discussed.

2.1 Circuit analysis structure

The circuit analysis in fire hazard analysis consists of a unique set of three tasks: cable failure analysis, circuit fault analysis, and functional impact assessment. This structure is illustrated in Figure 1. Note that the structure will involve iterative interactions between these three tasks as follows:

- Cable failure analysis methods represent the scope of cable fire damage. A fire damage analysis considers the electrical behavior of the cables given failure, and estimates the physical extent of damage and time to failure for electrical cables exposed to fire.
- Electrical circuit fault analysis determines how each circuit will respond to the various modes of cable failure. The result is expressed in terms of the potential circuit fault modes.
- The final task assesses the functional impact of the circuit faults on the potential for plant safe shutdown. This task identifies the risk important plant systems and communicates that information for use in the circuit fault and cable failure analysis tasks.

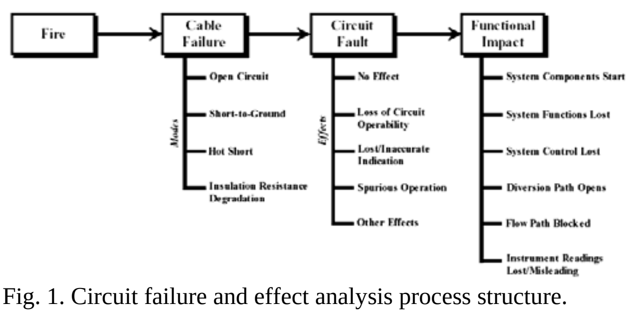

Fig. 1. Circuit failure and effect analysis process structure.

2.2 Importance of associated circuit analysis

The associated circuits are defined as circuits that do not meet the separation requirements for safe shutdown systems and components and are associated with safe shutdown systems and components by common power supply, common enclosure, or the potential to cause spurious operations that could prevent or adversely affect the capability to safely shut down the reactor as a result of fire induced failures (hot shorts, open circuits, and short to ground). Associated circuits are not required for post-fire safe shutdown, but could interfere with post-fire safe shutdown if damaged by fire.

An example of how fire-initiated spurious actuations of equipment may impact the shutdown capability is illustrated in Figure 2. For this case, MOV-1, located in Fire Area IV, is normally closed during plant operation and is required to remain closed for safe shutdown. In this figure, MOV-1 could spuriously actuate (open) as a result of fire in Fire Area I. Specifically, if fire damage to relay “R” control circuits in this area were to initiate a false “auto-open” signal, relay “R” would actuate, closing contact RC1. Since actuation of contact RC1 has the same effect as closing the “open” contact of the MOV control switch (CS-O), motor-contactor solenoid 42-O would energize, resulting in the inadvertent actuation (undesired opening) of MOV-1.

2.3 Approach for risk informed circuit analysis

The risk due to associated circuits can be expressed as a function of several factors as following basic form:

$R_i = f(S_i, F_i, C_i)$

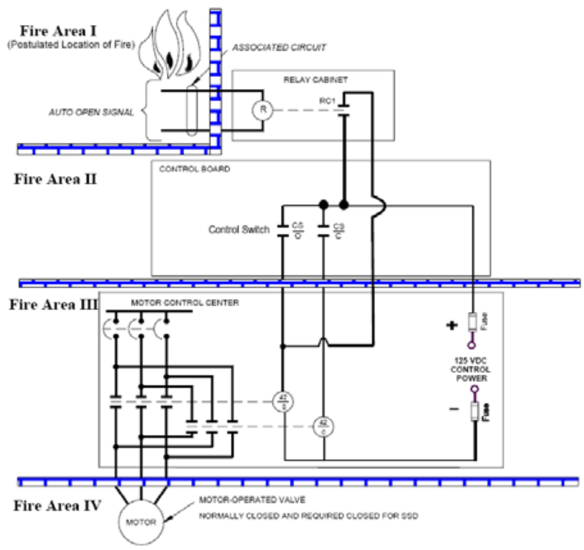

Fig. 2. Example of the spurious actuation associated circuit.

Where, R_i = risk of scenario i, S_i = scenario i, F_i = frequency of scenario i, and C_i = consequence of scenario i.

The frequency is interpreted as the occurring likelihood of associated circuit problem given a fire. And the consequence is the magnitude of impact of associated circuit to the safe shutdown function under the fire.

In the view point of frequency of cable failure, conductor-to conductor shorting within the same cable (intra-cable short) is the most common mode of failure. Therefore, it is reasonable to assume that given damage, more than one conductor-to-conductor short will occur in a given cable. A second primary mode of cable failure is conductor-to-conductor shorting between separate cables (inter-cable short). Inter-cable shorting is less likely than intra-cable shorting. Consistent with the current knowledge of fire-induced cable failures, the following configurations should be considered:

A. For any individual multiconductor cable (thermoset or thermoplastic), any and all potential spurious actuations that may result from intra-cable shorting may be postulated to occur concurrently regardless of number (Table 1).
B. For any thermoplastic cable, any and all potential spurious actuations that may result from intra-cable and inter-cable shorting with other thermoplastic cables may be postulated to occur concurrently regardless of number (Table 1).
C. For cases involving the potential damage of more than one multiconductor cable, a maximum of two cables should be assumed to be damaged concurrently.
D. For cases involving direct current (DC) circuits, the potential spurious operation due to failures of the associated control cables (even if the spurious operation requires two concurrent hot shorts of the proper polarity, e.g., plus-to-plus and minus-to-minus) should be considered when the required source and target conductors are each located within the same multiconductor cable.
E. Required instrumentation circuits must meet the same requirements as required power and control circuits

Determination of the potential consequence of the damaged associated circuits is based on the examination of specific P&IDs and review of components that could prevent operation or cause maloperation such as flow diversions, loss of coolant, or other scenarios that could significantly impair the ability to achieve and maintain hot shutdown. The time at which the prevented operation or maloperation occurs is very important. Failures that impede hot shutdown within the first hour of the fire tend to be most risk significant in a first-order evaluation. Cold shutdown circuits are not important compared to hot shutdown circuits.

3. Conclusions

Table 1. Intra-cable/Inter-cable shorts

		**Intra-cable short is the most likely and should be considered to occur regardless of cable type (thermoset or thermoplastic).**	
Thermoplastic (Non IEEE-383)	**Thermoplastic (Non IEEE-383)**	➡	**Inter-cable short is likely.**
Thermoset (IEEE-383)	**Thermoset (IEEE-383)**	➡	**Inter-cable short is less likely.**
Thermoplastic (Non IEEE-383)	**Thermoset (IEEE-383)**	➡	**Inter-cable short is less likely.**

In summary, the most important associated circuits are those circuits whose failure could cause flow diversion, loss of coolant, or other scenarios that could significantly impair the ability to achieve and maintain hot shutdown, paying particular attention to those events that occur in the first hour. Risk insights gained from cable fire testing have demonstrated that intra-cable (conductor-to-conductor) shorting in a multiconductor cable and inter-cable (cable-to-cable) shorting between thermoplastic cables are the most probable causes of spurious actuations. Therefore, when considering potential cable damage scenarios involving the spurious actuation of equipment, these two specific circuit configurations should be focused.

REFERENCES

[1] Risk-Informed Approach for Post-Fire Safe Shutdown Associated Circuit Inspections, Regulatory Issue Summary 2004-03, USNRC, 2004
[2] M. H. Salley, Knowledge Base for Post-Fire Safe Shutdown Analysis, Draft Report for Comments, NUREG-1778, USNRC, 2004
[3] Guidance for Post-Fire Safe Shutdown Analysis, NEI 00-01, Rev. 1, NEI Circuit Failure Issues Task Force, 2005
[4] Guidance for Implementing a Risk-Informed, Performance-Based Fire Protection Program under 10CFR50.48(c), NEI 04-02, Rev. 1, NEI, 2005
[5] Problems Associated with Post-Fire Safe Shutdown Circuit Analysis, Information Notice 99-17, USNRC, 1999
[6] Guidance for Post-Fire Safe Shutdown Analysis, Draft NUREG, 2002
[7] Risk-Informed Performance-Based Fire Protection for Existing Light-Water Nuclear Power Plants, Regulatory Guide 1.205, USNRC, 2006