A Technical Evaluation of the Donald C. Cook Nuclear Plant Fire Barrier Ampacity Assessments

A Letter Report to the USNRC

Revision 0

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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 is the second in a series of reports associated with fire barrier ampacity assessments for the Donald C. Cook Nuclear Plant (CNP). In June of 1996, SNL had reviewed an initial licensee submittal associated with the assessment of ampacity loads for fire barrier protected cables. Base in large part on the findings of this SNL review, the USNRC forwarded a Request for Additional Information (RAI) to the licensee in December 1996. The current document provides a review and assessment of the licensee response to this RAI. This work was performed as Task Order 3, Subtask 3 of USNRC JCN J-2503.

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. An SNL review of this submittal[1] recommended that the USNRC forward an RAI to the licensee to clarify several points in the submittal. Based in large part on these recommendations, a second RAI was forwarded to the licensee on December 2, 1996. The licensee has now responded to this RAI, and the current document provides the results, findings and recommendations of an SNL review of this licensee response.

The licensee RAI response reviewed by SNL was documented in a utility letter:

- Letter, March 20, 1997, (docket nos. 50-315, 50-316 item AEP:NRC:0692DL), E. E. Fitzpatrick, Indiana Michigan Power Co., to the USNRC Document Control Desk including six attachments as follows:
  - Attachment 1: Response to Request for Additional Information regarding Thermo-Lag Related Ampacity Derating Issues for Cook Nuclear Plant
  - Attachment 2: Table Depicting Correlation Between the Predicted and Measured Ampacities
  - Attachment 3: Model Computer Code
  - Attachment 4: Test Report CL-492
  - Attachment 5: Comparison Tables Providing Base Information Regarding Trays and Conduits Cable Full Load Amperes, and Comparison. of Calculated Ampacities vs ICEA Ampacities.
  - Attachment 6: Ampacity vs Depth of Fill Plot for #12 AWG Cable in Tray

SNL was requested to review this submittal under the terms of the general technical support contract JCN J-2503, Task Order 3, Subtask 3. This letter report documents the initial results of this review.

1.2 Report Organization

Section 2 provides a brief review of the licensee assessment approach. Section 3 provides a direct assessment of the licensee's specific RAI responses as presented in Attachment 1 of the submittal. Section 4 provides for a review of the five additional supporting attachments, Attachments 2-6, included in the licensee submittal. Section 5 provides a summary of SNL findings and recommendations. Section 6 identifies the referenced documents. In addition to the main text, supporting discussions are provided in three appendices. Appendix A provides for a re-analysis for many of the licensee cable tray

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[1]See SNL letter report to the USNRC, June 28, 1996, work performed under USNRC JCN J-2017.

ICEA margins assessments in which four specific errors identified by SNL in the licensee calculations have been corrected. Appendix B provides for a direct comparison of the licensee thermal modeling results to the nominal ICEA ampacity limits for those cables re-analyzed by SNL in Appendix A. Appendix C provides some supplemental analyses of the licensee mixed fill test results from test report CL-492 to assess their consistency with both the licensee heat rejection capacity partitioning method and the ICEA ampacity limits.

2.0 UTILITY AMPACITY DERATING APPROACH

2.1 Overview of Analysis Approaches

The licensee has provided two approaches to assessment. The first approach is a somewhat unconventional analytical assessment. This approach was documented in the earlier licensee submittal, and remains essentially unchanged from that documentation as originally reviewed by SNL in June 1996. The second approach is a somewhat more conventional margins assessment and has been provided in direct response to an USNRC RAI request. The sections that follow provide a brief overview of each of these two assessment approaches.

2.2 An Overview of the Licensee Thermal Model

This licensee analytical approach involves implementation of a thermal model for the direct assessment of clad case ampacity limits. This is considered somewhat unique in comparison to other approaches reviewed by SNL. In particular, in typical model-based assessments a thermal model is used only to assess the relative impact of the fire barrier. This relative impact is expressed as the estimated fire barrier ampacity correction factor (ACF) or ampacity derating factor (ADF). The actual ampacity limits for a given case are then typically based on application of this fire barrier ACF/ADF factor to tabulated ampacity limits.

In contrast, in the CNP analyses a thermal model is used to assess actual cable ampacity limits in the clad condition for a given cable tray or conduit application. No specific assessments of the base line case are made, and no specific estimates of the fire barrier ACF/ADF are made. The licensee makes the rather subtle distinction that the model is not used to determine ampacity limits, but rather, only to assess the acceptability of actual in-plant cable loads. This distinction appears to have no significant meaning, or that meaning is lost on the reviewer. In practice, the licensee exercises the thermal model as a means for estimating actual cable clad ampacity limits, and ultimately compares those predicted limits to in-plant cable loads to determine acceptability.

The thermal model implemented by CNP is also quite unique in certain other respects as well. 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 is 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, and does play a key role in the licensee thermal model development. In particular, the utility model is primarily aimed at addressing sparsely loaded cable trays, although the final results are apparently applied to conduits as well. Because of this fact, the licensee can appropriately ignore issues associated with conduction of heat through a large cable mass. It is also apparently upon this basis that the licensee model treats cable trays using a circular geometry comprised of annular thermal layers. A circular geometry does introduce some simplifications, but these are relatively minor in nature. It is only on the basis of the sparse loadings that the licensee treatment might be considered acceptable in this regard. SNL had previously raised some concerns regarding this practice which have not been fully resolved (see Section 3 below).

As a general finding, SNL would recommend that under no circumstances should this thermal modeling approach be applied to a random fill cable tray without maintained spacing or with more than a single layer of cables. The assumptions of the thermal model would clearly be compromised in such an application. The licensee has not made such applications; hence, this finding has no immediate impact on the evaluation of this licensee submittal.

The utility thermal model is actually exercised in two parts. Clarification of the exact intent of each step was one point addressed in the 12/96 RAI. The utility RAI response clarifies that the role of the two parts of the analysis are as follows:

- Part 1 Analysis: Calculate the overall heat rejection capacity for a given cable tray (or conduit) based on heat transfer correlations and calculations. In this part of the analysis, a series of calculations are performed for each uniquely sized cable in the tray, and the limiting heat intensity is used in the Part 2 analysis for all cables in the tray.

- Part 2 Analysis: Given an overall heat rejection capacity for the cable system, calculate the allowable ampacity limit for individual cables. This step is basically a partitioning of the total heat load to individual cables.

In some senses, the licensee analysis is an extension of the classical "Watts per foot" methodology in which the analysis is based on an assessment of the total heat rejection capacity of the tray only. In fact, a part of the licensee final assessments is based on the acceptability of the overall heat rejection capacity (actual heat load versus model predicted limiting heat load). As with other traditional Watts/ft based analyses, SNL recommends that this comparison be rejected as an appropriate basis for assessment. It is critical that an assessment of individual cable ampacity limits be made, and this stage of the analysis is at best a preliminary indication of potential problems (should a particular case exceed the overall heat capacity), but should not be credited as an indication of acceptability. Fortunately, the licensee has not stopped here, but has continued the analysis.

The licensee approach extends the traditional Watts/ft method by actually partitioning the total heat rejection capacity (the allowable Watts/ft of tray) to individual cables. In this sense, the licensee has attempted to address the primary shortcoming of the Watts/ft methodology by extending the analysis to include an assessment of individual cable ampacity loads. The licensee method for partitioning the heat load to individual cables is somewhat unconventional. While the approach may, in fact, be appropriate for the sparsely loaded CNP cable trays, the method has not been adequately validated.

In the licensee assessment this partitioning is based on cable diameter (or equivalently by cable surface area). This is somewhat in conflict with typical cable tray practices, such as that of Stolpe and the ICEA, in which heat load is partitioned by cross-sectional area rather than diameter. Since cross-sectional area is a function of diameter-squared, the two methods are not equivalent. Under the licensee approach, smaller cables may be assigned a disproportionately large fraction of the overall heat rejection capacity in comparison to the ICEA standards. This might lead to over-estimation of the ampacity loads for the smaller cables in a given tray, and under-estimation of ampacity loads for larger cables in the tray, again, in comparison to the ICEA limits. (This does appear to be the case as is discussed further in Appendices B and C.)

The licensee does present some arguments for why the diameter/cable surface area-based partitioning may be more appropriate, and in general, SNL agrees with the licensee observations in this regard. In particular, the licensee maintained spacing installations will imply a more significant role for the cable surface area in the heat transfer process. This would be in comparison to a random fill or tightly packed cable mass in which heat conduction through the cable mass and the smaller net exposed surface area of the overall cable mass would dominate the analysis. Only through validation against test data could such an approach be verified as appropriate. Unfortunately, the licensee validation studies have not addressed this point in any meaningful manner (see further discussion in Section 4 and in Appendix B below).

One important point clarified in the licensee RAI response is the fact that in practice the thermal model is exercised assuming an "equivalent" tray fill comprised entirely of cables of a common size. That is, the actual plant trays are populated by diverse cable loads (diverse in both size and ampacity load). In our earlier review SNL had assumed that the model was exercised just once for a tray in order to model the actual cable fill including diverse cable sizes. This apparently is not the case. It is now clear that for analysis the licensee apparently matches the actual cable fill with an "equivalent" fill comprised only of cables identical to the specific cable under analysis. The model is then exercised independently for each cable size present, and the limiting heat intensity (the lowest) from all runs is then applied in the Step 2 analysis for all of the cables in the tray.

One factor that SNL has not been able to fully assess is the fact that the licensee is imposing the "fill matching" based only on the effective width of the actual cable fill. That is, the licensee approach is to calculate the actual fill of an in-plant tray as the simple sum of the diameters of the individual cables. This is equivalent to lining the cables up side by side with no gaps and measuring the overall width of the cable group. This value is then matched for a single cable type by setting the number of cables to the overall fill width divided by the diameter of the specific cable under study. In this way, the number of cables may not be a whole number (in one validation case the number of cables is set to 12.875 cables, for example). This is a very unique practice. In general tray assessments, including those of Stolpe and the ICEA standard, depth of fill is considered the overriding parameter in a cable tray heat intensity analysis. The licensee approach reflects the maintained spacing installation practice and the model's strong emphasis on the total surface area of the cables as the governing parameter. By matching the width of the installation, the licensee also matches the total cable surface area as well. In this regard, the licensee is being self-consistent with their overall approach to modeling, and SNL would tend to agree with the licensee approach in this regard. However, as noted above, validation would be a key to assessing this assumption, but the licensee validation studies have not addressed this point in any meaningful manner.

A number of RAI items were asked by the USNRC dealing with specific aspects of the licensee thermal model. The licensee responses to these items are discussed in detail in Section 3 below. In addition, Sections 4.2 and 4.3 below provide more detailed reviews of submittal Attachment 2, which documents the licensee validation studies, and Attachment 3, which presents the actual model code listing, respectively. A final summary of findings and recommendations is also provided in Section 5.

2.3 An Overview of the ICEA Margins Analyses

The licensee has, in Attachment 5 of the current submittal, provided a new supplemental analysis of cable ampacity loads based on a direct comparison of in-plant cable loads to tabulated ampacity limits. Section 4.5 below provides a more comprehensive review of these assessments. The assessments include both cable tray and conduit applications

2 3.1 Cable Tray Margins Assessments

For cable trays the tabulated ampacity limits have generally been derived based on the Stolpe method of heat intensity [1], which also forms the basis for the ICEA P-54-440 standard. In some few cases, the licensee has chosen to cite ampacity limits directly from the ICEA P-54-440 ampacity tables. For a very few cases the NEC has been cited as well. Hence, the approach does conform, in principal, with accepted standards.

One important point in this regard is that the ICEA P-54-440 standard is intended to address random fill cable trays, whereas the licensee installations conform to maintained spacing requirements. This should represent a source of some conservatism for the licensee analyses. The maintained spacing approach implies greater thermal access of individual cables to the ambient because the full perimeter of each cable is exposed to the air. It also implies a reduced mutual heating impact because cables do not tough each other. Hence, the ICEA limits would be somewhat conservative for the licensee applications.

SNL did note that a number of errors were made by the licensee in calculation ICEA cable tray ampacity limits. However, the comparison by the licensee of in-plant cable loads to tabulated ampacity limits provides a more scrutable and direct method of assessment than does the licensee thermal analysis modeling approach. Hence, SNL has given considerable weight to this part of the licensee submittal in reaching our ultimate conclusions and recommendations. In particular, SNL has re-analyzed the most significant licensee cases to correct the identified errors. This process is documented in Appendix A. As a result, SNL has concluded that the majority of the licensee cables do, in fact, have adequate margin. However, additional analysis for ten specific cables has been recommended.

2.3.2 Conduit Margins Assessments

In addition to the cable tray assessments, the licensee has also provided comparisons between tabulated ampacity limits and in-plant cable service loads for cables in fire barrier clad conduits. The tabulated ampacity limits have generally been taken from the IPCEA P-46-426 standard. A detailed review of these assessments is provide in Section 4.5.2 below.

As with the cable trays, SNL has given considerable weight to these comparisons in reaching our final findings and recommendations. While SNL did identify one discrepancy in this analysis, even after correcting this error it can still be concluded that all of the licensee conduit applications do have sufficient ampacity margin available to allow for installation of the fire barrier.

3.0 ASSESSMENT OF LICENSEE DIRECT RAI RESPONSES

Attachment 1 to the licensee submittal provides the direct licensee response to each of the RAI items raised by the USNRC letter of 12/2/96. The following sections provide for an assessment of the adequacy of these responses to resolve the identified points. The organization of this presentation follows a similar organization to that provided in the licensee response. That is, RAIs are grouped by subject and identified using the same structure as that used by the licensee.

3.1 General Modeling Concerns

3.1.1 Request 1

Synopsis of Request: The licensee was asked to provide a summary of all ampacity derating assessment results for all Thermo-Lag enclosed raceway configurations.

Synopsis of Licensee Response: The licensee response has included a table as Attachment 5 that provides the requested information including a direct comparison of CNP full load ampacity (FLA) values and the ICEA ampacity limits.

Assessment of Licensee Response: The licensee response is fully adequate to resolve the identified concern. The information has been provided in a very concise format that allows for a direct and well founded assessment of the licensee ampacity derating results. SNL has given significant weight to these comparisons in its final assessments and recommendations (see section 4 below).

Recommendations: No further actions on this specific RAI item are recommended.

3.1.2 Request 2

Synopsis of Request: The licensee was asked to supplement the submittal documentation and to clarify how the two parts of the analysis were intended to work together.

Synopsis of Licensee Response: The licensee has provided significant supplemental information in its response. In particular, the licensee cites response section 2.3.2 and Attachment 2 as providing the requested information.

Assessment of Licensee Response: This response has generally resolved the identified concerns. Section 4.2 below provides a more complete review of the licensee Attachment 2 and Section 3.3.2 discusses the licensee's response from section 2.3.2 of the submittal. The licensee response has clarified the points of uncertainty that led to SNL's recommendation that additional documentation was needed. Hence, in this specific context SNL finds that the RAI item has been adequately resolved.

Recommendations: No further actions on this RAI item are recommended.

3.1.3 Request 3

Synopsis of Request: The licensee was asked to clarify how in-plant service loads were determined.

Synopsis of Licensee Response: The licensee response states that service loads are assessed based on the nameplate rating of the load items themselves.

Assessment of Licensee Response: This response is fully adequate to resolve the identified concern. The use of nameplate ratings will generally be accurate to somewhat conservative depending on the nature of the connected device. It is important to note that the licensee has apparently assumed that all connected devices might be operated simultaneously in the ampacity assessment. SNL also notes that the licensee response to another RAI item (see Section 3.4.5) indicates that motor feed cables have been designed using a 125% load factor to account for motor overload or under-voltage operation. These factors indicate that the licensee has taken a conservative approach to load assessment.

Recommendations: No further actions on this RAI item are recommended.

3.2 Part 1 Analysis

Synopsis of Request: This RAI cited that an adequate validation of the licensee heat load partitioning method had not been demonstrated. The licensee was specifically asked to provide the cited test reports purported to support this assumption.

Synopsis of Licensee Response: The licensee response has included the test report in question (as Attachment 4 to the submittal). The licensee response also cited that data from this report was used to develop the plot of ampacity versus $(d/R_{ac})^{1/2}$ presented in the original report as the basis for model validation.

Assessment of Licensee Response: The licensee response has been helpful, but has not resolved the identified concerns. In fact, it is now clear that the cited licensee plot and its initial validations were based only on those tests that involved a non-diverse cable fill. SNL's original concern in this regard was that the licensee has not shown that the thermal model, and in particular the diameter-based partitioning method, was appropriate for diverse cable loads such as those actually in the plant. While the licensee has performed diverse load tests, the data was not included in the analysis or validation of the partitioning method. SNL has performed a simplified analysis of the licensee diverse load test data to assess this assumption as documented in Appendix C below. The results indicate that the diameter-based partitioning is not consistent with the test data. In particular, this method will likely over-estimate ampacity limits for the smaller cables in a diverse load tray (assuming the overall heat rejection capacity is accurately estimated). However, SNL's has also compared the licensee measured cable ampacity limits for sparsely loaded cable trays to those derived from the ICEA standard (also in Appendix C). This exercise did indicate that the ICEA-derived ampacity limits were generally consistent with the licensee tests with one notable exception not considered relevant to the licensee's actual applications (see discussion in Appendix C). However, the test data for the "mixed fill" was not found to be consistent with the licensee diameter-based partitioning assumption.

Recommendations: SNL finds that the licensee has not adequately addressed the concerns expressed in this RAI. An SNL analysis of the licensee test data indicates that the licensee assumed diameter partitioning method may not be appropriate, and may result in over-estimation of the ampacity limits for smaller cables in diversely loaded trays. SNL recommends that the licensee thermal model not be accepted at this time without further review and evaluation of this and other related concerns.

3.3 Part 2 Analysis

3.3.1 Request 1

Synopsis of Request: The licensee was asked to further clarify its thermal model regarding the treatment of surface area on a consistent basis.

Synopsis of Licensee Response: The licensee has provided descriptions and clarifications which have satisfied the identified concern. The licensee does clarify how the diameters of each annular layer are calculated so as to ensure that the surface area is matched.

Assessment of Licensee Response: The licensee has resolved the specific point of uncertainty raised in this RAI.

Recommendations: No further actions on this RAI item are recommended.

3.3.2 Request 2

Synopsis of Request: The licensee was asked to provide for the direct comparison of it ampacity modeling results to experimental data.

Synopsis of Licensee Response: The licensee response is fairly extensive and addresses a number of points. In particular, the licensee response cites that the thermal model was used to model certain licensee tests. Attachment 2 is cited as providing these results. The results are cited as conservative. The licensee also provides an extended discussion of its overall assessment process.

Assessment of Licensee Response: The licensee response has only been partially responsive to the identified concerns.. In particular, model versus experiment comparisons have only been provided for two specific tests, one involving three cable groups, and one involving a single cable. None of these cables was loaded to its ampacity limit. SNL also notes that for one of the cable groups the model predicts an ampacity significantly higher than that measured in the test, a non-conservative result (see Section 4.2 below). The licensee validation studies are severely limited in scope, and have not considered the full range of test data available to the licensee. SNL also performed some supplemental validation studies as a part of this review. These include a comparison of the licensee thermal model predictions to the ICEA standard ampacity limits (see Appendix B) and an examination of the "mixed-fill" test results from licensee report CL-492 for consistency with the licensee assumed heat partitioning methods (see Appendix C). Both of these SNL assessments have identified potentially inconsistencies that have not been resolved by the licensee's cited validation studies.

Recommendations: SNL finds that the licensee validation study is inadequate to justify reliance on the CNP approach to thermal modeling. It is recommended that this methodology not be accepted as the basis for ampacity assessments without significant additional review and validation.

3.3.3 Request 3

Synopsis of Request: The licensee was requested to assess the impact of using modern heat transfer correlation in the model.

Synopsis of Licensee Response: The licensee cites that the chosen correlations provided satisfactory results, and stated that "we do not believe that using more modern correlations would prove to be effective."

Assessment of Licensee Response: The licensee was unresponsive to the request. In one sense, the licensee makes a correct assumption that validation is the key to proving acceptability. Unfortunately, as noted elsewhere, the licensee validation studies are not adequate to this need. The licensee has used very dated correlations in its model, but without a more complete validation it is impossible to assess the impact of these correlations on the reliability of the results.

Recommendations: SNL recommends that pursuit of a more complete response to this RAI items would not be fruitful without a more thorough general validation of the licensee model. Hence, SNL recommends no further actions on this RAI item at this time.

3.3.4 Request 4

Synopsis of Request: The licensee was requested to clarify one specific point regarding the treatment of thermal resistance factors.

Synopsis of Licensee Response: The licensee has clarified the point in question. In particular, the licensee cites that each individual calculation is performed assuming a cable fill comprised entirely of a single size of cable, and is then repeated for each unique cable size in a given tray.

Assessment of Licensee Response: This response has clarified the licensee intent in this regard satisfactorily. It is now clear that SNL had misunderstood this aspect of the licensee analysis, and this led to the identified concern.

Recommendations: No further actions on this RAI item are recommended.

3.3.5 Request 5

Synopsis of Request: This RAI item cited an apparent discrepancy between the licensee partitioning of heat transfer behavior in one part of the model based on conductor count while in other places partitioning was based on cable diameter. Clarification was requested.

Synopsis of Licensee Response: The licensee again cites the fact that any given analysis is based on an equivalent cable load comprised of just one cable size, and hence, the partitioning is appropriate.

Assessment of Licensee Response: The licensee response is fully adequate to resolve the identified concern. Given that all of the cables in a given analysis are assumed to be the same size, partitioning based on conductor count or on diameter would be equivalent. It is only if cables of different sizes were being modeled that the diameter versus conductor count partition would be of concern.

Recommendations: No further actions on this RAI item are recommended.

3.3.6 Request 6

Synopsis of Request: This RAI requested the licensee to provide the supporting validation results which justified its treatment of cable trays using equivalent annular regions.

Synopsis of Licensee Response: The licensee response has again cited the "Attachment 2" validation results.

Assessment of Licensee Response: The licensee validation study has been discussed elsewhere in this report (see Section 4.2). The treatment of the cable trays based on circular geometry correlations would be acceptable if a more thorough and satisfactory validation study were provided. Unfortunately, SNL has found the licensee validation studies to be inadequate, and in its own validation studies has identified inconsistencies and potential non-conservatisms in the licensee thermal model (see Appendices B and C).

Recommendations: SNL finds that the licensee has not adequately validated its thermal model. It is recommended that this thermal model not be accepted as a valid basis for cable ampacity assessments without significant additional validation and review.

3.3.7 Request 7

Synopsis of Request: This RAI item raised a specific question regarding the application of pipe-based convection correlation to a flat-plate tray geometry.

Synopsis of Licensee Response: The licensee response cites that its modeling results were found to be conservative by comparison to tests.

Assessment of Licensee Response: See discussion in 3.3.6 above.

Recommendations: See discussion in 3.3.6 above.

3.3.8 Request 8

Synopsis of Request: This RAI item requested that the licensee address the question of how cable spacing effects would impact radiative heat transfer behavior.

Synopsis of Licensee Response: The licensee response cites that the gaps between cables are not credited in the heat transfer analysis.

Assessment of Licensee Response: The licensee response does not appear to be an accurate reflection of the actual modeling assumptions. In fact, the thermal model assumes that the cables can be modeled as an equivalent single cylinder and the diameter of that cylinder is such that the surface area of the cylinder equals the total surface area of the individual cables. Hence, the licensee model actually gives full credit to 100% of the available surface area for each individual cable. This would be expected to be a non-conservative effect. Whether or not this is fully balanced by other conservative assumptions remains unclear.

Recommendations: The licensee response was not adequate to resolve the identified concern. However, given that SNL is recommending that this analysis methodology not be accepted without significant additional validation and review, no further actions on this specific RAI item are recommended.

3.3.9 Request 9

Synopsis of Request: The licensee was requested to provide specific inputs used in the sample calculations and to provide a copy of the source code for the thermal model.

Synopsis of Licensee Response: The licensee has specified the input parameters used for the two validation case studies cited in licensee Attachment 2, and has provided a copy of the source code as well.

Assessment of Licensee Response: SNL did review the input parameters for the two cases documented in licensee Attachment 2 (see Section 4.2 below). Some discrepancies were noted. SNL also reviewed and attempted to implement the licensee source code (see section 4.3 below). However, we were unable to successfully complete this effort due to uncertainties in the model logic structure, and the failure of the licensee to define two of the critical manually entered input values.

Recommendations: A number of potential problems in both the licensee input values and source code were identified by SNL. However, given that SNL is recommending that this analysis methodology not be accepted without significant additional validation and review, no further actions on this specific RAI item are recommended.

3.3.10 Request 10

Synopsis of Request: The licensee was asked to clarify its justification for application of the cable tray thermal model to conduits.

Synopsis of Licensee Response: The critical aspect of the licensee response cites that CNP design standards require that only a single power cable is installed in any given conduit.

Assessment of Licensee Response: Given that the licensee installs only a single cable in any one conduit, application of the thermal model to the CNP conduits is appropriate.

Recommendations: No further actions on this RAI item are recommended.

3.4 Representative Calculations

3.4.1 Request 1

Synopsis of Request: This RAI item cited that the licensee thermal model results appeared to be non-conservative in comparison to NEC ampacity limits. The licensee was requested to address these discrepancies.

Synopsis of Licensee Response: The licensee response cites its Attachment 5 as providing a direct comparison of the licensee ampacity loads to ICEA/NEC limits. The loads were all cited as within acceptable limits, hence, in the view of the licensee "no discrepancies are believed to exist."

Assessment of Licensee Response: The licensee response did, in principal, address the identified concern. In particular, licensee Attachment 5 did provide the requested comparisons. Unfortunately, SNL identified five mistakes made by the licensee in their ICEA assessments (four related to cable trays and one related to conduits). SNL has re-analyzed the ICEA ampacity limits for many of the licensee cables as documented in Appendix A. In addition, SNL has provided for a direct comparison of the licensee thermal modeling results and these corrected ICEA limits as documented in Appendix B. The results indicate that most, but not all, of the licensee predictions are, in fact, conservative in comparison to the ICEA limits. Four cases were identified for which the predicted clad case ampacity limits exceeded the ICEA limits for an open tray without a fire barrier installed. Six additional cases were identified for which there was some positive margin between the predicted and ICEA ampacity, but for which this margin was not sufficient to allow for the fire barrier installation. Note that the assessment of the necessary margin is supported by the insights documented in Appendix C regarding the licensee test results and inferred ACF/ADF factors. The uneven performance of the licensee thermal model indicates a clear potential for non-conservative results to be generated.

Recommendations: Based on the corrected comparisons, SNL finds that the performance of the licensee thermal model is neither consistent nor uniformly conservative. SNL recommends that this analysis methodology not be accepted without significant additional validation and review. Specific recommendations are made in Sections 4.2 and 4.3 and are summarized in Section 5.1 below regarding the recommended improvements needed to bring this model up to an acceptable level of quality and validation. Hence, no further actions on this specific RAI item are recommended.

3.4.2 Request 2

Synopsis of Request: To support model validation, the licensee was requested to compare its own modeling results to those derived from more conventional ampacity derating approaches.

Synopsis of Licensee Response: The licensee cites that "given the correlation between our thermal model and the 1983 test results ... we do not believe that using more conventional ampacity derating approaches ... would prove useful."

Assessment of Licensee Response: This answer appears non-responsive to the USNRC request. However, SNL does note that the licensee Attachment 5 does include a comparison between the calculated ampacity limit and the licensee calculated ICEA ampacity limits which in principal complies fully with the RAI. For further discussion of these licensee calculations and comparisons, see Section 3.4.1 immediately above.

Recommendations: See recommendations cited in Section 3.4.1 immediately above.

3.4.3 Request 3

Synopsis of Request: The licensee was requested to provide more detailed information on the physical characteristics of the systems under study in future submittals.

Synopsis of Licensee Response: The licensee concurs with this observation.

Assessment of Licensee Response: The licensee response is fully adequate to resolve the identified concern.

Recommendations: No further actions on this RAI item are recommended.

3.4.4 Request 4

Synopsis of Request: It was noted that the licensee thermal model had generated the exact same result for two conduit systems that appeared to be physically different, hence, for which different ampacity estimates should have been anticipated.

Synopsis of Licensee Response: The licensee has provided updated calculations that reflect the differences in these two cases.

Assessment of Licensee Response: The licensee response has resolved the identified concern to a large extent, although the exact nature of the discrepancy was not identified.

Recommendations: No further actions on this RAI item are recommended.

3.4.5 Request 5

Synopsis of Request: The licensee was asked to explain certain apparent discrepancies in the calculation of load ampacity for horsepower rated components.

Synopsis of Licensee Response: The licensee has cited that the distribution voltage at CNP was 600V versus the nominal 480V assumed by the USNRC RAI. This accounts for the discrepancy. In fact, the licensee also clarifies that cables have been rated for 125% of the nominal service load to account for under-voltage and overload conditions.

Assessment of Licensee Response: This response was fully adequate to resolve the identified concern.

Recommendations: No further actions on this RAI item are recommended.

3.4.6 Request 6

Synopsis of Request: The licensee was asked to further justify its assumed ampacity limits for 12 AWG cables.

Synopsis of Licensee Response: The main point of the licensee response to be noted is that the licensee cites a maximum fill of just 1/2". An extrapolated ampacity limit of 20A at this fill is identified based on the plot in licensee Attachment 6. This is cited as in comparison to a project estimated limit of 15A.

Assessment of Licensee Response: The estimation of an ampacity limit based on a graphical extrapolation of a ampacities plotted on such a course linear scale as that used by the licensee is poor practice because ampacity limits in ICEA P-54-440 tend to be logarithmic. However, this extrapolation has not apparently impacted any of the licensee actual cases studies. In general, the licensee's ultimate conclusion is correct.

Recommendations: No further actions on this RAI item are recommended.

3.4.7 Request 7

Synopsis of Request: The licensee was requested to provide a direct comparison between in-plant ampacity loads to the ICEA P-54-440 ampacity limits and to justify any cases which exceed those limits.

Synopsis of Licensee Response: An ICEA-based margins assessment has been provided in licensee Attachment 5. Based on its own analyses, no cases were found in which the ICEA limits were exceeded. A discussion is provided for each of the nine trays considered in this analysis.

Assessment of Licensee Response: SNL has reviewed the licensee Attachment 5 calculations as documented in Section 4.5 below. Four specific mistakes in the licensee cable tray assessments were identified. SNL has also performed a re-analysis of the most significant of the licensee cable applications in which these four analysis errors were corrected (see Appendix A). As a result, SNL identified four specific cables that appear to be nominally overloaded even in the absence of the fire barrier system, and six additional cables for which the available ampacity margin may be insufficient to allow for the fire barrier ACF/ADF. (Note that this comparison is not the same as the comparison discussed in Section 3.4.1 above. The earlier comparison considered the thermal model predictions versus the ICEA limits, whereas the current comparison considers in-plant service loads versus ICEA limits.)

Recommendations: SNL recommends that the licensee be asked to provide additional justification for the acceptability of ampacity loads on 10 specific cables. The specific cables are identified both in Appendix A and in Section 5.2 below.

3.4.8 Request 8

Synopsis of Request: The licensee was requested to provide a direct comparison between the ICEA P-46-426 ampacity limits to the in-plant service loads for all clad conduit applications.

Synopsis of Licensee Response: Licensee Attachment 5 has provided the requested comparisons. No discrepancies were noted by the licensee.

Assessment of Licensee Response: SNL has review the licensee conduit assessments as documented in Section 4.5.2 below. One discrepancy in the analysis was noted, although this discrepancy did not ultimately impact the validity of the licensee conclusions. SNL concurs with the licensee assessment that all of the cables considered are within the ICEA ampacity limits. Further, SNL finds that the licensee cited ampacity loads have sufficient margin to allow for installation of the 1-hour fire barrier system in all cases.

Recommendations: No further actions on this RAI item are recommended.

4.0 AN ASSESSMENT OF THE SUPPORTING ATTACHMENTS

4.1 Overview

In addition to its direct responses to the USNRC RAI items, the licensee has provided five additional supporting attachments. The sections which follow provide for a review and assessment of each of these supplemental attachments.

4.2 Licensee Attachment 2: Licensee Validation Study

Licensee Attachment 2 is entitled "Table Depicting Correlation Between the Predicted and Measured Ampacities." This attachment has been put forth as demonstrating the validity of the licensee thermal model for the assessment of cable ampacity limits. While the results are of interest and relevance, in an of themselves they are inadequate to demonstrate the reliability and acceptability of the licensee thermal model.

The attachment documents a comparison between licensee calculations and test results for just two tests. The tests chosen for comparison were "Test 1" and "Test 5" from Report CL-542 (which was provided in the original licensee submittal). No comparisons to the data presented in the second test report, CL-492 (provided as Attachment 4 of the current submittal), have been provided. As discussed further in Section 4.4 below, validation against the CL-492 results would actually be preferable to the validation studies that have been presented in Attachment 2 in at least one important respect. The CL-542 tests did not measure limiting conditions of operation for any of the tested cables. Hence, these tests will be inadequate to demonstrate the ability of the model to simulate such conditions. In contrast, the CL-492 tests did measure actual ampacity limits. Hence, the CL-492 tests provide a more direct basis for validation of the thermal model.

Of the two tests the licensee did consider, "Test 1" test involved two sizes of cables arranged in three power circuits, with each circuit energized at a pre-determined ampacity load. "Test 5" involved a single cable installed in a tray and energized to a predetermined ampacity. The test results cite the highest measured conductor temperature for each circuit during the test. The licensee analysis is based on an independent assessment of each of these circuits. In essence, the licensee has specified the ambient and hot-spot temperature for each circuit as well as the physical parameters of the cables, and has estimated the ampacity required to achieve the stated temperature conditions.

The results of this comparison are not uniformly favorably. The thermal model results for three of the four cases studied, two of the "Test 1" circuits and the one circuit from "Test 5", were conservative. In fact, the thermal model predicted ampacity limits well below those measured in the tests. However, for one of the "Test 1" circuits, the required ampacity was significantly over-estimated (6.96A calculated versus 3.8A measured). None of the results were what SNL would consider "excellent agreement" between test and calculation.

The licensee appears to base its own conclusion of conservative results on the fact that the overall heat rejection capacity of each case is conservatively estimated. In particular, for

Test 1 the sum of the three cable group total heat loads from the thermal model is lower than the total measured heat generation rate for the tray as a whole. This is an invalid basis for concluding that the model can be used to accurately or conservatively estimate the ampacity loads for individual cables. The overall heat load is only one part of the question. Estimating the actual ampacity values for individual cables is the ultimate and overriding concern, and the licensee results demonstrate one case in which the ampacity estimates were significantly non-conservative. SNL finds this to be the overriding and most compelling insight gained from these two limited case examples.

If a broader range of test conditions had been examined, and if all results were shown to be uniformly conservative, then one might concede the issue. However, for one of the four circuits considered the modeling result was significantly non-conservative. This does not support a conclusion that the thermal model will be uniformly conservative.

In addition to these overall findings, SNL reviewed the input parameters as provided in the Attachment and noted three discrepancies in the cited values:

- The calculated equivalent "# of cables" is cited in the first line of the input data tables. This value is purported to be set so as to match the overall fill width for the tray as a whole with an equivalent width of fill assuming the fill is entirely comprised of just one size cable, the cable under specific study (note that the licensee is not matching depth of fill, but rather the width of the fill). However, in the case of the 3TC#2AL cable in "Test 1", it would appear that a mistake was made. The value cited by the licensee is 8.04 cables whereas dividing the total installed width (4.12") by the cable diameter (0.92") yields 4.478 cables.

- The licensee has set the emissivity of the cable surface to 1.0. This is an unrealistic value. Cable insulation is normally assumed to have an emissivity of 0.9 for such calculations. This may have had a modest non-conservative impact on the code predictions.

- The model code listing includes two critical input parameters, "Y8" and "Z8", that are manually entered at the top of the code. These are cited only as "the limits of the cables" and the variables are not further defined. No values for these two variables have been provided in any of the cited case examples (see further discussion of these two variables in Section 4.3 below).

In summary, SNL finds that the licensee cited validation studies are inadequate to demonstrate the acceptability of the licensee thermal model. The validation performed by the licensee has not even considered the full range of test results provided in their own test reports, and in particular, no comparisons to those test in which cable ampacity limits have actually been measured were provided. SNL remains unconvinced of the acceptability of this thermal model as an ampacity assessment methodology. As noted in Section 4.3 immediately below, SNL has also identified certain concerns regarding the actual coding of the thermal model. SNL recommends that this thermal model not be credited as an appropriate basis for analysis without significant additional review and validation.

It is rather unfortunate that licensee has not taken full advantage of its own test data. It would be particularly enlightening to compare the licensee thermal model heat load calculations to the data for those tests from CL-492 that were performed using the "solid bottom/solid top/no barrier" and the "vented bottom/no top/solid fire barrier" tray configurations (SNL has referred to these as configurations C and D respectively elsewhere in this report). These two configurations are both directly relevant to the fire barrier evaluations in that they both represent enclosed raceway configurations with restricted air flow in and around the cables. In particular, the "solid bottom/solid top" configuration is essentially equivalent to a "thermally thin" fire barrier and the "vented bottom/no top/solid fire barrier" configuration represents a "thermally thick" fire barrier. While these tests did not involve Thermo-Lag, and recognizing that there is some uncertainty in the test results (see Appendix C), these two configurations would still provide for an excellent basis of validation for the licensee thermal model predictions of limiting cable tray heat rejection capacities. It is recommended that, as a minimum, the licensee be asked to validate its thermal model against each of the eleven CL-492 tests performed using these two tray configurations. There are a total of 6 tests for "configuration C" and 5 tests for "configuration D." If the licensee can successfully predict the total heat load for these 11 tests, then this would be a powerful validation basis for that aspect of the model. The comparison should be based on a direct comparison of the calculated heat load and the measured heat load for each of these eleven test cases.

4.3 Licensee Attachment 3: Thermal Model Code Listing

Attachment 3 to the licensee submittal provides a direct print-out of the licensee thermal model computer code. SNL did make an initial attempt to implement this code, but eventually gave up this approach as impractical. In particular, the code is written in a very convoluted manner with many conditional branch statements (conditional "GOTO" statements) for which the controlling variables are not defined. This made it virtually impossible to follow the code's flow and logic structure. With no clear understanding of the intent of the index counters and other internal control variables, verification of the model is not possible.

There were also two input parameters entered manually at the top of the code, variables "Y8" and "Z8", that are only identified as the "limits of the cables" but not further explained. No input information of these two variables was provided, and the case examples cited by the licensee did not provide the input values used. Given the other uncertainties in the code structure and logic, SNL was also unable to infer the definition of these variables. Unfortunately, it is these two parameters that appear to control the primary looping structure of the code; hence, their chosen values would appear to be a critical factor in the model results. Without a further explanation of these two input parameters, even if we had been successful in implementing the model, it would be virtually impossible to generate meaningful results.

As a final note, SNL found that the licensee had not explicitly defined, in a programming sense, its internal variables as is expected in conventional practice. There are two points of potential concern in this regard related to the designation of floating point (REAL) versus integer variables. As a general rule, it is important to define index and counter variables as integers in order to ensure accumulated round-off errors do not compromise loop statements and conditional comparisons. For example, in a statement such as "IF(C2.EQ.1)GOTO ...." if "C2" is not defined as an integer then accumulated round-off may raise its value to 1.00000001. In this case the "equals" comparison would fail, and the intent of the statement may be subverted.

The second aspect of this problem arises if the computer inadvertently treats variables intended as floating point real variables as integers instead. Conventional practice is for all variable names beginning with the letters "I" through "N" to be integers, and all others reals unless explicitly defined otherwise. This convention is typically assumed by most compilers as the default. The licensee code does not appear to follow this convention. Hence, if a variable name such as "M5" is used, most compilers will treat this as an integer variable unless an explicit REAL statement is included. If the intent is to treat this as a real variable, but it is not defined as such, then each time the variable is calculated, the value will simply be truncated to an integer. Not knowing what compiler the licensee has used, it is impossible to determine if this might have impacted the licensee program. However, the licensee has defined a variable "M5", for example, that appears to be intended as a real variable but has not been defined as such. This also raises some uncertainty in the licensee implementation.

Given these difficulties, SNL concluded that it would not be possible to either implement nor fully verify this model given the information provided in the licensee submittal; hence, we abandoned our attempts to do so. In fact, SNL was unable to even verify that the computer code is actually performing calculations consistent with the licensee's stated thermal modeling objectives and assumptions due to uncertainty in the logical structure of the code and the definition and values associated with various internal control parameters.

As noted elsewhere in this report, SNL remains unconvinced of the merits of this thermal model based on inadequate validation. Our failed attempts to verify and implement the model merely lend additional foundation to these SNL misgivings. Computer code Quality Assurance and Verification is an important aspect of a thermal model intended for use as a tool for compliance with USNRC requirements and regulations. SNL would expect that a code intended for use in any regulatory context would be implemented using a high standard of programming quality. The licensee thermal model has not met this burden. The fact that SNL was unable to successfully implement and exercise the code does not lend confidence to its appropriateness and validity.

SNL continues to recommend that this licensee thermal model not be accepted as an appropriate basis for analysis without significant further review and validation. Given that SNL was unable to either verify or implement the code, the validation process should include a further description of the code structure and internal variables. It would also be appropriate for the licensee to "clean up" the code to allow for a more scrutable flow and logical structure and to implement other aspects of currently accepted structured programming methods.

4.4 Licensee Attachment 4: Test Report CL-492

Attachment 4 to the licensee submittal presents Test Report CL-492. In this report the licensee has documented a series of tests performed to assess the ampacity limits for a range of cable installation and tray configurations including testing of a 3-M fire barrier product. Appendix C of the current report provides a detailed review and analysis of the test data and documents a number of relevant insights derived from that data.

In general the tests appear to have been performed in a conscientious manner, however, the tests do not conform to currently accepted ampacity testing practices. Recognizing that "hind-sight is 20-20", SNL notes the following deficiencies in comparison to currently accepted methods:

- There is no discussion of what criteria were used to ensure that steady state had been achieved. Current practices are quite specific in this regard. It would appear that the tests were run for a considerable time period, but there is no clear assurance that a true or consistent steady state was achieved.

- The temperature and current data are all hand recorded, apparently at a single (final) point in time. Current practices would require that several measurements made at regular intervals over the course of the last hour of the test be averaged to assure a reliable result.

- The licensee tests measure only the cable surface temperature, and did not measure conductor temperature for most cases. A correction has been applied to estimate conductor temperature, but the validity of the applied correction has not been demonstrated.

Given an awareness of these deficiencies, SNL is reluctant to place too much reliance on these test results. In particular, these tests should not be credited as an adequate direct measure of ampacity limits for any fire barrier configuration, and in fact, the licensee has <u>not</u> used the results in this manner. SNL does recommend that the data should be credited as an appropriate source of model validation data in the context of thermal modeling of cable tray ampacity configurations. However, the licensee has not provided any validation results for comparison of its thermal model to this set of test results. Only two validation cases have been cited by the licensee, and neither of these two cases was taken from this test set. Hence, the licensee has not demonstrated any physical consistency between its thermal model and the data from this set of tests.

In certain ways, this test set actually represents a much preferable validation basis than the alternate data set cited by the licensee (see the test report CL-542 from the original licensee submittal). The preferable aspects include the fact that the cables CL-492 were loaded to their approximate ampacity limits. This is preferable to test set CL-542 in which cable loads were arbitrarily set, and none of the cables approaches load limits. The licensee thermal model is purported to simulate limiting conditions of operation; hence, comparison to measured ampacity limits is desirable. The non-desirable aspect of the test is that it did not involve Thermo-Lag. This is a relatively minor shortcoming because the alternate barrier system that was tested is nominally similar to the Thermo-Lag panels, at least under non-fire conditions. Also, the diverse fill tests did not include a fully enclosed tray configuration as one of the tested configurations. As was discussed in Section 4.2 above, those 11 tests involving the "solid bottom/solid top/no fire barrier" and "vented bottom/no top/solid fire barrier" tray configurations would provide an especially appropriate basis for validation.

In summary, SNL recommends that the CL-492 test set would represent an appropriate basis for validation of the licensee model. Unfortunately, no validation comparisons have been documented by the licensee. Of particular interest would be validation of the thermal model in comparison to each of the 11 tests involving the "solid bottom/solid top/no fire barrier" and "vented bottom/no top/solid fire barrier" tray configurations would provide an especially appropriate basis for validation. As noted in 4.2 above, SNL finds that the licensee has not demonstrated an appropriate model validation in comparison to the cited CL-492 tests. A successful validation against these 11 tests in particular would represent a much more powerful and complete validation basis. It has been recommended that the licensee be asked to provide such validation comparisons.

4.5 Licensee Attachment 5: ICEA Margins Assessment

Licensee Attachment 5, "Comparison Tables Providing Base Information Regarding Trays and Conduits Cable Full Load Amperes, and Comparison of Calculated Ampacities vs ICEA Ampacities," provides a direct comparison between actual in plant cable loads, the licensee calculated ampacity limit, and the ampacity limit as derived by the licensee using the Stolpe/ICEA heat intensity approach for cable trays, and the tabulated ampacity limits for conduits from the NEC or IPCEA P-46-426. This assessment, in principal, provides a direct assessment of the available margin in comparison to nominal ICEA ampacity limits. As such, this is a powerful and widely accepted approach to assessment.

4.5.1 The Cable Tray Assessments

The general approach taken in this analysis by the licensee was based on Stolpe's concept of heat intensity. In particular, the licensee calculates a depth of fill, converts this to a percentage fill, obtains a heat intensity limit from Stolpe's paper, and calculates individual cable ampacity limits using Stolpe's Equation (9). In general, application of the Stolpe method is appropriate and is in fact the basis for the ICEA P-54-440 tables. Unfortunately, in reviewing this attachment SNL has identified four apparent errors that have compromised the results for most of these cables. For four of the nine trays, the heat intensity based results are clearly non-conservative. For the remaining trays, the results are actually conservative with a limited number of specific exceptions. Note that in a very few cases, for specific cables the licensee has simply cited a tabulated ampacity limit at a 1" depth of fill rather than calculating ampacity using the heat intensity approach, and these values would not be impacted by the cited errors.

The first problem in the analysis is an inconsistency in how the licensee has calculated the depth of fill and the individual cable ampacities. As SNL has noted in prior reviews, there are two methods for calculating the cross-sectional area of a cable, and hence, a cable tray's depth of [illegible] ICEA P-54-440 defines the cross-section as the equivalent cross-section of a square surrounding the cable:

$$A_{x\text{-}section\ ICEA} = d^2$$

and the corresponding depth of fill is defined as the sum of the cross-sections for all cables in the tray divided by tray width:

$$d_{fill\ ICEA} = \frac{\sum_{i=1}^{m} n_i d_i^2}{W_{tray}}$$

where (m) is the total number of distinct cable sizes present in the tray, (n_i) is the number of cables of a given size and (d_i) is the diameter of that cable size. In contrast, Stolpe defined the cross-section using the equivalent circular cross-section:

$$A_{x\text{-}section\ Stolpe} = \frac{\pi d^2}{4}$$

and the corresponding depth of fill is defined as:

$$d_{fill\ Stolpe} = \frac{\sum_{i=1}^{m} n_i \frac{\pi d_i^2}{4}}{W_{tray}}$$

Whether one uses the ICEA or Stolpe definitions really matters little, <u>so long as one is consistent</u>. However, the licensee has not been consistent in its analyses. Depth of fill for the in-plant trays has quite clearly been calculated using the ICEA definitions, but the individual cable ampacity limits have apparently been calculated using the Stolpe's equation (9) directly which implicitly assumes the Stolpe definition of cable cross-section (SNL can only reproduce the licensee values if the Stolpe equation (9) is applied directly). This mistake taken alone resulted in the calculation by the licensee of ICEA ampacity limits that were about 13% lower than would in reality be allowed. Hence this error is an apparent unintended source of conservatism in the analysis.

The second mistake in the licensee analysis is far more significant, and has had a pronounced non-conservative impact on certain of the assessments. This second mistake arose because the licensee has treated percentage fill as the critical parameter in the ampacity assessment rather than depth of fill. That is, the licensee has applied Stolpe's heat intensity results to in-plant trays by comparing fills on the basis of percentage fill. The licensee's error in this approach is that Stolpe calculated his percentage fills assuming a 3" tall tray, and the licensee calculates their percentage fill assuming a 6" tall tray. Hence, a 10% fill as cited by the licensee is not at all equivalent to a 10% fill cited by Stolpe, and yet the licensee has made this assumption. In fact, a 10% fill of a 6" tray (a

10% licensee fill is actually equivalent to a 20% fill of a 3" tray (a 20% Stolpe fill). In both cases the depth of fill would be 0.6" (licensee fill: 0.1*6"=0.6" or Stolpe fill: 0.2*3"=0.6"). In determining the heat intensity limit for a given tray, depth of fill is the critical factor. Percentage fill can be used as a surrogate for depth of fill, but only if the Stolpe and in-plant percentages are be based on trays of equal height. This error, taken alone, has resulted in overestimation of the allowable heat intensity, and hence, an overestimation of the ampacity limits.

In practice, this observation is particularly relevant to four of the nine cable trays considered (trays 1AI-P2, 1A-P20, 2AZ-P3, and 2AZ-P10). For the remaining 5 trays, the licensee has used a bounding limit of 10% "Stolpe fill" for trays which in reality have less than a 5% "licensee fill." A 5% "licensee fill" would be equivalent to a 10% "Stolpe fill", and hence, the assumed 10% fill will still bound these five trays, although the extent of the conservatism introduced by this bounding limit is significantly reduced. For the four specific trays cited, the licensee has not bounded the actual fill depth. For the four impacted cases, this licensee error taken alone would overstate allowable ampacity limits by about 40%-55% (depending on whether the actual or a "bounding" fill was assumed in the licensee analyses).

The third oversight noted by SNL is that the licensee has not considered the fact that ICEA P-54-440 establishes an upper-bound ampacity limit for random fill cable trays at 80% of the corresponding open air ampacity limit. It is especially in cases of low cable fills, such as those considered by the licensee, that the 80% limit will predominate. In particular, any case in which the cable diameter is larger than the cited depth of fill is a likely candidate for the 80% limit to be invoked. For several of the licensee cable installations, the 80% of open air ampacity limit would be the more conservative limit.

The final error noted in the licensee assessments involves cables identified as "control", "spare", or "cut and taped in tray." These are cables that are present in the tray but either carry only intermittent loads or are not in use. While it is not necessary to provide ampacity assessments for these cables, they should be included in the calculation of cable tray fill depth. Tray fill should be based on the total load of all cables in the tray. The licensee has calculated the fill depth based only on the active power cables and this is not appropriate. All cables, whether powered or not, contribute to some degradation of the heat transfer processes and should be included in the fill calculation. For example, when control, instrumentation and power cables are mixed in a tray, the fill depth for the power cables is to be estimated using the total fill, not just the power cable fill. As an extreme example, a single power cable embedded in a mass of control cables is by no means equivalent to a power cable alone in a tray. While the requirement to consider all cables in the load calculation does introduce some conservatism (no diversity credit is taken in this process), to ignore part of the cable load in the fill calculation introduces a source of non-conservatism. This observation has a minor impact on six of the nine trays considered by the licensee. Because none of the trays contains a significant number of such cables, and because the neglected cables are generally small, the impact on any give assessment is actually quite minor.

Appendix A of this report provides for a partial re-assessment of the licensee cable analyses to illustrate the impact of correcting these four errors on the licensee assessments. SNL has not attempted an exhaustive assessment of every licensee cable, but rather, has only considered a subset of the licensee cables for which potential margin problems might be anticipated. In particular, numerous "3TC#12 AWG" cables are cited as carrying ampacity loads of less than 5 amperes. Given the very sparse tray loadings, this will be a trivial ampacity load for these cables and is clearly acceptable.

The SNL re-analysis identified a total of four individual cables that appear to be nominally overloaded even in the absence of the fire barrier system and six additional cables that may have an inadequate nominal margin to allow for the barrier installation. It has been recommended that the licensee be asked to provide for additional justification for the acceptability of the cables loads for these ten cables.

4.5.2 The Conduit Assessments

In addition to the cable tray assessments, the licensee has also provided similar margins assessments for a number of conduit installations. An SNL review of these assessments revealed only one significant error, although this error ultimately does not compromise the licensee's final conclusions.

The error noted by SNL is that the licensee has cited an IPCEA P-46-426 ampacity limit for its "3TC#2AL" cables based on the tables on page 264 of the standard. Unfortunately, the cited tables are only applicable to copper-conductor cables, and do not apply to the licensee aluminum conductor cables. The correct conduit ampacity limit for the impacted #2AL cables should be 87A as compared to the licensee cited value of 112A. Note that the worst-case current load cited for a cable of this size is 71.9A. Hence, the worst-case margin is still 17.4%. This should be sufficient to bound the impact of a 1-hour conduit fire barrier system of the type cited by the licensee.

No other errors in these licensee conduit assessments were identified. All of the cables analyzed have been shown to have a margin sufficient to bound the ampacity derating impact of the fire barrier system. Hence, SNL recommends that the error identified above simply be brought to the attention of the licensee, but that no further actions on the conduit applications are needed.

4.6 Licensee Attachment 6: 12AWG Ampacity Plot

Attachment 6 to the licensee submittal is entitled "Ampacity vs Depth of Fill Plot for #12 AWG Cable in Tray." This plot appears to be a simple plot of data presented in Table 3-6 of ICEA P-54-440. While the specific plotted values appears nominally correct, a graphical extrapolation of ampacity limits must be done in a very careful manner. In particular, the ampacity behavior is logarithmic in nature, and graphical extrapolation based on a very course linear scale plot such as this is not appropriate. Extrapolation is acceptable, but should recognize and allow for the known logarithmic behavior. Typical extrapolations would plot the log of ampacity versus the log of fill depth, and then assume a linear extrapolations for specific ranges of fill depth. This is, in fact, a method commonly used by SNL in such analyses (see Appendices A and C for examples of this practice).

Ultimately, the licensee has not applied this plot to any of its actual case analyses, and hence, this observation has no real impact on the licensee assessments. SNL makes no specific recommendations regarding this attachment.

5.0 SUMMARY CONCLUSIONS AND RECOMMENDATIONS

5.1 The Licensee Thermal Model

SNL finds that the licensee has not adequately addressed certain of the points of technical concern identified in the USNRC RAI. In particular, SNL finds that the licensee validation studies are not adequate to conclude that the thermal model will yield either realistic or conservative ampacity estimates. In fact, one of the licensee validation analysis cases generated highly non-conservative estimates of ampacity in comparison to the measured values. Further, SNL finds that the actual computer code for this model has not been written in a manner consistent with acceptable engineering practice. SNL was unable to implement the thermal model independently due to code structure, internal control, and input uncertainties. SNL was also unable to verify that the code is performing the calculations consistent with the licensee's physical descriptions and assumptions.

SNL recommends that this thermal model should not be credited as an appropriate basis for analysis without significant further review and validation. If the licensee chooses to continue to pursue application of this model, then as a minimum, SNL recommends that the licensee be asked to provide the following:

- SNL recommends that the licensee be asked to reformulate the actual code implementation so as to comply with accepted engineering practice for structured programing. This should include a more organized logical code structure that allows for a direct and clear understanding of the program flow and flow control, and the explicit definition of internal variables, input variables, and flow control parameters. The code should be amenable to independent implementation and verification.

- SNL recommends that the licensee should be asked to supplement the validation study by providing a direct comparison between total allowable heat rejection capacity as calculated by the thermal model and as measured in the tests for eleven specific tests from the licensee CL-492 test report. These are those six tests performed using the "solid bottom/solid cover/no fire barrier" tray configuration and those five tests performed using the "vented bottom/no cover/solid fire barrier" tray configuration.

5.2 The Licensee ICEA Margins Assessments for Cable Trays

SNL finds that licensee Attachment 5 in which in-plant cable loads were compared to ICEA ampacity limits is, in principal, an acceptable approach in and of itself to demonstrate adequate ampacity margin for clad power cables. Unfortunately, SNL also identified a number of apparent errors in the licensee calculations. These include:

- The licensee has used an inconsistent treatment of cable cross-sectional area in the calculation of tray depth of fill and individual cable ampacity limits.

- The licensee has made an inappropriate comparison of in-plant tray fills and the Stolpe heat intensity limits using percentage fill instead of actual depth of fill without correcting for differences in the side rail height of the licensee trays versus those used by Stolpe.

- The licensee has failed to incorporate the ICEA P-54-440 restriction that for cable trays ampacity limits shall not exceed 80% of the corresponding cable open air ampacity.

- In calculating depth of fill, the licensee has neglected cables identified as "spare", "cut and taped in tray", or "control" whereas all cables should be included in the fill calculation whether or not they are powered.

Given these discrepancies, SNL has re-calculated the appropriate ICEA ampacity limits and made similar comparisons to the cited in-plant cable loads (see Appendix A). Based on these results, SNL has identified four specific cables that may be nominally overloaded even neglecting the fire barrier system (Tray 1A-P20 Cables 8984R and 8987R; and Tray 2AZ-P3 Cables 8204G and 8987G) and six additional cables for which the available ampacity margin may be inadequate to bound the impact of the fire barrier (Tray 1AI-P1 Cable 8755RH; Tray 1AI-P2 Cable 8755GH; and Tray 2AZ-P3 Cables 3012G, 3013G, 3014G, and 13945G). SNL recommends that the licensee be asked to provide a further assessment for these ten specific cable applications. For the remainder of the licensee tray applications, SNL finds that the licensee and SNL analyses have demonstrated an adequate ampacity margin and that no further consideration of these cables is needed.

5.3 ICEA Margins Assessments for Conduits

There was only one significant error identified in the licensee conduit assessments related to the ICEA ampacity limit of one aluminum conductor cable (see Section 4.5.2 above). A SNL re-analysis of the impacted case revealed that the cable in question did, in fact, have an adequate ampacity margin. For all other cases, SNL found the licensee assessment of ampacity margin for clad conduits to be acceptable. All cables were found to have a margin sufficient to bound the anticipated impact of the fire barrier system. SNL recommends that the identified error be brought to the attention of the licensee, but that no further actions on the conduit applications are needed.

5.4 The Licensee RAI Responses

The licensee responses to certain of the RAI items was not considered sufficient to resolve the identified concerns. However, all of those responses considered deficient were directly related to thermal modeling concerns. For the other RAI items SNL finds that the licensee responses are adequate to resolve the identified technical issues.

In leu of specific recommendations to further pursue the previous RAI items, SNL has instead made two specific recommendations intended to allow for an integrated resolution of the remaining concerns regarding the licensee thermal model and its implementation. These recommendations are documented in Section 5.1 above, and include improvements in the code structure and the implementation of additional validation studies using 11 specific test cases from the licensee's own test report CL-492. Provided these recommendations are satisfactorily and successfully implemented, the specific RAI concerns will be resolved. Hence, no further actions on any of the identified RAI items is currently recommended.

6.0 REFERENCES

1. Stolpe, J., "Ampacities for Cables in Randomly Filled Trays," *IEEE Transactions on Power Apparatus and Systems*, Vol. PAS-90, Pt. I, PP 962-974, 1971.

2. J. H. Neher and M. H. McGrath, "The Calculations of the Temperature Rise and Load Capacity of Cable Systems", AIEE Transactions pp752-772 Oct. 1957

Appendix A: An SNL Re-Analysis of the Licensee Attachment 5 ICEA Ampacity Limits and Margins Assessments

A.1 Approach and Assumptions

The SNL analyses as presented here are based on a uniform application of the ICEA approach to heat intensity-base ampacity assessments. This, in particular, includes application of ICEA definitions of both cable cross-section and depth of fill in which the equivalent square cross-section is assumed (as per the original licensee analyses). This allows for a direct application of the licensee cited depth of fill results without recalculation. However, SNL has applied the correct corresponding ampacity correlation for individual cables assuming this same cross-section applies (in contrast to the licensee application of Stolpe Equation (9) directly). For the ICEA definition of cross-sectional area, this expression is properly written as:

$$I = \sqrt{\frac{Q\,A_{x\text{-}section}}{n\,R_{ac}}} = \sqrt{\frac{Q\,d^2_{cable}}{n\,R_{ac}}} \doteq d_{cable}\sqrt{\frac{Q}{n\,R_{ac}}} \qquad \text{(A-1)}$$

To determine the heat intensity (Q) for a given depth of fill one must extrapolate the Stolpe/ICEA cited values. In this analysis, SNL has utilized the following logarithmic model of the Stolpe/ICEA heat intensity limits:

$$Q = 5.925\ d_{fill}^{-1.258} \qquad \text{(A-2)}$$

where (d_{fill}) is given in inches, and (Q) is given in W/ft/in^2. This correlation was developed using the ICEA cited heat intensity limits at 1" and 1.5" depth of fill (these values are identical to those of Stolpe at 33% and 50% fills respectively), and fitting those two values to a linear log-log relationship between heat intensity and depth of fill:

$$Log_{10}(Q) = A + B\ Log_{10}(d_{fill}) \qquad \text{(A-3)}$$

Using the two known (d_{fill}, Q) value sets, the value of the constants A and B in the above expression are readily determined. Rearranging the equation somewhat yields the more convenient form of Equation A-1. This correlation is appropriate for application to any depth of fill less than 1.5". This covers all of the licensee applications. (Other correlations must be developed to support other depth of fill ranges.)

SNL has also considered the 80% of open air ampacity limit in this assessment. For 8 AWG and larger cables, the ICEA P-46-426 limits have been used assuming either a triplex cable arrangement for the cables identified as either "3TC" or "3-1/C" in the licensee analyses. Note that P-46-426 does not address cables smaller than 8 AWG. Hence, for the cases involving the 12 AWG cables, SNL has, taken the IEEE 835-1994 standard value for ampacity in free air (36A for a triplex cable) as the basis for this assessment. As a general observation, for free air applications IEEE 835 sets somewhat more liberal ampacity limits than does ICEA P-46-426. Taking 80% of the 36A IEEE limit yields an nominal maximum tray installation ampacity limit of 28.8A which has been applied to all of the licensee cited 3TC12AWG cables.

In the specific case of cables cited as a 4/C#12CU cable (a 4-conductor cable) one additional correction is applicable. For general open air limits, P-46-426 and the NEC would apply a correction factor of 0.8 to allow for "more than three conductors in the cable or raceway". This correction factor derives from the same multiple conductor count correction factors as are applied to conduits. Hence, the 80% of open air limit for the 4/C cable is taken as (36*0.8*0.8=23A). This is likely a conservative estimate of the ultimate ampacity limit of these cables in a tray installation.

All cable diameter information has been used as provided by the licensee. The cable electrical resistance values have been take from standard tables of conductor resistance, and are for the conductor at a temperature of 90°C.

For screening purposes, SNL has compared the available margin to a nominal fire barrier ADF of 32%. This value derives from the TUE tests, but is also supported by the SNL analyses of the licensee's CL-492 test results as documented in Appendix C below. This value, 32%, may be a modestly conservative estimate for the sparsely loaded trays at D.C. Cook. In particular, one might have anticipated that the licensee practice of maintained spacing installation might provide a substantial margin over the nominal ICEA limits which assume a random tray fill. Unfortunately, the licensee's own test results do not substantiate this expectation. As documented in Appendix C below, the CL-492 results clearly indicate that a significant derating impact should be anticipated for the clad cables in comparison to the ICEA P-54-440 ampacity limits.

The first point to observe is that the ICEA limits were found to be only modestly conservative in comparison to open tray configuration ampacity limits measured by the licensee. The only exception to this observation was the cases involving the smallest cables in the mixed-fill tests where the fill was dominated by the very large 350 MCM and 750 MCM cables. For these specific cases the 12 AWG ICEA limits were found to be very conservative. This insight is not directly relavent to the licensee cases because all of the licensee's actual tray fills are comprised of cables much smaller than either the 350 MCM or 750 MCM cables used in the mixed fill tests. The largest active cable cited by the licensee is a 3TC#2/0AL cable, and most cases involve cables of #2 AWG or smaller. Hence, the licensee fills are not dominated by very large cables as where the CL-492 mixed-fill tests and the same degree of conservatism in smaller cable ampacity limit estimates should not be expected to hold true for the actual applications. Overall, one should only anticipate a modest margin between the ICEA P-54-440 limits and those one might measure in practice for the cited licensee tray fills.

The second point to observe is the ADF impact of the fire barrier. In the multiple like cable tests, the 3M fire barrier system had a measured ADF ranging from 25.6% to 44.2% in comparison to a "vented bottom/vented top/no fire barrier" configuration. There is no reason to believe that the ADF for the Thermo-Lag fire barriers will be substantially different from these 3M values. As an additional bench-mark, consider that the simple "solid bottom/solid top/no fire barrier" tray configuration is essentially a "thermally thin" fire barrier configuration. This configuration resulted in ADF values ranging from 14.4% to 32.2% in comparison to an open tray configuration for the single cable tests, and an ADF of 21.4% to 32.2% in comparison to a "vented bottom/vented top/no fire barrier" configuration in the multiple like-cable tests. This would certainly place an absolute lower bound on the anticipated ADF of a "thermally thick" fire barrier system such as Thermo-Lag. Given these insights, SNL considers the 32% screening value to be reasonable.

A.2 Re-Analysis Results for Selected Cables

A.2.1 Tray 1AI-P1

SNL has only reassessed the ampacity limits for one cable in tray 1A1-P1. For the remaining cables in this tray the licensee calculation has demonstrated an adequate margin and there is no need for further analysis. The licensee cites an actual depth of fill of 0.237" (or 3.95% assuming a 6" tray). This fill has neglected one "spare" cable, and hence, is somewhat understated. However, in assessing the heat intensity limits, the licensee assumed a 0.3" (or 10% of a 3" tray) fill as per Stolpe, and hence, this value would still bound the licensee actual fill. The majority of the cables in this tray have only trivial ampacity loads and are not of significant concern.

Of the cables in this tray, cable 8755RH is cited as having the lowest available margin, 27.44%. If the inconsistency in the treatment of cross-section area is corrected, then the cited ICEA heat intensity-based limit for this cable would increase by about 13% from 60.64A to about 68A. However, the open air limit for this cable is just 69A, and 80% of this value is just 55.2A. Thus the 80% of open air value would be the overriding limit for this application. Using 55.2 as the net ICEA limit yields a modified margin of about 20.3%. This margin is not within the SNL recommended 32% fire barrier ADF, and hence would not be deemed acceptable.

In summary, for tray 1AI-P1 it is recommended that the licensee be asked to further assess the ampacity load for cable 8755RH and to provide a further justification for its acceptability.

A.2.2 Tray 1AI-P2

Tray 1AI-P2 has a cited depth of fill of 0.6805". However, this fill has neglected two power cables identified as "spare". If these two cables are included, then the modified depth of fill is estimated by SNL as 0.7599". Using this corrected fill depth the corresponding heat intensity limit is:

$$Q_{0.6805} = 5.925 * (0.7599)^{-1.258} = 8.370\ W/ft/in^2$$

This tray is cited as containing 5 cable sizes. Of these, the 12 AWG applications all have trivial ampacity loads and are not considered. Two cables are cited as spares and are not considered further. For the remaining cables, the SNL analysis results are provided in Table A.1.

Table A.1: SNL re-analysis results for selected cables from Tray 1AI-P2							
Cable No.	Cable Type	Project Load FLA	Electric .Resist.	Heat Intesity Amp. Limit	80% Of Open Air Amp. Limit	Net ICEA Amp. Limit	% Margin FLA versus ICEA
8756GH	3TC350 AL	150.8	6.54E-5	392.4	317.6	317.6	52.5%
8751GH	3TC#6 AL	15.50	8.48E-4	39.6	55.2	39.6	60.8%
8753GH	3TC#2 AL	49.40	3.35E-4	84.9	101.6	84.9	41.8%
8755GH	3TC#6 AL	37.80	8.48E-4	39.6	55.2	39.6	4.6%
1500G	3TC2/0 AL	50.30	1.67E-4	164.1	164.8	164.1	69.4%

Given these results, the only cable in this tray with a potentially inadequate margin is cable 8755GH. This cable has a margin of just 4.6% to allow for the fire barrier which is clearly insufficient. In summary, for tray 1AI-P2 it is recommended that the licensee be asked to further assess the ampacity load for cable 8755GH and to provide a further justification for its acceptability.

A.2.3 Tray 1AI-P4

This tray contains just 3 cables, of which two have clearly trivial ampacity loads. The third cable, 2560G, is cited as a welding receptacle with only intermittent load. The maximum load on this circuit was based on the circuit "switch rating" of 60A. Given this estimate of the maximum load it would appear that this cable is nominally overloaded, even in the absence of the fire barrier. The open air ampacity limit for a 3TC#6AL cable is 69A. Taking 80% of this value establishes a tray limit of just 55.2A for a random fill tray in accordance with ICEA P-54-440.

For this specific case, an alternate analysis method may be more appropriate. The IPCEA P-46-426 standard does provide cable tray ampacity correction factors that are still appropriate for use in low-fill, maintained spacing applications (see Table VII of the standard). CNP has cited that its trays do meet the maintained spacing criteria. For a tray with just 3 cables arranged horizontally, a correction factor of 0.87 is recommended. Adjusting the open air ampacity by this factor yields an ampacity limit of 60.03A, which is essentially identical to the licensee cited load rating of 60A. Given the intermittent nature of this application, and the trivial ampacity load on the other two cables in this tray, SNL recommends that no further actions on this tray are needed.

As a passing note, the cited ICEA P-46-426 maintained spacing factors are nominally appropriate for analysis of any of the CNP power cable trays based on the information provided by the licensee. However, in practice this is actually the only tray for which these factors are actually appropriate. This is because IPCEA P-46-426 correction factors are only available for cable fills of up to 6 cables horizontally, and this is the only tray cited in the CNP study with fewer than six cables. Extrapolation of these factors to higher fills would not be appropriate; hence, SNL has not applied this method to any of the other licensee applications.

A.2.4 Tray 1AZ-P8

This tray is cited as having a fill depth of 0.1574" (or 2.62% of a 6" tray). This has neglected on cable that is "cut and taped in tray." Including this cable has no significant impact on the calculation, however, because a "Stope fill" of 0.3 inches was assumed in obtaining the heat intensity limit. Hence, this value would still bound the licensee fill.

For the 12AWG cable in this tray, the licensee has cited an ICEA limit of 29.04A. In reality, as was noted above the open air limit of a 12AWG wire is 36A, and hence, the corresponding ICEA limit would be 80% of this value or 28.8A. Hence, the licensee value of 29.04A is for all practical purposes acceptable. No further action on these 12AWG wires is recommended.

Of the cables in this tray, SNL has only re-analyzed one in detail, cable 1991R. This is cited as a 3TC#2AL cable with a 60A load current. The open air limit for such a cable is 127A, and 80% of this value is 101.6A. This is in contrast to the licensee calculated ICEA limit of 128.58A. Assuming this corrected ICEA limit, the margin for this cable is reduced to 40.9%, which is still sufficient to bound the 32% fire barrier ADF screening value recommended by SNL.

No further action on the cables in this tray are recommended.

A.2.5 Tray 1AZ-P9

Of the cables in this tray only two, 1440R and 8753RH, have non-trivial ampacity loads. The analysis of cable 1440R is identical to that of cable 1991R as discussed in A.2.4 above, and no further actions are required.

Cable 8753RH is cited as a 3TC#4AL cable with a 53A load. The open air ampacity limit for this cable is 94A, and 80% of this value is 75.2A. This is in comparison to the licensee cited ICEA limit of 88.68A. Using the 80% of open air value as the overriding limit, the ampacity margin for this cable is reduced to 29.5%. This value is somewhat lower than the nominal screening ADF of 32% recommended by SNL. However, in considering this margin, SNL notes that the remainder of the cables in the tray have only very minor to quite trivial ampacity loads indicating a very significant degree of load diversity in this tray. Further, the licensee has implemented maintained spacing installation methods, while the ICEA ampacity limits are applicable to random fill trays. Based on the combination of these two factors, SNL recommends that the demonstrated margin of 29.5% would be sufficient to ensure that this cable does not exceed its rated operating temperature of 90°C. No further action on this cable tray are recommended.

A.2.6 Tray 1A-P20

Tray 1AI-P2 has a cited depth of fill of 0.4952". This fill did neglect one 3TC#12CU cable identified as "spare." Addition of this cable would increase the fill depth to 0.5037". Because the "neglected" cable is small, the change in fill depth is quite minor. The corresponding heat intensity limit for this depth of fill was estimated by SNL as:

$$Q_{0.4952} = 5.925 * (0.5037)^{-1.258} = 14.04 \; W/ft/in^2$$

For this tray, SNL has re-analyzed several of the licensee cables. In particular, this cable tray is impacted by the licensee error in treatment of depth of fill versus percentage fill as discussed in the text. The re-analysis results are presented in Table A.2. Note that for the each cable type SNL has only considered that cable with the highest ampacity loads as conservative bounding cases. The ICEA limits for other cables of the same type in this tray would be the same, although the margins would be greater.

Table A.2: SNL re-analysis results for selected cables from Tray 1AI-P20

Cable No.	Cable Type	Project Load FLA	Electric Resist.	Heat Intensity Amp. Limit	80% Of Open Air Amp. Limit	Net ICEA Amp. Limit	% Margin FLA versus ICEA
2353R/2354R	4/C#12CU	16	2.07E-3	22.2	23.0	22.2	27.9%
8984R/8987R	3TC#12CU	15.6	2.07E-3	15.2	28.8	15.2	-2.6%
2361R	3TC#6 AL	31.4	8.48E-4	51.3	55.2	51.3	38.8%
8753RH	3TC#4AL	49	5.33E-4	75.0	75.2	75.0	34.7%
1440R	3TC#2 AL	60	3.35E-4	109.9	101.6	101.6	40.9%

Given these results, the only cables in this tray with potentially inadequate margins are certain of the 12AWG cables. In particular, cables 2353R and 2354R both have margins of about 28%. While this is nominally below the SNL recommended screening limit, it is recommended that these margins be accepted on the basis of load diversity and maintained spacing installation (see similar discussion in Section A.2.4 above). However, cables 8984R and 8987R appear to be nomially overloaded, even in the absence of the fire barrier system.

In summary, for tray 1A-P20 SNL finds that two cables, 8984R and 8987R, are apparently nominally overloaded even in the absence of the fire barrier system. It is recommended that the licensee be asked to further assess the ampacity loads for these cables and to provide additional justification for the acceptability of these loads.

A.2.7 Tray 2AZ-P3

This tray is cited as having a cable fill depth of 0.5364". However, this fill calculation has neglected four cables, two "spares" and two "control" cables. For one of the four neglected cables no information on cable diameter is available. This is cited as a

"7/C#12CU" cable. A typical diameter for such a cable would be on the order of 0.6". For the purposes of this assessment, SNL will assume this value for the diameter of this cables. Hence, the corrected fill depth including the four neglected cables would be approximately 0.592". The corresponding heat intensity limit is given by:

$$Q'_{0.4952} = 5.925 * (0.592)^{-1.258} = 11.46\ W/ft/in^2$$

For this tray, SNL has re-analyzed several of the licensee cables. In particular, this cable tray is impacted by the licensee error in treatment of depth of fill versus percentage fill as discussed in the text. The re-analysis results are presented in Table A.3. Note that for each cable type SNL has only considered that cable with the highest ampacity loads as conservative bounding cases. The ICEA limits for other cables of the same type in this tray would be the same, although the margins would be greater.

Table A.3: SNL re-analysis results for selected cables from Tray 2AZ-P3

Cable No.	Cable Type	Project Load FLA	Electric Resist.	Heat Intensity Amp. Limit	80% Of Open Air Amp. Limit	Net ICEA Amp. Limit	% Margin FLA versus ICEA
3012G/3013G	4/C#12CU	16	2.07E-3	19.3	23.0	19.3	17.3%
8204G	3TC#12CU	18	2.07E-3	13.7	28.8	13.7	-31%
8987G	3TC#12CU	16	2.07E-3	13.7	28.8	13.7	-16.8%
3014G	3TC#6 AL	36	8.48E-4	46.3	55.2	46.3	22.3%
13945G	3TC#2 AL	73	3.35E-4	99.3	101.6	99.3	26.5%
8756GH	3TC#2/0AL	96.4	1.67E-4	192	165	165	41.6%

Given these results, six of the cables in Tray 2AZ-P3 are either overloaded or may have insufficient margin. In particular:

- Cables 8204G (with a load of 18A) and 8987G (with a load of 16A) appear to be nominally overloaded, even in the absence of the fire barrier system. The nominal ICEA limit, even in the absence of the fire barrier is just 13.7A for these cables.

- Cables 3012G, 3013G, 3014G, and 13945G all have nominal margins ranging from 17.3-26.5%. This may be inadequate to allow for the fire barrier ADF, even if diversity and maintained spacing are credited. In particular, SNL notes that this tray has a much lower degree of load diversity than other of the licensee trays in which diversity was credited by SNL in the final evaluations. Crediting diversity for this tray would be difficult.

It is recommended that the licensee be asked to provide additional justification for the acceptability of the ampacity loads on these six specific cables for this application.

A.2.8 Tray 2A-P2

SNL has not re-analyzed any of the cables in this tray. The licensee analysis appears adequate to demonstrate a sufficient margin for all of the cables in this tray. No further actions on this application are recommended.

A.2.9 Tray 2AZ-P10

This tray is cited as having a 0.5315" fill depth. This fill calculation neglected one "spare" cable. When corrected, the actual fill depth is 0.5400", a very minor change. The corresponding heat intensity is given by:

$$Q_{0.4952} = 5.925 * (0.540)^{-1.258} = 12.86\ W/ft/in^2$$

For this tray, SNL has re-analyzed four of the licensee cables. This cable tray is impacted by the licensee error in treatment of depth of fill versus percentage fill as discussed in the text. The re-analysis results are presented in Table A.4.

Table A.4: SNL re-analysis results for selected cables from Tray 2AZ-P10

Cable No.	Cable Type	Project Load FLA	Electric Resist.	Heat Intensity Amp. Limit	80% Of Open Air Amp. Limit	Net ICEA Amp. Limit	% Margin FLA versus ICEA
8753RH	3TC#4AL	50.3	5.33E-4	71.7	75.2	71.1	29.9%
8755RH/1500R	3TC#2 AL	50.3	3.35E-4	105	101.6	101.6	50.5%
8756RH	3TC#2/0AL	100.5	1.67E-4	203	165	165	39.1%

Given these results only cable 8753RH has a nominal margin below the SNL recommended screening ADF of 32%. However, SNL recommends that this margin be accepted given that the "margin shortfall" is quite modest (just 2.3%). By crediting diversity and maintained spacing, as has been discussed above, SNL recommends that this margin is acceptable. No further actions on this tray application are recommended.

A.3 Summary of Tray Re-Analysis Findings and Recommendations

SNL finds that for most of the cable applications, an adequate margin is available to allow for the fire barrier installations. In this process, SNL has considered a nominal screening ADF of 32%. In a few limited cases, a final assessment of acceptability has included a qualitative consideration of both load diversity and maintained spacing installation procedures. However, SNL also finds that, in comparison to the ICEA P-54-440 ampacity limits, the following cables are either nominally overloaded even in absence of the fire barrier, or have insufficient margin to allow for the fire barrier installation:

- For tray 1AI-P1 SNL finds that cable 8755RH has a nominal margin of just 20.3% which is insufficient to bound the anticipated 32% fire barrier ADF. This is a 3TC#6AL cable with a cited load of 44A as compared to an estimated ICEA open tray limit of 55.2A.

- For tray 1AI-P2 SNL finds that cable 8755GH has a nominal margin of less than 5% which is not sufficient to bound the anticipated impact of the fire barrier system. This is a 3TC#6AL cable with a cited load of 37.8A as compared to an estimated ICEA open tray limit of 39.6A.

- For tray 1A-P20 SNL finds that two cables, 8984R and 8987R, are apparently nominally overloaded even in the absence of the fire barrier system. Both cables are 3TC#12CU cables, and each is cited as carrying an ampacity load of 15.6A as compared to an estimated ICEA open tray limit of 15.2A

- For Tray 2AZ-P3 SNL finds that the following cables are either overloaded or may have insufficient margin:
  - Cables 8204G and 8987G appear to be nominally overloaded, even in the absence of the fire barrier system. Both of these cables are 3TC#12CU cable. The cited load for 8204G is 18A, and the cited load for 8987G is 16A. These values are in comparison to an estimated ICEA open tray limit of 13.7A for each cable.
  - Cables 3012G and 3013G each have a nominal margin of 17.3% which may be inadequate to allow for installation of the fire barrier. Both cables are 4/C#12CU. The cited load for each is 16A as compared to a nominal ICEA open tray limit of 19.3A.
  - Cable 3014G has a nominal margin of 22.3% which may be inadequate to allow for installation of the fire barrier. This cable is a 3TC#6AL with a cited load of 36A as compared to a nominal ICEA open tray limit of 46.3A.
  - Cable 13945G has a nominal margins of 26.5% which may be inadequate to allow for installation of the fire barrier. This cable is a 3TC#2AL with a cited load of 73A as compared to a nominal ICEA open tray limit of 99.3A.

For these ten specific cable applications, it is recommended that the licensee be asked to provide additional justification for acceptance of the cited ampacity loads or to provide for some other means of resolving the ampacity concerns for these cables.

Appendix B: An Assessment of the Performance of the Licensee Thermal Model in Comparison to ICEA P-54-440

B.1 Overview

In preparing Appendix A, SNL has calculated the baseline ICEA allowable ampacity limits for many of the licensee cables. In Attachment 5 to the current submittal ampacity limits calculated using the licensee thermal model were presented for each of these cables in the clad condition. This provides an opportunity to directly assess the licensee thermal model results in comparison to the accepted ICEA methodology for determination of ampacity limits. This is the topic of the current Appendix.

In making this comparison, it is important to note that the licensee calculation includes the effects of the fire barrier system whereas the SNL calculated ICEA limits do not. Hence, it is appropriate to compare the two values in terms of the ampacity margin. That is, the comparison will assess the margin derived from the licensee calculation in comparison to the nominal baseline ampacity limits of the ICEA P-54-440 standard.

B.2 Comparison Results

As a basis for comparison, SNL has cited the TUE results for a nominal 1-hour Thermo-Lag clad cable tray in which an ADF of 32% was determined. SNL has cited this value as a conservative estimate of the derating impact for the cable trays at CNP. The expected conservatism derives from the sparse cable loads in the CNP trays and from the fact that ICEA P-54-440 addresses random fill trays whereas the licensee uses, in effect, a maintained spacing installation procedure. Hence, in order to demonstrate consistency with the ICEA standard, one should anticipate that the thermal model would provide ampacity limit estimates that were on the order of or somewhat below this 32% ADF margin in comparison to baseline ICEA limits.

The comparison results are presented in Table B.1. All of the cables for which ICEA ampacity limits were derived by SNL are presented in this table. Note that in many cases these results will also apply to other cables in the same tray, but only those specifically considered in the SNL analysis have been included here.

The results indicate a wide variability in the thermal model limits versus those of the ICEA. Indeed, for several of these specific cases, the licensee thermal model has yielded an ampacity limit that exceeds the nominal baseline ampacity limit for the corresponding cable under the ICEA P-54-440 standard (these are cited in the table as cases with a negative margin). In one case, cable 2560G, the thermal model ampacity limit also exceeds the somewhat more liberal ICEA P-46-426 "maintained spacing" based ampacity limit by a slim margin (0.4%) leaving no margin to allow for the fire barrier system (recall that because of the very light load in this tray, just 3 cables, SNL had analyzed this particular case using both the P-54-440 and P-46-426 methods).

The most non-conservative case in the set considered by SNL is that of cables 3012G and 3013G from tray 2AZ-P3 (both are 3TC#12CU cables). For these two cables the licensee thermal model predicted an ampacity limit that was 132.5% of (or 32.5% greater than) the nominal ICEA open tray ampacity limit. This is certainly a dubious result.

Overall, the licensee calculation provides a margin ranging from -32.5% to +55.4%, a wide range indeed. In most cases, more conservative results have been obtained for the larger cables, and less conservative results for the smaller cables. The one exception to this appears to be cable 2560G, a 3TC#6AL cable in a very lightly loaded tray. One critical observation in these results in the very inconsistent behavior of the thermal model in comparison to the ICEA approach.

B.3 Assessment of Results

The results of this analysis show that the performance of the licensee thermal model in comparison to the ICEA methods is highly variable. Some cases resulted in apparent conservatism even including the fire barrier system impact, while others resulted in non-conservative results even neglecting the fire barrier system impact. This demonstrates that there is no consistency whatsoever between the licensee thermal model and the ICEA standards. This rather uneven performance does not lend confidence to the licensee thermal model.

The ICEA P-54-440 standard has been a long and widely accepted standard of practice in ampacity assessments. Further, the licensee's own test data indicates that the ICEA P-54-440 approach is nominally consistent with the measured ampacity limits for open tray maintained spacing cable configurations as tested by the licensee (with one notable exception not considered by SNL to be relevant to the licensee's actual in-plant installations). The performance of the licensee model in comparison to the standard clearly indicates that, at the very least, the licensee methodology is in no way compatible with the ICEA standard. Rather, the licensee thermal model derives from an entirely different and incompatible basis. Acceptance of such a new basis of analysis should carry a heavy "burden of proof" before being accepted. This burden has been met by the Stolpe/ICEA approach through the standards development process. The licensee validation, at least as presented in the current submittal, consists of the comparison of the thermal model results to just two test cases. As was noted in Section 4.2 above, even these results are not uniformly conservative in comparison to the cited test data.

B.4 Summary and Recommendations

SNL finds that the licensee thermal model provides results that are highly inconsistent with the accepted ICEA standard ampacity assessment methods. Indeed, in certain cases the model has produced ampacity limits that are non-conservative in comparison to these accepted methods even neglecting the impact of the fire barrier system. Further, SNL finds the licensee validation studies as cited in the licensee submittals to be inadequate proof of the performance and acceptability of this thermal model for the stated purpose. SNL recommends that CNP thermal analysis model as it currently stands not be accepted as a valid approach to the assessment or prediction of clad cable tray ampacity limits.

Table B.1: Comparison of SNL derived ICEA ampacity limits to those derived by the licensee using the licensee's own thermal model.				
Tray	Cable	ICEA Baseline Limit (A)	Thermal Model Clad Limit (A)	Margin (%)
1AI-P1	8755RH	55.2	46.31	16.1
1AI-P2	8756GH	317.6	236.52	25.5
	8751GH/8755GH	39.6	45.53	(-14.9)
	8753GH	84.9	73.24	13.7
	1500G	164.1	121.34	26.1
1AI-P4	2560G *	55.2 / 60.0	60.27	(-9.2 / -0.4)
1AZ-P8	1991R	101.6	90.67	10.8
1AZ-P9	1440R	101.6	86.52	14.9
	8753RH	75.2	63.47	15.6
1A-P20	2353R/2354R	22.2	18.25	17.8
	8984R/8987R	15.2	16.67	(-9.7)
	2361R	51.3	37.68	26.5
	8753RH	75.0	51.16	31.8
	1440R	101.6	69.55	31.5
2AZ-P3	3012G/3013G	19.3	19.22	0.4
	8204G/8987G	13.7	18.15	(-32.5)
	3014G	46.3	39.8	14.0
	13945G	99.3	73.22	26.3
	8756GH	165	121.34	26.5
2AZ-P10	8753RH	71.1	54.17	23.8
	8755RH/1500G	101.6	73.61	27.5
	8756RH	165	120.86	26.8

* Note that cable 2560G was analyzed by SNL using both the P-54-440 random fill approach and the P-46-426 maintained spacing approach. The SNL results and the margins are presented for both assessments in the form (P-54-440 / P-42-426).

C.1 Overview

The licensee RAI response included a test report, CL-492, as Attachment 4. Some general discussion of this test report was provided in Section 4.4 of the main text. The purpose of this appendix is to examine the test data in detail for relevant insights. In particular, this SNL analysis has focused on a comparison of the test results to nominal ampacity limits derived from the ICEA P-46-426, ICEA P-54-440, and IEEE 835-1994 ampacity standards.

C.2 Tested Configurations

The licensee tests involved five different cable sizes, five different tray configurations, and six general cable arrangements. The characteristics of the tested cables are summarized in Table C.1. Note that all of the cables were copper conductor cables in a triplex configuration (a twisted 3-conductor arrangement with no overall jacket). (Many of the cables analyzed in the ampacity assessments are aluminum conductor cables, but apparently, no aluminum conductor cables were used in this particular set of tests).

Table C.1: Cable characteristics.

	d_c = Cable Diameter [1] (in)	d_c^2 (in^2)	Electical Resistance[2] (ohms/ft)
3TC#12 [3]	0.398	0.1584	2.07E-3
3TC#12 AWG[4]	0.387	0.1498	2.07E-3
3TC#10 AWG	0.452	0.2043	1.31E-3
3TC#2/0	1.256	1.578	1.05E-4
3TC350 MCM	1.849	3.418	4.18E-5
3TC750 MCM	2.670	7.129	2.19E-5

Notes:
1. The licensee has only specified individual conductor diameter and insulation thickness values. The overall triplex cable diameter is calculated by SNL using the Neher/McGrath approach where the diameter of a three cable bundle is 2.15 times the single cable diameter (including conductor and insulation diameter). This has been applied consistently to all cables.
2. The electrical resistance is taken from handbook values at 90C.
3. This cable was used only in the single-cable single-run 12 AWG cable test.
4. This cable was used in all tests with multiple runs of the 12 AWG cable.

The six general cable arrangements used in testing were:

- Single Cable Tests: A single run of a given cable
- Multiple Like Cables: Multiple runs of the same cable
- Mixed Fill: Four cable fills each comprised of two or three cable groups:
  - Mixed fill 1, two groups: fifteen 12AWG, and one 750 MCM
  - Mixed fill 2, two groups: two 12 AWG, and three 750 MCM
  - Mixed fill 3, three groups: six 12 AWG, three 2/0, and one 750 MCM
  - Mixed fill 4, three groups: two 12 AWG, two 2/0, and two 750 MCM

All installations were tested in a maintained spacing configuration. There were five different cable tray/fire barrier configurations tested:

- Configuration A: vented bottom tray / no top / no barrier
- Configuration B: vented bottom tray / vented top / no barrier
- Configuration C: solid bottom tray / solid top / no barrier
- Configuration D: vented bottom tray / no top / solid 3M fire barrier
- Configuration E: vented bottom tray / no top / vented 3M fire barrier

Also note that the measured test data includes the reported cable ampacity, the ambient temperature, and the inferred cable conductor temperature. In these tests, the licensee did not actually measure conductor temperature, but rather, cable surface temperature. An extrapolation was made to estimate conductor temperatures based on heat load and conduction through the cable insulation. Hence, some uncertainty derives from this practice.

In order to provide a consistent basis for analysis, SNL has "normalized" the measured cable ampacity values to correct for the actual temperatures measured in the test as compared to the standard 90°C/40°C conditions. That is, the measured conditions did not yield a 90°C conductor and 40°C ambient environment precisely, and hence, SNL has corrected the measured ampacity to these standard conditions using the same temperature correction equation as that cited in the IEEE P848 standard for ampacity tests.

C.3 Analysis of Single Cable Tests

The single cable tests were run for each of the five unique cable gauges. All five gauges were tested in tray configurations A and B, and the 12AWG, #2/0, and 750 MCM cables were also tested in tray configuration C. The test data are summarized in Table C.2. This table also includes the ICEA P-42-426 open air ampacity limits and the corresponding IEEE-385-1994 open air ampacity limits for comparison.

Table C.2: Summary of single cable test results

Cable	Config. A	Config. B	Config. C	ICEA Open Air Limit(1)	IEEE Open Air Limit(2)
3TC#12	42.2	41.1	36.2	N/A	36
3TC#10	53.0	52.6	N/A	N/A	48
3TC#2/0	286	261	227	247	264
3TC350	488	450	N/A	464	504
3TC750	779	721	528	747	815

Notes:
1. ICEA limits from page 260 of P-46-426
2. IEEE limits from page 31 of 835-1994, no sun, 0 ft/s air flow

Note that configuration A is, essentially, an open air installation. While the cable is placed in a tray, the bottom of the tray is ventilated so there is little obstruction of air flow. Hence, a comparison between the configuration A ampacity values and the open air limits is appropriate. Additional comparisons can also be made. For example, the ratio of the Configuration B to Configuration A tests indicates the relative impact of the ventilated top on these single cable ampacity values, and similarly the ratio of "C" to "A" illustrates the impact of installation in a solid bottom/solid top tray. These comparisons are provided in Table C.3.

Table C.3: Comparison of ampacity limits for single cable tests.					
Cable	"A"/ICEA	"A"/IEEE	"B" /"A"	"C" /"A"	"C" /"B"
3TC#12	N/A	1.172	0.974	0.858	0.881
3TC#10	N/A	1.104	0.992	N/A	N/A
3TC#2/0	1.158	1.083	0.913	0.794	0.870
3TC350	1.052	0.968	0.922	N/A	N/A
3TC750	1.043	0.965	0.926	0.678	0.732
Note: All values are the direct ratio of one case ampacity taken from Table C.2 to another as indicated.					

The results are quite interesting. First, note that the ICEA does not establish limits for the smaller 12 AWG and 10 AWG cables. However, for the larger cables, the licensee measured ampacity limits are uniformly larger than the ICEA limits by 4.3%-15.8%. In the case of the IEEE open air limit, the measured ampacity exceeds the IEEE open air limit for the smaller cables, but is actually modestly lower than the IEEE limit for the two largest cables. It is also interesting to note that the ratio of the measured to tabulated ampacity limits uniformly decreases with increasing cable size for both the ICEA and IEEE limits. This indicates that the tabulated open air ampacity limits provide more margin for smaller cables and less for larger cables. In fact, some of the values in IEEE 835 may be somewhat non-conservative if these test results are, in fact, a reliable measure of open air ampacity. Given that these tests were not performed to fully acceptable current standards, and there is evidence of inconsistency and potential problems in the test data (see further discussion below) this final point should not be taken as a definitive conclusion.

In summary, the primary insights to be gained from these test results and comparisons are:

- The ICEA open air ampacity limits provide a modest margin for open air cable ampacity. Similarly, at least in the case of the #2/0 and smaller cables, the IEEE open air limits also provide some modest margin of conservatism.

- The addition of a ventilated cover plate reduced measured ampacity limits by an average of 5.5% as compared to an uncovered, ventilated bottom cable tray for these single cable tests (based on "B" / "A" ratio). The percentage impact did not correlate consistently with cable size.

- The installation of the cables in a solid bottom-solid top tray reduced measured ampacity limits by an average of 22.3% as compared to an uncovered, ventilated bottom cable tray for these single cable tests (based on "C" / "A" ratio). The percentage reduction actually increased with increasing cable size, and ranged from 14.2% for the 12 AWG cable to 32.2% for the 750 MCM cable.

C.4 Analysis of Multiple Like Cable Tests

In order to perform similar comparisons for the multiple like cable fill tests, it is first necessary to calculate the depth of fill applicable to each cable fill. In this calculation SNL has applied the ICEA P-54-440 definition of fill depth which is based on the equivalent square cross-section of the cable. The results are summarized in Table C.4. This table also provides the corresponding heat intensity limit for each fill depth. These values have been calculated using the following two correlations:

$$for \quad (0 \le d_{fill} \le 1.5'') \qquad Q = 5.925\ d_{fill}^{-1.258}$$

$$for \quad (1.5'' \le d_{fill} \le 2.0'') \qquad Q = 6.096\ d_{fill}^{-1.329}$$

For the multiple like cable fill tests, four of the five tray configurations were tested; B, C, D, and E. The ampacity test results are summarized in Table C.5. Table C.6 provides for some case to case comparison of these results.

Table C.4: Cable fill and ICEA P-54-440 ampacity for multiple like cable fill tests.

Cable	Diameter d_c	X-Section d_c^2	No. cables m	Fill Depth d_{fill}	Heat Intensity Q	Heat-based ampacity
3TC#12	0.387	0.1498	21	0.2622"	31.92	27.7
3TC#10	0.452	0.2043	18	1.049"	26.23	36.9
3TC#2/0	1.256	1.578	7	1.166"	6.576	181
3TC350	1.849	3.418	4	1.071"	5.030	370
3TC750	2.670	7.129	3	1.256"	2.829	554

Notes:
1. $d_{fill} = md_c^2/w_{tray}$
2. $I = d_c*SQRT(Q/(nR_{ac}))$, all are less than corresponding 80% of open air limit (IEEE used for 12 and 10 AWG).

Table C.5: Summary of multiple like cable test results

Cable	Config. B	Config. C	Config. D	Config. E	ICEA P-54-440 Limit
3TC#12	23.8	18.7	17.7	18.7	27.7
3TC#10	38.7	N/A	21.6	N/A	36.9
3TC#2/0	211	157	135	N/A	181
3TC350	396	N/A	278	N/A	370
3TC750	696	472	452	479	554

Notes:
1. ICEA limits from page 260 of P-46-426
2. IEEE limits from page 31 of 835-1994

Table C.6: Comparison of ampacity limits for the multiple like cable tests.				
Cable	"B" / ICEA	"D" / ICEA	"C" / "B"	"D" / "B"
3TC#12	0.859	0.639	0.786	0.744
3TC#10	1.049	0.585	N/A	0.558
3TC#2/0	1.166	0.746	0.744	0.640
3TC350	1.070	0.751	N/A	0.702
3TC750	1.256	0.816	0.678	0.649
Note: All values are the direct ratio of one case ampacity taken from Table C.2 to another as indicated.				

Because configuration A was not tested in this set, configuration B is the closest to an open tray configuration available for this group of tests. Note that while configuration B did include a ventilated top cover, the ICEA limits are intended to apply to and bound solid bottom trays. The ventilated licensee trays are actually somewhat more open than would be a solid bottom tray; hence, one should anticipate that the configuration B ampacities might be modestly higher than the corresponding ICEA limits.

A comparison of the results reveals that this expectation is true for all but the 12AWG cable test. In this test the measured ampacity was modestly (14.1%) lower than the corresponding ICEA limit. For the other cases, the measured ampacities were 5-25% higher than the ICEA limits, although there is no clear pattern to these results based on cable size of depth of fill. In the case of the 12 AWG cable some special consideration should be given to the open air ampacity limit for this cable. In particular, SNL has noted that P-46-426 does not address this cable, and hence, cited the corresponding IEEE limit. However, it was also noted that the IEEE standard has generally increased the allowable ampacity limits in comparison to P-46-426.

Two additional comparisons can be made to assess the impact of the tested fire barrier system on ampacity limits. Recall that the fire barrier tested was a 3M product, not Thermo-Lag. Hence, the results will not apply directly to a Thermo-Lag installation. However, it can also be noted that both systems are based on panel installations, have a similar nominal thickness, and have nominally similar thermal properties including both thermal conductivity and emissivity. Hence, one should anticipate that the gross ampacity derating behavior would be quite similar (within a few percentage points of each other).

A comparison between Configurations B and E provides a direct assessment of the relative fire barrier ACF/ADF for these same maintained spacing configurations. The results indicate a net ACF ranging from 0.558 to 0.744, or an ADF ranging from 25.6% to 44.2%. The average ACF for the five tests was 0.658, corresponding to an ADF of 34.2%. This is surprisingly similar to the nominal 32% ADF cited by SNL for a nominal 1-hour Thermo-Lag cable tray fire barrier system based on testing by TUE.

The range of ADF/ACF results is rather wide; much wider than one should normally anticipate. It is also noted that there is no consistent trend in the ACF value based on either cable size or fill depth. This uneven behavior may well reflect uncertainty in the test data, or potentially the failure of the test lab to achieve a consistent steady-state condition.

An additional comparison of interest can be made between configurations "C" and "B". This comparison provides an assessment of the impact of a solid bottom/solid top configurations in comparison to the vented bottom/vented top configuration. The resulting effective ADF ranged from 21.4% to 32.2% with an average value of 26.4%. Recall that in Table C.3 a comparison of these same two configurations revealed an ADF ranging from 11.9% to 26.8% for the single cable tests with an average values of 17.2%. As one expects, the relative impact of the enclosure system is more severe for the multiple cable tests as compared to the single cable tests. In a sense, the enclosing box "looks" smaller and becomes more confining as the cable load increases. As the relative size of the box increases it will eventually approach the appearance of the overall ambient, and hence, the derating impact should decline as the relative size of the box increases. This is consistent with this test data and is also consistent with behavior noted by TVA in the testing of conduits in boxed enclosures of increasing size.

A final comparison can be drawn between the fire barrier clad test results for configuration E and the ICEA ampacity limits. In this case, the measured ampacity limits are from 28.4%-41.5% below the nominal ICEA limits. The average difference was 29.3%. Here again, the case-to-case variation was rather severe and may indicate some problems in the data. This is similar to an effective ADF in comparison to the ICEA limits, but SNL will not use this terminology in order to avoid confusion. ADF values should be based on comparison of one experiment to another experiment, not on comparison of an experiment an ampacity table. This comparison is made only to illustrate that the ICEA P-54-440 approach when applied to maintained spacing applications is not conservative unless the fire barrier impact is also accounted for independently.

The primary insights to be taken from this discussion are:

- For these maintained spacing configurations, the impact of a panel based fire barrier material will be significant. A very uncertain estimate of the 3M barrier impact is 34.2%, with the uncertainty band ranging from 25.6% to 44.2%. A nominally similar impact for the Thermo-Lag barriers should be anticipated.

- The ICEA P-54-440 heat intensity based ampacity limits were not found to be uniformly conservative in comparison to the test data even for the relatively open configuration B. In particular, the 12 AWG results were actually somewhat non-conservative in that the measured ampacity limit was 14.1% lower than the ICEA limit for this case. For the other four cables, the ICEA results were conservative, and the magnitude of the conservatism ranged from 5% to 25%.

- The ICEA open tray ampacity limits were significantly higher than the ampacity limits measure for the fire barrier clad cables in Configuration D. The average "shortfall" was 29.3%. This indicates that fire barrier derating is significant, and should be appropriately accounted for.

C.5 Analysis of Mixed Fill Test Results

Unfortunately, the only tray configuration for which the mixed fill tests were performed was the "ventilated tray/ventilated cover/no fire barrier" configuration B arrangement. Hence, this is the only configuration for which a direct evaluation is possible. This is somewhat disappointing because no direct validation for a mixed fill fire barrier clad tray is possible. Nonetheless, some interesting insights should be gained by an analysis of the test data.

Of particular interest is a comparison between the licensee measured ampacity limits and the nominal ICEA P-54-440 ampacity limits. The ICEA limits were calculated by SNL in exactly the same manner as documented in Appendix A. In particular, both depth of fill and individual cable ampacity calculations are based on the ICEA definitions of those parameters. The critical aspects and intermediate results of these calculations are provided in Table C.7.

Table C.7: Calculation of fill depth and ICEA heat intensity based ampacity limits for mixed fill cable tests.

	12 AWG Group	2/0 Group	750MCM Group
General Physical Parameters:			
conductors per cable	3	3	3
cable diameter (d (in))	0.387	1.256	2.670
electrical resistance (Ω/ft)	2.07E-3	1.05E-4	2.19E-5
Mixed Fill 1			
number of cables (m)	15	N/A	1
$m*d^2$	2.25	N/A	7.13
dfill = sum($m*d^2$)/ w_{tray}	0.781		
Heat Intensity limit (Q)	8.082		
ICEA Ampacity Limit	14.0	N/A	936 / 598
Mixed Fill 2			
number of cables (m)	2	N/A	3
$m*d^2$	0.30	N/A	21.39
dfill = sum($m*d^2$)/ w_{tray}	1.81		
Heat Intensity limit (Q)	2.81		
ICEA Ampacity Limit	8.24	N/A	552
Mixed Fill 3			
number of cables (m)	6	3	1
$m*d^2$	0.899	4.733	7.13
dfill = sum($m*d^2$)/ w_{tray}	1.06		
Heat Intensity limit (Q)	5.48		
ICEA Ampacity Limit	11.5	166	771 / 598
Mixed Fill 4			
number of cables (m)	2	2	2
$m*d^2$	0.30	3.16	14.26
dfill = sum($m*d^2$)/ w_{tray}	1.48		
Heat Intensity limit (Q)	3.63		
ICEA Ampacity Limit	9.36	135	628 / 598

Note that the ICEA limits have inculded consideration of the 80% of open air ampacity limit. Those cases impacted by this limit have two ampacity limit values cited (### / ###); the first is the heat intensity value and the second (lower) value is the 80% of open air value. The lower of the two values ultimately applies.

Table C.8 provides a summary comparison of the measured test ampacities and those derived based on the ICEA heat intensity approach. In particular, the final column provides the ratio of the measured ampacity to the net ICEA ampacity limit. Recall that the tray configuration was basically an open tray configuration, even though a ventilated top was installed. As noted above for the multiple like cable fill tests, it should be anticipated that the measured ampacity limits might be modestly higher than the ICEA nominal limits for this reason (ICEA limits are intended to bound solid bottom trays with less circulation than the license ventilated top and bottom trays).

Table C.8: Comparison of measured and ICEA ampacity limits for CL-492 mixed fill ampacity tests.

	Net ICEA P-54-440 Limit	Normalized Test Ampacity Limit	Ratio of Test to ICEA ampacity
Mixed Fill 1			
3TC 12 AWG CU	14.0	22.5	1.61
3TC 750 MCM CU	598	691	1.16
Mixed Fill 2			
3TC 12 AWG CU	8.24	22.8	2.77
3TC 750 MCM CU	552	668	1.21
Mixed Fill 3			
3TC 12 AWG CU	11.5	23.6	2.05
3TC 2/0 CU	166	216	1.30
3TC 750 MCM CU	598	658	1.10
Mixed Fill 4			
3TC 12 AWG CU	9.4	21.0	2.24
3TC 2/0 CU	135	205	1.52
3TC 750 MCM CU	598	651	1.10

The results of this exercise are somewhat mixed. For the larger cables, the results are as expected. The measured ampacity limits for the 750 MCM cables were 10% to 21% higher than the nominal ICEA limits for these cases. One factor that should have contributed to some additional conservatism for these cables in particular is the fact that three of the four 750 MCM ICEA ampacity limit calculations were dominated by the 80% of open air ampacity limit. This should have led to additional conservatism, especially for the lower fill cases (mixed fills 1 and 3). The conservatism does not, however, track with fill depth. In fact, the most significant finding in this regard may well be the fact that the conservatism was not even greater for these cases. For the #2/0 cables, the measured ampacity limits were 30% and 52% higher than the corresponding ICEA limits for fills 3 and 4 respectively. With only two data points, it is not approapriate to draw any conclusions regarding fill relationships.

The greatest level of conservatism in the ICEA limits was uniformly noted in the 12 AWG cable group. The measured ampacity ranged from 166% to 277% of the ICEA nominal limits (that is, 66% to 177% greater than the ICEA limits). It is quite interesting to note that the degree of conservatism appears to be correlated well with the extent to which the fill is dominated by larger cables. For example, mixed fill 1 contained 15 of the 12 AWG cables and just 1 750 MCM cable, the fill least dominated by large cables. The 12 AWG measured ampacity for this test was 161% of the ICEA value, the lowest margin for all of the four tests. In contrast, the highest margin, 277%, was for mixed fill 2 which had just 2 of the 12 AWG cables and 3 of the 750 MCM cables. This fill was that most dominated by the largest cables. Mixed fills 3 and 4 also follow this pattern.

Recall that the ICEA heat intensity approach partitions the overall heat load to individual cables base on the cable cross-section or diameter-squared. On the basis of these tests, it would appear that this is not entirely appropriate for these mixed fill, maintained spacing installations in which the variation between cable sizes is very great. The partitioning appears to "short-change" the smaller cables. A logical approach to a more reasoned partitioning would be to adjust the partitioning to allow for a larger apportionment to the smaller cables. The licensee approach was to partition based on diameter directly, and this certainly allocates a larger portion of the heat to smaller cables. These test results provide an opportunity to assess whether or not the licensee approach is consistent with the test results.

In order to assess the compatibility of the test data and the licensee diameter-based heat load partitioning method, SNL has calculated two additional values for each cable group in each test. The first is the total heat load for each of the cable groups, that is, for 12AWG group, the 2/0 group (if one was present), and the 750MCM group. SNL has then gone on to calculate the ratio of heat load to group width. It is this last value that forms the basis of comparison. The results are illustrated in Tables C.9.

Table C.9: Comparison of mixed fill heat distribution results to the licensee diameter based partitioning method.			
	12 AWG Group	2/0 Group	750MCM Group
Mixed Fill 1			
Group Heating Rate (W/ft)	47.2	N/A	31.4
Group Width (in)	5.805	N/A	2.67
Group Heat / Group Width	8.13	N/A	11.76
Mixed Fill 2			
Group Heating Rate (W/ft)	6.5	N/A	88.0
Group Width (in)	0.774	N/A	8.01
Group Heat / Group Width	8.40	N/A .	11.0
Mixed Fill 3			
Group Heating Rate (W/ft)	20.7	44.1	28.4
Group Width (in)	2.322	3.768	2.670
Group Heat / Group Width	8.91	11.7	10.6
Mixed Fill 4			
Group Heating Rate (W/ft)	5.5	26.5	56.7
Group Width (in)	0.774	2.512	5.340
Group Heat / Group Width	7.11	10.5	10.6
Note that group width is taken simply as the number of cables in the group times the diameter of an individual triplex cable of that size. Heating rates are based on the measured normalized ampacity and cable electrical resistance values at 90C and represent total heat generation for the each cable group.			

The licensee method assumes that the total heat load can be partitioned to individual cables based on the ratio of an individual cable diameter to the sum of the cable diameter for all cables in the tray (or the total fill width). If this assumption holds true, then the test should demonstrate that the ratio of the heat generation in each cable group to the total width of that cable group remains constant for a given test. That is, the heat generation per unit width of cables should be the same for each of the cable groups included in any single test.

The results of this exercise illustrate that the assumed diameter scaling is not consistent with the mixed fill test data. In particular the smallest cables in each test (the 12 AWG cables) show a consistently lower heating rate per unit width (identified as "heat/group width" in the tables) than do the larger cables in the same test. These differences are quite significant. However, it should also be noted that the differences do not appear to correlate to fill characteristics in the same way as did the ICEA comparisons discussed above. That is, there is no clear correlation between the heating rate per inch of group width and the degree to which the fill is dominated by the largest cables. In fact, the values for each cable group are quite consistent from test to test. The 12 AWG values range from 7.11 to 8.91 W/ft/in, and the 750 MCM cables vary from 10.6 to 11.6 W/ft/in. It is also somewhat curious that the 2/0 cable values are nearly identical to those of the 750 MCM cables. It would seem that the smallest of the cables, the 12 AWG, is the "odd man out."

It would appear clear that some other mechanism not fully accounted for in the licensee partitioning model is active. By assuming that the total heat load may be partitioned by simple diameter ratios, the licensee may over-estimate the allowable ampacity limits for smaller cables and under-estimate ampacity limits for the larger cables when a mixed cable fill is present. This, of course, assumes that the overall heat rejection capacity of the system as a whole is appropriately estimated. SNL would speculate that radiative heat transfer effects and the effect of larger cables on the view factor for smaller cables could in part account for the experimentally observed behavior. Another potential factor would be convective behavior which will vary with diameter and with the scale of the cables "surface roughness." That is, triplex cables have a rather uneven surface because there is not overall jacket. The absolute scale or size of this roughness will determine whether or not the air flow patterns around the cable are significantly impacted, which would in turn impact the convection efficiency. For the smaller cables, the convective heat transfer may simply not be as efficient as it is for the larger cables.

Given these results, it appears that the ICEA scaling based on cross-section, or diameter-squared, assigns too little of the heat load to the smaller cables, while the licensee scaling based on diameter directly assigns too much of the heat load to those cables. The correct answer would appear to lie somewhere between these two extremes. Unfortunately, the results also illustrate that no simple scaling based on diameter alone is likely to explain the test results. This is because the smallest cable, the 12 AWG, was identified as the "odd man out" and the larger two cables actually displayed rather consistent behavior, both from test to test and from cable to cable. Some mechanism is needed to account for the unique behavior of the smaller cables.

The primary insights to be taken from this analysis are as follows:

- For the larger cables, the ICEA P-54-440 approach, including consideration of the 80% of open air ampacity limit, provides a reasonable basis for assessment of ampacity limits even under these maintained spacing conditions.

- For mixed cable fills under maintained spacing conditions where the cable physical size and wire gauge varies significantly, the ICEA heat intensity approach assesses an inordinate penalty for the smaller cables in the tray. That is, using the heat intensity approach for such applications, the ampacity of smaller cables is significantly under-estimated. The extent, or magnitude, of the resulting conservatism in small cable ampacity limit estimates appears to correlate directly to the degree to which the cable fill is dominated by the larger cables.

- The licensee partitioning of heat generation or heat intensity based on cable diameter directly is not supported by the mixed fill test results. The test results indicate that this practice will assign too much of the heat load to the smaller cables. No clear correlation to cable size or dominance of the fill by larger cables was evident in these results; the 12 AWG was simply the "odd man out" displaying significantly lower heating limits per unit of cable width.

C.6 Summary and Recommendations

In summary SNL has attempted to "wring out" as much information as possible from the cited licensee CL-492 tests. As a result there were several important insights gained. However, in considering these insights, one should also consider that the data analysis also revealed certain unexplained inconsistencies in the test results that may be indicative of problems in the test data. In hind-sight, it is quite clear that these tests were neither performed nor documented to the same level of quality as one would demand in such a test program today. For this reason, SNL is reluctant to place too much reliance on the test results. The general insights derived from these tests are likely valid, and were generally consistent with our expectations. However, some anomalous and unexpected results were documented. While SNL does not recommend that the tests be dismissed out of hand for this reason, it is recommended that they should be viewed with some skepticism. In particular, the documented insights should be considered somewhat tentative until they are more fully explored and validated by more modern laboratory testing.