March 19, 2003

MEMORANDUM TO: Cynthia A. Carpenter, Chief
Inspection Program Branch
Division of Inspection Program Management
Office of Nuclear Reactor Regulation

FROM: John N. Hannon, Chief**/RA/**
Plant Systems Branch
Division of Systems Safety and Analysis
Office of Nuclear Reactor Regulation

SUBJECT: PROPOSED RISK-INFORMED INSPECTOR GUIDANCE FOR POST-FIRE SAFE-SHUTDOWN ASSOCIATED CIRCUIT INSPECTIONS

The purpose of this memorandum is to transmit SPLB's proposed input regarding risk-informing the inspector guidance for post-fire safe-shutdown associated circuit inspections.

On February 19, 2003, the NRC sponsored an open, public, facilitated workshop to discuss risk-informing the inspection of associated circuits. The workshop was well attended and provided valuable insights from all stakeholders who contributed. My staff has reviewed those insights and formulated input for the development of risk-informed inspector guidance.

If you require any additional information, please contact, Mark Salley of my staff. Mr. Salley can be reached at X-2840.

Attachments: As stated

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ATTACHMENT

INPUT TO DEVELOP INSPECTOR GUIDANCE TO RISK-INFORM THE INSPECTION OF ASSOCIATED CIRCUITS AS A PART OF THE FIRE PROTECTION TRIENNIAL INSPECTIONS

Background

Beginning in 1997, the NRC discovered a number of Licensee Event Reports (LERs) that identified plant specific problems related to potential fire induced electrical circuit failures that could prevent operation, or cause mal-operation of equipment necessary to achieve and maintain hot shutdown in the event of a fire. The staff documented this information in Information Notice 99-17 “Problems Associated with Post-Fire Safe-Shutdown Circuit Analysis.” On November 29, 2000, inspection of associated circuits was temporarily suspended (ML003773142). During this period, the Nuclear Energy Institute (NEI) developed NEI 00-01 “Guidance for Post-Fire Safe Shutdown Analysis” Rev. D (ML023010376). The staff contracted Brookhaven National Laboratory (BNL) to develop a Post-Fire Safe Shutdown Analysis guidance NUREG/CR. (ML023430533) The Electric Power Research Institute (EPRI) assembled an Expert Panel and issued, “Spurious Actuation of Electrical Circuits due to Cable Fires: Results of an Expert Elicitation.” (Report No. 1006961, May 2002). Using the above referenced documentation as background, the NRC conducted a public, Facilitated Workshop, on February 19, 2003, in Rockville, MD.

Discussion

Based on the background information above, with special emphasis on the Facilitated Workshop discussions, the staff has developed the following input guidance (and rational where necessary) for risk-informing the associated circuits inspection.

Basic Risk Equation

In order to determine the risk from associated circuits, a minimum three terms need to be identified. The equation is:

Risk = (fire frequency) x (likelihood of fire effects & cable attributes that contribute to failure) x (likelihood of undesired consequences)

1. Fire Frequency

The fire frequency is based on a statistical analysis of nuclear Power Plant (NPP) operating experience. The Fire Protection Significance Determination Process (SDP) provides a method and bases for estimating fire frequencies for plant areas. One unique aspect of circuit analysis finding is the potential need for evaluation of multiple areas (i.e., those areas through which a cable or common set of cables is routed).

2. Likelihood of Fire Effects & Cable Attributes that Contribute to Failure

There needs to be a creditable fire threat in the area under review to damage the cable of concern. This may be in the form of in situ combustibles, or the actual or maximum allowable transients as controlled by plant specific procedures including a combination thereof. The Fire Protection SDP provides methods and bases for the identification and analysis of these fire scenarios. When more than a qualitative analysis is necessary, the inspector should use the NRC fire dynamics spreadsheets to approximate the fire and its effects. The cable attributes should also be considered in assessing the likelihood of cable failure. Failures due to thermal insult from the fire may occur due to hot gas layer heating, immersion in the plume, immersion in the flame zone (direct flame impingement), or due to radiant heating. All modes of heat transfer should be considered as appropriate to a given fire scenario.

A Thermoplastic Cables Thermoplastic cables (typically non-IEEE 383 qualified) should be assumed to fail if exposed to hot gas layer or plume temperatures of 425°F or greater, for a minimum of 5 minutes. In the case of radiant heat transfer the cable should be assumed to fail if exposed to a minimum $5kW/m^2$ for 5 minutes. When a thermoplastic cable is within the flame zone of the fire (direct flame impingement), or a cable tray that is burning, damage should be assumed to occur in 5 minutes.

B Thermoset Cables Thermoset cables (typically IEEE 383 qualified) should be assumed to fail if exposed to hot gas layer or plume temperatures of 700°F or greater, for a minimum of 10 minutes. In the case of radiant heat transfer the cable should be assumed to fail if exposed to a minimum $10kW/m^2$ for 10 minutes. When a thermoset cable of concern is in the flame zone of the fire (direct flame impingement), or a cable tray that is burning, damage should be assumed to occur in 10 minutes.

C Cable Failure Modes Testing has demonstrated that, for multi-conductor cables, conductor-to-conductor shorting within the same cable is the most common mode of failure. This is commonly referred to as “intra-cable shorts.” It is reasonable to assume that given failure, 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, commonly referred to as inter-cable shorting. Inter-cable shorting is less likely than intra-cable shorting. At this time, the following configurations should be considered:

- For any individual multi-conductor cable, any and all potential spurious actuations that may result from intra-cable shorting, including any possible combination of conductors within the cable, may be postulated to occur concurrently regardless of number. However, as a practical matter the number of combinations of potential hot shorts increases rapidly with the number of conductors within a given cable. For example, a multi-conductor cable with three conductors (3C) has 3 possible combinations of 2 (including desired combinations), while a five conductor cable (5C) has 10 possible combinations of 2 (including desired combinations), while a seven conductor cable (7C) has 21 possible combinations of 2 (including desired combinations). To facilitate an inspection that considers most of the risk presented by postulated hot shorts within a multiconductor cable, inspectors should consider only a few (three or four) of the most critical postulated combinations.

- For cases involving the potential failure of more than one multi conductor cable, a maximum of two concurrent spurious actuations should be assumed. The consideration of more than two concurrent spurious operations will be deferred pending additional research.

- Inspectors will consider the potential spurious operation of a DC circuit given failures of the associated control cables even if the spurious operation requires two concurrent proper polarity hot shorts (e.g., plus-to-plus and minus-to-minus) providing the required source and target conductors are each located within the same multi conductor cable.

- The consideration of inter-cable shorts will be deferred pending additional research.

3. Likelihood of Undesired Consequences

Assessing the potential consequence of the associated circuit failure is paramount to the analysis. The inspector should review the specific Nuclear Power Plant (NPP), Process and Instrumentation Diagrams (P&ID)[1] for flow diversions, loss of coolant, or other scenarios that could significantly impede the NPP's ability to achieve and maintain Hot Shutdown[2]. For the specific area under evaluation, the inspector may wish to consider components that could prevent operation, or cause maloperation as the components of interest. When considering the potential consequence of such failures, the inspector should also consider the time at which the prevented operation or maloperation occurs. In most cases, those that impede Hot Shutdown within the first hour of the fire tend to be most risk significant in a first order evaluation. Consideration of cold shutdown circuits will be deferred pending additional research.

4. Items to be Deferred at this Time, Pending Additional Research

The following items are either considered of relatively low risk significance and/or are being deferred pending additional research insights:

- Inter-cable shorting for thermo-set cables is considered to be substantially less likely than intra-cable shorting. Hence, the inspection of potential spurious operation issues involving inter-cable shorting for thermo-set cables is being deferred pending additional research.

- Inter-cable shorting for thermo-plastic cables is considered less likely than intra-cable shorting, but is also more likely than inter-cable shorting for thermo-set cables. The inspection of spurious actuation issues involving inter-cable shorting of thermo-plastic cables is also being deferred pending additional research.

- Inter-cable shorting between thermo-plastic and thermo-set cables is considered less likely than intra-cable shorting of either cable type. The inspection of spurious actuation

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[1] For NPPs that do not use P&ID's the inspector will have to gather the same information from flow diagrams and cable routing/logic diagrams.

[2] Hot shutdown is defined in the NPP technical specifications.

issues involving inter-cable shorting between thermo-plastic and thermo-set cables is also being deferred pending additional research.

- Inspectors will not consider the impact of degraded control room instrumentation and indication circuits (e.g., that might confuse operators) pending additional research.

- Inspectors will not consider configurations involving three or more concurrent spurious operations unless all such spurious operations may occur as the result of intra-cable shorting within a single multi-conductor cable pending further research.

- Recent testing strongly suggests that a control power transformer (CPT) in a control circuit can substantially reduce the likelihood of spurious operation. The power output of the CPT relative to the power demands of the controlled device(s) appears critical. Pending additional research, inspectors may defer the consideration of multiple (i.e., two or more) concurrent spurious operations due to control cable failures if they can verify that the power to each impacted control circuit is supplied via a CPT with a power capacity of no more than 150% of that required to supply the control circuit in its normal modes of operation (e.g., that required to power one actuating device and any circuit monitoring or indication features).

- Recent testing strongly suggests that fire-induced hot shorts will likely self-mitigate (e.g., short to ground) after some limited period of time. Available data remains sparse, but no known source has reported a fire-induced hot short that was sustained for greater than 20 minutes. This is of particular importance to devices such as an air-operated valve (AOV) or pressure-operated relief valve (PORV) which will return to their de-energized position upon mitigation of a hot short cable failure. Pending further research, inspectors should defer the consideration of such faults if it can be verified that a spurious operation of up to 20 minutes duration will not compromise the ability of the plant to achieve hot shutdown.

5. Items Not to be Considered at this Time in Inspections

The following items are considered of very low likelihood and/or low risk, and will not be considered in the risk-informed inspection process:

- Open circuit (or loss of conductor continuity) conductor failures will not be considered as an initial mode of cable failure. Note that cable shorting (e.g., a short to ground) may result in an open circuit fault due to the tripping of circuit protection features.

- Inter-cable short circuits involving the conductors of an armored cable will not be considered. Such failures are considered virtually impossible to achieve without the short involving the cable's grounded armoring.

- Inter-cable short circuits involving the conductors of one cable within a conduit and the conductors of any other cable outside the conduit will not be considered. As with armored cables, such faults are considered virtually impossible. Note that inter-cable shorting between cables in a common conduit is possible, however it is a deferred pending additional research.

- Inspectors will not consider multiple high impedance faults on a common power supply. Although such faults have been considered using deterministic methods for critical safe shutdown circuits, such faults are considered of very low likelihood and often can be readily overcome by manual operator actions should they occur.

- Inspectors will not consider three-phase, proper polarity hot short power cable failures. In theory, such failures could cause a three-phase device to spuriously operate. However, such failure are considered of very low likelihood because the three distinct phases of power would have to align with the proper phase to operate, (i.e., in the proper phased sequence). Note that three-phase devices may still be subject to spurious operations due to faults in their related control and/or instrumentation circuits.

- Inspectors will not consider multiple proper polarity hot shorts leading to the spurious operation of a DC motor or motor-operated device when the postulated failures involve only the DC device's power cables (e.g., those cables that run from the Motor Control Center (MCC) to the device). Such failures are considered unlikely because there is a shunt and a field requiring five separate conductors to have the correct polarity and sequence in order to operate. DC devices may still be subject to spurious actuation given failures in their control and/or instrument circuits.

Summary

In summary, the inspectors should focus on associated circuits who's failure could cause flow diversion, loss of coolant, or other scenarios that could significantly impede the ability to achieve and maintain Hot Shutdown, paying particular attention to those events that occur in the first hour. The inspectors should be able to develop creditable fire scenarios that could produce a thermal insult resulting in cable damage. The inspectors should focus on conductor to conductor shorts within a multi conductor cable, since risk insights gained from cable fire testing demonstrated that intra cable shorting as the most probable cause of spurious actuations. The inspectors should assume a maximum of two concurrent spurious operations for each scenario evaluated.