A Technical Evaluation of the South Texas Project Analysis of Cable Ampacity Limits

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 is the second in a series of submittal review reports related to South Texas Project (STP). The submittals reviewed deal with the issues of Thermo-Lag 330-1 fire barriers, and in particular, the assessment of ampacity loads for protected cables. An initial review report was completed by SNL on June 28, 1996 based on a licensee submittal of April 24, 1995. A subsequent USNRC Request for Additional Information (RAI) was forwarded to the licensee on September 11, 1996. The current report documents an SNL review of a licensee response to this RAI as provided in a licensee document dated November 6, 1996. This work was performed as Task Order 2, Subtask 5 of USNRC JCN J-2503.

1.0 OVERVIEW AND OBJECTIVE

1.1 Background

In response to USNRC Generic Letter 92-08, South Texas Project (STP) provided initial documentation of the utility position regarding ampacity derating factors associated with its installed Thermo-Lag fire barrier systems in a submittal dated 4/24/95. SNL reviewed this submittal and provided a review findings report to the USNRC on 6/28/96. In large part as a result of this SNL review, a request for additional information (RAI) was forwarded to the licensee on 9/11/96.

1.2 Objective

The objective of this report is to document the findings and recommendations resulting from an SNL review of the licensee RAI response. The submittal reviewed was documented in a utility letter as follows:

- Letter, November 6, 1996, (item ST-HL-AE-5508), T. H. Cloninger, Houston Lighting and Power Co., STP, to the USNRC Document Control Desk (with one Attachment).
  - Attachment 1: "Addendum A - Reanalysis of Cable Life in Thermo-Lag Wrapped Applications"

SNL was requested to review this submittal under the terms of the general technical support contract JCN J-2503, Task Order 2, Subtask 5.

1.3 Report Organization

The licensee submittal did not identify the specific items included in the USNRC RAI, nor have specific responses to the RAI items been provided. Instead, the licensee has simply provided an updated description of its ampacity assessment process including example calculations and a summary of results. Hence, the SNL review has focused on a technical evaluation of the licensee assessment process and on a review of the licensee results. Chapter 2 provides SNL insights and findings in this regard. Chapter 3 summarizes SNL's findings and recommendations.

2.0 UTILITY AMPACITY DERATING APPROACH

2.1 Range of Applications

The licensee analyses include the consideration of both 1-hour and 3-hour nominal fire barrier systems for the protection of both conduits and cable trays. The analyses also encompass cables installed both in STP Unit 1 (STP-1) and Unit 2 (STP-2).

The barrier systems analyzed are described as typical of Thermo-Lag flat panel installations for cable trays and pre-formed conduit section installations for conduits. In the case of conduits, the licensee includes a description of a "pre-buttering" technique that appears to result in full contact between the inside of the fire barrier and the outer surface of the conduit. (This procedure is similar to that applied by Tennessee Valley Authority (TVA) in the majority of its own tests.)

2.2 Ampacity Derating Impact Assumptions

The licensee has applied an ampacity derating impact of 50% for all conduits. This value is clearly very conservative in comparison to typical test results, especially given the licensee's pre-buttering procedure as described in Section 2.1 above.

For cable trays, the licensee has applied either a 32% derating factor for 1-hour barriers (based on testing by Texas Utilities Electric (TUE)) or a 48% derating for 3-hour barriers based on testing by TVA.

The licensee's documentation includes a discussion of installation features of the STP barriers as compared to those tested by TVA and TUE. The licensee concludes on this basis that the cited values are applicable to the STP installations. Based on the descriptions provided, SNL concurs with this conclusion.

SNL finds that the licensee has applied an appropriate and conservative set of testing based ampacity derating factors in its ampacity analyses. In the specific case of conduits, the licensee has clearly applied a derating factor that is highly conservative.

2.3 Overview of Methodology

The licensee assessments are based on a three-step approach to analysis:

- The first step in the licensee analysis is referred to as the "ampacity analysis" and involves a direct comparison of ampacity loads to ampacity limits.

- The second step is referred to as the "heat analysis" and is only employed for cables that do not pass the ampacity analysis.

- The third step would involve a re-assessment of cables that fail to pass both of the step 1 and step 2 analyses. This step was not considered necessary for any cables considered in the analysis.

The subsections that follow provide a more complete review of the "Step 1 Ampacity Analyses" and the "Step 2 Heat Analysis."

As noted above, the step 3 supplemental analyses were never invoked by the licensee, and hence, will not be considered further here. As a general observation, SNL notes that the licensee has identified three potential paths to resolution of nominally overloaded cables, and these three paths are considered appropriate. However, without any actual applications, a review of the licensee implementation of this step is not possible.

2.4 The Step 1 Ampacity Analysis

In the first part of the analysis, the licensee has applied a fairly straight-forward ampacity margins analysis based on a direct comparison of in-plant cable loads to the derated ampacity limits for individual cables. In determining the in-plant loads it is important to note that:

- the licensee has employed a load factor of 1.25 to all loads except certain resistance heating loads and transformer loads.

This aspect of the licensee analysis will allow an ampacity margin in the event of motor overloads or for operation at nominal under-voltage conditions.

In determining the base line ampacity limits of the clad cables, the licensee has applied either the IPCEA P-46-426 tables for cables in conduits or the ICEA P-54-440 tables for cables in cable trays. SNL has "spot-checked" the licensee cited values, and found no discrepancies.

In the specific case of the cable tray ampacity limits, the licensee has cited depth of fill limits that extend beyond the upper limit of values cited in the ICEA tables. That is, P-54-440 only tabulates ampacity limits for cable fills of 3" or less. However, the licensee has cited equivalent fills of as much as 3.82"[1]. This does require some extrapolation of the ICEA tables to higher fill depths. SNL verified the validity of the licensee's calculations in this regard. In fact, SNL found that the licensee has apparently applied a fairly sophisticated extrapolation of the tables that is fully consistent with a proper extrapolation of the heat intensity table provided in Appendix B of the standard. In this process the licensee has apparently recognized the proper behavior of the heat intensity curve as being linear when plotted on a log-log scale (heat intensity versus fill depth).

A second factor of importance to the tray calculations is that the licensee has properly accounted for differences in the manner in which depth of fill can be calculated. That is:

- the licensee cited percentage fills are based on the actual cable fill assuming each cable has a circular cross-section ($A=\pi d^2/4$, this fill calculation method does not account for cable-to-cable air gaps),

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[1]This is the equivalent of the licensee cited 60% fill using the ICEA definition of fill depth. See further discussion of the area differences immediately below.

- in P-54-440, each cable is assumed to take up the equivalent space of a surrounding square, rather than the actual circular cross-section of the cable ($A=d^2$, this method allows for a conservative upper bound on cable-to-cable gaps).

So long as one is consistent either method is acceptable, but this is a subtle distinction that is often overlooked. For the STP analyses SNL finds that the licensee has properly treated this difference in its calculations. No discrepancies in this regard were noted.

SNL was able to directly verify several randomly selected base line ampacity cases. In this process, no discrepancies were noted. While SNL has not verified each and every ampacity limit cited by the licensee, on the basis of the verified samples, SNL concludes that the licensee assessment of base line ampacity limits is appropriate.

Given the base line ampacity, the licensee then applies derating factors to account for both the local ambient temperature and the presence of the fire barrier system. The ambient temperature assumed varies from case to case, but in all cases a value of either 40°C or 50°C has been used. For each case a given value is identified in the submittal. The fire barrier derating factors applied have been discussed in Section 2.2 above.

The result of this exercise is an estimate of the derated ampacity limit. As a final assessment for this step of the analysis, the in-plant cable loads are compared to the derated ampacity limit, and an assessment of the acceptability is made.

Based on the results of this step of the licensee has concluded that the majority of the cables considered are operating within acceptable limits. This included all of the conduits, all of the medium voltage cable trays, and most of the lower voltage cable trays. For the applications that have passed this step of the analysis, SNL finds that these "Step 1" licensee assessments are adequate to demonstrate acceptable operating conditions. For those applications that "pass" this step of the analysis, SNL recommends that no further documentation is required.

However, 13 trays in Unit 1 and 11 trays in Unit 2 apparently failed to pass this step of the analysis. For these trays, the licensee has gone on to apply a "Step 2 Heat Analysis". This aspect of the licensee's assessments is considered in Section 2.5 immediately below.

2.5 The Step 2 Heat Analysis

The licensee identified a total of 24 trays, 13 for STP-1 and 11 for STP-2, that apparently did not pass the "Step 1 Ampacity Analysis" and for which a "Step 2 Heat Analysis" was performed. For all 24 of these trays the current loads were deemed acceptable on the basis of having passed the "Step 2 Heat Analysis." As will be noted below, SNL finds that this conclusion is not adequately supported.

The details of how this step of the analysis is actually implemented as provided in the submittal are quite sparse. The licensee has only provided two detailed cable tray examples, and both of these cases passed on the basis of the "Step 1 Ampacity Analysis."

No examples of the "Step 2 Heat Analysis" are provided. Hence, it is difficult to assess this methodology with certainty. The only information provided on this step of the analysis is given on page 3 of the licensee "Addendum A." Here it is stated:

> "Step 2: Calculate the heat generation per foot of cable (f)or each circuit, excluding intermittent power loads, using the total load current from Step 1. Total the heat generation for all circuits in the tray with the maximum allowable heat generation per foot of tray based on a 50 percent fill (that fill which leaves no available space below the side rails) after applying the appropriate derating. If the total heat generation is less than or equal to the derated maximum allowable heat generation, no further analysis is required."

This description, while far from complete, is sufficient to raise significant concerns regarding this step of the analysis. It is apparent from this discussion that the licensee has applied the equivalent of a "watts per foot" type analysis. That is, the licensee has estimated the total heat load generated in the tray as a whole, and has compared this value to a limiting value of the heat rejection capacity of the clad system. This approach typically derives from early ampacity studies, such as those of Stolpe, but reduces the level of analysis detail to the point that individual cable loads are not assessed in any meaningful manner.

While the licensee has not provided any citations to support its treatment, SNL has encountered this approach in other USNRC submittal review efforts. In particular, the method has typically been cited as being based on a Bechtel design standard. Given that Bechtel was the Architect/Engineer for both STP-1 and STP-2, one must suspect that this STP assessment method also derives from the Bechtel design standard. SNL has provided a detailed review of the "watts per foot" methodology in a letter report to the USNRC associated with submittals for Palo Verde.[2]

The fundamental problem with this methodology is that it is inherently incapable of assessing the ampacity performance of individual cables. The method only considers the heat rejection capacity of the system as a whole, and gives no treatment to the actual local heating effects associated with individual cables. Use of this method can easily lead to highly misleading results. This is especially true for any situation involving significant load diversity. The methodology can easily result in false conclusions that significant current overloads are acceptable.

One example used to illustrate the fundamental flaw in the method is as follows:

- <u>Cable Diversity Effects</u>: The "Watts/ft analysis method provides for no significant treatment of cable diversity effects and how this would impact the total allowable heat loads for the cable tray system. All of the available ampacity tests typically cited as supporting the method are based on cable trays in which all of the cables are powered

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[2]See "A Review of the Palo Verde Analysis of Fire Barrier Ampacity Derating Factors," A Letter Report to the USNRC, Revision 0, September 27, 1994, report prepared under USNRC JCN J2017, Task Order 4.

uniformly. In real applications, cable trays contain a mixture of loaded and unloaded cables. It is unrealistic to assume that a diverse cable load would have the same overall heat rejection capacity as a uniform cable load. Recall that the objective is to ensure a hot spot of no greater than 90°C. Concentrating the heat generation is just a few cables would clearly create significant localized heating effects that would lead to higher hot-spot temperatures. This is not accounted for in the "Watts/ft" method.

Consider, for example, two cases involving a cable tray loaded with 49 power cables (an arbitrary number). In the first case, we assume that all 49 of the cables are powered uniformly. In the second case, we will assume that only a single cable is powered. The "Watts/ft" methodology would assume that the overall heat rejection capacity for these two cases would be identical. Hence, in effect, the heat load generated by the one cable which is powered in both cases could increase by a factor of 49 from case 1 to case 2, and still the tray would display the same overall heat load. This would imply a 7-fold increase in the ampacity of that cable from case 1 to case 2. (Heating load is proportional to the square of current so the "allowable" current increase would be given by the square root of 49, or 7 times the case 1 ampacity.) This is clearly unrealistic; however, the "Watts/ft" methodology in and of itself would erroneously conclude that each of these two cases was equally acceptable.

The total overall heat rejection capacity of the cable tray as a system must be reduced in cases involving diverse cable loads (although no one knows by how much for a given situation). This may seem counter-intuitive, but recall that even with a reduced overall heat rejection capacity for the system, the ampacity of the individual cables might still increase, the assumption typically associated with diversity. The "Watts/ft" method simply contains no mechanism for assessing these counterbalancing effects.

SNL has previously concluded that this method is incapable of meeting the objectives of a cable ampacity study, namely, to assess the adequacy of load currents for individual cables. Just because the heat load for the system as a whole is within some predetermined limit provides no assurance that any individual cable within that system is operating within acceptable limits.

2.6 Potential Alternative Analysis Approaches

The licensee has apparently identified 24 cable trays with one or more nominally overloaded cables in each. However, it remains unclear how many individual cables are nominally overloaded, and how severe these nominal overload conditions are. In theory, a single cable might be routed in several cable trays in different areas, and hence, the number of nominally overloaded cables could be quite small. The licensee has simply not provided enough information to judge this aspect of the analysis.

However, given that SNL finds the "Step 2 Heat Analysis" as currently documented to be unacceptable, SNL does recommend that the USNRC ask the licensee for some alternate basis for the resolution of these cable trays. There are a number of potential paths available to the licensee which might help to resolve these cases.

First, it should be noted that the licensee has already performed an assessment of the individual cables based on accepted ampacity analysis approaches from P-54-440 in the Step 1 analyses. Hence, it is unlikely that given the existing assumptions of the analysis that an alternate approach might be deemed acceptable and yet reach a conclusion that the ampacity loads are, in fact, acceptable. Rather, the most promising path towards resolution would involve relaxation of the assumptions of the analysis. Assumptions that might be relaxed include:

- Calculation of cable load: While little detail in this regard is offered, the licensee assumptions of cable load conditions might be conservative. For example, if a load has been based on a circuit breaker or transformer load rating, actual loads might prove lower if assessed on the basis of actual devices connected.

- Load factor: The licensee application of a 1.25 load factor to most loads might also be revisited. In particular, the licensee cites that cable design included a voltage-drop criteria, and hence, the licensee may be able to justify relaxation of this assumption for marginal cases. Alternatively, the licensee might provide an analysis based on nominal load ratings, and then provide a supplemental assessment of under-voltage and overload margin. This could be especially useful if it can be supported by a discussion of actual under-voltage history at the plant.

- Ambient temperature: The licensee has assumed an ambient temperature of either 40°C or 50°C depending on the particular case considered. While 40°C is considered quite typical of these analyses and any value lower than this would be difficult to justify, the licensee may be able to relax this assumption for those areas in which a 50°C temperature was assumed.

- Depth of fill: The licensee analysis states that a minimum fill of 25% was assumed for all cable trays. This is equivalent to an ICEA depth of fill of 1.6" (STP cites a nominal tray height of 5" so 25% fill is: $(5")*(0.25)*(4/\pi)=1.6"$, which includes the ICEA vs STP depth of fill correction as discussed in Section 2.5 above). If actual fill depths are lower than this limit then relaxation of this assumption would increase the allowable ampacity limits.

- Alternate ADF Values: The licensee assessment for, in particular, its 3-hour cable tray fire barriers was based on a 48% ADF taken from the TVA Watts Bar test program. However, unlike the licensee's barriers, the TVA tests included a significant upgrade to the base installations. The licensee could consider application of the Florida Power and Light (FPL) results obtained in testing for the Crystal River Plant. In these tests a basic 3-hour Thermo-Lag 330-1 single layer fire barrier system was found to have an ADF of 41.4%. This test would nominally appear to be more representative of the STP 3-hour barriers being considered. It appears that 6 of the 13 STP-1 trays and 8 of the 11 at STP-2 trays involve 3-hour barriers, and this change would impact these assessments.

- Load diversity: The ICEA P-54-440 standards are based on an assumption that all cables in a tray are equally loaded (in the context of the heat generation rate per

unit volume of cables). For cases in which the actual load is only marginally above the nominal limit, a supporting thermal analysis of the cable mass that includes diversity effects might be appropriate. This would, however, be a complicated approach to solution. However, SNL notes that TVA implemented such an approach for its Brown's Ferry plant in 1988-89 that was eventually accepted by the USNRC.

3.0 SUMMARY OF FINDINGS AND RECOMMENDATIONS

The current STP ampacity analysis submittal has adequately demonstrated acceptable ampacity loads for the majority of the licensee's applications at both STP-1 and STP-2. In particular, SNL finds that those cases that have been deemed acceptable by the licensee on the basis of the "Step 1 Ampacity Analysis" method are, in fact, acceptable. This includes all conduit applications, all of the identified medium voltage cable tray applications, and the majority of the identified lower voltage cable tray applications. No further actions on these applications is recommended.

However, the licensee has apparently identified a total of 24 cable trays, 13 for STP-1 and 11 for STP-2, that did not pass the "Step 1 Ampacity Analysis." For these 24 trays the licensee has performed a "Step 2 Heat Analysis." Based on the limited description provided by the licensee, SNL concludes that the "Watts per foot" methodology has been applied by the licensee in these Step 2 analyses. Based on earlier reviews associated with other licensees, SNL has concluded that the "Watts per foot" methodology is fundamentally incapable of providing an adequate assessment of the performance limits of individual cables. Hence, SNL finds that the licensee's apparent application of this methodology is inappropriate and cannot achieve the objectives of the analysis. It is recommended that the USNRC should not credit these analyses as a demonstration of load acceptability. It is further recommended that the USNRC ask the licensee to provide an alternate basis for the assessment of the 24 cable trays that were judged acceptable on this basis.