Attachment

A Second Review of the Palo Verde Analysis of Fire Barrier Ampacity Derating Factors

A Letter Report to the USNRC

Revision 0

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The United States Nuclear Regulatory Commission (USNRC) has solicited the support of Sandia National Laboratories (SNL) in the review of utility submittals associated with fire protection and electrical engineering. This report represents the second in an anticipated series of reports associated with the Palo Verde Nuclear Generating Station (PVNGS). These submittals deal with the issue of ampacity derating factors associated with localized cable tray fire barrier systems. The original licensee position regarding ampacity was documented in a submittal of September 1993 that was provided in response to USNRC Generic Letter 92-08 and a subsequent USNRC request for additional information (RAI). SNL reviewed this submittal under the auspices of USNRC JCN J-2017, as documented in a letter report of September 1994. In large part as a result of this SNL review, a second RAI was forwarded to the licensee requesting clarification of, or additional justification for, a number of points of technical concern. The current report documents an initial review by SNL of the licensee response to this second RAI. This effort has been conducted under the auspices of USNRC JCN J-2503, Task Order 4, Sub-task 3.

1.0 INTRODUCTION

1.1 Objective

In response to USNRC Generic Letter 92-08 and a subsequent USNRC Request for Additional Information (RAI), in September of 1993 the Palo Verde Nuclear Generating Station (PVNGS) provided documentation of the utility position regarding both the fire endurance rating and ampacity derating factors associated with its installed fire barrier systems. The ampacity derating portions of this submittal were review by SNL in September of 1994.[1] In large part as a result of this review, a second RAI was forwarded to the licensee on the subject of ampacity derating of fire barrier clad cables in cable tray applications. The objective of the current review is to assess the technical merits and adequacy of the licensee's response to this second RAI. The relevant documents reviewed in the current effort are:

- Letter, January 24, 1997, W. E. Ide, PVNGS to USNRC Document Control Desk, licensee reference item 102-03854-WEI/SAB/NLT with two supporting enclosures.

SNL was requested to review these submittals under the terms of the general technical support contract JCN J-2503, Task Order 4, Sub-task 3.

1.2 Overview of the Utility Approach

In its original submittal, PVNGS documented cable tray ampacity assessments using a method know generally as the "Watts per foot" approach to analysis. SNL found that this method was inherently incapable of adequately assessing the ampacity loads for individual power cables; hence, it was recommended that the submittal not be accepted as a demonstration of adequate ampacity margin. In its most recent submittal, the licensee has fully abandoned the "Watts per foot" method in favor of an alternate approach to analysis. The revised methodology has been presented in an *IEEE Transactions* paper by Leake [1], and a copy of this paper was included in the submittal. The new method represents a compromise position between the Stolpe [2] or ICEA P-54-440 [3] method and the "Watts per foot" method.

In addition to documenting the new diversity-based method, the licensee has also provided three example calculations; one based on traditional ICEA P-54-440 tray methods, one based on methods for maintained-spacing installations, and one illustrating an application of the diversity based methodology. No other specific plant calculations have been documented, although the licensee has provided a general description of its findings to date.

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[1]See SNL Letter Report, "A Review of the Palo Verde Analysis of Fire Barrier Ampacity Derating Factors", A Letter Report to the USNRC, Revision 0, September 27, 1994.

1.3 Organization of Report

This review has focused on an assessment of the acceptability of the revised licensee ampacity derating analyses, and on a specific review of the three example calculations presented in the submittal. Section 2 presents a review of the diversity-based analysis methodology being proposed by the licensee. Section 3 provides a brief review of the individual licensee sample calculations. Section 4 summarizes the SNL recommendations regarding the need for additional information to support the final assessment of the utility analyses.

2.0 THE REVISED LICENSEE ANALYSIS METHODOLOGY

2.1 Overview

The licensee has documented an entirely new method for the assessment of ampacity loads for fire barrier clad cables in cable tray applications as compared to the original "Watts per foot" method reviewed by SNL in September 1994. The new method has been presented in an *IEEE Transactions* paper by H. C. Leake of Arizona Public Service Company (APSC) [1]..

The specific intent of the revised model is to allow some credit for diversity in cable power loads as a part of the ampacity assessment process. As the paper cites, the widely accepted ICEA P-54-440 method [3], which derives from the work of Stolpe [2], assumes no diversity in its cable ampacity assessments. This is, recognizably, a conservative approach to analysis. The objective of the revised method is to relax this conservatism and to allow for at least some diversity credit.

One important factor to note is that the Leake method is only applied to open cable trays. The method is intended to address the baseline ampacity limits of the cables. The licensee will then apply the appropriate ampacity derating factor (ADF) to the baseline ampacity estimates to determine the derated ampacity limit for a clad cable.

2.2 The General Approach

Leake draws an excellent comparison between the various proposed methods of analysis in which some credit for diversity is taken, including the "Watts per foot" method. A significant portion of the paper is devoted to comparisons between the various approaches, and a demonstration the revised model is more conservative than those that have been put forth in the past.

The general approach taken by Leake is based on a single modification of the Stolpe tray modeling assumptions. In particular, Leake maintains Stolpe's model of heat transfer within a cable mass and the concept of uniform heat intensity within the tray. However, Leake modifies the treatment of cable mass-to-ambient heat transfer by using a reduced heat load based on actual cable loadings for this step of the analysis. That is, for in-tray heat transfer behavior a conservative non-diversity based heat load is assumed. For tray-to-ambient behavior, the lower actual heat load of the cables including diversity is used.

To elaborate, in Stolpe's model all the cables in a tray are assumed to be loaded to an equal level based on the rate of heat generation per unit of cable cross-section, the "heat intensity." This method assumes no diversity. For the in-tray behavior, that is conduction within the cable mass, a simplified expression for heat transfer in a one-dimensional mass with uniform heat generation is used to estimate the temperature rise from the surface of the mass to the hot spot. The same overall heat load is then used to estimate the temperature rise between the ambient and the cable surface, the tray-to-ambient heat transfer, based on simple convection and radiation correlations. The result is an estimate of the overall ambient to cable hot spot temperature rise. The heat load, or heat intensity,

is adjusted until the predicted cable hot-spot temperature matches the maximum allowable temperature rating of the cables. In terms of the Leake method, the critical point is that the exact same conservative heat load is used for both the in-tray and tray-to-ambient thermal behavior.

Leake's model makes the exact same assumptions for the in-tray behavior with no credit given to diversity. However, when the heat transfer between the cable mass and the ambient is considered, the tray-to-ambient behavior, Leake's method credits diversity by using the lower actual heat load of the cables in the tray rather than the conservative estimate based on worst-case uniform heat generation. The actual heat load on a tray may be just a small fraction of the heat load assumed in the Stolpe calculations. Using this method, the role of tray-to-ambient heat transfer in the overall process will be significantly reduced. For many cases, the in-tray behavior will dominate the calculation.

The net effect of this practice is a compromise solution that ranges between the method of Stolpe and that of other diversity based methods including the "Watts per foot" method. Leake acknowledges that the previously proposed diversity crediting methods including those outlined by Harshe and Black [4] can lead to non-conservative results, especially in the case of a highly diverse cable tray (a tray with only a few energized conductors). It is Leake's contention that by retaining Stolpe's cable mass thermal model, the method does assess the ampacity load for individual cables.

2.3 Some Words of Caution From Stolpe

It must be recognized that diversity in cable loads and the potential for crediting diversity is by no means a new subject. Leake clearly acknowledges this in his paper, and even provides an excellent discussion of the various methods that have been proposed and applied in practice. Leake also provides an acknowledgment of certain statements made by Stolpe in his original work. It bears repeating here that Stolpe had clear and significant reservations regarding any methodology which attempted to systematically or generically credit load diversity in ampacity assessments.

Stolpe's tests did include one very limited test of a diversity load case. As a part of his tests, Stolpe had assembled one cable tray containing eight different wire gauges, and for one wire gauge (12AWG) both a single-conductor and multi-conductor cable. In one particular test, Stolpe only applied power to three of the nine different cable groups. Each group was powered to the ampacity which his own model (assuming no diversity) predicted would lead to a 50°C temperature rise in the conductors. Stolpe made the following observations regarding the results of this test:

> "The No. 6 (AWG) cables ran about 15°C cooler than when all cables were energized but the 4/0 cable only ran 1°C cooler. It is from this experimental finding that it appears to be unwise to increase cable ampacities on the basis of diversity. The cables in the above diversity test were separated by about 6-inches of "dead" cable, but it is conceivable that the No. 6 cables could be placed adjacent to, or between, some 4/0 cables. If the cables in this configuration had increased ampacities base on assumed diversity, there would undoubtedly be a local hot spot in

the cable tray. Thus, it seems impossible to apply a general increase in the ampacities of smaller cables due to diversity because there is no general way to assure that small cables would remain separated from large cables in randomly filled trays."

It is quite clear from this passage that any method for crediting diversity will be controversial. Clearly, diversity is a real phenomena. The Stolpe method is conservative and credits no diversity. When significant levels of diversity can be demonstrated, it may be appropriate to relax this conservatism. Ultimately, there are two critical questions to be answered:

(1) What methods of credit are appropriate?

(2) Under what circumstances should credit for diversity be allowed?

Note that the two questions are related. That is, the method by which diversity is credited will impact the decision as to when that methodology is appropriate for use. The current topic of discussion is the Leake methodology, and hence, the observations and recommendations made are limited to that method.

2.4 The Critical Parameters and Leake's Model

As is obvious from the discussion above, there are two primary heat transfer behaviors of interest in a cable tray ampacity assessment; namely, in-tray behavior and tray-to-ambient behavior.

The in-tray behavior as modeled by both Stolpe and Leake is strictly a conduction problem. In reality, most trays will experience some convective air currents passing through the tray, but this effect is not modeled in any way (this is one source of conservatism in the in-tray treatment). As a conduction problem, the only parameter with a direct impact on the analysis results is the thickness of the cable mass (the tray depth of fill). Given the assumptions of the Stolpe model, there are no other "floating" parameters. Virtually all such analyses will cite the Stolpe assumed value for the cable mass thermal conductivity, and this is essentially the only other parameter with the potential to impact the final results, the limiting heat intensity. In particular, the assumed width of the tray has no impact whatsoever on the results of the in-tray analysis.

In contrast, the tray-to-ambient problem is a strictly convection/radiation problem. As such it is dominated by the assumptions regarding the surface of the cable mass. These include in particular the emissivity of the surface, and the convective heat transfer coefficient. A third critical parameter in general is the surface area assumed in the analysis. In the specific case of Stolpe's model, the assumed width of the tray again has no impact on the analysis whatsoever. This is because the heat transfer coefficient is not assumed to change with the width of the tray; hence, both the heat load and heat transfer rates increase in lock-step directly proportional to tray width. Using Stolpe's method one will obtain the exact same ampacity result for a 6" tray as one will for a 48" tray with the same depth of fill.

Leake's treatment of the tray-to-ambient behavior introduces one significant change to the this process. That is, in Leake's model, the heat load for the tray-to-ambient analysis is fixed based on the actual cable loads. However, this heat transfer is assumed to occur across the entire surface of the cable mass. Hence, as the tray width increases, the convective and radiative heat transfer rates also increase. Given this, the method will predict different ampacity limits for the same cable based only on changes in the tray width. This is an obvious potential criticism of the Leake method that will be explored in greater detail below. In particular unrealistic results might be expected for wide trays with only a very few powered cables and limited fill depth.

It should also be noted that Leake acknowledges this limitation. In particular, the Leake paper includes the following statements:

> "In cases where the depth of fill is close to the diameter of the largest cables, all of the methods which credit diversity may be non-conservative, and (the Stolpe method) is more appropriate. For example, in a tray containing a single layer of cables, the heat dissipated by a few current-carrying cables located side-by-side would not spread evenly to all of the unenergized cables, some of which could be a significant horizontal distance away. Hot spots could occur where the energized cables touch each other, and may not be identified by (the diversity crediting methods). This is illustrated in (certain of Stolpe's test results). In a tray with a 0.76" calculated depth of fill, the temperature of an energized #4/0 cable, with a diameter 105% of the calculated depth of fill, dropped only 1°C when a number of the other cables were deenergized."

Regarding Leake's citation to the Stolpe tests, it should be noted that Stolpe and ICEA P-54-440 use somewhat different methods to calculate depth of fill. If the ICEA method is used, then the specific #4/0 cable would have a diameter equal to about 82% of the calculated fill depth. PVNGS does use the ICEA definitions for fill depth and cable cross-section; hence, in this case basing the insight on comparison of cable diameter to the ICEA fill depth is more appropriate.

2.5 Exercising the Model

SNL has explored to a limited extent the results of the Leake method including a modest exploration of certain sensitivities in the model input parameters. For illustrative purposes, SNL chose to model a number of cases involving one or more powered 3-conductor, 12 AWG cables. The physical diameter of the cable was assumed to be 0.43" which is consistent with the ICEA assumptions as set forth in Table 3-3 of P-54-440. For all cases, a 40°C ambient and a 90°C conductor temperature were assumed. This allows a direct comparison of the modeling results to the ICEA ampacity limits.

The implemented MATHCAD model is presented in Appendix A. In implementing the model, SNL first verified that it could reproduce the ICEA limits directly. This verified the basic implementation of the heat transfer correlations to be consistent with Stolpe and the ICEA. We then considered the alternate treatment of Leake. To exercise the model, SNL considered three fill depths (0.5, 1.0 and 3.0 inches) and three different levels of

diversity, one powered cable, 10 powered cables, or 20 powered cables. SNL also considered the impact of tray width on the Leake results. The results of this exercise are illustrated in table 2.1.

Table 2.1: summary of example calculations performed by SNL using the Leake diversity-based ampacity method.

Fill Depth (in)	Tray width (in)	IEEE 835 open air limit*	Stolpe / ICEA P-54-440 limit	Leake limit for 1 powered cable	Leake limit for 10 powered cables	Leake limit for 20 powered cables
0.5	12	36 (28.8)	19	52.1	30.7	23.5
	24			55.5	38.2	30.6
1.0	12		13	28.8	22.5	19.1
	24			29.4	25.3	22.6
3.0	12		6	10.0	9.5	9.1
	24			10.0	9.8	9.6

* Open air ampacity for a 12 AWG triplex cable, 80% of open air limit cited in brackets

There are several points to be observed regarding these results. One feature somewhat unique to Leake (although also applicable to the Harshe/Black layering method) is that the method can potentially overstate the importance of tray width in determining local heating effects as was discussed above. That is, Leake assumes that heat transfer occurs with equal effectiveness over the entire top and bottom surface of the cable mass, and that the surface of the mass is at a uniform temperature. By this treatment, the actual heat generated in the tray is "stretched" or "spread" over the full width of the tray and potentially "diluted" beyond the point where the thermal model reflects the real tray. Several observations in this specific regard can be made from these examples:

- Note that the impact of the tray width on the estimated ampacity was modest for most of these cases. This is because the estimated temperature rise within the cable mass generally dominated the ampacity assessment, and the surface heat transfer played only a limited role.

- It is apparent that as the level of diversity decreased (that is as more cables were assumed to be powered) the role of the surface heat transfer increased. This is as expected since all cases for a given fill depth assume the same in-tray behavior, but the external heat load increases in direct proportion to the number of powered cables. The increasing external heat load implies a much more significant role for the surface heat transfer behavior. As was discussed above, the surface behavior in Leake's model will be influenced in direct proportion to tray width.

- It is also apparent that the role of the surface heat transfer increases in importance as the depth of fill decreases. Again, this is consistent with the expectation that the role of the in-tray temperature rise decreases as does the fill depth; hence, the relative

importance of the external surface behavior increases. It is likely that the importance of surface behavior is significantly overstated for the low-fill cases with high diversity (e.g., the single powered cable case).

Another point to be observed is the potential for this method to yield clearly unreasonable results:

- Many of the ampacity estimates generated by the Leake model, especially including those for the lower fill depth, exceed the open air ampacity limits for a triplex configuration 12 AWG cable as taken from the IEEE 835-1994 standard [5]. (The IEEE triplex ampacity limit is roughly equal to the NEC 3-conductor limit; 36 A versus 35 A.)

This is not surprising. In fact, the Stolpe/ICEA heat intensity method also suffers from a similar problem whenever the depth of fill in the tray is less than the diameter of the cable under analysis. Stolpe had recommended that for a given cable, the ampacity not exceed that calculated for a fill depth equal to one cable diameter regardless of the actual fill (if less than one diameter). In the ICEA P-54-440 method, a limit of 80% of the open air ampacity is established which effectively accomplishes the same goal. Clearly, some similar check on the Leake would be appropriate to ensure that unrealistic ampacity estimates are not generated or assumed. (Note that the licensee has provided some limited example analyses using both the conventional ICEA methods and the Leake diversity method. In the "conventional" ICEA-based assessments, it is clear that the licensee has implemented the 80% of open air ampacity limit for random fill trays. No similar check on the diversity-based method appears to have been implemented. See further discussion of these examples in Section 3 below.)

One case that is of particular interest is the case for 20 powered cables in a 12" tray with a 0.5" fill depth (the upper right corner entry). Note that given a cable diameter of 0.43", it would require about 32 cables to reach a fill depth of 0.5". Hence, this case assumes that about 2/3 of the cables in the tray are energized. The ICEA limit for this case was 19 A whereas the Leake method would allow a 23.5 A load for each of these cables. This represents an increase of 23.7% in the ampacity limit due to crediting 2/3 diversity. This is, indeed, a significant allowance for this case. In particular, with 2/3 of the cables energized, there is a significant possibility that many of the energized cables will be co-located. Hence, the allowance for the diversity may be overly optimistic.

2.6 Validation

One critical aspect of thermal models is validation through comparison to data. Leake cites his validation basis as being primarily by implication. That is, he compares his results to the other diversity crediting methods and cites that his method is more conservative. He cites in particular that the Harshe/Black method was validated by comparison to in-plant cable performance data; hence, by implication his own "more conservative" approach is also validated by those data. However, no direct comparisons of any specific measured data to modeling assessments has been provided either in the paper or in the licensee submittal.

Unfortunately, the range of data available for this type of validation is rather limited. Stolpe, for example, included only one diversity experiment in his test set. The measurements made by Harshe/Black on actual cable at the Palisades Plant have only been presented in a very limited context, and to SNL's knowledge, no direct one-to-one correspondence between individual installation features and measured temperature data has yet been published. Most of the other laboratory tests performed to date have not involved load diversity. Hence, any validation is problematic.

In this regard, it is especially interesting to note the Stolpe test result as discussed above. For one cable, the diverse load test resulted in a 15°C drop in the measured cable temperature, while for another cable in the same test, the drop was only 1°C. For the third intermediate cable, the #1/0 AWG cable, the difference in measured temperature appeared to be about 9°C. Clearly the diversity benefit to be gained is very case specific, and will depend on a number of factors.

2.7 Recommended Application Limitations

SNL finds that in general the Leake methodology represents a reasonable compromise solution that can quantify some modest relaxation of the conservative assumptions of the Stolpe/ICEA methods by allowing credit for cable load diversity. However, SNL also finds that the licensee has failed to establish a basis for deciding when the method is appropriate, nor have sufficient checks been established to ensure that unrealistic results are not credited. SNL recommends that a clear-cut set of limitations be established to resolve these potential concerns. SNL found no discussion by the licensee of any self-imposed limitations to application of the method.

The first point of concern is to ensure that clearly unrealistic ampacity limits are not credited. The recommended constraint to address this concern is essentially identical to that already provide in the ICEA P-54-440 standard:

> It is recommended that in the application of the Leake method to diverse random fill cable trays, the maximum baseline ampacity limit, or the maximum baseline heat intensity, should under no circumstances be assumed to exceed 80% of the corresponding open air limits. That is, any calculation that estimates a baseline ampacity limit (or equivalently the corresponding heat intensity level) that exceeds 80% of the cable's open air ampacity should be discounted and disregarded.

In addition, the discussions presented in 2.4 above identified one important limitation to the Leake methodology, the potential that the role of tray width might be overstated under certain circumstances in which a cable hot-spot might not be dissipated. Hence, SNL recommends that some specific limitations be established to prevent mis-application of the method. In order to address the specific concern cited in 2.4 above, SNL recommends that the following limitation on the method be employed:

> The Leake method for crediting diversity should not be applied to the analysis of any cable whose diameter is greater than or equal to ½ the tray fill depth as calculated using the ICEA definitions of cable cross-section and fill depth.

Note that SNL has made this recommendation specific to the analysis of a given cable. That is, the mere presence of a large cable in a tray should not be an automatic basis for disallowing the method. The concern is that comparatively large energized cables should not be analyzed using this method, where large is measured in comparison to the tray fill depth. In this submittal, the licensee has cited no limitations on the applicability of the method. Hence, a potential for mis-application exists.

There is also a second aspect to this question as well. That is, as the number of energized cables in a tray increases, the probability that those cables might be located in close proximity or grouped within the tray increases. Again, if a grouping of the powered cables occurs, then heat may not be evenly distributed over the tray surface and a hot spot could form that would not be accounted for by the Leake method. Hence, it would also be appropriate to establish some bound on the level of diversity at which credit using this method would be appropriate. To address this concern, it is recommended that the following limitation be placed on application of the method:

> The Leake method should not be applied to any cable tray with a diversity of 50% or more where, in this case, diversity is defined as the ratio of the cross-sectional area of cables which are assumed to carry continuos loads to the total cable mass cross-section.

SNL acknowledges that these last two recommendations in particular have cited specific application criteria which cannot be definitively justified based on experimental or practical evidence. In fact, the cited limits are admittedly based largely on judgment. However, Leake has presented essentially no direct experimental evidence for his method, and it is clear that the method does have potential shortcomings which should be rigorously acknowledged and observed in practice. Leake has provided no specific guidance for the application of his method, although he has provided a qualitative discussion of its limitations.

While the SNL recommended criteria are judgmental in nature, they do at least provide a firm set of criteria for establishing when the method might be employed. This is, in SNL's view, needed to prevent gross misapplications. There is, of course, a potential that future research or experience will show that the recommended limits were overly constraining. By the same token, the future may also reveal these limits were overly generous. Because direct evidence supporting the method is lacking, there is a potential that the cables sized using the method may eventually be found to have experienced some premature aging. Based on SNL's own exercising of the model, and on a limited review of the supporting documents cited by Leake (Harshe/Black, [5]), if the constraints identified here are employed, the extent of any potential overloads should be minimal. SNL recommends that, as a matter of prudence, these constraints be exercised unless and until direct corroborating evidence is made available to demonstrate that the cited constraints are overly restrictive. Even in that event, it is recommended that an equivalent set of alternate constraints will be needed.

3.0 THE LICENSEE EXAMPLE CALCULATION

3.1 Overview

The licensee has provided one set of three example calculations illustrating the ampacity method as applied to a general cable tray. The first uses the "conventional" ICEA P-54-440 methodology, the second documents an analysis of a tray with maintained spacing, and the third case involves a diversity-based ampacity assessment using the Leake model. Each of these analyses is reviewed in the following subsections.

3.2 The Random Fill Tray Conventional Analysis

The licensee has provided one example of a conventional case analysis using the ICEA P-54-440 analysis method. SNL reviewed the calculation and discovered no discrepancies in the analysis process. The cited results appear consistent with the methodology in all regards.

3.3 The Maintained Spacing Tray Analysis

The full basis for the maintained spacing example case has not been established. In particular, the licensee has cited the open air ampacity for the subject cable, has applied a temperature correction for a 60°C ambient, and has applied a 0.74 ACF apparently to allow for a steel cover plate.

However, the methodology for maintained spacing installations as set forth in IPCEA P-46-426 [6] also specifies that an additional correction factor based on the number of cables in the tray is also applied. These correction factors appear in Table VII of the standard. The licensee has either not applied the correction factors, or has assumed that this cable is the only cable in the tray. The basis for this is unclear.

- It is recommended that the USNRC ask the licensee to ensure that for the analysis of maintained spacing installed cables the ampacity correction factor from Table VII of the IPCEA P-46-426 standard are being applied as appropriate to each case example.

3.4 The Diversity-Based Tray Analysis

The licensee has provided a diversity-based analysis of one specific cable tray, 1EZA1DATKBB, using the Leake methodology. The analysis focuses in particular on one cable, 1EHS07AC1KA, that cable with the highest actual heat intensity in the tray. In reviewing the calculation, SNL found that the basic Leake methodology appears to have been followed, but we were unable to reproduce the numerical results.

In particular, the licensee cites that the "maximum allowable heat intensity" using the Leake method of analysis is 11.671 W/in^2/ft. Based on the size and gauge of the cable, this corresponds to a current limit of 26.3 A. SNL repeated the case analysis using our own implementation of the Leake model and the physical parameters cited by the licensee

(see Appendix A). Our analysis yielded a maximum allowable ampacity of 24.0 A which corresponds to a heat intensity limit of 9.732 W/in^2/ft. No explanation for this discrepancy could be readily identified by SNL.

This difference carries through directly to the margins assessment. In particular, for the cited cable, a maximum allowable heat intensity of 9.732 would correspond to an ampacity limit of 24 A. In this case this is well within the 80% of open air limit for the cable, and no adjustment for that constraint is needed. This limit must then be compared to the cited maximum actual current of 15.3 A. This leaves a margin of 36.25%, but the fire barrier is cited as having a 38.9% ADF. Hence, even assuming acceptability of the margins method, this cable appears to be nominally overloaded.

- It is recommended that the licensee be asked to resolve the apparent discrepancy regarding the cited diversity case example analysis, and to ensure that no similar discrepancies have been introduced into the other in-plant applications of the methodology.

- It is recommended that in resolving this discrepancy, the licensee be asked to provide for a resolution of the apparently overloaded cable in the cited example tray.

4.0 SUMMARY OF FINDINGS AND RECOMMENDATIONS

4.1 The Leake Diversity Model

SNL finds that in general the Leake methodology represents a reasonable compromise solution that can quantify some modest relaxation of the conservative assumptions of the Stolpe/ICEA methods by allowing credit for cable load diversity. However, SNL also finds that the licensee has failed to establish a basis for deciding when the method is appropriate, nor have sufficient checks been established to ensure that unrealistic results are not credited. SNL recommends that a clear-cut set of limitations be established to resolve these potential concerns as follows:

- It is recommended that in the application of the Leake method to diverse random fill cable trays, the maximum baseline ampacity limit, or the maximum baseline heat intensity, should under no circumstances be assumed to exceed 80% of the corresponding open air limits. That is, any calculation that estimates a baseline ampacity limit (or equivalently the corresponding heat intensity level) that exceeds 80% of the cable's open air ampacity should be discounted and disregarded.

- The Leake method for crediting diversity should not be applied to the analysis of any cable whose diameter is greater than or equal to ½ the tray fill depth as calculated using the ICEA definitions of cable cross-section and fill depth.

- The Leake method should not be applied to any cable tray with a diversity of 50% or more where, in this case, diversity is defined as the ratio of the cross-sectional area of cables which are assumed to carry continuos loads to the total cable mass cross-section.

4.2 The Licensee Example Calculations

No discrepancies were found in the licensee's one example calculation based on a direct application of the ICEA P-54-440 method for random fill cable trays. However, in both the maintained spacing and diversity based examples, some discrepancies were identified. For the maintained spacing analysis:

- It is recommended that the USNRC ask the licensee to ensure that for the analysis of maintained spacing installed cables the ampacity correction factor from Table VII of the IPCEA P-46-426 standard are being applied as appropriate to each case example. It would appear from the cited example that these factors have not been included in the assessment.

For the diversity-based calculation:

- SNL was unable to reproduce the licensee's cited numerical results. In particular, SNL's calculations estimated a baseline ampacity limit lower than that cited by the licensee even though the same methodology was applied. It is recommended that the licensee be asked to resolve the apparent discrepancy regarding the cited diversity

case example analysis, and to ensure that no similar discrepancies have been introduced into the other in-plant applications of the methodology.

- SNL's re-analysis of the example case indicated that the specific cable under study did not have sufficient margin to allow for the estimated fire barrier derating impact. It is recommended that in resolving the numerical results discrepancy described immediately above, the licensee also be asked to provide for a resolution of the apparently overloaded cable in the cited example tray.

5.0 REFERENCES

1. H. C. Leake, "Sizing of Cables in Randomly-Filled Trays With Consideration for Load Diversity," *IEEE Transactions on Power Delivery*, paper 96 SM 372-3 PWRD, Jan. 1997.

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3. *Ampacities of Cables in Open-Top Cable Trays*, ICEA P-54-440, NEMA WC 51, 1986.

4. B. L. Harshe and W. Z. Black, "Ampacity of Cables in Single Open-Top Cable Trays," *IEEE Transaction on Power Delivery*, Vol. 9, No. 1, pp. 1733-1739, Oct. 1994.

5. *IEEE Standard Power Cable Ampacity Tables*, IEEE 835-1994, Sept. 1994.

6. *Power Cable Ampacities*, IPCEA P-46-426, AIEE S-135-1, a joint publication of the Insulated Power Cables Engineers Association (now ICEA) and the Insulated Conductors Committee Power Division of AIEE (now IEEE), 1962.

APPENDIX A:

SNL MATHCAD Implementation of the Leak Diversity Model
for Random Fill Cable Trays

Summary:

SNL has implemented the Leake model of diversity credit for random fill trays as described in the attached MATHCAD workbook file. In practice, SNL's implementation is relatively crude. The initial calculation assesses the temperature rise within the cable mass as per the simplified one-dimensional heat transfer model. This establishes the surface temperature of the cable mass. Note that this treatment is identical for both a Stolpe/ICEA assessment and for Leake's model. The second part of the model then calculates the rate of heat transfer away from the cable mass to the ambient by convection and radiation using the estimated cable surface temperature and the specified ambient as the driving thermal potential.

The limiting ampacity is derived by manual iteration until the predicted external heat flow rate from the tray to the ambient matches the internal heat generation rate. The model can predict Stolpe/ICEA limits by simply matching the external heat transfer to the full non-diversity based cable heat load. For the Leake model, one simply matches the external heat load to the specified actual heat load of the tray. This is the only difference between the two methods.

The example cited in the file is that corresponding to the SNL re-analysis of the licensee example application for Tray 1EZA1DATKBB. Note that SNL's results differ substantially from those cited by the licensee.

An implementation of the Leake Diversity-Based ampacity assessment method for cable trays.
Programmed by: S. P. Nowlen, August 1997

"Mathcad 'trick': equate temperature to charge units for older versions of the program such as mine:

$K := 1 \cdot coul \qquad CtoK := 273.16 \cdot K$

Set up initial parameters: Cable and tray charateristics:

$d_{cable} := 0.49 \cdot in \qquad R_{cable} := 1.35 \cdot 10^{-3} \cdot \frac{ohm}{ft} \qquad T_{amb} := (50 \cdot K + CtoK)$

$k_{cable} := 400 \cdot K \cdot \frac{cm}{watt} \qquad n_{conductors} := 3 \qquad T_{hot} := 90 \cdot K + CtoK$

$w_{tray} := 24 \cdot in \qquad d_{fill} := 1.56 \cdot in \qquad A_{surf} := 2 \cdot w_{tray}$

Physical Constants:

$\varepsilon := 0.8$

$\sigma := 0.530 \cdot 10^{-8} \cdot \frac{watt}{ft^2 \cdot K^4}$

Set current flow, iterate to 90C conductor temperature:

$I_{cable} := 24.02 \cdot amp$

Initial Calculations:

Cable Heat Load:

$Q_{cable} := I_{cable}^2 \cdot R_{cable} \cdot n_{conductors} \qquad Q_{cable} = 2.337 \cdot \frac{watt}{ft}$

Cable Heat Intesity (assumes ICEA definitions of area):

$HI := \frac{Q_{cable}}{d_{cable}^2} \qquad HI = 9.732 \cdot \frac{watt}{in^2 \cdot ft}$

Stolpe/ICEA based total mass heat load:

$Q_{mass} := HI \cdot d_{fill} \cdot w_{tray} \qquad Q_{mass} = 364.372 \cdot \frac{watt}{ft}$

Calculate cable mass Temperature Rise as per Stolpe:

$dT_{mass} := \frac{Q_{mass} \cdot k_{cable} \cdot d_{fill}}{8 \cdot w_{tray}} \qquad dT_{mass} = 38.852 \cdot K$

Calculate convection coefficient as per Stolpe:

$T_{surf} := T_{hot} - dT_{mass} \qquad T_{surf} = 324.308 \cdot K \qquad T_{amb} = 323.16 \cdot K$

$h_{surf} := 0.101 \cdot \frac{watt}{ft^2 \cdot K^{\frac{5}{4}}} \cdot (T_{surf} - T_{amb})^{\frac{1}{4}} \qquad h_{surf} = 0.105 \cdot \frac{watt}{ft^2 \cdot K}$

Given the temperature dop from cable to ambient, calculate rate of heat flow:

$$Q_{external} := h_{surf} A_{surf} \left(T_{surf} - T_{amb}\right) + \sigma \cdot \varepsilon \cdot A_{surf} \left(T_{surf}^4 - T_{amb}^4\right)$$

- In this crude version, must iterate manually (adjust the cable current, I.cable) to match internal and external Q terms:

For Leake, match Q.ext to Q.actual:

$Q_{external} = 3.123 \cdot \frac{watt}{ft}$ $\qquad$ $Q_{actual} := 3.10 \cdot \frac{watt}{ft}$

For Stolpe/ICEA answer, match Q.ext to Q.mass:

$Q_{external} = 3.123 \cdot \frac{watt}{ft}$ $\qquad$ $Q_{mass} = 364.372 \cdot \frac{watt}{ft}$