NEI 00-01 Appendix I

I.1 Purpose

Prior to the recent activity related to the Industry's efforts to address Multiple Spurious Operations (MSOs) resulting from fire-induced hot short circuit failures, a limited number of Licensees have used shorting switches to prevent fire-induced spurious operations. To resolve the MSO issues outlined in NEI 00-01, additional Licensees have installed shorting switches primarily on valves to mitigate the effects of hot short induced spurious operation of the valves. Clear technical considerations are needed to assure that Licensees address the design and installation aspects necessary to assure effective implementation of a shorting switch for the specific conditions associated with the application. The technical considerations included in this document are as follows:

- Section I.3.2 – Circuit Design Considerations
    - Circuit Attributes, e.g. remotely operated valve; seal-in circuit; automatic operation circuit
- Section I.3.3 – Electrical Design Considerations
    - Target Coil minimum pick-up voltage
    - Potential credible aggressor sources
    - Computation of maximum expected voltage/current through target coil
- Section I.3.4 – Circuit Continuity Considerations
    - Cabinet fires
        - Fire spread between compartments
        - Fire damage to shorting switch and related components
    - Fire-induced Open Circuits
        - Fire damage
        - Energetic arcing from nearby fire damaged cables
    - Additional Mitigating Measures
        - Shorting switch with additional redundancy
        - Shorting switch to add time delay for operator manual actions
        - Shorting switch to increase sequential failures leading to a spurious operation

This Appendix identifies the technical considerations for designing valve control circuits that include shorting switches.

Additionally, Section I.3.1 is provided to clarify those licensing considerations that may make NRC approval a required step for certain shorting switch applications, e.g., fire modeling for required hot shutdown components related to open circuits.

- Section I.3.1 – Licensing Considerations
    - NFPA 805 Plants
    - Deterministic Plants using Appendix R or Standard License Condition
        - III.G.2
            - Required for Hot Shutdown
            - Important to Safe Shutdown
        - III.G.3/III.L

Finally, a Considerations Checklist and an example problem addressing the Considerations Checklist are included at the end of this appendix.

Although this Appendix provides technical considerations for the design of circuits containing shorting switches, there are a number of technical factors where specific implementing criteria could not be provided (e.g., circuit continuity for cabinet fires and potential collateral damage from associated circuits contained in the same raceway). The inability to supply specific implementing criteria in these areas is a direct result of the current state of knowledge available to the JACQUE-FIRE III Working Group and the numerous plant configurations and potential exposure condition present throughout the Nuclear Power Industry.

I.2 Background

The recommended design features of the shorting switch provided in this Appendix take advantage of recent developments in cable fire testing and cable failure modes research, and provide a design capable of preventing fire-induced spurious operation, given credible fire conditions. A Licensee's ability to take credit for credible fire conditions in the design of the shorting switch is a function of that Licensee's Current Licensing Basis (CLB). In this way, a Licensee's CLB may limit a Licensee's ability to use shorting switches without additional licensing actions. For this reason, in this Appendix, the CLB considerations on the use of shorting switches are discussed.

The shorting switch functions to prevent spurious operation of a component by placing a short across a coil in the circuit of concern when the circuit is in its "standby" state. When the component is desired to be operated, the motion of the hand switch removes the short before energizing the coil to actuate the component. Any circuit using a shorting switch should have this feature of removing the short provided by the shorting switch prior to energizing the coil (i.e., break-before-make). In this Appendix, examples of circuits for which the use of a shorting switch may be appropriate, provided the considerations itemized below are addressed, are provided. Examples of circuits where the use of the shorting switch may not be appropriate, without additional engineering considerations not specifically identified or discussed in this appendix, are also provided, e.g., Figures I.5.0 and I.6.0.

Figure I.1.0 provides a depiction of a simplified motor operated valve (MOV) Circuit. The MOV is shown in the closed position. If the control room hand switch (HS) is placed in the open position, the HS open contact will shut causing the open relay to energize resulting in the MOV stroking open. The 33L and 33U contacts (limit switch contacts dependent on valve position), change states with 33U closed (Red lamp) and the 33L open (Green lamp).

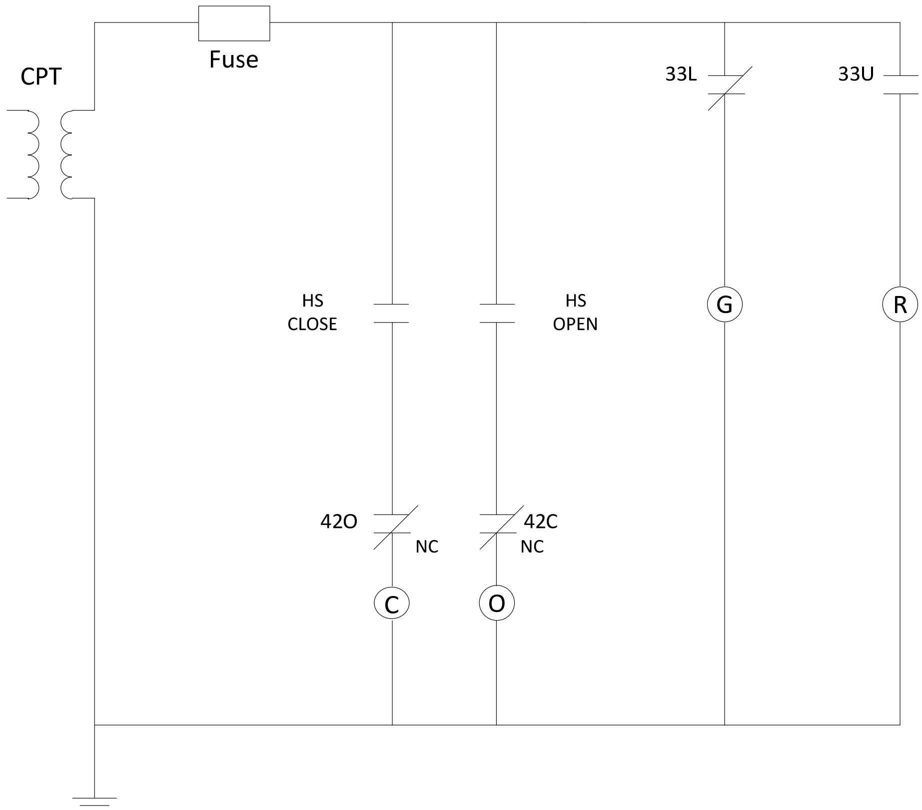

Figure I.1.0 – Simplified MOV Circuit

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

In the case of many valves, there is a desired and undesired position with respect to the safe shutdown analysis. The concern is that the valve could reposition due to a hot short induced spurious operation during a fire. For the purposes of this discussion, the valve will normally be in the closed position, and the goal is to prevent the valve from repositioning to the open position. That is, the valve is initially in the closed position and it is desired to remain in the closed position for the safe shutdown analysis. To accomplish this, the shorting switch is placed in the circuit, so that a hot short downstream of the HS open contact will have no impact on the circuit. See the Figure I.2.0 below.

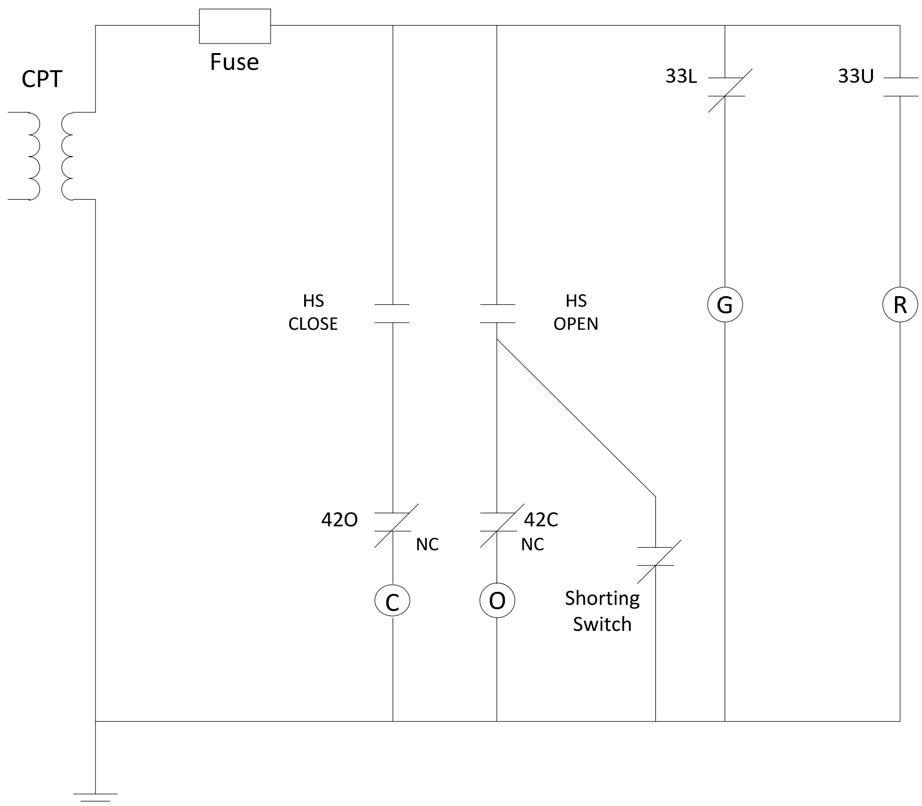

Figure I.2.0 – Simplified MOV Circuit with Shorting Switch

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

Another important consideration for the design of the shorting switch is that it should be electrically designed to short the potential from an aggressor[1] circuit away from the target coil, which if energized, could spuriously operate the component. The considerations for the electrical design aspects of the shorting switch are outlined in this Appendix.

Finally, as shown in the Figure I.3.0 below, the proper functioning of the shorting switch is completely dependent on maintaining the integrity of the shorting switch and other associated components, e.g., terminal blocks and conductors, necessary to maintain the continuity of the shorting path. An open circuit in the shorting path would eliminate the protection provided

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

by a shorting switch in preventing a spurious operation. Even with the presence of an open circuit, a spurious operation of the component will not occur without the presence of a subsequent hot short.

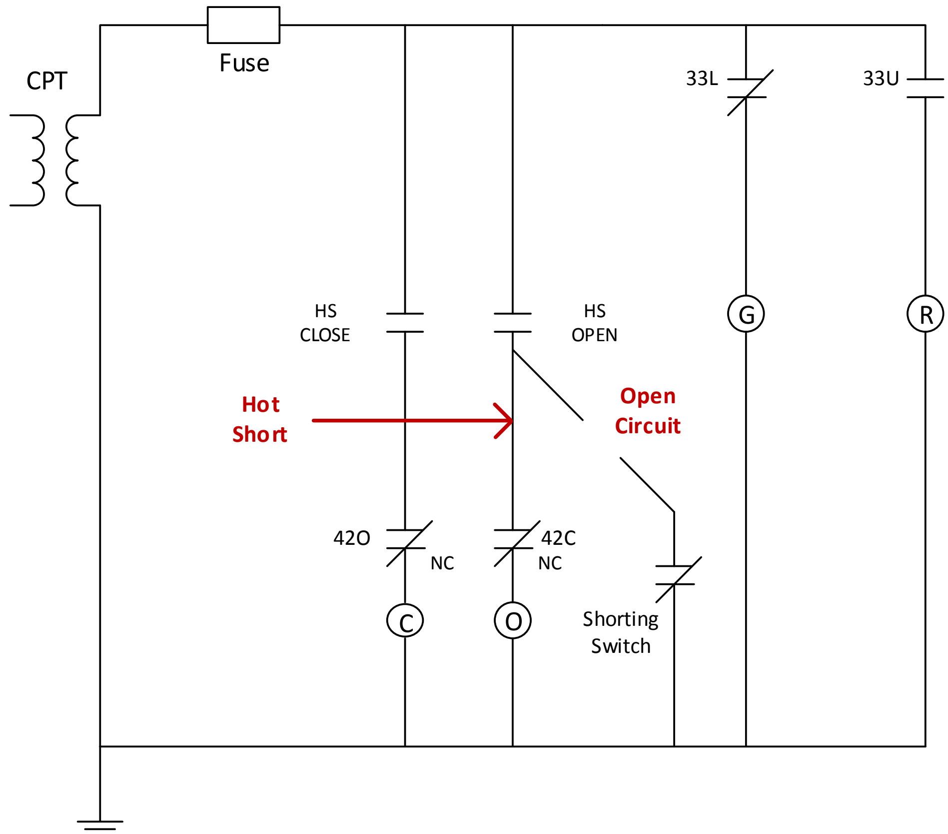


Figure I.3.0 – Simplified MOV Circuit with Shorting Switch & Open Circuit

Therefore, crediting the shorting switch for preventing a fire-induced spurious operation in a location where the shorting switch and other associated components are co-located with the fire, presents an additional challenge due to the potential for fire damage to the shorting switch and other related components required for proper circuit operation. For these conditions, some benefit in mitigating the impact to an overall spurious operation prevention strategy can be gained by including some measure of redundancy and/or time delay into the spurious operation prevention strategy. Redundancy can be gained by using a shorting switch to increase the sequential number of failures necessary for the spurious operation to create a negative impact on post-fire safe shutdown, i.e., failure of the shorting switch is only one component in the sequence required to fail in order for adverse effects to occur. Additionally, a shorting switch could be used to increase the time until adverse impacts occur thus allowing additional time for an operator action to be performed.

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

- Section I.3.1 – Licensing Considerations
  - NFPA 805 Plants
  - Deterministic Plants using Appendix R or Standard License Condition
    - III.G.2
      - Required for Hot Shutdown
      - Important to Safe Shutdown
    - III.G.3/III.L
- Section I.3.2 – Circuit Design Considerations
  - Circuit Attributes, e.g. remotely operated valve; seal-in circuit; automatic operation circuit
- Section I.3.3 – Electrical Design Considerations
  - Target Coil minimum pick-up voltage
  - Potential credible aggressor sources
  - Computation of maximum expected voltage/current through target coil
- Section I1.3.4 – Circuit Continuity Considerations
  - Cabinet fires
    - Fire spread between compartments
    - Fire damage to shorting switch and related components
  - Fire-induced Open Circuits
    - Fire damage
    - Energetic arcing from nearby fire damaged cables
  - Additional Mitigating Measures
    - Shorting switch with additional redundancy
    - Shorting switch to add time delay for operator manual actions
    - Shorting switch to increase sequential failures leading to a spurious operation

I.3 Considerations on the Use of Shorting Switches

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

A checklist of the considerations addressed in this paper for the design of a shorting switch and an example of the application of the considerations is provided at the end of this paper.

I.3.1 Licensing Considerations

As stated above, the effective use of a shorting switch is dependent on maintaining the integrity of the shorting path. To maintain the continuity of the shorting path, engineering evaluations, some using fire-modeling, may be needed to assess the impact of credible fire conditions on the shorting switch and on each of the components associated with the shorting path.

Because a specifically located and sequenced open circuit could defeat the functioning of the shorting switch, as shown in Figure I.3.0, the potential for open circuits needs to be evaluated. This consideration renders the shorting switch modification to be less of a stand-alone modification than most electrical circuit modifications. The shorting switch modification relies heavily on an accompanying technical evaluation performed within the context of the post-fire safe shutdown analysis to ensure that the switch can perform its function. This is largely due to the fact that a specifically located and sequenced open circuit must either not occur or, if one does, it must occur late in the fire event after aggressor circuits (that could cause the undesired hot short-induced spurious operation) have cleared. The use of a technical evaluation for determining the potential for an open circuit, however, in and of itself, does not necessarily align with statements in the regulations. This condition can create a regulatory inconsistency, despite the conclusions drawn in the technical evaluation. Specifically, statements in 10 CFR 50, Appendix R must be addressed when evaluating the need to consider open circuits in the design of the shorting switch.

III.G.2

"Except as provided for in paragraph G.3 of this section, where cables or equipment, including associated non-safety circuits that could prevent operation or cause maloperation due to hot shorts, open circuits, or shorts to ground . . ."

III.L.7

"The safe shutdown equipment and systems for each fire area shall be known to be isolated from associated non-safety circuits in the fire area so that hot shorts, open circuits, or shorts to ground in the associated circuits will not prevent operation of the safe shutdown equipment."

Additionally, Generic Letter 86-10 (Reference 4) states,

"Sections III.G.2 and III.L.7 of Appendix R define the circuit failure modes as hot shorts, open circuits, and shorts to ground. For consideration of spurious actuations, all possible functional failure states must be evaluated, that is, the component could be energized or de-energized by one or more of the above failure modes."

As described above, open circuits have always been a consideration for safe shutdown analyses. Since, in most cases, open circuits behave similarly to blown fuses, evaluating the effects of open circuits has been relatively straight forward, since the impact is the same as for a loss of power to the circuit. With the shorting switch, however, an open circuit takes on heightened importance. An open circuit, occurring at a specific location in a specific sequence, could defeat the purpose of the shorting switch modification and allow a subsequent hot short to cause an adverse spurious operation. Therefore, for the shorting switch to be effective, an open circuit cannot occur during a fire or it must occur late in the fire event after all aggressor circuits (that could cause the undesired hot short-induced spurious operation) have cleared.

As described below, a Licensee's CLB will affect the extent to which shorting switches may be used.

a. Performance-Based Compliance under NFPA 805:

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

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

Licensees who still maintain a deterministic compliance approach for their Fire Protection Program, however, may have some additional considerations depending on the classification of the component for which the shorting switch is being used. The two classifications of concern are "required for hot shutdown components" and "important to safe shutdown components".

The guidance for Protection for Components Important to Safe Shutdown is addressed in Regulatory Position 5.3.1.2 of RG 1.189, Rev. 2. One of the available protection options is the use of Fire Modeling, as discussed in Regulatory Position 5.3.1.4. The evaluations discussed in this Appendix would be considered as part of a Fire Modeling protection strategy for Components Important to Safe Shutdown.

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

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

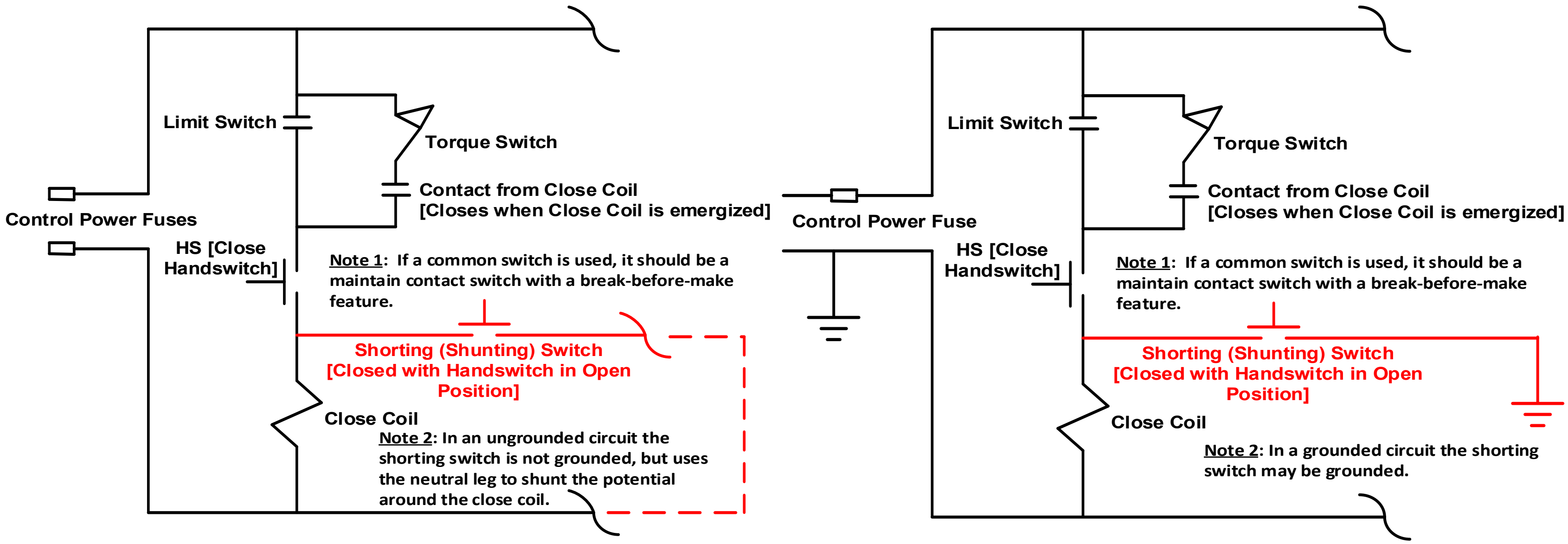
Conversely, Appendix R Section III.G.2 requires consideration of fire-induced open circuits and this requirement would apply to any "required for hot shutdown component". Additionally, Appendix R Section III.G.2.a through f do not include any allowance for fire-modeling as a means of mitigating the effects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

Finally, deterministic compliance for Alternative or Dedicated Shutdown under Appendix R Sections III.G.3 and III.L, the classifications of "required for hot shutdown" and "important to safe shutdown" are not applicable. Appendix R Sections III.G.3 and III.L neither preclude nor endorse the use of the type of engineering tools necessary to perform an engineering evaluation of a shorting switch. Acceptable approaches for use in the engineering analysis of shorting switches are provided below. These approaches are acceptable for use under Appendix R Sections III.G.3 and III.L.

I.3.2 Circuit Design Considerations

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

The following simplified examples are provided to illustrate conceptual approaches for utilizing shorting switches within typical control circuits. More complex designs are possible, but the use of more complex shorting switch designs increases the burden on the designer to assure that each of the features required for the successful operation of the shorting switch are identified and addressed. The considerations described in this appendix should be supplemented by an electrical circuit Failure Modes and Effects Analysis (FMEA) for more complex circuit designs. The FMEA should focus on the operational aspects of the circuit and it should assure that the addition of the shorting switch into the circuit will not create any unforeseen operational issues, e.g., unanticipated blown fuses or tripped breakers. Refer to Figures I.5.0 and I.6.0 for examples of circuits requiring an FMEA.



a) Shorting Switch in an Ungrounded DC Manually Operated Valve with No Seal-in

b) Shorting Switch in a Grounded AC Manually Operated Valve with No Seal-in

Figure I.4.0 – Simplified Illustration of Shorting Switch in Control Circuits Without Seal-In Features

The shorting (shunting) switch in Figure I.4.0 depicts a manually operated valve in an a) ungrounded DC circuit and a b) grounded AC circuit. The valve is normally open and the undesired state is a spurious closure of the valve. The shorting switch for this case would be designed to prevent the valve from spuriously closing by shorting (shunting) the potential applied by an aggressor circuit around the close coil bypassing the impedance (resistance) in the circuit and, thereby, blowing the fuse in either the aggressor (source) circuit (hot leg) or, in the case of the DC circuit, the targeted circuit (return leg). The valve has no automatic operation features that would automatically bypass the manual control switch and it does not have a seal-in around the close switch. If a common control/shorting switch is used, the manual control switch should be a maintain contact switch and it should have a break-before-make switch design to prevent the close switch and the shorting switch contacts on the manual switch from being closed simultaneously.

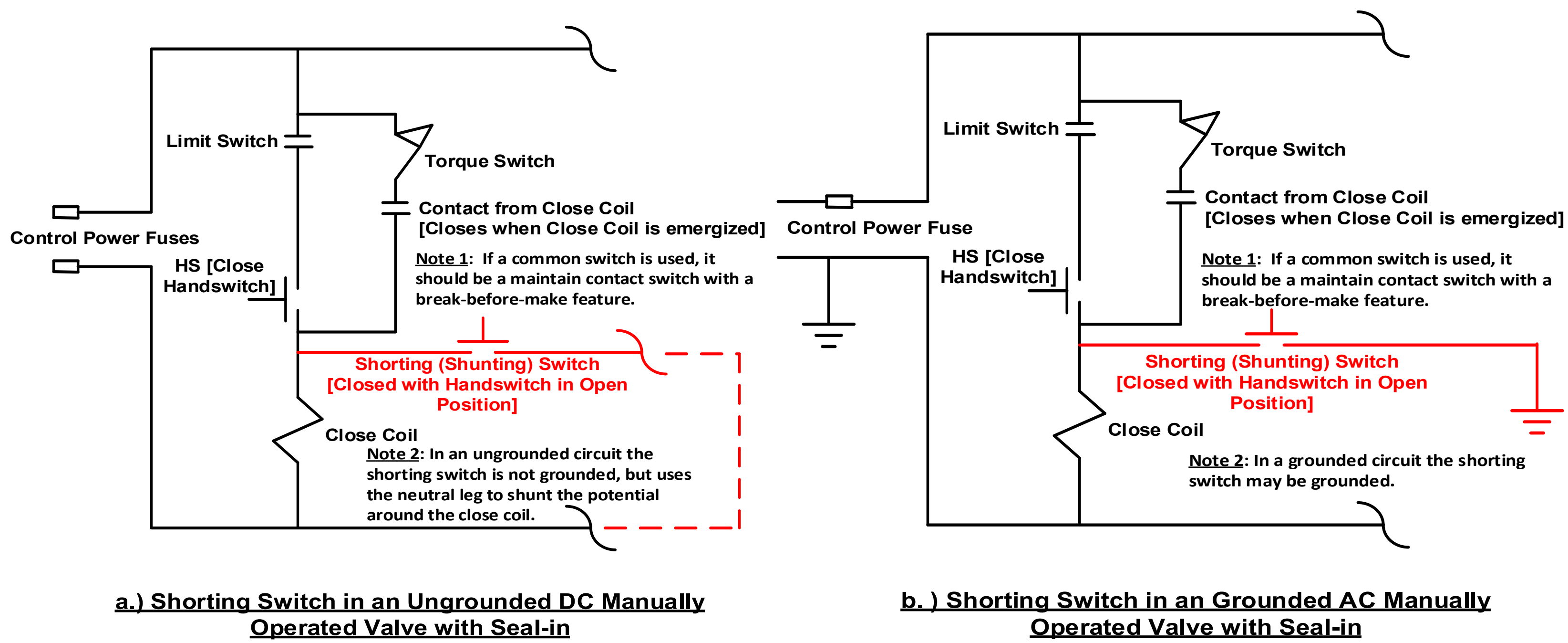
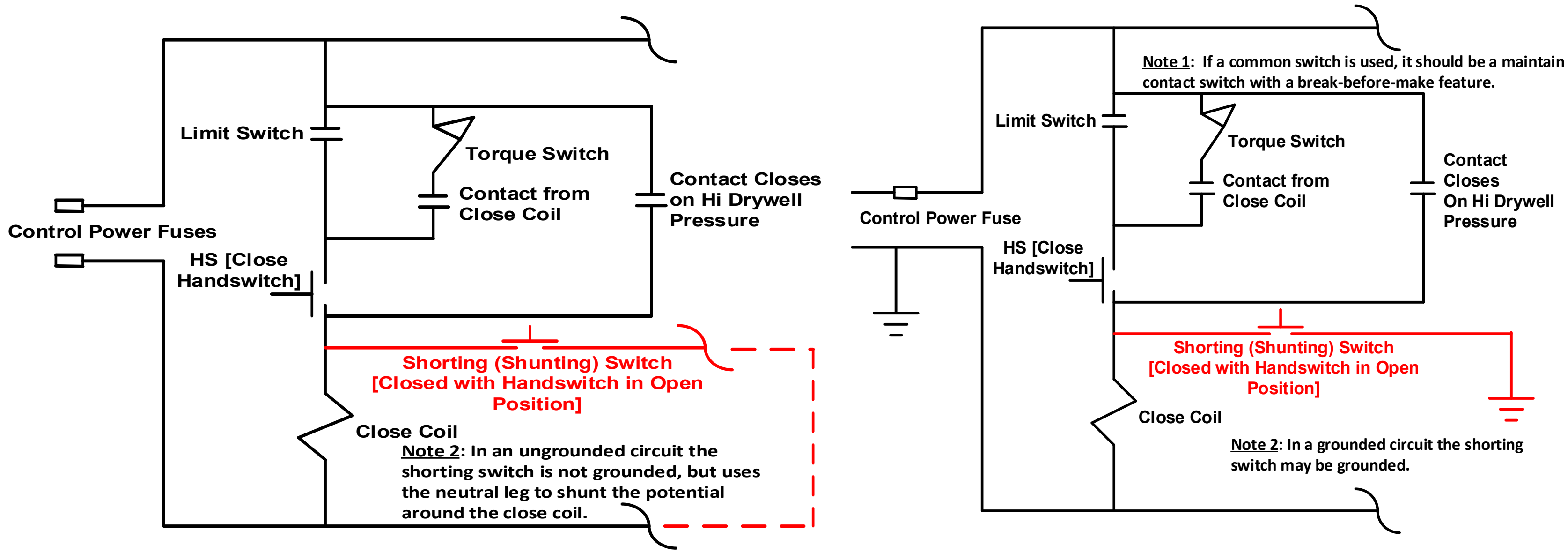


Figure I.5.0– Simplified Illustration of Shorting Switch in Control Circuits With Seal-In Features

The shorting (shunting) switch circuit in Figure I.5.0 is similar to the circuit in Figure I.4.0 with the following exception. The valve has no automatic operation features that would automatically bypass the manual control switch, but it does have a seal-in around the close switch. Even though the manual control switch is a maintain contact switch with a break-before-make switch design to prevent the close switch and the shorting switch contacts on the manual switch from being closed simultaneously, the seal-in feature of this circuit would make it a bad candidate for a shorting switch from an operational point of view, since the circuit control power fuses could be blown should the Operator reverse the position of the manual control switch prior to the valve fully completing its stroke to the fully closed position. The use of a shorting switch as depicted above on a circuit like this is not recommended without additional circuit changes and without the development of an FMEA to address the operational consideration mentioned above.



a.) Shorting Switch in an Ungrounded DC Automatically Operated Valve with No Seal-in

b.) Shorting Switch in an Grounded AC Automatically Operated Valve with No Seal-in

Figure I.6.0– Simplified Illustration of Shorting Switch in Control Circuits With Automatic Control and Without Seal-In Features

The shorting (shunting) switch circuit in Figure I.6.0 is similar to the circuit in Figure I.4.0 with the following exception. The valve has an automatic operation feature that would automatically bypass the manual control switch and blow the control power fusing to the circuit. This feature would make this valve an unacceptable candidate for a shorting switch from an operational point of view, unless the circuitry were significantly re-designed to be able to accomplish both features independently. The use of a shorting switch as depicted above on a circuit like this is not recommended without additional circuit changes and without the development of an FMEA to address the operational consideration mentioned above.

I.3.3 Electrical Design Considerations

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

- Minimum pick-up voltage of the coil
- Characterization of Potential Credible Aggressor Sources
- Computation of Maximum Expected Voltage/Current through the Target Coil

a. Minimum pick-up voltage of the coil:

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

b. Characterization of Potential Credible Aggressor Source:

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

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

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

The shorting switch prevents the target coil from picking up by shunting the aggressor conductor's voltage through a low-impedance path around the target coil. This low-impedance current flow path in most cases is carried by plant cables and a normally-closed control switch or relay contact. Control switch and relay contacts are typically rated for significant voltages and currents, are required to meet self-extinguishing requirements such as UL-94, and some have been tested to withstand currents well beyond their published rating.

For example, Sandia Test Report NUREG/CR-4596 identifies the potential for Agastat relay (EGP, ETR) sockets to deform under extreme high temperature conditions (210°C from NUREG/CR-4596, Figures 12 and 13). Therefore it is recommended that Agastat relays not be credited as a shorting switch in scenarios where they may be exposed to internal panel fires. Consideration should also be made for secondary (adjacent) panel fires since air temperatures could exceed 210°C as shown in NUREG/CR-4527, Figure 30.

Each application using the shorting switch should confirm that the as-installed configuration is capable of carrying the postulated momentary fault current that may be shunted through the wiring and normally-closed switch/relay contact does not result in an unacceptable condition (e.g., wire overheating, switch overheating) so severe that the shorting function would be disabled. Consideration of a voltage interaction of the shorting switch circuits with higher voltage source should be addressed when a higher voltage source is routed in the same raceway, i.e., conduit, cable tray or wireway, or housed in the same enclosure, i.e., Motor Control Center.

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

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

c. <u>Computation of Maximum Expected Voltage/Current through the Target Coil:</u>

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

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

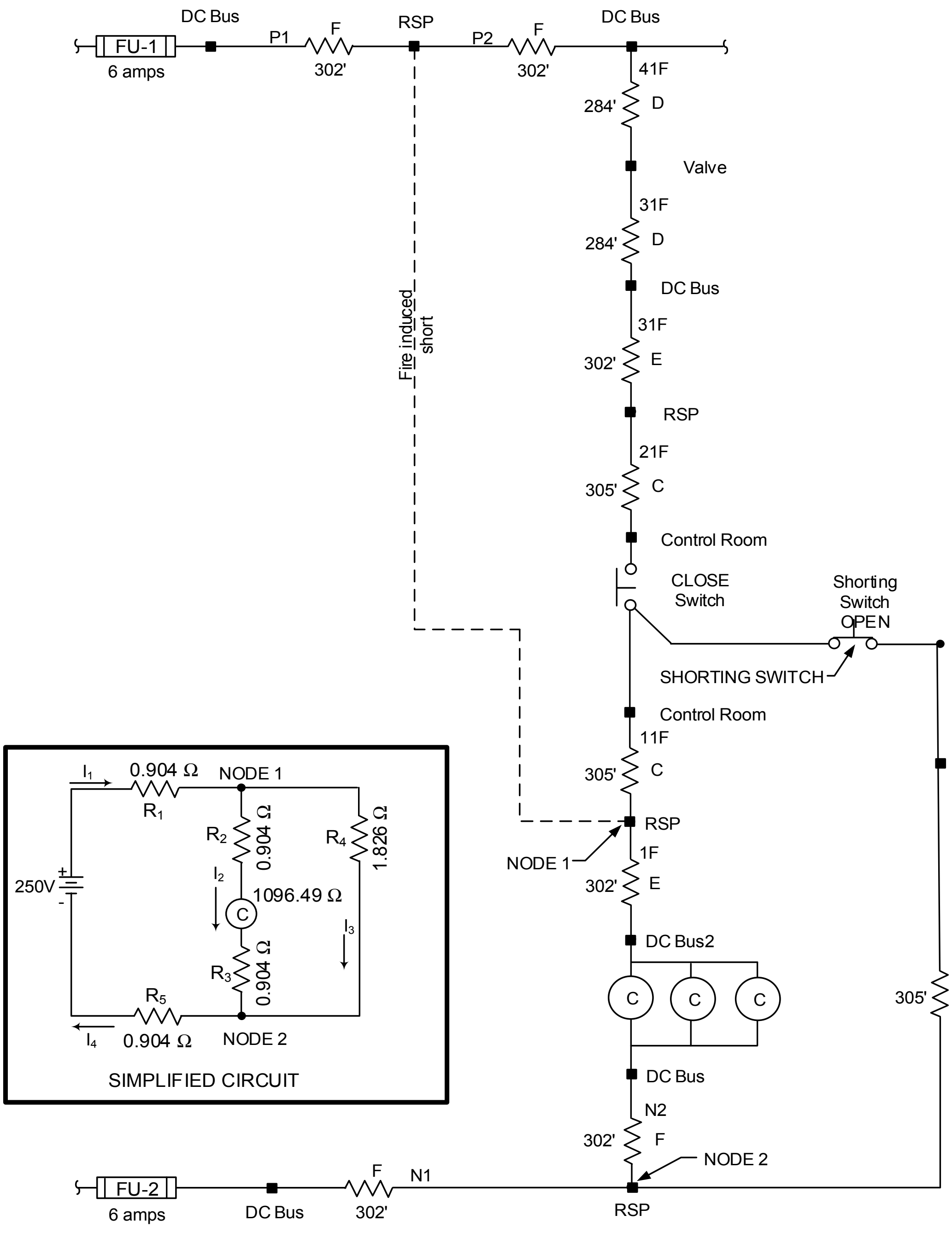
With the minimum pick-up voltage for the coil, the bounding aggressor cables and the bounding cable protective device characteristics for the aggressor cables, the specific electrical circuit containing the shorting switch should be analyzed. Figure I.7.0 below is an example of how the electrical circuit is modeled.

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

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

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

This electrical design process may impact control circuit components and conductor sizing of the shorting current flow path. In essence, it may impact the final circuit configuration chosen so as to optimize the effectiveness of the shorting circuit and the required changes may require modification beyond simply installing a shorting switch.



Simplified Circuit
(Lumped Model)
Figure I.7.0

I.3.4 Circuit Continuity Considerations

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

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

a. Cabinet Fires:

This section applies to shorting switch circuits where either the shorting switch or some other critical subcomponent, e.g., terminal block, of the shorting switch circuit other than cabling is to be credited for fires at the location of the switch or critical subcomponent itself. The most likely location for these considerations to apply are in the Control Room.

For this discussion, the fire is postulated to be at or near the panel containing the shorting switch; thus, the shorting switch, associated panel conductors, terminal blocks, or field cables near the panel are postulated to be susceptible to fire damage. The specific concern for this category is whether or not the fire can result in a failure of the shorting switch, terminal blocks, or other electrical devices inside the electrical cabinet/panel in which the failure mode is an open circuit.

In addressing Control Room Panel fires, realistic fire conditions should be addressed. Recent work within the Industry related to Panel Heat Release Rates (HRR) may be useful in determining the characteristics of a realistic fire. For these realistic fire conditions, both flame impingement, as well as, panel heat up considerations must be addressed. Flame impingement effects on the shorting switch can cause switch failure and this failure could allow a subsequent spurious operation to occur. It is the position of the Working Group for JACQUE-FIRE III that flame impingement effects on shorting switches and any screwed, crimped or soldered connections at the switch may be mitigated by the use of sheet metal enclosures similar to those used for Regulatory Guide 1.75 Electrical Separation. Even with the use of a sheet metal enclosure, however, compartment heat up effects must be addressed. The continued performance of shorting switches and any screwed, crimped or soldered connections at the switch post-fire can be demonstrated by either fire testing using realistic fire conditions or engineering analysis. Finally, exposure fires within the Control Room itself, although not considered to be a likely failure mode, should be assessed to make sure that any potential failure modes have been considered and addressed.

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

Furthermore, the testing concluded the following:

> "Fires in either bench-board or vertical cabinets with either IEEE-383 qualified cable or unqualified cable can be ignited and propagate. However, fires with IEEE-383 qualified cable do not propagate as rapidly nor to the

> extent that unqualified cable does. Furthermore, the results showed that the thermal environment in the test enclosure and adjacent cabinets is not severe enough to result in auto-ignition of other combustibles; although in some of the larger fires melting of plastic materials may occur . . . Essentially, a cabinet fire can propagate within a single cabinet; however, for the conditions tested it does not appear that the fire poses a threat outside the burning cabinet except the resulting smoke."

NUREG/CR-4527 gives further clarification to these conclusions:

> "For cables that do not pass IEEE-383 flame-spread test standard (unqualified cables), cabinet fires are easily ignited and propagate readily, generally resulting in combustion of all combustible materials within the cabinet. It was also demonstrated that even a low-intensity (170-W) electrically heated fault point could result in full cabinet involvement for unqualified cables.
>
> For cables that pass the IEEE-383 flame-spread testing standard (qualified cables), self-sustaining fires that resulted in full involvement of the cabinet were somewhat more difficult to induce. However, given the proper circumstances, such a fully involved cabinet fire is possible."

Additionally, it concludes:

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

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

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

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

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

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

Each Licensee using a shorting switch in a cabinet location should confirm through engineering analysis/testing that the switch and its associated subcomponents will perform as intended given the range of environmental conditions that could be produced by a credible fire.

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

- fire testing of the switch and associated subcomponents to either industry fire testing standards or specific temperature thresholds, if justified by plant specific fire hazards analysis, which demonstrates that they will survive for the required period of time.
- qualitative fire hazards analysis, addressing general peak cabinet temperatures and the potential for flame impingement possibly in combination with sheet metal isolation enclosures covering the switch and any crimped or soldered connections, showing that the in-situ combustibles and fire hazards are less severe than the testing, and thus not capable of driving the switch or its associated subcomponents to failure.
- engineering evaluations combining the testing and fire hazard analysis approaches described above that demonstrate the switch functionality for a specific "mission time", after which other strategies will be credited to prevent

spurious operation, or after which spurious operation can be tolerated for some other reason.

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

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

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

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

b. <u>Fire-induced Open Circuits in Raceway Routing:</u>

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

For typical fire conditions, the direct effects of the fire will be to burn off any insulation on the cable/wiring causing the conductor(s) to either lay bare (with no insulation) or be covered by a damaged, charred layer of insulation. In both the NEI/EPRI and CAROLFIRE cable testing programs, this phenomenon was observed and the cable failure progression included either an intra-cable hot short with the potential to cause a spurious operation or a short-to-ground clearing the control power fuse for the circuit. If the intra-cable hot short occurred first, then the fire-induced circuit failure sequence often rapidly progressed to a short-to-ground which cleared the control power fusing. In a vast majority of the tests conducted under the NEI/EPRI and

CAROLFIRE cable testing programs, the testing concluded with a loss of power to the control circuit based on clearing of the control power fusing for the circuit and, as a result, fire-induced open circuits were not observed. Fire-induced circuit failures occurred within the cable with very little interaction with any of the cables surrounding the primary cable. Each of these testing programs, however, included primarily ac circuits with small sized control power fuses and with a sufficient number of conductors within the cable to allow it to progress through the fire-induced circuit failure sequence described above. High energy circuits were not included in these testing programs.

In the DESIREE cable fire testing program, however, ungrounded DC circuits were tested. Some of these circuits included larger sized control power fuses, i.e. 30 amps. In the DESIREE cable fire testing program, those ungrounded DC control circuits with smaller sized control power fuses, i.e., 10 amps or less, behaved similarly to the circuits tested under the NEI/EPRI and CAROLFIRE cable testing programs. Those ungrounded DC circuits with the larger sized control power fuses, i.e., 30 amps, exhibited a different behavior. These ungrounded DC circuits with larger sized control power fuses did not always clear the fusing on both legs of the control power circuit. With either or both legs of the circuit still fused and energized, these circuits, in some cases, exhibited an arcing phenomenon with the potential to damage adjacent cables or cable tray components. In fact, some damage to cable tray rungs in the vicinity of the arcing cable was observed. Open circuits were observed in the DESIREE cable fire testing program. However, energetic arcing causing an open circuit in a nearby cable was not directly observed in the DESIREE cable fire testing program. This phenomenon was not a test objective and not something that was specifically investigated as a part of the DESIREE Testing. As such, open circuits as a result of energetic arcing of nearby 125 VDC cables with larger sized control power fuses cannot be ruled out.

Additionally, there have been recent industry events in which high energy 120 VAC cables have exhibited energetic arcing effects and post-event investigations have found open circuits. As such, the Working Group cannot rule out that an AC circuit with the proper current characteristic and with its cable jacket and insulation degraded could cause damage to nearby cables.

The DESIREE DC Cable Fire Testing and the industry events for AC circuits demonstrate that the concern for an energetic arcing cable faults causing an open circuit in an adjacent circuit containing a shorting switch must be considered and addressed.

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

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

- Fire-induced cable damage initially affects a cable by damaging the jacketing and conductor insulation associated with the cable.
- In the absence of effects from an adjacent energetic arcing cable, fire-induced circuit failures, in most cases, will occur first within the cable. In general, if the proper conductors exist within the cable, intra-cable hot shorts and/or shorts to ground will occur.
- For circuits, either grounded or ungrounded, with fuses sized at 10 amps or less, clearing of the fuses as fire damage progresses is likely. The working group judged that circuits fused with fuse sizes up to and including this size do not pose any threat to creating an open circuit in a nearby circuit containing a shorting switch regardless of whether they are power or control circuits.
- For ungrounded DC circuits with larger sized control power fuses, i.e., 30 amps, clearing of the control power fuses may not occur depending on the fault location and available fault current.
- Isolated legs of ungrounded DC control circuits with larger sized control power fuses where the control power fuse takes longer to clear or does not clear, have the potential to generate arcing faults, some of which have the potential to damage nearby components, i.e., cables and/or portions of cable trays.
- Energetic arcing in AC circuits with voltages as low as 120 VAC where the protection device (e.g., fuse, breaker) does not clear, have the potential to generate arcing faults, some of which have the potential to damage nearby components, i.e., cables and/or portions of cable trays.
- Depending on the energy available in the circuits, the failure sequence of the circuits in the fire scenario and the relative location of high energy circuits to the circuit containing the shorting switch, open circuiting cannot be ruled out and, as such must be assumed to have the potential to occur. This open circuit could be from AC or DC circuits with high energy in close proximity to the cabling for the shorting switch circuit.

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

Open circuits in circuits containing shorting switches routed in or near raceway containing energetic circuits can be addressed by either:

- Meeting the electrical separation distances of IEEE 384, as outlined below in Table 1.0, for any high energy circuits, either AC or DC, routed near the circuit containing the shorting switch, or
- Providing a technically sound engineering evaluation justifying
    - either reduced separation distances or

- o the acceptability of the shorting switch design in mitigating the effects of a spurious operation given the potential for nearby energetic arcing cables impacting the shorting switch circuit and causing an open circuit. To justify the acceptability of the shorting switch it must be demonstrated that an open circuit removing the shorting switch from the circuit and followed by a hot short energizing a coil of concern cannot reasonably occur.

To address the potential impact from high energy circuits, a criteria like that described in IEEE Std. 384-1992 for Electrical Separation could be applied. IEEE Std. 384-1992 gives recommended separation criteria for electrical cabling. This standard has been endorsed by the NRC through Regulatory Guide 1.75. The separation criteria contained in the standard is largely dependent upon both the hazards in the area and the energy level of the potential aggressor cable. The potential hazards are primarily missiles, pipe failures, and fires. For the purpose of this discussion, the primary concern is a fire. The standard defines three hazard classification:

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

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

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

Of primary concern when considering the potential for an open circuit is the location of the high energy, i.e., power or other, circuit aggressor cables in the immediate proximity of the target control cabling. These higher energy cables have the potential of faulting at such an energy level that other nearby cables could be damaged. The separation criteria for power cabling in IEEE 384-1992 is provided in Table 1. Use of these distances as the separation distance between the cables containing the conductors for a shorting switch and any high energy cable is considered to be an acceptable way to limit collateral damage with the potential to cause an open circuit in the shorting switch cable (e.g., cable in one raceway damaged due to arcing of a cable in a different raceway).

The following criteria are recommended to determine whether an open circuit could be caused in control circuit cabling run within the referenced separation distances from power cabling.

Table 1 [from IEEE 384-1992]

	For interactions involving low-voltage power circuits with cables size ≤2/0 AWG	For interactions involving low-voltage power circuits with cable sizes > 2/0 AWG and all medium-voltage power circuits
Open to open raceway configurations	6 in horizontal 12 in vertical	3 ft horizontal 5 ft vertical
Enclosed to enclosed configurations	1 in horizontal 1 in vertical	1 in horizontal 1 in vertical
Enclosed to open configurations	6 in horizontal 12 in vertical	3 ft horizontal 5 ft vertical

Electrical Separation for a Limited Hazard Area

(Excerpt from IEEE 384-1992)

In conclusion, unless the separation criteria of Table 1.0 is met, each Licensee should confirm through engineering analysis/testing that circuit damage by energetic arcing faults from nearby fire damaged cables produced by a credible fire will not defeat the functionality of the shorting switch.

c. Additional Mitigating Measures:

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

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

- Shorting Switch with Additional Redundancy:

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

- Shorting Switch as a Time Delay:

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

  If the component protected by the shorting switch can be isolated from the effects of the Control Room fire by actuation of the transfer switch at the Remote Shutdown Panel, then this finite number of minutes may be able to provide sufficient time for the Operator to evacuate the Control Room, traverse to the Remote Shutdown Panel and isolate the potential for a spurious operation of the component by actuation of the Remote Shutdown Panel transfer switch.

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

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

- Shorting Switch to Increase Sequencing to Spurious Operating:

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

  For example, the spurious closure of the Steam Return to the Suppression Pool Valve on a Steam Driven Turbine with the loss of the Hi Back Pressure Trip for that Steam Driven Turbine is one of the MSO required to be considered for some BWRs based on the list of MSO scenarios in Appendix G to NEI 00-01. For this scenario to occur, circuitry for the Steam Driven Turbine must initially be unaffected by the fire. After the Steam Driven

Turbine is up and running, the following sequence of fire-induced failures must occur:

- The circuitry for the Hi Back Pressure Trip for that Steam Driven Turbine must fail prior to the spurious closure of the Steam Return to the Suppression Pool Valve on a Steam Driven Turbine.
- The circuitry for the Steam Return to the Suppression Pool Valve on a Steam Driven Turbine must be subjected to a hot short causing spurious closure of the valve.

By installing a shorting switch in the circuitry for the Steam Return to the Suppression Pool Valve on a Steam Driven Turbine, the sequence of failures required for the spurious operation can be increased as follows:

- Fire-induced failure of the circuitry for the Steam Driven Turbine must be unaffected by the fire until the Steam Driven Turbine is up and running. [For HPCI, it takes approximately 30 seconds before the shaft driven oil pump takes over and the aux oil pump is no longer required.]
- Fire-induced failure of the circuitry for the Steam Driven Turbine must occur prior to reactor vessel level reaching the high level trip at which point the steam driven system will trip off. [For HPCI, the high level trip will be reached in approximately 3.5 minutes.] This allows a window of approximately 3 minutes for system damage to occur.
- If damage does not occur within the 3 minute window, fire-induced damage must again be deferred until after system restart at reactor vessel low, low level. [Typically, reactor vessel low, low level would not be reached again for approximately 20 minutes. This time frame by itself could allow adequate time for an operator manual action.]
- The circuitry for the Hi Back Pressure Trip for that Steam Driven Turbine, which is integral with the system re-start circuitry, must fail prior to the spurious closure of the Steam Return to the Suppression Pool Valve on a Steam Driven Turbine.
- A fire-induced open circuit must be introduced into the shorting switch circuitry at a location that eliminates the effectiveness of the shorting switch. This fire induced failure cannot cause the control power fusing in the shorting switch circuitry (ungrounded 125 VDC) to be lost since a loss of the control power to the shorting switch circuitry will prevent it from completing the spurious operation caused by the subsequent hot short described in the bullet below.
- The circuitry for the Steam Return to the Suppression Pool Valve on a Steam Driven Turbine must be subjected to a hot short causing spurious closure of the valve and this hot short must be at a location in the circuitry where it is between the fire-induced open circuit and the close coil.

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

I.4 References

I.4.1 NRC NUREG/CR-6931 "Cable Response to Live Fire (CAROLFIRE)", April 2008

I.4.2 NRC NUREG/CR-7100 "Direct Current Electrical Shorting in Response to Exposure Fire (DESIREE-Fire)", April, 2012

I.4.3 NUREG/CR-4596 [SAND860-394] "Screening Tests of Representative Nuclear Power Plant Components Exposed to Secondary Environments Created by Fires", June 1986

I.4.4 NUREG/CR-4527 (SAND86-0336) [ADAMS ML06090351] "An Experimental Investigation of Internally Ignited Fires in Nuclear Power Plant Control Cabinets", April 1987

I.4.5 EPRI TR-106857, Volume 30 "Preventive Maintenance Basis – Volume 30: Relays – Control", July 1998

I.4.6 NUREG 4596, Screening Tests of Representative Nuclear Power Plant Components Exposed to Secondary Environments Created by Fires, dated June 1986.

I.4.7 Temperatures in Flames and Fires, Dr. Vytenis Babrauskas, dated February 25, 2006.

I.4.8 IEEE Std 384-1992, IEEE Standard Criteria for Independence of Class 1E Equipment and Circuits, dated June 18, 1992.

I.4.9 Regulatory Guide 1.75, Criteria for Independence of Electrical Systems, dated February 2005.

I.4.10 NRC NUREG/CR-6931 "Cable Response to Live Fire (CAROLFIRE)", April 2008

General Consideration	Specific Consideration	Method(s) for Addressing	Comments
I.3.1 Licensing Considerations	Determine Licensing Basis for Change:		Depending on the Licensing Basis governing the Change, NRC approval may be required.
	- NFPA 805	Use fire modeling to address the potential for an open circuit defeating the functionality of the shorting switch and the impact on risk.	
	- Deterministic		
	- III.G.2		
	- Required for Hot Shutdown	Process a License Amendment Request to obtain NRC endorsement of the use of fire modeling to address the potential for an open circuit defeating the functionality of the shorting switch.	III.G.2 requires consideration of open circuits for required for hot shutdown components.
	- Important to Safe Shutdown	Use fire modeling to address the potential for an open circuit defeating the functionality of the shorting switch.	
	- III.G.3/III.L	Use fire modeling to address the potential for an open circuit defeating the functionality of the shorting switch.	
I.3.2 Circuit Design Considerations	Determine the Valve Circuit Design Type:		Depending on the type of valve circuity into which the shorting switch is being added, additional analysis may be required to demonstrate that the shorting switch does not introduce any valve operational concerns, e.g., blown fuses or tripped breakers as a result automatic valve functions.
	- Remotely Operated Valve	Review the circuit design with the shorting switch to assure that no operational impacts are created.	
	- Remotely Operated Valve with Seal-in	Perform an electrical circuit failure modes and effects analysis to assure that the shorting switch will not impact the valve from an operational perspective.	
	- Remotely Operated Valve with automatic function	Perform an electrical circuit failure modes and effects analysis to assure that the shorting switch will not impact the valve from an operational perspective.	
	- Other valve circuit design	Perform an electrical circuit failure modes and effects analysis to assure that the shorting switch will not impact the valve from an operational perspective.	
I.3.3 Electrical Design Considerations	- Determine target coil minimum pick up voltage	Obtain information from the manufacturer or perform a plant specific test of the target coil used with the shorting switch application.	Minimum pick up voltage is the minimum voltage at which the coil might pick up and not the minimum voltage at which the coil is guaranteed to pick up.
	- Identify potential aggressor voltage sources	Identify potential voltage sources that could impact the conductors in the shorting switch circuit. Consider cables run in the same raceway and, when appropriate, within the same enclosure, e.g., Motor Control Center (MCC).	
	- Determine the maximum voltage through the target coil given the target coil minimum pick up voltage	Developed a lumped-parameter model of the subject circuit with the shorting switch. Apply the voltage associated with the bounding aggressor source to the	Depending on the circuit design and the location of the identified aggressor voltage sources, more than

General Consideration	Specific Consideration	Method(s) for Addressing	Comments
	and the voltage associated with bounding aggressor source	lumped-parameter model. Calculate and demonstrate that the target coil will not reach its minimum pick up voltage with the voltage splitting between the shorting switch electrical flow path and the target coil electrical flow path.	one analytical model case may need to be evaluated. Additionally, aggressor sources from both within and external to the shorting switch cable need to be considered.
I.3.4 Circuit Continuity Considerations	- Assure Cabinet Fires will not defeat the functioning of the shorting switch or any of the components or conductors required for it to function. Consider: - Fire spread between cabinet compartments - Fire spread from sources external to the cabinet to within the cabinet. - Fire damage to the shorting switch itself. - Fire damage to any sub-components, e.g., solder connections, screwed connections, terminations, required for the shorting switch to function.	Use available manufacturer's information on thermal thresholds of the various components potentially affected coupled with fire modeling addressing credible fire sources. Use protective metal enclosures to avoid damage to the switch and its related sub-components from direct flame impingement. Use plant walk downs to assess credible fire sources and sizes and the robustness of any enclosures involved. Perform small scale fire testing to demonstrate the survivability of any affected components.	
	- Assure Fire-induced open circuits will not result in an open circuit in either the shorting path or in the path to the target coil that would defeat the functionality of the shorting switch should an open circuit occur.	Evaluate for the potential for a fire-induced open circuit. Typically, open circuits do not occur as a result of fire damage, with the exception of highly energetic circuits, i.e., high current carrying AC circuits or ungrounded DC circuits with fuses larger than 10 amps. Either - Confirm that Electrical Separation Criteria of IEEE 384 is satisfied, or - Perform a technically sound engineering evaluation justifying a reduced separation criteria for the cables containing the shorting switch.	
	- Credit the availability of additional mitigating measures in assuring the viability of the shorting switch design. - Demonstrate by using redundant shorting switch capability to prevent an MSO that the MSO will not occur, or - Demonstrate the survivability of the shorting switch for a period of time that will allow for a successful operator manual action, or - Demonstrate that the use of the shorting switch sufficiently increases the number of sequential failures needed to cause he MSO to the point where it effectiveness is assured.	Perform engineering analysis to demonstrate that the shorting switch, when coupled with other aspects of the plant design or the MSO scenario, provides sufficient redundancy to assure the effectiveness of the shorting switch in helping to assure that an MSO is effectively mitigated.	Additional mitigating measures can be used to increase the robustness of a shorting switch design where rigorous adherence to all of the parameters described above may not be possible. They also may be used to increase the robustness and conservatism in the design where full adherence to the parameters described above has already been demonstrated.

Purpose: The purpose of this example is to show one way in which the information in the Appendix can be used to design a shorting switch. It is not the intent of this example to preclude the use of other approaches or to cast doubt on other approaches used that are based on sound engineering principles.

Description of Example Circuit and MSO Scenario: A shorting switch is being added to the RCIC Suppression Pool Steam Return Line Valve to address a postulated MSO Scenario in which a spurious closure of the steam return line valve with the RCIC Turbine running, if preceded by a loss of the automatic turbine trip logic, could result in a high system back pressure with the potential to open the RCIC System Rupture Disc and lift the RCIC Room blow out panels. In all affected areas, i.e., Reactor Building and Control Room, the RCIC System is not classified as required for hot shutdown. In the Reactor Building, the RCIC System is classified as important to safe shutdown due to the potential for the MSO Scenario described above. In the Control Room, RCIC is used to support post-fire alternative safe shutdown at the Remote Shutdown Panel. In this capacity, it performs as alternate inventory make up function to SRVs and Low Pressure RHR. With the installation of the shorting switch, the required number of sequential failures necessary for the MSO to occur is increased. Additionally, the circuitry for the shorting switch becomes a redundant protective scheme to the circuitry for the high back pressure RCIC Turbine Trip. It is only in those locations where circuitry for each of these functions can be impacted by the fire that the MSO has the potential to occur. Even when the circuitry for both of these functions can be affected by a common fire, there is a time sequential relationship between the RCIC Valve shorting switch circuitry and the RCIC High Back Pressure Turbine Trip Circuitry. Where both functions co-exist, an open circuit must occur at the correct location in the shorting switch circuit prior to the hot short occurring in the shorting switch circuitry and this combination of failures must be preceded by a failure of the RCIC High Back Pressure Trip circuitry.

General Consideration	Specific Consideration	Method(s) for Addressing	Approach used to Address in this Example
I.3.1 Licensing Considerations	Determine Licensing Basis for Change:		
	- NFPA 805	Use fire modeling to address the potential for an open circuit defeating the functionality of the shorting switch.	N/A
	- Deterministic		Yes
	- III.G.2		Yes
	- Required for Hot Shutdown	Process a Licensing Amendment Request to obtain NRC endorsement of the use of fire modeling to address the potential for an open circuit defeating the functionality of the shorting switch.	N/A
	- Important to Safe Shutdown	Use fire modeling to address the potential for an open circuit defeating the functionality of the shorting switch in addition to causing the hot short-induced spurious operation.	The shorting switch in this example is used on a component classified as important to safe shutdown. As such, the design may proceed without prior NRC approval.
	- III.G.3/III.L	Use fire modeling to address the potential for an open circuit defeating the functionality of the shorting switch in addition to causing the hot short-induced spurious operation.	The shorting switch in this examples is used in an area classified as III.G.3/III.L. As such, the design may proceed without prior NRC approval.
I.3.2 Circuit Design Considerations	Determine the Valve Circuit Design Type:		
	- Remotely Operated Valve	Review the circuit design with the shorting switch to assure that no operational impacts are created.	The valves being modified are remote operated valves with no seal-ins or automatic functions. The valve circuitry with the shorting switch has been reviewed and the change creates no adverse operational considerations.
	- Remotely Operated Valve with Seal-in	Perform an electrical circuit failure modes and effects analysis to assure that the shorting switch will not impact the valve from an operational perspective.	N/A

General Consideration	Specific Consideration	Method(s) for Addressing	Approach used to Address in this Example
	- Remotely Operated Valve with automatic function	Perform an electrical circuit failure modes and effects analysis to assure that the shorting switch will not impact the valve from an operational perspective.	N/A
	- Other valve circuit design	Perform an electrical circuit failure modes and effects analysis to assure that the shorting switch will not impact the valve from an operational perspective.	N/A
I.3.3 Electrical Design Considerations	- Determine target coil minimum pick up voltage	Obtain information from the manufacturer, available industry literature or perform a plant specific test of the target coil used with the shorting switch application.	The required minimum pick up voltage for the target coil was conservatively estimated from manufacturer's data and available industry literature.
	- Identify potential aggressor voltage sources	Identify potential voltage sources that could impact the conductors in the shorting switch circuit. Consider cables run in the same raceway and, when appropriate, within the same enclosure, e.g., Motor Control Center (MCC).	The raceway routing for the shorting switch circuits cables determined that this raceway was routed with 125 VDC or 120 AC circuits only. There are 250 VDC cables in a common raceway above the 250 VDC Bus, but no credit is taken for the shorting switch in this plant area. Therefore, these cables are not included as viable aggressor sources.
	- Determine the maximum voltage through the target coil given the target coil minimum pick up voltage and the voltage associated with bounding aggressor source	Develop a lumped-parameter model of the subject circuit with the shorting switch. Apply the voltage associated with the bounding aggressor source to the lumped-parameter model. Calculate and demonstrate that the target coil will not reach its minimum pick up voltage with the voltage splitting between the shorting switch electrical flow path and the target coil electrical flow path.	An engineering analysis using a lumped parameter model has demonstrated that the maximum aggressor voltage at the worst case circuit location cannot pick up the target coil with the shorting switch functioning properly.
I.3.4 Circuit Continuity Considerations	- Assure Cabinet Fires will not defeat the functioning of the shorting switch or any of the components or conductors required for it to function. Consider: - Fire spread between cabinet compartments - Fire spread from sources external to the cabinet to within the cabinet. - Fire damage to the shorting switch itself. - Fire damage to any sub-components, e.g., solder connections, screwed connections, terminations, required for the shorting switch to function.	Use available manufacturer's information on thermal thresholds of the various components potentially affected coupled with fire modeling addressing credible fire sources. Use protective metal enclosures to avoid damage to the switch and its related sub-components from direct flame impingement. Use plant walk downs to assess credible fire sources and sizes and the robustness of any enclosures involved. Perform small scale fire testing to demonstrate the survivability of any affected components.	An engineering walk down of the Control Room and the Control Room Panel internals housing the RCIC shorting switch has concluded that: - There are insufficient Control Room combustibles to cause a fire external to the Control Panel with the potential to damage the RCIC shorting switch and it related sub-components. - The electrical separation features of the control panel internals is sufficient to prevent a damaging fire from occurring. - Fire damage in the sequence required cannot occur prior to the 15 minute time frame required to evacuate the control room and transfer control to the Remote Shutdown Panel.
	- Assure Fire-induced open circuits will not result in an open circuit in either the shorting path or in the	Evaluate for the potential for a fire-induced open circuit. Typically, open circuits do not occur as a result of fire damage, with the exception of highly	A review of the shorting switch circuit has confirmed that the cable routing for this circuit

General Consideration	Specific Consideration	Method(s) for Addressing	Approach used to Address in this Example
	path to the target coil that would defeat the functionality of the shorting switch should an open circuit occur.	energetic circuits, i.e., high current carrying AC circuits or ungrounded DC circuits with fuses larger than 10 amps. Either - Confirm that Electrical Separation Criteria of IEEE 384 is satisfied, or - Perform a technically sound engineering evaluation justifying a reduced separation criteria for the cables containing the shorting switch.	meets the Electrical Separation Criteria of IEEE 384. Therefore, an open circuit with the potential to defeat the functionality of the shorting switch is not a concern.
	- Credit the availability of additional mitigating measures in assuring the viability of the shorting switch design. - Demonstrate by using redundant shorting switch capability to prevent an MSO that the MSO will not occur, or - Demonstrate the survivability of the shorting switch for a period of time that will allow for a successful operator manual action, or - Demonstrate that the use of the shorting switch sufficiently increases the number of sequential failures needed to cause he MSO to the point where it effectiveness is assured.	Perform engineering analysis to demonstrate that the shorting switch, when coupled with other aspects of the plant design or the MSO scenario, provides sufficient redundancy to assure the effectiveness of the shorting switch in helping to assure that an MSO is effectively mitigated.	Additional mitigating measures are credited in two ways in the design of the RCIC shorting switch: - The design provides adequate delay to allow transfer of the controls for the RCIC Steam Return to the Suppression Pool Valve to the Remote Shutdown Panel for a Control Room Fire, and - With the installation of the shorting switch, the required number of sequential failures necessary for the MSO to occur is increased. Additionally, the circuitry for the shorting switch becomes a redundant protective scheme to the circuitry for the high back pressure RCIC Turbine Trip. It is only in those locations where circuitry for each of these functions can be impacted by the fire that the MSO has the potential to occur. Even when the circuitry for both of these functions can be affected by a common fire, there is a time sequential relationship between the RCIC Valve shorting switch circuitry and the RCIC High Back Pressure Turbine Trip Circuitry. Where both functions co-exist, an open circuit must occur at the correct location in the shorting switch circuit prior to the hot short occurring in the shorting switch circuitry and this combination of failures must be preceded by a failure of the RCIC High Back Pressure Trip circuitry.