# A Review of the 12/19/96 Entergy River Bend RAI Response and Supplemental Ampacity Derating Calculations

A Letter Report to the USNRC

March 21, 1997

Revision 0

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ATTACHMENT 4

# TABLE OF CONTENTS:

## TABLE OF CONTENTS (cont.):

# FORWARD

The United States Nuclear Regulatory Commission (USNRC) has solicited the support of Sandia National Laboratories (SNL) in the review of licensee submittals associated with fire protection and electrical engineering. This letter report represents the second report in a series of review reports associated with ampacity derating submittals from Entergy Operations Inc. (EOI) for the River Bend Station Unit 1 (RBS-1). The first report in this series was submitted by SNL to the USNRC on 6/7/96, and documented a number of concerns related to the original licensee ampacity assessments as presented in a licensee submittal of 11/9/95. Based in large part upon the SNL review findings, on 10/16/96 the USNRC forwarded a RAI to the licensee requesting resolution of a number of both specific and general concerns. The submittal reviewed by SNL under the current efforts documents (1) the licensee's direct response to the USNRC RAI items, (2) a set of new calculations to estimate the ampacity derating impact of untested Thermo-Lag fire barrier configurations, and (3) a revised licensee calculation documenting the application of the various fire barrier ampacity derating factors to in-plant cables. This work was performed as Task Order 2 of USNRC JCN J2503.

# 1.0 INTRODUCTION

## 1.1 Objective

The objective of this report is to document findings and recommendations resulting from a Sandia National Laboratories (SNL) review of a licensee submittal for the River Bend Station Unit 1 (RBS-1) on the subject of fire barrier cable ampacity derating. The subject submittal was forwarded to the USNRC Document Control Desk under an Entergy Operations Inc. (EOI) cover letter dated 12/19/96, and was provided by the licensee in response to an USNRC Request for Additional Information (RAI) of 10/16/96. This report represents the second in a series of SNL review reports for this plant.

## 1.2 Background

On 9/25/95 the USNRC issued a RAI requesting more information on ampacity load calculations for RBS-1. This information had originally been requested in Generic Letter 92-08. The licensee responded through a submittal to the USNRC Document Control Desk dated 11/9/95. This original submittal documented the licensee position regarding cable ampacity loads associated with its installed fire barrier systems. SNL was requested to review the technical merits of this submittal under the terms of a general task ordering agreement, USNRC JCN J2017. A letter report documenting SNL's review findings and recommendations was submitted to the USNRC on 6/7/96.

As a result of SNL's review a number of both specific and general concerns were identified, and a subsequent RAI was forwarded by the USNRC to the licensee on 10/16/96 requesting resolution of these concerns. In response to this supplemental RAI, EOI has provided a second and updated submittal to the USNRC Document Control Desk under a cover letter of 12/19/96:

- Letter from Rick J. King, EOI, to the USNRC Document Control Desk, 12/19/96, item RGB-43571 RBF1-96-0477. With three Attachments:
    - Attachment A: "Response to Request for Additional Information"
    - Attachment B: Draft, Calculation G13.18.14.0-178, Rev. 0, "Ampacity Derating Factors for Thermo-Lag 330-1"
    - Attachment C: Draft, Calculation E-218, Revision 1, "Ampacity Verification of Cables within Raceways Wrapped with Appendix R Fire Protection Barriers"

SNL has, again, been requested to review this licensee submittal to assess its technical validity and it acceptability as documenting that the licensee has adequately assessed its ampacity load factors for cables protected by fire barrier systems. The current review efforts have been performed under the terms of a general task ordering agreement, USNRC JCN J2503.

## 1.3 Overview of the Licensee Submittal and Overall Ampacity Derating Approach

The licensee submittal is presented in three parts as identified in the citation provided in Section 1.2 immediately above. The first part of the submittal, Attachment A, documents the licensee's direct response to the concerns identified in the USNRC RAI of 10/16/96. The second part, Attachment B, documents a new set of calculations performed by the licensee to estimate the ampacity derating factor (ADF) for certain fire barrier installations for which no test data was found available. These include certain three-hour fire barrier systems, and certain installations involving multiple cable raceways (potentially including both trays and conduits) enclosed in a common fire barrier structure. It will be noted below that these calculations represent a significant expansion in the scope of the licensee calculations as compared to that of the original licensee submittal review by SNL in 1996. The third part of the licensee submittal, Attachment C, documents the licensees actual application of fire barrier ADF to installed cables in the plant. This is presented in the form of a revision of licensee calculation E-218, the calculation that was the focus of SNL's earlier review efforts.

The overall approach to ampacity derating is to apply fire barrier ampacity correction factors (ACFs) to base line ampacity limits to determine a design cable ampacity (DCA) limit. The actual in-plant service loads are then compared to the DCA to determine acceptability. The licensee has utilized an apparently extensive internal data base on cable locations and loads in this process. Cables nominally identified as overloaded are reviewed on a case by case basis. The submittal outlines recommended resolution approaches for each such cable, but these recommendations have apparently not yet been acted upon.

### 1.4 Organization of this Report

Section 2 of this report provides a brief review of the licensee submittal Attachment A; namely, the specific licensee responses to the items identified in the USNRC RAI of 10/16/96. Section 3 provides for a critical evaluation of the untested configuration calculations presented as Attachment B of the licensee submittal. Section 4 provide a point by point review of the licensee applications as presented in the submittal's Attachment C. Section 5 summarizes the SNL findings and recommendations.

## 2.0 LICENSEE RESPONSE OF JULY 27, 1995

In an RAI of 10/16/96, the USNRC asked the licensee to respond to several concerns related to its ampacity derating calculations. The licensee response to these specific concerns was provided by EOI in Attachment A of the licensee's 12/19/96 submittal. The subsections that follow provide SNL's assessment of these responses.

The questions in the RAI were separated into five groups, identified in the RAI as sections 2.1-2.5. Within each group, anywhere from 2 to 6 individual questions might have been asked. The licensee responses have also adhered to a similar format. The SNL response assessments will also adhere to this format.

### 2.1 RAI Section 2.1

#### 2.1.1 Analysis of Cables if Barrier is Removed

Synopsis of Concern: One potential means of addressing nominally overloaded cables identified by the licensee was the removal of the fire barrier system. The concern identified in this RAI item was that the licensee analyses should include the assessment of the age degradation for nominally overloaded cables formerly protected by fire barriers.

Synopsis of Response: The licensee has cited that, with one minor exception, no Thermo-Lag fire barriers have yet been removed from the plant, and that Calculation E-218 includes the consideration of all cables enclosed in barriers throughout the plant. The licensee does go on to state that some of the analyzed fire barriers will likely be removed.

Assessment of Response: While this answer was not fully responsive, SNL notes that in response to another related RAI item (see Section 2.4.1 below) the licensee has committed to address the potential age degradation of cables for which the barriers are removed. The updated calculation E-218 identifies numerous cables that are nominally overloaded, and many of the recommended resolutions include the removal of the fire barrier system. No aging impact assessments have been provided in the current submittal.

Findings and Recommendations: This licensee response in combination with the response discussed in Section 2.4.1 below is considered adequate to resolve the identified concern provided that adequate aging analyses are eventually provided. It is recommended that the USNRC follow-up on this RAI item with the licensee to ensure that nominally overloaded cables that are resolved through removal of the fire barrier system are assessed for accelerated aging degradation.

#### 2.1.2 Depth of Fill Calculation

Synopsis of Concern: The wording of the licensee submittal implied that control cables would not be included in the calculation of a cable tray depth of fill. This was identified as inappropriate, and the licensee was asked to include all cables in the depth of fill calculation.

Synopsis of Response: The licensee response indicates that all tray fills are now calculated to include all cables in a tray regardless of function. The licensee also points out that the calculation does contain a potential source of conservatism in that cables that exit the tray at some point along the tray length are assumed to reside in the entire length of the tray. For some cases this may provide a conservative result.

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

Findings and Recommendations: SNL finds that the licensee has adequately addressed the identified concern, and no further actions on this item are recommended.

## 2.2 RAI Section 2.2

### 2.2.1 Cable Diameter Assumptions

Synopsis of Concern: The licensee had cited that cable diameters were based on the manufacturers guaranteed average diameter rather than the minimum diameter. The RAI item asked the licensee to provide additional information to regarding the significance of this assumption and its potential impact on the calculations.

Synopsis of Response: The licensee response states that diameter variations are on the order of 5%. The licensee has also stated that the revised calculation bases the depth of fill calculation on the maximum diameter. This results in the most conservative heat intensity factor, and hence, in the most conservative ampacity limit. An assessment was made to demonstrate that the resulting ampacity impact is on the order of just 2.6%.

Assessment of Response: The licensee response was fully adequate to resolve the identified concern. The revised calculation is based on a more conservative approach, and the licensee has demonstrated that the impact of this concern is quite minor.

Findings and Recommendations: SNL finds that the licensee has adequately addressed the identified concern, and no further actions on this item are recommended.

### 2.2.2 Use of an Assumed Depth of Fill for "K" Trays

Synopsis of Concern: The original licensee submittal had indicated that for "K" trays an assumed depth of fill of 1.5" was used. However, other supporting documents had recommended that a depth of fill of 2.5" be assumed for "K" trays. The licensee was asked to resolve this discrepancy and to ensure that the assumed depth of fill conservatively bounded the actual fills.

Synopsis of Response: The license response cites that the revised calculation now uses the actual depth of fill for each tray analyzed.

Assessment of Response: This response is adequate to resolve the identified concern. SNL did verify that each individual tray is assigned a unique depth of fill, although insufficient information was provided to verify the actual values cited.

Findings and Recommendations: SNL finds that the licensee has adequately addressed the identified concern, and no further actions on this item are recommended.

### 2.2.3 Analysis of 5 and 15 kV Cables

Synopsis of Concern: It was not clear that the licensee had analyzed 5 or 15 kV cables.

Synopsis of Response: The licensee response stated that there are no 15 kV cables in the plant that are fire barrier protected. It also pointed out the nomenclature associated with the 5 kV cables in the original calculation, and cites that 5 kV cables are considered in the revised calculation.

Assessment of Response: The licensee response was fully adequate to resolve the identified concern. SNL has verified that the 5 kV cables are included in the updated E-218 calculation.

Findings and Recommendations: SNL finds that the licensee has adequately addressed the identified concern, and no further actions on this item are recommended.

## 2.3 RAI Section 2.3

### 2.3.1 Discrepancies in Ampacity Chart

Synopsis of Concern: Two possible discrepancies in the licensee chart for cable ampacity were identified.

Synopsis of Response: The licensee acknowledged that the cited discrepancies were, in fact, errors in the chart. The new calculations are based on a somewhat different approach, and these discrepancies will no longer impact the results.

Assessment of Response: The licensee response has resolved the identified concern. SNL has "spot checked" the licensee revised ampacity tables, and the individual cable calculations for consistency and found no discrepancies in the revised calculations.

Findings and Recommendations: SNL finds that the licensee has adequately addressed the identified concern, and no further actions on this item are recommended.

### 2.3.2 NEC Conduit Conductor Grouping Factors

Synopsis of Concern: The licensee application of the NEC grouping factors for multiple conductors in a common conduit was incomplete.

Synopsis of Response: The licensee response indicates that the revised calculation E-218 has properly accounted for the total conductor count in a conduit.

Assessment of Response: The licensee response resolves the identified concern. The updated calculations appear to have been performed correctly using the NEC correction factors in an appropriate manner.

Findings and Recommendations: SNL finds that the licensee has adequately addressed the identified concern, and no further actions on this item are recommended.

### 2.3.3 Applicability of Open Air Ampacity to Trays

Synopsis of Concern: The licensee tables for base line ampacity of "L" and some "K" trays were based on open air ampacity limits. This was cited as requiring explicit justification.

Synopsis of Response: The licensee cites that the subject trays are "600V with maintained spacing". The licensee cites the revised calculations as outlining the method used to correct the open air ampacity loads for tray applications.

Assessment of Response: The licensee response and the updated calculations have resolved the identified concern. In particular, the licensee has, in other sections, explicitly justified its use of the maintained spacing provisions of the ICEA ampacity standards. SNL did verify that the ICEA correction factors have been appropriately applied to these cases.

Findings and Recommendations: SNL finds that the licensee has adequately addressed the identified concern, and no further actions on this item are recommended.

### 2.3.4 NEC Conduit Correction Factors

Synopsis of Concern: The licensee had cited the 1984 version of the NEC handbook as the basis for its conduit conductor count correction factors. This earlier version of the handbook had implicitly assumed a 50% load diversity in these factors. The licensee was asked to either apply the updated 1996 values which do not include diversity credit, or justify use of the older values based on the existing load diversity.

Synopsis of Response: The licensee states that the revised calculation utilizes the updated NEC correction factors.

Assessment of Response: This response is adequate to resolve the concern. SNL did verify that the updated correction factors have been used in the revised calculation.

Findings and Recommendations: SNL finds that the licensee has adequately addressed the identified concern, and no further actions on this item are recommended.

## 2.4 RAI Section 2.4

### 2.4.1 Aging of Nominally Overloaded Cables

Synopsis of Concern: The licensee was asked to provide an assessment of the aging impact for those cables nominally identified as overloaded even if the overload is resolved by barrier removal.

Synopsis of Response: The licensee has cited re-analysis results for the cables originally identified as overloaded. In each case, the modified analysis has determined that the cables are not overloaded, and hence, no aging impact has been experienced. The licensee cites that for future overload cases, final assessments will included aging assessments, although no such assessments are currently provided.

Assessment of Response: The licensee has committed to providing final resolutions for nominally overloaded cables that includes an aging assessment, although no such analyses are currently provided. In general, this is an adequate response, but some follow-up may be appropriate.

Findings and Recommendations: SNL finds that the licensee has committed to adequately addressing the identified concern. However, no final resolution of this concern is currently provided. It is recommended that the USNRC follow-up with the licensee to ensure that this commitment is achieved.

### 2.4.2 Dependence on Overload Ratings

Synopsis of Concern: Certain of the licensee's nominally overloaded cables were deemed to be acceptable on the basis of emergency overload ampacity ratings. This was found to be an inappropriate basis for analysis.

Synopsis of Response: The licensee acknowledges that this approach was not appropriate, and no longer applies this argument to its nominally overloaded cables.

Assessment of Response: This response clearly acknowledges the cited concern and accepts the judgement that this design practice was inappropriate.

Findings and Recommendations: SNL finds that the licensee has adequately addressed the identified concern, and no further actions on this item are recommended.

### 2.4.3 Citation to IEEE 242

Synopsis of Concern: The licensee had cited a specific passage from the IEEE 242 ampacity electrical design standard, and this passage appeared to have no relevance to the subject at hand.

Synopsis of Response: The ultimate licensee response to this item was to remove any reliance on the cited passage from its updated analyses.

Assessment of Response: This response is adequate to resolve the identified concern.

Findings and Recommendations: SNL finds that the licensee has adequately addressed the identified concern, and no further actions on this item are recommended.

### 2.4.4 Use of Equipment Qualification Test Results

Synopsis of Concern: The licensee was requested to provide further clarification as to how a particular EQ test report cited in the study was utilized in the analyses.

Synopsis of Response: The licensee has outlined what values from the report were used and how they were used. The licensee also cites that the updated analyses have found the impacted cables to be acceptable.

Assessment of Response: In general, this response is adequate. However, SNL is unable to confirm the appropriateness of this test report in the specific context of the licensee cables.

Findings and Recommendations: In the specific context of this RAI item, SNL finds that the licensee has adequately addressed the identified concern, and no further actions on this item are recommended. It is however recommended that should the licensee's ultimate resolution of nominally overloaded cables continue to cite this test report, then the test report should be obtained for review.

### 2.4.5 ADF for a 3-Hour Tray Barrier

Synopsis of Concern: The licensee assumption of a 20.5% ADF for a 3-hour cable tray fire barrier system was cited as unrealistic.

Synopsis of Response: The licensee's updated analyses are cited as using a value of 44% for the ADF of a 3-hour cable tray barrier system.

Assessment of Response: In general the licensee has clearly acknowledged that the original ADF estimates are non-conservative in the case of cable trays. While SNL has taken exception to the licensee's method of calculating the updated ADF value (See related discussion in Chapter 3 below) the updated value is clearly more reasonable than the original value.

Findings and Recommendations: SNL finds that the licensee has, in general, adequately addressed the identified concern, and no further actions on this specific item are recommended. However, note that SNL has taken exception to the reliability of the licensee calculations of ADF values for untested configurations (see Chapter 3) and the resolution of those concerns may impact the assumed ADF values cited by the licensee.

## 2.5 RAI Section 2.5

### 2.5.1 Document Precedence

Synopsis of Concern: The licensee was asked to clarify the relative precedence of the various documents submitted.

Synopsis of Response: The licensee response clearly indicates the precedence of documents as they currently exist at the plant.

Assessment of Response: The precedence of documents has been adequately addressed.

Findings and Recommendations: SNL finds that the licensee has adequately addressed the identified concern, and no further actions on this item are recommended.

### 2.5.2 Reference Cited as Basis for ADF Values

Synopsis of Concern: The licensee was requested to provide a specific reference for review that was cited in the submittal as the basis for certain ADF values.

Synopsis of Response: The licensee has provided a draft copy of the cited reference.

Assessment of Response: SNL had reviewed the cited reference as documented in Chapter 3.

Findings and Recommendations: In the specific context of this RAI item, SNL finds that the licensee has adequately addressed the identified concern, and no further actions on this item are recommended. However, SNL has significant concerns regarding the adequacy and technical validity of the licensee calculation provided. These concerns are addressed separately in Chapter 3 of this report.

### 2.5.3 Special Configurations

Synopsis of Concern: The licensee was asked to justify its assumptions regarding non-standard barrier configurations.

Synopsis of Response: The licensee response cited that the calculations to derive the ADF values for the untested configurations were documented in the calculations provided under the previous RAI item (see section 2.5.2). The licensee also states that "EOI is not committed to the recommendations and requirements of IEEE P848 ..."

Assessment of Response: The licensee has provided the calculations to support its ADF assessments for untested configurations. SNL has reviewed the document as discussed in Chapter 3 below. The meaning and implications of the last statement regarding the licensee's lack of commitment to IEEE 848 is entirely unclear.

Findings and Recommendations: Within the specific context of this RAI item, SNL finds that the licensee has adequately addressed the identified concern, and no further actions on this item are recommended. Concerns related to the actual licensee calculations are documented separately in Chapter 3 below.

## 2.6 Summary of Response Assessments

The licensee has adequately responded to all of the specific RAI items. However, in some cases it has been recommended that the USNRC should follow-up with the licensee to ensure that the identified concerns are fully addressed in the context of the updated licensee calculations. These items are:

- The licensee was asked to provide aging impact assessments for nominally overloaded cables even if the fire barriers for those cables were removed to resolve the overload condition (see related RAI items in Sections 2.4.1, 2.4.2 and 2.4.4). No such assessments are provided in the current submittal, although the licensee has committed to providing such analyses as a part of the final resolution of nominally overloaded cables. Note that a number of cables have been identified as nominally overloaded, and the recommended resolution for several includes removal of the fire barrier system. It is recommended that the USNRC should follow-up with the licensee to ensure that life-to-date aging assessments are performed even if the fire barriers are removed.

- The licensee has, as requested, provided the calculation upon which ADF values for untested configurations have been based (see related RAI items discussed in Sections 2.4.5, 2.5.2, and 2.5.3). This calculation was reviewed by SNL as documented in Chapter 3, below. Several points of significant concern have been identified. Hence, as separate items, it has been recommended that the USNRC should follow-up with the licensee to resolve the identified concerns.

# 3.0 A REVIEW OF CALCULATION G13.18.14.0-178

## 3.1 Overview

### 3.1.1 Intended Scope of the Licensee Calculation

The scope of Calculation G13.18.14.0-178 as cited by the licensee is to estimate the ampacity derating impact for certain fire barrier configurations for which no directly applicable test data was found to be available. These special configurations include the following:

- 1-hour and 3-hour standard conduit installations for aluminum (versus steel) conduits
- 3-hour standard installations for cable trays
- multiple raceways enclosed in a common fire barrier system

In addition, the licensee has also evaluated certain standard barrier configurations that have been tested in order to "validate" its analysis methodology.

### 3.1.2 Overview of Modeling Approach

The approach to these assessments is purely analytical in nature. Correlations taken from literature are applied to various aspects of the fire barrier heat transfer system. The intent of each individual calculation is to estimate the cable ampacity limit for a representative generic cable configuration under the prevailing conditions. With the exception of certain of the initial "validation" calculations, all of the calculations are performed to assess clad raceways. The predicted clad raceway ampacity limit is then compared to the corresponding base line ampacity limit derived from standard tables of ampacity, and an ampacity derating factor (ADF) is generated.

The thermal model in general accounts for all of the critical heat transfer phenomena, albeit, SNL will take exception to the manner in which many of these phenomena are treated. The model does credit both convective and radiative heat transfer both within the fire barrier system and from the external surface of the fire barrier to the ambient environment. The model also includes treatment of conduction both within the cable raceway (tray and/or conduit) and through the fire barrier system. As a general observation, SNL considers the licensee thermal model to be extremely poor. SNL's specific concerns will be discussed in Section 3.2 below.

### 3.1.3 Critical Modeling Assumptions

In implementing the thermal model the licensee has made a number of assumptions, some of which are conservative in nature and other that are not. The most critical assumptions that are considered to contribute to conservatism in the analysis include the following:

- The thickness of the fire barrier system is assumed to be the upper limit of the barrier thickness tolerance range specified by the manufacturer. This is considered an appropriate and modestly conservative approach.

- For conduits protected by pre-formed conduit sections, it is assumed that a 1/8" gap will exist between the outside surface of the conduit and the inside surface of the fire barrier. Given that the licensee does not have a site specific procedure requiring a full pre-buttering of the inner surface of the fire barrier during installation, some gap would exist. The licensee assumption of a 1/8" gap would conservatively bound this effect.

- No heat transfer is assumed to occur from the sides of a cable tray, only from the top and bottom surfaces of the cable mass. This assumption is common in such calculations. Given that the licensee is, in general, only performing a clad case calculation, this would result in a slightly conservative result.

- Laminar convection coefficients are assumed. This is generally considered an appropriate basis for such analyses but would be conservative for actual installations in areas with significant normal air flow currents present.

- For barrier systems in which the concrete walls/ceilings of the plant structure form one or more sides of the fire barrier enclosure, no credit is taken for heat transfer into the concrete. In general the concrete walls would absorb some heat from the system. However, in the steady state, this contribution might be minimal because concrete is not an especially efficient conductor of heat. If properly implemented, this assumption would result in a modest level of conservatism. It should also be noted that a proper implementation of a thermal model to credit heat transfer to and through the concrete walls/ceilings would be very complex and very difficult to achieve.

In addition to these assumptions, a number of assumptions are made that will have little on no impact on the final results. These include:

- All analyses are performed assuming a cable load comprised of a generic cable (a 3/C, 8AWG rubber insulated cable). The number of cables assumed to be present is adjusted to match the in-plant installations in terms of the percentage fill of the raceway.

- All analyses are performed assuming a 90°C conductor hot-spot temperature and a 40°C ambient. If the actual installations involve a different temperature condition, then the base line ampacity is adjusted using standard methods before the derating factor is applied.

- A minimum depth of fill of 1" is assumed for all cable trays in the ADF estimate calculations.

## 3.2 Points of Concern in the Licensee Calculation

### 3.2.1 Treatment of Internal Convection Behavior for Cable Trays

In the case of a cable tray, it is important and appropriate to consider that heat transfer does occur by convection and/or conduction through the air gap between the surfaces of the cable mass and the inside surface of the fire barrier system. In the licensee model, convective heat transfer is assumed to occur from both the upper and lower surfaces of the cable mass. The same correlation is used for both surfaces. There are two fundamental problems with this treatment.

First, it must be recognized that the heat transfer rates for the top and bottom surfaces of the cable mass will not be the same. In particular, the lower surface represents a "downward facing heated plate" and hence convection will not be enhanced by buoyancy driven air currents in the same manner as will the upper surface. The licensee cites that its assumed convection coefficients were "chosen to produce a low (i.e. conservative) heat transfer coefficient." SNL finds that the selected parameters do not correspond to a lower bound estimate (see further discussion in Section 3.2.3 below).

The second, and more serious, problem with the licensee treatment is that the licensee has inappropriately applied convection coefficients for heat transfer from a surface to an open (external) environment to the behaviors associated with the highly confined interior of the fire barrier system. That is, the correlations cited by the licensee apply only to a surface which is in an open and unrestricted ambient environment. When one considers the convective behavior that takes place in a confined space, such as the interior of a fire barrier system, very different convective behaviors are experienced. The use of the external surface heat transfer coefficients for this situation will significantly overestimate the actual rates of heat transfer that should be anticipated. In general, heat transfer in confined spaces is treated using the concept of an equivalent thermal conductivity or thermal conductivity enhancement term.

The licensee treatment in this regard is considered inappropriate for the general applications covered by this calculation. It is especially inappropriate in the context of the 3hr "standard" single tray configuration, and the tray stack configurations involving closer clearances between the tray and the barrier system. For these systems, the licensee treatment will result in non-conservative estimates of the ADF.

For the very large enclosure cited by the licensee as configuration "U1" the licensee may be able to argue that the size of the enclosure makes the open air correlations applicable. This, however, should be justified explicitly through a discussion of cable tray to cable tray clearances, cable tray to barrier clearances, and the overall physical dimensions of the enclosure. Even in the event that the correlations might be justified for this one analysis, the licensee should still address the concern related to surface orientation in these analyses.

### 3.2.2 Treatment of Conduit to Barrier Convection

The licensee treatment of heat transfer through the gap between the outer surface of the conduit and the inner surface of the fire barrier system is inappropriate for many of the configurations considered. In particular, as discussed in Section 3.2.1, the licensee has applied open air convection correlations to the confined spaces associated with the fire barrier system.

This treatment is especially inappropriate to the licensee analysis of single aluminum conduits. For the single conduit, the licensee analysis should be based on the confined space treatment of convection, or limited to conduction heat transfer. SNL also notes that the likely impact of this concern may, in fact, be small for these cases. This is because the licensee states that these situations were dominantly modeled as conduction based. However, the licensee treatment is in error, and should be corrected.

For those cases involving conduits enclosed in the larger, multiple raceway fire barrier enclosures, the treatment as an open convective environment might be justified. However, it is recommended that the licensee be asked to provide specific justification for each analysis case. In particular, an appropriate justification should include the consideration of clearances between the conduit of interest and other structures and raceways. For example, if a conduit is mounted directly to, or in close proximity to, a wall or ceiling, then a reduction in the convective heat transfer rates is certainly expected.

### 3.2.3 Treatment of External Convection Behavior

The treatment of external convective heat transfer behavior provided by the licensee is considered unnecessarily crude, and hence, inappropriate. All convective surfaces, regardless of geometry (flat plates versus cylindrical sections) or orientation (upward facing, vertical, or downward facing) are treated using a single convective heat transfer correlation. Equally simple but specialized heat transfer correlations are available to treat each of the configurations present in the licensee model, and hence, should be utilized by the licensee to enhance the robustness and reliability of the analysis results.

To some extent the licensee appears to recognize this deficiency. In fact the licensee cites that the parameters chosen for implementation of the convection model were "chosen to produce a low (i.e. conservative) heat transfer coefficient." SNL finds that the selected parameters do not correspond to a lower bound estimate. The lower bound convection value in this case would be the value associated with a downward-facing heated plate or an upward-facing cooled plate (this would correspond to the bottom of a base line tray or the surfaces of the lower fire barrier panel). The value cited by the licensee does represent a rough average of the upward- and downward-facing heated plate values, but this is not the basis cited by the licensee for its selection.

Implementation of separate correlations to address each of the important heat transfer surfaces, or even the use of a surface area weighted average coefficient would require some additional "bookkeeping" effort, but is easily accomplished. The impact of such a change on the licensee calculations would likely be modest given that SNL found the value used by the licensee in its calculations to represent an intermediate value. The primary impact of this change would be to increase the robustness of the calculations.

### 3.2.4 Treatment of Internal Conduit Heat Transfer

One factor that must be considered in a thermal analysis of a cable/conduit system is the internal heat transfer between the conduit and the cables, and within the cable bundle itself. The licensee thermal model has provided a very poor treatment of this part of the conduit thermal behavior.

The licensee has treated the conduit/cable system as a homogeneous cylindrical section with a uniform internal heat generation rate. The heat generation rate is based on the actual heating rate of the cables in the tray, but this heat is distributed evenly over the entire volume enclosed by the outside diameter of the conduit. This approach is similar to the approach taken by Stolpe in the modeling of the cable mass in a cable tray, but is not appropriate to the analysis of a cable/conduit system.

In reality, the heat generation is confined to the cable bundle itself. The licensee treatment fails to adequately treat the additional thermal resistance that results from the imperfect contact between the conduit and the cables. In general practice, the Buller/Neher[1] or Neher/McGrath[2] approach to internal heat transfer is taken. Under this approach, the thermal resistance between the cables and the conduit is treated explicitly.

The licensee treatment in this regard is considered inappropriate and would likely result in non-conservative estimates of the cable ampacity limits. In effect, because the licensee treatment is spreading the heat generation over a larger volume of the system than reality suggests, the predicted temperature rise through the interior of the system has quite likely been under-estimated. This would tend to produce a higher ampacity limit for a given cable operating temperature than would, in reality, be expected.

### 3.2.5 Radiation View Factors

It is quite apparent that the licensee has not calculated radiation view factors correctly. In most typical analyses performed to assess the ADF for a single tray or single conduit barrier system, radiation view factors play only a very minor role in the analysis. However, radiation view factors will play a critical role in the licensee calculations, especially for those cases involving multiple raceways in a common enclosure.

In general terms, a radiation view factor is a measure of the fraction of the radiating surfaces's "view" that is taken up by the receiving surface of interest. For example, if a the radiating surface is completely surrounded by the receiving surface, then the view factor is 1.0. This simply reflects that the only other surface that is "seen" by the radiating surface is, in fact, the receiving surface of interest. Conversely, if the direct line of sight view between the radiating surface and the receiving surface of interest is blocked by intervening bodies, then the view factor would be 0.0 indicating no direct radiative exchange is possible.

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[1]F. H. Buller and J. H. Neher, "The Thermal Resistance Between Cables and a Surrounding Pipe or Duct Wall," AIEE Transactions V69, 1950 pgs 342-349.

[2]J. H. Neher, and M. H. McGrath, "The Calculation of the Temperature Rise and Load Capacity of Cable Systems," AIEE Transactions, Oct. 1957, pgs 752-772.

For calculations involving multiple raceways in a single enclosure, it is necessary to calculate the radiative view factor from each of the heat producing items in the enclosure to the inside surface of the fire barrier system. This calculation must include the consideration of all geometric elements that "block" this "view". The surfaces considered include the conduit surfaces, and both the top and bottom surfaces of each cable tray inside the enclosure.

The licensee treatment in this regard is not correct, has generally overestimated the view factor values, and hence, has resulted in optimistic predictions of the clad case ampacity limits. This is a non-conservative aspect of the licensee analysis.

For example consider the conduit view factor cited on page 13 of 45 of the licensee calculation. The licensee calculates the radiative view factor from one conduit to its neighboring conduit as 0.15 based on handbook configuration factors and the separation between two conduits. The view factor for the conduit to the barrier is then taken as (V.F.=1.0-0.15=0.85). This apparently reflects the inherent assumption that the conduit will "see" only the other neighboring conduit or the fire barrier itself. This assumption does not hold for the geometries analyzed, and yet this value is applied directly.

To continue this example, consider the analysis of the barrier system cited as configuration "U1" on page 34 of 45 in the calculation. For Conduit 1CK600NA1 a shape factor of 0.85 is cited. However, it is clear from the drawing provided on page 40 that the shape factor between this conduit and the fire barrier will be significantly lower than 0.85 because of the intervention of the collocated cable trays, and the fact that two of the enclosure walls are made up of concrete walls (recall that the licensee has stated that they do not credit any heat transfer to the concrete surfaces, and hence, these surfaces must be excluded from the view factor calculation). While SNL has not performed an actual calculation, based on the dimensions provided in the drawing, and on the location of the conduit in the extreme upper left corner of the enclosure, that the view factor from this conduit to the fire barrier would likely be on the order of 0.1 or less.

Similar examples can be drawn for the cable tray view factors as well. Again the licensee cites on page 13 that the view factor "from the upper surface of the tray to the top of the enclosure" would be 0.5 based on an "area ratio." Presumably the licensee is refering to the fact that the upper surface represents 50% of the overall surface of the tray. However, for any tray that is located below another, the view factor from the upper surface to the fire barrier surface will be significantly reduced by the presence of the upper blocking tray. Again considering the licensee analysis of the "U1" configuration, the two trays considered are assigned veiw factors of 0.8 for the upper tray and 0.6 for the second tier tray. These values have no apparent basis, and appear to significantly overstate the actual view factors given the geometry involved.

The calculation of radiation view factors is a very complex process in general. The licensee treatment in this regard is clearly in error, and hence, is inappropriate. The licensee appears to have significantly overstated actual radiation view factors, and hence, has likely overestimated the heat rejection capacity of its fire barrier systems. This would especially impact any calculation involving more than one cable tray and/or conduit in a common enclosure. By overstating the heat rejection capacity of the system, the licensee would also overstate the clad case ampacity limits, and hence, understate the ampacity derating impact. Hence, this is a non-conservative error in the analysis.

### 3.2.6 Derating Factors Based on Conduit Conductor Count

For cables in conduits it is normally required that base line ampacity limits be reduced in any case in which a conduit houses more than three current-carrying conductors. The National Electric Code (NEC) provides specific uerating factors. One concern that was raised in the initial SNL review of 1996 was that the licensee was not properly applying these factors (see discussion of related RAI Item in Section 2.3.2 above). This, again, appears to be a source of error in this new licensee calculation.

In particular, the response to the USNRC RAI stated that the licensee would apply the NEC 1996 derating factors for its conduits consistent with the SNL/USNRC recommendation. However, it appears that either the earlier (and less conservative) NEC values have been applied in this calculation, or a mistake in their application has been made.

Consider, for example, the conduit 1CK600NA1 as presented on page 34 of the licensee calculation. The cable considered is a 3-conductor (3/C) 8AWG cable with a base line conduit ampacity limit of 52A. This particular conduit is assumed to contain 6, 3-conductor cables for a total conductor count of 18. Given this conductor count, the NEC 1996 derating factor of 0.5 should apply (see page 70-196 of the NEC 1996 handbook). The modified base line current would then be estimated as 52*0.5=26A. Instead, the licensee has applied a correction factor of 0.7, apparently consistent with pre-1990 versions of the NEC to derive a base line ampacity limit of 36.4A. In this case the licensee's apparent error actually has a net-conservative effect. That is, use of the corrected lower base line ampacity limit would reduce the estimated derating impact.

This inconsistency is noted simply in the interest of the completeness of this report. No specific actions to resolve this inconsistency are currently recommended. This is because the resolution of the issue discussed in Section 3.2.7 immediately below should result in the licensee removing from the analysis its dependence on tabulated base line ampacity limits, and hence, will render this concern moot.

### 3.2.7 Inconsistent Basis for Clad and Base Line Ampacity

As a general observation, SNL takes exception to the licensee's analysis approach in that the licensee is, in effect, comparing "apples to oranges." That is the clad case ampacity limits are estimated based on the results of the licensee thermal model. However, the base line ampacity limits are taken from tabulated ampacity values, and these tabulated values were derived on the basis of entirely different thermal models.

In the assessment of ampacity derating it is critical that the ADF values be based on the comparison of clad and base line case ampacity limits that have been derived on a consistent basis. If one value is determined by experiment, then the other value should also be determined from an experiment. Further, the two experiments must be performed on a consistent basis (e.g., using the same test specimen, experimental enclosure, and test procedures). In the case of an analysis-based approach, it is critical that both the base line and clad ampacity limits be determined using a self-consistent thermal model.

To illustrate one significant difference consider that the ICEA P54-440 ampacity tables for open top cable trays were based on the modeling work of Stolpe. However, it is important to realize that Stolpe's thermal model considered only the heat loss from the top surface of the cable mass. He neglected both heat transfer from the sides and from the bottom of the cable mass. Thus, in order to form a thermal model consistent with Stolpe, and hence with the ICEA tables, it would be necessary to similarly neglect any heat transfer from the bottom of the cable mass, and instead, consider only heat transfer from the upper surface of the cable mass. It would also be necessary to utilize the same values for all of the important parameters, and the same correlations for the important heat transfer effects. This is nearly impossible given that all of these details are not provided in Stolpe's paper, nor in the ICEA standard.

As a second example, the IPCEA P46-426 cable ampacity tables used by the licensee to assess base line ampacity limits for cables in conduits were based on the modeling work of Neher/McGrath. The licensee thermal model is not at all consistent with the Neher/McGrath thermal model. As has been discussed in Section 3.2.3 above, the methods used for modeling heat transfer within the cable bundle and between the cable bundle and the conduit are significantly different. The licensee has also taken a different approach to the modeling of convective and radiative losses than that documented by Neher/McGrath. Hence, a comparison of the licensee modeling results to the IPCEA tables is not appropriate.

It is also evident that the licensee approach can result in a very arbitrary result, especially in the case of the conduit analyses. To illustrate this point, SNL will return once again to the analysis of Conduit 1CK600NA1 on page 34 of the licensee calculation. The correct base line ampacity limit that should have been cited by the licensee for this case is 26A[3] (the IPCEA value corrected using the 1996 NEC correction factors for conductor count). However, this same base line current limit would apply for any number of conductors ranging from 10 to 20, and for any size conduit. This renders the licensee's base line ampacity assessment totally insensitive to certain critical physical and thermal parameters. In contrast, changes in these same parameters will significantly impact the licensee's clad case analysis.

For example, for a given ampacity, reducing the conductor count to the minimum value in this range, 10, would cut the heat load by 40% as compared to the licensee assumed value for a conductor count of 18. This would have a profound impact on the estimated temperature rise values, and hence, on the final estimates of the clad case ampacity limit. Given that a wide range of clad ampacity values could be derived while the nominal base line ampacity remains fixed, a wide range of "equally valid" (or equally suspect) ampacity derating results could be derived for this one particular case. This is clearly not a desirable result. While some minor variation should be expected, if properly executed an ampacity derating model should yield nominally similar ADF values for these cases regardless of the assumed conductor count. As a final note to this discussion, the licensee has not demonstrated that the one case chosen rather arbitrarily for analysis is representative of the most conservative configuration. In fact, it is likely that the use of the

[3]As was noted in Section 3.2.7 the licensee has incorrectly calculated the base line ampacity for this case by using the earlier pre-1990 conduit ampacity correction factors. The licensee RAI response cited that it would base all of its calculation on the updated NEC 1996 correction factors, and the corrected ampacity limit is based on application of the updated 1996 correction factors.

maximum conductor count in this range, i.e. 20, would render a more conservative result that the licensee analysis that assumed 18 conductors.

The only base line validation case cited in the licensee study was for a single 4"x24" cable tray (see Table 4.3 on page 18 of the calculation). In this case the licensee derived a base line ampacity limit of 31.6A as compared to a tabulated ampacity limit of 34A. Under most circumstances, this might be considered indicative of an overall conservative result. That is basing the ADF on the higher tabulated ampacity value would be more conservative. However, given the other concerns cited here, this result is considered fortuitous at best. The licensee analysis for this base line case must be considered suspect. No equivalent base line calculations for the conduits are presented.

It is recommended that the licensee be asked to base its ampacity derating estimates on the direct comparison of base line case and clad case ampacity limits in which both values are derived using essentially the same thermal model. That is, the base line case analyses should utilize the same basic physical configuration as the clad case analysis, and it should be assumed that each item of interest is in an open environment free of interference from other elements (this will render the base line analyses on a consistent basis with both the thermal model and the conditions assumed in the ampacity tables to which the ADF values will eventually be applied). The clad and base line thermal models must also be self-consistent. Self-consistent in this context means that each case should use the same basic modeling assumptions, parameter values, and correlations.

### 3.2.8 Inappropriate Treatment of Multiple Heat Sources

For cases involving multiple raceways (trays and conduits) in a single enclosure the licensee treats each of the raceway heat sources independently. That is, the analysis of each item is carried out independent of the analysis of the other collocated items. This is discussed very briefly at the top of page 12 of the calculation. The licensee concludes that:

> "The overall effect (of this treatment), however, is not expected to be significant since: (1) heat transfer mechanism is predominantly radiative rather than convective. The assumption described above applies only to the convective portion of the heat transfer; (2) Thermal resistance within the enclosure air space is only a small fraction of the overall thermal resistance of the system."

SNL finds this argument to be without technical merit. While the primary impact is on the convective terms, these assumptions will also impact the estimated temperature of the inside surface of the fire barrier system. This will in turn impact the accuracy of the radiative heat exchange terms as well. It is also important to note that the relative importance of radiation in the heat transfer process has, in fact, been overstated by the licensees analysis due to the errors made in the calculation of radiation view factors (see Section 3.2.5).

To explain further, the convection terms as treated by the licensee treat the heat transfer from each item in the enclosure, into the air, and then to the inner surface of the fire barrier independently. This treatment, in effect, assumes that each item has a totally independent convective path for delivery of heat to the fire barrier surface. In effect the air is allowed an independent opportunity to transfer the heat it absorbs from each individual heat source (raceway) to the fire barrier surfaces. This is simply not the case. While each of the items in the enclosure heats the air space somewhat independently (except in that all should be assumed to interact at the same air temperature), the air space then has only one opportunity (or path) to transfer that total heat load to the fire barrier inner surface. A proper treatment of the air/barrier interface must consider the total convective heat load as a whole. This could more than double the heat load between the air and the barriers inner surface as compared to the licensee's current treatment. Because the convection coefficient remains relatively fixed, a much larger temperature rise between the inner surface of the barrier and the enclosed air would be predicted than that estimated by the licensee.

Implementation of a proper treatment would significantly increase the temperature rises associated with the convective transport terms. This would also impact the radiative heat exchange terms as well (by increasing the difference in surface temperatures). However, because the licensee has made other errors in the radiative exchange terms (see Section 3.2.5), the net effect of correcting both errors would likely be a reduction in both the convective and radiative exchange rates. Hence, SNL must conclude that the licensee treatment is non-conservative.

SNL finds that in the analysis of multiple raceways in a single enclosure, the licensee practice of treating convective heat transfer within the fire barrier enclosure independently for each raceway is unacceptable. It is recommended that the licensee be asked to correct its thermal model to consider simultaneous convective heat transport. That is, it is recommended that the licensee model should be modified so as to ensure (1) that a single internal enclosure air temperature is predicted, and (2) that the temperature rise between the internal air and the inner surface of the fire barrier system is based on convective transfer of the total heat load for all enclosed raceways simultaneously.

### 3.2.9 Analysis of Aluminum Conduits

The licensee analysis of the ampacity derating factors for aluminum conduits appears to have reached a somewhat fallacious result. SNL acknowledges at the outset of this discussion that the licensee's treatment has apparently resulted in a conservative estimate of the ampacity derating factor. However, as discussed below, SNL finds that the licensee's treatment is unnecessary, and hence, complicates the licensee's overall treatment without good reason.

The general consensus of the IEEE committee on ampacity testing is that a test performed using steel conduits should conservatively bound the ampacity derating impact for aluminum conduits. Hence, only the testing of steel conduits is specified in the IEEE 848 standard. SNL agrees with this assessment. The primary difference between steel and aluminum is that aluminum will have a lower surface emissivity than will steel. The reduced emissivity will cause a significant reduction in the rate of radiative heat transfer from the bare conduit, and hence, a reduction in the measured base line ampacity values. However, for the clad case only a minor impact on the measured ampacity limits would be expected because radiative heat transfer from the conduit surface is far less significant for the clad case. The net result should be that a test involving an aluminum conduit would yield a less severe ampacity derating factor as compared to an equivalent steel conduit test. In applying industry data, the licensee must, of course, consider the tested barrier configurations and show that they are applicable to the RBS barriers. For any cases where a match can be demonstrated, a significant benefit should result.

The licensee analysis appears to have reached rather conservative estimates of the derating impact (21% for both 1-hour and 3-hour barriers) as compared to the values one should anticipate. For example the most conservative results currently available are those for Texas Utilities Comanche Peak. These tests had certain problems, and hence the final derating estimates accepted by the USNRC are considered to represent the most conservative possible interpretation of the test results and these results indicated conduit ADF values of 21.5-25%. However, more recent tests performed by TVA Watts Bar and by FPL Crystal River have identified more reliable ADF values typically in the range of 10% or less.

The licensee results for the aluminum conduits are considered unreliable because the identified modeling problems discussed above might significantly impact the licensees analysis results. This especially includes problems in the treatment of internal conduit heat transfer effects (see related discussion in Section 3.2.4 above) and the fact that the licensee has not actually analyzed the base line case, but rather, has compared the clad case analysis to the ampacity tables (see related discussion in Section 3.2.7 above).

SNL recommends that the USNRC ask the licensee to abandon the calculations for single aluminum conduits, and that instead the available test data for steel conduits be applied as conservative estimates of the ampacity derating impact for any cases in which an appropriate industry test result (i.e., for an equivalent fire barrier system) can be identified. While the net result may be somewhat less severe derating factors for some barrier installations, this would not only simplify the licensee submittal, but would also remove one source of uncertainty in the overall licensee ampacity assessments. This change in approach would also result in the licensee assessments being more consistent with general industry practices in this regard (see, for example, the treatments provided for Crystal River). Hence, SNL recommends that abandoning this particular set of calculations in favor of available test results would better serve the interests of both the licensee and the USNRC.

## 3.3 Summary of Review Findings and Recommendations

Section 3.2 above has discussed numerous points of concern regarding the current implementation of the licensee thermal model. These points of concern and the relevant recommendations are summarized as follows:

- SNL finds that the licensee has inappropriately applied convection coefficients for surface heat transfer in an unrestricted open (external) environment to the highly confined interior of the fire barrier systems analyzed. This observation applies to both the conduit and cable tray analyses. It is recommended that the licensee be asked to (1) modify its analysis and use close-cell convection correlations for the internal convection correlations, and (2) ensure that the modifications include proper treatment of surface orientation. SNL notes that the licensee may be able to justify the use of open air correlations for a very limited number of the larger, multiple raceway enclosures; however, it is recommended that the licensee be asked to provide an explicit justification for any such cases that includes a discussion of item-to-item, item-to-barrier surface, and item-to-wall/ceiling clearances. The current licensee treatment is considered to represent a significant potential non-conservatism in the analysis, especially as it will impact the single cable tray analyses.

- SNL finds that the licensee's treatment of external convection for cable tray systems is unnecessarily crude and does not adequately treat the differences associated with surface orientation. It is recommended that the licensee be asked to modify its thermal model so that more realistic external convective heat transfer coefficients are derived. Use of a composite average value and a single surface temperature would be considered acceptable, provided the composite coefficient is appropriately assessed. This item is expected to have only a modest impact on the licensee analyses.

- SNL finds that the licensee treatment of internal heat transfer behavior within a conduit has not been adequately justified, appears to be inappropriate, and is likely non-conservative. It is recommended that the licensee be asked to modify its analysis methodology to conform to accepted practices for the analysis of cable-to-conduit heat transfer. Specifically, application of the Neher/McGrath (1957) approach is recommended. This item is considered to represent a significant potential source of non-conservatism in the licensee analysis of conduits.

- SNL finds that the licensee has not calculated radiation view factors correctly, in particular, for those analyses involving multiple raceways in a common enclosure. It is recommended that the licensee be asked to correct its analysis in this regard. This item is considered a significant potential source of non-conservatism in the licensee analysis of multiple raceway enclosures.

- SNL finds that the licensee comparison of clad case ampacity limit estimates derived from its own thermal model to tabulated base line ampacity limits is inappropriate. The licensee has failed to demonstrate that its thermal model is consistent with the thermal models used to develop the standard tables, and consistency between the clad case and base line case analyses is critical to the reliability and robustness of the calculations. It is recommended that the licensee be asked to explicitly determine base line ampacity limits using a thermal model consistent with that applied to the clad case analyses. The impact of this change on the licensee analyses is difficult to assess, especially given the other errors noted in this review. For some cases a less conservative ADF result may be obtained, while for others a more conservative result may be obtained.

- SNL finds that the ampacity correction factors associated with the number of current carrying conductors in a conduit have either not been properly calculated or are still based on the older pre-1990 NEC correction factors. This item was also a concern identified in SNL's earlier review, and the licensee response to RAI Item 2.3.4 cited that the newer NEC correction factors would be used in all calculations. It is recommended that this item be brought to the attention of the licensee. However, provided that the other recommendations made by SNL are addressed by the licensee, this issue should be rendered moot in the context of this calculation.

- SNL finds that for cases involving multiple raceways (trays and/or conduits) in a single enclosure the licensee's independent treatment of convective heat transfer between each of the raceways and the inner surface of the fire barrier system is inappropriate. It is recommended that the licensee be asked to modify the thermal model to account for the simultaneous transfer of the total convective heat load from all sources. The licensee treatment is considered to represent a significant potential source of non-conservatism in the multiple raceway barrier analyses.

Given these specific observations it is SNL's overall finding that this calculation as it currently stands is of very poor quality, and hence, the results are considered highly suspect. It is recommended that the results of this calculation not be credited by the USNRC until the numerous errors identified by SNL are resolved.

As a final point, SNL also finds that the licensee calculations for single aluminum conduits may be unnecessary. The licensee could instead apply test data available from industry for steel conduits as conservative estimates of the ADF for an aluminum conduit (provided, of course, that the fire barrier configurations are roughly equivalent). While this may actually result in less conservative estimates of the derating impact as compared to the current licensee estimates, this would remove one significant source of uncertainty in the licensee assessments, and would simplify both this calculation and the overall licensee submittal. Hence, it is recommended that this approach is in the interest of both the licensee and the USNRC. SNL recommends that the USNRC ask the licensee to abandon its calculations for single aluminum conduits, and to instead rely on industry data for steel conduits in any cases in which an appropriate industry test result can be identified.

## 4.0 REVIEW OF CALCULATION E-218 REVISION 1

### 4.1 Overview

In 1996, SNL reviewed Revision 0 of the calculation E-218. A number of points of concern were identified regarding this calculation as identified in the USNRC RAI of 10/16/96. The current revision of the calculation is apparently intended, at least in part, to address these concerns. This section provides a review of the updated E-218 Rev. 1 calculations.

#### 4.1.1 Intended Scope of the Licensee Calculation

This calculation presents the actual licensee application of fire barrier ampacity derating factors to in-plant cables. It is stated that "all cables, Class 1E and non-1E, that are contained within a T-L 330-1 wrapped raceway are included in the scope of the PDMS ampacity calculation." It is further stated that "all wrapped raceway configurations are included in the scope of the ampacity calculation...." Hence, the scope of this calculations is intended to cover every cable at the plant that has been protected by any Thermo-Lag fire barrier system.

#### 4.1.2 Overall Approach

Revision 1 of Calculation E-218, while significantly improved, follows the same fundamental approach as compared to that of the Revision 0 version reviewed by SNL in 1996. In summary, the licensee approach is to first establish a base line ampacity limit for a given cable in a given raceway. These base line ampacity values are either taken either from the ampacity tables (for conduits and as a limiting case for cable trays) or are derived using the heat intensity approach for cable trays as defined by Stolpe.[4] In this process the licensee appears to have appropriately considered the most limiting case in its base line ampacity assessment. Of particular importance is the fact that the licensee has included consideration of the fact that the ICEA standard places an upper ampacity limit of 80% of the open air ampacity when a cable is installed in a general cable tray without maintained spacing, a concern raised in the earlier SNL review.

The base line value is then derated for various factors including primarily:

- cable grouping factors for conduits and maintained spacing trays,
- inductive heating effects for unbalanced loads, and
- the fire barrier system ADF (these values are taken from other sources including industry test data and Calculation G13.18.14.0-178).

The derated ampacity limit is then compared to the nominal ampacity load for the cable. This nominal load has included a "load factor" adjustment, and hence, is a conservative value that will account for some significant level of under-voltage operation (up to 25% in many cases). Provided that the nominal load is less than the derated ampacity limit, the cable is judged to be adequate.

[4] Stolpe, J., "Ampacities for Cables in Randomly Filled Trays," IEEE, 1970.

As was cited by SNL in its previous reviews this is, in principal, an acceptable approach to the analysis of individual cable ampacity loads. Appropriate consideration is given to the critical factors that impact cable ampacity, appropriate base line ampacity limits have been established, and conservative methods have been applied in the assessment of in-plant cable ampacity loads. Hence, the only points of concern that remain in the specific context of this calculation are of a relatively minor nature, and typically involve questions of follow-through and arguments related to the resolution of nominally overloaded cables.

As will be discussed further below, the most significant possible impact for this calculation may result from the correction of the technical problems in the licensee thermal model used to estimate ADF values for the untested configurations (see Chapter 3). Certain of the cases examined in E-218 are dependent on these derived ADF values, and hence, changes in the ADF would impact this calculation, and may impact the conclusions of acceptability for certain cases.

### 4.1.3 Resolution of Nominally Overloaded Cables

For cables nominally identified as overloaded "recommendations" for resolution have been outlined, but it is unclear to what extent these recommendations have been implemented. Several paths to resolution are considered by the licensee:

- Removal or replacement of the fire barrier: This is an obvious path to resolution provided that other regulatory requirements can be met in the absence of the fire barrier system. However, the life to date operation of nominally overloaded cables for the time period in which the barriers have been installed may have accelerated the cable aging process, and hence, may have compromised the "life expectancy" of the cable. This observation is also consistent with the RAI items discussed in Section 2.4.1, 2.4.2 and 2.4.4. It is recommended that the USNRC ask the licensee to provide some assessment remaining cable life expectancy for cables that have operated under nominally overloaded conditions for extended periods.

- Reduction of the assumed service load factor: This is generally considered an acceptable practice, but does reduce the conservatism of the analysis results. See related discussion in Section 4.1.4 immediately below.

- Recalculate conduit conductor count: For some cables in conduits, the number of current carrying conductors is reduced by eliminating MOV power cables and certain control cables. These are cited as intermittent loads, but in the base analyses they are treated as continuous loads. This reduces the multiple conductor correction factor associated with cables in conduits, and hence, increases the ampacity limit for the continuous load cables. This is considered acceptable practice and, in fact, is consistent with general industry practice in which MOV and control cables are considered to carry zero load for the purposes of ampacity derating assessments.

- Citation to NEC overcurrent protection provisions: For several "C" cables, the licensee has cited Articles 240-3(b) and 240-6 as the basis for the acceptability of cable ampacity loads. These citations are considered inappropriate to this assessment. The citations refer to sections dealing with overcurrent protection for smaller cables. It is recommended that the USNRC not accept these citations as the basis for resolving overloaded cable conditions. (See further discussion of this topic in Section 4.2.4 below.)

It is clear from the submittal that the licensee has not yet implemented these recommendations. SNL recommends that the USNRC follow up with the licensee to ensure that these recommendations are ultimately acted upon.

#### 4.1.4 Conservatism

There are certain points of conservatism in the licensee analysis approach. The most significant of these is considered to be the use of the AC load factor in the calculation of all nominal ampacity loads for installed cables. This factor is typically used to account for transient start-up surges, motor overloads, and under-voltage operating conditions. The licensee has typically applied a value of 1.25 to most of its loads, although the actual value varies (some loads have been assigned a load factor of 1.0, although these are all cases involving very low ampacity limits, typically less than 5A). This should conservatively bound any under-voltage operating conditions in particular.

However, it should also be noted that the licensee has actually relaxed this assumption in its final resolution of several nominally overloaded cables. That is, in some cases, a cable is ultimately found to be acceptable by reducing the load factor from 1.25 to as low as 1.10. The lower value is cited as allowing for operation at a nominal 10% under-voltage condition. In general, SNL finds this to be acceptable because it is not expected that equipment would be subjected to under-voltage operation for any significant fraction of its anticipated life. The licensee does retain a modest level of conservatism even using a 1.10 load factor for these cases. Typical practice in industry does not include the consideration of under-voltage conditions in an ampacity assessment.

A second source of conservatism, at least in comparison to typical plant practices, is that the licensee has explicitly included a correction for inductive heating associated with un-balanced current loads. In the experience of this reviewer, this is a unique treatment that will result in more conservative ampacity limits for those cases impacted by these assumptions.

### 4.2 Technical Concerns

#### 4.2.1 The Licensee Linear Heat Intensity Model

The following discussion is presented in the interest of completeness of the review. Ultimately it will be demonstrated that this concern is of little importance in the context of this licensee submittal. This issue is discussed here (1) for the record, and (2) because if the same model is used at another plant where cable tray fills are higher, then a significant error could result.

As a part of its thermal model, the licensee has developed a linear model (on a log-log scale) of the allowable cable mass heat intensity versus the percentage fill for a 3" cable tray. This model was developed on the basis of Stolpe's (1970) work. While in principal this approach is acceptable, the licensee model does have the potential to introduce significant error for cases involving cable tray percentage fills in excess of 40%.

In developing the fitting model the licensee has simply read two arbitrary values off of the plot presented in Stolpe's paper. These two points are then used to estimate the coefficients of the linear model. In principal, this model should not be applied to any value outside of the range of the two points chosen as the basis for the curve, namely, 10-40% fill. This is because the curve is not really linear, and in fact, "falls-off" at both the upper and lower ends. Hence, extrapolation of the model to fill values outside the range of these two end points could significantly overstate the heat intensity limits. Fortunately, the licensee has cited fill values for cable trays of no more than 58% and hence, the extent of the licensee's "worst case" extrapolation is not overly severe.

To illustrate the possible extent of this inaccuracy on the licensee calculations for the worst case cited, consider a 58% fill.[3] Using the licensee's linear model yields a heat intensity limit for this case of 3.04 W/ft/in$^2$. In contrast, using a direct extrapolation of the Stolpe plot to a 58% fill, SNL[4] obtained a heat intensity limit of 2.87 W/ft/in$^2$. Hence, in this "worst case" for River Bend the inaccuracy of the licensee linear model results in the heat intensity being over-estimated by about 6%. The resulting difference in the ampacity calculated using these two values would be about 3%. This difference is not very significant, but is non-conservative.

In summary, SNL finds that by a strict interpretation the licensee's linear model of heat intensity versus percent fill of a 3" cable tray should not be applied to fills outside the range of 10-40% fill, the limit values used in developing the curve. However, SNL also finds that the resulting error is only on the order of 3% for the worst-case fills cited by the licensee. Given the rather modest impact on the licensee submittal, no specific actions on this finding for the River Bend submittal are recommended. This item is, however, noted as potential point of concern should the same heat intensity model be applied at other plants where percentage fills might be higher.

### 4.2.2 Apparent Over-Filling of Conduits

SNL notes that the licensee has cited conduit fills of up to 124%. While the cited conduit fills have no direct impact on the derating assessment, this observation raises at least two questions:

- A conduit fill of greater than 100% seems to be physically impossible. It is recommended that the licensee be asked to explain under what circumstances any conduit can have a percentage file that exceeds 100%.

- The National Electric Code (NEC) limits conduit fills to 53% for single conductor fills and 40% for fills involving 3 or more conductors. It is recommended that the USNRC ask the licensee to reconcile its apparent violations of these code limits.

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[3]For higher depth of fill values a more significant error would result. For example, at a 100% fill the licensee model will overstate allowable base line currents by as much as 8%. Fortunately, the licensee has not cited fills greater than 58% for the cable trays.

[4]SNL digitized the plot from the Stolpe paper and used the digitized data points to obtain the cited value.

### 4.2.3 Citations to NEC Overcurrent Protection Articles

For a number of the nominally overloaded "C" cables, the licensee has argued that the ampacity loads are actually acceptable on the basis of citations to two passages in the NEC, namely, Articles 240-3(b) and 240-6. These cases are discussed in Sections 6.4.1, 6.4.2, and 6.4.3 of the licensee submittal.

The two passages cited deal exclusively with the issue of overcurrent protection or fusing. In particular, these passages allow that for certain low current limit cables, circuit protection can be provided by using the next higher available fuse or breaker rating. For example, a 12A cable could be protected by a 15A breaker because no 12A breaker is generally available. The licensee would appear to be arguing that these passages allow for a current load of up to 15A simply because a 15A breaker can be used to protect the circuit. This is an inappropriate interpretation of these passages. The passages are clearly not intended to increase the ampacity limits of the cable, but rather, are only intended to recognize practical limits related to fusing practices.

SNL finds that these passages have no relevance whatsoever to the determination of maximum current loads for the subject cables. Current limits are established strictly on the basis of the cable physical and installations features, not on the basis of the allowable overload protection ratings. To cite these passages as the basis for justifying an overload condition is inappropriate. It is recommended that the USNRC should reject these arguments, and that the licensee be asked to provide an alternate basis for the resolution of these nominally overloaded cables.

## 4.3 Summary of Review Findings and Recommendations

As a general conclusion regarding the licensee's ampacity assessment methodology, SNL makes the following findings and recommendations:

- SNL finds that the licensee methodology as documented in Calculation E-218 Rev. 1 is an appropriate basis for the analysis of individual cable ampacity loads and for the consideration of fire barrier ampacity derating factors. While one minor point of methodological concern was identified (related to the licensee linear heat intensity model, see Section 4.2.1), it was also demonstrated that the impact of this concern on this licensee's analysis in the worst case considered was quite minor. Hence, SNL recommends that the methodology documented by the licensee should be accepted as an appropriate means of demonstrating the adequacy of in plant cable loads.

Given this general finding, SNL recommends that the USNRC seek some resolution of the following concerns related to the resolution of cables nominally identified as overloaded using the licensee methodology:

- While the licensee has provided recommendations for the resolution of nominally overloaded cables, no definitive resolutions are provided. A number of nominally overloaded cables have been identified by the licensee. It is recommended that the USNRC follow-up with the licensee to ensure that an adequate resolution of these cables is eventually achieved.

- One approach considered by the licensee as a way to resolve nominally overloaded cables is the removal or replacement of the fire barrier. SNL finds that cables that have operated for a significant period of time at nominally overloaded conditions may have been subjected to significant acceleration of the aging degradation process. It is recommended that the USNRC ask the licensee to provide some assessment of the remaining cable life expectancy for cables that have operated under nominally overloaded conditions for extended periods, even if the overload condition is relieved by removal of the fire barrier. This observation is also consistent with the 10/16/96 RAI items discussed in Sections 2.4.1, 2.4.2 and 2.4.4 above.

- One argument tendered by the licensee to resolve overloads on certain of the type "C" cables presented in Section 6.4 of the licencee submittal depended on citations to two NEC articles on overcurrent protection. SNL finds that these sections have no relevance whatsoever to the determination of cable ampacity load limits, and hence, this licensee argument is considered inappropriate. It is recommended that the USNRC reject this line of argument as the basis for resolution of these overload conditions, and that the licensee be asked to provide an alternate basis for resolution.

SNL also noted two other apparent inconsistencies in the licensee submittal. While these inconsistencies will not directly impact the licensee's ampacity assessments, it is recommended that the USNRC follow-up with the licensee to resolve them. These two items are:

- The licensee has documented conduit cable fills as high as 124%. It appears physically unrealistic to have a conduit load of greater than 100%. It is recommended that the licensee be asked to explain this apparent inconsistency. This inconsistency would not, however, directly impact the ampacity assessments.

- The licensee has documented numerous conduits that appear to be loaded in excess of the loading limits established in the National Electric Code (NEC) (generally limited to 40-53% loads depending on the conductor count). It is recommended that the licensee be asked to reconcile these apparent violations of the NEC. This apparent discrepancy would not directly impact the licensee ampacity calculations.

Finally, SNL makes the following observation:

- The licensee E-218 calculations include the use of ampacity derating factors derived from the G13.18.14.0-178 Calculation that SNL has found to be significantly flawed (see related discussion in Chapter 3). Hence, it is recommended that the USNRC should not accept the E-218 calculation results for those cases involving untested barrier configurations until the concerns related to that Calculation G13.18.14.0-178 are resolved. This recommendation would not impact the acceptance of cases for which direct experimental data on ampacity derating have been applied.

# 5.0 SUMMARY OF FINDINGS AND RECOMMENDATIONS

## 5.1 Adequacy of the Specific RAI Responses

In general, SNL found that the licensee was responsive to all of the RAI items from the USNRC letter of 10/16/96. A summary of SNL's findings and recommendations has been provided in Section 2.6 above. Two areas were identified in which the final licensee resolution remained unclear because the final ampacity assessments and the resolution of nominally overloaded cables have not been completed. Hence, it has been recommended that the USNRC should follow-up on the following issues related to these RAI items:

- While the licensee has committed to providing assessments of the impact of life-to-date operating conditions on cable aging for nominally overloaded cables that are resolved through removal or replacement of the fire barrier system, no such assessments are provided in the current submittal.

- The licensee, as requested, provided the calculation upon which ADF values for untested configurations have been based (Calculation G13.18.14.0-178). Several points of significant technical concern were identified by SNL after reviewing this calculation (see related conclusions in Section 5.2 below). It is recommended that the USNRC should follow-up with the licensee to resolve the identified concerns.

## 5.2 Acceptability of Calculation G13.18.14.0-178

SNL finds that the licensee calculations to estimate ampacity derating factors for untested barrier configurations contain numerous serious and fundamental modeling inconsistencies and errors. A more complete discussion of recommendations in this regard is provided in Section 3.3 above. It is recommended that the results of these calculations not be accepted by the USNRC until the identified concerns have been resolved. The concerns identified include:

- SNL finds that the licensee has inappropriately applied convection coefficients for surface heat transfer in an unrestricted open (external) environment to the highly confined interior of the fire barrier systems analyzed. This observation applies to both the conduit and cable tray analyses. The current licensee treatment is considered to represent a significant potential non-conservatism in the analysis, especially as it will impact the single cable tray analyses.

- SNL finds that the licensee's treatment of external convection for cable tray systems is unnecessarily crude and does not adequately treat the differences associated with surface orientation. The impact of this treatment is, in all likelihood, minor but would vary depending on the particular application.

- SNL finds that the licensee treatment of internal heat transfer behavior within a conduit represents a significant departure from accepted practice, has not been adequately justified, appears to be inappropriate, and is likely non-conservative.

- SNL finds that the licensee has not calculated radiation view factors correctly, in particular, for those analyses involving multiple raceways in a common enclosure. The licensee treatment represents a significant source of non-conservatism in the analysis of multiple raceway enclosures.

- SNL finds that the licensee comparison of clad case ampacity limit estimates derived from its own thermal model to tabulated base line ampacity limits is inappropriate. The licensee's thermal model includes significant deviations from the thermal models used to develop the standard tables. Hence, the critical need for consistency between the clad case and base line case analyses has been compromised.

- SNL finds that the ampacity correction factors associated with the number of current carrying conductors in a conduit as applied to this calculation have either not been properly calculated or are still based on the older pre-1990 NEC correction factors. (Note that the updated E-218 calculations appear to have properly applied the updated correction factors.)

- SNL finds that for cases involving multiple raceways (trays and/or conduits) in a single enclosure the licensee's treatment of convective heat transfer between each of the raceways and the inner surface of the fire barrier system as independent heat flow paths is inappropriate and non-conservative.

- SNL has recommended that the licensee be asked that for any cases in which appropriate industry test data can be identified (i.e. for roughly equivalent or more conservative fire barriers) the licensee abandon the calculations for single aluminum conduits, and instead, utilize industry test data for steel conduits as a conservative estimate of the aluminum conduit derating impact. This would remove one source of uncertainty in the licensee analysis.

### 5.3 Acceptability of Calculation E-218 Revision 1

As a general methodology, SNL finds that the licensee Calculation E-218 Revision 1 represents an acceptable methodology for the analysis of individual cable loads. All of the significant concerns identified in the earlier SNL review of the Revision 0 version have been adequately resolved in the updated version. The licensee appears to have properly implemented its assessment methodology consistent with its verbal descriptions.

Given this general conclusion, SNL does recommend that the USNRC provide some follow-up to a number of specific items related to this calculation. A detailed discussion of the specific findings and recommendations of this review is provided in Section 4.3 above. The identified items are:

- The licensee analyses include the use of ampacity derating factors derived from the G13.18.14.0-178 calculation that SNL has found to be significantly flawed. Hence, it is recommended that the USNRC should not accept the calculation results for the impacted cases until the concerns related to that calculation are resolved.

- The licensee analysis has only identified recommendations for the resolution of overloaded cables, and has not demonstrated follow-through resolutions. A number of such cables are identified.

- One option considered by the licensee as a ·vay to resolve nominally overloaded cables is the removal or replacement of the fire barrier. However, the licensee has not provided an assessment of the remaining life expectancy for cables that have operated under nominally overloaded conditions during the time the barriers have been in place. (See related discussion in Section 5.1 above.)

- One argument used to resolve overloads on certain of the type "C" cables presented in Section 6.4 of the licencee submittal depended on a citations to NEC articles on overcurrent protection. SNL finds that these sections have no relevance whatsoever to the determination of cable ampacity load limits and has recommended that the USNRC reject this line of argument.

- The licensee has documented conduit cable fills as high as 124%. It appears physically unrealistic to have a load of greater than 100%. This inconsistency would not, however, directly impact the ampacity assessments.

- The licensee has documented numerous conduits that appear to be loaded in excess of the loading limits established in the National Electric Code (NEC). This apparent discfepancy would not directly impact the licensee ampacity calculations.