A Technical Evaluation of the Three Mile Island Unit 1 Fire Barrier Ampacity Derating Assessments

A Letter Report to the USNRC

Revision 0

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ATTACHMENT 1(a)

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FORWARD

The United States Nuclear Regulatory Commission (USNRC) has solicited the support of Sandia National Laboratories (SNL) in the review of utility submittals associated with fire protection and electrical engineering. This letter report represents the second in a series of documents associated with the review of submittals from the Three Mile Island (TMI) Unit 1 nuclear plant. These submittals deal with the assessment of ampacity loads for cable trays and conduits protected by Thermo-Lag 330-1 fire barriers. These documents were submitted by the utility in response to USNRC Generic Letter 92-08, and in response to a subsequent USNRC RAI of July 5, 1996. The current work was performed as Task Order 2, Subtask 4 of USNRC JCN J-2503.

1.0 INTRODUCTION

1.1 Background

In response to USNRC Generic Letter 92-08, the Three Mile Island (TMI) nuclear plant provided documentation of the licensee position regarding ampacity derating factors associated with its installed Thermo-Lag 330-1 fire barrier systems. The initial submittals were forwarded to the USNRC document control desk under cover letter dated March 29, 1995. SNL reviewed this submittal as documented in a letter report to the USNRC dated April 25, 1996.[1] Based in part on the SNL review findings, a Request for Additional Information (RAI) was forwarded to the licensee on July 5, 1996.

1.2 Objectives

The objective of the current review is to assess the adequacy of the licensee response to this RAI. The relevant documents reviewed under the current efforts are:

- Letter, October 22, 1996, J. Knubel, GPU Nuclear/TMI to the USNRC Document Control Desk, item 6710-96-2336 with two attachments as follows:
    - Attachment 1: "Response to the Request for Additional Information Related to Thermo-Lag Associated Derating Issues" (9 pages).
    - Attachment 2: Licensee Calculaltion C-1101-770-E420-018, Revision 0, on "TSI Derating of Cable Ampacity."

SNL was requested to review these submittals under the terms of the general technical support contract JCN J-2503, Task Order 2, Subtask 4. This letter report documents SNL's findings and recommendations regarding the acceptability of this licensee submittal to demonstrate that cables are operating within appropriate ampacity limits.

1.3 Organization of Report

Section 2 of this report provides a discussion of the utility approach to ampacity assessments. This discussion includes the identification of potential points of concern regarding the licensee's approach to assessment. Section 3 provides point-by-point assessments of the licensee's specific RAI responses. Section 4 summarizes the SNL findings and provides recommendations regarding the need for additional information to support the final assessment of the utility analyses.

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[1]The original SNL review efforts were performed under USNRC JCN J-2017.

2.0 OVERVIEW OF THE UTILITY APPROACH

2.1 Overview

The licensee approach to ampacity derating is somewhat different from that considered typical of such assessments. In particular:

- The licensee approach is based on use of the IPCEA P-46-426 methods for cable trays rather than the ICEA P-54-440 methods that are considered by SNL to be more typical. This aspect of the licensee approach is discussed further in Section 2.2 below.

- All cable ampacity limits have been analyzed as if the cable were in a clad cable tray regardless of the actual installation. This aspect of the licensee methodology is discussed further in Section 2.3 below.

As noted above, further discussion on how these assumptions will impact the analysis is provided below. For now, given these two critical starting assumptions, the licensee ampacity assessment proceeds as follows:

- The initial base line ampacity of a given cable is taken from manufacturer recommended ampacity limits for cables installed in open air. These values appear to correspond closely to the IPCEA P-46-426 ampacity tables, again, assuming operation in open air.

- This value of the open air ampacity is then adjusted for the assumed ambient temperature. A value of either 35°C (95°F) or 40°C (104°F) has been assumed for all cables with one exception that involves a winter heating load, and for winter conditions assumption of a lower ambient appears appropriate.

- The corrected open air base line ampacity is then further adjusted to account for the placement of the cable within a cable tray. This is based on the application of an ACF value taken from Table VIII of the IPCEA P-42-426 standard. This ACF is based on the total number of conductors in the tray. (See further discussion of these factors in Section 2.2 below.) The result is an estimate of the cable tray installation base line ampacity.

- The cable tray base line ampacity is then adjusted for the presence of the fire barrier system. All assessments have assumed a fire barrier ADF of 32% (ACF of 0.68). The result is an estimate of the derated ampacity limit for a given cable in a given cable tray including the fire barrier impact.

- Finally the derated ampacity limits are compared to actual in plant cable loads for an initial assessment of acceptability. This assessment has included consideration of potential under-voltage conditions of operation.

- For three cables nominally identified as overloaded, the licensee assessment has gone on to apply an alternate NEC based approach. For this particular case the NEC approach allows for slightly higher ampacity limits. (See further discussion of this case in Section 2.2.2 below.)

2.2 Application of P-46-426 to Random Fill Cable Trays

2.2.1 An Overview of Past and Current Methods

One very unique aspect of the licensee's treatment is that cable tray base line ampacity limits have been determined on the basis of the cable tray analysis approach outlined in IPCEA P-46-426, *Power Cable Ampacities*. In general, P-46-426 is widely used to determine the base line ampacity of cable in open air, conduits, duct banks, buried configurations, and for trays with maintained spacing. While the standard does discuss application of the results to random fill cable tray installations, this is the first instance in SNL's experience in which these provisions have been invoked. As will be clarified below, SNL finds the P-46-426 random fill tray correction factors to be inappropriate to this analysis.

In order to explain further, a brief review of the history of these standards is in order. In 1959 the ICEA (then still known as the IPCEA) published P-33-440, *Factors for Calculating Ampacities of Cable Installed in Ladder Supports, Trays, and Troughs*, a little known standard no longer maintained by the ICEA. Then in 1962, the more commonly recognized IPCEA P-46-426 *Power Cable Ampacities* was published. In section "D" of P-46-426, the correction factors for cables in cable tray (both with and without maintained spacing) taken directly from P-33-440 were reiterated. Finally, in 1986 ICEA Standard P-54-440, "Ampacity of Cable in Open Top Cable Trays" was published.

In considering the TMI-1 approach, it is appropriate to consider the following statement quoted directly from page 'iii' of P-54-440 under the section entitled "History":

> "Ampacity tables for cables in trays were published in IPCEA Publication No. P-33-440 April 2, 1959, which assumed a load diversity but did not specifically define the diversity. **The demands of modern generating plants, both nuclear and fossil fueled, require a more precise definition of operating conditions for the determination of cable ampacities.**
>
> Experimental work with various cables and the loading of trays by J. Stolpe (citation provided) and the theory developed by Stolpe, Underwriters Laboratories Inc., and others (citations provided) provided a more accurate means of calculating ampacities of cables in trays. This work was utilized by a joint committee of IPCEA and the IEEE Insulated Conductors Committee in preparing the ampacity tables which were published in the IPCEA/NEMA Standards Publication for *Ampacities of Cables in Open-top Cable Trays*, (IPCEA and NEMA citations provided), and **which superseded the factors in Table B for cables without maintained spacing in the IPCEA "Factors for Calculating Ampacities of Cables Installed in Ladder Supports, Trays, and Troughs," P-33-440, April 2,**

1959. Table A of that publication covering factors for cables with maintained spacing is not affected." (Emphasis in bold face added.)

The critical points to be taken from this discussion are:

1. P-33-440 included credit for an unspecified level of load diversity that has been removed in P-54-440.

2. The P-33-440 provisions were not considered accurate enough for use in modern generating plants.

3. The P-54-440 tables supercede the P-33-440 non-maintained spacing, or random fill, cable tray ampacity correction factors.

4. The P-46-426 ampacity correction factors for random fill trays derive directly from the P-33-440 tables, and hence, have been superceded by the P-54-440 ampacity tables and methods.

Given these observations, SNL finds that it is fundamentally inappropriate for the licensee to base its ampacity assessments for cable trays on the P-46-426 random fill tray correction factors when that methodology has been superceded by P-54-440.

SNL does note the following comment made in certain of the individual tray calculations provided in the original submittal (see, for example, the discussion of Tray 1019/1020 on page 7 of Attachment 2 to the licensee submittal of March 29, 1995):

> "An additional ampacity calculation was performed using ICEA P54-440 methodology, the current depth of fill was calculated to be one inch. TMI-1 cables and the P-54-440 rubber jacketed cable tray fill may not be sufficiently similar to provide an engineering basis for using this standard. Utilizing the interlocked armor cable diameter in the calculations yields cable ampacities in a one inch fill depth which approaches the Kerite free air ampacity."

Clearly the licensee has some recognition of the role of P-54-440 in such calculations. However, the licensee appears to have neglected to consider that P-54-440 also sets a limit of 80% of open air ampacity for any random fill tray (see Section 2.2 of the standard). For small depth of fill values it is expected that the Stople/P-54-440 heat intensity method will yield unrealistic results, and the 80% of open air limit will correct this known feature of the approach. In general, this "problem" is likely to occur for any cable whose actual diameter is greater than the calculated depth of fill for the tray as a whole. This provision should address the licensee's apparent concern regarding applicability of the P-54-440 standard.

SNL also notes the following statement included in the licensee response to RAI item 5 of the current submittal:

"ICEA P-54-440 was applied in some of the cases as an alternate verification of the ampacity values calculated by IPCEA P-46-426 methodology. Where ICEA P-54-440 was used, in some cases more margin was indicated and in other cases less margin was indicated."

The licensee goes on to state that the final assessments are based on the P-46-426 methodology. SNL finds that the P-54-440 approach is applicable to the licensee's cable trays. As will be discussed further below, SNL recommends that the licensee's assessments should include the consideration of the P-54-440 approach and the resulting ampacity limits.

However, in making this recommendation, SNL also recognized that a legitimate question that should also be considered is has the licensee obtained a conservative result in the final analysis? SNL has explored this question in some detail as discussed in sections 2.2.2 and 2.2.3 below. In particular, there are two (and only two) cases for which a direct comparison of the P-46-426 correction factors and the ampacity limits set in P-54-440 can be made by SNL based on the available information. The critical value that is not reported by the licensee for the rest of the applications is the total cable fill depth for each tray (including non-continuous load cables). Actually, given simply the width of each tray, the fill depth can be easily calculated given the other information in the licensee submittal.

2.2.2 Example Case 1: Tray 590

The first case for which the licensee has given the information needed for SNL to complete a P-54-440 analysis is "Tray 590". The "extra" information was actually presented in the context of the licensee's alternate analysis based on the NEC approach to tray ampacity assessments as documented on Page 17 of the calculation. Hence, a comparison to the NEC approach is also possible.

For comparison purposes, SNL has analyzed this tray using the P-54-440 approach. The details of the calculation are provided in Appendix A to this report. The results of this SNL analysis for each of the four cable sizes contained in Tray 590 are presented in Table 2.1. All values in this table are base line ampacity limits for the cable in a tray before accounting for the fire barrier ACF.

As shown in this table, the licensee's P-46-426 results are all conservative in comparison to P-54-440. The licensee's NEC-based analyses are uniformly non-conservative in comparison to the P-54-440 values, but with the exception of the 10 AWG conductor, the differences are quite modest (no more than 3.3% deviation).

For the 10 AWG cable the NEC-based result appears to be clearly questionable because the open air limit cited by the licensee for this cable is just 34 A (see licensee table 4). Hence, the licensee has actually concluded that an ampacity, 36 A, that exceeds it own cited open air limit of 34 A is actually acceptable. This is an inappropriate result and should not have been credited by the licensee.

Table 2.1: A comparison of the licensee "tray" ampacity limits derived from P-46-426 to those derived by SNL from P-54-440 for Tray 590.			
Cable Size:	Licensee cited base line tray limit from P-42-426	Licensee cited base line tray limit from NEC Article 318	Tray base line limit from P-54-440 (by SNL)
3/C #10	24	36	27
3/C #1/0	132	155	150
3/C #2/0	152	177	174
3/C #4/0	207	237	236

The observed conservatism of the P-46-426 methodology for this particular case can be directly attributed to two observations:

1. The tray fill for Tray 590 was relatively low. As a result, the allowable ampacity limits derived from the heat intensity method are only slightly lower than the open air limits. Hence, in this case the 80% of open air limit was dominant in the P-54-440 analysis.

2. The cable diameters at TMI-1 are significantly larger than normally expected for such cables. For example, the #10 AWG cable is cited as having a diameter of 1.08". In comparison, P-54-440 cites 0.48" to 0.64" as typical of a 3/C #10 AWG cable. The P-54-440 approach is fundamentally based on the concept of heat intensity, or the allowable volumetric heating rate. Under this method a physically larger cable of a given wire gauge is allowed a proportionateley higher ampacity limit. P-46-426 does not adjust for cable diameter because it is not based on the heat intensity approach. Hence, for the rather large diameter cables at TMI-1 this is a source of conservatism for P-46-426 as compared to P-54-440.

The bottom line on this example is that even under the P-54-440 approach the 80% of open air ampacity limit turned out to be the ultimate limiting factor. Further, because the licensee actually applied a 70% correction factor to the open air limits, a more conservative result was obtained. In this case the licensee's P-46-426 approach actually gave a conservative result. Hence, there is no impact on the ultimate conclusion regarding acceptability of the actual ampacity loads.

The NEC-based analysis did yield an apparently anomalous result for the smaller #10 AWG cable, actually giving an ampacity limit higher than the licensee cited open air limit. The licensee should not have credited this result, however, given the very small load on this cable, 4 A, there is plenty of margin available regardless of which result is considered.

2.2.3 Example Case 2: Tray 551/553

The second case that can be examined using P-54-440 based on the available information is Tray 551/553. In the March 1995 licensee submittal, Tray 531/533 was identified as a 6" wide cable tray (from both Attachment 2 and Attachment 3 of the earlier submittal). An analysis of this case is easily accomplished using this information plus the cable size information contained in Table 3 of the current submittal. Again, the details of the analysis are provided in Appendix A to this report.

In the analysis process, SNL did note two apparent discrepancies.

- First, the licensee's March 1995 submittal had cited a depth of fill of 2.6" for this tray. Given the information provided in the current submittal, and assuming a 6" wide tray, SNL has calculated a depth of fill of 4.43". The basis for the licensee's assessment of a 2.6" depth of fill is unclear. However, it would appear that the licensee has only allowed for one 4/C 350 MCM cable in the tray rather than the two cables apparently present. Using this assumption SNL does get a depth of fill of 2.6" as cited by the licensee.

- Second, the licensee has cited in Table 5 of the current submittal that the total conductor count for this case is 9. However, the information provided in Tables 3 and 4 of the current submittal imply a conductor count of 11 should apply. In contrast, if there is only one 4/C 350 MCM cable and one 3/C 4/0 cable, consistent with the 2.6" fill assumption, then the conductor count should be 7. Hence the conductor count of 9 is not consistent with either of these two interpretations of the cable loading.

Table 2.2 summarizes the results of the SNL analysis of this case. The second column provides the licensee cited base line ampacity limit for the tray applications (column 6 of licensee Table 4). The third column presents SNL's analysis results assuming that the information in Tables 3 and 4 is correct, and that the depth of fill for this tray should be 4.43". The final column presents the results obtained by SNL if it is assumed that the depth of fill is 2.6" as cited in the March 1995 submittal.

Table 2.2: Comparison of licensee results based on P-46-426 to those obtained by SNL using P-54-440 before application of the fire barrier derating factor.

Cable Size	Licensee P-46-426 Ampacity Limit	SNL P-54-440 Limit (4.43" Fill)	SNL P-54-440 Limit (2.6" Fill)
4/C 350 MCM	299	239	342
3/C #4/0	217	142	207

Given these results, in either case the licensee assessment of the ampacity limit for the 4/0 cable appears uniformly non-conservative. In the case of the 350 MCM cable whether or not the licensee's P-46-426 analysis is conservative depends on what the actual depth of fill is. If, as indicated by Tables 3 and 4 of the current submittal, the depth of fill is 4.43", then the licensee's analysis for this cables is also significantly non-conservative.

For the final assessment one must also include the fire barrier derating factor of 32%. Table 2.3 illustrates the results of this exercise, and includes a comparison to the cited circuit loads for these cables.

Table 2.3: Comparison of fire barrier derated ampacity limits and in-plant cable loads

Cable size	P-46-426 based derated limit	P-54-440 derated limit (4.43" fill)	P-54-440 derated limit (2.6" fill)	Cited in-plant ampacity load
4/C 350 MCM	203	162	233	80 A
3/C #4/0	147	96	141	140/146 A

Given these results, for the 4/C 350 MCM cable sufficient margin is available to allow for even the most conservative of these results. However, for the 3/C #4/0 cable, the licensee margin is not sufficient to allow for either of the two P-54-440 derated ampacity limits. This discrepancy is especially significant for the case of a 4.43" depth of fill, that case that appears to most accurately reflect the information provided by the licensee.

2.2.4 Summary of Insights and Assessment of Impact

SNL has reviewed the licensee's cable ampacity assessment method which is based on the random fill tray correction factors from IPCEA P-46-426. Two specific cases were analyzed in an effort to assess whether or not the licensee's treatment is conservative in relation to the P-54-440 methods which supercede those applied by the licensee. For one case, the licensee's assessments were conservative (Tray 590). However, for the second case, (Tray 531/533) the licensee's assessments were found to be non-conservative for at least one of the two cable sizes contained in the tray, and potentially for both cable sizes.

In general, SNL does note that given the very large cable diameters that predominate at TMI-1, the P-54-440 method will generally result in rather generous ampacity limits being derived for any case involving a depth of fill that is smaller than the diameter of the cables present in the tray. In these cases the 80% of open air ampacity limit will come into play, and the licensee's P-46-426 approach has generally bounded this limit already. Hence for these low fill depth cases the licensee analysis is likely conservative.

However, SNL is unable to determine from the information provided what the actual depth of fills are for the various trays, other than the two specific cases analyzed above. The only factor preventing SNL from analyzing the balance of the cases was that no information on the cable tray width was provided, again, except for the two cases examined by SNL. All of the other required information appears to be readily available in the licensee submittal.

The SNL analyses have shown that for at least some cases the licensee assessments will not be conservative. This will likely involve cases with deeper fill depths. Hence, cases involving just one or two cables in a tray will not likely be impacted by a re-analysis using P-54-440. In fact, for these cases P-54-440 may well yield a more generous ampacity limit depending on the conductor count. It is also likely that any cable for which a margin of 30% or more has been demonstrated using P-46-426 would still be found adequate under the P-54-440 method as well.

2.2.5 Findings and Recommendations

The methodology applied by the licensee was taken from IPCEA P-46-426, which in turn cites IPCEA publication P-33-440 as the basis for the cited ampacity correction factors for random fill trays. ICEA P-54-440 specifically states that the P-33-440 (a.k.a., the P-46-426) methodology for random fill trays is superceded by the P-54-440 approach. Hence, SNL finds that the licensee has applied and outdated and inappropriate methodology to the analysis of its cable tray ampacity limits. While the licensee approach may actually be conservative for some of the cases examined, SNL also demonstrated that the approach can lead to non-conservative results as well.

SNL also notes that the licensee response to RAI item 5 (see related discussion in Section 3.5 below) cited that P-54-440 analyses were performed for some cases, and that for a subset of those cases a more conservative result was obtained. Finally, SNL notes that the licensee did cite concerns related to some unrealistically high ampacity results deriving from the P-54-440 method in its March 1995 submittal, and hence, questioned the technical validity of applying that methodology to TMI-1 cables. However, consideration of the fact that P-54-440 establishes 80% of open air ampacity limit as a general upper bound of cable ampacities for random fill trays should address these concerns.

SNL finds that the P-54-440 methodology is applicable to the licensee cases and should be included in the evaluation. It is recommended that the USNRC ask the licensee to provide a re-assessment of it ampacity limits which includes consideration of the limits imposed using the ICEA P-54-440 methodology. In particular, it is recommended that reassessments be requested for any cable in a cable tray with three or more cables present and for which a margin of 30% or less was demonstrated. This includes the following seven circuits:

> LS6 (see SNL analysis of tray 531/533, #4/0 cable), ME1, ME2, MB11 (winter configuration only), MC12 (winter configuration only), CH61, and LS5.

Given the apparent depth of fill and conductor count discrepancies noted by SNL in the review of the Tray 531/533 case, it is recommended that the licensee should also be asked to document these calculations to a sufficient extent that both the depth of fill and ampacity limit calculations can be verified. This supplemental analysis should be easily accomplished by the licensee. The example analyses provided in Appendix A illustrate all of the important features of such an analysis.

2.3 Treatment of All Installations as Tray Installations

The licensee has cited that all of the cables have been assessed as if those cables were located in a cable tray with a general tray barrier installed. This is cited in particular as including cases in which a single cable has been wrapped individually, rather than having wrapped the tray as a whole (an air-drop like installation) and conduits. This approach is considered somewhat unique, and hence, warrants some consideration. As will be noted below, in the case of the TMI-1 analyses this approach has likely resulted in a conservative effect.

The licensee has not identified which of the cases analyzed involve either an air-drop style installation or a wrapped conduit. Hence, it is difficult to assess definitively whether or not this treatment is, in fact, conservative. As a general observation SNL agrees with the licensee assessment that this approach will be conservative. SNL offers the following rational for this conclusion:

> <u>Conduits</u>: The ADF associated with Thermo-Lag clad conduits in typical pre-formed conduit installation configurations of the type used at TMI-1 have generally been found to be quite modest; on the order or 10% or less for reliable test results. In IPCEA P-46-426 tables, an ampacity correction for cables in conduit of about 17-20% (0.80<ACF<0.83) is typically observed when the open air and conduit ampacity limits for equivalent cables are compared. Hence, combining a 0.9 ACF for the fire barrier with a 0.8 ACF for the conduit itself, the open air ampacity limits would be derated by an effective ACF of (0.9*0.8=0.72) for a clad conduit. This is bounded by the licensee application of a minimum ACF of 0.68 based on a cable tray fire barrier for all ampacities in its analyses.
>
> <u>Air Drops:</u> For air drop type installations, the ACF of the fire barrier system may easily equal or exceed that of a cable tray fire barrier system. However, the base line for the air drop is the open air condition, whereas the base line for the tray is the random fill open tray, a more restrictive condition. For random fill trays, P-54-440 sets an overall limit on cable ampacity of 80% of open air limit. As noted in Section 2.2 above the licensee has, in effect, incorporated such a limit in its analyses, although they have not explicitly cited this objective. Hence, combining the 0.8 ACF for the random fill tray and the 0.68 correction for the tray barrier, an effective ACF of (0.8*0.68=0.544) or greater has been applied to these installations as compared to the open air limit. This can be expected to conservatively bound the ACF of a Thermo-Lag air drop style installation.
>
> The single exception to this observation is the case of Circuit MD11 in Tray 731/732. This case apparently involves only a single cable in the tray, and hence, the open air ampacity limit has not been adjusted to reflect the cable tray 80% of open air limit for this installation. However, even if this case involves an air drop style barrier, the cable tray derating factor should bound the impact. This is because there is only the one cable and no mutual heating effects are anticipated. In this case, the impact of the fire barrier alone should be no worse than the combined impact of a conduit plus a fire barrier, and as noted above, this impact has also been bounded by the licensee's analyses.

Given these observations, SNL finds that the analysis of all installations as if they were cable trays will provide for a conservative assessment of the conduit and individual wrap installations at TMI-1. This assumes, of course, that the cable tray base line ampacity values are determined appropriately (see related discussion in Section 2.2 above). No specific actions on this aspect of the analysis are recommended.

3.0 ASSESSMENT OF SPECIFIC LICENSEE RAI RESPONSES

The USNRC RAI of July 5, 1996 included fifteen specific questions. The following sections provide point-by-point reviews of the licensee's responses to these RAI items as documented in Attachment 1 of the licensee submittal.

3.1 RAI Item 1: Document Organization

Synopsis of the RAI: RAI Item 1 cited that the licensee's documentation was not well organized and was difficult to follow. A more concise set of documentation was requested.

Synopsis of the Licensee Response: The licensee response includes an updated calculation for ampacity limits of Thermo-Lag clad cables.

Assessment of Response: The updated documentation is very complete, well organized, and is fully adequate to resolve the identified concerns.

Findings and Recommendations: SNL finds that the RAI item has been adequately resolved. No further actions regarding this RAI item are currently recommended.

3.2 RAI Item 2: Licensee Testing

Synopsis of the RAI: RAI Item 2 noted that the original licensee submittal from March 1995 include the discussion of a test plan. The licensee was asked to discuss various aspects of the status of the planned tests.

Synopsis of the Licensee Response: The licensee response cites that no tests have been performed at TMI-1, and that none are anticipated. The licensee has cited that it will depend on ACF values from other industry tests.

Assessment of Response: The licensee's response is fully adequate to resolve the identified concerns.

Findings and Recommendations: SNL finds that the RAI item has been adequately resolved. No further actions regarding this RAI item are currently recommended.

3.3 RAI Item 3: Ampacity Basis

Synopsis of the RAI: RAI Item 3 requested that the licensee more clearly identify the basis used to establish base line ampacity limits for the installed cables.

Synopsis of the Licensee Response: The licensee response cited manufacturer data as the primary source of its ampacity limits.

Assessment of Response: The licensee's response is fully adequate to resolve the identified concerns. The licensee's use of manufacturer data is considered appropriate, especially given that the cables used at TMI-1 are somewhat unique (very large overall diameters for a given cable in comparison to those considered typical).

Findings and Recommendations: SNL finds that the RAI item has been adequately resolved. No further actions regarding this RAI item are currently recommended.

3.4 RAI Item 4: Reconciliation with the NEC or ICEA Tables

Synopsis of the RAI: RAI Item 4 requested the licensee to reconcile the cited base line ampacity limits with the industry NEC or ICEA standards.

Synopsis of the Licensee Response: The licensee response cited, again, the use of manufacturer data, and concluded that reconciliation with the industry standards was not required.

Assessment of Response: The licensee's response is fully adequate to resolve the identified concerns. Given the licensee's reliance on manufacturer data, reconciliation is not considered necessary. At the time this question was raised, it was unclear where the ampacity limits had been obtained (see related RAI Item 3). This point has been adequately clarified by the licensee.

Findings and Recommendations: SNL finds that the RAI item has been adequately resolved. No further actions regarding this RAI item are currently recommended.

3.5 RAI Item 5: Use of ICEA P-54-440

Synopsis of the RAI: RAI Item 5 cited that the licensee calculations, which apparently derived from P-54-440, were inadequately documented to permit review.

Synopsis of the Licensee Response: The licensee response cites that the assessments have been based on the random fill tray methodology of P-46-426 or the NEC rather than P-54-440. The attached calculation also provides a significant expansion of the available information.

Assessment of Response: The licensee was very responsive to the identified concerns. The updated calculation included in the submittal in particular provides a much improved level of detail for review. SNL has also provided a separate discussion of the licensees application of the P-46-426 methodology in Section 2.2 above.

Findings and Recommendations: SNL finds that the concerns raise in the specific context of this RAI item have been adequately resolved. No further actions regarding this RAI item are currently recommended. Note the related discussions in Section 2.2 have identified one area for which some additional follow-up has been recommended.

3.6 RAI Item 6: Cable Physical Characteristics

Synopsis of the RAI: RAI Item 6 requested that the licensee provide more detailed information on the physical characteristics of the cables analyzed.

Synopsis of the Licensee Response: The licensee response has included a table of properties as a part of the attached calculation.

Assessment of Response: The licensee's response is fully adequate to resolve the identified concerns.

Findings and Recommendations: SNL finds that the RAI item has been adequately resolved. No further actions regarding this RAI item are currently recommended.

3.7 RAI Item 7: Tray 590 Experiment

Synopsis of the RAI: RAI Item 7 cited that the licensee experiment for cable tray 590 was not adequately documented.

Synopsis of the Licensee Response: The licensee response indicates that this experiment is no longer included as a part of the assessments.

Assessment of Response: The licensee's response is fully adequate to resolve the identified concerns.

Findings and Recommendations: SNL finds that the RAI item has been adequately resolved. No further actions regarding this RAI item are currently recommended.

3.8 RAI Item 8: ADF for Fire Barriers

Synopsis of the RAI: RAI Item 8 cited that the licensee's assumed fire barrier ADF of 28.04% was not conservative in comparison to more recent industry tests.

Synopsis of the Licensee Response: The licensee response indicates that a modified value of 32% has been applied to all cable tray analyses based on testing by TUE.

Assessment of Response: The licensee's response is fully adequate to resolve the identified concerns.

Findings and Recommendations: SNL finds that the RAI item has been adequately resolved. No further actions regarding this RAI item are currently recommended.

3.9 RAI Item 9: Barrier System for Trays 551/553

Synopsis of the RAI: RAI Item 9 requested that the licensee describe the fire barrier system installed on Trays 551/553.

Synopsis of the Licensee Response: The licensee response indicates that this particular barrier system is similar to all other 1-hr wrapped trays.

Assessment of Response: The licensee's response is fully adequate to resolve the identified concerns.

Findings and Recommendations: SNL finds that the RAI item has been adequately resolved. No further actions regarding this RAI item are currently recommended.

3.10 RAI Item 10: Cable Versus Conductor Counts

Synopsis of the RAI: RAI Item 10 cited that the licensee had based its correction factors on a cable count rather than a conductor count.

Synopsis of the Licensee Response: The licensee response indicates that the updated analyses have used a conductor count.

Assessment of Response: The licensee's response is fully adequate to resolve the identified concerns.

Findings and Recommendations: SNL finds that the RAI item has been adequately resolved. No further actions regarding this RAI item are currently recommended.

3.11 RAI Item 11: Assessments for Nominally Overloaded Cables

Synopsis of the RAI: RAI Item 11 requested that the licensee provide a definitive technical basis for its assessment of nominally overloaded cables that included an assessment of life impact.

Synopsis of the Licensee Response: The licensee response cites that the updated analyses show that no cables are overloaded, and hence, "measures for monitoring for signs of accelerated age-related degradation will not be required."

Assessment of Response: The licensee's response is fully adequate to resolve the identified concerns in the context of this particular RAI item. However, the concerns identified by SNL in Section 2.2 above may impact the licensee's assessment for certain cables.

Findings and Recommendations: SNL finds that the RAI item has been adequately resolved. No further actions regarding this RAI item are currently recommended.

3.12 RAI Item 12: Degraded Voltage and Overload

Synopsis of the RAI: RAI Item 12 requested that the licensee include the consideration of a 10% under-voltage condition of operation, and a 15% overload condition for applicable loads.

Synopsis of the Licensee Response: The licensee response has provided an assessment of the available margins in the context of the identified under-voltage and overload conditions. All were found acceptable to some level of margin.

Assessment of Response: The licensee's response has included consideration of degraded voltage conditions and maximum motor loads. This is considered adequate to resolve the identified concerns. Note, however, the a licensee reassessment of its cables in response to SNL's concerns identified in Section 2.2 above may impact this assessment as well.

Findings and Recommendations: SNL finds that the RAI item has been adequately resolved. No further actions regarding this RAI item are currently recommended.

3.13 RAI Item 13: Breaker Setting Tolerance

Synopsis of the RAI: RAI Item 13 asked the licensee to consider breaker setting uncertainty in the assessment of ampacity loads that are based on the circuit breaker setting.

Synopsis of the Licensee Response: The licensee response has demonstrated that use of the actual breaker setting without consideration of the uncertainty band provides a conservative assessment of the maximum possible circuit loads.

Assessment of Response: SNL agrees with the licensee's assessment that the actual breaker setting does provide sufficient conservatism for this case. The ampacity assessment is not intended to address breaker overload, but rather, actual normal operating loads. The licensee has adequately demonstrated that for this case, the analysis has been performed in a conservative manner.

Findings and Recommendations: SNL finds that the RAI item has been adequately resolved. No further actions regarding this RAI item are currently recommended.

3.14 RAI Item 14: Load Assessments

Synopsis of the RAI: RAI Item 14 cited that the cable load assessments should be based on either the actual current flowing or the breaker setting +10%.

Synopsis of the Licensee Response: The licensee response cites that actual current loads have been used in the updated analyses. In all cases, these values were apparently less than the nominal trip setting of the breaker.

Assessment of Response: The licensee's response is fully adequate to resolve the identified concerns. Actual loads have been used in the analysis.

Findings and Recommendations: SNL finds that the RAI item has been adequately resolved. No further actions regarding this RAI item are currently recommended.

3.15 RAI Item 15: Separation of MA9 and MB9

Synopsis of the RAI: RAI Item 15 noted that the two circuits MA9 and MB9 were located in a common tray and appeared to be redundant circuits. The licensee was asked to clarify how the separation criteria were achieved.

Synopsis of the Licensee Response: The licensee response cites that these are non-safety Balance of Plant Circuits, and hence, separation is not required.

Assessment of Response: The licensee's response is fully adequate to resolve the identified concerns. Separation of non-Appendix R systems is not required

Findings and Recommendations: SNL finds that the RAI item has been adequately resolved. No further actions regarding this RAI item are currently recommended.

3.16 Summary of RAI Response Assessments

SNL finds that the licensee has adequately responded to all of the RAI items raised in the USNRC RAI of July 5, 1996. No further actions on these RAI items is currently recommended.

Note that SNL has recommended that some reassessments be requested as discussed in Section 2.2 above. These reassessments may identify additional cables that are nominally overloaded. Hence, this reassessment may impact the licensee's response to RAI item 11, which is related to how the licensee will handle nominally overloaded cables.

4.0 SUMMARY OF FINDINGS AND RECOMMENDATIONS

In general, SNL finds the licensee's submittal of October 22, 1996 to represent a significant improvement over the original submittal of March 1995 that was reviewed by SNL in April of 1996. The current submittal is much more complete and concise. It is now possible for SNL to follow and understand the licensee's ampacity assessments.

In the specific context of the USNRC RAI of July 5, 1996, SNL finds that the licensee has adequately responded to all of the specific items of concern identified. It is recommended that no further actions on these RAI items is needed at the current time. Some re-examination of the licensee response to RAI item 11, regarding the treatment of nominally overloaded cables, may be warranted in the future given that the following SNL finding may impact the licensee's overload assessments.

SNL finds that the licensee has applied an outdated methodology to its analysis that has been specifically superceded by the ICEA P-54-440 methodology. For at least some of the licensee cables this has apparently resulted in the assessment of non-conservative ampacity limits. Further, SNL finds no basis for concluding that the P-54-440 procedure is not applicable to the TMI-1 analyses. It is recommended that the USNRC ask the licensee to reexamine its assessments and to include the consideration of P-54-440 random fill cable tray ampacity limits. In particular, SNL recommends that the USNRC ask the licensee to provide and consider P-54-440 based assessments for the following seven circuits:

> LS6, ME1, ME2, MB11 (winter configuration only), MC12 (winter configuration only), CH61, and LS5.

The USNRC should also ask the licensee to document these analyses to a sufficient extent that both the cable tray depth of fill and base line ampacity calculations can be verified. For the balance of the licensee cables either no impact is anticipated, or the licensee has demonstrated an adequate margin to allow for the methodology differences.

Given these findings, SNL recommends that a follow-up RAI be prepared by the USNRC. However, SNL also recommends that this RAI can be limited to a single question requesting a P-54-440 based re-examination of the seven cables cited above. SNL also notes that the requested analyses can be easily completed by the licensee based almost entirely on the information already contained in the submittal.

Appendix A:
ICEA P-54-440 Based Analysis of Cable Tray 590 and for Tray 551/553

A.1 Tray 590

The application of P-54-440 to the analysis of Tray 590 is quite straight forward and can be summarized as follows:

Depth of fill: Tray 590 is cited on page 17 of the calculation as a 12" wide tray with a total of 5 cables apparently installed. From P-54-440 section 2.2, the depth fill is calculated as:

$$d_{fill} = \frac{n_1 d_1^2 + n_2 d_2^2 + \ldots . n_n d_n^2}{W_{tray}}$$

where d_{fill} is the depth of fill in inches, n_i is the number of cables present with a diameter of d_i, and w_{tray} is the tray width.[2] Using the licensee values, the fill depth is calculated as:

$$d_{fill} = \frac{1}{12}\left((2)(1.08)^2 + (1.81)^2 + (1.91)^2 + (2.16)^2\right)$$

Using this expression a fill depth of 1.16" is calculated.

Base line tabulated ampacity: Given this depth of fill the nominal base line ampacity limit can be easily derived from P-54-440. To do this, SNL has taken the ampacity limits from Table 3-12, has performed a linear extrapolation of the values at 1" and 1.5" to get the value at 1.16". The results for each cable are as follows:

Cable	1" fill limit	1.5" fill limit	1.16" fill limit
4/0	229	229	229
2/0	172	165	170
1/0	149	139	146
#10	24	19	22

Diameter correction: The tabulated ampacity is corrected for the actual cable diameter as per P-54-440 Section 2.5 as shown in the following table:

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[2] Note that in the calculation of fill depth P-54-440 uses the equivalent cross-section of a square surrounding the cable rather than the actual circular cross-section. This is a common source of mistakes. Areas must be treated consistently.

Cable	Tabulated Limit	Diameter Correction (actual/table)	Corrected Limit
4/0	229	(2.16/1.87)=1.155	264
2/0	170	(1.91/1.56)=1.224	208
1/0	146	(1.81/1.47)=1.231	180
#10	22	(1.08/0.64)=1.688	37

Upper bound limit: P54-440 establishes an upper bound limit of 80% of the open air ampacity as per section 2.2, and this must also be considered as a potential ampacity limit. In this step, SNL has utilized the licensee manufacturer-based open air ampacity limits rather than the ICEA values. Note that in each case, the 80% of open air limit was found to control ampacity for these cases.

Cable	P-54-440 Limit	80% Open Air Limit	Bounding Limit
4/0	264	236	236
2/0	208	174	174
1/0	180	150	150
#10	37	264	264

Temperature Correction: This tray is cited as having a 40°C ambient, so no temperature correction is required, and these final values, column 4 above, are the correct P-54-440 based ampacity limits for this case.

A.2 Tray 531/533

Tray 551/553 was cited in the licensee's March 1995 submittal as a 6" wide tray with a 2.6" depth of fill (see either the licensee's Attachment 2 or Attachment 3). In the current submittal, the tray is cited as containing three cables, two 4/C 350MCM cables and one 3/C #4/0 cable (see licensee Table 3 in the calculation attached to the current submittal). Given the diameters of these cables (also as specified in licensee Table 3), the ICEA depth of fill is calculated as follows:

$$d_{fill} = \frac{1}{6}\left((2)(3.31)^2+(2.16)^2\right) = 4.43''$$

Note that SNL has obtained a depth of fill of 4.43" as compared to the licensee cited value of 2.6". If one assumes that there is only one 4/C 350 MCM cable and one 3/C #4/0 cable present, then a depth of fill of 2.6" is obtained. However, Tables 3 and 4 of the current licensee submittal appear to clearly indicate that there are, in fact, two 4/C 350 MCM cables present.

A cross-check of the conductor count cited in Table 5 of the current submittal was unable to clarify the correct answer. In particular, the conductor count cited in Table 5 is 9. However, if there are, in fact, two 4/C 350 MCM cables and one 3/C #4/0 cable (as per Tables 3 and 4), then the correct count should be 11. If on the other hand, there is just one 4/C 350 MCM cable and one 3/C #4/0 cable (consistent with a 2.6" depth of fill), then the correct count should be 7. Neither interpretation appears consistent with a conductor count of 9.

SNL will initialy proceed on the assumption that the correct depth of fill is 4.43" as calculated above. However, at the end of this section, SNL will also calculate the allowable ampacity assuming a 2.6" depth of fill.

Given a depth of fill of 4.43", the tray actually is outside the nominal limits of the ICEA tables which do not extend beyond 3" fills. Hence, some reversion to the original Stolpe heat intensity approach is required. This is easily accomplished.

Recall that the fundamental basis of P-54-440 standard is Stolpe's model of heat intensity, or heating rate per unit volume of the cable mass, based current limits. The ICEA provides a table of heat intensity limits versus depth of fill for fills ranging from 1 to 3 inches (see table in Appendix B of the standard). When plotted, these values represent a roughly linear curve on a log-log scale. This is illustrated in Figure A.1. Hence, to a first order approximation, we can extrapolate the values out to 4.43" depth of fill using a linear extrapolation of the ICEA log-log plot.

For this purpose, SNL will assume that the log-log curve is roughly linear, and hence, can be expressed using the following linear form:

$$\log_{10}(Q) = A*\log_{10}(d_{fill}) + B$$

This relationship can also be expressed in the following form:

$$Q = 10^{\left(A*\log_{10}(d_{fill}) + B\right)}$$

This expression can be simplified somewhat by extracting the powers and log terms as follows:

$$Q = 10^{B}*\left(10^{\log_{10}(d_{fill})}\right)^{A} = 10^{b}*(d_{fill})^{A}$$

The problem now is to determine the parameter values for 'A' and 'B' using the known value pairs for 'Q' and 'd_{fill}'. Observing the behavior in Figure A.1, note that the ICEA values are not actually linear on this log-log plot. Rather, the slope of the curve becomes steeper at higher heat intensity limits (this is also observed in Stolpe's original plots). Given this observation, the most accurate approach is to use the last two values in the ICEA table, namely, the values at 2.5" and 3" depth of fills, so as to preserve the slope at the end of the curve for extrapolation to higher fill depths. Using these two points, one can obtain two equations with two unknowns (A and B) that are easily solved:

$$\log_{10}(1.784) = A*\log_{10}(2.5) + B$$

$$\log_{10}(1.377) = A*\log_{10}(3.0) + B$$

Solving these two equations for A and B SNL obtained the following results:

$$A = -1.420 \qquad B = 0.8165$$

Substituting into the simplified expression above, SNL proposes the following simple model for extrapolation of the ICEA heat intensity limits beyond a fill depth of 2.5":

$$Q_{d_{fill}>2.5''} = 10^{0.8165}*d_{fill}^{-1.420} = 6.553*d^{-1.420}$$

Note that this expression should only be applied to depth of fills of 2.5" or greater. Application to lower fill depths would result in an over-estimation of the heat intensity because of the changing curve slope. To illustrate the effects of this fitting of the ICEA tables, the SNL linear model has been superimposed on the plot of Figure A.1 for depth of fills up to 5".

Using a depth of fill of 4.43" in this final expression yields a heat intensity limit of 0.79 W/ft/in^2. This value can now be used to estimate the ampacity limit for a given cable based on cable diameter and on the electrical resistance of the conductors using equation 8 from Stolpe's paper:

$$I = \sqrt{\frac{Q\,A_{cable}}{n_{conductor}\,R_{ac}}} = \sqrt{\frac{Q\,d^2_{cable}}{n_{conductor}\,R_{ac}}}$$

Some caution must be exercised because we have used the ICEA definition of depth of fill, and the ICEA heat intensity table. Hence, we should also use the ICEA implied definition of cable cross-sectional area, that based on a surrounding cube as discussed above. This is reflected in the right-most expression where d^2_{cable} has been substituted for A_{cable}.

For the 4/C 350 MCM cable, with an electrical resistance of approximately 4.18E-5 ohms per foot at 90°C and a diameter of 3.31", the allowable ampacity limit for each conductor is given by:

$$I_{350MCM} = \sqrt{\frac{0.79 * (3.31)^2}{4 * 4.18E\text{-}5}} = 227\ A$$

Similarly for the 3/C #4/0 cable, with an electrical resistance of approximately 6.71E-5 ohms per foot at 90°C and a diameter of 2.16", the ampacity of each conductor is estimated as:

$$I_{4/0} = \sqrt{\frac{0.79 * (2.16)^2)}{3 * 6.71E\text{-}5}} = 135\ A$$

As an additional exercise, it is also quite simple to repeat this process based on the assumption that 2.6" is, in fact, the correct depth of fill. In this case, a modified heat intensity limit of 1.687 is obtained. The corresponding 350 MCM current limit at this depth of fill would be:

$$I_{350MCM} = \sqrt{\frac{1.687 * (3.31)^2}{4 * 4.18E\text{-}5}} = 332\ A$$

in which case the 80% of open air limit (0.8*407A=326A) would apply. The corresponding 4/0 current limit would be:

$$I_{4/0} = \sqrt{\frac{1.687 * (2.16)^2)}{3 * 6.71E\text{-}5}} = 198\ A$$

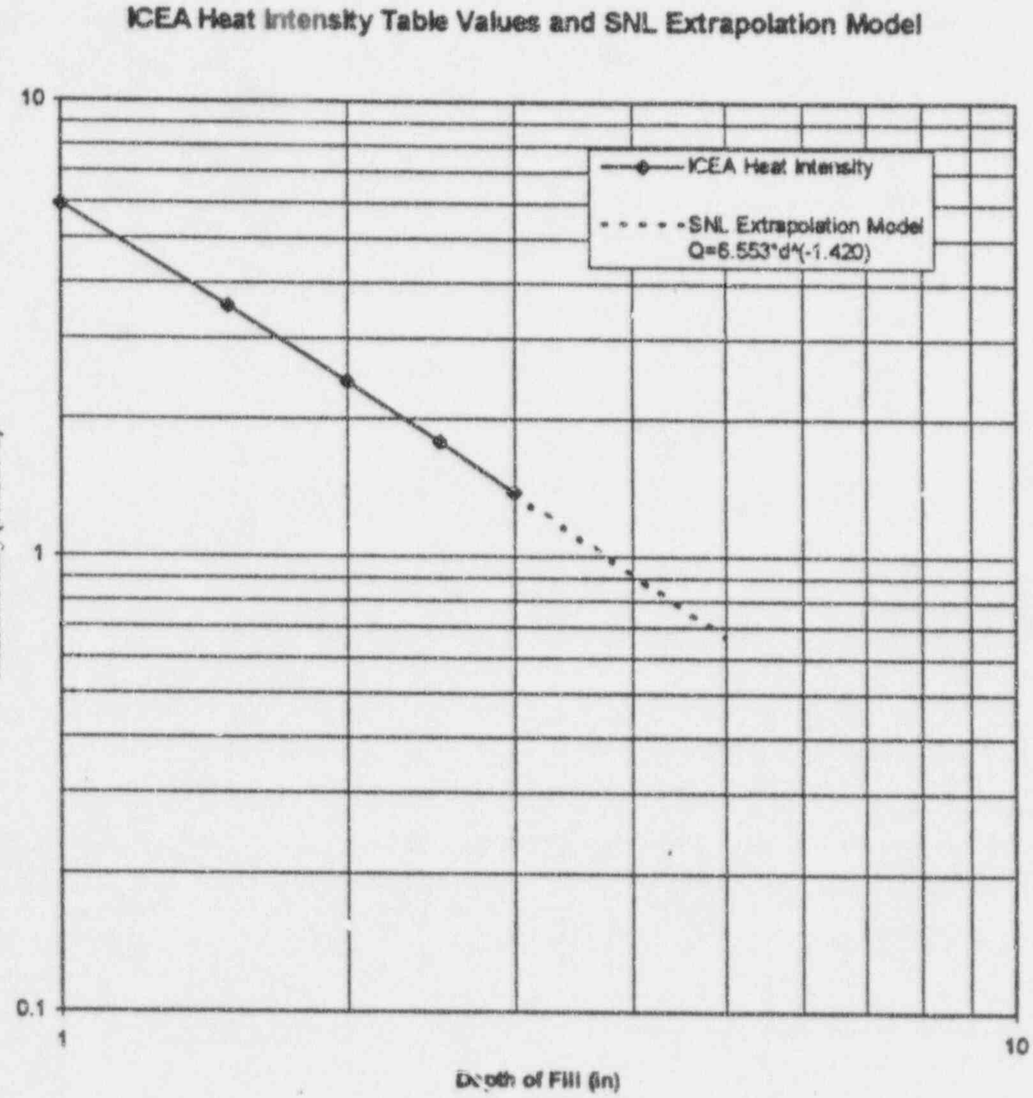
which is lower than the 80% of open air limit (0.8*295A=236A).

As a final step, all of the above values must be corrected for an ambient of 35°C rather than the nominal 40°C assumed in the tables. A correction factor of 1.05 accomplishes this. The final results are presented in the following table:

Cable size:	Source / tray fill	40°C Limit	35°C limit
4/C 350 MCM	P-54-440 / 4.43" fill	227	239
	P-54-440 / 2.6" fill	326	342
3/C #4/0	P-54-440 / 4.43" fill	135	142
	P-54-440 / 2.6" fill	198	207

By comparison, note that the licensee cited 299A for the 350 MCM cable and 217A for the 4/0 cable as the tray base line ampacity limits. Hence, the assessment of whether or not the licensee analysis is conservative will depend on the actual cable fill. If 2.6" is correct, then the licensee assessment is conservative. If the actual fill is 4.43", then the licensee assessment is non-conservative.

Figure A.1:



ICEA Heat Intensity Table Values and SNL Extrapolation Model
10
1
0.1
1
10
ICEA Heat Intensity
SNL Extrapolation Model
Q=6.553*d^(-1.420)
Heat Intensity (W/ft/in^2)
Depth of Fill (in)