A Review of the Millstone Nuclear Power Station Response to the USNRC RAI of 8/12/96 on Fire Barrier Ampacity Derating

A Letter Report to the USNRC

Revision 0

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Attachment

TABLE OF CONTENTS:

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 in a series of reports assessing the licensee implementation of fire barrier system ampacity derating analyses for cables installed at the Millstone Nuclear Power Station (MNPS). The current report documents the results of a SNL review of a submittal from the licensee provided in response to an USNRC Request for Additional Information (RAI) of 8/12/96. This work was performed as Task Order 3 of USNRC JCN J2503.

1.0 OVERVIEW AND OBJECTIVE

1.1 Objective

The objective of the current report is to document SNL's findings and recommendations resulting from a review of a licensee submittal from the Millstone Nuclear Power Station (MNPS). The subject submittal was forwarded to the USNRC in response to a Request for Additional Information (RAI) dated 8/12/96, and deals exclusively with the question of ampacity derating of cables protected by Thermo-Lag fire barrier systems.

1.2 Background

In response to USNRC Generic Letter 92-08 and a subsequent USNRC RAI, MNPS provided initial documentation of a methodology for the assessment of its cable ampacity loading factors and for the assessment of fire barrier ampacity derating impacts. This original submittal was dated 11/3/95, and included two specific case examples, one for a conduit and one for an air drop, to illustrate the licensee's ampacity assessment methodology.

On 5/16/96, SNL forwarded to the USNRC a letter report documenting the findings and recommendations resulting from a review of this initial submittal. Based in part on that letter report, on 8/12/96 the USNRC forwarded to the licensee a second RAI. The licensee response to this second RAI is the subject of the current review. Two submittals have in fact been reviewed by SNL. The first documents the licensee response for MNPS Unit 2 as in identified as follows:

- Letter, M. L. Bowling, MNPS-2 to the USNRC Document Control Desk, Dated 12/13/96, licensee identified item B16065 with two attachments:
  - Attachment 1: "Millstone Unit No. 2 Response to Request for Additional Information Regarding TAC No. M85571 Thermo-Lag Related Ampacity Derating Issues"
  - Attachment 2: "Millstone Unit No. 2 Response to Request for Additional Information Regarding TAC No. M85571 96-ENG-01528E2, Ampacity Derating of Cables Due to Thermo-Lag"

In addition, a separate response submittal was provided to respond to the same RAI points for MNPS Unit 2 identified as follows:

- Letter, J. P. McElwain, MNPS-1, to the USNRC Document Control Desk Dates 12/27/96, licensee identified item B16060 with two attachments:
  - Attachment 1: "Millstone Unit No. 1 Response to Request for Additional Information Regarding TAC No. M85570 Thermo-Lag Related Ampacity Derating Issues"
  - Attachment 2: "Millstone Unit No. 1 Response to Request for Additional Information Regarding TAC No. M85570 96-ENG-1559E1, Ampacity Derating of Cables Due to Thermo-Lag - MP1"

SNL was requested to review these submittals under the terms of the general technical support contract JCN J-2503, Task Order 3.

1.3 Report Organization

Chapter 2 provides a direct assessment of the licensee responses to the specific RAI items. This covers units 1 and 2 separately. Chapter 3 provides a review of the licensee calculation for both fire barrier ADF extrapolations and individual cable assessments as applied to Unit 2. Chapter 4 provides a similar discussion for the corresponding Unit 1 calculations. In each case, separate discussions are provided for the treatment of cable trays, conduits, air drops and "wire-ways" as appropriate. Summaries of specific SNL findings and recommendations are provided for MNPS-2 in Sections 3.1.6 (cable trays), 3.2.7 (conduits), 3.3 (air drops) and 3.4 (wire ways). Similar summaries for the MNPS-1 analyses, are provided in Section 4.7.

2.0 LICENSEE DIRECT RAI RESPONSES

2.1 MNPS Unit 2 Responses

2.1.1 RAI Item 1: Barrier Configuration

2.1.1.1 Synopsis of Concern

The licensee was asked to verify that the TU Comanche Peak tested barriers upon which the estimates of the MNPS ACF/ADF values were based were representative of the MNPS barriers.

2.1.1.2 Summary of Licensee Response

The licensee cited a new set of calculations as having provided for cite specific ACF/ADF values.

2.1.1.3 Assessment and Recommendations

The licensee response has not addressed the underlying concern of this RAI item. No discussion was provided comparing the TU tested barriers to those installed at MNPS. The fundamental question being asked is whether or not it is appropriate to extrapolate the TU results to MNPS, and this underlying question was not addressed by the licensee. It is recommended that the licensee be asked to re-address this item focusing on a description of the physical characteristics that will influence the heat transfer behavior for the TU tested barriers as compared to the licensee's installed barriers.

Also note that Chapter 3 provides a technical review of the new cable tray and conduit ACF calculations. Numerous problems were identified, and several actions on these calculations have been recommended.

2.1.2 RAI Item 2: Number of Barrier Layers

2.1.2.1 Synopsis of Concern

The licensee was asked to confirm if whether the 1" Thermo-Lag barriers were comprised of a single or double layer system.

2.1.2.2 Summary of Licensee Response

The licensee cites that its barriers are of a single layer configuration.

2.1.2.3 Assessment and Recommendations

This response has fully resolved the identified concerns. No further actions on this item are recommended.

2.1.3 RAI Item 3: Use of Overload Ratings

2.1.3.1 Synopsis of Concern

The licensee had cited emergency overload operating limits as the basis for resolution of certain of the cables nominally identified as overloaded in the example calculations. This was cited as a questionable practice requiring significant additional explanation and justification.

2.1.3.2 Summary of Licensee Response

The licensee has cited that an updated calculation has been performed, and that as a result an alternate set of six cables has been identified as nominally overloaded. No resolution for these nominally overloaded cables has been provided, although the licensee has committed to a resolution.

2.1.3.3 Assessment and Recommendations

The licensee response has, in a sense, side-stepped the question. In the updated analyses, no specific references to overload ratings was noted. However, if the final resolutions for any of the nominally overloaded cables involves a reliance on overload ratings, then the questions that were raised in this RAI item will need to be addressed. Until such time, SNL recommends that no further actions on this RAI item are needed.

2.1.4 Additional Questions

2.1.4.1 Synopsis of Concerns

The licensee cites that as a result of a USNRC/licensee conference call, further clarification of the following items was requested:

(1) consideration of the total number of conductors in derating cables in conduits,
(2) recognizing the impact of service factor of motors on cable ampacity,
(3) derating cable ampacity of cables in overfilled conduits, and
(4) alloy coating of copper conductors effect on ampacity.

2.1.4.2 Summary of Licensee Response

The license has responded as follows:

1) For conduit installations, ampacity was derated based on the number of conductors in the conduit and the grouping factor for the conduits.

2) Cable design loads were determined using the following multiplication factors:
   - 1.25 for motors
   - 1.2 for transformers, and
   - 1.1 for others.

3) As noted in item (1), the ampacity of conductors in the conduit is based on the number of conductors in the conduit. Industry standards do not require any additional derating based on percent fill.

4) All initial cable ampacities were based on a design ambient of 50°C and alloy coating for copper conductors.

2.1.4.3 Assessment and Recommendations

The licensee response has generally addressed the concerns identified. SNL notes that:

1) The licensee appears to be applying the older NEC conductor count derating factors that explicitly assume a 50% load diversity without explicit justification based on existing diversity.

2) SNL did review a selection of the design load calculations and the licensee has applied load factors as outlined in this response.

3) This response is somewhat inconsistent. The NEC standard ampacity ratings are based on the assumption that conduits will not be loaded in excess of the limits established elsewhere in the standard. For the licensee to invoke the standard, without including consideration of all standard provisions is potentially inappropriate. SNL notes that the NEC does identify methods of calculation for non-standard configurations under "engineering supervision." For conduits this specifically refers to the Neher/McGrath (1957) approach to analysis. For the nominally overloaded conduits, SNL recommends that the licensee be asked to verify its table-based results using the Neher/McGrath approach to analysis.

4) The licensee calculations for cable trays do appear to have used electrical resistance values that reflect coated conductors. This is noted in that the electrical resistence values are somewhat higher than those typically cited for copper conductors. In the context of the Stolpe methods applied by the licensee, this is an appropriate and conservative treatment. In contrast, the conduit analyses are based on a direct application of the IPCEA tables, and these tables are generally considered to contain adequate margin to account for minor deviations in conductor resistance values associated with coated versus non-coated conductors

Hence, SNL finds that points 2 and 4 of this question have been adequately resolved, While points 1 and 3 have not. It is recommended that the licensee be asked further address points 1 and 3 as discussed immediately above.

2.2 MNPS Unit 1 Responses

2.2.1 RAI Item 1: Barrier Configuration

The licensee response to this RAI item is essentially identical to that discussed in Section 2.1.1 for MNPS-2 above. As was conclude for MNPS-1, the licensee response has not addressed the underlying concern of this RAI item.

2.2.2 RAI Item 2: Number of Barrier Layers

The licensee response to this RAI item was identical to that provided for MNPS-2 as discussed in Section 2.1.2 above. This response has fully resolved the identified concerns. No further actions on this item are recommended.

2.2.3 RAI Item 3: Use of Overload Ratings

2.2.3.1 Synopsis of Concern

The licensee had cited emergency overload operating limits as the basis for resolution of certain of the cables nominally identified as overloaded in the example calculations. This was cited as a questionable practice requiring significant additional explanation and justification.

2.2.3.2 Summary of Licensee Response

This item was cited as not relevant to MNPS-1 because the configuration in question was only relevant to MNPS-2.

2.2.3.3 Assessment and Recommendations

The licensee response has in some senses bypassed the question. However, unless and until this argument is actually invoked by the licensee for MNPS-1, SNL agrees that the issue is not applicable to this unit. SNL has not noted any such cases in the current licensee submittal. Hence, SNL recommends that no further actions on this item be taken at the current time.

2.2.4 Additional Questions

2.2.4.1 Synopsis of Concerns

The licensee cites that as a result of a USNRC/licensee conference call, further clarification of the following items was requested:

(1) consideration of the total number of conductors in derating cables in conduits,
(2) recognizing the impact of service factor of motors on cable ampacity,
(3) derating cable ampacity of cables in overfilled conduits, and
(4) alloy coating of copper conductors effect on ampacity.

2.2.4.2 Summary of Licensee Response

The license has responded as follows:

5) For conduit installations, ampacity was derated based on the number of conductors in the conduit and the grouping factor for the conduits.

2) Cable design loads were determined from the Millstone Unit No. 1 OPAL Program, PMMS, and One-Lines Diagrams. See Attachment 2 for details.

3) There are no Thermo-Lag overfilled conduits on Millstone Unit No. 1.

4) All initial cable ampacities were based on IEEE-IPCEA Power Cable Ampacities, IPCEA P-46-426, Copper and Aluminum Conductors, at 40°C ambient air temperature and 90°C conductor temperature. The ampacity was then corrected to account for 50°C ambient air temperature in accordance with IPCEA P-46-426, Section II B.

2.2.4.3 Assessment and Recommendations

The licensee response has generally addressed the concerns identified. SNL notes that:

1) The licensee appears to be applying the older NEC conductor count derating factors that explicitly assume a 50% load diversity without explicit justification based on existing diversity (see further discussion of this item in Section 3.1.3 below).

2) The licensee design loads have included consideration of motor load factors of 1.25 to conservatively bound the identified concern.

3) The licensee response is adequate to resolve this concern.

4) There are apparently no Thermo-Lag clad cable trays at MNPS-1. For conduits, the IPCEA tables are generally considered to contain adequate margin to account for minor deviations in conductor resistance values associated with coated versus non-coated conductors. No further actions on this item are recommended by SNL.

Hence, SNL finds that all points with the exception of the first point have been adequately addressed by the licensee. It is recommended that the licensee be asked to either (1) on a case by case basis, explicitly justify its use of the older diversity based conductor count correction factors for those conduits in which these values have been applied or (2) apply the more recent (post-1990) NEC correction factors that do not credit diversity.

3.0 THE LICENSEE CALCULATIONS FOR MNPS UNIT 2

3.1 Cable Tray Analyses

3.1.1 Summary of Analysis Approach

The licensee cable tray analyses are documented in the supporting calculation submitted as Attachment 2 of the licensee response submittal, Calculation 96-ENG-01528E2. The calculation includes two major supporting analyses (see discussion of Steps 1 and 2 below) and several other minor attachments. The initial consideration of ampacity limits and in-plant loads at MNPS-2 is significantly modified as compared to the approach originally documented by MNPS in its earlier submittal. The modified methodology has actually been simplified in some respects, but has also introduced some new elements. The basic methodology follows a series of steps as follows:

Step 1: A calculation is performed to determine the base line ampacity limit of a given cable in a given cable tray installation based on the application of simplified heat transfer analyses. In effect, the licensee is reproducing the Stolpe (1970) analyses in which an allowable heat load per unit volume of the cable mass (the heat intensity) is determined. Based on the heat intensity calculated, an allowable ampacity limit in the base line case is determined. This aspect of the analysis is new to this submittal and did not appear in the earlier documents. These analyses are documented in the licensee's Attachment B to the Calculation cited above.

Step 2: Building upon the base line ampacity model, the licensee has implemented a supplemental thermal model to estimate the clad case ampacity limits, and hence, the ampacity correction factors (ACF) associated with its installed fire barrier systems. These calculations have fully abandoned the original licensee approach that was based on a simple thickness scaling of the Texas Utilities ACF test results. These analyses are documented in the licensee's Attachment A to the Calculation cited above.

Step 3: The base line ampacity from Step 1 is derated to allow for the installed fire barrier system using the ACF from Step 2. As a result, an estimate of the clad case ampacity limit for an individual cable in a specific application is obtained.

Step 4: The utility estimates the actual in-plant cable ampacity loads. Non-continuous loads such as MOV power and control cables are not included. For the single largest load on any given cable a load factor of 1.25 is typically applied. If the cable services more than one load (for example a transformer power feed cable) the smaller loads are not load factor adjusted.

Step 5: The actual in-plant operating ampacity of the cable is compared to the estimated clad ampacity limit to determine acceptability. This also represents a modest change from the original submittal in which operating temperatures were estimated, and that value compared to the 90°C limit. The net result of either approach is essentially identical, but the modified approach is somewhat more direct.

In effect, the MNPS analysis method is quite similar to a straight-forward ampacity margins analysis. In general, SNL finds this overall approach to analysis to be acceptable, however, as will be discussed further below, errors and inconsistencies in implementation have compromised the integrity of the results. The identified problems are primarily associated with the supporting calculations for Steps 1 and 2, the base line ampacity assessments and the ACF determinations.

The sections that follow discuss specific aspects of the MNPS analysis methodology. This discussion includes identification of major source of analysis conservatism, as well as points of technical concern.

3.1.2 Basic Input Assumptions

The utility has made a number of basic assumptions in its analyses, certain of which will contribute to significant conservatism in the ultimate results. These assumptions include:

- The utility has not considered instrumentation cables as a heating source in its ampacity calculations. This is consistent with general ampacity derating analyses, and is considered an appropriate method of analysis.

- The utility assumes an ambient temperature of 40°C for MNPS unit 1, and 50°C for MNPS unit 2. A value of 40°C is typical of such analyses, and a value of 50°C would be expected to introduce some level of conservatism, possibly a significant level of conservatism for some cases.

- For power feed cables, the largest single load on a given cable has been adjusted using a load factor of 1.25 to allow for worst-case degraded voltage conditions (if the cable services only a single motor or other device then the largest single load is actually the entire load). This approach is apparently somewhat less conservative than the original licensee assessments in which all motor loads on a circuit were apparently adjusted with a 1.25 load factor. However, the modified approach is consistent with NEC guidelines on cable load assessments, and hence, is considered appropriate.

- Control cables that, when energized, are powered for less than two minutes at a time are not considered as heating sources in the ampacity analysis. This impacts items such as MOV's which simply reposition and are then de-energized. This is a typical and appropriate approach to analysis.

- All high voltage cables (4.16 kV or higher) are apparently installed in a "maintained spacing" configuration consistent with the NEC guidelines. Hence, the licensee cites that derating of these cables for grouping within trays is not necessary as per NEC guidelines. However, in the final assessments, it appears that the licensee has actually applied general random fill cable ampacity limits to these cables. This would be a source of significant conservatism for these maintained spacing cable installations.

One significant change from the earlier versions is that the original licensee submittal had provide an explicit reliance on allowable emergency overload conditions of operation to resolve certain nominally overloaded cables. As discussed in Chapter 2 above, an RAI item on this subject was forwarded to the licensee. The current submittal has deleted these references, although as will be cited below, there may in fact be at least two cables for which such allowances may be appropriate.

3.1.3 Step 1: Determination of Base Line Current Limits

3.1.3.1 Methodology Overview

For cable trays, the licensee considers two possible sources for the base line ampacity limit of a given cable and ultimately chooses the more conservative of the two. This is an appropriate approach. One possible limit is based on the fact that the ICEA cable tray ampacity standard limits tray ampacity values to 80% of the open air ampacity regardless of cable fill (unless the cables are installed with maintained spacing). The licensee has appropriately considered this limit in its analyses. In general, this limit will be exercised when the cable tray is only lightly loaded.

The second source considered is based on a rough reproduction of the Stolpe (1970) thermal model for cable trays. (As will be noted in Section 3.1.5 below, the licensee has, in fact, implemented a far more extensive analysis than is actually required.) Recall that in his work Stolpe performed a series of ampacity experiments in order to validate a very simple model of the heat transfer processes associated with a cable tray. As per the original Stolpe work, in this step only the base line, unprotected cable tray is considered. It is assumed that heat is generated at a uniform rate throughout the cable mass, and that the cable mass is evenly distributed across the tray. Both convection and radiation are credited in removing heat from the cable mass. Heat transfer within the cable mass is also accounted for using the same simplified model as that applied by Stolpe.

The objective of the licensee calculation is to determine for a given tray width and depth of fill the volumetric heating rate, or heat intensity, that will yield a peak cable temperature of 90°C. This heat intensity is then applied to individual cables, based on the size and electrical resistance of the cable, to determine the base line ampacity. In this regard the licensee is consistent with both the original Stolpe approach and the approach used to develop the ICEA P54-440 ampacity tables.

In the licensee model there is one notable deviation from the Stolpe model. That is, in the licensee model heat transfer from both the top and bottom surfaces of the cable mass are credited. In the original Stolpe work, only heat transfer away from the top surface of the cable mass was credited. Ultimately this has little impact on the licensee results because it would appear that the licensee has "calibrated" the heat transfer correlations to yield the same ultimate values of heat intensity as those derived by Stolpe, despite this modeling difference, although no explicit discussion of this topic is provided.

3.1.3.2 Unnecessary Calculations

The licensee's implementation of a Stolpe-like thermal model for the determination of base line ampacity limits is largely unnecessary. Recall that the whole objective of the licensee thermal model is to determine the allowable heat intensity for a given tray based on the actual cable depth of fill. In the specific context of the base line ampacity assessments Stolpe has already done this, and reports his results directly in his paper. Hence, the licensee could simply cite the Stolpe paper, and utilize his published heat intensity limits directly. The determination of individual cable ampacity limits could then proceed directly from the Stolpe heat intensity limits. Hence, in this specific context the licensee's repeated exercising of its base line thermal model is unnecessary. As will be discussed in Section 3.1.3.3 below, this has also resulted in numerous errors being introduced into the results.

The fact that the licensee has applied this model to the ACF determination as well is somewhat relevant (see related discussion in Section 3.1.4 below), and does introduce one need for this thermal model. That is, one important aspect of the ACF assessment is to demonstrate the consistency and reliability of the base line ampacity assessment model. The exercise of calibrating the licensee model to the Stolpe heat intensity tables is a valid approach to this need, provided that consistency with the clad case analysis is maintained. It is not, however, necessary for the licensee to repeatedly apply the same thermal model to each and every one of its individual cable analyses. Rather, to support the ACF determination the model could be exercised in the ACF context for just two bounding cases, and the results extrapolated to the other intermediate cases. The bounding case selection could easily be based on bounding the depth of fill values. The individual base line ampacity assessments could simply be based on the Stolpe results directly.

It might be noted that one case for which a direct implementation of the Stolpe-Like licensee model would be necessary would be for depth of fills that exceed the Stolpe limit of 100% fill or 3". However, SNL noted no such cases in the licensee analysis. In cases where the actual fill is lower than Stolpe's lower limit of 10% or 0.3", a licensee calculation might also be appropriate. However, the analyst will ultimately find that for these very small fills the 80% of open air ampacity limit will likely dominate. Hence, in this case, a direct implementation will likely prove unnecessary as well.

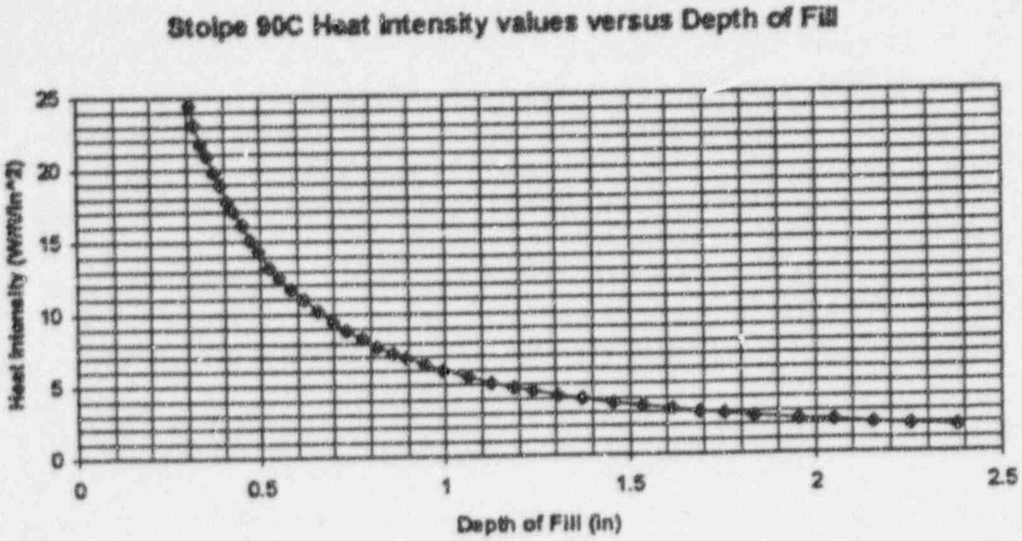
For illustrative purposes, SNL has reproduced the Stolpe heat intensity results as Figure 3.1 here. In producing this plot, SNL has simply digitized the original Stolpe plot for a 90°C cable as presented in his own Figure 4. For illustrative purposes, SNL has converted the "x-axis" from "percent tray fill" to "depth of fill" knowing that Stolpe's percentages were based on a 3" tray height. Hence, depth of fill is simply given by:

$$d_{fill} = \frac{\%_{fill}}{100} * 3''$$

Also to make interpolation easier, SNL has plotted the results on a linear-linear scale as compared to Stolpe's original log-log scale. However, the data remains unchanged. The

licensee could easily replace the majority of its thermal model implementations with a citation to this or a similar plot of Stolpe's original heat intensity limits.

Figure 3.1:



Ultimately, the impact of this observation on the licensee's analysis results is quite minimal. The licensee calculated values of heat intensity are uniformly conservative to a very modest degree. That is, the licensee model has yielded slightly lower heat intensity limits in each case as compared to those of Stolpe, although the differences are quite modest. Hence, if the licensee were to abandon its thermal model in favor of a direct citation to Stolpe's results, only a very modest impact on the ultimate ampacity limits would result, and in fact, the estimated base line ampacity limits would increase very slightly. As will be discussed in Section 3.1.6 below, mistakes in implementation have had a far more pronounced impact on the calculation results. The primary benefits to be gained would be (1) a significant simplification of the submittal, (2) an increase in the consistency of the licensee submittal with the ICEA tables, (3) an improvement in the reliability of the calculation, and (4) an increase in the scrutability of the submittal.

In the interest of completeness of this review, SNL also notes that the licensee model does contain certain technical shortcomings. These include:

- The licensee correlation for convective heat transfer has not been adequately developed. The licensee has not cited the basis for the coefficient values used. In general, it is appropriate to give some consideration to surface orientation in convection, even if an area-weighted average value is ultimately used. Some discussion of this development would be appropriate.

- SNL also notes that an entirely different, and in fact better, set of correlations has been applied in the analysis of the fire barrier clad cable tray. This actually

becomes a point of additional concern in the context of the ACF/ADF determinations as discussed in Section 3.1.4 below.

- Convective heat transfer coefficients for horizontal surfaces are typically assumed to be functions of the width of the surface. The correlation cited by the licensee appears to be of the type that typically includes a surface width term, and yet the licensee appears to have uniformly assumed a 24" width in developing the convective relationship even for trays of width 6" or 12".

If the objective of the model was limited to reproducing Stolpe's results, these shortcomings would not be considered especially important. A demonstration that the Stolpe results were, in fact, being accurately reproduced would be sufficient. It is actually in the context of the ACF/ADF determinations that the inconsistencies and shortcomings here become more significant. This is discussed in Section 3.1.4 below.

3.1.3.3 Errors in Implementation of the Base Line Ampacity Calculations

In reviewing the individual cable tray base line ampacity limit calculations that are attached as appendices to the licensee calculation, SNL noted numerous errors. In general, the errors take the form of relatively trivial mistakes in data input, but in some cases the results of the analysis have been severely compromised. In some cases the errors have actually led to overly conservative results. Correction of these errors will clearly be in the licensee's interest. In other cases, the errors have led to inappropriate and non-conservative results, and hence, corrections may result in more restrictive ampacity limits. It was also noted that in some cases errors in the base line calculations have not actually carried over to the body of the calculation, but have carried over to the Step 2 assessments of fire barrier ACF/ADF.

For purposes of discussion, the errors identified by SNL will be discussed for each individual tray calculation as presented in Appendices A through B2 of the licensees Attachment B to Calculation 96-ENG-01528E2. In several cases, the same type of error has been made in more than one calculation. The errors noted by SNL are as follows:

Appendix B, model Z23HB10 for a 500 MCM Triplex Cable (Cu): The width of the cable tray is cited at the top of page 1 as 12", and yet the surface area is cited as 4 ft^2/ft (square feet of surface area per linear foot of cable tray). The cited surface area is intended to represent the combined surface area of the top and bottom surfaces of the cable mass, and hence, for a 12" wide tray should be just 2 ft^2/ft. This error has led an inappropriately high value of the heat intensity, and hence, an over-estimate of the base line ampacity derived from the heat intensity. Note that in one respect the impact of this error was negated because the constraint of 80% of the ICEA open air ampacity was more limiting than the heat intensity based limit. However, this error did impact the calculation of the ACF for this case as the incorrect heat intensity limit was applied directly in the step 2 analysis.

Appendix C, model Z23GE10, for a 500 MCM triplex cable: While the calculation appears to have been performed properly, the licensee has chosen the wrong value as

the limiting case. Note that the corrected ampacity based on the heat intensity was found to be about 402A whereas that based on 80% of open air ampacity was found to be about 413A. The licensee incorrectly identifies the 413A value as the limiting case. The 402A value should have been cited as most limiting.

Appendix F, model Z14FM20, for a 3/C 12AWG cable:
Apparent Error 1: In this calculation the effective thermal resistivity of the cable mass is cited as "492.496". In comparison, every other calculation performed assumes a value of "400" for this parameter consistent with Stolpe. No obvious reason for a change in this value is noted by either the licensee nor SNL, and hence, this is suspected to be a simple oversight. This has apparently resulted in a somewhat conservative (i.e., lower) estimate of the heat intensity as compared to the value anticipated.
Apparent Error 2: The licensee does not cite the open air ampacity limit for this cable, but based on the information provided it appears that a value of about 37A was assumed (26.24/0.8/0.89=36.854). The NEC cites an open air ampacity limit for this cable of 32A so the correct open air based ampacity limit should be 22.78A (32*0.8*0.89=22.78) not 26.24A as cited by the licensee. Note that in the tables summarizing the analysis results presented in Section 6.2 of the calculation, the licensee has apparently cited the correct ampacity limit of 22.78A. Hence, in this case it would appear that the mistake has not actually carried over to the body of the calculation.

Appendix G, model Z24FL10, for a 4/0 cable: There is an inconsistency between the cited values for the cable diameter and the number of conductors. The stated diameter of the cable is 0.738" which is quite typical for this gauge of electrical cable in a single conductor configuration. However, the licensee calculation (at the top of page 3) cites the number of conductors as 3. These two values, the conductor count and cable diameter, are clearly not compatible. Either the cable diameter or the conductor count has apparently been misstated. The impact, regardless of which value is wrong, is that the licensee has understated the base line ampacity limit. The licensee calculation cited an ampacity limit of about 242A. However, in the body of the calculation, an ampacity limit of 238.52 is actually used (based on a triplex cable and the ICEA 80% of open air limit). Given these discrepancies, it is not at all clear what the appropriate answer is.

Appendix I, model Z24FL20, for a 4/0 cable: The same apparent error as discussed in the context of Appendix G was apparently made in Appendix I as well. That is, the diameter is consistent with a single conductor cable, but the conductor count is set to 3.

Appendix K, model Z25BG20, for a 3/C 8AWG cable: The licensee calculation of the 80% of open air ampacity limit appears to be in error. The ICEA tables establish a 59A limit for this cable in open air, and hence, 80% of this value would be 47.2A as compared to the value of 52.48 cited by the licensee. It would appear that the licensee inadvertently applied the temperature correction factor for a 50°C ambient, 0.89, rather than the 80% correction factor of 0.80 (SNL notes this because indeed

52.48/0.89=59, and hence, SNL can reproduce the ICEA open air ampacity limit). The correct bounding ampacity limit for this case should be 42A (59*0.8*0.89=42) as compared to the value of 43.85 cited by the licensee.

Appendix X, model Z24FL10, for a 7/C 14AWG cable: The licensee basis for the open air ampacity limit appears to be in error. The NEC cites the open air ampacity limit for a 3/C 14AWG cable as 25A (See NEC Table B310-4). However, this value should be adjusted downward because there are more than three conductors in the cable[1]. The correction factors to be used are the same as those used for more than three cables in a conduit and appear in "Note 8a" to the ampacity tables presented in NEC article 310 (on page 70-196 in the 1996 edition). For a 7/C cable, a correction factor of 0.7 should be applied. Hence, the open air ampacity limit for the 7/C cable should be 17.5A (25*0.7=17.5). Correcting for the 80% of open air limit (0.8) and for the 50°C ambient (0.89) yields a corrected ampacity limit of about 15.6A (25*0.7*0.8*0.89=15.575). This is as compared to the licensee cited limit of 17.57A for this case.

Appendix B1, Model Z52EA10, for a 750 MCM triplex Al cable: An error similar to that discussed above in the context of the Appendix B has also been made in Appendix B1. In this case, the tray width is specified as 6" and yet the cable mass surface area per foot of tray is still cited as 4 ft^2/ft. The correct value in this case should be just 1 ft^2/ft. As in the case of Appendix B this error has resulted in a significant over-estimate of the heat intensity, and hence in the heat intensity based ampacity limit. In this particular case the corrected heat intensity based current limit is more restrictive than the open air based limit cited as the limiting case by the licensee. Hence, in this respect the impact of the error has been partially negated. However, when corrected it appears that the heat intensity limit should actually be identified as the more limiting case. Using the Stolpe value of heat intensity at the cited depth of fill[2] (1.935" depth of fill implies a heat intensity of approximately 2.5 $W/ft/in^2$) SNL has estimated the base line ampacity limit for this cable, including correction for a 50°C ambient, as 380.7A. This is compared to the licensee cited base line limit of 418.7 derived from the 80% of open air limit. SNL also notes that the erroneous heat intensity limit has been applied directly by the licensee in the corresponding ACF/ADF calculation.

Appendix B2, model Z22EA10, for a 350 MCM triplex AL cable: An error has been made in this calculation that is virtually identical to that discussed immediately above for Appendix B1. In this case, SNL has calculated a corrected heat intensity based ampacity limit of 297.8A as compared to the value of 452.5 cited by the licensee.

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[1]In the case of a conduit, the correction is only applied once as discussed by the licensee in the submittal. However, the correction must also be applied for other open air based ampacity calculations as well including bounding cable tray limits.

[2]SNL has not attempted to reproduce the licensee calculation of heat intensity. Rather, SNL has used the Stolpe value for heat intensity directly as discussed in Section 3.1.5 above.

However, because the depth of fill for this tray is low, and the subject cable is rather large, the 80% of open air ampacity limit remains the more limiting case. Hence, the licensee cited ultimate limit of 262A remains valid. The erroneous heat intensity limit has, however, been applied directly by the licensee in the corresponding ACF/ADF calculation.

3.1.4 Step 2: Determination of Fire Barrier ACF/ADF Values

In its original submittal, the licensee had applied a simple linear scaling of ADF based on material thickness to extrapolate the Texas Utilities (TU) fire barrier test result ADF values to the physically similar but slightly thicker fire barriers used at MNPS. Mathematically this was expressed as:

$$ADF_{MNPS} = ADF_{TU} * \left(\frac{t_{MNPS}}{t_{TU}} \right)$$

where (t) is the thickness of the material. In the earlier SNL review, this relationship was cited as not technically valid, but conservative given that the thicknesses at MNPS were greater than those tested.

The licensee has abandoned this approach in its current analyses. In fact, for cable trays the licensee has completely abandoned its earlier reliance on industry test data for roughly equivalent fire barriers, and instead, has implemented an extremely simplistic thermal model to the analysis. The licensee has cited a 3M Corp. Letter as a part of this assessment, but as will be discussed below, it is unclear what this 3M letter states and to what extent the citation is relevant to the licensee analyses.

In essence, the licensee has extended the thermal model used to determine base line ampacity limits (as documented in Attachment B to the licensee calculation and discussed in Section 3.1.3 above) to the clad case. However, in doing this the licensee has changed certain of its fundamental assumptions. It is also quite apparent that the licensee model has generated highly non-physical intermediate results. As will be discussed further below, these inconsistencies invalidate the model results. The licensee has ultimately determined an ADF, 40% (ACF=0.60), that is probably a fair estimate of the actual impact for the MNPS 1" cable tray barriers. However, this result is considered entirely fortuitous and is not supported by a technically sound calculation.

To illustrate and evaluate the licensee's approach, SNL will use the first of the case analyses as presented in Appendix A of Attachment A to the licensee calculation. This case deals with tray Z23HA10. The tray is cited as 24" in width with a 0.509" depth of fill.

In the first step of the licensee ADF assessment, the results of the base line case analysis from Attachment B are cited. The actual value cited is the calculated heat intensity limit derived from the licensee's Stolpe-like thermal model, in this case, about 13 W/ft/in^2. In this particular case, the cited heat intensity is correct. However, in Section 3.1.3.3 above SNL identified three cases in which the calculation of the allowable base line heat intensity

had been compromised by mistakes in the analyses. These involve cable trays Z23HB10, Z52EA10 and Z22EA10. These erroneous heat intensity limits have been carried over directly into the ACF calculations, and hence, directly compromise these analyses as well.

The next step is to convert this value to the total heat generation rate for the tray of interest. This is done simply by multiplying by the cross-sectional area of the cable mass. In this case, a value of about 160 W/ft is obtained. No errors in this particular step were noted by SNL, although an exhaustive review was not performed.

The next step of the analysis is to estimate the corresponding heat intensity limit for a cable tray with "tight cover". This value is apparently based on a 3M Corp. letter that cites a 0.59 ACF value for a tightly covered cable tray. Assuming an ACF of 0.59, for this case the licensee estimates the total heating rate for an equivalent covered cable tray is about 56 W/ft ($56=160*0.59^2$).

Given an estimate of the covered case allowable heat load, the next step is to calculate the equivalent thermal resistance between the cables and the outer surface of the tray/cover system. This is done by (1) modeling the convective and radiative heat transfer processes between the tray/cover system and the ambient, (2) using this thermal model to estimate the tray/cover surface temperature, and (3) calculating the cables to tray/cover thermal resistance based on the heat load of 56 W/ft and the difference between the 90°C cable hot spot and the estimated tray/cover surface temperature ($R=\Delta T/Q$).

While no concise explanation is provided, it is clear that the licensee is assuming that the thermal resistance between the cables and the inside surface of a Thermo-Lag fire barrier system would be the same as the thermal resistance between the cables and the surface of the tray/cover system. The licensee is then using the 3M citation in an attempt to estimate this thermal resistance value. In principle this approach can work if all of the critical factors are properly considered[3]. There are, however, reasons why this might not work for MNPS:

- The 3M letter and the supporting test data were not made available for SNL review, and hence, the validity and appropriateness of this value cannot be determined. Hence, SNL finds that the licensee has failed to establish an adequate basis for the applicability of the cited 3M ACF value to the licensee calculations.

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[3]For example, this approach is quite similar to that taken by Braidwood, but at Braidwood the licensee had a more complete set of both open and covered tray test results for the specific solid-bottom cable trays used at the plant. The measured data included cable current (and hence heating loads) for both the base line and clad conditions, as well as tray cover temperatures. Further, the licensee fire barrier system actually included steel tray covers in addition to a Thermo-Lag layer. Hence Braidwood has successfully applied a very similar analysis approach to their own derating assessments. For further information see SNL letter reports on the Braidwood analyses dated 8/25/95, 8/16/96, and 12/20/96, all under JCN J2017.

- The licensee has failed to demonstrate a physical basis for assuming the 3M findings will apply to the trays at MNPS. This would require a demonstration that the cable trays considered by 3M are substantially similar to those at MNPS (width and height, configuration (e.g., ladder versus solid bottom), cable fills, air gap locations, etc.).

- The licensee has not established that the 3M values have any valid basis in experimental results. That is, if the 3M values are based on an alternate analysis, or are based on experiments that would today be considered inadequate, then their application by the licensee might well be inappropriate.

- The emissivity of the Thermo-Lag should be significantly higher than that of a steel cover plate, and this would impact the cable-to-cover versus cable-to-Thermo-Lag thermal resistance. This would normally be expected to introduce a conservative effect because the lower emissivity for the covered tray should lead to a more conservative internal thermal resistance than would be observed for a Thermo-Lag fire barrier. However, given the licensee's approach this has actually resulted in non-conservative and non-physical results (see further discussion below).

- It is unclear whether or not the term "tightly covered" includes a solid cover over the bottom of an open ladder back cable tray as well as over the top of the cable tray. Given the rather harsh impact cited, an ADF of 41%, one would suspect that this is the case, however, this point should be explicitly addressed by the licensee. This would be critical to demonstrating a physical similarity to a fully enclosing fire barrier system. For example, if the results are based on a covered, solid bottom cable tray, then they might not apply to MNPS because there may well be significant contact between the bottom surface of the tray and the bottom of the cable mass. This would not be the case for a Thermo-Lag clad ladder back cable tray. If the results refer to a tray with an open bottom, then again, the results would not apply to a fully enclosing fire barrier system.

As noted this approach may be acceptable, but some additional level of explanation and justification on the part of the licensee is warranted.

Returning again to the licensee calculation, recall that the last step was to estimate the surface temperature for the tightly covered tray case. It is at this point that obviously non-physical results appear. In this particular case the licensee estimates the temperature of the tray/cover surface to be 90.997°C. Unfortunately, this is higher than the cable hot-spot temperature of 90°C. The cables are by definition assumed to be the hot spot of the system, and the tray/cover should be at a lower temperature. For other cases, especially those impacted by errors in the calculation of base line heat intensity limit, the results are even worse. SNL noted at least one case where the tray/cover temperature was estimated at 106°C.

The next step is to calculate the internal cables-to-cover thermal resistance. Unfortunately, because the tray/cover is actually calculated to be hotter than the cables, and yet heat is assumed to be flowing from the cables to the tray/cover, a negative thermal resistance is calculated, (in this case -0.018). This is a physically meaningless result. There is no such thing as a negative thermal resistance.

These physically impossible results should have been seen as a clear sign of problems by the licensee. Unfortunately, the licensee blindly continues the calculation. SNL finds that the licensee calculation fails to appropriately balances the internal and external heat transfer behaviors, and the assumptions that have been made have led to physically meaningless results.

The obvious source for these problems is the licensee assumption that 0.1 is the tray/cover emissivity. This is a lower bound value, and would be typical only of a very shiny metal surface such as stainless steel or high-polish aluminum. It is unlikely that this value is representative of an actual cable tray cover system. Normally, assuming a lower bound estimate would be conservative, however, given the licensee approach in this case the effect has been highly non-conservative. This is because the emissivity value of 0.1 is only applied by the licensee to the external heat transfer relationships. Hence, a lower bound emissivity has the effect of maximizing the external tray-to-ambient resistance, and hence, maximizing the estimated cover temperature for a given rate of heat flow. Recall that the objective is to estimate the internal cables-to-cover thermal resistance. By maximizing the calculated cover temperature the licensee minimizes the estimated internal resistance. In fact, the non-conservative effect is so pronounced that a physically meaningless result of a negative internal thermal resistance has been obtained.

Unfortunately, any emissivity value chosen would be quite arbitrary given that the licensee apparently does not have (or has not used) either a measured value for emissivity or the actual surface temperature of the cover system in the 3M study. Either could be used to more accurately balance the internal and external heat transfer processes. Without either, the licensee is simply speculating and will in any case obtain a rather arbitrary result. Given this situation, one of two approaches would be appropriate:

- Use a conservative limiting value: Given the licensee approach as it currently exists, this would imply use of an upper bound emissivity estimate, such as 0.8, so that the external resistance is minimized and the internal resistance would be maximized. This would be the most conservative approach, but should result in more reliable and physically consistent estimates.

- Impose an internal/external heat balance: This would be a more realistic approach, but would require that the licensee model both the internal and external heat transfer processes. The objective would be to achieve a balance in the internal and external heat flow rates. Both convection and radiation should be treated. For the internal behavior, closed cell conduction/convection relationships should be used in place of the open air correlations cited for the external surfaces. This would generally be based on a conduction enhancement approach. A conservative bound for internal convection would be to simply

assume no convection enhancement (i.e, only model conduction and radiation through the trapped air gap rather than closed cell convection and radiation). The licensee could use the temperature and emissivity of the cover plates as the "fitting" parameters (two heat transfer equations, internal and external, and two unknowns, temperature and emissivity, represents a solvable mathematical set). That is, emissivity and temperature could be adjusted within a reasonable range until the internal and external heat loads are balanced. The licensee could then proceed with the rest of the calculation using the modified internal thermal resistance value.

The next step of the model is to calculate the added thermal resistance represented by heat conduction through a Thermo-Lag box imposed over the surface of the tray/cover system. This is done using a standard expression for the thermal resistance of a rectangular box system. At this point it is important to note that:

- The licensee is allowing full credit for heat transfer through the sides of the cable tray / fire barrier system.

- It has implicitly been assumed that there are no air gaps in the system. Air gaps would be expected if (1) there are, in fact, metal covers on the trays at MNPS in addition to the fire barrier itself, (2) if the tray has either a solid bottom or a bottom cover, and (3) between the side rails of the tray and the barrier side panels in any configuration. This is a potential non-conservatism in the analysis.

The crediting of heat transfer through the sides in particular is a clear point of inconsistency with the base line analysis in which heat transfer from the sides of the tray was neglected (consistent with Stolpe). It is also clearly inconsistent with the initial treatment of the 3M-based tightly covered tray case analysis in which the sides were also neglected. Recall that consistency between the base line and clad case analyses is critical to a quality ampacity derating analysis. At this point, the licensee has clearly compromised this consistency.

Once the conductive thermal resistance of the Thermo-Lag box has been estimated, it is simply added to the previously determined cable mass-to-tray/cover thermal resistance to estimate the total resistance between the cable mass and the outer surface of the fire barrier system. The final major step of the analysis is to assess the heat transfer behavior between the fire barrier outer surface and the ambient. Here, again, both radiative and convective heat transport are credited. However, SNL notes that:

- the licensee has again credited heat transfer from the sides of the tray/barrier system in this analysis, and

- an entirely new set of convective heat transfer correlations is applied to this analysis (actually a much better set that acknowledges the importance of surface orientation in convection, but nonetheless different).

Hence, the licensee has again compromised the consistency that must exist between the base line and clad case analyses in order to ensure a quality ampacity derating analysis.

The result of this final step of the analysis is an estimate of the clad case heat load limit. A direct comparison of the original base line heat load limit to that for the clad case provides an estimate of the fire barrier ACF, in this case, 0.693.

It must be considered somewhat unusual that the ADF for the fire barrier system, 30.7%, is so much lower than that cited for the tight cover system alone, 41%. It is possible for the analysis to predict a somewhat lower fire barrier ADF value depending on the thickness of the fire barrier material. This is because the increase in emissivity for the fire barrier as compared to the steel covers will offset to some extent the insulating effects of the fire barrier material itself. However, given the licensee assumptions, the magnitude of the ADF differences is greater than one should expect, and hence, is considered indicative of other potential problems in the licensee model. In particular, this result may be an artifact of (1) the very low value of emissivity assumed for the tray/cover surface, (2) the licensee calculated negative thermal resistance discussed above, (3) crediting of the sides of the system only in the last steps of the analysis, and (4) the change to an alternate set of convection correlations for the final step of the analysis. While SNL has only examined this one cable tray case in detail, it is clear from the results that all of the tray ACF/ADF analyses suffer from the same shortcomings.

3.1.5 Resolution of Nominally Overloaded Cables

As a result of the licensee assessments, a number of cables have been identified as nominally overloaded. No specific resolution has been provided for most of these cables. Hence, in this sense the licensee submittal is incomplete.

One of the concerns identified in the previous SNL review was that the licensee had cited emergency overload operation condition limits as the basis for resolution of certain cable nominally identified as overloaded. SNL cited this as a highly questionable practice given the identified cable loads and the circumstances under which an overload was expected to occur. For two specific cases cited in the current submittal, SNL finds that the emergency overload argument might actually be applicable.

The specific cases in question are discussed by the licensee in Section 2.0 of the calculation, and involve two emergency safety bus cross-ties (Z5A501A/A and Z5A505A/B). In each case the licensee found that the normal operating load could be carried by the cables within the established ampacity limits. However, under certain emergency conditions, an overload could result. The licensee went on to cite that an emergency calling for such an overload demand has never been experienced in the life of the plant. SNL finds that in cases such as this the provisions for emergency overload might appropriately be invoked. This would, of course, require an assessment of the overload condition on cable operating temperatures for all cables in the raceway. It might also be appropriate for the licensee to commit to a re-evaluation of the cables should such an actual overload demand be experienced. In this case, the licensee has not provided

specific resolution for this nominal overload potential, and hence, SNL's observations in this regard are merely speculative in nature.

As a final observation, SNL notes that the listing of overloaded cables may, in fact, change somewhat once the SNL concerns identified in Sections 3.1.3 and 3.1.4 above have been resolved. Some cables may be deleted from the list based on an increase in the estimated ampacity limit while others may be added to the list due to a decrease in the ampacity limit. Hence, SNL recommends that final resolutions cannot be considered complete until the other concerns have been resolved.

3.1.6 Summary of Findings and Recommendations for MNPS-2 Cable Tray Analyses

With respect to the determination of base line cable tray ampacity limits:

- SNL finds that while the demonstration of a thermal model consistent with the Stolpe analyses is an appropriate aspect of the cable tray ACF calculation, in the context of determining base line ampacity limits it is unnecessary for the licensee to implement its own version of Stolpe's thermal model in attempt to reproduce his results for each and every case examined. Instead, it is recommended that the USNRC ask the licensee to abandon its own model implementation for the purposes of base line ampacity calculations, and to instead rely on the heat intensity limits as published by Stolpe directly. This would remove one source of several errors in the licensee submittal, will simplify the submittal, and will increase the overall reliability and scrutability of the licensee results. While this will result in a very modest increase in the estimated ampacity limits for most of the cable trays considered, it is recommended that this simplification of the licensee analysis will serve the long term interests of both the licensee and the USNRC.

- SNL has identified numerous errors in the licensee implementation of base line ampacity calculations for individual applications. It is recommenced that the USNRC ask the licensee to address these discrepancies in the cable tray base line ampacity calculations. However, as noted immediately above, many of the licensee individual case heat intensity calculations are, in fact, unnecessary and could be eliminated. SNL also recommends that the licensee could more reliably depend on the Stolpe published values of heat intensity, and hence, could significantly simplify this aspect of the analysis. If this recommendation were acted upon by the licensee, then certain of the errors identified by SNL would be rendered moot.

With respect to the estimation of fire barrier ADF assessments, SNL finds that the licensee analysis of cable tray ACF/ADF values as currently presented is fundamentally flawed. The licensee treatment has not only compromised the critical need for consistency between the base line and clad analysis cases, but has also violated the fundamental laws of thermodynamics. It is recommended that the licensee analyses as currently documented should not be credited by the USNRC as the basis for the assessment of cable tray fire barrier ACF values. It is further recommended that the USNRC ask the licensee to either

(1) correct the identified concerns regarding the analyses, or (2) provide an alternate basis for the assessment of cable tray fire barrier ACF values. Specific problems with the licensee model include:

- SNL finds that the licensee has failed to demonstrate that the cited 3M ACF value of 0.59 for a tightly covered cable tray is applicable to this analysis. While this approach may be justified, it is recommended that the USNRC should ask the licensee to include the cited 3M letter and any supporting analyses or experimental results as a part of the submittal, and to explicitly justify the applicability of the 3M results to the licensee analyses of its fire barrier systems.

- SNL finds that the licensee has compromised the consistency between the base line and clad case analyses by (1) crediting heat transfer from the sides of the tray only in the last steps of the clad case analysis while not crediting the sides in either the base line analysis nor the analysis of the 3M covered tray case, and (2) applying an entirely different set of convective heat transfer correlations to the final analysis of heat transport away from the surface of the fire barrier system. Consistency between the base line and clad case analyses is critical to a quality derating analysis. SNL finds that, even putting all other concerns aside, this is a critical flaw in the licensee analysis. It is recommended that the USNRC should ask the licensee to modify its analyses so as to ensure that its base line and clad analyses are self consistent throughout.

- SNL finds that because a lower bound estimate of the cable tray cover emissivity was selected the licensee analysis has calculated a tray/cover surface temperature that exceeds the hot-spot temperature of the cables. Further, the licensee has calculated a negative cable-to-tray/cover thermal resistance value. Both results are clearly non-physical and represent a fundamental violation of the laws of thermodynamics. One of two approaches was cited as methods to resolve this discrepancy; namely, (1) given the current licensee approach the use of a conservative upper bound estimate of the cover emissivity, such as 0.8, would ensure that a conservative bound on the internal thermal resistance is obtained or (2) supplementing the thermal model so as to impose a balance between the internal and external rates of heat flow for the cables-to-cover-to-ambient system would result in more realistic results. It is recommended that the USNRC ask the licensee to provide for a resolution of this concern.

3.2 Conduit Applications for MNPS Unit 2

3.2.1 Summary of Analysis Approach

The general approach to analysis for conduits at MNPS-2 is essentially identical to that used for the assessment of cable trays as discussed in Section 3.1.1 above. In some respects, the individual evaluations of current loads for cables in conduit are much more simplistic than the corresponding cable tray calculations. In particular, the conduit base line ampacity limit calculations derive directly from the ampacity tables, rather than from a

thermal model. The basis for the assessment of the conduit ACF/ADF values is also significantly different. In all other respects the process is essentially the same.

For conduits, the licensee has simply taken the tabulated base line ampacity limit from either the ICEA (for larger cables) or NEC tables (for smaller cables), has applied correction factors for ambient temperature, conduit grouping, and conductor count, and has then applied a derating factor of 23% for the fire barrier. The result is an estimate of the derated ampacity limit. This value is simply compared to the actual load for each cable, and a determination of acceptability is made accordingly.

3.2.2 Basic Input Assumptions

Some of the basic input assumptions utilized by the licensee are:

- The conduit ACF/ADF test results reported by Texas Utilities (TU) can be extrapolated to the conduit fire barriers in use at MNPS. This assumes a basic similarity in broad aspects of barrier construction.

- Some aspects of the Neher/McGrath (1957) approach have been utilized in the licensee's ACF/ADF analysis for conduits.

- One source of conservatism in the analysis is that, unless field verified, each conduit is assumed to reside as a member of a 6x6 array of conduits. This results in an additional ampacity correction factor of 0.68 being applied to most conduits. This approach should be conservative for all but a limited number of cases, and is viewed as a strength in the licensee treatment. SNL found that the licensee has applied the methodology consistently. No errors in this regard were identified.

3.2.3 Step 1: Determination of Base Line Current Limits

For conduits, the licensee has simply taken the tabulated base line ampacity limit from either the ICEA (for larger cables) or NEC tables (for smaller cables) as the initial basis for the base line ampacity. This value is then adjusted to account for both grouping of conductors within a conduit, and for the grouping of multiple conduits. As noted above, the use of a conservative bound of the multiple conduit grouping factor is considered a significant conservatism in the analysis for most cases. Only one point of potential concern in this process was identified by SNL.

The licensee has applied the older, pre-1990, NEC-based conduit conductor count correction factors without explicit justification. That is, the nominal ampacity limits for conduits are based on the assumption that there are no more than three current carrying conductors present. If the conduit holds more than three current carrying conductors, then the ampacity limits are to be adjusted downwards. (See related RAI item discussed in Section 2.1.4 item (1) above.)

The licensee actually cites the "EPRI Volume 4" document as the source of its correction factors, and this document has not been reviewed by SNL. In fact, this particular citation, licensee reference 3.1.44, is incomplete and it is impossible to identify the cited document from the information provided. In any event, the correction factors cited by the licensee appear to ultimately derive from pre-1990 versions of the NEC handbook. The concern is that the cited values implicitly assume a load diversity of 50% (no more than half of the conductors should be powered at any one time). Since 1990, an alternate set of correction factors has been published by the NEC for use in cases where diversity cannot be confirmed. While use of the older, diversity-based values may be appropriate, their application should be accompanied by an explicit discussion of the existing diversity or the licensee's diversity assumptions. In general, many of the licensees cases might be justified in using the older diversity based correction factors. In particular, for those cases involving large numbers of smaller control cables, an assumed diversity of 50% might easily apply. However, the licensee has provided no such discussions or justifications in the current submittal.

3.2.4 Step 2: Determination of Fire Barrier ACF/ADF Values

The determination of conduit fire barrier ACF/ADF values is based on a thermal model. In this case, the licensee has utilized certain of the TU conduit derating test results directly in the analysis. That is, the licensee ACF/ADF estimates are based on a re-analysis of ampacity derating tests performed by TU. The MNPS analyses have attempted to adjust the TU ACF/ADF values to allow for a thicker fire barrier system. In principle, this is considered an acceptable approach. However, as will be noted below, the licensee has made certain critical mistakes in the analysis that have compromised the results.

The licensee has considered just one of the TU tests, that involving a 5" conduit as reported in a TU/Omega Point Laboratory Test Report of March 19, 1993. The general approach to analysis is as follows:

- Step (a) The total thermal resistance between the cables and the ambient is estimated for the clad case. This value includes the cable-to-conduit, conduit-to-barrier inner surface, fire barrier conduction, and fire barrier outer surface-to-ambient resistance factors. The licensee also estimates the same value for the base line case, although this calculated value is never actually used or cited again.

- Step (b) The thermal resistance for the fire barrier itself is estimated using standard correlations for heat conduction through a cylindrical section.

- Step (c) The barrier outer surface-to-ambient thermal resistance is estimated by modeling the convective and radiative heat transfer processes at the external surface.

- Step (d) The cable-to-barrier inside surface resistance is estimated as the total cable-to-ambient resistance from (a) minus the fire barrier conduction resistance from (b), minus the surface-to-ambient resistance from (c).

- Step (e) A modified fire barrier conduction thermal resistance value is calculated to allow for the increased thickness of the fire barrier using the same approach as (c).

- Step (f) A modified cable-to-fire barrier outer surface resistance is calculated based on the sum of the original cable-to-fire barrier inner surface value from (d) and the modified fire barrier conduction resistance from (e).

- Step (g) A modified clad case heating rate is calculated by imposing a thermal balance between the internal and external heat exchange rates. In this process, the surface temperature of the fire barrier is used as the "floating" or "fitting" parameter.

- Step (h) The modified clad case heating rate is compared to the original measured heating rate for the base line case to generate an estimate of the ACF value.

In principle, this is an appropriate basis for extrapolating the TU test results to the thicker MNPS fire barriers. Of particular importance in this regard is the fact that the licensee has provided for a consistent analysis for the unmodified TU clad test case and for the modified clad case assessment for the thicker MNPS barriers. This consistency is critical to the analysis. However, in reviewing the calculation, SNL noted two discrepancies.

The first discrepancy is related to Step (a) and more critically to Step (h). The concern is related specifically to the base line ampacity or base line heating rate assumed by the licensee. In this regard the licensee treatment is considered inadequate because:

- The TU conduit tests were conducted using separate physical test specimens for the base line and clad tests in each derating test set. This resulted in considerable uncertainty because the licensee had not assured that the conduits used were sufficiently similar in physical properties, in particular, as related to the emissivity of the conduits, to allow for a direct comparison of the base line and clad results. A bounding analysis of this uncertainty was performed by SNL.[4] This calculation found that using worst-case assumptions a "corrected" base line ampacity limit might be as much as 119% of the value reported by TU. It was on this basis that the USNRC has only accepted the use of the conservative bounding estimate of the TU test results as developed by SNL. For the case considered by MNPS, the ADF was adjusted from the nominal test value of 10.3% up to a conservative bounding estimate of 25% based on the "corrected" worst case base line ampacity limit.

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[4]See Attachment 4 to SNL Letter Report, "Technical Evaluation of TUE Response to Ampacity Derating Questions Raised August 30, 1994," Revision 0, February 15, 1995 (work performed under USNRC JCN J2017, Task Order 1).

SNL finds that this uncertainty has not been allowed for in the licensee analysis, and hence, the licensee's analysis is non-conservative in this respect.

The second discrepancy is related to the licensee's implementation of the Neher/McGrath[5] expression for heat transfer from the surface of a cylindrical section, in this case the outer surface of the fire barrier, to the ambient. In particular, the licensee has apparently applied equation 42 from that paper. However, in doing so, the licensee has not properly implemented the term groupings. The original equation given by Neher/McGrath is as follows:

$$R_e = \frac{15.6\ n'}{D'_s\left[\left(\frac{\Delta T}{D'_s}\right)^{1/4} + 1.6\ \epsilon\ (1 + 0.0167\ T_m)\right]}$$

Note the grouping in the denominator and in particular, the fact that D_s' is a multiplier on the rest of the denominator. In contrast, the licensee implementation does not properly maintain this grouping, but rather, uses the expression:

$$R_e = \frac{15.6\ n'}{D'_s\left(\frac{\Delta T}{D'_s}\right)^{1/4} + 1.6\ \epsilon\ (1 + 0.0167\ T_m)}$$

The denominator grouping is important to this expression, especially given that the values used in the licensee analysis are either 5.5" or 6.5" depending on the specific case. The licensee's error in implementation actually appears to have led to a more conservative result and may have offset to some extent the non-conservative effects of the failure of the licensee to include consideration of the uncertainty in the measured base line ampacity. SNL has not, however, repeated the calculation to confirm this.

3.2.5 Application of Results to In-Plant Cables

SNL did not note any discrepancies in the licensees application of the ampacity derating factors to the in-plant conduits. However, it should be noted that the concerns identified in Section 3.2.4 above are likely to change the licensee's estimate of the ampacity derating impact for the conduits. Hence, it will likely be necessary for the licensee to reconsider each of the individual cable-in-conduit assessments using the updated derating impact estimates.

3.2.6 Resolution of Nominally Overloaded Cables

No specific resolutions for nominally overloaded cables have been provided in this submittal. In this context, the submittal is considered incomplete.

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[5]Neher, J. H., and McGrath, M. H., "The Calculation of the Temperature Rise and Load Capacity of Cable Systems," AIEE Transactions, October 1957.

3.2.7 Summary of Findings and Recommendations for MNPS-2 Conduit Analyses

With respect to the determination of base line ampacity limits for cables installed in conduits:

- SNL finds that the licensee has not demonstrated that the older, pre-1990 diversity-based conduit conductor count correction factors can be applied to the cases cited. It is recommended that the USNRC ask the licensee to either (1) justify its use of the pre-1990 NEC diversity-based correction factors on the basis of existing cable load diversity, or (2) apply the newer post-1990 NEC correction factors for cases in which diversity cannot be verified.

With respect to the licensee estimation of fire barrier ACF values:

- SNL finds that the licensee approach to the estimation of conduit ACF/ADF values is acceptable in principle, but that the implementation of this analysis as currently documented is deficient. Two discrepancies were noted; namely, (1) the licensee has not accounted for the uncertainty inherent in the measured base line ampacity for the TU tests and the limitations under which the USNRC has accepted the application of those test results, and (2) the licensee implementation of Neher/McGrath equation 42 for heat transfer between the outer surface of the fire barrier and the ambient contains a mistake in how the terms in the denominator of that expression have been grouped. It is recommended that the USNRC ask the licensee to (1) address the first concern by assuming a base line ampacity of 119% of the reported measured value (or 680A) for the case cited by the licensee in its analysis, and (2) address the second concern by correcting the term groupings in the Neher/McGrath external heat transport expression.

3.3 Air Drop Applications for MNPS Unit 2

The licensee discussions include the discussion of cases in which a single cable within a cable tray but not in conduit has been wrapped using a conduit-style barrier system. This would appear to be the equivalent of an "air-drop" type application. SNL was not able to identify any such cases in the actual cable analyses, and hence was unable to verify the approach to analysis. However, given the general descriptions that are provided, the licensee approach to analysis may not be appropriate as applied to the assessment of air drop ampacity limits. In Section 4.6 of the licensee calculation it is stated that:

> "Cables that are wrapped using conduit wrap (not in conduit) in cable tray will have the cable's ampacity determined based upon cable fill. The derate ACF for the cable will use the worse case (tray or conduit ACF) to ensure that the cables are evaluated conservatively. The conduit wrap around cables without the conduit by inspection is bounded by the conduit model (one conduit barrier is eliminated) thus, the conduit model ACF will be utilized as it is more conservative than the free air wrapped cable(s)"

Further in Section 5.0 the licensee states that for "free air cable" as compared to conduits and trays:

> The maximum allowable ampacity for free air cables as required will be obtained from IPCEA (ref. 3.1.5) or the National Electrical Code (Ref. 3.1.4) for smaller cables not included in the IPECA. This value will be multiplied by the appropriate Thermo-Lag derating value from Attachment 1. The cable load current will be compared to the maximum allowable ampacity (Imax) and if it is more than the load current the cable will be considered acceptable as installed."

The exact meaning and intent of these passages is unclear. However, SNL interprets this to imply that for cases in which an individual cable in a cable tray has been wrapped using a conduit-style barrier system, then the derated ampacity limit will be taken as the open air ampacity limit multiplied by the conduit fire barrier ACF. If SNL has correctly interpreted these passages, then this is an inappropriate basis of analysis.

Testing by TU has clearly demonstrated that air drop configurations suffer a much greater relative ampacity derating impact than do conduit installations. The TU tests identified air drop derating factors of as much as 32% as compared to the 23% ADF assumed by the licensee for conduits. The conduit ADF values should be much lower than those for an equivalent air drop because, in effect, the conduit itself introduces a penalty on cable ampacity even in the absence of the fire barrier. Hence, the <u>relative</u> impact of adding a fire barrier is reduced. In contrast, for an air drop the base line configuration is the open air condition, and the <u>relative</u> impact of the fire barrier is much larger.

Unfortunately, SNL was unable to determine for which cables the individual wrap has been applied. Hence, SNL was unable to verify the actual approach taken by the licensee. In general, SNL would consider that one of two approaches might be appropriate for this type of situation:

- if the base line ampacity is based on open air ampacity limits, then the fire barrier ampacity derating factor should be based on air drop test results rather than on conduit test results, or

- if the base line ampacity is based on the ampacity of the cable in conduit, then application of the conduit-based ADF test results might be justified.

It is not, however, acceptable to apply conduit ADF values to open air ampacity limits to determine clad case ampacity values for an air-drop type configuration.

As a general conclusion, SNL finds that the adequacy of the licensee's treatment for individually wrapped cables is indeterminate. It is recommended that the USNRC ask the licensee to (1) describe the physical characteristics of the individual cable wrap systems as applied by the licensee, (2) explicitly identify all such applications and their corresponding ampacity assessments, (3) cite the assumed source for the base line ampacity of each cable in question, and (4) state the assumed ampacity derating value applied to that cable and further clarify the basis for that assumption.

3.4 Wire-Way Analysis

The licensee analyses include the consideration of one "wire-way" (item Z25XA10). This application is analyzed as if it were a simple conduit, although no explicit justification for this assumption is provided. Given that the wire-way is cited as containing 146 conductors, SNL is skeptical of its treatment as a conduit.

SNL finds that the licensee discussion of the Z25XA10 Wire-Way is inadequate to assess its appropriateness. It is recommended that the USNRC ask the licensee to (1) provide a physical description of the wire-way, (2) provide a description of the installed fire barrier system, and (3) further justify its treatment of ampacity derating for this wire-way as a conduit.

4.0 THE LICENSEE CALCULATIONS FOR MNPS UNIT 1

4.1 Overview

There are apparently only three applications of Thermo-Lag in MNPS-1. All three apparently involve conduits. Hence, the licensee assessment for MNPS-1 is considerably simplified.

4.2 Basic Assumptions

The MNPS-1 conduit calculations closely parallel those of the MNPS-2 analyses discussed in Section 3.2 above.

4.3 Determination of Base Line Ampacity Limits

The determination of base line ampacity limits for MNPS-1 is essentially identical to the process utilized by the licensee for conduits at MNPS-2. The values derive directly for the IPCEA tables. Similar to MNPS-1, an ambient temperature of 50°C has been assumed, and a correction factor of 0.89 has been applied to the IPCEA table values. Two points of potential concern have been identified by SNL:

- For "Installation 1" base line ampacity limits are based on the open air ampacity of the subject cables, and yet, the ampacity derating factors for a conduit installation have been applied. This is an inappropriate basis for analysis as has been discussed in Section 3.3 above.

- Unlike the MNPS-1 calculation, no derating factor for conduit grouping has been applied. Both "Installations 2 and 3" involve grouped conduits. Hence, application of a conduit grouping correction factor would appear to be appropriate.

4.4 Determination of Fire Barrier ACF

The licensee has invoked the results presented for MNPS-2 as applicable to MNPS-1. Hence the same concerns and errors identified by SNL in Section 3.2.4 will also apply to the MNPS-1. These concerns may impact the licensee's estimate of the conduit fire barrier ACF values.

SNL also notes that the physical diagrams provided by the licensee in attachment A to the submittal indicate that sections of each installation include non-standard configurations (that is, configurations other than a single conduit with an individual wrap system). In particular:

- "Installation 1" appears to involve cables not in conduit but protected by a conduit-style fire barrier system. This is essentially an air-drop type installation, but ACF values for a conduit installation have been applied. As

noted in Section 3.3 above, air drop ACF values are more severe than are conduit ACF values. (Also see related discussion in Section 4.3 above.)

- "Installation 2" involves a pair of conduits that are each first wrapped in Thermo-Lag and then as a pair are further enclosed by an external box (three sides and a top) made up of two layers of gypsum wall board (actually 2 layers of 3 panels each with an air gap between the two layers for a total of six layers of 1/2" gypsum wall board and a 3-5/8" air gap) on a steel support frame with a steel cover over the top panels. The assumption that the ACF typical of a single conduit wrapped in Thermo-Lag but otherwise in open air does not appear appropriate to this installation. Fortunately, for this case, the available margin is apparently quite large, and a qualitative assessment of the magnitude of the available margin may well suffice to resolve this concern.

- "Installation 3" includes a variety of non-standard configurations. The most limiting would appear to be "Section G-G" in which five conduits are housed in a common box configuration. SNL notes that testing by TVA has shown that the ACF for six conduits in a common box configuration was as high as 26% as compared to the 23% value assumed by the licensee.

Despite these special configurations, all of the fire barrier ACF values have been based on the standard single conduit configuration.

SNL finds that the licensee has not given adequate consideration to the impact of non-standard configurations on fire barrier ACF values. It is recommended that the licensee be asked to provide a more realistic assessment of the ampacity derating impact for the configuration identified as "Installation 2." Further, for the configuration identified as "Installation 3" it is recommended that the USNRC ask the licensee to consider the results of industry "special configuration tests", and in particular interes the TVA results for multiple conduits in a boxed configuration. The objective of this recommendation is to ensure that the ACF values assumed will conservatively bound the various configurations present at MNPS-1.

4.5 Application to In-Plant Cables

The licensee treatment has apparently identified the cables for which the ampacity assessments are needed. Several cables have been eliminated from consideration, but SNL finds that the reasons for elimination have been adequately explained, and are appropriate. The licensee has basically considered only the major power cable loads. Computer feed cables, and short duration loads have not been considered. This is an appropriate basis for analysis.

4.6 Resolution of Nominally Overloaded Cables

None of the cables analyzed by the licensee were found to be nominally overloaded. Hence, no specific resolutions were provided.

4.7 Summary of Findings and Recommendations for MNPS-1

For the purpose of summarizing SNL's findings and recommendations, each of the three installations at MNPS-1 will be discussed separately. As a general observation, SNL notes that the licensee has demonstrated that a significant ampacity ma· ·n is available for each case analyzed. Hence, SNL anticipates that the resolution of the identified concerns will not ultimately effect the licensee's assessment that cables are operating within acceptable limits. However, given that each analysis was found to be deficient for one or more reasons, a formal resolution of the identified concerns is recommended.

4.7.1 MNPS-1 Installation 1

Installation 1 involves a pair of cables each wrapped individually in a conduit-style barrier. SNL finds that the licensee analysis of this installations is inadequate because the licensee has applied conduit ACF values to what is effectively an air drop application. It is recommended that the licensee be asked to adjust its analysis to either (1) estimate the base line ampacity assuming that the cable is installed in conduit and then apply the conduit ADF value, or (2) use the open air ampacity limit for the base line assessment but use a more severe ADF value to reflect the harsher penalty associated with air drop fire barrier systems.

It is not anticipated that these findings will ultimately impact the final results of the licensee analysis. That is, the licensee has demonstrated a level of margin available that will likely bound SNL's concerns in this regard.

4.7.2 MNPS-1 Installation 2

For Installation 2 SNL finds the licensee's treatment to be inadequate because in addition to the Thermo-Lag, the installation includes enclosing of the two conduits in question within an outer box made up of several layers of gypsum wall board, and yet the licensee has applied only the standard derating factor associated with a standard single layer conduit installation. This ADF value is considered non-conservative for this application. It is recommended that the licensee be asked to provide an alternate and more complete analysis for this case that more accurately reflects the actual installations conditions.

Ultimately, SNL anticipates that the licensee can demonstrate the acceptability of these particular ampacity loads. This is because the licensee has cited an available margin of at least 83%.

4.7.3 MNPS-1 Installation 3

For Installation 3 SNL finds the licensee analysis to be deficient for the following reasons:

- The installation includes various special configurations that will likely result in a more severe ampacity derating impact that would the single conduit configuration assumed by the licensee.

- The licensee assessment of base line ampacity limits has neglected the effects of conduit grouping on ampacity limits.

SNL recommends that the USNRC should ask the licensee to resolve these concerns. Here again, SNL expects that the available margin will be sufficient to cover the identified concerns.