

**NEI 00-01 [Rev 4]**

# **Guidance for Post Fire Safe Shutdown Circuit Analysis**

**December 2019**

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**Nuclear Energy Institute**

**Guidance for Post Fire  
Safe Shutdown Circuit  
Analysis**

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Amir Afzali, Dominion Power  
Gordon Brastad, Energy Northwest  
Maurice Dingler, Wolf Creek Nuclear Operating Corporation  
Tom Gorman, PPL, Susquehanna (Retired)  
Dennis Henneke, GE Hitachi  
Randy Jamison, Seabrook Nuclear Station  
Robert Kassawara, EPRI  
Harvey Leake, Arizona Public Service (Retired)  
Bijan Najafi, SAIC  
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- Edan Engineering: Wrote the EPRI report on the circuit failure testing and the analysis in Appendix B.1 on Multiple High Impedance Faults.

## **NOTICE**

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## **EXECUTIVE SUMMARY**

NEI 00-01 was developed to provide a deterministic methodology for performing post-fire safe shutdown analysis. In addition, NEI 00-01 includes information on risk-informed methods (when allowed within a Plant's License Basis) that may be used in conjunction with the deterministic methods for resolving circuit failure issues related to Multiple Spurious Operations (MSOs). The risk-informed method is intended for application by utilities to determine the risk significance of identified circuit failure issues related to MSOs. The deterministic safe shutdown analysis method described in Revision 0 of this document reflected practices in place for many years at a wide cross-section of U.S. nuclear plants and widely accepted by NRC. These practices were generally reflected in the plant's licensing basis. In Revision 1, these deterministic methods were revised to address insights gained from EPRI/NEI circuit failure testing and reflected in NRC's RIS 2004-03. While these insights do not change a plant's licensing basis, they reflect the NRC's new emphasis on considering potential safety implications of MSOs. This emphasis on MSOs became apparent as the NRC revised their inspection guidance to resume the inspection of circuits in January 2005. The methods presented in Revision 1 were intended to support licensees preparing for the resumed NRC circuit failure inspections.

In Revision 2 changes were made to document the Resolution Methodology presented by the Industry to the NRC Staff for resolving the MSO Issue subsequent to the rejection of the Staff's generic letter on MSOs by the Commission. The methodology in Revision 2 reflects insights gained from, not only the EPRI/NEI Cable Fire Testing, but also the CAROLFIRE Cable Fire Testing, the outcome of meetings with the NRC Staff and information provided within SECY 08-0093 and a draft revision to Regulatory Guide 1.189. These changes were made to address NRC comments related to segregating those components necessary for post-fire hot shutdown ("green box", defined in 10CFR50, Appendix R, Section III.G.1.a as one train of systems necessary to achieve and maintain hot shutdown conditions) and those whose mal-operation could provide a potential impact to post-fire safe shutdown ("orange box", defined 10CFR50, Appendix R, Section III.G.1 as components important to safe-shutdown that could adversely affect safe shutdown capability or cause mal-operation of safe shutdown systems). The methodology contained in Revision 2 is one method of addressing post-fire safe shutdown and the MSO Issue.

Revision 3 was issued to NRC for review in October of 2011. Changes were made to resolve exceptions NRC took in their endorsement of Revision 2, and to clarify MSO scenarios in Appendix G based on industry feedback. After submittal, however, NEI and NRC agreed that the review should be suspended. Therefore, no formal NRC review of Revision 3 was performed.

Revision 4 of this document is issued to incorporate information from the NRC Research and EPRI effort under JACQUE-FIRE Volume 3. The JACQUE-FIRE Volume 3 effort by NRC Research and EPRI provided specific recommendations for addressing fire-induced circuit failures in a deterministic post-fire safe shutdown analysis based on an analysis of the work performed in JACQUE-FIRE Volumes 1 and 2. [Reference NUREG/CR 7150 Volume 1, 2 and 3.] Revisions to MSO Tables in Appendix G are identical to those shown in Rev 3. Section 5 on Risk Methods has been eliminated since this section has not been endorsed by NRC and has not been kept current. Appendices I and J, which are entirely new appendices, have been added.

This document neither changes nor supports any individual plant's licensing basis. The assumptions used in the licensing basis and the nature of any approvals the NRC may have provided for these assumptions, are a plant-specific matter between each licensee and the NRC.

This methodology also contains information for application to circuit failures involving MSOs. All MSO impacts should be placed in the plant Corrective Action Program with an appropriate priority for action.

It is expected that plants adopting a new fire protection licensing basis using NFPA 805 will be able to reference certain sections of NEI 00-01 as an acceptable method for addressing circuit failure issues, including the MSO Issue. It is noted that plants adopting the NFPA 805 licensing basis in accordance with NEI 04-02, Revision 1 utilized NEI 00-01 Revision 1 as part of the review and confirmation process of the nuclear safety methodology review. NEI 00-01 Revision 1 Section 3 serves as the basis for nuclear safety methodology reviews performed in accordance with NEI 04-02, Revision 1, Regulatory Guide 1.205, Revision 0, as supplemented by NFPA 805 Frequently Asked Question 07-0039, Revision 2 (ADAMS Accession No. ML082590466).

[Note: Technical agreement on this FAQ has been reached. The closure memo is dated 1/15/2010 and is contained in ML091320068.]



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# **GUIDANCE FOR POST FIRE SAFE SHUTDOWN CIRCUIT ANALYSIS**

## **1 INTRODUCTION**

For some time there has been a need for a comprehensive industry guidance document for the performance of post-fire safe shutdown circuit analysis to implement existing fire protection regulations. Such a document is needed to consistently apply the regulatory requirements for post-fire safe shutdown analysis contained in 10 CFR 50.48 (Reference 7.4.1) and 10 CFR 50 Appendix R (Reference 7.4.3), as well as to supplement the guidance currently available for NFPA-805.

From the standpoint of deterministic safe shutdown analysis, Generic Letter 86-10 (Reference 7.1.10) provided standardized answers to certain questions related to specific issues related to this topic. The answers provided, however, did not comprehensively address the entire subject matter. The lack of comprehensive guidance for post-fire safe shutdown analysis, in combination with the numerous variations in the approach used by the architect engineers responsible for each plant design, has resulted in wide variation in plant-specific approaches to deterministic post-fire safe shutdown circuit analysis.

Some of these approaches are based on long-held industry interpretations of the NRC regulations and guidance. In many cases, these interpretations were not documented in a manner that indicated a clear NRC acceptance of the position. The Boiling Water Reactor Owners Group (BWROG) developed a comprehensive document for BWRs to compile deterministic safe shutdown circuit analysis practices based on existing regulatory requirements and guidance. That document, developed in 1999, was adopted into NEI 00-01 with minor changes to address PWR-specific safe shutdown analysis considerations. Neither the BWROG Document NEI 00-01 Revision 0 or 1 were endorsed by the NRC.

Changes were made in Revision 2 to provide an approach for addressing fire-induced multiple spurious operations (MSO's). This revision of NEI 00-01 was endorsed in part by NRC in Regulatory Guide 1.189 Revision 2. Despite this NRC endorsement, there were still a number of open issues related to fire-induced circuit failures. The work performed by NRC Research and EPRI and documented in NUREG/CR 7150 Volumes 1, 2 and 3 addressed a number of the gaps remaining after NRC endorsement of NEI 00-01 Revision 2 in Regulatory Guide 1.189 Revision 2.

Revision 3 provided an update to the Generic Multiple Spurious Operations (MSOs) Lists in Appendix G. The list changes are as a result of the initial assessment of Appendix G by the Expert Panels at individual plants. The changes to the generic lists should be treated similar to other operating experience (OE) issues following the same process as the initial list. After submittal, however, NEI and NRC agreed that the review of Revision 3 should be suspended. Therefore, no formal NRC review of Revision 3 was performed.

Revision 4 of NEI 00-01 includes the results of the work performed by NRC Research and EPRI in NUREG/CR 7150 Volumes 1, 2 and 3. It also includes portions of the work previously included in NEI 00-01 Revision 3. Section 5 on Risk Methods has been eliminated since this section has not been endorsed by NRC and has not been kept current. Appendices I and J, which are entirely new appendices, have been added. It is recommended that the changes included in Revision 4 be reviewed by each licensee using their operating experience (OE) program for impacts to their post-fire safe shutdown analysis.

## **1.1 PURPOSE**

The purpose of this document is to provide a consistent process for performing a post-fire safe shutdown circuit analysis. Upon subsequent acceptance of this document by NRC in a revision to Regulatory Guide 1.189, it will represent one acceptable means of performing a post-fire safe shutdown analysis. Refer to Regulatory Guide 1.189 to determine the specific sections of this document that have NRC endorsement and to determine if NRC has taken any exceptions to the information contained in this document.

Issuance of NEI 00-01 Revision 4 or endorsement of it in a revision to a Regulatory Guide does not re-define or alter any plant's licensing basis. A plant's licensing basis is defined in its FSAR. A plant's licensing basis could be modified if a plant chooses to adopt the NRC endorsed revision of NEI 00-01 and to include it in their FSAR. A plant's licensing basis could also be modified if the NRC issues rulemaking that requires compliance with the criteria outlined in the endorsed revision of NEI 00-01. The guidance provided in this document addresses differences and uncertainties in licensing basis assumptions about circuit failures that have been the subject of debate between the NRC and Industry. It also provides a method for the resolution of the differences between the NRC and the industry related to fire-induced circuit failures resulting in MSOs.

This document provides deterministic methods for addressing potential fire-induced circuit failure issues, either within or beyond the existing plant's licensing basis, as determined by each licensee using their currently approved licensing basis for Fire Protection and Post-Fire Safe Shutdown. The deterministic method is provided for analyzing and resolving circuit failure issues. Methods are provided to (1) select circuits and appropriate combinations thereof for the analysis of MSOs (note: the terms spurious actuation and spurious operation are considered synonymous. The term "spurious operation" is used in this document for consistency), and (2) determine the risk significance of identified circuit failure combinations (MSOs). While the selection of circuit failure combinations, MSOs, has not traditionally been included in plant circuit analysis methods to date, it is appropriate to consider such combinations in the light of the results of recent fire-induced cable failure testing, EPRI/NEI, CAROLFIRE and DESIREE. The Resolution Methodology for MSOs included in this document will assist the licensee in determining whether potentially risk-significant interactions could impact safe shutdown, but this Resolution Methodology does not change the plant licensing basis. When an individual licensee's licensing basis is either unclear or silent on the need to or method for addressing MSOs, the Resolution Methodology provides an industry consensus approach for addressing the issue. Each licensee must be prepared to defend the integrity of their licensing basis relative to any actions taken to classify conditions relative to the resolution of the MSO issue as not being part of the current licensing basis.

The methods in this document do not require the systematic re-evaluation of a plant's post-fire safe shutdown circuit analysis. A decision to perform such a systematic re-evaluation is entirely a licensee decision that may be based on NRC inspection findings, licensee self-assessment results, or industry experience. Neither do these methods take precedence over specific requirements accepted by the NRC in a plant's post-fire safe shutdown analysis.



## 1.2 BACKGROUND

Reviewing past fire events can substantiate the uncertainty associated with the behavior of actual plant fires. On March 22, 1975, the Browns Ferry Nuclear Power Plant had the worst fire ever to occur in a commercial nuclear power plant operating in the United States. (Reference U.S. Nuclear Regulatory Commission (NRC) Inspection and Enforcement (IE) Bulletin Nos. 50-259/75 and 50-260/75-1, dated 2/25/75.) The Special Review Group that investigated the Browns Ferry fire made two recommendations pertaining to assuring that the effectiveness of the fire protection programs at operating nuclear power plants conform to General Design Criterion (GDC) 3.

- The NRC should develop specific guidance for implementing GDC 3.
- The NRC should review the fire protection program at each operating plant, comparing the program to the specific guidance developed for implementing GDC 3.

In response to the first recommendation, the NRC staff developed Branch Technical Position (BTP) Auxiliary Power Conversion Systems Branch (APCSB) 9.5-1, "Guidance for Fire Protection for Nuclear Power Plants," May 1, 1976; and Appendix A to BTP APCS 9.5-1, "Guidelines for Fire Protection for Nuclear Power Plants Docketed Prior to July 1, 1976," August 23, 1976. The guidance in these documents focused on the elements of fire protection defense-in-depth (DID): (1) prevention; (2) mitigation through the use of detection and suppression (automatic and manual); (3) passive protection of structures, systems and components (SSCs) important to safety and post-fire safe shutdown. [Note: Other revisions to these documents also exist.]

In response to the second recommendation, each operating plant compared its fire protection program with the guidelines of either BTP APCS 9.5-1 or Appendix A to BTP APCS 9.5-1. The staff reviewed the fire protection programs for compliance with the guidance. [Note: Some licensee's may have been reviewed to other revisions of these documents. For details refer to each licensee's current licensing basis.]

The guidance in BTP APCS 9.5-1 and Appendix A to BTP APCS 9.5-1, however, did not provide sufficiently specific guidance for performing post-fire safe shutdown analysis. Also, independent testing sponsored by the NRC indicated that some of the separation concepts proposed by licensees under the BTP, such as coating intervening cable trays with fire retardant coatings, would not provide sufficient protection in the event of a severe fire. Thirdly, some licensees did not implement aspects of the BTP that the NRC Staff considered essential in order to achieve adequate protection. To address these issue and to provide the necessary guidance, the NRC issued 10 CFR 50.48, "Fire Protection," and Appendix R, "Fire Protection Program for Nuclear Power Facilities Operating Prior to January 1, 1979," to 10 CFR Part 50 (45 FR 36082). The NRC published in the Federal Register (45 FR 76602) the final fire protection rule (10 CFR 50.48) and Appendix R to 10 CFR Part 50 on November 19, 1980. The Appendix R Regulation required compliance with sections III.G, III.J, and III.O for all plants licensed to operate before January 1, 1979, and also required individual licensees to comply with other lettered sections, based on the status of their outstanding items under the BTP review, as reflected by NRC correspondence to the individual licensees. Section III.G.2 of Appendix R reflected the results of

the NRC's independent cable tray fire testing program, overriding any previous approvals the NRC may have granted regarding the protection of cables with fire retardant coatings.

This regulation applies to plants licensed to operate prior to January 1, 1979. For plants licensed to operate after January 1, 1979, the NRC staff, in most cases, required compliance with Appendix A to BTP APCSB 9.5-1 and Sections III.G, J & O of Appendix R. For these licensees, the sections of Appendix R apply to the plant as a licensing commitment, rather than as a legal requirement imposed by the code of federal regulations. Some other licensees provided comparisons to the guidelines of Section 9.5-1, "Fire Protection Program," of NUREG-0800, "Standard Review Plan," which incorporated the guidance of Appendix A to BTP APCSB 9.5 1 and the criteria of Appendix R, or BTP CMEB 9.5-1. Additionally, some plants had aspects of their programs reviewed to the criteria contained in Draft Regulatory Guide 1.120 Revision 1 ("Fire Protection Guidelines for Nuclear Power Plants," November 1977), which primarily reflected the content of BTP APCSB 9.5-1 Revision 1. Therefore, even though fire protection programs can be essentially equivalent from plant to plant, the licensing basis upon which these programs are founded can be very different. Most plants licensed after January 1, 1979 have also been granted by the NRC a standard fire protection license condition allowing them to self-approve and make changes to their NRC approved fire protection program provided such changes do not adversely affect the ability to achieve and maintain safe shutdown in the event of a fire. Therefore, even for plants with a common regulatory basis traceable back to one of the regulations and/or guidance listed above, the details of implementing the fire protection program can be different.

The plant design changes required for passive and active fire protection features and administrative controls required by the regulations discussed were fairly specific. These changes have been implemented throughout the industry. These changes have been effective in preventing a recurrence of a fire event of the severity experienced at Browns Ferry; have increased the likelihood that a fire will be detected rapidly and extinguished; and have reduced the potential consequences of a fire (see Appendix A for a brief history of the Browns Ferry fire and a description of the fire protection improvements for nuclear plants since the Browns Ferry fire).

To clarify the regulations, the NRC staff has issued numerous guidance documents in the form of Regulatory Guides, memorandums, Regulatory Issue Summaries, Generic Letters and Information Notices. These documents provide insights as to the NRC staff's interpretation of the regulations, their views on acceptable methods for complying with the regulations, and clarification of the requirements for performing a post-fire safe shutdown analysis.

### **1.3 OVERVIEW OF POST FIRE SAFE SHUTDOWN ANALYSIS**

A fire in an operating nuclear power plant is a potentially serious event. In general, the likelihood of a large fire with the potential to damage plant equipment needed for post-fire safe shutdown is considered to be small. The expected fire would be contained in a single electrical panel or a localized portion of one room or area. Typical plant design segregates important cables and equipment from threats such as missiles, flooding, and significant fire sources. The expected plant response to this type of event would be to maintain continued operation and to dispatch the plant fire brigade to extinguish the fire.

Despite this, the consequences of an event that damages plant equipment needed for post-fire safe shutdown can be significant. The concern is an “exposure fire,” capable of damaging multiple trains of Safe Shutdown Component’s (SSC’s), despite the existing physical separation provided by criteria such as Regulatory Guide 1.75. The Browns Ferry fire resulted in damage to plant equipment needed for safe shutdown. Although safe shutdown of the Browns Ferry unit was ultimately accomplished, the event was of sufficient significance to warrant major changes in fire protection design features of a nuclear power plant. Appendix A to this document provides a description of the improvements made in the fire protection design of nuclear power plants in response to the Browns Ferry fire event.

In addition to plants making changes to the fire protection design features, the extended response to the Brown’s Ferry fire also placed increased attention on identifying those systems and equipment needed for the post-fire safe shutdown of each unit. A safe plant design is achieved by identifying the systems and equipment needed for post-fire safe shutdown in each area of the plant; making conservative assumptions regarding the extent of fire damage; and assuring adequate separation of the redundant safe shutdown trains or protection of an alternative/dedicated shutdown train. When applied to the fire protection program of a nuclear power plant, these aspects of post-fire safe shutdown design, in combination with the other changes made in the design of the plant fire protection programs in response to the Browns Ferry fire, provide reasonable assurance that a plant fire will not prevent safe plant shutdown.

The goal of post-fire safe shutdown is to assure that a single fire in any plant fire area will not result in any fuel cladding damage, rupture of the primary coolant boundary or rupture of the primary containment. This goal serves to prevent an unacceptable radiological release as a result of the fire. This goal is accomplished by assuring, in accordance with NRC Regulatory requirements, the following deterministic criteria are satisfied for a single fire in any plant fire area:

- One safe shutdown path necessary to achieve and maintain hot shutdown is free of fire damage. The set of components necessary to achieve and maintain post-fire hot shutdown is referred to throughout this document as the “required for hot shutdown”.
- Potential fire-related impacts to components with the potential to mal-operate and adversely impact the ability of the safe shutdown path described above to perform its post-fire safe shutdown functions are prevented or can be adequately mitigated. The set of components whose mal-operation could impact the components on the required safe shutdown path in a particular fire area are referred to throughout this document as “important to safe shutdown”.
- Repairs to systems and equipment required to achieve and maintain cold shutdown can be accomplished within the required time frame.
- Any operator manual actions required to support achieving either hot or cold shutdown are identified and meet the applicable regulatory acceptance requirements.

The deterministic methods in Section 3 integrate the requirements and interpretations related to post-fire safe shutdown into a single location, and assure that these criteria are satisfied. These methods:

- Identify the systems, equipment and cables required to support the operation of each safe shutdown path.
- Identify the equipment and cables whose spurious operation could adversely impact the ability of these safe shutdown paths to perform their required safe shutdown function.
- Provide techniques to mitigate the effects of fire damage to components on or affecting the required safe shutdown path in each fire area.

Using these methods and the information in the appendices referenced in Section 3 to perform the post-fire safe shutdown analysis will provide an acceptable level of safety resulting in a safe plant design. These methods are consistent with the fire protection defense-in-depth concept that addresses uncertainties associated with the actual behavior of fires in a nuclear power plant. Post-fire safe shutdown is one part of each plant's overall defense-in-depth fire protection program.

The information contained in Sections 4 is provided for use in resolving the longstanding issues of MSOs. Using the Resolution Methodology described in these Sections and in the appendices referenced within Sections 4 is one way for a licensee to address the MSO issue.

### **1.3.1 General Methodology Description**

The deterministic methodology described in this document is intended to provide an acceptable method of performing a post-fire safe shutdown circuit analysis to address the current regulatory requirements and to resolve the outstanding areas of disagreement between NRC and Industry. The Resolution Methodology for MSOs described in this document is intended to provide a method for addressing MSOs that is acceptable to NRC. The deterministic approach to performing a post-fire safe shutdown analysis is contained in Sections 1, 2 and 3. Certain aspects of the deterministic approach, such as Alternate or Dedicated Shutdown under III.G.3/III.L and High/Low Pressure Interface Components have criteria slightly different from the methodology outlined in Sections 1, 2 and 3. In an effort to provide as much clarity as possible and to not confuse the user with numerous exception statements, the criteria differences for these topics have been addressed in appendices. High/Low Pressure Interfaces have been addressed in Appendix C. [Note: Information contained in Appendix J, Use of PIRT Information, changes some of the information in Appendix C on High/Low Pressure Interfaces. Appendix C, however, is being maintained as the basis document for those licensee where High/Low Pressure Interfaces still remain in their licensing basis.] Alternate and Dedicated Shutdown has been in Appendix D. Appendix E provides guidance for evaluating the acceptability of operator manual actions. In an effort to clarify which fire-induced component impacts may be allowed to use operator manual actions, Appendix H has been added. [Note: Operator Manual Actions, meeting the guidance in Appendix E, may be used for components classified as "important to safe shutdown". The use of Operator Manual Actions for components classified as "required for hot shutdown", in general, require pre-approval by NRC.] Appendix H provides guidance related to classifying components as either required for hot shutdown or important to safe shutdown. Appendix H is to be used in conjunction with Section 3 in making these classifications.

Additionally, Appendix H is to be used to determine whether flow diversion valves affecting the required for hot shutdown systems, which are initially classified as required for hot shutdown, can be re-classified as important to safe shutdown based on more detailed analysis. Appendix I has been added to provide design considerations applicable to the use of shorting switches. Appendix J has been added to clarify the final positions of JACQUE-FIRE Volume 1, 2 and 3 on fire-induced circuit failures.

The Resolution Methodology for addressing MSOs, which addresses a longstanding issue between the Industry and the NRC, is contained in Section 4, Appendix B and J, Appendix F and Appendices G-1 and G-2.

### **1.3.2 Deterministic Method**

When using the deterministic methodology described in Section 3 of this document, a basic assumption of the methodology is that there will be fire damage to systems and equipment located within a common fire area. The size and intensity of the fire required to cause this type of system and equipment damage is not determined. Rather, fire damage is assumed to occur regardless of the level of combustibles in the area, the ignition temperatures of any combustible materials, the lack of an ignition source or the presence of automatic or manual fire suppression and detection capability. Fire damage is also postulated for all cables and equipment in the fire area that may be used for safe shutdown, even though many plant fire areas do not contain sufficient fire hazards for this to occur.

It is with this basic and conservative assumption regarding fire damage that the use of the Section 3 methodology begins. The methodology progresses by providing guidance on selecting systems and equipment needed for post-fire safe shutdown, on identifying the circuits of concern relative to these systems and equipment and on mitigating each fire-induced effect to the systems, equipment and circuits for the required safe shutdown path in each fire area. As a part of the mitigating strategy for each of the fire-induced effects, the analysis of specific fire protection features and their effects on preventing damage to specific safe shutdown circuits or components may be performed. These analyses are typically documented in exemption requests, deviations requests, 86-10 evaluations or engineering analysis, as dictated by a licensee's CLB. Additionally, fire modeling, as described in Section 4, may be used to assess whether or not a particular fire in a particular location presents a potential impact to circuits for safe shutdown components classified as important to safe shutdown. This methodology represents a comprehensive and safe approach for assuring that an operating plant can be safely shut down in the event of a single fire in any plant fire area.

To address the MSO issue, consideration is given to the MSO List in Appendix G and the circuit failure criteria contained in Appendix B and J. The circuit failure criteria contained in Appendix B and J, along with the implementation examples provided in Section 3.5, is intended for use with the MSO List in Appendix G and the MSO Resolution Methodology described in Section 4. Using the Resolution Methodology described in Section 4, a licensee can determine the potential fire-induced MSO impacts applicable to its facility. These potential fire-induced impacts can then be dispositioned

using the deterministic methods described in Section 3. In addressing MSOs, the conservative assumptions discussed above for the Section 3 analysis are not necessarily applied, (e.g., fire modeling or risk assessment may be an acceptable resolution approach). The mitigating techniques available for use with any particular MSO is a function of whether that MSO is classified as being comprised of required for hot shutdown components or important to safe shutdown components. Refer to Section 3 and Appendix H for a description of the criteria to be used to classify components as either required for hot shutdown or important to safe shutdown components. Additionally, the MSO's listed in Appendix G are to be evaluated separately. Other than the cases described in Section 4, and as limited in Section 3.5, involving an evaluation by the Expert Panel of the need to combine MSO's, there is no need to evaluate for the combined effect of multiple MSOs. The potential effect of each MSO on post-fire safe shutdown is to be evaluated individually.

In performing a deterministic post-fire safe shutdown analysis, the analyst must be cautious not to improperly apply the conservative assumptions described above. For example, one cannot rule out fire damage to unprotected circuits in a given fire area. This assumption is conservative only in terms of not being able to credit the systems and equipment associated with these circuits in support of post-fire safe shutdown. If the analyst, however, were to assume that these circuits were to be damaged by the fire when this provided an analytical advantage, this would be non-conservative. For example, assuming that fire damage results in a loss of offsite power may be non-conservative in terms of heat load assumptions used in an analysis to determine the need for room cooling systems for the 72-hour fire coping period.

The methodology for performing deterministic post-fire safe shutdown analysis is depicted in Figure 1-1. The specific steps are summarized in Sections 1.3.2.1 through 1.3.2.6, and discussed in depth in Section 3. The criteria for determining whether a component is a required for hot shutdown or important to safe shutdown component is contained in Section 3 and supplemented by Appendix H.

#### **1.3.2.1 Safe Shutdown Function Identification**

The goal of post-fire safe shutdown is to assure that a single fire in any single plant fire area will not result in any fuel cladding damage, rupture of the primary coolant boundary or rupture of the primary containment. This goal is accomplished by determining those functions important to safely shutting down the reactor and assuring that systems with the capability to perform these functions are not adversely impacted by a single fire in any plant fire area. The safe shutdown functions important to the plant are: (1) reactivity control; (2) pressure control; (3) inventory control; and (4) decay heat removal. To accomplish the required safe shutdown functions, certain support system functions (e.g., electrical power, ventilation) and process monitoring capability (e.g., reactor level, pressure indication) are also required.

In addition, the analyst must assure that fire-induced spurious operations do not occur that can prevent equipment in the required safe shutdown path from performing its intended safe shutdown function. Examples of spurious operations

that present a potential concern for the safe shutdown functions described above are those that can cause a: (1) loss of inventory in excess of the makeup capability; (2) flow diversion or a flow blockage in the safe shutdown systems being used to accomplish the inventory control function; (3) flow diversion or a flow blockage in the safe shutdown systems being used to accomplish the decay heat removal function<sup>1</sup>.

[BWR] Although an inadvertent reactor vessel overfill condition is not a safe shutdown function listed above, the NRC has identified this as a concern. The acceptability of the current design features of the BWR to mitigate the effects of an inadvertent reactor vessel overfill condition as a result of either a fire or equipment failure has been addressed by the BWROG in GE Report No. EDE 07—390 dated April 2, 1990, in response to NRC Generic Letter 89-19. The NRC subsequently accepted the BWROG position in a Safety Evaluation dated June 9, 1994. Despite this, some of the MSOs listed in Appendix G for BWRs relate to an inadvertent reactor vessel overfill. These will be addressed as a part of the MSO review.

When performing a post-fire safe shutdown analysis, the decision as to whether to include specific components on the post-fire safe shutdown component list may be made by the use of thermal-hydraulic/transient analysis. If by use of a thermal-hydraulic/transient analysis, the worst-case failure of the component can be demonstrated to have no impact on the ability to achieve and maintain post-fire hot shutdown, then the component need not be included on the post-fire safe shutdown component list and it need not be included in the post-fire safe shutdown analysis. The same is true of evaluations performed to address the MSOs contained in Appendix G to this document. When performing thermal-hydraulic/transient analysis in support of post-fire safe shutdown impacts determinations, the criteria contained in Appendix H should be applied.

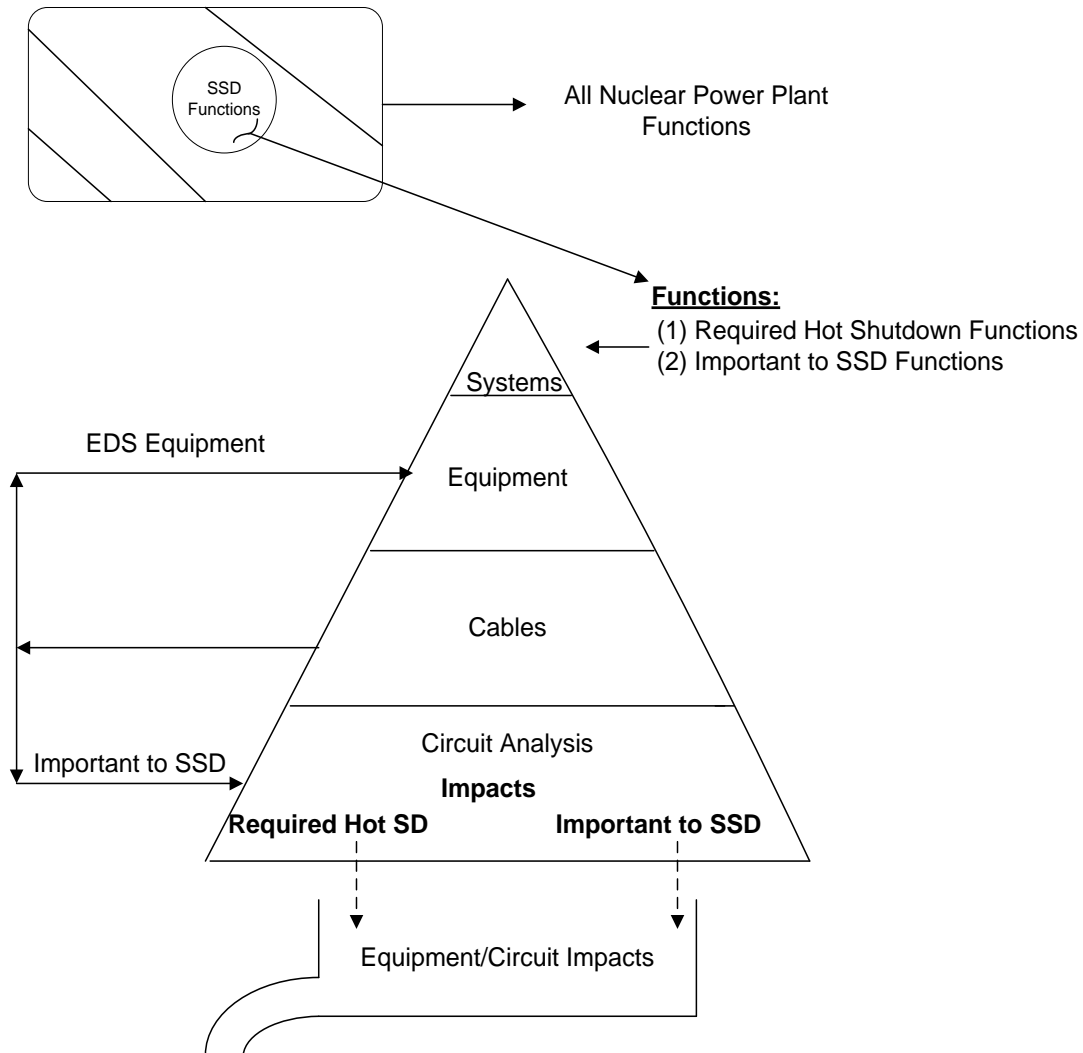
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<sup>1</sup> Licensing Citation: Brown's Ferry SER dated November 2, 1995 Section 3.7.3 third paragraph. Monticello Inspection report dated December 3, 1986 paragraph (2) page 16.

Therefore, thermal-hydraulic/transient analysis is an acceptable basis for excluding plant components from consideration in the post-fire safe shutdown analysis. Similarly, thermal-hydraulic/transient analysis is an acceptable basis for excluding a particular MSO from further consideration in a plant post-fire safe shutdown analysis. Finally, thermal-hydraulic/transient analysis coupled with a generic operator manual action(s) meeting all of the requirements of this document can be an acceptable way of addressing a potential impact to post-fire safe shutdown without including all of the affected cabling for a component or set of components into the post-fire safe shutdown analysis.



## **Figure 1-1, Deterministic Post-Fire Safe Shutdown Overview**



### **Mitigation Techniques**

#### **Required Hot Shutdown Components**

Reroute, Re-analyze or Re-design Circuit  
Protect in accordance with III.G.2

Other Plant Unique Approach:

- 86-10 Evaluation
- Exemption Request
- Deviation Request - LAR

#### **Important to SSD Components**

Any of the options available for  
Required Safe Shutdown  
Components

- Operator Manual Action
- Fire Modeling,
- Fire PRA [with LAR]

### **1.3.2.2 Safe Shutdown System and Path Identification**

Using the safe shutdown functions described above, the analyst identifies a system or combination of systems with the ability to perform each of these shutdown functions. The systems are combined to form safe shutdown paths.

### **1.3.2.3 Safe Shutdown Equipment Identification**

Using the safe shutdown path, the analyst identifies the mechanical equipment required for the operation of the system and the equipment whose spurious operation could affect the performance of the safe shutdown systems. Equipment that is required for the operation of a safe shutdown system for a particular safe shutdown path is related to that path (and is designated as a required hot shutdown component).

From a review of the associated P&IDs, the equipment that could spuriously operate as a result of fire-induced circuit damage and result in a flow blockage, a flow diversion (e.g., inventory makeup capability), loss of pressure control (due to overfeeding, excessive steam leakage, etc.), with the potential to impact the systems performing the required for hot shutdown functions, is identified. Similarly, this equipment is related to the particular safe shutdown path that it can affect. These components are classified as important to safe shutdown, unless they represent a potential flow diversion from the flow path for any system performing a required for hot shutdown function. Flow diversion components from the flow path for any system being used to perform a required for hot shutdown function are initially classified as required for hot shutdown. They may be re-classified as important to safe shutdown based on further analysis using the criteria in Appendix H.

Using the criteria in Section 3 and Appendix H, the analyst classifies the components identified above either as required for hot shutdown component or as an important to SSD component.

Classifying components as required for hot shutdown is done by reviewing the P&IDs and determining which components on the flow path are required to perform the required safe shutdown functions, (e.g., suction valve, pump, injection valve). Refer to Section 3 and Appendix H for additional discussion on classifying components as either required for hot shutdown or important to safe shutdown.

Once a component is classified as required for hot shutdown in a particular fire area, it and its required circuitry, (i.e., those circuits required for the operation of the component), must be protected from the effects of fires. If such protection is not feasible, then a different set of required for hot shutdown components may need to be selected until a set is found that can be assured to be free of fire damage in the fire area under consideration. The safe shutdown path for each fire area is comprised of the set of components classified as required for hot shutdown, (i.e., those that perform the required for hot shutdown functions), and the set of components classified as important to safe shutdown, (i.e., those whose

failure or spurious operation could potentially impact the required for hot shutdown components). If it is determined that protection of at least one safe shutdown path from the effects of fire is not possible, then alternative or dedicated shutdown capability may be used in accordance with Appendix R Section III.G.3 (see Appendix D for details for alternative or dedicated shutdown capability). Components used for alternative or dedicated shutdown under Appendix R Section III.G.3 are not classified as either required for hot shutdown or important to safe shutdown.

The required safe shutdown path for any particular fire area is comprised of required for hot shutdown and important to SSD components. The classification for a particular component in regards to being either a required for hot shutdown or an important to SSD component can vary from fire area to fire area. Refer to Section 3 and Appendix H for additional details.

The analyst reviews the P&IDs for the systems physically connected to the reactor vessel to determine the equipment that can result in a loss of reactor inventory in excess of make-up capability. This includes a special class of valves known as “high/low pressure interfaces.” Refer to Appendix C for a discussion of high/low pressure interface valves. Equipment in this category is typically related to all safe shutdown paths, since a loss of reactor vessel inventory with an interfacing system LOCA outside of Containment would be a concern for any safe shutdown path. Refer to Appendix J for additional information on spurious operation of the power cables for High/Low Pressure Interface Valves.

#### **1.3.2.4 Safe Shutdown Cable Identification**

Using the electrical schematic drawings for the equipment identified above, the analyst identifies all the cables required for the proper operation of the safe shutdown equipment. This will include, in addition to the cables that are physically connected to the equipment, any cables interlocked to the primary electrical circuit schematic through secondary circuit schematics. The cables identified are related to the same safe shutdown path as the equipment they support.

While reviewing the electrical schematics for the equipment, the analyst identifies the safe shutdown equipment from the electrical distribution system (EDS). The EDS equipment (bus) for the safe shutdown path is associated with the equipment that it powers. All upstream busses are identified and similarly related to the safe shutdown path. In addition, all power cables associated with each bus in the EDS are identified and related to the same safe shutdown path as the EDS equipment. This information is required to support the Breaker Coordination Analysis.

#### **1.3.2.5 Safe Shutdown Circuit Analysis**

Using information on the physical routing of the required cables and the physical locations of all safe shutdown equipment, the analyst determines equipment and cable impacts for each safe shutdown path in each plant fire area. Based on the number and types of impacts to these paths, each fire area is assigned a required

safe shutdown path(s). Initially, it is assumed that any cables related to a required safe shutdown component in a given fire area will cause the component to fail in the worst-case position (i.e., if the safe shutdown position of a valve is closed, the valve is assumed to open if the required cable is routed in the fire area).

If necessary, a detailed analysis of the cable for the specific effect of the fire on that safe shutdown path is performed. This is accomplished by reviewing each conductor in each of these cables for the effects of a hot short, a short-to-ground or an open circuit (test results indicate that open circuits are not the initial fire-induced failure mode) and determining the impact on the required safe shutdown component. The impact is assessed in terms of the effect on the safe shutdown system, the safe shutdown path, the safe shutdown functions and the goal for post-fire safe shutdown. Refer to Appendix I for a discussion of the considerations appropriate to addressing open circuits when using a “shorting switch” as a mitigation measure for fire-induced circuit failures.

#### **1.3.2.6 Safe Shutdown Equipment Impacts**

Using the process described above, the analyst identifies the potential impacts to safe shutdown equipment, systems, paths, and functions relied upon in each fire area, and then mitigates the effects on safe shutdown for each safe shutdown component impacted by the fire. The mitigating techniques must meet the regulations. For example, for required for hot shutdown components the mitigating techniques listed in Figure 1-1 for required hot shutdown components apply. For required for hot shutdown components, unless the available options of re-designing the systems and/or re-designing/re-routing the affected circuits and processing Exemption Requests, License Amendment Requests (LARs) or Deviation Request, the protection schemes of Appendix R Section III.G.2 must be applied. If the component, however, is classified as an important to SSD component, mitigating tools in addition to those available for required safe shutdown components may be credited as an alternate to those available for required for safe shutdown components. Refer to Figure 1-1, Section 3 and Appendix H for additional details. One of the mitigating tools for an important to SSD circuit component is the use of an operator manual action. If an operator manual action is relied upon as the mitigating tool, then it must meet the regulatory acceptance criteria related to operator manual actions. Refer to Appendix E for additional information related to the regulatory acceptance criteria for operator manual actions.

Another mitigation tool is the use of “shorting switch”. Refer to Appendix I for a description of the considerations that need to be addressed when designing a “shorting switch”.

The process of identifying and mitigating impacts to the required safe shutdown path(s) described above is explained in more detail throughout this document.

#### **1.3.2.7 Risk Significance Methods**

The Resolution Methodology for determining the Plant Specific List of MSOs is contained in Section 4. Refer to Section 4 for additional details. The method details both the determination of applicable plant-specific MSOs and the disposition/mitigation of the MSOs using either deterministic methods, Fire Modeling or risk (e.g., Focused Scope Fire PRA) methods. A licensee's ability to use risk methods is a function of their approved Licensing Basis.

## 2 APPENDIX R REQUIREMENTS AND CONSIDERATIONS

This section provides a general overview of the Appendix R regulatory requirements including the criteria for classifying the various shutdown methods. It describes the distinctions between redundant, alternative and dedicated shutdown capabilities and provides guidance for implementing these shutdown methods. In addition, the considerations dealing with a loss of offsite power and associated circuits are also discussed. Refer to Figure 2-1.

### 2.1 REGULATORY REQUIREMENTS

10 CFR 50 Appendix A, General Design Criterion 3 establishes the overarching goals of NRC's fire protection requirements.

*Criterion 3 -- Fire Protection.* Structures, systems, and components important to safety shall be designed and located to minimize, consistent with other safety requirements, the probability and effect of fires and explosions. Noncombustible and heat resistant materials shall be used wherever practical throughout the unit, particularly in locations such as the containment and control room. Fire detection and fighting systems of appropriate capacity and capability shall be provided and designed to minimize the adverse effects of fires on structures, systems, and components important to safety. Firefighting systems shall be designed to assure that their rupture or inadvertent operation does not significantly impair the safety capability of these structures, systems, and components.

10 CFR 50.48 Appendix R establishes the regulatory requirements for protecting structures, systems and components important to safety, in order to satisfy the first sentence of GDC 3. Appendix R Section III.G establishes the safe shutdown requirements to address the third level of defense-in-depth. Sections III.G.1 and III.G.2 discuss the requirements for “required for hot shutdown” and “important to safe shutdown” and Section III.G.3 discusses the requirements for “alternative or dedicated” shutdown. The requirements for each of these shutdown classifications will be considered separately.

The following sections discuss the regulations and distinctions regarding redundant shutdown methods. Requirements specifically for alternative/dedicated shutdown methods that are different from those used for redundant shutdown methods are discussed in Appendix D to this document:

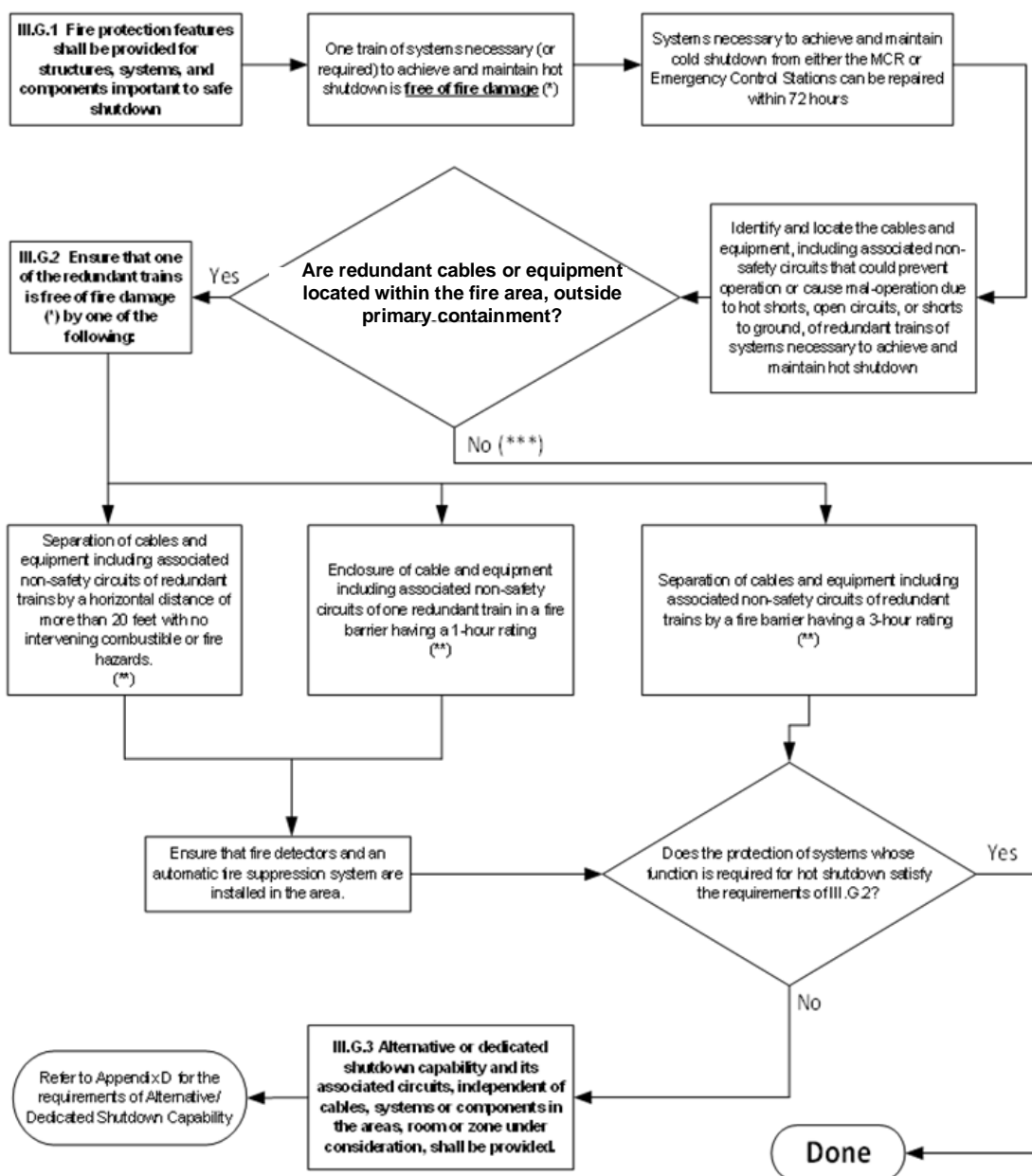
### **Requirements for Redundant Safe Shutdown**

Section III.G.1 provides the requirements for fire protection of safe shutdown capability and states the following:

#### *III. G. Fire protection of safe shutdown capability.*

- 1. Fire protection features shall be provided for structures, systems, and components important to safe shutdown. These features shall be capable of limiting fire damage so that:*
  - a. One train of systems necessary to achieve and maintain hot shutdown conditions from either the control room or emergency control station(s) is free of fire damage; and*
  - b. Systems necessary to achieve and maintain cold shutdown from either the control room or emergency control station(s) can be repaired within 72 hours.*

**Figure 2-1  
Appendix R Requirements Flowchart**



(\*) "Free of Fire Damage" is achieved when the structure, system or component under consideration is capable of performing its intended function from either the Control Room or the emergency control stations during and after the postulated fire, as needed

(\*\*) Exemption Requests, Deviation Requests, LARs, GL 86-10 Fire Hazards Evaluations or Fire Protection Design Change Evaluations may be developed as necessary.

(\*\*\*) For non-inerted containment, provide one of the protection methods identified in Appendix R Section III G.2 (a), (b), or (c) or provide for 20 ft separation with no intervening combustibles or fire hazards, fire detection and automatic suppression systems, or non-combustible radiant energy shields as specified in Appendix R Section III G.2 (d), (e), or (f)





In Section III.G.1 there are no functional requirements specifically itemized for the structures, systems or components. The only requirements identified are those to initially achieve and maintain hot shutdown and to subsequently achieve cold shutdown once any required repairs have been completed.

Section III.G.1 establishes the requirement to ensure that adequate fire protection features exist for systems structures and components important to safe shutdown. This is the regulatory basis for the classification of components important to safe shutdown. By Section III.G.1, components classified as important to safe shutdown must have adequate fire protection features, but the available fire protection features are not limited to those options described in III.G.2. Adequate fire protection features for components classified as important to safe shutdown include the use of operator manual actions. Therefore, prior NRC acceptance of operator manual actions for components classified as important to safe shutdown is not required.

Section III.G.1.a establishes the requirement for one train of systems necessary to achieve and maintain hot shutdown to be free of fire damage. Section III.G.1.a is the regulatory basis for components classified as required for hot shutdown. Section III.G.1 presumes that some preexisting fire protection features have been provided, such as barriers (previously approved by the NRC under Appendix A to BTP APCSB 9.5-1).

When considering the consequences of a fire in a given fire area during the evaluation of the safe-shutdown capabilities of the plant, licensees should demonstrate that one safe shutdown path, (i.e., success path of SSCs, that can be used to bring the reactor to hot-shutdown or hot-standby conditions) remains free of fire damage. Some plant designs (those that use low-pressure systems for their success path) pass through hot shutdown in a short time and then proceed directly to cold shutdown. For the purpose of this document, the term “safe shutdown” will be used to indicate bringing a plant to safe-shutdown condition, either hot shutdown or cold shutdown (when low-pressure systems are used as the success path), as applicable to each reactor design and as defined by the plant technical specifications. The analysis should also demonstrate that fire damage to one safe shutdown path, (i.e., success path of SSCs, needed for achieving cold shutdown) will be limited so that a success path will be returned to an operating condition within 72 hours, or for areas requiring alternative or dedicated shutdown, the licensee should demonstrate that cold-shutdown capability can be restored and cold shutdown achieved within 72 hours. For reactor designs that do not remain in hot shutdown for 72 hours, the analysis should demonstrate that a cold-shutdown condition can be achieved and maintained within the required period of time.

Equipment used for cold shutdown only is neither classified as required for hot shutdown nor important to safe shutdown. The only requirement associated with equipment used for cold shutdown only is that fire protection features be provided so that the equipment, if damaged by an exposure fire, can be repaired within 72 hours. The basis for this is Appendix R Section III.G.1.b.

*III.G.2 Except as provided for in paragraph G.3 of this section, where cables or equipment, including associated non-safety circuits that could prevent operation or cause mal-operation due to hot shorts, open circuits, or shorts to ground, of redundant trains of systems necessary to achieve and maintain hot shutdown conditions are located within the same fire area outside of primary containment, one of the following means of ensuring that one of the redundant trains is free of fire damage shall be provided:*

- a. *Separation of cables and equipment and associated non-safety circuits of redundant trains by a fire barrier having a 3-hour rating. Structural steel forming a part of or supporting such fire barriers shall be protected to provide fire resistance equivalent to that required of the barrier;*
- b. *Separation of cables and equipment and associated non-safety circuits of redundant trains by a horizontal distance of more than 20 feet with no intervening combustible or fire hazards. In addition, fire detectors and automatic fire suppression system shall be installed in the fire area; or*
- c. *Enclosure of cable and equipment and associated non-safety circuits of one redundant train in a fire barrier having a 1-hour rating. In addition, fire detectors and an automatic fire suppression system shall be installed in the fire area;*

*Inside non-inerted containments one of the fire protection means specified above or one of the following fire protection means shall be provided:*

- d. *Separation of cables and equipment and associated non-safety circuits of redundant trains by a horizontal distance of more than 20 feet with no intervening combustibles or fire hazards;*
- e. *Installation of fire detectors and an automatic fire suppression system in the fire area; or*
- f. *Separation of cables and equipment and associated non-safety circuits of redundant trains by a noncombustible radiant energy shield.*

Section III.G.2 provides separation requirements that must be utilized where redundant trains required for hot shutdown are located in the same fire area. To comply with the regulatory requirements in Section III.G.1 and 2, the analyst must determine which fire barriers are needed to provide separation essential for safe shutdown. Those barriers previously reviewed and approved by the NRC under Appendix A to APCS 9.5-1 may be credited, (e.g., barriers evaluated as adequate for the hazard). Where redundant trains of systems required for hot shutdown are located in the same fire area outside of primary containment, one must provide fire protection features consistent with the requirements of Section III.G.2.a, b, or c (III.G.2.d, e, and f are also acceptable options inside non-inerted containments) to protect structures, systems, components and cables for one train capable of achieving and maintaining hot shutdown conditions. The protective measures of Section III.G.2 may also be applied to systems and components classified as important to safe shutdown. One must also assure that any repairs required to equipment necessary to achieve and maintain cold shutdown, from either the MCR or emergency control station(s) can be made within 72 hours.

Depending on a plant's current licensing basis and Fire Protection License Condition, exemptions, or deviations, LARs or GL 86-10 fire hazards analyses and/or fire protection design change evaluations may be used to justify configurations that meet the underlying goals of Appendix R but not certain specific requirements.

## **2.2 REGULATORY GUIDANCE ON ASSOCIATED CIRCUITS OF CONCERN**

- 2.2.1 To ensure that required for hot shutdown systems remain available to perform their intended functions, the post-fire safe shutdown analysis also requires that other failures be evaluated to

ensure that the safe shutdown system functions are not defeated. The analysis requires that consideration be given to cable failures that may cause spurious operations resulting in unwanted conditions. Also, circuit failures resulting in the loss of support systems such as the electrical power supply from improperly coordinated circuit protective devices must be considered. As defined in Generic Letter 81-12, these types of circuits are collectively referred to as “Associated circuits of concern”.<sup>2</sup>

- 2.2.2 Associated circuits of concern need to be evaluated to determine if cable faults can prevent the operation or cause the mal-operation of redundant systems required for hot shutdown or adversely affect the post-fire safe shutdown capability.

From time to time, the NRC has issued Staff Positions (e.g., memorandum, Information Notices, Generic Letters, inspection findings) documenting their positions as to what systems they consider necessary to achieve and maintain hot shutdown conditions, as well as documenting what types of fire-induced faults should be considered credible for affecting these necessary systems.

- 2.2.3 NRC GL 81-12, Fire Protection Rule (45 FR 76602, November 19, 1980), dated February 20, 1981, provides additional clarification related to associated circuits of concern. With respect to these associated circuits of concern, GL 81-12 describes three types of associated circuits of concern. The Clarification of Generic Letter 81-12 defines associated circuits of concern as those cables and equipment that:

- a). Have a physical separation less than that required by Section III.G.2 of Appendix R, and:*
- b). Have either:*
  - i) A common power source with the shutdown equipment (redundant or alternative) and the power source is not electrically protected from the circuit of concern by coordinated breakers, fuses, or similar devices, or*
  - ii) A connection to circuits of equipment whose spurious operation would adversely affect the shutdown capability (i.e., RHR/RCS isolation valves, ADS valves, PORVs, steam generator atmospheric dump valves, instrumentation, steam bypass, etc.), or*
  - iii) A common enclosure (e.g., raceway, panel, junction) with the shutdown cables (redundant and alternative) and,*
    - (1) are not electrically protected by circuit breakers, fuses or similar devices, or*
    - (2) will not prevent propagation of the fire into the common enclosure.*

Although protecting the fire-induced failures of associated circuits of concern is required, to reinforce that Generic Letter 81-12 simply provides guidance rather than requirements, the Clarification of Generic Letter 81-12 further states the following regarding alternatives for protecting the safe shutdown capability:

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<sup>2</sup> See the definition of “associated circuits of concern” in GL 81-12.

*The guidelines for protecting the safe shutdown capability from fire-induced failures of associated circuits are not requirements. These guidelines should be used only as guidance when needed. These guidelines do not limit the alternatives available to the licensee for protecting the safe shutdown capability. All proposed methods for protection of the shutdown capability from fire-induced failures will be evaluated by the [NRC] staff for acceptability.*

### 2.3 REGULATORY INTERPRETATION ON LOSS OF OFFSITE POWER

- 2.3.1 The loss of offsite power has the potential to affect safe shutdown capability. In addition, the regulatory requirements for offsite power differ between the redundant and alternative/dedicated shutdown capability. Therefore, consideration must be given for the loss of offsite power when evaluating its effect on safe shutdown. The Appendix R requirement to consider a loss of offsite power is specified in Section III.L.3 as follows:

*The shutdown capability for specific fire areas may be unique for each such area, or it may be one unique combination of systems for all such areas. In either case, the alternative shutdown capability shall be independent of the specific fire area(s) and shall accommodate post-fire conditions where offsite power is available and where offsite power is not available for 72 hours. Procedures shall be in effect to implement this capability.*

- 2.3.2 Alternative/dedicated systems must demonstrate shutdown capability where offsite power is available and where offsite power is not available for 72 hours. If such equipment and systems used prior to 72 hours after the fire will not be capable of being powered by both onsite and offsite electric power systems because of fire damage, an independent onsite power system shall be provided. Equipment and systems used after 72 hours may be powered by offsite power only.
- 2.3.3 For redundant shutdown, offsite power may be credited if demonstrated to be free of fire damage, similar to other safe shutdown systems.
- 2.3.4 If offsite power is postulated to be lost for a particular fire area, and is not needed for the required safe shutdown path for 72 hours, actions necessary for its restoration are considered to be performed under the purview of the emergency response organization and do not require the development of specific recovery strategies or procedures in advance.
- 2.3.5 Since in an actual fire event offsite power may or may not be available, the potential availability of offsite power should also be considered to confirm that it does not pose a more challenging condition. For example, additional electric heat loads may affect HVAC strategies.

### **3 DETERMINISTIC METHODOLOGY**

This section discusses a generic deterministic methodology and criteria that licensees can use to perform a post-fire safe shutdown analysis to address regulatory requirements. For a complete understanding of the deterministic requirements, work this section in combination with the information in Appendix C, High/Low Pressure Interfaces, Appendix D, Alternative and Dedicated Shutdown Requirements, Appendix E, Acceptance Criteria for Operator Manual Actions and repairs, Appendix H, Hot Shutdown versus Important to Safe Shutdown Components, Appendix I, Design Considerations for Shorting Switches, Appendix J, Application of PIRT Results and Appendix I, Design Basis Determination. To resolve the industry issue related to MSOs, refer to Section 4, Appendix B, Appendix F, Appendix G, Appendix I and Appendix J. The plant-specific analysis approved by NRC is reflected in the plant's licensing basis. Once endorsed by NRC in a regulatory guide, the methodology described in this section is an acceptable method of performing a post-fire safe shutdown analysis. This methodology is depicted in Figure 3-1. Other methods acceptable to NRC may also be used. Regardless of the method selected by an individual licensee, the criteria and assumptions provided in this guidance document may apply. The methodology described in Section 3 is based on a computer database oriented approach, which is utilized by several licensees to model Appendix R data relationships. This guidance document, however, does not require the use of a computer database oriented approach.

The requirements of Appendix R Sections III.G.1, III.G.2 and III.G.3 apply to equipment and cables required for achieving and maintaining safe shutdown in any fire area. Although equipment and cables for fire detection and suppression systems, communications systems and 8-hour emergency lighting systems are important features, this guidance document does not address them. The requirements of Appendix R Section III.G.2 do not apply to the circuits for fire detection and suppression systems, communications systems and 8-hour emergency lighting systems.

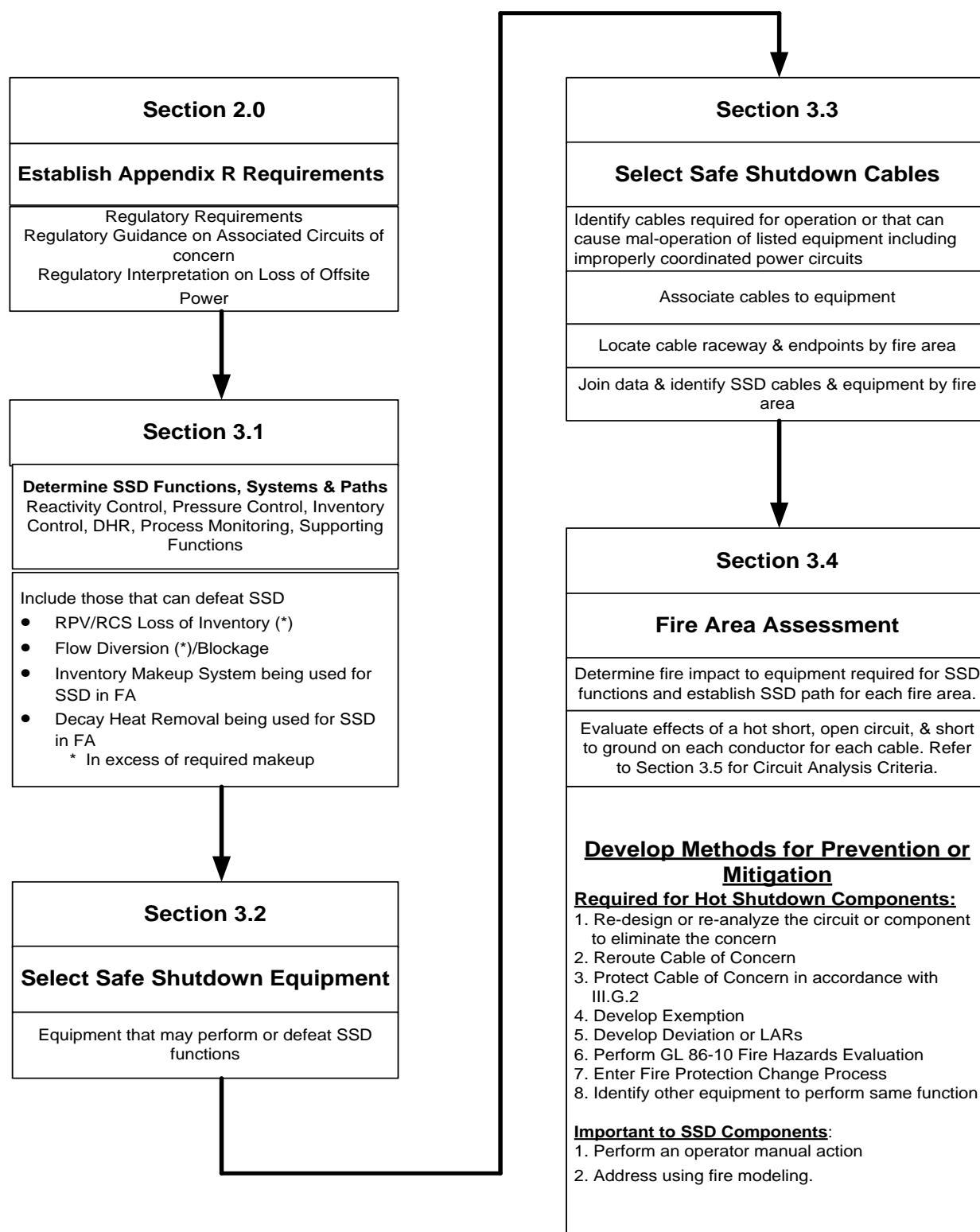
Additional information is provided in Appendix B and Appendix J to this document related to the circuit failure criteria to be applied in assessing impacts to post-fire safe shutdown, including MSOs. The criteria in Appendix B and Appendix J developed for MSOs has also been included in Section 3.5 for assessing the potential effects of fire-induced impacts to individual components on the required safe shutdown path for a particular III.G.1 and 2 fire area. Section 4 provides the Resolution Methodology for determining the Plant Specific List of MSOs to be evaluated

### **3.1 SAFE SHUTDOWN AND PATH DEVELOPMENT**

This section discusses the identification of systems necessary to perform the required for hot shutdown and important to safe shutdown (SSD) functions. It also provides information on the process for combining these systems into safe shutdown paths. Appendix R Section III.G.1.a requires that the capability to achieve and maintain hot shutdown be free of fire damage. Appendix R Section III.G.1.b requires that repairs to systems and equipment necessary to achieve and maintain cold shutdown be completed within 72 hours. This section provides some guidance on classifying components as either required or important to SSD circuit components. It also provides some guidance on the tools available for mitigating the effects of fire-induced circuit failures to each of these classes of equipment. For a supplemental discussion of the topic of required for hot shutdown and important to SSD components refer to Appendix H.



**Figure 3-1  
Deterministic Guidance Methodology Overview**



The goal of post-fire safe shutdown is to assure that a one train of shutdown systems, structures, and components required to achieve hot shutdown remains free of fire damage for a single fire in any single plant fire area. This goal is accomplished by determining those functions required to achieve and maintain hot shutdown. Safe shutdown systems are selected so that the capability to perform these required functions is a part of each safe shutdown path. The functions required for post-fire safe shutdown generally include, but are not limited to the following:

- Reactivity control
- Pressure control systems
- Inventory control systems
- Decay heat removal systems
- Process monitoring (as defined in NRC Information Notice 84-09)
- Support systems
  - Electrical power and control systems
  - Component Cooling systems
  - Component Lubrication systems

These functions are of importance because they have a direct bearing on the safe shutdown goal of being able to achieve and maintain hot shutdown, which ensures the integrity of the fuel, the reactor pressure vessel and the primary containment. If these functions are preserved, then the plant will be safe because the fuel, the reactor and the primary containment will not be damaged. By assuring that this equipment is not damaged and remains functional, the protection of the health and safety of the public is assured.

The components required to perform these functions are classified as required for hot shutdown components. These components are necessary and sufficient to perform the required safe shutdown functions and their selection is made based on their ability to perform the required safe shutdown functions in the absence of fire damage to components that could fail or could be spuriously operated and, potentially impact the required for hot shutdown components. Since fire-induced impacts to the other components with the potential to impact the required for hot shutdown components within a common fire area could occur, these potential fire-induced impacts must also be addressed.

In the post-fire safe shutdown analysis, the components required for hot shutdown are analyzed for potential fire impacts and protected from the effects of these potential impacts. Additionally, the components not necessary to complete the required safe shutdown functions, but which could be impacted by the fire and cause a subsequent impact to the required safe shutdown components are also identified, analyzed and protected from potential fire effects. This latter set of components is classified as important to SSD components. Refer to Appendix H for supplemental discussion on classifying components as required for hot shutdown or important to safe shutdown.

Depending on the classification of the components, (i.e., required for hot shutdown or important to safe shutdown), the tools available for mitigating the effects of fire-induced damage vary. The available tools for mitigating the effects of potential fire damage are discussed in this section and

in Appendix H. The classification of a component may vary from fire area to fire area. The required safe shutdown path for any given fire area is comprised of required for hot shutdown components and important to SSD components. The distinction and classification for each component in each required safe shutdown path for each fire area should be discernible in the post-fire safe shutdown analysis.

Generic Letter 81-12 specifies consideration of associated circuits of concern with the potential for spurious equipment operation and/or loss of power source, and the common enclosure failures. As described above, spurious operations/actuators can affect the accomplishment of the required safe shutdown functions listed above. Typical examples of the effects of the spurious operations of concern are the following:

- A loss of reactor pressure vessel/reactor coolant inventory in excess of the safe shutdown makeup capability
- A flow loss or blockage in the inventory makeup or decay heat removal systems being used for the required safe shutdown path. All components with the potential to cause a flow diversion from the flow path for a system performing a required for hot shutdown function are to be initially classified as required for hot shutdown components. Refer to Appendix H for an acceptable approach for re-classifying these flow diversion components as important to safe shutdown.

Spurious operations are of concern because they have the potential to directly affect the ability to achieve and maintain hot shutdown, which could affect the fuel and cause damage to the reactor pressure vessel or the primary containment. To address the issue of multiple spurious operations, Section 4 provides a Resolution Methodology for developing a Plant Specific List of MSOs for evaluation. Section 3.5, Appendix B and Appendix J provide the circuit failure criteria applicable to the evaluation of the Plant Specific list of MSOs.

Common power source and common enclosure concerns could also affect the safe shutdown path and must be addressed in accordance with the guidance in Generic Letter 81-12 clarification letter dated March 22, 1982.

In addition to the tools described for components classified as required for hot shutdown, fire-induced impacts to cables and components classified as important to SSD may be mitigated using some additional tools. For important to SSD component failures, operator manual actions, fire modeling and/or a focused-scope fire PRA may be used to mitigate the impact. (If the use of a Focused-Scope Fire PRAs is not permitted in the Plants Current License Basis, then, a License Amendment Request (LAR) will be necessary to use the Focused-Scope Fire PRA).

### 3.1.1 Criteria/Assumptions

The following criteria and assumptions should be considered, as applicable, when identifying systems available and necessary to perform the required safe shutdown functions and combining these systems into safe shutdown paths. This list provides recognized examples of criteria/assumptions but should not be considered an all-inclusive list. The final set of criteria/assumptions should be based on regulatory requirements and the performance criteria for post-fire safe shutdown for each plant.

- 3.1.1 [BWR] GE Report GE-NE-T43-00002-00-01-R01 entitled “Original Safe Shutdown Paths For The BWR” addresses the systems and equipment originally designed into the GE boiling water reactors (BWRs) in the 1960s and 1970s, that can be used to achieve and maintain safe shutdown per Section III.G.1 of 10 CFR 50, Appendix R. Any of the shutdown paths (methods) described in this report are considered to be acceptable methods for achieving redundant safe shutdown.
- 3.1.2 [BWR] GE Report GE-NE-T43-00002-00-03-R01 provides a discussion on the BWR Owners' Group (BWROG) position regarding the use of Safety Relief Valves (SRVs) and low pressure systems (LPCI/CS) for safe shutdown. The BWROG position is that the use of SRVs and low pressure systems is an acceptable methodology for achieving redundant safe shutdown in accordance with the requirements of 10 CFR 50 Appendix R Sections III.G.1 and III.G.2. The NRC has accepted the BWROG position and issued an SER dated Dec. 12, 2000.
- 3.1.3 [PWR] Generic Letter 86-10, Enclosure 2, Section 5.3.5 specifies that hot shutdown can be maintained without the use of pressurizer heaters (i.e., pressure control is provided by controlling the makeup/charging pumps). Hot shutdown conditions can be maintained via natural circulation of the RCS through the steam generators. The cooldown rate must be controlled to prevent the formation of a bubble in the reactor head. Therefore, feedwater (either auxiliary or emergency) flow rates as well as steam release must be controlled.
- 3.1.4 The classification of shutdown capability as alternative/dedicated shutdown is made independent of the selection of systems used for shutdown. Alternative/dedicated shutdown capability is determined based on an inability to assure the availability of a redundant safe shutdown path. Compliance to the separation requirements of Sections III.G.1 and III.G.2 may be supplemented by the use of operator manual actions to the extent allowed by the regulations and the licensing basis of the plant (see Appendix E), repairs (cold shutdown only), exemptions, deviations, GL 86-10 fire hazards analyses or fire protection design change evaluations permitted by GL 86-10, as appropriate. These may also be used in conjunction with alternative/dedicated shutdown capability.
- 3.1.5 At the onset of the postulated fire, all safe shutdown systems (including applicable redundant trains) are assumed operable and available for post-fire safe shutdown. Systems are assumed to be operational with no repairs, maintenance, testing,

Limiting Conditions for Operation, etc. in progress. The units are assumed to be operating at full power under normal conditions and normal lineups.

- 3.1.6 No Final Safety Analysis Report accidents or other design basis events (e.g., loss of coolant accident, earthquake), single failures or non-fire-induced transients need be considered in conjunction with the fire.
- 3.1.7 For the case of redundant shutdown, offsite power may be credited if demonstrated to be free of fire damage. Offsite power should be assumed to remain available for those cases where its availability may adversely impact safety (i.e., reliance cannot be placed on fire causing a loss of offsite power if the consequences of offsite power availability are more severe than its presumed loss). No credit should be taken for a fire causing a loss of offsite power. For areas where train separation cannot be achieved and alternative shutdown capability is necessary, shutdown must be demonstrated both where offsite power is available and where offsite power is not available for 72 hours. Refer to Appendix D for the requirements related to Alternative or Dedicated Shutdown.
- 3.1.8 Post-fire safe shutdown systems and components are not required to be safety-related.
- 3.1.9 The post-fire safe shutdown analysis assumes a 72-hour coping period starting with a reactor scram/trip. Fire-induced impacts that provide no adverse consequences to hot shutdown within this 72-hour period need not be included in the post-fire safe shutdown analysis. At least one train can be repaired or made operable within 72 hours using onsite capability to achieve cold shutdown. Reasonable actions by the Nuclear Emergency Response Organization during the 72 hour coping period may be credited, if justified, (e.g., actions to address room flooding, actions to open plant doors or fire dampers to re-establish room or equipment cooling). These types of actions are not classified as operator manual actions.
- 3.1.10 Manual initiation from the main control room or emergency control stations of systems required to achieve and maintain safe shutdown is acceptable where permitted by current regulations or approved by NRC (See Appendix E); automatic initiation of systems selected for safe shutdown is not required but may be included as an option, if the additional cables and equipment are also included in the analysis. Spurious actuation of automatic systems (Safety Injection, Auxiliary Feedwater, High Pressure Coolant Injection, Reactor Core Isolation Cooling, etc.) due to fire damage, however, should be evaluated.
- 3.1.11 Where a single fire can impact more than one unit of a multi-unit plant, the ability to achieve and maintain safe shutdown for each affected unit must be demonstrated (GDC 5).

### **3.1.2 Shutdown Functions**

The following discussion on each of these shutdown functions provides guidance for selecting the systems and equipment required for hot shutdown. For additional

information on BWR system selection, refer to GE Report GE-NE-T43-00002-00-01-R01 entitled “Original Safe Shutdown Paths for the BWR.”

### **3.1.2.1 Reactivity Control**

#### **[BWR] Control Rod Drive System**

The safe shutdown performance and design requirements for the reactivity control function are met by scrambling the reactor. The reactor can scram either automatically, when prescribed parameters exist, manually from the control room or manually by the local venting of the instrument air header or local opening of Reactor Protection System Power Supply Breaker. The post-fire safe shutdown analysis must provide one of these means of scrambling the reactor for each fire area.

Each plant’s emergency operating procedures contain the action to either vent the instrument air header or to remove RPS power in the event of a failure to scram, (i.e., ATWS). Operators are trained extensively on the use of the emergency operating procedures and performance of this action. In an ATWS condition, performing one of these actions is treated as a very high priority action. Shift manning must be adequate at all times for implementing the emergency operating procedures. Therefore, procedures coupled with operator training and the necessary staffing are always available to address this condition with the appropriate priority.

Based on this, each licensee should have an operator manual action to either vent the instrument air header or to remove RPS power in their post-fire safe shutdown procedures. The presence of this action precludes the need to perform circuit analysis for the reactivity control function and is an acceptable way to accomplish this function. [For additional information related to the reactor scram function, refer to BWROG Report No. BWROG-TP-11-011 Revision 0 June 2011 NEDO-33638, BWROG Assessments of Generic Multiple Spurious Operations (MSOs) in Post-Fire Safe Shutdown Circuit Analysis for Operating BWR Plants.]

#### **[PWR] Makeup/Charging**

There must be a method for ensuring that adequate shutdown margin is maintained from initial reactor scram to cold shutdown conditions, by controlling Reactor Coolant System temperature and ensuring borated water is utilized for RCS makeup/charging.

### **3.1.2.2 Pressure Control**

The systems discussed in this section are examples of systems that can be used for pressure control. This does not restrict the use of other systems for this purpose.

#### **[BWR] Safety Relief Valves (SRVs)**

Initial pressure control may be provided by the SRVs mechanically cycling at their setpoints (electrically cycling for EMRVs). Mechanically-actuated SRVs require no electrical analysis to perform their overpressure protection function. The SRVs may also be opened to maintain hot shutdown conditions or to depressurize the vessel to allow

injection using low pressure systems. The SRVs are operated manually. Automatic initiation of the Automatic Depressurization System (ADS) is not a required function. Automatic initiation of the ADS may be credited, if available. If automatic ADS is not available from the Control Room and use of ADS is credited as a required for hot shutdown system, an alternative means of initiation of ADS separate from the automatic initiation logic in the Control Room for accomplishing the pressure control function may be credited provided the components used are permanent plant equipment, provided these components are included on the safe shutdown component list and provided these components (and their required circuits) are assured to be protected from the effects of fires in the fire area where credited.

If a high pressure system is selected for post-fire safe shutdown and if pressure is being controlled by the SRVs lifting on their spring set point, then ADS and SRVs would be classified as important to safe shutdown.

#### **[PWR] Makeup/Charging**

RCS pressure is controlled by controlling the rate of charging/makeup to the RCS. Although utilization of the pressurizer heaters and/or auxiliary spray reduces operator burden, neither component is required to provide adequate pressure control, but may be used. Pressure reductions are made by allowing the RCS to cool/shrink, thus reducing pressurizer level/pressure. Pressure increases are made by initiating charging/makeup to maintain pressurizer level/pressure, or by using the pressurizer heaters. Manual initiation of the related pumps is acceptable.

#### **3.1.2.3 Inventory Control**

[BWR]: Systems selected for the inventory control function should be capable of supplying sufficient reactor coolant to achieve and maintain hot shutdown. Manual initiation of these systems is acceptable. Automatic initiation functions are not required. Spurious actuation of automatic systems, however, should be evaluated (High Pressure Coolant Injection, High Pressure Core Spray, Reactor Core Isolation Cooling, etc.). If a low pressure system is selected for post-fire safe shutdown, then a sufficient number of SRVs or ADS Valves must be available to achieve and maintain reactor pressure below the shutoff head for the low pressure pumps. For this case, the SRVs or ADS valves selected to perform the depressurization function would be required for hot shutdown components.

[PWR]: Systems selected for the inventory control function should be capable of maintaining level to achieve and maintain hot shutdown. Typically, the same components providing inventory control are capable of providing pressure control. Manual initiation of these systems is acceptable. Automatic initiation functions are not required. Spurious actuation of automatic systems, however, should be evaluated (Safety Injection, High Pressure Injection, Auxiliary Feedwater, Emergency Feedwater, etc.).

#### **3.1.2.4 Decay Heat Removal**

[BWR] Systems selected for the decay heat removal function(s) should be capable of:

- Removing sufficient decay heat from primary containment, to prevent containment over-pressurization and failure.
- Satisfying the net positive suction head requirements of any safe shutdown systems taking suction from the containment (suppression pool).
- Removing sufficient decay heat from the reactor to achieve cold shutdown. (This is not a hot shutdown requirement.)

[PWR] Systems selected for the decay heat removal function(s) should be capable of:

- Removing sufficient decay heat from the reactor to reach hot shutdown conditions. Typically, this entails utilizing natural circulation in lieu of forced circulation via the reactor coolant pumps and controlling steam release via the Atmospheric Dump valves.
- Removing sufficient decay heat from the reactor to reach cold shutdown conditions. (This is not a hot shutdown requirement.)

This does not restrict the use of other systems.

### **3.1.2.5 Process Monitoring**

The process monitoring function is provided for all safe shutdown paths. IN 84-09, Attachment 1, Section IX “Lessons Learned from NRC Inspections of Fire Protection Safe Shutdown Systems (10 CFR 50 Appendix R)” provides guidance on the instrumentation acceptable to and preferred by the NRC for meeting the process monitoring function. This instrumentation is that which monitors the process variables necessary to perform and control the functions specified in Appendix R Section III.L.1. Such instrumentation must be demonstrated to remain unaffected by the fire. The IN 84-09 list of process monitoring is applied to alternative/dedicated shutdown (III.G.3). The use of this same list for III.G.2 redundant Post-Fire Safe Shutdown is acceptable, but the analyst needs to review the specific license basis for the plant under evaluation. In general, process monitoring instruments similar to those listed below are needed to successfully use existing operating procedures (including Abnormal Operating Procedures).

#### BWR

- Reactor coolant level and pressure
- Suppression pool level and temperature
- Emergency or isolation condenser level
- Diagnostic instrumentation for safe shutdown systems
- Level indication for tanks needed for safe shutdown

#### PWR

- Reactor coolant temperature (hot leg / cold leg)



- Pressurizer pressure and level
- Neutron flux monitoring (source range)
- Level indication for tanks needed for safe shutdown
- Steam generator level and pressure
- Diagnostic instrumentation for safe shutdown systems

The specific instruments required may be based on operator preference, safe shutdown procedural guidance strategy (symptomatic vs. prescriptive), and systems and paths selected for safe shutdown.

### **3.1.2.6 Support Systems**

#### **3.1.2.6.1 Electrical Systems**

##### **AC Distribution System**

Power for the Appendix R safe shutdown equipment is typically provided by a medium voltage system such as 4.16 KV Class 1E busses either directly from the busses or through step down transformers/load centers/distribution panels for 600, 480 or 120 VAC loads. For redundant safe shutdown performed in accordance with the requirements of Appendix R Section III.G.1 and 2, power may be supplied from either offsite power sources or the emergency diesel generator depending on which has been demonstrated to be free of fire damage. No credit should be taken for any beneficial effects of a fire causing a loss of offsite power. Refer to Section 3.1.1.7.

##### **DC Distribution System**

Typically, the 125VDC distribution system supplies DC control power to various 125VDC control panels including switchgear breaker controls. The 125VDC distribution panels may also supply power to the 120VAC distribution panels via static inverters. These distribution panels may supply power for instrumentation necessary to complete the process monitoring functions.

For fire events that result in an interruption of power to the AC electrical bus, the station batteries are necessary to supply any required control power during the interim time period required for the diesel generators to become operational. Once the diesels are operational, the 125VDC distribution system can be powered from sources feed from the diesels through the battery chargers.

[BWR] Certain plants are also designed with a 250VDC Distribution System that supplies power to Reactor Core Isolation Cooling and/or High Pressure Coolant Injection equipment.

The DC control centers may also supply power to various small horsepower Appendix R safe shutdown system valves and pumps. If the DC system is relied upon to support safe shutdown without battery chargers being available, it must be verified that sufficient battery capacity exists to support the necessary loads for sufficient time (either until power is restored, or the loads are no longer required to operate).

### **3.1.2.6.2 Cooling Systems**

Various cooling water systems are required to support safe shutdown system operation, based on plant-specific considerations. The cooling systems supporting the required for hot shutdown systems are classified as required for hot shutdown. Typical uses include:

- RHR/SDC/DH Heat Exchanger cooling water
- Safe shutdown pump cooling (seal coolers, oil coolers)
- Diesel generator cooling

### **3.1.2.6.3 HVAC Systems**

HVAC Systems are classified as important to safe shutdown since they do not directly perform any of the hot shutdown functions of reactivity control, inventory control, pressure control, or decay heat removal.

HVAC systems, however, are not needed to support post-fire safe shutdown in all cases. The need for HVAC system operation is based on plant-specific configurations and plant specific heat loads. Typical potential uses include:

- Main control room, cable spreading room, relay room
- ECCS pump compartments
- Diesel generator rooms
- Switchgear rooms

Plant-specific evaluations are necessary to determine which HVAC systems could be needed to support post-fire safe shutdown. Transient temperature response analyses are often utilized to demonstrate that specific HVAC systems would or would not be needed. If HVAC systems are credited, the potential for adverse fire effects to the HVAC system must also be considered, including:

- Dampers closing due to direct fire exposure or due to hot gases flowing through ventilation ducts from the fire area to an area not directly affected by the fire. Where provided, smoke dampers should consider similar effects from smoke.
- Recirculation or migration of toxic conditions (e.g., smoke from the fire, suppressants such as Carbon Dioxide).

In certain situations, adequate time exists to open doors or to place small portable fans, (e.g., water-powered fans), to provide adequate cooling to allow continued equipment operation. The action of opening doors or placing portable temporary fans is not considered to be either a manual operator action or a repair, but the plant temperature analysis must demonstrate that there is adequate time to accomplish such actions. Rebuilding or re-constructing sections of the HVAC System for required equipment cooling would be considered to be a repair.

### **3.1.3 Methodology for Shutdown System Selection**

Refer to Figure 3-2 for a flowchart illustrating the various steps involved in selecting safe shutdown systems and developing the shutdown paths.

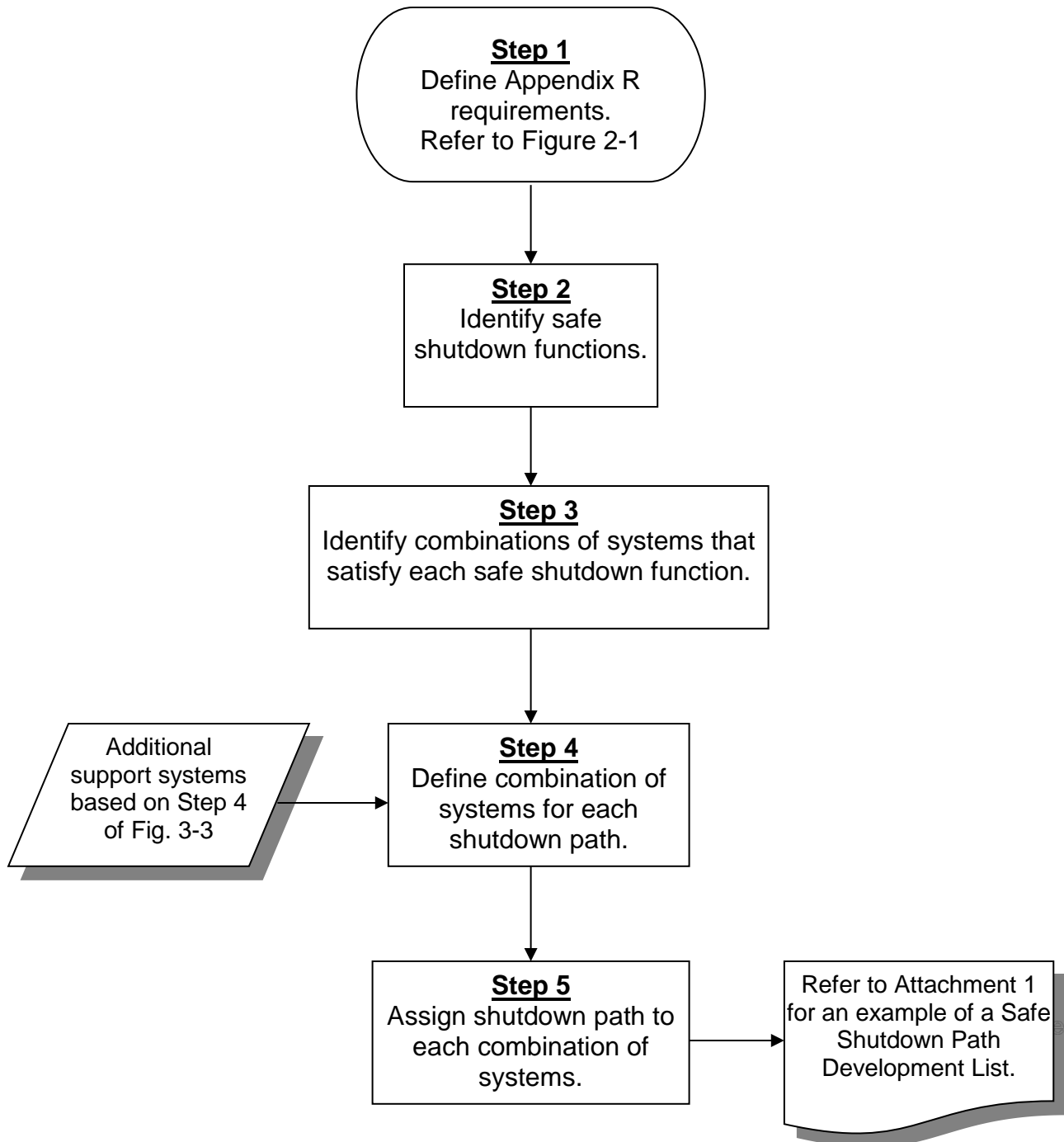
The following methodology may be used to define the safe shutdown systems and paths for an Appendix R analysis:

#### **3.1.3.1 Identify Safe Shutdown Function**

Review available documentation to obtain an understanding of the available plant systems and the functions required to achieve and maintain safe shutdown. Documents such as the following may be reviewed:

- Operating Procedures (Normal, Emergency, Abnormal)
- System descriptions
- Fire Hazard Analysis
- Single-line electrical diagrams
- Piping and Instrumentation Diagrams (P&IDs)
- [BWR] GE Report GE-NE-T43-00002-00-01-R02 entitled “Original Shutdown Paths for the BWR”
- Other NSSS Vendor Guidance

**Figure 3-2**  
**Safe Shutdown System Selection and Path Development**



### **3.1.3.2 Identify Combination of Systems That Satisfy Each Safe Shutdown Function**

Given the criteria/assumptions defined in Section 3.1.1, identify the available combinations of systems capable of achieving the safe shutdown functions of reactivity control, pressure control, inventory control, decay heat removal, process monitoring and support systems such as electrical and cooling systems (refer to Section 3.1.2). This selection process does not restrict the use of other systems. In addition to achieving the required safe shutdown functions, consider other equipment whose mal-operation or spurious operation could impact the required safe shutdown function. The components in this latter set are classified as either required for hot shutdown or as important to SSD as explained in this section and in Appendix H.

### **3.1.3.3 Define Combination of Systems for Each Safe Shutdown Path**

Select combinations of systems with the capability of performing all of the required safe shutdown functions and designate this set of systems as a safe shutdown path. In many cases, paths may be defined on a divisional basis since the availability of electrical power and other support systems must be demonstrated for each path. During the equipment selection phase, identify any additional support systems and list them for the appropriate path.

### **3.1.3.4 Assign Shutdown Paths to Each Combination of Systems**

Assign a path designation to each combination of systems. The path will serve to document the combination of systems relied upon for safe shutdown in each fire area. Refer to Attachment 1 to this document for an example of a table illustrating how to document the various combinations of systems for selected shutdown paths.

## **3.2 SAFE SHUTDOWN EQUIPMENT SELECTION**

The previous section described the methodology for selecting the systems and paths necessary to achieve and maintain safe shutdown for an exposure fire event (see Section 5.0 DEFINITIONS for “Exposure Fire”). This section describes the criteria/assumptions and selection methodology for identifying the specific safe shutdown equipment necessary for the systems to perform their Appendix R functions. The selected equipment should be related back to the safe shutdown systems that they support and be assigned to the same safe shutdown path as that system. The list of safe shutdown equipment will then form the basis for identifying the cables necessary for the operation or that can cause the mal-operation of the safe shutdown systems. For each path it will be important to understand which components are classified as required safe shutdown components and which are classified as important to safe shutdown components. When evaluating the fire-induced impact to each affected cable/component in each fire area, this classification dictates the tools available for mitigating the affects.

### 3.2.1 Criteria/Assumptions

Consider the following criteria and assumptions when identifying equipment necessary to perform the required safe shutdown functions:

3.2.1.1 Safe shutdown equipment can be divided into two categories. Equipment may be categorized as (1) primary components or (2) secondary components. Typically, the following types of equipment are considered to be primary components:

- Pumps, motor operated valves, solenoid valves, fans, gas bottles, dampers, unit coolers, etc.
- All necessary process indicators and recorders (i.e., flow indicator, temperature indicator, turbine speed indicator, pressure indicator, level recorder).
- Power supplies or other electrical components that support operation of primary components (i.e., diesel generators, switchgear, motor control centers, load centers, power supplies, distribution panels, etc.).

Secondary components are typically items found within the circuitry for a primary component. These provide a supporting role to the overall circuit function. Some secondary components may provide an isolation function or a signal to a primary component via either an interlock or input signal processor. Examples of secondary components include flow switches, pressure switches, temperature switches, level switches, temperature elements, speed elements, transmitters, converters, controllers, transducers, signal conditioners, hand switches, relays, fuses and various instrumentation devices.

Some secondary components, although necessary for operation of the primary safe shutdown component, may not be specifically listed on the safe shutdown equipment list (SSEL), since they are an assumed part of the primary component. Regardless of whether or not a sub-component is specifically listed on the SSEL, the fire effects on it and the subsequent effects on the primary component must be accounted for in the post-fire safe shutdown analysis. Additionally, a means of associating cables with primary and secondary components must be developed to assure that all fire-induced cable effects are easily traced back to their ultimate safe shutdown component and system impact(s).

3.2.1.2 Assume that exposure fire damage to manual valves and piping does not adversely impact their ability to perform their pressure boundary or safe shutdown function (heat sensitive piping materials, including tubing with brazed or soldered joints, are not included in this assumption). Fire damage should be evaluated with respect to the ability to manually open or close the valve should this be necessary as a part of the post-fire safe shutdown scenario. For example, post-fire coefficients of friction for rising stem valves cannot be readily determined. Hand wheel sizes and rim

pulls are based on well lubricated stems. Any post-fire operation of a rising stem valve should be well justified using an engineering evaluation.

- 3.2.1.3 Assume that all components, including manual valves, are in their normal position as shown on P&IDs or in the plant operating procedures, that there are no LCOs in effect, that the Unit is operating at 100% power and that no equipment has been taken out of service for maintenance or surveillance. [Note: The assessment of fire risk and the implementation of risk mitigating measures when equipment is out of service is addressed separately by Licensee's.]
- 3.2.1.4 Assume that a check valve closes in the direction of potential flow diversion and seats properly with sufficient leak tightness to prevent flow diversion. Therefore, check valves do not adversely affect the flow rate capability of the safe shutdown systems being used for inventory control, decay heat removal, equipment cooling or other related safe shutdown functions.
- 3.2.1.5 It is not necessary to consider water hammer occurring in non-credited equipment. The primary concern for fire-induced water hammers in Nuclear Power Plants occurring in non-credited equipment is the potential effects of the subsequent flooding on the credited safe shutdown equipment. Since this type of catastrophic failure was not evident in the water hammer studies performed in response to Unresolved Safety Issue (USI) A-1 and subsequent to that by EPRI in their Report on Water Hammer, the need to consider this phenomenon is neither required by fire protection regulations & guidance, nor warranted based on experience. This section applies to both BWRs and PWRs. [Refer to BWROG Report No. BWROG-TP-11-011 Revision 0 June 2011 NEDO-33638.]
- 3.2.1.6 In the absence of an engineering failure modes and effects analysis demonstrating conditions to the contrary, instruments (e.g., resistance temperature detectors, thermocouples, pressure transmitters, and flow transmitters) are assumed to fail upscale, midscale, or downscale as a result of fire damage, whichever is worse. An instrument performing a control function is assumed to provide an undesired signal to the control circuit.

An instrument circuit engineering failure modes and effects analysis (FMEA) could consider factors such as instrument loop bias, loop failure mode (i.e., fail high or low on short to ground, short conductor-to-conductor, or open circuit) and normal loop position (i.e., controller dialed to the closed position which corresponds to low signal), as well as, the specific circuit and cable design for the instrument.

[Refer to NUREG/CR-6776 and NUREG/CR-5546.] Other factors to consider in a FMEA include but are not limited to the type of cable, (i.e. shielded twisted pairs), cable insulation type, whether the necessary conductors for the

erroneous signal are within the same cable and the type of instrument and whether or not it is potentially damaged by the fire.

### **3.2.2 Methodology for Equipment Selection**

Refer to Figure 3-3 for a flowchart illustrating the various steps involved in selecting safe shutdown equipment.

Use the following methodology to select the safe shutdown equipment for a post-fire safe shutdown analysis:

#### **3.2.2.1 Identify the System Flow Path for Each Shutdown Path**

Mark up and annotate a P&ID to highlight the specific flow paths for each system in support of each shutdown path. Refer to Attachment 2 for an example of an annotated P&ID illustrating this concept. Determine which equipment should be included on the Safe Shutdown Equipment List (SSEL). As an option, include secondary components with a primary component(s) that would be affected by fire damage to the secondary component. By doing this, the SSEL can be kept to a manageable size and the equipment included on the SSEL can be readily related to required post-fire safe shutdown systems and functions.

#### **3.2.2.2 Identify the Equipment in Each Safe Shutdown System Flow Path Including Equipment that May Spuriously Operate and Affect System Operation**

Review the applicable documentation (e.g., P&IDs, electrical drawings, instrument loop diagrams) to assure that all equipment in each system's flow path has been identified. Assure that any equipment that could spuriously operate and adversely affect the desired system function(s) is also identified. Additionally, refer to Section 4 for the Resolution Methodology for determining the Plant Specific List of MSOs requiring evaluation. Criteria for making the determination as to which of these components are to be classified as required for hot shutdown or as important to SSD is contained in Section 3.1 and in Appendix H. If additional systems are identified which are necessary for the operation of the safe shutdown system under review, include these as required for hot shutdown systems. Designate these new systems with the same safe shutdown path as the primary safe shutdown system under review (Refer to Figure 3-1).

#### **3.2.2.3 Develop a List of Safe Shutdown Equipment and Assign the Corresponding System and Safe Shutdown Path(s) Designation to Each.**

Prepare a table listing the equipment identified for each system and the shutdown path that it supports. Identify any valves or other equipment that could spuriously operate and impact the operation of that safe shutdown system. Criteria for making the determination as to which of these components are to be classified as required for hot shutdown or as important to SSD is contained in Section 3.1 and in Appendix H. Assign the safe shutdown path for the affected system to this equipment. During the cable selection phase, identify additional equipment required to support the safe shutdown function of the path (e.g., electrical distribution system equipment). Include this additional equipment



in the safe shutdown equipment list. Attachment 3 to this document provides an example of a (SSEL). The SSEL identifies the list of equipment within the plant considered for post-fire safe shutdown and it documents various equipment-related attributes used in the analysis.

Identify instrument tubing that may cause subsequent effects on instrument readings or signals as a result of fire. Determine and consider the fire area location of the instrument tubing when evaluating the effects of fire damage to circuits and equipment in the fire area.

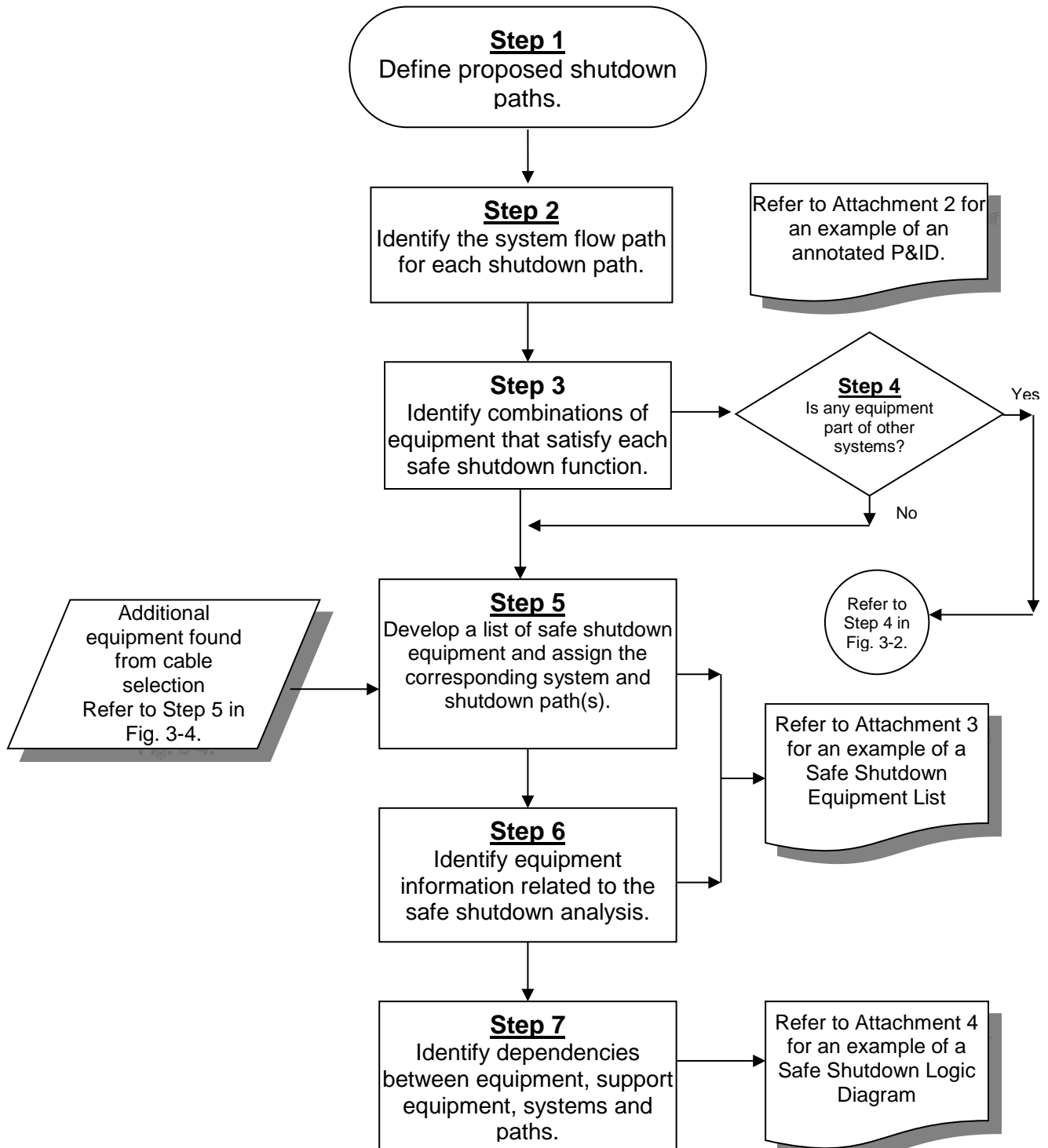
#### **3.2.2.4 Identify Equipment Information Required for the Safe Shutdown Analysis**

Collect additional equipment-related information necessary for performing the post-fire safe shutdown analysis for the equipment. In order to facilitate the analysis, tabulate this data for each piece of equipment on the SSEL. Refer to Attachment 3 to this document for an example of a SSEL. Examples of related equipment data should include the equipment type, equipment description, safe shutdown system, safe shutdown path, drawing reference, fire area, fire zone, and room location of equipment. Other information such as the following may be useful in performing the safe shutdown analysis: normal position, hot shutdown position, cold shutdown position, failed air position, failed electrical position, high/low pressure interface concern, and spurious operation concern. Criteria for making the determination as to which of these components are to be classified as required for hot shutdown or as important to SSD is contained in Section 3.1 and in Appendix H.

#### **3.2.2.5 Identify Dependencies Between Equipment, Supporting Equipment, Safe Shutdown Systems and Safe Shutdown Paths**

In the process of defining equipment and cables for safe shutdown, identify additional supporting equipment such as electrical power and interlocked equipment. As an aid in assessing identified impacts to safe shutdown, consider modeling the dependency between equipment within each safe shutdown path either in a relational database or in the form of a Safe Shutdown Logic Diagram (SSLD). Attachment 4 provides an example of a SSLD that may be developed to document these relationships.

### Figure 3-3 Safe Shutdown Equipment Selection



### 3.3 SAFE SHUTDOWN CABLE SELECTION AND LOCATION

This section provides industry guidance on one acceptable approach for selecting safe shutdown cables and determining their potential impact on equipment required for achieving and maintaining safe shutdown of an operating nuclear power plant for the condition of an exposure fire. The Appendix R safe shutdown cable selection criteria are developed to ensure that all cables that could affect the proper operation or that could cause the mal-operation of safe shutdown equipment are identified and that these cables are properly related to the safe shutdown equipment whose functionality they could affect. Through this cable-to-equipment relationship, cables become part of the safe shutdown path assigned to the equipment affected by the cable. The classification of a cable as either an important to SSD circuit cable or a required safe shutdown cable is also derived from the classification applied to the component that it supports. This classification can vary from one fire area to another depending on the approach used to accomplish post-fire safe shutdown in the area. Refer to Section 3.1 and Appendix H for the criteria to be used for classifying required and important to SSD components.

#### 3.3.1 Criteria/Assumptions

To identify an impact to safe shutdown equipment based on cable routing, the equipment must have cables that affect it identified. Carefully consider how cables are related to safe shutdown equipment so that impacts from these cables can be properly assessed in terms of their ultimate impact on safe shutdown components, systems and functions.

Consider the following criteria when selecting cables that impact safe shutdown equipment:

- 3.3.1.1.1 The list of cables whose failure could impact the operation of a piece of safe shutdown equipment includes more than just those cables connected to the equipment. The relationship between cable and affected equipment is based on a review of the electrical or elementary wiring diagrams. To assure that all cables that could affect the operation of the safe shutdown equipment are identified, investigate the power, control, instrumentation, interlock, and equipment status indication cables related to the equipment. Review additional schematic diagrams to identify additional cables for interlocked circuits that also need to be considered for their impact on the ability of the equipment to operate as required in support of post-fire safe shutdown. As an option, consider applying the screening criteria from Section 3.5 as a part of this section.
- 3.3.1.1.2 In cases where the failure (including spurious operations) of a single cable could impact more than one piece of safe shutdown equipment, associate the cable with each piece of safe shutdown equipment that could be impacted.
- 3.3.1.1.2.1 Electrical devices such as relays, switches and signal resistor units are considered to be acceptable isolation devices. In the case of instrument

loops and electrical metering circuits, review the isolation capabilities of the devices in the loop to determine that an acceptable isolation device has been installed at each point where the loop must be isolated so that a fault would not impact the performance of the safe shutdown instrument function. Refer to Section 3.5 for the types of faults that should be considered when evaluating the acceptability of the isolation device being credited.

- 3.3.1.1.3 Screen out cables for circuits that do not impact the safe shutdown function of a component (i.e., annunciator circuits, space heater circuits and computer input circuits) unless some reliance on these circuits is necessary. To be properly screened out, however, the circuits associated with these devices must be isolated from the component's control scheme in such a way that a cable fault would not impact the performance of the circuit. Refer to Section 3.5 for the types of faults that should be considered when evaluating the acceptability of the isolation device being credited.
- 3.3.1.1.4 For each circuit requiring power to perform its safe shutdown function, identify the cable supplying power to each safe shutdown and/or required interlock component. Initially, identify only the power cables from the immediate upstream power source for these interlocked circuits and components (i.e., the closest power supply, load center or motor control center). Review further the electrical distribution system to capture the remaining equipment from the electrical power distribution system necessary to support delivery of power from either the offsite power source or the emergency diesel generators (i.e., onsite power source) to the safe shutdown equipment. Add this equipment to the safe shutdown equipment list. The set of cables described above are classified as required safe shutdown cables. Evaluate the power cables for breaker coordination concerns. The non-safe shutdown cables off of the safe shutdown buses are classified as required for hot shutdown or as important to SSD based on the criteria contained in Section 3.1 and Appendix H.
- 3.3.1.1.4.1 The automatic initiation logics for the credited post-fire safe shutdown systems are generally not required to support safe shutdown, although exceptions may exist where logic must remain intact to support the availability of a permissive, (i.e., reactor low pressure permissive for LPCI injection), needed for component operation. Typically, each system can be controlled manually by operator actuation in the main control room or emergency control station. The emergency control station includes those plant locations where control devices, such as switches, are installed for the purpose of operating the equipment. If operator actions to manually manipulate equipment at locations outside the MCR or the emergency control station are necessary, those actions must conform to the regulatory requirements on operator manual actions (See Appendix E). If not protected from the effects of fire, the fire-induced failure of automatic initiation logic circuits should be considered for their potential to adversely affect any post-fire safe shutdown system function.

- 3.3.1.1.5 Cabling for the electrical distribution system is a concern for those breakers that feed circuits and are not fully coordinated with upstream breakers. With respect to electrical distribution cabling, two types of cable associations exist. For safe shutdown considerations, the direct power feed to a primary safe shutdown component is associated with the primary component and classified as a required safe shutdown cable. For example, the power feed to a pump is necessary to support the pump. Similarly, the power feed from the load center to an MCC supports the MCC. However, for cases where sufficient branch-circuit coordination is not provided, the same cables discussed above would also support the power supply. For example, the power feed to the pump discussed above would support the bus from which it is fed because, for the case of a common power source analysis, the concern is the loss of the upstream power source and not the connected load. Similarly, the cable feeding the MCC from the load center would also be necessary to support the load center. Additionally, the non-safe shutdown circuits off of each of the required safe shutdown components in the electrical distribution system can impact safe shutdown if not properly coordinated. These cables are classified as required for hot shutdown based on the criteria contained in Section 3.1 and Appendix H.
- 3.3.1.1.6 Exclusion analysis may be used to demonstrate a lack of potential for any impacts to post-fire safe shutdown from a component or group of components regardless of the cable routing. For these cases, rigorous cable searching and cable to component associations may not be required.

### 3.3.2 Associated Circuit of Concern Cables

Appendix R, through the guidance provided in NRC Generic Letter 81-12, requires that separation features be provided for associated non-safety circuits that could prevent operation or cause mal-operation due to hot shorts, open circuits, or shorts to ground, of redundant trains of systems necessary to achieve hot shutdown. The three types of associated circuits were identified in Reference 7.1.5 and further clarified in a NRC memorandum dated March 22, 1982 from R. Mattson to D. Eisenhower, Reference 7.1.6. They are as follows:

- Spurious actuations<sup>3</sup>
- Common power source
- Common enclosure.

Each of these cables is classified as an associated circuit of concern cable.

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<sup>3</sup> As explained in Section 3.1 and in Appendix H, components whose spurious operations could directly prevent the required safe shutdown path in any fire area from performing its required hot shutdown function due to a flow diversion from a required for hot shutdown flow path are initially classified as required for hot shutdown components. Components whose spurious operation could affect important to safe shutdown components might be associated circuits of concern for spurious actuation.

### **Cables Whose Failure May Cause Spurious Operations**

Safe shutdown system spurious operation concerns can result from fire damage to a cable whose failure could cause the spurious operation/mal-operation of equipment whose operation could affect safe shutdown. These cables are identified in Section 3.3.3 together with the remaining safe shutdown cables needed to support control and operation of the equipment. As outlined in Appendix H, valves with the potential to cause flow diversions from the flow path credited to perform a hot shutdown function are classified as required for hot shutdown unless they meet the criteria outlined in Section 3.1 and Appendix H.

### **Common Power Source Cables**

The concern for the common power source associated circuits of concern is the loss of a safe shutdown power source due to inadequate breaker/fuse coordination. In the case of a fire-induced cable failure on a non-safe shutdown load circuit supplied from the safe shutdown power source, a lack of coordination between the upstream supply breaker/fuse feeding the safe shutdown power source and the load breaker/fuse supplying the non-safe shutdown faulted circuit can result in loss of the safe shutdown bus. This would result in the loss of power to the safe shutdown equipment supplied from that power source preventing the safe shutdown equipment from performing its required safe shutdown function. Identify these cables together with the remaining safe shutdown cables required to support control and operation of the equipment. Refer to Section 3.5.2.4 for an acceptable methodology for analyzing the impact of these cables on post-fire safe shutdown.

### **Common Enclosure Cables**

The concern with common enclosure associated circuits of concern is fire damage to a cable whose failure could propagate to other safe shutdown cables in the same enclosure either because the circuit is not properly protected by an isolation device (breaker/fuse) such that a fire-induced fault could result in ignition along its length, or by the fire propagating along the cable and into an adjacent fire area. This fire spread to an adjacent fire area could impact safe shutdown equipment in that fire area, thereby resulting in a condition that exceeds the criteria and assumptions of this methodology (i.e., multiple fires). Refer to Section 3.5.2.5 for an acceptable methodology for analyzing the impact of these cables on post-fire safe shutdown.

### **3.3.3 Methodology for Cable Selection and Location**

Refer to Figure 3-4 for a flowchart illustrating the various steps involved in selecting the cables necessary for performing a post-fire safe shutdown analysis.

Use the following methodology to define the cables required for safe shutdown including cables that may be circuits of concerns for a post-fire safe shutdown analysis. Criteria for making the determination as to which circuits are to be classified as required for hot shutdown or as important to SSD is contained in Section 3.1 and Appendix H.

### **3.3.3.1 Identify Circuits Necessary for the Operation of the Safe Shutdown Equipment**

For each piece of safe shutdown equipment defined in section 3.2, review the appropriate electrical diagrams including the following documentation to identify the circuits (power, control, instrumentation) required for operation or whose failure may impact the operation of each piece of equipment:

- Single-line electrical diagrams
- Control wiring diagrams
- Elementary wiring diagrams
- Electrical connection diagrams
- Instrument loop diagrams

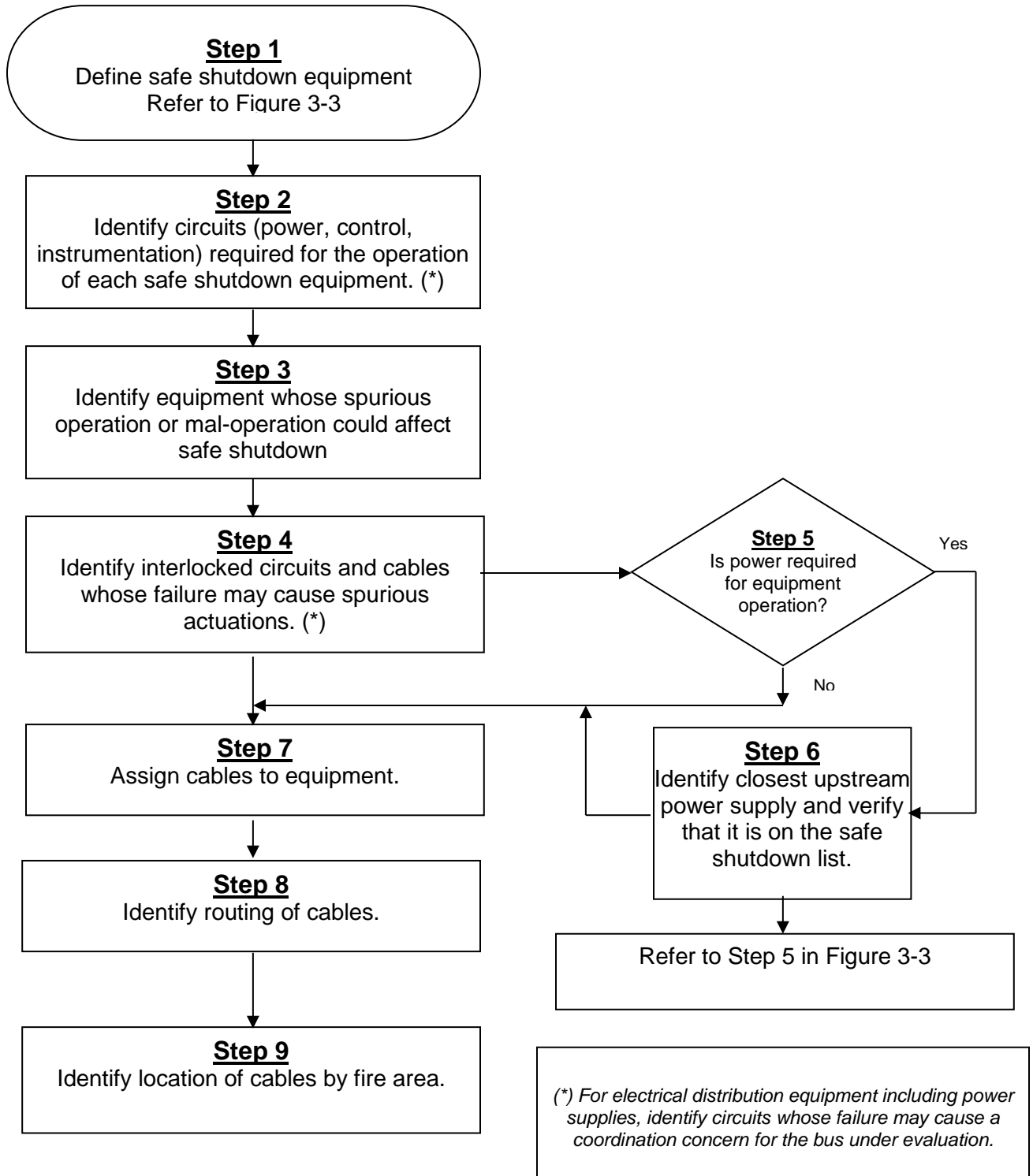
For electrical power distribution equipment such as power supplies, identify any circuits whose failure may cause a coordination concern for the bus under evaluation.

If power is required for the equipment, include the closest upstream power distribution source on the safe shutdown equipment list. Through the iterative process described in Figures 3-2 and 3-3, include the additional upstream power sources up to either the offsite or the emergency power source.

### **3.3.3.2 Identify Interlocked Circuits and Cables Whose Spurious Operation or Mal-operation Could Affect Shutdown**

In reviewing each control circuit, investigate interlocks that may lead to additional circuit schemes, cables and equipment. Assign to the equipment any cables for interlocked circuits that can affect the equipment. Circuits feeding the interlocks in a components primary circuit are typically referred to as secondary circuits.

### Figure 3-4 Safe Shutdown Cable Selection





While investigating the interlocked circuits, additional equipment or power sources may be discovered. Include these interlocked equipment or power sources in the safe shutdown equipment list (refer to Figure 3-3) if they can impact the operation of the equipment under consideration in an undesirable manner that impacts post-fire safe shutdown.

### **3.3.3.3 Assign Cables to the Safe Shutdown Equipment**

Given the criteria/assumptions defined in Section 3.3.1, identify the cables required to operate or that may result in mal-operation of each piece of safe shutdown equipment.. Cables are classified as either required for hot shutdown or important to SSD based on the classification of the component to which they are associated and the function of that component in supporting post-fire safe shutdown in each particular fire area. Refer to Appendix H for additional guidance.

Tabulate the list of cables potentially affecting each piece of equipment in a relational database including the respective drawing numbers, their revision and any interlocks that are investigated to determine their impact on the operation of the equipment. In certain cases, the same cable may support multiple pieces of equipment. Relate the cables to each piece of equipment, but not necessarily to each supporting secondary component.

If adequate coordination does not exist for a particular circuit, relate the power cable to the power source. This will ensure that the power source is identified as affected equipment in the fire areas where the cable may be damaged. Additional criteria for making the determination as to which cables are to be classified as required for hot shutdown or as important to SSD is contained in Appendix H.

### **3.3.3.4 Identify Routing of Cables**

Identify the routing for each cable including all raceway and cable endpoints. Typically, this information is obtained from joining the list of safe shutdown cables with an existing cable and raceway database.

### **3.3.3.5 Identify Location of Raceway and Cables by Fire Area**

Identify the fire area location of each raceway and cable endpoint identified in the previous step and join this information with the cable routing data. For raceway and cable endpoints in multiple fire areas, each fire area where the raceway or cable endpoint exists must be included. In addition, identify the location of field-routed cable by fire area. This produces a database containing all of the cables requiring fire area analysis, their locations by fire area, and their raceway.

### **3.4 FIRE AREA ASSESSMENT AND COMPLIANCE STRATEGIES**

By determining the location of each component and cable by fire area and using the cable to equipment relationships described above, the affected safe shutdown equipment in each fire area can be determined. Using the list of affected equipment in each fire area, the impacts to safe shutdown systems, paths and functions can be determined. Based on an assessment of the number and types of these impacts, the required safe shutdown path for each fire area can be determined. The specific impacts to the selected safe shutdown path can be evaluated using the circuit analysis and evaluation criteria contained in Section 3.5 of this document. Knowing which components and systems are performing which safe shutdown functions, the required and important to SSD components can be classified. Once these component classifications have been made the tools available for mitigating the effects of fire induced damage can be selected. Refer to Appendix H for additional guidance on classifying components as either required for hot shutdown or important to safe shutdown. For MSOs the Resolution Methodology outlined in Section 4, Appendix B, Appendix G, Appendix J and Appendix K should be applied. Components in each MSO are classified as either required for hot shutdown or important to safe shutdown components using the criteria from Section 3.1 and Appendix H. Similarly, this classification determines the available tools for mitigating the effects of fire-induced damage to the circuits for these components.

Having identified all impacts to the required safe shutdown path in a particular fire area, this section provides guidance on the techniques available for individually mitigating the effects of each of the potential impacts.

#### **3.4.1 Criteria/Assumptions**

The following criteria and assumptions apply when performing "deterministic" fire area compliance assessment to mitigate the consequences of the circuit failures identified in the previous sections for the required safe shutdown path in each fire area.

- 3.4.1.1 Assume only one fire in any single fire area at a time.
- 3.4.1.2 Assume that the fire may affect all unprotected cables and equipment within the fire area. This assumes that neither the fire size nor the fire intensity is known. This is conservative and bounds the exposure fire that is postulated in the regulation.
- 3.4.1.3 Address all cable and equipment impacts affecting the required safe shutdown path in the fire area. All potential impacts within the fire area must be addressed. The focus of this section is to determine and assess the potential impacts to the required safe shutdown path selected for achieving post-fire safe shutdown and to assure that the required safe shutdown path for a given fire area is properly protected.
- 3.4.1.4 Use the criteria from Section 3.1 and Appendix H to classify each impacted cable/component as either a required or important to SSD cable/component.
- 3.4.1.5 Use operator manual actions where appropriate, for cable/component impacts classified as important to SSD cable/components, to achieve

and maintain post-fire safe shutdown conditions in accordance with NRC requirements (refer to Appendix E). For additional criteria to be used when determining whether an operator manual action may be used for a flow diversion off of the primary flow path, refer to Appendix H.

3.4.1.6 Where appropriate to achieve and maintain cold shutdown within 72 hours, use repairs to equipment required in support of post-fire shutdown.

3.4.1.7 For the components on the required safe shutdown path classified as required hot shutdown components as defined in Section 3.1 and Appendix H, Appendix R compliance requires that one train of systems necessary to achieve and maintain hot shutdown conditions from either the control room or emergency control station(s) is free of fire damage (III.G.1.a). When cables or equipment are within the same fire area outside primary containment and separation does not already exist, provide one of the following means of separation for the required safe shutdown components impacted circuit(s):

- Separation of cables and equipment and associated non-safety circuits of redundant trains within the same fire area by a fire barrier having a 3-hour rating (III.G.2.a)
- Separation of cables and equipment and associated non-safety circuits of redundant trains within the same fire area by a horizontal distance of more than 20 feet with no intervening combustibles or fire hazards. In addition, fire detectors and an automatic fire suppression system shall be installed in the fire area (III.G.2.b).
- Enclosure of cable and equipment and associated non-safety circuits of one redundant train within a fire area in a fire barrier having a one-hour rating. In addition, fire detectors and an automatic fire suppression system shall be installed in the fire area (III.G.2.c).

For fire areas inside non-inerted containments, the following additional options are also available:

- Separation of cables and equipment and associated non-safety circuits of redundant trains by a horizontal distance of more than 20 feet with no intervening combustibles or fire hazards (III.G.2.d);
- Installation of fire detectors and an automatic fire suppression system in the fire area (III.G.2.e); or
- Separation of cables and equipment and associated non-safety circuits of redundant trains by a noncombustible radiant energy shield (III.G.2.f).

- Use exemptions, deviations, LARs and licensing change processes to satisfy the requirements mentioned above and to demonstrate equivalency depending upon the plant's license requirements.

3.4.1.8 Consider selecting other equipment that can perform the same safe shutdown function as the impacted equipment. In addressing this situation, each equipment impact, including spurious operation, is to be addressed in accordance with regulatory requirements and the NPP's current licensing basis. With respect to MSOs, the criteria in Section 3.5, Section 4, Appendix B, Appendix G, Appendix H, Appendix I, and Appendix J should be used.

3.4.1.9 Consider the effects of the fire on the density of the fluid in instrument tubing and any subsequent effects on instrument readings or signals associated with the protected safe shutdown path in evaluating post-fire safe shutdown capability. This can be done systematically or via procedures such as Emergency Operating Procedures.

### **3.4.2 Methodology for Fire Area Assessment**

Refer to Figure 3-5 for a flowchart illustrating the various steps involved in performing a fire area assessment.

Use the following methodology to assess the impact to safe shutdown and demonstrate Appendix R compliance:

#### **3.4.2.1 Identify the Affected Equipment by Fire Area**

Identify the safe shutdown cables, equipment and systems located in each fire area that may be potentially damaged by the fire. Provide this information in a report format. The report may be sorted by fire area and by system in order to understand the impact to each safe shutdown path within each fire area (see Attachment 5 for an example of an Affected Equipment Report).

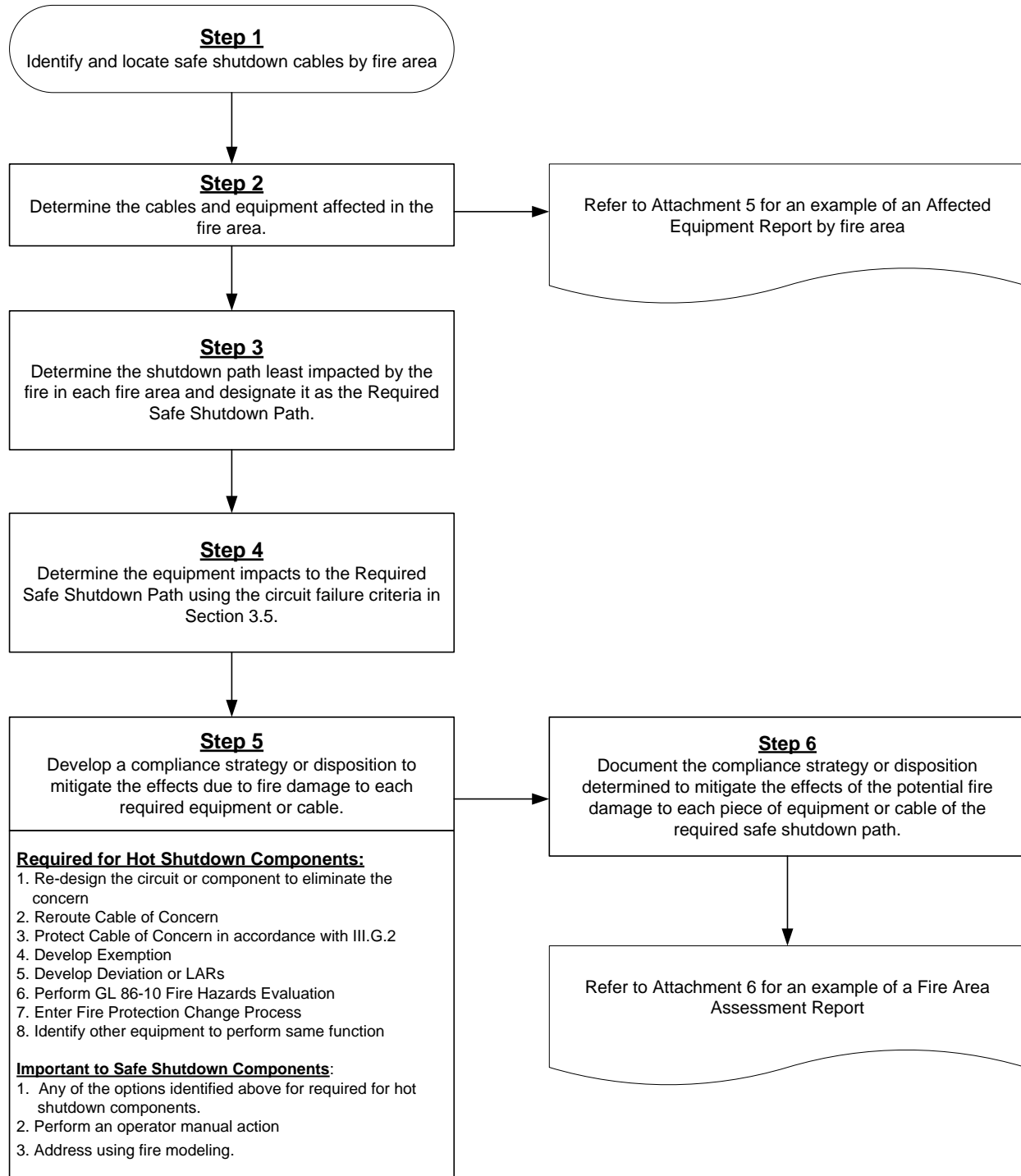
#### **3.4.2.2 Determine the Shutdown Paths Least Impacted By a Fire in Each Fire Area**

Based on a review of the systems, equipment and cables within each fire area, determine which shutdown paths are either unaffected or least impacted by a postulated fire within the fire area. Typically, the safe shutdown path with the least number of cables and equipment in the fire area would be selected as the required safe shutdown path. Consider the circuit failure criteria and the possible mitigating strategies, however, in selecting the required safe shutdown path in a particular fire area. Review support systems as a part of this assessment since their availability will be important to the ability to achieve and maintain safe shutdown. For example, impacts to the electric power distribution system for a particular safe shutdown path could present a major impediment to using a particular path for safe shutdown. By identifying this early in the assessment process, an unnecessary amount of time is not spent assessing impacts to the frontline systems that will require this power to support their operation. Determine which components are required hot shutdown components and which components are important to SSD components using the guidance in Section 3.1 and Appendix H.

Based on an assessment as described above, designate the required safe shutdown path(s) for the fire area. Classify the components on the required safe shutdown path necessary to perform the required safe shutdown functions as required safe shutdown components. Identify all equipment not in the safe shutdown path whose spurious operation or mal-operation could affect the shutdown function. Criteria for classifying these components as required for hot shutdown or as important to SSD is contained in Section 3.1 and Appendix H. Include the affected cables in the shutdown function list. For each of the safe shutdown cables (located in the fire area) that are part of the required safe shutdown path in the fire area, perform an evaluation to determine the impact of a fire-induced cable failure on the corresponding safe shutdown equipment and, ultimately, on the required safe shutdown path.

When evaluating the safe shutdown mode for a particular piece of equipment, it is important to consider the equipment's position for the specific safe shutdown scenario for the full duration of the shutdown scenario. It is possible for a piece of equipment to be in two different states depending on the shutdown scenario or the stage of shutdown within a particular shutdown scenario. Document information related to the normal and shutdown positions of equipment on the safe shutdown equipment list.

**Figure 3-5  
Fire Area Assessment Flowchart**



### **Determine Safe Shutdown Equipment Impacts**

Using the circuit analysis and evaluation criteria contained in Section 3.5 of this document, determine the equipment that can impact safe shutdown and that can potentially be impacted by a fire in the fire area, and what those possible impacts are.

#### **3.4.2.3 Develop a Compliance Strategy or Disposition to Mitigate the Effects Due to Fire Damage to Each Required Component or Cable**

The available deterministic methods for mitigating the effects of circuit failures are summarized as follows (see Figure 1-1):

Required for Hot Shutdown Components:

- Re-design the circuit or component to eliminate the concern. This option will require a revision to the post-fire safe shutdown analysis.
- Re-route the cable of concern. This option will require a revision to the post-fire safe shutdown analysis.
- Protect the cable in accordance with III.G.2.
  - Provide a qualified 3-fire rated barrier.
  - Provide a 1-hour fire rated barrier with automatic suppression and detection.
  - Provide separation of 20 feet or greater with automatic suppression and detection and demonstrate that there are no intervening combustibles within the 20 foot separation distance.
- Identify other equipment not affected by the fire capable of performing the same safe shutdown function.
- Develop exemptions, deviations, LARs, Generic Letter 86-10 evaluation or fire protection design change evaluations with a licensing change process.

Important to Safe Shutdown Components:

- Any of the options provided for required for hot shutdown components.
- Perform and operator manual action in accordance with Appendix E.
- Address using fire modeling.

Cold Shutdown Only Components:

- Any of the options provided for important to safe shutdown components.
- Perform a repair in accordance with Appendix E.

Additional options are available for non-inerted containments as described in 10 CFR 50 Appendix R section III.G.2.d, e and f.

#### **3.4.2.4 Document the Compliance Strategy or Disposition Determined to Mitigate the Effects Due to Fire Damage to Each Required Component or Cable**

Assign compliance strategy statements or codes to components or cables to identify the justification or mitigating actions proposed for achieving safe shutdown. The justification should address the cumulative effect of the actions relied upon by the licensee to mitigate a fire in the area. Provide each piece of safe shutdown equipment, equipment not in the path whose spurious operation or mal-operation could affect safe shutdown, and/or cable for the required safe shutdown path with a specific compliance strategy or disposition. Refer to Attachment 6 for an example of a Fire Area Assessment Report documenting each cable disposition.

### **3.5 CIRCUIT ANALYSIS AND EVALUATION**

This section on circuit analysis provides information on the potential impact of fire on circuits used to monitor, control and power required for hot shutdown and important to safe shutdown equipment. Applying the circuit analysis criteria will lead to an understanding of how fire damage to the cables may affect the ability to achieve and maintain post-fire safe shutdown in a particular fire area. This section should be used in conjunction with Section 3.4, to evaluate the potential fire-induced impacts that require mitigation.

Appendix R Section III.G.2 identifies the fire-induced circuit failure types that are to be evaluated for impact from exposure fires on required for hot shutdown equipment. Section III.G.2 of Appendix R requires consideration of hot shorts, shorts-to-ground and open circuits.

#### **3.5.1 Criteria/Definitions**

Apply the following criteria/definitions when performing fire-induced circuit failure evaluations. Refer to Appendix J to this document for the basis for these criteria. Appendix J also classifies circuit failure types as either “implausible” or “incredible”. These terms are defined in Appendix J.

Circuit failure types classified as “incredible” do not need to be considered in a deterministic or risk-informed (e.g., Fire PRA, NFPA 805) post-fire safe shutdown analysis.

Circuit failure types classified as “implausible” need to be considered in a deterministic or risk-informed (e.g., Fire PRA, NFPA 805) post-fire safe shutdown analysis for any components classified as “high impact components”. “High impact components” are defined in Appendix J.

Any circuit failure type described below that is not classified in Appendix J as either “implausible” or “incredible” is considered to be “plausible”. Circuit failure types classified as “plausible” need to be considered in a deterministic or risk-informed (e.g., Fire PRA, NFPA 805) post-fire safe shutdown analysis for any safe shutdown component.



### 3.5.1.1 Circuit Failure Criteria:

The criteria provided below are to be combined with the circuit analysis information provided in Section 3.5.2 and the circuit failure type classifications provided in Appendix J. Applying these criteria will address the effects of single and multiple fire-induced circuit failures impacting circuits for components classified as either “required for hot shutdown” or “important to safe shutdown”. Criteria differences apply to those components classified as “high impact components”. Refer to Appendix J and Section 3.5.2 for the list of circuit failure types, (i.e., “implausible” circuit failure types), that apply to “high impact components” only.

Consider the following circuit failure types on each conductor of each unprotected cable (e.g., not a fire-rated cable, not wrapped with a qualified, protective fire wrap). These types of circuit failures are to be applied to the circuit types depicted in Section 3.5.2.

- A hot short may result from a fire-induced insulation breakdown between conductors of the same cable, or conductors from a different cable or from some other external source resulting in a compatible but undesired impressed voltage or signal on a specific conductor. A hot short may cause a spurious operation of safe shutdown equipment.
  - A hot short in the control circuitry for an MOV can bypass the MOV protective devices, (i.e., torque and limit switches). This is the condition described in NRC Information Notice 92-18. In this condition, the potential exists to damage the MOV motor, operator and/or valve. Damage to the MOV could result in an inability to operate the MOV either remotely, using separate controls with separate control power, or manually using the MOV hand wheel. This condition could be a concern in two instances: (1) For fires requiring Control Room evacuation and remote operation from the Remote Shutdown Panel, the Auxiliary Control Panel or Auxiliary Shutdown Panel; (2) For fires where the selected means of addressing the effects of fire induced damage is the use of an operator manual action. In each case where such a hot short is not prevented by circuit re-design, analysis must be performed to demonstrate that the MOV can be subsequently operated electrically or manually, (e.g., valve pressure boundary integrity maintained; valve hand-wheel torque capability not exceeded), as required by the safe shutdown analysis.
  - For ungrounded circuits, a combination of shorts-to-ground can have the same effect as a hot short, (i.e., result in a compatible, but undesired impressed voltage or signal on a specific conductor). Shorts-to-ground that combine in this way to impact a components circuitry are referred to as Ground Fault Equivalent Hot Shorts (GFEHS). GFEHS must be evaluated for their impact on any ungrounded circuits for all safe shutdown equipment. Refer to

Appendix J for special considerations for ungrounded AC circuits from an individual control power transformer (CPT).

- An open circuit may result from a fire-induced break in a conductor resulting in the loss of circuit continuity, or from a blown fuse or tripped breaker. [Note: These latter conditions of a blown fuse or tripped breaker typically result from a short-to-ground.] An open circuit may prevent the ability to control or power the affected equipment. An open circuit may also result in a change of state for normally energized equipment. (e.g., [for BWRs] loss of power to the Main Steam Isolation Valve (MSIV) solenoid valves due to an open circuit will result in the closure of the MSIVs). This is not considered to be a spurious operation. These types of failures are considered to be fire damage. In the NRC/Industry Cable Fire Testing conducted between 2002 and 2012, open circuits as an initial failure mode were not often observed. Based on this, engineering evaluations for circuits for components classified as important to safe shutdown may be performed for applications such as the use of shorting switches. In applications such as the use of “shorting switches” installed in a component’s control circuitry to prevent spurious operation of the component, open circuits can defeat the ability of the “shorting switch” to perform its intended function. Refer to Appendix I for more information on the potential impact of open circuits on “shorting switches”.
- A short-to-ground may result from a fire-induced breakdown of a cable insulation system, resulting in the potential on the conductor being applied to ground potential. A short-to-ground may have all of the same effects as an open circuit and, in addition, a short-to-ground may also cause an impact to the control circuit or power train of which it is a part. A short-to-ground may also result in a change of state for normally energized equipment. This is not considered to be a spurious operation. These types of failures are considered to be fire damage. [Note: Impacts to a component resulting from a set of shorts-to-ground equating to a ground fault equivalent hot short is considered to be similar to a hot short, as discussed above, and is, therefore considered to be a spurious operation.]

### **3.5.1.2 Duration of a Hot Short:**

The duration of a hot short in an AC circuit may be assumed to be limited to 20 minutes. The duration of a hot short in an DC circuit may be assumed to be limited to 40 minutes. Refer to NUREG/CR-7150 Volume 3.

### **3.5.1.3 Number of Spurious Operations and Hot Shorts:**

In addition to the circuit failure type outlined in Appendix J, the following criteria are to be applied in addressing the effects of combined circuit/component failures resulting in a single MSO or to combining MSOs already listed in Appendix G. [Reference NUREG/CR-7150 Volume 3.] The criteria apply regardless of whether the circuitry is for

a component classified as required for hot shutdown or important to safe shutdown. They also apply regardless of the target cable insulation type or power supply type, unless noted otherwise. The term “concurrent” in this document means existing together at some point in time and includes “simultaneous” occurring at the exact same point in time.

- Number of Hot shorts for Transient In-rush - If the MSO requires the consideration of inrush current from more than one (1) end device to cause an overload condition for a power supply, then the MSO is not required to be considered, as long as the assumptions/limitations provided below are satisfied.

Any MSO scenario involving the potential failure of a safe shutdown power supply resulting from a temporary overload condition caused by multiple, concurrent inrush currents (i.e., overlapping inrush transient current from multiple separate loads) due to spurious operation of multiple loads as a result of hot shorts on the control cable for each load is not required to be considered, provided the load sequencer is not damaged (if applicable) by the fire, and the hot short target conductors for each of the potentially spuriously operated loads are in separate cables. With respect to this scenario, load sequencer damage is defined as any fire-induced mal-operation that causes unintended overlapping inrush current from multiple loads.

In this case, the power supply availability for the fire event can be assessed by the steady-state loading (i.e., anticipated load plus fire-induced spurious operation load) in combination with the worst case individual (or anticipated by design) inrush current transient load.

This criteria assumes:

- The load spurious operation(s) is caused by fire damage to control cables for the load(s) from the power supply of concern. The load is otherwise operating correctly and has no potential for power cable fire damage. Thus, the load transient inrush current expected is normal and not impacted by the fire event.
- The load sequencer, if applicable, for the associated power supply is not damaged by the fire such that the fire damage may cause multiple loads to simultaneously spuriously start
- Target conductors that could spuriously start/energize loads powered from the same power supply are in separate cables.
- Number of Inter-cable Hot Shorts Regardless of Latching Characteristics or Copping Time – If the MSO requires four (4) or more separate target cables with inter-cable hot shorts (excluding GFEHS), then the MSO is not required to be considered, regardless of whether

the circuits are latching or non-latching. There is no sustained time duration consideration required for this case.

- The ground fault equivalent hot short (GFEHS) is not included as an inter-cable failure mode for this recommendation. For ungrounded power supplies, credible GFEHS is significantly more likely than inter-cable hot shorts and as such, is not included in this recommendation. Spurious operation(s) for the MSO scenario that can be caused by GFEHS must be considered unless otherwise limited by the guidance in Appendix J. Inter-cable failures that can result in a GFEHS cannot be counted as part of this limit of four or more separate inter-cable hot shorts.
- Number of Non-Latching Hot Shorts with 10 minute Coping Time regardless of Circuit Failure Mode – If the MSO requires (a) three (3) or more concurrent fire-induced hot shorts on separate target cables in non-latching circuits and (b) the hot shorts must be sustained for more than 10 minutes to cause a condition that cannot be tolerated, refer to NEI 00-01 Appendix H, then the MSO is not required to be considered regardless of conductor hot short failure mode (i.e., intra-cable, inter-cable, or GFEHS). For MSO scenarios that result in conditions that cannot be tolerated for 10 minutes or less, any number of non-latching intra-cable circuit failures should be considered, unless otherwise limited by the guidance in Appendix J. In addition, for latching fire induced hot shorts, any number of intra-cable circuit failures should be considered unless otherwise limited by the guidance in Appendix J.
- Sequentially Selected Fire-Induced Circuit Failures – If the MSO requires a selective sequence of five (5) or more independent, (i.e., separate, target cables with specific fire induced cable failures), where the adverse condition will not occur if the sequence is not produced by the fire-induced circuit failures (e.g., hot short, short to ground, open circuit), then the MSO is considered “Incredible” and need not be considered for MSOs regardless of fire-induced failure durations, circuit configurations, or fire-induced failure types. [Note: At least two (2) of these failures must be hot short induced spurious operations.]
  - To be beyond what needs to be considered for MSOs, the total number of sequential failures must exceed the threshold established above without including the following as one of the sequential failures: (1) the more probable failures of conductor grounding of grounded AC circuits in armored cable<sup>1</sup> or (2) for ungrounded DC circuits, the more probable failures of intra-cable short or ground fault equivalent hot short in armored cable<sup>1</sup>.

<sup>1</sup>Metal armor of armored cable is assumed to always be grounded in accordance with NFPA 70.

### 3.5.2 Types of Circuit Failures

Appendix R requires that nuclear power plants must be designed to prevent exposure fires from defeating the ability to achieve and maintain post-fire safe shutdown. Fire damage to circuits that provide control and power to equipment required for hot shutdown and important to safe shutdown in each fire area must be evaluated for the effects of a fire in that fire area. Only one fire at a time is assumed to occur. The extent of fire damage is assumed to be limited by the boundaries of the fire area. Given this set of conditions, it must be assured that one redundant train of equipment necessary to achieve and maintain hot shutdown is free of fire damage for fires in every plant location. To provide this assurance, Appendix R requires that equipment and circuits required for hot shutdown be free of fire damage and that these circuits be designed for the fire-induced effects of a hot short, short-to-ground, or an open circuit. With respect to the electrical distribution system, the issue of breaker coordination must also be addressed. Criteria for making the determination as to which breakers are to be classified as required for hot shutdown is contained in Appendix H.

This section will discuss specific examples of each of the following types of circuit failures and how they need to be combined for these circuit types in order to address the issues of component operation and single or multiple hot shorts causing spurious operations. Within the limitations contained in Appendix J and Section 3.5.1.3 above, these individual spurious operations are then combined into multiple spurious operations (MSOs). MSOs include multiple fire-induced circuit failures causing the spurious operation of a single component and combinations of these individually spurious operated components, as discussed in Section 4 and listed in Appendix G. Mitigating the potential effects of these multiple spurious operations using the mitigating strategies outlined in this document is one method for resolving the MSO Issue for a licensee. The types of circuit failures discussed in this section are defined in Section 3.5.1 and listed below:

- Open circuit
- Short-to-ground
- Hot short
  - Ground Fault Equivalent Hot Short (GFEHS)

The circuits shown in the figures associated with Sections 3.5.2.1, 3.5.2.2, 3.5.2.3 and 3.5.2.4 are all single break design circuits. As explained in Appendix J, Table J-1, each of these circuit failure types for the circuits shown in Sections 3.5.2.1, 3.5.2.2, 3.5.2.3 and 3.5.2.4 are considered to be “plausible” circuit failure types, with the exceptions noted below and in Appendix J, Table J-1. These circuit failure types are considered to be “plausible” regardless of target and source conductor insulation types and, for hot shorts, regardless of whether the source conductor is an intra-cable, inter-cable or GFEHS, except as noted below and in Appendix J, Table J-1. Exceptions apply for inter-cable hot shorts affecting circuits using metal foil wrap cable and armored cable where the foil and the armor provide robust shields. Additionally, for ungrounded AC circuits from an

individual CPT, special considerations could apply depending on the routing, cable conductor configuration and circuit wiring characteristics. The special considerations could change the classification, (i.e., plausible), for this case. The special considerations are discussed in Appendix J, Section J.3.2. Finally, should an action be taken to remove the control power from any of these single break design circuits depicted in Sections 3.5.2.1, 3.5.2.2, 3.5.2.3 and 3.5.2.4, the circuit configuration with power removed becomes analogous to the double break circuit designs shown in Section 3.5.2.5, (i.e., pseudo-double break design circuits). Refer to Section 3.5.2.5 for the information applicable to a single break design circuit with the power removed, (i.e., pseudo-double break design circuits).

### **3.5.2.1 Circuit Failures Due to an Open Circuit [Classified as a Plausible Circuit Failure Type]**

This section provides guidance for addressing the effects of an open circuit for required for hot shutdown and important to safe shutdown equipment. An open circuit is a fire-induced break in a conductor resulting in the loss of circuit continuity, or from a blown fuse or tripped breaker. [Note: These latter conditions of a blown fuse or tripped breaker typically result from a short-to-ground.] An open circuit will typically prevent the ability to control or power the affected equipment. An open circuit can also result in a change of state for normally energized equipment. For example, a loss of power to the main steam isolation valve (MSIV) solenoid valves [for BWRs] due to an open circuit will result in the closure of the MSIV. This is not considered to be a spurious operation. These types of failures are considered to be fire damage.

Open circuits as an initial failure mode were not a predominant failure mode in the NRC and Industry cable fire testing programs. Based on this, for equipment classified as important to safe shutdown, fire modeling or other types of engineering evaluations can be used to demonstrate that an open circuit will not occur for a specific circuit subjected to a specific exposure fire. Refer to Appendix I on Shorting Switches for additional guidance on considering open circuits when designing shorting switches.

- Loss of electrical continuity may occur within a conductor resulting in de-energizing the circuit and causing a loss of power to, or control of, the required for hot shutdown and important to safe shutdown equipment.
- In selected cases, a loss of electrical continuity may result in loss of power to an interlocked relay or other device. This loss of power may change the state of the equipment. Evaluate this to determine if equipment fails safe.
- Open circuit on a medium voltage (i.e., up to and including 15 kV primary circuit voltage) ammeter current transformer (CT) circuit has been hypothesized to result in secondary damage, possibly resulting in the occurrence of an additional fire in the location of the CT itself. The Working Group for JACQUE-FIRE Volume 3 concluded that this phenomenon is not a concern for CT used in any medium voltage applications, (i.e., up to and including 15 kV primary circuit voltage). This

conclusion is documented in Appendix J and is based on CT testing performed at Brookhaven National Labs and documented in NUREG/CR 7150 Volume 3.

Figure 3.5.2-1 shows an open circuit on a grounded control circuit.

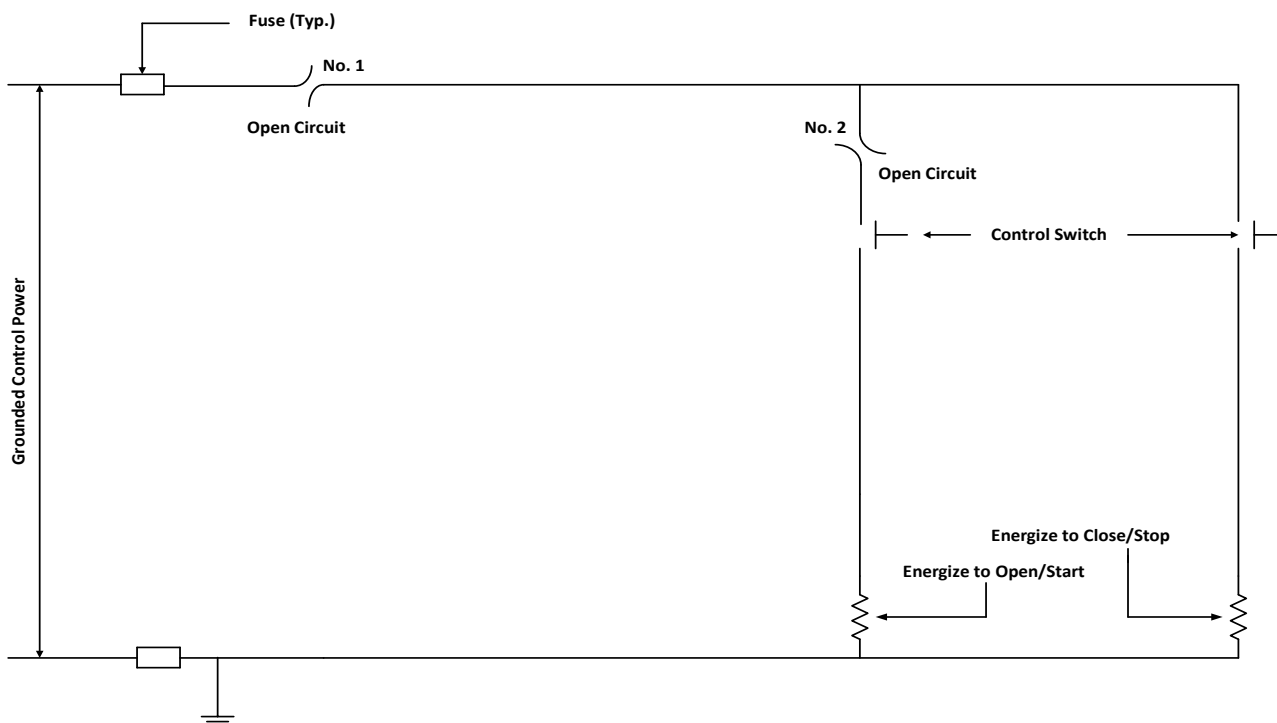


Figure 3.5.2-1 Open Circuit (Grounded Control Circuit)

**Open circuit No. 1:**

An open circuit at location No. 1 will prevent operation of the subject equipment.

**Open circuit No. 2:**

An open circuit at location No. 2 will prevent opening/starting of the subject equipment, but will not impact the ability to close/stop the equipment.

In applications such as the use of “shorting switches” installed in a component’s control circuitry to prevent spurious operation of the component, open circuits can defeat the ability of the “shorting

switch” to perform its intended function. Refer to Appendix I for more information on the potential impact of open circuits on “shorting switches”



### **3.5.2.2 Circuit Failures Due to a Short-to-Ground [Classified as a Plausible Circuit Failure Type]**

This section provides guidance for addressing the effects of a short-to-ground on circuits for required for hot shutdown and important to safe shutdown equipment. A short-to-ground is a fire-induced breakdown of a cable insulation system resulting in the potential on the conductor being applied to ground potential. A short-to-ground can cause a loss of power to or control of required safe shutdown equipment. In addition, a short-to-ground may affect other equipment in the electrical power distribution system in the cases where proper coordination does not exist.

There is no limit to the number of shorts-to-ground that could be caused by the fire.

Note: The effect of a set of shorts-to-ground equating to a ground fault equivalent hot short is considered to be similar to a hot short. Circuit failures involving ground fault equivalent hot shorts are considered to be spurious operations. The effects of ground fault equivalent hot shorts causing a spurious operation is addressed under Section 3.5.2.4. Refer to Appendix J for additional information on GFEHS.

Consider the following consequences in the post-fire safe shutdown analysis when determining the effects of circuit failures related to shorts-to-ground:

- A short to ground in a power or a control circuit may result in tripping one or more isolation devices (i.e., breaker/fuse) and causing a loss of power to or control of required safe shutdown equipment.
- In the case of certain energized equipment such as HVAC dampers, a loss of control power may result in loss of power to an interlocked relay or other device that may cause one or more spurious changes of state. The spurious changes of state due to this phenomenon are not considered to be spurious operations. These types of failures are considered to be fire damage.

#### **Short-to-Ground on Grounded Circuits**

Typically, in the case of a grounded circuit, a short-to-ground on any part of the circuit would present a concern for tripping the electrical protective device thereby causing a loss of control power.

Figure 3.5.2-2 illustrates how a short-to-ground fault may impact a grounded circuit.

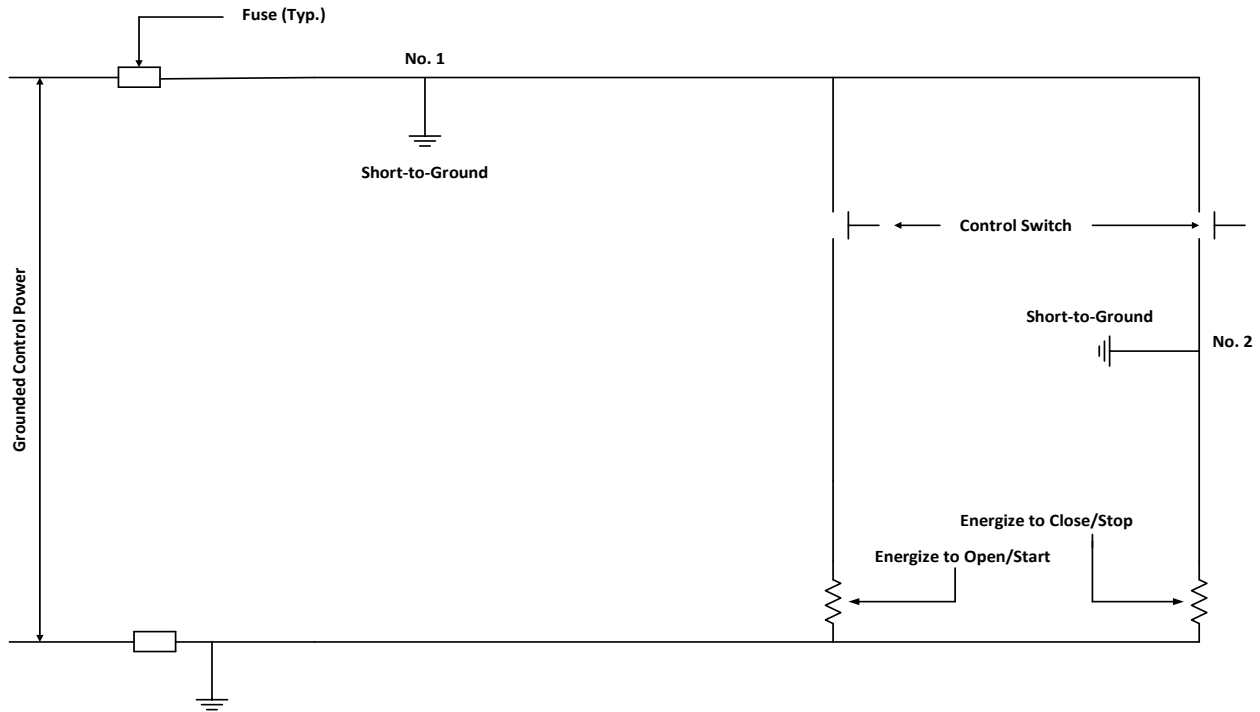


Figure 3.5.2-2 Short-to-Ground (Grounded Control Circuit)

### **Short-to-ground No. 1:**

A short-to-ground at location No. 1 will result in the control power fuse blowing and a loss of power to the control circuit. This will result in an inability to operate the equipment using the control switch. Depending on the coordination characteristics between the protective device on this circuit and upstream circuits, the power supply to other circuits could be affected.

### **Short-to-ground No. 2:**

A short-to-ground at location No. 2 will have no effect on the circuit until the close/stop control switch is closed. Should this occur, the effect would be identical to that for the short-to-ground at location No. 1 described above. Should the open/start control switch be closed prior to closing the close/stop control switch, the equipment will still be able to be opened/started.

### **Short-to-Ground on Ungrounded Circuits**

In the case of an ungrounded circuit, postulating only a single short-to-ground on any part of the circuit may not result in tripping the electrical protective device. Another short-to-ground on the circuit or another circuit from the same source would need to exist to cause a loss of control power to the circuit.

Figure 3.5.2-3 illustrates how a short to ground fault may impact an ungrounded circuit.

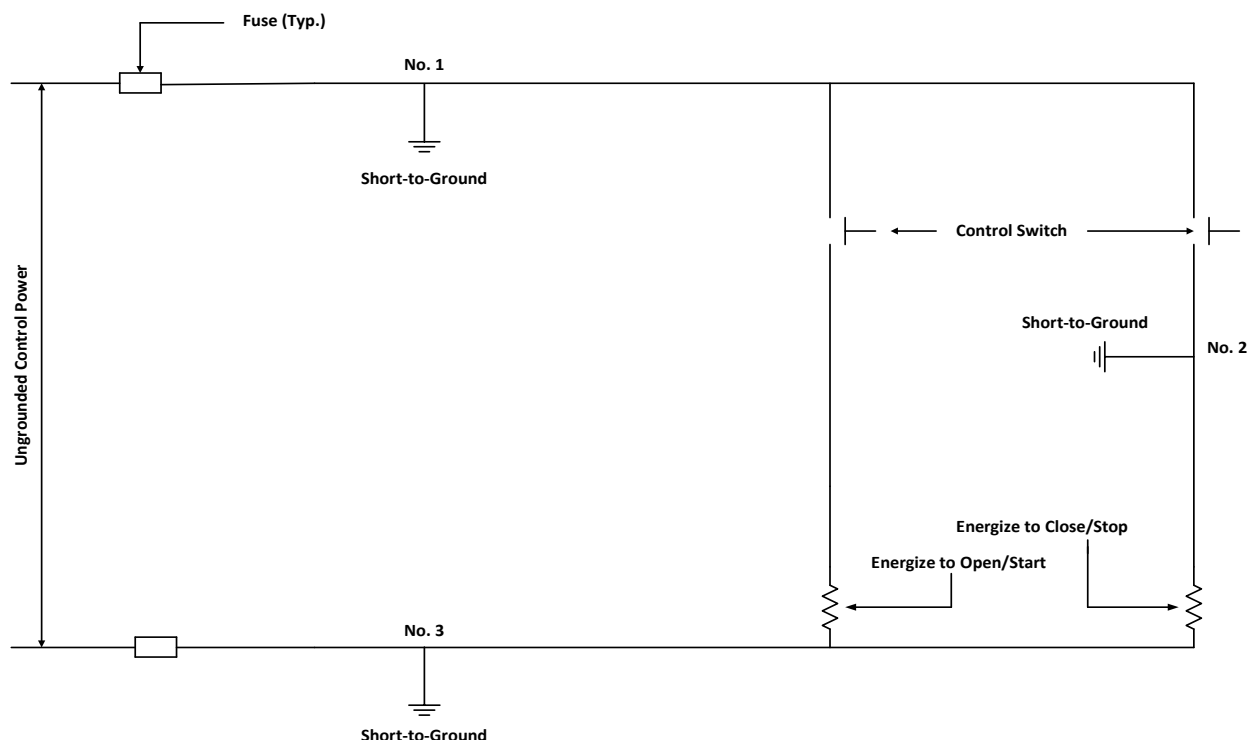


Figure 3.5.2-3 Short-to-Ground (Ungrounded Control Circuit)

### **Short-to-ground No. 1:**

A short-to-ground at location No. 1 will result in the control power fuse blowing and a loss of power to the control circuit if short-to-ground No. 3 also exists either within the same circuit or on any other circuit fed from the same power source. This will result in an inability to operate the equipment using the control switch. Depending on the coordination characteristics between the protective device on this circuit and upstream circuits, the power supply to other circuits could be affected. If multiple grounds can occur in a single fire area, they should be assumed to occur simultaneously unless justification to the contrary is provided.

### **Short-to-ground No. 2:**

A short-to-ground at location No. 2 in combination with a short-to-ground at location No. 3 will have no effect on the circuit until the close/stop control switch is closed. Should this occur, the effect would be identical to that for the short-to-ground at location No. 1 described above. Should the open/start control switch be closed prior to closing the close/stop control switch, the equipment will still be able to be opened/started. If multiple grounds can occur in a single fire area, they should be assumed to occur simultaneously unless justification to the contrary is provided. Note that a simultaneous short-to-ground at locations No. 1 and No. 2 could result in a spurious close/stop, (i.e., GFEHS). This condition is identical to that portrayed in Figure 3.5.2-5 should a hot short occur on the ungrounded circuit shown in Figure 3.5.2-5 at location No. 1. This set of shorts-to-ground equating to a ground fault equivalent hot short is discussed in more detail in Section 3.5.2.3 on hot shorts.

### **3.5.2.3 Circuit Failures Due to a Hot Short [Classified as a Plausible Circuit Failure Type]**

This section provides guidance for analyzing the effects of a hot short on circuits for required for hot shutdown and important to safe shutdown equipment. A hot short is defined as a fire-induced insulation breakdown between conductors of the same cable, conductors from a different cable or some other external source resulting in an undesired impressed voltage on a specific conductor. The potential effect of the undesired impressed voltage would be to cause equipment to operate or fail to operate, (i.e., maintain its initial position), in an undesired manner. The impressed voltage can occur between two conductors within the same cable, intra-cable hot short, or two conductors in separate cables, inter-cable hot short.

Consider the following specific circuit failures related to hot shorts as part of the post-fire safe shutdown analysis. [Note: The considerations can be different depending on whether the circuit is grounded or ungrounded. Both cases are addressed below.]

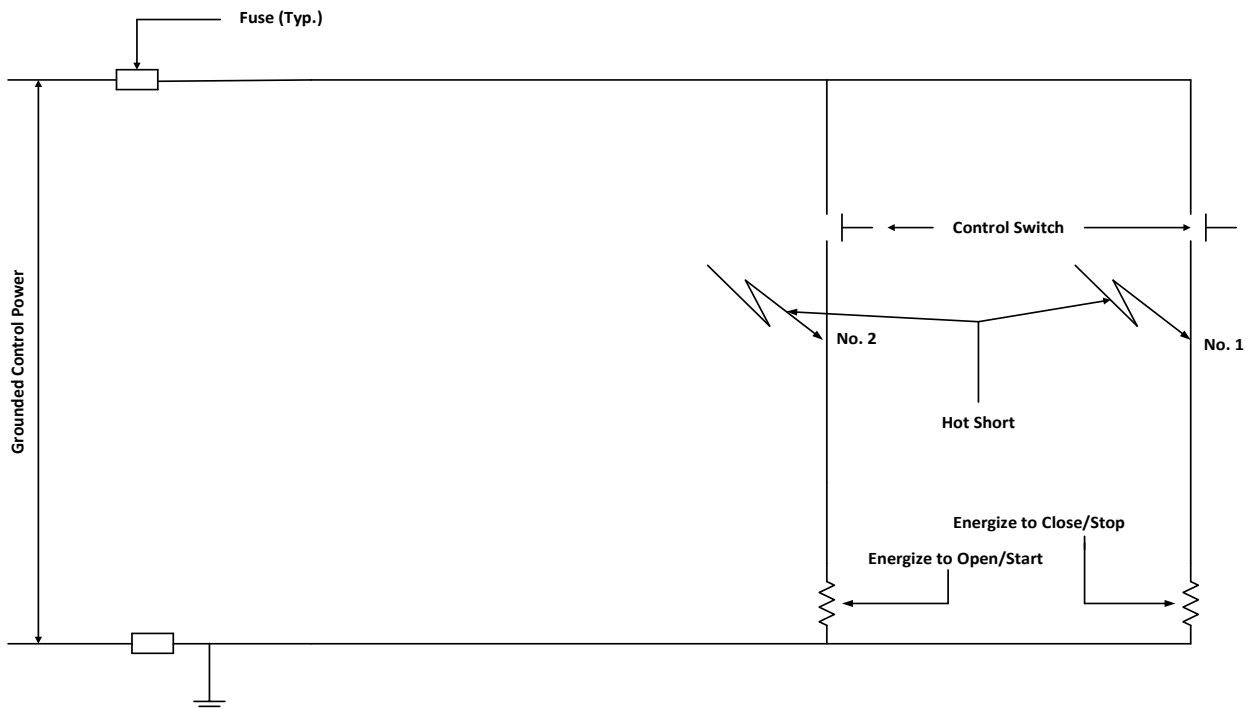
- A hot short between an energized conductor and a de-energized conductor within the same cable may cause a spurious operation of equipment. The spuriously operated device (e.g., relay) may be interlocked with another circuit that causes the spurious operation of other equipment. This type of hot short is called an intra-cable hot short (also known as conductor-to-conductor hot short or an internal hot short).
- A hot short between any external energized source such as an energized conductor from another cable and a de-energized conductor may also cause a spurious operation of equipment. This is called an inter-cable hot short (also known as cable-to-cable hot short/external hot short).
- A hot short in the control circuitry for an MOV can bypass the MOV protective devices, (i.e., torque and limit switches). This is the condition described in NRC Information Notice 92-18. In this condition, MOV motor or actuator damage could potentially occur. Damage to the MOV motor or actuator could result in an inability to operate the MOV either remotely, using separate controls with separate control power, or manually using the MOV hand wheel. This condition could be a concern in two instances: (1) For fires requiring Control Room evacuation and remote operation from the Remote Shutdown Panel; (2) For fires where the selected means of addressing the effects of fire induced damage is the use of a local operator manual action. In this latter case, analysis must be performed to demonstrate that the MOV thrust at motor failure does not exceed the capacity of the MOV hand wheel. For either case, analysis must demonstrate the MOV thrust at motor failure does not damage the MOV pressure boundary.

- For ungrounded circuits, a combination of shorts-to-ground can have the same effect as a hot short. Shorts-to-ground that combine in this way to impact a components circuitry are referred to as Ground Fault Equivalent Hot Shorts (GFEHS). GFEHS must be evaluated for their impact on any ungrounded circuits for all safe shutdown equipment.

### **A Hot Short on Grounded Circuits**

A short-to-ground is another failure mode for a grounded control circuit. A short-to-ground as described above would result in de-energizing the circuit. This would further reduce the likelihood for the circuit to change the state of the equipment either from a control switch or due to a hot short. Nevertheless, a hot short still needs to be considered. Figure 3.5.2-4 shows a typical grounded control circuit that might be used for a motor-operated valve. However, the protective devices and position indication lights that would normally be included in the control circuit for a motor-operated valve have been omitted, since these devices are not required to understand the concepts being explained in this section. In the discussion provided below, it is assumed that a single fire in a given fire area could cause any of the hot shorts depicted.

The following discussion describes the impact of these individual cable faults on the operation of the equipment controlled by this circuit.



**Figure 3.5.2-4** Hot Short (Grounded Control Circuit)

### **Hot short No. 1:**

A hot short at this location would energize the close relay and result in the undesired closure of a motor-operated valve.

### **Hot short No. 2:**

A hot short at this location would energize the open relay and result in the undesired opening of a motor-operated valve.

### **A Hot Short on Ungrounded Circuits**

In the case of an ungrounded circuit, a single hot short may be sufficient to cause a spurious operation. A single hot short can cause a spurious operation if the hot short comes from a circuit from the positive leg of the same ungrounded source as the affected circuit. For ungrounded circuits, the hot short should be assumed to come from the same source unless it can be demonstrated that this cannot happen. If this latter condition is used to demonstrate that the component will not spuriously operate, then provisions must be included in the design and configuration control process to prevent the occurrence from happening by a future plant circuit change.

In reviewing each of these cases, the common denominator is that in every case, the conductor in the circuit between the control switch and the start/stop coil must be involved.

Figure 3.5.2-5 depicted below shows a typical ungrounded control circuit that might be used for a motor-operated valve. However, the protective devices and position indication lights that would normally be included in the control circuit for a motor-operated valve have been omitted, since these devices are not required to understand the concepts being explained in this section.

In the discussion provided below, it is assumed that a single fire in a given fire area could cause any one of the hot shorts depicted. The discussion provided below describes the impact of these cable faults on the operation of the equipment controlled by this circuit.

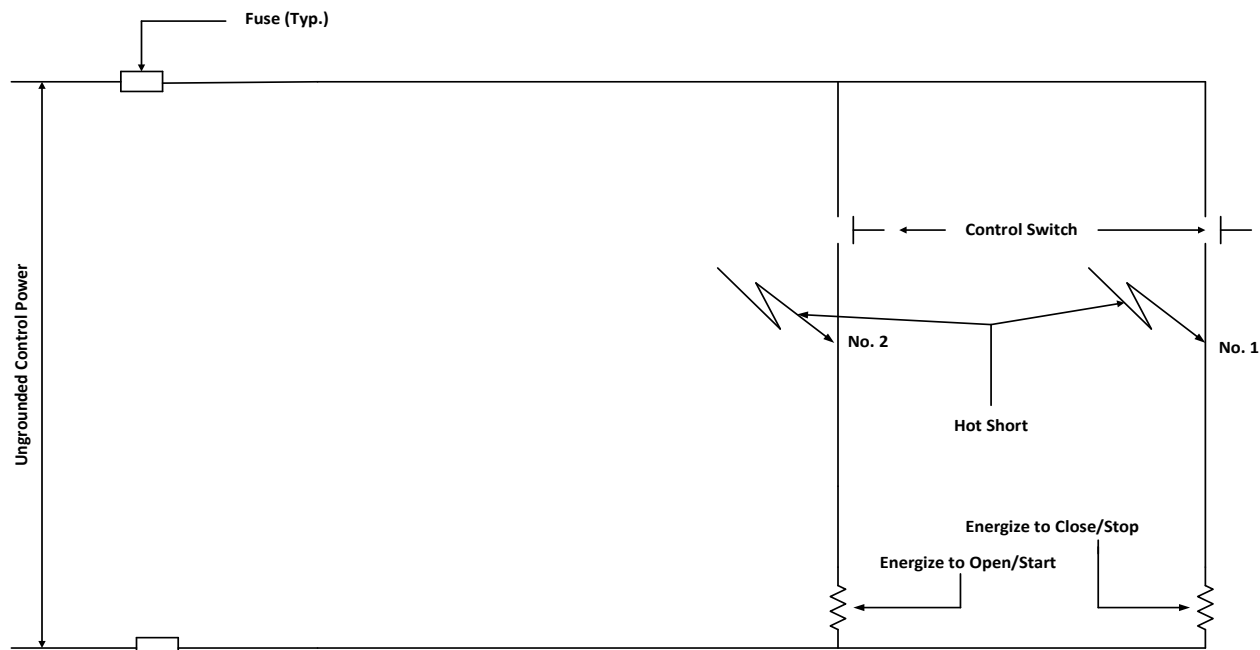


Figure 3.5.2-5 Hot Short (Ungrounded Control Circuit)

**Hot short No. 1:**

A hot short at this location from the same control power source would energize the close relay and result in the undesired closure of a motor operated valve.

**Hot short No. 2:**

A hot short at this location from the same control power source would energize the open relay and result in the undesired opening of a motor operated valve.

### 3.5.2.4 Circuit Failures Due to a Ground Fault Equivalent Hot Short [Classified as a Plausible Circuit Failure Type]

#### A Ground Fault Equivalent Hot Short on Ungrounded Circuits

In the case of an ungrounded circuit, multiple shorts to ground can have the same effect as a single hot short, (i.e., they may be sufficient to cause a spurious operation). A single hot short can cause a spurious operation if the hot short comes from a circuit from the positive leg of the same ungrounded source as the affected circuit. For ungrounded circuits, the multiple shorts to ground from the same source can cause a spurious operation.

In reviewing each of these cases, the common denominator is that in every case, the conductor in the circuit between the control switch and the start/stop coil must be involved.

Figure 3.5.2-6 depicted below shows a typical ungrounded control circuit that might be used for a motor-operated valve. However, the protective devices and position indication lights that would normally be included in the control circuit for a motor-operated valve have been omitted, since these devices are not required to understand the concepts being explained in this section.

In the discussion provided below, it is assumed that a single fire in a given fire area could cause any one of the GFEHS's depicted. The discussion provided below describes the impact of these cable faults on the operation of the equipment controlled by this circuit.

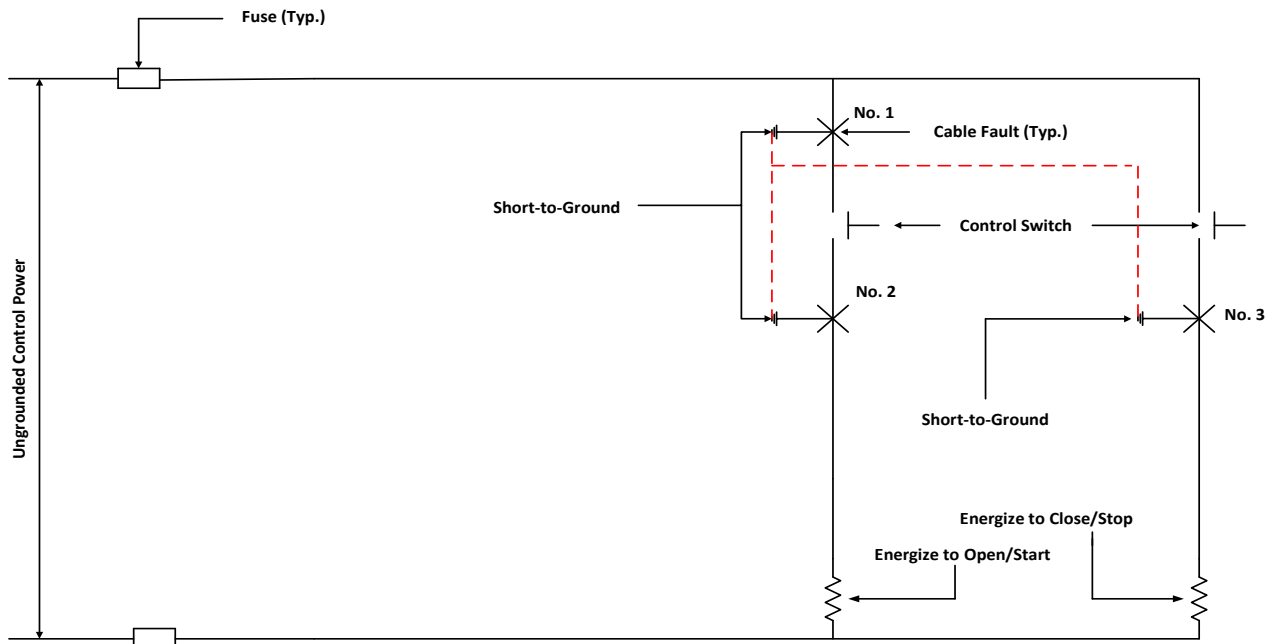




Figure 3.5.2-6

### **Short to Ground No. 1 & 2:**

A short to ground at these locations from the same control power source would energize the open relay and result in the undesired opening of a motor operated valve.

### **Short to Ground No. 1 & 3:**

A short to ground at these locations from the same control power source would energize the close relay and result in the undesired closure of a motor operated valve.

#### **3.5.2.5 Double Break and Pseudo-Double Break Design Circuits [Refer to Appendix J for Circuit Failure Type Classifications]**

Double break design circuits are a special circuit design used in the Nuclear Power Industry to limit the potential impact of fire-induced spurious operations. The double-break design circuits discussed in this section are all associated with ungrounded circuits. The double break design circuit uses a combination of open contacts, both above and below a component's actuating device, to create a condition where hot shorts must occur on two specific and separate conductors in order for a spurious operation to occur.

By creating this circuit configuration, the actuating device is essentially isolated from the balance of the circuit. As an isolated component, the actuating device can be energized only by either closing the open contacts or providing a proper polarity potential path above and below the actuating device. The term "proper polarity" indicates that, in order for a spurious operation to occur, two concurrent hot shorts of opposite polarity must occur. Further, these two concurrent hot shorts must involve both polarities of an aggressor power source such that a voltage is impressed across the target end device, thereby creating a complete path for current to flow. Depending on the specific characteristics of the circuit designs (i.e., both the target and aggressor circuits) the potential for the spurious operation could be supplied through either a ground fault equivalent hot short (GFEHS) or a ground as is the case for a grounded AC aggressor circuit. The term proper polarity hot short is used in this discussion to represent all of these circuit failure mode interactions.

The proper polarity hot short failure mode generally requires special consideration for double break circuit designs. Double break circuits are those where connections to the end device (e.g., a solenoid valve or relay) are opened on both polarities of the end device as part of the control or isolation design. Double break designs include:

- Control switches or relays that open two sets of contacts in the control circuit, one set in each leg of the end device circuit.
- Fuses pulled from both legs of a single break control circuit. (This is a pseudo-double break design.)
- Two-pole circuit breaker opens both legs of the control circuit. (This is a pseudo-double break design.)

For most actuating devices, a proper polarity potential path can involve the positive potential either above or below the actuating device with the negative potential return path on the opposite conductor. Additionally, as explained in Section 2.1 of NUREG/CR 7150 Volume 3, JACQUE-FIRE Volume 3, due to the broad range of possible actuating devices and due to the uncertain characteristics of cable fire interactions, it must be assumed that AC actuating devices can be energized and actuated by either another AC device, or even, another DC device. Similarly, it must be assumed that a DC actuating devices can be energized and actuated by another DC device, or even, another AC device. Although for specific actuating devices in specific circuit configurations, it is possible to demonstrate that AC devices cannot energize and actuate DC devices and vice-a-versa, in the absence of a specific engineering evaluation, supported, as necessary, by testing, demonstrating this conclusion, the assumptions outlined above must be used. The information discussed above is explained in more detail in Section 2.1 of NUREG/CR 7150 Volume 3 and is depicted in the figure below.

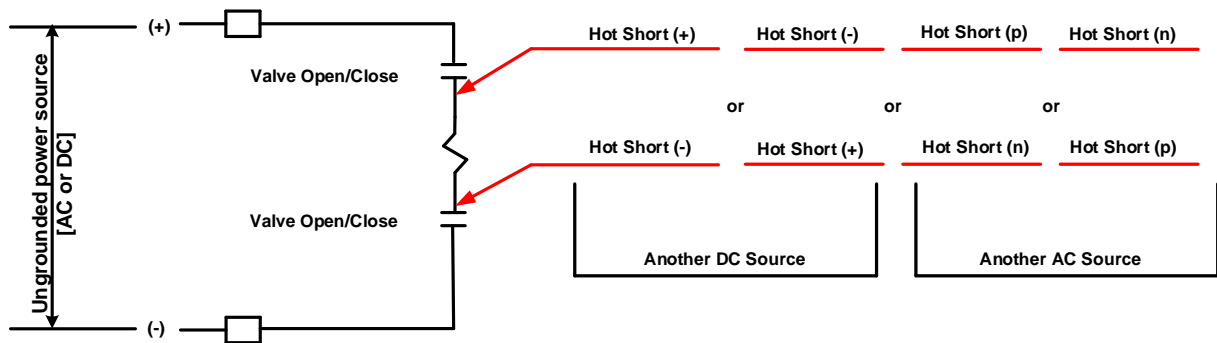


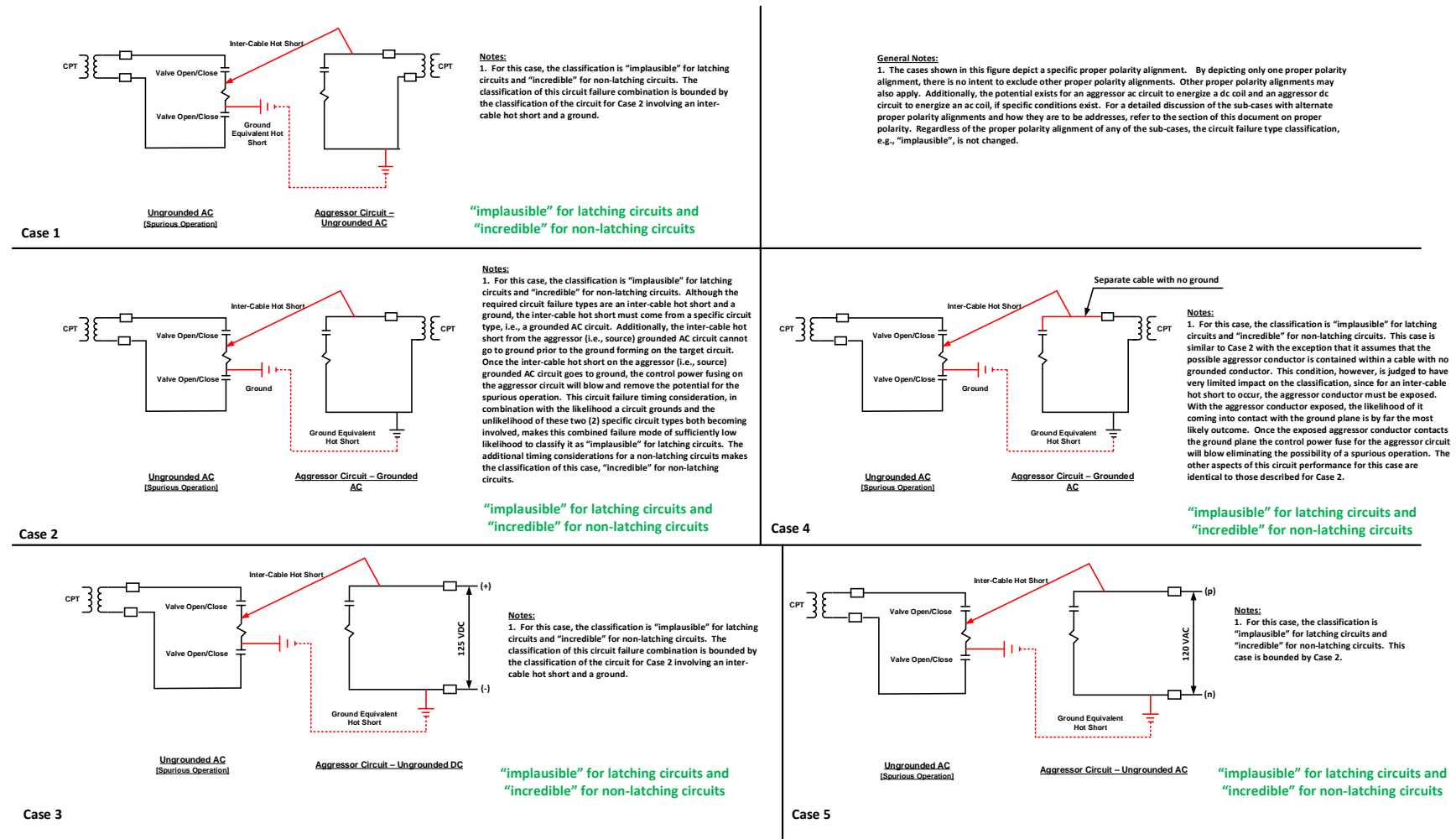
Figure 3.5.2-7 Proper Polarity Configurations

Appendix J, Table J-2 addresses double break design circuits. In Table J-2, two (2) inter-cable hot shorts on target conductors with thermoset insulation is considered to be an “incredible” circuit failure mode. Based on this, a double break design circuit configuration using thermoset insulated conductors does not need to consider the potential for two (2) inter-cable hot shorts to occur. Despite this, a circuit with the characteristics described above could also be susceptible to an inter-cable hot short and a GFEHS. A circuit with the characteristics described above when subjected to an inter-cable hot short and a GFEHS would be classified as “implausible” if the circuit were a latching circuit and “incredible” if the circuit were non-latching. Similar considerations apply to double break design circuits with conductors having thermoplastic conductor insulation. For these cases, the case of both two (2) inter-cable hot shorts and one (1) inter-cable hot short and a GFEHS, the circuit would be classified as “implausible” if the circuit were a latching circuit and “incredible” if the circuit were non-latching. As outlined in Appendix J, Table J-2 the spurious operation of a double break designed circuit involving at least one (1) intra-cable hot short would be classified as “plausible”. For the classification of circuits with other characteristics, refer to Appendix J Table J-2.

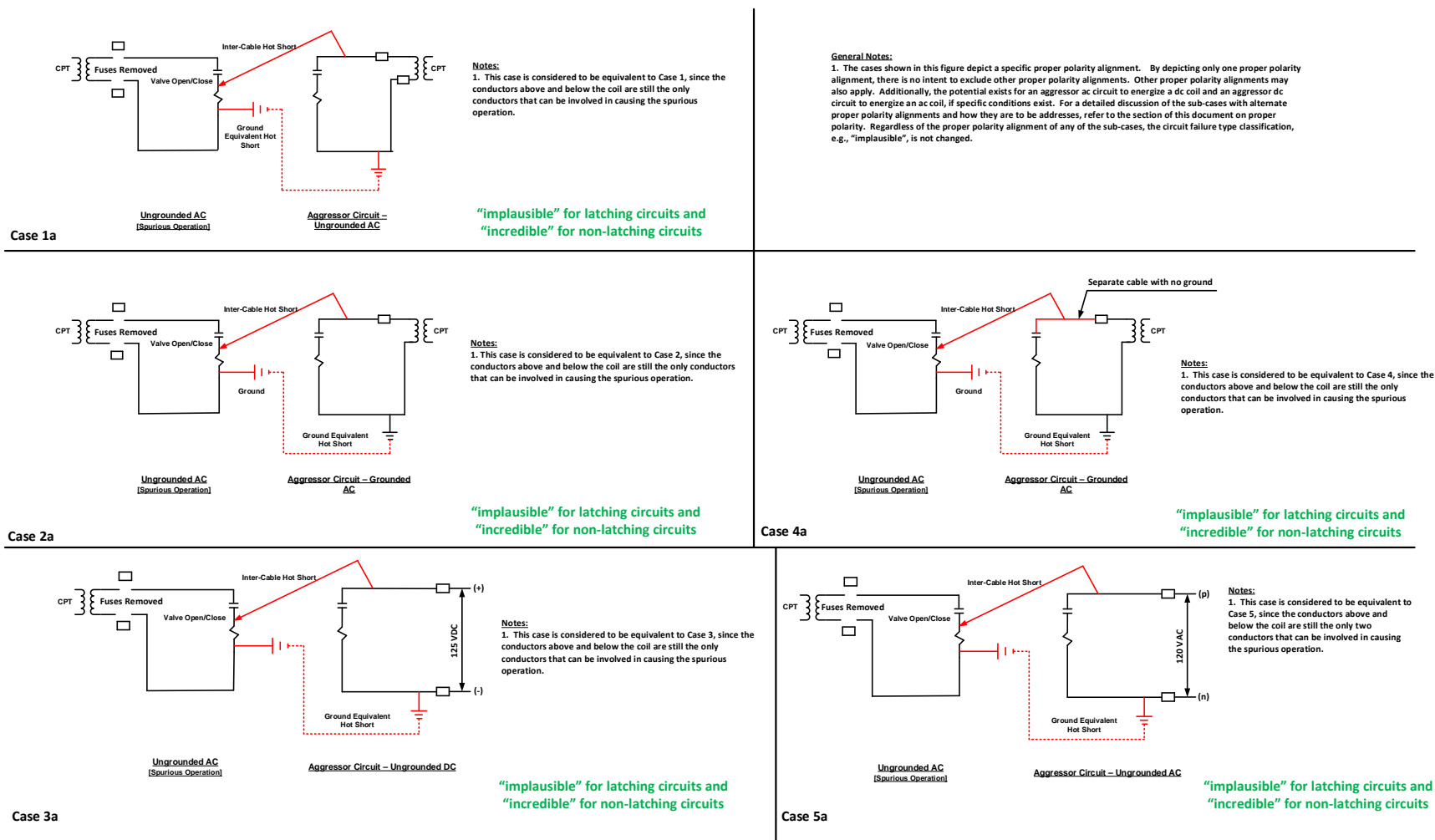
A pseudo-double break design can be achieved by removing the control fusing from an ungrounded single break design. When an ungrounded single break design has its control power fusing removed, it may be treated in the same manner as a double break design circuit.

Considerations for the design of these circuit failure types are outlined in the figures below. For each double break design circuit, a counterpart pseudo-double break design circuit is shown. In the figures below, the bounding cases, from a likelihood perspective, involving one (1) inter-cable hot short and a GFEHS are shown.

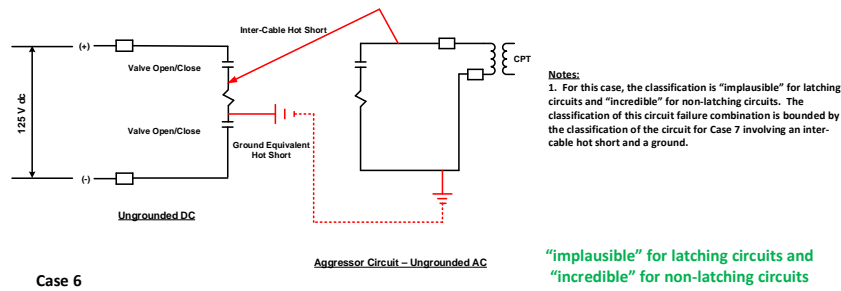
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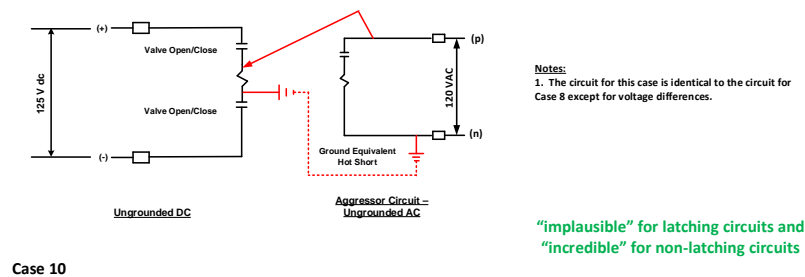
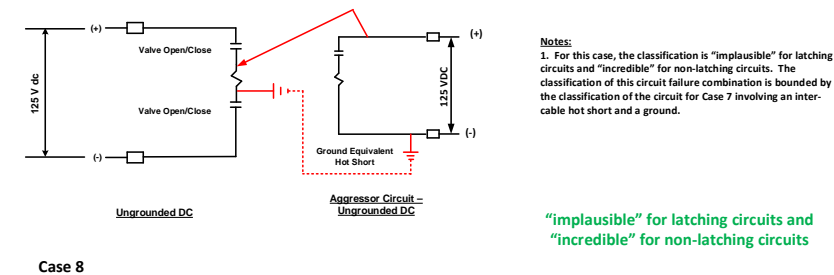
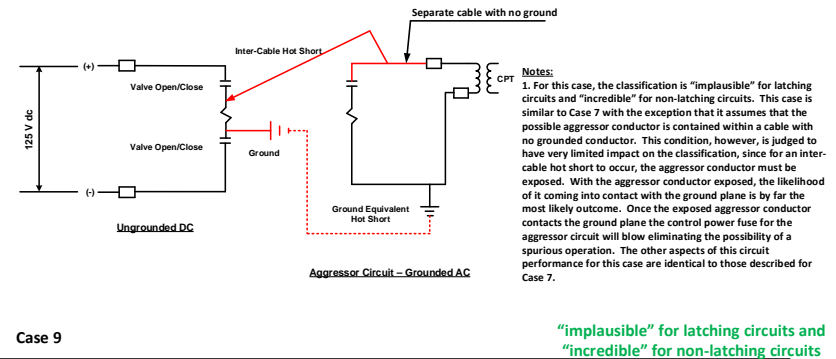
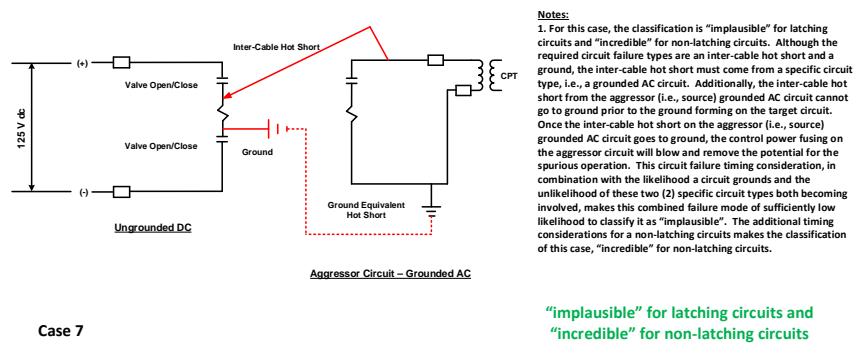
**Figure 3.5.2-8 - Ungrounded AC from a CPT – Double Break Design**



**Figure 3.5.2-9 - Ungrounded AC from a CPT – Pseudo-Double Break Design**

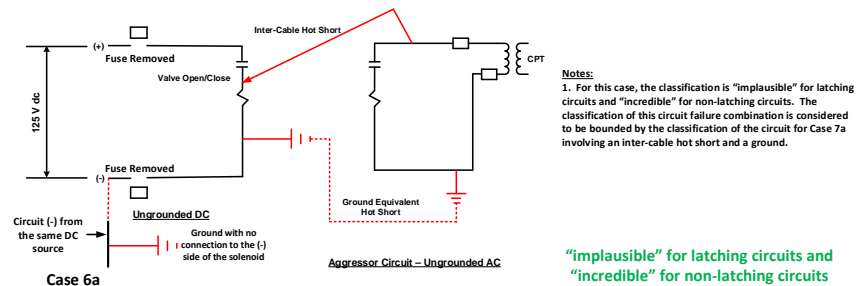


**General Notes:**  
1. The cases shown in this figure depict a specific proper polarity alignment. By depicting only one proper polarity alignment, there is no intent to exclude other proper polarity alignments. Other proper polarity alignments may also apply. Additionally, the potential exists for an aggressor ac circuit to energize a dc coil and an aggressor dc circuit to energize an ac coil, if specific conditions exist. For a detailed discussion of the sub-cases with alternate proper polarity alignments and how they are to be addressed, refer to the section of this document on proper polarity. Regardless of the proper polarity alignment of any of the sub-cases, the circuit failure type classification, e.g., "implausible", is not changed.

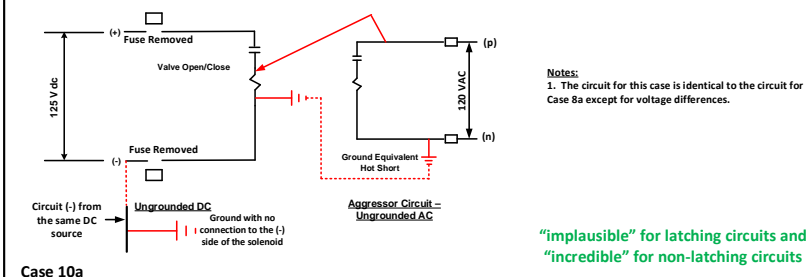
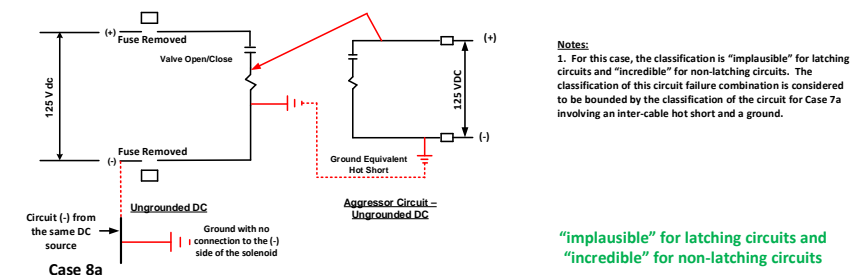
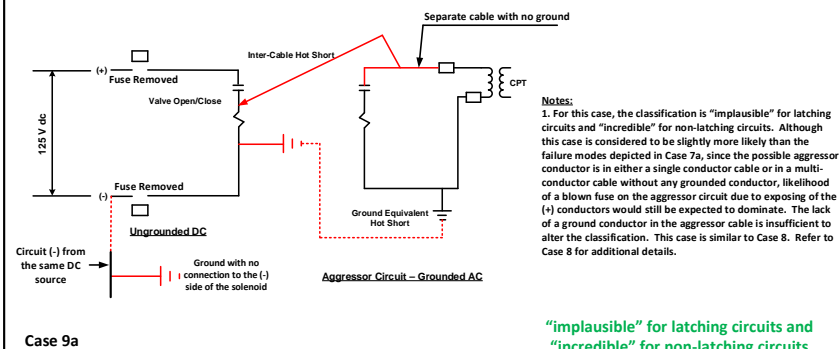
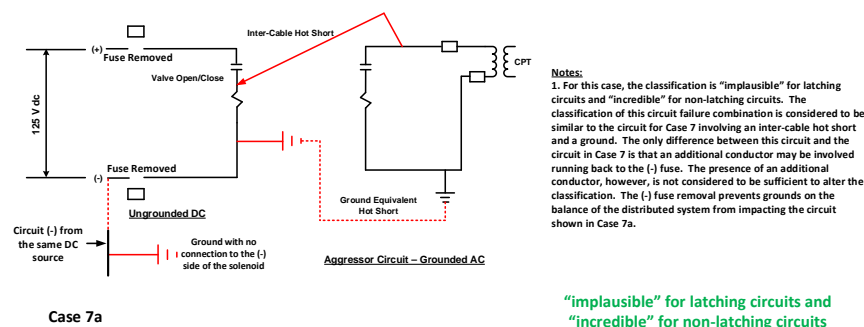


**Figure 3.5.2-10 - Ungrounded DC – Double Break Design**

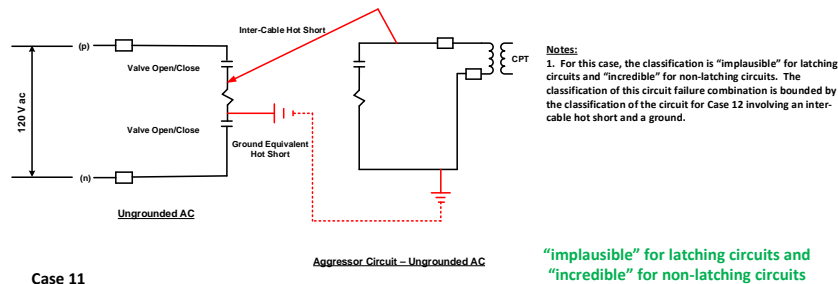




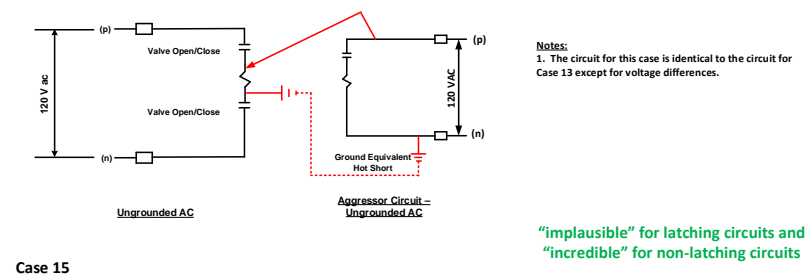
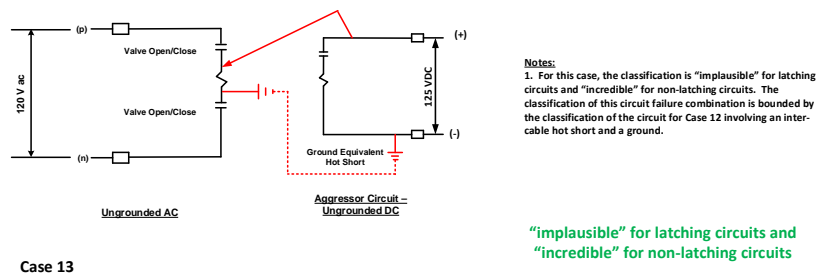
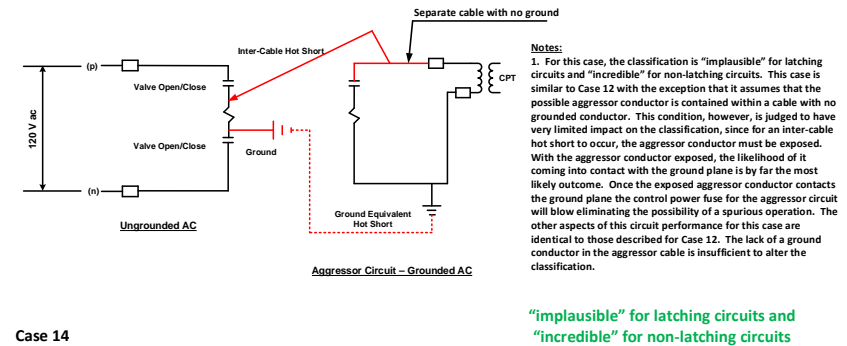
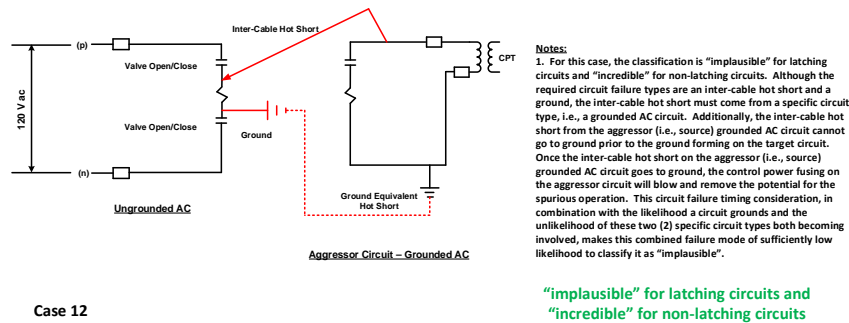
**General Notes:**  
1. The cases shown in this figure depict a specific proper polarity alignment. By depicting only one proper polarity alignment, there is no intent to exclude other proper polarity alignments. Other proper polarity alignments may also apply. Additionally, the potential exists for an aggressor ac circuit to energize a dc coil and an aggressor dc circuit to energize an ac coil, if specific conditions exist. For a detailed discussion of the sub-cases with alternate proper polarity alignments and how they are to be addressed, refer to the section of this document on proper polarity. Regardless of the proper polarity alignment of any of the sub-cases, the circuit failure type classification, e.g., "implausible", is not changed.



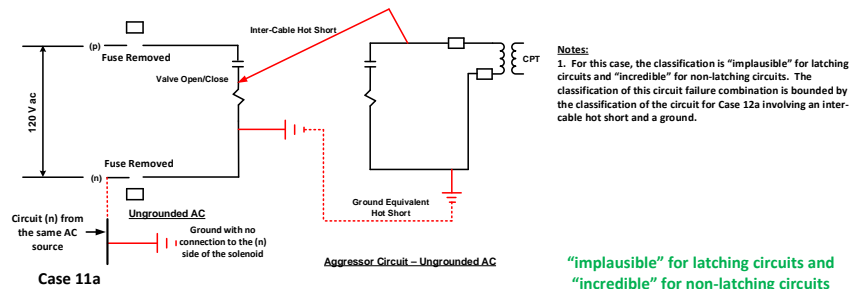
**Figure 3.5.2-11 - Ungrounded DC – Pseudo-Double Break Design**



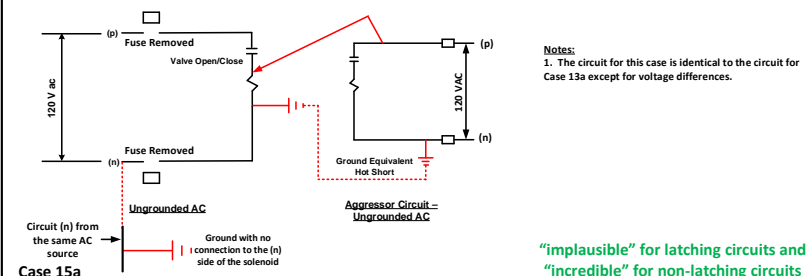
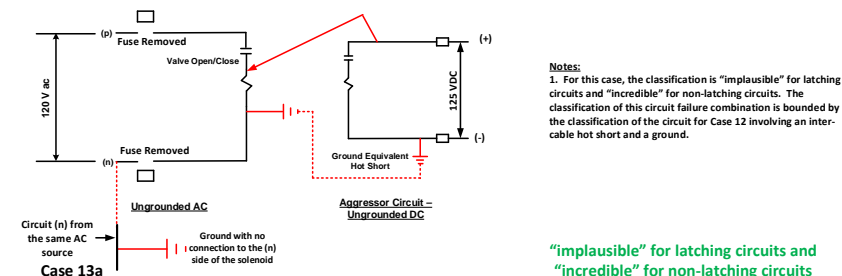
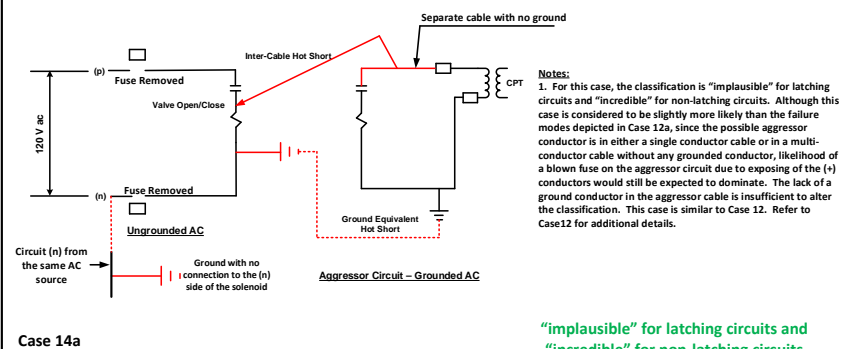
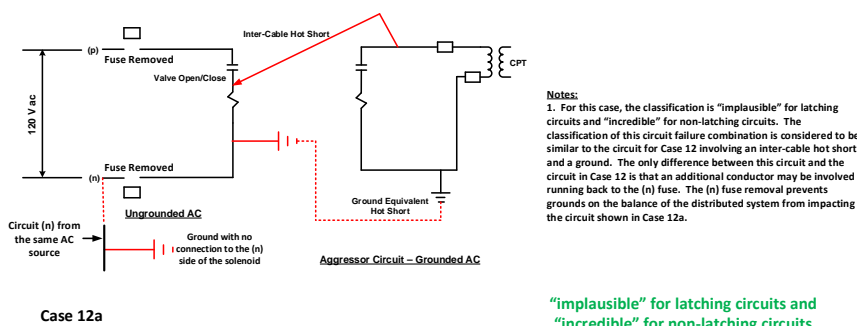
**General Notes:**  
1. The cases shown in this figure depict a specific proper polarity alignment. By depicting only one proper polarity alignment, there is no intent to exclude other proper polarity alignments. Other proper polarity alignments may also apply. Additionally, the potential exists for an aggressor ac circuit to energize a dc coil and an aggressor dc circuit to energize an ac coil, if specific conditions exist. For a detailed discussion of the sub-cases with alternate proper polarity alignments and how they are to be addressed, refer to the section of this document on proper polarity. Regardless of the proper polarity alignment of any of the sub-cases, the circuit failure type classification, e.g., “implausible”, is not changed.



**Figure 3.5.2-12 - Ungrounded AC Distributed – Double Break Design**



**General Notes:**  
1. The cases shown in this figure depict a specific proper polarity alignment. By depicting only one proper polarity alignment, there is no intent to exclude other proper polarity alignments. Other proper polarity alignments may also apply. Additionally, the potential exists for an aggressor ac circuit to energize a dc coil and an aggressor dc circuit to energize an ac coil, if specific conditions exist. For a detailed discussion of the sub-cases with alternate proper polarity alignments and how they are to be addressed, refer to the section of this document on proper polarity. Regardless of the proper polarity alignment of any of the sub-cases, the circuit failure type classification, e.g., "implausible", is not changed.



**Figure 3.5.2-13 - Ungrounded AC Distributed – Pseudo-Double Break Design**

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For other configurations involving either different circuit failure types or different conductor insulation materials, refer to Table J-2 to determine the circuit failure type classification and any caveats for any specific case being evaluated.

### **3.5.2.6 Power Circuits**

The following figures apply to fire-induced circuit failures involving power cables. Based on the work performed under the JACQUE-FIRE Project, NUREG/CR-7150 Volumes 1, 2 and 3, which is summarized in Appendix J, each of the circuit failure types depicted below are classified as “incredible”. Therefore, fire-induced circuit failures in the types of circuits shown below are classified as “incredible” for the power feeds for all safe shutdown components.

Additionally, based on this classification, fire-induced circuit failures as shown below for power circuits for high/low pressure interface components are no longer required to be evaluated for the types of fire-induced circuit failures shown below. Appendix C on high/low pressure interface valves has been updated with the latest information from Appendix J. Appendix C, although changed by the information in Appendix J, still remains a valid supporting document for the licensing basis for those plants that have not yet adopted the changes in Appendix J.

### Power Cables for AC Motors:

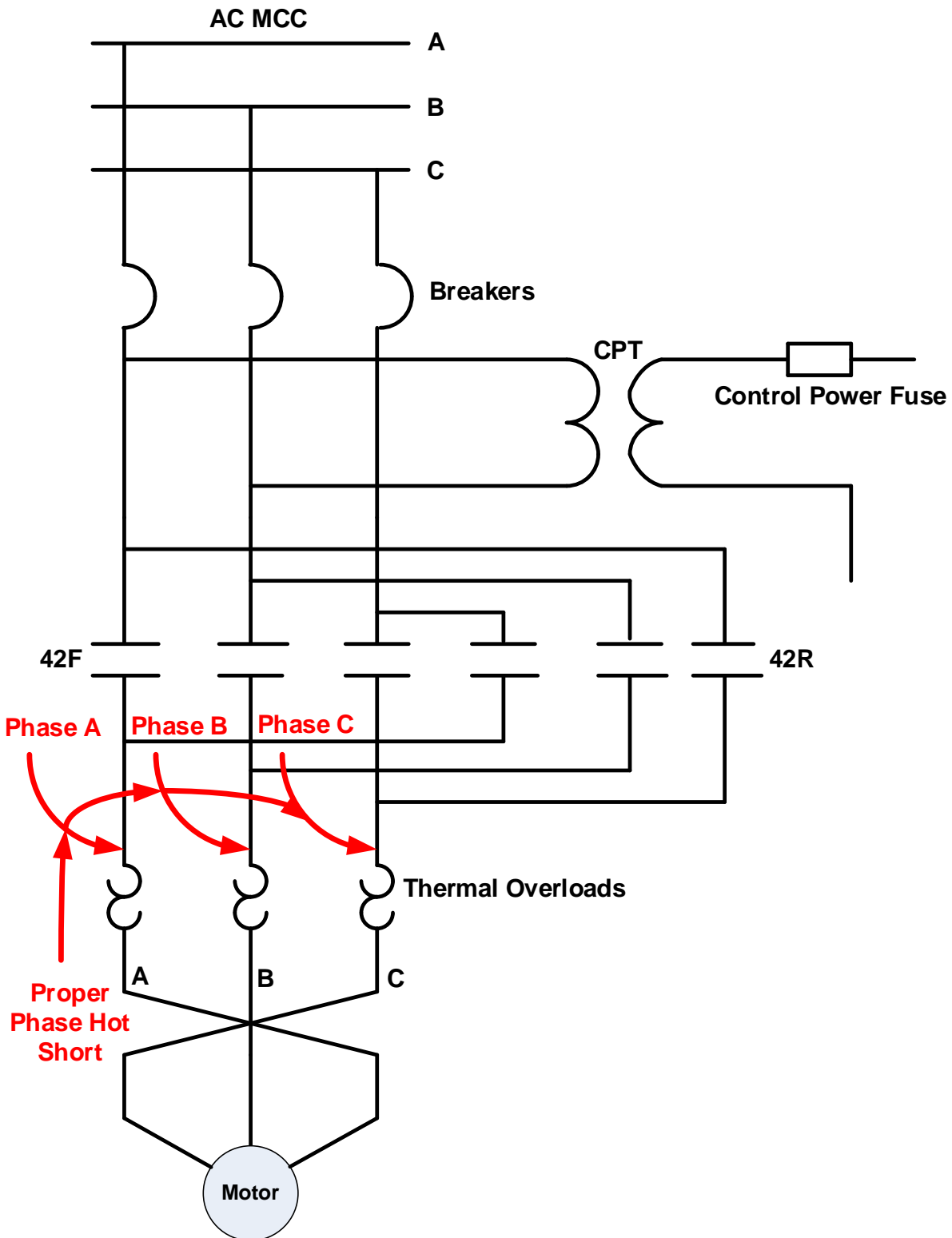


Figure 3.5.2-14 Three phase hot shorts on the AC Power - Motive Power Cables

### Power Cables for Ungrounded DC Motors:

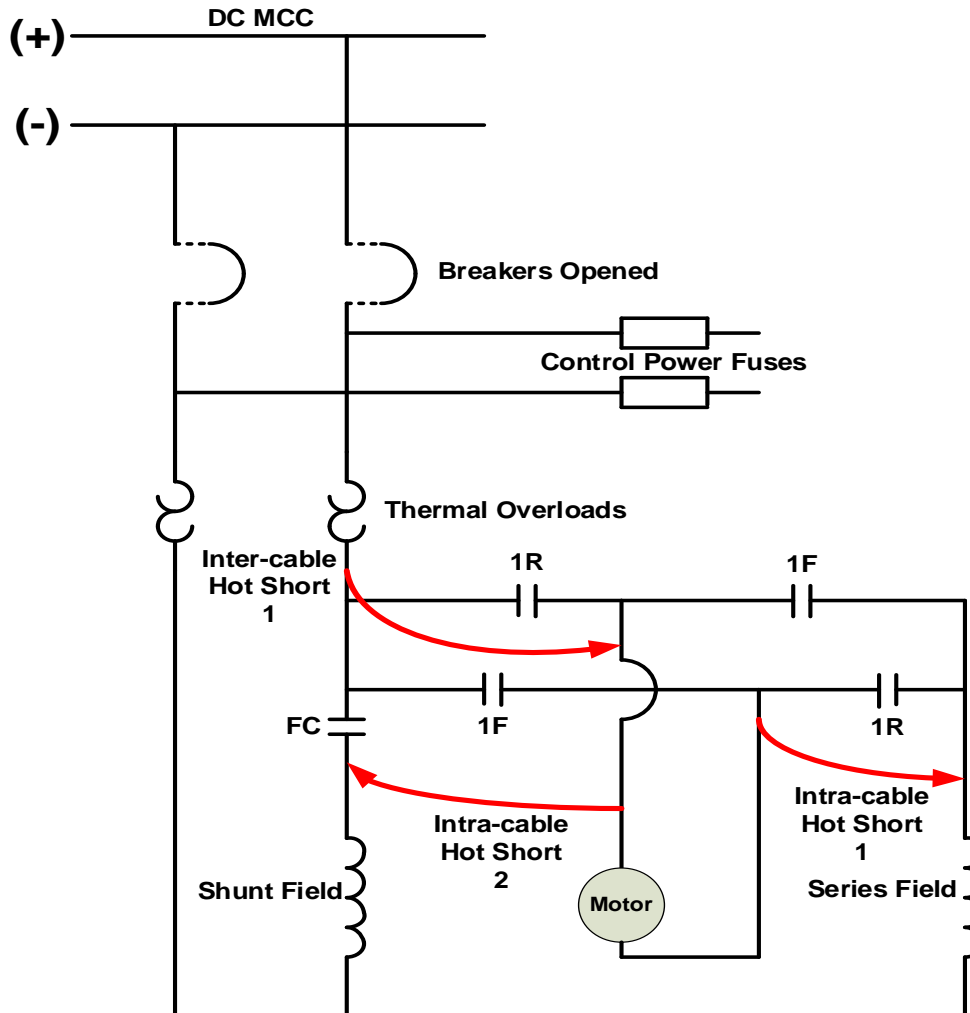


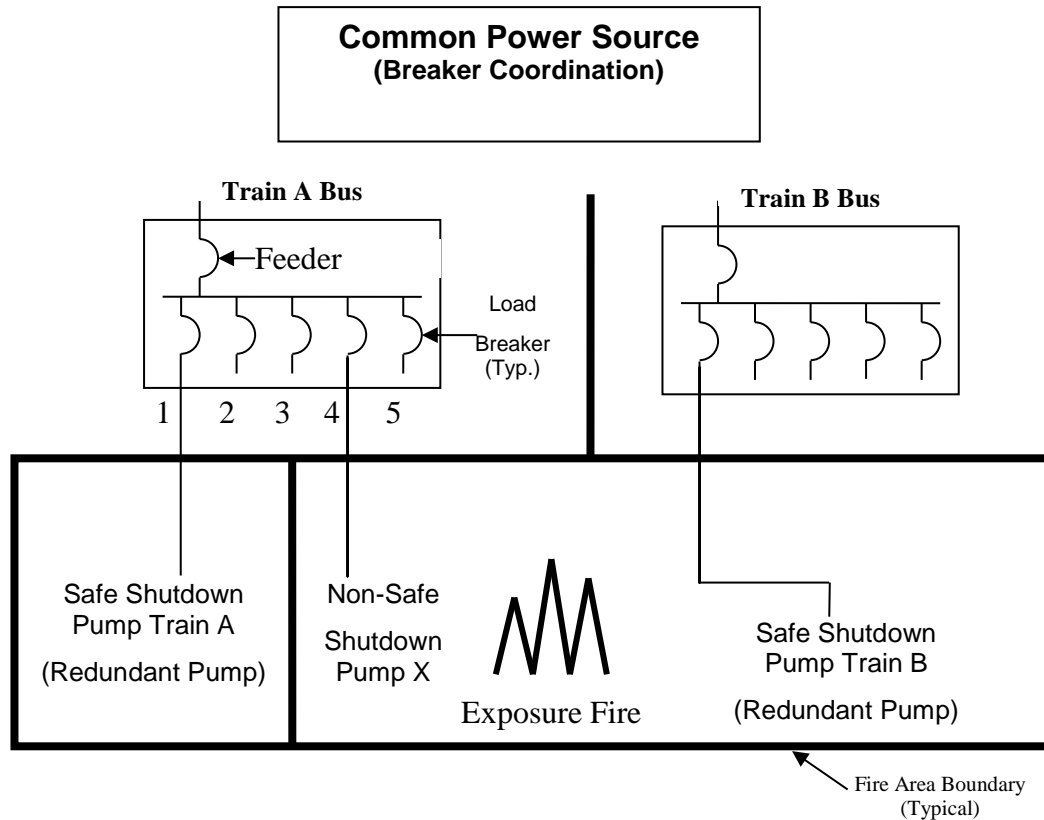
Figure 3.5.2-15 Proper Polarity Hot Shorts on ungrounded DC Power - Motive Power Cables

#### 3.5.2.7 Circuit Failures Due to Inadequate Circuit Coordination

The evaluation of circuits of a common power source consists of verifying proper coordination between the supply breaker/fuse and the load breakers/fuses for power sources that are required for hot shutdown. The concern is that, for fire damage to a single power cable, lack of coordination between the supply breaker/fuse and the load breakers/fuses can result in the loss of power to a safe shutdown power source that is required to provide power to safe shutdown equipment.

For the example shown in Figure 3.5.2-16, the circuit powered from load breaker 4 supplies power to a non-safe shutdown pump. This circuit is damaged by fire in the same fire area as the circuit providing power to from the Train B bus to the Train B pump, which is redundant to the Train A pump.

To assure safe shutdown for a fire in this fire area, the damage to the non-safe shutdown pump powered from load breaker 4 of the Train A bus cannot impact the availability of the Train A pump, which is redundant to the Train B pump. To assure that there is no impact to this Train A pump due to the circuits' common power source breaker coordination issue, load breaker 4 must be properly coordinated with the feeder breaker to the Train A bus.



**Figure 3.5.2-16 Common Power Source (Breaker Coordination)**

A coordination study should demonstrate the coordination status for each required common power source. For coordination to exist, the time-current curves for the breakers, fuses and/or protective relaying must demonstrate that a fault on the load circuits is isolated before tripping the upstream breaker that supplies the bus. Furthermore, the available short circuit current on the load circuit must be considered to ensure that coordination is demonstrated at the maximum fault level. When determining the maximum fault current for the fire condition, credit may be taken for any length of cable between the breaker and the first location where fire damage to the cable could impact post-fire safe shutdown. GFEHS's do not need to be considered when evaluating the effect of cable length on short circuit current. Only the length of the cable for the protective device under evaluation needs to be considered.

The methodology for identifying potential circuits of a common power source and evaluating circuit coordination cases on a single circuit fault basis is as follows:



- Identify the power sources required to supply power to safe shutdown equipment.
- For each power source, identify the breaker/fuse ratings, types, trip settings and coordination characteristics for the incoming source breaker supplying the bus and the breakers/fuses feeding the loads supplied by the bus.
- For each power source, demonstrate proper circuit coordination using acceptable industry methods. For example, for breakers that have internal breaker tripping devices and do not require control power to trip the breaker, assure that the time-current characteristic curve for any affected load breaker is to the left of the time-current characteristic curve for the bus feeder breaker and that the available short circuit current for each affected breaker is to the right of the time-current characteristic curve for the bus feeder breaker or that the bus feeder breaker has a longer time delay in the breaker instantaneous range than the load breaker. For breakers requiring control power for the breaker to trip, the availability of the required control power must be demonstrated in addition to the proper alignment of the time-current characteristic curves described above. The requirement for the availability of control power would apply to load breakers fed from each safe shutdown bus where a fire-induced circuit failure brings into questions the availability of coordination for a required for hot shutdown component.
- For power sources not properly coordinated, tabulate by fire area the routing of cables whose breaker/fuse is not properly coordinated with the supply breaker/fuse. Evaluate the potential for disabling power to the bus in each of the fire areas in which the circuits of concern are routed and the power source is required for hot shutdown. Prepare a list of the following information for each fire area:
  - Cables of concern.
  - Affected common power source and its path.
  - Raceway in which the cable is enclosed.
  - Sequence of the raceway in the cable route.
  - Fire zone/area in which the raceway is located.

For fire zones/areas in which the power source is disabled, the effects are mitigated by appropriate methods.

- Develop analyzed safe shutdown circuit dispositions for the circuit of concern cables routed in an area of the same path as required by the power source. Evaluate adequate separation and other mitigation measures based upon the criteria in Appendix R, NRC staff guidance, and plant licensing bases.

- As discussed in Appendix J and Appendix B.1, multiple high impedance faults (MHIFs) are classified as “incredible” for associated circuits of concern whose breakers are properly coordinated provided the breakers are properly tested and maintained.

#### **3.5.2.8 Circuit Failures Due to Common Enclosure Concerns**

The common enclosure concern deals with the possibility of causing secondary failures due to fire damage to a circuit either whose isolation device fails to isolate the cable fault or protect the faulted cable from reaching its ignition temperature, such that the fire somehow propagates along the cable into adjoining fire areas.

The electrical circuit design for most plants provides proper circuit protection in the form of circuit breakers, fuses and other devices that are designed to isolate cable faults before ignition temperature is reached. Adequate electrical circuit protection and cable sizing are included as part of the original plant electrical design maintained as part of the design change process. Proper protection can be verified by review of as-built drawings and change documentation. Review the fire rated barrier and penetration designs that preclude the propagation of fire from one fire area to the next to demonstrate that adequate measures are in place to alleviate fire propagation concerns.

## **4 IDENTIFICATION AND TREATMENT OF MULTIPLE SPURIOUS OPERATIONS**

### **4.1 INTRODUCTION**

The purpose of this section is to provide a methodology for addressing multiple fire- induced circuit failures and multiple spurious operations (MSOs) by individual licensees. This methodology uses identification and analysis techniques similar to methods applied under NEI 04-02 for Risk-Informed Fire Protection, but do not include steps for self-issued change analysis as allowed under NEI 04-02 and NFPA-805. MSOs identified during this process will include both required for hot shutdown and important to SSD circuit components, with different mitigation strategies for each type of MSO as shown on Figure 3-1 above.

With NRC acceptance, the methodology presented in this document addresses multiple spurious operations resulting from fire-induced circuit failures for safe shutdown in accordance with 10 CFR 50 Appendix R, Sections III.G.1 and III.G.2.

The basic philosophy behind this method is that the Fire Safe Shutdown Procedures and associated Operator Actions should focus on potentially risk important scenarios. This agrees with the philosophy as described in RIS 2004-03, which was developed for inspection criteria. Application of the deterministic criteria in Section 3 of this document to multiple spurious operations would require all potential fire-induced spurious operations to be identified and a mitigating action to be developed for each. This mitigating action may be an action taken prior to the start of the fire event that precludes the condition from occurring or as a post fire action that mitigates the effects of the condition prior to it reaching an unrecoverable condition relative to safe shutdown. The corresponding mitigating action for each potential spurious operation must be known and this action must be capable of limiting the potential adverse effects of the spurious operation without reliance on any other equipment that is also potentially susceptible to a spurious operation resulting from a fire in the same fire area.

If the procedures and actions were expanded to include very low risk scenarios, the operator actions would become too complex, resulting in higher expected operator failures for the important scenarios. Additionally, if the required timing for actions were to consider all low risk scenarios, the resulting procedural actions would likely be modified to include actions that can raise the overall plant risk, such as implementing a Self-Induced Station Blackout. Mitigation might also require significant modification to plant safety-related systems and logics that could have the undesired consequence of reducing their reliability in mitigating the effects of other events, thereby causing an overall increase in plant risk. By placing bounds on the number of scenarios that the procedures address, this results in lower plant risk by ensuring optimal operator response for the potential risk important scenarios.

This philosophy is similar to the development of plant emergency operating procedures, where low risk scenarios are not included in the procedures while potentially high-risk scenarios and "Design Basis" scenarios are addressed.

If a mitigating action is not taken for multiple spurious operations identified using the methods described below, a regulatory submittal (Exemption/Deviation) may be needed depending on the plant's current licensing basis. In order to minimize the number of regulatory submittals, the method provided must limit the multiple spurious operations to be consistent with RIS 2004-03

by concentrating identification on circuit failures that have a relatively high likelihood of occurrence.

Additionally, the methodology must provide a process for incorporating new information on spurious operations that are determined to be risk significant. This may include new information gained from additional fire testing, or as a result of feedback from plants implementing this method (or NFPA 805).

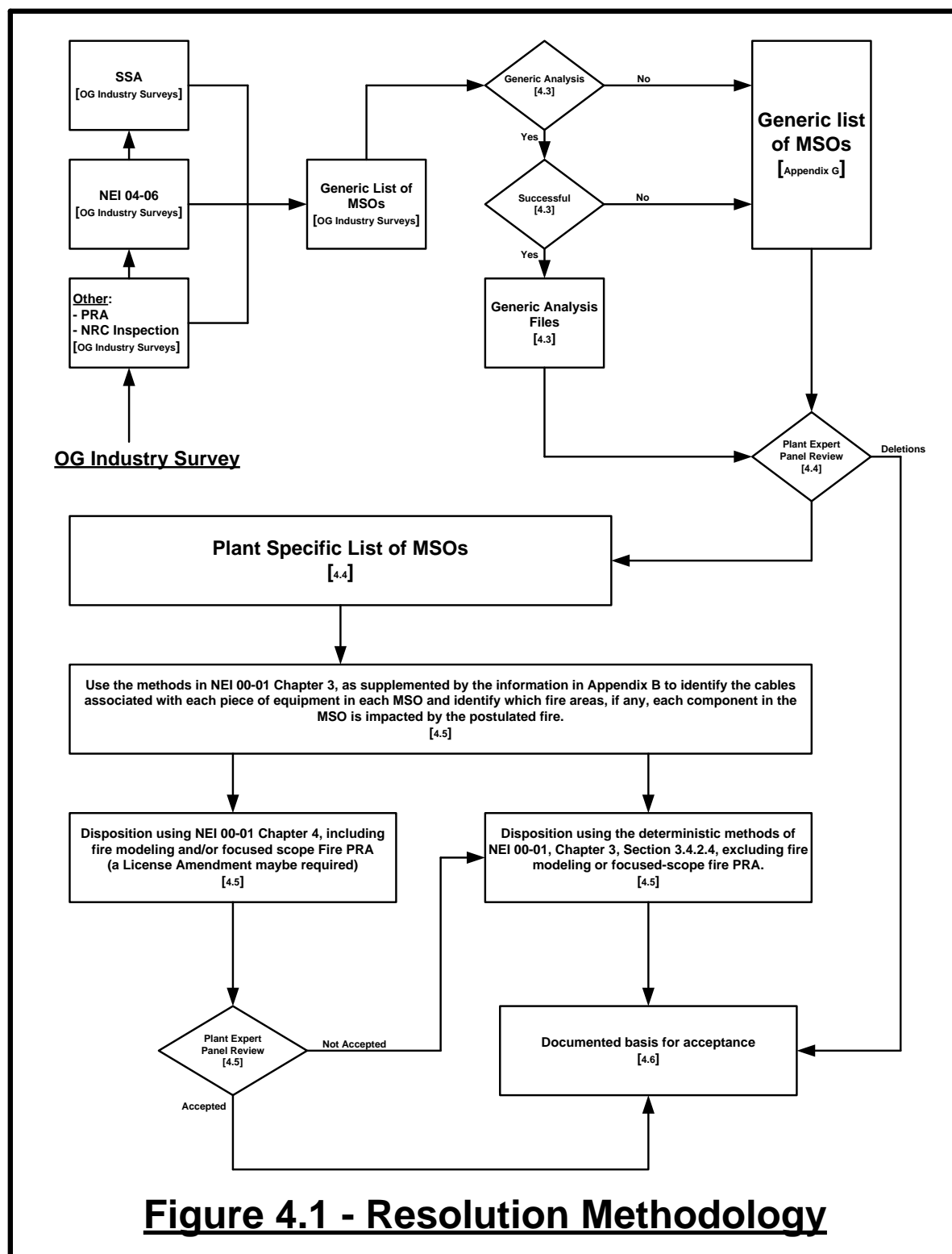
The list of Generic Multiple Spurious Operations developed by the Owner's Groups and required to be considered in conjunction with the information in this section are contained in Appendix G. The Generic MSO lists include both required for hot shutdown and important to SSD component MSO combinations. Guidance for classification of each MSO is provided in Appendix G, however, the classification should be confirmed by the licensee. The types of circuit failures and the number of these types of circuit failures that are to be considered in each circuit type when evaluating the impact of an MSO on post-fire safe shutdown are described in Section 3.

Section 3 is used to address multiple spurious operations (both required for hot shutdown and important to SSD MSOs).

The process described below, including the generic MSO lists, do not artificially limit the number of spurious operations or hot shorts included in each scenario considered. The MSO lists describe 'scenarios' with potential safety significance, and do not consider the number of circuit failures needed to cause the scenario. In some cases, spurious operation of a specific component may require multiple hot shorts. Depending on the type of circuit involved, guidance on the appropriate assumptions to be made relative to this condition is contained in Section 3. It is also intended that if multiple hot shorts are required to cause the MSO, this should not result in any screening of MSOs from consideration prior to the inclusion of the MSO combination in the Safe Shutdown analysis. The multiple hot shorts would be considered when reviewing the hot shorts against the cable criteria in Sections 3.3 and 3.5 or in the PRA calculations.

## **4.2 OVERVIEW OF THE MSO IDENTIFICATION AND TREATMENT PROCESS**

Figure 4-1 provides an overview of the MSO Identification and Treatment Process. Sections 4.3 to 4.5 below provide a description of each of the steps in the figure.



### 4.3 GENERIC LIST OF MSO'S

Appendix G provides a list of generic scenarios to consider in a plant specific evaluation for multiple spurious operations. The generic list of MSOs was developed from an industry survey of all US plants. The survey asked the plants to "Describe the extent to which multiple hot shorts and multiple spurious operations (MSOs) have been addressed for your facility in each of the following areas:"

1. Licensing Basis Safe Shutdown Analysis
2. Assessments performed for NRC RIS 2004-03 using NEI 04-06
3. Evaluations performed as a result of NRC Inspections
4. MSO Expert Panel Reviews conducted for Fire PRA or NFPA 805
5. Other Instances where MSOs [Combined Equipment Impacts] with potential risk significance been identified (e.g., PRA Analysis Internal Events Model, Fire PRA or other source)

The results of the survey responses were then compiled into a table, and draft lists were developed for each reactor type. The draft lists were used in the NEI 00-01 pilot application and during initial NFPA 805 applications, and were revised based on feedback from both. The final generic lists are contained in Appendix G to Revision 2 of this document. The final lists contain some clarifications to certain scenarios originally contained on the draft lists. The final lists contain additional scenarios identified during the pilots. Additionally, feedback from plants' use of Revision 2 has led to clarifications in Revision 3 and 4.

Although not all scenarios for a reactor type are considered applicable to every reactor, the list is provided here as an input to the MSO identification and treatment process.

The generic MSO list in Appendix G requires a classification of each MSO scenario as either "required for hot shutdown" or "important to SSD" component MSO. MSOs for required circuit components are addressed differently than MSOs for important to SSD components, with the use Operator Manual Actions, Fire Modeling or Focused-scope FPRA not generically authorized by the NRC to be applied to MSOs categorized as required for hot shutdown component MSOs. Exemptions, deviations or LARs, depending on a licensee's current licensing basis, may be required to use operator manual actions, fire modeling or focused-scope fire PRAs for required for hot shutdown MSOs. Operator manual actions may be used for important to safe shutdown components within the bounds established in Appendix E. Fire modeling and focused-scope fire PRA may also be used for important to safe shutdown components with the following stipulations: (1) A review by the Expert Panel is required; (2) If necessary, a LAR has been obtained from the NRC to use focused-scope fire PRA for the current licensing basis issues. The categorization for each MSO in Appendix G should be developed by licensees depending on the safe shutdown methodology used in each of their fire areas using the guidance in Section 3.1 and Appendix H.

As can be seen from Figure 4-1, generic Owner's Group analysis can be performed for a given reactor type to disposition generic MSO scenarios. The generically dispositioned scenarios do not need to be included in the plant specific MSO list, provided an individual licensee performs a review of the generic analysis, verifies plant specific parameters bound those critical

parameters used in the generic analysis and obtain the concurrence of its plant specific Expert Panel. The method and the critical parameters used for each generic analysis will vary, depending on the MSO. These aspects of the generic analysis are not described further in this document. Refer to each generic analysis for the required information.

#### **4.4 EXPERT PANEL REVIEW OF MSOS**

The Expert Panel Review is performed to systematically and completely review all spurious and MSO scenarios and determine whether or not each individual scenario is to be included or excluded from the plant specific list of multiple spurious operation scenarios to be considered in the plant specific post-fire SSA. Input to the expert panel is provided from a number of sources, resulting in a comprehensive review of spurious operation scenarios. Determinations made by the Expert Panel during the initial development of the Plant Specific MSO List may change as more detailed analysis is performed. Whenever such changes arise, the Expert Panel should be re-convened to provide their concurrence with such changes.

The team for an expert panel review includes operations, engineering, electrical, PRA, and others. This process involves four phases:

- Phase 1: Pre-Review of Fire Induced MSO's
- Phase 2: Preparation for the Expert Panel Meeting
- Phase 3: Performance of the Expert Panel Review
- Phase 4: Develop Comprehensive Plant-Specific MSO List

##### **4.4.1 The Following Provides a Discussion of Each Phase. Phase I: Pre-Review of Fire-Induced MSO's**

This phase involves the analytical preparation performed prior to conducting the MSO expert panel review with the full complement of expert panel members. The step may take a number of weeks or months to perform, depending on the level of support (number of people) involved in the preparation. The key steps in this phase are discussed in the following sections.

##### **4.4.1.1 Review of the Generic MSO List for Applicability**

The screening of generic MSO scenarios can be performed to remove from consideration scenarios not applicable for a given plant. The screening process involves the review of each scenario in the generic list for applicability and disposition. Scenarios can be screened from the plant specific MSO list, given the following:

1. Components identified in the scenario do not exist in the plant, and the scenario is not applicable to similar components or systems, or
2. Specific plant design features (see additional comments below) make the scenario either not possible, or the MSO does not fail the safe shutdown function.

Some of the scenarios that are listed in Appendix G are described as being applicable to a specific vintage of plant design. For example, most of the scenarios listed for BWR 2's, might be assumed to have no applicability to BWR 3's or 4's. This may be the case for the particular scenario listed. Item 1 above, however, requires that each licensee look at the scenarios provided and examine them for similar components or systems used in the design of the plant under evaluation. Conversely, even when the scenario is listed for a particular design vintage of plants, such as the BWR 2's, a scenario related to isolation condensers would only be applicable to BWR 2's that have isolation condensers. The considerations described above need to be employed in each licensee's plant specific evaluation of MSOs.

Additionally, scenarios screened from the plant specific MSO list should be reviewed with the following considerations:

1. If the design feature that makes the scenario not possible for the plant involves cable routing, circuit design, electrical protection, or other similar design feature, the scenario should not be screened from consideration at this step. Similarly, if an operator manual action or operational configuration (e.g., maintaining a breaker open during normal operation) is in place that would prevent/mitigate the consequences of the scenario, the scenario should not be screened at this step. The process for these scenarios would be to include the scenario in the Plant Specific MSO list, and to use the design feature as a disposition for the MSO within the plant's post-fire safe shutdown analysis. This way, as future plant and plant procedure changes are made, the impact of these changes can be reviewed relative to the basis for dispositioning of the MSO.
2. Documentation that the scenario does not fail the safe shutdown function should be based on the original SSA assumptions. If specific analysis is performed to show the MSO doesn't fail the function, then the MSO should be included in the plant specific MSO list, and the analysis used in the disposition of the MSO. This way, as future plant and plant procedure changes are made, the impact of these changes can be reviewed relative to the basis for dispositioning of the MSO.



3. If a generic analysis is available for an MSO, the generic analysis should be reviewed to verify that the analysis is applicable to the plant being reviewed and that no plant unique features invalidate the inputs, assumptions, methodology, results or conclusions of the generic analysis. The expert panel should review the MSO in conjunction with the generic analysis and, if acceptable, disposition the MSO for the plant under review without additional consideration in the plant specific analysis. The MSO, the generic analysis used to disposition the MSO and any additional considerations should be documented in the expert panel report and in the licensee's SSA.

For item 1) above, the general concept is that if the design/operational feature can possibly change as a result of a design/operational change, the MSO needs to be included in the site specific MSO list. This would ensure that changes to the design/operation would be reviewed against the MSO to ensure the MSO remains not possible as changes are made to the plant over the course of time. For item 2) it is intended that whenever a specific assumption is credited in the original SSA, the specific MSO under review is carried forward to the Plant Specific MSO list to assure continued compliance. For example, if there are two injection trains credited for all "A" train fire areas, and an MSO fails only one of the two trains, then the MSO can be screened at this point. In this example, however, the post-fire SSA must be revised to make it clear that only a single injection train is credited in all "A" train fire areas. Another example would be a scenario that drains a water supply tank into the containment sump, and analysis is performed to show the water can be provided from the sump to an injection pump using equipment unaffected by fires that could cause the drain down. In this example, if the sump flow path was not in the original SSA, the MSO should not be screened.

Screening of the Generic List of MSOs is subject to review and concurrence by the expert panel. One alternative to the initial screening of generic MSOs is to perform the screening during the expert panel process. This can be done simultaneously with the expert panel exploration of new MSO scenarios. Documentation of screened MSOs would be required, whether performed with the initial screening or by the expert panel. Screening of the MSOs during the expert panel review may add significant time to the performance of the panel meetings, so pre-screening is generally recommended.

It is helpful to address as a part of the pre-screening the question of whether the MSO Scenario is already addressed in the SSA. This can be answered through the coordinated review of the SSA, discussed below. The review helps in the preparation for the expert panel review, and also provides information as to the plant response given the MSO. For example, if the MSO is addressed by analysis, showing a diversion flow path is small and does not fail the SSA train, the information is captured in the pre-review. Finally, this information can be used during the review of possible combinations of MSO scenarios, as discussed in 4.4.3.3 below.

#### **4.4.1.2 Perform PRA Runs Per Appendix F**

The plant PRA model may evaluate combinations of components that are not explicitly treated in the SSA. These combinations may also be non-intuitive. As a prudent measure, the PRA model may be exercised to highlight these MSO combinations for consideration by the Expert Panel.

The method used for this process is described in Appendix F. The outcome of the review is a list of possible MSO combinations that may fail SSA and potentially lead to core damage. Only new MSO combinations not already included in the generic MSO list or already addressed in the SSA should be included in the Plant Specific MSO List.

Based on the Pilot Application of NEI 00-01, the PRA Run results can provide MSO scenarios that are not in the generic MSO list. The Pilot Application results show additional scenarios in support systems would be most likely found using the PRA methods.

#### **4.4.1.3 Review of the Existing SSA**

As an input to the expert panel process, a list of the existing SSA spurious operations components and scenarios should be developed. Much of the information for this list is already available in SSA supporting documents, but may not be in a form to support external review or an expert panel review. This list should provide both a description of the scenario of concern and the disposition of the scenario in the SSA. Operator Manual Actions associated with any disposition should also be documented, including documentation of feasibility criteria (timing, etc.). Key to the documentation are any assumptions made for the SSA, since these assumptions may not be valid for MSO scenarios. Both generic and scenario specific assumptions should be documented as an input to the expert panel review.

Scenarios that are dispositioned as not needing operator manual action (or other compliance strategies), due to the presence of additional components downstream of the initial component, should be reviewed by the expert panel in detail. Pre-identification of these scenarios as additions to the MSO list should be performed. For example, if a diversion includes two MOVs, and the first MOV is dispositioned as not a concern due to the presence of the second MOV, then the expert panel should consider spurious operation of both MOVs as a potential

multiple spurious operation scenario. Similarly, if a non-post-fire safe shutdown credited pump start is not a concern due to a closed discharge MOV/AOV, then the expert panel should consider the scenario (Pump spuriously starts and valve spuriously opens).

Similarly, for a post-fire safe shutdown credited pump start with a normally open minimum flow valve, then the expert panel should consider the scenario (Pump spuriously starts and the minimum flow valve spuriously closes).

Scenarios where positive operator manual action is taken where both single and multiple spurious operations are addressed may need to be considered further. The scenario would need to be reviewed for the effect on timing and operator action feasibility to ensure no further review is required. For example, if operator action on a flow path is determined to have 20 minutes prior to reaching an unrecoverable state, but a second spurious operation can change the timing to 10 minutes, then a review by the expert panel is needed. This timing issue is especially critical for spurious pump operation. For example, for PWR SG overfeed or for the pressurizer going solid, the timing for single pump spurious start/run can be much different than when two or three pumps start/run, and the credited operator manual action may not be completed in time for the MSO.

An Example SSA Results Table is provided in Table 1 below. Notice that in the table, there are several examples where expert panel consideration will be required. For example, for MOV-1, the expert panel will need to consider the timing to see if additional spurious operations will result in failure of the feasibility criteria. For MOV-2, the credited disposition is the use of another valve, MOV-3. If the same fire can damage this MOV-3, then an MSO scenario may result. MOV-4 is likely to not be a concern for MSO scenarios, unless it can be involved in scenarios involving hot standby. In this case, it could affect the timing of an existing scenario or result in a new scenario being introduced.

<b>Table 1 (example)</b> <b>Existing SSA Spurious Operations Components and Scenarios</b>			
<b>Component</b>	<b>Scenario</b>	<b>Disposition</b>	<b>Reference for Disposition</b>
MOV-1	Spurious Opening Results in Excess Letdown	Local Operator Manual Action per procedure OP-3	Procedure OP-3, step 12
MOV-2	Spurious Closure results in a loss of injection	Use of second injection valve, MOV-3	Procedure OP-3, step 17
MOV-4	Spurious Closure will result in failure of letdown. This will result in the inability to achieve cold shutdown in 72 hours	Manual Action per procedure OP-3	Procedure OP-3, step 18

Based on the pilot application of the NEI 00-01 methods, the focus of the above table should be to document any MSOs already addressed (or discussed) in the existing SSA. If the MSO is already addressed, then this documentation can assist in the review of the generic MSO list. If the MSO is addressed, but not on the generic MSO list, then the MSO is added to the plant specific MSO list and should be considered a candidate to send to NEI and the applicable Owner's Group for addition to the MSO list. Finally, if the MSO is discussed in the SSA, but does not have a compliance strategy, then this will need to be addressed in the SSA. In this last category, if the SSA specifically mentions that the MSO requires multiple hot shorts (or multiple spurious operations), which is considered beyond the design, then, the original SSA disposition would need to be revisited based on the guidance in this document. However, the MSO may need additional analysis in order to verify the MSO fails safe shutdown.

Development of Table 1 above is not intended to be a review of whether the existing SSD method (including manual action feasibility) is sufficient for each MSO per the Section 3.5 guidance. This validation would be performed on all MSOs in the plant specific MSO list during the Fire Area Assessment performed in 4.5 below.

#### **4.4.2 Phase II: Preparation for the Expert Panel Meeting**

The following steps are performed in preparation for the expert panel once Phase I is complete.

#### **4.4.2.1 Select Expert Panel**

Key to the expert panel process is the diverse review of Safe Shutdown Functions. This diverse review is performed by an expert panel comprised of experienced personnel in the major aspects of plant operation and fire safe shutdown. The expert panel should include the following expertise:

- Fire Protection
- Fire Safe Shutdown Analysis: This expert should be familiar with the SSA input to the expert panel and with the SSA documentation for existing spurious operations.
- PRA: This expert should be familiar with the PRA input to the expert panel.
- Operations
- System Engineering
- Electrical Circuits

Additional experts may be needed, depending on the system interactions that are discussed. For example, water relief from a safety valve may require expertise in relief valve. Additionally, a single individual may provide expertise in multiple areas, such as Fire Protection and Fire SSA.

#### **4.4.2.2 Schedule Expert Panel**

The expert panel review for identification of MSOs performed per the guidance in Phase III below will likely require 2-4 days of time, depending on a number of factors. If the prescreening of non-applicable MSOs is performed and well documented, this should save time for the panel. Additionally, if the existing SSA addresses many of the MSOs in the generic list, the panel review would be easier.

The expert panel review may result in questions and open action items from the MSO review. It may be necessary to schedule follow-up meetings of the expert panel, depending on the outcome of the action items. Additionally, if Fire Modeling or Focused-Scope PRA are used to disposition one or more MSOs, expert panel review of the dispositions would be required.

#### **4.4.2.3 Training**

Training is performed prior to the beginning of the expert panel. This training should include:

1. Purpose and scope of the SSA
2. PRA overview and results
3. Overview training on the MSO issue, including
  - a. Appendix G to this document

- b. Background on Fire-Induced MSOs
- c. “Required for Hot Shutdown” vs. “Important to Safe Shutdown”
- d. Types of circuit failures that can occur, including shorts to ground that can cause spurious component operation.
- e. Results of the Fire Testing (EPRI/NEI Testing), including:
  - i. Likelihood of various spurious operation probabilities.
  - ii. Timing including the likelihood that failures will occur close in time, and issues affecting time to damage.
  - iii. Duration

An Example training package for the expert panel was provided in Appendix F to Revision 2. Refer to Revision 2 if this information is required.

#### **4.4.3 Phase III: Performance of the Expert Panel Meetings**

Experts used in the MSO expert Panel are provided the information developed in Phase I above, and the training discussed above, prior to the performance on the expert panel meetings. The meetings provide a systematic review to identify any fire-induced MSOs that should be addressed in the plant’s SSA. The process involves a number of steps, which can be addressed together or as separate steps during the meeting. For example, when reviewing scenarios for applicability, the panel would likely also ask additional questions of whether there are similar scenarios of concern or whether the MSO combined with other MSOs would be a concern. Each of the key functions of the expert panel is discussed in the following sections.

If the expert panel is held over a several day period, and substitute expert panel members are used, substitute members should also be provided the information developed in Phase I and training prior to participating.

##### **4.4.3.1 Review MSOs on the Generic List for Applicability**

The MSO expert panel will review all recommended screening dispositions on the generic MSO list. In this review, the expert panel will perform the following functions:

1. Review the justification for screening. Ensure the justification follows the guidance above in 4.4.1, and the justification is adequate.
2. Discuss the possible addition of alternate and similar MSO scenarios applicable for the plant.

The expert panel review of the screened MSOs should be documented in a report and retained in support of the MSO review process.

#### **4.4.3.2 Review Generic MSO List for Similar or Additional MSOs**

The MSO expert panel review results in a list of potential MSOs that supplements the generic MSO list. The identification of similar scenarios (to those on the MSO list) is performed in a similar manner to the systematic review discussed in the next section.

The generic MSO lists in Appendix G include typical scenarios, including possible flow diversion paths. Plant-specific design, however, could result in different flow diversion paths. The review for similar or new scenarios should completely review all flow diversion paths related to each safe shutdown function.

#### **4.4.3.3 Review P&IDs and Electrical Diagrams for New Scenarios**

The expert panel will review and discuss one Safe Shutdown Function at a time. For that Safe Shutdown Function, the panel will identify possible failure mechanisms that can result from spurious operation or a combination of spurious operation and direct fire damage. Using various tools, identify “Choke Points” that could defeat safe shutdown through the previously identified failure mechanisms:

- Flow Diagrams
- Safe Shutdown Logic Diagrams
- PRA Event Trees
- PRA Results or Sensitivity Analysis

The panel will build these “Choke Points” into fire scenarios to be investigated. The scenario descriptions that result should include the identification of specific components whose failure or spurious operation would result in a loss of a safe shutdown function or lead to core damage.

The expert panel process can be run in a number of ways. A typical expert panel process involves a structured team review of systems and functions using a P&ID review. The P&ID review progresses through each P&ID by having the group review each possible flow path and consider the possibility and effect of a fire-induced MSO for that flow path. This consideration includes:

- a. Consideration of an MSO resulting in failure of the primary flow path or function.
- b. Consideration of an MSO that combines the failure of the flow path being considered in combination with other possible spurious operation to fail the primary flow path or function.

The first example would occur if two or more valves spuriously open, resulting in a diversion and failure of the credited train. The second example could occur given spurious closure of an RCP seal-cooling valve, and a simultaneous spurious closure of a seal injection valve, resulting in a possible RCP seal LOCA.

The expert panel review can also be performed using a review of flow diagrams, PRA events trees, Safe Shutdown Logic Diagrams, or similar logic structure. The general process for review of each is similar, although the methods for discussion may differ, given the variation in the information being presented to the expert panel.

The expert panel systematically reviews each system (P&IDs, etc.) affecting safe shutdown and the core, for the following Safe Shutdown Functions:

- Reactivity Control
- Decay Heat Removal
- Reactor Coolant
  - Inventory Control
  - Pressure Control
- Process Monitoring
- Support Functions

Safe Shutdown Failure Mechanisms to be considered are discussed in Appendix B. These mechanisms are supplemented with input from:

- The PRA Results and sensitivity
- Additional scenarios as previously identified in the corrective action program, inspections, or other identification methods (i.e., previously identified issues).

The expert panel should make a conservative determination of the impact and likelihood of the scenario. This determination should be documented for each scenario, with specific information on each scenario being provided. Where needed, the expert panel should identify where additional information is needed to justify a disposition. For example, if a diversion flow path is considered too small to affect flow in a main flow path but some additional calculations are needed to justify the opinion, then the additional calculations should be noted. These open items should be closed prior to completion of the expert panel report.

The expert panel will likely have to meet several times to initially disposition all possible systems and flow paths potentially affecting plant safe shutdown. Additional follow-up meetings may be needed, if open items are found to not support the initial disposition of the expert panel. If, for example, the small diversion flow path discussed above does result in a significant diversion where the main flow path does not provide sufficient flow to fulfill its function, the expert panel would need to meet again on this issue.



#### **4.4.3.4 Review of MSO Combinations**

As a final measure, the expert panel should review the plant specific list of MSOs to determine whether any of the individual MSOs should be combined due to the combined MSO resulting in a condition significantly worse than either MSO individually. This step may involve a review of MSOs which were previously screened as too insignificant to impact safe shutdown by themselves, but which might provide a significant impact to safe shutdown when combined with another MSO. Considerations might include MSOs where the timing of critical actions could be significantly impacted, and the available time to perform a required operator manual action is significantly reduced for the new combined MSO scenario. Consideration might also include situations where the combined effect of flow diversions from systems credited for post-fire safe shutdown provides a drastically different result than the effect of any of the individual flow diversions.

In this review, consideration of key aspects of the MSOs should be factored in, such as the overall number of spurious operations in the combined MSOs, the circuit attributes in Section 3.5 and Appendix J, and other physical attributes of the scenarios. Specifically, if the combined MSOs involve more than a total of four components or if the MSO scenario requires any of the circuit failure combinations described in either Appendix J or Section 3.5.1.3.

The goal of this additional step is to identify any new MSO combinations (which are combinations of other MSOs) that could potentially provide worse consequences or timing than any of the individual MSOs of which it is comprised. The results of this review should be documented. New combined MSOs that are potentially significant should be added to the Plant Specific MSO List. New combined MSO should also be forwarded to NEI and the responsible OG for their consideration in revising the generic list of MSOs. Refer to Section 3.5 for guidance on combining and generating new MSOs.

#### **4.4.3.5 Review of PRA Results**

During the expert panel review, the PRA scenarios identified in Phase I are reviewed by the expert panel. The expert panel should review the potential scenarios to determine:

1. Do the scenarios fail Fire Safe Shutdown?
2. Are the scenarios already identified in the previously review MSOs, such as MSOs on the generic MSO list?

If the scenario is applicable and not previously analyzed, the new scenario should be added to the plant specific MSO list discussed below. New MSOs should also be forwarded to NEI and the responsible Owner's Group for their consideration in revising the generic list of MSOs.

#### **4.4.4 Phase IV: Develop Comprehensive Plant-Specific MSO List**

Once the expert panel review is complete, the following steps are performed resulting in the development and documenting of a plant-specific MSO list.

##### **4.4.4.1 Develop the Comprehensive Plant-Specific MSO List**

Based on the expert panel Review above, the final MSO list would include all MSO scenarios. The details of the scenarios should be expanded to include the applicable components, which will eventually be included in the SSA (if not already included).

##### **4.1.1.1 MSO Categorization**

Prior to looking at the compliance strategies for each MSO, the plant-specific list is reviewed to determine the MSO categorization (i.e., Required for hot shutdown or important to safe shutdown, as explained in Section 3.1 and Appendix H). Some of the MSOs on the generic list were pre-categorized for the generic list. However, most required a plant-specific review to confirm their plant specific classification. In general, the categorization of MSOs as either required for hot shutdown or important to safe shutdown is performed on a fire area basis by the Fire Safe Shutdown Engineer. Expert Panel concurrence with the classification is neither expected nor required.

##### **4.1.1.2 Document Expert Panel Review and Post-Review**

A report of the expert panel findings should be developed. This report should be treated as a living calculation/report, and updated if any new information is developed or if any additional multiple spurious scenarios require disposition. The expert panel report should identify a list of scenarios that need to be addressed by the SSA. Documentation of both issues and non-issues, and the reason for the classification, is important. For example, if a possible scenario was considered not possible due to power being removed from a valve, then this is documented. This documentation can be carried over into the SSA.

One of the lessons learned from the initial expert panels performed was that all scenarios considered, including those considered low likelihood or scenarios that would not go to core damage, should be documented. Additionally, the reason the scenario was not added to the plant specific MSO list should be documented in the report. Any supporting or supplemental analysis should be either added to the report or referenced.

The documentation should include details of the new MSOs to be considered, as well as possible MSO scenarios that were not considered for treatment under the SSA and the reasoning for not recommending them for consideration.

#### **4.1.1.3 Fire Area Assessment of MSOs**

This step is discussed in 4.5 below. Documentation should be included in the Fire Area Assessment, as discussed in 3.4.2.5. The Fire Area Assessment may refer to additional analysis supporting the disposition such as the PRA or Fire Modeling Analysis.

#### **4.1.1.4 Expert Panel Review of Fire Modeling & Focused Scope Fire PRA Dispositions**

As can be seen from Figure 4-1 above, MSOs dispositioned using the methods described in 3.4.2.4 or using the circuit failure criteria from Appendix B and Appendix J as explained above do not need to be reviewed by the expert panel. All other methods of disposition, however, need to be reviewed by the expert panel (See 4.5.2.2 & 4.5.2.3 below).

In this review, the expert panel will review the disposition for adequacy. This review includes:

1. Review the justification for disposition. Ensure the justification follows the guidance above, and the justification is adequate.
2. Discuss the possible alternative dispositions for the MSO scenario, including traditional compliance methods discussed in 3.4.2.

The review in item 2 should include the uncertainty/sensitivity of the evaluation being performed, the effect the traditional compliance strategy would have on other MSOs or spurious operations, the cumulative effect of spurious operations and fire risk in the area, and other factors the expert panel determines are important.

The review of the disposition of an MSO using Fire PRA will vary slightly between the MSO using a focused-scope Fire PRA and a Full Fire PRA. With a full Fire PRA, the analysis of a compartment or area will include analysis of all potentially important fire scenarios. The expert panel should become familiar with the general compartment/area results, and the characteristics of the area that affect both overall risk and the risk for the MSO. These characteristics should be consistent, and given they are consistent; the expert panel review of the MSO analysis is somewhat simpler. With a focused-scope Fire PRA, the expert panel will need to ensure that the characteristics affecting the MSO analysis are consistently and accurately applied. The sensitivity and uncertainty analysis should include the effects of assumptions made for the fire characteristics, including basic factors such as fire size assumptions, non-suppression probabilities, etc.

#### **4.1.2 Expert Panel Review Supporting NFPA 805**

The expert panel review supporting application of NFPA 805 has similar steps to the above process, as discussed in NFPA 805 FAQ 07-38, Lessons Learned on Multiple Spurious Operations. The proposed NFPA 805 process involves the

identification of a plant specific MSO list, which is then used to update the Fire PRA model and the Nuclear Safety Capability Assessment (i.e., safe shutdown analysis).

Since the NFPA 805 process differs slightly from the NEI 00-01 process, several of the steps above are not needed under NFPA 805. For example, the analysis of the PRA model using Appendix F is not needed, since the PRA model would be used as the basis for the Fire PRA model. Additionally, the development of Table 1 (pre-review of the SSA for spurious operations) may not be needed if the Fire PRA steps involve the review of the SSA scope versus the PRA scope to ensure the Fire PRA model includes or dispositions all SSA spurious operations.

The actual performance of the expert panel to review the generic MSO list and to systematically review for additional scenarios beyond the generic list is basically performed the same. Once the plant specific MSO list is developed, the treatment of the MSOs are significantly different, with the PRA results being used to help determine SSA requirements (referred to as Nuclear Safety Capability Assessment) during the NFPA 805 process.

## **4.5 ADDRESSING THE PLANT SPECIFIC LIST OF MSOS**

### **4.1.3 Cable Selection & Association for Each Component in an MSO**

Components contained in any MSO that are not already included in the base SSA are added to the Safe Shutdown Equipment list and analyzed in the same manner as other components in that list. The approach outlined in Section 3.3 can be used to determine the cables associated with each component in an MSO combination. Cables are associated with MSO components in the same manner as they are associated with any other safe shutdown component. In some cases, only those cables with the potential to spuriously operate the component need to be added to the SSA.

### **4.1.4 Fire Area Assessment and Compliance Strategies for MSOs**

Impacts to specific MSOs are assessed on a fire area basis in the same manner as other impacts to post-fire safe shutdown components. If all components associated with a particular MSO are located in a common fire area where they have the potential, if damaged by a fire, to impact the required safe shutdown path for that fire area, then a mitigating strategy must be provided for the MSO.

Mitigation strategies applicable to MSOs include the following as described in Section 3.4.2.4:

1. Disposition based on consideration of Circuit Failure Criteria as applied to required for hot shutdown components
2. Disposition based on use of operator manual actions.
3. Disposition based on Fire Modeling

#### 4. Disposition based on a Focused-Scope Fire PRA

Mitigation strategy 2, 3 and 4 are not generically authorized by the NRC for use with required for hot shutdown component MSOs. Exemptions, deviations or LARs, depending on a licensee's current licensing basis, may be required when using mitigation strategies 2, 3 and 4 for required for hot shutdown MSOs. Operator manual actions may be used within the bounds established in Appendix E for components classified as important to safe shutdown. Use of fire modeling and/or focused-scope fire PRA requires review by the Expert Panel. Finally, use of focused-scope fire PRA requires a LAR, depending on a plant's current licensing basis, for resolving current licensing basis issues. Risk methods, however, may be used as a mitigating measure for issues determined to be outside a plant's CLB to assess risk and to determine the need for additional actions.

Several considerations may affect the disposition method chosen for an MSO. First, the least expensive method for dispositioning an MSO may be the traditional compliance strategy, such as a design change or use of an approved operator manual action. If the PRA or Fire Modeling analysis takes more resources to perform than fixing the design or adding a simple operator manual action, then cost may dictate the approach used. If an approved operator manual action is used, however, consideration of the effect of this operator manual action on other fire response operator manual actions should be considered. For example, if the addition of a new operator manual action means the fire response procedure is more difficult, then the existing actions may become less reliable. In this case, the addition of the operator manual action may increase overall risk rather than reducing risk as intended.

This balance is to be considered prior to selecting a mitigating strategy that relies upon operator manual action.

##### **4.1.4.1 Mitigation through Consideration of Circuit Failure Criteria**

Circuit failure criteria applicable to MSOs is contained in Section 3 and Appendix J. When evaluating the impact of an MSO on a particular fire area, the circuit failure types for the circuit types contained in Section 3 and Appendix J should be considered. Using the circuit failure criteria, MSOs should be considered as potential "combined equipment impacts". Stated differently, if any of the fire induced circuit failures as described in Section 3 and Appendix J can cause an impact to the group of components in the MSO, this must be evaluated. For example, if the listed MSO were the failure of the block valve to close in conjunction with a spurious opening of a PORV, the block valve would need to be evaluated for circuit failure types that could prevent closure of the block valve, (i.e., a short-to-ground causing a loss of control power or an open circuit causing a loss of circuit continuity). Similarly, if an immediate operator manual action to close the block valve at the start of the fire were credited and, if a hot short could subsequently spuriously open the block valve in the same fire area where another hot short could cause the spurious opening of the PORV, then this condition also needs to be addressed.

If all potential fire-induced circuit failures outlined in Section 3 and Appendix J are addressed and, if none leads to all components in the MSO being damaged in a manner that impacts the required post-fire safe shutdown path, then the MSO is dispositioned on the basis of circuit analysis.

If mitigation by the use of circuit analysis is not possible, then another means of mitigation, either one of the traditional means described in Section 3.4.2.4 for required for hot shutdown components, operator manual actions for important to safe shutdown components or one of the means listed below, must be developed. If either of the means listed below is used as the mitigating strategy for the MSO, then review and acceptance of the disposition by the Expert Panel is required.

#### **4.1.4.2 Fire Modeling Disposition**

Licensees currently perform qualitative fire ignition, fire spread and fire damage analysis as a part of fire hazard analyses, engineering equivalency evaluations, deviation requests and/or exemption requests, as appropriate. Use of industry accepted Fire Modeling tools serve as an upgrade to this current practice. Additionally, process improvements developed for NFPA 805 applications should be considered, as applicable. As an alternative to obtaining NRC review and concurrence for these types of equivalency evaluations, the Resolution Methodology proposes an additional enhancement to the equivalency evaluation process by the introduction of an Expert Panel review and concurrence for those instances where fire modeling is used to disposition an identified MSO Impact.

Fire Models used for the disposition of MSOs must be appropriate for the application. The Fire Models described in NUREG-1824 should be used where applicable. In cases where the Fire Models described in NUREG-1824 are not applicable, other Fire Modeling methods may be used. The basis for the selected Fire Modeling method must be provided and the Fire Modeling approach must be described and documented per Section 4.6.

The most challenging fire that could reasonably be expected for the application should be selected. This determination is based on the types of fuel packages present, the use of the space, the general practices in the area, and the ignition sources present. Transient ignition sources and transient fuel packages that could be reasonably expected in the area must also be considered. The presence and size of transient ignition sources and transient fuel packages should be based on the plant design and operation and should include consideration administrative controls. Typical administrative controls include combustible free zones, transient combustible zones, procedures governing hot work and control of combustibles, etc. The postulated fire locations should include consideration of cable routing pinch points and possible ignition of secondary combustibles. Passive fire protection features such as fire barriers and fire rated construction should be credited where applicable; however, the amount of protection provided by such features should consider the rating of the system, the exposure conditions the system was rated against, and the postulated exposure conditions for the scenario considered. A generic approach using the 98th percentile fire size heat release rate

as described in NUREG/CR-6850, NUREG/CR 6850 Supplement 1, and NUREG-2178 may be used to characterize the heat release rate from generic fuel packages typically found in commercial nuclear facilities, provided it is suitable for the application. The basis for the fire size selected and the assumed location must be documented per Section 4.6.

Active fire suppression features may be assumed to prevent further fire spread and growth if they are shown to actuate for the postulated fire, have a high reliability, are designed to suppress or extinguish the postulated fire type, are code compliant, and are maintained per applicable code. Other active fire protection features, such as fire dampers, may be credited to function given the same constraints as active fire suppression features. High reliability active fire protection features would include wet pipe sprinkler systems and other fire protection systems with a failure rate that is the same or better.

As discussed above, dispositions using Fire Modeling are not generically authorized by the NRC to be applied to MSOs categorized as required for hot shutdown component MSOs. Exemptions, deviations or LARs, depending on a licensee's current licensing basis, are required to use fire modeling for required for hot shutdown MSOs.

#### **4.1.4.3 Fire PRA Disposition**

As discussed above, dispositions using Focused-scope Fire PRA are not generically authorized by the NRC to be applied to MSOs categorized as required for hot shutdown component MSOs. Exemptions, deviations or LARs, depending on a licensee's current licensing basis, are required to use the Fire PRAs for required for hot shutdown MSOs. The Licensee will need to review their existing Licensing basis to determine if a Fire PRA is currently permitted. If not, a License Amendment may be required. Use of a fire PRA as a mitigating measure requires review by the Expert Panel.

#### **4.1.5 Feedback to the Generic MSO List**

As this and other MSO methods are implemented (e.g., implementation of NFPA 805), the MSO list has the potential to grow. For the method above, the following criteria should be used to determine if any new MSO should be added to the generic MSO list:

- a. Any new MSO not on the generic list,
- b. The MSO does not screen using conservative screening criteria or is not analyzed using Fire PRA resulting in a compliance strategy being applied.

Prior to the issuance of Revision 3, each new MSO was to be provided to NEI and the responsible Owner's Group. [Note: This approach was not to be used as a substitute for the issuance by each individual licensee of industry OE, when appropriate.] When provided, the new MSO should include a preliminary classification as to whether the MSO is for a required for hot shutdown or an

important to SSD component combination. The responsible Owner's Group will review the new MSO for generic applicability and revise their generic MSO list, as appropriate. NEI will add the new MSO list to their webpage and notify the industry of the change. The list of MSOs will be maintained on the NEI Webpage and by each responsible Owner's Group.

The revised MSO list was issued to the industry in Revision 3 to this document. The issuance of the list in a revision to NEI 00-01 is considered to be the formal notification to the industry to act. Upon issuance of the revised list, all licensees should repeat the process provided in this section to determine the applicability of the changes to their facility. Any generic list changes beyond the NRC EGM date of May 2, 2010 will not be covered by the enforcement discretion outlined in NRC EGM 09-002. These list changes, however, should be treated in a manner similar to any other Operating Experience (OE) received, that is: (1) review the issue for plant applicability; (2) if applicable, include the issue into the corrective action program; (3) if necessary, institute compensatory measures to restore any plant margin potentially eroded by the issue; (4) evaluate the issue and perform corrective actions on a schedule consistent with the safety/risk significance of the issue to the plant.

There will be no changes to the list subsequent to the issuance of Revision 3 to NEI 00-01. Any new potential scenarios should be evaluated using the criteria in this section. If the screening criteria are met, then the identifying licensee should process and distribute to the industry as OE. Each licensee is to evaluate the OE following the guidance in the paragraph above.

#### **4.6 DOCUMENTATION**

Documentation should be included in the Fire Area Assessment, as discussed in 3.4.2.5 above. The Fire Area Assessment may refer to additional analysis supporting the disposition such as the PRA or Fire Modeling Analysis.



## 5 DEFINITIONS

The following definitions are consistent with NRC-recognized definitions.

The numbers in brackets [ ] refer to the IEEE Standards in which the definitions are used. Refer to Section 2 of IEEE Standard 380-1975 for full titles.

Those definitions without a specific reference are consistent with those specified in reference 7.4.32.

### **Associated circuits of Concern**

*Generic Letter 81-12* – Those cables (safety related, non-safety related, Class 1E, and non-Class 1E) that have a physical separation less than that required by Appendix R Section III.G.2 and have one of the following:

#### **Common Power Source**

A common power source with the shutdown equipment (redundant or alternative) and the power source is not electrically protected from the circuit of concern by coordinated breakers, fuses, or similar devices, or

#### **Spurious Operation**

A connection to circuits of equipment whose spurious operation would adversely affect the shutdown capability (e.g., Residual Heat Removal/Reactor Coolant System isolation valves, Automatic Depressurization System valves, Pressure-Operated Relief Valves, steam generator atmospheric valves, instrumentation, steam bypass, etc.), or

#### **Common Enclosure**

A common enclosure (e.g., raceway, panel, junction, etc.) with the shutdown cables (redundant or alternative), and are not electrically protected by circuit breakers, fuses or similar devices, or will allow the propagation of the fire into the common enclosure.

### **Cable**

*IEEE Standard 100-1984* – A conductor with insulation, or a stranded conductor with or without insulation and other coverings (single-conductor cable) or a combination of conductors insulated from one another (multiple-conductor cable).

Target Cable - A target cable is a cable containing specific conductors that when viewed from the perspective of a components electrical schematic have the potential to cause the undesired spurious operation of the component if impacted by an aggressor cable.

Aggressor Cable - An aggressor cable is a cable with conductor(s) having the requisite characteristics, (e.g., voltage, to cause the undesired condition to occur for the component associated with the target cable).

## **Circuit**

*IEEE Standard 100-1984* – A conductor or system of conductors through which an electric current is intended to flow.

## **Circuit failure modes**

The following are the circuit failure modes that are postulated in the post-fire safe shutdown analysis as a result of a fire:

### **Hot Short**

A fire-induced insulation breakdown between conductors of the same cable, a different cable or from some other external source resulting in a compatible but undesired impressed voltage or signal on a specific conductor. [**Note:** Hot shorts need not be postulated in fiber optic cables.]

### **Ground Fault Equivalent Hot Short [GFEHS]**

□ For ungrounded circuits, a combination of shorts-to-ground that have the same effect on the control circuitry for a component as a hot short, (i.e., result in a compatible, but undesired impressed voltage or signal on a specific conductor). Shorts-to-ground that combine in this way to impact a components circuitry are referred to as Ground Fault Equivalent Hot Shorts (GFEHS). GFEHS must be evaluated for their impact on any ungrounded circuits for all safe shutdown equipment.

### **Open Circuit**

A fire-induced break in a conductor resulting in a loss of circuit continuity.

### **Short-to-Ground**

A fire-induced breakdown of a cable's insulation system resulting in the potential on the conductor being applied to ground/neutral.

## **Cold Shutdown Repair**

Repairs made to fire damaged equipment required to support achieving or maintaining cold shutdown for the required safe shutdown path.

## **Concurrent, (i.e., fire-induced circuit failure)**

Separate fire-induced circuit failures existing together at some point in time. This definition would include “simultaneous” occurring at the exact same point in time.

## **Component**

Components can be either mechanical or electrical.

Those mechanical devices, such as pumps, fans, valves, dampers, process instruments providing an input to a system control function and instruments credited for satisfying the process monitoring safe shutdown function, are considered to be components for the purposes of this document. Breakers and starters required for the operation of the mechanical component are considered to be subcomponents of the mechanical components.

The electrical components, such as generators, switchgear, load centers, motor control centers, batteries, inverters and distribution panels required to provide the motive or control power to mechanical components are defined as electrical distribution equipment and are also considered to be components for the purposes of this document.

These mechanical and electrical components are considered to be primary components in Section 3.2.1.1. Devices, such as relays, switches and motors, necessary to support the functioning of the mechanical and electrical components are considered to be secondary components for the purposes of this document.

Elementary logics controlling the automatic functioning of multiple components based on changes in plant process variables are not classified as components. Their potential impact on post-fire safe shutdown is determined based on the input they provide to the electrical schematics for the components that support or could impact the required safe shutdown path in any fire area. In general, these logic diagrams are classified as secondary circuits with the potential to affect the primary circuit for a safe shutdown component.

### **Conductor**

*IEEE Standard 100-1984* – A substance or body that allows a current of electricity to pass continuously along it. *Clarification:* a single “wire” within a cable; conductors could also be considered a circuit or a cable.

### **Design Basis Fire**

A postulated event used in the post-fire safe shutdown analysis. See Exposure Fire.

### **Emergency Control Station**

Location outside the main control room where actions are taken by operations personnel to manipulate plant systems and controls to achieve safe shutdown of the reactor. [NRC RIS 2005-30]

### **Enclosure**

*IEEE Standard 380-1975* – An identifiable housing such as a cubicle, compartment, terminal box, panel, or enclosed raceway used for electrical equipment or cables. [384]

## **Exposure Fire**

*SRP Section 9.5.1* – An exposure fire is a fire in a given area that involves either in-situ or transient combustibles and is external to any structures, systems, or components located in or adjacent to that same area. The effects of such fire (e.g., smoke, heat, or ignition) can adversely affect those structures, systems, or components important to safety. Thus, a fire involving one train of safe shutdown equipment may constitute an exposure fire for the redundant train located in the same area, and a fire involving combustibles other than either redundant train may constitute an exposure fire to both redundant trains located in the same area.

## **Fire Area**

*Generic Letter 86-10* – The term "fire area" as used in Appendix R means an area sufficiently bounded to withstand the hazards associated with the fire area and, as necessary, to protect important equipment within the fire area from a fire outside the area.

In order to meet the regulation, fire area boundaries need not be completely sealed with floor to ceiling and/or wall-to-wall boundaries. Where fire area boundaries were not approved under the Appendix A process, or where such boundaries are not wall-to-wall or floor-to-ceiling boundaries with all penetrations sealed to the fire rating required of the boundaries, licensees must perform an evaluation to assess the adequacy of fire area boundaries in their plants to determine if the boundaries will withstand the hazards associated with the area and protect important equipment within the area from a fire outside the area.

## **Fire Barrier**

*SRP Section 9.5.* – those components of construction (walls, floors, and their supports), including beams, joists, columns, penetration seals or closures, fire doors, and fire dampers that are rated by approving laboratories in hours of resistance to fire and are used to prevent the spread of fire.

## **Fire Damage**

Damage to structures, systems or components, including cabling, as a result of an exposure fire within any given fire area.

## **Fire Frequency ( $F_f$ )**

The frequency of fires with a potential to damage critical equipment if left alone.

## **Fire Protection Design Change Evaluation**

The process replacing the 50.59 evaluation process (described in NEI 02-03) that is used by a licensee to document compliance with the fire protection license condition to assure that changes to the approved fire protection program do not adversely affect the ability to achieve and maintain safe shutdown in the event of a fire.

## **Fire Protection Program**

*10 CFR 50, Appendix R, Section II.A* – the fire protection policy for the protection of structures, systems, and components important to safety at each plant and the procedures, equipment, and personnel required to implement the program at the plant site. The fire protection program shall extend the concept of defense-in-depth to fire protection in fire areas important to safety, with the following objectives:

- Prevent fires from starting.
- Rapidly detect, control, and promptly extinguish those fires that do occur.
- Provide protection for structures, systems, and components important to safety so that a fire that is not promptly extinguished by the fire suppression activities will not prevent the safe shutdown of the plant.

## **Fire Zone**

The subdivision of fire area(s) for analysis purposes that is not necessarily bound by fire-rated barriers.

## **Free of Fire Damage**

“The structure, system, or component under consideration is capable of performing its intended function during and after the postulated fire, as needed, without repair.” [Regulatory Guide 1.189 Revision 2]

## **Generic Letter 86-10 Fire Hazards Evaluation**

A technical engineering evaluation used to evaluate equivalency of fire protection features to those required by the regulations or to evaluate fire protection features that are commensurate with the potential fire hazard. For plants licensed prior to 1979, these evaluations may form the basis for an Appendix R exemption request or support a plant change evaluation using accepted regulatory processes. For plants licensed after January 1, 1979, these evaluations may be used in conjunction with a fire protection design change evaluation to alter the current licensing basis or they may be submitted to the NRC for review and acceptance as a deviation request. (Note: Previously approved deviation requests may be altered using a fire protection design change evaluation without re-submittal to the NRC.)

## **Ground Fault Equivalent Hot Short (GFEHS)**

The term “ground fault equivalent hot short,” also known as GFEHS, is a subset of an intra-cable or inter-cable hot short phenomena and is a circuit failure mode wherein multiple shorts to ground can cause a spurious operation. For this failure mode to occur, both a source and target conductor must short to the same ground plane and have a compatible power supply.

## **High Impedance Fault**

*Generic Letter 86-10* – electrical fault below the trip point for a breaker on an individual circuit. See “Multiple High Impedance Fault.”

**High/Low Pressure Interface**

Refer to Appendix C to this document.

## **Hot Short**

See “Circuit failure modes.”

## **Important to Safe Shutdown (SSD)**

10 CFR 50, Appendix R, Section III.G.1 describes Structures, Systems and Components (SSC) important to safe shutdown for which fire protection features apply. Components classified as important to SSD in accordance with Section 3 and Appendix H may apply different mitigation tools than components classified as required for hot shutdown.

## **Isolation Device**

*IEEE Standard 380-1975* – A device in a circuit that prevents malfunctions in one section of a circuit from causing unacceptable influences in other sections of the circuit or other circuits. [384]

## **Implausible**

The term “implausible” when used in conjunction with a fire-induced circuit failure phenomenon, supports the PIRT Panel’s conclusion that the happening, while theoretically possible, would require the convergence of a combination of factors that are so unlikely to occur that the likelihood of the phenomenon can be considered statistically insignificant. In these cases, the PIRT Panel could find no evidence of the phenomenon ever occurring either in operating experience or during a fire test.

## **Incredible**

The term “incredible” used in conjunction with the phenomenon of a fire-induced circuit failure, signifies the PIRT panel’s conclusion that the event will not occur. In these cases, the PIRT panel could find no evidence of the phenomenon ever occurring, and there were no credible engineering principles or technical arguments to support its happening during a fire.

## **Latching Component Designs**

Latching component designs are defined as component or signal that do not return to their original (i.e., pre-spurious operation) position when the fire-induced circuit failure(s) causing the spurious operation terminates.

An example of a latching circuit configuration is a closed motor operated valve (MOV) that spuriously opens as a result of a fire-induced hot short and *will not* return to its original position (closed) when the hot short terminates.

## **Local Operation**

Operation of safe shutdown equipment by an operator outside the Main Control Room when automatic, remote manual, or manual operation are no longer available (e.g., opening of a motor operated valve using the hand wheel).

## **Mal-operation**

A faulty or incorrect operation or repositioning of a device, component, process or system.

**Multiple High Impedance Fault(s)**

A condition where multiple circuits fed from a single power distribution source each have a high impedance fault. See Appendix B.1.

**Non-Latching Component Designs**

Non-latching component designs are defined as component or signal that return to their original position when the fire-induced circuit failure(s) causing the spurious operation terminates.

An example of a non-latching circuit configuration is a solenoid operated valve (SOV) that changes position as a result of a fire-induced hot short and *will* return to its original position when the hot short terminates.



### **Operator Manual Action**

Action performed by operators to manipulate components and equipment from outside the main control room to achieve and maintain post-fire hot shutdown, not including “repairs.”

### **Open Circuit**

See 'Circuit Failure Modes'.

### **Plausible**

The term “plausible” used in conjunction with the phenomenon of a fire-induced circuit failure, signifies the PIRT panel’s conclusion that the event will occur given appropriate conditions. In these cases, the PIRT panel finds adequate evidence of the phenomenon occurring during a fire. This classification of the hot short-induced spurious operation failure mode(s) warrants being included in the post-fire safe-shutdown circuit analysis. In the PIRT report these events are termed “possible” in Table 3-3, and represented as “blank” cells in Figures 3-5, 3-6 and 3-7 and Tables 3-6 and 3-7” of the PIRT Report (Ref. 14), as clarified and updated in Appendix B of NUREG/CR 7150 Volume3.

### **Primary & Secondary Circuits**

Primary circuits are the main control circuitry for a safe shutdown component. All contacts in the primary circuit need to be investigated as interlocks to determine the potential impacts to the primary circuit from any secondary circuits that has input to the primary circuit through a set of contacts. The circuit failure criteria in Section 3.5.1.1 describe the considerations for concurrent circuit failures with the potential to impact the primary and any secondary circuits for a safe shutdown component. These circuits are sometimes referred to as on-scheme for primary circuits and off-scheme for secondary circuits.

### **Probability of Spurious Actuation (P<sub>SA</sub>)**

The probability of undesirable spurious operation(s) of the component, or of component being potentially impacted by the fire-induced circuit failure.

### **Raceway**

*IEEE Standard 380-1975* – Any channel that is designed and used expressly for supporting wires, cable, or busbars. Raceways consist primarily of, but are not restricted to, cable trays and conduits. [384]

### **Remote Control**

Plant design features that allow the operation of equipment through a combination of electrically powered control switches and relays. Remote control can typically be performed from the control room or from local control stations, including the remote shutdown panel and other locations with control capability outside the control room.

### **Remote Manual Operation**

Operation of safe shutdown equipment on the required safe shutdown path using remote controls (e.g., control switches) specifically designed for this purpose from a location other than the main control room.

**Remote Shutdown Location**

A plant location outside the control room with remote control capability for shutdown.

### **Remote Shutdown Panel**

The panel included within the plant design for the purpose of satisfying the requirements of 10 CFR 50 Appendix A General Design Criterion 19. If electrical isolation and redundant fusing are provided at this location, it may also be suitable for use in achieving and maintaining safe shutdown for an event such as a control room fire. [Note: Some Licensees may refer to this panel as the Auxiliary Control Panel or the Auxiliary Shutdown Panel.]

### **Repair Activity**

Those actions required to restore operation to post-fire safe shutdown equipment that has failed as a result of fire-induced damage. Actions to operate a component in accordance with its design intent, (e.g., operation of a manual valve using its hand wheel; changing out of a gas bottle after its content has been exhausted) are not considered to be repair activities, since the actions are not being performed to address fire-induced damage to the component. Repairs may include installation, removal, assembly, disassembly, or replacement of components or jumpers. Repair activities are to use materials, tools [use of a tool, however, does not automatically make an activity a repair], procedures, and personnel available on site. Replacement of fuses [fuse removal is considered to be an operator manual action not a repair]), installation of temporary cables or power supplies, installation of air jumpers are examples of repair activities. Credit for repair activities for post-fire safe shutdown may only be taken for equipment required to achieve and maintain cold shutdown. Repairs may require additional, more detailed instructions, including tools to be used, sketches, and step-by-step instructions for the tasks to be performed. Repair activities are intended to restore functions and not equipment since the equipment may be destroyed in a fire event. Repair activities may rely on exterior security lighting or portable lighting if independent 8-hour battery backed lighting is unavailable.

### **Required Safe Shutdown Path**

The safe shutdown path selected for achieving and maintaining safe shutdown in a particular fire area. This safe shutdown path must be capable of performing all of the required safe shutdown functions described in this document.

### **Required Safe Shutdown System**

A system that performs one or more of the required safe shutdown functions and is, therefore, a part of the required safe shutdown path for a particular fire area.

### **Required Hot Shutdown Component**

Equipment that is required to either function or not malfunction so that the required safe shutdown path will be capable of achieving and maintaining hot shutdown in a particular fire area and meet the established regulatory criteria. Refer to Section 3 and Appendix H for additional guidance on this classification.

### **Required Hot Shutdown Cable/Circuit**

Cable/circuit required to support the operation of required hot shutdown component in a particular fire area.

### **Safe Shutdown**

[Reference 7.4.38] A shutdown with (1) the reactivity of the reactor kept to a margin below criticality consistent with technical specifications, (2) the core decay heat being removed at a controlled rate sufficient to prevent core or reactor coolant system thermal design limits from being exceeded, (3) components and systems necessary to maintain these conditions operating within their design limits, and (4) components and systems necessary to keep doses within prescribed limits operating properly.

[Reference 7.4.14] For fire events, those plant conditions specified in the plant Technical Specifications as Hot Standby, Hot Shutdown, or Cold Shutdown.

For those plants adopting NFPA 805, the term “safe shutdown” is not explicitly defined. Please refer to the discussion of “Nuclear Safety Performance Criteria” in NFPA 805 for more information about performance criteria that, if met, provide reasonable assurance in the event of a fire that the plant is not placed in an unrecoverable condition.

### **Safe Shutdown Capability**

#### **Redundant**

Any combination of equipment and systems with the capability to perform the shutdown functions of reactivity control, inventory control, decay heat removal, process monitoring and associated support functions when used within the capabilities of its design.

#### **Alternative**

For a given fire area/zone where none of the redundant safe shutdown capability are “free of fire damage” and dedicated equipment is not provided, the shutdown strategy used is classified as alternative.

#### **Dedicated**

A system or set of equipment specifically installed to provide one or more of the post-fire safe shutdown functions of inventory control, reactivity control, decay heat removal, process monitoring, and support as a separate train or path.

### **Safe Shutdown Equipment/Component**

Equipment or component that performs a function that is required for safe shutdown either by operating or by not mal-operating. Safe Shutdown Equipment/Component includes both required for hot shutdown and important to safe shutdown.

### **Short-to-Ground**

See “Circuit Failure Modes.”

**Simultaneous, (i.e., fire-induced circuit failures)**

Simultaneous fire-induced circuit failures are fire-induced circuit failures occurring at the exact same point in time.

**Spurious Operation (or Spurious Actuation)**

Mal-operation of equipment due to fire damage considering all possible functional states (e.g., open/close, start/stop, low/high, etc.).

**Multiple Spurious Operation (MSO)** - A Multiple Spurious Operation (MSO) is the possible inadvertent mal-operation of either a single piece of equipment resulting from more than a single fire-induced hot short or multiple pieces of equipment resulting from multiple fire-induced hot shorts caused by fire damage. In general, MSO's have the potential to impact a post-fire safe shutdown function through their relationship to each other and their combined effect on the specific post-fire safe shutdown function.

## **6 REFERENCES**

### **6.1 NRC GENERIC LETTERS**

- 6.1.1 80-45: Fire Protection Rule
- 6.1.2 80-48: Revision to 5/19/80 Letter on Fire Protection
- 6.1.3 80-56: Commission Memorandum and Order on Equipment Qualification
- 6.1.4 80-100: Appendix R to 10 CFR 50 Regarding Fire Protection – Federal Register Notice
- 6.1.5 81-12: Fire Protection Rule (45 FR 766602, 11/19/80)
- 6.1.6 81-12 Clarification: Clarification Letter to Generic Letter 1981-012
- 6.1.7 82-21: Technical Specifications for Fire Protection Audits
- 6.1.8 83-33: NRC Positions on Certain Requirements of Appendix R to 10 CFR 50
- 6.1.9 85-01: Fire Protection Policy Steering Committee Report
- 6.1.10 86-10: Implementation of Fire Protection Requirements
- 6.1.11 86-10, Supp. 1: Fire Endurance Test Acceptance Criteria for Fire Barrier Systems Used to Separate Redundant Safe Shutdown Trains within the Same Fire Area
- 6.1.12 88-12: Removal of Fire Protection Requirements from Technical Specifications
- 6.1.13 88-20, Supp. 4: Individual Plant Examination of External Events (IPEEE) for Severe Accident Vulnerabilities
- 6.1.14 89-13, Supp. 1: Service Water System Problems Affecting Safety-Related Equipment
- 6.1.15 92-08: Thermo-Lag 330-1 Fire Barriers
- 6.1.16 93-06: Research Results on Generic Safety Issue 106, “Piping and the Use of Highly Combustible Gases in Vital Areas”
- 6.1.17 95-01: NRC Staff Technical Position on Fire Protection for Fuel Cycle Facilities

### **6.2 BULLETINS**

- 6.2.1 75-04: Cable Fire at Browns Ferry Nuclear Power Station
- 6.2.2 77-08: Assurance of Safety and Safeguards During an Emergency: Locking Systems

- 6.2.3 81-03: Flow Blockage of Cooling Water to Safety System Components by Corbicula sp. (Asiatic Clam) and Mytilus sp. (Mussel)
- 6.2.4 92-01: Failure of Thermo-Lag 330 Fire Barrier System to Maintain Cabling in Wide Cable Trays and Small Conduits Free from Damage
- 6.2.5 92-01, Supp. 1: Failure of Thermo-Lag 330 Fire Barrier System to Perform its Specified Fire Endurance Function

### **6.3 NRC INFORMATION NOTICES**

- 6.3.1 80-25: Transportation of Pyrophoric Uranium
- 6.3.2 83-41: Actuation of Fire Suppression System causing Inoperability of Safety-Related Equipment
- 6.3.3 83-69: Improperly Installed Fire Dampers at Nuclear Power Plants
- 6.3.4 83-83: Use of Portable Radio Transmitters Inside Nuclear Power Plants
- 6.3.5 84-09: Lessons learned from NRC Inspections of Fire Protection Safe Shutdown Systems (10 CFR 50, Appendix R)
- 6.3.6 84-16: Failure of Automatic Sprinkler System Valves to Operate
- 6.3.7 84-92: Cracking of Flywheels on Cummins Fire Pump Diesel Engines
- 6.3.8 85-09: Isolation Transfer Switches and Post-fire Shutdown Capability
- 6.3.9 85-85: System Interaction Event Resulting in Reactor Safety Relief Valve Opening Following a Fire-protection Deluge System Malfunction
- 6.3.10 86-17: Update of Failure of Automatic Sprinkler System Valves to Operate
- 6.3.11 86-35: Fire in Compressible Material at Dresden Unit 3
- 6.3.12 86-106: Feedwater Line Break
- 6.3.13 86-106, Supp. 1: Feedwater Line Break
- 6.3.14 86-106, Supp. 2: Feedwater Line Break
- 6.3.15 86-106, Supp. 3: Feedwater Line Break
- 6.3.16 87-14: Actuation of Fire Suppression System Causing Inoperability of Safety Related Ventilation Equipment
- 6.3.17 87-49: Deficiencies in Outside Containment Flooding Protection

- 6.3.18 87-50: Potential LOCA at High and Low Pressure Interfaces from Fire Damage
- 6.3.19 88-04: Inadequate Qualification and Documentation of Fire Barrier Penetration Seals
- 6.3.20 88-04, Supp. 1: Inadequate Qualification and Documentation of Fire Barrier Penetration Seals
- 6.3.21 88-05: Fire in Annunciator Control Cabinets
- 6.3.22 88-45: Problems in Protective Relay and Circuit Breaker Coordination
- 6.3.23 88-56: Potential Problems with Silicone Foam Fire Barrier Penetration Seals
- 6.3.24 88-60: Inadequate Design and Installation of Watertight Penetration Seals
- 6.3.25 88-64: Reporting Fires in Nuclear Process Systems at Nuclear Power Plants
- 6.3.26 89-52: Potential Fire Damper Operational Problems
- 6.3.27 90-69: Adequacy of Emergency and Essential Lighting
- 6.3.28 91-17: Fire Safety of Temporary Installations or Services
- 6.3.29 91-18: High-Energy Piping Failures Caused by Wall Thinning
- 6.3.30 91-37: Compressed Gas Cylinder Missile Hazards
- 6.3.31 91-47: Failure of Thermo-Lag Fire Barrier Material to Pass Fire Endurance Test
- 6.3.32 91-53: Failure of Remote Shutdown Instrumentation Because of Incorrectly Installed Components
- 6.3.33 91-77: Shift Staffing at Nuclear Power Plants
- 6.3.34 91-79: Deficiencies in the Procedures for Installing Thermo-Lag Fire Barrier Materials
- 6.3.35 91-79, Supp. 1: Deficiencies in the Procedures for Installing Thermo-Lag Fire Barrier Materials
- 6.3.36 92-14: Uranium Oxide Fires at Fuel Cycle Facilities
- 6.3.37 92-18: Potential for Loss of Remote Shutdown Capability During a Control Room Fire
- 6.3.38 92-28: Inadequate Fire Suppression System Testing



- 6.3.39 92-46: Final Report of the Special Review Team for the Review of Thermo-Lag Fire Barrier Performance
- 6.3.40 92-55: Current Fire Endurance Test Results for Thermo-Lag Fire Barrier Material
- 6.3.41 92-82: Results of Thermo-Lag 330-1 Combustibility Testing
- 6.3.42 93-40: Fire Endurance Test Results for Thermal Ceramics FP-60 Fire Barrier Material
- 6.3.43 93-41: One Hour Fire Endurance Test Results for Thermal Ceramics Kaowool, 3M Company FS-195 and 3M Company Interam E-50 Fire Barrier Systems
- 6.3.44 93-71: Fire at Chernobyl Unit 2
- 6.3.45 94-12: Insights Gained From Resolving Generic Issue 57: Effects of Fire Protection System Actuation on Safety-Related Equipment
- 6.3.46 94-22: Fire Endurance and Ampacity Derating Test Results for 3-hour Fire-Rated Thermo-Lag 330-1 Fire Barriers
- 6.3.47 94-26: Personnel Hazards and Other Problems From Smoldering Fire-Retardant Material in the Drywell of a Boiling-Water Reactor
- 6.3.48 94-28: Potential Problems with Fire-Barrier Penetration Seals
- 6.3.49 94-31: Potential Failure of Wilco, Lexan-Type HN-4-L Fire Hose Nozzles
- 6.3.50 94-34: Thermo-Lag 330-660 Flexi-Blanket Ampacity Derating Concerns
- 6.3.51 94-58: Reactor Coolant Pump Lube Oil Fire
- 6.3.52 94-86: Legal Actions Against Thermal Science, Inc., Manufacturer of Thermo-Lag
- 6.3.53 94-86, Supp. 1 : Legal Actions Against Thermal Science, Inc., Manufacturer of Thermo-Lag
- 6.3.54 95-27: NRC Review of Nuclear Energy Institute, “Thermo-Lag Combustibility Evaluation Methodology Plant Screening Guide”
- 6.3.55 95-32: Thermo-Lag 330-1 Flame Spread Test Results
- 6.3.56 95-33: Switchgear Fire and Partial Loss of Offsite Power at Waterford Generating Station, Unit 3
- 6.3.57 95-36: Potential Problems with Post-Fire Emergency Lighting
- 6.3.58 95-36, Supp. 1: Potential Problems with Post-Fire Emergency Lighting

- 6.3.59 95-48: Results of Shift Staffing Survey
- 6.3.60 95-49: Seismic Adequacy of Thermo-Lag Panels
- 6.3.61 95-49, Supp. 1: Seismic Adequacy of Thermo-Lag Panels
- 6.3.62 95-52: Fire Endurance Test Results for Electrical Raceway Fire Barrier Systems Constructed From 3M Company Interam Fire Barrier Materials
- 6.3.63 95-52, Supp. 1: Fire Endurance Test Results for Electrical Raceway Fire Barrier Systems Constructed From 3M Company Interam Fire Barrier Materials
- 6.3.64 96-23: Fire in Emergency Diesel Generator Exciter During Operation Following Undetected Fuse Blowing
- 6.3.65 97-01: Improper Electrical Grounding Results in Simultaneous Fires in The Control Room and The Safe- Shutdown Equipment Room
- 6.3.66 97-23: Evaluation and Reporting of Fires and Unplanned Chemical Reactor Events at Fuel Cycle Facilities
- 6.3.67 97-37: Main Transformer Fault with Ensuing Oil Spill Into Turbine Building
- 6.3.68 97-48: Inadequate or Inappropriate Interim Fire Protection Compensatory Measures
- 6.3.69 97-59: Fire Endurance Test Results of Versawrap Fire Barriers
- 6.3.70 97-70: Potential Problems with Fire Barrier Penetration Seals
- 6.3.71 97-72: Potential for Failure of the Omega Series Sprinkler Heads
- 6.3.72 97-73: Fire Hazard in the Use of a Leak Sealant
- 6.3.73 97-82: Inadvertent Control Room Halon Actuation Due to a Camera Flash

#### **6.4 OTHER RELATED DOCUMENTS**

- 6.4.1 10 CFR 50.48 Fire Protection (45 FR 76602)
- 6.4.2 10 CFR 50 Appendix A GDC 3 Fire Protection
- 6.4.3 10 CFR 50 Appendix R Fire Protection for Operating Nuclear Power Plants
- 6.4.4 Branch Technical Position APCS 9.5-1 Guidelines for Fire Protection
- 6.4.5 Appendix A to Branch Tech Position 9.5-1 Guidelines for Fire Protection
- 6.4.6 NUREG-0800 9.5.1 Fire Protection Program

- 6.4.7 NRC Insp. Procedure 64100 Post-fire Safe Shutdown, Emergency Lighting, Oil Collection
- 6.4.8 NRC Insp. Procedure 64150 Triennial Post-fire Safe Shutdown Capability
- 6.4.9 NRC Insp. Procedure 64704 Fire Protection Program
- 6.4.10 NUREG/BR-0195 Enforcement Guidance
- 6.4.11 Regulatory Guide 1.120 Fire Protection Guidelines for Nuclear Power Plants
- 6.4.12 Regulatory Guide 1.120 Rev. 1, Fire Protection Guidelines for Nuclear Power Plants
- 6.4.13 Regulatory Guide 1.189 Fire Protection for Operating Nuclear Power Plants
- 6.4.14 NUREG-0654 Criteria for Preparation of Emergency Response Plans
- 6.4.15 Temporary Instruction 2515/XXX Fire Protection Functional Inspection
- 6.4.16 SECY-82-13B (4/21/82) Fire Protection Schedules and Exemptions
- 6.4.17 SECY-82-267 (6/23/82) FP Rule for Future Plants
- 6.4.18 SECY-83-269 FP Rule for Future Plants
- 6.4.19 SECY-85-306 Recommendations Regarding the Implementation of App R to 10 CFR 50
- 6.4.20 NRC Temp Instruction 2515/62 Inspection of Safe Shutdown Requirements of 10 CFR 50
- 6.4.21 NRC Temp Instruction 2515/61 Inspection of Emergency Lighting & Oil Collection Requirements
- 6.4.22 NUREG-0050, 2/76; Recommendations Related to Browns Ferry Fire
- 6.4.23 NRC Letter (12/82), Position Statement on Use of ADS/LPCI to meet Appendix R Alternate Safe Shutdown Goals, discusses need for exemption if core uncover occurs.
- 6.4.24 SECY-93-143 Assessment of Fire Protection Programs
- 6.4.25 SECY-95-034 Re-assessment of Fire Protection Programs
- 6.4.26 SECY-96-134 Fire Protection Regulation Improvement
- 6.4.27 Appendix S Proposed Rulemaking

- 6.4.28 NRC letter to NEI dated March 11, 1997; general subject NRC positions on fire-induced circuit failures issues
- 6.4.29 NEI letter to NRC dated May 30, 1997, general subject industry positions on fire-induced circuit failures issues
- 6.4.30 GE-NE-T43-00002-00-02, Revision 0, “Generic Guidance for BWR Post-Fire Safe Shutdown Analysis,” November 1999
- 6.4.31 NFPA 805, “Performance-Based Standard for Fire Protection for Light Water Reactor Electric Generating Plants,” November 2000 ROP
- 6.4.32 NSAC-179L, “Automatic and Manual Suppression Reliability Data for Nuclear Power Plant Fire Risk Analyses”, February 1994
- 6.4.33 EPRI TR-100370, “Fire-Induced Vulnerability Evaluation (FIVE)”, April 1992
- 6.4.34 EPRI TR-105928, “Fire PRA Implementation Guide”, December 1995
- 6.4.35 ANSI/ANS-52.1-1983 “Nuclear Safety Criteria for the Design of Stationary Boiling Water Reactor Plants” and ANSI/ANS-51.1-1983 “Nuclear Safety Criteria for the Design of Stationary Pressurized Water Reactor Plants”
- 6.4.36 SU-105928, “Guidance for Development of Response to Generic Request for Additional Information on Fire Individual Plant Examination for External Events (IPEEE), a Supplement to EPRI Fire PRA Implementation Guide (TR-105928)” EPRI, March 2000
- 6.4.37 EPRI Report 1006961, “Spurious Actuation of Electrical Circuits Due to Cable Fires: Results of An Expert Elicitation”
- 6.4.38 EPRI Report 1003326, “Characterization of Fire-Induced Circuit Faults: Results of Cable Fire Testing”
- 6.4.39 NRC Memorandum J. Hannon to C. Carpenter, “Proposed Risk-Informed Inspector Guidance for Post-Fire Safe-Shutdown Associated Circuit Inspections,” March 19, 2003, ADAMS Accession Number ML030780326
- 6.4.40 NRC Paper to ANS “Topical Meeting on Operating Reactor Safety, Preliminary Screening of Fire-Induced Circuit Failures for Risk Significance,” November, 2004
- 6.4.41 EPRI Report 1003111, “Fire Events Database and Generic Ignition Frequency Model for U.S. Nuclear Power Plants”
- 6.4.42 NRC Inspection Manual Chapter 0609, Appendix F, “Fire Protection Significance Determination Process,” May 2004

- 6.4.43 NEI 00-01, Revision 0, “Guidance for Post-Fire Safe Shutdown Analysis,” May 2003
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## **6.5 ADMINISTRATIVE LETTERS**

- 6.5.1 95-06 Relocation of Technical Specification Administrative Controls

## **6.6 REGULATORY ISSUE SUMMARIES**

- 6.6.1 2004-03, Risk-Informed Approach for Post-Fire Safe-Shutdown Associated Circuit Inspection

## ATTACHMENT 1

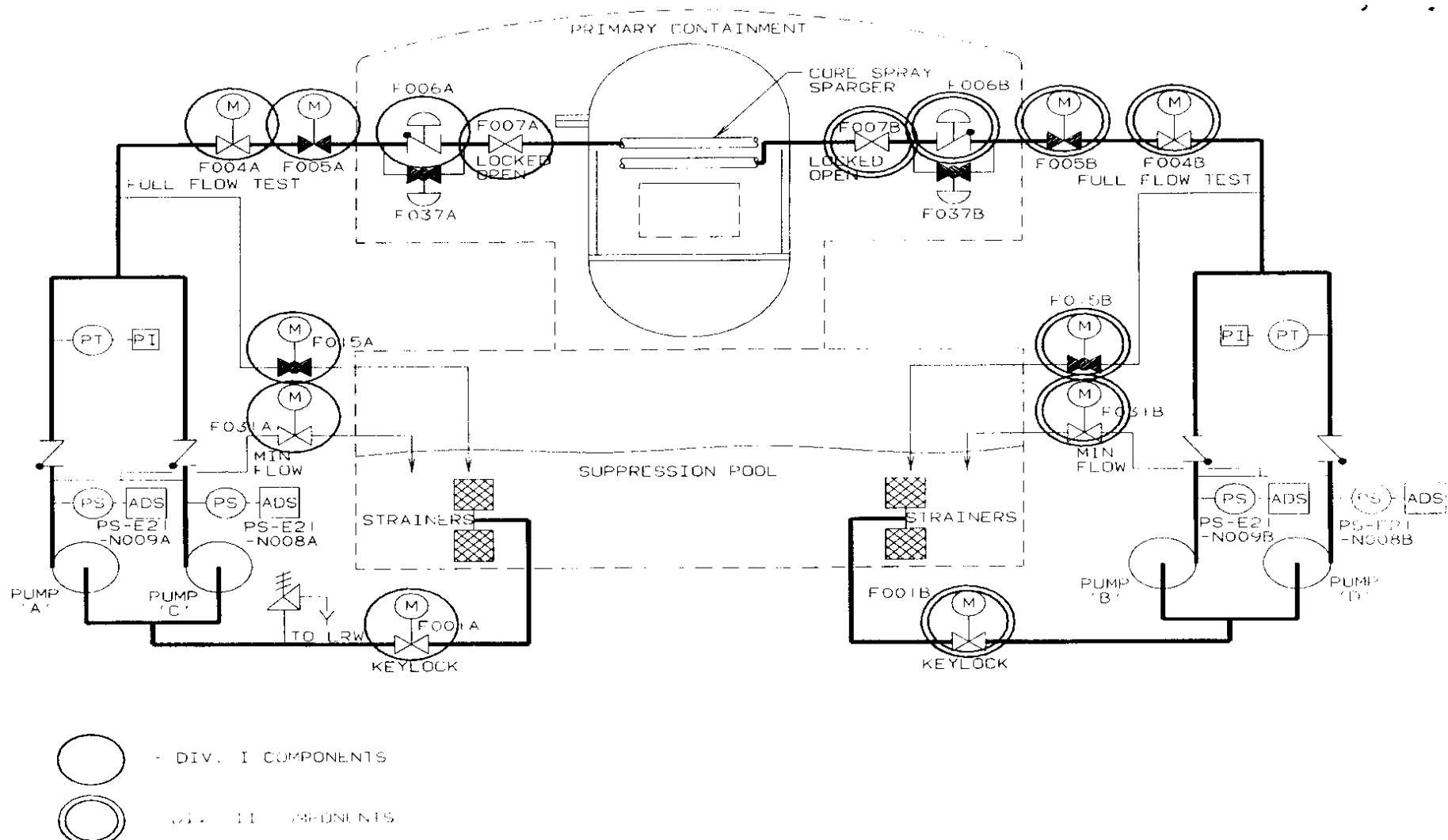
### EXAMPLE OF TYPICAL BWR SAFE SHUTDOWN PATH DEVELOPMENT

Safe Shutdown Path 1	Safe Shutdown Path 2	Safe Shutdown Path 3
<u><b>Reactivity Control</b></u>	<u><b>Reactivity Control</b></u>	<u><b>Reactivity Control</b></u>
CRD (Scram Function) Manual Scram and/or Operator Manual Action to remove RPS Power or to vent the instrument air header	CRD (Scram Function) Manual Scram and/or Operator Manual Action to remove RPS Power or to vent the instrument air header	CRD (Scram Function) Manual Scram and/or Operator Manual Action to remove RPS Power or to vent the instrument air header
<u><b>Pressure Control</b></u>	<u><b>Pressure Control</b></u>	<u><b>Pressure Control</b></u>
Manual ADS/SRVs using available Control Room and Remote Switches	SRVs using the available Remote Shutdown Panel and Remote Switches	Manual ADS/SRVs using available Control Room and Remote Switches
<u><b>Inventory Control</b></u>	<u><b>Inventory Control</b></u>	<u><b>Inventory Control</b></u>
Core Spray	RCIC RHR LPCI	RHR LPCI
<u><b>Decay Heat Removal</b></u>	<u><b>Decay Heat Removal</b></u>	<u><b>Decay Heat Removal</b></u>
RHR Supp. Pool Cooling Mode Service Water Core Spray, Alt. SDC Mode	RHR Supp. Pool Cooling Mode Service Water RHR Shutdown Cooling Mode	RHR Supp. Pool Cooling Mode Service Water RHR, Alt. SDC Mode
<u><b>Process Monitoring</b></u>	<u><b>Process Monitoring</b></u>	<u><b>Process Monitoring</b></u>
Supp. Pool Monitoring Nuc. Boiler Instru.	Supp. Pool Monitoring Nuc. Boiler Instru.	Supp. Pool Monitoring Nuc. Boiler Instru.
<u><b>Associated Support Functions</b></u>	<u><b>Associated Support Functions</b></u>	<u><b>Associated Support Function</b></u>
<u><b>Cooling Systems</b></u>	<u><b>Cooling Systems</b></u>	<u><b>Cooling Systems</b></u>
RHR Room Coolers	RHR Room Coolers RCIC Room Coolers	RHR Room Coolers
Service Water Pumphouse HVAC EDG HVAC	Service Water Pumphouse HVAC EDG HVAC	Service Water Pumphouse HVAC EDG HVAC
<u><b>Electrical</b></u>	<u><b>Electrical</b></u>	<u><b>Electrical</b></u>
EDGs or Offsite Power Electrical Distribution Equipment	EDGs or Offsite Power Electrical Distribution Equipment	EDGs or Offsite Power Electrical Distribution Equipment



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## ATTACHMENT 2: ANNOTATED P&ID SSD SYSTEM PATHS [BWR EXAMPLE]



### Attachment 3: Example of Safe shutdown equipment (Sorted by Equipment ID)

[illegible]

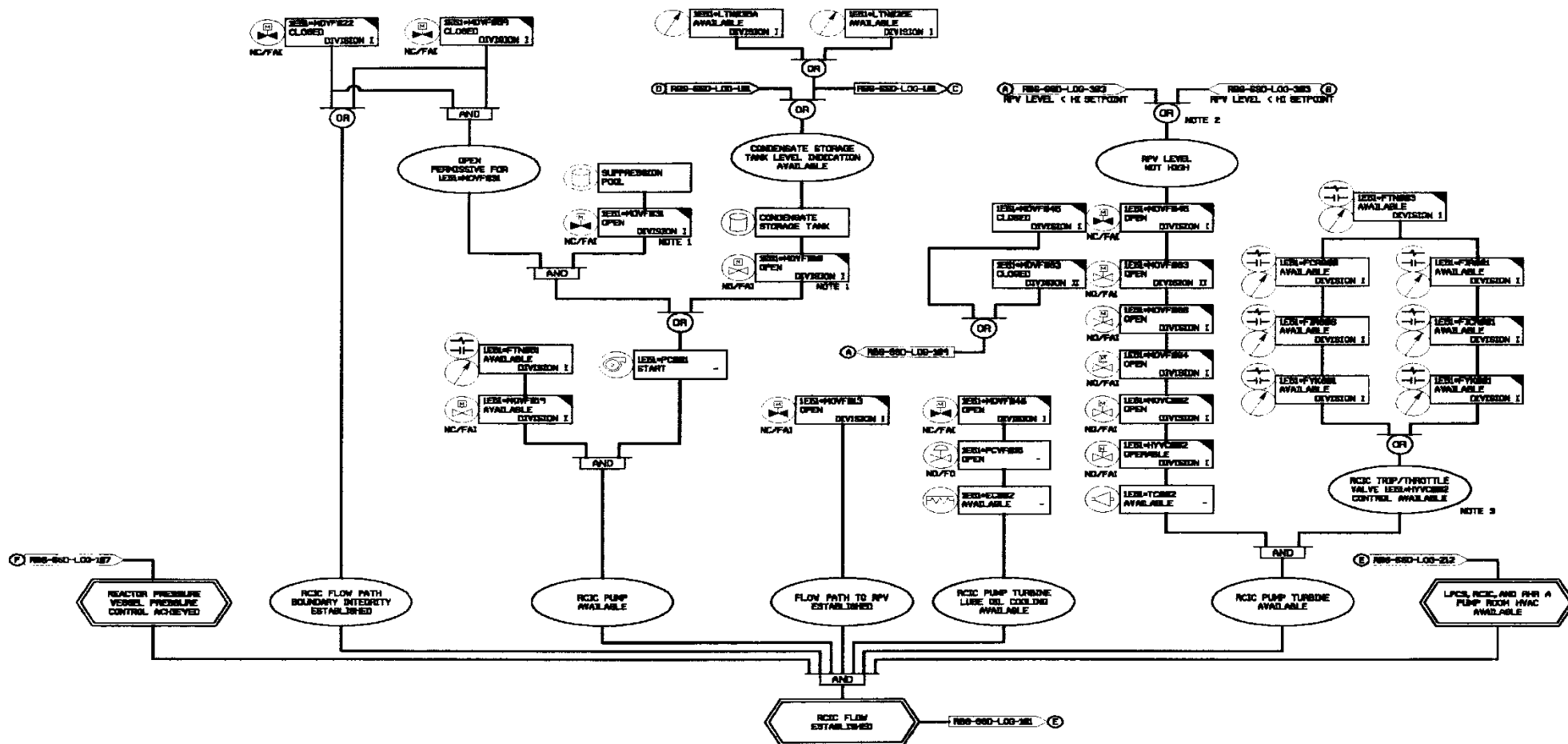
### **Attachment 3**

#### **(Continued)**

A description of the Safe Shutdown Equipment List column headings is provided as follows:

<b>Equipment ID</b>	Identifies the equipment/component ID No. from the P&ID or one line diagram.
<b>Logic Diagram</b>	Identifies a safe shutdown logic diagram reference that may illustrate the relationship between the equipment and other system components
<b>System</b>	Identifies the Appendix R Post-Fire Safe Shutdown System of which the equipment is part.
<b>Unit</b>	Identifies the Unit(s) that the equipment supports.
<b>Equipment Type</b>	Identifies the type of equipment (e.g., MOV, pump, SOV).
<b>SSD Path</b>	Identifies the safe shutdown path(s) for which the equipment is necessary to remain functional or not mal-operate.
<b>Equipment Description</b>	Provides a brief description of the equipment.
<b>Equip FA</b>	Identifies the fire area where the equipment is located.
<b>Normal Mode</b>	Identifies the position or mode of operation of the equipment during normal plant operation.
<b>Shutdown Mode(s)</b>	Identifies the position or mode of operation of the equipment during shutdown conditions.
<b>High/Low</b>	Identifies whether the equipment is considered part of a high/low pressure interface.
<b>Air Fail</b>	If applicable, identifies the position of equipment resulting from a loss of air supply.
<b>Power Fail</b>	Identifies the position of equipment resulting from a loss of electrical power.
<b>Reference</b>	Identifies a primary reference drawing (P&ID or electrical) on which the equipment can be found

## ATTACHMENT 4: SAFE SHUTDOWN LOGIC DIAGRAM [BWR EXAMPLE]



## ATTACHMENT 5: EXAMPLE OF AFFECTED EQUIPMENT REPORT

*(Sorted by Fire Area, System, Unit & Equipment ID – [other sorts may also be useful])*

Fire Area:			Required Path(s):				FA Description:					Suppression:				Detection:			
System	Unit	Logic Diagram	Equipment ID	Equip Type	SSD Path	Equip FA	Equipment Description		Normal Mode	Shutdown Mode(s)	High/ Low	Air Fail	Power Fail	Disp Code	Compliance Strategy				


## Attachment 5 (Continued)

A description of the Affected Equipment Report column headings is provided as follows:

<b>Fire Area</b>	Identifies the fire area where the equipment or cables are located.
<b>Required Path(s)</b>	Identifies the safe shutdown path(s) relied upon to achieve safe shutdown in the fire area.
<b>FA Description</b>	Provides a brief description of the fire area.
<b>Suppression</b>	Identifies the type of fire suppression (e.g., manual, auto, none) within the fire area.
<b>Detection</b>	Identifies the type of fire detection within the fire area.
<b>System</b>	Identifies the Appendix R Post-Fire Safe Shutdown System of which the equipment is part.
<b>Unit</b>	Identifies the Unit(s) that the equipment supports.
<b>Logic Diagram</b>	Identifies a safe shutdown logic diagram reference that may illustrate the relationship between the equipment and other system components
<b>Equipment ID</b>	Identifies the equipment/component ID No. from the P&ID or one line diagram.
<b>Equip Type</b>	Identifies the type of equipment (e.g., MOV, pump, SOV).
<b>SSD Path</b>	Identifies the safe shutdown path(s) for which the equipment is necessary to remain functional or not mal-operate.
<b>Equip FA</b>	Identifies the fire area where the equipment is located.
<b>Equipment Description</b>	Provides a brief description of the equipment.
<b>Normal Mode</b>	Identifies the position or mode of operation of the equipment during normal plant operation.
<b>Shutdown Mode(s)</b>	Identifies the position or mode of operation of the equipment during shutdown conditions.
<b>High/Low</b>	Identifies whether the equipment is considered part of a high/low pressure interface.
<b>Air Fail</b>	If applicable, identifies the position of equipment resulting from a loss of air supply.
<b>Power Fail</b>	Identifies the position of equipment resulting from a loss of electrical power.
<b>Disp Code</b>	A code that corresponds to specific compliance strategies and enables sorting and grouping of data.
<b>Compliance Strategy</b>	A brief discussion of the method by which the equipment is resolved to meet Appendix R compliance.

## ATTACHMENT 6: EXAMPLE OF FIRE AREA ASSESSMENT REPORT

*(Sorted by Fire Area, System, Unit & Equipment ID – [other sorts may also be useful])*

Fire Area:			Required Path(s):				FA Description:					Suppression:				Detection:			
System	Unit	Logic Diagram	Equipment ID	Equip Type	SSD Path	Equip FA	Equipment Description		Normal Mode	Shutdown Mode(s)	High/ Low	Air Fail	Power Fail	Disp Code	Compliance Strategy				




## Attachment 5 (Continued)

A description of the Affected Equipment Report column headings is provided as follows:

<b>Fire Area</b>	Identifies the fire area where the equipment or cables are located.
<b>Required Path(s)</b>	Identifies the safe shutdown path(s) relied upon to achieve safe shutdown in the fire area.
<b>FA Description</b>	Provides a brief description of the fire area.
<b>Suppression</b>	Identifies the type of fire suppression (e.g., manual, auto, none) within the fire area.
<b>Detection</b>	Identifies the type of fire detection within the fire area.
<b>System</b>	Identifies the Appendix R Post-Fire Safe Shutdown System of which the equipment is part.
<b>Unit</b>	Identifies the Unit(s) that the equipment supports.
<b>Logic Diagram</b>	Identifies a safe shutdown logic diagram reference that may illustrate the relationship between the equipment and other system components
<b>Equipment ID</b>	Identifies the equipment/component ID No. from the P&ID or one line diagram.
<b>Equip Type</b>	Identifies the type of equipment (e.g., MOV, pump, SOV).
<b>SSD Path</b>	Identifies the safe shutdown path(s) for which the equipment is necessary to remain functional or not mal-operate.
<b>Equip FA</b>	Identifies the fire area where the equipment is located.
<b>Equipment Description</b>	Provides a brief description of the equipment.
<b>Normal Mode</b>	Identifies the position or mode of operation of the equipment during normal plant operation.
<b>Shutdown Mode(s)</b>	Identifies the position or mode of operation of the equipment during shutdown conditions.
<b>High/Low</b>	Identifies whether the equipment is considered part of a high/low pressure interface.
<b>Air Fail</b>	If applicable, identifies the position of equipment resulting from a loss of air supply.
<b>Power Fail</b>	Identifies the position of equipment resulting from a loss of electrical power.
<b>Disp Code</b>	A code that corresponds to specific compliance strategies and enables sorting and grouping of data.
<b>Compliance Strategy</b>	A brief discussion of the method by which the equipment is resolved to meet Appendix R compliance.

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## **APPENDIX A**

### **SAFE SHUTDOWN ANALYSIS AS PART OF AN OVERALL FIRE PROTECTION PROGRAM**

#### **A.1 PURPOSE**

This appendix discusses the significant improvements that have been made within nuclear industry fire protection programs since the Browns Ferry fire. The discussion will include what defense-in-depth features, in aggregate, constitute a complete and comprehensive fire protection program and what part the safe shutdown analysis plays in that aggregate.

#### **A.2 INTRODUCTION**

Each licensee's fire protection program is based on the concept of defense-in-depth. The Appendix R safe shutdown assumptions related to fire intensity and damage potential represent a conservative design basis in that they postulate conditions significantly beyond those that are ever expected to occur based on the existing defense-in-depth plant features. Fire damage and equipment failures, to the extent postulated in an Appendix R safe shutdown analysis, have never been experienced in an operating U.S. nuclear power plant. The worst-case fire ever experienced in a U.S. nuclear power plant was in 1975 at the Browns Ferry Nuclear Power Plant Unit 1. Changes made in the design of U.S. nuclear power plants since this fire have significantly improved the fire safety of these units such that the sequence of events that occurred at Browns Ferry is not expected to recur.

The sections that follow discuss the Brown's Ferry fire, the investigation of that fire, the recommendations made to prevent recurrence of such a fire and the improvement made by the U.S. nuclear power industry relative to these recommendations.

#### **A.3 OVERVIEW**

##### **A.3.1 Browns Ferry Fire: Regulatory History**

In March of 1975, a fire occurred at the Browns Ferry Nuclear Plant Unit 1. Due to unusual circumstances, the fire was especially severe in its outcome and resulted in considerable loss of systems and equipment with temporary unavailability of systems that would normally be utilized to safely shut down the plant for such events.

The severity of the fire caused the NRC to establish a review group that evaluated the need for improving the fire protection programs at all nuclear plants. The group found serious design inadequacies regarding general fire protection at Browns Ferry and recommended improvements in its report, NUREG-0050, "Recommendations Related to Browns Ferry Fire" issued in February 1976. This report also recommended development of specific guidance for implementation of fire protection regulation, and for a comparison of that guidance with the fire protection programs at each nuclear facility.

The NRC developed technical guidance from the recommendations set forth in the NUREG and issued those guidelines as Branch Technical Position (BTP) APCS 9.5-1, "Guidelines for Fire Protection for Nuclear Power Plants," May 1976. The NRC asked each licensee to compare their operating reactors or those under construction with BTP APCS 9.5-1 requirements and, in September 1976, informed the licensees that the guidelines in Appendix A of the BTP would be used to analyze the consequences of a fire in each plant area.

In September 1976, the NRC requested that licensees provide a fire hazards analysis that divided the plant into distinct fire areas and show that systems required to achieve and maintain cold shutdown are adequately protected against damage by a fire. Early in 1977 each licensee responded with a fire protection program evaluation that included a Fire Hazards Analysis. These evaluations and analyses identified aspects of licensees' fire protection programs that did not conform to the NRC guidelines. Thereafter, the staff initiated discussions with all licensees aimed at achieving implementation of fire protection guidelines by October 1980. The NRC staff has held many meetings with licensees, has had extensive correspondence with them, and has visited every operating reactor. As a result, many fire protection open items were resolved, and agreements were included in fire protection Safety Evaluation Reports issued by the NRC.

By early 1980, most operating nuclear plants had implemented most of the basic guidelines in Appendix A of the BTP. However, as the Commission noted in its Order of May 23, 1980, the fire protection programs had some significant problems with implementation. Several licensees had expressed continuing disagreement with the recommendations relating to several generic issues. These issues included the requirements for fire brigade size and training, water supplies for fire suppression systems, alternative and dedicated shutdown capability, emergency lighting, qualifications of seals used to enclose places where cables penetrated fire barriers, and the prevention of reactor coolant pump lubrication system fires. To resolve these contested subjects consistent with the general guidelines in Appendix A to the BTP, and to assure timely compliance by licensees, the NRC, in May of 1980, issued a fire protection rule, 10 CFR 50.48 and 10 CFR 50 Appendix R. NRC described this new rule as setting forth minimum fire protection requirements for the unresolved issues. The fire protection features addressed in the 10 CFR 50 Appendix R included requirements for safe shutdown capability, emergency lighting, fire barriers, fire barrier penetration seals, reactor coolant pump lubrication system, and alternative shutdown systems.

Following the issuance of Appendix R, the NRC provided guidance on the implementation of fire protection requirements and Appendix R interpretations at nuclear plants through Generic Letters, regional workshops, question and answer correspondence and plant specific interface. This guidance provided generic, as well as specific, analysis criteria and methodology to be used in the evaluation of each individual plant's post-fire safe shutdown capability.

### **A.3.2 Fire Damage Overview**

The Browns Ferry fire was a moderate severity fire that had significant consequences on the operator's ability to control and monitor plant conditions. Considerable damage was

done to plant cabling and associated equipment affecting vital plant shutdown functions. The fire burned, uncontrolled, while fire-fighting efforts, using CO<sub>2</sub> and dry chemical extinguishers, continued for approximately 7 hours with little success until water was used to complete the final extinguishing process.

During the 7-hour fire event period, the plant (Unit 1) experienced the loss of various plant components and systems. The loss of certain vital systems and equipment hampered the operators' ability to control the plant using the full complement of shutdown systems. The operators were successful in bringing into operation other available means to cool the reactor. Since both Units 1 and 2 depended upon shared power supplies, the Unit 2 operators began to lose control of vital equipment also and were forced to shut down. Since only a small amount of equipment was lost in Unit 2, the shutdown was orderly and without incident.

The results of the Browns Ferry fire event yielded important information concerning the effects of a significant fire on the ability of the plant to safely shut down. Although the Browns Ferry fire event was severe and the duration of the fire and the loss of equipment were considerable, the radiological impact to the public, plant personnel and the environment was no more significant than from a routine reactor shutdown. At both Unit 1 and Unit 2, the reactor cores remained adequately cooled at all times during the event.

Due to numerous design and plant operational changes implemented since 1975, including post-TMI improvements in emergency operating procedures, nuclear power plants in operation today are significantly less vulnerable to the effects of a fire event such as that experienced at Browns Ferry. Since 1975, a wide range of fire protection features, along with regulatory and industry guided design and procedural modifications and enhancements, has been implemented. The combination of these upgrades has resulted in a significant increase in plant safety and reliability, and, along with preventative measures, they help to ensure that events similar in magnitude to the Browns Ferry fire will not occur again. The improvements in plant design and procedural operations incorporated since the Browns Ferry fire are described below. The designs and operating procedures that existed at Browns Ferry at the time of the fire are also detailed.

### **A.3.3 Causes of the Browns Ferry Fire, its Severity and Consequences**

The following factors contributed directly to the severity and consequences of the Browns Ferry fire.

- Failure to evaluate the hazards involved in the penetration sealing operation and to prepare and implement controlling procedures.
- Failure of workers to report numerous small fires experienced previously during penetration sealing operations, and failure of supervisory personnel to recognize the significance of those fires that were reported and to take appropriate corrective actions.
- Use of an open flame from a candle (used to check for air leaks) that was drawn into polyurethane foam seal in a cable penetration between the Reactor Building and the cable spreading room.

- Inadequate training of plant personnel in fire-fighting techniques and the use of fire-fighting equipment (e.g., breathing apparatus, extinguishers and extinguishing nozzles).
- Significant delay in the application of water in fighting the fire.
- Failure to properly apply electrical separation criteria designed to prevent the failure of more than one division of equipment from cable tray fires. Examples are:
  - Safety-related redundant divisional raceways were surrounded by non-safety related raceways that became combustible paths routed between divisions (i.e., even though separation between redundant division cable trays was consistent with the specified horizontal and vertical required distances, the intervening space was not free of combustibles as required by the existing electrical separation criteria).
  - Contrary to electrical separation criteria, one division of safety related cabling was not physically separated from the redundant division due to cabling of one division routed in conduit within the “zone of influence” of the open redundant division cable tray. Proper application of electrical separation criteria requires that a tray cover or other barrier be installed on the top and/or bottom of the open redundant raceway or between redundant raceways to contain the fire within the open tray and not affect redundant division conduits.
  - Failure to properly separate redundant equipment indicating light circuits, leading to the loss of redundant equipment necessary for safe plant shutdown.
- Cabling utilized within the Browns Ferry raceway system included cable jacket and insulation materials that were less resistant to fire propagation (e.g., PVC, nylon, polyvinyl, nylon-backed rubber tape, and neoprene).

#### **A.3.4 Fire Protection Program Improvements Since Browns Ferry**

The Browns Ferry nuclear facility generally conformed to the applicable fire protection and electrical separation criteria and guidelines that existed when it was licensed to operate by the NRC in 1968. However, the 1975 fire identified a number of areas concerning fire protection design, plant operating criteria, electrical separation and defense-in-depth considerations that required improvement. As described above, the NRC provided the industry with guidance for improvement of fire protection programs through BTP APCSB 9.5-1, Appendix A, 10 CFR 50 Appendix R and other related regulatory correspondence. The improvements addressed in NRC guidance are as follows:

##### **1. Fire Prevention Features:**

- Fire hazards, both in-situ and transient, are identified and eliminated where possible, and/or protection is provided.
- Sufficient detection systems, portable extinguishers, and standpipe and hose stations have been provided. These systems are designed, installed, maintained, and tested by qualified fire protection personnel.

- Ignition sources controlled.

## **2. Fire Protection Features:**

- Fire barriers and/or automatic suppression systems have been installed to protect the function of redundant systems or components necessary for safe shutdown.
- Surveillance procedures have been established to ensure that fire barriers are in place and that fire suppression systems and components are operable.
- Water supplies for fire protection features have been added, both for automatic and manual fire-fighting capability.
- Automatic fire detection systems have been installed with the capability of operating with or without offsite power availability.
- Emergency lighting units with at least 8 hours' battery capacity were provided in those areas where safe shutdown system control was necessary as well as in access and egress areas thereto.
- Fire barrier qualification programs have been established to qualify and test prospective barrier materials and configurations to ensure that their fire endurance and resistivity is acceptable.

## **3. Fire Hazards Control:**

- Administrative controls have been established to ensure that fire hazards are minimized.
- The storage of combustibles in safe shutdown areas has been prohibited or minimized. Designated storage areas for combustibles have been established.
- Transient fire loads such as flammable liquids, wood and plastic have been limited.
- The use of ignition sources is controlled through procedures and permits.
- Controls for the removal of combustibles from work areas, following completion of work activities, have been established.
- Proposed work activities are reviewed by in-plant fire protection staff for impacts on fire protection.
- Noncombustible or less flammable materials including penetration seals, cable jackets, fire retardant wood products, etc., are being used.
- Self-closing fire doors have been installed.
- Oil collection systems have been installed for reactor coolant pumps for containments that are not inerted.

## **4. Fire Brigade/Training:**



- Site fire brigades have been established to ensure adequate manual firefighting capability is available.
- A fire brigade training program has been established to ensure that the capability to fight potential fires is maintained. Classroom instruction, firefighting practice and fire drills are performed at regular intervals.
- Fire brigade training includes:
  - Assignment of individual brigade member responsibilities
  - The toxic and corrosive characteristics of expected products of combustion
  - Identification and location of firefighting equipment
  - Identification of access and egress routes
  - Proper use of firefighting equipment to be used for electrical equipment fires, fires in cable trays and enclosures, hydrogen fires, flammable liquids fires, hazardous chemical fires, etc.
  - Proper use of communication, emergency lighting, ventilation and breathing equipment
  - Review of detailed firefighting strategies and procedures.

## **5. Post-Fire Safe Shutdown Capability**

- Strengthening class 1E separation criteria, (IEEE 384) to more explicitly address fire considerations, and to require evidence of acceptability for isolation devices.
- A comprehensive post fire safe shutdown analysis program, using the methodology and criteria similar to those described in this report, has been established to ensure that post-fire safe shutdown capability is provided.
- Fire damage is limited so that one train of safe shutdown equipment necessary to achieve and maintain hot shutdown is protected and free from fire damage.
- Cabling for redundant trains of safe shutdown equipment is separated by 1- or 3-hour fire rated barriers. In areas where 1-hour rated barriers are used, additional protection is provided by fire detection and an automatic suppression system.
- Twenty feet of separation, containing no intervening combustibles, is provided in lieu of barriers, where applicable. Additional protection is provided by fire detection and an automatic suppression system
- Where redundant trains of equipment, necessary for post-fire safe shutdown, are located in the same fire area and adequate protection for one train cannot be achieved, an alternative or dedicated fire safe shutdown system has been established as follows:

Alternative or dedicated fire safe shutdown systems are capable of achieving and maintaining sub-critical reactivity conditions in the reactor, maintaining reactor coolant inventory, achieving cold shutdown conditions within 72 hours and maintaining cold shutdown conditions thereafter.

- Process monitoring instrumentation is provided with the capability of directly monitoring those process variables necessary to perform and control post-fire safe shutdown functions.
- Supporting functions (cooling, lubrication, HVAC, etc.) necessary to ensure continued operation of post-fire safe shutdown systems/equipment are provided.

#### **A.4 CONCLUSION**

The changes made to the plant fire protection programs in response to the Browns Ferry fire as described above provide reasonable assurance that the plant design and operation will be safe from the effects of fire. When these changes are integrated into an approach similar to that outlined in the body of this document for assuring the ability to achieve and maintain post-fire safe shutdown, the result is a significantly enhanced plant design with emphasis on precluding any unacceptable consequences resulting from plant fires.

#### **A.5 REFERENCES**

- A.5.1 Branch Technical Position BTP APCSB 9.5-1, "Guidelines for Fire Protection for Nuclear Power Plants," May 1976
- A.5.2 NUREG-0050, "Recommendations Related to Browns Ferry Fire" issued in February 1976
- A.5.3 10 CFR 50.48 Fire Protection (45 FR 76602)
- A.5.4 10 CFR 50 Appendix R Fire Protection for Operating Nuclear Power Plants
- A.5.5 Browns Ferry Nuclear Plant, Regulatory Inspection Report 50-259/75-1 and 50-260/75-1, dated 07/25/1975

## **APPENDIX B: DETERMINISTIC CIRCUIT FAILURE CRITERIA**

### **B.1 PURPOSE**

The purpose of this appendix is to provide the basis for the criteria for evaluating circuit failures as outlined in Section 3.5. This appendix serves to identify the types of circuit failures that need to be considered as part of a post-fire safe shutdown analysis, including the analysis of MSOs. It also identifies how these circuit failure types need to be considered in the various circuit types employed in a nuclear power plant. In addition, a sub-appendix provides information supporting the elimination of multiple high impedance faults (MHIFs) from a plant's analysis. Since the circuit failure criteria required to be considered in a post-fire safe shutdown analysis are not specifically defined in the regulations and since numerous circuit failure criteria have historically been used, reference to and analysis of Industry and NRC sponsored fire cable test results is used to define the criteria to be used in performing an evaluation of fire-induced circuit failures, including MSOs.

A significant contribution to the understanding of the types and numbers of fire-induced circuit failures necessary to be considered in a post-fire safe shutdown analysis came from the work performed by NRC Research and EPRI that is documented in NUREG/CR 7150 Volumes 1, 2 and 3. The results of this effort are discussed in this Appendix and summarized in Appendix J to this document.

The fire-induced circuit failure criteria used in the post-fire safe shutdown analysis is only one component of the defense-in-depth provided by a Fire Protection Program in an operating Nuclear Power Plant. It is the combination of all aspects of the defense-in-depth provided by a Fire Protection Program in an operating Nuclear Power Plant that minimizes the effects of fires on structures, systems and components important to safety as required by Criterion 3 of 10 CFR 50 Appendix A.

### **B.2 INTRODUCTION**

In the 1990's, NRC Staff began to question the validity and level of conservatism associated with the assumption of being able to evaluate and mitigate fire-induced spurious operations on a one-at-a-time basis. This questioning was the genesis for a series of efforts on the part of both the NRC and the Industry to attempt to demonstrate and define the proper set of assumptions to be used for a post-fire SSA. Included within the efforts undertaken by both NRC and the Industry was a series of cable fire tests. The initial cable fire tests were conducted by NEI/EPRI. Subsequent to the NEI/EPRI testing, the NRC conducted the CAROLFIRE cable testing program for AC circuits and the DESIREE cable testing program for DC circuits.

Each of these cable fire testing programs demonstrated that hot shorts resulting in spurious operations were possible. The probabilities developed to capture the likelihood of a hot short resulting in a spurious operation, however, were conditional and based on

the subject cable being damaged by the fire. For thermoset cables, cable damage occurred when the cable temperature reached approximately 600 to 700°F. For thermoplastic cables, cable damage occurred when cable temperatures reached approximately 400 to 500°F. In either of these cases, cable failure was not instantaneous. When cable damage did result in a hot short with the potential to cause a spurious operation, the hot short was typically of short duration. The longest lasting AC hot short was 11.7. The duration of DC hot shorts was longer, with one DC hot short lasting until the cable fire test was stopped.

When the factors listed above are integrated with the actual fire hazards present in an operating nuclear power plant and with the defense-in-depth fire protection programs described above, it can be concluded that the use of a reasonably bounded circuit failure criteria is appropriate.

Given the fact that circuit failures are not likely until temperature conditions in the vicinity of the cable reach elevated temperatures, cables that are located in areas with limited combustibles are very unlikely to fail. A typical nuclear power plant places strict controls on the introduction of in-situ and transient combustibles into plant areas where equipment required for hot shutdown or important to safe shutdown are located.

Additionally, where the in-situ fire hazards are greater, a typical nuclear power plant uses automatic suppression and detection for early identification and suppression of any fire that could occur. The availability of automatic fire suppression in these plant areas will prevent plant temperatures in the area of the hazard from reaching the levels necessary for cable failure.

The likelihood of a fire of a sufficient magnitude to exist in an area that is not properly protected with automatic suppression and detection is remote. When this likelihood is combined with an assumption of having the right two, three or more cables in close proximity to each other in the same area, the likelihood is even smaller. To further postulate that the fire in this area damages each of these cables and, additionally, damages all other unprotected equipment in the plant with the capability to mitigate the effects of the fire, would be to propose a fire-induced circuit failure criteria that is beyond that required to demonstrate the level of reasonable assurance expected and provided in essentially all other aspects of nuclear power plant design.

Due to the presence of a number of mitigating factors in the design of a Nuclear Power Plant, the NRC and Industry cable fire testing programs were designed with the intent of damaging the tested cables and observing the progression of the cable failure modes once the cable was sufficiently damaged. As a result, the cable failures identified and the likelihoods of occurrence assigned to each of the failure modes is conditional on the cable being damaged by the fire. Certainly, the sequence of events leading to actual cable failure in an operating Nuclear Power Plant designed on the basis of Defense-In-Depth Fire Protection would render the likelihood of each of these cable failure types to be a number of orders of magnitude lower than the likelihood of failure given cable damage.

In this appendix, the cable fire test results are examined to justify the changes recommended to the current deterministic criteria historically used for post-fire SSA circuit failures to assure that the effects of MSOs on post-fire safe shutdown are adequately addressed.

## **B.3 CIRCUIT FAILURES CONSIDERED IN DETERMINISTIC ANALYSIS**

### **B.3-1 Overview of Analysis:**

A typical deterministic Appendix R analysis, as described in this document, includes the following steps:

- Identifying Required Safe Shutdown Systems
- Identifying Required Safe Shutdown Equipment
- Identifying Required Safe Shutdown Cables
- Identifying Physical Plant Locations for each
- Assuring **“One”** Safe Shutdown Path with the capability to achieve and maintain safe shutdown in the event of a single plant fire is available for each fire area.

In assuring the availability of a single safe shutdown path in each fire area, the following conservatisms typically apply:

- Fire areas represent large areas of the plant and damage throughout the fire area is assumed.
- All unprotected equipment and cables within the fire area are assumed to be damaged by the fire.
- All unexamined equipment and cables are not credited for mitigating the effects of fires.
- Equipment damage is assumed unless the damage, were it to be postulated, provided a benefit to achieving or maintaining safe shutdown.

In assessing the impact to post-fire safe shutdown in each fire area, the guidance in NEI 00-01 does the following:

- It provides a methodology for identifying equipment and cables of concern for Appendix R Safe Shutdown.
- It provides a means of mitigating every equipment impact and any impacts to the selected combinations of equipment impacts, MSOs, identified in Appendix G.
- It represents an approach that can be consistently applied by licensees throughout the entire industry.

### **B.3-2 Description of Circuits and Circuit Failure Characteristics:**

The types of circuit failures considered in the guidance provided in this document are as follows:

- Open Circuit
- Short-to-Ground
- Hot Short, or for ungrounded circuits a ground fault equivalent hot short (GFEHS)

- High Impedance Fault (NEI CFITF has recommended that consideration of MHIFs in the post-fire safe shutdown analysis be eliminated for circuits with coordinated breakers that are properly tested and maintained. Refer to Appendix B.1)

The types of circuits that can be affected by the circuit failure types described above are as follows:

- Power circuits that provide motive power to components once a control circuit properly aligns the component to its bus.
- Primary control circuits that provide operating signals to specific components.
- Secondary logic circuits that provide input through auxiliary contacts to primary control circuits based on instrumentation feedback from plant instruments.
- Control power to primary control and secondary logic circuits that provide the control power necessary for the primary control power and secondary logic circuits to function.
- Instrument circuits that provide either indication to operators or input to primary control or logic circuits.

For a circuit designed to energize to function, an open circuit will result in a loss of function for the circuit type. [Note: Refer to Appendix I for a description of the considerations for open circuits in circuits designed using “shorting switches” as a means to prevent spurious operations.] For a circuit designed to de-energize to function, an open circuit will result in the fulfillment of the function.

Similarly, a short-to-ground in any of the circuit types described above has the potential to result in a loss of function for the circuit and it has the additional potential to result in loss of power to components powered from electric sources upstream from the affected circuit.

Hot shorts have the potential to energize circuits from a source different than the power source designed for that purpose or from the circuit’s power source for a failure that bypasses a device such as a control switch. For ungrounded circuits, a short to ground on the positive of hot leg of the circuit, or a circuit from a common battery source, coupled with another short to ground above the relay coil, could result in a spurious operation of the component controlled by the ungrounded circuit. This special type of hot short is called a ground fault equivalent hot short (GFEHS) and its effects are identical to that of a hot short on a grounded circuit. As a result, hot shorts have the potential to spuriously start/stop or open/close components. Depending on the affected component and its function within the shutdown scheme, this starting/stopping or opening/closing could pose a potential impact to post-fire safe shutdown. A hot short can cause a circuit to actuate that is designed for that purpose. For example, fire damage can cause conductors running to a control switch to short together replicating the action of circuit control switch. Solenoids valves controlling the opening or closing of valves, for example, also have the potential to experience an undesired change of state as a result of an open circuit or short-to-ground.

Typically, any of the circuit failure types described above, should they be experienced by a component on the required safe shutdown path in a given fire area, will require mitigation. A component on the required safe shutdown path in a given fire area must be able to perform its required safe shutdown function. Since a hot short, a short-to-ground or an open circuit needs to be postulated for any conductor in any affected safe shutdown cable in the fire area and since a short-to-ground or an open circuit will result in a loss of function, little analysis is required to conclude that such a potential cable impact is a concern that needs to be addressed.

Conversely, for components that are not specifically required to function in support of post-fire safe shutdown in a particular fire area, but whose malfunction can result in an impact to the systems and components that must function in support of post-fire safe shutdown, the hot short is the primary circuit failure of concern. This is true because hot shorts have the potential to cause equipment to change state to an undesired position that can result in conditions such as, flow diversions from reactor vessel make-up or decay heat removal systems being used in support of post-fire safe shutdown.

This appendix, in combination with Appendix J, provides criteria for addressing each of the fire-induced circuit failures described above in each of the circuit types described above based on the results of the NRC and Industry cable fire testing. The criteria provided in this appendix apply to the evaluation of MSOs and to the circuit failures for other aspects of post-fire safe shutdown contained in Section 3.

## **B.4 INSIGHTS FROM CABLE FIRE TESTS**

### **B.4-1 NEI/EPRI Cable Fire Testing: [EPRI Report TR1003326]**

The conclusions of the NEI/EPRI Cable Fire Testing are documented in Section 14.4 of EPRI Report 1003326, Characterization of Fire-Induced Circuit Failures. Pertinent Key Observations and Conclusions from the EPRI Report are provided below:

- Given cable damage, single spurious operations are credible and multiple spurious operations cannot be ruled out. External cable hot shorts are also credible, but have a significantly lower probability of occurrence than do internal hot shorts. An important outcome of the tests is that no external cable hot shorts produced a spurious operation in thermoset cable.
- Given that a hot short occurs in a multi-conductor cable, it is highly probable (over 80%) that multiple target conductor cables will be affected (i.e., multiple simultaneous dependent hot shorts).
- The proximity of conductors to each other is the predominant influence factor in determining fault mode. “Opportunity” must exist for two conductors to short together.
- No open circuit faults occurred during the Test Program. Open circuits do not appear to be a credible primary cable failure mode for fire-induced cable faults.
- Statistical characterization of fire-induced cable failures is achievable. General trends are predictable and primary influence factors are understood. However, probability estimates still carry a relatively high uncertainty.

- Definitive predictions of fire-induced circuit failure outcomes are not viable. The specific behavior and characteristics of any one fault cannot be predicted with full certainty. Failure mode is a function of localized conditions and subtle aspects of geometry and configuration. A full understanding of the fault dynamics and interdependencies is beyond the current state of knowledge.
- The dominant influence factors for the likelihood of spurious operations are: cable type; power supply characteristics; tray fill; conductor connection pattern, circuit design (grounded versus ungrounded).
- Cables do not fail immediately. The average time to failure exceeded 30 minutes for thermoset and armored cables and 15 minutes for thermoplastic cables. These statistics are meaningful and important in real world application of test results. The time frames show that early action in a fire is highly likely to be effective at accomplishing the desired function. Preplanned high value actions have a high probability of success and should reduce both likelihood and consequences of serious fires. Similarly, early pre-emptive action for high risk spurious operation components will significantly reduce the risk posed by these components. [**Note:** This result from the NEI cable fire test program is predicated upon a 350 kw fire source located at a specified distance from the cables. Larger fires at closer distances could provide significantly shorter cable failure times.]
- Spurious operations are a transient and finite event; ultimately circuit conditions will degrade to a point that a ground fault de-energizes the source conductor. Postulating that spurious operations will last indefinitely in the absence of intervening action appears to be unrealistic. Probability calculations for thermoset cable indicate that over 96% of all spurious operations will terminate within 10 minutes. This probability estimate carries an uncertainty of approximately 7% at the 95% confidence level. [**Note:** This testing was performed on AC Circuits. Testing on DC Circuits could provide different results. Hot short termination times could be longer.]

#### **B.4-2 CAROLFIRE Cable Fire Testing: [NUREG/CR-6931, Volume 1 & 2]**

The conclusions of the CAROLFIRE Cable Fire Testing are documented in Section 9 of Volume 1 of the CAROLFIRE Test Results. Pertinent Key Observations and Conclusions from the CAROLFIRE Report are provided below:

- The following is Bin 2 Item A as quoted directly from the RIS:

*"Inter-cable shorting for thermoset cables, since the failure mode is considered to be substantially less likely than intra-cable shorting."*

Based on the available data with respect to Bin 2 Item A the CAROLFIRE project has reached the following conclusions:

*Inter-cable shorting between two TS-insulated cables that could cause hot shorts and the spurious operation of plant equipment was found to be a plausible failure mode, although the likelihood of this failure mode is low in comparison to intra-cable short circuits leading to spurious operation. While no detailed statistical analysis has been performed, it appears that the*



*conditional probability (give cable failure) of spurious operations arising from this specific failure mode is small in comparison to that previously estimated for spurious operations from intra-cable shorting.*

- The following is Bin 2 Item B as quoted directly from the RIS:

*"Inter-cable shorting between thermoplastic and thermoset cables, since this failure mode is considered less likely than intra-cable shorting of either cable type or inter-cable shorting of thermoplastic cables."*

Based on the available data with respect to Bin 2 Item B the CAROLFIRE project has reached the following conclusions:

*Inter-cable shorting between two a TP-insulated cable and a TS-insulated cable that could cause hot shorts and the spurious operation of plant equipment was found to be a plausible failure mode, although the likelihood of this failure mode is low in comparison to intra-cable short circuits leading to spurious operation. While no detailed statistical analysis has been performed, it appears that the conditional probability (give cable failure) of spurious operations arising from this specific failure mode is very small in comparison to that previously estimated for spurious operations from intra-cable shorting.*

- The following is Bin 2 Item C as quoted directly from the RIS:

*"Configurations requiring failures of three or more cables, since the failure time and duration of three or more cables require more research to determine the number of failures that should be assumed to be "likely".*

Given the available data relevant to Bin 2 Item C, the CAROLFIRE project has reached the following conclusions:

*The currently available data provide no basis for establishing an a -priori limit to the number of spurious operations that might occur during a given fire. We further find that the timing of spurious operation is a strong function of various case-specific factors including in particular the relative location of various cables relative to the fire source, the routing configuration (e.g., open cable trays or air drops versus conduits), the thermal robustness of the cables insulation material, and the characteristics of the fire source.*

- The following is Bin 2 Item D as quoted directly from the RIS:

*"Multiple spurious operations in control circuits with properly sized control power transformers (CPTs) on the source conductors, since CPTs in a circuit can substantially reduce the likelihood of spurious operation. Specifically, where multiple (i.e., two or more) concurrent spurious operations due to control cable damage are postulated, and it can be verified that the power to each impacted control circuit is supplied via a CPT with a power capacity of no more than 150 percent of the power required to supply the control circuit in its normal mode of operation (e.g., required to power one actuating device and any circuit monitoring or indication features)."*

Given the available data relevant to Bin 2 Item D, the CAROLFIRE project has reached the following conclusions:

*The currently available data provide no basis for establishing an a-priori limit to the number of spurious operations that might occur during a given fire even given that the circuit is powered by a "properly sized" CPT. We further find that, as with non-CPT cases, the timing of spurious operations is dependent on the timing of cable electrical failure which is in turn a strong function of various case-specific factors including the relative location of different cables relative to the fire source, the routing configuration (e.g., open cable trays or air drops versus conduits), the thermal robustness of the cables insulation material, and the characteristics of the fire source.*

- The following is Bin 2 Item E as quoted directly from the RIS:

*"Fire-induced hot shorts that must last more than 20 minutes to impair the ability of the plant to achieve hot shutdown, since recent testing strongly suggests that fire-induced hot shorts will likely self-mitigate (e.g., short to ground) in less than 20 minutes. This is of particular importance for devices such as air-operated valves (AOVs) or power-operated relief valves (PORVs) which return to their de-energize position upon abatement of the fire-induced hot short."*

Given the available data relevant to Bin 2 Item E, the CAROLFIRE project has reached the following conclusions:

*While the available data cannot definitively support the conclusion that no hot short would ever persist for greater than 20 minutes, the available data do provide a strong basis for concluding that hot shorts lasting greater than 20 minutes are of at most very low probability. Hence we conclude that with high probability, hot short-induced spurious operation signals will clear within less than 20 minutes. We further conclude that on clearing of the hot short signal, the effects of the spurious operation on plant equipment could persist for a longer time depending on the nature of the impacted equipment. For example, a normally closed Motor Operated Valve might well remain open or partially open even after the hot short-induced spurious operation signal is mitigated whereas a Solenoid Operated Valve would return to its fail safe condition on mitigation of the hot short-initiated spurious operation signal.*

[Note: Some of the Penlight series tests exhibited longer durations than those exhibited during the Intermediate scale tests. Based on this, consideration should be given to the potential for hot short durations in hot gas layers being longer.]

#### **B.4-3 DESIREE Cable Fire Testing: [NUREG/CR-7100]**

There were five general observations on the behavior of the dc-powered cables as compared to previously tested ac-powered cables that were made through the course of DESIREE-Fire testing that are worthy of note:

- The faulting behavior of the dc-powered cables was more energetic than comparable ac-power cables observed in prior testing efforts. Both ac- and dc-powered cables displayed arcing behavior when short circuits form. However, with the dc-powered cables, the arcs were more substantial, more sustained and more damaging.
- Related to the first observation, short-circuit faulting in the dc-powered cables often led to destructive damage to the cable conductors. That is, it was often observed that the arc formed during faulting was sufficient to sever a conductor or even an entire multi-conductor cable. The effect observed was analogous to welding operations where the welding rods are consumed in the process. This sort of destructive damage was not seen as the result of ac-power cable short circuits. Open circuits are a unique failure mode that was not observed in the ac testing but was common in the dc testing.
- In some cases the dc-powered cables were left energized even after they had experienced destructive damage as described immediately above. This behavior was tied to the fuse sizes used. Typically, the smaller 5A and 10A fuses would clear, de-energizing the conductors once failures occurred. However, as the fuse size increased, it became more common for the conductors to be left severely damaged but still energized. This behavior was not observed for the ac-powered cables, but none of the ac-powered cable tests have used fuses as large as those used in some of the tested dc-powered circuits.
- Corresponding to the prior observation, the positive and negative fuses for any given dc circuit did not necessarily clear at the same time. It was not uncommon to have one blown fuse while the other remained functional. An actively fused conductor could become grounded (through the tray, for example) and a transition of the relative ground potential (i.e., from positive to negative or vice versa) could generate a sufficient amount of current to cause the intact fuse to clear.
- In general, more long-duration HSs and spurious operations were observed for the dc powered circuits than had been observed in corresponding ac-powered circuits.

#### **B.4.4 Overall Implications from the Cable Fire Testing:**

The scope of each of the test reports for the cable fire testing programs was limited to objective reporting of the test data. It was not the intent of this report to interpret the test results beyond a factual representation of the progression of events observed in each test. To provide a proper interpretation and analysis of the test results, the NRC assembled two expert panels whose charter was to interpret the test results and assess their implications for various applications. One panel, the PIRT Panel, focused on the electrical aspects of the data, reference NUREG/CR-7150 Volume 1, and the second panel, the Expert PRA Panel, dealt with the statistical and risk aspects, reference NUREG/CR-7150 Volume 2. Both panels were conducted using the Phenomena Expert Elicitation process. Additionally, at the completion of the work for each of these panels, the NRC assembled a Working Group to review the results of each panel for consistency, to assure that any insights from JACQUE-FIRE Volume 2 were reflected into the determinations made in JACQUE-FIRE Volume 1 and to make final determinations pertinent to the application of the results into the industry guidance for performing a post-

fire safe shutdown circuit analysis, reference NUREG/CR-7150 Volume 3. Any differences between JACQUE-FIRE Volume 1 and Volume 3 based on the insights from JACQUE-FIRE Volume 2 are documented and justified in JACQUE-FIRE Volume 3.

As an interim measure, the Working Group for JACQUE-FIRE Volume 3, (i.e., NUREG/CR-7150 Volume 3), issued interim documents for use by the Industry in revising the Industry Guidance for post-fire safe shutdown circuit analysis and for use by NRR in reviewing for this revised guidance. The results of the work by the Working Group for JACQUE-FIRE Volume 3 have been factored included in this revision to NEI 00-01.

The results of the work performed by the Working Group under JACQUE-FIRE Volume 3 are summarized below:

- The circuit failure criteria outlined in Appendix J are to be applied to the analysis of fire-induced circuit failures in the post-fire safe shutdown analysis. Appendix J has been included as an appendix in NEI 00-01 and the criteria have been incorporated into Section 3.5 of NEI 00-01.
- The duration of a hot short in an AC circuit may be limited to 20 minutes. The duration of a hot short in a DC circuit may be limited to 40 minutes. The criteria for duration of a hot short have been incorporated into Section 3.5 of NEI 00-01.
- Consideration of the effects of reversed polarity on AC and DC solenoid valves, (e.g., double break designs), should be as outlined in NUREG/CR 7150 Volume 3. The criteria for reverse polarity on AC and DC solenoids have been incorporated into Section 3.5 of NEI 00-01.
- MSOs meeting the criteria outlined in NUREG/CR 7150 Volume 3 are considered to be incredible and do not require further consideration in a post-fire safe shutdown analysis. These criteria have been incorporated into Section 3.5 of NEI 00-01.
- Appendix I providing the design considerations for the design of a circuit containing a “shorting switch” has been added as an appendix to NEI 00-01.

## **B.5 CONCLUSIONS RELATIVE TO CIRCUIT FAILURES & MSO's:**

The results of the NEI/EPRI, CAROLFIRE and DESIREE Cable Fire Testing did demonstrate that the previous approach to addressing fire-induced circuit failures on an “any-and-all taken one-at-a-time” basis is not likely to capture all of the fire-induced effects on post-fire safe shutdown systems. Multiple hot shorts can occur as a result of the same single fire. Additionally, multiple components can be impacted by the effects of fire-induced circuit failures resulting from the same single fire. This conclusion requires that changes from the previously applied approach to addressing circuit failures on an “any-and-all taken one-at-a-time” basis needs to be made.

The following changes are recommended based on the information provided by JACQUE-FIRE Volume 3, reference NUREG/CR-7150 Volume 3 as provided in the interim papers provided by the Working Group for JACQUE-FIRE Volume 3.

**Circuit Failure Criteria:** The criteria provided in Appendix J are to be applied to the analysis of fire-induced circuit failures in the post-fire safe shutdown analysis. The design considerations outlined in Appendix I are to be used in the design of “shorting switches” used to prevent fire-induced spurious operations. Additionally, the duration of a hot short in an AC circuit may be limited to 20 minutes. The duration of a hot short in a DC circuit may be limited to 40 minutes. Finally, consideration of the effects of reversed polarity on AC and DC solenoid valves, (e.g., double break designs), should be as outlined in NUREG/CR 7150 Volume 3.

Criteria consistent with that outlined above in Appendix J have been incorporated into Section 3.5 of NEI 00-01. Appendices I and J have been included as appendices in NEI 00-01.

**Spurious Operation Criteria:** The following criteria address the effect of multiple spurious operations of components classified as either “required for hot shutdown” or “important to safe shutdown” on post-fire safe shutdown. These criteria are to be applied to the population of components whose spurious operation has been determined to be possible based on an application of the circuit failure criteria described above when assessing impacts to post-fire safe shutdown capability in any fire area.

- The set of concurrent combinations of spurious operations provided through the MSO Process outlined in Section 4 and the list of MSO contained in Appendix G must be included in the analysis of MSO’s.
- MSOs meeting the criteria outlined in NUREG/CR 7150 Volume 3 are considered to be incredible and do not require further consideration in a post-fire safe shutdown analysis. Criteria consistent with that outlined in NUREG/CR 7150 Volume 3 have been incorporated into Section 3.5 of NEI 00-01.

## **APPENDIX B.1: JUSTIFICATION FOR THE ELIMINATION OF MULTIPLE HIGH IMPEDANCE FAULTS**

### **B.1-1 PURPOSE**

This appendix is provided to demonstrate that the probability of Multiple High Impedance Faults (MHIFs) is sufficiently low such that they do not pose a credible risk to post-fire safe shutdown when certain criteria are met.

This appendix analyzes and characterizes cable fault behavior with respect to the MHIF concern to determine if and under what conditions this circuit failure mode poses a credible risk to post-fire safe shutdown. In this capacity, the MHIF analysis is intended to serve as a generic analysis for a *Base Case* set of conditions. The base case approach is recognized as a viable means of establishing specific boundary conditions for applicability, thereby preserving the integrity of the analysis.

### **B.1-2 INTRODUCTION**

#### **B.1-2.1 Overview**

In 1986 the NRC issued Generic Letter 86-10 [1] to provide further guidance and clarification for a broad range of 10 CFR 50 Appendix R issues. Included in the generic letter was confirmation that the NRC expected utilities to address MHIFs as part of the Appendix R associated circuits analysis.<sup>4</sup> MHIFs are a unique type of common power supply associated circuit issue, as discussed in Section B.1-2.2 below.

Regulatory Guide 1.189 (Section 5.5.2) [2] reiterates the NRC's position that MHIFs should be considered in the evaluation of common power supply associated circuits. Of importance is the regulatory guide's endorsement of IEEE Standard 242, *IEEE Recommended Practices for Protection and Coordination of Industrial and Commercial Power Systems*, [7] as an acceptable means of achieving electrical coordination of circuit protective devices. Confirmation of adequate electrical coordination for safe shutdown power supplies is the primary means of addressing common power supply associated circuits.

#### **B.1-2.2 Defining the MHIF Concern**

The MHIF circuit failure mode is an offshoot of the common power supply associated circuit concern. A common power supply associated circuit is considered to pose a risk to safe shutdown if a fire-induced fault on a non-safe shutdown circuit can cause the loss of a safe shutdown power supply due to inadequate electrical coordination between

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<sup>4</sup> A general discussion of associated circuits is contained in Section 2.2 and 3.3.2 of this guidance document. NRC intends that a future generic communication will clarify associated circuits.

upstream and downstream overcurrent protective devices (e.g., relays, circuit breakers, fuses).

The accepted method for evaluating the potential impact of common power supply associated circuits is a *Coordination Study*. A coordination study involves a review of the tripping characteristics for the protective devices associated with the electrical power distribution equipment of concern – post-fire safe shutdown power supplies in this case. The devices are considered to “coordinate” if the downstream (feeder or branch circuit) device trips before the upstream (supply circuit) device over the range of credible fault current.<sup>5</sup> In conducting a traditional coordination study, each circuit fault is evaluated as a single event.

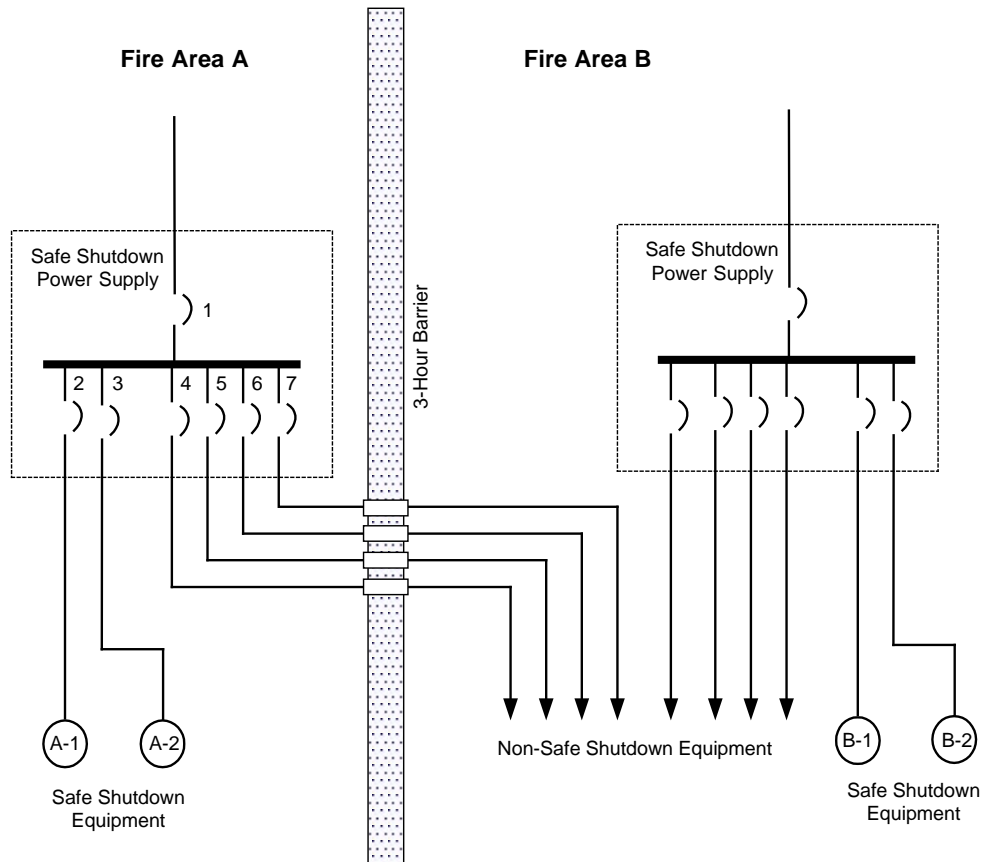
The concept of MHIFs deviates from baseline assumptions associated with conventional electrical coordination. The MHIF failure mode is based on the presumption that a fire can cause short circuits that produce abnormally high currents that are below the trip point of the individual overcurrent interrupting devices for the affected circuits. Faults of this type are defined by Generic Letter 86-10 as *high impedance faults* (HIFs). Under the assumed conditions, circuit overcurrent protective devices will not detect and interrupt the abnormal current flow. Consequently, the fault current is assumed to persist for an indefinite period of time. Since HIFs are not rapidly cleared by protective devices, the NRC position is that simultaneous HIFs should be considered in the analysis of associated circuits. The specific concern is that the cumulative fault current resulting from multiple simultaneous HIFs can exceed the trip point of a safe shutdown power supply incoming protective device, causing it to actuate and de-energize the safe shutdown power supply before the downstream (load-side) protective devices clear individual circuit faults.

Figure B.1-1 illustrates the MHIF failure mode. Note that the description of MHIFs assumes that redundant safe shutdown equipment is affected by the postulated fire. Detailed reviews can be conducted to determine exactly which cables and scenarios are potentially susceptible to MHIFs. However, this type of “spatial” analysis typically involves a highly labor-intensive effort to trace the routing of hundreds of non-safe shutdown cables. Furthermore, ongoing configuration control of such analyses is overly burdensome. For this reason, the preferred means of addressing the issue is at a system performance level, independent of cable routing. The systems approach offers a great deal of conservatism because, in actuality, not all circuits will be routed through every fire area and not all circuits are non-safe shutdown circuits.

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<sup>5</sup> The range of credible fault current includes short circuit current levels up to the maximum possible fault current for the configuration. For simplicity, the maximum credible fault current is usually based on a bolted fault at the downstream device. However, in some cases the maximum credible fault current is refined further by accounting for additional resistance of the cable between the downstream device and the fault location of concern.

**Figure B.1-1  
Example MHIF Sequence**



Safe shutdown components A-1 and B-1 are redundant, as are A-2 and B-2. A fire in Fire Area B is assumed to render B-1 and B-2 inoperable, and thus A-1 and A-2 are credited as available for safe shutdown. Circuit Breakers 4 – 7 supply non-safe shutdown equipment via circuits that traverse Fire Area B. The fire is assumed to create high impedance faults on several of these circuits simultaneously. The nature of the faults is such that an abnormal current is produced in each circuit, but in each case the current is not sufficient to cause the affected branch feeder breaker to trip. The cumulative effect of the fault current flowing in each branch causes the incoming supply breaker (Circuit Breaker 1) to trip before the downstream breakers are able to isolate the individual faults. The safe shutdown power supply is de-energized, causing a loss of power to the credited safe shutdown equipment, A-1 and A-2.



### B.1-2.3 Framework for Resolution

From inception, debate has persisted regarding the technical validity of MHIFs. The NRC's concern with MHIFs can be traced to a November 30, 1984, NRC internal correspondence [3]. The stated purpose of the correspondence was to "...present one paper which can be used in the evaluation of safe shutdown submittals." The paper describes the MHIF issue as an "...expansion on associated circuits" and describes the concern in much the same manner as covered in Section B.1-2.2 above. Noteworthy is that the document limits the issue to AC power circuits. The NRC's concern with MHIFs on AC power circuits does not appear to stem from any specific test data or operating experience. Rather, the concern is voiced as one of conservative judgment for a postulated failure mode in the absence of definitive information to the contrary.

With this understanding as a starting point, the framework for addressing the MHIF issue is based on the following tenets:

- A *Base Case* set of conditions must be defined to ensure the limits of applicability are bounded. Within the defined limits, the MHIF analysis serves as a generic evaluation and is considered to satisfy the regulatory requirement that high impedance faults be considered in the analysis of associated circuits.
- To ensure consistency and agreement in the fundamental bases for analysis, technical positions should be based on and referenced to test results, industry consensus standards, and NRC generated or approved documents. Test data and technical references must be representative of the *Base Case*.
- Elements of the analysis may be probabilistically-based and employ risk-informed arguments. This approach is deemed acceptable within the framework of a deterministic analysis and is not without precedent.<sup>6</sup> However, consistent with risk-informed decision making, consequence of failure shall be addressed by the analysis.
- Analysis uncertainty must be included in the evaluation to ensure conservative application of results.

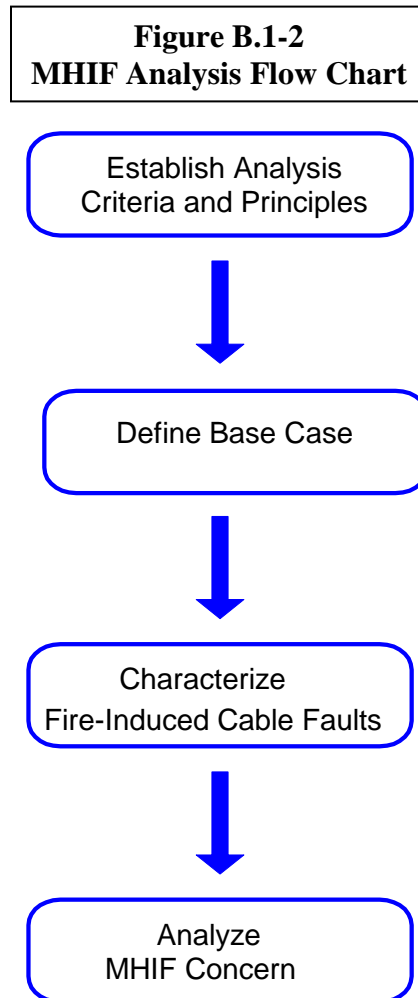
### B.1-3 ANALYSIS METHOD AND APPROACH

The approach for conducting this analysis is depicted by the flow chart of Figure B.1-2. A brief description of each step is provided. The most important aspect of this analysis is the ability to characterize fire-induced cable faults. Research and test data to accomplish this characterization for all voltage levels of interest has until recently been scant, forcing past assessments of MHIFs (both industry and NRC assessments) to make assumptions and extrapolate theories beyond a point that achieved general agreement. Test data from recent industry and NRC fire testing [3, 12] allows fault behavior to be characterized at a level not previously possible. Interpretation of test data and application of analysis results

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<sup>6</sup> Generic Letter 86-10, Question 5.3.1 excludes on the basis of low probability the need to consider three-phase hot shorts and proper polarity hot shorts for ungrounded DC circuits in the analysis of spurious actuations (except for high/low pressure interfaces).

will follow accepted and prudent engineering principles, as set forth by consensus standards and other acknowledged industry references.



**Step 1 – Establish Analysis Criteria and Principles:** Analysis criteria and relevant engineering principles are identified. The rationale behind the analysis criteria is explained and the engineering principles relied upon to evaluate results are documented.

**Step 2 – Define Base Case:** A base case set of conditions is defined. These conditions establish the limits of applicability for the analysis.

**Step 3 – Characterize Fire-Induced Cable Faults:** Relevant fire test data and engineering research are analyzed to characterize fire-induced cable faults. Recent industry and NRC fire tests, as well as other credible industry tests and research studies, are considered in the evaluation.

**Step 4 – Analyze MHIF Concern:** The characteristic behavior of fire-induced faults is considered within the context of the MHIF concern to determine if and under what conditions MHIFs pose a credible risk to post-fire safe shutdown for the defined *Base Case* conditions. Analysis uncertainty is included in the evaluation.

## **B.1-4 ANALYSIS CRITERIA AND PRINCIPLES**

The criteria and engineering principles that form the basis of this analysis are discussed below.

1. The legitimacy of the MHIF concern is centered on the premise that a fire can create HIFs that are not readily detected and cleared by the intended overcurrent protective device [1, 4]. Thus, characterizing the expected behavior of fire-induced faults is paramount in determining the potential risk posed by this failure mode. If fires are able to initiate faults that “hang up” and produce low-level fault currents (near or just below the trip device setting) for extended periods, MHIFs should be considered a viable failure mode. If, however, the faults do not exhibit this behavior, but instead reliably produce detectable fault current flow, a properly designed electrical protection scheme can be relied upon to clear the fault in a timely manner in accordance with its design intent. Based on this principle, the primary line of inquiry for this analysis is to quantitatively characterize fault behavior for the voltage classes of interest. Analysis uncertainty will be included in the assessment to further quantify the results.
2. MHIFs are not usually considered in the design and analysis of electrical protection systems, primarily because operating experience has not shown them to be a practical concern [6, 7, 10]. For this reason, industry has not established nor endorsed any particular analytical approach for MHIFs. Acknowledging the lack of consensus industry standards and conventions, this analysis relies on objective evidence and the application of recognized engineering principles; however, some element of engineering judgment is inevitable because of the unconventional nature of the analysis.
3. As constrained by the *Base Case* requirements, this analysis is considered sufficiently representative of nuclear plant electrical power system and protective device design, construction, and operation:
  - Regardless of make, model, or vintage, electrical protective devices conforming to the *Approval*, application, and test/maintenance requirements specified for the *Base Case* can be expected to function in the manner credited by this analysis [5, 7, 9].
    - Electrical power systems satisfying the design and performance requirements specified for the *Base Case* will respond to electrical faults in the manner assumed by this analysis [6, 7, 10].
4. This analysis assumes that electrical protection and coordination have been achieved following the guidance of ANSI/IEEE 242, or other acceptable criteria. Regulatory Guide 1.189 recognizes this ANSI standard as the primary reference for this subject. A more detailed investigation into supporting references listed by the standard reveals

a substantial number of tests and research studies that have applicability to this MHIF analysis [13 – 22]. These documents provide additional insight into the expected behavior of high resistance electrical faults and accordingly are considered by this analysis. As these documents have essentially shaped the engineering basis for the ANSI/IEEE 242 recommended practices, they are considered viable and credible source references for this analysis.

5. The test data obtained from the recent industry and NRC tests [3, 7] is considered directly applicable to nuclear plant installations. The test parameters (including test specimens, circuit configuration, and physical arrangement) were specifically tailored to mimic a typical nuclear plant installation. The overall test plan was scrutinized by utility and NRC experts before implementation.
6. The actual impedance of a fault can vary widely and depends on many factors. These factors include such things as fault geometry, system characteristics, environmental conditions, and the circumstances causing the fault. Different fault impedances produce different levels of fault current; hence, electrical coordination studies generally consider a range of credible fault currents [7]. Circuit faults resulting from fire damage are highly dynamic, but do exhibit a predictable and repeatable pattern that can be characterized and explained by engineering principles and an understanding of material properties. The same general characteristics have been observed by several different tests and studies [3, 12, 13 – 22].
7. The primary test data relied upon for this MHIF analysis is the recent nuclear industry and NRC fire tests [3, 12]. The electrical circuits for these tests were 120 V, single-phase, limited-energy systems. The analytical results for the 120 V data indicate these low energy circuits behave differently than high-energy circuits operating at distribution level voltages. The bases for this position are:
  - The ability of electrical system hardware to sustain and withstand local fault conditions decreases as the fault energy increases. Highly energetic faults on systems operating above 208 V release tremendous amounts of energy at the fault location. These faults are explosive in nature and will destroy equipment in a matter of seconds, as confirmed by recent industry experience. Conversely, fault energy associated with 120 V, single-phase systems is considerably less punishing to the equipment and will not necessarily cause immediate wide-spread damage.
  - Test results from the recent industry and NRC fire tests confirm a correlation between the rate of localized insulation breakdown and the available energy (applied voltage gradient and available fault current). For example, once insulation degradation began, the rate of breakdown for instrument cable was notably slower than the rate observed for cables powered by 120 V laboratory power supplies. The lower energy circuits are less able to precipitate the cascading failure of insulation that characteristically occurs during the final stages of insulation breakdown because the rate of energy transfer to the fault is lower. The final cascading failure of a 480 V power circuit can be expected to occur within milliseconds, where the final stage of insulation failure for a 120 V circuit might last several seconds, as demonstrated by the test results. Note that the final cascading failure is typically preceded by a period of much slower insulation

degradation. During this phase of degradation, the cable can be expected to exhibit higher levels of leakage current; however, the leakage current levels are not sufficiently high to affect proper operation of power and control circuits. The point at which the slow, low-level degradation transitions to rapid breakdown and failure is termed the transition phase. (Cable failure characteristics are discussed in detail in Section B.1-6.1.)

- Arcing faults become increasingly more likely as system voltage increases because of the higher voltage gradient and longer creepage distances.<sup>7</sup> The “effective” current for arcing faults increases as a function of the applied voltage. A higher fault current will hasten the time for protective action. (The arcing fault phenomena are discussed in detail in Section B.1-6.2.)
8. High impedance faults on conductors of power systems operating at 480 V and above manifest themselves as arcing faults [13 – 22]. Thus, the analysis of postulated HIFs for these systems assumes an arcing fault (detailed discussion contained in Section B.1-6.1). The bases for this position are:
- With respect to cables, distances between energized conductors and between energized conductors and grounded surfaces are not appreciably different from 120 V systems. Thus, as insulation integrity is lost, the high voltage gradient associated with these systems more readily strikes an arc in the absence of a sufficient air gap.
  - As discussed in Item 7 above, the highly energetic nature of faults on higher voltage power systems results in a significant release of energy at the fault location, which rapidly elevates localized temperatures to vaporization levels. This large release of energy at the fault manifests itself in one of three ways:
    - Metal components are fused, thereby creating a bolted fault.
    - Material is vaporized and forcibly ejected, blowing the fault open
    - Material is vaporized and ejected, but the conductive vapor cloud allows an arcing fault to develop, which may or may not be sustained
  - The electrical power industry conducted numerous studies and tests pertaining to faults on high energy electrical power systems in the 1960s and 1970s. These efforts were sparked by a rash of significant property losses and extensive outages resulting from highly damaging electrical faults. These studies significantly increased our understanding of high energy faults and resulted in numerous changes to recommended electrical protection practices (primarily IEEE 242). High impedance, non-arcing faults were not observed by these studies.

## **B.1-5 BASE CASE AND APPLICABILITY**

The intent of defining a *Base Case* is to establish set limits for application of the analysis results. This approach places measurable bounds on the analysis and ensures results are not inadvertently applied to conditions not considered in the study.

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<sup>7</sup> Creepage distance is defined as the shortest distance between two conducting parts measured along the surface of the insulating material.

The following requirements constitute the *Base Case* conditions inherent in this analysis:

- The power supply in question must operate at a nominal AC or DC voltage greater than 110 V. Specifically, this analysis does not apply to AC and DC control power systems operating at 12 V, 24 V, or 48 V. Nor is the analysis applicable to instrument loops regardless of operating voltage.
- For the power supply in question, electrical coordination must exist between the supply-side overcurrent protective device(s) and load-side overcurrent protective devices of concern<sup>8</sup>. Achievement of proper selective tripping shall be based on the guidance of IEEE 242, or other acceptable criteria.
- For 120 V AC and 125 V DC power supplies, in addition to adequate electrical coordination, a minimum size ratio of 2:1 shall exist between the supply-side protective device(s) and load-side devices of concern (for example, a distribution panel with a 50 A main circuit breaker cannot have any load-side breakers larger than 25 A). This stipulation adds additional margin to account for slower protective device clearing times of low-energy circuits.
- The electrical system must be capable of supplying the necessary fault current for sufficient time to ensure predictable operation of the overcurrent protective devices in accordance with their time-current characteristics.
  - Each overcurrent protective device credited for interrupting fault current shall be applied within its ratings, including voltage, continuous current, and interrupting capacity
  - Be *Listed* or *Approved* by a nationally recognized test laboratory (e.g., UL, ETL, CSA, etc.) to the applicable product safety standard (fuses, molded case circuit breakers, circuit protectors, GFI devices) or be designed and constructed in accordance with applicable ANSI and NEMA standards (protective relays, low and medium voltage switchgear)
- Proper operation of the overcurrent devices shall be ensured by appropriate testing, inspection, maintenance, and configuration control.
  - The electrical system associated with the power supply in question shall conform to a recognized grounding scheme. Recognized schemes include solidly grounded, high impedance or resistance grounded, or ungrounded.

## **B.1-6 CHARACTERIZATION OF FAULTS**

### **B.1-6.1 Characterization of Fire-Induced Cable Faults for 120V Systems**

This section contains an analysis of fault behavior for fire-induced faults on single-phase, 120 V systems. The primary source data for the analysis is recent industry and NRC fires tests conducted specifically to characterize fire-induced cable faults.

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<sup>8</sup> Coordination is not required for circuits that are inherently not a common power supply associated circuit of concern – for example, a circuit that is entirely contained within the same fire area as the power supply itself. Similarly, coordination is only required up to the maximum credible fault current for the configuration, which might include an accounting of cable resistance between the load-side protective device and the fault location of concern.

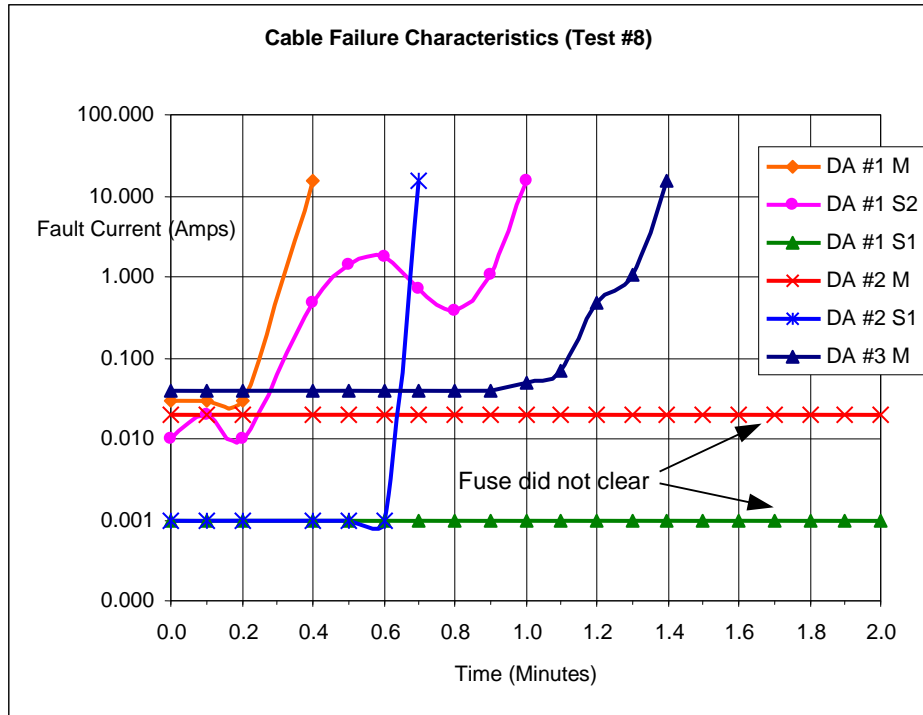
#### **B.1-6.1.1 EPRI/NEI Fire Test Results**

The EPRI/NEI fire tests are documented in EPRI Report 1003326, *Characterization of Fire-Induced Circuit Failures: Results of Cable Fire Testing* [12]. The functional circuits developed for this testing were heavily monitored, allowing significant insights into the nature and behavior of fire-induced cable faults.

##### **B.1-6.1.1.1 Cable Failure Sequence**

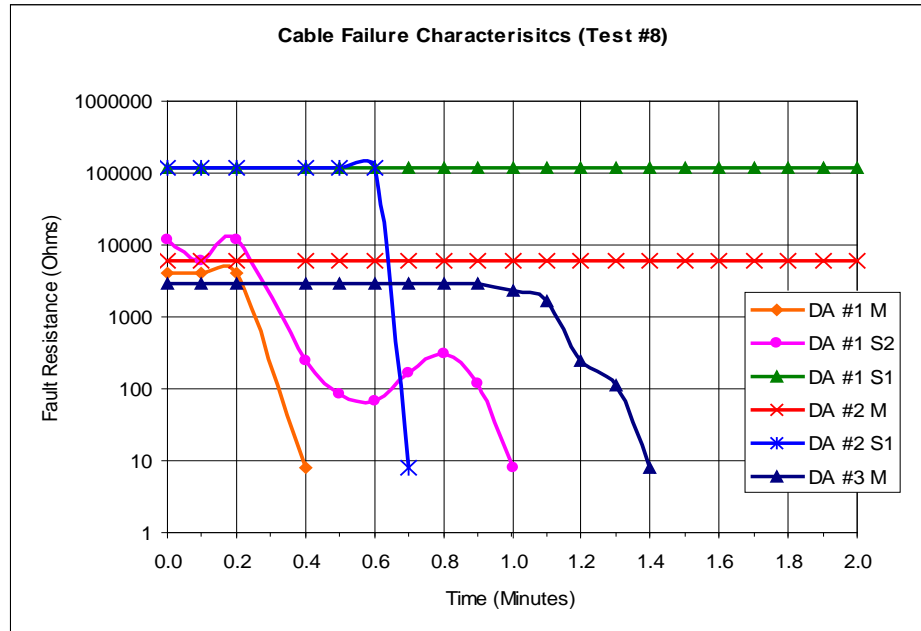
When driven to failure, cables followed a predictable and repeatable sequence. Initial degradation was first observed as a relatively slow reduction in insulation resistance down to approximately  $10\text{ k}\Omega - 1,000\text{ }\Omega$ . At these levels the circuits remained fully functional and produced leakage current in the milliamp range. The next phase of degradation has been termed the *transition phase*. In the transition phase, the fault undergoes a cascade effect and the rate of insulation resistance (IR) degradation increases significantly, causing fault resistance to drop rapidly. The circuit remains functional, but leakage current ramps upward quickly. The fault resistance associated with this phase is approximately  $5\text{ k}\Omega$  down to  $600\text{ }\Omega$ . Note that at  $600\text{ }\Omega$  the leakage current is only about 0.2 A, and the circuit is still functioning. The transition phase lasts from seconds to minutes. The final phase involves full failure of the cable. Insulation resistance drops to a very low level and leakage current now becomes fault current. The fault current escalates above the fuse rating, causing the fuse to open and de-energize the circuit. This final phase typically occurs within seconds or 10s of seconds for low-energy 120 V circuits. Figures B.1-3 and B.1-4 show current and fault resistance for a typical set of cables driven to failure.

**Figure B.1-3**  
**Fault Current for Fire-Induced Cable Failure**





**Figure B.1-4**  
**Fault Resistance for Fire-Induced Cable Failure**



The observed results can be explained by an understanding of the localized phenomena at the fault location. As the insulation degrades leakage current increases. At some point, the leakage current measurably contributes to localized heating, accelerating the rate of insulation degradation. As current increases, the rate of degradation increases until it finally cascades to a full fault. Important in this observation is that the power source must be able to supply sufficient energy to drive the cascading effect to completion. Test circuits with limited current capacity demonstrated the same basic failure sequence; however, the final phase typically took longer and did not produce predictable final fault resistances. This behavior can be seen in the NRC/SNL data in which the test circuit was limited to 1.0 A. This observation leads to the *Base Case* condition that the power supply must be able to produce sufficient fault current to ensure the protective devices operate predictable.

A key observation of the failure characteristics is that once the insulation resistance enters the transition phase it does not “hang up” at an intermediate point; it cascades to full failure within seconds or 10s of seconds. From the data it appears that once leakage current exceeds about 0.2 A, the fault can be expected to cascade to levels that trigger protective action.

In a few cases this process was dynamic. The fault cascaded and produced a high fault current momentarily (a few seconds), but quickly subsided back to low levels. This cycle generally repeated itself two or three times before fault current ramped and remained

high. Importantly, in no cases did fault current stabilize for an extended period at an intermediate level such that it was not detected and cleared by the fuse.

#### **B.1-6.1.1.2 Fault Clearing Times**

The fire test data was analyzed to establish a correlation between fault current level and the time required to clear the circuit fuse. The results of this tabulation are presented in Table B.1-1. The data here deals only with cases in which a fault caused the fuse to clear. Data for thermoset and thermoplastic cable are shown separately because the different insulation material exhibited slightly different characteristics.

The table provides statistics for the amount of time it took to clear the fuse once current had reached a certain threshold level. The clearing times are shown for three thresholds: 0.25 A, 1.0 A, and 2.0 A. The 0.25 A level was selected because it represents the approximate lower bound of the transition phase. 2.0 A was selected because it represents a current flow well below a value considered to pose a HIF concern for the established circuit. 1.0 A is an intermediate point that provides additional understanding.

The table is interpreted as follows: For thermoset cable, once fault current reached a level of 0.25 A, it took on average 0.46 minutes for the fuse to clear; once fault current reached 1.0 A it took on average 0.23 minutes to clear the fuse; and so on.

**Table B.1-1  
Fault Clearing Time**

	Time to Clear Fault (min)		
Current Threshold	0.25 A	1.0 A	2.0 A
<b>Thermoset Cable</b>			
Population	75	75	75
Average	0.46	0.23	0.14
Range	0.1 to 4.8	0.1 to 2.1	0.1 to 0.7
Std Dev	0.67	0.29	0.13
2 Std Dev	1.33	0.59	0.26
<b>Thermoplastic Cable</b>			
Population	39	39	39
Average	0.12	0.10	0.10
Range	0.1 to 0.3	0.1	0.1
Std Dev	0.07	0.00	0.00
2 Std Dev	0.14	0.00	0.00

The statistics presented in the table lend themselves to the following observations:

- The values contained in the table are highly conservative. The sample rate for the test monitoring system was limited to 0.1 min (6 sec). In many cases the fuse cleared between sample times. For these cases, the clearing time has been conservatively assigned a value of 0.1 min. This approach holds true for all values. Inherent in this approach is that the analysis uncertainty associated with determining the statistical values is completely incorporated into the values.
- All cables that reached a minimum leakage current of 0.25 A ultimately cleared the fuse. This is evident in that the population for all three threshold currents is the same. This is an important observation because it demonstrates that once fault resistance has degraded to the transition point, the cascade effect dominates the ultimate outcome and the fault does not then “hang up” at an intermediate resistance value that results in a prolonged abnormal low-level current flow.
- Once fault current surpassed 1.0 A, the cascade effect accelerated, as evidenced by the smaller delta between the 1.0 A to 2.0 A average and the 0.25 A to 1.0 A average.
- Once fault current for thermoset cable exceeded 2.0 A, the average clearing time was 0.14 min, with a 95% (2 standard deviations) upper bound of 0.4 min. From this it can be stated that 95% of the faults cleared within 24 sec.

#### **B.1-6.1.1.3 Assessment of Probability**

A different – and arguably better – way to tabulate the data is to determine the fraction of faults that were cleared by the fuse within a specified time. This tabulation is shown in Table B.1-2.

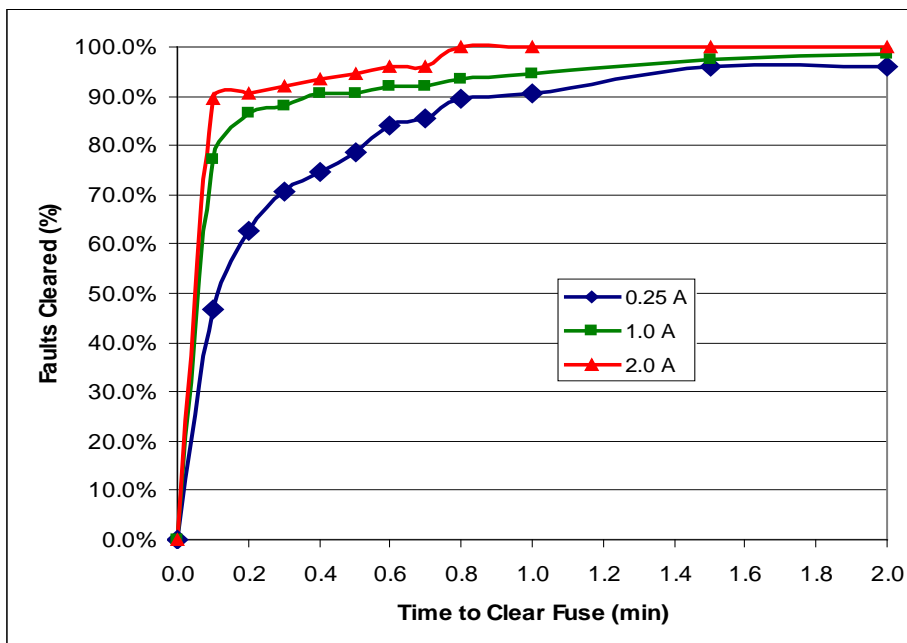
Viewed from this perspective, the data represents a go – no go or success – failure data set. In this format the data is readily analyzed in a manner useful in addressing the MHIF concern. The table is interpreted as follows: For thermoset cable, once fault current reached a level of 0.25 A, 62.7% of the faults were cleared within 0.2 min; 78.7% of the faults were cleared within 0.5 min; and so on.

**Table B.1-2**  
**Probability of Clearing Faults Within a Specified Time**

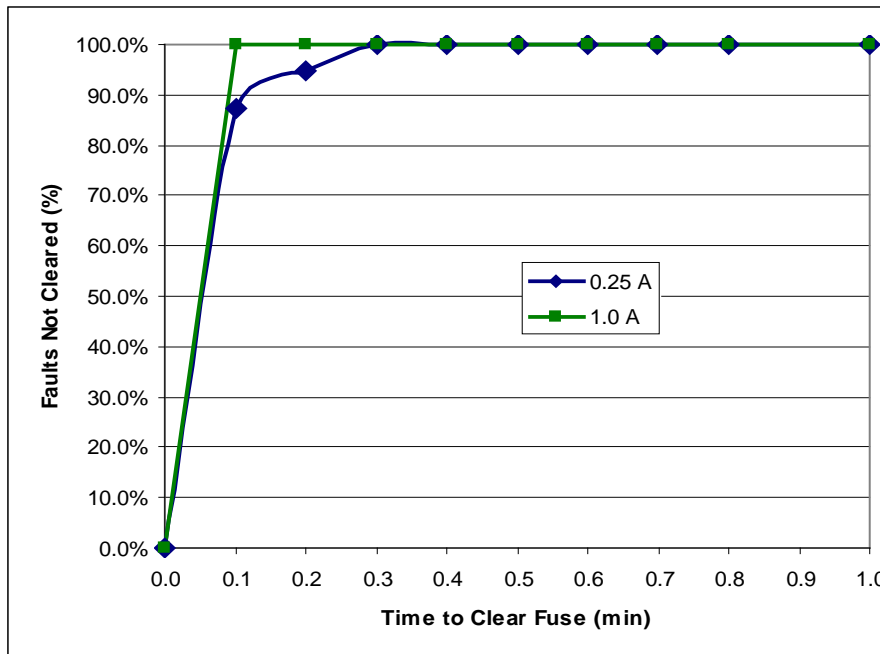
	Percentage of Faults Cleared		
Time (min)	0.25 A	1.0 A	2.0 A
<b>Thermoset Cable</b>			
0	0.0%	0.0%	0.0%
0.1	46.7%	77.3%	89.3%
0.2	62.7%	86.7%	90.7%
0.3	70.7%	88.0%	92.0%
0.4	74.7%	90.7%	93.3%
0.5	78.7%	90.7%	94.7%
0.6	84.0%	92.0%	96.0%
0.7	85.3%	92.0%	96.0%
0.8	89.3%	93.3%	100.0%
1.0	90.7%	94.7%	100.0%
1.5	96.0%	97.3%	100.0%
2.0	96.0%	98.7%	100.0%
<b>Thermoplastic Cable</b>			
0	0.0%	0.0%	0.0%
0.1	87.2%	100.0%	100.0%
0.2	94.9%	100.0%	100.0%
0.3	100.0%	100.0%	100.0%

Figures B.1-5 and B.1-6 graphically illustrate the data contained in Table B.1-2.

**Figure B.1-5**  
**Percent Faults Cleared for Specified Time – Thermoset Cable**



**Figure B.1-6**  
**Percent Faults Cleared for Specified Time – Thermoplastic Cable**



The following observations can be made about the probability data:

- Faults for thermoplastic cable essentially degrade to full failure immediately. Given the limitations of the monitoring system sample rate (6 sec) and the conservative treatment of the data, it is suspected that the actual failure times are in the millisecond range and not seconds. On this basis the observations for thermoset cable are considered to bound the thermoplastic cable.
- Figure B.1-5 shows that the 1.0A curve is approaching the 2.0 A curve. This graphically illustrates that once current has surpassed the 1.0 A threshold, the cascade effect drives the outcome and full failure is inevitable. Again, with respect to the MHIF concern, this confirms that the inherent fault behavior does not support the concept that fault current can stabilize at some intermediate value. Once cascading begins, the fault will progress to full failure, provided the system is capable of delivering sufficient energy to the fault.
- Once fault current reaches 2.0 A, 89% of the faults are cleared within 0.1 min and 100% of the faults are cleared within 0.8 min. Again, considering the limitations of the monitoring circuit, the actual times are less than indicated.
- From the 1A current threshold only one fault took longer than 2 min to clear – it cleared in 2.1 min.

#### B.1-6.1.1.4 Uncertainty Analysis

An uncertainty analysis of the data contained in Section B.1-6.1.1.3 is needed to establish a confidence level in the results. The dataset conforms to the requirements for a binomial distribution [23, 24], and thus a binomial confidence interval will be used to assess uncertainty. The confidence interval will be calculated at the 95% level. Only thermoset cable data is included in the calculation since it bounds the thermoplastic cable data.

The binomial confidence interval calculation is particularly punishing in this case because of the relatively small sample population and low number of failures. This factor adds additional margin to the calculated values of uncertainty.

The binomial confidence limits are calculated as follows:

$$P_l = 1 - \frac{x}{n} \pm z \sqrt{\left(\frac{1}{n}\right) x \left(\frac{x}{n}\right) x \left(1 - \frac{x}{n}\right)}$$

where:  $P_l$  = Probability confidence limits

$n$  = Sample population

$x$  = Number of observations failing criteria

$z$  = Desired confidence level factor (1.96 for 95%)

Table B.1-3 shows the calculated 95% confidence factors and Table B.1-4 shows the 95% lower confidence limit values for the dataset.

**Table B.-3**  
**Binomial Distribution 95% Confidence Factors**

	Binomial Distribution 95% Confidence Factors		
Time (min)	0.25 A	1.0 A	2.0 A
0	0.0%	0.0%	0.0%
0.1	11.3%	9.5%	7.0%
0.2	10.9%	7.7%	6.6%
0.3	10.3%	7.4%	6.1%
0.4	9.8%	6.6%	5.6%
0.5	9.3%	6.6%	5.1%
0.6	8.3%	6.1%	4.4%
0.7	8.0%	6.1%	4.4%
0.8	7.0%	5.6%	0.0%
1.0	6.6%	5.1%	0.0%
1.5	4.4%	3.6%	0.0%
2.0	4.4%	2.6%	0.0%

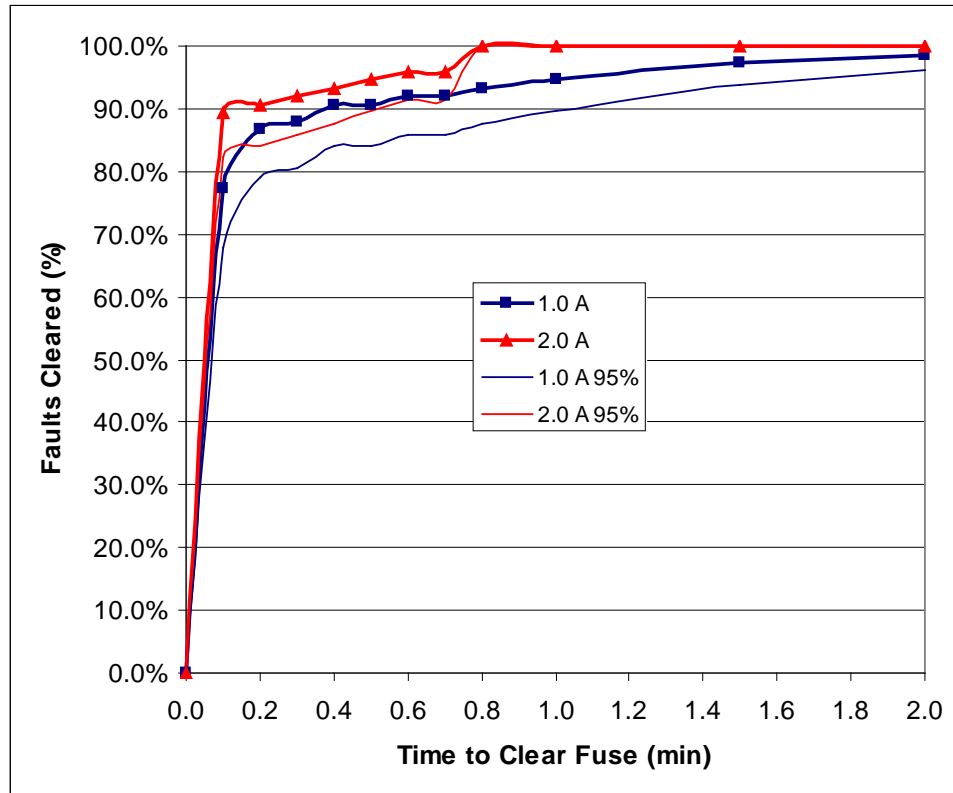
**Table B.1-4**  
**Fault Clearing Time 95% Lower Confidence Limit**

	95% Lower Confidence Limit		
Time (min)	0.25 A	1.0 A	2.0 A
0	0.0%	0.0%	0.0%
0.1	35.4%	67.9%	82.3%
0.2	51.7%	79.0%	84.1%
0.3	60.4%	80.6%	85.9%
0.4	64.8%	84.1%	87.7%
0.5	69.4%	84.1%	89.6%
0.6	75.7%	85.9%	91.6%
0.7	77.3%	85.9%	91.6%
0.8	82.3%	87.7%	100.0%
1.0	84.1%	89.6%	100.0%
1.5	91.6%	93.7%	100.0%
2.0	91.6%	96.1%	100.0%



Figure B.1-7 shows the 1.0 A and 2.0 A fuse clearing probabilities with the 95% confidence limits applied. Note that the  $t = 0$  confidence limits have no real meaning since no fails have occurred at this point.

**Figure B.1-7**  
**Probability of Clearing Fault Within Specified Time**  
**With 95% Uncertainty Bound Applied**



#### B.1-6.1.1.5 Leakage Current for Non-Failures

The data presented in Sections B.1-6.1.1.2 and B.1-6.1.1.3 demonstrates the behavior of faults for those cases in which the fuse did not clear. Just as important in addressing the MHIF concern is: What was the behavior for cases in which the fuse did not clear? The key issue, of course, is whether any cases occurred in which fault current increased to a level of concern without triggering the fuse.

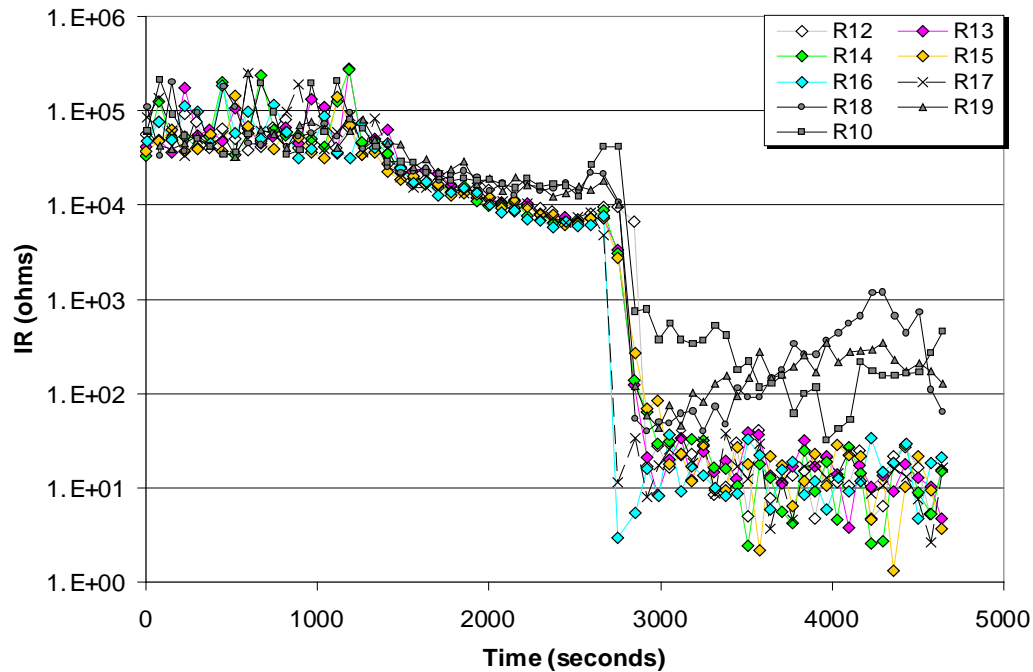
A review of the data for all cases in which the fuse did not clear indicates that the highest fault current observed without the fault ultimately cascading to full failure and clearing the fuse was 0.17 A, which correlates to a fault resistance of 700  $\Omega$ . No cases existed in which the failure progresses to the cascade point and did not ultimately fully fail.

#### **B.1-6.1.2 NRC /SNL Fire Test Results**

The NRC/SNL fire tests are documented in NUREG/CR-6776, *Cable Insulation Resistance Measurements Made During Cable Fire Tests* [3]. It is not intended that this analysis conduct a comprehensive review of the data associated with the NRC/SNL report. Rather, the test results are reviewed to ascertain any trends or insights different than observed in the EPRI/NEI test results.

The NRC/SNL test results show the same basic progression for cable failure. Insulation resistance drops predictably down to the 10 k $\Omega$  to 1,000  $\Omega$  range, at which points the failure cascades rapidly to full failure. The monitoring equipment sample rate was approximately 75 sec, and thus the measurements do not fully capture the dynamics of the cascade effect. Like the EPRI/NEI data, in many cases the IR is high one measurement then low for the subsequent measurement. The final IR values are more erratic than observed in the EPRI/NEI test data. This is attributed to the limited-energy circuit used for the testing. The circuit was designed to limit current to 1.0 A, which prevented the system from consistently driving faults to their conclusion. This observation further supports the *Base Case* requirement that the system be capable of supplying sufficient energy to the fault. A typical plot of insulation resistance from the NRC/SNL fire tests is shown in Figure B.1-8.

**Figure B.1-8**  
**Insulation Resistance Values for Typical Test Series**  
*(Courtesy of USNRC and Sandia National Laboratories)*



### B.1-6.2 Characterization of Arcing Faults

As discussed in Section B.1-4.0, high impedance faults on systems operating at 480 V and above are manifested as arcing faults. Arcing-type faults are unique in their behavior and must be treated differently than conventional bolted faults [7, 13 – 22].

Arcing faults are characterized by relatively high fault impedance and low, erratic fault current. The rms current for an arcing fault can be substantially lower than the maximum available fault current (bolted fault). Arcing faults on high energy systems are extremely damaging and must be cleared rapidly to avoid extensive damage.

#### B.1-6.2.1 Fire as an Initiator of Arcing Faults

Operating history for electrical power systems shows the most common cause of arcing faults to be:

- Loose connections that overheat, causing minor arcing that escalates into an arcing fault
- Surface conduction due to dust, moisture, or other contaminants on insulating surfaces
- Electrical mishaps involving conducting materials (e.g., dropping a metal wrench into energized switchgear) or foreign objects in enclosures

- Insulation damage.

From a circuit failure perspective, fire is an external event with the propensity to damage any circuits in the vicinity of the fire; however, industry experience does not identify fire as a major initiator of faults on high energy systems. It is surmised that in many cases, operators take action to de-energize high voltage equipment before it is engulfed by an escalating exposure fires. Nonetheless, fire-induced arcing faults can occur on high energy systems and must be addressed.

#### **B.1-6.2.2 Classification of Faults**

Arcing faults may take the form of a line-to-line fault or a line-to-ground fault. Arcing faults include:

Three Phase (3-⊙) Systems: 3-∅ line-to-line  
3-⊙ line-to-ground  
1-⊙ line-to-line  
1-⊙ line-to-ground.

Single Phase (1-⊙) Systems: 1-⊙ line-to-line  
1-⊙ line-to-ground.

Line-to-ground arcing faults pose less of a concern than line-to-line arcing faults for electrical distribution systems equipped with ground fault protection. Ground fault sensors may be set with high sensitivity to low magnitude currents because ground current is not expected under normal conditions. In contrast, line-to-line arcing faults can take longer to detect since the phase overcurrent devices are less capable of discriminating between a relatively harmless overload and a highly damaging, low-magnitude arcing fault.

Line-to-ground faults on solidly grounded electrical systems that are not equipped with ground fault sensors can produce faults that are not instantaneously cleared. Systems of this design rely on the phase overcurrent devices for protection, which do not offer the same degree of sensitivity to ground faults as do ground fault sensors. It is important to maintain perspective on this point. A highly energetic ground fault that is allowed to persist for even several seconds will generally cause widespread damage. Concern over this type of fault has initiated changes to recommended practices for protection against arcing ground faults. High-resistance grounded systems are generally not susceptible to damaging ground current flow because a grounding resistor or reactor limits the current to a very low level. Ungrounded systems require a fault on at least two phases to produce fault current flow. This type of fault is essentially a line-to-line fault.

Operating experience shows that arcing faults are most prevalent in metal-enclosed switchgear and open busways containing an uninsulated bus bar. Insulated cables in conduit or tray more frequently suffer bolted faults. These characteristics are attributable to the nature of the arc. Arcing faults on uninsulated conductors tend to travel away from the source because of magnetic force interactions with the ionized arc. Movement of the arc minimizes the concentration of fault energy. In contrast, insulated cable does not

allow rapid movement of the arc. Consequently, the arc energy and the damage it inflicts remain concentrated at the initial arc location, causing a more rapid degradation of the fault to a bolted fault.

### **B.1-6.2.3 Arc Voltage Drop and Wave-shape**

The arc voltage drop ranges from 100 – 150 volts for fault currents between 500 and 20,000 amps. The voltage is effectively constant over a wide range of current. The length of the arc for distribution level voltages varies but usually ranges between 1 and 2 inches.

Test data shows that the arc voltage wave-shape is significantly distorted. The wave-shape is initially sinusoidal and then quickly flattens at a magnitude of 100 – 150 volts, depending on the exact arc length and local conditions. The arc voltage wave-shape does not increase in a linear fashion as a function of the system voltage. The voltage contains a significant third harmonic component, which is on the order of five times the normal value.

Once an arc is initiated, it extinguishes at current-zero and then reignites when instantaneous voltage reaches some threshold value. A key relationship exists between the re-ignition, or re-strike voltage, and the level of fault current. The lower the re-ignition voltage the higher the fault current. As re-ignition voltage approaches zero, fault current approaches its maximum value (bolted fault). And, as re-ignition voltage approaches system voltage, fault current approaches zero (open circuit). As a result of this inverse relationship, it is evident that higher re-ignition voltages represent more of a concern than lower voltages with respect to the MHIF concern. Analyses of distribution-level arcing faults generally assume a re-ignition voltage of 375 V (peak instantaneous). This voltage is considered a conservative practical upper limit for re-ignition based on typical system designs.

Arcing fault re-ignition has several important implications:

- Arcing faults with a re-ignition voltage above the system voltage are self-extinguishing. Thus, a lower threshold of fault current exists for which a fault can sustain itself beyond one cycle.
- An arc is not self-extinguishing at or above voltage levels with a peak instantaneous voltage greater than approximately 375 volts. 375 volts instantaneous corresponds to 265 volts rms.
- Sustained arcing faults on single phase 120/208 V AC systems are exceedingly rare. Two factors are involved: (1) the low system voltage reduces the likelihood of exceeding the re-ignition voltage, and (2) unlike three phase faults, periods of no current flow exist for single phase configurations, affording the ionized hot gasses a better chance of dissipating. This is not to say that arcing faults cannot occur at these voltage levels and cause equipment damage. It does, however, support a position that “sustained” arcing faults at this level very seldom occur.
- The fault current associated with arcing faults increases as a percentage of the bolted fault current as system voltage increases. This characteristic is due the

nature of the arc voltage, which remains relatively constant regardless of system voltage. Thus, the higher the system voltage, the longer will be the conduction portion of the arc ignition-extinguishment cycle.

- High impedance arcing faults are primarily an AC system phenomenon. The low-magnitude current associated with an arcing fault is largely due to the ignition – extinguishment cycle of the fault, which serves to lower the rms fault current. In a DC system, a periodic ignition – extinguishment cycle does not exist. Voltage is constant and thus current flows continuously once an arc is established.

#### **B.1-6.2.4 Arc Fault Current**

The current wave-shape consists of non-continuous alternating pulses, with each pulse lasting about  $\frac{1}{4}$  –  $\frac{3}{4}$  of a cycle. The arc is extinguished each half cycle and reignited in the succeeding half cycle as discussed in Section B.1-6.2.3 above.

The generally accepted multipliers (expressed in % of bolted fault current) for estimating rms arcing fault current for 480/277 V systems are listed below. The multipliers are based on establishing the lower values of probable fault current for realistic values of arc voltage. Arc length is assumed to be 2 inches and arc voltage 140 V (line-to-neutral) / 275 V (line-to-line), independent of current. Neither of these assumptions is strictly true because of the dynamic movement of the arc and other configuration variables at the fault location. Thus, actual fault current may also vary. The estimated current values are, however, representative of the values produced during testing.

3-Ø Arcing Fault:	89%
Line-to-Line Arcing Fault:	74%
Line-to-Ground Arcing Fault:	38%

Note: Some industry papers addressing arcing fault protection suggest a multiplier of 19% for line-to-ground arcing faults. However, documented occurrences of cases below 38% appear exceedingly rare and appear to be associated with switchgear faults, which tend to have longer arc lengths. The 38% value is considered reasonable for this assessment since the concern is with cables and not switchgear.

Minimum values of arcing fault current have not been established for medium voltage systems. However, as noted in Section B.1-6.2.3 above, the values will increase with system voltage, and as a minimum will be higher than the 480 V values listed above. Practical experience indicates that arcing fault currents for medium voltage systems actually approach bolted fault levels.

#### **B.1-6.2.5 Arc Energy**

Even though the rms current for an arcing fault is less than that of a bolted fault, arcing faults can cause a great amount of damage. Most of the energy in the arc is released as heat at the arcing points; very little heat is conducted away from the arc by the conductors. In contrast, a bolted fault dissipates energy throughout all resistive elements

in the distribution system and does not cause the concentrated energy release seen in arcing faults.

Fire can cause unspecified damage to cable and equipment insulation, which in turn can initiate an arcing fault in energized conductors. The failure sequence starts with a progressively decreasing insulation resistance. At some point under the applied voltage stress, the insulation allows sufficient leakage current to cause excessive localized heating in the insulation (usually at some minor imperfection in the cable). The localized heating escalates rapidly due to the high energy capacity of the system, and within moments conductor and insulation temperature reach their vaporization point. Conductive material is expelled, forming a vapor cloud in the vicinity of the fault. The vapor cloud readily conducts electricity and an arc is formed. The cloud of vaporized metal tends to quickly condense on surrounding surfaces, which creates a cascading effect for the arcing fault as additional arc paths are created. The loss of material due to vaporization contributes to the dynamic nature of arcing faults. Depending on the fault geometry and conditions, the arc might persist, blow open, or degrade to a bolted fault.

The amount of conductor vaporized during an arcing fault is directly related to the energy released at the fault. The industry-accepted correlation (supported by test results) is that 50 kW/sec of energy will vaporize approximately 1/20 in<sup>3</sup> of copper. The significance of this characteristic is that arcing faults at medium voltage levels (above 1,000 V) cannot sustain themselves beyond a few seconds. The tremendous energy release at these higher voltages vaporizes conductor material so fast that the fault degrades almost immediately or blows open. This category of fault can completely demolish equipment in a matter of seconds if not cleared.

## **B.1-7 ANALYSIS OF MHIFS**

This section analyzes the MHIF concern within the framework of knowledge about fire-induced fault behavior developed in Section B.1-6. This characterization of fault behavior shows that faults manifest themselves differently at different voltage levels. Accordingly, the analysis conducted here is broken down by voltage classification.

### **B.1-7.1 Medium Voltage Systems (2.3 kV and Above)**

Medium voltage systems at nuclear plants typically operate within the 2.3 kV to 13.8 kV range. Overcurrent protection for this class of equipment usually includes electro-mechanical or solid state overcurrent relays that actuate power circuit breakers. High voltage fuses may be used for some installations. Most systems also include sensitive ground fault detection designed to rapidly clear ground faults, which can be highly volatile and damaging.

HIFs for this class of power manifest themselves as arcing faults. The electrical properties and characteristics for arcing faults are discussed in Section B.1-6.2. The expected impact of arcing faults at the medium voltage level is addressed by the items below:

- The typical arc voltage drop of 100 – 150 volts is small in relation to the overall system voltage. Thus, an arcing fault at medium voltage levels will not appreciably reduce fault current in the same manner as it does for low-voltage systems. Based on the 480 V multipliers presented in Section B.1-6.2.4, very conservative assumed lower arcing fault currents of 40% (line-ground) and 80% (line-to-line) of the symmetrical rms bolted fault current produce highly damaging levels of current flow. An adequately designed protective system can be expected to clear faults at these levels very rapidly (within a few seconds). Systems coordinated in accordance with the guidance of ANSI/IEEE 242 (or other acceptable criteria) are considered to be adequately designed.
- Most all medium voltage power systems include sensitive ground fault protection devices. These devices are set to clear ground faults at very low levels (20 A – 100 A) – well below the assumed 40% lower fault current limit. Systems that are high resistance grounded inherently limit fault current to a low value. Accordingly, these systems are designed to be extremely sensitive to ground fault current, and are expected to rapidly clear any type of ground fault.
- Certain cable runs may not be protected by overcurrent relays, but instead may use differential protection schemes. Differential protection is very sensitive and any cable protected this type of circuit will clear in-zone faults within milliseconds. Sensitivity varies, but is in the 10s to hundreds of amps and not thousands of amps.

Arcing faults on medium voltage systems produce explosive energies. An arcing fault with an arc voltage of 140 volts (very conservative for this voltage level) and fault current of 2,000 A (also a conservative value) will vaporize copper conductor at a rate of:

  - $\text{Volume Vaporized} = (140 \times 2.00 \times 1/20) / 50 = 0.4515 \text{ in}^3 \text{ copper} / \text{sec}$
  - At this vaporization rate for busbar or cable, the fault conditions cannot be sustained for more than a few moments before the dynamic nature of the fault produces near bolted conditions or blows open.
- Operating experience shows that even with highly sensitive protection that clears arcing faults within a fraction of a second (or in the worst case seconds) severe localized damage is likely. Given the energies involved, from a hardware integrity perspective it is not plausible that arcing faults can be sustained for a prolonged period of time at medium voltage levels.



## **Conclusion**

HIFs at medium voltage levels will manifest themselves as arcing faults. The minimum credible fault current produced by these faults will be rapidly detected by an adequately designed protective scheme and the fault will be cleared immediately, typically within milliseconds. The energies produced by arcing faults for this class of power system cannot be sustained by the hardware for more than a few seconds due to physical destruction of the conductor, insulating materials, and surrounding equipment. The analysis supports a conclusion that, for medium voltage power supplies conforming to the *Base Case*, the probability of MHIFs is sufficiently low to classify the failure mode as an incredible event that does not pose a credible risk to post-fire safe shutdown.

### **B.1-7.2 480 V – 600 V Low Voltage Systems**

480 V systems are most common at nuclear plants; however, some 600 V systems exist. A variety of overcurrent protective devices are used for this class of equipment. Load centers are generally protected by low voltage power circuit breakers configured with an internal electro-mechanical or solid-state trip unit. Motor control centers and distribution panels typically contain molded case circuit breakers or fuses. Some 480 V systems are configured with separate ground fault detectors and some are not.

HIFs for this class of power manifest themselves as arcing faults. The electrical properties and characteristics for arcing faults are discussed in Section B.1-6.2. The expected impact of arcing faults at this voltage level is addressed by the items below:

- Credible lower limits for sustained arcing faults on 480 V systems are presented in Section B.1-6.2.4. Arcing fault currents of 38% (line-ground) and 74% (line-to-line) of the symmetrical rms bolted fault current produce damaging levels of current flow. An adequately designed protective system can be expected to clear faults at these levels rapidly (although maybe not instantaneously). Systems coordinated in accordance with the guidance of ANSI/IEEE 242 (or other acceptable criteria) are considered to be adequately designed. A worst-case example is developed below to substantiate this position.
- A worst-case scenario might involve an arcing ground fault on a solidly grounded system that is not configured with individual ground fault detection. Assume an end-of-line fault has a symmetrical rms bolted fault current of 5,000 A (highly conservative as most 480 V systems produce fault current in the range of 10 kA to 25 kA). This case would result in an arcing fault current of 1,900 A ( $.38 \times 5,000$ ). It is conceivable that this level of fault current might not trigger the instantaneous trip element of the affected overcurrent device; however, the inverse time element will assuredly detect and clear the fault as no realistic system contains feeders operating at 1,900 A continuous. In this case it is plausible that the fault might take 10 – 15 sec to clear. However, due to the destructive power this fault would unleash, it is doubtful that the hardware would survive these conditions.
- If the above scenario is postulated to occur at the switchgear, it is distinctly possible that the switchgear main breaker might not readily detect the fault, as

these breakers can be rated at 800 A – 4,000 A. Literature documents such cases, and complete destruction of the switchgear was the outcome. However, switchgear and bus faults requiring main breaker protective action are not of concern for the MHIF issue.

- 480 V systems configured with properly coordinated ground fault detection can be expected to clear low-level arcing ground faults immediately.
- As with medium voltage systems, arcing faults on 480 V systems produce tremendous energies at the fault location. An arcing fault with an arc voltage of 100 volts (conservative) and fault current of 1,900 A will vaporize copper conductor at a rate of:
  - $\text{Volume Vaporized} = (100 \times 1.90 \times 1/20) / 50 = 0.190 \text{ in}^3 \text{ copper / sec}$
  - Although not as severe as that seen on medium voltage systems, this vaporization rate for bus-bar or cable cannot be sustained, and the fault will progress rapidly to a bolted condition or will blow open as localized destruction escalates.

### **Conclusion**

HIFs on 480 V – 600 V power systems manifest themselves as arcing faults. The minimum credible fault current produced by these faults will be detected by an adequately designed protective scheme and the fault will be cleared (although maybe not instantaneously). The energies produced by arcing faults for this class of power system cannot be sustained by the hardware for extended periods of time before physical destruction of the conductor, insulating materials, and surrounding equipment result in widespread and catastrophic damage. The analysis supports a conclusion that, for 480 V – 600 V power supplies conforming to the *Base Case*, the probability of MHIFs is sufficiently low to classify the failure mode as an incredible event that does not pose a credible risk to post-fire safe shutdown.

#### **B.1-7.3      120 V and 208 V Systems**

120 V systems are most often used for control and control power circuits; 208 V systems are typically associated with lighting, small motors, heaters, etc. 120 V single-phase circuits are of greatest interest for this study. For nuclear plant applications, overcurrent protective devices are generally molded case circuit breakers or fuses located within power distribution panels. The systems are most often powered by battery-backed inverters or relatively small transformers.

The recent industry and NRC fire tests confirm that the behavior of cable faults on 120 V systems is fundamentally different than that for faults on 480 V and higher systems. Theory predicts that sustained arcing faults at the 120 V level are not credible because the system is not able to repeatedly overcome the re-ignition voltage of 375 V. Indeed testing appears to confirm this point. This is not to say that arcing faults cannot occur at the 120 V level, but rather that they cannot be sustained. Arcing faults on 120 V systems have

been said to be “sputtering” faults. They arc, extinguish, and then re-arc and extinguish in a random manner based on the local conditions and geometry at the fault. The test data identified two cases that may have fallen into this category. These cases are included in the data set analyzed in Section B.1-6.1. It is noteworthy that the current profiles for these cases show current to be erratic and unpredictable, but at no time did current rise to HIF levels and remain there for more than a few seconds. Ultimately, the fault in each case degraded to a low level and was cleared by the fuse. These faults may also have simply been a case in which the localized insulation breakdown effect shifted as a result of the fire dynamics. Regardless of the specific phenomena at work, these cases are included in the analysis.

The test data clearly shows that faults at these levels on average do not clear as rapidly as faults at higher voltages. With our understanding of fault behavior, the reason for this is somewhat intuitive. The applied voltage stress and available fault current are orders of magnitude lower than for higher voltage power systems. Hence, the local conditions are not nearly as violent and the cable failure sequence simply progresses at a slower rate. That is, the energy released at the fault is much lower, and thus the insulation is not driven to full failure as rapidly. Additionally, the magnetic forces at this level do not cause the dynamic effects (movement of conductors) observed for high energy system faults.

The electrical properties and characteristics for faults on 120 V systems are discussed in Section B.1-6.1. The expected impact of these faults is addressed by the items below:

- The test data indicates that 120 V faults do not manifest themselves in a manner conducive to sustained HIF conditions. Once the fault has progressed to a certain level, it cascades rapidly to full failure within seconds or 10s of seconds, as shown by the test data (summarized below). This phenomenon was observed consistently in all the EPRI/NEI test data and NRC/SNL data, with the exception of instrument circuits,<sup>9</sup> which are not within the scope of this analysis. The transition region at which the cascading effect begins appears to range from approximately 10 k $\Omega$  to 1,000  $\Omega$ . But in all instances, when leakage current exceeded 0.25 A the fault was driven to failure and the fuse cleared. The 0.25 A (480  $\Omega$  fault resistance) threshold is important because this level of fault current (more appropriately classified as leakage current at this level) poses no conceivable risk for any realistic circuit with respect to the MHIF concern.
  - This analysis uses 2 A as the benchmark value for fault current flow that represents a lower limit of current potentially of concern from a MHIF perspective. This value represents 67% of the test circuit continuous current capability (i.e., 3 A fuses). Analysis of the test data provides us with the following probabilities associated with the time frames for clearing faults once fault current has risen to 2 A. The 95% confidence level is also shown to quantify uncertainty in the data set.

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<sup>9</sup> The inability of instrument power supplies to transfer appreciable energy to the fault appears to preclude rapid failure in some cases. The impact of this effect on instrument circuits is discussed in the NRC/SNL report [3].

Time (min)	Probability of Clearing Fault	95% Lower Confidence Limit
0.1	89.3%	82.3%
0.2	90.7%	84.1%
0.3	92.0%	85.9%
0.4	93.3%	87.7%
0.5	94.7%	89.6%
0.6	96.0%	91.6%
0.7	96.0%	91.6%
0.8	100.0%	100.0%
1.0	100.0%	100.0%

- The two key observations gleaned from the probability values are:
  - Over 80% of the faults are cleared in less than 0.1 min at a 95% confidence level
  - 100% of the faults (or nearly 100% if some margin is added for general uncertainty) clear within 0.8 min at a 95% confidence level
- The EPRI/NEI test data revealed NO cases in which the test circuit fuse failed to clear once current exceed 0.17 A (700  $\Omega$  fault resistance) – an important observation supporting the premise that faults do not “hang up” once cascade failure begins.
- The test circuits upon which the probability values are based contained 3 A fuses. A fair question to ask is whether the probability values are applicable to circuits with larger protective devices, for instance a 5 A or 10 A branch circuit fuse. Based on the fault characteristics, applying the results to high rated devices appears justified. Once current has passed 2 A, the fault resistance has degraded to a low level and the system, rather than the fault, becomes the primary determinant of the fault current magnitude. Provided the protective devices are adequately coordinated and the system provides sufficient fault current, the relative timing of the devices will be maintained over the entire fault current range. The important behavior here is that the faults do not “hang up” and thereby jeopardize the coordination scheme by producing fault currents below detectable levels.

## **Conclusion**

A detailed analysis of fault behavior for 120 V systems indicates that these faults do not exhibit characteristics that are conducive to sustained HIF conditions. The analysis demonstrates that once fault current surpasses a certain threshold level, the fault repeatedly and reliably degrades to a low level that will trigger overcurrent protective action for an adequately designed system. This threshold level varies but appears to be near 0.2 A at the lower limit. This level of “abnormal current flow” does not pose a risk with respect to the MHIF failure mode and in fact does not even render the affected circuit inoperable. The fundamental fault characteristics upon which this conclusion is based were readily apparent in the EPRI/NEI tests and the NRC/SNL tests. Additionally, a similar utility-sponsored test conducted in 1987 revealed the same basic behavior [27]. The analysis supports a conclusion that, for 120 V power supplies conforming to the *Base Case*, the probability of MHIFs is sufficiently low to classify the failure mode as an incredible event that does not pose a credible risk to post-fire safe shutdown.

### **B.1-7.4      125 V and 250 V DC Systems**

125 V and 250 V DC systems provide control power and motive power to essential equipment, including switchgear and motor control circuits, motor-operated and solenoid operated valves, instruments, and emergency lighting. Overcurrent protective devices are generally molded case circuit breakers or fuses located within power distribution panels. Low voltage power circuit breakers are sometimes used at the DC control centers.

The test data and industry information presented in Section B.1-6.0 apply to AC power systems and thus cannot be directly applied to DC systems. However, the well-understood differences between AC and DC power allow the results to be reasonably applied to DC systems as explained below:

- Arcing type faults on low voltage DC systems cannot be ruled out using the same logic applied to low voltage AC systems. Once an arc is struck on a DC system, it has no sinusoidal waveform to initiate the ignition-extinguishment cycle, and thus the concept of a minimum re-ignition voltage does not apply. However, high impedance arcing faults are primarily an AC system phenomenon. The low-magnitude current associated with an arcing fault is largely due to the ignition - extinguishment cycle of the fault, which serves to lower the rms fault current. In a DC system, fault current more readily flows without interruption once a short circuit begins. This continuous current flow is not conducive to prolonged, sporadic arcing conditions. Once the fault begins, theory predicts that it will quickly escalate in magnitude and will be rapidly cleared by a properly designed protective system. Operating experience supports this theory in that high impedance arcing faults are not identified as a concern by industry standards and literature.
- For non-arcing faults on 125 V DC systems, the analytical results for 120 V AC systems can be conservatively applied. The key failure phenomenon observed in the test data is the cascading effect once leakage current exceeds

the threshold level. Here again the continuous nature of DC power supports a position that energy will be transferred to the fault faster in a DC system because the voltage stress applied at the fault is constant and will precipitate a quicker breakdown of the insulation.

- As a second factor affecting the rate of cascade failure, the test data shows a correlation between available fault current and the expected clearing time. DC systems at nuclear power plants are battery-backed, and thus are capable of delivering high fault currents almost instantaneously. These fault currents are often an order of magnitude larger than exists on 120 V AC systems.
- Virtually all DC power distribution systems at nuclear plants operate ungrounded. Thus, ground faults are not of concern in a manner similar to AC power systems. Operating experience with faults on battery-backed DC power systems is that the fault will likely blow open but it can also quickly weld itself. In either case, whatever is going to happen happens almost instantaneously.

### **Conclusion**

Test data and industry literature pertaining to fault characteristics for representative DC power systems are not readily available. However, a reasonable extrapolation of the analysis results for AC systems is accomplished using engineering rationale based on the differences between AC and DC power. The inherent characteristics of DC power do not introduce any known factors that preclude application of the analysis results to DC systems. To the contrary, DC power characteristics lend credence to a position that the AC results are conservative with respect to DC power system performance. Although not a technical basis, it is noteworthy that the NRC limits its stated concern with MHIF to AC power systems [4]. It would appear that NRC technical experts investigating the issue concur that the postulated phenomena are limited to AC power systems.

## **B.1-7.5 Failure Consequence Analysis**

Elements of this MHIF evaluation contain risk-informed arguments. As such, it is prudent to assess not only likelihood of the postulated failure mode, but also the potential consequences of failure.

### **B.1-7.5.1 Loss of Safe Shutdown Power Supply**

The MHIF failure mode can result in a safe shutdown power supply becoming de-energized, which in turn could potentially lead to de-energization of safe shutdown equipment. This failure mode is fundamentally different than electrical failures resulting from the direct effects of fire. The direct effect failure modes (i.e., shorts-to-ground, hot shorts, open circuits) cause circuit damage that can only be rectified through repairs. The MHIF failure mode is not unrecoverable in the sense that restoration involves resetting an overcurrent relay, closing a circuit breaker, or replacing a fuse. (It is acknowledged that fuse replacement is generally classified as a “repair activity” within the compliance guidelines for Appendix R. Nonetheless, from a “consequence” point of view, replacing a fuse – which typically requires no tool or a simple tool – is fundamentally different than a

repair involving the replacement of cables and components.) It is understood that operators are credited with identifying the problem and taking steps to restore the affected power supply to service. Given that almost all safe shutdown power supplies require some local action for alternative shutdown or spurious operation mitigation, it is also probable that critical power supplies are covered by emergency lights and that access/egress paths have been considered. On this basis, the MHIF failure mode is considered to have a low consequence and is not a significant contributor to fire risk.

## **B.1-8 CONCLUSIONS**

This analysis investigates fire-induced circuit failure characteristics to determine if and under what conditions the MHIF failure mode poses a credible risk to post-fire safe shutdown. The analysis is based on objective test data and recognized engineering principles as documented in test reports, consensus standards, and other credible industry references. The analysis considers both likelihood and consequence, and also addresses analysis uncertainty for critical results.

A *Base Case* set of conditions has been established to define the limits of applicability for the analysis. Within the defined limits, this MHIF analysis is intended to serve as a generic evaluation and is considered to satisfy the regulatory requirement that high impedance faults be considered in the analysis of associated circuits. Circumstances that fall outside the defined *Base Case* will require a plant-specific analysis.

A detailed analysis of fault characteristics for the voltage levels of interest indicates that these faults do not exhibit characteristics that coincide with that of concern for MHIFs. The analysis supports a conclusion that the probability of MHIFs for power supplies conforming to the *Base Case* is sufficiently low to classify the failure mode as an incredible event that does not pose a credible risk to post-fire safe shutdown.

The results and conclusions of this analysis may be used to support a licensing basis change (using an approved regulatory process) under the following condition:

- The power supply conforms to the *Base Case* requirements.

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## **APPENDIX C: HIGH/LOW PRESSURE INTERFACES**

### **C.1 PURPOSE**

The purpose of this appendix is to identify considerations necessary to address the issue of circuit analysis of high/low pressure interface components. Based on the work performed under JACQUE-FIRE Volume 1, 2 and 3 [NUREG/CR-7150 Volumes 1, 2 and 3], those licensees adopting Appendix J will no longer be required to postulate fire-induced circuit failures to the power circuit for high/low pressure interface valves. Appendix J to NEI 00-01 captures the results of JACQUE-FIRE Volume 1 and 3 related to fire-induced circuit failures. JACQUE-FIRE Volumes 1 and 3 concluded that three (3) phase hot shorts and two (2) hot shorts of the proper polarity on compound DC motors were “incredible” fire-induced circuit failure types. As such, these fire-induced circuit failure types do not need to be considered in the post-fire safe shutdown analysis.

The previous revision to this appendix (Revision 2, June 2009, ML09177026) determined that the Shutdown Cooling Suction Line Containment Isolation Valves, depending upon the plant specific design, may be the only valves required to be classified as high/low pressure interface valves, based on the criteria discussed in Section C.3. In addition, the methodology in the previous revision of this Appendix was endorsed in RG 1.189, Revision 3. The previous revision to this appendix also determined that based on this classification as high/low pressure interface valves, that these valves needed to be protected from the effects of three (3) phase hot shorts and two (2) shorts of the proper polarity on compound DC motors.

As stated above, however, Appendix J concludes that three (3) phase hot shorts and two (2) shorts of the proper polarity on compound DC motors are no longer required to be considered. As such, the special circuit failures outlined in this appendix for high/low pressure interface valves do not need to be considered in a post-fire safe shutdown analysis.

Additionally, in Appendix J, however, the Shutdown Cooling Suction Line Containment Isolation Valves have been classified as “high impact components”. Since these valves are classified as “high impact components” they are now required to be protected from the effects of any “implausible” circuit failure types. Refer to Appendix J for a more detailed understanding of the requirements related to “high impact components” and “implausible” circuit failure types.

**Although some of the information in this Appendix C is changed by the information in Appendix J, still remains a valid supporting document for the licensing basis for those plants that have not yet adopted the changes in Appendix J.**

### **C.2 INTRODUCTION**

10 CFR 50 Appendix R analyses must evaluate the potential for spurious operations that may adversely affect the ability to achieve and maintain safe shutdown. A subset of

components considered for spurious operation involves reactor coolant pressure boundary (RCPB) components whose spurious operation can lead to an unacceptable loss of reactor pressure vessel/Reactor Coolant System (RPV/RCS) inventory via an interfacing system loss of coolant accident (ISLOCA). Because an ISLOCA is a significant transient, it may be beyond the capability of a given safe shutdown path to mitigate. As a result of this concern, selected RCPB valves are defined as high/low pressure interface valve components requiring special consideration and criteria.

Note: As part of industry efforts to support transition of fire protection programs to 10 CFR 50.48(c) (NFPA 805), a Frequently Asked Question (FAQ) 06-0006 was written to clarify the definition of high/low pressure interface components. In the closure memo for FAQ 06-0006 dated March 12, 2007, the NRC stated:

*“...the staff concluded that the definition provided in NEI-00-01 for the term “high-low pressure interface” is acceptable.”*

### **C.3 IDENTIFYING HIGH/LOW PRESSURE INTERFACE COMPONENTS**

#### **Regulatory Guidance**

The criteria for defining high/low interface valve components are described in the following NRC documents.

Generic Letter 81-12 states, in part:

*The residual heat removal system is generally a low pressure system that interfaces with the high pressure primary coolant system. To preclude a LOCA through this interface, we require compliance with the recommendations of Branch Technical Position RSB 5-1. It is our concern that this single fire could cause the **two valves** to open resulting in a fire initiated LOCA.*

BTP RSB 5-1, Rev. 2 Dated July 1981 states in part:

#### *B. RHR System Isolation Requirements*

*The RHR system shall satisfy the isolation requirements listed below.*

*1. The following shall be provided in the suction side of the RHR system to isolate it from the RCS.*

*a. Isolation shall be provided by at least two power-operated valves in series. The valve positions shall be indicated in the control room.*

*b. The valves shall have independent diverse interlocks to prevent the valves from being opened unless the RCS pressure is below the RHR system design pressure. Failure of a power supply shall not cause any valve to change position.*

- c. The valves shall have independent diverse interlocks to protect against one or both valves being open during an RCS increase above the design pressure of the RHR system.*
- 2. One of the following shall be provided on the discharge side of the RHR system to isolate it from the RCS:*
  - a. The valves, position indicators, and interlocks described in item 1(a) thru 1(c) above,*
  - b. One or more check valves in series with a normally closed power-operated valve. The power-operated valve position shall be indicated in the control room. If the RHR system discharge line is used for an ECCS function, the power-operated valve is to be opened upon receipt of a safety injection signal once the reactor coolant pressure has decreased below the ECCS design pressure.*
  - c. Three check valves in series, or*
  - d. Two check valves in series, provided that there are design provisions to permit periodic testing of the check valves for leak tightness and the testing is performed at least annually.*

NRC Information Notice 87-50 reiterates:

*Appendix R also states that for these areas, the fission product boundary integrity shall not be affected, (i.e., there shall be no rupture of any primary coolant boundary). Thus, for those low pressure systems that connect to the reactor coolant system (a high pressure system), at least one isolation valve must remain closed despite any damage that may be caused by fire. Since the low pressure system could be designed for pressures as low as 200 to 400 psi, the high pressure from the reactor coolant system (approximately 1000 to 1200 psi for BWRs and 2000 to 2200 psi for PWRs) could result in failure of the low pressure piping. In many instances, the valves at the high pressure to low pressure interface are not designed to close against full reactor coolant system pressure and flow conditions. Thus, spurious valve opening could result in a LOCA that cannot be isolated, even if control of the valve can be reestablished.*

The NRC has taken the position that high/low pressure interface equipment must be evaluated to more stringent requirements than non-high/low pressure interfaces when considering spurious operations. The purpose of the requirements is to ensure that a fire-induced LOCA does not occur.

The NRC concern is one of a breach of the RCS boundary, by failure of the downstream piping due to a pipe rupture outside of Primary Containment. However, if the spurious opening of RCS boundary valves cannot result in a pipe rupture (i.e., downstream piping is rated for the range of RCS pressures), then the subject boundary valves do not constitute high/low pressure interfaces. Historically, the following combinations of

valves may have been typically evaluated for inclusion as high/low pressure interface concerns:

- a. RCS to shutdown cooling system (e.g., Residual Heat Removal/Decay Heat Removal, etc.) suction valves.
- b. RCS letdown isolation valves (e.g., letdown to radwaste, condensate (BWRs), main condenser (BWRs) or volume control system (PWRs).
- c. RCS high point vent isolation valves

Although, the use of this list of valves would represent a bounding list of high low pressure interface valves of concerns, not all of these valves meet the original criteria identified in GL 81-12, nor is RSB 5-1 applicable to each example. This expansion in scope is the result of conservative interpretations by licensees and the NRC as safe shutdown compliance strategies at individual plants have evolved.

Based on the above guidance, the following criterion is established to determine if a RCPB valve is considered a high/low pressure interface valve component: *A valve whose spurious opening could result in a loss of RPV/RCS inventory and, due to the lower pressure rating on the downstream piping, an interfacing LOCA outside of Primary Containment (i.e., pipe rupture in the low pressure piping).* Depending upon plant-specific design, this criteria could likely result in only the RCS to shutdown cooling system (e.g., Residual Heat Removal/Decay Heat Removal, etc.) suction valves being characterized as high/low pressure interfaces.

Although spurious relief valve operations do result in a loss of RPV/RCS inventory, the downstream piping is designed for the discharge pressures. As a result, spurious relief valve operation will not result in an interfacing system LOCA and spurious relief valve operation is not considered to be a high low pressure interface condition. Similarly, A PORV/PORV Block Valve pathway that could result in a similar fluid path loss concern is not considered to be a high/low pressure interface condition.. Even though this PORV/PORV Block Valve pathway could result in the eventual rupture of the pressurizer relief tank rupture disk, this is not a piping system failure and, as such, does not require the PORV/PORV Block Valve pathway to be treated as a high/low pressure interface.

## **C.4 CIRCUIT ANALYSIS CONSIDERATIONS**

The specific differences made in addressing circuit analysis of high/low pressure interface components are described in NRC Generic Letter 86-10, Question 5.3.1, which requests a clarification on the classification of circuit failure modes. The question and the response are provided below.

### *5.3.1 Circuit failure modes*

#### Question

*What circuit failure modes must be considered in identifying circuits associated by spurious actuation?*

Response

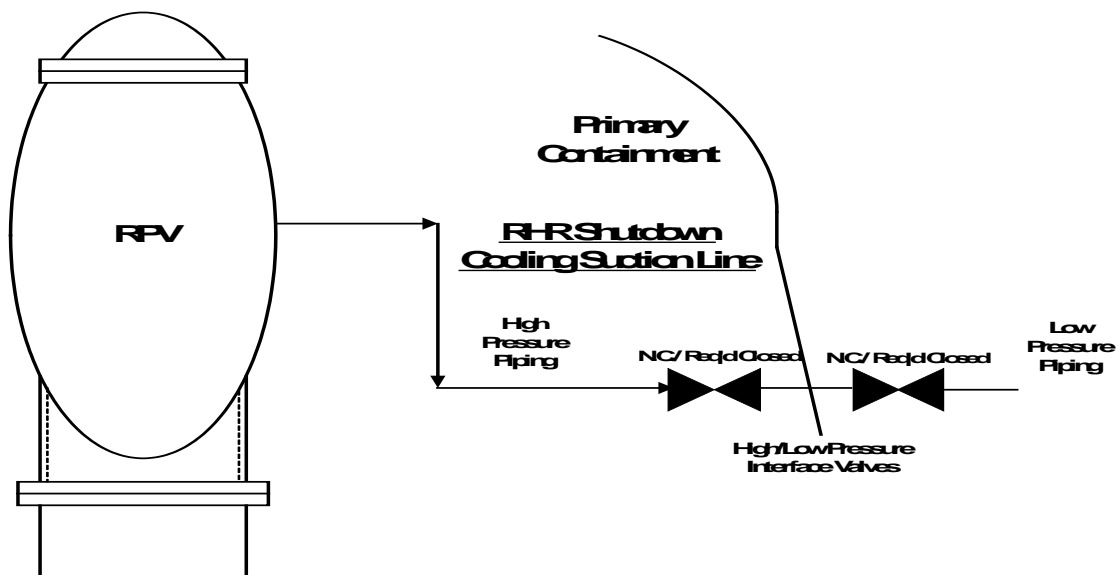
*Sections III.G.2 and III.L.7 of Appendix R define the circuit failure modes as hot shorts, open circuits, and shorts to ground. For consideration of spurious actuations, all possible functional failure states must be evaluated, that is, the component could be energized or de-energized by one or more of the above failure modes. Therefore, valves could fail open or closed; pumps could fail running or not running, electrical distribution breakers could fail open or closed. For three-phase AC circuits, the probability of getting a hot short on all three phases in the proper sequence to cause spurious operation of a motor is considered sufficiently low as to not require evaluation except for any cases involving Hi/Lo pressure interfaces. For ungrounded DC circuits, if it can be shown that only two hot shorts of the proper polarity without grounding could cause spurious operation, no further evaluation is necessary except for any cases involving Hi/Lo pressure interfaces.*

The response to Question 5.3.1 establishes a basis for limiting the number of credible circuit failure modes that need to be postulated for non-high/low pressure interface components. At the same time it implies that further evaluation is required when considering circuit failures of high/low pressure interface components. Further evaluation is required for cases involving high/low pressure interfaces, specifically, the case of two hot shorts on an ungrounded DC circuit. The discussion involving the DC circuit implies that two hot shorts need not be postulated except for high/low pressure interface components.

High/low pressure interface valves are identified separately from other safe shutdown components because the cable fault analysis and the effects on safe shutdown due to spurious operation of the high/low interface valves are evaluated more stringently than the safe shutdown components. The potential for spuriously actuating redundant valves in any one high/low pressure interface as a result of a fire in a given fire area must also be postulated. This includes considering the potential for a fire to spuriously actuate both valves from a selective hot short on different cables for each valve.

## C.5 FIRE AREA ASSESSMENT OF HIGH/LOW PRESSURE INTERFACES

**Figure C-1**  
**High/Low Pressure Interface Example**



In this example, the postulated fire damage is evaluated for two cases. In the first case, Case (a), the fire is assumed to have the potential to cause the spurious opening of one of the two series normally closed high/low pressure interface valves. In the second case, Case (b), the fire is assumed to have the potential to cause the spurious opening of both series high/low pressure interface valves.

### Case (a):

For this case, the spurious opening of either one of the two series high/low pressure interface valves can be justified on the basis that the other valve will remain closed and prevent an interfacing system LOCA.

### Case (b):

For this case, the argument applied above would be unacceptable. Examples of acceptable alternatives would be to protect the control circuits for either valve in the fire area, to reroute the spurious circuits or to de-power one of the valves to prevent spurious opening. When using this latter option, it must be assured that a three-phase hot short cannot cause the spurious opening of the valve. This can be done by assuring that no

three phase cables of the same or higher voltage are routed in the same raceway between the MCC and the valve.

A mitigating action may be taken prior to the start of the fire event that precludes the condition from occurring, or a post-fire action may be taken that mitigates the effects of the condition prior to it reaching an unrecoverable condition relative to safe shutdown, if this can be shown to be feasible. When mitigating actions are taken, they must comply with the applicable regulations and licensing bases.

## **C.6 REFERENCES**

- C.6.1 Branch Technical Position BTP RSB 5-1 Rev. 2, July 1981.
- C.6.2 Generic Letter 81-12, "Fire Protection Rule," February 20, 1981.
- C.6.3 Generic Letter 86-10 "Implementation of Fire Protection Requirements," April 24, 1986.
- C.6.4 IN 87-50 – Potential LOCA at High and Low Pressure Interfaces from Fire Damage, October 9, 1987.
- C.6.5 NUREG/CR-7150, Volume 1, 2 and 3, Joint Assessment of Cable Damage and Quantification of Effects from Fire JACQUE-FIRE)



## **APPENDIX D: ALTERNATIVE/DEDICATED SHUTDOWN REQUIREMENTS**

### **D.1 PURPOSE**

The purpose of this appendix is to explain the requirements for alternative and dedicated shutdown that are distinct and different from the requirements for redundant shutdown. Refer to the introduction to Appendix G for information on the treatment of MSOs for III.G.3 areas.

### **D.2 INTRODUCTION**

The use of alternative/dedicated shutdown capability is required in those specific fire areas where protection of a redundant safe shutdown path from the effects of fire was not possible. Alternative/dedicated shutdown capability is generally specified for the control room. Other plant areas where alternative/dedicated shutdown capability may be required include the cable spreading room, electrical distribution room, relay room(s), or other plant areas where significant quantities of control cables are routed and redundant trains of safe shutdown equipment have not been separated in accordance with the requirements specified in Section III.G.2 of Appendix R. The areas where alternative or dedicated shutdown is credited are defined in the licensing basis documents for each plant. Use of the term alternative or dedicated shutdown is applied to the specific plant area(s) and not to the equipment or methodology (capability) employed to achieve safe shutdown. The alternative/dedicated shutdown capability may be different for each of the defined areas. Manual actions may be utilized for alternative/dedicated shutdown capability in accordance with NRC requirements and guidance. Refer to Appendix E.

Alternative/dedicated shutdown capability requires physical and electrical independence from the area of concern. This is usually accomplished with isolation/transfer switches, specific cable routing and protection, and remote/auxiliary shutdown panel(s). The alternative/dedicated safe shutdown system(s) must be able to be powered from the onsite power supplies, which must be physically and electrically independent from the area under consideration. The availability or loss of offsite power and loss of automatic initiation logic signals must be accounted for in the equipment and systems selected or specified. All activities comprising the alternative/dedicated shutdown capability are considered mitigating actions and need to be evaluated against regulatory acceptance criteria to ensure that the goals and criteria in Section III.L are met.

Appendix R Section III.G.3 requires that the equipment, cabling, and associated circuits required for alternative shutdown must be independent of the fire area being evaluated. Therefore, in the case of a control room fire, the safe shutdown systems and components may be similar to those used in other areas for redundant shutdown; however, they must be physically located outside the fire area and, if required, the control of the components must be electrically isolated by transferring control to a remote/auxiliary shutdown panel(s). Examples of components and cables that must be physically and electrically independent of the control room for alternative or dedicated shutdown use include the components that can be controlled from a remote/auxiliary shutdown panel and the cables

that provide control from that panel once they are isolated from the control room circuit. GL 81-12 requested, in support of the regulatory requirement in 10CFR50.48 Paragraph (c), that each Appendix R plant submit its modification plans for their alternative shutdown capability for prior staff review and approval. These submittals typically included details of the proposed isolation/transfer design.

This appendix describes those aspects of the methodology and guidance for alternative/dedicated shutdown that are different from the methodology and guidance applied for redundant post-fire safe shutdown in the body of this document. Section D.3 overviews the methodology as it relates to control room fires, since the control room is the fire area where alternative shutdown is predominantly used. Section D.4 describes the regulatory requirements for alternative and dedicated shutdown. Section D.5 itemizes the differences in shutdown methodology between alternative/dedicated shutdown and those supplied in the body of this document for redundant shutdown. Section D.6 recommends additional operator actions that should be considered for use on a plant-unique basis for fires requiring control room evacuation.

### **D.3 OVERVIEW**

Since many nuclear plants use the alternative/dedicated shutdown scheme exclusively for a control room fire, this overview addresses this fire location only. An exposure fire in the Control Room of an operating nuclear power plant would be a potentially serious event. The likelihood of a control room fire, however, is considered to be small. The worst-case expected fire for a control room would be one that is contained within a single section of a control panel. This is true because the control room is continuously manned, the introduction of combustible materials and ignition sources is strictly controlled, and the fire protection and separation features designed into the control room are focused on the prevention of such an event. The expected plant response to this type of event would be to immediately extinguish the fire and to determine the need to initiate alternative/dedicated shutdown. While the fire is being extinguished, assuming that the Control Room remains habitable, the remaining Control Room operators would continue to perform their duties as trained, responding to alarms and monitoring important plant parameters.

Despite this, the post-fire safe shutdown analysis for a control room fire must assume fire damage to all of the systems and equipment located within the Control Room fire area. Additionally, the analysis assumes that all automatic functions will be lost and a loss of offsite power either has occurred or has not occurred (both cases must be considered). Consequently, the operators will be forced to evacuate the control room and to safely shut down the unit from an emergency control station(s). The size and intensity of the exposure fire necessary to cause this damage are not determined, but are assumed to be capable of occurring regardless of the level of combustibles in the area, the ignition temperatures of these combustible materials, the lack of an ignition source, the presence of automatic or manual suppression and detection capability, and the continuous manning in the control room.

Generic Letter 86-10, Response to Question 5.3.10, states, “*Per the criteria of Section III.L of Appendix R a loss of offsite power shall be assumed for a fire in any fire area concurrent with the following assumptions:*

- a. The safe shutdown capability should not be adversely affected by any one spurious actuation or signal resulting from a fire in any plant area; and*
- b. The safe shutdown capability should not be adversely affected by a fire in any plant area which results in the loss of all automatic function (signals, logic) from the circuits located in the area in conjunction with one worst case spurious actuation or signal resulting from the fire; and*
- c. The safe shutdown capability should not be adversely affected by a fire in any plant area which results in spurious actuation of the redundant valves in any one high-low pressure interface line.*

The analysis must consider the effects of each potential spurious operation and the mitigating action(s) that may be necessary for each. These conservative assumptions form the design basis for control room fire mitigation.

As with the post-fire safe shutdown analysis performed in areas where redundant safe shutdown paths are used, the analyst must be cautious not to improperly apply the conservative assumptions described above, for example, the assumption that unprotected circuits in a given fire area are damaged by the fire. This assumption is conservative only in terms of not being able to credit the systems and equipment associated with these circuits in support of post-fire safe shutdown. If the analyst, however, were to assume that these circuits were to be damaged by the fire when this provided an analytical advantage, this would be non-conservative. For example, assuming that fire damage results in a loss of offsite power may be non-conservative in terms of heat load assumptions used in an analysis to determine the need for HVAC systems.

#### **D.4 APPENDIX R REGULATORY REQUIREMENTS AND GUIDANCE**

Appendix R Section III.G.3 provides the requirements for alternative or dedicated shutdown capability used to provide post-fire safe shutdown. Section III.G.3 states:

- 3. Alternative or dedicated shutdown capability and its associated circuits,<sup>1</sup> independent of cables, systems or components in the areas, room or zone under consideration, shall be provided:*
  - a. Where the protection of systems whose function is required for hot shutdown does not satisfy the requirement of paragraph G.2 of this section; or*
  - b. Where redundant trains of systems required for hot shutdown located in the same fire area may be subject to damage from fire suppression activities or from the rupture or inadvertent operation of fire suppression systems.*

*In addition, fire detection and a fixed fire suppression system shall be installed in the area, room, or zone under consideration.*

*III.G.3 Footnote 1 - Alternative shutdown capability is provided by rerouting, relocating or modification of existing systems; dedicated shutdown capability is provided by installing new structures and systems for the function of post-fire shutdown.*

To satisfy the requirements of Section III.G.3 and use alternative or dedicated shutdown capability, the cables, systems or components comprising the alternative or dedicated shutdown capability must be independent of the area under consideration.

Alternative/dedicated shutdown capability meeting the requirements of Section III.G.3 must satisfy the requirements of Section III.L. Section III.L.1 provides requirements on the shutdown functions required for the systems selected for alternative/dedicated shutdown. It also provides the minimum design criterion for the systems performing these functions.

*L. Alternative and dedicated shutdown capability.*

- 1. Alternative or dedicated shutdown capability provided for a specific fire area shall be able to (a) achieve and maintain subcritical reactivity conditions in the reactor; (b) maintain reactor coolant inventory; (c) achieve and maintain hot standby<sup>2</sup> conditions for a PWR (hot shutdown<sup>2</sup> for a BWR), (d) achieve cold shutdown conditions within 72 hours; and (e) maintain cold shutdown conditions thereafter. During the postfire shutdown, the reactor coolant system process variables shall be maintained within those predicted for a loss of normal a.c. power, and the fission product boundary integrity shall not be affected; (i.e., there shall be no fuel clad damage, rupture of any primary coolant boundary, or rupture of the containment boundary).*

*III.L.1 Footnote 2 – As defined in the Standard Technical Specifications.*

*III.G.3 Footnote 1 – Alternative shutdown capability is provided by rerouting, relocating or modification of existing systems; dedicated shutdown capability is provided by installing new structures and systems for the function of post-fire shutdown.*

When utilizing the alternative or dedicated shutdown capability, transients, (e.g. fire-induced spurious operations) that cause deviations in system process variables from those expected conditions for a normal shutdown resulting from a loss of normal a.c. have been previously evaluated. A short-duration partial core uncover (approved for BWRs when using alternative or dedicated shutdown capability) and a short duration of RCS level below that of the level indication in the pressurizer for PWRs are two such transients. These transients do not lead to unrestorable conditions and thus have been deemed to be

acceptable deviations from the performance goals<sup>10</sup>. For Appendix R plants, these conditions may not meet the requirements of III.L and an exemption request may be needed.

Section III.L.2 identifies the performance goals for the shutdown functions of alternative/dedicated shutdown systems as follows:

2. *The performance goals for the shutdown functions shall be:*
  - a. *The reactivity control function shall be capable of achieving and maintaining cold shutdown reactivity conditions.*
  - b. *The reactor coolant makeup function shall be capable of maintaining the reactor coolant level above the top of the core for BWRs and be within the level indication in the pressurizer for PWRs.*
  - c. *The reactor heat removal function shall be capable of achieving and maintaining decay heat removal.*
  - d. *The process monitoring function shall be capable of providing direct readings of the process variables necessary to perform and control the above functions.*
  - e. *The supporting functions shall be capable of providing the process cooling, lubrication, etc., necessary to permit the operation of the equipment used for safe shutdown functions.*

These performance goals essentially define functional design requirements (sizing, capacity, capability) for the Alternative/Dedicated shutdown capability. For these capacities and capabilities to be meaningful, they must be placed in the context of what the initial conditions are (LOOP, etc.) and how many spurious operations they are intended to overcome. Typically, licensees proposed and designed their capabilities to be sufficient to overcome a single spurious actuation in accordance with the guidance in NRC Generic Letter 86-10 Paragraph 5.3.10.

When utilizing the alternative or dedicated shutdown capability, transients that cause deviations from the makeup function criteria (i.e., 2.b above) have been previously evaluated. A short-duration partial core uncover (approved for BWRs when using alternative or dedicated shutdown capability) and a short duration of RCS level below that of the level indication in the pressurizer for PWRs are two such transients. These

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<sup>10</sup> NRC Letter December 12, 2000 (ML003776828) states, with respect to BWRs, "The staff reiterates its longstanding position that SRV/LPS is an appropriate means of satisfying Section III.G.3 of Appendix R (regardless of whether SRV/LPS can be considered to be a means of redundant hot shutdown capability). Later the staff also concludes that "SRV/LPS meets the requirements of a redundant means of post-fire safe shutdown under Section III.G.2 of 10 CFR Part 50, Appendix R." NRC Memorandum from Sunil Weerakkody, Chief Fire Protection and Special Projects Section, to John Hannon, Chief Plant Systems Branch, Resolution of Questions Concerning Compliance with Section III.L.2 of Appendix R, dated February 10, 2005 (ML050330417)

transients do not lead to unrestorable conditions and thus have been deemed to be acceptable deviations from the performance goals<sup>11</sup>. For Appendix R plants, these conditions may not meet the requirements of III.L and an exemption request may be needed.

Section III.L.7 also highlights the importance of considering associated non-safety circuits for alternative shutdown capability by stating the following:

*“The safe shutdown equipment and systems for each fire area shall be known to be isolated from associated non-safety circuits in the fire area so that hot shorts, open circuits, or shorts to ground in the associated circuits will not prevent operation of the safe shutdown equipment.”*

Additional guidance on the topic of alternative/dedicated shutdown has been provided in the following documents:

- NRC Generic Letter 81-12
- NRC Information Notice 84-09
- NRC Generic Letter 86-10.

Furthermore, based on the guidance information in IN 85-09 as indicated below, the availability of redundant fusing should be considered when relying on transfer switches.

*During a recent NRC fire protection inspection at the Wolf Creek facility, it was discovered that a fire in the control room could disable the operation of the plant's alternate shutdown system. Isolation transfer switches of certain hot shutdown systems would have to be transferred to the alternate or isolated position before fire damage occurred to the control power circuits of several essential pumps and motor-operated valves at this facility. If the fire damage occurred before the switchover, fuses might blow at the motor control centers or local panels and require replacements to make the affected systems/components operable. This situation existed because the transfer scheme depended on the existing set of fuses in the affected circuit and did not include redundant fuses in all of the alternate shutdown system circuits. For most of the transfer switches, the situation would not cause a problem because the desired effect after isolation is the deenergization of power. In instances where the system/component has to be operable or where operation might be required to override a spurious actuation of a component (such as a motor-operated valve), replacement of fuses may have become necessary. In such cases, troubleshooting/repair would be required to achieve or maintain hot shutdown.*

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<sup>11</sup> NRC Letter December 12, 2000 (ML003776828) states, with respect to BWRs, “The staff reiterates its longstanding position that SRV/LPS is an appropriate means of satisfying Section III.G.3 of Appendix R (regardless of whether SRV/LPS can be considered to be a means of redundant hot shutdown capability).” Later the staff also concludes that “SRV/LPS meets the requirements of a redundant means of post-fire safe shutdown under Section III.G.2 of 10 CFR Part 50, Appendix R.” NRC Memorandum from Sunil Weerakkody, Chief Fire Protection and Special Projects Section, to John Hannon, Chief Plant Systems Branch, Resolution of Questions Concerning Compliance with Section III.L.2 of Appendix R, dated February 10, 2005 (ML050330417)

Additional guidance for selecting the process monitoring functions for alternative shutdown is provided in IN 84-09 as indicated in the following excerpt from GL 86-10.

*1. Process Monitoring Instrumentation*

*Section III.L.2.d of Appendix R to 10 CFR Part 50 states that “the process monitoring function shall be capable of providing direct readings of the process variables necessary to perform and control” the reactivity control function. In I&E Information Notice 84-09, the staff provides a listing of instrumentation acceptable to and preferred by the staff to demonstrate compliance with this provision. While this guidance provides an acceptable method for compliance with the regulation, it does not exclude other alternative methods of compliance. Accordingly, a licensee may propose to the staff alternative instrumentation to comply with the regulation (e.g., boron concentration indication). While such a submittal is not an exemption request, it must be justified based on a technical evaluation.*

For Appendix R Section III.G.3, the area/room/zone under consideration should be provided with a fixed suppression system and fire detection.

Additional guidance regarding the requirements for suppression and detection in rooms or fire zones relying on alternative/dedicated shutdown is provided in GL 86-10 Question 3.1.5.

*3.1.5 Fire Zones*

*QUESTION*

*Appendix R, Section III.G.3 states “alternative or dedicated shutdown capability and its associated circuits, independent of cables, systems or components in the area room or zone under consideration...” What is the implied utilization of a room or zone concept under Section III.G of Appendix R? The use of the phraseology “area, room or zone under consideration” is used again at the end of the Section III.G.3. Does the requirement for detection and fixed suppression indicate that the requirement can be limited to a fire zone rather than throughout a fire area? Under what conditions and with what caveats can the fire zone concept be utilized in demonstrating conformance to Appendix R?*

*RESPONSE*

*Section III.G was written after NRC's multi-discipline review teams had visited all operating power plants. From these audits, the NRC recognized that it is not practical and may be impossible to subdivide some portions of an operating plant into fire areas. In addition, the NRC recognized that in some cases where fire areas are designated, it may not be possible to provide alternate shutdown capability independent of the fire area and, therefore, would have to be evaluated on the basis of fire zones within the fire area. The NRC also recognized that*

*because some licensees had not yet performed a safe shutdown analysis, these analyses may identify new unique configurations.*

*To cover the large variation of possible configurations, the requirements of Section III.G were presented in three Parts:*

*Section III.G.1 requires one train of hot shutdown systems be free of fire damage and damage to cold shutdown systems be limited. [NRC has stated that 1) Section III.G.2 does not allow the use of operator manual actions without prior approval to demonstrate compliance with Section III.G.2 when redundant trains are located in the same fire area, and 2) despite Section III.G.1, compliance with Section III.G.2 needs to be demonstrated when redundant trains are located in the same fire area. Repairs to, or manual operation of, equipment required for cold shutdown are allowed in accordance with current regulations and regulatory guidance.]*

*Section III.G.2 provides certain separation, suppression and detection requirements within fire areas; where such requirements are met, analysis is not necessary. [As clarified in Section 3.4.1.6 of this document (excepting emergency control stations), depending on a plant's licensing basis, exemption requests, deviation requests and GL 86-10, Fire Hazards Evaluations or Fire Protection Design Change Evaluations may be used to demonstrate equivalency to the separation requirements of Section III.G.2 as long as the ability to achieve and maintain safe shutdown is not adversely affected.] [Note the current NRC position above on the use of unapproved operator manual actions]*

*Section III.G.3 requires alternative dedicated shutdown capability for configurations that do not satisfy the requirements of III.G.2 or where fire suppressants released as a result of fire fighting, rupture of the system or inadvertent operation of the system may damage redundant equipment. If alternate shutdown is provided on the basis of rooms or zones, the provision of fire detection and fixed suppression is only required in the room or zone under consideration.*

*Section III.G recognizes that the need for alternate or dedicated shutdown capability may have to be considered on the basis of a fire area, a room or a fire zone. The alternative or dedicated capability should be independent of the fire area where it is possible to do so (See Supplementary Information for the final rule Section III.G). When fire areas are not designated or where it is not possible to have the alternative or dedicated capability independent of the fire area, careful consideration must be given to the selection and location of the alternative or dedicated shutdown capability to assure that the performance requirement set forth in Section III.G.1 is met. Where alternate or dedicated shutdown is provided for a room or zone, the capability must be physically and electrically independent of that room or zone. The vulnerability of the equipment and personnel required at the location of the alternative or dedicated shutdown capability to the*



*environments produced at that location as a result of the fire or fire suppressant's must be evaluated.*

*These environments may be due to the hot layer, smoke, drifting suppressants, common ventilation systems, common drain systems or flooding. In addition, other interactions between the locations may be possible in unique configurations.*

*If alternate shutdown is provided on the basis of rooms or zones, the provision of fire detection and fixed suppression is only required in the room or zone under consideration. Compliance with Section III.G.2 cannot be based on rooms or zones.*

*See also Sections #5 and #6 of the "Interpretations of Appendix R."*

Fire detection and a fixed fire suppression system must be installed in the area, room or zone being classified as a III.G.3 area. This requirement does not apply to the location where Alternate or Dedicated shutdown is being performed (e.g., emergency control station, local control station), but rather it applies to the location where fire damage is driving the need to implement Alternate or Dedicated shutdown, (e.g., control room).

Additional guidance regarding alternative shutdown is found in GL 86-10 Enclosure 1 "Interpretations of Appendix R" and Enclosure 2 "Appendix R Questions and Answers" Section 5. Question 5.3.10 of GL 86-10 addresses the plant transients to be considered when designing the alternative or dedicated shutdown system:

#### *5.3.10 Design Basis Plant Transients*

##### *QUESTION*

*What plant transients should be considered in the design of the alternative or dedicated shutdown systems?*

##### *RESPONSE*

*Per the criteria of Section III.L of Appendix R a loss of offsite power shall be assumed for a fire in any fire area concurrent with the following assumptions:*

- a. The safe shutdown capability should not be adversely affected by any one spurious actuation or signal resulting from a fire in any plant area; and*
- b. The safe shutdown capability should not be adversely affected by a fire in any plant area which results in the loss of all automatic function (signals, logic) from the circuits located in the area in conjunction with one worst case spurious actuation or signal resulting from the fire; and*

*c. The safe shutdown capability should not be adversely affected by a fire in any plant area which results in spurious actuation of the redundant valves in any one high-low pressure interface line.*

The response to question 5.3.10 provides a bounding plant transient which describes the expected worse case conditions for such an event. Additionally, NRC IP 64100 clarified “The three assumptions of Appendix R Question and Answer 5.3.10 are meant for independent use (that is, only one assumption applies for any given configuration in a reactor plant). These assumptions are therefore consistent with the established NRR review practice of requiring licensees to analyze for any and all spurious actuations or failures where no such spurious actuations or failures occur simultaneously.” This leads to the scenarios below being applied independently, not in combination. The following is a discussion of the four conditions of the response to question 5.3.10 (including the first condition of a loss of offsite power in the introductory sentence):

- The first condition that must be met is to be able to achieve and maintain safe shutdown in the event that offsite power is lost. This condition was specified as a part of the design basis because including a loss of offsite power during a fire where the protection of neither of the redundant trains can be protected provides a worst-case scenario. The assumption of a complete loss of offsite power considers that the loss is simultaneous with the start of the fire. There is no requirement to assume a delayed complete loss of offsite power. In accordance with GL 86-10, all fire damage is postulated to occur at the beginning of the event. There is no requirement to assume delayed/progressive failures, as this leads to an unbounded analysis. The extent of fire-induced impact to the offsite power system is determined by the same fire-induced circuit failure criteria that applies to other plant systems and circuits, e.g., a single spurious operation closing a breaker may cause a partial loss of offsite power rather than a complete loss of offsite power. For fire-induced impacts to offsite power, safe shutdown impacts are assessed based on actual portions of the offsite power system that are lost.
- The second condition that must be satisfied is that a single spurious operation resulting from a single spurious signal may occur as a result of fire damage and this spurious operation cannot adversely impact the safe shutdown capability. (**Note:** The postulated spurious operation is as a result of fire damage. Any Spurious operation not resulting from fire damage is not required to be postulated.) This condition was specified because there is some potential for a spurious operation to occur due to the high concentration of equipment controls within areas like the Control Room where Alternative/Dedicated Shutdown may be required. The specific worst-case single spurious operation, however, was not defined. The requirement for addressing a worst-case spurious signal causing a worst-case single spurious operation is met by identifying any spurious operation that has the potential to adversely affect the safe shutdown capability and to evaluate the effects on the safe shutdown capability on a in accordance with the plant’s approved FPP.
- The third condition is that it should be assumed that circuits for any automatic functions capable of mitigating the effects of the postulated spurious actuation that

are located within the fire area are also defeated by the fire. This condition was prescribed in order to prevent crediting automatic functions for mitigating the effects of a worst-case single spurious signal when the controls for these automatic functions are also contained in an area such as the Control Room.

- The fourth condition is that protection must be provided to assure that the safe shutdown capability is not adversely affected by a fire that causes the spurious actuation of two redundant valves in any high-low pressure interface line. Preventing the spurious actuation of two redundant valves in a high-low pressure interface during Alternative/Dedicated Shutdown is important because the systems available at the emergency control station may not be specifically designed to mitigate the effects of a LOCA. By imposing this condition, it eliminates the need to require additional systems to be installed on the emergency control station(s) with the capability to mitigate the effects of an interfacing-system LOCA.

If the required safe shutdown path for Alternative/Dedicated Shutdown has the capability to perform all of the required safe shutdown functions and meet the requirements of the response to question 5.3.10, then an adequate level of safety is demonstrated for this unlikely event.

Although GL 86-10 was issued after most Alternative Shutdown GL 81-12 submittals and NRC approvals were issued, the assumptions and criteria in GL 86-10 are generally consistent with what was used by licensees to design their Alternative Shutdown capability and by the NRC to perform their review of this capability.

Because of its specialized nature, the alternative/dedicated shutdown capability needs to be specifically directed by plant procedure(s). The Emergency Operating Procedures (EOPs) in combination with off-normal procedures identifying specific potential fire impacts is an acceptable approach to meeting the requirement for plant procedures. Other regulatory acceptance criteria must also be met.

## **D.5 METHODOLOGY DIFFERENCES APPLICABLE TO ALTERNATIVE / DEDICATED SHUTDOWN**

The following are the differences between the “baseline” methodology provided in the body of this document and the requirements that must be applied to alternative/dedicated shutdown.

- (1) The Alternative/Dedicated Shutdown capability must be physically and electrically independent of the area where the fire has occurred. Independence may be achieved via a combination of physical separation, manual manipulations, isolation devices, or isolation transfer switches. Where circuits are vulnerable to fire-induced faults prior to isolation being achieved, the design must address the potential for failure to occur prior to isolation, and restore functionality after the transfer (e.g., redundant fusing if credit is taken for functionality of the circuitry after transfer). In addition, repairs may be credited for equipment not required to achieve hot shutdown/hot-standby. (i.e., required to achieve and maintain cold shutdown).
- (2) The ability to achieve and maintain safe shutdown must be demonstrated with and without the availability of offsite power.

- (3) The design criteria described below applies wherein hot standby/hot shutdown can be achieved and maintained even considering the effects of one worst-case spurious signal/operation in conjunction with a loss of all automatic functions whose cables or equipment are located in the fire area.
- (4) Actuation of an isolation transfer switch is an acceptable technique for mitigating the effects of a potential spurious operation of the equipment controlled by the transfer switch.  
  
The isolation transfer switch must isolate the potential fault and restore the capability to operate the equipment at the remote or auxiliary shutdown panel, (i.e., provide redundant fusing).  
  
Spurious operation prior to transfer must be assumed and the postulated spurious operation must not result in an unrecoverable condition, (e.g., NRC IN 92-18).
- (5) Specific Shutdown Procedures must be developed for Alternative/Dedicated Shutdown. These procedures should address isolation transfer switch operation and should include provisions for actions required to address potential spurious operations prior to transfer, recovery from any postulated spurious operations and any actions necessary to establish required alignments altered by potential spurious operations.
- (6) Cold shutdown (as defined in Plant's Current Licensing Basis) must be capable of being achieved within 72 hours and maintained thereafter.
- (7) Areas where Alternative/Dedicated Shutdown is credited must have fixed suppression and detection.

## **D.6 ADDITIONAL OPERATOR ACTIONS RECOMMENDED FOR CONTROL ROOM EVACUATION**

The primary goal for Control Room fires is to achieve safe shutdown. Guidance on actions to be taken is found in Generic Letter 86-10 Question 3.8.4. The following additional operator actions, however, could be useful, if included in a plant's Alternative/Dedicated Safe Shutdown Analysis and the procedures used for Alternative/Dedicated Shutdown, in helping to minimize the impact of the effects of a fire on the ability to safely shutdown the unit.

The following actions should be considered for inclusion in the control room evacuation procedures as immediate operator actions to be performed prior to leaving the control room. These actions are in addition to performing the reactor scram/trip that is already endorsed for this event.

- [BWR] A tie between the emergency operating procedure actions to affect the scram by either removing RPS Power or venting the scram instrument air header in the event that a control room scram is not achieved. [Reference NRC IN 2007-07]
- Closing the Main Steam Isolation Valves.
- [BWR] Closing the Main Steam drain lines.
- [BWR] Tripping the feed pumps and closing the feed pump discharge valves.

- [PWR] Isolation of letdown. [This is done at the Auxiliary Shutdown Panel for some PWRs.]

The latter four (4) actions could be a benefit in minimizing the potential for flooding of the main steam lines outside of primary containment (BWRs), minimizing the potential of an overcooling event (PWRs), and conserving RCS inventory (PWRs).

To prevent damage to equipment important to alternative post-fire safe shutdown at the remote or auxiliary shutdown panel, the following actions should be considered for immediate operator actions in the procedures governing shutdown at the remote or auxiliary shutdown panel (some of these actions are performed by operators not at the remote or auxiliary shutdown panel):

- Upon arrival at the emergency control station, assure that the pumps (Service Water, Component Cooling Water, etc.) that provide cooling to the Emergency Diesel Generators are running. If the pumps are not running, start them immediately. [In the event of a loss of offsite power, the Emergency Diesel Generators may receive a start signal. If the pumps providing cooling to the Emergency Diesel Generators are not running, then the Diesel Generators could be damaged. Performing this action as an immediate operator action upon arrival at the emergency control station will provide added assurance that the Diesel Generators will not be damaged.]
- Upon arrival at the emergency control station, assure that an open flow path exists for any pumps that are running. If the pump is running, but not injecting, then assure that the pump minimum flow valve is open. If the pump minimum flow valve cannot be opened, trip the pump. Performing this as an immediate operator action upon arrival at the emergency control station will provide added assurance that these pumps will not be damaged.
- [PWR] Upon arrival at the emergency control station, trip the Reactor Coolant Pump (RCP) to protect the RCP seals.

The addition of these latter actions provides reasonable measures to prevent damage to equipment required for Alternative/Dedicated Shutdown.

Consideration should be given to including each of the actions described above in each licensee's Alternative/Dedicated Shutdown Procedures, as appropriate. With the addition of these supplemental actions, as appropriate, there is no need to justify the performance of these actions relative to an assumed fire impact time line. All of these actions are reasonable actions to take and can be accomplished in a short time frame prior to Control Room Evacuation and upon arrival at the emergency control station.

Additionally, it is recommended that licensee's confirm, as appropriate, that provisions have been included in the Alternative/Dedicate Safe Shutdown Analysis to preclude the following:

- Spurious opening of both Containment Sump Valves resulting in a drain down of the RWST. [PWR]
- Spurious Flow Diversion of suppression pool inventory to the CST via HPCI/RCIC. [BWR]

- Spurious reactor vessel overfill and flooding of the main steam lines by HPCI when RCIC is being credited for Alternative Safe Shutdown. [BWR]
- Spurious initiation of the Containment Spray System by including the capability to stop the pump or close the injection valve. [BWR]

## **D.7 REFERENCES**

D.7.1 Generic Letter 81-12, "Fire Protection Rule," February 20, 1981.

D.7.2 Generic Letter 86-10, "Implementation of Fire Protection Requirements," dated April 24, 1986.

D.7.3 10 CFR 50 Appendix R, Fire Protection for Operating Nuclear Plants.

D.7.4 IN 84-09 – Lessons Learned from NRC Inspections of Fire Protection Safe Shutdown Systems (10 CFR 50 Appendix R), Revision 1, March 7, 1984.

D.7.5 IN 85-09 - Isolation Transfer Switches and Post-Fire Safe Shutdown Capability, January 31, 1985

## **APPENDIX E: ACCEPTANCE CRITERIA OPERATOR MANUAL ACTIONS AND REPAIRS**

### **E.1. PURPOSE**

This appendix provides guidance regarding the use of operator manual actions and repairs to equipment required for post-fire safe shutdown. Operator manual actions as defined in NUREG 1852 includes only “those actions performed by operators to manipulate equipment and components from outside the main control room to achieve and maintain post-fire hot shutdown, but not including “repairs”. As stated in footnote number 1 on page 1-1 of NUREG 1852, operator manual actions do not include any actions within the main control room or the action(s) associated with abandoning the main control room in the case of fire.

### **E.2. INTRODUCTION**

Operator manual actions may involve manual control, local control or manual operation of equipment. Operator manual actions on equipment in support of achieving safe shutdown are allowed as follows:

- For components classified as important to safe shutdown where:
  - The Operator Manual Action is determined to be feasible and reliable as outlined in this appendix.
- For components classified as either required for hot shutdown or important to safe shutdown where:
  - Operator manual actions taken inside of the Control Room or at the Emergency Control Station are allowed. [Note: The Emergency Control Station includes specific plant locations where remote controls have been provided for operating plant equipment.] To credit the use of the equipment at the Emergency Control Station, the equipment must be included in the post-fire safe shutdown analysis and circuits for the components must be appropriately protected from the effects of fires as outlined in Section 3 of this document. Additionally, the action at the Emergency Control Station must be determined to be feasible and reliable as outlined in this appendix.
  - Operator manual actions taken to achieve and maintain cold shutdown are allowed when determined to be feasible and reliable as outlined in this appendix.
  - Operator manual actions to manually operate a valve specifically designed for accomplishing the function, (e.g. operation of a manual valve designed into the system specifically for system isolation), are allowed when determined to be feasible and reliable as outlined in this appendix.

- Operator manual actions taken for Appendix R Section III.G.3/III.L are allowed.

Repairs may be performed to equipment required for cold shutdown. This appendix provides the criteria to assure that the reliance on operator manual actions or repairs is appropriate. These criteria are intended to assure that the actions specified are capable of being performed, and that reliance on them is balanced within the overall safe shutdown strategy for a given fire area.

### **E.3. RELIANCE ON OPERATOR MANUAL ACTIONS**

Automatic control functions are a design feature provided to mitigate or limit the consequences of one or more design basis accidents. NRC Generic letter 86-10 Section 5.3.10 suggests that post-fire safe shutdown may be accomplished without reliance on these automatic functions. Therefore, automatic control functions are not required for post-fire safe shutdown. As a result, manual initiation of the systems available for mitigating the effects of plant fires is allowed. This Appendix provides the criteria for determining when an operator manual action is allowed by NRC and when NRC approval for the use of an operator manual action in support of post-fire safe shutdown is required.

Specific plant protective functions, due to the nature of their design in assuring safe and reliable plant operation, require special consideration for a fire event. The Reactor Protection System (RPS) Scram function is one such system for a BWR. The Reactor Trip System (RTS) is one such system for a PWR. Due to the required design features of the RPS/RTS Scram System, automatic or manual Reactor Scram circuitry is impractical to fully protect from the effects of fire-induced circuit failures. Each of these systems is designed to the requirements of General Design Criteria 23. Due to the importance of this system to reactor safe shutdown for multiple design conditions, re-design of the RPS Scram circuitry is not feasible. To assure the Reactor is scrammed for all fire conditions, it is recommended that each licensee assure that the Emergency Operating Procedure (EOP) action to implement the requirements of EO-113 to either de-power RPS/RTS or to vent the scram air header is linked to their post-fire safe shutdown procedures. This action is considered to be acceptable, feasible and reliable for all fire conditions, (i.e., III.G.1/III.G.2 and/or III.G.3/III.L). [Reference BWROG NEDO-33638.]

### **E.4. DIFFERENTIATING BETWEEN OPERATOR MANUAL ACTIONS AND REPAIRS**

The fundamental difference between operator manual actions and repairs is definitional. Both are subject to timing limitations, feasibility, and resource constraints. The NRC has placed additional limitations on the use of repairs, such that they may only be used for cold shutdown conditions. This distinction provides the opportunity for licensees to maintain hot shutdown for an extended period of time, if necessary, while repairs are performed to equipment that is required to either transition to, or maintain cold shutdown.

From an operational perspective, there is no meaningful distinction whether an action is defined as an operator manual action or a repair, since the same considerations apply.



## **E-5. DEFINITIONS**

This appendix on operator manual actions relies upon definitions contained in Section 5. For the definition of terms used in this appendix, refer to Section 5, Definitions.

## **E.6. CRITERIA**

To credit the use of operator manual actions or repairs to achieve post-fire safe shutdown, certain criteria must be met. The first criterion for operator manual actions is that the operator manual action must be allowed under the current regulations either through compliance with the criteria outlined in this document or based on an approved exemption, deviation request or license amendment. Those actions described in Section E.2 and E.3 above are considered to be approved with no additional action required on the part of a licensee. For those actions that are allowed, unless noted otherwise under Section E.2 or E.3, the remaining sections of this Appendix apply in determining whether the specific allowed action is feasible and reliable. To credit an operator manual action not allowed based on the criteria in this appendix, NRC approval through an exemption request or a license amendment is required. In processing an exemption request and/or license amendment, the licensee submitting the exemption request or amendment should consider the requirements of NUREG 1852. NRC has stated that exemption requests and license amendments for operator manual actions will be evaluated for feasibility and reliability against the criteria contained in NUREG 1852.

Due to the similarity between operator manual actions and repairs from the operational perspective, most of these criteria in this appendix apply to both. There are, however, a small number of additional criteria applied only to repairs. These additional criteria for repairs only are identified as such below.

### **Criteria Applicable to Both Operator Manual Actions and Repairs**

NOTE: The generic term "actions" is used below, in order to refer to operator manual actions and repairs collectively, without creating cumbersome language. If the specific term Operator Manual Action or Repair is used below, it is used intentionally to show some specific distinction.

- There shall be sufficient time with adequate margin to travel to each action location and perform the action. Actions should be verified and validated by plant walkdowns using the current procedure. The action must be capable of being identified and performed in the time required to support the associated shutdown function(s) such that an unrecoverable condition does not occur. Previous action locations should be considered when sequential actions are required.
- There shall be a sufficient number of plant staff available to perform all of the required actions in the times required, based on the minimum shift staffing. The use of personnel to perform actions should not interfere with any collateral fire brigade or control room duties they may need to perform as a result of the fire. Administrative controls shall exist to ensure that the personnel necessary to perform actions are available when required, and that unexpected absences are promptly

corrected. If staff augmentation consistent with the licensee's Emergency Plan Implementing Procedures is credited, then the licensee must demonstrate that unrecoverable conditions would not occur in the time period before staff augmentation is achieved.

- The action location shall be accessible. In evaluating actions and the route through the plant for performing any actions, consideration should be given to the potential effects of temperature, humidity, radiation levels, smoke, and toxic gases. Actions required in a fire area experiencing a fire, or that require travel through a fire area experiencing a fire, may be credited if it is demonstrated that these actions are not required until the fire has been sufficiently extinguished to allow completion of necessary actions in the fire area. Generally, one-hour post-fire start is a reasonable time frame for meeting this criterion. In addition, if the action required is to be performed in the fire area experiencing the fire, it must be assured that fire damage within the fire area does not prevent completion of the action.
- The action locations and the access and egress path for the actions shall be lit with 8-hour battery-backed emergency lighting. Tasks that are not required until after 8 hours do not require emergency lights as there is time to establish temporary lighting. The path to and from actions required at remote buildings (such as pump house structures) does not require outdoor battery backed lights, if other lighting provisions are available (portable lights, security lighting, etc.).
- There should be indication, which is unaffected by the postulated fire, that confirms that an action is necessary and that the action, once completed, has achieved its objective. This indication is not required to be a direct reading instrument and may be a system change (level, pressure, flow, amps, temperature, etc.). Additional instrumentation may be needed to properly assess spurious operations, however, it may not be necessary to make a diagnosis of the specific spurious operation that occurred, if symptom-based plant procedures provide the appropriate guidance to respond to the situation. If pre-emptive actions will be taken to preclude spurious actuations, then event-based procedures should be provided for the situation.
- Administrative controls shall be provided to ensure that any tools, equipment or keys required for the action are functional, available, and accessible. This includes consideration of self-contained breathing apparatus (SCBA) and personnel protective equipment, if required. This also includes the availability of ladders or special equipment, if these items are required for access.
- There shall be provisions for communications to allow coordination of actions with the main control room or the alternative shutdown facility, if required. The nature of the action, and the need for coordination with other related actions or the control room should be considered when determining what type of communication is required.
- Guidance (e.g., procedures, pre-fire plan, etc.) should be provided to alert the operator as to when actions may be required in response to potential fire damage. This guidance shall be provided in locations that will be accessible during and after the fire. The guidance may be prescriptive or symptomatic. Specific event-based

procedures are required for activities not addressed in existing operating procedures (normal, abnormal, emergency) for actions and repairs as a result of fire-induced failures that are pre-emptive. Pre-emptive specific event based procedures should be used for those situations where the fire-induced failure cannot be readily diagnosed using fire protected information, (i.e., implicit or explicit indication), available to the operator. Use of Emergency Operating Procedures is an acceptable approach for all other conditions, since EOPs direct the operator to use all available systems to achieve safe shutdown and, in all likelihood, fire damage to plant systems will be limited. The "skill of the craft" should be considered when determining the level of procedural guidance to provide. Typically, plant operators should be capable of performing actions without detailed instructions. Detailed instructions may be required for non-routine evolutions and, in these cases, should be readily available. Guidance should likewise be provided to the operator as to when to perform repairs in response to potential fire damage. The guidance shall provide the level of detail required to enable plant personnel to perform the task.

- Personnel shall be trained and qualified, as appropriate, to perform the specified actions, in accordance with INPO's Systematic Approach to Training.
- The complexity and number of operator manual actions required for safe shutdown shall be limited, such that their successful accomplishment under realistically severe conditions is ensured for a given fire scenario. Actions to address the effects of MSOs should be assessed individually.

#### **Additional Criteria Specific to Repairs**

- Repairs may only be used to achieve and maintain cold shutdown (not hot shutdown).
- Hot shutdown must be capable of being maintained for the time required to perform any necessary repairs to equipment or systems needed to transition to and/or maintain cold shutdown.
- Additional non-operating personnel (e.g., maintenance, instrument and control technicians, electricians) may be relied upon to perform repairs, provided their availability is consistent with plant's Emergency Plan Implementing Procedures and/or the plant's licensing commitments.

#### **Other Types of Actions**

When performing the post-fire safe shutdown analysis, additional actions that are not credited in the post-fire safe shutdown analysis may be identified that have a positive benefit to the safe shutdown scenario such as minimizing the shutdown transient or reducing commercial property damage. Since these actions are not specifically required by the regulations or the safe shutdown analysis, it is not necessary to provide 8-hour emergency lighting or communication for these actions. It is also not required to specifically address the required timing for these actions. Similarly, operator manual actions specified as precautionary or confirmatory backup actions (prudent, but unnecessary or redundant) for a primary mitigating technique that are not credited in the

post-fire safe shutdown analysis do not require 8-hour emergency lights, communications or timing considerations.

When these types of actions are included in the post-fire safe shutdown procedures, provisions should be made to identify which actions are “required” and/or which are “prudent” so that the operator is aware of which actions must be addressed on a priority basis and which are more discretionary. This will help assure that the operator is properly focused on those actions that are of most importance.

## **E.7 REFERENCES**

10 CFR 50 Appendix R Fire Protection for Operating Nuclear Power Plants

Draft NRC Response to 03-29-06 EPM letter, May 25, 2006 (ML061440237)

Draft NRC Response to 05-03-06 NEI letter, May 25, 2006 (ML061440251)

NRC Inspection Procedure 71111.05, March 18, 2005

NRC letter to NEI, Use of Manual Actions to Achieve Safe Shutdown for Fire Events, dated May 16, 2002 (ML021410026)

NRC Meeting Summary of 06-09-06 OMA Meeting, July 19, 2006 (ML061950327)

NRC Revision to Draft Response to EPM March 2006 letter, July 19, 2006 (ML061980016)

NRC Revision to Draft Response to NEI May 2006 letter, July 19, 2006 (ML061980035)

NUREG-1778, Knowledge Base for Post-Fire Safe-Shutdown Analysis, January 2004

Public Meeting Notice 20060609 on Manual Action Clarifications, May 26, 2006 (ML061390156)

RIS 2006-10 Regulatory Expectations with Appendix R Paragraph III.G.2 Operator Manual Actions, June 30, 2006 (ML061650389)

SECY-03-0100, Rulemaking Plan on Post-Fire Operator Manual Actions, June 17, 2003

NUREG-1852, Demonstrating the Feasibility and Reliability of Operator Manual Actions in Response to Fire, October 2007

## **APPENDIX F: SUPPLEMENTAL SELECTION GUIDANCE (DISCRETIONARY)**

### **F.1 INTRODUCTION**

This appendix is be used to supplement the information in Section 4 in support of the plant specific review of the Generic List of MSO in Appendix G to supplement the list of MSOs to be reviewed on a Plant Unique basis. The information in this appendix is provided for guidance only. There is no intent that this appendix be treated as a required step-by-step process for addressing MSOs. The power point slide presentation for Expert Panel has been removed from Revision 4. Refer to Revision 2 if the information in this slide presentation is needed.

### **F.2 P&ID OR LOGIC DIAGRAM REVIEW**

The first step is to select target components/combinations that could impact safe shutdown. This first step limits consideration to combinations of multiple spurious actuation evaluations whose mal-operation could result in loss of a key safety function, or immediate, direct, and unrecoverable consequences comparable to high/low pressure interface failures. These consequences are noted hereafter as “unacceptable consequences.” Potential circuit failures affecting these safe shutdown target components may have been considered in previous circuit analyses, but perhaps not for IN 92-18 or multiple spurious actuation concerns.

A system engineer can identify component combinations that can result in a loss of system safety function or immediate and unrecoverable consequences. Then, an electrical or safe shutdown engineer can identify areas where these component combinations have power, control, or instrument cables routed in the same fire area.

The review for component combinations can be performed with P&IDs or safe shutdown logic diagrams (if available) or both. The review should focus in on “pinch points” where the system function or safe shutdown (SSD) function would be failed. Failure of the entire SSD function is not necessary for identification of component combinations but would be a limiting case assuming all identified components can fail with the same fire. Component combinations that do not fail the entire SSD function can be as important as combinations failing the entire function, especially if there is only a single component or manual/operator action remaining for the SSD function, or if the remaining SSD equipment is potentially unreliable. Some internal events PRA input may be helpful for determining potentially unreliable equipment or manual/operator actions.

The results of the P&ID or logic diagram review would be a list of potentially important component combinations to be treated with the NEI 00-01 methodology. Since the internal events PRA scope and fire protection SSD scope are different, the SSD review may provide potential combinations that have not been included in the internal events PRA. Also, it is possible for this review of the P&ID to identify component combinations not identified by SSD analysis (because it requires multiple spurious operations) or internal events PRA (because of a high level of redundancy). The final list of identified

component combinations should be combined with any internal events PRA combinations (from the PRA review below) for a final list for analysis.

### **F.3 PRA REVIEW**

The internal events PRA can be used to determine potentially important component combinations through either cutset review or through model reanalysis. These are both described below. Note that a PRA review may identify combinations which include equipment not included in the Fire Protection Safe Shutdown list. The important components identified in the pilot applications were already in the Safe Shutdown Equipment List, but the internal events PRA scope includes additional equipment that is not in this list.

#### **F.3.1 Cutset or Sequence Review**

The plant analyst may review cutsets or sequence results (in this discussion, this is simplified to “cutsets”) with high contributions to core damage frequency, including common cause failures that include combinations with unacceptable consequences as noted above. These cutsets will generally contain few terms, have a significant contribution to core damage frequency, and include one or more basic events that can be affected by fire, either through direct damage or through spurious operation. Cutsets reviewed should include cutsets sorted by probability, and cutsets sorted by order (from least number of events in the cutset to most). Review of the cutsets would identify combinations where one or more components may spuriously operate, and whose spurious operation may be significant. The pilot project showed the spurious operation components are typically not in the top cutsets, since random (non fire-induced) spurious operation is typically a low probability event. It may be helpful to manipulate the cutsets using a cutset editor by setting the basic event probabilities associated with spurious operation events to 1.0, and re-sorting the cutsets<sup>12</sup>. For example, by setting all of the motor-operated valve (MOV) spurious operation events to 1.0 and re-sorting, the top cutsets may now include potentially important component combinations for MOV cables.

Generally, the significance of each combination cannot be determined from a cutset review. However, the relative significance of one combination versus another can be performed when the cutsets include similar equipment. For example, when two similar cutsets, one with two spurious operations required and one with the same two and one additional spurious operation required are compared, the latter combination is probably less important. This type of comparison would require review of the other events in the cutsets, and the fire characteristics for the event causing equipment damage.

One additional consideration is that the cutset a review does not need to include review of cutsets for initiating events that cannot be fire induced. For example, cutsets for steam generator tube rupture or large LOCA need not be reviewed. Typically, the review can be performed on turbine/reactor trip cutsets, loss of offsite power cutsets, and induced small LOCA cutsets. Similarly, cutsets requiring failure of components in both redundant trains

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<sup>12</sup> If the licensee has a full internal events PRA model, re-running with spurious failures set to a high screening value (>0.1) could recover cutsets truncated in the internal events PRA that could contribute non-negligibly to the core damage frequency due to fire.

can be dismissed as long as it can be assured that one redundant train's component is protected in each fire area, and that the protected train is not failed by the failures in the redundant train. A review of the plant's fire Individual plant Examination of External Events (IPEEE) can determine what initiating events can result from a fire.

### **F.3.2 PRA Model Manipulation**

If a logic model of the plant core damage sequences including all possible fire events is available, this model can be exercised/manipulated to identify component combinations of interest.

The level and amount of model manipulation can range from a single re-resolution of the model, to many re-resolutions following modeling changes. The analysis discussed below is based on the limited analysis used in support of the pilot application of NEI-00-01, with discussion of additional runs considered during the pilot.

A basic analysis that can provide significant results is solution of the internal events PRA model with all basic events set to 1.0 (True) that can potentially spuriously operate following a major fire. The McGuire pilot performed this analysis by also setting the transient and loss of offsite power initiating events to 1.0. The types of components and PRA basic events that should be set to 1.0 in the model include:

- MOV spuriously open or close
- AOV spuriously open or close
- PORV spuriously open or close
- Spurious actuation of automatic actuation signals

The cutsets or sequence results can be reviewed to identify component combinations that are potentially significant. Review of the results will show patterns of cutsets that can be grouped or combined. For example, a cutset with a PORV spuriously operating and charging injection failures could repeat hundreds of times with both PORVs combined with the multiple combinations failing injection and the random failures not set to 1.0 in the model. These hundreds of cutsets can be grouped into limiting combinations based on order (less spurious operations leading to core damage) and/or likelihood (less random failures leading to core damage). Initial review of the cutsets should also look for other component basic events that could occur due to spurious operation following a fire. If additional basic events are identified, additional model solutions may be necessary prior to selection of the component combinations to be analyzed.

If the PRA model includes some fire PRA sequences, additional runs with the fire PRA initiating events set to 1.0 should be performed. In this case, the PRA results would identify component combinations important for particular fire areas (or fire areas with similar characteristics).

If the PRA model does not include any fire PRA sequences, model manipulation can be performed to simulate fire PRA results. For example, in the McGuire pilot analysis, additional internal events PRA runs were performed where the 4160 VAC switchgear was failed. This included two PRA runs, one with A train 4160 VAC failed, and one with

B train failed. These runs simulated a switchgear fire, but also provided representative runs important if opposite train components were located in the same area. For example, cutset were identified where A train cooling water failed due to the A train 4160 VAC failure, and B train cooling water failed due to spurious operation. This sequence could be potentially important if the cables causing the B train failure were located in an A train fire area. The B train failure (in this example) could be as a result of a diversion due to an A train valve spuriously opening.

Additional PRA runs can be performed based on the IPEEE results. The IPEEE can provide a list of important fire areas, and the equipment that potentially fails due to a fire in these areas. By setting the component basic events to 1.0 for a selected fire area, and also setting our list of spurious operation components to 1.0, a list of potentially important component combinations can be developed for the selected fire areas. This type of analysis was not performed for the pilots, other than the fire sequences already included in the PRA models.

### F.3.3 Analysis of the New PRA Sequences

Some important fire-induced accident sequences of interest involving spurious operation may have been screened from the internal events and Fire PRAs. New scenarios or accident sequences not previously considered may result from Fire-Induced damage or as a result of operator actions taken in response of a fire. For example, manual action to close a PORV or PORV block valve in response to spurious operation concerns would result in the Pressurizer Safety Valve (PSV) being challenged following a pressure increase. Spurious injection could also challenge the PSV, and if water relief were to occur, it is likely the PSV would stick open. A stuck open PSV is generally considered a low probability event in an internal events PRA, but may show up as significant in a Fire PRA. Scenarios involving Steam Generator overfeed may not be considered important for an internal events PRA, but may be important for sequences involving control room evacuation where a turbine driven pump is the credited safe shutdown equipment.

Performing a Fire PRA update in order to develop possible multiple spurious combinations would not be an efficient method for developing a complete list of combinations. However, if a Fire PRA were being updated, either the scenario development process or PSA cutset results could provide insight to developing a complete list. The scenario development, including the development of new event trees or accident sequences, could provide a useful input to the SSA analyst.

NUREG/CR-6850 (EPRI TR-1011989) methods for consideration for MSOs includes the following additions to the PRA in step 2.5.1:

- *Sequence Considerations that were screened out of the Internal Events PRA may become relevant to the Fire PRA and need to be implemented in the Fire PRA model. For example, spurious safety injection is often screened out from the Internal Events PRA and yet may be important for fires that could cause both the spurious injection and damage to one or more pressurizer PRA such that the pressurizer SRVs are challenged. These SRVs could subsequently stick-open causing a complicating LOCA accident sequence. A review should be conducted for such scenarios originally eliminated from the Internal Events PRA to determine if the analysis needs to add*



*components to the Fire PRA Component List as well as model those components (and failure modes) in new sequences in the Fire PRA Model.*

- *Particularly when considering the possible effects of spurious operation, new accident sequences and associated components of interest may be identified that should be addressed in the Fire PRA and go beyond considerations in the Internal Events PRA. Typically, these new sequences arise as a result of spurious events that:*
  - *Cause a LOCA: (e.g., PORV opening, reactor cooling pump seal failure),*
  - *Adversely affect plant pressure control: (e.g., vessel or steam generator overfill that if unmitigated could subsequently fail credited safe shutdown equipment such as a turbine-driven feedwater or auxiliary feedwater pumps), or*
  - *Introduce other “new” scenarios that may not be addressed in the Internal Events PRA.*

These fundamental steps for performing a baseline PRA review (for possible scope increases) can also be performed in support of a review for new MSO scenarios. Additional guidance is given in NUREG/CR-6850 in the following sections:

- Fire-induced initiating events, including those not modeled in the Level 1 PRA (2.5.3)
- Equipment with the potential for spurious actuation for failing Safe Shutdown Equipment (2.5.4), including new accident sequences not previously modeled.
- Additional Mitigating, Instrumentation and Diagnostic equipment important to Human Response (2.5.5).

One of the key areas of screened sequences from the internal events PRA is the modeling of Interfacing Systems LOCA (ISLOCA) accident sequences. The internal events screening criteria for ISLOCA pathways would screen flow paths with 3 normally closed MOVs due to the low random failure rate of an MOV to remain closed. However, the fire-induced failure rate of an MOV spurious operation is significantly higher, and the screened scenario may need to be considered in the plant specific MSO list, given the scenario is possible (if one or more of the MOVs have power removed, then the cable criteria considerations in Appendix H would indicate the MSO is not likely).

In reviewing the Internal Events PRA for screened (or even combined) initiating events, the following should be considered:

1. The Initiating Event is more likely than the internal events PRA estimate (i.e., pressurizer heaters fail on).
2. The resulting Consequences can be worse (i.e., loss of HVAC coincident with a fire).
3. The Fire introduces new accident sequences not considered in the Internal Events PRA (i.e., spurious injection with PORVs closed, result in water relieve from the SRVs).

During the review of the PRA scope for possible new MSOs, the plant and operator response to a fire should be understood. In particular, if the plant procedures direct the operator to turn off power to a train of SSE, isolate a train or function, or otherwise disable equipment, then this should be accounted for in the review. In this regard:

- Credit for plant procedures to mitigate an MSO should not be used during the MSO scenario identification step, but should be used in the disposition of the MSO in the SSA.
- Negative effects of plant procedures (operator actions) should be considered when determining if a new MSO scenario should be considered.

These assumptions for the PRA input to the MSO list are conservative, but will result in a more complete list of MSOs for consideration.

The output of the above review can be used as either an input to a Fire PRA, or as consideration for additional MSOs to be identified by the Expert Panel. See the information below for additional information on this topic.

### **F.3.4 Event Tree Linking Models**

For Event tree linking models, Fussel-Vesely and Risk Achievement Worth of individual basic events representing spurious actuations can be calculated in a similar manner to that performed for fault tree linking models. However the process of identifying potentially risk significant multiple spurious actuations is slightly more involved with a linked event tree model due to the lack of sequence cutsets. In this case the spurious actuation basic events are set to 1.0 and the sequences (combinations of split fractions leading to core damage) are resolved. The new set of dominant sequences should then be compared with those derived from the base case quantification to identify those sequences that have risen significantly in value. This is followed by an investigation of the cutsets associated with those split fractions which contribute to the inflated sequence values to identify spurious and multiple spurious actuation combinations.

### **F.3.5 Additional Considerations**

The above PRA reviews do not include a complete list of sensitivity studies or analysis that can be performed using an existing PRA. In addition, a simple review of risk importance measures, especially Risk Achievement Worth (RAW) of spurious operations, would be useful.

## **F.4 EXPERT PANEL REVIEW**

### **F.4.1 Expert Panel Review**

The expert panel process described herein supplements the information provided in Section 4. An MSO identification Checklist is provided in Table F-1 below. This table provides a step-by-step process to ensure each of the critical steps are performed for the plant-specific MSO identification process using an expert panel.

## **F.5 SELECTION OF POTENTIALLY IMPORTANT COMPONENT COMBINATIONS**

Based on the results, performance of some or all of the types of analysis discussed above will provide hundreds of thousands of possible component combinations for review. Analysis of all these combinations is not possible. The PRA output provides the largest number of possible combinations. These combinations can be screened in the expert panel or self-assessment process to reduce the scenarios to those that can actually occur and those of potential significance. The final selection of component combinations for analysis needs to account for various factors affecting the final expected risk for the combinations, including:

- Expected spurious operation probability, including the combined frequency for multiple components. For example, it could be shown that for an MSO involving a large number of spurious operation components that component locations would most likely be unimportant, since the probability of spurious operation alone is on the order of 1E-06.
- Conditional core damage probability listed in the cutsets
- Additional factors not in the cutsets affecting the core damage probability, including both positive factors where additional equipment may be available and negative factors such as human actions that may be less reliable following a fire
- Expected fire frequencies (i.e., combinations in high fire frequency areas may be more important than those in low fire frequency areas).

These and other factors should be used by the analysts in determining the potentially important component combinations for review, and the number of combinations that need to be evaluated for risk significance. Combining the PRA-identified combinations with the P&ID or logic diagram review should provide a comprehensive list of potentially important component combinations that should be added to the Generic List of MSOs from Appendix G.

## **F.6 DETERMINATION OF MSO COMPONENT CATEGORY**

MSO scenarios identified above are categorized as involving either required for hot shutdown components or important to SSD components. Guidance on categorization of components and the related MSOs is provided in Section 3 and Appendix H.

**Table F-1**  
**NEI 00-01 MSO Identification Checklist**

<b>Phase</b>	<b>Step</b>	<b>Outcome</b>	<b>Complete?</b>
<b>Phase I: Pre-review of MSOs</b>	Review Generic MSO List for Applicability	Identification of each MSO on the generic list as either applicable or not applicable to the plant	
	Perform PRA runs per NEI 00-01, Appendix F	Identification of potential MSO scenarios. These scenarios are reviewed by the expert panel for applicability	
	Review Existing SSA for Spurious operations and MSOs already addressed	Development of "Table 1" as input to the expert panel. Table should identify: a) new scenarios not on the generic list, b) Scenarios already addressed by the SSA, and c) Scenarios dispositioned as requiring multiple spurious operations (and not addressed).	
<b>Phase II: Prepare for Expert Panel</b>	Select the expert panel	Diverse Review Group, including Operations, Electrical, Fire Safe Shutdown, PRA, Fire Protection and Systems Engineers.	
	Schedule MSO expert panel	Experts are scheduled for 2-3 days of expert panel review, provided preparatory work (Phase I) is performed satisfactorily.	
	Develop Training Package for expert panel	Training Material as required by NEI 00-01. Example package is provided in NEI 00-01, Appendix F.	
	Perform Training	All experts are trained prior to starting the expert panel meeting.	
<b>Phase III: Perform the Expert Panel</b>	Review MSOs on generic MSO list for applicability	Expert panel documentation of agreement or disagreement with pre-screening	
		Expert panel agreement on MSOs that are applicable to the plant, with additional discussion.	
	Review MSOs on generic MSO list for additional scenarios.	Identification of similar scenarios not on the MSO list.	
	Review applicable P&IDs, Electrical Diagrams or Logic Diagrams for new scenarios.	Identification of new scenarios not on the MSO list.	
	Review MSO Combinations	Determine whether any of the individual MSOs should be combined with other spurious operations or MSOs.	
	Review PRA Results	Determine if any PRA recommended scenarios affect the SSA and are not previously identified.	
<b>Phase IV: Post-Review</b>	Develop comprehensive plant-specific MSO list	Single location for all MSOs that will need to be addressed in the SSA.	
	Perform MSO categorization	All MSOs are categorized as Required or Important to the SSA (green or orange) per Section 3 and Appendix H.	
	Document Expert Panel Review and post-review.	Documentation supporting SSA implementation of NEI 00-01.	
	Add MSOs to the SSA, and address supplemented with NEI 00-01 performance-based tools (Fire Modeling).	SSA is updated to include MSOs. Implementation of this step may need to be performed on a phased-approach.	
	Expert Panel Review of Fire Modeling Disposition	If Fire Modeling is used in the disposition of the MSO, the expert panel reviews the disposition prior to incorporating into the SSA. expert panel Training on Fire Modeling would be required for this step.	

## **APPENDIX G: GENERIC LIST OF MSO'S**

The attached tables provide BWR and PWR MSO scenarios to be included in the generic MSO lists for evaluating fire-induced impacts to III.G.2 areas. This list is the same list of MSOs that was included in Revision 3 to this document. No revision bars have been added to the list of MSOs in Revision 4 to prevent readers from thinking that there is a difference between the Revision 3 and the Revision 4 tables.

The generic MSO lists provided below, however, may include scenarios that may also be applicable to III.G.3 areas. As outlined in Appendix D, the criteria for addressing spurious operations for III.G.3 areas is different than for III.G.2 areas. MSOs listed in this appendix that apply to III.G.3 areas only, with the exception listed below, need not be included in the analysis of impacts to the III.G.3 analysis, since the spurious operation analysis of impacts to III.G.3 areas is addressed by the criteria in Appendix D. Although MSOs with applicability to III.G.3 areas are not intended to alter a licensee's current licensing basis related to III.G.3 where the III.G.3 areas has been approved by NRC, some evaluation of the risk implications of the scenario may be warranted. The licensing basis for NRC approved III.G.3 areas is as outlined in Appendix D or in a licensee's current licensing basis. The MSOs with applicability to III.G.3 areas for these licensees are intended, at most, for use in a voluntary effort performed by a licensee to assess fire risk in III.G.3 areas. Since this type of a review is a voluntary review, any Licensee's electing to assess risk in these previously approved III.G.3 areas may use any of the available tools to disposition the MSO, including Focused-scope Fire PRA or qualitative assessments of risk without prior NRC approval. III.G.3 areas not previously approved by the NRC in an SER, however, but re-classified from III.G.2 to III.G.3 by an individual licensee using the standard license condition should evaluate the MSOs as though the area were a III.G.2 area.

## Summary of Changes; BWR Generic MSO List

The following provides a summary of non-minor changes to the BWROG MSO List. Non-minor changes should be reviewed for possible impact on the present plant-specific MSO list, if already developed. Minor changes are clarifications, format changes, additional description or clarifications that do not affect the MSO selection or other changes that would not be expected to result in any identification of plant specific MSOs. The list does not include the changes to the MSO list involving guidance on possible “required for hot shutdown (yes/no)” which was added to the BWR MSO list for this revision.

Scenario 2	Description of the Change
1a,1b	Added reference to GEH report NEDO-33638.
2e	Added description that may help in the plant specific evaluation of the SDV vent scenario.
2i	Separate the two possible flow paths for the original scenario into new scenarios 2i-1 and 2i-2. No new flow paths were added to the MSO list.
2j,2k,2m,2n,2o	Added a concern of possible pump runout for RHR/LPCI diversion MSOs.
2m	Removed F010 scenario from the discussion since this is covered under scenario 2o.
2o	Added additional description for consideration of the non-credited train.
2q	Revised the notes to clarify the scenario, making it consistent with other discharge check valve scenarios in the MSO list.
2s,2t	Clarified scenario notes which were too specific (for one site only).
2w	Revised MSO description and notes to provide clarification on the scenario of concern.
2x,2y	Additional clarification notes were added due to possible MSO on both the credited and non-credited train.
2z	Revised MSO description and notes to provide clarification on the scenario of concern.
2aa	Added notes that may help in the plant specific evaluation of the RCIC diversion scenario, and revised notes details.
2ab	Revised MSO notes to provide clarification on the scenario of concern.
2ad	Removed plant specific notes for the MSO scenario.
2af	Separate the two possible flow paths for the original scenario into new scenarios 2af-1 and 2af-2. No new flow paths were added to the MSO list. Also revised description slightly for clarification.
2ai	Removed plant specific description notes for the MSO scenario.
2aj	Added additional possible causes for the MSO scenario of concern.
2-new-1 to 2-new-9	Added nine new scenarios to be considered in the plant specific MSO list.
4b	Revised MSO notes to provide clarification on the scenario of concern.
4h	Revised MSO notes to provide clarification on the scenario of concern.
4i	Revised MSO notes to provide clarification on the scenario of concern.
4l, 4m, 4n	Simplified the notes and description section, but no impact on the MSO scenarios of concern.
4r	Changed scenario descriptions to indicate spurious containment sprays may be applicable to plants not crediting COP. Modified notes to clarify non-COP scenario.
5e	Added notes that may help in the plant specific evaluation of the RHRSW diversion scenario.
Table Note i and ii.	Added two notes that some of the scenarios should also be reviewed for applicability during alternate shutdown cooling mode, if this mode of operation is credited in achieving and maintaining <u>Hot Shutdown</u> . Scenarios involving main steam, RHR and

Scenario 2	Description of the Change
	related systems could be applicable, and may involve a separate evaluation of the MSO during this mode of operation.

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<b>Table G-1</b>					
<b>BWR Generic MSO List</b>					
<b>MPL</b>	<b>#</b>	<b>Scenario Description</b>	<b>Notes</b>	<b>Plant type (note: may be applicable to other plant types)</b>	<b>Required for Hot Shutdown (No, Yes or plant specific analysis required)</b>
		<b>Reactivity Control</b>			
C71	1a	RPS SCRAM Circuits: Refer to the BWROG NEDO-33638 on IN 2007-07. The NEDO explains that a single hot, should it occur in the right location in the right circuit, could prevent 1/4 of the rods from inserting. Similarly, two (2) hot shorts in the right location in the right circuit could prevent a full scram. Note: Single hot short cannot also fail backup scram system.	May be addressed by actions already included in the plant EOPs. This is an issue inside and outside of the Control Room. Reactivity Control is addressed by having as link between the Fire Safe Shutdown Procedures and the Procedure to either vent the scram air header or depower RPS (or reactor trip bus) to accomplish the SCRAM should manual scram from the Control Room not be effective.	All	Yes - See BWROG NEDO-33638.
C71	1b	Multiple pilot valve fail to de-energize SV 1-17 & SV 1-18	Scram pilot solenoids failure to de-energize so scram valve pilot air header stays pressurized (might be redundant with 1a, check NEDO-33638)	All	Yes - See BWROG NEDO-33638.
		<b>Reactor Coolant Makeup Control<sup>13</sup></b>			

<sup>13</sup> Note: If Alternate Shutdown Cooling Mode is credited for achieving and maintaining Hot Shutdown, Scenarios should be reviewed for applicability to Alternate Shutdown Cooling Mode.

<b>Table G-1</b>					
<b>BWR Generic MSO List</b>					
<b>MPL</b>	<b>#</b>	<b>Scenario Description</b>	<b>Notes</b>	<b>Plant type (note: may be applicable to other plant types)</b>	<b>Required for Hot Shutdown (No, Yes or plant specific analysis required)</b>
B21	2a	(Main Steam) Head vent valves (2) Spuriously Open.	Valve Numbers MS-V-1, MS-V-2 or similar. Scenario may be screened, depending on line size and criteria for required versus available RCS Injection rate. Refer to the PRA criteria about how big of a steam line break is of concern, and use that to determine if the Scenario is of interest.	All	No (see note i)
B21	2b	(Main Steam) MSIV's hot short results in MSIVs failing to close or re-opening.	Valve numbers MS-V-22A-D, MS-V-28A-D or similar. The postulated scenario involves failure of redundant, normally open, Main Steam Isolation Valves (MSIV) in one of the four Main Steam Lines (MSL) to close on demand. Each MSIV has an AC and a DC solenoid valve (Note: Some BWRs use all DC solenoids). Both valves de-energize to close the MSIV. May need to look at MSIV reopening, if closed on a fire. Pressure differential across closed MSIVs may prevent them from being re-opened by spurious actuation.	BWR2/3/4/5/6	No (see note i)
B21	2c	(Main Steam), Main Steam Line Drain Shutoffs spuriously open.  Flow diversions may exist at Leakage Control System Valves MSLC-V-3A and -2A, MSIV V 3B and -2B, MSLC-V-3C and MSLC-V-2C, and MSLC-V-3D and MSLC-V-2D if inboard MSIVs MS-V-22A, MS-V 22B, MS-V 22C and MS-V-22D are open.	Valve numbers MS-V-16, MS-V-19 (F016 and F019) or similar. May be an additional downstream manual valve MS-V-21 (F021) with an orificed bypass. Valve Motor may be removed or have power disconnected. May be able to analyze flow rate as an acceptable inventory loss.  Leakage control valves are typically minor leakage and are not of concern, but should be reviewed for completeness.	BWR2/4/5/6	No (see note i)
B31	2d	Failure to trip the Recirc pump on loss of cooling. Recirc pump seal failure LOCA	Reactor seal leakage. Spurious closure of IV-70-92, loss of RBCLC pumps and loss of service water, results in loss of RBCLC and seal LOCA.	Applicable to one BWR2	No

<b>Table G-1</b>					
<b>BWR Generic MSO List</b>					
<b>MPL</b>	<b>#</b>	<b>Scenario Description</b>	<b>Notes</b>	<b>Plant type (note: may be applicable to other plant types)</b>	<b>Required for Hot Shutdown (No, Yes or plant specific analysis required)</b>
C11	2e	RPV coolant drain through the SDV vent and drain	This scenario is a MSO initiated drain of reactor coolant from the SCRAM Discharge Volume to the Reactor Building sump. The scenario is triggered by MSO opening of the solenoid valves that supply control air to the air operated isolation valves. NOTE: In some plant designs, the solenoid valves (if they exist) provide a "remote test" capability, and cannot prevent the fulfillment of the SDV isolation function on an actual SCRAM. The design of the SCRAM air header ensures that if the SCRAM was successful (scenario 1a), these valves close.	All	No
E12	2f	Inventory control Hi/Lo pressure interface valve spurious operation - (Residual Heat Removal) SDC Suction Isolation Valves	RHR-V-8, RHR-V-9 (F008, F009) or similar. Removal of DC Control Power Fuses may resolve (may not resolve 3-phase proper rotation hot shorts). This is the traditional Hi/Lo pressure interface.	BWR3/4/5/6	No (see note i)
E12	2g	Inventory control valve spurious operation - (Residual Heat Removal) Discharge to Recirc Loop Isolation Valves	RPV Inventory loss due to reverse flow back thru RHR. Possible path includes the Warm-up line. Valves RHR-V-53A & B, RHR-V-50A & B (F015A&B, F017A&B) or similar. Testable check valve will go closed on DP. Need to consider whether RHR crosstie is open. T-H analysis of piping pressure/temperature may resolve. Power may be removed on Bypass.	BWR4/5/6	No
E12	2h	Inventory control valve spurious operation - (Residual Heat Removal) RHR Head Spray Valves	RPV Inventory loss due to reverse flow back thru RHR. MOV -F022, MOV-F023 or similar. May be cut and Capped for some plants, or have a check valve to prevent back flow.	BWR3/4	No

<b>Table G-1</b>					
<b>BWR Generic MSO List</b>					
<b>MPL</b>	<b>#</b>	<b>Scenario Description</b>	<b>Notes</b>	<b>Plant type (note: may be applicable to other plant types)</b>	<b>Required for Hot Shutdown (No, Yes or plant specific analysis required)</b>
E12	2i.1	Spurious Operations that creates RHR Pump Flow Diversion from RHR/LPCI.	RHR flow can be diverted to the containment through the Containment Spray isolation valves (E11-F016A, B and E11-F021A, B or similar),  Note: if excessive flow is diverted (drywell spray), pump runout may be a concern.	BWR4	LPCI diversion is GREEN (Yes). Inadvertent spray is ORANGE (No). (see note i)
	2i.2	Spurious Operations that creates RHR Pump Flow Diversion from LPCI.	See 2i.1 above. Consider the possibility of failing either the primary containment boundary (drywell/torus junction) or internal structural elements of the pressure suppression design as a result of spraying the drywell under conditions where drywell sprays are not allowed by EOPs. Spraying into a hot dry environment in the drywell could result in a pressure reduction beyond what can be addressed by the containment vacuum breakers.		No (see note i)
E12	2j	Spurious Operations that creates RHR Pump Flow Diversion from RHR/LPCI, including diversion to the Torus or Suppression Pool, or diversion to the FPC	RHR flow can be diverted to the containment through the RHR Torus or Suppression Pool return line isolation valves (E11-F024A, B and E11-F028A, B). FPC valves are typically manual valves for most plants.  Note: if excessive flow is diverted, pump runout may be a concern.		GREEN (Yes) when LPCI credited for Hot SD. (see note i)

<b>Table G-1</b>					
<b>BWR Generic MSO List</b>					
<b>MPL</b>	<b>#</b>	<b>Scenario Description</b>	<b>Notes</b>	<b>Plant type (note: may be applicable to other plant types)</b>	<b>Required for Hot Shutdown (No, Yes or plant specific analysis required)</b>
E12	2k	Spurious Operations that creates RHR Pump Flow Diversion from RHR/LPCI, including diversion to the Torus or Suppression Pool Spray Header. May also involved diversion through the RHR HX Vent.	RHR flow can be diverted to the containment through the Torus or Suppression Pool Spray Header isolation valve (E11-F027A, B and F028 or similar) or RHR Warm-up Line (E11-F026B). F026 typically has power removed, and 53 is in line, typically normally closed. RHR HX Vent 1A (B): RHR-V-73A (B) & 74A (B); may be capped for some plants.  Note: if excessive flow is diverted, pump runout may be a concern.  [most plants HX vents are manual valves.]		GREEN (Yes) when LPCI credited for Hot SD. (see note i)
E12	2l	Spurious RHR min flow failure to open or spurious closure with failure to establish a discharge path. If min-flow is closed, scenario could be a single spurious scenario.	RHR min flow failure to open (with spurious pump start at high pressure or RPV injection line valves spuriously fail close) may lead to pump overheating/failure likely III.G.3 scenario.	All	Plant Specific Analysis Required
E12	2m	Spurious operation (open) of valve RHR A DISCH TO RADWASTE INBOARD ISOLATION and RHR radwaste isolation valve	Valves F049, F040 (Radwaste letdown) or similar. LPCI flow diverted.  Note: if excessive flow is diverted, pump runout may be a concern.	BWR4/6	Use Appendix H for classification of flow diversion. (see note i)
E12	2n	Spurious opening of two series RHR unit cross tie valves	BFN Only.  Note: if excessive flow is diverted, pump runout may be a concern.	BWR4	Use Appendix H for classification of flow diversion (see note i)

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<b>BWR Generic MSO List</b>					
<b>MPL</b>	<b>#</b>	<b>Scenario Description</b>	<b>Notes</b>	<b>Plant type (note: may be applicable to other plant types)</b>	<b>Required for Hot Shutdown (No, Yes or plant specific analysis required)</b>
E12	2o	Spurious opening of two series RHR loop cross tie valves	F010 (Crosstie) valve or similar. Breaker power may be removed. May require additional spurious actuations on the non-credited loop before LPCI flow to the RPV is actually diverted.  Note: if excessive flow is diverted, pump runout may be a concern.	BWR4	Use Appendix H for classification of flow diversion.  (see note i)
E12	2p	Spurious opening of F073 and F074 RHR service water to RHR injection flood up may result in diversion of RHR. If Service Water is at higher pressure, this would be a diversion of SW to RHR. May also involve Spurious opening of HPSW to RHR "Ultimate Cooling" inter-cross-tie valves	ESW emergency containment (core) flooders valves. HPSW to RHR crosstie line provided for HPSW injection ("ultimate cooling"). If both these valves open, then HPSW is diverted from cooling RHR HX, failing HPSW heat removal function. Long-term issue with too much water in torus, submerging vacuum breakers.		Use Appendix H for classification of flow diversion.  If this occurs on non-credited train, then ORANGE (No).
E21	2q	Spurious Operation of normally closed Core Spray Discharge Check bypass valve (equalizing valve) or testable check valves, and core spray discharge valve F005.	RPV Inventory loss due to reverse flow back thru Core Spray discharge. Possible path includes the Warm-up line. Testable check valve will go closed on DP. T-H analysis of piping pressure/temperature may resolve. Power may be removed on Bypass.	BWR5	No
E21	2r	Spurious Operations that Create Core Spray Pump Flow Diversion for injection to the RPV	CS flow can be diverted to the Torus or Suppression Pool through the CS test line MOVs (E21-F015A, B or similar). Test Line is typically a 10" line with Orifice. This is a single spurious operation, so should already be addressed in SSA (unless the line includes 2 series valves).	BWR2/4	Use Appendix H for classification of flow diversion.

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<b>MPL</b>	<b>#</b>	<b>Scenario Description</b>	<b>Notes</b>	<b>Plant type (note: may be applicable to other plant types)</b>	<b>Required for Hot Shutdown (No, Yes or plant specific analysis required)</b>
E21	2s	Core Spray flow diversion to the equipment drains IV-40-30, 31, 32, 33 and to the containment spray raw water system.	Core Spray diversion to the RB equipment drain tank.	Applicable to one BWR2	Use Appendix H for classification of flow diversion
E21	2t	Path from Core Spray injection discharge valve to reactor building equipment drain tank vent isolation valves, scenario is plant specific	Spurious actuation of CS Injection (IV-40-10 or 11) or loop 2 (IV-40- 09 or 08) Core Spray diversion to the RB equipment drain tank.	Applicable to one BWR2	Use Appendix H for classification of flow diversion
E22	2u	Spurious HPCS/HPCI operation (Note: for plants where HPCI is a subset of Feedwater, scenario may involve continued operation of HPCI)	Vessel Overfill into steam lines. Could Impair RCIC operation (if credited) due to vessel overfill and water in the steam line. Can occur as a result of: a) Spurious valve Operation: Turbine Stop Valve and HPCI Discharge Shutoff Valve Spurious Operation (HPCI-F067, F006 or similar), b) Damage to Cabling for transmitters (two required to start HPCI), c) Damage to High Level Trip Circuitry, or d) HPCI pump controls hot short (for either motor or TD HPCI).		No
E41	2v	HPCI inject to Core Spray (F037 & F048 valves opening) over pressurizing CS.	Potential Core Spray Pipe Rupture scenario.	BWR4	No
E41	2w	HPCI drain pot drains spuriously opening, or failing to close when system is started.	AOV F004/F005 (F028, F029, and bypass is F055.) or similar. Open drain flow path may not be sufficient to fail HPCI function. RPV inventory loss expected to be very small.	BWR4	Use Appendix H for classification of flow diversion.

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<b>MPL</b>	<b>#</b>	<b>Scenario Description</b>	<b>Notes</b>	<b>Plant type (note: may be applicable to other plant types)</b>	<b>Required for Hot Shutdown (No, Yes or plant specific analysis required)</b>
E41/E22	2x	Spurious operation (open) of both of HPCI/HPCS CST Test Return/Bypass valves.	MSOs to the HPCI/HPCS discharge test line valves can divert flow to the Condensate Storage Tank. If suction is from the Suppression Pool, the Suppression Pool inventory is diverted to the CST. Valves E41-F011, E41-F008 [E22*MOVF010 and E22*MOVF011] (MO2316, CV2315), E41-F042, E41-F041 (MO2321, MO2322), or similar." When HPCI/HPCS is credited, can divert flow and fail injection function. When HPCI/HPCS is not credited, can divert suppression pool inventory, leading to NPSH issues later in the event.	BWR4/6	When HPCI/HPCS is credited for hot Shutdown, use Appendix H for classification of flow diversion.  No when HPCI/HPCS is not credited for hot shutdown.
E51	2y	RCIC Test flow to CST Stop and throttle valves flow diversion	Valve numbers F022 and F011 or similar. The throttle valve and isolation valve in the return line to the Condensate Storage Tank are normally closed and at least one of the valves must remain closed to prevent flow diversion from the RCIC pump to support the reactor inventory control function, especially during suppression pool cooling. When RCIC is credited, can divert flow and fail injection function. When RCIC is not credited, can divert suppression pool inventory, leading to NPSH issues later in the event.	BWR6	Use Appendix H for classification of flow diversion  No when RCIC is not credited for hot shutdown.
E51	2z	RCIC drain pot drains spuriously opening, or failing to close when system is started.	AOV F025/F026 (RCIC) on the drain to the sump failing open. Open drain flow path may not be sufficient to fail RCIC function. RPV inventory loss expected to be very small.	BWR4	Use Appendix H for classification of flow diversion.



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E51	2aa	RCIC Pump Diversion through Mini Flow Line to the Suppression Pool.	RCIC min flow line MOV E51-F019 is another path and a path from the pump suction to the suppression pool through MOVs E51-F029 and E51-F031. Note RCIC turbine may still meet rated injection requirements with min flow valve open, due to governor response.	BWR4	Yes when RCIC is credited, unless min flow diversion does not fail credited injection function.
E51	2ab	Spurious operation (open) of both of RCIC TEST RETURN TO CONDENSATE STORAGE TANK valves with suction on the Suppression Pool may route the RCIC inventory to the CST.	Valves 1E51*MOVF022 and 1E51*MOVF059 and a Spurious startup signal or valves RCIC PUMP DISCHARGE TEST LINE ISOLATION E51-F022, RCIC PUMP TORUS SUCTION INBOARD ISOLATION E51-F03, RCIC PUMP TORUS SUCTION OUTBOARD ISOLATION E51-F029, and HPCI/RCIC TEST RETURN REDUNDANT SHUTOFF VALVE E41-F011 or similar. May result in the pump down of the suppression pool to the CST	BWR4/6	Yes when RCIC is credited for Hot SD.
E51	2ac	RCIC Suction Valves	(F010, F031 or similar) CST and Suppression Pool Suction Valves - There is a potential to isolate the suction paths from the CST and Suppression pool to the RCIC pump. Note this is likely a "single" spurious for most plants.	BWR4	Yes when RCIC is credited for Hot SD.
G31	2ad	RPV bottom drain isolations to reactor building equipment drain tank spuriously opening	Spurious operation of valves BV-37-08 and BV-37-09	Applicable to one BWR2	No

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G33	2ae	Spurious operation (open) of BOTH REACTOR WATER CLEAN-UP ISOLATION Valves may route RPV inventory into the RWCU system. Valves are normally open, and will close on low reactor level. Scenario may involve a combination of spurious opening after re-close, or failure to close of one or more of the RWCU valves.	1G33*MOV001, 1G33*MOV004 or similar. Net effect is a loss of RPV inventory occurring faster than had previously been analyzed, accelerating the time to establish RPV injection beyond what has been currently analyzed. May also be secondary effects due to water/steam coming out of somewhere in the RWCU system in the reactor building. Closed loop system, but may be an additional concern due to high temperature in the piping for plants with low pressure RWCU piping (e.g., older BWRs).	All	No
G33	2af.1	Spurious operation of RX Water Clean Up valves (RWCU drain to condenser and/or radwaste collection tanks, drain via the filter/demin. flush lines).	Valves RWCU-FCV-33, and RWCU-V-34 or RWCU-V-35, or similar. Would require additional MOVs open to RWC; MOV 1 or 4 (or similar).	BWR2/3/4/5	No
B21	2af.2	Spurious operation of FW long-path recirculation valves.	FW long-path recirc valves. May divert HPCI and RCIC injection. May also create a RPV inventory loss thru RWCU to the condenser, if RWCU is not isolated.	BWR2/3/4/5	Plant Specific Analysis Required.

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G38	2ag	Suppression Pool Drain down: One example: Suppression Pool Water Management system suction flow is diverted or that the return flow is diverted for some there may also have the safeguards keep fill pumps with lines to the ECCS injection lines.	May be unique flow paths for each BWR, involving any drain down path from the suppression pool. One example: If the one of two Torus Water Management System pumps are either running or spuriously starts, and one of two normally closed suction isolation MOVs open, and the normally closed condenser isolation valve opens, then Suppression Pool water is pumped to the condenser. Torus Cleanup may be locked closed for many plants. Drain to the Condenser typically a 3" line. Another example – Containment Spray at a plant that has a connection to RADWASTE that would divert torus water if failed open.	BWR4-6	No
N21	2ah	Spurious Operations that Create Standby Feedwater System(SBFW) (AC Driven FW Pump) Flow Diversion from RPV	Applicable to BWRs with SBFW system or other motor driven FW pump.	BWR4	No
N21	2ai	Spurious operation of a feedwater or booster pump and a level control valve may cause uncontrolled feedwater injection into the RPV.	Valves 1FWS-P1A (B, C), 1FWS-MOV26A (B, C), 1C33-LVF001A (B, C, D), 1C33-LVF002 or similar. Booster Pump operation would require decreased vessel pressure. Feedwater pumps may not be a concern if steam driven,	BWR2/3/6	No

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P11	2aj	Loss of CST Inventory to Hot Well	Several paths exist that can cause a gravity drain of the CST to the Hotwell. The condition can happen due to spurious operation of MOVs alone, malfunctions within the Hotwell level control system (ex., loss of signal to master level controller). Hotwell vacuum can drag water from the CST, and if the normal hotwell pump or emergency hotwell pumps spuriously start, the condition is worsened. Standpipes for drain paths may limit the minimum level in the CST. Should review Fire SSA assumptions for minimum level and effect of drain down.	BWR2/4	No
P11	2ak	CST supply to Condensate Return Tank (CRT) supply shutoff MOV spurious operation	This MSO involves spurious operation of MOVs in the piping connecting the CST and CRT. If either of two valves spuriously open, a gravity transfer can occur which can lower the water level significantly in the CST. See discussion above on Standpipes. Scenario not applicable to plants without a CRT or equivalent.	BWR4	No
P11	2al	CST discharge to Radwaste system shutoff MOV spurious operation or OP155A/B , condensate transfer pump pumps CST to radwaste	Spurious operation of two MOVs in the Condensate system can set up a gravity drain path from the CST to the radwaste system. The water loss may need to be evaluated to support the time line to reach such a step in a manual action feasibility study. See discussion above on Standpipes.	BWR4	No

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E51	2-New-1	Spurious RCIC operation w/loss of high level trip	Vessel overfills into steam lines. Could impair HPCI operation (if credited) due to vessel overfill and water in the steam line. Can occur as a result of: a) spurious valve operation: turbine stop valve and RCIC discharge shutoff valve spurious operation , b) damage to cabling for transmitters, c) damage to high level trip circuitry, or d) RCIC pump controls hot short (for either motor or td RCIC).  Expected to be a very gradual event, with significant time for operator response.	All	No
P11	2-NEW-2	OP157A/B, refueling water pumps pump water from RWST TO CST and overpressurizes CST. Additional pumps feeding the CST (Condensate pumps, etc) should also be reviewed as a part of this scenario.	Examine overflow line on CST to determine if this line is sized to prevent damage to CST.	All	No
E21	2-NEW-3	For a multi-unit site with shared electrical, Core Spray or RHR pump logic failure - determine if fire damage to the other/opposite unit control logic could prevent safe shutdown. Also may involve a Spurious accident signal on two units while on onsite power causing the non-priority RHR and CS pumps to trip.	Needs to be analyzed with the loss of the inability to override the trip (open circuit).	Multi-Unit Site only	Plant Specific Analysis Required

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E41/E51	2-NEW-4	Drain the CST to the Suppression Pool through HPCI/RCIC.	The CST AND SP suction valves for the HPCI system may operate in series. The flow path would be suction from the CST through the HPCI/RCIC min flow lines or test return lines. May be a single spurious.	All	No
B31	2-NEW-5	Multiple fire-induced failures that prevent recirc pump trip or cause recirc pump restart.	May prevent or delay RHR injection due to discharge backpressure pressure from the recirc. Pump on the injection check valve. Involves the Recirculation Pump Motor Supply Breaker controls. Delay in injection may be offset by increased core flow, but may not be analyzed.	All	Plant Specific Analysis Required
E41/E51	2-NEW-6	Spurious start of CS, RCIC, HPCI, or RHR pump without flow path.	May be a single spurious. Could be an auto-start from actuation signals, with spurious closure of the min-flow or discharge valve. Could be a III.G.3 scenario only. Applicable to all credited ECCS Pumps (in areas where they are credited).	All	Plant Specific Analysis Required
E12	2-NEW-7	During alternate shutdown cooling, ECCS or RCIC injection from unprotected systems due to spurious actuation or automatic injection on RPV depressurization. (RHR-P-2A, RHR-P-2B, RHR-P-2C, LPCS-P-1, RCIC-P-1 and HPCS-P-1).	High Pressure Overfill - This scenario can degrade alternate shutdown cooling. The initial vessel injection may not be a concern since cooling is being provided, but may complicate or delay depressurization to use alternate shutdown cooling and may require credited RHR system to be re-aligned from RPV injection to suppression pool cooling.	All	No See Note i

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E21	2-NEW-8	If LPCS-V-5 opens and LPCS-P-1 starts, water will be injected into the RPV when the RPV pressure decreases below the shutoff head of the LPCS-P-1. This can occur spuriously as well as automatically during RPV depressurization. Circuit failures prevent stopping of LPCS-P-1. Similar scenarios possible for RHR pumps.	This scenario can degrade alternate shutdown cooling. The initial vessel injection may not be a concern since cooling is being provided, but may complicate or delay depressurization to use alternate shutdown cooling and may require credited RHR system to be re-aligned from RPV injection to suppression pool cooling.	All	No (see note i)
E41/E51	2-NEW-9	The RCIC system will automatically start on low reactor water level (RPV Level 2,-50") or spuriously starts. If RCIC-V-68 (steam line return to suppression pool) spuriously closes, steam would discharge to atmosphere (Main Steam Tunnel) through RCIC RD 1 and -2 (rupture disks). Similar scenario may occur with HPCI.	Steam Line to Steam tunnel is a 10-inch line. Multiple valves can isolate the leak. May be a single spurious (with auto start or RCIC), with fire-damage to multiple RCIC steam valves. Would mainly be a concern for plants with steam driven pumps credited for SSD. Check to see if closure of the discharge MOV results in Rupture Disk rupture. RCIC/HPCI Interlock may prevent start with discharge valve closed. RCIC/HPCI should trip before rupture disc operates based on high discharge pressure.	All	No
<b>Reactor Coolant System Pressure Control</b>					
B21	3a	Potential opening of all SRVs	Multiple spurious can open a portion or all of the SRVs from conductor to conductor (cable) failures or pressure switch instrumentation racks containing all switches for the SRVs. GE Calc. NEDO-33638]	BWR2/4/5/6	No

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B21	3b	Multiple ERV (SRV) opening	Safety Relief Valve-Two or More Spuriously Open "this failure requires two or more sustained fire induced failures in cables or within a control room panel to open more than one SRV."	BWR2/4/5	No
B21	3c	Spurious ADS: Safety Relief Valve-Failure of ADS Initiation Logic, opening SRVs simultaneously due to energization of relays	This postulated scenario features a failure that will open multiple SRVs simultaneously and requires energization of relays K6A and K7A or K6B and K7B in a two out of two taken twice logic scheme (ref. APED-B21-018<2>). As such this failure requires two sustained fire induced failures within the control room panel with no damage to the individual SRV control circuits to initiate ADS. It should be noted that the individual SRV control circuits are powered from and contain control logic within the panel. May not be applicable to plants that have installed confirmatory logic in ADS to prevent ADS for control room fires.	BWR2/4	No
<b>Hot Shutdown Decay Heat Removal</b>					
E12	4a	Loss of RHR suppression pool cooling due to suction valve interlock interactions. This is a plant-specific design feature that would not be applicable to most plant's design if RHR suction interlock interactions do not occur.	Fire causes the loss of both loops of RHR suppression pool cooling (flow control valve for RHR A unavailable due to fire damage to cables; hot short causes shutdown cooling suction MOV RHR-V-6B to fail open, which fails RHR B suppression pool cooling due to interlocks).	BWR3/4/5/6	Plant Specific Analysis Required



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E12	4b	Failure due to diversion of suppression pool decay heat removal through Drywell Spray valves 16B & 17B.	Loss of both loops of RHR suppression pool cooling.  May not fail pool cooling function, since heat is removed from the pool either way. Small amount of water may be held up on drywell floor, slightly lowering pool level. However, may need to look at suppression pool volume and NPSH due to slightly lower suppression pool level.	BWR3/4/5/6	Plant Specific Analysis Required
E14	4c	Dedicated Shut Down Cooling System - "Spurious opening of SDC heat exchanger bypass valves(FCV-38- 128, 131, and 134)"	Spurious opening of normally closed heat exchanger bypass air operated valves FCV-38- 128, 131, and 134. These valves fail open on loss of instrument air and control power. SDC is a manually operated system and is used several hours after the event. If needed, these valves can be operated manually. May be a cold shutdown issue, if cooling is not needed for Hot standby.	Applicable to one BWR2	Plant Specific Analysis Required
E15	4d	Dedicated Shut Down Cooling System - "Spurious closure of Pump suction valves from torus (IV-80-01, 02, 21 and 22)"	IV-80-01, 02, 21 and 22. Spurious closure {DWG 18012, sh. 2} May be a cold shutdown issue, if cooling is not needed for Hot standby.	BWR2	Plant Specific Analysis Required
E15	4e	Dedicated Shut Down Cooling System - "Spurious closure of Pump discharge to drywell valves (IV-80-15, 16, 35 and 36)"	IV-80-15, 16, 35 and 36. Spurious closure {DWG 18012, sh. 1} Note: All four IV-80-15, 16, 35 and 36 valves go open and they cannot be re-positioned on loss of instrument air. May be a cold shutdown issue, if cooling is not needed for Hot standby.	BWR2	Plant Specific Analysis Required

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E15	4f	Dedicated Containment Spray System - "Spurious closure of the normally open Containment spray raw water discharge valves (MOV's BV-93-25, 26, 27 and 28.)"	Spurious closure of the normally open MOVs BV-93-25, 26, 27 and 28. {DWG 18012, sh. 1}	Applicable to one BWR2	Plant Specific Analysis Required
E15	4g	Dedicated Containment Spray System - Spurious opening of normally closed Containment spray raw water to containment spray supply valves (MOV's FCV-93-72 and 73)	Spurious opening of normally closed MOVs FCV-93-72 and 73. {DWG 18012, sh. 1} FCV-93-72 and 73 are interlocked with BV-93-28 and 26 respectively (per system description SDBD 203). If raw water intertie occurs when conditions are wrong, spraying the drywell with cold raw water could cause a failure of the pressure suppression function of containment.	Applicable to one BWR2	No
E15	4h	Dedicated Containment Spray System - Spurious opening of normally closed Containment spray raw water to core spray supply valves (MOV's FCV-93-71 and 74)	Spurious opening of normally closed MOVs FCV-93-71 and 74. FCV-93-71 and 74 are interlocked with BV-93-25 and 27 respectively (per system description SDBD 203). May prevent core spray injection due to interlock.	Applicable to one BWR2	Plant Specific Analysis Required
E15	4i	Dedicated Containment Spray System - Spurious opening of normally closed Containment spray venting valves (MOV's IV-80-114 and 115)	Spurious opening of normally closed MOVs IV-80-114 and 115 causing flow diversion in containment spray. May not fail spray function, since heat is removed from the pool either way.	Applicable to one BWR2	No
E21	4j	Dedicated Core Spray System - "Spurious closure of normally open torus suction valves (MOV's IV-81-01, 02, 21 and 22)"	Spurious closure of normally open MOVs IV-81-01, 02, 21 and 22. {DWG 18007, sh. 1} This item is likely an "Inventory Control" issue rather than decay heat removal., but is retained in this section of the MSO list for historical reference.	Applicable to one BWR2	Yes (when system is credited for Hot SD)

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E21	4k	Dedicated Core Spray System - Spurious closure of normally open RPV injection valve (MOV's IV- 40-02 and 12)	Spurious closure of normally open MOV's IV-40-02 and 12. {DWG 18007, sh. 1}  This item is likely an "Inventory Control" issue rather than decay heat removal, but is retained in this section of the MSO list for historical reference.	BWR2	Yes (when system is credited for Hot SD)
E52	4l	Isolation Condenser - "Spurious closure of Steam line isolation valves (IV-39-07, 08, 09 or 10) results in failure of decay heat removal.	Spurious closure of IV-39-07, 08, 09 or 10 results in failure of decay heat removal.	BWR2/3	Yes (When IC is credited)
E52	4m	Isolation Condenser - Condensate return isolation valve failure to move/remain in correct position	AOVs IV-39-05, 06 fail to open resulting in failure of IC system.	BWR2/3	Yes (when IC credited)
E52	4n	Isolation Condenser - Failure of Vent to main steam line valve (IV- 05-02 and 03) to close or hot short(s) that keeps both valves open results in loss of inventory.	Failure of IV-05-02 and 03 to close or hot short(s) that keeps both valves open results in loss of RPV inventory.  Small diversion of steam, and may not result in any RPV inventory loss, if returned to main steam system inside containment.	BWR2/3	No
E52	4o	Isolation Condenser - "Failure of Vent to main steam line valves (IV-05-01, 11, 12, 04) to close results in loss of inventory."	Failure of IV-05-01, 11, 12, 04 to close results in loss of inventory.  Small diversion of steam, and may not result in any RPV inventory loss, if returned to main steam system inside containment.	BWR2/3	No

<b>Table G-1</b>					
<b>BWR Generic MSO List</b>					
<b>MPL</b>	<b>#</b>	<b>Scenario Description</b>	<b>Notes</b>	<b>Plant type (note: may be applicable to other plant types)</b>	<b>Required for Hot Shutdown (No, Yes or plant specific analysis required)</b>
E52	4p	Isolation Condenser - Spurious opening of normally-closed Vent to torus valves (BV-05-05 and 07) results in loss of inventory.	Spurious opening of normally-closed BV-05-05 and 07 results in loss of inventory. {DWG 18017, sh. 1} Applicable to one BWR2.	BWR2/3	No
E52	4q	Isolation Condenser - Spurious closure of Cross-connect valve (BV-60-13) on makeup line results in loss of cross-connect capability of makeup source.	Spurious closure of BV-60-13 results in loss of cross-connect capability of makeup source. {DWG 18017, sh. 1} Applicable to one BWR2.	BWR2/3	No
T23	4r	Spurious initiation of containment sprays.	A General Review of NPSH and Containment Over Pressure should be performed to look for other pathways such as containment inerting system or other containment isolations, other than the 3 listed here. COP is only an issue for plants that credit COP for NPSH concerns.  Additionally, sprays initiated with hot, dry drywell could result in a rapid depressurization of the drywell, that is so rapid the vacuum breakers cannot mitigate, resulting in a challenge to containment integrity.	all	No
T23	4s	Spurious opening of Containment Vents.	Spurious opening of Containment Vent, resulting in Containment depressurization, following a loss of Suppression pool cooling. Containment vent through pathways not including the rupture disc. May result in a loss of COP, which is only an issue for plants that credit COP for NPSH concerns.	Mark I (BWR2/3/4)	No

<b>Table G-1</b>					
<b>BWR Generic MSO List</b>					
<b>MPL</b>	<b>#</b>	<b>Scenario Description</b>	<b>Notes</b>	<b>Plant type (note: may be applicable to other plant types)</b>	<b>Required for Hot Shutdown (No, Yes or plant specific analysis required)</b>
T23	4t	Containment Over Pressure (COP), NPSH loss, Spurious opening of the drywell floor drain sump valves.	Spurious opening of the drywell floor drain sump, since it is directly connected to the airspace. COP is only an issue for plants that credit COP for NPSH concerns.	Mark I (BWR2/3/4)	No
T23	4u	Spurious opening of torus vent and purge valves.	Spurious opening of torus vent and purge valves IV-201-07, 08, 16, and 17 or BV-201-21 and 22 will lead to loss of containment isolation.	BWR2	No
T23	4w	Mark I containment with Torus Ring Header: too much flow through the ring header due to spurious operation of multiple pumps (more than allowed by design) from the ring header.	NPSH Issue for the operating/credited pump. May be caused by a false LOCA signal.		No (involves spurious/inadvertent operation of non- credited trains/equipment)
<b>Support Systems</b>					
E12	5a	Additional components load onto credited diesel generator	Scenario causes diesel generator overloading and inoperability. Note: Scenario very site specific. Interlocks may prevent this from occurring. In addition, overloading may also occur if proper load sequencing is bypassed via hot shorts, causing simultaneous loading of multiple components onto the EDG.	All	No (involves spurious/inadvertent operation of non- credited trains/equipment)
G38	5b	Spurious operation (open) of both SUPPRESSION POOL CLEAN-UP ISOLATION Valves.	Drain down of suppression pool below minimal level. 1RHS*AOV62, 1RHS*AOV63 or similar	BWR6	No

<b>Table G-1</b>					
<b>BWR Generic MSO List</b>					
<b>MPL</b>	<b>#</b>	<b>Scenario Description</b>	<b>Notes</b>	<b>Plant type (note: may be applicable to other plant types)</b>	<b>Required for Hot Shutdown (No, Yes or plant specific analysis required)</b>
P41	5c	Emergency Service Water pump operation at shutoff head	Prior to isolation of the circuits and component control at the remote shutdown panel, the Auto start or spurious Control Room fire induced start of the Emergency Service Water (ESW) Pump followed by a spurious closure of the ESW Pump Discharge Valve. The ESW Pump would be operating with no flow until isolation and control from remote station is achieved. III.G.3 only because for non-III.G.3 areas not employing isolation transfer switches such fire damage would also disable the ability of the pump to operate.	BWR4/6	N/A
P41	5d	Spurious RHR Service Water pump operation at shutoff head	Prior to isolation of the circuits and component control at the remote shutdown panel, the Control Room fire causes a start of the Residual Heat Removal Service Water (RHRSW) Pump followed by a spurious closure of the RHRSW Pump Discharge Valve. The RHRSW Pump would be operating with no flow until isolation and control from remote station is achieved. III.G.3 only because for non-III.G.3 areas not employing isolation transfer switches such fire damage would also disable the ability of the pump to operate.	BWR4/6	N/A
P41	5e	Spurious operation (open) of both RHR SERVICE WATER ISOLATION (Crosstie) valves in a loop may result in diversion of service water flow from the RHR heat exchangers.	1E12*MOVF094 AND 1E12*MOVF096 or similar. Diversion of Service Water could also cause failure of the credited Service Water Pump due to runout.  May require additional spurious actuations on non-credited loop before an unacceptable flow diversion can occur. May not fail any performance goals within 1 hour.	BWR6	Use Appendix H for classification of flow diversion.

<b>Table G-1</b>					
<b>BWR Generic MSO List</b>					
<b>MPL</b>	<b>#</b>	<b>Scenario Description</b>	<b>Notes</b>	<b>Plant type (note: may be applicable to other plant types)</b>	<b>Required for Hot Shutdown (No, Yes or plant specific analysis required)</b>
R43	5f	Non-synchronous paralleling of EDG with on-site and off-site sources through spurious breaker operations	Scenario causes damage to diesel generator by closing into a live bus out-of-phase. Note: Scenarios are very site specific. Interlocks may prevent this from occurring.	All	No  (involves spurious/inadvertent operation of non-credited trains/equipment)
R43	5g	Non-Synchronous Paralleling - inadvertent cross tie breaker operation between opposite divisions (e.g., 4160V, 480V) of Div 1(2) EDGs through Spurious Operation of 480 V Breakers or the Divisional Cross-Tie through 4160 V Maintenance Tie Breakers	Scenario causes damage to diesel generator by closing into a live bus out-of-phase. Note: Scenario very site specific. Interlocks may prevent this from occurring.	All	No  (involves spurious/inadvertent operation of non-credited trains/equipment)
R43	5h	Non-Synchronous Paralleling - inadvertent cross tying the offsite power sources through the on-site busses & breakers.	Spurious breaker closings between separate divisions of off-site power.	All	No  (involves spurious/inadvertent operation of non-credited trains/equipment)

<b>Table G-1</b>					
<b>BWR Generic MSO List</b>					
<b>MPL</b>	<b>#</b>	<b>Scenario Description</b>	<b>Notes</b>	<b>Plant type (note: may be applicable to other plant types)</b>	<b>Required for Hot Shutdown (No, Yes or plant specific analysis required)</b>
R43	5i	Spurious Diesel generator operation without cooling water. For III.G.3, Fire damage or LOP could start the diesel generator and trip the cooling water pumps.	The fire causes the startup of the Emergency Diesel Generator, Spurious closure of the ESW Pump Discharge Valve or trip of the ESW Pump would stop the cooling water supply to the Emergency Diesel Generator. Running the Emergency Diesel Generator with a loss of cooling water could trip the diesel on high temperature. If the fire has resulted in the actuation of a LOOP or LOCA bypass of the high temperature trip, the diesel could continue to run until damage from over-temperature conditions stop it. For III.G.3, this MSO is likely beyond the required design basis for control room fire.	All	N/A
R43	5j	Service Water System - Spurious operation (open) of both cross-connection valves would cause an uncontrolled loss of service water to the opposite division. Also possible flow diversion to interconnections to TBCCW, RBCCW, or other connections to Service Water.	1SWP*MOV505A, 1SWP*MOV505B or similar, for RHR Service Water, F119A/B or similar would have to open.	All	Use Appendix H for classification of flow diversion.



<b>Table G-1</b>					
<b>BWR Generic MSO List</b>					
<b>MPL</b>	<b>#</b>	<b>Scenario Description</b>	<b>Notes</b>	<b>Plant type (note: may be applicable to other plant types)</b>	<b>Required for Hot Shutdown (No, Yes or plant specific analysis required)</b>
R24N/A	5k	Spurious motor-operated valve operation, AND Wire-to-wire short(s) bypass torque and limit switches	General scenario is that fire damage to motor-operated valve circuitry causes spurious operation. If the same fire causes wire-to-wire short(s) such that the valve torque and limit switches are bypassed, then the valve motor may stall at the end of the valve cycle. This can cause excess current in the valve motor windings as well as valve mechanical damage. This mechanical damage may be sufficient to prevent manual operation of the valve. Scenario only applies to motor-operated valves. Note this generic issue may have already been addressed during disposition of NRC Information Notice 92-18. This disposition should be reviewed in the context of multiple spurious operations and multiple hot shorts.	All	Plant Specific Analysis Required
T41	5l	Loss of HVAC: Spurious isolation of HVAC to credited loads	Perform review to identify spurious failures that could cause isolation of Heating Ventilation and Air Conditioning (HVAC) to credited loads. Credited loads may include pump rooms, switchgear rooms, and rooms containing solid state control systems. Examples of spurious failures include spurious damper isolation and spurious isolation of cooling flow to chillers. Also look at Fire-induced damage causes loss of both cooling fans and cooling pumps on startup transformer when offsite power is credited.	All	No
W25/W24	5m	Cooling pond (UHS) inventory loss - Cooling pond to tower cross tie. HV12-111, HV12-113 fail open, Can pump spray pond to the cooling tower (non-UHS).	Drain down of dedicated ultimate heat sink (cooling pond) to non- safety systems	All	Use Appendix H for classification of flow diversion.
<b>Process Monitoring</b>					

<b>Table G-1</b>					
<b>BWR Generic MSO List</b>					
<b>MPL</b>	<b>#</b>	<b>Scenario Description</b>	<b>Notes</b>	<b>Plant type (note: may be applicable to other plant types)</b>	<b>Required for Hot Shutdown (No, Yes or plant specific analysis required)</b>
	6a	No generic Scenarios identified			

## PWR Generic MSO List

### Revision 2.1 (March 2011)

Record of Revisions						
Rev	Description					
0	Original Issue.					
1	Scenarios 1, 2, 3, 9, 55b (Rev 0 Scenario 54b). Clarified that CE plants generally do not have RCP seal injection.					
	Scenario 7. Removed applicability to B&W plants, in which letdown relieves to the pressurizer and not the PRT.					
	Added new Scenario 14 "Charging Pump Runout when RCS is Depressurized". Note new numbering of all subsequent scenarios.					
	Scenario 15 (Rev 0 Scenario 14). Noted that some plants have check valve(s) in sump line that would prevent scenario from occurring.					
	Scenario 24 (Rev 0 Scenario 23). Clarified that spurious opening of a closed MSIV may be very difficult due to differential pressure across valve.					
	Scenario 26 - (Rev 0 Scenario 25). Expanded scenario to include search for other steam loads and not just steam header drain valves.					
	Scenario 32 (Rev 0 Scenario 31). Added note that scenario could be caused by non-spurious failure (i.e., loss of instrument air, loss of valve air or power, etc.).					
	Scenario 34 (Rev 0 Scenario 33). Added potential applicability to B&W plants with replacement steam generators.					
	Scenario 35 (Rev 0 Scenario 34). Added note that scenario may screen if AFW makeup flowrate exceeds flowrate lost through sample system.					
	Scenario 36 (Rev 0 Scenario 35). Added note that spurious opening of pressurizer auxiliary spray would have similar consequence.					
	Deleted Rev. 0 scenario 51 and renumbered Rev. 0 scenario 52 as scenario 51.					
	Added new Scenarios 52 "Pump damage from operation outside design flow either at shutoff head or pump run-out conditions." and 53 "Spurious Operation of various valves causing flow diversion"					
	Renumbered scenarios 53 through 55e as scenarios 54 through 56e.					
	Added new Scenario 56f "RCS Makeup Pump Failure" due to spurious Recirculation Actuation Signal (RAS) causing alignment to dry containment sump.					
	Generically replaced term "inoperability", which has a specific Tech Spec meaning, with the term "failure".					

	Made minor clarifications throughout document.
2	Added suggested "Required" / "Important" Classification for each scenario.
	Scenario 45 (Rev 0 Scenario 44). Added note that heat up to the ultimate heat sink may occur due to spurious alignment of cooling water recirculation paths.



Scenarios may be added or deleted with each WCAP revision. The following table provides a mapping of scenario number from revision to revision. This is intended to facilitate utility review of the updated generic list against previous revisions of the WCAP. Note that the revision level of this spreadsheet is not matched to the WCAP revision (i.e., spreadsheet revision 1 was issued to the NEI MSO Web Board without a corresponding WCAP revision and spreadsheet revision 2 corresponds to WCAP revision 1).

WCAP-16933 REV 0 SCENARIO #	WCAP- 16933 REV 1 SCENARIO #	NOTES
<i>RCS Inventory Control/ RCS Integrity</i>		
1	1	No Change
2	2	No Change
3	3	No Change
4	4	No Change
5	5	No Change
6	6	No Change
7	7	No Change
8	8	No Change
9	9	No Change
10	10	No Change
11	11	No Change
12	12	No Change
13	13	No Change
14	14	No Change
15	15	No Change
16	16	No Change
17	17	No Change
18	18	No Change
19	19	No Change
20	20	No Change
21	21	No Change
22	22	No Change
<i>Decay Heat Removal</i>		
23	23	No Change
24	24	No Change
25	25	No Change
26	26	No Change
27	27	No Change
28	28	No Change

WCAP-16933 REV 0 SCENARIO #	WCAP- 16933 REV 1 SCENARIO #	NOTES
29	29	No Change
30	30	No Change
31	31	No Change
32	32	No Change
33	33	No Change
34	34	No Change
35	35	No Change
<i>RCS Pressure Control</i>		
36	36	No Change
37	37	No Change
<i>Support Functions</i>		
38	38	No Change
39	39	No Change
40	40	No Change
41	41	No Change
42	42	No Change
43	43	No Change
44	44	No Change
45	45	No Change
46	46	No Change
47	47	No Change
48	48	No Change
49	49	No Change
<i>Other Scenarios</i>		
50	50	No Change
51	Deleted	
52	Now Scenario 51	
-	52	Generic Pump Outside Design Flow
-	53	Generic Flow Diversion
53	Now Scenario 54	Loss of HVAC

WCAP-16933 REV 0 SCENARIO #	WCAP- 16933 REV 1 SCENARIO #	NOTES
54	Now Scenario 55	Valve Failure
55	Now Scenario 56	Fire-Induced Inadvertent ESFAS
55a	Now Scenario 56a	RCS Makeup Pump Failure
55b	Now Scenario 56b	Loss of all Seal Cooling
55c	Now Scenario 56c	Loss of all Seal Cooling
55d	Now Scenario 56d	RWST Drain Down
55e	Now Scenario 56e	PORV(s) open
55f	Now Scenario 56f	RCS Makeup Pump Failure

ID #	SCENARIO	DESCRIPTION	NOTES	PLANT DESIGN	"REQUIRED" / "IMPORTANT" CLASSIFICATION
<b>RCS INVENTORY CONTROL / RCS INTEGRITY</b>					
<b>1</b>	Loss of all RCP Seal Cooling	Spurious isolation of seal injection header flow, <b>AND</b> Spurious isolation of CCW flow to Thermal Barrier Heat Exchanger (TBHX)	<p>Scenario causes loss of all RCP seal cooling and subsequent increase in RCP seal leakage, challenging the RCS Inventory Control Function.</p> <p>Westinghouse Tech Bulletin 04-22 Rev. 1 provides a summary of the issue. Tech Bulletin references provide additional detail. B&amp;W plants with Westinghouse designed seals may have similar concerns.</p> <p>Seal injection flow isolation can occur at main header or at supply to each individual pump. In addition, scenarios that cause loss of all charging (i.e., multiple pump failure due to loss of suction, non-spurious pump failures such as loss of power, etc.) can also cause loss of seal injection.</p> <p>Loss of all seal cooling to any individual RCP is a problem (i.e., does not have to occur on all RCPs to be a problem)</p> <p>Westinghouse plants refer to Letter LTR-RAM-I-10-053 of White Paper on Westinghouse Reactor Coolant Pump Seal Behavior for Fire Scenarios, Revision 2.</p> <p>* CE plants generally do not have seal injection and can lose seal cooling for an extended period of time without increased seal leakage. These plants can lose all seal cooling due to spurious isolation of CCW. Refer to WCAP-16175.</p>	B&W CE* W	<p>"IMPORTANT"</p> <p>RCP Seal Cooling is not part of the "required" SSD path. Consequence is a large flow diversion from the RCS. Similar to spurious opening of PORV(s), reactor head vents, RHR letdown, normal letdown, and excess letdown causing flow diversions from the RCS.</p> <p>Refer to Scenario 9 for loss of makeup (i.e. Seal Injection)</p> <p>Note that this scenario is "REQUIRED" if seal injection is required RCS makeup flow path.</p>



ID #	SCENARIO	DESCRIPTION	NOTES	PLANT DESIGN	"REQUIRED" / "IMPORTANT" CLASSIFICATION
2	Loss of all RCP Seal Cooling	Spurious opening of valves causing flow diversion away from seals, <b>AND</b> Spurious isolation of CCW flow to thermal barrier heat exchanger	Flow diversion away from seal injection could be caused by spurious opening of charging injection valves. Note, spurious opening of #1 seal bypass valve is judged to not fail seal injection function due to orifice restricting bypass flow to ~1gpm (Reference Letter #OG-09-156)  See notes for Scenario #1, Loss of all RCP Seal Cooling.  Westinghouse plant please refer to Letter LTR-RAM-I-10-053 of White Paper on Westinghouse Reactor Coolant Pump Seal Behavior for Fire Scenarios, Revision 2.	B&W CE* W	"IMPORTANT"  See Scenario #1
3	Thermally Shocking RCP Seals	Loss of all seal cooling to any RCP(s). See Scenarios 1 & 2, <b>AND</b> Spurious re-initiation of seal cooling (i.e., seal injection or CCW to TBHX)	Scenario is assumed to cause RCP seal failure and a subsequent RCP seal LOCA, challenging the RCS Inventory Control Function.  Westinghouse Tech Bulletin 04-22 Rev. 1 (Reference 11) provides summary of issue. Tech Bulletin references provide additional detail.  Westinghouse plant please refer to Letter LTR-RAM-I-10-053 of White Paper on Westinghouse Reactor Coolant Pump Seal Behavior for Fire Scenarios, Revision 2.  * CE plants generally do not have seal injection and can lose seal cooling for an extended period of time without increased seal leakage. These plants can lose all seal cooling due to spurious isolation of CCW. Refer to WCAP-16175.	B&W CE* W	"IMPORTANT"  See Scenario #1

ID #	SCENARIO	DESCRIPTION	NOTES	PLANT DESIGN	"REQUIRED" / "IMPORTANT" CLASSIFICATION
4	Catastrophic RCP Seal Failure	<p>Loss of all seal cooling to any RCP(s). See Scenarios 1 &amp; 2,</p> <p><b>AND</b></p> <p>Fire prevents tripping, or spuriously starts, RCP(s)</p>	<p>Scenario causes catastrophic RCP seal failure and subsequent RCP seal LOCA, challenging the RCS Inventory Control Function.</p> <p>Westinghouse Tech Bulletin 04-22 Rev. 1 provides summary of issue. Tech Bulletin references provide additional detail. Additionally refer to Letter LTR-RAM-I-10-053 of White Paper on Westinghouse Reactor Coolant Pump Seal Behavior for Fire Scenarios, Revision 2.</p> <p>Refer to WCAP-16175 for RCP seal behavior on loss of seal cooling at CE plants.</p>	B&W CE W	<p>"IMPORTANT"</p> <p>See Scenario #1</p>
5	RCP Seal No. 2 Failure	<p>Loss of all seal cooling to any RCP(s). See Scenarios 1 &amp; 2,</p> <p><b>AND</b></p> <p>Spurious isolation of No. 1 seal leakoff valve(s)</p>	<p>Isolation of the No. 1 seal leakoff line during a loss of all seal cooling event would force the No. 2 RCP seal into a high pressure mode of operation at high temperature, which is beyond the design bases of the No. 2 seal. This could cause failure of the No. 2 seal and increase RCP seal leakage.</p> <p>Westinghouse Tech Bulletin 04-22 Rev. 1 provides summary of issue. Tech Bulletin references provide additional detail.</p> <p>Also reference Letter WOG-05-163 DW-04-004 "Isolation RCP#1 Seal Leakoff" and Letter LTR-RAM-I-10-053 of White Paper on Westinghouse Reactor Coolant Pump Seal Behavior for Fire Scenarios, Revision 2.</p> <p>This scenario would apply to B&amp;W plants with Westinghouse designed RCP seals.</p>	B&W W	<p>"IMPORTANT"</p> <p>RCP No. 2 seal integrity is not part of the "required" SSD path. Consequence is RCS flow diversion similar to Scenario 1.</p>

ID #	SCENARIO	DESCRIPTION	NOTES	PLANT DESIGN	"REQUIRED" / "IMPORTANT" CLASSIFICATION
6	Letdown Fails to Isolate and Inventory Lost to CVCS	<p>Spurious opening of (or failure to close) letdown isolation valve(s),</p> <p><b>AND</b></p> <p>Spurious opening of (or failure to close) letdown orifice valve(s)</p>	<p>Scenario causes loss of RCS inventory, challenging the RCS Inventory Control Function.</p> <p>In a typical Post-Fire Safe Shutdown (PFSS) Analysis, the Chemical and Volume Control System (CVCS) downstream of the letdown isolation valve(s) and upstream of the Volume Control Tank (VCT) isolation valve(s) is not evaluated, and the RCS inventory (letdown) is conservatively assumed lost and unavailable for makeup. In reality, additional failures downstream of the letdown isolation valves would have to occur for this RCS inventory to be unavailable for makeup.</p> <p>Also note that the letdown isolation valves and letdown orifice valves are often interlocked such that the isolation valves will not open without the orifice valves being open. Letdown failure to isolate can be a single spurious operation with interlocked valves.</p> <p>Note B&amp;W plants do not have letdown orifice valves. Scenario applicable to B&amp;W is spurious operation of multiple letdown isolation valves.</p>	B&W CE W	<p>"IMPORTANT"</p> <p>Letdown is not part of the "required" SSD path. Consequence is RCS flow diversion.</p>

ID #	SCENARIO	DESCRIPTION	NOTES	PLANT DESIGN	"REQUIRED" / "IMPORTANT" CLASSIFICATION
7	Letdown Fails to Isolate and Inventory Lost to PRT	Letdown fails to isolate (see Scenario 6), <b>AND</b> Spurious closure of downstream containment isolation valve	Scenario causes letdown flow to Pressurizer Relief Tank (PRT) through relief valve. This letdown flow is assumed unavailable for RCS makeup.	CEW	"IMPORTANT" Letdown is not part of the "required" SSD path. Consequence is RCS flow diversion.
8	Excess Letdown Fails to Isolate	Spurious opening of (or failure to close) multiple series excess letdown isolation valves	Scenario causes loss of RCS inventory to the CVCS system, challenging the RCS Inventory Control Function. The RCS inventory (letdown) is conservatively assumed lost and unavailable for makeup. In reality, additional failures downstream of the excess letdown isolation valves would have to occur for this RCS inventory to be unavailable for makeup.  This scenario often requires three spurious operations.	B&W W	"IMPORTANT" Excess letdown is not part of the "required" SSD path. Consequence is RCS flow diversion.

ID #	SCENARIO	DESCRIPTION	NOTES	PLANT DESIGN	"REQUIRED" / "IMPORTANT" CLASSIFICATION
9	RCS Makeup Isolation	<p>Spurious isolation of seal injection flow path,</p> <p><b>AND/OR</b></p> <p>Spurious isolation of normal charging flow path,</p> <p><b>AND/OR</b></p> <p>Spurious isolation of charging / safety injection flow path</p>	<p>Scenario isolates all high head RCS makeup flow paths, challenging the RCS Inventory Control Function.</p> <p>Each flow path contains a number of series and/or parallel valves. P&amp;ID review is required to identify each relevant combination of valves.</p> <p>Note that isolation of all RCS makeup may also involve non-spurious failures. For example, the charging injection valves are normally closed, and a fire-induced loss of valve power (not a spurious operation) would cause these valves to fail closed. On the other hand, these valves could spuriously close after they have been opened.</p> <p>*Note CE plants generally do not have seal injection.</p>	B&W CE* W	<p>"REQUIRED"</p> <p>RCS Makeup via RCP seal injection, normal charging, or charging injection is part of the "required" SSD path for RCS Inventory Control Function</p>

ID #	SCENARIO	DESCRIPTION	NOTES	PLANT DESIGN	"REQUIRED" / "IMPORTANT" CLASSIFICATION
10	Charging Pump Failure	<p>Initial condition is charging pump running with normal lineup taking suction from VCT.</p> <p>Spurious isolation of suction from VCT to running charging pump,</p> <p><b>AND</b></p> <p>Spurious isolation of (or failure to open) suction from RWST to running charging pump</p>	<p>Scenario causes charging pump failure, challenging the RCS Inventory Control Function. This is especially challenging if the credited charging pump is running at the time of the fire.</p> <p>Can be a single spurious scenario if the RWST valves are normally closed MOVs and they are not interlocked with the VCT outlet valves.</p> <p>Note that valve interlocks may prevent scenario if they prevent VCT and RWST outlets from both being in closed position simultaneously.</p>	B&W CE W	<p>The credited charging pump and suction path are always "REQUIRED"</p> <p>Plant-specific classification required and depends if RWST is included in the credited flow path.</p> <p>"REQUIRED" if VCT flow path is credited for post-fire SSD analysis</p> <p><b>OR</b></p> <p>"IMPORTANT" if RWST flow path is credited for post-fire SSD analysis</p>

ID #	SCENARIO	DESCRIPTION	NOTES	PLANT DESIGN	"REQUIRED" / "IMPORTANT" CLASSIFICATION
11	Charging Pump Failure	Initial condition is charging pump running and drawing suction from RWST. Spurious isolation of two parallel RWST outlet valves.	Scenario causes loss of charging pump suction, causing subsequent pump cavitation and failure. This challenges the RCS Inventory Control Function.	B&W CE W	The credited charging pump and suction path are always "REQUIRED" because damage could happen quickly. Plant-specific classification required and depends if RWST is included in the credited flow path. "REQUIRED" if RWST flow path is credited for post-fire SSD analysis <b>OR</b> "IMPORTANT" if VCT flow path is credited for post-fire SSD analysis

ID #	SCENARIO	DESCRIPTION	NOTES	PLANT DESIGN	"REQUIRED" / "IMPORTANT" CLASSIFICATION
12	Charging Pump Failure	Spurious opening (or failure to close) of multiple series VCT outlet valves	<p>Scenario causes VCT drain down and hydrogen cover gas entrainment into charging pump suction, ultimately causing charging pump failure and challenging the RCS Inventory Control Function. This is especially challenging if the credited charging pump is running at the time of the fire. Note this scenario assumes that VCT makeup has been isolated (i.e., letdown isolated).</p> <p>Note that spurious starting of idle charging pump(s) may cause failure of additional pumps. Spurious pump starting can occur for several reasons, including fire damage to control circuitry or an inadvertent ESFAS signal.</p> <p>Potential resolution is comparison of charging pump suction header pressure provided by the RWST versus the VCT. Specifically, the RWST may provide sufficient pressure such that the check valve to the VCT remains seated and hydrogen is not entrained into the pump suction.</p>	B&W CE W	<p>Plant-specific classification required and depends if VCT is included in the credited flow path.</p> <p>"REQUIRED" if VCT flow path is credited for post-fire SSD analysis</p> <p><b>OR</b></p> <p>"IMPORTANT" if VCT flowpath is not credited for post-fire SSD analysis. Note: Damage scenarios that involve non-credited equipment (i.e. non-credited pumps, inadvertent ESFAS signals are also IMPORTANT.</p>



ID #	SCENARIO	DESCRIPTION	NOTES	PLANT DESIGN	"REQUIRED" / "IMPORTANT" CLASSIFICATION
13	Charging Pump Failure	Letdown fails to isolate (see Scenario 6), <b>AND</b> Spurious isolation of CCW cooling to the letdown heat exchanger	Scenario causes elevated charging pump suction temperature and subsequent pump failure. Charging pump failure challenges the RCS Inventory Control Function. This is especially challenging if the credited charging pump is running at the time of the fire.  Starting of additional charging pumps can cause failure of additional pumps. Spurious pump starting can occur for several reasons, including fire damage to control circuitry or an inadvertent ESFAS signal.	B&W CE W	"IMPORTANT"  Letdown and CCW cooling of letdown are not part of the "required" SSD path.
14	Charging Pump Failure	Charging pump runout when RCS is depressurized	Scenario causes charging pump runout and failure. Pump(s) must be running when RCS is at a depressurized condition. Unintentional RCS depressurization could occur due to spurious opening of pressurizer PORV(s), for example. Charging pump(s) can spuriously start if they are not already running. Scenario may also require failure of other components (e.g., charging flow control valve, etc.).	B&W CE W	"IMPORTANT"  Based on the fact that associated circuit failures (e.g., spurious PORV opening) would have to be affected for the pump to reach runout conditions.

ID #	SCENARIO	DESCRIPTION	NOTES	PLANT DESIGN	"REQUIRED" / "IMPORTANT" CLASSIFICATION
15	RWST Drain Down via Containment Sump	Spurious opening of multiple series containment sump valves	<p>Scenario causes RWST drain down to the containment sump. Since typical PFSS analyses do not credit alignment of containment sump, the RWST inventory becomes unavailable for RCS makeup, challenging the RCS Inventory Control Function.</p> <p>Scenario may be applicable to containment sump valves providing suction to the RHR pumps and/or containment spray pumps.</p> <p>Number of valves required to spuriously operate varies by plant.</p> <p>Note that some plants may have check valves in the sump line that would prevent this scenario.</p>	B&W CE W	<p>"IMPORTANT"</p> <p>Containment sump valves are not part of "required" SSD path. Consequence is RWST flow diversion.</p>
16	RWST Drain Down via Containment Spray	<p>Spurious opening of containment spray header valve(s),</p> <p><b>AND</b></p> <p>Spurious starting of containment spray pump(s) and/or RHR pump(s)</p>	<p>Scenario causes a pumped RWST drain down via the containment spray ring. The RWST inventory ultimately settles to the containment sump. Since typical PFSS analyses do not credit alignment of the containment sump, the RWST inventory is assumed unavailable for RCS makeup, challenging the RCS Inventory Control Function.</p> <p>Note that either the RHR pumps or the containment spray pumps could cause this RWST pumped diversion to the spray ring.</p> <p>Note that the spurious pump starting can occur for several reasons, including fire damage to control circuitry or inadvertent ESFAS signal.</p>	B&W CE W	<p>"IMPORTANT"</p> <p>Containment spray not part of "required" SSD path. Consequence is RWST flow diversion.</p>

ID #	SCENARIO	DESCRIPTION	NOTES	PLANT DESIGN	"REQUIRED" / "IMPORTANT" CLASSIFICATION
17	Interfacing System LOCA	Spurious opening of multiple series RHR suction valve from RCS	<p>Scenario causes interfacing system LOCA, challenging the RCS Inventory Control Function.</p> <p>The valve operators are typically maintained de-energized during normal plant operation. If so, spurious operation of each valve would generally require three proper phase hot shorts.</p> <p>Note B&amp;W plants have three series valves.</p> <p>From a Fire PRA perspective, this interfacing system LOCA scenario generally screens out if at least two series valves are normally de-energized.</p> <p>From a PFSS analysis perspective, this is classified as a high/low pressure interface and maintaining the valves de-energized generally complies with fire protection regulatory requirements.</p>	B&W CE W	<p>"IMPORTANT"</p> <p>Isolation of the RHR pump suction valves from the RCS is not part of the "required" SSD path. Consequence is RCS flow diversion.</p>
18	Multiple Pressurizer PORVs	Spurious opening of multiple (two or three) Pressurizer PORVs with corresponding block valves in normal, open position	<p>Scenario causes loss of RCS inventory through the pressurizer PORVs, challenging the RCS Inventory Control Function. Scenario also causes pressurizer depressurization, challenging the RCS Pressure Control Function.</p> <p>Note some CE plants do not have any PORVs. Scenario would not be applicable to these plants.</p> <p>Note B&amp;W plants only have one PORV. Scenario would not be applicable to these plants.</p>	CE W	<p>"IMPORTANT"</p> <p>Isolation of the pressurizer PORV(s) is not part of the "required" SSD path. Consequence is RCS flow diversion.</p>

ID #	SCENARIO	DESCRIPTION	NOTES	PLANT DESIGN	"REQUIRED" / "IMPORTANT" CLASSIFICATION
19	Pressurizer PORV and Block Valve	Spurious opening of Pressurizer PORV(s), <b>AND</b> Spurious opening of block valve(s) after it has been closed.	<p>Scenario causes loss of RCS inventory through the pressurizer PORV(s), challenging the RCS Inventory Control Function. Scenario also causes pressurizer depressurization, challenging the RCS Pressure Control Function.</p> <p>In this scenario, operators may have closed the block valve either to 1) mitigate a fire-induced PORV LOCA or as a 2) pre-emptive action to prevent PORV LOCA from occurring. The first spurious operation is the PORV and the second is the block valve that has been closed.</p> <p>Note that the initial PORV LOCA, caused by spurious operation of PORV alone, is a single spurious since block valve is normally open.</p>	B&W CE W	<p>"IMPORTANT"</p> <p>Isolation of the pressurizer PORV(s) is not part of the "required" SSD path. Consequence is RCS flow diversion.</p>

ID #	SCENARIO	DESCRIPTION	NOTES	PLANT DESIGN	"REQUIRED" / "IMPORTANT" CLASSIFICATION
20	Reactor Head Vent Valves	Spurious opening of multiple series reactor head vent valves	<p>Scenario causes loss of RCS inventory through open reactor head vent flow path(s), challenging the RCS Inventory Control Function.</p> <p>Spurious operation of one head vent flow path generally requires two spurious operations. Likewise, spurious operation of two head vent flow paths generally requires four spurious operations.</p> <p>Note B&amp;W plants only have one head vent flow path. Hot leg vents should be also be evaluated for B&amp;W plants.</p> <p>From a PRA perspective, note that this scenario may screen out due to the low RCS inventory loss rate through these flow paths. The scenario may also screen if the head vent valves are normally de-energized.</p> <p>From a PFSS analysis perspective, a head vent LOCA may be acceptable if the available makeup mass flow rate exceeds the LOCA mass flow rate.</p>	B&W CE W	<p>"IMPORTANT"</p> <p>The reactor head vent valves are not part of the "required" SSD flowpath. Consequence is RCS flow diversion.</p>

ID #	SCENARIO	DESCRIPTION	NOTES	PLANT DESIGN	"REQUIRED" / "IMPORTANT" CLASSIFICATION
21	Excess RCS Makeup	<p>Spurious starting of additional high head charging pump(s),</p> <p><b>AND</b></p> <p>Spurious opening of additional RCS makeup flow paths (i.e., charging injection)</p>	<p>Scenario causes increasing RCS inventory, leading to a water solid pressurizer and PORV or safety valve opening. This scenario challenges both RCS Inventory and RCS Pressure Control Functions.</p> <p>Similar to inadvertent SI.</p> <p>Note that the spurious pump starting can occur for several reasons, including fire damage to control circuitry or an inadvertent ESFAS signal.</p> <p>Also note that other failures (spurious or non-spurious) in the makeup control system could contribute to this scenario.</p>	B&W CE W	<p>"IMPORTANT"</p> <p>Scenario involves malfunction of non-credited components. These components are therefore not part of the "required" SSD path. For example, if seal injection is the credited flowpath, then the SI flowpath (subject to spurious operation) is non-credited.</p>

ID #	SCENARIO	DESCRIPTION	NOTES	PLANT DESIGN	"REQUIRED" / "IMPORTANT" CLASSIFICATION
22	Primary Sample System	<p>Spurious opening of RCS sample valve(s) (i.e., hot leg, pressurizer liquid space, pressurizer steam space, etc.), <b>AND</b></p> <p>Spurious opening of inside containment isolation valve, <b>AND</b></p> <p>Spurious opening of outside containment isolation valve, <b>AND</b></p> <p>Spurious opening of downstream sample valve(s)</p>	<p>Scenario causes loss of reactor coolant through the primary sample system, challenging the RCS Inventory Control Function.</p> <p>From a PRA perspective, scenario will generally screen due to requirement of 3+ spurious operations and the small magnitude of the leak. Also note that existing thermal hydraulic evaluation of loss of coolant through head vents may bound loss of coolant via the primary sample system.</p> <p>Scenario can be screened from consideration if a manual isolation valve prevents the flow. Scenario may also screen if it is within a closed loop capable of withstanding expected pressure.</p>	B&W CE W	<p>"IMPORTANT"</p> <p>Primary sample system is not part of the "required" SSD path. Consequence is RCS flow diversion.</p>

ID #	SCENARIO	DESCRIPTION	NOTES	PLANT DESIGN	"REQUIRED" / "IMPORTANT" CLASSIFICATION
<b>DECAY HEAT REMOVAL</b>					
23	Inadvertent Steam Dumping	Spurious opening of multiple atmospheric steam dump valves upstream of MSIV	<p>Scenario causes RCS over-cooling. Also, the overcooling can cause RCS shrinkage, causing low pressurizer level, and challenging the RCS Inventory Control Function.</p> <p>Note that spurious operation of each individual steam dump valve may require multiple hot shorts.</p> <p>Note some B&amp;W designs do not have MSIVs.</p>	B&W CE W	<p>"IMPORTANT" since the scenario creates excessive flow that exceeds the minimum requirement for the decay heat removal at hot standby conditions. Additionally, Main Steam piping off steam generator is treated as an extension of the steam generator vessel boundary for classification purposes. For example, when steam generator safeties are credited for hot standby decay heat removal, the steam generator atmospheric dump valves, and steam bypass are not part of the credited SSCs required for hot standby and are classified as "IMPORTANT".</p>



ID #	SCENARIO	DESCRIPTION	NOTES	PLANT DESIGN	"REQUIRED" / "IMPORTANT" CLASSIFICATION
24	Inadvertent Steam Dumping	MSIV(s) spurious opening, or failure to close, <b>AND</b> Spurious opening, or failure to close, of downstream steam loads (e.g., condenser steam dumps, turbine inlet valves, etc.)	Scenario causes RCS over-cooling. Also, the overcooling can cause RCS shrinkage, causing low pressurizer level, and challenging the RCS Inventory Control Function.  Note that spurious opening, or failure to close, each individual MSIV may require multiple hot shorts. In addition, re-opening an MSIV once it has been closed may be very difficult due to differential pressure across valve.  Note some B&W designs do not have MSIVs.	B&W CE W	"IMPORTANT" See Scenario #23
25	Inadvertent Steam Dumping	MSIV bypass valve(s) spurious opening, or failure to close, <b>AND</b> Spurious opening, or failure to close, of downstream steam loads (e.g., condenser steam dumps, turbine inlet valves, etc.)	Scenario may cause RCS over-cooling. Also, the overcooling can cause RCS shrinkage, causing low pressurizer level, and challenging the RCS Inventory Control Function.  Note, depending on size and number of bypass lines failing open, scenario may not cause overcooling.  Note some B&W designs do not have MSIVs.	B&W CE W	"IMPORTANT" See Scenario #23

ID #	SCENARIO	DESCRIPTION	NOTES	PLANT DESIGN	"REQUIRED" / "IMPORTANT" CLASSIFICATION
26	Inadvertent Steam Dumping	Spurious operation of other steam loads (e.g., main steam header drain valve(s), steam supply to turbine driven AFW pump, etc.)	Scenario may cause RCS over-cooling. Also, the overcooling can cause RCS shrinkage, causing low pressurizer level, and challenging the RCS Inventory Control Function.  Thermal hydraulic analysis may show that the drain valve flowpath is not large enough to be a problem.	B&W CE W	"IMPORTANT"  See Scenario #23
27	Turbine Driven AFW Pump Steam Supply	Spurious isolation of redundant steam supply valves to turbine driven AFW pump	Scenario causes turbine driven AFW pump loss of function, which challenges the Decay Heat Removal Function.	B&WCE W	"REQUIRED"  TD AFW pump is part of the "required" SSD path for Decay Heat Removal Function.
28	AFW Flow Isolation	Spurious closure of multiple valves in AFW pump discharge flow path(s)	Scenario isolates AFW flow to the required steam generator(s), challenging the Decay Heat Removal Function.  AFW flow isolation can occur due to several combinations of valve closures in the pump discharge and/or discharge cross-connect flow paths. Review P&IDs to identify specific valves.	B&W CE W	"REQUIRED"  AFW flowpaths from pumps to steam generators are part of the "required" SSD path for Decay Heat Removal.

ID #	SCENARIO	DESCRIPTION	NOTES	PLANT DESIGN	"REQUIRED" / "IMPORTANT" CLASSIFICATION
29	AFW Flow Isolation	Spurious closure of steam supply valve(s) to turbine driven AFW pump, <b>AND</b> Spurious isolation of AFW pump discharge flow path(s)	Scenario isolates AFW flow to the steam generator(s) and causes turbine driven AFW pump loss of function, challenging the Decay Heat Removal Function.	B&W CE W	"REQUIRED" See Scenario #27
30	AFW Flow Diversion	Combination of spurious valve operations in the AFW pump discharge flowpaths to the steam generators	Scenario causes AFW flow diversion to a non-credited steam generator(s), challenging the Decay Heat Removal Function. A steam generator may be "non-credited" by the SSA for a number of reasons including unavailability of instrumentation, failure of steam dumps on that loop, etc.  Scenario may be a single spurious event in some cases.  Also note that plants with unit-crossties may be subject to flow diversion to steam generators for another unit.	B&W CE W	"REQUIRED" if flow diversion results in loss of flow to credited steam generator.  "IMPORTANT" if flow diversion affects non-credited steam generator.

ID #	SCENARIO	DESCRIPTION	NOTES	PLANT DESIGN	"REQUIRED" / "IMPORTANT" CLASSIFICATION
31	AFW Pump Runout	Spurious full opening of multiple AFW flow control and/or isolation valves	<p>Scenario may cause AFW pump runout and failure, challenging the Decay Heat Removal Function.</p> <p>Note that this scenario may occur even without spurious operations if the fail-safe position of relevant valves is full open.</p>	B&W CE W	<p>"IMPORTANT"</p> <p>Failure of valves associated with non-credited SGs would be necessary to cause the required pump to reach runout conditions.</p>
32	CST Diversion to Condenser	Spurious opening of valves between the CST and condenser hotwell	<p>Scenario causes inadvertent draining of CST inventory to the condenser. This CST inventory becomes unavailable as an AFW source, challenging the Decay Heat Removal Function.</p> <p>In some plants, this requires spurious operation of multiple valves. In other plants, this only requires spurious operation of one valve. And in other plants, this may occur due to loss of instrument air or a non-spurious valve failure (e.g., loss of air / power).</p> <p>Other CST drain down paths may exist. P&amp;ID review required.</p> <p>Some plants may have a standpipe that prevents the CST from draining below a certain level.</p>	B&W CE W	<p>"IMPORTANT"</p> <p>Condenser hotwell makeup valves are not part of "required" SSD path. Consequence is CST flow diversion.</p>

ID #	SCENARIO	DESCRIPTION	NOTES	PLANT DESIGN	"REQUIRED" / "IMPORTANT" CLASSIFICATION
33a	Excess Feed Flow to Steam Generator	Scenario can occur due to various combinations of spurious AFW pump starts, spurious opening (or failure to close) of valves in AFW pump discharge flowpaths, and spurious opening of MFW isolation valves with MFW pump(s) running.	<p>Scenario causes RCS over-cooling and/or steam generator overfill, both challenging the Decay Heat Removal Function. RCS over-cooling can cause RCS shrinkage and low pressurizer level. Steam generator overfill can affect operability of turbine-driven AFW pump.</p> <p>Note that the spurious pump starting can occur for several reasons, including fire damage to control circuitry or an inadvertent ESFAS signal.</p>	B&W CE W	<p>"IMPORTANT"</p> <p>Scenario involves malfunction of non-credited components. These components are therefore not part of the "required" SSD path</p>
33b	Excess Feed Flow to Steam Generator Fails TD Pump	Excessive flow to credited steam generator may fail turbine driven AFW pump	Spurious operations that fully open feedwater control valves to the credited generator could result in failure of the turbine driven pump due to SG overfill.	B&W CE W	<p>"IMPORTANT"</p> <p>See Notes column if turbine driven pump is credited.</p>

ID #	SCENARIO	DESCRIPTION	NOTES	PLANT DESIGN	"REQUIRED" / "IMPORTANT" CLASSIFICATION
34	Steam Generator Blowdown	Spurious opening of, or failure to close, multiple series steam generator blowdown valves	<p>Scenario causes drain down of steam generator inventory through the blowdown system, challenging the Decay Heat Removal Function.</p> <p>The number of valves required to spuriously open varies by plant design.</p> <p>B&amp;W plants generally do not have a steam generator blowdown system. However, some B&amp;W plants with replacement steam generators may have this system.</p> <p>Potential Resolution: Scenario may screen if available AFW mass flow rate exceeds steam generator inventory mass loss rate through blowdown.</p>	B&W CE W	"IMPORTANT" because valves are not on the required SSD flowpath.

ID #	SCENARIO	DESCRIPTION	NOTES	PLANT DESIGN	"REQUIRED" / "IMPORTANT" CLASSIFICATION
35	Secondary Sample System	<p>Spurious opening of steam generator sample valve(s) inside containment,</p> <p><b>AND</b></p> <p>Spurious opening of isolation valve(s) outside containment,</p> <p><b>AND</b></p> <p>Spurious opening of downstream sample valve(s)</p>	<p>Scenario causes drain down of steam generator inventory through the sample system, challenging the Decay Heat Removal Function.</p> <p>From a PRA perspective, scenario will generally screen due to requirement of 3+ spurious operations and the small magnitude of leak.</p> <p>Scenario can be screened from consideration if a manual isolation valve prevents the flow or if the system is closed loop capable of withstanding expected pressure.</p> <p>Scenario may also screen if available AFW mass flow rate exceeds steam generator inventory mass loss rate through the sample system.</p> <p>B&amp;W plants sample directly from the steam generator (i.e., not through blowdown system).</p>	B&W CE W	"IMPORTANT" because valves are not on the required SSD flowpath.

ID #	SCENARIO	DESCRIPTION	NOTES	PLANT DESIGN	"REQUIRED" / "IMPORTANT" CLASSIFICATION
<b>RCS PRESSURE CONTROL</b>					
<b>36</b>	RCS Pressure Decrease	<p>Spurious opening of pressurizer spray valve(s),</p> <p><b>AND</b></p> <p>Inability to trip, or spurious operation of, RCP,</p> <p><b>AND</b></p> <p>Failure of pressurizer heater(s)</p>	<p>Many factors influence pressure control such as secondary side heat removal, PZR spray, PZR heaters etc.</p> <p>Scenario causes a RCS pressure transient, challenging the RCS Pressure Control Function. Typical PFSS analyses address this issue; PRAs often consider scenario negligible since there is no real threat of core uncover.</p> <p>Potential candidate for generic analysis to evaluate various spray / heater combinations and show no adverse impact on safe shutdown capability.</p> <p>Note that spurious opening or failure to isolate pressurizer auxiliary spray could have similar consequence; however this is typically a single spurious scenario.</p>	B&W CE W	Plant-specific classification based on TH analysis.



ID #	SCENARIO	DESCRIPTION	NOTES	PLANT DESIGN	"REQUIRED" / "IMPORTANT" CLASSIFICATION
37	RCS Pressure Increase	Spurious operation of multiple pressurizer heaters, <b>AND</b> Failure of pressurizer spray or auxiliary spray	Scenario causes a RCS pressure transient, challenging the RCS Pressure Control Function. RCS pressure increase could cause PORV(s) and/or safety valve(s) to open.	B&W CE W	Plant-specific classification required and depends if pressurizer heaters are credited for pressure control. "REQUIRED" if heaters are credited for pressure control. <b>OR</b> "IMPORTANT" if heaters are not credited for pressure control.

ID #	SCENARIO	DESCRIPTION	NOTES	PLANT DESIGN	"REQUIRED" / "IMPORTANT" CLASSIFICATION
REACTIVITY CONTROL					

	Inadvertent Boron Dilution	<p>Unborated water supply to the RCS can occur due to combinations of the following:</p> <ul style="list-style-type: none"> <li>• Spurious start of reactor makeup pump(s) (supplies unborated water to the VCT),</li> <li>• Spurious opening of valves between reactor makeup pump(s) and VCT,</li> <li>• Spurious full opening of the reactor makeup flow control valve,</li> <li>• Spurious closure of the boric acid flow control valve</li> </ul>	<p>Scenario decreases RCS boron concentration, potentially causing reactivity increase, and challenging the Reactivity Control Function.</p> <p>The reactor makeup flow control valve would normally provide the setpoint flowrate instead of being fully open.</p> <p>Potential Solution: The maximum flow from the reactor makeup pump may be limited due to the plant specific design (e.g., installation of a flow orifice to limit the pump's maximum flow, boron dilution protection system, etc.).</p> <p>Potential Solution: The reactivity increase may occur at a very slow rate, allowing operators sufficient time to mitigate.</p>	B&W CE W	<p>"IMPORTANT"</p> <p>Boron dilution components are not part of the hot standby SSD flowpath.</p>
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ID #	SCENARIO	DESCRIPTION	NOTES	PLANT DESIGN	"REQUIRED" / "IMPORTANT" CLASSIFICATION
39	Fire Prevents Reactor Trip	Fire damage to RPS may prevent reactor trip.	<p>BWRs have identified scenarios where fire-induced hot shorts could prevent all control rod groups from inserting when required. Reference NRC Information Notice 2007-07.</p> <p>No cases at PWRs were identified by the survey results that supported this MSO list. However, each plant should consider performing a review to determine if scenario is plausible at their plant. Note that this review may have already been performed for the disposition of Information Notice 2007-07.</p>	B&W CE W	<p>"REQUIRED"</p> <p>Plant trip is part of safe shutdown path to reach hot standby.</p>

ID #	SCENARIO	DESCRIPTION	NOTES	PLANT DESIGN	"REQUIRED" / "IMPORTANT" CLASSIFICATION
<b>SUPPORT FUNCTIONS</b>					
40	CCW Header Isolation	<p>CCW flow can be isolated via several combinations of spurious valve closures.</p> <p>Pertinent valves include:</p> <ul style="list-style-type: none"> <li>• Pump discharge valves,</li> <li>• Pump crosstie valves,</li> <li>• CCW heat exchanger inlet valves,</li> <li>• CCW heat exchanger outlet valves,</li> <li>• -CCW heat exchanger crosstie valves,</li> <li>• Etc.</li> </ul>	<p>Scenarios cause failure of CCW function to provide cooling to safe shutdown loads.</p> <p>Review P&amp;IDs to identify relevant valve combinations.</p>	B&W CE W	"REQUIRED" if plant credits CCW cooling of SSD equipment.

ID #	SCENARIO	DESCRIPTION	NOTES	PLANT DESIGN	"REQUIRED" / "IMPORTANT" CLASSIFICATION
41	CCW to Credited Loads	Spurious isolation of CCW cooling to credited loads (including lube oil coolers, RHR heat exchangers, etc.)	<p>Scenario isolates CCW cooling to credited loads causing safe shutdown equipment inoperability of credited trains.</p> <p>For example, a plant may have two redundant charging pumps. Each charging pump may have a lube oil system that is cooled by the corresponding train of CCW. If CCW flow to both lube oil coolers spuriously isolates, then both charging pumps would become inoperable.</p> <p>All credited CCW loads should be reviewed.</p>	B&W CE W	"REQUIRED" if plant credits CCW cooling of SSD equipment.
42	CCW Flow Diversion to Non-Credited Loop	Flow diversion can occur via several combinations of spurious valve operations in the CCW pump discharge and CCW loop crosstie flowpaths.	<p>Scenario causes CCW flow to be diverted to the non-credited loop. This ultimately prevents CCW cooling of credited safe shutdown loads.</p> <p>Review P&amp;IDs to identify relevant valve combinations.</p>	B&W CE W	<p>"REQUIRED" if flow diversion results in failure of the credited train, unless a plant specific analysis shows no unacceptable consequences occur within 1 hour (per NEI 00-01 Appendix H)</p> <p>"IMPORTANT" if analysis shows diversion will not fail credited train.</p>

43	ESW Header Isolation	<p>ESW flow to credited loads can be isolated via several combinations of spurious valve closures.</p> <p>Pertinent valves include:</p> <ul style="list-style-type: none"> <li>• pump discharge valves,</li> <li>• pump crosstie valves,</li> <li>• ESW heat exchanger inlet valves,</li> <li>• ESW heat exchanger outlet valves,</li> <li>• ESW heat exchanger crosstie valves,</li> <li>• Etc.</li> </ul> <p>Review P&amp;IDs to identify relevant combinations.</p>	<p>Scenario causes isolation of ESW, which can fail cooling to the CCW system and other safe shutdown components directly cooled by ESW (e.g., EDG cooling).</p> <p>All credited ESW loads should be reviewed for spurious isolation.</p>	B&W CE W	"REQUIRED" if plant credits ESW cooling of SSD equipment.
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ID #	SCENARIO	DESCRIPTION	NOTES	PLANT DESIGN	"REQUIRED" / "IMPORTANT" CLASSIFICATION
44	ESW to Credited Loads	Spurious isolation of ESW cooling to credited loads (including CCW heat exchangers, EDG cooling, etc.)	<p>Scenario isolates ESW cooling to credited loads causing safe shutdown equipment failure on credited trains.</p> <p>For example, redundant EDGs may be cooled by ESW. If ESW flow to both EDGs spuriously isolates, then both EDGs could fail.</p> <p>All credited ESW loads should be reviewed.</p>	B&W CE W	"REQUIRED" if plant credits ESW cooling of SSD equipment.
45	ESW Flow Diversion to Non-Credited Loops / Systems	Flow diversion can occur via several combinations of spurious valve operations in the ESW pump discharge and loop crosstie flowpaths and/or wire-to-wire short(s) bypass torque and limit switches. Review P&IDs to identify relevant combinations.	<p>Scenario causes ESW flow to be diverted to a non-credited loop or interconnected system. This ultimately prevents ESW cooling of credited loads.</p> <p>May include heat up of ultimate heat sink due to spurious alignment of cooling water recirculation paths.</p> <p>Review P&amp;IDs to identify relevant valve combinations.</p>	B&W CE W	<p>"REQUIRED" if flow diversion results in failure of the credited train, unless a plant specific analysis shows no unacceptable consequences occur within 1 hour (per NEI 00-01 Appendix H)</p> <p>"IMPORTANT" if analysis shows diversion will not fail credited train.</p>



ID #	SCENARIO	DESCRIPTION	NOTES	PLANT DESIGN	"REQUIRED" / "IMPORTANT" CLASSIFICATION
46	Emergency Power	Overload of credited diesel generator due to spurious operation of non-credited component breakers	Scenario causes diesel generator overloading and failure. Note: Scenario very site specific. Interlocks may prevent this from occurring.	B&WCE W	"IMPORTANT"  Components that spuriously operate are not required for DG function. They are therefore not part of the "required" safe shutdown path.
47	Emergency Power	Overload of credited diesel generator due to simultaneous loading of credited equipment.	<p>Scenarios causes diesel generator overloading and failure due to bypass of proper load sequencing via hot shorts, causing simultaneous loading of credited components onto the EDG.</p> <p>Note: Scenarios very site specific. Interlocks may prevent these from occurring or analysis may show that the diesel can accept simultaneous loading of required loads without failure.</p> <p>In addition to Scenario 46, overloading may also occur if proper load sequencing is bypassed via hot shorts, causing simultaneous loading of multiple components onto the EDG.</p>	B&W CE W	<p>Simultaneous loading for credited equipment is a "REQUIRED" scenario unless plant specific analysis shows failure of credited diesel will not result.</p> <p>Non-credited loads are "IMPORTANT"</p>
48	Emergency Power	Diesel generator spuriously starts without service water cooling	The fire causes startup of the Emergency Diesel Generator and spurious isolation of ESW cooling (See Scenarios 43 & 45). Running the Emergency Diesel Generator with a loss of cooling water could trip and/or damage the diesel on high temperature.	B&W CE W	<p>"REQUIRED"</p> <p>The DG is credited and part of the "required" SSD path.</p>

ID #	SCENARIO	DESCRIPTION	NOTES	PLANT DESIGN	"REQUIRED" / "IMPORTANT" CLASSIFICATION
49	Emergency Power	Non-synchronous paralleling of EDG with on-site and off-site sources through spurious breaker operations	Scenario causes damage to diesel generator by closing into a live bus out-of-phase. Note: Scenario very site specific. Interlocks may prevent this from occurring.	B&W CE W	"IMPORTANT" if involves non credited breakers

ID #	SCENARIO	DESCRIPTION	NOTES	PLANT DESIGN	"REQUIRED" / "IMPORTANT" CLASSIFICATION
49.1	Emergency Power	Similar to non-synchronous paralleling-inadvertent crosstie breaker operation between opposite divisions or non-synchronous paralleling-inadvertent cross tying the offsite power sources through the on-site busses and breakers, with synchronous faults. Spurious closure on alt feeder and failure of normal to open (i.e., parallel supply) + circuit fault could result in short circuit currents above withstand / interrupt ratings.	May apply to Electrical Boards with normal and alternate feeder breakers without physical mechanical interlocks.	B&W CE W	"IMPORTANT" if involves non credited breakers

ID #	SCENARIO	DESCRIPTION	NOTES	PLANT DESIGN	"REQUIRED" / "IMPORTANT" CLASSIFICATION
<b>OTHER SCENARIOS</b>					
50	Generic - Loss of Pump Suction	Spurious isolation of various combinations of pump suction valves	<p>Suction flow paths for all credited pumps should be reviewed for MSO scenarios causing loss of suction and pump failure. An example of a pump suction MSO was previously identified in which both the VCT outlet valve(s) and RWST outlet valve(s) spuriously close.</p> <p>Another example involves pump suction cross-connect valves. Three pumps may be supplied from a common suction header that includes several cross connect valves. If two valves spuriously isolate, the pump drawing suction from the common header between the two isolated valves can lose suction and fail.</p> <p>The spurious operation of idle pumps after suction has been spuriously isolated should also be considered. Spurious pump starting can occur for several reasons, including fire damage to control circuitry or an inadvertent ESFAS signal.</p>	B&W CE W	<p>"REQUIRED" if the pump is "required" and the spurious operation occurs on a "required" flowpath</p> <p>"IMPORTANT" if the inadvertent operation of non-credited pump(s) is required to cause damage to the credited pump(s).</p>

ID #	SCENARIO	DESCRIPTION	NOTES	PLANT DESIGN	"REQUIRED" / "IMPORTANT" CLASSIFICATION
51	Generic - Pump Shutoff Head	Spurious isolation of pump discharge flow, <b>AND</b> Spurious isolation of recirculation valve(s)	Scenario causes pump operation at shutoff head and subsequent inoperability. All credited pumps should be reviewed for this scenario.  Note that spurious starting of idle pump(s), in combination with isolation of discharge flow and recirculation, may cause inoperability of additional pumps. Spurious pump starting can occur for several reasons, including fire damage to control circuitry or a spurious ESFAS signal.	B&W CE W	"REQUIRED" if the pump is "required" and the spurious operation occurs on a "required" flowpath  "IMPORTANT" if the inadvertent operation of non-credited pump(s) is required to cause damage to the credited pump(s).
52	Generic - Pump Outside Design Flow	Pump damage from operation outside design flow either at shutoff head or pump run-out conditions.	Scenario causes pump failure. All credited pumps should be reviewed for this scenario.  Operation at shutoff head can occur, for example, if pump discharge flow spuriously isolates with the recirculation valves closed. Run-out can occur, for example, if the discharge header is at reduced pressure conditions.  Note that spurious starting of idle pump(s), in combination with isolation of discharge flow and recirculation, may cause failure of additional pumps. Spurious pump starting can occur for several reasons, including fire damage to control circuitry or an inadvertent ESFAS signal.	B&W CE W	"REQUIRED" if the pump is "required" and the spurious operation occurs on a "required" flowpath  "IMPORTANT" if the inadvertent operation of non-credited pump(s) is required to cause damage to the credited pump(s).

ID #	SCENARIO	DESCRIPTION	NOTES	PLANT DESIGN	"REQUIRED" / "IMPORTANT" CLASSIFICATION
53	Generic Flow Diversion	Spurious operation of various valves causing flow diversion	All credited flow paths should be reviewed for MSO scenarios that can divert flow away from desired location. An example is AFW pump flow diversion through the recirculation flow path back to the Emergency Feed water Storage Tank failing the AFW makeup to steam generator function.	B&W CE W	Diversions from a required SSD flow path are required unless an evaluation shows that the diversion does not result in failing the threshold criteria for longer than 1 hour so that the scenario can be reclassified important.
54	Loss of HVAC	Spurious isolation of HVAC to credited loads	Perform review to identify spurious failures that could cause isolation of Heating Ventilation and Air Conditioning (HVAC) to credited loads. Credited loads may include pump rooms, switchgear rooms, and rooms containing solid state control systems. Examples of spurious failures include spurious damper isolation and spurious isolation of cooling flow to chillers.	B&W CE W	"IMPORTANT" per Section 3.1.2.6.3 of NEI 00-01.

ID #	SCENARIO	DESCRIPTION	NOTES	PLANT DESIGN	"REQUIRED" / "IMPORTANT" CLASSIFICATION
55	Valve Failure	Spurious motor-operated valve operation, <b>AND</b> Wire-to-wire short(s) bypass torque and limit switches	<p>General scenario is that fire damage to motor-operated valve circuitry causes spurious operation. If the same fire causes wire-to-wire short(s) such that the valve torque and limit switches are bypassed, then the valve motor may stall at the end of the valve cycle. This can cause excess current in the valve motor windings as well as valve mechanical damage. This mechanical damage may be sufficient to prevent manual operation of the valve.</p> <p>Scenario only applies to motor-operated valves.</p> <p>Note this generic issue may have already been addressed during disposition of NRC Information Notice 92-18. This disposition should be reviewed in the context of multiple spurious operations and multiple hot shorts.</p>	B&W CE W	Plant Specific Analysis Required
56	Fire-Induced Inadvertent ESFAS	Fire-induced inadvertent ESFAS signals (e.g., safety injection, containment isolation, etc), combined with other fire-induced failures, can adversely affect safe shutdown capability. An example of a fire-induced ESFAS signal is a fire causing open circuits on 2/3 main steam pressure instruments on one loop resulting in a spurious safety injection signal. ESFAS signals can result from open circuits, shorts to ground, and/or hot shorts. Fire-induced failure of instrument inverters may also cause inadvertent ESFAS signals. The plant should perform a systematic review to assess the potential for fire-induced inadvertent ESFAS to adversely affect safe shutdown capability.		B&W CE W	"IMPORTANT" unless ESFAS is credited for SSD analysis.

ID #	SCENARIO	DESCRIPTION	NOTES	PLANT DESIGN	"REQUIRED" / "IMPORTANT" CLASSIFICATION
56a	RCS Makeup Pump Failure	Spurious safety injection signal, <b>AND</b> Spurious isolation of makeup pump suction	Safety injection signal starts multiple RCS makeup pumps. Fire causes makeup pump suction valves to fail closed. Scenario results in cavitation / failure of multiple RCS makeup pumps.	B&W CE W	"IMPORTANT" See Scenario 56.
56b	Loss of all Seal Cooling	Spurious containment isolation signal isolates CCW to the thermal barrier heat exchangers for all RCPs, <b>AND</b> Spurious isolation of seal injection header flow	Scenario causes loss of all RCP seal cooling and subsequent increase in RCP Seal leakage for Westinghouse designed RCP seals.  Westinghouse Tech Bulletin 04-22 Rev. 1 provides a summary of the issue. Tech Bulletin references provide additional detail. B&W plants with Westinghouse designed seals would have similar concerns.  *CE plants generally do not have seal injection and can lose seal cooling for an extended period of time without increased seal leakage. These plants can lose all seal cooling due to spurious isolation of CCW. Refer to WCAP-16175.	B&W CE* W	"IMPORTANT" See Scenario 56.



ID #	SCENARIO	DESCRIPTION	NOTES	PLANT DESIGN	"REQUIRED" / "IMPORTANT" CLASSIFICATION
56c	Loss of all Seal Cooling	Spurious containment isolation signal isolates CCW to the thermal barrier heat exchangers for all RCPs, <b>AND</b> Spurious opening of charging injection valve(s) causing insufficient flow to seals	Scenario causes loss of all RCP seal cooling and subsequent RCP Seal LOCA. *This scenario is not applicable to CE plants without pressurizer PORVs	B&W CE* W	"IMPORTANT" See Scenario 56.
56d	RWST Drain Down	Spurious high containment pressure on multiple channels causing spurious containment spray signal	Scenario causes a pumped RWST drain down via the containment spray pumps and containment spray ring.	B&W CE W	"IMPORTANT" See Scenario 56.

ID #	SCENARIO	DESCRIPTION	NOTES	PLANT DESIGN	"REQUIRED" / "IMPORTANT" CLASSIFICATION
56e	PORV(s) Open	Spurious high pressurizer pressure on multiple channels causes high pressurizer pressure signal	Spurious high pressurizer pressure signal causes PORV(s) to open and challenges the RCS Inventory and Pressure Control Functions	B&W CE W	"IMPORTANT" See Scenario 56.
56f	RCS Makeup Pump Failure	Spurious Recirculation Actuation Signal (RAS) starting and aligning pumps to a dry containment sump.	Scenario causes failure of RCS makeup pump(s) due to cavitation.	B&W CE W	"IMPORTANT" See Scenario 56.

TERMINOLOGY LEGEND	
AFW	<p>Auxiliary Feedwater System. Provides feedwater for removing decay heat via the steam generators.</p> <p>B&amp;W plants generally refer to this as Emergency Feedwater (EFW).</p>
Charging	<p>This is the RCS high head makeup system.</p> <p>B&amp;W plants refer to this simply as the Makeup System</p>
CVCS	<p>Chemical and Volume Control System. System allows for RCS letdown, cleanup, chemical addition, and makeup.</p> <p>B&amp;W plants refer to this as the Makeup and Purification (MU&amp;P) System</p>
EFWST	<p>Some plants have an "Emergency Feedwater Storage Tank" (EFWST) that provide a dedicated source of Auxiliary Feedwater.</p>
RWST	<p>Refueling Water Storage Tank. Provides borated water source for RCS makeup.</p> <p>Also referred to as Safety Injection Refueling Water Tank (SIRWT) or Refueling Water Tank (RWT).</p> <p>B&amp;W plants refer to this as the Borated Water Storage Tank (BWST)</p>
VCT	<p>Volume Control Tank. Provides NPSH to high head charging pumps during normal operation.</p> <p>B&amp;W plants refer to this as the Makeup Tank.</p>

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## **APPENDIX H: REQUIRED FOR HOT SHUTDOWN VERSUS IMPORTANT TO SSD COMPONENTS**

### **H-1.0 Introduction**

The purpose of this appendix is to provide additional guidance on classifying required for hot shutdown components versus important to safe shutdown components, particularly as it relates to flow diversions off of the flow paths for systems performing the required safe shutdown functions. This appendix should be used in combination with Section 3 for other aspects of this classification. The reason for the distinction between these two (2) groups of components is that a required for hot shutdown component's fire protection features are governed specifically by the requirements of Appendix R Sections III.G.1.a and III.G.2, whereas, an important to safe shutdown component's fire protection features are not directly addressed in terms of specific fire protection features under Appendix R III.G.1. For plants required by 10CFR50.48 to meet the requirements of Appendix R Section III.G, the only available mitigating actions for addressing fire-induced impacts to the circuits for the required for hot shutdown components governed by Appendix R Section III.G.1, other than re-design, re-routing, exemptions or deviations, is protection of these circuits using the specific fire protection features required by Appendix R Section III.G.2. Although the use of the Standard License Condition is available for Plants licensed post-1979, the use of measures other than those described above for required for hot shutdown components will be heavily scrutinized by NRC relative to the justification for no adverse impact. For fire-induced impacts to circuits for components classified as important to safe shutdown components, additional mitigating strategies are available as defined in this appendix and within the body of NEI 00-01.

The distinction between required for hot shutdown and important to safe shutdown, however, is a legal distinction related to the requirements in Appendix R Section III.G.1 and its legal relationship to Appendix R Section III.G.2. Required for hot shutdown components are not necessarily more critical to safe shutdown than important to safe shutdown components. Fire-induced damage to both required for hot shutdown and important to safe shutdown components must be appropriately addressed using an appropriate mitigating strategy to address the potential fire-induced damage to post-fire safe shutdown equipment and cables.

In classifying flow diversion components as either required for hot shutdown or important to safe shutdown, the use of thermal hydraulic or transient analysis may be required. The acceptance criteria and the set of acceptable initial conditions for the thermal hydraulic/transient analysis used in support of making this classification or for other aspects of the post-fire safe shutdown are described below. Best estimate/nominal values for the parameters used in the thermal hydraulic/transient analysis may be used. The use of these criteria allow the thermal hydraulic/transient analysis performed for the plant internal events PRA to be usable in assessing impacts and timelines for post-fire safe shutdown events when the postulated failure conditions are the same. Best estimate/nominal values are also appropriate whenever a reference is made to a bounding value in the body of this document. Note that RG 1.189, Branch Technical Position 9.5.1

and Appendix R do not require postulation of a fire concurrent with any other Accident, Transient, or Severe Natural Phenomenon. For the Control Room fire or other scenario involving alternate or dedicated shutdown, (i.e., Appendix R Section III.G.3/III.L), a loss of offsite power must be postulated.

## H-2.0 Definitions

This appendix provides a definition of the required for hot shutdown components and important to safe shutdown components. The components required to perform the post-fire safe shutdown functions are classified as required for hot shutdown components. These components are necessary and sufficient to perform the required safe shutdown functions and their selection is made based on their ability to perform the required safe shutdown functions in the absence of fire damage to components that could fail or could be spuriously operated and, potentially impact the required for hot shutdown components. Since fire-induced impacts to the other components with the potential to impact the required for hot shutdown components within a common fire area could occur, these potential fire-induced impacts must also be addressed. This latter set of components with the potential to impact the required for hot shutdown components and thereby, impact post-fire safe shutdown, are classified as important to safe shutdown components.

- The required for hot shutdown components are those components on the required safe shutdown path for a particular fire area that are designated to perform the following safe shutdown functions: reactivity control, pressure control, inventory control, decay heat removal, process monitoring, as defined in NRC information Notice 84-09 and support systems, including electrical power, component cooling and lube oil cooling.
- Based on the GE NEDO-33638, BWROG Assessment of Generic Multiple Spurious Operations (MSOs) in Post-Fire Safe Shutdown Circuit Analysis, protecting the RPS/RTS scram function can rely upon operator manual actions contained in post-fire safe shutdown procedures rather than circuit analysis to assure the reactivity control function.
- For the remaining required for hot shutdown functions, fire-induced impacts to circuits for any required for hot shutdown components must be protected by a means meeting the requirements of the appropriate section of Appendix R or approved licensing basis for post-1979 Plants. The use of operator manual actions that have not been accepted by the NRC is not allowed to mitigate the effect of fire-induced circuit damage resulting from a hot short, a short-to-ground or an open circuit. Re-routing or re-design of components and/or circuits may be used to eliminate safe shutdown impacts. Deviation or exemption requests may also be used.
- Fire-induced circuit damage to valves resulting in a flow diversion from the main flow path for a required for hot shutdown systems are initially classified as required for hot shutdown components. Only when an engineering evaluation concludes that a flow diversion will not impact the required safe shutdown function can these components be re-classified as important to safe shutdown.

Each flow path is to be evaluated individually. To be re-classified as an important to safe shutdown component, the flow diversion must meet the following criteria:

- If as a result of the flow diversion, assuming the valve in the flow diversion path opens at the start of the fire, (i.e., time zero, it must take longer than 1 hour<sup>14</sup> for any of the following threshold conditions to be met), then the valve would be classified as important to safe shutdown. For multiple series valves in a flow diversion path, in the absence of technical justification to the contrary, all valves in the series are assumed to be opened at the start of the fire, (i.e., time zero). Fire modeling, however, may be used to determine the amount of time required to open any subsequent valves for cases involving the need to open series valves to cause the flow diversion. Since the threshold criteria listed below will not be exceeded until all series valves in a given flow diversion path are opened, the time determined through fire modeling to open subsequent valves may be credited as part of the required time to exceed the threshold criteria. The threshold criteria for any analysis performed is provided below:
  - Core Damage ( $PCT \geq 1800^{\circ}\text{F}$ ) – Reference NUREG 0562
  - Rupture of the Primary Coolant Boundary
  - Rupture of the Primary Containment
- The initial conditions for the thermal hydraulic/transient analysis performed is as follows:
  - Reactor scrammed
  - MSIVs closed

When performing thermal-hydraulic analysis in support of post-fire safe shutdown scenarios, best estimate values along with the core damage measurement of  $PCT \geq 1800^{\circ}\text{F}$  may be used. These criteria are similar to those used for the Internal Events PRA thermal hydraulic analysis. The use of these same criteria for post-fire safe shutdown provides for a consistent approach and a cost effective use of the information developed on plant response to various transient conditions.

The initial conditions specified above are consistent with the initial conditions used in the Internal Events PRA thermal hydraulic analysis. These initial conditions are used in the Internal Events PRA thermal hydraulic analysis because most of the thermal hydraulic models do not model the balance of plant systems (BOP). If the MSIVs were to remain open, the response of the BOP systems would need to be modeled. With respect to the fire condition, due to the high priority placed on scrambling

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<sup>14</sup> The 1 hour criterion is based on NUREG 1852.

the reactor by Operations and due to the difficulty in keeping the MSIVs open under fire-induced transient conditions, the use of these assumptions for thermal hydraulic effects under fire conditions is justified.

- If the evaluation indicates that there is no impact, for an unlimited amount of time, to the required hot shutdown system to perform its required safe shutdown function or until the component/function is no longer needed, then the flow diversion is classified as “non-impacting”. The lack of impact can be as a result of a quantitative evaluation addressing the parameters described above or as a results of a qualitative evaluation related to the small size of the flow diversion path, (e.g., flow diversion paths  $\leq 1$ "), or the flow diversion path having no adverse consequence, (e.g., flow diversion through the Suppression Pool Spray line in a Mark II BWR when RHR is being used in the Suppression Pool Cooling mode). The flow diversion through a 1" line is considered to provide an insignificant loss of inventory when compared to the capacities of any of the systems with the capability to provide adequate make-up to the reactor during shutdown conditions. For the flow diversion through the Suppression Pool Spray line with the RHR System operating in the Suppression Pool Cooling mode of operation, there is no impact to the function of the system since water is still being taken from the Suppression Pool, run through the RHR Heat Exchanger and returned to the Suppression Pool.
- The threshold criteria described above should be viewed as a measure of risk of the flow diversion to post-fire safe shutdown as opposed to an acceptable time frame for performing an alternate mitigating strategy. Even though the threshold criteria described above may not be exceeded for a period in excess of 1 hour, the use of an operator manual action as a mitigating measure for a particular flow diversion must still justify that there is sufficient time to diagnose and perform the operator manual action. For example, if the threshold criteria are not exceeded for 2 hours, but the only available operator manual action would take 2.5 hours to accomplish, the use of the operator manual action would not be justified in this case.
- Any impacts associated with simultaneous flow loss through multiple flow diversion paths on the same required safe shutdown system should be captured as a part of the MSO review.
- In evaluating flow diversions, consideration should also be given to the effect of the flow diversion on voiding in the discharge piping and the potential for a subsequent waterhammer. Refer to Section 3 of this document.
- In evaluating flow diversions, consideration should also be given to the effect of the flow diversion on the suction path for a pump required for hot shutdown resulting in pump damage due to cavitation.



- Fire-induced damage to associated circuits of concern for a breaker off of a bus for a required component requires that the breaker feeding the associated circuit of concern be classified as a required for hot shutdown component. Coordination is required for these breakers.
- Circuits for required for hot shutdown components are classified as required for hot shutdown circuits.
- Important to safe shutdown components are all components with the potential for a fire-induced impact to post-fire safe shutdown that are not classified as required for hot shutdown components. Important to safe shutdown components can impact post-fire safe shutdown in other ways, (e.g., inventory loss from tanks providing a suction source for a required for hot shutdown pump, or inventory losses from the reactor coolant system).
- Circuits for important to SSD components are classified as important to SSD circuits.
- HVAC Systems (See Section 3.1.2.6.3)

Refer to Figure H-1 for a pictorial presentation of this information.

### **H-3.0 Regulatory Basis**

#### **H-3.1 Required for Hot Shutdown Components**

The origin for the requirements associated with required for hot shutdown components is Appendix R Section III.G.1.a. Appendix R Section III.G.1.a requires that one train of systems necessary to achieve and maintain hot shutdown be “free of fire damage”.

The information in italics is intended to be wording taken verbatim from the Code of Federal Regulations.

#### ***III. G. Fire protection of safe shutdown capability.***

- 1. Fire protection features shall be provided for structures, systems, and components important to safe shutdown. These features shall be capable of limiting fire damage so that:*
  - a. One train of systems necessary to achieve and maintain hot shutdown conditions from either the control room or emergency control station(s) is free of fire damage; and*
  - b. Systems necessary to achieve and maintain cold shutdown from either the control room or emergency control station(s) can be repaired within 72 hours.*

If circuits for the components required to perform the hot shutdown functions on the systems selected for safe shutdown in any fire area could be damaged by the fire, then protection of these circuits in accordance with the requirements of Appendix R Section III.G.2 is required.

#### **H-3.2 Important to Safe Shutdown Components**

Important to Safe Shutdown components are described in Paragraph III.G.1 of Appendix R not specifically addressed in Appendix R. Paragraph III.G.1 reads as follows:

*Fire protection features shall be provided for structures, systems, and components important to safe shutdown.*

Paragraph III.G.1, however, does not specifically describe the requirements for the fire protection features to be provided for important to safe shutdown components. Because of this, there is some latitude in selecting the fire protection features that can be used to mitigate the effects of fire-induced damage with the potential to impact the required components.

#### **H-4.0 Required for Hot and Important to Safe Shutdown Components**

##### **H-4.1 Criteria for Segregating**

###### Required Safe Shutdown Components:

- Review the safe shutdown methodology for each fire area.
- Identify those systems being used to support each of the required hot shutdown functions in the absence of fire damage to any components that fail and/or spuriously operate and potentially impact the required for hot shutdown system. Refer to the guidance in Section 3 for additional discussion on the definition of components required for post-fire safe shutdown.
- Identify the components required for those systems to be able to perform the required safe shutdown function for the system in the absence of fire damage to any components that fail and/or spuriously operate and potentially impact the required for hot shutdown component.
- Identify the potential flow diversion off of the flow path for the systems being used to perform the required safe shutdown functions.
- Evaluate whether or not the size of the flow diversion can impact the ability to achieve and maintain safe shutdown based on the threshold criteria provided above.
- For flow diversions off of the flow path for the systems being used to the required for hot shutdown function where the flow diversion impact exceeds the threshold criteria in less than or equal to 1 hour, classify the flow diversion component as a required for hot shutdown component. Classify the remaining flow diversion components as important to safe shutdown or non-impacting depending on whether the flow diversion needs to be isolated using an operator manual action or its affect can be tolerated.
- Identify the power supplies for each of required for safe shutdown components.
- Identify the circuits for all breakers coming off of a bus powering a required safe shutdown component.
- Determine if these circuits represent associated circuits of concern.

- Address breaker coordination for all breakers that are associated circuits of concern.

For any component classified as a required component, classify its power supplies for both motive and control power as required safe shutdown components for the particular fire area under review. Any cable required for the operation of this set of components is a required for safe shutdown circuit.

Important to Safe Shutdown Components:

- Any component, other than those described above, whose fire-induced spurious operation can cause a flow diversion with the potential to impact a system performing one of the required safe shutdown functions is an important to safe shutdown component.
- Any component whose fire-induced spurious operation can cause an inventory loss from the RPV, from the reactor coolant system or from a tank providing a suction source for a system performing a required safe shutdown function is an important to safe shutdown component.
- Any component with the potential to impact a system performing a required safe shutdown function that is not classified as a required component is classified as an important to safe shutdown component.

Cables associated with the important to safe shutdown components described above are classified as important to safe shutdown circuits.

## **H-4.2 Acceptable Mitigating Tools**

Required Safe Shutdown Components:

- Assure they are free of fire damage by re-routing or re-designing the component or circuit.
- Protect the circuits in accordance with Appendix R Section III.G.2.a, b or c.
- Process a licensing change in accordance with the licensee's current licensing basis (CLB) to demonstrate the acceptability of the condition. Depending on change and the licensee's CLB, NRC approval of the change may be required. Plants licensed to operate after January 1, 1979 with standard license condition for their Fire Protection Program may make changes to their approved Fire Protection Program as long as the change does not adversely impact the ability to achieve and maintain safe shutdown in the event of a plant fire. Plants licensed to the requirements of 10CFR50.48 must obtain NRC approval prior to making changes governed by the requirements of Appendix R Section III.G.1 and II.G.2.
- Perform a risk informed analysis using the tools available for important to safe shutdown components in accordance with Regulatory Guide 1.174 and 1.200. This approach will require a license amendment, if the use of risk is not a part of the CLB.

Important to Safe Shutdown Components:

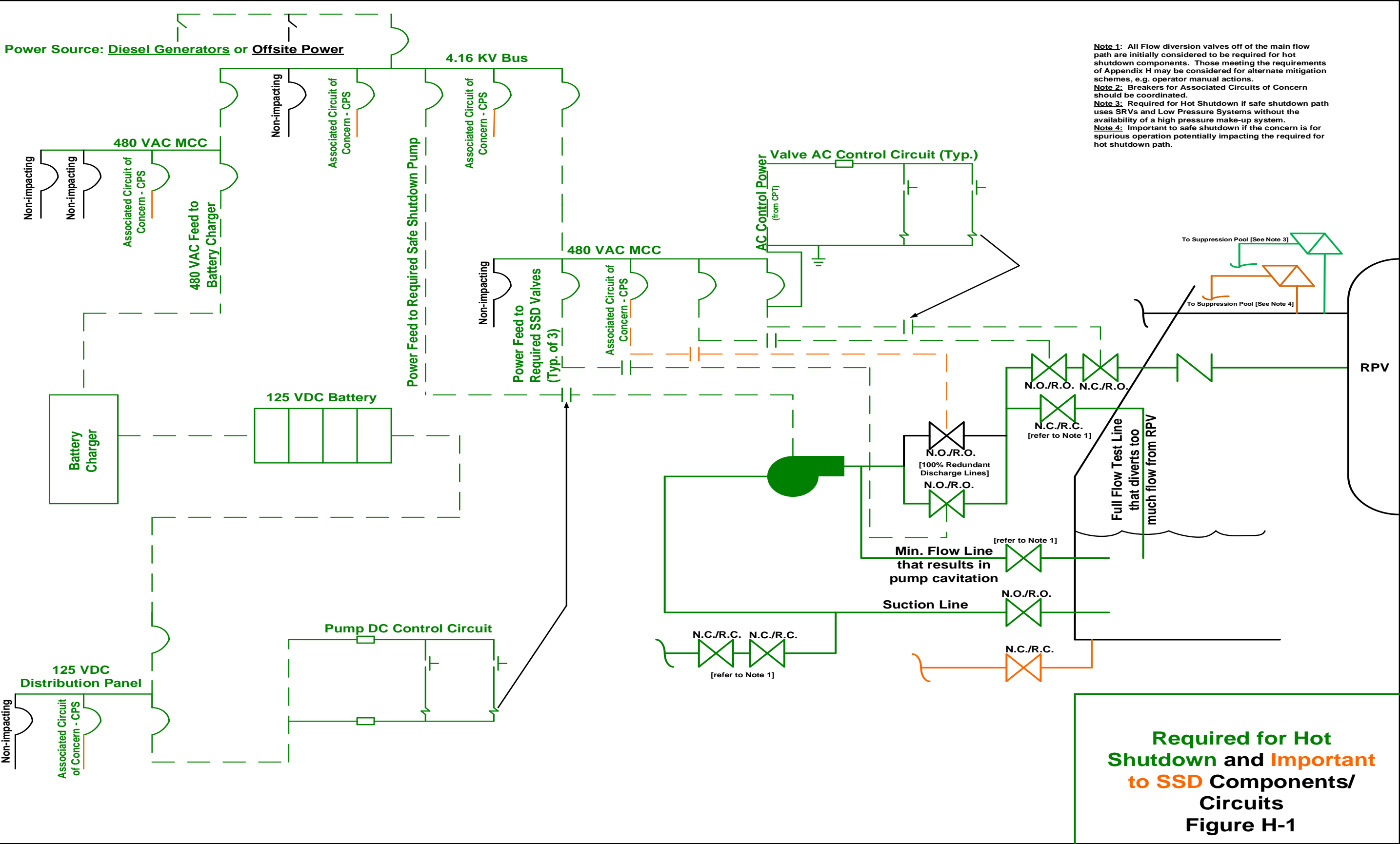
- Either protect as outlined for required safe shutdown components above, or

- Use a feasible and reliable operator manual action with defense-in-depth.
- Use fire modeling analysis with defense-in-depth, or
- Use a fire PRA to justify the acceptability of the condition. A licensing basis change or license amendment may be required to use a focused-scope fire PRA.

Non-Impacting Components:

- No mitigating action beyond the analysis demonstrating that there is no impact to post-fire safe shutdown is required.

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## **APPENDIX I: DESIGN CONSIDERATIONS FOR SHORTING SWITCHES**

### **I.1 Purpose**

Prior to the recent activity related to the Industry's efforts to address Multiple Spurious Operations (MSOs) resulting from fire-induced hot short circuit failures, a limited number of Licensees have used shorting switches to prevent fire-induced spurious operations. To resolve the MSO issues outlined in NEI 00-01, additional Licensees have installed shorting switches primarily on valves to mitigate the effects of hot short induced spurious operation of the valves. Clear technical considerations are needed to assure that Licensees address the design and installation aspects necessary to assure effective implementation of a shorting switch for the specific conditions associated with the application. Diligent use of the shorting switch guidance, with special attention to the application circumstances and conditions, ensures that the design and installation factors are properly considered and will result in effective implementation of shorting switch modifications. The technical considerations included in this document are as follows:

- Section I.3.2 – Circuit design considerations
  - Circuit attributes, (e.g., remotely operated valve; seal-in circuit; automatic operation circuit)
- Section I.3.3 – Electrical design considerations
  - Target coil minimum pick-up voltage
  - Potential credible aggressor sources
  - Computation of maximum expected voltage/current through target coil
- Section I.3.4 – Circuit continuity considerations
  - Cabinet fires
    - Fire spread between electrical enclosures
    - Fire damage to shorting switch and related components
  - Fire-induced open circuits
    - Fire damage
    - Energetic arcing from nearby fire damaged cables
  - Additional mitigating measures
    - Shorting switch with additional redundancy
    - Shorting switch to add time delay for operator manual actions
    - Shorting switch to increase sequential failures leading to a spurious operation

This Appendix identifies the technical considerations for designing valve control circuits that include shorting switches.

Additionally, Section I.3.1 is provided to clarify those licensing considerations that may make NRC approval a required step for certain shorting switch applications, (e.g., fire modeling for required hot shutdown components related to open circuits).

- Section I.3.1 – Licensing Considerations
  - NFPA 805 Plants
  - Deterministic Plants using Appendix R or Standard License Condition
    - III.G.2
      - Required for Hot Shutdown
      - Important to Safe Shutdown
    - III.G.3/III.L

Finally, a Considerations Checklist and an example problem addressing the Considerations Checklist are included at the end of this appendix.

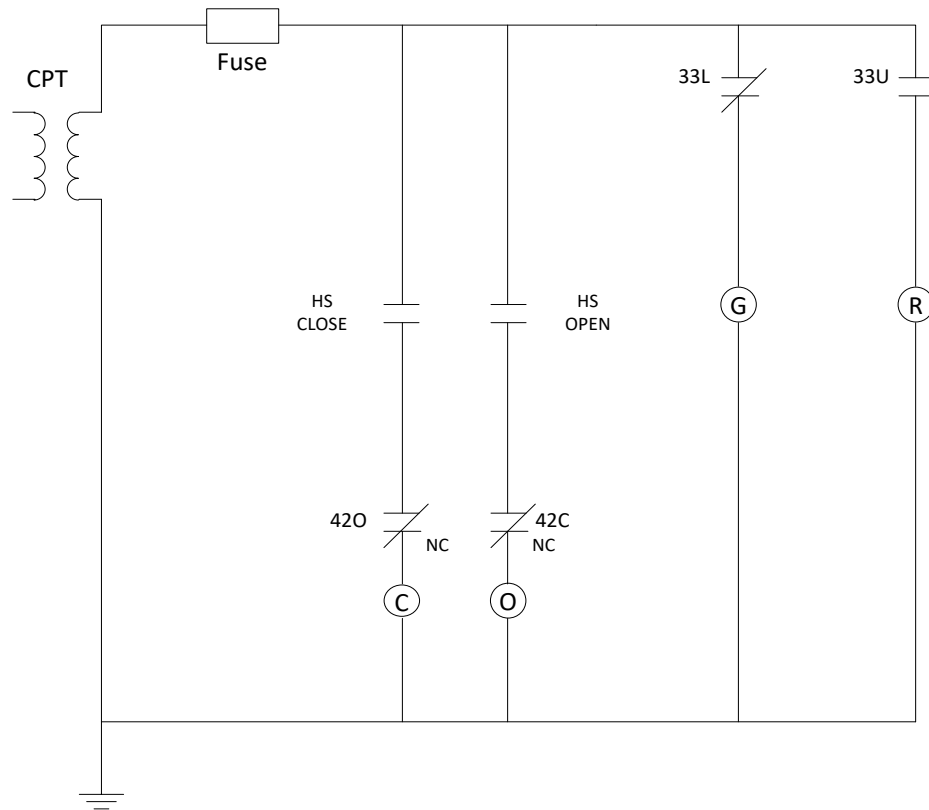
Technical considerations are provided here for the design of circuits containing shorting switches. There are, however, a number of technical factors where specific implementing criteria could not be provided (e.g., circuit continuity for cabinet fires and potential collateral damage from associated circuits contained in the same raceway). The inability to supply specific implementing criteria in these areas is a direct result of the current state of knowledge and the numerous plant configurations and potential exposure conditions present throughout the nuclear power industry.

## **I.2 Background**

The recommended design features of the shorting switch take advantage of recent developments in cable fire testing and cable failure modes research, and provide a design capable of averting fire-induced spurious operation, given credible fire conditions. A licensee's current licensing basis may limit a licensee's ability to use shorting switches without additional licensing actions. For this reason, in this Appendix, the CLB considerations on the use of shorting switches are discussed.

The shorting switch functions to prevent spurious operation of a component by placing a short across a coil in the circuit of concern when the circuit is in its "standby" state. When the component is desired to be operated, the motion of the hand switch removes the short before energizing the coil to actuate the component. Any circuit using a shorting switch should have this feature of removing the short provided by the shorting switch prior to energizing the coil (i.e., break-before-make).

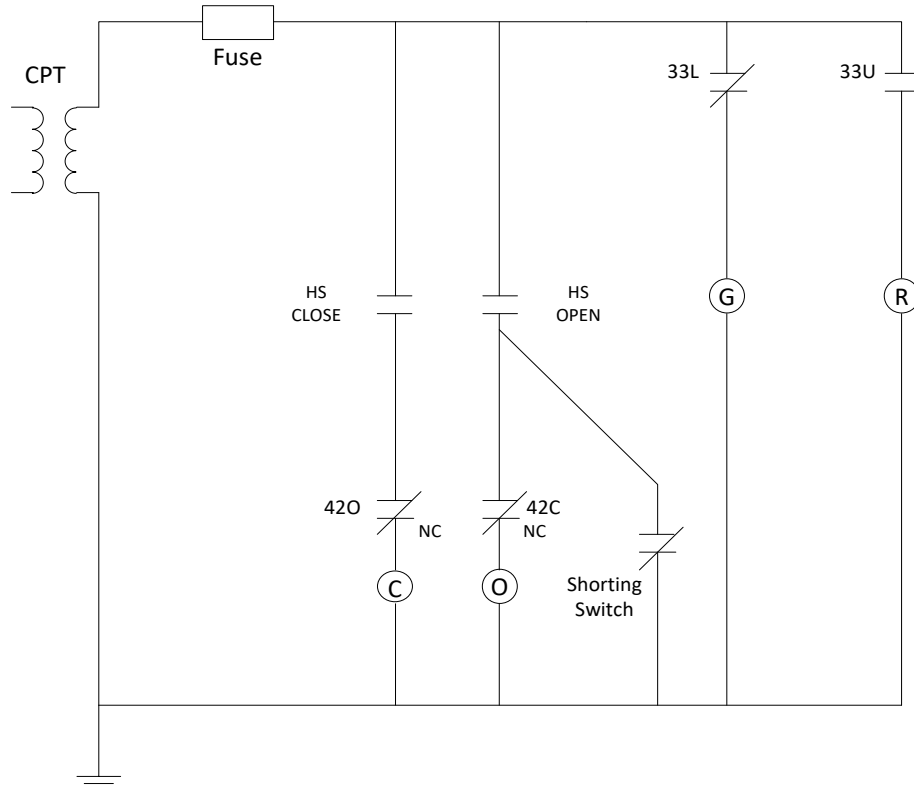
Figure I.1.0 shows a simplified MOV circuit. R and G signify green and red indicator lamps; C and O signify the close and open coils. The circuit is shown with the MOV in the closed position (green lamp lit). If the main control room hand switch (HS) is placed in the open position, the HS open contact will shut causing the open relay to energize resulting in the MOV stroking open. The 33L and 33U contacts (limit switch contacts dependent on valve position), change states with 33U closed (red lamp) and the 33L open (green lamp).



**Figure I.1.0 – Simplified MOV Circuit**

To produce a spurious operation during a fire, a hot short would have to provide power to the close or open relays; therefore, the hot short would need to provide power downstream of either the “HS close” or “HS open” contacts. If the valve was originally in the closed position, a hot short downstream of the HS open contact would cause the valve to reposition open. If the valve were originally in the open position, a hot short, downstream of the HS close contact would cause the valve to reposition closed.

For the safe shutdown analysis, there are desired and undesired valve positions. The concern is that the valve could reposition due to a hot short induced spurious operation during a fire. For the purposes of this discussion, the valve is assumed to be in the closed position, and the goal is to prevent the valve from repositioning to the open position. That is, the valve is initially in the closed position and it is desired to remain in the closed position for the safe shutdown analysis. To accomplish this, the shorting switch is placed in the circuit, so that a hot short downstream of the HS open contact will have no impact on the circuit. See Figure I.2.0 below.



**Figure I.2.0 – Simplified MOV Circuit with Shorting Switch**

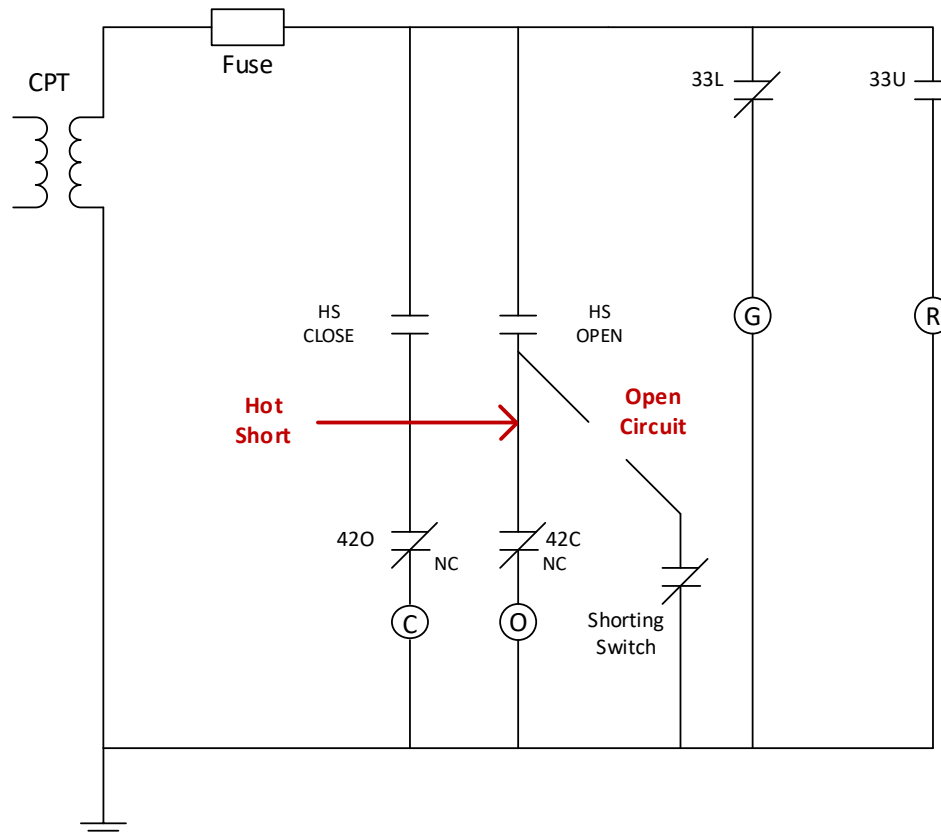
If a hot short occurs between the HS open contact and the open relay coil, the electrical potential will be shorted to ground through the closed shorting switch contact. This action by the shorting switch prevents the valve from repositioning to the undesired, open position. When it is desirable to position the valve in the open position, the operator will manually reposition the shorting switch such that the shorting switch contact will change state from closed to open. The shorting switch itself could be a separate switch, or it could be a third position on the same switch that operates the HS open or HS close contacts. If it is the same switch, then, if it is desirable to open the valve, the operator will simply move the switch from the position that closes the shorting switch contact and place it in the open position.

Another important consideration for the design of the shorting switch is that it should be electrically designed to short the potential from an aggressor<sup>15</sup> circuit away from the target coil, which if energized, could spuriously operate the component.

Finally, as shown in Figure I.3.0 below, the proper functioning of the shorting switch is completely dependent on maintaining the integrity of the shorting switch and other associated components, (e.g., terminal blocks and conductors), necessary to maintain the continuity of the shorting path. An open circuit in the shorting path would eliminate the protection provided by a shorting switch in preventing a spurious operation. Even with the presence of an open circuit, a

<sup>15</sup> The term aggressor circuit is used in this document to represent the circuit with the potential to cause a spurious operation of the target circuit. The term aggressor cable is used to describe a cable of higher voltage or with a larger fuse size with the potential to cause an open circuit, capable of defeating the functionality of the shorting switch, in the target circuit due to common routing or physical proximity.

spurious operation of the component will not occur without the presence of a subsequent hot short.



**Figure I.3.0 – Simplified MOV Circuit with Shorting Switch & Open Circuit**

Therefore, crediting the shorting switch for preventing a fire-induced spurious operation in a location where the shorting switch and other associated components are co-located with the fire, presents an additional challenge due to the potential for fire damage to the shorting switch and other related components required for proper circuit operation. For these conditions, some benefit in mitigating the impact to an overall spurious operation prevention strategy can be gained by including some measure of redundancy and/or time delay into the spurious operation prevention strategy. Redundancy can be gained by using a shorting switch to increase the sequential number of failures necessary for the spurious operation to create a negative impact on post-fire safe shutdown, (i.e., failure of the shorting switch is only one component in the sequence required to fail in order for adverse effects to occur). Additionally, a shorting switch could be used to increase the time until adverse impacts occur thus allowing additional time for an operator action to be performed.

The key to successful implementation of a shorting switch is to assess its use for specific cases and not attempt to implement a “one size fits all” approach. In this way, the number of uncontrolled variables can be reduced to a point that analyses can be conducted to demonstrate expected performance within definable limits. The shorting switch design considerations are discussed in more detail in Section I.3 below

### **I.3 Considerations on the Use of Shorting Switches**

There are a number of considerations that should be addressed in the design of the shorting switch. Each of these considerations is discussed below. Those situations where the shorting switch is used solely as the means of mitigation should be examined very carefully to assure that all of the considerations have been rigorously addressed.

A checklist of these considerations for the licensing and design of a shorting switch and an example application of the these considerations is provided at the end of this appendix.

### **I.3.1 Licensing Considerations**

The effective use of a shorting switch is dependent on maintaining the integrity of the shorting path.

A specifically located and sequenced open circuit could defeat the functioning of the shorting switch, as shown in Figure I.3.0. Therefore, the potential for open circuits needs to be evaluated. This consideration renders the shorting switch modification to be less of a stand-alone modification than most electrical circuit modifications. The shorting switch modification relies heavily on an accompanying technical evaluation performed within the context of the post-fire SSD analysis to ensure that the switch can perform its function. This is largely due to the fact that a specifically located and sequenced open circuit must either not occur or, if one does, it must occur late in the fire event after aggressor circuits (that could cause the undesired hot short-induced spurious operation) have cleared. The licensee should ensure the technical evaluation and evaluation approaches are within the current licensing basis.

As described below, a plant's current licensing basis will affect the extent to which shorting switches may be used.

a. Performance-Based Compliance under National Fire Protection Association (NFPA) 805:

Licensees who have transitioned to performance-based compliance under NFPA 805 for their fire protection program should be able to perform the necessary engineering evaluations using the available performance-based engineering tools (e.g., fire modeling) to assess the impact of credible fire conditions on each of the components in the shorting path and address their potential to cause an open circuit.

b. Deterministic Compliance under Appendix R (or Fire Protection License Condition):

Through Regulatory Guide 1.189 Revision 2, NRC has endorsed the use of fire modeling for components classified as "important to safe shutdown". This endorsement allows the use of the types of engineering evaluations that are needed to assess the impact of credible fire conditions on each of the components in the shorting path and their potential to cause an open circuit. For example, fire modeling could be used to demonstrate:

- fire damage to the shorting switch conductors (or other associated components) is insufficient to cause an open circuit.
- cables/components associated with the shorting switch are not damaged in the same fire scenarios that could also cause the hot-short induced spurious operation.

- mitigating capability for the spurious operation of concern (i.e., if the shorting switch failed and undesired spurious operation were to occur) is unaffected by the fire scenarios that result in loss of the intended function of the shorting switch.

Conversely, Appendix R Section III.G.2 requires consideration of fire-induced open circuits and this requirement would apply to any “required for hot shutdown component”. Additionally, Appendix R Section III.G.2.a through f do not include any allowance for fire-modeling as a means of mitigating the effects of fire-induced circuit failures, including open circuits. As such, strict compliance with the deterministic requirements of Appendix R Section III.G.2 for “required for hot shutdown components” would dictate the inclusion of an open circuit as a design requirement for the shorting switch. A specifically located and sequenced open circuit could defeat the functionality of the shorting switch and render it ineffective in preventing a fire-induced spurious operation. For licensees in this category, the use of a shorting switch for a component classified as “required for hot shutdown” could necessitate an exemption or license amendment.

Finally, deterministic compliance for alternative or dedicated shutdown under Appendix R, Sections III.G.3 and III.L, the classifications of “required for hot shutdown” and “important to safe shutdown” are not applicable. Appendix R, Sections III.G.3 and III.L neither preclude nor endorse the use of the type of engineering tools necessary to perform an engineering evaluation of a shorting switch.

### **I.3.2 Circuit Design Considerations**

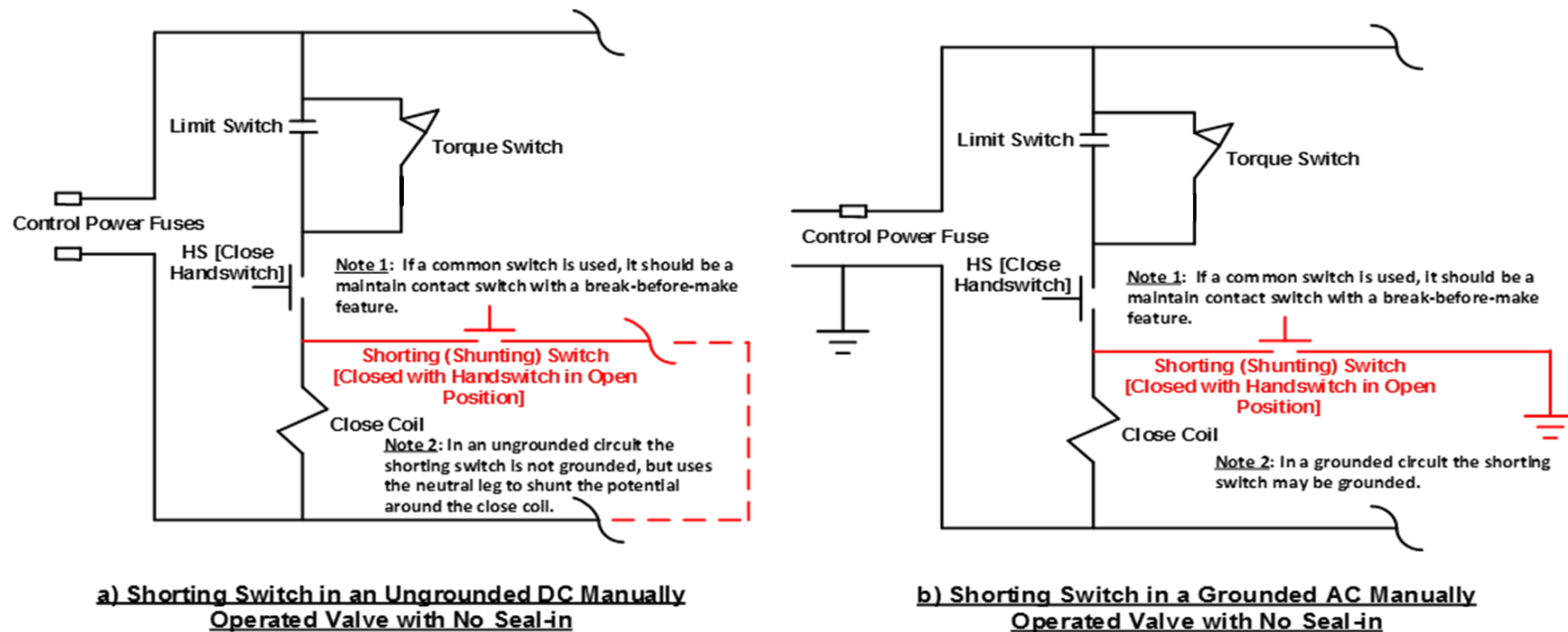
Any circuit using a shorting switch should have a feature of removing the short provided by the shorting switch prior to energizing the coil (i.e., break-before-make). This is necessary in order to prevent the shorting switch from blowing the control power fusing for the circuit and preventing the circuit from being able to perform its required function. This latter consideration is a design and operational consideration as opposed to a fire safety consideration. Regardless, reconfiguration of a circuit for fire safety considerations should also address any design or operational considerations.

For simple circuit designs, such as remotely operated valves, the circuit design and shorting switch should be reviewed to confirm no operational impacts are created. For more complex circuit designs (such as remotely operated valves with seal-in, automatic function, etc.) a more thorough electrical circuit Failure Modes and Effects Analysis (FMEA) should be performed. The FMEA should focus on the operational aspects of the circuit and it should confirm that the addition of the shorting switch into the circuit will not create any unforeseen operational issues, e.g., unanticipated blown fuses or tripped breakers. Figures I.4.0 through I.6.0 present simplified examples to illustrate conceptual approaches for utilizing shorting switches within typical control circuits. More complex designs are possible, but the use of more complex shorting switch designs increases the burden on the designer to confirm that each of the features required for the successful operation of the shorting switch are identified and addressed. Figures I.5.0 and I.6.0 are examples needing an FMEA, if a shorting switch is added.



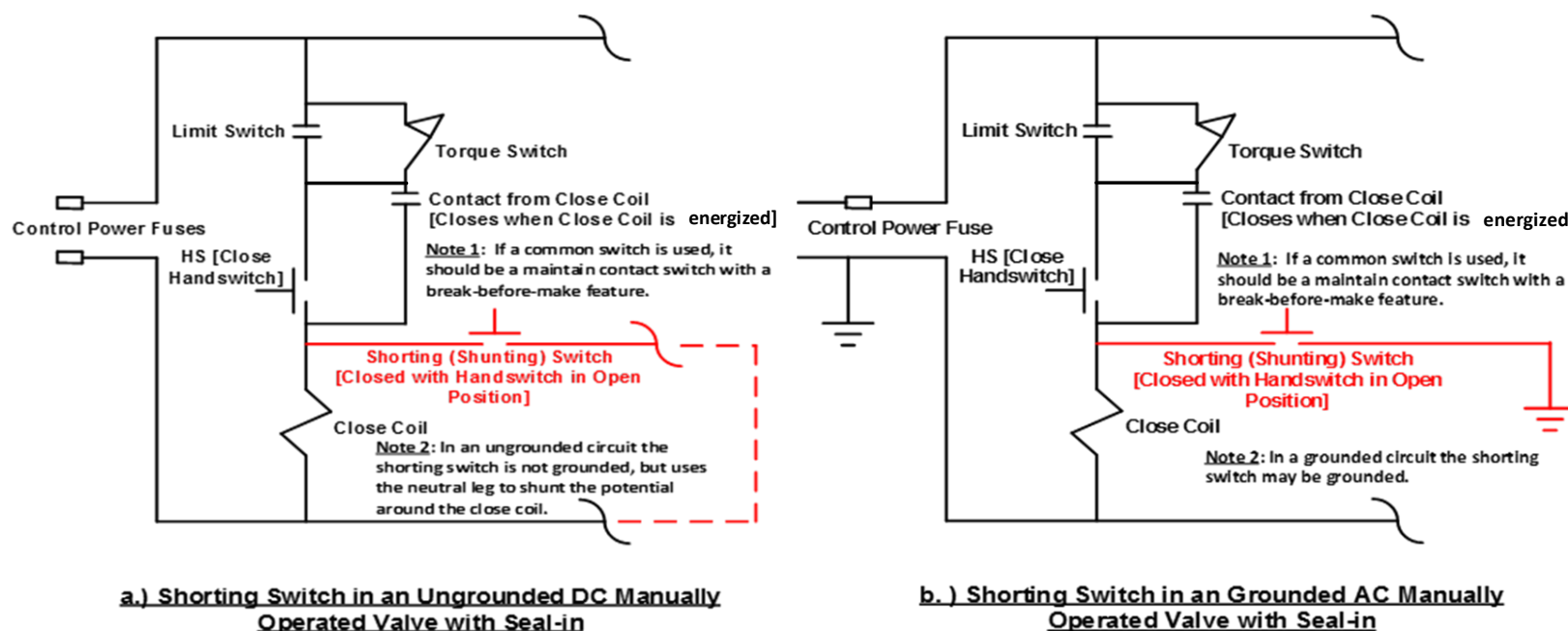


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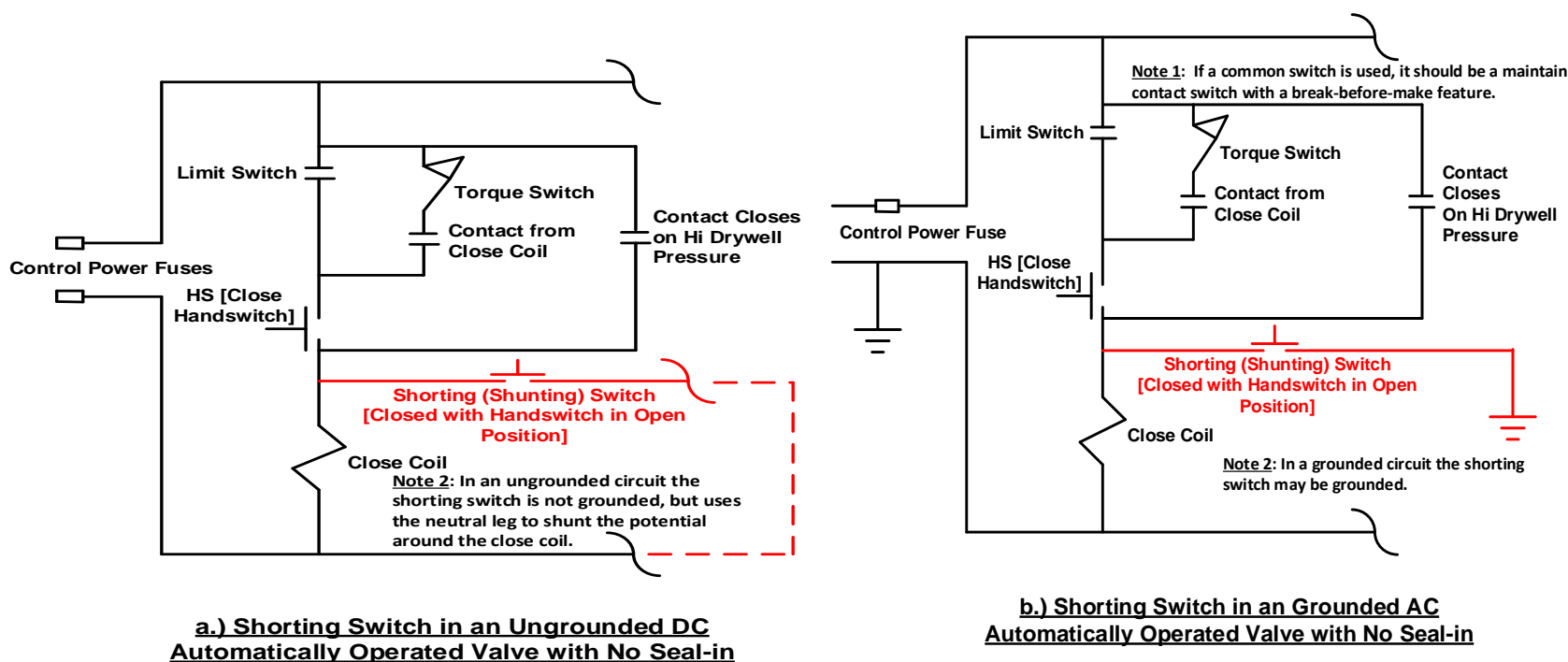
**Figure I.4.0 – Simplified Illustration of Shorting Switch in Control Circuits Without Seal-In Features**

The shorting (shunting) switch in Figure I.4.0 depicts a motor operated valve in a) an ungrounded DC circuit and b) a grounded AC circuit. The valve is normally open and the undesired state is a spurious closure of the valve. The shorting switch for this case would be designed to prevent the valve from spuriously closing by shorting (shunting) the potential applied by an aggressor circuit around the close coil bypassing the impedance (resistance) in the circuit and, thereby, blowing the fuse in either the aggressor (source) circuit (hot leg) or, in the case of the DC circuit, the targeted circuit (return leg). The valve has no automatic operation features that would automatically bypass the manual control switch and it does not have a seal-in around the close switch. If a common control/shorting switch is used, the manual control switch should be a maintain contact switch and it should have a break-before-make switch design to prevent the close switch and the shorting switch contacts on the manual switch from being closed simultaneously.



**Figure I.5.0– Simplified Illustration of Shorting Switch in Control Circuits With Seal-In Features**

The shorting (shunting) switch circuit in Figure I.5.0 is similar to the circuit in Figure I.4.0 with the following exception. The valve has no automatic operation features that would automatically bypass the manual control switch, but it does have a seal-in around the close switch. Even though the manual control switch is a maintain contact switch with a break-before-make switch design to prevent the close switch and the shorting switch contacts on the manual switch from being closed simultaneously, the seal-in feature of this circuit would make it a poor candidate for a shorting switch from an operational point of view, since the circuit control power fuses could be blown should the operator reverse the position of the manual control switch prior to the valve fully completing its stroke to the fully closed position. The use of a shorting switch as depicted above on a circuit like this is not recommended without additional circuit changes and without the development of an FMEA to address the operational consideration mentioned above.



**Figure I.6.0– Simplified Illustration of Shorting Switch in Control Circuits With Automatic Control and Without Seal-In Features**

The shorting (shunting) switch circuit in Figure I.6.0 is similar to the circuit in Figure I.4.0 with the following exception. The valve has an automatic operation feature that would automatically bypass the manual control switch and blow the control power fusing to the circuit. This feature would make this valve an unacceptable candidate for a shorting switch from an operational point of view, unless the circuitry were significantly re-designed to be able to accomplish both features independently. The use of a shorting switch as depicted above on a circuit like this is not recommended without additional circuit changes and without the development of an FMEA to address the operational consideration mentioned

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### I.3.3 Electrical Design Considerations

The installation of a shorting switch into the circuitry for a component does not in and of itself guarantee that the component will not spuriously operate. Depending on the characteristics of the subcomponents within the component's circuitry, spurious operation of the component may or may not be prevented. The characteristics of concern are as follows and each is discussed individually below:

- Minimum pick-up voltage of the coil
- Characterization of Potential Credible Aggressor Sources
- Computation of Maximum Expected Voltage/Current through the Target Coil

a. Minimum pick-up voltage of the coil:

Typically, manufacturers publish a guaranteed pick-up voltage for their coils (contactors). This guaranteed pick-up voltage is the voltage at which the coil will consistently pick-up. When designing a shorting switch, however, the minimum pick-up voltage is the value of concern. The minimum pick-up voltage will not be guaranteed by the manufacturer, but it is a voltage at which the coil is likely to pick-up. In most cases, the coil will pick-up well below the published or guaranteed pick-up voltage, but there may be variability in performance when operating below this guaranteed pickup voltage. In order to design an effective shorting switch circuit, a "minimum pickup" voltage should be determined either through information from the manufacturer or a plant-specific test of the target coil used in the shorting switch application. This will become a critical design attribute for the shorting switch circuit. Given variability in manufacturing tolerances, this may need to be tracked on a per-device basis, or per-product-line basis, and would need to be incorporated into the design basis for that device going forward, so that when component replacements occur, the technical bases for the shorting switch circuit are not invalidated. The minimum pick-up voltage is a parameter used in the computation of the maximum expected voltage/current through the coil calculation discussed below.

b. Characterization of potential credible aggressor source:

A summary of potential aggressor sources is needed to show that the voltage/current through the target coil will not result in pickup. Plant-specific cable segregation design rules for design of the raceway system (power, control, and instrument) may be helpful in screening out certain cabling as being non-credible aggressor sources. Additionally, the contents of the raceways of concern within the specific fire area(s) should be examined to determine the maximum potential aggressor source(s).

Once the potential aggressor sources are determined, the characteristics of the cable protection devices for those sources will need to be determined and bounded. The shorting switch is designed to short or shunt the potential from the aggressor circuit to ground and to, thereby, trip the cable protection devices for the aggressor circuit.

The potential aggressor sources and the bounding characteristics for the cable protection devices for these bounding aggressor sources are used in the computation of the maximum expected voltage/current through the coil discussed below.

The shorting switch prevents the target coil from picking up by shunting the aggressor conductor's voltage through a low-impedance path around the target coil. This low-impedance current flow path in most cases is carried by plant cables and normally-closed control switches or relay contacts. Control switches and relay contacts are typically rated for significant voltages and currents, are required to meet self-extinguishing requirements such as UL-94, Standard for Tests for Flammability of Plastic Materials for Parts in Devices and Applications. Some have been tested to withstand currents well beyond their published rating.

For example, NUREG/CR-4596, Screening Tests of Representative Nuclear Power Plant Components Exposed to Secondary Environments Created by Fires, identifies the potential for AGASTAT relay (EGP, ETR) sockets to deform under extreme high temperature conditions (210°C from NUREG/CR-4596, Figures 12 and 13). Therefore it is recommended that AGASTAT relays not be credited as a shorting switch in scenarios where they may be exposed to internal panel fires. Consideration should also be made for secondary (adjacent) panel fires since air temperatures could exceed 210°C as shown in Figure 30 of NUREG/CR-4527.

Each application using the shorting switch should confirm that the as-installed configuration is (1) capable of carrying the postulated momentary fault current, that may be shunted through the wiring and normally-closed switch/relay contact; and (2) does not result in an unacceptable condition (e.g., wire overheating, switch overheating) such that the shorting function would be disabled.

A voltage interaction of the shorting switch circuits with a higher voltage source should be addressed when a higher voltage source is routed in the same raceway (e.g., conduit, cable tray or wireway) or housed in the same enclosure (e.g., MCC).

The shorting switch prevents the target coil from picking up by shunting the aggressor's voltage through a low impedance path around the target coil. For most control circuits, the effects of shorting the target coil are fairly obvious. In the case of power circuit breaker close coils, the effects are not necessarily obvious. Power circuit breakers have an internal anti-pump scheme that prevents breaker cycling if a close and trip are coincident. Additionally, internal circuitry could lock up if a second close signal comes in after the initial momentary close signal cleared while the breaker springs are still being charged. The nuances of anti-pump circuits are manufacturer and circuit breaker unique. The shorting contact would be applied across the circuit breaker close coil as soon as the control switch is released. These effects of the shorting switch need to be closely scrutinized when there is potential for the shorting switch circuit to be impacted by cabling from a power circuit breaker.

Situations where circuits containing shorting switches are credited as the sole mitigation measure, such as in MCC and DC busses, present difficult challenges related to the impact of 480VAC cables on 120VAC control circuits. With the presence of higher voltage potential aggressor cables, the higher voltage aggressor cable may have sufficient voltage to energize the target coil even with the shorting path remaining fully functional. These interactions of lower voltage circuits in the same cubicles with higher voltage sources could preclude the use of a shorting switch as an effective means of mitigating potential spurious operations.



c. Computation of maximum expected voltage/current through the target coil:

The shorting switch electrical design should show that the electrical circuit with the shorting switch will function as desired, i.e., it will short or shunt the potential from all aggressor cables away from the coil of concern and to ground so that the cable protective devices on the aggressor cable will be tripped. The design should ensure that all components in the circuit will be capable of withstanding the effects of the electrical parameters to which they could be subjected in performing the shorting function.

Each application using the shorting switch should confirm that the as-installed configuration is capable of carrying the postulated momentary fault current that may be shunted through the wiring and normally-closed switch/relay contact without introducing an unacceptable condition (e.g., wire overheating, switch overheating) so severe that the shorting function would be disabled.

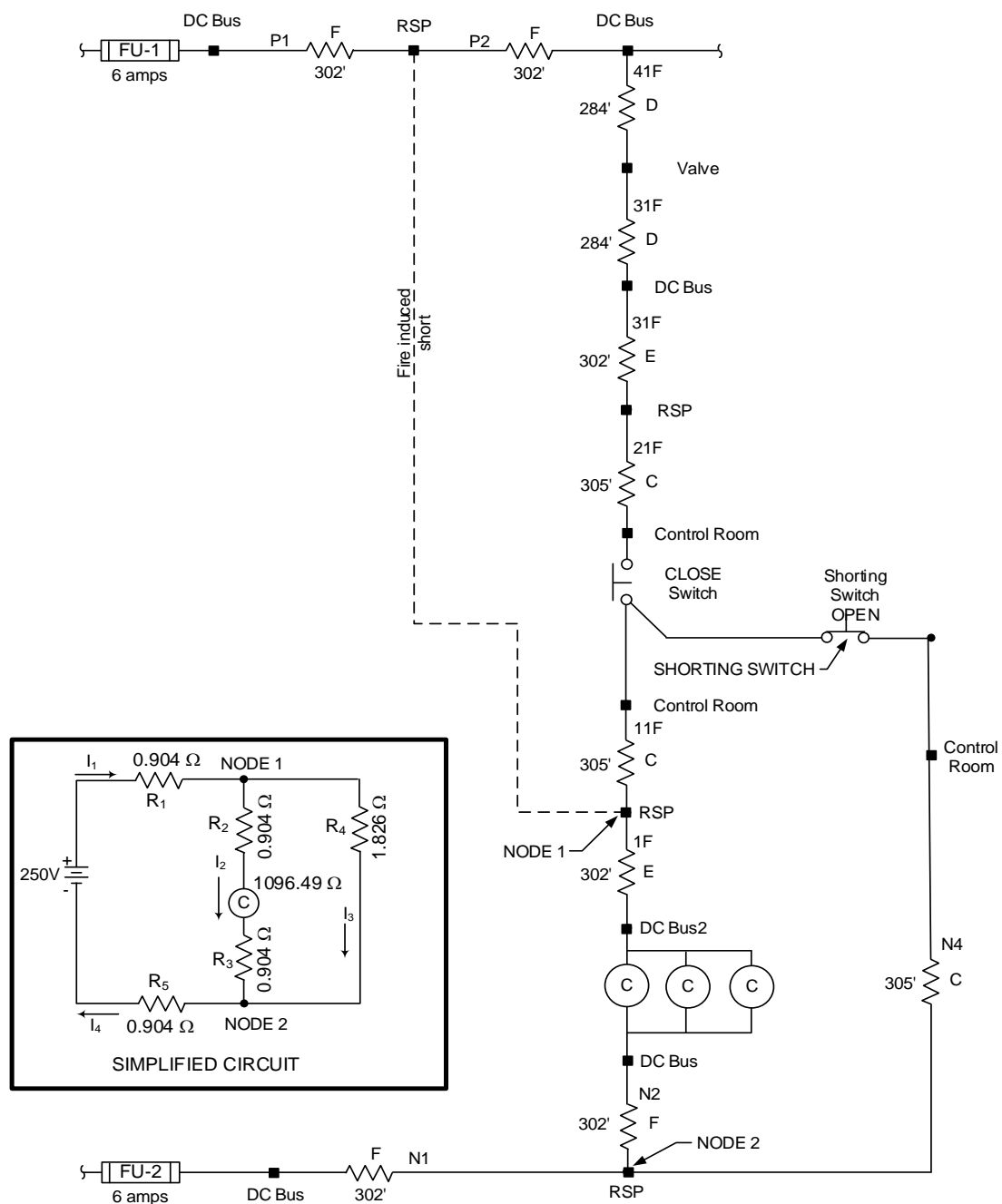
The specific electrical circuit containing the shorting switch should be analyzed with the minimum pick-up voltage for the coil, the bounding aggressor cables and the bounding cable protective device characteristics for the aggressor cables. Figure I.7.0 below provides an illustrative example of how an electrical circuit is modeled.

With all of this information compiled, the discrete locations on the circuit where the aggressor cable could interface with the shorting switch circuit should be identified. Multiple analyses are likely to be necessary to address all of the potential cases.

The analysis attempts to place both ends of the target coil in equilibrium by shorting out the coil. Due to the circuit length of the shorting wire and the resultant voltage drop, however, some voltage may still be impressed on the target coil. Therefore, an application-specific computation is necessary to show the credible voltage sources from aggressor wires, and demonstrate that the resultant voltage/current across the coil is insufficient to pick up the target coil even with the installed shorting switch. In the absence of information to the contrary, this evaluation conservatively assumes that if sufficient voltage reaches the coil to trigger the minimum pick-up voltage, then the pick-up time is less than the time required to trip the cable protective devices on the aggressor cable.

For each case, the voltage and current experienced by each of the components throughout the circuit should be assured to be within the electrical design capability for those components.

This electrical design process may impact control circuit components and conductor sizing of the shorting current flow path. In essence, optimizing the effectiveness of the shorting circuit may impact the final circuit configuration and may require modification beyond simply installing a shorting switch.



**Simplified Circuit  
(Lumped Model)**  
**Figure I.7.0**

### **I.3.4 Circuit Continuity Considerations**

Successful use of the shorting switch is dependent on maintaining the integrity of the shorting switch and other associated components, e.g., control switches, terminal blocks and conductors that are necessary to maintain the continuity of the shorting path.

Therefore, crediting the shorting switch for preventing a fire-induced spurious operation in a location where the shorting switch or other associated components are co-located with the fire, presents additional challenges and considerations. These considerations are discussed in more detail below.

a. Cabinet Fires:

When either the shorting switch or some other critical subcomponent, (e.g., terminal block), of the shorting switch circuit (other than cabling) are credited for fires at the location of the switch/critical subcomponent, the impact of cabinet fires should be considered. The most likely location for these considerations to apply is in the main control room. The following scenarios should be evaluated:

- Fire spread between electrical enclosures
- Fire spread from sources external to the cabinet to within the cabinet
- Fire damage to the shorting switch itself
- Fire damage to any sub-components (e.g., soldered connections, screwed connections, terminations) required for the shorting switch to function.

In such a scenario, the fire is postulated to be at or near the panel containing the shorting switch; thus, the shorting switch, associated panel conductors, terminal blocks, or field cables near the panel are postulated to be susceptible to fire damage. The specific concern for this category is whether or not the fire can result in a failure of the shorting switch via an open circuit.

In addressing main control room electrical fires, realistic fire conditions should be postulated. Recent work related to electrical enclosure heat release rates (HRR) may be useful in determining the characteristics of a realistic fire. For these realistic fire conditions, both flame impingement, as well as panel heat up considerations should be addressed. Flame impingement effects on the shorting switch can cause switch failure and this failure could result in spurious operation. Flame impingement effects on shorting switches and any screwed, crimped or soldered connections at the switch may be mitigated by the use of sheet metal enclosures similar to those used for Regulatory Guide 1.75, Criteria for Independence of Electrical Safety Systems. Even with the use of a sheet metal enclosure, however, electrical enclosure heat up effects must be addressed. The continued performance of shorting switches (and any screwed, crimped or soldered connections at the switch post-fire) can be demonstrated by either fire testing, using realistic fire conditions or engineering analysis. Also, exposure fires within the main control room itself, although not considered to be a likely failure mode, should be assessed to make sure that all potential failure modes have been considered and addressed.

NUREG/CR-4527, An Experimental Investigation of Internally Ignited Fires in Nuclear Power Plant Control Cabinets, described fire testing on both vertically mounted main control room panels and bench-board type panels.

NUREG/CR-4527 concluded the following:

Fires in either bench-board or vertical cabinets with either IEEE-STD 383 qualified cable or unqualified cable can be ignited and propagate. However, fires with IEEE-STD 383 qualified cable do not propagate as rapidly nor to the extent that unqualified cable does. Furthermore, the results showed that the thermal environment in the test enclosure and adjacent cabinets is not severe enough to result in auto-ignition of other combustibles; although in some of the larger fires melting of plastic materials may occur. Essentially, a cabinet fire can propagate within a single cabinet; however, for the conditions tested it does not appear that the fire poses a threat outside the burning cabinet except the resulting smoke.

For cables that do not pass IEEE-STD 383 flame-spread test standard (unqualified cables), cabinet fires are easily ignited and propagate readily, generally resulting in combustion of all combustible materials within the cabinet. It was also demonstrated that even a low-intensity (170W) electrically heated fault point could result in full cabinet involvement for unqualified cables.

For cables that pass the IEEE-STD 383 flame-spread testing standard (qualified cables), self-sustaining fires that resulted in full involvement of the cabinet were somewhat more difficult to induce. However, given the proper circumstances, such a fully involved cabinet fire is possible.

NUREG/CR-4527 concludes by stating:

Ignition, development rate, and spread of a cabinet fire are dependent on ‘critical’ (i.e., just the right combination of variables) ignition sources, in situ fuel type, geometries, and amounts, and on cabinet style and ventilation. These ‘critical’ values are interdependent on many variables and therefore no ‘critical’ values can be identified based on these tests.

The testing in NUREG/CR-4527 also tried to establish if the potential existed for propagating fire and/or fire damage beyond the cabinet of origin. The results of the testing were not conclusive for all configurations; however, the testing did determine that for a panel with a solid steel, double-wall barrier, spontaneous cabinet-to-cabinet spread of fire was considered unlikely. NUREG/CR-4527, however, qualifies its conclusions by stating that this result does not apply to single-wall barriers and barriers susceptible to warping. It states, “Based on the results of these tests, partial or incomplete barriers and unsealed cable penetrations can be expected to allow further spread of fire, given a fully involved cabinet fire.” While NUREG/CR-4527 does not elaborate on the definition of a fully involved cabinet fire, the fires that actually did spread throughout the cabinet during testing all involved unqualified cable. Additionally, the report noted that “the vulnerability of cables in raceways above or below a burning cabinet was also not investigated.”

Based upon the discussion in the report, it can be concluded that a fire inside a panel that consisted of IEEE-STD 383 qualified cable might be able to propagate, but it would require critical ignition sources, in situ fuel type, geometries, and amounts. While these critical parameters cannot be ruled out, it would appear that by the time fire spread outside the panel would occur, the fire would likely be extinguished, or fire spread prevented, by either automatic or manual suppression systems. Because of the heightened flammability of unqualified cable/wiring and the testing results which concluded that unqualified cable will easily ignite and propagate in a cabinet, it is much less clear whether a fire will be contained within the panel.

Each shorting switch application should confirm through engineering analysis/inspection and/or testing that the characteristics of their panels will not allow passage of fire effects to adjacent panels given the range of environmental conditions that could be produced by a credible fire.

The NRC also tested switches to determine any secondary effects of the fire. The results of this testing are contained in NUREG/CR-4596, Screening Tests of Representative Nuclear Power Plant Components Exposed to Secondary Environments Created by Fires. The testing focused on “component survivability in secondary environments created by fires, specifically increased temperatures, increased humidity, and the presence of particulates and corrosive vapors.” This testing concluded that, for a switch, “in no case did the corrosion (produced by fire secondary effects) cause any noted malfunctions.”

These results would appear to indicate that the effects of a fire external to a panel will not result in a failure of the switch to operate. Since these tests were focused on secondary fire effects, however, extrapolation of these results to components located directly in the panel containing the fire would not be accurate for two reasons. First, the conditions in a panel are much more severe than the condition outside of the panel. Second, there is the possibility of flame impingement on the actual switch in the panel which would again produce much more severe results to the component than secondary fire effects.

Shorting switch applications within a cabinet should confirm through engineering analysis/testing that the switch and its associated subcomponents will perform as intended given the range of environmental conditions that could be produced by a credible fire.

Some of the means available to demonstrate the functionality of the shorting switch and its associated subcomponents are as follows. These approaches may be used individually or in combination with each other.

- Fire testing of the switch and associated subcomponents to either industry fire testing standards or specific temperature thresholds, if justified by plant specific fire hazards analysis, which demonstrates that they will survive for the required period of time.
- Qualitative fire hazards analysis, addressing general peak cabinet temperatures and the potential for flame impingement possibly in combination with sheet metal isolation enclosures covering the switch and any crimped or soldered connections, showing that the in-situ combustibles and fire hazards are less severe than the testing, and thus not capable of failing the switch or its associated subcomponents.

- Engineering evaluations that combine the testing and fire hazard analysis approaches described above and that demonstrate the switch functionality for a specific "mission time", after which other strategies will be credited to prevent spurious operation, or after which spurious operation can be tolerated for some other reason.

In the absence of applying the techniques outlined above, assumptions pertaining to damage associated with the switch for the shorting switch modifications should be limited to the conclusions already given by NRC sponsored testing. These results indicate that the switch could be damaged by a fire located within the same panel as the switch. Protecting the switch with a metal isolation similar to those used for RG 1.75 should prevent direct flame impingement damage to the switch. For this case, switch heat-up due to the high temperature environment still needs to be evaluated. The effects on multiple shorting switches located in different panels (e.g., adjacent panels) would be totally dependent upon the type of cables/wiring, the configuration of the panels, and the proximity of the panels to each other.

As a bottom line, assuming that the shorting switch will not be damaged, and will not result in an open circuit/contact, in a main control room fire is not a valid assumption without additional supporting technical justification. Therefore, the use of the shorting switch to prevent spurious operations would have to be limited by one of the following:

1. It would need to be used primarily for spurious operations that occurred outside of the main control room; or
2. If the application is attempting to take credit for the shorting switch during a main control room fire, it would have to be accompanied by a detailed evaluation addressing fire damage and/or by a feasible manual action(s).

The evaluation in number 2 would need to show that a fire in the area of the shorting switch would not adversely impact the shorting switch or any of the components in its circuitry. Fire modeling would most likely play an important part of any such evaluation. In performing any engineering evaluations of the type discussed above, engineers should consider the guidance in NRC Generic Letter 86-10 and Regulatory Guide 1.189 Revision 3, Regulatory Position 5.4.1, for addressing a single worst case spurious operation.

b. Fire-induced open circuits in raceway routing:

Fire-induced open circuits have the potential to defeat the functionality of the shorting switch by creating an open circuit that could effectively remove the shorting switch from the circuit. As such, fire-induced open circuits for conductors comprising the shorting path must be addressed in the design of a shorting switch circuit.

For typical fire conditions, the direct effects of the fire will be to burn off any insulation on the cable/wiring causing the conductor(s) to either lay bare (with no insulation) or be covered by a damaged, charred layer of insulation. In both the NEI/EPRI and CAROLFIRE cable testing programs, this phenomenon was observed and the cable failure progression included either an intra-cable hot short with the potential to cause a spurious operation or a short-to-ground clearing the control power fuse for the circuit. If the intra-cable hot short occurred first, then the fire-induced circuit failure sequence often

rapidly progressed to a short-to-ground which cleared the control power fusing. In a vast majority of the tests conducted under the NEI/EPRI and CAROLFIRE cable testing programs, the testing concluded with a loss of power to the control circuit based on clearing of the control power fusing for the circuit and, as a result, fire-induced open circuits were not observed. Fire-induced circuit failures occurred within the cable with very little interaction with any of the cables surrounding the primary cable. Each of these testing programs, however, included primarily AC circuits with small sized control power fuses and with a sufficient number of conductors within the cable to allow it to progress through the fire-induced circuit failure sequence described above. Circuits with larger sized control power fusing, however, were not included in these testing programs.

Ungrounded DC circuits were tested in the DESIREE-FIRE cable fire testing program. Some of these circuits included larger sized control power fuses. In the DESIREE-FIRE cable testing program, those ungrounded DC control circuits with smaller sized control power fuses, (i.e., 10 amps or less), behaved similarly to the circuits tested under the NEI/EPRI and CAROLFIRE cable testing programs. Those ungrounded DC circuits with the larger sized control power fuses exhibited a different behavior. These ungrounded DC circuits with larger sized control power fuses did not always clear the fusing on both legs of the control power circuit. With either or both legs of the circuit still fused and energized, these circuits, in some cases, exhibited an arcing phenomenon with the potential to damage adjacent cables or cable tray components. In fact, some damage to cable tray rungs in the vicinity of the arcing cable was observed. Open circuits were observed in the DESIREE-FIRE cable testing program. However, fire-induced cable failure resulting in arcing that could cause an open circuit in a nearby cable was not directly observed in the DESIREE-FIRE cable testing program. This phenomenon was not a test objective and not something that was specifically investigated as a part of the DESIREE-FIRE Testing. Therefore, open circuits as a result of energetic arcing of nearby 125 VDC cables with larger sized control power fuses cannot be ruled out.

A recent industry event (references I.5.12, I.5.13) involving AC circuits demonstrated that under selected conditions an arcing cable failure can cause an open circuit in an adjacent cable. During this event, 120 VAC power cables supplying a distribution panel exhibited arcing behavior which resulted in open circuits as found during post-event investigations<sup>16</sup>. Therefore, the working group cannot rule out that an AC circuit with the proper current characteristic and with its cable jacket and insulation degraded could cause damage to nearby cables.

Although no specific cases of these events causing an open circuit as an initial failure mode were observed in the DESIREE-FIRE cable testing program and although there is no specific data available from the industry events, the working group could not rule out the possibility of arcing causing damage to nearby conductors such that an open circuit condition results.

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<sup>16</sup> The 120 VAC Instrument Bus had a full load current of 156A. The feed cables were protected by a General Electric (GE) molded case circuit breaker, type TFJ200, with an adjustable magnetic trip and a fixed thermal (200A long time). The magnetic trip was set one below "Hi", or a 1440 – 1800 Amp band. Arc fault currents were estimated to be in the range of 600A to 700A.

When all of the data from each of the major NRC and Industry cable testing programs and anecdotal evidence from actual fire events is evaluated in aggregate, the following conclusions are reached:

- Fire-induced cable damage initially affects a cable by damaging the jacketing and conductor insulation associated with the cable.
- Absent any damaging effects external to the cable, fire-induced circuit failures, in most cases, will occur first within the cable. In general, if the proper conductors exist within the cable, intra-cable hot shorts and/or shorts to ground will occur.
- For circuits, either grounded or ungrounded, with fuses sized at 10 amps or less, clearing of the fuses as fire damage progresses is likely. The working group judged that circuits fused with fuse sizes up to and including this size do not pose a threat to creating an open circuit in a nearby circuit regardless of whether they are power or control circuits.
- For ungrounded DC circuits with larger sized control power fuses, clearing of the control power fuses may not occur depending on the fault location and available fault current.
  - Isolated legs of ungrounded DC control circuits with larger sized control power fuses where the control power fuse takes longer to clear, or does not clear, have the potential to generate arcing faults, some of which have the potential to damage nearby components (i.e., cables and/or portions of cable trays).
- In AC circuits with voltages as low as 120 VAC where the protection device (e.g., fuse, breaker) does not clear, the potential exists to generate arcing faults, some of which have the potential to damage nearby components, (i.e., cables and/or portions of cable trays).
- Depending on the energy available in the circuits, the failure sequence of the circuits in the fire scenario and the relative location of the circuits fused with larger than 10 amp fuses, open circuiting cannot be ruled out and, as such, must be assumed to have the potential to occur. This open circuit could be from AC or DC circuits with fusing greater than 10 amps in close proximity to the cabling for the shorting switch circuit.

Based on these conclusions, open circuits in control circuits containing shorting switches cannot be generically ruled out. A means of addressing the potential for open circuits in circuits containing shorting switches must be included in the design of the shorting switch circuit.

Open circuit conditions in circuits containing shorting switches routed in or near raceway containing AC or DC circuits with fusing greater than 10 amps can be addressed by either:

- Meeting the electrical separation distances of IEEE STD 384 - 1992, as outlined for any low voltage circuit, either AC or DC, routed near the circuit containing the shorting switch, (See Table 2 of IEEE 384-1992)



- Providing a technically sound engineering evaluation justifying
  - reduced separation distances or
  - the acceptability of the shorting switch design in mitigating the effects of a spurious operation given the potential for nearby cables impacting the shorting switch circuit and causing an open circuit.

IEEE STD 384-1992 gives recommended separation criteria for electrical cabling. This standard has been endorsed by the NRC through Regulatory Guide 1.75. The separation criteria contained in the standard is largely dependent upon both the hazards in the area and the energy level of the potential aggressor cable. For the purpose of this discussion, the primary concern is a fire. The standard defines three hazard classification:

1. Non-hazard area;
2. Limited hazard area;
3. Hazard area.

A hazard area contains highly flammable solids and liquids. Since the flammable materials in the area are the overwhelming concern, cable separation criteria is focused on the effects of the fire on separate 1E redundant divisions. Electrical aggressor cables affected by the fire are not the overriding concern.

The standard defines a limited hazard area as a plant area “from which potential hazards such as missiles, non-electrically induced fires, and pipe failure are excluded.” It also states, “In both a limited hazard area and a non-hazard area, the only energy available to damage electrical circuits is that energy associated with failure or faults internal to electrical equipment or cables within the area. The primary difference between a limited hazard area and a non-hazard area is that power circuits and equipment are restricted in the non-hazard area.” The limited hazard area portion of the standard is the most applicable for this technical evaluation, because the assumption for this discussion is that the fire has occurred, and the effect of concern is the electrically induced damage from an aggressor cable.

The separation criteria for limited hazard areas, containing low-voltage power circuit cabling, are provided in Table 2 of IEEE 384-1992. Use of these distances as the separation distance between the cables containing the conductors for a shorting switch and any low-voltage power cables should limit collateral damage with the potential to cause an open circuit in the shorting switch cable (e.g., cable in one raceway damaged due to arcing of a low-voltage power circuit cable in the same or an adjacent raceway).

c. Additional mitigating measures:

The shorting switch is an engineered solution. Due to the numerous considerations related to the design of a shorting switch circuit, in a particular design, there may be gaps where not all aspects of all of the considerations can be fully met. The use of additional mitigating measures may be beneficial in addressing any gaps.

As discussed above, there are a large number of factors to consider when using a shorting switch to mitigate the effects of a fire-induced spurious operation. Some of these factors present specific challenges for the shorting switch circuit designer, (e.g., cabinet fires, aggressor circuits with higher voltages and larger fuse sizes). Given these challenges and the uncertainties they present, designs to mitigate the effects of fire-induced spurious operation relying solely on a shorting switch are less robust than those that incorporate additional mitigating measures that must also be defeated for the fire-induced spurious operation to occur. Three examples of potential additional mitigating measures that can be used, along with their potential benefits, are discussed below. These additional mitigating measures are not an all-inclusive list. Additionally, they may be used either individually or in combination with each other to enhance their effectiveness.

- Shorting switch with additional redundancy:

Redundancy can be gained by using a shorting switch on multiple components in an MSO scenario, placing the multiple shorting switches in separate locations where damage to each is not likely or even possible due to a single fire. It can also be advantageous to closely examine the specific sequence of failures required for the spurious operation to occur and judiciously employ operator manual actions where time is available.

- Shorting switch as a time delay:

A shorting switch could be used to increase the time until adverse impacts occur, thus allowing additional time for an operator action to be performed. For example, a shorting switch installed in a main control room cabinet that has been evaluated for the effects of realistic fire conditions could be evaluated to show that the shorting switch and its associated circuitry will last for a fixed number of minutes.

If the component protected by the shorting switch can be isolated from the effects of the main control room fire by actuation of the transfer switch at the remote shutdown panel, then this fixed number of minutes may be able to provide sufficient time for the operator to evacuate the main control room, traverse to the remote shutdown panel and isolate the potential for a spurious operation of the component by actuation of the remote shutdown panel transfer switch.

There are similar strategies that could be employed where the increased time afforded by the installation of a shorting switch can be effective in allowing time for an operator to de-power a component or actuate a “kill” switch at a location remote from the main control room and unaffected by the main control room fire.

Finally, for instances where spurious operation of multiple components are required for the adverse consequences of the spurious operation to occur, multiple shorting switches for separate components located in separate cabinets could be used to significantly increase the time available for other mitigating actions to be performed by the operating staff.

- Shorting switch to increase sequencing to spurious operating:

A shorting switch can be used to increase the number of sequential failures necessary for a spurious operation to occur.

For example, the spurious closure of the steam return to the suppression pool valve on a steam driven turbine with the loss of the high back pressure trip for that steam driven turbine is one of the MSO required to be considered for some BWRs based on the list of MSO scenarios in Appendix G to NEI 00-01. For this scenario to occur, circuitry for the steam driven turbine must initially be unaffected by the fire. After the steam driven turbine is up and running, the following sequence of fire-induced failures must occur:

- The circuitry for the high back pressure trip for that steam driven turbine must fail prior to the spurious closure of the steam return to the suppression pool valve on a steam driven turbine.
- The circuitry for the steam return to the suppression pool valve on a steam driven turbine must be subjected to a hot short causing spurious closure of the valve.

By installing a shorting switch in the circuitry for the steam return to the suppression pool valve on a steam driven turbine, the sequence of failures required for the spurious operation can be increased as follows:

- Fire-induced failure of the circuitry for the steam driven turbine must be unaffected by the fire until the steam driven turbine is up and running. [For HPCI, it takes approximately 30 seconds before the shaft driven oil pump takes over and the aux oil pump is no longer required.]
- Fire-induced failure of the circuitry for the steam driven turbine must occur prior to reactor vessel level reaching the high level trip at which point the steam driven system will trip off. [For HPCI, the high level trip will be reached in approximately 3.5 minutes.] This allows a window of approximately 3 minutes for system damage to occur.
- If damage does not occur within the 3 minute window, fire-induced damage must again be deferred until after system restart at reactor vessel low, low level. [Typically, reactor vessel low, low level would not be reached again for approximately 20 minutes. This time frame by itself could allow adequate time for an operator manual action.]
- The circuitry for the high back pressure trip for that steam driven turbine, which is integral with the system re-start circuitry, must fail prior to the spurious closure of the steam return to the suppression pool valve on a steam driven turbine.
- A fire-induced open circuit must be introduced into the shorting switch circuitry at a location that eliminates the effectiveness of the shorting switch. This fire induced failure cannot cause the control power fusing in the shorting switch circuitry (ungrounded 125 VDC) to be lost since a loss of the control power to the shorting switch circuitry will prevent it from completing the spurious operation caused by the subsequent hot short described in the next bullet.

- The circuitry for the steam return to the suppression pool valve on a steam driven turbine must be subjected to a hot short causing spurious closure of the valve and this hot short must be at a location in the circuitry where it is between the fire-induced open circuit and the close coil.

It is clear from the description above that the use of a shorting switch, in this case, makes the likelihood of a spurious operation much more remote.

#### I.4.0 Conclusion

This section contains guidance on the design, use, and implementation of shorting switches to protect against spurious operation. The working group developed supplementary technical information that, in combination with the existing information, provide a comprehensive set of design considerations and recommendations for effective implementation of shorting switch application. Guidance is provided in the areas of circuit design, electrical design, and circuit continuity considerations. A shorting switch considerations checklist has been developed and is included in the first table below. An example application using the checklist is presented in the second table below.

## **I.5 References**

- I.5.1 NRC NUREG/CR-6931 "Cable Response to Live Fire (CAROLFIRE)", April 2008
- I.5.2 NRC NUREG/CR-7100 "Direct Current Electrical Shorting in Response to Exposure Fire (DESIREE-Fire)", April, 2012
- I.5.3 NUREG/CR-4596 [SAND860-394] "Screening Tests of Representative Nuclear Power Plant Components Exposed to Secondary Environments Created by Fires", June 1986
- I.5.4 NUREG/CR-4527 (SAND86-0336) [ADAMS ML06090351] "An Experimental Investigation of Internally Ignited Fires in Nuclear Power Plant Control Cabinets", April 1987
- I.5.5 EPRI TR-106857, Volume 30 "Preventive Maintenance Basis – Volume 30: Relays – Control", July 1998
- I.5.6 NUREG 4596, Screening Tests of Representative Nuclear Power Plant Components Exposed to Secondary Environments Created by Fires, dated June 1986.
- I.5.7 Temperatures in Flames and Fires, Dr. Vytenis Babrauskas, dated February 25, 2006.
- I.5.8 IEEE Std 384-1992, IEEE Standard Criteria for Independence of Class 1E Equipment and Circuits, dated June 18, 1992.
- I.5.9 Regulatory Guide 1.75, Criteria for Independence of Electrical Systems, dated February 2005.
- I.5.10 NRC NUREG/CR-6931 "Cable Response to Live Fire (CAROLFIRE)", April 2008
- I.5.11 NUREG/CR-7150 Volume III and EPRI **3002009214**.
- I.5.12 Licensee Event Report 05000265/2014-002-01, "Cable Tray Fire Caused by Non-Conforming Cable Routing". ML14195A004
- I.5.13 NRC Inspection Report 05000254/2014003; 05000265/2014003. ML14225A200

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Shorting Switch Considerations List			
General Consideration	Specific Consideration	Method(s) for Addressing	Comments
I.3.1 Licensing Considerations	Determine Licensing Basis for Change:		Depending on the Licensing Basis governing the Change, NRC approval may be required.
	- NFPA 805	Use fire modeling to address the potential for an open circuit defeating the functionality of the shorting switch and the impact on risk.	
	- Deterministic		
	- III.G.2		
	- Required for Hot Shutdown	Process a License Amendment Request to obtain NRC endorsement of the use of fire modeling to address the potential for an open circuit defeating the functionality of the shorting switch.	III.G.2 requires consideration of open circuits for required for hot shutdown components.
	- Important to Safe Shutdown	Use fire modeling to address the potential for an open circuit defeating the functionality of the shorting switch.	
	- III.G.3/III.L	Use fire modeling to address the potential for an open circuit defeating the functionality of the shorting switch.	
I.3.2 Circuit Design Considerations	Determine the Valve Circuit Design Type:		Depending on the type of valve circuitry into which the shorting switch is being added, additional analysis may be required to demonstrate that the shorting switch does not introduce any valve operational concerns, (e.g., blown fuses or tripped breakers) as a result automatic valve functions.
	- Remotely Operated Valve	Review the circuit design with the shorting switch to assure that no operational impacts are created.	
	- Remotely Operated Valve with Seal-in	Perform an electrical circuit failure modes and effects analysis to assure that the shorting switch will not impact the valve from an operational perspective.	
	- Remotely Operated Valve with automatic function	Perform an electrical circuit failure modes and effects analysis to assure that the shorting switch will not impact the valve from an operational perspective.	
	- Other valve circuit design	Perform an electrical circuit failure modes and effects analysis to assure that the shorting switch will not impact the valve from an operational perspective.	
I.3.3 Electrical Design Considerations	- Determine target coil minimum pick up voltage	Obtain information from the manufacturer or perform a plant specific test of the target coil used with the shorting switch application.	Minimum pick up voltage is the minimum voltage at which the coil might pick up and not the minimum voltage at which the coil is guaranteed to pick up.

Shorting Switch Considerations List			
General Consideration	Specific Consideration	Method(s) for Addressing	Comments
	- Identify potential aggressor voltage sources	Identify potential voltage sources that could impact the conductors in the shorting switch circuit. Consider cables run in the same raceway and, when appropriate, within the same enclosure, (e.g., Motor Control Center (MCC)).	
	- Determine the maximum voltage through the target coil given the target coil minimum pick up voltage and the voltage associated with bounding aggressor source	Developed a lumped-parameter model of the subject circuit with the shorting switch. Apply the voltage associated with the bounding aggressor source to the lumped-parameter model. Calculate and demonstrate that the target coil will not reach its minimum pick up voltage with the voltage splitting between the shorting switch electrical flow path and the target coil electrical flow path.	Depending on the circuit design and the location of the identified aggressor voltage sources, more than one analytical model case may need to be evaluated. Additionally, aggressor sources from both within and external to the shorting switch cable need to be considered.
I.3.4 Circuit Continuity Considerations	- Assure Cabinet Fires will not defeat the functioning of the shorting switch or any of the components or conductors required for it to function. Consider: <ul style="list-style-type: none"><li>- Fire spread between cabinet compartments</li><li>- Fire spread from sources external to the cabinet to within the cabinet.</li><li>- Fire damage to the shorting switch itself.</li><li>- Fire damage to any sub-components, (e.g., solder connections, screwed connections, terminations), required for the shorting switch to function.</li></ul>	Use available manufacturer’s information on thermal thresholds of the various components potentially affected coupled with fire modeling addressing credible fire sources. Use protective metal enclosures to avoid damage to the switch and its related sub-components from direct flame impingement. Use plant walk downs to assess credible fire sources and sizes and the robustness of any enclosures involved. Perform small scale fire testing to demonstrate the survivability of any affected components.	
	- Assure Fire-induced open circuits will not result in an open circuit in either the shorting path or in the path to the target coil that would defeat the functionality of the shorting switch should an open circuit occur.	Evaluate for the potential for a fire-induced open circuit. Typically, open circuits do not occur as a result of fire damage, with the exception of highly energetic circuits, (i.e., high current carrying AC circuits or ungrounded DC circuits with fuses larger than 10 amps). Either <ul style="list-style-type: none"><li>- Confirm that Electrical Separation Criteria of IEEE 384 is satisfied, or</li></ul>	



Shorting Switch Considerations List			
General Consideration	Specific Consideration	Method(s) for Addressing	Comments
		- Perform a technically sound engineering evaluation justifying a reduced separation criteria for the cables containing the shorting switch.	
	<ul style="list-style-type: none"><li>- Credit the availability of additional mitigating measures in assuring the viability of the shorting switch design.</li><li>- Demonstrate by using redundant shorting switch capability to prevent an MSO that the MSO will not occur, or</li><li>- Demonstrate the survivability of the shorting switch for a period of time that will allow for a successful operator manual action, or</li><li>- Demonstrate that the use of the shorting switch sufficiently increases the number of sequential failures needed to cause he MSO to the point where it effectiveness is assured.</li></ul>	Perform engineering analysis to demonstrate that the shorting switch, when coupled with other aspects of the plant design or the MSO scenario, provides sufficient redundancy to assure the effectiveness of the shorting switch in helping to assure that an MSO is effectively mitigated.	Additional mitigating measures can be used to increase the robustness of a shorting switch design where rigorous adherence to all of the parameters described above may not be possible. They also may be used to increase the robustness and conservatism in the design where full adherence to the parameters described above has already been demonstrated.

## RCIC Steam Return Line Valve Shorting Switch Example

### Illustrative Example:

**Purpose:** The purpose of this example is to show one way in which the information in the Appendix can be used to design a shorting switch. It is not the intent of this example to preclude the use of other approaches or to cast doubt on other approaches used that are based on sound engineering principles.

**Description of example circuit and MSO scenario:** A shorting switch is being added to the reactor core isolation cooling (RCIC) suppression pool steam return line valve to address a postulated MSO scenario in which a spurious closure of the steam return line valve with the RCIC turbine running, if preceded by a loss of the automatic turbine trip logic, could result in a high system back pressure with the potential to open the RCIC system rupture disc and lift the RCIC room blow out panels. In all affected areas, (i.e., reactor building and main control room), the RCIC system is not classified as required for hot shutdown. In the reactor building, the RCIC System is classified as important to safe shutdown due to the potential for the MSO scenario described above. In the main control room, RCIC is used to support post-fire alternative safe shutdown at the remote shutdown panel. In this capacity, it performs as alternate inventory make up function to SRVs and low pressure RHR. With the installation of the shorting switch, the required number of sequential failures necessary for the MSO to occur is increased. Additionally, the circuitry for the shorting switch becomes a redundant protective scheme to the circuitry for the high back pressure RCIC turbine trip. It is only in those locations where circuitry for each of these functions can be impacted by the fire that the MSO has the potential to occur. Even when the circuitry for both of these functions can be affected by a common fire, there is a time sequential relationship between the RCIC valve shorting switch circuitry and the RCIC high back pressure turbine trip circuitry. Where both functions co-exist, an open circuit must occur at the correct location in the shorting switch circuit prior to the hot short occurring in the shorting switch circuitry and this combination of failures must be preceded by a failure of the RCIC high back pressure trip circuitry.

RCIC Steam Return Line Valve Shorting Switch Example			
General Consideration	Specific Consideration	Method(s) for Addressing	Approach used to Address in this Example
I.3.1 Licensing Considerations	Determine Licensing Basis for Change:		
	- NFPA 805	Use fire modeling to address the potential for an open circuit defeating the functionality of the shorting switch.	N/A
	- Deterministic		Yes
	- III.G.2		Yes
	- Required for Hot Shutdown	Process a Licensing Amendment Request to obtain NRC endorsement of the use of fire modeling to address the potential for an open circuit defeating the functionality of the shorting switch.	N/A
	- Important to Safe Shutdown	Use fire modeling to address the potential for an open circuit defeating the functionality of the shorting switch in addition to causing the hot short-induced spurious operation.	The shorting switch in this example is used on a component classified as important to safe shutdown. As such, the design may proceed without prior NRC approval.
	- III.G.3/III.L	Use fire modeling to address the potential for an open circuit defeating the functionality of the shorting switch in addition to causing the hot short-induced spurious operation.	The shorting switch in this examples is used in an area classified as III.G.3/III.L. As such, the design may proceed without prior NRC approval.
I.3.2 Circuit Design Considerations	Determine the Valve Circuit Design Type:		
	- Remotely Operated Valve	Review the circuit design with the shorting switch to assure that no operational impacts are created.	The valves being modified are remote operated valves with no seal-ins or automatic functions. The valve circuitry with the shorting switch has been reviewed and the change creates no adverse operational considerations.
	- Remotely Operated Valve with Seal-in	Perform an electrical circuit failure modes and effects analysis to assure that the shorting switch will not impact the valve from an operational perspective.	N/A
	- Remotely Operated Valve with automatic function	Perform an electrical circuit failure modes and effects analysis to assure that the shorting switch will not impact the valve from an operational perspective.	N/A
	- Other valve circuit design	Perform an electrical circuit failure modes and effects analysis to assure that the shorting switch will not impact the valve from an operational perspective.	N/A

RCIC Steam Return Line Valve Shorting Switch Example			
General Consideration	Specific Consideration	Method(s) for Addressing	Approach used to Address in this Example
I.3.3 Electrical Design Considerations	- Determine target coil minimum pick up voltage	Obtain information from the manufacturer, available industry literature or perform a plant specific test of the target coil used with the shorting switch application.	The required minimum pick up voltage for the target coil was conservatively estimated from manufacturer’s data and available industry literature.
	- Identify potential aggressor voltage sources	Identify potential voltage sources that could impact the conductors in the shorting switch circuit. Consider cables run in the same raceway and, when appropriate, within the same enclosure, (e.g., Motor Control Center (MCC)).	The raceway routing for the shorting switch circuits cables determined that this raceway was routed with 125 VDC or 120 AC circuits only. There are 250 VDC cables in a common raceway above the 250 VDC Bus, but no credit is taken for the shorting switch in this plant area. Therefore, these cables are not included as viable aggressor sources.
	- Determine the maximum voltage through the target coil given the target coil minimum pick up voltage and the voltage associated with bounding aggressor source	Develop a lumped-parameter model of the subject circuit with the shorting switch. Apply the voltage associated with the bounding aggressor source to the lumped-parameter model. Calculate and demonstrate that the target coil will not reach its minimum pick up voltage with the voltage splitting between the shorting switch electrical flow path and the target coil electrical flow path.	An engineering analysis using a lumped parameter model has demonstrated that the maximum aggressor voltage at the worst case circuit location cannot pick up the target coil with the shorting switch functioning properly.
I.3.4 Circuit Continuity Considerations	- Assure Cabinet Fires will not defeat the functioning of the shorting switch or any of the components or conductors required for it to function. Consider: <ul style="list-style-type: none"><li>- Fire spread between cabinet compartments</li><li>- Fire spread from sources external to the cabinet to within the cabinet.</li><li>- Fire damage to the shorting switch itself.</li><li>- Fire damage to any sub-components, (e.g., solder connections, screwed connections, terminations), required for the shorting switch to function.</li></ul>	Use available manufacturer’s information on thermal thresholds of the various components potentially affected coupled with fire modeling addressing credible fire sources. Use protective metal enclosures to avoid damage to the switch and its related sub-components from direct flame impingement. Use plant walk downs to assess credible fire sources and sizes and the robustness of any enclosures involved. Perform small scale fire testing to demonstrate the survivability of any affected components.	An engineering walk down of the Control Room and the Control Room Panel internals housing the RCIC shorting switch has concluded that: <ul style="list-style-type: none"><li>- There are insufficient Control Room combustibles to cause a fire external to the Control Panel with the potential to damage the RCIC shorting switch and it related sub-components.</li><li>- The electrical separation features of the control panel internals is sufficient to prevent a damaging fire from occurring.</li><li>- Fire damage in the sequence required cannot occur prior to the 15 minute time frame required to evacuate the control room and transfer control to the Remote Shutdown Panel.</li></ul>

RCIC Steam Return Line Valve Shorting Switch Example			
General Consideration	Specific Consideration	Method(s) for Addressing	Approach used to Address in this Example
	- Assure Fire-induced open circuits will not result in an open circuit in either the shorting path or in the path to the target coil that would defeat the functionality of the shorting switch should an open circuit occur.	Evaluate for the potential for a fire-induced open circuit. Typically, open circuits do not occur as a result of fire damage, with the exception of highly energetic circuits, (i.e., high current carrying AC circuits or ungrounded DC circuits with fuses larger than 10 amps). Either <ul style="list-style-type: none"><li>- Confirm that Electrical Separation Criteria of IEEE 384 is satisfied, or</li><li>- Perform a technically sound engineering evaluation justifying a reduced separation criteria for the cables containing the shorting switch.</li></ul>	A review of the shorting switch circuit has confirmed that the cable routing for this circuit meets the Electrical Separation Criteria of IEEE 384. Therefore, an open circuit with the potential to defeat the functionality of the shorting switch is not a concern.
	- Credit the availability of additional mitigating measures in assuring the viability of the shorting switch design. <ul style="list-style-type: none"><li>- Demonstrate by using redundant shorting switch capability to prevent an MSO that the MSO will not occur, or</li><li>- Demonstrate the survivability of the shorting switch for a period of time that will allow for a successful operator manual action, or</li><li>- Demonstrate that the use of the shorting switch sufficiently increases the number of sequential failures needed to cause the MSO to the point where its effectiveness is assured.</li></ul>	Perform engineering analysis to demonstrate that the shorting switch, when coupled with other aspects of the plant design or the MSO scenario, provides sufficient redundancy to assure the effectiveness of the shorting switch in helping to assure that an MSO is effectively mitigated.	Additional mitigating measures are credited in two ways in the design of the RCIC shorting switch: <ul style="list-style-type: none"><li>- The design provides adequate delay to allow transfer of the controls for the RCIC Steam Return to the Suppression Pool Valve to the Remote Shutdown Panel for a Control Room Fire, and</li><li>- With the installation of the shorting switch, the required number of sequential failures necessary for the MSO to occur is increased. Additionally, the circuitry for the shorting switch becomes a redundant protective scheme to the circuitry for the high back pressure RCIC Turbine Trip. It is only in those locations where circuitry for each of these functions can be impacted by the fire that the MSO has the potential to occur. Even when the circuitry for both of these functions can be affected by a common fire, there is a time sequential relationship between the RCIC Valve shorting switch circuitry and the RCIC High Back Pressure Turbine Trip Circuitry. Where both functions co-exist, an open circuit must occur at the correct location in the shorting switch circuit prior to the hot short occurring in the shorting switch circuitry and this combination of failures must be preceded by a failure of the RCIC High Back Pressure Trip circuitry.</li></ul>

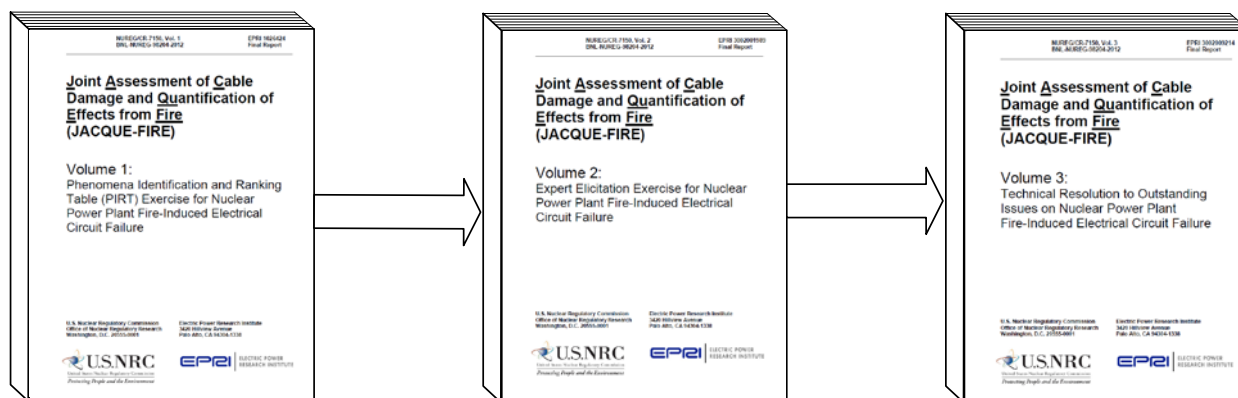
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## APPENDIX J: APPLICATION OF PIRT RESULTS

### J.1 Purpose:

The purpose of this appendix is to provide implementing guidance to the nuclear industry for application of the results presented in Joint Assessment of Cable Damage and Quantification of Effects from Fires (JACQUE-FIRE), NUREG/CR-7150 Volume 1 / EPRI 1026424, “Phenomena Identification and Ranking Table (PIRT) Exercise for Nuclear Power Plant Fire-Induced Electrical Circuit Failure”, Joint Assessment of Cable Damage and Quantification of Effects from Fires (JACQUE-FIRE), NUREG/CR-7150 Volume 2 / EPRI 3002001989, “Expert Elicitation Exercise for Nuclear Power Plant Fire-Induced Electrical Circuit Failure into the evaluation of fire-induced circuit failures in the post-fire safe shutdown analysis” and NUREG/CR-7150 Volume 3, JACQUE-FIRE Volume 3<sup>17</sup>. NUREG/CR-7150 Volume 1 may also be referred to as the “PIRT Report.” The group who prepared the PIRT Report may also be referred to in this appendix as the “PIRT Panel”. NUREG/CR-7150 Volume 2 may also be referred to as the “PRA Expert Panel Report”. The group who prepared the Expert Panel Report may also be referred to in this appendix as the “PRA Expert Panel”. When referred to as a group in this appendix, these two reports may also be referred to as JACQUE-FIRE Volume 1 and 2. The justification for any differences identified in the work by the PIRT Panel and the PRA Expert Panel are reconciled in NUREG/CR-7150 Volume 3, JACQUE-FIRE Volume 3 by the JACQUE-FIRE Volume 3 Working Group.

The documents involved in this process are depicted in Figure J-1 below.



**Figure J-1**

<sup>17</sup> Seven of the eight members of the Working Group for JACQUE-FIRE Volume 3 were members of the PIRT Panel for JACQUE-FIRE Volume 1. Three of these seven members were also part of the PRA Expert Panel Process for JACQUE-FIRE Volume 2.

Included in this appendix is the guidance for:

- determining the revised or new fire-induced circuit failure criteria that apply to conductors for (refer to Tables J-1 and J-2):
  - All “post-fire safe shutdown components”, and
  - The subset of post-fire safe shutdown components classified as “high impact components”<sup>18</sup>.
- determining the “incredible” circuit failure types that do not need to be considered or that, based on the electrical characteristics of the control circuit cannot occur.

Additionally, this appendix determines

- the “high impact” set of components to which more conservative, (i.e., “implausible”), fire-induced circuit failure criteria apply,
  - Refer to Section J.3.1 for the list of “high impact components” to be considered in the post-fire safe shutdown analysis.

The conductors for “high impact components” identified in this appendix are the set of conductors for which assurance is to be provided such that, even if conductors for these components are affected by any of the fire-induced circuit failures classified as “implausible”, there is still an acceptable means of mitigating the effects of the fire-induced failures without affecting the ability to safely shut down in the event of a plant fire. By applying the classification of “high impact” to the conductors for these components, it is assured that the basis for achieving post-fire safe shutdown is not solely based on the low likelihood of certain fire-induced circuit failures.

## **J.2 Background:**

The information in this appendix has been extracted from JACQUE-FIRE Volume 1 and merged with the insights from JACQUE-FIRE Volume 2. Where appropriate, justification addressing any of the differences between JACQUE-FIRE Volumes 1 and 2 has been included in JACQUE-FIRE Volume 3.

JACQUE-FIRE Volume 1 provided input to the PRA Expert Panel who developed hot short induced spurious operation conditional probabilities, as documented in NUREG/CR-7150, Volume 2.

This appendix will provide input, along with the justification in NUREG/CR-7150, Volume 3, for consideration by the NRC’s Office of Nuclear Reactor Regulation (NRR) in revising the existing circuit failure criteria and guidance used in the deterministic post-fire safe shutdown analysis.

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<sup>18</sup> The term “high impact component” was described using the term “high consequence component” in previous drafts of NEI 00-01, Appendix J (e.g., ML13294A606) and in industry meetings. In order to avoid potential confusion with other uses of the term “high consequence” in Fire PRA applications (e.g., NUREG/CR-6850 Vol. 1 Section 2.3.2.1 and Vol. 2 Section 2.5.6), the term has been changed to “high impact component” in NEI 00-01.



The revised circuit failure criteria may have applicability to licensees maintaining compliance under 10 CFR 50, Appendix R (or their fire protection license condition), as well as to licensees transitioning to NFPA 805 under 10 CFR 50.48(c).

As a part of the JACQUE-FIRE Project, the results of recent cable fire testing, conducted to assess the likelihood of hot shorts causing spurious operations, was reviewed in detail. The assessments summarized in JACQUE-FIRE Volumes 1, 2 and 3 supersede the assessments provided in Reference 4, Expert Elicitation Process for the NEI EPRI Cable Fire Testing. The cable fire test data reviewed includes results from:

- EPRI 1003326, “Characterization of Fire-Induced Circuit Faults: Results of Cable Fire Testing,” Electric Power Research Institute, Palo Alto, California, December 2002 (Reference 3),
- NRC NUREG/CR-6931, Vol. 1, “Cable Response to Live Fire (CAROLFIRE) Volume 1: Test Descriptions and Analysis of Circuit Response Data,” April 2008 (Reference 5), and
- NRC NUREG/CR-7100, “Direct Current Electrical Shorting in Response to Exposure Fire (DESIREE-FIRE): Test Result” April 2012 (Reference 8).

The data analysis for the characteristics determined by the PIRT Panel to be of most importance to hot shorts causing spurious operations was analyzed in NUREG-2128 – Electrical Cable Test Results and Analysis During Fire Exposure (ELECTRA-FIRE) (Reference 2). Reference 2 used the test results from References 3, 5 and 8 to determine the actual number of occurrence for each of the circuit characteristics determined by the PIRT Panel to be of importance. The PIRT report used the data analysis from Reference 2 and applied specific circuit failure types to typical circuit designs considered most representative of the circuit designs used throughout the commercial nuclear power industry. This information was used by the PIRT Panel to make determinations as to whether specific circuit failure types were plausible, implausible or incredible. **Note:** The PIRT Report used both “plausible” and “possible” to refer to the same circuit failure types. This appendix uses “plausible” to represent both “plausible” and “possible.”

Section 2.3.1 of JACQUE-FIRE Volume 3 provides the following definitions to aid in classifying the specific circuit failure types reviewed by the PIRT Panel under Volume 1 and the Working Group under Volume 3.

**Incredible** – “The term “incredible” used in conjunction with the phenomenon of a fire-induced circuit failure, signifies the PIRT panel’s conclusion that the event will not occur. In these cases, the PIRT panel could find no evidence of the phenomenon ever occurring, and there were no credible engineering principles or technical arguments to support its happening during a fire.”

Circuit failure types classified as “incredible” do not need to be considered in a deterministic or risk-informed (e.g., Fire PRA, NFPA 805) post-fire safe shutdown analysis. Licensees may use this appendix as the basis for removing consideration of these circuit failure types from their Current Licensing Basis (CLB). Removing these circuit failure types from consideration in a licensee’s CLB was evaluated by the PIRT Panel as having no adverse effect on the ability to achieve and maintain safe shutdown in the event of a fire (i.e., pass the criteria in the standard fire protection license condition for plants that have not transitioned to NFPA 805 under 10 CFR 50.48(c)) using the information in this appendix.

**Implausible** – “The term “implausible” when used in conjunction with a fire-induced circuit failure phenomenon, supports the PIRT Panel’s conclusion that the happening, while theoretically possible, would require the convergence of a combination of factors that are so unlikely to occur that the likelihood of the phenomenon can be considered statistically insignificant. In these cases, the PIRT Panel could find no evidence of the phenomenon ever occurring either in operating experience or during a fire test.”

The term “plausible” used in conjunction with the phenomenon of a fire-induced circuit failure, signifies the PIRT panel’s conclusion that the event will occur given appropriate conditions. In these cases, the PIRT panel finds adequate evidence of the phenomenon occurring during a fire. This classification of the hot short-induced spurious operation failure mode(s) warrants being included in the post-fire safe-shutdown circuit analysis. In the PIRT report these events are termed “possible” in Table 3-3, and represented as “blank” cells in Figures 3-5, 3-6 and 3-7 and Tables 3-6 and 3-7” of the PIRT Report (Ref. 14), as clarified and updated in Appendix B of JACQUE-FIRE Volume 3.

It is the position of the industry that circuit failure types classified as “implausible” in the PIRT Report and in Volume 3 of JACQUE-FIRE Volume 3 only need to be considered in the post-fire safe shutdown evaluation for conductors for “high impact components” since the consequence of the fire-induced failure of conductors for these components is considered significant enough to warrant additional conservatism in the analysis. To support this position, this appendix provides a definition of “high impact components.” Conservatively defining a set of “high impact components” provides assurance that the low likelihood of circuit failures is not the sole means of assuring the ability to achieve and maintain safe shutdown in the event of a plant fire.

Finally, the PIRT Report identified a new plausible fire-induced circuit failure type called a Ground Fault Equivalent Hot Short (GFEHS). This new failure type is described in this appendix.

In Table 3-3 of JACQUE-FIRE Volume 1, the PIRT Panel deferred classification for the double break design with target and aggressor conductors having thermoplastic insulation. The classification of this circuit failure type is addressed in this Appendix in Table J-2. Refer to the Technical Justification for Appendix J in Section 3 of JACQUE-FIRE Volume 3.

With a few exceptions, the PRA Expert Panel used the input from the PIRT Report as a starting point in determining the probability of occurrence of each of the fire-induced circuit failure modes described in JACQUE-FIRE Volume 1. One notable exception was that the PRA Expert Panel removed consideration of the insulation characteristics of the aggressor (i.e., source) conductor because of the difficulty in tracking, in a configuration control program, the insulation characteristics of all possible aggressor (i.e., source) conductors. As a result, many of the specific circuit failure modes identified by the PIRT Panel did not have a specific corresponding probability of failure determined. This made a one-to-one comparison of the conclusions of JACQUE-FIRE Volume 1 and 2 not possible.

Despite this, the insights from JACQUE-FIRE Volume 2 are useful in enhancing the qualitative judgements made by the PIRT Panel in JACQUE-FIRE Volume 1.

The appropriate enhancements have been included into this appendix. Where differences between JACQUE-FIRE Volume 1 and 2 altered the qualitative judgements made in JACQUE-

FIRE Volume 1, the technical justification for the final position(s) provided in this appendix is documented in Section 3 of JACQUE-FIRE Volume 3.

### **J.3 Guidance:**

Provided below is guidance for determining:

- the components in a post-fire safe shutdown analysis that are to be considered as “high impact components”,
- the circuit failure types that need to be evaluated in a post-fire safe shutdown analysis for conductors associated with cables for individual components, and
- the component classifications to which each type of fire-induced circuit failure needs to be applied.

An understanding of the components classified as “high impact components” is crucial to the application of the revised circuit failure criteria, since circuit failures classified as “implausible” must be applied only to conductors for components classified as “high impact”. Incredible circuit failures no longer need to be considered in the post-fire safe shutdown analysis. Plausible circuit failures need to be addressed for all post-fire safe shutdown components.

#### **J.3.1 High Impact Components:**

The JACQUE-FIRE Volume 3 Working Group identified a set of components whose fire-induced failure is significant enough to warrant a more rigorous treatment. This set of components is referred to as “high impact components.” Based on the consensus viewpoints of the Working Group, failure of these components due to fire damage could pose a significant threat to plant safety. As such, the Working Group recommends that the “implausible” circuit failure mode classification be applied to these components. A definition of “implausible” circuit failure modes is provided in Section 2.3.1 of JACQUE-FIRE Volume 3.

The Working Group recommends “high-low pressure interface” components be classified as “high impact components<sup>19</sup>.” Spurious opening of both shutdown cooling suction valves could result in an interfacing system loss of coolant accident (LOCA) outside of containment with no effective mitigating actions available.

The Working Group also recommends that boiling water reactor (BWR) reactor pressure vessel safety relief valves (SRVs) and pressurized water reactor (PWR) pressurizer power operated relief valves (PORVs) be classified as “high impact components.” Spurious opening of relief valves, in combination with the fire-induced failure of reactor vessel makeup capability is considered to be a plant transient with the potential to significantly challenge the plant operations staff and potentially damage the reactor core. As such, more restrictive treatment is warranted for safety relief and power operated relief valves.

Based on the collective judgment of the Working Group, the list of “high impact components” is presented below. This set of components is considered bounding and represent the complete list of components that are recommended to be evaluated for the effects of “implausible” circuit failure modes.

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<sup>19</sup> Appendix C of NEI 00-01, provides a methodology for determination of high-low pressure interface components, when applied in conjunction with Revision 2 of RG 1.189.

As such, the Working Group recommends “implausible” circuit failure modes be applied to circuits for these “high impact components.”

For BWRs:

- Spurious opening of both shutdown cooling suction valves (classified as “high/low pressure interfaces”).
- Spurious opening of multiple reactor pressure vessel SRVs and failure (due to fire damage effects) of a sufficient number of low pressure make-up systems such that the inventory loss is not bounded by design basis accident analysis.

For PWRs:

- Spurious opening of the shutdown cooling suction valves (to SDC/LPSI/RHR); these are the “high/low pressure interface” valves.
- Spurious opening of one or more pressurizer PORVs and failure (due to “fire damage” effects) of their associated block valves to close or remain closed.

### J.3.2 Circuit Failure Considerations:

The PIRT Panel provided technical recommendations on certain aspects of fire-induced circuit failures associated with control and power circuits in the analyses of post-fire safe shutdown circuits for conductors associated with cables for individual components. For the criteria for addressing multiple spurious operations (MSOs), refer to Chapters 3 and 4. The recommendations provided by the PIRT Panel included consideration of the conductor insulation type for both target and aggressor conductors. In developing the probabilities of occurrence for these circuit failure types, the PRA Expert Panel eliminated consideration of the conductor insulation type for the aggressor (i.e., source) conductor. In developing the final positions in this Appendix, the JACQUE-FIRE Volume 3 Working Group also eliminated any consideration for the insulation type on the aggressor conductor. Refer to Section 3 in JACQUE-FIRE Volume 3 for the justification for eliminating consideration of the insulation type on the aggressor (i.e., source) conductor.

The conclusions of the PIRT Panel related to control circuits were reviewed by the PRA Expert Panel. The PRA Expert Panel did not review the conclusions of the PIRT Panel relative to power circuits. The JACQUE-FIRE Volume 3 Working Group reviewed the conclusions from JACQUE-FIRE Volume 1 with enhancements from the insights from the PRA Expert Panel from JACQUE-FIRE Volume 2. The final positions from all of these reviews are summarized below and in Tables J-1 and J-2. Additionally, the thought process behind any changes in classification between JACQUE-FIRE Volumes 1 and 2 are described below and the justification for the final position described below is documented in Section 3 of JACQUE-FIRE Volume 3.

- i. **Power Circuits:** Based on the evaluation of the Industry and NRC Cable Fire Testing by the JACQUE-FIRE Volume 1, 2 and 3 Panels, the following conclusions are reached relative to power circuits.

The following circuit failure types are **incredible** with no exceptions:

- The spurious operation of a three-phase AC motor due to proper polarity hot shorts on three-phase power cabling.
- The spurious operation of DC compound-wound motor due to proper polarity hot shorts in the motive/power cabling.
- The ignition of a secondary fire from an open circuited CT secondary circuit for CT applications up to and including 15kV primary circuit voltage.

The following circuit failure types are **incredible** with the exceptions noted:

- The guidance given in Nuclear Energy Institute, NEI 00-01, Rev. 2, Appendix B.1, can be applied to post-fire safe-shutdown methodologies used for Appendix R Section III.G and III.L, as well as, NFPA 805 for addressing concerns associated with Multiple High Impedance Faults (MHIFs). (**Note:** Appendix B.1 of NEI 00-01, Rev. 2 offers a basis for concluding that MHIFs need not be considered for any circuits damaged by the fire provided the breaker for that circuit is coordinated and provided the breaker has been appropriately tested and is appropriately maintained, as discussed in that Appendix). (Note: See Appendix B.1 for detailed discussion of MHIFs. The discussion in Appendix B.1 is consistent with the NEI 00-01, Rev. 2 discussion referenced in the JACQUE-FIRE documents).
- ii. **Control Circuits:** Based on the evaluation of the Industry and NRC Cable Fire Testing by the JACQUE-FIRE Volume 1, 2 and 3 Panels, the following conclusions are reached relative to Control Circuits.
- a. **Single Break Designed Circuits:** Table J-1 and the descriptions below provide a summary of the conclusions for single break designed circuits.
- i. Intra-cable, inter-cable and ground fault equivalent hot shorts are classified as “plausible” for all cases with the following exceptions:
- [Refer to Section 3 of JACQUE-FIRE Volume 3 for the justification for the change in classification from “implausible” to “plausible” for an inter-cable hot short on thermoset insulated conductors.]
1. Inter-cable hot shorts on grounded metal foil shield wrap and armored cables are classified as “incredible” since the source conductor will be grounded prior to contacting a target conductor. The metal foil shield wrap, however, must be robust, (i.e., it must be of substantial physical characteristics), (e.g., a zinc or copper spirally wound tape), rather than an aluminized mylar overwrap. The shield wrap or the armor prevents a conductor from an external cable from interfacing directly with the target conductor. A GFEHS on the metal foil shield or armor, however, can cause a spurious operation of an ungrounded AC or DC circuit. The plausibility of this phenomenon is addressed in the Column for Ground Fault Equivalent Hot Short in Table J-1.
  2. Inter-cable hot shorts on grounded AC circuits, where the cable has a grounded, uninsulated drain wire, are classified as “implausible” due to the high likelihood of grounding of the source conductor through the grounded, uninsulated drain wire. This classification applies to both thermoset and thermoplastic insulated conductors.

3. The special case referred to in Note c on Table J-1 for the case of ungrounded AC circuit from an individual CPT. Refer to Section 3 of JACQUE-FIRE Volume 3 for the justification for the treatment of ungrounded AC circuits. Typically, an ungrounded AC circuit from an individual CPT will have multiple control cables as a part of the circuit including one (1) cable running from the MCC to the valve and one (1) cable running from the MCC to the Control Room. With this configuration, depending on the routing of the two (2) cables, interactions between the two (2) cables, either an inter-cable hot short or GFEHS, can cause a spurious operation. For the case where the target conductor required for the spurious operation is isolated from any other conductors associated with the CPT powering the circuit, a single inter-cable hot short or a GFEHS cannot cause a spurious operation.

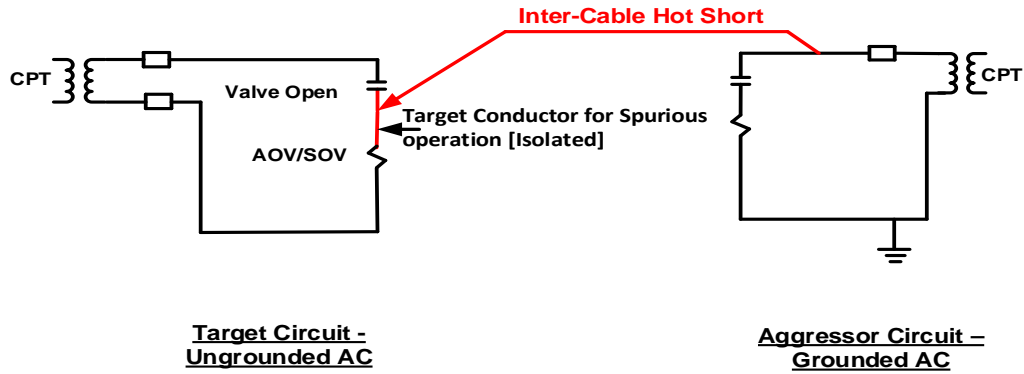
The figures below describe this circuit.

For this special case, a spurious operation cannot be caused by a single inter-cable hot short (or GFEHS) since there is no hot leg conductor from the same CPT with the potential to interact with the target conductor that can be affected by the same fire, refer to Figure J-2.

For a spurious operation to occur, either two (2) inter-cable hot shorts or an inter-cable hot short in combination with a GFEHS from a common power source would be required, refer to Figure J-3.

If the aggressor circuit were a grounded AC circuit, then a spurious operation could occur with one (1) inter-cable hot short and a ground, refer to Figures J-4 and J-5.

This latter combination of fire-induced circuit failures is similar to the types of circuit failures required to cause a spurious operation in a double break designed circuit. Therefore, this special case would be classified as “incredible” for non-latching designs and “implausible” for latching designs, refer to Sections b.v and b.vi below. Also refer to the Section 3 of JACQUE-FIRE Volume 3 for the justification for this classification.

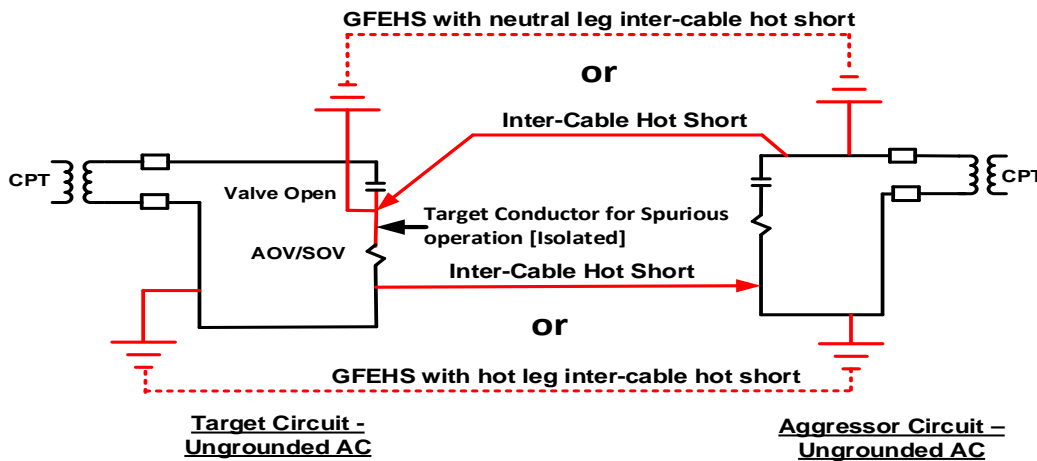


**Possible Spurious Operations:**

1. Spurious Operation not possible since the single inter-cable hot short is from a separate CPT.

## Sub-case 1 – Single Inter-cable Hot short

**Figure J-2**



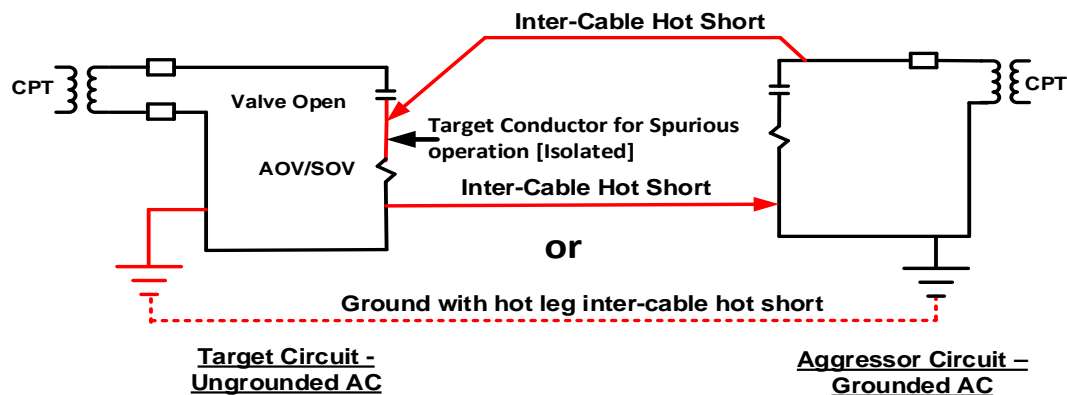
**Possible Spurious Operations:**

1. Two (2) inter-cable hot shorts.
2. One (1) inter-cable hot short (hot leg) and one (1) GFEHS (neutral leg).
3. One (1) inter-cable hot short (neutral leg) and one (1) GFEHS (hot leg).

## Sub-case 2 – Multiple Inter-cable Hot Shorts or Single Inter-cable Hot Short & GFEHS

**Figure J-3**





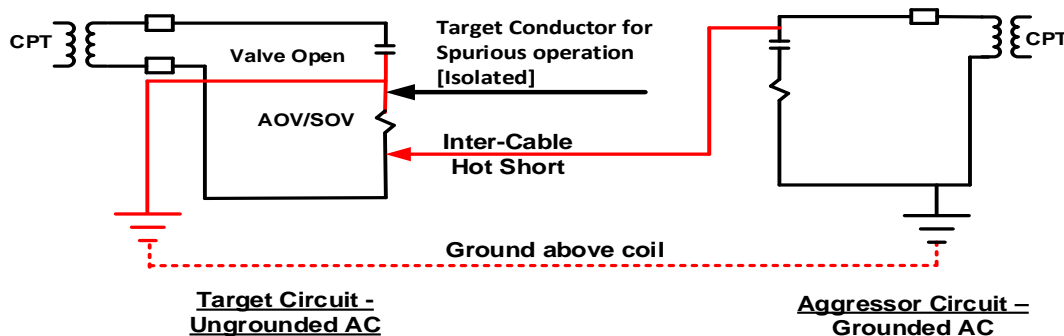
**Possible Spurious Operations:**

1. Two (2) inter-cable hot shorts.
2. One (1) inter-cable hot short (hot leg) and one (1) ground (neutral leg).

## Sub-case 3a – Inter-cable Hot Short & Ground

**Figure**

**J-4**



**Possible Spurious Operations:**

1. One (1) inter-cable hot short (below coil) and one (1) ground (above coil).

## Sub-case 3b - Inter-cable Hot Short & Ground [reverse polarity]

**Figure J-5**

**b. Double Break Designed Circuits:** Table J-2 and the description below provide a summary of the conclusions for double break designed circuits.

- i. All configurations involving two (2) intra-cable hot shorts are classified as “plausible”.
- ii. All configurations involving one (1) intra-cable hot short and one (1) ground equivalent hot short are classified as “plausible”.
- iii. Configurations with thermoset or thermoplastic insulated conductors and involving one (1) inter-cable hot short and one (1) intra-cable hot short are classified as “plausible”.
- iv. All configurations involving an inter-cable hot short on grounded metal foil shield wrap and armored cables are classified as “incredible” since the source conductor will be grounded prior to contacting a target conductor. The metal foil shield wrap, however, must be robust, (i.e., it must be of substantial physical characteristics), (e.g., a zinc or copper spirally wound tape), rather than an aluminized mylar overwrap. For the case of an intra-cable hot short and an inter-cable hot short, the shield wrap or the armor prevents a conductor from an external cable from interfacing directly with the target conductor. A GFEHS on the metal foil shield or armor, however, in combination with the intra-cable hot short, can cause a spurious operation. The plausibility of this case is addressed in the Column for Intra-Cable & Ground Fault Equivalent Hot Short in Table J-2
- v. All configurations involving two (2) inter-cable hot shorts are classified as “incredible”, except for circuit with thermoplastic target conductors. This latter case is classified as “incredible” for non-latching designs and “implausible” for latching designs. [Note: For the case of one thermoplastic target conductor and one thermoset target conductor, the criteria for all thermoplastic target conductors should be used.] Refer to Section 3 of JACQUE-FIRE Volume 3 for the justification for this classification.
  1. Latching designs are defined as component or signal that do not return to their original position (pre-spurious operation) when the fire-induced circuit failure(s) causing the spurious operation terminates. For example, an MOV that is spuriously opened by a hot short will not return to its original position, (e.g., closed), when the aggressor circuit, (e.g., hot short), terminates.
  2. Non-latching designs are defined as component or signal that return to their original position when the fire-induced circuit failure causing the spurious operation terminates. For example,

an SOV or an air operated valve with a pilot solenoid will change position when a hot short energizes the solenoid. When the hot short terminates, the solenoid will de-energize and the affected component will return to its original position.

- vi. Configurations with thermoset or thermoplastic insulated conductors and involving one (1) inter-cable hot short and one (1) ground fault equivalent hot short are classified as “incredible” for non-latching designs and “implausible” for latching designs. For TS and TP insulated conductors, if the aggressor circuit is a grounded AC circuit, an inter-cable hot short and a ground could cause a spurious operation. This configuration has been evaluated in Section 3 of JACQUE-FIRE Volume 3. The evaluation concluded that even for the case of an aggressor grounded AC circuit, the classification would remain as “implausible” for latching circuits and “incredible” for non-latching circuits. Refer to Section 3 of JACQUE-FIRE Volume 3 for the justification for this classification.

#### **J.4 Conclusion:**

The JACQUE-FIRE Volume 3 Working Group has determined the list of components that are to be classified as “high impact” components. This list of “high impact” components is contained in Section J.3.1 of this Appendix and is summarized in Table J-3. Fire-induced circuit failure types classified as “implausible” need to be applied in evaluating fire-induced circuit failure impacts to the circuitry for the subset of post-fire safe shutdown components classified as “high impact” components. Fire-induced circuit failure types classified as “implausible” **only** need to be applied to the control circuitry for any post-fire safe shutdown components classified as “high impact” components.

The JACQUE-FIRE Volume 3 Working Group has also provided the **final position** on the classification, (i.e., incredible, implausible or plausible), for the fire-induced circuit failure types applicable to the post-fire safe shutdown analysis. Tables J-1 and J-2, shown on the next pages, provide a summary of the JACQUE-FIRE Volume 3 Working Group conclusions. The detailed justification for the conclusions provided by the JACQUE-FIRE Volume 3 Working Group in this Appendix are documented in Section 3 of JACQUE-FIRE Volume 3.

The information in this appendix is applicable to conductors for cables associated with individual components. Refer to Chapters 3 and 4 for the criteria applicable to MSO’s

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Single Break Control Circuits					
Power Supply	Grounded AC		Ungrounded AC (from CPT or distributed) or DC		
	Conductor Hot Short Failure Mode				
Target Cable Configuration	Intra-Cable	Inter-Cable	Intra-Cable	Inter-Cable	Ground Fault Equivalent
Thermoset Insulated Conductor Cable	Plausible	Plausible <sup>b</sup>	Plausible	Plausible <sup>c</sup>	Plausible
Thermoplastic Insulated Conductor Cable	Plausible	Plausible <sup>b</sup>	Plausible	Plausible <sup>c</sup>	Plausible
Metal Foil Shield Wrap Cable <sup>a</sup>	Plausible	Incredible	Plausible	Incredible <sup>d</sup>	Plausible
Armored Cable <sup>a</sup>	Plausible	Incredible	Plausible	Incredible <sup>d</sup>	Plausible

**Table J-1**

<sup>a</sup> Robust metal foil shield wraps and armor for all of the cables in this row must be grounded. [Robust metal foil shield wraps must be of substantial physical characteristics (e.g., a zinc or copper spirally wound tape rather than an aluminized mylar overwrap.)]

<sup>b</sup> If the cable has a grounded, uninsulated drain wire, this configuration is classified as “implausible”.

<sup>c</sup> For ungrounded AC from an individual CPT, special considerations could apply depending on the routing, cable conductor configuration and circuit wiring characteristics. The special considerations could change the classification for this case. The special considerations are discussed in Section J.3.2.

<sup>d</sup> The shield wrap or the armor prevents a conductor from an external cable from interfacing directly with the target conductor. A GFEHS on the metal foil shield or armor, however, can cause a spurious operation. The plausibility of this phenomenon is addressed in the Column for Ground Fault Equivalent.

Double Break Control Circuits (includes single break control circuits with control power fuses removed) [Ungrounded AC w/CPTs, Ungrounded DC (Ungrounded AC w/o CPTs)]					
Target Cable Configuration	Intra-Cable & Intra-Cable	Intra-Cable & Inter-Cable	Inter-Cable & Inter-Cable	Intra-Cable & Ground Fault Equivalent	Inter-Cable & Ground Fault Equivalent
Thermoset Insulated Conductor Cable	Plausible	Plausible	Incredible	Plausible	Implausible (latching) <sup>b</sup> Incredible (non-latching)
Thermoplastic Insulated Conductor Cable	Plausible	Plausible	Implausible (latching) Incredible (non-latching)	Plausible	Implausible (latching) <sup>b</sup> Incredible (non-latching)
Metal Foil Shield Wrap Cable <sup>a</sup>	Plausible	Incredible <sup>c</sup>	Incredible	Plausible	Incredible
Armored Cable <sup>a</sup>	Plausible	Incredible <sup>c</sup>	Incredible	Plausible	Incredible

**Table J-2**

<sup>a</sup> Robust metal foil shield wraps and armor for all of the cables in this row must be grounded. [Robust metal foil shield wraps must be of substantial physical characteristics (e.g., a zinc or copper spirally wound tape rather than an aluminized mylar overwrap.)]

<sup>b</sup> For TS and TP insulated conductors, if the aggressor circuit is a grounded AC circuit, an inter-cable hot short and a ground could cause a spurious operation. This configuration has been evaluated in the Technical Justification for Appendix J in NUREG/CR 7150 Volume 3. The evaluation concluded that even for the case of an aggressor grounded AC circuit, the classification would remain as “implausible” for latching circuits and “incredible” for non-latching circuits.

<sup>c</sup> The shield wrap or the armor prevents a conductor from an external cable from interfacing directly with the target conductor. A GFEHS on the metal foil shield or armor, however, can cause a spurious operation. The plausibility of this phenomenon is addressed under the Column for Intra-Cable & Ground Fault Equivalent.

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Table J-3 High Impact Components for BWRs and PWRs					
Component(s)	RCS Inventory Loss	Inventory Loss has potential to damage fuel in less than 1 hour	Containment Bypass (potential radiation release to the atmosphere)	Mitigating Measures Considered [providing adequate mitigating capability]	Comments/Conclusion
BWR – List of Components Evaluated					
1. Shutdown Cooling Suction Containment Isolation Valves	Yes	Yes	Yes	<p>This condition could result in a system interfacing LOCA outside of containment with no acceptable mitigating actions, i.e., unrecoverable.</p> <p>Acceptable mitigating measures include assuring “plausible” and “implausible” circuits failures outlined in Table J-1 and J-2 will not result in an adverse impact to the components.</p>	<p>Since the shutdown cooling containment isolation valves are classified as “high/low pressure interface components” in Appendix C to NEI 00-01, they are also classified as “high impact” components based on the potential significant and immediate consequences of this event.</p> <p>Acceptable mitigating measures include assuring “plausible” and “implausible” circuits failures outlined in Table J-1 and J-2 will not result in an adverse impact to the components.</p>
2. Spurious Opening of Multiple SRVs	Yes	Yes, high pressure steam-driven systems are lost. Low pressure make-up capability could be lost if not protected from the effects of the fire.	No	<p>The availability of low pressure make-up systems can provide adequate mitigating capability for this condition. Additionally, the RCS inventory loss is directed to the Suppression Pool which keeps the inventory within a closed system. Should sufficient low pressure make-up capability not be protected from the effects of the fire and an operator manual action (recovery action) outside of the Control Room be required to inject with the low pressure system, then the use of this approach would not be considered to be acceptable unless the use of this approach were accompanied by a detailed thermal-hydraulic analysis and operator action timing study which demonstrates a high degree of assurance of the success of the operator action, i.e., feasible and reliable. The use of NUREG-1852 provides an acceptable approach for addressing operator action timing considerations.</p>	<p>SRVs are classified as “high impact” components. Should adequate mitigating not be readily available, a significant inventory loss from the RPV could occur uncovering the core in minutes and creating a condition for imminent damage to the fuel. Fire-induced spurious ADS is also considered to be “high impact” if a single signal can cause the initiation of ADS and the loss of the low pressure make-up systems.</p> <p>Acceptable mitigating measures include assuring “plausible” and “implausible” circuits failures outlined in Table J-1 and J-2 will not result in adversely impacting the components or assuring the availability of low pressure make-up systems controllable from the Control Room or, if not controllable from the Control Room, accompanied by thermal hydraulic analysis and operator timing studies that demonstrate any actions outside of the Control Room to be feasible and reliable.</p>



Table J-3 High Impact Components for BWRs and PWRs					
Component(s)	RCS Inventory Loss	Inventory Loss has potential to damage fuel in less than 1 hour	Containment Bypass (potential radiation release to the atmosphere)	Mitigating Measures Considered [providing adequate mitigating capability]	Comments/Conclusion
PWR – List of Evaluated Components					
3. Shutdown Cooling Suction Isolation Valves	Yes	Yes	Yes	<p>This condition could result in a system interfacing LOCA outside of containment with no acceptable mitigating actions, i.e., unrecoverable.</p> <p>Acceptable mitigating measures include assuring “plausible” and “implausible” circuits failures outlined in Table J-1 and J-2 will not result in an adverse impact to the components.</p>	<p>Since the shutdown cooling containment isolation valves are classified as “high/low pressure interface components” in Appendix C to NEI 00-01, they are also classified as “high impact” components based on the potential significant and immediate consequences of this event.</p> <p>Acceptable mitigating measures include assuring “plausible” and “implausible” circuits failures outlined in Table J-1 and J-2 will not result in an adverse impact to the components.</p>
4. PZR PORVs	Yes	Yes, if normal make-up or high head injection is not protected from the effects of the fire.	No, PORV relief is into containment with no radiation release to the atmosphere.	With a stuck open PORV, the time to uncover the core and, subsequent, core damage could be less than one hour even with make-up. In the event of a spuriously opened PORV, closing the PORV or block valve will mitigate the effects of the event. Should PORV or block valve closure be protected from the effects of fire and be available from the Control Room the use of this approach would be considered to be acceptable. Should an operator action outside of the Control Room be required to close the PORV or block valve (e.g., from an MCC or electrical panel), this approach would not be considered to be acceptable, unless the use of this approach were accompanied by a detailed thermal-hydraulic analysis and operator action timing study which demonstrates a high degree of assurance of the success of the operator action. The use of NUREG-1852 provides an acceptable approach for addressing operator action timing considerations.	<p>PORVs are classified as “high impact” components. Should adequate mitigation not be readily available, a significant inventory loss from the RPV could occur uncovering the core in minutes and creating a condition for imminent damage to the fuel.</p> <p>Acceptable mitigating measures include assuring “plausible” and “implausible” circuits failures outlined in Table J-1 and J-2 will not result in adversely impacting the components or assuring the capability of closing the block valve (or PZR PORV) from the Control Room or, if the valve cannot be closed from the Control Room that there is a thermal hydraulic analysis and operator timing studies that demonstrate any actions outside of the Control Room are feasible and reliable.</p>

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