August 29, 1997

Mr. J. E. Cross
President - Generation Group
Duquesne Light Company
Post Office Box 4
Shippingport, PA 15077

SUBJECT: REQUEST FOR ADDITIONAL INFORMATION (RAI) REGARDING THERMO-LAG RELATED AMPACITY DERATING ISSUES - BEAVER VALLEY POWER STATION, UNIT NO. 2 (BVPS-2) (TAC NOS. M85517)

Dear Mr. Cross:

By letter dated March 25, 1997, Duquesne Light Company (DLC) submitted a response to the NRC's RAI related to ampacity derating of cables enclosed in Thermo-Lag 330-1 fire barriers at BVPS-2. The NRC staff, in conjunction with its contractor, Sandia National Laboratories (SNL), has completed a preliminary review of DLC's March 25, 1997, submittal and has determined that additional information is required to complete our review. The additional information that is required is identified in the enclosed RAI (Enclosure 1). Enclosure 2 is "A Preliminary Review of the Beaver Valley Fire Barrier Clad Cable Ampacity Evaluation Methods, A Letter Report to USNRC, Revision. 0," dated July 18, 1997, prepared by Steve Nowlen of SNL. DLC is requested to provide this additional information within 45 days of the date of this letter to enable the NRC staff to complete its review within a timely manner.

Should you have any questions on this matter, please contact me on (301) 415-1409.

Sincerely,

original signed by Leonard Olshan for

Donald S. Brinkman, Project Manager
Project Directorate I-2
Division of Reactor Projects - I/II
Office of Nuclear Reactor Regulation

Docket No. 50-412

Enclosures: 1. RAI
2. SNL Fire Barrier Report

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UNITED STATES
NUCLEAR REGULATORY COMMISSION
WASHINGTON, D.C. 20555-0001

August 29, 1997

Mr. J. E. Cross
President - Generation Group
Duquesne Light Company
Post Office Box 4
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REQUEST FOR ADDITIONAL INFORMATION

REGARDING FIRE BARRIER AMPACITY DERATING ISSUES

BEAVER VALLEY POWER STATION, UNIT 2

DOCKET NO. 50-412

1.0 BACKGROUND

By letter dated March 25, 1997, Duquesne Light Company (the licensee) submitted a response to the NRC's Request for Additional Information (RAI) related to Generic Letter (GL) 92-08, "Thermo-Lag 330-1 Fire Barriers," for Beaver Valley Power Station Unit No. 2 (BVPS-2).

The thermal model cited by the licensee is based on a methodology utilized by the industry to calculate heat losses from insulated pipes. The model is implemented in two steps. In the first step, the licensee model analyzes the heat transfer behavior from the outer surface of an individual cable out to the ambient environment. The second step involves the evaluation of the heat transfer behavior through the cable jacket and insulation for an individual conductor. The objective of the licensee thermal model is to estimate the actual ampacity limits for the cables in Thermo-Lag enclosed conduits based on the actual installation characteristics.

The NRC staff, in conjunction with its contractor, Sandia National Laboratories (SNL), has completed the preliminary review of the licensee's submittal, and requires that the following questions be addressed by the licensee.

2.0 QUESTIONS

After a review of the licensee's cable ampacity assessment methodology, SNL raised the following concerns:

2.1 SNL identified a number of potential concerns regarding the licensee's heat transfer analysis methodology and implementation. SNL recommended that the licensee pursue one of the following options to permit a more comprehensive review and assessment of the licensee's modeling approach:

<u>Option 1 - Continued Reliance on Wetted Perimeter Approach</u>: If the licensee desires to continue its reliance on the partially filled pipe/wetted diameter approach, then additional documentation of the model development and implementation is needed, and the resolution of specific points of apparent error or inconsistency should be addressed as follows:

- Provide, for review, a copy of the Okonite Bulletin EHB-90 as referenced in the licensee's submittal dated March 25, 1997. This document is cited as the basis for the wetted diameter calculation approach.

- Correct or explicitly derive and justify the first term in the denominator of the expression for U_0 appearing near the center of page 3 of the attachment to the licensee's submittal dated March 25, 1997. This term, associated with heat transfer to and through the conduit itself, appears to be in error, and does not appear to properly account for the reduction in heat transfer rates associated with the partial "wetted diameter" approach.

- Explicitly state the intent of the apparent air interface term appearing in the expression for cable conductor temperature calculation as it appears on page 5 of the attachment to the licensee's submittal dated March 25, 1997. Explain the consistency of this expression with the stated intent to base the analysis on a "wetted diameter" approach to analysis. If it is the licensee's intent to include an air gap at this stage of analysis, then the selected value of the "film coefficient," 1.65 BTU/hr/ft^2/°F, should be explicitly justified as applicable to this analysis. Alternatively, the air gap should be treated as an annular ring similar to the treatment provided for the conduit-to-fire barrier air gap.

- Explicitly state how the effects of heat transfer within the cable bundle have been addressed in the licensee's model. In particular, discuss how the thermal model includes consideration of heat conduction through to the center of the cable bundle in addition to the thermal effects of the individual conductor insulation and jacket materials.

Option 2 - Implementation of the Buller/Neher Approach: As an alternative, the licensee should consider modification of the thermal model so as to comply with the accepted Buller/Neher (1950 AIEE) approach to analysis of cable bundle to conduit heat transfer behavior. This would require that the second step of the licensee's analysis model be replaced by an implementation of the Buller/Neher correlations for hot-spot to conduit thermal resistance factors. In particular, Buller/Neher's Equation 1 is recommended for use. This option would also require that the discrepancy regarding the equation for U_0 as it appears at the center of page 3 of the attachment be addressed.

Option 3 - Implementation of a Conservative Air Gap Approach: As an alternative, the licensee might consider implementation of a conservative approach to conduit-to-cable heat transfer in which the cable bundle and conduit are separated by an annular air gap, and heat transfer within the bundle is treated based on simplified correlations for the temperature at the center of a cylinder with uniform heating. Holman's

Heat Transfer (1976) provides such an expression as equation 2-25, and Stolpe (1957 AIEE) provides an estimate of cable bundle conductivity appropriate for such an application. This option would also require that the discrepancy regarding the equation for U_0 as it appears at the center of page 3 of the attachment be addressed.

The concerns addressed by the above comments and options are primarily associated with the heat transfer behavior internal to the conduit. In addition to these concerns, there is one additional point of concern that would be relevant to all three of these options:

- With regard to the treatment of external system heat transfer, SNL finds that the licensee has not established a basis for the cited "ambient air film coefficient" for exchange between the outer surface of the fire barrier and the ambient environment (a uniform value of 1.65 BTU/hr-sq.ft-degF has been cited in the example analyses). The licensee is requested to explain the intent of this factor, to explicitly state how it was derived, and to discuss its relevance to the conduits and fire barrier systems under consideration in this analysis specifically, the physical size of the system, the driving temperature difference, and the surface emissivity.

In conclusion, the licensee is requested to consider the adoption of one of the above options in order to achieve closure of the concerns identified or propose an alternate approach which addresses the thermal modeling issues. (See Sections 2.1 and 2.2 of the SNL Letter Report (Enclosure 2) for further details).

2.2 SNL made the following comments regarding the licensee's validation case study:

SNL finds that the licensee has incorrectly cited the test results (i.e., measured clad case ampacity) from the TUE test program, and has incorrectly set the fire barrier thickness to 1/4" as compared to the actual tested value of ½" nominal. The results of this case analysis appear conservative but are uncertain. The licensee is requested to correct its analysis to address the apparent errors.

SNL had the following comments regarding the two plant applicable example cases:

- Both case examples appear to have resulted in very conservative estimates of cable ampacity limits. However, given the apparent errors in approach and implementation, SNL views these results with some skepticism.

- In the case of conduit 2CL6070D the information provided in the calculation is not consistent with the information provided in the licensee's application summary table in regard to the conductor count for the three #4AWG cables. The calculation cites that these are 4-conductor cables whereas the table indicates that they are of a 3-conductor configuration (size and conductor count may have been confused in the calculation). This apparent error has compromised the calculation by artificially increasing the estimated heat load.

The licensee is requested to reconsider its validation and example case calculations in light of the specific SNL findings and the thermal modeling concerns identified in Item 2.1 above. (See Sections 2.3 and 2.4 of the SNL Letter Report (Enclosure 2) for further details).

2.3 After a review of the licensee's application summary table which was provided in the submittal of March 25, 1997, SNL finds that the ampacity concerns for 24 of the 26 conduits identified have been adequately resolved by the subject documentation. The licensee is requested to provide explicit justification for the ampacity loads for the cables in the remaining two conduits for which an adequate ampacity margin had not yet been demonstrated; namely, electrical raceways 2CL213ND and 2CL6070E which were cited in the subject summary table. (See Section 3.3 of the SNL Letter Report (Enclosure 2) for further details).

A Preliminary Review of the Beaver Valley Fire Barrier Clad Cable Ampacity Evaluation Methods

A Letter Report to the USNRC

Revision 0

July 18, 1997

Prepared by:
Steve Nowlen
Sandia National Laboratories
Albuquerque, New Mexico 87185-0747

Prepared for:
Ronaldo Jenkins
Electrical Engineering Branch
Office of Nuclear Reactor Regulation
U. S. Nuclear Regulatory Commission
Washington, DC 20555
USNRC JCN J-2503

Enclosure 2

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Note this document is printed on both sides!

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 first report in an anticipated series of review reports associated with a set of submittals from the Beaver Valley Power Station Unit 2 (BVPS-2). The submittal deals with the assessment of ampacity loads for conduits protected by Thermo-Lag 330-1 fire barriers. This report documents the results of a SNL review of the licensee submittal and an evaluation of the cited methods of analysis. The documents were originally submitted by the licensee in response to USNRC Generic Letter 92-08. This work was performed as Task Order 4, Subtask 5 of USNRC JCN J-2503.

1.0 INTRODUCTION

1.1 Objective

In response to a request from the USNRC, Beaver Valley Power Station (BVPS) has documented the methodology it proposes to use in the evaluation of ampacity loads for fire barrier clad cables along with a summary table of fire barrier applications and corresponding power cable load ampacities. The objective of this report is to document the results of an SNL review and evaluation of this licensee submittal. The submittal reviewed by SNL is identified as follows:

- Letter, S. C. Jain, Duquesne Light Company BVPS, to the USNRC Document Control Desk, March 25, 1997 (with one attachment).

SNL was requested to review this submittal under the terms of the general technical support contract JCN J-2503, Task Order 4, Subtask 5. This letter report documents the results of SNL's review.

1.2 Overview of the Licensee Ampacity Derating Approach

The licensee approach to the determination of cable ampacity loads is based on a licensee thermal model developed specifically for this purpose. For the most part the model uses conventional thermal modeling approaches and correlations, although it is rather unique in certain regards as will be discussed further in Section 2 below. The intent of the model is to estimate the actual ampacity limits for clad power cables. These estimated limits are then compared to actual in-plant power loads for a final assessment of acceptability. In this regard it is especially important to note that the licensee is not attempting to calculate an ampacity derating factor (ADF) nor are they applying any given ADF (either experimental or analytical) to tabulated ampacity limits. Rather, actual ampacity limits are determined directly by calculation.

The current licensee submittal focuses on the model development and limited validation. Individual case analysis results are presented for for just two of the 26 clad conduits actually in the plant. In this sense, the licensee submittal documents a proposed approach to analysis but does not provide the "final answer." However, the licensee has also provided a table which summarizes the most critical aspects of the licensee barrier applications, and SNL has given considerable weight to this summary table in reaching its conclusions and final recommendations.

The summary table identifies all of the installed fire barrier systems, the cables enclosed in each system, the in-plant ampacity load for each cable, and the nominal ampacity limits derived from standard ampacity tables for each of the cables assuming it is alone in the conduit (which is not always the case). This comparison provides a reasonably direct assessment of the nominal ampacity margin available. With some minimal additional treatment the available margin can be compared directly to the anticipated fire barrier ADF providing an initial indication of potential problem applications. SNL has included such assessments in our review findings.

1.3 Organization of Report

This review has focused on (1) a technical review of the licensee thermal model, and (2) a review of the licensee application summary table. Section 2 of this report documents the results of SNL's review and evaluation of the thermal model. Section 3 provides a summary of insights developed based on the licensee application summary table. Section 4 summarizes the SNL findings and recommendations. Section 5 identifies referenced documents.

2.0 THE LICENSEE THERMAL MODEL

2.1 Overview of the Licensee Mod-ling Approach

The objective of the licensee thermal model is to estimate the actual ampacity limits for cables in clad conduits based on the actual installation characteristics of the individual conduits and cables. In many respects, the licensee's thermal model follows standard and accepted analysis practice as commonly applied to such assessments. However, in certain other regards the thermal model deviates from accepted practice and this is a point of potential concern.

The thermal model is cited by the licensee as being based on methods "used by the mechanical engineering industry for calculating heat losses from insulated pipes. (The Neher and McGrath method (N-M) also uses the similar theory.)" Despite this statement, it is clear that the licensee has deviated significantly from the widely accepted Neher/McGrath methods in at least one important regard as will be discussed further below (see section 2.2). For now, discussion will focus on what the licensee has done and apparent errors in implementation.

The licensee model is essentially implemented in two steps with the "split" made at a rather unusual "place" in thermal system. In the licensee model the first step is intended to treat the heat transfer behavior from the outer surface of an individual cable out to the ambient, and the second step treats the heat transfer behavior through the jacket and insulation of an individual conductor. A more typical approach makes a somewhat different "split". In a typical model, the heat transfer from the inner surface of the conduit out to the ambient is treated in one step, and the heat transfer from the hot spot of the cable bundle, through the cables, and to the inner surface of the conduit is treated as a separate consolidated step of the analysis.

This difference between the licensee model and general practice is critical, and somewhat complicates the presentation of SNL's review findings. This is especially true because it would appear that at least one critical mistake has been made in the first part of the model, and that in reality the licensee has not appropriately treated the cable bundle-to-conduit heat transfer effects. The sub-sections which follow address each of the two steps in the licensee model as implemented in the submittal.

2.1.1 Step 1: Ambient to Cable Surface Treatment

The licensee step 1 analysis is purported to result in the calculation of the surface temperature of an individual insulated and jacketed conductor. Hence, the important physical elements (or effects) which must be accounted for in this step of the analysis are:

1. convection and radiation between the outer surface of the fire barrier and the ambient,
2. heat conduction through the fire barrier material itself,
3. heat conduction through the air gap assumed to exist between the inner surface of the fire barrier and the outer surface of the conduit,

4. heat conduction through the metal conduit,
5. the net contact resistance between the cable bundle and the inner surface of the conduit, and
6. heat conduction within the cable bundle and potential hot-spot behavior.

In the licensee thermal model the first three of these elements (1-3 above) are treated in a fairly straight forward manner. No specific mistakes or problems in this part of the analysis were noted with the following exception:

- The licensee has not provided an adequate basis for the "ambient air film coefficient" used to characterize the exchange between the outer surface of the fire barrier and the ambient environment. A uniform value of 1.65 BTU/hr-sq.ft-degF has been cited in the example analyses. It is unclear what the exact intent and basis for this factor is. The manner of its use implies that the factor is intended to represent a composite linear convection/radiation heat transfer coefficient. The use of such a composite value is not inherently a problem, but the basis for the chosen value should be established. In general, radiation is a very strong function of the temperature difference and the emissivity of the emitting surface. Convection coefficients are functions of the temperature difference, the system orientation, and the assumed system physical diameter. Hence, it would be anticipated that the cited value would be justified as compatible with the actual physical system in these regards. A further explanation of this factor would be appropriate.

It is, however, in regard to the last three elements (4-6 above) of the physical system, those dealing with the conduit itself, conduit-to-cable bundle contact resistance, and cable bundle internal heat transfer processes that the licensee thermal model appears to most significantly fall short. Only minimal documentation is provided regarding this aspect of the thermal model, hence, the licensee's intent in some instances cannot be clearly discerned. However, based on the information provided, SNL must conclude that the licensee treatment is not adequate and in fact is not even consistent with their apparent intent.

The licensee states that its thermal model is based on typical models of heat loss from partially filled pipes. This does appear to be reflected in the licensee's implementation of a "wetted perimeter" concept in the problem formulation. However, in practice, the licensee either misunderstands the wetted perimeter concept, or has made a mistake in implementation. (The general appropriateness of this approach is taken up further in Section 2.2 below.)

In particular, consider the expression for the value of the heat transfer coefficient, U_0, as it appears near the center of page 3 of the attachment. There are four individual terms appearing in the denominator of this expression, three of which can be traced directly to heat transfer through the air gap (2nd term), heat transfer through the barrier material (3rd term) and heat transfer away from the outer surface to the ambient (4th term). The first term in the denominator however, appears to be in error.

Given the known nature of the other three terms and the stated objective of this step of the analysis, one should expect that the first term would account for heat transfer through the conduit itself, the effects of contact resistance between the cables and the conduit, and any cable bundling effects of importance. However, the term as written does not appear to even fully account for the effects of conduction through the conduit, let alone the contact resistance problem.

To understand this part of the problem, it is important to note that the licensee thermal model is formulated in terms of the "heat transfer coefficient" approach to thermal analysis. Under this approach, a heat transfer coefficient "U" is defined such that heat fluence or flow "q" is calculated as:

$$q = U A \Delta T$$

where "A" is the corresponding heat transfer area and "ΔT" is the corresponding temperature difference. In effect, the heat transfer coefficient, U, is a "thermal conductance" and the higher this value, the higher the rate of heat flow for a given temperature difference. A thermal system can be viewed as a set of thermal conductances in series. The total conductance for the system is obtained in a manner similar to summing resistive elements that appear in parallel:

$$U_{total} = \frac{1}{\sum_{i=1}^{n} 1/U_i}$$

This is a perfectly acceptable approach in principal, and the format is clearly reflected in the licensee equation.

One critical aspect in the use of this approach is the derivation of the "U" factor such that all elements of a system are referenced (or normalized) to the same heat transfer area "A" (in this case "A" is interpreted as the area per foot of conduit, and "q" is the rate of heat transfer per foot of conduit). In the case of the licensee analysis, the area chosen as the reference area is clearly the outer-most surface of the fire barrier:

$$A = \pi D_0 L$$

where "D_0" is the outer diameter of the Thermo-Lag barrier and the length "L" is set to one. Hence, the "U" for each element in the system must be corrected to allow for this area.

Returning to the licensee implementation, consider the heat transfer coefficient for simple conduction through the conduit itself. The conduit is treated as an annular ring of aluminum. The heat transfer through this ring is given by:

$$q = \frac{2\pi k_{al} \Delta T}{\ln(D_3/D_2)}$$

where "k_{al}" is the conductivity of the aluminum conduit, "D_3" is the outer diameter of the conduit, and "D_2" is the inner diameter of the conduit. This is a standard expression for this problem. The two available expressions for the heat flow "q" can now be equated:

$$q = U\,A\,\Delta T = \frac{2\pi k_{al} \Delta T}{\ln(D_3/D_2)}$$

and one can now solve for the heat transfer coefficient "U" for just conduction through the metal conduit itself:

$$U = \frac{2\pi k_{al}}{A\,\ln(D_3/D_2)} = \frac{2\pi k_{al}}{\pi D_0\,\ln(D_3/D_2)} = \frac{2k_{al}}{D_0\,\ln(D_3/D_2)}$$

This is similar to the cited licensee expression as shown on page 3 of 16 of the licensee attachment. That is, the inverse of this expression appears as the first term in the denominator of the equation for the value of "U_0" appearing near the middle of the page. However, SNL notes that the licensee has replaced the value "D_0" with the value "D'_0". In effect the licensee has assumed a heat transfer coefficient of the form:

$$U = \frac{2k_{al}}{D'_0\,\ln(D_3/D_2)}$$

apparently intended to account for the thermal elements 4-6 as listed above. However, note that "D'_0" is cited as the "equivalent diameter of the cable contact surface with the inside surface of the conduit" and is much smaller than "D_0" the outer diameter of the overall system (in the example case, D'_0=0.09 feet versus D_0=0.52 feet, for example).

Because this value appears in the denominator of the above expression for "U", the licensee calculated heat transfer coefficient is actually much greater than the correct value for conduction through the conduit itself which still ignores the effects of contact resistance and heat transfer within the cable bundle. Recall that the higher the coefficient value, the greater the heat transfer rate. Hence, the actual heat transfer coefficient that would account for all three of the important physical factors should be much lower than that characterizing conduction through the conduit alone. The licensee analysis has apparently made some error in formulation, and the result is non-conservative.

In summary, SNL finds that in the development of the expression for "U_0" on page 3 of the licensee attachment, it would appear that the first term in the denominator of this expression has not been properly normalized consistent with each of the other individual terms. Further, It would appear that this term has not properly accounted for either the contact resistance between the cable bundle and the conduit, nor for the heat transfer effects associated with the cable bundle itself. It is recommended that the USNRC ask the licensee to either explain or correct its analysis in this regard.

2.1.2 Step 2: Individual Conductor Analyses

As noted in 2.1.1 above, the result of the first step of the analysis is purported to be an estimate of the surface temperature of an individual insulated and jacketed conductor. For the final step of the analysis, the licensee then calculates the temperature rise through the jacket and insulation to the conductor itself. This aspect of the model appears to involve three terms, two of which are clear and one of which is not at all clear. The expression in question appears at the top of page 5 of the licensee attachment. The terms of interest appear as three terms summed in the large brackets.

The first two terms in this group are clearly annular heat transfer expressions for the cable insulation and jacket respectively. However, the third term appears to be an air interface term similar to that applied to the outside surface of the overall system. Why such a term should appear at this stage of the analysis is entirely unclear. It would appear that the licensee is assuming an air interface somewhere within the cable, but why and where is unclear. That is, the first step was purportedly intended to estimate the cable surface temperature, and clearly there are no significant air gaps between a conductor and its insulation.

One potential interpretation is that the licensee in fact is assuming that the step one calculation yielded a conduit temperature, and that in the second step the licensee is assuming that the individual conductor is suspended in the center of the conduit in which case a cable-to-conduit air gap must be allowed for. If this is the case, then there are three points of concern:

- There is no basis for assigning the exact same "film coefficient" to a confined space air gap as that assigned to the outside surface, and yet the licensee has done so. If this is a confined space air gap, then the treatment should be based on conduction through the air gap as was done for the conduit-to-fire barrier air gap.

- In this step the licensee has treated heat transfer from each conductor independent of the other conductors. If this is in fact an intended cable-to-conduit air gap, then all of the heat loads for all conductors should be considered simultaneously. The air gap would be common to all cables, hence, should be evaluated on the basis of the total heat transfer rate, not that of an individual conductor.

- The licensee treatment appears to provide no consideration of the effects of cable bundling on heat transfer and the hot-spot behavior. That is, it is appropriate for a conduit thermal model to include some consideration of heat conduction through the cable bundle because the hot-spot is likely to occur near the center of the bundle. The licensee has apparently only considered heat transfer through and individual conductor's insulation layers, not through the bundle as a whole.

As will be discussed further below (see sections 2.3 and 2.4), the net results for the licensee thermal model for the limited selection of case examples presented have been modestly to grossly conservative. SNL attributes this conservatism entirely to the inclusion of this unexplained air interface term in the second step of the analysis. Other aspects of the model, especially including the treatment of heat transfer to and through the conduit, the apparent neglecting of cable bundle internal heat transfer effects, and the treatment of conductor loads independently in the second step analysis are clearly or potentially non-conservative as discussed above. For the example cases however, the conservatism introduced by the inclusion of an air interface in the step 2 analysis has apparently dominated the net calculation. There is no assurance that this would hold true for all cases.

2.2 Compatibility with Accepted Approaches to Conduit Ampacity Analysis

Calculations are one widely accepted methodology commonly employed in conduit ampacity assessments. In fact, the National Electric Code (NEC) Handbook specifically cites the Neher/McGrath methodology [2] as an acceptable basis of analysis under engineering supervision. Hence, this approach is in principal acceptable. However, the licensee analyses do not appear to conform to accepted practice, and may be inappropriate.

One critical aspect of a conduit thermal analysis involves the estimation of the net thermal resistance between the cable bundle hot spot and the inner surface of the conduit. This is, in fact, a very complex thermal problem that can be quite difficult to analyze. The processes involve both the heat transfer behavior within the cable bundle itself as well as that between the cable bundle and the conduit. The cable bundle itself is a very complex two-dimensional geometry in general, especially when there is more than one cable present in the conduit. This can lead to no direct contact between individual cables and the surface of the conduit, an effect not allowed for in the licensee analyses. The heat transfer between the bundle and the conduit itself is also relatively complex involving a combination of radiation, conduction with high contact resistance, and confined space convection. The most common approach is to simplify this step of the analysis using empirical engineering correlations.

The only widely accepted correlations for directly modeling this aspect of the problem are those that derive from the work Buller/Neher [1] (this work also forms the basis for the simplified correlations presented in Neher/McGrath [2]). These works treated this problem directly by analyzing a series of ampacity tests and developing engineering correlations to characterize those test results. (Of particular note SNL has obtained excellent agreement with current test results using Buller/Neher Equation 1, although use of the less accurate but simplified Neher/McGrath expressions is generally accepted in practice.) The main advantage of these correlations is that they consider the contact resistance and cable bundle conduction problems simultaneously. That is, the correlations take one directly from the cable bundle hot spot to the conduit surface in a single step.

A second and generally more conservative approach sometimes used is to simply assume that the cable bundle in located in the center of the conduit, and that there is no direct contact between the cables and the conduit. Under this approach, the air gap between the cables and the conduit is simply treated as one more annular ring of material and analyzed accordingly. This is clearly conservative in comparison even to the Neher/McGrath approach as regards contact resistance between the cables and the conduit. It does, however, leave the question of behavior within the cable bundle unresolved. That is, this method only estimates the surface temperature of the bundle and the critical question that must be answered is "what is the hot spot temperature at the center of the bundle?" Hence, some additional assessment of heat transfer within the bundle is needed. This will typically be a case specific analysis in which conduction though the cable bundle is modeled using a composite thermal conductivity value such as that cited by Stolpe [4] in his modeling work for cable trays. Using this value, a simplified expression for the temperature at the center of a solid cylinder with uniform heat generation may be applied with reasonable accuracy (see for example Holman Equation 2-25 [5]). Again, this is a fairly straight-forward and conservative approach, but does require treatment in two parts.

In contrast, as discussed above, the licensee cites that its analysis is based on those models used to estimate heat loss from insulated pipes combined with a very simplistic treatment of the cable insulation and jacket thermal effects. As has been noted in Section 2.1 above, the actual implementation of the model does not appear to conform with this intent, either due to mistakes or due to a misunderstanding on the part of either SNL or the licensee. In principal, the partially filled pipe approach would assume intimate contact between the fluid in the pipe and the pipe surface over only a portion of the pipe. Hence, the concept of "wetted diameter" is introduced to allow for the actual "wetted" area of contact as compared to the total surface area of the pipe. The intent is to reduce the actual heat flow to allow for the limited contact area. The licensee stated that its intent was to apply this same concept to a conduit/cable bundle analysis.

Unfortunately, a pipe that is partially filled with fluid is not at all the same as a conduit/cable bundle situation. In particular, the wetted perimeter of a fluid in a pipe is easily defined whereas the equivalent wetted perimeter of a cable bundle is not (the licensee treatment in this regard appears to be based on an Okonite bulletin that was not available for SNL review, licensee reference 1). Second, fluids are generally considered to be uniform in temperature in such a calculation, and the correlations are derived accordingly. In the case of a conduit, the cable bundle is quite clearly not uniform in temperature, and a unique treatment is appropriate.

While the licensee has provided for a very simplistic analysis of cable insulation temperature drops, including an unexplained air gap that appears to contribute to significant conservatism (see 2.1.2 above), the licensee approach apparently fails to adequately allow for the supplemental effects of heat transfer within the cable bundle in addition to the surface contact problem. At best, the wetted perimeter approach might be cited as estimating the temperature at the point of contact between the bundle and conduit and the corresponding heat transfer rates, but does not appear to provide an estimate of the bundle hot-spot behavior. This aspect of the problem is especially important for conduits with high conductor counts. The licensee's simplistic treatment of the jacket and insulation effects for an individual conductor is also not adequate to this need because it fails to allow for the fact that the conductor may be located at the center (or top) of the bundle, rather than being in actual contact with the conduit.

In summary, SNL finds that the licensee approach to the modeling of heat transfer effects within the conduit has not been adequately documented, does not appear to have been followed in the actual model implementation, and may not be consistent with accepted practice. There is no assurance that the licensee treatment will be conservative for all cases.

2.3 The Licensee Validation Case Study

As a basis for validation, the licensee has provided a direct comparison between one experiment from the Texas Utilities Electric (TUE) ampacity test series [3] to a corresponding calculation using the cited thermal model. The licensee cites that result of the calculation was an estimated ampacity limit of 513 A as compared to a tested value of 564 A, an apparently conservative result. However, SNL notes that the licensee discussion of this test appears to deviate from the TUE test report in two critical areas. These are:

- The licensee calculation has set the thickness of the Thermo-Lag to 1/4" (see page 9 of the licensee attachment just above the center of the page, t_{tal}). However, the TUE test report clearly states that the 5" conduit clad configuration was constructed using 1/2" nominal thickness pre-formed conduit sections (see page 8 of the TUE test report). The licensee appears to be confusing this product with the alternate TSI upgrade product used on the 3/4" conduit, the 2" conduits and the air drop applications.

- The licensee cites that "at 89.4 deg. C the conductor current was 564 A." However, the TUE report cites an actual measured ampacity of 509 A and a corrected ampacity for standard conditions of 510 A for the clad 5" conduit (see table on page 12 of the TUE test report). The licensee appears to be citing (incorrectly) the raw <u>baseline</u> case ampacity which was actually 567 A at a temperature of 89.4°C.

Given these observations, this licensee calculation cannot be concisely assessed. However, it is interesting to note that the estimated ampacity for a 1/4" thick barrier was 513 A as compared to a measured ampacity for a 1/2" thick barrier of 510 A. Increasing the barrier thickness to 1/2" should reduce the estimated ampacity limit by a very modest amount. Hence, this result be a nominal indication of limited net conservatism. However, given the observations regarding apparent mistakes and uncertainties in the thermal model, SNL considers this finding to be largely fortuitous.

Based on this one example case there is no assurance that the thermal model will yield conservative results for all cases considered. In particular, SNL notes that the licensee conduits contain as many as 18 individual conductors whereas the chosen validation test case contained only 4 conductors. Given the licensees treatment in "step 2" of the analysis, in particular the treatment of individual conductor heat loads as independent in the final analysis step, SNL would anticipate that for higher conductor counts, the results might well be non-conservative. This may, however, be offset by the inclusion of an air interface in the Step 2 analysis by the licensee (see Section 2.1.2 above). There is simply not enough information provided to tell for certain how conservative the results might be in any given application.

2.4 The Licensee Example Analyses

In addition to the validation case study described in 2.3 above, the licensee has also provided example analyses for two actual conduit applications at the plant. These are discussed briefly in the following sub-sections.

2.4.1 Example Analysis of conduit 2CH957OB

This conduit contains only a single triplex #4/0 power cable, hence, it represents a very simple analysis case. The licensee analysis of this case estimates a clad case ampacity limit of 162 A as compared to an in-plant service load of 146 A and a nominal ICEA conduit limit of 280 A in the absence of the fire barrier. As discussed further in section 3 below, SNL has concluded that this case can be deemed acceptable based on the large margin alone (146 A service load versus 280 A nominal unclad limit). However, it would appear that the license calculation has resulted in a conservative estimate of the cable ampacity limit for this case. The actual ampacity limit would likely be on the order of the ICEA conduit limit, plus or minus 5% depending on the barrier configuration and test chosen as representative. Hence, a more realistic estimate of the actual ampacity limit might be on the order of 266 A as compared to the licensee calculated value of 162 A. In this case, the conservative effect of the unexplained air interface in the step 2 analysis has clearly dominated the net result.

2.4.2 Example Analysis of conduit 2CL607OD

This case involves a large conduit with four separate cables. However, there is a discrepancy between the licensee calculation and the application summary table. In particular, the calculation cites that three of the four cables are 4-conductor while the application summary table cites that all four cables are of either a 3-conductor or triplex arrangement. If one assumes that the summary table is correct and that the calculation is in error, then the calculation has significantly over-estimated the actual heat load on the system. Hence, the cited ampacity limits have been artificially reduced.

SNL also notes that this is a case where all of the cables appear to have a very large margin available. In comparison to the nominal ampacity limits for a single cable in the conduit, each cable has a margin of between 79% and 93%. Hence, these cables are all carrying only very modest ampacity loads. SNL's analysis of this case (see section 3.3 below) indicated that even considering a multiple conductor count correction factor, all of these cables still have margins in excess of 50%.

The licensee thermal analysis has been considerably more conservative in its results. For the largest cable, an ampacity limit of just 53A is predicted. Even by conventional methods, the allowable ampacity limit for this cable would be at least 142 A (the ICEA limit of 317A times a 0.5 NEC correction factor for 10-20 conductors times a conservative ACF of 0.9 to account for the fire barrier). The licensee model appears to have yielded a grossly conservative result for this case. No clear explanation is apparent, although the apparent overstatement of the total heat load on the system due to the conductor count discrepancy is clearly a likely cause for this result.

3.0 THE LICENSEE APPLICATION SUMMARY TABLE

3.1 Overview

The final page of the licensee submittal presents a summary table for its fire barrier applications. This table is of particular interest because it provides, in a very concise format, the most critical information needed to support an ampacity margins assessment. In particular the table:

- identifies each of the clad conduits in the plant,
- identifies each of the cables enclosed within each conduit including the wire gauge and conductor count of each cable,
- quantifies the in-plant service loads for each cable, and
- cites the nominal ampacity limits for the given cable in a conduit application assuming the cable is alone in the conduit (not always the case).

Regarding the last point above, it is critical recognize that the cited nominal ampacity limits are those applicable to a single triplex or 3-conductor cable in a conduit alone. No additional derating for more than three conductors in a conduit have been applied. None-the-less, this summary table provides a firm basis for the identification of those cables which are clearly loaded well below any anticipated ampacity limits, and those for which some additional follow up assessment would be appropriate. In particular, the application summary table provides a clear basis for resolution of any potential ampacity concerns for many of the cables at BVPS.

3.2 Applications with Only a Single Cable Present

The licensee table identifies a total of 21 (out of 26) conduits that each houses only a single cable. SNL recommends that for these 21 applications this table, in an of itself, is sufficient to demonstrate the acceptability of the cited cable ampacity loads on the following bases:

- There are 18 conduits that contain only a single 3-conductor or triplex cable. For these cases the cited IPCEA P-46-426 ampacity limits are directly applicable, and the cited nominal margin can be compared directly to the anticipated fire barrier ADF. For these cases, the minimum available ampacity margin cited is 28.8%. Based on available test results from both Tennessee Valley Authority (TVA) and TUE, this margin is clearly sufficient to bound the worst case ampacity impact for a Thermo-Lag clad conduit application including both 1-hour and 3-hour installations.

- There are three additional conduits cited as containing only a single 4-conductor ("type: QUAD") cable. The ampacity loads for these three applications are clearly trivial as demonstrated by margins in excess of 90%. No further assessment of these cases is needed.

Hence, for these 21 single-cable conduit applications, SNL recommends that no further documentation or evaluation by the licensee nor by the USNRC is warranted.

3.3 Multiple Cable Applications

In addition to the applications involving only a single installed cable, there are five (out of 26) conduits identified as containing more than one cable. The number of cables present ranges from two to six, and the total conductor count for these applications ranges from 6 to 18.

For three of these applications, a nominal assessment based on the cited IPCEA P-46-426 ampacity limits for a 3-conductor or triplex application in combination with the National Electric Code (NEC) correction factors for more than three conductors in a conduit[1] can be cited as a sufficient basis for demonstration of acceptable ampacity loads. These are:

- Raceway 2CL607OD: This raceway is cited as containing four cables with a total conductor count of 12. The NEC correction factor for 10 through 20 conductors is 50%. Even considering the cable with the lowest identified margin, correcting the base ampacity by a 0.5 ACF stills yields an available margin of well over 50%. This is clearly sufficient to bound the worst-case ampacity derating impact of a Thermo-Lag clad conduit.

- Raceway 2CL607OF: This raceway is cited as containing six cables with a total conductor count of 18. Hence, the analysis of this conduit is identical to that cited immediately above for Raceway 2CL607OD, and the minimum available margin for the cited cables is well in excess of 50%.

- Raceway 2CL923OA: This raceway is cited as containing two cables with a total conductor count of six. The NEC correction factor for 4 through 6 conductors is 80%. Applying a 0.8 ACF to the nominal ampacity limits still yields an available ampacity margin of over 60% for both cables. This is clearly sufficient to bound the worst-case ampacity derating impact of a Thermo-Lag clad conduit.

For the remaining two raceways, there is some potential that certain of the cables contained within the raceway may be nominally overloaded. These applications are described as follows:

- Raceway 2CL213ND: This raceway is cited as containing five cables with a total conductor count of 10 (all five cables are cited as duplex type). It should also be noted that this application involves a 3-hour barrier installation. As noted above, the NEC correction factor for 10 through 20 conductors is 50%. When the cited ampacity limits are corrected using this factor, the available ampacity margin may not be sufficient to allow for the fire barrier installation. In fact, for two of the five cables, the ampacity loads are nominally in excess of the ICEA/NEC limits (a cited load of 54.6A versus a nominal limit of 37.5A). It is likely that an "engineering evaluation" of this case would yield more generous ampacity limits because the

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[1]In this analysis, SNL has used the NEC 1995 ampacity correction factors from Article 310 presented on page 70-196 of the handbook under "Notes to Ampacity Tables of 0 to 2000 Volts", item 8(a). These factors do not credit load diversity.

conductor count of 10 is at the lower limit of the NEC count range. For example, if the conductor count were 9 instead of 10, then the correction factor would be 70% instead of 50%, a significant difference. In this case, three of the five cables would clearly have sufficient margin, but the remaining two cables would not. Even applying a 0.7 correction factor, two of the cables appear to be nominally overloaded (cables 2SCANNL025 and 2SCANNL026 each with a cited load of 54.6A versus a nominal modified limit of 52.5A). SNL recommends that the USNRC ask the licensee to provide an explicit justification for the ampacity loads of the cables in this raceway.

– Raceway 2CL607OE: This raceway is cited as containing three cables with a total conductor count of nine. The NEC correction factor for 7 through 9 conductors is 70%. Applying this correction to the cited IPCEA ampacity limits, one of the three cables appears to be nominally overloaded even in the absence of the fire barrier system (cable 2HVSAOL200 with a cited load of 280A versus a nominal IPCEA/NEC limit of 269A). Of the remaining two cables, one may have insufficient margin to allow for the fire barrier (cable 2HVSAOL210 with a cited load of 277A versus a nominal IPCEA/NEC limit of 334A indicating a nominal margin of about 13%). SNL recommends that the USNRC ask the licensee to provide an explicit justification for the ampacity loads of the cables in this raceway.

4.0 SUMMARY OF FINDINGS AND RECOMMENDATIONS

4.1 The Licensee Thermal Model

Regarding the licensee's heat transfer analysis methodology and implementation, this review has identified a number of points of potential concern. SNL recommends that the USNRC ask the licensee to follow one of three potential paths to closure for these concerns. SNL has phrased these findings in the form of a recommended request for additional information that identifies the information that in our view would be necessary to allow for a more complete review and assessment of the licensee modeling approach.

- Option 1 - Continued Reliance on Wetted Perimeter Approach: If the licensee desires to continue its reliance on the partially filled pipe/wetted diameter approach then additional documentation of the model development and implementation is needed, and the resolution of specific points of apparent error or inconsistency should be addressed as follows:
  - Provide, for review, a copy of the Okonite Bulletin EHB-90 (licensee reference 1) cited as the basis for the wetted diameter calculation approach.
  - Correct or explicitly derive and justify the first term in the denominator of the expression for U_0 appearing near the center of page three of the submittal attachment. This term, associated with heat transfer to and through the conduit itself, appears to be in error, and does not appear to properly account for the reduction in heat transfer rates associated with the partial "wetted diameter" approach.
  - Explicitly state the intent of the apparent air interface term appearing in the expression for cable conductor temperature calculation as it appears on Page 5 of the attachment. Explain the consistency of this expression with the stated intent to base the analysis on a "wetted diameter" approach to analysis. If it is the licensee intent to include an air gap at this stage of analysis, then the selected value of the "film coefficient", 1.65 BTU/hr/ft^2/°F, should be explicitly justified as applicable to this analysis. Alternatively, the air gap should be treated as an annular ring similar to the treatment provide for the conduit-to-fire barrier air gap.
  - Explicitly state how the effects of heat transfer within the cable bundle have been addressed in the model. In particular, ensure that the thermal model includes consideration of heat conduction through to the center of the cable bundle in addition to the thermal effects of the individual conductor insulation and jacket materials.

- Option 2 - Implementation of the Buller/Neher Approach: As an alternative, the licensee should consider modification of the thermal model so as to comply with the accepted Buller/Neher [1950 AIEE] approach to analysis of cable bundle to conduit heat transfer behavior. This would require that the second step of the licensee analysis model be replaced by an implementation of the Buller/Neher correlations for hot-spot to conduit thermal resistance factors. In particular, Buller/Neher Equation 1 is recommended. This option would also require that the discrepancy regarding the equation for U_0 as it appears at the center of page 3 of the attachment be addressed.

- Option 3 - Implementation of a Conservative Air Gap Approach: As a third alternative the licensee might consider implementation of a conservative approach to conduit-to-cable heat transfer in which the cable bundle and conduit are separated by an annular air gap, and heat transfer within the bundle is treated based on simplified correlations for the temperature at the center of a cylinder with uniform heating. Holman's *Heat Transfer* [1976] provides such an expression as equation 2-25, and Stolpe [1957 AIEE] provides an estimate of cable bundle conductivity appropriate for such an application. This option would also require that the discrepancy regarding the equation for U_0 as it appears at the center of page 3 of the attachment be addressed.

The concerns addressed by the above comments and options are primarily associated with the heat transfer behavior internal to the conduit. In addition to these concerns, there is one additional point of concern that would be relevant to all three of these options:

- With regard to the treatment of external system heat transfer, SNL finds that the licensee has not established a basis for the cited "ambient air film coefficient" for exchange between the outer surface of the fire barrier and the ambient environment (a uniform value of 1.65 BTU/hr-sq.ft-degF has been cited in the example analyses). It is recommended that the USNRC ask the licensee to explain the intent of this factor, to explicitly state how it was derived, and to discuss its relevance to the conduits and fire barrier systems under consideration in this analysis as regards the physical size of the system, the driving temperature difference, and the surface emissivity.

4.2 The Licensee Validation and Case Examples

In addition to documenting the thermal model, the licensee has provided specific calculation examples in the form of one validation case and two in-plant example cases. Regarding the licensee validation case study:

- SNL finds that the licensee has incorrectly cited the test results (i.e., measured clad case ampacity) from the TUE test program, and has incorrectly set the fire barrier thickness to 1/4" as compared to the actual tested value of 1/2" nominal. The results of this case analysis appear conservative but are uncertain. It is recommended that the USNRC ask the licensee to correct its analysis to address the apparent errors.

With regard to the two in-plant case analysis examples:

- Both case examples appear to have resulted in very conservative estimates of cable ampacity limits. However, given the apparent errors in approach and implementation, SNL views these results with some scepticism.

– In the case of conduit 2CL607OD the information provided in the calculation is not consistent with the information provided in the licensee application summary table as regards the conductor count for the three #4AWG cables. The calculation cites that these are 4-conductor cables whereas the table indicates that they are of a 3-conductor configuration (size and conductor count may have been confused by the licensee in the calculation). This has apparently compromised the calculation by artificially increasing the estimated heat load well above that actually present.

It is recommended that the USNRC ask the licensee to reconsider its validation and case example quantification studies in light of both these specific findings and the general modeling concerns identified above.

4.3 Insights from the Application Summary Table

Based on an SNL review of the licensee application summary table (the last page of the licensee attachment) SNL finds that ampacity concerns for 24 of the cited 26 conduits have been adequately resolved by virtue of this table alone. It is recommended that the USNRC ask the licensee to focus its attention on the remaining two conduits for which an adequate ampacity margin has not yet been demonstrated; namely, raceways 2CL213ND and 2CL607OE. It is further recommended that the licensee be asked to provide an explicit justification for the ampacity loads for the cables in these two raceways. These assessments should be made consistent with accepted practice. This could include thermal modeling analyses provided that the items of concern identified in Section 4.1 immediately above are addressed.

5.0 REFERENCES

1. F. H. Bulier and J. H. Neher, "The Thermal Resistance Between Cables and a Surrounding Pipe or Duct Wall," *AIEE Transactions*, Volume 69, pgs 342-349, 1950.

2. J. H. Neher and M. H. McGrath, "The Calculation of the Temperature rise and Load Capability of Cable Systems," *AIEE Transactions*, pgs 752-772, Oct. 1957.

3. *Ampacity Derating of Fire Protected Cables - Electrical Test to Determine the Ampacity Derating of a Protective Envelope for Class 1E Electrical Circuits*, Prepared for TU Electric Comanche Peak Steam Electric Station by Omega Point Laboratories, March 19, 1993.

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

5. J. P. Holman *Heat Transfer*, McGraw-Hill, Fourth Edition, 1976.