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Final Report

Joint Assessment of Cable Damage and Quantification of Effects from Fire (JACQUE-FIRE)

Volume 3:

Technical Resolution to Open Issues On Nuclear Power Plant Fire-Induced Circuit Failure

U.S. Nuclear Regulatory Commission
Office of Nuclear Regulatory Research
Washington, D.C. 20555-0001

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ABSTRACT

This report builds upon two previous reports, titled Joint Assessment of Cable Damage and Quantification of Effects from Fire (JACQUE-FIRE), Volume 1 and Volume 2. This work aims at providing a better understanding of failure modes in electrical control circuits that might occur in nuclear power plants as a result of fire damage to electric cables. This research was conducted by the United States Nuclear Regulatory Commission (NRC) and the Electric Power Research Institute (EPRI) under a Memorandum of Understanding using a balanced team of experts from the regulator and the industry. The objectives of this report are to present technical recommendations on a number of circuit analysis issues and to update or clarify positions developed in earlier research. The recommendations for resolution of these issues in a technical setting are intended to facilitate development of a solid technical foundation and a stable framework to support a consistent approach for conducting and reviewing post-fire safe-shutdown analyses.

This working group was convened to address several remaining circuit analysis issues related to deterministic post-fire safe-shutdown analysis. The working group findings are presented as clarifications and recommendations. Clarifications are presented on circuit failure modes and terminology. Recommendations are provided on: design considerations for shorting switches, hot short-induced multiple spurious operations in DC and AC control circuits, and secondary fire risk due to fire-induced open-circuited current transformers. Risk-insights, developed from the PRA expert panel (JACQUE-FIRE Volume 2), have been used to revise earlier PIRT panel findings from JACQUE-FIRE Volume 1.

CONTENTS

LIST OF FIGURES

LIST OF TABLES

EXECUTIVE SUMMARY

PRIMARY AUDIENCE: Fire protection and safe-shutdown engineers conducting or reviewing deterministic post-fire safe-shutdown analysis items related to fire-induced circuit failures and hot short spurious operations.

SECONDARY AUDIENCE: Engineers, reviewers, utility managers, and other stakeholders who conduct, review, or manage deterministic post-fire safe-shutdown analyses and need to understand the underlying technical basis for specific circuit failure criteria.

KEY RESEARCH QUESTION

How can users apply the insights from cable fire testing, operating experience, and expert judgment to perform, update, and review deterministic post-fire safe-shutdown analyses?

RESEARCH OVERVIEW

This report (JACQUE-FIRE, Volume 3) builds upon two prior reports aimed at better understanding failure modes that might occur in electrical control circuits of nuclear power plants as a result of fire damage to electric cables. The two earlier reports are: Joint Assessment of Cable Damage and Quantification of Effects from Fire (JACQUE-FIRE), Volume 1 and Volume 2. JACQUE-FIRE, Volume 1 describes a phenomena identification and ranking table (PIRT) exercise that was performed to systematically rank possible fire-induced circuit failure modes and their influence factors. A particularly important failure mode is hot short-induced spurious equipment operation. Findings from cable fire tests, operating experience, and expert judgment were used to identify and rank circuit configurations vulnerable to such hot short-induced spurious operations. The PIRT findings were provided to a follow-on panel of PRA experts that used a structured expert elicitation process to develop estimates for conditional probabilities of occurrence and duration of hot short-induced spurious operations-given fire damage. The conclusions from the expert elicitation of the PRA Panel are documented in JACQUE-FIRE, Volume 2. Together, these three reports provide information and technical recommendations to support both deterministic and probabilistic post-fire analyses.

Efforts over the last few years have improved the clarity of criteria and guidance for use in fire probabilistic risk assessment. However, discussions between the regulator and utility representatives concluded that interpretations of deterministic fire guidance differed and needed updating and clarification. In an effort to resolve these differences, a balanced group of technical experts was assembled to develop a common understanding of the issues and to provide recommendations for resolution.

The objectives of this report are to: (1) present technical recommendations on a number of open issues related to fire-induced circuit analysis, and (2) revise and clarify certain previous positions in JACQUE-FIRE, Volume 1 (Ref. 1). This report documents the technical consensus on several open issues related to deterministic post-fire safe-shutdown analyses reached by a balanced team of experts sponsored through EPRI and the U.S. NRC. The recommendations for resolution of these issues in a technical setting are intended to facilitate development of a solid technical foundation and a stable framework to support a consistent approach for conducting and reviewing post-fire safe-shutdown analyses.

KEY FINDINGS

This research yields progress in resolving long-standing issues related to evaluation of multiple spurious operations and deterministic post-fire safe-shutdown analysis. The results from this research support a more consistent application of the following topics including:

- Clarification of circuit failure modes and terminology (Section 2) including;
  - Proper polarity
  - Latching versus non-latching
  - High impact components
  - Failure mode classifications
  - Ground fault equivalent hot short
- Recommendations for revision to several PIRT Panel positions/findings using the risk-insights developed from the PRA expert panel of JACQUE-FIRE, Volume 2. (Section 3)
- Technical design considerations for shorting switch applications (Section 4.2) including:
  - Circuit design
  - Electrical design
  - Circuit continuity
- Recommendations for evaluation of specific combinations of hot short-induced multiple spurious operations (Section 5.2):
  - Number of hot shorts for transient inrush considerations
  - Number of inter-cable hot shorts regardless of latching characteristics or coping time
  - Number of non-latching hot shorts with 10-minute coping time regardless of circuit failure mode
  - Sequentially selected fire-induced circuit failures
- Recommendations for the duration of hot short-induced spurious operations in DC and AC control circuits for deterministic post-fire safe-shutdown analysis (Section 6.5):
  - 20-minute duration for AC control circuits
  - 40-minute duration for DC control circuits
- Disposition of secondary fires due to a fire-induced open circuited current transformer (Section 7)
  - Secondary fires resulting from open circuited CTs are considered incredible for low and medium voltage applications. No further consideration of secondary fires as a result of CT secondary circuit failures is recommended for low and medium voltage switchgear (up to and including 15 kV).

Findings from this effort revised certain conclusions from Section 3 of NUREG/CR-7150 Volume 1 / EPRI 1026424. These changes are summarized below and explained in more detail in Section 3.2.

- Consideration of insulation type for the aggressor cable conductor is eliminated. This was eliminated due to the impracticality of tracking the conductor insulation for aggressor cables. As a result, the reported classifications are a function of the conductor insulation of the target conductor.

- Classification of inter-cable hot shorts for thermoset insulated conductors from "implausible" to "plausible" based on the PRA expert panel probabilities that did not support a classification of "implausible."
- Grouped single break ungrounded AC (from common CPT or distributed) with DC due to similarities in circuit failure type classification. Failure modes for single and double break control circuits are reported in Table 3-1 and 3-2, respectively.
- Classified inter-cable hot shorts for double break design circuit with TP insulated conductors as "implausible" for latching and "incredible" for non-latching circuits. This classification was deferred until the PRA Expert Panel completed their estimation.

WHY THIS MATTERS

This report provides technical recommendations to assist U.S. NRC staff and nuclear power plant engineers performing and reviewing deterministic post-fire safe-shutdown analyses. The balanced working group has developed a consensus on technical recommendations for consistent treatment of difficult and unresolved circuit analysis issues.

HOW TO APPLY RESULTS

Engineers performing and reviewing deterministic post-fire safe-shutdown analyses should focus on Sections 2 through 7 of this report. Users of this report are encouraged to also consult JACQUE-FIRE, Volume 1, which documents the results of the PIRT exercise, and JACQUE-FIRE, Volume 2, which provides conditional probabilities of occurrence and duration of hot short-induced spurious operations of control circuits—given fire damage.

LEARNING AND ENGAGEMENT OPPORTUNITIES

Users of this report may be interested in the annual fire PRA training, Module II – Electrical Analysis, sponsored jointly between EPRI and the US NRC-RES.

PREFACE

This report supplements previous work related to the effects of fire on cable failure modes and circuit response.

In 2002, EPRI published EPRI 1003326, *Characterization of Fire-Induced Circuit Faults: Results of Cable Fire Testing.* This report documented the results of a comprehensive research and test effort undertaken jointly by EPRI and the Nuclear Energy Institute to investigate, characterize, and quantify fire-induced circuit failures. This testing series also included monitoring cable electrical performance with a patented system developed and fielded by Sandia National Laboratories. The results of this work are presented in NUREG/CR-6776, *Cable Insulation Resistance Measurements Made During Cable Fire Tests,* June 2002.

In 2003, NRC published NUREG/CR-6834, *Circuit Analysis – Failure Mode and Likelihood Analysis*, to address weaknesses in existing fire PRA circuit analysis methods. This report reviewed the existing data available on fire-induced cable failure and characterized the state of knowledge by conducting a formal failure modes and effects analysis.

In 2008, the NRC published NUREG/CR-6931, Volumes 1-3, *Cable Response to Live Fire (CAROLFIRE)*, documenting the results of fire-induced failure cable test results to support resolution of Regulatory Issue Summary 2004-03, *Risk-Informed Approach for Post-Fire Safe-Shutdown Circuit Inspections*, and to provide improvements to fire modeling in the area of cable response to fires.

In 2012, the NRC published NUREG/CR-7100, *Direct Current Electrical Shorting in Response to Exposure Fire (DESIREE-Fire): Test results*, documenting the results of fire-induced circuit damage to control cables and circuits powered from a direct current power source.

In 2012, the NRC and EPRI published NUREG/CR-7150 Volume 1 (EPRI 1026424), *Joint Assessment of Cable Damage and Quantification of Effects from Fire (JACQUE-FIRE): Phenomena Identification and Ranking Table (PIRT) Exercise for Nuclear Power Plant Fire-Induced Electrical Circuit Failure.* This report identified configurations of control circuits that are vulnerable to hot short-induced spurious operation after their electric cables are damaged by fire. An objective of the PIRT panel was to provide a fundamental understanding of parameters that affect failures modes to support the PRA Expert Panel's elicitation documented in NUREG/CR-7150 Volume 2 (EPRI 3002001989).

In 2013, the NRC published NUREG-2128, *Electrical Cable Test Results and Analysis during Fire Exposure (ELECTRA-FIRE).* This report systematically evaluated the test data from the three major fire-induced circuit damage testing programs and provided graphical analysis of various parametric effects on the likelihood of circuit failure modes and the associated hot short durations.

In 2014, the NRC and EPRI published NUREG/CR-7150 Volume 2 (EPRI 3002001989), *Joint Assessment of Cable Damage and Quantification of Effects from Fire (JACQUE-FIRE): Expert Elicitation Exercise for Nuclear Power Plant Fire-Induced Electrical Circuit Failure.* This report developed the conditional probabilities of hot short-induced spurious operation occurrence and duration of various control circuit applications, given fire damage to their electrical cables.

This document does not constitute regulatory requirements. NRC/RES participation in this study does not constitute or imply regulatory approval of its applications based upon this methodology.

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This report has undergone numerous reviews by NRC and EPRI member identified representatives who provided valuable feedback and comments to improve the final version of this report. In this respect, we are grateful to Gurcharan Matharu of NRC/NRR for his comments on the proper polarity write up. We recognize-Dan Frumkin, Chris Pragman, and Steve Hutchins for their review and feedback on the early versions of this report.

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ACRONYMS

A or Amp	ampere
AC	alternating current
BNL	Brookhaven National Laboratory
BWR	boiling water reactor
CAROLFIRE	Cable Response to Live Fire
CCDP	conditional core damage probability
CFR	Code of Federal Regulations
CPT	control power transformer
CT	current transformer
DESIREE-FIRE	Direct Current (dc) Electrical Shorting in Response to Exposure Fire
DC	direct current
EGM	enforcement guidance memorandum
ELECTRA-FIRE	Electrical Cable Test Results and Analysis During Fire Exposure
EOP	emergency operating procedure
EPRI	Electric Power Research Institute
EQ	equipment (or environmental) qualification
FAQ	frequently asked question
Fire PRA	fire probabilistic risk assessment
FMEA	failure mode and effects analysis
FPP	fire protection program
GFEHS	ground fault equivalent hot short
GL	generic letter
HPCI	high pressure coolant injection
HRR	heat release rate
HS	hand switch
I&C	instrumentation and control
IEEE	Institute of Electrical and Electronics Engineers
IRMS	insulation resistance measurement system
IT	intermediate-scale test
JACQUE-FIRE	Joint Assessment of Cable Damage and Quantification of Effects from Fire
kV	kilovolt
LER	licensee event report
LOCA	loss of coolant accident
LPSI	low pressure safety injection
MCC	motor control center
MOU	Memorandum of Understanding
MOV	motor operated valve
MSO	multiple spurious operation
n/C	‘n’ number of conductor
NC	normally closed
NEI	Nuclear Energy Institute
NFPA	National Fire Protection Association
NO	normally open
NPP	nuclear power plant
NRC	Nuclear Regulatory Commission

NRR	Office of Nuclear Reactor Regulation, NRC
PIRT	phenomena identification and ranking table
PORV	power operated relief valve
PRA	probabilistic risk assessment
PWR	pressurized water reactor
R	resistive impedance
RCIC	reactor core isolation cooling
RES	Office of Nuclear Regulatory Research, NRC
RG	regulatory guide
RHR	residual heat removal
SDC	shutdown cooling
SNL	Sandia National Laboratories
SOV	solenoid operated valve
SRV	safety relief valve
SSHAC	Senior Seismic Hazard Analysis Committee
SSD	safe shutdown
STD	standard
TP	thermoplastic
TS	thermoset
US	United States
V	volt
VAC	voltage in AC
VDC	voltage in DC
X	reactive impedance

1
INTRODUCTION

All commercial nuclear power plants (NPPs) in the U.S. are required to have a comprehensive fire protection program (FPP). The primary objective of a FPP is to minimize the probability of occurrences of fire and its consequences. FPPs provide reasonable assurance, through the defense-in-depth concept, that a fire will not prevent the operation of necessary equipment relied on to achieve and maintain the NPP in a safe shutdown condition. Three echelons of safety constitute the defense-in-depth concept, namely: (1) preventing fires from starting, (2) rapidly detecting and suppressing those fires that do occur, and (3) protecting structures, systems, and components important to safety from the effects of fire. For this last echelon, the FPP describes the means to limit fire damage to structures, systems, and components important to safety through a process commonly referred to as a post-fire safe shutdown (SSD) analysis.

Significant advancements in the state of knowledge and practices for conducting a post-fire SSD analysis have occurred in the 40 years since the issuance of the fire protection regulations. These advancements supported development of and revisions to NRC and industry guidance documents. However, limitations in the understanding and knowledge necessary to address some specific aspects of SSD analyses remained. Since the last regulatory guidance update in the 2009 timeframe, additional work and testing has been completed by the NRC and the Electric Power Research Institute (EPRI) to quantify the likelihood of fire damage causing certain circuit failure modes of SSD equipment. Using this new information, along with expert knowledge in several fields of study relevant to post-fire SSD, this report provides technical recommendations to support future updates to guidance used for conducting and reviewing deterministic fire analyses.

1.1 Background

The Browns Ferry Fire of 1975 and subsequent confirmatory testing of representative circuits revealed that a fire-induced failure of an electrical circuit can lead to spurious equipment operation. The type of circuit failure that may result from fire-induced electric cable damage, depends on many factors, including the type of circuits (i.e., power, control, or instrument), the cable failure modes (i.e., open circuit, short to ground, or hot short), the specific circuit design and construction, and the location of the cable with respect to the site of the fire (e.g., the cable's orientation, raceway routing and fill, and circuit grounding). Once a cable is damaged by a fire, faults in a circuit can result in the malfunction of a component or system. These malfunctions include partial or total failures, hot short-induced spurious operation of components, and false indication from instrumentation and control (I&C) circuits.

From inception in the early 1980s, analysis of fire-induced circuit failures has suffered from inconsistent interpretation of requirements and controversy over specific application criteria.[1] To clarify requirements associated with analysis of fire-induced circuit failures, NRC issued several supplemental guidance documents, including Generic Letter (GL) 81-12, *Fire Protection*

[1] Inception is taken as issuance of 10 CFR 50.48 and Appendix R, which require a methodical consideration of fire-induced circuit failures in support of post-fire safe shutdown analysis.

Rule (45 FR 76602), and Generic Letter 86-10, *Implementation of Fire Protection Requirements*. GL 81-12 and its associated clarification memorandum are the first formal correspondence to industry that contain reference to fire-induced spurious operation of equipment. Misunderstandings about fire-induced circuit failures persisted subsequent to issuance of Generic Letter 81-12. Consequently, NRC held a series of regional workshops in 1984 and issued Generic Letter 86-10 to provide further interpretation of requirements for analysis of fire-induced circuit failures, and specifically hot short-induced spurious operations of equipment.

A series of licensee event reports (LERs) in the late 1990's identified plant-specific problems related to potential fire-induced electrical circuit failures that could prevent operation or cause maloperation of equipment necessary to achieve and maintain hot shutdown (Ref. 2). To better understand these phenomena, both the NRC's Office of Nuclear Regulatory Research (RES) through Sandia National Laboratories (SNL), and the Electric Power Research Institute (EPRI), in collaboration with the Nuclear Energy Institute (NEI), conducted fire testing of various cables in controlled environments. These tests supported estimates of the likelihood of such failures, and understanding parameter effects on the hot short phenomenon in electrical circuits during a fire.

In 2002, EPRI/NEI completed a cable-test program addressing the nature and characteristics of such fire-induced failures of alternating current (AC) control circuits, particularly the potential of hot shorts to initiate the spurious operation of equipment (Ref. 3). Also in 2002, EPRI published a technical report (EPRI 1006961, *Spurious Operation of Electrical Circuits Due to Cable Fires – Results of an Expert Elicitation*) detailing the results of an expert elicitation on the EPRI/NEI cable-fire test results to develop best-estimate conditional probabilities for spurious operation of devices in electrical circuits due to fire-induced damage to electrical cables (Ref. 4). These results were incorporated into the method for conducting Fire Probabilistic Risk Assessments (Fire PRAs) documented in NUREG/CR-6850, *EPRI/NRC-RES Fire PRA Methodology for Nuclear Power Facilities* (Ref. 5). In addition, findings from the EPRI/NEI and CAROLFIRE tests were included in the industry's deterministic guidance document NEI 00-01, Rev. 2, *Guidance for Post Fire Safe Shutdown Circuit Analysis* (Ref. 6).

In 2003, a public workshop was held to discuss and gather stakeholder input on a proposed NRC risk-informed post-fire SSD inspection approach. The outcome of that workshop was documented in Regulatory Issue Summary 2004-03, "Risk-Informed Approach for Post-Fire Safe-Shutdown Associated Circuit Inspections," which identified circuit configurations using three bins (Ref. 7). Subsequently, NRC sponsored the CAROLFIRE (Cable Response to Live Fire) test program to: (1) develop an experimental basis for resolving the issues identified as "Bin 2 Items" in RIS 2004-03; (2) improve fire-modeling tools to aid in predicting cable damage under fire conditions; and, (3) complement the EPRI/NEI test results for AC control circuits. In 2008, NRC/SNL published the results of this CAROLFIRE test program on electrical performance and fire-induced cable failure (Ref. 8). The CAROLFIRE results were used to inform Revision 2 of NEI 00-01 (Ref. 6). An open issue was that the use of data from AC control circuits may not bound the failure modes for circuits powered from a direct current (DC) power source. To address this issue NRC/RES, with support from EPRI under a collaborative research agreement, sponsored tests, as part of the DESIREE-FIRE (Direct Current Electrical Shorting in Response to Exposure Fire) effort. These tests assessed cable failure modes and effects on the behavior of DC control circuits. The draft findings were made available in 2010, and published as final in 2012 (Ref. 9).

Given the substantial amount of additional data available from the NRC sponsored testing, NRC/RES and EPRI began a collaborative research initiative to advance the state of knowledge and methods for evaluating fire-induced effects on electrical circuits. This joint program, referred to as the Joint Assessment of Cable Damage and Quantification of Effects from Fire (JACQUE-FIRE), was performed by NRC/RES and EPRI under the NRC-RES and EPRI Memorandum of Understanding (MOU) (Ref. 10). The JACQUE-FIRE program consisted of a series of deliberations by subject-matter experts and the results are documented in three volumes of reports containing conclusions and recommendations from three separate efforts. These are discussed in more detail in the following paragraphs.

Starting in 2010, NRC/RES and EPRI initiated a joint effort to advance the state-of-the-art knowledge and methods in the area of fire-induced effects on circuit functionality using available data, expert judgement, and engineering principles. The first effort, a Phenomena Identification and Ranking Table (PIRT) exercise is documented in Volume 1 of NUREG/CR-7150 / EPRI 1026424 (Ref. 1). The PIRT used a balanced team of NRC and EPRI members with expertise in the area of electrical circuits, post-fire safe-shutdown circuit analysis, nuclear power plant operations, and fire protection. The PIRT Report documents the process and results related to the identification of influencing factors and ranking their importance to the hot short phenomenon in the failure of electrical circuits leading to spurious operation of devices after the cable is damaged by fire. In addition to following the traditional PIRT process, the PIRT Panel conducted an additional effort by using the results obtained from the PIRT process along with engineering principles and judgment to provide consensus technical recommendations on several fire protection issues. These issues include:

- Three-phase AC power circuits
- DC compound wound motor power circuits
- multiple high-impedance faults
- open circuit secondary current transformer (CT) faults
- control power transformers
- Kapton®-insulated cables
- panel wiring
- high conductor trunk cables

Another recommendation from the PIRT panel resulted in additional testing by Brookhaven National Laboratory (BNL). Testing was performed to determine whether fire-induced open circuiting of the secondary circuit of a current transformer would result in an excessively high voltage sufficient to start another fire at the location of the CT itself or at some other remote location of the secondary circuit. The CT testing is discussed in Section 7 of this report.

Secondly, the PIRT panel used the results to develop a framework for the follow-on fire PRA expert elicitation effort. This was a quantitative effort focused on the parameters that most influence fire-induced circuit faults.

The formal structured expert elicitation process was conducted by a PRA Expert Panel. The expert elicitation followed an enhanced senior seismic hazard analysis committee (SSHAC) Level 2 process. The SSHAC process has been used for previous expert elicitations performed for the NRC (Ref. 11). The PRA Expert Panel consisted of a balanced group of experts sponsored by the NRC and EPRI with knowledge in the area of electrical circuits, post-fire SSD circuit analysis, fire PRA, and reliability modeling. The PRA Expert Panel developed conditional likelihood estimates for hot short-induced spurious operations as a result of fire damage to electrical cables. The results of this effort are documented in Volume 2 of NUREG/CR-7150 / EPRI 3002001989 (Ref. 12) and represent the state-of-the-art methods and data to support quantification of fire-induced cable failures and circuit faults in a fire PRA.

Soon after the publication of Volumes 1 and 2 of NUREG/CR-7150, licensees began using certain insights in their FPPs. During triennial fire protection inspections, several instances were brought to the authors' attention where licensees and NRC inspectors had differing views on the intent of these recommendations. After discussions, it was determined that clarifications on the intent of the recommendations would be beneficial. Also, after the issuance of the PIRT Report, an NEI circuit analysis task force began development of Appendix J to NEI 00-01 (Ref. 13) that would be included as part of subsequent revisions to NEI 00-01 and included guidance on the recommendations made in the PIRT Report. A draft version was provided to the NRC and several public meetings were held to discuss and provide feedback. During these meetings, it was apparent that agreement could not be reached on how the recommendations were interpreted. Industry and NRC staff suggested that more work be conducted to provide clarity and resolution, along with considering the quantitative insights from the nearly completed PRA Expert Panel work. Thus, after issuance of the PRA Expert Report, the PIRT panel was re-convened. This report (JACQUE-FIRE Volume 3) documents the working group's technical recommendations to support development of a stable regulatory framework for post-fire SSD.

The evolution of these three volumes was serial in nature as depicted in Figure 1-1. The "working group" consisting of mostly the same electrical and fire protection engineers.

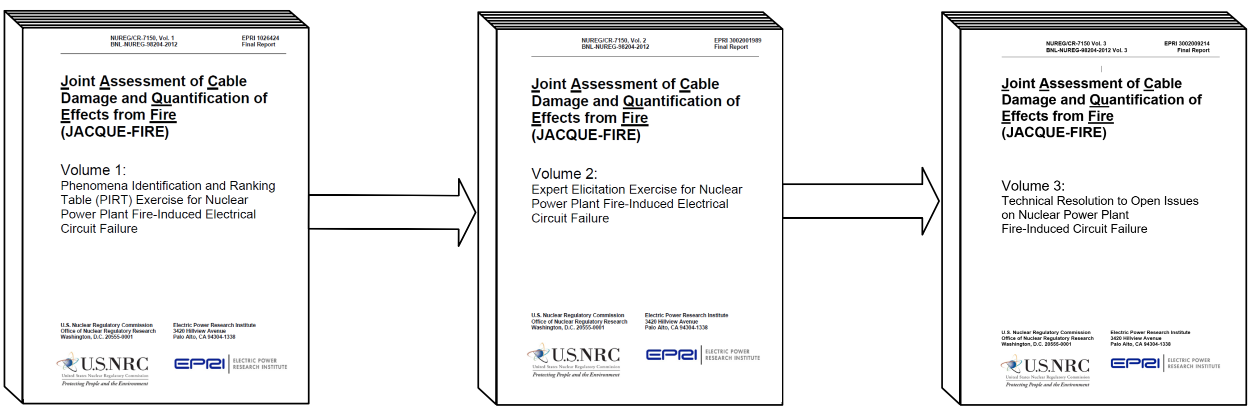


Figure 1-1 JACQUE-FIRE Reports

The JACQUE-FIRE reports identified in Figure 1-1 and the corresponding groups who developed the individual reports are referred to as follows:

- The "PIRT Report" refers to NUREG/CR-7150 Volume 1 (EPRI 1026424)
  - The "PIRT Panel" prepared the "PIRT Report"
- The "PRA Expert Panel Report" refers to NUREG/CR-7150 Volume 2 (EPRI 3002001989)
  - The "PRA Expert Panel" prepared the "PRA Expert Panel Report"
- The report, "JACQUE-FIRE Volume 3" refers to NUREG/CR-7150 Volume 3 (EPRI 3002009214)
  - The "working group" prepared "JACQUE-FIRE Volume 3"

1.2 Objectives

During the last decade a significant amount of empirical data and practical experience has been gained that can be used to increase the state of knowledge with respect to fire-induced circuit failures. To that end, the PIRT Panel identified parameters that influence the likelihood and duration of specific fire-induced failure modes. The PRA Expert Panel Report presents conditional probability estimates for important configurations and influencing parameters.

The objective of this work (JACQUE-FIRE Volume 3) is to:

1) Provide clarifications to recommendations made in the PIRT Report,
2) Reassess certain recommendations in the PIRT Report based on the results of the fire PRA Expert Panel Report and
3) Provide additional technical recommendations to support future development of regulatory guidance.

This report (Volume 3) provides the technical recommendations to reconcile any differences between the previous efforts (Volumes 1 and 2).

The working group developed technical recommendations on a number of items. For some of these items, white papers were developed, made publicly available prior to the publication of this report, and discussed at a March 17, 2016 NRC public meeting. Based on feedback received during the public meeting on the original document (Item 1 below), the working group revised the document to address comments. This report incorporates the revisions made by the working group. Early issuance of these white papers was intended to support timely revisions to regulatory guidance documents (i.e., NEI 00-01, and Regulatory Guide 1.189). The meeting summary can be found in NRC ADAMS under Accession No. ML16082A120. For the other five items that were made publicly available, the ADAMS Accession numbers are provided below:

1. Multiple Spurious Operation (MSO) Consideration Recommendation (ADAMS Accession No. ML16047A379)

2. Proper polarity short circuit conditions in double break designed circuits. (ML16047A370)

3. Technical recommendations on the use of shorting switches to mitigate spurious operation of control devices. (ML16068A435)

4. Recommended number of hot shorts to be considered in the evaluation of multiple spurious operation (MSO) scenarios for deterministic analyses. (ML16047A379)[2]

5. Durations for hot short-induced spurious operation in AC and DC control circuits for deterministic analyses. (ML16047A375)

6. Technical justification and clarification for failure mode classifications for deterministic analysis made in the PIRT report. (ML16047A388)

[2] Based on feedback received during the March 17, 2016 public meeting on the original document (ADAMS Accession No. ML16047A379) the working group revised the document to address comments. This report incorporates the revisions made by the working group.

Additional recommendations and clarifications made by the working group that were not previously made available include:

7. The need to postulate secondary fires in current transformer (CT) circuits is presented in Section 7 of this report.

8. Corrections to typographical errors and clarifications to illustrations in the PIRT Report are presented in Appendix B of this report.

1.3 The Approach

The working group's expertise consisted of expertise in electrical circuits, post-fire SSD circuit analysis, and fire PRA. The eight panel members were balanced between the regulator (three NRC staff members and one NRC-sponsored consultant) and four members from EPRI/nuclear power industry.

The working group members are listed below, along with their affiliations. Resumes for all eight members and the moderator are provided in Appendix A.

Harold Barrett, NRC/NRR
Robert Daley, NRC/Region 3
Daniel Funk, JENSEN HUGHES
Thomas Gorman, JENSEN HUGHES
Shannon Lovvorn, Tennessee Valley Authority
Steven Nowlen, Consultant to BNL for NRC
Andy Ratchford, JENSEN HUGHES
Gabriel Taylor, NRC/RES

Seven of the eight members of the working group for JACQUE-FIRE Volume 3 were members of the PIRT Panel for JACQUE-FIRE Volume 1. Three of these seven members were also part of the PRA Expert Panel Process for JACQUE-FIRE Volume 2. The moderator served as such on all three panels.

The project sponsors attended all working group meetings and offered general assistance and oversight. Mano Subudhi from BNL served as the moderator of working group meetings held at the NRC/RES's Church Street Office in Rockville, Maryland from September 2014 through December 2015. Since then, the working group members held a number of teleconferences to finalize the technical recommendations associated with each issue included in this report.

1.4 Report Organization

The following sections and appendices document the technical justifications and clarifications on the outstanding circuit analysis issues:

Main Report Sections

- Section 2 clarifies and defines terminology used in the JACQUE-FIRE report series.
- Section 3 provides final circuit classifications for certain control circuit spurious operation failure modes.
- Section 4 provides technical recommendations for shorting switch applications.
- Section 5 presents the recommended number of hot shorts to be considered in the evaluation of MSOs.
- Section 6 summarizes recommendations for durations of hot short-induced spurious operation in AC and DC control circuits for deterministic analyses.
- Section 7 presents updated recommendations regarding treatment of potential secondary fires due to open circuits on the secondary side of CTs used in the AC electrical distribution systems of NPPs.
- Section 8 presents the summary and conclusions of this work.
- Section 9 lists references.

Report Appendices

- Appendix A presents the resumes of the working group members and moderator.
- Appendix B contains an errata sheet applicable to the PIRT Report and corrected figures of control circuits depicted in Section 3 and Appendix C of the PIRT Report (Ref. 1).
- Appendix C provides illustrations to promote clear understanding of the reclassification of two (2) inter-cable hot shorts for a double break designed circuit with thermoplastic (TP) insulated conductors.

2
UPDATE OF CIRCUIT ANALYSES TERMINOLOGY

This section describes the updates and clarifications to analyses and terminology used in the PIRT Report (Ref. 1) including: proper polarity, latching versus non-latching, high impact components and failure mode classifications.

2.1 Update of Proper Polarity and Latching

2.1.1 Proper Polarity Short Circuit Conditions in Double Break Circuit Designs

This subsection addresses two aspects of proper polarity hot shorts as they relate to the potential for fire-induced spurious operation of solenoids and relays in AC and DC circuits with a double break design. See Section 3.3.2 and Figure 3-1 of JACQUE-FIRE Volume 1 for the definition and discussion of single and double break circuits (Ref. 1).

Aspect 1. The first aspect is whether a reversal of polarity, i.e., negative connection above the solenoid and positive connection below the solenoid versus positive connection above the solenoid and negative connection below the solenoid (as illustrated in Figures 2-1 and 2-2), will affect the solenoid's ability to operate when the applied voltage is from a compatible power source. Compatible power sources are: an AC circuit interfacing with an AC target device, or a DC circuit interfacing with a DC target device.

Aspect 2. The second aspect is whether a device designed for an AC application will operate if the applied voltage is from a DC circuit and, conversely, whether a device designed for a DC application will operate if the applied voltage is from an AC circuit.

2.1.1.1 Background

The term “proper polarity” indicates that, in order for a spurious operation to occur, two concurrent hot shorts of opposite polarity must occur. Further, these two concurrent hot shorts must involve both polarities of an aggressor power source such that a voltage is impressed across the target end device, thereby creating a complete path for current to flow. Depending on the specific characteristics of the circuit designs (i.e., both the target and aggressor circuits) the potential for the spurious operation could be supplied through either a ground fault equivalent hot short (GFEHS) or a ground as is the case for a grounded AC aggressor circuit. The term proper polarity hot short is used in this discussion to represent all of these circuit failure mode interactions. The proper polarity hot short failure mode generally requires special consideration for double break circuit designs. Double break circuits are those where connections to the end device (e.g., a solenoid valve or relay) are opened on both polarities of the end device as part of the control or isolation design. Double break designs include:

- Control switches or relays that open two sets of contacts in the control circuit, one set in each leg of the end device circuit, e. g., Figure 2-1.
- Fuses pulled from both legs of a single break control circuit. (This is a pseudo-double break design.)
- Two-pole circuit breaker opens both legs of the control circuit. (This is a pseudo-double break design.)

A proper polarity hot short can result when aggressor conductors (source conductors) of each polarity concurrently make contact with their respective conductor for the end device. This case, shown in Figures 2-1 and 2-2, represents the most common case for the proper polarity hot short failure mode.

2.1.1.2 Technical Discussion

1. Proper Polarity Aspect #1: [AC Circuits to AC Devices; DC Circuits to DC devices]

Based on a review of general industry literature and manufacturer's data, solenoids (Ref. 14 and 15), AC solenoids, DC solenoids, and relays (Ref. 16) are not polarity sensitive, i.e., the coil will operate regardless of the orientation of the applied positive and negative voltage to the coil. The two cases shown in Figure 2-1 are both considered "proper polarity" hot shorts since they have the same functional impact of producing a spurious operation.

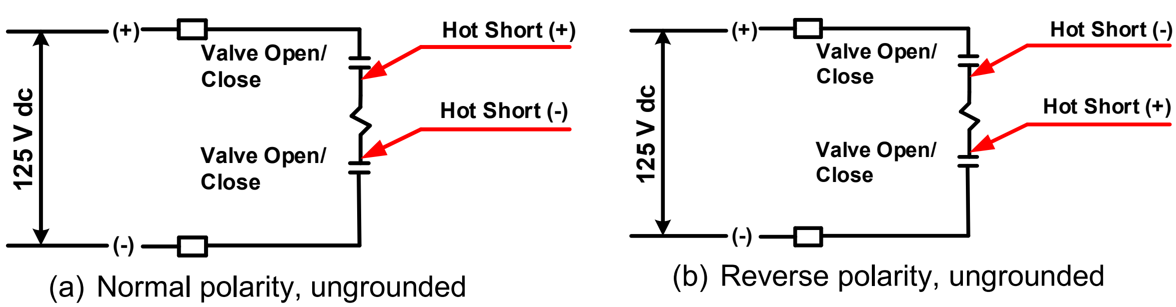


Figure 2-1 Proper Polarity [Normally Anticipated Configuration]

In some special cases, DC solenoids are designed to be "polarity sensitive." This type of construction is generally limited to low voltage DC designs that incorporate voltage suppressors for basic circuit protection against transients. This design feature is typically used only for solenoids rated 24 VDC or below (Ref. 15).

The illustrations shown in Figure 2-1 are for a 125 VDC ungrounded circuit, but the principles also apply to ungrounded AC circuits as shown generically in Figure 2-2.

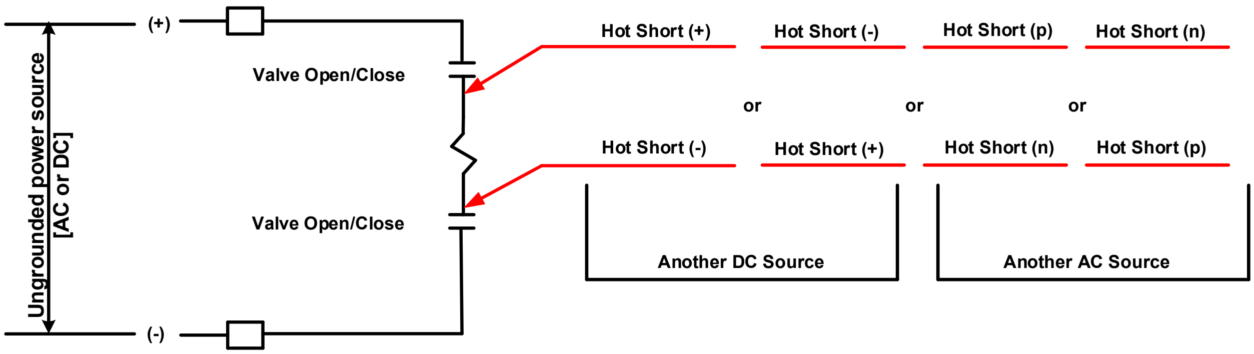


Figure 2-2 Generic Proper Polarity Potential Configuration

2. <u>Proper Polarity Aspect #2: [DC Circuits to AC Devices; AC Circuits to DC Devices]</u>

The discussion of the second aspect of proper polarity hot shorts is broken down by device type; solenoids or relays.

Solenoids

AC and DC solenoids are engineered to operate under specific voltage conditions. Given the somewhat random and inconsistent conditions caused by fire-induced circuit failures, it is unlikely that the conditions produced in a fire environment can duplicate, with any predictability, the specific design conditions for which these devices are designed. In addition to the design differences of the solenoids, there are other secondary effects between AC and DC voltage that reduce the likelihood of a spurious operation of the coil. Inrush currents and opening transients are very different between AC and DC coils due to the inductive effect of AC. The air gap between coil and the central core also has an impact on operating performance. Finally, DC voltage can cause residual magnetism in AC coils, which can lead to improper operation during switching.

AC and DC solenoids are designed differently to account for the different impedance ($Z = R + jX$) characteristics exhibited by the coil when AC and DC voltage is applied. Under AC voltage, a coil has both a resistive (R) and inductive element (X); under DC voltage the exhibited impedance is only the resistive element ($Z = R$). Thus, DC voltage will typically produce much higher current flow over the equivalent AC voltage (due to the same voltage with very different impedances). Since the force produced in the magnetic field is a function of current, DC voltage will produce a greater force than an equivalent AC voltage, i.e. lower coil impedance under DC voltage produces higher current, which in turn produces greater magnetic field.

Based on the above principle, a coil designed for a DC application would require a higher applied AC voltage to produce an equivalent force. Depending on the solenoid design and the counter force produced by the reset spring, an equivalent AC voltage may or may not be able to overcome the spring force. From available documentation, it appears that an AC voltage will typically not be able to overcome spring force in a DC solenoid of the same voltage class (e.g., a 120 VAC hot short is not likely to cause a 125 VDC solenoid to pick up). However, it is possible for higher AC voltages to be present, e.g., 208 VAC; or 277 VAC. Although these higher voltages do not guarantee a 125 VDC solenoid will operate should it come into contact with a conductor from one of these higher voltage circuits, they do present the possibility that spurious operation could occur. Operation of a DC solenoid by a conductor from an AC circuit requires a coincidental combination of a sufficient number of factors that, although theoretically possible, it is considered to be of low likelihood. Some of the coincidental factors, required for the interaction described above to occur, include:

(1) Sufficient fire damage to the conductors feeding the DC solenoid to allow an interaction with conductors of one or more adjacent cables;

(2) The presence of conductors of an adjacent cable(s) at a voltage level compatible with the required power characteristics of the solenoid;

(3) Sufficient fire damage to the conductors of the adjacent cable(s) that allow it to interface with the conductors supplying the solenoid without first going to ground;

(4) Insulation resistance characteristics at the interface between the fire-damaged conductors that provide a current transfer path consistent with the characteristics required for the operation of the device.

Despite the low likelihood of these conditions occurring, due to the wide range of available DC solenoids available, the occurrence cannot be ruled out. As such, operation of a DC solenoid by a conductor from an AC circuit should be assumed unless a specific engineering analysis, factoring in bounding values for all of the appropriate plant specific parameters, is documented and/or testing demonstrates that the specific solenoid will not operate under the identified plant conditions.

Based on the previously discussed principles, a solenoid designed for AC application would require a much lower applied DC voltage to produce equivalent force. In the case of equivalent DC voltage applied to an AC solenoid, the likely failure mode is that the significantly higher current flow for equivalent DC voltage will cause an over-temperature condition that will burn out the coil, in some cases rather quickly. Although coil burnout under the conditions postulated could occur, factors such as the timing of the burnout and insulation resistance of the fire-induced short on the postulated aggressor conductor make it impossible to predict that coil burnout in a prescribed period of time is assured. Furthermore, impedance of the fire-induced-short could lower the DC voltage applied to the coil, making the coil burnout less likely. Thus, it must be assumed that DC voltage applied to an AC solenoid will cause it to energize. Accordingly, operation of an AC solenoid by a conductor from a DC circuit must be assumed unless a specific engineering analysis, factoring in bounding values for all of the appropriate plant specific parameters, is documented and/or testing is conducted showing that the specific solenoid will not operate under the identified plant conditions.

Relays

The recommendations provided above for AC and DC solenoids are also applicable to AC and DC relays used in control circuits.

When operating a DC relay from an AC source, the alternating current decreases to zero every half cycle, which results in the relay armature releasing every half cycle. This continual movement of the armature not only causes a “buzz,” but will result in the contacts rapidly opening and closing (i.e., relay chatter) as the armature moves. Depending on the characteristics of the device being operated and the circuit itself, this relay chatter could result in the spurious operation of the device. Should the device be a latching device, a permanent change of state could occur. Additionally, if the relay manufacturer uses a shading ring (or shading coil) on the top of the relay core, the shading ring could compensate for the cycling effect described above. When a shading ring is used, an AC source could be capable of operating a DC relay coil. Based on these considerations, for any safe-shutdown components using DC relays, the construction of the DC relays, the characteristics of the device to be operated, and the circuit characteristics itself should be reviewed to assure that the AC source is incapable of operating the DC relay. In the absence of this review, it should be assumed that an AC source can operate the DC relay.

Similar to the AC solenoid discussion above, sustained operation of an AC relay from a DC source is impractical without reducing the DC voltage to a level less than the AC rating of the relay. However, for similar reasons to those cited for an AC solenoid, it should be assumed that operation of an AC relay by a conductor from a DC circuit can occur unless a specific engineering analysis, factoring in bounding values for the appropriate plant specific parameters, is documented and/or testing demonstrates that the specific relay will not operate under the plant conditions found.

2.1.1.3 Conclusions

The following conclusions were reached by the working group.

<u>Reversal of polarity</u>

AC and DC solenoids and relays used in double break control circuits are assumed "polarity insensitive," unless specific manufacturer's technical data indicates the device is "polarity sensitive." "Polarity insensitive" means that the coil will operate regardless of the orientation of the applied positive and negative voltage to the coil.

<u>AC Devices Interfacing with DC Circuits</u>

- AC solenoids used in double break control circuits should be assumed capable of being operated by a DC source, unless a specific engineering analysis, factoring in bounding values for all of the appropriate plant specific parameters, is documented and/or testing demonstrates that the specific solenoid will not operate under the plant conditions found.

- AC relays used in double break control circuits should be assumed capable of being operated by a DC source, unless a specific engineering analysis, factoring in bounding values for all of the appropriate plant specific parameters, is documented and/or testing demonstrates that the specific relay will not operate under the plant conditions found.

<u>DC Devices Interfacing with AC Circuits</u>

- DC solenoids used in double break control circuits should be assumed capable of being operated by an AC source, unless a specific engineering analysis, factoring in bounding values for all of the appropriate plant specific parameters, is documented and/or testing demonstrates that the specific solenoid will not operate under the plant conditions found.

- DC relays used in double break control circuits should be assumed capable of being operated by an AC source, unless a specific engineering analysis, factoring in bounding values for all of the appropriate plant specific parameters, is documented and/or testing demonstrates that the specific relay will not operate under the plant conditions found.

The discussion provided here should be considered when reviewing and interpreting the behavior of the simplified circuit designs depicted in the PIRT Report, Section 3 and Appendix C (Ref. 1).

2.1.2 Latching and Non-Latching

Differing interpretations of the term "latching" arose with regard to several of the recommendations made in the PIRT Report. To clarify, the working group recommends that the following definitions for "Latching" and "Non-Latching" circuits be used in the context of post-fire SSD circuit analysis.

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

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

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

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

2.2 Update of High Impact Components

The working group identified a set of components whose fire-induced failure is significant enough to warrant a more rigorous treatment. This set of components is referred to as "high impact components." Based on the consensus viewpoints of the working group, failure of these components due to fire damage could pose a significant threat to plant safety. As such, the working group recommends that the "implausible" circuit failure mode classification be applied to these components. A definition of "implausible" circuit failure modes is provided in Section 2.3.1.

The working group recommends "high-low pressure interface" components be classified as "high impact components[3]." Spurious opening of both shutdown cooling suction valves could result in an interfacing system loss of coolant accident (LOCA) outside of containment with no effective mitigating actions available.

[3] Appendix C of NEI 00-01, Rev. 2 provides a methodology for determination of high-low pressure interface components, when applied in conjunction with Revision 2 of RG 1.189.

The working group also recommends that boiling water reactor (BWR) reactor pressure vessel safety relief valves (SRVs) and pressurized water reactor (PWR) pressurizer power operated relief valves (PORVs) be classified as "high impact components." Spurious opening of relief valves, in combination with the fire-induced failure of reactor vessel makeup capability is considered to be a plant transient with the potential to significantly challenge the plant operations staff and potentially damage the reactor core. As such, more restrictive treatment is warranted for safety relief and power operated relief valves.

Based on the collective judgment of the working group, the list of "high impact components" is presented below. This set of components is considered bounding and represent the complete list of components that are recommended to be evaluated for the effects of "implausible" circuit failure modes. As such, the working group recommends "implausible" circuit failure modes be applied to circuits for these "high impact components."

For BWRs:

- Spurious opening of both shutdown cooling suction valves (classified as "high/low pressure interfaces").
- Spurious opening of multiple reactor pressure vessel SRVs and failure (due to fire damage effects) of a sufficient number of low pressure make-up systems such that the inventory loss is not bounded by design basis accident analysis.

For PWRs:

- Spurious opening of the shutdown cooling suction valves (to SDC/LPSI/RHR); these are the "high/low pressure interface" valves.
- Spurious opening of one or more pressurizer PORVs and failure (due to "fire damage" effects) of their associated block valves to close or remain closed.

2.3 Update of Classification and Ground Fault Equivalent Definitions

Another objective of this project is to "reassess certain recommendations in the PIRT Report based on the results of the Fire PRA Expert Panel Report." As will be discussed in later sections, the working group made several changes to the classifications presented in the PIRT Report. To promote a common understanding of these classifications, several definitions are restated below.

2.3.1 Failure Mode Classifications

The definitions of the terms "incredible" and "implausible" were initially developed and stated in the PIRT Panel Report. Subsequently the PRA Expert Elicitation Panel recommended that the last sentence of the PIRT Panel definitions be deleted (Ref. 12). The PRA Expert Elicitation Panel developed conditional probability estimates for cases identified as "implausible" by the PIRT Panel. No conditional probability estimates were developed for the cases identified as "Incredible." Based on the PIRT Panel and PRA Expert Elicitation Panel recommendations, the updated definitions of these terms are as follows:

Incredible

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

Implausible

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

Plausible

The term “plausible” used in conjunction with the phenomenon of a fire-induced circuit failure, signifies the PIRT panel’s conclusion that the event will occur given appropriate conditions. In these cases, the PIRT panel finds adequate evidence of the phenomenon occurring during a fire. This classification of the hot short-induced spurious operation failure mode(s) warrants being included in the post-fire safe-shutdown circuit analysis. In the PIRT report these events are termed “possible” in Table 3-3, and represented as “blank” cells in Figures 3-5, 3-6 and 3-7 and Tables 3-6 and 3-7” of the PIRT Report (Ref. 1), as clarified and updated in Appendix B of this report.

2.3.2 Ground Fault Equivalent Hot Short

The term “ground fault equivalent hot short,” also known as GFEHS, is a subset of an intra-cable or inter-cable hot short phenomena and is a circuit failure mode wherein multiple shorts to ground can cause a spurious operation (Ref. 17). For this failure mode to occur, both a source and target conductor must short to the same ground plane and have a compatible power supply.

3

TECHNICAL JUSTIFICATION FOR FAILURE CLASSIFICATION CHANGES TO PIRT REPORT

This section provides the technical justification for the circuit failure classifications (i. e., incredible, implausible, and plausible) assigned to inter-cable failure modes for several circuit configurations.

3.1 Background

The PIRT Report (Ref. 1) provided technical recommendations for the classification of certain fire-induced circuit failures associated with control and power circuits as they pertain to a SSD deterministic analysis. The classifications used are either “plausible,” “implausible,” or “incredible.” The latest definitions are given in Section 2.3 of this report. The PIRT Panel made numerous recommendations with regard to classification of certain fire-induced circuit failures based on their knowledge and understanding of the circuit design, applicable test data, and engineering judgment. Subsequent to those classifications, the PRA Expert Panel developed conditional probabilities for a variety of cases. The working group reviewed the results presented in the PRA Expert Panel report (Ref. 12) to ensure that the quantitative results supported the qualitative classification recommendations.

When the working group reviewed the quantitative results (Ref. 12) in comparison to the PIRT Report recommendations, there were instances where the quantitative results from the PRA Expert Panel Report conflicted with the recommendations provided in the PIRT Report.
In addition, the PIRT Panel deferred providing a classification for the case of two inter-cable hot shorts on thermoplastic-insulated conductors. For this case, the PIRT Panel recommended a classification of “plausible” until insights from the quantification effort (Ref. 12) could be reviewed to support a definitive classification. The changes are discussed in Section 3.2 and summarized in Tables 3-3 through 3-5.

3.2 Failure Classification Changes

The following four changes to the conclusions provided in the PIRT Report are recommended by the working group based on the quantitative likelihood estimates from the PRA Expert Panel Report.

1. Consideration of insulation type for the aggressor (source) cable conductors is eliminated. The classifications provided by the PIRT Panel in JACQUE-FIRE Volume 1 were predicated on the insulation characteristics of both the aggressor (source) and target conductors. The PRA Expert Panel in JACQUE-FIRE Volume 2 eliminated consideration of the insulation characteristics of the aggressor (source) conductor. For the reasons cited below, the working group also eliminates consideration of the insulation characteristics of the aggressor (source) conductor in determining their final classification for each of the circuit failure types. The elimination of consideration of the insulation characteristics of the aggressor (source) conductor, in some cases, contributes to a change in classification of a circuit failure type.

2. The classification of an inter-cable hot short for thermoset (TS) insulated conductors is changed from "implausible" to "plausible." This change impacts the classification of circuit failure types for both single and double break designed circuits. Refer to Tables 3-1 and 3-2 for the working group's classification recommendations.

3. Due to the similarity in circuit failure type classification, ungrounded AC single break designed circuits from a common control power transformer (CPT) are grouped with ungrounded DC and ungrounded distributed AC circuits for purposes of classifying the circuit failure type. Refer to Table 3-1 for the working group's classification recommendations.

4. The PIRT Panel in JACQUE-FIRE Volume 1, Table 3-3 deferred classifying the case of two inter-cable hot shorts for a double break designed circuit with thermoplastic insulated conductors until the PRA Expert Panel completed their likelihood of occurrence work in JACQUE-FIRE Volume 2. This case and other similar cases were reviewed by the working group based on insights from JACQUE-FIRE Volume 2 to determine the appropriate classification. As a result of this review, the working group recommended a classification of "implausible" for latching circuits and "incredible" for non-latching circuits. This classification was applied to other circuit failure types with similar likelihood of occurrence. Refer to Table 3-2 for the working group's specific classification recommendations.

3.2.1 Technical Justification for Failure Classification Changes

The reasons for the changes cited above and the technical justification for each circuit failure classification change is discussed in the subsections below.

3.2.1.1 Consideration of Insulation Type for the Aggressor (source) Cable

Consideration of insulation type on the conductors for the aggressor (source) cable conductors is eliminated.

Reason for Change

The classifications provided by the PIRT Panel in JACQUE-FIRE Volume 1 were predicated on the insulation characteristics of both the aggressor (source) and target conductors. The PRA Expert Panel in JACQUE-FIRE Volume 2 did not determine probabilities of occurrence for conductor insulation type on the aggressor (source) conductors, due to the impracticality of tracking, from a configuration control perspective, the conductor insulation type for all possible aggressor (source) conductors. This made a one-to-one comparison' between the classifications made in JACQUE-FIRE Volume 1 with the relative probabilities of occurrence determined in JACQUE-FIRE Volume 2, impossible. As such, the working group revised the classifications to be a function of the conductor insulation only on the target conductor.

Technical Justification for Change

Other than in specifically controlled circumstances, identification and design configuration control of all insulation types on all conductors in each raceway is a difficult, if not impossible, task from a practical perspective. Thus, elimination of the classifications based on both target and aggressor (source) conductor insulation types are consistent with typical capabilities of the existing design organizations and the cable and raceway management systems within the nuclear power industry. Although insulation types for most conductors in a nuclear power plant are known and controlled, the task of comparing and controlling the insulation types for all conductors on a raceway-by-raceway basis is an unreasonable configuration control expectation.

3.2.1.2 Classification of an Inter-Cable Hot Short for Thermoset Insulated Conductors

The classification of an inter-cable hot short for thermoset insulated conductors is changed from “implausible” to “plausible.” This change impacts the classification of circuit failure types for both single and double break designed circuits. Refer to Tables 3-1 and 3-2.

Reason for Change

The PRA Expert Panel in JACQUE-FIRE Volume 2 determined a probability of occurrence on the order of 1E-02 for a single inter-cable hot short on a single break grounded AC circuit with a TS insulated conductor. Similarly, the PRA Expert Panel in JACQUE-FIRE Volume 2 determined the probability of occurrence on the order of 6.3E-03 for a single inter-cable hot short on a single break ungrounded AC or DC circuit with a TS insulated conductor. The PIRT Panel previously classified these circuit failure types as “implausible.”

In reviewing the test data used by the PRA Expert Panel to develop their probabilities, the working group concluded that the test data, in fact, did support a higher probability of occurrence for a single inter-cable hot short on a single break grounded AC circuit with a TS insulated conductor. The working group also concluded that the probability established by the PRA Expert Panel did **not** support a classification of “implausible.” Accordingly, the working group changed the classification to ”plausible” for a single inter-cable hot short, with a TS insulated conductor: on a single break grounded AC circuit, an ungrounded distributed AC circuit; and on an ungrounded DC circuit.

Due to this change and the higher probability of occurrence of intra-cable hot shorts (i.e., on the order of 0.28 to 0.64), the classification for double break designed circuits with thermoset insulated conductors requiring an inter-cable hot short and an intra-cable hot short is also changed from “implausible” to “plausible.”

Technical Justification for Change

With respect to the single inter-cable hot short on a single break grounded AC circuit the PRA Expert Panel used eight inter-cable interactions from the EPRI testing (Test #s. 3, 4, 6, 8, 9, 10, 12, 17) and one inter-cable interaction from the CAROLFIRE insulation resistance measurement system (IRMS) testing (Test # IT-1) as evidence to support their elicitation for calculating the conditional probability of occurrence. In reviewing this data, the working group concludes that seven of the eight interactions in the EPRI testing are valid and representative of actual plant fire conditions for specific configurations. The only interaction questioned is the interaction in EPRI Test #3. This interaction was questioned because the cable tray was inadvertently ungrounded in this test. The lack of grounding may have contributed in some way to the inter-cable interactions. In the CAROLFIRE intermediate-scale test (IT) #1, valid indications of inter-cable interactions were found. Finally, in the DESIREE-FIRE inter-cable testing, Section 6.5 of the DESIREE-FIRE report (Ref. 9), many of the cable bundles showed signs of inter-cable interactions. For this testing, however, spurious operations did not occur because this testing was designed to simulate a double break circuit design that would require two circuit failure interactions in order for a spurious operation to occur. Although the DESIREE-FIRE testing did effectively show the very low likelihood of spurious operations in double break circuit designs, the cable interactions observed during the testing preclude eliminating this failure mode for single break designs, since several of the tested configurations showed indications of a number of single inter-cable interactions.

The working group concludes that intra-cable hot shorts would, in an overwhelming number of cases, be the first fire-induced circuit failure mode for multi-conductor cables and that this failure mode bounds the effects of inter-cable hot shorts. Despite this, with respect to both single conductor and multi-conductor cable configurations in grounded AC, ungrounded AC, or ungrounded DC circuits, conductor interactions involving external hot shorts are likely to appear with the same frequency seen in the industry and NRC cable fire tests, where a path to ground or to a grounded conductor does not readily exist. This likelihood, estimated by the PRA Expert Panel to be on the order of 1E-02, does **not** support a classification of “implausible.” Based on this information, the working group *recommends* a classification of “plausible” for inter-cable hot shorts in grounded AC, ungrounded distributed AC, and ungrounded DC circuits, where the target conductor has TS insulation. The working group recognized that the same classification is being used for cases ranging in probability from 1E-02 to about 6.4E-01, and observes that, within the bounds of a deterministic analysis, “plausible” will inevitably cover a broad range of fault types and likelihoods.

Due to this change and the higher probability of occurrence of intra-cable hot shorts (i.e., on the order of 0.28 to 0.64), the classification for double break designed circuits with thermoset insulated conductors requiring an inter-cable hot short and an intra-cable hot short is also recommended by the working group to be changed from “implausible” to “plausible.”

3.2.1.3 Classification of Ungrounded AC Single Break Designed Circuits from a Common CPT

Due to the similarity in circuit failure type classification, ungrounded AC single break designed circuits from a common CPT are grouped with ungrounded DC and ungrounded distributed AC circuits for purposes of classifying the circuit failure type. Refer to Table 3-1.

Reason for Change

Ungrounded AC single break designed circuits from a common CPT will behave very similarly to ungrounded distributed AC or ungrounded DC single break designed circuits. The one exception is where the target conductor required for spurious operation is isolated from other possible aggressor conductors off of the same CPT. Since a circuit configuration with the target conductor isolated is a very limited exception for ungrounded circuits off of a common CPT, the classifications for this circuit type are grouped with the classification for ungrounded distributed AC and ungrounded DC.

Technical Justification for Change

Typically, an ungrounded AC circuit from an individual CPT will have multiple cables as a part of the circuit: one cable running from the motor control center (MCC) to the valve; one cable running from the MCC to the main control room; and possibly other cables running to interlock or permissive contacts. With this configuration, depending on the routing of the two cables, interactions between the two cables, either an inter-cable hot short or a GFEHS, can cause a spurious operation. Either of these circuit failure types would be classified as "plausible." In addition, ungrounded CPT configurations may have conductors from both legs (i.e., positive and neutral) leaving the MCC. In these configurations, if either CPT conductor is grounded due to fire damage, the likelihood of hot shorts on the opposite ungrounded conductor from aggressor circuits changes from only those conductors powered by the individual CPT to any grounded aggressor circuit (i.e., grounded by the fire or grounded by design). This configuration would make the hot short probability closer to that of ungrounded distributed AC and ungrounded DC.

For the "special case" where the target conductor required for the spurious operation is isolated from any other conductors associated with the CPT powering the circuit, a single inter-cable hot short or a GFEHS cannot cause a spurious operation. This "special case" is described below with supporting Figures 3-1 through 3-4.

- For this "special case," a spurious operation cannot be caused by a single inter-cable hot short (or GFEHS) since there is no aggressor conductor from the same CPT with the potential to interact with the target conductor that can be affected by the same fire; refer to Figure 3-1.

- For a spurious operation to occur, either two inter-cable hot shorts or an inter-cable hot short in combination with a GFEHS from a common power source would be required; refer to Figure 3-2.

- If the aggressor circuit were a grounded AC circuit, then a spurious operation could occur with one inter-cable hot short and a ground; refer to Figures 3-3 and 3-4.

This latter combination of fire-induced circuit failures is similar to the types of circuit failures required to cause a spurious operation in a double break designed circuit. Therefore, for this special case of an isolated target conductor, the classification is the same as for the similar double break designed circuits. Refer to the technical justification in Section 3.2.1.4. Without an isolated target conductor, the classification is "plausible."

Summary of Chapter 3 Figures

- Figure 3-1: Sub-Case 1 – Single Inter-cable Hot Short
- Figure 3-2: Sub-Case 2 – Multiple Inter-cable Hot Shorts or Single Inter-cable Hot Short and GFEHS
- Figure 3-3: Sub-Case 3a – Inter-cable Hot Short and Ground
- Figure 3-4: Sub-Case 3b – Inter-cable Hot Short and Ground [Reverse Polarity]

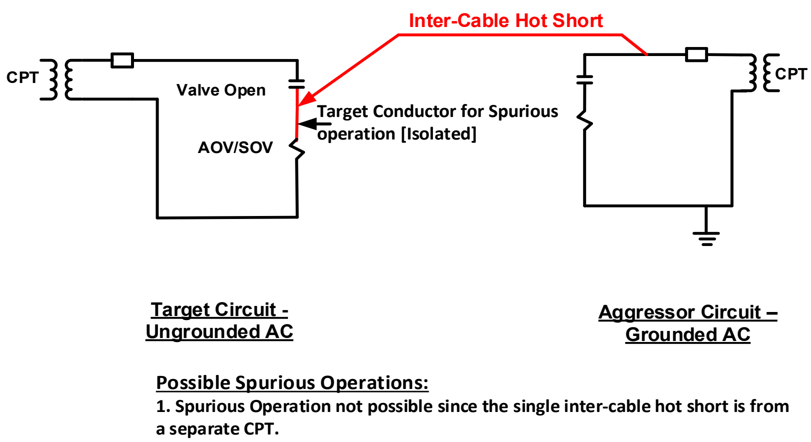


Figure 3-1 Sub-Case 1 – Single Inter-cable Hot Short

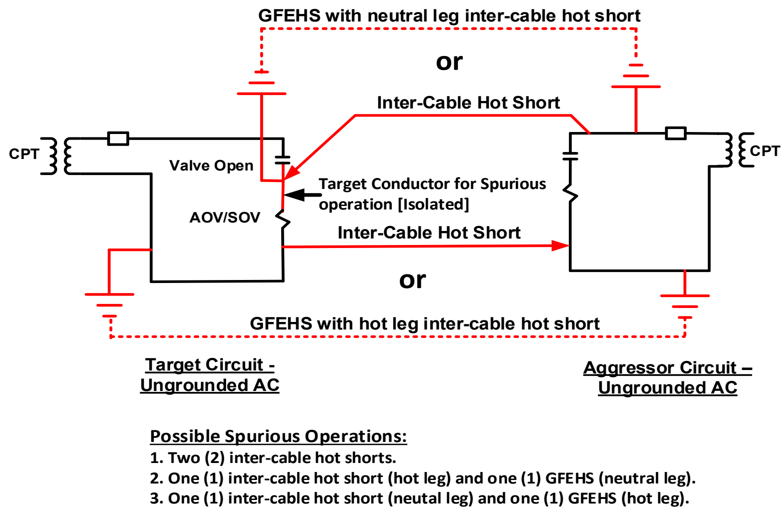


Figure 3-2 Sub-Case 2 – Multiple Inter-cable Hot Shorts or Single Inter-cable Hot Short and GFEHS

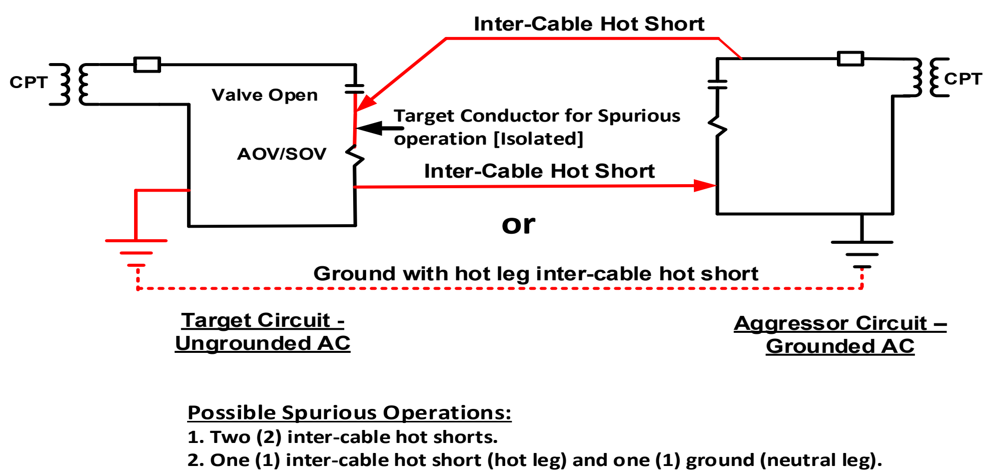


Figure 3-3 Sub-Case 3a – Inter-cable Hot Short and Ground

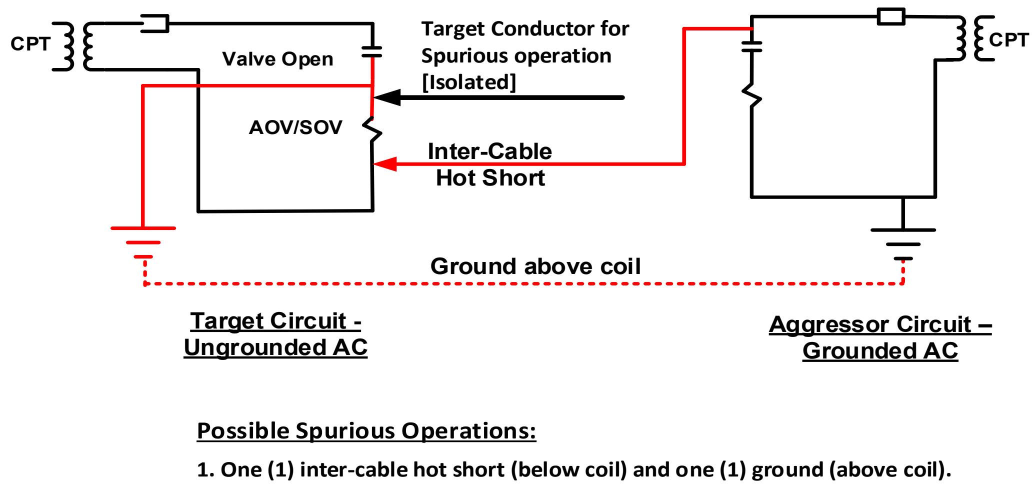


Figure 3-4 Sub-Case 3b – Inter-cable Hot Short and Ground [Reverse Polarity]

Table 3-1 Failure Modes for Single Break Control Circuits

Power Supply	Grounded AC		Ungrounded AC (from common CPT[4] or Distributed) or DC		
	Conductor Hot Short Failure Mode				
Target Cable Configuration	**Intra-Cable**	**Inter-Cable**	**Intra-Cable**	**Inter-Cable**	**Ground Fault Equivalent**
Thermoset Insulated Conductor Cable	Plausible	Plausible[5,6]	Plausible	Plausible[7]	Plausible
Thermoplastic Insulated Conductor Cable	Plausible	Plausible[6]	Plausible	Plausible	Plausible
Metal Foil Shield Wrap Cable[8]	Plausible	Incredible	Plausible	Incredible[9]	Plausible
Armored Cable[8]	Plausible	Incredible	Plausible	Incredible[10]	Plausible

[4] Ungrounded AC from common CPT included with distributed ungrounded AC and ungrounded DC. Refer to Section 3.2.1.3. For the classification of the special case of an isolated target conductor also refer to Section 3.2.1.4.
[5] Classification from JACQUE-FIRE Volume 1 changed from "implausible" to "plausible". Refer to Section 3.2.1.2.
[6] If the cable has a grounded, uninsulated drain wire, this configuration is classified as "implausible."
[7] Classification from JACQUE-FIRE Volume 1 changed from "implausible" to "plausible". Refer to Section 3.2.1.2.
[8] Robust metal foil shield wraps and armor for all of the cables in this row must be grounded. Robust metal foil shield wraps must be of substantial physical characteristics (e.g., a zinc or copper spirally wound tape rather than a Mylar overwrap.)
[9] The shield wrap or the armor prevents a conductor from an external cable from interfacing directly with the target conductor. A GFEHS on the metal foil shield or armor, however, can cause a spurious operation. The plausibility of this phenomenon is addressed in the column for Ground Fault Equivalent.
[10] The shield wrap or the armor prevents a conductor from an external cable from interfacing directly with the target conductor. A GFEHS on the metal foil shield or armor, however, can cause a spurious operation. The plausibility of this phenomenon is addressed in the column for Ground Fault Equivalent.

Table 3-2 Failure Modes for Double Break Control Circuits

Target Cable Configuration	Intra-Cable & Intra-Cable	Intra-Cable & Inter-Cable	Inter-Cable & Inter-Cable	Intra-Cable & Ground Fault Equivalent	Inter-Cable & Ground Fault Equivalent
Thermoset Insulated Conductor Cable	Plausible	Plausible[11]	Incredible	Plausible	Implausible (latching)[12] Incredible (non-latching)
Thermoplastic Insulated Conductor Cable	Plausible	Plausible	Implausible (latching)[13] Incredible (non-latching)	Plausible	Implausible (latching)[14] Incredible (non-latching)
Metal Foil Shield Wrap Cable[15]	Plausible	Incredible[16]	Incredible	Plausible	Incredible
Armored Cable[15]	Plausible	Incredible[17]	Incredible	Plausible	Incredible

Table 3-2 includes single break control circuits with control power fuses removed.
Table 3-2 also addresses the following circuit types: Ungrounded AC (from common CPT or distributed) or DC

[11] Classification from JACQUE-FIRE Volume 1 changed from “implausible” to “plausible”. Refer to Section 3.2.1.2.
[12] Classification from JACQUE-FIRE Volume 1 changed to “implausible” for latching circuits and “incredible” for non-latching circuits. Refer to Section 3.2.1.4. For TS and TP insulated conductors, if the aggressor circuit is a grounded AC circuit, an inter-cable hot short and a ground could cause a spurious operation. This configuration has been evaluated in Section 3.2.1.4. The evaluation concluded that even for the case of an aggressor grounded AC circuit, the classification would remain as “implausible” for latching circuits and “incredible” for non-latching circuits.
[13] Classification from JACQUE-FIRE Volume 1 changed to “implausible” for latching circuits and “incredible” for non-latching circuits. Refer to Section 3.2.1.4.
[14] Classification from JACQUE-FIRE Volume 1 changed to “implausible” for latching circuits and “incredible” for non-latching circuits. Refer to Section 3.2.1.4. For TS and TP insulated conductors, if the aggressor circuit is a grounded AC circuit, an inter-cable hot short and a ground could cause a spurious operation. This configuration has been evaluated in Section 3.2.1.4. The evaluation concluded that even for the case of an aggressor grounded AC circuit, the classification would remain as “implausible” for latching circuits and “incredible” for non-latching circuits.
[15] Robust metal foil shield wraps and armor for all of the cables in this row must be grounded. Robust metal foil shield wraps must be of substantial physical characteristics (e.g., a zinc or copper spirally wound tape rather than an aluminized Mylar overwrap.)
[16] The shield wrap or the armor prevents a conductor from an external cable from interfacing directly with the target conductor. A GFEHS on the metal foil shield or armor, however, can cause a spurious operation. The plausibility of this phenomenon is addressed under the column for Intra-Cable & Ground Fault Equivalent.
[17] The shield wrap or the armor prevents a conductor from an external cable from interfacing directly with the target conductor. A GFEHS on the metal foil shield or armor, however, can cause a spurious operation. The plausibility of this phenomenon is addressed under the column for Intra-Cable & Ground Fault Equivalent.

3.2.1.4 Classification of Two Inter-Cable Hot Shorts for a Bouble Break Designed Circuit Whit Themoplastic Insulated Conductors

In Table 3-3 of JACQUE-FIRE Volume 1, the PIRT Panel deferred classifying the case of two inter-cable hot shorts for a double break designed circuit with TP insulated conductors until the PRA Expert Panel completed their quantitative likelihood of occurrence work. This case and other similar cases were reviewed by the working group based on insights gained from JACQUE-FIRE Volume 2 to determine the appropriate classification based on their likelihood of occurrence. As a result of this review, recommended classifications of “implausible” for latching circuits and “incredible” for non-latching circuits were developed. This classification was applied to other circuit failure types with similar likelihood of occurrence. Refer to Table 3-2.

Reason for Change

The PIRT Panel, in Table 3-3 of JACQUE-FIRE Volume 1, deferred classifying the case of two inter-cable hot shorts for a double break designed circuit with thermoplastic insulated conductors. Insights provided by the PRA Expert Panel in JACQUE-FIRE Volume 2 provide additional information that used to develop a classification for this case. Based on the PRA Expert Panel results, the working group recommends a classification of "implausible" for latching circuits and "incredible" for non-latching circuits for the deferred case.

- The case of a double break designed circuit subjected to two inter-cable hot shorts with TP insulated target conductors

The working group identified three additional cases where the classifications in JACQUE-FIRE Volume 1 were inconsistent with the numerical estimates in JACQUE-FIRE Volume 2. The classification of “implausible” for latching and “incredible” for non-latching circuits is recommended by the working group for these cases listed below.

- The case of a double break designed circuit subjected to one inter-cable hot short and one GFEHS with TS insulated target conductors

- The case of a double break designed circuit subjected to one inter-cable hot short and one GFEHS with TP insulated target conductors

- The special case of an ungrounded AC single break designed circuit from a common CPT with an isolated target conductor as described in Section 3.2.1.3.

Technical Justification for Change

Double break designed circuits with TS and TP insulated conductors were specifically tested in the DESIREE-FIRE test program for the occurrence of inter-cable hot shorts. The inter-cable testing performed under the DESIREE-FIRE testing program is discussed in Section 6.5 and Appendix A.5 of the DESIREE-FIRE report (Ref. 9). Although a limited number of single cable-to-cable interactions did occur, there were no instances where the two cable-to-cable interactions required to produce a spurious operation occurred. This testing forms a solid basis for concluding that the occurrence of two inter-cable hot shorts on a double break designed circuit with TS insulated conductors is “incredible.” In Penlight Test #47 of the DESIREE-FIRE testing (Ref. 9), however, which used TP insulated conductors, there were signs of a voltage cascade across the target conductors starting to form, but the voltage was insufficient to cause a spurious operation. This result suggests that the likelihood of two inter-cable hot shorts in double break designed circuits with TP insulated conductors is slightly more likely than for TS insulated conductors. Based on this, the case of a double break design with two inter-cable hot shorts with TS insulated conductors is classified as “incredible” and the case of a double break design with two inter-cable hot shorts with TP insulated conductors is classified as “incredible” for non-latching circuits and “implausible” for latching circuits.

Other than in the DESIREE-FIRE inter-cable testing described above, the double break configuration with TP target and aggressor (source) cables was not specifically tested in any of the other cable fire tests. In general, TP insulated cables were shown to be exposed at a lower threshold temperature than their counterpart TS insulated cables. In a configuration with exposed conductors, there are two possible outcomes: (1) the exposed conductors can short to reference ground removing the potential from the circuit; and (2) the exposed conductors (target) could contact exposed conductors from adjacent cables (i.e., source) transferring potential and, if the potential has the correct characteristics, a spurious operation could result. In the cable fire testing, only a few instances of inter-cable hot shorts between TP insulated cables were observed. With respect to double break designed circuits, the testing cited above provides a good basis for the classification of circuit failure modes involving two inter-cable hot shorts in cables with either TS or TP insulated conductors. Due to a lack of specific testing performed, with respect to circuit failure modes involving one inter-cable hot short and one ground fault equivalent hot short (or a ground for the case of a grounded AC aggressor circuit), the insights for classifying this circuit failure type comes from the information provided by the PRA Expert Panel in JACQUE-FIRE Volume 2 (Ref. 12).

The possible failure modes for double break designed circuits involving an inter-cable hot short and a GFEHS (or a ground in the case of a grounded AC aggressor circuit) are depicted in Appendix C, Figures C-1 through C-6 of this report. Figures C-1 through C-6 include: (1) actual double break designed circuits which use an open contact above and below the actuating device and (2) “pseudo” double break designed circuits which are single break design circuits with their control power fuses removed giving them similar characteristics for preventing spurious actuation to the actual double break designed circuits.

The cases shown in Figures C-1 through C-6 depict potential spurious operations resulting from one inter-cable hot short and one GFEHS or, in the case of a grounded AC aggressor circuit, one inter-cable hot short and one ground. These figures also depict double break designed circuits and "pseudo" double break designed circuits.

All of the cases depicted in Figures C-1 through C-6 require multiple fire-induced circuit failures for a spurious operation to occur. Each case involves, at least, one inter-cable hot short and either a GFEHS, or a ground for a grounded AC aggressor circuit. Since each case involves an inter-cable hot short coupled with a ground path back to a common power source and since, conductors in both the aggressor and target circuits must be exposed, i.e., conductor insulation burned off, grounding of the conductor providing the inter-cable hot short is highly likely. With the insulation removed from the conductor providing the inter-cable hot short and with the need for the involvement of a ground path back to the common power source, it is highly likely that the exposed conductor will, by some means, contact the ground plane resulting in a fuse blow on the aggressor circuit.

The bounding cases, i.e., those with the highest probability of occurrence, for this phenomenon are those involving a grounded AC aggressor circuit and a grounded AC circuit for which the aggressor cable does not have a ground conductor. This configuration provides a more challenging path to ground for the exposed conductor providing the inter-cable hot short. Additionally, a “pseudo” double break designed circuit would bound a true double break designed circuit, since in the “pseudo” double break designed circuit, there would be more than one conductor below the coil that could ground and provide a return ground path for the inter-cable hot short to the common power supply.

Even for this bounding configuration, the classification of "implausible" for latching circuits and "incredible" for non-latching circuits is justified for the reasons cited below.

With respect to the case of a grounded AC aggressor circuit, involving an inter-cable hot short in combination with a ground on the target circuit (which completes the circuit path to the aggressor circuit), the inter-cable hot short must come from a specific circuit type, i.e., a grounded AC circuit. Additionally, the inter-cable hot short from the aggressor (source) grounded AC circuit cannot go to ground prior to the ground forming on the target circuit. Once the inter-cable hot short on the aggressor (source) grounded AC circuit goes to ground, the control power fusing on the aggressor circuit will blow and remove the potential for the spurious operation. This circuit failure timing consideration, in combination with the likelihood of circuit grounds and the low likelihood of these two specific circuit types from a common power source both becoming involved simultaneously with the target circuit, makes this combined failure mode much less likely, supporting a failure mode classification of “implausible.”

Even if the ground plane does not exist within the aggressor cable, the lack of a ground plane would have limited impact on the likelihood of occurrence, since with the conductors exposed on both the aggressor and target circuit, the potential for an interaction with the ground plane is high. Finally, even if the target circuit is a “pseudo” double break designed circuit, there are still a limited number of conductors in the target circuit with the potential to provide the return ground path. Therefore, even for this type of circuit, very specific circuit failure types on very specific circuit conductors must occur concurrently for the spurious operation to occur. Note that for target circuits of the “pseudo” double break design in distributed AC or DC systems, only those conductors on either side of the coil can provide the required potential and the required return ground path. This is true since all other conductors in the distributed system are isolated from the coil by the removal of the control power fuses.

The circuit failures described in the paragraph above have been further evaluated and classified using insights from JACQUE-FIRE Volume 2 and information from the industry and NRC fire testing. Given that a single inter-cable hot short for TP insulated cables is unlikely, when this failure mode must be combined with another unlikely failure mode, i.e., a GFEHS, in order for the spurious operation to occur, the working group concluded that coupling these unlikely failure types together would make the occurrence significantly less likely. For two inter-cable hot shorts or the combination of one inter-cable hot short and one ground equivalent hot short, the very low likelihood of these combined failures occurring at the same time for the same circuit, has led to a classification of “implausible” for this combination of circuit failure types. When the limited duration aspects of each of these circuit failure types is factored in, the likelihood of occurrence of a spurious operation, for either of the configurations discussed above, becomes even less likely. For the case of a grounded AC aggressor circuit, specific conductors from both the target and aggressor circuits must become involved concurrently in a specific way. Based on these factors, a classification of “implausible” is justified for each of the configurations discussed above for a latching circuit. This classification is consistent with the definition of “implausible” in that, while the combinations discussed above are theoretically possible, their occurrence would require the convergence of a combination of factors that are so unlikely that the phenomenon can be considered statistically insignificant.

For non-latching circuits, when the two circuit failures are required to co-exist, the spurious operation will not occur without concurrent existence of the failures. Additionally, if either of the two circuit failures terminates, the spurious operation will also terminate. Based on this set of conditions, the occurrence of a spurious operation in a non-latching circuit is judged to be even less likely by the working group.

For a spurious operation in a non-latching circuit to occur, the same convergence of a combination of unlikely circuit failure types required for a latching circuit must occur. Additionally, the unlikely combination of circuit failure types must co-exist. With regard to the concurrence, testing has shown that hot shorts do not last for long periods of time and the insulation resistance tends to cascade quickly (avalanche) at the onset of fire induced cable damage from a severe thermal exposure. Given the relatively short duration of circuit failure modes observed during testing and the stochastic nature of cable failures associated with the timing of the onset of the cable failure mode, the required combination of the two circuit failure types co-existing at the same time and on the required conductors is extremely unlikely. In fact, testing performed under the DESIREE-FIRE cable fire testing program specifically aimed at testing for the occurrence of two hot shorts causing a spurious operation in a double break designed circuit found no spurious operations (Section 6.5 and Appendix A.5 of Reference 9). Although the DESIREE-FIRE testing did not specifically test for the combination of an inter-cable hot short and a GFEHS, this combination of failures is similar to those tested and the combination was not observed to occur in any other industry or NRC cable testing programs. Based on this, the working group recommends that these non-latching circuit failure types be classified as “incredible” for either of the configurations discussed above. This classification is consistent with the definition of “incredible” in that: (1) the testing performed in an attempt to demonstrate the occurrence of this phenomenon could find no evidence of the phenomenon ever occurring; and (2) there were no credible engineering principles or technical arguments to support its happening during a fire.

Based on the arguments provided above, a classification of “implausible” for latching circuits and “incredible” for non-latching circuits applies to the three cases below:

- Double break designed circuits with TP insulated target cables subjected to two inter-cable hot shorts.

- Double break designed circuits with TP or TS insulated target cables subjected to one inter-cable hot short and one GFEHS.

The case of an aggressor grounded AC “pseudo” double break designed circuit with no ground conductor in the aggressor cable and with the target circuit being either an ungrounded AC or DC circuit is considered to be the bounding case. Even for this bounding case, however, the classification of “implausible” for latching circuits and “incredible” for non-latching circuits still applies.

- The special case of an ungrounded AC circuit from a common CPT with isolated target conductors. Refer to the Section 3.2.1.3 for additional information related to this case.

3.3 Conclusions

The PIRT Report (Ref. 1) classifies numerous circuit types and configurations with respect to fire-induced vulnerability. For this purpose, three categories were created – incredible, implausible, and plausible. The classification was performed based on the PIRT Panel members’ knowledge, operating experience and interpretation of test results. Subsequent to the original classification, the PRA Expert Panel conducted additional refinement of test data and statistical analysis, which led to development of conditional probabilities for a variety of cases, as documented in JACQUE-FIRE Volume 2 (Ref. 12). The PRA Expert Panel’s work produced additional information that was not available when the PIRT Panel made their original recommendations. Based on the collective data and insights from the PIRT Panel and PRA Expert Panel, the working group re-assessed the original circuit failure classifications to:

- Ensure consistency between the PIRT and PRA Expert Panel reports
- Change the classification as appropriate and supported by the more complete set of test data
- Provide classification for cases deferred in the original classification effort

The updated recommendations represent a consensus opinion among the working group members and promotes consistent failure mode classification. Table 3-3 and Table 3-4 summarize the working group’s recommendations for classification changes. Table 3-5 identifies the recommended classification for new circuit failure modes. Where differences exist between the recommendations in this report and the PIRT Report (Ref. 1), the recommendations contained in this report represent the current state-of-knowledge and should be used.

Table 3-3 Summary of Changes to Circuit Failures Originally Classified as Incredible

Incredible Circuit Failure Types as Determined by PIRT Panel *[Section numbers from JF Vol. 1]*	**Updated Circuit Failure Types as Determined by the working group** *[Section numbers from JF Vol. 3]*
1. 3-phase hot shorts for AC motors *[Section 4.2]*	No change.
2. Consequential hot shorts for DC compound motors *[Section 4.3]*	No change.
3. Multiple high impedance fault (provided the criteria of NEI 00-01 Revision 2 (Ref. 6) are met) *[Section 6.1]*	No change.
4. Secondary fires from an open circuited CT with turns ratio of 1200:5 or less *[Section 6.2]*	The working group recommends no further consideration of secondary fires as a result of CT failures for low and medium voltage switchgear. Refer to Section 7 of this report for exceptions.
5. Single break design – inter-cable hot short with TP – source cable/TS – target cable *[Section 3.3.2, Table 3-3]*	The working group consolidated this item since it relies upon the insulation characteristics of the source conductor. *[Section 3.2.1.1]* For a single break design on a thermoset insulated cable, the working group reclassified the item as "plausible." *[Section 3.2.1.2]*
6. Double break design – inter-cable hot shorts with: a. TP – source cable / TS – target cable b. TS – source cable / TS – target cable *[Section 3.3.2; Table 3-3 and Table 3-6 and Table 3-7]*	The working group consolidated this item since it relies upon the insulation characteristics of the source conductor. *[Section 3.2.1.1]* For two inter-cable hot shorts on thermoset insulated cables, the working group agrees with a classification of "incredible" for this item. *[Section 3.2.1.4]*
7. Double break design – ungrounded DC (or ungrounded distributed AC) – 1 inter-cable hot short + 1 GFEHS TS – target cable / TS – source cable *[Section 3.3.2; Table 3-3 and Table 3-7]*	The working group consolidated this item since it relies upon the insulation characteristics of the source conductor. *[Section 3.2.1.1]* For latching circuits, the working group has re-classified the circuit failure type as "implausible." For non-latching circuits, the working group recommends maintaining the original classification of "incredible." *[Section 3.2.1.3]*
8. Single or double break circuit designs involving at least one inter-cable hot short with the target cable including: a. A grounded metal, foil shield wrap, or b. A grounded armored cable design *[Section 3.4.1; Figure 3-5, 3-6, and 3-7, Table 3-6 and Table 3-7]*	No change.

Table 3-4 Summary of Changes to Circuit Failures Originally Classified as Implausible

Implausible Circuit Failures Types as Determined by PIRT Panel (Consider for components classified as "high impact") *[Section numbers from JF Vol. 1]*	**Updated Circuit Failure Types as Determined by the working group** *[Section numbers from JF Vol. 3]*
1. Single break design – inter-cable hot short with TS – target cable / TS – source cable *[Section 3.3.2; Figure 3-5 and 3-6; Table 3-3, 3-6 and 3-7]*	The working group consolidated this item since it relies upon the insulation characteristics of the source conductor. *[Section 3.2.1.1]* The working group reclassified to "plausible." *[Section 3.2.1.1]* This re-classification is applicable to all cases except for the special consideration cases described for ungrounded AC from a CPT. *[Section 3.2.1.3]*
2. Double break design – inter-cable hot shorts with TP – target cable / TS – source cable *[Section 3.3.2; Table 3-6 and 3-7]*	The working group consolidated this item since it relies upon the insulation characteristics of the source conductor. *[Section 3.2.1.1]* The working group agrees with the classification of "implausible" on this item for latching circuits. For non-latching circuits, the working group agrees to the classification of "incredible." *[Section 3.2.1.4]*
3. Double break design – ungrounded DC (or ungrounded distributed AC) – 1 inter-cable hot short + 1 GFEHS TP – target cable / TS – source cable *[Section 3.3.2 and Table 3-7]*	The working group consolidated this item since it relies upon the insulation characteristics of the source conductor. *[Section 3.2.1.1]* The working group agrees with the classification of "implausible" for latching circuits. For non-latching circuits, the working group agrees to the classification of "incredible." *[Section 3.2.1.4]*
4. Single break design a. Inter-cable hot short with the target cable including an un-insulated grounded drain wire for grounded AC circuit. *[Section 3.4.1; Figure 3-5]*	No change.

Table 3-5 Classification of Additional Failure Modes

New Circuit Failure Types (Consider for all affected safe shutdown components)	**Updated working group recommendations on Circuit Failure Type**
1. GFEHS (in ungrounded circuits)	The working group agrees with the "plausible" classification.

4
TECHNICAL RECOMMENDATIONS FOR SHORTING SWITCH APPLICATIONS

In response to MSO concerns, a limited number of licensees have used shorting switches as a design feature to protect against hot short-induced spurious operations caused by fire damage. An NEI task force developed guidance on the use of a shorting switch that was intended for future inclusion in NEI 00-01 as Appendix I (Ref. 13). The purpose was to provide generic guidance on the design, use, and implementation of shorting switches to protect against the spurious operation concerns. NEI and NRC discussed Appendix I at several public meetings however, a clear path forward to achieve consensus was not evident.

As an alternative approach for resolution of this issue, the NRC and industry agreed that the JACQUE-FIRE working group should investigate the issue. Starting with the original NEI guidance (draft Appendix I), the working group provided supplemental technical information that, in combination with the original guidance, provide a comprehensive set of design considerations and recommendations for the reliable use and application of shorting switches. Diligent use of the shorting switch guidance, with special attention to the application circumstances and conditions, ensures that the design and installation factors are properly considered and will result in effective implementation of shorting switch modifications. The technical considerations included:

- Circuit design considerations
    - Circuit attributes, e.g. remotely-operated valve; seal-in circuit; automatic operation circuit

- Electrical design considerations
    - Target coil minimum pick-up voltage
    - Potential credible aggressor sources
    - Computation of maximum expected voltage/current through target coil

- Circuit continuity considerations
    - Cabinet fires
        - Fire spread between electrical enclosures
        - Fire damage to shorting switch and related components
    - Fire-induced open circuits
        - Fire damage
        - Energetic arcing from nearby fire damaged cables
    - Additional mitigating measures
        - Shorting switch with additional redundancy
        - Shorting switch to add time delay for operator manual actions
        - Shorting switch to increase sequential failures leading to a spurious operation

Technical considerations are provided here for the design of circuits containing shorting switches. However, there are a number of technical factors where specific implementing criteria could not be provided (e.g., circuit continuity for cabinet fires and potential collateral damage from associated circuits contained in the same raceway). The inability to supply specific implementing criteria in these areas is a direct result of the current state of knowledge and the numerous plant configurations and potential exposure conditions present throughout the nuclear power industry.

4.1 Background

The recommended design features of the shorting switch take advantage of recent developments in cable fire testing and cable failure modes research, and provide a design capable of averting fire-induced spurious operation, given credible fire conditions. A licensee's current licensing basis may limit a licensee's ability to use shorting switches without additional licensing actions.

The shorting switch functions to prevent spurious operation of a component by placing a short across a coil in the circuit of concern when the circuit is in its "standby" state. When the component is desired to be operated, the motion of the hand switch removes the short before energizing the coil to actuate the component. Any circuit using a shorting switch should have this feature of removing the short provided by the shorting switch prior to energizing the coil (i.e., break-before-make).

Figure 4-1 shows a simplified MOV circuit. R and G signify green and red indicator lamps; C and O signify the close and open coils. The circuit is shown with the MOV in the closed position (green lamp lit). If the main control room hand switch (HS) is placed in the open position, the HS open contact will shut causing the open relay to energize resulting in the MOV stroking open. The 33L and 33U contacts (limit switch contacts dependent on valve position), change states with 33U closed (red lamp) and the 33L open (green lamp).

To produce a spurious operation during a fire, a hot short would have to provide power to the close or open relays; therefore, the hot short would need to provide power downstream of either the "HS close" or "HS open" contacts. If the valve was originally in the closed position, a hot short downstream of the HS open contact would cause the valve to reposition open. If the valve were originally in the open position, a hot short, downstream of the HS close contact would cause the valve to reposition "closed."

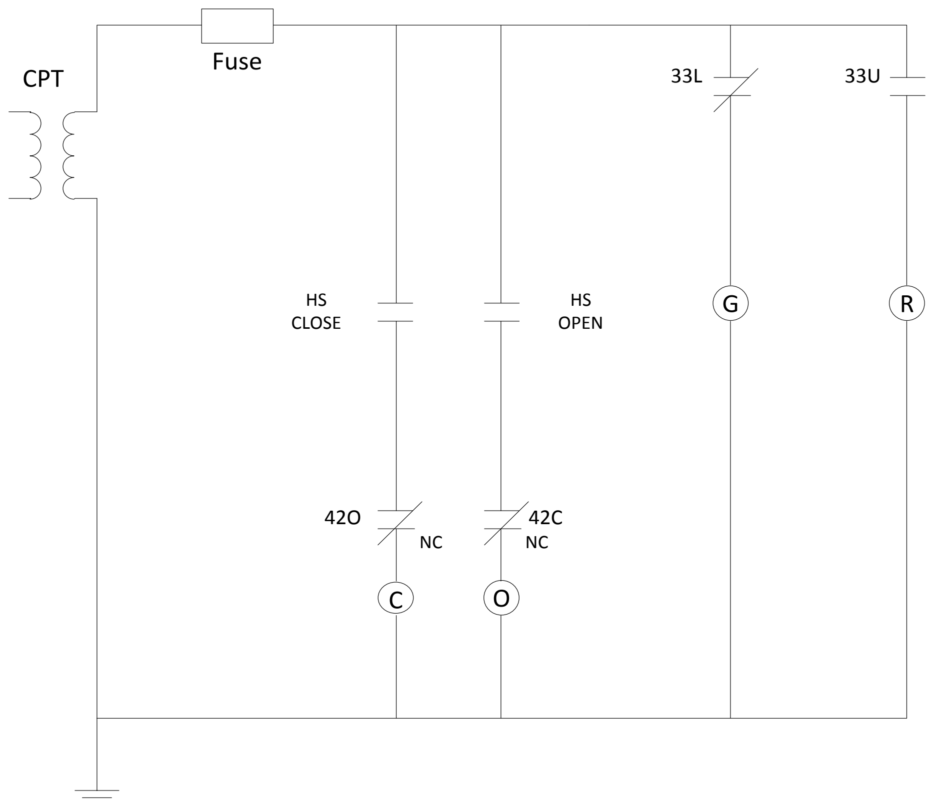


Figure 4-1 Simplified MOV Circuit

For the safe shutdown analysis, there are desired and undesired valve positions. The concern is that the valve could reposition due to a hot short-induced spurious operation during a fire. For the purposes of this discussion, the valve is assumed to be in the closed position, and the goal is to prevent the valve from repositioning to the open position. That is, the valve is initially in the closed position and it is desired to remain in the closed position for the safe shutdown analysis. To accomplish this, the shorting switch is placed in the circuit, so that a hot short downstream of the HS open contact will have no impact on the circuit. See Figure 4-2.

If a hot short occurs between the HS open contact and the open relay coil, the electrical potential will be shorted to ground through the closed shorting switch contact. This action by the shorting switch prevents the valve from repositioning to the undesired open position. When it is desirable to position the valve in the open position, the operator will manually reposition the shorting switch such that the shorting switch contact will change state from closed to open. The shorting switch itself could be a separate switch, or it could be a third position on the same switch that operates the HS open or HS close contacts. If it is the same switch, then, if it is desirable to open the valve, the operator will simply move the switch from the position that closes the shorting switch contact and place it in the open position.

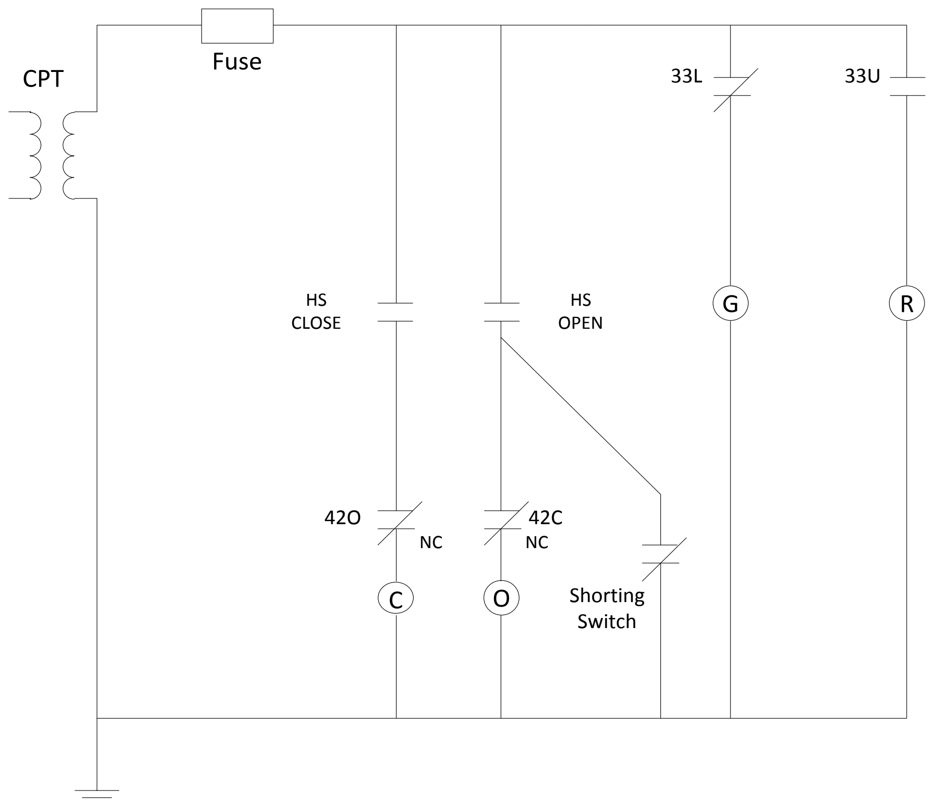


Figure 4-2 Simplified MOV Circuit with Shorting Switch

Another important consideration for the design of the shorting switch is that it should be electrically designed to short the potential from an aggressor[18] circuit away from the target coil, which if energized, could spuriously operate the component.

Finally, as shown in Figure 4-3, the proper functioning of the shorting switch is completely dependent on maintaining the integrity of the shorting switch and other associated components, e.g., terminal blocks and conductors, necessary to maintain the continuity of the shorting path. An open circuit in the shorting path would eliminate the protection provided by shorting switch in preventing a spurious operation. Even with the presence of an open circuit, a spurious operation of the component will not occur without the presence of a subsequent hot short.

Therefore, crediting the shorting switch for preventing a fire-induced spurious operation in a location where the shorting switch and other associated components are co-located with the fire, presents an additional challenge due to the potential for fire damage to the shorting switch and other related components required for proper circuit operation. For these conditions, some benefit in mitigating the impact to an overall spurious operation prevention strategy can be gained by including some measure of redundancy and/or time delay into the spurious operation

[18] The term "aggressor circuit" is used in this document to represent the circuit with the potential to cause a spurious operation of the target circuit. The term "aggressor cable" is used in this section to describe a cable of higher voltage or with a larger fuse size with the potential to cause an open circuit, capable of defeating the functionality of the shorting switch, in the target circuit due to common routing or physical proximity.

prevention strategy. Redundancy can be gained by using a shorting switch to increase the sequential number of failures necessary for the spurious operation to create a negative impact on post-fire safe shutdown, i.e., failure of the shorting switch is only one component in the sequence required to fail in order for adverse effects to occur. Additionally, a shorting switch could be used to increase the time until adverse impacts occur, thus allowing additional time for an operator action to be performed.

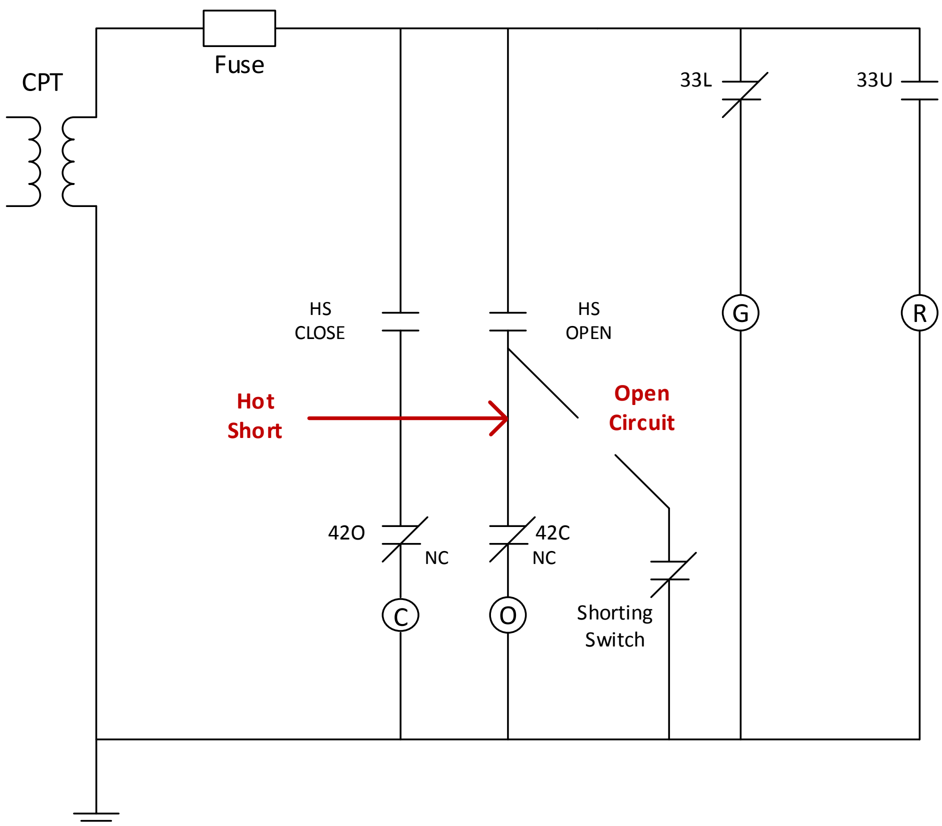


Figure 4-3 Simplified MOV Circuit with Shorting Switch & Open Circuit

The key to successful implementation of a shorting switch is to assess its use for specific cases and not attempt to implement a "one size fits all" approach. In this way, the number of uncontrolled variables can be reduced to a point that analyses can be conducted to demonstrate expected performance within definable limits. These considerations are discussed in more detail in Section 4.2.

4.2 Considerations on the Use of Shorting Switches

There are a number of considerations that should be addressed in the design of the shorting switch. Each of these considerations is discussed below. Those situations where the shorting switch is used solely as the means of mitigation should be examined very carefully to assure that all of the considerations have been rigorously addressed.

A checklist of these considerations for the licensing and design of a shorting switch and an example application of these considerations is provided at the end of this section.

4.2.1 Licensing Considerations

The effective use of the shorting switch is dependent on maintaining the integrity of the shorting path. A specifically located and sequenced open circuit could defeat the functioning of the shorting switch, as shown in Figure 4-3. Therefore, the potential for open circuits needs to be evaluated. This consideration renders the shorting switch modification to be less of a stand-alone modification than most electrical circuit modifications. The shorting switch modification relies heavily on an accompanying technical evaluation performed within the context of the post-fire SSD analysis to ensure that the switch can perform its function. This is largely due to the fact that a specifically located and sequenced open circuit must either not occur or, if one does, it must occur late in the fire event after aggressor circuits (that could cause the undesired hot short-induced spurious operation) have cleared. The licensee should ensure the technical evaluation and evaluation approaches are within the current licensing basis.

As described below, a plant's current licensing basis will affect the extent to which shorting switches may be used.

a. Performance-Based Compliance under National Fire Protection Association (NFPA) 805 (Ref. 18):

   Licensees who have transitioned to performance-based compliance under NFPA 805 for their fire protection program should be able to perform the necessary engineering evaluations using the available performance-based engineering tools (e.g., fire modeling) to assess the impact of credible fire conditions on each of the components in the shorting path and address their potential to cause an open circuit.

b. Deterministic Compliance under Appendix R (or Fire Protection License Condition):

   Through Regulatory Guide 1.189 Revision 2 (Ref. 27), NRC has endorsed the use of fire modeling for components classified as "important to safe shutdown." This endorsement allows the use of the types of engineering evaluations that are needed to assess the impact of credible fire conditions on each of the components in the shorting path and their potential to cause an open circuit. For example, fire modeling could be used to demonstrate:

   - fire damage to the shorting switch conductors (or other associated components) is insufficient to cause an open circuit
   - cables/components associated with the shorting switch are not damaged in the same fire scenarios that could also cause the hot short-induced spurious operation
   - mitigating capability for the spurious operation of concern (i.e., if the shorting switch failed and undesired spurious operation were to occur) is unaffected by the fire scenarios that result in loss of the intended function of the shorting switch.

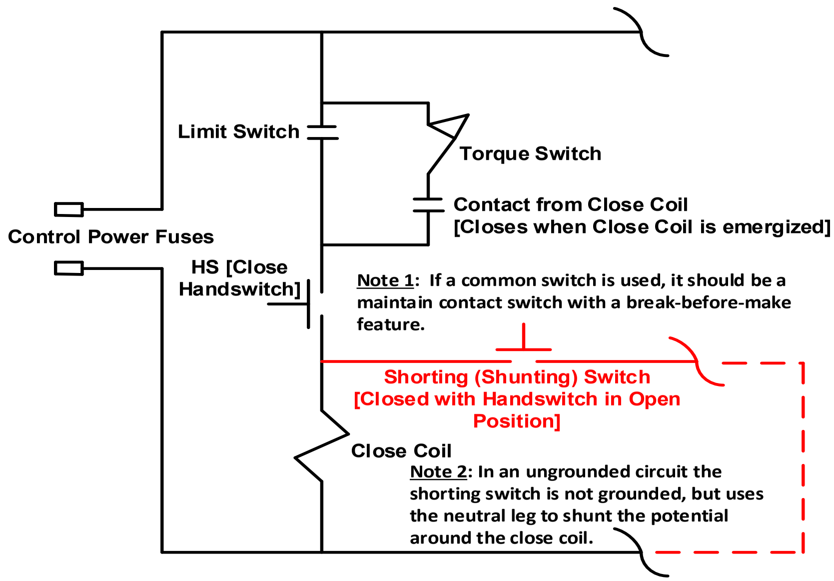
Conversely, Appendix R, Section III.G.2 (Ref. 19) requires consideration of fire-induced open circuits and this requirement would apply to any "required for hot shutdown component." Additionally, Appendix R, Section III.G.2.a through Section III.G.2.f does not include any allowance for fire modeling as a means of mitigating the effects of fire-induced circuit failures, including open circuits. As such, strict compliance with the deterministic requirements of Appendix R, Section III.G.2 for "required for hot shutdown components" would dictate the inclusion of open circuit as a design requirement for the shorting switch. A specifically located and sequenced open circuit could defeat the functionality of the shorting switch and render it ineffective in preventing a fire-induced spurious operation. For licensees in this category, the use of a shorting switch for a component classified as "required for hot shutdown" could necessitate an exemption or license amendment.

Finally, for alternative or dedicated shutdown under Appendix R, Sections III.G.3 and III.L, the classifications of "required for hot shutdown" and "important to safe shutdown" are not applicable. Appendix R, Sections III.G.3 and III.L neither preclude nor endorse the use of the type of engineering tools necessary to perform an engineering evaluation of a shorting switch.

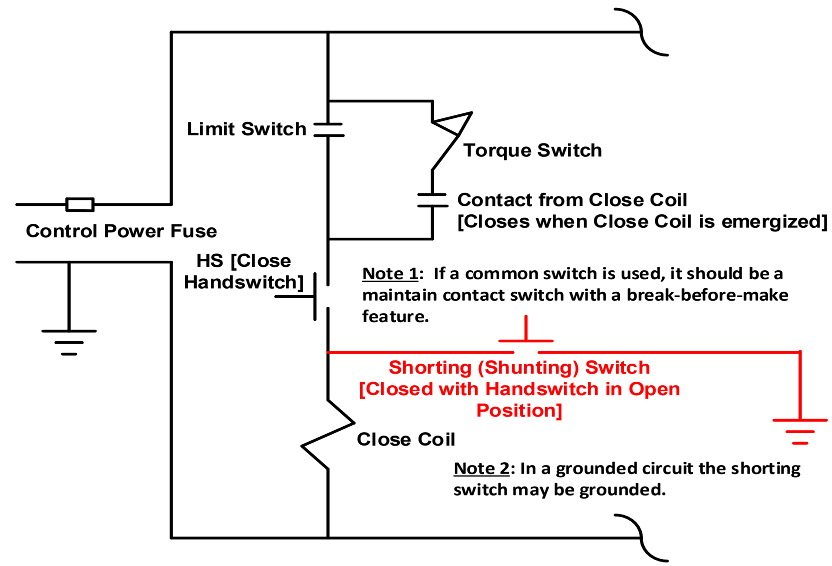
4.2.2 Circuit Design Considerations

Any circuit using a shorting switch should have a feature of removing the short provided by the shorting switch prior to energizing the coil (i.e., break-before-make). This is necessary in order to prevent the shorting switch from blowing the control power fusing for the circuit and preventing the circuit from being able to perform its required function. This latter consideration is a design and operational consideration as opposed to a fire safety consideration. Regardless, reconfiguration of a circuit for fire safety considerations should also address any design or operational considerations.

For simple circuit designs, such as remotely operated valves, the circuit design and shorting switch should be reviewed to confirm no operational impacts are created. For more complex circuit designs (such as remotely operated valves with seal-in, automatic function, etc.) a more thorough electrical circuit Failure Modes and Effects Analysis (FMEA) should be performed. The FMEA should focus on the operational aspects of the circuit and it should confirm that the addition of the shorting switch into the circuit will not create any unforeseen operational issues, e.g., unanticipated blown fuses or tripped breakers. Figures 4-4 through 4-6 present simplified examples to illustrate conceptual approaches for utilizing shorting switches within typical control circuits. More complex designs are possible, but the use of more complex shorting switch designs increases the burden on the designer to confirm that each of the features required for the successful operation of the shorting switch are identified and addressed. Figures 4-5 and 4-6 are examples needing an FMEA, if a shorting switch is added.



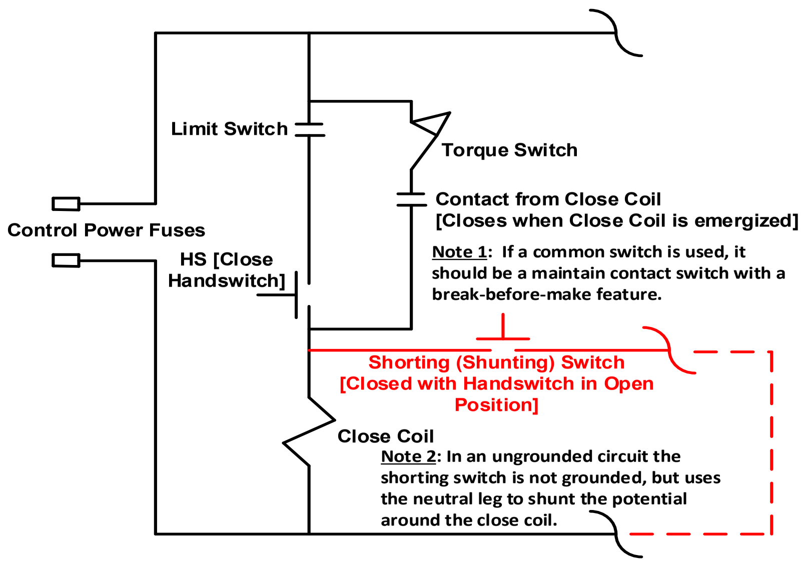
a) Shorting switch in an ungrounded DC operated valve without automatic operation features with no seal-in



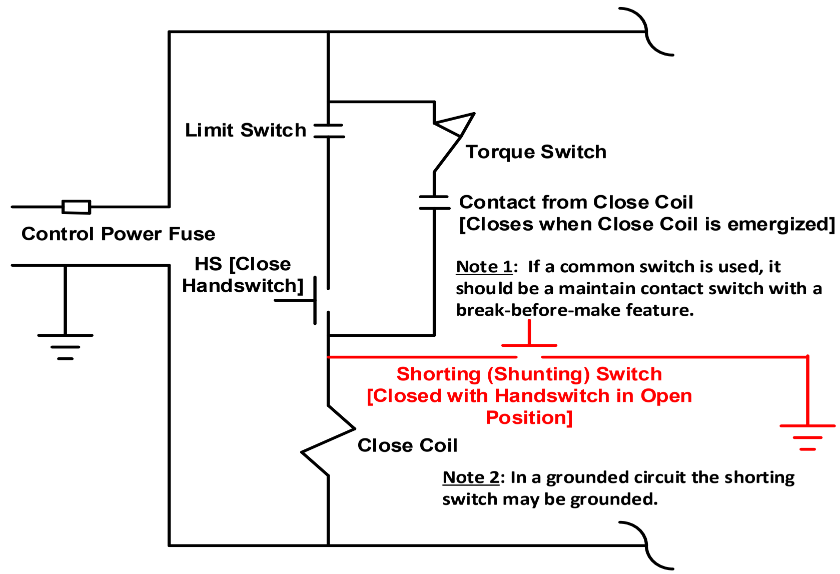
b) Shorting switch in a grounded AC operated valve without automatic operation features with no seal-in

Figure 4-4 Simplified Illustration of Shorting Switch in Control Circuits Without Seal-In Features

The shorting (shunting) switch in Figure 4-4 depicts a motor operated valve in a) an ungrounded DC circuit and b) a grounded AC circuit. The valve is normally open and the undesired state is a spurious closure of the valve. The shorting switch for this case would be designed to prevent the valve from spuriously closing by shorting (shunting) the potential applied by an aggressor circuit around the close coil bypassing the impedance (resistance) in the circuit and, thereby, blowing the fuse in either the aggressor (source) circuit (hot leg) or, in the case of the DC circuit, the targeted circuit (return leg). The valve has no automatic operation features that would automatically bypass the manual control switch and it does not have a seal-in around the close switch. If a common control/shorting switch is used, the manual control switch should be a maintain contact switch and it should have a break-before-make switch design to prevent the close switch and the shorting switch contacts on the manual switch from being closed simultaneously.



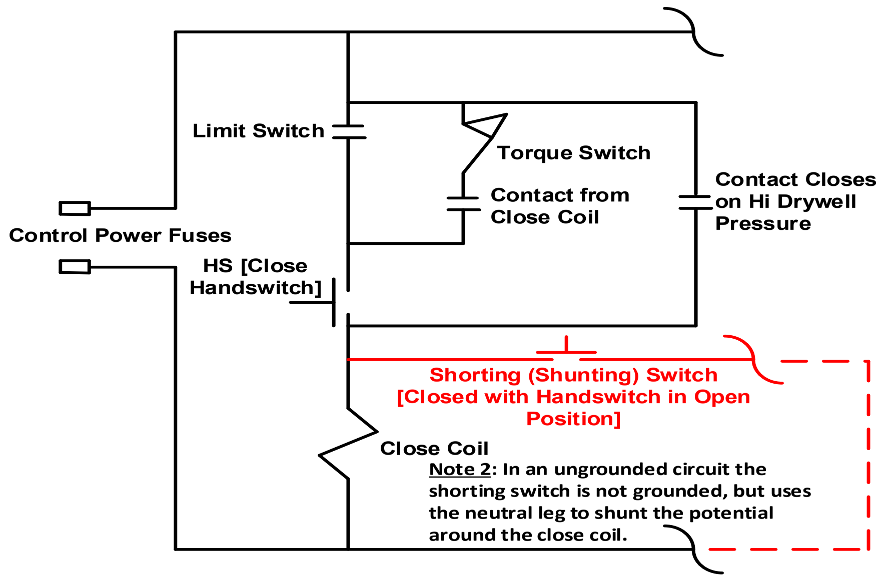
a.) Shorting switch in an ungrounded DC operated valve without automatic operation features with seal-in



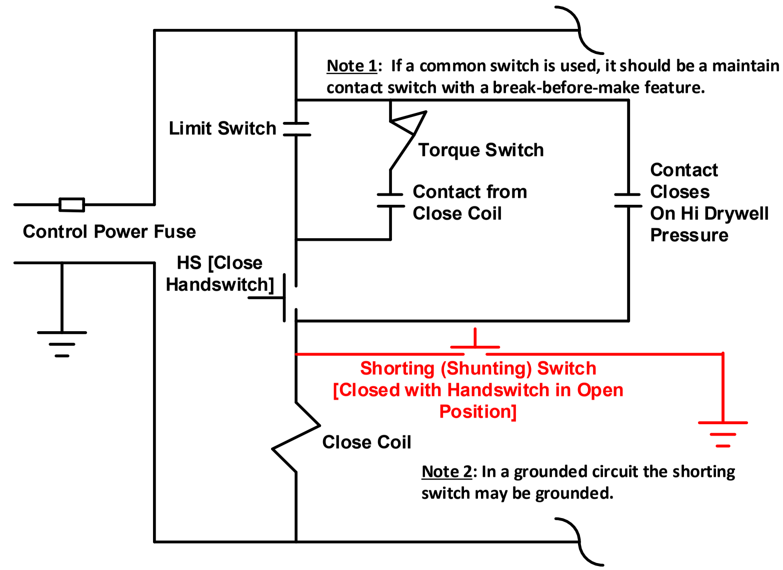
b.) Shorting switch in a grounded AC operated valve without automatic operation features with seal-in

Figure 4-5 Simplified Illustration of Shorting Switch in Control Circuits With Seal-In Features

The shorting (shunting) switch circuit in Figure 4-5 is similar to the circuit in Figure 4-4 with the following exception. The valve has no automatic operation features that would automatically bypass the manual control switch, but it does have a seal-in around the close switch. Even though the manual control switch is a maintain contact switch with a break-before-make switch design to prevent the close switch and the shorting switch contacts on the manual switch from being closed simultaneously, the seal-in feature of this circuit would make it a poor candidate for a shorting switch from an operational point of view, since the circuit control power fuses could be blown should the operator reverse the position of the manual control switch prior to the valve fully completing its stroke to the fully closed position. The use of a shorting switch as depicted above on a circuit like this is not recommended without additional circuit changes and without the development of an FMEA to address the operational consideration mentioned above.



a.) <u>Shorting switch in an ungrounded dc operated valve with automatic operation features with no seal-in</u>



b.) <u>Shorting switch in a grounded ac operated valve with automatic operation features with no seal-in</u>

Figure 4-6 Simplified Illustration of Shorting Switch in Control Circuits With Automatic Control and Without Seal-In Features

The shorting (shunting) switch circuit in Figure 4-6 is similar to the circuit in Figure 4-4 with the following exception. The valve has an automatic operation feature that would automatically bypass the manual control switch and blow the control power fusing to the circuit. This feature would make this valve an unacceptable candidate for a shorting switch from an operational point of view, unless the circuitry were significantly re-designed to be able to accomplish both features independently. The use of a shorting switch as depicted above on a circuit like this is not recommended without additional circuit changes and without the development of an FMEA to address the operational consideration mentioned above.

4.2.3 Electrical Design Considerations

The installation of a shorting switch into the circuitry for a component does not in and of itself guarantee that the component will not spuriously operate. Depending on the characteristics of the subcomponents within the component's circuitry, spurious operation of the component may or may not be prevented. The characteristics of concern are as follows and each is discussed individually below:

- Minimum pick-up voltage of the coil (Section 4.2.3.1)
- Characterization of potential credible aggressor sources (Section 4.2.3.2)
- Computation of maximum expected voltage/current through the target coil (Section 4.2.3.3)

4.2.3.1 Minimum Pick-up Voltage of the Coil

Typically, manufacturers publish a guaranteed pick-up voltage for their coils (contactors). This guaranteed pick-up voltage is the voltage at which the coil will consistently pick-up. When designing a shorting switch, however, the minimum pick-up voltage is the value of concern. The minimum pick-up voltage will not be guaranteed by the manufacturer, but it is a voltage at which the coil is likely to pick-up. In most cases, the coil will pick-up well below the published or guaranteed pick-up voltage, but there may be variability in performance when operating below this guaranteed pickup voltage. In order to design an effective shorting switch circuit, a "minimum pickup" voltage should be determined either through information from the manufacturer or a plant-specific test of the target coil used in the shorting switch application. This will become a critical design attribute for the shorting switch circuit. Given variability in manufacturing tolerances, this may need to be tracked on a per-device basis, or per-product-line basis, and would need to be incorporated into the design basis for that device going forward, so that when component replacements occur, the technical bases for the shorting switch circuit are not invalidated. The minimum pick-up voltage is a parameter used in the computation of the maximum expected voltage/current through the coil calculation discussed below.

4.2.3.2 Characterization of Potential Credible Aggressor Source

A summary of potential aggressor sources is needed to show that the voltage/current through the target coil will not result in pickup. Plant-specific cable segregation design rules for design of the raceway system (power, control, and instrument) may be helpful in screening out certain cabling as being non-credible aggressor sources. Additionally, the contents of the raceways of concern within the specific fire area(s) should be examined to determine the maximum potential aggressor source(s).

Once the potential aggressor sources are determined, the characteristics of the cable protection devices for those sources will need to be determined and bounded. The shorting switch is designed to short or shunt the potential from the aggressor circuit to ground and to, thereby, trip the cable protection devices for the aggressor circuit.

The potential aggressor sources and the bounding characteristics for the cable protection devices for these bounding aggressor sources are used in the computation of the maximum expected voltage/current through the coil discussed below.

The shorting switch prevents the target coil from picking up by shunting the aggressor conductor's voltage through a low-impedance path around the target coil. This low-impedance current flow path in most cases is carried by plant cables and normally-closed controls switch or relay contact. Control switch and relay contacts are typically rated for significant voltages and currents, are required to meet self-extinguishing requirements such as UL 94 *Standard for Tests for Flammability of Plastic Materials for Parts in Devices and Applications* (Ref. 20). Some have been tested to withstand currents well beyond their published rating.

For example, NUREG/CR-4596 *Screening Tests of Representative Nuclear Power Plant Components Exposed to Secondary Environments Created by Fires* (Ref. 21) identifies the potential for AGASTAT relay (EGP, ETR) sockets to deform under extreme high temperature conditions (210°C from NUREG/CR-4596, Figures 12 and 13). Therefore, it is recommended that AGASTAT relays not be credited as a shorting switch in scenarios where they may be exposed to internal panel fires. Consideration should also be made for secondary (adjacent) panel fires since air temperatures could exceed 210°C as shown in Figure 30 of NUREG/CR-4527 (Ref. 22).

Each application using the shorting switch should confirm that the as-installed configuration is: (1) capable of carrying the postulated momentary fault current, that may be shunted through the wiring and normally-closed switch/relay contact; and (2) that does not result in an unacceptable condition (e.g., wire overheating, switch overheating) such that the shorting function would be disabled.

A voltage interaction of the shorting switch circuits with a higher voltage source should be addressed when a higher voltage source is routed in the same raceway (e.g., conduit, cable tray or wire way) or housed in the same enclosure (e.g., MCC).

The shorting switch prevents the target coil from picking up by shunting the aggressor’s voltage through a low impedance path around the target coil. For most control circuits, the effects of shorting the target coil are fairly obvious. In the case of power circuit breaker close coils, the effects are not necessarily obvious. Power circuit breakers have an internal anti-pump scheme that prevents breaker cycling if a close and trip are coincident. Additionally, internal circuitry could lock up if a second close signal comes in after the initial momentary close signal cleared while the breaker springs are still being charged. The nuances of anti-pump circuits are manufacturer and circuit breaker unique. The shorting contact would be applied across the circuit breaker close coil as soon as the control switch is released. These effects of the shorting switch need to be closely scrutinized when there is potential for the shorting switch circuit to be impacted by cabling from a power circuit breaker.

Situations where circuits containing shorting switches are credited as the sole mitigation measure, such as in MCC and DC busses, present difficult challenges related to the impact of 480VAC cables on 120VAC control circuits. With the presence of higher voltage potential aggressor cables, the higher voltage aggressor cable may have sufficient voltage to energize the target coil even with the shorting path remaining fully functional. These interactions of lower voltage circuits in the same cubicles with higher voltage sources could preclude the use of a shorting switch as an effective means of mitigating potential spurious operations.

4.2.3.3 Computation of Maximum Expected Voltage/Current Through the Target Coil

The shorting switch electrical design should show that the electrical circuit with the shorting switch will function as desired, i.e., it will short or shunt the potential from all aggressor cables away from the coil of concern and to ground so that the cable protective devices on the aggressor cable will be tripped. The design should ensure that all components in the circuit will be capable of withstanding the effects of the electrical parameters to which they could be subjected in performing the shorting function.

Each application using the shorting switch should confirm that the as-installed configuration is capable of carrying the postulated momentary fault current that may be shunted through the wiring and normally-closed switch/relay contact without introducing an unacceptable condition (e.g., wire overheating or switch overheating) so severe that the shorting function would be disabled.

The specific electrical circuit containing the shorting switch should be analyzed with the minimum pick-up voltage for the coil, the bounding aggressor cables, and the bounding cable protective device characteristics for the aggressor cables. Figure 4-7 provides an illustrative example of how an electrical circuit is modeled.

With all of this information compiled, the discrete locations on the circuit where the aggressor cable could interface with the shorting switch circuit should be identified. Multiple analyses are likely to be necessary to address all of the potential cases.

The analysis attempts to place both ends of the target coil in equilibrium by shorting out the coil. However, due to the circuit length of the shorting wire and the resultant voltage drop, some voltage may still be impressed on the target coil. Therefore, an application-specific computation is necessary to show the credible voltage sources from aggressor wires, and demonstrate that the resultant voltage/current across the coil is insufficient to pick up the target coil even with the installed shorting switch. In the absence of information to the contrary, this evaluation conservatively assumes that, if sufficient voltage reaches the coil to trigger the minimum pick-up voltage, then the pick-up time is less than the time required to trip the cable protective devices on the aggressor cable.

For each case, the voltage and current experienced by each of the components throughout the circuit should be assured to be within the electrical design capability for those components.

This electrical design process may impact control circuit components and conductor sizing of the shorting current flow path. In essence, optimizing the effectiveness of the shorting circuit may impact the final circuit configuration and may require modification beyond simply installing a shorting switch.

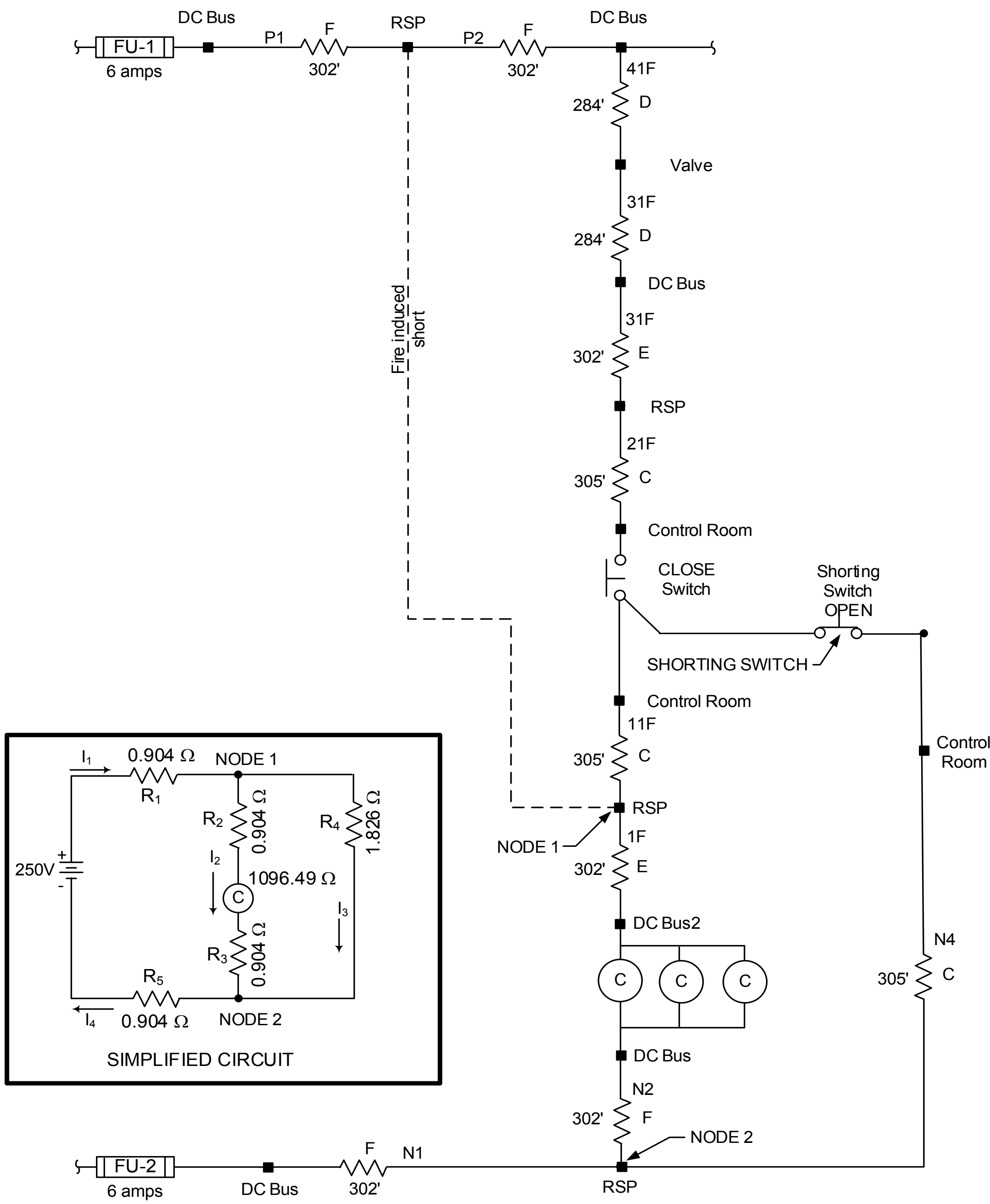


Figure 4-7 Simplified Circuit (Lumped Model)

4.2.4 Circuit Continuity Considerations

Successful use of the shorting switch is dependent on maintaining the integrity of the shorting switch and other associated components, e.g., control switches, terminal blocks and conductors that are necessary to maintain the continuity of the shorting path.

Therefore, crediting the shorting switch for preventing a fire-induced spurious operation in a location where the shorting switch or other associated components are co-located with the fire, presents additional challenges and considerations. These considerations are discussed in more detail below.

4.2.4.1 Cabinet Fires

When either the shorting switch or some other critical subcomponent (e.g., terminal block) of the shorting switch circuit (other than cabling) are credited for fires at the location of the switch / critical subcomponent, the impact of cabinet fires should be considered. The most likely location for these considerations to apply is in the main control room. The following scenarios should be evaluated:

- Fire spread between electrical enclosures
- Fire spread from sources external to the cabinet to within the cabinet
- Fire damage to the shorting switch itself
- Fire damage to any sub-components (e.g., soldered connections, screwed connections, terminations) required for the shorting switch to function.

In such a scenario, the fire is postulated to be at or near the panel containing the shorting switch; thus, the shorting switch, associated panel conductors, terminal blocks, or field cables near the panel are postulated to be susceptible to fire damage. The specific concern for this category is whether or not the fire can result in a failure of the shorting switch, via an open circuit.

In addressing main control room electrical fires, realistic fire conditions should be postulated. Recent work related to electrical enclosure heat release rates (HRR) (Ref. 23) may be useful in determining the characteristics of a realistic fire. For these realistic fire conditions, both flame impingement, as well as, panel heat up considerations should be addressed. Flame impingement effects on the shorting switch can cause switch failure and this failure could result in a spurious operation. Flame impingement effects on shorting switches and any screwed, crimped or soldered connections at the switch may be mitigated by the use of sheet metal enclosures similar to those used for Regulatory Guide 1.75 *Criteria for Independence of Electrical Safety Systems* (Ref. 24). Even with the use of a sheet metal enclosure, however, electrical enclosure heat up effects must be addressed. The continued performance of shorting switches (and any screwed, crimped or soldered connections at the switch post-fire) can be demonstrated by either fire testing, using realistic fire conditions, or engineering analysis. Also, exposure fires within the main control room itself, although not considered to be a likely failure mode, should be assessed to make sure that all potential failure modes have been considered and addressed.

NUREG/CR-4527 (Ref. 22), *An Experimental Investigation of Internally Ignited Fires in Nuclear Power Plant Control Cabinets*, describes fire testing on both vertically mounted main control room panels and bench-board type panels.

Reference 22 concluded the following:

> Fires in either bench-board or vertical cabinets with either IEEE STD-383 (Ref. 25) qualified cable or unqualified cable can be ignited and propagate. However, fires with IEEE STD-383 qualified cable do not propagate as rapidly nor to the extent that unqualified cable does. Furthermore, the results showed that the thermal environment in the test enclosure and adjacent cabinets is not severe enough to result in auto-ignition of other combustibles; although in some of the larger fires melting of plastic materials may occur. Essentially, a cabinet fire can propagate within a single cabinet; however, for the conditions tested it does not appear that the fire poses a threat outside the burning cabinet except the resulting smoke.
>
> For cables that do not pass IEEE STD-383 flame-spread test standard (unqualified cables), cabinet fires are easily ignited and propagate readily, generally resulting in combustion of all combustible materials within the cabinet. It was also demonstrated that even a low-intensity (170W) electrically heated fault point could result in full cabinet involvement for unqualified cables.
>
> For cables that pass the IEEE STD-383 flame-spread testing standard (qualified cables), self-sustaining fires that resulted in full involvement of the cabinet were somewhat more difficult to induce. However, given the proper circumstances, such a fully involved cabinet fire is possible.

NUREG/CR-4527 concludes by stating:

> Ignition, development rate, and spread of a cabinet fire are dependent on 'critical' (i.e., just the right combination of variables) ignition sources, in situ fuel type, geometries, and amounts, and on cabinet style and ventilation. These 'critical' values are interdependent on many variables and therefore no 'critical' values can be identified based on these tests.

The testing in NUREG/CR-4527 also tried to establish if the potential existed for propagating fire and/or fire damage beyond the cabinet of origin. The results of the testing were not conclusive for all configurations; however, the testing did determine that for a panel with solid steel, double-wall barrier, spontaneous cabinet-to-cabinet spread of fire was considered unlikely. However, NUREG/CR-4527 qualifies its conclusions by stating that this result does not apply to single-wall barriers and barriers susceptible to warping. It states, "Based on the results of these tests, partial or incomplete barriers and unsealed cable penetrations can be expected to allow further spread of fire, given a fully involved cabinet fire." While NUREG/CR-4527 does not elaborate on the definition of a fully involved cabinet fire, the fires that actually did spread throughout the cabinet during testing all involved unqualified cable. Additionally, the report noted that "the vulnerability of cables in raceways above or below a burning cabinet was also not investigated."

Based upon the discussion in the report, it can be concluded that a fire inside a panel that consisted of IEEE STD-383 qualified cable might be able to propagate, but it would require critical ignition sources, in situ fuel type, geometries, and amounts. While these critical parameters cannot be ruled out, it would appear that by the time fire spread outside the panel would occur, the fire would likely be extinguished, or fire spread prevented, by either automatic or manual suppression systems. Because of the heightened flammability of unqualified cable/wiring and the testing results which concluded that unqualified cable will easily ignite and propagate in a cabinet, it is much less clear whether a fire will be contained within the panel.

Each shorting switch application should confirm through engineering analysis/inspection and/or testing that the characteristics of their panels will not allow passage of fire effects to adjacent panels given the range of environmental conditions that could be produced by a credible fire.

The NRC also tested switches to determine any secondary effects of the fire. The results of this testing are contained in NUREG/CR-4596, *Screening Tests of Representative Nuclear Power Plant Components Exposed to Secondary Environments Created by Fires* (Ref. 21). The testing focused on “component survivability in secondary environments created by fires, specifically increased temperatures, increased humidity, and the presence of particulates and corrosive vapors.” This testing concluded that, for a switch, “in no case did the corrosion (produced by fire secondary effects) cause any noted malfunctions.”

These results would appear to indicate that the effects of a fire external to a panel will not result in a failure of the switch to operate. However, since these tests were focused on secondary fire effects, extrapolation of these results to components located directly in the panel containing the fire would not be accurate for two reasons. First, the conditions in a panel are much more severe than the condition outside of the panel. Second, there is the possibility of flame impingement on the actual switch in the panel which would again produce much more severe results to the component than secondary fire effects.

Shorting switch application within a cabinet should confirm through engineering analysis/testing that the switch and its associated subcomponents will perform as intended given the range of environmental conditions that could be produced by a credible fire.

Some of the means available to demonstrate the functionality of the shorting switch and its associated subcomponents are as follows. These approaches may be used individually or in combination with each other.

- Fire testing of the switch and associated subcomponents to either industry fire testing standards or specific temperature thresholds, if justified by plant specific fire hazards analysis, which demonstrates that they will survive for the required period of time.

- Qualitative fire hazards analysis, addressing general peak cabinet temperatures and the potential for flame impingement possibly in combination with sheet metal isolation enclosures covering the switch and any crimped or soldered connections, showing that the in-situ combustibles and fire hazards are less severe than the testing, and thus not capable of failing the switch or its associated subcomponents.

- Engineering evaluations that combine the testing and fire hazard analysis approaches described above and that demonstrate the switch functionality for a specific "mission time,” after which other strategies will be credited to prevent spurious operation, or after which spurious operation can be tolerated for some other reason.

In the absence of applying the techniques outlined above, assumptions pertaining to damage associated with the switch for the shorting switch modifications should be limited to the conclusions already given by NRC sponsored testing (Ref. 22). These results indicate that the switch could be damaged by a fire located within the same panel as the switch. Protecting the switch with metal isolation similar to that used for RG 1.75 (Ref. 24) should prevent direct flame impingement damage to the switch. For this case, switch heat-up due to the high temperature environment still needs to be evaluated. The effects on multiple shorting switches located in different panels (e. g., adjacent panels) would be totally dependent upon the type of cables/wiring, the configuration of the panels, and the proximity of the panels to each other.

As a bottom line, assuming that the shorting switch will not be damaged, and will not result in an open circuit/contact in a main control room fire is not a valid assumption without additional supporting technical justification. Therefore, the use of the shorting switch to prevent spurious operations would have to be limited by one of the following:

1. It would need to be used primarily for spurious operations that occurred outside of the main control room; or
2. If the application is attempting to take credit for the shorting switch during a main control room fire, it would have to be accompanied by a detailed evaluation addressing fire damage and/or by a feasible manual action(s).

The evaluation in (2.) would need to show that a fire in the area of the shorting switch would not adversely impact the shorting switch or any of the components in its circuitry. Fire modeling would most likely play an important part of any such evaluation. In performing any engineering evaluations of the type discussed above, engineers should consider the guidance in NRC Generic Letter 86-10 (Ref. 26) and Regulatory Guide 1.189 Revision 2 (Ref. 27) for addressing a single worst case spurious operation.

4.2.4.2 Fire-induced Open Circuits in Raceway Routing

Fire-induced open circuits have the potential to defeat the functionality of the shorting switch by creating an open circuit that could effectively remove the shorting switch from the circuit. As such, fire-induced open circuits for conductors comprising the shorting path must be addressed in the design of a shorting switch circuit.

For typical fire conditions, the direct effects of the fire will be to burn off any insulation on the cable/wiring causing the conductor(s) to either lay bare (with no insulation) or be covered by a damaged, charred layer of insulation. In both the NEI/EPRI (Ref. 3) and CAROLFIRE (Ref. 8) cable testing programs, this phenomenon was observed and the cable failure progression included either an intra-cable hot short with the potential to cause a spurious operation or a short-to-ground clearing the control power fuse for the circuit. If the intra-cable hot short occurred first, then the fire-induced circuit failure sequence often rapidly progressed to a short-to-ground which cleared the control power fusing. In a vast majority of the tests conducted under the NEI/EPRI and CAROLFIRE cable testing programs, the testing concluded with a loss of power to the control circuit based on clearing of the control power fusing for the circuit and, as a result, fire-induced open circuits were not observed. Fire-induced circuit failures occurred within the cable with very little interaction with any of the cables surrounding the primary cable. Each of these testing programs, however, included primarily AC circuits with small sized control power fuses and with a sufficient number of conductors within the cable to allow it to progress through the fire-induced circuit failure sequence described above. Circuits with larger sized control power fusing, however, were not included in these testing programs.

Ungrounded DC circuits were tested in the DESIREE-FIRE (Ref. 9) cable fire testing program. Some of these circuits included larger sized control power fuses. In the DESIREE-FIRE cable testing program, those ungrounded DC control circuits with smaller sized control power fuses, i.e., 10 amps or less, behaved similarly to the circuits tested under the NEI/EPRI and CAROLFIRE cable testing programs. Those ungrounded DC circuits with the larger sized control power fuses, exhibited a different behavior. These ungrounded DC circuits with larger sized control power fuses did not always clear the fusing on both legs of the control power circuit. With either or both legs of the circuit still fused and energized, these circuits, in some cases, exhibited an arcing phenomenon with the potential to damage adjacent cables or cable tray components. In fact, some damage to cable tray rungs in the vicinity of the arcing cable was observed. Open circuits were observed in the DESIREE-FIRE cable fire testing program. However, fire-induced cable failure resulting in arcing that could cause an open circuit in a nearby cable was not directly observed in the DESIREE-FIRE cable fire testing program. This phenomenon was not a test objective and not something that was specifically investigated as a part of the DESIREE-FIRE testing. Therefore, open circuits as a result of energetic arcing of nearby 125 VDC cables with larger sized control power fuses cannot be ruled out.

A recent industry event involving AC circuits demonstrated that under selected conditions an arcing cable failure can cause an open circuit in an adjacent cable. During this event, 120 VAC cables exhibited arcing behavior which resulted in open circuits as found during post-event investigations. Therefore, the working group cannot rule out that an AC circuit with the proper current characteristic and with its cable jacket and insulation degraded could cause damage to nearby cables.

Although no specific cases of these events causing an open circuit as an initial failure mode were observed in the DESIREE-FIRE testing program and although there is no specific data available from the industry events, the working group could not rule out the possibility of arcing, causing damage to nearby conductors such that an open circuit condition results.

When all of the data from each of the major NRC and industry cable testing programs and anecdotal evidence from actual fire events is evaluated in aggregate, the following conclusions are reached:

- Fire-induced cable damage initially affects a cable by damaging the jacketing and conductor insulation associated with the cable.

- Absent any damaging effects external to the cable, fire-induced circuit failures, in most cases, will occur first within the cable. In general, if the proper conductors exist within the cable, intra-cable hot shorts and/or shorts to ground will occur.

- For circuits, either grounded or ungrounded, with fuses sized at 10 amps or less, clearing of the fuses as fire damage progresses is likely. The working group judged that circuits fused with fuse sizes up to and including this size do not pose a threat to creating an open circuit in a nearby circuit regardless of whether they are power or control circuits.

- For ungrounded DC circuits with larger sized control power fuses, clearing of the control power fuses may not occur depending on the fault location and available fault current.

    - Isolated legs of ungrounded DC control circuits with larger sized control power fuses where the control power fuse takes longer to clear or does not clear, have the potential to generate arcing faults, some of which have the potential to damage nearby components, i.e., cables and/or portions of cable trays.

- In AC circuits with voltages as low as 120 VAC where the protection device (e.g., fuse, breaker) does not clear, the potential exists to generate arcing faults, some of which have the potential to damage nearby components, i.e., cables and/or portions of cable trays.

- Depending on the energy available in the circuits, the failure sequence of the circuits in the fire scenario and the relative location of the circuits fused with larger than 10 amp fuses, open circuiting cannot be ruled out and, as such must be assumed to have the potential to occur. This open circuit could be from AC or DC circuits with fusing greater than 10 amps in close proximity to the cabling for the shorting switch circuit.

Based on these conclusions, open circuits in control circuits containing shorting switches cannot be generically ruled out. A means of addressing the potential for open circuits in circuits containing shorting switches must be included in the design of the shorting switch circuit.

Open circuit conditions in circuits containing shorting switches routed in or near raceway containing AC or DC circuits with fusing greater than 10 amps can be addressed by either:

- Meeting the electrical separation distances of IEEE STD 384-1992 (Ref. 28), as outlined for any low-voltage power circuits, either AC or DC, routed near the circuit containing the shorting switch (See Table 2 of IEEE 384-1992)

- Providing a technically sound engineering evaluation justifying

    - reduced separation distances, or

    - the acceptability of the shorting switch design in mitigating the effects of a spurious operation given the potential for nearby cables impacting the shorting switch circuit and causing an open circuit.

IEEE Std. 384-1992 (Ref. 28) gives recommended separation criteria for electrical cabling. This standard has been endorsed by the NRC through Regulatory Guide 1.75 (Ref. 24). The separation criteria contained in the standard is largely dependent upon both the hazards in the area and the energy level of the potential aggressor cable. For the purpose of this discussion, the primary concern is a fire. The standard defines three hazard classifications:

1. Non-hazard area;
2. Limited hazard area;
3. Hazard area.

A hazard area contains highly flammable solids and liquids. Since the flammable materials in the area are the overwhelming concern, cable separation criteria is focused on the effects of the fire on separate 1E redundant divisions. Electrical aggressor cables affected by the fire are not the overriding concern.

The standard defines a limited hazard area as a plant area "from which potential hazards such as missiles, non-electrically induced fires, and pipe failure are excluded." It also states, "In both a limited hazard area and a non-hazard area, the only energy available to damage electrical circuits is that energy associated with failure or faults internal to electrical equipment or cables within the area. The primary difference between a limited hazard area and a non-hazard area is that power circuits and equipment are restricted in the non-hazard area." The limited hazard area portion of the standard is the most applicable for this technical evaluation, because the assumption for this discussion is that the fire has occurred, and the effect of concern is the electrically induced damage from an aggressor cable.

The separation criteria for limited hazard areas, containing low-voltage power circuit cabling, are provided in Table 2 of IEEE 384-1992. Use of these distances as the separation distance between the cables containing the conductors for a shorting switch and any low-voltage power cables should limit collateral damage with the potential to cause an open circuit in the shorting switch cable (e.g., cable in one raceway damaged due to arcing of a low-voltage power circuit cable in the same or adjacent raceway).

4.2.4.3 Additional Mitigating Measures

The shorting switch is an engineered solution. Due to the numerous considerations related to the design of a shorting switch circuit, in a particular design, there may be gaps where not all aspects of all of the considerations can be fully met. The use of additional mitigating measures may be beneficial in addressing any gaps.

As discussed above, there are a large number of factors to consider when using a shorting switch to mitigate the effects of a fire-induced spurious operation. Some of these factors present specific challenges for the shorting switch circuit designer, e.g., cabinet fires, aggressor circuits with higher voltages and larger fuse sizes. Given these challenges and the uncertainties they present, designs to mitigate the effects of fire-induced spurious operation relying solely on a shorting switch are less robust than those that incorporate additional mitigating measures that must also be defeated for the fire-induced spurious operation to occur. Three examples of potential additional mitigating measures that can be used, along with their potential benefits, are discussed below. These additional mitigating measures are not an all-inclusive list. Additionally, they may be used either individually or in combination with each other to enhance their effectiveness.

- Shorting switch with additional redundancy

    Redundancy can be gained by using a shorting switch on multiple components in an MSO scenario, placing the multiple shorting switches in separate locations where damage to each is not likely or even possible due to a single fire. It can also be advantageous to closely examine the specific sequence of failures required for the spurious operation to occur and judiciously employ operator manual actions where time is available.

- Shorting switch as a time delay

    A shorting switch could be used to increase the time until adverse impacts occur, thus allowing additional time for an operator action to be performed. For example, a shorting switch installed in a main control room cabinet that has been evaluated for the effects of realistic fire conditions could be evaluated to show that the shorting switch and its associated circuitry will last for a fixed number of minutes.

    If the component protected by the shorting switch can be isolated from the effects of the main control room fire by actuation of the transfer switch at the remote shutdown panel, then this fixed number of minutes may be able to provide sufficient time for the operator to evacuate the main control room, traverse to the remote shutdown panel and isolate the potential for a spurious operation of the component by actuation of the remote shutdown panel transfer switch.

There are similar strategies that could be employed where the increased time afforded by the installation of a shorting switch can be effective in allowing time for an operator to de-power a component or actuate a "kill" switch at a location remote from the main control room and unaffected by the main control room fire.

Finally, for instances where spurious operation of multiple components are required for the adverse consequences of the spurious operation to occur, multiple shorting switches for separate components located in separate cabinets could be used to significantly increase the time available for other mitigating actions to be performed by the operating staff.

- Shorting switch to increase sequencing to spurious operation

A shorting switch can be used to increase the number of sequential failures necessary for a spurious operation to occur.

For example, the spurious closure of the steam return to the suppression pool valve on a steam driven turbine with the loss of the high back pressure trip for that steam driven turbine is one of the MSOs for some BWRs based on the list of MSOs in Appendix G to revised NEI 00-01 (Ref. 6). For this scenario to occur, circuitry for the steam driven turbine must initially be unaffected by the fire. After the steam driven turbine is up and running the following sequence of fire-induced failures must occur:

  - The circuitry for the high back pressure trip for the steam driven turbine must fail prior to the spurious closure of the steam return to the suppression pool valve on a steam driven turbine.

  - The circuitry for the steam return to the suppression pool valve on a steam driven turbine must be subjected to a hot short causing spurious closure of the valve.

By installing a shorting switch in the circuitry for the steam return to the suppression pool valve on a steam driven turbine, the sequence of failures required for the spurious operation can be increased as follows:

  - Fire-induced failure of the circuitry for the steam driven turbine must be unaffected by the fire until the steam driven turbine is up and running. [For high pressure coolant injection (HPCI), it takes approximately 30 seconds before the shaft driven oil pump takes over and the aux oil pump is no longer required.]

  - Fire-induced failure of the circuitry for the steam driven turbine must occur prior to reactor vessel level reaching the high level trip at which point the steam driven system will trip off. [For HPCI, the high level trip will be reached in approximately 3.5 minutes.] This allows a window of approximately 3 minutes for system damage to occur.

- If damage does not occur within the 3 minute window, fire-induced damage must again be deferred until after system restart at reactor vessel low, low level. [Typically, reactor vessel low, low level would not be reached again for approximately 20 minutes. This time frame by itself could allow adequate time for an operator manual action.]

- The circuitry for the high back pressure trip for that steam driven turbine, which is integral with the system re-start circuitry, must fail prior to the spurious closure of the steam return to the suppression pool valve on a steam driven turbine.

- A fire-induced open circuit must be introduced into the shorting switch circuitry at a location that eliminates the effectiveness of the shorting switch. This fire induced failure cannot cause the control power fusing in the shorting switch circuitry (ungrounded 125 VDC) to be lost since a loss of the control power to the shorting switch circuitry will prevent it from completing the spurious operation caused by the subsequent hot short described in the next bullet.

- The circuitry for the steam return to the suppression pool valve on a steam driven turbine must be subjected to a hot short causing spurious closure of the valve and this hot short must be at a location in the circuitry where it is between the fire-induced open circuit and the close coil.

It is clear from the description above that the use of a shorting switch, in this case, makes the likelihood of a spurious operation much more remote.

4.3 Conclusions

This section contains guidance on the design, use, and implementation of shorting switches to protect against spurious operation. The working group developed supplementary technical information that, in combination with the existing information, provide a comprehensive set of design considerations and recommendations for effective implementation of shorting switch application. Guidance is provided in the areas of circuit design, electrical design, and circuit continuity considerations. A shorting switch considerations checklist has been developed and is included in Table 4-2. An example application using the checklist is presented in Table 4-3.

Table 4-1 Shorting Switch Considerations Checklist

General Consideration	Specific Consideration	Method(s) for Addressing	Comments
Licensing Considerations	Determine licensing basis for change:		
	- NFPA 805	Use fire modeling to address the potential for an open circuit defeating the functionality of the shorting switch and the impact on risk.	
	- Deterministic		
	- III.G.2		
	- Required for hot shutdown	Process a License Amendment Request to obtain NRC endorsement of the use of fire modeling to address the potential for an open circuit defeating the functionality of the shorting switch.	III.G.2 requires consideration of open circuits for required for hot shutdown components.
	- Important to safe shutdown	Use fire modeling to address the potential for an open circuit defeating the functionality of the shorting switch.	
	- III.G.3/III.L	Use fire modeling to address the potential for an open circuit defeating the functionality of the shorting switch.	
Circuit Design Considerations	Determine the valve circuit design type:		Depending on the type of valve circuity into which the shorting switch is being added, additional analysis may be required to demonstrate that the shorting switch does not introduce any valve operational concerns, e.g., blown fuses or tripped breakers as a result automatic valve functions.

General Consideration	Specific Consideration	Method(s) for Addressing	Comments
	- Remotely operated valve	Review the circuit design with the shorting switch to assure that no operational impacts are created.	
	- Remotely operated valve with seal-in	Perform an electrical circuit FMEA to assure that the shorting switch will not impact the valve from an operational perspective.	
	- Remotely operated valve with automatic function	Perform an electrical circuit FMEA to assure that the shorting switch will not impact the valve from an operational perspective.	
	- Other valve circuit design	Perform an electrical circuit FMEA to assure that the shorting switch will not impact the valve from an operational perspective.	
Electrical Design Considerations	- Determine target coil minimum pick up voltage	Obtain information from the manufacturer or perform a plant specific test of the target coil used with the shorting switch application.	Minimum pick up voltage is the minimum voltage at which the coil might pick up and not the minimum voltage at which the coil is guaranteed to pick up.
	- Identify potential aggressor voltage sources	Identify potential voltage sources that could impact the conductors in the shorting switch circuit. Consider cables run in the same raceway and, when appropriate, within the same enclosure, e.g., MCC.	
	- Determine the maximum voltage through the target coil given the target coil minimum pick up voltage and the voltage associated with bounding aggressor source	Developed a lumped-parameter model of the subject circuit with the shorting switch. Apply the voltage associated with the bounding aggressor source to the lumped-parameter model. Calculate and demonstrate that the target coil will	Depending on the circuit design and the location of the identified aggressor voltage sources, more than one analytical model case may need to be evaluated. Additionally, aggressor sources from both

General Consideration	Specific Consideration	Method(s) for Addressing	Comments
		not reach its minimum pick up voltage with the voltage splitting between the shorting switch electrical flow path and the target coil electrical flow path.	within and external to the shorting switch cable need to be considered.
Circuit Continuity Considerations (continued)	- Assure fire-induced open circuits will not result in an open circuit in either the shorting path nor in the path to the target coil that would defeat the functionality of the shorting switch should an open circuit occur.	Evaluate for the potential for a fire-induced open circuit. Typically, open circuits do not occur as a result of fire damage, with the exception of highly energetic circuits, i.e., high current carrying AC circuits or ungrounded DC circuits with fuses larger than 10 amps. Either: - Confirm that Electrical Separation Criteria in IEEE 384 is satisfied, or - Perform a technically sound engineering evaluation justifying a reduced separation criterion for the cables containing the shorting switch. or - The acceptability of the shorting switch design in mitigating the effects of a spurious operation given the potential for nearby cables impacting the shorting switch circuit causing an open circuit.	
	- Credit the availability of additional mitigating measures in assuring the viability of the shorting switch design.	Perform engineering analysis to demonstrate that the shorting switch, when coupled with other aspects of the plant design or the MSO scenario,	Additional mitigating measures can be used to increase the robustness of a shorting switch design where rigorous adherence to all of the parameters

General Consideration	Specific Consideration	Method(s) for Addressing	Comments
	- Demonstrate by using redundant shorting switch capability to prevent a MSO, that the MSO will not occur, or - Demonstrate the survivability of the shorting switch for a period of time that will allow for a successful operator manual action, or - Demonstrate that the use of the shorting switch sufficiently increases the number of sequential failures needed to cause he MSO to the point where it effectiveness is assured.	provides sufficient redundancy to assure the effectiveness of the shorting switch in helping to assure that an MSO is effectively mitigated.	described above may not be possible. These measures also may be used to increase the robustness and conservatism in the design where full adherence to the parameters described above has already been demonstrated.

ILLUSTRATIVE EXAMPLE

Purpose: The purpose of this example is to show one way in which the guidance in Table 4-2 can be used to design a shorting switch. This example does not preclude the use of other approaches.

Description of example circuit and MSO scenario: A shorting switch is being added to the reactor core isolation cooling (RCIC) suppression pool steam return line valve to address a postulated MSO scenario in which a spurious closure of the steam return valve with the RCIC turbine running, if preceded by a loss of the automatic turbine trip logic, could result in a high system back pressure with the potential to open the RCIC system rupture disc and lift the RCIC room blow out panels. In all affected areas, i.e., reactor building and main control room, the RCIC system is not classified as required for hot shutdown. In the reactor building, the RCIC System is classified as important to safe shutdown due to the potential for the MSO scenario described above. In the main control room, RCIC is used to support post-fire alternative safe shutdown at the remote shutdown panel. In this capacity, it performs as an alternate inventory make up function to SRVs and low pressure RHR. With the installation of the shorting switch, the required number of sequential failures necessary for the MSO to occur is increased. Additionally, the circuitry for the shorting switch becomes a redundant protective scheme to the circuitry for the high back pressure RCIC turbine trip. It is only in those locations where circuitry for each of these functions can be impacted by the fire that the MSO has the potential to occur. Even when the circuitry for both of these functions can be affected by a common fire, there is a time sequential relationship between the RCIC valve shorting switch circuitry and the RCIC high back pressure turbine trip circuitry. Where both functions co-exist, an open circuit must occur at the correct location in the shorting switch circuit prior to the hot short occurring in the shorting switch circuitry, and this combination of failures must be preceded by a failure of the RCIC high back pressure trip circuitry.

Table 4-2 Shorting Switch Example

General Consideration	Specific Consideration	Method(s) for Addressing	Approach used to Address in this Example
Licensing Considerations	Determine licensing basis for change:		
	- NFPA 805	Use fire modeling to address the potential for an open circuit defeating the functionality of the shorting switch and the impact on risk.	N/A
	- Deterministic		Yes
	- III.G.2		Yes
	- Required for hot shutdown	Process a licensing amendment request to obtain NRC endorsement of the use of fire modeling to address the potential for an open circuit defeating the functionality of the shorting switch.	N/A
	- Important to safe shutdown	Use fire modeling to address the potential for an open circuit defeating the functionality of the shorting switch in addition to causing the hot short-induced spurious operation.	The shorting switch in this example is used on a component classified as important to safe shutdown.
	- III.G.3/III.L	Use fire modeling to address the potential for an open circuit defeating the functionality of the shorting switch in addition to causing the hot short-induced spurious operation.	The shorting switch in these examples is used in an area classified as III.G.3/III.L.
Circuit Design Considerations	Determine the valve circuit design type:		
	- Remotely operated valve	Review the circuit design with the shorting switch to assure	The valves being modified are remote operated valves with no

General Consideration	Specific Consideration	Method(s) for Addressing	Approach used to Address in this Example
		that no operational impacts are created.	seal-ins or automatic functions. The valve circuitry with the shorting switch has been reviewed and the change creates no adverse operational considerations.
	- Remotely operated valve with seal-in, OR remotely operated valve with automatic function, OR other valve circuit design	Perform an electrical circuit FMEA to assure that the shorting switch will not impact the valve from an operational perspective.	N/A
Electrical Design Considerations	- Determine target coil minimum pick up voltage	Obtain information from the manufacturer, or perform a plant specific test of the target coil used with the shorting switch application.	The required minimum pick up voltage for the target coil was conservatively estimated from manufacturer's data and available industry literature.
	- Identify potential aggressor voltage sources	Identify potential voltage sources that could impact the conductors in the shorting switch circuit. Consider cables run in the same raceway and, when appropriate, within the same enclosure, e.g., MCC.	The raceway routing for the shorting switch circuits cables determined that this raceway was routed with 125 VDC or 120 AC circuits only. There are 250 VDC cables in a common raceway above the 250 VDC Bus, but no credit is taken for the shorting switch in this plant area. Therefore, these cables are not included as viable aggressor sources.
	- Determine the maximum voltage through the target coil given the target coil minimum pick up voltage and the voltage associated with bounding aggressor source	Develop a lumped-parameter model of the subject circuit with the shorting switch. Apply the voltage associated with the bounding aggressor source to the lumped-parameter model. Calculate and demonstrate that the target coil will not reach its minimum pick up voltage with the voltage splitting between the shorting switch electrical	An engineering analysis using a lumped parameter model has demonstrated that the maximum aggressor voltage at the worst case circuit location cannot pick up the target coil with the shorting switch functioning properly.

General Consideration	Specific Consideration	Method(s) for Addressing	Approach used to Address in this Example
		flow path and the target coil electrical flow path.	
Circuit Continuity Considerations	- Assure cabinet fires will not defeat the functioning of the shorting switch or any of the components or conductors required for it to function. Consider: - Fire spread between electrical enclosures - Fire spread from sources external to the cabinet to within the cabinet. - Fire damage to the shorting switch itself. - Fire damage to any sub-components, e.g., solder connections, screwed connections, terminations, required for the shorting switch to function.	Use available manufacturer's information on thermal thresholds of the various components potentially affected coupled with fire modeling addressing credible fire sources. Use protective metal enclosures to avoid damage to the switch and its related sub-components from direct flame impingement. Use plant walk downs to assess credible fire sources and sizes and the robustness of any enclosures involved. Perform small scale fire testing to demonstrate the survivability of any affected components.	An engineering walk down of the main control room and the main control room panel internals housing the RCIC shorting switch has concluded that: - There are insufficient main control room combustibles to cause a fire external to the control panel with the potential to damage the RCIC shorting switch and it related sub-components. - The electrical separation features of the control panel internals are sufficient to prevent a damaging fire from occurring. - Fire damage in the sequence required cannot occur prior to the 15 minute time frame required to evacuate the main control room and transfer control to the remote shutdown panel.

5
TECHNICAL JUSTIFICATION FOR COMBINATION OF HOT SHORTS TO CONSIDER FOR MULTIPLE SPURIOUS OPERATIONS

The purpose of this section is to provide technical recommendations for MSO evaluations using insights gained from cable testing and JACQUE-FIRE Volume 2 (Ref. 12). This section provides the working group's recommendations for the number of fire-induced circuit failures of specific types to consider when addressing MSOs.

An MSO is defined in NRC Enforcement Guidance Memorandum (EGM) 09-002 (Ref. 29) as "multiple fire induced circuit faults causing an undesired operation of one or more systems or components." It is also worth noting that the definition in EGM 09-002 is for multiple spurious actuations, which is identical to multiple spurious operations. The terms are used interchangeably.

This section documents the qualitative basis for the working group's consensus recommendations regarding specific MSO criteria in a deterministic SSD analysis. The quantitative discussions included in the technical basis for the MSO recommendations in this section provide a summary of risk insights from JACQUE-FIRE Volume 2. These quantitative insights supplement the working group's qualitative technical basis and support the confirmation that certain aspects of MSO considerations being discussed in this section are not safety significant. These quantitative insights are included in JACQUE-FIRE Volume 3 for informational purposes.

5.1 Background

5.1.1 Current Regulatory Framework

The purpose of this sub-section is to provide context for the discussions that follow. The intent is simply to re-iterate the working group's understanding of the current regulatory framework.

Section 3.5.1.1 "Circuit Failure Criteria" of NEI 00-01, Rev. 2 (Ref. 6), provides fire-induced circuit failure evaluation criteria and assumptions. Section 3.5.1.1 under circuits for "required for hot shutdown" components states in part:

> Because Appendix R Section III.G.1 requires that the hot shutdown capability remain "free of fire damage," there is no limit on the number of concurrent/simultaneous fire-induced circuit failures that must be considered for circuits for components "required for hot shutdown: located within the same fire area. For components classified as "required for hot shutdown," there is no limit on the duration of the hot short. It must be assumed to exist until an action is taken to mitigate its effects…

TECHNICAL JUSTIFICATION FOR COMBINATION OF HOT SHORTS TO CONSIDER FOR MULTIPLE SPURIOUS OPERATIONS

The 6th and 7th bullets under circuits for “Important to safe shutdown” components from Section 3.5.1.1 of NEI 00-01 Rev. 2 state:

- Multiple fire-induced circuit failures affecting separate conductors in separate cables with the potential to cause a spurious operation of an “important to safe shutdown” component must be assumed to exist concurrently when the effect of the fire-induced circuit failure is sealed-in or latched.

- Conversely, multiple fire-induced circuit failures affecting separate conductors in separate cables with the potential to cause a spurious operation of an “important to safe shutdown” component need not be assumed to exist concurrently when the effect of the fire-induced circuit failure is not sealed-in or latched. This criterion applies to consideration of concurrent hot shorts in secondary circuits and to their effect on a component’s primary control circuit. It is not to be applied to concurrent single hot shorts in primary control circuit for separate components in an MSO combination.

The NRC staff endorsement of NEI 00-01, Rev. 2, took an exception to Section 3.5.1.1 with respect to multiple fire-induced circuit failures. Section 5.3, “Fire Protection of Safe-Shutdown Capabilities” of RG 1.189, Rev. 2 (Ref. 27), states in part:

> The NRC has not fully endorsed NEI 00-01, Section 3.5.1.1, titled “Circuits for ‘Important to Safe Shutdown’ Components.” Specifically, the seventh bullet relates to concurrent hot shorts in circuits that are not sealed-in or latched. The NRC does not endorse this position as written in NEI 00-01, Revision 2. For circuits not sealed-in or latched for equipment important to safe shutdown, licensees should consider multiple fire-induced circuit failures in at least two separate cables. For circuits not sealed-in or latched for equipment important to safe shutdown that involves high-low pressure interfaces, licensees should consider circuit failures in at least three cables. This applies where defense-in-depth features, such as automatic suppression and limits on ignition sources and combustibles, are present. Where defense-in-depth features are not present, the number of cables to consider should not be limited to two or three as described above. In addition, for multi-conductor cables, all circuit faults that could occur within the cable should be assumed to occur.

Section 3.5.1.2 “Spurious Operation Criteria” of NEI 00-01, Rev. 2, provides fire-induced spurious operation criteria and assumptions. Section 3.5.1.2, states in part:

> In this review, consideration of key aspects of the MSOs should be factored in, such as the overall number of spurious operations in the combined MSOs, the circuit attributes in Appendix B, and other physical attributes of the scenarios.
>
> o Specifically, if the combined MSOs involve more than a total of four components or if the MSO scenario requires consideration of sequentially selected cable faults of a prescribed type, at a prescribed time, in a prescribed sequence in order for the postulated MSO combination to occur, then this is considered to be beyond the required design basis for MSOs.

5.1.2 Discussion

NEI 00-01 Rev. 3 (Ref. 13) was issued to incorporate exceptions taken by the NRC staff and attempted to consolidate and clarify the requirements. However, the NRC neither endorsed nor reviewed NEI 00-01 Rev. 3. With respect to the spurious operation criteria in Section 3.5.1.2 of NEI 00-01 Rev. 2; Revision 3 of NEI 00-01 attempted to provide additional clarifying criteria. Section 3.5.1.3 “Number of Spurious Operations and Hot Shorts” of NEI 00-01 Rev. 3 states:

> When considering the need to combine MSOs, add a new MSO or in evaluating an existing MSO, the following criteria apply:
>
> If the MSO involves more than a total of four (4) components requiring independent, i.e. in separate cables, hot shorts to cause each component to spuriously operate or if the MSO contains four (4) or fewer components, but requires more than four (4) independent, i.e. in separate cables, hot shorts to cause all components in the MSO to spuriously operate, then these cases are considered to be beyond the required design basis for MSOs.
>
> If the MSO involves assumptions related to selective timing of multiple fire-induced circuit failures with an assumed or fire-induced loss of offsite power where an adverse condition would not result if the postulated timing did not occur, this is considered to be beyond the required design basis for MSOs.

The working group’s assessment of this discussion in NEI 00-01 Rev. 3, Section 3.5.1.3, identified concerns with the discussion’s alignment to the current state of knowledge of circuit failure behavior. The working group’s consensus opinion is that the relevant considerations should focus more on the associated cable interactions than the affected components themselves. The recommendations provided in this section apply to fire-induced circuit failures where a source cable or source conductor contacts a separate target cable or target conductor. A target cable or target conductor (initially energized or not) is defined as a cable or conductor that, if energized by contact (directly or indirectly) with an appropriate source cable or conductor, would generate a hot short, and possibly, a spurious operation if the target cable or conductor was associated with equipment or device(s) that would operate spuriously. Similarly a source cable or source conductor is a cable or conductor that is energized (either before or during a fire event) and, therefore, can produce a hot short should it make contact with a target conductor (Ref. 1). The recommendations apply regardless of the number of source cables or source conductors involved, i.e., one or more.

Since NEI 00-01, Rev. 2 (Ref. 6) and RG 1.189, Rev. 2 (Ref. 27) guidance documents were issued; additional work and testing have been accomplished. Insights gained from these efforts have improved the understanding of fire-induced circuit failure behaviors. The current state of knowledge provides insights for additional “Spurious Operation Criteria” considerations that can be applied to a deterministic post-fire safe shutdown analysis.

5.2 Technical Resolution

Based on the insights gained from testing and JACQUE-FIRE Volume 2 (Ref. 12), the working group developed the following recommendations. These recommendations are in addition to the working group’s recommendations provided in Sections 2 and 3 of this report. The recommendations apply regardless of target cable insulation type or power supply type, unless noted otherwise. The term “concurrent” in this document means existing together at some point in time and includes simultaneously occurring at the exact same point in time. The term “separate target cables” in this document refers to the independent and separate cables carrying target conductors of concern for a particular failure more (e.g., hot short). For intra-cable hot short interactions, the conductor providing the source of power to cause the hot short is contained within the target cable. For inter-cable hot short interactions, the conductor providing the source of power to cause the hot short is not within the target cable. The recommendations address the following topics:

1. Number of hot shorts for transient inrush considerations
2. Number of inter-cable hot shorts regardless of latching characteristics or coping time
3. Number of non-latching hot shorts with 10-minute coping time regardless of circuit failure mode
4. Sequentially selected fire-induced circuit failures

5.2.1 Spurious Operation Recommendation 1: Number of Hot Shorts for Transient Inrush Considerations

If the MSO requires the consideration of inrush current from more than one end device to cause an overload condition for a power supply, then the working group recommends that the MSO not be considered, as long as the assumptions/limitations provided below are satisfied.

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

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

5.2.1.1 Assumptions/Limitations

This recommendation assumes,

- Normal transient inrush current duration for the affected loads is typical of that described in the technical basis below.
- The load spurious operation(s) is caused by fire damage to control cables for the load(s) from the power supply of concern. The load is otherwise operating correctly and has no potential for power cable fire damage. Thus, the load transient inrush current expected is normal and not impacted by the fire event.

- The load sequencer, if applicable, for the associated power supply is not damaged by the fire such that the fire damage may cause multiple loads to simultaneously spuriously start.
- Target conductors that could spuriously start/energize loads powered from the same power supply are in separate cables.

5.2.1.2 Technical Basis

Rigorous evaluation of potentially unbounded transient current combinations caused by fire damage can prove to be impractical. However, in the unlikely event that two or more loads from the same power supply did experience concurrent transient inrush currents, the power supply would likely accelerate/energize the loads with no adverse impact. The inrush current (e.g., motor starting current or transformer magnetization current) is the initial transient current, prior to magnetization or motor acceleration. As a transformer core is magnetized or a motor is accelerated to near synchronous speed, the transient current decays to normal steady-state running current. Given the power supply is not degraded, the transient inrush current is load component dependent. The inrush current may be less than a second for many transformers and smaller motors and a few seconds for larger motors (typically 3-5 seconds). The recommendation to not consider MSOs that require consideration of inrush currents is based on the short duration for more than one end device to cause an overload condition for a power supply, as long as the assumptions/limitations provided above are satisfied.

5.2.2 Spurious Operation Recommendation 2: Number of Inter-Cable Hot Shorts Regardless of Latching Characteristics or Coping Time

If the MSO requires four or more separate target cables with inter-cable hot shorts (excluding GFEHS), then the working group recommends that the MSO not be considered, regardless of whether the circuits are latching or non-latching. There is no sustained time duration consideration required for this case.

5.2.2.1 Assumptions/Limitations

This recommendation includes the following limitation,

- The GFEHS is not included as an inter-cable failure mode for this recommendation. For ungrounded power supplies, credible GFEHS is significantly more likely than inter-cable hot shorts and as such, is not included in this recommendation. Spurious operation(s) for the MSO scenario that can be caused by GFEHS should be considered unless otherwise limited. Inter-cable failures that can result in a GFEHS cannot be counted as part of this limit of four or more separate inter-cable hot shorts.

5.2.2.2 Technical Basis

For ungrounded power supplies, a GFEHS is significantly more likely than inter-cable hot shorts and as such, is not included in this recommendation. Control cables used in NPP applications are typically of multi-conductor construction and commonly associated with an individual circuit. As such, control cables commonly contain target, source and common return conductors within a jacketed multi-conductor cable. To experience a spurious operation caused by the inter-cable failure mode, the cables containing the source and target conductors must not first experience an internal (intra-cable) failure mode that would negate the spurious operation circuit fault from an inter-cable failure mode.

Industry (Ref. 3) and NRC (Ref. 8) fire tests were configured to facilitate the occurrence of an inter-cable hot short. In the NEI/EPRI cable fire testing program, the target cable bundle was a seven conductor cable bundled with three single conductor cables. Although some inter-cable interactions were noted in a small percentage of the tests, no spurious operations resulted from these interactions. This led to a conclusion for the NEI/EPRI testing that an inter-cable hot short had a very low likelihood for multi-conductor cables.

Similarly, in the CAROLFIRE testing, valid indications of inter-cable interactions were found, but these interactions did not result in a spurious operation. This led to a conclusion for the CAROLFIRE testing that an inter-cable hot short had a very low likelihood.

Finally, as discussed in Section 6.5, “Intercable test circuit results,” of the DESIREE-FIRE report (Ref. 9), the target cables were surrounded by two sets of cables: some with only positive conductors and others with only negative conductors. The cables were also isolated from the ground plane. The objective of this test was to drive the failure mode towards inter-cable hot shorts causing a spurious operation. This test accomplished this objective by significantly biasing the test configuration towards inter-cable hot shorts. In general, even in this spurious operation biased configuration, spurious operations did not occur because this testing was designed to simulate a double break circuit design that would require two hot short circuit failure interactions in order for a spurious operation to occur. The inter-cable interactions experienced individually, were limited and in many cases of insufficient voltage level to cause a spurious operation.

The composite results of the testing described above, led to a conclusion by the working group that inter-cable hot shorts leading to spurious operations are very unlikely. Since inter-cable hot shorts, although rare, have been seen; however, establishing the limit at two was considered by the working group to be too low. The working group, in their evaluation of three phase hot shorts on power circuits, concluded that the addition of a third hot short sufficiently reduced the likelihood of occurrence due to the additional need for specific polarity on each conductor for power circuits.

To allow for additional margin, the working group set a limit of four for this recommendation to compensate for cases in which the target equipment is indifferent to polarity. The evidence available suggests that an inter-cable hot short failure mode is of low likelihood. The empirical evidence suggests that a single inter-cable hot short spurious operation is possible. The evidence also suggests that for the inter-cable hot short interactions that do occur, spurious operations (as assumed above) are infrequent, i.e., many of the hot shorts experienced were of insufficient quality to result in a spurious operation. Thus, the likelihood of having four or more inter-cable hot short failures in separate target cables resulting in spurious operations that are related to the same MSO scenario does not warrant further consideration in a post-fire safe shutdown circuit analysis.

5.2.2.3 Quantitative Discussion

The working group recommends that four inter-cable shorts (excluding GFEHS) are not considered regardless of latching or duration considerations. A cable configuration of thermoplastic grounded AC was used for calculating the bounding probability using SOV single break-control circuits, which typically is the more probable bounding circuit configuration.

Grounded AC, four inter-cable shorts, thermoplastic cables (Table 4-1, Ref. 12)

> Using the mean values, and given a fire, the probability of four separate target cables with inter-cable shorts for single break SOV grounded AC and thermoplastic cables is $(2.5E\text{-}02)^4$ = 3.9E-07.

The likelihood of this event leading to core damage is considerably less. Considering a conservative fire ignition frequency of 1E-02, and a reasonable conditional core damage probability (CCDP) of 1E-01, then the probability of core damage is further reduced by approximately 1E-03. (This does not account for other potential reductions from the fire severity factor or probability of non-suppression that could reduce the probability even further.) Therefore, the likelihood of this fire event case causing core damage is approximately 3.9E-10.

With reasonably conservative estimates used and potential further risk parameters not included, the quantitative evaluation provides risk insights that these MSO scenarios are not safety significant and they do not warrant further consideration.

5.2.3 Spurious Operation Recommendation 3: Number of Non-Latching Hot Shorts with 10 Minute Coping Time Regardless of Circuit Failure Mode

If the MSO requires (a) three or more concurrent fire-induced hot shorts on separate target cables in non-latching circuits and (b) the hot shorts must be sustained for more than 10 minutes to cause a condition that cannot be tolerated, (refer to NEI 00-01, Appendix H), then the working group recommends this MSO not be considered regardless of conductor hot short failure mode (i.e., intra-cable, inter-cable, or GFEHS). For MSO scenarios that result in conditions that cannot be tolerated for 10 minutes or less, any number of non-latching intra-cable circuit failures should be considered, unless otherwise limited. In addition, for latching fire induced hot shorts, any number of intra-cable circuit failures should be considered unless otherwise limited.

5.2.3.1 Assumptions/Limitations

There are no additional assumptions or limitations for this recommendation.

5.2.3.2 Technical Basis

The possibility of cable failure modes caused by fire conditions has been explored in all three of the major fire testing programs (EPRI/NEI Ref. 3, CAROLFIRE Ref. 8, and DESIREE-FIRE Ref. 9). One of the primary findings of the cable fire testing performed is that the duration of hot shorts is limited. In aggregate, the tests performed on AC circuits resulted in 111 fire-induced spurious operations, the longest being 11.3 minutes which was observed in the NEI testing. The DC circuit testing (Ref. 9) resulted in approximately 76 fire-induced spurious operations (excluding switchgear) with five of the 76 lasting longer than the longest AC spurious operation duration (i.e., 13.5, 17.5, 19.9, 23.8, and 107 minutes). Although there were a limited number of hot shorts that lasted longer than 10 minutes, the vast majority of spurious operations identified lasted from a few seconds to a few minutes. Fire-induced spurious operations were not experienced in every cable fire test. In many of the cable fire tests conducted, cable failures other than hot shorts occurred. For example, once a source conductor in a circuit experiences a short-to-ground that actuates the circuit protective device, spurious operation of a component by that circuit, as a result of a single hot short in that circuit, is impossible. Therefore, the quantities of fire-induced spurious operations listed above represent only a subset of the total number of circuit failures experienced in the cable fire tests conducted. The balance of the circuit failures did not result in a spurious operation. A numerical tabulation of the results from the NRC/EPRI cable fire testing for those circuits monitored with a surrogate circuit diagnostic unit is summarized in Table 5-1 below:

Table 5-1 Test Data for Circuits with a Surrogate Circuit Diagnostic Unit

Reference	Table	# of Cables (or Bundles) with at least 1 HS / Spur. Op	# Cables (or Bundles)	% HS / Spur. Op
Ref. 8	7.2	31	61	50.8%
Ref. 9	6-22	9	24	37.5%
	6-24	7	18	38.9%
Ref. 3	11-3	1	8	12.5%
	11-4	15	42	35.7%
	11-5	10	13	76.9%
Totals	N/A	73	166	43.9%

Spurious operations lasting more than ten minutes were rare, but were experienced. Based on this, the working group concluded that establishing the limit at one was too low. By adding a second failure, the working group considered that sufficient margin was established, since both hot shorts of extended duration would need to affect components associated with the same MSO. To allow for further margin, the working group concluded that the limit be set at three (3).

Given the fact that a limited number of hot shorts lasted for more than a few minutes with most lasting on the order of a few seconds to a minute, the working group considered it to be virtually impossible to have three hot shorts existing at the same time for more than a ten minute timeframe and affecting components associated with the same MSO. Without the coexistence of these three hot shorts, the MSO cannot exist due to the non-latching aspects of the circuit design. Since the impact to post-fire shutdown, by this recommendation, must be tolerable for up to ten minutes and since the MSO is concluded to be incapable of lasting for that duration, post-fire safe shutdown is assured. The working group concluded that having three hot shorts associated with components common to a single MSO scenario having duration of longer than ten minutes is not a realistic scenario and the working group recommends this configuration is beyond what needs to be considered when addressing MSOs for post-fire safe shutdown.

5.2.3.3 Quantitative Discussion

As illustrated in Table 6-3 of Reference 12, the spurious operation duration conditional probability values reach their floor value by 10 minutes. Examples are calculated for the various cable configurations using SOV single break-control circuits, which typically are the more probable bounding circuit configuration, and aggregate conductor hot short failure mode conditional probabilities.

Ungrounded DC, aggregate shorts, armored cables (Table 4-1 & Table 6-3, Ref. 12)

Armored cable is used for this case to conservatively bound the ungrounded DC case for all target cable configurations.

Using the mean values, and given a fire, the probability of three separate target cables with aggregate hot short failure mode for single break SOV, ungrounded DC circuit, and armored cables is $(8.6E\text{-}01)^3$ = 6.4E-01.

Using the mean value and given a fire, for the floor of the spurious operation duration for DC circuits of 2.2E-02, the joint conditional duration probability for three separate target cables is $(2.2E\text{-}02)^3$ = 1.1E-05.

Using the mean value and given a fire, for the floor of the spurious operation duration for DC circuits of 2.2E-02, then the probability for all three independent hot shorts in separate target cables to persist beyond 10 minutes becomes 6.4E-01 x 1.1E-05 = 6.7E-06.

Ungrounded AC, three aggregate shorts, thermoplastic cables (Table 4-1 & Table 6-3, Ref. 12)

Using the mean values, the probability of three separate target cables with aggregate hot short failure mode for single break SOV, ungrounded AC circuit, and thermoplastic cables is $(6.4E\text{-}01)^3$ = 2.6E-01.

Using the mean value for the floor of the spurious operation duration for AC circuits of 7.1E-03, the joint conditional duration probability for three separate target cables is $(7.1E\text{-}03)^3$ = 3.6E-07. However, Section 7.3.4.2 of Reference 12 states, "For MSOs occurring due to fire in separate cables, (for both AC and DC circuits) the application of conditional duration probabilities for MSO's should be limited to a joint minimum value of 1.0E-05."

Using the spurious operation duration joint minimum value of 1.0E-05, then the probability for all three independent hot shorts in separate target cables to persist beyond 10 minutes becomes 2.6E-01 x 1.0E-05= 2.6E-06.

Grounded AC, three aggregate shorts, thermoplastic cables (Table 4-1 & Table 6-3, Ref. 12)

Using the mean values, the probability of three separate target cables with aggregate hot short failure mode for single break SOV grounded AC and thermoplastic cables is $(4.4E\text{-}01)^3$ = 8.5E-02.

Using the mean value for the floor of the spurious operation duration for AC circuits of 7.1E-03, the joint conditional duration probability for three separate target cables is $(7.1E\text{-}03)^3$ = 3.6E-07. However, Section 7.3.4.2 of Reference 12 states, "For MSOs occurring due to fire in separate cables, (for both AC and DC circuits) the application of conditional duration probabilities for MSO's should be limited to a joint minimum value of 1.0E-05."

Using the spurious operation duration joint minimum value of 1.0E-05, then the probability for all three independent hot shorts in separate target cables to persist beyond 10 minutes becomes 8.5E-02 x 1.0E-05= 8.5E-07.

The likelihood of the event, evaluated in Section 5.2.3, leading to core damage is considerably less. Considering a conservative fire ignition frequency of 1E-02, and a reasonable CCDP of 1E-01, then the probability of core damage is further reduced by approximately 1E-03. (This does not account for other potential reductions from the fire severity factor or probability of non-suppression that could reduce the probability even further.) Therefore, the likelihood of this fire event case causing core damage, for the three configurations evaluated above, is approximately 6.7E-09, 2.6E-09, 8.5E-10 respectively or less.

With reasonably conservative estimates used and potential further risk parameters not included, the quantitative evaluation provides risk insights that these MSO scenarios are not safety significant and they do not warrant further consideration.

5.2.4 Spurious Operation Recommendation 4: Sequentially Selected Fire-Induced Circuit Failures

For this recommendation, an MSO requires:

- a selective sequence of five or more separate target cables,
- each with specific fire induced cable failures,
- the adverse condition will not occur if the sequence is not produced by the fire-induced circuit failures (e.g., hot short, short to ground, open circuit), at least two of these failures being hot shorts

If these three bullets are satisfied, then the MSO does not need to be considered for MSOs regardless of fire-induced failure durations, circuit configurations, or fire-induced failure types.

5.2.4.1 Assumptions/Limitations

To be beyond what needs to be considered for MSOs, the total number of sequential failures must exceed the threshold established above without including the following as one of the sequential failures: (1) the more probable failures of conductor grounding of grounded AC circuits in armored cable or (2) for ungrounded DC circuits, the more probable failures of intra-cable short or ground fault equivalent hot short in armored cable.

The metal armor of armored cable is assumed to always be grounded in accordance with NFPA 70 (Ref. 30).

5.2.4.2 Technical Basis

The possibility of cable failure modes caused by fire conditions has been explored in all three of the major testing programs (EPRI/NEI, CAROLFIRE, and DESIREE-FIRE). These test programs have shown that the conditional probability of a single spurious operation for cables with certain insulation types and circuit configurations is plausible. Hence, if only two failures are needed in sequence, it is very likely that they could fail in the proper sequence. When three items, however, must fail in the correct sequence that likelihood drops notably. The working group considered that four sequential failures provided reasonable margin, however for added conservatism, the working group concluded that five sequential failures were sufficient to preclude the need to consider the MSO for post-fire safe shutdown.

For a fire, which is a random event, to cause a sequence of failures involving five or more cables all related to a common system interaction, seems highly unlikely. Based on this, the working group recommends that selective sequence MSO scenarios involving five or more cables are beyond a plausible scenario to be considered in a post-fire safe shutdown circuit analysis.

5.2.4.3 Quantitative Discussion

To be considered an MSO scenario, there must be at least two hot short-induced spurious operations involved in the scenario of concern. The aggregate conditional probability of spurious operation for a SOV single break circuit for thermoplastic is 0.44, 0.64, 0.55 for grounded AC, ungrounded AC, and ungrounded DC, respectively [Table 4-1, Ref. 12]. For this discussion, it is conservative to ignore the probability of the target cable not being fire damaged at all because without the prescribed fire damage sequence the MSO scenario does not occur. In addition, it is conservative to ignore the late sequence end state where all circuits are essentially grounded as the spurious operation events would be terminated. Therefore, for this technical discussion, the probability of the same target cable resulting in short to ground with no potential for spurious operation or an open circuit is assumed to be the converse of the hot short probability 0.56, 0.36, 0.45 for Grounded AC, Ungrounded AC, and Ungrounded DC, respectively. This is nearly an equal opportunity for a hot short (0.5) versus not (0.5). With five cables involved and each cable assumed to have equal opportunity to have a hot short or not for simplification, then the number of cable failure choices is simplified to 10 (e.g., 5 cables A, B, C, D, and E that either result in a (1) a hot short or (2) non-hot short). These choices are represented in Table 5-2.

Initially, there are 10 choices for the first cable failure mode. Once the first cable and failure mode is established, then 8 choices remain. Once the second cable and failure mode is selected, then 6 choices remain. Once the third cable and failure mode is selected, then 4 choices remain. Once the fourth cable and failure mode is selected, then 2 choices remain. Therefore, the number of permutations is 10 x 8 x 6 x 4 x 2 = 3840. The probability of the specific unique MSO failure sequence occurring is then 1 / 3840 = 2.6E-04. Given that at least two of the cable failure modes must be hot short spurious operations for the condition to be an MSO, and the other three cables also require a prescribed failure mode (either hot short, short to ground, open circuit), the approximate probability of the unique sequence required is multiplied out to give 2.6E-04 x 0.5 x 0.5 x 0.5 x 0.5 x 0.5 = <u>8.1E-06.</u>

Table 5-2 Cable Failure Choices

	(1) Hot Short	(2) Non-Hot Short
Cable A	A1	A2
Cable B	B1	B2
Cable C	C1	C2
Cable D	D1	D2
Cable E	E1	E2

The likelihood of this event leading to core damage is considerably less. Considering a conservative fire ignition frequency of 1E-02, and a reasonable CCDP of 1E-01, then the probability of core damage is further reduced by approximately 1E-03. Therefore, the likelihood of this fire event causing core damage is approximately 8.1E-09.

As stated previously, the quantitative evaluation result ignores the possibility of any of the five target cables not being in fire zone of influence. It also does not account for severity factor or probability of non-suppression that would reduce the probability even further. With reasonably conservative estimates used and potential further risk parameters not included, the quantitative evaluation provides risk insights that these MSO scenarios do not warrant further consideration.

5.3 Summary

Consideration of key aspects of the MSOs should be factored in and included in the guidance. When considering the need to combine MSOs, add a new MSO or in evaluating an existing MSO, the following limitations apply:

- If the MSO requires the consideration of inrush current from more than one end device to cause an overload condition for a power supply, then the working group recommends that the MSO not be considered, as long as the assumptions/limitations of Section 5.2.1 are satisfied.

- If the MSO requires four or more separate target cables with inter-cable hot shorts (excluding GFEHS), then the working group recommends that the MSO does not need to be considered, regardless of whether the circuits are latching or non-latching. There is no sustained time duration consideration required for this case. An MSO scenario should consider up to three separate target cable inter-cable hot shorts (excluding GFEHS) and any number of GFEHS combinations unless otherwise limited.

- If the MSO requires (a) three or more concurrent fire-induced cable shorts on separate target cables in non-latching circuits and (b) the hot shorts must be sustained for more than 10 minutes to cause a condition that cannot be tolerated (refer to NEI 00-01 Appendix H), then the working group recommends that this MSO should not be considered regardless of conductor hot short failure mode (i.e., intra-cable, inter-cable, or GFEHS). For MSO scenarios that result in conditions that cannot be tolerated for 10 minutes or less, any number of non-latching intra-cable circuit failures should be considered, unless otherwise limited. In addition, for latching fire-induced hot shorts, any number of intra-cable circuit failures should be considered, unless otherwise limited.

- If the MSO scenario requires consideration of five or more sequentially selected cable failures of a prescribed type and in a prescribed selective sequence in order for the postulated MSO combination to occur, then the working group recommends that the MSO should not be considered. A limiting condition, however, applies as the following cannot be counted as one of the sequential failures: (1) the more probable failures of conductor grounding of grounded AC circuits in armored cable or (2) for ungrounded DC circuits, the more probable failures of intra-cable short or ground fault equivalent hot short in armored cable.

6
HOT SHORT-INDUCED SPURIOUS OPERATION DURATION FOR AC AND DC CONTROL CIRCUITS

Fire testing has shown that hot short-induced spurious operations are a credible failure mode when cables are exposed the thermally damaging environments (Refs. 3, 8, 9, 17). Testing has also shown that the duration of these hot short-induced spurious operations is finite (Ref. 17). The PRA Expert Panel Report (Ref. 12) developed probabilistic distributions for the likelihood of a spurious operation lasting for a specified time. These distributions support conducting a circuit failure mode likelihood analysis for risk-informed approaches, however, they are not directly relevant to deterministic analysis. This section uses the probabilistic information and supporting test data to develop technical recommendations for specifying spurious operation duration in AC and DC control circuits for post-fire safe shutdown circuit analysis.

6.1 Background

Current Regulatory Framework

The purpose of this sub-section is to provide context for the discussions that follow. The intent is simply to re-iterate the working group's understanding of the current regulatory framework.

Current guidance on the performance of a post-fire safe shutdown circuit analysis is contained in NRC and industry documents. These documents specify assumptions and criteria to use when performing these evaluations. One criterion relates to the maximum duration of a hot short that should be considered for specific circuit classifications.

Section 3.5.1, "Criteria/Assumptions" of NEI 00-01, Rev. 2 (Ref. 6), provides fire-induced circuit failure evaluation criteria and assumptions. The criteria for circuit failures include a discussion on assumed duration of a fire-induced spurious operation. Section 3.5.1.1, "Circuit Failure Criteria," states in part:

> …For components classified as "required for hot shutdown," there is no limit on the duration of the hot short. It must be assumed to exist until an action is taken to mitigate its effects. …
>
> For components classified as "important to safe shutdown," the duration of a hot short may be limited to 20 minutes. (If the effect of the spurious operation involves a "sealing in" or "latching" mechanism, that is addressed separately from the duration of the spurious actuation,…[discussed elsewhere in NEI 00-01, Rev. 2])

The NRC staff's endorsement of NEI 00-01, Rev. 2, took an exception to the 20-minute criteria. Section C.5.3, "Fire Protection of Safe-Shutdown Capabilities," of RG 1.189 (Ref. 27), states in part:

> …The eighth bullet [under the sub-heading "Circuit for 'important to safe shutdown' components" of Section 3.5.1.1 in NEI 00-01, Rev. 2] discusses limiting the duration of

> the hot short to 20 minutes; the NRC does not endorse this assumption for direct current (dc) circuits. …

Therefore, the current guidance is that all circuits for "required for hot shutdown" components and direct current (DC) circuits for "important to safe shutdown" components are assumed vulnerable to spurious operations with no limit on duration. The maximum spurious operation duration of 20-minutes can be applied to alternating current (AC) circuits for "important to safe shutdown" components.

6.2 Technical Discussion

At the time NEI 00-01, Rev. 2 and the subsequent revision to RG 1.189 were being developed, there was no publically available data on the fire-induced spurious operation behavior of DC circuits. Based on limited proprietary utility testing (Ref. 31), there were indications that the fire-induced circuit failure behavior of DC circuits may differ from AC circuits. Due to these apparent behavioral differences, the NRC sponsored a confirmatory testing project to evaluate DC circuit fire-induced failure modes which were ongoing at the time these guidance documents (NEI 00-01, Rev. 2 and RG 1.189, Rev. 2) were under development. Design differences between AC and DC circuits also suggested that the spurious operation duration for AC and DC circuits might differ. As such, the staff determined that it was not prudent to endorse the 20 minute criteria for DC circuits until additional supporting information could be collected, analyzed, and presented.

6.3 Supporting Information

The NRC-sponsored testing is documented in NUREG/CR-7100, "Direct Current Electrical Shorting in Response to Exposure Fire (DESIREE-FIRE): Test Results" (Ref. 9). Additional data analysis was conducted and documented in NUREG-2128, "Electrical Cable Test Results and Analysis during Fire Exposure (ELECTRA-FIRE), A Consolidation of Three Major Fire-Induced Circuit and Cable Failure Experiments Performed Between 2001 and 2011" (Ref. 17). Both of these efforts were conducted under a cooperative research agreement (Memorandum of Understanding) between the US NRC/RES and EPRI.

Following the joint NRC-RES/EPRI testing and circuit analysis efforts for DC circuits, expert panels were formed to evaluate the phenomena that influence the spurious operation duration and to develop conditional spurious operation duration estimates as inputs to fire probabilistic risk assessments (fire PRAs). The results of these efforts are documented in NUREG/CR-7150, Volumes 1 and 2 (EPRI 1026424 and EPRI 3002001989), "Joint Assessment of Cable Damage and Quantification of Effects from Fire (JACQUE-FIRE)" (Ref. 1 and 12). In Volume 2, an approach for quantifying the conditional spurious operation duration likelihood was developed for AC and DC circuits for incorporation into fire PRAs. In this approach, a floor estimate was added to the conditional spurious operation duration likelihood curve to represent the probability of a fire-induced spurious operation never clearing. The floor point estimates are 0.0071 for AC circuits and 0.022 for DC circuits. Although this approach is technically adequate when used in a risk-informed / performance-based fire protection program, the simplified assumptions and dataset rejection techniques do not support direct development of a spurious operation duration limit for use in deterministic analysis.

Additionally, the duration likelihood estimates contained in JACQUE-FIRE Volume 2 can be applied to several spurious operations within a scenario, provided a joint probability limit is not exceeded. While this is an acceptable approach in fire PRA, for deterministic analysis, placing a limit on the duration of a spurious operation is only applicable for a single component or signal. The test data and duration likelihood estimates are used elsewhere to assist in determining a limit on the number of spurious operations to consider.

6.4 Testing Data Analysis

To support development of a fire-induced spurious operation duration limit for a single hot short-induced spurious operation, the test data documented in NUREG/CR-2128 (Ref. 17) was used as a starting point. Two bins were developed:

(1) An AC duration data bin that included all hot short-induced spurious operation duration data from the NEI/EPRI, NRC-CAROLFIRE, and NRC-DESIREE-FIRE (AC portion) data; and
(2) A DC duration data bin included all hot short-induced spurious operation duration data from the NRC-DESIREE-FIRE (DC portion) tests, with the exception that the medium voltage switchgear control circuits were not included.

The switchgear data was not used because by design, only a momentary spurious operation is needed to cause the device to change state (i.e., momentary energization of either the close or trip coil). The histograms with best fit distributions for the empirical data are presented in Figure 6-1. Figure 6-1(a) and 6-1(b) present the distributional fit (shown as probability density functions) and data histograms for the AC and DC data bins, respectively. Figure 6-1(c) and 6-1(d) provide illustrations for the empirical data set and distributional fit, including a 95th percentile confidence interval for AC and DC bins, respectively. Figure 6-1(e) presents the AC and DC empirical data on the same plot. Figure 6-1(c) through (e) are shown as survivor functions, which is the same as the complementary cumulative distribution function. These figures can be used to visualize the likelihood of a hot short-induced spurious operation exceeding a certain time.

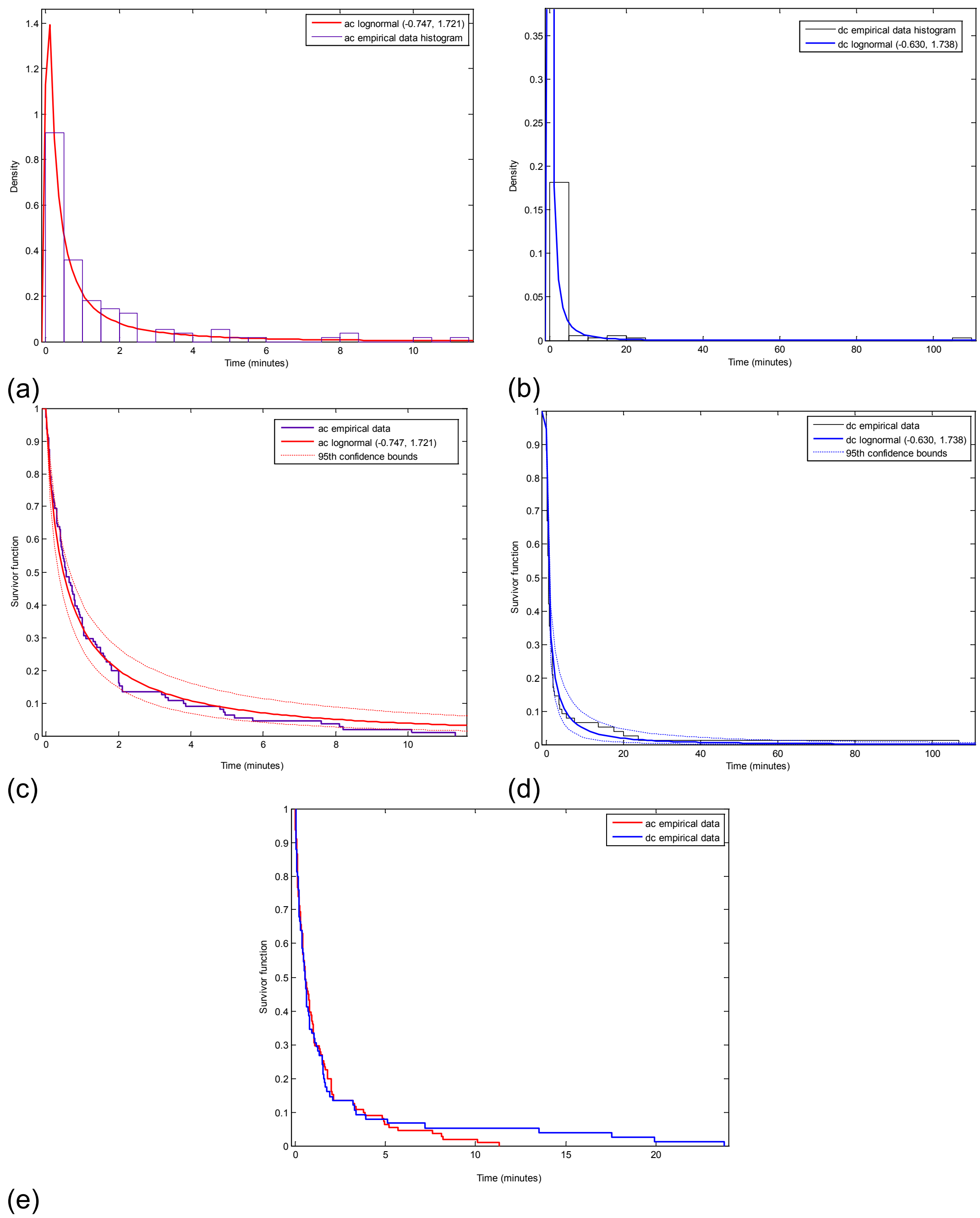


Figure 6-1 Empirical Data and Parametric Distributions for AC and DC Spurious Operation Duration. Histogram and Probability Desnit Function (a,b), Emperical and Distribution Survivor Function (c,d), Emperical Data Survivor Function (e).

6.5 Technical Resolution

Based on the knowledge and review of the test data, along with discussions held during the meetings, the working group reached a consensus recommendation, as stated below.

6.5.1 Recommendation and Basis

Recommendation: *The duration of a single hot short-induced spurious operation may be limited to 20 minutes for AC circuits, and 40 minutes for DC circuits. This limitation is not applicable to spurious operations of circuits involving a "sealing in" or "latching" mechanism.*

Basis: The tests performed on AC circuits resulted in 111 fire-induced spurious operations, the longest being 11.3 minutes which was observed in the NEI testing. The DC circuit testing resulted in approximately 76 fire-induced spurious operations (excluding switchgear) with five of the 76 lasting longer than the longest AC spurious operation duration (i.e., 13.5, 17.5, 19.9, 23.8, and 107 minutes). Based on an understanding of the test data, and consensus amongst working group members, a limit of 20-minutes for AC circuits and 40-minutes for DC circuits appears reasonable. The working group chose to maintain the existing 20-minute limit for AC circuits based on the margin between this limit and the longest observed AC circuit spurious operation duration. The 20-minute limit equates to less than a 1 percent chance of experiencing a fire-induced spurious operation lasting greater than 20 minutes for AC circuits, based on currently available test data and the distribution fit in Figure 6-1(c). Using this same criterion of less than 1 percent for DC circuits, along with the comparison of the relative difference between the DC and AC data, the corresponding limit for DC circuits is 40-minutes.

The recommendation of the working group on this topic is technical in nature. From an electrical engineering perspective, components and cables will behave the same regardless of component classification (i.e., required vs important). Therefore, component classification does not influence the duration of a hot short induced spurious operation.

7
OPEN SECONDARY OF CURRENT TRANSFORMERS

7.1 Background

Current transformers (CTs), a subgroup of instrument transformers, are used throughout AC electrical distribution systems in NPPs. These devices monitor current levels at select locations (e.g., cable, bus bar) and provide a signal from their secondary winding that is proportional to the current flowing through the main (primary) winding. CTs measure the primary current through magnetic coupling and thus do not have a physical connection to the primary circuit they are monitoring. Therefore, CTs provide isolation from the high voltage and high current in the primary circuit being monitored.

The CT's secondary current signal is commonly used for relay, protection, and indication circuits (both local and remote). In many cases the protective relays and/or indicators associated with the CT are located at the same locations as the CT. For these cases, the secondary circuit is typically confined to the switchgear/equipment containing the CT. In other instances, the secondary circuit of the CT may provide a signal to remotely located protective relay(s) or indicator(s), e.g., differential protective relays and remote ammeters. As such, the secondary circuit may span numerous fire areas within a NPP. These latter cases present a potential safety concern, as discussed below.

Engineering principles and testing confirm that as long as current is flowing in the primary circuit, an open-circuit in a CT's secondary can cause high crest (or peak) voltage on the secondary circuit as the CT attempts to maintain the current relationship dictated by the transformer's winding turn ratio. This condition presents a shock hazard to personnel, and can generate voltages that may exceed the dielectric strength of the CT's insulating materials. This may then cause arcing, to connected or nearby components, potentially damaging the components.

Should a fire-induced open circuit occur in the run of instrumentation cable, a high voltage condition in the secondary circuit would occur. It was then theorized that this high voltage condition could result in a secondary fire due to insulation breakdown. A secondary fire, as used in this context, refers to a fire at a location remote, e.g., in a separate fire area from the original fire that is responsible for the initial open-circuit in the CT's secondary circuit. The resulting secondary fire caused by a fire-induced open-circuited CT introduces a potential concern for fire protection strategies in NPPs for both deterministic and performance-based approaches.

The PIRT Panel investigated this postulated failure mode as documented in Section 6.2.3 of Volume 1 to NUREG/CR-7150 (Ref. 1). The PIRT Panel concluded that the concern of a secondary fire resulting from a fire-induced open circuited CT was more theoretical than real. However, given the lack of data, the PIRT panel's recommendation was limited to CTs with turn ratios 1200:5 and below. This conclusion was based on a number of points, including:

- Propensity for a fire to produce an open circuit condition

  For a fire to produce an open circuit in the secondary, damage to the jacket, insulation and conductors (e.g., 1980°F (1082°C) for copper conductors) would need to occur. Falling debris or some other mechanism as a result of the fire could cause an open circuit. While the possibility of an open circuit to a CT's secondary conductors cannot be completely ruled out, the likelihood of such an event is judged low.

- Clean open circuit condition with no intermittent arcing

  Once an open circuit in the secondary circuit occurs, an increase in voltage occurs. Note that "increase in voltage" as used here is intended to indicate a voltage higher than the primary circuit voltage, but is not intended to represent a voltage in a high voltage class, i.e., >100,000 Volts. This higher than normal voltage in the secondary will remain as long as the secondary circuit remains fully open (i.e., no arcing or shorting at the location of the initial open circuit) and a primary current is present. If the gap between the open circuited conductors were decreased to a gap distance that supports arcing, then an arc will form and the secondary voltage will be reduced. Thus, to exhibit high voltages on the secondary circuit due to an open circuit, the open circuit must remain open with sufficient air gap distance to not allow for arcing or shorting to occur at the initial fire damage location. Although possible, it is unlikely that the fire will cause a clean open with sufficient air gap to maintain no arcing. As such, the PIRT Panel concluded that arcing would most likely occur at the point of least resistance (location of fire-induced open circuit) and once arcing or shorting occurs, the secondary voltage would drop to a level that poses no risk of fire outside the initial fire area.

- Secondary fire ignition source / combustible configuration

  Given a fire-induced open circuit in the CT secondary, where the open circuit remained open without any arcing or shorting due to the high voltage (both unlikely events), then the high voltage conditions would have to damage the circuit in a location other than the initial fire location to pose a concern beyond that covered by analysis assumptions. The most likely location would be the CT itself, which is located within a metal enclosure, typically metal clad switchgear or similar enclosure (medium voltage switchgear, load center, etc.). CTs are typically located in the power conductor or bus section of the electrical enclosures. That area has limited combustibles, but typically does include the CT itself, bus insulation, cable insulation and in some cases limited amounts of panel wiring not in direct contact with the CT. Given the limited energies available in the CT secondary circuit and the lack of combustibles in the immediate vicinity of the CT itself, achieving ignition and establishing burning conditions is unlikely.

- Operating experience

  Review of operating experience, via the NRC's LER database and the EPRI fire events database (Ref. 32), did not identify a single fire that was a result of an open-circuited CT. Operating experience from non-nuclear industries was also reviewed by the PIRT panel. This review did not identify any instance where fire was caused by an open-circuited current transformer. Therefore, no instances were identified supporting the postulated failure mode of concern.

Despite the lack of data to support a fire induced by open secondaries of CTs, the PIRT panel recommended that additional testing be performed for CTs with turn ratios greater than 1200:5. A separate report NUREG/CR-7228, “Open Secondary Testing of Window-Type Current Transformers” (Ref. 33), documents the results of the CT testing completed in early 2016.

7.2 Open Secondary CT Testing

In response to the PIRT Panel’s request, two AMRAN window-type CTs were provided by EPRI under the NRC-RES/EPRI MOU. These CTs are shown in Figure 7-1 and were tested by BNL (Ref. 33). The primary purpose of this test program was to better understand the following scenario:

> Will fire-induced open circuiting of the secondary circuit of a wound-type CT, which is operating within its rated continuous primary current limits, result in an excessively high voltage in the secondary circuit sufficient to start a fire in the form of explosion or arcing in the circuit’s insulation at the location of the CT itself or at some other location in the secondary circuit?

The testing was performed under the guidance of the working group.

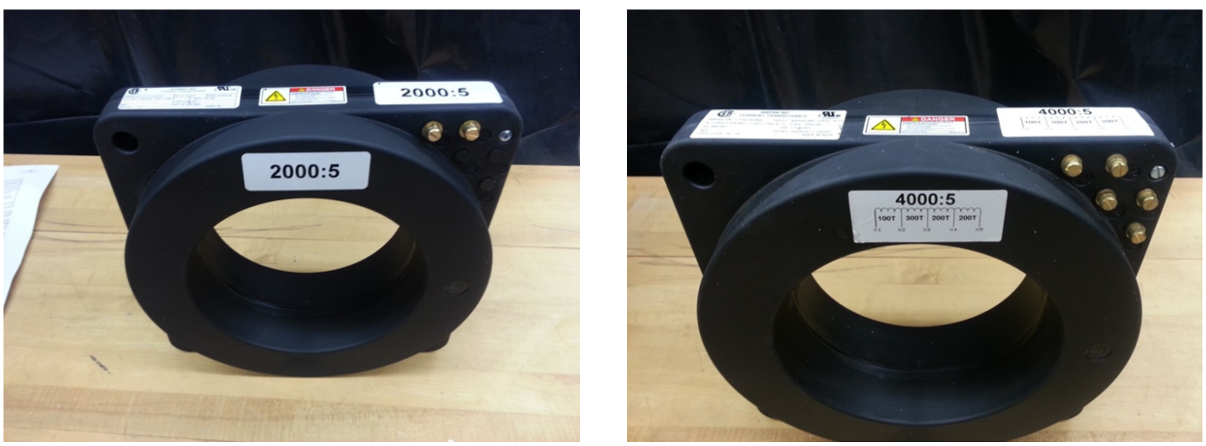


Figure 7-1 Photograph of 2000:5 CT (Left), and 4000:5 CT (Right)

The objective of this testing was to develop additional data that could be used to supplement the current body of knowledge in an effort to inform technical decision making regarding the validity of secondary fires due to fire damage to secondary circuits of current transformers (CTs). To evaluate the plausibility of this scenario, the testing visually observed the behavior of the secondary circuit, as well as, recording the transient characteristics of the core’s magnetic behavior. This included monitoring the effects of primary voltage and current at 60 Hz line frequency on the secondary voltage peaks as it transitions from normal conditions to an abnormal open secondary condition.

OPEN SECONDARY OF CURRENT TRANSFORMERS

The testing assumed that an open circuit condition of an energized CT occurred (due to fire damage). Based on engineering principals and device characteristics, the open circuit was expected to cause abnormally high voltages in the secondary circuit while primary current remained present. The desired outcome of this investigation was to observe whether the high voltage causes arcing or catastrophic failure at locations remote from the open circuit, which in turn could start a secondary fire with the potential to damage nearby equipment.

The following test parameters were considered and varied:

- Primary Voltages[19]: 500V, 250V, 125V
- Two AMRAN CT Types: fixed-ratio 2000:5 CT, multi-ratio 4000:5 CT
- For the fixed-ratio of 2000:5: varied primary current from 60A to 4000A
- For the multi-ratio CT: varied turn ratios of 500:5 to 4000:5 (or primary current ratings) and primary current for fixed turn ratios at 2000:5 and 4000:5
- Open secondary mode: fast open, intermittent opening, arcing simulations
- Thermal measurements of CT surface and electrical enclosure air space

Sixty-three tests in fifty-one different test configurations were performed using both the fixed-ratio CT 2000:5 (AM2CT) and the multi-ratio CT 4000:5 (AM4CT). Additional tests of certain configurations were performed to: simulate long durations, test repeatability, perform intermittent relay opening, time step optimization, and test other conditions such as arcing. The sixty-three test configurations were divided into: twenty-nine tests on the 2000:5 CT (AM2CT) and thirty-four tests on the 4000:5 CT (AM4CT). In each test the primary voltage and primary current remained constant and independent of what was happening in the secondary circuit conditions (i.e., from a closed secondary circuit to an open secondary configuration).

The working group ***hypothesized*** that the following potential failures modes may occur due to the saturation of the CT's magnetic core, resulting higher than normal voltage in the open secondary circuit, and a possible secondary fire.

- The CT itself overheats after being exposed to a very long duration core saturation conditions or an arcing occurs at the CT's secondary taps.

- The open secondary crest voltage in the secondary circuit exceeds the breakdown voltage of the cable's insulating system. Insulation failure (breakdown) could also potentially occur at lower voltage if the cable insulation system contains a latent defect or has been damaged.

[19] Test voltage was limited to 500V due to 1) limitations of the power supply available, 2) test personnel safety concerns, and 3) logistical burden of high energy testing. The working group judged that the voltage limitation would not preclude obtaining representative data for higher voltage applications.

7.3 Evaluation of Test Results

Based on the results discussed in the test report (Ref. 33), the following findings either were observed or derived:

- Parameters that affect the *open secondary crest voltage* include the following:
  - Primary voltage source: Secondary crest voltage increases with increasing primary voltage under open circuited conditions.
  - Primary current level: Secondary crest voltage increases with increasing primary current under open circuited conditions.
  - CT's turn ratio: Secondary crest voltage increases with increasing CT turns ratio.
  - The material and construction of the CT's magnetic core varies between manufacturers and even between different models from the same manufacturer.
- Intermittent opening/closing via a relay (i.e., clean open/close) or via arcing over a small gap does not affect the magnitude of the crest voltage.
- Electrical arcing, however, diminishes the magnitude of the open secondary crest voltage.
- No degradation of the CT's secondary coil insulation was found during any tests. The temperature rise of the CT was insignificant (<5°C per test).
- The insulation of the secondary cable did not indicate any degradation. The periodic Hipot tests indicated no leakage current at 10 kV.

The repeatability of each test is excellent based on the open secondary crest voltage and the deviations noted were well below 5%.

- Neither the CT nor its secondary circuit showed any signs of arcing or explosive failure in any of the 63 tests performed.

For more information and detailed results from the CT testing see NUREG/CR-7228, "Open Secondary Testing of Window-Type Current Transformers" (Ref. 33).

7.4 Conclusions and Recommendations

The working group's conclusions and recommendations from the CT tests are as follows:

- Visual observation of the CT tests determined that no damage or arcing occurred in the secondary circuit at the CT itself, its secondary taps or at any location of the secondary cable's insulating system. This observation supports the PIRT Panel's recommendation that a CT secondary circuit when used in an application for which it is designed will not result in a secondary fire.

- In tests where arcing was induced by the test engineer, it was observed that the arc formed at the initial open circuit location in the secondary circuit, immediately caused the crest voltage to diminish significantly. This observation supports the PIRT Panel's recommendation that the onset of arcing in the circuit will significantly reduce the crest voltage.

- Although the full range of primary voltages could not be tested, the results from the tests performed confirm the behavior postulated by the PIRT Panel for CT applications in nuclear power plant distribution systems operating at 15kV and below.

- Since any arcing that may result from the high crest voltage will occur at the point of least resistance, the most probable location for arcing is where the cable is damaged by the fire. Therefore, fire damage is expected to cause arcing, which will in turn significantly reduce crest voltage and circuit damage at locations remote from the fire location, thereby eliminating the possibility of a secondary remote to the original fire.

- Results obtained from the BNL CT testing are consistent with the engineering principles and failure sequences postulated by the PIRT Panel.

These conclusions lead to the following recommendation by the working group.

> *Given the absence of secondary fires or any other fire precursor and the unique combination of low probability events needed for its occurrence; the working group concluded that secondary fires resulting from open circuited CT installations up to and including 15kV primary circuit voltage are incredible. On this basis, the working group recommends no further consideration of secondary fires as a result of CT failures for low and medium voltage switchgear (up to and including 15kV).*

This recommendation represents a consensus opinion among the working group members. The recommendation is consistent with the technical discussions and operating experience documented in the PIRT Report, but eliminates the original 1200:5 turns ratio limitation contained in the PIRT Report. This recommendation applies to <u>CTs used in low voltage and medium voltage switchgear</u>. This recommendation does not apply to high ratio pedestal-style CTs used in high voltage switchyards or transmission systems.

8
SUMMARY AND CONCLUSIONS

The objectives of this report are to: (1) present technical recommendations on a number of open issues related to fire-induced circuit failures, and (2) revise and clarify certain previous positions in JACQUE-FIRE, Volume 1 (Ref. 1). This report documents the technical consensus on several open issues related to deterministic post-fire safe-shutdown analyses reached by a balanced team of experts sponsored through EPRI and the U.S. NRC. The recommendations for resolution of these issues in a technical setting are intended to facilitate development of a solid technical foundation and a stable framework to support a consistent approach for conducting and reviewing post-fire safe-shutdown analyses.

The key findings from this research include:

- Clarification of circuit failure modes and terminology including;
    - Proper polarity (Section 2.1.1)
    - Latching versus non-latching (Section 2.1.2)
    - High impact components (Section 2.2)
    - Failure mode classifications (Section 2.3.1)
    - Ground fault equivalent hot short (Section 2.3.2)
- Recommendations for revision to several PIRT Panel positions and findings using the risk-insights developed from the PRA expert panel (JACQUE-FIRE Volume 2, Ref. 12), (Section 3)
- Technical design considerations for shorting switch applications including:
    - Circuit design (Section 4.2.2)
    - Electrical design (Section 4.2.3)
    - Circuit continuity (Section 4.2.4)
- Recommendations for evaluation of specific combinations of hot short-induced multiple spurious operations:
    - Number of hot shorts for transient inrush considerations (Section 5.2.1)
    - Number of inter-cable hot shorts regardless of latching characteristics or coping time (Section 5.2.2)
    - Number of non-latching hot shorts with 10-minute coping time regardless of circuit failure mode (Section 5.2.3)
    - Sequentially selected fire-induced circuit failures (Section 5.2.4)
- Recommendations for the duration of hot short-induced spurious operations in DC and AC control circuits for deterministic post-fire safe-shutdown analysis.
    - 20 minute duration for AC control circuits (Section 6.5.1)
    - 40 minute duration for DC control circuits (Section 6.5.1)
- Disposition of secondary fires due to a fire-induced open circuited current transformer (Section 7)
    - Secondary fires resulting from open circuited CTs are considered incredible for low and medium voltage applications. No further consideration of secondary fires as a result of CT secondary circuit failures is recommended for low and medium voltage switchgear (up to and including 15 kV).

The summary of the technical recommendations for the open issues addressed by the working group are presented as follows:

1. Clarification of Circuit Analysis Terminology in the PIRT Report

Proper Polarity

The clarification to proper polarity was broken down into two parts: 1) reversal of polarity and 2) actuation by a different power source type for relays and solenoids. Regarding the first clarification, the working group recommended that *AC and DC solenoids and relays used in double break control circuits be assumed "polarity insensitive," unless specific manufacturer's technical data indicates the device is "polarity sensitive."* Thus, the recommendation is that the analyst or inspector should assume that the orientation of the voltage to the target device is capable of actuating the end device, unless specific documentation is available to demonstrate otherwise.

For the second clarification, the working group recommended that it be assumed that AC devices can be energized by DC power sources and DC devices can be energized by AC power sources, unless a specific engineering analysis, factoring in bounding values for all of the appropriate plant specific parameters, is documented and/or testing demonstrates that the specific relay will not operate under the plant conditions found.

Latching versus Non-Latching

The working group clarified that, in the context of circuit analysis, a latching circuit configuration is one where the component or signal that *will not* return to its original (i.e., pre-spurious operation) position when the fire-induced circuit failures causing the spurious operation terminates. Conversely, a non-latching circuit configuration is one where the component or signal that *will* return to their original position when the fire-induced circuit failure causing the spurious operation terminates.

High Impact Components

The term “high impact components” are the set of components whose fire-induced failure could pose a significant threat to plant safety that is high enough to warrant a more rigorous treatment in the post-fire safe shutdown analysis.

Failure Mode Classifications

The definitions of the terms “incredible” and “implausible” remain unchanged from Section 2.2.2 of Volume 2. However, the term “plausible” instead of “possible” used in the PIRT Report has been used in this report. Therefore, the definition of the term “plausible” is given in Section 2.3.1 of this report.

Ground Fault Equivalent Hot Short (GFEHS)

The term “ground fault equivalent hot short,” also known as GFEHS, is a subset of an intra-cable or inter-cable hot short and is a circuit failure mode wherein multiple shorts to ground may cause a target device in the circuit to spuriously operate.

2. Failure Classification Changes to PIRT Results

With the benefit of the risk-insights gained from Volume 2, the working group reassessed the recommendations made by the PIRT panel in Volume 1. Based this effort, the working group recommended changes to several classifications to promote consistency between performance-based and deterministic approaches. Specifically, this volume documents the technical justification for the specific changes made in reclassifying the hot short-induced spurious operation failure modes of control circuits (incredible, implausible, and plausible) from those suggested in JACQUE-FIRE Volume 1, the PIRT Report (Ref. 1). The recommended changes are presented in Tables 3-1 through 3-4 of this report.

3. Shorting Switch Recommendations

The use of shorting switches as a design feature, to protect against hot short-induced spurious operations, has been implemented by a limited number of licensees. An NEI task force developed guidance on the use of a shorting switch and the working group was tasked with investigating the issue. Starting with the original draft NEI guidance (Appendix I, Ref. 13), the working group provided supplemental technical information that, in combination with the original guidance, provide a comprehensive set of design considerations and recommendations for the reliable use and application of shorting switches. Guidance is provided in the areas of circuit design, electrical design, and circuit continuity considerations. Diligent use of the shorting switch guidance, with special attention to the application circumstances and conditions, ensures that the design and installation factors are properly considered and will result in effective implementation of shorting switch modifications. A shorting switch considerations checklist and an example application using the checklist are presented in Section 4.

4. Combination of Hot Shorts to Consider in Multiple Spurious Operations

Regulatory and industry guidance exist for evaluating multiple spurious operations, including the number of MSOs to consider. Using insights grained from Volume 2 and fire testing, the working group identified additional recommendations on the number of fire-induced circuit failures of specific types to consider when addressing MSOs. Technical recommendations are provided for four specific configurations that are based on both qualitative and quantitative insights.

5. Duration for Hot Short-Induced Spurious Operation in AC and DC Control Circuits

In the PRA Report (Ref. 12), an approach for quantifying the conditional spurious operation duration likelihood was developed for both AC and DC circuits. Although technically adequate when used in a performance-based risk-informed application, the simplified assumptions and dataset rejection techniques do not support direct development of a spurious operation duration limit to be used in deterministic analysis.

Therefore the working group evaluated this issue and recommends the duration of a single hot short-induced spurious operation be limited to 20 minutes for AC circuits and 40 minutes for DC circuits. The basis for this recommendation stemmed from a better understanding of the circuit failure results, rigorous statistical analysis of the data, and judgement of the working group. This limitation is not applicable to spurious operations of circuits involving a “sealing-in” or “latching” mechanism.

6. Assessment of Secondary Fire in Open Secondary Current Transformers (CTs)

Results from the CT tests performed at BNL indicated no damage or arcing in the secondary circuit at the CT itself and its secondary taps or at any location of the secondary cable's insulating system. When an arc was deliberately initiated in the secondary circuit, the crest voltage diminished significantly. Given the absence of secondary fires or any other fire precursor and the unique combination of low probability events needed for its occurrence; the working group concluded that secondary fires resulting from open circuited CT installations up to and including 15kV primary circuit voltage are incredible. On this basis, the working group recommended that no further consideration of secondary fires as a result of CT failures be considered for low and medium voltage switchgear (up to and including 15kV).

The recommendation is consistent with the technical discussions and operating experience stated in the PIRT Report, but expands the range of CT ratios that do not require evaluation. This recommendation applies to CTs used in low voltage and medium voltage switchgear. This recommendation does not apply to high ratio pedestal-style CTs used in high voltage switchyards.

9
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17. U.S. Nuclear Regulatory Commission, *Electrical Cable Test Results and Analysis during Fire Exposure (ELECTRA-FIRE) – A consolidation of the three major fire-induced circuit and cable failure experiments performed between 2001 and 2011*, NUREG-2128, Washington DC, September 2013.

18. NFPA 805, "Performance-Based Standard for Fire Protection for Light-Water Reactor Electric Generating Plants," 2001 Edition, National Fire Protection Association, Quincy, MA.

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21. *Screening Tests of Representative Nuclear Power Plant Components Exposed to Secondary Environments Created by Fires,* NUREG/CR-4596, Washington DC, June 1986.

22. U.S. Nuclear Regulatory Commission, *An Experimental Investigation of Internally Ignited Fires in Nuclear Power Plant Control Cabinets: Part 1: Cabinet Effects Tests*, NUREG/CR-4527, Washington DC, April 1987.

23. *Refining and Characterizing Heat Release Rates from Electrical Enclosure During Fire (RACHELLE-FIRE): Peak Heat Release Rates and Effect of Obstructed Plume*, U.S. Nuclear Regulatory Commission, Washington, DC, and EPRI, Palo Alto, CA, NUREG-2178, EPRI 3002005578, April 2016.

24. U.S. Nuclear Regulatory Commission, *Criteria for Independence of Electrical Safety Systems*, Regulatory Guide 1.75 Revision 3, Washington DC, February 2005.

25. *IEEE Standard for Type Test of Class 1E Electric Cables, Field Splices, and Connections for Nuclear Power Generating Stations*, IEEE STD 383,1974 edition New York, NY.

26. U.S. Nuclear Regulatory Commission, *Implementation of Fire Protection Requirements*, Generic Letter 86-10, Washington DC, April 24, 1986.

27. U.S. Nuclear Regulatory Commission, *Fire Protection for Nuclear Power Plants,* NRC Regulatory Guide 1.189, Revision 2, Washington, DC, October 2009.

28. *IEEE Standard Criteria for Independence of Class 1E Equipment and Circuits,* IEEE STD 384-1992, New York, NY, June 18, 1992.

29. U.S. Nuclear Regulatory Commission, *Enforcement Discretion for Fire Induced Circuit Faults,* Enforcement Guidance Memorandum 09-002, Washington, DC, May 14, 2009.

30. NFPA 70, "National Electric Code," 2017 Edition, National Fire Protection Association, Quincy, MA.

31. Results and Observations from Duke Armored Control Cable Fire-Induced Spurious Operation Testing, ML071200168, April 27, 2007, Redacted Version

32. The Updated Fire Events Database: Description of Content and Fire Event Classification Guidance, 1025284, EPRI, Palo Alto, California, July 2013.

33. U.S. Nuclear Regulatory Commission, *Open Secondary Testing of Window-Type Current Transformer* NUREG/CR-7228/BNL-NUREG-112163-2016, May, 2017.

APPENDIX A
PANELIST AND FACILITATOR RESUMES

Harold Barrett, NRC

TITLE/POSITION: Senior Fire Protection Engineer Years of Experience: 41

SUMMARY

Mr. Barrett has provided a wide range of engineering and management services for the nuclear industry. His experience includes nuclear plant regulation, engineering, maintenance and operations, plant technical support, procedure development, site emergency plan participation and direction, shift supervision, training, start-up testing and design reviews. Mr. Barrett has extensive expertise in the day-to-day operation of various U.S. nuclear power plants. In addition, he has provided extensive engineering support in the areas of fire protection, safe-shutdown analysis, valve engineering, motor operated valves (MOVs) and air operated valves (AOVs).

Mr. Barrett is currently the lead technical reviewer for NFPA 805 License Amendment Requests in the U. S. Nuclear Regulatory Commission's Office of Nuclear Reactor Regulation (NRR).

EDUCATION

BS, Marine Nuclear Science, State University of New York Maritime College at Fort Schuyler, 1975

PROFESSIONAL AFFILIATIONS/CERTIFICATIONS

U. S. NRC Qualified Technical Reviewer
Society of Fire Protection Engineers (SFPE) – Member Grade
NEI Fire Protection Working Group NFPA 805 Task Force
NEI Fire Protection Working Group
NEI Fire Protection Rule Making Task Force
Senior Reactor Operator (SRO), U.S. Nuclear Regulatory Commission (NRC)
Second Assistant Engineer, Steam Vessels of Any Horsepower, U.S. Coast Guard
Third Assistant Engineer, Motor Vessels of Any Horsepower, U.S. Coast Guard

PROFESSIONAL EXPERIENCE
Senior Fire Protection Engineer
U. S. Nuclear Regulatory Commission
Office of Nuclear Reactor Regulation
Division of Risk Assessment
Washington, DC 20555-0001
4/07 to present

Lead technical reviewer of NFPA 805 License Amendment Requests for the Fire Protection Branch (AFPB) in the Division of Risk Assessment. Responsible for reviewing fire protection, nuclear safety assessment (post-fire safe-shutdown including circuit analysis), fire modeling, non-power operations, radioactive release, monitoring program, programmatic, and performance-based, risk-informed, changes.

Worked closely with the Office of Nuclear Regulatory Research (RES) on fire testing of Direct Current (DC) electrical circuits performed as part of the DESIREE-Fire testing program.

Technical Project Manager and lead reviewer for the first NFPA 805 pilot plant, Shearon Harris. Provided technical oversight of the technical review and development of the first NFPA 805 safety evaluation.

Provided significant technical input to NRC's NFPA 805 infrastructure (Regulatory Guide 1.205, Standard Review Plan Chapter 9.5.1.2, Safety Evaluation Template) and interfaced with industry through the NFPA 805 Frequently Asked Question (FAQ) process.

Principal Engineer
Duke Power Company
Oconee Nuclear Station
Seneca, SC
Dates: 4/99 to 4/07

Project Manager and corporate lead engineer for the NFPA 805 Transition Project. Responsible for program cost, schedule and quality. This program transitioned the fire protection program for all three Duke nuclear sites from deterministic requirements to a Risk-Informed, Performance-Based Program under 10CFR50.48(c) and NFPA 805. Oconee was granted Pilot Plant status during the transition. This required significant coordination and interface with both internal and external groups, including NRC regulators.

Lead engineer for the development and performance of fire testing of armored cable in simulated, representative circuits in both AC and DC configurations.

Responsible for the Appendix R Reconstitution Project at Oconee. This project is reconstituting the post-fire safe-shutdown analysis, including component selection, cable selection and analysis, fire zone/area analysis and compliance assessments.

Engineering Support Program (application, performance, problem resolution and maintenance) for Power Operated Valves (AOVs or MOVs). Responsibilities included program management, maintenance of design basis calculations, diagnostic testing and analysis, performance trending, troubleshooting and root cause analysis, problem resolution as well as equipment failure analysis (root cause analysis processes); component monitoring and trending; valve specification, selection, application; Minor Modification development and support; procedure development; generation and review of calculations.

Senior Engineer
Duke Engineering & Services, Inc.
Charlotte, NC
Dates: 11/97-4/99

Lead Systems Engineer on an Appendix R reanalysis project to reduce the overall reliance on electrical raceway fire barrier wrap for the Salem Nuclear Generating Station. Responsible for development of System and Component Logic, development and population of the Safe-shutdown Equipment List, circuit selection and analysis and resolution of safe-shutdown compliance issues and safe-shutdown procedures development. Responsible for update of licensee configuration documents and generation of the Appendix R Safe-shutdown Analysis Report.

Senior Consultant
HGP, Inc.
Greenville, SC 29615
Dates: 10/94-10/97

Provided engineering, technical and management consulting services to a variety of clients ranging from nuclear utilities to law firms. Performed a Probabilistic Risk Assessment (PRA) of a petrochemical production plant and performed due diligence reviews of nuclear utilities in support of merger and acquisitions. In support of expert testimony in a major litigation case, analyzed management effectiveness and schedule delays related to an extended outage at a large, late model dual unit pressurized water reactor (PWR) in the southwest. Analyzed heat loads to support several real-time temperature transient analyses of nuclear power plant heating, ventilating and air conditioning (HVAC) systems, including loss of ventilation during station blackout and loss of coolant accident (LOCA).

Mechanical Engineer IV, Nine Mile Point Unit 1
Niagara Mohawk Power Corporation
Nine Mile Point Nuclear Station
Lycoming, NY 13093
Dates: 10/92-10/94

Managed the technical aspects of the Generic Letter 89-10 Motor Operated Valve (MOV) Program for Nine Mile Point Unit 1. Defined the MOV program scope, developed maximum expected operating conditions and MOV sizing calculations for all GL 89-10 MOVs. Performed cable voltage drop and DC MOV stroke time calculations. Served as Design System Engineer for numerous systems at the plant, including nuclear instrumentation and automatic depressurization system. Appendix R program design engineer responsible for maintenance of safe-shutdown analysis, transient analysis, inventory loss boundaries, and high and low pressure interface maintenance. Provided direct support to operations during fire and control room evacuation special operating procedure flow chart development.

Program Coordinator, Operations Oversight Operations Support
Nine Mile Point Unit 1
Niagara Mohawk Power (Same address as above)
Dates: 04/92-10/92

Provided operations and technical support to the operations branch. Served as a member of the Station Operations Review Committee (SORC). Served as procedure owner for all operations department procedures.

General Supervisor, Shift Operations, Nine Mile Point Unit
1 Niagara Mohawk Power (Same address as above)
Dates: 10/90-04/92

Served as SRO providing day-to-day supervision of shift operations. Supervised a staff of 65 licensed and unlicensed operators, including eight shift supervisors. Responsible for compliance to NRC license, as well as protection of public health and safety and maximum power generation at the lowest cost. Performed the duties of control room advisor and/or site emergency director as part of the Emergency Response Organization. Acted as procedure owner for operations department procedures. Served as a member of the Station Operations Review Committee (SORC).

Associate Senior Engineer, Plant Productivity Group 05/90-10/90
Nine Mile Point Units 1 & 2
Niagara Mohawk Power (Same address as above)
Dates: 05/90-10/90

Served as task manager for resolving reactor feedwater pump testing problems. Managed troubleshooting, disassembly, repair, re-assembly and successful testing of reactor feedwater pumps at Nine Mile Point Unit 1. Discovered pump impellers were installed backwards on pump shafts.

Consulting Engineer
Compis Services
Liverpool, NY 13088
Dates: 11/89-05/90

Developed safety classification basis documents in accordance with 10CFR50 Appendix B for numerous electronic and electrical circuits including 125 VDC ground detector circuits, emergency diesel generator voltage regulator and emergency diesel generator governor control circuits.

Senior Engineer/Training Instructor
General Physics Corporation
Columbia, MD 21046
Dates: 02/89-11/89

Implemented systematic approach to training (SAT) -based programs. Developed training material on symptom-based emergency operating procedures for Savannah River Site.

Level III Test Engineer
Newport News Shipbuilding
Newport News, VA 23607
Dates: 07/88-02/89

Performed naval nuclear propulsion plant testing to support new construction. Directly supervised new system flushes, hydrostatic testing, and reactor plant system start-up testing. Developed, implemented and cleared electrical and mechanical tagouts to support nuclear plant testing and construction.

<u>Assistant Operations Superintendent</u> Shift
Operations, Nine Mile Point Unit 1
Niagara Mohawk Power (Same address as above)
Dates: 07/85-06/88

Provided technical and management support of day-to-day operations of a commercial nuclear station. Directly responsible for symptom-based Emergency Operating Procedure (EOP) development and implementation. Represented NMPC on the boiling water reactor (BWR) Owner's Group Emergency Procedures Committee. Performed QR reviews of all Instrument and Control (I&C) and Maintenance (both Mechanical and Electrical) procedure revisions and temporary procedure changes. Reviewed all new design changes and plant modifications for Operations.

<u>Assistant Supervisor</u>, Technical Support
Nine Mile Point Unit 1
Niagara Mohawk Power (Same)
Dates: 10/83-07/85

Supervised engineers performing plant engineering, operations experience assessment (OEA), modifications, pre-operational testing, LERs and inspection report responses. Reviewed operational occurrences for reportability and acted as a site operations review committee alternate member. Provided technical and operations input into the Limited Scope Probabilistic Safety Assessment (PSA) of Nine Mile Point Unit 1. Provided technical and operations input into a component level safety classification database or Q-List.

<u>Senior Technical Assistant</u>, Technical Support Group
Nine Mile Point Unit 1
Niagara Mohawk Power (Same)
Dates: 08/81-10/83

Performed Operations Experience Assessment (OEA). Performed design review of numerous electrical and electronic control systems such as failure modes and effects analysis of feedwater control system and 125 VDC control power distribution system. Proposed and performed conceptual design, as well as supervised the installation and final pre-operational testing on several control system design improvement modifications. Obtained SRO License. Acted as a key member of the Appendix R Safe-shutdown Analysis team. Established safe-shutdown equipment list, inventory loss paths, and hi/low pressure interfaces. Performed electrical circuit analysis for spurious operation as well as developed confirmatory and redundant relay logic schemes for protection of safe-shutdown components. Performed conceptual design, intermediate design, field installation and final pre-operational testing of electrical design modifications implemented to meet 10CFR50 Appendix R. Supervised the installation of two Shutdown Supervisory Control Cabinets, two Shutdown Supervisory Distribution Cabinets, approximately 60 auxiliary relays, and several thousand feet of control cable. Performed circuit analysis of reactor recirculation pump motor generator set tachometer/voltage regulator circuit. Designed and developed temporary modifications to substitute a solid state power supply to replace the volts/hertz voltage regulator input from the tachometer to prevent premature pump trip and prevent loss of electric generation and subsequent risk of reactor scram.

<u>Nuclear Engineer</u>, GS-11, Code 2340, Test Engineering Group
Norfolk Naval Shipyard
Portsmouth, VA
Dates: 09/80-07/81

Performed reactor plant testing on naval nuclear propulsion plants. Performed work control, technical and operations management activities. Received and provided training on submarine PWR reactor plants.

<u>U.S. Coast Guard Licensed Marine Engineer</u>
Department of the Navy
Military Sealift Command, Atlantic
Bayonne, NJ
Dates: 12/76-05/77 and 08/78-08/80

Served as a U.S. Coast Guard licensed marine engineer and a third, second and first assistant engineer. Operated, maintained and supervised an engineering department on a 16,000 SHP Steam Geared Turbine Powered Refrigerated Stores Ship.

<u>Associate Mechanical Engineer</u>, Haddam Neck Plant
Connecticut Yankee Atomic Power Company
East Haddam, CT
Dates: 06/77-08/78

Performed plant engineering and supervised the installation and testing of modifications on a 580 MW 4 Loop Westinghouse PWR. Coordinated and managed the installation of replacement pressurizer power operated relief valves (PORVs) including installation of new motor operated PORV blocking valves and the associated electrical design, installation and testing. Installed: 1. An instrument air system inside primary containment including the associated electrical design, installation and testing; 2. Added a new mixed bed demineralizer including the associated automated control logic testing; and 3. Installed main turbine moisture separator reheater scavenging steam vent chambers. Served as plant engineering group representative on backshifts during the plant outage. Represented the plant on a team to alleviate spent fuel rack bulging and assisted in developing a spent fuel rack poison cavity venting tool.

<u>Nuclear Engineer</u>, GS-7, 9, Code 2370, Nuclear Refueling Engineering
Mare Island Naval Shipyard
Vallejo, CA 94590
Dates: 09/75-12/76

Revised procedures to support reactor refueling activities on Naval Nuclear Propulsion Plants. Performed reactor plant shield surveys. Received training on submarine reactor plant refueling procedures, equipment, support systems and design.

Robert Daley, NRC

TITLE/POSITION: Engineering Branch Chief – United States Nuclear Regulatory Commission

SUMMARY

- Manages electrical, I&C, and fire protection engineers
- Specialist in the area of 10 CFR 50.59 evaluations
- Skilled and proficient in the area of fire protection safe-shutdown analysis
- Certified as an NRC Operator Licensing Examiner for BWR and PWR nuclear plants
- Manages, plans, and directs present and future efforts in the growing areas of digital systems and cyber security
- Managed the complete cycle of cyber security Milestone 1 through 7 inspections in Region III (15 nuclear sites)
- Design Electrical Engineer at Grand Gulf Nuclear Plant
- Technical Specification Coordinator while at River Bend Station
- Member of the BWROG Fire-Induced Circuit Failures Task Force
- BWR-6 Senior Reactor Operator Certification

PROFESSIONAL EXPERIENCE

United States Nuclear Regulatory Commission **2000 - Present**
Engineering Branch Chief
Supervises engineering inspectors in the implementation of the NRC's Reactor Oversight Program to assure the safety of licensed activities and compliance with requirements. Provides administrative oversight of engineering inspectors.

- Manages technical issues and inspection in the areas of electrical engineering, instrumentation and controls, digital systems, fire protection, cyber security, and 10 CFR 50.59.
- Manages and schedules all regional team Fire Protection inspections, Cyber Security inspections, and Modification and 10 CFR 50.59 inspections.
- Agency regional lead for all four NRC regions for the Open Phase degraded voltage generic issue (Bulletin 2012-01).
- Member of the IMC 0612 (Power Reactor Inspection Reports) and IMC 0620 (Inspection Documents and Records) working groups.
- Organized for the agency, and participated in, the 2015 industry/NRC Operability Workshop
- Organized, led, and facilitated a two day agency-wide Modifications and 10 CFR 50.59 workshop.
- Member of the Office of Research PIRT Electrical Expert Panel for fire-induced cable failure modes.
- Led an agency-wide self-assessment of inspection report quality. The assessment team consisted of staff from all four regions and NRC headquarters.

Senior Reactor Engineer
Led and participated in engineering team inspections at nuclear power plants including the Component Design Basis Inspections, Modification and 50.59 Inspections, Fire Protection Inspections, and In-service Inspections.

- Certified as an Operator Licensing Examiner. Qualified to write, review, and administer NRC exams for the qualification of Senior Reactor Operators and Reactor Operators for BWR and PWR nuclear plants.
- Regional contact for engineering modification and 10 CFR 50.59 issues and inspections.
- Provided significant technical and inspection support during the Davis-Besse extended shutdown for reactor vessel head corrosion and for the Point Beach 95003 supplemental inspection.
  - Led an electrical issues inspection at Davis-Besse during their extended shutdown.
  - Led the Point Beach CDBI that that was used as a basis for their exit from the 95003 process.
- Regional Power Uprate point of contact.
- Expertise and specialty areas include:
  - Fire Protection Safe-shutdown Circuitry Analysis
  - 10 CFR 50.59
  - Technical Specifications
  - Electrical and I&C Design
  - Station Blackout
  - Equipment Qualification (EQ)
  - 10 CFR 50, Appendix J

Entergy Operations, Inc. **1991-2000**
Senior Engineer – Grand Gulf Nuclear Power Station
Evaluated and resolved electrical system and component design and performance problems. Developed electrical engineering specifications/standards, design drawings, and design changes. Proficient in protective relaying and fuse/breaker coordination. Design changes have included complex control circuitry modifications.

- Performed electrical system design including fuse/breaker replacement, electrical coordination calculations, transformer replacement, and re-design of the airlock door control circuitry.
- Fire Protection Safe-shutdown Engineer.
- Technical lead for the license basis reconstitution project for Fire Protection, Electrical Engineering, and I&C.
- Member of the fire protection (Appendix R) Safe-shutdown Analysis Owner's Group (BWROG) committee.
- Entergy's representative on the BWROG circuit failures task force.
- Operations Test Coordinator for surveillances and equipment testing during plant outage activities.

Senior Engineer – River Bend Station
Performed a variety of assignments in the areas of electrical engineering, nuclear licensing, nuclear safety assessment, and operations.

- Served as Technical Specification Coordinator for four years. Coordinated plant activities and resolved issues regarding Technical Specifications and the Technical Requirements Manual.
- River Bend representative on the Technical Specifications Task Force (TSTF).
- Senior Reactor Operator certified.

- Root Cause Team Leader. Led root cause evaluations for significant plant events. Trained and proficient in:
  - Kepner-Tregoe
  - TapRoot
  - Management Oversight and Risk Tree (MORT)
- Developed and implemented License Amendment Requests (LAR) and Licensee Event Reports (LER). Developed and submitted the first 10 CFR 50, Appendix J, Option B, License Amendment in the nuclear industry.
- Directed and assisted in assessments and analyses of plant processes and adverse trends/issues.

RCA (Thomson Consumer Electronics) 1990 - 1991
Shift Supervisor
Supervised two production lines and 43 personnel in the manufacturing of high optical quality glass for television screens. Coordinated the technical efforts involved in keeping a high-speed, fully automated production line in constant operation. Responsibilities included the maintenance and repair of robotics and complex machinery as well as the adjustment of equipment to maintain maximum productivity.

United States Navy Nuclear Officer 1984 - 1989
Served as a naval officer assigned to the USS Long Beach.

- Supervised 25 personnel in the daily maintenance of all shipboard electrical distribution equipment, electrical machinery and electronic hardware.
- Supervised and coordinated the operational staff in 2 nuclear power plants as a fully qualified Nuclear Reactor Watch Officer and Engineering Duty Officer.

EDUCATION AND CERTIFICATIONS

US NRC
- Operator Licensing Examiner Certification for BWR and PWR nuclear plant designs
- GE BWR Technology Series
- Westinghouse PWR Technology Series
- Reactor Inspector qualification

Entergy Operations, Inc.
- Senior Reactor Operator Certification – River Bend Station
- Successfully passed the Engineer in Training (EIT) exam

US Navy
- Engineering Duty Officer and Engineering Officer of the Watch (USS Long Beach)
- Surface Warfare Officer Qualification
- Naval Nuclear Power School and Naval Nuclear Power Prototype School.

College Level Coursework
Northwestern University – Bachelor of Science in Electrical Engineering (1984)
Ohio State University – Finished 1/3 of Master's Degree in Electrical Engineering (1990)

Other Pertinent Training
Team and Meeting Facilitator
ANSI/ISA-S67.04-2006: Set points for Nuclear Safety-Related Instrumentation

Understanding Power Cable Characteristics - Univ. of Wisconsin
Ultrasonic Testing, Level I and II
ASME Section XI In-Service Inspection
Fire Protection SDP
Software Verification and Validation
ETAP Power System Engineering Workshop
GE EHC and Turbine Trip and Monitoring System
RCIC System and Control Circuitry
GE Neutron Monitoring Systems

Daniel Funk, JENSEN HUGHES

SUMMARY

Daniel Funk, PE, is a Senior Technical Consultant with 35 years' experience. Mr. Funk is the Branch Office Manager for JENSEN HUGHES' Tokyo, Japan office. In this capacity he is responsible for business operations in Japan, including oversight of technical work and business development. Mr. Funk continues to manage large-scale nuclear projects while maintaining an active technical role in his specific area of expertise: electrical power, control systems, and fire protection. Mr. Funk has 35 years of engineering analysis, research and testing, and management experience. He has held positions as director, engineering manager, principal engineer, engineering supervisor, and project manager. He is highly proficient at completing complex, multi-discipline projects on time, within budget, and to high quality standards. He is an accomplished project manager and has established expertise in the design, analysis, evaluation, testing, maintenance, modification, and operation of electrical power systems, instrumentation and control systems, and complex industrial equipment. Mr. Funk has extensive experience with nuclear power plants, Department of Defense facilities, electrical power distribution systems, industrial power and control systems, electrical and fire safety, and codes and standards.

EDUCATION/CERTIFICATIONS

Bachelor of Science Degree, Electrical & Computer Engineering, Oregon State University, 1981
Naval Nuclear Power School

Registered Professional Engineer:
Washington 30516, 1993
California E17744, 2005

PROFESSIONAL AFFILIATIONS

Institute of Electrical and Electronic Engineers (IEEE)

PROFESSIONAL EXPERIENCE

Senior Technical Consultant *2011 – Present*
JENSEN HUGHES (Hughes Associates)

Director for Japan nuclear power business operations; manages all aspects of the Tokyo branch operations, including technical oversight of projects and business development. Maintains an active role in circuit failure research activities and failure analysis methodology improvements. Strives to advance and promote state-of-the-art methods, techniques, and tools for addressing fire risk at nuclear plants. Primary areas of expertise and recent accomplishments are summarized below:

Fire PRA - Currently managing PRA and fire protection projects in Japan; Over the past 15 years participated in numerous key activities for Fire PRA, including research, analytical methods development, and application. Mr. Funk's specific areas of expertise are PRA circuit analysis, associated circuits, spurious operations likelihood analysis, Fire PRA equipment selection, and Fire PRA data management. Participated in PRA activities for EPRI, NEI, and numerous nuclear plants, including International plants, Southern Nuclear Fleet (Vogtle, Hatch, Farley), Entergy (Palisades, Waterford 3), Progress Entergy (Harris, Brunswick, Robinson), Diablo Canyon, Palo

Verde, Turkey Point, Browns Ferry, VC Summer, Milestone, and Nine Mile Point. Industry representative for joint NRC/EPRI expert panel for assessment of fire-induced circuit failures (Electrical Jacque-Fire Workgroup, PIRT Panel, and Fire PRA Panel). These panels are developing the circuit analysis failure modes and spurious operation probabilities that are to be used in future Fire PRA analysis. Co-author of NUREG 6850, with primary responsibility for development of advanced analytical methods for the analysis of fire-induced circuit failures.

Primary author for Task 3, Task 9, Task 10, and related appendices. Participated in three Fire PRA peer reviews as lead for cable selection and circuit failure supporting requirements. Principal instructor for on-going EPRI/NRC Fire PRA course. Instruct the circuit analysis module. Active participant in industry and NRC fire-induced circuit failure tests, including EPRI/NEI, CAROL-FIRE, and DESIREE-FIRE. These tests serve as the basis for industry and regulatory guidance for Fire PRA circuit analysis. Principal author for report of EPRI/NEI fire-induced cable failure test program (EPRI 1003326). Member of industry-wide Expert Panel to assess spurious operation likelihood (EPRI 1006961). Conduct fire risk assessments for electrical process equipment as part of U.S. and European Union equipment safety certifications.

Fire Protection – Extensive experience with fire protection requirements and issues for electrical systems and equipment at nuclear power plants and hazardous industrial facilities. Expertise and experience includes both traditional deterministic fire safe shutdown analysis and fire probabilistic analysis of these designs. Provided engineering and QA/QC oversight at seven of these installations. Participated in or managed Appendix R and NFPA 805 deterministic safe shutdown analysis activities for many nuclear plants, including Southern Nuclear Fleet (Vogtle, Hatch, Farley), Entergy (Palisades, Waterford 3, River Bend, Grand Gulf, Pilgrim, Indian Point 2/3), Progress Entergy (Harris, Brunswick, Robinson), PSE&G (Salem, Hope Creek), Diablo Canyon, SONGS, Columbia Station, Point Beach, Palo Verde, Duane Arnold, Turkey Point, Browns Ferry, VC Summer, Limerick, Milestone, and Nine Mile Point. Has specific expertise in the evaluation and analysis of fire-induced circuit failures, spurious operations, and associated circuits. Fully versed in all aspects of fire safe shutdown analysis for Appendix R and NFPA 805. Serving as project manager and/or lead electrical for numerous Appendix R, NFPA-805, Fire PRA, and Multiple Spurious Operation projects. Provides direction and technical consulting to utilities for major projects involving NFPA 805 transition and implementation, multiple spurious operation analysis, and fire-induced circuit failure issues. Expert in the use of ARCPlus® and CAFTA software as applied to safe shutdown analysis, nuclear safety capability assessment, and multiple spurious operations. Developer of the Fire Data Manager (FDM®) module of ARCPlus. Member of project team to develop optimization techniques for fire protection equipment maintenance programs at nuclear plants (EPRI 1006756); techniques developed by the project are being introduced into NFPA codes and standards. Principle author for several EPRI projects involving surveillance and calibration reduction efforts for fire protection equipment, emergency lighting and instrumentation (EPRI Reports 1006756, 106154, 106752-R2, and 100249-R1). Conducts fire risk assessments for electrical process equipment as part of U.S. and European Union equipment safety certifications.

Electrical Power Systems - Extensive engineering design and analysis expertise with electrical power systems for nuclear power plants, DoD facilities, DoE facilities, and hazardous industrial facilities. Conducted numerous full-scope electrical engineering studies, including short circuit, power flow, electrical protection and coordination, arc flash, motor starting, and power quality. Directed managed comprehensive master planning studies of electrical distribution systems at DoD facilities. Projects typically involve: 100% field walkdown of equipment, regeneration of one-line and layout drawings, Geobase satellite coordinate determination, characterization of all equipment and development of Geobase-compliant equipment databases, development of electrical software models, full-scope electrical analysis, reliability and vulnerability assessment, and 10-year system plan. Managed all aspects of electrical design projects requiring professional engineer certification. Prepared designs for projects with construction value up to $50M. Developed operation, maintenance, and training manuals for electrical distribution systems. Provided electrical analysis, electrical design, and electrical safety training to engineers and electrical linemen. Performed design, analysis, maintenance, and testing of batteries and critical DC power systems. Received national recognition for accomplishments in advancing techniques for battery performance testing.

Codes and Standards – Broad knowledge of electrical and fire safety codes and standards, including IEEE, ANSI, NFPA, UL, NEMA, NETA, SEMI, IEC, UFC, MIL, and European Directives.

PREVIOUS EXPERIENCE

Principal Engineer *1990 – November 2012*
Edan Engineering Corporation

Founder and co-owner. Directed technical and business operations for over 20 years. Helped build a solid engineering and test firm with nationally recognized expertise in several fields.

Project Manager *1989 – 1990*
Precision Interconnect

In charge of product development for customized electrical connection systems used in military and aerospace guidance and navigation systems. Led a team of engineers and technicians through the development and qualification cycle for several unique products. Instrumental in obtaining government approval to supply military components under a certified quality assurance program. Gained extensive knowledge of military specifications and standards, and developed the qualification test plan and procedures for component certification.

Electrical Engineering Manager *1986 – 1989*
Portland General Electric Company

Accountable for budget, schedule, and technical adequacy of engineering design and analysis activities. Managed over 80 engineers, designers, and drafters, and an annual budget in excess of $20M. Responsible for electrical, instrumentation & control, fire protection, and environmental qualification engineering activities.

Navy Submarine Officer *1981 – 1986*
US Navy

Duties included Assistant Weapons Officer, Damage Control Assistant, Reactor Controls Assistant, and Quality Assurance Officer. Received numerous commendations and was consistently rated as the top junior officer on board.

PUBLICATIONS

- NUREG/CR-7150, Volume 1: Phenomena Identification and Ranking Table (PIRT) Exercise for Nuclear Power Plant Fire-Induced Electrical Circuit Failure, Joint Assessment of Cable Damage and Quantification of Effects from Fire (JACQUE-FIRE), October 2012.
- Advanced Circuit Analysis Methods Development for Fire-Risk Analyses, presented at 2005 ANS Conference
- NUREG/CR-6850, Fire PRA Methodology for Nuclear Power Facilities, September 2005
- EPRI Report 1003326, Characterization of Fire-Induced Circuit Faults: Results of Cable Fire Testing, December 2002
- Air Force Manual 32-1181, Design Standards for Facilities Interior Electrical Systems
- EPRI Report 1006756, Fire Protection Equipment Surveillance Optimization and Maintenance Guide, July 2003
- EPRI Report 1969001, Spurious Actuation of Electrical Circuits Due to Cable Failures: Results of an Expert Elicitation, May 2002
- EPRI Report 1006522, Stationary Battery Monitoring by Internal Ohmic Measurements
- EPRI Report 106154, Instrument Monitoring and Calibration Product Guide, October 2000
- EPRI Report 106752-R2, Instrument Performance Analysis Software System (IPASS), July 1999
- Air Force Pamphlet 32-1186, Valve Regulated Lead Acid Batteries for Stationary Applications, January 1999
- EPRI Report 100249-R1, Emergency Battery Lighting Unit Maintenance and Application Guide, June 1997

Thomas Gorman, JENSEN HUGHES

TITLE/POSITION: Technical Consultant

EDUCATION:

Rensselaer Polytechnic Institute, 1974
Bachelor of Science in Civil Engineering

Syracuse University, 1982
Master's in Business Administration

PPL Susquehanna, LLC , 1993
Plant Operations Certification Program

PROFESSIONAL AFFILIATIONS:

Registered Professional Engineer – Pennsylvania

Society of Fire Protection Engineers – Member Grade

BWROG – Chairman of the Appendix R Committee & Fire Protection Sub-Committee of the IRIR Committee

NEI Circuit Failures - Issue Task Force Member

PROFESSIONAL EXPERIENCE:

Chicago Bridge & Iron Company – 1974 to 1976 – Engineer

Niagara Mohawk Power Corporation – 1976 to 1982 – Civil Group Supervising Engineer

PPL Susquehanna, LLC – 1982 to 2015– Sr. Staff Engineer

JENSEN HUGHES, 2015 to present – Technical Consultant

Mr. Gorman has 41 years of design engineering experience with 38 of the years in the Electric Power Industry and 37 in the Nuclear Power Industry. He has specialized in Appendix R post-fire safe shutdown analysis for 33 years. He has been a contributing author to the development of the following industry documents:

- GE-NE-T43-00002-00-03 R01, BWROG Position on the Use of SRVs and Low Pressure Systems as Redundant Safe-shutdown Paths, dated August 1999.
- GE-NE-T43-00002-00-02 R0, Generic Guidance for BWR Post-Fire Safe-shutdown Analysis, dated November of 1999.
- NEI 00-01 Revision 2, Guidance for Post-Fire Safe Shutdown Circuit Analysis, dated June of 2009.

- NEDO 33638, BWROG Assessment of Generic Multiple Spurious Operations (MSOs) in Post-Fire Safe-shutdown Circuit Analysis, dated June of 2011.
- NUREG/CR 7150 Volume 1, (JACQUE-FIRE) Phenomena Identification and Ranking Table (PIRT) Exercise for Nuclear Power Plant Fire-Induced Electrical Circuit Failure.

Shannon Lovvorn, TVA

Education:

The University of Alabama in Huntsville - Huntsville, AL
Bachelor of Science Degree in Electrical Engineering
Graduated: August, 1997 Summa Cum Laude

Registered Professional Engineer
Alabama, Reg. No. 24716

Professional Experience:

TVA, Browns Ferry Nuclear Plant, Athens, AL Sept. 2009 - Present
NFPA 805 Transition Project Technical Lead (Temporary Assignment)
- Technical Lead Engineer for On-Site NFPA 805 Project Staff
- Technical oversight of NFPA 805 Transition Project contractor support
- Primary author for the BFN NFPA 805 Transition Project Plan
- Technical oversight of 10 CFR50.48(c) NFPA 805 License Amendment Request development project for BFN

TVA, Browns Ferry Nuclear Plant, Athens, AL Aug. 2008 - Sept. 2009
Equipment Reliability Manager (Temporary Assignment)
- Responsible for BFN Site Equipment Reliability Program
- Administrator of Plant Health Committee
- Lead initiative for producing new TVA NPG Fleet Equipment Reliability procedures

TVA, Browns Ferry Nuclear Plant, Athens, AL Feb. 2008 - Aug. 2008
Electrical/I&C Design Manager
- Manager of Electrical / I&C Design Section
- Schedule Development, Prioritization and Status Reporting
- Oversight of Elect./I&C Design Product Quality Improvement
- Corrective Action Plan Development and Oversight

TVA, Browns Ferry Nuclear Plant, Athens, AL Dec. 2005 - Feb. 2008
Extended Power Uprate (EPU) Project Engineer
- Prepared responses to NRC Request for Addition Information (RAI)
- Electrical and Instrumentation oversight of vendor engineered designs
- Field support of EPU design modifications
- Corrective Action Plan Development and Oversight

TVA, Browns Ferry Nuclear Plant, Athens, AL July. 2002 - Dec. 2005
Electrical Design Engineer
- Secure funding for plant modifications
- Plant modifications and engineering change control including detailed design
- Electrical analysis update and maintenance to support plant design and operation
- Task engineer responsible for detailed design and design change documentation.

State Engineering Company, Decatur, AL **Mar. 2000 - July 2002**
Instrument & Electrical Engineer

- Project estimates, detailed design, construction support, testing and consulting
- Specifying, sizing, and requisitioning of process control instrumentation and electrical equipment
- PLC system integration, configuration, start-up and programming
- Coordinate, supervise and review CAD designer work on construction drawings
- Responsible registered Professional Engineer for various project designs.

BP Amoco PLC, Decatur, AL **Aug. 1997 - Mar. 2000**
Instrument & Electrical Unit Reliability Engineer

- Single I&E Engineer for two operating units performing design, system, and equipment reliability engineer functional support
- Provided technical support for all electrical, instrumentation, and control issues including engineering, procurement, installation and testing
- Responsible for initiating and implementing reliability focused programs
- Project management of large and small capital project
- Oversight of capital improvement budget

Achievements:
Electrical Engineering Honor Society
Engineering Honor Society
Math Honor Society
National Collegiate Engineering Award
The National Dean's List
All-American Scholar
ETAP Power Station Qualified
Procedure Professionals Association (PPA) Writer Certification
System Assurance & Fire protection Engineering - PB (SAFE-PB) Qualified

Steven Nowlen, SNL

TITLE/POSITION: Consultant

Former Distinguished Member of the Technical Staff:
Sandia National Laboratories
Risk and Reliability Analysis Department

EDUCATION AND HONORS:

Appointed to the rank of Distinguished Member of the Technical Staff at Sandia National Laboratories, October 2001, an honor reserved for no more than 10% of the SNL engineering/science staff.

Master of Science, Mechanical Engineering, Michigan State University, East Lansing Michigan, March 1984.

DuPont Research Fellow, Department of Mechanical Engineering, Michigan State University, 1981-1983.

Bachelor of Science with High Honor, Mechanical Engineering, Michigan State University, East Lansing Michigan, December 1980, Graduated Phi Beta Kappa.

PROFESSIONAL EXPERIENCE:

Since joining Sandia in 1983, I have been active in both experimental and analytical research in the fields of nuclear power plant safety with a focus on fire safety and quantitative fire risk analysis. I have been Sandia's technical and programmatic lead for the nuclear power fire research programs since 1987. My responsibilities include direct technical contributions, technical team leadership, sponsor interactions, program planning and program management.

The most important application of my research has been in the development and application of probabilistic risk assessment (PRA) methods for fires in nuclear power plants; that is, quantitative assessments of the impact of fires on nuclear power plant safety and operations. I also have experience in harsh environment equipment qualification testing and accelerated thermal and radiation aging of materials.

My experimental work has included the planning, execution, evaluation, and reporting of fire safety experiments, as well as the interpretation, evaluation, and application of experimental results generated by other researchers. Specifically, I have experience in the testing of fire growth behavior, large-scale room fires, enclosure ventilation and smoke purging, cable and electrical equipment fire-induced damage, smoke particulate characterization, fire barriers, smoke damage effects on digital equipment, and cable ampacity and ampacity derating.

As a secondary aspect of my experimental experience, I have also participated in Equipment Qualification tests assessing the performance of electrical equipment in the harsh steam and radiation environments associated with nuclear power plant severe accidents. This work has included both accelerated thermal and radiation aging of electrical cables and the evaluation of equipment performance during harsh environmental exposures such as loss of coolant accidents.

Related analytical efforts in the area of fire safety have included the evaluation and validation of computer fire simulation models, the review and analysis of actual fire events in nuclear power plants, fire risk assessment analytical support work, the development and evaluation of fire risk assessment methods, and the development and evaluation of analytical methods for cable ampacity and fire barrier ampacity derating assessments. I have also participated as an expert consultant in various inspection activities for U.S. Nuclear Regulatory Commission (NRC).

I have performed training for the NRC staff in the application of the NRC Significance Determination Process (SDP) for fire protection inspection findings. I am currently participating in an effort to develop and deploy inspector training for application to those NRC licensees transitioning to the new risk-informed, performance-based fire protection requirements. I also act as technical coordinator and classroom instructor for the annual Fire PRA training course offered as a part the NRC Office of Nuclear Reactor Research (RES) and Electric Power Research Institute (EPRI) collaboration on fire research. This training course has been conducted annually since 2005 and routinely attracts well over 100 participants per year.

I was a member of the U.S. NRC Senior Review Board for the review of Individual Plant Examination for External Events (IPEEE). I am currently a member of the ASME/ANS Joint Committee on Nuclear Risk Management Subcommittee on Standard Maintenance. I also co-chair the associated working group on fire risk.

My publication list is available on request and includes 10 journal articles, approximately 30 formal SNL technical reports, five invited conference papers and over 20 other general conference papers. I also co-authored a Section of the SFPE *Handbook of Fire Protection Engineering* entitled “Risk Assessment for Nuclear Power Plants.”

NOTABLE ROLES AND ACCOMPLISHMENTS:

SNL technical area lead and program manager for nuclear power plant related fire research (1987-present)

Voting member of the American Society of Mechanical Engineers (ASME) American Nuclear Society (ANS) Joint Committee for Nuclear Risk Management (JCNRM) Subcommittee on Standards Maintenance

Co-Chair of the ASME/JCNRM *Standard for Level 1 / Large Early Release Frequency Probabilistic Risk Assessment for Nuclear Power Plant Applications* Fire Working Group (RA-Sa-2009)

Leading member of the core writing team for the American Nuclear Society (ANS) Standard on Fire PRA methodology (ANSI/ANS-58.23-2007)

Lead author and NRC technical team lead for the consensus Fire PRA methodology NUREG/CR-6850 which has developed as a collaboration between the NRC and the Electric Power Research Institute (EPRI))

Technical Coordinator for development of the U.S. NRC Significance Determination Process (SDP) for risk-informed fire inspections (2003-2004)

Technical coordinator and instructor for the annual NRC/EPRI Fire PRA methodology training sessions (2004-present)

Member of the Nuclear Regulatory Commission (NRC’s) Senior Review Board for the review and evaluation of licensee submittals under the Individual Plant Evaluation of External Events Program (1995-2001)

Technical advisor to the U.S. NRC staff during development of the National Fire Protection Association (NFPA) *Performance-Standard for Fire Protection for Light Water Nuclear Reactor Electric Generating Plants* (NFPA 805) (1995-2001).

Andy Ratchford, JENSEN HUGHES

TITLE/POSITION: Senior Consultant

SUMMARY

Mr. Ratchford is the President of Ratchford Diversified Services, LLC, an engineering services consulting firm providing fire protection and risk management consulting services. Mr. Ratchford has more than 27 years of experience in the nuclear field, including 22 years in nuclear power plant fire protection. He has provided fire protection and post-fire safe-shutdown technical support to more than one half of the nuclear power plants in the United States. He is actively involved in industry activities, such as development of risk-informed guidance for fire protection (NFPA 805), the implementation guidance for NFPA 805 (development of NEI 04-02), NFPA 805 transition pilot plant activities, and resolution of major nuclear plant fire protection issues such as multiple spurious operations and operator manual actions.

EDUCATION/TRAINING

B.S., Civil Engineering, Clemson University, 1984
U.S. Navy Nuclear Power Program
Cooperative Education Program, Savannah River Site, Aiken, SC, 1981 - 1983

PROFESSIONAL AFFILIATIONS/CERTIFICATIONS

Registered Professional Mechanical Engineer, State of California
Member, American Nuclear Society
Member, Society of Fire Protection Engineers
Member, National Fire Protection Association (NFPA)
Member, NFPA Technical Committee on Fire Protection for Nuclear Facilities (alternate)
Member, NEI NFPA 805 Task Force
Member, NEI Circuit Failures Task Force
Member, NEI Fire PRA Task Force

PROFESSIONAL EXPERIENCE

JENSEN HUGHES ***01/16-Present***

Principal ***09/99-12/2015***
Ratchford Diversified Services/KGRS Strategic Alliance

Principal of Ratchford Diversified Services, an engineering consulting firm that provides technical services to the nuclear industry. He has provided consulting services to a number of clients directly and as a subcontractor to a number of engineering consulting firms.

He is an active participant in the nuclear fire protection community, including participation in numerous NRC and NEI workshops and meetings as a member of the KGRS Strategic Alliance. He is a member of the NFPA Technical Committee on Fire Protection for Nuclear Facilities and has been actively involved in the development of NFPA 805 and its implementing guidance for transition to a risk-informed, performance-based fire protection program (NEI 04-02). He has served as an NEI representative in the NFPA 805 pilot plant process and is actively involved in the NFPA 805 Task Force meetings, Pilot Observation Meetings, and other pilot activities. He has been involved in all aspects of NFPA 805 transition, including lead roles in the resolution of industry issues related to multiple spurious operations and operator manual actions. He has developed a number of NFPA 805 Frequently Asked Questions (FAQs) in support of pilot plant activities.

He has worked closely with the Fire PRA community in the integration of Fire PRA into the NFPA 805 application and resolution of industry issues. This includes technical support and reviews of Fire PRA Component and Cable Selection, modeling of spurious operations, and use of the Fire PRA in support of change evaluations. He has also participated in Fire PRA Peer Reviews, with an emphasis on the Fire PRA Component Selection, Fire PRA Model Development, Cable Selection, and Circuit Analysis tasks. He is a participant on the Phenomena Identification and Ranking Table (PIRT) panel for fire-induced circuit failures as applied to Nuclear Power Plant applications, an activity sponsored by the NRC Fire Research Branch.

He serves in technical oversight and consultant roles on a number of NFPA 805 transition projects, including both pilot plants (Harris Nuclear Plant and Oconee Nuclear Station) and fleet transition projects for Florida Power and Light and Southern Nuclear Corporation. He was instrumental in the development of the pilot plant NFPA 805 License Amendment Requests, having worked extensively with Progress Energy, Duke Energy, and NEI on the format, content, and level of detail in the submittals.

He has also been very active in industry efforts in the resolution of fire-induced circuit failures using the processes in NEI 00-01. He was an active participant in the NEI Circuit Failures Task Force group that developed NEI 00-01, Revision 2. He also a led or participated in 15 Expert Panels addressing fire-induced multiple spurious operations and their impact on plant safety.

In addition to primary roles in the NFPA 805 transition, he also has supported licensees during NRC Triennial Fire Protection Inspections and performed and led self-assessments addressing fire protection, post-fire safe-shutdown, and fire-induced circuit failure issues.

Fire Protection Manager ***08/96-09/99***
Duke Engineering & Services
Managed the Western Region Fire Protection and Hazards Analysis group. Responsible for project quality and business performance, including nuclear and commercial and industrial business areas. This included managing fire protection and Appendix R program validation projects, self-assessments, and resolution of complex technical issues for numerous clients.

Supervisor ***06/94-08/96***
VECTRA Technologies
Supported American Electric Power with an Appendix R Revalidation Project for Cook Nuclear Plant (CNP). Was the primary author and project manager for an Appendix R Topical Design Basis Document and a Fire Protection Topical Design Basis Document for CNP. Project Engineer for a comprehensive Thermo-Lag Fire Barrier Resolution Project for Entergy at River Bend Station.

Lead Senior Engineer ***02/90-06/94***
ABB Impell

Assigned to the Mechanical Engineering Group responsible for support of Diablo Canyon Power Plant (DCPP) for Pacific Gas and Electric. He was the project engineer of the comprehensive DCPP Fire Protection/ Appendix R Upgrades Project, which included responsibility for all technical and financial aspects of this multi-disciplined project.

Commissioned Officer ***02/85-1/90***
U.S. Navy Submarine Force

He served 5 years in the U.S. Navy as a submarine officer in the Nuclear Propulsion Program. This included training and education, as well as a tour of duty as a Submarine Officer. Certified as Engineer Officer of Naval Nuclear Power Plants by the Department of Energy and the U.S. Navy.

PUBLICATIONS

Mr. Ratchford has been a principal contributor to many nuclear industry fire protection documents. A listing of documents and his level of participation in the development of the document is provided below:

Document	Level Of Participation
NFPA 805, Performance-Based Standard for Fire Protection for Light Water Reactor Electric Generating Plants, 2001	Code Committee Member, Contributing Author
NEI 04-02, Guidance for Implementing a Risk-Informed, Performance-Based Fire Protection Program Under 10 CFR 50.48(c)	Principal Contributor
NEI 00-01, Guidance for Post-Fire Safe Shutdown Circuit Analysis	Task Force Member, Reviewer
EPRI Technical Report 1010981, Transition Process Pilot Report – NEI 04-02 Guidance for Implementing a Risk-Informed, Performance-Based Fire Protection Program Under 10 CFR 50.48(c)	Principal Contributor
EPRI Technical Report 1001442, A Pilot Plant Evaluation NFPA-805, "Performance-Based Standard for Fire Protection for Light Water Reactor Electric Generating Plants"	Principal Contributor
NUREG/CR-6850, EPRI Technical Report 1011989, Fire PRA Methodology for Nuclear Power Facilities, September 2005	Independent Reviewer (selected Sections)
NUREG/CR-7150, Joint Assessment of Cable Damage and Quantification of Effects from Fire (JACQUE-FIRE), Volume 1, Phenomena Identification and Ranking Table (PIRT) Exercise for Nuclear Power Plant Fire-Induced Electrical Circuit Failure	Principal Contributor
EPRI Technical Report 1006756, Fire Protection Equipment Surveillance Optimization and Maintenance Guide, July 2003	Principal Contributor

Mano Subudhi, BNL

TITLE/POSITION: Engineer (Scientific Staff)

EDUCATION:

1969 - B.S., Mechanical Engineering, Banaras Hindu University, India
1970 - M.S., Mechanical Engineering, Massachusetts Institute of Technology
1974 - Ph.D., Mechanical Engineering, Polytechnic Institute of New York

PROFESSIONAL EXPERIENCE:

1976-Present
Brookhaven National Laboratory, Currently performing piping design certification reviews for ESBWR, APWR and EPR and revising design-specific review standards (DSRSs) for small modular reactors. Conducted workshops and classes on various topics associated with NRC regulations in FSU countries.

Developed SER templates for the new reactor licensing. Moderator and Technical lead for expert panel for material degradation PIRT. Served as lead engineer, principal investigator, and group leader. Completed engineering projects for NRC, DOE, and other federal agencies. Developed qualification guidelines for the dynamic and seismic evaluation of Class 1E equipment. Studied alternate procedures for calculating the inertia and pseudo-static responses for multiple supported piping systems. Developed the EPIPE finite element computer code for benchmarking and confirmatory analyses of several as-built piping systems. Principal Investigator for the NRC's equipment aging research program to develop maintenance practices including ISI/IST to mitigate equipment failures. Conducted tests on equipment performance. Studied impact of aging on seismic capacity in the event of an earthquake. Evaluating environmental qualification procedures for cables. Completed studies and issued reports on: NPP EDG performance, reliability, and inspection techniques; snubber performance and inspection; risk-based inspection; system performance and aging; and component performance and aging. Reviewed relief requests for ISI requirements and applications for license renewal. The LR review primarily included reactor coolant system in PWR plants (e.g., ANO1, North Anna and Surry, and Catawba and McGuire). Performed LRA audits of reactor coolant system at BWR sites (e.g., Brown's ferry, Brunswick, Oyster Creek and FitzPatrick).

1975-1976
Bechtel Power Corp., Mechanical Engineer. Involved in the stress analysis of nuclear power plant components subjected to thermal, dead weight, seismic, thermal transients, pressure and fatigue loads; special problems including water hammer, flow-induced vibrations, and sudden valve closures; and preparation of Nuclear Class I Reports for licensing purpose. Represented Bechtel in the interfacing with manufacturers, clients and vendors.

1974-1975
Nuclear Power Service, Sr. Stress Analyst. Performed stress analysis of mechanical and piping systems according to the requirements of ASME B&PVC, Section III, and ANSI B31.1 Code. Applied finite element techniques in the analysis and certification of components, which did not meet the code requirements. Have written computer programs for incorporating the ASME standards for solving complex stress problems.

<u>SELECTED PUBLICATIONS</u>:

"Seismic Evaluation of the Brookhaven High Flux Beam Research Reactor," BNL *Technical Report*, December 1979.

"Seismic Analysis of Piping Systems Subjected to Independent Support Excitations by Using Response Spectrum and Time History Methods," *BNL Technical Report No. BNL-NUREG-31296,* April 1982. Also, *Presented at the ASME Summer PVP Conference,* Portland, Oregon, PVP-Vol. 73, June 1983.

"The Assessment of Alternate Procedures for the Seismic Analysis of Multiply Supported Piping Systems," *Proceedings of the 1985 ASME PVP Conference, New Orleans, PVP-Vol. 98.3,* June 1985.

"Improving Motor Reliability in Nuclear Power Plants," *NUREG/CR-4939, BNL-NUREG-52031, Vols. 1,2,3,* November 1987. Also, *Proceeding of the 15th WRSM,* October 1987.

"Age-Related Degradation of Westinghouse 480-Volt Circuit Breaker," *NUREG/CR-5280, BNL-NUREG-52178, Vols. 1&2,* November 1990.

"Degradation Modeling with Application to Aging and Maintenance Effectiveness Evaluations," (Co-author), *NUREG/CR-5612, BNL-NUREG-52252,* March 1991.

"Life Testing of a Low Voltage Air Circuit Breaker to Assess Age-Related Degradation," *Nuclear Technology, Vol. 97, pp.362-370,* March 1992.

"Managing Aging in Nuclear Power Plants: Insights from NRC's Maintenance Team Inspection Reports," *Nuclear Safety, Vol. 35, No. 1,* January-June 1994.

"Literature Review of Environmental Qualification of Safety-Related Electric Cables," *NUREG/CR-6384, BNL-NUREG-52480, Vols. 1&2,* April 1996.

"RAPTOR Gas Gun Testing Experiment," (Co-author) Proprietary, CRADA BNL-C-96-01, June 1998.

"IAEA Verification Experiment at the Portsmouth Gaseous Diffusion Plant," (Co-author), BNL-65714, September 1998.

"Review of Industry Responses to NRC Generic Letter 97-06 on Degradation of Steam Generator Internals," NUREG/CR-6754, BNL-NUREG-52646, December 2001.

"A Reliability Physics Model for Aging of Cable Insulation Materials," NUREG/CR-6869, BNL-NUREG-73676-2005, March 2005.

"Application of laser generated ultrasonic pulses in diagnostics of residual stresses in welds," Proc. of SPIE, 2005.

"Expert Panel Report on Proactive Material Degradation Assessment," NUREG/CR-6923, BNL-NUREG-77111-2006, February 2007.

Gabriel Taylor, NRC

EDUCATION

Masters of Science in Fire Protection Engineering, May 2012
Bachelor of Science in Electrical Engineering, December 2004

Registered Professional Engineer
Maryland, Fire Protection (38236), 2013

PROFESSIONAL EXPERIENCE

U.S. Nuclear Regulatory Commission - Rockville, MD August 2013- Present
Senior Fire Protection Engineer, Office of Nuclear Regulatory Research

- Performed testing to evaluate cable coating performance
- Managed testing program to evaluate the credibility of secondary fires due to open circuited current transformers
- Participated on numerous internal NRC review panels (OCAA, PRB, GIRP)
- Lead development and issuance of IEEE standard on fire resistive cables
- Evaluated the effectiveness of aspirated smoke detection systems for use in NPP fire PRA applications, NUREG-2180
- Instructed NUREG/CR-6850 training related to fire-induced circuit failure probability estimation
- Supported development of post-fire safe shutdown training for regional inspectors
- Working group member of the electrical enclosure heat release rate effort RACHELLE-FIRE (NUREG-2178)
- Chair IEEE 1844, IEEE 634, Co-chaired IEEE 1202

U.S. Nuclear Regulatory Commission - Rockville, MD October 2007- August 2013

Fire Protection Engineer, Office of Nuclear Regulatory Research

- Expert Member of the Probabilistic Risk Assessment (PRA) expert elicitation on fire-induced cable damage spurious operation probability
- Expert Member of the Phenomena Identification and Ranking Table (PIRT) exercise on Nuclear Power Plant Fire-Induced Electrical Circuit Failure
- Instructed NUREG/CR-6850 training related to fire-induced circuit failure probability estimation
- Witnessed fire tests, analyzed results and wrote test reports on Duke Armored cable testing, Navy Digital I&C testing, Progress Penetration Seal Testing.
- International OECD Fire-Events Database and High Energy Arcing Fault Task Group
- Managed DOE work on fire-induced failure circuit testing and conducted supplementary data analysis (DESIREE-FIRE, KATE-FIRE)

- Presented research at numerous conferences and to the Advisory Committee on Reactor Safeguards (ACRS)

U.S. Nuclear Regulatory Commission - Rockville, MD April 2005 - October 2007

NSPDP General Engineer, Office of Nuclear Reactor Regulation

- Graduate of NSPDP Class of 2007
- DORL: Evaluated proposed changes to license amendments in regards to their effect to public safety
- ACRS: Prepared summary report for committee members and assisted with meeting preparations
- RII/Watts Bar Resident Office: Became basic inspector qualified IMC 1245 Appendix A

The Pennsylvania State University - University Park, PA August 2003 - February 2004

Undergraduate Research Assistant, Dr. P.M. Lenahan

- Modified magnet power supply to operate correctly using U.S. power system
- Designed data acquisition system to signal average ESR and SDR signals using LabVIEW 7
- Reviewed, ordered, and installed SDR spectroscopy system

OSRAM Sylvania Inc. - St. Marys, PA January - March 2005 & January- August 2003

Process Engineer & Engineering Co-Op (R&D, Process, EH&S, Electrical Departments)

- Developed and conducted tests to examine customer complaints and analyzed the safety of products
- Developed a recycling program to reduce net residual waste and increase gain from recyclable materials
- PLC programming using VersaPro for GE PLC's (Latter-logic)
- Designed and constructed electrical cabinet using AutoCAD (ergonomic layout for operator and maintenance)

ACHIEVEMENTS

NRC Federal Engineer of the Year, 2015
Member of NSPE
Member of IEEE, PES, ICC
Eagle Scout - Troop #95, Bucktail Council
Eta Kappa Nu (HKN) - Epsilon Chapter - National Electrical/Computer Engineering Honors Society
Dale Carnegie Program Graduate
Penn State Conservation Leadership School Graduate
Rivers Conservation Leadership School Graduate

PUBLICATIONS

Taylor, G., Cooper, S., D'Agostino, A., Melly, N., Cleary, T., NUREG-2180, "Determining the Effectiveness, Limitations, and Operator Response for Very Early Warning Fire Detection Systems in Nuclear Facilities (DELORES-VEWFIRE)," December 2016.

Taylor, G., Gallucci, R., Melly, N., Cleary, T., "Statistical Characterization of the Advanced Notification in Detection Time for Very Early Warning Fire Detection in Nuclear Plant Electrical Enclosures," American Nuclear Society, International Topical Meeting on Probabilistic Safety Assessment and Analysis (PSA 2015), April 2015.

Taylor, G., Cleary, T., "Very Early Warning Fire Detection of Incipient Sources in Nuclear Power Plant Applications," National Fire Protection Association, Fire Protection Research Foundation, Suppression, Detection, and Signaling Research and Applications Symposium (SUPDET 2015), Orlando, FL, March 2015.

Cleary, T., Zarzecki, M. Taylor, G., "Very early warning fire detection in nuclear power plant electrical cabinet enclosures," 15th International Conference on Automatic Fire Detection (AUBE '14), Duisburg, Germany, October 2014.

Cleary, T., Zarzecki, M. Taylor, G., "Characterization of overheated wire sources for electrical fire detection applications," 15th International Conference on Automatic Fire Detection (AUBE '14), Duisburg, Germany, October 2014.

Subudhi, M., Martinez-Guridi, G., Taylor, G., et. al., NUREG/CR-7150, Volume 2, "Joint Assessment of Cable Damage and Quantification of Effects from Fire (JACQUE-FIRE), Expert Elicitation Exercise for Nuclear Power Plant Fire-Induced Electrical Circuit Failure," U.S. NRC, Washington, DC, 2014.

Taylor, G., Melly, N.B., Pennywell, T., "Expert Judgment, An Application in Fire-Induced Circuit Analysis," International Workshop on Fire PRA, OECD/NEA Committee on the Safety of Nuclear Installations, Garching, Germany, April 2014.

Melly, N.B., Taylor, G., Stroup, D.W., "U.S. NRC Fire Safety Research Activities," International Workshop on Fire PRA, OECD/NEA Committee on the Safety of Nuclear Installations, Garching, Germany, April 2014.

Taylor, G., Gallucci, R.H.V., Subudhi, M., Martinez-Guiridi, G., "Fire PRA Advancements in Estimating the Likelihood of Fire-Induced Spurious Operations," American Nuclear Society, PSA 2013, International Topical Meeting on Probabilistic Safety Assessment Analysis, Columbia, SC, September 2013.

Taylor, G., Melly, N., Woods, H., Pennywell, T., Olivier, T., Lopez, C., NUREG-2128, "Electrical Cable Test Results and Analysis During Fire Exposure (ELECTRA-FIRE), A Consolidation of Three Major Fire-Induced Circuit and Cable Failure Experiments Performed Between 2001 and 2011," U.S. NRC, Washington, DC, 2013.

Subudhi, M., Higgins, J., Taylor, G.J., et.al., NUREG/CR-7150, Volume 1, "Joint Assessment of Cable Damage and Quantification of Effects from Fire (JACQUE-FIRE), Phenomena Identification and Ranking Table (PIRT) Exercise for Nuclear Power Plant Fire-Induced Electrical Circuit Failure," U.S. NRC, Washington, DC, 2012.

Taylor, G., "Evaluation of Critical Nuclear Power Plant Electrical Cable Response to Severe Thermal Fire Conditions," Masters of Science Thesis, Graduate School of the University of Maryland, College Park, MD 2012.

Taylor, G., Barrett, H., Funk, D., Nowlen, S., "Advances in Understanding the Phenomena of Electrical Cable Fire-Induced Hot Shorting," American Nuclear Society, Annual Meeting, June 2011.

Nowlen, S.P., Brown, J.W., Taylor, G.J., "Electrical Failure Behavior of Kerite® FR Insulated Electrical Cables," American Nuclear Society, Annual Meeting, June 2011.

Taylor, G., Salley, M.H., NUREG-1924, "Electrical Raceway Fire Barrier Systems in U.S. Nuclear Power Plants," U.S. NRC, Washington, DC, 2010.

Taylor, G., McGrattan, K., Nowlen, S.P., "Electrical Circuit and Cable Testing," Interflam 2010, 12th International Fire Science and Engineering Conference, University of Nottingham, UK, July 2010.

Taylor, G., Salley, M.H., "10 Rules of Fire Induced Cable Failure," National Institute of Standards and Technology, Annual Conference on Fire Research, Gaithersburg, MD, 2008.

APPENDIX B

CORRECTIONS AND CLARIFICATIONS TO THE PIRT REPORT

Since its issuance, the NUREG/CR-7150 Volume 1 - EPRI 1026424 ("PIRT Report") has been reviewed and used by NPP licensees and NRC staff. Over time there have risen instances where clarifications of the terms used in the report were needed and differences in interpretation of the intended recommendations were apparent. Although limited in number, these concerns, if not addressed, could result in substantial effort on both the utility and regulatory staff to resolve and may result in differing interpretations. The purpose of this appendix is to provide corrections to the NUREG/CR-7150 Volume 1 report where errors were identified and to provide additional clarification to figures of Appendix C of the PIRT Report.

B.1 ERRATA to the PIRT Report

The following pages of the PIRT Report (NUREG/CR-7150, Volume 1) contain erroneous information as described:

Page #	**Description**
Cover Page	Street Address for EPRI should read as 3420 Hillview Avenue instead of 3412 Hillview Avenue
xix, Citations	Street Address for EPRI should read as 3420 Hillview Avenue instead of 3412 Hillview Avenue
1-2, Objective	A "period" at the end of the sentence "Using these PIRT results, BNL…fire-induced damage to the cable" is missed. See one before the last sentence on this page.
3-34, Table 3-3	Word "Possible" in the last column should be read as "Plausible". The information in Table 3-3 is replaced by Tables 3-1 and 3-2 in this report.
3-39 to 3-41, Figures 3-5 to 3-7	Replaced by the information in Table 3-1 in this report.
3-43 and 3-45 Table 3-6 and 3-7	Replaced by the information in Table 3-2 in this report.
3-42, Second Para	Last sentence "Figures 3-8 through 3-11 show the associated tables and figures." should be deleted.

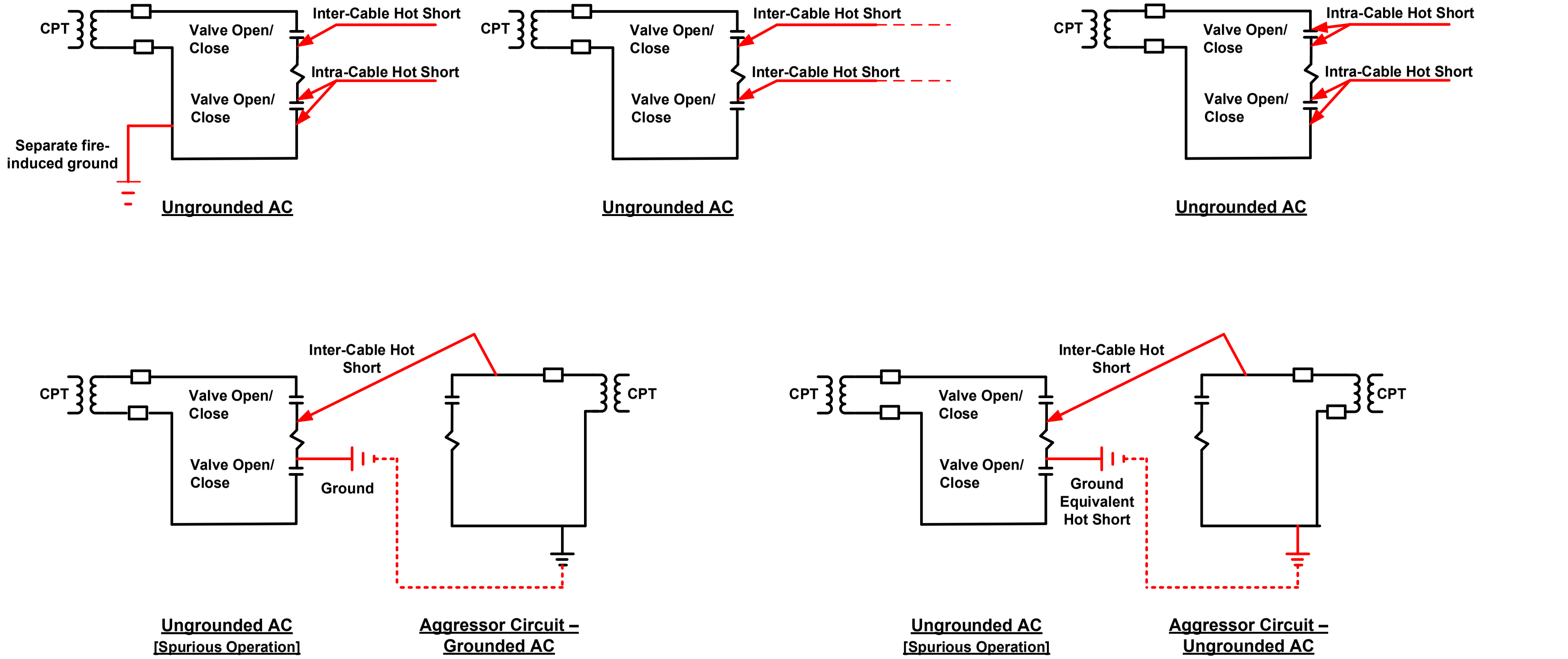
5-3, Entire Page — Entire page is a duplicate of Page 5-2 and should be deleted.

B.2 Revised Control Circuit Figures in Section 3 and Appendix C of the PIRT Report

Figures illustrating single and double break designs of control circuits that are vulnerable to hot short-induced spurious operations are presented in Section 3 of the PIRT Report. Additional examples are also presented in the PIRT Report, Appendix C for reference purpose only. The working group noted that these figures are often misinterpreted by the users and in certain cases there are errors in defining certain circuit configurations. The following two sets of figures are revised to illustrate the actual interpretation of the working group:

1. SECTION 3 of the PIRT Report: PIRT PANEL EVALUATION OF CONTROL CIRCUITS – Figure 3-8 and Figure 3-9.

2. APPENDIX C of the PIRT Report: CONTROL CIRCUIT CONFIGURATIONS FOR SINGLE AND DOUBLE BREAK DESIGNS – Case 1 through Case 8.



Note: The examples in this figure show one proper polarity alignment that could result in a spurious operation. Refer to the section of this NUREG/CR Report that describes Proper Polarity to understand those additional proper polarity alignments that may also apply.

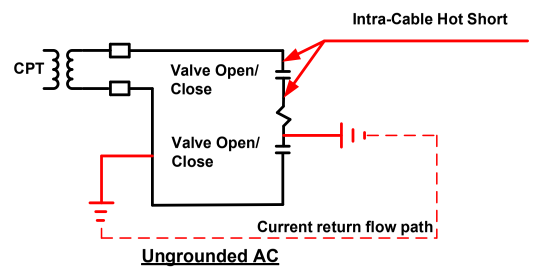
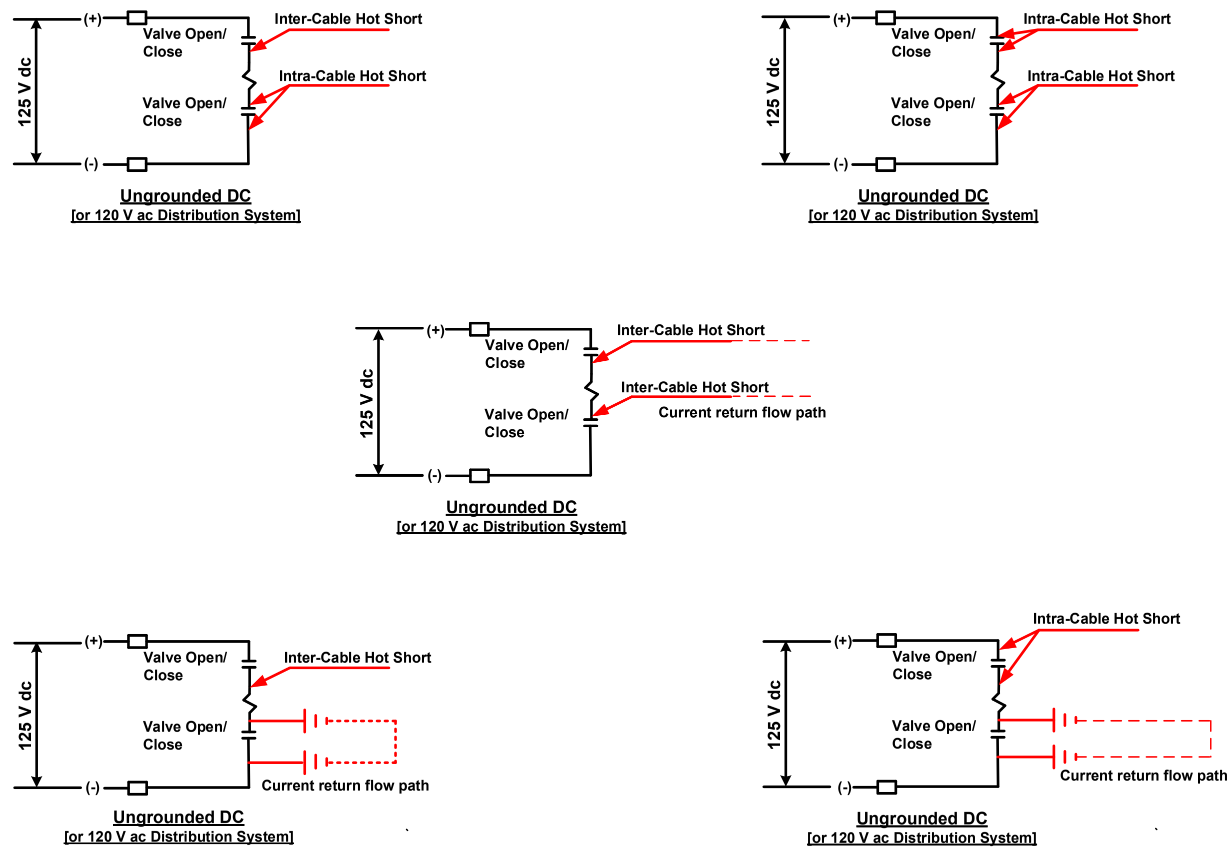
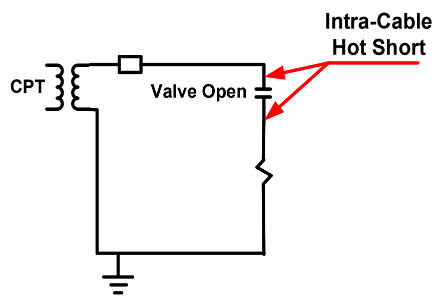


Figure B-1 Double Break Ungrounded AC Schematics

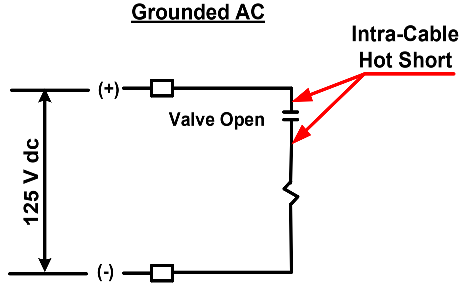


Note: The examples in this figure show one proper polarity alignment that could result in a spurious operation. Refer to the section of this NUREG/CR Report that describes Proper Polarity to understand those additional proper polarity alignments that may also apply.

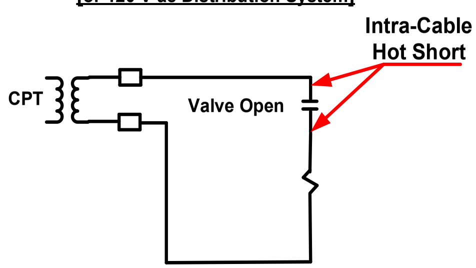
Figure B-2 Double Break Ungrounded DC Schematics



Grounded AC

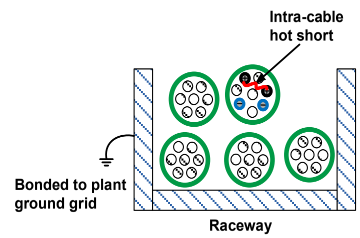


Ungrounded DC
[or 120 V ac Distribution System]



Ungrounded AC

Simplified Schematic Configuration – Single Break Control Circuit

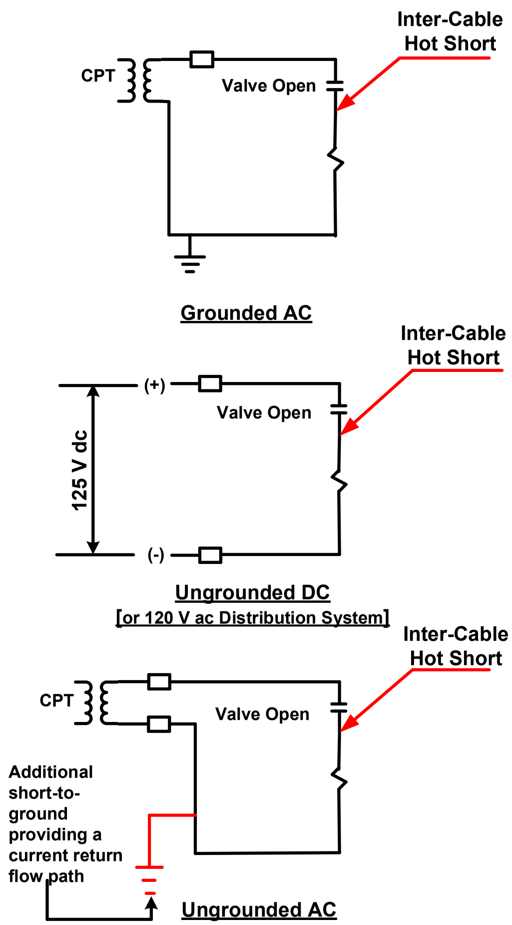


Physical Configuration

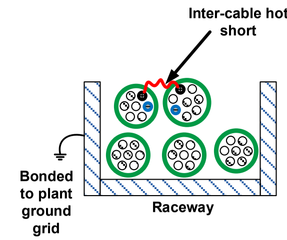
Notes:

1. Component is energize to open.
2. A fire-induced intra-cable hot short will open the component.
   a. If the component is a latching circuit, the component will remain open even if the intra-cable hot short is eliminated, e.g., goes to ground.
   b. If the component is a non-latching circuit, the component will close when the intra-cable hot short is eliminated, e.g., goes to ground.
   c. If power is lost to the target control circuit prior to device actuation by blowing the control power fuses or by a failure of the power supply to the fuses, the component will not open regardless of whether or not it is a latching or non-latching circuit.
3. The behavior described on this drawing is typical of an intra-cable hot short from a conductor within the same circuit. If the intra-cable hot short is from a conductor in the same cable, but from a different circuit, the behavior will be governed more by the characteristics described for the inter-cable hot short in Case 2.

Case 1 – Single Contact Intra-Cable Hot Short-Induced Spurious Operation



Simplified Schematic Configuration – Single Break Control Circuit

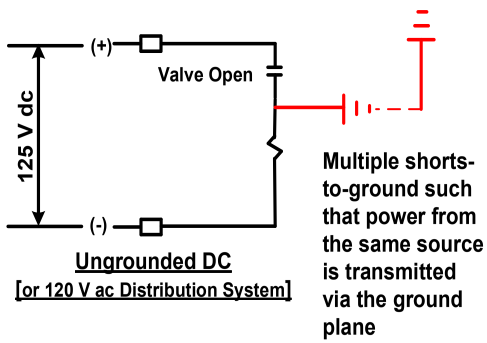


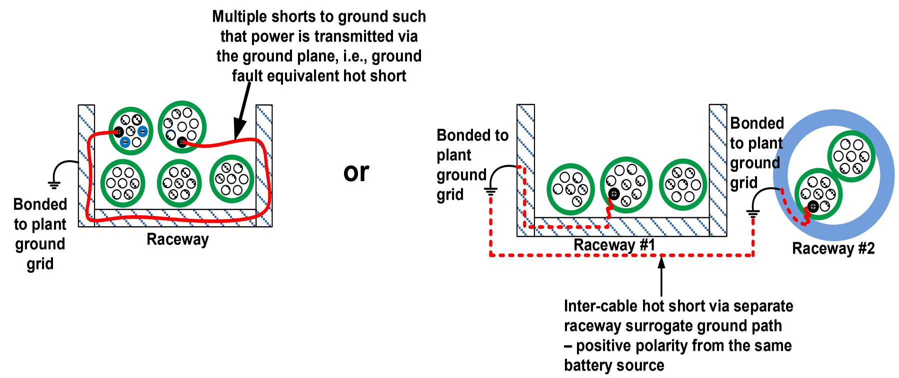
Physical Configuration

Notes:

1. Component is energize to open.
2. A fire-induced inter-cable hot short will open the component.
   a. If the component is a latching circuit, the component will remain open even if the inter-cable hot short is eliminated, e.g., goes to ground.
   b. If the component is a non-latching circuit, the component will close when the inter-cable hot short is eliminated, e.g., goes to ground.
   c. If power is lost to the control circuit by blowing the control power fuses on the aggressor circuit or by a failure of the power supply to the fuses in either the primary or aggressor circuit, the component will close regardless of whether or not it is a latching or non-latching circuit.
3. For the case of the ungrounded DC or ungrounded distributed AC circuit, the inter-cable hot short must come from the same battery or power source. This is required since an inter-cable hot short from a different battery or power source will not have a current return flow path.
4. For the case of the ungrounded AC circuit power from a CPT, the inter-cable hot short must be accompanied by a short to ground on the return leg of the circuit providing a current return flow path to the power source of the aggressor circuit that is grounded. If the aggressor circuit is an ungrounded AC source off of a CPT, the aggressor circuit will also require a ground on the return leg to complete the circuit and cause the spurious operation.
5. For the case of the grounded AC circuit powered from a CPT, if the aggressor circuit is an ungrounded AC source off of a CPT, the aggressor circuit will also require a ground on the return leg to complete the circuit and cause the spurious operation.

Case 2 – Single Contact Inter-Cable Hot Short-Induced Spurious Operation





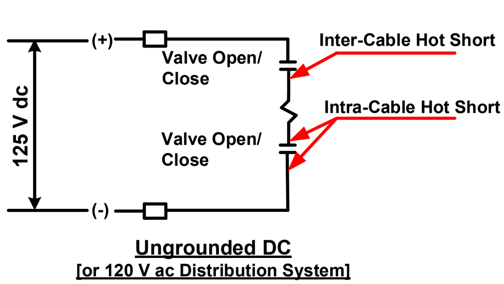
Simplified Schematic Configuration – Single Break Control Circuit

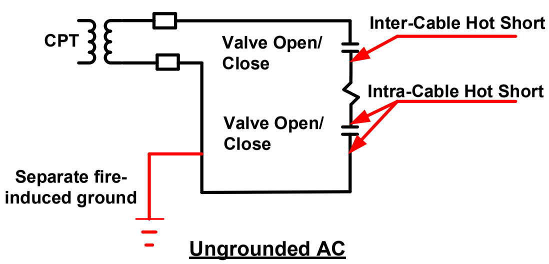
Physical Configuration

Notes:

1. Component is energize to open.
2. A fire-induced hot short can open the component.
   a. If the component is a latching circuit, the component can remain open even if the hot short is eliminated.
   b. If the component is a non-latching circuit, the component will close when the hot short is eliminated.
   c. If power is lost to the control circuit by blowing the control power fuses or by a failure of the power supply to the fuses, the component will close regardless of whether or not it is a latching or non-latching circuit.
3. For the case of the ungrounded DC or an ungrounded AC distribution system circuit, the ground equivalent hot short hot short must come from the same battery source. This is required since a ground fault equivalent hot short from a different battery source will not have a current return flow path.

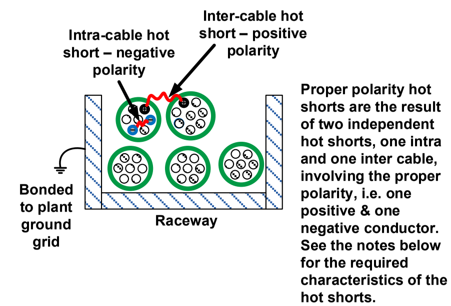
Case 3 – Single Contact Inter-Cable Hot Short-Induced Spurious Operation Via A Ground Plane Interaction From Cables In The Same Or Different Raceway





Schematic Configuration – Double Break Control Circuit

Note: The examples in this figure show one proper polarity alignment that could result in a spurious operation. Refer to the section of this NUREG/CR Report that describes Proper Polarity to understand those additional proper polarity alignments that may also apply.

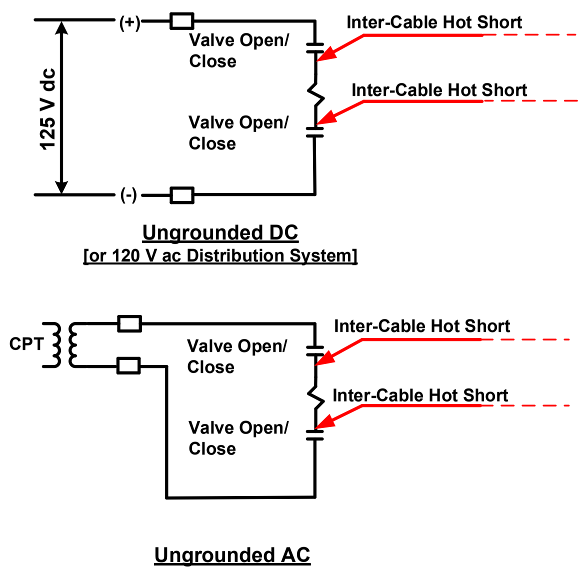


Physical Configuration

Notes:

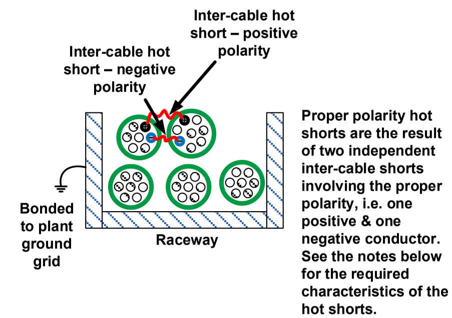
1. The component is energized to either open or close a respective valve. In this example, when the component is de-energized, the valve will return to its original position.
2. The double break design requires two hot shorts to energize the component.
3. A fire-induced inter-cable plus an intra-cable hot short will energize the component.
   a. If either hot short is eliminated, the component will de-energize and the affected component will return to its original position.
   b. If power is lost to the control circuit by blowing the control power fuses or by a failure of the power supply to the fuses, the component will de-energize and the affected component will return to its original position.
3. For the case of the ungrounded DC or the ungrounded AC distribution system circuit, the inter-cable hot short must come from the same battery or power source. This is required since an inter-cable hot short from a different battery or power source will not have a current return flow path.
4. For the case of the ungrounded AC circuit powered from a CPT, the inter-cable hot short must come from a separate and compatible ac source. If the aggressor circuit is an ungrounded AC circuit powered from a CPT, the aggressor circuit must also experience a fire-induced ground on its return leg to provide a ground path for the return current. Additionally the target circuit must also be accompanied by a fire-induced short to ground on its return leg providing a current return flow path. In summary, for the case of an ungrounded AC circuit powered from a CPT attacked by another ungrounded AC circuit powered from a CPT, for the spurious operation to occur, a third fire-induced circuit failure, i.e., a ground equivalent hot short, must occur.
5. The behavior described on this drawing for the intra-cable hot short is typical of an intra-cable hot short from a conductor within the same circuit. If the intra-cable hot short is from a conductor in the same cable, but from a different circuit, the behavior will be governed more by the characteristics described for the inter-cable hot short in Case 5.

Case 4 – Double Break - One Intra and One Inter-Cable Hot Short-Induced Spurious Operation



Schematic Configuration – Double Break Control Circuit

Note: The examples in this figure show one proper polarity alignment that could result in a spurious operation. Refer to the section of this NUREG/CR Report that describes Proper Polarity to understand those additional proper polarity alignments that may also apply.

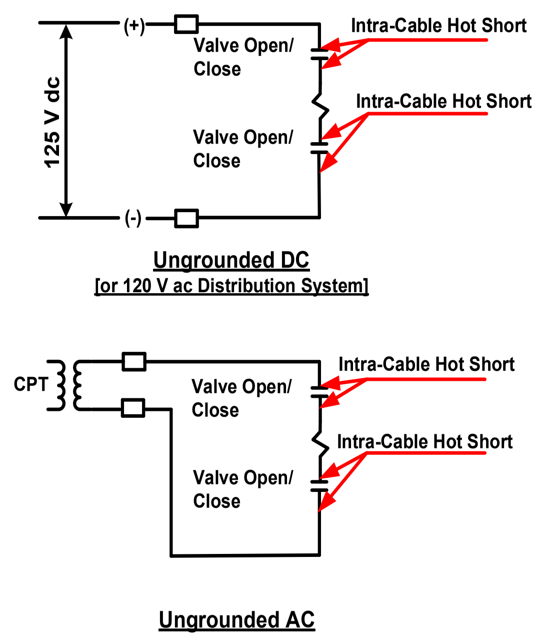


Physical Configuration

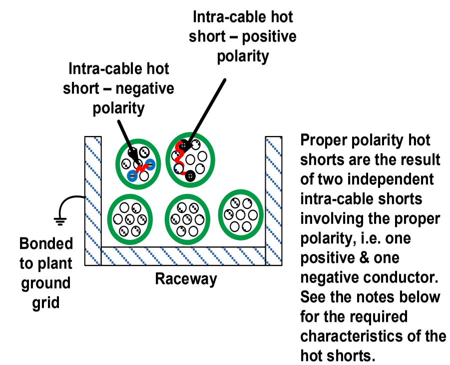
Notes:

1. The component is energized to either open or close a respective valve. In this example, when the component is de-energized, the valve will return to its original position.
2. The double break design requires two hot shorts to energize the component.
3. Two fire-induced inter-cable hot shorts will energize the component.
   a. If either hot short is eliminated, the solenoid will de-energize and the affected component will return to its original position.
   b. If power is lost to the target control circuit by blowing the control power fuses or by a failure of the power supply to the fuses, the component will remain energized since the hot shorts are powered from a separate aggressor circuit.
   c. If power is lost to the circuit for the aggressor cables, the component will de-energize and the affected component will return to its original position.
4. For all cases aggressor cables must be from a compatible source, i.e., a common source providing both the positive (or hot) and negative (or neutral, i.e., return) legs so that the current will have a flow path to the same power source.
5. For the ungrounded AC case, if the aggressor circuit is a grounded AC circuit with a CPT, then a single ground on the underside of the coil is sufficient to cause a spurious operation. Both the inter-cable hot short and GFEHS are from the grounded AC circuit CPT power source.

Case 5 – Double Break – Two Inter-Cable Hot Shorts-Induced Spurious Operation



Schematic Configuration – Double Break Control Circuit



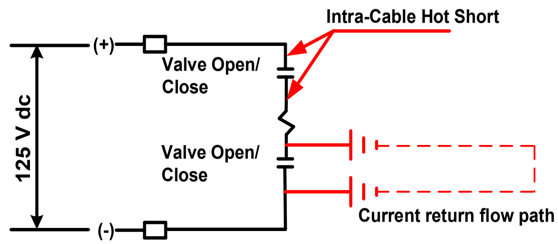
Physical Configuration

Notes:

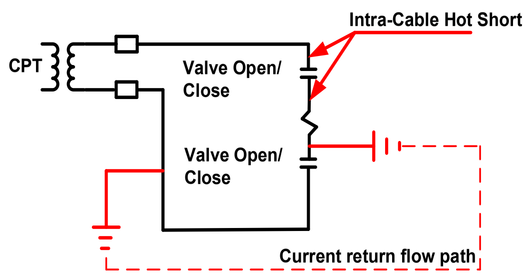
1. The component is energized to either open or close a respective valve. In this example, when the component is de-energized, the valve will return to its original position.
2. The double break design requires two hot shorts to energize the component.
3. Two fire-induced intra-cable hot shorts will energize the component.
   a. If either hot short is eliminated, the component will de-energize and the affected component will return to its original position.
   b. If power is lost to the control circuit by blowing the control power fuses or by a failure of the power supply to the fuses, the component will de-energize and the affected component will return to its original position.
4. The behavior described on this drawing is typical of intra-cable hot shorts from conductors within the same circuit. If the intra-cable hot shorts are from conductors in the same cable, but from a different circuit, the behavior will be governed more by the characteristics described for the inter-cable hot short in Case 5.

Note: The examples in this figure show one proper polarity alignment that could result in a spurious operation. Refer to the section of this NUREG/CR Report that describes Proper Polarity to understand those additional proper polarity alignments that may also apply.

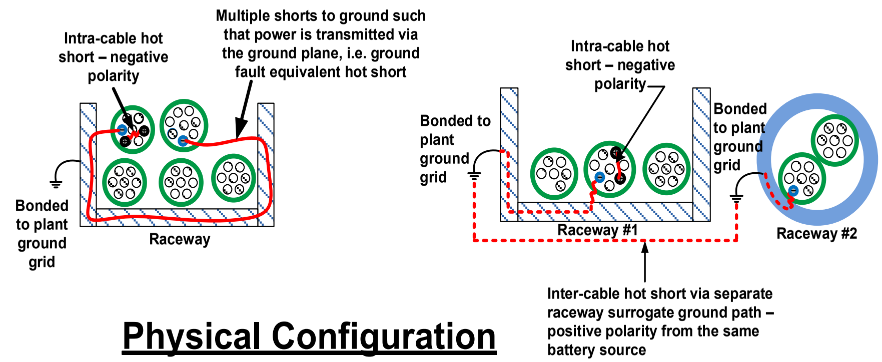
Case 6 – Double Break – Two Intra-Cable Hot Shorts-Induced Spurious Operation



Ungrounded DC
[or 120 V ac Distribution System]



Ungrounded AC



Physical Configuration

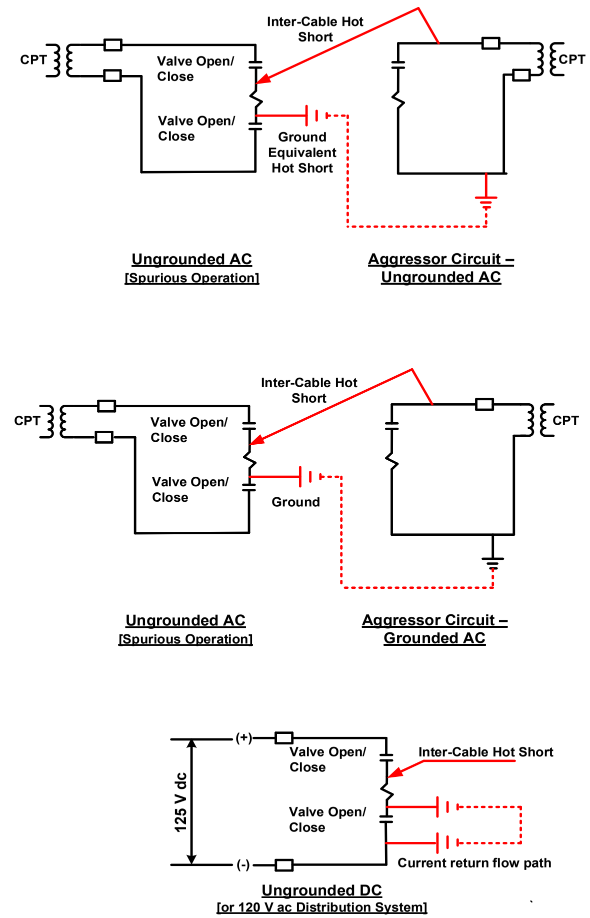
Schematic Configuration – Double Break Control Circuit

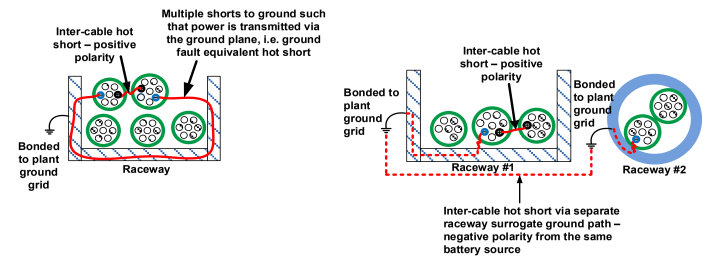
Note: The examples in this figure show one proper polarity alignment that could result in a spurious operation. Refer to the section of this NUREG/CR Report that describes Proper Polarity to understand those additional proper polarity alignments that may also apply.

Notes:

1. The component is energized to either open or close a respective valve. In this example, when the component is de-energized, the valve will return to its original position.
2. The double break design requires two hot shorts to energize the component.
3. A fire-induced intra-cable plus a ground equivalent hot short will energize the component.
   a. If either hot short is eliminated, the component will de-energize and the affected component will return to its original position.
   b. If power is lost to the control circuit by blowing the control power fuses or by a failure of the power supply to the fuses, the component will de-energize and the affected component will return to its original position.
3. For the case of the ungrounded DC or an AC ungrounded distribution system circuit, the ground equivalent hot short must include a ground on the negative (or return) leg of a circuit from the same battery source. This is required since a ground equivalent hot short from a different battery (or power) source will not have a current return flow path. The orientation of the two types of hot shorts, i.e., either above or below the coil, has no impact on the spurious operation of this circuit.
4. For the case of the ungrounded AC circuit powered from a CPT, the ground equivalent hot short must include a short to ground on the negative leg of the ungrounded AC circuit providing a current return flow path. The orientation of the two types of hot shorts, i.e., either above or below the coil, has no impact on the spurious operation of this circuit.
5. The behavior described on this drawing is typical of an intra-cable hot short from a conductor within the same circuit. If the intra-cable hot short is from a conductor in the same cable, but from a different circuit, the behavior will be governed more by the characteristics described for the inter-cable hot short in Case 8.

Case 7 – Double Break – Intra and Ground Fault Equivalent Hot Short-Induced Spurious Operation





Physical Configuration

Notes:

1. The component is energized to either open or close a respective valve. In this example, when the component is de-energized, the valve will return to its original position.
2. Except as noted below, the double break design requires two hot shorts to energize the component.
3. Except as noted below, a fire-induced inter-cable plus a ground equivalent hot short will energize the component.
   a. If either hot short is eliminated, the component will de-energize and the affected component will return to its original position.
   b. If power is lost to the control circuit by blowing the control power fuses on the aggressor circuit or by a failure of the power supply to the fuses on the aggressor circuit, the component will de-energize and the affected component will return to its original position.
3. For the case of the ungrounded DC or an ungrounded AC distribution system circuit, the inter-cable hot short and the negative (or return) leg of the ground equivalent hot short must come from the same battery (or power) source. This is required since hot shorts from a different battery (or power) source will not have a current flow path. The orientation of the two types of hot shorts, i.e., either above or below the coil, has no impact on the spurious operation of this circuit.
4. For the case of the ungrounded AC circuit powered from a CPT, the aggressor circuit can be either a grounded or an ungrounded AC circuit. In either case, the inter-cable and return leg of the ground equivalent hot short must be from the same AC circuit powered from the same CPT. This assures the availability of a current flow path through the aggressor circuit. If the aggressor circuit is a grounded AC circuit, then all that is required is a ground below the solenoid, since the ground in the aggressor circuit will provide the current flow path.

Schematic Configuration – Double Break Control Circuit

Note: The examples in this figure show one proper polarity alignment that could result in a spurious operation. Refer to the section of this NUREG/CR Report that describes Proper Polarity to understand those additional proper polarity alignments that may also apply.

Case 8 – Double Break – Inter and Ground Fault Equivalent Hot Short-Induced Spurious Operation

APPENDIX C

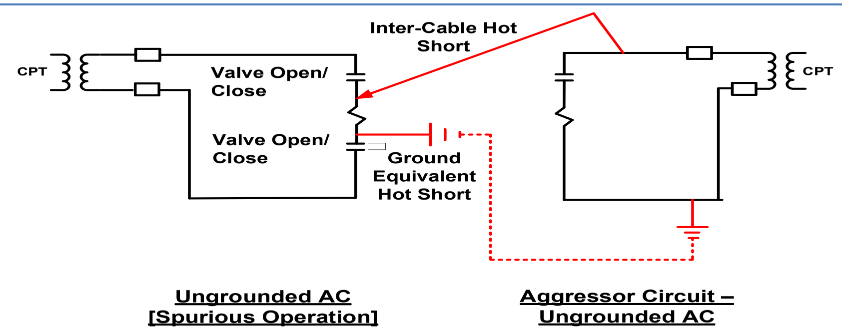
RECLASSIFICATION OF TWO (2) INTER-CABLE HOT SHORTS FOR A DOUBLE BREAK DESIGNED CIRCUIT WITH THERMOPLASTIC INSULATED CONDUCTORS

Section 3.2.1.4 of this report provides technical justification for the changes made to the failure mode classifications for specific circuit configurations. To support those recommendations, the following figures have been developed / revised to illustrate the possible failure modes for double break designed circuits involving an inter-cable hot short and a ground fault equivalent hot short (or a ground in the case of a grounded AC aggressor circuit).

General Note:

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

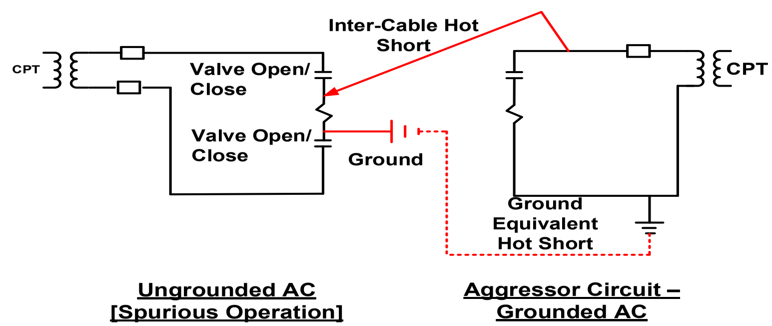
Case 1



Note:
For this case, the classification is "implausible" for latching circuits and "incredible" for non-latching circuits. The classification of this circuit failure combination is bounded by the classification of the circuit for Case 2 involving an inter-cable hot short and a ground.

"implausible" for latching circuits and "incredible" for non-latching circuits

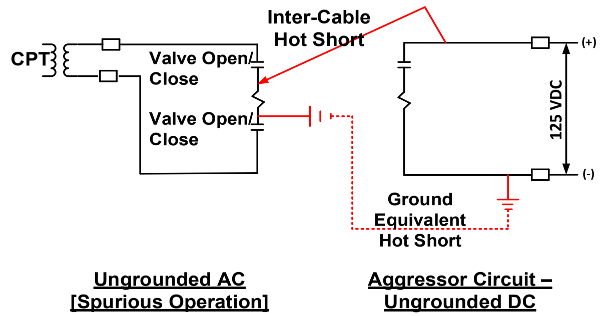
Case 2



Note:
For this case, the classification is "implausible" for latching circuits and "incredible" for non-latching circuits. Although the required circuit failure types are an inter-cable hot short and a ground, the inter-cable hot short must come from a specific circuit type, i.e., a grounded AC circuit. Additionally, the inter-cable hot short from the aggressor (i.e., source) grounded AC circuit cannot go to ground prior to the ground forming on the target circuit. Once the inter-cable hot short on the aggressor (i.e., source) grounded AC circuit goes to ground, the control power fusing on the aggressor circuit will blow and remove the potential for the spurious operation. This circuit failure timing consideration, in combination with the likelihood a circuit grounds and the unlikelihood of these two (2) specific circuit types both becoming involved, makes this combined failure mode of sufficiently low likelihood to classify it as "implausible" for latching circuits. The additional timing considerations for a non-latching circuits makes the classification of this case, "incredible" for non-latching circuits.

"implausible" for latching circuits and "incredible" for non-latching circuits

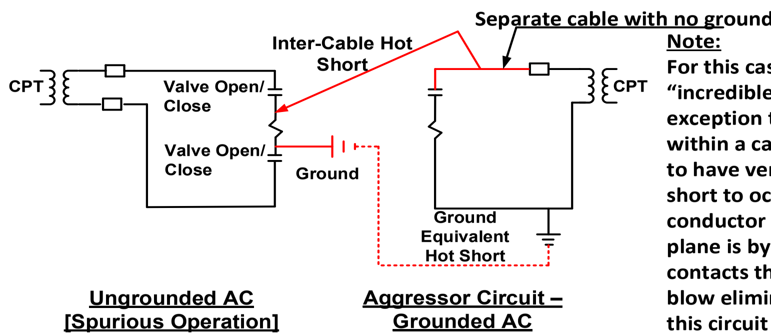
Figure C-1 Ungrounded AC from a CPT – Double Break Design



Note:
For this case, the classification is "implausible" for latching circuits and "incredible" for non-latching circuits. The classification of this circuit failure combination is bounded by the classification of the circuit for Case 2 involving an inter-cable hot short and a ground.

"implausible" for latching circuits and "incredible" for non-latching circuits

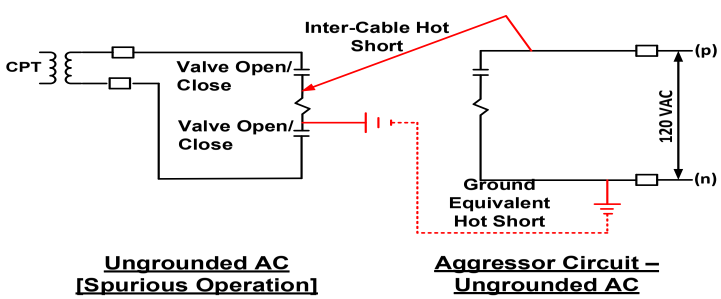
Case 3



Note:
For this case, the classification is "implausible" for latching circuits and "incredible" for non-latching circuits. This case is similar to Case 2 with the exception that it assumes that the possible aggressor conductor is contained within a cable with no grounded conductor. This condition, however, is judged to have very limited impact on the classification, since for an inter-cable hot short to occur, the aggressor conductor must be exposed. With the aggressor conductor exposed, the likelihood of it coming into contact with the ground plane is by far the most likely outcome. Once the exposed aggressor conductor contacts the ground plane the control power fuse for the aggressor circuit will blow eliminating the possibility of a spurious operation. The other aspects of this circuit performance for this case are identical to those described for Case 2.

"implausible" for latching circuits and "incredible" for non-latching circuits

Case 4



Note:
For this case, the classification is "implausible" for latching circuits and "incredible" for non-latching circuits. This case is bounded by Case 2.

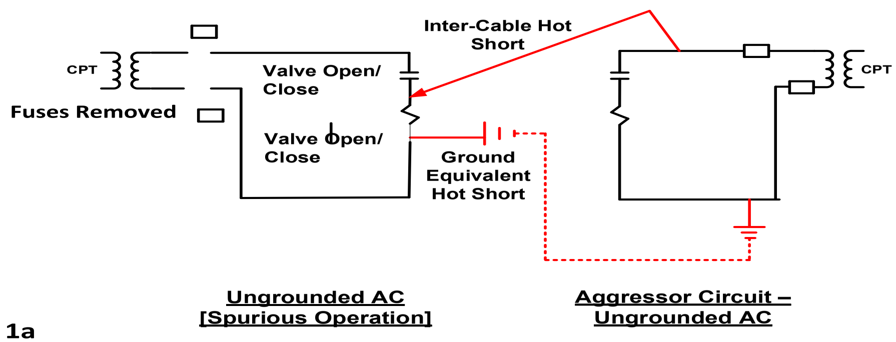
"implausible" for latching circuits and "incredible" for non-latching circuits

Case 5

Figure C-1 Ungrounded AC from a CPT – Double Break Design (Continued)

General Note:

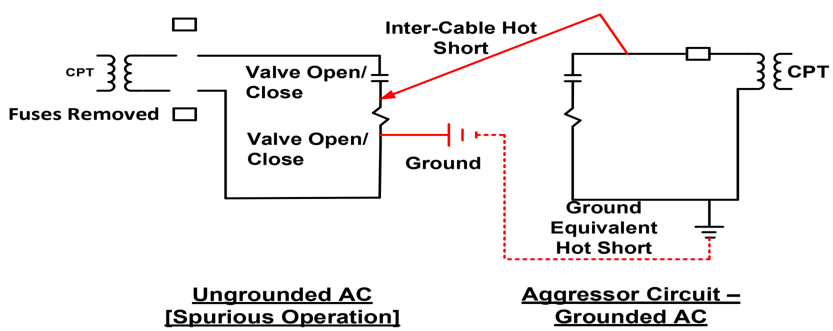
The cases shown in this figure depict a specific proper polarity alignment. By depicting only one proper polarity alignment, there is no intent to exclude other proper polarity alignments. Other proper polarity alignments may also apply. Additionally, the potential exists for an aggressor AC circuit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



Case 1a

Note:
This case is considered to be equivalent to Case 1, since the conductors above and below the coil are still the only conductors that can be involved in causing the spurious operation.

"implausible" for latching circuits and "incredible" for non-latching circuits

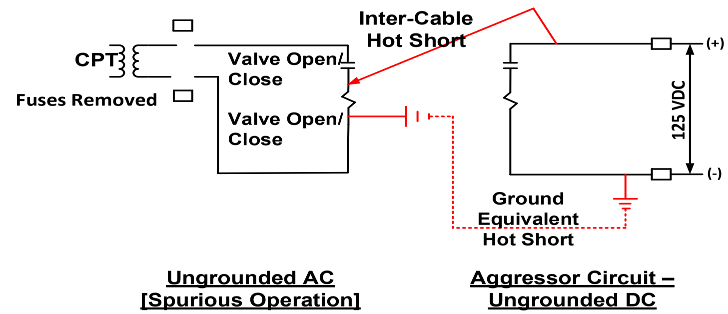


Case 2a

Note:
This case is considered to be equivalent to Case 2, since the conductors above and below the coil are still the only conductors that can be involved in causing the spurious operation.

"implausible" for latching circuits and "incredible" for non-latching circuits

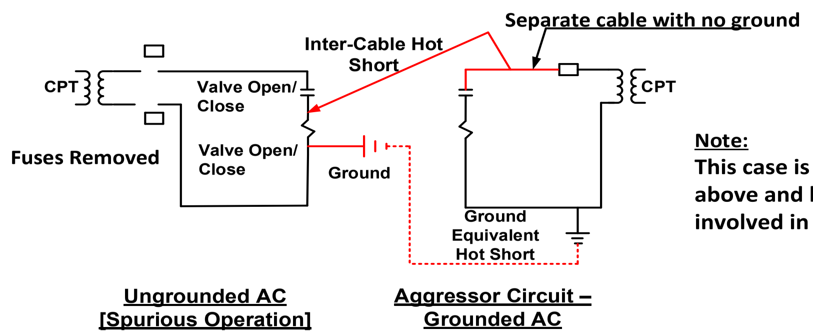
Figure C-2 Ungrounded AC from a CPT – Pseudo-Double Break Design



Note:
This case is considered to be equivalent to Case 3, since the conductors above and below the coil are still the only conductors that can be involved in causing the spurious operation.

"implausible" for latching circuits and "incredible" for non-latching circuits

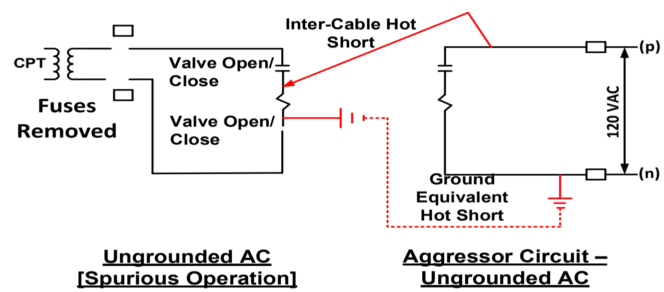
Case 3a



Note:
This case is considered to be equivalent to Case 4, since the conductors above and below the coil are still the only conductors that can be involved in causing the spurious operation.

"implausible" for latching circuits and "incredible" for non-latching circuits

Case 4a



Note:
This case is considered to be equivalent to Case 5, since the conductors above and below the coil are still the only two conductors that can be involved in causing the spurious operation.

"implausible" for latching circuits and "incredible" for non-latching circuits

Case 5a

Figure C-2 Ungrounded AC from a CPT – Pseudo-Double Break Design (Continued)

General Note:

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

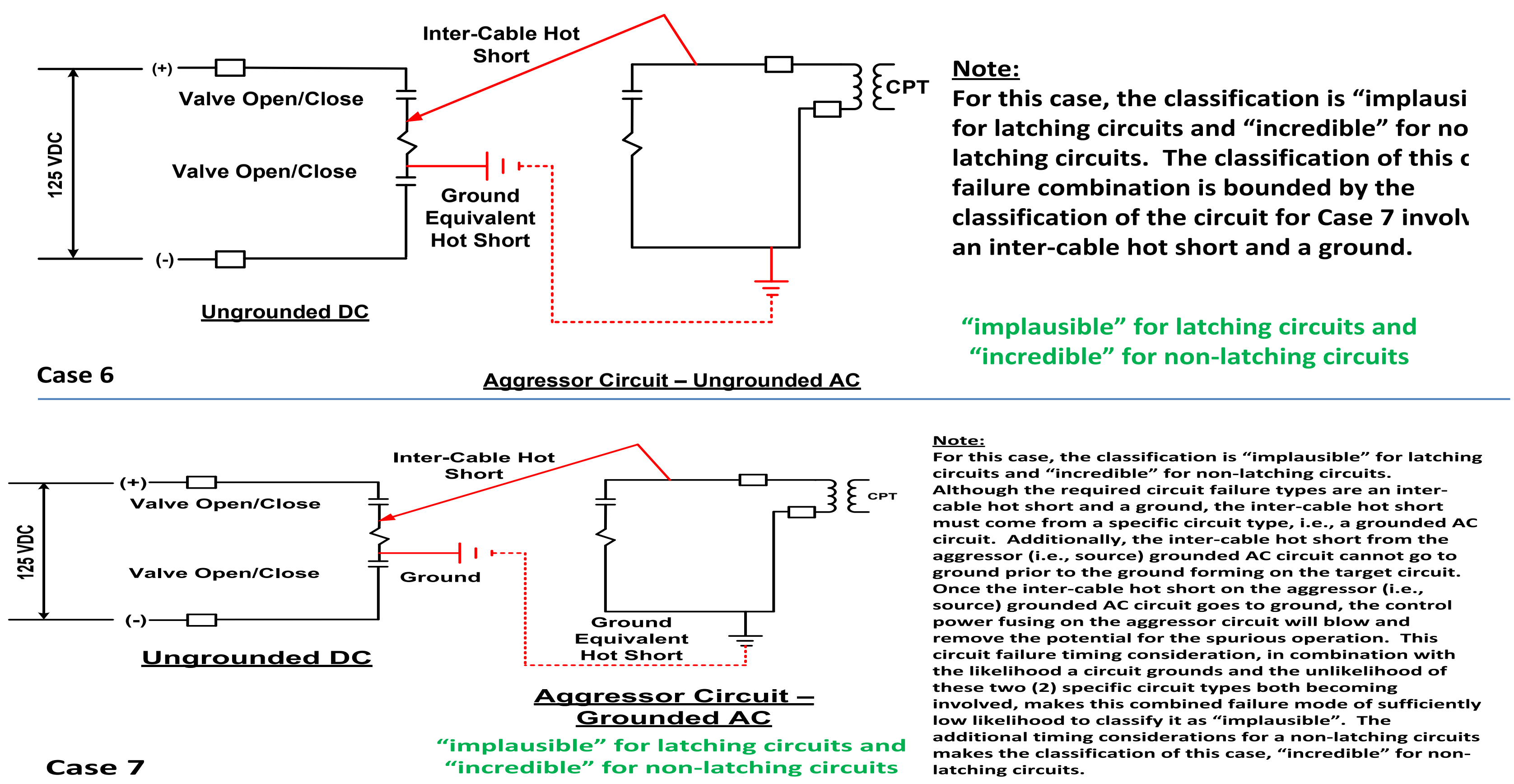
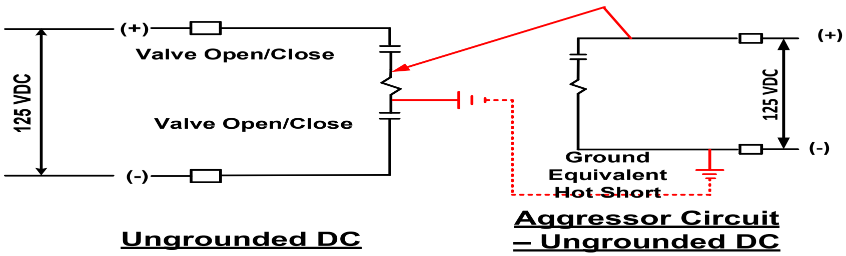


Figure C-3 Ungrounded DC – Double Break Design

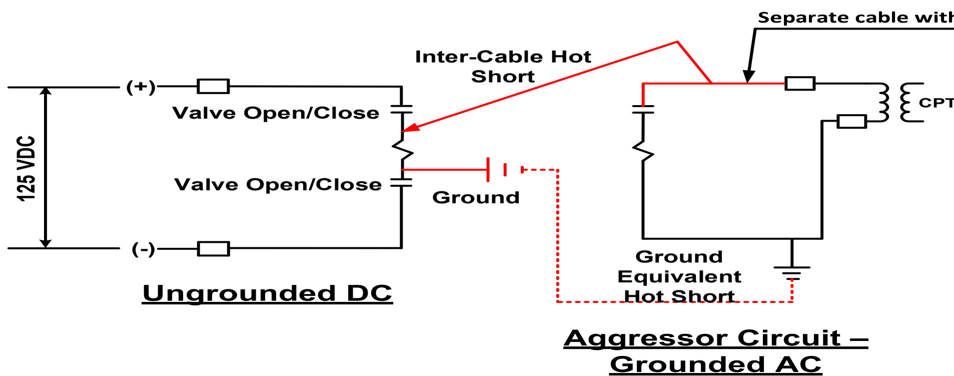
RECLASSIFICATION OF TWO INTER-CABLE HOT SHORTS FOR A DOUBLE BREAK DESIGNED CIRCUIT WITH THERMOPLASTIC INSULATED CONDUCTORS



Case 8

Note:
For this case, the classification is "implausible" for latching circuits and "incredible" for non-latching circuits. The classification of this circuit failure combination is bounded by the classification of the circuit for Case 7 involving an inter-cable hot short and a ground.

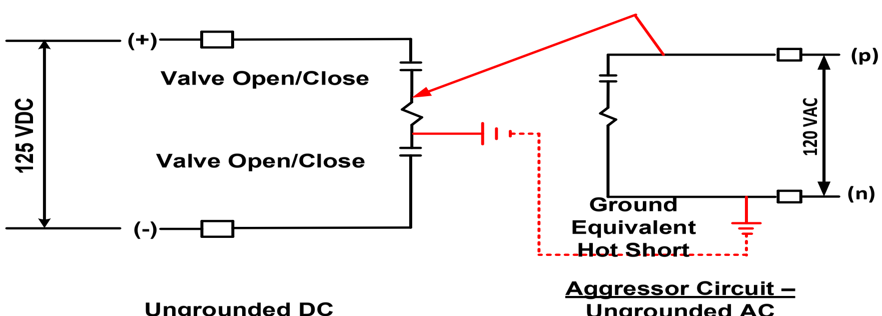
"implausible" for latching circuits and "incredible" for non-latching circuits



"implausible" for latching circuits and "incredible" for non-latching circuits

Case 9

Note:
For this case, the classification is "implausible" for latching circuits and "incredible" for non-latching circuits. This case is similar to Case 7 with the exception that it assumes that the possible aggressor conductor is contained within a cable with no grounded conductor. This condition, however, is judged to have very limited impact on the classification, since for an inter-cable hot short to occur, the aggressor conductor must be exposed. With the aggressor conductor exposed, the likelihood of it coming into contact with the ground plane is by far the most likely outcome. Once the exposed aggressor conductor contacts the ground plane the control power fuse for the aggressor circuit will blow eliminating the possibility of a spurious operation. The other aspects of this circuit performance for this case are identical to those described for Case 7.



Case 10

Note:
The circuit for this case is identical to the circuit for Case 8 except for voltage differences.

"implausible" for latching circuits and "incredible" for non-latching circuits

Figure C-3 Ungrounded DC – Double Break Design (Continued)

General Note:

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

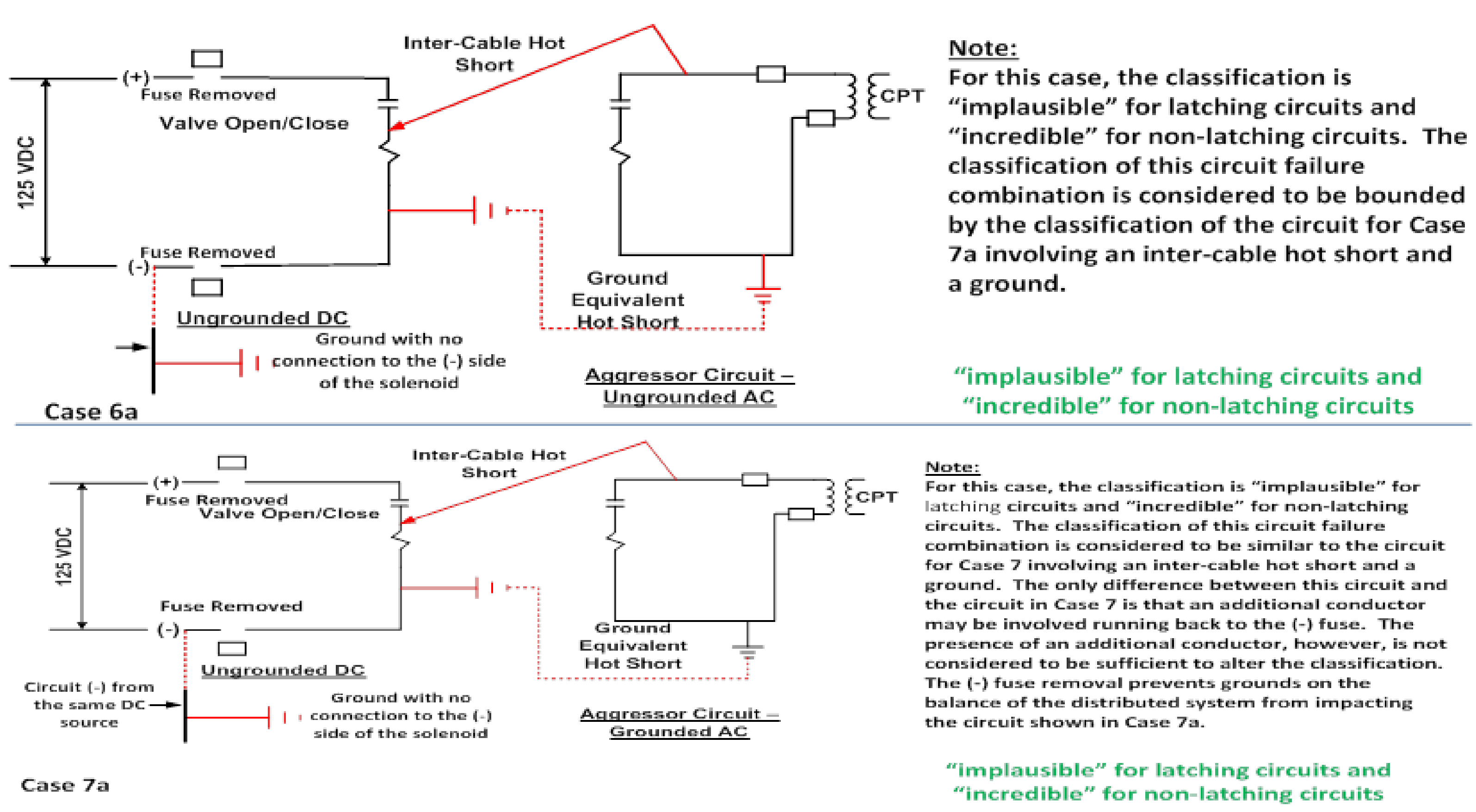


Figure C-4 Ungrounded DC – Pseudo-Double Break Design

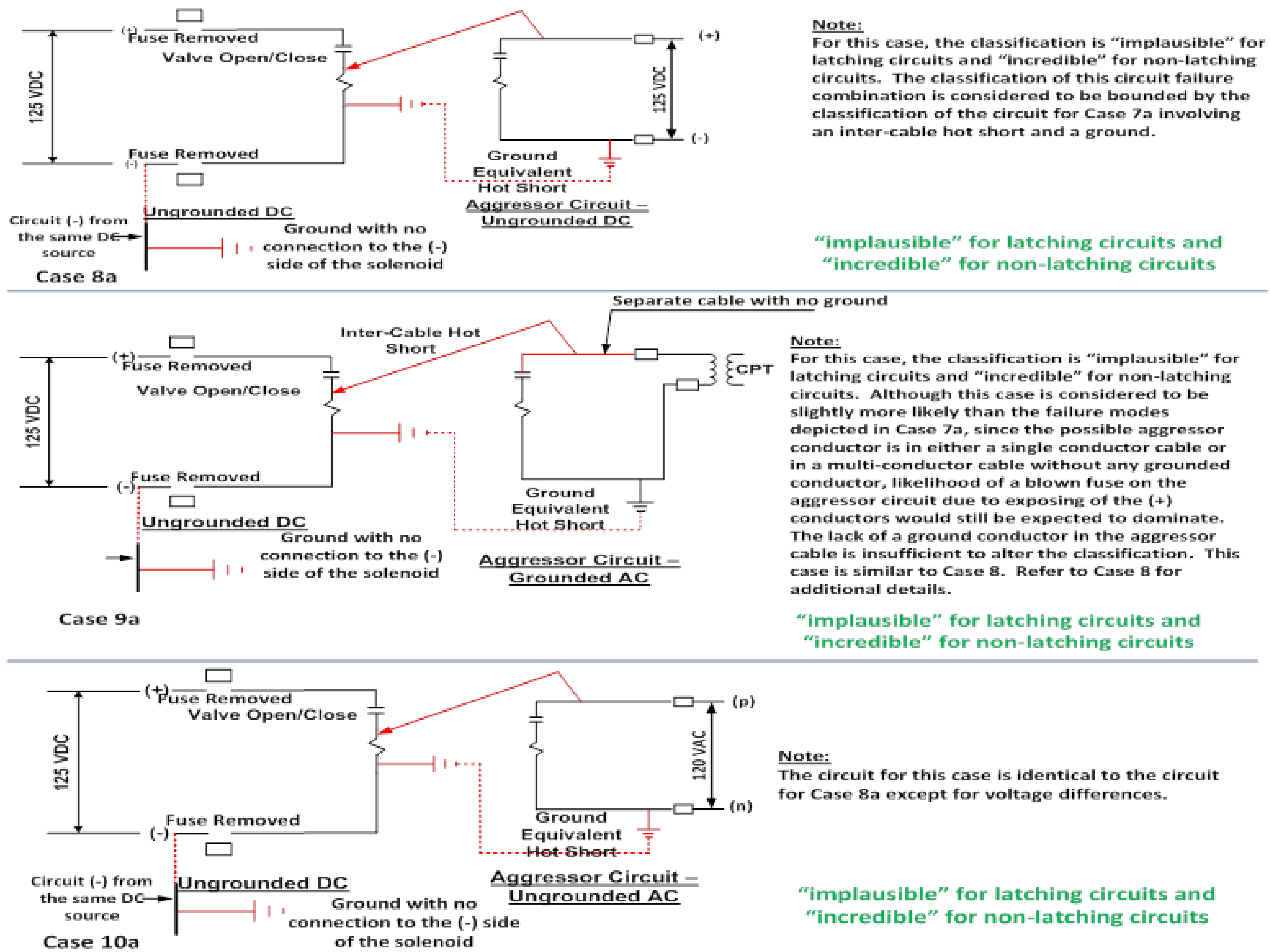
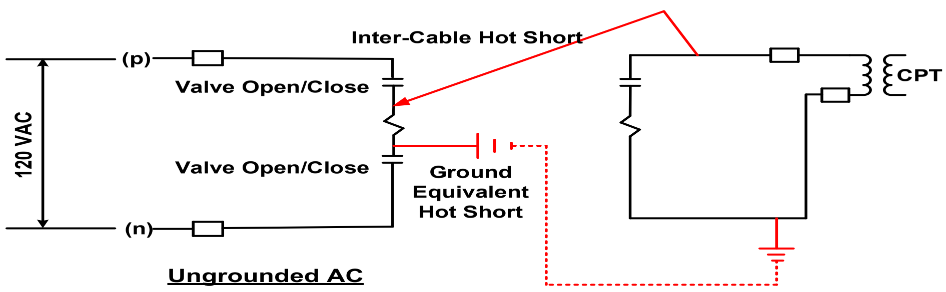


Figure C-4 Ungrounded DC – Pseudo-Double Break Design (Continued)

General Note:

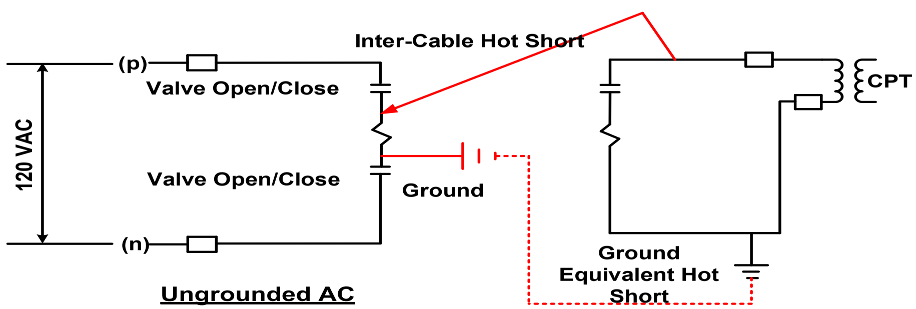
The cases shown in this figure depict a specific proper polarity alignment. By depicting only one proper polarity alignment, there is no intent to exclude other proper polarity alignments. Other proper polarity alignments may also apply. Additionally, the potential exists for an aggressor AC circuit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



Case 11

Note:
For this case, the classification is "implausible" for latching circuits and "incredible" for non-latching circuits. The classification of this circuit failure combination is bounded by the classification of the circuit for Case 12 involving an inter-cable hot short and a ground.

"implausible" for latching circuits and "incredible" for non-latching circuits

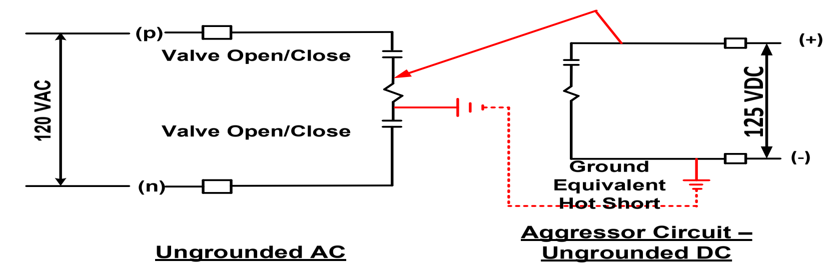


Case 12

"implausible" for latching circuits and "incredible" for non-latching circuits

Note:
For this case, the classification is "implausible" for latching circuits and "incredible" for non-latching circuits. Although the required circuit failure types are an inter-cable hot short and a ground, the inter-cable hot short must come from a specific circuit type, i.e., a grounded AC circuit. Additionally, the inter-cable hot short from the aggressor (i.e., source) grounded AC circuit cannot go to ground prior to the ground forming on the target circuit. Once the inter-cable hot short on the aggressor (i.e., source) grounded AC circuit goes to ground, the control power fusing on the aggressor circuit will blow and remove the potential for the spurious operation. This circuit failure timing consideration, in combination with the likelihood a circuit grounds and the unlikelihood of these two (2) specific circuit types both becoming involved, makes this combined failure mode of sufficiently low likelihood to classify it as "implausible".

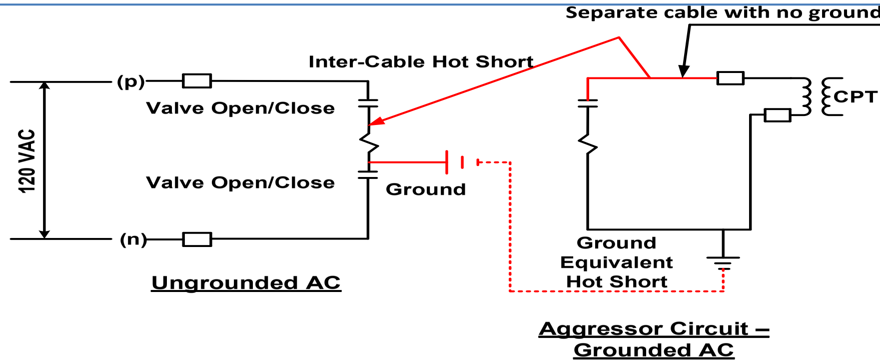
Figure C-5 Ungrounded AC Distributed – Double Break Design



Case 13

Note:
For this case, the classification is "implausible" for latching circuits and "incredible" for non-latching circuits. The classification of this circuit failure combination is bounded by the classification of the circuit for Case 12 involving an inter-cable hot short and a ground.

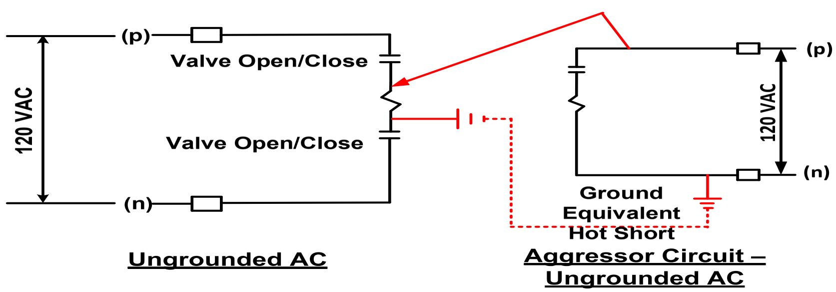
"implausible" for latching circuits and "incredible" for non-latching circuits



"implausible" for latching circuits and "incredible" for non-latching circuits

Case 14

Note:
For this case, the classification is "implausible" for latching circuits and "incredible" for non-latching circuits. This case is similar to Case 12 with the exception that it assumes that the possible aggressor conductor is contained within a cable with no grounded conductor. This condition, however, is judged to have very limited impact on the classification, since for an inter-cable hot short to occur, the aggressor conductor must be exposed. With the aggressor conductor exposed, the likelihood of it coming into contact with the ground plane is by far the most likely outcome. Once the exposed aggressor conductor contacts the ground plane the control power fuse for the aggressor circuit will blow eliminating the possibility of a spurious operation. The other aspects of this circuit performance for this case are identical to those described for Case 12. The lack of a ground conductor in the aggressor cable is insufficient to alter the classification.



Case 15

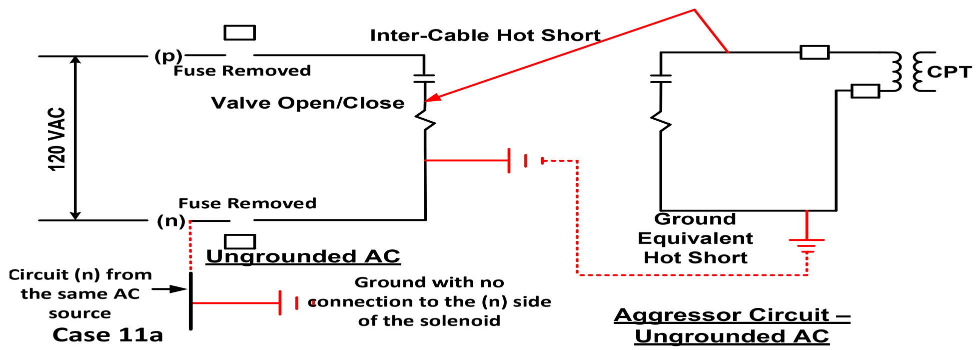
Note:
The circuit for this case is identical to the circuit for Case 13 except for voltage differences.

"implausible" for latching circuits and "incredible" for non-latching circuits

Figure C-5 Ungrounded AC Distributed – Double Break Design (Continued)

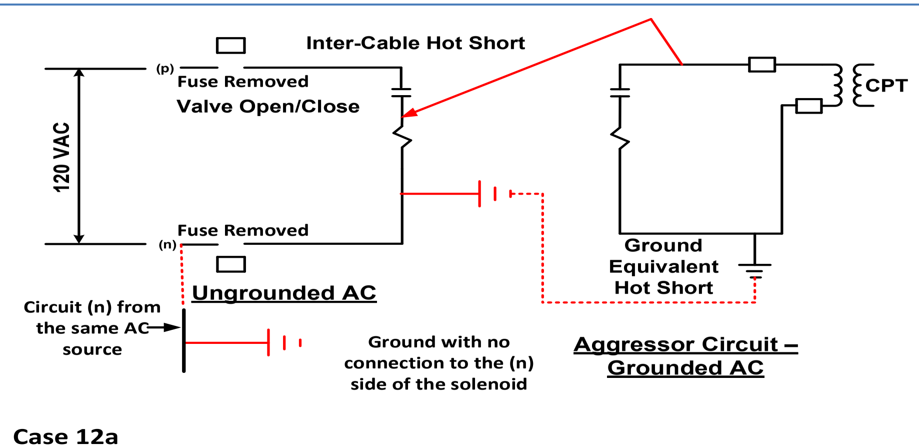
General Note:

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



Note:
For this case, the classification is "implausible" for latching circuits and "incredible" for non-latching circuits. The classification of this circuit failure combination is bounded by the classification of the circuit for Case 12a involving an inter-cable hot short and a ground.

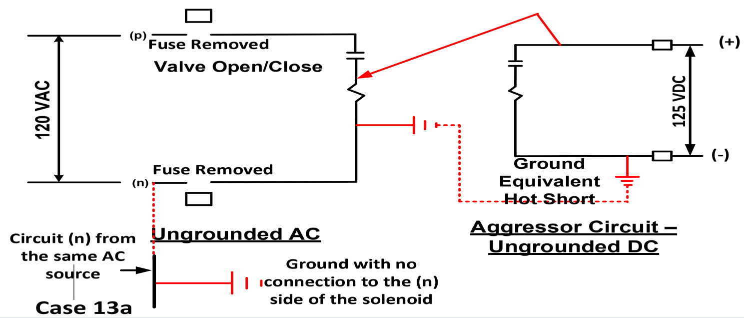
"implausible" for latching circuits and "incredible" for non-latching circuits



Note:
For this case, the classification is "implausible" for latching circuits and "incredible" for non-latching circuits. The classification of this circuit failure combination is considered to be similar to the circuit for Case 12 involving an inter-cable hot short and a ground. The only difference between this circuit and the circuit in Case 12 is that an additional conductor may be involved running back to the (n) fuse. The (n) fuse removal prevents grounds on the balance of the distributed system from impacting the circuit shown in Case 12a.

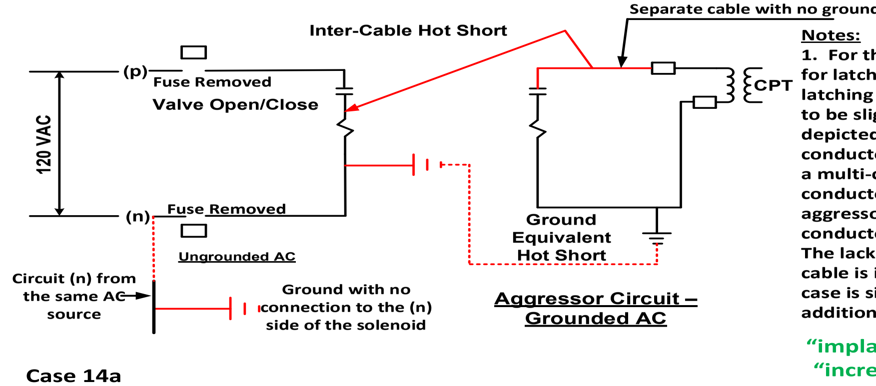
"implausible" for latching circuits and "incredible" for non-latching circuits

Figure C-6 Ungrounded AC Distributed – Pseudo-Double Break Design



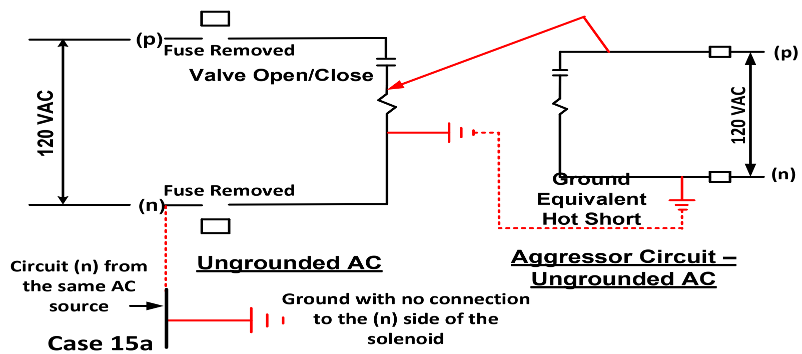
Note:
For this case, the classification is "implausible" for latching circuits and "incredible" for non-latching circuits. The classification of this circuit failure combination is bounded by the classification of the circuit for Case 12 involving an inter-cable hot short and a ground.

"implausible" for latching circuits and "incredible" for non-latching circuits



Notes:
1. For this case, the classification is "implausible" for latching circuits and "incredible" for non-latching circuits. Although this case is considered to be slightly more likely than the failure modes depicted in Case 12a, since the possible aggressor conductor is in either a single conductor cable or in a multi-conductor cable without any grounded conductor, likelihood of a blown fuse on the aggressor circuit due to exposing of the (+) conductors would still be expected to dominate. The lack of a ground conductor in the aggressor cable is insufficient to alter the classification. This case is similar to Case 12. Refer to Case12 for additional details.

"implausible" for latching circuits and "incredible" for non-latching circuits



Note:
The circuit for this case is identical to the circuit for Case 13a except for voltage differences.

"implausible" for latching circuits and "incredible" for non-latching circuits

Figure C-6 Ungrounded AC Distributed – Pseudo-Double Break Design (Continued)

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10. SUPPLEMENTARY NOTES
G. Taylor, NRC Contracting Officer Representative

11. ABSTRACT (200 words or less)
This report builds upon two previous reports, titled Joint Assessment of Cable Damage and Quantification of Effects from Fire (JACQUE-FIRE), Volume 1 and Volume 2. This work aims at providing a better understanding of failure modes in electrical control circuits that might occur in nuclear power plants as a result of fire damage to electric cables. This research was conducted by the United States Nuclear Regulatory Commission (NRC) and the Electric Power Research Institute (EPRI) under a Memorandum of Understanding using a balanced team of experts from the regulator and the industry. The objectives of this report are to present technical recommendations on a number of circuit analysis issues and to update or clarify positions developed in earlier research. The recommendations for resolution of these issues in a technical setting are intended to facilitate development of a solid technical foundation and a stable framework to support a consistent approach for conducting and reviewing post-fire safe-shutdown analyses.

This working group was convened to address several remaining circuit analysis issues related to deterministic post-fire safe-shutdown analysis. The working group findings are presented as clarifications and recommendations. Clarifications are presented on circuit failure modes and terminology. Recommendations are provided on: design considerations for shorting switches, hot short-induced multiple spurious operations in DC and AC control circuits, and secondary fire risk due to fire-induced open-circuited current transformers. Risk-insights, developed from the PRA expert panel (JACQUE-FIRE Volume 2), have been used to revise earlier PIRT panel findings from JACQUE-FIRE Volume 1.

12. KEY WORDS/DESCRIPTORS (List words or phrases that will assist researchers in locating the report.)
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Fire safety
Hot short
Multiple spurious operations (MSOs)
Nuclear power plant (NPP)
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