FAQ Number 08-0051 **FAQ Revision** Draft

FAQ Title **Hot Short Duration**

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Purpose of FAQ:

The existing industry guidance for the treatment of hot short induced spurious operations does not address the duration of the spurious signal. The duration of this signal could have a measurable impact on the risk treatment of the fire induced failure for those devices/components that fail to their desired state upon loss of all motive power (air/electric). The duration may only be relevant if the component returns to its original state upon termination of the short. If the component remains in its changed/failed state after termination, then the duration may not affect the risk treatment of the ~~fire induced~~fire-induced failure.

Is this Interpretation of guidance? [Yes] / No

Proposed new guidance not in NEI 04-02? [Yes] / No

Details:

NEI 04-02 guidance needing interpretation (include section, paragraph, and line numbers as applicable):

N/A

Circumstances requiring guidance interpretation or new guidance:

Lessons learned from the pilot review of the FPRA Standard indicate there is no industry-accepted method for including spurious operation duration in an FPRA. As shown by both the NEI/EPRI Cable testing and the CAROLFIRE testing, eventual grounding of fire-damaged cables can limit the expected duration for most spurious operations. When a component's credited function is automatically restored once the hot short induced spurious operation is cleared, credit for the finite duration of the hot short can be included in the FPRA estimates. Guidance is needed to establish what credit can be taken in the FPRA for spurious operations that are self-terminating due to limited hot short duration, and when this credit can be applied.

Detail contentious points if licensee and NRC have not reached consensus on the facts and circumstances:

None.

Potentially relevant existing FAQ numbers:

Response Section:

Proposed resolution of FAQ and the basis for the proposal:

NUREG/CR-6850 [1] does not provide guidance on when and how to take credit for the expected limited duration of hot short induced spurious operations. Open issues regarding FPRA treatment of hot shorts are discussed in Section 3.3.2 of Volume 1 of NUREG/CR-6850, including hot short duration. EPRI report TR-1003326 [2] documents the EPRI/NEI Fire Testing and observes that fire induced cable hot shorts are generally a transient failure state, whose duration can be statistically quantified (See 12.2.6 of TR-1003326). However, neither the EPRI report nor NUREG/CR-6850 provides any guidance on when and how to apply the limited hot short duration likelihood. Additionally, the EPRI report and NUREG/CR-6850 were issued prior to the completion of the NRC's CAROLFIRE testing [3]. The CAROLFIRE test results further demonstrate that hot short duration can be statistically quantified. Finally, the NRC's Fire Significance Duration (SDP) guidance [4] suggests that spurious operation durations of greater than 20 minutes are highly unlikely and can be ignored for SDP issues.

A recent technical paper [5] provides a statistical examination of cable hot short duration, and includes both the EPRI/NEI cable results and CAROLFIRE results. The combination of these results into a single analysis provides the most complete review to date of hot short and spurious operation duration. The hot short duration probability density function (PDF) developed in this paper is recommended for application to FPRAs, when appropriate. Two areas of additional guidance are needed to supplement these results, including a) When to apply the resulting PDF, and b) what PDF should be applied for DC circuits (which were not a part of the two testing programs). These areas are discussed below.

Application of limited hot short and spurious operation duration:

The follow discussion is provided on the various aspects of applying the PDF developed for hot short duration:

A. Testing showed that cable hot shorts are a transient condition whose duration is limited by the eventual grounding of the damaged cable. For hot short induced spurious operations, termination of the hot short can be correlated to termination of the hot short signal. In some cases, however, a spurious operation can be caused by a short to ground, which is generally a more likely initial failure mode than a hot short. For example, a spurious High Pressure Injection (HPI) Pump start might occur when low pressurizer pressure is indicated. If the pressurizer pressure signal indicates low pressure when the transmitter cable is grounded, the HPI pump start can occur if multiple transmitter cables become grounded due to fire damage. The grounding of the cables will generally not clear, since this is the most electrically stable state for the failed circuit. The resulting guidance is that the spurious operation duration PDF should not be applied to spurious operations caused by grounding of one or more cables (i.e., not caused by hot shorts).

B. During the EPRI/NEI and CAROLFIRE testing, the eventual cable ground resulted in a blown fuse that stopped the hot short (i.e., the circuit transitioned from a transient hot short condition to its electrically stable state for the damaged condition). In a typical valve circuit, a ground across the indicating lights is what usually caused the fuse to blow (or resulted in a circuit breaker trip). A review of numerous valve control circuits resulted in the identification of some cables that if eventually grounded, might not result in a blown fuse or hot short cessation. In these example circuits, cables routed to an Auxiliary Shutdown Panel Transfer Switch, where the transfer switch did not indicate the valve position, would not cause the fuse to blow if an eventual ground occurs. These particular circuits would, when grounded, result in the valve transferring position from open to closed and back to open, repeatedly. It is likely the valve motor operator would eventually burn out (depending on circuit design, it is also possible that the valve overloads would heat up and open), given this scenario. However, the valve position when the valve motor failed would not be predictable. The resulting guidance is that the circuit involved in the hot short should be reviewed to ensure the hot short would clear once the cable is grounded, including identification of the device (e.g., fuse or circuit breaker) that would clear the hot short.

C. Hot shorts from auxiliary or “off-scheme” circuits that are powered from a separate power supply should be reviewed for the impact of grounding the circuit. The spurious operation may not stop when the ground occurs and the hot short on the auxiliary circuit terminates. The functional impact depends on the circuit design, whether a “seal-in” contact is in the circuit, and the component failure mode once the auxiliary circuit has grounded. The resulting guidance is that credit for recovery of a component after a hot short (of a certain duration) clears or grounds in which the circuit involved is an auxiliary or "off-scheme" circuit needs to include circuit analysis demonstrating the effect of a short to ground on the auxiliary circuit.

D. Motor Operated Valve (MOV) and certain pump control circuits generally cannot be electrically recovered once their control circuit goes to ground. Almost all MOVs fail-as-is, and cannot be operated once the cable failure mode transitions from a hot short to ground. Credit for manual operation of the MOV locally (for restoration of the MOV) should consider that the hot short might not have cleared. Additionally, credit for local MOV operation should consider the circuit design to ensure that prolonged operation of the MOV motor (i.e., torque and limit switches do not deactivate the motor) did not damage the valve stem or actuator (local operation may no longer be possible if significant stem or actuator damage occurs). Larger pumps that use medium voltage or low voltage power circuit breakers as their "on/off" control device will generally fail as-is once a hot short on the breaker's control circuit eventually clears and power to the control circuit is lost due to a ground fault causing the control circuit fuse to blow. Review of pump circuits needs to be performed to determine the effect of subsequent grounding of the control circuit after a hot short has resulted in pump spurious operation.

E. Most of the AC circuit testing involved testing of grounded AC circuits, which is the most prevalent configuration for MOV circuits. However, some MOV control circuits use an ungrounded design. One set of testing was reviewed involving ungrounded AC circuits in armored cable. The hot short duration results from this testing are bounded by the results in reference 5, with an average hot short duration of less than 30 seconds. Based on review of these test results, it is concluded that the results of reference 5 are applicable to ungrounded AC circuits.

Hot Short Duration for DC circuits

At present, there is no applicable test data for hot short duration of DC circuits. Two armored cable tests included DC circuits, but the circuit design for these tests did not appear to represent a typical configuration installed in a nuclear power plant. Although not directly applicable, these tests were reviewed for this FAQ in order to derive any useful trends or factors affecting hot short duration. Unfortunately, the results did not yield readily useful information.

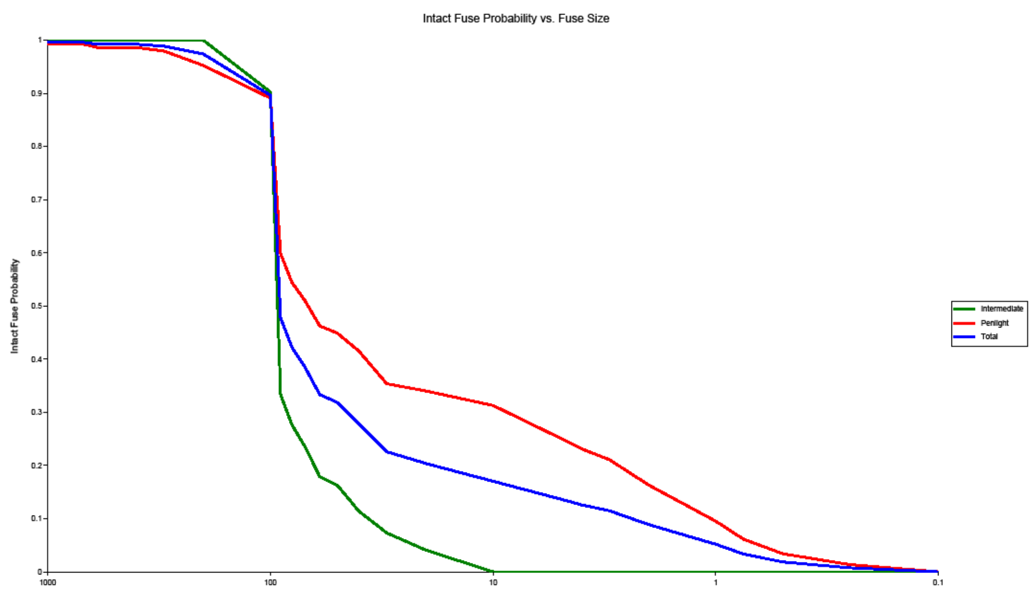
Discussions with circuit experts indicate a number of factors could likely affect the hot short probability, as well as the hot short duration, when comparing DC circuits with AC circuits. Even within DC circuit designs, there are a number of factors that can plausibly affect hot short probabilities and duration. The main factors are 1) whether the circuit is grounded and 2) the component type. Each of these main factors is discussed below.

Grounded versus ungrounded DC Circuits: A grounded DC circuit is expected to react similarly to a grounded AC circuit with respect to hot short duration. With a grounded circuit, shorting of a non-grounded conductor will result in a blown fuse (or circuit breaker trip) in a similar manner. With an ungrounded DC circuit, grounding of either the positive or negative conductors (but not both) simply changes the reference potential for the circuit (discussion is not applicable to AC circuits), but will likely not cause the fuse to blow or circuit breaker to trip. In this case, both a positive and negative conductor needs to be shorted to ground for short circuit to develop and terminate the hot short. A reasonable deduction for this case is that the hot short would persist for a slightly longer duration for ungrounded DC circuits in comparison to grounded DC circuits.

Component Type: DC control circuits are used for a number of component types. For Fire PRAs, we are generally concerned with DC controls for pumps and for valves, including air operated, solenoid, and power operated valves. DC controls for pumps can range in complexity for both starting and stopping the pump. The complexity would affect both the hot short probability and duration, as discussed in NUREG/CR-6850, Appendices J and K. DC controls for valves are generally simpler than controls for MOVs, due primarily to the circuit only requiring power for a single valve solenoid. If, for example, the valve is a “failed-closed” valve, then the control signal would need to actuate the open solenoid, with power being removed when the valve is closed. It is expected that the circuit complexity will have less of an effect on the hot short duration than other factors, but this effect is not known at this point. Finally, with DC controls for valves, the overcurrent protection device (fuse or circuit breaker) may be sized larger than it would be for similar AC circuits. With a larger fuse/breaker, the short to ground would need to be more fully developed (better contact resulting in lower fault impedance), thereby resulting in a higher fault current to ground prior to the hot short being terminated. This fuse/breaker sizing is not applicable to all DC circuits, but is common for DC valve controls. Consequently, fire damage is expected to cause the eventual grounding of the circuit; however, it is expected that it will take slightly longer than for an equivalent AC circuit.

Minimum Insulation Resistance (IR) Results from CAROLFIRE [3]:
CAROLFIRE test results included IR measurements in most of the test performed. The IR results were reviewed for the two general tests performed, the Penlight tests and the Intermediate-Scale Tests. The Minimum IR for an equivalent DC circuit was estimated for each result by adding the IR for both conductors in each cable. This IR is used to estimate the minimum IR that would be expected for an ungrounded DC circuit, given fire damage and spurious operation. The minimum IR for damaged cables varied from less than 2 ohms total to over 100 ohms total. From these ranges, the probability that a fuse of various sizes would blow can be predicted. For example, if the minimum IR was estimated as 12.5 ohms, then a 10-amp fuse would be the minimum fuse size to blow for an ungrounded 125 vdc circuit.

The surprising result from the CAROLFIRE review was the difference between the two test types. The PENLIGHT tests simulated cable damage for a radiant heat source, while the Intermediate-scale tests simulated cable damage for direct flame damage. Surprisingly, the PENLIGHT tests showed higher minimum IR results than the Intermediate-scale tests. This is assumed to be a result of the cable and conductor insulation not being fully burnt away during the Penlight tests. The result would indicate that a cable damaged via radiant or Hot Gas Layer (HGL) Damage where cable ignition may not occur is likely to have a higher residual IR after damage, and would therefore be more likely to not clear the spurious operation by blowing the circuit fuse. For example, all of the Intermediate Scale IR results predict a fuse of less than 10 amps would have blown for all of the tests, while the Penlight tests predict almost a third of the circuits would not blow a 10 amp fuse. This predicted impact results in a separate recommendation for assigning the probability for spurious operation duration. If the impact predicted by the Penlight tests were extended, it would seem to indicate that a spurious operation for an actual component circuit would also be less likely for cables damaged via radiant or HGL. However, this extension of the analysis is not a part of this FAQ. The resulting data analysis for the CAROLFIRE tests is shown on the graph below.



Based on the expected longer hot short duration due to ungrounded circuit design and possible larger circuit protective device, the overall hot short duration for ungrounded DC circuits is conservatively postulated to be slightly longer than that of a similar AC circuit. As a conservative estimate for this additional time, the following approach is used to establish a PDF for ungrounded DC circuits:

a) The PDF shape for ungrounded DC circuits is assumed to be similar to that of AC circuits.
b) The mean and median for ungrounded DC circuits is set to equal twice the AC circuit mean and median, respectively. This results in a change to the mean and median from 1.7 minutes and 0.77 minutes, respectively, to 3.4 minutes and 1.5 minutes respectively. The resulting formula is provided below.
c) The minimum HS duration recovery factor should account for the fuse size and the type of fire damage to the cable as shown in the figure above.

Given the factors discussed above, the fuse/breaker sizing complication is still applicable for grounded circuits. Therefore, the same PDF is conservatively recommended for both grounded and ungrounded circuits. The resulting PDF for DC circuits is provided below.

If appropriate, provide proposed rewording of guidance for inclusion in the next Revision:

Based on the above assessment, the following method is recommended when determining hot short durations:

1. The PDF for hot short duration for AC circuits (both grounded and ungrounded) is as follows, based on Reference 5;

$$f(t) = \{\exp(-[\ln t + 0.266]^2/2[1.26]^2)\}/(1.26t)(2\pi)^{0.5}$$

t = time in minutes

$f(t \geq 15 \text{ minutes}) = 0.01$ (minimum recommended value)

Use of this PDF results in the following hot short duration probabilities:

Table FAQ-051-1
Probability HS Duration, AC Circuits

Time (minutes)	AC Circuits Probability Hot Short Lasts ≥ Time
1	0.42
2	0.22
3	0.14
4	0.095
5	0.068
6	0.051
7	0.040

8	0.031
9	0.025
10	0.021
11	0.017
12	0.014
13	0.012
14	0.011
15	0.010
>15	0.01

2. The spurious operation duration PDF should not be applied to cases in which the spurious operation is caused by grounding of one or more circuit conductors (i.e., the spurious operation is not caused by hot shorts).
3. The circuit involved in the hot short should be reviewed to ensure the hot short will terminate once the fire damaged cable is grounded, including identification of the protective device (e.g., fuse or circuit breaker) that would open to deenergize the circuit, thereby terminating the hot short.
4. Credit for hot short duration recovery of a component where the circuit involved is an auxiliary or “off-scheme” circuit needs to include a functional circuit analysis demonstrating the effect of a short to ground on the auxiliary circuit.
5. Motor Operated Valves (MOVs) generally cannot be electrically recovered once their control circuit goes to ground. Almost all MOVs fail-as-is, and cannot be electrically operated once the hot short transitions to a short to ground. Credit for manual operation of the MOV locally (for restoration of the MOV) should consider that the hot short might not have cleared. Additionally, credit for local MOV operation should consider the circuit design to ensure that prolonged operation of the MOV motor (due to torque and/or limit switches being bypassed) did not damage the valve stem or actuator (local operation may no longer be possible if significant stem or actuator damage occurs).
6. For pumps that use power circuit breakers as their control device, a review of the pump control circuit needs to be performed to determine the effect of grounding the control circuit subsequent to a hot short that caused spurious operation of the pump.
7. The hot short duration PDF for grounded and ungrounded DC circuits is recommended as follows:

$$f(t) = \{\exp(-[\ln t + 0.4279]^2/2[1.26]^2)\}/(1.26t)(2\pi)^{0.5}$$

t = time in minutes

$f(t \geq 15 \text{ minutes}) = 0.03$ (minimum recommended value)

Use of this PDF results in the following hot short Duration probabilities

Table FAQ-051-2a Probability HS Duration, DC Circuits (Use in conjunction with Table 2b)	
Time (minutes)	**DC Circuits Probability Hot Short Lasts ≥ Time***
1	0.63
2	0.42
3	0.30
4	0.22
5	0.17
6	0.14
7	0.11
8	0.095
9	0.080
10	0.068
11	0.059
12	0.051
13	0.045
14	0.040
15	0.035
>15	0.03

* Minimum Probability should not go below the recommended value, based on fuse size and type of fire damage.

8. For DC Circuits, the Minimum probability should be set to the **maximum** of the above-recommended value and the value from the following table[rhg1]:

Table FAQ-051-2b Minimum Probability HS Duration Given Fuse Size and Fire Damage Type, DC Circuits (Use in conjunction with Table 2a)		
Fuse Size (Amps)	Minimum Probability, HS Duration, Direct Fire Damage	Minimum Probability, HS Duration, HGL or Radiant Fire Damage
30	0.073	0.35
29	0.073	0.35
28	0.073	0.35
27	0.057	0.35
26	0.057	0.35
25	0.057	0.35
24	0.057	0.35

Table FAQ-051-2b Minimum Probability HS Duration Given Fuse Size and Fire Damage Type, DC Circuits (Use in conjunction with Table 2a)		
Fuse Size (Amps)	Minimum Probability, HS Duration, Direct Fire Damage	Minimum Probability, HS Duration, HGL or Radiant Fire Damage
23	0.057	0.34
22	0.049	0.34
21	0.041	0.34
20	0.041	0.34
19	0.041	0.34
18	0.041	0.33
17	0.033	0.33
16	0.0240.03	0.33
15	0.03*0.016	0.33
14	0.03*0.016	0.32
13	0.03*0.008	0.32
12	0.03*0.008	0.32
11	0.03*0.000	0.32
10	0.03*0.000	0.31
9	0.03*0.000	0.31
8	0.03*0.000	0.30
7	0.03*0.000	0.30
6	0.03*0.000	0.27
5	0.03*0.000	0.25
4	0.03*0.000	0.23
3	0.03*0.000	0.21
2	0.03*0.000	0.16
1	0.03*0.000	0.10

* Based on minimum from Table 2a above

References:

1) U.S. NRC/EPRI, *EPRI/NRC-RES Fire PRA Methodology for Nuclear Power Facilities*, NUREG/CR-6850, EPRI TR-1011989, September 2005
2) EPRI, *Characterization of Fire-Induced Circuit Faults: Results of Cable Fire Testing*, EPRI TR-1003326, December 2002.
3) S. NOWLEN, F. WYANT, *Cable Response to Live Fire* (*CAROLFIRE) Test Report Volume 1: General Test Descriptions and the Analysis of Circuit Response Data*, NUREG/CR-6931/V1, SAND2007-600, Sandia National Laboratories, Albuquerque, New Mexico, March 2007.
4) Fire SDP

5) Gallucci, Raymond HV, Ph.D, Probabilistic/Statistical Examination of Cable Hot Short Durations Due to Nuclear Plant Fires, to be published, ANS PSA-08, Knoxville, TN, September 2008.