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

SAFETY EVALUATION BY THE OFFICE OF NUCLEAR REACTOR REGULATION

GENERIC LETTER 92-08 THERMO-LAG-RELATED AMPACITY DERATING ISSUES

PECO ENERGY COMPANY

PEACH BOTTOM ATOMIC POWER STATION, UNITS 2 AND 3

LIMERICK GENERATING STATION, UNITS 1 AND 2

DOCKET NOS. 50-277, 50-278, 50-352, AND 50-353

1.0 BACKGROUND

By letters dated March 13, 1998, and March 12, 1999, PECO Energy Company (the licensee) submitted a response to the U.S. Nuclear Regulatory Commission's (NRC's) Request for Additional Information (RAI) dated November 14, 1997, related to Generic Letter (GL) 92-08, "Thermo-Lag 330-1 Fire Barriers," for Peach Bottom Atomic Power Station (Peach Bottom), Units 2 and 3, and Limerick Generating Station (Limerick), Units 1 and 2.

Listed below is a brief outline of the history associated with the matter under review:

3/24/97: In response to GL 92-08 and an NRC RAI dated June 22, 1995, the licensee provided documentation of its methodology intended to assess the ampacity derating factors associated with its installed fire barriers systems.

11/14/97: NRC's RAI was issued to request information regarding licensee's ampacity methodology.

3/13/98: Licensee's response addressed RAI questions.

11/4/98: A meeting was held between the NRC staff, Sandia National Laboratories (SNL), and licensee's representatives to discuss the licensee's conduit validation studies.

3/12/99 Licensee's response addressed RAI questions.

The staff's evaluation of the ampacity derating methodology for Peach Bottom and Limerick Stations follows.

Enclosure

2.0 EVALUATION

After reviewing the licensee's submittals and SNL's Technical Letter Reports (TLRs, see Attachments 1 and 2 of this safety evaluation), the staff agrees with the SNL analyses and conclusions. The ampacity derating analysis questions, the licensee's responses, and the staff's evaluations of the responses follow.

2.1 Ampacity Derating Analysis Review

Question 1

SNL found that the licensee's thermal model development had the following areas of technical concern which may contribute to non-conservatism in the models:

Modeling of Internal Convection

a. The licensee has treated internal air spaces using correlations only appropriate to the analysis of open unobstructed surfaces. SNL finds that this treatment is inappropriate as a general model of internal convection behavior. It is recommended that the licensee either: (1) justify its current treatment on a case-by-case basis for each case considered, and/or (2) implement an alternate treatment of internal convection based on accepted methods of confined space convection analysis.

b. The licensee has treated multiple heat sources in a common enclosure independently rather than simultaneously. This treatment will overestimate the rates of convective heat transfer for many typical applications. To correct this problem, it is recommended that the licensee modify its assumptions regarding the effective barrier heat transfer area available for convective exchange to each individual commodity. A specific approach to resolution has been documented in the SNL Letter Report dated September 23, 1997.

Radiation Shape Factors

c. In the analysis of radiative heat transfer for stacked cable trays, the licensee apparently intends to utilize a generic value to characterize tray-to-side panel radiation view factors for intermediate (blocked) trays. SNL finds that the cited value has not been shown to conservatively bound the anticipated value of this coefficient, and was nonconservative for the one relevant example case cited in the licensee's submittal. It is recommended that the licensee either: (1) demonstrate that the generic value used is conservatively bounding for all cases to be analyzed; or (2) calculate the correct value on a case-by-case basis for each configuration (simplified correlations for this process were cited in the SNL Letter Report dated September 23, 1997).

Concerns Specific to Junction Box and Gutter Models

d. SNL finds that the thermal model as applied to junction boxes and cable gutters was not as thoroughly documented as were the conduit and cable tray models.

SNL recommends that the licensee clarify its treatment of the following aspects of these applications: (1) How has heat transfer between the cable bundle and the enclosure (the junction box or gutter) and between the enclosure and the fire barrier been handled? (2) How does the assumed baseline ampacity impact the results of the analysis? (3) What is the rationale for treating cable gutters in a manner unique from that of a general cable tray?

In conclusion, the licensee is requested to address the concerns identified or propose an alternate approach which addresses the thermal modeling issues.

Licensee's Response

In its submittal dated March 13, 1998, the licensee provided the following information in their responses to each of the thermal modeling issues identified above (Questions 1.a through 1.d):

Response to Q1.a.

The majority of the raceway and enclosure configurations analyzed using the thermal model have large and often irregular internal spaces which cannot be idealized as "cavities" with clearly defined parallel faces and no intervening objects. The raceways analyzed using the thermal model involved the following protected raceways and enclosures:

1. Single conduits (Limerick)
2. Single trays (Limerick)
3. Cable gutters (Limerick)
4. Multiple trays in a common enclosure (Limerick)
5. Multiple conduits in a common enclosure (Peach Bottom)
6. Junction boxes (Limerick and Peach Bottom)

Of the raceways and enclosures listed above, only the single tray and gutter enclosures could be considered to have "cavities" for which a cavity heat transfer equation might have been more appropriate than the simplified free convection equation used in the model. The single conduit enclosures are formed using flat panels, such that, instead of a single gap of a uniform thickness between the conduit and the fire barrier, four interconnected spaces of varying width are formed. The junction boxes have large internal air spaces cris-crossed with cables such that a clearly defined "cavity" between the cables and the enclosure does not exist. Similarly, the multiple conduits or trays in a common enclosure have a large, single air space interrupted by the raceways.

A detailed justification of the approach used in the model is provided in Attachment 2 of the March 13, 1998, submittal, where the film equation used in the model is compared with the "cavity" equation for a protected cable tray. The results of this comparison show that the average interior heat transfer coefficient based on the film equation produces a heat transfer coefficient that is about 10 to 20 percent smaller than the average heat transfer coefficient calculated using the cavity equation. The convective heat transfer is significantly smaller than the radiative heat transfer so that a 20-percent change in the convective heat transfer coefficient affects the overall heat transfer coefficient for the entire cable-tray fire barrier assembly by only about 1 percent. The overall effect of this approach on the ampacity derating factor is approximately half a percent.

Therefore, a thermal model based on the simple film coefficient has been found more appropriate and less restrictive than the cavity heat transfer equation. The incremental benefit to be gained from a more sophisticated model is well within the uncertainties introduced into these analyses due to approximations elsewhere.

Staff's Evaluation

Based on the NRC staff review of the information provided by the licensee, as described above, we conclude that the licensee has justified its current treatment of internal air spaces on a case-by-case basis for each case considered. The information provided by the licensee fully resolves the staff's concerns.

Response to Q1.b.

The issue of independent treatment of multiple heat sources has raised concerns regarding the proper use of the enclosure air space temperature and the effective barrier heat transfer area. Both concerns are addressed below.

The thermal model treats each raceway independently only as far as the calculation of the convective heat transfer coefficient from the raceway to the air inside the enclosure is concerned. The barrier temperature (inside and outside) is based on the total heat generated simultaneously by all of the raceways enclosed within the barrier. Since different raceways within the same barrier may have different thermal resistances, it is natural to expect that they may also have different surrounding air temperatures. This difference, however, is not very large. Examination of the Limerick and Peach Bottom calculations shows that the deviation from the mean air temperature is well within 10 °F. This deviation from the mean air temperature does not introduce non-conservatism into the results. On the contrary, it introduces conservatism, though negligibly small, because the raceway-to-barrier convective heat transfer coefficient attains its highest value when based on the mean temperature. Any temperature above or below it produces a smaller heat transfer coefficient. Since the recommended approach (simultaneous heat transfer) would result in a single internal enclosure air temperature very close to the mean air temperature, and therefore a somewhat higher heat transfer coefficient, we have concluded that the approach used in the model is an adequate alternative because of its conservatism and practicality.

With regard to the concern of proper allocation of the effective barrier heat transfer area, the thermal model has been revised as recommended such that each raceway in a common enclosure is allocated a barrier heat transfer area proportional to its own surface area. This modification has been applied to all enclosures containing two or more raceways, and the Limerick and Peach Bottom ampacity derating calculations will be revised accordingly.

Staff's Evaluation

Based on the NRC staff's review of the information provided by the licensee, we find the proposed alternative regarding the use of enclosure space, as well as the revised allocation of the effective heat transfer areas, as recommended by SNL in Question 1.b., to be acceptable. The information provided by the licensee fully resolves the staff's concerns.

Response to Q1.c.

In accordance with the SNL recommendation, the radiation shape factors have been calculated on a case-by-case basis using the actual raceway/enclosure dimensions in lieu of the generic values, and the Limerick and Peach Bottom ampacity derating calculations will be revised accordingly.

Staff's Evaluation

The staff finds that the licensee's adoption of the SNL recommendation in the calculation of the radiation shape factors and the commitment to revise the ampacity derating factors accordingly fully resolve the staff's concerns.

Response to Q1.d.

The discussion of the junction boxes and cable gutters has been expanded to provide greater clarification. In brief, the answers to the questions raised are as follows:

1. For junction boxes, the heat transfer from the cables to the junction box is by conduction through the cable bundle and convection plus radiation from the surface of the cable bundle to the junction box. The cables in each conduit attached to the junction box are assumed to stay in a solid circular bundle. The heat transfer from the junction box to the fire barrier is by conduction in the air gap plus radiation. The cable gutters are treated similar to the junction boxes except that only a single cable bundle is assumed.

2. The baseline ampacity for cables in the junction boxes and gutters is used as a reference value to calculate the ampacity derating factor. Thus, the higher the baseline ampacity, the higher the ampacity derating factor is and vice versa. Unlike the conduits, for which the baseline ampacity is also used to calculate the thermal resistance of the cable-conduit assembly, the baseline ampacities for junction boxes and gutters serve as reference values. The thermal resistance of the cable bundle is calculated from the classic conduction equation for solids with internal heat generation. The baseline ampacities are assigned in accordance with the IEEE/NEC [Institute of Electrical and Electronics Engineers/National Electric Code] guidelines applicable to conduits.

3. The rationale for treating the cable gutters differently from the cable trays is that, unlike the cable trays, gutters have a solid metal enclosure on all four faces. As a result of this, the gutters may also have a continuous but narrow air gap between the metal enclosure and the fire barrier. For these reasons, gutters are

closer to junction boxes than to trays. Treating the gutters as cable trays would require neglecting the effect of the air gap between the metal enclosure and the fire barrier which would result in a lower ampacity derating factor.

Staff's Evaluation

The staff has reviewed the additional clarifying information provided in the licensee's response and finds that it provides the appropriate data to support the application of the licensee's thermal model as it applies to junction boxes and cable gutters and fully resolves the staff's concerns on this issue.

Question 2

SNL found that the current licensee validation studies to be insufficient because the licensee calculations do not make direct comparison to all of the available experimental data. SNL recommends that the licensee document validation results for the following cases:

a. In the case of the conduit calculations, it is recommended that the licensee be asked to document validation results for the conduit barrier enclosure tests performed by Tennessee Valley Authority (TVA) for the Watts Bar plant as follows: (1) Test Article 7.4, three one-inch conduits in a common, tight-fitting enclosure, (2) Test Article 7.5, six one-inch conduits in a common, tight-fitting enclosure, (3) Test Article 7.8, six one-inch conduits in an oversize enclosure, (4) Test Article 7.7a, single one-inch conduit in a small, boxed enclosure, and (5) Test Article 7.7b, single one-inch conduit in an oversized, boxed enclosure.

b. For the cable tray calculations, it is recommended that the licensee be asked to document validation results which are directly comparable to available experiments from Texas Utilities (TU), TVA, and/or Florida Power Corporation. These evaluations should include at least one representative case for a single tray enclosure and the TVA 3-tray stack test (TVA Test Article 7.3).

The licensee is requested to reconsider its validation of its thermal model and to provide example case calculations in light of the specific SNL findings and the thermal modeling concerns identified in Question 1 above. (See Sections 3.1 through 3.4 of the SNL Letter Report dated September 23, 1997, for further details).

Licensee's Response

In its submittal dated March 13, 1998, the licensee provided the following responses to each of the thermal modeling issues identified above (Questions 2.a and 2.b):

a. The conduit model was validated against test data from TU. In accordance with the SNL recommendation, the validation of the conduit model has been expanded to include additional test cases from the available TVA Watts Bar test series for single and multiple conduits.

On the basis of these results, it is concluded that the conduit model is reasonably conservative, except for the case of a single conduit in a box enclosure for which the model's prediction is 0.3 to 1.3 percentage point lower than the test data. To compensate for this small deviation, the ampacity derating factor results of the conduit model for single conduits in box enclosures are increased by two percentage points. This increase will be applied to the revised Peach Bottom and Limerick cable ampacity derating factors.

b. The cable tray model was validated against test data from TU. The validation cases have been expanded to include additional tests from the available TVA Watts Bar three-stack trays. Data for Florida Power Corporation single-tray test case are treated proprietary and are not made available to the public. The results of the validation study and example case calculations are provided in the March 13, 1998, submittal. Below is a brief summary of the test cases and the results.

Test Case	**ADF**	
	Test	**Model**
Single Unprotected Tray (IPCEA Table 3.6) - Baseline Ampacity	55 amp	51.8 amp
Single Protected Tray (TU Test AT-1)	31.6%	32.4%
Three Trays in a Tight Enclosure (TVA Test 7.3)	35.5%	41.4%

This comparison shows that the predictions of the cable tray model reasonably bound the test data.

On the basis of these comparisons, it is concluded that the cable tray model is sufficiently conservative, and no adjustment of the results is necessary to provide additional margin.

Staff's Evaluation

The information provided by the licensee indicates that the cable tray model was validated against applicable industry data thereby resolving the staff's concerns for Question 2.b. For Question 2.a, the information provided by the meeting held on November 4, 1998, with the licensee's representatives and the licensee's submittal dated March 12, 1999, clarified the validation studies for the conduit ampacity derating analyses thereby resolving the staff's concerns.

Question 3

The licensee is requested to identify the industry ampacity derating values being applied to the Peach Bottom and Limerick plant-installed configurations. The licensee should also explain the technical basis used to ensure that any installed plant configurations which utilize industry test data are representative in terms of design and construction of the applicable tested fire barrier configurations.

Licensee's Response

In its submittal dated March 13, 1998, the licensee provided the following information:

The ampacity derating factors for Peach Bottom are all based on heat transfer calculations using the thermal model. None of the Peach Bottom configurations compared with the industry test configurations and, therefore, no industry ampacity test values were used for Peach Bottom.

Industry ampacity derating values have been applied to Limerick-installed plant configurations for 1-hour rated single trays, 1-hour rated single conduits, and 1-hour rated two-stacked trays. The ampacity derating factors for 1-hour rated single trays and single conduits are based on TU's test data as revised by the NRC Safety Evaluation Report for Comanche Peak Steam Electric Station dated June 14, 1995. The technical basis to ensure that tested configurations are representative of the Limerick configurations is provided below.

Table 1: Comparison of Limerick Raceway Configurations with TU Test Configurations

Raceway Attribute	Limerick As-Designed Configuration	Comanche Peak Tested Configuration	Comments
Cable Trays			
Cable Tray Size	24" x 4"	24" x 4"	As Designed is the same as Tested.
Cable Trays Material	Aluminum	Steel	See Note 1 below.
Barrier Material	Thermo-Lag 330-1 Prefabricated V-rib Panel	Thermo-Lag 330-1 Prefabricated V-rib Panel	As-Designed is the same as Tested.
Barrier Thickness	5/8" (± 1/8")	5/8" (± 1/8")	As-Designed is the same as Tested.
Joint Types	Pre-buttered with trowel grade material	Pre-buttered with trowel grade material	As-Designed is the same as Tested.
Joint Upgrade Methods	Stress Skin, Trowel Grade, Wire, Staples	Stress Skin, Trowel Grade, Wire, Staples	As-Designed is the same as Tested.
Conduits			
Raceway Type	Conduit	Conduit	As-Designed is the same as Tested.

Raceway Attribute	Limerick As-Designed Configuration	Comanche Peak Tested Configuration	Comments
Conduit Size	0.75" to 6"	2.0" & 5.0"	Tested sizes are representative of the range of As-Designed.
Conduit Material	Steel	Steel	As-Designed is the same as Tested.
Barrier Material	Thermo-Lag 330-1 Prefabricated Conduit Sections	Thermo-Lag 330-1 Prefabricated Conduit Sections	As-Designed is the same as Tested.
Barrier Thickness	5/8" (± 1/8")	5/8" (± 1/8")	As-Designed is the same as Tested.
Joint Types	Pre-buttered with trowel grade material	Pre-buttered with trowel grade material	As-Designed is the same as Tested.

Note:
1. Tray material is not a factor in ampacity testing of ladder type open trays since the heat transfer is directly from the surface of the cables to the fire barrier.

Staff's Evaluation

The licensee stated that no industry ampacity test values were applicable for Peach Bottom and that the industry test data utilized for Limerick-installed plant configurations are representative of the tested fire barrier configurations; thereby, resolving the staff's concerns.

2.2 Application of Ampacity Derating Methodology

The intent of the licensee's thermal model is to analytically predict fire barrier ampacity derating factor (ADF) values for untested configurations. The same basic model is applied to single tray, to single conduit, and to unique configurations such as multiple raceways in a common fire barrier envelope. The model is also used to analyze barrier enclosures that include concrete walls as one or more sides of the barrier system. The ultimate objective of the PECO methodology is to predict the ADF (or equivalently, the ampacity correction factor (ACF)), for a specific raceway (conduit, cable tray, junction box, etc.) in a given fire barrier installation.

In practice, the licensee analyzes a "generic" raceway using the specific as-installed barrier configuration information and a representative cable fill. That is, the fire barrier is modeled as installed in the plant, but in the model the raceway is assumed to carry a roughly equivalent cable fill intended to represent but not reproduce the cables actually installed in the subject raceway. For simplicity of modeling, the cable fill is assumed to be made up of a single size of cable for which tabulated ampacity limits are readily available (rather than a mixture of cable sizes and ampacity loads as actually encountered in the plant). It is analogous to testing a standard cable tray with a standard cable load and extrapolating the results to a specific plant installation. Indeed, the approach introduces one source of conservatism in that the effects of ampacity load diversity are neglected.

Estimating the ADF requires the clad and baseline case ampacity limits. The role of the thermal model in this process is to estimate the clad case ampacity limit for the "generic" raceway in a given fire barrier configuration. The corresponding baseline limit is taken from standard industry tables of cable ampacity (i.e., IPCEA P-46-426 and ICEA P-54-440). The ADF is then based on a comparison of the predicted clad case ampacity limit to the nominal tabulated baseline ampacity limit for the same "generic" raceway. This ADF value for the fire barrier would then be applied to the existing ampacity limits of the installed cables for a final assessment of ampacity loads. Given that the thermal model for the clad case is consistent with the thermal model that underlies the original ampacity tables this approach is acceptable.

Given that the information provided by the licensee has addresses all of the identified concerns, the staff finds that the licensee has provided adequate basis to resolve the ampacity-related points of concern raised in GL 92-08 for the applicable thermo-lag configurations.

3.0 CONCLUSIONS

From the above evaluation the staff concludes that the licensee has provided an adequate technical basis to assure that the enclosed cables are operating within acceptable ampacity limits. Therefore, the staff finds that there are no outstanding safety concerns with respect to GL 92-08 ampacity issues for Peach Bottom, Units 2 and 3, and Limerick, Units 1 and 2.

Attachments:
1. Technical Letter Report, "A Final Technical Review of the PECO Ampacity Assessment Methodology and RAI Responses for Limerick and Peach Bottom," dated April 30, 1998
2. Technical Letter Report, "A Final Technical Evaluation of the PECO Conduit Ampacity Assessment Methodology for Limerick and Peach Bottom," dated October 19, 1999

Principle Contributor: R. Jenkins

Date: January 12, 2000

A Final Technical Review of the PECO Ampacity Assessment Methodology and RAI Responses for Limerick and Peach Bottom

A Letter Report to the USNRC

April 30, 1998

Revision 0

Prepared by:
Steven P. Nowlen
Accident and Consequence Analysis Dept.
Sandia National Laboratories
Albuquerque, New Mexico 87185-0748

Prepared for:
Ronaldo Jenkins
Electrical Engineering Branch
Office of Nuclear Reactor Regulation
U. S. Nuclear Regulatory Commission
Washington, DC 20555
USNRC JCN J2503

Attachment 1

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FORWARD

The United States Nuclear Regulatory Commission (USNRC) has solicited the support of Sandia National Laboratories (SNL) in the review of licensee submittals associated with fire protection and electrical engineering. This letter report represents the second report in a series of review reports associated with submittals from PECO Energy for the Peach Bottom Atomic Power Station (PBAPS) and the Limerick Generating Station (LGS). The subject submittals are related to the assessment of the ampacity derating impact of Thermo-Lag 330-1[1] fire barriers when installed on cable trays, conduits, junction boxes, and cable gutters. The original licensee submittal was reviewed by SNL as documented in a letter report of September 23, 1997. Based in large part on SNL's findings, a Request for Additional Information (RAI) was forwarded to the licensee by the USNRC on November 14, 1997. The objective of the current review is to assess the adequacy of the licensee's response to this RAI as documented in a licensee submittal of March 13, 1998. This report document SNL's findings and recommendations The original documents were submitted by the licensee in response to USNRC Generic Letter 92-08 and a subsequent USNRC Request for Additional Information (RAI). This work was performed as Task Order 4, Sub-task 5 of USNRC JCN J-2503.

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[1]Thermo-Lag 330-1 is a registered trademark of Thermal Sciences Inc.

1.0 INTRODUCTION

1.1 Objective

In response to USNRC Generic Letter 92-08 and a subsequent USNRC Request for Additional Information (RAI) of June 22, 1995, PECO Energy provided documentation of the methodology that the licensee intends to utilize in assessing the ampacity derating factors associated with its installed fire barrier systems. The methodology is to be applied at both the Peach Bottom Atomic Power Station (PBAPS) and the Limerick Generating Station (LGS). SNL was asked to review the licensee's submittals under the terms of a general technical support task ordering agreement JCN J-2503, Task Order 4, Sub-task 5. The original licensee submittal review by SNL was documented in:

- Letter, G. A. Hunger, Jr., PECO, to the USNRC Document Control Desk, March 24, 1997 with two attachments.

SNL's findings based on a review of this submittal were documented in a letter report to the USNRC dated September 23, 1997. Based in large part on the SNL findings, the USNRC forwarded a second RAI to the licensee on November 14, 1997. The licensee has now responded to this RAI via the following submittal:

- Letter, G. D. Edwards, PECO Nuclear, to the USNRC Document Control Desk, March 13, 1998 with two attachments.

The objective of this report is to document SNL's findings and recommendations based on a review of the above licensee submittal to assess the adequacy of the licensee's response to resolve the identified technical concerns.

1.2 Overview of the Licensee Ampacity Derating Approach

The licensee approach is based on a direct application of ampacity derating factors (ADFs) to tabulated ampacity limits for the installed cables. The ADF values to be used will derive from one of two sources:

- For plant configurations which correspond to configurations tested by other members of the industry, PECO will directly apply the experimentally determined ADF value.

- For untested configurations, the licensee applies a thermal model to assess the clad case ampacity limits and determines an ADF value for the application based on a comparison of the calculated clad case ampacity to tabulated nominal ampacity limits for the same application. The intent is that these ADF values would then be applied to each cable in the given application.

The SNL review has focused on the licensee thermal modeling approach and its technical validity. The direct application of a test-based ADF to like configurations is considered common and acceptable practice, so long as a sufficient basis for "thermal similarity" is established (one of the RAI items relates directly to this question). In this submittal, the licensee has not provided specific case examples to illustrate the in-plant application of either method; hence, no judgements in this regard have been made by SNL.

1.3 Organization of Report

Section 2 provides a very brief review of the licensee thermal model and identifies the areas of technical concern identified by SNL in our previous review. Section 3 considers the licensee response to each of the identified RAI items. Section 4 summarizes the SNL findings and recommendations. Section 5 identifies the referenced documents.

2.0 THE LICENSEE THERMAL MODEL

2.1 Objective of this Section

This section provides a brief overview of the licensee thermal modeling approach and summarizes the related technical concerns identified in SNL's 9/97 review. For a more complete discussion of the thermal model and the basis for SNL's concerns, refer to the SNL letter report of September 23, 1997 as cited above.

2.2 Summary of the Modeling-Based Approach

Recall that the intent of the licensee thermal model was to analytically predicted fire barrier ACF values for untested configurations. It is apparently intended that the same basis model will be applied to both single tray or single conduit configurations and to unique configurations such as multiple raceways in a common fire barrier envelope. This could include combinations of trays and conduits, boxed conduits (as compared to conduits clad with pre-formed conduit sections of the barrier material), and clad electrical enclosures such as junction boxes and wire-ways. The model is also intended to treat barrier enclosures that include concrete walls as one or more sides of the barrier system.

It is quite clear that no licensee, nor indeed even the industry as a whole, could perform enough tests to encompass all such applications. It has consistently been SNL's recommendation that when one must assess these types of unique installations, thermal modeling is the most appropriate and only viable approach. Given this "global" view, the questions which remain are the issues of the modeling details, avoiding optimism in the model implementation, overall technical acceptability, and validation. It is these questions that have been the focus of SNL's review.

2.3 Model Implementation

The ultimate objective of the PECO methodology is to predict the ampacity derating factor (ADF, or equivalently, the ampacity correction factor ACF), for a specific raceway (conduit, cable tray, junction box, etc.) in a given fire barrier installation. In practice, the licensee analyzes a "generic" raceway using the specific as-installed barrier configuration information. That is, the raceway that is analyzed is assumed to carry a roughly equivalent cable fill (as compared to the actual installed raceway) but the fill is assumed to be made up of a single size of cable for which tabulated ampacity limits are readily available (rather than a mixture of cable sizes and ampacity loads). This approach, for example, ignores the effects of load diversity on ampacity limits, and this is one source of conservatism in the model. All cables that make up the raceway fills are assumed to be energized while in reality, not all of the installed cables will be energized at any given time. It is important to note that the physical factors associated with the fire barrier and the physical arrangement of the raceways within the barrier are based on the as-installed conditions. SNL noted no specific concerns regarding this aspect of the general approach.

Estimating the ADF requires two bits of information; namely, the clad and baseline case ampacity limits. The role of the thermal model in this process is to estimate the clad case ampacity limit for the "generic" raceway in the given fire barrier configuration. The corresponding baseline limit is taken from standard industry tables of cable ampacity (IPCEA P-46-426 [1] and ICEA P-54-440 [2]). The ADF is then based on a comparison of the predicted clad case ampacity limit to the nominal tabulated baseline ampacity limit for the same "generic" raceway. This same ADF value would then be applied to baseline ampacity limits for specific installed cables for a final assessment of ampacity loads.

2.4 Summary of Initial Review Findings and Recommendations

As was noted by SNL in our 9/97 review and in the review of other licensee submittals, the comparison of thermal modeling based clad ampacities to tabulated baseline ampacities can be a very tenuous and potentially inappropriate approach to assessment. In this context the technical concerns focus primarily on issues of consistency between the clad and baseline case analyses and adequate validation. These concerns did weigh heavily in SNL's findings and recommendations. SNL also identified a number of technical concerns related to the actual implementation of the thermal model and the selection and implementation of the modeling correlations. The following summarizes the findings and recommendations that were cited in SNL's initial review as documented in the 9/97 letter report.

With regard to the thermal model, in general, SNL found that the PECO thermal model was well documented and did account for all of the significant thermal effects of interest. With a limited number of potential exceptions, as noted below, SNL found that the licensee utilized appropriate assumptions and correlations. Based on a review of the case examples, the model appears to have been implemented consistent with the text discussion, and SNL was able to reproduce the licensee numerical results for certain selected case examples.

There were, however, specific areas of technical concern identified by SNL that might contribute to optimism in the model results. In addition, SNL was unable to determine how certain aspects of the heat transport problem were handled for applications involving junction boxes and cable gutters. It was recommended that the licensee be asked to address these concerns as follows:

- SNL found that the licensee treatment of internal convection was potentially inappropriate and optimistic. Two points of specific concern were identified:
    - The licensee treated internal air spaces using correlations intended for the analysis of open unobstructed surfaces which may be optimistic.
    - The licensee treated heat transfer for multiple heat sources in a common enclosure independently rather than simultaneously and this was cited as an optimistic practice.

- SNL found that in the analysis of radiative heat transfer for stacked cable trays, the licensee apparently intended to utilized a generic value to characterize tray-to-side panel radiation view factors for intermediate (blocked) trays. However, the cited value was not shown to conservatively bound the anticipated value of this coefficient, and was non-conservative for the one relevant example case cited in the licensee submittal.

- SNL found that an inadequate basis had been established for the application of the thermal model to junction boxes and cable gutters.

- As noted above, validation of the licensee's modeling approach was considered by SNL to be a critical concern. However, SNL found the included licensee validation studies to be unconvincing and inadequate. SNL recommended that the licensee be asked to document validation results for a number of specific test cases for which data was readily available. In particular, it was recommended that additional validation for cases involving multiple raceways in a common enclosure was needed.

3.0 THE LICENSEE'S RAI RESPONSES

3.1 RAI Item 2.1a: Treatment of Internal Convection

3.1.1 Synopsis of Concern

The licensee was requested to either justify or modify the treatment of internal convection for the fire barrier systems based on use of external convection correlations rather than confined space correlations.

3.1.2 Synopsis of the Licensee Response

The licensee has provided arguments justifying its continued application of the external surface correlations for internal convection. The reasons given include:

- The typical barriers being analyzed "have large and often irregular internal spaces" which do not conform to the configurations generally considered in the confined space correlations, hence the film coefficient approach is more "appropriate."
- The impact of using the confined space correlation was found to <u>increase</u> the net convective coefficients by "about 10 to 20%." (Note that this shows the licensee treatment is actually more conservative.)
- Given the relative role of convection in the overall heat transfer, a 20% change in the convection coefficient increased the ADF by about one-half of one percent. (Again with the licensee approach being the more conservative.)
- The incremental benefit to be gained is "well within the uncertainties introduced into these analyses due to approximations elsewhere."

3.1.3 Assessment of Response Adequacy

The licensee response is adequate to resolve the identified concern. In particular, the licensee has demonstrated that their approach is actually more conservative in net effect than would be use of the SNL recommended confined space correlations. This somewhat unexpected result can be directly attributed to the licensee's choice of a very conservative value for the leading coefficient used in the cited open surface convection correlation. Recall that the licensee uses the same correlation for all surfaces regardless of orientation and chose a conservative leading coefficient for the general correlation to reflect an average or composite value. This was noted in SNL's 9/97 review as a generally conservative practice. In the current submittal the licensee has clearly demonstrated that this approach is conservative in comparison to confined space treatments.

3.1.4 Recommendations

SNL recommends that no further action on this RAI item is required.

3.2 RAI Item 2.1b: Simultaneous Heat Transfer

3.2.1 Synopsis of Concern

It was noted in the 9/97 review by SNL that the licensee had treated the heat transfer between each raceway and the inner surface of the barrier as independent for each raceway rather than simultaneous for all raceways even when the problem involved multiple raceways in a common enclosure. This was cited as a non-conservative approach. The licensee was asked to justify or modify this practice. An SNL recommended approach to the resolution of this problem was suggested.

3.2.2 Synopsis of the Licensee Response

The licensee response reiterates in part its original position in this regard. However, the licensee also states that the SNL recommended approach of apportioning the inner surface area of the barrier between the various commodities for the convective analysis will be incorporated into the model.

3.2.3 Assessment of Response Adequacy

The licensee has incorporated SNL's recommended "fix" for the cited concern. SNL also notes that the licensee new validation studies which include the "fix" (see RAI item 2.2b below) also support acceptance of the modified methodology. Hence, SNL finds that the licensee response is fully adequate to resolve the identified concern.

3.2.4 Recommendations

No further action on this RAI item is recommended.

3.3 RAI Item 2.1c: Radiation View Factors

3.3.1 Synopsis of Concern

The licensee assumptions regarding radiation view factors was cited as inappro priate and non-conservative. The licensee was asked to either demonstrate and use a conservative bounding value for the view factor or to calculate view factors on a case by case basis.

3.3.2 Synopsis of the Licensee Response

The licensee cites that view factors will be calculated on a case by case basis.

3.3.3 Assessment of Response Adequacy

The licensee response is fully adequate to resolve the identified concern.

3.3.4 Recommendations

No further actions on this RAI item are recommended.

3.4 RAI Item 2.1d: Junction Boxes and Cable Gutters

3.4.1 Synopsis of Concern

The licensee was asked to further explain and justify its approach to the analysis of junction boxes and cable gutters.

3.4.2 Synopsis of the Licensee Response

The licensee has clarified its treatment of these commodities. In particular, the licensee has provided a physical description of each, has explained the treatment that is provided, and has provide a technical justification for the cited approach.

3.4.3 Assessment of Response Adequacy

The licensee response is fully adequate to resolve the identified concerns. Given the physical descriptions provided, SNL finds the licensee treatment is acceptable and appropriate.

3.4.4 Recommendations

No further actions on this RAI item are recommended.

3.5 RAI Item 2.2a: Validation for Conduits

3.5.1 Synopsis of Concern

The licensee was asked to provide additional validation for the conduit thermal model, in particular, for multiple conduits in a common enclosure.

3.5.2 Synopsis of the Licensee Response

The licensee has applied the thermal model to several of the available conduit ampacity experiments, including in particular, the TVA multiple raceway tests. The results as cited by the licensee illustrate generally conservative estimates of the derating impact. Of the cases considered, the licensee concludes that in only two of the seven cases were optimistic results obtained, and in these two cases the level of optimism was quite modest.

3.5.3 Assessment of Response Adequacy

SNL has examined the licensee validation case studies in some detail as documented in Appendix A to this report. Based on this review, SNL finds that the licensee approach to the validation studies was fundamentally inconsistent with the intended approach to the evaluation of in-plant application. This renders the cited validation studies inappropriate and inadequate.

In particular, the validation cases were not evaluated in the same way that in-plant applications would be evaluated in practice. The validation study ADF results were base on the measured baseline ampacity values from the tests whereas, in practice, such data will not be available; hence, the in-plant applications will depend on standard ampacity tables for the determination of baseline ampacity. SNL has reevaluated the validation cases by nominally correcting this flaw and recalculating ADF predictions using tabulated baseline ampacity limits. (There is some uncertainty in the SNL assessments versus the intended PECO practice because the licensee has not fully documented its approach to the assessment of conduit baseline ampacities; hence, we have cited this work here as a "nominal" correction of the analysis.)

The results of the SNL re-analyses do not reflect well on the proposed method. The "corrected" ADF predictions were significantly optimistic for three of the four single conduit cases and for two of the three multiple conduit cases originally considered by the licensee. It was also noted that the actual results would be heavily dependent on the choice of how the baseline ampacity limits were actually determined. SNL's assessments were based on application of the IPCEA P-46-426 or NEC 1996 tables, which appear nominally consistent with the licensee approach.

The underlying concern that has not been addressed by the licensee is the consistency of the clad case model with the assumptions used to determine the baseline case ampacity. As discussed further below, for cable trays these concerns have been addressed. However, for conduits there is no assurance provided that such consistency has been achieved. As was noted by SNL in our original review of 9/97, establishing this consistency is critical to the validity of the licensee approach.

3.5.4 Findings and Recommendations

SNL finds that the licensee validation studies are insufficient to support acceptance of the proposed analysis method for conduit applications. Further, SNL finds that when the same set of validation cases is examined in a manner nominally consistent with the actual intended application practice, significantly optimistic estimates of the ADF impact resulted for five of the seven cases considered.

The fundamental flaw in the licensee validation studies is that the validations were not performed in a manner consistent with the intended in-plant applications. In terms of the thermal model itself, the underlying concern is the apparent lack of consistency between the thermal model and the baseline ampacity tables for conduits. The SNL re-analyses of the validation cases illustrate that this consistency is apparently lacking the conduit cases. Further interactions to address the optimistic nature of the SNL re-calculated results is recommended. In particular, it is recommended that the licensee be asked to either:

- implement a corresponding and self consistent thermal model for the analysis of the conduit baseline ampacity values (this is quite simple given the work already performed) and to base the ADF estimates on the comparison of two self-consistent ampacity limits, or
- demonstrate the acceptability of the current method using a validation approach that is fully consistent with the intended application practice (i.e., ADF's should be based on comparison of the model-based clad ampacity to a standard table-based baseline

ampacity where the method of analysis for the baseline ampacity is consistent with that used to assess in-plant cables).

In either case, it is further recommended that the licensee be asked to re-examine the validation cases using the full approach to analysis as it will be applied in the analysis of actual in-plant applications. This should include the analysis of the tested fire barrier systems using "generic" representative cable fills for which the baseline ampacity limits can be readily obtained from the standard tables as intended in practice. Under these conditions, the licensee should demonstrate that the ADF values can be reproduced without significant optimism in the results.

3.6 RAI Item 2.2b: Validation for Cable Trays

3.6.1 Synopsis of Concern

The licensee was requested to provide additional validation of the cable tray calculation methods through comparison of the proposed methods to available test results.

3.6.2 Synopsis of the Licensee Response

The licensee has provided validation results for three case examples. One involves a baseline tray with no barrier, the second a single wrapped cable tray, and the third is the three-tray stack test performed by TVA.

3.6.3 Assessment of Response Adequacy

The licensee's validation studies have been reviewed in detail by SNL as documented in Appendix A of this report. In the case of the cable tray applications, SNL finds that the licensee validation studies are adequate. In particular, the licensee has demonstrated that:

- The cable tray modeling assumptions are conservative for the baseline case as compared to the standard ICEA P-54-440 ampacity tables.

- For single tray configurations, the modeling results quite accurately predicted the ADF impact, and indeed, the actual clad case ampacity measured in the test.

- For the TVA three tray stack test, the thermal model provided a very conservative estimate of the ADF impact.

3.6.4 Findings and Recommendations

SNL finds that the cited validation studies have adequately addressed the identified concerns as applied to cable tray applications. SNL recommends that the licensee modeling approach be accepted for application to multiple tray configurations.

3.7 RAI Item 2.3: Use of Industry Data

3.7.1 Synopsis of Concern

The licensee was requested to verify that the cited industry ampacity derating values for test configurations were applicable to the Peach Bottom and Limerick installed fire barriers. The licensee was specifically asked to consider the physical features of the installed versus tested barriers as they might impact ampacity performance.

3.7.2 Synopsis of the Licensee Response

The licensee has stated that the use of industry test results in only relevant for the Limerick analyses as no such values were applied at Peach Bottom. For the Limerick single cable tray and single conduit applications a comparison table is provided that compares the installed versus tested barrier systems.

3.7.3 Assessment of Response Adequacy

The licensee response is fully adequate to resolve the identified concerns. The information provided does indicate that application of the cited industry data to the Limerick fire barriers is appropriate.

3.7.4 Findings and Recommendations

SNL finds that the licensee has adequately resolved the identified concerns. No further actions on this RAI item are recommended.

4.0 SUMMARY OF FINDINGS AND RECOMMENDATIONS

SNL finds that the licensee has adequately addressed all of the RAI questions raised in the USNRC RAI of 11/97 with one important exception. The exception is related to RAI Item 2.2a and the issue of validation for the conduit applications. With regard to the conduit analysis methods:

> SNL finds that (1) the licensee validation studies are insufficient to support acceptance of the proposed analysis method for conduit applications and (2) the validations were not performed in a manner consistent with the intended in-plant applications. SNL supplemental analyses demonstrate (1) an apparent lack of consistency between the thermal model and the baseline ampacity tables for conduits and (2) a significantly optimistic performance when exercised as-intended for in-plant applications.

Further interactions to address the optimistic nature of the SNL re-calculated conduit validation results is recommended. In particular, it is recommended that the licensee be asked to either:

- implement a self consistent thermal model for the analysis of the conduit baseline ampacity values (this is quite simple given the work already performed) and to base conduit fire barrier ADF estimates on the comparison of two self-consistent model based ampacity limits, or

- demonstrate the acceptability of the current method using a validation approach that is fully consistent with the intended application practice (i.e., estimated ADF's for the validation cases should be based on comparison of the model-based clad ampacity to standard table-based baseline ampacity limits where the methods used to determine the baseline ampacity are consistent with those used to assess in-plant cables).

In either case, it is further recommended that the licensee be asked to re-examine the conduit validation cases using the full approach to analysis as it will be applied in the analysis of actual in-plant applications. This should include the analysis of the tested fire barrier systems using "generic" representative cable fills for which the baseline ampacity limits can be readily obtained from the standard tables as intended in practice. Under these conditions, the licensee should demonstrate that the ADF values can be reproduced without significant optimism in the results.

5.0 REFERENCES

1. *Power Cable Ampacities*, IPCEA P-46-426, AIEE S-135-1, a joint publication of the Insulated Power Cables Engineers Association (now ICEA) and the Insulated Conductors Committee Power Division of AIEE (now IEEE), 1962.

2. *Ampacities of Cables in Open-Top Cable Trays*, ICEA P-54-440, NEMA WC 51, 1986.

3. *IEEE Standard Power Cable Ampacity Tables*, IEEE 835-1994, Sept. 1994.

Appendix A: Examination of the Licensee Validation Case Studies

A.1 Objectives

The objective of this appendix is to review and assess the licensee validation case studies as presented in Attachment 2 of the licensee submittal. The discussion is divided into two sections. Section A.2 considers the three cable tray cases cited in Table A.5.1 of the licensee submittal and Section A.3 considers the conduit cases cited in Tables A.5.2 and A.5.3 of the submittal.

A.2 Cable Tray Validation Cases

A.2.1 Case 1: Single Unprotected Tray

This case is documented in the second column of Table A.5.1 in the licensee submittal. The case deals with a single cable tray with no fire barrier installed (only the baseline case is considered). This is the only case that provides a direct comparison of the licensee model to the standard ampacity tables for cable tray baseline applications.

There is a minor discrepancy in the cited results for this case. The licensee cites in the summary table that the cable diameter assumed in the analysis is 0.72" and that there are 46 cables present. However, an examination of the supporting calculation sheet, Table A.5.5, reveals that the actual simulation assumed a cable diameter of 0.90" and just 30 cables present. Both lead to an assumed cable depth of fill of 1". This point is quite important because the two cases would not have the same baseline ampacity. If the cable parameters cited in Table A.5.1 were correct, 0.72" and 46 cables, then the baseline ampacity would be 44A rather than the cited 55A. However, using the cable parameters cited in Table A.5.5, 0.90" and 30 cables, the 55A baseline current is correct. Given the final estimated ampacity from the thermal model of 51.8 A this is quite a significant difference. It would appear that this is a simply typographical error in the preparation of Table A.5.1. It would appear that the actual analysis used the cable assumptions that correctly correspond to the cited baseline ampacity; hence, the cited conclusions are valid. No specific recommendation are made to further resolve this minor discrepancy.

The one significant factor illustrated by this case is that the licensee thermal model is conservative in comparison to the ICEA P-54-440 standard ampacity tables. This conservatism likely derives from the licensee's use of a more conservative (i.e., lower) thermal conductivity value for the cable mass as compared to the value assumed in the standard, and potentially to the more conservative treatment of convective heat transfer. In general, all other factors in the analysis are consistent with the ICEA assumptions including the fact that the licensee has not credited the side rails in the analysis.

SNL finds this case example to be an important element of the validation studies. The demonstration of conservatism (or at the least a lack of optimism) in comparison to the standard ampacity tables is quite critical to the licensee approach. This is because in practice, the ampacity tables will be used to determine the baseline ampacity while the thermal model will be used to predict clad ampacity. Recall that the higher the baseline ampacity, the more severe the derating impact. In this case use of the standard tables yeilds a higher baseline ampacity and hence a more conservative ADF. If the licensee were to use the model to predict both the clad and baseline cases, a more optimistic ADF would result. Hence, this case is critical to demonstrating that the licensee practice will be conservative given the current thermal model and the current modeling approach.

A.2.2 Case 2: Single Clad Cable Tray

This case is presented in the third column in Table A.5.1. The case considers a single clad cable tray as per the tests performed by Texas Utilities Electric (TUE). Note that there were no discrepancies noted between the supporting calculation sheet in Table A.5.6 and the summary information in Table A.5.1.

There is, however, one minor discrepancy in the cited results. This relates to the manner in which the baseline ampacity has been assessed for the validation study as compared to how the value would be obtained in practice. The calculation as shown in the table assumes the baseline ampacity using the measured value from the TUE tests, 23.1 A. However, in practice the licensee approach is to assess the baseline ampacity using the ICEA tables. Hence, to properly assess the performance of the thermal model in comparison to the test, the licensee should apply the ICEA baseline ampacity compared to the calculated clad ampacity (rather than the measured baseline compared to the calculated clad).

The difference in this case is quite modest. The ICEA baseline ampacity 22.7 A as compared to the measured value of 23.1 A. This changes the calculated derating factor (ADF) to 31.2% versus the calculated value originally cited in the table of 32.4% and the measured value of 31.6%. The "corrected" ADF is quite consistent with the test data and is only very modestly optimistic. The overall conclusion of the case remains valid, namely, the model did perform well for this simple case.

A.2.3 Case 3: Three Tray Stack

This case is presented in the fourth column in Table A.5.1. The case considers a stack of three cable trays, of which two are powered, as per a test performed by Tennessee Valley Authority (TVA). Note that there were no discrepancies noted between the supporting calculation sheet in Table A.5.7 and the summary information in Table A.5.1.

There is, however, one minor discrepancy in the cited results. This relates to the manner in which the baseline ampacity has been assessed for the validation study as compared to how the value would be obtained in practice and is essentially the same as the discrepancy discussed for case 2 as discussed in A.2.2 immediately above. In this case, however, the actual ICEA baseline ampacity is slightly higher than that measured in the TVA tests. In particular, the measured baseline ampacity was 26.19 A (as cited by the licensee) but the ICEA ampacity is 27.6 A. This translates into a more conservative ADF of 44.4% using the ICEA baseline ampacity as compared to the licensee cited result of 41.4% and the test result of 35.5%.

This case clearly indicates that for this particular multiple tray configuration, the thermal model is conservative. This conservatism likely derives at least in part from the fact that heat transfer through the lower unpowered tray is not credited in the thermal model, but would be a factor in the tests.

A.2.4 Summary of Tray Validation Insights

There were some minor discrepancies noted in the cited validation results:

- In case 1 there were some apparent typographical errors in the summary table results which did not impact the fundamental validity of the case study.

- In cases 2 and 3 the licensee assumed the baseline ampacity using the value measured in the test when in practice the licensee would use the standard tables of ampacity to assess the baseline ampacity. When the results were re-calculated by SNL, the change was found to be either very modest (case 2) or resulted in a more conservative result than that shown in the table (case 3). This minor discrepancy did not impact the validity of the licensee conclusions.

Hence, SNL finds that the general conclusions of the licensee are valid, and that the validation studies reflect quite favorably on the thermal model as currently applied to cable trays. In particular, SNL finds that the cable tray case validation studies cited by the licensee are sufficient to show that:

- The modeling assumptions are conservative for the baseline case as compared to the standard ICEA P-54-440 ampacity tables.

- For single tray configurations, the modeling results quite accurately predicted the ADF impact, and indeed, the actual clad case ampacity measured in the test.

- For the TVA three tray stack test, the thermal model provided a very conservative estimate of the ADF impact.

Based on these results, SNL recommends that the licensee modeling approach be accepted for application to tray configurations.

A.3 Conduit Validation Cases

The licensee has presented results for a total of seven conduit cases. The cases range from single conduits in an enclosure to as many as six conduits in a common enclosure. All are based on tests performed by TVA.

Note that SNL finds the licensees validation studies for each of the conduit cases to be flawed in one important regard. The concern is quite similar to the concern noted for tray cases 2 and 3 as discussed above. That is, the licensee has utilized the measured baseline ampacity (from the test) compared to the predicted clad ampacity (from the model) to estimate the ADF. In practice, the licensee would instead rely on tabulated ampacity limits for the baseline case and the thermal model for the clad case. The SNL evaluations for each case have "corrected" this flaw. That is, SNL has re-calculated the ADF predicted using the tabulated baseline ampacity limits.

A.3.1 Single Conduit Cases

The licensee has examined four separate validation cases involving single conduits in a thermal barrier. The four cases are:

- Case 4: Small conduit in round enclosure (standard configuration),
- Case 5: Large conduit in round enclosure (standard configuration),
- Case 6: Small conduit in a small boxed enclosure,
- Case 7: Small conduit in a large boxed enclosure.

Case 4:

This case involves a 4/C #10 AWG cable in a 1" conduit clad with a standard barrier made of preformed Thermo-Lag 330-1 conduit sections 1.25" thick plus two layers of 770-1 3/8" upgrade. In the test cited by the licensee (TVA item 7.6a) the measured baseline ampacity was 32.65A and the clad case limit was 29.66 A for a net ADF of 9.2% (both ampacities are corrected for temperature). In the thermal model the predicted clad ampacity is 28.1 A, a somewhat conservative value compared to the test. The estimated ADF using the measured baseline ampacity and the predicted clad ampacity is 13.9%, again a conservative value.

However, for this case the tabulated baseline ampacity should be considered. However, while the tabulated baseline ampacity can be determined in different ways, it cannot be obtained directly from the IPCEA P-46-426 tables. This is because the IPCEA tables do not provide for cables smaller than 8 AWG, and corrections must be made for more than three conductors present in the conduit. As an alternative, the tabulated baseline ampacity can be obtained as follows:

- Using the NEC Handbook, the ampacity limit for a three-conductor 10AWG would be 40 A (Table 310-16 of the 1996 edition). A correction factor 0.8 for 4-6 conductors in conduit applies (see note 8 to the ampacity tables in section 310). Hence, the corrected baseline ampacity would be 32 A.

Using the NEC baseline ampacity of 32 A, and the predicted clad ampacity, the predicted ADF would be 12.2%. In this case the predicted ADF compares favorably to the measured ADF of 9.2%.

Case 5:

This case is similar in nature to Case 4, but involves larger cables and a larger conduit. In this case, there were 12, 3/C #6 AWG cables present for a total conductor count of 36. The licensee predicts a clad case ampacity limit of 23.3 A as compared to the measured value of 25.56 A. Using the measured baseline ampacity limit of 29.21 A, an ADF of 20.2% is predicted as compared to the measured ADF of 12.5%.

Again, the actual practice would be to use a tabulated ampacity limit for the baseline analysis. The baseline ampacity can be estimated in more than one way (IPCEA, NEC, IEEE, direct calculation). However, the "most correct" way in comparison to the intended licensee practice is to apply the IPCEA standard as follows:

- IPCEA P-46-426 establishes a nominal ampacity limit for a 3/C 6 AWG cable in conduit of 59 A. With no diversity and 31-40 conductors, a correction factor of 0.4 applies. Hence, the corrected baseline ampacity would be 23.6 A.

Using this as the baseline ampacity, the estimated ADF would be just 1.3%, a clearly optimistic value compared to the measured ADF of 9.2%. In this case, the IPCEA tabulated ampacity is somewhat conservative in comparison to the measured ampacity.

Case 6:

This case is qute similar to Case 4 except in that the fire barrier is constructed of a boxed configuration with four sides formed from flat panels of the Thermo Lag. In this particular case, the box was just large enough to accommodate the conduit. The licensee predicts a clad case ampacity of 29.7 A compared to the measured value of 29.26 A. Hence, assuming the measured baseline ampacity of 33.0 A, the estimated ADF is 10% compared to the measured value of 11.3%. For this case a modestly optimistic result is obtained even using the measured baseline ampacity.

Note that using the standard table, the baseline ampacity is identical to that of Case 4 as discussed above. Hence, using the NEC baseline ampacity of 32 A would result in an estimated ADF of just 7.2% compared to the measured value of 11.3%. This change increases the level of optimism in the estimated ADF, and once again use of the measured versus tabulated baseline ampacity is shown to be an important factor.

Case 7:

The final single conduit case is identical to Case 6 except in that the fire barrier was a boxed configuration much larger than the conduit itself. In this case, the licensee predicts a clad case ampacity limit of 31.4 A versus the measured limit of 31.28 A. Using the measured baseline ampacity of 33 A, the licensee predicts an ADF of 4.9% compared to the measured 5.2%, a very modestly optimistic result.

For this case the baseline ampacity from the tables is identical to that for Cases 4 and 6. Using the NEC value of 32 A would yield an ADF of just 1.9%. Again, using the tabulated ampacity for the baseline value results in an optimistic ADF prediction.

A.3.2 Multiple Conduit Cases

The licensee has examined three cases involving multiple conduits in a common enclosure as follows:

- Case 8: Three conduits in a tight fitting box,
- Case 9: Six conduits in a tight fitting box,
- Case 10: Six conduits in an oversize box.

Case 8:

For this case the licensee thermal model predicts a clad case ampacity limit of 23.6 A versus the measured limit of 29.22 A, a conservative result. Using the measured baseline ampacity of 31.67 A, an ADF of 25.4% is predicted versus the measured ADF of 7.7%.

However, once again consideration should be given to the nominal baseline ampacity from the standard ampacity tables. In this case, one can take the 32 A NEC ampacity limit derived for Case 2 above, and apply an additional correction factor for the conduit grouping. In this case the grouping is three wide by one high, so the grouping correction factor is 0.91 (from Table IX of the IPCEA P-46-426). This yields a tabulated ampacity limit for this case of 29.12 A. In this case the measured ampacity limit is virtually identical to the tabulated limit, and the results of the thermal model are still found to be significantly conservative.

Case 9:

For this case the licensee thermal model predicts a clad case ampacity limit of 20.5 A versus the measured limit of 23.18 A, again a conservative result. Using the measured baseline ampacity of 31.11 A, an ADF of 34.2% is predicted versus the measured ADF of 25.5%.

However, once again consideration should be given to the nominal baseline ampacity from the standard ampacity tables. This case is similar to Case 8 except in that the grouping is three wide by two high, so the grouping correction factor is 0.84 (from Table IX of the IPCEA P-46-426). This yields a tabulated ampacity limit for this case of 26.88 A. For this case the tabulated ampacity limit is significantly lower than that measured in the test. Using the tabulated baseline value and the predicted clad value yields an estimated ADF of 13.8% compared to the measured value of 25.5%. In this case, use of the tabulated ampacity limit yields an optimistic estimate of the ADF.

Case 10:

Case 10 is identical to Case 9 except in that a larger enclosure is built around the conduits. For this case the licensee predicts a clad case ampacity limit of 25.8 A compared to the measured 28.32, once again a conservative result. Using the measured baseline ampacity of 31.11 A and the predicted clad ampacity an ADF of 17% is obtained versus the measured ADF of 9%.

The tabulated baseline ampacity for this case is identical to that for Case 9, 26.88 A. Hence, using the tabulated baseline ampacity and the predicted clad ampacity yields an estimated ADF impact of 4% which is optimistic compared to the measured ADF of 9%.

A.3.3 Summary of Findings for the Conduit Validation Studies

The licensee validation studies have shown some interesting insights. These include the following:

- For the single conduit cases, the thermal model predicted the clad case ampacity limits measured in the tests with somewhat surprising accuracy. This does lend some significant support to the specific modeling approach used for the clad case analyses.

- For three of the four single conduit cases considered, re-analysis of the cases using baseline ampacity limits derived from the standard tables resulted in significantly optimistic ADF estimates.

- For the multiple conduits in a common enclosure cases, the licensee thermal model predictions of clad case ampacity were generally conservative.

- However, it was also noted that the measured baseline ampacity limits were quite optimistic in comparison to the corresponding tabulated limits. Hence, while comparison to the measured baseline ampacity limits yielded conservative ADF predictions, for two of the three cases studied, comparison to the tabulated ampacity limits (which is consistent with the licensee's intended actual practice) resulted in optimistic ADF estimates.

These studies, especially as supplemented by SNL, clearly illustrate the sensitivity of the licensee results to the assumed value of the baseline ampacity. The licensee's own intended practice in actual applications is not consistent with the practice used in the validation studies. This is because in practice, the licensee will be dependent on tabulated ampacity limits for the baseline case, whereas in the validation studies the licensee has assumed the baseline ampacity measured in the test applies. The supplemental SNL assessments have nominally corrected this flaw in the validation studies.

For most of the validation cases studied, the measured baseline ampacity was higher than the tabulated ampacity limits. This is as expected and reflects the existence of some level of conservatism in the standard tables. However, this also means that when the tabulated ampacity limits are used to estimate the ADF (as would be the actual licensee practice) less restrictive ADFs were generally derived. For the single conduits the differences in the measured versus tabulated baseline ampacity values were generally modest, while for the multiple conduit cases, the differences were quite large. However, in terms of the estimated ADF, use of the tabulated baseline limit compared to the predicted clad limit resulted in optimistic ADF values for three of the four single conduit cases, and for two of the three multiple conduit cases. This is not an encouraging result, and appears to indicate a need for a more reasonable and reliable approach that is not subject to such uncertainty.

It should also be noted that, unlike the cable tray studies, the licensee has not analyzed any baseline conduit cases and hence has not demonstrated either consistency with or conservatism in comparison to the standard ampacity tables. Also note that while for cable trays there is really only one accepted source of ampacity limits (ICEA P-54-440, [1]), for conduits there are at least four accepted sources of baseline ampacity values, and these sources are not fully consistent (IPCEA P-46-426 [2], IEEE 835 [3], the NEC handbook tables, and "analysis under engineering supervision" as per the NEC). SNL has based its baseline ampacity re-evaluations on the IPCEA or NEC tables because this is most nearly consistent with the stated approach of the licensee. However, it should be recognized that use of an alternate source of baseline ampacity limits coupled with the same predicted clad ampacity limit will result in entirely different ADF results. For example, the IEEE 835 standard is the most recent and most current, but it also establishes the most conservative ampacity limits for cables in conduit. Hence, if the ADF is based on comparison to the IEEE 385 ampacity limits, then significantly more optimistic ADF values would result. This illustrates that the licensee approach is subject to a high level of uncertainty in the process, and carries a potential for misuse.

A.4 Summary of Validation Insights for Trays and Conduits

The overall findings of the validations studies are markedly different for the cable tray versus conduit applications. In the case of the cable trays, the licensee did successfully demonstrated that (1) the thermal model was nominally consistent with or somewhat conservative in comparison to the ICEA P-54-440 standard ampacity tables, (2) the predictions of clad case ampacity limits for single trays were reasonable, and (3) the predictions of clad case ampacity limits for multiple cable tray configurations were conservative. Hence, SNL finds that the approach is acceptable as applied to cable trays, and recommends its acceptance for this application.

However, in the case of the conduit analysis, the licensee approach to the validation studies was found to be fundamentally inconsistent with the intended approach to the evaluation of in-plant applications. In particular, the validation cases considered only the measured baseline ampacity values whereas the in-plant applications will depend on standard ampacity tables for the baseline ampacity. SNL has nominally corrected this flaw by recalculating ADF predictions using tabulated baseline ampacity limits. As a result, the predicted ADF was significantly optimistic for three of the four single conduit cases and for two of the three multiple conduit cases. On this basis SNL finds that the licensee approach to the analysis of conduits is not acceptable, and further interactions to address the optimistic nature of the results is recommended. In particular, it is recommended that the licensee should be asked to implement a corresponding thermal model for the analysis of the conduit baseline ampacity values, or to comprehensively demonstrate acceptable performance using a validation approach fully consistent with the intended application practice.

A Final Technical Evaluation of the PECO Conduit Ampacity Assessment Methodology for Limerick and Peach Bottom

A Letter Report to the USNRC

October 19, 1999

Revision 0

Prepared by:
Steven P. Nowlen
Risk Assessment and Systems Modeling Department
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 J2503

Attachment 2

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FORWARD

The United States Nuclear Regulatory Commission (USNRC) has solicited the support of Sandia National Laboratories (SNL) in the review of licensee submittals associated with fire protection and electrical engineering. This letter report represents the third and final report in a series of review reports associated with submittals from PECO Energy for the Peach Bottom Atomic Power Station (PBAPS) and the Limerick Generating Station (LGS). The current report deals exclusively with remaining points of technical concern associated with the licensee's conduit applications. This work was performed as Task Order 6 of USNRC JCN J-2503.

1.0 INTRODUCTION

1.1 Objective

The objective of this effort is to assess the adequacy of the licensee's (PECO) approach to analysis of ampacity derating issues associated with the installation of protective fire barrier systems on cable raceways at the Limerick and Peach Bottom nuclear power generating stations. In particular, this report deals exclusively with one final point of technical concern associated with the licensee conduit validation studies. Note that all other points of technical concern have been resolved previously (see related SNL letter report of 4/30/98).

1.2 Background

The history of this review effort is summarized as follows:

- Feb. 29, 1996: The USNRC sent a Request for Additional Information (RAI) to PECO requesting that the licensee provide a specific response to ampacity derating concerns identified in Generic Letter 92-08.

- March 24, 1997: PECO Energy provided documentation of the methodology that the licensee intended to utilize in assessing the ampacity derating factors associated with its installed fire barrier systems at both the Peach Bottom Atomic Power Station (PBAPS) and the Limerick Generating Station (LGS).

- Sept. 23, 1997: SNL completed a review of the 3/97 licensee submittal. Several points of technical concern were identified. (A letter report was submitted by SNL to the USNRC documenting the review findings.)

- Nov. 14, 1997: USNRC forwards a second RAI to the licensee requesting resolution of the concerns identified by SNL in its 9/97 review.

- March 13, 1998: PECO responds to the 11/97 USNRC RAI.

- April 30, 1998: SNL completes a review of the 3/98 licensee submittal. SNL finds that the licensee has resolved all points of technical concern associated with its cable tray, junction box, and cable gutter applications. However, one unresolved technical concern associated with the licensee's conduit validation studies remains. (A letter report was submitted by SNL to the USNRC documenting the review findings.)

- Nov. 18, 1998: A meeting between the USNRC, SNL, and the licensee is held at USNRC headquarters in Washington DC to discuss the one remaining point of technical concern. As a result of these discussions, it becomes apparent that the remaining concern is the result of mis-interpretation of the licensee submittal. The licensee agrees to formally document the meeting discussion and to clarify its analyses to specifically address the concern identified by SNL in 4/98.

- March 12, 1999: A formal submittal in response to the 11/98 meeting is provided to the USNRC by the licensee.

- Oct. 19, 1999: SNL completes the current review.

Note that based on the current submittal, the last remaining technical concern has been fully resolved. SNL has recommended no further licensee interactions, and no further review efforts are anticipated. Hence, SNL anticipates that this will be the final report in this review series.

1.3 Overview of the Licensee Ampacity Derating Approach

The licensee approach is based on a direct application of ampacity derating factors (ADFs) to tabulated ampacity limits for the installed cables. The ADF values are determined for each individual case or application, and derive from one of two sources:

- For plant configurations which correspond to configurations tested by other members of the industry, PECO will directly apply the experimentally determined ADF value.

- For untested configurations, the licensee applies a thermal model to assess the clad case ampacity limits and determines an ADF value for the application based on a comparison of the calculated clad case ampacity to tabulated nominal ampacity limits for the same application. The intent is that these ADF values would then be applied to each cable in the given application.

The SNL review efforts have focused on the licensee thermal modeling approach and its technical validity. The direct application of a test-based ADF to like configurations is considered common and acceptable practice, so long as a sufficient basis for "thermal similarity" is established. In this case, the licensee has previously established an appropriate basis for this approach in their applications.

The second approach is based on thermal modeling. It is with regard to validation of the thermal model for conduit applications that the one remaining point of technical concern identified in SNL's review of 4/98 arises. In particular, SNL identified a potential concern associated with the manner in which the licensee had apparently performed its validation studies for conduit applications only. It appeared that the approach to validation was not consistent with the intended approach to actual in-plant applications. It is this concern that is the subject of the current review effort.

1.4 Organization of Report

This report is relatively brief and focuses exclusively on the one remaining point of technical concern associated with the licensee's conduit thermal model validation studies. All other technical concerns have been previously resolved as documented in SNL's letter report of 4/98 cited above. Section 2 discusses the licensees approach to analysis, the technical concern raised by SNL, and the licensee response to this concern. Section 3 summarizes the SNL findings and recommendations. Section 4 identifies the referenced documents.

2.0 POINTS OF TECHNICAL CONCERN AND RESOLUTION

This section provides a brief overview of the licensee thermal modeling approach and summarizes the technical concerns identified in SNL's 4/98 review. For a more complete discussion of the thermal model and the basis for SNL's concerns, refer to the SNL letter reports of 9/97 and 4/98 as cited above.

2.1 Overview of the Licensee Thermal Model

The intent of the licensee thermal model is to analytically predict fire barrier ADF values for untested configurations. The same basic model is applied to single tray, to single conduit, and to unique configurations such as multiple raceways in a common fire barrier envelope. The model is also used to analyze barrier enclosures that include concrete walls as one or more sides of the barrier system. The ultimate objective of the PECO methodology is to predict the ampacity derating factor (ADF, or equivalently, the ampacity correction factor ACF), for a specific raceway (conduit, cable tray, junction box, etc.) in a given fire barrier installation.

In practice, the licensee analyzes a "generic" raceway using the specific as-installed barrier configuration information and a representative cable fill. That is, the fire barrier is modeled as installed in the plant, but in the model the raceway is assumed to carry a roughly equivalent cable fill intended to represent but not reproduce the cables actually installed in the subject raceway. For simplicity of modeling, the cable fill is assumed to be made up of a single size of cable for which tabulated ampacity limits are readily available (rather than a mixture of cable sizes and ampacity loads as actually encountered in the plant). This approach is found to be acceptable. It is analogous to testing a standard cable tray with a standard cable load and extrapolating the results to a specific plant installation. Indeed, the approach introduces one source of conservatism in that the effects of ampacity load diversity are neglected.

Estimating the ADF requires two bits of information; namely, the clad and baseline case ampacity limits. The role of the thermal model in this process is to estimate the clad case ampacity limit for the "generic" raceway in a given fire barrier configuration. The corresponding baseline limit is taken from standard industry tables of cable ampacity (IPCEA P-46-426 [1] and ICEA P-54-440 [2]). The ADF is then based on a comparison of the predicted clad case ampacity limit to the nominal tabulated baseline ampacity limit for the same "generic" raceway. This same ADF value would then be applied to baseline ampacity limits for specific installed cables for a final assessment of ampacity loads. This practice is considered acceptable provided that the thermal model for the clad case is either consistent with, or more conservative than, the thermal model that underlies the original ampacity tables (e.g., Stolpe for cable trays [3] and Neher/McGrath for conduits [5]). In this case the licensee has demonstrated acceptability (conservatism) through its validation studies.

2.2 One Unresolved Technical Concern Identified in the 4/98 Review

In its submittal of 3/98, PECO documented a series of validation case studies for its various applications. For most applications SNL found these validation studies to be sufficient to demonstrate acceptability of the model. However, in the specific case of the conduit applications, SNL found the licensee approach to be unacceptable. It is this one remaining point of technical concern that is the primary subject of the current review effort.

In support of the 4/98 review, SNL examined the licensee validation case studies in some detail as documented in Appendix A to that report. Based on this review, SNL found that the licensee approach to the validation studies appeared fundamentally inconsistent with the intended approach to the evaluation of in-plant application. This was cited as rendering the cited validation studies for conduit applications inappropriate and inadequate.

2.3 Synopsis of Technical Concern for Conduit Validation Case Studies

It appeared, based on the 3/98 licensee submittal, that the conduit validation cases were not evaluated in the same way that in-plant applications would be evaluated in practice. The validation study ADF results were based on comparing the measured baseline ampacity values from the tests to the estimated clad case ampacity limits taken from the model. In actual practice, the in-plant applications will require the comparison of the standard ampacity tables to the clad case ampacity estimates from the model. This was perceived to be a critical and inappropriate difference between the validation studies and the actual plant applications.

SNL had reevaluated the validation cases by applying tabulated baseline ampacity limits and re-calculating the ADF values. SNL did cite that there was some uncertainty in these SNL assessments and cited this work as a "nominal correction of the analysis." The results of the SNL re-analyses did not reflect well on the proposed method. The "corrected" ADF predictions were significantly optimistic for three of the four single conduit cases and for two of the three multiple conduit cases originally considered by the licensee.

The underlying concern that had apparently not been addressed by the licensee is the consistency of the clad case model with the assumptions used to determine the baseline case ampacity. As discussed further below, for cable trays these concerns had been addressed. However, for conduits there was no clear evidence provided that consistency has been maintained. As was noted by SNL in our original review of 9/97, establishing this consistency is critical to the validity of the licensee approach.

2.4 Assessment of the Licensee's Resolution of the Identified Concern

The licensee response to the one remaining point of technical concern has been to clarify their actual practice in performing the calculations. The critical factor that had not been clear in the 3/98 submittal is that the licensee does, in fact, implement one critical part of a general baseline conduit case analysis, and that the results of this analysis are carried forward into the clad case analysis. This understanding is critical as this practice ultimately ensures that the baseline and clad case analyses are inherently self-consistent.

In particular, the licensee had not explicitly discussed in its 3/98 submittal how the thermal resistance from a cable bundle to the conduit was estimated. SNL had been led to assume that the Neher/McGrath model, or an equivalent model, had been applied. However, the 11/98 meeting and the 3/99 submittal clarify that the assumed baseline ampacity is used to "back-calculate" "the overall heat transfer coefficient for a conduit."

That is, the thermal resistance between the cable and the conduit is estimated using the assumed baseline ampacity limit. This same value is then applied to the analysis of the clad case, with the addition of the fire barrier material to the outside of the conduit. Finally, the ADF is based on the original baseline and the new clad case ampacity limits.

This practice inherently ensures that the baseline and clad case analyses are self consistent. This is the most critical factor in assessing the acceptability of the licensee's validation studies. In fact, this clarification also makes clear that SNL's nominal correction of the baseline case studies was not appropriate. That is, SNL had imposed an inconsistent treatment of the baseline case as compared to that used in the analysis of the clad case. This was inappropriate and renders SNLs re-analysis results invalid.

2.5 Findings

SNL finds that the licensee response is fully adequate to resolve the last remaining point of technical concern.

3.0 SUMMARY OF FINDINGS AND RECOMMENDATIONS

The licensee has previously resolved all but one point of technical concern regarding its fire barrier clad ampacity derating analyses for Limerick and Peach Bottom. The final point of technical concern related to apparent inconsistencies between the manner in which the licensee had performed its conduit application validation studies and its intended practice for actual in-plant applications. The licensee submittal of 3/99 demonstrates that this concern was the result of mis-interpretation of the licensee's modeling practice as regards the validation studies.

Given the supplemental information provided in the 3/99 licensee submittal, SNL finds that both the validation studies and the in-plant applications of the proposed analysis approach do, in fact, ensure an acceptable level of self consistency between the clad and baseline case analyses. This consistency is ensured regardless of where the baseline case is obtained (i.e., whether the baseline case is test data or tabulated ampacity limits). Given this clarification, SNL finds that the licensee conduit validation studies are an appropriate basis for demonstrating model performance. Further, the case studies demonstrate that the thermal model yields appropriate or modestly conservative results over a range of test applications.

Overall, SNL finds that the licensee has fully resolved the last remaining point of technical concern regarding its approach to analysis of fire barrier clad cable ampacity limits. No further interactions are required or recommended.

4.0 REFERENCES

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