PRELIMINARY SCREENING OF FIRE-INDUCED CIRCUIT FAILURES FOR RISK SIGNIFICANCE

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INTRODUCTION

The Nuclear Energy Institute (NEI) developed an approach for preliminary screening of very low risk-significant, fire-induced circuit spurious actuations [Ref. 1]. Actuations that screened based on (1) the fire frequency in the zone where the circuits are located; (2) the probability of spurious actuation; and (3) automatic or manual suppression, or an alternate means to achieve hot shutdown; could be screened as very low risk-significant without further review. The Nuclear Regulatory Commission (NRC) has adapted this approach to develop a "risk screening tool" for fire-induced, circuit spurious actuation inspection findings that arise from the Fire Protection Significance Determination Process (FPSDP) [Ref. 2]. These findings typically involve the multiple fire zones through which the circuits pass. The FPSDP focus on individual zones necessitates repeated application zone-by-zone. To streamline the process, it is advantageous to screen zones where the "circuit issue" is expected to be of very low risk-significance.

BACKGROUND

The NRC's motivation to develop this risk screening tool arose from two sources. At a public meeting in October 2003 on the proposed update of the FPSDP, both the NRC and NEI noted that a "pre-filter" would be desirable to facilitate the processing of "circuit findings" through the new FPSDP. This filter would screen the potentially large number of fire zones through which the circuit(s) passed such that only a few would remain for processing through the FPSDP to determine risk-significance.

Subsequently, the NRC staff at headquarters, faced with several pressing issues related to fire protection at nuclear power plants, sought to assess the relative risk-significance of Unresolved Issues (URIs) in these areas. One such area involved URIs for "associated circuits." A simple, but conservative, method was needed to gauge the risk-significance of these issues short of performing a full FPSDP or more involved risk analysis.

The "risk screening tool" presented here is the result of the NRC's effort to develop this method. Adapted from Ref. 1, it is relatively simple, based on measures readily available from the FPSDP, but conservative in that credits are limited to ensure the likelihood of "screening out" a circuit issue that could be of greater-than-very-low-risk-significance is minimized. Examples of this conservatism include use of generic fire frequencies based on fire zone or major components; treatment of potentially independent spurious actuations as dependent (i.e., no multiplication of more than two probabilities); crediting of manual suppression in a fire zone only if detection is present there; and choice of the most stringent screening criterion from Ref. 1. Note that none of the "additional considerations" among the screening factors below is permitted to introduce a factor <0.01 as a multiplier.

SCREENING FACTORS

To transform the NEI approach into a conservative screening tool appropriate for NRC use, the following modifications have been performed.

<u>Fire Frequency (F)</u>

Table 1.4.2 of the FPSDP (modified here as Table 5 for use in the subsequent example application) and Table 4-3 of EPRI-1003111 [Ref. 3] list the mean fire frequencies at power by plant location and ignition source. The frequencies are characteristic of a fire

occurring anywhere within the location. The mean fire frequencies by location range from a minimum of ~0.001/yr (Cable Spreading Room in Ref. 2; Battery Room in Ref. 3) to maximum of ~0.1/yr (Boiling Water Reactor Building in Ref. 2; Turbine Building in both Ref. 2 and Ref. 3). These values used in Ref. 2 and Ref. 3 eliminate fire events judged to be "non-challenging." Considering uncertainties in their probability distributions (somewhat reflected in the two-sided 90% upper and lower confidence bounds in Ref. 3), we select the following ranges for fire frequencies:

- HIGH, ≥0.03/yr but ≤1/yr
- MEDIUM, ≥0.003/yr but <0.03/yr
- LOW, <0.003/yr

Probability of Spurious Actuation (P)

Table 2.8.3 of the FPSDP (modified here as Table 6 for use in the subsequent example application) and Tables 7.1 and 7.2 of EPRI-1006961 [Ref. 4] provide point estimates for the probability of spurious actuation ranging from a minimum of "virtually impossible" (armored inter-cable interactions in Ref. 2; armored thermoset inter-cable interactions in Ref. 4) to a maximum approaching 1.0 ("no available information about cable type or current limiting devices" in Ref. 2; any intra-cable short in Ref. 4). Ref. 4 also provides ranges for these estimates. The lowest non-zero values are 0.01 for "in-conduit, inter-cable only" in Ref. 2 and 0.002 for the "high confidence range" on intra-cable, armored thermoset with fuses in Ref. 4.

NRC Regulatory Issue Summary 2004-03 states that "for cases involving the potential damage of more than one multiconductor cable, a maximum of two cables should be assumed to be damaged concurrently" [Ref. 5]. Therefore, no more than two multiple spurious actuations within separate cables are assumed to be independent when calculating the probability P, i.e., no more than two of the spurious actuation probabilities in Ref. 2 or Ref. 4 should be multiplied together. Consideration of this conservative assumption and the ranges cited in these reports suggests the following ranges for probability of spurious actuation:

- HIGH, ≥0.3 but ≤1
- MEDIUM, ≥0.03 but <0.3
- LOW, ≥0.003 but <0.03
- VERY LOW, <0.003

Multiplying F and P over their respective ranges yields the maxima shown in Table 1 for the pairings F • P.

Additional Considerations

The F • P pairings represent the frequency of a fire-induced spurious actuation of a component combination. Core damage will occur only if (1) the fire is localized and severe enough to induce spurious actuation; (2) the fire is not suppressed prior to inducing the spurious actuation; and (3) other non-fire related contingencies, including human actions and equipment operation, are unsuccessful. Thus, for core damage to occur, there must also be a "challenging" fire; failure to suppress the fire prior to the spurious actuation; and failure to avoid core damage via non-fire means, represented by the conditional core damage probability (CCDP). The number of potentially vulnerable locations (zones) addresses possible variation in the screening threshold frequency depending upon the number of zones which the equipment traverses where there is a potential for fire damage.

Challenging Fire (G)

Fires can vary in magnitude, ranging from small, essentially self-extinguishing, electrical relay fires to complete combustion of an entire compartment. To estimate how challenging a fire could be for screening purposes, we consider the largest fire source in the zone and combustible type. The FPSDP specifies categories (bins) for both fire type and size.[1] We base the factor (G), independent from the fire frequency, for a challenging fire on combustible type.

Table 2.3.1 of the FPSDP (modified here as Table 7 for use in the subsequent example application) assigns both 75th and 98th percentile fires for various combustibles to fire size bins ranging from heat release rates of 70 kW to 10 MW. Fires in the 70 kW-200 kW range are considered small; 200 kW-650 kW moderate; and ≥650 kW large. Typically, some train separation is built into plant designs in accordance with NRC Regulatory Guide 1.75 [Ref. 6]. Therefore, small fires are not likely to damage separated trains. Although

[1] Room size and other spatial factors also influence how challenging a fire can be. However, we do not consider these for screening purposes.

moderate fires are more damaging, some credit for train separation can still be expected.

Based on the above, for small or moderate size fires that are not expected to be challenging, such as small electrical fires, a factor of 0.01 is applied. For moderate severity fires, including larger electrical fires, a factor of 0.1 is applied. For large fires, including those from oil-filled transformers or very large fire sources, the factor is 1.

Fire Suppression (S)

Automatic and, to a limited extent, manual fire suppression (including detection by automatic or manual means) are creditable.[2]

Automatic Suppression

It is assumed that automatic is preferred and a more reliable suppressor than manual. Task 2.7.4 of the FPSDP cites reliabilities of 0.98 for wet-pipe sprinklers and 0.95 for dry-pipe or deluge systems, or gaseous suppression system.. Concurrent or subsequent manual suppression is likely to be limited, if not precluded, by the discharge of a gaseous suppression system, suggesting a non-suppression probability for gaseous systems of no lower than 1.00 - 0.95 = 0.05, which can be bounded by a value of 0.1. Concurrent or subsequent manual suppression should be possible given discharge of water-based fixed systems, so additional reduction in the non-suppression probabilities for these systems (nominally 1.00 - 0.95 = 0.05 for dry-pipe or deluge and 1.00 - 0.98 = 0.02 for wet-pipe) seems reasonable. Halving each yields non-suppression probabilities of 0.03 for dry-pipe or deluge and 0.01 for wet-pipe, which can be considered bounding.

Manual Suppression

As indicated by Table A8.1 of the FPSDP, the probabilities of manual non-suppression vary with the type of fire and the time between detection and damage. Maximum credit (factor of 0.01) is applied for fires that are not expected to be challenging, i.e., fires classified as "small electrical," "engines and heaters" or "solid and transient combustibles" in Table 2.3.1 of the FPSDP. If we assume a "rule of thumb" time differential between detection and damage of thermoset cables = 15 min (dropping to 10 min for thermoplastic, using time as a surrogate for the lower damage threshold), with detection creditable only if fire detection or constant occupancy is present, we find the following approximate probabilities of manual non-suppression from Table A8.1 of the FPSDP for the three fire types and two cable types as follows:

	Cable Type	
	Thermoset	Thermoplastic
Fire Type	($\Delta t = 15$)	($\Delta t = 10$)
Small Electrical	0.2	0.3
Engines/Heaters	0.2	0.3
Solids/Transients	0.1	0.3

where both the "small electrical" and "engines/heaters" fires are treated as "electrical fires" from Table A8.1. These values "suggest" probabilities of manual non-suppression of 0.1 for thermoset cables and 0.3 for thermoplastic cables for these three fire types (or a type deemed equivalent).[3]

Intermediate credit (factor of 0.1) is applied for fires that are expected to somewhat challenging, i.e., "large electrical fires" in Table 2.3.1 of the FPSDP. While Table A8.1 of the FPSDP does not distinguish between "small" and "large" for "electrical fires," it seems reasonable to use the probabilities of manual non-suppression for "electrical fires" once again as a surrogate, reducing the time differentials for thermoset and thermoplastic cable damage each by 5 min (i.e., 10 min for thermoset and 5 min for thermoplastic). The approximate probabilities of manual non-suppression become 0.3 for thermoset and 0.6 for thermoplastic. These values "suggest"increasing the probabilities of manual non-suppression by a factor of 3 relative to the previous fire types, i.e., 0.3 for thermoset cables and 1 for thermoplastic cables when the fire type is "large electrical" (or a type deemed equivalent), again assuming only manual suppression can be credited.

No credit (factor of 1) is applied for fires that are expected to very challenging, i.e., "indoor oil-filled transformers" and "very large fire sources"in Table 2.3.1 of the FPSDP. Given the high heat release rates of these fires and the expected severities, it seems appropriate to

2 To credit manual suppression, detection must be present in the fire zone.

3 If the cable type is unknown or mixed, assume thermoplastic.

give no manual suppression credit, i.e., probability of manual non-suppression = 1. This would hold for fire types deemed equivalent as well.

A special case can be made for main control room fires, since Table A8.1 of the FPSDP provides separate probabilities of manual non-suppression for this fire type. Once again using the time differentials of 15 min and 10 min as surrogates for thermoset and thermoplastic cable damage, we find approximate probabilities of manual non-suppression of 0.03 and 0.09, respectively, from Table A8.1. These values "suggest" probabilities of manual non-suppression ≈ 0.03 for thermoset cables and 0.1 for thermoplastic cables for main control room fires that are expected to be of the "small electrical" type, assuming prompt detection. If "large," rather than "small," "electrical fires"are assumed, we can make an assumption parallel to that employed earlier, namely reducing the time differentials for thermoset and thermoplastic cable damage each by 5 min (i.e., 10 min for thermoset and 5 min for thermoplastic). The resulting probabilities of manual non-suppression from Table A8.1 of the FPSDP increase by a factor of approximately 3 to 0.09 at 10 min for thermoset cables (rounded off to 0.1) and 0.3 at 5 min for thermoplastic cables. As before, for fire types more severe than "large electrical" in the main control room, no manual suppression credit should be given (probability of manual non-suppression = 1).

Summarizing the preceding results yields the following probabilities of manual non-suppression for the various combinations of fire and cable types:

	Cable Type	
Fire Type	Thermoset	Thermoplastic
Small Electrical	0.1	0.3
Engines/Heaters	0.1	0.3
Solids/Transients	0.1	0.3
Large Electrical	0.3	0
Main Control Room		
Small Electrical	0.03	0.1
Large Electrical	0.1	0.3

If the distance between the fire source and the target cables is such that damage is likely to occur much more quickly, the preceding credits for manual suppression may be overly conservative. than is allowed in the assumptions for manual suppression. One way to estimate the distances below which no credit for manual suppression should be given is via the spreadsheet for calculating the centerline temperature of a buoyant fire plume in the NRC's Fire Dynamics Tools, as follows [Ref. 7]. The area of the combustible source was set to 6 ft^2, and the room ambient temperature to 77°F. The fire temperature after 15 min was calculated as representative of the damage temperature, based on a heat release rate of 70 kW as a surrogate for thermoset cables (using Table A9.6 of the FPSDP, which shows a time to failure of 15 min for temperatures between 651°F and 660°F). For thermoplastic cables, the fire temperature after 10 min was employed at 70 kW (which Table A9.7 of the FPSDP, which shows a time to failure of 10 min for temperatures between 525°F and 550°F[4]). For the 200-kW fires, 10 min was used for thermoset cables (5.5 ft provides a value between 500°F and 525°F). (Recall the no manual suppression credit is allowed for the larger fires when the cable type is thermoplastic.)

Based on this analysis, we can supplement the preceding table for crediting manual suppression as follows, such that no credit is allowed if the critical distance between fire source and targets lies within the distance limits:

	Cable Type	
Fire Type	Thermoset	Thermoplastic
Small Electrical	1ft	1.5 ft (cabinets[5])
Engines/Heaters	2 ft	2.5 ft
Solids/Transients	2 ft	2.5 ft
Large Electrical	4.5 ft	N/A (cabinets)
Main Control Room	Not applicable	

It is considered to be acceptable to apply these distance limits liberally. For example, it is appropriate to assume that the distances are acceptable until they have been verified that the limits are exceeded. Also, it is appropriate to use the average distance to equipment, rather than the limiting (minimum) distance. This second assumption only applies when the location of the target in question is unknown. If the target location is known, the actual distance should be used for calculating the limit.

If automatic can be credited, than manual will not (although it is implicitly credited for fixed water

4 Actually this is 8 min at 2.5 ft, but we limited distance resolution to the nearest 0.5 ft.

5 For electrical cabinet fires, the FPSDP assumes the fire source lies 1 ft below the top of the cabinet.

suppression systems). Manual will only be credited if automatic cannot. Thus, the product F • P will never be reduced by a factor > 0.01 (if automatic wet-pipe suppression is creditable).[6] Note that energetic electrical fires (e.g., switchyard) and oil fires (e.g., turbine-generator), which are likely to be the most severe fires at a nuclear power plant, may grow too quickly or too large to be controlled reliably by even a fully creditable automatic suppression system. This is not due to degradation of the system but to the characteristics of the fire. Therefore, for fire zones where energetic electrical[7] or oil fires may occur, no credit will be given to manual suppression, while that for water-based automatic systems will be reduced to 0.1.

CCDP (C)

There should be at least one fire-independent combination of human actions and equipment operation to prevent core damage, provided these are not precluded by the fire itself or its effects. To incorporate this, a CCDP, given the preceding ignition and failures, must be appended to the F • P • G • S value. Table 2.1.1 of the FPSDP (modified here as Table 8 for use in the subsequent example application) specifies three types of "remaining mitigation capability" for screening CCDP unavailabilities based on safe shutdown path. These are (1) 0.1 if only an automatic steam-driven train can be credited; (2) 0.01 if a train that can provide 100% of a specified safety function can be credited; and (3) 0.1 or 0.01 depending upon the credit that can be assigned to operator actions.[8]

For this last group, a value of 0.1 is assumed if the human error probability (HEP) lies between 0.05 and 0.5, and 0.01 if the HEP lies between 0.005 and 0.05. Credit is based on additional criteria being satisfied, as listed in Table 2.1.1 of the FPSDP.[9]

Factor for Number of Vulnerable Zones (Z)

While there is no way to know *a priori* the exact number of fire zones through which the vulnerable equipment will pass, or the number of these where there is potential for fire damage, something on the order of 10 zones will be assumed for screening purposes. Theoretically, the total frequency of core damage from spurious actuation would be the sum of the frequencies from the individual zones. In general, a higher value would be expected for a higher number of zones. Thus, we give some type of credit for a scenario where the number of vulnerable zones is less than the assumed generic number of 10, say, e.g., five zones or less.

This type of credit would translate into an increase in the screening threshold frequency per zone (call it X), or equivalently a decrease in the zonal core damage frequency (call it D). If we assume limiting the number of vulnerable zones to five or less produces at least a 10% increase in the allowable frequency for zonal screening, i.e., 1.1X, this translates into a decrease in the zonal core damage frequency (D) by a factor Z. To estimate Z, consider the following.

For zonal core damage frequency (D) to meet the threshold (X), D must be < X. For five or less vulnerable zones, we allow an increase to at least 1.1X, such that the zonal core damage frequency meets this new threshold, D < 1.1X. Relative to the original threshold, X, we require X > D/1.1, or X > 0.9D. The factor 0.9 corresponds to a maximum value for Z for five or less vulnerable zones.

6 If neither is creditable (e.g., no automatic suppression system and timing/location/nature/intensity of fire precludes manual suppression), there will be no reduction in the product F • P. This would apply to scenarios where the source and target are the same or very close to one another, or insufficient time is available between detection and damage for manual suppression. Fire suppression may also not be creditable due to insufficient time for automatic suppression prior to cable damage. This latter case is expected to be a rare event and should not be considered unless the configuration clearly shows that immediate component damage is likely to occur.

7 Ref. 8 documents energetic faults only in nuclear power plant switchgear >4 kV. The FPSDP considers both switchgear and load centers as low as ~400 V subject to energetic faults. Consistent with the nature of this screening tool, the FPSDP approach is suggested (i.e., considering switchgear and load centers down to ~400 V as subject to energetic faults).

8 Even the lower value of 0.01 is considered conservative based on Ref. 9, which cites several examples where non-proceduralized actions by plant personnel averted core damage during severe fires. Of the 25 fires reviewed, none resulted in core damage.

9 These criteria include available time and equipment; environmental conditions; procedural guidance; and nature of training.

SIX-FACTOR FREQUENCY OF CORE DAMAGE (F • P • G • S • C • Z)

The maximum frequencies that result from assuming the maximum credits for G (0.01), S (0.01), C (0.01) and Z (0.9), i.e., a joint credit of 9E-7, for the F • P pairings are shown in Table 2. In Ref. 1, NEI states that "[t]he criteria for risk significance are ... consistent with Regulatory Guide 1.174 [Ref. 10] guidance." In their plant-specific risk significance screening, NEI states that "the criteria for determining that component combinations are not risk significant are as follows:

- If the change in core damage frequency (delta-CDF) for each component combination for any fire zone is less than 1E-7 per reactor year, AND
- If the delta-CDF for each component combination is less than 1E-6 per reactor year for the plant, i.e., sum of delta-CDF for all fire zones where circuits for the component combinations (circuits for all) are routed, AND
- If the delta-CDF for each fire zone is less than 1E-6 per reactor year for the plant, i.e., the sum of delta-CDF for all combinations of circuits in the fire zone."

Of these three criteria, the most stringent is the first, requiring the delta-CDF to be <1E-7/yr. This seems to be the appropriate criterion to apply to the Six-Factor Frequency of Core Damage since this is the preliminary screening stage.[10] In Table 2, neither of the shaded boxes satisfies this criterion exclusively, while the unshaded boxes may satisfy this criterion in certain cases.

FINAL SCREENING TABLE

Restricting the values for challenging fires (G), fire suppression (S), CCDP (C) and the factor for number of vulnerable zones (Z) as shown via the point assignments below,[11] the cases where this criterion is satisfied are indicated in Table 3. These correspond to the cases where preliminary "screening to green" can be assumed successful.[12]

Steps to Use Table 3

1. Determine the fire frequency. Use either the generic fire zone frequency or the fire frequency refined by the component-based fire frequency tool in the FPSDP.

2. Determine the probability of spurious actuation, from the FPSDP. If multiple spurious actuations are involved, no more than two of the spurious actuation probabilities should be multiplied together.

3. Determine the block on the table that corresponds to the fire frequency and probability of spurious actuation.

4. Determine if the fire is challenging and, if so, to what degree. Use the fire type for the single largest fire source in the zone. For example, a zone with both small and large fires would be considered subject to large fires only (i.e., there is no combination).

5. Determine the fire suppression factor. If both manual and automatic suppression can be credited, the more effective (automatic) is the only one receiving credit (i.e., there is no combination).[13]

6. Determine the CCDP. If no mitigation capability remains, assume a CCDP = 1.

7. Determine the number of vulnerable zones.

8. Sum the points as assigned below to determine if the zone can be screened to green.

   Challenging Fires (G)

10 For this preliminary screening delta-CDF is conservatively approximated by CDF itself.

11 Each point is roughly equivalent to a factor of ten reduction or the negative exponent of a power of 10, e.g., 1 point corresponds to 1E-1 = 0.1, 2.5 points correspond to 1E-2.5 = 0.003.

12 "Screening to green" in the FPSDP indicates a finding of very low risk-significance that need not be processed further.

13 Credit is reduced for energetic electrical and oil fires.

- Large fires = 0 point
- Moderate fires = 1 point
- Small fires = 2 points

Fire Suppression (S)
- None fully creditable = 0 point
- Only manual fully creditable:[14]
  - Assign points per the following table:[15]

	Cable Type	
Fire Type	Thermoset	Thermoplastic
Small Electrical	1	0.5
Engines/Heaters	1	0.5
Solids/Transients	1	0.5
Large Electrical	0.5	0
Main Control Room		
Small Electrical	1.5	1
Large Electrical	1	0.5

- Automatic fully creditable:[16]
  - Gaseous system = 1 point
  - Dry-pipe or deluge system = 1.5 points
  - Wet-pipe sprinklers = 2 points

CCDP (C)
- No mitigation capability creditable = 0 point
- Only an automatic steam-driven train or operator actions with 0.05 < HEP < 0.5 creditable = 1 point[17]
- A train providing 100% of a specified safety function creditable = 2 points

Factor for Number of Vulnerable Zones (Z)
- Greater than five zones = 0 point
- Five zones or less = 0.5 point

As shown in Table 3, screening at this preliminary stage is not possible if the fire frequency is HIGH and the probability of spurious actuation is HIGH or MEDIUM. All other combinations may be screenable if the point criteria are satisfied.

Relative Ranking Evaluation

For analyses where all zones screen, Table 4 can be used to evaluate which zone is likely to be the most risk-significant. Table 4 converts the F • P maximum frequencies from Table 1 into their point equivalents for each F • P pairing.[18] The pairing point equivalent should be added to the total point credits from the preliminary screening to establish the total risk-significance of each zone. The zone with the lowest point total is viewed as the most risk-significant. At least this one zone should be processed through the FPSDP to verify the validity of the tool, i.e., to verify that the tool did not give a false positive. These FPSDP results, and not the results from the preliminary screening tool, should be used to determine the risk-significance of the finding in Phase 2 of the FPSDP.

EXAMPLE APPLICATION

The following example, somewhat exaggerated for illustration purposes, presents the use of the preliminary screening tool. Assume an FPSDP inspection finding that cables for a pressurized water reactor (PWR) power-operated relief valve and its accompanying block valve are routed through the following five fire zones: the auxiliary building, battery room, cable spreading room, emergency diesel generator room, and main control room. Fire damage to the cables can result in the spurious opening of these valves. The cables are thermoset throughout and are encased in an armor jacket only in the battery room. Table 6 assigns a probability of spurious actuation of 0.6 to thermoset cables for which no other information is known, which lies in the HIGH range in Table 3. Spurious actuation in an armored thermoset cable is considered virtually impossible, corresponding to the VERY LOW range.

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14 As mentioned earlier, detection must be present in the fire zone to take credit for manual suppression. Credit is reduced to zero for energetic electrical and oil fires.

15 No credit is allowed if the critical distance between fire source and targets lies within these distance limits:

	Cable Type	
Fire Type	Thermoset	Thermoplastic
Small Electrical	1ft	1.5 ft (cabinets)
Engines/Heaters	2 ft	2.5 ft
Solids/Transients	2 ft	2.5 ft
Large Electrical	4.5 ft	N/A (cabinets)
Main Control Room	Not applicable	

16 For water-based systems, credit is reduced to one point for energetic electrical and oil fires.

17 As mentioned earlier, the credit for operator actions is based on additional criteria being satisfied, including available time and equipment; environmental conditions; procedural guidance; and nature of training.

18 Recall that each point is roughly equivalent to a factor of ten reduction, or the negative exponent of a power of 10. Thus, the F • P pairing for HIGH-HIGH in Table 1 (1/yr = 1E-0/yr) receives 0 point in Table 4, while that for LOW-VERY LOW (1E-5/yr) receives 5 points.

The auxiliary building and cable spreading room are protected by automatic wet-pipe sprinklers. The emergency diesel generator room has an automatic halon-1301 system. The battery room and main control room have smoke detectors but rely on hand-held extinguishers and hoses for manual fire suppression.

Auxiliary Building

Table 5 indicates a generic fire frequency for an auxiliary building of 0.04/yr, which lies in the HIGH range in Table 3. Since the corresponding probability of spurious actuation is also HIGH, this zone cannot be screened using this tool.

Battery Room

Table 5 indicates a generic fire frequency for a battery room of 0.004/yr, which lies in the MEDIUM range. Since the cable is armored in this room, the probability of spurious actuation is virtually nonexistent, corresponding to the VERY LOW range. Table 3 indicates that preliminary screening is possible for this zone with > 3 points.

Small fires can be expected in the battery room, which earns 2 points from Table 7 for fire size (G). Only manual suppression can be credited because of the portable fire extinguishers and automatic detection. Since the cables are thermoset and only small electrical fires are expected, we can credit 1 point for fire detection/suppression (S). No mitigation capability is creditable since both DC trains could be lost in a battery room fire; no point is assigned from Table 8 for CCDP (C).[19] There are a total of 5 vulnerable zones, so 0.5 point is assigned for the number of vulnerable zones (Z). The points for the battery room total to 3.5, therefore permitting preliminary screening.

Cable Spreading Room - Cables Only

Table 5 indicates a generic fire frequency for a cable spreading room with cables only of 0.002/yr, which lies in the LOW range. With no other information known, the thermoset cable has a probability of spurious actuation of 0.6 from Table 6, i.e., lying in the HIGH range in Table 3. As a result, >4.5 points are needed to screen this zone.

Small fires can be expected in the cable spreading room, which earns 2 points from Table 7 for fire size. The wet-pipe sprinklers result in a credit of 2 points for fire detection/suppression. A remote shutdown station can be credited, meriting 1 point from Table 8 for CCDP.[20] There are a total of 5 vulnerable zones, so 0.5 point is assigned. The points for the cable spreading room total to 5.5, therefore permitting preliminary screening.

Emergency Diesel Generator Building

Table 5 indicates a generic fire frequency for an emergency diesel generator room of 0.03/yr, which lies in the HIGH range. With no other information known, the thermoset cable has a probability of spurious actuation of 0.6 from Table 6, i.e., lying in the HIGH range in Table 3. As a result, this zone cannot be screened using this tool.

Main Control Room

Table 5 indicates a generic fire frequency for a main control room of 0.008/yr, which lies in the MEDIUM range. With no other information known, the thermoset cable has a probability of spurious actuation of 0.6 from Table 6, i.e., lying in the HIGH range in Table 3. As a result, >5.5 points are needed to screen this zone.

Moderate-sized fires are expected in the main control room due to the large number of cables present. Therefore, 1 point is assigned from Table 7 for fire size. A moderate-sized fire is conservatively treated as "large electrical," for which we credit 1 point for fire detection/suppression since the cables are thermoset. One of two completely independent and redundant trains providing 100% of the specified safety function

19 This conservative assumption of total loss of DC power is for illustration only.

20 A human error probability for Operator Action between 0.05 and 0.5 is assumed for operator actions at a remote shutdown station, which yields a credit of 1 point. As per Table 8, this credit also assumes that: (1) sufficient time is available; (2) environmental conditions allow access, where needed; (3) procedures describing the appropriate operator actions exist; (4) training is conducted on the existing procedures under similar conditions; and (5) any equipment needed to perform these actions is available and ready for use.

(Residual Heat Removal)[21] remains fully creditable, meriting 2 points from Table 8 for CCDP. There are a total of 5 vulnerable zones so 0.5 point is assigned. The points for the main control room total to only 4.5, therefore preventing preliminary screening.

Conclusions

Only the Battery Room and Cable Spreading Room could be screened using this tool. The remaining zones would require more detailed analyses to assess each delta-CDF through the FPSDP. In this example the cables ran through fire zones with different fire initiator frequencies, cable types (and therefore spurious actuation probabilities), potential fire sizes, suppression systems, and core damage mitigation capabilities. The example illustrates that it is easier to screen zones with lower fire initiator frequencies and probabilities of spurious actuation than zones with higher values. Fire zones with lower F • P pairings require less credit from the "additional considerations" (G • S • C • Z) to satisfy the screening threshold of delta-CDF < 1E-7/yr.

SUMMARY

The NRC has converted a preliminary risk screening approach developed by NEI into a "risk screening tool" for fire-induced, circuit spurious actuation inspection findings that arise from the FPSDP. These findings typically involve the multiple fire zones through which the circuits pass. To streamline the FPSDP, the tool screens zones where the "circuit issue" is expected to be of very low risk-significance based on (1) the fire frequency in the zone where the circuits are located; (2) the probability of spurious actuation; and (3) automatic or manual suppression, or an alternate means to achieve hot shutdown.

The tool estimates six factors to calculate the frequency of core damage: (1) zonal fire frequency; (2) spurious actuation probability; (3) challenging fire factor; (4) probability of non-suppression; (5) CCDP; and (6) factor based on number of vulnerable zones. The tool determines if a fire zone, once it has been assigned to a fire frequency-spurious actuation probability pairing (i.e., the first two factors), can be screened at a maximum delta-CDF threshold of 1E-7/yr based on a point system for the remaining four factors. This paper provides an example of how the tool would be applied.

To date, the tool has been exercised only for a limited set of "associated circuit" URIs. The NRC plans to benchmark the tool against FPSDP evaluations for circuit issues. The results will determine if further refinements are warranted before the tool is offered to NRC inspectors and licensees as one option for preliminary screening of multiple fire zones for circuit issues prior to FPSDP analysis.

[21] Residual Heat Removal need not be the only safety function to achieve safe shutdown. This is an assumption for illustration only.

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5. NRC Regulatory Issue Summary 2004-03, "Risk-Informed Approach for Post-Fire Safe-Shutdown Associated Circuit Inspections," March 2004.

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8. Raughley, W., and G. Lanik, "Operating Experience Assessment - Energetic Faults in 4.16 kV to 13.8 kV Switchgear and Bus Ducts That Caused Fires in Nuclear Power Plants, 1986-2001," NRC Office of Nuclear Regulatory Research, February 2002.

9. Nowlen, S., and M. Kazarians, "Risk Methods Insights Gained from Fire Incidents," NUREG/CR-

6738, September 2001.

10. NRC Regulatory Guide 1.174, " An Approach for Using Probabilistic Risk Assessment in Risk-Informed Decisions on Plant-Specific Changes to the Licensing Basis," Revision 1, November 2002.

TABLE 1. Maxima for the Pairings F • P (With Round off to the Nearest "3" or "1" for Convenience)		**Fire frequency (F)**		
		HIGH, ≥0.03/yr but ≤1/yr	**MEDIUM, ≥0.003/yr but <0.03/yr**	**LOW, <0.003/yr**
Probability of spurious actuation (P)	**HIGH, ≥0.3 but ≤1**	1/yr	0.03/yr	0.003/yr
	MEDIUM, ≥0.03 but <0.3	0.3/yr	0.009/yr (~ 0.01/yr)	9E-4/yr (~0.001/yr)
	LOW, ≥0.003 but <0.03	0.03/yr	9E-4/yr (~ 0.001/yr)	9E-5/yr (~1E-4/yr)

	VERY LOW, <0.003	0.003/yr	9E-5/yr (~1E-4/yr)	9E-6/yr (~1E-5/yr)

TABLE 2. Maxima That Result from Maximum Credits for G (0.01), S (0.01), C (0.01) and Z (0.9), i.e., a Joint Credit of 9E-7		**Fire frequency (F)**		
		HIGH, ≥0.03/yr but ≤1/yr	**MEDIUM, ≥0.003/yr but <0.03/yr**	**LOW, <0.003/yr**
Probability of spurious actuation (P)	**HIGH, ≥0.3 but ≤1**	9E-7/yr	3E-8/yr	3E-9/yr
	MEDIUM, ≥0.03 but <0.3	3E-7/yr	9E-9/yr	9E-10/yr
	LOW, ≥0.003 but <0.03	3E-8/yr	9E-10/yr	9E-11/yr
	VERY LOW, <0.003	3E-9/yr	9E-11/yr	9E-12/yr

TABLE 3. Point Requirements for Screening (Note use of ">" vs. "≥," i.e., points must EXCEED numbers shown)		**Fire frequency (F)**		
		HIGH, ≥0.03/yr but ≤1/yr	**MEDIUM, ≥0.003/yr but <0.03/yr**	**LOW, <0.003/yr**
Probability of spurious actuation (P)	**HIGH, ≥0.3 but ≤1**	Do not screen	Screen to green with > 5.5 points	Screen to green with > 4.5 points
	MEDIUM, ≥0.03 but <0.3	Do not screen	Screen to green with > 5 points	Screen to green with > 4 points
	LOW, ≥0.003 but <0.03	Screen to green with > 5.5 points	Screen to green with > 4 points	Screen to green with > 3 points
	VERY LOW, <0.003	Screen to green with > 4.5 points	Screen to green with > 3 points	Screen to green with > 2 points

TABLE 4. Establishing Relative Risk Ranking When All Zones Preliminarily Screen[22]				
Fire frequency (F)	**Probability of spurious actuation (P)**	**Points**		
		Preliminary screen total	**Table 1 equivalents**	**Risk-ranking total**

[22] Table 4 includes an example (items in parentheses) where none of a total of seven zones satisfied the preliminary screening criteria of Table 3. When ranked relative to one another using the point equivalents from Table 1, Zone C proved to be of highest relative risk-significance (lowest total points, 3.5). At a minimum, Zone C would be processed through Phase 2 of the FPSDP (followed by Zone A, Zone B, etc., if the analyst chose to process more).

HIGH	**HIGH**	(Zone A - 4)	0	(Zone A - 4)
	MEDIUM		0.5	
	LOW	(Zone B - 3)	1.5	(Zone B - 4.5)
	VERY LOW		2.5	
MEDIUM	**HIGH**	(Zone C - 2)	1.5	(Zone C - 3.5)
	MEDIUM		2	
	LOW	(Zone D - 2.5) (Zone E - 3)	3	(Zone D - 5.5) (Zone E - 6)
	VERY LOW		4	
LOW	**HIGH**		2.5	
	MEDIUM	(Zone F - 3.5)	3	(Zone F - 6.5)
	LOW		4	
	VERY LOW	(Zone G - 1.5)	5	(Zone G - 6.5)

TABLE 5. Generic Location Fire Frequencies

Room Identifier	Generic Fire Frequency (Range)
Auxiliary Building (PWR)	4E-2 (HIGH)
Battery Room	4E-3 (MEDIUM)
Cable Spreading Room - Cables Only	2E-3 (LOW)
Cable Spreading Room - Cables Plus Other Electrical Equipment	6E-3 (MEDIUM)
Cable Vault or Tunnel Area - Cables Only	2E-3 (LOW)
Cable Vault or Tunnel Area - Cables Plus Other Electrical Equipment	6E-3 (MEDIUM)
Containment - PWR or Non-inerted Boiling Water Reactor (BWR)	1E-2 (MEDIUM)
Emergency Diesel Generator Building	3E-2 (HIGH)
Intake Structure	2E-2 (MEDIUM)
Main Control Room	8E-3 (MEDIUM)
Radwaste Area	1E-2 (MEDIUM)
Reactor Building (BWR)	9E-2 (HIGH)
Switchgear Room	2E-2 (MEDIUM)
Transformer Yard	2E-2 (MEDIUM)
Turbine Building - Main Deck (per unit)	8E-2 (HIGH)

TABLE 6. Probabilities of Spurious Actuation Based on Cable Type and Failure Mode (Range)

<table>
<tr><th>State of Cable Knowledge</th><th>Thermoset</th><th>Thermoplastic</th><th>Armored</th></tr>
<tr><td>No available information about cable type or current limiting devices</td><td colspan="3">0.6 (HIGH)</td></tr>
<tr><td>Cable type known, no other information known (NOI)</td><td colspan="2">0.6 (HIGH)</td><td>0.15 (MEDIUM)</td></tr>
<tr><td>Inter-cable interactions only</td><td>0.02 (LOW)</td><td>0.2 (MEDIUM)</td><td>0 (VERY LOW)</td></tr>
<tr><td>In conduit, cable type known, NOI</td><td>0.3 (HIGH)</td><td>0.6 (HIGH)</td><td rowspan="3">(VERY LOW)</td></tr>
<tr><td>In conduit, inter-cable only</td><td>0.01 (LOW)</td><td>0.2 (MEDIUM)</td></tr>
<tr><td>In conduit, intra-cable</td><td>0.075 (MEDIUM)</td><td>0.3 (HIGH)</td></tr>
</table>

TABLE 7. General Fire Scenario Characterization Type Bins Mapped to Fire Intensity Characteristics

Fire Size Bins	Generic Fire Type Bins with Simple Predefined Fire Characteristics (Points Assigned)					
	Small Electrical Fire (2 points)	**Large Electrical Fire (1 point)**	**Indoor Oil-Filled Transformers (0 point)**	**Very Large Fire Sources (0 point)**	**Engines and Heaters (2 points)**	**Solid and Transient Combustibles (2 points)**
70 kW	75^{th} %ile fire				75^{th} %ile fire	75^{th} %ile fire
200 kW	98^{th} %ile fire	75^{th} %ile fire			98^{th} %ile fire	98^{th} %ile fire
650 kW		98^{th} %ile fire	75^{th} %ile fire	75^{th} %ile fire		
2 MW			98^{th} %ile fire			
10 MW				98^{th} %ile fire		

TABLE 8. Total Unavailability Values for SSD Path-Based Screening CCDP

Type of Remaining Mitigation Capability	Screening Unavailability Factor (Points Assigned)
1 Automatic Steam-Driven Train: A collection of associated equipment that includes a single turbine-driven component to provide 100% of a specified safety function. The probability of such a train being unavailable due to failure, test, or maintenance is assumed to be approximately 0.1 when credited as "Remaining Mitigation Capability."	0.1 (1 point)
1 Train: A collection of associated equipment (e.g., pumps, valves, breakers, etc.) that together can provide 100% of a specified safety function. The probability of this equipment being unavailable due to failure, test, or maintenance is approximately 0.01 when credited as "Remaining Mitigation Capability."	0.01 (2 points)
Operator Action Credit: Major actions performed by operators during accident scenarios (e.g., primary heat removal using bleed and feed, etc.). These actions are credited using three categories of human error probabilities: (1) Operator Action = 1.0, which represents no credit given; (2) Operator Action = 0.1, which represents a failure probability between 0.05 and 0.5; and (3) Operator Action = 0.01, which represents a failure probability between 0.005 and 0.05. Credit is based upon the following criteria being satisfied: (1) sufficient time is available; (2) environmental conditions allow access, where needed; (3) procedures describing the appropriate operator actions exist; (4) training is conducted on the existing procedures under similar conditions; and (5) any equipment needed to perform these actions is available and ready for use.	1.0 (0 point), 0.1 (1 point), or 0.01 (2 points)