A Review of the Watts Bar Fire Barrier Ampacity Derating Tests and Applications

A Letter Report to the USNRC

Revision 0

April 5, 1996

Prepared by:
Steve Nowlen
Tina Tanaka
Sandia National Laboratories
Albuquerque, New Mexico 87185-0737
(505)845-9850

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

ATTACHMENT 2

TABLE OF CONTENTS:

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 documents the results of a SNL review of 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. In particular, the submittals document tests performed by Tennessee Valley Authority (TVA) to assess ampacity derating factors for certain "special configurations" of the fire barriers at WBN. These documents were submitted by the utility in response to USNRC Generic Letter 92-08. This work was performed as Task Order 8, Subtask 1 of USNRC JCN J2017.

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 utility position regarding ampacity derating factors associated with its installed Thermo-Lag 330-1 fire barrier systems. The objective of this review was to review and evaluate the utility submittals. In particular, the submittals included documentation of tests performed to assess ampacity derating factors for certain unique configurations of the fire barriers which have been installed at WBN. These include both cable tray and conduit fire barrier systems.

The relevant documents reviewed are:

- 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.)

SNL was requested to review these submittals under the terms of the general technical support contract JCN J-2017, Task Order 8, Subtask 1. This letter report documents the initial results of this review. The intent of this review was to provide support to the USNRC in determining the adequacy of the utility submittals, and in the potential development of a supplemental RAI. Based on the results of this review, it is recommended that such a request be pursued to clarify certain relatively minor points related to the manner in which the utility plans to apply the test results.

1.2 Overview of the Utility 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, WBN has now performed a series of ampacity derating experiments to assess both generic configurations for cable trays and conduits, and to assess certain unique configurations involving multiple trays or conduits housed within a single fire barrier enclosure. These experimental have determined the ampacity derating factors (ADF) associated with each installation at WBN. These factors 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.

1.3 Organization of Report

This review has focussed on a technical review of the utility tests. In particular, this review has focussed on the most recent tests in which the unique configurations were tested. Section 2 of this report provides the results of a technical review of the utility tests focussing on the overall methodology utilized and consistency with the relevant standards. Section 3 documents the results of the WBN tests, and discusses certain aspects of the data analysis and application. This includes a review of the earlier test results for the more generic single tray and single conduit tests performed by WBN. Section 4 summarizes the SNL findings and recommendations regarding the need for additional information to support the final assessment of the utility analyses.

Note that in the discussions which follow, the tests performed by TVA/WBN will be referred to in terms of the "Phase" of the program in which the tests were performed. SNL will refer to Phases 1-4, each corresponding to one of the four separate test reports reviewed by SNL. These reports and the corresponding "Phase" for each are identified immediately above. In effect, the Phases 1-4 correspond to the chronological order of the four test reports.

2.0 TECHNICAL REVIEW OF THE UTILITY TESTS

2.1 Overview

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). For purposes of this review, the tests are grouped into four phases consistent with the four test reports submitted by TVA/WBN. Section 1.1 above provides a breakdown of test reports and how each report is identified in this review. 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 1 tests were documented in a CLS report dated July 6, 1993. (Note that this report has received considerable previous review within the USNRC and to a more limited extent involving SNL.)

- The Phase 2 tests include tests of cable trays and conduits in both a generic single item configuration and in certain unique configurations. These tests are unique primarily because they investigate certain special barrier configurations. These Phase 2 tests were documented an OPL report dated March 28, 1995.

- 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. This test was documented in an OPL report dated June 30, 1995.

- 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. This test was documented in an OPL report dated August 21, 1996.

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 follows 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 has gone beyond this procedure in the performance of its tests. Even in these special configuration tests, SNL finds that TVA/WBN has 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 1 and 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. Note that in 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.

The test specimens evaluated by TVA/WBN consisted of "randomly" filled cable trays and steel conduits. In the phase 1 conduit tests, both 1" and 4" steel conduits were evaluated. A variety of cable fills, conduit sizes, and powering schemes were also used.

The cables used in Phase 1 were 3/C #6AWG, 4/C #6AWG, and 1/C 750 MCM. In the Phase 2 and Phase 3 cable tray tests, all of the trays used were filled with 3/C #6 AWG 600 V (consistent with P848 guidelines). The Phase 2 conduit tests all involved 1" steel conduits containing 4/C #10 AWG 600 V cable also as specified in the P848 standard. The phase 3 and 4 tests also involved use of these same cable types. All of the cables used by TVA/WBN were supplied by Rockbestos and have cross-linked polyethylene (XLPE) insulation and chlorosulfonated polyethylene (CSPE) jackets.

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

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 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 practice that each barrier section be 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.

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 items 7.1, 7.3, 7.4, and 7.5, 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 barrier is secured directly to the cable tray or conduit with only the minimum required clearances needed to secure and support the panels. In the case of conduit test items 7.7a and 7.7b, and 7.8, the fire barrier was constructed so as to create a fixed, predetermined enclosure size which was significantly larger than the nominal volume of the conduit groupings themselves. This is described further below.

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. This is not considered typical practice, and would 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.

For items 7.7a and 7.7b, the Phase 2 single conduit tests, and for test items 7.4, 7.5 and 7.8, the multiple conduit arrays, the Thermo-Lag 330-1 barrier was built using a somewhat unique construction approach. Instead of a preformed cylindrical Thermo-Lag pieces used in Phase 1, in Phase 2 flat panel sections were used to build a rectangular box 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). For these test articles, the fraction of the internal volume made up of "dead air space" was significantly larger than that of the other systems. As will be noted below, this did impact the results of the testing.

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.

One potential discrepancy in the testing procedure was noted regarding the cure time allowed for the Thermo-Lag 330-1. That is, while the panels are provided by TSI as a fully cured solid product, in order to form the fire barrier an uncured trowel-grade form of Thermo-Lag is used to seal the joints. The trowel grade material requires an extended cure time, and the TVA/WBN test plan called for 30 days of curing time before the testing of the protected assemblies. This curing time requirement was observed for all cases except for item 7.3. This item was tested 27 days after the fire barrier was finished. No specific information was provided regarding the impact of this shortened cure time and no documentation was provided on a moisture content measurement as suggested by the test plan as an alternative to the 30 day cure time. In general, this is considered a minor point given that a significant cure time only slightly shorter than that called for in the test plan was allowed. It is recommended that the utility be asked to provide for its own assessment of the potential impact of this deviation from the test plan, and in particular, be asked whether or not moisture content measurements were made prior to the final testing.

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 installation of Thermo-Lag 330-1 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). 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. It is recommended that the utility be asked to verify this point because the presence or absence of the cover plate would significantly impact the ampacity results.

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 Compliance with the IEEE P848 Draft Standard

2.4.1 Compliance with Experimental Procedures

In all of the TVA/WBN tests, the experimental procedures were bases on the IEEE P848 draft test standard. In the case of the Phase 1 tests, Draft 12 of the standard is cited. In the Phase 2-4 tests, Draft 14 of P848 is specifically cited. In the context of these tests, and in particular given the manner in which TVA/WBN pursued its testing, the differences between these two versions of the standard are relatively unimportant. The principal change was that Draft 14 introduced a specification that the baseline and clad tests must be performed using the same physical test specimen. In large part, the TVA/WBN Phase 1 test insights were the motivating factor in this change, and TVA/WBN has given thorough consideration to the impact of having used different physical test specimens in its baseline and clad Phase 1 tests. This is discussed further below.

It is useful to note at the outset certain aspects of the IEEE P848 draft test standard relevant to the review of the TVA/WBN tests. Recall that ampacity derating is a measure of the percentage loss in the maximum current that can be carried by a cable that is protected by a fire barrier system in comparison to the maximum current that can be carried by the same cable without any fire protection. The current must be limited in order to ensure that the maximum rated temperature for the cable is not exceeded. Since fire protection barriers act to isolate the cables from the external environment, some insulating effect is to be expected. As a result, adding fire protection almost always reduces the maximum allowable current.

In P848 the maximum temperature for the cable is assumed to be 90°C while the air temperature of the test enclosure is maintained at 40° C. These values correspond to the typical life exposure temperature rating of the cable insulation materials, and to the typical ambient conditions assumed in standard tables of cable ampacity. The TVA/WBN tests all complied with both the tolerance limits and the steady state achievement criteria set forth in P848. No significant discrepancies were noted in this regard.

For a cable tray or conduit, the primary measurement of the conductor temperature is taken at the middle of the cable tray or conduit test specimen, (in the standard this is identified as position 2). Temperatures are also measured at two "side" locations, Positions 1 and 3, which are located 3 feet on each side of the central position 2. The draft standard provides criteria for the allowable variation between the center and side locations, and these criteria were satisfied in the TVA/WBN tests.

Note that in the Phase 1 tests the center location was not always the hottest location. While it is nominally expected that the center location should be the hottest, the P848 standard does not require that such a condition be achieved. TVA/WBN went to significant lengths to understand and address this situation. In the final analysis, it appears that minor differences in the surface emissivity of the conduit sections used in test item construction were sufficient to account for the observed behavior. In the final analysis, this situation has been explored appropriately by the utility, and this situation would not significantly impact the final results of the TVA/WBN tests. However, the fact that this condition did exist, and that TVA/WBN did use different physical conduit sections for its baseline and clad tests does mean that there is some uncertainty in the results. This is discussed further below.

The ambient temperature is generally assumed to be based on the air temperature within the test enclosure, and this is the typical value reported in such tests. TVA/WBN did comply with the provisions in P848 regarding the need to achieve, maintain and monitor the ambient environment. It is interesting to note that in the Phase 2-4 tests, TVA/WBN actually included measurements of the wall temperatures as well. This is presumed to be in response to questions which had been raised regarding the potential impact on the tests if the walls of the test enclosure were significantly different in temperature from the air. The P848 standard does not address either enclosure wall construction nor wall temperature. The TVA/WBN practice of measuring the wall temperature is a laudable extension of the P848 methodology which will eliminate this issue as a potential point of concern.

2.3.2 Compliance with Test Documentation Requirements

P848 includes a list of the documentation required to demonstrate compliance with the provisions of the standard. This list includes; a description of the test articles, information of the test equipment, calibration of the test equipment, and quality control records. Overall each of the three TVA/WBN reports was found to be quite well documented, concise, and informative. However, while the reports satisfied most of the requirements of the P848/D14 documentation, three exceptions were noted; namely, the qualification and certification for test personnel has not been provided, documentation that the product does or does not react at temperatures below 90°C has not been explicitly provided, and documentation that moisture equilibrium has been achieved was also not provided.

With regard to documentation of test personnel, both OPL and TVA/WBN are known to have extensive expertise in the area of ampacity testing, and hence, this is not considered a point of significant concern. Even in the case of the CLS tests, while the qualification of CLS in this area are not known, oversight of the activities by TVA/WBN was documented and would generally be considered an acceptable practice. It is also clear from the review that the tests were performed in a very rigorous and professional manner. Hence, while SNL does not consider this issue to be of significant concern, a follow-up question to the utility to provide such documentation is recommended.

With regard to the reactivity of the product at temperature below 90°C, while no information was included on this aspect of the fire barrier product, it is well known that Thermo-Lag does not exhibit significant changes in behavior at or near these temperature levels. Hence, this is considered an unimportant observation, and no specific actions are recommended in this area.

With regards to the demonstration of moisture equilibrium, for nearly all of the TVA/WBN specimens a full 30 day cure period was allowed consistent with manufacturer recommended practices. This is generally considered acceptable to demonstrate that the test articles have achieved moisture equilibrium. However, in the case of Phase 2 test item 7.3, testing was completed after only 27 days of curing. As noted in Section 2.3 above, this is not considered a significant concern, but a follow-up question to the utility is recommended. In particular, the utility should be asked to provide any documentation of moisture content measurements if such measurements were made for this test article.

2.5 Extensions to the P848 Test Standard

2.5.1 Supplemental Instrumentation

In all of its tests TVA/WBN has significantly extended the scope of the measurements made beyond those required in the standard. This supplemental information has proven especially useful in interpreting the test results, and in no way invalidates any of the basic required data measurements nor the analysis of test results. In particular, the Phase 1 tests included extensive measurements of the conduit surface temperatures in addition to the cable temperatures. These supplemental measurements significantly expanded the general knowledge of heat transfer and ampacity derating and led directly to TVA/WBN's ability to interpret the results of its testing.

One item of particular note is that for the Phase 2-4 tests the temperature of the enclosure walls were also measured. On some of the tests, the floor of the enclosure was insulated for both the baseline and clad tests. Floor insulation is not addressed in P848/D14, and is probably not an issue, but it could help in maintaining the ambient temperature. This practice was presumably in response to previous questions which had been raised regarding the lack of specification for the test enclosure wall properties or monitoring. In earlier reviews of the TVA/WBN Phase 1 tests, this was identified as a potential contributing factor to the anomalous behavior noted in those tests (see further discussion below).

The TVA/WBN tests included many thermocouples in excess of those required by the standard. These supplemental thermocouples measured various surface temperatures which will be of great interest for modeling of these types of tests. Of particular note in this regard are the Phase 2 tests. For example, temperatures were measured on both the inside and outside surfaces of the fire barriers. Also, 9 to 14 temperature measurements were made of the ambient room air temperature, and 6 measurements were made of the enclosure wall temperatures. Some measurements were also made of the outside surface of the cables (as compared to the conductor temperature below the insulation).

Finally, as suggested in P848/D14, surface emissivity measurements were made on many of the surfaces in the test enclosure including various parts of the test articles. In particular, TVA/WBN has reported a range of values for conduit surfaces, the cable tray side rails, the cables, and the fire barrier materials. These measurements will be most helpful to possible future efforts to model and understand these test results.

2.5.2 Methodological Extensions for Stacked Cable Trays

Test item 7.3 consisted of a stack of three cable trays within one fire barrier enclosure. This type of configuration is not addressed by the P848 standard, and hence, extension of the general methodology of P848 to this special configuration was needed. In both the baseline and clad tests, all of the cables in the top two trays were powered. All of the conductors in the top two cables trays were connected in a single series and served by a single current supply. Hence, the two top trays had equal power densities applied to them. In effect, the top two trays represented two of the P848 standard cable trays stacked one above the other and powered equally in testing.

Thermocouples were installed in each of the top two trays in the same locations as are recommended for the single tray in P848. The third, bottom cable tray was loaded with the same cable fill as the upper two trays, but was not powered during the test, and was apparently not instrumented either. This configuration apparently corresponds to the configuration being evaluated in the plant (i.e. three trays in a single box in which only the top two trays contain power cables), and hence is considered an appropriate extension of the P848 test.

In implementing the necessary extensions to the P848 protocol to meet the needs of this particular test article, TVA/WBN adhered closely to both the intent and spirit of the standard. In particular, the utility has provided an equivalent level of instrumentation, and has followed an appropriate and well documented protocol for performance of the tests. SNL has identified no concerns related to the testing protocol used by TVA/WBN in the evaluation of this test article.

2.5.3 Methodological Extensions for Grouped Conduits

Test items 7.4, 7.5 and 7.8 each involved the testing of a group of conduits rather than the testing of a single protected conduit. These configurations are not specifically addressed by the P848 test protocol, and hence, extensions of the standard test procedure were required to suit the needs of these tests. As with the stacked cable tray test described in Section 2.5.2 above, the extensions to the test protocol implemented by TVA/WBN in its testing have been well documented, adhere to both the spirit and intent of the P848 standard, and are considered by SNL to be appropriate.

One important factor to consider in reviewing the test results is that for the grouped conduit tests, all of the conduits were provided with identical cable loads, and all of the cables in each conduit were powered equally during the actual tests. With regard to test instrumentation, for test item 7.4, thermocouples were provided for each of the three conduits in the array. For items 7.5 and 7.8, the double row of three conduits, thermocouples were placed in all 6 conduits. In each case, the thermocouples were positioned consistent with the specifications from P848 for testing of a single conduit.

2.5.4 Simultaneous Experiments Performed

In the actual execution of testing, TVA/WBN typically evaluated two separate ampacity test items simultaneously. This was presumably intended to make testing more efficient and to expedite the program. However, no provisions are included in P848 for this type of simultaneous testing of multiple test items, and this practice may have slightly affected the results of the tests.

In this type of testing, the surface temperatures of the test articles are significantly higher than that of the surroundings (the air and walls of the test enclosure). This situation may lead to the direct interchange of radiant energy between test articles when more than one test article is tested simultaneously. The intent of the test standard is to ensure that the test articles exchange energy only with the ambient surroundings (the air and walls of the test chamber). Hence, the practice of simultaneous testing introduce an unanticipated thermal effect which could impact the test results.

To illustrate the possible effects, consider that items 7.1 and 7.4 were tested simultaneously. For the clad test, it was also noted that for test item 7.4, the "left" conduit was the hottest of the three conduits. This is somewhat unexpected as one would normally anticipate a relatively symmetric behavior, and hence, one would expect the center conduit to have been the hottest of the three. One potential explanation for this behavior would be the presence of item 7.1, the cable tray test item, in the test enclosure during the test. Even in the clad tests the data indicate that the exterior of the fire barrier cladding on item 7.1 was approximately 46° C at equilibrium. Because test item 7.4 was subject to some level of radiative exchange with test item 7.1, and because 7.1's outer surface was significantly warmer than the ambient, this may have caused a minor shift in the location of the hot spot for item 7.4 towards the side nearest item 7.1 due to radiant energy exchange. This is, unfortunately, all conjecture since it is not obvious from the pictures whether the left or right conduit was closest to item 7.1. Also, given the rather unexpected behaviors noted for the conduits in the Phase 1 tests, alternate explanations of the behavior are certainly possible (e.g., variations in surface emissivity of the various conduits in the array might also have led to this behavior).

In general, it is not expected that this situation would have significantly impacted the test results, particularly if consistency was maintained between the baseline and clad tests. However, SNL recommends that limited follow-up questions to the utility should be pursued. In particular, the utility should be asked to describe the physical separations between test articles, any measures taken to ensure that direct radiative heat transfer did not occur between the specimens, and to describe the actual pairing of test items in both the baseline and clad tests. The utility should also be asked to perform a limited review of its test data to determine if any of the non-symmetric heating behavior might be attributed to the simultaneous testing of two test articles, and to provide its own assessment of the potential impact this practice may have had on the test results.

In addition, this question should also be viewed in a broader context as a point of general concern regarding the P848 standard. The practice of running two (or potentially more) test items simultaneously in the same test enclosure should be addressed in the standard. In particular, it may be prudent for the test standard specify (1) that some minimum separation distance between the test articles be maintained, (2) that an insulating panel be place midway between the test articles so as to prevent direct radiative heat exchange between them, and (3) that the placement of one test article directly above another test article should be prohibited. This is an issue which should be directed to the standards committee rather than to the utility.

3.0 REVIEW OF TEST RESULTS AND APPLICATIONS

3.1 Overview

The TVA/WBN tests have 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.

3.2 Summary of TVA/WBN Test Results

3.2.1 Results for Phase 1 Conduit Configurations

The Phase 1 conduit tests resulted in a relatively complex set of test results which are relatively 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. Early into the testing program, TVA/WBN realized that inductive heating effects were being experienced due to the unbalanced electrical loads passing through the conduits. This resulted in the direct heating of the conduit itself through induced currents, and in a distortion of the test results. 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. In the final analysis, it was determined that differences in the individual conduit sections used to construct the test specimens were to blame for the behavior. In particular, differences in the surface emissivity of the conduits was attributed as the primary culprit in this behavior. 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. This resulted in the desired behavior with the hot-spot subsequently being located, as expected, in the center of the specimen.

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. That is, in testing, TVA/WBN would use the same cable bundle in both the baseline and clad tests, but this cable bundle would first be installed in one unprotected conduit for the baseline test, and then reinstalled into a separate clad conduit for the clad test. This practice, when combined with the significant difference in thermal behavior noted by TVA/WBN for different conduit sections, introduces uncertainty into the final test results.

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. In the overall context of interpreting the test results, the TVA/WBN practice of using different physical conduit specimens in the baseline and clad tests is of most significance. That is, it is this practice that is most difficult to quantify, and hence, it is this factor that lead to the most significant unquantifiable uncertainty in the final test results.

The final results of the TVA/WBN tests are summarized in Table 3.1. 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). This is a matter of convenience in order to avoid confusion related to negative ADF values. That is, several of the TVA/WBN tests resulted in clad case ampacity values greater than the baseline ampacity values. This implies that the presence of the fire barrier actually led to an increase in allowable ampacity. This situation can arise primarily due to an increase in the radiative efficiency of the fire barrier surface in comparison to the conduit surface. The TVA/WBN practice of filling the gap between conduit and barrier makes this situation far more likely. This behavior would be reflected as either a negative ADF or as an ACF which was greater than unity. The relationship between ACF and ADF is simply:

$$ADF = 1.0 - ACF$$

In presenting the results we have not attempted to provide all of the various ampacity measurements made by TVA/WBN, nor have we addressed the issues of 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. This approach is considered fully appropriate given the available cable ampacity margin apparently available at TVA/WBN. However, it does leave the question open should some other utility or other plant choose to utilize the TVA/WBN results, and wishes to use other than the most conservative values reported. This review has not further pursued this concern as it is considered outside the scope of the review of TVA/WBN's approach to ampacity derating.

Table 3.1: 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.			

Some seemingly unexpected results can be noted. In particular, for the 4" conduit the worst-case derating impact for the 3/8"+3/8" system (item 3) was somewhat worse than that of the 5/8"+3/8" system (item 2). This is not an expected result, and the reason for this discrepancy is somewhat unclear. However, it should also be noted that for both items the worst case derating impact was associated with the 3-conductor single phase experiments in which the inductive heating effects would have been most pronounced. The source of this discrepancy may be related to these effects.

Another interesting point was noted in this review. It has previously been postulated by SNL (in discussions with the USNRC) that the net effect of inductive heating on ampacity derating tests would be to drive the results toward more conservative values (higher ADF or lower ACF). The primary effect of inductive heating is to move some of the heat generation source away from the cable conductors and into the conduit itself. The presence of the barrier introduces a more significant change in behavior for the conduit (as a heating source) than it does for the cables inside the conduit. This is because the conduit itself starts out with direct thermal access to the environment whereas the cables begin with some level of isolation due to the surrounding conduit. The fire barrier cuts off direct access of the conduit to the ambient, and hence, the relative change is more profound. This would also imply that the derating impact would be magnified in this situation. This postulate appears to have been the case in these tests. In particular, with the exception of item 1, the worst case derating impact was uniformly associated with the 3-conductor single phase test. As noted above, it is this configuration that would have experienced the most significant inductive heating problems.

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

The ampacities measured in the TVA/WBN Phase 2-4 tests are summarized in Table 3.2. Table 3.2 provides both the actual and corrected currents measured for both the baseline and clad (protected) tests for each test article. Table 3.3 provides a simplified summary of the test configurations and derived ampacity deratings.

Table 3.2: Ampacity measurements for TVA/WBN Phase 2 Tests

Test Item	Item Description	Barrier Condition	Actual Current (A)	Cable Hot-spot Temp. (°C)	Room Temp. (°C)	Corrected Current (A)
7.1	1 Tray, 1hr barrier	baseline*	29.73	90.8	39.9	29.50
		clad	17.50	89.5	41.3	17.81
7.2	1 Tray, 3hr Barrier	baseline*	29.73	90.8	39.9	29.48
		clad	15.51	89.3	40.0	15.60
7.3	3 Trays, one 1hr box	baseline	25.96	90.8	41.6	26.20
		clad	16.65	89.3	40.9	16.90
7.4	3 - 1" Conduits, small 1hr box	baseline	31.65	89.8	39.9	31.67
		clad	29.15	90.4	40.6	29.23
7.5	6 - 1" Conduits, small 1hr box	baseline	30.96	90.9	41.3	31.13
		clad	23.15	90.9	40.9	23.18
7.6a	1" Conduit, 3hr wrap	baseline	32.64	90.2	40.2	32.56
		clad	29.54	89.3	39.8	29.66
7.6b	4" Conduit, 3hr wrap	baseline	29.59	90.6	39.2	29.21
		clad	25.85	90.5	39.3	25.56
7.7a	1" Conduit, small 1hr box	baseline	33.20	90.5	39.9	33.03
		clad	29.17	89.9	40.1	29.22
7.7b	1" Conduit, large 1hr box	baseline	33.20	90.5	39.9	33.03
		clad	31.20	90.0	40.2	31.26
7.8	6 - 1" Conduits, large 1hr box	baseline	30.96	90.9	41.3	31.13
		clad	28.40	90.3	40.0	28.33

* The same baseline test was used for items 7.1 and 7.2 because the exact same cable tray was used in both test articles.

The TVA/WBN derived deratings 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:

> <u>Boxed Enclosure versus Preformed Conduit Sections</u> 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. In the case of the single conduit, for example, the Phase 1 test for a 1" conduit show ADF values ranging from -2.7 to +3.5% for the preformed, cylindrically-shaped Thermo-Lag 330-1 using three different cables (recall that the Phase 1 tests included some tests with negative ADFs). The phase 2 tests

show a much higher ampacity derating factor for the single conduit contained in Unistrut-supported panels of 12% and 9% (items 7.7a and 7.7b). This difference is primarily attributed by SNL to the absence of any air gaps in the Phase 1 barrier installations.

Table 3.3: 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

Effects of Boxed Enclosure Size: Another result of interest is that 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.

This can be illustrated by comparing the single conduit test items 7.7a and 7.7b: 12% ADF for the small box versus 6% ADF for the larger box. One can also compare the 6-conduit grouping from test items 7.5 and 7.8: 26% for the smaller box and 9% for the larger box. These differences are attributed by SNL to two factors. First, the increased surface area of the larger box leads to a greater rate of heat transfer through the box and to the ambient for a given temperature drop across the barrier, and second, the increased volume of the enclosure allows for the development of more energetic and hence more efficient convective air flow currents within the box. These two effects working together could easily account for these results. To further illustrate, if the fire barrier enclosure continued to grow in volume, it would eventually resemble the ambient environment of the test chamber itself. Hence, in the limit of a very large box, the ampacity derating impact would be expected to approach zero (no impact).

In the case of the stacked cable trays, it is more difficult to draw direct comparisons of the test results because the fire barrier system for the single tray test and the multiple tray test included one very significant difference. That is, the single tray test included installation of a solid steel tray cover before installation of the barrier, and the stacked configuration apparently did not. Certain supplemental insights related to the cable tray stacking effects are discussed in Section 3.3 below.

3.3 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. These supplemental insights are gained 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. This subsection of the report documents the initial insights gained through a review of the TVA/WBN results.

3.3.1 Comparison of TVA/WBN Cable Tray Results to those of Texas Utilities

As a part of this review, SNL performed a simple comparison of the TVA/WBN results for the single P848 cable tray ampacity derating tests to those obtained by Texas Utilities in a similar test from 1993.[1] As a result of this comparison, one interesting insight was developed. This insight is related to the added impact of the steel cover plate used by TVA/WBN in its single tray ampacity test (test item 7.1).

---

[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).

That is, the TVA test evaluated the ampacity impact of a combined barrier system including both a steel cover plate and a 5.8" nominal Thermo-Lag enclosure. This test can be compared directly to the TU test of a similar cable tray. In the TU tests, no steel cover plate was used, but a fiberglass blanket was placed directly on top of the cables prior to installation of the barrier (this is a thin flexible blanket installed to protect the cables from damage during installation of the barrier). In all other senses the trays tested were essentially identical, and in fact, both tests were conducted at OPL.

For the TU tests an ADF of 31.6% was determined, and for the TVA/WBN tests an ADF of 40% was determined. This significant difference can be attributed, at least in part, to a conclusion that the close contact between the blanket and the cables in the TU tests had a relatively minor impact on derating, whereas the steel tray cover had a significant impact on derating. The higher impact of the steel cover plate is not unexpected because it was both remote from the surface of the cables, and it created a second air gap in the barrier system (that between the cover and the top panel of the barrier enclosure. Each of these factors would contribute to the significance of the ampacity impact. In general, the TU test results would be expected to more closely match the behavior of a cable tray in the absence of either a blanket or steel cover.

It should be noted that there is a second factor which may have influenced the test results. That is, the TU and TVA/WBN test items used different cable depths of fill. In the TU tests, the cable tray contained 126 lengths of the 3/C 6AWG wire whereas in the TVA tests only 96 passes of a similar 3/C 6AWG cable were used. This difference significantly impacted the actual ampacity limits. (TVA/WBN measured a base line ampacity (corrected) of 29.5A while TU measured a base line ampacity (corrected) of 23.1A.) However, in the context of ampacity derating this should have been a secondary parameter.

3.3.2 Effects of Stacking Cable Trays

One area in which the TVA/WBN test results provide insights not previously available is the impact of cable tray stacking on cable ampacity limits. These insights can be derived by comparing the baseline results for test item 7.1, the single cable tray test item, to the base line results for test item 7.3, the stack of three cable trays.

Recall that all of the cable trays in each test are essentially identical. All were constructed in accordance with the cable loadings set forth in the P848 standard. Each tray measured 24" wide by 4" high, and had a cable depth of fill of approximately 2.25". For test item 7.1, all of the cables in the single tray were powered uniformly. For test item 7.3, all of the cables in both of the top two trays were powered uniformly, and the cables in the lowest tray were not powered at all. For each of the two baseline tests, the current in the powered tray(s) was set so as to achieve a nominal hot spot temperature in the system of 90°C in an ambient environment of 40°C.

One insight gained from these tests relates to identification of the predominant effect of the stacking configuration on heat transfer behavior. There are three potential effects to consider; namely, (1) buoyancy driven heating of the upper trays by lower trays, (2) the insulating effect of surrounding a cable tray with other powered and unpowered cable trays, and (3) the heating effects of radiative exchange between the powered cable trays. If buoyancy heating of the upper tray were the predominant effect, then the overall system hot-spot would be expected to occur in the top-most tray. In contrast, if either the insulating effect or the insulating effect in combination with the mutual heating effect is predominant, then the hot spot would be expected to occur in the center tray.

In the ICEA P-54-440 ampacity tables, it is buoyancy heating which is implied to be the predominant effect. In Section 2.4 of that standard it is stated "If trays are stacked, the ambient temperature of the upper trays will obviously be higher depending on the amount of ventilation around the trays." This statement implies that the predominant effect of interest is buoyancy driven heating of the air volume which would result in higher ambient conditions for the upper trays in a tray stack. The standard recommends "In cable tunnels without forced ventilation, a 50°C (122°F) ambient will frequently exist at the top of the tunnel." The implied practice is to rate the cables located "at the top of the tunnel" using a somewhat higher ambient temperature. A derating impact of 10% is recommended for the 50°C versus 40°C condition cited in the standard (see the first table in Section 2.4 of the standard). This practice does not appear consistent with the test data from TVA/WBN.

The TVA/WBN test data show that the overall system hot-spot occurred in the center tray, not in the top tray. Based on this, one can infer that the insulating effects of surrounding the center tray by the top and bottom trays combined with the effects of radiant energy exchange between the powered trays was, in fact, the predominant effect of the stacked configuration. It was also noted that even for this very simple arrangement, just 3 trays with only 2 of the 3 powered, a 11.2% effective derating impact was measured (see further discussion of this factor immediately below). It would appear that the recommended practices in the ICEA/NEMA standards do not adequately account for these test results.

A second insight can be gained by considering the effective ampacity derating impact of this simple three-tray stack configuration. For test item 7.1 a baseline current of 29.5 A was measured (this is the value corrected for deviations from the nominal temperature conditions). For test item 7.3 a corrected baseline current of 26.2 A was measured. This change in limiting current corresponds to an effective ampacity derating impact of:

$$ADF_{3\text{-}stack} = \left(1.0 - \frac{26.2}{29.5}\right) x\ 100\% = 11.2\%$$

Hence, the TVA/WBN tests have shown that the impact of placing one powered tray above, and one unpowered tray below a uniformly loaded cable tray is on the order of 11.2% reduction in ampacity limits.

A third and final insight which can be gained from these test results is to consider the measured ampacities in these two cases in comparison to the ICEA/NEMA open top cable tray ampacity limits. For this cable and the depth of fill used by TVA/WBN, as discussed above, the nominal ampacity limit from the ICEA/NEMA tables is approximately 27 A. As noted above, the measured ampacity for test item 7.1, the single cable tray, was 29.5 A, showing that the ampacity tables do contain some margin for this case. However, when the base ampacity for test item 7.3, the three tray stack, is considered the ICEA/NEMA tables are found to be nonconservative. That is, the measured ampacity limit of 26.2 A is slightly lower than the tabulated value of 27 A. Again, given that this limiting factor was associated with the center tray, even the ICEA/NEMA recommended practice of derating the top tray would not have addressed this result.

3.3.3 Effects of Grouped Conduits

The effect of grouping conduits in close proximity is similar to the effect of stacked trays. This effect can again be characterized by considering the results of the baseline tests for test items 7.7 (the single conduit), 7.4 (the group of three conduits), and 7.5 (the group of six conduits). For these three test items, corrected ampacities of 33.03 A, 31.67 A, and 31.13 A were measured, respectively. Since each of the conduits was nominally identical (both with respect to cable and electrical loading) the results are directly comparable.

The data clearly show that the more conduits that are grouped together, the lower the ampacity limit. However, it is also apparent that the effect is not as severe for conduits as that which was noted for the stacked cable trays. The net derating impact of the six conduit group in comparison to the single conduit can be estimated as:

$$ADF_{3\text{-}stack} = \left(1.0 - \frac{31.13}{33.03}\right) x\ 100\% = 5.8\%$$

It is interesting to note that considerations is given to grouping of conduits in direct burial situations, and in situations involving the installation of conduits in underground duct banks. The ICEA/NEMA P-53-426 ampacity tables do provide for ampacity corrections for configuration of this type, that is, for the installation of multiple conduits in close proximity for direct burial or for multiple conduits enclosed in a common underground duct bank. SNL has not pursued a direct comparison of the TVA/WBN test results to these ampacity rating procedures as this is considered outside the scope of the TVA/WBN submittal review efforts.

4.0 SUMMARY OF REVIEW FINDINGS

The TVA/WBN tests of ampacity derating factors were all well planned and executed. The utility 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 tests performed by TVA/WBN included single trays, multiple trays, single conduits and multiple conduits in Thermo-Lag fire barriers. The results of these tests have been summarized in tables provide in Section 3 of this report. Also documented are various supplemental insights derived from this review effort. Note that the results of the Phase 1 tests and in particular, the anomalous behaviors noted in those tests, have been the focus of considerable prior USNRC review. Hence, this review has focussed primarily on the Phase 2-4 tests.

As a result of this review SNL has identified only a three minor points about which the utility should be asked to provide additional information:

> Use of Steel Tray Cover Plate For test item 7.1 it is noted that a steel cover plate was used as a part of the barrier system. Two points of clarification are needed:
>
> > (1) The utility should be asked to verify that this cover plate was not in place for the baseline test of item 7.1 (based on the test report, this is clearly implied, hence, this is a question of verification only).
> > (2) It is not explicitly stated whether on not a similar cover plate was installed as a part of the fire barrier system for test item 7.2, the cable tray with a 3-hour fire barrier system. From the photographs provided, it appears that this barrier system did not include the cover plate. The utility should be asked to verify whether or not a cover plate was installed as a part of the Test Item 7.2 fire barrier system.
>
> Failure to achieve planned cure time for test item 7.3 The TVA/WBN test plan called for a full 30 day barrier cure period before performance of the clad ampacity tests. This cure period appears to have been allowed in all cases except that of test item 7.3 of the Phase 2 tests. For this test item, the clad ampacity test was completed 27 days after installation of the barrier system. No measurements are provided of the barrier moisture level prior to or after testing. Hence, the utility has not demonstrated that an adequate cure time was allowed. Given that the cure time nearly achieved the 30 day planned period, this is not considered a significant point of concern. It is recommended that the utility be asked to provide its own assessment of the shortened cure time and to provide any measurements of the moisture content of the fire barrier which may have been made for this test item.
>
> Simultaneous testing of more than one item The TVA/WBN test procedures included the testing of two different test articles simultaneously in the same test enclosure. This practice, while not specifically prohibited in the P848 standard,

may have influenced some of the temperature responses for the test articles. In general, this is not considered a significant issue in the review of the TVA/WBN tests. However, it is recommended that the utility be asked to (1) describe the physical separations between its test articles, (2) discuss any measures taken to ensure that direct radiative heat transfer did not occur between the specimens, (3) describe the actual pairing of test items in both the baseline and clad tests, (4) examine its test results in light of these observations to determine if a pattern of mutual influence for the simultaneously tested items can be identified, and (5) provide its own assessment of how simultaneous testing of test items may have influenced the test results.

As a part of this review SNL has also identified a number of supplemental insights. These supplemental insights would not significantly impact the review and final assessment of the TVA/WBN submittals. However, the TVA/WBN tests have provided valuable new information which indicates certain areas of concern regarding both the published ICEA/NEMA ampacity tables, and the IEEE P848 draft ampacity derating test standard. The appropriate venue for resolution of these concerns is considered to by the appropriate standards committees rather than TVA/WBN. These areas of concern are as follows:

<u>Simultaneous testing of test items</u> As noted above, TVA/WBN performed simultaneous tests of, typically, two test items in the same test enclosure. It is recommended that the USNRC ask the IEEE P848 committee to address such practices in the test standard. In particular, possible provisions which might be included in the standard include (1) provide for minimum separation distances to be maintained between test articles, (2) prohibit the placing of one test item directly above another, and (3) require that an insulating panel be placed mid-way between adjacent test items to prevent direct radiative exchange.

<u>Effects of cable tray stacking and conduit grouping</u> 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) that the ICEA/NEMA tables may not contain sufficient margin to encompass this effect, and (3) that the insulating and mutual heating effects of the surrounding cable trays appear to be the predominant thermal effect rather than buoyancy driven heating of the upper cable trays as implied in the ampacity tables (because the center tray was the hottest of the three when tested). Similar changes in measured baseline ampacity were also noted for the tests involving grouped conduits as compared to single conduits. 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.