NUREG-1778

Knowledge Base for Post-Fire Safe-Shutdown Analysis

Draft Report for Comment

U.S. Nuclear Regulatory Commission
Office of Nuclear Reactor Regulation
Washington, DC 20555-0001

AVAILABILITY OF REFERENCE MATERIALS IN NRC PUBLICATIONS

NRC Reference Material

As of November 1999, you may electronically access NUREG-series publications and other NRC records at NRC's Public Electronic Reading Room at http://www.nrc.gov/reading-rm.html. Publicly released records include, to name a few, NUREG-series publications; *Federal Register* notices; applicant, licensee, and vendor documents and correspondence; NRC correspondence and internal memoranda; bulletins and information notices; inspection and investigative reports; licensee event reports; and Commission papers and their attachments.

NRC publications in the NUREG series, NRC regulations, and *Title 10, Energy*, in the Code of *Federal Regulations* may also be purchased from one of these two sources.

1. The Superintendent of Documents
   U.S. Government Printing Office
   Mail Stop SSOP
   Washington, DC 20402–0001
   Internet: bookstore.gpo.gov
   Telephone: 202-512-1800
   Fax: 202-512-2250
2. The National Technical Information Service
   Springfield, VA 22161–0002
   www.ntis.gov
   1–800–553–6847 or, locally, 703–605–6000

A single copy of each NRC draft report for comment is available free, to the extent of supply, upon written request as follows:

Address: Office of the Chief Information Officer,
Reproduction and Distribution
Services Section
U.S. Nuclear Regulatory Commission
Washington, DC 20555-0001
E-mail: DISTRIBUTION@nrc.gov
Facsimile: 301–415–2289

Some publications in the NUREG series that are posted at NRC's Web site address http://www.nrc.gov/reading-rm/doc-collections/nuregs are updated periodically and may differ from the last printed version. Although references to material found on a Web site bear the date the material was accessed, the material available on the date cited may subsequently be removed from the site.

Non-NRC Reference Material

Documents available from public and special technical libraries include all open literature items, such as books, journal articles, and transactions, *Federal Register* notices, Federal and State legislation, and congressional reports. Such documents as theses, dissertations, foreign reports and translations, and non-NRC conference proceedings may be purchased from their sponsoring organization.

Copies of industry codes and standards used in a substantive manner in the NRC regulatory process are maintained at—

The NRC Technical Library
Two White Flint North
11545 Rockville Pike
Rockville, MD 20852–2738

These standards are available in the library for reference use by the public. Codes and standards are usually copyrighted and may be purchased from the originating organization or, if they are American National Standards, from—

American National Standards Institute
11 West 42nd Street
New York, NY 10036–8002
www.ansi.org
212–642–4900

Legally binding regulatory requirements are stated only in laws; NRC regulations; licenses, including technical specifications; or orders, not in NUREG-series publications. The views expressed in contractor-prepared publications in this series are not necessarily those of the NRC.

The NUREG series comprises (1) technical and administrative reports and books prepared by the staff (NUREG–XXXX) or agency contractors (NUREG/CR–XXXX), (2) proceedings of conferences (NUREG/CP–XXXX), (3) reports resulting from international agreements (NUREG/IA–XXXX), (4) brochures (NUREG/BR–XXXX), and (5) compilations of legal decisions and orders of the Commission and Atomic and Safety Licensing Boards and of Directors' decisions under Section 2.206 of NRC's regulations (NUREG–0750).

NUREG-1778

Knowledge Base for Post-Fire Safe-Shutdown Analysis

Draft Report for Comment

Manuscript Completed: November 2003
Date Published: January 2004

Prepared by:
M.H. Salley

S.D. Weerakkody, NRC Project Manager

Prepared for:
Division of Systems Safety and Analysis
Office of Nuclear Reactor Regulation
U.S. Nuclear Regulatory Commission
Washington, DC 20555-0001

COMMENTS ON DRAFT REPORT

Any interested party may submit comments on this report for consideration by the NRC staff. Comments may be accompanied by additional relevant information or supporting data. Please specify the report number (**Draft NUREG-1778**), in your comments, and send them — by the end of the 60-day comment period specified in the *Federal Register* notice announcing availability of this draft — to the following address:

Chief, Rules Review and Directives Branch
Mail Stop: T6-D59
U.S. Nuclear Regulatory Commission
Washington, DC 20555-0001

You may also submit comments electronically using the NRC's Web site:

http://www.nrc.gov/public-involve/doc-comment/form.html

For any questions about the material in this report, please contact:

Mark H. Salley
Mail Stop: O-11A11
U.S. Nuclear Regulatory Commission
Washington, DC 20555-0001
Phone: (301) 415-2840
Email: MXS3@nrc.gov

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.

This page intentionally left blank.

CONTENTS

CONTENTS (continued)

CONTENTS (continued)

Appendices

Figures

Tables

THE AUTHOR

Mark Henry Salley is a Fire Protection Engineer in the Office of Nuclear Reactor Regulation (NRR) of the U.S. Nuclear Regulatory Commission (NRC). Mr. Salley holds Master and Bachelor of Science degrees in fire protection engineering, both from the University of Maryland at College Park. He is a registered professional engineer in fire protection engineering and a member of the National Fire Protection Association (NFPA), American Nuclear Society (ANS), and Society of Fire Protection Engineers (SFPE).

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.

This page intentionally left blank.

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.

This page intentionally left blank.

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).

This page intentionally left blank.

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

This page intentionally left blank.

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).

---

[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.

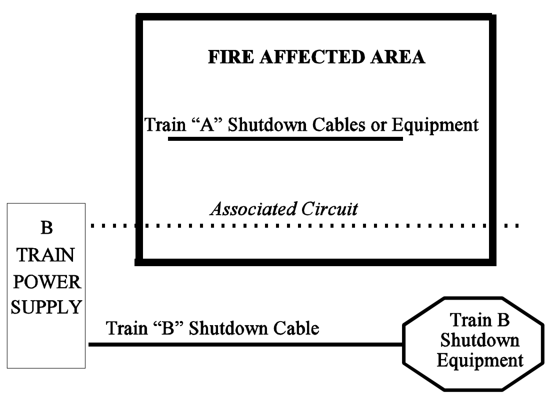
Appendix R Cables
The set of cables that must remain free of fire damage to ensure that safe-shutdown conditions can be achieved within established criteria. [Synonym: required cables.]

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.

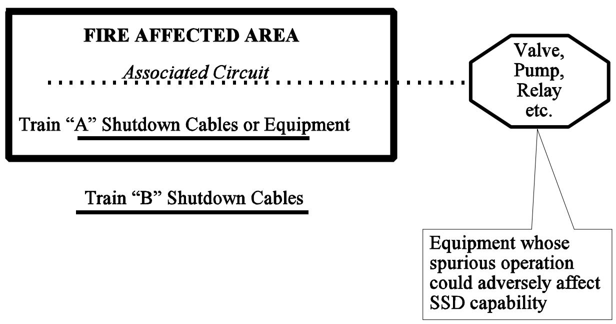


Associated Circuit Concern - Common Power Source

---

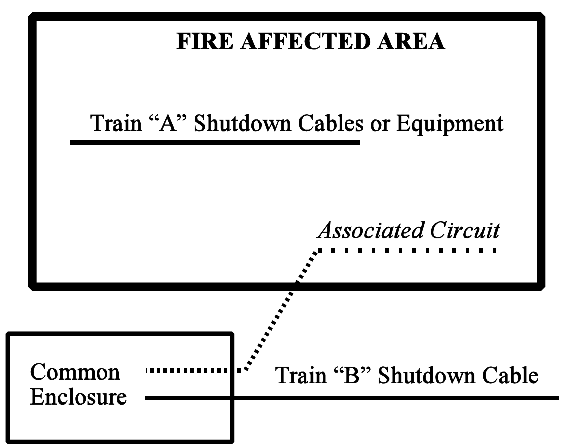
[3] High/low-pressure interfaces are considered a special case to their severe consequence. (GL 86-10, Question 5.3.1)

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.

This page intentionally left blank.

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.

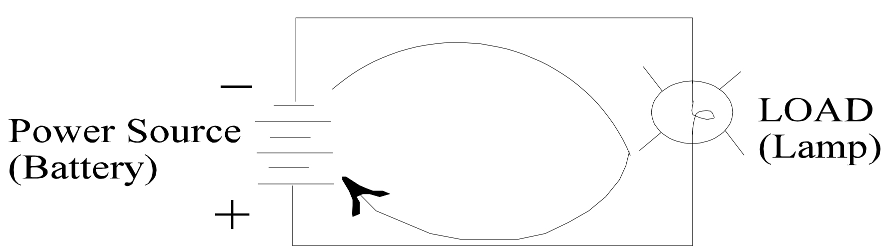
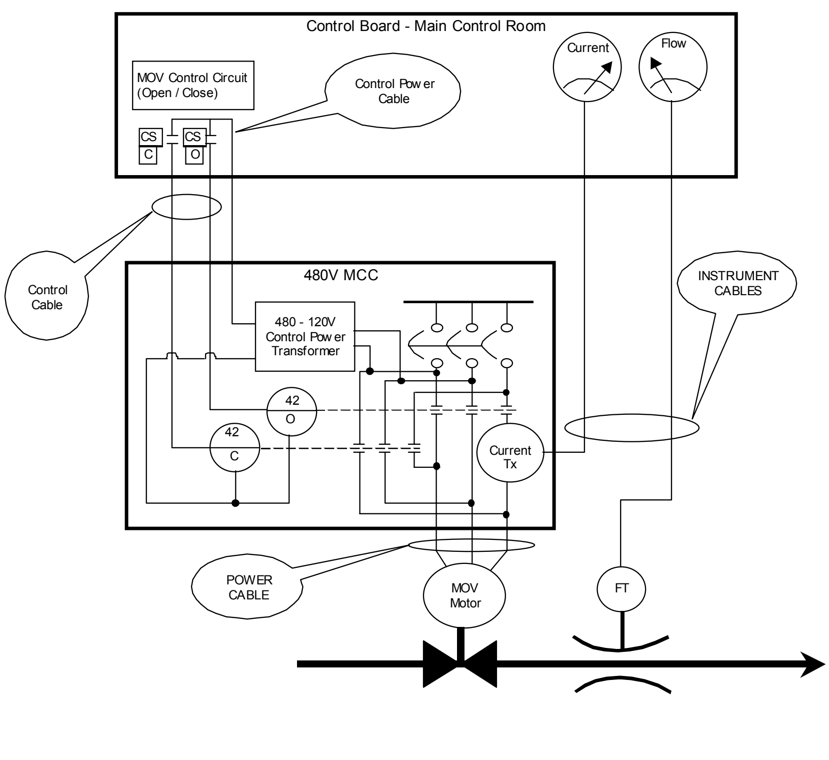


Figure 3-1 Circuit Illustration

[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.

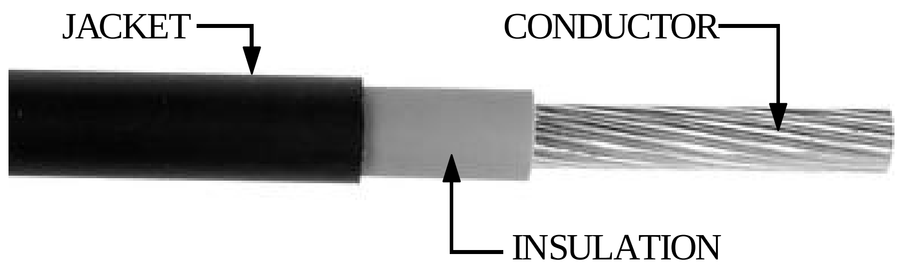


Figure 3-3 Cable Components

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.

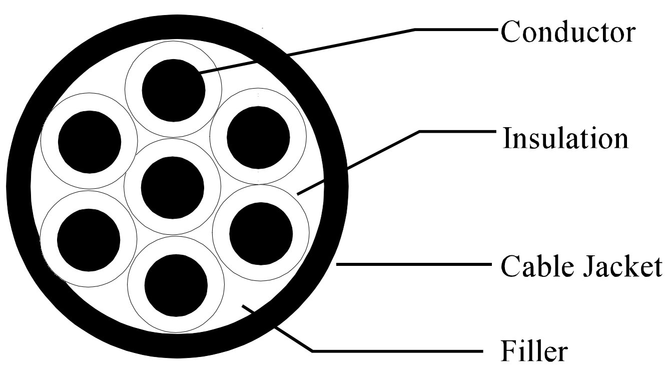


Figure 3-4 Multi-Conductor Cable (7-Conductor)

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 (≤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.

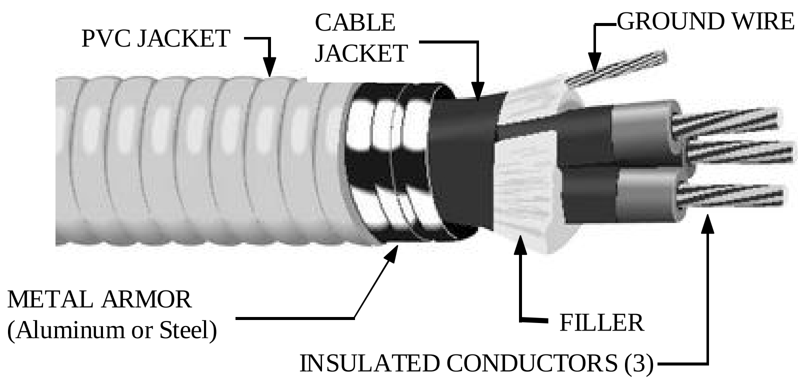


Figure 3-5 Armored Cable

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.

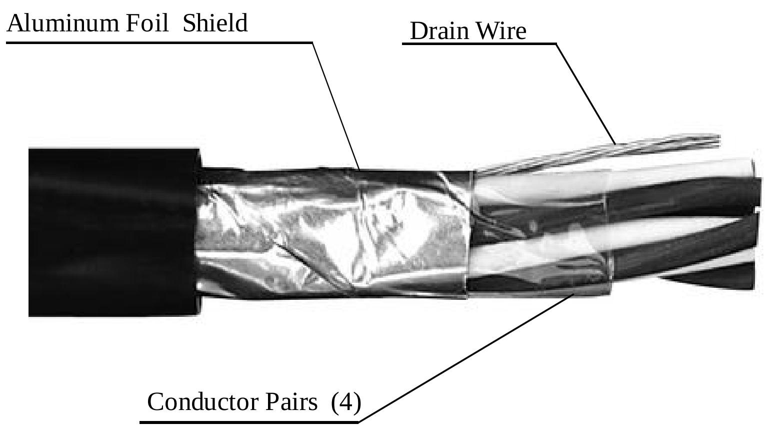


Figure 3-6 Illustration of Instrument Cable

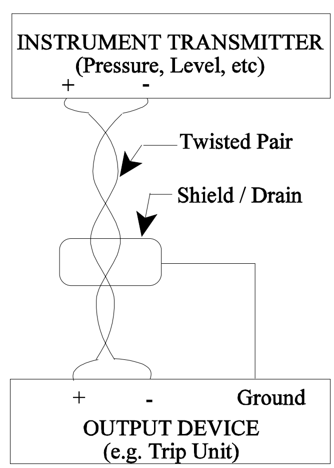


Figure 3-7 Twisted/Shielded Pair

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 x 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.

---

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.

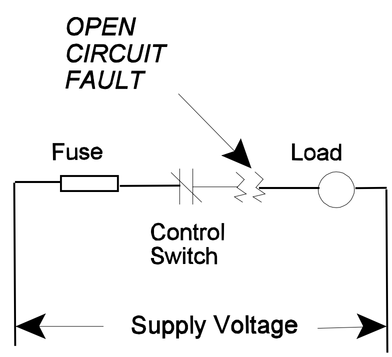


Figure 3-8 Open Circuit Fault

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

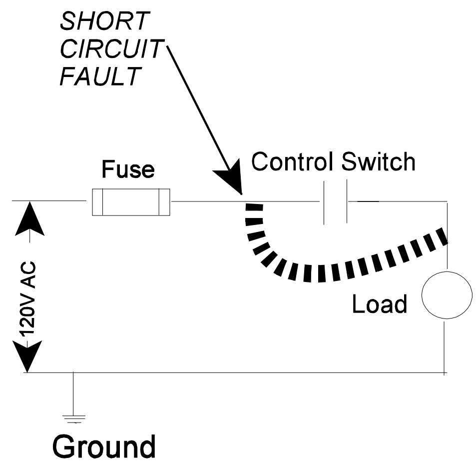


Figure 3-9 Short Circuit Fault

- *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.

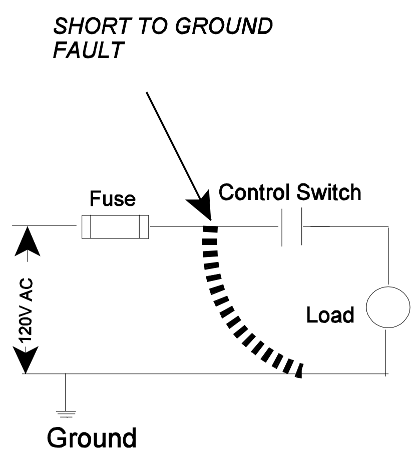


Figure 3-10 Short-to-Ground Fault

- *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.

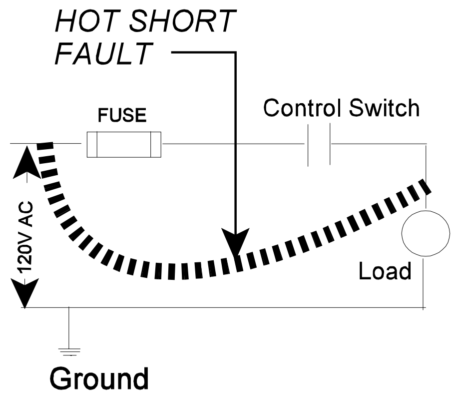


Figure 3-11 Hot Short Fault

- *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.

---

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.”*

This page intentionally left blank.

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.

---

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.

---

[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.

[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

---

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.I 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]

---

[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.

---

[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.*

---

[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.

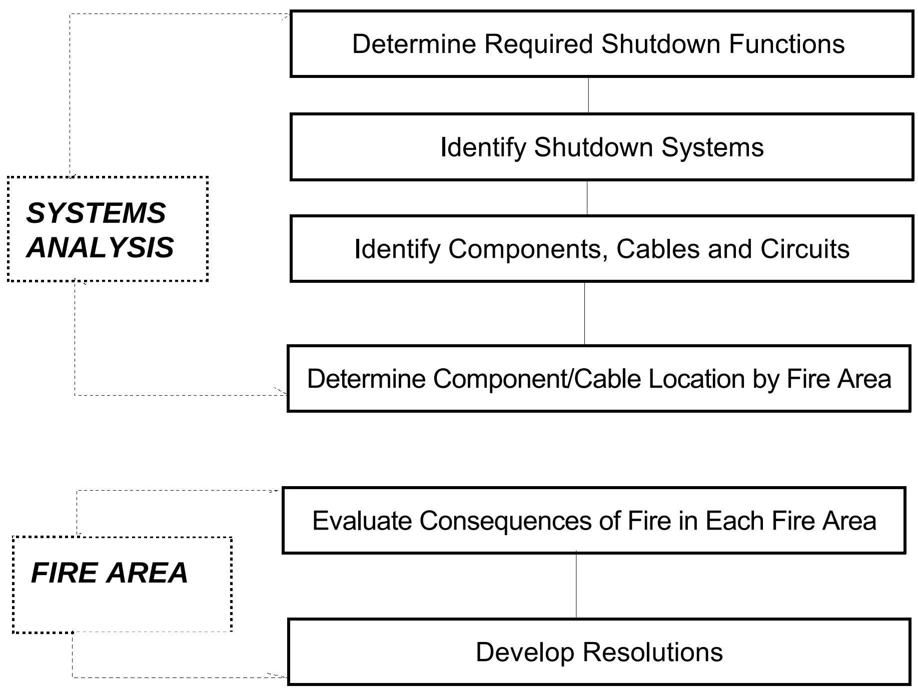


Figure 5-1 Overview of the Safe-Shutdown Evaluation Process

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.

---

[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.