SUPPLEMENTAL INTERIM TECHNICAL GUIDANCE ON FIRE-INDUCED CIRCUIT FAILURE MODE LIKELIHOOD ANALYSIS PENDING PUBLICATION OF EXPERT ELICITATION RESULTS[1]

INTRODUCTION

Previously, the NRC issued an interim technical guidance (Agency-wide Document Access and Management System (ADAMS) Accession No. ML13346A092) on hot short-induced spurious operation conditional likelihood estimates that were based on the work being performed jointly by the NRC and Electric Power Research Institute (EPRI) under a Memorandum of Understanding (MOU) Addendum on Fire Risk. That guidance was issued to support ongoing license amendment requests (LARs) being reviewed by the NRC and to provide stakeholders with preliminary results on the hot short-induced spurious operation likelihood estimates for use in Fire Probabilistic Risk Analysis (PRA). At the time of issuance, only a fraction of the cases evaluated by the team of experts had been calculated and reviewed. These cases were for solenoid operated valves (SOVs) and represented bounding values for other types of circuits.

Currently, all cases evaluated by the team of experts have been calculated, reviewed, and finalized. However, issuance of the final report will not occur until the spring/summer of 2014. As such, to continue the support of risk-informed applications with the latest state-of-the-art data, methods, and tools, NRC has developed this supplement to the previous guidance pending publications of expert elicitation results. In addition to repeating the information presented in the first technical guidance document, this supplement includes hot short-induced spurious operation conditional likelihood estimates for motor operated valves (MOVs) and power circuit breaker control circuits (medium- and low-voltage), along with providing a method for calculating the duration of hot-short induced spurious operations for both ac and dc control circuits. The guidance provide in this supplement is intended to supersede the previous technical guidance (ADAMS Accession No. ML13346A092). It should be noted that this document provides guidance and does not constitute regulatory requirements.

BACKGROUND

Task 10 of NUREG/CR-6850, EPRI 1011989, "Fire PRA Methodology for Nuclear Power Facilities," Volume 2, presents a method for conducting a circuit failure mode likelihood analysis. The method uses likelihood estimates that were developed from the EPRI/Nuclear Energy Institute (NEI) tests and an expert elicitation performed by EPRI (see EPRI 1003326 and

[1] This supplemental interim technical guidance documents the current state of knowledge regarding the quantification of hot short-induced spurious operations of control circuits caused by fire damage. These results will be used to update and supersede the current versions of NUREG/CR-6850 (EPRI 1011989) "EPRI/NRC-RES Fire PRA Methodology for Nuclear Power Facilities," and its Supplement 1 (EPRI 1019259) "Fire Probabilistic Risk Assessment Methods Enhancements."

1006961) in 2002. Task 10 currently presents two methods (Option #1 or Option #2) for assigning hot short-induced spurious operation likelihood estimates. Option #1 is used for the majority of circuit analysis scenarios and consists of five look-up tables containing values from the EPRI elicitation (EPRI 1006961). Option #2 presents an alternative method used in lieu of the look-up tables. This method consists of formulas that were reverse-engineered from the EPRI fire test data and attempts to take into consideration various circuit parameters that could affect the likelihood of hot short-induced spurious operations resulting from cable damage.

Following the EPRI/NEI testing, the NRC sponsored several circuit testing projects and performed data analysis to better understand the phenomena of fire-induced spurious operations. These programs include;

- NUREG/CR-6931, Vol. 1-3, Cable Response to Live Fire (CAROLFIRE)
- NUREG/CR-7100, Direct Current Electrical Shorting in Response to Live Fire (DESIREE-Fire)
- NUREG/CR-7102, Kerite Analysis in Thermal Environment of Fire (KATE-Fire)
- NUREG-2128, Electrical Cable Test Results and Analysis during Fire Exposure (ELECTRA-FIRE)

Recently, the NRC in cooperation with EPRI has conducted two expert panel projects aimed at advancing the state-of-the-art understanding and knowledge on how fire effects influence hot short-induced spurious operation phenomena. These two projects were initiated to use the substantial amount of new data and expert judgment to re-evaluate the quantification conducted in previous studies and to provide quantification for scenarios currently not available. The first project used a balanced panel (half NRC-sponsored members, half EPRI-sponsored members) of electrical experts to evaluate the parameters that can have an influence on fire-induced circuit failures. That work is documented in Volume 1 of NUREG/CR-7150, EPRI 1026424, "Joint Assessment of Cable Damage and Quantification of Effects from Fire (JACQUE-FIRE): Phenomena Identification and Ranking Table (PIRT) Exercise for Nuclear Power Plant Fire-Induced Electrical Circuit Failure." The second project included a similarly balanced panel of PRA experts and followed the Senior Seismic Hazard Analysis Committee (SSHAC) method for using expert judgment as documented in NUREG/CR-6372, "Recommendations for Probabilistic Seismic Hazard Analysis: Guidance on Uncertainty and Use of Experts." An enhanced SSHAC Level 2 method was followed to quantify the likelihood of fire damage to electrical cables to cause hot short-induced spurious operations, along with quantifying the duration of spurious operations. The results of this second effort will be documented in Volume 2 of NUREG/CR-7150 (EPRI 3002001989) to be issued in 2014.

DISCUSSION

Section 10.5.3 of NUREG/CR-6850, EPRI 1011989, presents Option #1, consisting of five look-up tables containing failure mode probability best estimates and high confidence ranges. Tables 10-1 through 10-4 are differentiated by cable insulation type and the presence of a control power transformer (CPT) in the circuit being analyzed. Table 10-5 is applicable to armored cables only.

These tables make a distinction between cable insulation types; however the corresponding values for a thermoset-insulated cable are no different from the corresponding table values for a thermoplastic-insulated cable, except for the same reductions in each estimate if a CPT is present. (Tables 10-1 and 10-3 provide the same values; similarly Tables 10-2 and 10-4). That is, for analogous cable configurations, the only distinction between the first four tables are the values associated with circuits powered from a CPT versus circuits with no CPT, the difference being a factor of two (2) reduction in the likelihood estimates for circuits containing a CPT compared to circuits without a CPT.

The initial EPRI/NEI test data indicated that the presence of a CPT appeared to reduce the likelihood of a fire damaged circuit from spuriously operating. From this insight, the EPRI expert elicitation panel members hypothesized that, as the cable fire damage progressed, a substantial amount of electrical current was shunted away from the circuit via ground paths, thus causing the CPT to saturate. Since CPTs are power-limited devices, as leakage current increased due to insulation breakdown resulting from the fire damage, voltage of the CPT would drop as a result of the inherent CPT power limitations. At some point, the voltage of the CPT drops below the pick-up voltage of the device of concern, thus eliminating the possibility of the device spuriously operating.

NUREG/CR-6931 (CAROLFIRE) concluded in 2008 that tests were not able to confirm the results of the original NEI/EPRI tests with regard to degraded voltage and an observable impact on spurious operation likelihood due to the presence of CPTs, stating; "The currently available data provide no basis for establishing an *a-priori* limit to the number of spurious operations that might occur during a given fire even given that the circuit is powered by a 'properly sized' CPT". Follow-up testing, included as a part of the DESIREE-Fire project (NUREG/CR-7100), also failed to reproduce the voltage collapse effect seen in the original EPRI/NEI testing. The overall conclusion in NUREG-7150, Volume 1 (JACQUE-FIRE), was that neither CPT size alone, nor indeed the mere presence of a CPT as the powering device, is a predictable and repeatable circuit design parameter that reliably yields fewer spurious operations, and that CPT size should not be used as a basis for reducing spurious operation likelihoods.

Therefore from the NRC sponsored testing, subsequent test data analysis and the NRC/EPRI sponsored PIRT and PRA expert elicitation projects, the effect of any CPT reduction to the hot short-induced spurious operation likelihood could not be substantiated. As such, the PRA expert elicitation panel developed spurious operation conditional likelihood estimates independent of considering CPT effects[2].

The PRA expert elicitation project is nearing completion and the developed conditional likelihood estimates forming the basis for this work have been established. However, the framework of this work will not be a direct replacement of the information in Tables 10-1 through 10-5 of NUREG/CR 6850, EPRI 1011989, since many of the high impact parameters

[2] When developing their estimates, the test results for circuits powered from CPTs were retained and processed along with the test data for non-CPT powered circuits.

differ between the Task 10 guidance of that document and the current NRC-RES/EPRI expert panel results.

The tables provided below contain the latest state-of-the-art numerical values for quantification of the conditional likelihood of hot-short induced spurious operation due to fire damage for control circuits. These estimates are not intended to be used for low-energy instrumentation signal circuits (e.g., 4-20mA, 0-10V). This information is supplemental interim guidance pending the publication of NUREG/CR-7150, Volume 2, which will fully document the PRA expert elicitation process and results. The information presented below is based on the preliminary expert elicitation process results.

The advancements in the state of the art methods by the expert panels as presented in this interim guidance also affect the applicability of Appendices J and K to NUREG/CR – 6850, EPRI 1011989. The methods, tools and data used in those appendices are expected to be updated subsequent to publication of NUREG/CR-7150, Volume 2.

Supplemental Interim Guidance Associated with Option #1 of Task 10

Several changes to the format of Tables 10-1 through 10-5 in NUREG/CR-6850, EPRI 1011989, are recommended based on the results of NUREG/CR-7150, Volume 1. These include:

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

The conditional likelihood estimates developed by the PRA panel are separated into the following circuit design categories:

1. Single Break (or Contact) Control Circuit Design
    a. Base Case – SOV (Table 1)
    b. MOV (Table 2)
    c. Power Circuit Breaker (medium- and low-voltage) (Table 3)

2. Double Break (or Contact) Control Circuit Design
    a. Base Case – SOV (Tables 4 & 5)
    b. MOV (Tables 6 & 7)

Each sub-case in the likelihood estimate tables (Tables 1-7) provide five (5) values. The first two values are the parameters for a beta distribution. The last three values present the 5th percentile, mean, and 95th percentile, respectively.

The tables are organized by circuit power supply; Grounded AC, Ungrounded AC (with individual CPT), and Ungrounded DC (or Ungrounded Distributed AC). Under each of these circuit power configurations are the individual circuit failure modes along with an aggregate column. Aggregate values are provided for each case where all failure modes are applicable. Unlike the current method in NUREG/CR-6850, the new PRA expert elicitation estimates are explicit parametric distributions. The aggregate row in the subsequent tables represents the case where all failure modes are applicable (intra-cable; inter-cable; and, for Ungrounded DC [or Ungrounded Distributed AC], GFEHS). The rows represent the different target cable configurations; thermoset-insulated, thermoplastic insulated, metal foil shield wrap or armored cable.

The PRA panel made the following recommendations when using these results.

1. The "Aggregate" estimate should be used unless a detailed circuit analysis is completed to justify the use of a specific hot short failure mode for the target conductor of interest. That is, justification based on the specific circuit design and configuration should be provided for excluding a failure mode (either intra-cable or inter-cable) from the quantification analysis. For example, if a grounded AC MOV control circuit was only subject to the inter-cable failure mode, then the inter-cable estimate could be used in the quantification analysis rather than the aggregate estimate which includes both intra-cable and inter-cable failure mode estimates.

2. For cables constructed with a robust metal foil shield wrap or armor; the respective rows labeled "Metal Foil Shield Wrap" or "Armored Cable" of the applicable table (Tables 1-2, and Tables 4-7) should be used regardless of the cable's insulation type. For example, an armored TS insulated cable should use the applicable estimate documented in row 4 "Armored Cable" rather than the estimate documented in Row 1 "Thermoset-Insulated Conductor Cable." This is based on the PIRT panel's finding that the effect of a ground plane outweighs that of the cable's conductor insulating material on the fire-induced hot short failure modes in control circuits.

3. For the power circuit breaker case (medium- and low-voltage), the estimate documented in Table 3 represents the aggregate as this estimate was developed assuming all failure modes (i.e., inter-cable, inter-cable, and GFEHS of the circuit breakers ungrounded dc control circuit). Since individual failure modes were not developed for this case, the PRA panel recommends that, for inter-cable and GFEHS failure modes, the corresponding SOV values (Table 1) should be used to quantify the circuit breaker

conditional spurious operation probability for the respective failure mode (inter-cable or GFEHS). The PRA panel also recommends using the aggregate value in Table 3 for the power circuit breaker intra-cable failure mode.

4. For trunk cables and panel wiring, the applicable aggregate values should be used for quantifying the conditional spurious operation likelihood.

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

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

◊ The term “Incredible” is defined in Volume 1 of NUREG/CR-7150 (EPRI 1026424). Cells marked with “Incredible” represent a sub-case where no numerical estimates were developed because it is believed that the event will not occur.

Table 2: Conditional Probability of Spurious Operation: MOV Single Break Control Circuits

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

◊ Cells marked with "Incredible" represent a sub-case where no numerical estimates were developed because it is believed that the event will not occur.

Table 3: Conditional Probability of Spurious Operation Ungrounded DC Control Circuits Power Circuit Breaker (medium- and low-voltage) – Aggregate

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

Note: Table 3 represents estimates for the *Aggregate* and *Intra-cable* cases. For *inter-cable* and *GFEHS* failure modes, the PRA Panel recommended using the applicable estimates from Table 1 (Single Break SOV)

Table 4: Conditional Probability of Spurious Operation: Double Break Control Circuits for Ungrounded AC (with individual CPTs) Base Case - SOV

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

◊ Cells marked with "Incredible" represent a sub-case where no numerical estimates were developed because it is believed that the event will not occur.

Table 5: Conditional Probability of Spurious Operation: Double Break Control Circuits Ungrounded DC (or Ungrounded Distributed AC) Base Case - SOV

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

◊ Cells marked with "Incredible" represent a sub-case where no numerical estimates were developed because it is believed that the event will not occur.

Table 6: Conditional Probability of Spurious Operation: Double Break Control Circuits for Ungrounded AC (with individual CPTs)
Motor Operated Valve

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

◊ Cells marked with "Incredible" represent a sub-case where no numerical estimates were developed because it is believed that the event will not occur.

Table 7: Conditional Probability of Spurious Operation: Double Break Control Circuits Ungrounded DC (or Ungrounded Distributed AC) Motor-Operated Valve

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

◊ Cells marked with "Incredible" represent a sub-case where no numerical estimates were developed because it is believed that the event will not occur.

Interim Guidance Associated with Option #2 of Task 10

Both the electrical expert PIRT and PRA expert elicitation panels agreed that the Option #2 "formula" method of Task 10 in NUREG/CR-6850, EPRI 1011989, does not provide an adequate method for quantifying the likelihood of hot short-induced spurious operations. Option #2 was based on the limited test data obtained and engineering evaluation conducted on the results from the 2001 EPRI/NEI testing. Given the subsequent substantial amount of data from the NRC sponsored testing, electrical expert PIRT ranking of influencing parameters, and refined quantification tables developed by the PRA expert elicitation panel (to be published in 2014), the experts cannot endorse Option #2 or some variation because it does not take into consideration all of the "high impact" parameters that have an effect on the likelihood of a fire-damaged cable causing hot short-induced spurious operations. Finally, the Option #2 method was never validated to quantify the uncertainties associated with its application. Therefore, the current state of knowledge does not support the continuation of its use.

Supplemental Interim Guidance Associated with FAQ 08-0051

The PRA panel developed two Weibull distributions to model the duration of hot short-induced spurious operations, one for ac powered control circuits and the other for dc powered control circuits. The distributions were based on test data and expert judgment. The 5th and 95th percentile uncertainty bounds were also added to each distribution. Lastly, the team added "floors" to the distributions which represent the likelihood of a hot short never clearing. These floor estimates are modeled as parametric distributions. The overall format and application of these results are similar to NFPA 805 FAQ 08-0051 (which was incorporated into Supplement 1 to NUREG/CR-6850 / EPRI 1019259), however the numerical results differ from the FAQ. The estimates presented in this guidance are expected to supersede the FAQ 08-0051 estimates. Figures 1 and 2 present distribution curves for ac and dc powered control circuits, respectively. Table 8 provides the numerical results for these two curves. Table 9 provides the results characterizing the floor parametric distributions. The PRA Panel also provided guidance on the use of these curves. This guidance is provided with several clarifications, after Table 9.

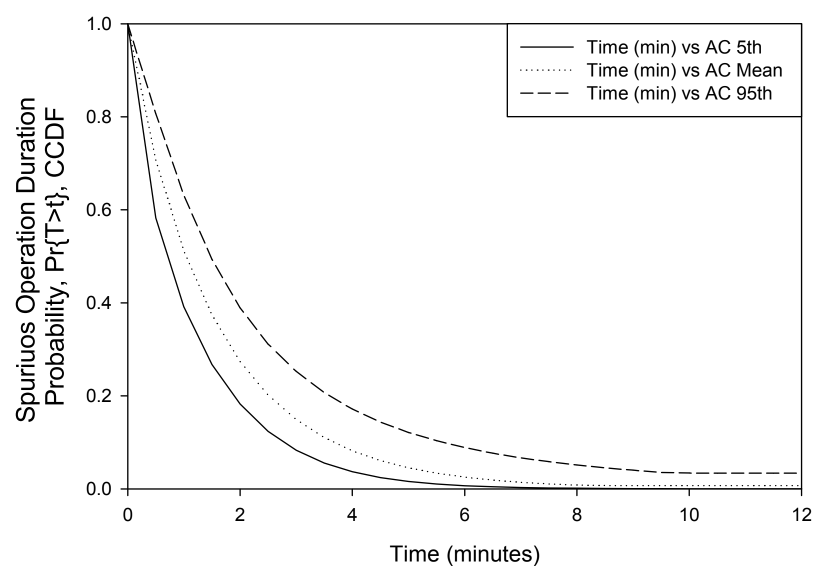

Figure 1: AC Control Circuit Spurious Operation Duration Conditional Probability Curve

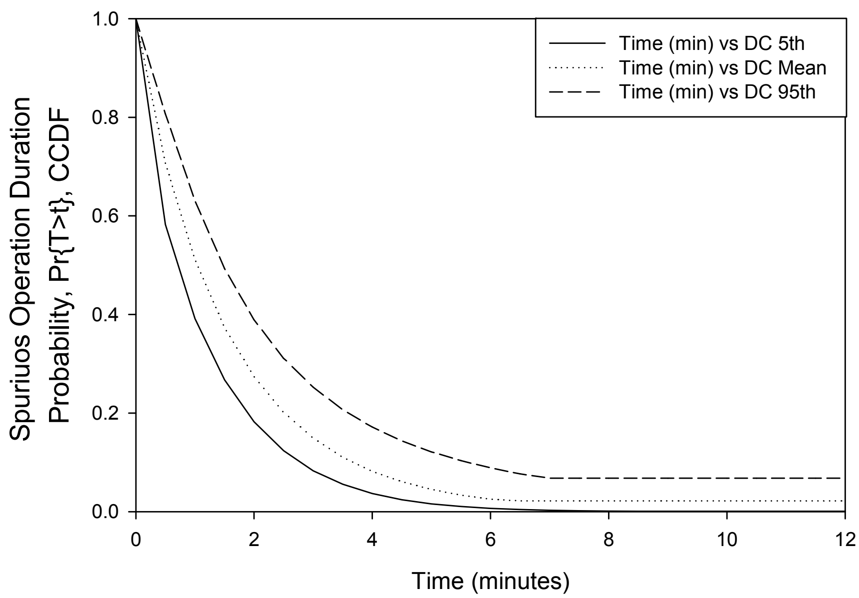

Figure 2: DC Control Circuit Spurious Operation Duration Conditional Probability Curve

Table 8: Tabulated Conditional Probability Values for AC and DC Control Circuits

AC Pr{T>t} CCDF			Time (minutes)	DC Pr{T>t} CCDF		
5^{th}	Mean	95^{th}		5^{th}	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

Table 9: Spurious Operation Duration – Conditional Probability Floors with Uncertainties

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

Spurious Operation Duration Analysis

Volume 2 of NUREG/CR-7150 (EPRI 3002001989) provides guidance on using the conditional probabilities developed. The discussion below is copied from that draft report with several clarifications added and is applicable to the spurious operation duration analysis.

With a few exceptions, primarily involving DC circuits where the hot shorts did not clear during the test, testing has shown that fire-induced spurious operations typically do not persist for long times. Thus, the analysis of the duration of spurious operation attempts to quantify the likelihood that a hot short-induced spurious operation will last for more than a specified amount of time (necessary for PRA-component failure / irreversible undesired consequence). The specific amount of time depends on the system and its components and typically requires some type of analysis (e.g., thermal hydraulic) to determine the time available for a hot short-induced spurious operation to clear before failure of the safety function occurs.

As a caution to the analyst, using the probability of duration of a spurious operation in a fire PRA can be a time- and resource-consuming process, as this involves the performance of engineering calculations or review and reliance on existing calculations to determine the length of time the spurious operation must persist to ensure failure of a safety function. The analyst should determine if such an analysis is suitable for that particular scenario. The application of duration probability to a spurious operation typically is not required to complete a circuit failure likelihood analysis.

In many instances, if a flow diversion or other system response that causes equipment functional failure is terminated (spurious operation clears) within a predetermined time, there will be minimal or no adverse consequences from it. In the case of valves, one of the most common issues is the spurious opening of a pressurizer power-operated relief valve (PORV) in a pressurized water reactor (PWR) plant, which results in a loss of coolant accident (LOCA). If the PORV LOCA is terminated within a specified time, core damage could be demonstrated to be avoided altogether.

In general, MOVs fail as-is when the hot short-induced spurious operation clears, unlike most SOVs/air operated valves (AOVs), which return to a fail-safe position once the hot short-induced spurious operation clears. Thus, only equipment/components that return to their de-energized state upon clearing the hot short should be analyzed and credited for duration (assuming the de-energized state is the desired state). Valves that spuriously reposition to the undesired position and remain so should not receive any credit for the duration time, which only is relevant if they transfer, not for how long (since they do not "recover"). This should be confirmed before applying the recovery event for hot short-induced spurious operation duration. There are circuit designs which will not recover from a hot short-induced spurious operation and the duration quantification should not be used. Examples of some of these include, power circuit breaker control circuits and circuits that have trip bi-stables or latch/release relays.

Therefore, application of a probability that the hot short causing the spurious event will "self-clear" within the appropriate time window can result in a lower assessment of the frequency of core damage. In this report the terms "recovery event" and "self-clear" are synonymous with each other and represent the occurrence of a hot short-induced spurious operation terminating due to a protective device (e.g., fuse or breaker) clearing as a result of fire damage.

Duration curves have been provided in Figures 1 and 2, along with Tables 8 and 9 that assess the likelihood of a spurious event clearing. To use these curves, a defendable success criterion is needed, i.e., how much time is available to return the component or circuit to its fail-safe position before the adverse effects are manifested.

Analyzing the spurious operation duration conditional probability on plant response entails three steps, namely:

1. Determine the time available (for the component or system under evaluation),
2. Analyze the spurious operation duration, and,
3. Document the analysis.

The conditional probability of failure can be illustrated in the following formula. Where, given a hot short-induced spurious operation has occurred, the conditional probability of failure is equal to the product of the probability that the spurious operation occurred and the probability of a spurious operation duration lasting longer than the time available to recover the safety system.

$$P\{\text{failure}|\text{fire\_damage}\} = P\{\text{spurious operation}\} * P\{\text{spurious operation duration} > \text{time available}\}$$

Determine the Time Available

The time available is defined as the time between the calculated occurrence of fire damage and the time to recover the safety function or mitigate an irreversible undesired consequence. Thus, the time available is based on the time between fire damage occurring and the minimum time the spurious operation needs to clear to recover the function. This may be the time when core damage occurs; the time for an operator to perform a recovery action; the time when a safety function is fully recovered; the time to fail a safe shutdown function; or some other defined state. Clearing of a hot short-induced spurious operation involves removal of the hot short, which typically results from a power circuit breaker opening or a fuse clearing in the fire-damaged circuit, such that the affected component "returns" to its pre-hot short state. Regardless of the state, the time available must be determined.

The success criteria for determining the available time may need to include a thermal-hydraulic analysis similar to that performed for determining other criteria for success in Fire PRA accident-sequences. The documentation of this analysis should be equivalent to that of the previously analyzed success criteria. For multiple spurious operations (MSOs), the success criteria also consider if one MSO clearing will suffice to recover the desired plant response function, or if more than one (or all) spurious operations in the MSO scenario need to be cleared. For example, if the containment isolation function for a given path is provided by two fail closed AOVs, each with a de-energize to vent solenoid operated pilot valve, then two hot shorts (i.e. one SOV hot short for each of the associated AOVs) is required to fail the containment isolation function. Once the hot short clears on one of the AOV control circuits, the isolation function would be recovered (i.e. SOV(s) de-energize and the AOV(s) return to the fail safe position).

Regardless of the success or failure state used to determine the time available, an "adequate analysis" must be performed and documented to identify the time available.

Perform the Spurious Operation Duration Analysis

The probability that the spurious operation will self-clear is calculated by using the time available calculated in "Determining the Time Available" to derive a probability from the duration curves presented above (Figures 1 & 2, Tables 8 & 9). This probability is referred to in the discussion below as "conditional duration probability." The estimated conditional duration probability must not be lower than the recommended minimum probability. In determining the conditional duration probability for self-clearing the spurious operation (or MSOs), the following should be applied:

1. When a single circuit failure or hot short can result in single- or multiple-spurious operations (e.g., multiple components affected as a result of a single hot short), then the dependencies should be modeled in the PRA. Typically, this involves applying the same basic event name both to the spurious operation and the conditional duration probability.

2. For MSOs, since only a limited number of tests were performed and analyzed for this report, with a limited analysis of dependencies between spurious operation events or duration; the dependency between the duration of events is not fully known and is highly uncertain. Consequently, limited credit is recommended for the MSO conditional duration probabilities, based on the following rules[3]:

    a. If the MSOs result from damage to the same cable, only one conditional duration probability is recommended [i.e., the second spurious operation is assumed to not self-clear (non-clearance probability is set to be 1.0)].

[3] The rules described here were developed by the PRA panel outside of any formal Senior Seismic Hazard Analysis (SSHAC) Workshop. Therefore, development of these rules does not have the same pedigree or acceptance by the PRA panel members as the development of the conditional probability estimates.

- Analysis of the circuits with multiple targets in the same cable (e.g., two MOV coils) shows that, in a majority of cases, both targets were energized simultaneously or near simultaneously. Additionally, the targets were energized and de-energized at the same or similar times in most cases. As a result, a conservative approach (setting the second conditional duration non-clearance probability to 1.0) is recommended.

- The above is considered conservative for trunk cables with significantly more than the 8 conductors present in the cables on which the tests were based. It is likely that for trunk cables with more than 8 conductors (e.g., 37 conductors), the durations may be somewhat independent.

b. For MSOs occurring due to fire in separate cables, (for both AC and DC circuits), the application of conditional duration probabilities for MSO's should be limited to a joint minimum value of 1.0E-05 for the MSO duration likelihood analysis. This limitation[4] on the application of conditional duration probabilities is being recommended due to several scenario dependent variables that may influence dependencies among MSO's with regard to spurious operation duration.

- The joint minimum value of 1.0E-05 is a limit and should not be interpreted as an estimate to use generically to quantify the conditional MSO duration probability. The joint minimum value limit is recommended due to the large unknowns related to conditional duration probability estimates that were developed for single spurious events being applied to MSO scenarios.

- This joint minimum value is recommended regardless of the circuit types (AC or DC) involved in the MSO scenario.

- The following two examples[5] provide clarification on the use of this joint minimum value limit.

    - If an MSO scenario requires two (2) hot short-induced spurious operations and the conditional spurious operation duration probability of each is determined to be 2.0E-02, then the conditional MSO duration probability is 4.0E-04. Since the joint minimum value (1.0E-05) was not reached, the calculated 4.0E-04 estimate (with uncertainty) should be used to quantify the conditional MSO duration probability.

    - If an MSO scenario requires three (3) hot short-induced spurious operations and the conditional spurious operation duration probability of

[4] The PRA panel expressed several views regarding the limitation on the use of the floor value solely to the joint conditional duration probabilities, including dissents. The final report will document those views.

[5] Note that these two examples use point estimates to illustrate the guidance. In practice, the PRA modeling of conditional MSO duration probability should use the results documented in Tables 8 and 9, which characterize uncertainty.

each is determined to be 2.0E-02, then the conditional MSO duration probability is 8.0E-06. Since the joint minimum value (1.0E-05) was reached, the joint minimum value of 1.0E-05 should be used to quantify[6] the conditional MSO duration probability.

The guidance related to the joint minimum value is recommended for spurious operation duration analysis only, and is not applicable to the spurious operation conditional probability of occurrence analysis, which may be treated as independent.

3. For double break failures (e.g., the two hot shorts required to engender a single spurious operation), the above rules also apply. If the spurious operation requires two separate cable failures, then the application of two conditional duration probability values is acceptable based on item 2 discussed above. However, if a single cable is involved, only a single conditional duration probability is recommended.

The conditional probabilities of duration are not separated for intra-cable, inter-cable, or aggregate spurious operation events. Therefore, regardless of the cable failure that occurs, the conditional duration probabilities are applicable to any spurious operation caused by hot short events. The conditional duration probability values are not applicable to spurious operations resulting from shorts either to ground (other than GFEHS failure mode) or to open circuits.

The resulting spurious operation duration probability values applied to the Fire PRA should also include the estimated uncertainty bounds presented above.

<u>Document the Spurious Operation Duration Analysis</u>

Documentation of the duration analysis should include the supporting documentation for the following three areas:

1. The safe-shutdown function is restored, given the spurious operation clears.
2. The timing analysis is described in “Determine the Time Available”
3. The duration probability analysis is described in “Perform the Spurious Operation Duration Analysis.”

Documentation for restoring the safe-shutdown function should consider the circuit-specific impact on the component, as well as the circuit-specific impact for clearing of each hot short.

For example, even for an SOV that returns to its fail-safe position, the spurious operation of an auxiliary- or actuation-circuit may result in a seal-in of the valve. When the hot short on the auxiliary circuit clears, the valve may remain as-is. However, clearing of a hot short on the main control switch circuit most likely would result in the SOV returning to its fail-safe position; since

[6] This guidance recommends a point estimate for cases where the conditional MSO duration probability is less than the joint minimum floor value. The analysts should consider this impact on the overall decision making process.

power would be removed from the seal-in circuit when the circuit clears. Thus, when a hot short clears, not all circuits result in the recovery of the component and function.

References

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10.7 NUREG/CR-6931, SAND2007-600/V1, V2, and NISTIR 7472 Vol. 3, *Cable Responses to Live Fire* (CAROLFIRE), April 2008.

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