MSO Consideration Recommendation

1.0 Purpose

The purpose of this document is to provide technical recommendations for Multiple Spurious Operation (MSO) evaluations using insights gained from the joint NRC-RES/EPRI testing and the NUREG/CR-7150 JACQUE-FIRE Vol. 2 work. This paper provides recommendations related to the number of fire-induced circuit failures of specific types that need to be considered when addressing MSOs.

The qualitative discussion for each of the recommendations provided below provides the basis for the JACQUE-FIRE Volume 3 working group's conclusion that the specific MSO criteria discussed is beyond what needs to be considered in a deterministic analysis for MSOs.

Quantitative discussions included provide a summary of risk insights from JACQUE-FIRE Volume 2. These quantitative insights support the conclusion that the MSO consideration discussed has no safety significance.

2.0 Background

Current Regulatory Framework

Section 3.5.1.1 "Circuit Failure Criteria" of NEI 00-01, Rev. 2, provides fire-induced circuit failure evaluation criteria and assumptions. Section 3.5.1.1 under 'Circuits for "required for hot shutdown" components' states:

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

Section 3.5.1.1 under 'Circuits for "important to safe shutdown" components', the sixth and seventh bullets state:

- "Multiple fire-induced circuit failures affecting separate conductors in separate cables with the potential to cause a spurious operation of an "important to safe shutdown" component must be assumed to exist concurrently when the effect of the fire-induced circuit failure is sealed-in or latched.
- Conversely, multiple fire-induced circuit failures affecting separate conductors in separate cables with the potential to cause a spurious operation of an "important to safe shutdown" component need not be assumed to exist concurrently when the effect of the fire-induced circuit failure is not sealed-in or latched. This criterion applies to consideration of concurrent hot shorts in secondary circuits and to their

> effect on a components primary control circuit. It is not to be applied to concurrent single hot shorts in primary control circuit for separate components in an MSO combination."

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

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

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

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

<u>Discussion</u>

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

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

The working group's assessment of this discussion in NEI 00-01 Rev. 3, Section 3.5.1.3 identified concerns with the discussion's alignment to the current state of knowledge of circuit failure behavior. The working group's consensus opinion is that the relevant considerations should focus more on the associated cable interactions and not the affected components themselves.

Since NEI 00-01, Rev. 2 and RG 1.189, Rev. 2 guidance documents were issued, additional work and joint NRC-RES/EPRI testing have been accomplished. As would be expected, insights gained from these efforts have improved the understanding of fire-induced circuit failure behaviors. The current state-of-the-art knowledge provides risk-informed, performance-based insights for additional "Spurious Operation Criteria" considerations that can be applied to a deterministic post-fire safe shutdown analysis.

3.0 Resolution

Based on the insights gained from testing and JACQUE-FIRE Vol. 2 (Ref. 1), the recommendations provided below from the working group apply to "required for hot shutdown" and "important to safe shutdown" circuits. These recommendations are in addition to the working group's guidance and recommendations for NEI 00-01 Appendix J. The recommendations apply regardless of target cable insulation type or power supply type, unless noted otherwise. The term "concurrent" in this document means existing together at some point in time and includes simultaneous occurring at the exact same point in time. The term "separate target cables" in this document refers to the independent and separate cables carrying target conductors of concern for a particular failure more (e.g., hot short). For intra-cable hot short interactions, the conductor providing the aggressor source of power to cause the hot short is contained within the target cable. For inter-cable hot short interactions, the conductor providing the aggressor source of power to cause the hot short is not within the target cable. The recommendations address the following topics:

- Number of Hot Shorts for Transient Inrush Considerations
- Number of Inter-Cable Hot Shorts Regardless of Latching Characteristics or Coping Time
- Number of Non-Latching Hot Shorts with 10 minute Coping Time regardless of Circuit Failure Mode
- Sequentially Selected Fire-Induced Circuit Failures

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

Any MSO scenario involving the failure of a safe shutdown power supply as a result of a potential overload condition caused by more than a single load inrush current (i.e., overlapping inrush current from multiple separate loads) from control cable hot short spurious operation is not required to be considered provided the load power supply function or load sequencer, if applicable, is not degraded by the fire effects and the hot short target conductors for each of the potentially spuriously operated loads are in separate cables. In these cases, the power supply availability for the fire event can be assessed by the steady-state loading (i.e., anticipated load plus fire-induced spurious operation load) in combination with the worst case individual (or anticipated by design) inrush current transient load is considered in the power supply analysis.

3.1.1 Assumptions/Limitations

This recommendation assumes,

- Normal transient inrush current duration for the affected loads is typical of that described in the basis section below.
- The load spurious operation(s) is caused by fire damage to control cables for the load(s) from the power supply of concern. The load is otherwise operating correctly and has no potential for power cable fire damage. Thus, the load transient inrush current expected is normal and not impacted by the fire event.
- The power supply is not degraded by the effects of the fire damage.
- The load sequencer, if applicable, for the associated power supply is not degraded by effects of the fire damage such that the fire damage could cause multiple loads to start simultaneously.
- Target conductors that could spuriously start/energize loads powered from the same power supply are in separate cables.

3.1.2 Basis

Rigorous evaluation of potentially unbounded transient current combinations can prove to be impractical for a fire event. However, in the unlikely event that two or more loads from the same power supply did experience concurrent transient inrush currents, the power supply would likely accelerate/energize the loads with no adverse impacts. The inrush current (e.g., motor starting current, transformer magnetization current) is the initial transient current, prior to magnetization or motor acceleration. As a transformer core is magnetized or a motor is accelerated to near synchronous speed, the transient current decays to normal steady-state running current. Given the power supply is not degraded, the transient inrush current is load component dependent. The inrush current may be less than a second for many transformers and smaller motors and a few seconds for larger motors (typically 3-5 seconds). Due to the inherent short duration of transient inrush currents, the working group judged the scenario of a fire event causing two or more loads from the same power supply to experience overlapping transient inrush current and result in power supply or load failure to be so unlikely to not warrant further consideration.

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

If the MSO requires four (4) or more separate target cables with inter-cable hot shorts (excluding GFEHS), then the MSO is not required to be considered, regardless of whether the circuits are latching or non-latching. There is no sustained time duration consideration required for this case.

3.2.1 Assumptions/Limitations

This recommendation includes the following limitation,

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

3.2.2 Basis

<u>Qualitative Discussion</u>

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

If the MSO requires three inter-cable hot shorts involving proper polarity shorts of a three phase power cable, this scenario was determined to be "Incredible" in JACQUE-FIRE Vol. 1. The proper polarity shorts of a three phase power cable event involved with that recommendation not only required three specific inter-cable hot shorts, but required the proper phase sequence which lessened the probability by 0.5. Therefore, this recommendation to consider up to three (3) separate inter-cable hot shorts, but not consider MSOs that require four (4) separate inter-cable hot shorts is not unreasonable.

The evidence available suggests that an inter-cable hot short failure mode is of low likelihood. The empirical evidence suggests that a single inter-cable hot short spurious operation is possible. The evidence also suggests that for the inter-cable hot short interactions that do occur, spurious operations (as assumed above) are infrequent, i.e., many of the hot shorts experienced were of insufficient quality to result in a spurious operation. Thus, the likelihood of having four or more inter-cable hot short failure modes in separate target cables resulting in spurious operations that are related to the same MSO scenario is highly unlikely and does not warrant further consideration based on the evidence.

<u>Quantitative Discussion</u>

Four (4) inter-cable shorts (excluding GFEHS) are not required to be considered regardless of latching or duration considerations. Thermoplastic Grounded AC was used for calculating the bounding probability for the cable configuration using SOV Single Break-Control Circuits which typically are the more probable bounding circuit configuration.

GROUNDED AC, FOUR INTER-CABLE SHORTS, THERMOPLASTIC CABLES [Table 4-1, Ref. 1]

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

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

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

3.3 Spurious Operation Recommendation 3: Number of Non-Latching Hot Shorts with 10 minute Coping Time regardless of Circuit Failure Mode

If the MSO requires (a) three (3) or more concurrent fire-induced cable shorts on separate target cables in non-latching circuits and (b) the hot shorts must be sustained for more than 10 minutes to cause the MSO condition, then the MSO is not required to be considered regardless of conductor hot short failure mode (i.e., intra-cable, inter-cable, or GFEHS). For MSO scenarios that result in conditions that cannot be tolerated for 10 minutes or less, any number of non-latching intra-cable circuit failures must be considered. In addition, for latching fire induced hot shorts, any number of intra-cable circuit failures must be considered unless otherwise limited by the guidance.

3.3.1 Assumptions/Limitations

There are no additional assumptions or limitations required for this recommendation.

3.3.2 Basis

Qualitative Discussion

The possibility of cable failures modes caused by fire conditions has been explored in all three of the major testing programs (EPRI/NEI, CAROLFIRE, DESIREE-FIRE). One of the primary findings of the cable fire testing performed is that the duration of hot shorts is limited. The tests performed on ac circuits resulted in 111 fire-induced spurious operations, the longest being 11.3 minutes which was observed in the NEI testing. The dc circuit testing resulted in approximately 76 fire-induced spurious operations (excluding switchgear) with five of the 76 lasting longer than the longest ac spurious operation duration (i.e., 13.5, 17.5, 19.9, 23.8, and 107 minutes). Although there were a very limited number of hot shorts that lasted longer than 10 minutes, the vast majority of spurious operations identified lasted on the order of a few seconds to a few minutes. When these three hot shorts also are required to be induced by the same fire in approximately the same timeframe, the likelihood is further reduced. Finally, when these three hot shorts need to be associated with components common to a single MSO scenario, the likelihood is further reduced to a level that makes it beyond what needs to be considered when addressing MSOs.

Quantitative Discussion

As illustrated in Table 6-3 of Reference 1, the Spurious Operation Duration Conditional Probability Values reach their floor value by 10 minutes. Examples are calculated for the various cable configurations using SOV Single Break-Control Circuits which typically are the more probable bounding circuit configuration and aggregate conductor hot short failure mode conditional probabilities.

UNGROUNDED DC, AGGREGATE SHORTS, ARMORED CABLES [Table 4-1 & Table 6-3, Ref. 1]

[Note: Armored cable is used for this case to conservatively bound the Ungrounded DC case for all target cable configurations]. Using the mean values, the probability of three separate target cables with aggregate hot short failure mode for single break SOV ungrounded DC and armored cables is $(8.6E\text{-}01)^3$ = 6.36E-01.

Using the mean value for the floor of the spurious operation duration for DC circuits of 2.2E-02, the joint conditional duration probability for three separate target cables is $(2.2E\text{-}02)^3$ = 1.06E-05.

Using the mean value for the floor of the spurious operation duration for DC circuits of 2.20E-02, then the probability for all three independent hot shorts in separate target cables to persist beyond 10 minutes becomes 6.36E-01 x 1.06E-05 = <u>6.7E-06</u>.

UNGROUNDED AC, THREE AGGREGATE SHORTS, THERMOPLASTIC CABLES [Table 4-1 & Table 6-3, Ref. 1]

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

Using the mean value for the floor of the spurious operation duration for AC circuits of 7.1E-03, the joint conditional duration probability for three separate target cables is $(7.1E\text{-}03)^3$ = 3.58E-07. However, section 7.3.4.2 of Reference 1 states, "For MSOs occurring due to fire in <u>separate cables</u>, (for both AC and DC circuits) the application of conditional duration probabilities for MSO's should be limited to a joint minimum value of 1.0 E-05."

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

GROUNDED AC, THREE AGGREGATE SHORTS, THERMOPLASTIC CABLES [Table 4-1 & Table 6-3, Ref. 1]

Using the mean values, the probability of three separate target cables with aggregate hot short failure mode for single break SOV grounded AC and thermoplastic cables is $(4.4E\text{-}01)^3$ = 8.52E-02.

Using the mean value for the floor of the spurious operation duration for AC circuits of 7.1E-03, the joint conditional duration probability for three separate target cables is $(7.1E\text{-}03)^3$ = 3.58E-07. However, section 7.3.4.2 of Reference 1 states, "For MSOs occurring due to fire in <u>separate cables</u>, (for both AC and DC circuits) the application of

> conditional duration probabilities for MSO's should be limited to a joint minimum value of 1.0 E-05."
>
> Using the spurious operation duration joint minimum value of 1.0E-05, then the probability for all three independent hot shorts in separate target cables to persist beyond 10 minutes becomes 8.52E-02 x 1.0E-05= 8.5E-07.

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

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

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

If the MSO requires a selective sequence of more than four separate target cables with specific fire induced cable failures (i.e., failure 1 must occur before failure 2, failure 2 before 3, failure 3 before 4 and failure 4 before 5), where the adverse condition will not occur if the specific sequence is not produced by the fire-induced circuit failures (e.g., hot short, short to ground, open circuit), then the MSO need not be considered for MSOs regardless of fire-induced failure durations, circuit configurations, or fire-induced failure types. [Note: At least two of these failures must be hot shorts to be considered a multiple spurious operation.]

3.4.1 Assumptions/Limitations

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

[1]Metal armor of armored cable is assumed to always be grounded in accordance with NFPA 70.

3.4.2 Basis

Qualitative Discussion

The possibility of cable failures modes caused by fire conditions has been explored in all three of the major testing programs (EPRI/NEI, CAROLFIRE, DESIREE-FIRE). It is recognized that the conditional probability of a single spurious operation for cables with certain insulation types and circuit configurations in some cases is approximately 0.5. It may be determined that for a MSO scenario requiring five or more independent cable failures, that all five target cables of concern are located in the same Fire Area. However, for a given realistic fire scenario, it is unlikely that all five independent target cables would even be damaged by the same fire. It is even more unlikely that the realistic fire damage would occur in such a manner to meet a required unique sequence of failures of five or more independent cables with at least two of those failures being a hot short that results in spurious operation. The working group determined that selective sequence MSO scenarios involving more than four cables would be highly unlikely and beyond what is required to be considered.

Quantitative Discussion

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

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

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

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

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

MSO Consideration Recommendation

4.0 Summary

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

- Any MSO scenario involving the failure of a safe shutdown power supply as a result of a potential overload condition caused by more than a single load inrush current (i.e., overlapping inrush current from multiple, separate loads) from control cable hot short spurious operation is not required to be considered provided the load power supply function or load sequencer, if applicable, is not degraded by the fire effects and the hot short target conductors for each of the potentially spuriously operated loads are in separate cables. In these cases, the power supply availability for the fire event can be assessed by the steady-state loading (i.e., anticipated load plus fire-induced spurious operation load) in combination with the worst case individual (or anticipated by design) inrush current transient load is considered in the power supply analysis.
- If the MSO requires four (4) or more separate target cables with inter-cable hot shorts (excluding GFEHS), then the MSO is not required to be considered, regardless of whether the circuits are latching or non-latching. There is no sustained time duration consideration required for this case. An MSO scenario should consider up to three (3)separate target cable inter-cable hot shorts (excluding GFEHS) and any number of GFEHS combinations unless otherwise limited by the guidance.
- If the MSO requires (a) three (3) or more concurrent fire-induced cable shorts on separate target cables in non-latching circuits and (b) the hot shorts must be sustained for more than 10 minutes to cause the MSO condition, then the MSO is not required to be considered regardless of conductor hot short failure mode (i.e., intra-cable, inter-cable, or GFEHS).
    - For MSO scenarios that result in conditions that cannot be tolerated for 10 minutes or less, any number of circuit failures must be considered unless otherwise limited by the guidance.
    - For latching fire induced hot shorts, any number of intra-cable circuit failures must be considered unless otherwise limited by the guidance.
    - MSO scenarios involving hot short of two (2) separate non-latching circuits must be considered beyond 10 minutes and in accordance with the spurious operation duration guidance.
- MSO scenarios should consider up to four (4) sequentially selective cable failures. If the MSO scenario requires consideration of more than four (4) sequentially selected cable failures of a prescribed type and in a prescribed selective sequence in order for the postulated MSO combination to occur, then then the MSO is not required to be considered. However, a limiting condition applies as the following cannot be counted as one of the sequential failures: (1) the more probable failures of conductor grounding of

grounded AC circuits in armored cable or (2) for ungrounded DC circuits, the more probable failures of intra-cable short or ground fault equivalent hot short in armored cable.

5.0 References

1. NUREG/CR-7150, Vol. 2 (EPRI Report 3002001989), Joint Assessment of Cable Damage and Quantification of Effects from Fire (JACQUE-FIRE).
2. NUREG/CR-6931, Vol. 1, Cable Response to Live Fire (CAROLFIRE) Volume 1: Test Descriptions and Analysis of Circuit Response Data.
3. NUREG/CR-7100, Direct Current Electrical Shorting in Response to Exposure Fire (DESIREE-Fire): Test Results.
4. NUREG-2128, Electrical Cable Test Results and Analysis During Fire Exposure (ELECTRA-Fire).

Reference Excerpts:

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		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*

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

AC Pr{T>t} CCDF			Time (minutes)	DC Pr{T>t} CCDF		
5th	Mean	95th		5th	Mean	95th
1.0	1.0	1.0	0	1.0	1.0	1.0
3.91E-01	5.12E-01	6.31E-01	1	3.91E-01	5.12E-01	6.31E-01
1.82E-01	2.74E-01	3.90E-01	2	1.82E-01	2.74E-01	3.90E-01
8.31E-02	1.49E-01	2.52E-01	3	8.31E-02	1.49E-01	2.52E-01
3.68E-02	8.17E-02	1.71E-01	4	3.68E-02	8.17E-02	1.71E-01
1.59E-02	4.51E-02	1.21E-01	5	1.59E-02	4.51E-02	1.21E-01
6.76E-03	2.51E-02	8.86E-02	6	6.76E-03	2.51E-02	8.86E-02
2.82E-03	1.40E-02	6.65E-02	7	2.82E-03	2.20E-02	6.80E-02
1.16E-03	7.85E-03	5.10E-02	8	1.16E-03		
4.74E-04	7.10E-03	3.98E-02	9	8.20E-04		
1.91E-04		3.40E-02	10			
7.64E-05			11			
3.03E-05			12			
1.19E-05			13			
4.67E-06			14			
1.82E-06			15			
7.03E-07			16			
2.71E-07			17			
2.40E-07			18			
			19			
			20			
2.40E-07	7.10E-03	3.40E-02	>20	8.20E-04	2.20E-02	6.80E-02