April 3, 2006

MEMORANDUM TO: Sunil D. Weerakkody, Chief
Fire Protection Branch
Division of Risk Assessment
Office of Nuclear Reactor Regulation

FROM: Raymond Gallucci, Senior Fire Probabilistic Safety Assessment Engineer
Fire Protection Branch ***/RA/***
Division of Risk Assessment
Office of Nuclear Reactor Regulation

SUBJECT: TRANSMITTAL OF ANALYSIS, "BOUNDING THE FIRE RISK FROM CIRCUIT SPURIOUS ACTUATIONS AT NUCLEAR POWER PLANTS," TO SUPPORT REGULATORY ANALYSIS FOR GL 2006-XX, "POST-FIRE SAFE-SHUTDOWN CIRCUIT ANALYSIS SPURIOUS ACTUATIONS"

Attached is the analysis "Bounding the Fire Risk from Circuit Spurious Actuations at Nuclear Power Plants," to support the Regulatory Analysis for GL 2006-xx, "Post-fire Safe-Shutdown Circuit Analysis Spurious Actuations" (ADAMS ML060540247). If you have any questions, please contact Ray Gallucci at 415-1255.

Enclosure:
As stated

CONTACT: Ray Gallucci, DRA/NRR
301-415-1255

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OFFICE	NRR/DRA/AFPB	NRR/DRA/AFPB
NAME	RGallucci	SWeerakkody
DATE	03/31/06	04/03/06

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Bounding the Fire Risk from Circuit Spurious Actuations at Nuclear Power Plants

Raymond H.V. Gallucci, Ph.D., P.E.

U.S. Nuclear Regulatory Commission (NRC), MS O-11 A-11, Washington, D.C. 20555
rhg@nrc.gov

INTRODUCTION[1]

The U.S. NRC has requested that nuclear power plant (NPP) licensees review their fire protection (FP) programs to confirm compliance with regulatory requirements related to the phrase "one-at-a-time" for multiple spurious circuit actuations [1]. The Electric Power Research Institute (EPRI)/Nuclear Energy Institute (NEI) cable fire tests showed a relatively high probability of simultaneous or rapidly successive multiple spurious actuations during or after a fire [2]. This paper presents a bounding analysis on the potential fire risk in terms of core damage frequency (CDF).

BASELINE

The Individual Plant Examination for External Events (IPEEE) at a typical "older" NPP reported a fire CDF = 3.3E-5/y [3]. This included the modeling of "hot short" failures (i.e., spurious openings/closures of motor- or air-operated valves [MOVs or AOVs]), for which a maximum failure probability of 0.1 was assumed.[2] A review of the importance measures for the 24 hot short basic events that appeared in cut sets above the truncation level (1E-10/y) indicates a summed Fussell-Vesely (FV) importance of 0.0547, corresponding to a fire CDF contribution of (3.3E-5/y)(0.0547) = 1.8E-6/yr.[3] Among these 24 hot short basic events are 10 that correspond to five pairs of components, i.e., systemically symmetric components in redundant trains for which the failure characteristics, locations, and, presumably, cable run locations are similar. The summed FV contribution from these 10 events is 0.0320, corresponding to a fire CDF contribution of (3.3E-5/y)(0.0320) = 1.1E-6/y.[4]

For these 10 paired hot short events, the cut sets in which they appeared are assumed to be of the following forms:

- For "A" train hot short basic events – $CDF_A = F_A \bullet A \bullet 3(B_j' \bullet X_j)$
- For "B" train hot short basic events – $CDF_B = F_B \bullet B \bullet 3(A_k' \bullet Y_k)$

where:

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1 This paper was prepared by an employee of the U.S. NRC. The views presented do not represent an official staff position.

2 The value of 0.1 was assumed for all MOV and AOV control cable hot shorts; 0.001 was used for hot shorting of multi-phase AC power cables for MOVs.

3 The sum of the individual FV's represents an upper bound on the total contribution from all hot short basic events because there may be cut sets where multiple hot short basic events appear, such that summing their individual FV's produces some "double-counting." Given that the maximum individual FV is 0.0109 for PORV failure (two such events), the effect of any double-counting is believed to be small and the sum of the individual FV's reasonably representative of the total hot short contribution to fire CDF.

4 The same caveat as in the immediately preceding footnote regarding double-counting applies here as well.

- CDF_i = fire CDF contribution from cut sets containing i = A or B, each representing a hot short basic event for that train (A or B)
- F_i = fire initiator that induces hot short failure i
- A' or B' = non-hot-short-induced basic event failure corresponding to hot short failure for train A or B, i.e., A' pairs with B and B' with A
- X or Y = non-fire-induced failures that complete the cut sets for CDF_A or CDF_B, respectively, i.e., X pairs with A●B' and Y pairs with B●A'

Probabilistically, A = B = 0.1.[5] We can further express $3(B_j{'}\bullet X_j)$ as $\underline{B}'\bullet 3(X_j)$, where $\underline{B}' = 3(B_j{'}\bullet X_j)/3(X_j)$. Doing likewise, we obtain $3(A_k{'}\bullet Y_k) = \underline{A}'\bullet 3(Y_k)$, where $\underline{A}' = 3(A_k{'}\bullet Y_k)/3(Y_k)$. Because of the symmetry involved with these paired hot short events, we can further assume $\underline{A}' = \underline{B}'$ and $3(X_j) = 3(Y_k)$ in probabilistic terms.

With these simplifying assumptions, the contribution to fire CDF from the 10 paired hot short events becomes the following:

- $CDF_A + CDF_B = (F_A + F_B)\bullet A\bullet \underline{B}'\bullet 3(X_j)$ = 1.1E-6/y

which we can express as $(F_A + F_B)\bullet 3(X_j)$ = (1.1E-6/y)/($A\bullet\underline{B}'$). We already know that A = 0.1, so the ratio on the right will be minimized for a maximum value of $\underline{B}'$, which is a weighted average of the various values of B' that appear in the cut sets. Since we are dealing with hot shorts for MOVs and AOVs, the non-hot-short-induced failures that comprise the various values of B' are the familiar "random" component failures, such as valve failure to open/close. Unreliabilities or demand failure probabilities for these tend to peak around 0.001. So, assuming $\underline{B}'$= 0.001 will minimize the above ratio, such that $(F_A + F_B)\bullet 3(X_j)$ = (1.1E-6/y)/([0.1][0.001]) = 0.011.

BOUNDING ANALYSIS

For the 10 paired events, any dual failures caused by a pair of hot shorts would appear in cut sets of the following forms:

- If initiated by F_A – $s\bullet F_A\bullet A\bullet B\bullet 3(X_j)$
- If initiated by F_B – $s\bullet F_B\bullet A\bullet B\bullet 3(Y_k)$

where s = fire severity factor reducing the likelihood of the more extreme fire (i.e., $s\bullet F_i$ [i = A or B]) assumed necessary to cause dual hot shorts.[6] Probabilistically, we can employ the previously assumed equivalences to express the total contribution to fire CDF from these paired hot shorts as follows:

- $CDF_{pairs} = s\bullet(F_A + F_B)\bullet A^2\bullet 3(X_j)$

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5 We ignore the contributions from those hot shorts for AC power cables for MOVs, where the probability is 0.001, since cut sets from these will likely contribute negligibly compared to those resulting from control cable hot shorts.

6 An implicit assumption here is that a fire of lower intensity but higher frequency, characterized by F_A (or F_B) alone (i.e., without the fire severity factor "s"), would not be extreme enough to cause dual hot shorts, but only hot short "A" (or "B"). Thus, without the factor "s" present to characterize the fire of higher intensity but lower frequency (i.e., $s\bullet F_A$ [or $s\bullet F_B$]), assumed extreme enough to cause dual hot shorts, it was not possible to have both A and B (or B and A) in a cut set initiated by F_A (or F_B) alone as on the previous page. With the factor "s" present, both A and B can be caused by either fire ($s\bullet F_A$ or $s\bullet F_B$). This is a surrogate approach used in lieu of actual fire modeling for this analysis since the details required to perform fire modeling are not available. The factor "s" is assumed to be the same for either fire initiator.

To approximates, we note that the Fire Protection Significance Determination Process (FPSDP) uses a value of 0.1 to reflect the fraction of fires of a particular type that will produce the 98^{th} (vs. the 75^{th}) %ile heat release rate, characteristic of an extreme fire of that particular type [4]. To approximate A, we note that the FPSDP assumes a maximum probability of hot shorting of 0.6 for non-conduit thermoplastic or thermoset cables where intra-cable or inter-cable hot shorts are possible. NUREG/CR-6850, the basis reference for the FPSDP, reduces this value to 0.3 if the cable is protected by a control power transformer, which is the typical case [5]. Since this typical "older" plant likely has a mix of thermoplastic and thermoset cables, 0.3 seems a reasonable assumption for A as the hot short probability. Therefore, assuming s = 0.1, A = 0.3, and using the quantification from above for the remaining terms, we obtain the following bounding estimate for fire CDF due to simultaneous or rapidly successive multiple spurious actuations:

- $CDF_{pairs} = (0.1)(0.011)(0.3)^2 =$ 9.9E-5/y . 1E-4/y.[7]

CONCLUSION

There likely are some conservative assumptions in this estimate, especially in terms of fire characteristics and cable layout. However, it is instructive to note that, even if the estimate is an order of magnitude too high, it would still be fairly significant at ~ 1E-5/y.[8] Thus, at least for a typical "older" plant, one cannot *a priori* dismiss multiple hot shorts as being of low risk significance.

REFERENCES

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2. EPRI, *Spurious Actuation of Electrical Circuits Due to Cable Fires: Results of an Expert Elicitation*, EPRI TR-1006961, Palo Alto, California, May 2002.

3. "Response to Request for Additional Information on IPEEE," Letter to Guy S. Vissing, USNRC, from Robert C. Mecredy, Rochester Gas & Electric Corp., R.E. Ginna Nuclear Power Plant, July 30, 1999.

4. USNRC*, Inspection Manual Chapter 609, Appendix F, "Fire Protection Significance Determination Process,"* Washington, D.C., February 2005.

5. USNRC, *EPRI/NRC-RES Fire PRA Methodology for Nuclear Power Facilities*, NUREG/CR-6850, Washington, D.C., September 2005.

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7 If we employed the re-evaluated fire CDF discussed in the first footnote (1.1E-5/y), this value would be reduced by a factor of ~3 to 3.3E-5/y.

8 Or ~ 3E-6/y, following the preceding footnote.