A Review of the Donald C. Cook Nuclear Plant Methodology for the Analysis of Fire Barrier Ampacity Derating Factors

A Letter Report to the USNRC

Revision 0

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Attachment to the Enclosure

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FORWARD

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 letter report documents the results of a SNL review of a submittal from the Donald C. Cook Nuclear Plant (CNP). This submittal deals with the assessment of ampacity loads for fire barrier protected cables. This document was submitted by the utility in response to USNRC Generic Letter 92-08 and in response to a subsequent USNRC Request for Additional Information (RAI). This work was performed as Task Order 9, Subtask 4 of USNRC JCN J2017.

1.0 OVERVIEW

1.1 Objective

In response to USNRC Generic Letter 92-08, and a subsequent USNRC Request for Additional Information (RAI) the Donald C. Cook Nuclear Plant (CNP) provided documentation of a methodology for the assessment of its cable ampacity loading factors including the effects of fire barrier ampacity derating impacts. This submittal included two sets of specific case examples, one for a series of conduits and one for a cable tray, to illustrate the methodology. The utility has also included a test report which is cited as supporting the validity of the utility calculation method.

The submittal reviewed was documented in a utility letter:

- Letter, May 12, 1995, (docket nos. 50-315, 50-316 item AEP:NRC:0692DF), E. E. Fitzpatrick, Indiana Michigan Power Co., to the USNRC Document Control Desk including six attachments as follows:
  - Attachment 1: Summary of Ampacity Derating Analyses
  - Attachment 2: AIEE Transactions Papers 57-660 & 50-52
  - Attachment 3: Cable Tray Allowable Fill Design Standard
  - Attachment 4: Analyses and Mathematical Models
  - Attachment 5: Representative Ampacity Derating Calculation Results
  - Attachment 6: Results from Test Report #CL-542

SNL was requested to review this submittal under the terms of the general technical support contract JCN J-2017, Task Order 9, Subtask 4. This letter report documents the initial results of this review.

1.2 Report Organization

Section 2 provides a review of the technical aspects of the utility analytical approach to ampacity assessments. In particular, two separate analytical models are developed by the utility, and each is reviewed independently. In addition, consideration is given to the validation, or lack thereof, of each of the two models. Section 3 provides a review of the example calculations provided by CNP. This includes calculations for one cable tray and for an undetermined number of conduits. SNL's review has included a comparison of the utility results to more conventional approaches involving the derating of tabulated ampacity limits. Section 4 provides a summary of the major issues and concerns identified in this review. Section 5 identified the referenced documents.

2.0 UTILITY AMPACITY DERATING APPROACH

2.1 Overview of Analysis Approach

The approach taken by CNP is based on a largely analytical assessment of actual cable ampacity limits with limited experimental validation of the overall analysis method. The analysis approach taken by CNP is quite unique in certain respects. In particular, the utility has cited that its cable installation procedures for power cables in cable trays required the use of, in effect, a maintained spacing approach. That is, power cables in cable trays at CNP were all installed so as to conform to the following features:

- no more than a single layer of power cables is installed in any tray,
- each cable in the tray to be separated from its neighbors with a gap of no less than 1/3 of the diameter of the larger of the two cables,
- the sum of the installed cable outer diameters shall not exceed 75% of the full tray width.

This is an important observation. The bulk of the utility model development is aimed at addressing sparsely loaded cable trays, although the final results are apparently applied to conduits as well.

The utility analyses are actually performed in two parts. The exact intent of each step remains somewhat unclear, and may have been misinterpreted in this review (a point requiring clarification). The utility discussion implies the following interpretation:

- Part 1 Analysis: Given an overall heat rejection capacity for the cable tray, calculate the allowable ampacity limit for individual cables. The method used in this part of the analysis is documented in Appendix A of the utility Attachment 4.

- Part 2 Analysis: Calculate the overall heat rejection capacity for a given cable tray (or conduit) based on heat transfer correlations and calculations. The method used in this part of the analysis is documented in Appendix B of the utility Attachment 4.

However, the utility description of the Part 2 analysis step appears to include both aspects of the problem to some extent. In particular, the Part 2 theoretical development presents equations for the calculation of ampacity limits, not for the calculation of total heat rejection capacity. In fact, the method appears to be intended to assess the ampacity limits of individual cables. Hence, it remains unclear as to the intent of the Appendix A and Appendix B methods, and how each works with the other to provide a complete solution. It is also unclear how the methods have been applied to conduits. That is, the utility provides examples involving conduits, but the Part 1 partitioning method would clearly not apply to conduit applications. Hence, how these conduits were analyzed remains unclear.

Each of the two parts of the overall utility analysis approach will be reviewed in detail in the following subsections. These discussions will include areas of potential concern identified during the review and the acceptability of the utility validation arguments. However, overall, the utility should provide for some discussion of how the two parts of the analysis work together in practice, and should provide more detailed examples which illustrate how the two parts of the analysis were used individually to obtain actual cable ampacity limit estimates. Note that Section 3 of this report will discuss this final point, the example analyses, in more detail.

2.2 The Utility Part 1 Analysis Method

2.2.1 Basis and Underlying Assumptions

As noted above, it is our interpretation that the intent of methodology described in Section A of utility Attachment 4 (which will be referred to here as the Part 1 analysis for convenience) is to determine the ampacity of individual power cables given an estimate of the overall heat rejection capacity of a given cable tray. (Note that the heat rejection capacity is calculated separately as discussed in Section 2.3 below.) The utility methodology, in effect, partitions the overall heat rejection capacity to individual cables. This partitioning is ultimately based on a ratio of the available surface area of a given cable to the total surface area for all cables in the tray. Once the heat rejection capacity for the given cable is established, the corresponding ampacity limit is calculated using a simple "I^2R" type calculation.

The critical underlying assumption in this analysis derives directly from the utility cable installation practice which, as discussed in Section 1 above, required that only a single layer of cable be installed, and that those cables be installed with, in effect, a maintained spacing between cables. Based on this practice, the utility concludes that the heat transfer behavior of its cable trays is dominated by convection and radiation, rather than by conduction. This is an important distinction because convection and radiation are both driven primarily by the available heat transfer surface area, in this case, the actual surface area of the installed cables.

In contrast, for general cable trays, such as those tested by Stolpe [1] in his pioneering cable tray ampacity work, heat transfer within the cable mass is dominated by conduction. This, CNP notes, is reflected in the fact that open top cable tray ampacity tables in that the ampacity limits are cited as a function of the cable depth of fill and based on the limiting heat generation rate per unit volume of the cable mass for a given cable size. In some senses, the utility appears to take this analogy a little father than it should be taken, although this is not considered to be directly relevant to the ultimate validity of the utility methodology.[1]

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[1] That is, CNP cites the comparison made by Stolpe between the volume occupied by seven #12AWG cables as essentially equal to that of a single 4/0 cable. The utility then states that "thus the heat generated by the two configurations should be equivalent under uniform heat distribution conditions." However, this idealism did not hold true for Stolpe's final results. A review of the ICEA P-54-440 ampacity tables will reveal

2.2.2 Theoretical Development

For the sparsely loaded trays at CNP convection and radiation are considered the governing modes of heat transfer. This assumption is considered to accurately reflect the sparsely loaded cable trays at CNP (with one possible exception as will be discussed in Section 2.2.4 below). Based on this assumption, the utility postulates that individual cable ampacity limits can be established based on consideration of the heat generation rate per unit of cable surface area. It is this assumption which drives the utility method.

The utility development of itsthermal model is presented in Sections A.3 and A.4 of Attachment 4 to its submittal. The development first begins by considering a case in which all the cables are assumed to be of the same size. The total available surface area of the cables in the tray is then given by:

$$A_s = n \pi d \qquad (1)$$

Where (A_s) is the cable total surface area, (n) is the number of cables, and (d) is the outer diameter of the cable. The utility then defines the "percentage fill of the tray" (F) as:

$$F = n d \qquad (2)$$

The utility acknowledges that this definition of percentage fill is not consistent with general industry practice. SNL further notes that to describe this value as a percentage fill is not accurate. The quantity (n*d) is a linear dimension which quantifies the total width of the installed cables. Hence, (F) will have units which are the same as those used to express (d), inches for example. This is by no means a "percentage fill" term because a "percentage" term is a ratio of one quantity to another of equal dimension. A "percentage" term should be dimensionless. It would be more accurate to simply call this value the "total fill" rather than the "percentage fill." This is a minor point of nomenclature, and so long as the value is used consistently, should introduce no errors.

The utility then goes on to express the total heat generation rate (Q) for a tray as a whole based on simple "I^2R" heating:

$$Q = 3n\, I^2 R_{ac} \qquad (3)$$

where (I) is the cable current and (R_{ac}) is the AC resistance of the cable of interest. Note that the constant (3) appears because the utility assumes that each of the cables is a three-conductor cable. Combining equations (2) and (4), the utility eliminates the variable (n):

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that the limiting heat generating capacity for a 4/0 cable is on the order of 12-18 times that of a 12AWG cable, not 7 times as this idealization would suggest. This is only a very minor point and has no real impact on the utility methodology.

$$Q = 3\frac{F}{d}I^2R_{ac} \qquad (4)$$

CNP then rearranges this expression to solve for the current (I) as a function of heat rejection capacity (Q). While this same equation is written in at least three formats through the development, the final expression is presumably utility equation 9 as follows:

$$I = \sqrt{\frac{Qd}{3FR_{ac}}} \qquad (5)$$

or by rearranging the terms in this expression:

$$I = \sqrt{\frac{Q}{3F}} \times \sqrt{\frac{d}{R_{ac}}} \qquad (6)$$

This, then, is the ultimate method of partitioning the total heat rejection capacity of a cable tray as a whole down to individual cables. Note that as shown in (6), the grouping ($[d/R_{ac}]^{1/2}$) is a function of the individual cable; the diameter divided by the AC resistance. For larger cables, the diameter increases and the AC resistance decreases, so the value of this grouping increases with cable size. The grouping ($[Q/3F]^{1/2}$) is a function of the tray; the limiting tray heat load divided by the total cable fill.

2.2.3 Validation

The utility validation of this thermal model is presented in Figure A-1 of the utility Attachment 4. This figure plots current (I) versus the ($[d/R_{ac}]^{1/2}$) cable characteristic grouping. Consistent with equation (6), the utility anticipates a linear relationship passing through the origin. This is, in fact, demonstrated for three specific cable tray configurations, each involving a 67% fill of the tray. The configurations involve a ventilated tray with a ventilated cover, a solid tray with a solid cover, and a ventilated tray with a 1hr barrier system. In each case the linear relationship holds true. While this plot does provide some encouraging results, it is not sufficient to fully validate the utility Part 1 analysis method. The most important factor which has not been established by the utility is related to the heat loads (Q) which were measured in these experiments.

That is, the utility method assumes that for a given cable tray, the total limiting heat rejection capacity is a function of the total available cable surface area, which is in turn a function of the loading factor (F). Hence, in order to validate this assumption, the utility must demonstrate that in its experiments, for any one combination of tray configuration (e.g. for an open tray) loading factor (F) and temperature difference (T_{cable}-$T_{ambient}$), the same overall heat load was measured independent of the size of cables tested. For example, all trays were apparently loaded to 67% of the available width. We must assume that cables were current-loaded to establish a hot-spot

temperature of 90°C (an assumption which needs to be verified by CNP). To validate its model, CNP should show that the total resistance heating load measured for the various cable sizes remained constant for each of the tray configurations tested regardless of the cable size installed. Without additional information regarding the nature of the tests cited by CNP, this assessment cannot be made.

In order to complete this assessment the utility must provide additional information on its test protocol and results. For example, providing a copy of the missing Appendix C may prove sufficient. At the least, the utility should ensure that the following points are addressed:

- The physical description of the experimental setup and test articles should be provided. This should include a physical description of the test articles themselves (tray widths, height and length), a physical description of the cables tested (size and conductor count), a description of test instrumentation, and a description of the installation of cables in the test article (types, spacing and locations).

- A discussion of the testing protocol is needed. This should include the a discussion of the specific objective of the test. For example, were cable currents adjusted to achieve a desired temperature state? What was the desired final end state of the experiments in terms of temperature and current? Were different sized cables installed in the same test article, and if so how were the currents for these different sized cables determined? How did the tests verify that a steady state condition was achieved?

- A summary of the test results in needed. This should include the final measured values of current and temperature for each of the cables in any given test article.

- The utility should describe the units associated with its Figure A-1 and describe how tested cable parameters correspond to the plotted values.

- The current (I) shown in Figure A-1 is assumed to be given in units of Amps, but this would imply that mostly very large cables were used in testing. The measured current values range as high as 700A which would generally imply a cable of on the order of 750 kcmil, which appears to be much larger than the cables considered elsewhere (the largest cable identified elsewhere in the submittal is a #4/0 cable). The physical cable sizes tested should be described, and the applicability of the tested cables to the cables considered elsewhere in the analysis should be established.

2.2.4 Summary of Technical Concerns

The primary technical concern regarding the utility Part 1 analysis method which must be addressed is one of validation. The utility analysis is based on two fundamental assumptions:

- The total limiting heat load for a given cable tray is a function of the total surface area of the cables, and

- This total heat load can be partitioned to individual cables based on each cables contribution to the overall available cable surface area.

CNP has not provided sufficient information to determine that it has, in fact, validated these two critical assumptions. Additional detail regarding the experiments it performed to validate this aspect of the thermal analysis models is required. Section 2.2.3 above provides a description of the additional information required.

There is one particular factor which may be inadequately treated in the utility analysis. That is, the cable temperature rating of 90°C is based on the conductor temperature, not the surface temperature of the cable. I would agree that once the heat reaches the cable surface, convection and radiation become predominant. However, within the cable itself, conduction of heat through the insulation and jacket materials remains a critical factor. While the utility Part 2 analysis includes a thermal resistance element associated with the insulation, the concern here is with the Part 1 partitioning analysis in which increasing diameter is credited for increasing ampacity in proportion to the cable diameter. This would be correct if the surface temperature of the cable remained fixed (for example at 90°C) but will not hold true if the cable surface temperature changes with diameter. In fact, because the electrical insulation is also a thermal insulation, the thicker that insulation becomes, the higher the temperature drop through the insulation will be for a given overall rate of heat flow, and hence, the lower will be the surface temperature of the cable. This would cause some error in the utility method, although based on the information provided, it is impossible to assess the magnitude of the error introduced.

The potential pitfall can be illustrated as follows. For two cables of the same wire gage, the thickness of the insulation would depend primarily on the voltage rating of the cable. Thus, a 600V cable would have a smaller overall diameter than would a 5000V cable. In the utility method, this would imply that if these two cables were in the same tray, the allowable ampacity of the 5000V cable would be predicted as higher than that of the 600V cable in accordance with the ratio of their diameters. In reality, the increased thickness of the insulation for the 5000V cable would generally result in a reduced ampacity for the more "open" (maintained spacing) application such as those at CNP. (For tightly packed cable trays, as per Stolpe, the volume is the overriding factor and ampacity does increase with cable voltage rating. However, more open conditions allow more generous ampacity limits, and cable volume is not the overriding factor in these ratings.) This is particularly true for the larger cable sizes. Note, for example, that the open air ampacity tables in IPCEA P-46-426 will generally decrease the allowable ampacity limits for single conductor cables with increasing voltage rating for cables larger than about 1/0AWG (the transition point depends on the table considered and the temperature rating of the cable). The utility method would allow just the opposite effect.

The utility should provide for some assessment of this question. One approach which might prove fruitful would be for the utility to examine the open air ampacity tables

for the types of cables in use at CNP, and for CNP to attempt to validate their assumptions regarding ampacity as a function of cable diameter. For example, with the three conductor cables (which seem to be quite common at CNP) the transition point in the tables is at much larger cable sizes. Alternatively, the utility tests may provide some further information on this question for the specific cables in use at CNP. The information provided in the submittal is insufficient to determine whether or not such a comparison can be made. In any case, the utility must demonstrate that its diameter-based partitioning approach appropriately reflects these ampacity limit behaviors with increasing voltage rating and increasing cable diameter. That is, the utility should show that, in fact, for its cables ampacity limits increase with cable overall diameter (voltage rating), and that this increase is consistent with their diameter scaling assumptions. The utility might also consult manufacturer recommended ampacity limits of cables in comparison to cable diameters.

2.3 The Utility Part 2 Analysis

2.3.1 Basis and Underlying Assumptions

Section B of the CNP Attachment 4 documents a second, separate but related, thermal analysis method (this method will be referred to here as the utility "Part 2" analyses). This method is based loosely on the Neher-McGrath approach to cable thermal analysis, although considerable liberties are taken with that methodology. The intent of the method is, apparently, to provide estimates of the total limiting heat rejection capacity of a given cable tray based on the configuration of the tray, the number of cables installed in the tray, and the nature of the protective features (barrier) installed on the tray.

In executing this calculation the utility is inherently assuming that it can accurately model the physical phenomena of interest and thereby estimate the actual cable heat rejection capacity of a given cable tray or conduit system. This overall system heat rejection capacity is then partitioned to individual cables in the tray through the Part 1 analysis method as discussed in 2.2 above.

2.3.2 Theoretical Development

The basic structure of the Part 2 thermal model derives directly from Neher-McGrath. The general expression is quite simple and straight forward. The approach is based on forcing a steady state balance between the rate of heat generation in the cables and the rate of heat dissipation from the cables to the ambient. The rate of heat generation can be expressed as:

$$Q_{gen} = I^2 R_{ac} = I^2 R_{dc}(1 + Y_c) \tag{7}$$

where (R_{ac}) is the cable AC resistance, (R_{dc}) is the cable DC resistance, and (Y_c) is the AC/DC resistance increment. In its most simple form, the rate of heat dissipation can be expressed as:

This assumption is acknowledged by the utility to be of questionable validity. In general, the treatment of a rectangular system using circular geometry can introduce anomalous behavior, often associated with the paradox of surface area changes. That is, a system of nested annular bodies experiences an increase in the available surface area as one moves outward through the system. This is not a characteristic of a typical one-dimensional rectangular system, and hence, great care must be taken to ensure that the surface areas assumed do not distort the heat transfer behavior. Because the utility has provided no detailed calculation examples it is impossible to determine how significant this effect would be for the utility analyses. While CNP states that they achieved "excellent correlation between computer data and test data" no evidence of this validation is provided. This aspect of the utility model is still considered suspect. This question will be revisited in 2.3.4 below.

The utility calculation of the cable-to-ambient thermal resistance apparently includes consideration of the various layers in the system (the cable insulation, the tray or conduit, the barrier itself) and the air gaps between layers. However, the exact manner in which these various factors are implemented in the model is unclear because the utility simply cites certain correlations, but does not provide any description of the overall final structure of its thermal model.

While the overall method is taken from Neher-McGrath, the correlations used to characterize the various layers are actually taken from a paper by Buller and Neher [3]. While this paper was published in 1950, it cites a 1933 text by McAdams [4] as the original source of the correlations presented. Hence, these heat transfer correlations are quite dated, and in fact, predate any but the most elementary of heat transfer investigations. This is a point of significant potential concern. Since 1933 the field of heat transfer has advanced significantly, and much improved correlations for heat transfer behavior are now available. In particular, it is only in the period since that time that extensive scientific investigations of critical heat transfer phenomena have been undertaken which took advantage of sophisticated instrumentation and electronic data gathering methods. In fact, SNL was unable to obtain a copy of the McAdams text, now being long out of print.

The use of such dated correlations would appear inappropriate. Of particular concern in this regard would be the convection, conduction and radiation terms associated with the air gaps as given by utility equations 17-19. These are quite crude estimates of air gap behavior, and would not be considered good practice by today's standards.

A related, but somewhat different finding is a particular concern related to the modeling of heat transfer from the outer surface of the barrier to the ambient environment (utility equation 21). In this particular case there are two points of concern. First, this expression actually derives from a 1929 work [5], and hence, must also be considered quite dated. Second, the correlation applies only to pipes, and derives from studies of black pipes that ranged in size from 1.3 to 10.8 inches in diameter. (Given the vintage of the correlation, this is not very surprising as most of the then current studies were focussed on the fairly simple cylindrical and spherical geometries.) In no case should correlations based on heat transfer from a pipe be applied to flat plate surfaces such as those which would be experienced around a cable

tray. The physical configuration of a pipe is quite different from that of a flat plate, and hence, the buoyancy driven convective air flows surrounding a pipe are quite different from those surrounding a rectangular object. In general, the convective currents around a pipe would be far more efficient, and hence, convective heat transfer is also typically far more effective for a pipe than for a flat plate on a per unit of surface area basis (the average heat transfer coefficient for a pipe would be significantly larger than that of a rectangular box). This would be particularly true for downward facing heated surfaces such as those on the bottom of a tray. This is one area where the treatment of the cable trays using cylindrical assumptions would be both inappropriate and optimistic (tend to overestimate the efficiency of heat transfer).

Overall I was unable to assess the potential impact that use of more modern correlations would have on the results because no listing of the actual program has been given, because no specific values for the various inputs have been provided to support the example calculations cited by CNP, and because of other uncertainties in the utility analysis method. As a general point, the utility might be able to overcome this shortcoming through a thorough validation of the model results. That is, so long as the model yields conservative results for a full range of applications, then the issue of using dated or inappropriate correlations might be considered of secondary importance. As will be discussed in Section 2.2.3 below, the utility has not met such a burden of validation.

One other point regarding the various heat transfer correlations is how the utility accounted for the effects of the actual available surface area in each layer. That is, the utility treats each layer as a progressively larger cylinder. This is not an accurate representation of a cable tray system. In particular, a cable tray is, in reality, a largely one-dimensional heat transfer problem with heat flowing upwards and downwards away from the centrally located cables. Hence, the surface area remains fixed as one passes from layer to layer. In the utility model, the surface area continuously increases as one moves from layer to layer. How this would impact the utility results in again unclear. In general, the utility treatment might yield results which are in significant error (either conservative or nonconservative). The actual rate of heat transfer from (convection and radiation) or through (conduction) a surface is directly proportional to the available surface area. Hence, if the surface areas are not maintained at the same value in the model as those of the actual physical system, then significant errors could result. This would directly translate into errors in the ampacity limits predicted because the ampacity limits are directly related to the limiting rate of heat transfer. The utility treatment provides no assurance that the surface areas have been appropriately treated. This is especially important in a direct calculation of limiting heat loads such as that implemented by the utility.

Another point of concern related to a particular factor (variable) introduced into equations 16-21. This concern raises additional questions regarding the intent and general validity of the utility analysis. That is, the stated intent of the Part 2 analysis is to calculate the limiting heat load for a cable tray as a system. However, the treatment appears to be based on calculation of individual cable ampacities directly, and quite possibly uses a thermal partitioning assumption which is in direct conflict

with the stated assumptions of the Part 1 analysis. For example, consider utility equation 16:

$$\overline{R} = 0.0104\ \overline{\rho}\ n'\ \left(\frac{t}{D-t}\right) \qquad \text{(CNP16)}$$

This equation is cited as characterizing "the thermal resistance through relatively thin cylinders (i.e., cable jacket, tray, fire barrier)". The variable (n') is stated to be "the number of conductors within the section." This would appear to be a rather strange relationship for expressing the thermal resistance of the fire barrier, for example. What possible impact would the number of conductors within the fire barrier have on the thermal resistance of the fire barrier itself? There is no direct contact between the two, and hence, the fire barrier system should not be impacted by the number of cables inside of it. In reviewing the Buller-Neher paper, a somewhat different definition is given, but the exact meaning remains unclear. It would appear that this is, in effect, a "thermal partitioning factor." That is, it would appear that Buller-Neher use this factor to partition the overall system heat load to individual conductors based simply on the conductor count. So long as the cables are all identical, such an approach might be considered appropriate. However, the utility analysis involves cables of different types and sizes in the same cable tray. Hence, partitioning based on the simple conductor count would be inappropriate. This would also appear to be in direct conflict with the assumptions made in the Part 1 analysis. That is, in the Part 1 analysis, CNP has assumed that the thermal load for the cable tray as a system can be partitioned to individual cables based on each cables contribution to the available surface area. Clearly, the use of the factor (n') is not consistent with this stated assumption. How the utility implemented this factor is entirely unclear.

As a related finding, there was on quite puzzling statement made during the discussion of utility equation 20 as well. In the paragraph immediately preceding that equation the utility states:

> "The thermal resistance per conductor will be the total number of conductors divided by the total thermal conductance."

The intent, basis, and impact of this statement is completely unclear. Here again, the utility introduces the parameter (n') as the number of electrical conductors. In effect, the utility seems to be partitioning the total thermal resistance associated with this layer (the air gap) by the number of conductors present to estimate the resistance per conductor. (In effect, this is a treatment in which the overall system thermal resistance is treated as a set of individual resistance elements, one for each conductor, arranged in a parallel resistor configuration. Hence, the thermal resistance for the overall system is actually less than that associated with a single cable.)

Why this apparent partitioning of the thermal resistance is necessary is unclear. How this assumption accounts for cables with different physical diameters is also unclear. Finally, this apparent partitioning appears to be in direct conflict with the Part 1 analysis assumption in which the partitioning is assumed to be based on surface area ratios. Again, the level of documentation is insufficient to determine exactly how this

particular factor was implemented in the final utility model (no listing is provided) and whether or not the problem is self-correcting (for example, the computer model may simply multiply by (n') in one spot and then divide by (n') somewhere else and thereby neutralize the assumption entirely). In any case some additional explanation of how these equations relate to each other and to the Part 1 analysis, and the basis, intent, and impact of the factor (n') is needed.

One final factor which appears to be lacking in the utility model is a treatment of the effects of spacing on the radiative heat transfer behavior of the cables. That is, the utility assumes that the full surface of each cable is equally effective as a radiating body for the dissipation of heat. This would not be correct, and would become more incorrect as the spacing between cables became smaller. That is, in effect, the sides of the cable "see" the neighboring cables and exchange heat with those neighboring cables as well as with the next layer of the thermal system (the inside of the fire barrier for example). This is normally treated through the application of a radiation view factor. This would be a value between 0.0 and 1.0 which relates the relative fraction of the radiating body which effectively "sees" the other participating surface. In this case, this value would likely be on the order of 0.5-0.7 depending on the cable-to-cable spacing, and on the uniformity of the cable sizes. This factor would significantly reduce radiant heat transfer in comparison to that assumed by the utility. In effect, the utility has assumed an ideal view factor of 1.0, and this is certainly not correct.

2.3.3 Validation

As noted above, the utility states that it obtained "excellent correlation between computer data and test data". SNL was unable to find evidence of this in the utility submittal. The submittal does include a description of 6 specific experiments performed to measure cable operating conditions under very specific ampacity loads. The utility has also provided the final results of its thermal analysis of one specific cable tray and an undetermined number of conduits (possibly as many as 12 conduits or as few as three depending on how the results are interpreted). However, there is no direct correlation between the experiments performed and the cable trays or conduits analyzed.

Such a comparison may be difficult to draw considering the nature of the experiments documented. The utility test report cites that the objective of the experiments was "to simulate as closely as possible the actual conditions of tray and conduit runs proposed for Cook Plant and determine the final conductor temperature for the specified amperage and tray fill." This objective is not compatible with the goal of validating an analytical model which purports to estimate ultimate cable ampacity limits.

Validation of the ampacity limit model would require that the utility show that its estimated ampacity limits conservatively bound actual measured ampacity limits in the corresponding physical system. This would require that a test be performed on a particular physical system, and that the ampacity limit of each of the cables in that system when operated simultaneously be determined experimentally. These experimental values should then be compared to the estimated ampacity limits as a

final validation. In contrast, the utility has performed tests in which the ampacity loads were predetermined, and the test simply measured the operating temperatures of the cables. This would be a useful test for assessing the actual operating conditions of specific in-plant installations, but would not be useful in the validation of the utility model because there is no determination of the actual ampacity limits for the tested case.

It is possible that the tests originally described in Appendix C of the utility analysis development document would be more helpful in resolving this uncertainty. However, because Appendix C was not provided, it is impossible to make this assessment. Given the documentation provided, SNL must conclude that the utility has provided no meaningful validation of its analysis method for calculating cable ampacity limits and cable tray limiting heat rejection capacities.

2.3.4 Summary of Technical Concerns

A number of areas of specific concern were identified in this review. Overall, the thermal model for the estimation of total limiting heat rejection capacities was found to be poorly founded, and poorly validated. It is not recommended that this model be accepted until the technical concerns identified are resolved, and the model receives an adequate validation treatment. In particular, the following items were identified:

- The utility treats all cable tray systems using a model based on circular geometries. This practice is said to have been validated based on the "excellent correlation between computer data and test data". However, no evidence of such validation has been provided.

- In general, the treatment of an inherently rectangular geometry based on cylindrical correlations can lead to significant errors. This is particularly true for convection correlations. The convective heat transfer from a cylinder is more efficient than that from a flat rectangular box. The utility use of convection and radiation correlations based on heat transfer from pipes (utility equation 21) is inappropriate and nonconservative.

- This utility treatment of equivalent annular regions also appears to ignore the importance of the available surface area in heat transfer correlations. That is, heat transfer rates are directly proportional to the surface area. The utility has provided no assurance that in generating its equivalent annular regions, appropriate heat transfer areas representative of the actual physical system have been maintained. This could easily distort the modeling results in either a conservative or nonconservative manner. This is especially true since the utility is attempting to directly calculate absolute heat transfer rates, which in turn determines the ampacity limits of the installed cables.

- In a more general context, given the documentation provided, SNL must conclude that the utility has provided no meaningful validation of its analysis method for calculating cable ampacity limits and cable tray limiting heat

rejection capacities. Such validation should be required before the analysis methodology is accepted.

- The utility model is based on heat transfer correlations which were orignially published in the 1929-1933 time frame. These correlations are badly dated, and the impact of using more modern correlations in the model should be assessed.

- The utility has made a very confusing statement regarding the relationship between the thermal resistance of individual cables and that of the system as a whole (see the first sentence in the paragraph immediately preceding equation 20 of the utility analysis: "The thermal resistance per conductor will be the total number of conductors divided by the total thermal conductance"). The basis, intent, and impact of this statement needs to be further explained and clarified particularly in the context of the stated objective of estimating the limiting heat load for the cable tray as a system rather than individual cable heat loads (the apparent purview of the Part 1 analysis method).

- The utility correlation for "the thermal resistance through relatively thin cylinders (i.e., cable jacket, tray, fire barrier)" (utility equation 16) includes a factor (n') described as "the number of conductors within the section." A similar treatment is also noted in the case of utility equation 21, the "thermal resistance from the last surface to ambient." It is unclear how this factor has been applied in the utility analysis. It would appear that this is, in effect, a partitioning factor for heat transfer from the system down to individual conductors. If this is a correct interpretation, then this partitioning is in direct conflict with the Part 1 analysis in which heat is partitioned on the basis of available surface area. The use of this factor in the context of the utility analysis is unclear, and may be inappropriate. In particular, the utility is dealing with situations involving cables of various sizes, types, insulation thicknesses and conductor number. How this factor is implemented by the utility and the net effect of this factor on its analysis needs to be clarified. The basis, intent, and implementation of these equations, and the factor (n') in particular, should be clarified.

- The utility model has provided no treatment of the effects of spacing on the radiative heat transfer behavior of the cables. The utility should include consideration of radiation view factors in the development of its radiative heat transfer correlations which might significantly reduce the predicted rates of radiant heat transfer.

2.4 Conduit Applications of the Model

The development of both the utility Part 1 and Part 2 thermal models is presented primarily in the context of cable trays. However, it appears that the same thermal model is also being applied to conduits. This raises certain unique questions which should be addressed by the utility.

It must be noted at the outset that the level of information provided with regards to its conduit applications was even more sparse than that provided for the cable trays. In particular, the utility has provided no discussion of how the model was applied to conduits, and yet, example results for cables in conduits are presented (see the utility Attachment 5). With regard to these example results, while the utility has provided several example analyses of cables in conduits, it is unclear whether each cable is housed in an individual conduit, or whether more than one cable might be housed in a common conduit. Given the size of the cables (the largest is 1.14" in diameter), and the size of the conduits (up to 4"), it is quite possible that more than one cable is installed in a given conduit.

First, recall that the use of a maintained spacing installation procedure for its cable trays was cited in this review as a critical factor in the thermal modeling of the cable trays. This same factor would certainly not apply in general to conduits. Of particular concern would be any conduit which houses more than one cable. For a conduit with a single installed cable, the utility thermal model might be considered appropriate. That is, in a direct calculation of ampacity limits, the most conservative approach would be to assume that the cable is located in the center of the conduit and that there is no contact between the cable and the conduit itself.[2] In the case of a single cable, the full surface of the cable would be available for heat transfer. However, in the case of any conduit with more than one cable installed, the cables would be arranged in a bundle of some type, and hence, only a fraction of the total cable surface area would actually be active in the surface heat transfer processes. The utility model would, apparently, assume that the full surface area of the cables was available for direct thermal exchange with the next layers in the system (convection to the air gap and radiation to the inner surface of the conduit). This would be a nonconservative assumption for multiple cable installations.

The lack of maintained spacing for cables in conduits would also effect the validity of the utility Part 1 partitioning analysis. That is, for conduits with more than one cable installed, the partitioning of the total allowable heat limit for the system to individual cables based on the surface area of the cables could not be justified on the same basis as that applied to the cable trays (maintained spacing). This, again, is because the active surface area would not be equal to the total surface area. In fact, it is quite possible to have a cable fully surrounded by other cables, and hence, to have in effect no active heat transfer surface area for direct exchange with the next layer in the system (convection to the air gap and radiative exchange with the inner surface of the conduit).

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[2] Recall that this is in contrast to the case in which a model is attempting to assess a relative derating impact. In the case of a relative calculation, assuming that the cable is in contact with the conduit is both more realistic and more conservative because this maximizes the relative change due to addition of the fire barrier. CNP has not performed a relative calculation, but rather, an absolute calculation of ampacity limits. Hence, the central location assumption would be conservative.

A second factor which is, again, not clear relates to the general treatment of surface area in the utility model. As noted above in the context of the cable trays, heat transfer rates are directly proportional to the available surface area. Hence, it is critical that the surface area values assumed in the model accurately represent the physical system. This would be especially true for the conduits because the available surface area is generally small, and minor increases in the assumed diameter of a conduit would severely effect the heat transfer rates. The input variables identified by the utility imply that such an artificial increase might inadvertently result from the structure of the utility model. That is because the model inputs are given in terms of the initial diameter of the inner layer and then the thickness of the air gaps between layers. Hence, depending on how the model was implemented, these layer thicknesses might simply be accumulated to determine the equivalent diameter of each layer. Because the computer code has not been supplied, it is impossible to tell how this was implemented by the utility. In the utility model it is a direct calculation of heat transfer rates which determines ampacity limits, and hence, errors in the estimation of heat transfer rates translate directly into ampacity errors.

2.5 Coordination of the Utility Analysis Package Elements

As discussed in Sections 2.2 and 2.3 above, the utility analysis methodology is presented in two parts. The text accompanying the model descriptions implies that the first part of the analysis (as documented in utility Attachment 4, Section A) provides a basis for assessing individual cable ampacities based on the overall heat rejection capacity of the thermal system as a whole. Similarly, it is implied that the second part of the analysis (as documented in utility Attachment 4, Section B) is intended to provide for the estimation of the overall heat rejection capacity of the thermal system as a whole. That is, the Part 2 analysis estimates overall heat rejection capacity, and the Part 1 analysis partitions that overall capacity to the individual cables in the system.

However, upon review of the Part 2 analysis description, it is not entirely clear how the two parts of the analysis, in fact, work together. The development in the part two analysis provides an expression for the ampacity of the cables directly as a function of the environmental and electrical conditions. This would appear to make the Part 1 analysis method entirely obsolete. The Part 2 analysis also incorporates a conductor count factor, (n'), which appears to act as a thermal partitioning factor. If this interpretation is correct, then this partitioning is in direct conflict with the assumptions made in the Part 1 analysis. That is, in the Part 1 analysis thermal partitioning is assumed to be in proportion to the cable surface area. In the Part 2 analysis, thermal partitioning appears to be based on a simple conductor count (each conductor is partitioned equally regardless of size). This is an inconsistency which must be resolved.

The utility should be asked to clarify the intent of each part of its overall analysis method, and to describe how the two parts of the analysis work together. The examples provided should illustrate both aspect of the analysis (the Part 1 and Part 2 analyses) and should provide sufficient information to verify the calculations.

As a final point of general concern, I must remain skeptical of any purely analytical predictions of actual ampacity limits. In our own work[3], it was found that while predicting a relative change in ampacity limits due to addition of a fire barrier system was relatively simple, predicting actual ampacity limits based on direct thermal modeling was much more difficult, and led to much greater uncertainties. The problems generally arise from the rather large uncertainties inherent in general heat transfer correlations for such factors as convective heat transfer. This is a particular concern given that the utility is basing its analysis on correlations of 1929-1933 vintage. This means that there is a significant inherent uncertainty in the utility calculations, and that significant validation against known conditions should be provided. One potential approach which might prove fruitful would be for the utility to compare its modeling predictions to other, more common, ampacity derating approaches and test results. This is discussed further in Section 3 in conjunction with a review of the utility examples provided in CNP Attachment 5.

[3]See the results of USNRC JCN J2018, Task Order 2.

3. UTILITY EXAMPLE CALCULATIONS

3.1 Overview

The utility has provided two sets of example ampacity calculations, one for a particular cable tray, and a second set associated with certain conduits. In general, the level of detail provided by the utility is insufficient to fully review these calculations. For example, in no case has the utility identified the nature of the fire barrier installed (nominal 1hr or 3hr, nor installation characteristics such as thickness, materials, upgrades, etc.). For the cable tray example, no information on the physical characteristics of the cable tray are provided (width, height, covers, or configuration such as solid bottom, ventilated bottom, or ladder type). For the conduits, it is not possible to determine whether each cable is housed in a separate conduit or whether multiple cables might be located in a common conduit (grouping factors for conduits are a particularly important consideration).

As a part of this review of the utility example results, SNL has attempted to compare the utility results to those one might obtain using more "conventional" approaches to ampacity derating. In particular, a more typical approach to the derating would involve an initial assessment of the baseline ampacity of the cables from published ampacity tables, and the derating of those values based on factors such as ambient temperature, grouping and the fire barrier itself. In this review, SNL has attempted to make such comparisons as appropriate to the particular example.

3.2 Cable Tray 1AZ-P8

In the case of sparsely loaded cable trays such as those at CNP, the more conventional approach to ampacity derating would be to begin with the base ampacity values from the tables using the approach of "maintained spacing" as per IPCEA P-46-426. Then a generic estimate of the ampacity correction factor (ACF) for the fire barrier could be applied, and a nominal ampacity limit for the protected cables found. This value could then be compared to the predictions of the utility model for a rough assessment of how well the model would reflect the current ampacity tables. One obvious source of uncertainty in this approach is that there may not be good tests upon which to estimate the ACF of a fire barrier system installed on a sparsely loaded tray. In general, one might expect a marginally higher ACF for a sparse tray than one would for a heavily loaded tray due to the more profound effect on convective air currents for the sparsely loaded tray. However, as a first order approximation this approach would certainly help lend confidence to, or highlight deficiencies of, the utility analysis models.

SNL has performed such a comparison for the one cable tray identified in CNP Attachment 5 (Tray 1AZ-P8). Unfortunately for this tray CNP has given no information regarding the nature of the installed fire barrier system, and from the information provided it is impossible to deduce whether this is a nominal 1hr or 3hr system. Hence, the following analysis will remain speculative. It is provided for illustrative purposes only. The utility has cited 12, 3/C cables in this tray. Eleven of these are 12AWG copper conductor cables (one of which is unpowered "cut in tray and taped"), and one is a #2AWG aluminum conductor cable. All are type "TC"

cables (indicating the service conditions allowable for this cable). Table 3.1 summarizes the ampacity service factors for this cable tray.

Table 3.1: A comparison of CNP predictions and a nominal analysis based on tabulated ampacity values, maintained spacing and a nominal fire barrier ACF for CNP cable tray 1AZ-P8.

	#12AWG, 3/C, Cu, TC	#2AWG, 3/C, Al, TC
Open air ampacity[1]	32A	108A
Maintained spacing ACF[2]	.82	.82
Derated open ampacity	26.2A	88.6A
Nominal fire barrier ACF[3]	.684	.684
Nominal derated ampacity	17.9A	60.6A
Utility estimated ampacity	21.58A	90.67A
Utility highest actual load cited	20A	60A

1. from NEC Table B310-3, 1996
2. Maximum value from IPCEA P-46-426, Table VII for a single layer of cables
3. Based on nominal 1hr cable tray fire barrier system tested by Texas Utilities. This is a crude estimate for illustrative purposes only. The actual fire barrier configuration at CNP is unknown.

Note that the results, even assuming a nominal ampacity correction factor (ACF) based on a 1hr barrier system tested by Texas Utilities, shows that the CNP estimated ampacity limits may be overly optimistic, and that certain of the cables may be operating at or above their actual ampacity limits. This example illustrates the importance of proper model validation, and the importance of comparisons of the model predictions to published ampacity limits.

3.3 The CNP Appendix R Conduits

As was noted above, the utility has not provided any discussion of how its two thermal models were applied to conduits, and yet, results for certain cables in conduits are presented as a part of the utility package. Hence, one must conclude that the same thermal model was used for conduits as well. The conduit results are also presented in CNP Attachment 5. Here again the utility has provided only a minimal amount of information upon which to base this comparison. For example, the utility has failed to identify whether or not each cable is located in its own conduit, or whether more than one cable might be installed in a common conduit. In some cases, the answer is obvious (it is difficult to get more than one cable of 0.32" diameter into a 1/2" conduit, for example). However, in other cases several cables might well be located in a common conduit (a 4" cable might well hold more than one 1.14" diameter cable). Further, the nature of the fire barriers installed on these conduits is also unknown.

Hence, as above, this discussion is for illustrative purposes only. In all cases, it has been assumed that only a single cable is located in any given conduit. Hence, no ACF for grouping of cables in a conduit has been applied. If this assumption is incorrect, then the estimated ampacity limits given here would be too generous and would require reduction for grouping of cables. Table 3.2 summarizes the results of this comparison.

Table 3.2: A comparison of CNP predictions and a nominal analysis based on tabulated ampacity values and a nominal fire barrier ACF for CNP conduits.

	#12AWG, 3/C, Cu, TC	#2AWG, 3/C, Al, TC
Nominal conduit ampacity[1]	24.6A	84.6A
Nominal fire barrier ACF[2]	.9	.9
Nominal derated ampacity	22.1A	76.2A
Utility estimated ampacity	25.85A	99.04A
Utility highest actual load cited	2.7A	71.9A

1. from NEC Table B310-1, 1996. Includes correction of ampacity to ambient temperature of 40°C.
2. Based on nominal 1hr conduit fire barrier systems tested by Texas Utilities. This is a crude estimate for illustrative purposes only. The actual fire barrier configuration at CNP is unknown.

Note that the ampacity limits predicted by CNP are larger than the estimated derated ampacity limits for these cables, even using nominal values for the fire barrier ACF. In fact, the derated ampacity limits predicted by CNP are larger than the nominal ampacity limits specified in the NEC tables without consideration of additional fire barrier derating. This discrepancy indicates potential problems in the CNP thermal model, and clearly indicate that the model may be generating nonconservative estimates of cable ampacity limits. These discrepancies must be resolved.

In this particular case, the in-plant service loads remain bounded by the estimated derated ampacity values. However, this is based on only a nominal analysis. As noted above, the inclusion of cable grouping factors, if such factors would be applicable at CNP, or the presence of a 3hr rated barrier system might significantly alter the final ampacity estimates. It is also unclear whether or not the specific cables cited by CNP are either all-inclusive of conduit fire barriers or are representative of bounding applications.

As noted in Section 2.4 above, there is considerable uncertainty regarding how the conduit modeling applications were implemented. It is interesting to note here that the utility results provide a uniform value of ampacity for a given cable size. Provided that all of the cables are installed in the exact same configuration, this would be an appropriate result. However, it the number of cables in a conduit varies from

application to application, or if the conduit size varied from case to case for the same cable, then one should see some differences in the allowable ampacity limits. One should expect that any change in the physical system would be reflected in a change in the ampacity limits calculated. The utility results for a given cable size are all identical, and hence, one must assume that the installations are all identical (for a given cable size). This is not the case for at least one of the two cable sizes considered.

Consider the 3/C #12 AWG results for a 1/2" conduit (cable 8026R) in comparison to those for the same size cable in a 1" conduit (cable 8505R for example). In this case the utility has cited the exact same ampacity limit down to four significant figures (25.85A). This clearly indicates some sort of error in the utility model, or in the implementation of the model. Given the same cables in two different conduits of significantly different size one would certainly expect significant differences in the numerical modeling results. While the ampacity tables would not distinguish between these two cases, the thermal model certainly should. The fact that the two results are listed as identical indicates that the thermal model is not properly accounting for the physical characteristics of the system.

3.4 Summary of Insights and Findings

A nominal comparison was made between the ampacity results provided by the utility and those which might be obtained using more conventional approaches to the ampacity assessment. In both the cable tray and conduit cases cited, it was found that the CNP estimated ampacity limits were nonconservative in comparison to nominal ampacity limits derived from derating of the published cable ampacity tables. In the case of the conduits, the utility estimated ampacity limits including derating for the fire barrier system were in excess of the tabulated ampacity limits for cables in conduits without a fire barrier as set forth in the NEC tables.

These results indicate potential problems in the CNP thermal model. The prediction of actual cable ampacity limits based on direct thermal modeling is quite difficult, and would be expected to hold considerable uncertainty. The results of the comparisons made here indicate that the CNP thermal model may well be generating unrealistic and nonconservative estimates of actual cable ampacity limits. Additional validation of the utility thermal model is needed.

As a part of the validation process, the utility should provide a direct comparison of its own modeling results to the results obtained using more conventional ampacity derating approaches, and/or to actual test results in which ampacity limits were measured directly. This should include both cable tray and conduit applications if the model is to be applied to both types of installations. The SNL comparisons must be viewed in the context of illustrative examples only, due primarily to the fact that insufficient information has been provided by the utility upon which to base more definitive analyses. In its submittal, the utility should also provide a sufficient base of information on its particular applications to allow for a complete review and assessment of the results. This must include more detailed descriptions of the physical characteristics of each system, and the characteristics of the installed fire barrier system.

The examination of the conduit results also raised a particular point of concern which indicates that there are errors either in the thermal model or in the utility implementation of that model. In the case of the 3/C 12AWG wires, the utility predicted the same ampacity limits for a cable in a 1/2" conduit and for the same cable in a 1" conduit. While the ampacity tables would not distinguish between these two cases, the thermal model certainly should. This is a clear indication of an error of some type. Based on the information provided, it is impossible to identify the source of this error.

4. SUMMARY OF FINDINGS AND RECOMMENDATIONS

With respect to the adequacy of the overall utility documentation, SNL finds that:

- The level of documentation provided is not adequate to complete full evaluation of the utility ampacity assessments. Specific areas in which further documentation is required are documented below. In general, there is no discussion of how the two parts of the utility analysis methodology are made to work together, the example calculations do not provide enough information to verify the calculations, and the experiments purported to support validation of the thermal models are either not provided, or no direct one-to-one comparison of the experiments to modeling results is provided.

- While the utility has documented the results of its analysis for one cable tray and an indeterminate number of conduits, no summary of the balance of the plant results has been provided. The utility should provide a summary of the ampacity assessment results for its installed fire barrier systems.

- No discussion has been provided as to how in-plant cable service loads were determined, which cables have been considered in the analysis, and the basis for the elimination of other cables from consideration. This information is needed to assess the adequacy of the utility treatment.

With respect to the utility ampacity "partitioning" analysis methodology (referred to in this review as the Part 1 analysis) SNL finds that:

- The utility has provided an inadequate basis for validation of its assumption that the overall heat rejection capacity of a sparsely loaded cable tray can be partitioned to individual cables in proportion to the cable diameter. The limited information provided by the utility (one plot with no supporting data and no indicated units) is unconvincing. The utility has cited a set of experiments as the basis for this plot, and hence, for the validation of this methodology (see reference to Appendix C in the utility Attachment 4). However, no documentation of these experiments has been provided. Documentation of the validation experiments cited in this portion of the utility analysis is needed. This should include a discussion of the utility analysis and application of the test data.

With respect to the utility thermal heat rejection capacity calculation method (referred to in this review as the Part 2 analysis):

- The utility treats all cable tray systems using a model based on circular geometries. This practice is said to have been validated base on the "excellent correlation between computer data and test data". However, no evidence of such validation has been provided. The utility must validate its assumptions in this regard.

- The utility assumption of equivalent annular regions appears to give inadequate treatment to the importance of surface area in heat transfer calculations. The actual rates of heat transfer are directly proportional to surface area, hence, it is important that the thermal model use actual available surface areas in its formulation. The utility should provide examples to illustrate the effective heat transfer areas assumed for each of the layers in its modeling and compare those assumed areas to the actual heat transfer areas available in the physical system. These examples should cover both conduits and cable trays. (For cable trays it is recommended that, consistent with other modeling efforts, the utility should assume that only the upper and lower surfaces of the tray and fire barrier are active in the heat transfer process. Both experiments and detailed modeling (Stolpe, e.g.) have shown that the sides of a cable tray are relatively unimportant in the overall heat transfer process.)

- SNL finds that the utility has provided no meaningful validation of its analysis method for calculating cable ampacity limits and cable tray limiting heat rejection capacities. The utility should provide for the direct comparison of predicted cable ampacity limits to those measured in experiments on the corresponding system in order to validate its calculations.

- The utility thermal model is based on heat transfer correlations which were originally published in the 1929-1933 time frame. These correlations are badly dated, and the impact of using more modern correlations in the model should be assessed. (This issue might be considered of secondary importance provided that a sufficient base of validation were provided. Such a validation base has not been provided as per the preceding finding.)

- The submittal states, in the development of correlation for heat transfer from the cables to the surrounding air gap, that "the thermal resistance per conductor will be the total number of conductors divided by the total thermal conductance" (see the first sentence in the paragraph immediately preceding equation 20 of the utility analysis). The basis, intent, and impact of this statement needs to be further explained and clarified.

- Directly related to the preceding comment, the utility correlations for "the thermal resistance through relatively thin cylinders (i.e., cable jacket, tray, fire barrier)" (utility equation 16) and for the "thermal resistance from the last surface to ambient" (utility equation 21) each include a factor (n') described as "the number of conductors within the section." The basis, intend, and implementation of this factor (n') should be clarified as it is applied to each of these two equations. This would appear to be, in effect, a thermal partitioning factor which is based on a simple conductor count, and as such, may be in direct conflict with the stated assumptions of the model described in "Appendix A" of utility Attachment 4 (where it is assumed that surface area will be the basis for thermal partitioning). The basis, intent, and impact of this factor must be clarified and justified. Also, the utility must explain how this factor applies when cables of different physical dimensions are present in a common cable tray.

- The correlation cited for the thermal resistance between the outer surface of the barrier and the ambient environment (utility equation 21) applies only to pipes. These correlations should not be applied to flat plate surfaces such as those which would be experienced around a cable tray.

- The utility model provides no treatment of the effects of spacing on the radiative heat transfer behavior of the cables. Reduced view factors due to cable proximity might significantly reduce the predicted rates of radiant heat transfer. This should be accounted for in the radiative heat transfer correlations.

- It is not possible to verify the utility calculations because no information on the specific inputs used in any example case have been provided, and the listing of the utility computer code was not provided.

- The utility has apparently applied one or both of its thermal models to the analysis of cables in conduits as well as those in trays. The applicability of both parts of the utility analysis model to conduits needs to be addressed. In particular, the utility model for cable trays is based on the unique configuration of "maintained spacing" for its power cables in cable trays. This same factor cannot generally be assumed to exist for cables in conduits. The utility should provide an explicit discussion of the applicability of its two thermal models (the "Appendix A" surface area based heat load partitioning model and the "Appendix B" direct thermal analysis model) to conduits, and should discuss how the models were implemented for conduit analyses.

With regard to the specific example calculations provided in the submittal SNL finds that:

- A nominal comparison between the utility ampacity predictions and those obtained using more conventional approaches to the ampacity assessment showed that the CNP estimated ampacity limits were nonconservative. In the case of the conduits, the utility estimated ampacity limits including derating for the fire barrier system were in excess of the tabulated ampacity limits for cables in conduits without a fire barrier as set forth in the NEC tables, even given the most generous interpretation of the conduit loadings (only a single cable per conduit with no more than three conductors). These results indicate that the CNP thermal model may be generating unrealistic and nonconservative estimates of actual cable ampacity limits. These discrepancies must be resolved by CNP.

- As a part of the validation process, the utility should provide a direct comparison of its own modeling results to the results obtained using more conventional ampacity derating approaches.

- In its submittal, the utility should also provide a sufficient base of information on its particular applications to allow for a complete review and assessment of the results. This must include more detailed descriptions of the

physical characteristics of each system, and the characteristics of the installed fire barrier system.

- The example results for conduits predicted the exact same ampacity limits down to four significant figures (25.85A) for a 3/C #12AWG cable in both a 1/2" conduit (cable 8026R) and a 1" conduit (cable 8505R for example). While the ampacity tables would not distinguish between these two cases, given the differences in the physical configurations, the thermal model certainly should. This is a clear indication of an error either in the model or in the implementation of the model. CNP should identify the source of, and resolve, this discrepancy.

It is recommended that an RAI to the utility be prepared to clarify these points. In general, it is likely that significant additional consideration will be required on the part of the utility to resolve the concerns identified in this review. Significantly more complete documentation of the utility models, the example calculations, and a summary of the overall analysis results will also be needed before a final assessment of the utility ampacity load factors can be made.

5.0 REFERENCES

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