Module II – Circuit Analysis

Circuit Analysis Basics
Introduction

Joint EPRI/NRC-RES Fire PRA Workshop
August 24-28

Dan Funk – Jensen Hughes

Gabe Taylor – U.S. NRC

A Collaboration of the Electric Power Research Institute (EPRI) & U.S. NRC Office of Nuclear Regulatory Research (RES)

CIRCUIT ANALYSIS INTRODUCTION
Introductions

- Instructors
  - Daniel Funk, P.E., Jensen Hughes
  - Gabriel Taylor, P.E., NRC Office of Nuclear Regulatory Research

- Who's here and Why?
  - Name, Organization, Experience
  - What do you want from this course?

- Logistics

CIRCUIT ANALYSIS INTRODUCTION
Course Prerequisites

- Who Should Attend?
  - Nuclear plant personnel with electrical and plant operating knowledge, but limited exposure to Appendix R and PRA
  - Nuclear plant personnel with substantial Appendix R and/or PRA experience, but limited circuit analysis experience
  - Anyone who has a fundamental understanding of nuclear power plant equipment electrical operation will benefit from this course
    - *NOTE: This is a working level course and is NOT intended for individuals that do not have at least a fundamental understanding of electrical drawings and electrical control circuits*

CIRCUIT ANALYSIS INTRODUCTION
What we'll cover this week…

The purpose of this presentation is to provide an Overview of Module 2 – Electrical Analysis

– Course Introduction
– Circuit Analysis Basics
– Fire-Induced Circuit Failure Concepts and Fault Modes
– Circuit Analysis Process, Methods, and Criteria
– Walk Through Sample Problems
– Hands-on Sample Problem Exercises
– Project Considerations and Lessons Learned

CIRCUIT ANALYSIS INTRODUCTION
Training Approach and Ground Rules

- Our intent:
  - To deliver practical implementation training
  - To convey fundamental electrical concepts pertinent to fire-induced circuit failures
  - To illustrate and demonstrate application of circuit analysis concepts and methods
- We expect and want significant participant interaction
  - Class size should allow for *questions and discussion*
  - We will answer questions about *methodology* and *application*
  - We *cannot* answer questions about a *specific application*
  - We *cannot* answer questions about *regulatory interpretations*
  - *We* will moderate *constructive* discussions, but will judge when the course must move on to meet objectives

CIRCUIT ANALYSIS INTRODUCTION
Background

- This module covers technical tasks for analysis of fire-induced circuit failures in support of a Fire PRA
- This module is geared toward PRA practitioners and fire safe shutdown analysts with a practical understanding of the concepts and methods of fire-induced circuit failure analysis within the context of Fire PRA or Appendix R circuit failure assessments.
- Familiarity with the following topics is recommended:
  - General circuit design and operation for typical plant equipment
  - Working level knowledge of typical electrical drawings, including one-line diagrams, schematic diagrams, electrical block diagrams, wiring/connection diagrams, raceway layout drawings, instrument loop diagrams, etc.
  - Appendix R safe shutdown or Fire PRA circuit analysis industry documents
  - Basic circuit analysis techniques for identifying and classifying fire-induced circuit failure modes
  - Cable and raceway, Appendix R safe shutdown, and Fire PRA database structures and software
  - Emerging issues and challenges associated with fire-induced circuit failures and failure probabilities

CIRCUIT ANALYSIS INTRODUCTION
Objectives

- It is expected that upon completion of the Circuit Analysis Module attendees will:
  - Have a basic understanding of fire-induced circuit failure modes
  - Be able to explain how circuit design parameters influence cable failure modes and the associated functional impact on circuit operation
  - Have sufficient working knowledge of techniques and methods to perform at a practical level the electrical analysis tasks for typical plant equipment
  - Have a precise understanding of circuit analysis terms and acronyms so as to avoid common misconceptions and misapplications
  - Have an general understanding of the fire-induced circuit failure testing that has been conducted and the resulting changes in circuit analysis concepts
  - Have an appreciation for circuit analysis challenges and potential impacts on a Fire PRA project
  - Be able to explain basic circuit analysis concepts and use typical techniques to perform and document a circuit analysis
- Methodology presentations will show relationships to the PRA Standard and NEI 00-01, Rev. 2

CIRCUIT ANALYSIS INTRODUCTION
Presentation Road Map

- Course Introduction
- Circuit Analysis Basics
- Fire-Induced Circuit Failure Concepts and Fault Modes
- Circuit Analysis Process, Methods, and Criteria
- Walk Through Sample Problems
- Hands-on Sample Problem Exercises
- Project Considerations and Lessons Learned

CIRCUIT ANALYSIS INTRODUCTION
Schedule / Agenda

Module II - Circuit Analysis Agenda		
Day		**Title**
Monday	AM	Introduction & Overview to Circuit Analysis
	PM	Circuit Analysis Fundamentals / Fire Research
Tuesday	AM	Cable Failure Modes - Theory and Application
	PM	Circuit Failure Modes - Theory and Application
Wednesday	AM	Task 3 - Cable Selection / Task 9 - Detailed Circuit Analysis
	PM	Task 10 - Failure Mode Likelihood / Example Walk Through
Thursday	AM	Practical Exercises
	PM	Practical Exercises
Friday	AM	Practical Exercises / Summary
		Wrap up and adjourn

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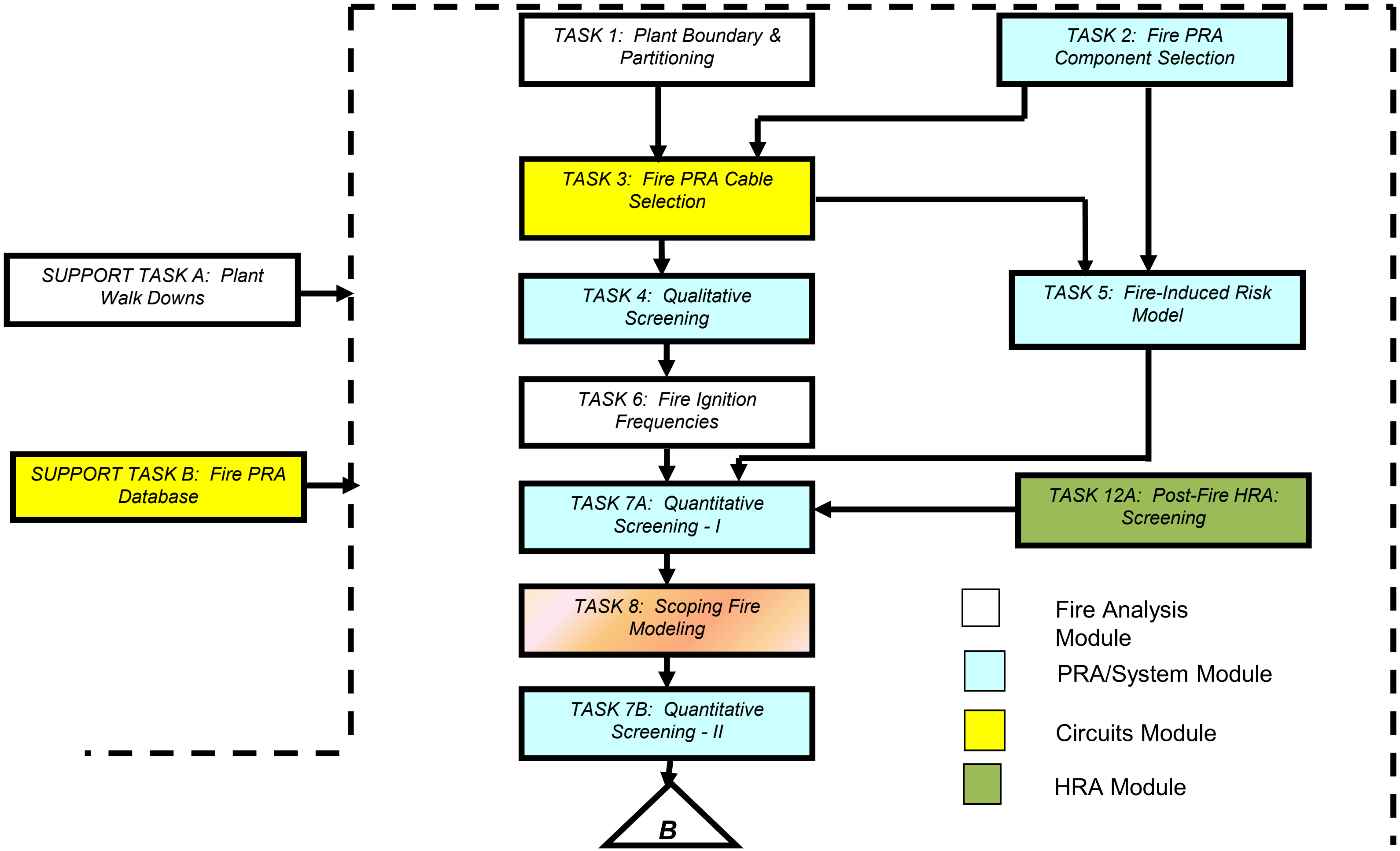
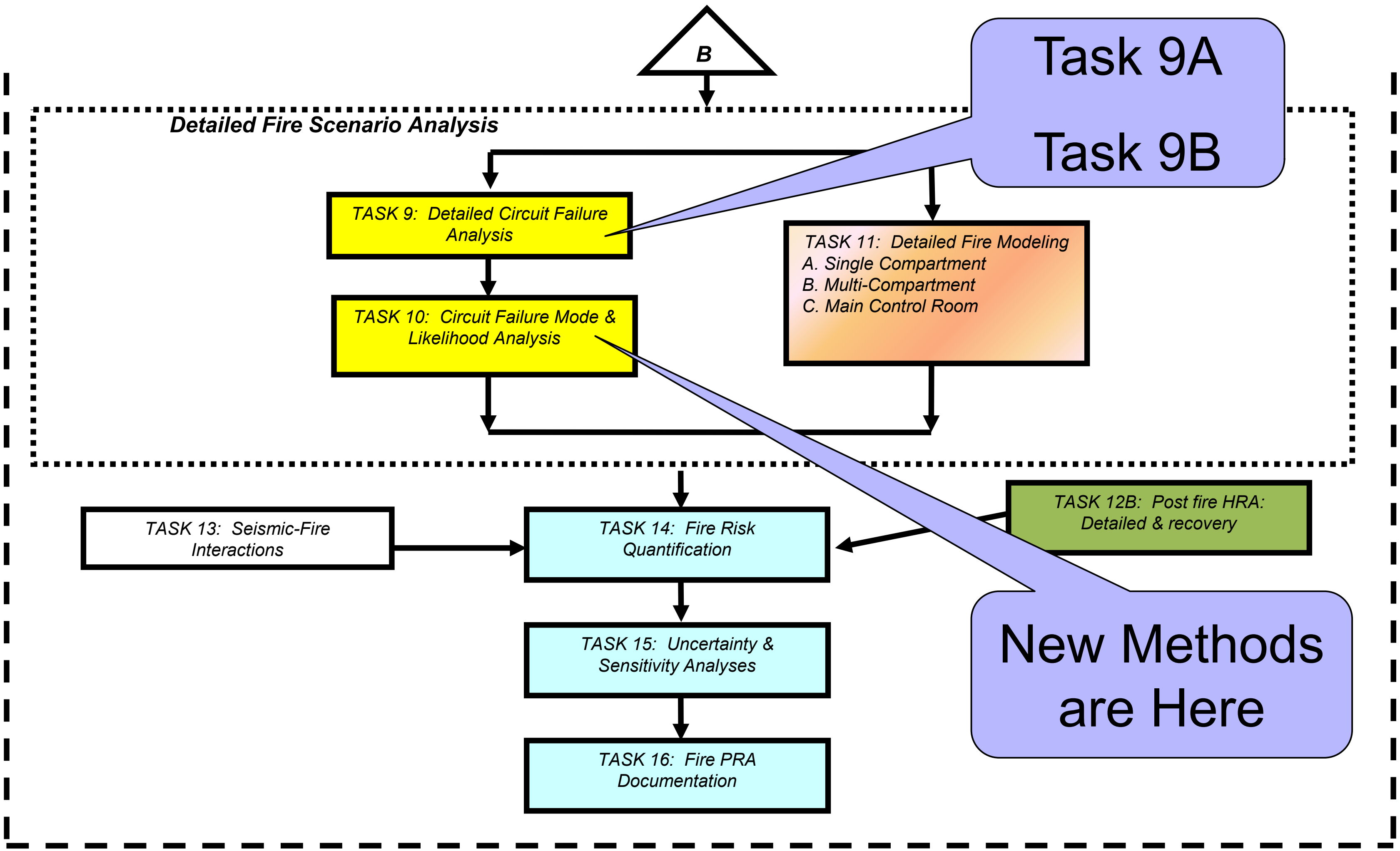
CIRCUIT ANALYSIS INTRODUCTION
Circuit Analysis Tasks

- Task 3: Fire PRA Cable Selection
  - What cables are associated with the FPRA components?
- Task 9: Detailed Circuit Analysis
  - Which cables can affect the credited functionality?
  - Task 9A / 9B Split
  - What failure modes are possible given fire damage to the cable?
- Task 10: Circuit Failure Mode Likelihood Analysis
  - How likely to occur are the failure modes of concern?
  - NUREG/CR-7150, Vol. 2, May 2014
- Support Task B: Fire PRA Database
  - Warehousing data and determining impacts

CIRCUIT ANALYSIS INTRODUCTION
Circuit Analysis Tasks



CIRCUIT ANALYSIS INTRODUCTION
Circuit Analysis Tasks, cont.



CIRCUIT ANALYSIS INTRODUCTION
Key Considerations

- Each Circuit Analysis task represents a refined level of detail (i.e., graded approach)
- Existing Appendix R Circuit Analysis is **NOT** as useful as originally envisioned
- Circuit Analysis for Fire PRA is more complex and difficult compared to Appendix R
- Circuit Analysis (including cable tracing) can consume 40%-70% of overall budget
- Circuit Analysis scope **MUST** be a primary consideration during project planning

CIRCUIT ANALYSIS INTRODUCTION
Questions

Any questions before we start ???

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Circuit Analysis Basics

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CIRCUIT ANALYSIS BASICS
Objectives

- Provide the minimum level of information needed to understand the functionality of common circuits analyzed in the remainder of the course
- Focus on three common circuits
  - Solenoid operated valve
  - Motor operated valve
  - Circuit Breaker
- Present overviews of typical nuclear power plant electrical power distribution system

CIRCUIT ANALYSIS BASICS
Circuit Design Basics

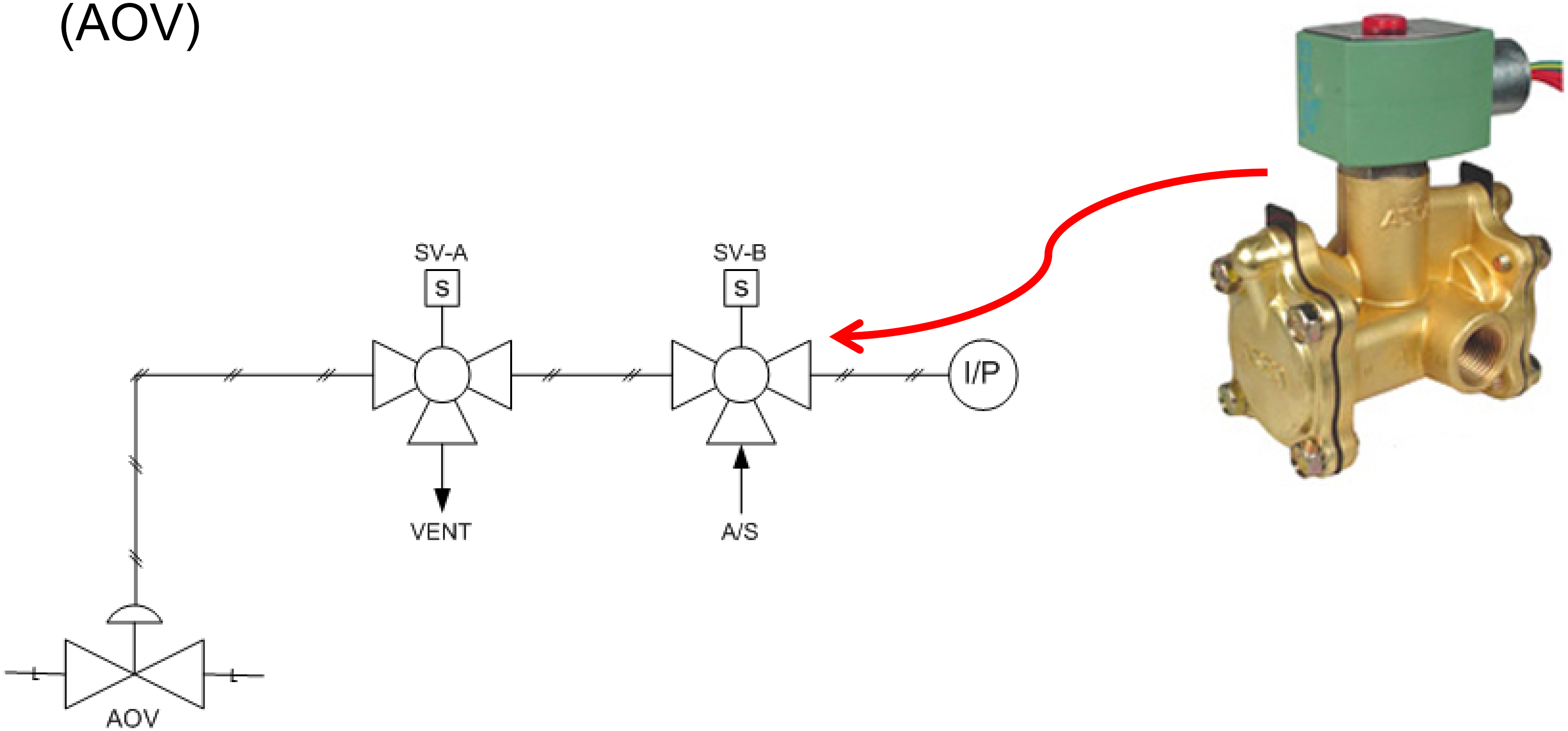
- Concepts
  - Typical Circuit Devices & Symbols
  - Types of Drawings and How to Read Them
  - General Conventions
  - Grounded vs. Ungrounded Circuits
  - ANSI/IEEE Standard Device Numbers

CIRCUIT ANALYSIS BASICS
Typical Circuit Devices & Symbols

- Circuit Breakers & Fuses
- Motor Starters & Contactors
- Relays & Contacts
- Terminal Blocks
- Control Power Transformers
- Actuating Coils
- Indicating Lamps & Alarms
- Switches
  - Control/Hand (maintained, momentary, spring-return to normal)
  - Limit & Torque
  - Sensors
  - Transfer & Isolation
  - Position

Solenoid Operated Valve (SOV)

- An SOV is an electromechanically operated device
  - Valve is controlled by electric current
  - Commonly used to control air operated valves (AOV)



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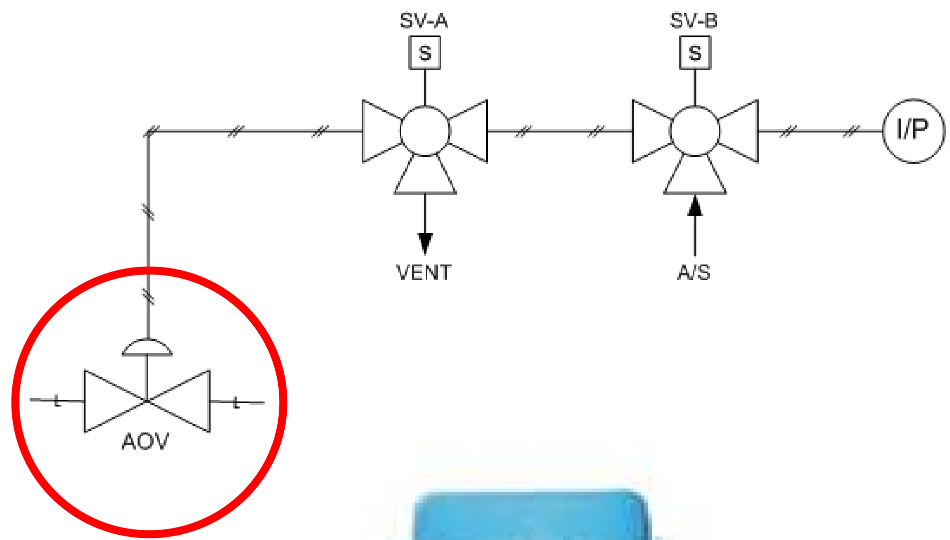
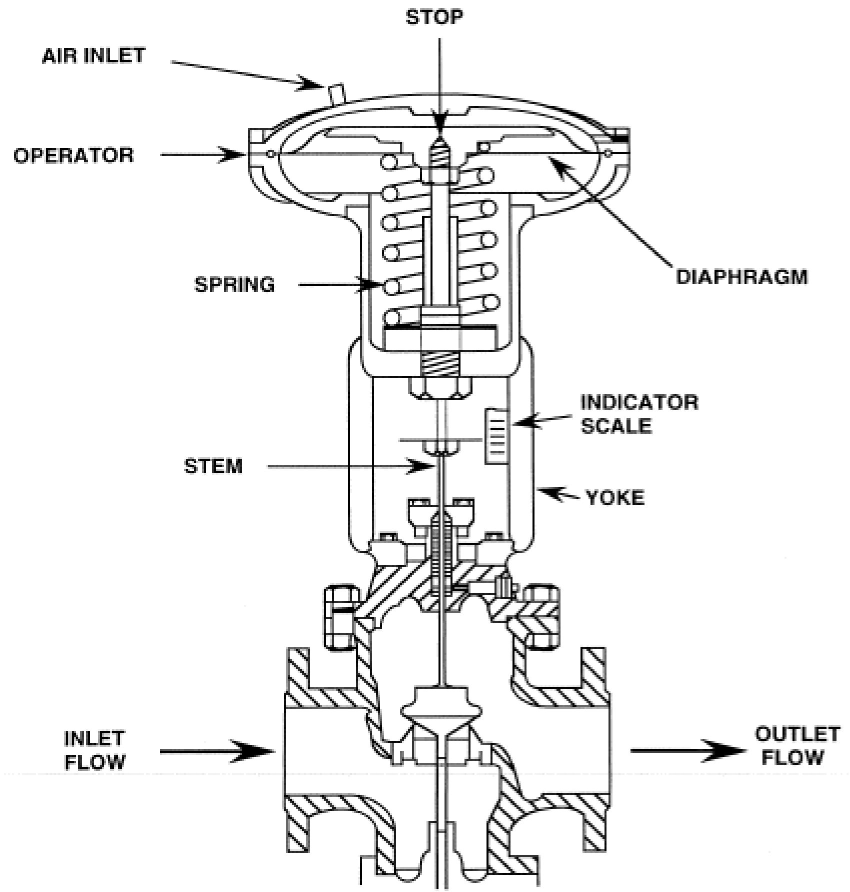
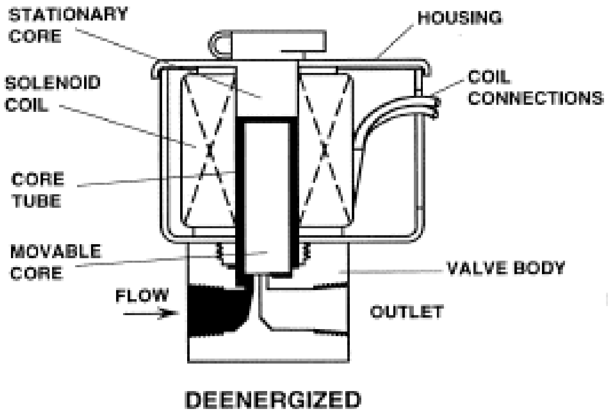
Air Operated Valve



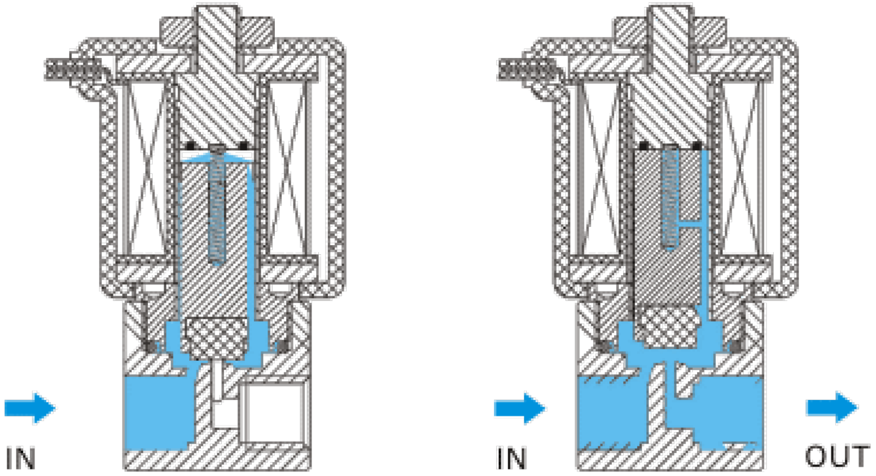


Where is the AOV in this picture?

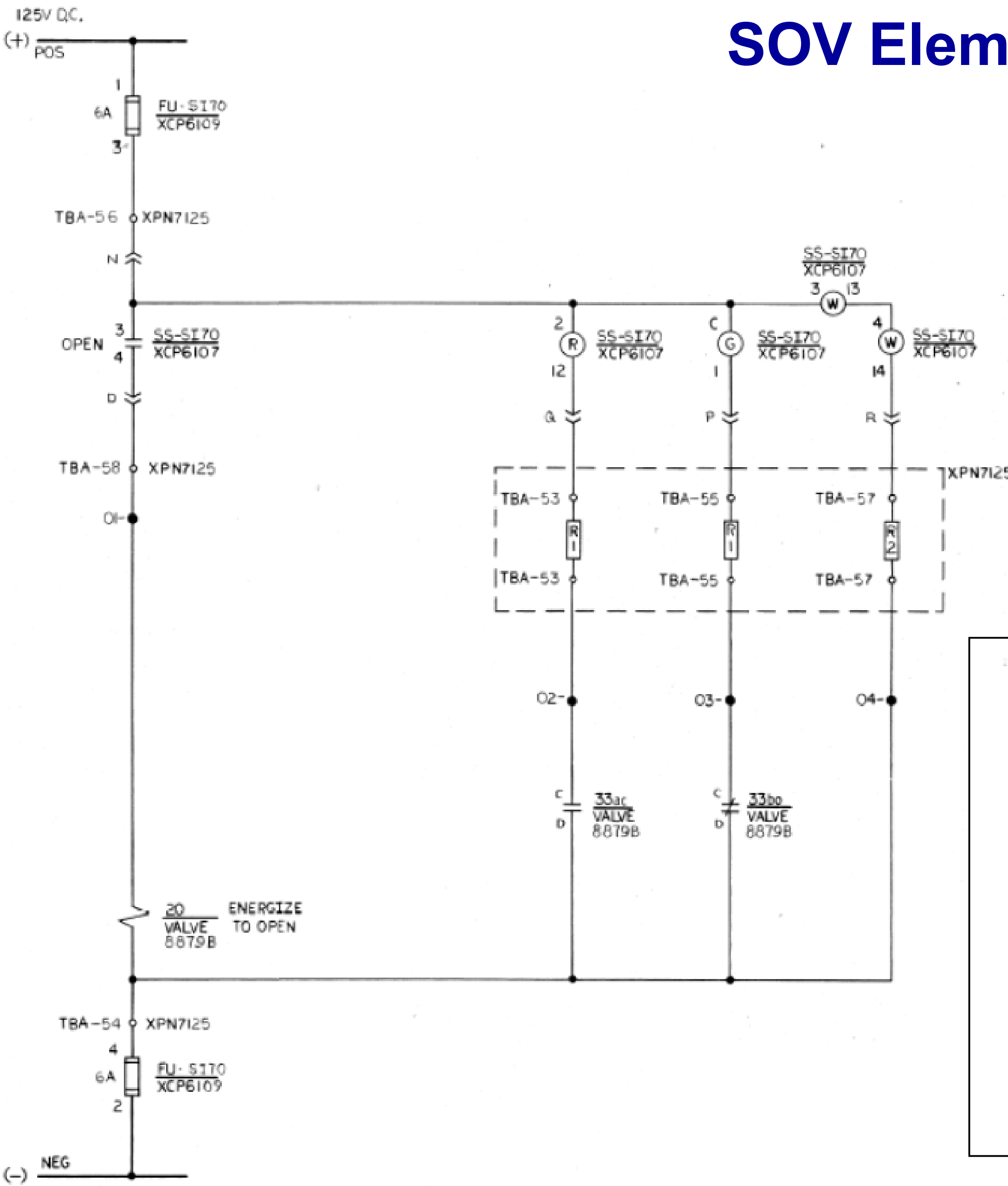
Direct Acting SOV

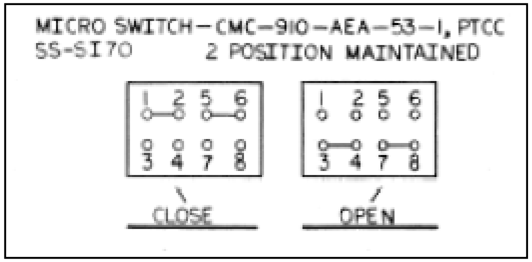


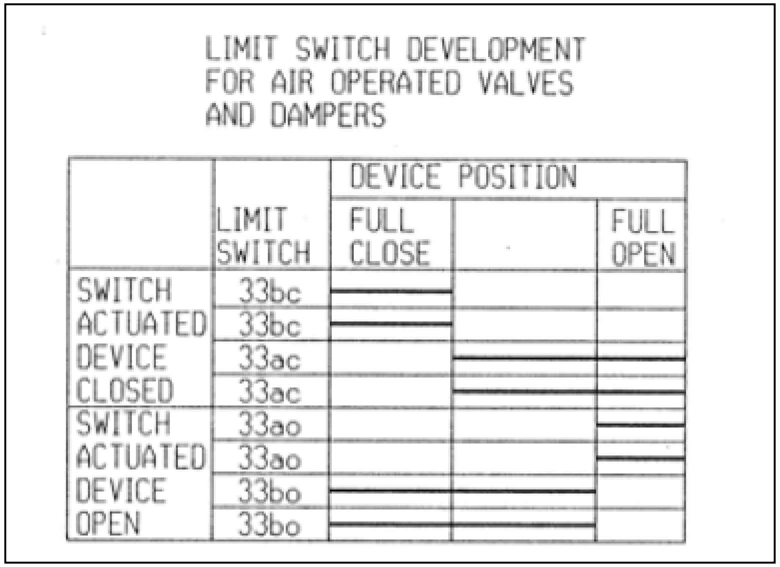
A. Direct-Acting Solenoid Valve



SOV Elementary Diagram







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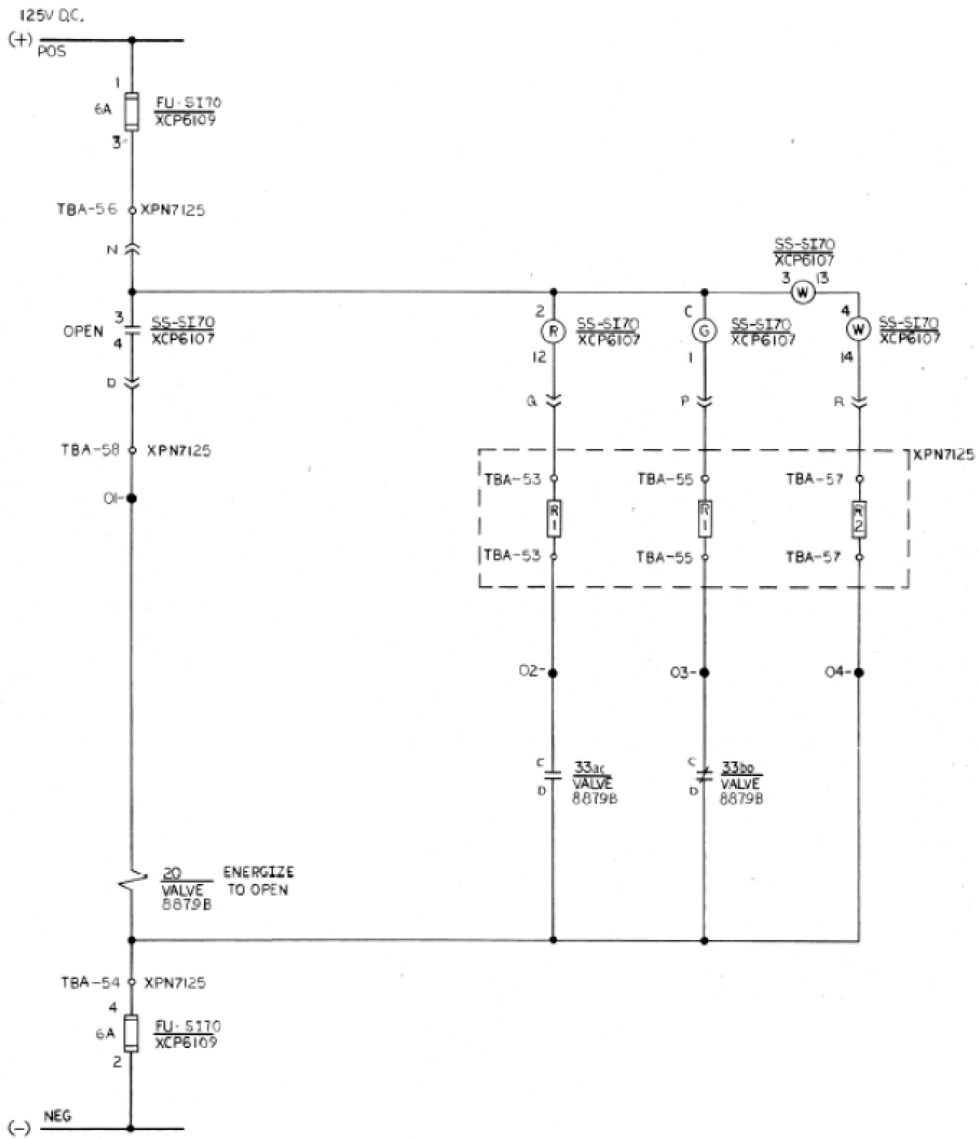
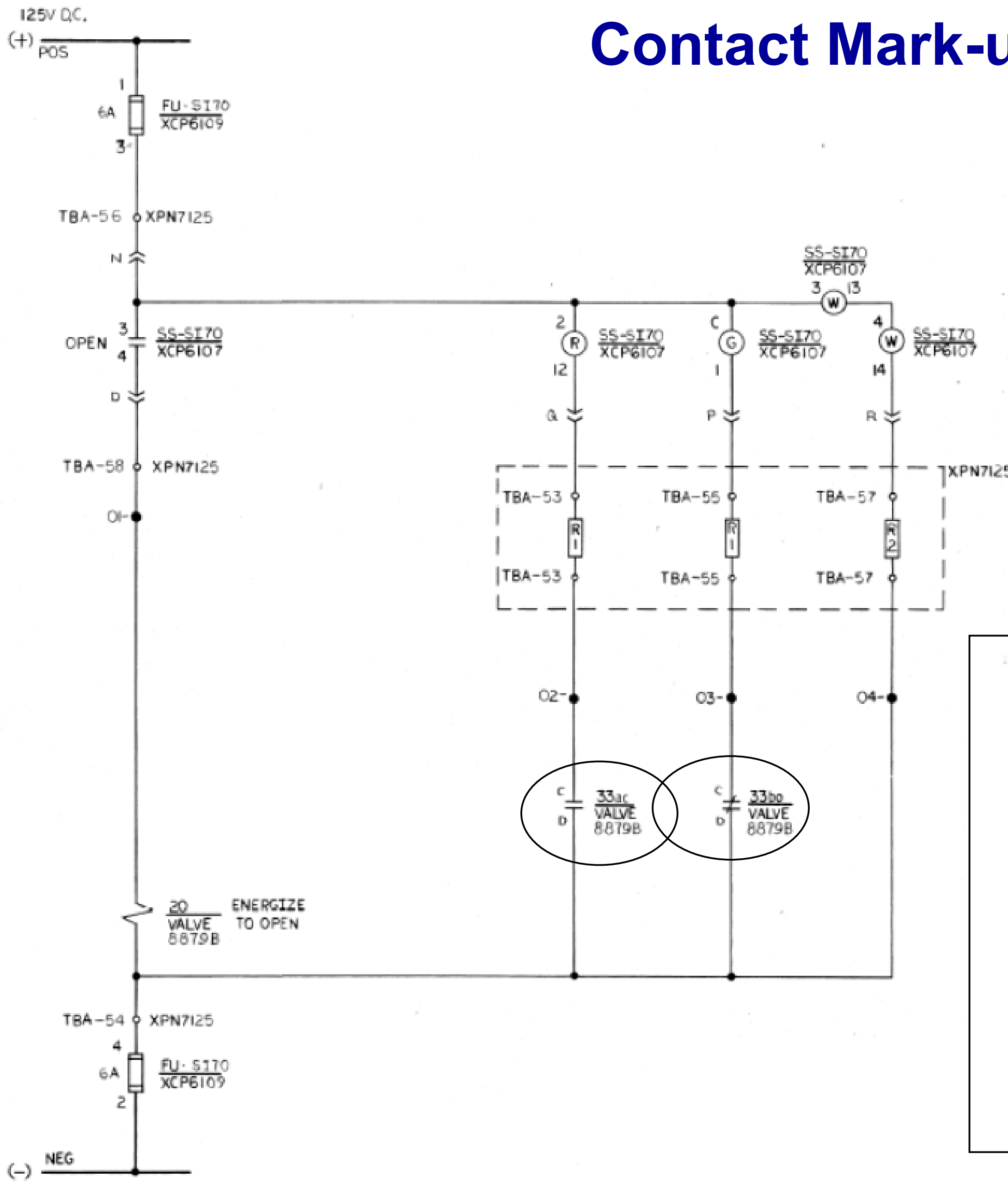
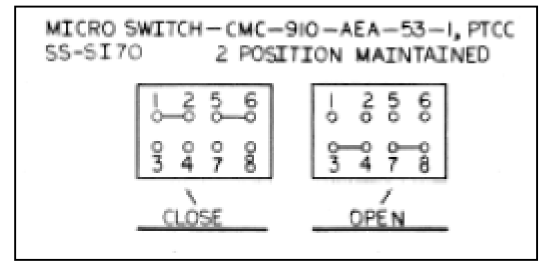
Lets Mark up Contacts

- Assume
  - Valve is initially
    - closed



Contact Mark-up

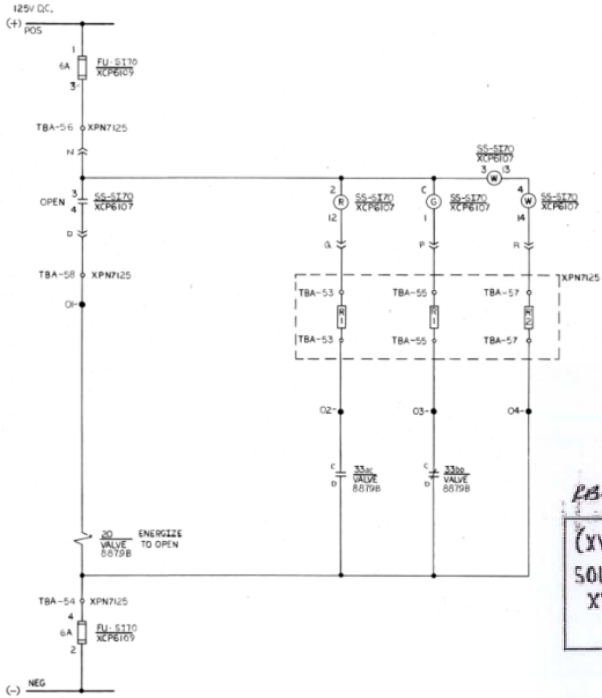


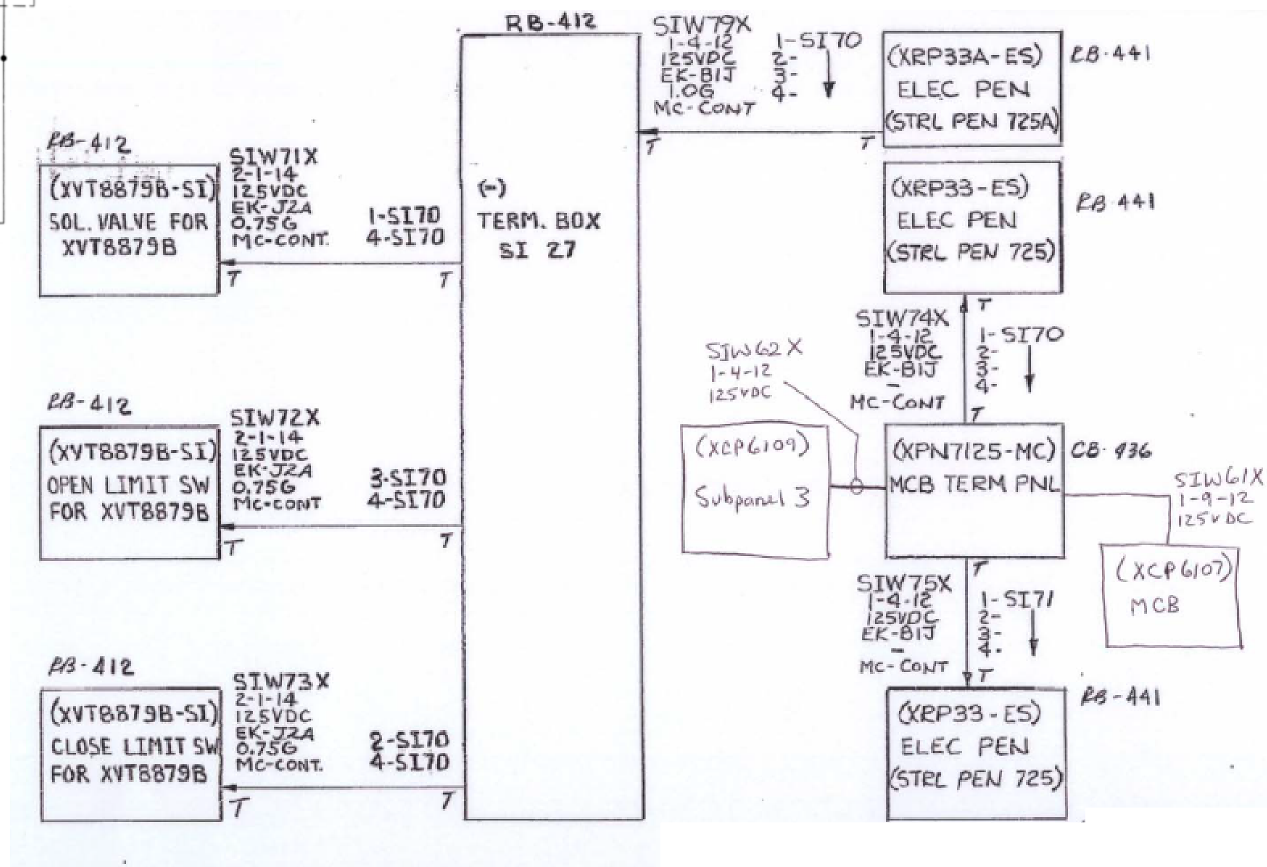


LIMIT SWITCH DEVELOPMENT
FOR AIR OPERATED VALVES
AND DAMPERS

	LIMIT SWITCH	DEVICE POSITION FULL CLOSE		FULL OPEN
SWITCH ACTUATED DEVICE CLOSED	33bc			
	33bc			
	33ac			
	33ac			
SWITCH ACTUATED DEVICE OPEN	33ao			
	33ao			
	33bo			
	33bo			

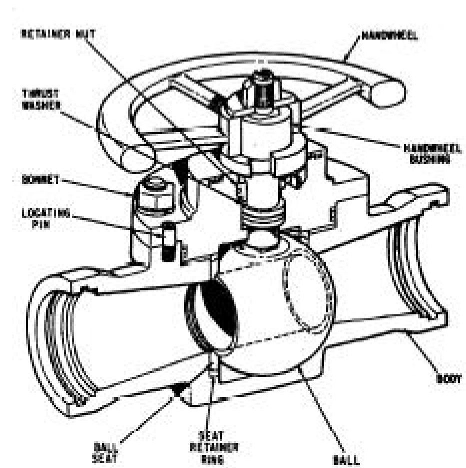
SOV Block Diagram



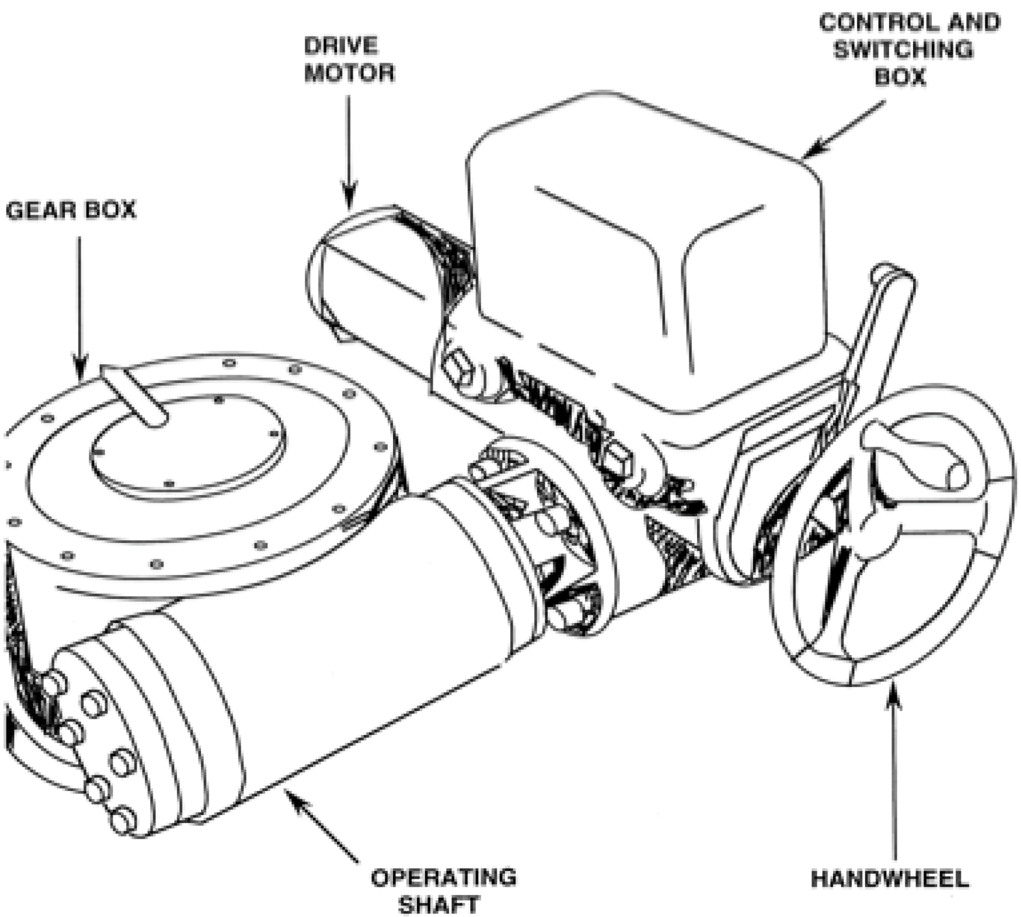


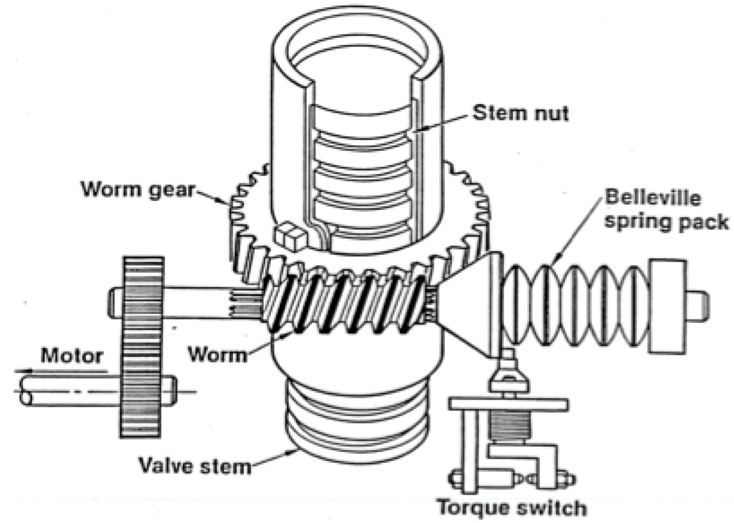
Motor Operated Valve

- A Motor Operated Valve (MOV) is a valve with an actuator driven by an electric motor
- MOVs typically serve an “On-Off” or “Open-Close” purpose
- MOVs are not typically used for throttling
- MOV valve types can include
  - Gate
  - Ball
  - Butterfly

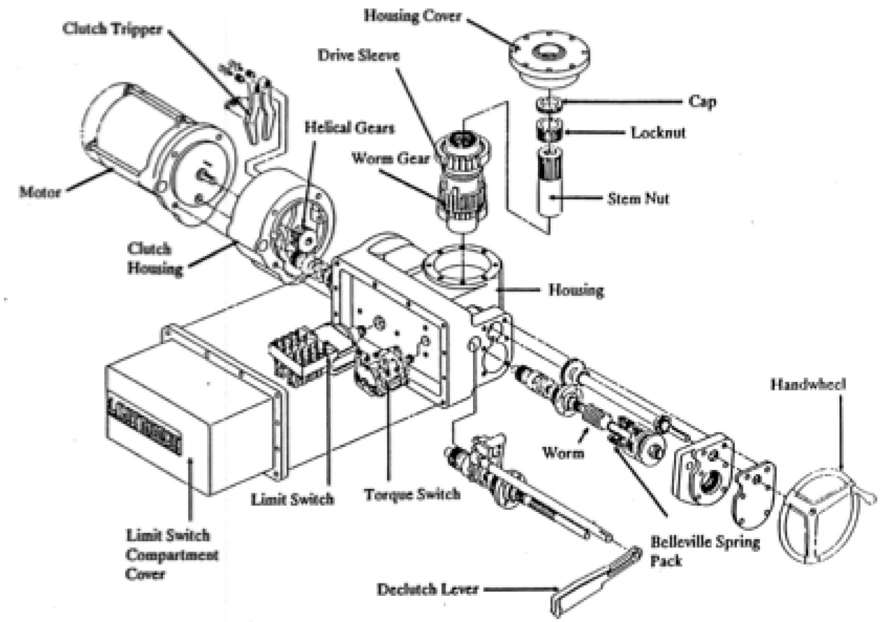


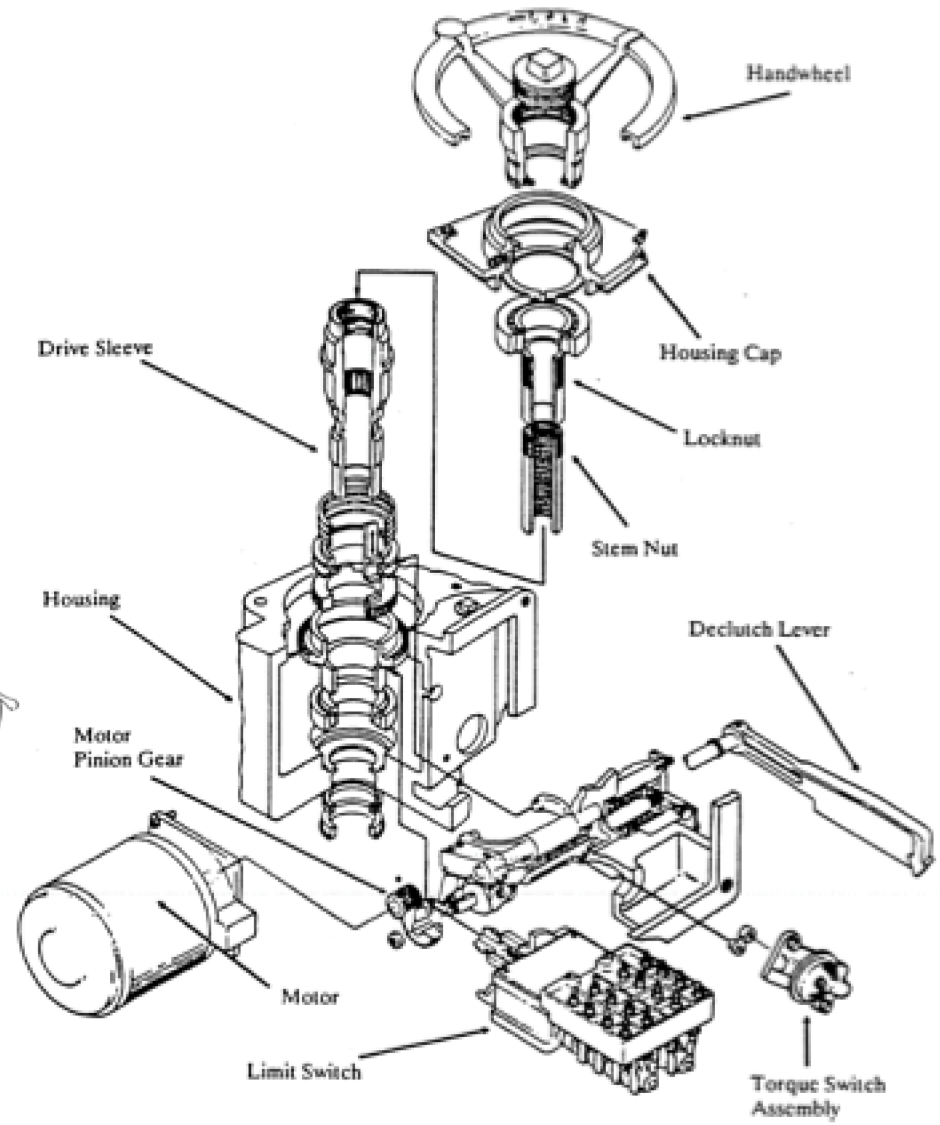
MOV Actuator





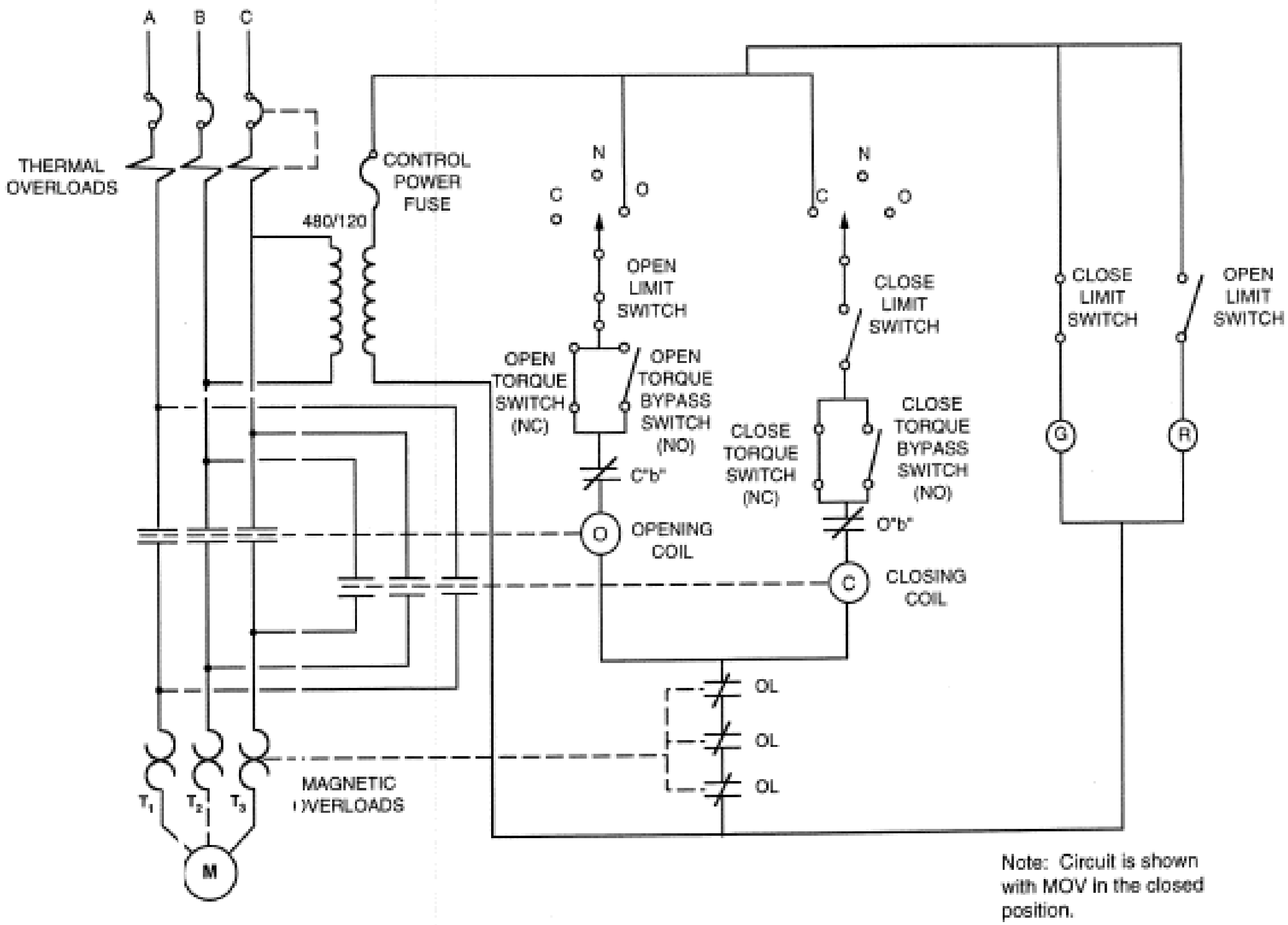
MOV Actuator (cont.)



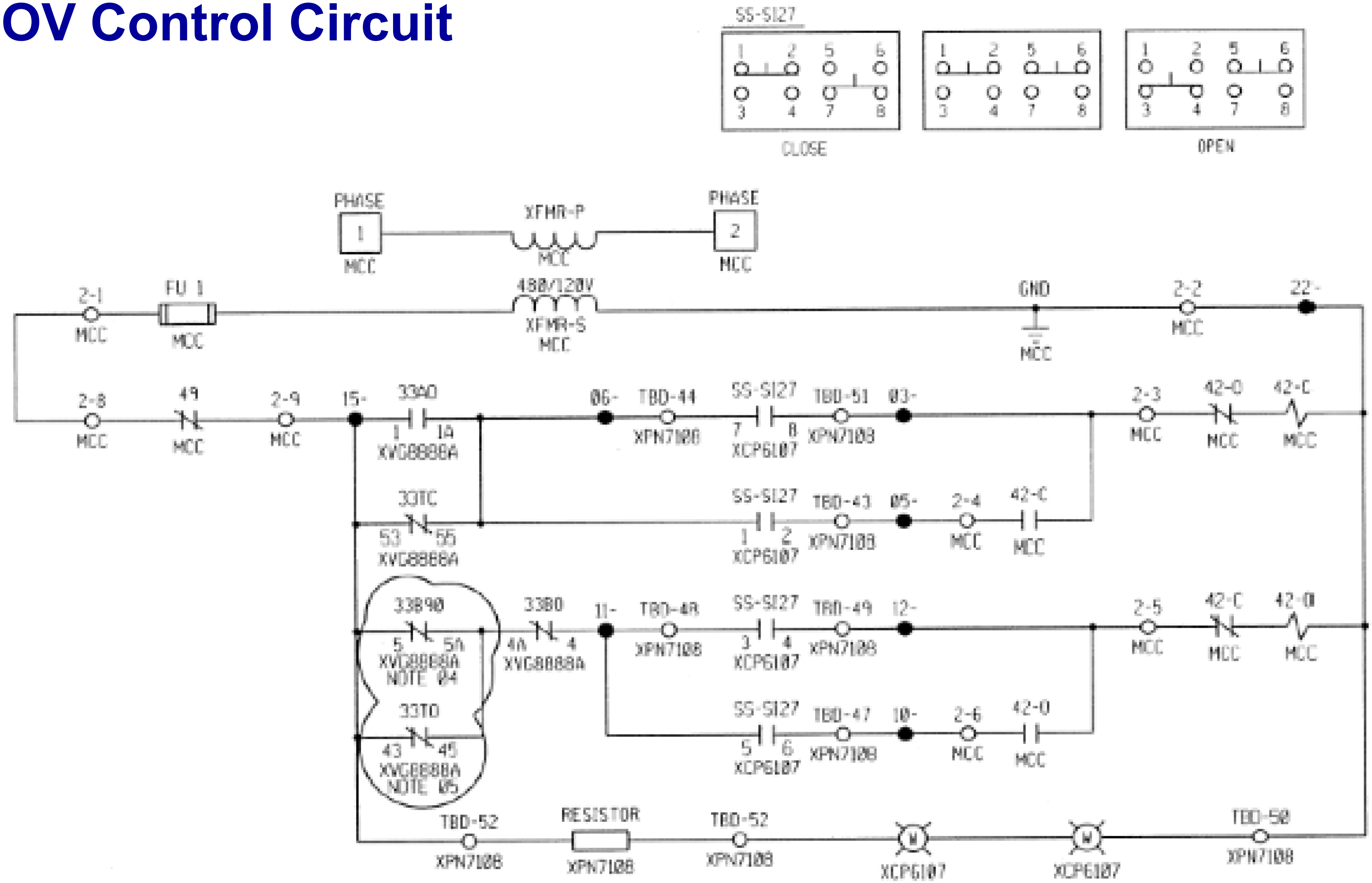


SMB-000 Limitorque Operator (Exploded View)

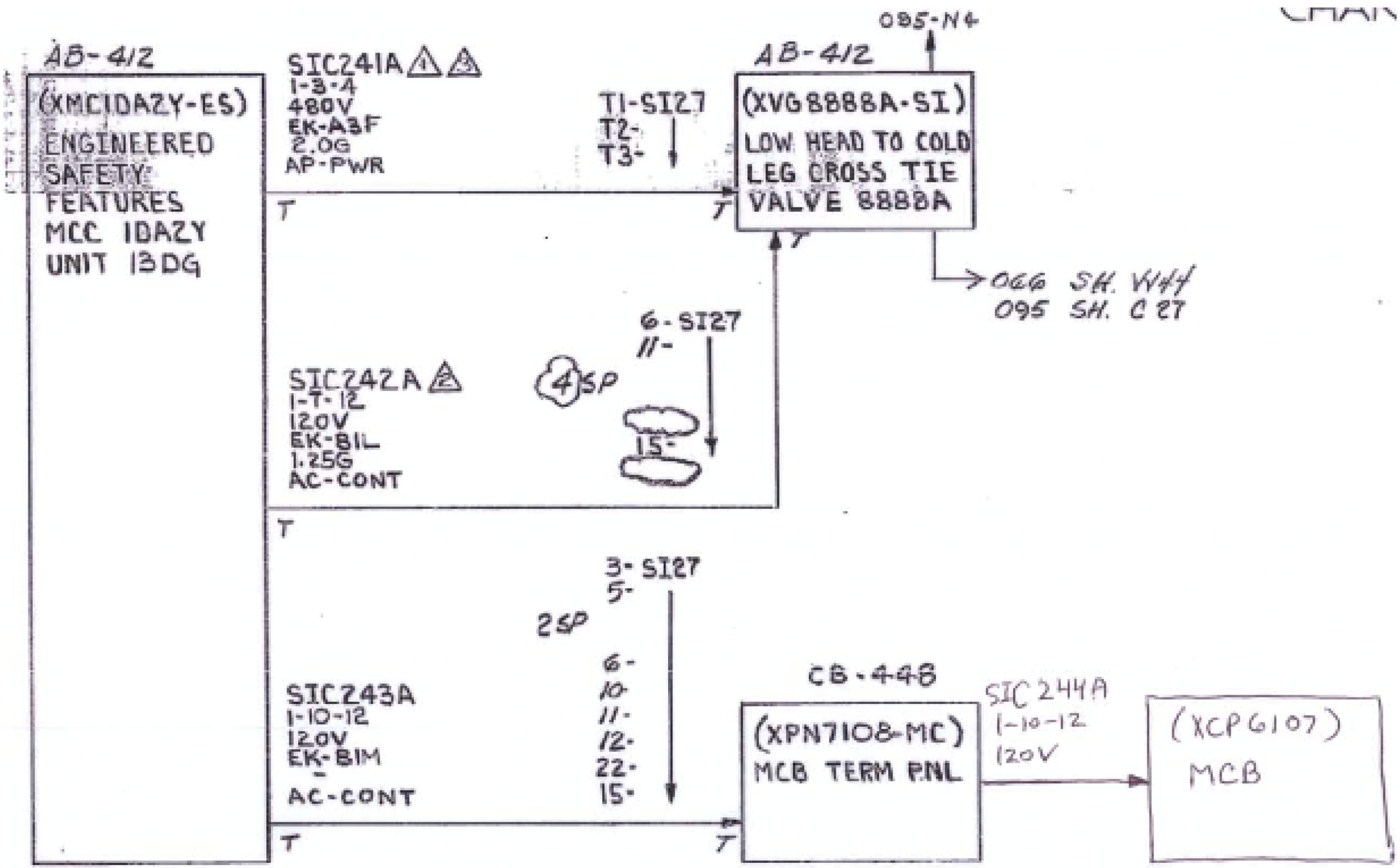
Simplified MOV circuit: Power vs. Control



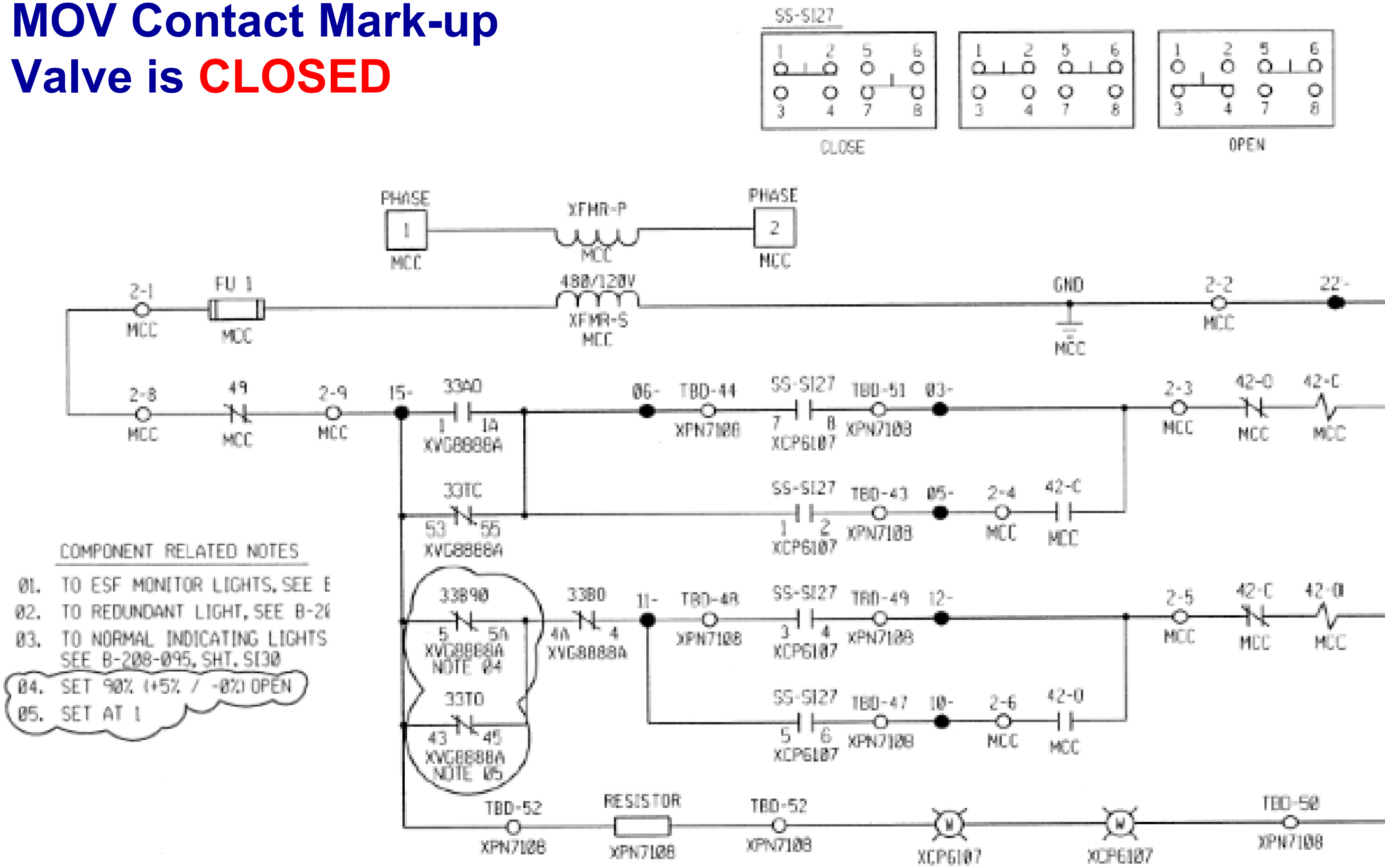
MOV Control Circuit



MOV Block Diagram



MOV Contact Mark-up
Valve is CLOSED



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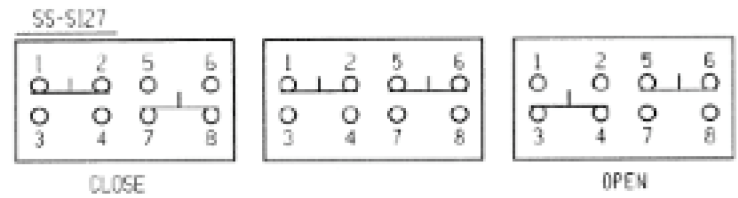
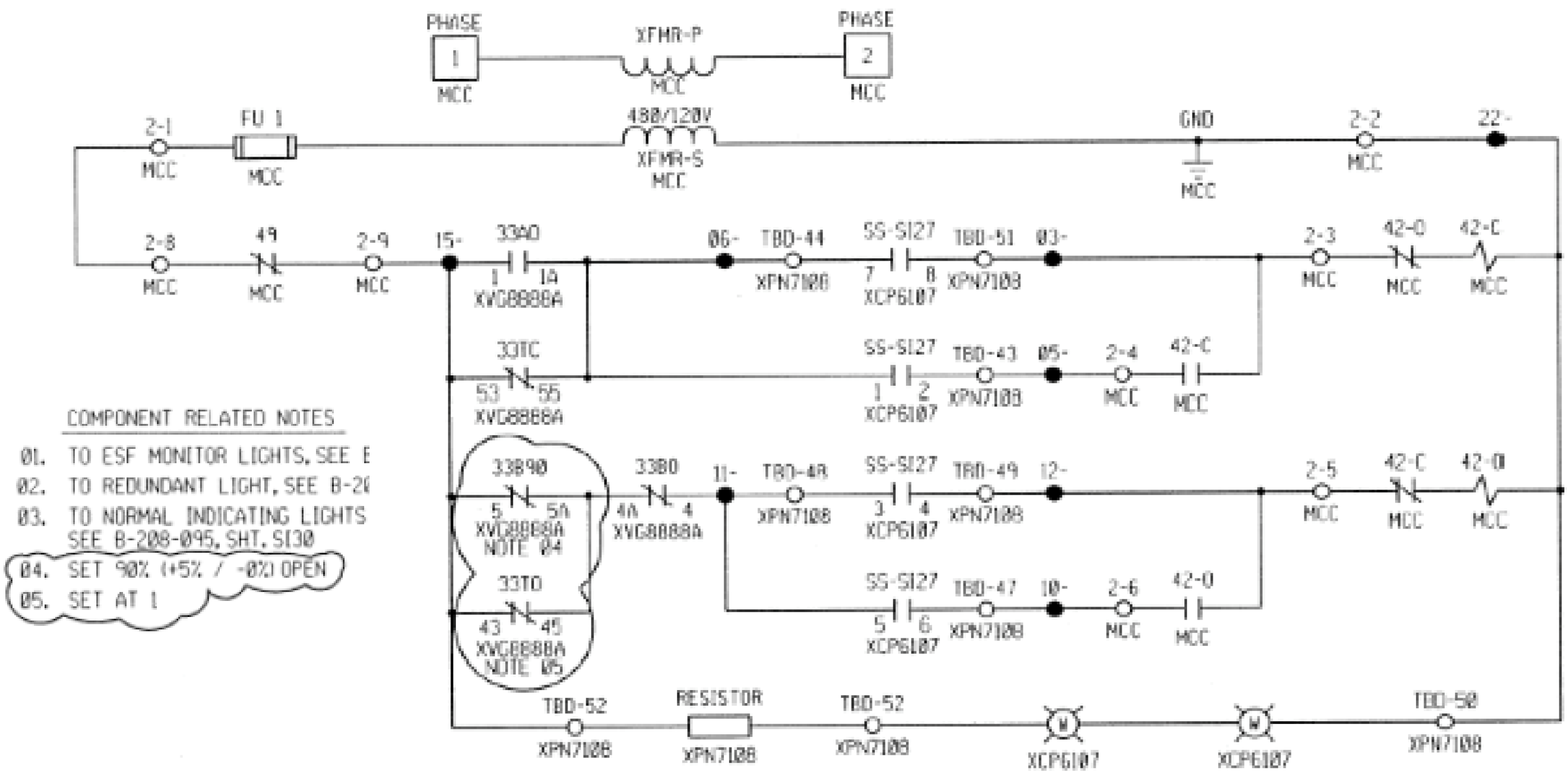
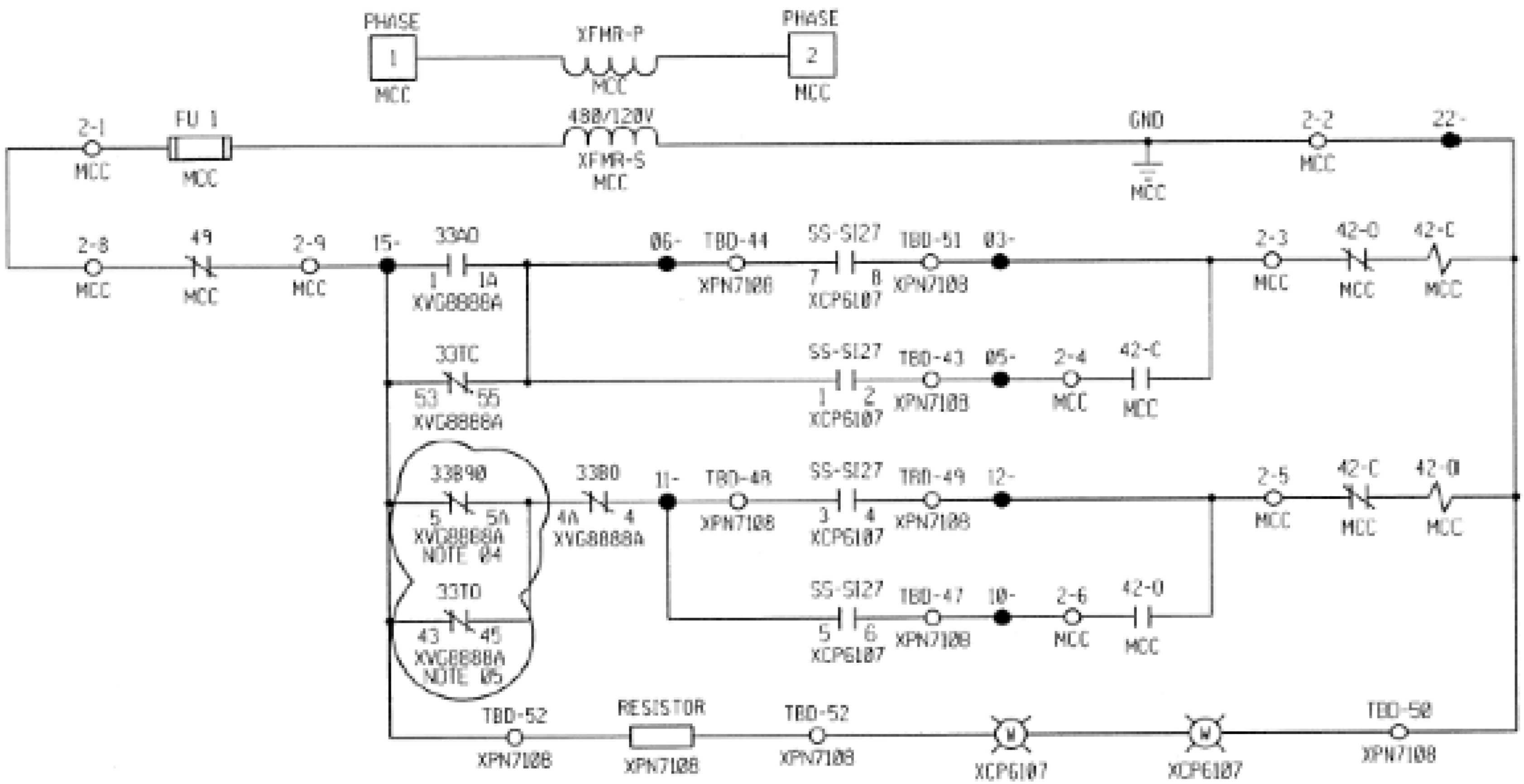
Valve Closed, Now Operator Opens Valve





MOV Contact Mark-up
Valve is OPEN

Refer to handouts!!!



CIRCUIT FAILURE MODE LIKELIHOOD ANALYSIS
Questions

Any Questions?

Circuit Breaker

- Refer to Handouts

Module II – Circuit Analysis

Circuit Analysis Basics
Cable and Circuit Failure Modes

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CABLE AND CIRCUIT FAILURE MODES
Objectives

- Review circuit design parameters that influence cable/circuit failure modes and resultant equipment functional impacts
- Review fire-induced cable failures and the manifestation of different failures for various circuit types
- Review the concepts and engineering principles behind fire-induced cable failures
- Identify credible and non-credible failure modes based on NUREG/CR-7150 results
- Discuss practical aspects of performing circuit analysis for the wide variety of possible failure modes
- Focus on hot-short induced spurious operations

CABLE AND CIRCUIT FAILURE MODES
What are we going to cover?

- Definitions
- Circuit Design Parameters and Conventions
- Grounding Configurations
- Cable Fault Modes
- Circuit Failure Modes - Control Circuit
- Circuit Failure Modes - Special Cases
- Influence Parameters
  - Spurious Operation Likelihood
  - Spurious Operation Duration
- Complex Applications

CABLE AND CIRCUIT FAILURE MODES
Definitions

- Precise use of definitions is important to avoid misinterpretations and misapplications
- Surprisingly high number of people that still carry misconceptions and legacy issues
- Need to have clear understanding of key definitions to make full use of this course

CABLE AND CIRCUIT FAILURE MODES
Definitions (continued)

Available Short-Circuit Current – The maximum current that the power system can deliver through a given circuit point to any negligible impedance short circuit applied at the given point, or at any other point that will cause the highest current to flow through the given point.

Bolted Fault – The highest magnitude short circuit current for a particular fault location. The impedance at the fault location is typically very low or zero for a bolted fault.

Cable Fire Damage – If a cable is exposed to a fire (i.e., in the form of a plume, hot gas layer, flame, and/or radiant heating), damage to the cable may occur progressively from a base state of initial heating up to an end state of complete cable burn up.

Cable Failure Modes – The mode by which a conductor or cable fails due to a fire. The following are general circuit failure modes of interest:

CABLE AND CIRCUIT FAILURE MODES
Definitions (continued)

- **Open Circuit** – A fire-induced break in a conductor resulting in a loss of circuit continuity.

  Note: NUREG/CR-6850 does not require consideration of open circuits as a primary cable failure mode. However, in the interest of consistency with the existing Appendix R circuit analyses, open circuits will be considered as a credible failure mode.

- **Short-to-Ground** – A fire-induced breakdown of a cable's insulation system resulting in the potential of a conductor being applied to a grounded medium. The grounding medium refers to any conduction path associated with the reference ground of the circuit or earth ground. This might include structural elements (tray, conduit, enclosures, metal beams, etc.) or intentionally grounded conductors of the circuit (neutral conductor). Ground may be either earth ground or reference ground. Note that for ungrounded systems, a single short to earth ground will not cause fault current to flow. For grounded circuits, reference ground and earth ground are one in the same.

CABLE AND CIRCUIT FAILURE MODES
Definitions (continued)

Hot Short – A fire-induced insulation breakdown between conductors of the same cable, a different cable or from some other external source resulting in a compatible but undesired impressed voltage or signal from one conductor (source conductor) to one or more different conductors (target conductor). Within the context of fire-induced faults, the target conductor is assumed to be an ungrounded conductor.

Note: A hot short is characterized by an abnormal connection between conductors that does not produce a high fault current because of inherent impedance in the connection path attributable to circuit components. A defining characteristic of a hot short is that it is not detectable by normal circuit protective devices and thus will not trigger an overcurrent protective action. A hot short has the potential to cause undesired energization of components connected to the target conductor (i.e., spurious operation); however, the term hot short is not synonymous with the term spurious operation.

NUREG/CR-7150 – Fire-induced hot shorts: Individual conductors of the same or different cables that come in contact with each other and that may result in an impressed voltage or current on the circuit being analyzed (definition per Regulatory Guide 1.189).

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CABLE AND CIRCUIT FAILURE MODES
Definitions (continued)

- **High Impedance Fault** – A fire induced partial breakdown of a cable's insulation resulting in an abnormal but high resistance short-circuit between two or more conductors in which ground may or may not be involved. This failure more results in partial diversion of the available electrical energy and may not be detected by overcurrent protective devices.

- **Multiple High Impedance Fault(s)** – A condition where multiple circuits fed from a single power distribution source each have a high impedance fault.

- **Line-to-Line Fault** – A fault generally involving a three-phase power system in which conductors from two or more phases make contact and result in abnormal current flow. Unlike hot shorts, line-to-line faults cause high fault currents, which are generally detectable by circuit overcurrent devices.

CABLE AND CIRCUIT FAILURE MODES
Definitions (continued)

- **Conductor-to-Conductor Short** – An abnormal connection (including an arc) of relatively low impedance between two conductors. A conductor-to-conductor short between an energized conductor of a grounded circuit and a grounded conductor results in a ground fault. A conductor-to-conductor short between an energized conductor and a non-grounded or neutral conductor results in a hot short. Conductor-to-conductor shorts between an energized conductor of an ungrounded circuit and the reference ground or neutral conductor(s) has the same functional impact as a ground fault.

- **Three-Phase Bolted Fault** – A fault in which all three phases short with zero impedance. A three-phase bolted fault produces the highest short circuit currents in virtually all electrical power distribution systems. Most short circuit studies conducted to determine maximum available short circuit currents are based on three-phase bolted faults.

CABLE AND CIRCUIT FAILURE MODES
Definitions (continued)

Circuit Failure Mode – The manner in which a conductor fault is manifested in the circuit. Circuit failure modes include loss of motive power, loss of control, loss of or false indication, open circuit conditions (e.g., a blown fuse or open circuit protective device), and spurious operation.

Coordination – The application of overcurrent protective devices in series such that (of the devices carrying fault current) only the device nearest the fault will open and the devices closer to the source will remain closed and carry the remaining load.

Overcurrent – A current that exceeds a continuous current rating, including overloads, short circuits, and ground faults.

Overcurrent Protection – A form of protection that operates when current exceeds a predetermined value.

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CABLE AND CIRCUIT FAILURE MODES
Definitions (continued)

Off-Scheme Circuits/Cable – Circuitry and cables located off of the primary component scheme (e.g., interlock and permissive circuitry that could actuate contacts on the component of concern or otherwise prevent proper operation of the component).

Active Component Function – A component whose credited function requires the component to actively change state(s) or operate to accomplish the credited PRA function. This type of component includes power-operated valves that must change positions, motors that must run, electrical power supplies and their switching devices, and process monitoring instruments. Note that some components may perform both active and passive functions, depending upon the Basic Events associated with the component.

Passive Component Function – A component whose credited function does not require motive or control power for the component to accomplish the function.

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CABLE AND CIRCUIT FAILURE MODES
Definitions (continued)

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

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

Required Cables – The set of cables that must remain free of fire damage to ensure that the subject component can perform all of its required functions from the control room or emergency control station. Cables that are associated circuits by spurious actuation and/or associated circuits by common power supply are also considered required cables since these cables can also affect proper performance of credited systems or equipment.

Source Cable or Source Conductor – A cable or conductor that is energized (e.g., before the fire) and is therefore capable of producing a hot short should it come in contact with a target conductor(s).

CABLE AND CIRCUIT FAILURE MODES
Definitions (continued)

Target Cable or Target Conductor – A cable or conductor (initially energized or not) that, if energized by contact with an appropriate source cable or conductor, would lead to a hot short and possibly a spurious operation if the target cable or conductor was associated with equipment or device(s) that would spurious operate.

Hot Short-Induced Spurious Operations – A circuit fault mode wherein an operational mode of the circuit is initiated (in full or in part) due to failure(s) in one or more components (including cables) of the circuit. For example, a pump (starting or stopping) or a valve spuriously repositioning.

> *NOTE: The PIRT panel defined this based on the definition of spurious actuation in RG 1.189 (Ref. 16), "The undesired operation of equipment, considering all possible functional states, resulting from a fire that could affect the capability to achieve and maintain safe-shutdown."*

CABLE AND CIRCUIT FAILURE MODES
Definitions (continued)

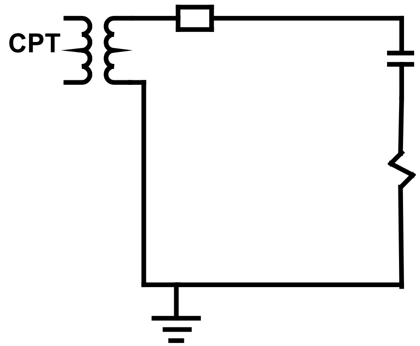
Incredible – The term "incredible" when used in conjunction with a fire-induced circuit failure phenomenon, is used to support the PIRT panel's conclusion that the phenomenon cannot occur. In these cases, the PIRT panel could find no evidence of the phenomenon ever occurring, and there was no credible technical argument to support its occurrence during a fire. Any probabilistic numbers assigned to these types of phenomena would have little meaning.

Implausible – The term "implausible" when used in conjunction with a fire-induced circuit failure phenomenon, is used to support the PIRT panel's conclusion that the phenomenon, while possible in theory, 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 in operating experience or during a fire test. Any likelihood value assigned to these types of phenomena would not be meaningful.

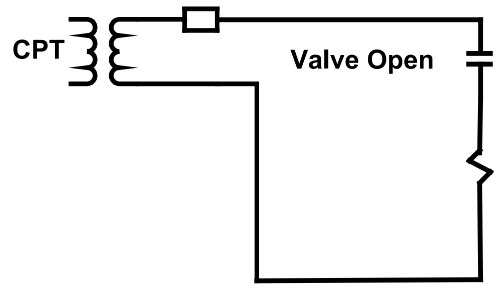
CABLE AND CIRCUIT FAILURE MODES
General Conventions

- Polarity – AC & DC Circuits
- 3-Phase vs. Single-Phase Power
- Delta vs. Wye Connected Circuits
- Normally Open vs. Normally Closed Contacts
- Conductor, Cable, & Raceway IDs
- Electrical vs. Physical Connectivity

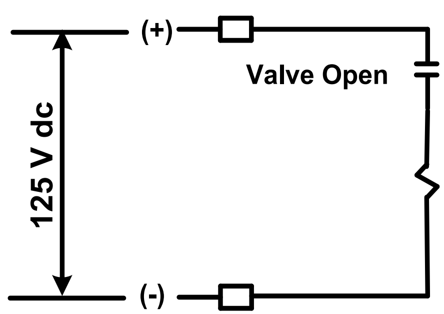
CABLE AND CIRCUIT FAILURE MODES
Circuit Design Basic Configurations



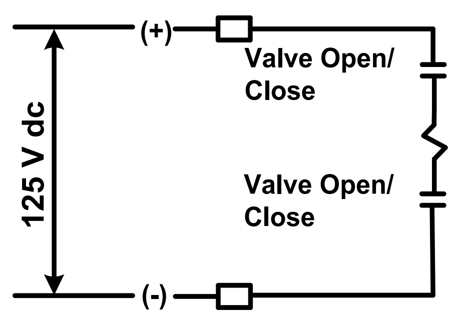
Grounded AC



Ungrounded AC



Ungrounded DC
[or 120 V ac Distributed]



Ungrounded DC
[or 120 V ac Distributed System]

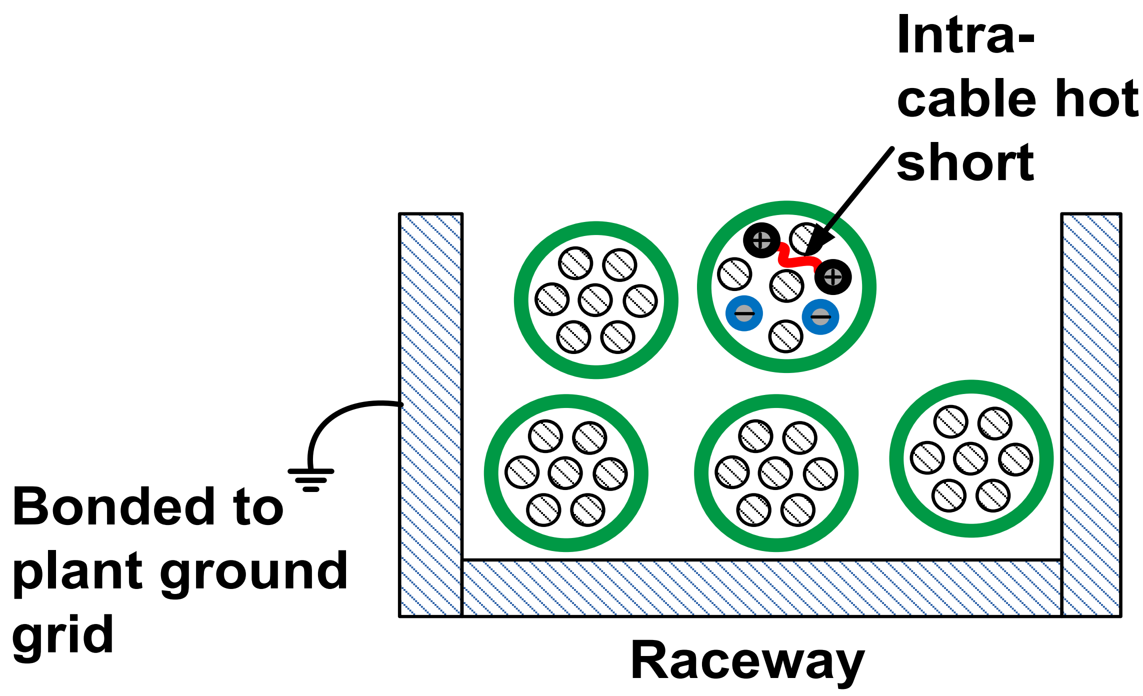
CABLE AND CIRCUIT FAILURE MODES
Grounded vs. Ungrounded Circuits

- How can you tell?
- Why one or the other?
- Advantages & disadvantages
- Affect during normal circuit operation?
- Affect during abnormal circuit operation?
- Where will you likely see in practice?
- Types of grounding
  - Solid
  - High Impedance or Resistance
  - Low Impedance or Resistance
- Where is ground point established?
- Why do we care so much about grounding?

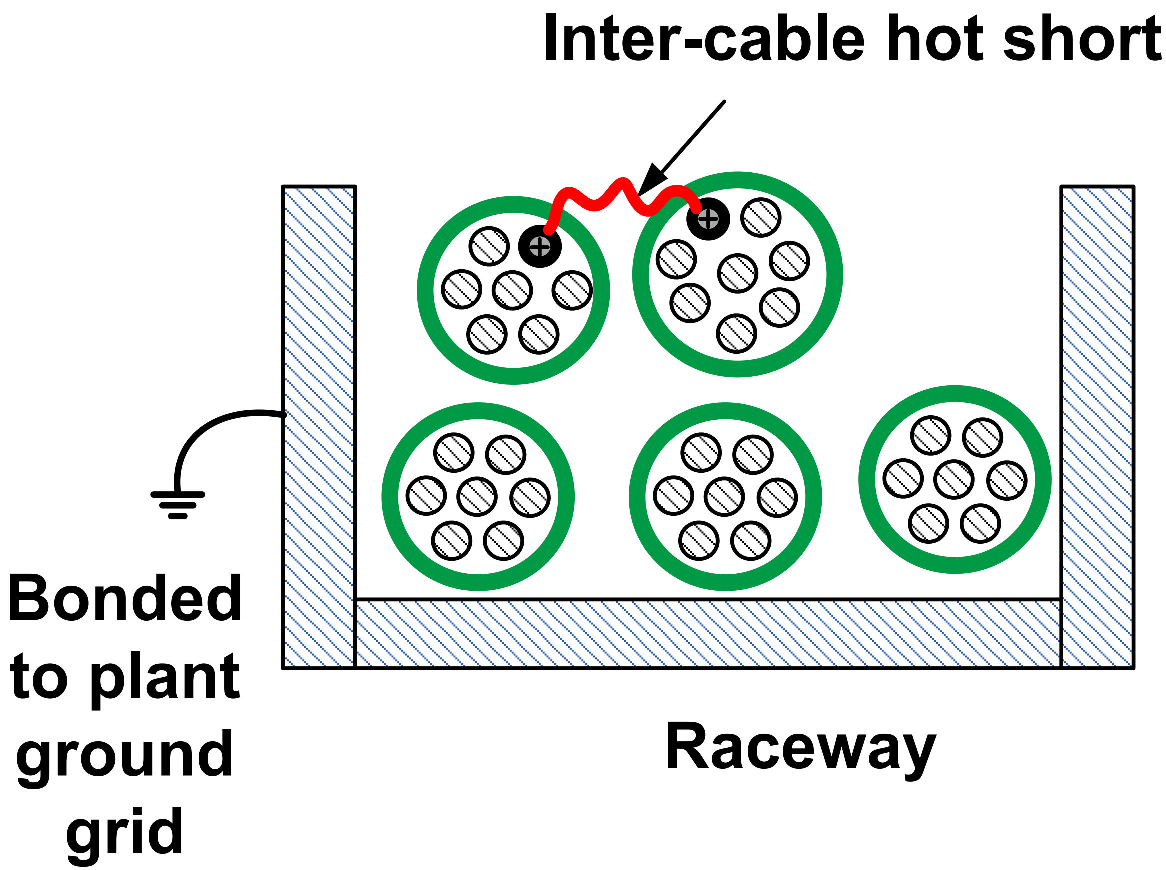
CABLE AND CIRCUIT FAILURE MODES
Fault Modes

- Open Circuit
- Short-to-Ground
- Hot Short
  - Proper Polarity Hot Short
  - Multiple Hot Shorts
    - Independent Circuits
    - Dependent Circuits
  - Ground Equivalent Hot Shorts
  - Three Phase Hot Shorts
- Inter-Cable & Intra-Cable

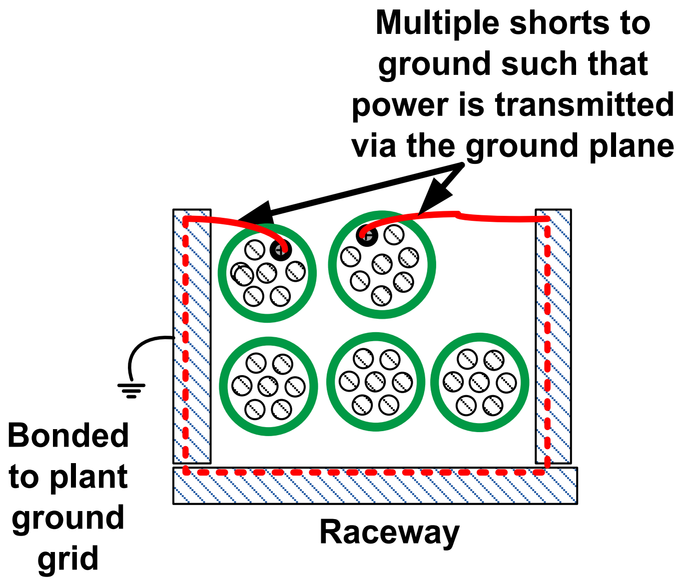
Intra-Cable Hot Short

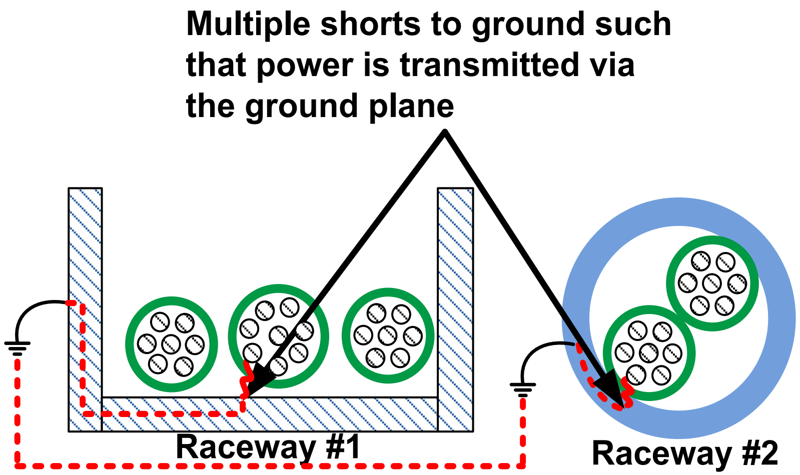


Inter-Cable Hot Short

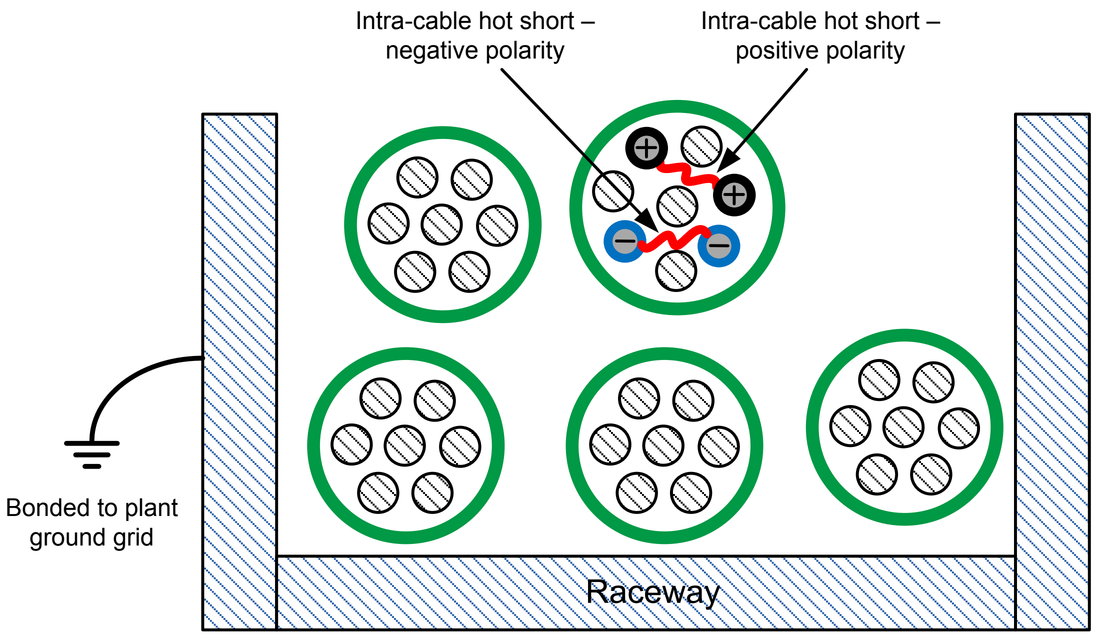


Ground Fault Equivalent Hot Short



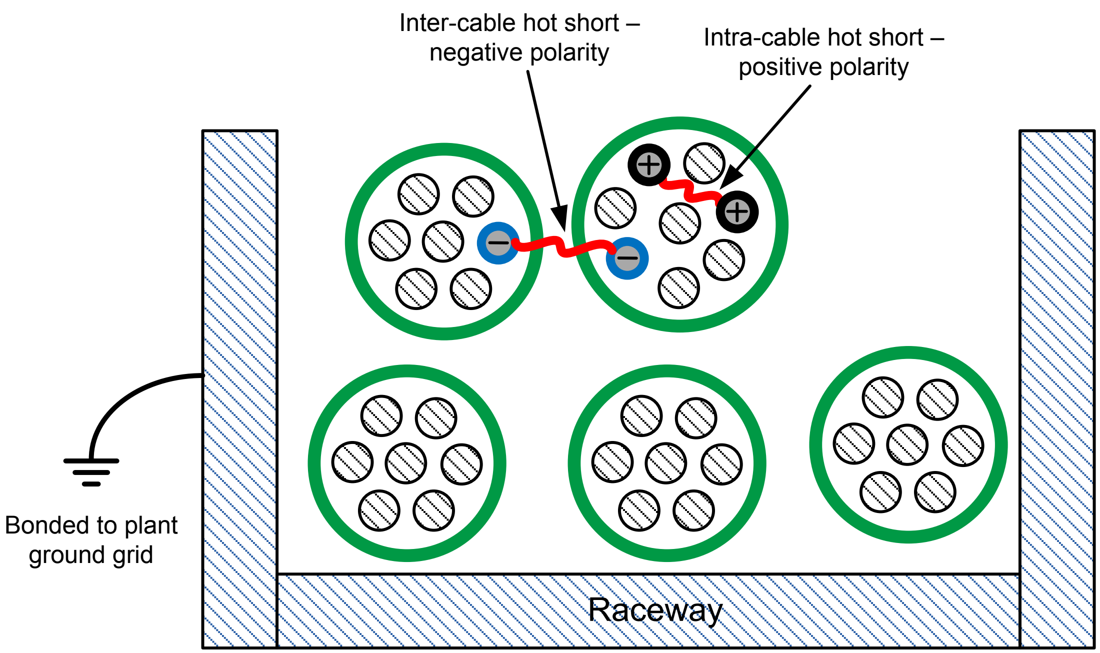


Proper Polarity Hot Short – Intra / Intra



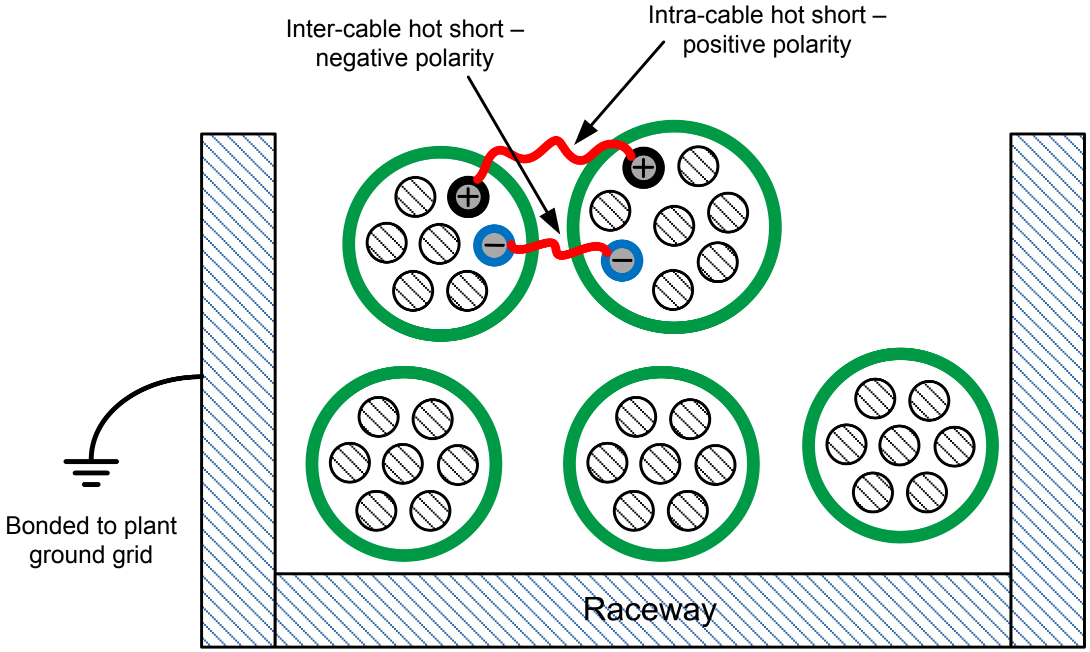
CASE 1:
Proper polarity hot shorts are the result of selective shorts betweens same polarity conductors within a single cable.

Proper Polarity Hot Short – Intra / Inter



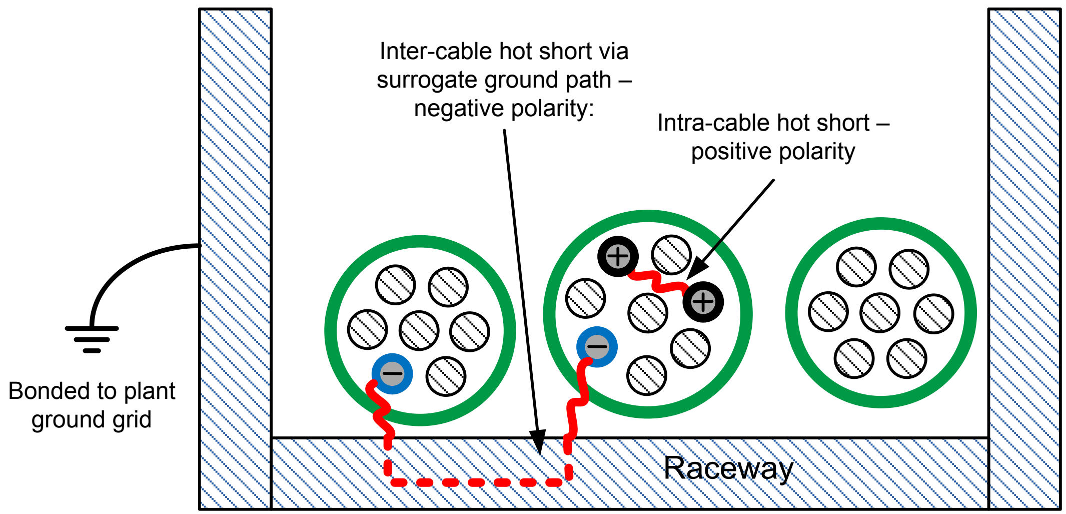
CASE 2A:
Proper polarity hot shorts are the result of one intra-cable short and one inter-cable short.

Proper Polarity Hot Short – Inter / Inter



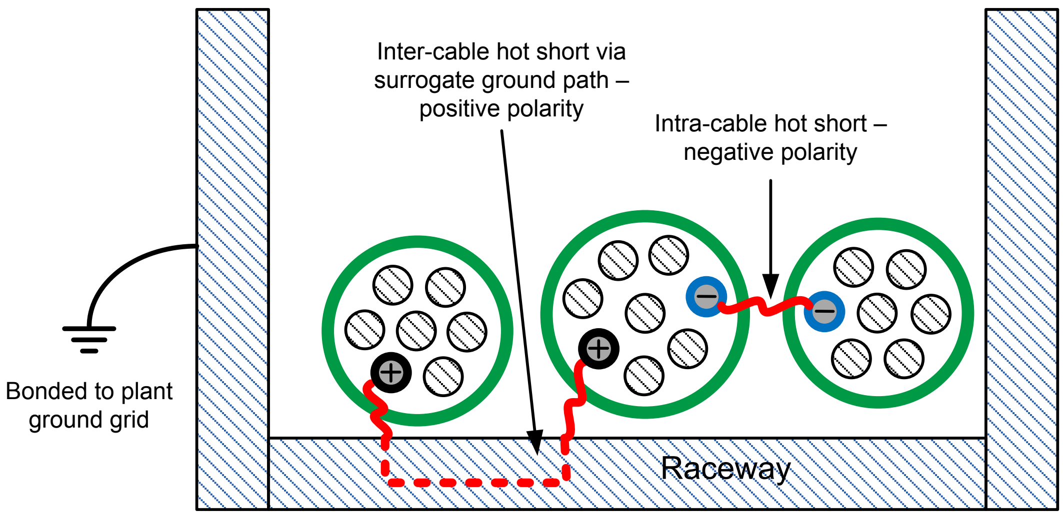
CASE 3A:
Proper polarity hot shorts are the result of two independent inter-cable shorts involving the proper polarity. The inter-cable shorts do not need to be between the same cables.

Proper Polarity Hot Short – Intra / GFE



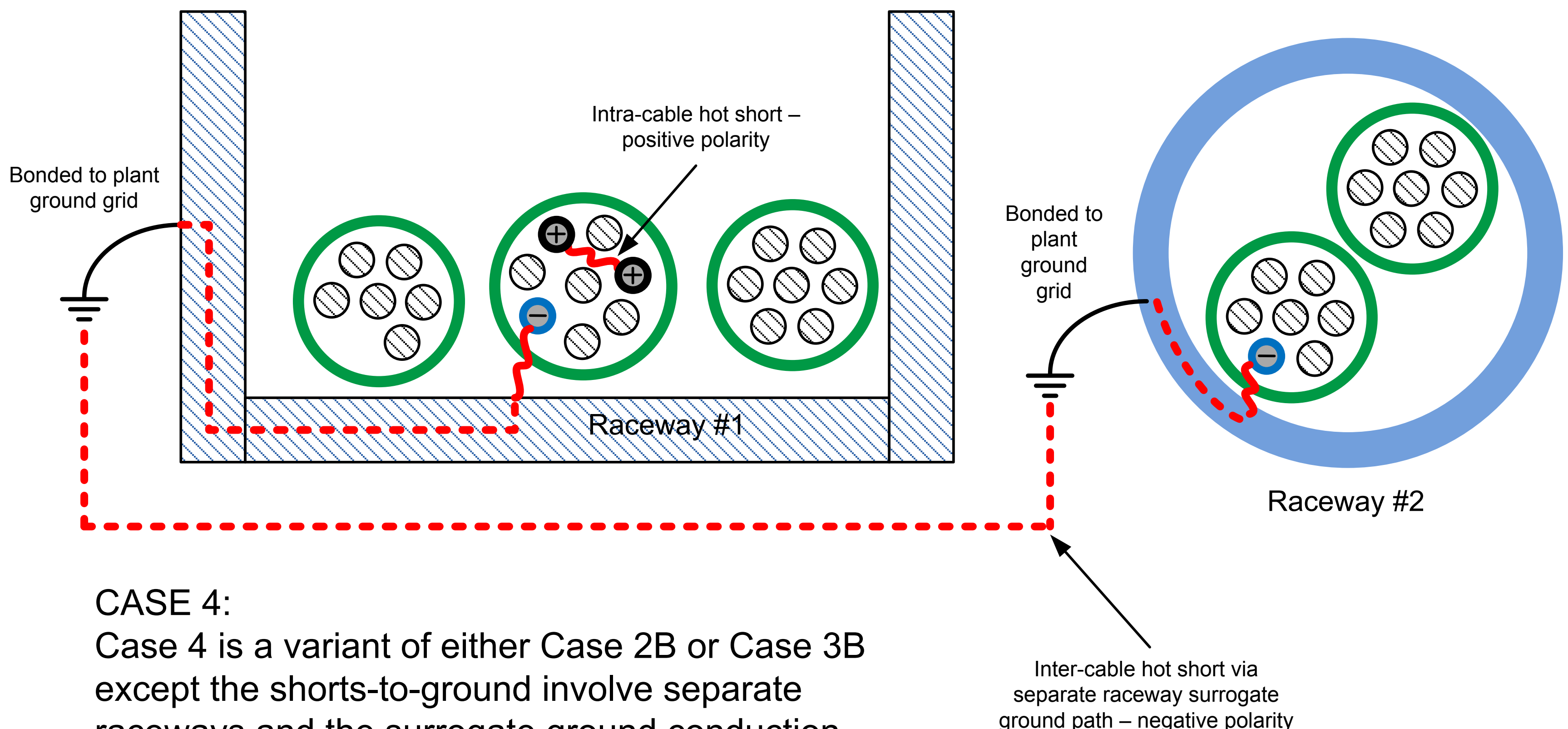
CASE 2B:
Proper polarity hot shorts are the result of one intra-cable short and one inter-cable short. The inter-cable short is caused by two conductors of the same polarity shorting to the raceway with the raceway then serving as a surrogate conduction path.

Proper Polarity Hot Short – Inter / GFE



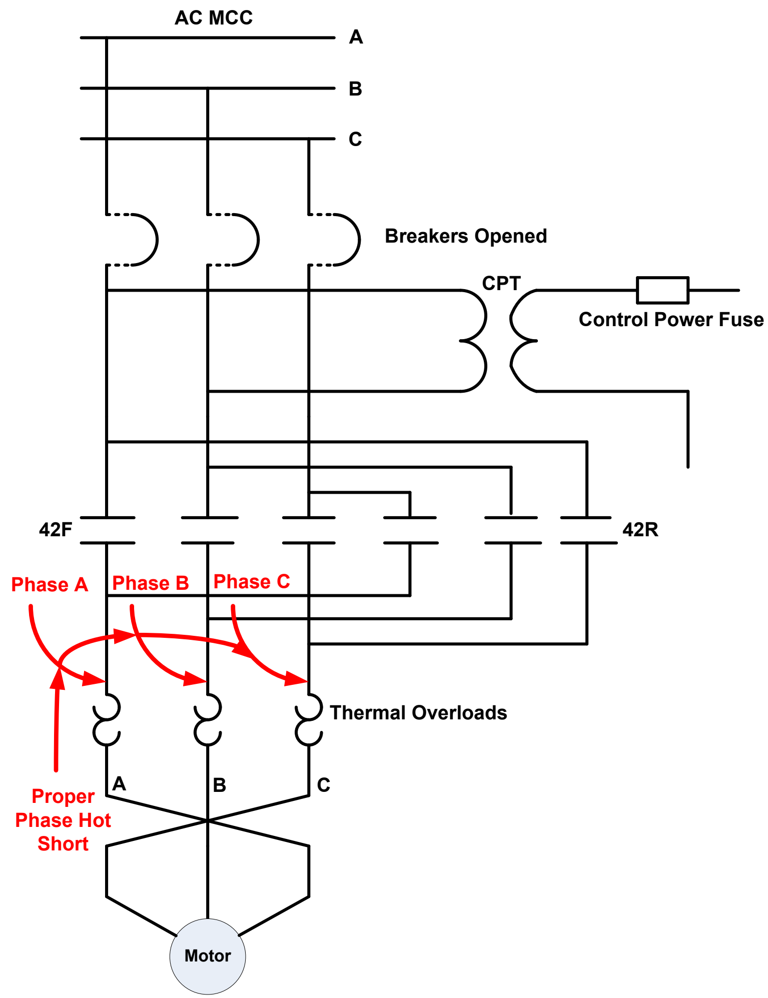
CASE 3B:
Proper polarity hot shorts are the result of two independent inter-cable shorts involving the proper polarity. For this case one of the two inter-cable shorts is caused by two conductors of the same polarity shorting to the raceway with the raceway then serving as a surrogate conduction path.

Proper Polarity Hot Short – Intra / GFE (Variation)

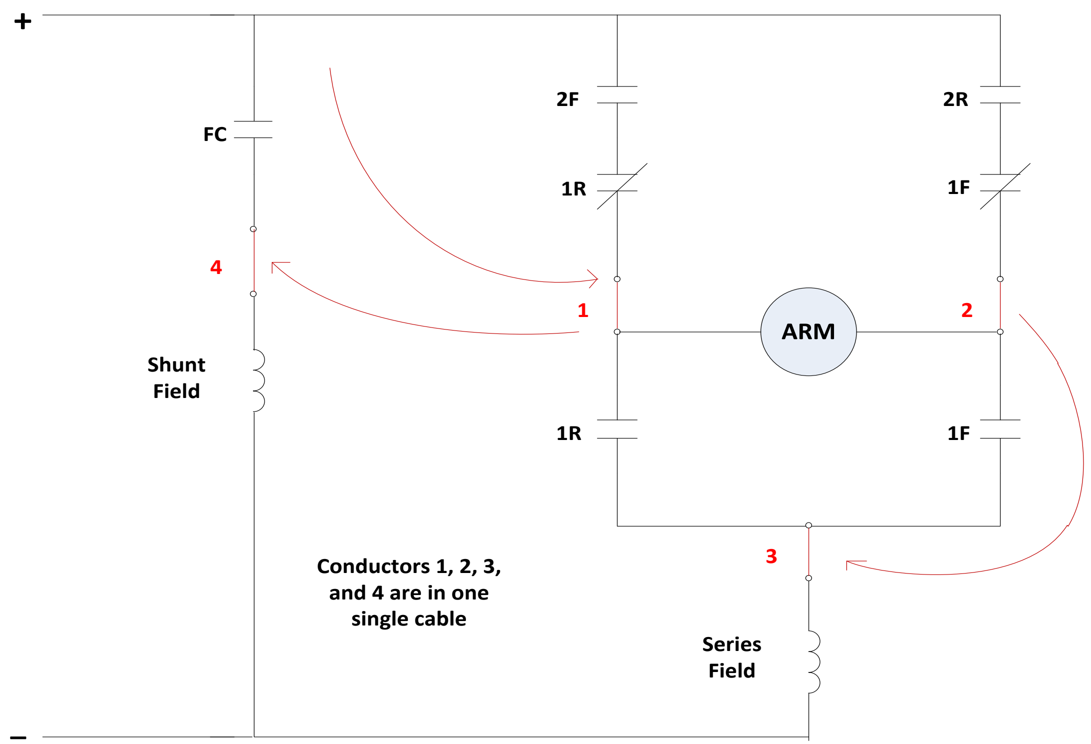


CASE 4:
Case 4 is a variant of either Case 2B or Case 3B except the shorts-to-ground involve separate raceways and the surrogate ground conduction path is via an unspecified route in the plant ground grid.

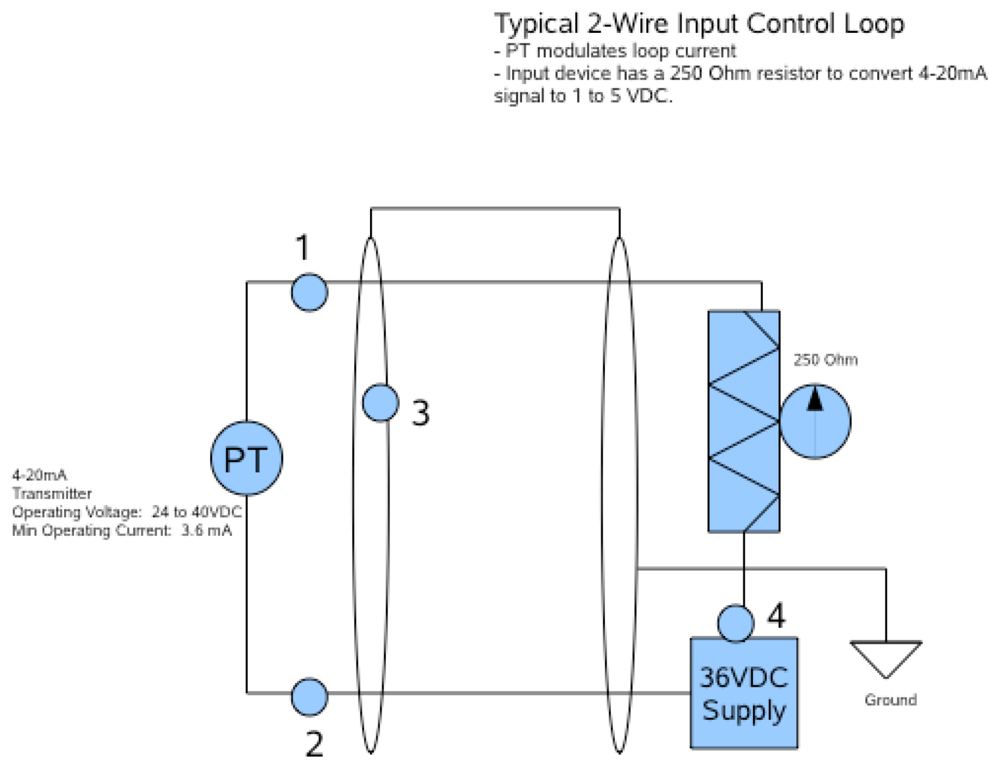
Three-Phase Proper Polarity Hot Short



DC Compound Motor Proper Phase Hot Short



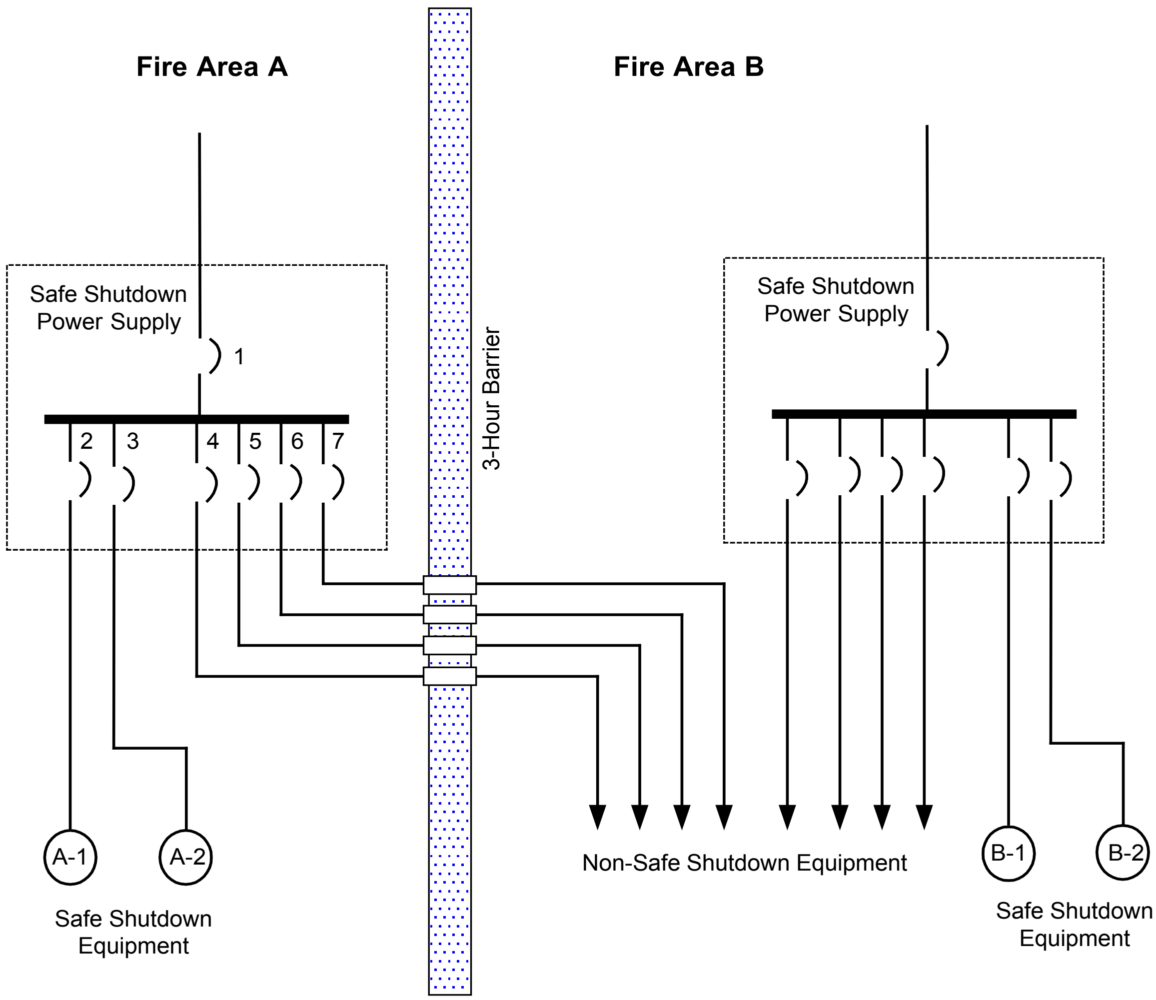
Instrument Loop Short Circuit



Short between 1 and 2 would remove could cause current passing through input device to vary between 4mA and ~ 144mA depending upon the output of the transmitter and the quality of the short.

Short between any other points could cause current passing through input device to vary between 0mA and <20mA. depending upon the output of the transmitter and the quality of the short. Exception: Points 3 and 4 are at the same potential with respect to ground.

Multiple High Impedance Faults (MHIFs)



Open Circuit Current Transformer

- 1200:5 Ratio and Lower: Incredible
- Greater than 1200:5 Ratio: Possible
- NRC/EPRI Testing Planned for Fall 2015

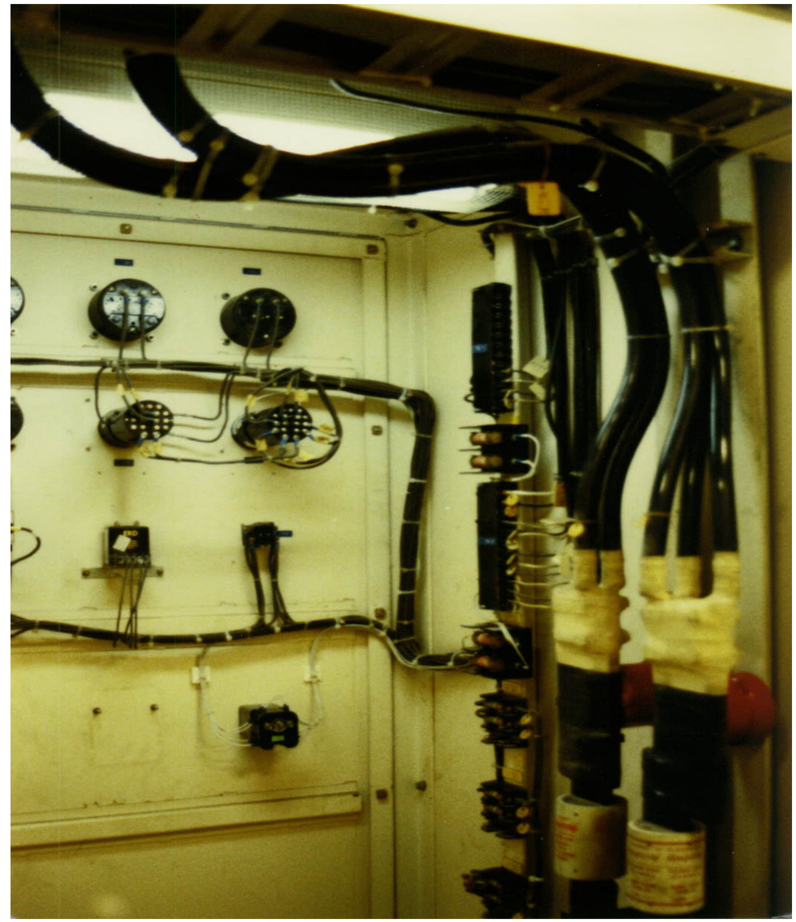
CABLE AND CIRCUIT FAILURE MODES
High Ranked Parameters for Spurious Operation

- Cable Routing/Raceway – panel wiring
- Cable Raceway Fill – bundles (Note: PIRT panel considered important even though it is ranked medium)
- Conductor Insulation Material [for inter-cable hot shorts (thermoset (TS) versus thermoplastic (TP))]
- Cable Grounding Configuration – ac only (e.g., ground or drain wire, shield wrap)
- Armor Grounded versus Ungrounded Circuit (for ac) and Armored versus Unarmored (for dc)
- Cable Wiring Configuration (number of sources, target, ground/neutral and their locations)
- Grounded versus Ungrounded Circuits for ac only (for inter-cable hot shorts)

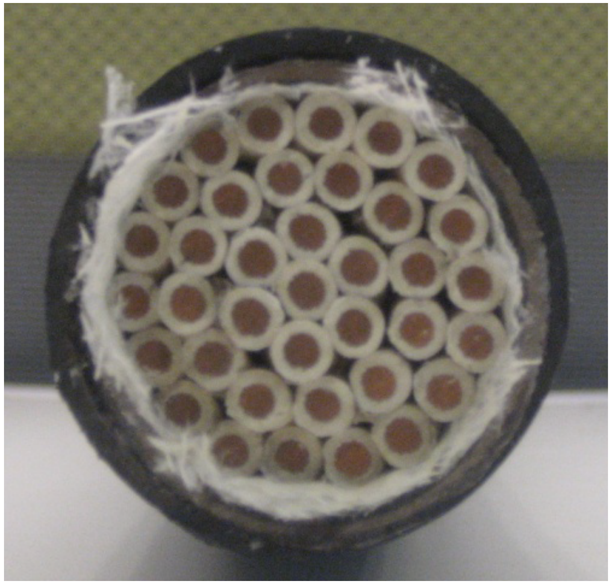
CABLE AND CIRCUIT FAILURE MODES
High Ranked Parameters for Spurious Duration

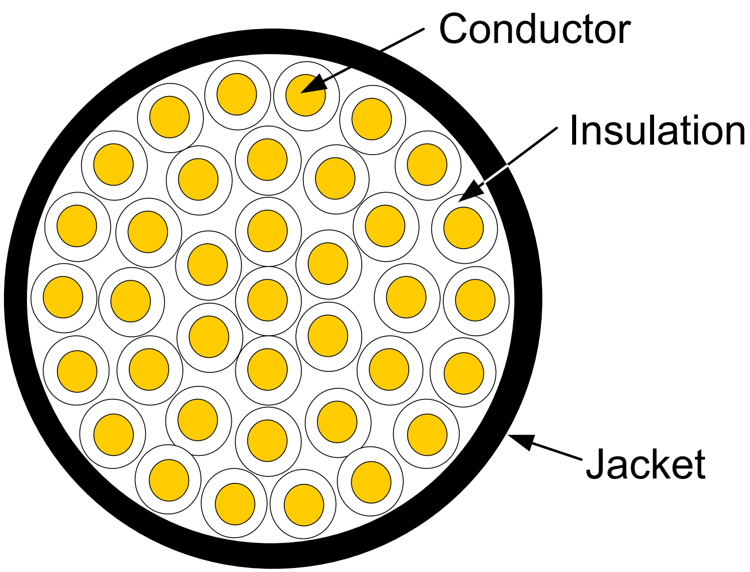
- Fire Exposure Condition
- Cable Routing/Raceway – panel wiring
- Cable Raceway Fill – bundles (Note: PIRT panel considered important even though it is ranked medium)
- Time-Current Characteristics – fuses/breaker size
- Cable Wiring Configuration (number of sources, targets, ground/neutrals and their locations)
- Latching versus Non-latching devices (e.g., motor operated valves)

Panel Wiring

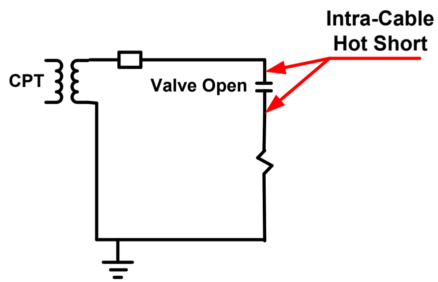


Trunk Cables

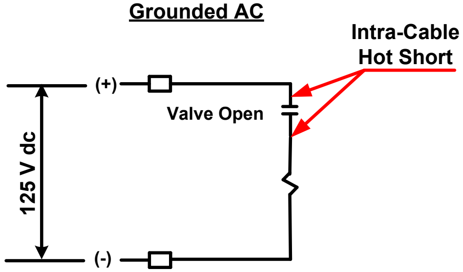




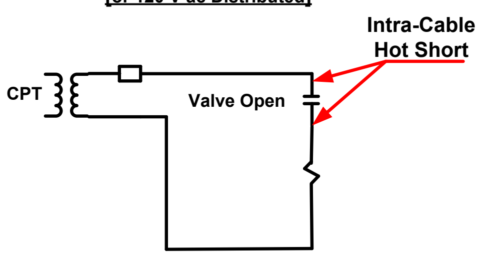
Single Break Control Circuit
Intra-Cable Hot Short



Grounded AC

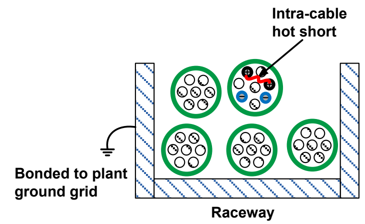


Ungrounded DC
[or 120 V ac Distributed]



Ungrounded AC

Simplified Schematic Configuration – Single Break Control Circuit



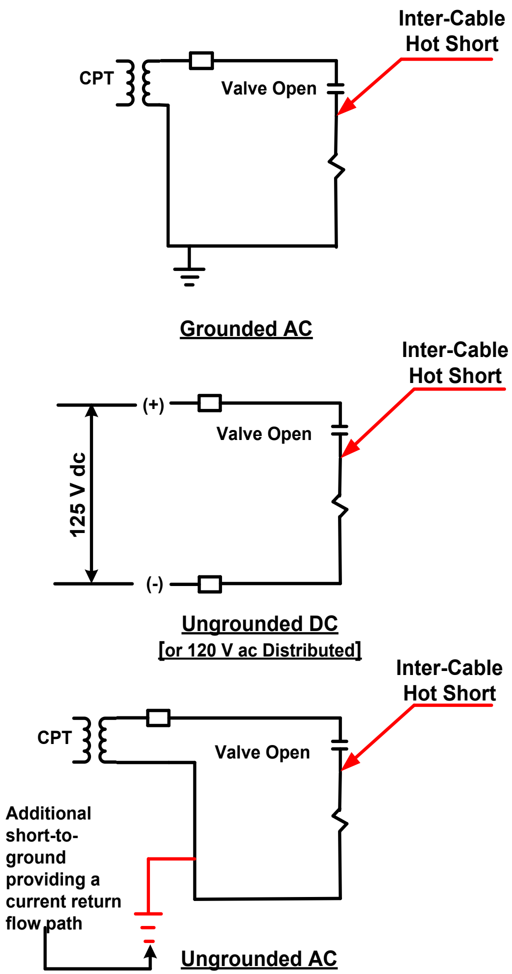
Physical Configuration

Notes:

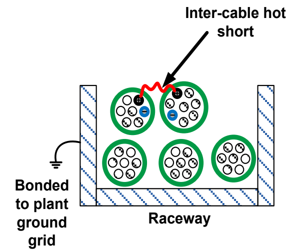
1. Component is energize to open.
2. A fire-induced intra-cable hot short will open the component.
   a. If the component is a latching circuit, the component will remain open even if the intra-cable hot short is eliminated, e.g., goes to ground.
   b. If the component is a non-latching circuit, the component will either close, stay in an interim or stay in an open position when the intra-cable hot short is eliminated, e.g., goes to ground. The specific behavior of the component will depend on the component types, i.e., AOV/SOV, MOV.
   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 if the component is an AOV/SOV. It will fail as is if it is an MOV
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 Sub-Case 1.2.

Sub-Case 1.1 – Single Contact Intra-Cable Hot Short – Induced Spurious Operation

Single Break Control Circuit
Inter-Cable Hot Short



Simplified Schematic Configuration – Single Break Control Circuit



Physical Configuration

Notes:

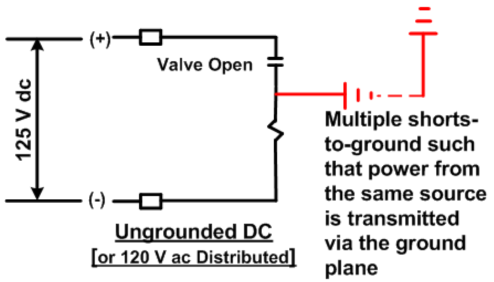
1. Component is energize to open.
2. A fire-induced inter-cable hot short will open the component.
   a. If the component is a latching circuit, the component will remain open even if the inter-cable hot short is eliminated, e.g., goes to ground.
   b. If the component is a non-latching circuit, the component will either close or fail as is when the inter-cable hot short is eliminated, e.g., goes to ground. An AOV/SOV will close. A MOV will fail as is.
   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, if it is an AOV/SOV will close regardless of whether or not it is a latching or non-latching circuit. If the component is an MOV, it will fail as is.
3. For the case of the ungrounded DC or ungrounded distributed AC circuit, the inter-cable hot short must come from the same battery source. This is required since an inter-cable hot short from a different battery 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 negative leg of the circuit providing a current return flow path to the power source of the aggressor circuit. If the aggressor circuit is an ungrounded AC source off of a CPT, the aggressor circuit will also require a ground on the negative 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 negative leg to complete the circuit and cause the spurious operation.

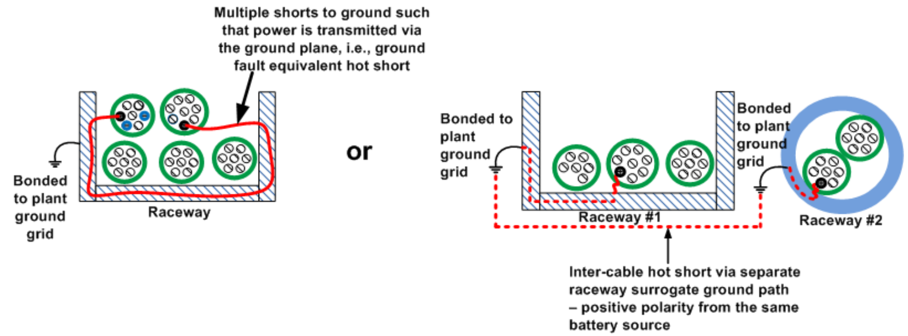
Sub-Case 1.2 – Single Contact Inter-Cable Hot Short – Induced Spurious Operation

U.S.NRC United States Nuclear Regulatory Commission Protecting People and the Environment

EPRI ELECTRIC POWER RESEARCH INSTITUTE

Single Break Control Circuit
Ground Equivalent Hot Short





Simplified Schematic Configuration – Single Break Control Circuit

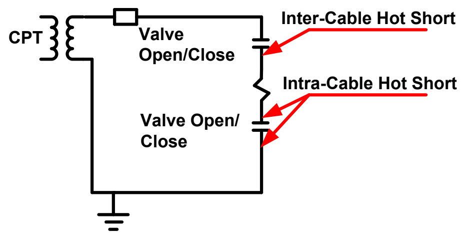
Physical Configuration

Notes:

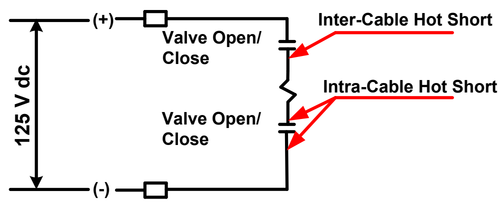
1. Component is energize to open.
2. A fire-induced ground equivalent hot short can open the component.
   a. If the component is a latching circuit, the component can remain open even if the hot short is eliminated.
   b. If the component is a non-latching circuit, the component, if it is an AOV/SOV will close when the hot short is eliminated. If the component is a MOV, it will fail as is.
   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, if it is an AOV/SOV will close regardless of whether or not it is a latching or non-latching circuit. If the component is a MOV, it will fail as is.
3. For the case of the ungrounded DC or an ungrounded distributed AC 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.
4. For either grounded or ungrounded AC circuits powered from a CPT, a ground fault equivalent hot short will not cause a spurious operation because the control power fuses in the aggressor circuit will blow prior to a spurious operation occurring.

Sub-Case 1.3 – Single Contact Inter-Cable Hot Short – Induced Spurious Operation via a ground plane interaction from cables in the same or different raceway

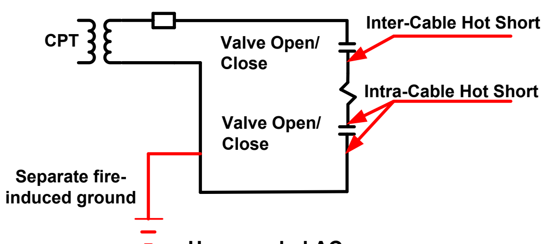
Double Break Control Circuit
Intra-Cable and Inter-Cable Hot Short



Grounded AC

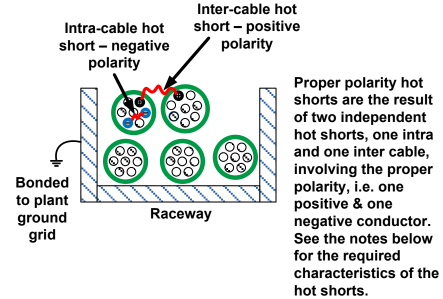


Ungrounded DC
[or 120 V ac Distributed System]



Ungrounded AC

Schematic Configuration – Double Break Control Circuit



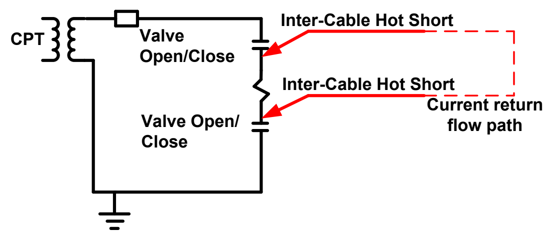
Physical Configuration

Notes:

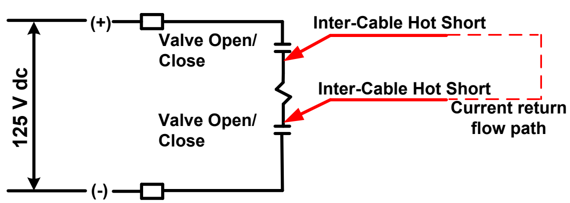
1. The component, assumed to be an SOV, is energized to either open or close a respective valve.
2. The double break design requires two hot shorts to energize the component.
3. A fire-induced inter-cable + an intra-cable hot short will energize the component.
   a. If either hot short is eliminated, 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 distributed AC circuit, the inter-cable hot short must come from the same battery source. This is required since an inter-cable hot short from a different battery 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 negative 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 negative 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 hot short, i.e., a ground equivalent hot short, must occur.
5. For the case of the grounded 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 experience a fire-induced ground on its negative leg to provide a flow path through the ground plane for the return current.
6. 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 Sub-Case 3.2.

Sub-Case 3.1 – Double Break - One Intra and One Inter-Cable Hot Short – Induced Spurious Operation.

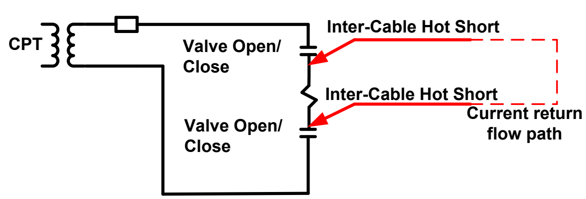
Double Break Control Circuit
Two Inter-Cable Hot Shorts



<u>Grounded AC</u>

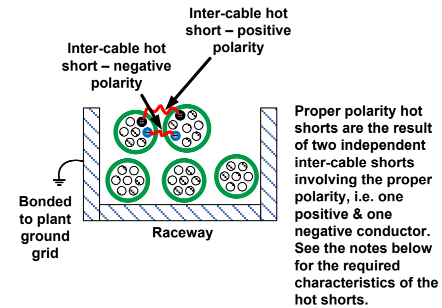


<u>Ungrounded DC</u>
<u>[or 120 V ac Distributed System]</u>



<u>Ungrounded AC</u>

<u>**Schematic Configuration – Double Break Control Circuit**</u>

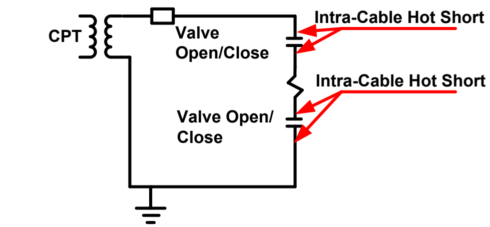


<u>Physical Configuration</u>

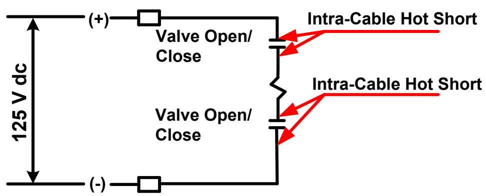
<u>Notes</u>:
1. The component, assumed to be an SOV, is energized to either open or close a respective valve.
2. The double break design requires two hot shorts to energize the component.
3. Two fire-induced inter-cable hot shorts will energize the component.
   a. If either hot short is eliminated, the solenoid will de-energize and the affected component will return to its original position.
   b. If power is lost to the 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 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.
3. For all cases aggressor cables must be from a compatible ungrounded source, i.e., a common source providing both the positive and negative legs so that the current will have a flow path to the same power source.
4. For the grounded or ungrounded AC case, if the aggressor circuit is a grounded AC circuit, then a single ground on the underside of the coil is sufficient to cause a spurious operation.

Sub-Case 3.2 – Double Break - Two Inter-Cable Hot Shorts – Induced Spurious Operation.

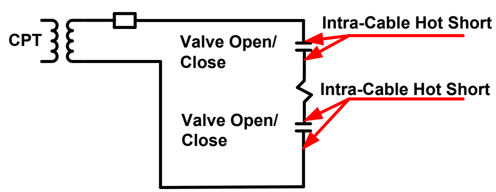
Double Contact Control Circuit
Two Intra-Cable Hot Shorts



Grounded AC

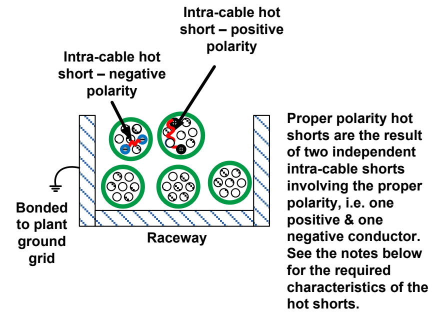


Ungrounded DC
[or 120 V ac Distributed System]



Ungrounded AC

Schematic Configuration – Double Break Control Circuit

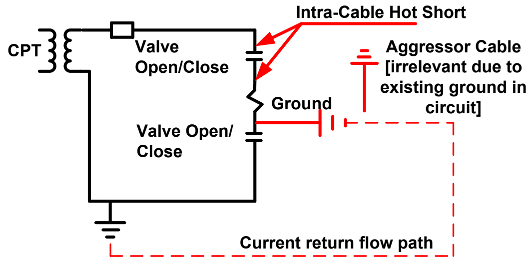


Physical Configuration

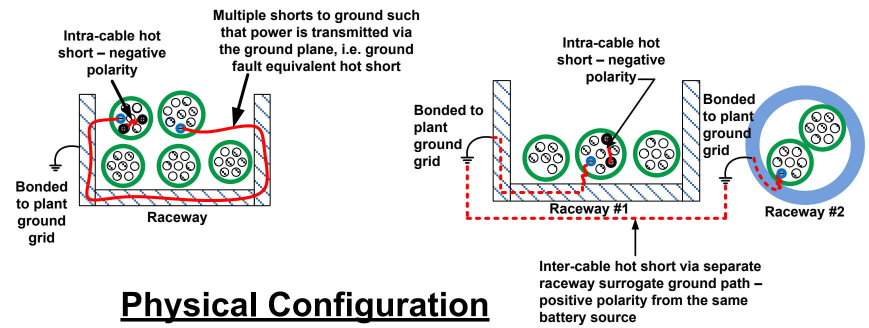
Notes:
1. The component, assumed to be an SOV, is energized to either open or close a respective valve.
2. The double break design requires two hot shorts to energize the component.
3. Two fire-induced intra-cable hot shorts will energize the component.
   a. If either hot short is eliminated, the component 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 Sub-Case 3.2.

Sub-Case 3.3 – Double Break - Two Intra-Cable Hot Shorts – Induced Spurious Operation.

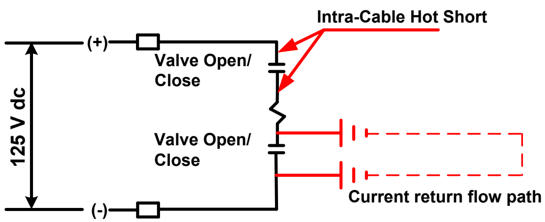
Double Contact Control Circuit
Intra-Cable and GFE Hot Shorts



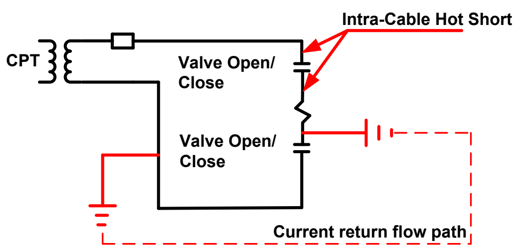
Grounded AC



Physical Configuration



Ungrounded DC
[or 120 V ac Distributed System]



Ungrounded AC

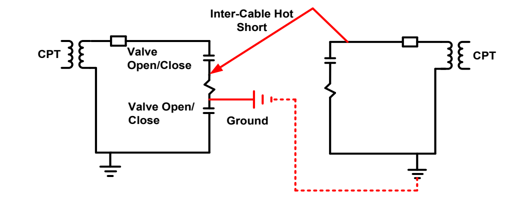
Schematic Configuration – Double Break Control Circuit

Notes:
1. The component is energized to either open or close a respective valve.
2. The double break design requires two hot shorts to energize the component.
3. A fire-induced intra-cable + 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 ungrounded distributed AC circuit, the ground equivalent hot short must include a ground on the negative leg of a circuit from the same battery source. This is required since a ground equivalent hot short from a different battery 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. For the case of the grounded AC circuit powered from a CPT, only an intra-cable hot short and a ground is required for the spurious operation to occur. The aggressor cable for the ground equivalent hot short is irrelevant due to the ground that already exists within the grounded circuit. The existing circuit ground on the negative leg of the circuit provides a current return flow path. The orientation of the two types of hot shorts, i.e., either above or below the coil, does have an impact on the spurious operation of this circuit. With the ground fault hot short above the coil, the positive leg of the ground equivalent hot short will blow a fuse and no spurious operation will occur.
6 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 Sub-Case 3.5.

Sub-Case 3.4 – Double Break - Intra (+) and Ground Fault Hot Short (-) – Induced Spurious Operation.

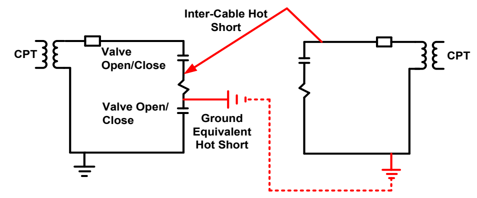
Double Contact Control Circuit

Inter-Cable and GFE Hot Shorts



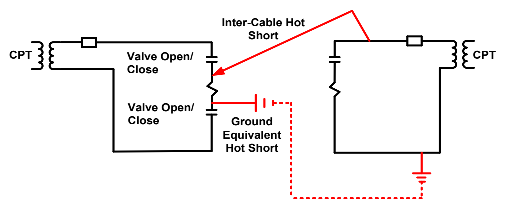
Grounded AC
[Spurious Operation]

Aggressor Circuit – Grounded AC



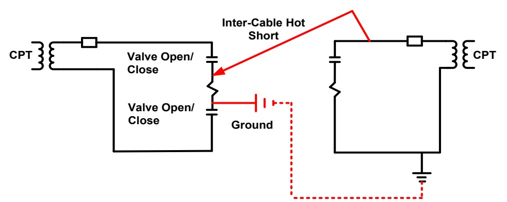
Grounded AC
[Spurious Operation]

Aggressor Circuit – Ungrounded AC



Ungrounded AC
[Spurious Operation]

Aggressor Circuit – Ungrounded AC

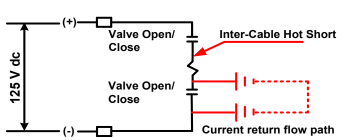


Ungrounded AC
[Spurious Operation]

Aggressor Circuit – Grounded AC

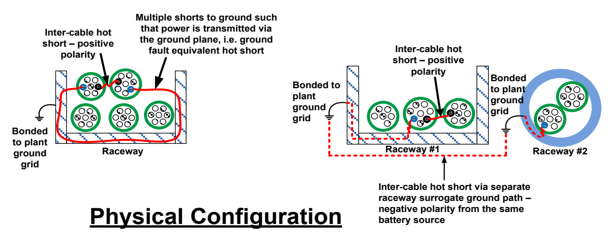
Notes:

1. The component, assumed to be an SOV, is energized to either open or close a respective valve.
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 + 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 distributed AC circuit, the inter-cable hot short and the negative leg of the ground equivalent hot short must come from the same battery source. This is required since hot shorts from a different battery 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 negative 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. The orientation of the two types of hot shorts, i.e., either above or below the coil, does have an impact on the spurious operation of this circuit, if the aggressor circuit is an grounded AC circuit. With the ground fault hot short above the coil, the positive leg of the ground equivalent hot short in the aggressor circuit will blow the fuse in the aggressor circuit and no spurious operation will occur.
5. For the case of the grounded 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 negative 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. The orientation of the two types of hot shorts, i.e., either above or below the coil, does have an impact on the spurious operation of this circuit, if the aggressor circuit is a grounded AC circuit. With the ground fault hot short above the coil, the positive leg of the ground equivalent hot short in the aggressor circuit will blow the fuse in the aggressor circuit and no spurious operation will occur.



Ungrounded DC
[or 120 V ac Distributed System]

Schematic Configuration – Double Break Control Circuit



Physical Configuration

Sub-Case 3.5 – Double Break - Inter (+) and Ground Fault Hot Short (-) – Induced Spurious Operation.

Failure Mode Basics

QUESTIONS ??

Module II – Circuit Analysis

Fire-Induced Circuit Failures Research

Joint EPRI/NRC-RES Fire PRA Workshop
August 24-28

Dan Funk – Jensen Hughes

Gabe Taylor – U.S. NRC

A Collaboration of the Electric Power Research Institute (EPRI) & U.S. NRC Office of Nuclear Regulatory Research (RES)

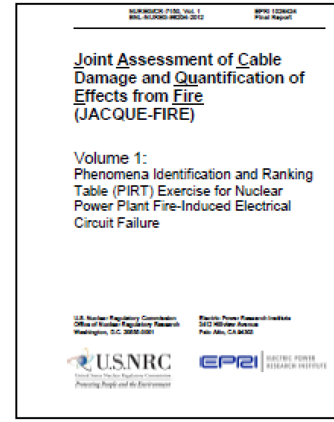
CIRCUIT FAILURE RESEARCH
Objectives

- To provide a status update on the recent research efforts related to fire-induced cable damage and circuit failures
- Topics covered
  - Circuit Failure Testing
  - Electrical Expert PIRT Panel (NUREG/CR-7150, Vol. 1 / EPRI 1026424)
  - PRA SSHAC Level 2 Expert Elicitation (NUREG/CR-7150, Vol. 2 / EPRI 3002001989)
  - Data Analysis
  - NUREG/CR-6850 Impacts
  - Overview of JACQUE-FIRE 3 – Working Group
- Presentation *<u>does not</u>* present regulatory guidance or direction

CIRCUIT FAILURE RESEARCH
Testing Programs

- Testing programs include:
  - NEI/EPRI 2002
  - NRC/SNL CAROLFIRE 2008
  - NRC/SNL DESIREE-FIRE 2010
  - NRC/SNL KATE-FIRE 2011
  - NRC HEAF Tests (In Progress)
  - CT Testing (In Progress)
  - Instrumentation circuit testing (Planned)
  - Panel Wiring (Future)
  - Others in progress or near publications

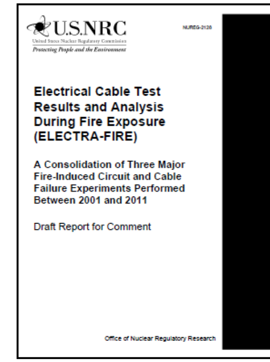
CIRCUIT FAILURE RESEARCH
Electrical PIRT Panel: NUREG/CR-7150, Vol. 1


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

- PIRT
  - Phenomena Identification and Ranking Table
  - Structured expert elicitation (use of expert judgment)
- Purpose
  - Identify phenomena that influences the failure mode of electrical cables during severe fire conditions
  - If possible, arrive at consensus technical positions on longstanding fire-induced circuit failure issues
  - Provide technical basis for follow-on PRA Expert Panel
- Report - JACQUE-FIRE
  - Results of PIRT <u>*are not*</u> regulatory guidance
  - NRR will establish regulatory positions on the technical results presented in the PIRT Report

CIRCUIT FAILURE RESEARCH
Data Analysis Effort: NUREG-2128


U.S.NRC

Electrical Cable Test Results and Analysis During Fire Exposure (ELECTRA-FIRE)

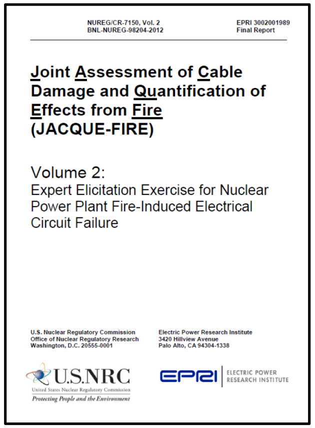
A Consolidation of Three Major Fire-Induced Circuit and Cable Failure Experiments Performed Between 2001 and 2011

Draft Report for Comment

Office of Nuclear Regulatory Research

- NRC ELECTRA FIRE
  - ELECTRA-FIRE
    - Electrical Cable Test Results and Analysis During Fire Exposure
  - Objective
    - Consolidate three major fire-induced circuit and cable failure experiments between 2001 and 2011
    - Further refine available test data to obtain additional insights from existing data
  - Scope
    - Evaluate parameters that effect hot-short failure modes and hot-short durations
    - Intra-cable & Inter-cable faults
    - Concurrence
    - Ground equivalent hot shorts

CIRCUIT FAILURE RESEARCH
PRA Expert Panel NUREG/CR-7150, Vol. 2


NUREG/CR-7150, Vol. 2
BNL-NUREG-98204-2012

EPRI 3002001989
Final Report

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

Volume 2:
Expert Elicitation Exercise for Nuclear Power Plant Fire-Induced Electrical Circuit Failure

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

Electric Power Research Institute
3420 Hillview Avenue
Palo Alto, CA 94304-1338

U.S.NRC United States Nuclear Regulatory Commission Protecting People and the Environment

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- PRA SSHAC Level 2 Expert Elicitation
  - Following SSHAC Level 2 process for use of expert judgment
  - Formal process for soliciting, judging, and weighing input
- Purpose
  - Use expanded data set to revise/develop conditional probabilities of hot short given cable damage
  - Results will be used to update NUREG/CR-6850, Task 10
- Status
  - Final Report Issued May 2014

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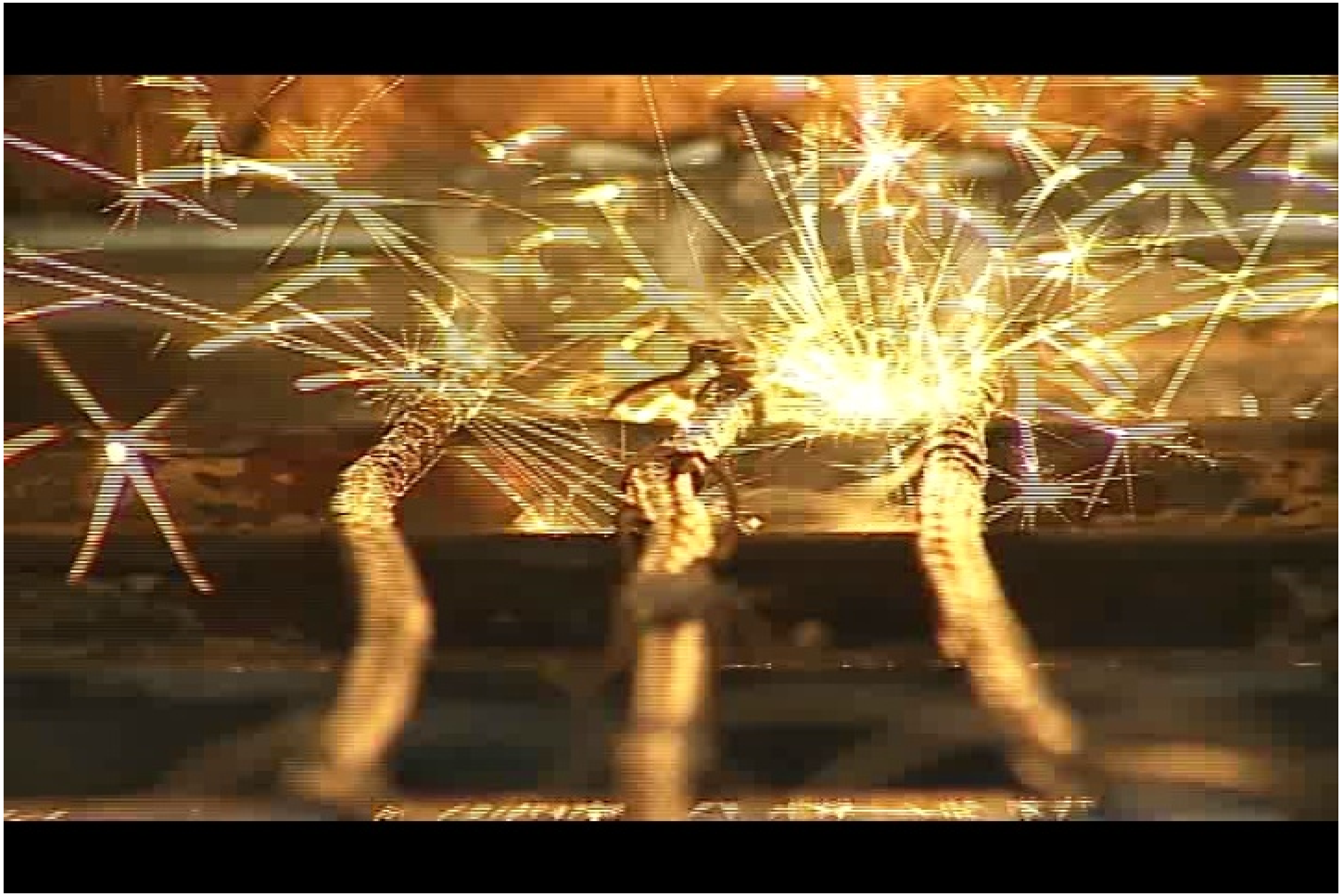
CIRCUIT FAILURE RESEARCH
Working Group: NUREG/CR-7150, Vol. 3 (not yet published)

- Purpose
  - Provide technical basis/positions on several fire protection circuit analysis issues
    - Use of the PIRT results (Clarifications to Appendix J NEI 00-01)
    - Limits on the number of hot-short circuit failures to assume for MSOs
    - Update to hot-short classifications for select cases (i.e., plausible, implausible, incredible)
    - Shorting switch criteria and design considerations
    - Limit on Spurious Operation Duration
    - Clarifications to Volume 1, based on Volume 2 results
- Report - JACQUE-FIRE
  - Results of working group ***are not*** regulatory guidance
  - NRR will establish regulatory positions on the technical results presented in the working group report

CIRCUIT FAILURE RESEARCH
DC Test Video and Pictures



CIRCUIT FAILURE RESEARCH
Questions

QUESTIONS ABOUT RESEARCH ??

Module II – Circuit Analysis

Circuit Analysis Basics
Task 3: Fire PRA Cable Selection

Joint EPRI/NRC-RES Fire PRA Workshop
August 24-28

Dan Funk – Jensen Hughes

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A Collaboration of the Electric Power Research Institute (EPRI) & U.S. NRC Office of Nuclear Regulatory Research (RES)

FIRE PRA CABLE SELECTION
Purpose & Scope (per NUREG/CR-6850, EPRI 1011989)

- Identify circuits/cables associated with Fire PRA components
- Determine routing/location of the identified cables
- Use component-to-cable-to-location relationships to determine what components could be affected for postulated Fire Scenarios

  Note: A Fire Scenario can involve a Fire Area, Room/Compartment, Raceway, or Other Specific Location

- Identify Fire PRA power supplies
- Screen for Associated Circuits

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FIRE PRA CABLE SELECTION
Corresponding PRA Standard Element

- Primary match is to element CS – Cable Selection
  - CS Objectives (as stated in the PRA standard):

    "[T]o ensure that

    (a) all cables needed to support proper operation of equipment selected per technical element ES (see 4-2.2) are identified and assessed for relevance to the Fire PRA plant response model

    (b) the plant location information for selected cables is sufficient to support the Fire PRA and its intended applications."

FIRE PRA CABLE SELECTION
HLRs (per the PRA Standard)

- HLR-CS-A: The Fire PRA shall identify *and* locate the plant cables whose failure could adversely affect credited equipment or functions included in the Fire PRA plant response model, as determined by the equipment selection process (HLR-ES-A, HLR-ES-B, and HLR-ES-C). (11 SRs)
- HLR-CS-B: The Fire PRA shall

  (a) perform a review for additional circuits that are either required to support a credited circuit (i.e., per HLR-CS-A) or whose failure could adversely affect a credited circuit

  (b) identify any additional equipment and cables related to these additional circuits in a manner consistent with the other equipment and cable selection requirements of this Standard. (1 SR)
- HLR-CS-C: The Fire PRA shall document the cable selection and location process and results in a manner that facilitates Fire PRA applications, upgrades, and peer review. (4 SRs)

FIRE PRA CABLE SELECTION

NEI 00-01, Rev. 2, Section 3.3 – Safe Shutdown Cable Selection and Location

- NEI 00-01, Rev. 2, “Guidance for Post-Fire Safe Shutdown Circuit Analysis,” May 2009.
- Generally follows the Task 3/9 methodology of NUREG/CR-6850, EPRI 1011989.
- Figure 3-4 in NEI 00-01 provides a flowchart illustrating the steps involved in selecting the cables necessary for performing a post-fire safe shutdown analysis:

  Step 1 – Define safe shutdown equipment.

  Step 2 – Identify circuits (power, control, instrumentation) required for the operation of each safe shutdown equipment.

  Step 3 – Identify equipment whose spurious operation or mal- operation could affect safe shutdown.

FIRE PRA CABLE SELECTION

NEI 00-01, Rev. 2, Section 3.3 – Safe Shutdown Cable Selection and Location (continued)

Step 4 – Identify interlocked circuits and cables whose failure may cause spurious actuations.

Step 5 – *Decision:* Is power required for equipment operation?

Step 6 – If power is required, identify closest upstream power supply and verify that it is on the safe shutdown list.

Step 7 – Assign cables to equipment.

Step 8 – Identify routing of cables.

Step 9 – Identify location of cables by fire area.

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FIRE PRA CABLE SELECTION
Introduction (per NUREG/CR-6850, EPRI 1011989)

- Conducted for all Fire PRA Components

  Note: Exceptions do exist

- Cable selection is a **Deterministic** process

- Selected cables are associated to components based on <u>specified functionality</u>
  - Basic circuit analysis (Task 9A) incorporated into Task 3 work to prevent overwhelming the PRA model with inconsequential cable failures during cutset reviews and quantification runs
  - Final output is a listing of defined Basic Events (component and credited function) that could be impacted by a fire in a given location (Fire Area, Compartment, etc.) or for a specific Fire Scenario

FIRE PRA CABLE SELECTION
Introduction (continued)

- Cable Selection procedure is subdivided into six (6) distinct steps

  Step 1: Compile and Evaluate Prerequisite Information and Data

  Step 2: Select Fire PRA Circuits/Cables

  Step 3: Identify and Select Fire PRA Power Supplies

  Step 4: Perform Associated Circuits Review

  Step 5: Determine Cable Routing and Plant Locations

  Step 6: Generate Fire PRA Cable List and Target Equipment Location Reports

FIRE PRA CABLE SELECTION
Task Interfaces - Input

- Plant Boundary Partitions (Task 1)
- Fire PRA Component List (Task 2)
- Fire PRA Database (Support Task B)
- Appendix R Circuit Analysis
- Plant Cable & Raceway Database
- Plant Drawings

FIRE PRA CABLE SELECTION
Task Interfaces - Output

- Fire PRA Cable List
- Fire PRA Power Supply List
- Associated Circuits Review
- Component Analysis Packages
- Target Equipment Loss Reports
  - Potential equipment functional losses broken down by location or fire scenario
  - Generally managed by a database (e.g., FRANX)

FIRE PRA CABLE SELECTION
Step 1 – Prerequisite Information

- Confirm Plant Partitioning is compatible
  - Do partitions align with cable location data?
  - What data is available and what is missing?
  - Are routing assumptions used?
- Confirm PRA Equipment List is Stable
  - Easier said than done…
  - Input into a formal and controlled database
  - For NFPA-805 transition projects a joint “consistency” review of NSCA and PRA component lists is highly recommended

    NOTE: Critical that electrical analysts understand the functional requirements for the PRA Model Basic Events

  (Corresponds to NEI 00-01, Rev. 2, Step 1)
- Evaluate Database Requirements and Controls are in Place
  - How is data to be managed and controlled?
  - This is a “Biggie”

FIRE PRA CABLE SELECTION
Step 2 – Select Fire PRA Cables

- Analysis Cases
  - Appendix R / NSCA Component with *Same* Functional Requirements
    - Must consider which (if any) automatic features are included in the existing analysis
    - Aligning existing analyses to Fire PRA Basic Events is not straightforward
  - Appendix R Component with *Different* Functional Requirements
  - New Component (Non-Appendix R/NSCA)

- Analysis Sub-Steps
  - *Step 2.1:* Analysis Strategy
  - *Step 2.2:* Plant Specific Rules
  - *Step 2.3:* Select Cables

- Corresponding PRA Standard SRs: CS-A1, A3
- Corresponding NEI 00-01, Rev. 2, Steps: 2 & 4

FIRE PRA CABLE SELECTION
Step 2.1 – Analysis Strategy

- Coordinate with Systems Analysts to establish Functional Requirements and General Rules
  - MUST WORKOUT THE DETAILS OF HOW PRA BASIC EVENTS ARE TO BE CORRELATED TO CIRCUIT ANALYSIS
  - Consistent conventions for equipment functions & positions
  - Equipment-level dependencies and primary components – must understand what is beneficial to PRA and what is a waste of time
  - Multiple function components
  - “Super” or “Pseudo” components
- Evaluate Appendix R Component & Circuit Data
  - Ensure equipment list comparison was conducted during Task 2
  - Review in detail the comparison list – ask questions!!!
  - Essential that comparison includes detailed review/assessment of “desired functional state(s)”

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FIRE PRA CABLE SELECTION
Step 2.1 – Analysis Strategy (continued)

- Goal – Efficient and accurate process to obtain required information
- Revisit past assumptions, conventions, and approach
- Potential trouble areas
  - How is off-site power going to be handled?
  - Instrument circuits – understand exactly what is credited
  - ESFAS, Load-Shed, EDG Sequencer, other automatic functions
  - Medium-voltage switchgear control power
- Extent that Circuit Analysis (Task 9) is to be conducted concurrently

  Note: This will be discussed as part of the Task 9 presentation

FIRE PRA CABLE SELECTION
Step 2.2 – Plant Specific Cable Selection Rules

- Objective is Consistency
- Approach for Groups of Components
- Approach for Spurious Actuation Equipment
- Auxiliary Contacts – Critical Area for Completeness
- System-Wide Actuation Signals
- Bus or Breaker?
- Subcomponents & Primary Components
- Identification of Permanent Damage Scenarios
- Procedure - Develop Circuit Analysis Procedure/Guidelines

FIRE PRA CABLE SELECTION
Step 2.2 – Ready to Start?

- Develop Written Project Procedure/Guidelines
  - Consistency, Consistency, Consistency
  - Checking Process?
  - Data Entry
  - Problem Resolution

- Training for Analysts
  - Prior circuit analysis experience is a prerequisite for key team members or personnel that will work with minimal supervision
  - Familiarity with plant drawings and circuit types is a requirement
  - A junior engineer with no prior circuit analysis experience <u>will not be able to work independently</u>

FIRE PRA CABLE SELECTION
Step 2.3 – Select Cables

- *Case 1:* Incorporate Existing Appendix R Analysis
  - Confirm adequacy of existing analyses IAW plan
  - Careful consideration of automatic functions
  - Exact alignment for credited functionality

- *Case 2A:* New Functional State / New Component
  - Collect drawings and/or past analysis information
  - Identify/select cables IAW plant specific procedure/guidelines
  - Conduct circuit analysis (Task 9A) to the extent decided upon
  - Formally document cable selection IAW established procedures/guidelines

FIRE PRA CABLE SELECTION
Step 2.3 – Select Cables (continued)

- *Case 2B:* New Functional State / New Component (no cable routing information)
  - Same as Case 2A, plus…
  - Determine cable routing and associate with plant locations, including cable end points

- Analysis Work Packages
  - Retrieve from past Appendix R Analysis (if available)
  - Highly recommended for new components
  - Major time saver for future work

Note: More on Work Packages later in this presentation…

FIRE PRA CABLE SELECTION
Step 3 – Select Fire PRA Power Supplies

- Identify Power Supplies as integral part of Cable Selection
  - Make sure to differentiate between “Required” and “Not Required” power supplies
  - Switchgear and instrument power supplies can be tricky
  - Useful to identify the applicable breaker/fuse
- Add New Power Supplies to Fire PRA Component List
- Make sure Fire PRA model, equipment list, and circuit analysis are consistent with respect to power supplies
- Does Fire PRA model consider spurious circuit breaker operations?
  - Must understand how this is modeled to correctly select cables
- Corresponding PRA Standard SRs: CS-B1
- Corresponding NEI 00-01, Rev. 2, Steps: 5 & 6

FIRE PRA CABLE SELECTION
Step 4 – Associated Circuits Review

- Objective is to confirm existing studies are adequate
- View the process as a “Gap Analysis”
- Common Power Supply Circuits - Assess Plant Coordination Studies
  - Be cautions of coordination studies that credit cable length
  - Understand implications of adding new non-vital equipment
- Common Enclosure Circuits - Assess Plant Electrical Protection
- Roll up results to Circuit Analysis or Model as appropriate
- Corresponding PRA Standard SRs: CS-A6, CS-B1
- Corresponding NEI 00-01, Rev. 2: Step 3
  and Sections 3.5.2.4 & 3.5.2.5 (circuit analysis and evaluation)

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FIRE PRA CABLE SELECTION
Step 5 – Determine Cable Routing and Locations

- Correlate Cables-to-Raceways-to-Locations
- Conceptually Straightforward
- Logistically Challenging
  - Labor intensive
  - Manual review of layout drawings
  - Plant walkdowns often required
- Determine Cable Protective Features
  - Fire wraps
  - Embedded conduit
- Corresponding PRA Standard SRs: CS-A10
- Corresponding NEI 00-01, Rev. 2, Steps: 7, 8, & 9

FIRE PRA CABLE SELECTION
Step 6 – Target Equipment Loss Reports

- Data Entered into Fire PRA Database
- Mapping of Circuit Analysis to Model Basic Events is CRITICAL to accurate results
- Sorts and Queries to Generate Target Equipment Loss Reports

Perspective – Cable selection process should be viewed as providing "Design Input" to the Fire PRA. It does not, however, provide any risk-based results. In its simplest form it provides a list of equipment that could be affected by a fire at a specified location or for a specific fire scenario.

- Corresponding PRA Standard SRs: CS-C1, C2, C4

FIRE PRA CABLE SELECTION
Work Packages

- A work package for each Fire PRA component consists of a compilation of drawings and documents that provide the basis of the circuit analysis results for that component
- Contents typically include
  - One-line diagram(s) (highlighted to show the component's power supply)
  - Elementary diagram(s) (marked up to show cable associations)
  - Block diagram(s) (highlighted)
  - Loop diagram(s) (if applicable)
  - Component circuit analysis worksheets
  - Other descriptive/supporting information

FIRE PRA CABLE SELECTION
Questions

Any Questions?

FIRE PRA CABLE SELECTION

Mapping HLRs & SRs for the CS technical element to NUREG/CR-6850, EPRI 1011989

Technical Element	HLR	SR	6850/1011989 Sections that cover SR	Comments
CS	A	The Fire PRA shall identify and locate the plant cables whose failure could adversely affect credited equipment or functions included in the Fire PRA plant response model, as determined by the equipment selection process (HLR-ES-A, HLR-ES-B, and HLR-ES-C).		
		1	3.5.2	
		2	9.5.2	Covered in "Detailed Circuit Failure Analysis" chapter
		3	3.5.2, 9.5.2	Also covered in "Detailed Circuit Failure Analysis" chapter
		4	3.5.3	
		5	9.5.2	Covered in "Detailed Circuit Failure Analysis" chapter
		6	3.5.4, 9.5.2	Also covered in "Detailed Circuit Failure Analysis" chapter
		7	9.5.2	Covered in "Detailed Circuit Failure Analysis" chapter
		8	9.5.2	Covered in "Detailed Circuit Failure Analysis" chapter
		9	9.5.2	Covered in "Detailed Circuit Failure Analysis" chapter
		10	3.5.5	
		11	3.5.5	
	B	The Fire PRA shall (a) perform a review for additional circuits that are either required to support a credited circuit (i.e., per HLR-CS-A) or whose failure could adversely affect a credited circuit (b) identify any additional equipment and cables related to these additional circuits in a manner consistent with the other equipment and cable selection requirements of this Standard		
		1	3.5.3, 3.5.4	
	C	The Fire PRA shall document the cable selection and location process and results in a manner that facilitates Fire PRA applications, upgrades, and peer review.		
		1	3.5.6	
		2	3.5.6	
		3	3.5.6	
		4	3.5.6	

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FIRE PRA CABLE SELECTION

Mapping NEI 00-01, Rev. 2, Safe Shutdown Cable Selection to NUREG/CR-6850, EPRI TR 1011989

NEI 00-01, Rev. 2, Section	NEI 00-01, Figure 3-4 Step	6850/1011989 Sections that cover step	Comments
3.3 - Safe Shutdown Cable Selection and Location	1	3.5.1	
	2	3.5.2	
	3	3.5.4	
	4	3.5.2	
	5	3.5.3	
	6	3.5.3	
	7	3.5.5	
	8	3.5.5	
	9	3.5.5	

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Module II – Circuit Analysis

Circuit Analysis Basics
Task 9: Detailed Circuit Failure Analysis

Joint EPRI/NRC-RES Fire PRA Workshop
August 24-28

Dan Funk – Jensen Hughes

Gabe Taylor – U.S. NRC

A Collaboration of the Electric Power Research Institute (EPRI) & U.S. NRC Office of Nuclear Regulatory Research (RES)

DETAILED CIRCUIT FAILURE ANALYSIS
Purpose & Scope (per NUREG/CR-6850, EPRI 1011989)

The Detailed Circuit Failure Analysis Task is intended to:

- Identify the potential response of circuits and components to specific cable failure modes associated with fire-induced cable damage
- Screen out cables that do not impact the ability of a component to complete its credited function

DETAILED CIRCUIT FAILURE ANALYSIS

Corresponding PRA Standard Elements

- One match is to element CS – Cable Selection
  - CS Objectives (as stated in the PRA standard):

    "[T]o ensure that

    (a) all cables needed to support proper operation of equipment selected per technical element ES (see 4-2.2) are identified and assessed for relevance to the Fire PRA plant response model

    (b) the plant location information for selected cables is sufficient to support the Fire PRA and its intended applications."

DETAILED CIRCUIT FAILURE ANALYSIS

Corresponding PRA Standard Elements (continued)

- Another match is to element CF – Circuit Failures
  - CF Objectives (as stated in the PRA standard):

    "[T]o

    (a) refine the understanding and treatment of fire-induced circuit failures on an individual fire scenario basis

    (b) ensure that the consequences of each fire scenario on the damaged cables and circuits have been addressed"

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DETAILED CIRCUIT FAILURE ANALYSIS

HLRs (per the PRA Standard) – CS element

- HLR-CS-A: The Fire PRA shall identify *and* locate the plant cables whose failure could adversely affect credited equipment or functions included in the Fire PRA plant response model, as determined by the equipment selection process (HLR-ES-A, HLR-ES-B, and HLR-ES-C). (11 SRs)
- HLR-CS-B: The Fire PRA shall

  (a) perform a review for additional circuits that are either required to support a credited circuit (i.e., per HLR-CS-A) or whose failure could adversely affect a credited circuit

  (b) identify any additional equipment and cables related to these additional circuits in a manner consistent with the other equipment and cable selection requirements of this Standard. (1 SR)
- HLR-CS-C: The Fire PRA shall document the cable selection and location process and results in a manner that facilitates Fire PRA applications, upgrades, and peer review. (4 SRs)

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DETAILED CIRCUIT FAILURE ANALYSIS
HLRs (per the PRA Standard) – CF element

- HLR-CF-A: The Fire PRA shall determine the applicable conditional probability of the cable and circuit failure mode(s) that would cause equipment functional failure and/or undesired spurious operation based on the credited function of the equipment in the Fire PRA. (2 SRs)
- HLR-CF-B: The Fire PRA shall document the development of the elements above in a manner that facilitates Fire PRA applications, upgrades, and peer review. (1 SR)

DETAILED CIRCUIT FAILURE ANALYSIS

NEI 00-01, Rev. 2, Section 3.5 – Circuit Analysis and Evaluation

- NEI 00-01, Rev. 2, “Guidance for Post-Fire Safe Shutdown Circuit Analysis,” May 2009.
- Follows closely to Task 9 methodology of NUREG/CR-6850, EPRI 1011989.
- Types of circuit failures to be considered:
  - Open circuits
  - Shorts-to-ground / Short circuits
  - Hot shorts (90% of the difficult cases)
- Other considerations:
  - Common power supplies (i.e., inadequate coordination)
  - Common enclosures (i.e., inadequate circuit protection)

DETAILED CIRCUIT FAILURE ANALYSIS
Introduction (per NUREG/CR-6850, EPRI 1011989)

- Fundamentally this is a <u>deterministic analysis</u>
- Perform <u>coincident</u> with cable selection (Task 3) to the extent feasible and cost effective ("Task 9A")
- Difficult cases generally reserved for situations in which Quantitative Screening indicates a clear need and advantage for further analysis
- Detailed Failure Modes Analysis
  - Requires knowledge about desired functionality and component failure modes
  - Conductor-by-conductor evaluation (Hot Probe method recommended)
- Objective is to screen out all cables that **CANNOT** impact the ability of a component to fulfill the specific function of interest

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DETAILED CIRCUIT FAILURE ANALYSIS
Introduction (continued)

- Failure modes considered
  - Single shorts-to-ground (reference ground)
    - Grounded system
    - Ungrounded system
    - Resistance grounded system
  - Single hot shorts
  - Compatible polarity multiple hot shorts for ungrounded AC and DC circuits (see PIRT Report fault mode tables)
    - Includes ground equivalent hot shorts
  - Coincident independent hot shorts on separate cables
  - Multiple intra-cable hot shorts
  - Cables associated through a common power supply

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DETAILED CIRCUIT FAILURE ANALYSIS
Introduction (continued)

- Failure modes **NOT** considered
  - 3-phase proper sequence hot shorts
    - NUREG/CR-6850: Consider for high consequence equipment with thermoplastic insulated conductor or ungrounded configuration
    - NUREG/CR-7150: Excluded in all cases
  - Certain compatible polarity multiple hot shorts for ungrounded AC and DC circuits (see PIRT Report fault mode tables)
  - Open circuit conductor failures (Reconsider)
  - Multiple high-impedance faults

Note: If conducting a combined NFPA-805 and Fire PRA circuit analysis, NEI 00-01 requires open circuits be considered.

DETAILED CIRCUIT FAILURE ANALYSIS
Introduction (continued)

Application of Task 9A versus Task 9B:

- Task 9A circuit analysis performed as part of the Task 3, Cable Selection, process
  - Intended to be a quick screening determination whether a given cable is able to adversely impact the ability of a required component to complete its credited function, and thus should be put on the Fire PRA Cable List
- Detailed circuit analysis (Task 9B) is performed as described by the Task 9 methodology (i.e., the basis of this presentation)
  - Intended to be a more robust assessment of a cable's potential impact on the Fire PRA component of interest and is performed later in the overall Fire PRA process, after some screening has occurred

Note: The more experience an analyst has performing Task 9B level analyses, the more proficient they become in performing Task 9A level screening.

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DETAILED CIRCUIT FAILURE ANALYSIS
Process

- The Task 9 procedure is subdivided into three (3) primary steps:
  - Step 1: Compile and Evaluate Prerequisite Information and Data
  - Step 2: Perform Detailed Circuit/Cable Failure Analysis
  - Step 3: Generate Equipment Failure Response Reports

DETAILED CIRCUIT FAILURE ANALYSIS
Task Interfaces - Inputs

- Fire PRA Components List (Task 2)
- Fire PRA Cable List (Task 3)
- Fire PRA Database (Support Task B)
- Results of Quantitative Screening (Task 7)
- Results of Detailed Fire Modeling (Task 11)
- Appendix R Circuit Analysis
- Plant Drawings
- CRS Database

DETAILED CIRCUIT FAILURE ANALYSIS
Task Interfaces - Outputs

- Same as Task 3

- May include updates to:
  - Component Analysis (“Work”) Packages and circuit analysis data
  - Circuit Analysis Data
  - Fire PRA Database & Model Updates

DETAILED CIRCUIT FAILURE ANALYSIS

Step 1 - Compile Prerequisite Information

- Same prerequisites as Task 3
- Might need additional drawings or information to ascertain failure modes

DETAILED CIRCUIT FAILURE ANALYSIS
Step 2 - Perform Circuit Failure Analysis

- Step 2.1: Develop Strategy/Plan for Circuit Analysis
- Step 2.2: Develop Plant-Specific Rules for Performing the Detailed Circuit Analysis
- Step 2.3: Perform Detailed Circuit Failure Analysis
- Document Analysis Results $\Rightarrow$ Component Work Packages
- Corresponding PRA Standard SRs: CS-A2, A3, A5, A6, A7, A8, A9
- Corresponding NEI 00-01, Rev. 2, Section: 3.5.2

DETAILED CIRCUIT FAILURE ANALYSIS
Considerations in Developing Plant-Specific Rules

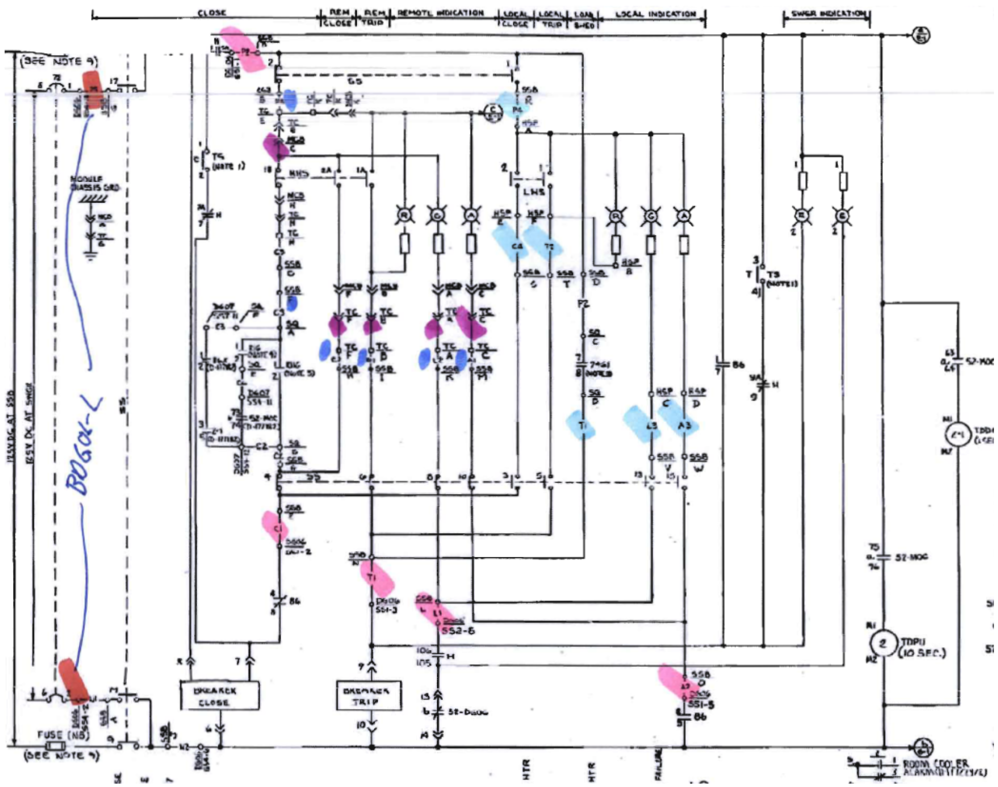
- Translate the credible failure modes to practical working instructions
- Pay attention to ungrounded control circuits – they are the most difficult to get right
- Set conventions so analysts perform and document the analysis in a consistent manner
- What sub-component breakouts are beneficial
- Where should pseudo components be used
- How will cable fault codes be used

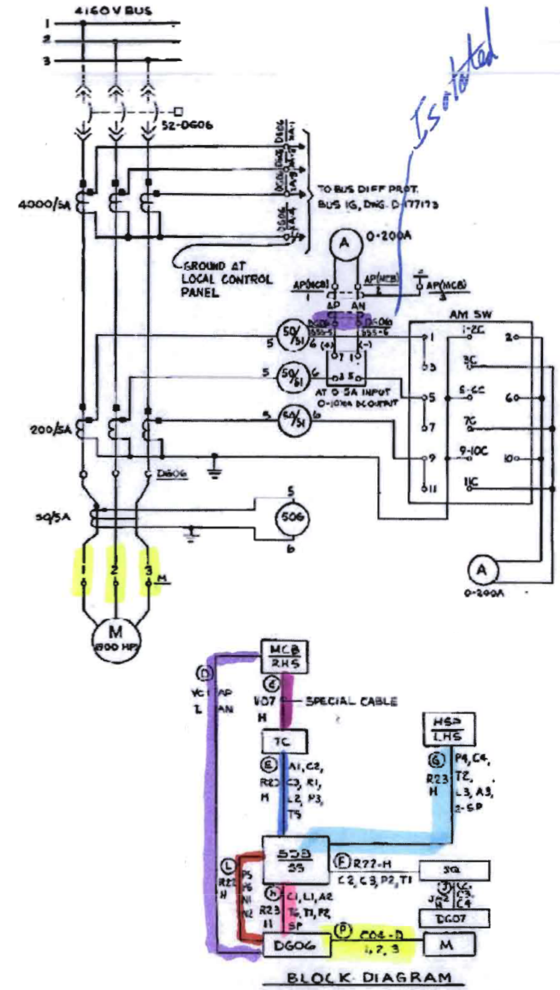
DETAILED CIRCUIT FAILURE ANALYSIS
Performing Analysis

- You cannot perform detailed circuit analysis if you do not know how the circuit works
- You cannot perform detailed circuit analysis if you do not know the initial state and desired state of the component that corresponds to the PRA Basic Event
- You cannot perform detailed circuit analysis if you do not know the position of auxiliary contacts
- You do need to approach the analysis in a systematic manner
- Highlighting drawings is the best means of doing the analysis

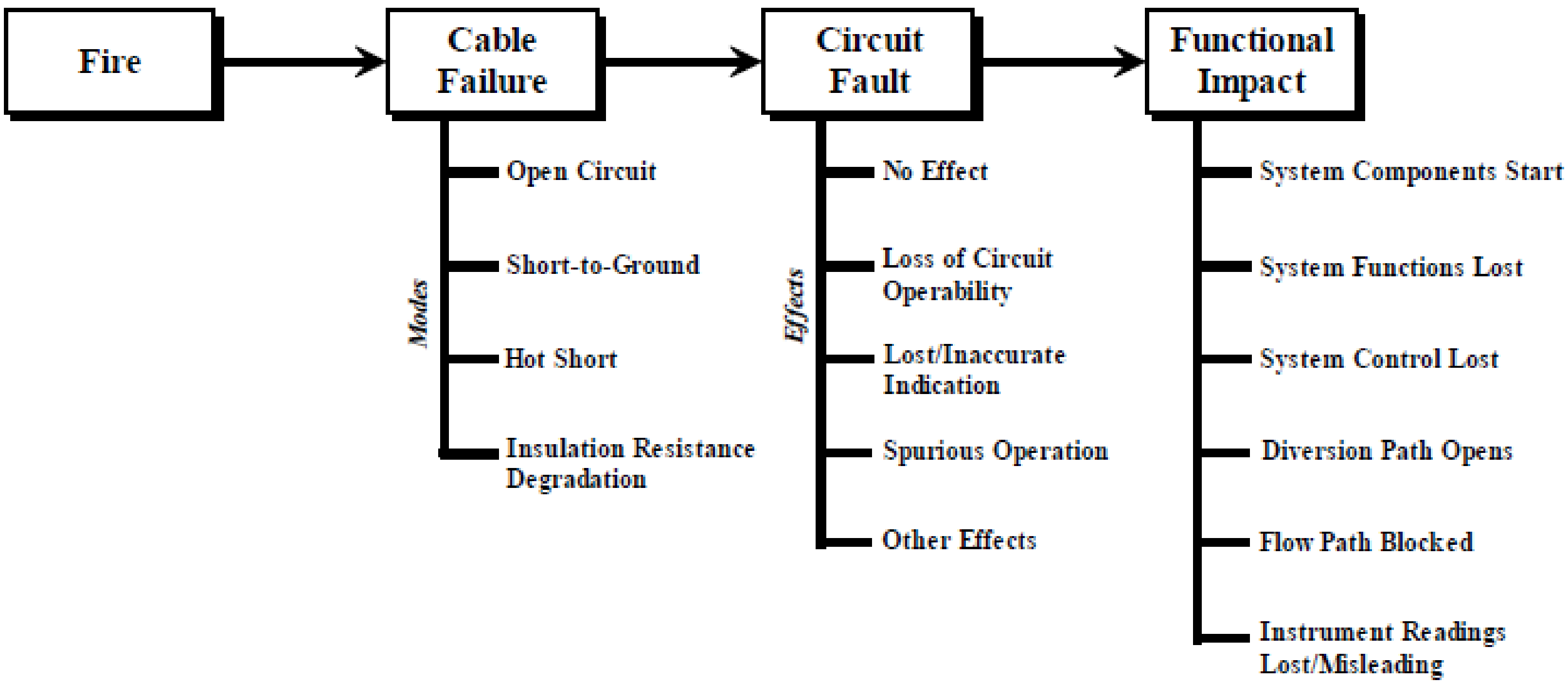
DETAILED CIRCUIT FAILURE ANALYSIS
Performing Analysis (continued)

- Analyze conductors
- Document cables





DETAILED CIRCUIT FAILURE ANALYSIS
Logical Thinking



DETAILED CIRCUIT FAILURE ANALYSIS
Step 3 – Target Equipment Failure Response

- Same process as described for Task 3
  - Data Entered into Fire PRA Database
  - Mapping of Circuit Analysis to Model Basic Events is CRITICAL to accurate results
  - Sorts and Queries to Generate Target Equipment Loss Reports
- Corresponding PRA Standard SRs: CF-B1

DETAILED CIRCUIT FAILURE ANALYSIS
Caveats & Recommendations

- This detailed circuit failure analysis methodology is a Static Analysis (no timing issues are considered)
- Be aware of possible Cable Logic Relationships
- Work Packages (Highly Recommended!)
- "Hot Probe" (Conductor-to-Conductor) analysis must be rolled-up to cable/component level
- Outputs need to be Compatible with Fire PRA Database format and field structure
- Coordinate with the Fire PRA Modelers/Analysts early-on to Define the Fire PRA Component Failure Modes of Concern

DETAILED CIRCUIT FAILURE ANALYSIS
Caveats & Recommendations (Continued)

- In most cases the “Hot Probe” method is all inclusive of intra- and inter-cable hot shorts
- When doing detailed circuit analysis think in terms of the “Target” conductors and not the “Source” conductors
- Task 9A analysis is fundamentally “design based” and not “configuration based”
  - Is the fault mode possible by the inherent design and required functionality?
  - Configuration-based screening often boils down to determining if credible source conductors exist
- Be cautious of screening cables based on old fault codes assigned to cables

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DETAILED CIRCUIT FAILURE ANALYSIS
Recommended Notation for Analysis

- It is highly recommended that the analysts employ a consistent notation for documenting results
- In this training course, we will use the following notations:

Primary Circuit Failure Mode Descriptions

EI	Erroneous Indication
EIS	Erroneous Indicating Signal
LIS	Loss of Indicating Signal
LOC	Loss of Control
LOCP	Loss of Control Power (usually applies only to metalclad switchgear that depend on a separate control power source to actuate)
LOI	Loss of Indication
LOP	Loss of Power (to the circuit)
SA	Spuriously Actuates or Spurious Actuation
SC	Spuriously Closes
SO	Spuriously Opens
SS	Spuriously Starts/Runs

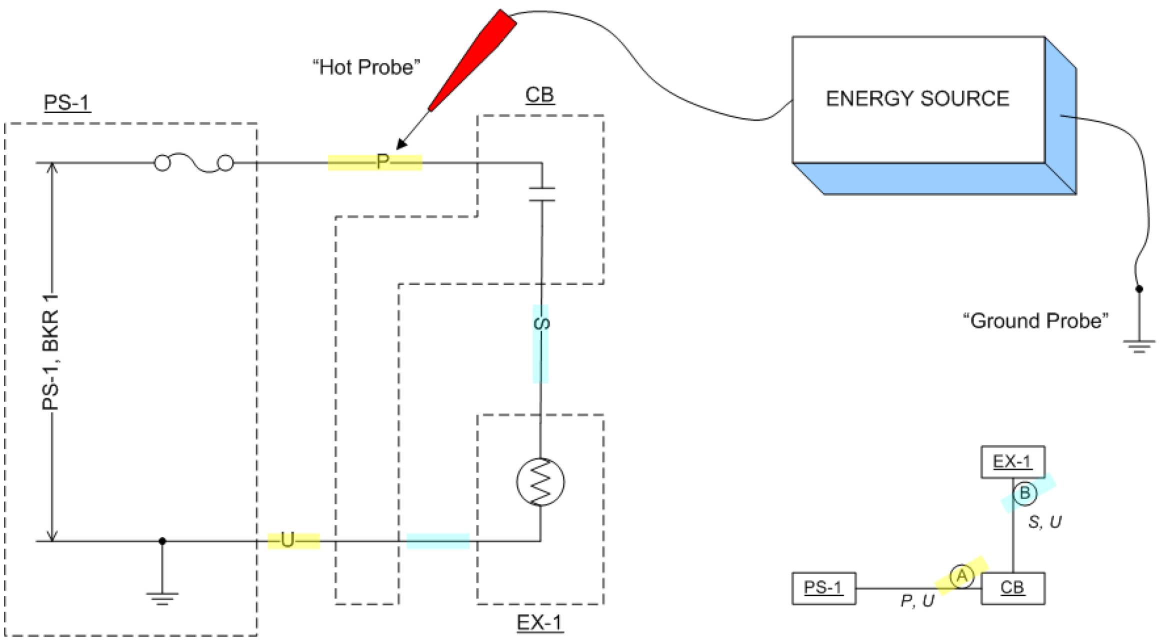
Causal Modifiers

BF	Blown Fuse
HS	Hot Short
PR	Protective Relay
SG	Short to Ground

Example Usage:

LOP-BF:	Loss of power due to a blown fuse
SO-HS:	Spuriously opens due to a hot short
LOC-PR:	Loss of control due to a protective relay

DETAILED CIRCUIT FAILURE ANALYSIS
Hot Probe Method – A very simple example



What happens when the **Hot** & **Ground** probes contact:

Conductor	Hot (+) Probe	Ground Probe
P?		
S?		
U?		

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DETAILED CIRCUIT FAILURE ANALYSIS
Hot Probe Method Results & Documentation

CIRCUIT ANALYSIS WORKSHEET

Component ID: Ex-1 Component Type: Electrical Component

Component Description: Example 1

Normal Position: DEENERGIZED

Failed Electrical Position: DEENERGIZED

Failed Air Position: N/A

Function State:

Initial Position: DEENERGIZED

Desired Position DEENERGIZED

BE Code: EX1-SA

High Consequence Component Yes ☐ No ☒

Power Supplies: PS-1 Breaker: 1 Req'd ☐

Breaker: Req'd ☐

Cable Analysis:

Cable ID	Req'd ?	MHS ?	Fault Consequence	Comments
EX1A	N			
EX1B	Y		SA, LOC	Pos. hot probe on S causes SA Pos. hot probe on U causes LOC
				Ground probe on S causes LOC

This information should be available from component selection.

If not complete, then get the missing information before beginning.

This part and 2nd page ***you*** will complete.

Basically, this documents your analysis.

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DETAILED CIRCUIT FAILURE ANALYSIS
Questions

Any Questions?

DETAILED CIRCUIT FAILURE ANALYSIS

Mapping HLRs & SRs for the CS technical element to NUREG/CR-6850, EPRI 1011989

Technical Element	HLR	SR	6850/1011989 Sections that cover SR	Comments
CS	A	The Fire PRA shall identify and locate the plant cables whose failure could adversely affect credited equipment or functions included in the Fire PRA plant response model, as determined by the equipment selection process (HLR-ES-A, HLR-ES-B, and HLR-ES-C).		
		1	3.5.2	Covered in "Fire PRA Cable Selection" chapter
		2	9.5.2	
		3	3.5.2, 9.5.2	Also covered in "Fire PRA Cable Selection" chapter
		4	3.5.3	Covered in "Fire PRA Cable Selection" chapter
		5	9.5.2	
		6	3.5.4, 9.5.2	Also covered in "Fire PRA Cable Selection" chapter
		7	9.5.2	
		8	9.5.2	
		9	9.5.2	
		10	3.5.5	Covered in "Fire PRA Cable Selection" chapter
		11	3.5.5	Covered in "Fire PRA Cable Selection" chapter
	B	The Fire PRA shall (a) perform a review for additional circuits that are either required to support a credited circuit (i.e., per HLR-CS-A) or whose failure could adversely affect a credited circuit (b) identify any additional equipment and cables related to these additional circuits in a manner consistent with the other equipment and cable selection requirements of this Standard		
		1	3.5.3, 3.5.4	Covered in "Fire PRA Cable Selection" chapter
	C	The Fire PRA shall document the cable selection and location process and results in a manner that facilitates Fire PRA applications, upgrades, and peer review.		
		1	3.5.6	Covered in "Fire PRA Cable Selection" chapter
		2	3.5.6	Covered in "Fire PRA Cable Selection" chapter
		3	3.5.6	Covered in "Fire PRA Cable Selection" chapter
		4	3.5.6	Covered in "Fire PRA Cable Selection" chapter

DETAILED CIRCUIT FAILURE ANALYSIS

Mapping HLRs & SRs for the CF technical element to NUREG/CR-6850, EPRI 1011989 (continued)

Technical Element	HLR	SR	6850/1011989 Sections that cover SR	Comments
CF	A	The Fire PRA shall determine the applicable conditional probability of the cable and circuit failure mode(s) that would cause equipment functional failure and/or undesired spurious operation based on the credited function of the equipment in the Fire PRA.		
		1	10.5.2, 10.5.3	Covered in "Circuit Failure Mode Likelihood Analysis" chapter
		2	10.5.3	Covered in "Circuit Failure Mode Likelihood Analysis" chapter
	B	The Fire PRA shall document the development of the elements above in a manner that facilitates Fire PRA applications, upgrades, and peer review.		
		1	9.5.3, 10.5.3	Also covered in "Circuit Failure Mode Likelihood Analysis" chapter

DETAILED CIRCUIT FAILURE ANALYSIS

Mapping NEI 00-01, Rev. 2, Circuit Analysis and Evaluation to NUREG/CR-6850, EPRI 1011989

NEI 00-01, Rev. 2, Section	NEI 00-01, Section 3.5.2 – Types of Circuit Failures	6850/1011989 Sections that cover step	Comments
3.5 – Circuit Analysis and Evaluation	3.5.2.1: Due to an Open Circuit	N/A	Open circuits not considered in 6850/1011989 as discussed in 9.5.2
	3.5.2.2: Due to a Short-to-Ground	9.5.2	
	3.5.2.3: Due to a Hot Short	9.5.2	
	3.5.2.4: Due to Inadequate Circuit Coordination	3.5.4	Covered in "Fire PRA Cable Selection" chapter
	3.5.2.5: Due to Common Enclosure Concerns	3.5.4	Covered in "Fire PRA Cable Selection" chapter

Module II – Circuit Analysis

Circuit Analysis Basics Task 10: Circuit Failure Mode Likelihood Analysis

Joint EPRI/NRC-RES Fire PRA Workshop
August 24-28

Dan Funk – Jensen Hughes

Gabe Taylor – U.S. NRC

A Collaboration of the Electric Power Research Institute (EPRI) & U.S. NRC Office of Nuclear Regulatory Research (RES)

CIRCUIT FAILURE MODE LIKELIHOOD ANALYSIS
Disclaimer

Recent advances in the state of knowledge related to the information contained in Task 10 of NUREG/CR-6850, EPRI 1011989 has provided refined methods for calculating the likelihood and duration of hot short-induced spurious operations caused by fire damage.

This presentation will focus on the use and application of the state-of-the-art methods and data presented in NUREG/CR-7150, Volume 1 & 2.

Content of this presentation doesn't constitute Regulatory Positions

CIRCUIT FAILURE MODE LIKELIHOOD ANALYSIS
Purpose & Scope (per 6850/1011989)

The Circuit Failure Mode Likelihood Analysis Task is intended to:

- Establish first-order probability estimates for the Circuit Failure Modes of interest

AND

- Correlate those Failure Mode Probabilities to specific components

Circuit Failure Mode Likelihood Analysis (CFMLA) Guidance

EPRI 1011989 NUREG/CR-6850
Final Report

EPRI/NRC-RES
Fire PRA Methodology for Nuclear Power Facilities
Volume 2: Detailed Methodology

Electric Power Research Institute

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10
CIRCUIT FAILURE MODE LIKELIHOOD ANALYSIS (TASK 10)

10.1 Purpose

Conducting a Fire PRA in accordance with this methodology necessitates an analysis of fire-induced circuit failures beyond that typically conducted during original Fire PRAs. The circuit analysis elements of the project are conducted in three distinct phases:

4. Fire PRA cable selection (Task 3),
5. Detailed circuit failure analysis (Task 9), and
6. Circuit failure mode likelihood analysis (Task 10).

This task provides methods and instructions for conducting the third phase of circuit analysis – circuit failure mode likelihood analysis for Fire PRA cables. Task 10 estimates the probability of hot short cable failure modes of interest, which in turn can be correlated to specific component failure modes. As discussed in Section 3.3.2 of Volume 1, the methods and techniques for deriving circuit failure mode probability estimates are based on limited data and experience. Consequently, this area of analysis is not yet a mature technology, and undoubtedly further advances and refinements will come with time. Nonetheless, the methods and techniques presented in this chapter represent the current state of knowledge and provide a reasonable approach for establishing first-order circuit failure mode probability estimates, albeit with relatively high uncertainty tolerances.

10.2 Scope

Chapter 10 provides methods and technical considerations for assigning probability estimates to specific cable failure modes associated with fire-induced cable damage.

This task does not address the implementation of plant-specific quality assurance or configuration control requirements that might apply to a Fire PRA. Nor is it intended to validate the accuracy of plant-specific data extracted from plant drawings, documents, or databases. Each plant should follow appropriate quality assurance, administrative, and configuration control procedures applicable to the work being conducted. The need to validate input source documents should be addressed as part of assembling the prerequisite information in Step 1.

10-1

J
APPENDIX FOR CHAPTER 10, TECHNICAL BASIS FOR CIRCUIT FAILURE MODE LIKELIHOOD EQUATIONS

J.1 Computational Probability Estimates

This method involves application of the Circuit Failure Mode Probability Estimation Formulas. The likelihood of occurrence for a specific failure mode (P_{fM}) is estimated by using the formula

$$P_{fM} = CF \times P_{CC}$$

Where:

P_{fM} = The probability that a specific hot short failure mode of interest will occur in a specific circuit given a fire of sufficient intensity to cause cable damage,

P_{cc} = The probability that a conductor-to-conductor short will occur prior to a short-to-ground or short to a grounded conductor, and

CF = A configuration factor applied to P_{cc} to accounts for the relative number of source conductors and target conductors. Target conductors are those conductors of a circuit that, if contacted by an electrical source of proper magnitude and voltage, will result in abnormal energization of the circuit, component, or device of concern. Source conductors represent energized conductors that are a potential source of electrical energy.

J.1.1 Estimating P_{cc}

P_{cc} is a probability factor that accounts for the likelihood of conductor-to-conductor faults occurring before a conductor-to-ground fault. A conductor-to-ground fault could be a short directly to a grounded surface (e.g., conduit, tray, steel member, etc.), or a short to an intentionally grounded conductor (i.e., the neutral or common conductor of a circuit). The predicted outcome is the same in either case. For an energized conductor, fault current will flow, causing a circuit overcurrent protective device (circuit breaker or fuse) to actuate. For a non-energized conductor, the ground fault places the grounded conductor in a benign state, since any subsequent fault to an energized conductor will behave as a short-to-ground, as described above[24].

[24] This argument is not strictly true for ungrounded systems because earth ground does not provide a free return path for fault current to the reference ground. A dead short only develops when an energized conductor touches a reference ground conductor of the ungrounded system.

K
APPENDIX FOR CHAPTER 10, EXAMPLES OF COMPONENT CIRCUIT FAILURE MODE LIKELIHOOD ANALYSES

This appendix demonstrates the procedure for estimating the likelihood of specific hot short cable failure modes for a number of circuits, each with particular and (in some cases) unique features or characteristics. The examples presented here correspond to the examples provided for detailed circuit analysis (Appendix I) and include:

- A typical ungrounded DC SOV control circuit
- A typical MOV control circuit
- A control circuit employing double-pole isolation switches
- An ungrounded AC MOV control circuit with contacts on the downstream leg and normal contract arrangement
- An ungrounded AC MOV control circuit with normal contract arrangement
- An MOV with redundant main contactors and fully independent control circuits

K.1 Typical SOV Control Circuit

Figure K-1 shows a block diagram for the component SOV with the specific cables of interest highlighted. The cable of interest for this analysis is identified as Cable B. Figure K-2 shows an overall schematic diagram of the control circuit for the SOV in its normal operating state (i.e., deenergized, open, with the red status indication lit). The conductors contained within Cable B are also noted on the schematic—P00, N00, R00, G00, SV0, and SV1.

As a result of the detailed circuit analysis during Task 9 activities, it was determined that there were three possible component failure responses: Loss of control, erroneous status indications, and spurious closure of the valve. These equipment responses correspond to the component failure codes LOC, EI, and SO, respectively.

The analyst should first note the characteristics of the cable and circuit: A seven-conductor thermoset cable associated with an ungrounded DC circuit without a CPT and with one common conductor (N00) and three energized conductors (P00, R00, and SV1). For the purpose of this example, it is assumed that the cable is routed in an open cable tray with other multi-conductor cables.

K-1

Existing "Old" Guidance

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CFMLA Guidance

Existing “Old” Guidance

- NUREG/CR-6850
  - Section 10, CFMLA (Task 10)
  - Appendix J, Technical Basis for Equations
  - Appendix K, Examples
- NFPA 805 FAQ 08-0047, Cable Dependency (NUREG/CR-6850, Supp. 1, Ch. 15)
- NFPA 805 FAQ 08-0051, Hot Short Duration (NUREG/CR-6850, Supp. 1, Ch. 16)

CFMLA Guidance

NUREG/CR-7150, Vol. 1
BNL-NUREG-98204-2012

EPRI 1026424
Final Report

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

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

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NUREG/CR-7150, Vol. 2
BNL-NUREG-98204-2012

EPRI 3002001989
Final Report

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

Volume 2:
Expert Elicitation Exercise for Nuclear Power Plant Fire-Induced Electrical Circuit Failure

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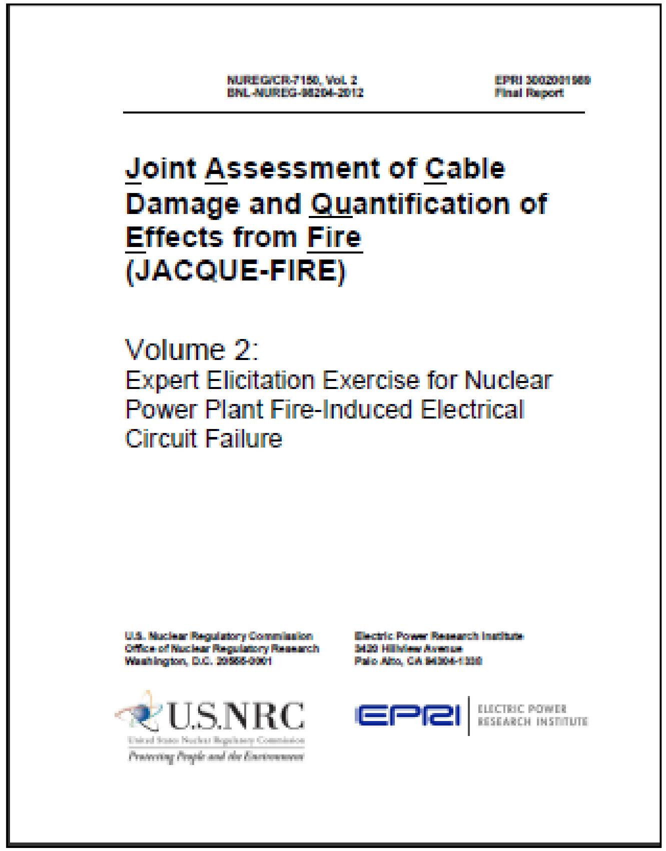
"New" Guidance

CFMLA Guidance

“New” and Existing Guidance

- NUREG/CR-6850, Ch. 10, Appendices J&K (as supplemented)
- NFPA 805 FAQ 08-0047, Cable Dependency (NUREG/CR-6850, Supp. 1, Ch. 15)
- NRC Interim Guidance
  - 2/12/14 (NRC ADAMS ML14017A135)
  - NRC-NEI letter dated 4/23/14 (ML14086A165).
- NUREG/CR-7150 / EPRI 1026424, JACQUE-FIRE, Volume 1 (ML12313A105)
- NUREG/CR-7150 / EPRI 3002001989, JACQUE-FIRE, Volume 2 (ML14141A129)

NUREG/CR-7150, Vol. 2 (JACQUE-FIRE)



NUREG/CR-7150, Vol. 2
BNL-NUREG-98204-2012

EPRI 3002001989
Final Report

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

Volume 2:
Expert Elicitation Exercise for Nuclear Power Plant Fire-Induced Electrical Circuit Failure

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

Electric Power Research Institute
3420 Hillview Avenue
Palo Alto, CA 94304-1338

NUREG/CR-7150, JACQUE-FIRE, Volume 2, Expert Elicitation Exercise for Nuclear Power Plant Fire-Induced Electrical Circuit, May 2014 (ML14141A129)

NUREG/CR-7150, Vol. 2 (JACQUE-FIRE)

- Advance the state-of-the-art for quantification of fire-induced circuit failure model likelihood analysis
- Use expert judgment and recent test results to quantify conditional hot short-induced spurious operation likelihood estimates and conditional probability of spurious operation duration
- Used results from NUREG/CR-7150 Vol. 1 and test data
- Panel proponents presented/defended their estimates or models.
- Technical integration team determined direction on how to use proponent input
- BNL combined proponents input and developed report

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- These five variables resulted in developing spurious operation conditional probability tables for the following two control circuit configurations, namely;
- 1. Single Break (or Contact) Control Circuits
  a. Base Case - SOV
  b. MOV
  c. Medium Voltage* Circuit Breaker
- 2. Double Break (or Contact) Control Circuits (for ungrounded circuits)
  a. Base Case - SOV
  b. MOV

*1,000 to 15,000Volts

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- The control circuit cases for hot short-induced spurious operation evaluated by the PRA panel were categorized in Volume 1 using the following five (5) circuit variables:
  - Circuit Configurations – Single Break, Double Break
  - Circuit Type Cases – SOV, MOV, Medium Voltage Circuit Breaker
  - Circuit Grounding/Power Supply Types – Grounded AC, Ungrounded AC (with Individual CPTs), Ungrounded DC (or Ungrounded Distributed AC*)
  - Target Cable Constructions – TS-insulated conductor cable, TP-insulated conductor cable, Metal Foil Shield Wrap Cable**, Armored Cable
  - Conductor Failure Modes – Intra-cable hot short, Inter-cable hot short, GFEHS

* Distributed ac is a term used in NUREG/CR-7150 to describe an ungrounded ac system that is not associated with a single motor control center control power transformer.

** Grounded robust metallic shield wrap (not simply aluminized Mylar).

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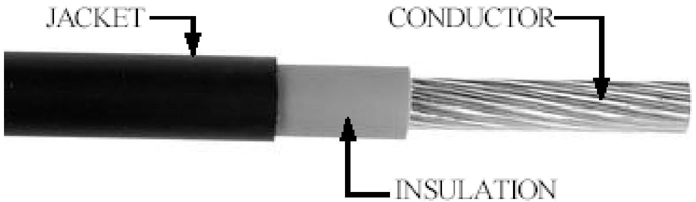


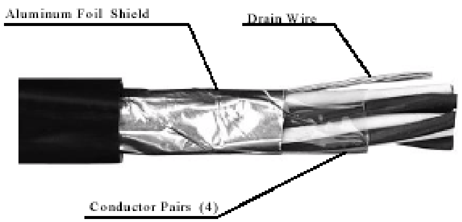
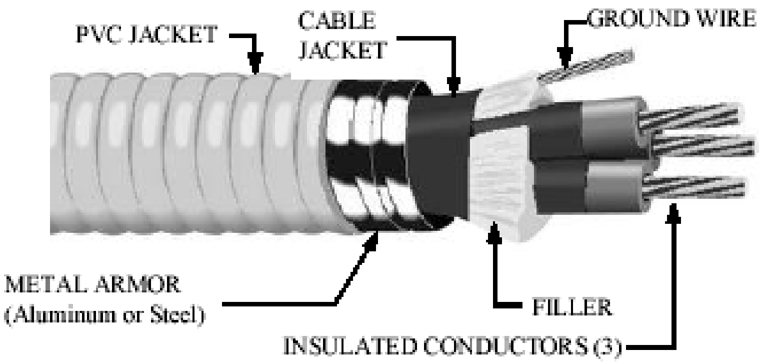


Figure 3.6 Illustration of Instrument Cable



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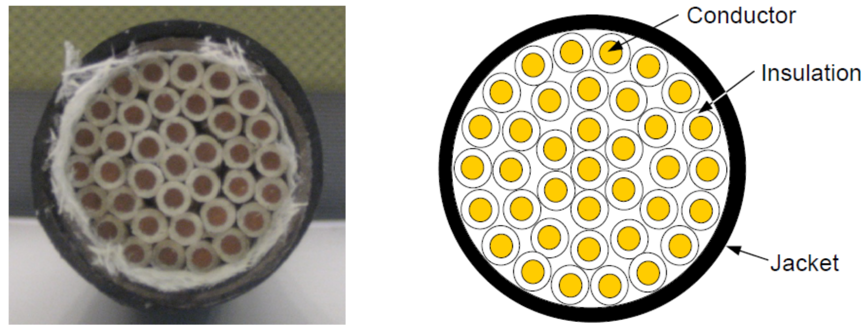

Figure 6-5. Photo and Illustration of 37/C Trunk Cable

Figure 6-4. Typical Panel Wiring Configurations

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- **Spurious Operation Duration**
  - Section 7 of NUREG/CR-7150, Vol. 2 offers guidance in applying the spurious operation conditional probability tables, the spurious operation duration plots, and related issues that should be considered in analyzing the fire PRA circuit.
  - Two duration curves are provided that estimate the likelihood of a spurious operation lasting for “T > t” minutes (i.e., P(T>t))
  - To determine what T to use, the analysis must determine the critical spurious operation duration for the particular system being analyzed
  - Reactor and system engineers, along with PRA analysis will likely have to be involved to determine this time. Thermal-hydraulic analysis of the system under evaluation will likely have to be performed
  - Once this time is determined, a conditional spurious operation duration likelihood estimate can be obtained

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- **Durations – Assumptions and Limitations**

Durations should NOT be applied to

- Grounded ac circuits, spurious operations of equipment caused by grounding of one or more conductors.
- If spurious operations produced by a hot short would not clear once the cable is grounded (e.g., switchgear breaker control power after breaker spuriously closed)
- Shorts to ground on an "off-scheme" circuit. Duration could be applied if a functional circuit analysis demonstrating the effect of a short to ground on the auxiliary circuit were conducted and indicated that application of duration is appropriate.
- Circuit with a "seal-in" or "lock-in" design. Circuits that only require a momentary spurious operation to cause the device to change states.

NUREG/CR-7150, Vol. 2

Spurious Operation Duration

- NUREG/CR-7150, Vol. 2 Section 7.3.4.2 contains considerations and limitations in applying durations.
- During final issuance of NUREG, this information was developed and refined.
- Guidance provides limits on MSO dependency treatment.
- Guidance/considerations provided based on:
  - Number of cables involved
  - Number of conductors
  - Single or double break

CFMLA Guidance

Key Insights/Changes NUREG/CR-7150 Vol. 2

- There is no longer a distinction among raceway type (i.e., Tray or Conduit).
- There is no longer a distinction between multi-conductor cable (M/C) and single conductor cable (1/C).
- There is no longer a distinction between circuits with a CPT and those without a CPT.
- The table has been split into spurious operation probabilities separated by three distinct circuit configurations, namely; grounded AC, ungrounded AC (powered from an individual CPT), and ungrounded DC (or ungrounded distributed AC).
- The segregation in the tables for ungrounded AC (powered from an individual CPT) and ungrounded DC (or ungrounded distributed AC) deals with the failure modes associated with these different types of circuit power configurations and not the specific inclusion of a CPT.
- Ground fault equivalent hot short (GFEHS) have been included as a failure mode for ungrounded DC or ungrounded distributed AC circuits.

Methodology

NUREG/CR-7150 Vol. 2 Process

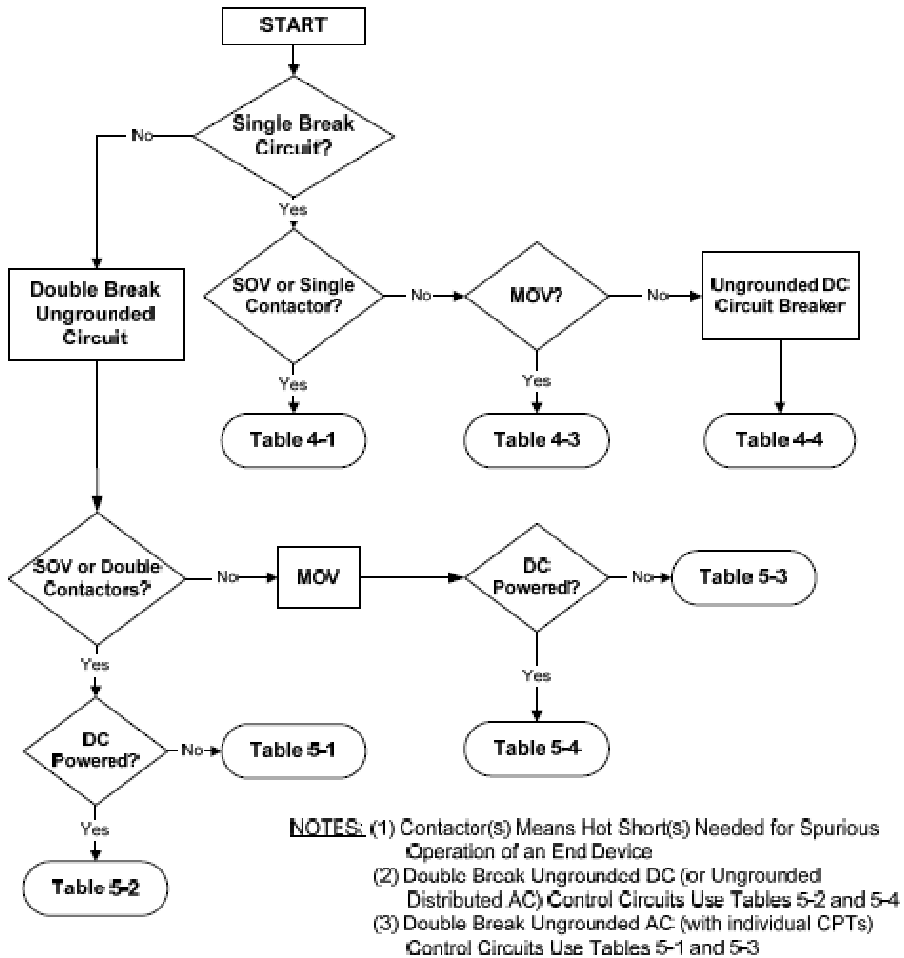

Figure 7-1. Flowchart Showing Process Used to Determine Appropriate Spurious Operation Table

NUREG/CR-7150, Vol. 2 Process

- Step 1: Compile and Evaluate Prerequisite Information and Data
- Step 2: Perform Circuit Failure Mode Likelihood Analyses
- Step 3: Document the Results

NUREG/CR-7150, Vol. 2 Process

Step 1: Compile and Evaluate Prerequisite Information and Data

- Ensure that prerequisite information and data are available and usable before beginning the analyses.
- Confirm completion of Detailed Circuit Analysis for components of interest
- Collect important cable and circuit configuration attribute information:
- Applicable cable Failure Modes (from Detailed Circuit Analysis)
  - Intra-cable, Inter-cable, GFEHS
- Circuit Design
  - Single or Double Break

NUREG/CR-7150, Vol. 2 Process

Step 1: Compile and Evaluate Prerequisite Information and Data (cont'd)

- Circuit Type
  - SOV (single contactor type), MOV, Breaker
- Circuit Grounding and Power source(s)
  - Grounded vs. Ungrounded
  - AC vs. DC
- Cable Configuration
  - Thermoset-insulated, Thermoplastic-insulated, Metal Foil Shield Wrap, Armored

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Step 2: Circuit Failure Mode Likelihood Analysis

- **Current "Old" Method: Failure Mode Probability Estimate Tables**
  - Table 10-1, Thermoset Cables with CPTs
  - Table 10-2, Thermoset Cables without CPTs
  - Table 10-3, Thermoplastic Cables with CPTs
  - Table 10-4, Thermoplastic Cables without CPTs
  - Table 10-5, Armored or Shielded Cables

NUREG/CR-7150, Vol. 2 Process

Step 2: Circuit Failure Mode Likelihood Analysis (cont'd)

- **New Method-Failure Mode Probability Estimate Tables**
  - Table 4-1. Conditional Probability of Spurious Operation: SOV Single Break-Control Circuits
  - Table 4-3. Conditional Probability of Spurious Operation: MOV Single Break Control Circuits
  - Table 4-4. Conditional Probability of Spurious Operation: Ungrounded DC Control Circuits for Medium Voltage Circuit Breaker

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Step 2: Circuit Failure Mode Likelihood Analysis (cont'd)

- **New Method-Failure Mode Probability Estimate Tables**
  - Table 5-1 - Conditional Probability of Spurious Operation: Double Break Control Circuits for Ungrounded AC (w/ individual CPTs) Base Case – SOV
  - Table 5-2 - Conditional Probability of Spurious Operation: Double Break Control Circuits
  - Table 5-3 - Conditional Probability of Spurious Operation: Double Break Control Circuits for Ungrounded AC (w/ individual CPTs) Motor-Operated Valve
  - Table 5-4 - Conditional Probability of Spurious Operation: Double Break Control Circuits Ungrounded DC (or Ungrounded Distributed AC)

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Step 2: Circuit Failure Mode Likelihood Analysis

- **Spurious Operation Duration Tables or Probability Distribution**
  - Table 6-3. Tabulated Spurious Operation Duration Conditional Probability Values for AC and DC Control Circuits

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Step 2: Circuit Failure Mode Likelihood Analysis (cont'd)

- **Choosing the Values**
  - "Aggregate" represents a mathematical summation of probability distributions for all possible circuit failure modes due to hot shorts within a specific cable insulation-power supply scenario.
  - (NUREG/CR-7150, Vol. 2, Section 7.2) Aggregate values are given for every case where all potential hot short-induced failure modes are applicable. Unlike NUREG/CR-6850, the new estimates are explicit parametric distributions.
  - Aggregate row in the tables represents the summation from using these parametric distributions for all applicable modes of hot short failure.
  - Unless it is demonstrated that a cable under evaluation is only susceptible to a single failure mode, the aggregate values should be used.

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NUREG/CR-7150, Vol. 2 Process

Step 2: Circuit Failure Mode Likelihood Analysis (cont'd)

- **Choosing the Values**

- Ungrounded DC (or ungrounded distributed AC) control circuits are subject to three possible hot short failure modes. The Aggregate column provides the conditional probability when all three hot short modes are applicable. When 2 out of these 3 hot short modes are applicable; the combined conditional probability of the two hot short failure modes must use their sum (using Boolean OR). See NUREG/CR-7150, Vol. 2 Section 7.2

- As noted in Section 6, the conditional probabilities of duration are not separated for intra-cable, inter-cable, or aggregate spurious operation events.

NUREG/CR-7150 Vol. 2 Tables

Table 4-1. Conditional Probability of Spurious Operation: SOV Single Break-Control Circuits

Power Supply →			Grounded AC			Ungrounded AC (w/ Individual CPTs)			Ungrounded DC (or Ungrounded Distributed AC)			
Target Cable Configuration		Beta Distribution Characteristics	Conductor Hot Short Failure Mode									
			Intra-Cable	Inter-Cable	Aggregate	Intra-Cable	Inter-Cable	Aggregate	Intra-Cable	Inter-Cable	Ground Fault Equivalent	Aggregate
			1	2	3	4	5	6	7	8	9	10
Thermoset-Insulated Conductor Cable	1	Alpha	8.54	0.36	8.79	4.73	0.60	4.74	10.16	0.32	2.27	12.76
		Beta	11.74	35.25	11.81	2.69	613.31	2.69	11.70	50.01	11.45	10.18
		5%	*2.5E-01*	*4.6E-06*	*2.6E-01*	*3.4E-01*	*8.9E-06*	*3.4E-01*	*2.9E-01*	*1.2E-06*	*3.8E-02*	*3.9E-01*
		Mean	**4.2E-01**	**1.0E-02**	**4.3E-01**	**6.4E-01**	**9.7E-04**	**6.4E-01**	**4.6E-01**	**6.3E-03**	**1.7E-01**	**5.6E-01**
		95%	*6.0E-01*	*4.3E-02*	*6.1E-01*	*8.9E-01*	*3.5E-03*	*8.9E-01*	*6.4E-01*	*2.8E-02*	*3.5E-01*	*7.2E-01*
Thermoplastic-Insulated Conductor Cable	2	Alpha	8.54	0.85	9.19	4.73	0.27	4.86	10.16	0.92	1.83	12.66
		Beta	11.74	32.67	11.90	2.69	17.16	2.71	11.70	44.19	10.36	10.19
		5%	*2.5E-01*	*8.6E-04*	*2.7E-01*	*3.4E-01*	*5.2E-07*	*3.5E-01*	*2.9E-01*	*8.7E-04*	*2.6E-02*	*3.8E-01*
		Mean	**4.2E-01**	**2.5E-02**	**4.4E-01**	**6.4E-01**	**1.5E-02**	**6.4E-01**	**4.6E-01**	**2.0E-02**	**1.5E-01**	**5.5E-01**
		95%	*6.0E-01*	*7.9E-02*	*6.1E-01*	*8.9E-01*	*7.2E-02*	*8.9E-01*	*6.4E-01*	*6.2E-02*	*3.4E-01*	*7.2E-01*
Metal Foil Shield Wrap Cable	3	Alpha	1.22	Incredible	1.22	2.63	Incredible	2.63	2.54	Incredible	1.97	4.68
		Beta	3.77		3.77	2.24		2.24	2.79		4.54	2.69
		5%	*2.5E-02*		*2.5E-02*	*1.9E-01*		*1.9E-01*	*1.6E-01*		*6.7E-02*	*3.4E-01*
		Mean	**2.4E-01**		**2.4E-01**	**5.4E-01**		**5.4E-01**	**4.8E-01**		**3.0E-01**	**6.3E-01**
		95%	*5.9E-01*		*5.9E-01*	*8.7E-01*		*8.7E-01*	*8.1E-01*		*6.1E-01*	*8.9E-01*
Armored Cable	4	Alpha	0.22	Incredible	0.22	4.00	Incredible	4.00	9.82	Incredible	2.77	14.63
		Beta	4.52		4.52	4.93		4.93	3.59		2.97	2.34
		5%	*2.3E-07*		*2.3E-07*	*1.9E-01*		*1.9E-01*	*5.2E-01*		*1.7E-01*	*7.1E-01*
		Mean	**4.7E-02**		**4.7E-02**	**4.5E-01**		**4.5E-01**	**7.3E-01**		**4.8E-01**	**8.6E-01**
		95%	*2.4E-01*		*2.4E-01*	*7.1E-01*		*7.1E-01*	*9.0E-01*		*8.0E-01*	*9.7E-01*

NUREG/CR-7150 Vol. 2 Tables

Table 4-3. Conditional Probability of Spurious Operation: MOV Single Break Control Circuits

Power Supply →			Grounded AC			Ungrounded AC (w/ Individual CPTs)			Ungrounded DC (or Ungrounded Distributed AC)			
			Conductor Hot Short Failure Mode									
Target Cable Configuration		Beta Distribution Characteristics	Intra-Cable	Inter-Cable	Aggregate	Intra-Cable	Inter-Cable	Aggregate	Intra-Cable	Inter-Cable	Ground Fault Equivalent	Aggregate
			1	2	3	4	5	6	7	8	9	10
Thermoset-Insulated Conductor Cable	1	Alpha	5.55	0.36	5.80	4.81	0.58	4.81	5.53	0.32	1.93	7.65
		Beta	14.98	40.31	15.16	7.69	687.61	7.68	12.03	56.43	14.97	11.63
		5%	*1.3E-01*	*4.1E-06*	*1.3E-01*	*1.8E-01*	*7.1E-06*	*1.8E-01*	*1.5E-01*	*1.0E-06*	*2.1E-02*	*2.2E-01*
		Mean	**2.7E-01**	**8.8E-03**	**2.8E-01**	**3.8E-01**	**8.5E-04**	**3.9E-01**	**3.1E-01**	**5.6E-03**	**1.1E-01**	**4.0E-01**
		95%	*4.4E-01*	*3.8E-02*	*4.5E-01*	*6.1E-01*	*3.1E-03*	*6.1E-01*	*5.0E-01*	*2.5E-02*	*2.6E-01*	*5.8E-01*
Thermoplastic-Insulated Conductor Cable	2	Alpha	5.55	0.84	6.20	4.81	0.27	5.02	5.53	0.91	1.50	7.58
		Beta	14.98	37.19	15.43	7.69	19.75	7.75	12.03	49.25	13.25	11.55
		5%	*1.3E-01*	*7.2E-04*	*1.4E-01*	*1.8E-01*	*4.5E-07*	*1.9E-01*	*1.5E-01*	*7.4E-04*	*1.3E-02*	*2.2E-01*
		Mean	**2.7E-01**	**2.2E-02**	**2.9E-01**	**3.8E-01**	**1.3E-02**	**3.9E-01**	**3.1E-01**	**1.8E-02**	**1.0E-01**	**4.0E-01**
		95%	*4.4E-01*	*7.0E-02*	*4.5E-01*	*6.1E-01*	*6.3E-02*	*6.2E-01*	*5.0E-01*	*5.6E-02*	*2.5E-01*	*5.8E-01*
Metal Foil Shield Wrap Cable	3	Alpha	1.20	Incredible	1.20	3.64	Incredible	3.64	2.62	Incredible	2.11	4.85
		Beta	6.15		6.15	6.15		6.15	5.95		7.41	5.72
		5%	*1.5E-02*		*1.5E-02*	*1.5E-01*		*1.5E-01*	*8.9E-02*		*4.9E-02*	*2.2E-01*
		Mean	**1.6E-01**		**1.6E-01**	**3.7E-01**		**3.7E-01**	**3.1E-01**		**2.2E-01**	**4.6E-01**
		95%	*4.2E-01*		*4.2E-01*	*6.3E-01*		*6.3E-01*	*5.8E-01*		*4.6E-01*	*7.1E-01*
Armored Cable	4	Alpha	0.21	Incredible	0.21	3.76	Incredible	3.76	7.52	Incredible	3.10	10.97
		Beta	5.94		5.94	10.05		10.05	9.24		7.72	7.12
		5%	*6.7E-08*		*6.7E-08*	*1.0E-01*		*1.0E-01*	*2.6E-01*		*9.5E-02*	*4.2E-01*
		Mean	**3.4E-02**		**3.4E-02**	**2.7E-01**		**2.7E-01**	**4.5E-01**		**2.9E-01**	**6.1E-01**
		95%	*1.7E-01*		*1.7E-01*	*4.8E-01*		*4.8E-01*	*6.5E-01*		*5.2E-01*	*7.8E-01*

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NUREG/CR-7150 Vol. 2 Tables

Table 4-4. Conditional Probability of Spurious Operation: Ungrounded DC Control Circuits for Medium Voltage Circuit Breaker

Characteristics of Beta Distribution	Probability Value
Alpha	5.54
Beta	8.47
5%	*2.0E-01*
Mean	**4.0E-01**
95%	*6.1E-01*

NUREG/CR-7150 Vol. 2 Tables

Table 5-1. Conditional Probability of Spurious Operation: Double Break Control Circuits for Ungrounded AC (w/ individual CPTs)
Base Case – SOV

Target Cable Configuration		Beta Distribution Characteristic	Conductor Hot Short Failure Mode Combinations			
			Intra-Cable & Intra-Cable	Intra-Cable & Inter-Cable	Inter-Cable & Inter-Cable	Aggregate
			1	2	3	4
Thermoset-Insulated Conductor Cable	1	Alpha Beta *5%* **Mean** *95%*	2.12 2.78 *1.2E-01* **4.3E-01** *7.8E-01*	0.68 9.83 *1.1E-03* **6.5E-02** *2.1E-01*	Incredible	2.58 2.92 *1.5E-01* **4.7E-01** *8.0E-01*
Thermoplastic-Insulated Conductor Cable	2	Alpha Beta *5%* **Mean** *95%*	2.12 2.78 *1.2E-01* **4.3E-01** *7.8E-01*	0.34 3.85 *3.2E-05* **8.2E-02** *3.5E-01*	0.48 89.92 *1.6E-05* **5.3E-03** *2.1E-02*	2.52 2.71 *1.6E-01* **4.8E-01** *8.1E-01*
Metal Foil Shield Wrap Cable	3	Alpha Beta *5%* **Mean** *95%*	1.18 2.35 *3.6E-02* **3.3E-01** *7.5E-01*	0.88 6.43 *5.0E-03* **1.2E-01** *3.5E-01*	Incredible	1.86 2.64 *9.4E-02* **4.1E-01** *7.8E-01*
Armored Cable	4	Alpha Beta *5%* **Mean** *95%*	1.56 5.34 *3.4E-02* **2.3E-01** *5.1E-01*	0.86 4.42 *6.8E-03* **1.6E-01** *4.6E-01*	Incredible	2.44 4.50 *1.0E-01* **3.5E-01** *6.5E-01*

Note: Inter-cable hot shorts are assumed to involve GFEHS failure modes.

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NUREG/CR-7150 Vol. 2 Tables

Table 5-2. Conditional Probability of Spurious Operation: Double Break Control Circuits
Ungrounded DC (or Ungrounded Distributed AC)
BASE CASE – SOV

Target Cable Configuration		Beta Distribution Characteristics	Conductor Hot Short Failure Mode Combinations					
			Intra-Cable & Intra-Cable	Intra-Cable & Inter-Cable	Inter-Cable & Inter-Cable	Intra-Cable & Ground Fault Equivalent	Inter-Cable & Ground Fault Equivalent	Aggregate
			1	2	3	4	5	6
Thermoset-Insulated Conductor Cable	1	Alpha	3.90	0.32	Incredible	2.21	Incredible	4.66
		Beta	13.36	109.19		26.64		11.64
		5%	*8.5E-02*	*5.1E-07*		*1.6E-02*		*1.2E-01*
		Mean	**2.3E-01**	**2.9E-03**		**7.7E-02**		**2.9E-01**
		95%	*4.0E-01*	*1.3E-02*		*1.7E-01*		*4.8E-01*
Thermoplastic-Insulated Conductor Cable	2	Alpha	3.90	0.87	0.30	1.80	0.60	4.67
		Beta	13.36	90.66	352.91	24.12	193.16	11.56
		5%	*8.5E-02*	*3.4E-04*	*9.7E-08*	*1.1E-02*	*2.8E-05*	*1.2E-01*
		Mean	**2.3E-01**	**9.5E-03**	**8.6E-04**	**7.0E-02**	**3.1E-03**	**2.9E-01**
		95%	*4.0E-01*	*3.0E-02*	*3.9E-03*	*1.7E-01*	*1.1E-02*	*4.8E-01*
Metal Foil Shield Wrap Cable	3	Alpha	1.06	Incredible	Incredible	1.53	Incredible	1.48
		Beta	2.92			9.16		2.63
		5%	*2.1E-02*			*1.9E-02*		*5.7E-02*
		Mean	**2.7E-01**			**1.4E-01**		**3.6E-01**
		95%	*6.5E-01*			*3.4E-01*		*7.5E-01*
Armored Cable	4	Alpha	4.45	Incredible	Incredible	3.04	Incredible	6.07
		Beta	3.65			5.55		2.60
		5%	*2.7E-01*			*1.2E-01*		*4.3E-01*
		Mean	**5.5E-01**			**3.5E-01**		**7.0E-01**
		95%	*8.1E-01*			*6.3E-01*		*9.1E-01*

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NUREG/CR-7150 Vol. 2 Tables

Table 5-3. Conditional Probability of Spurious Operation: Double Break Control Circuits for Ungrounded AC (w/ individual CPTs) Motor-Operated Valve

Target Cable Configuration		Beta Distribution Characteristics	Conductor Hot Short Failure Mode Combinations			
			Intra-Cable & Intra-Cable	Intra-Cable & Inter-Cable	Inter-Cable & Inter-Cable	Aggregate
			1	2	3	4
Thermoset-Insulated Conductor Cable	1	Alpha Beta *5%* **Mean** *95%*	2.96 6.84 *9.8E-02* **3.0E-01** *5.5E-01*	0.68 9.83 *1.1E-03* **6.5E-02** *2.1E-01*	Incredible	3.28 6.10 *1.3E-01* **3.5E-01** *6.1E-01*
Thermoplastic-Insulated Conductor Cable	2	Alpha Beta *5%* **Mean** *95%*	2.96 6.84 *9.8E-02* **3.0E-01** *5.5E-01*	0.34 3.85 *3.2E-05* **8.2E-02** *3.5E-01*	0.48 89.92 *1.6E-05* **5.3E-03** *2.1E-02*	2.96 5.17 *1.2E-01* **3.6E-01** *6.5E-01*
Metal Foil Shield Wrap Cable	3	Alpha Beta *5%* **Mean** *95%*	1.53 5.03 *3.5E-02* **2.3E-01** *5.3E-01*	0.88 6.43 *5.0E-03* **1.2E-01** *3.5E-01*	Incredible	2.24 4.59 *8.4E-02* **3.3E-01** *6.3E-01*
Armored Cable	4	Alpha Beta *5%* **Mean** *95%*	1.72 9.20 *2.6E-02* **1.6E-01** *3.6E-01*	0.86 4.42 *6.8E-03* **1.6E-01** *4.6E-01*	Incredible	2.40 5.77 *7.9E-02* **2.9E-01** *5.7E-01*

Note: Inter-cable hot shorts are assumed to involve GFEHS failure modes.

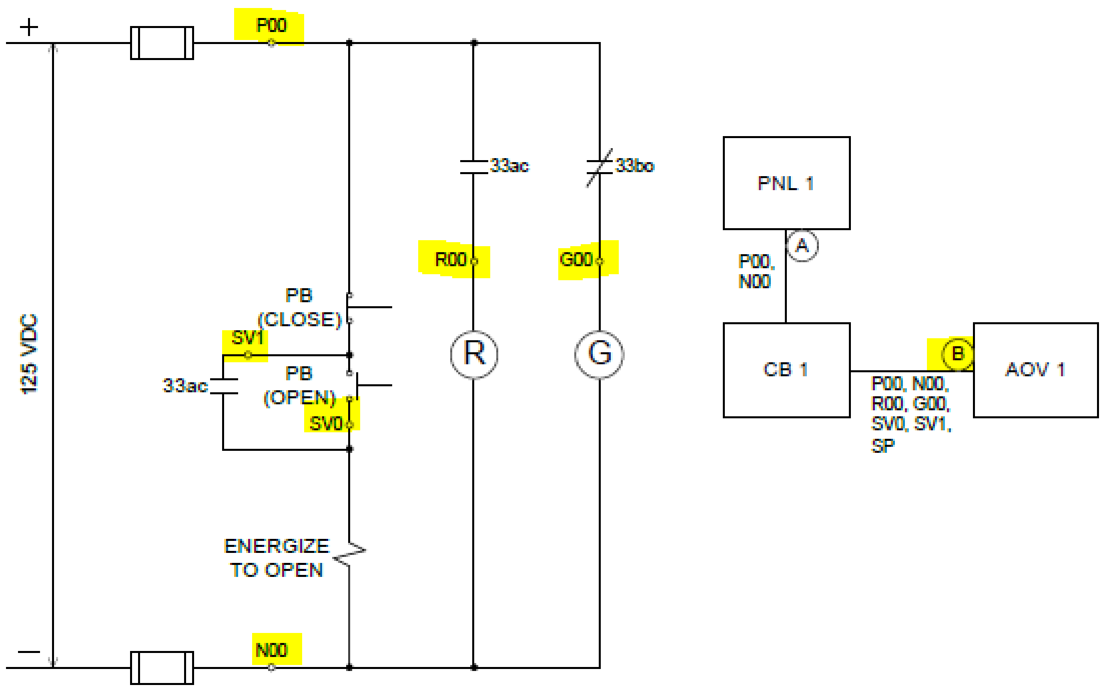
NUREG/CR-7150 Vol. 2 Tables

Table 5-4. Conditional Probability Of Spurious Operation: Double Break Control Circuits
Ungrounded DC (or Ungrounded Distributed AC)
Motor-Operated Valve

Target Cable Configuration		Beta Distribution Characteristics	Conductor Hot Short Failure Mode Combinations					
			Intra-Cable & Intra-Cable	Intra-Cable & Inter-Cable	Inter-Cable & Inter-Cable	Intra-Cable & Ground Fault Equivalent	Inter-Cable & Ground Fault Equivalent	Aggregate
			1	2	3	4	5	6
Thermoset-Insulated Conductor Cable	1	Alpha Beta *5%* **Mean** *95%*	4.11 21.86 *5.9E-02* **1.6E-01** *2.9E-01*	0.32 109.19 *5.1E-07* **2.9E-03** *1.3E-02*	Incredible	2.21 38.98 *1.1E-02* **5.4E-02** *1.2E-01*	Incredible	4.83 18.74 *8.6E-02* **2.0E-01** *3.5E-01*
Thermoplastic-Insulated Conductor Cable	2	Alpha Beta *5%* **Mean** *95%*	4.11 21.86 *5.9E-02* **1.6E-01** *2.9E-01*	0.87 90.66 *3.4E-04* **9.5E-03** *3.0E-02*	0.30 352.91 *9.7E-08* **8.6E-04** *3.9E-03*	1.81 35.42 *7.9E-03* **4.9E-02** *1.2E-01*	0.60 193.16 *2.8E-05* **3.1E-03** *1.1E-02*	4.88 18.48 *8.9E-02* **2.1E-01** *3.6E-01*
Metal Foil Shield Wrap Cable	3	Alpha Beta *5%* **Mean** *95%*	1.19 5.17 *1.7E-02* **1.9E-01** *4.7E-01*	Incredible	Incredible	1.58 14.13 *1.4E-02* **1.0E-01** *2.4E-01*	Incredible	1.61 4.50 *4.3E-02* **2.6E-01** *5.8E-01*
Armored Cable	4	Alpha Beta *5%* **Mean** *95%*	6.53 10.50 *2.0E-01* **3.8E-01** *5.8E-01*	Incredible	Incredible	3.46 10.47 *8.7E-02* **2.5E-01** *4.5E-01*	Incredible	7.18 6.31 *3.1E-01* **5.3E-01** *7.5E-01*

5-9

NUREG/CR-7150 Vol. 2 Tables



QUESTION: What is the *probability* that damage to Cable B will result in spurious opening of the AOV?

See next slide →

General Example

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NUREG/CR-7150 Vol. 2 Tables

- Detailed circuit analysis completed & documented? ***Yes***

Cable	+125 VDC Hot Probe	-125 VDC Reference Ground Probe
A	LOP-FB	LOP-FB
B	LOP-FB, EI-HS, SO-HS	LOP-FB, LOC

- Collect important cable and configuration data:
  - Circuit Design? ***Single Break***
  - Circuit Type? ***SOV***
  - Circuit Grounding/Power source? ***Ungrounded DC bus***
  - Cable Configuration? ***Thermoset-insulated***
  - Cable Configuration? ***Intra, Inter, GFEHS (use Aggregate)***

General Example

NUREG/CR-7150 Vol. 2 Tables

Table 4-1. Conditional Probability of Spurious Operation: SOV Single Break-Control Circuits

Power Supply →			Grounded AC			Ungrounded AC (w/ Individual CPTs)			Ungrounded DC (or Ungrounded Distributed AC)			
			Conductor Hot Short Failure Mode									
Target Cable Configuration		Beta Distribution Characteristics	Intra-Cable	Inter-Cable	Aggregate	Intra-Cable	Inter-Cable	Aggregate	Intra-Cable	Inter-Cable	Ground Fault Equivalent	Aggregate
			1	2	3	4	5	6	7	8	9	10
Thermoset-Insulated Conductor Cable	1	Alpha	8.54	0.36	8.79	4.73	0.60	4.74	10.16	0.32	2.27	12.76
		Beta	11.74	35.25	11.81	2.69	613.31	2.69	11.70	50.01	11.45	10.18
		5%	*2.5E-01*	*4.6E-06*	*2.6E-01*	*3.4E-01*	*8.9E-06*	*3.4E-01*	*2.9E-01*	*1.2E-06*	*3.8E-02*	*3.9E-01*
		Mean	**4.2E-01**	**1.0E-02**	**4.3E-01**	**6.4E-01**	**9.7E-04**	**6.4E-01**	**4.6E-01**	**6.3E-03**	**1.7E-01**	**5.6E-01**
		95%	*6.0E-01*	*4.3E-02*	*6.1E-01*	*8.9E-01*	*3.5E-03*	*8.9E-01*	*6.4E-01*	*2.8E-02*	*3.5E-01*	*7.2E-01*
Thermoplastic-Insulated Conductor Cable	2	Alpha	8.54	0.85	9.19	4.73	0.27	4.86	10.16	0.92	1.83	12.66
		Beta	11.74	32.67	11.90	2.69	17.16	2.71	11.70	44.19	10.36	10.19
		5%	*2.5E-01*	*8.6E-04*	*2.7E-01*	*3.4E-01*	*5.2E-07*	*3.5E-01*	*2.9E-01*	*8.7E-04*	*2.6E-02*	*3.8E-01*
		Mean	**4.2E-01**	**2.5E-02**	**4.4E-01**	**6.4E-01**	**1.5E-02**	**6.4E-01**	**4.6E-01**	**2.0E-02**	**1.5E-01**	**5.5E-01**
		95%	*6.0E-01*	*7.9E-02*	*6.1E-01*	*8.9E-01*	*7.2E-02*	*8.9E-01*	*6.4E-01*	*6.2E-02*	*3.4E-01*	*7.2E-01*
Metal Foil Shield Wrap Cable	3	Alpha	1.22		1.22	2.63		2.63	2.54		1.97	4.68
		Beta	3.77		3.77	2.24		2.24	2.79		4.54	2.69
		5%	*2.5E-02*	Incredible	*2.5E-02*	*1.9E-01*	Incredible	*1.9E-01*	*1.6E-01*	Incredible	*6.7E-02*	*3.4E-01*
		Mean	**2.4E-01**		**2.4E-01**	**5.4E-01**		**5.4E-01**	**4.8E-01**		**3.0E-01**	**6.3E-01**
		95%	*5.9E-01*		*5.9E-01*	*8.7E-01*		*8.7E-01*	*8.1E-01*		*6.1E-01*	*8.9E-01*
Armored Cable	4	Alpha	0.22		0.22	4.00		4.00	9.82		2.77	14.63
		Beta	4.52		4.52	4.93		4.93	3.59		2.97	2.34
		5%	*2.3E-07*	Incredible	*2.3E-07*	*1.9E-01*	Incredible	*1.9E-01*	*5.2E-01*	Incredible	*1.7E-01*	*7.1E-01*
		Mean	**4.7E-02**		**4.7E-02**	**4.5E-01**		**4.5E-01**	**7.3E-01**		**4.8E-01**	**8.6E-01**
		95%	*2.4E-01*		*2.4E-01*	*7.1E-01*		*7.1E-01*	*9.0E-01*		*8.0E-01*	*9.7E-01*

General Example

NUREG/CR-7150, Vol. 2

- **Durations**.
  - In some cases, the duration of a spurious operation can have a significant effect for a specific PRA scenario.
  - Up until now, the duration of a spurious operation have not been considered (i.e., all durations have been assumed to be infinite).
  - In many scenarios, the analyst can "live" with the final results without expending the effort to account for duration effects.
  - Analysis of the spurious operation duration has several assumptions and limitations that must be understood.
  - The mean conditional probability value of the AC floor at 9 minutes is 0.0071 and that of the DC floor at 7 minutes is 0.022.

NUREG/CR-7150 Vol. 2 Tables

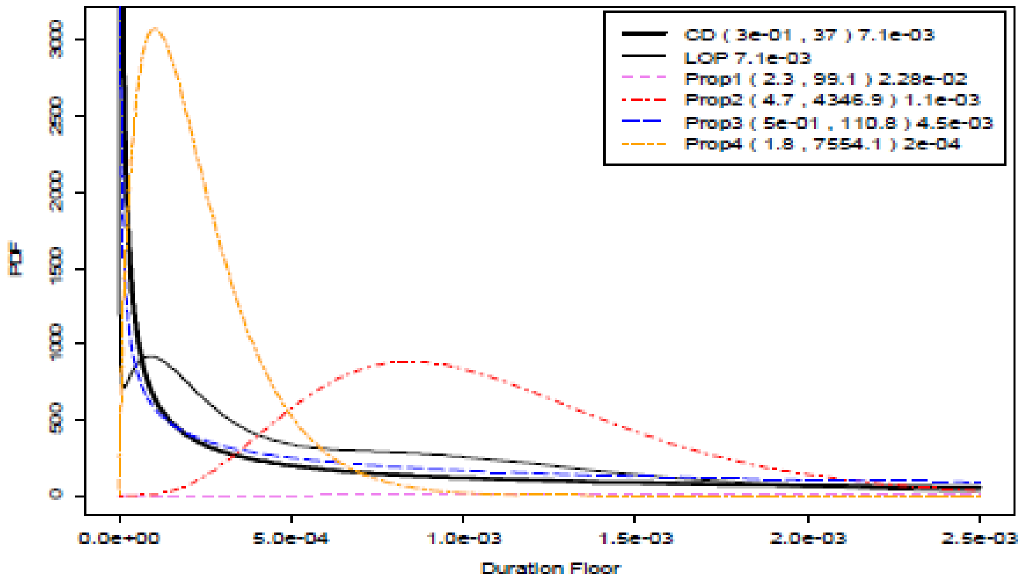

Figure 6-2. Community Distribution for AC Duration Floor

Table 6-2. Duration Conditional Probability Floors with Uncertainties

Beta Distribution Parameter	AC Control Circuits	DC Control Circuits
Alpha	0.27	0.88
Beta	36.99	39.28
5th	*2.4E-07*	*8.2E-04*
Mean	**7.1E-03**	**2.2E-02**
95th	*3.4E-02*	*6.8E-02*

NUREG/CR-7150 Vol. 2 Tables

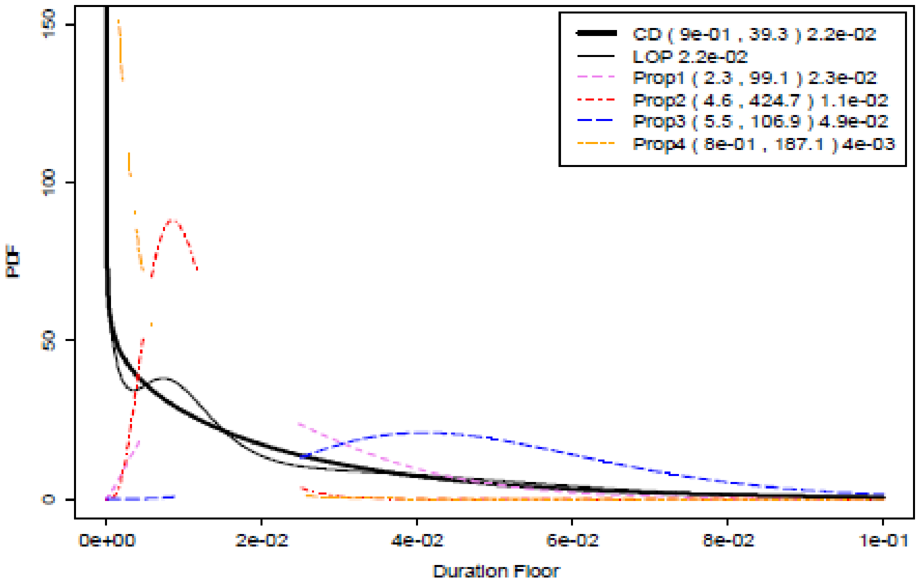

Figure 6-3. Community Distribution for DC Duration Floor

Table 6-2. Duration Conditional Probability Floors with Uncertainties

Beta Distribution Parameter	AC Control Circuits	DC Control Circuits
Alpha	0.27	0.88
Beta	36.99	39.28
5th	*2.4E-07*	*8.2E-04*
Mean	**7.1E-03**	**2.2E-02**
95th	*3.4E-02*	*6.8E-02*

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NUREG/CR-7150, Vol. 2 Process

Step 3: Document the Results (NUREG/CR-7150, Vol. 2, Section 7.3.4.3)

- Documentation of the duration analysis should include the supporting documentation for the following three areas:
  - The safe-shutdown function is restored, given the spurious operation clears.
  - The timing analysis is described in Section 7.3.4.1.
  - The duration probability analysis is described in Section 7.3.4.2.
- Documentation for restoring the safe-shutdown function should consider the circuit-specific impact on the component, as well as the circuit-specific impact for clearing of each hot short.

NUREG/CR-7150, Vol. 2 Process

Step 3: Document the Results (NUREG/CR-7150, Vol. 2, Sections 7.3.4.3, 7.3.6)

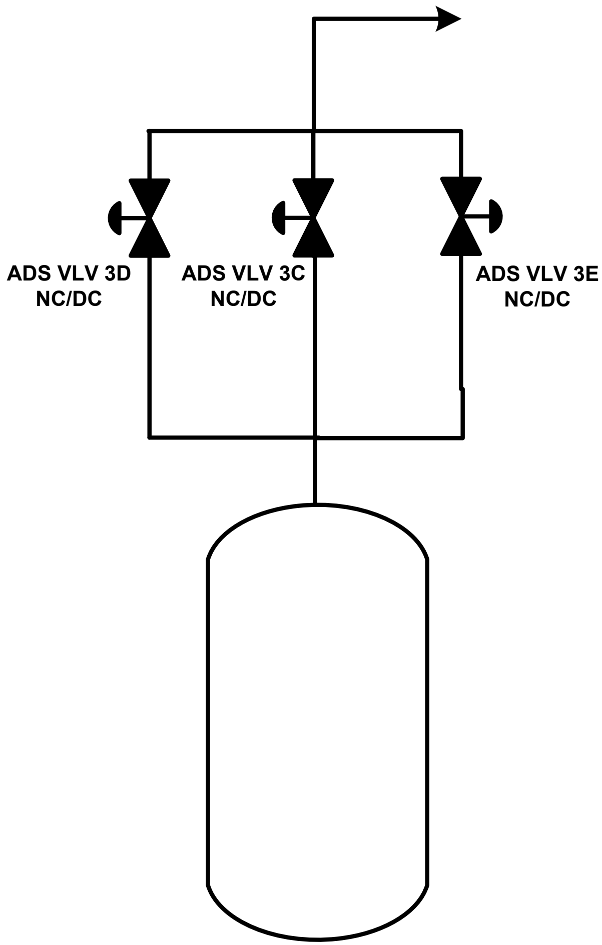
- CF analysis and duration should be performed in accordance with the fire PRA plan similar to that discussed in NUREG/CR-6850, Section 10.5.4.
- During this process, the uncertainty values also are developed, and should be documented as an integral part of the analysis. The standard State-of-Knowledge-Correlation (SOKC) employed when the underlying failure data are based on common data sets needs to be evaluated and any increase in the mean value relative to the point or best estimate reported (along with the uncertainty range).
- Documentation should also include a discussion on the assumptions as well as the sources of uncertainty.

Application in the Fire PRA

– Aggregation of cable failures on a cable level is already addressed in NUREG/CR-7150 Vol. 2 and previous slides
– Multiple cables for a given component/BE, if failed, could result in the spurious operation of a component
– Some cables may be from the same power source/protective device (e.g., dc fuses/breakers, same CPT control power source)
– Others may be from different power supplies/sources (e.g., “off scheme” cables, automatic initiation logic cables)
– Summing probabilities as independent variables [FAQ 08-0047 (NUREG/CR-6850, Supplement 1, Chapter 15)] is overly conservative (exclusive “OR” arrangement)
– NUREG/CR-7150, Vol. 2 does include in its methodology a requirement to sum cable probabilities

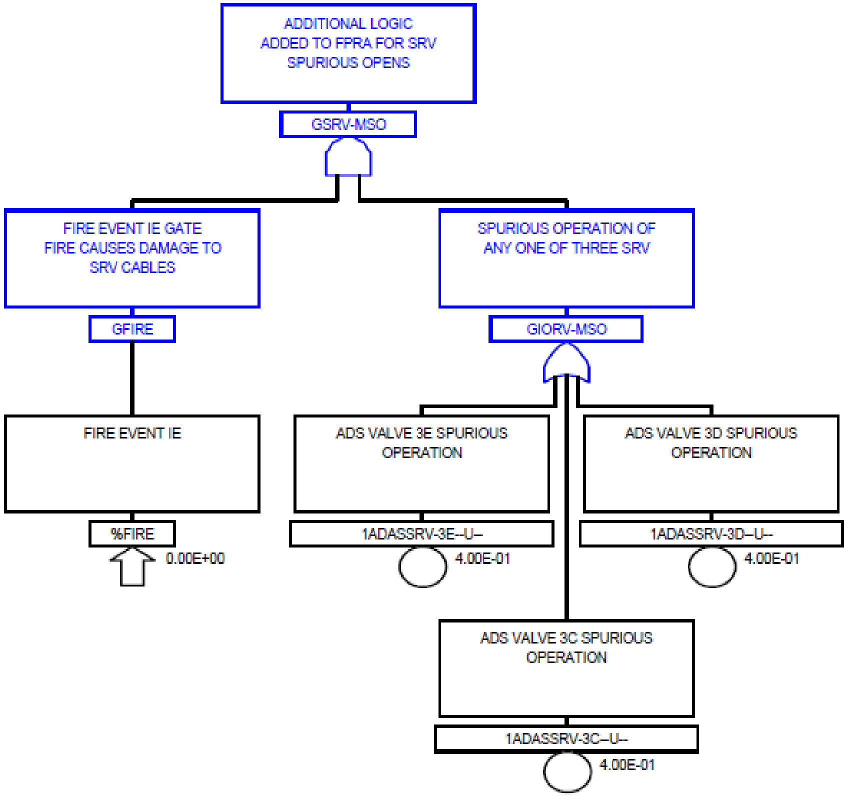
Application in the Fire PRA

Fault Tree Modeling (Example Configuration)



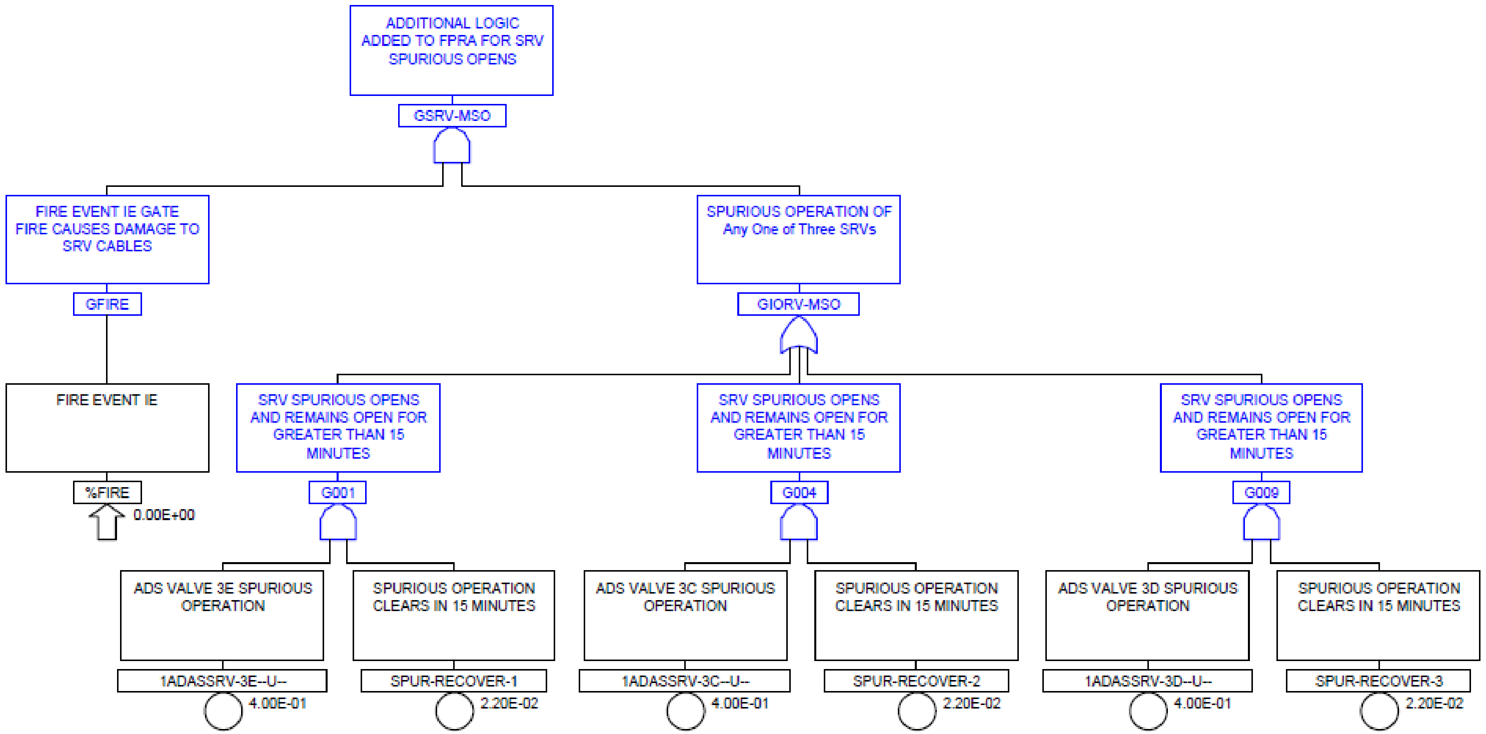
Application in the Fire PRA

Fault Tree Modeling (spurious operation probability)



Application in the Fire PRA

Fault Tree Modeling (spurious operation probability & duration)



Additional Insights and Lessons Learned

PRA Panel – Other Cable Configurations

- Panel Wiring (control cabling within electrical panels as opposed to cables routed in cable trays/conduit) - Considering the lack of applicable test data and the potential risk importance of panel wiring, the PRA panel recommends using **aggregate** values in the tables in Sections 4 and 5.
- Trunk Cables (term used to describe cables containing a large number of conductors, e.g., 37/C, common in certain NPP applications) - Because of this dearth of data, the PRA panel recommends using the **aggregate** values to quantify trunk cable conditional spurious operation estimates**.**
- Instrument Cables – probability values should not be used.

[NUREG/CR-7150, Vol. 2, Section 7.4]

CFMLA Data Input

- Failure Mode
- Single or Double Break Circuit
- SOV, MOV, Breaker
- Grounded, Ungrounded
- AC or DC
- TS, TP, Armored, Foil Shielded
- Database that is created can be integrated in to current FSS database.

Examples

Examples

Example Circuits for Analysis

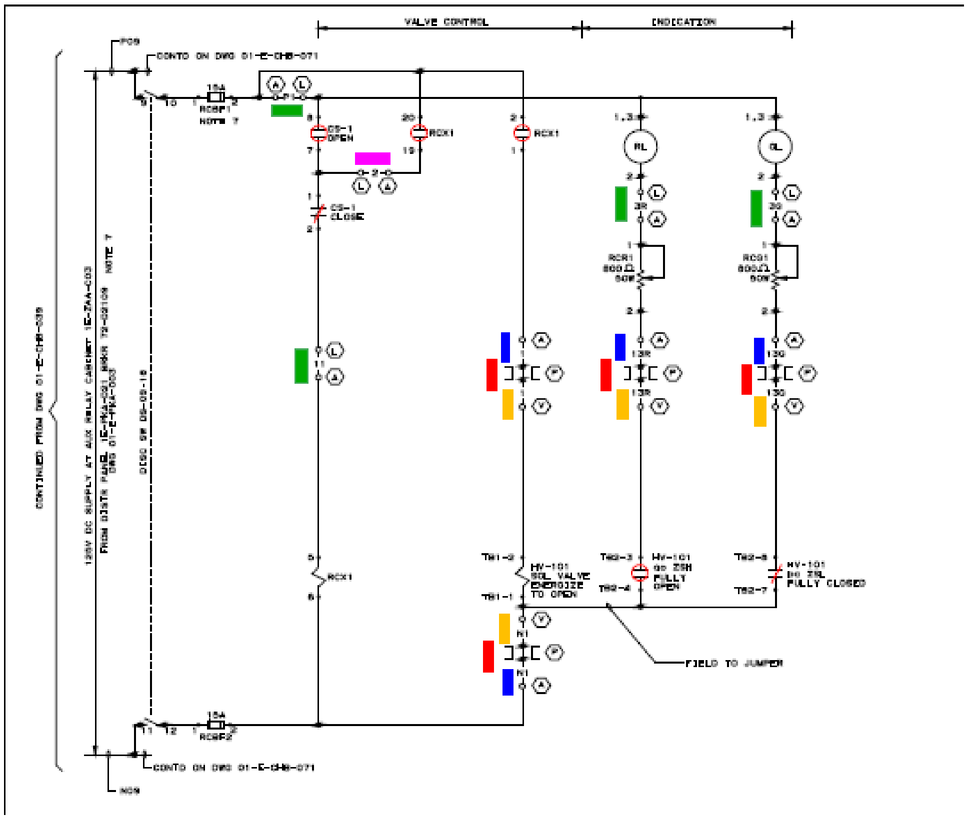
- Solenoid Operated Valves (SOVs)
- Motor Operated Valves (MOVs)
- Breaker Controls

Examples - SOVs

Table 4-1. Conditional Probability of Spurious Operation: SOV Single Break-Control Circuits

Power Supply →			Grounded AC			Ungrounded AC (w/ Individual CPTs)			Ungrounded DC (or Ungrounded Distributed AC)			
			Conductor Hot Short Failure Mode									
Target Cable Configuration		Beta Distribution Characteristics	Intra-Cable	Inter-Cable	Aggregate	Intra-Cable	Inter-Cable	Aggregate	Intra-Cable	Inter-Cable	Ground Fault Equivalent	Aggregate
			1	2	3	4	5	6	7	8	9	10
Thermoset-Insulated Conductor Cable	1	Alpha	8.54	0.36	8.79	4.73	0.60	4.74	10.16	0.32	2.27	12.76
		Beta	11.74	35.25	11.81	2.69	613.31	2.69	11.70	50.01	11.45	10.18
		5%	*2.5E-01*	*4.6E-06*	*2.6E-01*	*3.4E-01*	*8.9E-06*	*3.4E-01*	*2.9E-01*	*1.2E-06*	*3.8E-02*	*3.9E-01*
		Mean	**4.2E-01**	**1.0E-02**	**4.3E-01**	**6.4E-01**	**9.7E-04**	**6.4E-01**	**4.6E-01**	**6.3E-03**	**1.7E-01**	**5.6E-01**
		95%	*6.0E-01*	*4.3E-02*	*6.1E-01*	*8.9E-01*	*3.5E-03*	*8.9E-01*	*6.4E-01*	*2.8E-02*	*3.5E-01*	*7.2E-01*
Thermoplastic-Insulated Conductor Cable	2	Alpha	8.54	0.85	9.19	4.73	0.27	4.86	10.16	0.92	1.83	12.66
		Beta	11.74	32.67	11.90	2.69	17.16	2.71	11.70	44.19	10.36	10.19
		5%	*2.5E-01*	*8.6E-04*	*2.7E-01*	*3.4E-01*	*5.2E-07*	*3.5E-01*	*2.9E-01*	*8.7E-04*	*2.6E-02*	*3.8E-01*
		Mean	**4.2E-01**	**2.5E-02**	**4.4E-01**	**6.4E-01**	**1.5E-02**	**6.4E-01**	**4.6E-01**	**2.0E-02**	**1.5E-01**	**5.5E-01**
		95%	*6.0E-01*	*7.9E-02*	*6.1E-01*	*8.9E-01*	*7.2E-02*	*8.9E-01*	*6.4E-01*	*6.2E-02*	*3.4E-01*	*7.2E-01*
Metal Foil Shield Wrap Cable	3	Alpha	1.22	Incredible	1.22	2.63	Incredible	2.63	2.54	Incredible	1.97	4.68
		Beta	3.77		3.77	2.24		2.24	2.79		4.54	2.69
		5%	*2.5E-02*		*2.5E-02*	*1.9E-01*		*1.9E-01*	*1.6E-01*		*6.7E-02*	*3.4E-01*
		Mean	**2.4E-01**		**2.4E-01**	**5.4E-01**		**5.4E-01**	**4.8E-01**		**3.0E-01**	**6.3E-01**
		95%	*5.9E-01*		*5.9E-01*	*8.7E-01*		*8.7E-01*	*8.1E-01*		*6.1E-01*	*8.9E-01*
Armored Cable	4	Alpha	0.22	Incredible	0.22	4.00	Incredible	4.00	9.82	Incredible	2.77	14.63
		Beta	4.52		4.52	4.93		4.93	3.59		2.97	2.34
		5%	*2.3E-07*		*2.3E-07*	*1.9E-01*		*1.9E-01*	*5.2E-01*		*1.7E-01*	*7.1E-01*
		Mean	**4.7E-02**		**4.7E-02**	**4.5E-01**		**4.5E-01**	**7.3E-01**		**4.8E-01**	**8.6E-01**
		95%	*2.4E-01*		*2.4E-01*	*7.1E-01*		*7.1E-01*	*9.0E-01*		*8.0E-01*	*9.7E-01*

Examples - SOVs



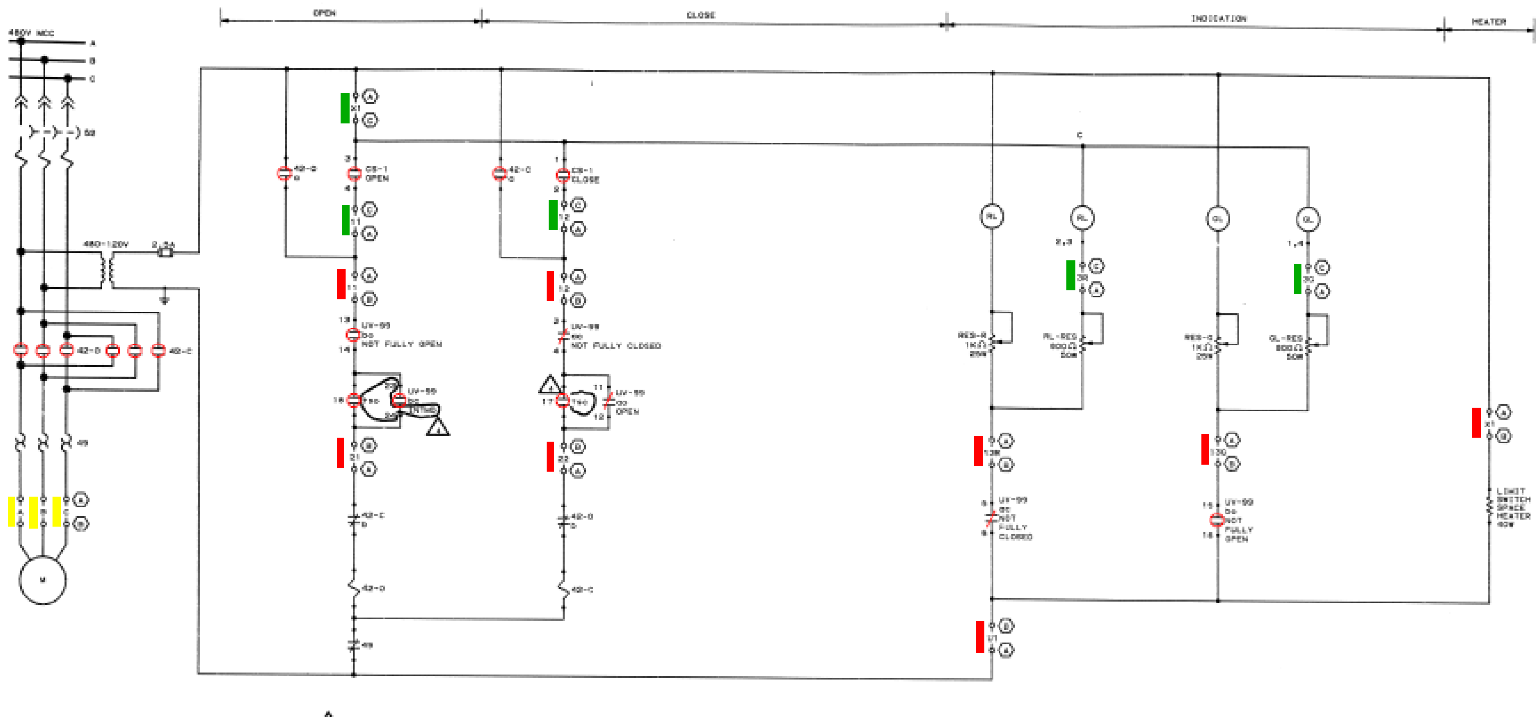
Rx Coolant Vent Valve

Examples - MOVs

Table 4-3. Conditional Probability of Spurious Operation: MOV Single Break Control Circuits

Power Supply →			Grounded AC			Ungrounded AC (w/ Individual CPTs)			Ungrounded DC (or Ungrounded Distributed AC)			
			Conductor Hot Short Failure Mode									
Target Cable Configuration		Beta Distribution Characteristics	Intra-Cable	Inter-Cable	Aggregate	Intra-Cable	Inter-Cable	Aggregate	Intra-Cable	Inter-Cable	Ground Fault Equivalent	Aggregate
			1	2	3	4	5	6	7	8	9	10
Thermoset-Insulated Conductor Cable	1	Alpha	5.55	0.36	5.80	4.81	0.58	4.81	5.53	0.32	1.93	7.65
		Beta	14.98	40.31	15.16	7.69	687.61	7.68	12.03	56.43	14.97	11.63
		5%	*1.3E-01*	*4.1E-06*	*1.3E-01*	*1.8E-01*	*7.1E-06*	*1.8E-01*	*1.5E-01*	*1.0E-06*	*2.1E-02*	*2.2E-01*
		Mean	**2.7E-01**	**8.8E-03**	**2.8E-01**	**3.8E-01**	**8.5E-04**	**3.9E-01**	**3.1E-01**	**5.6E-03**	**1.1E-01**	**4.0E-01**
		95%	*4.4E-01*	*3.8E-02*	*4.5E-01*	*6.1E-01*	*3.1E-03*	*6.1E-01*	*5.0E-01*	*2.5E-02*	*2.6E-01*	*5.8E-01*
Thermoplastic-Insulated Conductor Cable	2	Alpha	5.55	0.84	6.20	4.81	0.27	5.02	5.53	0.91	1.50	7.58
		Beta	14.98	37.19	15.43	7.69	19.75	7.75	12.03	49.25	13.25	11.55
		5%	*1.3E-01*	*7.2E-04*	*1.4E-01*	*1.8E-01*	*4.5E-07*	*1.9E-01*	*1.5E-01*	*7.4E-04*	*1.3E-02*	*2.2E-01*
		Mean	**2.7E-01**	**2.2E-02**	**2.9E-01**	**3.8E-01**	**1.3E-02**	**3.9E-01**	**3.1E-01**	**1.8E-02**	**1.0E-01**	**4.0E-01**
		95%	*4.4E-01*	*7.0E-02*	*4.5E-01*	*6.1E-01*	*6.3E-02*	*6.2E-01*	*5.0E-01*	*5.6E-02*	*2.5E-01*	*5.8E-01*
Metal Foil Shield Wrap Cable	3	Alpha	1.20	Incredible	1.20	3.64	Incredible	3.64	2.62	Incredible	2.11	4.85
		Beta	6.15		6.15	6.15		6.15	5.95		7.41	5.72
		5%	*1.5E-02*		*1.5E-02*	*1.5E-01*		*1.5E-01*	*8.9E-02*		*4.9E-02*	*2.2E-01*
		Mean	**1.6E-01**		**1.6E-01**	**3.7E-01**		**3.7E-01**	**3.1E-01**		**2.2E-01**	**4.6E-01**
		95%	*4.2E-01*		*4.2E-01*	*6.3E-01*		*6.3E-01*	*5.8E-01*		*4.6E-01*	*7.1E-01*
Armored Cable	4	Alpha	0.21	Incredible	0.21	3.76	Incredible	3.76	7.52	Incredible	3.10	10.97
		Beta	5.94		5.94	10.05		10.05	9.24		7.72	7.12
		5%	*6.7E-08*		*6.7E-08*	*1.0E-01*		*1.0E-01*	*2.6E-01*		*9.5E-02*	*4.2E-01*
		Mean	**3.4E-02**		**3.4E-02**	**2.7E-01**		**2.7E-01**	**4.5E-01**		**2.9E-01**	**6.1E-01**
		95%	*1.7E-01*		*1.7E-01*	*4.8E-01*		*4.8E-01*	*6.5E-01*		*5.2E-01*	*7.8E-01*

Examples - MOVs



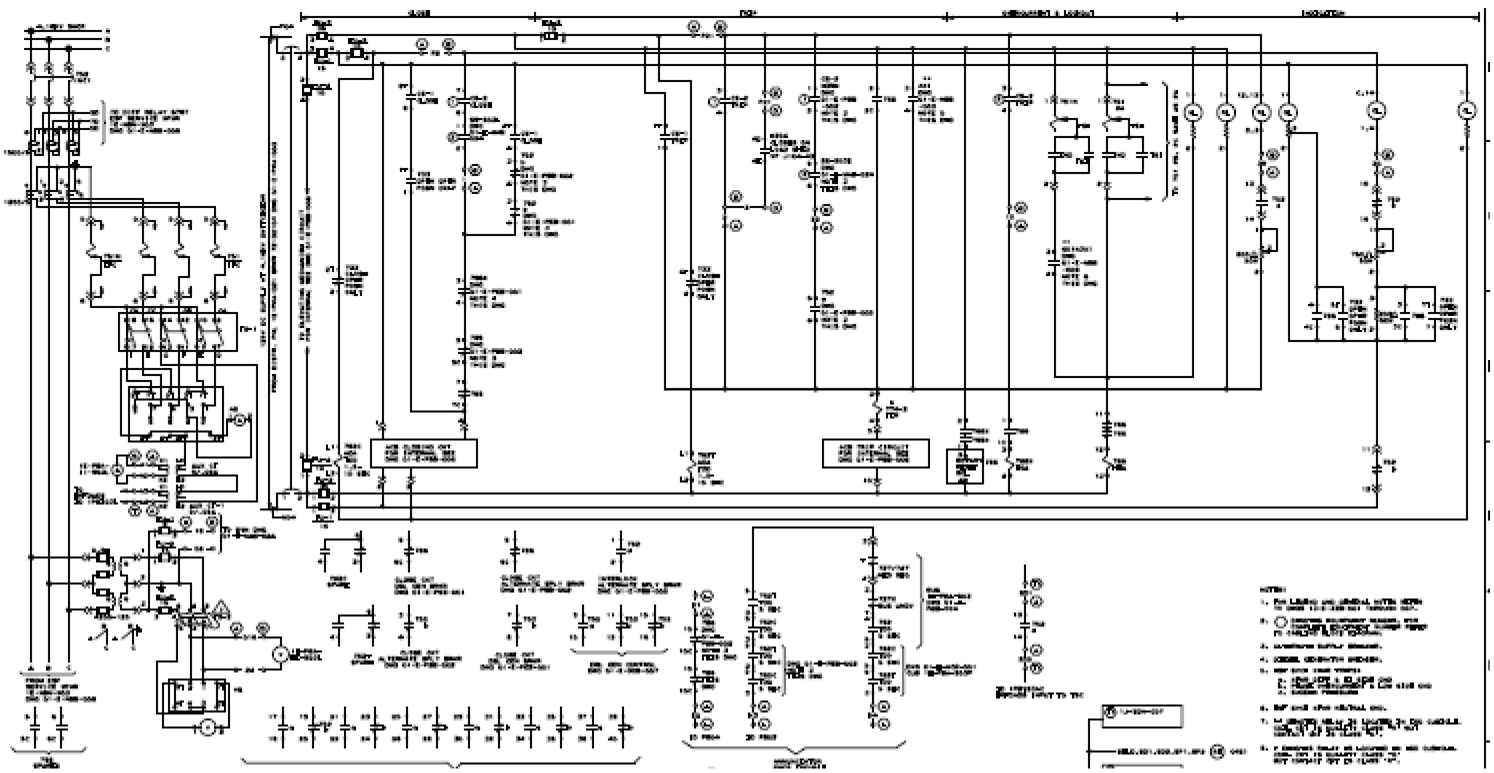
CCW Motor Operated Valve

Examples – Breaker Controls

Table 4-4. Conditional Probability of Spurious Operation: Ungrounded DC Control Circuits for Medium Voltage Circuit Breaker

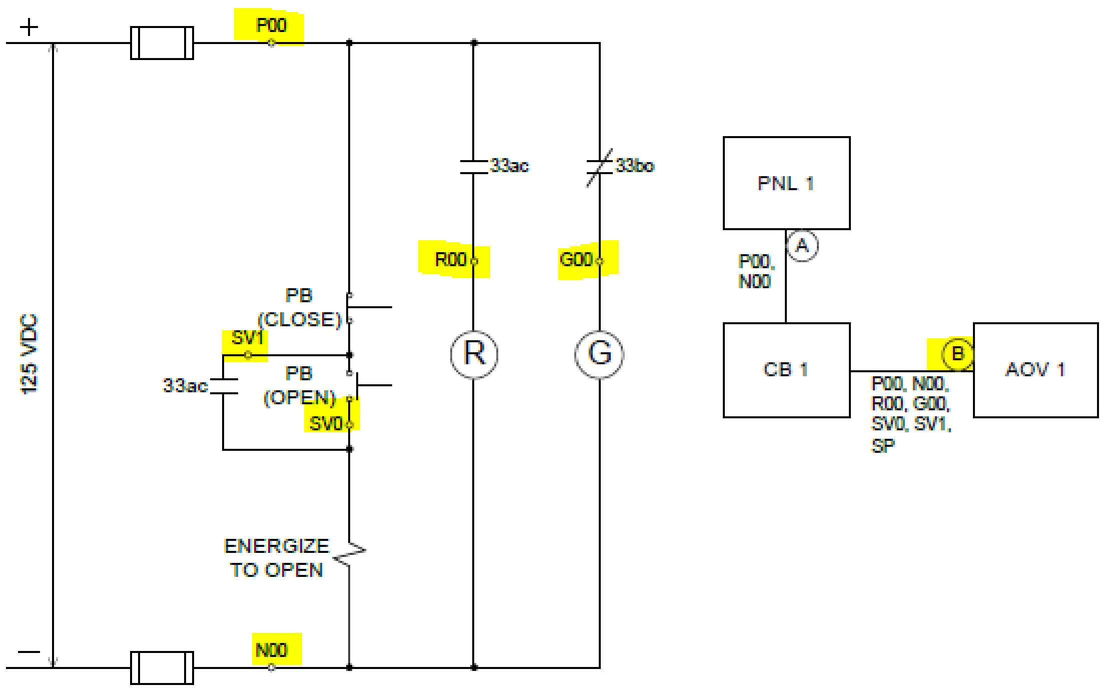
Characteristics of Beta Distribution	Probability Value
Alpha	5.54
Beta	8.47
5%	*2.0E-01*
Mean	**4.0E-01**
95%	*6.1E-01*

Examples – Breaker Controls



Generic Examples NUREG/CR-7150 Vol. 2 Tables

NUREG/CR-7150 Vol. 2 Tables

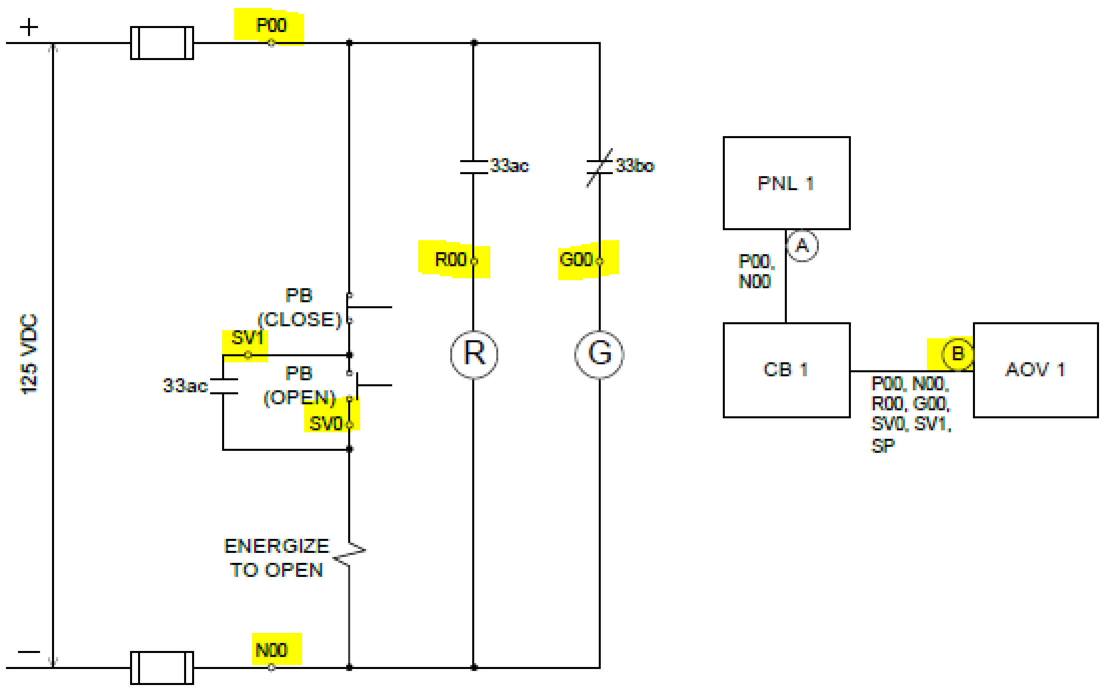


QUESTION: What is the *probability* that damage to Cable B will result in spurious opening of the AOV?

See next slide →

General Example

NUREG/CR-7150 Vol. 2 Tables



QUESTION: What is the *probability* that damage to Cable B will result in spurious opening of the AOV?

See next slide →

General Example

NUREG/CR-7150 Vol. 2 Tables

- Detailed circuit analysis completed & documented? *Yes*

Cable	+125 VDC Hot Probe	-125 VDC Reference Ground Probe
A	LOP-FB	LOP-FB
B	LOP-FB, EI-HS, SO-HS	LOP-FB, LOC

- Collect important cable and configuration data:
  - Circuit Design? *Single Break*
  - Circuit Type? *SOV*
  - Circuit Grounding/Power source? *Ungrounded DC bus*
  - Cable Configuration? *Thermoset-insulated*
  - Cable Configuration? *Intra, Inter, GFEHS (use Aggregate)*

General Example

NUREG/CR-7150 Vol. 2 Tables

Table 4-1. Conditional Probability of Spurious Operation: SOV Single Break-Control Circuits

Power Supply →			Grounded AC			Ungrounded AC (w/ Individual CPTs)			Ungrounded DC (or Ungrounded Distributed AC)			
			Conductor Hot Short Failure Mode									
Target Cable Configuration		Beta Distribution Characteristics	Intra-Cable	Inter-Cable	Aggregate	Intra-Cable	Inter-Cable	Aggregate	Intra-Cable	Inter-Cable	Ground Fault Equivalent	Aggregate
			1	2	3	4	5	6	7	8	9	10
Thermoset-Insulated Conductor Cable	1	Alpha	8.54	0.36	8.79	4.73	0.60	4.74	10.16	0.32	2.27	12.76
		Beta	11.74	35.25	11.81	2.69	613.31	2.69	11.70	50.01	11.45	10.18
		5%	*2.5E-01*	*4.6E-06*	*2.6E-01*	*3.4E-01*	*8.9E-06*	*3.4E-01*	*2.9E-01*	*1.2E-06*	*3.8E-02*	*3.9E-01*
		Mean	**4.2E-01**	**1.0E-02**	**4.3E-01**	**6.4E-01**	**9.7E-04**	**6.4E-01**	**4.6E-01**	**6.3E-03**	**1.7E-01**	**5.6E-01**
		95%	*6.0E-01*	*4.3E-02*	*6.1E-01*	*8.9E-01*	*3.5E-03*	*8.9E-01*	*6.4E-01*	*2.8E-02*	*3.5E-01*	*7.2E-01*
Thermoplastic-Insulated Conductor Cable	2	Alpha	8.54	0.85	9.19	4.73	0.27	4.86	10.16	0.92	1.83	12.66
		Beta	11.74	32.67	11.90	2.69	17.16	2.71	11.70	44.19	10.36	10.19
		5%	*2.5E-01*	*8.6E-04*	*2.7E-01*	*3.4E-01*	*5.2E-07*	*3.5E-01*	*2.9E-01*	*8.7E-04*	*2.6E-02*	*3.8E-01*
		Mean	**4.2E-01**	**2.5E-02**	**4.4E-01**	**6.4E-01**	**1.5E-02**	**6.4E-01**	**4.6E-01**	**2.0E-02**	**1.5E-01**	**5.5E-01**
		95%	*6.0E-01*	*7.9E-02*	*6.1E-01*	*8.9E-01*	*7.2E-02*	*8.9E-01*	*6.4E-01*	*6.2E-02*	*3.4E-01*	*7.2E-01*
Metal Foil Shield Wrap Cable	3	Alpha	1.22	Incredible	1.22	2.63	Incredible	2.63	2.54	Incredible	1.97	4.68
		Beta	3.77		3.77	2.24		2.24	2.79		4.54	2.69
		5%	*2.5E-02*		*2.5E-02*	*1.9E-01*		*1.9E-01*	*1.6E-01*		*6.7E-02*	*3.4E-01*
		Mean	**2.4E-01**		**2.4E-01**	**5.4E-01**		**5.4E-01**	**4.8E-01**		**3.0E-01**	**6.3E-01**
		95%	*5.9E-01*		*5.9E-01*	*8.7E-01*		*8.7E-01*	*8.1E-01*		*6.1E-01*	*8.9E-01*
Armored Cable	4	Alpha	0.22	Incredible	0.22	4.00	Incredible	4.00	9.82	Incredible	2.77	14.63
		Beta	4.52		4.52	4.93		4.93	3.59		2.97	2.34
		5%	*2.3E-07*		*2.3E-07*	*1.9E-01*		*1.9E-01*	*5.2E-01*		*1.7E-01*	*7.1E-01*
		Mean	**4.7E-02**		**4.7E-02**	**4.5E-01**		**4.5E-01**	**7.3E-01**		**4.8E-01**	**8.6E-01**
		95%	*2.4E-01*		*2.4E-01*	*7.1E-01*		*7.1E-01*	*9.0E-01*		*8.0E-01*	*9.7E-01*

General Example

U.S.NRC United States Nuclear Regulatory Commission Protecting People and the Environment

EPRI ELECTRIC POWER RESEARCH INSTITUTE

NUREG/CR-7150 Vol. 2 Tables

Example # 1

- MOV control circuit
- Normally closed desired closed valve
- Control cable X could cause spurious opening
- Single break design
- 120 vac grounded, thermoset cable
- Fire-induced cable spurious operation could occur from both an intra and inter-cable hot short

NUREG/CR-7150 Vol. 2 Tables

Table 4-3. Conditional Probability of Spurious Operation: MOV Single Break Control Circuits

Power Supply →			Grounded AC			Ungrounded AC (w/ Individual CPTs)			Ungrounded DC (or Ungrounded Distributed AC)			
			Conductor Hot Short Failure Mode									
Target Cable Configuration		Beta Distribution Characteristics	Intra-Cable	Inter-Cable	Aggregate	Intra-Cable	Inter-Cable	Aggregate	Intra-Cable	Inter-Cable	Ground Fault Equivalent	Aggregate
			1	2	3	4	5	6	7	8	9	10
Thermoset-Insulated Conductor Cable	1	Alpha	5.55	0.36	5.80	4.81	0.58	4.81	5.53	0.32	1.93	7.65
		Beta	14.98	40.31	15.16	7.69	687.61	7.68	12.03	56.43	14.97	11.63
		5%	*1.3E-01*	*4.1E-06*	*1.3E-01*	*1.8E-01*	*7.1E-06*	*1.8E-01*	*1.5E-01*	*1.0E-06*	*2.1E-02*	*2.2E-01*
		Mean	**2.7E-01**	**8.8E-03**	**2.8E-01**	**3.8E-01**	**8.5E-04**	**3.9E-01**	**3.1E-01**	**5.6E-03**	**1.1E-01**	**4.0E-01**
		95%	*4.4E-01*	*3.8E-02*	*4.5E-01*	*6.1E-01*	*3.1E-03*	*6.1E-01*	*5.0E-01*	*2.5E-02*	*2.6E-01*	*5.8E-01*
Thermoplastic-Insulated Conductor Cable	2	Alpha	5.55	0.84	6.20	4.81	0.27	5.02	5.53	0.91	1.50	7.58
		Beta	14.98	37.19	15.43	7.69	19.75	7.75	12.03	49.25	13.25	11.55
		5%	*1.3E-01*	*7.2E-04*	*1.4E-01*	*1.8E-01*	*4.5E-07*	*1.9E-01*	*1.5E-01*	*7.4E-04*	*1.3E-02*	*2.2E-01*
		Mean	**2.7E-01**	**2.2E-02**	**2.9E-01**	**3.8E-01**	**1.3E-02**	**3.9E-01**	**3.1E-01**	**1.8E-02**	**1.0E-01**	**4.0E-01**
		95%	*4.4E-01*	*7.0E-02*	*4.5E-01*	*6.1E-01*	*6.3E-02*	*6.2E-01*	*5.0E-01*	*5.6E-02*	*2.5E-01*	*5.8E-01*
Metal Foil Shield Wrap Cable	3	Alpha	1.20	Incredible	1.20	3.64	Incredible	3.64	2.62	Incredible	2.11	4.85
		Beta	6.15		6.15	6.15		6.15	5.95		7.41	5.72
		5%	*1.5E-02*		*1.5E-02*	*1.5E-01*		*1.5E-01*	*8.9E-02*		*4.9E-02*	*2.2E-01*
		Mean	**1.6E-01**		**1.6E-01**	**3.7E-01**		**3.7E-01**	**3.1E-01**		**2.2E-01**	**4.6E-01**
		95%	*4.2E-01*		*4.2E-01*	*6.3E-01*		*6.3E-01*	*5.8E-01*		*4.6E-01*	*7.1E-01*
Armored Cable	4	Alpha	0.21	Incredible	0.21	3.76	Incredible	3.76	7.52	Incredible	3.10	10.97
		Beta	5.94		5.94	10.05		10.05	9.24		7.72	7.12
		5%	*6.7E-08*		*6.7E-08*	*1.0E-01*		*1.0E-01*	*2.6E-01*		*9.5E-02*	*4.2E-01*
		Mean	**3.4E-02**		**3.4E-02**	**2.7E-01**		**2.7E-01**	**4.5E-01**		**2.9E-01**	**6.1E-01**
		95%	*1.7E-01*		*1.7E-01*	*4.8E-01*		*4.8E-01*	*6.5E-01*		*5.2E-01*	*7.8E-01*

Example #1

NUREG/CR-7150 Vol. 2 Tables

Example # 2

- MOV control circuit
- Normally open, desired open valve
- Control cable X could cause spurious closing
- Single break design
- 120 vac grounded, thermoplastic cable
- Fire-induced cable spurious operation could occur from only an inter-cable hot short (there are no intra-cable hot short "source" conductors in Cable X)

NUREG/CR-7150 Vol. 2 Tables

Table 4-3. Conditional Probability of Spurious Operation: MOV Single Break Control Circuits

Power Supply →			Grounded AC			Ungrounded AC (w/ Individual CPTs)			Ungrounded DC (or Ungrounded Distributed AC)			
			Conductor Hot Short Failure Mode									
Target Cable Configuration		Beta Distribution Characteristics	Intra-Cable	Inter-Cable	Aggregate	Intra-Cable	Inter-Cable	Aggregate	Intra-Cable	Inter-Cable	Ground Fault Equivalent	Aggregate
			1	2	3	4	5	6	7	8	9	10
Thermoset-Insulated Conductor Cable	1	Alpha	5.55	0.36	5.80	4.81	0.58	4.81	5.53	0.32	1.93	7.65
		Beta	14.98	40.31	15.16	7.69	687.61	7.68	12.03	56.43	14.97	11.63
		5%	*1.3E-01*	*4.1E-06*	*1.3E-01*	*1.8E-01*	*7.1E-06*	*1.8E-01*	*1.5E-01*	*1.0E-06*	*2.1E-02*	*2.2E-01*
		Mean	**2.7E-01**	**8.8E-03**	**2.8E-01**	**3.8E-01**	**8.5E-04**	**3.9E-01**	**3.1E-01**	**5.6E-03**	**1.1E-01**	**4.0E-01**
		95%	*4.4E-01*	*3.8E-02*	*4.5E-01*	*6.1E-01*	*3.1E-03*	*6.1E-01*	*5.0E-01*	*2.5E-02*	*2.6E-01*	*5.8E-01*
Thermoplastic-Insulated Conductor Cable	2	Alpha	5.55	0.84	6.20	4.81	0.27	5.02	5.53	0.91	1.50	7.58
		Beta	14.98	37.19	15.43	7.69	19.75	7.75	12.03	49.25	13.25	11.55
		5%	*1.3E-01*	*7.2E-04*	*1.4E-01*	*1.8E-01*	*4.5E-07*	*1.9E-01*	*1.5E-01*	*7.4E-04*	*1.3E-02*	*2.2E-01*
		Mean	**2.7E-01**	**2.2E-02**	**2.9E-01**	**3.8E-01**	**1.3E-02**	**3.9E-01**	**3.1E-01**	**1.8E-02**	**1.0E-01**	**4.0E-01**
		95%	*4.4E-01*	*7.0E-02*	*4.5E-01*	*6.1E-01*	*6.3E-02*	*6.2E-01*	*5.0E-01*	*5.6E-02*	*2.5E-01*	*5.8E-01*
Metal Foil Shield Wrap Cable	3	Alpha	1.20	Incredible	1.20	3.64	Incredible	3.64	2.62	Incredible	2.11	4.85
		Beta	6.15		6.15	6.15		6.15	5.95		7.41	5.72
		5%	*1.5E-02*		*1.5E-02*	*1.5E-01*		*1.5E-01*	*8.9E-02*		*4.9E-02*	*2.2E-01*
		Mean	**1.6E-01**		**1.6E-01**	**3.7E-01**		**3.7E-01**	**3.1E-01**		**2.2E-01**	**4.6E-01**
		95%	*4.2E-01*		*4.2E-01*	*6.3E-01*		*6.3E-01*	*5.8E-01*		*4.6E-01*	*7.1E-01*
Armored Cable	4	Alpha	0.21	Incredible	0.21	3.76	Incredible	3.76	7.52	Incredible	3.10	10.97
		Beta	5.94		5.94	10.05		10.05	9.24		7.72	7.12
		5%	*6.7E-08*		*6.7E-08*	*1.0E-01*		*1.0E-01*	*2.6E-01*		*9.5E-02*	*4.2E-01*
		Mean	**3.4E-02**		**3.4E-02**	**2.7E-01**		**2.7E-01**	**4.5E-01**		**2.9E-01**	**6.1E-01**
		95%	*1.7E-01*		*1.7E-01*	*4.8E-01*		*4.8E-01*	*6.5E-01*		*5.2E-01*	*7.8E-01*

Example #2

U.S.NRC
UNITED STATES NUCLEAR REGULATORY COMMISSION
Protecting People and the Environment

ELECTRIC POWER RESEARCH INSTITUTE

NUREG/CR-7150 Vol. 2 Tables

Example # 3

- AOV control circuit with 125vdc solenoid pilot
- Normally open, desired open valve
- Control cable X could cause spurious closing
- Single break design
- 125 vdc ungrounded, thermoset cable
- Fire-induced cable spurious operation could occur from all inter-cable and GFEHS failure modes of Cable X (there are no intra-cable hot short “source” conductors in Cable X)

NUREG/CR-7150 Vol. 2 Tables

CONDITIONAL PROBABILITY OF SPURIOUS OPERATION FOR SINGLE BREAK CONTROL CIRCUITS

Table 4-1. Conditional Probability of Spurious Operation: SOV Single Break-Control Circuits

Power Supply →			Grounded AC			Ungrounded AC (w/ Individual CPTs)			Ungrounded DC (or Ungrounded Distributed AC)		
			Conductor Hot Short Failure Mode								
Target Cable Configuration		Beta Distribution Characteristics	Intra-Cable	Inter-Cable	Aggregate	Intra-Cable	Inter-Cable	Aggregate	Intra-Cable	Inter-Cable	Ground Fault Equivalent	Aggregate
			1	2	3	4	5	6	7	8	9	10
Thermoset-Insulated Conductor Cable	1	Alpha	8.54	0.36	8.79	4.73	0.60	4.74	10.16	0.32	2.27	12.76
		Beta	11.74	35.25	11.81	2.69	613.31	2.69	11.70	50.01	11.45	10.18
		5%	*2.5E-01*	*4.6E-06*	*2.6E-01*	*3.4E-01*	*8.9E-06*	*3.4E-01*	*2.9E-01*	*1.2E-06*	*3.8E-02*	*3.9E-01*
		Mean	**4.2E-01**	**1.0E-02**	**4.3E-01**	**6.4E-01**	**9.7E-04**	**6.4E-01**	**4.6E-01**	**6.3E-03**	**1.7E-01**	**5.6E-01**
		95%	*6.0E-01*	*4.3E-02*	*6.1E-01*	*8.9E-01*	*3.5E-03*	*8.9E-01*	*6.4E-01*	*2.8E-02*	*3.5E-01*	*7.2E-01*
Thermoplastic-Insulated Conductor Cable	2	Alpha	8.54	0.85	9.19	4.73	0.27	4.86	10.16	0.92	1.83	12.66
		Beta	11.74	32.67	11.90	2.69	17.16	2.71	11.70	44.19	10.36	10.19
		5%	*2.5E-01*	*8.6E-04*	*2.7E-01*	*3.4E-01*	*5.2E-07*	*3.5E-01*	*2.9E-01*	*8.7E-04*	*2.6E-02*	*3.8E-01*
		Mean	**4.2E-01**	**2.5E-02**	**4.4E-01**	**6.4E-01**	**1.5E-02**	**6.4E-01**	**4.6E-01**	**2.0E-02**	**1.5E-01**	**5.5E-01**
		95%	*6.0E-01*	*7.9E-02*	*6.1E-01*	*8.9E-01*	*7.2E-02*	*8.9E-01*	*6.4E-01*	*6.2E-02*	*3.4E-01*	*7.2E-01*
Metal Foil Shield Wrap Cable	3	Alpha	1.22	Incredible	1.22	2.63	Incredible	2.63	2.54	Incredible	1.97	4.68
		Beta	3.77		3.77	2.24		2.24	2.79		4.54	2.69
		5%	*2.5E-02*		*2.5E-02*	*1.9E-01*		*1.9E-01*	*1.6E-01*		*6.7E-02*	*3.4E-01*
		Mean	**2.4E-01**		**2.4E-01**	**5.4E-01**		**5.4E-01**	**4.8E-01**		**3.0E-01**	**6.3E-01**
		95%	*5.9E-01*		*5.9E-01*	*8.7E-01*		*8.7E-01*	*8.1E-01*		*6.1E-01*	*8.9E-01*
Armored Cable	4	Alpha	0.22	Incredible	0.22	4.00	Incredible	4.00	9.82	Incredible	2.77	14.63
		Beta	4.52		4.52	4.93		4.93	3.59		2.97	2.34
		5%	*2.3E-07*		*2.3E-07*	*1.9E-01*		*1.9E-01*	*5.2E-01*		*1.7E-01*	*7.1E-01*
		Mean	**4.7E-02**		**4.7E-02**	**4.5E-01**		**4.5E-01**	**7.3E-01**		**4.8E-01**	**8.6E-01**
		95%	*2.4E-01*		*2.4E-01*	*7.1E-01*		*7.1E-01*	*9.0E-01*		*8.0E-01*	*9.7E-01*

4-3

Prob. = Boolean OR = (6.3E-03) + (1.7E-01) - (6.3E-03)*(1.7E-01) = 1.8E-01

Example #3

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NUREG/CR-7150 Vol. 2 Tables

Example # 4

- 4kV pump control circuit with 125vdc control power
- Pump is normally off, spurious start of the pump could have undesired consequences
- Control cable X could cause spurious start of the pump
- Single break design
- 125 vdc ungrounded, thermoset cable
- Fire-induced cable spurious operation could occur from intra-cable, inter-cable, and GFEHS failure modes of Cable X.

NUREG/CR-7150 Vol. 2 Tables

Table 4-4. Conditional Probability of Spurious Operation: Ungrounded DC Control Circuits for Medium Voltage Circuit Breaker

Characteristics of Beta Distribution	Probability Value
Alpha	5.54
Beta	8.47
5%	*2.0E-01*
Mean	**4.0E-01**
95%	*6.1E-01*

Example #4

NUREG/CR-7150 Vol. 2 Tables

Example # 5

- AOV control circuit with 125vdc solenoid pilot
- Normally closed, desired closed valve
- Control cable X could cause spurious opening
- Single break design, but breaker is maintained open during normal operation, creating a "double break" configuration
- 125 vdc ungrounded, thermoset cable
- Since power is removed during normal operation, the only failure modes for cable X are:
    - 2 proper polarity inter-cable hot shorts, or
    - an inter-cable hot short and a GFEHS.

NUREG/CR-7150 Vol. 2 Tables

Table 5-2. Conditional Probability of Spurious Operation: Double Break Control Circuits Ungrounded DC (or Ungrounded Distributed AC) BASE CASE – SOV

Target Cable Configuration		Beta Distribution Characteristics	Intra-Cable & Intra-Cable	Intra-Cable & Inter-Cable	Inter-Cable & Inter-Cable	Intra-Cable & Ground Fault Equivalent	Inter-Cable & Ground Fault Equivalent	Aggregate
			1	2	3	4	5	6
Thermoset-Insulated Conductor Cable	1	Alpha Beta *5%* **Mean** *95%*	3.90 13.36 *8.5E-02* **2.3E-01** *4.0E-01*	0.32 109.19 *5.1E-07* **2.9E-03** *1.3E-02*	Incredible	2.21 26.64 *1.6E-02* **7.7E-02** *1.7E-01*	Incredible	4.66 11.64 *1.2E-01* **2.9E-01** *4.8E-01*
Thermoplastic-Insulated Conductor Cable	2	Alpha Beta *5%* **Mean** *95%*	3.90 13.36 *8.5E-02* **2.3E-01** *4.0E-01*	0.87 90.66 *3.4E-04* **9.5E-03** *3.0E-02*	0.30 352.91 *9.7E-08* **8.6E-04** *3.9E-03*	1.80 24.12 *1.1E-02* **7.0E-02** *1.7E-01*	0.60 193.16 *2.8E-05* **3.1E-03** *1.1E-02*	4.67 11.56 *1.2E-01* **2.9E-01** *4.8E-01*
Metal Foil Shield Wrap Cable	3	Alpha Beta *5%* **Mean** *95%*	1.06 2.92 *2.1E-02* **2.7E-01** *6.5E-01*	Incredible	Incredible	1.53 9.16 *1.9E-02* **1.4E-01** *3.4E-01*	Incredible	1.48 2.63 *5.7E-02* **3.6E-01** *7.5E-01*
Armored Cable	4	Alpha Beta *5%* **Mean** *95%*	4.45 3.65 *2.7E-01* **5.5E-01** *8.1E-01*	Incredible	Incredible	3.04 5.55 *1.2E-01* **3.5E-01** *6.3E-01*	Incredible	6.07 2.60 *4.3E-01* **7.0E-01** *9.1E-01*

Conductor Hot Short Failure Mode Combinations: columns 1–6.

Example #5

CIRCUIT FAILURE MODE LIKELIHOOD ANALYSIS
Questions

Any Questions?

CIRCUIT FAILURE MODE LIKELIHOOD ANALYSIS

Corresponding PRA Standard Element

- Primary match is to element CF – Circuit Failures
  - CF Objectives (as stated in the PRA standard):

"[T]o

(a) refine the understanding and treatment of fire-induced circuit failures on an individual fire scenario basis

(b) ensure that the consequences of each fire scenario on the damaged cables and circuits have been addressed"

CIRCUIT FAILURE MODE LIKELIHOOD ANALYSIS

HLRs (per the PRA Standard) – CF element

- HLR-CF-A: The Fire PRA shall determine the applicable conditional probability of the cable and circuit failure mode(s) that would cause equipment <u>functional failure</u> and/or <u>undesired spurious operation</u> based on the credited function of the equipment in the Fire PRA. (2 SRs)

- HLR-CF-B: The Fire PRA shall document the development of the elements above in a manner that facilitates Fire PRA applications, upgrades, and peer review. (1 SR)

CIRCUIT FAILURE MODE LIKELIHOOD ANALYSIS

NEI 00-01, Rev. 2, Section 5.2.1.2 – Probability of Spurious Actuation

- NEI 00-01, Rev. 2, "Guidance for Post-Fire Safe Shutdown Circuit Analysis," May 2009.
- Generally follows Option #1 of the Task 10 methodology in NUREG/CR-6850, EPRI TR 1011989.
- Recommends the use of spurious actuation probability point estimates from:
  - Table 2.8.3 in NRC Inspection Manual 0609, Appendix F ("FP SDP")
  - Tables 7.1 and 7.2 from EPRI Report 1006961 ("Expert Elicitation")

CIRCUIT FAILURE MODE LIKELIHOOD ANALYSIS

Mapping HLRs & SRs for the CF technical element to NUREG/CR-6850, EPRI TR 1011989

Technical Element	HLR	SR	6850/1011989 Sections that cover SR	Comments
CF	A	The Fire PRA shall determine the applicable conditional probability of the cable and circuit failure mode(s) that would cause equipment functional failure and/or undesired spurious operation based on the credited function of the equipment in the Fire PRA.		
		1	10.5.2, 10.5.3	
		2	10.5.3	
	B	The Fire PRA shall document the development of the elements above in a manner that facilitates Fire PRA applications, upgrades, and peer review.		
		1	9.5.3, 10.5.3	Also covered in "Detailed Circuit Failure Analysis" chapter

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CIRCUIT FAILURE MODE LIKELIHOOD ANALYSIS

Mapping NEI 00-01, Rev. 2, Risk Significance Analysis to NUREG/CR-6850, EPRI TR 1011989

NEI 00-01, Rev. 2, Section	NEI 00-01 – Probability of Spurious Actuation	6850/1011989 Sections that cover step	Comments
5 – Risk Signifi-cance Analysis	5.2.1.2	10.5.3	NEI 00-01, Rev. 2, only recommends use of tables to determine spurious actuation probability estimates. NUREG/CR-6850, EPRI TR 1011989 also offers formula method.

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CIRCUIT FAILURE MODE LIKELIHOOD ANALYSIS
Step 3 – Related FAQ

- FAQ 08-0047 Cable Dependency
  - Issue:
    - Guidance (Vol. 2, Page 10-7, Bullet 3) states that when more than one cable can cause the same spurious actuation you combine probabilities using “exclusive or” (XOR)
    - This assumes faults/effects are independent
  - General approach to resolution:
    - Consensus reached that “exclusive or” is not appropriate if faults are dependent (e.g., a common power supply for both cables)
    - Clarify treatment to determine and address dependency
  - Status:
    - Closed

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Module II – Circuit Analysis

Circuit Analysis Basics
Fire PRA Circuit Analysis
Summary

Joint EPRI/NRC-RES Fire PRA Workshop
August 24-28

Dan Funk – Jensen Hughes

Gabe Taylor – U.S. NRC

A Collaboration of the Electric Power Research Institute (EPRI) & U.S. NRC Office of Nuclear Regulatory Research (RES)

CIRCUIT ANALYSIS SUMMARY
Topics

- Circuit Analysis “Big Picture” Road Map
- Interface with Fire PRA Group
- Circuit Analysis Strategy & Implementation
- Key Considerations & Factors
- Relationship to Appendix R & NFPA 805
- Lessons Learned

CIRCUIT ANALYSIS SUMMARY
Circuit Analysis Road Map

- Task 3 / 9A
  - Fire PRA Cable Selection
  - Circuit Analysis (Part A): Design Attributes
- Task 9B / 10
  - Circuit Analysis (Part B): Configuration Attributes
  - Circuit Failure Mode Likelihood Analysis
- Support Task B – Fire PRA Database

Remember – You cannot work in a vacuum! You must interface continuously with all team members!

CIRCUIT ANALYSIS SUMMARY
Interface with Fire PRA Group

- Coordination with Task 2 (Component Section) is essential – MUST understand the EXACT functionality credited for each component
- Essential that Fire PRA and NFPA-805 data be fully integrated

  Note: The subtleties of aligning Fire PRA and traditional Appendix R / NFPA-805 data is more complex than originally anticipated. This primarily shows up in Component Selection (Task 2), but has major ramifications to the circuit analysis

- Existing Appendix R Circuit Analysis is **NOT** as useful as originally envisioned

CIRCUIT ANALYSIS SUMMARY
Interface with Fire PRA Group (continued)

- Be forewarned…the PRA process is iterative and the components / function states will change (i.e., you will redo some analyses)

- Do not expect the PRA analysts to fully understand the various nuances with the circuit analysis for any given functional state – you will need to question them on inherent assumptions with the Basic Events

  Example: What automatic functions are inherently credited for a given Basic Event? Is the automatic function really required for the Fire Scenario?

CIRCUIT ANALYSIS SUMMARY
Strategy and Implementation

- Each Circuit Analysis task represents a refined level of detail (i.e., graded approach)
- Level-of-effort for the electrical work is a key driver for project scope, schedule, and resources
  - High programmatic risk if not carefully controlled
  - Analysis and routing of all cables can be a large resource sink with minimal overall benefit
  - Concerns validated by most projects
- Important to screen out obvious "Not Required" cables during the initial cable selection process (Task 9A), with refinement driven by quantitative screening (Task 9B)

CIRCUIT ANALYSIS SUMMARY
Strategy and Implementation (continued)

- Circuit Analysis (including cable tracing) can consume 40%-70% of overall budget
- Circuit Analysis scope **MUST** be a primary consideration during project planning
- Qualified and experienced circuit analysts must be integral members of the PRA team
- Evaluation, coordination, and integration with Appendix R must occur early and must be rigorous
- Long-term strategy for data configuration control – especially if sharing data with Appendix R / NFPA 805

CIRCUIT ANALYSIS SUMMARY

Key Considerations & Factors

- Circuit Analysis remains a technically and logistically challenging area
  - Practical aspects of dealing with an integrated data set
  - Practical approach for dealing with MSOs
  - Circuit Analysis is more complex and difficult than analyses performed under Appendix R
- Availability, quality, and format of cable data
- Availability of electrical engineering support
  - Circuit Analysis is a developed expertise
  - Do not expect to be a proficient analyst based on a simple introductory course

CIRCUIT ANALYSIS SUMMARY
Key Considerations & Factors (continued)

- Usability of Appendix R circuit analysis data
  - Not as useful as originally envisioned
  - Automated tools are essential
  - Functional state analysis is critical – overly conservative cable selection will not work for Fire PRA
  - Many plants are finding that circuit analysis re-baseline is necessary to support upgraded Fire PRA and NFPA-805 projects
- User-friendliness of electrical drawings
- Be aware of pending changes based on PIRT and PRA Expert Panel (NUREG/CR-7150, Vol. 1 & 2)

CIRCUIT ANALYSIS SUMMARY
Relationship to Appendix R & NFPA 805

- Practical aspects of dealing with an integrated data set
- Practical approach for dealing with MSOs
- Implication of these Advances: Circuit Analysis is more complex and difficult than analyses performed under Appendix R

CIRCUIT ANALYSIS SUMMARY
Lessons Learned

- Do not underestimate scope
- Ensure proper resources are committed to project
- Doable but **MUST** work smart
- Do not “broad brush” interface with Appendix R – have a detailed plan before starting
- Interface between PRA and Electrical groups is typically poor
- Develop project procedures – but don’t get carried away
- Compilation and management of large volume of data
  – Automated tools imperative for efficient process
  – Long-term configuration management often overlooked until very end of the project

CIRCUIT ANALYSIS SUMMARY
Lessons Learned (continued)

- NFPA 805 projects assume too much about the ability of the Fire PRA model to answer specific Appendix R questions
- Resolution of VFDRs via the FRE process is complicated and challenging to get right…to a large degree the consistency of the circuit analysis determines how well the process goes

CIRCUIT ANALYSIS SUMMARY
Questions

Any Questions?