July 9, 1997

Ms. Irene Johnson, Acting Manager
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Executive Towers West III
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SUBJECT: REQUEST FOR ADDITIONAL INFORMATION REGARDING THERMO-LAG RELATED AMPACITY DERATING ISSUES FOR BYRON AND BRAIDWOOD STATIONS (TAC NO. M82809)

Dear Ms. Johnson:

By letter dated March 21, 1996, as supplemented July 12, 1996, Commonwealth Edison Company (ComEd) responded to the staff's Request for Additional Information (RAI) dated December 4, 1995, related to Generic Letter (GL) 92-08, "Thermo-Lag 330-1 Fire Barriers," for the Braidwood Station. The supplemental response included a new set of analytical calculations and ampacity methodology for a range of fire barrier installations. The staff, in conjunction with its contractor, Sandia National Laboratories (SNL), has reviewed the submittals and has identified a need for further information, as discussed in the enclosed RAI.

Please provide your response to the RAI so that we may continue to review your submittals. Due to contractor scheduling restrictions, please respond to the RAI within 60 days of receipt of this letter.

Sincerely,

ORIGINAL SIGNED BY:

George F. Dick, Jr., Project Manager
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Office of Nuclear Reactor Regulation

Docket Nos. STN 50-454, STN 50-455,
STN 50-456, and STN 50-457

1/1

Enclosure: RAI

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REQUEST FOR ADDITIONAL INFORMATION

THERMO-LAG AMPACITY DERATING ISSUES

COMMONWEALTH EDISON COMPANY

BYRON STATION, UNITS 1 AND 2 AND BRAIDWOOD STATION, UNITS 1 AND 2

DOCKET NOS. STN 50-454, STN 50-455, STN 50-456 AND STN 50-457

1.0 BACKGROUND

By letter dated February 15, 1995, Commonwealth Edison Company (ComEd, the licensee) submitted documents that were requested during phone conversations between ComEd and NRC staff, related to Generic Letter (GL) 92-08, "Thermo-Lag 330-1 Fire Barriers," for the Braidwood Station. In their response of March 28, 1995, the licensee indicated that their analytical approach has been shown conservative to actual ampacity derating test results, and ampacity testing is not planned for abandoned in-place Thermo-Lag fire barriers. The staff, in conjunction with its contractor, Sandia National Laboratories (SNL), completed a preliminary review of the licensee's analytical approach based on the February 15, 1995, submittal and identified a number of open issues and concerns requiring clarification by the licensee. The staff transmitted a Request for Additional Information (RAI) to the licensee on December 4, 1995, (erroneously referred to in the attachment as the November 2, 1995, RAI) requesting a response on the outstanding issues and concerns.

By letter dated March 21, 1996, as supplemented July 12, 1996, ComEd provided a response to the staff's RAI. The supplemental response included a new set of analytical calculations that was identified in the July 12, 1996, submittal as Calculation BYR-96-082/BRW-96-194, Revision 0, covering a range of fire barrier installations for both cable trays and conduits. Calculation BYR-96-082/BRW-96-194, that was also applicable to Byron Station, introduced a new methodology and addressed ampacity analyses for single cable trays in "special" barrier configurations, multiple horizontal trays in a single fire barrier enclosure, single vertical cable tray risers, and multiple cable tray risers in a single fire barrier enclosure.

The staff has completed its review of the licensee's supplemental submittal and requests that the following questions be addressed by the licensee.

2.0 ADDITIONAL INFORMATION REQUIRED

SNL has identified several points of concern regarding Calculation BYR-96-082/BRW-96-194, which was included in ComEd's submittal dated July 12, 1996.

(See Section 3.0 of the attached SNL letter report.) Please address the following questions:

2.1 It appears that ComEd' base case comparisons are not applied on a consistent basis. In particular, the licensee is comparing a calculated clad case ampacity limit to a base case ampacity derived on a different basis. The estimates of fire barrier Ampacity Derating Factor (ADF) should be based on self-consistent treatment of the clad and base line cases. In this case, it is considered critical to assess both the clad and base line ampacity limits using a self-consistent thermal model. If the thermal model is used to predict the clad ampacity limits, then a thermal model fully consistent with the clad case analyses should also be used to assess the base line ampacity limits as well. The licensee is requested to implement a thermal model for the analysis of the base line case ampacity that is fully consistent with its clad case analyses, and to then base its final ampacity derating assessments on a comparison of the clad and base line thermal analysis results.

2.2 The licensee has presented a table of heat intensity versus depth of fill values (Item 13 of page 13 of BYR-96-082/BRW-96-194). This table is in apparent conflict with the heat intensity values cited by Stolpe and in the ICEA standard P-54-440. The cited values appear to modestly over-state allowable heat intensity limits, and hence might lead to optimistic estimates of the cable ampacity limits.

2.2.1 The licensee is requested to establish the basis for how this heat intensity table was developed and how it is applied in practice, and to reassess the ampacity limit calculations in light of this apparent discrepancy.

2.2.2 The licensee is also requested to provide the supporting calculation cited in BYR-96-082/BRW-96-194 as the basis for this table (i.e., Calculation ESI150-1, Revision 0).

2.3 The licensee cites in Item 2 on page 12 of BYR-96-082/BRW-96-194 that the base line ampacity for a 3/C, #6 AWG, 600 V cable with a 2.5" depth of fill is 27.5 A. The basis for this value is not clear. SNL was unable to reproduce this limit using standard approaches to ampacity analysis given that the licensee thermal model has cited the ICEA definition as the basis for fill depth calculations. The licensee is requested to describe, in detail, how this value was obtained, or alternately the subject calculation should delete references to and reliance upon this value as the "base line ampacity" for the cases examined.

2.4 Several references are made in BYR-96-082/BRW-96-194 to a "SilTemp Sheet," but the fire barrier descriptions do not include a discussion of any such sheet used in the installation process. The licensee is requested to clarify if such a material is used in its fire barrier constructions.

Attachment: Report to U.S. NRC, Revision 0, dated May 2, 1997, prepared by Sandia National Laboratories

A Review of the Braidwood Station Calculation BYR96-082/BRW-96-195 on Fire Barrier Ampacity Derating Factors for Special Configurations

A Letter Report to the USNRC

Revision 0

May 2, 1997

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ATTACHMENT

9705290107 31pp.

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FORWARD

The United States Nuclear Regulatory Commission (USNRC) has solicited the support of Sandia National Laboratories (SNL) in the review of utility submittals associated with fire protection and electrical engineering. This letter report documents the results of an initial SNL review of a set of supplemental calculations included in the licensee response to an USNRC RAI sent to the Braidwood Station on November 2, 1995 (Calculation BYR96-082/BRW-96-194). These new calculations deal with the issue of fire barrier ampacity derating factors for cable tray fire barrier systems involving certain special cable tray fire barrier configurations. This report is the fourth in a series of review reports, of which the first three dealt with calculations for more standard barrier configurations and were prepared under USNRC JCN J2017, Task Order 6. The current efforts were performed under USNRC JCN J2503, Task Order 3, Subtask 5.

1.0 INTRODUCTION

1.1 Background

In response to USNRC Generic Letter 92-08, Braidwood Station provided documentation of the licensee position regarding ampacity derating factors associated with its installed fire barrier systems. In particular, the original licensee submittals included documentation of analyses performed to assess the adequacy of in-plant cable ampacity factors for two types of Appendix R cable tray and conduit fire barrier systems; namely, Thermo-Lag and Darmatt. On August 25, 1995 SNL prepared a letter report which documented the results of an extensive review of the licensee approach and calculations[1]. Based largely on the findings of this review, on November 2, 1995 the USNRC sent a Request for Additional Information (RAI) to the licensee requesting clarification of several points of concern identified in the review.

In a letter dated March 21, 1996 the licensee provided an initial response to this RAI. SNL provided a review of this initial response to the USNRC in a letter report dated August 16, 1996. Subsequently, the USNRC forwarded an additional set of response documents to SNL for review. This supplemental set of licensee response documents included documentation of an entirely new set of analytical calculations covering a range fire barrier installations for both cable trays and conduits. SNL submitted a third letter report on December 20, 1996 that focused on the updated calculations that corresponded to those originally submitted by the licensee and reviewed by SNL in 1995. The licensee documents provided for SNL review were:

- Letter, Denise Saccomando to USNRC Document Control Desk, March 21, 1996 with one attachment. (This is the initial response document reviewed in the August 16, 1996 letter report.)

- Letter, John B. Hosmer to the USNRC Document Control Desk, July 12, 1996 with three attached licensee calculations (BYR-96-059/G-70-96-092 Rev. 0, BYR-96-082/BRW-96-194 Rev. 0, and G-63 Rev. 4).

1.2 Objectives of the Current Review

The current report documents an initial review by SNL of the licensee's new calculations presented in BYR-96-082/BRW-96-194, Rev. 0. Initially, it had been intended that this would be a final review of the licensee RAI response. However, as the review progressed potential areas of concern not previously noted were identified which might significantly compromise the reliability of the calculation results. Hence, the objective of this review then became to identify potential areas of concern that might warrant a supplemental RAI.

---

[1] See letter S. Nowlen, SNL, to R. Jenkins, USNRC, Dated 8/25/95 and the attached letter report "A Review of the Braidwood Station Analysis of Fire Barrier Ampacity Derating Factors," Draft Revision 0, 8/25/95.

This effort represents a continuation of work initially undertaken as a part of general technical support contract JCN J-2017, Task Order 6. The current efforts have been performed as a part of the follow-on efforts under JCN J2503, Task Order 3, Subtask 5.

1.3 Overview of the Licensee Approach

In general the licensee approach to ampacity derating is based on analysis with limited validation of the analysis process. This review has focused on the licensee Calculation BYR-96-082/BRW-96-194 Rev. 0 which covers single cable trays in "special" barrier configurations, multiple horizontal trays in a single fire barrier enclosure, single vertical cable tray risers, and multiple cable tray risers in a single fire barrier enclosure.

The approach taken by the licensee in its calculations is rather unique. In most ampacity thermal models the objective is to calculate a limiting ampacity for a given set of predefined cable installations, typically for both the base line and clad conditions. However, in the Braidwood submittal the licensee sets an arbitrary value of the actual current, and then calculates a limiting depth of fill for that current level. This is then compared to standard values of ampacity for the base line case to determine the derating impact. Such an approach to analysis can be risky because it is important to establish that the thermal model is consistent with the base line ampacity tables. This is discussed further below.

For each case a similar approach to analysis is undertaken:

- A nominal "base line" ampacity limit of 27.5A is assumed for all cases. This value is cited as being the base line ampacity for a 3/C 6AWG 600V light power cable installed in a tray to a depth of fill of 2.5". (As will be noted below, SNL takes exception to this characterization, but this concern ultimately has no real impact on the results of the analysis.)

- Using this value as an assumed input, the licensee implements a thermal model to calculate the maximum depth of fill under clad conditions for which this current value will result in a cable hot-spot temperature of 90°C.

- The clad ampacity limit is converted to an equivalent "Heat Intensity" factor for the clad case in a manner similar to that taken by Stolpe and by the ICEA ampacity standard for open top cable trays (P-54-440).

- This clad case heat intensity value is then compared to a "base line" heat intensity value derived for the same depth of fill from a table developed by the licensee.

- The ampacity derating factor (ADF) is then calculated based on a ratio of the two heat intensity values in a manner similar to that taken when actual cable current limits are compared.

While somewhat unusual, this process could, in principle, work. As will be discussed further below, SNL has identified four points of concern regarding these calculations, one of which is considered especially significant. SNL's most serios concerns are primarily associated with issues of modeling consistency. These concerns are discussed at length in Section 3.2 below.

1.4 Organization of This Report

Chapter 2 provides a more detailed discussion of the licensee modeling approach, and certain fundamental concepts critical to the understanding of that approach. Chapter 3 provides for a direct review of the licensee BYR-96-082/BRW-96-194 Rev. 0 calculation, and in particular, focuses on potential shortcomings in that method as currently documented. Chapter 4 summarizes the SNL recommendations regarding the adequacy of these licensee responses and calculations.

2.0 THE LICENSEE APPROACH TO ANALYSIS

2.1 Overview

Licensee Calculation BYR96-082/BRW-96-194 documents the results of a set of case analyses performed to assess the derating impact for a number of special barrier and cable tray configurations. In particular, the assessments include 3 hour barriers comprised of both single and double layers of material, Thermo-Lag and Darmatt materials, horizontal and vertical cable trays, and cases with either a single tray or multiple trays in the same fire barrier enclosure. These calculations include certain very unique analysis approaches, and include a number of assumptions that should result in a net conservative result if properly applied.

The objective of this chapter is to describe the details of the licensee analysis method, and to identify the critical assumptions that will impact the reliability and conservatism of the results. These items are taken up primarily in Section 2.3 below. As a preliminary to these discussions, Section 2.2 provides a brief review of certain concepts and approaches that are critical to an understanding of the licensee analyses. The specific items of concern regarding the licensee implementation of its analysis model will be taken up separately in Chapter 3.

2.2 Methods of Calculation for the Base Line Ampacity

There are at least three methods by which one can estimate the base line ampacity of a cable in an open cable tray; namely, (1) use of the standard tables of ampacity such as the ICEA P-54-440 tables, (2) use of the Stolpe/ICEA concept of heat intensity limits, and (3) implementation of a thermal model. The licensee analysis does implement a thermal model, but is also heavily dependent on the second of these approaches, the heat intensity approach, although this approach is not especially common in practice. Hence, an understanding of the heat intensity approach is critical to understanding the licensee calculations.

The discussions in this section serve two purposes. First, each of these three methods of analysis will be briefly summarized in order to establish a firm understanding of each. In addition, as a part of each discussion, a single case example taken directly from the licensee analyses will be considered to illustrate each approach. These case analysis results will also support discussions in Section 3 below.

The specific case example considered by SNL corresponds to the base line case equivalent to the clad tray cases examined in the first six calculations presented in the licensee submittal.; namely, those cases used by the licensee to assess the sensitivity of the results to the assumed width of the side rail-to-barrier air gap and to the cable mass-to-bottom barrier panel air gap. The base line case considers a 4"x24" cable tray filled to a depth of 2.5" based on the ICEA definition of fill depth (see discussion in 3.2.2 below) with 3/C, #6 AWG, 600 V cable with an outside diameter of 0.953". SNL will evaluate this same tray for the base line condition using each of the three methods of analysis. Note that the licensee assumed a "base line" ampacity for this case of 27.5 A.

2.2.1 The ICEA Ampacity Tables

Use of the ICEA P54-440 standard tables of ampacity for open top cable trays is by far the most common approach taken to estimate cable ampacity limits for general cable tray applications. This includes those cases requiring the application of a separately derived estimate of a fire barrier ampacity derating factors. The process can be illustrated for the specific case example cited in 2.2 above quite easily. In this example it is assumed that the depth of fill, 2.5", is consistent with the ICEA definition of this parameter. SNL has made this assumption because the thermal model clearly uses the ICEA definition of depth of fill (see further discussion of depth of fill issues in 2.2.2 below).

The ampacity limit of a 3/C, 6 AWG, 600V cable can be calculated using either Table 3-3 or 3-6; the final result will be the same. Using Table 3-6, the base ampacity for a 6AWG cable with a 2.5" depth of fill is given as 30A. This value must be corrected for the actual cable diameter as compared to that assumed in the standard. This is done using the equation in Section 2.3 of the standard as follows:

$$I = \frac{d_{actual}}{d_{table}} I_{table} = \frac{0.953''}{0.900''} (30A) = 31.77A$$

where 0.953" is the cable diameter cited by the licensee, and 0.900" is the cable diameter cited in the ICEA tables. Hence, the tabulated base line ampacity would be this modified value, 31.77 A.

2.2.2 ICEA Heat Intensity Approach

A second and less commonly applied method of obtaining cable ampacity limits set forth in the ICEA standard is to use the "heat intensity" limits in Appendix A of P54-440. This method is generally applied when extrapolation of the tabulated limits in needed (for smaller cables, or depth of fill values outside the tabulated range of 1"-3"). The fundamental basis of Stolpe's work, and of the ICEA tables, is that the allowable maximum value of heat intensity, that is the rate of heat generation per unit volume of cables, is a function of cable tray depth of fill <u>only</u>. It is therefore assumed that for any combination of cables loaded into any open top cable tray, the maximum heating rate of each conductor in the tray can be calculated based only on knowledge of the total tray depth of fill and the corresponding heat intensity. It is also important to note that the licensee has cited Stolpe as the basis for their treatment, and hence, the results which follow should be viewed as an appropriate basis for assessment of the licensee results.

In order to illustrate this approach let us first briefly review the concept of heat intensity as defined by Stolpe. For this presentation we will use the notation of Stolpe in which (Q) is the heat intensity, (q) is the actual heat generation rate for a single conductor, and ($n_{conductors}$) is the number of conductors in the cable. Heat intensity (Q) is basically the allowable total heat generation rate per foot of cable tray per square inch of cable cross-section. (Note that this is distinguished from the "Watts per foot" method in that the value heat intensity is volume based whereas "Watts per foot" is simply length based, allowable heat per foot of tray.) Mathematically, this can be expressed for a single cable as (see Stolpe, eq. 1):

$$Q = \frac{q*n_{conductors}}{A_{x\text{-}section}}$$

Note that (Q) is typically given in units W/ft/in^2 so that (q) is given in units of W/ft, and ($A_{x\text{-}section}$) is the cross-sectional area of the n-conductor cable(s) in units of in^2. If one is given the allowable maximum heat intensity and the characteristics of the cable, then the allowable rate of heat generation per conductor, (q), and the cables maximum current (I) can be calculated. Given the conductor heating rate, the corresponding maximum cable current is easily calculated using (see Stolpe, eq. 2):

$$q = I^2 R_{cable}$$

where (R_{cable}) is the AC electrical resistance per foot of cable.

In this process, there is one additional issue which must be understood. This has to do with how the cross-sectional area of the cable and hence the depth of fill of a cable mass is calculated. The most obvious approach for a single cable is to simply assume the cable is circular, and to calculate the cable cross-section as:

$$A_{cable} = \frac{\pi d^2}{4}$$

However, under the definition provided in the ICEA standard, the area to be used is the equivalent area of a square section fully surrounding the cable, rather than the actual cross section of the round cable itself (see Section 2.2 of the standard):

$$A_{cable} = d^2$$

This issue also has implications for the calculation of depth of fill as well. In general, the depth of fill is related to the number of cables in the tray (n_{cables}), the width of the tray (w_{tray}), and the cable cross-sectional area as follows:

$$d_{fill} = \frac{n_{cables} A_{cable}}{W_{tray}}$$

However, the answer obtained is, quite obviously, dependent of which method is used to calculate the cable cross section. If one uses the actual circular cross section, then depth of fill is given as:

$$d_{fill} = \frac{n_{cables}\,\pi\, d^2}{4\, w_{tray}}$$

In effect, one is assuming that the cables are very tightly packed with essentially no air gaps. It is this definition that was used by Stolpe in his original paper. In contrast, the ICEA standard very clearly assumes the equivalent square cable area because depth of fill is specifically cited as being calculated as:

$$d_{fill} = \frac{n_{cables}\, d^2}{w_{tray}}$$

The ultimate lesson to be taken from this discussion is that in order to properly apply the heat intensity approach, the cross section of a single cable, the depth of fill of the cable mass, and the heat intensity must all be based on the same analysis approach. In particular, a 2.5" fill as defined by Stolpe is not the same as a 2.5" fill as defined by the ICEA. In fact, a 2.5" "ICEA fill" is really equal to a (2.5*π/4) or 1.96" "Stolpe fill". However, for a given tray, either method should yield essentially the same result.

As a final note to this discussion, observe the fact that the ICEA cited heat intensity limits are actually identical to those cited by Stolpe at any given depth of fill. Heat intensity is a function of depth of fill only, and because Stolpe and the ICEA have used different definitions for this parameter, one might not expect a one-to-one correspondence between the Stolpe and the ICEA heat intensities. However, is it simple to verify that, for example, the ICEA heat intensity at 2.5" "ICEA fill" is identical to the Stolpe heat intensity for a 83.3% or 2.5" "Stolpe fill." As noted above, for a given cable arrangement the Stolpe method will yield a smaller fill depth than will the ICEA approach. Hence, the Stolpe fill method would yield a higher heat intensity limit due to the lower fill. The ampacity one would calculate ends up essentially the same because the higher heat intensity is offset by the correspondingly lower cable cross-section area given by the Stolpe versus ICEA method. Hence, in the end a given cable is allowed to generate approximately the same level of heat in either case, and hence, ends up with essentially the same ampacity limit.

Returning to the our specific case example, the ampacity limit of a 6AWG wire in a cable tray with a 2.5" depth of fill can be easily determined. However, the result will depend on whether we consider 2.5" depth of fill to be a "Stolpe fill" or an "ICEA fill." Based on an examination of the licensee thermal model, it is clear that in that model the licensee has implemented a definition of depth of fill based on the ICEA approach (see further discussion in Section 2.3.1 below). Hence, a comparison based on the ICEA definitions appears most appropriate. However, for illustrative purposes, SNL will consider both possible definitions.

For a 2.5" ICEA fill, ICEA specifies a heat intensity limit of 1.784W/ft/in². In accordance with the ICEA approach using the square-equivalent, the cross section of the cable is given by:

$$A_{cable} = d^2 = (0.953in)^2 \approx 0.908in^2$$

Rearranging Stolpe eq. 1 as given above, we can now calculate the allowable heating rate for each of the three conductors in the licensees cable based on the heat intensity as specified in the ICEA tables:

$$q_{ICEA} = \frac{Q_{ICEA\text{-}2.5}\,A_{cable}}{n_{conductors}} = \frac{1.784 \bullet 0.908}{3} = 0.540\ W/ft$$

Rearranging Stolpe's eq. 2, the corresponding current can be calculated as:

$$I_{ICEA} = \sqrt{\frac{q_{ICEA}}{R_{cable}}} = \sqrt{\frac{0.540}{0.000513}} = 32.45\ A$$

As one expects, this value is quite similar to the actual value extrapolated directly from the ICEA tables (31.77 A as discussed above). The minor difference, about 2%, is easily attributed to round-off in the standard tables.

For illustration let us assume that the 2.5" were in fact based on Stolpe's definition of fill depth. The corresponding heat intensity must be obtained by extrapolation because Stolpe only plots his results for up to a 2.4" depth of fill (80% fill of a 3" cable tray). The value estimated by SNL for a 2.5" fill based on extrapolation of Stolpe's plot is 1.75 W/ft/in². As noted above, this is roughly identical to the ICEA heat intensity values cited above. However, if this is a "Stolpe fill" then the one must also use the circular cable cross-section in the calculation of allowable current. Hence, the ampacity limit for this 2.5" "Stolpe fill" is given by:

$$I = \frac{D}{2}\sqrt{\frac{Q\,\pi}{n_{cond}\,R_{ac}}} = \frac{0.953}{2}\sqrt{\frac{(1.75)\,(3.14)}{(3)\,(5.13E\text{-}4)}} = 28.5\ A$$

Thus, if the 2.5" is assumed to be based on Stolpe's definition of fill depth then an ampacity of 28.5 A which is much more consistent with the 27.5 A value cited by the licensee.

As a final example, let us assume that the 2.5" fill was based on the ICEA definition. In this case as cited above the equivalent "Stolpe fill" would in fact be about 1.96". Using this value, the heat intensity limit given by Stolpe would be about 2.4 W/ft/in², and the corresponding ampacity limit would be:

$$I = \frac{D}{2}\sqrt{\frac{Q\pi}{n_{cond}\,R_{ac}}} = \frac{0.953}{2}\sqrt{\frac{(2.4)(3.14)}{(3)(5.13E-4)}} = 33.3\ A$$

As noted above, when the depth of fill and cable cross-section are treated consistently, the Stolpe method yield essentially the same ampacity, 33.3 A, as did the ICEA method, 32.45 A. The key is to ensure that depth of fill and cable cross-section are used consistently.

2.2.3 Use of a Thermal Model

A third approach to the estimation of base line ampacity values is to apply a thermal model and to simply calculate the allowable ampacity limit for a given case. This approach is rarely, if ever, used in practice for cable trays, but is relatively common for the calculation of conduit ampacities (the National Electric Code, NEC, specifically allows this approach for example). With a direct calculation of actual ampacity limits for a given case there is more potential for error. This is because modeling assumptions and any mistakes made in the development or execution of the thermal model will directly impact the results. However, in the context of relative analysis of ampacity derating factors this is, by far, the preferable option.

In particular, in the context of the ampacity derating issue, the objective is to assess the relative impact of the fire barrier system on cable ampacity limits. It is especially important in this process to ensure that both the base line and clad case ampacity values have been assessed on a consistent basis. This holds for both testing and analysis based approaches. In the specific case of testing, it is important that the sample be tested in both the base line and clad conditions, and that these two test results be compared. It is not considered appropriate to, for example, compare a tested clad ampacity to a base line ampacity from the standard tables. The topic of the licensee analysis in this regard will be taken up in Chapter 3.

In the case of our specific example problem, the licensee has not provided any thermal modeling results to assess the base line ampacity. However, given the effort that has been applied to the clad case analyses, the implementation of a fully consistent base line case analysis is quite easily accomplished. SNL, as a part of this review, has implemented such a model. The MATHCAD analysis file for this case is presented in Appendix A, and the model will be taken up in detail in Chapter 3.

The final result of the SNL base line thermal model analysis estimated the base line ampacity to be 32.58 A. This value is in remarkably good agreement with the ICEA table-based value of 31.77 A, and with the ICEA heat intensity based value of 32.45 A. However, the value is, once again, significantly higher than the 27.5 A value cited by the licensee as the base line ampacity for this case.

2.3 The Licensee Thermal Model

2.3.1 Overview of Approach

The thermal model developed by the licensee employs as set of well known and well characterized heat transfer correlations incorporated into a single analysis package which is "tuned" to suit a specific case analysis as needed. There is, however, one aspect of the model which is unique in comparison to other ampacity derating analyses reviewed by SNL.

In a typical cable tray fire barrier ampacity derating analysis a given cable tray configuration is defined in terms of the physical characteristics of the cable tray and cables. This hypothetical tray is then analyzed with a thermal model to determine the current load that will yield a predicted conductor temperature of 90°C while the ambient is at 40°C. The calculation is repeated for the base line and for the clad conditions, and the resulting ampacity values compared to estimate the derating impact. In this approach, the physical characteristics of the system remain fixed, and the cable current is used as the "floating" parameter that is adjusted to match the desired thermal conditions. In effect, this mimics the process of an ampacity derating test in which currents are adjusted for a given specimen to obtain the desired thermal conditions.

In contrast, the licensee calculations in BYR96-082/BRW-96-194 are based on a substantially different approach. The one aspect of the licensee submittal that is most unique is that the licensee analysis has used the cable depth of fill as the "floating" parameter in the analysis, rather than the cable current. That is, the licensee modeling approach is to fix the cable ampacity at the outset of the calculation to a preset value, and to then adjust the depth of fill until the hot spot temperature condition is satisfied. This approach can be made to work because reducing the depth of fill is the same as reducing the number of cables assumed to be present in the tray. This, in turn, reduces the total heat load on the system and hence reduces the estimated temperature drops through each element of the thermal model. The depth of fill, i.e. the total heat load, can be adjusted until a match is obtained.

The results of the initial thermal analysis are an allowable depth of fill for the chosen "nominal (rated) ampacity of the cable" for the cable tray in a clad condition. In order to establish the ampacity derating factor, the corresponding base line current must be estimated. This is accomplished by using the heat intensity approach and a set of special licensee derived heat intensity versus depth of fill values. That is, the depth of fill determined in clad case analysis is used to establish an allowable base line heat intensity based on a pre-set "look-up table." This heat intensity value is used in turn to establish the allowable ampacity limit. This value is then compared to the clad case ampacity in the standard manner to determine the derating impact.

In principle, the concept of adjusting the depth of fill to match the thermal conditions is an acceptable approach to the problem. However, as will be noted in Chapter 3 SNL has certain concerns related to the licensee implementation of this thermal model that could significantly impact the results of the licensee analysis.

2.3.2 Critical Modeling Assumptions

The licensee's analysis has incorporated a number of modeling assumptions, both conservative and non-conservative, that will significantly impact the analysis results. In some regards, the licensee thermal model has followed standard and accepted engineering practices. These include:

- Standard, modern correlations for the convection rates both inside and outside of the fire barrier have been employed in an apparently proper manner. For the outside surfaces, the orientation of the surface has been included. For the inside surfaces both orientation and gap width have been considered as appropriate. (Note that this had been a point of concern raised in the original 1995 review.)

- The analysis as presented by the licensee is clearly documented and relatively easy to follow. The model has been implemented using commercially available computer software, and includes proper handling of all units in the analysis. Sources for all correlations have been cited.

- The analysis has included consideration of the heat transfer effects within the cable mass itself, albeit in a rather simplified manner.

Those assumptions considered by SNL to be of a non-conservative nature include:

- Full credit is given for heat transfer through the sides of the cable tray system in addition to the heat transfer from the upper and lower surfaces. This practice is contrary to common practice in which heat transfer from the sides is neglected. In general, so long as the base line and clad cases are treated consistently, this would not be a significant point of concern. It is the potential inconsistencies in this treatment that are of concern to SNL.

- In treating the sides of the cable tray, the licensee has assumed that the entire height of the cable tray side rail will be at the same temperature as the surface of the cable mass (also assumed to be at a uniform temperature). This assumption is non-conservative for two reasons. First, there will be some temperature drop from the cable to the side rail due to contact thermal resistance between the two items. Second, the cables only come into contact with a fraction of the side rail (typical depth of fills for the licensee calculations are in the range of 1" or less). Hence, the rest of the side rail will act somewhat like a fin to lower the average temperature of the side rail below that of the cable mass. The licensee treatment assumes a side rail temperature higher than that to be expected in reality which could over-estimate the role of the side rails in the heat transfer process. Here again, the primary concern of SNL is related to the consistency of the treatment.

- In treating the bottom of the solid bottom cable trays used by the licensee, it has been assumed that the temperature of the bottom plate will be identical to that of the cable mass surface. This is potentially non-conservative because it ignores the thermal contact resistance between the two surfaces. However, given the configuration of the licensee trays, solid bottom, this will likely be a minor effect in this case.

However, offsetting these potential sources of non-conservatism are several other assumption of a conservative nature. These include:

- For all analyses involving multiple trays in a single enclosure, the licensee has assumed that any un-powered cable trays present will act as perfect insulators and fully block the heat transfer through the "shadowed" portion of the fire barrier.

- An emissivity of 0.4 has been assumed for the unpainted Thermo-Lag surface. This value is much lower than the 0.9 value typically assumed in such analyses. This will be conservative because it will reduce the heat rejection capacity of the fire barrier system.

- Painted barriers are assumed to have an emissivity of 0.9 at the outside (cited as typical of a painted surface) but will retain the 0.4 emissivity assumption noted immediately above for the inner surfaces. Hence, a lesser level of conservatism is realized when a painted barrier is considered.

- A sensitivity analysis was performed to assess the impact of the assumed tray rail height, side rail-to-barrier gap width, and bottom tray-to-barrier gap height on the estimated derating impact. The most conservative values (the minimum values) have been used in subsequent analyses.

Overall, the net impact of the licensee modeling assumptions should result in a reasonable assurance that the ampacity derating impact has been conservatively estimated in this regards. As will be noted in Chapter 3, there are aspects of the thermal model that still render the final results of questionable reliability.

3.0 POTENTIAL POINTS OF CONCERN

3.1 Overview

As a part of this review, SNL has identified four points of concern in the licensee's analyses. These items are taken up in Section 3.2 below. The most significant of these concerns relate to the manner in which the licensee has performed the base line case assessments. The concerns in this regard relate to both the lack of consistency between the base line and clad case assessments, and to certain errors and inconsistencies in how the actual values were obtained. As will be noted below, SNL finds that the licensee calculations have been seriously compromised by these problems. As an alternative, SNL considers that the most appropriate basis for an analysis of this type is for the clad case and base line case to both be calculated using a consistent thermal model. SNL has implemented such a model for the base line case analyses as a part of its review efforts. The approach to modeling taken by SNL and the results of these analyses are discussed in Section 3.3 below. Finally, SNL has considered whether on not the observed concerns will impact the earlier Braidwood analyses for standard configurations, Calculation G-63, as discussed in Section 3.4 below.

3.2 Points of Concern

3.2.1 Consistency

Of the concerns identified by SNL the one that is of most significance is the observation that the licensee is comparing a calculated clad case ampacity limit to a base line ampacity derived on an entirely different basis. In any ampacity derating assessment, either experimental or analytical, it is critical that both the base line and clad ampacity values have been determined on a consistent basis. By comparing a given analysis result to a standard table of ampacity limits, the licensee is potentially comparing "apples to oranges" and this renders the results of the analysis highly suspect.

The concern can be easily illustrated through an analogy to the testing approach. In particular, it had once been proposed that ampacity derating values be based on a comparison of a tested value of clad case ampacity to the ICEA tabulated value of the open tray base line ampacity. This practice was considered inappropriate, and is no longer allowed in the testing standard. Ampacity derating values in testing must now be based on the comparison of a clad case test result to a corresponding base line case test result. This ensures self-consistency in the test results.

The intent of ampacity derating is to establish the actual relative impact of the fire barrier system on the ampacity limits. In testing, it has been concluded that this can only be accomplished by comparing a base line test to a clad case test where each has been performed under consistent test conditions. By the same reasoning, the only appropriate basis for the analysis of ampacity derating factors is the comparison of clad and base line analyses in which each analysis has been performed using the same modeling assumptions, correlations, and parameters.

The primary basis for this constraint is that in previous efforts[2] SNL has demonstrated that calculations of the absolute ampacity limits of a cable tray system in comparison to experimental or tabulated values can be very difficult, and that these calculations are subject to significant variation based on nominally innocuous modeling changes. It was, however, found that it was much easier to reliably reproduce the relative ampacity derating impact from an experiment using a pair of self-consistent thermal models. That is, the relative calculation of ADF was relatively simple provided that the base line and clad cases were analyzed on a consistent basis. This is because the relative ADF impact is actually presented as the ratio of two calculated ampacity values, and hence, minor errors in the thermal model tend to be self-canceling provided that consistency is maintained.

In the case of the licensee submittals this consistency between the base line and clad case analyses has not been maintained. In particular, the licensee has only exercised its thermal model in the analysis of the clad cases under consideration. The base line case ampacity limit is not assessed using a corresponding thermal model, but rather, is based on tabulated values for the base line ampacity (as derived from the licensee's own table of heat intensity values versus cable depth of fill). No assurance whatsoever has been provided that the licensee thermal model is at all consistent with the cited heat intensity limits. This is considered to represent a serious flaw in the licensee approach that renders the results highly suspect.

Findings and Recommendations: SNL finds that the licensee's comparison of a clad case ampacity limit to a base line ampacity derived from tabulated ampacity values (or heat intensity limits) is an inappropriate basis for the derivation of ampacity derating factors. It is recommended that the licensee be asked to reassess its ampacity derating estimates using a thermal model for the base line case analyses that is fully consistent with the thermal model used to estimate the clad case ampacity limits. (See further discussion of a SNL implementation of such a model in Section 3.3 below.)

3.2.2 Possible Error in ICEA versus Stolpe Application

In calculating ampacity limits, it would appear that the licensee has made an error of analysis. This impacts both the individual sensitivity analysis cases cited by the licensee and the specific special configuration cases. The error is related to the manner in which the licensee has calculated used depth of fill to calculate base line ampacity limits.

As was noted in 2.2.2 above, Stolpe and the ICEA provide different definitions for how depth of fill is to be calculated. These differences also apply directly to how the cross-sectional area of an individual cable is calculated as well. So long as one is consistent in the calculation of both values, then essentially the same result will be obtained for either case. In the licensee analyses this consistency appears to have been violated.

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[2] See "Fire Barrier System Cable Ampacity Derating: A Review of Experimental and Analytical Studies," A Letter Report to the USNRC, August 15, 1995, Final, prepared by SNL under USNRC JCN J2018.

In the licensee's clad case analyses an examination of the thermal model quickly and clearly reveals that the ICEA definition of depth of fill has been used. For example, see page 16 of the licensee calculation. Near the middle of the page the value "n_{trial}" is calculated from the given depth of fill. This equation also defines depth of fill as it is defined by the ICEA standard. The depth of fill definition is also repeated at the top of page 20, and again, it is quite clear that the ICEA definition has been applied. This same definition has been used throughout the balance of the licensee clad case analyses as well.

In the analysis, the clad case ampacity is used directly to set the total heat load on the system using the electrical resistance of the conductors and the total number of conductors present ($q_{tray}=I_{cable}^{2}*n_{cable}*n_{conductors}$). Thus, the total heat load and the depth of fill are intimately linked through the conductor count parameter ($n_{cable}*n_{conductors}$). Given this it is quite apparent that the clad ampacity limit is based on the ICEA definition of fill depth. This applies to both the sensitivity and special configuration analyses.

Consider now the sensitivity cases. As was illustrated in Section 2.2 above, a direct application of the ICEA P-54-440 standard yields a base line ampacity limit significantly higher than the 27.5 A values cited by the licensee. SNL has explored two potential explanations for this discrepancy:

- The only way that SNL can come even close to reproducing this value based on a direct application of the ampacity tables is to assume that the 2.5" is based on Stolpe's definition of fill depth so that the Stolpe definition of cable cross-section applies. If this interpretation is correct, then the result has been to artificially reduce the base line ampacity in comparison to the clad ampacity, and hence, to artificially reduce the calculated ADF.

- One additional explanation considered by SNL is that the value of 27.5 may have been derived for a cable tray with a solid cover. Recall that in the Braidwood G-63 calculations, the licensee cited that solid bottom cable trays with solid steel covers were used predominantly at the plant. Licensee testing was cited as indicating a 15% derate because of the solid tray covers. Indeed, if the values of 27.5 is divided by 0.85 (in order to "remove" a 15% derating of the ICEA value), a modified ampacity of 32.35A is obtained. This is, in fact, very close to the value derived from the ICEA heat intensity tables (see discussion in Section 2.2.2 above). This is one alternative explanation for how this values was derived.

Either explanation is considered a significant point of concern. If the value derives from using a mixed definition of depth of fill versus cable cross-section, then this is a clear error. If it derives from an assumption of a 15% derate for a covered tray, then it is also an inappropriate basis for the base line case which should reflect an open top tray. (Recall that many of the cases examined in BYR96-092/BRW-96-194 did not include a solid cover on the cable tray. This included all of the sensitivity cases. It would be inappropriate for the licensee to apply a base line ampacity for a covered tray to these analyses. The base line case should be the solid bottom, open top tray case.)

The impact of this apparent discrepancy on the sensitivity cases in very significant. For example, if the base line ampacity assumed for the first of these sensitivity studies (see pages 16-28 of 297) is raised to the ICEA ampacity (31.77A) then the calculated ADF increases to 47.4% as compared to 39.3% calculated by the licensee.

It is unclear if the ADF values from any of these case studies will be used by the licensee in actual applications. The summary of results presented at the end of the calculation does not include these sensitivity cases, and hence, it is generally assumed that the values will not be used. It should also be noted that this change would not impact the final sensitivity conclusions in that the relative ranking of the case study ADFs would remain the same.

The same observation also applies to the specific case studies included by the licensee to assess the special configurations. As was noted above, all of the clad case analyses have been based on the ICEA definition of fill depth. The corresponding base line case analyses for the various applications are all presented in the very last set of calculations which begin on page 292. For the base line case analysis, the licensee simply sets the depth of fill derived in an individual clad case analysis, uses a "look-up table" to get the corresponding base line heat intensity for that depth of fill, and then calculates the corresponding ampacity. The error is clearly seen in this last step. The fourth equation on page 293 clearly defines the ampacity relationship used (see equation: "Ampacity(DOF)=..."). This equation is clearly based on the Stolpe definition of fill depth (note the presence of the factor π/4 in this equation which is only used when the Stolpe definitions are invoked).

Findings and Recommendations: SNL finds that the licensees has failed to establish an adequate basis for its assumption that the base line ampacity limit of a 6 AWG, 3/C, 600 V cable in a open cable tray with a 2.5" depth of cable fill is 27.5 A. It is recommended that the licensee be asked to remove references to this value, and to assess the base line ampacity values using a compatible thermal model for an open tray case without solid covers (such as that discussed in Section 3.2.3 below).

Further, SNL finds that in performing its assessments, the licensee has apparently mixed ICEA and Stolpe definitions of depth of fill in an apparently inappropriate manner. The licensee results have significantly understated the ampacity limits for the base line case. As was noted in Section 3.2.1 above, it is ultimately SNL's recommendation that the licensee should be asked to base it base line assessments on a consistent thermal model. If this broader recommendation is implemented, then SNL's concern in this regarding inconsistencies in the depth of fill treatment would be rendered moot.

3.2.3 Licensee Heat Intensity Tables

As a part of its submittal, the licensee has presented its own table of heat intensity values similar to that provided in the ICEA tables (see licensee item 13 on page 13 of 297). This licensee table allegedly was derived from the work of Stolpe and the ICEA tables, although the values do not appear to be compatible with either of those two works.

As was noted in Section 2.2.2 above, the heat intensity values of the ICEA and Stolpe are essentially identical for any given value of the depth of fill, even though the two sources use different definitions of fill depth. In comparison to the ICEA/Stolpe tables, the licensee table appears to modestly over-state the limiting heat intensity values for all depth of fills cited. For example, at a depth of fill of 2.5", the ICEA/Stolpe heat intensity limit is 1.784 W/ft/in^2. In comparison, the licensee cites a value somewhere between 1.962 and 2.095 W/ft/in^2 (the licensee values at 2.594" and 2.473" respectively, SNL has not attempted to interpolate between the two values).

The basis for this discrepancy is unclear. The licensee has not discussed how its own heat intensity table was derived in the submittal. The submittal does cite a separate licensee document (Calculation ESI150-1 Rev. 0, licensee ref. 16). However, this document is not available for review.

SNL does note that at the end of each calculation the licensee has presented a conversion for heat intensity for "square cables" to heat intensity for "round cables." This correction does indicate that the licensee has some appreciation of the differences between the two methods. However, the basis for and purpose of this "correction" is unclear. As noted above, despite the differences in depth of fill between "square cables" as per the ICEA and "round cables" as per Stolpe, both present essentially identical heat intensity limits for a given fill depth. Hence, the objective of the licensee is entirely unclear in this regard.

Findings and Recommendations: SNL finds that the licensee cited heat intensity table (item 13 on page 13 of 297 of the licensee submittal) is in apparent conflict with the ICEA/Stolpe tables of heat intensity. It is recommended that the licensee be asked to resolve the apparent discrepancy. It is also recommended that the licensee be asked to review its actual cable ampacity calculations to ensure that this discrepancy has not adversely impacted its assessment of cable ampacity limits.

3.2.4 References to "SilTemp Sheet"

In several of the licensee calculation, there is a reference made to the "thickness of the SilTemp sheet" (see for example page 24 of 297, 4th line from the bottom). No references to the use of a SilTemp sheet, a glass fiber blanketing material, in the construction of the licensee fire barriers is provided elsewhere in the submittal. It is presumed by SNL that this is a "spurious" reference carried over from some previous application of the model, but this should be verified.

Findings and Recommendations: SNL has identified references in the licensee calculations to a "SilTemp sheet" that appear inconsistent with the licensee descriptions of their fire barrier installations. It is recommended that the licensee should be asked to verify if such a SilTemp sheet is used in any of its fire barrier systems, and if so, how the material is used. The licensee should verify that each of its case analyses have either considered the sheet if used, or not considered the sheet if it is not used.

3.3 SNL Analysis of the Base Line Case

3.3.1 Overview and Approach

While the licensee has not provided any thermal analysis of the base line cable tray cases in its submittal, it is a relatively trivial manner to implement a base line case model given the work already performed by the licensee. In previous efforts SNL had already implemented a MATHCAD file to reproduce the licensees single tray ampacity calculations from Calculation G-63. As a part of the current review, SNL modified this file in order to develop a base line cable tray thermal analysis model fully consistent with the licensee's own thermal models for its analysis of the clad case ampacities as presented in the current calculation. In implementing this model, SNL has retained all of the critical modeling assumptions used in the licensee' analyses. This includes:

- SNL has retained all of the physical and thermal properties specified by the licensee (for the cables, the cable tray, and the ambient).
- Full credit has been given for radiation and convection from the top of the cable mass, from the sides of the cable tray, and from the bottom of the cable tray.
- The cable tray sides and bottom have been assumed to be at the same temperature as the surface of the cable mass
- The surface of the cable mass has been assumed to be characterized by a single temperature (i.e., an isothermal surface, as per the licensee's model).
- All of the exact same convection correlations have been applied.
- The same simplified model for heat transfer within the cable mass has been applied.
- SNL has retained the ICEA definition of fill depth as per the licensee clad case thermal model.

SNL has calculated the base line case ampacity limit in essentially the same manner as that applied by the licensee to the clad case analysis. The major difference in the SNL implementation is that the depth of fill is set to the value derived by the licensee for the clad case, and the ampacity is adjusted until the desired thermal conditions (90°C hot spot) are achieved. However, as in the licensee clad case analyses, the depth of fill is uniformly based on the ICEA definition, and the total heat load on the tray is calculated directly from the cable current using the conductor count and electrical resistance factors. This completely eliminates the calculation's dependence on any pre-set table of ampacity or heat intensity limits.

The result of this exercise is a thermal model for the base line case that is fully consistent with the licensee's treatment for clad cable tray cases. Appendix A provides a listing of the SNL implemented base line cable tray thermal model.

3.3.2 SNL Base Line Analysis for the Sensitivity Study Cases

As an initial case study, SNL assessed the base line ampacity limit for a single, open top, 4"x24" cable tray with a 2.5" depth of fill of the #6 AWG cables considered in all of the licensee analyses. This case corresponds directly to the first six analyses presented by the licensee in its submittal; namely, those used to perform the air gap sensitivity assessments for both the side rails and the tray bottom. All six of these case studies can be considered to have the exact same base line condition.

The results of this thermal model indicate a base line ampacity limit for this case of 32.58 A. This value is remarkably similar to the values derived from the ICEA tables (31.77 A) and from the ICEA heat intensity approach (32.45 A). However, the value derived is significantly higher than the nominal base line value cited in the licensee study (27.5 A) which apparently derives from the licensee's own set of heat intensity values.

The impact of changing the estimated base line ampacity for these sensitivity cases is quite profound, and illustrates the importance of this issue. Consider, for example, the first of the licensee sensitivity case studies (presented on pages 16-28 of the submittal). This case study involved a 3-hour, double layer, Thermo-Lag 330-1 fire barrier system with no tray cover in place and the outer surface of the Thermo-Lag unpainted. The licensee has cited an estimated derating impact for the fire barrier system of 39.3% based on a base line ampacity of 27.5 A and a clad ampacity of 16.7 A. In contrast, if the base line ampacity is raised to 32.58 A, and the clad ampacity is maintained at 16.7 A, an ADF of 48.7% is obtained. This difference is very significant.

As a basis for the comparison and validation of these results, consider that in tests performed by Florida Power and Light (FPL) the ADF for a 3-hour single layer Thermo-Lag 330-1 cable tray fire barrier system with no upgrades and no tray cover plate was found to be 41.4%. The impact of a 3-hour double layer system, such as that considered in the licensee analysis, will certainly be greater than this based on the presence of an additional air gap in the system (between the two barrier layers). Hence, it is clear that the licensee cited ADF of 39.3% is non-conservative. The modified estimate generated by SNL, 48.7%, is in all likelihood modestly conservative due to the nature of the assumptions used by the licensee in the development of the clad case thermal model (see discussion of modeling assumptions in Section 2 above), but is also far more consistent with the available experimental results.

3.3.3 SNL Base Line Analysis Results for the Licensee Case Studies

The licensee has implemented a total of 14 specific case analyses involving different configurations of cable trays and fire barriers. Recall that the "floating parameter" in these assessments was the cable depth of fill. Hence, in order to re-assess the results, it is necessary to estimate the base line ampacity for a given depth of fill using the thermal model. Using the SNL implementation of the thermal model, this is again easily accomplished. The approach is to simply set the depth of fill to the final value from the licensee case analysis, and to then adjust the ampacity until a match to the desired thermal conditions is obtained.

As a nominal validation of this approach, SNL calculated the ampacity limit for a 1" depth of fill. A value of 59.5 A was obtained. In comparison, using the ICEA table 3-6 values a base line current limit of 58.2 A is obtained, and using the ICEA heat intensity approach a value of 59.1 A is obtained. Each of these values is in excellent agreement. This result, coupled with the earlier results for a 2.5" fill depth which also matched the ICEA tables quite well, provides a reasonable assurance that this thermal model is providing self-consistent results when the depth of fill is varied.

The licensee's analyses resulted in 10 specific values of the limiting fill depth that covered all 14 of the case studies (some cases yielded the same depth value). SNL has produced corresponding base line ampacity limits for each of these depth of fill values, and has assessed the impact of these modified values on the ADF as summarized in table 3.1. The modified SNL results can be applied directly to the case examples cited by the licensee based on matching the case depth of fill limit to that of the table.

Table 3.1: Summary of SNL case study base line analysis ampacity limit and ampacity derating results for the depth of fill conditions analyzed by the licensee.

Depth of Fill (in)	Licensee Cited Values		SNL Model Results	
	Base Line Ampacity Limit (A)	ADF (%)	Base Line Ampacity Limit (A)	ADF (%)
0.68	69.755	60.6	75.0	63.3
0.72	67.475	59.2	72.5	62.1
0.76	65.41	58.0	70.2	60.8
0.83	62.117	55.7	66.6	58.7
0.87	60.422	54.5	64.8	57.6
0.91	58.855	53.3	63.0	56.3
0.98	56.303	51.2	60.3	54.4
1.06	53.722	48.8	57.4	52.1
1.10	52.522	47.6	56.1	51.0
1.14	51.381	46.5	54.9	49.9

3.3.4 Summary of Findings and Recommendations

SNL finds that the licensee practice of comparing a calculated clad ampacity limit derived from its thermal model to a base line ampacity value derived from the licensee heat intensity tables is unacceptable. It is recommended that the licensee should be asked to implement a base line thermal analysis model fully consistent with the clad case thermal model (i.e., using all of the same fundamental modeling assumptions and the same heat transfer correlations). The results of this base line thermal model should be used to develop the derating factors.

As an alternative, given that SNL has implemented a base line case analysis model of the type needed as a part of this review, this item might nominally be considered resolved provided that the licensee adopts the SNL analysis model and results directly. However, it is recommended that some formal resolution of this point of concern should be undertaken.

3.4 Implications for the G-63 Calculations

Under prior efforts[3], SNL had reviewed the licensee G-63 Calculations for single cable trays and conduits. Given the observations made in this review for the special configuration calculations, SNL returned to the G-63 calculations to determine if the same observations might be applicable.

In the case of the conduit calculations, the concerns identified in the current review have no impact on SNLs conclusions. The conduit calculations had already been performed on a basis consistent with the "best practices" approach discussed here. Namely, the base line and clad case ampacity values were calculated using a consistent thermal model and compared to determine the derating impact.

In the case of the cable tray calculations, a similar but somewhat different approach to analysis was taken. That is, the licensee had utilized their own test results to establish the thermal resistance between the cables and the closed top, solid bottom cable trays analyzed. This value was then maintained as consistent throughout the balance of the calculation. Hence, while the licensee did not conduct a full base line case thermal modeling analysis, the licensee did ensure that the base line and clad cases were treated on a consistent basis. This treatment was considered fully appropriate given the licensee's approach to analysis, the unique configuration of the licensee trays, and the unique ampacity data available to the licensee.

Findings and Recommendations: SNL finds that the concerns identified in this review will have no impact on the findings and conclusions documented by SNL for the G-63 calculations. No actions in this regard are recommended.

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[3] See, for example, SNL Letter Report of 12/20/96, "A Supplemental Review of the Braidwood Station Response to the USNRC RAI of 11/2/95 on Fire Barrier Ampacity Derating," prepared under JCN J-2017, Task Order 6.

4.0 SUMMARY OF REVIEW FINDINGS AND RECOMMENDATIONS

4.1 Overview

The calculations presented in BYR96-082/BRW-96-194 represent a significant expansion in scope of the overall package of licensee calculations as compared to the original package reviewed by SNL in August 1995. These calculations cover a broad range of "special installations" involving both single tray installations and installations with more than one tray in a single protective envelope.

In general the thermal model developed by the licensee for these analyses is well documented, clearly defined, and based on modern and accepted thermal modeling tools. Aspects of the licensee approach to modeling are unique in SNL's experience, but overall the approach is acceptable in principle. While SNL considered that the model does include certain non-conservative assumptions, it was also noted that the model includes several other offsetting conservative assumptions. In the balance, it is expected that once the points of concern identified in Section 4.2 are resolved, the licensee analyses will provide for a conservative assessment of the ampacity derating impact for these configurations.

4.2 Remaining Points of Concern

As a result of this review SNL has identified four points of concern. It is recommended that the licensee be asked to resolve these concerns through the RAI process. Of the identified concerns, one is considered far and away the most significant. This is:

- SNL finds that the licensee submittal is, in effect, comparing "apples and oranges." In particular, the licensee assessments of base line ampacity limits derive from a licensee table of allowable heat intensity limits while the clad case ampacities derive from the thermal model. This is considered by SNL to be extremely poor practice, and hence, is unacceptable. SNL recommends that estimates of fire barrier ADF should universally be based on self-consistent treatment of the clad and base line cases. In this case, it is considered critical to assess both the clad and base line ampacity limits using a self-consistent thermal model, and the licensee has not done this. If the thermal model is used to predict the clad ampacity limits, then a thermal model fully consistent with the clad case analyses should also be used to assess the base line ampacity limits as well. It is recommended that the licensee be asked to implement a thermal model for the analysis of the base line case ampacity that is fully consistent with its clad case analyses, and to then base its final ampacity derating assessments on a comparison of the clad and base line thermal analysis results.

Note that as a part of this review SNL did implement a base line thermal analysis model fully consistent with the licensee's clad case thermal model. The SNL model is documented in Appendix A, and has been discussed in Section 3.3 above. Results have been presented for all of the cases considered in the licensee analysis (including both the sensitivity studies and the 14 specific case examples). The licensee's adoption of this analysis model for the base line case assessments would fully resolve this point of concern.

The remaining three points of concern are all considered of less significance, especially assuming that the above item is resolved. These items are as follows:

- The licensee has presented a table of heat intensity versus depth of fill values as item 13 on page 13 of the licensee submittal. This table is in apparent conflict with the heat intensity values cited by Stolpe and in the ICEA standard P-54-440. The cited values appear to modestly over-state allowable heat intensity limits, and hence, might lead to optimistic estimates of the cable ampacity limits. It is recommended that the licensee should be asked to establish the basis for how this heat intensity table was developed and how it is applied in practice. It is also recommended that the licensee be asked to reassess its ampacity limit calculations in light of this apparent discrepancy. (A comparison of licensee approach in comparison to a direct application of the ICEA standard for a specific and well defined case example would be very helpful in this regard. Also, the licensee should be asked to provide the supporting calculation cited in the study as the basis for this table (Calculation ESI150-1, Rev. 0, licensee ref. 16).)

- The licensee cites in item 2 on page 12 that the base line ampacity for a 3/C, #6 AWG, 600 V cable with a 2.5" depth of fill is 27.5 A. The basis for this value is not established. SNL was unable to reproduce this limit using standard approaches to ampacity analysis given that the licensee thermal model has cited the ICEA definition as the basis for fill depth calculations. Two possible explanations were noted by SNL in this review, either of which would appear to be inconsistent with the objectives of the analysis. It is recommended that the licensee be asked describe in detail how this value was obtained and/or that the licensee be asked to delete references to and reliance upon this value as the "base line ampacity" for the cases examined.

- Several of the licensee calculations include a reference to a "SilTemp Sheet" but the fire barrier descriptions do not include a discussion of any such sheet used in the installation process. This reference may well be a "spurious" carry-over from a previous application of the thermal model. It is recommended that the licensee be asked to clarify if and when such a material is used in its barrier constructions. This is considered a minor point that will not have a significant impact on the final licensee assessments.

4.3 Implications of the Current Finding for the G-63 Calculations

SNL concludes that the findings of this current review will in no way impact the conclusions previously reached for the G-63 calculations. The basis of the G-63 calculations is significantly different from that used in the BYR96-092/BRW-96-194 calculations. Hence, the observations and inconsistencies noted here will not impact these other calculations. No actions in this regard are recommended.

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Appendix A:

A reproduction of the Commonwealth Edison Co. method of calculation for cable trat heat transfer and barrier ampacity derating analysis.

This is basically a reproduction of the calculation methods of calculation G-63 Rev. 4, and of BYR 96-082/BRN-96-194 in that all of the basic modeling assumptions have been implemented as defined by the utility. This includes:

- uniform surface temperature for the cable mass including the same temperature assumed for the full height of the side rails, and for the bottom of the solid-bottom cable tray,
- same size cable: 3/C 6AWG 600V with diameter of 0.953"
- uniform heating in cable mass
- Stolpe/Holmann simplified treatment of cable mass internal heat transfer
- Holmann correlations for convective heat transfer
- full credit for radiation/convection from all surfaces

For this calculation, SNL has implemented a Base Line case analysis of an un-clad tray fully consistent with the corresponding clad tray analyses pursued by the utility in its calculations, especially those of BYR-96-082/ ....

This case is for a 24"x4" cable tray, 2.5" depth of fill, no fire wrap, open top, solid bottom.

To start, must define a fundamental temperature unit (older version of MATHCAD). As per MathCad standard approach, we use the otherwise unused coulomb charge units and redefine this a one unit of absolute Kelvin temperature:

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

Now set some fixed physical parameters:

The Cables: $d_{cable} := 0.953 \cdot in \qquad n_{cond} := 3 \qquad R_{cable} := 0.000513 \cdot \frac{ohm}{ft}$

The Tray: $w_{tray} := 24 \cdot in \qquad h_{tray} := 4 \cdot in \qquad d_{fill} := 2.5 \cdot in$

The cable mass: $\rho_{cable} := 13.12 \cdot K \frac{ft}{watt}$ cable mass thermal resistivity in C-ft/W as per stolpe 400 C-cm/W

The approach is to set an actual ampacity, calculate temperature and heat flow values by a thermal model, and noodle on ampacity until a cable hot spot of 90C is obtained. This is where the licensee thermal model comes into play. SNL has implemented this model fully consistent with the licensee implementation and assumptions, but has not included any fire barriers in the analysis.

Need to set some constants, cable properties and metal propertiess as per those used in BYR96-092/....

$\sigma := 5.6691 \cdot 10^{-8} \frac{watt}{m^2 \cdot K^4}$ Stephan-Boltzmann

$\epsilon_{cable} := 0.95$ This is cable emmisivity

$\epsilon_{steel} := 0.33$ This is the metal emmisivity, very low value assumes by CE

$A_{cable\_top} := w_{tray} \qquad A_{side} := 2 \cdot h_{tray}$

$A_{steel} := w_{tray} + 2 \cdot h_{tray} \qquad A_{top\_bott} := w_{tray}$

Heat transfer surface areas

$T_{amb} := 40 \cdot K + CtoK \qquad T_{amb} = 313.16 \cdot K$ ambient temp is 40C:

Step 1: Set the ampacity and calculate internal cable heating rate:

$I := 32.58\cdot \mathrm{amp}$ Start with a guess then iterate to get the right ampacity
NOODLE HERE TO GET 90C CABLE TEMP.

$A_{mass} := w_{tray}\cdot d_{fill}$

$n_{cable} := \frac{A_{mass}}{d_{cable}^{2}}$ $n_{cable} = 66.064$

$Q_{cables} := n_{cable}\cdot n_{cond}\cdot I^{2}\cdot R_{cable}$ $Q_{cables} = 107.921\frac{\mathrm{watt}}{\mathrm{ft}}$

Step 2: Calculate Temperature of the outside surface of cable mass by balancing the internal heating rate calculated above to the external heat losses by radiation and convection. (Recall that top of cable mass, side rails, and bottom panel on tray all assumed to be at same temperature):

Seed the surface temperature value for root finder below:

$T_{surf} := 320\cdot K$

Recall that we assume rails and tray bottom are all at same temp as cable mass surface so can treat radiation to ambient as single equation:

$$Q_{rad}(T_{surf}) := \sigma\cdot\left(T_{surf}^{4} - T_{amb}^{4}\right)\cdot\left[\left(\varepsilon_{steel}\cdot A_{steel}\right) + \left(\varepsilon_{cable}\cdot A_{cable\_top}\right)\right]$$

Convection Formulas:

sides:

$$h_{side}(T_{surf}) := 1.42\cdot\frac{\mathrm{watt}}{\mathrm{m}^{2}\cdot K}\cdot\left(\frac{\mathrm{m}}{K}\right)^{.25}\cdot\left(\frac{T_{surf} - T_{amb}}{h_{tray}}\right)^{.25}$$

$$Q_{conv\_side}(T_{surf}) := h_{side}(T_{surf})\cdot A_{side}\cdot\left(T_{surf} - T_{amb}\right)$$

Top:

$$h_{top}(T_{surf}) := 1.32\cdot\frac{\mathrm{watt}}{\mathrm{m}^{2}\cdot K}\cdot\left(\frac{\mathrm{m}}{K}\right)^{.25}\cdot\left(\frac{T_{surf} - T_{amb}}{w_{tray}}\right)^{.25}$$

$$Q_{conv\_top}(T_{surf}) := h_{top}(T_{surf})\cdot A_{top\_bott}\cdot\left(T_{surf} - T_{amb}\right)$$

Bottom:

$$h_{bott}(T_{surf}) := 0.61\cdot\frac{\mathrm{watt}}{\mathrm{m}^{2}\cdot K}\cdot\left(\frac{\mathrm{m}}{K}\right)^{.25}\cdot\left(\frac{T_{surf} - T_{amb}}{w_{tray}}\right)^{.25}$$

$$Q_{conv\_bott}(Tsurf) := h_{bott}(T_{surf})\cdot A_{top\_bott}\cdot\left(T_{surf} - T_{amb}\right)$$

Total Heat Transfer:

$$Q_{total}(T_{surf}) := Q_{rad}(T_{surf}) + Q_{conv\_side}(T_{surf}) + Q_{conv\_top}(T_{surf}) + Q_{conv\_bott}(T_{surf})$$

Review Values:

$$Q_{total}(T_{surf}) = 18.924 \cdot \frac{watt}{ft} \qquad Q_{rad}(T_{surf}) = 12.712 \cdot \frac{watt}{ft}$$

$$h_{side}(T_{surf}) = 4.068 \cdot \frac{watt}{m^2 \cdot K} \qquad Q_{conv\_side}(T_{surf}) = 1.723 \cdot \frac{watt}{ft}$$

$$h_{top}(T_{surf}) = 2.416 \cdot \frac{watt}{m^2 \cdot K} \qquad Q_{conv\_top}(T_{surf}) = 3.07 \cdot \frac{watt}{ft}$$

$$h_{bott}(T_{surf}) = 1.116 \cdot \frac{watt}{m^2 \cdot K} \qquad Q_{conv\_bott}(T_{surf}) = 1.419 \cdot \frac{watt}{ft}$$

Use ROOT to solve for surface temperature at which total heat transfer equals heat generation in cables:

$$T_{surf} := root\left(Q_{total}(T_{surf}) - Q_{cables}, T_{surf}\right)$$

$$T_{surf} = 344.713 \cdot K \qquad T_{surf} - CtoK = 71.553 \cdot temperaturmass$$

Step 3: Now we have surface temp, need to analyze internal behavior of the cable mass to get the hot spot temperature. As per the licensee, we use the simplified model of Stolpe/Holmann:

$$T_{cable} := \frac{Q_{cables} \cdot \rho_{cable} \cdot d_{fill}}{8 \cdot w_{tray}} + T_{surf}$$

$$T_{cable} = 363.15 \cdot K \qquad T_{cable} - CtoK = 89.99 \cdot temperaturmass$$

This is the cable hot-spot temperature in degrees C, need to fiddle value until about 90:

Recall current:

$$I = 32.58 \cdot amp$$

Final Result of Calculation: Using the utility modeling assumptions and correlations, the base line current is estimated as 32.58A. This is in very close agreement with the ICEA values obtained either from the tables themselves (31.77) or from the ICEA heat intensity values (32.44). It is, however, significantly larger that the values cited in the licensee calculation (27.5A). The impact on the resulting ampacity derating factors could be very significant.