Assessing the Distribution of the Probability of Spurious Operation
PROPONENT #4

Case	**P_SB_01_01** **Single Break Generic** **Grounded AC** **Intra-Cable** **TS source cable** **TS target cable**

Statistical Analyses

Description of Analyses	The 'count' from the global approach is based on whether either of the two target conductors in the cable was 'hit'. Taking a simple ratio based on the global approach yields a probability of 0.60. However, when applied to a circuit with only a single target conductor, the global approach results would over-predict the occurrence. Therefore, the target based results were reviewed. The average of the C5 and C6 results (0.49 and 0.51) yields an average of 0.50. Based on the information presented in the summary section, a probability of 0.53 is proposed when applied to an application with only a single target conductor. This case is also applicable to an MOV circuit. However, the review for an MOV circuit requires a more detailed treatment. The target approach results show an average probability for either the open or close operating coils being spuriously energized of 0.53 as noted above. The results also indicate that both the open and closed coils are spuriously energized (concurrently) 42% of the time. Given that a fire induced intra-cable hot short has occurred, the conditional probability that both open and closed coils will be spuriously energized is 0.79 (.42/.53 = .79). Because of the interlock that exists in the circuitry for MOV circuits, only one coil (open or close) can be energized. Both cannot be concurrently energized. If both were to be energized, the closure of both sets of contactors would results in a line-to-line short circuit on the power circuit. There is no evidence or test results that support a case that one would preferentially occur over the other. Therefore, it is assumed that there is a 50/50 chance that it will be open or closed. Combining with the 0.79 factor previously noted, there is a 0.21 (1 – 0.79) probability that either the open or close coil will be the only coil energized. For the case where the both the open and closed coils are energized, the treatment is complicated. This is because the circuitry could have experienced the so-called 92-18 failure mode in which case, the valve will only stroke in one direction. If the circuitry did not experience that failure mode, then there's a reasonable expectation that the valve will stroke repeatedly until the valve fails thermally (valve actuator motors are not designed for continuous operation – AC MOV motors are typically designed for a 15 minute duty cycle while DC MOV motors are typically designed for a 5 minute duty cycle). In the absence of more extensive examination of the test data, it is not clear to what extent the additional circuit shorting that

	would be necessary to cause the '92-18' failure mode occurred. However, it can be inferred that the relatively high conditional probability of multiple internal shorting of the C5 and C6 target conductors (79%) is indicative of a high expectation that the 92-18 failure mode would occur unless some circuit design precluded its occurrence. In addition, a review of the Carolfire and DESIREE test data finds that the 'spare' C4 was also energized 9 out of 14 times that both the C5 and C6 conductors were 'hit' which is the same result for the 'spare' C8 conductor. This fraction yields a conditional probability of 0.64. This value will be used for the occurrence of the 92-18 failure mode. These values were applied to the MOV event tree that was developed and discussed in a separate document. The results of that event tree are a spurious close probability of 0.27 and a spurious open probability of 0.30. The event tree treatment was also applied for the valve active functions of open and close. The result of this treatment yielded a failure to close probability of 0.77 and a failure to open probability of 0.74.
Distribution obtained	Several values are developed above: 1. Single target case – P = 0.53 (5^{th} / 95^{th} values of 0.38 / 0.61, respectively) 2. MOV case – P_{SO} = 0.30 (5^{th} / 95^{th} values of 0.22 / 0.34, respectively) 3. MOV case – P_{SC} = 0.27 (5^{th} / 95^{th} values of 0.19 / 0.31, respectively) 4. MOV case – P_{FTO} = 0.74 (5^{th} / 95^{th} values of 0.70 / 0.81, respectively) 5. MOV case – P_{FTC} = 0.77 (5^{th} / 95^{th} values of 0.73 / 0.84, respectively)

Expert's Additional Comments

The pooled test data was used in the development of the parameter estimates provided above. The following provides a summary of the individual results.

Dataset	C5 Conductor	C6 Conductor	Both
Pooled	26/53 0.49	27/53 0.51	20/53 0.38
Carolfire	11/17 0.65	10/17 0.59	9/17 0.53
DESIREE	5/10 0.50	7/10 0.70	5/10 0.50
EPRI	10/26 0.38	10/26 0.38	6/26 [1] 0.23
Average [2]	0.51	0.56	0.42

Note 1: It was noted that the sum of the individual results for both C5 and C6 being 'hit' sums to 8 in the supporting Excel file, but 2 of them are inter-cable faults and are excluded resulting in a count of 6 which provides a total of 20 which is consistent with the aggregate data provided.

Note 2: The average is determined by summing the individual probabilities for Carolfire DESIREE and EPRI and dividing by 3. This approach was used to eliminate any skewing that may arise due simply to the number of trails.

While efforts were taken to define the test configurations to represent actual plant installations, it is not realistically possible for the tests to be entirely accurate representations. This is because of a variety of issues that include likely variations in wiring configurations. It is not believed that the test results can be used to predict a measurable difference in the spurious actuation probability in the open versus close coils. An average of the six test results was used to generate a composite value of 0.53 that will be used for both the open and close direction as well as for single coil applications.

For establishing the distribution for the point estimate of 0.53, a 'binomial' calculator is used with a test population of (17 + 10 + 26) x 2 = 106 to obtain the 5^{th} and 95^{th} given an idealized case. This generates a 5^{th} and 95^{th} percentile value of 0.44 and 0.61, respectively. The test population was purposely increased to treat each directional case individually to yield a narrower distribution. The upper bound value of 0.61 is retained but the lower bound of 0.44 is reduced to 0.38. This lower bound was calculated as the 5^{th} percentile value using the same medium probability but with a test population using half of the EPRI tests (17 + 10 + 13) = 40.

A simplistic distribution was generated for the MOV failure states by propagating the 5^{th} and 95^{th} percentile values using the MOV event tree. The other nodes in the event tree maintained the 42% value for both C5 and C6 being energized, and the 64% value for the IEN 92-18 upset state.

Case	**P_SB_01_02** **Single Break Generic** **Grounded AC** **Inter-Cable** **TS source cable** **TS target cable**

Statistical Analyses

Description of Analyses	The available test data for this item shows no occurrences in 48 tests. As raw data, this result could be used to conservatively calculate a probability: 0.5/(48+1) ~ 0.01 Various assessments of the data could be performed to decrease the population of applicable tests. These reductions would appear to be appropriate because some tests were configured such that an inter-cable hot short are inherently precluded. However, it is believed that had additional test samples been included, the same results would be observed. Therefore, expert judgment is used to recommend a probability for this event. Because of the nature of TS materials and the behavior of these circuits during the test as described to this reviewer by the two PIRT representatives, a lower value of 5E-3 is recommended. This value is half of the lowest value that would be calculated using a statistical approach. For MOV applications, the occurrence of other shorts that are required for the treatment should be taken from P_SB_01_01 based on intra-cable shorting. If additional inter-cable shorting is required, then those additional events should be treated as independent events.
Distribution obtained	0.005 (5^{th} / 95^{th} values of 3E-4 / 0.10, respectively)

Expert's Additional Comments

For establishing the distribution for the point estimate of 0.005, a 'binomial' calculator is used with a test population of 200 to obtain the 5^{th} and 95^{th} given an idealized case. This generates a 5^{th} and 95^{th} percentile value of 3E-4 and 0.02, respectively. Because of the use of expert judgment, the calculated 5^{th} percentile is retained. The 95^{th} percentile is set to 0.10. This higher 95^{th} percentile value is determined using a binominal calculator based on a test population of 44.

Case	**P_SB_01_03** **Single Break Generic** **Grounded AC** **Aggregate** **TS source cable** **TS target cable**

Statistical Analyses

Description of Analyses	This item is intended to address the aggregate of the inter and intra cable hot shorts. The proposed treatment for the inter-cable hot short results in a recommended value that is two orders of magnitude lower than the values recommended for intra-cable shorts. As such, the aggregate becomes identical to the intra-cable hot short case for multi-conductor target cables. For single conductor target cables, the inter-cable values would apply.
Distribution obtained	NA

Case	**P_SB_01_04** **Single Break Generic** **Ungrounded AC** **Intra-Cable** **TS source cable** **TS target cable**

Statistical Analyses

Description of Analyses	The treatment for this case is similar to that provided for P_SB_01_01. The other than the lack of grounding, these two cases are identical. The lack of grounding is expected to have an upward impact on the conditional likelihood of intra-cable short as opportunities to disrupt the source of power via the ground are not available. The raw data reflects a conditional probability of 0.75 (6/8) and is higher than P_SB_01_01 as would be anticipated. A review of the data found that all information is from Carolfire and that the occurrence of shorting to C5 occurred concurrently with shorting to C6 in all cases. This yields a conditional probability that the open and close coils are energized concurrently at 100%. In additional, spare conductors C4 and C8 participated in the shorting 4 and 5 out of the 6 occurrences, respectively. This yields a conditional probability of 0.75 for the occurrence of the 92-18 failure. Given this information, the approach described for

	P_SB_01_01 can repeated using the updated parameters from the testing of ungrounded CPT circuits. For the more general case of ungrounded AC power supplies (from utility distribution panels instead of a CPT), the results from the ungrounded DC testing should be used. The results of that event tree are a spurious close probability of 0.38 and a spurious open probability of 0.42. The event tree treatment was also applied for the valve active functions of open and close. The result of this treatment yielded a failure to close probability of 0.67 and a failure to open probability of 0.63.
Distribution obtained	Several values are developed above: 6. Single target case – P = 0.75 (5^{th} / 95^{th} values of 0.40 / 0.95, respectively) 7. MOV case – P_{SO} = 0.42 (5^{th} / 95^{th} values of 0.23 / 0.53, respectively) 8. MOV case – P_{SC} = 0.38 (5^{th} / 95^{th} values of 0.20 / 0.48, respectively) 9. MOV case – P_{FTO} = 0.63 (5^{th} / 95^{th} values of 0.53 / 0.80, respectively) 10. MOV case – P_{FTC} = 0.67 (5^{th} / 95^{th} values of 0.58 / 0.83, respectively)

Expert's Additional Comments

For establishing the distribution for the point estimate of 0.75, a 'binomial' calculator is used with a test population of 8 to obtain the 5^{th} and 95^{th} given an idealized case. This generates a 5^{th} and 95^{th} percentile value of 0.40 and 0.95, respectively.

A simplistic distribution was generated for the MOV failure states by propagating the 5^{th} and 95^{th} percentile values using the MOV event tree. The other nodes in the event tree maintained their previously calculated values.

Case	**P_SB_01_05** **Single Break Generic** **Ungrounded AC** **Inter-Cable** **TS source cable** **TS target cable**

Statistical Analyses

Description of Analyses	There is limited (no) test data for this case. Qualitatively, the expectation is that the likelihood of this case occurring should be lower than that associated with P_SB_01_02. Referring to the assessment prepared for P_SB_01_02, the estimate for a single conductor target was 0.009 (binominal distribution with 5th and 95th values of 5E-4 and 0.04, respectively). The estimate for a multi-conductor target was developed by considering the likelihood that an intra-cable short had not already occurred. Using the same approach, the adjusted valve is 0.009 x (1 – 0.75) = 0.002. However, as noted, the estimates for this case should be lower than the equivalent values from P_SB_01_02. In the absence of any specific test data or other objective evidence, qualitative judgment is applied. For the single conductor target case, in order for an inter-cable hot short to cause a spurious actuation, the individual hot short must occur concurrently with additional shorting to establish a neutral return path. As such, this would effectively be two hot shorts. Since multiple 'grounding' of conductors creating a neutral return path could be reasonably be expected to occur, a probability of 10x the prior value is assumed. The product of these two events (0.009 x 0.009 x 10) yields a probability of 8E-4. For the multi-conductor case, a similar treatment would apply – (0.002 x 0.002 x 10) = 4E-5.
Distribution obtained	Single Conductor Target – 8E-4 (5th / 95th values of 1E-4 / 0.003, respectively) Multi-conductor Target – 4E-5 (5th / 95th values of 7E-6 / 1E-4, respectively)

Expert's Additional Comments

For establishing the distribution for the point estimate of 8E-4, a 'binomial' calculator is used with a test population of 2,500, which is twice of the smallest population that can be used consistent with the point estimate, to obtain the 5th and 95th given an idealized case. A value of twice is used to reduce the arbitrary 'width' of the distribution. The resulting 5th and 95th percentile values are 1E-4 and 0.003, respectively.

The process was repeated for the 4E-5 point estimate using a test population of 50,000. The resulting 5th and 95th percentile values are 7E-6 and 1E-4, respectively.

Case	**P_SB_01_06** **Single Break Generic** **Ungrounded AC** **Aggregate** **TS source cable** **TS target cable**

Statistical Analyses

Description of Analyses	Refer to assessment prepared for P_SB_01_03 – the same basic justification and treatment applies here. This item is intended to address the aggregate of the inter and intra cable hot shorts. The proposed treatment for the inter-cable hot short results in a recommended value that is several orders of magnitude lower than the values recommended for intra-cable shorts. As such, the aggregate becomes identical to the intra-cable hot short case for multi-conductor target cables. For single conductor target cables, the inter-cable values would apply.
Distribution obtained	NA

Case	**P_SB_01_07** **Single Break Generic** **Ungrounded DC** **Intra-Cable** **TS source cable** **TS target cable**

Statistical Analyses

Description of Analyses	The treatment described for this case using the tests data for an ungrounded DC system is judged to apply for ungrounded AC systems (not CPT powered). The test results show a ratio of 43 occurrences out of 87 possibilities yielding a conditional probability of 0.49. However, the testing reflects the aggregation of multiple types of circuits – MOV, SOV, large coil, and circuit breaker. Further review of the data found that the test results tend to be somewhat grouped as follows: Breaker – close coil 6/10 = .60 averages to 29/46 = .63 MOV 17/27 = .63 Coil – small 6/9 = .67 Breaker – trip coil 3/10 = .30 averages to 5/20 = .25 Coil – large 2/10 = .20

	SOV 9/21 = .43 However, further review of the tests and comparison to the assessment for P_SB_01_01 indicate that the variations in the results should not be a basis for segregating the test results. It is also noted that if the SOV data were to be pooled with the breaker close coil and the coil-small, the results - (6+6+9)/(10+9+21) = 0.525 – is comparable with the aggregate result of 0.49 noted above. Therefore, the 0.49 value is proposed as the spurious actuation probability for non-MOV circuits. For the MOV circuits, only 3 of the 17 occurrences involved multiple concurrent hot shorts on conductor 3 and 4 (YC1 and YO1) – 3/17 ~ 0.18. The data for hot shorts also found that in all but one case, the spurious actuation occurred with other 'spare' conductors involved in the shorting condition. Consistent with the approach used for case P_SB_01_01, that ratio of 1/17 ~ .06 is the fraction of time that a 92-18 failure is not assumed to occur. When this data is applied to the MOV event tree consistent with that used for case P_SB_01_01, the results show a spurious close probability of 0.315 and a spurious open probability of 0.317. The event tree treatment was also applied for the valve active functions of open and close. The result of this treatment yielded a failure to close probability of 0.687 and a failure to open probability of 0.685.
Distribution obtained	Several values are developed above: 11. Single target case – P = 0.49 (5^{th} / 95^{th} values of 0.36 / 0.59, respectively) 12. MOV case – P_{SO} / P_{SC} = 0.32 (5^{th} / 95^{th} values of 0.23 / 0.39, respectively) 13. MOV case – P_{FTO} / P_{FTC} = 0.69 (5^{th} / 95^{th} values of 0.61 / 0.78, respectively)

Expert's Additional Comments

For establishing the distribution for the point estimate of 0.49, a 'binomial' calculator is used with a test population of 87 to obtain the 5^{th} and 95^{th} given an idealized case. This generates a 5^{th} and 95^{th} percentile value of 0.40 and 0.59, respectively. The test population was purposely increased to treat each directional case individually to yield a narrower distribution. The upper bound value of 0.59 is retained but the lower bound of 0.40 is reduced to 0.36. This lower bound was calculated as the 5^{th} percentile value using approximately the same medium probability but with a test population reduced to 40.

A simplistic distribution was generated for the MOV failure states by propagating the 5^{th} and 95^{th} percentile values using the MOV event tree. The probability used for MOV circuits is 0.63 (17/27) which generates calculated binomial distribution values of 0.45 and 0.78 for the 5^{th} and 95^{th} percentile values, respectively. The other nodes in the event tree maintained the 18% value for both C5 and C6 being energized, and the 6% value for the IEN 92-18 upset state.

Case	**P_SB_01_08** **Single Break Generic** **Ungrounded DC** **Inter-Cable** **TS source cable** **TS target cable**

Statistical Analyses

Description of Analyses	Refer to assessment prepared for P_SB_01_02 – the same basic justification and treatment applies here. However, given the lack of any specific test data, a qualitative assessment is performed. A comparison of the results from P_SB_01_01 and P_SB_01_07 found that the probability values are comparable with those from P_SB_01_07 being slightly higher. Given the ungrounded nature of the circuits, the higher probability values could be expected. As such, it would be reasonable to expect the inter-cable hot short probability values to be slight higher than that associated with a grounded system. Given the small values being considered and the minor increase that would applicable, it is recommended, that the grounded AC circuit probability values be used.
Distribution obtained	Same as P_SB_01_02

Case **P_SB_01_09**
Single Break Generic
Ungrounded DC
Multiple Shorts Ground
TS source cable
TS target cable

Statistical Analyses

Description of Analyses

A review of the data found 9 highlighted instances where a ground plane interaction occurred. The distribution of the 9 identified occurrences as well as the total number of related trials from P_SB_01_07 are:

Breaker – close coil	0/9 (.05)	total of 10 trials (.045)
MOV	3/9 (.33)	total of 27 trials (.11)
Coil – small	1/9 (.11)	total of 9 trials (.11)
Breaker – trip coil	0/9 (.05)	total of 10 trails (.045)
Coil – large	2/9 (.22)	total of 10 trials (.20)
SOV	3/9 (.33)	total of 21 trails (.14)

Taken in aggregate, the total test pool would result in a probability of (3 + 1 + 2 + 3)/(10 + 27 + 9 + 10 + 10 + 21) ~ 0.10. If the MOV related data were excluded, the resulting probability would remain unchanged at 0.10.

These results indicate that circuit where multiple intra or inter-cables shorts would be required to cause a spurious actuation would actually have a higher likelihood of occurrence because of a ground plane interaction. For such cases, instead of multiplying individual values for intra or inter-cables shorts, a single value of 0.10 should be used.

For MOV applications, if multiple shorts are required to cause a spurious control circuit actuation, the event tree used for P_SB_01_07 is used with the 0.10 value.

Distribution obtained

Several values are developed above:

14. Single target case – P = 0.10 (5^{th} / 95^{th} values of 0.05 / 0.17, respectively)
15. MOV case – P_{SO} / P_{SC} = 0.05 (5^{th} / 95^{th} values of 0.02 / 0.13, respectively)
16. MOV case – P_{FTO} / P_{FTC} = 0.95 (5^{th} / 95^{th} values of 0.87 / 0.99, respectively

Expert's Additional Comments

For establishing the distribution for the point estimate of 0.10, a 'binomial' calculator is used with a test population of 87 to obtain the 5^{th} and 95^{th} given an idealized case. This generates a 5^{th} and 95^{th} percentile value of 0.06 and 0.17, respectively. The upper bound value of 0.17 is

retained but the lower bound of 0.06 is reduced to 0.05. This lower bound was qualitatively established based on similar reductions applied to other cases.
A simplistic distribution was generated for the MOV failure states by propagating the 5th and 95th percentile values using the MOV event tree. The probability used for MOV circuits is 0.10 (3/27) which generates calculated binomial distribution values of 0.03 and 0.26 for the 5th and 95th percentile values, respectively. The other nodes in the event tree maintained the 18% value for both C5 and C6 being energized, and the 6% value for the IEN 92-18 upset state.

Case	**P_SB_01_10** **Single Break Generic** **Ungrounded DC** **Aggregate** **TS source cable** **TS target cable**

Statistical Analyses

Description of Analyses	This item involves the aggregation of the results from P_SB_01_07, P_SB_01_08, and P_SB_01_09. For non-MOV circuits: From P_SB_01_07: 43/87 = .49 From P_SB_01_08: Single Conductor Target – 0.009 (5th / 95th values of 5E-4 / 0.04, respectively) Multi-conductor Target – 0.004 (5th / 95th values of 2E-4 / 0.02, respectively) From P_SB_01_09: 6/45 = 0.13 The larger of the values above is selected as the aggregate (0.49). For MOV circuits, a similar process is applied and the larger of the results should be used - P_{SO} / P_{SC} = 0.32 and P_{FTO} / P_{FTC} = 0.84.
Distribution obtained	Several values are developed above: 17. Single target case – P = 0.49 (5th / 95th values of 0.36 / 0.59, respectively) 18. MOV case – P_{SO} / P_{SC} = 0.32 (5th / 95th values of 0.23 / 0.39, respectively) 19. MOV case – P_{FTO} / P_{FTC} = 0.84 (5th / 95th values of 0.65 / 0.95, respectively)

Case	**P_SB_02_01** **Single Break Generic** **Grounded AC** **Intra-Cable** **TP source cable** **TP target cable** These two cases were combined into a single case.

Statistical Analyses

Description of Analyses	The 'count' from the global approach is based on whether either of the two target conductors in the cable was 'hit'. Taking a simple ratio based on the global approach yields a probability of 0.50 (16/32). The process applied to P_SB_01_01 was repeated for this item. The average of the C5 (15/32) and C6 (12/32) results (0.47 and 0.38) yields an average of 0.42. Based on the information presented in the summary section, a probability of 0.37 is proposed when applied to an application with only a single target conductor. This case is also applicable to an MOV circuit. However, the review for an MOV circuit requires a more detailed treatment. The target approach results show an average probability for either the open or close operating coils being spuriously energized of 0.37 as noted above. The results also indicate that both the open and closed coils are spuriously energized (concurrently) 34% of the time if the data is pooled. Instead, the probability values are individually computed for the Carolfire, DESIREE, and EPRI test, and those three values are averaged yielding a value of 31%. Given that a fire induced intra-cable hot short has occurred, the conditional probability that both open and closed coils will be spuriously energized is 0.84 (.31/.37 = .84). Because of the interlock that exists in the circuitry for MOV circuits, only one coil (open or close) can be energized. Both cannot be concurrently energized. If both were to be energized, the closure of both sets of contactors would results in a line-to-line short circuit on the power circuit. There is no evidence or test results that support a case that one would preferentially occur over the other. Therefore, it is assumed that there is a 50/50 chance that it will be open or closed. Combining with the 0.84 factor previously noted, there is a 0.16 (1 – 0.84) probability that either the open or close coil will be the only coil energized. For the case where the both the open and closed coils are energized, the treatment is complicated. This is because the circuitry could have experienced the so-called 92-18 failure mode in which case, the valve will only stroke in one direction. If the circuitry did not experience that failure mode, then there's a reasonable expectation that the valve will stroke repeatedly until the valve fails thermally (valve actuator motors are not designed for continuous operation – AC MOV motors are typically designed for a 15 minute duty cycle while DC MOV motors are typically

	designed for a 5 minute duty cycle). In the absence of more extensive examination of the test data, it is not clear to what extent the additional circuit shorting that would be necessary to cause the '92-18' failure mode occurred. However, it can be inferred that the relatively high conditional probability of multiple internal shorting of the C5 and C6 target conductors (84%) is indicative of a high expectation that the 92-18 failure mode would occur unless some circuit design precluded its occurrence. In addition, a review of the Carolfire and DESIREE test data finds that the 'spare' C4 was also energized 7 out of 11 times that both the C5 and C6 conductors were 'hit'. The C8 conductor was 'hit' 10 out of 11 times. Averaging the two resulting values provides a conditional probability of 0.77. This value will be used for the occurrence of the 92-18 failure mode. These values were applied to the MOV event tree that was developed and discussed in a separate document. The results of that event tree are a spurious close probability of 0.19 and a spurious open probability of 0.20. The event tree treatment was also applied for the valve active functions of open and close. The result of this treatment yielded a failure to close probability of 0.83 and a failure to open probability of 0.82.
Distribution obtained	Several values are developed above: 20. Single target case – P = 0.37 (5^{th} / 95^{th} values of 0.23 / 0.48, respectively) 21. MOV case – P_{SO} = 0.20 (5^{th} / 95^{th} values of 0.13 / 0.26, respectively) 22. MOV case – P_{SC} = 0.19 (5^{th} / 95^{th} values of 0.12 / 0.24, respectively) 23. MOV case – P_{FTO} = 0.82 (5^{th} / 95^{th} values of 0.78 / 0.90, respectively) 24. MOV case – P_{FTC} = 0.83 (5^{th} / 95^{th} values of 0.76 / 0.89, respectively)

Expert's Additional Comments

The pooled test data was used in the development of the parameter estimates provided above. The following provides a summary of the individual results.

Dataset	C5 Conductor	C6 Conductor	Both
Pooled	15/32 0.47	12/32 0.38	11/32 0.34
Carolfire	9/14 0.64	7/14 0.50	7/14 0.50
DESIREE	1/6 0.17	1/6 0.17	1/6 0.17
EPRI	5/12 0.42	4/12 0.33	3/12 0.25
Average [1]	0.41	0.33	0.31

Note 1: The average is determined by summing the individual probabilities for Carolfire DESIREE and EPRI and dividing by 3. This approach was used to eliminate any skewing that may arise due simply to the number of trails.

While efforts were taken to define the test configurations to represent actual plant installations, it is not realistically possible for the tests to be entirely accurate representations. This is because of a variety of issues that include likely variations in wiring configurations. It is not believed that the test results can be used to predict a measurable difference in the spurious actuation probability in the open versus close coils. An average of the six test results was used to generate a composite value of 0.37 that will be used for both the open and close direction as well as for single coil applications.
For establishing the distribution for the point estimate of 0.37, a 'binomial' calculator is used with a test population of (32) x 2 = 64. Because the calculator requires integer values, the values used were determined as follows: 64 x 0.37 = 23.7 ~ 24. 24/0.37 = 64.9 ~ 65. Use of this ratio (24/65) generates a 5^{th} and 95^{th} percentile value of 0.27 and 0.48, respectively given an idealized case. The test population was purposely increased to treat each directional case individually to yield a narrower distribution. The upper bound value of 0.48 is retained but the lower bound of 0.27 is reduced to 0.23. This lower bound was calculated as the 5^{th} percentile value using the same approximate medium probability but with a test population of 32 (12/32). A simplistic distribution was generated for the MOV failure states by propagating the 5^{th} and 95^{th} percentile values using the MOV event tree. The other nodes in the event tree maintained the 84% value for both C5 and C6 being energized, and the 77% value for the IEN 92-18 upset state.

Case	**P_SB_02_02** **Single Break Generic** **Grounded AC** **Inter-Cable** **TP source cable** **TP target cable**

Statistical Analyses

Description of Analyses	The available test data for this item shows no occurrences in 53 tests. As raw data, this result could be used to conservatively calculate a probability: 0.5/(24+1) = 0.02 However, it should also be noted that the assessment in P_SB_01_02 also involves no identified failures in 48 trials. Because of the anticipated behavior of TP insulated cables and the expectation that the likelihood of inter-cable shorting would be higher as compared to TS insulated cables, the recommended treatment for this case is to use the same approach as that proposed for TS cables in P_SB_01_02 and use half of the calculated value.
Distribution obtained	0.01 (5^{th} / 95^{th} values of 5E-4 / 0.09, respectively)

Expert's Additional Comments

For establishing the distribution for the point estimate of 0.01, a 'binomial' calculator is used with a test population of 100 to obtain the 5th and 95th given an idealized case. This generates a 5th and 95th percentile value of 5E-4 and 0.05, respectively. Because of the use of expert judgment, the calculated 5th percentile is retained. The 95th percentile is set to 0.09. This higher 95th percentile value is determined using a binominal calculator based on a test population of 53.

Case	**P_SB_02_03** **Single Break Generic** **Grounded AC** **Aggregate** **TP source cable** **TP target cable**

Statistical Analyses

Description of Analyses	This item is intended to address the aggregate of the inter and intra cable hot shorts. The proposed treatment for the inter-cable hot short results in a recommended value that is two orders of magnitude lower than the values recommended for intra-cable shorts. As such, the aggregate becomes identical to the intra-cable hot short case for multi-conductor target cables. For single conductor target cables, the inter-cable values would apply.
Distribution obtained	

Case	**P_SB_02_04** **Single Break Generic** **Ungrounded AC** **Intra-Cable** **TP source cable** **TP target cable** These two cases were combined into a single case.

Statistical Analyses

Description of Analyses	The treatment for this case is similar to that provided for P_SB_01_01. The other than the lack of grounding, these two cases are identical. The lack of grounding is expected to have an upward impact on the conditional likelihood of intra-cable short as opportunities to disrupt the source of power via the ground are not available. The raw data reflects a conditional probability of 1 (5/5).

	A review of the data found that C5 was shorted 3/5 times (0.60) and C6 was shorted 4/5 times (0.80). An average of the individual C5 and C6 values is recommended as the probability for an intra-cable hot short – 0.70. The concurrent shorting of C5 and C6 occurred 2/5 times (0.40). Therefore, the conditional probability is 0.40/0.70 = 0.57. In additional, spare conductors C4 and C8 participated in the shorting once and 3 times, respectively. This yields a conditional probability of 0.75 for the occurrence of the 92-18 failure. Given this information, the approach described for P_SB_01_01 can repeated using the updated parameters from the testing of ungrounded CPT circuits. For the more general case of ungrounded AC power supplies (from utility distribution panels instead of a CPT), the results from the ungrounded DC testing should be used. The results of that event tree are a spurious close probability of 0.35 and a spurious open probability of 0.38. The event tree treatment was also applied for the valve active functions of open and close. The result of this treatment yielded a failure to close probability of 0.68 and a failure to open probability of 0.65.
Distribution obtained	Several values are developed above: 25. Single target case – P = 0.70 (5^{th} / 95^{th} values of 0.39 / 0.91, respectively) 26. MOV case – P_{SO} = 0.38 (5^{th} / 95^{th} values of 0.21 / 0.49, respectively) 27. MOV case – P_{SC} = 0.35 (5^{th} / 95^{th} values of 0.20 / 0.46, respectively) 28. MOV case – P_{FTO} = 0.65 (5^{th} / 95^{th} values of 0.55 / 0.81, respectively) 29. MOV case – P_{FTC} = 0.68 (5^{th} / 95^{th} values of 0.58 / 0.82, respectively)

Expert's Additional Comments

For establishing the distribution for the point estimate of 0.70, a 'binomial' calculator is used with a test population of 10 to obtain the 5^{th} and 95^{th} given an idealized case. This generates a 5^{th} and 95^{th} percentile value of 0.39 and 0.91, respectively.

A simplistic distribution was generated for the MOV failure states by propagating the 5^{th} and 95^{th} percentile values using the MOV event tree. The other nodes in the event tree maintained their previously calculated values.

Case	**P_SB_02_05** **Single Break Generic** **Ungrounded AC** **Inter-Cable** **TP source cable** **TP target cable**

Statistical Analyses

Description of Analyses	There is limited (no) test data for this case. Qualitatively, the expectation is that the likelihood of this case occurring should be lower than that associated with P_SB_01_02. This treatment has already been provided in P_SB_01_05. The documentation of that assessment is not repeated here.
Distribution obtained	Same values as P_SB_01_05

Expert's Additional Comments

Refer to P_SB_01_05 for details.

Case	**P_SB_02_06** **Single Break Generic** **Ungrounded AC** **Aggregate** **TP source cable** **TP target cable**

Statistical Analyses

Description of Analyses	Refer to assessment prepared for P_SB_01_03 – the same basic justification and treatment applies here. This item is intended to address the aggregate of the inter and intra cable hot shorts. The proposed treatment for the inter-cable hot short results in a recommended value that is several orders of magnitude lower than the values recommended for intra-cable shorts. As such, the aggregate becomes identical to the intra-cable hot short case for multi-conductor target cables. For single conductor target cables, the inter-cable values would apply.
Distribution obtained	NA

Case	**P_SB_02_07** **Single Break Generic** **Ungrounded DC** **Intra-Cable** **TP source cable** **TP target cable** These two cases were combined into a single case.

Statistical Analyses

Description of Analyses

The treatment described for this case using the tests data for an ungrounded DC system is judged to apply for ungrounded AC systems (not CPT powered).

The test results summary shows a ratio of 36 occurrences out of 64. However, a counting of the actual data entries found only 35 occurrence out of 63 instances. The resulting ratio is 35/63 ~ 0.56. However, the testing reflects the aggregation of multiple types of circuits – MOV, SOV, large coil, and circuit breaker. Further review of the data found that the test results tend to provide similar results:

Breaker – close coil	4/7 = .57
MOV	12/20 = .60
Coil – small	4/6 = .67
Breaker – trip coil	4/8 = .50
Coil – large	4/6 = .67
SOV	7/16 = .44

Therefore, the 0.56 value is proposed as the spurious actuation probability for non-MOV circuits.

For the MOV circuits, none of the 12 occurrences involved multiple concurrent hot shorts on conductor 3 and 4 (YC1 and YO1). However, there were three instances where conductor 3 and 4 (YC1 and YO1) were sequentially 'actuated'. In these three instances, none of the other 'spare' conductors were concurrently actuated. Therefore, the ratio of 3/12 = 0.25 represents the fraction of occurrences where the valve would 'cycle'. The data for hot shorts also found that in 6 of the remaining 9 occurrences (0.67), the spurious actuation occurred with one other 'spare' conductor involved in the shorting condition. This would represent the fraction of occurrences where the valve has undergone a single directional stroke, experienced a 92-18 failure and is therefore not recoverable unless separate justification (analysis) is performed on an application specific basis.

When this data is applied to the MOV event tree consistent with that used for case P_SB_01_01, the results show a spurious close probability of 0.28 and a spurious open probability of 0.29.

The event tree treatment was also applied for the valve active functions of open and close. The result of this treatment yielded a failure to close probability of 0.73

	and a failure to open probability of 0.72.
Distribution obtained	Several values are developed above: 30. Single target case – P = 0.56 (5^{th} / 95^{th} values of 0.42 / 0.65, respectively) 31. MOV case – P_{SO} = 0.29 (5^{th} / 95^{th} values of 0.22 / 0.34, respectively) 32. MOV case – P_{SC} = 0.28 (5^{th} / 95^{th} values of 0.21 / 0.33, respectively) 33. MOV case – P_{FTO} = 0.72 (5^{th} / 95^{th} values of 0.68 / 0.79, respectively) 34. MOV case – P_{FTC} = 0.73 (5^{th} / 95^{th} values of 0.69 / 0.80, respectively)

Expert's Additional Comments

For establishing the distribution for the point estimate of 0.56, a 'binomial' calculator is used with a test population of 83 to obtain the 5^{th} and 95^{th} given an idealized case. This generates a 5^{th} and 95^{th} percentile value of 0.46 and 0.65, respectively. The test population was purposely increased to treat each directional case individually (increasing the test population from 63 to 83 and the number of occurrences from 35 to 46) to yield a narrower distribution. The upper bound value of 0.65 is retained but the lower bound of 0.46 is reduced to 0.42. This lower bound was calculated as the 5^{th} percentile value using the same medium probability but with a test population reduced to 43.

A simplistic distribution was generated for the MOV failure states by propagating the 5^{th} and 95^{th} percentile values above using the MOV event tree.

Case	**P_SB_02_08** **Single Break Generic** **Ungrounded DC** **Inter-Cable** **TP source cable** **TP target cable**

Statistical Analyses

Description of Analyses	Refer to assessment prepared for P_SB_02_02 – the same basic justification and treatment applies here. However, given the lack of any specific test data, a qualitative assessment is performed. A comparison of the results from P_SB_02_01 and P_SB_02_07 found that the probability values are comparable with those from P_SB_01_07 being higher. Given the ungrounded nature of the circuits, the higher probability values are expected. As such, it would be reasonable to expect the inter-cable hot short probability values to be also higher than that associated with a grounded system. Given the small values being considered and the minor increase that would applicable, it is recommended, that the grounded AC circuit probability values be

	used.
Distribution obtained	Same as P_SB_02_02

Case **P_SB_02_09**
Single Break Generic
Ungrounded DC
Multiple Shorts Ground
TP source cable
TP target cable

Statistical Analyses

Description of Analyses

A review of the data found that the 4 identified instances occurred on tests PT-11 and PT-41. There were 2 occurrences on PT-11 (the large and small coil circuits interacted with each cross-energizing the other). The two occurrences happened sequentially. In the case of PT-41, there were 3 occurrences. The interactions occurred between the MOV-1 open coil and the MOV-2 close coil. There was also a third interaction between the P and N conductors of the two cables but this did not result or cause a spurious actuation. The distribution of the 5 identified occurrences as well as the total number of related trials from P_SB_02_07 are:

Breaker – close coil	0/5 (.08)	total of 7 trials (.06)
MOV	2/5 (.40)	total of 20 trials (.10)
Coil – small	1/5 (.20)	total of 6 trials (.17)
Breaker – trip coil	0/5 (.08)	total of 8 trails (.06)
Coil – large	1/5 (.20)	total of 6 trials (.17)
SOV	0/5 (.08)	total of 16 trails (.03)

Taken in aggregate, the total test pool would result in a probability of (2 + 1 + 1)/(7 + 20 + 6 + 8 + 6 + 16) ~ 0.06. If the MOV related data were excluded, the resulting probability would be 0.05. Based on this result, it is recommended that a single value of 0.05 be used.

For MOV applications, a value of 0.10 should be considered in the ttreatment of MOV circuits using an event tree. For this purposes of this case, the event tree used for P_SB_01_07 is used with the 0.10 value.

Distribution obtained

Several values are developed above:

35. Single target case – P = 0.05 (5^{th} / 95^{th} values of 0.008 / 0.14, respectively)
36. MOV case – P_{SO} / P_{SC} = 0.05 (5^{th} / 95^{th} values of 0.01 / 0.15, respectively)
37. MOV case – P_{FTO} / P_{FTC} = 0.95 (5^{th} / 95^{th} values of 0.86 / 0.99, respectively

Expert's Additional Comments

For establishing the distribution for the point estimate of 0.05, a 'binomial' calculator is used with a test population of 43 to obtain the 5th and 95th given an idealized case. This generates a 5th and 95th percentile value of 0.008 and 0.14, respectively.
A simplistic distribution was generated for the MOV failure states by propagating the 5th and 95th percentile values using the MOV event tree. The probability used for MOV circuits is 0.10 (2/20) which generates calculated binomial distribution values of 0.02 and 0.29 for the 5th and 95th percentile values, respectively. The other nodes in the event tree maintained the 25% value for both C5 and C6 being energized, and the 75% value for the IEN 92-18 upset state.

Case	**P_SB_02_10** **Single Break Generic** **Ungrounded DC** **Aggregate** **TP source cable** **TP target cable**

Statistical Analyses

Description of Analyses	This item involves the aggregation of the results from P_SB_02_07, P_SB_02_08, and P_SB_02_09. For non-MOV circuits: From P_SB_02_07: 35/63 = .56 From P_SB_02_08: Single Conductor Target – 0.009 (5th / 95th values of 5E-4 / 0.04, respectively) Multi-conductor Target – 0.004 (5th / 95th values of 2E-4 / 0.02, respectively) From P_SB_02_09: 2/47 = 0.05 The larger of the values above is selected as the aggregate (0.56). For MOV circuits, a similar process is applied and the larger of the results should be used – from P_SB_02_07.
Distribution obtained	Several values are developed above: 38. Single target case – P = 0.56 (5th / 95th values of 0.42 / 0.65, respectively)

39. MOV case – P_{SO} = 0.26 (5^{th} / 95^{th} values of 0.20 / 0.30, respectively)
40. MOV case – P_{SC} = 0.28 (5^{th} / 95^{th} values of 0.21 / 0.33, respectively)
41. MOV case – P_{FTO} = 0.72 (5^{th} / 95^{th} values of 0.68 / 0.79, respectively)
42. MOV case – P_{FTC} = 0.73 (5^{th} / 95^{th} values of 0.69 / 0.80, respectively)

Case	**P_SB_03_01** **Single Break Generic** **Grounded AC** **Intra-Cable** **Cable includes a grounded metal foil shield wrap**

Statistical Analyses

Description of Analyses	The process applied to P_SB_01_01 was repeated for this item. The test results show 2 occurrences of an MOV circuit spurious actuation for the 5 tests that were performed. Of particular interest is that both occurrences involved the C6 conductor. There were no occurrences where the C5 conductor participated in a spurious actuation. The simple ratio of 2/5 yields a probability of 0.40. This value is lower than the value recommended in P_SB_01_01 but higher than the value recommended in P_SB_01_02 which would be expected. This case is also applicable to an MOV circuit. However, the review for an MOV circuit requires a more detailed treatment. The target approach above generates a probability of 0.40. However, since an MOV circuit effectively has two targets conductors (open vs. close), the probability for any individual direction should be half this value – 0.20. The results also show that both the open and closed coils were never spuriously energized concurrently. In one instance, a spare conductor was concurrently energized while the C6 conductor was energized. For application to the MOV event tree, the information above shows a conditional probability of a hot short induced spurious actuation of 0.40. It shows a conditional probability of both the open and close directions being concurrently energized of 0.50/6 ~ .08, and a conditional probability for the IEN 92-18 failure mode of ½ = 0.50. These values were applied to the MOV event tree that was developed and discussed in a separate document. The results of that event tree are a spurious open/close probability of 0.20 and a failure to open/close probability of 0.80.
Distribution obtained	Several values are developed above: 43. Single target case – P = 0.40 (5^{th} / 95^{th} values of 0.23 / 0.61, respectively) 44. MOV case – P_{SO} / P_{SC} = 0.20 (5^{th} / 95^{th} values of 0.12 / 0.31, respectively) 45. MOV case – P_{FTO} / P_{FTC} = 0.80 (5^{th} / 95^{th} values of 0.70 / 0.89, respectively)

Expert's Additional Comments

For establishing the distribution for the point estimate of 0.40, a 'binomial' calculator is used with a test population of 5 to obtain the 5th and 95th given an idealized case. This generates a 5th and 95th percentile value of 0.08 and 0.80, respectively. However, this results in an upper bound estimate being greater than the equivalent value from P_SB_01_01. Therefore, the recommended upper bound of 0.61 is taken to be same value of that reported for P_SB_01_01. A similar situation occurs with the lower bound estimate in that it is lower than the corresponding value from P_SB_02_01. Therefore, the lower bound value of 0.23 is taken from P_SB_02_01. A simplistic distribution was generated for the MOV failure states by propagating the 5th and 95th percentile values using the MOV event tree. The other nodes in the event tree maintained the 8% value for both C5 and C6 being energized, and the 50% value for the IEN 92-18 upset state.

Case	**P_SB_03_03** **Single Break Generic** **Grounded AC** **Aggregate** **Cable includes a grounded metal foil shield wrap**

Statistical Analyses

Description of Analyses	This item is intended to address the aggregate of the inter and intra cable hot shorts. The proposed treatment for the inter-cable hot short is to exclude its consideration on the basis that shorting of a grounded power supply source through a grounded shield wrap to a conductor within that shield wrap is not credible. Therefore, the aggregate becomes identical to the intra-cable hot short case.
Distribution obtained	NA

Case	**P_SB_03_04** **Single Break Generic** **Ungrounded AC** **Intra-Cable** **Cable includes a grounded metal foil shield wrap**

Statistical Analyses

Description of Analyses	No actual test data is available for this particular circuit configuration. As such, a specific data based analysis is not possible. Instead, a qualitative approach is used that relies on statistical analyses for other circuit configurations. A comparison of the results for cases 1_1, 2_1, and 3_1 are used in a ratio with values from cases 1_4 and 2_4 to infer recommended values for case 3_4.

	$\frac{0.40-0.37}{0.53-0.37}=\frac{x-0.70}{0.70-0.75} \qquad x=0.71$ This result is approximately equal to the results for case 2_4. Therefore, the distribution for case 2_4 will be used. For the MOV case, the recommended value from case 2_1 is essentially the same as from case 3_1. Therefore, the equivalent values from case 2_4 will also be used.
Distribution obtained	The values below for the MOV cases are identical to that recommended for case 2_4. 46. Single target case – P = 0.71 (5^{th} / 95^{th} values of 0.39 / 0.91, respectively) 47. MOV case – P_{SO} = 0.38 (5^{th} / 95^{th} values of 0.21 / 0.49, respectively) 48. MOV case – P_{SC} = 0.35 (5^{th} / 95^{th} values of 0.20 / 0.46, respectively) 49. MOV case – P_{FTO} = 0.65 (5^{th} / 95^{th} values of 0.55 / 0.81, respectively) 50. MOV case – P_{FTC} = 0.68 (5^{th} / 95^{th} values of 0.58 / 0.82, respectively)

Case	**P_SB_03_06** **Single Break Generic** **Ungrounded AC** **Aggregate** **Cable includes a grounded metal foil shield wrap**

Statistical Analyses

Description of Analyses	This item is intended to address the aggregate of the inter and intra cable hot shorts. The proposed treatment for the inter-cable hot short is to exclude its consideration on the basis that shorting through a grounded shield wrap to a conductor within that shield wrap is not credible. Therefore, the aggregate becomes identical to the intra-cable hot short case.
Distribution obtained	NA

Case	**P_SB_03_07** **Single Break Generic** **Ungrounded DC** **Intra-Cable** **Cable includes a grounded metal foil shield wrap**

Statistical Analyses

Description of Analyses	The treatment described for this case using the tests data for an ungrounded DC system is judged to apply for ungrounded AC systems (not CPT powered). The test results summary shows a ratio of 3 occurrences out of 7. In other test groups, the population of samples was large enough to consider parsing out the individual test results for the various types of devices. However, in this case, with only 7 tests, this approach is not justified. A simple ratio yields a value of 0.43. Because there is insufficient data to evaluate this configuration to the same level of detail as cases 1_7 and 2_7, a simple ratio using the results of case 3_1 will be used for the distribution. The associated ratio terms are: 0.43/0.40 ~ 1.075 0.22/0.20 ~ 1.1 0.78/0.80 ~ 0.975
Distribution obtained	Several values are developed above: 51. Single target case – P = 0.43 (5^{th} / 95^{th} values of 0.25 / 0.66, respectively) 52. MOV case – P_{SO} / P_{SC} = 0.22 (5^{th} / 95^{th} values of 0.13 / 0.34, respectively) 53. MOV case – P_{FTO} / P_{FTC} = 0.78 (5^{th} / 95^{th} values of 0.68 / 0.87, respectively)

Case	**P_SB_03_09** **Single Break Generic** **Ungrounded DC** **Multiple Shorts Ground** **Cable includes a grounded metal foil shield wrap**

Statistical Analyses

Description of Analyses	The test results summary shows a ratio of 2 occurrences out of 7. In other test groups, the population of samples was large enough to consider parsing out the individual test results for the various types of devices. However, in this case, with only 7 tests, this approach is not justified. A simple ratio yields a value of 0.29. The resulting value is notably higher than that of cases 1_9 or 2_9. The presence of a grounded shield would tend to support a higher relatively likelihood of a ground plane interaction, but it is not clear that such a large increase over the values from cases 1_9 and 2_9 is reasonable.

	Given the minimal test data and the inherent difficulty in testing for this failure mode, a qualitative judgment based recommendation to use half of the value from case 3_7 is proposed.
Distribution obtained	Several values are developed above: 54. Single target case – P = 0.22 (5^{th} / 95^{th} values of 0.13 / 0.33, respectively) 55. MOV case – P_{SO} / P_{SC} = 0.11 (5^{th} / 95^{th} values of 0.07 / 0.17, respectively) 56. MOV case – P_{FTO} / P_{FTC} = 0.89 (5^{th} / 95^{th} values of 0.78 / 0.99, respectively)

Case

P_SB_03_10
Single Break Generic
Ungrounded DC
Aggregate
Cable includes a grounded metal foil shield wrap

Statistical Analyses

Description of Analyses	This item involves the aggregation of the results from P_SB_03_07 and P_SB_03_09. For non-MOV circuits: From P_SB_03_07: 57. Single target case – P = 0.43 (5^{th} / 95^{th} values of 0.25 / 0.66, respectively) From P_SB_03_09: 1. Single target case – P = 0.22 (5^{th} / 95^{th} values of 0.13 / 0.33, respectively) Because the results from case 3_9 are a significant fraction of the results from case 3_7, the two must be combined. 0.43 + (1-0.43) x 0.22 = 0.56 The resulting value of 0.56 was then applied to the MOV event tree that was used for Case 3_1 yielding 0.29 and 0.28 for spurious opening and closing, respectively. The active failure results are 0.73 and 0.72 for failure to close and failure to open, respectively.
Distribution obtained	1. Single target case – P = 0.56 (5^{th} / 95^{th} values of 0.17 / 0.86, respectively) 2. MOV case – P_{SO} = 0.29 (5^{th} / 95^{th} values of 0.09 / 0.44, respectively) 3. MOV case – P_{SC} = 0.28 (5^{th} / 95^{th} values of 0.09 / 0.43, respectively) 4. MOV case – P_{FTO} = 0.72 (5^{th} / 95^{th} values of 0.78 / 0.57, respectively)

5. MOV case – P_{FTC} = 0.73 (5^{th} / 95^{th} values of 0.78 / 0.58, respectively)

Expert's Additional Comments

For establishing the distribution, the data from Case 3_1 was used as a starting point. That data was based on a test population of 5. A a 'binomial' calculator is used with an event count of 3 and a test population of 6 to obtain the 5^{th} percentile value of 0.15. it is noted that the 3/6 ratio is about 12% lower than the 0.56 value that is being recommended. Therefore, the 5^{th} percentile value is increase to 0.17. An event count of 3 with a test population of 5 was used to obtain the 95^{th} percentile value of 0.92. It is noted that the 3/5 ratio generates a probability of 0.60 which is about 7% higher than the 0.56 value that is being recommended. Therefore, the 95^{th} percentile value is decreased to 0.86.

A simplistic distribution was generated for the MOV failure states by propagating the 5^{th} and 95^{th} percentile values using the MOV event tree. The other nodes in the event tree maintained.

Case	**P_SB_04_01** **Single Break Generic** **Grounded AC** **Intra-Cable** **Cable includes an un-insulated grounded drain wire**

Statistical Analyses

Description of Analyses	There is essentially no test data for this case. The single test example was considered together with a qualitative assessment as to the behavior of this circuit relative to the other cases that were studied. In general, it would be expected that the behavior of this circuit would fall between that of Case 1_1 and 3_1, but closer to 1_1. Given the relatively small difference between these results, it is recommended that until such time more information is available, the results from Case 1_1 should be used.
Distribution obtained	See results for Case 1-1.

Case	**P_SB_04_02** **Single Break Generic** **Grounded AC** **Inter-Cable** **Cable includes an un-insulated grounded drain wire**

Statistical Analyses

Description of Analyses	There is no test data for this case. In general, it would be expected that the behavior of this circuit would fall between that of Case 1_2 and 3_2, but closer to 1_2. The results from Case 1_2 are relatively small values and no result is provided for Case 3_1 as it was judged not credible. Given the relatively small values already provided for Case 1_2, it is recommended that until such time more information is available, the results from Case 1_2 should be used.
Distribution obtained	See results for Case 1-2.

Case	**P_SB_04_03** **Single Break Generic** **Grounded AC** **Aggregate** **Cable includes an un-insulated grounded drain wire**

Statistical Analyses

Description of Analyses	This item is intended to address the aggregate of the inter and intra cable hot shorts. The proposed treatment for the inter-cable hot short results in a recommended value that is two orders of magnitude lower than the values recommended for intra-cable shorts. As such, the aggregate becomes identical to the intra-cable hot short case for multi-conductor target cables. For single conductor target cables, the inter-cable values would apply.
Distribution obtained	NA

Case	**P_SB_05_01** **Single Break Generic** **Grounded AC** **Intra-Cable** **Armored 7/C Cable**

Statistical Analyses

Description of Analyses	The test data for this case consists of only MOV circuits. The single occurrence of a hot short included concurrent shorting of the C5 and C6 conductors together with 'spare' conductor C8. In all other instances, no spurious or hot shorting was reported for any of the conductors. It was noted that all of the tests involved an exposure in the hot gas layer only. A comparison with the other tests found a higher relatively likelihood of occurrence when the target was in the plume or flame. This creates a complicating consideration. The expectation for this test case is similar to that for Case 3_1 – that the resulting probability values would be lower than Case 1_1. It is unclear why the armored cable results should be reasonably expected to be substantially lower than the results for Case 3_1 unless nuances associated with the armoring, thermal conduction, and contact (pressure) with individual conductors results in a higher conditional likelihood of rapid internal failure of insulation. In the absence of any additional information, the test data will be used to generate results. The ratio of 1/7 yields a probability of 0.14. The MOV treatment is developed using the MOV Event Tree – but with a conditional probability of concurrent shorting of C5 and C6 taken as 0.75 instead of 1.0 – essentially, it is assumed that there is a 50% probability that the 'next' test occurrence of an MOV spurious actuation will also include concurrent shorting of C5 and C6. An identical approach is used for the IEN 92-18 failure mode. The MOV event tree approach yields values of 0.08 and 0.07 for spurious open and spurious close, respectively. The failure to open and failure to close values are 0.93 and 0.94, respectively.
Distribution obtained	Several values are developed above: 58. Single target case – P = 0.14 (5^{th} / 95^{th} values of 0.007 / 0.52, respectively) 59. MOV case – P_{SO} = 0.08 (5^{th} / 95^{th} values of 0.004 / 0.28, respectively) 60. MOV case – P_{SC} = 0.07 (5^{th} / 95^{th} values of 0.004 / 0.26, respectively) 61. MOV case – P_{FTO} = 0.73 (5^{th} / 95^{th} values of 0.74 / 0.99, respectively) 62. MOV case – P_{FTC} = 0.74 (5^{th} / 95^{th} values of 0.76 / 0.99, respectively)

Expert's Additional Comments

For establishing the distribution for the point estimate of 0.14, a 'binomial' calculator is used with the test data. This generates 5^{th} and 95^{th} percentile values of 0.007 and 0.52, respectively given an idealized case.

A simplistic distribution was generated for the MOV failure states by propagating the 5th and 95th percentile values using the MOV event tree. The other nodes in the event tree maintained the 75% value for both C5 and C6 being energized, and the 75% value for the IEN 92-18 upset state.

Case	**P_SB_05_03** **Single Break Generic** **Grounded AC** **Aggregate** **Armored 7/C Cable**

Statistical Analyses

Description of Analyses	This item is intended to address the aggregate of the inter and intra cable hot shorts. The proposed treatment for the inter-cable hot short is to exclude its consideration on the basis that shorting of a grounded power supply source through a grounded armored exterior is not credible. Therefore, the aggregate becomes identical to the intra-cable hot short case.
Distribution obtained	NA

Case	**P_SB_05_04** **Single Break Generic** **Ungrounded AC** **Intra-Cable** **Armored 7/C Cable**

Statistical Analyses

Description of Analyses	There is no test data available for review for this case. Given this situation, the recommended treatment for this case will be based on a qualitative assessment given the results of other cases. It is noted that the results for Cases 1_1, 2_1 and 3_1 are all relatively similar and there is a substantial decrease in the value for Case 5_1. The results for Cases 1_4, 2_4, and 3_4 are similar in that they are relatively close in value. Therefore, the value for Case 5_4 should also reflect a substantial decrease. The decrease for the grounded AC case is about 40%. If this same decrease were to occur for the ungrounded AC case, then the resultant values would be between 0.75 x 0.40 = 0.30 and 0.70 x 0.40 = 0.28. For the MOV case, the value would be between 0.42 x 0.40 = 0.17 and 0.38 x 0.40 = 0.15. A simple average of these values are taken and recommended for this case.

Distribution obtained	Several values are developed above: 63. Single target case – P = 0.29 (5^{th} / 95^{th} values of 0.16 / 0.37, respectively) 64. MOV case – P_{SO} / P_{SC} = 0.16 (5^{th} / 95^{th} values of 0.09 / 0.20, respectively) 65. MOV case – P_{FTO} / P_{FTC} – not developed

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Case **P_SB_05_06**
Single Break Generic
Ungrounded AC
Aggregate
Armored 7/C Cable

Statistical Analyses

Description of Analyses	This item is intended to address the aggregate of the inter and intra cable hot shorts. The proposed treatment for the inter-cable hot short is to exclude its consideration on the basis that shorting of a grounded power supply source through a grounded armored exterior is not credible. Therefore, the aggregate becomes identical to the intra-cable hot short case.
Distribution obtained	NA

Case	**P_SB_05_07** **Single Break Generic** **Ungrounded DC** **Intra-Cable** **Armored 7/C Cable**

Statistical Analyses

Description of Analyses

The treatment described for this case using the tests data for an ungrounded DC system is judged to apply for ungrounded AC systems (not CPT powered).

The test results summary shows a ratio of 9 occurrences out of 12. The resulting ratio is 9/12 = 0.75. However, the testing reflects the aggregation of multiple types of circuits – MOV, SOV, large coil, and circuit breaker. However, the small test population does not support extracting any meaningful results at this level of detail.

Breaker – close coil	2/2 = 1.0
MOV	2/3 ~ .67
Coil – small	1/1 = 1.0
Breaker – trip coil	1/2 = .50
Coil – large	1/1 = 1.0
SOV	2/3 ~ .67

Therefore, the 0.75 value is proposed as the spurious actuation probability for non-MOV circuits.

For the MOV circuits, both of the occurrences involved multiple concurrent hot shorts on conductor 3 and 4 (YC1 and YO1). In both of these two occurrences other 'spare' conductors were concurrently actuated. Because of the small test population, instead of assigning a conditional probability of 1.0 for these two cases, a value of 2.5/3 is used instead – effectively assuming a 50% likelihood had another test been conducted. This yields a value of 0.83 for the conditional probability that both the open and close coils are concurrently spuriously energized. This same value is also used for the conditional probability of the IEN 92-18 failure.

When this data is applied to the MOV event tree consistent with that used for case P_SB_01_01, the results show a spurious close probability of 0.38 and a spurious open probability of 0.40.

The event tree treatment was also applied for the valve active functions of open and close. The result of this treatment yielded a failure to close probability of 0.65 and a failure to open probability of 0.63.

Distribution obtained	Several values are developed above: 66. Single target case – P = 0.75 (5^{th} / 95^{th} values of 0.47 / 0.89, respectively) 67. MOV case – P_{SO} = 0.40 (5^{th} / 95^{th} values of 0.25 / 0.48, respectively) 68. MOV case – P_{SC} = 0.38 (5^{th} / 95^{th} values of 0.24 / 0.45, respectively) 69. MOV case – P_{FTO} = 0.63 (5^{th} / 95^{th} values of 0.56 / 0.77, respectively) 70. MOV case – P_{FTC} = 0.65 (5^{th} / 95^{th} values of 0.59 / 0.78, respectively)

Expert's Additional Comments

For establishing the distribution for the point estimate of 0.75, a 'binomial' calculator is used with a test population of 12 to obtain the 5^{th} and 95^{th} given an idealized case. This generates a 5^{th} and 95^{th} percentile value of 0.47 and 0.93, respectively. The test population was then doubled to recalculate a 95^{th} percentile value of 0.89.

A simplistic distribution was generated for the MOV failure states by propagating the 5^{th} and 95^{th} percentile values above using the MOV event tree.

Case	**P_SB_05_09** **Single Break Generic** **Ungrounded DC** **Multiple Shorts Ground** **Armored 7/C Cable**

Statistical Analyses

Description of Analyses	The test results summary shows a ratio of 2 occurrences out of 12. In other test groups, the population of samples was large enough to consider parsing out the individual test results for the various types of devices. However, in this case, with only 12 tests, this approach is not justified. A simple ratio yields a value of 0.17. The resulting value is notably higher than that of cases 1_9 or 2_9, but is comparable with the result for case 3_9. It is noted that the calculated 0.17 value is lower than the raw calculated value of 0.29 that was obtained for Case 3_9. The lower relative value developed for this case is consistent with the overall lower values being generated for all of the armored cable cases. The recommended value to be used for this case is 0.17. The recommended value for the MOV cases and the distribution for all cases is simply derived by ratio to the values recommended for case 3_9.
Distribution obtained	Several values are developed above: 71. Single target case – P = 0.17 (5^{th} / 95^{th} values of 0.10 / 0.26, respectively) 72. MOV case – P_{SO} / P_{SC} = 0.09 (5^{th} / 95^{th} values of 0.05 / 0.13, respectively) 73. MOV case – P_{FTO} / P_{FTC} – not developed

Case	**P_SB_05_10** **Single Break Generic** **Ungrounded DC** **Aggregate** **Armored 7/C Cable**

Statistical Analyses

Description of Analyses	This item involves the aggregation of the results from P_SB_05_07 and P_SB_05_09. For non-MOV circuits: From P_SB_05_07: 74. Single target case – P = 0.75 (5^{th} / 95^{th} values of 0.47 / 0.89, respectively) From P_SB_05_09: 2. Single target case – P = 0.17 (5^{th} / 95^{th} values of 0.10 / 0.26, respectively)

	0.75 + (1-0.75) x 0.17 = 0.79 The resulting value of 0.79 was then applied to the MOV event tree that was used for Case 5_7 yielding 0.42 and 0.40 for spurious opening and closing, respectively. The active failure results are 0.63 and 0.61 for failure to close and failure to open, respectively. The distribution values are simply scaled for the single target case. The distribution for the MOV was determined by propagating the single target 5^{th} and 95^{th} percentile values through the MOV event tree.
Distribution obtained	6. Single target case – P = 0.79 (5^{th} / 95^{th} values of 0.50 / 0.94, respectively) 7. MOV case – P_{SO} = 0.42 (5^{th} / 95^{th} values of 0.27 / 0.50, respectively) 8. MOV case – P_{SC} = 0.40 (5^{th} / 95^{th} values of 0.25 / 0.47, respectively) 9. MOV case – P_{FTO} = 0.61 (5^{th} / 95^{th} values of 0.53 / 0.75, respectively) 10. MOV case – P_{FTC} = 0.63 (5^{th} / 95^{th} values of 0.56 / 0.77, respectively)