A Technical Evaluation Report on the Watts Bar Fire Barrier Ampacity Derating Tests and Applications

A Letter Report to the USNRC

Revision 0

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ATTACHMENT 1

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FORWARD

The United States Nuclear Regulatory Commission (USNRC) has solicited the support of Sandia National Laboratories (SNL) in the review of licensee submittals associated with fire protection and electrical engineering. This letter report represents the second, and likely the final, report in a series of review reports associated with a set of submittals from the Watts Bar Nuclear Plant (WBN). These submittals deal with the assessment of ampacity loads for cable trays and conduits protected by Thermo-Lag 330-1 fire barriers, and in particular, with tests performed by Tennessee Valley Authority (TVA) to assess ampacity derating factors for certain "special configurations" of the fire barriers at WBN. An initial review report was prepared by SNL on April 5, 1996, and as a result the USNRC sent a RAI to the licensee on August 29, 1996 requesting clarification of four items. This report documents the results of a SNL review of the licensee response to this RAI. The documents were originally submitted by the licensee in response to USNRC Generic Letter 92-08. This work was performed as Task Order 2, Subtask 1 of USNRC JCN J2503.

1.0 INTRODUCTION

1.1 Objective

In response to USNRC Generic Letter 92-08, the Tennessee Valley Authority (TVA) Watts Bar Nuclear Plant (WBN) provided documentation of the licensee position regarding ampacity derating factors associated with its installed Thermo-Lag 330-1 fire barrier systems. In particular, the licensee cited that it would rely on test results both from other industry sources and from TVA/WBN specific tests. SNL was asked to review the following TVA/WBN test reports:

- Central Laboratories Services Report 93-0501, *Testing to Determine Ampacity Derating Factors for Fire Protected Cables for Watts Bar Nuclear Plant*, Revision 0, July 6, 1993, submitted for USNRC review July 9, 1993. (This report and the tests documented therein will be subsequently referred to in this review as the "Phase 1 report" and the "Phase 1 tests" respectively.)

- Omega Point Laboratories Report 11960-97332,97334-6,97768-70, *Ampacity Derating of Cables Enclosed in One-Hour Electrical Raceway Fire Barrier Systems (ERFBS)*, March 28, 1995, submitted for USNRC review April 25, 1995. (This report and the tests documented therein will be subsequently referred to in this review as the "Phase 2 report" and the "Phase 2 tests" respectively.)

- Omega Point Laboratories Report 11960-97333, *Ampacity Derating of Cables Enclosed in Cable Tray with Thermo-Lag® 330-1/770-1 Upgrade Electrical Raceway Fire Barrier Systems (ERFBS)*, June 30, 1995, submitted for USNRC review September 14, 1995. (This report and the tests documented therein will be subsequently referred to in this review as the "Phase 3 report" and the "Phase 3 tests" respectively.)

- Omega Point Laboratories Report 11960-97337 & 97338, *Ampacity Derating of Cables Enclosed in Conduits with Thermo-Lag® 330-1/770-1 Upgrade Electrical Raceway Fire Barrier Systems (ERFBS)*, August 21, 1995, submitted for USNRC review September 14, 1995. (This report and the tests documented therein will be subsequently referred to in this review as the "Phase 4 report" and the "Phase 4 tests" respectively.)

A report documenting the initial results of that review was completed on April 5, 1996. SNL recommended that the USNRC ask for additional clarification to resolve three minor points of uncertainty regarding those tests. The USNRC forwarded to the licensee a RAI including the three items raised by SNL and one additional item raised directly by the USNRC. The objective of the current review was to assess the adequacy of the licensee response to this RAI.

The licensee response reviewed by SNL was presented in the form of a letter to the USNRC Document Control Desk as follows:

- Letter, J. A. Scalice, TVA/WBN, to the USNRC Document Control Desk, Oct. 24, 1996 with one enclosure entitled "Watts Bar Nuclear Plant Unit 1 Request for Additional Information Thermo-Lag Related Ampacity Derating Factors".

SNL was requested to review this submittal under the terms of the general technical support contract JCN J-2503, Task Order 2, Subtask 1. This letter report documents the results of SNL's review.

1.2 Overview of the Licensee Ampacity Derating Approach

The consideration of ampacity derating factors for fire barriers at WBN is based on a primarily experimental approach to the problem. That is, TVA and WBN have now performed a series of ampacity derating experiments to assess both generic configurations for cable trays and conduits, and certain unique configurations involving multiple trays or conduits housed within a single fire barrier enclosure. These experiments, in combination with other results available from other industry sources, have determined the ampacity derating factors (ADF) associated with each installation at WBN.

Once determined experimentally, these ADFs are then applied to tabulated cable ampacity limits to determine the maximum allowable current for the various cables installed at WBN. Actual in-plant current loads are compared to these limits to determine the acceptability of the ampacity values. SNL has not reviewed the results of this final application step because the related documents were not provided. The licensee does cite in its response that these documents are available on-site for NRC review.

1.3 Organization of Report

This review has focused on a technical review of the licensee RAI response. Section 2 of this report provides a brief summary of the initial SNL review findings as documented in the April 5, 1996 letter report. Section 3 provides a point by point review of the licensee responses to the four RAI questions from the USNRC letter of August 29, 1996. Section 4 summarizes the SNL findings and recommendations.

1.4 Summary of Recommendations

Based on the results of this review, no further actions are recommended at this time. It is recommended that the USNRC accept these test results as an adequate demonstration of ampacity derating factors for the tested configurations.

2.0 SUMMARY OF PREVIOUS REVIEW FINDINGS

2.1 Overview

In March and April of 1996, SNL reviewed a set of test reports submitted by TVA/WNB to support its assessment of fire barrier ampacity derating factors both for generic configurations and for certain "special configurations" (see Section 1.1 above for a list of the subject reports). A report documenting the results of this review was issued by SNL on April 5, 1996. The objective of this chapter is to briefly summarize the scope and findings of that earlier review. This information derives directly from the 4/5/96 report. Retention of this information here is considered important to establish a perspective from which the RAI responses can be viewed in context.

The TVA/WBN tests were performed at either Central Laboratory Services (CLS) (the Phase 1 tests) or Omega Point Laboratory (OPL) (the Phase 2-4 tests). In brief, the various test phases can be characterized as follows:

- The Phase 1 tests covered generic testing of single conduit configurations associated with pre-formed conduit section of the Thermo-Lag 330-1 material in a 1-hour configuration.

- The Phase 2 tests include tests of cable trays and conduits in both a generic single item configuration and in certain unique configurations.

- The Phase 3 tests evaluated a single cable tray with a three-hour fire barrier system comprised of a basic Thermo-Lag 330-1 barrier system supplemented by a Thermo-Lag 770-1 upgrade.

- The Phase 4 tests evaluated one 1" and one 4" steel conduit enclosed in a 3-hour fire barrier system nominally similar to that of the Phase 3 cable tray.

It is important to note that the TVA/WBN tests included both standard ampacity derating tests of simple barriers systems (a single tray or single conduit) and tests of multiple trays or multiple conduits in a common fire barrier. The test procedure generally followed the guidance provided in the IEEE P848 draft standard, "Procedure for the Determination of the Ampacity Derating of Fire Protected Cables" (Draft 12 of the standard is cited in the Phase 1 CLS report, and Draft 14 is cited in the Phase 2 and 3 test reports from OPL). However, because some of the tests involve multiple trays or multiple conduits in a single enclosure, and because the P848 standard does not explicitly address such configurations, TVA/WBN went beyond this procedure in the performance of its tests. Even in these special configuration tests, SNL found that TVA/WBN had adhered to the "spirit and intent" of the P848 standard. No specific concerns related to TVA's extension of the P848 methods to its special configuration tests were noted.

2.2 Physical Description of TVA/WBN Test Items

Tables 2.1 and 2.2 describe the physical configurations evaluated by TVA/WBN in Phase 1 and in Phases 2-4 of its test program, respectively. The test item identifications used here are the same as those used in the original TVA/WBN test reports. For the Phase 2-4 tests, Test Items 7.1, 7.2, 7.6a, 7.6b, 7.7a and 7.7b correspond to generic or standard configurations in that they involve a single cable tray or conduit consistent with the IEEE P848 test protocol. Test Items 7.3, 7.4, 7.5 and 7.8 represent the special configuration test articles in that each consists of multiple trays or multiple conduits enclosed in a common fire barrier system.

Table 2.1: Description of the TVA/WBN Phase 1 Test Items

Test Item	Description
93-0501-1	4" conduit with 5/8" base layer
93-0501-2	4" conduit with 5/8" base layer plus 3/8" upgrade layer
93-0501-3	4" conduit with 3/8" base layer plus 3/8" upgrade layer
93-0501-4	4" conduit with no barrier installed, 3-piece conduit section
93-0501-5	1" conduit with 5/8" base layer
93-0501-6	1" conduit with 5/8" base layer plus 3/8" upgrade layer
93-0501-7	1" conduit with 3/8" base layer plus 3/8" upgrade layer
93-0501-8	1" conduit with no barrier installed, 3-piece conduit section
93-0501-9	4" conduit with no barrier, 2-piece section
93-0501-10	1" conduit with no barrier, 2-piece section

2.3 Barrier Installations

2.3.1 Phase 1 Barrier Installations

In the Phase 1 tests, three different fire barrier configurations were tested (as noted in Table 2.1 above). All of the barriers were constructed using pre-formed conduit sections of the Thermo-Lag 300-1 material. The three installations tested were (1) a basic 5/8" fire barrier system, (2) a 5/8" base layer plus a 3/8" upgrade layer, and (3) a 3/8" base layer with a 3/8" upgrade layer.

It is also critical to note that the installation procedures utilized by TVA/WBN in the installation of the pre-formed conduit sections include a unique practice in that each barrier section is fully "pre-buttered" along the length of the section on the inner surface of the panel. The result of this procedure is to completely fill, with trowel grade material, the gap between the inner barrier surface and the outer conduit surface, and the gap between the inner and outer barrier layers for those installations involving a second barrier layer. This is a unique installation procedure which could significantly impact the ampacity derating results. In particular, if this full surface pre-buttering procedure is not applied, then an air gap could exist between the conduit and the inner surface of the fire barrier, and possibly between barrier layers as well. In this case, a more severe ampacity derating impact would be expected. This condition should be carefully noted, in particular, if the results are to be applied to other plants and other utilities.

Table 2.2: Description of Phase 2-4 Test Items

Test Item	Description
7.1	Single 24" x 4" tray with solid sheet steel top cover and 5/8" (nominal) 330-1 fire barrier.
7.2	Same cable tray as item 7.1, barrier made up of 1-1/4" base installation of 330-1 plus an upgrade layer of 3/8" thick 770-1 matting, no steel tray cover installed. (This test item is the only Phase 3 test item.)
7.3	Three stacked 24" x 4" trays, spaced on 12" centers, in a common 5/8" 330-1 fire barrier enclosure. Power applied only to top two trays
7.4	Three 1" diameter steel conduits in a horizontal row surrounded by a common rectangular 5/8" 330-1 fire barrier. Conduit-to-conduit gap of approximately 1/2 diameter. All conduits powered.
7.5	Six 1" diameter steel conduits arranged in a two rows of three conduits each in a small common rectangular 330-1 fire barrier enclosure, 5/8" thick. conduit-to-conduit gap 1/2 diameter. All conduits powered.
7.6a	Single 1" diameter steel conduit, barrier made up of 1-1/4" base installation of 330-1 pre-formed conduit sections plus an upgrade layer of 3/8" thick 770-1 matting (this test item is the first of two Phase 4 test items).
7.6b	Single 4" diameter steel conduit, barrier as per item 7.6a (this is the second of two Phase 4 test items).
7.7a	Single 1" diameter steel conduit in a small square 330-1 fire barrier enclosure, 5/8" thick, 4 3/4" on a side, supported by Unistrut frame.
7.7b	Single 1" diameter steel conduit in a large square 330-1 fire barrier enclosure, 5/8" thick, 30" on a side, supported by Unistrut frame.
7.8	Six 1" diameter steel conduits, in a large square fire 330-1 barrier enclosure, 5/8" thick, 30" on a side, supported by Unistrut frame

2.3.2 Phase 2 Barrier Installations

The fire barriers for all of the test items in the Phase 2 tests were constructed out of nominal 5/8" Thermo-Lag 330-1 flat panels. For the conduits, this is the most significant difference between the Phase 1 and Phase 2 tests. That is, in the Phase 1 tests the conduits were protected using preformed conduit sections of Thermo-Lag 330-1. In the Phase 2 tests, all of the conduits were protected using flat panels to form a "boxed" configuration.

For items 7.1, 7.3, 7.4, and 7.5 (a single tray, three stacked trays, a single 1" conduit, and a group of six conduits respectively), the fire barriers were constructed so as to form a minimal volume. That is, the construction of the barrier followed standard installation procedures in which the flat barrier panels are secured directly to the cable tray(s) or conduit(s) with only the minimum required clearances needed to secure and support the panels. For items 7.7a and 7.7b (single conduit tests), and items 7.4, 7.5 and 7.8 (multiple conduit arrays), the Thermo-Lag 330-1 barrier was built using a somewhat unique construction approach. Flat panel sections were used to build a rectangular box of a predetermined overall size that was significantly larger than the nominal size of the test item itself. To do this, the flat panels were supported on a fixed Unistrut frame surrounding the conduits. These boxes varied in size from test article to test article (as described in Table 2.2 above). As will be noted below, this did impact the results of the testing.

It should also be noted that the TVA/WBN Phase 2 test of the single cable tray, test item 7.1, included the installation of a solid steel cover plate on top of the tray prior to installation of the fire barrier (the cover was not in place during the base line test of this test article). Use of a solid cover plus a fire barrier would not be considered typical practice, and the presence of the cover could significantly impact the ampacity derating results. In effect, the steel tray cover represents an additional layer of thermal material between the trays and the environment. Hence, the ampacity derating associated with this system would be expected to be somewhat more severe than that for a barrier without the tray cover. As discussed further below, this expectation proved to be true (see discussion comparing TVA and TUE test results).

In the case of the Phase 2 experiments, after the ampacity derating tests were completed, the actual installed thickness of the Thermo-Lag 330-1 panels was measured in different locations for the various fire barrier systems. The actual installed thickness ranged from 0.82 to 1.78 inches. This variation was attributed to attempts to achieve a smooth final surface for the fire barrier through the application of additional trowel grade Thermo-Lag 330-1 material. In the context of ampacity derating, a thicker barrier than that minimally required would be a more conservative configuration.

2.3.3 Phase 3 Barrier Installations

The Phase 3 barrier installation was significantly different that those of either Phases 1 or 2. In this case a 1-1/4" base layer of Thermo-Lag 330-1 panel was installed, with an additional upgrade overlay of 770-1 Thermo-Lag matting material. Two layers of the 770-1 matting material were installed. This barrier system was identified as a 3-hour barrier as compared to the 1-hour barrier evaluated in the Phase 1 and 2 tests.

Destructive evaluation of the barrier thickness after the completion of testing revealed general material overall thicknesses in the range of 2.56" to 3.31". In locations on the bottom of the specimen, gaps had formed between the base 330-1 panels and the 770-1 overlay (due to physical sagging of the matting during installation and curing). In these areas, overall thicknesses including the air gaps were as high as 5.19".

While it is not explicitly stated it is apparent from the photographs of the barrier installation process that the steel cable tray cover plate installed in the case of test item 7.1 was not installed in the case of item 7.2. This is an important difference which should be considered in any comparison of the two tests or in any subsequent applications of the test results to other trays.

2.3.4 Phase 4 Barrier Installations

The Phase 4 conduit installations were essentially identical to those of the Phase 3 cable tray installation. That is, the barrier consisted of a 1-1/4" 330-1 base layer plus an overlay of the 3/8" 770-1 matting. Two layers of the upgrade matting material were installed. The 330-1 layer was formed using pre-formed conduit sections of the material. The 770-1 is a flexible matting material and is simply wrapped around the item to form the desired shape.

In this case it is also important to note that the conduit sections were "dry fit to the conduit and secured with stainless steel bands ... The joints and seams were then post-buttered with Thermo-Lag 330-1 Trowel Grade material." This practice is important because it means that for these installations, a natural gap was allowed to form between the conduit outer surface and the fire barrier inner surface. No attempts to fill this gap were apparently made. In terms of ampacity derating, this is the most conservative configuration. That is, the ADF with the gap should be greater than the ADF if the gap were filled. This is in apparently marked contrast to the barrier installations of Phase 1.

Destructive evaluations of the fire barrier thickness were performed after the completion of testing. For item 7.6a, the 1" conduit, thicknesses ranged from 2.76" to 2.84". For item 7.6b, the 4" conduit, thickness was consistently found to be approximately 2.6".

2.4 Review of Test results and Applications

2.4.1 Overview

The TVA/WBN tests provided numerous results which are of significant interest both to TVA/WBN and potentially to other utilities. The TVA/WBN test results also provide a wealth of information of significant potential interest to the development and validation of computer models of the heat transfer processes associated with the problem of ampacity derating.

This section of the report first summarizes the test results as presented by TVA/WBN in its test reports. The discussion then considers certain aspects of the test data which highlight significant and interesting behaviors which can be derived from the TVA/WBN test results. These insights have been discussed in detail in the April 5, 1996 SNL Letter Report, and are merely summarized here.

2.4.2 Results for Phase 1 Conduit Configurations

The Phase 1 conduit tests resulted in a complex set of test results which are can be difficult to interpret. This resulted from certain unexpected behaviors noted by TVA in the performance of its tests. In fact, much of the testing performed by TVA/WBN in Phase 1 was specifically aimed at resolving the discrepancies which were noted early in the test program. Two behaviors were noted in these tests that contributed to uncertainty in the test results:

- Many of the TVA/WBN test articles were to be tested using an odd number of conductors in the conduit. This led to unbalanced electrical loads passing through the conduits and in the direct inductive heating of the conduit itself. Much of the TVA/WBN testing was performed in an attempt to understand and eliminate this behavior from the tests.

- In certain of the TVA/WBN baseline conduit tests, it was noted that the hot-spot in the cable mass was not occurring at the center of the conduit section as expected, but rather, at one of the two "side" measurement locations. TVA/WBN went to considerable lengths to address this condition. TVA/WBN's final resolution of the issue was to re-construct the conduit sections using one 10' section in the center and 2 - 5' sections (cut from a single 10' section), one place on each end of the center section.

In addition, there was one aspect of the TVA/WBN Phase 1 tests which introduces additional uncertainty into the test results, and which complicates the final assessment of the test data:

- In the TVA/WBN Phase 1 tests, different physical conduit sections were used in the baseline and clad tests.

Overall, the TVA/WBN efforts to understand and address these unexpected behaviors are considered both appropriate and fully responsive to the situation. The final analysis of test results is somewhat confused by this situation, but the final results of the TVA tests should not be considered to have been fundamentally compromised by this situation.

The final results of the TVA/WBN tests are summarized in Table 2.3. Note that for these tests the derating impact is presented in terms of the Ampacity Correction Factor (ACF) rather than the Ampacity Derating Factor (ADF). The relationship between ACF and ADF is simply:

$$ADF = 1.0 - ACF$$

In presenting the results no attempt has been made to provide all of the various ampacity measurements made by TVA/WBN, nor to assess which of the results are "most correct" for a given conduit. Rather for each physical system a range of ACF values is reported. TVA/WBN has indicated (in public meetings with the USNRC) that it intends to use the most conservative of the test results as applicable to a given situation.

Table 2.3: Summary of TVA/WBN Phase 1 Test Results			
Conduit Size	Test Item	Barrier Description	ACF
4"	93-0501-1	5/8" 330-1 preformed conduit sections	1.018-1.073
	93-0501-2	5/8" 330-1 preformed conduit sections with 3/8" upgrade overlay	0.975-1.041
	93-0501-3	3/8" 330-1 preformed conduit sections with 3/8" upgrade overlay	0.918-1.031
1"	93-0501-5	5/8" 330-1 preformed conduit sections	0.965-1.027
	93-0501-6	5/8" 330-1 preformed conduit sections with 3/8" upgrade overlay	0.956-1.002
	93-0501-7	3/8" 330-1 preformed conduit sections with 3/8" upgrade overlay	0.969-1.016
Note: test results include the full range of cable loading and powering schemes evaluated by TVA/WBN, including those with known inductive heating effects.			

2.4.3 Results for Phase 2-4 Conduit and Cable Tray Configurations

Table 2.4 provides a simplified summary of the test configurations and derived ampacity derating factors (ADF). The TVA/WBN derived ADF values for the conduits ranged from a low of 6% for the single conduit in a large box (item 7.7b) to a high of 26% for the group of six conduits in a small common enclosure (item 7.5). The differences noted by TVA/WBN are pronounced. Some of the insights which are directly apparent from the TVA/WBN results include:

> Boxed Enclosure versus Preformed Conduit Sections The boxed enclosure derating factors are significantly larger than the derating factors found in the Phase 1 tests for conduits enclosed in barriers made up of pre-formed panels.
>
> Effects of Boxed Enclosure Size: For the two conduit configurations tested using both a "small" and "large" enclosure, the smaller enclosure had a higher derating factor than that of the larger enclosure.

2.5 Supplemental Insights Gained from the TVA/WBN Test Results

Certain insights may be gained from the TVA/WBN test results which will not necessarily directly impact the review or final assessments of the TVA/WBN test results. Again, a range of such insights has been discussed in detail in the April 5, 1996 SNL letter report, but that discussion is far from exhaustive. There are many additional insights which could be gained from a more thorough examination of the test data.

Table 2.4: Ampacity derating results for TVA/WBN Phase 2-4 Tests			
Test Item	Description	Barrier Description: All barriers made from 5/8" (nominal) Thermo-Lag 330-1 flat panels, plus trowel grade except where noted otherwise.	ADF (%)
7.1	1 - P848 tray, 24"x4"	Steel tray cover plate installed, then enclosed in rectangular box with panels in contact with cable tray and top cover.	40
7.2	1 - P848 tray, 24"x4"	3-hour fire barrier system of 1-1/4" 330-1 with two layers of 3/8" 770-1 as upgrade	48
7.3	3 P848 trays, top 2 powered	Housed in a common rectangular enclosure, panels applied in contact with cable trays, no steel covers on any of the 3 trays.	36
7.4	3 Conduits, 1", all powered	Conduits in a horizontal row, surrounded by a common enclosure, conduit-to-conduit spacing of approximately 1/2-diameter, panels applied directly to conduits.	8
7.5	6 Conduits, 1", all powered	Conduits arranged in a two rows of three conduits each, common rectangular fire barrier enclosure, conduit-to-conduit gap 1/2 diameter, panels applied directly to conduits.	26
7.6a	1 Conduit, 1"	Similar to item 7.2, 330-1 used in 1-1/4" preformed conduit sections.	10
7.6b	1 Conduit, 4"	Same as 7.6a	13
7.7a	1 Conduit, 1"	Conduit in a small square fire barrier enclosure, 4 3/4" on a side (inside dimension of panels), panels supported by Unistrut frame.	12
7.7b	1 Conduit, 1"	Conduit in a large square fire barrier enclosure, 30" on a side (inside dimension of panels), panels supported by Unistrut frame.	6
7.8	6 Conduits, 1", all powered	Same conduit array as in 7.5, in a single large square fire barrier enclosure, 30" on a side (inside dimension of panels), panels supported by Unistrut frame.	9

Such supplemental insights can be obtained, for example, by comparing the TVA/WBN results to other tests, by comparing the results for one test item from the TVA/WBN tests to another in somewhat unconventional ways, and by comparing the TVA/WBN ampacity measurements to the standard ampacity tables. The TVA/WBN tests provide a wealth of new and valuable insights which are considered worth noting here. Areas in which additional insights were documented in SNLs initial review include:

- A comparison was made between the TVA/WBN cable tray results to those of Texas Utilities in a similar test from 1993.[1] These comparisons illustrated the importance of the solid steel tray cover used by TVA to the test results.

- The effects of stacking cable trays on ampacity were also evaluated and the TVA test results were compared to the ICEA ampacity tables. These comparisons highlighted certain potential shortcomings in the ICEA tables and recommended practice for stacked cable trays.

- The effects of grouped conduit ampacity limits were also reviewed and the TVA test results were compared to the ICEA ampacity tables. While these comparisons were somewhat incomplete, a potential weakness in the ICEA tables for grouped conduits was identified.

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[1]The TU tests are documented in an OPL report 12340-94583,95165-95168,95246 which has been submitted by TU to the USNRC for review. This test report was reviewed by SNL under Task Order 1 of this JCN (J2017).

3.0 AN ASSESSMENT OF THE SPECIFIC LICENSEE RAI RESPONSES

The USNRC RAI of August 29, 1996 raised four specific questions. The licensee response to each of these questions is assessed in this chapter.

3.1 RAI Item 1: Steel Tray Covers

3.1.1 Summary of Concern

It remained somewhat unclear exactly when in the testing process solid tray covers had been installed. In particular, for test items 7.1 and 7.2 it was considered appropriate to ensure that the base line tests had been conducted without the tray covers in place. The licensee was asked to clarify this uncertainty.

3.1.2 Summary of Licensee Response

The licensee response has provided explicit descriptions documenting where and when the tray covers were installed. The response also makes clear that the base line tests were conducted without tray covers installed, as is appropriate.

3.1.3 Assessment of Licensee Response Adequacy

The licensee response to this RAI item was fully adequate to resolve the question. The licensee response had clarified the uncertainties identified in the RAI. The tests all appear to have been performed in a prudent manner consistent with the intent of the test standards. No further actions on this item are recommended.

3.2 RAI Item 2: Cure Time

3.2.1 Summary of Concern

It was noted that for one of the licensee test items, Item 7.3 the stacked cable tray array, the nominal 30 day cure time had not been fully achieved. This presented a potential concern that excessive moisture loss from uncured material may have impacted the test results.

3.2.2 Summary of Licensee Response

The licensee response has clarified the time line associated with this test article. It noted that after initial completion, it was deemed necessary to remove the bottom from the barrier, and to then subsequently reinstall the bottom panel using some additional panel material, stress skin, and skin coating by trowel grade material. The licensee time line clearly indicates that even with this reconstruction, a minimum cure time of 25 days was allowed, and that most of the test article cured somewhat longer. The licensee went on to provide its reasoning for why this would not have impacted the test results, primarily because a significant cure time was allowed, and only a small fraction of the test article surface area was impacted.

3.2.3 Assessment of Licensee Response Adequacy

The licensee response to this RAI item was fully adequate to resolve the question. In particular, SNL agrees with the licensee arguments in this regard. Of particular importance is the licensee observation that the effected surface area was minimal, and the allowed cure time was only nominally below the recommended 30 days. Based on the licensee description, SNL also notes that most of the trowel grade material applied during the rework efforts was applied to the outside of the test article, and hence, a rapid cure would be expected (if the rework had involved extensive applications of trowel grade to the inside surfaces of the barrier, then a more significant concern might remain. The impact of the shortened cure time for the reworked section on the TVA test results would have been negligible. No further actions on this item are recommended.

3.3 RAI Item 3: Simultaneous Testing

3.3.1 Summary of Concern

A potential concern had been identified in that TVA had tested more than one test article at a time during at least some of its tests. The licensee's documentation had not provided explicit descriptions of the test article arrangements, and hence, a potential existed that mutual heating effects between the test articles might have influenced the tests. One specific case was cited in which such effects may have caused asymmetric heating. The licensee was asked to provide more discussion of this topic.

3.3.2 Summary of Licensee Response

The licensee response provided detailed descriptions of the test arrangements illustrating that these arrangements did in fact comply with the IEEE P848 test standard. Minimum horizontal separation distances of 36" were maintained throughout. The licensee also provide a discussion of the specific case cited by SNL as potentially illustrating the concerns. This discussion clarified that the asymmetric heating was actually biased away from the other test article in the enclosure, and hence, that other factors were responsible for the effects.

3.3.3 Assessment of Licensee Response Adequacy

The licensee response to this RAI item was fully adequate to resolve the question. In particular, SNL agrees with the licensee's assessment that (1) the tests were performed consistent with the IEEE P848 standard and that (2) any mutual heating effects would have been quite minimal. The licensee response was adequate to assure that mutual heating effects would have had no significant impact on the test results. No further actions on this item are recommended.

3.4 RAI Item 4: Application of Results

3.4.1 Summary of Concern

The licensee was asked to "confirm that the existing ampacity design margins are adequate and sufficient for each installed fire barrier configuration." Further, the licensee was asked to "delineate the minimum excess ampacity derating margins ... at the Watt Bar Nuclear Plant."

3.4.2 Summary of Licensee Response

The licensee response states that "all power cables have adequate ampacity margin." A TVA design standard and a specific WBN calculation are cited as supporting this conclusion, but these documents were not provided for review (the documents are cited as available on-site for review). The question of the minimum excess ampacity margin is not addressed.

3.4.3 Assessment of Licensee Response Adequacy

This response is generally considered adequate, although somewhat incomplete. In particular, the utility has not answered the question as to what the minimum available ampacity margin identified in its assessments is. Of the two, this aspect of the RAI item is considered to be of less significance. Of greater significance is the fact that the utility has clearly stated that all of its power cable ampacity levels have been assessed and found to be adequate. The supporting documents were not available to SNL, and hence, have not been reviewed as a part of this assessment. SNL acknowledges that TVA has available a considerable expertise in this area. Based on (1) the known level of expertise available at TVA, (2) the overall quality and comprehensiveness of the TVA/WBN testing program, (3) the reliance by TVA/WBN on the most conservative of the recorded ADF values for a given configuration, and (4) the reliance upon direct test data (rather than on modeling results), SNL recommends that no further actions on this RAI item be taken.

4.0 SUMMARY OF REVIEW FINDINGS

4.1 Overall Conclusions

As was noted in the earlier SNL initial review efforts, the TVA/WBN tests of ampacity derating factors were all well planned and executed. The licensee has gone to extensive lengths to understand certain anomalous behaviors in the original Phase 1 tests, and in its Phase 2-4 tests has explored unique conduit and cable tray configurations which have provided new and valuable insights into the physics of ampacity and ampacity derating. The overall quality of the test program is considered to be outstanding, and hence, the test results are considered to be highly reliable. It is recommended that the USNRC accept these tests as a reliable representation of the ampacity derating impact for the tested configurations.

In the specific case of the Phase 1 single conduit tests, there is clearly some uncertainty in the test results. TVA has gone to extensive lengths to quantify and understand this uncertainty. For these tests it is recommended that only the most conservative results for each conduit and barrier configuration tested be applied in practice. This is, in fact, consistent with the approach taken by TVA in its own applications.

4.2 Adequacy of Licensee RAI Responses

As a result of the initial review SNL had recommended that the USNRC pursue clarifications related to three minor points. Questions on these three points were forwarded to the licensee in the form of RAI Items 1-3 by letter from the USNRC dated August 29, 1996. The licensee response to these three RAI items was considered fully adequate to resolve the identified concerns and uncertainties.

In addition, the USNRC RAI included a fourth RAI item asking the utility to (1) confirm that its cables were operating within acceptable ampacity limits, and (2) to quantify the minimum available excess ampacity margin for its installed electrical distribution cables. The utility response only addressed the first aspect of this final RAI item. The second aspect of this RAI item is considered of lesser significance. Hence, while the utility has not addressed this RAI item, SNL does not consider this oversight to significantly impact the acceptability of the utility test reports. SNL recommends that no further actions on this RAI item be undertaken.

It should also be noted that the licensee response to the first aspect of RAI Item 4 cited two second tier documents as supporting the conclusion of cable adequacy. These second tier documents have not been reviewed by SNL. The focus of the SNL review efforts was to assess the adequacy of the utility tests. SNLs primary conclusions in this regard are provided in Section 4.1 above.

4.3 A Potential Concern for Cable Tray Stacking and Conduit Grouping

As a part of this review process SNL identified a number of supplemental insights. These are insights that would not directly impact the review and final assessment of the

TVA/WBN submittals, but rather, provide valuable new information of a more general nature. One of these insights, that associated with cable tray stacking and conduit grouping effects, indicates that certain aspects of the published ICEA/NEMA ampacity tables may not conservatively bound the TVA test results. The appropriate venue for resolution of these concerns is considered to be the appropriate standards committees rather than TVA/WBN.

In particular, the TVA/WBN stacked tray test results indicate that the effective ampacity derating impact of placing one powered tray above, and one unpowered tray below a central powered cable tray is on the order of 12%. It was also noted that the baseline ampacity measured for the three-tray TVA/WBN stack was lower than the nominal ampacity limits established in the ICEA/NEMA open top cable tray ampacity tables. The test results indicate that (1) the practice of cable tray stacking can significantly impact actual cable ampacity limits, even in the fairly simple and limited configuration of the TVA/WBN tests, (2) the ICEA/NEMA tables may not contain sufficient margin to bound this effect, and (3) the implicit assumption in the standard tables that buoyancy driven heating of the top trays would be the predominant effect in a cable tray stack, and hence that the top tray would be the most severely impacted by stacking effects, is not supported by the TVA test results.

The ICEA/NEMA tables suggest that for cable tray stacks, the top tray(s) be derated by some nominal percentage (10%). This practice is not supported by the TVA test results. In particular, the TVA tests illustrate that insulating and mutual heating effects of the surrounding cable trays appear to be more important than buoyancy heating of the top trays. In the TVA tests, the center tray was found to be hotter than the top tray, and the bottom of the three trays was not even powered. Standard practices do not address this phenomena.

Similar changes in measured baseline ampacity were also noted for the tests involving grouped conduits as compared to single conduits. It remains unclear whether or not the standard practices for derating of grouped conduits bound this effect. (This was beyond the scope of the SNL review efforts, and hence, the SNL evaluations were somewhat incomplete.)

It is recommended that the USNRC consider requesting that the cognizant industry organizations update the published standards on cable ampacity so that more explicit treatment of cable tray stacking and conduit grouping are provided. This will likely require that additional testing of the cable tray stacking and conduit grouping effects be undertaken to provide a sufficient base of data upon which to base a new design approach for future installations.