EXPERT JUDGMENT
AN APPLICATION IN FIRE-INDUCED CIRCUIT ANALYSIS

Gabriel Taylor, P.E.
Nicholas Melly (Presenter)
Tammie Pennywell

JACQUE-FIRE

- Joint Assessment of Cable Damage and Quantification of Effects from Fire
  - NUREG/CR-7150 Vol. 1&2, (EPRI 1026424, EPRI 3002001989)
- U.S. Nuclear Regulatory Commission (NRC) and Electric Power Research Institute (EPRI) sponsored collaborative research
- Uses balanced group of experts and available data to make informed decisions related to fire-induced effects to electrical circuits.

Volume 1 – PIRT Process

- Phenomena Identification and Ranking Table (PIRT)
  - Identifies influencing parameters and ranks parameters
  - Focused on Fire-Induced spurious operation and duration of spurious operations
- Rankings include
  - Parameter Applicability
  - Research Ease
  - Parameter Importance
  - State of Knowledge

PIRT Objectives

- A primary focus of the PIRT was to provide information to be used by the follow-on Expert Elicitation PRA Panel for revising the probability numbers currently used in the Fire PRA (JACQUE-FIRE Volume 2)
- A secondary focus was to provide information useful in performing a deterministic post-fire safe shutdown circuit analysis (JACQUE-FIRE Volume 1)

Figures of Merit (FOM)

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

- Spurious Operation
  - After fire-induced cable damage has occurred to an appropriate conductor in an electrical circuit resulting in a hot short(s), a spurious operation(s) of the component occurs
- Duration
  - Duration is the amount of time during which the fire-induced hot short transfers voltage or current to an appropriate conductor of a specific component or device that then can cause the component to move or travel in the undesired direction.

How were parameters ranked?

- Parameter Applicability
  - How common is it?
- Research Ease
  - How easy would it be to research?
- Parameter Importance
  - How important based on figure-of-merit?
- State of Knowledge
  - How much do we know about the parameters effect?

Ranking Tables

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

Identification	Influencing Parameter	Parameter Applicability	Research Ease	Effect of Parameters on the Likelihood - INTRA-CABLE HOT SHORT-INDUCED SPURIOUS OPERATION	Parameter Importance	State of Knowledge	Effect of Parameters on the Likelihood - INTER-CABLE HOT SHORT-INDUCED SPURIOUS OPERATION	Parameter Importance	State of Knowledge	Effect of Parameters on the Likelihood - INTER-CABLE GROUND FAULT EQUIVALENT HOT SHORT-INDUCED SPURIOUS OPERATION	Parameter Importance	State of Knowledge	Effect of Parameters on the DURATION - HOT SHORT-INDUCED SPURIOUS OPERATION	Parameter Importance	State of Knowledge
1	**Conductor Count**			**L**			**L**			**NA**			**L**		
	a. 1/C	M	NA		NA	NA		L	M					L	M
	b. 2-6/C	H	H		L	M		L	M					L	M
	c. 7-9/C	H	H		L	H		L	H					L	H
	d. 10-15/C	H	H		L	M		L	M					L	M
	e. >15/C	H	H		L	L		L	L					L	L

Fire Research Branch

Parameters Ranked as HIGH

- Spurious Operation
  - Cable Routing/Raceway: Panel Wiring
  - Cable Raceway Fill: Bundles
  - Conductor Insulation Type: Inter-cable
  - Cable Grounding Configuration: Drain/Shield
  - Armor: Grounded vs. Ungrounded circuit
  - Cable Wiring Configuration: Source/Target/Ground
  - Grounded vs. Ungrounded circuits: Inter-cable

Parameters Ranked as HIGH

- Duration
  - Fire Exposure Conditions
  - Cable Routing/Raceway: Panel wiring
  - Cable Raceway Fill: Bundles
  - Time-Current Characteristics: Fuse/Breaker Size
  - Cable Wiring Configuration: Source/Target/Ground
  - Latching vs. Non-latching

Define Terms

- Incredible
  - Signifies the PIRT panel's conclusion that the event cannot occur
  - In these cases, the PIRT panel could find no evidence of the phenomenon ever occurring, and there are no apparent credible engineering principles or technical argument to support its happening during a fire
  - Probabilistic numbers assigned to these types of phenomena would have little or no meaning

Define Terms (2)

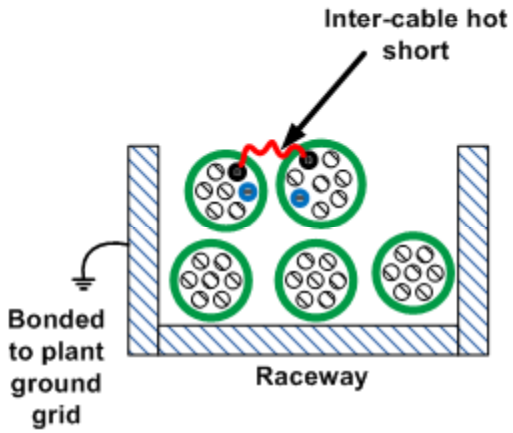
- Implausible
  - Supports the PIRT panels conclusion that the happening, while theoretically possible, would require the convergence of a combination of factors that are so unlikely to occur that the likelihood of the phenomenon can be considered statistically insignificant
  - PIRT Panel could not find any evidence of the phenomenon ever occurring during fire tests or real world fires

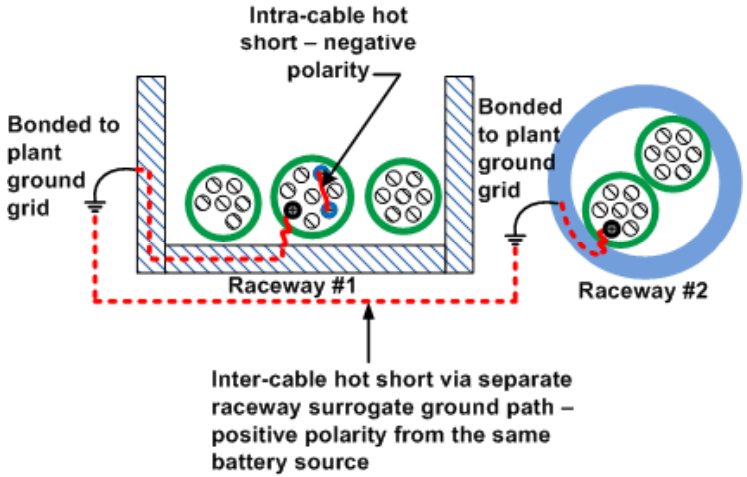
Deterministic Fire Protection Insights

- The PIRT Panel agreed to address various legacy issues pertaining to unusual circuit failure modes
  - 3-Phase Hot Shorts
  - Multiple Hot Shorts on DC Motors
  - Open Circuit CT Secondaries
  - Multiple High Impedance Faults (MHIF)
  - Associated Circuits
  - Instrument Signal Failure Modes

GFEHS

- Ground Fault Equivalent Hot Short (GFEHS)
- Analysis of test data per NUREG-2128 found evidence of multiple shorts to ground causing spurious operations
- Although additional testing is recommended, GFEHS are considered to be possible and were seen in the DESIREE Testing





Future Research Recommendations

- Control configurations as identified in PIRT tables
- Instrumentation signal failure modes
- Surrogate ground path – likelihood
- Current Transformers
- Panel wiring
- Trunk cables

Insights, Summary & Conclusion

- Balanced 50/50 split of RES/EPRI experts worked well
- Consensus approach to acquiring expert judgment has pros and cons
- Results of PIRT provide valuable information for deterministic and PRA applications
- Formed basis for follow on PRA expert elicitation work

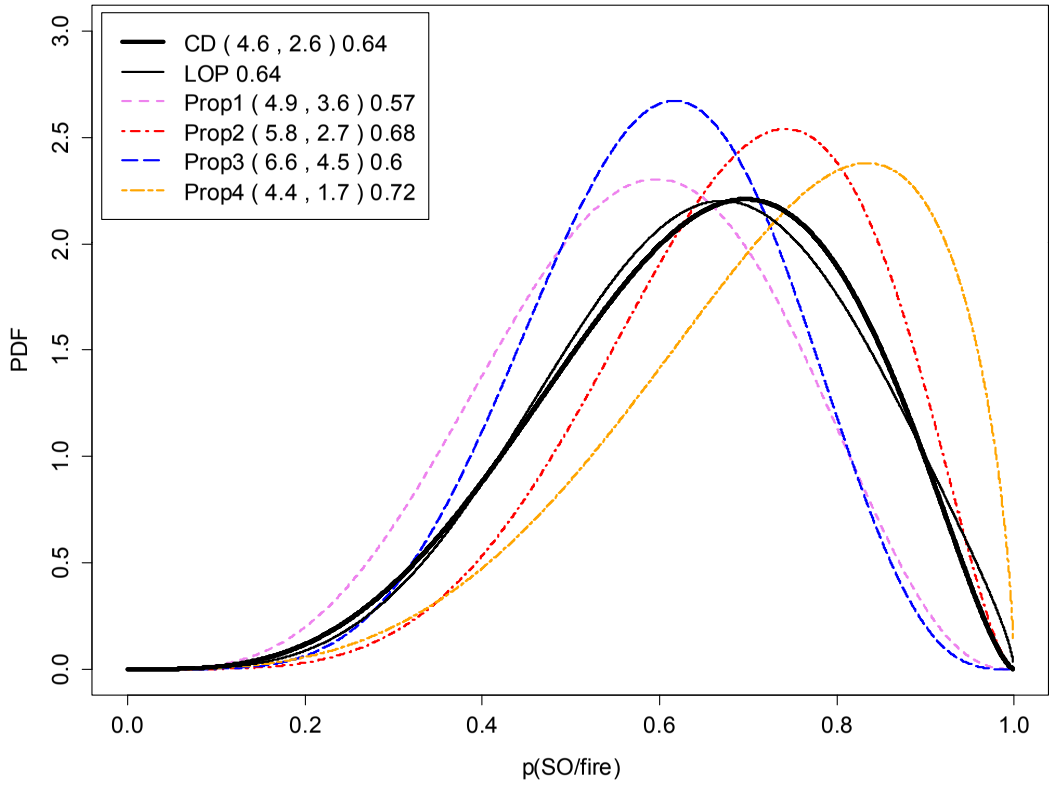
Volume 2 – Expert Elicitation

- PRA Expert Elicitation Panel
  - Use information from PIRT panel and test data to develop spurious operation likelihood and duration estimates
  - New estimates to replace or update NUREG/CR-6850, Task 10 values
- Followed NUREG/CR-6372, Senior Seismic Hazard Analysis Committee (SSHAC) Process
  - Level 2 +
    - "+" represents addition of peer review group and in-person workshops

SSHAC – Level 2+ Process

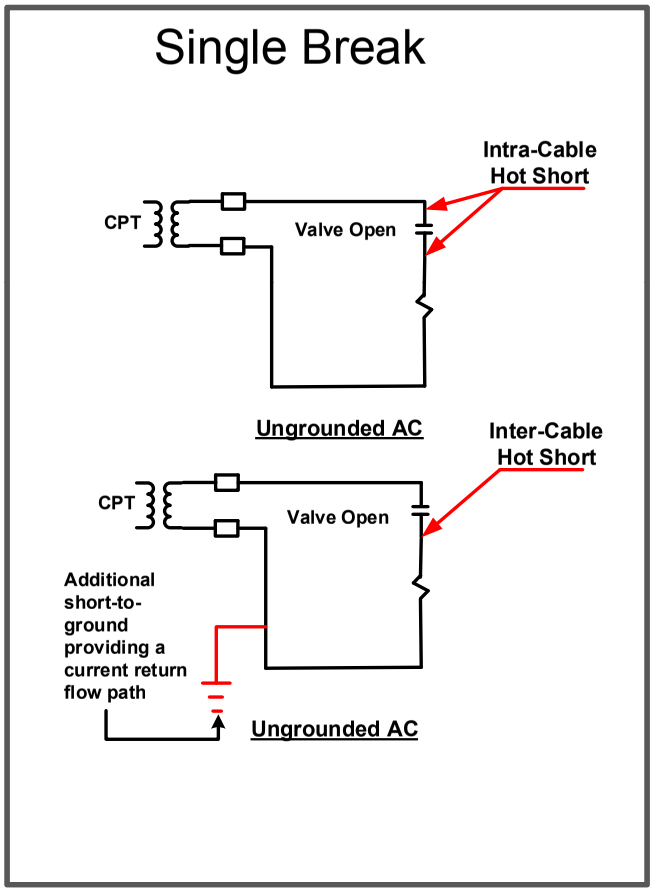
- Balanced group of experts broken into groups
  - Technical Integration Team
  - Proponent Experts
  - Resource Experts
  - Participatory Peer Review Panel (PPRP)
  - Technical Support Staff
- Three week-long workshops allowed for detailed discussions and presentation of experts opinions
- Peer review team allowed for sufficient feedback to meet objective of project and added quality.

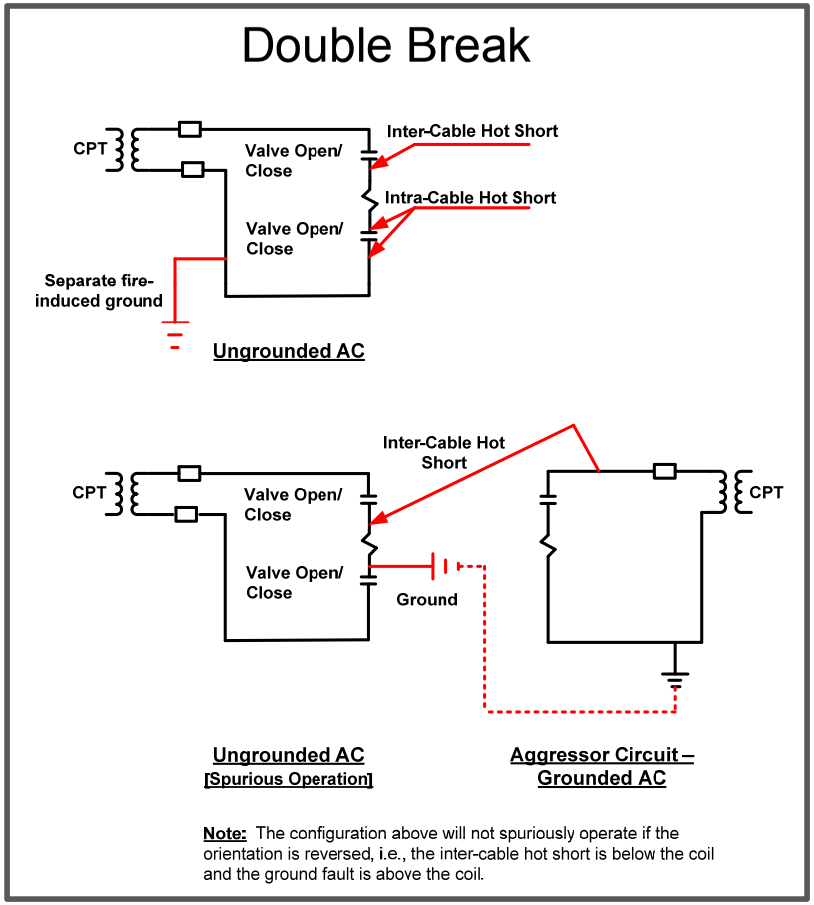
Expert Input Aggregation



- Fit proponents' input to standard beta distribution (SBD)
- Feedback from proponents on SBD fit
- Develop Linear Opinion Pooling (LOP) distribution by averaging individual proponent distributions
- Develop community distribution (CD) by fitting an SBD to LOP distribution

Single vs. Double Break





Single Break SOV Table

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

MOV and Double Break Circuits

- MOV estimates are based on SOV distributions and a multiplying factor distribution based on input from three proponents

- Double break estimates are developed based on SOV single break distributions and combining proponent distributions; MOV estimates are based on proponent input

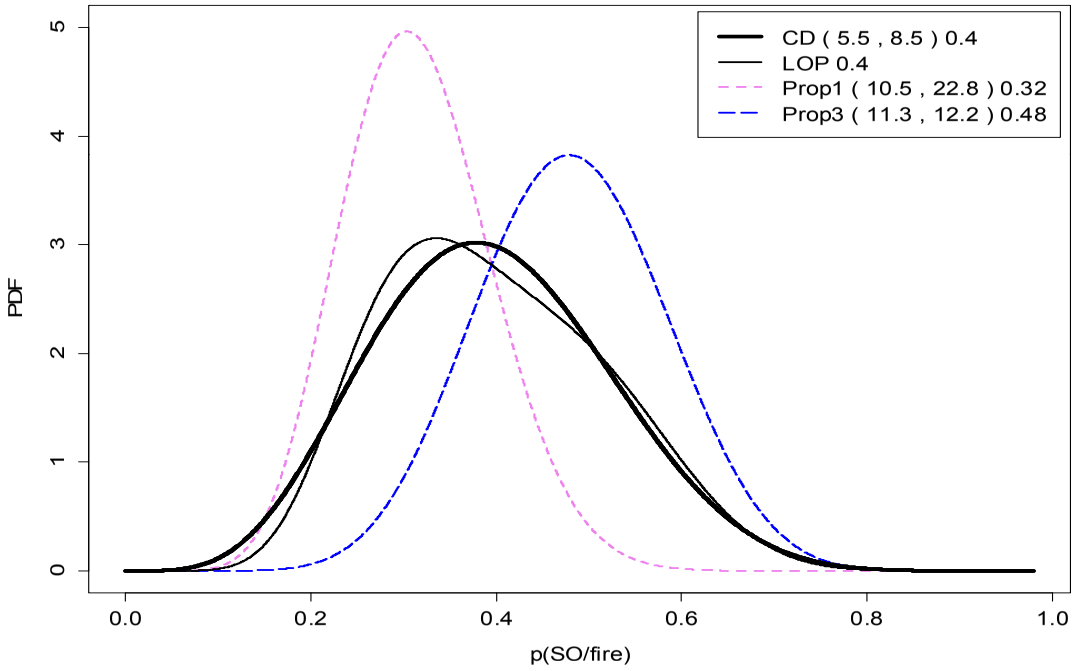
Single Break MOV Table

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	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		1.20	3.64		3.64	2.62		2.11	4.85
		Beta	6.15		6.15	6.15		6.15	5.95		7.41	5.72
		5%	1.5E-02	Incredible	1.5E-02	1.5E-01	Incredible	1.5E-01	8.9E-02	Incredible	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		0.21	3.76		3.76	7.52		3.10	10.97
		Beta	5.94		5.94	10.05		10.05	9.24		7.72	7.12
		5%	6.7E-08	Incredible	6.7E-08	1.0E-01	Incredible	1.0E-01	2.6E-01	Incredible	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

Ungrounded DC Control Circuits for Medium Voltage Circuit Breaker

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

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



Fire Research Branch

NUREG/CR-6850 Task 10 Changes

- NUREG/CR-6850, EPRI 1011989
  - Insulation Type
  - CPT
  - Raceway type
  - M/C vs. 1/C
- JACQUE-FIRE Volume 2
  - Circuit design (single break vs. double break)
  - Spurious Operation Device (SOV, MOV, Breaker)
  - Power supply/grounding configuration (Grounded AC, Ungrounded AC, Ungrounded DC)
  - Cable Configuration (Thermoset, Thermoplastic, Shield, Armor)
  - Use Aggregate unless only one failure mode possible

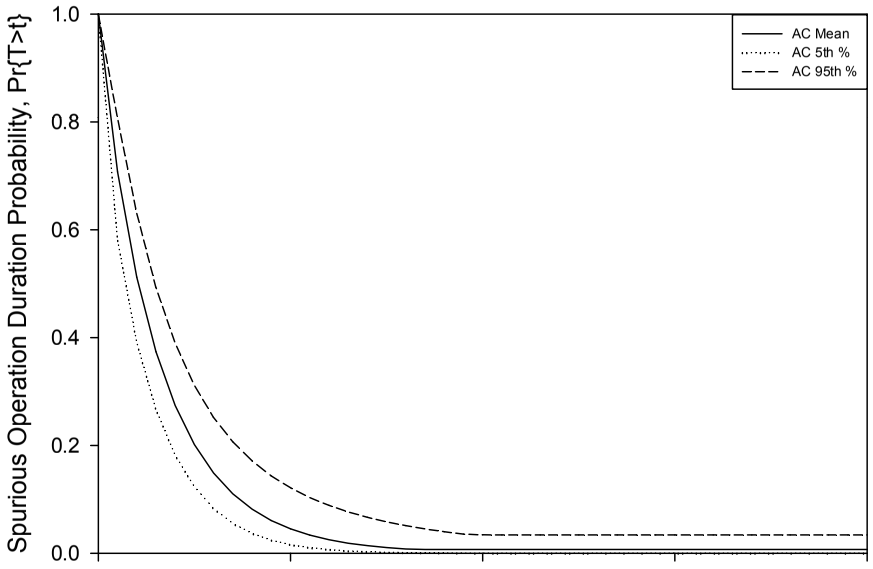
Table 10-1
Failure Mode Probability Estimates Given Cable Damage
Thermoset Cable with Control Power Transformer (CPT)

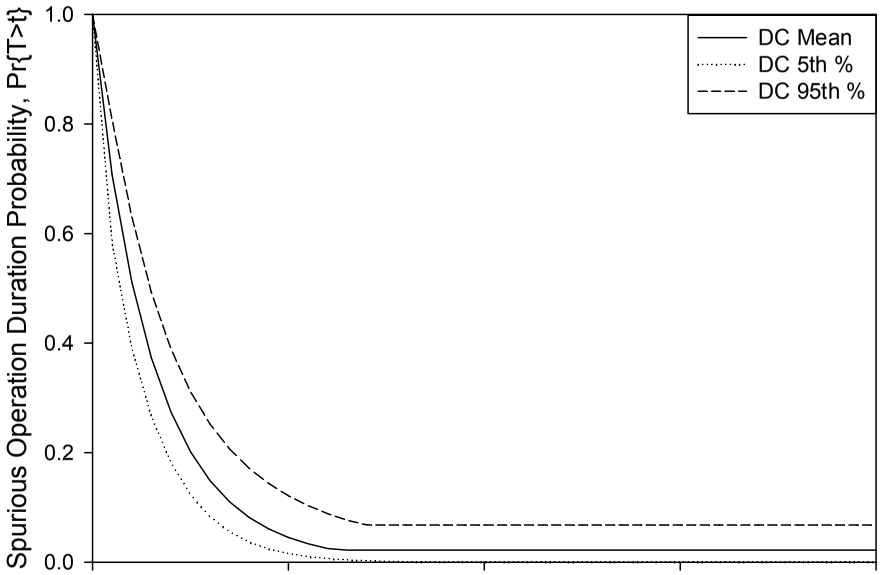
Raceway Type	Description of Hot Short	Best Estimate	High Confidence Range
Tray	M/C Intra-cable	0.30	0.10 – 0.50
	1/C Inter-cable	0.20	0.05 – 0.30
	M/C → 1/C Inter-cable	0.10	0.05 – 0.20
	M/C → M/C Inter-cable	0.01 – 0.05	
Conduit	M/C Intra-cable	0.075	0.025 – 0.125
	1/C Inter-cable	0.05	0.0125 – 0.075
	M/C → 1/C Inter-cable	0.025	0.0125 – 0.05
	M/C → M/C Inter-cable	0.005 – 0.01	

Spurious Operation Duration

- Based on data and expert judgment
- Data was pooled based on Kolmogorov-Smirnov (K-S)
- "C-S" model developed by NRC staff (M. Stutzke)
  - "Accelerated fatigue" model allows proponent experts to propose adjustments to data-based curve
  - "c" shifts curve and widens uncertainty
  - "s" adjusts uncertainty
- "Floor" probabilities added for AC and DC
  - Expert input combined using LOP method

Duration Curves





Interim Guidance

- Memo between RES and NRR to provide preliminary results to support NRR review of NFPA 805 applications (ADAMS Accession No. ML14017A084)
- Provides all numerical estimates developed under JACQUE-FIRE
- Identified that Option 2 of NUREG/CR-6850 is not technically adequate
- Issuance of NUREG/CR-7150, Vol. 2, will supersede this guidance

Thank You!

Questions?

Gabriel Taylor, P.E.
Sr. Fire Protection Engineer

E-mail:
gabriel.taylor@nrc.gov

Phone:
301-251-7576