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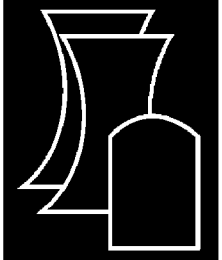

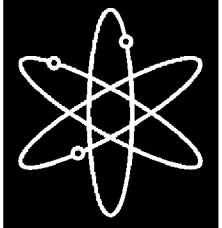

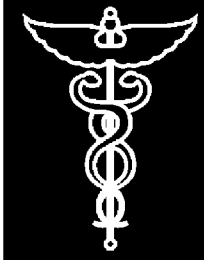

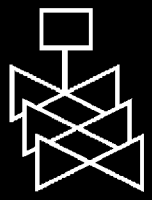

Knowledge Base for Post-Fire Safe-Shutdown Analysis

Draft Report for Comment

U.S. Nuclear Regulatory Commission
Office of Nuclear Reactor Regulation
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NUREG-1778

Knowledge Base for Post-Fire Safe-Shutdown Analysis

Draft Report for Comment

Manuscript Completed: November 2003
Date Published: January 2004

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ABSTRACT

Every operating nuclear power plant is required to have a program that demonstrates the capability to safely shut down and maintain the reactor in the event of a fire. The U.S. Nuclear Regulatory Commission (NRC) initially issued its requirements in the Fire Protection Rule set forth in Title 10, Section 50.48, of the *Code of Federal Regulations* (10 CFR 50.48) and Appendix R to 10 CFR Part 50. The NRC has since issued numerous related generic communications over the past 20 years. The purpose of this document is to facilitate understanding of this technically challenging process and the regulatory framework upon which it is based by compiling all essential information in a single source. This document also lays the groundwork for future risk-informed activities in the post-fire safe-shutdown area.

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Prior to joining the NRC, Mr. Salley was the Corporate Fire Protection Engineer for the Tennessee Valley Authority Nuclear (TVAN) program. There, he was responsible for the overall TVAN Fire Protection and Fire Safe-Shutdown Program. Mr. Salley worked on the restart of Sequoyah Nuclear Plant, Units 1 and 2; Browns Ferry Nuclear Plant, Units 2 and 3; and the completion of construction, licensing, and startup of Watts Bar Nuclear Plant, Unit 1.

Mr. Salley has an extensive background in fire protection engineering, including firefighting, design engineering, fire testing, and analytical analysis. Mr. Salley has authored a number of papers in the area of fire protection engineering.

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ACKNOWLEDGMENTS

This NUREG-series report began as a training tool used in the quarterly workshops that the U.S. Nuclear Regulatory Commission (NRC) sponsors for new regional fire protection inspectors. The technical basis for the workshops was a draft letter report prepared principally by Mr. Kenneth Sullivan of Brookhaven National Laboratory (BNL) under contract to the NRC. In light of the NRC's move toward a more risk-informed, performance-based approach, Mr. Steve Nowlen of Sandia National Laboratories (SNL) contributed insights to the integration of deterministic criteria and risk-informed approaches. The NRC's regional fire protection inspectors and staff from the NRC's Office of Nuclear Reactor Regulation (NRR) provided numerous comments in the training sessions, which were factored into BNL's final draft Revision 1 of the letter report. Naeem Iqbal, a Fire Protection Engineer in the NRR Plant Systems Branch (SPLB) must also be acknowledged for helping to compile this information into a single coherent resource, and for providing peer review.

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EXECUTIVE SUMMARY

As a result of a major fire that occurred at the Browns Ferry Nuclear Power Plant in 1975, the U.S. Nuclear Regulatory Commission (NRC) significantly revised its regulatory framework to enhance fire protection programs (FPPs) at operating nuclear power plants (NPPs). The revised criteria used in this framework had three main objectives to (1) prevent significant fires, (2) ensure the capability to shut down the reactor and maintain it in a safe-shutdown condition, and (3) minimize radioactive releases to the environment in the event of a significant fire.

Recent studies by Sandia National Laboratories (SNL) have shown that the revised criteria are beneficial to safety. Plant design changes required by the new regulatory framework have been effective in preventing a recurrence of a fire event of the severity experienced at Browns Ferry. In addition, according to a 1989 study performed by SNL, plant modifications made in response to the new requirements have reduced the core damage frequencies (CDFs) at some plants by a factor of 10.

The NRC's regulatory framework provides several options for ensuring that structures, systems, and components (SSCs) important to safe shutdown are adequately protected from the effects of fire. Because of the potentially unacceptable consequences that an unmitigated fire may have on plant safety, each operating plant must perform a documented evaluation to demonstrate that, in the event a fire were to initiate and continue to burn (in spite of prevention and mitigation features), the performance of essential shutdown functions will be preserved and radioactive releases to the environment will be minimized. The document that describes this evaluation process and its results is commonly referred to as a "safe-shutdown analysis" (SSA).

Fire protection for NPPs is a complex subject. The purpose of this document is to facilitate understanding of the regulatory framework of the Fire Protection Program by compiling the related knowledge into a single document. This document assumes that the reader has had little or no involvement in the development and/or implementation of fire protection criteria, post-fire safe-shutdown analysis, or any of its related engineering disciplines. The criteria and assumptions described in this document are based on the NRC's regulatory framework for fire protection, as it was in place at the time of this writing. This document only clarifies existing criteria. This document does not contain any new or different staff positions and does not impose any new requirements. The knowledge base documented in this NUREG-series report must be used within the context of the licensing basis of each individual plant and with due consideration for the NRC's Backfit Rule, as specified in Title 10, Section 50.109, of the *Code of Federal Regulations* (10 CFR 50.109).

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ABBREVIATIONS

Φ	Phase
AC	Alternating Current
ACRS	Advisory Committee on Reactor Safeguards (NRC)
ADS	Automatic Depressurization System
AFW	Auxiliary Feedwater
ANS	American Nuclear Society
ANSI	American Nuclear Standards Institute
AOV	Air-Operated Valve
APCSB	Auxiliary and Power Conversion Systems Branch
AWG	American Wire Gauge
B&W	Babcock and Wilcox
BL	Bulletin
BFN	Browns Ferry Nuclear Power Plant
BNL	Brookhaven National Laboratory
BTP	Branch Technical Position
BWR	Boiling-Water Reactor
BWROG	Boiling-Water Reactor Owners Group
CCDF	Conditional Core Damage Frequency
CCDP	Conditional Core Damage Probability
CDF	Core Damage Frequency
CE	Combustion Engineering
CFR	Code of Federal Regulations
CLB	Current Licensing Basis
cm	Centimeter
CMEB	Chemical and Mechanical Engineering Branch
CO_2	Carbon Dioxide
CPT	Control Power Transformer
CRGR	Committee for Review Generic Requirements
CS	Core Spray
CSR	Cable Spreading Room
CSPE	Chlorosulfonated Polyethylene
CST	Condensate Storage Tank
CT	Current Transformer
DC	Direct Current
DHR	Decay Heat Removal
DID	Defense-in-Depth
ECCS	Emergency Core Cooling System
EDG	Emergency Diesel Generator
EDO	Executive Director for Operation (NRC)
EDS	Electrical Distribution System
FHA	Fire Hazard Analysis
FPP	Fire Protection Program
ft	Foot (or Feet)
ft^2	Square Foot (or Square Feet)
EOP	Emergency Operating Procedure
EPRI	Electric Power Research Institute

FSAR	Final Safety Analysis Report
GDC	General Design Criterion
GE	General Electric
GL	Generic Letter
HIF	High-Impedance Fault
HP	Horse Power
HPCI	High-Pressure Coolant Injection
HVAC	Heating, Ventilation, and Air-Conditioning
IEEE	Institute of Electrical and Electronic Engineers
IN	Information Notice
IPEEE	Individual Plant Examination of External Events
IR	Insulation Resistance
kV	kilo-Volts (1,000 Volts)
LCO	Limiting Condition of Operation
LERF	Large-Early Release Frequency
LOCA	Loss-of-Coolant Accident
LOOP	Loss of Offsite Power
LPCI	Low-Pressure Coolant Injection
LPI	Low Pressure Injection
m	Meter(s)
m^2	Square Meter(s)
MCC	Motor Control Center
MCM	One Thousand Circular Mils
MCR	Main Control Room
MHIF	Multiple High Impedance Faults
MOV	Motor-Operated Valve
MSIV	Main Steam Isolation Valve
NEC	National Electrical Code®
NEI	Nuclear Energy Institute
NEMA	National Electrical Manufacturers Association
NFPA	National Fire Protection Association
NPP	Nuclear Power Plant
NRC	U.S. Nuclear Regulatory Commission
NRR	Office of Nuclear Reactor Regulation (NRC)
NSSS	Nuclear Steam Supply System
NUREG	Nuclear Regulatory
OPL	Omega Point Laboratories
P&ID	Piping and Instrument Diagram or Process and Instrument Diagram
Pa	Pascal
PASV	Pressurizer Auxiliary Spray Valve
PE	Polyethylene
PFSSD	Post-Fire Safe-Shutdown
PORV	Power-Operated Relief Valve
PRA	Probabilistic Risk Assessment
PU	Polyurethane
PVC	Polyvinyl Chloride
PWR	Pressurized-Water Reactor
RCIC	Reactor Core Isolation Cooling
RCS	Reactor Coolant System

RES	Office of Nuclear Regulatory Research (NRC)
RG	Regulatory Guide
RHR	Residual Heat Removal
RMS	Root-Mean Square
RSP	Remote Shutdown Panel
RWST	Refueling Water Storage Tank
SDP	Significance Determination Process
SECY	Secretary of the Commission (NRC)
SER	Safety Evaluation Report
SFPE	Society of Fire Protection Engineers
SLCS	Standby Liquid Control Systems
SNL	Sandia National Laboratories
SOV	Solenoid-Operated Valve
SRG	Special Review Group
SRP	Standard Review Plan
SRU	Signal Resistor Unit
SRV	Safety Relief Valve
SSA	Safe Shutdown Analysis
SSC	Structures, Systems, and Components
SSD	Safe Shutdown
SSEL	Safe Shutdown Equipment List
SWGR	Switchgear
TS	Technical Specification
TVA	Tennessee Valley Authority
TVAN	Tennessee Valley Authority Nuclear
V	Voltage
V&V	Verification and Validation
VCT	Volume Control Tank
XLPE	Cross-Linked Polyethylene

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CHAPTER 1. INTRODUCTION

1.1 Background

The fundamental safety objective of the regulatory program established by the U.S. Nuclear Regulatory Commission (NRC) is to ensure adequate protection of public health and safety. This means that the risk to the public from normal operation, anticipated transients, and accidents must be acceptably low, and the likelihood of accidents more severe than those postulated for design purposes must be extremely small. To achieve this goal, the NRC has promulgated regulations, staff positions, and clarification documents, which require that nuclear power plants (NPPs) must be conservatively designed, soundly constructed, and judiciously operated.

An NPP contains an extensive array of systems and components. To achieve a high level of safety, redundant (i.e., identical or diverse) safety systems are incorporated into the design of all NPPs that are currently operating in the United States. Redundancy provides assurance that failures affecting one system will not have a significant impact on plant safety because the plant design provides a "backup" system. The safety benefits of this important design feature could be negated, however, if the redundant systems were both susceptible to failure from a single cause. Fire is one example of such "common-mode" failure mechanisms. In the absence of suitable protection features and/or separation distances, a single fire could render redundant safety systems inoperable. In addition to a total loss of equipment function, lessons learned from actual fire events and cable fire test programs have shown that fire damage to power, control, and instrumentation circuits and cables may cause equipment to operate in undesired and frequently unexpected ways. Specific examples include spurious (unintended) equipment operations in the form of maloperations (failure to start/stop/actuate, inadvertent start/stop/actuation, etc.), false instrument signals, misleading indications, and loss of normal equipment control methods.

On March 22, 1975, the Brown's Ferry Nuclear Power Plant (BFN), operated by the Tennessee Valley Authority (TVA), experienced the worst fire (from a nuclear safety perspective), ever to occur in a commercial NPP operating in the United States. Although the licensee ultimately achieved safe-shutdown of the reactor, the event highlighted significant inadequacies in the fire protection programs (FPPs) established by the plants that were operating at that time. As a result of lessons learned from the Browns Ferry fire, the NRC issued new requirements and guidance, which significantly enhanced the FPPs (personnel, procedures, equipment, and plant design features) of NPPs. The revised program had three main objectives to (1) prevent significant fires, (2) ensure the capability to shut down the reactor and maintain it in a safe-shutdown condition, and (3) minimize radioactive releases to the environment in the event of a significant fire. Implementation of these three objectives satisfies the defense-in-depth (DID) approach as it applies to fire safety.

The NRC's regulatory framework for nuclear power plant FPPs is set forth in a number of regulations and supporting guidelines, including, but not limited to the following:

- Title 10, Section 50.48, of the *Code of Federal Regulations* (10 CFR 50.48)
- Appendix R to 10 CFR Part 50
- General Design Criterion 3 (GDC 3) of Appendix A to 10 CFR Part 50
- regulatory guides (RGs)
- generic communications [e.g., generic letters (GLs), bulletins (BLs), and information notices (INs)]
- NUREG-series technical reports, including NUREG-0800, "NRC Standard Review Plan" (SRP)
- associated branch technical positions (BTPs) and industry standards

The principal objective of this regulatory framework is to provide assurance that a fire will not significantly increase the risk of radioactive releases to the environment. The NRC's regulatory framework does not provide specific guidance for protection against economic or property loss.

The need to evaluate the effects of fire on circuits associated with the safe-shutdown systems was not explicitly stated in Appendix A to the Auxiliary and Power Conversion Systems Branch (APCSB) BTP 9.5-1. However, it is explicitly required in Appendix R to 10 CFR Part 50.[1] A commercial NPP contains a very large number of power, control, and instrument cables. A typical boiling-water reactor (BWR) requires approximately 60 miles of power cable, 50 miles of control cable and 250 miles of instrument cable. The fire at BFN damaged more than 1,600 cables, even though the fire was confined to a relatively small area of the plant (approximately 800 ft^2). While a single fire could affect a large number of cables, damage to many of these cables will have little or no impact on the operation of plant systems needed to achieve and maintain safe-shutdown conditions. Therefore, the NRC is concerned with those circuits and cables for which damage attributable to fire could impact the shutdown capability.

Specifically, these "circuits and cables of concern" to the NRC are as follows:

(1) circuits/cables needed to ensure the proper operation of *essential* shutdown systems and equipment (*"required circuits"*)

(2) circuits/cables associated with nonessential systems and equipment for which failure or maloperation resulting from a fire could impact the shutdown capability (*"associated circuits"* [2]).

Because circuits and cables of required shutdown systems (i.e., required circuits) frequently share certain physical or electrical configurations with cables of nonessential systems and equipment (i.e., associated circuits) fire damage to certain associated (nonsafety) circuits could impact the shutdown capability. Section III.G.2 of Appendix R to 10 CFR Part 50 provides various options for protecting circuits of concern (both required and associated) for post-fire safe-shutdown. Specifically, this section of the regulation reads as follows:

> *Where cables or equipment, including associated nonsafety circuits that could prevent operation or cause maloperation...of redundant trains of systems necessary to achieve and maintain hot shutdown conditions are located within the same fire area… one of the following means of ensuring that one of the redundant trains is free of fire damage shall be provided…*

Compliance with this requirement could be interpreted to mean, for example, that for each fire area, the specified fire protection features must (shall) be provided for *all* circuits and cables for which damage attributable to fire could impact the capability to achieve and maintain hot shutdown conditions. In its clarification of GL 81-12, the NRC defined "associated circuits" of concern. In addition, this clarification permitted the use of detailed circuit analyses as a means of demonstrating that fire damage to these nonessential circuits would not significantly impact the ability to achieve and maintain hot shutdown conditions. It should be noted that the use of circuit analysis in lieu of fire protection features is only permitted in the evaluation of fire damage to "associated circuits" (as defined in GL 81-12).

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[1] SECY-80-438A, "Commission Approval of the Final Rule on Fire Protection Program," September 30,1980.

[2] For the purpose of this NUREG-series report, the term "associated circuits" is understood to be the "associated circuits of concern.

Circuits of equipment for which proper operation is needed to ensure the successful accomplishment of required hot shutdown functions (required circuits) must be provided with fire protection features sufficient to satisfy Section III.G.2 of Appendix R to 10 CFR Part 50 if damage to those circuits could adversely impact the desired operation of that equipment. The NRC has permitted the use of feasible manual actions under certain conditions, and rulemaking is underway to codify this alternative.

Therefore, it is not sufficient to consider only the effects of fire damage to cables of equipment needed to ensure operation of required shutdown systems and equipment (required circuits). Rather, the scope of the evaluation must also include consideration of the effects of fire damage to nonessential equipment and systems whose failure or inadvertent actuation could impact the shutdown capability (associated circuits of concern).

1.2 Purpose

To demonstrate compliance with the Fire Protection Rule (10 CFR 50.48) all operating plants have performed a deterministic evaluation of the capability to safely shut down the reactor in the event of fire. The purpose of this document is to facilitate understanding of this technically challenging process and the regulatory framework upon which it is based. This document assumes that the reader has had little or no involvement the development and/or implementation of fire protection criteria, post-fire safe-shutdown analysis, or related engineering disciplines. Explanatory text and/or graphic illustrations are used wherever practical.

It should be noted that this document describes only one possible approach for performing a deterministic assessment of the potential impact of fire on the ability to achieve and maintain safe-shutdown conditions. There are many acceptable methods of performing this type of analysis, and the NRC does not prescribe or endorse any one specific approach. This report does not discuss other important aspects of a comprehensive FPP, such as fire prevention measures, fire detection, or suppression systems. The criteria and assumptions described in this document are based on the NRC's regulatory framework for fire protection as it was in place at the time of this writing. This document only clarifies existing criteria. It does not contain any new or different staff positions or impose any new requirements. The information presented in this report must be used within the context of the licensing basis of each individual plant and with due consideration for the NRC's Backfit Rule, as specified in 10 CFR 50.109.

1.3 Document Summary

- Chapter 2, "Terminology," provides consistent interpretations of terms and phrases that may be encountered during the development or review of post-fire safe-shutdown analysis.

- Chapter 3, "Background Information and Experience Related to Fire-Induced Circuit Failures," provides fundamental design information to facilitate understanding of circuits and cables used in NPPs. In addition to describing the principal aspects of their design, construction, and application, this chapter discusses such topics as design and operational factors that influence cable selection, potential failure modes of circuits and cables, and the mechanisms (stressors) that can cause their failure. To illustrate the potential consequences that circuit and cable failures may have on plant operations, this technical discourse is followed by a chronicle of the impact that fire-induced cable and circuit failures had on the operation

of redundant trains of safety systems during the Browns Ferry fire, as well as observations of various experts who participated in a recent cable fire test program sponsored by the Nuclear Energy Institute (NEI) and Electric Power Research Institute (EPRI).

- Chapter 4, "NRC Regulatory Requirements," provides a brief history of the development of fire protection regulations and guidelines governing the U.S. commercial nuclear power industry. In addition, this chapter presents a comprehensive discussion of requirements, guidelines, and staff positions that are specifically applicable to the performance of a deterministic analysis of post-fire safe-shutdown capability.

- Chapter 5, "Discussion of Post-Fire Safe-Shutdown Capability," describes the primary objectives of a comprehensive deterministic evaluation of the effects of fire damage, the qualitative hierarchy of fire damage limits, an overview of the evaluation process used to assess the potential effects of fire and its related perils on plant safety, the fundamental principles and assumptions that establish the "ground rules" for performing an appropriate evaluation, and a discussion of specific issues to be considered in the evaluation.

- Chapter 6, "Deterministic Analysis Process for Appendix R Compliance," describes the fundamental principals, assumptions, and criteria of a deterministic analysis for demonstrating compliance with regulatory requirements. In addition to defining the principal criteria and assumptions that form the basis of the analysis, this chapter presents a step-by-step description of a safe-shutdown analysis process.

- Chapter 7, "Maintaining Compliance," describes the impact that plant modifications may have on the plant's post-fire safe-shutdown capability and the administrative controls (procedures) that are typically needed to prevent future modifications from jeopardizing long-term compliance with the plant's fire protection licensing basis.

- Chapter 8, "Integration of Deterministic Criteria and Risk-Informed Information," provides risk-informed perspectives on post-fire safe-shutdown circuit analysis issues. This chapter was developed specifically to give staff responsible for plant inspection activities a general understanding of the fire risk analysis process and insights into the risk significance of fire-related circuit analysis issues.

- Appendix A, "Examples of Successful Implementation," describes various options available to resolve identified circuit/cable vulnerabilities. This discussion is supplemented by specific "real-world" examples to show how various licensees have successfully identified and appropriately resolved circuit/cable vulnerabilities.

- Appendix B, "Specific Circuit Analysis Issues," describes the NRC's expectations regarding certain specific circuit analysis issues that have been the subject of much recent debate. Specific topics discussed in this section include multiple spurious actuations, fire damage to nonessential systems, and multiple circuit faults. As in Appendix A, this appendix describes staff expectations in terms of "real world"examples of technical issues that the NRC staff identified during the reviews of SSAs developed by various licensees.

CHAPTER 2. TERMINOLOGY

The NRC developed the following definitions as an aid to ensuring consistent interpretations of terms that are commonly used in post-fire safe-shutdown analyses. To the extent practical, the staff derived these definitions from established fire protection guidance documents promulgated by the NRC (RGs, GLs, and INs) and industry-recognized standards including the Institute for Electrical and Electronics Engineers (IEEE) Standard 100, "IEEE Standard Dictionary of Electrical and Electronics Terms," and IEEE Standard 242, "IEEE Recommended Practice for Protection and Coordination of Industrial and Commercial Power Systems." In an effort to further minimize ambiguity, certain terms are supplemented with additional discussion, notes, graphic illustrations, and/or examples.

Actuated Equipment
The assembly of prime movers and driven equipment used to accomplish a protective action. (IEEE Std. 100-1988)

Actuation Device
A component or assembly of components that directly controls the motive power (electricity, compressed air, etc.) for actuated equipment. Examples of actuation devices include a circuit breaker, a relay, and a pilot valve used to control compressed air to the operator of a containment isolation valve. (IEEE Std. 100-1988)

Actuation
A change in position or operating state of a component. [See: Spurious Actuation/Operation.]

Adverse Effect
An undesired change in the operation or functional integrity of structures, systems, or components (SSCs). Adverse effects may occur as a result of exposure to the effects of fire (i.e., heat or smoke) and/or fire-suppression activities.

Affected Systems and Components
SSCs that may be adversely affected as a result of fire (including an exposure fire) or subsequent fire suppression activities in a single fire area.

Alternative Shutdown
The capability to safely shut down the reactor in the event of a fire using existing systems that have been rerouted, relocated, or modified. (RG 1.189)

Alternative Shutdown Capability
A defined and documented process (including equipment, personnel, and procedures) for accomplishing safe-shutdown conditions in the event of fire in areas where one train of the redundant systems (see note below) needed to achieve and maintain hot shutdown conditions has not been ensured to remain free of fire damage (i.e., not provided with fire protection features sufficient to satisfy applicable requirements. (Section III.G.2 of Appendix R to 10 CFR Part 50 or Position C.5.b of SRP Section 9.5.1)

Note: If the system is being used to provide its design function, it is generally considered to be *redundant*. If the system is being used *in lieu of* the preferred system because the redundant components of the preferred system do not meet the separation criteria of Section III.G.2, the system is considered to be an *alternative* shutdown capability. (GL 86-10, Question 5.8.3)

Ampacity
Current carrying capacity, expressed in amperes, of a wire or cable under stated thermal conditions. (IEEE Std. 100-1988)

Clarification: When current flows in a conductor, heat is produced because every conductor offers some resistance to the flow of current. The National Electrical Code® (NEC) (ANSI/NFPA 70) defines ampacity as "the current (in amperes) a conductor can carry continuously under the conditions of use without exceeding its temperature rating." The current-carrying capacity of a particular wire is dictated by its "ampacity" (that is, how many amps it can handle). Ampacity is a function of the cross-sectional area or diameter of the wire and its material type (e.g., copper or aluminum) and cable insulation condition for basic installation conditions. For more complex installation conditions, IEEE 835 provides more extensive and detailed tables. For installations involving cables in open cable trays, ICEA/NEMA P-54 should be consulted. Larger-diameter wires have larger cross-section areas and can safely carry more electrical current without overheating. The ampacity rating of a specific conductor may be obtained from tables in the NEC. These tables are based on the size of the wire, the maximum allowable operating temperature of the insulation material, and the installation conditions. The nominal ampacity values include a safety margin that is sufficient for most installations. However, there are instances where application of the NEC ampacity tables is insufficient. For example, although the addition of fire barrier wrap around cable trays and conduits will affect the ampacity of a conductor, the NEC tables do not address this problem. Several inches of fire barrier material can have a significant effect on the ampacity rating specified in the NEC tables. Since there are no derating tables in the NEC for this kind of situation, calculations must be performed to determine the current carrying capacity of the enclosed cables.

American Wire Gauge (AWG)
A standardized system used to designate the size or "gauge" of wire. As the diameter of wire decreases, the "AWG" number of the wire increases. The smallest AWG size is 40 and looks like a metal thread. "Four ought" (0000) is the largest AWG wire size designation. Wires larger than this size are designated by the "thousand circular mill" system or "KCMIL" sizes (known until recently as MCM).

Ampere
A standard unit of electric current flow (equal to a flow of 1 coulomb per second).

Any-and-All/One-at-a-Time
All potential spurious actuations that may occur as a result of fire in a single fire area must be addressed and prevented or their effects must be appropriately mitigated on a one-at-time basis. That is, in evaluating non-high/low-pressure interface components[3], the analyst must assume that "any and all" spurious actuations that could occur, will occur on a sequential, one-at-a-time, basis. For each fire area, the analyst should identify all potential spurious operations that may occur as a result of a postulated fire. While it is not assumed that all potential spurious actuations will occur instantaneously at the onset of fire, the analyst must consider the possibility that each spurious actuation will occur sequentially, as the fire progresses, on a one-at-a-time basis. If not appropriately prevented or mitigated, such sequential failures could result in concurrent failure of multiple devices.

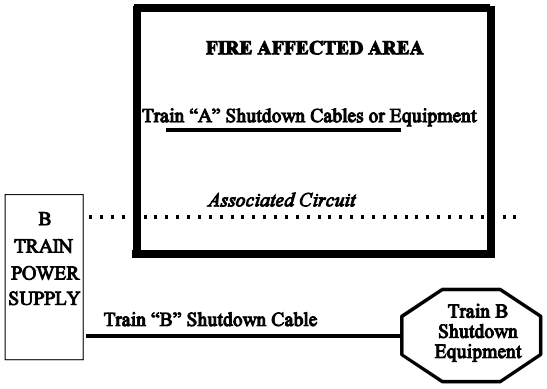
Appendix R Cables
The set of cables that must remain free of fire damage to ensure that safe-shutdown conditions can be achieved within established criteria. [Synonym: required cables.]

Arcing Fault
See: High-impedance fault.

Associated Circuit Analysis
A documented, systematic evaluation of associated circuits of concern to post-fire safe-shutdown.

Associated Circuits (of Concern)
Those safety-related and nonsafety-related Class 1E and non-Class 1E cables that have a physical separation less than that specified in Section III.G.2 of Appendix R to 10 CFR Part 50 and have one of the following: (Reference GL 81-12 Clarification, Enclosure 2)

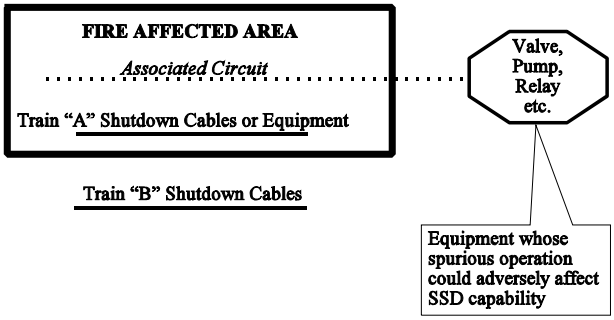
a. *A power source that is shared with the shutdown equipment* (redundant or alternative) and is not electrically protected from the circuit of concern by coordinated breakers, fuses, or similar devices.



Associated Circuit Concern - Common Power Source

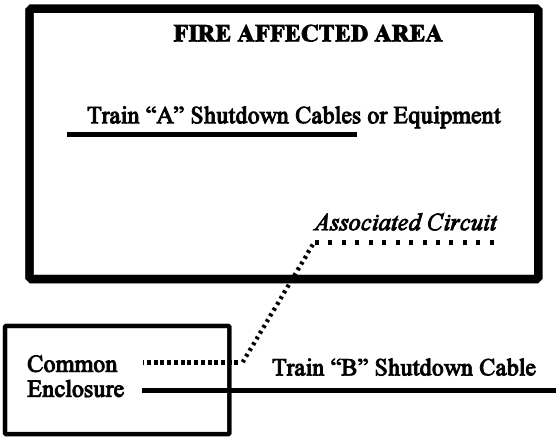
[3] High/low-pressure interfaces are considered a special case to their severe consequence. (GL 86-10, Question 5.3.1)

b. *A connection to circuits of equipment of which spurious operation would adversely affect the shutdown capability* [e.g., residual heat removal (RHR)/reactor coolant system (RCS) isolation valves, automatic depressurization system (ADS) valves, power-operated relief valves (PORVs), steam generator atmospheric dump valves, instrumentation, steam bypass].



Associated Circuit of Concern - Spurious Operation

c. *An enclosure (e.g., raceway, panel, or junction box) that is shared with the shutdown cables* (redundant or alternative) and (1) is not electrically protected by circuit breakers, fuses, or similar devices, or (2) will allow propagation of the fire into the common enclosure.



Associated Circuits of Concern - Common Enclosure

(SECY 80-438A, "Commission Approval of the Final Rule on Fire Protection Program," September 30, 1980)

Clarification: An *associated circuit of concern to post-fire safe-shutdown* may include any circuit or cable that is not needed to support the proper operation of required shutdown equipment (i.e., a nonessential circuit), but could adversely affect the plant's ability to achieve and maintain safe-shutdown conditions if it is damaged by fire. For example, while operation of the PORV in a pressurized-water reactor (PWR) may not be needed to ensure the operation of a defined shutdown system, its maloperation as a result of fire damage to connected cabling could have a significant impact on the plant's overall safe-shutdown capability.

Automatic
Self-acting; operating by its own mechanism when actuated by some monitored parameter, such as a change in current, pressure, temperature, or mechanical configuration. (RG 1.189)

Automatic Actuation Signal
A signal that is initiated in response to a previously defined variable or set of variables that will cause equipment to change position or operating mode, such as the undervoltage signal that causes an emergency power source [e.g., emergency diesel generator (EDG)] to automatically start and load in response to a low-voltage condition on safety-related switchgear (SWGR).

Bolted Fault
(1) A short circuit or electrical contact between two conductors at different potentials, in which the impedance or resistance between the conductors is essentially zero. (IEEE Std. 100-1988)
(2) A simplifying assumption used when calculating the value of short-circuit fault current to ensure that the short-circuit ratings of the equipment are adequate to handle the currents available at their locations. This assumption simplifies calculations, since the resulting values are a maximum and equipment selected on this basis will always have an adequate rating.
(ANSI/IEEE Std. 242-1986)

Cable
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). (IEEE Std. 100-1988)

Cable Failure
A breakdown in the physical and/or chemical properties (e.g., electrical continuity, insulation integrity) of the cable conductor(s), such that the functional integrity of the electrical circuit cannot be ensured (e.g., interrupted or degraded).

Cable-Fire Break
Material, devices, or an assembly of parts, installed in a cable system, other than at a cable penetration of a fire-resistive barrier, to prevent the spread of fire along the cable system. (IEEE Std. 100-1988)

Cable Jacket
A protective covering over the insulation, core, or sheath of a cable. (IEEE Std.100-1988)

Cable and Raceway Database
A database, unique to the plant, which delineates the routing and location of cables and their associated raceways. (cable trays, conduits, pull-boxes, etc.)

Cable Penetration
An assembly or group of assemblies for electrical conductors to enter and continue through a fire-rated structural wall, floor, or floor-ceiling assembly. (IEEE Std. 100-1988)

Cable Routing
The pathway electrical wiring takes through the plant from power source or control point to component location.

Cable Size
See American Wire Gauge (AWG).

Cable-to-cable Fault
A fault condition of relatively low impedance between conductors of one cable and conductors of a different cable.

Circuit
(1) A conductor or system of conductors through which electrical current flows. (IEEE Std. 100-1988)
(2) Interconnection of components to provide an electrical path between two or more components.

Circuit Analysis
A systematic evaluation of the impact of fire-induced circuit/cable failure modes (e.g., hot shorts, open circuits, and shorts to ground) on the defined/credited shutdown capability.

Note: Performance of a detailed circuit analysis is not a requirement. Section III.G of Appendix R and Regulatory Position C.5.b of SRP Section 9.5.1 establish the fire protection design features that are necessary to ensure that SSCs important to safe-shutdown will remain free of fire damage. Where these fire protection features are provided, analysis is not necessary. When relied on in lieu of providing these features, circuit analyses must demonstrate a level of safety equivalent to that which would be achieved through compliance with applicable regulatory requirements.

Circuit Breaker
(1) A device designed to open and close a circuit by nonautomatic means, and to open the circuit automatically on a predetermined overload of current without injury to itself when properly applied within its rating. (IEEE Std. 100-1988)
(2) A mechanical switching device capable of making, carrying, and breaking currents under normal circuit conditions and also, making, carrying for a specified period of time, and breaking currents under specified abnormal circuit conditions such as those of a short circuit. (IEEE Std. 100-1988)

Circuit/Cable Fault
See: Fault, Fire-Induced Fault

Cold Shutdown Repair
Repair activities performed on equipment needed to bring the plant to cold shutdown conditions.

Note: Systems and equipment needed to achieve and maintain hot shutdown conditions must remain free of fire damage (i.e., repairs are not permitted).

Common Enclosure
An enclosure (e.g., cable tray, conduit, junction box) that contains circuits required for the operation of safe-shutdown components and circuits for non-safe-shutdown components. [See: Associated Circuits of Concern.] (RG 1.189)

Common-Mode Failure
Multiple failures that are attributable to a common cause, such as circuit faults resulting from the exposure of cables to the direct effects of fire (heat, smoke) and subsequent fire-suppression activities in a single fire area. (IEEE Std. 100-1988)

Common Power Supply/Source
A power supply that feeds safe-shutdown circuits and non-safe-shutdown circuits. [See: Associated Circuits of Concern.] (RG 1.189)

Conductor
(1) A substance or body that allows a current of electricity to pass continuously along it. (IEEE Std. 100-1988)
(2) A wire or combination of wires, not insulated from one another, suitable for carrying an electric current. (IEEE Std. 100-1988)

Clarification: For cables, the term “conductor” commonly refers to a single insulated wire located within a cable; for circuits, the term “conductor” may refer to a single wire, contact, wire termination, or other conductive pathway such as those used on printed circuit boards.

Conductor-to-Conductor Fault
(1) A circuit fault condition of relatively low impedance between two or more conductors of the same or different circuit.
(2) A cable failure mode of relatively low impedance between two or more conductors of the same multi-conductor cable (intra-cable fault) or between two or more separate cables (inter-cable fault).

Contact
A conducting part that co-acts with another conducting part to make or break a circuit. (IEEE Std. 100-1988)

Control Cable
Cable applied at relatively low current levels or used for intermittent operation to change the operating status of a utilization device of the plant’s auxiliary system. (IEEE Std. 100-1988)

Control Circuit
The circuit that carries the electrical signals directing the performance of the controller, but does not carry the main power circuit. (IEEE Std. 100-1988)

Clarification: A control circuit is a low-voltage (typically 120-VAC or 125-VDC) circuit, consisting of switches, relays, and indicating devices, which direct the operation of remotely located plant equipment that is powered from a completely separate power supply.

Control Panel
An assembly of man/machine interface devices. (IEEE Std. 100-1988)

Control Power/Voltage
The voltage applied to the operating mechanism of a device to actuate it. (IEEE Std. 100-1988)

Clarification: Electrical power/voltage (typically 120-VAC or 125-VDC) used to power control circuit devices (e.g. relays, indicating lights).

Control-Power Transformer
A transformer that supplies power to motors, relays, and other devices used for control purposes. (IEEE Std. 100-1988)

Coordination (of Electrical Protection Devices)
The selection and/or setting of protective devices to sequentially isolate only that portion of the system where the abnormality occurs. To achieve this isolation, it is necessary to set protective devices so that only the device nearest the fault opens and isolates the faulted circuit from the system. It is obvious that such selectivity becomes more important with devices that are closer to the power source, as a greater portion of the system can be affected. Backup protective devices are set to operate at some predetermined time interval after the primary device fails to operate. A backup device is able to withstand the fault conditions for a longer period than the primary device. If a primary device fails to clear a fault and the backup device must clear it, the design of the protective system becomes suspect. To optimize the coordination of protective devices, good engineering practice require consideration of (1) the available maximum short-circuit currents, (2) the time interval between the coordination curves; and (3) load current. (IN 88-45)

Clarification: The design must ensure that electrical fault currents generated as a result of fire damage will not cause an interruption in the power being supplied to required shutdown equipment. To ensure this “continuity of service,” cables and equipment fed from electrical power sources required for post-fire safe-shutdown must either be provided with suitable fire protection features (e.g. meet the criterial in Section III.G.2 of Appendix R to 10 CFR Part 50) or the fault-protection devices (relays, fuses, and/or circuit breakers) of the required power sources must be selectively coordinated. [See also: High-Impedance Fault.]

Coordination Study
The process of evaluating the performance of electrical distribution system protection devices (breakers, fuses, relays) to ensure that fault conditions caused by fire will be isolated and power outages to unaffected equipment will be minimized. A coordination study is based on a comparison of the time it takes individual overcurrent protection devices (circuit breakers, fuses, relays) to operate (trip) under abnormal (faulted) conditions. For post-fire safe-shutdown, this study must ensure that electrical power to shutdown equipment will not be interrupted as a result of fire-induced faults in nonessential loads (equipment or cables) of a required power supply [SWGR, load center, motor control center (MCC), fuse panel, etc.].

ANSI/IEEE Std. 242-1986, "IEEE Recommended Practices for Protection and Coordination of Industrial and Commercial Power Systems," provides detailed guidance on achieving proper coordination. (RG 1.189 and IN 88-45)

Credited Shutdown Equipment
The set of equipment that is relied on (credited in the SSA) for achieving post-fire safe-shutdown conditions in the event of fire in a specific fire area.

Current Carrying Capacity
See Ampacity.

Current Licensing Basis (CLB)
The set of NRC requirements applicable to a specific plant and a licensee's written commitments for ensuring compliance with and operation within applicable NRC requirements and the plant-specific design basis (including all modifications and additions to such commitments over the life of the license) that are docketed and in effect. The CLB includes the NRC regulations contained in 10 CFR Parts 2, 19, 20, 21, 26, 30, 40, 50, 51, 54, 55, 70, 72, 73, and 100, as well as the appendices thereto; orders; license conditions; exemptions; and technical specifications (TSs). The CLB also includes the plant-specific design basis information defined in 10 CFR 50.2, as documented in the most recent final safety analysis report (FSAR), as required by 10 CFR 50.71 and the licensee's commitments remaining in effect that were made in docketed licensing correspondence such as licensee responses to NRC BLs, GLs, and enforcement actions, as well as licensee commitments documented in NRC safety evaluations or licensee event reports. [See also RG 1.189.] (10 CFR 54.3)

Current Transformer
A device used to transform high currents used by a large equipment and SWGRs to lower levels that can safely be measured by standard metering equipment. The current reduction ratio of a current transformer (CT) is given on its nameplate. A CT with a current reduction ratio of 400:5 would reduce the current by a ratio of 400 divided by 5 or 80 times.

Note: The hazard of electric shock, burn, or explosion exists on an open-circuited CT. Death, severe personal injury, or equipment damage can result if the leads are touched when the CT is open-circuited. As much as 4,000 V has been measured on the secondary on large-core CTs with an open-circuited secondary. CTs must *always* be shorted *or* connected to a burden such as a meter or relay. Open-circuiting may also damage the CT insulation. Once a CT has been open-circuited, it must be demagnetized or accuracy may be reduced.
(Square D Application Bulletin No. 4200PD9203R8/95, April 1996)

Dedicated Shutdown
The ability to shut down the reactor and maintain shutdown conditions using SSCs dedicated to the purpose of accomplishing post-fire safe-shutdown functions. (RG 1.189)

Diagnostic Instrumentation
Attachment 1 to IN 84-09 lists the instruments that are necessary to achieve safe shutdown. Diagnostic instrumentation includes any additional instruments (beyond those listed in Attachment 1 to IN 84-09) that are needed to ensure proper actuation and functioning of safe-shutdown equipment and support equipment (e.g., flow rate, pump discharge pressure). The diagnostic instrumentation needed depends on the design of the alternative shutdown capability. (GL 86-10, Question 5.3.9)

Clarification: Section IX of IN 84-09 establishes the minium set of instrumentation that the NRC staff deems acceptable for meeting the alternative shutdown process monitoring function. Although this list includes “diagnostic instrumentation,” it does not specifically define that term. Alternative shutdown strategies that rely on operator intervention (recovery actions) to mitigate equipment maloperations and/or failures that may occur as a result of fire must be supported by sufficient monitoring capability (diagnostic instrumentation) to ensure prompt detection of any failure(s) that may occur and confirm proper system response.

Emergency Control Station
The control stations located outside the main control room (MCR), where operations personnel take actions to manipulate plant systems and their controls to achieve safe-shutdown of the reactor.

Enclosure
An identifiable housing such as a cubicle, compartment, terminal box, panel, or raceway used for electrical equipment or cables. (IEEE Std. 100-1988)

Exposed (Circuits/Cables/Equipment/Structures)
(1) SSCs, that are subject to the effects of fire and/or fire-suppression activities.
(2) SSCs not provided with fire protection features sufficient to satisfy Section III.G.2 of Appendix R to 10 CFR Part 50 or Position C.5.b of SRP Section 9.5.1.

Exposure Fire
A fire in a given area that involves either in situ or transient combustibles and is external to any SSCs located in or adjacent to that same area. The effects of such fire (e.g., smoke, heat, or ignition) can adversely affect those SSCs that are important to safety. Thus, a fire involving one success path of safe-shutdown equipment may constitute an exposure fire for the redundant success path located in the same area, and a fire involving combustibles other than either redundant success path may constitute an exposure fire to both redundant trains located in the same area. (RG 1.189)

Failsafe Circuits
Circuits designed so that fire-induced faults will result in logic actuation(s) to a desired, safe mode that cannot be overridden by any subsequent circuit failures.

Fault
(1) Any undesired state of a component or system. A fault does not necessarily require failure. For example, a pump may not start when required because its feeder breaker was inadvertently left open. (IEEE Std. 100-1988)
(2) A partial or total local failure in the insulation or continuity of a conductor. (IEEE Std. 100-1988)
(3) A physical condition that causes a device, component, or element to fail to perform in a required manner (for example a short circuit, a broken wire, an intermittent connection). (IEEE Std.100-1988)

Fault Current
(1) A current that flows from one conductor to ground or another conductor owing to an abnormal connection (including an arc) between the two. (IEEE Std. 100-1988)
(2) A current that results from the loss of insulation between conductors or between a conductor and ground. (NEMA Std. ICS-1, 1988)

Clarification: Fault current is an abnormal level of current that is induced in an electrical circuit. Fault currents may be initiated by various mechanisms including insulation degradation, arcing, or physical contact between two conductors. Fault currents include short-circuit current (bolted fault), high-impedance (arcing) fault currents, and overload currents.

Feeder Breaker/Feeder
A general term used to describe a circuit breaker or fuse located upstream of an electrical load. Depending on usage, it may refer to a circuit breaker provided for a specific component (load breaker) or it may refer to a breaker located upstream of a SWGR, load center, or distribution panel. Opening a feeder breaker will cause a loss of power to all downstream loads.

Fire Area
The portion of a building or plant that is separated from other areas by rated fire barriers adequate for the fire hazard. (RG 1.189)

Fire Area Boundaries
As used in Appendix R to 10 CFR Part 50, the term "fire area" means an area that is sufficiently bounded to withstand the associated hazards and, as necessary, to protect important equipment within the area from a fire outside the area. In order to meet the regulation, fire area boundaries need not be completely sealed floor-to-ceiling, wall-to-wall boundaries. However, all unsealed openings should be identified and considered when evaluating the effectiveness of the overall barrier. Where fire area boundaries are not floor-to-ceiling, wall-to-wall boundaries with all penetrations sealed to the fire rating required of the boundaries, licensees must perform an evaluation to assess the adequacy of their plant's fire boundaries to determine whether the boundaries will withstand the hazards associated with the area. This analysis must be performed by at least a fire protection engineer and, if required, a systems engineer. (GL 86-10)

Fire-Induced Fault
An electrical failure mode (e.g., hot short, open circuit, or short to ground) that may result from circuit/cable exposure to the effects of fire (e.g., heat and smoke) and/or subsequent fire-suppression activities (e.g., water spray, hose streams).

Fire Suppression
Control and extinguishing of fires (firefighting). Manual fire suppression employs the use of hoses, portable fire extinguishers, or manually actuated fixed systems by plant personnel. Automatic fire suppression is the use of automatically actuated fixed systems such as water, Halon, or carbon dioxide (CO_2) fire suppression systems. (RG 1.189)

Fire-Suppression Impacts
The susceptibility of SSCs and operations response to suppressant damage (attributable to discharge or rupture). (NFPA 805)

Fire Zones
Subdivisions of fire areas (RG 1.189)

Note: Compliance with Section III.G.2 cannot be based on rooms or zones.
(GL 86-10, Question 3.1.5)

Free of Fire Damage
In promulgating Appendix R to 10 CFR Part 50, the Commission provided acceptable methods for ensuring that necessary SSCs are free of fire damage (see Section III.G.2a, b and c); that is, the SSCs under consideration are capable of performing their intended functions during and after the postulated fire, as needed. Licensees seeking exemptions from Section III.G.2 must show that the proposed alternative provides reasonable assurance that this criterion is met. The term "damage by fire" also includes damage to equipment from the normal or inadvertent operation of fire-suppression systems. (GL 86-10)

Note: Section III.G.2 of Appendix R and Position C.5.b of SRP Section 9.5.1 establish the fire protection features that are necessary to ensure that systems needed to achieve and maintain hot shutdown conditions remain free of fire damage.

Fuse
(1) A device that protects a circuit by fusing open its current responsive element when an overcurrent or short-circuit current passes through it. (IEEE Std. 100-1988)
(2) A protective device that opens by the melting of a current-sensitive element during specified overcurrent conditions. (NEMA Std. FU-1 1986)

Fuse Current Rating
The AC or DC ampere rating that the fuse is capable of carrying continuously under specified conditions. (NEMA Std. FU-1 1986)

Fuse Voltage Rating
The maximum root-mean-square (RMS) AC voltage or the maximum DC voltage at which the fuse is designed to operate. (NEMA Std. FU-1 1986)

Ground
A conducting connection, whether intentional or accidental, by which an electric circuit or equipment is connected to the earth, or to some conducting body of relatively large extent that serves in place of the earth. (IEEE Std. 100-1988)

Grounded Circuit
A circuit in which one conductor or point (usually the neutral conductor or neutral point of transformer or generator windings) is intentionally grounded, either solidly or through a non-interrupting current-limiting grounding device. (IEEE Std. 100-1988)

High/Low-Pressure Interface
Reactor coolant boundary valves of which spurious operation as a result of a fire could (1) potentially rupture downstream piping on an interfacing system, or (2) result in a loss of reactor coolant inventory in excess of the available makeup capability.

High-Impedance Fault (HIF)
(1) An electrical fault of a value that is below the trip point of the breaker on each individual circuit. (GL 86-10, Question 5.3.8)
(2) A circuit fault condition resulting in a short to ground, or conductor-to-conductor hot short, where residual resistance in the faulted connection maintains the fault current level below the component's circuit breaker long-term setpoint. (RG 1.189)

Clarification: HIFs are typically initiated by damaged or degraded insulation and are characterized by low and erratic current flow. Unlike a short circuit (bolted fault), a HIF has an element of resistance between the affected power conductor and its return path (typically ground). This resistance limits the value of fault current. Because of these characteristics, HIFs may continue undetected by conventional circuit protective devices. (GL 86-10, Question 5.3.8) Should a sufficient number of these faults occur, the summation of fault currents may be sufficient to cause a trip of the upstream feeder breaker, resulting a loss of power to required shutdown loads connected to the affected power source. With regard to the analysis of their potential impact on post-fire safe-shutdown capability, HIFs should be postulated to occur simultaneously on all exposed cables located in the fire area and should be assumed to be of a magnitude that is just below the long-term trip point setting of the individual load breaker. (GL 86-10, Question 5.3.8)

Hot Short
Individual conductors of the same or different cables come in contact with each other and may result in an impressed voltage or current on the circuit being analyzed. (RG 1.189)

Clarification: The term "hot short" is used to describe a specific type of short circuit fault condition between energized and deenergized conductors. Should a deenergized conductor come into electrical contact with an energized conductor (or other external source), the voltage, current, or signal being carried by the energized conductor (or source) would be impressed onto one or more of the deenergized conductors.

Important to Safety
NPP SSCs that are "important to safety" are those required to provide reasonable assurance that the facility can be operated without undue risk to the health and safety of the public. (RG 1.189)

Instrument Sensing Line
Small-diameter tubing (usually stainless steel, but sometimes copper) used to interconnect plant process instrumentation.

Inter-Cable Fault
A fault between conductors of two or more separate cables.

Intra-Cable Fault
A fault between two or more conductors within a single multi-conductor cable.

Interlock
A device actuated by the operation of some other device with which it is directly associated to govern succeeding operations of the same or allied devices.

Note: Interlocks may be either electrical or mechanical. (IEEE Std.100-1988)

Interrupting Device
A breaker, fuse, or similar device installed in an electrical circuit to isolate the circuit (or a portion of the circuit) from the remainder of the system in the event of an overcurrent or fault downstream of the interrupting device. (RG 1.189)

Isolating Device/Isolation Device
A device in a circuit which prevents malfunctions in one section of the circuit from causing unacceptable influences in other sections of the circuit or other circuits. (IEEE Std. 100-1988; RG 1.189)

Isolation Transfer Switch
A device used to provide electrical isolation from the fire-affected area and transfer control of equipment from the main control room to the local control station (alternate shutdown panel).

Insulated Conductor
A conductor covered with a dielectric (other than air) having a rated insulating strength equal to or greater than the voltage of the circuit in which it is used. (IEEE Std. 100-1988)

Insulation (Cable, Conductor)
That which is relied on to insulate the conductor or other conductors or conducting parts from ground. (IEEE Std. 100-1988)

Leakage Current (Insulation)
The current that flows through or across the surface of insulation and defines the insulation resistance at the specified direct current potential. (IEEE Std. 100-1988)

Local Control
Operation of shutdown equipment using remote controls (e.g., control switches) specifically designed for this purpose from a location other than the main control room (for example, Operating the EDG from controls provided at the remote/alternate shutdown panel).

Local Control Station
A control panel located in the plant which allows operation and monitoring of plant equipment from outside of the main control room. For post-fire safe-shutdown control functions and monitoring, variables on these panels must be independent (physically and electrically) from those in the MCR.

Local Operation
Manipulation of plant equipment from a location outside of the main control room (for example, manual operation of the circuit breakers or turning the handwheel on the valve to change its position).

Load Breaker
A circuit breaker that is located on the load side of a power source. [Synonym: branch breaker.]

Maloperation
The inability of a component to operate as desired or when expected.

Manual Action
Manual manipulation (operation) of equipment. These actions may be subdivided into the broad categories of “operator action” or “operator manual action.”

Manual Valve
A valve that does not have the capability to be manipulated remotely.

Manually Operated Valve
A valve credited in the SSA or shutdown procedures for being manually manipulated.

Note: A manually operated valve may be a manual valve or a remotely motor-operated valve (e.g., MOV) that has its power and control capability disabled or removed.

Mitigating Action
A manual action (operator action or operator manual action) designed to stop the progression or reduce the severity of the unwanted condition.

Molded-Case Circuit Breaker
A circuit breaker that is assembled as an integral unit in a supporting and enclosing housing of molded insulating material. (IEEE Std. 100-1988)

Multi-Conductor Cable (Multiple-Conductor Cable)
A combination of two or more conductors cabled together and insulated from one another and from sheath or armor where used.

Note: Specific cables are referred to as 3-conductor cable, 7-conductor cable, 50-conductor cable, etc. (IEEE Std. 100-1988)

Nonessential (Conductor, Cable, Component, or System)
Class 1E, Non-Class 1E, safety-related, or nonsafety-related SSCs of which operation is not required to support the performance of systems credited in the SSA for accomplishing post-fire safe-shutdown functions.

Normally Closed or Normally Open
The status of a given component during the plant's normal operating modes. This terminology is usually applied to valve, circuit breaker, and relay operating positions.

Open Circuit
A failure condition that results when a circuit (either a cable or individual conductor within a cable) loses electrical continuity. (RG 1.189)

Clarification: A circuit fault condition where the electrical path has been interrupted or "opened" at some point so that current will not flow. Open circuits may be caused by a loss of conductor integrity as a result of heat or physical damage (break).

Operator Actions
Those actions taken by operators from inside the MCR to achieve and maintain post-fire safe-shutdown. These actions are typically performed by the operators controlling equipment that is located remote from the MCR.

Operator Manual Actions
Those actions taken by the operators to manipulate components and equipment from outside the MCR to achieve and maintain post-fire safe-shutdown. These actions are performed locally by operators typically at the equipment.

Overcurrent
Any current in excess of the rated current of equipment or the rated ampacity of a conductor. Overcurrent may result from overload, short-circuit, or ground-fault. A current in excess of rating may be accommodated by certain equipment and conductors for a given set of conditions. Hence, the rules for overcurrent protection are specific for particular situations.
(IEEE Std. 100-1988)

Overcurrent Protection
A form of protection that operates when current exceeds a predetermined value.
(IEEE Std. 100-1988)

Overcurrent Relay
A relay that operates when its input current exceeds a predetermined value.
(IEEE Std. 100-1988)

Overload
(1) Loading in excess of the normal rating of equipment. (IEEE Std. 100-1988)
(2) Generally used in referring to an overcurrent that is not of sufficient magnitude to be termed a short circuit. (IEEE Std. 100-1988)

Clarification: An overload is a circuit fault condition that occurs when the amount of current flowing through the circuit (cable, wire) exceeds the rating of the protective devices (fuse, circuit breaker, etc.). Without proper overload protection, wires can get hot or even melt the insulation and start a fire. Overloads are most often between 1 and 6 times the normal current level. Usually, they are caused by harmless temporary surge currents that occur when motors are started or transformers are energized. Such overload currents, or transients, are normal occurrences. Since they are of brief duration, any temperature rise is trivial and has no harmful effect on the circuit components. (It is important that protective devices do not react to them). A sustained overload current results in overheating of conductors and other components and will cause deterioration of insulation, which may eventually result in severe damage and short-circuits if not interrupted.

Paired Cable
A cable in which all of the conductors are arranged in the form of twisted pairs.
(IEEE Std. 100-1988)

Potential Transformer
A special class of transformer used to step down high distribution system-level voltages (typically 480 V and above) to a level that can be safely measured by standard metering equipment. Potential transformers (PTs) have a voltage reduction ratio given on their nameplates. A PT with a voltage reduction ratio of 200:5 would reduce the voltage by a ratio of 200 divided by 5 or 40 times.

Power Cable/Circuit
A circuit used to carry electricity that operates a load.

Pre-Fire Position/Operating Mode
Terminology used to indicate equipment status before a fire.

Protective Relay
A device used to detect defective lines or apparati or other power system conditions of an abnormal or dangerous nature and to initiate appropriate control action. A protective relay may be classified according to its input quantities, operating principal, or performance characteristics. (IEEE Std. 100-1988)

Clarification: Protective relays are small, fast-acting, automatic switches designed to protect an electrical system from faults and overloads. A single 4,160-V SWGR may have many relays, each with a specific purpose. Protective relays are classified by the variable they monitor or the function they perform. When a relay senses a problem (e.g., short circuit), it quickly sends a signal to one or many circuit breakers to open, or trip, thus protecting the remainder of the distribution system.

Raceway
An enclosed channel of metal or nonmetallic materials designed expressly for holding wires, cables, or busbars, with additional functions as permitted by code. Raceways include, but are not limited to, rigid metal conduit, rigid nonmetallic conduit, intermediate metal conduit, liquid-tight flexible conduit, flexible metallic tubing, flexible metal conduit, electrical nonmetallic tubing, electrical metallic tubing, underfloor raceways, cellular concrete floor raceways, cellular metal floor raceways, surface raceways, wireways, and busways. (RG 1.189; IEEE Std. 100-1988)

Rated Voltage
(1) The voltage at which operating and performance characteristics of apparatus and equipment are referred. (IEEE Std. 100-1988)
(2) For either single-conductor or multiple-conductor cables, the rated voltage is expressed in terms of phase-to-phase voltage of a three-phase system. For single-phase systems, a rated voltage of $\sqrt{3}$ * the voltage to ground should be assumed. (IEEE Std. 100-1988)

Recovery Action
Activities to achieve the nuclear safety performance criteria that takes place outside the MCR or outside of the primary control station(s) for the equipment being operated, including the replacement or modification of components. (NFPA 805, 2001 Edition)

Redundant Shutdown
(1) If the system is being used to provide its design function, it is generally considered to be redundant. If the system is being used in lieu of the preferred system because the redundant components of the preferred system do not meet the separation criteria of Section III.G.2, the system is considered to be an alternative shutdown capability. (GL 86-10, Question 5.8.3)
(2) For the purpose of analysis to Section III.G.2 criteria, the safe-shutdown capability is defined as one of the two normal safe-shutdown trains. If the criteria of Section III.G.2 are not met, an alternative shutdown capability is required. (GL 86-10, Question 5.1.2)

Note: For BWRs, the use of safety relief valves and low-pressure injection systems has been found to meet the requirements of a redundant means of post-fire safe-shutdown under Section III.G.2 of Appendix R to 10 CFR Part 50 (Letter from S. Richards, NRC, to J. Kenny, BWR Owners Group, dated December 12, 2000).

Relay
An electrically controlled, usually two-state, device that opens and closes electrical contacts to affect the operation of other devices in the same or another electric circuit. (IEEE Std. 100-1988)

Remote Control
Control of an operation from a distance; this involves a link, usually electrical, between the control device and the apparatus to be operated. (IEEE Std. 100-1988)

Note: Remote control may be accomplished from the control room or local control stations.

Remote Shutdown Location
A plant location external to the MCR that is used to manipulate or monitor plant equipment during the safe-shutdown process. Examples include the remote shutdown panel (RSP) or valves requiring manual operation.

Remote Shutdown Panel (RSP)
Depending on usage, the term "RSP" may refer to control and monitoring stations (panels) having significantly different design capabilities. For example, RSP may refer to either of the following:

(1) The control panel included in the plant design for the purpose of satisfying GDC 19 (shutdown attributable to loss of control room habitability).
Note: The controls and instruments on this panel are not necessarily isolated from the effects of fire. For GDC 19, damage to the control room is not considered.

(2) The control panel included in the plant design for the purpose of controlling and monitoring alternative shutdown functions from outside the MCR.
Note: Alternative shutdown systems need not be redundant, but must be both physically and electrically independent of the control room. (GL 86-10, Question 5.3.11)

Repair
To restore by replacing a part or putting together what is broken. (Webster's 9th New Collegiate Dictionary)

Clarification: In general, a repair may include any operator manual action involving (1) the use of a tool (screwdriver, pliers, wrench, etc.), (2) the installation of components (e.g., fuse, electrical/pneumatic jumpers), or (3) a modification of plant SSCs. Such repairs are only permitted on equipment needed to achieve and maintain cold shutdown conditions.

Note: (1) Tools do not include appropriately controlled equipment provided to facilitate the implementation of procedurally directed operator manual actions, such as ladders, flashlights, fuse pullers, extension bars/handles. (2) Removal of fuses (fuse pulling) is generally not considered a repair. However, this determination must be made on a case-by-case basis considering such factors as feasibility, time, adequacy of emergency lighting, potential for human error and personnel safety hazards. [See IN 84-09, Attachment I, XI for additional information.]

Required Circuits and Cables
Circuits and cables needed to support operation or prevent the maloperation of components identified as being necessary to achieve and maintain safe-shutdown for a particular fire area. In general, a circuit/cable is considered to be *required* for safe-shutdown if it is needed to ensure the operation of required equipment *and* fire-induced faults in the circuit (cable) can cause the required component(s) to fail and/or maloperate in an undesired condition for safe-shutdown.

Note: Required equipment designations may be found to vary between fire areas (e.g., a cable may be required for shutdown in the event of fire in one area, but not required in another).

Required Equipment List
See Safe-Shutdown Equipment List

Required Shutdown Equipment/Components
Equipment needed to ensure the capability to achieve and maintain post-fire safe-shutdown conditions may be accomplished within established criteria.

Required Shutdown System
The systems credited in the SSA for performing each nuclear safety function.

Resistance
Opposition of the flow of electricity through a material.

Clarification: A number of factors(such as wire diameter, wire length and any impurities in the makeup of the wire) determine the resistance to current flow. In general, smaller-diameter wires have more resistance than larger-diameter wires, and longer wires have more resistance than shorter wires. When electricity flows through any resistance, it dissipates energy in the form of heat.

Safe-Shutdown Analysis (Post-Fire Safe-Shutdown Analysis)
A documented evaluation of the potential effects of a postulated fire (including an exposure fire) and fire-suppression activities in any single area of the plant (fire area), on the ability to achieve and maintain safe-shutdown conditions in a manner that is consistent with established performance goals and safety objectives. (Sections III.G and III.L of Appendix R to 10 CFR Part 50 or Position C.5.b of SRP Section 9.5.1)

Safe-Shutdown Equipment List (SSEL)
A documented list of equipment and components that must operate or be prevented from maloperating to ensure the capability to achieve and maintain post-fire safe-shutdown conditions within established criteria. [Synonym: Required equipment list]

Safe-Shutdown System
All structures, equipment (components, cables, raceways, cable enclosures, etc.), and supporting systems [heating, ventilation, and air-conditioning (HVAC)] electrical distribution, station and instrument air, cooling water, etc.] needed to perform a shutdown function.

Selectivity
A general term describing the interrelated performance of relays and breakers, and other protective devices; complete selectivity is obtained when a minimum amount of equipment is removed from service for isolation of a fault or other abnormality. [See also: Coordination.] (IEEE Std. 100-1988)

Short Circuit
An abnormal connection (including an arc) of relatively low impedance, whether made accidentally or intentionally, between two points of different potential. (IEEE Std. 100-1988)

Short-Circuit Current (I_{sc})
Current that flows outside the normal conducting paths (e.g., conductor to ground).

Note: Unlike HIFs, this fault current is generally very large, since only the combined impedance of the object responsible for the short, the wire, and the transformer limit its magnitude. Short-circuit current is often 2 orders of magnitude greater than normal operating current. The symbol I_{sc} is frequently used to represent the value/magnitude of current flowing during a short-circuit fault condition.

Short to Ground
A short circuit between conductor(s) and a grounded reference point (e.g., grounded conductor, conduit, raceway, metal enclosure, shield wrap, or drain wire within a cable).

Solid Conductor
A conductor consisting of a single wire. (IPEEE Std. 100-1988)

Spurious Actuation/Operation
A full or partial change in the operating mode or position of equipment. These operations include, but are not limited to, (1) opening or closing normally closed or open valves, (2) starting or stopping of pumps or motors, (3) actuation of logic circuits, or (4) inaccurate instrument readings.

Spurious Indications
False indications (process monitoring, control, annunciator, alarm, etc.) that may occur as a result of fire and fire-suppression activities.

Spurious Signals
False control or instrument signals that may be initiated as a result of fire and fire -uppression activities.

Stranded Conductor
A conductor made from a number of smaller wire strands wrapped around each other.

Sub-Component
Components that are required to ensure the proper control and/or operation of main flowpath components (e.g., pumps, flowpath valves) and components such as flow switches, temperature switches, relays, transmitters, or signal conditioners that provide isolation or actuation signals to main components.

Tenability
The effects of smoke and heat on personnel actions. (NFPA 805)

Thermal/Hydraulic Timeline
A documented evaluation of the response of important reactor plant parameters to a postulated transient (thermal/hydraulic analysis) with respect to the time available to accomplish required shutdown functions. For example, the time available to establish auxiliary feedwater (AFW) following a reactor scram in a PWR would be determined by a thermal/hydraulic analysis. The objective of the thermal/hydraulic timeline is to compare this time to the time needed for operators to perform all system and equipment alignments necessary to establish a secure source of AFW.

Thermoplastic
A cable material that will soften, flow, or distort appreciably when subjected to sufficient heat and pressure. Examples include polyvinyl chloride (PVC) and polyethylene(PE).

Note: Cables using thermoplastic insulation *are not* usually qualified to survive the full environment qualification exposure condition of IEEE Std. 383. Many thermoplastic cables will, however, pass the limited flame spread test included in the IEEE Std. 383.

Thermoset
A cable material that will not soften, flow, or distort appreciably when subjected to heat and pressure. Examples include rubber and neoprene.

Note: Cables using thermoset insulation *are* usually qualified to IEEE Std. 383.

Time/Current Characteristic Curve (Trip Curves)
A graphic illustration of the operating characteristics of electrical protection devices (fuses, circuit breakers, or relays). The tripping characteristics of protective devices are represented by a characteristic tripping curve that plots tripping time versus current level. The curve shows the amount of time required for the protective device to trip at a given overcurrent level. The larger the overload or fault current, the faster the breaker/fuse will operate to clear the circuit (referred to as inverse time characteristics). A comparison of characteristic trip curves is necessary to determine whether proper coordination exists between devices.

Triplex Cable
A cable composed of three insulated single-conductor cables twisted together. (IEEE Std. 100-1988)

Note: AC 3-phase (3Φ) power cables are commonly of triplex design.

Unprotected Circuit/Cable
A circuit/cable that is not provided with fire protection features sufficient to satisfy applicable requirements. (Section III.G.2 of Appendix R or Position C.5.b of SRP Section 9.5.1)

Voltage
The effective RMS potential between any two conductors or between a conductor and ground. Voltages are expressed in nominal values unless otherwise indicated. (IEEE Std. 100-1988)

Clarification: The electrical force that causes free electrons to move from one atom to another. Voltage is similar to pressure in a water pipe.

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CHAPTER 3. BACKGROUND INFORMATION AND EXPERIENCE RELATED TO FIRE-INDUCED CIRCUIT FAILURES

3.1 Background

Like any large industrial complex, an NPP contains an extensive array of systems and components, and nearly all of this equipment directly or indirectly depends on the continuous operation of one or more electrical circuits and cables. A typical BWR requires approximately 96 km (60 miles or 316,000 ft) of power cable, 77 km (50 miles or 254,000 ft) of control cable and 402 km (250 miles or 1,320,000 ft) of instrument cable. More than 1,600 km (1,000 miles or 5,280,000 ft) of cable went into the containment building of Waterford Steam Electric Generating Station, Unit 3, a pressurized-water reactor (PWR).[4] Because of their large quantity and the fact that much of the cable material is combustible (e.g., polymer insulation and outer jacket), cables frequently comprise a significant portion of the total combustible fire loading in many areas of a plant.

As evidenced by the Browns Ferry fire in 1975, electrical circuit failures resulting from fire-damaged cables can have a substantial impact on safe plant operations. Although the BFN fire was contained to a relatively small interior area of the plant, temperatures as high as 815.5 °C (1,500 °F) caused damage to more than 1,600 cables routed in 117 conduits and 26 cable trays. As described below, circuit failures resulting from damage to these cables caused equipment to operate in unexpected ways and significantly impeded the operators' ability to monitor and control reactor safety functions.

3.2 Circuit and Cable Primer

An electrical circuit is analogous to a circular path through which electrons flow. In the circuit illustrated in Figure 3-1, the flow path is from the negative battery terminal through the load (lamp) and back to the positive battery terminal. In more complex circuits, many paths may split off to various components, but they always form a line from one side (polarity) of the power source and return to the opposite side (polarity) of the power source.

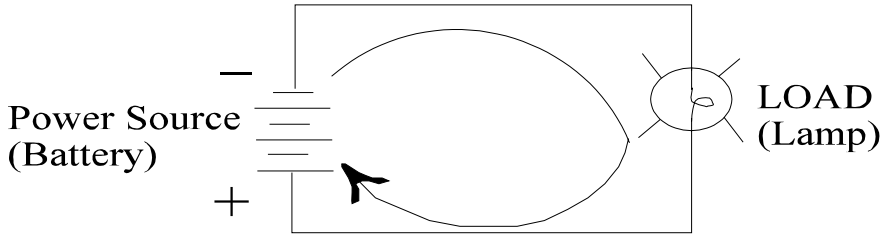
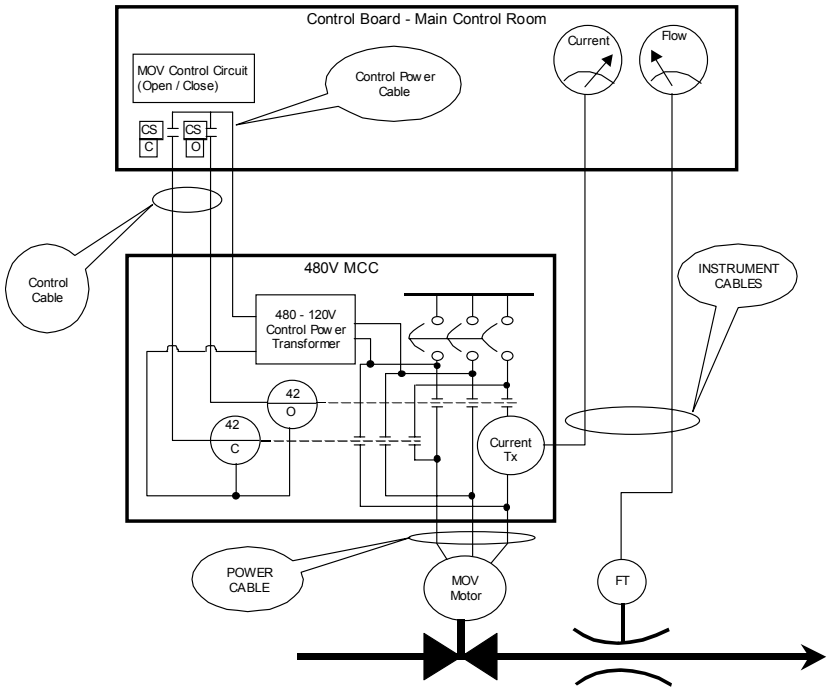


Figure 3-1 Circuit Illustration

[4] NUREG/CR-6384, "Literature Review of Environmental Qualification of Safety-Related Electric Cables," Volume 1, April 1996.

For small, simple circuits, such as the one illustrated in Figure 3-1, the electrical path between components could be established by short lengths of individual wire conductors. However, in a large installation such as an NPP, the circuit components may be located at great distances from each other. For example, the power source in the above illustration may be a fuse panel that is located in the service water intake structure, while the load is a pump status indicator lamp that is located in the control room. For such applications, long lengths of cable containing one or more insulated wires or conductors are needed to establish the path for current to flow (i.e., complete the circuit). By contrast, in a complex facility, such as a power plant, many cables of various types, construction, and sizes are needed to distribute electric power, control signals, and process system information. As depicted in Figure 3-2, these cables are generally classified by the function they perform:

- *Power cables* distribute power from power supplies (SWGRs, MCCs, panel boards) to utilization equipment. Within the plant, power cables are classified by the level of voltage they carry. Medium-voltage power cables (4.16-kV, 6.9-kV) distribute power to auxiliary transformers, electrical SWGRs, and large motors. Low-voltage power cables (<1,000-V) supply power to MCCs, MOVs, pumps, and motors.
- *Control cables* allow remote control of a component or a permissive/interlock signal.
- *Instrument cables* transmit low-level signals from the instrument sensor to an indicator, controller, or recorder.



LEGEND
CS: Control Switch
C: Close
O: Open
42O: Open Relay
42C: Close Relay
FT: Flow Transmitter
MOV: Motor Operated Valve
TX: Transformer

Figure 3-2 General Cable Classifications

3.2.1 Cable Construction and Materials

As illustrated in Figure 3-3, most cables used in an NPP are composed of three parts, including a metallic conductor, insulation, and a protective polymer jacket.

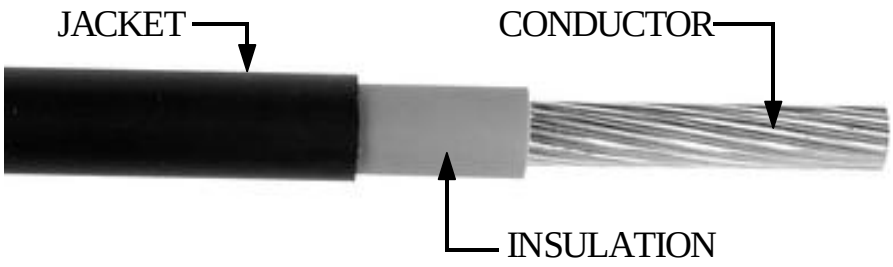


Figure 3-3 Cable Components

The conductor provides a low-resistance path for electrical current or signals. Copper and aluminum are popular conductor materials and may be either solid or stranded. As its name implies, a solid conductor is a single length of wire, whereas a stranded conductor is made by twisting individual strands of wire around each other until the desired conductor diameter or "gauge" is achieved. The conductor shown above in Figure 3-3 is a stranded conductor. While there is little difference in their electrical capabilities, stranded conductors are far more flexible than solid conductors of the same gauge, making them easier to install. The majority of cables found in plants contain stranded copper conductors. A cable may contain a single conductor (Figure 3-3), or a large number of separately insulated conductors. A cable containing more than one conductor is called a "multi-conductor cable." Figure 3-4 shows cross-sectional view of a multi-conductor cable containing seven conductors.

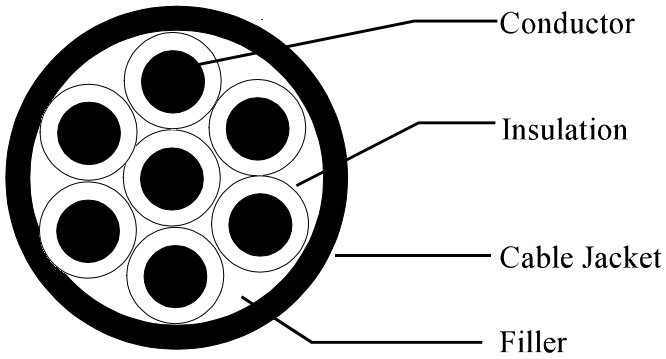


Figure 3-4 Multi-Conductor Cable (7-Conductor)

Insulation isolates the conductor from unwanted paths of current flow (e.g., grounded conduit or cable tray, other conductors, and personnel). Many different types of insulation materials are available to accommodate the specific application, environment, and service conditions of a cable. In most nuclear power applications, cables are insulated with either thermoset or thermoplastic materials. Thermoplastic materials are made from compounds that will re-soften and distort from their formed shapes by heating above a critical temperature peculiar to the material. Polyvinyl chloride (PVC) and polyethylene (PE) are examples of thermoplastic compounds. Thermoset insulation and jacket compounds will not re-soften or distort from their formed shapes by heating until a destructive temperature is reached. Insulation and cable outer jackets made from cross-linked polyethylene (XLPE), chlorosulfonated polyethylene (CSPE, commonly called Hypalon), and Neoprene are examples of thermoset materials. Cables that survive the full range of environment and flame spread conditions of IEEE 383 (IEEE 383-qualified cables) will likely have thermoset jackets and insulation with a failure temperature of approximately of 371 °C (700 °F). Cables that are not IEEE 383-qualified typically have thermoplastic jackets and insulation and may have a failure temperature as low as 218 °C (425 °F) depending on the melting or softening temperature of the specific thermoplastic polymer.

The voltage rating of a cable is the highest voltage that may be continuously applied and is generally a function of the type and amount (thickness) of insulation used. Cables used in low-voltage applications ($\leq$600 V) are generally rated at 600 V regardless of their actual application voltage. Cables in the low-voltage range include instrument circuits (50 V or less), control and control power circuits (120–250 V range) and certain power circuit applications (120, 480, and 600 V). Single- and multi-conductor cables used in medium-voltage applications (e.g., 4,160 V) are available with nominal voltage ratings of 5 kV, 8 kV, 15 kV, 25 kV, and 35 kV.

The cable jacket is usually a plastic cover that protects the cable from mechanical damage and chemical attack during installation and throughout its service life. Some of the more common jacket materials are PVC, Neoprene, and Hypalon. The jacket does not perform any electrical function. Where a high degree of physical protection is desired, cables may be furnished with a metallic outer sheath (or armor) made from interlocked aluminum or steel. Cables of this type are called "armored cables." Armoring protects the cable from penetration by sharp objects, crushing forces, and damage from gnawing animals or boring insects. Armored cables may be bare (i.e., exposed metal armor), or the armor may be covered with an additional layer of polymer jacket. Figure 3-5 illustrates an example of an armored power cable.

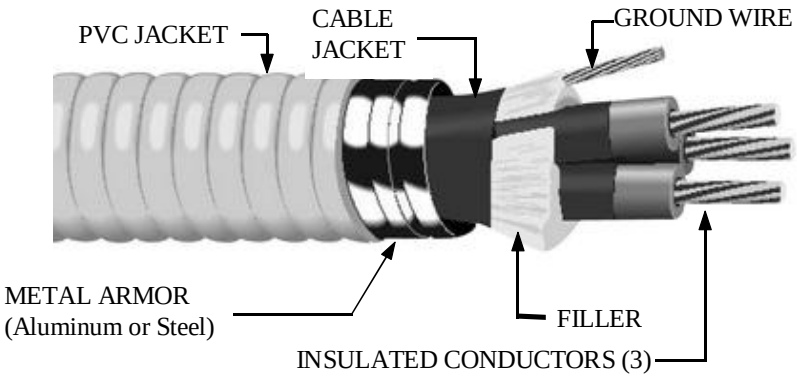


Figure 3-5 Armored Cable

Power cables may be of single- or multi-conductor design. Single-conductor cables are typically found inside electrical enclosures and cabinets, such as SWGRs and MCCs. A special type of multi-conductor cable called "Triplex cable" is commonly used in three-phase power applications, such as supplying power to an MOV from an MCC. A triplex cable contains three individually insulated conductors that are twisted around each other and contained within an outer jacket.

As shown in Figures 3-4 and 3-5, multi-conductor cables use a nonconductive "filler" material to occupy the openings (gaps) that are formed when a group of individual conductors are assembled. In addition to forming the shape (roundness) of the cable, fillers may also contribute to the flexibility and tensile strength of the cable.

Control and instrument cables are typically of multi-conductor design, as illustrated in Figure 3-7. Although the number of conductors that may be contained in a multi-conductor cable is theoretically unlimited, practical considerations such as the difficulty of installing long runs of very large-diameter cable tend to limit their size. Common control circuits employ multi-conductor cables having 3-, 7-, or 11-conductor configurations. Because of the need to block external sources of electrical "noise" generated by other plant equipment, instrument cables frequently use a number of "twisted/shielded pairs" of conductors contained within a protective outer jacket, as illustrated in Figure 3-7. The twisting of conductors reduces magnetic noise, while the shield and drain wire reduce electrostatic and radio-frequency interference. The shield consists of a conductive material (typically aluminum foil) that is wrapped around the twisted pairs of conductors. The uninsulated drain wire, which is in physical and electrical contact with the shield, provides for easier termination of the foil shield to a common ground point.

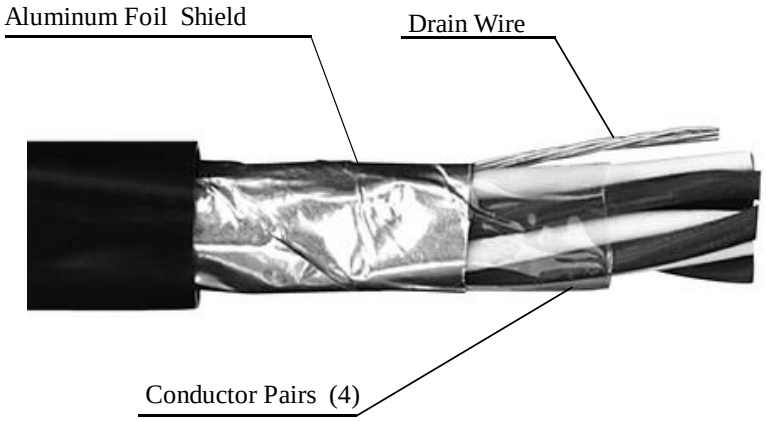


Figure 3-6 Illustration of Instrument Cable

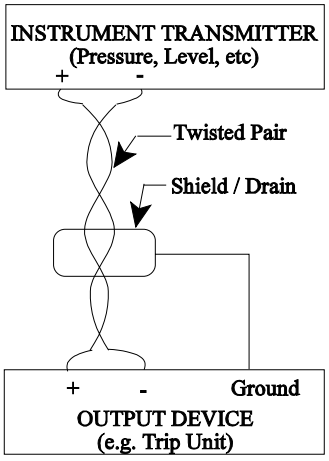


Figure 3-7 Twisted/Shielded Pair

3.2.2 Functional Considerations of Conductors and Cables

The fundamental purpose of a conductor is to provide a path for electrons to move from one location to another across a cable. The force or pressure that causes the electrons to move through the conductor is called *voltage*, which is measured in "volts." The quantity or flow rate of electrons moving through the conductor is called *current*. Current is measured in units called "amperes" or "amps," where 1 amp is equal to a flow of 1 coulomb per second through a wire (a coulomb is 6.28×10^{23} electrons). Simply stated, voltage causes current. Given a voltage and a complete path for the electrons (i.e., a complete circuit), current will flow. Given the path, but no voltage, or voltage without a path (e.g., an open circuit), there will be no current.

Resistance is a force that opposes the flow of electrons. Every material, including the most effective conductors (e.g., silver and gold), offers some resistance to current flow. Principal factors affecting the amount of resistance presented by a conductor include the following:

(1) Length: The longer the conductor, the higher the resistance.
(2) Diameter (gauge): The smaller the diameter of the conductor, the higher the resistance.
(3) Temperature: The higher the temperature, the higher the resistance.
(4) Material: Some materials are better conductors than others. Gold and silver are excellent conductors, but are also very expensive. Copper is widely used because it is a very good conductor and is not cost-prohibitive.

In the United States, cables are manufactured in accordance with the American Wire Gauge (AWG) standard, where "gauge" refers to the diameter of the metallic conductor (without insulation). The higher the gauge number, the smaller the diameter of the wire conductor. For example, wiring used to power receptacles in most U.S. households is AWG 12 or 14, while telephone wire is usually AWG 22 or 24. Because it has less electrical resistance over a given length, thick wire (i.e., small AWG number) can carry more current than thin wire (large AWG number). For example, a copper AWG 12 conductor is approximately 0.2 cm (0.08 inches) in diameter and can carry about 20 amperes of current. Conversely, an AWG 1 conductor has a diameter of approximately 0.76 cm (0.30 inches) and can carry about 150 amperes of current. Power cable conductors may range from 0.2 cm (0.08 inches) in diameter (AWG 12) to over 2.54 cm (1 inch). Because they carry less current, control cables commonly range from AWG 16 up through AWG 10, and instrumentation cables are generally AWG 16 or smaller.

The largest-diameter conductor specified in the AWG system is 0000 or 4/0 (pronounced "four ought"). Wire sizes larger than those covered in the AWG system are specified in "circular mills" (cmill). By definition, a circular mill is the area of a circle with a diameter of "1 mil" (1 one-thousandth of an inch). Because this unit is so small, the prefix "M" is normally used in denoting wire sizes. For example, a conductor that is 250,000 circular mils is normally denoted 250 MCM.

In most applications, the size of a cable is expressed in terms of the gauge (AWG) of its individual conductor(s) and the number of conductors it contains. For example, a cable that contains three AWG 12 conductors would be described as a "three conductor number 12" or "3/C, 12 AWG" cable.

Many people tend to think of a conductor's size (gauge) only in terms of its current-carrying capability (ampacity). For example, one general rule-of-thumb is that a cable containing AWG 12 copper conductors is sufficient to power loads supplied from a circuit breaker that has a 20-ampere trip point. While this rule-of-thumb may be sufficient for most home wiring applications, in large facilities such as NPPs, other factors such as cable length and ambient temperature may also have a significant impact on cable selection. As indicated above, the resistance of a conductor increases as its length increases, its diameter decreases, or the temperature of its surrounding environment (ambient temperature) increases. Heat is generated whenever a current flows through a conductor and, as the length of a cable increases, so does its resistance. This resistance, in turn, creates a voltage loss or "drop" in the cable. For example, if a cable is supplying power to a motor that is located some distance from its power source (e.g., MCC) and the gauge (diameter) of the cable conductors is not properly sized (increased) to accommodate for the additional resistance presented by the length of cable, the voltage measured at the motor will be less than that measured at the MCC and, in certain cases, may be insufficient for proper motor operation. Depending on the specific application, voltage drop and ambient temperature may be important considerations in the selection of cables.

The temperature rating of a cable/conductor is the maximum temperature at which its insulating material may be used in continuous operation without loss of its basic properties. The most common ratings are 60, 75, and 90 °C (or 140, 167, and 194 °F). Ampacity is the amount of current a cable/conductor can carry continuously under conditions of use without exceeding its temperature rating. This definition of ampacity recognizes that the maximum current that a conductor can carry continuously varies with the conditions of use as well as with the temperature rating of the conductor's insulation. For example, ambient temperature is a condition of use. A conductor with 60 °C (140 °F) insulation installed near a furnace so that the ambient temperature is 60 °C (140 °F) continuously has no current carrying capacity. Any current flowing through the conductor will raise its temperature beyond the 60 °C (140 °F) insulation rating. The ampacity of this conductor, regardless of its size, is therefore zero.[5]

The normal ambient temperature of a cable installation is the temperature the cable would assume at the installed location with no load being carried on the cable.[6] Ampacity limits for various combinations of cables and ambient temperatures are given in the NEC (ANSI/NFPA 70). In addition to ambient temperature, many other external factors can affect the ampacity of an electrical conductor. Examples include cable tray fill, heat generated by the conductor as a result of load current flow, heat generated by adjacent cables (e.g., within the same cable tray), and any insulating material that may surround the cable (e.g., fire-protective wrapping over a cable tray). Such factors must be taken into consideration when selecting conductors for a specific application.

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5 *The National Electric Code Handbook*, P.J. Schram, Editor, National Fire Protection Association, Quincy, MA, 1997.

6 ANSI/IEEE Std. 141-1986.

3.3 Circuit Failure Modes and Mechanisms

As previously discussed, cables are composed of one or more electrical conductors. The individual conductors are electrically isolated from each other and from other possible diversion paths (e.g., ground) by a layer of electrical insulation material. When exposed to the effects of fire and its related perils (e.g., firefighting activities), insulation and other protective materials (e.g., jacket) may be subjected to a broad range of potentially damaging stressors or failure mechanisms. For example, heat could cause a significant reduction in the quality of electrical isolation provided by the conductor's insulation material or (in certain cases) cause it to completely melt away. Heat, combined with smoke and products of combustion, could initiate faults in electronic components and printed circuit boards. The addition of fire suppression agents could further exacerbate the effects of already damaged insulation. Mechanical forces, such as those that may be inflicted during firefighting activities (e.g., impact of a fire hose stream), could cause a further reduction in the physical and electrical integrity of circuits and cables. As a result, circuits and cables that are exposed to the effects of fire are expected to experience one or a combination of the following fault conditions or failure modes:

- *Open Circuit:* The loss of electrical continuity (i.e., the conductor is broken and the signal or power does not reach its destination), as illustrated in Figure 3-8.

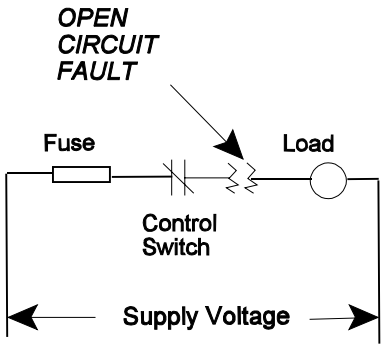

Figure 3-8 Open Circuit Fault

- *Short Circuit:* An abnormal connection of relatively low-impedance between two points of different potential , as illustrated in Figure 3-9.

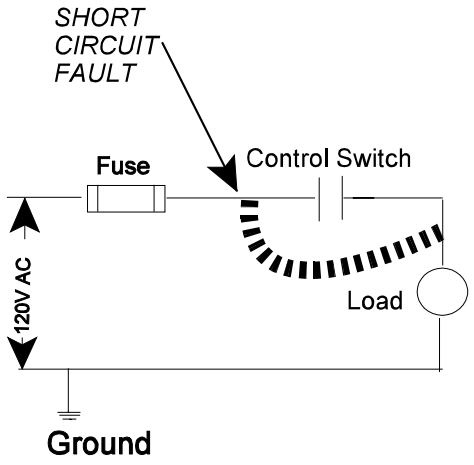

Figure 3-9 Short Circuit Fault

- *Shorts to Ground:* A conductor comes into electrical contact with a grounded conducting medium, such as a cable tray, conduit, or grounded conductor, as illustrated in Figure 3-10.

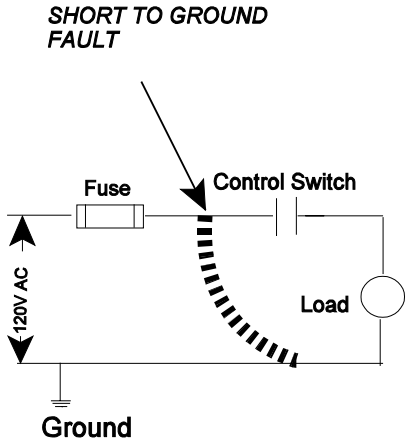

Figure 3-10 Short-to-Ground Fault

- *Hot Short:* A special type of short circuit condition that causes a previously un-energized conductor to become energized. As a result of this fault, the voltage, current, or instrument signal present in the energized conductor(s) is impressed on the previously un-energized conductor(s). As illustrated in Figure 3-11, a hot short could bypass circuit protective features and cause the unintentional actuation of equipment.

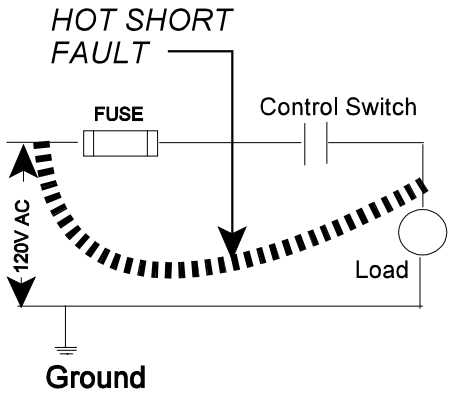

Figure 3-11 Hot Short Fault

- *High-Impedance Fault*: A special type of short-circuit condition in power cables where the fault contains some element of resistance to current flow. An arcing fault is a specific type of HIF. Rather than having direct contact offering minimal resistance to fault current (i.e., "bolted" fault condition), the arcing fault current must flow through or "arc over" a small air gap or water. "Because of the resistance of the arc and the impedance of the return path, current values are substantially reduced from the "bolted fault level."[7] For analytical purposes, HIF current is postulated to be a value that is just below the trip point of the individual circuit protective device (fuse or circuit breaker).

3.4 The Browns Ferry Fire

On March 22, 1975, a severe fire involving electrical cables occurred at BFN Unit 1, which is operated by TVA. The Browns Ferry plant consists of three BWRs, each of which is designed to produce 1,067 megawatts (MW) of electrical power. At the time of the fire, Units 1 and 2 were operating at 100-percent capacity, while Unit 3 was still under construction.

The fire began in a bank of cable trays in an area of the Unit 1 cable spreading room (CSR) where the trays passed through a penetration in a wall separating the CSR from the reactor building. At BFN, the reactor building functions as the secondary containment for the nuclear steam supply systems (NSSSs). To preclude uncontrolled and unmonitored releases of airborne radioactivity, the reactor building is designed (and required by license condition) to be maintained at a negative pressure of 62.3 Pa (0.25 inches of H_2O), in relation to the remainder of the plant and the outside environment. Each penetration through the reactor building wall was sealed with polyurethane (PU) foam to prevent leakage.

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[7] ANSI IEEE Standard 242-1986, "IEEE Recommended Practice for Protection and Coordination of Industrial and Commercial Power Systems."

The penetration seal inspection process in place at the time of the fire used differential pressure as a means of identifying defective seals. If a penetration seal was defective, the flame would flicker and smoke from a candle would be drawn toward the seal. When workers used this method to test a modified seal, however, the candle flame was drawn into the penetration, igniting the sheet polyurethane (PU) foam that was used as a sealant material. The pressure differential between the CSR and the reactor building then fanned the fire, causing it to rapidly spread to a large number of cables located in trays on the opposite side of the wall.

The fire continued to burn for more than 7 hours as a result of a number of contributing factors, including the large amount of combustible cable insulation involved in the fire, the inaccessibility of fire in cable trays located approximately 6.5 meters (20 feet) above the floor, dense smoke, limited availability of breathing apparatuses and the operators' reluctance to use water to extinguish an electrical fire. Although the fire had a significant impact on plant operations, only a relatively small area of the plant was actually involved. In the CSR, damage was limited to a 2.32-m^2 (25-$ft^{2)}$ area adjacent to the penetration where the fire started. The major fire damage occurred on the opposite side of this penetration in an area of the reactor building measuring approximately 12.16 m x 6.08 m (40 ft x 20 ft).

Although damage was limited to a relatively small area of the plant, temperatures as high as 815.5 °C (1,500 °F) caused damage to more than 1,600 cables routed in 117 conduits and 26 cable trays. Of those, 628 cables were safety-related and their damage caused the loss of a significant number of plant safety systems, including redundant trains of emergency core cooling systems (ECCSs) and electric power and control systems. Fire-induced damage to cables located in the area, also impeded the functioning of normal cooling systems and degraded the capability to monitor the status of the plant.

As described in Section 3.3, when conductors of circuits and cables are exposed to the effects of fire and/or firefighting activities, their electrical integrity and, hence, their ability to properly function is compromised. The Browns Ferry fire demonstrated the impact that fire-induced cable faults can have on the operability of redundant plant safety systems. Table 3-1 depicts some of the more important consequences of the fire in Unit 1. Although not as severe, the fire also impacted Unit 2 operations for approximately 6 hours following initiation of the fire. Examples of abnormalities noted by Unit 2 operators include the loss of electrical power supplied from various 4-kV and 480-V shutdown boards, closure of the main steam isolation valves (MSIVs), loss of the manual actuation capability of all safety relief valves (SRVs), and loss of high-pressure coolant injection (HPCI) as a result of spurious closure of torus suction valves.

While certain operational consequences developed as the fire progressed, a review of the documented chronology of the event indicates that many abnormalities, including spurious ECCS alarms, false instrument indications, reductions in power level (resulting from a run-back of the reactor recirculation pumps for no apparent reason), and spurious starts and stops of RHR, core spray (CS), reactor core isolation cooling (RCIC), and HPCI pumps, were observed to occur rather quickly, during the first 20–30 minutes following the ignition of PU sealant material. The Browns Ferry fire was a clear demonstration of the impact that a fire involving redundant trains of electrical circuits and cables can have on operators' ability to monitor and control important plant parameters.

Table 3-1. Consequences of Cable Damage Attributable to Fire at Browns Ferry Unit 1[8]	
Consequence of Fire Damage	Attributed Cause
Loss of power supplied from 480-V shutdown boards 1A and 1B	• Fire-induced hot-short in circuit breaker trip indicator light caused voltage to be backfed to the breaker trip coil, thereby keeping it energized • Power cable faults
Spurious closure and inability to reopen MSIVs	Fire damage to MSIV control circuits
Spurious trip of reactor feedwater pump "A"	False high reactor water level signal to feedwater pump controller (Note remaining feed pumps B and C were manually tripped at the time of the scram)
Inoperability of HPCI	Fire-induced faults to cables associated with 250-VDC MOV board 1A (which powers HPCI valve controls), and cables associated with 480-V MOV board 1A (which powers the steam isolation valve)
Inoperability of redundant RHR systems (1A, 1B, 1C, and 1D)	Fire-induced failure of 480-V MOV boards 1A and 1B caused loss of power to valves. Also, fire-induced loss of power supplied from 4-kV shutdown board C caused a loss of RHR pump 1B.
Inoperability of redundant core spray (CS) systems (1A, 1B, 1C, and 1D)	Fire-induced failure of 480-V MOV board 1A and 1B caused loss of power to valves. Also, fire-induced loss of power supplied from 4-kV shutdown board C caused loss of CS pump 1B
Inoperability of redundant trains of standby liquid control systems (SLCSs) (1A, 1B)	Fire-induced loss of power from redundant 480-V shutdown boards 1A and 1B to pump motors and valves
Inoperability of RCIC	Inability to electrically operate steam isolation valve as a result of a cable fault and loss of power on 480-V MOV board 1B

[8] "Hearings Before the Joint Committee on Atomic Energy, Congress of the United States, First Session," September 16, 1975.

Table 3-1. Consequences of Cable Damage Attributable to Fire at Browns Ferry Unit 1 (continued)	
Consequence of Fire Damage	Attributed Cause
Loss of ability to operate all relief valves	Spurious closure and inoperability of 7 of 11 relief valves attributed to loss of power supplied from redundant 250-VDC boards 1A and 1B. Subsequent spurious closure of drywell air compressor flow control valve cut off air supply to remaining 4 relief valves, thereby rendering them inoperable for 4 hours
Abnormal behavior of instrumentation: • Observed ECCS alarms were contrary to system status • Random lights on ECCS panel began glowing alternately bright and dim	Fire damage to ECCS instrumentation circuits
Loss of operability of EDG "C" and loss of remote control capability of EDG "B" and EDG "D"	Fire damage to EDG control and instrumentation circuits

3.5 Insights and Observations Resulting from the Nuclear Energy Institute Fire Test Program

To further investigate the effects of fire conditions on circuit integrity and the potential for fire-induced spurious actuations, NEI and EPRI sponsored a series of 18 cable fire tests at Omega Point Laboratories (OPL), located in Elmendorf, Texas, during the period from January 8 through June 1, 2001. All tests were conducted within a steel enclosure that was 3.04 m x 3.04 m x 2.43 m (10 ft x 10 ft x 8 ft) with a single natural ventilation opening in one wall. Since the primary objective was to assess the potential for fire to cause undesired spurious actuations of equipment, the test included only control and control power (120-VAC) cables and did not include ungrounded DC circuits and power cables (480-VAC and 4,160-VAC). As a result, the tests did not fully evaluate the potential for fire to cause certain types of power circuit-fault conditions, such as HIFs.

In conducting the tests, OPL used three types of cables, including a specific type of multi-conductor armored cable having thermoset insulation, several types of thermoplastic cable, and several types of thermoset cable. OPL connected the tested cables to a single control circuit that had been selected as the object of study for spurious actuation. That control circuit was a NEMA-1 starter for an MOV. Important insights gained from this testing are highlighted by the following observations elicited from the experts responsible for reviewing the test results: [9]

[9] "Spurious Actuation of Electrical Circuits Due to Cable Fires: Results of Expert Elicitation," EPRI Technical Report 1006961, Final Report, EPRI Palo Alto, California, May 2002.

- *"Hot shorts leading to spurious actuations cannot be regarded as of negligible importance if the fire under consideration produces cable temperatures above the thresholds identified herein."*
- *"For the majority of the tests there was at least one devise actuation observed, and for several tests multiple actuations were observed… There was at least one spurious operation for almost every configuration tested… Overall, the likelihood of spurious actuation given failure was found to be somewhat higher than I might have assumed prior to conduct of the tests."*
- *"Thermoplastic cable is more likely to degrade to the point of allowing leakage currents large enough to cause device actuations or blown fuses than either armored cable or thermoset cable for the same exposure conditions."*
- *"It appears that 204.5 °C (400 °F) is the approximate degradation temperature of the thermoplastic cable used in these experiments and 371 °C (700 °F) is the approximate degradation temperature of the thermoset cable used in these experiments."*
- *"Water spray on damaged cables can cause spurious actuations to occur."*
- *"The available test data as a whole demonstrates that at least four factors are critical to the assessment of spurious actuation likelihood: armored versus non-armored cables; cables in trays versus cables in conduits; cable-to-circuit wiring configuration; and circuits without control power transformers (CPTs) versus circuits with CPTs."*
- *"The tested configuration used a 150 VA CPT on a nominal 120 V circuit. This application may bound, for example, NEMA size 1 starters which are limited to typically a maximum 7.5 HP motor. For circuits with a higher range, it is suggested to use the non-CPT values."*
- *"No open-circuit type of failures were observed which places an upper bound on such an end-point in the range of a 1-percent probability, given the number of possible open circuits."*
- *"Shorting to another conductor within the same cable is much more likely than shorting to a conductor in another cable."*
- *"The probability that a source conductor in a multi-conductor cable will short to an adjacent (different) single conductor cable (cable-to-cable short) is generally lower than the probability that a conductor-to-conductor short will occur within the multi-conductor cable."*
- *"For the cable configuration tested, the data indicate that a single-conductor cable will usually short to ground before shorting to another single conductor cable. For thermoset cables the probability is about 85–90-percent. For thermoplastic cables the probability is about 70–75-percent."*
- *"Undesired spurious actuations were caused by a single conductor cable shorting to an adjacent single conductor cable without grounding (cable-to-cable short). The probability for this case is estimated to fall between 0.05 and 0.30 with a best estimate point value near 0.20."*
- *"Undesired spurious actuations were caused by an interaction between an energized conductor within a multi-conductor cable having one grounded conductor and an adjacent single conductor cable. The probability for this case is estimated to fall between 0.05 and 0.20 with a best estimate point value near 0.10.*"
- *"Several instances of multiple spurious actuations were observed in the same test, sometimes involving different conductors in the same multi-conductor cable."*
- *"For armored, multi-conductor, thermoset, cable having its armor shield maintained at ground potential, the probability of conductor-to-conductor shorts is estimated to be in the 20–30-percent range. This is significantly lower than the 70–80-percent range estimated for unarmored cable."*
- *"The opportunity for armored cable shorting to another cable (cable-to-cable short) was observed to be nil… this probability should be zero."*

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CHAPTER 4. NRC REGULATORY REQUIREMENTS

4.1 Safety Objective

The fundamental safety objective of the NRC's regulatory program is to ensure adequate protection of public health and safety. This means that the risk to the public from normal operation, anticipated transients, and accidents must be acceptably low, and the likelihood of accidents more severe than those postulated for design purposes must be extremely small. To achieve this high level of safety, redundant (i.e., identical or diverse) safety systems are incorporated into the design of all NPPs that are currently operating in the United States. Redundancy provides assurance that failures affecting one system will not have a significant impact on plant safety because the plant design provides a "backup" system.

To further increase that assurance, the safety equipment and cables of the redundant subsystems are typically segregated into divisions. The separate and redundant divisions of safety systems provide confidence that the failure of components or cables within one division will not adversely affect the plant's ability to accomplish required safety functions. In the absence of suitable protection features, such as separation distance or structural barriers, however, redundant trains of cables and equipment could be susceptible to a phenomenon known as "common-mode" failure, in which multiple failures in redundant systems may occur as a result of a common cause[10]. If a single event could induce failures in more than one of the redundant elements, the safety and reliability benefits afforded by this essential design feature could be negated. Flooding, earthquakes, and fire are three examples of events that have the potential to initiate common-mode failures in redundant safety systems.

As discussed in Chapter 3, a major fire at BFN Unit 1 on March 22, 1975, illustrated the impact that common-mode failures attributable to fire may have on the operation of a commercial NPP. Four days after that event, the NRC established a Special Review Group (SRG) to investigate the cause of the fire and evaluate the need to improve the FPPs at all NPPs. The SRG found serious design inadequacies regarding fire protection at Browns Ferry. In its report, entitled "Recommendations Related to the Browns Ferry Fire" (NUREG-0050, dated February 1976), the SRG provided more than 50 recommendations for improving fire prevention and control in existing facilities. The SRG specifically noted that the independence of redundant equipment at Browns Ferry was negated by not having a suitable degree of separation between cables associated with redundant trains of safety equipment. As a result, the SRG recommended that a suitable combination of electrical isolation, physical distance, barriers, and sprinkler systems should be applied to maintain the independence of redundant safety equipment and, therefore, the availability of safety functions despite postulated fires. In view of its findings, the SRG called for the development of specific guidance for implementing fire protection regulations, and for a comparison of that guidance with the FPP at each operating plant.

[10] IEEE Std. 100, "The Authoritative Dictionary of IEEE Standards Terms" (IEEE Standard Dictionary of Electrical and Electronics Engineers), 1988.

The Browns Ferry fire was sufficiently significant to warrant major changes in the FPPs of NPPs operating in the United States. As discussed in this section, in the years following the Browns Ferry fire, the NRC and the nuclear industry expended considerable resources to develop and implement fire protection guidelines and regulatory requirements that would minimize both the probability of occurrence and the possible consequences of postulated fires. As a result, each operating plant currently has an approved FPP that is anchored in the long-established defense-in-depth (DID) safety principle of providing multiple protective barriers to prevent and mitigate accidents. This protection consists of administrative controls and personnel training to reduce the potential for fire to start, as well as plant design features to rapidly detect and promptly extinguish those fires that may occur. In addition, because of the potentially unacceptable consequences that an unmitigated fire may have on plant safety, each operating plant must demonstrate that in the event a fire were to initiate and continue to burn (despite prevention and mitigation features), the performance of essential shutdown functions will be preserved and radioactive releases to the environment will be minimized.

Recent studies have shown that the revised requirements for protecting SSCs that are important to safe-shutdown are beneficial to safety in the event of fire. Plant design changes required by the new regulatory framework (Appendix R to 10 CFR Part 50) have been effective in preventing a recurrence of a fire event of the severity experienced at Browns Ferry. In addition, according to a"Fire Risk Scoping Study" performed in 1989 by Sandia National Laboratories (SNL), plant modifications made in response to the new requirements have reduced the core damage frequencies (CDFs) at some plants by a factor of 10. The study also suggested that improper implementation of the regulatory requirements and degradation of fire protection DID could be risk-significant. The study concluded, for example, that weaknesses in either manual firefighting effectiveness or control system interactions could raise the estimated fire-induced CDF by an order of magnitude.

In GL 88-20, Supplement 4, the NRC asked each licensee to perform an individual plant examination of external events (IPEEE) for plant-specific severe accident vulnerabilities that are initiated by external events. Under the IPEEE program, the licensees systematically assessed the fire risk for each operating reactor and submitted the results to the NRC. The results of the IPEEE fire analyses provide important insights regarding reactor fire risk and confirm the results of the SNL "Fire Risk Scoping Study." For example, the IPEEE results show that fire events are important contributors to the reported CDF for a majority of plants, ranging on the order of $1 \times 10^{-9} – 1 \times 10^{-4}$ core damage events per reactor-year, with the majority of plants reporting a fire CDF in the range of $1 \times 10^{-6} – 1 \times 10^{-4}$ core damage events per reactor-year. In some cases, the reported CDF contribution from fire events can exceed that from internal events[11].

[11] SECY 99-140, "Recommendation for Reactor Fire Protection Inspections," U.S. Nuclear Regulatory Commission, Washington, DC, May 20, 1999.

4.2 Background

Appendix A to 10 CFR Part 50, "General Design Criteria for Nuclear Power Plants," establishes the necessary design, fabrication, construction, testing, and performance requirements for SSCs that are important to safety. With regard to fire protection, GDC 3 states:

> *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 ensure that their rupture, or inadvertent operation does not significantly impair the safety capability of these structures, systems, and components.*

During the first decade or so of the U.S. nuclear reactor program, regulatory acceptance of FPPs at the Nation's NPPs was based on the broad performance objectives of GDC 3. Because of the lack of detailed implementation guidance at that time, however, the level of fire protection was generally found to be acceptable if the facility complied with local fire codes and received an acceptable rating from its fire insurance underwriter. Thus, the fire protection features in early U.S. NPPs were very similar to those of conventional, fossil-fueled, power generating stations.

The lessons learned from the Browns Ferry fire brought fundamental change to fire protection and its regulation in the U.S. nuclear power industry. As described in Section 3.4, the fire was started by plant workers who used a candle flame to test for air leakage through a penetration in a wall that separated the CSR from the reactor building. Although most of the fire damage was contained to a relatively small area of the reactor building [approximately 74.32 m^2 (800 ft^2)], the fire affected more than 1,600 cables, routed in 117 conduits and 26 cable trays, of which 628 were important to safety. The resulting damage impeded the functioning of both normal and standby reactor cooling systems, significantly degraded the operators' ability to monitor important plant parameters, and forced operators to initiate emergency repairs in order to restore systems needed to place the reactor in a safe-shutdown condition.

The Browns Ferry fire demonstrated that the occupant safety and property protection concerns of the major fire insurance underwriters did not sufficiently encompass nuclear safety issues, particularly with regard to the potential for fire to cause the failure of systems and components that are important to safe-shutdown of the reactor. Investigations of the cause and possible consequences of this event revealed several significant fire protection vulnerabilities, including the following examples:

- apparent ease with which the fire started
- hours that elapsed before the fire was fully extinguished
- unavailability of redundant trains of plant safety equipment as a result of fire damage

On the basis of these findings, the NRC concluded that additional guidance and requirements beyond the existing fire protection regulation (GDC 3) were necessary. In recognition of the potential consequences of fire, and to ensure adequate fire safety in the overall design and

operation of all NPPs operating in the United States, the NRC determined that established DID safety principles should be applied in the defense against fires.

DID is a fundamental safety philosophy that provides multiple layers of protection (i.e., barriers) to prevent and mitigate accidents. With regard to fire protection, the DID concept is aimed at achieving the following objectives:

- Prevent fires from starting.
- Rapidly detect, control, and extinguish those fires that do occur.
- Protect SSCs that are important to safety so that a fire that is not promptly extinguished by the fire protection activities will not prevent the safe-shutdown of the plant.[12]

The multiple levels of protection that are embodied in the DID philosophy ensure fire safety throughout the life of the plant by minimizing both the probability and the consequence of fires. While the NRC recognizes that no one level can be perfect or complete by itself, and strengthening any one level can compensate in some measure for known or unknown weaknesses in the others, each level of protection must meet certain minimum requirements.

Consistency with the DID philosophy is maintained if the plant meets the following criteria:

- Preserve a reasonable balance among prevention of core damage, prevention of containment failure, and mitigation of consequences.
- Avoid over-reliance on programmatic activities to compensate for weaknesses in plant design.
- Preserve system redundancy, independence, and diversity commensurate with the expected frequency and consequences of challenges to the system, as well as the associated uncertainties (e.g., no risk outliers).
- Preserve defenses against potential common-cause failures, and assess the potential for the introduction of new common-cause failure mechanisms.
- Prevent degradation of the independence of barriers.
- Preserve defenses against human errors.
- Maintain the intent of the the GDCs in Appendix A to 10 CFR Part 50.[13]

4.3 Development of Fire Protection Program Requirements

To assist licensees in enhancing their FPPs, the NRC staff incorporated the recommendations from the Browns Ferry SRG into a single technical guidance document identified as BTP APCSB 9.5-1, “Guidelines for Fire Protection for Nuclear Power Plants,” dated May 1976. In so doing, the staff asked each licensee to submit an analysis that divided the plant into distinct fire areas and demonstrated that redundant trains of equipment required to achieve and maintain cold shutdown conditions were adequately protected from fire damage. However, the guidance contained in BTP APCSB 9.5-1 was only relevant to plants that filed an application for construction after July 1, 1979.

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[12] 10 CFR Part 50, Appendix R , Section II, “General Requirements, Paragraph A, Fire Protection Program.”

[13] Regulatory Guide 1.174, “An Approach for Using Probabilistic Risk Assessment In Risk-Informed Decisions On Plant-Specific Changes to the Licensing Basis,” U.S. Nuclear Regulatory Commission, Washington, DC, July 1998.

Consequently, the NRC staff sought to establish a suitable FPP without significantly affecting the design, construction, or operation of "older" plants that were either already operating or well past the design stage and into construction. Toward that end, in September 1976, the NRC issued Appendix A to BTP APCSB 9.5-1 "Guidelines for Fire Protection for Nuclear Plants Docketed Prior to July 1, 1976". This guidance provided acceptable alternatives in areas where strict compliance with BTP APCSB 9.5-1 would require significant modifications. Additionally, the NRC informed each plant that the staff would use the guidance in Appendix A to analyze the consequences of a postulated fire within each area of the plant, and asked licensees to provide results of the fire hazards analysis performed for each unit and TSs for the present fire protection systems.

Early in 1977, each pre-1979 licensee responded with an FPP evaluation that included a fire hazards analysis (FHA). The NRC staff reviewed these analyses using the guidelines of Appendix A to BTP APCSB 9.5-1. The staff also conducted inspections of operating reactors to examine the relationship between SSCs important to safety and the fire hazards, potential consequences of fires, and fire protection features. Based on the results of its reviews, the staff determined that additional guidance on the management and administration of FPPs was needed and, on August 29, 1977, the staff issued GL 77-02, "Nuclear Plant Fire Protection Functional Responsibilities, Administrative Controls, and Quality Assurance." This document provided the criteria used by the staff in reviewing specific elements of a licensee's FPP, including organization, training, combustible and ignition source controls, firefighting procedures, and quality assurance.

By the late 1970s, most operating plants had completed their analyses and implemented most of the FPP guidance of Appendix A to the BTP. Many fire protection issues were resolved during the BTP review process, and agreements were included in the NRC-issued safety evaluation reports (SERs). In certain instances, however, licensees refused to adopt some of the specified fire protection recommendations, such as the requirements for fire brigade size and training, water supplies for fire suppression systems, alternative or dedicated shutdown capability, emergency lighting, qualifications of penetration seals used to enclose places where cables penetrated fire barriers, and the prevention of reactor coolant pump oil system fires. Following deliberation, the Commission determined that, given the generic nature of some of the disputed issues, a rulemaking was needed to ensure proper implementation of the NRC's fire protection requirements. Accordingly, the Commission amended its regulations and, in November 1980, issued 10 CFR 50.48, "Fire Protection" (which specified broad performance requirements), and Appendix R, "Fire Protection Program for Nuclear Power Plants Operating Prior to January 1, 1979" (which specified detailed regulatory requirements for resolving the disputed issues).

As originally proposed (*Federal Register*, Vol. 45, No. 1&5, May 22, 1980), Appendix R would have applied to all plants that were licensed to operate before January 1, 1979, including those for which the staff had previously accepted the fire protection features as meeting the provisions of Appendix A to BTP APCSB 9.5-1. However, after analyzing comments on the proposed rule, the Commission determined that only 3 of the 15 items in Appendix R were of such safety significance that they should apply to all plants that were licensed before January 1, 1979. These three items are (1) fire protection of safe-shutdown capability, including alternative or dedicated shutdown systems; (2) emergency lighting; and (3) the reactor coolant pump oil system. The final rule required all reactors licensed to operate before January 1, 1979,

to comply with these three items *even if the NRC had previously approved alternative fire protection features in these areas* (*Federal Register*, Vol. 45, November 19, 1980). In addition, the rule provided an exemption process that a licensee can request, provided that a required fire protection feature to be exempted would not enhance fire protection safety in the facility or that such modifications may be detrimental to overall safety.

By letter dated November 24, 1980, the Commission informed all power reactor licensees with plants licensed before January 1, 1979, of new fire protection regulations contained in 10 CFR 50.48 (to ensure that each plant had an FPP) and Appendix R to 10 CFR Part 50 (to ensure satisfactory resolution of disputed items). In its letter, the Commission stated that the provisions of Appendix R can be divided into two categories:

(4) Those provisions that the new rule requires licensees to backfit in their entirety, regardless of whether the NRC staff previously approved alternatives to the specific requirements of these sections. These requirements are set forth in Sections III.G, "Fire Protection of Safe-Shutdown Capability"; III.J, "Emergency Lighting"; and III.O, "Oil Collection Systems for Reactor Coolant Pump."

(5) Requirements concerning the "open items" of previous NRC staff fire protection reviews. (An "open item" is defined as a fire protection feature that the staff has not previously approved as satisfying the provisions of Appendix A to BTP APCSB 9.5-1, as reflected in a fire protection SER.)

The two enclosures to this letter included (1) a copy of the *Federal Register* Notice (45 FR 76602) and (2) a summary of open items that the staff identified during its evaluation of the plant's implementation of Appendix A to BTP APCSB 9.5-1.

4.3.1 NPPs Licensed Before January 1, 1979

With the exception of Sections III.G, J,and O (which were backfit by all plants operating before January 1, 1979, regardless of previous staff approvals of alternatives), those portions of Appendix A to the BTP APCSB 9.5-1 that were previously accepted by the staff remained valid. Therefore, Appendix R does not, by itself, define the FPP of any plant. For plants licensed before January 1, 1979 (pre-1979 plants), the FPP is defined by Appendix A to the BTP, the *applicable portions* of Appendix R to 10 CFR Part 50 (i.e., open issues from BTP APCSB 9.5-1 Appendix A reviews), and any additional commitments made by the licensee, as stated in the conditions of its operating license.

4.3.2 NPPs Licensed After January 1, 1979

As stated above, Appendix R is only required to be implemented by plants licensed to operate before January 1, 1979. FPPs at plants licensed after this date were typically reviewed by the staff during their initial licensing process. Certain plants in this category were required to implement specific sections of Appendix R (typically sections III.G., J, and O), as specified in their "Fire Protection" license condition. Consequently, there was no need to "backfit" Appendix R to plants licensed after January 1, 1979. Additionally, only two paragraphs of the Fire Protection Rule (10 CFR 50.48) apply to plants that were licensed after January 1, 1979. Specifically,

those paragraphs are Paragraph A (requiring plants to have a fire protection plan that satisfies Criterion 3 of Appendix A to 10 CFR Part 50) and Paragraph B (requiring plants to complete all fire protection modifications needed to satisfy GDC 3 of Appendix A to 10 CFR Part 50 in accordance with the provisions of their operating licenses).

Guidelines acceptable to the staff for implementing GDC 3 at plants licensed after January 1, 1979, are presented in SRP Section 9.5.1, "Fire Protection Program." This document consolidates the guidance of BTP APCSB 9.5-1, Appendix A to BTP APCSB 9.5-1 (originally issued in August 1977), and the criteria of Appendix R to 10 CFR Part 50. Thus, SRP Section 9.5.1 may be considered a single-source reference that describes the features of an acceptable FPP.

4.4 Requirements, Guidelines, and Clarifications Related to Post-Fire Safe-Shutdown Capability

The NRC's regulatory framework for nuclear power plant FPPs is set forth in a number of regulations and supporting guidelines, including, but not limited to the following:

- Title 10, Section 50.48, of the *Code of Federal Regulations* (10 CFR 50.48)
- Appendix R to 10 CFR Part 50
- General Design Criterion 3 (GDC 3) of Appendix A to 10 CFR Part 50
- regulatory guides (RGs) and generic communications [e.g., generic letters (GLs), bulletins (BLs), and information notices (INs)]
- NUREG-series technical reports, including NUREG-0800, "NRC Standard Review Plan" (SRP)
- associated branch technical positions (BTPs) and industry standards

The comprehensive fire protection guidance and regulatory criteria described in these documents address the broad range of features that comprise an acceptable FPP. Consistent with the objectives of this report, however, this section discusses only those requirements, guidelines, and generic communications (clarification documents) that specifically relate to post-fire safe-shutdown capability and the performance of a safe-shutdown analysis.

Regulatory requirements of primary interest include GDCs 3, 5, 19, and 23 of Appendix A to 10 CFR Part 50; 10 CFR 50.48; and Sections III.G and III.L of Appendix R to 10 CFR Part 50. While the NRC recognizes that Appendix R is not applicable to plants that were licensed to operate after January 1, 1979, the technical requirements of Sections III.G and III.L were subsumed into the review guidance that the NRC staff developed for plants that were licensed to operate after that date (i.e., Position C.5.b of SRP Section 9.5-1). It is important to note that some of the regulations and guidelines described below are not applicable to each plant. Therefore, licensees and reviewers must refer to the plant-specific fire protection licensing bases when determining the applicability of regulations and guidelines for a specific NPP.

4.4.1 10 CFR Part 50, Appendix A, "General Design Criteria for Nuclear Power Plants"

For those plants to which its provisions apply, 10 CFR Part 50, Appendix A, "General Design Criteria for Nuclear Power Plants," establishes the necessary design, fabrication, construction, testing, and performance requirements for SSCs that are important to safety. Of these requirements, the following criteria have apply specifically to fire protection of NPPs.

- **GDC 3, "Fire Protection,"** requires that SSCs important to safety must be designed and located to minimize (consistent with other safety requirements) the probability and effect of fires and explosions. Noncombustible and heat-resistant materials are required to be used wherever practical, and particularly in locations such as the containment and control room. Fire detection and firefighting systems of appropriate capacity and capability are required to be provided and designed to minimize the adverse effects of fires on SSCs important to safety. GDC 3 also requires that firefighting systems must be designed to ensure that their failure, rupture, or inadvertent operation does not significantly impair the safety capability of these SSCs.

- **GDC 5, "Sharing of Structures, Systems, and Components,"** requires that SSCs important to safety must not be shared among nuclear power units unless it can be shown that such sharing will not significantly impair their ability to perform their safety functions, including, in the event of an accident in one unit, an orderly shutdown and cooldown of the remaining units.

- **GDC 19, "Control Room,"** requires that the design must provide a control room from which operators can take actions to operate the nuclear power unit under both normal and accident conditions, while limiting radiation exposure to control room personnel under accident conditions for the duration of the accident. GDC 19 also requires that equipment and locations outside the control room must be provided with the design capability to accomplish hot shutdown of the reactor, as well as a potential capability for subsequent cold shutdown of the reactor. It should be noted that the GDC 19 design criteria were largely based on environmental/habitability concerns within the control room. As a result, GDC 19 does not specifically consider the effect of equipment damage as a result of fire.

- **GDC 23, "Protection System Failure Modes,"** requires that the protection system must be designed to fail into a safe state or into a state demonstrated to be acceptable on some other defined basis if the plant experiences conditions such as disconnection of the system, loss of energy (e.g., electric power, instrument air), or postulated adverse environments (e.g., extreme heat or cold, fire, pressure, steam, water, radiation).

4.4.2 10 CFR 50.48, "Fire Protection"

Section 50.48(a) of 10 CFR Part 50 requires that each operating NPP must have a fire protection plan that satisfies GDC 3 of Appendix A to 10 CFR Part 50. It also specifies what such a plant should contain and lists the basic fire protection guidelines for the plan. Section 50.48(b) requires that all plants licensed before January 1, 1979, must satisfy the requirements of Sections III.G, J, and O, and other sections of Appendix R to 10 CFR Part 50, where approval of similar features had not been obtained prior to the effective date of Appendix R. Alternatively, plants licensed to operate after January 1, 1979, must meet the provisions of 10 CFR 50.48(a). The required schedules for licensees to comply with the provisions of Appendix R were established in 10 CFR 50.48(c). The rule also included provisions to allow licensees to file requests for exemptions from Appendix R requirements on the basis that the required modifications would not enhance the facility's fire protection safety or would be detrimental to overall facility safety. Upon approval by the staff, these exemptions become a part of the plant's fire protection licensing basis. The provisions of 10 CFR 50.48(c) have since expired and been deleted from the regulations.

In accordance with 10 CFR 50.48, each operating NPP must provide the means to limit fire damage to SSCs important to safety in order to ensure the capability to safely shut down the reactor. Licensees should develop an SSA that demonstrates the plant's capability to safely shut down for a fire in any given area. (See Chapter 6.)

4.4.3 10 CFR Part 50, Appendix R, "Fire Protection Program for Nuclear Power Facilities Operating Prior to January 1, 1979"

One of the principal goals of regulatory requirements and staff guidance issued since the Browns Ferry fire is to ensure that, in the event of fire in any area of the plant, one train of equipment needed to achieve and maintain safe-shutdown conditions in the reactor will remain free of fire damage. To achieve this objective, 10 CFR 50.48(b), which became effective on February 17, 1981, requires all NPP licensed before January 1, 1979, to meet the requirements of Section III.G, "Fire Protection of Safe-Shutdown Capability," of Appendix R to 10 CFR Part 50, regardless of any previous NRC approvals for alternative design features. Compliance with this criterion requires each licensee to reassess all areas of the plant and demonstrate for each area that suitable fire protection features (as specified in Section III.G.2 of Appendix R) are provided for redundant trains of cables and equipment necessary to achieve and maintain hot shutdown conditions. As part of this evaluation, the rule requires licensees to consider the potential effects of fire on associated nonsafety-related circuits and cables that could impact the shutdown capability. (See Chapters 3 and 6.) With regard to the fire protection of safe-shutdown capability, facilities that commenced operation on or after January 1, 1979, are subject to essentially the same criteria as those contained in Appendix R. These criteria have been imposed through license conditions or licensing commitments.

In developing the Fire Protection Rule, the Commission decided that the overall interest of public safety is best served by establishing some conservative level of protection and ensuring that level of compliance. The objective for fire protection of safe-shutdown capability is to ensure that at least one means of achieving and maintaining safe-shutdown conditions will remain available during and after any postulated fire in the plant. Because it is not possible to predict the specific conditions under which fire may occur and propagate, the design-basis protective features are specified rather than the design-basis fire. The fire protection features specified in Section III.G are not unique to the nuclear industry. Rather, they are based upon principles long accepted within that portion of U.S. industry that has been classified by their insurance carriers as "improved risk" or "highly protected risk."[14]

Section III.G.1 of Appendix R to 10 CFR Part 50 requires that fire protection features must be provided for SSCs that are important to safe-shutdown. These features must be capable of limiting fire damage so that the following conditions are maintained:

(a) One train of systems necessary to achieve and maintain hot shutdown conditions from either the control room or emergency control station(s) is maintained free of fire damage.

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[14] SECY 80-438A, "Rule on Fire Protection Program for Nuclear Power Plants Operating Prior to January 1, 1979," Enclosure A, U.S. Nuclear Regulatory Commission, Washington, DC, September 30, 1980.

(b) The extent of fire damage to redundant trains of systems and equipment necessary to achieve and maintain cold shutdown is limited so that at least one train can be repaired or made operable within 72 hours using onsite capabilities.

The fire areas falling under the requirements of III.G.1(b) are those for which an alternative or dedicated shutdown capability is not being provided. For those fire areas, Section III.G.1(b) requires only the capability to repair the systems necessary to achieve and maintain cold shutdown from either the control room or emergency control station(s) within 72 hours, not the capability to repair and achieve cold shutdown within 72 hours as required for the alternative or dedicated shutdown modes by Section III.L.[15]

Section III.G.2, provides various options for protecting the capability to achieve and maintain hot shutdown conditions, as follows:

> *Where cables or equipment, including associated nonsafety circuits that could prevent operation or cause maloperation 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 nonsafety 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; or*
>
> *(b). Separation of cables and equipment and associated nonsafety circuits of redundant trains by 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; or*
>
> *(c) Enclosure of cable and equipment and associated nonsafety 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 nonsafety circuits of redundant trains by horizontal distance of more than 20 feet with no intervening combustibles or fire hazards; or*
>
> *(e) Installation of fire detectors and an automatic fire suppression system in the fire area; or*
>
> *(f) Separation of cables and equipment and associated nonsafety circuits of redundant trains by a noncombustible radiant energy shield.*

Note: Since fire areas are frequently described in terms of the section of III.G that they meet, additional clarification is warranted with regard to the use of this terminology:

- For a fire area to "meet III.G.1," at least one train of shutdown systems and equipment must be completely independent (physically and electrically) of the fire area.

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[15] GL 86-10, Enclosure 1, Paragraph 2, "Repair of Cold Shutdown Equipment," U.S. Nuclear Regulatory Commission, Washington, DC.

- A “III.G.2 Fire Area” contains redundant trains of shutdown equipment; however, one train has been ensured to remain free of fire damage (per the criteria contained in this section of the regulation).
- A “III.G.3 Fire Area” contains redundant trains of shutdown equipment or cables and one train has *not* been ensured to remain free of fire damage (per III.G.2 criteria) or redundant trains are vulnerable to damage as a result of fire suppression activities or the inadvertent actuation of fire suppression systems.

Interpretation 3 of GL 86-10 defines the term “free of fire damage” in Section III.G.1.a. The NRC provided this interpretation to clarify Section III.G.1.a, during the exemption process, for licensees who are attempting to justify the lack of III.G.2 separation features for redundant trains within a single fire area. For any fire area, an approved exemption is required where neither alternative safe-shutdown nor the separation features of Section III.G.2 are provided. [Reference: “Generic Guidance for Post-Fire Safe-Shutdown Analysis Assessment,” Rev. G, Boiling-Water Reactor Owners Group (BWROG), p. 3-48, June 24, 1998.]

As indicated in the above text, Appendix R to 10 CFR Part 50 uses the term “free of fire damage.” In promulgating Appendix R, the Commission provided acceptable methods for ensuring that necessary SSCs are free of fire damage. (See Appendix R, Section III.G.2a, b and c.) Specifically, the SSCs under consideration must be capable of performing their intended functions during and after the postulated fire, as needed.[16]

Where the protection of systems that are required to function properly for hot shutdown does not satisfy the requirement of Section III.G.2, or 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, Section III.G.3 requires that an alternative or dedicated shutdown capability must be provided and must be independent of cables, systems, or components in the area, room, or zone under consideration. In addition, Section III.G.3 further requires that fire detection and a fixed fire suppression system must be installed in the area, room, or zone under consideration. Specific criteria for implementing this capability are contained in Appendix R, Section III.L, “Alternative and Dedicated Shutdown Capability.”

Although 10 CFR 50.48(b) does not specifically include Section III.L with Sections III.G, J, and O of Appendix R to 10 CFR Part 50 as a requirement applicable to all power reactors licensed before January 1, 1979, the appendix, read as a whole, and the Court of Appeals decision on the appendix, in the case of Connecticut Light and Power et al. vs. NRC, 673 F2d. 525 (D.C. Cir., 1982), demonstrate that Section III.L applies to the alternative safe-shutdown option under Section III.G if and where that option is chosen by the licensee[17].

Section III.G recognizes that the need for alternative or dedicated shutdown capability may have to be considered on the basis of a fire area, room, or fire zone. The alternative or

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[16] GL 86-10, Enclosure 1, Paragraph 3, “Fire Damage,” U.S, Nuclear Regulatory Commission, Washington, DC.

[17] GL 86-10, Enclosure 2, Question 5.1.3, U.S, Nuclear Regulatory Commission, Washington, DC.

dedicated capability should be independent of the fire area where it is possible to do so. 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 ensure that the performance requirement set forth in Section III.G.l is met. Where alternative 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 suppressants must be evaluated.

These environments may be due concerns such as the hot gas 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 alternative 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[18]. While "independence" is clearly achieved where alternative shutdown equipment is outside the fire area under consideration, alternative shutdown equipment in the same fire area but independent of the room or the zone may also result in compliance with the regulation. The "room" concept must be justified by a detailed fire hazards analysis that demonstrates that a single fire will not disable both the normal shutdown equipment and the alternative shutdown capability.[19]

The remote shutdown systems recommended in Chapter 7 of the SRP are needed to meet GDC 19. These remote shutdown systems need to be redundant and physically independent of the control room in order to meet GDC 19. For GDC 19, damage to the control room is not considered. Alternative shutdown systems for Appendix R need not be redundant, but must be both physically and electrically independent of the control room.[20]

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[18] GL 86-10, Enclosure 2, Question 3.1.5, U.S. Nuclear Regulatory Commission, Washington, DC.

[19] GL 86-10, Enclosure 1, Paragraph 6, "Alternative or Dedicated Shutdown," U.S. Nuclear Regulatory Commission, Washington, DC.

[20] GL 86-10, Enclosure 2, Question 5.3.11, U.S. Nuclear Regulatory Commission, Washington, DC..

4.4.4 Generic Communications

To aid in developing a common understanding between licensees and NRC reviewers and inspectors, the staff has promulgated a number of clarification documents, principally in the form of GLs and INs. When considering guidance contained in generic communications, it is essential to note the following points:

(4) It is the Commission's position that regulatory guidance by itself cannot alter the specific regulatory requirements contained in the Commission's fire protection regulations.[21]

(5) NRC generic letters cannot legally create a new requirement for a specific course of action to resolve an issue. Generic communications have been used, however, to provide new or clarified interpretations of existing requirements.[22]

Table 4-1 summarizes the salient generic communications related to post-fire safe-shutdown capability.

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[21] Letter from J. Hannon, NRC, to A. Marion, Nuclear Energy Institute; Subject: Adoption of NFPA Standard 805, dated April 6, 2001.

[22] Statement presented by Shirley Ann Jackson, Chairman, NRC, to the U.S. Senate Committee on Environment and Public Works, Subcommittee on Clean Air, Wetlands, Private Property, and Nuclear Safety, concerning NRC programs and nuclear safety regulatory issues, July 30, 1998.

Table 4-1. NRC Generic Communications	
Generic Communication	Description
GL 77-02	Provided guidance to supplement Appendix A BTP APCSB 9.5-1, regarding a licensee's fire protection organization, training of the fire brigade, control of combustibles and ignition sources, firefighting procedures, and quality assurance.
GL 81-12 and Clarification of GL 81-12	In these letters, the staff identified the information necessary to review licensee compliance with the alternative or dedicated shutdown requirements of Section III.G.3 of Appendix R to 10 CFR Part 50. These letters defined safe-shutdown objectives, reactor performance goals, necessary safe-shutdown systems and components, and associated circuit identification and analysis methods. GL 81-12 also asked licensees to develop TSs for safe-shutdown equipment that was not previously included in the existing plant-specific TSs.
GL 83-33	Provided clarification on the following requirements of Appendix R to 10 CFR Part 50: (a) detection and automatic suppression (b) fire areas (c) structural steel related to fire barriers (d) fixed suppression system (e) intervening combustibles (f) transient fire hazards It should be noted that certain licensees disagreed with, or found it difficult to implement, the interpretations provided in this GL. To pursue the matter with senior NRC management, the nuclear power industry formed the Nuclear Utility Fire Protection Group. To "…examine all licensing, inspection and technical issues and to make policy recommendations for expediting Appendix R implementation and for ensuring consistent levels of fire protection at all plants," by direction of the Executive Director for Operations (EDO), the staff formed the Steering Committee on Fire Protection Policy. Disagreements in the implementation of interpretations provided in GL 83-33 were ultimately resolved by issuance of GL 86-10, "Implementation of Fire Protection Requirements," on April 24, 1986.

Table 4-1. NRC Generic Communications	
Generic Communication	Description
IN 84-09	Provided guidance for conducting analyses and/or making modifications to implement requirements of Appendix R to 10 CFR Part 50, with respect to the following issues: (a) fire areas (b) fire barrier testing and configuration (c) protection of equipment necessary to achieve hot shutdown (d) licensee's reassessment for conformance with appendix r (e) identification of safe-shutdown systems and components (f) combustibility of electrical cable insulation (g) detection and automatic suppression (h) applicability of 10 CFR Part 50, Appendix R, Section III.L (i) instrumentation necessary for alternative shutdown (j) procedures for alternative shutdown capability (k) fire protection features for cold shutdown systems (l) RCP oil collection systems
IN 85-09	Alerted licensees to potential deficiencies in the electrical design of isolation/transfer switches, which do not provide redundant fuses upon transfer

Table 4-1. NRC Generic Communications	
Generic Communication	Description
GL 86-10	Provided additional guidance on acceptable methods of satisfying the NRC's regulatory requirements. Although the staff issued this document, it had the review and approval of the Commission. This letter addressed the following specific topics: (a) scheduler exemptions (b) documentation required to demonstrate compliance (c) applicable quality assurance requirements (d) NRC notification of deficiencies (e) incorporation of FPP into FSAR (f) standard fire protection license condition Through the implementation and adoption of a standard license condition, a licensee is allowed to make changes to its FPP without prior notification to the NRC in accordance with the provisions of 10 CFR 50.59, provided that the changes do not adversely affect the plant's ability to achieve and maintain post-fire safe-shutdown. Upon modification of the license to adopt the standard condition, the licensee could also amend the license to remove the fire protection TSs. (g) interpretations of Appendix R: • process monitoring instrumentation • repair of cold shutdown equipment • fire damage • fire area boundaries • automatic detection and suppression • alternative or dedicated shutdown capability (h) Appendix R questions and answers To assist the industry in understanding the NRC's requirements, and improve the staff's understanding of the industry's concerns, a series of workshops were conducted in each NRC region. This section presents the NRC's position as responses to the questions posed by the industry during these workshops.
GL 88-12	Provided additional guidance for implementation of the standard license condition and removal of the TSs associated with fire detection and suppression, fire barriers, and fire brigade staffing. The TSs associated with safe-shutdown equipment and the administrative controls related to fire protection audits were to be retained under the guidance of the GL.
IN 99-17	Alerted licensees to potential problems associated with post-fire safe-shutdown circuit analysis that could prevent the operation or lead to malfunction of equipment necessary to achieve and maintain post-fire safe-shutdown.

4.5 Fire Protection Licensing and Design Bases

With the issuance of the Fire Protection Rule (10 CFR 50.48, and Appendix R to 10 CFR Part 50), the NRC established the applicability of certain fire protection requirements, including those within the rule, on the basis of the licensing date for a given plant being before or after January 1, 1979. However, the progression of regulatory guidelines and requirements outlined above, coupled with a broad range of plant-specific attributes (design features, operating preferences, and exemptions to certain technical requirements), has created a unique set of circumstances for nearly every plant. Design and construction factors, such as plant type (PWR vs. BWR), age, size, NSSS supplier [Westinghouse Electric, Combustion Engineering (CE), Babcok and Wilcox (B&W), General Electric (GE)], architect/engineer, degree of separation provided for redundant shutdown systems in the initial plant design, type of cabling used (e.g., thermoset vs. thermoplastic insulation), and the individual preferences of a utility for system and equipment configurations can significantly influence the type and quantity of fire protection features needed to provide an acceptable level of protection. The influence that such factors have on the protection of safe-shutdown capability is considered by the staff and documented in plant-specific SERs (see below). As a result of these plant-specific differences, fire protection features imposed on one plant often differ considerably from those at another.

4.5.1 Plants Licensed Before January 1, 1979

The primary licensing basis for plants licensed to operate before January 1, 1979, comprises the plant's license conditions, Appendix R and any approved exemptions, and the staff's SERs of the FPP.

4.5.2 Plants Licensed After January 1, 1979

Plants licensed after January 1, 1979, are subject only to the requirements of 10 CFR 50.48(a) and, as such, must meet the provisions of GDC 3 as specified in their license conditions and as accepted by the NRC in their SERs. These plants are typically reviewed to the guidance of SRP Section 9.5-1. For these plants, where commitments to specific guidelines cannot be met, or alternative approaches are proposed, the differences between the licensee's program and the guidelines are documented in deviations.

4.5.3 Safety Evaluation Reports

Safety evaluation reports (SERs) document the staff acceptance of the plant's FPP or elements thereof. For plants licensed to operate prior to January 1, 1979, the staff's SERs also establish the extent to which the requirements of Appendix R to 10 CFR Part 50 apply. Plants for which the NRC previously accepted alternative fire protection features as satisfying the provisions of Appendix A to BTP APCSB 9.5-1, or accepted such alternatives in comprehensive SERs issued prior to publication of Appendix A to BTP APCSB 9.5-1 in August 1976, were only required to meet the provisions of Sections III.G (III.L), III.J, and III.O of Appendix R.

4.5.4 Exemptions and Deviations

When it promulgated Appendix R to 10 CFR Part 50, the Commission recognized that there would be plant conditions and configurations where strict compliance with specified fire protection design features would not significantly enhance the level of fire safety already provided by the licensee. Therefore, in cases where an FHA could adequately demonstrate that alternative fire protection features provided a level of fire safety equivalent to that required by the regulation, the licensee could apply for an exemption from the prescriptive requirements of Appendix R. Thus, the exemption process provided a means of allowing flexibility to meet the performance objectives of Appendix R through alternative means. For plants that began operation after January 1, 1979, guidance for the plants' FPPs is provided in BTP Chemical and Mechanical Engineering Branch (CMEB) 9.5-1. For these newer plants, the staff approved "deviations" from the guidance during the licensing process. Since Appendix R requirements are included in BTP CMEB 9.5-1, this report uses the term "exemptions" to refer to both BTP CMEB 9.5-1 deviations as well as Appendix R exemptions.

Through the performance of a detailed FHA of plant-specific conditions, a licensee may demonstrate that certain configurations, which do not meet the technical requirements of the regulation, will provide an adequate level of fire safety. For example, the evaluation of a fire area at a certain plant may find that although redundant shutdown components are adequately separated [>6.08 m (>20 ft) of horizontal separation distance)], the area between the components contains a small quantity of intervening combustibles in the form of cables routed in cable trays. Although this configuration does not satisfy the technical requirements of the rule (which specifies that the separation area must be free of intervening combustibles or fire hazards), when other protection features are considered (such as the use of armored sheathed cables, adequacy of installed fire detection systems, automatic and manual suppression capabilities, and the quantity and type of combustibles in the area), it may be shown that strict compliance with the technical requirements would not enhance fire safety. When such plant-specific conditions exist, licensees may request NRC approval of an exemption from the technical requirements of the regulation under 10 CFR 50.12. Under this provision, the Commission may grant exemptions from the requirements of the regulations in 10 CFR Part 50, which are authorized by law, will not present an undue risk to public health and safety, and are consistent with the common defense and security. The Commission will not consider granting an exemption unless special circumstances are present, as in the following cases:

- Application of the regulation in the particular circumstances conflicts with other rules or requirements of the Commission.
- Application of the regulation in the particular circumstances would not serve the underlying purpose of the rule or is not necessary to achieve the underlying purpose of the rule.
- Compliance would result in undue hardship or other costs that are significantly in excess of those contemplated when the regulation was adopted, or that are significantly in excess of those incurred by others similarly situated.
- The exemption would result in benefit to the public health and safety that compensates for any decrease in safety that may result from the grant of the exemption
- The exemption would provide only temporary relief from the applicable regulation and the licensee or applicant has made good faith efforts to comply with the regulation.

- There is present any other material circumstance not considered when the regulation was adopted for which it would be in the public interest to grant an exemption. If such condition is relied on exclusively for compelling the Commission to grant the exemption, the exemption may not be granted until the EDO has consulted with the Commission.

As previously stated, plants licensed after January 1, 1979, have FPPs that were typically reviewed and approved under the guidance contained in SRP Section 9.5.1 and, therefore, are not subject to the specific regulatory requirements of 10 CFR 50.48 and Appendix R. For these plants, a license amendment or NRC staff approval of a deviation from a specific NRC guideline is necessary when an alternative approach is used to satisfy the requirements of GDC 3. As with an exemption, the licensee must submit a sound technical justification for the alternative approach for NRC review and approval, along with its license amendment or deviation request.

4.5.5 Standard Plant License Condition

Most operating plant licenses contain a section on fire protection. License conditions for plants licensed prior to January 1, 1979, typically contain a condition requiring implementation of modifications to which the licensee committed as a result of the FPP review with respect to the BTP. These license conditions were added by amendments issued between 1977 and February 17, 1981, the effective date of 10 CFR 50.48 and Appendix R. As a result of numerous compliance, inspection, and enforcement issues associated with the various plant license conditions, the staff developed a "standard licensing condition (see below), which the staff transmitted to licensees in GL 86-10, along with the NRC's recommendation that licensees should adopt the standard condition. The staff also issued GL 88-12 to provide additional guidance regarding removal of the fire protection requirements from the plant-specific TSs. The staff promulgated these changes specifically to give licensees greater flexibility in managing and implementing their FPPs and to clarify the fire protection licensing basis for each facility.

If the licensee has adopted the standard license condition and incorporated the FPP in its FSAR, the licensee may make changes to the approved FPP without prior Commission approval only if those changes would not adversely affect the ability to achieve and maintain safe-shutdown in the event of a fire, as documented in a safety evaluation. In addition to planned changes, a safety evaluation may be required for nonconforming conditions. GL 86-10 recommended that licensees incorporate the FPP by reference in the facility's FSAR. Incorporating the FPP and major commitments (including the FHA) by reference in the FSAR places the FPP (including the systems, administrative and technical controls, organization, and other plant features associated with fire protection) on a consistent status with other plant features described in the FSAR. GL 86-10 further recommended adopting the standard license condition, requiring licensees to comply with the provisions of the approved FPP as described in the FSAR and establishing when NRC approval is required for changes to the program. The licensee should maintain, *in auditable form*, a current record of all such changes, including an analysis of the effects of the changes on the FPP, and should make such records available to NRC inspectors upon request. All changes to the approved program should be reported, along with the FSAR revisions required by 10 CFR 50.71(e).

If the FPP committed to by the licensee is required by a specific license condition and is not part of the FSAR for the facility, licensees may be required to submit amendment requests even for relatively minor changes to the FPP.

The NRC transmitted to licensees the following standard license condition for fire protection in April 1986 as part of GL 86-10 with information on its applicability to specific plants:

> ***Fire Protection***
> *[Name of Licensee] shall implement and maintain in effect all provisions of the approved fire protection program as described in the Final Safety Analysis Report for the facility (or as described in submittals dated ----------) and as approved in the SER dated ---------- (and supplements dated ---------) subject to the following provision:*
>
> *The licensee may make changes to the approved fire protection program without prior approval of the Commission only if those changes would not adversely affect the ability to achieve and maintain safe-shutdown in the event of a fire.*

The adoption of the standard license condition in conjunction with the incorporation of the FPP in the facility's FSAR provides a more consistent approach to evaluating changes to the facility, including those associated with the FPP.

Within the context of the standard fire protection license condition, the phrase "not adversely affect the ability to achieve and maintain safe-shutdown in the event of a fire," means to maintain sufficient safety margins. (See RG 1.174 for additional information.)

If a proposed change involves a change to a license condition or technical specification that was used to satisfy NRC requirements, a license amendment request should be submitted. When a change that falls within the scope of the changes allowed under the standard fire protection license condition is planned, an evaluation is made to determine whether the change would adversely affect the ability to achieve and maintain safe-shutdown. The evaluation should include the effect on the FHA and the consideration of whether circuits or components, including associated circuits, for a success path of equipment needed for safe-shutdown are being affected or a new element introduced in the area. If this evaluation concludes that there is no adverse effect, this conclusion and its basis should be documented and be available for future inspection and reference. If the evaluation finds that there is an adverse effect, or that it is outside the basis for an exemption (or deviation) that was granted (or approved) for the area involved, the licensee should make modifications to achieve conformance, justify and request an exemption, or deviation from the NRC. (See GL 86-10, Questions 8.19, 8.20, and 8.21 for additional information.)

CHAPTER 5. DISCUSSION OF POST-FIRE SAFE-SHUTDOWN CAPABILITY

5.1 Fire Protection Program Objectives

The primary objective of FPPs at U.S. nuclear power reactors is to minimize both the probability of occurrence and the consequences of fire. As discussed in Chapter 4, to achieve this goal, FPPs are based on a "DID" safety concept that is aimed at achieving the following objectives::

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

This section focuses on the final element of the DID concept—ensuring that in the event a fire were to occur (despite prevention efforts) and continue to develop (despite features provided for its rapid detection and prompt extinguishment), the SSCs important to safe-shutdown would remain free of fire damage.

Redundancy is a fundamental safety feature incorporated into the design of all commercial NPPs operating in the United States. In essence, redundancy provides assurance that failures affecting one system will not have a significant impact on plant safety because the plant design provides a "backup" system. To further increase that assurance, the safety equipment and cables of the redundant subsystems are typically segregated into divisions. The separate and redundant divisions of safety systems provide confidence that the failure of components or cables within one division will not adversely affect the plant's ability to accomplish required safety functions.

To a certain extent, this design feature also provides a measure of safety against the possible consequences of fire. The level of confidence achieved through redundancy, however, is highly dependent on the degree of separation and independence provided for the redundant elements. In the absence of suitable protection features, such as separation distance or structural barriers, however, redundant trains of cables and equipment could be susceptible to a phenomenon known as "common-mode" failure, in which multiple failures in redundant systems may occur as a result of a common cause[23]. If a single event could induce failures in more than one of the redundant elements, the safety and reliability benefits afforded by this essential design feature could be negated. As demonstrated by the Browns Ferry fire, common-mode failures attributable to fire may cause equipment to fail and/or interact in ways that are not readily predictable.

The need to fully consider the potential consequences of fire damage to redundant divisions of safety equipment was emphasized by the SRG established by the NRC to investigate the Browns Ferry fire event:

> *The chronicle of the Browns Ferry fire includes many examples of unavailability of redundant equipment. Evidently, the independence provided between redundant subsystems and equipment was not sufficient to protect against common-mode failures.*

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[23] IEEE Std. 100, "The Authoritative Dictionary of IEEE Standards Terms" (IEEE Standard Dictionary of Electrical and Electronics Engineers), 1988.

Minimizing the potential for fire to cause common-mode failures in redundant divisions of shutdown equipment, is an essential element of the "DID" philosophy for fire protection. Achieving this objective requires that plant safety systems must be designed so that in the event that a fire should start (despite the fire prevention program) and continue to burn for a considerable time, it will not preclude the capability to achieve safe-shutdown functions.

5.2 Fire Damage Limits

Achieving safe-shutdown conditions is a sequential process that relies on the operation of various plant systems to achieve and maintain both hot and cold shutdown conditions. While certain shutdown functions, such as initial reactivity control must be immediately available, other functions, such as decay heat removal (DHR) may not be needed for some time after a reactor trip. The longer after reactor trip that a function is required, the more time the operators have to analyze the situation and take the necessary steps in order to effectively operate the systems that are needed to provide the function. Thus, fire damage to systems that are needed to achieve and maintain hot shutdown conditions poses a greater threat to safety than damage to equipment that is only needed to achieve and maintain cold shutdown. The need to ensure an adequate level of fire protection for systems and equipment needed to perform hot shutdown functions was underscored in the Commission's comments on Appendix R to 10 CFR Part 50. In its Statements of Considerations on the Fire Protection Rule (SECY 80-438A), the Commission included the following statement:

> *When considering the consequences of a fire in a given fire area, in evaluating the safe-shutdown capabilities of the plant, we must be able to conclude that one train of equipment that can be used immediately to bring the reactor to hot shutdown conditions remains unaffected by that fire.*

The regulation clearly specifies the relationship between the specific shutdown functions performed (i.e., hot or cold shutdown) and the level of fire damage permitted to plant systems. Specifically, Appendix R, Section I, "Introduction and Scope," establishes the fire damage limits based on the safety function of the SSCs, as summarized in Table 5-1.

Table 5-1. Fire Damage Limits Based on the Safety Function of the SSCs

Safety Function	Fire Damage Limit
Hot Shutdown	One train of equipment necessary to achieve hot shutdown from the control room or emergency control station(s) must be maintained free of damage by a single fire, including an exposure fire
Cold Shutdown	Both trains of equipment necessary to achieve cold shutdown may be damaged by a single fire, but damage must be limited so that at least one train can be repaired or made operable within 72 hours using onsite capabilities
Design-Basis Accident	Both trains of equipment necessary for mitigation of consequences following design-basis accidents may be damaged by a single exposure fire

Additionally, 10 CFR 50.48(b) requires that all licensed NPPs operating prior to January 1, 1979, must meet the requirements of Section III.G, "Fire Protection of Safe Shutdown Capability," of Appendix R to 10 CFR Part 50, regardless of any previous approvals by the NRC for other design features. Compliance with this criterion requires that each licensee must demonstrate that, in the event of an exposure fire in any single area of the plant, one of the redundant trains of cables and equipment necessary to achieve and maintain hot shutdown conditions will remain free of fire damage. Although hot shutdown equipment must remain free of fire damage, equipment required to achieve and maintain cold shutdown may be damaged, provided that the necessary repairs can be completed within the time restrictions established in the regulation. (Note: Facilities that began operation on or after January 1, 1979, are subject to essentially the same criteria as those contained in Appendix R ,which have been imposed through license conditions or licensing commitments).

It should also be noted that not all safety-class equipment requires the same level of protection from fire. SSCs that are only used to mitigate the consequences of design-basis accidents do not require the same level of fire protection as those needed to accomplish post-fire safe-shutdown. The basis for this position is provided in Section I, "Introduction and Scope," of Appendix R to 10 CFR Part 50:

> *Because fire may affect safe-shutdown systems and because the loss of function of systems used to mitigate the consequences of design-basis accidents under post-fire conditions does not per se impact public safety, the need to limit fire damage to systems required to achieve and maintain safe-shutdown conditions is greater than the need to limit fire damage to those systems required to mitigate the consequences of design-basis accidents.*

5.3 Evaluation Process Overview

To ensure the ability of achieve and maintain safe-shutdown conditions in the event of fire, licensees perform a comprehensive assessment of the potential effects of fire and its related perils (direct flame impingement, hot gases, smoke migration, firefighting water damage, etc.) in each fire area. The overall objective of this deterministic evaluation, which is frequently referred to as an "SSA," is to identify potential fire vulnerabilities and develop protective measures that are consistent with established requirements.(e.g., Section III.G of Appendix R to 10 CFR Part 50). This is a technically complex process, involving personnel who have expertise in fire protection, plant operations, electrical engineering, and mechanical systems engineering disciplines.

Information developed during performance of the FHA provides the initial input for the SSA. For example, in addition to identifying the plant fire areas, the FHA will contain important information related to fire barrier ratings, equipment locations, fire detection and suppression capabilities, etc. This information is then supplemented by facility design and engineering data, additional analyses and studies, and data developed by direct observation or walkdown of facility spaces and systems.

The NRC neither prescribes nor endorses a specific approach for performing a deterministic assessment of fire damage on the ability to achieve safe-shutdown conditions (i.e., SSA). Differences in plant design, construction, equipment layout and operating preferences have resulted in many variations in plant-specific approaches. However, the overall process of performing an SSA remains fairly consistent between plants.

As illustrated in Figure 5-1, the determination of post-fire safe-shutdown capability typically includes two principal assessments, namely a "systems analysis" and a "fire area analysis." As part of the systems analysis, the licensee defines required shutdown functions and identifies redundant trains or "paths"of plant systems capable of accomplishing each of these functions. The licensee then identifies equipment, cables, and circuits that are needed to ensure the operation of these systems or that may adversely affect the shutdown capability if they are damaged as a result of fire. After identifying the equipment and cabling needed to ensure safe-shutdown, the licensee may determine their physical location (by fire area). The licensee then performs a "fire area analysis" to assess the potential consequences that a postulated fire in each area may have on the plant's ability to achieve and maintain safe-shutdown conditions. Figure 5-1 provides an overview of this process, and Chapter 6 presents a more detailed discussion of the SSA process.

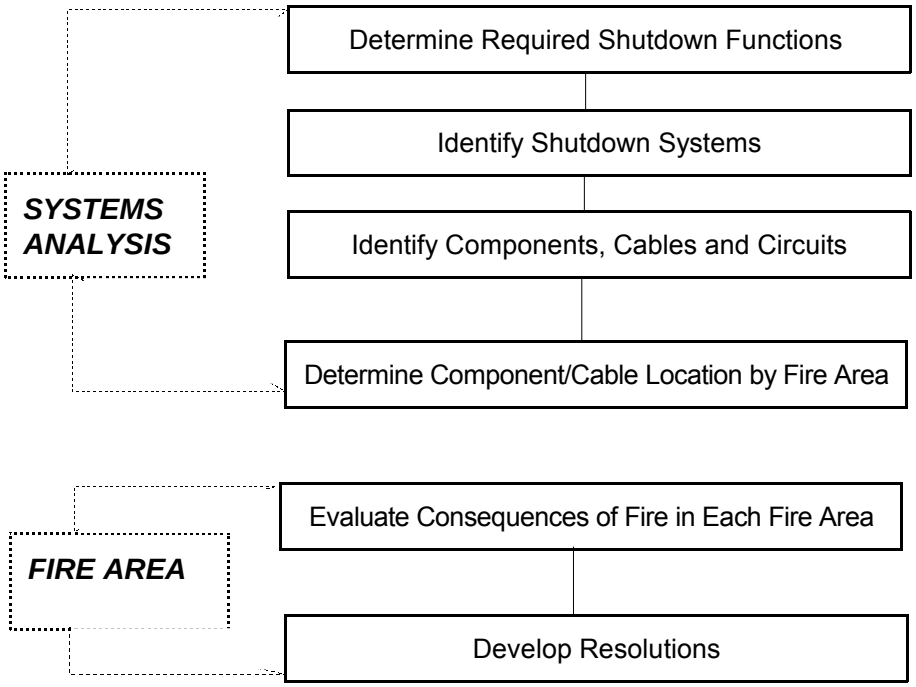

Figure 5-1 Overview of the Safe-Shutdown Evaluation Process

Because the SSA is based on large quantities of information and data, computer programs are frequently used to sort, manage, and analyze the data needed develop a safe-shutdown capability for the facility.

Conducting an SSA is an iterative process. As changes to the SSA database are implemented and facility modifications are installed, additional analysis must be performed to demonstrate that the changes have not compromised the previous analysis.

5.4 Analysis Assumptions

The following fundamental principles and assumptions establish the "ground rules" for performing an acceptable SSA:

Fire Hazards Analysis
An FHA, performed by qualified individuals, divides the plant into distinct fire areas and identifies fire hazards and major equipment located within each of those areas.

Shutdown Functions, Systems and Equipment
The systems and equipment needed for post-fire safe-shutdown are those systems necessary to perform the shutdown functions defined in Section III.L of Appendix R to 10 CFR Part 50. These functions are reactivity control, reactor coolant makeup, reactor heat removal, process monitoring, and associated support functions. Section III.L also defines the acceptance criteria for systems performing these functions:

> *During the post-fire 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*).

Except for BWR shutdown methodologies that rely on the use of low-pressure injection systems (see below), these criteria apply to the systems needed to satisfy both Section III.G and III.L of Appendix R to 10 CFR Part 50.[24]

Exposure Fire
The evaluation of safe-shutdown capability is based on the occurrence of a single *exposure fire* in an area containing (or presenting a fire hazard to) components, equipment, or cabling relied on for post-fire safe-shutdown. An exposure fire is defined as a fire in a given area that involves either in situ (permanently installed) or transient combustibles, but is external to any SSCs located in (or adjacent to) that same area. The effects of such fire (e.g., heat, smoke, or ignition) can adversely affect SSCs 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 fire area. Also, a fire involving combustibles other than either redundant train may constitute an exposure fire to both redundant trains located in the same fire area. Each fire area must be analyzed for the effects of an exposure fire.

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[24] IN 84-09, Section V, p. 4, U.S. Nuclear Regulatory Commission, Washington, DC, February 13, 1984.

Damage Expectations

In general, all cables and equipment that are exposed to the effects of fire (i.e., do not meet protection criteria of Appendix R, Section III.G.2) should be assumed to experience damage unless the staff has reviewed and approved a plant-specific exemption to these requirements. Licensees cannot take credit for fire to cause a loss of function if such a loss would simplify the shutdown scenario. For example, assuming that fire causes a loss of offsite power may be nonconservative.

Cause of Failures

The only failures considered are those that are directly attributable to the fire and/or fire-suppression activities. No other failures or independent events are assumed to occur concurrently with the fire.

Availability of Shutdown Systems

At the onset of the postulated fire, all safe-shutdown systems (including applicable redundant trains) are assumed to be operable and available for post-fire safe-shutdown. Systems are assumed to be operational with no repairs, maintenance, testing limiting conditions of operation (LCOs), etc., in progress. The unit is assumed to be operating at full (100-percent) power under normal conditions and normal lineups with a 3-month 100-percent power history.

Use of Low-Pressure Injection Systems at BWRs

The use of SRVs in conjunction with low-pressure injection (LPI) systems meets the requirements of a redundant means of post-fire safe-shutdown under Section III.G.2 of Appendix R to 10 CFR Part 50. When this methodology (SRV/LPI) is employed, the shutdown performance criteria identified in Section III.L do not apply. Rather, licensees who designate SRV/LPI as a redundant means of post-fire safe-shutdown must show that SRV/LPI can achieve and maintain hot shutdown in accordance with Sections III.G.1 and III.G.2 of Appendix R.[25]

Availability of Offsite and Onsite Power Sources

For the case of redundant shutdown, licensees may credit offsite power if it can be demonstrated to be free of fire damage. For fires not requiring implementation of an alternative or dedicated shutdown capability, offsite power is assumed to remain available unless fire can result in its loss. In the absence of an evaluation of the impact of fire on the availability of the offsite power sources, the analysis should demonstrate the capability of achieving shutdown conditions where offsite power is available *and* where offsite power is not available for up to 72 hours. For fire areas requiring an alternative or dedicated shutdown capability, the analysis should demonstrate the capability of achieving shutdown conditions where offsite power is available *and* where offsite power is not available for up to 72 hours. After 72 hours, offsite power can be assumed to be restored.

[25] Letter from S. Richards, NRC, to J. Kenny, BWROG, dated December 12, 2000.

Multiple-Unit Sites
Unrelated fires in two or more units are not postulated to occur simultaneously. However, where a single fire can impact more than one unit of a multi-unit site, the licensee must demonstrate the ability to achieve and maintain safe-shutdown conditions in each of the affected units.

Automatic Equipment Operation
Automatic equipment operation may or may not occur during a fire. Licensees cannot take credit for fire to cause a loss of automatic functions if such a loss would simplify the alternative shutdown scenario. For fire areas requiring alternative shutdown capability, licensees should consider the "worst case" scenario. For other fire areas, licensees may credit automatic operation of components and logic circuits in the analysis if they demonstrate that the circuitry associated with the automatic operation will remain unaffected by the postulated fire (i.e., satisfies established fire protection/separation criteria).

Relay/Switch Contact Positions
All relay, position switch, and control switch contacts in control circuits are in the position or status that correspond to the normal operation of the device. Test and transfer switches in control circuits are in their normal position.

Repair Activities
Repair activities (e.g., wiring changes, fuse replacement, use of pneumatic or electric jumpers, or other modifications) are not permitted for systems that are required to achieve and maintain hot shutdown conditions. Modifications and repair activities are permitted for cold shutdown systems provided that (1) for areas *not requiring* an alternative shutdown capability, the licensee can demonstrate that all repair activities can be accomplished within 72 hours or, (2) for areas requiring an alternative shutdown capability, all needed repairs can be performed and cold shutdown achieved within 72 hours.

Cable and Circuit Failure Modes
It is not deemed possible to accurately predict the manner in which damaged cables or circuits may fail. Various types of electrical failure modes (e.g., hot shorts, open circuits, or shorts to ground) must be assumed to occur as a result of fire damage.

Single-Failure Criterion
Because it is only one of several levels of defense, the shutdown capability does not have to meet the single-failure criterion.

Redundant vs. Alternative Shutdown Systems and Equipment
For the purpose of analysis of compliance with Section III.G.2 criteria (i.e., redundant train shutdown capability), the safe-shutdown capability is defined as one of the two normal safe-shutdown trains. If the system is being used to provide its design function, it is generally is considered to be redundant. If the system is being used in lieu of the preferred system because the redundant components of the preferred system do not meet the separation criteria of Section III.G.2, the system is considered an alternative shutdown capability. (Reference GL 86-10.)

Post-Fire Operating Procedures

The only requirement for post-fire operating procedures is for those areas where alternative shutdown is required. For other areas of the plant, shutdown would be achieved utilizing one of the two normal trains of shutdown systems. Shutdown in degraded modes (one train unavailable) should be covered by present operator training and abnormal and emergency operating procedures (EOPs). If the degraded modes of operation are not presently covered, the operations staff should assess the need for additional training or procedures. (Reference GL 86-10.)

5.5 Redundant Shutdown Capability

As experienced during the Browns Ferry fire, SSCs that are exposed to the effects of fire may be damaged, and this damage may lead to unexpected consequences in the operation of plant safety systems. On February 20, 1981, the NRC forwarded GL 81-12, which restated the regulatory requirement for each licensee to reassess areas of the plant containing cables or equipment, including associated nonsafety circuits, of redundant trains of systems necessary to achieve and maintain hot shutdown conditions.

Failing to adequately identify circuits, components, and systems required to achieve and maintain safe-shutdown and protect them from the effects of fire could result in damage to redundant trains of shutdown systems and significantly impair the ability to safely shutdown the plant in the event of fire. Consequently, one of the key outcomes of the SSA evaluation process is the identification of plant locations (fire areas) that contain redundant trains of SSCs important to safe-shutdown. As described in Section 4.3 above, when redundant trains of cables or equipment, including associated nonsafety circuits necessary to achieve and maintain hot shutdown are found to be located in the same fire area, the fire protection requirements of Section III.G.2 of Appendix R must be satisfied. If not, the licensee must provide an alternative or dedicated shutdown capability or request an exemption.

Areas of the plant that meet the separation requirements of Section III.G.2 are frequently referred to as “redundant shutdown” fire areas.

5.6 Alternative Shutdown Capability (10 CFR Part 50, Appendix R, Section III.G.3)

In certain areas of the plant, redundant trains of equipment required for hot shutdown may be located in close proximity. Typical examples include the MCR and CSR, where redundant trains of shutdown equipment may be separated by only a few inches. In such cases, compliance with fire protection features specified in Section III.G.2 of Appendix R cannot be readily achieved. When areas such as these are identified, an alternative or dedicated shutdown capability must be provided that is both physically and electrically independent of the area under consideration.

Alternative shutdown capability is provided by rerouting, relocating, or modifying existing systems. An example of an alternative shutdown capability would be the installation of isolation switches to isolate safety-related circuits from fire damage. Alternative shutdown capability can also be provided by implementing procedures specifying “alternative” methods of operation, such as manual operations and/or evacuation of the normal control station(s) such as the control room.

Dedicated shutdown capability is provided by installing new structures and systems for the sole function of post-fire safe-shutdown. Examples of dedicated shutdown capability include installation of emergency generators, process instrumentation, or other equipment which is intended to be used only for safe-shutdown purposes (i.e., dedicated to safe-shutdown).

The alternative or dedicated shutdown capability may be unique for each area, or it may be one unique combination of systems for all fire areas requiring this capability. For those areas requiring alternative or dedicated shutdown capability, fire detection and a fixed fire-suppression system must also be installed in the fire area of concern.

The design-basis event for considering the need for alternative or dedicated shutdown capability is a postulated fire in a specific fire area containing redundant safe-shutdown cables/equipment in close proximity where it has been determined that fire protection means cannot ensure that safe shutdown capability will be preserved. Licensees should consider two cases in which (1) offsite power is available; and (2) offsite power is not available. (Reference GL 86-10.)

The SSA must demonstrate that, during a post-fire safe-shutdown, the reactor coolant process variables will be maintained within those predicted for a loss of normal AC power and the integrity of the fission product boundary will not be affected. Integrity of the fission product boundary includes (1) no fuel clad damage, (2) no rupture of any primary coolant boundary, and (3) no rupture of the containment boundary.

The alternative or dedicated shutdown capability shall be able to achieve and maintain sub-critical conditions in the rector, maintain the reactor coolant inventory, achieve and maintain hot standby conditions (hot shutdown for a BWR) for an extended period of time, achieve cold shutdown conditions within 72 hours, and maintain cold shutdown conditions thereafter.

Performance goals for the shutdown functions identified in the SSA are as follows:

- The reactivity control function should be capable of achieving and maintaining cold shutdown reactivity conditions.
- The reactor coolant makeup function should be capable of maintaining the reactor coolant level above the top of the core for BWRs and within the level indication of the pressurizer for PWRs.
- The reactor heat removal function should be capable of achieving and maintaining DHR.
- The process monitoring function should be capable of providing direct readings of the process variables necessary to perform and control the above functions.

The systems used for alternative or dedicated shutdown need not be designed to (1) seismic Category I criteria, (2) single-failure criteria, or (3) other design-basis accident criteria, except for the portions of these systems that interface with or impact existing safety systems.

It should be noted that safe-shutdown performance goals and functions to be performed are specified in the regulation (Appendix R, Section III.L). However, specific methods for achieving these objectives are left to the individual plants to determine and demonstrate.

Implementation of an alternative or dedicated shutdown capability will require operators to perform many activities at local control stations outside the MCR. All operator activities should be prescribed in abnormal operating procedures that have been integrated into the overall plant operator training and qualification program. As alternative/dedicated shutdown procedures are developed, timely performance of all manual operator actions in the process must be ensured. Verification that time-dependent actions are satisfied in the written procedures is accomplished by performing a thermal-hydraulic timeline analysis, where various types of transients are analyzed to determine how much time the operating crew has to implement each of the safe-shutdown functions before exceeding the established performance criteria. These transients may involve a fire-induced spurious equipment operation or the generation of a false signal, with an assumed concurrent loss of offsite power. Typical examples include the loss of main feedwater in a PWR or inadvertent opening of the turbine bypass valves in a BWR that could cause over-pressurization of the main condenser as a result of the loss of circulating water (resulting from the concurrent loss of offsite power).

In summary, this analysis and verification will include the following confirmations:

- The procedural steps or operator manual actions can be performed (by verifying that operators will have access to required equipment).
- The analysis criteria are satisfied. For example, the performance of time-sensitive steps within allotted times (derived from the results of the plant's thermal-hydraulic analysis).
- Required support equipment (such as ladders and valve handles) are available (pre-positioned and administratively controlled) for use when needed.

Other alternative/dedicated shutdown implementation considerations include the following:

- Confirmation that the minimum shift complement of operators, exclusive of operators who are part of the fire brigade, is adequate to properly implement the safe-shutdown procedures.
- Job performance measures covering the major tasks in the post-fire safe-shutdown procedures have been integrated into the overall plant operator training and qualification program.
- Confirmation of the availability and adequacy of emergency lighting (this is necessary because alternative/dedicated shutdown procedures frequently require the performance of operator manual actions throughout the plant). Section III.J of Appendix R requires that fixed emergency lighting units must be provided for locations in the plant associated with post-fire safe-shutdown implementation, including the ingress and egress routes of the operators to those locations.
- Confirmation of the availability and adequacy of communication systems. Most alternative and dedicated shutdown strategies rely heavily on the operators' ability to confirm or verify the operation of plant equipment and then report this information back to another operator stationed at central location (typically the RSP). The communication system relied on to ensure this capability provides a vital shutdown support function. In addition to remaining free of fire damage, the designated method of communications should not (1) be affected by a loss of offsite power, (2) interfere with any in-plant instrumentation, or (3) have dead zones in areas where communication is vital to the shutdown process.

5.7 Specific Considerations

5.7.1 Operator Manual Actions

In the early 1990s, the NRC identified significant performance deficiencies with Thermo-lag fire barrier material. At that time, the industry used this material extensively to meet the fire protection requirements specified in Section III.G.2 of Appendix R for cable trays, conduits, and other enclosures containing circuits required to achieve and maintain hot shutdown conditions. During the subsequent Thermo-lag resolution process, many licensees attempted to minimize the use of this material by re-analyzing their plants and developing alternative protection strategies. While many approaches, such as cable rerouting, use of different equipment, or use of rated fire barriers of different materials are clearly acceptable, some licensees replaced the fire barriers with the use of operator manual actions. In some cases, this may not provide the level of fire protection required by the regulation.

In general, reliance on operator manual actions does not satisfy the specific technical requirements of Section III.G.2 of Appendix R to 10 CFR Part 50. However, in certain cases, the staff has reviewed and approved the use of operator manual actions on a plant-specific basis. These approvals are documented in plant-specific safety evaluations and incorporated into the plants' fire protection licensing bases. One example is an exemption granted to Alabama Power Company for the Joseph M. Farley Nuclear Plant, dated November 19, 1985 (NUDOCS Accession No. 8512060395). The staff has developed a rulemaking plan, identified in SECY 03–100, to allow use of feasible operator manual actions in Section III.G.2 areas without prior staff approval. The Commission approved the proposed rulemaking plan in September 2003, as well as the staff's proposal to provide enforcement discretion for feasible manual actions without prior staff approval.

As discussed in Section 5.6, operator manual actions are permitted to accomplish alternative shutdown in accordance with Appendix R, Section III.G.3, provided that the required operator manual actions are incorporated into post-fire operating procedures, verified to be physically possible, and capable of being performed within the time constraints defined by a thermal-hydraulic analysis developed for the specific shutdown scenario (e.g., fire in control room with one worst-case spurious actuation), *and* provided that sufficient staffing, communications, and emergency lighting are ensured to remain available.

Where operator manual actions are relied on to ensure the successful accomplishment of required shutdown functions, it is expected that they can be safely and effectively performed in a sufficiently timely manner. The following factors should be considered when determining the acceptability of operator manual actions:

- Available indications: If credited to support operator manual actions, diagnostic indications shall have the following capabilities:
  - Show the need for the action.
  - Operate effectively, given the postulated fire.
  - Verify that the intended safety function has been accomplished.

- Environmental considerations: Environmental considerations encountered while accessing and performing operator manual actions shall be demonstrated to be consistent with the human factor considerations for visibility, habitability, and accessibility, including the following:
  - Emergency lighting shall be provided as required in Appendix R, Section III.J, or by the licensee's approved fire protection program.
  - Radiation shall not exceed the limits specified in 10 CFR 20.1201.
  - Temperature and humidity conditions shall not adversely affect the capability to perform the operator manual actions (e.g., see NUREG/CR-5680, "The Impact of Environmental Conditions on Human Performance"), or the licensee shall provide an acceptable rationale for why temperature and/or humidity do not adversely affect the ability to perform operator manual actions.
  - Smoke and toxic gases from the fire shall not adversely affect the capability to access the required equipment to perform the operator manual actions.
  - All locations where operator manual actions are performed, including the pathways to those locations, shall be accessible.
- Staffing and training: All plant operators, under all staffing levels, shall be capable of performing all required actions in the times required for a given fire scenario. The use of operators shall be independent from any collateral fire brigade or control room duties that they may need to perform as a result of the fire. Operators required to perform the manual actions shall have been appropriately trained and shall be continuously available to perform the actions required to achieve and maintain safe shutdown.
- Communications: To achieve and maintain safe shutdown, communications capability shall be adequate for performance of the operator manual actions that must be coordinated with other plant operations, with this communications capability continuously available.
- Equipment: Any equipment required to support operator manual actions, including keys, self-contained breathing apparatuses (SCBAs), and personnel protective equipment, shall be readily available, easily accessible, and functional. Credit shall not be taken for the use of non-functional equipment or equipment for which functionality may have been adversely affected by the fire as a result of smoke, heat, water, combustion products, or spurious actuation effects (e.g., over-torquing an MOV as a result of a spurious signal, as discussed in IN 92-18).
- Procedures: Procedural guidance on the use of required operator manual actions shall be readily available and easily accessible.
- Demonstration: The capability to successfully accomplish required operator manual actions within the time allowable using the required procedures and equipment shall be demonstrated using the same personnel/crews who will be required to perform the actions during the fire. Documentation of the demonstration, as well as any training periodically provided to the operators, shall be provided.
- Complexity and number: The degree of complexity and total number of operator manual actions required to effect safe shutdown shall be limited, such that their successful accomplishment under realistically severe conditions is ensured for a given fire scenario. The need to perform operator manual actions in different locations shall be considered when sequential actions are required. Analyses of the postulated fire time line shall demonstrate that there is sufficient time to travel to each action location and perform each action required to support the associated shutdown function(s), such that an irrecoverable condition does not occur.

These factors represent an expansion of the “Inspection Criteria for FP Manual Actions,” which the NRC issued in March 2003 as Enclosure 2 to Attachment 71111.05 of the FP Inspection Procedure. Specifically, the March 2003 inspection criteria, gave significant latitude, as follows:

> *For an interim period, while rulemaking is in progress… acceptance criteria can be developed which would facilitate evaluations of certain manual actions.*

The March 2003 inspection criteria were based on the NRC’s inspection experience and addressed the following factors:

- diagnostic instrumentation
- environmental considerations
- staffing and training
- communications and accessibility
- procedures
- verification and validation (V&V)

In addition to these factors, manual operator actions may not include repair activities that are needed to achieve and maintain hot shutdown conditions. Appendix A to this document provides additional guidance on the use of operator manual actions. In addition, consult the following reference sources for the FP inspection criteria:

- NRC Inspection Manual Chapter 0609, “Significance Determination Process”
- Input from FP risk-related studies sponsored by the NRC’s Office of Nuclear Regulatory Research (RES)
- Feedback from a meeting with the Advisory Committee on Reactor Safeguards (ACRS), Subcommittee on Fire Protection
- Performance-shaping factors used in human reliability analysis techniques

5.7.2 Repairs

Section III.G.1 of Appendix R to 10 CFR Part 50 states that one train of systems needed to achieve and maintain hot shutdown conditions must be free of fire damage. Thus, one train of systems needed for hot shutdown must be ensured to remain operable both during and after a fire. Operability of the hot shutdown systems must exist without repairs. In general, fuse removal for the purpose of preventing the maloperation of equipment is not considered a repair, provided that the fuse removal is routine and can be performed in a manner that does not subject the operator to an undue safety hazard (e.g., reaching into an energized 4 kV SWGR). However, the replacement of fuses is considered a repair.

Repairs are allowed for cold shutdown systems. However, the time requirements for completing repairs is dependent on the shutdown method employed. For areas provided with an alternative or dedicated shutdown capability, Appendix R, Section III.L.5, states that, *"equipment and systems comprising the means to achieve and maintain cold shutdown conditions shall not be damaged by fire; or the fire damage to such equipment and systems shall be limited so that the systems can be made operable and cold shutdown can be achieved within 72 hours."*

This time limit should not to be confused with the requirements for completing repairs for areas that do not require an alternative shutdown capability. For these areas, Section III.G.1.b requires only the capability to repair the systems necessary to achieve and maintain cold shutdown from either the control room or emergency control station(s) within 72 hours, not the capability to repair and achieve cold shutdown within 72 hours as required for the alternative or dedicated shutdown modes by Section III.L.

Procedures for repairing damaged cold-shutdown equipment should be prepared in advance with replacement equipment stored on site. All repairs should be of sufficient quality to ensure safe operation until the plant is restored to an operating condition.

5.7.3 Diagnostic Instrumentation

Certain post-fire safe-shutdown strategies rely on the operators to take mitigating actions in response to equipment perturbations that may be caused by fire. For example, a shutdown strategy for one fire area may rely on operators to manually close a tank discharge valve in the event that it spuriously changes position (i.e., opens) as a result of fire damage to its control cabling. To ensure this capability, sufficient “diagnostic instrumentation” (such as tank level indicator and/or level alarm annunciators) must be available to enable the operators to promptly detect the undesired change in valve position and take corrective actions necessary to defeat it (i.e., manually close the valve).

As stated in GL 86-10, “diagnostic instrumentation” is instrumentation, beyond that identified in Attachment 1 to IN 84-09, which is needed to ensure proper actuation and functioning of safe- shutdown and support equipment (e.g., flow rate, pump discharge pressure). The specific diagnostic instrumentation needed depends on the design of the shutdown capability. When the shutdown strategy relies on the use of procedures to direct operator actions or operator manual actions in response to equipment upsets that may occur as a result of fire, sufficient diagnostic instrumentation must be ensured to remain available (i.e., free of fire damage) so that the success of operator activities can be readily confirmed.

CHAPTER 6. DETERMINISTIC ANALYSIS PROCESS FOR APPENDIX R COMPLIANCE

The Browns Ferry event was of sufficient significance to warrant major changes in fire protection design features of NPPs in the United States. Consequently, the NRC issued its new regulation as 10 CFR 50.48 and Appendix R to 10 CFR Part 50, which became effective on February 17, 1981. One of the key requirements of this regulation was to backfit Section III.G, "Fire Protection of Safe Shutdown Capability," to all NPPs that were licensed to operate before January 1, 1979. This section establishes the minimum acceptable fire protection design features that are necessary to ensure that licensees can achieve safe-shutdown in the event of fire in any area of the plant. The fundamental objective of Section III.G is to extend the DID concept to fire safety by obtaining reasonable assurance that, in the event a fire were to start (despite the fire prevention program) and continue to propagate (despite fire protection activities), one train of SSCs needed to achieve and maintain safe-shutdown conditions will remain available. Figure 6-1 illustrates how fire damage to circuits and cables may adversely affect the shutdown capability.

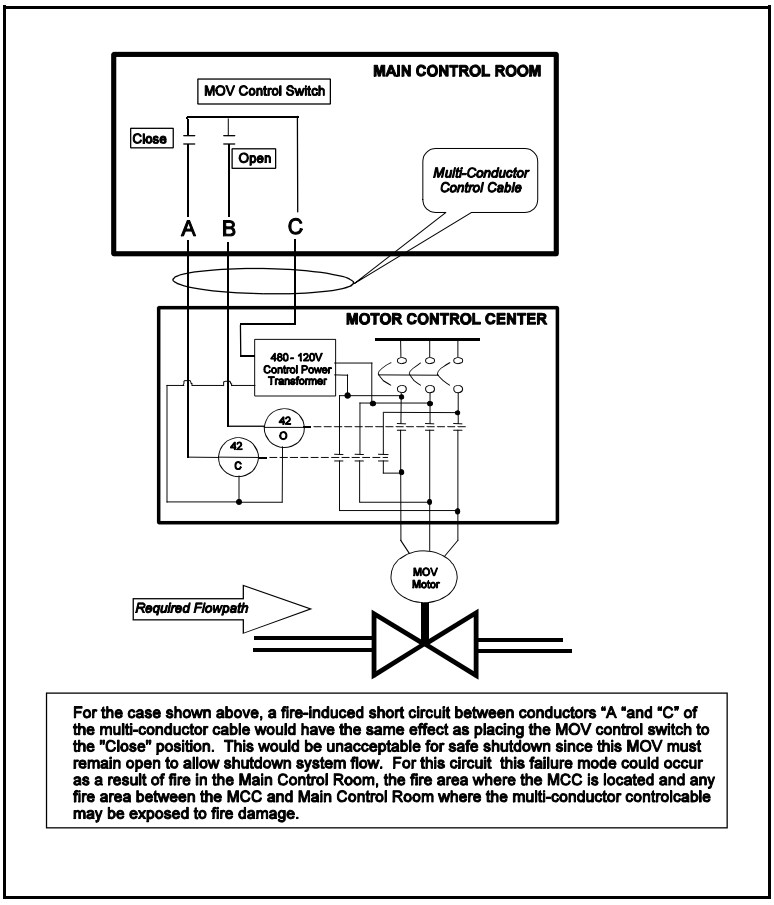

Figure 6-1 Potential Effect of a Fire-Induced Circuit Failure

Section III.G required each licensee to perform a comprehensive evaluation of each fire area and demonstrate, through the performance of a deterministic assessment of potential fire damage, that SSCs of which failure (or maloperation) could impact the ability to achieve and maintain safe-shutdown conditions are provided with suitable fire protection features (i.e., as required by Section III.G.2 of Appendix R, or justified in a staff-approved exemption). For locations of the plant where compliance with the the fire protection design features specified in Section III.G.2 may not be feasible because redundant trains of cables and/or equipment are located in close proximity (such as the control room or CSR), Section III.G.3 requires licensees to provide an alternative or dedicated shutdown capability that is independent (both physically and electrically) from the fire area under consideration. In either case, the evaluation of a fire in any area must conclusively demonstrate that one train of equipment that can be used to immediately bring the reactor to hot shutdown conditions remains unaffected by fire.

6.1 Principles of a Deterministic Evaluation of Post-Fire Safe-Shutdown Capability

The SSA for each plant must specifically identify all systems and equipment upon which the licensee will depend to perform essential shutdown functions. It must also include an evaluation of any circuits or cables in the fire area that could (1) adversely affect the operability of identified shutdown systems and equipment or (2) initiate transients that could preclude the successful accomplishment of required shutdown functions by feeding back potentially disabling fault conditions to power supplies, control logic or instrumentation circuits. In addition, the SSA must describe how the licensee will prevent or appropriately mitigate such disabling conditions. Otherwise, the licensee cannot ensure its reliance on the identified safe-shutdown equipment. Because it is not possible to predict the manner in which equipment (cables, circuits or components) may fail, the SSA must assume that the fire will damage any unprotected equipment located in the fire area under evaluation and, unless otherwise demonstrated through the performance of more detailed evaluations, it must be assumed that this damage will fail the affected equipment in a mode that adversely impacts safe-shutdown. In summary, the NRC expects that such evaluations will be based on the following deterministic premise:

> *Cables and components that are exposed to the effects of fire and its related perils (i.e., not provided with fire protection features sufficient to meet Section III.G of Appendix R) will be damaged, and, unless demonstrated otherwise through the performance of suitably comprehensive and conservative engineering evaluations, it is assumed this damage will cause connected equipment to fail or malfunction in an undesired manner for shutdown.*

Not all circuit/cable failures that may occur as a result of fire will necessarily have an adverse impact on the plant's ability to achieve and maintain post-fire safe-shutdown conditions. The electrical distribution, instrumentation, communications, control, and process systems of a commercial NPP are composed of a diverse array of electrical circuits/cables, and fire damage to many (if not most) of these circuits will have no adverse effect on the ability to achieve and maintain safe-shutdown conditions. In certain instances, it may be possible to demonstrate, through the performance of a detailed analysis of the potential effects of fire damage, that even if a fire were to damage certain circuits of required shutdown components, the damage would be acceptable because it will not have any effect on the ability of the component to perform its intended shutdown function. For example, consider the circuit illustrated in Figure 6-2.

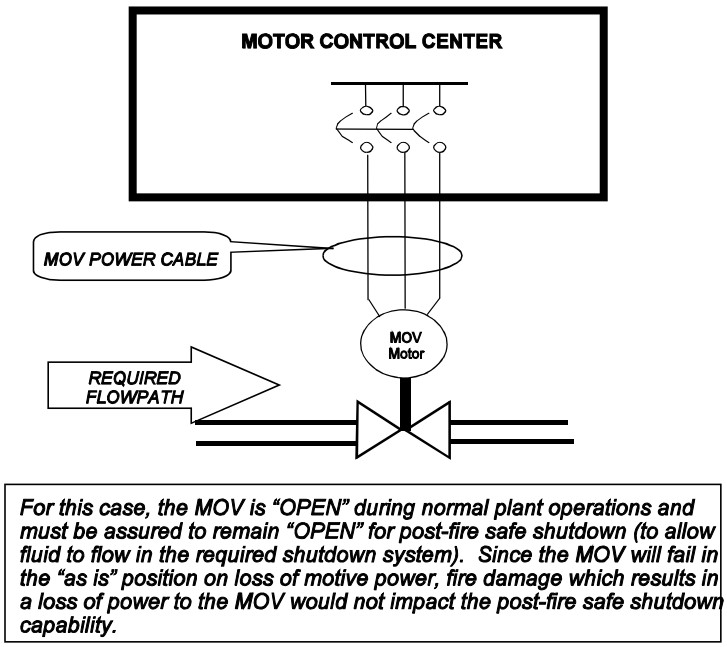

Figure 6-2 Fire Damage to Certain Circuits of Required Shutdown Equipment May Not Pose a Threat to the Shutdown Capability

In this case, an MOV is open during normal plant operations. To ensure successful achievement of safe-shutdown conditions, the MOV must remain open to allow fluid to flow through the required flowpath. For this case, the required shutdown component is an MOV which, by design, will fail in the "as-is" (open) position upon a loss of motive power. Therefore, if it can be shown that fire damage to the power cable would only result in a loss of motive power to the MOV, the analysis has demonstrated a level of safety equivalent to that which would be achieved through compliance with Section III.G.2, and the power cable would not require any additional fire protection features. As stated in the staff's clarification of GL 81-12, *"Our interest is only with those circuits (cables) whose fire-induced failure could affect shutdown."*

6.2 Use of "Appendix R" Terminology

Throughout this document, and particularly in this section, reference is made to post-fire safe-shutdown criteria contained in Sections III.G and III.L of Appendix R to 10 CFR Part 50. Since its inception, reference to "III.G.2" has become synonymous with redundant train shutdown capability, and "III.L" is commonly referred to when discussing alternative shutdown capability irrespective of the actual requirements specified in the plant's fire protection licensing basis.

In addition to simplifying the discussion, the use of such "Appendix R terminology" is generally acceptable because the guidelines contained in SRP Section 9.5.1 include the acceptance criteria listed in Appendix R to 10 CFR Part 50 and 10 CFR Part 50.48. It should be noted, however, that the use of this terminology is not intended to imply that Appendix R requirements are applicable to all plants. As described in Section 4, Appendix R is *only* specifically applicable to a limited number of plants that were fully licensed and operating before January 1, 1979. The staff typically reviewed the post-fire safe-shutdown capabilities of plants licensed after this date during the initial licensing process for conformance to guidelines contained in Position C.5.b of SRP Section 9.5.1.

6.3 Overview of the Post-Fire Safe-Shutdown Analysis Process

A comprehensive evaluation of the potential impact of fire damage on the ability to achieve and maintain safe-shutdown conditions within the performance goals and criteria specified in Appendix R to 10 CFR Part 50 is a technically challenging process, involving the expertise of personnel knowledgeable in plant operations and specialists from various engineering disciplines. There are many acceptable methods of performing a fire SSA, and the NRC neither prescribes nor endorses any one approach. The SSA should be a bounding analysis that identifies the range of possible fire impacts within each fire area and ensures that appropriate measures are in place to prevent this damage from affecting the ability to safely shut down the plant. For each fire area, the SSA will define the set of systems necessary to accomplish required shutdown functions in accordance with established performance criteria. The selected systems form the basis for the selection of individual components and cables needed to ensure that each system will be capable of accomplishing its intended shutdown function.

The detailed methods used by a particular plant operating organization will vary with plant-specific conditions, such as design, construction, cable configuration, equipment layout, and operating preferences. Therefore, it is not possible to develop a "one-size-fits-all" procedural process for performing a deterministic analysis sufficient to satisfy Appendix R concerns. However, the *overall approach* for ensuring the availability of at least one shutdown *"success path"* (i.e., the minimum set of SSCs necessary to achieve and maintain safe-shutdown in the event of a fire) for each fire area, is fairly consistent among plants regardless of plant design or vintage. Figure 6-3 illustrates an overview of this approach and provides references to the specific subsection of this chapter that describes each of the steps.

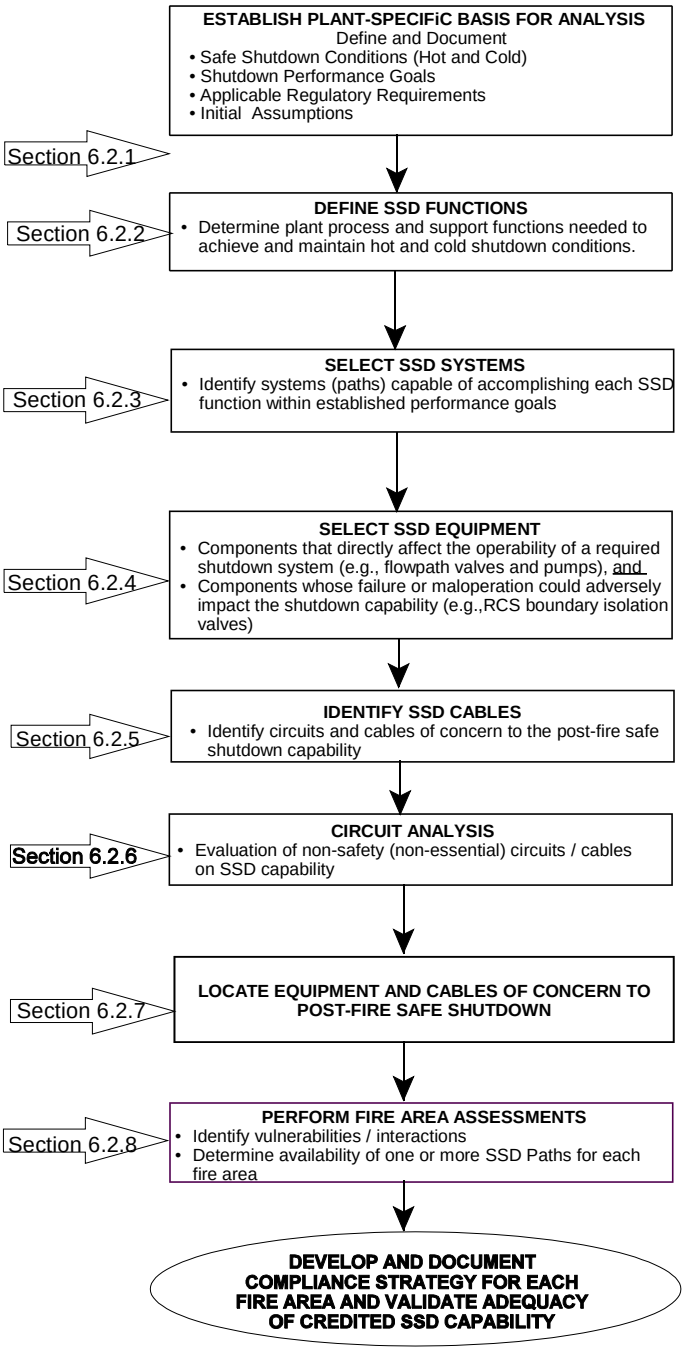

Figure 6- 3 Overview of Post-Fire Safe Shutdown Analysis Process

It should be noted that, for the purpose of this discussion, it is assumed that a comprehensive FHA has already been performed by qualified fire protection engineers to divide the plant into separate and distinct fire areas that are separated from other fire areas by rated fire barriers that are adequate for the anticipated fire hazard. As depicted in Figure 6-4, the fire area boundaries represent the extent of fire spread assumed in the SSA.

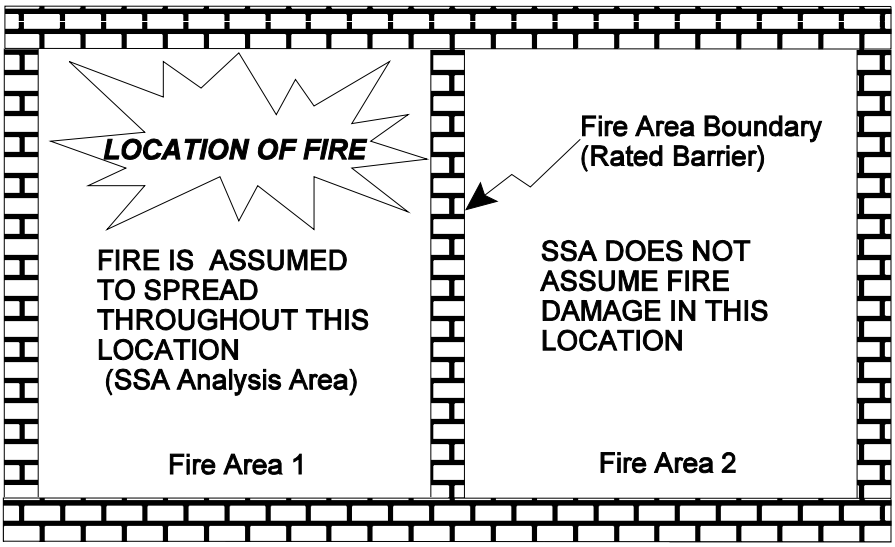

Figure 6-4 Fire-Rated Boundaries Determine Extent of Fire Spread Assumed in SSA

6.4 Methodology

In demonstrating the plant's safe-shutdown capability, the SSA integrates the following evaluations:

(1) **Safe-Shutdown System Selection/Path Development** identifies systems that are capable of accomplishing shutdown safety functions (e.g., reactivity control, reactor coolant makeup, DHR, etc.).

(2) **Plant Configuration** compares equipment locations and cable routing with the fire area boundary information established in the FHA.

(3) **Safe-Shutdown System Performance** demonstrates that, following a fire, sufficient equipment of adequate capacity and capability will remain available to achieve and maintain the reactor in a safe-shutdown condition.

(4) **Associated Circuits Effects** demonstrates that a fire cannot, through its effects on nonessential/nonsafety electrical circuits, prevent safe-shutdown systems and equipment from accomplishing their intended functions or initiate an event that is beyond the capability of the safe-shutdown systems.

6.4.1 Establish the Plant-Specific Technical and Licensing Bases for the Safe-Shutdown Analysis

6.4.1.1 Assemble Plant-Specific Information

The first step in the SSA process is to review available documentation to obtain an understanding of the available plant systems and functions required to achieve and maintain safe-shutdown. The following documentation is typically needed to perform the SSA:

- *Fire Protection Licensing Basis Documents* include the FSAR, plant operating license conditions, TSs, applicable regulatory requirements (Appendix R or SRP Section 9.5.1), and fire protection safety evaluations issued by the staff.
- *Fire Hazards Analysis* identifies the fire areas, characterizes the hazards, and describes the fire protection features within each fire area.
- *Plant System Descriptions* are the detailed descriptions of the functions and capabilities of each plant system, including those systems capable of accomplishing the safe-shutdown functions. They should include both front line and support systems necessary for operation of the system. Support systems do not directly provide safety functions, but are required to ensure that the front line systems can perform the safety functions as required. Examples of support systems include cooling water, electrical power distribution, instrument air, and HVAC.
- *Plant System Design Drawings,* also known as piping and instrumentation diagrams (P&IDs), identify the components that make up a system and the flowpath of that system, and identify any interconnections to other systems that could degrade the system under certain fire damage conditions. Electrical drawings needed for review typically include electrical distribution one-line diagrams, cable block diagrams, logic diagrams, cable and raceway layout drawings, and instrument loop diagrams.
- *Applicable Operating Procedures* document the plant's normal, emergency, and abnormal operating procedures.

6.4.1.2 Define and Document Safe-Shutdown Conditions for the Plant

In order to develop an effective strategy for achieving and maintaining the reactor in a "safe-shutdown" condition, it is first necessary to define the plant-specific parameters that must be satisfied in order to declare that a "safe-shutdown" condition has been achieved. For fire events, safe-shutdown includes both hot shutdown and cold shutdown conditions. The plant's TSs document the plant-specific parameters for each of these conditions.

6.4.1.3 Define and Document the Safe-Shutdown Performance Goals

Guidance for determining the functional and performance requirements of systems upon which the plant relies to accomplish both redundant (III.G.2) and alternative (III.L) shutdown was initially provided by the NRC in IN 84-09, "Lessons Learned from NRC Inspections of Fire Protection Safe Shutdown Systems." Specifically, IN 84-09 states that the systems and equipment needed for post-fire safe-shutdown (*both* redundant and alternative) are those systems necessary to perform the safe-shutdown functions defined in Section III.L of Appendix R. Section III.L defines the acceptance criteria for such systems as follows:

- During post-fire safe-shutdown, the reactor coolant system process variables shall be maintained within those predicted for a loss of normal AC power
- 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).

By letter dated December 12, 2000 (Reference: Richards Letter) the staff documented its evaluation of a BWR Owners Group (BWROG) Fire Protection Committee position regarding the use of low-pressure injection systems as "redundant" shutdown systems under Appendix R. The staff position documented in this evaluation clarified the information initially provided in IN 84-09. Specifically, in its review of the applicability of Section III.L requirements, the staff concluded that *"Section III.L performance criteria are applicable only to alternative or dedicated shutdown capability, and need not be met for redundant post-fire safe-shutdown capability."* As a result of the staff's clarification of IN 84-09, RG 1.189 now defines performance criteria for shutdown systems as follows:

> **Regulatory Position 5.1 Safe-Shutdown Performance Goals for Redundant Systems**
> *"Ensure that fuel integrity is maintained and that there are no adverse consequences on the reactor pressure vessel integrity or the attached piping. Fuel integrity is maintained provided the fuel design limits are not exceeded*."
>
> **Regulatory Position 5.2 *Alternative or Dedicated Shutdown Design and Performance Goals***
> ***5.2.1 Alternative or Dedicated Safe-Shutdown System Design Goals***
> *During the post-fire safe-shutdown, the reactor coolant system process variables should be maintained within those predicted for a loss of normal ac power, and the fission product boundary integrity should not be affected (i.e., there should be no fuel clad damage, rupture of any primary coolant boundary, or rupture of the containment boundary).*
>
> *The systems used for alternative or dedicated shutdown need not be designed to (1) seismic Category I criteria, (2) single-failure criteria, or (3) other design-basis accident criteria, except the portions of these systems that interface with or impact existing safety systems.*

5.2.2 Safe-Shutdown Performance Goals for Alternative or Dedicated Systems

The performance goals for the safe-shutdown functions should be:

- *The reactivity control function should be capable of achieving and maintaining cold shutdown reactivity conditions.*
- *The reactor coolant makeup function should be capable of maintaining the reactor coolant level above the top of the core for BWRs and within the level indication of the pressurizer for PWRs.*
- *The reactor heat removal function should be capable of achieving and maintaining DHR.*
- *The process monitoring function should be capable of providing direct readings of the process variables necessary to perform and control the above functions.*

RG 1.189 further states that the capability of the required shutdown functions should be based on a previous analysis, if possible (e.g., those analyses in the FSAR). The equipment required for alternative or dedicated shutdown should have the same or equivalent capability as that relied on in the above referenced analysis. It should be noted that specific methods for achieving these objectives are left to the individual plants to determine and demonstrate.

6.4.1.4 Define and Document Initial Assumptions

In order to proceed with the analysis, it is necessary to establish a set of initial assumptions or "ground rules" that define the fundamental criteria and conditions under which the evaluation process is to be performed. For compliance with Appendix R, the SSA must be based on the following considerations:

- *Exposure Fire:* The analysis must assume that a single *"exposure fire"* will occur in any fire area. An exposure fire is defined as a fire in a given fire area that involves either in-situ (permanently installed) or transient combustibles, but is external to any SSCs located in (or adjacent to) that same fire area. The effects of such fire (e.g., smoke, heat or ignition) can adversely affect those SSCs 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 fire area. Also, a fire involving combustibles other than the redundant train may constitute an exposure fire to both redundant trains located in the same area
- *Extent of Fire Damage:* For analysis purposes, it is assumed that only a single exposure fire will occur in any fire area at a given time. Since it is not deemed possible to accurately predict the manner in which equipment (cables, circuits or components) may fail, this analysis must assume that the fire will damage any unprotected equipment located in the fire area under evaluation, and, unless demonstrated otherwise through the performance of more detailed evaluations, it must be assumed this damage will cause the affected equipment to fail in an undesired manner for safe-shutdown. The fire area boundaries represent the extent of fire spread assumed in analysis. During the performance of a comprehensive SSA, all areas of the plant will be individually analyzed for an exposure fire.
- *Failures*: The only failures considered are those that are directly attributable to the fire. No other failures or independent events are assumed to occur concurrently with the fire. No other design-basis events or failure consequences need be postulated in conjunction with the exposure fire, except for those caused by the fire itself.
- *Equipment Availability:* At the onset of fire, all safe-shutdown systems are assumed to be operable and available for post-fire safe-shutdown.

- *Availability of Offsite Power:* For fires not requiring implementation of an alternative or dedicated shutdown capability, offsite power is assumed to remain available unless fire can result in its loss. In the absence of an evaluation of the impact of fire on the availability of the offsite power sources, the analysis should demonstrate the capability of achieving shutdown conditions where offsite power is available and where offsite power is not available for up to 72 hours. For fire areas requiring an alternative or dedicated shutdown capability, the analysis should demonstrate the capability of achieving shutdown conditions where offsite power is available and where offsite power is not available for up to 72 hours. After 72 hours, offsite power can be assumed restored.
- *Automatic Equipment Operation*: Automatic equipment operation may or may not occur during a fire. For fire in areas requiring an alternative or dedicated shutdown capability, a loss of automatic functions must be assumed. For example, in the event of a loss of offsite power (LOOP) the EDGs will normally start automatically on undervoltage. However, in developing the alternative shutdown capability operation of this automatic start feature cannot be assumed. For other fire areas, automatic operation of components and logic circuits may be credited in the analysis, but only if the circuitry associated with the automatic operation is known to be unaffected by the postulated fire (i.e., satisfy separation requirements of Section III.G.2 of Appendix R). If the automatic actuation of equipment will be lost as a result of fire in these areas, manual initiation of systems required to achieve and maintain safe-shutdown, via manipulation of controls located in the main control room, is acceptable if it can be demonstrated that reliance on such operator actions will provide an equivalent level of safety to that which would be achieved by performance of the automatic functions.
- *Plant Status*: The plant is operating at 100-percent power upon the occurrence of the fire.
- *Equipment Status:* Components are in their normal operating position or status at the time of the fire. All relay, position switch, an control switch contacts are in the position or status that corresponds to the normal operation of the device. Test and transfer switches in control circuits are in their normal position.
- *Use of Repair Activities*: Repair activities, (which are generally defined as any activity requiring the use of tools such as wiring changes, installation of electrical or pneumatic jumpers, and fuse replacements) are not permitted for systems required to achieve and maintain hot shutdown conditions. Modifications and repairs are permitted for cold shutdown systems as described below.
- *Multi-Unit Sites*: Where a single fire can impact more than one unit, the ability to achieve and maintain safe-shutdown for each affected unit must be demonstrated.
- *Passive Components:* The operation of passive components that are not electrically controlled or operated, such as manually actuated valves and check valves, is not assumed to be affected by fire damage.

- *Time Constraints and Limitations of Fire Damage*

  Hot Shutdown Systems (All Areas)
  When considering the consequences of fire in a given fire area, it must be conclusively demonstrated that one success path of equipment, that can be used immediately to bring the reactor to *hot shutdown* conditions, remains unaffected by fire.

  Cold Shutdown Systems (Areas not Requiring an Alternative Shutdown Capability)
  For areas of the plant not requiring an alternative or dedicated shutdown capability, it must be demonstrated that fire damage to one success path of equipment needed for achieving cold shutdown will be limited so that equipment can be returned to an operating condition within 72 hours.

  Cold Shutdown (Areas Requiring an Alternative or Dedicated Shutdown Capability)
  For areas requiring an alternative or dedicated shutdown capability, it must be demonstrated that cold shutdown capability can be restored *and cold shutdown conditions achieved* within 72 hours.

6.4.2 Define Required Safe-Shutdown (SSD) Functions

Required shutdown functions are those plant process and support functions that must be accomplished and controlled to ensure that the reactor is brought to and maintained in a safe-shutdown condition without exceeding the shutdown performance goals described above. (See Section 6.4.1.3.) Successful accomplishment of each of the following shutdown functions is necessary to preclude the occurrence of an unrecoverable plant condition (e.g., uncontrolled primary depressurization, loss of DHR capability or breach of the RCS boundaries):

- *Reactivity Control*
  This function is necessary to decrease the power output of the reactor core to the decay heat level. The reactivity control function must be capable of achieving and maintaining reactor shutdown from the initial scram shutdown to cold shutdown conditions. This function must be capable of compensating for any positive reactivity increases as a result of Xenon-135 decay, reactor coolant temperature decreases occurring during cooldown, and RCS dilution. The safe-shutdown performance and design requirements for the reactivity control function can be met without automatic scram/trip capability. The SSA must only provide the capability to manually scram/trip the reactor. For PWR the analysis must demonstrate that a method for ensuring that adequate shutdown margin is maintained. This is typically accomplished by ensuring an adequate concentration of borated water is utilized during RCS makeup/charging.

- *Reactor Coolant Makeup Control*
  The reactor coolant makeup control function must be capable of ensuring that sufficient makeup inventory is provided to compensate for reactor coolant system fluid shrinkage during cooldown and to replace any coolant that may leak from the system. Maintenance of adequate inventory prevents overheating of the reactor fuel, which could lead to core damage.

Systems performing this function must be capable of maintaining reactor coolant level above the top of the core for BWRs[25] and within the level indication of the pressurizer for PWRs.

- *Reactor Coolant Pressure Control*
  Pressure control is required to ensure that the RCS is operated within prescribed pressure-temperature limits, to prevent RCS peak pressure limitations from being exceeded and (for PWRs) to minimize void formation within the reactor vessel during natural circulation cooldown.

- *Decay Heat Removal*
  The DHR function must be capable of removing both decay and latent energy from the reactor core and primary systems at a rate such that overall system temperatures can be maintained within acceptable limits. This function shall also be capable of achieving cold shutdown conditions and maintaining cold shutdown thereafter.

- *Process Monitoring*
  To adequately change system alignments, control safe-shutdown equipment, and ensure the shutdown process remains within acceptable performance criteria, operators must be provided with sufficient instrumentation to monitor the status of process system variables. Direct readings of the variables used to control the shutdown process are required.

  In GL 81-12, "Fire Protection Rule," and IN 84-09, "Lessons Learned form NRC Inspections of Fire Protection Safe Shutdown Systems" the NRC provides guidance regarding the minimum set of instrumentation deemed necessary for *alternative* or *dedicated* shutdown capabilities. The minimum process monitoring capability described in these documents includes the following instruments:

  Instrumentation Needed for Alternative or Dedicated Shutdown of a BWR:
  a. Reactor water level and pressure.
  b. Suppression pool level and temperature.
  c. Emergency or isolation condenser level.
  d. Diagnostic instrumentation for shutdown systems. (See Note 1.)
  e. Level indication for all tanks used.

  Instrumentation Needed for Alternative or Dedicated Shutdown of a PWR:
  a. Pressurizer pressure and level.
  b. Reactor coolant hot leg temperature or core exit thermocouples, and cold leg temperature.
  c. Steam generator pressure and level (wide range).
  d. Source range neutron flux. (See Note 2.)
  e. Diagnostic instrumentation for shutdown systems. (See Note 1.)
  f. Level indication for all tanks used [e.g., condensate storage tank (CST)].

  Note 1 Diagnostic instrumentation is instrumentation, beyond that identified above, that is needed to ensure the proper actuation and functioning of safe-shutdown equipment and associated support equipment (e.g., flow rate, pump discharge

[25] Short-term core uncovery may be permissible when using low-pressure injection systems at BWRs (see Richards Letter to BWROG, December 2000).

pressure). The diagnostic instrumentation needed is plant-specific and should be based on the design of the alternative shutdown capability (GL 86-10). Sufficient instrumentation must be ensured to remain available (unaffected by fire) to allow operators to detect malfunctions that may occur, take appropriate corrective actions without resorting to potentially complex troubleshooting activities, and ensure activity was successfully accomplished.

Note 2 In a letter dated September 10, 1985, the NRC Committee for Review Generic Requirements (CRGR) instructed the Office of Nuclear Reactor Regulation (NRR) to eliminate the staff position for a source range neutron flux monitor as part of the Appendix R alternative shutdown instrumentation in PWRs.

Enclosure 1 of GL 86-10, "Implementation of Fire Protection Requirements" states that the instrumentation listed above provides an acceptable method for compliance with the *alternative shutdown* requirements of the regulation (i.e., Section III.L.2.d of Appendix R). This list, however, does not exclude other alternative methods of compliance. 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.

Instrumentation Needed for Redundant Shutdown Capabilities:

For redundant shutdown capabilities, where shutdown activities are controlled from within the main control room, one train of systems needed to achieve and maintain hot shutdown conditions must remain free of fire damage. (Section III.G of Appendix R) As a result, additional specific guidance, such as that discussed above for alternative shutdown capabilities is not necessary. For these areas, the determination of required process and diagnostic instrumentation should to be based on the plant-specific operating procedures (including normal, abnormal, and EOPs) that would be used to shutdown the reactor in the event of an unmitigated fire. Since the same shutdown functions are generally required to be performed for both alternative and redundant shutdown, this monitoring capability is expected to be fairly consistent with the instrumentation listed above.

Sufficient instrumentation must be ensured to remain available to implement the shutdown methodology described in the SSA and applicable procedures. For shutdown strategies that rely on operator actions as a means of mitigating equipment maloperations that may occur as a result of fire damage, sufficient diagnostic instrumentation must be available for operators to detect the maloperations and initiate appropriate responses in a timely manner, without resorting to complex and potentially hazardous troubleshooting activities.

When sufficient diagnostic instrumentation is not ensured to remain unaffected by fire, reliance on the operators ability to detect fire-induced maloperations that may occur and perform activities needed to defeat them before an unrecoverable condition is achieved cannot be ensured. For example, during a fire an operator observes the ensured method of monitoring pressurizer level to be decreasing. Since many possible maloperations of plant equipment are capable of causing this indication (e.g., spurious closure of a makeup flowpath valve, loss of a makeup pump, open bypass valve, open PORV or open head vent)

without the benefit of additional diagnostic instrumentation, the operator's ability to determine the cause of this indication (pressurizer level decreasing) may be significantly compromised.

It should be noted that the use of operator actions as an immediate response to a confirmed fire has been shown to reduce the need for diagnostic instrumentation. An example of this approach would be a shutdown procedure that, immediately upon confirmation of fire, directs operators to close the MSIVs in the control room as a means of preventing their undesired operation (failure to close) as a result of potential fire damage to their control circuits.

For this case, an immediate action is taken to prevent a possible undesired outcome. Since no reliance is placed on the operators ability to detect a possible failure, the need for some diagnostic instrumentation may be eliminated.

- *Supporting Functions*
  To ensure the successful accomplishment of the above shutdown functions, several support systems and equipment are necessary. The supporting functions shall be capable of providing the process cooling, lubrication, etc., necessary to permit the operation of equipment used to accomplish the above shutdown functions. The specific support systems needed will vary with the shutdown methodology developed by the plant. Typical examples include electrical distribution systems, HVAC and essential room cooling, component cooling water, essential service water, and communications capability (e.g., portable radios, sound powered phones).

6.4.3 Select Shutdown Systems

The next step in the process is to identify a system or combination of systems capable of accomplishing each of the required shutdown functions described above (Section 6.4.2). This may be accomplished by a review the design documentation, such as system descriptions, system drawings, and plant procedures, described in Section 6.4.1.1. Once identified, these systems can be combined into safe-shutdown success paths and given a unique designation (e.g., SSD Path 1, SSD Path 2, etc.). A description of each path should then be documented. For example, shutdown paths for a BWR may be described as follows:

Path 1 Control Rod Drive System; Division I train of ADS, Division I CS in Alternative Shutdown Cooling and Division I of RHR in Suppression Pool Cooling Mode

Path 2 Control Rod Drive System; Division II train of ADS, Division II CS in Alternative Shutdown Cooling and Division II RHR in Suppression Pool Cooling Mode

In addition, systems necessary to support the operation of the above "front line" systems should also be identified as safe-shutdown systems (e.g., electrical distribution systems, instrumentation, cooling water systems and HVAC). A summary of the post-fire safe-shutdown analysis process to this point is illustrated in Figure 6-4a.

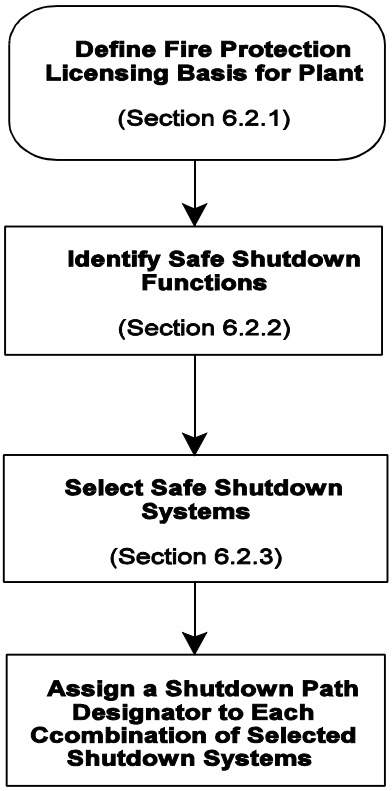

Figure 6.4a Safe Shutdown System Selection and Path Development

6.4.4 Select and Locate Required Shutdown Equipment

The systems identified above form the basis for the selection of safe-shutdown components. The next step in the process is to identify the specific equipment necessary for the identified systems to perform their shutdown function. This process is illustrated in Figure 6-4b.

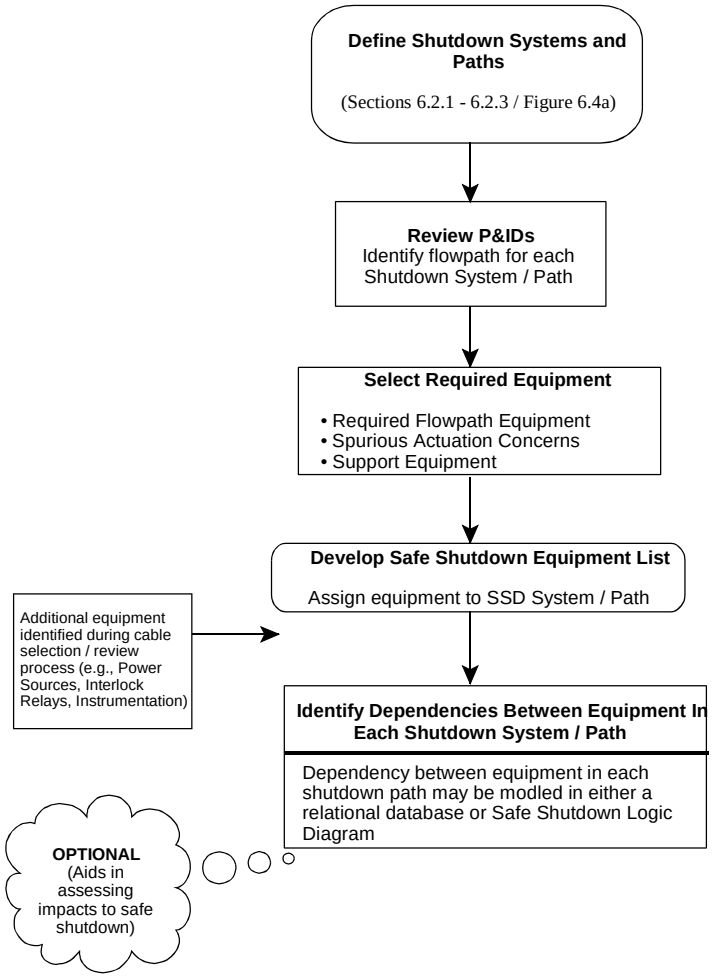

Figure 6.4b Safe Shutdown Equipment Selection

Using piping and instrumentation drawings (P&IDs) for the systems comprising each safe-shutdown path, the mechanical equipment required for the operation of each system may be identified. The selected equipment should be related back to the safe-shutdown systems it supports and be assigned to the same safe-shutdown path as that system. Equipment that could spuriously operate and impact the safe-shutdown capability may also be identified during the review of the P&IDs. This equipment should be related to the particular safe-shutdown path that it can affect. Equipment that can result in a loss of reactor inventory in excess of the available make up capability (i.e., initiate a fire-induced LOCA) should also be identified by a review of P&IDs for systems physically connected to the reactor vessel. The following criteria and assumptions are applicable to the selection of safe-shutdown equipment:

- Exposure fire damage to manual valves and piping is not assumed to adversely impact their ability to perform their safe-shutdown function.
- Manual valves are assumed to be in their normal position as shown on P&IDs.
- A check valve that closes in the direction of potential flow diversion is assumed to seat properly with sufficient leak tightness to prevent flow diversion.
- The effects of fire on instrument tubing must be considered. Heat generated by the fire may cause subsequent effects on instrument readings and/or signals. The fire area location of the instrument tubing should be determined and the effects of fire damage to it should be considered when evaluating the effects of a postulated fire in the area. In addition, the effects of fire on heat sensitive components such as copper sweated fittings should also be considered.

As a result of this review process, a list of “safe-shutdown components” also called “required components” will be generated for each system. This list should include: (1) components that are required to operate in order to ensure the proper operation of systems credited in the analysis (e.g., SSA) for achieving and maintaining post-fire safe-shutdown conditions; *and* (2) components of which inadvertent actuation or maloperation could significantly degrade the capability of these credited systems to perform their intended shutdown function. The following examples represent the typical required components:

(1) Components that must start and/or continue to operate on demand such as required pumps, fans, air compressors and motors.

(2) Electrically actuated or controlled components that must change operating status or position, such as a normally closed valves located in a required flowpath.

(3) Electrically actuated or controlled components that must *not* change position or operating mode. Examples include a normally closed valves that constitute a system boundary or diversion flowpath and normally open valves located in a required flowpath.

(4) Components needed to ensure the proper operation of shutdown equipment and systems. Examples include: Power supplies (EDGs, battery banks, inverters, battery chargers, SWGRs, MCCs, load centers, and distribution panels) room coolers and air bottles.

(5) Components that can cause equipment and systems to automatically actuate and/or change operating state in an undesired manner for safe-shutdown. Examples include interlock circuits, pressure switches, temperature switches, solid-state control systems, and various instrumentation devices.

The resulting list of equipment SSEL establishes the basis for identifying *required circuits and cables* (i.e., circuits and cables needed to support operation of the identified shutdown paths) ***as well as*** *associated nonsafety circuits* for which damage attributable to fire could impact (adversely affect) the achievement of safe-shutdown conditions.

Illustration of Equipment Selection Process

The following are *guidelines* regarding which components to include on the SSEL for each system evaluated. (Refer to Figure 6-5.)

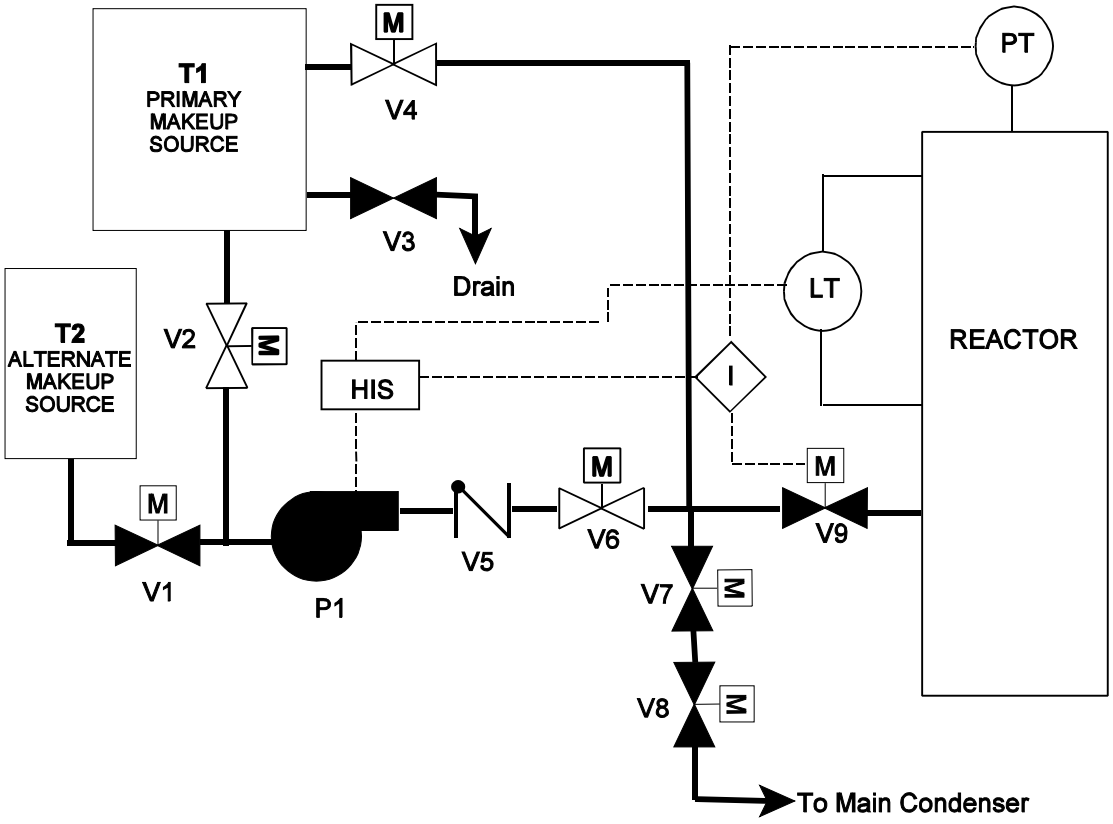

Figure 6-5 Example System

Components of interest are those needed to ensure the successful accomplishment of a required shutdown functions. This includes components that are needed to ensure the proper functioning of required shutdown systems (e.g., pumps and valves located in a required flowpath) as well as components of which maloperation attributable to fire could impact the shutdown capability (e.g., pressurizer PORVs, ADS valves, instrumentation). The following examples represent the typical components to be included in the SSEL:

- *Valves and HVAC dampers that constitute system boundaries* should be included if fire-induced faults could cause them to change position *and* their maloperation (e.g., inadvertent/spurious opening) would significantly impact the capability of the system to perform its intended shutdown function (e.g., by creating a flow leakage/diversion path that cannot be adequately compensated for by the system). Valves V7 and V8 in Figure 6-5 fall into this category.
- *Valves and dampers (e.g., HVAC dampers) in the flow path* that are power operated should be included. Associated valve operators should also be included as part of the valve/damper. These components should be included whether or not they are required to change position during shutdown if a fire-induced fault could cause them to change position. These components ensure that the process flow path is maintained. [Valves V1, V2, P1, V4 and V9 in Figure 6-5) fall into this category.]
- *For tanks*, all inlets and outlet lines should be evaluated for their functional requirements and isolation. For lines that are not required to be functional, a means of isolation should be included when necessary to prevent unnecessary drawdown of the tank. Tank inventory must be evaluated to ensure that it is always sufficient to support the system requirements. Tanks T1 and T2 in Figure 6-5 are an example of this category.
- *Interlock circuitry* between safe-shutdown components and safe-shutdown/non-safe shutdown components should be reviewed to determine if additional components require inclusion. This is to ensure that a failure of a non-safe-shutdown component would not prevent the safe-shutdown system from operating as required. (In Figure 6-5, the interlocks between the reactor level and the pump and the reactor pressure and valve V9 and the pump are examples of this category.)
- *All necessary process and diagnostic instrumentation* (e.g., process flow, pressure, temperature, level, indicators and recorders)
- *Power supplies* or other electrical components that support operation of required shutdown components should be included (SWGR, EDGs, MCCs, load centers, inverters, batteries, relays, control switches, flow switches, pressure switches, level switches, transmitters, controllers, transducers, and signal conditioners).

6.4.5 Identify Required Circuits and Cables

As discussed above, to achieve safe-shutdown conditions certain *shutdown functions* (e.g., reactivity control, DHR, reactor coolant inventory and pressure control, etc.) must be accomplished and controlled to ensure that the reactor is brought to and maintained in a safe-shutdown condition within design parameters established in the applicable licensing basis documents. The systems identified as being needed to accomplish these functions are classified as *"required shutdown systems.*" Similarly, the equipment that must operate or be prevented from mal-operating in order for the required shutdown systems to accomplish their intended shutdown functions, are considered *"required equipment" or "required components."* Once identified, required components are listed on the SSEL. The SSEL establishes a starting point for identifying *required circuits and cables* (i.e., circuits and cables needed to support operation of the identified/credited shutdown paths) ***as well as*** the *associated nonsafety circuits* for which damage attributable to fire could impact (adversely affect) the achievement of safe-shutdown conditions by initiating an event that exceeds the design capability of the credited/required shutdown systems.

After the listing of required components is developed SSEL for each shutdown path, the circuits/cables needed to support the operation of this equipment are identified and evaluated. For each required component, all circuits (cables) that: (a) are needed to ensure proper operation, or (b) could cause maloperation/undesired actuation must be identified.
A circuit/cable is considered to be *required for safe-shutdown* if it is connected to or associated with the operation of a required shutdown component *and* fire damage to the circuit/cable can cause the component to fail in an undesired manner for post-fire safe-shutdown. In addition to the set of circuits/cables needed to ensure the acceptable operation of required shutdown components, *associated circuits of concern to post-fire safe-shutdown* must also be identified and analyzed. As discussed below, these circuits have one of the following:

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

(2) A *common enclosure* (e.g., raceway, panel, junction box) with shutdown cables and a) are not electrically protected by suitably sized circuit breakers, fuses or similar devices, or b) will allow fire to propagate into the common enclosure

(3) *A connection to equipment of which spurious operation or maloperation may adversely affect the shutdown capability* (Note: As discussed in Section 6.4.4 above, the identification of "spurious operation components" is typically performed as part of the review of P&IDs to identify required shutdown equipment)

The following paragraphs provide criteria and guidance for selecting safe-shutdown cables and determining their potential impact to equipment required for achieving and maintaining safe shutdown for the condition of an exposure fire. The objective of the cable selection criteria is to ensure that circuits and cables of required shutdown equipment are identified and that these cables are properly related to equipment with functionality they could affect. Through this cable-to-equipment relationship, cables become associated with the same safe-shutdown path as the equipment affected by the cable.

6.4.5.1 Cable Identification

- *Scope:* The list of cables of which failure could impact the operation of a piece of safe shutdown equipment includes more than those cables that are directly connected to the equipment. The relationship between cable and affected equipment should be based on a review of electrical or elementary wiring diagrams. In addition to the cables that are physically connected to the equipment, the list of required cables will include any cables interlocked to the primary electrical schematic through secondary schematics. To ensure that all cables that could affect the operation of the safe shutdown equipment are identified, the power, control, instrumentation, interlock, and equipment status indications should be investigated. Schematic diagrams should be reviewed to identify additional circuits and 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.
- *Cable/Component Associations:* Each cable should be related back to the same shutdown path as the equipment it supports. In cases where the failure of a single cable could impact more than one piece of shutdown equipment, the cable should be associated with each piece of shutdown equipment.
- *Isolation Devices:* Electrical devices such as relays, switches, and signal resistor units (SRUs) are considered to be acceptable isolation devices. In the case of instrument loops, the isolation capabilities of the devices in the loop should be evaluated 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 instrument function.
- *Screening:* Circuits that do not impact the desired safe-shutdown performance or expected operation of a component, such as those illustrated in Figure 6-2 above, may be screened from further evaluation unless some reliance on these circuits is necessary. However, these circuits must be ensured to be isolated from the component's control scheme in such a way that a cable fault would not impact the performance of the circuit.
- *Power Cables:* Electrical distribution system (EDS) equipment needed to provide power to shutdown equipment may be identified from a review of the electrical schematics associated with the shutdown equipment. For each component requiring electric power to perform its safe-shutdown function, the cable that supplies power to the component should be identified. Initially, only the power cables from the immediate upstream power source are identified for these interlocked circuits and components. A further review of the electrical distribution system is needed 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 EDGs to the safe-shutdown equipment. This equipment should then be added to the SSEL. This information will be needed to support the *Associated Circuits — Common Power Source Analysis* described in Section 6.4.5.2.
- *Automatic Initiation Logic:* The automatic initiation logic for the credited post-fire safe-shutdown systems is not required to support safe-shutdown; each system can be controlled manually by operator actuation. However, if not protected from the effects of fire, the fire-induced failure of automatic initiation logic circuits must be verified to not adversely affect any post-fire safe-shutdown system function. Otherwise it would need to be included in the SSEL.

6.4.5.2 Identification of Associated Circuits

The overall objective of the SSA, is to demonstrate that in the event of an exposure fire in any single area of the plant, SSCs important to safe-shutdown will remain available to accomplish required shutdown functions (e.g., reactivity control, reactor coolant makeup, and pressure control, DHR) as needed. Because circuits and cables of the required shutdown systems frequently share certain physical or electrical configurations with cables of nonessential systems and equipment (i.e., not required for post-fire safe-shutdown) it is not sufficient to only consider the effects of fire damage to cables of required components. For example, consider the cable configuration shown in Figure 6-6. In this case, the cable that supplies power to a nonessential load is powered from the same power supply as equipment relied on for safe-shutdown. While a fire that causes a loss of the nonessential load may not directly impact the shutdown capability, a fire that damages the power cable of the nonessential load could significantly impact the shutdown capability if damage to this cable resulted in a loss of the required (Train B) power supply. Because fire damage to certain nonessential equipment and cables may adversely affect the operability of required shutdown systems, in performing the SSA the analyst must consider the effect of fire on both the primary, or "front-line" shutdown equipment and any nonessential equipment and cabling that may affect the ability of required shutdown systems to accomplish their intended shutdown function if they are damaged by fire. That is, the scope of the evaluation must extend beyond the limited set of equipment that comprises the defined shutdown paths. A suitably comprehensive evaluation will address the potential impact of fire damage to any circuit/cable located within the fire area that could adversely affect the post-fire safe-shutdown capability.

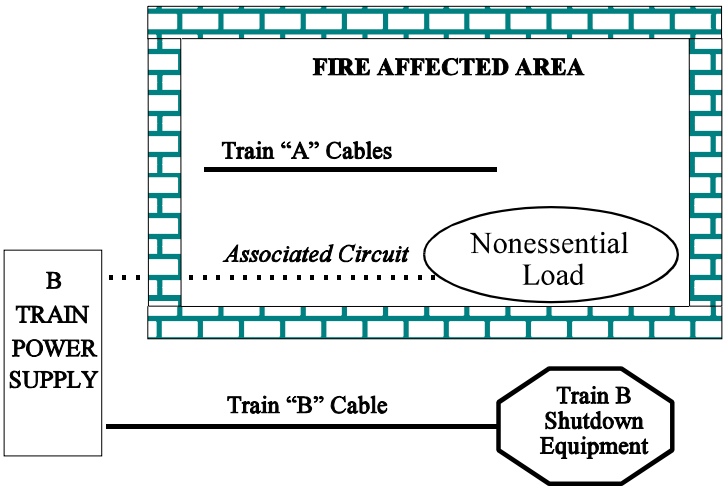

Figure 6-6 Associated Circuit

6.4.5.2.1 Associated Circuit Configurations of Concern to Post-Fire Safe Shutdown

Section III.G.2 of Appendix R to 10 CFR Part 50 requires that separation features be provided for equipment and cables, including associated nonsafety circuits that could prevent the operation or cause the maloperation (attributable to hot shorts, open circuits, or shorts to ground) of redundant trains of systems necessary to achieve and maintain hot shutdown conditions. An *associated circuit of concern* to post-fire safe-shutdown may include any circuit or cable that, while not needed to support the proper operation of required shutdown equipment (i.e., a nonessential/nonsafety circuit), could adversely affect the plant's ability to achieve and maintain safe-shutdown conditions. Associated circuits of concern may be found to be associated with circuits of required systems through any of the following configurations:

- Circuits that share a **common power source** (e.g., SWGR, MCCs, fuse panel) with circuits of equipment required to achieve safe-shutdown
- Circuits that share a **common enclosure**, (e.g., raceway, conduit, junction box, etc.) with cables of equipment required to achieve safe-shutdown
- Circuits of equipment of which **spurious operation** or maloperation may adversely affect the shutdown capability

Methods for identifying each type of associated circuit defined above are discussed in the following sections.

Circuits Associated by Common Power Source

The electrical distribution system is one of the most important support systems of any installation. Electrical power supplies (e.g., SWGRs, MCCs, fuse and circuit breaker panels) required to power shutdown equipment in the event of fire are identified during the selection of required shutdown equipment (Section 6.4.4). Once identified, the analyst must then ensure that in the event of fire, the required power supplies will remain available, as needed to ensure the continuity of service to essential shutdown loads. In the event of an electrical fault condition, a properly engineered system will allow only the protective device nearest the fault to open while not disturbing the remainder of the system.

In many cases, relatively few of the components that are normally powered from a specific power supply are needed to accomplish required shutdown functions. While providing power to the remaining "nonessential" loads (equipment) may not be necessary to accomplish safe-shutdown, it must be ensured that fire initiated faults on the power cables to this equipment will not affect the shutdown capability by causing a trip of the protective devices (e.g., circuit breaker, fuse, or relay) located upstream of the required supply. To address this concern, the SSA must be extended to consider the effects of fire-induced faults on all circuits of required power supplies identified in Section 6.4.4. To ensure that fire-induced faults on these circuits will not affect the capability of achieving safe-shutdown conditions, this analysis must ensure that circuits which share a common power source with circuits of required equipment are provided with: (a) fire protection features sufficient to satisfy Section III.G.2, or (b) suitably coordinated electrical protective devices.

The common power source associated circuit concern is illustrated in Figure 6-7a. In this case, in the event of fire in Fire Area II, Train A safe-shutdown equipment (Pump A) located in Fire

Area I and powered by safe-shutdown Bus A, is relied on to accomplish safe-shutdown. Although the Train A pump is located in a separate fire area, it may be vulnerable to loss as a result of fire in Fire Area II. This is because, as shown in Figure 6-7a, a Train A *associated circuit power cable* is also located in Fire Area II. Although this cable and its connected load (Pump X) are not needed to perform a shutdown function, the absence of suitable *coordination of electrical protective devices*, a fire-induced electrical fault on the this cable could cause the upstream feeder breaker of Bus A (Breaker 1) to trip before the individual branch breaker (Breaker 2). Because this would result in a loss of electrical power to all shutdown equipment powered from safe-shutdown Bus A, failures of this type are unacceptable.

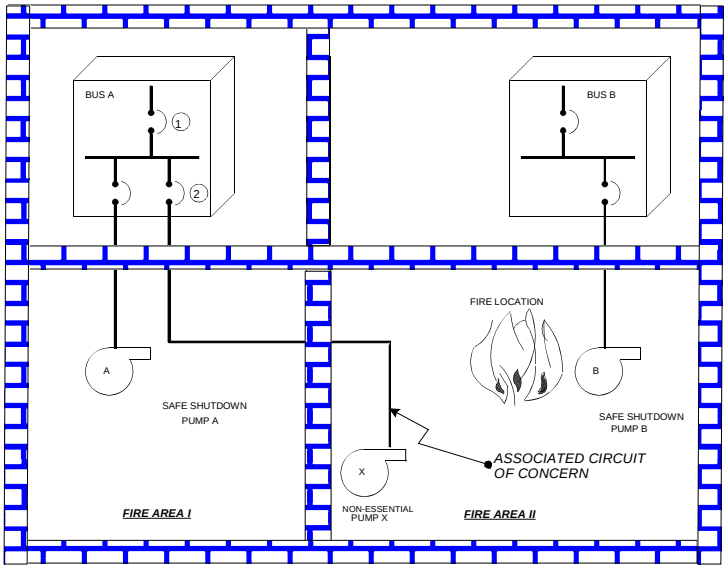

Figure 6-7a Common Power Source Associated Circuit

The common power source associated circuit concern consists of two items:

(1) coordination of electrical protective devices (circuit breakers, relays, fuses, etc.)
(2) multiple high impedance faults (MHIFs)

Coordination of Electrical Protective Devices

To minimize the effect of an electrical fault on system operation, the tripping characteristics of electrical protective devices (fuses, circuit breakers and relays) should be sufficiently coordinated so that electrical faults will be rapidly isolated by the protective device located nearest the fault. Although the term “coordination” is often used, “selectivity” or “selective tripping” more precisely describes post-fire safe-shutdown concerns. Selectivity means positive coordination over the entire range of possible fault currents, ensuring that the faulted circuit is cleared and that other parts of the system are not affected. Examples of both a non-selective system and a system that is provided with fully selective protective devices are illustrated in Figures 6-7b and 6-7c. In the non-selective system shown in Figure 6-7b, a branch circuit fault would cause fuses D, C and B to open, resulting in a loss of power to all loads supplied from the system. In the fully selective system shown in Figure 6-7c, the fault is isolated by fuse D and the remainder of the system remains undisturbed.

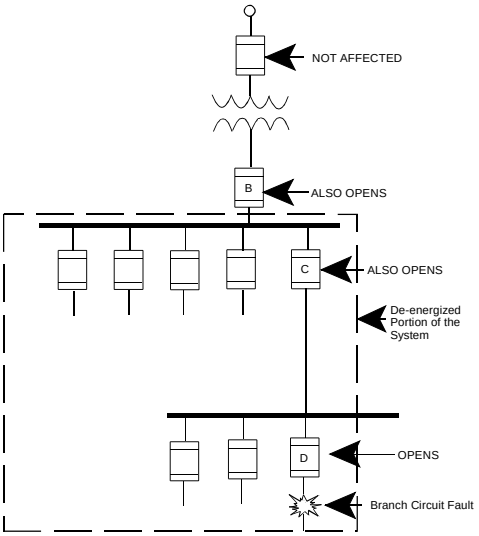

Figure 6.7b - Non-Selective Coordination

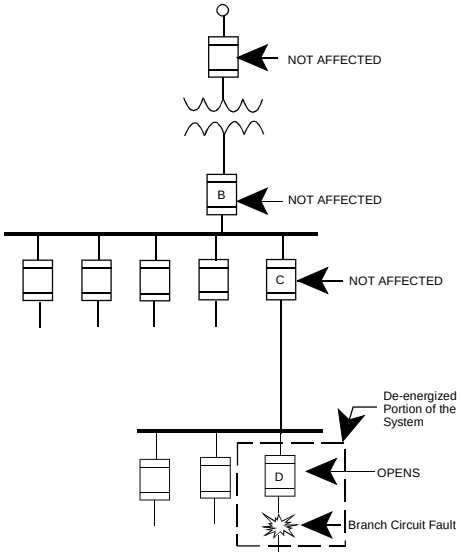

Figure 6.7c - Selective Coordination

Depending on their design and/or individual trip settings, fault protective devices of the same type (e.g., fuse or circuit breaker) and rating (20 amp, 30 amp etc.) may have significantly different tripping characteristics. A coordination study consists of the selection or setting of all series protective devices from the load upstream to the power supply. In selecting or setting these protective devices, a comparison is made of the operating times of all the devices in response to various levels of overcurrent. The objective, of course, is to design a selectively coordinated electrical power system. The operating response of a specific protective device is graphically represented by time-current characteristic curves. Time-current characteristic curves are presented on a log-log graph where the ordinate (y-axis) represents a time range from 0.01 to 1,000 seconds, and the abscissa (x-axis) represents the current level. By overlaying the time-current curves of two protective devices or comparing them in some other manner, their selectivity may be quickly determined. If the curves of the two devices intersect, for example, the intersection area indicates conditions under which both devices may trip. If such a pair of circuit breakers were used in an electrical distribution system, those conditions could result in both devices tripping. On the other hand, if the curves of the circuit breakers are distinctly separate and do not intersect, the circuit breakers are said to be coordinated.

A new or revised coordination study should be made when the available short-circuit current from the power supply is increased; when new large loads are added or existing equipment is replaced with larger equipment; or when protective devices are upgraded.

Multiple High-Impedance Faults

In the previous paragraphs, the need for circuit protective device "selectivity" was discussed. The evaluation of selectivity typically considers "worst-case" fault conditions initiated by "bolted faults." A "bolted fault" develops when the conductor of a faulted cable is in firm contact with a conductor that is at a different potential, such as a cable tray (phase to ground fault). Since this fault condition offers little, if any, impedance (resistance) to the flow of fault current, it will result in a maximum value of fault current being drawn from the affected power source. In a properly coordinated (selective) system, this high value of fault current will be rapidly interrupted and cleared by the circuit protective device closest to the fault. Under certain conditions, however, insulation degradation resulting from fire damage may cause a different kind of fault condition known as an "HIF." In almost every case, this type of fault occurs between one phase and ground. However, instead of establishing direct contact to ground potential (as for a "bolted fault"condition) the faulted conductor is not mechanically firm or is erratic. As a result an arc develops in the air gap between the faulted conductor and ground. This arc introduces an element of resistance to the flow of fault current that is not present in a bolted fault. As a result, the magnitude of high-impedance fault currents are relatively low (in comparison to a bolted fault) and in many cases, the arcing fault will be of such a low value that it is less than the continuous current rating of the overcurrent protective for the circuit involved.

In the majority of cases, an arcing fault starts as a small breakdown in insulation. Ionization of the atmosphere and destruction of insulation cause the fault to develop into a self-sustaining arcing fault. In a 480-V system, tests and calculations have indicated that this sustained current can be as low as 20-percent of the available bolted three-phase current[26]. Although the individual faults are not of sufficient magnitude to cause a trip of the individual load breakers, a coordination problem could exist if the cumulative effect of these faults were to cause the upstream feeder breaker of a required power source to trip. To fully demonstrate that a required power source will not be impacted by fire damage to its connected cabling, the potential impact of HIFs should be considered. This evaluation involves determining the effect of such faults on all cables of a required power supply that may exposed to fire damage. (See Figure 6-8.)

For the purpose of performing this analysis, the following assumptions are applicable:

- The HIF current of each cable that may be exposed to fire damage is postulated to be a value that is just below the trip point setting of the individual protective device for the load.
- All unprotected load cables of the power supply being evaluated, that are located within the zone of influence of the fire (e.g., located in the same fire area/zone), are assumed to simultaneously fault to the HIF condition.
- The total load current to be considered is the sum of all high-impedance faults *plus* the normal operating load current on the bus.

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[26] "Good Design Prevents High-Impedance Fault," *Actual Specifying Engineer*, Vol. 17, No.4, Medalist Publications, Inc., Chicago, IL, 1967.

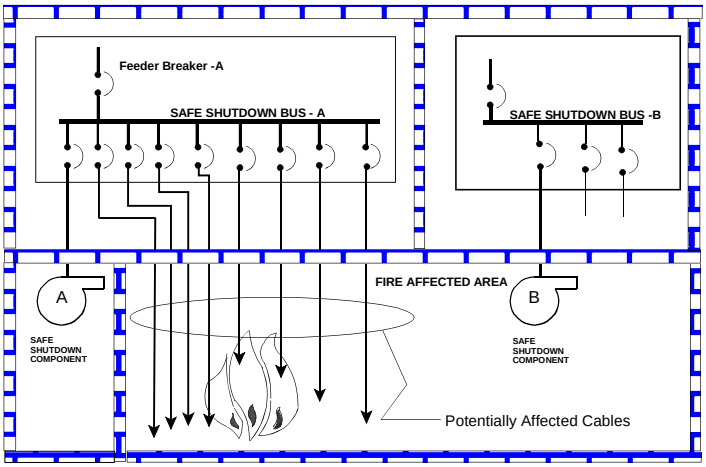

Figure 6-8 Illustration of Multiple HIF Concern

Circuits Associated by Common Enclosure

Cables that are not needed to perform a shutdown function (nonessential cables) frequently share a common enclosure (e.g., cable tray, conduit, junction box, panel, etc) with cables of shutdown equipment. Since the routing of these nonessential cables is generally unknown, they may be damaged by fire in any area of the plant. In the absence of suitably sized electrical protection devices (fuse or circuit breaker) and/or fire protection features, damage to these cables could also damage the required cables located within the common enclosure. In addition, if fire were to spread along these cables into an adjacent fire area due to inadequate cable penetration seals, the safe shutdown equipment or cables located in the adjacent fire area could also be impacted. This condition would exceed the criteria and assumptions of this methodology (i.e., multiple fires and fire spread beyond area under consideration).

Circuits that share enclosures with safe-shutdown circuits must be analyzed to determine the potential effect that fire damage to these circuits (cables) may have on the safe-shutdown capability. This concern consists of two issues:

(1) *Cable ignition*: Fire-initiated electrical faults on inadequately protected cables could cause an over current condition, resulting in secondary ignition.

(2) *Fire propagation*: The effects of the fire may extend outside of the immediate area or into the common enclosure by means of fire propagation.

As described in the following paragraphs, either of these cases could result in damage that could disable redundant trains of required shutdown equipment.

Case 1: Common Enclosure — Cable Ignition

Cables of nonessential equipment may share a common enclosure (e.g., raceway, conduit, or panel) with cables of equipment required for safe-shutdown. In the absence of adequate electrical protection (i.e., properly sized fuses and circuit breakers), heat generated by fire-induced faults on the nonessential cables may cause a secondary fire to occur within the common enclosure, thereby damaging required cables.

Figure 6-9 illustrates the common enclosure concern associated with "cable ignition." As shown in this diagram, a fire occurs in fire area II and causes a fault on an associated circuit cable that is not properly protected by a suitably sized fuse. As a result of this condition, the fault current will propagate along the entire length of the affected cable, into an adjacent fire area (Fire Area I). If the value of fault current exceeds the current carrying capacity of the cable, a secondary fire may be initiated in Fire Area I, resulting in the loss of redundant trains of shutdown equipment (Instruments A and B).

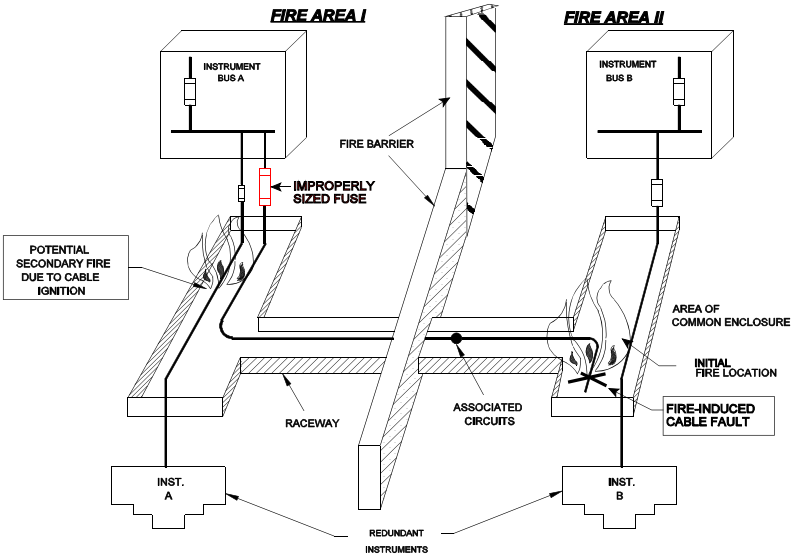

Figure 6-9 Common Enclosure - Case 1: Cable Ignition

Case 2 Common Enclosure — Fire Propagation

Cables of equipment that is not needed for safe-shutdown may traverse fire areas containing redundant trains of shutdown equipment. When fire protection features, such as fire stops and penetration seals are not provided, there is a potential for a cable to serve as a pathway for fire to propagate (travel) into adjacent fire areas. This concern is illustrated in Figure 6-10. In the example shown, the initial fire in Fire Area II will render instrument “B" inoperable. Since the cable tray is not provided with suitable protection features (e.g., penetration seals or fire stops), a fire that affects Instrument “B”cables could also propagate along the associated circuit cables and impact the redundant Instrument “A”cables located in the adjacent fire area.

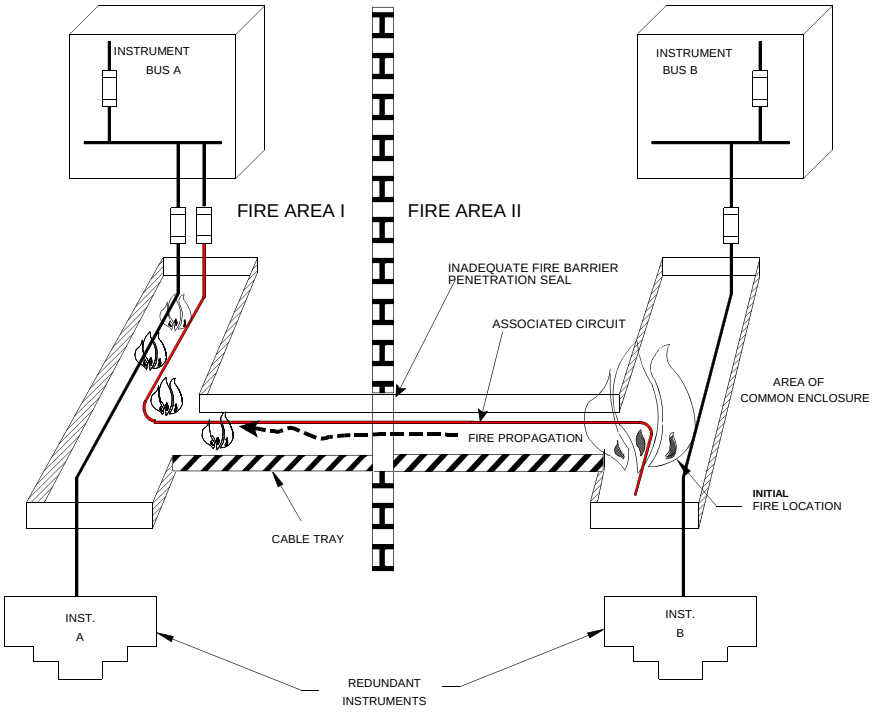

Figure 6-10 Common Enclosure Associated Circuit Case 2: Fire Propagation

Spurious Actuations and Signals

Cable damage attributable to fire or its related perils (e.g., firefighting and fire-suppression activities) can cause connected equipment to operate in an undesirable and/or unexpected manner. For example, a fire-induced short circuit on control wiring of a normally open MOV, could cause the valve to inadvertently close, thereby blocking a required flow path. Conversely, the spurious opening of a normally closed valve could divert flow from a required flow path. Additional examples include false instrument indications, the spurious starting or stopping of electrically powered equipment, such as pumps and motors, and the initiation of false control and interlock signals.

The achievement of safe-shutdown is dependent on the active control of some components and preventing the maloperation of other components. The circuits of both categories of components have the potential for being associated circuits of concern by spurious operation. Components which must actively operate (change position or operating status) at some point in the safe-shutdown sequence must be analyzed to identify circuits (cables) which if damaged could prevent the desired component operation; likewise, passive components, such as a normally closed MOV that is required to remain closed for safe shutdown, must be analyzed to ensure that fire-induced cable faults cannot cause the spurious maloperation of the component.

An example of how fire-initiated spurious actuations of equipment may impact the shutdown capability is illustrated in Figure 6-11. For this case, MOV-1, located in Fire Area IV, is normally closed during plant operation and is required to remain closed for safe-shutdown. As depicted in the illustration, MOV-1 could spuriously actuate (open) as a result of fire in Fire Area I. Specifically, if fire damage to relay “R” control circuits in this area were to initiate a false “auto-open” signal, relay “R” would actuate, closing contact RC1. Since actuation of contact RC1 has the same effect as closing the “open” contact of the MOV control switch (CS-O), motor-contactor solenoid 42-O would energize, resulting in the inadvertent actuation (undesired opening) of MOV-1.

Circuits that could cause undesirable spurious equipment operations must be identified and evaluated for their effect on safe-shutdown capability. The specific method used to prevent or control spurious equipment operations must be consistent with the potential severity of the spurious actuation. For example, since their inadvertent operation may place the plant in a potentially unrecoverable condition [loss of coolant accident (LOCA)], the spurious opening of valves which form a high/low pressure interface boundary would have a high consequence on the shutdown capability. As discussed in Section 6.3, given the severe consequences associated with this event, high/low-pressure interface boundaries are subject to more stringent analysis criteria. For example, the analysis must consider multiple, simultaneous, hot shorts of the required polarity and sequence as a credible event.

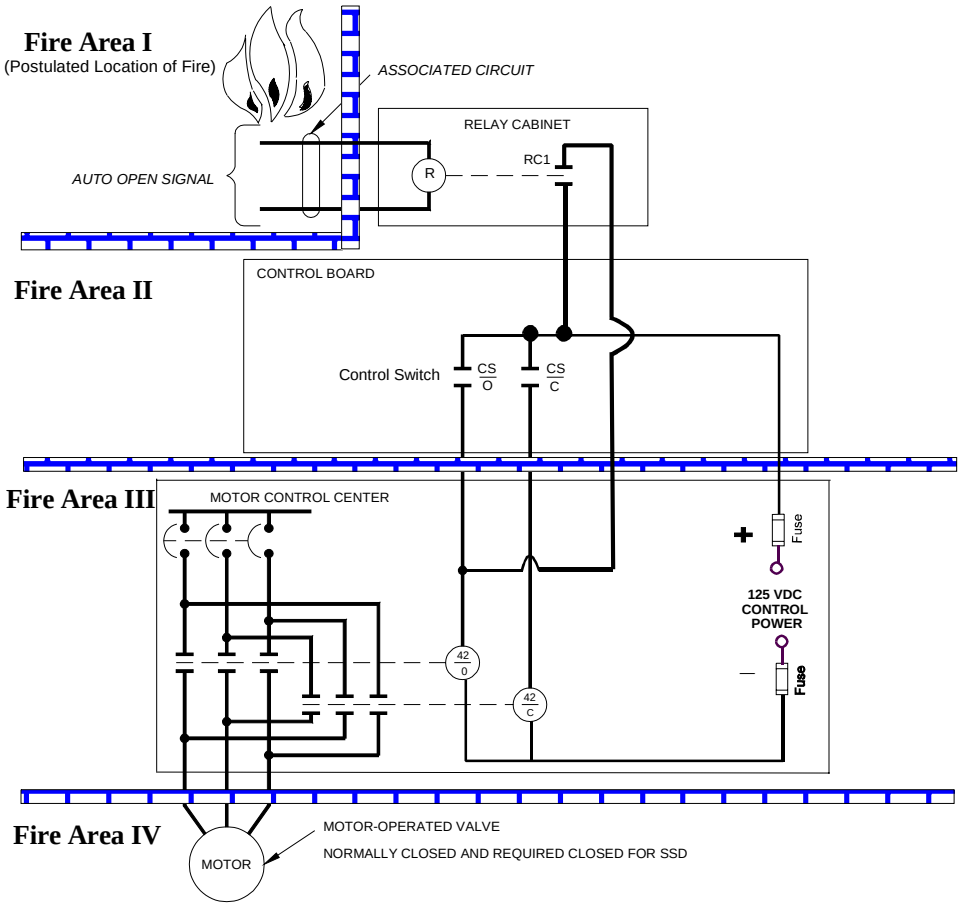

Figure 6-11 Example of the Spurious Actuation Associated Circuit Concern

While the spurious actuation of components having a high consequence on the ability to achieve safe-shutdown conditions must be precluded, other spurious equipment operations may not require this level of protection, provided it can be demonstrated that their inadvertent or "spurious" actuation would not impact on the safe-shutdown capability of the plant. A specific example of this case is a spurious actuation which causes the loss of ventilation in an area containing safe-shutdown equipment. If it can be demonstrated that the required equipment will remain operable (i.e., capable of performing its intended function) for a sufficient length of time without ventilation, plant modifications necessary to preclude the spurious operation may not be necessary.

As described in Section 6.4.4, potential spurious components of concern may be identified from a review of system design documents (e.g., flow diagrams, electrical schematics, etc.). During this review, components of which inadvertent operation could prevent the system from performing its intended shutdown function are identified and included in the SSEL. This list should include components of nonessential systems of which spurious operation could affect the shutdown capability. Once identified, appropriate methods of control can be planned. However, it is imperative that the safe-shutdown analysis include a thorough evaluation of all plant systems so that potential spurious equipment operations of concern can be properly identified for each fire area.

6.4.6 Circuit Analysis

> *"The need to evaluate the effects of fire on circuits associated with the safe-shutdown systems was not explicitly stated in Appendix A to BTP APCSB 9.5-1. It is explicitly required in Appendix R."* (Reference: SECY-80-438A, "Commission Approval of the Final Rule on Fire Protection Program," September 30,1980.)

6.4.6.1 Background/Objective

The evaluation of the consequences of fire in a given fire area must conclusively demonstrate that one train of equipment that can be used immediately to bring the reactor to hot shutdown conditions remains unaffected by fire. The systems and equipment that will be depended upon to perform essential shutdown functions must be identified in the FHA and/or the SSA for the plant. It follows that any circuits or cables in the fire area that could (1) adversely affect the operability of identified shutdown equipment and systems or (2) initiate plant transients that could preclude the successful accomplishment of required shutdown functions, by feeding back potentially disabling fault conditions to power supplies, control logic or instrumentation circuits, must be evaluated and such disabling conditions prevented or appropriately mitigated. Otherwise, reliance on the identified safe-shutdown equipment cannot be ensured.

In addition to establishing protection requirements for redundant trains of systems necessary to achieve and maintain hot-shutdown conditions (i.e., the set of "required" shutdown equipment identified in Section 6.4.4 above), Section III.G.2 of Appendix R further specifies that the ability to achieve and maintain hot shutdown conditions must not be impacted by fire which damages nonsafety circuits that are associated with the required shutdown systems. Additionally, with regard to alternative or dedicated shutdown capabilities, Sections III.L.3 and III.L.7 of Appendix R require the shutdown capability to be independent (physically and electrically) of the specific fire area(s) under consideration and isolated from associated nonsafety circuits such that a postulated fire involving associated circuits will not prevent safe-shutdown.

Associated circuits of concern are defined as cables (circuits) that may affect the safe-shutdown capability and/or prevent the achievement of post-fire safe-shutdown conditions if they are damaged by fire. Associated circuits may be safety-related or nonsafety-related. These circuits are a concern as long as their failure could impact the defined method of achieving and maintaining post-fire safe-shutdown conditions (i.e., the method credited in the plant's SSA). Specific associated circuit configurations of concern to post-fire safe-shutdown include circuits that share a common enclosure or power source with shutdown circuits and circuits that could cause equipment to spuriously actuate in an undesired manner for safe-shutdown. Each of these configurations is described above in Section 6.4.5.

6.4.6.2 Circuit Analysis Criteria and Assumptions

The fire protection design options delineated in Section III.G.2 of Appendix R provide assurance that cables and equipment located in a specific fire area under consideration will remain free of fire damage. It is not deemed possible to accurately predict the manner in which cables or circuits which lack such protection may fail when subjected to fire and its related perils (e.g., fire-suppression system actuation and physical insults resulting from fire-damaged equipment and firefighting activities). Therefore, analytical approaches used to demonstrate an equivalent level of fire safety to that which would be achieved through compliance with the

regulation, are expected to assume that the exposed cables (circuits) will be damaged and then evaluate the possible consequences of this damage on the ability to achieve and maintain safe-shutdown conditions. Such an evaluation would require consideration of one or more (i.e., combination) of the following failure modes:

(1) Open circuits resulting in a loss of electrical continuity (see Section 6.4.6)

(2) Short circuits between individual conductors of a multi-conductor cable (see Section 6.4.6).

(3) Short circuits between conductors of different cables (see Section 6.4.6)

(4) "Hot shorts" where un-energized circuits are inadvertently energized by fire damage which causes conductors of different potential to establish electrical contact (short). A "hot-short" may be compared to the actuation of a light switch. Prior to actuation of the switch, the light is off because its conductors are not energized. Following actuation of the switch (or in our case, development of a hot short) a pathway for current flow is completed between the energized conductors and the formally de-energized conductors and the light illuminates (see Section 6.4.6)

(5) Short circuits between conductors of logic circuits located in equipment and cabinets that are exposed to fire damage (e.g., MCCs, control boards, instrument panels).

(6) Direct or "bolted" low-impedance short circuits of energized conductors to grounded reference potentials. (see Section 6.4.5)

(7) Arcing (high impedance) short circuits of energized conductors. (see Section 6.4.5)

Criteria/Assumptions

For the purpose of performing an evaluation of fire-induced circuit failures, the following criteria and assumptions are applicable:

- The fire is assumed to occur anywhere in the fire area and to extend throughout the fire area under consideration. Unless provided with suitable fire protection features (per Section III.G.2 of Appendix R) the fire must be assumed to impact the performance of all equipment and cables located in the fire area.
- Credit cannot be taken for the proper function of any electrical circuit that has not been fully analyzed.
- Credit may be taken for automatic actuation signals to position equipment to the desired shutdown condition but only if it can be demonstrated that the fire will not affect the proper operation of the circuits and equipment that generate the automatic signals. Credit cannot be taken for automatic signals if the equipment or circuits that generate the automatic signals are exposed to fire damage.
- It cannot be assumed that fire will affect any electrical circuit in such a way as to cause equipment to fail in its desired safe-shutdown position.
- There is no limit on the number of circuit/cable faults that may occur as a result of fire damage in a given fire area. Any circuit/cable located in the fire area of consideration that lacks suitable fire protection features (per Section III.G.2) must be assumed to be damaged by the effects of fire and/or its related perils.

- In determining the potential for fire to cause undesired spurious equipment actuations, components other than high/low pressure interface valves, need only consider the effect of a single hot short. However, this single fault (hot short) must be considered to occur in combination with other possible circuit failure modes (open circuits, shorts to ground).
- If it is determined that more than one hot short is required to cause a component to spuriously actuate and the component is not a high/low pressure interface valve *and* the conductors of concern are not located in a single (multi-conductor) cable, then spurious operation of the component is not considered credible. (See Figure 6-11a.)

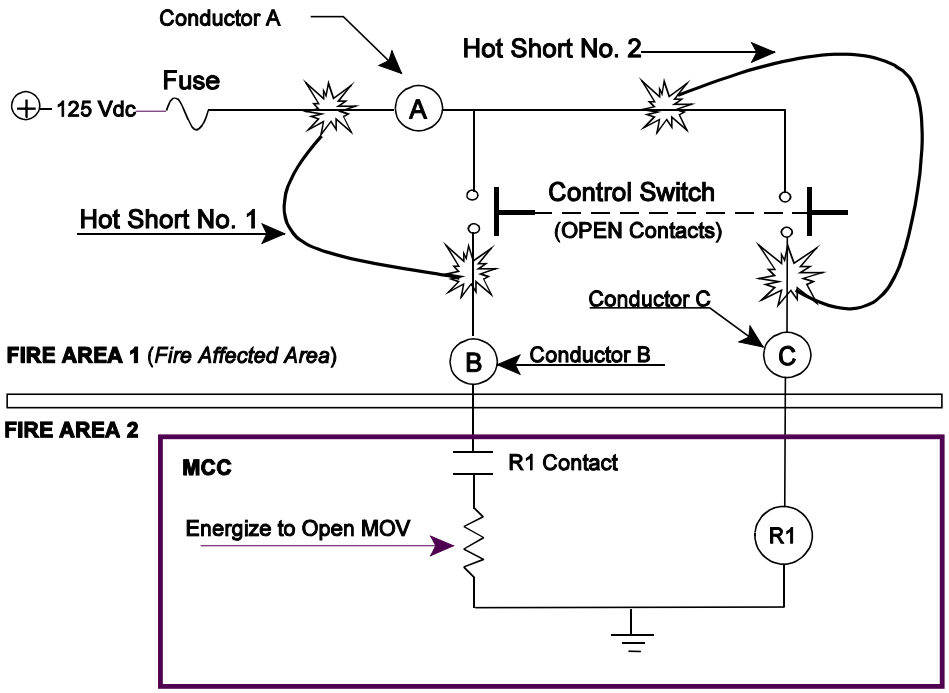

Figure 6.11a Consideration of Multiple Hot-Shorts

For fire in Fire Area 1 Both Hot Short No. 1 [Conductor A to B] and Hot Short No. 2 [Conductor A t o C must occur to cause the spurious opening of the MOV. With the following two exceptions, multiple hot shorts of this nature are not considered credible:

1. For High / Low Pressure interface valves, each valve having exposed circuits in the fire affected area would need to consider the occurrence of multiple hot shorts as a credible event. OR
2. IF: Conductors necessary to cause a spurious actuation (e.g., A, B, and C)are all located in same multi-conductor cable and the cable is not adequately protected from fire damage (per III.G.2)
   THEN : Spurious operation of the component must be considered as a credible event , whether or not the component is part of a High / Low Pressure interface.

- The evaluation of high/low pressure interface components must consider the occurrence of multiple, simultaneous, hot shorts of the required polarity and sequence as a credible event. Given the unacceptable consequences associated with this event, the analysis must consider the occurrence of hot shorts on all three phases of the components power cable in the proper sequence (i.e., Phase A to Phase A; Phase B to Phase B and Phase C to Phase C) as a credible event.
- Multiple conductor-to-conductor hot shorts in cables containing more than a single conductor (i.e., multi-conductor cables) are credible and must be evaluated. It is not sufficient to only consider the effect of a single fault on each conductor on a one at a time basis (see Figure 6-11a).
- "Hot shorts" may result from a fire-induced insulation breakdown between conductors of the same cable (circuit), a different cable (circuit), or from some other external source resulting in an undesired impressed voltage or signal on specific conductors.
- Circuit failures resulting in spurious actuations of equipment must be assumed to exist until action is taken to isolate the affected circuit from the fire area or other actions are taken, as appropriate, to negate the effects of the faulted condition that is causing the spurious actuation. It cannot be assumed that the fire would eventually clear the circuit faults.
- "Open circuits" may result from a fire-induced break in conductors resulting in the loss of circuit continuity.
- "Shorts to ground" may result from a fire-induced breakdown of cable (circuit) insulation, resulting in the conductor being applied to ground potential.
- Where a single fire can impact cables that can cause the spurious opening of high/low pressure interface isolation valves, it must be assumed that all of the affected valves will spuriously actuate *simultaneously*.
- For each fire area all potential spurious operations that may occur as a result of a postulated fire should be identified and evaluated for their impact on the safe shutdown capability. With the exception of components comprising a high/low pressure interface boundary, spurious actuations having the potential to impact the shutdown capability must either be prevented or the effects of each actuation must be appropriately mitigated on a one-at-time basis. That is, the analyst must assume that "any and all" spurious actuations that could occur, will occur, but on a sequential, one-at-a-time, basis. It is not assumed that all spurious actuations that could occur as a result of fire damage will occur instantaneously at the onset of the fire. However, the analyst must consider the possibility for each spurious actuation to occur sequentially, as the fire progresses, on a one-at-a-time basis. In the absence of suitable fire protection features, the potential for such sequential failures to result in the concurrent failure of two or more devices must be considered. Analysis approaches that arbitrarily limit the number of spurious actuations that may occur (such as assuming that only one spurious actuation will occur for each fire event) as a result of fire damage are inconsistent with regulatory requirements. GL 86-10 Question and Answer Section 5.3 provides additional guidance.

- Analysis methodologies that attempt to predict the number of circuit faults and/or spurious equipment actuations that may occur as a result of fire damage to exposed circuits and cables may lack sufficient technical basis may not be valid. For example, without additional justification it is not acceptable to assume that only one spurious actuation or one hot short would occur as a result of fire in any fire area, unless it has been reviewed by the staff for a specific licensee's application.
- All cables, regardless of type or manufacture, including IEEE-383 qualified cables, will support combustion. No credit may be taken for the ability of cables to "self-extinguish".
- For fires requiring implementation of an alternative or dedicated shutdown capability, it is necessary to identify all potential spurious operations that may result from the fire and evaluate the impact of each on the ability to achieve and maintain safe shutdown. Spurious operations could occur on a circuit that is isolated from the fire area under consideration during the time it takes the operator to evacuate the MCR and assume control of the plant at a remote location (e.g., RSP, therefore, spurious operations must be postulated on circuits that can be isolated as well as circuits that cannot be isolated from the fire area under consideration. That is, the potential for spurious operations of equipment to occur prior to actuation of isolation devices (e.g., isolation/transfer switches) must be considered. If the actuation can be appropriately controlled or mitigated by actuation of the isolation/transfer switch, actuation of the transfer switch is considered to be an adequate mitigating action. For those circuits that are not capable of being isolated from the fire area under consideration, it must be assumed that they will spuriously actuate as a result of fire damage on a one-at-a-time, sequential basis.
- A "hot short" between conductors of different cables does not need to be postulated to occur on a safe-shutdown cable that is routed individually (by itself) in a metallic conduit or in a metallic conduit that does not contain other energized circuits (conductors). If this justification is used provisions must be made to ensure that future circuit changes or cable routing modifications do not alter this condition.
- Fire is not expected to damage cables that are routed in "embedded" conduits (i.e., conduits that are located within the confines of a structural concrete floor, wall or ceiling).
- All components are assumed to be in their normal position as shown on the P&IDs.
- Circuit contacts are assumed to be positioned (i.e., open or closed) consistent with the normal mode of the component as shown on the schematic drawings.
- Unless demonstrated otherwise, the effect of fire damage to instrumentation circuits cannot be predicted. That is, the instrument may fail full scale high, full scale low or at some intermediate point. It cannot be assumed that fire damage would always cause an instrument to fail at some pre-determined point (e.g., full downscale, mid-range or full upscale).
- The evaluation of the potential impact of fire-induced spurious actuations on safe shutdown capability must consider all possible failure modes of the equipment or components under consideration. This includes, for example, the potential for fire-induced circuit/cable damage to cause mechanical failure of MOVs as described in IN 92-18.

6.4.6.3 Types of Circuit Failures

Sections III.G.2 and III.L.7 of Appendix R delineate the cable and circuit failure modes that must be considered in the evaluation of post-fire safe-shutdown capability as open circuits, shorts to ground and hot shorts. This section provides specific examples of each of these types of circuit failure conditions.

6.4.6.3.1 Open Circuits

An open circuit is a fire-induced break in a conductor resulting in a loss of circuit continuity. An open circuit will prevent the ability to control or power the affected equipment. Deterioration of fiber optic cables leads to a loss of signal and has a similar effect.

Potential consequences of open circuits on the safe-shutdown capability include, but are not limited to the following:

- a loss of power to required shutdown equipment
- an inability to control essential shutdown equipment
- a loss of power to an interlocked relay or other device that may change the state of the equipment (e.g., a solenoid that is required to remain energized for safe shutdown becomes de-energized)
- an open circuit on the secondary winding of certain types of current transformers may result in initiation of secondary fires at the location of the current transformer. The potential for this occurrence is largely dependent on the rating, type and design of current transformers used and, therefore, must be evaluated on a case-by-case basis

The condition of an open circuit on a grounded control circuit is illustrated in Figure 6-12. In the circuit illustrated an open circuit at location No. 1 is equivalent to a blown fuse — equipment operation will not be possible. An open circuit at location No. 2 will prevent opening or starting of the equipment but will not impact the ability to close or stop the equipment.

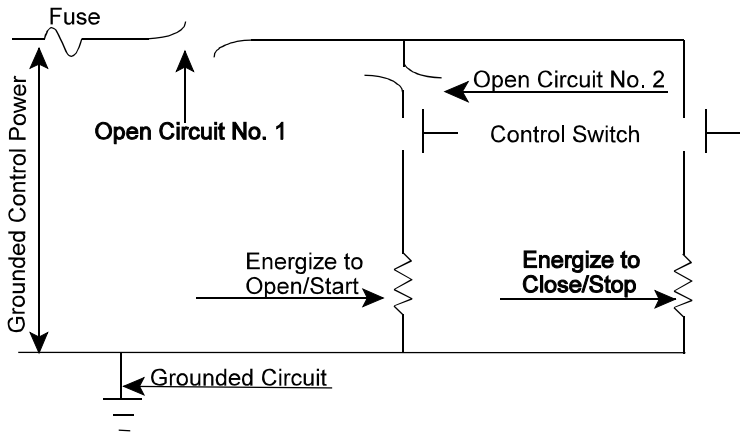

Figure 6-12 Open Circuit Example

6.4.6.3.2 Shorts to Ground: Grounded Circuits

A short to ground results from a degradation (breakdown) of cable/conductor insulation. This fault condition results in a ground potential on the affected conductor. A short to ground can have all of the same effects as an open circuit and, in addition, a short to ground can also impact the control circuit or power train of which it is a part. In the case of a grounded circuit illustrated in Figure 6-13, a short on any part of the circuit would present a concern for tripping the isolation device (i.e., fuse) thereby causing a loss of control power. For the circuit illustrated 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. As discussed in Section 6.4.5.2.1, depending on the coordination characteristics (selectivity) between the fuse and its upstream protective devices (fuses, circuit breakers that provide power to the fuse in this circuit) the power to other circuits could also be affected. This failure mechanism should be evaluated as part of the associated circuits common power source analysis. A short to ground at location No.2 will have no effect on equipment operation until the close/stop control switch is closed. Should this occur the effect will be identical to the short to ground at location No.1. A short to ground at this location would not affect the ability to open/start the equipment until the close/stop control switch is placed in the closed position.

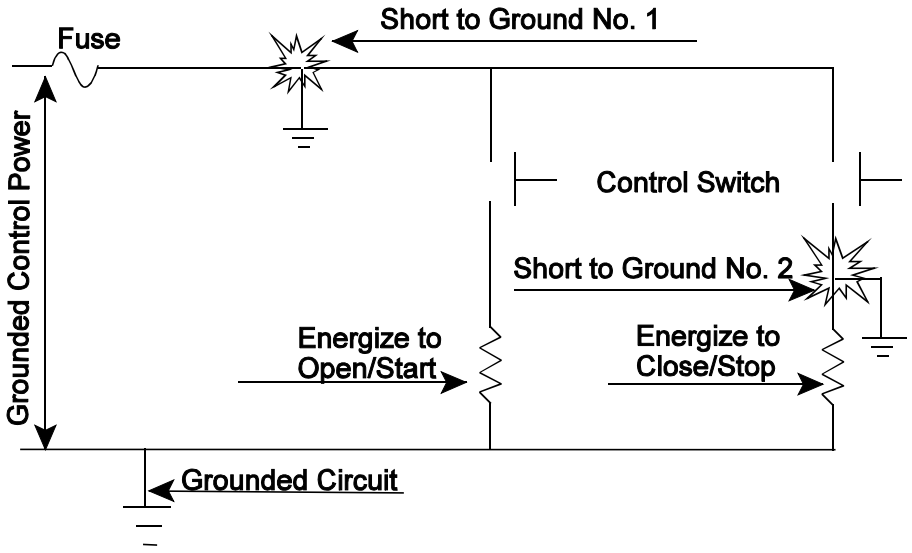

Figure 6-13 Shorts to Ground (Gounded Circuit)

6.4.6.3.3 Shorts to Ground: Ungrounded Circuits

In the case of an ungrounded circuit (such as most 125 VDC control power schemes) a single short to an external ground reference (e.g., cable tray, conduit or metallic enclosure) on any part of the circuit may not cause the circuit isolation device to trip. To illustrate this concept consider the simple light circuit illustrated in Figure 6-14. In this case a battery is being used to supply power to the lamp and there is no reference to any external grounded reference potential, such as a metal cable tray. This is a simple example of an ungrounded circuit. For a circuit such as this, connecting a single wire (to simulate a short) from the positive (+) side of the battery to a grounded cable tray will not have any effect on the operation of the lamp since there is no complete path for fault current to flow back to the battery. However, the occurrence of an additional (second) short on the negative (-) side of the circuit will provide a complete path for current to flow, causing the fuse to blow and resulting in an inability to illuminate the lamp. It should be noted that the second ground fault may occur as a result of fire damage to this circuit or any other circuit that is also fed from the same ungrounded power source (e.g., battery). Therefore, the potential for an ungrounded circuit to become grounded as a result of fire damage must be considered.

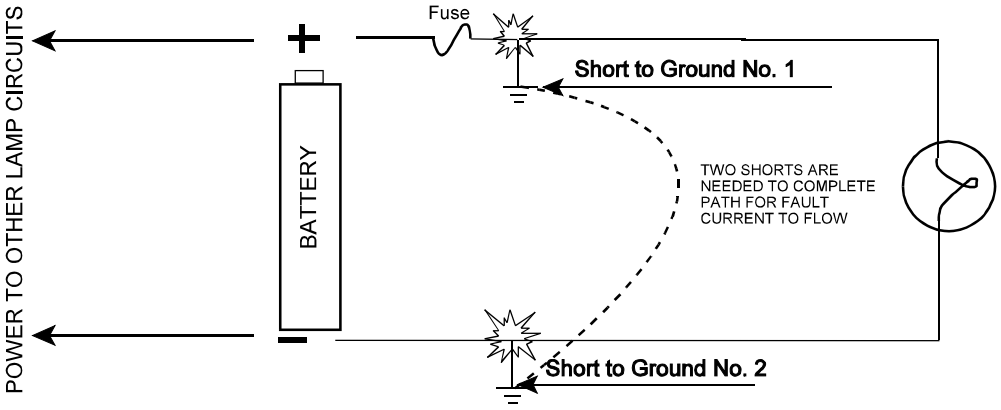

Figure 6-14 Ungrounded Circuit Illustration

6.4.6.3.4 Hot Shorts

In a “hot short” fault condition an energized conductor comes in electrical contact with other un-energized conductors. As a result of this fault, (short circuit between conductors) an undesired voltage or signal is impressed on conductors that were previously un-energized. A hot short fault condition may occur between conductors of the same cable, a different cable, or some other external source. An example of a hot short fault condition is illustrated in Figure 6-15. For the circuit illustrated in Figure 6-15, a hot short at location no.1 would energize the open/start relay and result in the undesired (spurious) opening or starting of the equipment being controlled by this circuit. This condition would be unacceptable for safe-shutdown if the desired operating mode of the affected equipment were closed or stop. A hot short at location No.2 would energize the close/stop relay and result in the undesired (spurious) closure or stopping of the equipment being controlled by this circuit. This condition would be unacceptable for safe-shutdown if the desired operating mode of the affected equipment were open/start.

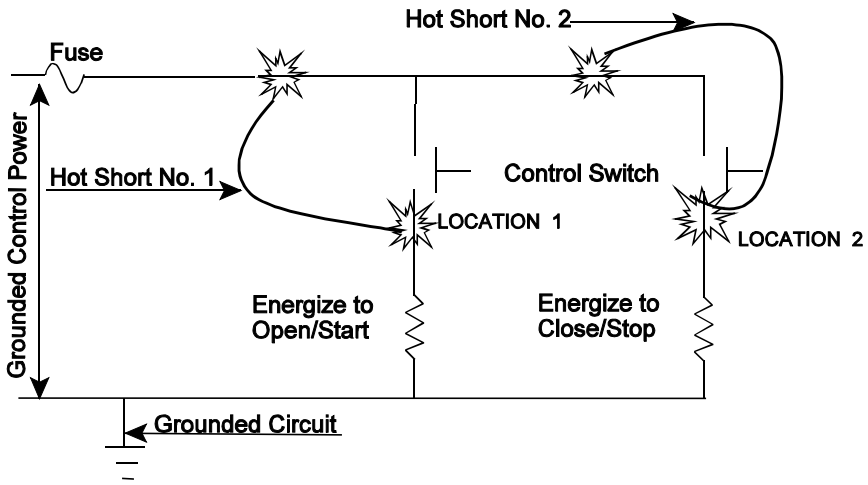

Figure 6-15 Hot Short Example

The hot shorts illustrated in Figure 6-15 are derived from energized conductors in the same circuit. However, it should be noted that the same hot short fault conditions could also be established as a result of electrical contact (short) between locations 1 and 2 and conductors connected to any other energized source, including those that may be external to this circuit.

In the case of an ungrounded circuit, a single hot short may be sufficient to cause a spurious actuation. A single hot short can cause a spurious actuation if the hot short comes from a circuit from the positive leg of the same ungrounded source as the affected circuit. There are also additional cases where a hot short on an ungrounded circuit, in combination with a short to ground can cause a spurious actuation. In reviewing these cases, the “common denominator” is that in every case, the conductor in the circuit between the control switch and the control coils (open/start or close/stop) must be involved.

Given the possibility of a short to ground being caused by the fire, it should be assumed that a spurious operation will result whenever the fire affects the conductor between the control switch and the control coils. Since a hot short from the same source or grounding of ungrounded circuits cannot be ruled out, it should be assumed that ungrounded circuits will behave the same as grounded circuits in their response to hot shorts.

6.4.7 Locate Equipment, Cables, and Circuits of Concern to Post-Fire Safe Shutdown

At this point in the analysis process, plant process and support *functions* that must be accomplished to achieve and maintain hot and cold shutdown conditions have been defined (Section 6.4.2), *shutdown systems* (redundant and/or alternative) capable of accomplishing each of the required shutdown functions have been determined and assigned a unique safe-shutdown path designation (Section 6.4.3). With the shutdown paths defined, the equipment needed to ensure the proper operation of each path is identified and documented in the SSEL (See Sections 6.4.4). The SSEL establishes a starting point for identifying *required circuits and cables* (i.e., circuits and cables needed to support operation of the identified shutdown paths) ***as well as*** *associated nonsafety circuits* that could impact (adversely affect) the achievement of safe-shutdown conditions if they are damaged by fire. (See Section 6.4.5.) Following their identification, associated circuits of concern are then evaluated to assess the potential impact of fire and related perils (e.g., fire suppression activities) on the shutdown capability of the plant. (See Section 6.4.6.)

As discussed in Section 6.1, the post-fire safe-shutdown analysis is performed on a fire area basis. With the equipment, circuits and cables of concern to post-fire safe-shutdown identified, their physical location in the plant is then determined. The specific fire area where each piece of shutdown equipment is located may be determined from a comparison of plant design documents (e.g., equipment layout drawings) to the fire area delineations identified in the FHA. The location of this equipment (i.e., fire area) should then be verified as necessary by field walkdowns and entered into the SSEL.

The routing of cables, including all raceway and cable endpoints, may be determined from a review of plant design drawings (e.g., conduit and cable raceway drawings) and/or cable installation data (e.g., cable pull tags). In certain cases, cable routing information may be obtained by joining the list of safe-shutdown cables with an existing cable and raceway database. For either case, field walkdowns should be performed as necessary to confirm the accuracy of the design information used in the evaluation.

To understand the potential impact of an exposure fire within each fire area, the results of the preceding evaluations should be tabulated in a report that includes such information as:

- fire area designation, location, and description
- shutdown path/systems relied on to achieve SSD [required path(s)]
- potentially affected unit(s)
- potentially affected shutdown path/system
- potentially affected cables [identify function (power, control, instrument) and whether damage can result in a spurious actuation, SSD path/system, affected equipment]
- potentially affected equipment (ID, type, description, SSD path, location, normal operating mode, required operating mode/position for SSD, etc.)

6.4.8 Perform Fire Area Assessments

For each fire area the evaluation of the consequences of fire must conclusively demonstrate that one train of equipment that can be used immediately to bring the reactor to hot shutdown conditions remains unaffected by fire. Systems needed to achieve and maintain cold shutdown may be damaged by fire but the extent of damage to these systems must be limited so that any necessary repairs can be implemented and shutdown conditions achieved within the time constraints described in Section 6.4.1.4.

There are many acceptable approaches to achieve the above objectives and the NRC does not prescribe or endorse any one specific approach. The approach presented in this document starts by defining safe-shutdown success paths (See Section 6.4.1–Section 6.4.5) and then each fire area is evaluated to determine the affected equipment in each fire area. From the resulting list of affected equipment, the impact of fire on the ability to achieve and maintain safe-shutdown conditions can be determined for each area. The various steps involved in this approach are illustrated in Figure 6-16. Another approach may start with the fire area and identify the redundant divisions (trains) of equipment and cables that are located in the fire area. From this information a shutdown success path that relies on the use of equipment associated with the "least affected" division could be developed. With the shutdown success path determined for the area, the impact of any interactions between cables and equipment in the area can then be assessed.

Regardless of the approach used, the SSA should be a bounding analysis which identifies the range of possible fire impacts within each fire area and ensures that appropriate measures are in place to prevent this damage from affecting the ability to safely shutdown the plant. For each fire area, the SSA must define a set of systems and equipment that are capable of accomplishing the required shutdown functions in accordance with established performance criteria.

The degree of physical separation provided for redundant trains of shutdown systems may vary widely among plants. Later generation plants that were designed and/or constructed after the Browns Ferry fire, tend to have a greater amount of physical separation inherent in their design. Older plants, however, (typically those receiving an operating license prior to the promulgation of Appendix R) typically were not designed with this concept in mind. Regardless of plant vintage however, the evaluation of a specific fire area may find at least one shutdown success path to be completely independent (both physically and electrically) of the fire area under evaluation. For these cases, the method(s) [e.g., SSD success path(s)] available to achieve safe-shutdown in the event of fire in the area is documented and no further evaluation is necessary. In other cases, however, an adequate level of separation may not already exist (i.e., at least one train of shutdown equipment/shutdown path is *not* independent of the fire area). For these cases, at least one shutdown success path must be identified and provided with suitable fire protection features as described below.

'igure 6.16 Fire Area Assessment Flowchart

One train of systems necessary to achieve and maintain hot shutdown conditions must be free of fire damage (Appendix R Section III.G.1.a). For cases where adequate fire area separation does not exist (i.e., redundant trains of shutdown systems are located in the same fire area), Section III.G of Appendix R provides several options for ensuring that the hot shutdown capability is protected from fires. The first three options, as defined in Section III.G.2, provide the following methods for protecting redundant trains of equipment located in fire areas that are *outside* of non-inerted containments:

- Enclose one of the redundant systems, including cables, equipment and associated nonsafety circuits, in a 3-hour fire-rated barrier. (III.G.2.a)
- Separate redundant systems, including cables, equipment and associated nonsafety circuits, by a horizontal distance of more than 6.08 m (20 ft) with no intervening combustibles or fire hazards. In addition, fire detection and an automatic fire-suppression system are required. (III.G.2.b)
- Enclose redundant systems (including cables, equipment and associated nonsafety circuits) in a 1-hour fire-rated barrier. In addition, fire detection and an automatic fire-suppression system are required. (III.G.2.c).

The next three options, as defined in Section III.G.2, provide methods for protecting redundant trains of equipment located in fire areas that are *inside* non-inerted containments:

- Separate redundant systems, including cables, equipment and associated nonsafety circuits, by a horizontal distance of more than 6.08 m (20 ft) with no intervening combustibles or fire hazards. (III.G.2.d)
- Install fire detection and an automatic fire suppression systems. (III.G.2.e)
- Separate redundant systems (including cables, equipment and associated nonsafety circuits) by a noncombustible radiant energy shield. (III.G.2.f)

The last option, as defined by Section III.G.3, provides an alternative or dedicated shutdown capability to the redundant trains damaged by a fire:

- Ensure that alternative (or dedicated) shutdown equipment are independent (both physically and electrically) of the cables, equipment, and associated nonsafety circuits of the redundant systems damaged by the fire.

CHAPTER 7. MAINTAINING POST-FIRE SAFE-SHUTDOWN:
Configuration Management for Post-Fire Safe-Shutdown Analysis

A post-fire safe-shutdown analysis is based on a "snapshot" of the configuration of plant SSCs and cable routing information that existed at the time the analysis was performed. However, the plant design features and operating practices that form the basis of the analysis are rarely static. Over its operating life, a plant may make modifications to improve its safety, reliability, and efficiency. If not properly evaluated, plant modifications can significantly compromise the results presented in the SSA and, in certain instances, may threaten the plant's ability to achieve and maintain safe-shutdown conditions in the event of fire. Effective maintenance of the plant's post-fire safe-shutdown capability, as described in the SSA and its supporting calculations and procedures, requires that all proposed changes to the plant design and operations, whether permanent or temporary, must be evaluated for their impact on the shutdown capability.

Figure 7-1 illustrates how even a seemingly straightforward modification involving the installation of nonsafety-related equipment can impact the shutdown capability. In this case, the licensee is making a modification to provide a more efficient means of transferring water between two nonsafety-related tanks. Key components being added as part of this modification include a pump (Pump X), piping, a nonsafety-related SWGR (SWGR 1A-1), motor-operated pump suction and discharge valves, and related controls and instrumentation. The pump is to be located in a fire area where the SSA credits the use of Division B equipment and is to be powered from a new Division A power source (SWGR 1A-1).

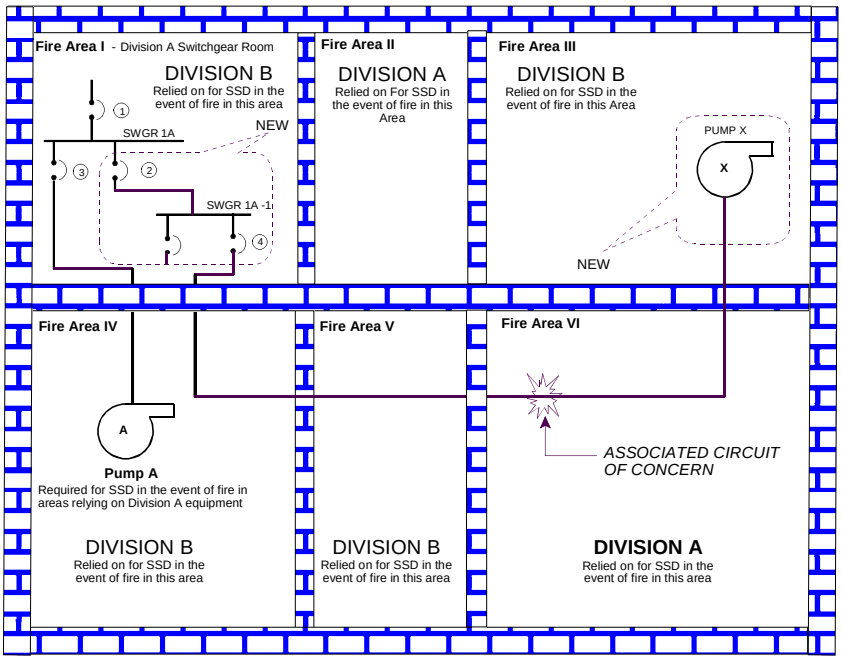

Figure 7-1 Modification Impacting the SSD Capability

The proposed design also includes the following attributes:

- The pump and the entire system in which it is located will not need to remain operational to accomplish required shutdown functions.
- Maloperation of the pump (e.g., an unintended start or stop) would have no impact on the shutdown capability of the plant.
- The pump is powered from a nonsafety-related power source (SWGR 1-1A) that does not power any safe-shutdown components. A fire-induced loss of SWGR 1-1A would not impact safe-shutdown.
- The power source (SWGR 1-1A) is physically located in a fire area where equipment from the redundant division (Division B) is relied on to accomplish post-fire safe-shutdown.
- Before installing this modification, the SSA demonstrated an acceptable level of coordination between load and feeder breakers of SWGR 1A.

While these considerations may suggest that the planned modification would not impact the plant's post-fire safe-shutdown capability, a potential vulnerability still exists. Specifically, as shown in Figure 7-1, the cable that provides power to Pump X traverses several fire areas. Note that this routing includes an area (Fire Area VI) where Division A equipment (including required SSD Pump A powered from SWGR 1A) is relied on for post-fire safe-shutdown. Because the cable has not been provided with fire protection features (e.g., rated barrier wrap), it is susceptible to fire damage. If this modification were to be installed without ensuring that the new circuit breakers installed in SWGR1A (Breaker 4) and SWGR 1A-1 (Breaker 2) properly coordinate with the upstream feeder breaker (Breaker 1), a fire in Fire Area VI could cause Breaker 1 to trip and, thereby, result in the loss of equipment (Pump A) that is relied on to accomplish essential shutdown functions in the event of fire in Fire Area VI. (Refer to Section 6.4.5.2.1 for a more detailed discussion of circuit breaker coordination.)

Other examples of plant changes that may affect the shutdown capability include replacing a passive component (e.g., a manual valve) with an electrically controlled device (e.g., an MOV), rerouting cables, replacingf circuit protective devices (fuses, circuit breakers, relays), installing or removing interlocks, modifying control circuits (e.g., changing from manual to automatic control), making temporary modifications to facilitate plant maintenance activities (e.g., welding), and changing the plant's operating procedures (normal, abnormal or emergency).

Requirements governing the fire protection of safe-shutdown capability must be maintained over the life of the plant. This capability is provided through the establishment of administrative control procedures, which specify that changes in plant design and operations (both permanent and temporary) must be subjected to an appropriate level of review. This assessment must be performed by qualified personnel knowledgeable of the plant's post-fire safe-shutdown analysis. These procedures must address the following specific configuration control issues:

- **Modifications:** All modifications (i.e., permanent or temporary additions, deletions, or changes) to plant SSCs must be reviewed for their potential impact on the plant's post-fire safe-shutdown capability (as documented in the SSA, its supporting calculations, and procedures).
- **Fuse Replacement and Changes in Circuit Breaker or Relay Settings:** Ensure that fuses, circuit breakers, and relays having ratings or settings other than those selected to ensure proper coordination for post-fire safe-shutdown are not accidentally used. To ensure that future plant changes will not compromise circuit breaker and fuse coordination studies referenced in the SSA, the replacement of fuses in power sources required for post-fire safe-shutdown should be performed in accordance with approved procedures. In addition, the coordination study should be maintained current with the most recent modification.
- **Procedure Changes**: The review of permanent and/or temporary procedure changes should consider the following factors:
  (a) the effects of the change on the plant's capability to achieve and maintain post-fire safe-shutdown
  (b) changes to responsibilities and tasks assigned to fire brigade members
  (c) changes to responsibilities and tasks assigned to operations staff members who are responsible for achieving and maintaining safe-shutdown from inside the control room and from alternative shutdown location(s)

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CHAPTER 8. INTEGRATION OF DETERMINISTIC CRITERIA AND RISK-INFORMED INFORMATION

8.1 Overview of a Risk-Informed Approach

It is NRC policy to increase the use of risk information in the regulatory decisionmaking process (Reference Final Policy Statement, 1995). Risk combines two factors, including (1) the likelihood (or frequency) that an event will occur and lead to undesired consequences and (2) the severity of those undesired consequences. In this chapter, the event of interest is a fire that challenges nuclear safety. The potential undesired consequence of such an event is an offsite release of radioactive materials. For the commercial nuclear power industry, the severity of the release consequences is measured by the potential impact on public health.

In practice, risk is usually quantified using probabilistic risk assessment (PRA). PRA results are most often expressed using two intermediate risk measures; namely, CDF and large-early release frequency (LERF)[27]. CDF reflects the frequency (in events per reactor year) with which a given plant might expect to experience an accident leading to core damage. LERF reflects the frequency with which one might expect an accident to occur and lead to a large release of radioactive materials relatively early in the accident sequence. In this context, the term "early" is measured in relation to population evacuation times. Both CDF and LERF are considered indirect measures of risk because they do not directly quantify the public health consequences of potential plant accidents. CDF and LERF are used as risk measures because they are generally indicative of the potential that public health consequences might occur.

The NRC's risk-informed policy, as embodied in RG 1.174, weighs regulatory compliance issues against both CDF and LERF criteria. To date, the NRC has not formally risk-informed the fire protection portions of the regulatory requirements (e.g., Appendix R to 10 CFR Part 50). However, aspects of the fire protection regulatory process have begun to incorporate risk information. For example, the NRC staff is currently engaged in a rulemaking activity related to the recently adopted 2001 Edition of the National Fire Protection Association Standard 805 (NFPA 805), "Performance-Based Standard for Fire Protection for Light-Water Reactor Electric Generating Plant." NFPA 805 utilizes risk information in evaluating the acceptability of proposed plant changes that impact fire protection. A second example is the significance determination process (SDP) and, in particular, the fire protection SDP, which assesses fire-related inspection findings based on risk measures.

The current discussion is intended to provide risk-informed perspectives on the post-fire safe shutdown circuit analysis issues for use by the NRC staff and, in particular, those staff members responsible for plant inspection activities. The discussion does not establish any new requirements or regulatory compliance criteria. Rather, the discussion is intended to assist the NRC staff in understanding, and potentially assessing, the risk-significance of the fire-related safe-shutdown circuit analysis issue.

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[27] Note that the calculation of CDF is also known as the Level 1 analysis. Level 2 refers to the containment performance analysis (e.g., LERF), and Level 3 refers to the analysis of offsite release and public health consequences.

It should be noted that fire-induced circuit failure modes and effects risk analysis is an area of ongoing technical discussion and development. Some aspects of the problem are in their first stages of application, and quantification methods have not yet been fully developed or demonstrated. Hence, this discussion is preliminary and subject to change as additional insights develop. Efforts to further develop risk analysis methods for fire-induced circuit faults is ongoing through the NRC's Office of Nuclear Regulatory Research (RES). More detailed discussions on this topic can, for example, be found in LaChance, et al., 2000.

8.2 Fire Risk Analysis Overview

For the purposes of this chapter, risk insights will be discussed in the context of CDF as the primary risk measure of interest. It should be recognized that the success criteria assumed in a typical fire PRA are not the same as those applied in a regulatory fire protection framework. In the regulatory context, the fire safe-shutdown analysis considers the ability to achieve both hot and cold shutdown. Hot shutdown must be possible within 24 hours, and the regulations do not allow for hot shutdown repair actions. Cold shutdown has a longer mission time, 72 hours, and, within certain limits, repair actions are allowed. In contrast, a typical PRA considers success to be achieving and maintaining a stable hot shutdown condition such that core damage is prevented. In a typical PRA, scenarios are analyzed until a safe and stable plant condition is achieved, but generally only out to 24 hours. (Note that the potential for core damage accidents that occur beyond this period should not be dismissed out of hand.) PRAs do not generally consider cold shutdown. Hence, the PRA/CDF success criteria align most closely with the regulatory hot shutdown requirements. The only correspondence to the regulatory cold shutdown requirements would be found in a low power and shutdown fire risk analysis and very few of these have been performed to date. This section provides an overview of current fire CDF quantification practice. This overview provides a convenient framework for our discussion of risk perspectives on post-fire safe-shutdown circuit analysis.

Both regulatory requirements and fire PRAs focus first and foremost on the fire hazard, or risk, associated with fires that impact some bounded region of the plant. However, how these bounded regions are defined in the regulatory context often differs from the definitions used in a fire PRA. In the regulatory context plants are partitioned into fire areas; that is, physical regions that are bounded on all sides by fire-rated boundary elements sufficient to contain the fire hazards(RG 1.189). Fire PRAs are generally based on fire compartments[28], a less rigorously defined subdivision of the plant. In a fire PRA, a given fire area may be retained in whole as a fire PRA compartment, or the fire area may be partitioned into two or more fire compartments. Defining fire PRA compartments involves the application of analyst judgment. Fire PRA compartments may credit features that would not be credited in defining fire areas in the regulatory context. This may include non-fire-rated partitions, partitions with unsealed penetrations, active partitions (e.g., heat activated roll-up doors), water curtains, and even extended spatial separation. In most fire PRAs, each fire compartment represents a region wherein, based on the judgement of the analyst, the damaging effects of the majority of fires are expected to be confined.

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[28] Note that the terminology applied varies between analyses. Some analysts may refer to fire zones, analysis zones, rooms, or other designations to describe the physical analysis boundaries drawn to support the fire PRA. The concept remains the same.

The CDF analysis systematically considers risk contributions arising from fires in each fire compartment. The risk quantification results may be reported at a fire scenario level (e.g., for a given fire ignition source), but are more typically reported at a compartment level. Hence, PRAs will often cite a CDF contribution for each individual fire compartment (e.g., the Cable Spreading Room). An explicit analysis is also conducted to assess the risk contribution of fires that might impact multiple fire compartments. The results for the multi-compartment (or room-to-room) fire scenarios are often reported separately. It is also common to report a total fire-induced CDF for the plant as a whole (i.e., the sum of the individual compartment and multi-compartment contributors).

In the most general terms, the likelihood that a fire might initiate a core damage accident is assessed on the basis of the following three-factor formula:

$$CDF = \sum_i f_i \left(\sum_j P_{cd,j|i} \left(\sum_k P_{CD:k|i,j} \right) \right)$$

The first term (f_i) on the right-hand side represents the fire occurrence frequency. The summation over the index "I" implies that the plant-wide fire-induced CDF is based on the sum of contributions from many individual fires involving a number of fire compartments. Fire frequency includes consideration of both fixed (e.g., fixed electrical and mechanical equipment; fixed components that might experience a leak of lubricating oil or flammable gases including hydrogen; semi-permanent storage items; etc.) and transient fire ignition sources (e.g., maintenance materials staged in anticipation of an outage, inservice maintenance support materials, welding and cutting operations, refuse, etc.).

Consistent with the fire PRA plant partitioning practices as described previously, fire frequency may be quantified at a compartment level reflecting all possible fire ignition sources in a given fire compartment (e.g., a battery room). However, fire frequency may also be quantified at a more detailed level. For example, fire frequency may be expressed for a particular fire ignition source (e.g., a motor or pump), or for a specific group of fire ignition sources (e.g., a bank of SWGR or general transient fuel sources). Fire frequency is usually based on statistical analysis of the evidence provided by past fire events; i.e., a fire event database. A number of such databases are available from both public and private sources. (Reference NUREG/CR-4586 and EPRI TR-1000894.)

The second term ($P_{cd,j|I}$) reflects the conditional probability that, given a particular fire (I), a particular physical damage state (j) will be induced. The physical damage state is defined by the plant equipment, components, and/or electrical cables damaged by the fire. Note that the nomenclature P_{cd} implies the **p**robability of either "component damage" or "critical damage," depending on the analysts' use of terminology. The second summation implies that a given fire might lead to more than one physical damage state depending, for example, on the duration of the fire and, by implication, the physical extent of fire damage. Calculation of the component damage term typically involves the analysis of fire growth behavior, component thermal response and damage, and fire detection and suppression. It is in this part of the analysis that fire models, for example, are applied.

Given the first and second terms, the analyst is postulating that a fire has occurred and has damaged some set of plant components. The loss of some plant components implies that some subset of the plant systems and/or functions are damaged and/or rendered inoperable. The third and final term ($P_{CD,k|i,j}$) reflects the conditional probability that given the physical damage state (j) resulting from the fire (I), operators will fail to achieve safe-shutdown and **c**ore **d**amage will result. Summation over the index (k) implies that for a given physical damage state, the plant will still have available various options (or paths) for achieving safe-shutdown. Each safe-shutdown path will have a unique likelihood of success/failure. The calculation of P_{CD} includes consideration of system faulting behaviors given the fire damage, operator performance, and random equipment failures independent of the fire. The summation of the contributions from each failure path leading to core damage is often referred to as the conditional core damage probability (CCDP) associated with a given physical plant damage state.

The risk importance of any given fire compartment can be weighed in terms of the absolute CDF contribution and based on the relative contribution of a given fire compartment to the overall fire CDF. For example, even if a plant has a total fire CDF that is considered low, the fire PRA will still typically identify and analyze in detail the risk-dominant fire compartments; that is, those compartments that contribute most to fire risk. Typically, on the order of two-to-ten fire compartments are found to dominate the plant fire risk estimates. The risk-dominant fire compartments often include areas such as the main control room, cable spreading room, auxiliary electrical equipment or relay rooms, and emergency SWGR areas. Other compartments may be risk important on a plant-specific basis.

One of the most significant factors in determining which compartments are fire risk dominant is the routing of important power, control, and instrument cables through the plant. Fire risk is often dominated by fires leading to the failure of electrical cables. Hence, fire compartments through which important electrical cables pass tend to be fire risk-dominant. A second significant factor is the presence, or absence, of significant fire ignition sources in a fire compartment. For example, even a fire compartment such as the cable spreading room may be found to have a relatively low fire risk if it lacks significant fire ignition sources.

Many fire compartments will ultimately be found to contribute little to plant risk. In a fire PRA, a formal process is used to 'screen out' such compartments. The first screening step is usually based on qualitative arguments. For example, compartments that contain no safety-related equipment or electrical cables, and where fires cannot induce a plant transient (e.g., manual trip), are often qualitatively screened as insignificant risk contributors. A second stage of screening is typically conducted based on conservative quantification of the three-factor formula cited previously. Quantitative screening generally focuses on the potential severity of fire damage and the likelihood of core damage given fire damage (i.e., the second and third terms). Compartments will rarely screen on fire frequency alone because virtually all compartments have a non-trivial fire frequency (generally no less than $1x10^{-4}$ fires per reactor year, or $1x10^{-4}$/ry and often higher).

It is important to note that fire PRAs usually credit components, systems, and functions that are not credited in the post-fire safe-shutdown analysis[29]. The post-fire safe-shutdown analysis is, first and foremost, intended to ensure that one train of equipment necessary to achieve and maintain safe shutdown will remain free of fire damage. However, other plant systems not credited in the post-fire safe-shutdown analysis will likely survive any given fire event and, in reality, could be used as available to support the post-fire plant recovery efforts. This fact presents a sometimes difficult challenge to fire risk analysis. Fire is a very spatially-oriented phenomena. Even given a rather severe fire, fire-induced component and electrical cable failures will likely occur only in a specific and limited physical region of the plant. Hence, accurate information on component and cable locations is often critical to the fire damage analysis. The more accurate the available information is, the more accurate the risk estimates can be made.

Because the post-fire safe-shutdown analysis is, in essence, a success-path analysis, it credits a limited subset of the plant systems. The electrical cables and components required to support these credited systems are traced within the plant and their locations are generally well known, at the least to the level of their presence in, or absence from, each fire area. However, for systems not credited in the safe-shutdown analysis, the associated components and electrical cables may not be traced and their locations may not be known. To avoid undue optimism, the analyst must verify that a fire cannot cause damage to a system's components and electrical cables before credit for the system's function can be taken in the risk analysis. For those systems not credited in the safe-shutdown analysis, this can require tedious and time consuming efforts, in particular, to trace electrical cables through the plant. An approach that is often taken is to assume failure of a system unless the lack of a fire threat to the system's components and electrical cables can be verified for a given fire scenario. If the failure assumption is found to be critical to the quantification, then additional verification and cable tracing efforts may be undertaken.

8.3 Circuit Analysis and the Risk Analysis Framework

It is now possible to express the issues of circuit analysis in the context of the computational framework described previously. The first term in the CDF equation, the fire frequency, has essentially no interaction with the circuit analysis issues. Similarly, the second term, the likelihood that the fire will lead to some level of physical damage, is also not directly relevant to the circuit analysis issues. Circuit analysis comes into play through the third term, the likelihood that the fire-induced equipment failures will lead to core damage. In this context, we are especially interested in the fire-induced failure of electrical cables.

A fire may cause failures in power, control/indication, and/or instrument cables associated with various plant systems and functions. The response of the impacted systems, the circuit or system fault mode, will depend on the mode of electrical cable failure observed. The process of examining the various electrical cable failure modes in order to identify the potential circuit or system fault modes is referred to here as the process of circuit analysis. More formally, this is referred to as the electrical cable failure modes and effects circuit analysis.

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[29] Note that some methods used in the Individual Plant Examination External Events (IPEEE) studies credited only the Appendix R systems (NUREG/CR-1742). When rigorously applied, such approaches typically yield conservative estimates of fire risk.

Circuit analysis is complicated in part because electrical cables may experience one or more of several failure modes. Furthermore, the failure behavior may be dynamic, changing throughout the course of the fire event. Each unique combination of electrical cable failures can potentially induce a unique circuit fault mode. Circuit fault modes of potential interest include loss of function, loss of control, loss of indication, corrupted indications or signals, and spurious actuation. Since the electrical cable failure behavior may be dynamic, the circuit's faulting behavior may also be dynamic. To illustrate, consider that two of the possible cable failure modes of particular importance are hot shorts and shorts to ground. Conductor-to-conductor short circuit cable failure modes, including hot shorts, are likely to transition to shorts to ground given an enduring fire exposure. Therefore, in some cases it may be important to assess both the initial cable failure mode, the anticipated duration of a specific failure modes, and the impact of an ultimate short to ground. As the fire scenario develops, multiple cables may fail at discrete points in time, and multiple circuit faults may come into play. This introduces the further question of concurrent behavior involving multiple circuits; for example, how likely is it that two or more circuits might experience concurrent spurious actuations.

It is not possible to exhaustively explore all of the potential electrical cable failure modes in a fully dynamic context for any but the most simplistic of fire damage state scenarios. Hence, it is widely recognized that some optimization of the circuit analysis process is both necessary and desirable. The specific optimization framework being discussed here is fire-induced core damage risk. That is, the process of circuit analysis is optimized to focus attention on those electrical cables, cable failure modes, and circuit fault modes that may be risk significant.

Typically, a given circuit or system will have a limited set of specific fault modes that will be unique in the context of fire risk. Depending on the circuit, some fault modes may be benign while others might challenge the safe-shutdown process. For example, loss of function in a valve may have little risk impact if operation of the valve is not required to mitigate the accident scenario. However, spurious actuation of that same valve might challenge safe-shutdown by opening an undesired coolant flow diversion path, or by closing a desired coolant flow path.

Circuit faulting behavior influences the likelihood of successful shutdown in three primary ways:

- Circuit faulting can lead to the unavailability of one or more desired plant systems.
- Circuit faulting might cause the maloperation of one or more plant systems (e.g., a spurious actuation or change of operational state).
- Circuit faulting may compromise instrument and control signals that operators depend on in their response to the event (e.g., the loss of control and instrument signals, or transmission of corrupted signals).

Each of these circuit faulting effects can have unique implications for fire risk. The practical objective of PRA circuit analysis is to identify the risk-important circuits and circuit fault modes, and to then quantify the likelihood that such faults might be observed during a given fire. Insights gained to date related to this objective are discussed below.

8.4 A Mechanistic View of the Problem

A mechanistic view of the circuit analysis problem is being developed in support of broader fire PRA development activities (LaChance, et al., 2000). As an entry condition to the fire PRA circuit analysis task, it is assumed that fire modeling tools of some type (potentially including expert judgement) have been applied separately and have predicted the failure of one or more electrical cables. Under the mechanistic view of circuit analysis, the problem is first split into two major pieces; namely, the electrical cable failure mode analysis and the circuit fault mode analysis. The discussions provided in this chapter are organized based on this mechanistic view.

The cable failure mode analysis addresses the short circuiting behavior of the damaged electrical cables. That is, given electrical cable failure, an analysis is performed to determine the relative likelihood that a particular mode of cable failure will occur. The circuit fault mode analysis considers the potential responses of the circuit to various cable failure modes. For example, the circuit fault mode analysis determines whether or not spurious actuation is possible given failures involving a particular electrical cable, and if so, what combination(s) of conductor shorting behaviors could lead to a spurious actuation fault mode.

There is a degree of iteration between the cable failure mode and circuit fault mode analyses. The circuit fault mode analysis will likely identify a unique combination of conductors that, if they short together, would cause a spurious actuation. Furthermore, the circuit fault mode analysis might also find that if one particular conductor were to become involved in the short circuit (e.g., a grounded conductor), the spurious actuation would be self-mitigated. Based on these insights, the cable failure mode analysis would be asked to estimate the likelihood that a combination of conductors leading to spurious actuation, and not involving the grounded conductor, will short together given electrical cable failure.

In practice, the iterative nature of the problem is addressed by dividing the cable failure mode analysis into two further steps. The first step is to consider the electrical cable failure behavior independent of the circuit. That is, the electrical cable in and of itself will experience some combination of conductor short circuits or failure modes. Conductors may short to other conductors in the same cable, they may short to the conductors of another electrical cable, or they may short to an external ground. This behavior should, at least to some extent, be relatively independent of the nature of the circuit to which the cable is connected. However, cable failures must also be considered in the context of the circuit to which the cable is connected, and this is the second step in the cable failure mode analysis.

A circuit utilizes each conductor in a given cable in a particular way. In a control circuit, for example, some conductors are energized to supply control power to the circuit, some conductors are normally de-energized and carry control power to an actuating device when the circuit is exercised (e.g., a control action is taken), other conductors will typically carry control indication signals back to the control station, one or more conductors may be grounded, and finally, some conductors may not be used in the circuit at all (spare conductors). The circuit fault behavior (i.e., how the circuit responds to the cable failures) will typically depend on the types of short circuits (the failure modes) experienced by key conductors among those conductors servicing the circuit. For example, short circuits between the normally energized (or source) conductors, and those normally de-energized conductors that feed power to actuating devices (the potential

spurious actuation target conductors) can lead to spurious actuation of the circuit (the so-called hot short induced spurious actuation).

In the consideration of circuit faulting behavior, the initial cable failure behavior is often of paramount importance. In particular, the relative likelihood of conductor-to-external ground versus conductor-to-conductor short circuits is critical. Shorts to ground will generally trip circuit protective features leading to a loss of either control or motive power (see Section 8.6 below). In contrast, conductor-to-conductor short circuits carry the potential to cause spurious actuation of circuits and components. Hence, if a short to ground is the first failure mode observed, other potential failure modes may be rendered essentially moot. That is, if circuit protection is tripped open by a short to ground, then it may not be possible for a subsequent hot short to energize or spuriously actuate that system. However, the importance of subsequent failures and failure mode transitions must be viewed in the context of the circuit under analysis. For example, multiple shorts to ground on an ungrounded DC circuit may have more significant risk implications than only the first such short to ground.

It should also be noted that the cable failure and circuit fault mode discussions which follow are based largely on information gathered during fire experiments involving the failure of electrical cables. Virtually all of the available data is based on small-to-medium scale tests. Small-scale tests in particular cannot fully simulate actual plant installation and fire exposure conditions. Medium scale tests come closer to an actual application, but still cannot, or do not, capture potentially important features and variations of actual plant installations, fire exposure conditions, and conditions during fire suppression. This is true even of the most recent NEI/EPRI electrical cable fire tests (EPRI TR-1003326), even though these tests represent one of the most relevant data sources currently available. Hence, the data and insights derived from such data must be viewed in the context of how those data were gathered.

The available data are both limited and uncertain. The direct extrapolation any given test result to a particular application may be inappropriate. This is especially true in the circuit analysis context given that the data available have illustrated, but not fully investigated, the importance of various factors to the cable failure and circuit response behavior. In the discussion which follows, the author has tried to stress the uncertainties associated with our current understanding of cable failure behavior while at the same time providing as many numerical probability insights as possible. Both the qualitative and quantitative insights described here must be considered preliminary.

8.5 Electrical Cable Failure Modes

In both the regulatory and risk contexts, the failure of an electrical cable implies that the cable is no longer free of fire damage; that is, it is no longer “capable of performing its intended function during and after the postulated fire, as needed” (GL 86-10). From an electrical perspective, the function of an electrical cable is to provide a medium for the transmission of electrical energy (power and/or signals) between two points in a common electrical circuit while simultaneously maintaining the electrical isolation of the transmission path from other elements of the same circuit and from other co-located circuits. Failure, therefore, implies loss of continuity in the energy transmission path or diversion of a sufficient fraction of the available electrical energy to an unintended circuit destination such that proper function of the circuit is no longer ensured.

As discussed previously in Chapter 3, electrical cables are manufactured in a wide range of configurations. The primary configuration features that define a given electrical cable are the size of the individual conductors (expressed using the AWG), the number of conductors, shielding and/or armoring features, and the insulation/jacket materials used in the construction.

There are four primary modes of cable failure of potential interest. These failure modes relate to the electrical behavior of the conductors associated with a given electrical cable, as follows:

- A ***conductor to external ground short circuit*** results in the diversion of electrical energy to ground.
- A ***conductor to conductor short circuit*** may result in the diversion of electrical energy from one conductor (the source conductor) to one or more unintended conductors [the target conductor(s)]. One special case of the conductor to conductor short circuit is the *hot short*, that is, the shorting of an energized conductor to a non-energized and non-grounded conductor.
- ***Conductor insulation resistance degradation*** may result in the partial diversion of the available electrical energy to an unintended conductor path.
- A ***loss-of-conductor continuity*** (or open circuit conductor failure) is a physical break in the conductor that will result in electrical energy being unable to reach the intended circuit destination.

Before proceeding, two points related to cable failure behavior should be observed. First, the likelihood estimates discussed here are all conditional values given that an electrical cable has been damaged. That is, the likelihood that a particular fire might cause electrical cable damage is not included, only the likelihood that certain failure modes might be observed given that one or more electrical cables have been damaged by a fire.

Second, the discussion focuses on the initial failure mode (that is, the first failure mode that might be observed given failure). As noted previously in Section 8.4, cable failure behavior may be dynamic, but the initial failure mode is of paramount importance. Some limited discussion of this dynamic behavior is provided, primarily in the context of the duration of hot shorts. Given a fire exposure of sufficient duration and intensity, the available experimental evidence indicates that all of the conductors in the damaged electrical cables will ultimately short to the grounded raceway. However, in the context of a real fire event, fires do not burn forever, and fires do not always create intensely damaging exposures. Hence, the shorting behavior of a given electrical cable could, for example, involve sustained hot shorts, shorts to ground, or hot shorts that later transition to shorts to ground.

8.5.1 Conductor-to-Conductor Short Circuits

Conductor-to-conductor short circuits are broadly categorized as either intra- or inter-cable. Intra-cable conductor-to-conductor shorting implies that the short circuit involves conductors within a single multi-conductor electrical cable. Inter-cable conductor-to-conductor shorting implies that the short circuit involves the conductors of two or more separate electrical cables (single and/or multi-conductor). Note that it is possible to have both intra- and inter-cable conductor-to-conductor short circuits active concurrently.

Conductor-to-conductor short circuit electrical cable failures have the potential to induce a range of circuit faulting behaviors. Such failures can lead to loss of circuit function, corrupted indications, loss of control, and spurious actuations. The actual circuit fault observed is entirely dependent on which conductors actually short together. However, the relative likelihood of conductor-to-conductor short circuits is of critical interest to the risk quantification.

In this context, we are primarily interested in initial cable failures that are manifested as a conductor-to-conductor short circuit that does not simultaneously involve a short to an external ground. As discussed below, one or more of the shorting conductors may be grounded, in which case, the conductor-to-conductor short circuit may have the same circuit fault effect as a conductor-to-external ground short. However, from a mechanistic view of cable failure, the first question to ask is the likelihood that the initial short circuit involves only conductors and not an external ground. One can then consider the nature of the conductors present and potential combinations of conductors, each of which may have unique circuit faulting effects.

There is currently little data available on cable failure modes and effects. A recent review sponsored by the RES identified a small number of experiments providing relevant data but also concluded that most electrical cable fire experiments provided little or no information on cable failure modes and effects (LaChance, et al., 2000). Hence, of particular note is a recently completed set of tests performed by NEI and EPRI with the participation of the NRC (NUREG/CR-6776 and EPRI TR-1003326). These tests provide the most relevant data on cable failure modes and effects currently available and will be discussed in some detail.

A total of 18 fire tests were conducted, each involving a cable tray and four to five monitored cable bundles. The tests explored a limited range of fire exposure conditions, cable types, and routing conditions. The data have provided many interesting insights into cable failure modes and effects behavior. However, the data are subject to substantial limitations, and caution must be exercised in extrapolating the results to any specific application.

First, the data were gathered in an atypical room. The test room was a steel plate box of limited dimension [3.04 m x 3.04 m x 2.43 m (10 ft x 10 ft x 8 ft)]. Given the steel room construction, heat losses from the walls and ceiling of the room were much greater than would be anticipated given a wall material such as concrete or gypsum wallboard. Hence, the relationship between the fire intensity and the room temperature was somewhat distorted in comparison to other room fire tests. In many of the tests, the room temperatures hovered very near the anticipated failure threshold temperatures for, in particular, the thermoset cables being tested. Hence, consistent with past experiments, the fire damage times were often prolonged (in some cases in excess of one hour). At higher exposure temperatures, the damage times would have certainly been shorter. It was also observed that some of the larger fires burned in an under-ventilated condition (as evidenced by an increase in room temperature when the size of the ventilation opening was increased during a given test). Hence, fires may not have reached the full burning intensity cited as the nominal fire intensity in the test reports.

Second, the circuit tests conducted by NEI used a surrogate MOV control circuit. The same circuit, with some variations, was used in all tests. The characteristics of this circuit may not be typical of other types of control circuits. Further, quantification of the circuit fault mode results is in part dependent on the circuit design, in particular, the number and placement of fuses, the number of energized conductors, the number of target conductors, and the presence of a ground conductor in the control cable. For another circuit with a different combination of

conductors, the results could be quite different. For example, the presence of a grounded conductor in each multi-conductor electrical cable almost certainly contributed to a higher incidence of shorts to ground and a lower likelihood of spurious actuation.

Finally, the tests used primarily AC power sources. The NRC portions of the tests did involve some DC testing, but experimental problems caused much of the DC data to be compromised. The data did result in some conflicting information, hence, the applicability of AC circuit test results to DC circuits remains uncertain.

The results for the NEI MOV circuits were expressed primarily in the context of two circuit fault modes; namely, fuse blows (indicating an energized conductor shorting to ground or to a grounded conductor) versus spurious actuations. Overall, a substantial fraction of the cable failures resulted in a spurious actuation circuit fault mode.

The NRC sponsored portions of the tests focused on monitoring conductor shorting behavior through measurements of the conductor insulation resistance (IR) values during the fire tests. As the electrical cables are heated, the electrical insulation value of the insulation material is degraded. This degradation was monitored for both conductor-to-conductor and conductor-to-external ground. As a result, the actual shorting patterns between various conductors and between each conductor and ground could be determined. The initial cable failures were dominated by intra-cable conductor-to-conductor short circuits. The conditional probability of this mode of cable failure was estimated as 80-percent or higher based on these and other tests (conditional on electrical cable failure attributable to fire).

One possible explanation for the high likelihood of intra-cable conductor-to-conductor short circuits revolves around manufacturing practices associated with multi-conductor electrical cables. When multi-conductor electrical cables (with more than two conductors) are constructed, the individual conductors are first formed and insulated. The various insulated conductors are then brought together and the filler[30] and jacket materials are applied. In the jacketing process, the insulated conductors are generally twisted around each other to form a tight arrangement. If, for example, a length of a multi-conductor electrical cable is laid out along the floor, one typically observes a spiral pattern in the outer ring of conductors. This spiraling may leave a residual tension between the conductors. As the insulation materials are heated and lose their physical integrity (i.e., either melting or charring) this residual tension may draw the conductors together.

8.5.2 Combinatorial Models for Conductor-to-Conductor Shorting

Section 8.5.1 has discussed conductor-to-conductor short circuit failures in a very broad context that is essentially independent of the circuit to which the electrical cable is attached. There is, however, an interest in more specific modes of conductor-to-conductor shorting that would be relevant to a given circuit. Some analysts have proposed the application of combinatorial models to address this problem. To date, such models have not been assessed for validity, hence, their application to risk analysis remains unproven.

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[30] Filler materials fill voids between the individual conductors within a multi-conductor electrical cable and may include materials such as paper, natural fibers, or polymeric (e.g., nylon) fibers.

The most obvious example where such a model might be applied is in estimating the likelihood of hot shorts leading to spurious actuation. To illustrate the combinatorial model approach, consider a circuit where there is one specific conductor (one target conductor) within a seven-conductor electrical cable that, if energized, would cause a spurious actuation. Further assume that there is one other conductor in the same electrical cable that can provide the energizing source for the hot short (act as the source conductor). The analyst concludes that intra-cable shorting is the mode of cable failure most likely to cause a spurious actuation. The spurious actuation analysis then needs to estimate the likelihood that a cable failure will create a hot short between the one source conductor and the one target conductor of interest. The analyst might then consider the total number of conductor pair shorting combinations available. For a seven-conductor electrical cable there are 21 such combinations possible. Only one of these pair combinations leads to spurious actuation. Hence, the analyst might conclude that the likelihood of the spurious actuation is 1 in 21. This is a very simplistic example intended only to illustrate the approach; however, it is not a recommended approach. Indeed, the available experimental evidence would indicate a much higher likelihood of spurious actuation for this configuration illustrating that this simplistic model fails to capture the important behaviors adequately.

Potential problems with such approaches have not yet been resolved. First, the shorting behavior of multi-conductor cables is complex and often involves more than two conductors in a shorting group. Second, the conductor shorting behavior is not totally random, but rather, tends to involve adjacent conductors within the electrical cable. Hence, the likelihood that any two conductors might short together is dependent in large part on their relative proximity to each other within the electrical cable. In most cases the analyst will not know the exact orientation of circuit functions and individual conductors in an electrical cable. The conductor-to-circuit wiring configuration may need to be treated as an aleatory uncertainty, and that uncertainty could be substantial. Third, many circuits will contain a “mitigating conductor” (e.g., a grounded conductor) that if involved in the shorting could mitigate a hot short (e.g., by tripping the circuit protection features). Again, the combinatorial models need to address this aspect as well.

Combinatorial models represent a potentially valuable approach that will likely see further development in the near future. For example, one participant in the recent EPRI expert panel proposed a more complex combinatorial model that incorporates an advanced view of cable failure behavior (see Appendix B of EPRI TR-1006961). The model appeared to work well in comparison to the experimental data available to the expert panel, but remains unproven in a more general context.

8.5.3 Conductor-to-External Ground Short Circuits

For all electrical cables, there is a potential that the insulated conductors will short to an external ground source. In particular, the raceways in which electrical cables are routed (trays and/or conduits) are generally metal (often galvanized steel and less commonly aluminum) and are typically grounded. Hence, most electrical cables have more or less ready access to an external ground plane once the cable insulation breaks down.

Note that a conductor-to-conductor short circuit that happens to involve a grounded conductor will have the same circuit faulting effect as a conductor-to-external ground short circuit. However, in the mechanistic view of cable failure modes and effects, the relative likelihood of a conductor-to-conductor short involving a grounded conductor is treated separately. The current

discussion focuses on the role of the external ground sources in cable failure modes and effects behavior.

The conductor to external ground failure mode can introduce unique circuit consequences. For most AC circuits, shorts to ground will render a control or power circuit non-functional, but will also have a mitigating effect on, in particular, the possibility of spurious actuation circuit faults. Shorts to ground on an energized electrical cable of a grounded circuit will generally cause circuit protection devices to trip deactivating the impacted circuit. This could impact either the control or motive power of a circuit depending on which electrical cables are impacted (see Section 8.5). Also note that if a conductor-to-conductor short circuit does form, and if any one of the involved conductors shorts to an external ground (or is itself grounded), then all of the involved conductors will also short to ground. In a risk context, the primary interest is the conditional likelihood that a short to ground will be observed before a hot short that might lead to a spurious actuation failure. Note that ungrounded DC circuits are unique with regard to shorts to an external ground. A single short to ground on an ungrounded DC circuit has essentially no impact on circuit performance. However, multiple shorts to ground may adversely impact the circuit. In effect, for an ungrounded DC circuit, the external ground acts as an external conduit for the formation of conductor-to-conductor shorts.

For multi-conductor electrical cables, 20-percent or less of the observed cable failures are likely to involve an initial short to external ground. For single conductor electrical cables the likelihood of a short to external ground failure is estimated to be substantially higher (perhaps 50-percent or higher) but there is little experimental data available to support this contention.

Experiments show that given a sustained damaging fire, all of the conductors in the damaged electrical cables will ultimately short to ground. Hence, another potentially important consideration in the context of fire risk is the transition time associated with this behavior (e.g., transitions from conductor-to-conductor to conductor-to-external ground short circuits). This transition behavior is important because it may, for example, determine whether a valve might fully reposition, or for how long a PORV might remain open, or how long an operator might have to recover a spurious actuation before the control function is lost.

Experimental evidence indicates that, given a sustained damaging fire, initial cable failures will likely transition to shorts to external ground over a wide range of times. In the recent NEI tests (EPRI TR-100326), for example, some of the spurious actuation circuit faults were of momentary duration (e.g., less than one second) while others were maintained for in excess of 11 minutes. The average duration of a spurious actuation signal was 1-3 minutes depending on the cable type. It should also be noted that in the NEI tests, one of the conductors in the multi-conductor control cable was grounded, and short circuits to this grounded cable would mitigate the actuation signal.

Overall, the test data available do suggest that sustained conductor-to-conductor shorts are possible. It should also be noted that suppression of the fire could “lock in” conductor-to-conductor electrical cable failures such that the short to external ground transition might not be observed in all cases. Hence, it would not be appropriate to assume that shorts to an external ground would mitigate all potential spurious actuation failure within any given time period. Statistically this is certainly a non-trivial possibility that increases in likelihood the longer a fire lasts. However, it is far from certain that this transition will occur, especially given aggressive firefighting activities.

Overall, short to external ground cable failures are high likelihood events given fire-induced cable failures and should be considered in a risk-informed analysis. Recall also that conductor-to-conductor short circuits may have the exact same impact as a conductor to external ground short circuit if one (or more) of the involved conductors happens to be grounded.

8.5.4 Loss of Conductor Insulation Resistance (IR)

Polymeric insulation materials, thermoset and thermoplastic, dominate the current electrical cable applications in the U.S. nuclear power industry. When these materials are heated, they lose their electrical insulation value. Based on available equipment qualification test results (NUREG/CR-4537), the degradation in resistance is logarithmic with linear increases in temperature. An example of this behavior is illustrated in Figure 8-1 (reproduced from NUREG/CR-6681). This same mechanism can lead to a loss of insulation resistance failure mode when electrical cables are heated in a fire.

In general terms, this mode of failure is associated with a degradation of the electrical cable that is less severe than an actual short circuit condition. This mode would be active at temperatures below the melting point of a thermoplastic material, and below the nominal gross failure threshold of thermoset materials. For some circuits, a significant degradation in the insulation resistance between individual conductors or between conductors and ground could compromise the performance of the circuit.

This mode of failure is particularly relevant to instrumentation circuits. A typical instrumentation circuit operates at 4-20 mA. Given the nature of the instrument loop circuit, a breakdown in the instrument cable insulation could cause all or part of the intended current signal to be diverted, bypassing the instrument display device. This would bias, or corrupt, the instrumentation reading. Note that the direction of the bias will be predictable because while one can divert some of the intended signal, one cannot increase the current flow to the indication device. The direction of the bias will always be towards the low-current indication, although whether low current corresponds to high or low on the process variable scale must be determined for each specific case. For other types of circuits (i.e., those with more robust electrical energy), this mode of failure is unlikely to compromise circuit function. Rather, for higher-energy circuits, actual short-circuit conditions will be the failure modes of interest.

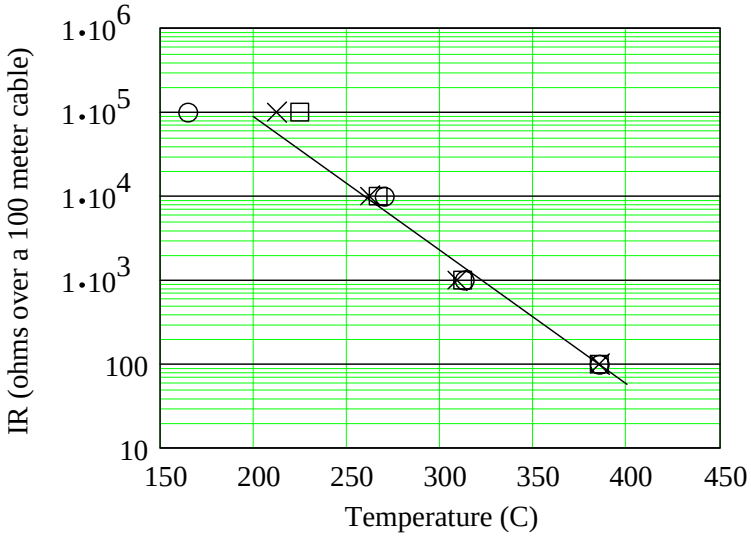

Figure 8.1 IR versus Temperature Behavior of a Typical Electrical Cable Insulation Material

This plot shows test data and a linear regression curve fit for a Brand Rex cross-linked polyethylene (XLPE) insulated 12 AWG 3-conductor electrical cable. The data are from Table 4 of NUREG/CR-5655, "Submergence and High-Temperature Steam Testing of Class 1E Electrical Cables" (NUREG/CR-5655). Similar plots can be generated for any given cable type, size and voltage rating given test data that reports IR as a function of temperature.

A recent test series examined this behavior for instrument circuits (NUREG/CR-6776). In general, a pronounced difference was noted between the behavior of thermoset and thermoplastic insulated instrument cables. Thermoplastic insulated electrical cables tended to fail abruptly and catastrophically with little or no indication of degraded signals prior to loss of signal. Thermoset insulated electrical cables illustrated a prolonged period of corrupted signal transmission before a complete loss of signal was observed. Hence, the use of thermoset insulated electrical cables appears to increase the potential that operators might be misled by a corrupted signal. An offsetting observation was that the thermoplastic insulated electrical cables failed far more quickly than did the thermoset insulated electrical cables. This is also consistent with the observation that thermoset insulated electrical cables are generally more resistant to fire-induced failure than are thermoplastic insulated electrical cables.

8.5.5 Loss of Conductor Continuity

As noted previously, a loss of conductor continuity implies that the physical and electrical integrity of the conductor itself is lost. That is, the conductor breaks. Note that this mode of failure may also be referred to as an open circuit cable failure, although this may lead to confusion with use of the term open circuit in the context of a mode of circuit faulting. An open circuit as a fault mode generally implies the opening of circuit protection devices (fuses or breakers). A loss-of-conductor continuity cable failure can have similar effects on a circuit, especially if the failure is associated with an energized power supply conductor.

Loss-of-continuity conductor failures have been observed both in actual fires and during tests. However, this mode of failure is considered highly unlikely to occur as the initial failure mode. Evidence taken from both experience and experiments indicates that fire-induced loss-of-conductor continuity failures may be observed under three circumstances as follows:

- During a prolonged fire exposure, the conductor material may melt causing a loss of conductor continuity. This is often a progressive behavior over an exposed length of electrical cable, rather than an abrupt or localized failure. In most cases, all of the electrical cable insulation materials would have long since burned away; hence, all of the conductors would have shorted to ground long before a loss-of-conductor continuity failure were observed.
- Loss-of-continuity may also be associated with other physical behaviors that could place an undue physical load on the electrical cables. This might include, for example, the collapse of cable supports or raceways, the impact of a hose stream on a badly damaged electrical cable, or physical stressors that may cause electrical cables to come loose from a terminal connection.
- High-energy electrical cables (i.e., those with a high voltage and/or current potential) may experience repeated, short duration, high-intensity arcing shorts (either phase-to-ground or phase-to-phase). These shorts are typically of such high energy that the conductor material is melted and/or vaporized at the location of the short causing the short to self-mitigate. Circuit protection devices (fuses and breakers) have a finite current/time response behavior, and conventional circuit protection devices are not designed to detect arcing faults (arcing fault circuit interrupters are available but are not widely used in the U.S. nuclear power industry). Hence, the circuit protective features may not be activated/tripped by these short duration arcing short circuits. If this behavior is repeated a sufficient number of times, the conductor continuity may eventually be lost.

The risk implications of a loss-of-continuity cable failure must be viewed in the context of the circuit under analysis. No concise risk analysis of this question has yet been conducted. Loss-of-conductor continuity failures are not expected to be risk-significant, in part because of their low likelihood of occurrence and in part because they are not expected to introduce unique risk scenarios or insights. The rationale for the second part of this conclusion depends on the type of circuit considered, as follows:

- **For control and instrument cables** the available power is not sufficient to induced high-energy arcing conditions. Hence, loss-of-conductor continuity failures will only be observed in long duration fires, and then only after all conductors have shorted to ground. This implies that other modes of cable failure (i.e., conductor-to-conductor and conductor-to-external ground short circuits) will determine the circuit faulting behavior.
- **For power cables** it is possible that a loss-of-conductor continuity might occur as a result of high-energy arcing. However, for power circuits, the loss-of-conductor continuity cable failure will mimic an open circuit fault associated with tripping of circuit protection features; namely, power will be unable to reach its intended destination. This same mode of circuit faulting is observed given a sustained short-to-external ground or phase-to-phase conductor shorting behaviors. Hence, in terms of the impact on the power electrical cables' own circuit, no unique fault modes are introduced. The only difference given a loss-of-conductor continuity failure is that the side of the broken conductor(s) leading back to the power supply source might remain energized; hence, these conductors might be available as a hot short source for other electrical cables. In the hot short analysis, the existence of an appropriate source is generally assumed unless the lack of such a source can be confirmed. Hence, again, the loss-of-conductor continuity failure should introduce no unique risk scenarios or insights.

8.5.6 Summary of Electrical Cable Failure Mode Insights

For multi-conductor electrical cables the dominant mode of cable failure anticipated is intra-cable conductor-to-conductor short circuits. Evidence in this area is strong and indicates that 80% or more of all fire-induced multi-conductor cable failures will initially involve intra-cable conductor-to-conductor short circuits. This appears to apply to both thermoset and thermoplastic insulated electrical cables. (Recall that not all intra-cable conductor-to-conductor shorts involve hot shorts leading to spurious actuation as discussed further below.)

The available data indicate that inter-cable conductor-to-conductor shorting is possible, but is less likely to occur than is intra-cable conductor-to-conductor shorting. The data also indicate that inter-cable shorting is more likely given thermoplastic insulated electrical cables than it is given thermoset insulated electrical cables. The available data on inter-cable shorting is not sufficient to provide firm estimates of conditional likelihoods. However, for thermoplastic insulated electrical cables, the likelihood of inter-cable conductor-to-conductor short circuits is probably 0.5 or less. For thermoset insulated electrical cables the likelihood of inter-cable shorting is probably 0.1 or less. For both electrical cable types the likelihood of inter-cable shorting may be much lower depending on the cable raceway configuration and fire exposure conditions.

For both electrical cable types, thermoplastic and thermoset, the likelihood of a hot short versus a short to ground will depend on a number of configuration factors that are currently not well characterized. While some of these factors may have little influence on the intra-cable shorting behavior, they likely have a stronger influence on the likelihood of inter-cable shorting. That is, for some configurations inter-cable shorts cannot be considered a rare event while for others, the likelihood may be very low. Factors that are believed to have a significant impact on the likelihood of inter-cable shorting include the following (NUREG/CR-6776):

- The nature of the fire exposure: Direct flame/plume exposures that heat the cables from below may be more prone to cause shorts to ground than would radiant heating that heats the cables from above.
- The loading of the raceway: A tray with many electrical cables would be more likely to experience inter-cable shorting than a sparsely loaded cable tray.
- Trays with maintained spacing of the electrical cables: For such configurations (generally used only for larger power cables), inter-cable shorting independent of the grounded raceway appears to be highly unlikely.
- The position of the critical electrical cables within the raceway: Electrical cables located at the bottom of a tray would be more likely to short to ground than electrical cables located on top of a cable load.
- Cable tray type: Cable tray type (e.g., ladder back versus solid bottom) impacts the cable support loading and may impact the failure behavior, but this parameter has not been investigated.
- Use of conduits: Electrical cables in conduits appear to have a higher likelihood of shorts to ground and a lower likelihood of hot-short induced spurious actuation in comparison to electrical cables in cable trays. This appears to apply to both intra- and inter-cable shorting behaviors.

It also appears that loss-of-conductor continuity failures are unlikely to occur as an initial failure mode. Such failures are likely to occur, but only after extended fire exposures or after repeated arcing faults for higher energy electrical cables. This failure mode is not expected to contribute significantly to fire risk.

Combinatorial models may be used in the future as a tool to estimate the likelihood of specific cable failure modes, and in particular the likelihood of hot shorts leading to spurious actuation. However, these models have not been fully developed and remain unproven.

8.6 Circuit Fault Modes

The risk implications of cable failure induced circuit faults will be discussed in the context of the three primary circuit types or functions; namely, power, indication/control, and instrumentation. For each circuit type, the cable failure modes and circuit fault modes of potential interest are somewhat unique. Fault modes of interest for each circuit type are as follows:

- Power circuit fault modes
  a. Loss of primary or motive power to a system or component
  b. Hot shorts leading to spurious actuation
  c. Multiple high impedance faults

- Control and indication circuit fault modes
  d. Loss of control function or power
  e. Spurious actuation in control circuits
  f. Loss of control indications
  g. False control indications

- Instrumentation circuit fault modes
  h. Loss of permissive signals
  i. False permissive signals
  j. Corrupted instrument gage readings

Each of these circuit types is discussed in detail in the subsections that follow.

8.6.1 Power Circuit Fault Modes

Loss of Primary Motive Power

For power circuits, many electrical cable failures will lead to a loss of primary motive power to plant devices[31]. A loss of primary motive power implies that the faulted system stops operating. Continuously operated devices such as pumps, fans, and motors will stop and/or will be unable to start. Intermittent operating devices such as MOVs would cease movement, if movement were in progress at the time of the cable failure, and would be unable to move through normal control functions (in some cases manual repositioning would still be possible, e.g., using a handwheel). Devices that require continuous power to maintain position, such as a solenoid operated valve, would cease to be operable and would stay in, or reposition to, their de-energized condition.

Loss of primary motive power could result from the following power cable failures:
- phase-to-ground short circuits involving an energized conductor
- phase-to-phase short circuits involving two or more energized conductors
- hot shorts to a power circuit of higher voltage potential

In each case, the cable failures would lead to opening of circuit protective features (e.g., breakers and/or fuses) — an open circuit fault mode for the power supply circuit.

Given the many ways that power cable failures might lead to an open circuit fault condition, the loss of motive power will be the predominant fault mode given the failure of power cables. It can nominally be assumed that 99-percent or more of the power cable failures would lead to this mode of circuit faulting.

Power Cable Hot Shorts Leading to Spurious Actuation

The likelihood of power cable failure induced spurious operations depends in large part on the nature of the power supply system. Single-phase AC power systems may be somewhat vulnerable to spurious actuation faults, whereas three-phase AC and ungrounded DC systems appear to have a far lower likelihood of spurious operation.

For the ungrounded DC and three-phase AC systems, multiple concurrent inter-cable hot shorts of the proper polarity are required to induce spurious actuation of plant components as a result of failures in power cables. However, the conditions leading to this fault mode are quite specific and are considered highly unlikely to occur. In general, a spurious actuation induced by power cable failures for these two types of systems requires either two or three (depending on whether the system is DC or three-phase AC) concurrent hot shorts of the proper polarity such that the attached device is appropriately powered.

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[31] Motive power is distinguished from control power. Motive power is the source of energy that runs a primary electrical device such as a motor, while control power is a separate, although potentially dependent, light power circuit used to energize secondary control devices such as relays which in turn control the flow of motive power to the primary component.

For a single-phase AC system, the neutral power leg is typically tied to ground. Hence, a single hot short from the 'hot' leg of the AC system to a hot leg power lead for another device can cause spurious operation. Return power can be transmitted through the common ground, bypassing the neutral conductor (hence, a neutral-to-neutral short circuit may not be required). General practice for NPPs in the United States is to use separate electrical cables for each power supply circuit. Hence, spurious actuation would generally require an inter-cable hot short. Given that only one inter-cable conductor-to-conductor hot short is required, the likelihood is higher in comparison to the DC and three-phase AC cases. In all three cases, the voltage and current characteristics of the source conductors must be compatible with the target device. Application of an excessive voltage may damage the target device rather than cause it's actuation. Similarly, application of a DC source to an AC device (or vise-versa) would likely damage rather than activate the target device. Finally, if the current available to the source conductors is not sufficient to power the target device, then an overcurrent condition will likely trip the source conductors' protective circuit features mitigating the fault.

Nominally, the probability of such spurious actuation faults given the failure of power cables is judged to be low for all three cases, although no specific investigation of this potential has yet been undertaken. The conditions required depend on the nature of the power source involved:

- For three-phase AC power circuits (typical of large motors and MOVs), a spurious actuation would require three concurrent hot shorts, each provided by a source of compatible power (voltage and current). Shorts to an incompatible power source (wrong voltage or inadequate current) would likely either damage the target component or trip circuit protection on the source bus. All three source conductors must also be powered from the same electrical bus. Reversal of two phases of the source/target configuration could cause the target device to operate in reverse, and could well damage the target device. Spurious actuations for this configuration are considered highly unlikely and are estimated to have a 0.001 conditional likelihood or less. Note that if a ground conductor is routed with the energized conductors (e.g., a triplex cable with ground), the likelihood of a spurious actuation will be further reduced.
- For single-phase AC power circuits (typical of smaller motors and MOVs), the neutral is generally tied to ground so only one hot short from a power source of proper voltage and current would be required. Again, shorts to a source bus of improper voltage or inadequate current would likely either damage the target component or trip circuit protection for the source conductors. This is also considered an unlikely occurrence, but the conditional probability of occurrence given cable failure may be as high as 0.1 depending on the nature of the power cables and grounding provisions. For most cases the likelihood should be lower. For example, if an explicit ground conductor is routed with the high and low potential power cables (e.g., a two-conductor electrical cable with ground or three-conductor electrical cable), then the likelihood of a spurious actuation will be lower. Use of armored electrical cables could essentially eliminate this possibility because there is virtually no possibility of inter-cable shorts independent of the grounded armor. Routing of electrical cables in conduits would also reduce the likelihood even if the conduit contains more than one power cable such that inter-cable shorting remains a possibility.
- For an ungrounded DC power system, two concurrent hot shorts of the proper polarity are required to induce a spurious actuation. Alternatively, one of the two polarity hot shorts might be provided through the effects of multiple shorts to ground, however, one side of the power supply system must remain isolated from ground or circuit protection would be tripped.

If the DC voltage is not appropriate to the target device, the device would either fail to operate or might be damaged. Adequate current is also needed.

Overall, spurious actuations that are induced by failures in those electrical cables that provide motive power to a device are considered unlikely. The highest likelihood case is single-phase power systems, and while unlikely, this type of circuit fault might still have some non-trivial contribution to risk and should be considered. For the ungrounded DC and three-phase AC power systems, the occurrence of a power cable failure induced spurious actuation appears unlikely. Hence, consideration of such fault modes for other than high consequence applications (e.g., high-low pressure interfaces) does not appear to be warranted. The conditions required to cause such faults are simply too specific and too restrictive to be considered likely, and the potential for such faults will likely have little risk significance.

Multiple High-Impedance Faults

There is a potential that concurrent failures involving several power cables could introduce a unique failure mode for plant power distributions systems. In particular, if multiple power cables fed from a common bus experience low quality or high impedance shorts, each electrical cable could experience current leakage beyond that expected as a result of the normal operation of the powered component. Enough faults of this type could create a demand on a higher level circuit protection device that exceeds the protection level of the higher level bus, without exceeding the protection level of the individual circuits. The physics of such behaviors remain poorly understood, and cannot be dismissed out of hand. However, based on the knowledge we have regarding cable failure behavior, this mode of failure is considered to be unlikely in practice. Several factors work against such an occurrence.

One such factor is the precise quality of the faults required to create such a situation. The multiple high impedance fault scenario postulates that several electrical cables are leaking current at levels just below the trip point of the nearest up-stream circuit protection device. This would require a sustained fault with a rather precise resistance, and indeed a resistance that is relatively low.

However, the shorting behavior of energized electrical cables does not favor the formation of such shorts. Experiments do show that electrical cables will tend to degrade progressively over time (NUREG/CR-6776, NUREG/CR-5655, and NUREG/CR-5546). The data show that electrical cables energized to a non-trivial level (i.e., greater than approximately 50 V) display an abrupt shorting behavior beyond a certain level of degradation. It appears that once the degradation reaches the point where the insulation is providing about 1,000–10,000 ohms IR, there is an abrupt transition to a low-impedance or dead-short fault.

A second factor working against this scenario is timing. The multiple high impedance fault scenario requires that several faults be active concurrently. This is certainly possible, but experimental evidence suggests that even electrical cables located in a common tray will fail at discrete times rather than all at once. The issue of timing combined with the need for a sustained fault of a rather precise resistance value would appear to indicate that a multiple high-impedance fault, leading to the tripping of a higher level power distribution bus, while possible, is of low likelihood.

Finally, the risk implications of the multiple high impedance fault issue are mitigated to some extent given that operator response could potentially recover the undamaged circuits The scenario does not postulate that the higher level bus is damaged beyond recovery, simply that

the circuit protection trips at a level higher in the distribution system than the level at which the actual cable failures occurred. Hence, isolating the damaged circuits would allow for re-setting of the tripped breaker/fuse and recovery of the higher level bus. The timing of such recovery actions, and the likelihood of success, would need to be considered in a risk assessment.

In the context of a fire PRA, the loss of a higher level bus, when treated, would typically be assumed to occur as a result of a random failure of the nearest circuit protection feature to trip on demand. In this scenario, a single electrical cable failure might fail to be isolated by the first upstream circuit protection feature, and would therefor cascade to the next level bus. The risk implications of the multiple high impedance issue could be estimated using a similar approach by increasing the random failure probability of the local circuit protection device to reflect the likelihood of the multiple high impedance fault scenario. The effect on the plant systems would be similar, although the multiple high impedance fault scenario would require that more failed circuits be isolated before the higher level bus can be recovered. Such an exercise has not yet been conducted.

8.6.2 Control and Indication Circuit Fault Modes

In U.S. NPPs, the control and indication functions tend to be combined in a common circuit for a given device. For example, the open/close/in-motion indicator lights for an MOV tend to be a part of the overall control circuit and the conductors associated with the indication functions are often routed in the same electrical cable as those associated with the control functions. Hence, circuit fault modes for both control and indication circuits are treated as a common subject.

Loss of Control Function or Power

One likely mode of circuit faulting for control and indication circuits is a loss of control function. For continuously operating systems, a loss of control function may leave the system components running. For some devices, such as solenoid operated valves, a loss of control power can lead to repositioning of the device to the fail-safe condition. For other devices, such as an MOV, the loss of control function would leave the device in its prior state and render the normal controls ineffective at changing that state. Loss of control function fault modes are of potential risk importance if the system or function lost must be manipulated to support hot shutdown. This would include both front line and support systems. Loss of control function failures impacting only cold shutdown functions are not likely to be risk significant provided that hot shutdown can be achieved. Loss of control function failures for containment isolation functions are also of low risk significance unless the ability to achieve hot shutdown is also compromised.

A loss of control function would typically be associated with failures in the control system electrical cables, and in particular, either a loss of control power or other short circuit conditions that will divert the control power in the event that a control operation is attempted. In most cases, a loss of control function will be associated with a loss of the control power source. If the conductors that supply control power to the control circuit short to ground (or across polarities for DC circuits), then circuit protection for the control power circuit would likely trip. In some cases, a control cable failure can leave a control circuit nominally intact. However, upon any attempt to manipulate the control circuit various faults can occur that would render the control system inoperable (e.g., see MOV circuit analysis examples in LaChance, et al., 2000).

Spurious Actuation in Control Circuits

The issue of spurious actuations (or spurious operations) has received much attention. Spurious actuation is one specific type of "maloperation" fault as identified in the NRC fire regulations. Spurious actuation involves activation of a functional mode of a system or component caused by fire-induced electrical cable failures. Based on current understanding of the circuit analysis issues, the most likely source of spurious actuations will be control circuit electrical cable failures. Because the shorting behavior of the electrical cable conductors is complex, the analysis of spurious actuations is also complex.

A spurious actuation is generally caused by hot shorts, but not all hot shorts will lead to a spurious actuation, so care must be taken in estimating the likelihood of a spurious actuation. The short circuit must involve the right set of conductors. For many circuits, a specific pair of conductors must be involved in a common short. For grounded circuits, the short must not involve an external ground or grounded conductor. For ungrounded DC circuits, a pair of correct-polarity hot shorts is required. The exact configuration of shorts that could cause spurious actuation is potentially unique for each circuit in the plant; however, in practice many circuits will share common configurations and common failure/fault modes. The number of unique configurations that might need to be considered has not been determined.

A detailed analysis of spurious actuation is a tedious undertaking for most circuits. For the purposes of regulatory compliance, simplified methods of analysis are often employed. One common approach is the "hot probe" analysis. Under this approach the analyst assumes that a source conductor of proper voltage and current will be available. Each conductor in a circuit is then systematically energized by this "hot probe" source conductor to determine if a spurious actuation is possible. For the purposes of risk assessment, the regulatory analysis results can be applied, but generally only with some considerable uncertainty in quantification of the results. A more rigorous quantification requires a more rigorous analysis.

Time may also be a factor for some cases. Time may be important from two primary perspectives. Specifically, time may be important from the perspective of when the spurious actuation occurs and how long it persists. For example, a spurious actuation may open an solenoid-operated valve (SOV), but if the actuation is mitigated within a short period of time, the fault may have minimal risk implications. Similarly, a hot short may initiate a spurious actuation of an MOV, and the duration of the hot short may determine whether the valve fully repositions or only partially repositions. For some systems, a hot short might start the system (e.g., a pump), but mitigation of the hot short might cause the system to stop.

The questions of timing are also important when the issue of multiple spurious actuations is considered. In some cases, spurious actuations may only be risk significant if they are postulated in combination with other spurious actuations (or potentially other specific system faults). Hence, the timing of onset and the duration of the faults will influence the likelihood that any two or more spurious actuations might be active simultaneously.

The only experimental study that has directly assessed electrical cable failures leading to spurious actuation are the recent joint NEI/NRC electrical cable failure modes and effects tests described previously. In particular, the NEI MOV circuit tests provided many insights into spurious actuations.

As previously noted, a number of spurious actuations were observed, and the likelihood of spurious actuation given electrical cable failure was found to depend on a number of factors. Overall, the likelihood of spurious actuation given cable failure cannot be considered small. For most configurations a screening value ranging from 0.1 to 1.0 would be appropriate. A recent EPRI expert panel estimated the spurious actuation likelihood for the "base case" configuration[32] of this circuit ranges from 0.1 to 0.5 due only to intra-cable hot shorts (Reference EPRI TR-1006961). Variations from the base case led to other likelihood estimates, including the following general effects:

- Armored electrical cables showed a somewhat lower likelihood of intra-cable hot shorting, presumably due to the prevalent ground plane represented by the grounded armor.
- Electrical cables in conduits appeared less susceptible to hot-short induced spurious actuations, again presumably due to the prevalent ground plane represented by the grounded conduit.
- The lack of a CPT in the circuit increased the likelihood of a hot-short induced spurious actuation (by a factor of approximately 2). Note that CPTs are common in MOV control circuits.
- Inter-cable conductor-to-conductor short circuits are substantially less likely than intra-cable conductor-to-conductor short circuits. One explanation for the lower likelihood of inter-cable shorting is that there is no inherent residual tension between the conductors of two separate electrical cables as there is between the conductors of a multi-conductor electrical cable (see previous description).
- As compared to thermoset insulated electrical cables, the thermoplastic insulated electrical cables showed a similar likelihood of intra-cable hot shorts leading to spurious actuation, but an increased likelihood of inter-cable hot shorts leading to spurious actuation.

Multiple Spurious Actuations

A particular aspect of the spurious actuation question is the likelihood that multiple spurious actuations might be observed during a given fire. The evidence both from testing an actual fire experience clearly indicates that multiple spurious actuations are possible. However, it is appropriate to consider multiple spurious actuations in a more structured context.

There are several potential aspects to the multiple spurious actuation question, each of which may have unique risk implications. One of the most critical questions relates to timing. Specific issues related to timing include the following:

- Simultaneous behaviors: Simultaneous implies that events occur at essentially the same moment in time. To date no specific applications where simultaneity has been a critical factor to risk have been identified. Based on our understanding of electrical cable failure behavior, the onset of multiple cable failures simultaneously is possible, but appears unlikely. The most likely case leading to simultaneous spurious actuation faults would be where multiple faults might be created by the failure of a single cable. If the multiple faults require the failure of multiple cables, simultaneity appears unlikely. Fire testing indicates that even within a given raceway cable failures tend to be somewhat distributed over some time period, usually

[32] The base case involved a thermo-set insulated electrical cable in a cable tray with a control power transformer (CPT) in the circuit to limit the available total circuit power.

measured in minutes. Several factors likely account for this observation. For example, the heating from a fire is generally nonuniform; variations in electrical cable size lead to variations in their thermal response; variations in cable placement within a raceway lead to variations in the heating rate. Overall, it would appear that simultaneous spurious actuation faults are not of substantial concern in the risk context unless they can be induced by the failure of a single electrical cable.

- Concurrent behaviors: Concurrent implies that multiple faults occur at discrete points in time, but that they endure for a sufficient period of time that they overlap. Note that in this context we are referring to circuit faults, not cable failure. Note in particular that a self-mitigating cable hot short (e.g., a hot short that subsequently shorts to ground) may not mitigate the fault condition. For example, a repositioned MOV may not return to its original position when the hot short self-mitigates. Rather, some active intervention by plant operators may be required to mitigate the fault.
- Sequential behaviors: Sequential faulting implies that one fault is mitigated before being followed by another fault at a later time. Clearly, sequential behaviors are possible if not likely. For example, it appears that the 1975 Browns Ferry fire involved primarily a sequential series of spurious actuations (see discussion below) that were either self-mitigated or mitigated through operator actions during the event. However, even with sequential faults, some risk important scenarios may arise.

The test data and experience clearly indicate that concurrent hot shorts are possible. Hence, concurrent spurious operations are also possible. During the NEI MOV circuit tests, for example, some tests experienced concurrent hot shorts on two separate control circuits given the exposure of just four control circuits to potential actuation. This would tend to indicate a high potential for concurrent hot shorts and spurious actuation faults. One factor in this behavior was likely the co-location of the cables in a common raceway. The failure behavior for electrical cables located in separate raceways has not been explored extensively, although some data is available. The intensity of the fire exposure will be the primary factor in determining the timing of electrical cable failures, especially when multiple raceways are exposed.

An example where concurrent spurious actuation faults would be important is a case with two normally-closed SOVs in series in a significant diversion path. For the diversion path to open both valves must open and be held open concurrently. Self-mitigation of either hot short (e.g., by a subsequent short to ground) would return that valve to the normally closed position closing the diversion path.

A similar situation involving two MOVs, rather than SOVs, presents some interesting insights. Even given sequential self-mitigating hot short cable failures, both valves may be left open concurrently. That is, once each MOV repositions, mitigation of the hot short may not return the valve to a closed position. Rather, it is likely that mitigation of the hot short will cause a loss of control power and a loss of the normal control function while leaving the valve in the open position. Similar behaviors could be observed in circuits with latching or locking relays where even a momentary hot short might lock in a spurious actuation circuit fault. Again, the existence of concurrent spurious actuation faults is distinct from the existence of concurrent hot short cable failures for certain cases.

The assumption of sequential faults is, in essence, the basis most commonly used for current fire safe-shutdown analyses, and is the so called “any and all, one at a time” approach (a detailed discussion of the application of this approach is provided in Appendix B of this document). Two additional considerations related to multiple spurious actuations are as follows:

- Multiple actuations of a single system: It appears likely that a system that experiences one spurious actuation signal will experience two or more such signals. This was observed in both the 1975 Browns Ferry fire and during the NEI MOV circuit tests. It is also nominally consistent with the NRC/RES insulation resistance measurements made during the NEI tests as well. In the NRC/RES measurements, groups of conductors were observed to form dynamic conductor shorting groups, a behavior that could lead to multiple actuations of a circuit as a result of the failure of a single control cable.
- Actuations involving multiple systems: Both experience and testing demonstrate the potential for the actuation of multiple systems. During the NEI MOV circuit tests, for example, as many as three of the four exposed circuits experienced spurious actuations during a given test.

Overall, one cannot dismiss the possibility of multiple spurious actuations, either concurrently or sequentially. Further, one cannot dismiss either multiple actuations of a single system, or the spurious actuation of multiple systems. The obvious question is how likely are such events and how many spurious actuations are reasonable to postulate? Given the NEI MOV circuit tests in particular, the likelihood of spurious actuation of a circuit (given damage to a susceptible control cable[33]) was relatively high. The likelihood was found to be dependent on a number of factors, and varied over a fairly wide range. Important factors explored in the tests were discussed previously.

Given the identification of several important factors, it is not possible to cite a single value that would be characteristic of a “typical” control circuit. In broad terms, the mean likelihood of actuation (given failure of a susceptible control cable as observed in the NEI MOV circuit tests) ranged from about 0.1 to about 0.6, depending on how the tests are parsed. For at least one configuration, the EPRI expert panel cited an upper bound estimate of the spurious actuation likelihood of 1.0. This range represents a significant variation even given that a limited set of potential factors of importance were varied, that only one basic control circuit configuration was tested, and that the factors varied were only explored over a limited range. Overall, there is still at least one order of magnitude uncertainty in the likelihood of spurious actuation for any given circuit (assuming some level of susceptibility).

Given spurious actuation likelihoods of this order, the possibility of multiple spurious actuations cannot be dismissed. Given the data, the number of spurious actuations may be limited only by the number of susceptible cables damaged by the fire. This still, however, leaves open the questions of likelihood (how likely is it that two or more actuations would be experienced) and timing (sequential versus concurrent faults). Neither question, unfortunately, has a clear cut answer. One can, for estimation purposes, assume nominal likelihoods based on the NEI tests for a given circuit. If the conditions of the associated electrical cables are well characterized, then the estimates can be refined. If one assumes circuits with the highest level of susceptibility (e.g., a mean value of 0.6 given cable damage), and assuming independence between failures, then as many as four spurious actuations would still have a likelihood of $(0.6)^4$, which equals 0.13.

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[33] By susceptible control cable we mean a control cable configuration wherein intra-cable shorts do hold the potential to cause a spurious actuation.

It is likely that more risk consequence mitigation will be achieved by considering the likelihood of damage to multiple control cables than from consideration of the likelihood of spurious actuation given control cable failure. In particular, most electrical cables used by the U.S. nuclear industry are fairly robust and resistant to fire damage (thermoset insulated electrical cables in particular). Experience illustrates that most fires are small, causing damage to few, if any, exposed electrical cables. These observations substantially reduce the likelihood that fires leading to multiple spurious actuations will occur. Nonetheless, given a severe fire and damage to many electrical cables, it appears that one or more spurious actuations are likely.

Lost or Misleading Control Indications

As noted previously, the indication functions are generally carried by conductors that reside in the same electrical cable with the control functions for the same circuit. (Note that instrument signals are discussed in Section 8.6.3 below.) There are various circuit fault modes of potential interest to these indication functions. Fault modes of potential interest include the following:

- Hot shorts can illuminate indicators inconsistent with the actual system status (e.g., a valve open light might illuminate even though the valve is actually closed).
- A short to ground can fail an indication (e.g., an indication lamp may go out).
- Some indication faults may not be manifested until an attempt is made to operate circuit (e.g., given an attempt to operate a valve, both the open and closed indicator lights might be illuminated).

The importance of such faults to risk is primarily driven by the operator's response. Operators take control actions based on the signals presented to them. False indications may lead to unsafe actions. The importance of such faults may be mitigated by redundancy in the signals available to operators. Further, inconsistency between corrupted and intact signals may lead operators to diagnose control circuit problems. For example, if an operator sees both open and closed indicators illuminated for a single valve, they may conclude a circuit fault has occurred and will not place much faith in that circuit. Indeed, experience includes cases where operators have diagnosed the existence of a fire based on faults in their control circuits.

The risk importance of indication circuit faults has not yet been assessed. No fire risk analysis to date has explicitly considered this issue.

8.6.3 Instrumentation Circuit Fault Modes

Instrument circuits present potentially unique circuit analysis concerns. Instrument circuits provide critical information regarding the status of the plant to operators. As opposed to status indicators (discussed previously in Section 8.6.2), instrument circuits provide a variable output reading that is proportional to some process variable (e.g., temperature, pressure, level, flow rate, current draw on an electrical circuit, etc.). Instruments are important to post fire safe-shutdown for several reasons:

- Instruments provide operators with needed information on the status of the plant. The degradation of instrument reading (e.g., transmission of a corrupted reading) might mislead operators into taking improper response. A complete loss of an instrument reading might be more obvious, but deprives the operator of potentially important information.

- Instruments are often associated with permissive interlocks. A loss of an instrument signal might cause a loss of the permissive signal. This could in turn cause the shutdown, or prevent the startup, of a desired system. (An example of this is cited below where the fire-induced failure of an oil pressure signal cable caused a false low oil pressure signal and prevented the operators from starting the associated pump.)
- Some instrument signals are tied to automatic control systems or functions. Degradation in these instrument readings could lead to the undesired actuation of automated control functions.

Note that to date no fire PRA has systematically evaluated the implications of fire-induced failures in instrument circuits. Hence, the available insights in this area are limited.

Instrument Loop Fire Damage Testing

During the joint NEI/NRC electrical cable fire tests described previously, several instrument cables were tested (NUREG/CR-6776). These tests utilized a simulated 4–20 A instrument loop, a common instrument circuit configuration. With respect to instrumentation cable failures, the following insights were observed:

- The instrument cables failed earlier in the test than did the co-located control cables. The instrument cables tested were all rather small, and this result generally reflects the thermal mass effect. That is, smaller cables heat more quickly, and hence fail more quickly, than do larger cables.
- Thermoplastic insulated instrument cables failed early in the fire tests, and the signal was lost quite abruptly. The instrument readings in such cases would abruptly change from normal to full loss of signal (off-scale low). Such behavior would likely be an obvious indicator to plant operators of a problem in the circuit.
- Thermoset insulated cables experienced degradation and failure later in the exposures, and over a more extended time period, typically of several minute duration. The initial degradation was manifested as an unsteady drop in the simulated process variable value. The degradation in some cases became progressively worse over a period of some minutes. Eventually, a sudden loss of signal was observed in each case. Such behavior may not be as obviously indicative of instrument circuit degradation.
- The behavior of an instrument circuit given cable degradation (e.g., the signal bias direction) can be predicted based on fairly simple circuit analysis.

Loss of Permissive Signal

The loss of a permissive instrument reading may induce a loss of function for the associated system. In some cases, multiple signal losses may be required to cause a loss of function (e.g., given a two out of three polling scheme). Loss of function faults might be recoverable, but only if operators can bypass the permissive signal and re-start the system. Such recovery actions are probably not covered by the operator's procedures, and hence, may be unlikely. Success would require 'on-the-fly' circuit diagnosis and modification. Such operations would not typically be credited in a fire PRA.

It appears that few fire PRAs have explicitly considered the implications of loss of permissive signals. The extent to which such failures are captured would depend on the approach taken. If the regulatory compliance safe-shutdown equipment list included those electrical cables that carry the permissive signal for safe-shutdown systems, then loss of those electrical cables was likely assumed to cause loss of the system. However, particularly for systems not credited in the safe shutdown analysis but credited in the fire PRA, permissive signals may or may not have been identified as a part of the plant shutdown model, and as a part of the electrical cable tracing efforts.

False Permissive Signal

There is a potential that certain types of corrupted or lost signals could cause a spurious actuation signal to be generated through automatic control systems. This potential would depend on the control logic. For example, multiple sensor line polling might make such spurious control signals unlikely. Some advanced circuits may also be designed to detect and reject corrupted signals. Again, the potential risk significance of such faults has not been addressed in any PRA known to the authors of this chapter.

Corrupted Instrument Gage Readings

As noted previously, the instrument signals are of critical importance to operators and are used to guide the operator actions or operator manual actions. A complete loss of several control signals may mean that operators would not know the actual reactor status. This, of course, depends on number of independent or redundant sensors available. It is also important to note that an instrument reading that is completely lost is likely to be readily apparent to operators as a damaged circuit. A more difficult question arises if one postulates that corrupted signals are transmitted to operators.

If corrupted signals are transmitted to operators, they may be misled as to reactor status and may take improper response. For example, a false low water level signal could lead operators to activate additional water sources leading to overcooling of the reactor vessel. A false high level reading could lead operators to shut down or throttle coolant injection systems potentially leading to voiding of the core. To date, no fire PRA known to the authors has systematically addressed such issues.

As noted previously, a pronounced difference between thermoplastic and thermoset insulated cables has been observed which is directly relevant to the potential for transmission of corrupted signals. Thermoplastic insulated cables experienced a sudden failure with no appreciable pre-failure degradation of the transmitted signal. In contrast, thermoset insulated cables degraded over a period of minutes before ultimate loss of signal. Hence, it would appear that the potential for corrupted signals is primarily a factor for plants that utilize thermoset insulated instrument wires. While thermoset insulated cables are known to be predominant in control and power cable applications in the United States, the proportion of plants using thermoplastic versus thermoset insulated instrument cables is not known.

8.6.4 Summary of Circuit Fault Insights

Circuit faults have been discussed in the context of three primary circuit functions; namely, power, control/indication, and instrument circuits. Insights have been derived from both testing, and as discussed in Section 8.7 below, experience.

For power circuits, it is anticipated that most electrical cable failures will lead to a loss of motive power to the related components. Such losses will generally not be recoverable without some repair to replace or bypass the damaged electrical cables. Spurious actuations attributable to hot shorts in power cables are considered unlikely, but the actual likelihood depends on the nature of the power supply system.

The highest likelihood case involves single-phase AC power systems where only a single hot short is needed to cause a spurious operation. In general, an inter-cable hot short is required because of the common practice of utilizing separate electrical cables for each power circuit. A nominal upper bound conditional probability for these cases is estimated at 0.1, although a number of factors could reduce this probability substantially. For these systems some consideration of the risk implications of power cable failure induced spurious actuations would appear appropriate.

The likelihood of spurious actuation for ungrounded DC and three-phase AC power systems is far lower because multiple concurrent correct-polarity, correct voltage inter-cable hot shorts are required. Given the configuration of most power cables, and the apparently low likelihood of inter-cable hot shorts, such concurrent faults appear of low likelihood. Furthermore inter-cable hot shorts in power cables are unlikely to be sustained for any substantial period of time; hence, they are not likely to be risk significant.

One unique aspect of power cables discussed is the issue of multiple high-impedance faults. These scenarios postulate the concurrent existence of several electrical cable short circuits. Furthermore, the short circuit fault paths must each be of a very specific quality (i.e., fault resistance) in order for the postulated scenario to come about. For a number of reasons discussed previously, this would appear to be an unlikely scenario. In a risk context, loss of a higher-level bus attributable to failures in lower-level supply cables can be addressed based on random failure of the first line of circuit protection. In order to further assess the potential risk significance of such scenarios, these random failure probabilities could be adjusted to account for multiple high impedance fault scenarios, but no analysis of this type has yet been undertaken.

For control/indication circuits, many potential failure modes involving both the control and indication functions were discussed. The indication function circuit faults are primarily of interest to risk analysis in relation to their potential impact on operator actions or operator manual actions. No fire PRA to date has considered these issues; hence, their importance to risk is not known. The control functions, on the other hand, have broad-ranging implications. The one control circuit fault mode given the most attention has been spurious actuations. Both experience and experiments indicate that spurious operations are of relatively high likelihood given the failure of electrical cables that are susceptible to inducing such faults. Although a number of factors have been identified that substantially impact this behavior. Spurious

actuation probabilities conditional on cable damage vary by at least one order of magnitude given variations in the identified factors.

A particular aspect of the spurious actuation fault mode discussed at some length was the question of multiple spurious actuations. Based on the existing evidence, multiple spurious actuations are both possible and potentially likely given the failure of multiple control cables susceptible to inducing such faults. Using the current estimates of the conditional probability of spurious actuation (given electrical cable failure), it is difficult to justify the screening of any given number of spurious actuation faults based on low likelihood and on a generic basis. For some special cases, such screening might be justified (e.g., cases involving armored electrical cables, cases involving electrical cables in conduits, and cases that require inter-cable hot shorts rather than intra-cable hot shorts). However, no firm basis for such screening has yet been established.

In the case of instrument circuits, the importance of circuit faults was discussed in the context of permissive signals and their impact on operator actions or operator manual actions. Again, no fire PRA to date has included a rigorous treatment of instrument circuit failure; hence, risk insights in this area are lacking.

8.7 Experience-Based Spurious Actuation Insights

As a closing discussion, this section provides a brief summary of insights related to spurious actuation circuit faults that derive from actual fire experience. In the experience base there are several fire incidents, both in the US and abroad, that illustrate spurious actuations. Chapter 3 of this report has already discussed the occurrence of multiple spurious actuations during the 1975 Browns Ferry electrical cable fire. The following additional spurious actuation examples are cited in NUREG/CR-6738:

- During a 1982 fire at the Armenian NPP, three reported spurious actuations and other control and indication problems are reported, all apparently caused by fire-induced electrical cable failures.
- The main generator breakers were closed inadvertently as a result of fire damage to the associated control cables. This led to the non-operating generators being connected to the grid and in turn caused secondary fires in one of the turbine-generators and in the startup transformer.
- One of the diesel generators spuriously disconnected from its emergency loads apparently as a result of control cable damage. Attempts to correct the failure during the fire were not successful.
- One feedwater pump spuriously started following damage to an electrical cable, apparently, in the control circuits. In this last case, the fault that actuated the pump by-passed the normal start logic allowing the pump to start without first starting the lube-oil pumps. Hence, the pump ran for some period without proper lubrication. The fault also by-passed or defeated the normal control room start/stop functions and operator attempts to shut down the pump from the main control room failed. The pump was ultimately secured by electrical technicians who isolated the pump from the power bus manually.
- Neutron flux and other reactor related instrumentation indicated conditions that may not have been the actual conditions of the reactor. This was likely because many of the instrument

cables were degraded and/or failed by the fire. These indications led to the actuation of various emergency signals. This incident is one of the few incidents where there is specific information indicating that multiple spurious actuations actually occurred during a fire.

- During a 1988 fire at the Ignalinan NPP, there were a number of cases where equipment was lost as a result of spurious trip signals caused by the failure of instrument and control cables. These included the following events:
- The control room received oil level alarms for one of the main coolant pumps and the pump tripped automatically. Failures in the oil level indicator and alarm circuit electrical cables are suspected to be the cause of the trip (rather than an actual drop in oil inventory).
- Instrumentation and control cable failures led to the opening of supply breakers for two normal 6 kV buses and two essential (nonsafety) buses.
- Control cable damage tripped Transformer 5 and prevented it from taking up the loads for these buses.
- A 1991 fire at Chernobyl Unit 2 was attributed to cable damage that resulted from poor cable pulling practices during plant construction. In this instance, a conductor-to-conductor short in a multi-conductor electrical cable led to spurious closure of a generator breaker, grid back-feed into the generator, generator rotor failure, turbine oil and generator hydrogen release and a large fire. In this case, an electrical cable failure caused spurious component actuations that in turn caused the fire.
- During a 1995 fire at Waterford, the event sequence log and the control room operator observations indicate erratic behavior in the position indication of a breaker or a pump. There is no verification in the incident report regarding the behavior of these items in the field. Hence, it is not clear if these are spurious indications only or are, in fact, spurious actuations.

Based on this experience, it is reasonable to conclude that given fire-induced electrical cable failures, spurious actuations are possible, if not likely. Event reports are not sufficiently detailed, however, to allow for a reliable statistical estimate of the likelihood of a spurious actuation given a fire and/or given fire damage. Fire event descriptions do not, in general, provide a sufficient level of detail regarding component/electrical cable damage and systems performance during a fire to support such an analysis with confidence.

The data also show that multiple spurious actuations involving either a single system (i.e., a system that actuates repeatedly during an event) or multiple systems are also possible. Again, data limitations prevent us from providing reliable estimates of the likelihood that any given number of actuations might occur in a fire. The cases noted previously show spurious actuations impacting up to three independent systems during a single fire event.

CHAPTER 9. REFERENCES

U.S. Nuclear Regulatory Commission Documents

Regulations

10 CFR Part 50, “Domestic Licensing of Production and Utilization Facilities.”

10 CFR 50.48, “Fire Protection.”

10 CFR Part 50, Appendix A, “General Design Criteria for Nuclear Power Plants.”
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APPENDIX A.
SUCCESSFUL IMPLEMENTATION OF APPENDIX R CIRCUIT ANALYSIS

APPENDIX A.
SUCCESSFUL IMPLEMENTATION OF APPENDIX R CIRCUIT ANALYSIS

A.1 Circuits of Concern to Post-Fire Safe-Shutdown

As described in Chapter 6, circuits of concern to post-fire safe-shutdown, fall into one of two broad categories:

(1) Circuits/cables of equipment needed to ensure the proper operation of the *systems* credited in the SSA for performing essential shutdown functions ("required" or "safety" circuits)

(2) Circuits/cables of equipment that, if damaged by fire, could impact the shutdown capability ("associated, "nonessential" or "nonsafety" circuits of concern)

Required Circuits

Because a cable or circuit is related to the operation of a required shutdown component does not necessarily mean it is of concern to post-fire safe-shutdown. As discussed below in Section A.2 below, the determination of whether or not a specific cable is required for safe-shutdown may depend on such factors as the specific function of the cable, the position/status (open, closed, running, stopped, etc.) of the component at the onset of fire, and the desired position/status of the component for shutdown. In general, a circuit/cable is considered to be required for safe-shutdown if it has the following characteristics:

(1) It is related to the operation of a required shutdown component

(2) Fire-induced faults in the circuit/cable can prevent the operation or cause a maloperation of the shutdown system in which the component is located

Power and control cables of Pump P-1 in Figure A-1 and control cables of valve V6 are typical examples of "required cables." In contrast,"associated nonsafety cables" are not directly related with the operation of any of the credited shutdown systems. Cable/circuits related to the operation of Valves V-9 and V-10 in Figure A-1 are examples. Although not needed to ensure operation of the credited shutdown systems, fire damage to circuits such as these could significantly impact the shutdown capability.

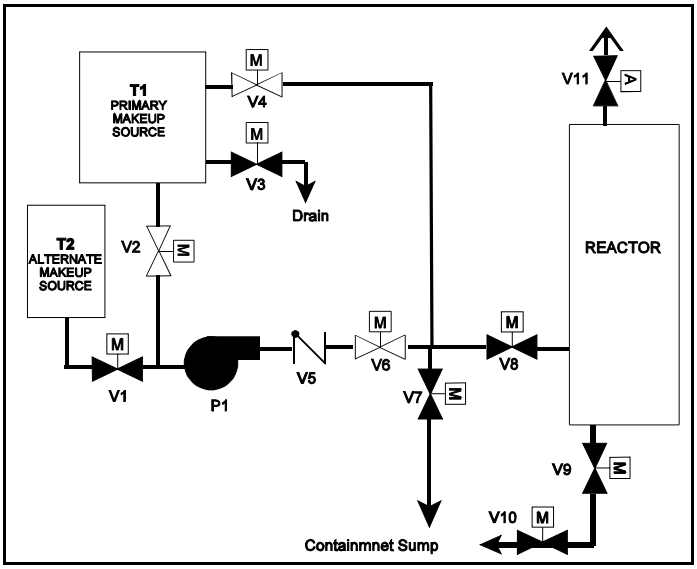

Figure A-1 Simplified Shutdown System Flowpath

Associated Circuits of Concern

The achievement of safe-shutdown is dependent on ensuring the active control of some components and preventing the maloperation of other components. A post-fire safe-shutdown analysis should be a bounding analysis that identifies the range of possible fire impacts within each fire area (vulnerabilities) and ensures that appropriate measures are in place to prevent this damage from affecting the ability to safely shutdown the plant. Therefore, it is not sufficient to only consider the effects of fire damage to cables of equipment needed to ensure operation of credited shutdown *systems* (required circuits). The scope of a successful shutdown strategy will consider the effects of fire damage to nonessential equipment and systems of which inadvertent or spurious actuation could impact the shutdown capability (associated nonsafety circuits).

The principal staff guidance related to the potential impact of fire-induced circuit failures in "nonessential" or "associated" circuits is contained in GL 81-12, dated February 20, 1981, and its subsequent clarification, dated March 22, 1982. As described in these documents, there are three specific configurations of associated circuits of concern to post-fire safe-shutdown:

- Nonessential circuits that share a **common power supply** (e.g., SWGR, MCC, Fuse Panel) with circuits of equipment required to achieve and maintain safe-shutdown; or,
- Nonessential circuits that share a **common enclosure**, (e.g., raceway, conduit, junction box, etc.) with cables of equipment required to achieve and maintain safe-shutdown
- Circuits and cables that have a connection to equipment of which **spurious operation** would adversely affect the shutdown capability.

With few exceptions, most licensees successfully resolve common power supply and common enclosure associated circuit concerns on a plant-wide basis through the performance of generic evaluations of electrical protective devices (e.g., fuse/breaker coordination studies). When resolved in this manner, the types of circuits/cables of concern to post-fire safe-shutdown are then reduced to two specific classifications:

(1) *Required Cables*: Circuits/cables of equipment needed to ensure the proper operation or functioning of shutdown systems defined/designated in the SSA.

(2) *Spurious Nonsafety Cables*: Circuits/cables of systems and equipment that are not needed to ensure the operation of shutdown systems credited in the SSA, but of which inadvertent (spurious) actuation or maloperation could impact the shutdown capability.

In its clarification of GL 81-12, the staff defined the scope of the spurious operation associated circuit concern as those circuits/cables that could impact the safe-shutdown capability if they are damaged by fire. As shown in Figure A-2 (Reference GL 81-12 Clarification, Enclosure 2), a fundamental presumption of the GL is that circuits/cables of equipment that could prevent operation or cause the maloperation of redundant shutdown systems (i.e., required circuits) are provided with fire protection features sufficient to meet Section III.G.2 of Appendix R, and therefore, would remain *free of fire damage*. As shown in Figure A-2, however, even when redundant trains of "required" cables meet III.G.2 criteria, fire damage to circuits/cables of "nonessential" systems and equipment (i.e., not needed to ensure operation of the defined/credited shutdown systems) may significantly impact the shutdown capability.

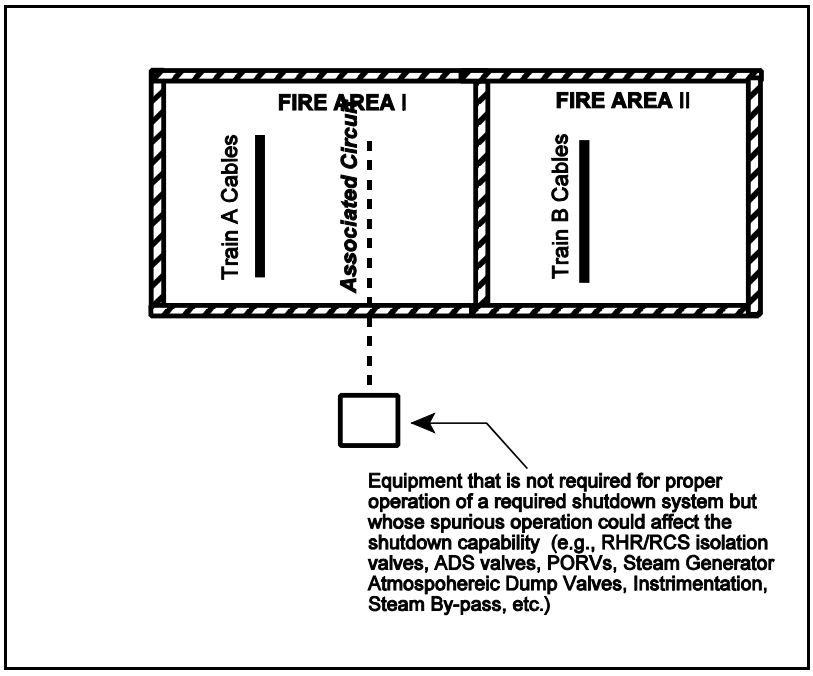

Figure A-2 Spurious Operation Associated Circuits of Concern

As described in this document, a common approach for ensuring that the SSA sufficiently bounds the range of circuit failures of concern to post-fire safe-shutdown starts by defining *shutdown success paths* (redundant and alternative), where each path is comprised of a set of systems (i.e., credited shutdown systems) capable of accomplishing each of the required shutdown functions (e.g., reactivity control, DHR). With the shutdown paths and systems defined, equipment needed to ensure the proper operation of the credited shutdown systems (required components) *and* nonessential/nonsafety equipment or systems of which spurious actuation could impact the shutdown capability are then identified and documented on a SSEL. As a result of this process, the SSEL will include all components (essential and nonessential) that could impact the shutdown capability if they are damaged by fire, and will not be limited to only those components needed to ensure the operation of the defined shutdown systems. From this comprehensive listing of equipment, the SSEL can then serve as a starting point for identifying circuits and cables of concern to post-fire safe-shutdown in each fire area.

A.2 Resolving Identified Vulnerabilities

When circuits/cables of concern to post-fire safe-shutdown are found to be located in a specific fire area under evaluation, the analyst has several options for ensuring that an appropriate level of fire safety is achieved, as illustrated by the following examples:

(1) Assuming that fire damage to affected circuits/cables will cause connected equipment to fail in an undesired manner and providing fire protection features sufficient to satisfy Section III.G.2 of Appendix R (while this approach requires no additional analysis it may not be cost-effective),

(2) Revising the shutdown strategy developed for the specific fire area under evaluation (e.g., use of other equipment)

(3) Demonstrating, through the performance of a detailed circuit failure mode and effects analysis (circuit analysis), that the credible range of circuit faults (as described in Chapter 6) to all exposed circuits/cables of concern will not impact the shutdown capability

(4) Requesting an exemption or deviation from specific technical requirements of regulatory requirements (see Section 4.5)

The challenge to the fire safety analyst and plant operating organization is to determine the best solution possible based on its ability to provide cost-effective protection against the threat of fire in a manner that is consistent with regulatory criteria and the plant's fire protection licensing basis.

During the initial stages of a fire area assessment, it is not uncommon to identify a large number of cable/circuit "interactions" or "cable hits." Since each "interaction" or "hit" represents a potential noncompliance with established separation/protection requirements, all interactions must be resolved. This may be accomplished by either the installation of additional fire protection features (e.g., meet Section III.G.2 of Appendix R), or through a rigorous analysis of the effect of fire damage to each circuit/cable involved in the identified interactions (circuit analysis).

Since it is typically not desirable to perform unnecessary plant modifications, most plants elect to perform a comprehensive analysis of each interaction. Since such an analysis can also be a time-consuming, resource-intensive process (particularly if excessive engineering effort is expended in the evaluation of circuits/cables that would not impact safe-shutdown if they are damaged by fire), it is desirable to limit its scope to only those circuits/cables that could actually impact the shutdown capability if they are damaged by fire. In cases where the SSEL is sufficiently comprehensive to bound the range of circuit failures of concern to post-fire safe-shutdown, licensee's have shown that the number of circuits/cables requiring a detailed review can be significantly reduced by considering the function, normal operating mode/status, and desired operating mode/status of components related to the identified cable/circuit interactions. The application and benefits of this screening technique are illustrated in the following example.

As discussed in Chapter 6, not all cable/circuit failures identified as "potential interactions" will impact the ability of connected equipment to function as needed for post-fire safe-shutdown. For example, since MOVs fail to the "as-is" position upon a loss of motive power, a loss of power to "normally closed" MOVs V-3, V-7, V-9 and V-10 (shown in Figure A-1), will not impact the shutdown capability. A loss of motive power to these valves will only cause them to remain "closed" which is their desired position for post-fire safe-shutdown. Additionally, if spurious actuation (opening) would not result in a LOCA, (i.e., the valves do not comprise a high/low pressure interface boundary) the power cables may be screened from further consideration for spurious actuation concerns. For the example shown, this would include power cables for valves V-3 and V-7. Since valves V-9 and V-10 comprise a high/low pressure interface, their power cables can not be screened at this point in the evaluation.

A.2.1 Use of Operator Manual Actions

Section III.G.2 of Appendix R requires that circuits that could prevent the operation or cause maloperation of redundant trains of safe-shutdown equipment have one of the specified fire protection features. Operator manual actions to respond to maloperations are not listed as an acceptable method for satisfying this requirement. However, the NRC has previously accepted plant-specific operator manual actions in formal exemption/deviation requests and in SERs. Rulemaking is currently in progress to codify the use of acceptable manual operator actions as discussed below.

Based on inspection results and industry comments the NRC determined that licensees have, without request for exemption/deviation from the code, implemented operator manual actions where the specified requirements of Section III.G.2 cannot be met. The staff concluded that rulemaking would be required to allow licensees committed to Appendix R to substitute operator manual actions in lieu of Section III.G2 compliance. For an interim period, while rulemaking is in progress, the staff determined that acceptance criteria can be developed which would facilitate evaluations of certain operator manual actions. Authority to approve a licensee methodology that does not meet NRC regulations is not delegated to the inspectors. However, inspectors will ensure that plant-specific operator manual actions meet the following guidelines:[34]

[34] NRC Inspection Procedure 71111.05, March 6, 2003.

- **Diagnostic Instrumentation**
  Adequate diagnostic instrumentation, unaffected by the postulated fire, is provided for the operator to detect the specific spurious operation or maloperation that occurred. Additional instrumentation beyond that identified in IN 84-09 may be needed to properly assess a spurious operation. Annunciators, indicating lights, pressure gages, and flow indicators are typical examples. Sufficient instrumentation should also be available to verify that the operator manual action accomplished the intended objective.
- **Environmental Considerations**
  The environmental conditions the operator may encounter while accessing and performing the operator manual action have been fully considered. Radiation levels should not exceed normal 10 CFR Part 20 limits. Emergency lighting should be provided as required in Appendix R, Section III.J or by the licensee's approved FPP. Temperature and humidity conditions should be reviewed to ensure that temperature and humidity do not affect the capability to perform the operator manual action. Fire effects should be reviewed to ensure that smoke and toxic gases from the fire do not affect the capability to perform the operator manual action.
- **Staffing**
  Adequate qualified personnel are on shift and available perform the required operator manual actions and to safely operate the reactor.
- **Communications**
  If operator manual action coordination with other plant operations is required, then communications capability must be protected from effects of a postulated fire.
- **Special Tools**

  If special tools are required they are dedicated for use and readily available from an accessible nearby location.
- **Training**
  Operators are trained on the operator manual actions and the procedure is adequate and current.
- **Accessability**
  Operator is capable of reaching the required location without personal hazard. If a ladder or other special access equipment is needed, it should be readily available.
- **Procedures**
  Procedural guidance has been developed to implement the operator manual actions. Operators should not rely on having time to study normal plant procedures to find a method of operating plant equipment that is seldom used.
- **Verification and Validation**
  All operator manual actions have been verified and validated (V&V) by plant walkdowns using the current procedure. The licensee has adequately evaluated the capability to perform the operator manual action in the time available before the plant will be placed in an unrecoverable condition.

A.3 Plant-Specific Examples of Successful Implementation

The following six examples show how cable/circuit vulnerabilities have been successfully identified and resolved by licensees. The examples are based on actual problems that were identified by licensees during recent re-evaluations for Appendix R compliance. In addition to illustrating the potential impact that fire-induced circuit failures may have on the ability to achieve and maintain safe-shutdown conditions, the examples also illustrate the extent and depth of the analysis.

Case 1 Potential for Secondary Fire Initiation

Problem During a reevaluation of its Appendix R program in 1997, a licensee of a PWR discovered that fault currents generated as a result of fire damage to power cables could be larger than the interrupting capability of the connected SWGR. If the associated SWGR is located in a different fire area, then this overcurrent condition could lead to another, secondary fire. This condition is unacceptable because the SSA assumes the occurrence of a single fire. The capability of the plant to achieve and maintain safe-shutdown for fires in multiple fire areas had not been demonstrated.

Resolution In order for the failure scenario described above to occur two conditions must exist: (1) the fault current must exceed the interrupting capability (rating) of the SWGR and (2) the fire must occur in a fire zone other than where the SWGR is located. Since cable impedance (which is generally proportional to cable length) will reduce the magnitude of fault current, the licensee performed an evaluation to determine the minimum distance away from the SWGR that a fault must occur for the cable's impedance to reduce the magnitude of fault current to a value within the rating of the SWGR. In addition, the routing of each cable was reviewed to determine whether the cable's route took it through different fire areas than that in which the SWGR was located. As a result of this review, the licensee identified six fire zones where the initiating fire had a potential to cause a secondary fire at the associated SWGR. As an immediate corrective action the licensee implemented compensatory measures to establish a roving fire watch in each of the six identified fire zones. As a permanent corrective action, the licensee implemented design changes to ensure that the subject SWGRs are capable of interrupting fault currents that may be generated during a fire.

Case 2 Inadequate Coordination Could Disable Essential Instrumentation

Problem In 1997, during a review of electrical cable routing, a PWR licensee discovered that a 125 VDC power cable was exposed to the effects of fire damage. Fire-induced faults (short to ground) in this cable, coupled with a lack of circuit breaker coordination on the 125 VDC system, could result in a loss of power to instrumentation that is essential for achieving and maintaining post-fire safe-shutdown. The licensee determined that this condition was caused by an inadequate review of a plant modification for Appendix R concerns. (See Chapter 7.) The modification routed a new "associated circuit" cable without verifying the adequacy of circuit breaker coordination.

Resolution Compliance with Section III.G.2 of Appendix R was achieved by implementing a plant modification to enclose the power cable in a 1-hour rated fire wrap.

Case 3 **"Hot Short" Could Result in a Loss of the Service Water System**

Problem In year 2000 the licensee of a BWR discovered that a fire-induced circuit fault resulting from fire in the CSR could lead to a loss of all service water cooling to essential shutdown systems. Although three sources of water to the service water pump seals are normally available, all three sources could be lost as a result of fire damage in the cable spreading room. The specific vulnerability involved a multi-conductor cable that carries 24 VDC start control circuits for the pump that is credited in the licensee's analysis for providing cooling water to the gland seals of the service water pumps. A conductor-to-conductor short, either between individual conductors of the multi-conductor cable, or between conductors of the multi-conductor cable and conductors of two other cables located inside the same conduit, could cause the 24 VDC start control circuits to be energized by 120 VAC power. This condition could disable the automatic starting and running of the pump relied on to provide cooling water to the service water pump gland seals. The service water pumps are required to operate during and after a fire to supply cooling water to essential shutdown equipment. The loss of the service water system would prevent the plant from achieving and maintaining safe-shutdown conditions.

Resolution The licensee has developed modifications to eliminate this vulnerability. In the interim, the licensee posted a continuous fire watch in the cable spreading room.

Case 4 **Multiple Circuit Faults Could Cause a Loss of all Makeup/Charging Capability**

Problem During a re-evaluation of its Appendix R analysis a licensee of a PWR discovered that a fire could result in damage to any of the operating charging pumps. The charging system provides makeup water to the RCS, reprocesses water letdown from the RCS, and provides seal water injection to the reactor coolant pump seals. During normal plant operations two pumps are running and the third pump is secured in standby. At least one pump must be available to support safe-shutdown. A temporary loss of charging is acceptable as long as one pump can be restored within 30 minutes with full pump capacity. However, if the running pump(s) is the only credited pump available (i.e., other pumps are unavailable because of fire-induced failures), its failure/loss as a result of fire would lead to a total loss of all charging capability.

The normal suction supply to the operating charging pumps is from the volume control tank (VCT). During its re-evaluation the licensee discovered that multiple circuit faults could cause a loss of all charging capability. Specifically, a hot short on the control cable of an MOVs located in the VCT supply line could cause the valve to shut. Although an alternative source of water is available from the refueling water storage tank (RWST), the same fire could also damage cables for the charging water supply valve and prevent that valve from opening. The spurious actuation (close) of the VCT isolation valve and a failure of the RWST valve to open would result in a loss of suction and subsequent pump damage.

Resolution The licensee identified the specific fire zones where this scenario may occur and installed modifications to correct cable routing and separation deficiencies.

Case 5 **Potential Loss of All Vital Buses As a Result of Multiple Faults In Ungrounded DC Control Circuits**

Problem The alternative shutdown strategy developed by a licensee of a PWR relied on operator manual actions to isolate 125 VDC control power to breakers of 4 kV SWGR. This was accomplished by opening the feed breaker to the bus. With the control power isolated, the licensee had assumed that the 4kV breakers could then be manually operated as needed. During a recent, 1999 reassessment of its safe-shutdown analysis, however, the licensee discovered that in the event of fire in certain alternative shutdown areas, cables associated with the 125 VDC control circuits could experience fire damage resulting in an external hot short on the positive side of the open/close coils. If this fault were to occur in combination with multiple grounds on the negative legs of the 125 VDC circuit, the closing or trip coils would become energized. Fire-induced shorting/grounding of 4 kV circuit breaker 125 VDC control circuits could result in inadvertent opening or closing of these breakers, or inability to locally position these breakers manually. This scenario could lead to a loss of all three vital buses.

Since the 125 VDC system was ungrounded, the licensee had assumed that a review of these circuits for spurious actuation was not required. At the time of its original analysis, operator manual actions to remove 125 VDC control power from the breakers was considered adequate to isolate the 4 kV breakers from the alternative shutdown areas and allow manual manipulation of the breakers. During its re-evaluation, however, the licensee recognized that this assumption was not consistent with staff guidance described in Question 5.3.1 of GL 86-10, which requires an analysis of sufficient depth to determine the adverse impacts of hot shorts, shorts to ground, or open circuits on safe shutdown related control circuits and their associated logic.

Resolution The licensee intends to implement corrective actions necessary to resolve compliance with Appendix R as part of its corrective action program.

Case 6 **Spurious Opening of Multiple Safety Relief Valves**

Problem During a reevaluation for compliance with Appendix R to 10 CFR Part 50 the licensee of a BWR determined that a control room or relay room fire could cause multiple SRVs to spuriously open resulting in rapid depressurization and inventory loss. The cables associated with the SRVs share a common cable tray, and single hot short will result in the spurious opening of each SRV. Given the potential for fire-induced failures high-volume makeup systems capable of mitigating this event [CR, RHR, low-pressure coolant injection (LPCI) and HPCI] may not be immediately available. The consequence of multiple SRV failures without the availability of a high-volume injection system could lead to core uncovery.

There are 11 DC-operated SRV, of which seven in the ADS are automatically controlled by relay logic circuits. The remaining four SRVs are manually controlled. For each valve, one of the two solenoids is operable from the control room. The other solenoid is operated from the local SRV control panel located in the reactor building. The solenoids are powered from redundant DC power sources. In the event of fire requiring control room evacuation, all eleven SRVs can be operated manually at the Local SRV control panel. However, since there was no provision for isolating the SRV solenoids from the control room, a control room or reactor building fire could induce a hot short and spuriously open these valves irrespective of the position of control switches located in the control room.

Resolution To ensure SRV operation in the event of a control room fire the licensee implemented plant modification to install a dedicated isolation switch for each of the eleven SRVs in a new auxiliary shutdown panel located outside the control room. In addition, the licensee modified the circuitry of the seven ADS valves and the four manual SRVs to provide additional isolation capability in the event of a reactor building or control room fire.

APPENDIX B.
SPECIFIC CIRCUIT ANALYSIS ISSUES

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This appendix discussed certain circuit analysis issues that specific have been the subject of much confusion and debate and include: multiple spurious actuations, fire damage to nonessential systems, and multiple circuit faults. The discussion is provided in terms of "real world"examples of technical issues that were identified during the review of safe-shutdown analyses developed by various licensees.

B.1 Multiple Spurious Actuations

In Question 5.3.10 of GL 86-10, the staff provides a response to a question posed by industry regarding the type of plant transients that should be considered in the *design of the alternative or dedicated shutdown systems*. In its response the staff states, in part: *"the safe shutdown capability should not be adversely affected by any one spurious actuation or signal resulting from a fire in any plant area."*

The intent of the guidance contained in the staff's response is to ensure that the *design* of the alternative or dedicated shutdown capability is sufficiently robust to be capable of mitigating the occurrence of one worst-case spurious actuation prior to isolation of potentially affected circuits from the fire-affected area. In certain instances, however, the staff's response has been mis-interpreted to mean that only a single spurious actuation need be considered for any fire area, without any further consideration of the number, type, function, or specific location of potentially affected circuits and cables. This misunderstanding appears to have been further complicated by the fact that this approach (i.e., assumption of a single spurious actuation per fire event) has been accepted in several NRC safety evaluations of plant-specific post-fire safe-shutdown methodologies. While the fire protection licensing basis for these facilities would only require consideration of a single spurious actuation, it should be noted that certain licensees recognize that the application of this assumption could result in a shutdown strategy that is inconsistent with the fundamental objective of ensuring that one train of systems needed to achieve and maintain hot-shutdown conditions remains free of fire damage. For example, although the "single spurious actuation per fire event" assumption was accepted by the staff in a safety evaluation of a BWR, an NRC inspection of this facility did not identify any cases where the potential for fire to cause multiple spurious actuations had not been sufficiently evaluated. Specific cases of how this "single spurious actuation per fire event" assumption can impact the shutdown capability are illustrated by the following examples:

- At one PWR cooling water flow to the EDG may be provided by one of two parallel flowpaths. Since a "normally open" MOV is located in each flowpath, at least one of these valves must remain open to ensure an adequate supply of cooling water is supplied to the EDG. Based on its interpretation of Question 5.3.10 of GL 86-10, however, the licensee had not considered the potential for both valves to spuriously change position as a result of fire damage. In lieu of identifying the routing of cabling associated with both valves by fire area and evaluating for the potential effects of fire damage to these circuits/cables within each fire area, the licensee had dispositioned this potential vulnerability on the assumption (per its interpretation of GL 86-10 Question 5.3.10) that only one spurious actuation would occur per fire event. As a result of its interpretation, the potential for fire to cause both valves to inadvertently change position as a result of fire damage was not considered in the analysis.

- As described in Chapter 6, the SSEL identifies equipment that is needed to ensure the successful accomplishment of essential shutdown functions. Based on its assumption that only one spurious actuation would occur per fire event, the shutdown methodology developed by a licensee of a 4-loop Westinghouse PWR relied on operator intervention to mitigate this “one” actuation should it occur. Since no action is taken before fire damage occurs, the successful implementation of this approach is largely predicated on the operators’ ability to detect the spurious actuation and perform manual actions in a timely manner to defeat its effect on safe-shutdown capability. Based on this approach, the SSEL did not include any automatically actuated flow-path valves MOVs or air-operated valves (AOVs)] that were in their desired position for post-fire safe-shutdown during normal plant operations (e.g., a normally open MOV in the flowpath of a required shutdown system). Since the SSEL serves as a starting point for identifying circuits and cables that could impact the shutdown capability if they are damaged by fire, the routing of cables associated with these components was not considered. As a result, the potential for fire to cause more than one automatically actuated valve to spuriously change position in an undesired manner for post-fire safe-shutdown had not been evaluated for each fire area.
- A review of the SSA submitted by the licensee of a BWR identified examples where redundant components may be subject to spurious actuations (i.e., undesirable change of position or operating state) as a result of a single hot short on each of their respective control circuits. Although the control circuits of the redundant MOVs were subject to damage by a single fire, in its evaluation of this issue, the licensee stated: “*For both valves to open simultaneously, a hot short on each valve is required. NRC GL 86-10 does not require the assumption of multiple hot shorts for non-high/low-pressure interfaces. Therefore, one of these two valves is assumed to remain closed."* In subsequent meetings and correspondence, the staff informed the licensee of its concern that the application of this assumption may result in an inability to adequately demonstrate compliance with Sections III.G.2 and III.L of Appendix R to 10 CFR Part 50. In a subsequent response, the licensee submitted revised criteria it had developed and employed for the analysis of potential spurious operations. Under its revised methodology, all circuits which could cause undesirable spurious operations were identified and evaluated for potential fire damage. With the exception of components which comprise a high/low pressure interface boundary the licensee's evaluation considered any and all spurious operations that may occur as a result of a single fire, on a one-at-a-time basis (i.e., sequential, nonconcurrent). That is, for each fire area all potential spurious operations that may occur as a result of a postulated fire were identified, and corrective actions were implemented as needed on a one-at-a-time basis. Fire-initiated faults were assumed to exist until action was taken to negate their effects. The fire was not postulated to eventually clear the faults. For redundant components which form a high/low pressure interface boundary, the evaluation considered the potential for concurrent, simultaneous, spurious operations. When cables or equipment of which spurious operation could affect safe-shutdown were identified, they were included as required cables in the licensee’s Appendix R separation analysis.
- The licensee of a BWR used the single spurious actuation per fire event assumption as a basis for not providing fire protection features for redundant trains of shutdown equipment. In this case, although redundant suction valves of the RCIC system were identified as being required to achieve and maintain hot shutdown conditions and their cables were located in close proximity [<4.56 m (<15 ft)], the licensee did not consider the separation requirements of Section III.G.2 to be applicable on the basis that both valves must fail (spuriously actuate to the closed position) in order to cause a total loss of makeup capability.

Section III.G of Appendix R to 10 CFR Part 50 requires, in part, that circuits and cables that could prevent operation or cause maloperation of SSCs important to safe-shutdown be provided with a level of fire protection necessary to ensure that such circuits will remain free of fire damage. Consistent with the deterministic approach described in Chapter 6, circuits and cables which lack a suitable level of fire protection (as delineated in Section III.G.2 of Appendix R) must be assumed damaged by their exposure to fire and this damage should be expected to cause one or a combination of circuit faults to occur between conductors of each cable or circuit that may be affected by the fire. Accordingly, if, because of a lack of fire protection features, there is a potential for multiple cables or circuits to be faulted, it follows that faults between the conductors of the affected cables or circuits may lead to the occurrence of one or more (i.e., multiple) spurious actuations. In a letter to the NEI dated March 11, 1997, the staff reiterated the deterministic approach where the number of spurious signals or changes in operational configuration that may be expected to occur as a result of fire damage to unprotected cables or circuits cannot be predicted.

As described in Chapter 6 and Appendix A to this document, licensees have historically identified equipment (safety-related and nonsafety-related) of which spurious operation could impact the safe shutdown capability described in the plant-specific SSA. If it can be demonstrated that the occurrence of all credible circuit failure modes (hot shorts, open circuits and shorts to ground), will not cause the connected equipment to spuriously actuate or malfunction in a manner that would adversely impact the post-fire safe-shutdown capability, no further analysis is necessary and the component may be screened from further evaluation. For example, a review of plant P&IDs may indicate that the spurious actuation (opening) of two, series connected, MOVs has the potential to impact the shutdown capability by creating an undesired diversion (i.e., loss) of process coolant flow. If it can be shown that this failure mode (both valves open) would not impact the shutdown capability (e.g., if the amount of flow lost was small compared to the makeup capability of the system) the components (MOVs) can be screened from further consideration. However, if this initial evaluation determines that spurious actuation of the components (opening of both MOVs) could impact the shutdown capability (flow loss in excess of makeup capability), a detailed circuit analysis that considers the impact fire damage to connected circuits and cables is necessary.

As discussed in Chapter 6, with the exception of components that comprise a high/low pressure interface boundary, the evaluation should consider any and all spurious operations that may occur as a result of a single fire, on a one-at-a-time basis. That is, for each fire area, all potential spurious operations that may impact the shutdown capability should be identified. While it is not assumed that all such spurious actuations will occur instantaneously at the onset of fire, the analyst must consider the possibility for each spurious actuation to occur in a sequential manner, as the fire progresses, on a one-at-a-time basis. Since it is not assumed that the fire will clear the fault(s) that caused the undesired actuation (Reference GL 86-10, response to Question 5.3.2), the potential for sequentially occurring failures to result in the concurrent failure of two or more components (such as the MOVs described above) must be considered. Accordingly, if control cables of two components (e.g., normally-closed MOVs) are subject to damage, the potential for both valves to spuriously actuate (open) as a result of fire damage cannot be ignored. Since the control cable of neither valve is ensured to remain free of fire damage, it is considered credible that both valves could spuriously open sequentially during a fire event. It is expected that such conditions would be identified where they may exist and appropriate preventive or mitigating actions implemented.

Although they do not satisfy the certain technical requirements of Appendix R, the use of operator manual actions to mitigate this event may provide an acceptable resolution (see Appendix A). For example, the licensee's evaluation of a control room fire at one BWR found circuits of three valves to be susceptible to fire damage. Since the spurious opening of all three valves would result in a drain down of the suppression pool, the potential for all three valves to spuriously actuate could not be ignored. To mitigate this event, the licensee implemented procedural changes which require one of the valves to be ensured closed by operator manual actions.

B.2 Fire Damage to Nonessential Systems

Fire damage to systems that are not needed to perform essential shutdown functions (i.e., nonessential or nonsafety systems) can have a significant impact on shutdown capability, as illustrated by the following examples:

- Inadvertent initiation of the HPCI system: The analysis performed by one BWR revealed that inadvertent initiation of the HPCI system and concurrent loss of the 137.16-cm (54-in.) high-water trip for HPCI as a result of a control room fire could, in a short time period (approximately 3 minutes), cause a vessel overfill condition to the point where HPCI would be disabled and the main steam lines would be filled with high pressure water.
- Inadvertent feedwater initiation: Certain BWRs employ steam-driven feedwater pumps in their design. Since these pumps are not electrically powered they will continue to provide flow during feedwater system coast down as long as sufficient steam is available. The concern with this configuration is that a fire-induced spurious signal on the feedwater pump control circuit (typically located in the control room) could cause a false demand for the steam-driven pumps to inject coolant at maximum capacity. If this were to occur, operators would have a very short time frame to implement mitigating actions, such as closing the MSIVs, closing of the feedwater discharge valves, and tripping the feedwater turbine from outside the MCR.
- The normal charging line to the RCS was not credited for post-fire safe-shutdown by the licensee of a PWR. This flowpath, which branches off the credited RCP seal injection flowpath, includes four normally open valves before entering the regenerative heat exchanger. The pressurizer auxiliary spray valve (PASV), which is located downstream of the regenerative heat exchanger, is a normally closed MOV. Since the normal charging flowpath was not credited for safe-shutdown, none of the valves in its flowpath were included in the SSEL. As a result, none of the cables associated with these valves were fully evaluated for the effects of fire damage. While not needed to perform an essential shutdown function, the spurious opening of PASV as a result of fire-induced faults in its control circuitry could have a significant impact on the shutdown capability by causing a collapse of the steam bubble in the pressurizer and rapid depressurization of the RCS.
- The shutdown strategies developed by most PWRs do not credit the use of pressurizer heaters. While not needed for safe-shutdown, fire damage that causes the heaters to inadvertently actuate (load) at a time when power is being supplied from the onsite source of electrical power (e.g., EDG) could significantly impact safe-shutdown capability if the EDG was not capable of supplying this additional load (EDG overload).

As discussed in Chapter 6 and Appendix A, the achievement of safe-shutdown is dependent on ensuring the active control of some components and preventing the maloperation of other components. A post-fire safe-shutdown analysis should be a bounding analysis that identifies the range of possible fire impacts within each fire area (vulnerabilities) and ensures that appropriate measures are in place to prevent this damage from affecting the ability to safely shutdown the plant. Therefore, it is not sufficient to only consider the effects of fire damage to cables of equipment needed to ensure operation of credited shutdown systems. The scope of successful shutdown strategies also includes consideration of the effects of fire damage to nonessential equipment and systems of which inadvertent or spurious actuation could impact the shutdown capability.

B.3 Multiple Circuit Faults

In GL 81-12 and GL-86-10, the NRC established that either physical protection from fire (per Section III.G.2 of Appendix R), or detailed electrical circuit analyses may be used to demonstrate that fire will not cause equipment to mal-operate in a manner that could adversely affect the post-fire safe-shutdown capability of the plant. While either approach is acceptable, the use of analytical techniques places greater importance on the assumptions, criteria, and review methodology which form the basis of the analysis. Also in GL 86-10, the NRC staff defined the circuit failures to be considered. Specifically, in Question 5.3.1 the staff provided the following guidance:

> *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 (emphasis added). Therefore, valves could fail open or closed; pumps could fail running or not running; electrical distribution breakers could fail open or closed…*

In accordance with this guidance, when performing a circuit failure analysis, one or more circuit failure modes (e.g., multiple hot shorts, a hot short combined with a ground or open circuit etc.) must be considered. When considering the effects of fire damage to a multi-conductor cable, the potential for fire to cause multiple hot shorts between individual conductors must be considered. The failure to fully evaluate the potential for fire to cause more than a single fault in each circuit/cable under consideration may have potentially significant consequences on the plant's shutdown capability.

For example, the circuit analysis performed by a licensee of a BWR was found to arbitrarily limit the number of failure modes to one hot short, or one short to ground, or one open circuit on an individual device or component basis. As a result of this approach, the potential for fire to cause electrical contact between individual conductors of two twisted-pairs of conductors located within a single multiconductor cable was not considered credible by the licensee. In this case, an instrument cable contained two pairs of twisted conductors. If fire were to cause the individual conductors of the twisted pairs to short together (i.e., a short between conductors of twisted pair No. 1 and a short between conductors of twisted pair No. 2) two false high RCS pressure signals would be generated. The two high pressure signals would cause all 16 SRVs to fully open to rapidly de-pressurize the reactor. In addition, the fault current associated with these two circuit failures would not be large enough to open the protective fuse. Fire test data provided by the cable vendor showed that the wires could short in about 3 minutes when exposed to a test fire.

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NRC FORM 335 (2-89) NRCM 1102, 3201, 3202

U.S. NUCLEAR REGULATORY COMMISSION

BIBLIOGRAPHIC DATA SHEET

(See instructions on the reverse)

1. REPORT NUMBER (Assigned by NRC, Add Vol., Supp., Rev., and Addendum Numbers, if any.)

NUREG-1778

2. TITLE AND SUBTITLE

Knowledge Base for Post-Fire Safe-Shutdown Analysis

Draft Report for Comment

3. DATE REPORT PUBLISHED

MONTH	YEAR
January	2004

4. FIN OR GRANT NUMBER

5. AUTHOR(S)

M.H. Salley

6. TYPE OF REPORT

Technical

7. PERIOD COVERED *(Inclusive Dates)*

8. PERFORMING ORGANIZATION - NAME AND ADDRESS *(If NRC, provide Division, Office or Region, U.S. Nuclear Regulatory Commission, and mailing address; if contractor, provide name and mailing address.)*

Division of Systems Safety and Analysis
Office of Nuclear Reactor Regulation
U.S. Nuclear Regulatory Commission
Washington, DC 20555-0001

9. SPONSORING ORGANIZATION - NAME AND ADDRESS *(If NRC, type "Same as above"; if contractor, provide NRC Division, Office or Region, U.S. Nuclear Regulatory Commission, and mailing address.)*

Same as above

10. SUPPLEMENTARY NOTES

S.D. Weerakkody, NRC Project Manager

11. ABSTRACT *(200 words or less)*

Every operating nuclear power plant is required to have a program that demonstrates the capability to safely shut down and maintain the reactor in the event of a fire. The U.S. Nuclear Regulatory Commission (NRC) initially issued its requirements in the Fire Protection Rule set forth in Title 10, Section 50.48, of the Code of Federal Regulations (10 CFR 50.48) and Appendix R to 10 CFR Part 50. The NRC has since issued numerous related generic communications over the past 20 years. The purpose of this document is to facilitate understanding of this technically challenging process and the regulatory framework upon which it is based by compiling all essential information in a single source. This document also lays the groundwork for future risk-informed activities in the post-fire safe-shutdown area.

12. KEY WORDS/DESCRIPTORS *(List words or phrases that will assist researchers in locating the report.)*

Circuit analysis
Post-fire safe-shutdown
Appendix R
Risk-informed approach

13. AVAILABILITY STATEMENT

unlimited

14. SECURITY CLASSIFICATION

(This Page)

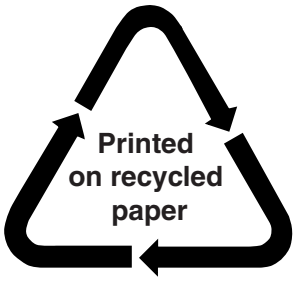
unclassified

(This Report)

unclassified

15. NUMBER OF PAGES

16. PRICE



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