September 27, 1995 50-445/446

Mr. Steve P. Nowlen
Nuclear Energy Technology
Organization 6449
Sandia National Laboratories
Albuquerque, New Mexico 87185-0737

Dear Mr. Nowlen:

Our comments on the draft Technical Letter Report entitled, "An Assessment of Cable Functionality Performance Issues for the TUE Comanche Peak Unit 1 Thermo-Lag Fire Endurance Tests," dated April 5, 1995, are summarized on the attached Enclosure. These staff comments pertain to the ongoing work under the Task Order #2 under JCN J-2017.

As an additional aid to assist you in timely resolution of our comments, we faxed you a copy of these comments on September 25, 1995.

Finally, since the majority of the NRC staff comments are editorial in nature it is expected that the final Technical Evaluation Report will be dispatched within two weeks of the receipt of this letter so that the subject Task Order can be closed out as soon as possible.

If you have any questions, please call me. Thank you for your assistance.

Sincerely,

Original signed by R. Jenkins

Ronaldo Jenkins
Electrical Engineering Branch
Division of Engineering
Office of Nuclear Reactor Regulation

Enclosure: As stated

cc: Michael Bohn, SNL

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UNITED STATES
NUCLEAR REGULATORY COMMISSION
WASHINGTON, D.C. 20555-0001

September 27, 1995

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cc: Michael Bohn, SNL

Enclosure

STAFF COMMENTS ON DRAFT SNL REPORT FOR JCN J-2017: TASK ORDER NO. 2

1. Change "regards" to "regard" (pgs. 1, 7, 25).
   Change "sub-set" to "subset" (pg. 3).
   Correct spelling - logarithmicly (pg. 4); asses (pg. 4).
   Change "provided" to "provide" (pg. 4).
   Change "use" to "used" (pg. 13).
   Change "1.0E6Ω-1000ft" to "1.0E3Ω-1000ft" (pg. 13).

2. Deliverable should be a Technical Evaluation Report not a Technical Letter Report.

3. List TUE test reports which were reviewed in Section 2.

4. Add REFERENCE Section for cited documents (e.g., for NUREG/CR-5546).

5. Explain in greater detail the estimation of the cable IR using the hot spot temperature (2nd sentence, 1st paragraph, Section 3.2.2, pg. 5).

6. Add the phrase "for the subject CPSES-1 fire barriers" to the end of Section 3.2.2 (last sentence, 3rd paragraph, pg. 5).

7. Change "...considered the most accurate possible analytical..." to "...considered an accurate analytical" in Section 3.2.3 (2nd sentence, pg. 6).

8. Change in Case 2 paragraph, Section 3.2.4, last sentence from "...during the fire tests." to "...during a fire."

9. Change in 2nd paragraph, 1st sentence, Section 3.2.4 from "...actual measured cable temperatures." to "...surface temperatures of the cables."

10. Insert "for instrument and control cables" between " ...been measured" and "had such..." in 2nd paragraph, last sentence, Section 3.2.4.

11. Revise Section 3.2.5 and Table 3.1 to reflect the actual data provided by TUE. Please see attached sheet from TUE.

12. Change in 1st paragraph, last sentence, pg.7, Section 3.3 from "...for those cables and those cases" to "for those cables and cases...."

13. Change in 2nd paragraph, 3rd sentence, Section 4.3, pg. 16, "...such as this were..." to "such as the subject tests where...."

14. In 3rd paragraph, last sentence, Section 4.3, pg. 16, insert between "...experienced and" and "not fully..." the word "was" and add to the end of the sentence the phrase "by the test data."

15. Change sentence at the top of pg. 18 from "The calculated TUE values cannot be directly compared to the USNRC criteria until normalized." to "The calculated TUE values cannot be directly compared to the USNRC criteria until those values have been normalized for length."

16. Delete "at most" at the end of the last sentence, 1st paragraph, pg. 18, Section 5.2.

17. Change "recommends" to "finds" in the first sentence, 4th paragraph, pg. 18, Section 5.2.

18. Change "run" to "placed" in the third sentence, 1st paragraph, pg. 19, Section 5.4. Insert "the" between "...thermocouples and" and "survival of..." in the second sentence, 2nd paragraph, pg. 19, Section 5.4.

19. Insert "range" between "Note that this..." and "represents the ..." in the third sentence, 2nd paragraph, pg. 21, Section 6.2.1.

20. Replace "TUE" with "Omega Point Laboratories" in the first sentence, 1st paragraph, pg. 22, Section 6.2.2. Also replace "This was considered in excess of..." with "This observation violated" in the second sentence of the 1st paragraph, pg. 22, Section 6.2.2.

21. Insert "finding" between "In fact, this..." and "included calculations..." in the second sentence, pg. 2, Section 6.2.3.

22. Insert "temperature" between "...the hot-spot" and "may not..." and change "renders" to "rendered" in the fourth sentence, 2nd paragraph, pg. 23, Section 6.2.4.

23. Replace "TUE" with "Omega Point Laboratories" in the second sentence and insert "test" between "...provided in the" and "report, the..." in the third sentence in the second paragraph, pg. 23, Section 6.2.4.

24. Replace "leading" with "which leads" in the last sentence, 3rd paragraph, pg. 23, Section 6.2.4.

25. Insert "estimate" between "This..." and "included calculations..." in the second sentence, pg. 24, Section 6.2.5.

26. Replace "are" with "were" in the first sentence and replace "meets" with "met" in the second sentence, 1st paragraph, pg. 24, Section 6.2.6. Add "for this test article" to the end of the first sentence, 2nd paragraph, Section 6.2.6 and to the end of the second sentence, Section 6.2.8, pg. 24.

27. Insert "observations regarding" between "...while the" and "melted thermocouples..." in the fourth sentence, pg. 25, Section 6.2.9.

28. Replace "is" with "was" in the second sentence and replace "This does meet..." with "This value..." in the third sentence, 1st paragraph, pg. 25, Section 6.2.10.

29. Add "in the test data" to the end of the first sentence, 2nd paragraph, pg. 25, Section 6.2.10. Replace "concern" with "concerns" in the first sentence, third paragraph, and replace "concludes" with "concluded" in the second sentence, fourth paragraph of Section 6.2.10, pg. 25.

30. Address the adequacy of the licensee response to staff questions as documented in the licensee submittal dated August 8, 1994 (You can reference any previous report input).

31. Is it value or values for the hot spot cable IR (Section 6.0)?

32. Identify the reference where SNL had previously informed the staff regarding pre- and post-test measurements for cable performance assessment (Section 3.1, 1st paragraph).

33. Add a summary table describing the sensitivity of the IR estimates for the failed/not accepted test articles to the USNRC acceptance and SNL final recommended criteria.

MARKED UP PAGES WHICH SHOW REVISIONS FOLLOW THIS PAGE

1.0 Introduction

1.1 Overview

The work described in this letter report was performed by Sandia National Laboratories (SNL) under USNRC contract JCN J2017, Task Order 2. The objective of this task order is to provide support to the USNRC in the evaluation of the acceptability of the Texas Utilities Electric (TUE) fire endurance tests performed on the fire barrier material Thermo-Lag 330-1 as applied at Comanche Peak Unit 1 (CPSES-1). Several test reports have been submitted by TUE for USNRC consideration. A list of those reports which remain under consideration, and which were evaluated as a part of the current work, is provided in Section 2.

This document represents the second review report prepared by SNL. The first was submitted for USNRC consideration on March 15, 1994[1]. In that initial review, a number of questions and issues were raised. Based in part on this initial SNL review, the USNRC prepared a Request for Additional Information[2] (RAI) which was submitted to TUE. TUE has responded to this RAI through a submittal under a cover letter from W.J. Cahill Jr. to the USNRC dated August 8, 1994 (TUE Log Number TXX-94173) and through a second submittal under a cover letter from C.L. Terry to the USRNC dated November 9, 1994 (TUE Log Number TXX-94267). These TUE submittals and the original test reports form the basis for the SNL review documented here.

1.2 Scope of the Current Review

The scope of the current review includes two primary objectives. The first is to determine whether or not the questions raised in the RAI have been resolved. The second objective was to assess cable functionality performance during the TUE tests. In initial reviews of the TUE response, it was determined that the utility had not adequately addressed the questions raised by the USNRC in this regard~~s~~. Hence, at the request of the USNRC, SNL has performed cable functionality analyses using the test data reported by TUE. SNL has also provided a recommended procedure and acceptance criteria for the ultimate evaluation of cable performance acceptability during the TUE tests which is based on these SNL analyses.

1.3 Report Organization

Section 2 of this report identifies those specific test articles which are considered in this review. It is the understanding of SNL that TUE has withdrawn its request for approval of the remainder of the Unit 1 test articles. Hence, this review is limited only to those test articles for which approval is still being sought by TUE. Section 3

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[1] See letter S. Nowlen, SNL, to R. Jenkins, USNRC, March 15, 1994.

[2] See letter T.A. Bergman, USNRC, to W.J. Cahill Jr., TUE, June 15, 1994.

2.0 Identification of Tests Considered

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In this review SNL has considered only a sub-set of the test articles which have been submitted by TUE for USNRC consideration. Note that in general each of the TUE test reports deals with multiple test articles which were tested simultaneously. Hence, the current reviews often include only a portion, or portions, of a given TUE test report. The test articles considered in this review are: X

Scheme 9-3	1½" and 2" conduits only
Scheme 11-2	1½" and 2" air drops
Scheme 11-4	Box assembly
Scheme 11-5	24" center cable tray assembly only
Scheme 13-2	12" cable tray and 2" conduit
Scheme 15-2	Individual power cable wraps

It is the understanding of SNL that TUE has withdrawn its request for consideration of the balance of the CPSES-1 test articles. No further consideration of the "withdrawn" test articles, or of the sections of those test reports dealing with these test articles, has been given here.

3.0 SNL Performance Evaluation Methods

3.1 Basis for Cable Functionality Concerns

The issue of cable performance during the TUE tests remains problematic because TUE did not make insulation resistance (IR) measurements during the actual fire exposures. Rather, only pre- and post-test cable IR measurements were made. SNL has previously cited that such pre- and post-test measurements provide no assurance of cable performance during the fire exposures. Hence, these measurements should not be credited as a demonstration of test success in the light of other signs of potential cable degradation noted during the post-test examinations (jacket swelling and blistering, discoloration, charring, etc.).

This conclusions is based on the fact that the IR of a cable insulation material is a very strong function of temperature (IR decreases logarithmicly with increasing temperature). This has been conclusively demonstrated through a variety of Equipment Qualification (EQ) tests performed by cable manufacturers, commercial test laboratories and by SNL under USNRC sponsorship. Hence, the post-test IR measurements made by TUE are insufficient to demonstrate cable performance during the fire exposures because significant cooling of the cables from their peak exposure temperatures occurred before the measurements were made. In particular, recall that the hose stream application preceded the post-test IR measurements.

This situation implies that cable functionality cannot be demonstrated based on the direct measured test data, but rather, must be assessed indirectly through analysis. Such supporting analyses were requested in the USNRC RAI, and an acceptable methodology for performing those analyses was provided (the SNL composite cable analysis method). TUE's response to the USNRC RAI failed to provided the requested cable IR analyses to support the evaluation of each of the cables in each of the TUE tests, failed to demonstrate that the tested cables met the cable IR acceptance criteria set forth in Suzanne Black's letter of 10/29/92, and failed to provide alternate or supplemental cable functionality assessments. Hence, the USNRC has requested that SNL performed the needed analyses in order to provide a basis for the final determination of test acceptability by the USNRC.

Section 3.2 of this report provides the basis for the SNL analyses which have been performed and which are documented here. Section 3.3 provides the results of the SNL analyses. Section 4 provides a recommended procedure and criteria for assessing the ultimate acceptability of cable IR performance during the TUE tests.

3.2 SNL Cable Functionality Analysis Methodology

3.2.1 Overview

In order to asses cable functionality performance during the TUE tests, SNL has extrapolated Equipment Qualification (EQ) LOCA and Severe Accident test data to the exposure temperatures experienced in the TUE tests. The analyses are based on Rockbestos EQ test reports which provide experimentally determined analytical correlations for the IR of cross-linked polyethylene (XLPE) cable insulation as a function of temperature (op.cit., 3/15/94). This aspect of the analyses is consistent with the approach taken by TUE in those limited functionality analyses which the utility has performed.

The SNL analyses have been performed in two parts. The first part will be referred to as the "hot-spot analysis" and reflects the more conservative analysis approach. The second part of the analysis uses the "composite cable analysis method" described by SNL in its previous review submittal (op.cit., 3/15/94). This second part of the analysis will be referred to as the "composite analysis." Each of these two analysis steps are described in the sections immediately below.

3.2.2 Part 1: Hot-Spot Performance Analysis

In the first part of the SNL analysis, the single-point hot-spot temperatures were used to provide an initial assessment of cable IR performance. That is, the individual hot-spot temperature measured along the length of the test article is used in conjunction with the EQ IR versus temperature correlation to estimate the cable IR at the measured hot-spot temperature.

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Note that in presenting the results the IR values are normalized to "ohms over 1000 feet of cable" (Ω-1000ft). The effect of this normalization is simply to remove the cable's exposure length in a given test article as a parameter in the assessment. This normalization also allows for a direct comparison between each test and the USNRC acceptance criteria.

Note that in one respect the hot-spot analysis is also used as a screening tool. That is, the hot-spot analysis is much simpler to perform, being based on only one temperature, and is also the more conservative of the two analyses. Hence, if a given cable passes the USNRC IR acceptance criteria based on the conservative hot-spot analysis, then the more tedious composite analysis is not pursued for that case. Note however, that the hot-spot analysis also plays in integral role in SNL's final recommended acceptance criteria (see further discussion in Section 4 below).

for the subject [illegible]
fire barriers

3.2.3 **Part 2**: Composite Cable Functionality Analysis

The second part of the SNL analysis utilizes the "composite cable method." In this analysis each of the individual temperature measurement points along the length of a cable or surface are used to assess cable IR performance over that individual segment of cable. For each measurement point the peak temperature value measured (typically the last recorded value) is used as the basis for analysis. That is, each temperature measurement is assumed to be representative of the cable temperature over a limited length of the subject cable. The characteristic length is taken as the actual distance between measurement points (typically 6" or 12"). Thus, each measurement point is used to estimate the local IR for that length of cable. All of the individual segment IR values are then summed as parallel resistance elements. This "composite" value provides an estimate of the cable IR over the full exposure length of the test cable. It is this value which can be considered ~~the most~~ an accurate ~~possible~~ analytical estimate of the actual cable IR which might have been measured had such measurements been made at the peak of the fire exposure. As in the "hot-spot analysis" the "composite" IR results are normalized to Ω-1000ft.

3.2.4 Analysis Temperature Selection Bases

In each of the two parts of the SNL analysis, the "hot-spot" and "composite" analyses, the calculations were repeated for either two or three cases as follows.

Case 1: Each part of the analysis is performed using the highest temperature(s) measured along the surface of each individual cable. That is, for Case 1 the analysis is based on the actual measured cable surface temperatures.

Case 2: FOR THE POWER CABLES ONLY each part of the analysis is repeated using the highest measured cable surface temperature(s) plus an increment of 40°C. Case 2 is intended to provide for an assessment of power cable self heating effects on cable performance during ~~the~~ a fire ~~tests~~.

Case 3: For each cable, each part of the analysis is repeated using the maximum temperature(s) measured on the metal surfaces enclosed within the fire barrier system. For cable tray test articles this would be the cable tray side rail temperatures. For conduit test articles the conduit surface temperature is used. For air drops and individually wrapped cables the temperatures measured on the bare 8AWG wire segment are used.

As further clarification, note that Case 1 is the base-case in that it utilizes the ~~actual~~ surface ~~measured cable~~ temperatures of the cables. In particular, the Case 1 "composite" analysis provides the best-estimate of the actual cable IR which would have been measured had such measurements been made during the peak exposure period.

Case 2 represents a conservative assessment of power cable self-heating effects on cable performance. In the case of the TUE tests, a temperature increment of 40°C was chosen because TUE has sized its cables using an assumed cable operating temperature of 90°C and an ambient temperature of 50°C for a net ambient-to-cable increment of 40°C (see JCN J2017 Task Order 1 cable ampacity assessment efforts). The need for these assessments arises from the requirements set forth in Suzanne Black's letter of 10/29/92.

Case 3 addresses additional concerns and requirements expressed by the USNRC in Suzanne Black's letter and in Supplement 1 to Generic Letter 92-08. One of the issues raised in these documents was the need for fire barrier performance assessments to include the consideration of cable tray raceway and external conduit temperatures. It should, however, be noted that the final recommendations made regarding the TUE test acceptability do not include the consideration of this case.

3.2.5 Assumed Cable Properties

In performing the analyses described here certain assumptions regarding the physical characteristics of the cables had to be made. This included assumptions regarding both the composition of the cable insulation materials and the physical dimensions of the cable conductors and insulation.

The information provided by TUE identified Rockbestos cross-linked polyethylene (XLPE) as the predominant insulation material in use at CPSES-1. Hence, all of the SNL analyses have been performed assuming this as the insulation material. The correlation for IR versus temperature cited by SNL in its previous reviews were used throughout in this analysis. (Note that the TUE response included an agreement that the correlation cited by SNL in its review was an appropriate basis for analysis.)

The TUE information provided in the various test reports also identified the gross physical characteristics of the cables used in testing. However, the specific details of cable insulation thickness and conductor diameters was not provided. Hence, SNL has made assumptions regarding these parameters based on available product literature for Rockbestos cables. In particular, TUE has used cables of 5 different gages; namely, 16AWG, 12AWG, 8AWG, 6AWG, and 750MCM. All of the cables are cited as being rated for 600V. In SNL's previous review, only nominal values for the cable physical parameters were used in order to demonstrate the methods and concerns. For more accurate assessments it is important that more realistic parameters be used in the analysis. Table 3.1 summarizes the values SNL has assumed as typical of both stranded wire dimensions and 600V insulation thicknesses for cables of these sizes.

Note that in reviewing the TUE specifications and the Rockbestos cable product literature, very close matches were identified for each cable type cited by TUE. The Rockbestos product literature reviewed is provided in Attachment A of this document. SNL also reviewed product literature from other nuclear qualified cable manufacturers and found that the insulation thicknesses cited in the Rockbestos literature were quite typical of general industry practices in this regard~~s~~. Hence, SNL has confidence that these assumed values are well founded.

3.3 SNL Cable Functionality Analysis Results

The results of the initial Part 1 hot-spot analyses are summarized in Table 3.2. Recall that in this step, the single point hot-spot temperature is used to estimate the IR value, with this value normalized to "ohms over 1000ft of cable" (Ω-1000'). The results of the Part 2 composite analyses are summarized in Table 3.3. Recall that this analysis is only performed for those cables and ~~those~~ cases in which the hot-spot analysis (from Table 3.2) showed a local IR value of less than 1.0×10^6 Ω-1000' (the balance of the cases are identified in Table 3.3 as "screened").

Table 3.1: Assumed values for physical dimensions of TUE cables

Cable Size	Applicable TUE Cable Types[1]	d_{ru} Standard Wire Diameter	L_{insul} Insulation Thickness[2]	D_c Diameter of Insulated Conductor[3]
16 AWG	W-063 W-071	0.060"	~~0.025"~~ 0.030"	~~0.110"~~ 0.120"
12 AWG	W-046 W-047 W-048	0.092"	0.030"	0.152"
8 AWG	W-023	0.146"	~~0.060"~~ 0.045"	0.266"
6 AWG	W-020	0.184"	~~0.060"~~ 0.045"	~~0.304"~~ 0.334"
750 MCM	W-008	0.998"	~~0.110"~~ 0.080"	~~1.218"~~ 1.288"

1. Cable types as identified in TUS test reports.
2. This value ignores any secondary jacket which might be applied to the individual conductors and represents only the primary insulation thickness.
3. This is not the same as overall cable diameters identified by TUE because of multi-conductor construction and/or secondary jacket materials not considered.

NOTE: Stiked out numbers were the original numbers provided by the NRC.

- It is recommended that a test be accepted if all of the cables meet the USNRC cable IR acceptance criteria of 1.0E6 Ω-1000ft when calculated using the SNL composite cable analysis method. This calculation should be based, in this case, on the actual measured cable surface temperatures. This is consistent with the original USNRC acceptance criteria set forth in Suzanne Black's letter. If the calculated cable IRs exceed this criteria, then the effects of power cable operation would be bounded by the margin which is inherent in this criteria.

- In the event that the nominal USNRC IR acceptance criteria is not met, it is recommended that an analysis of the measured hot-spot IR performance be made using a single-point hot-spot analysis such as the analyses presented above as the Part 1 Hot-Spot Analyses (see Table 3.2).

used

- In performing this analysis, the hot-spot temperature should be use to estimate cable IR with the result normalized to "Ω-1000ft" so as to provide a consistent basis for comparison. It is further recommended that a value of 1.0E3 Ω-1000ft be utilized as the minimum acceptable IR limit for the predicted hot-spot behavior. This IR threshold is based on the following: X

  - One of the concerns regarding cable performance is that as power cable leakage currents increase (due to IR breakdown) an added heat load is introduced due to resistance heating in the insulation itself. As this heating effect increases, a progressive and accelerating breakdown of the cable insulation at a localized point will occur. Given a hot-spot IR of 1.0E3 Ω-1000ft, the localized heating effect due to leakage currents for a cable energized to 480V (typical upper end voltage applied to a 600V rated cable) would amount to 0.23 Watts per foot of cable (based on simple $V=IR$ and $Q=I^2R$ calculations where R would equal 1.0E6 Ω-ft). A typical power cable could absorb this much heat with only a minor impact on cable temperature (on the order of 5°C increase after a full hour of such leakage based on scoping calculations for a 3-conductor 8AWG power cable). Hence, this level of degradation would not be expected to trigger localized cable breakdown. X

    1,0E3 Ω-1000ft

  - If the IR were reduced locally by one additional order of magnitude (to 1.0E2 Ω-1000ft) then localized heating would increase by an order of magnitude to 2.3 W/ft for the same voltage. While a power cable might survive localized heating of this magnitude for a limited period (i.e., on the order of a few minutes), sustained exposure would likely lead to progressive thermal breakdown of the cable.

  - When cable thermal damage limits determined in fire exposure testing have been compared to the IR measurements made during severe accident temperatures were measured, and hence, the true hot-spot temperature cannot be determined.

It was also noted as a part of these reviews that the issues of surface charring and excessive point-to-point temperature variation were closely linked. In particular, all of the tests in which surface charring of the protected cables was noted also experienced the highest point-to-point temperature variations. This is not overly surprising given that the presence of localized surface charring would be indicative of localized temperatures well in excess of the average temperatures experienced by the cables. As will be noted below, for these tests acceptance is not recommended based on the high level of uncertainty inherent in the cable performance analyses.

The accurate characterization of the hot-spot behavior is considered critical to the appropriate assessment of cable performance. For tests in which charring damage to the protected cables is noted, or for which other evidence of very large point-to-point variations in measured cable temperature are found, no definitive assessment of cable performance can be made in the absence of actual IR measurements due to the large uncertainty in the actual hot-spot temperatures experienced. SNL's methodology is not intended to account for situations such as this were a very significant and demonstrated uncertainty regarding actual hot-spot exposure temperatures exists. A "hard and fast" limit on how large a variation would be considered excessive is difficult to identify. As a general rule, cases which display point-to-point variations of 75°F or more should be examined closely. In particular, for such cases the post-test examination results should be carefully reviewed for other evidence that significant uncertainty exists regarding the actual hot spot temperatures (such as charring between thermocouple locations).

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Given this uncertainty it is considered appropriate to include a performance margin in these calculations. Note that a margin of one-to-two orders of magnitude in cable IR corresponds to a margin of about 50-100°F (28-56°C) in cable temperature given the IR versus temperature correlations cited by TUE. That is, the IR versus temperature correlation predicts a drop in cable IR by one order of magnitude for each 50°F increase in exposure temperature. As noted above, for most of the TUE tests point-to-point variations of 30-50°F were routinely noted. Hence, the margin inherent in the SNL methodology would encompass the implied uncertainty with regards to how accurately the true hot-spot temperatures were measured. This margin would not, however, encompass those cases for which evidence indicates that highly localized cable heating may have been experienced and not fully characterized (such as local cable charring and/or very large point-to-point temperature variations).

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those values have been

minimum IR of 1.0E6 Ω-1000ft. The calculated TUE values cannot be directly compared to the USNRC criteria until normalized. for length X

Also noted in the TUE analysis is the fact that all of the cable IR analyses have been performed using only nominal values for the cable physical parameters. In particular, this involved the values assumed for the conductor diameter and the insulation thickness (which together imply an outer cable diameter). In fact, the values used in all cases by TUE are typical of instrument cables, and are not representative of either power or control cables. The actual physical parameters of the tested cables should be used for each analysis. In general the errors introduced by this difference would be relatively small because insulation thickness increases as cable size increases. Since these values appear in the calculations in the form of a ratio, and because the ratio changes only slightly for various cables (provided they are all rated at the same voltage as are the TUE test cables) the net effect on cable IR estimates due to changing cable sizes would be on the order of a factor of 2-3 ~~at most~~. X

With regards to the cable functionality assessments themselves, there are two significant shortcomings to the utility analyses. First, the analyses only consider the performance of an single simulated instrument circuit as the basis for the assessment of performance for all of the tested cables. No consideration is provided for the performance of cables in either power or control circuits. The use of an instrument circuit analysis to assess the acceptability of power and control cable performance is not adequate. As a secondary aspect of this concern, the TUE analyses have not provided any consideration of the impact of power cable operating temperatures on cable performance. The USNRC acceptance criteria clearly indicate that power cable operating temperatures must be included in any cable functionality assessments.

One final shortcoming of the TUE analyses is that all of the circuit performance analyses are based on the cable exposure length which happened to be used in the fire endurance tests. This assumption has not been justified by TUE. In particular, It would be appropriate to perform circuit analyses based on the maximum credible cable exposure length, rather than on the very arbitrary test article cable exposure lengths. Given that the test exposure lengths were typically 8-13 feet, and that significantly longer exposure lengths could be postulated in actual plant applications, the circuit performance errors predicted could increase significantly.

Based on these errors and shortcomings, SNL ~~recommends~~ finds that the TUE cable functionality assessments provided in TXX-94267 are inadequate to demonstrate the acceptability of the TUE fire endurance tests. Note that, at the request of the USNRC, SNL has provided supplemental analyses to support a final assessment of cable performance in these tests as documented in Section 3 above.

5.3 Test Scheme 9-3, 2" Conduit Test Article

For this test article it was noted by SNL that the post-test examinations revealed extensive regions of full material burn-through. This included a statement in the test report that "(n)o Thermo-Lag remained uncharred against the conduit in most areas."

This condition was considered contrary to the criteria set for in the USNRC letter of 10/29/92. The utility provided no significant response to this concern.

5.4 Test Scheme 15-2, Front and Rear Power Cables

In the initial review of this test report it was noted that several of the thermocouple lead wires within each of the two fire barrier envelopes tested had melted during the fire exposures. This was a significant concern because it potentially indicated that the thermocouple data was not valid for this test. The TUE response included a clarification that in both cases (both the front and rear power cable envelopes) the melted thermocouples were all associated with the base 8AWG conductor which was placed run through the envelope along with the power cable. None of the power cable X thermocouples failed during the exposure. This is a credible explanation given the very massive size of the power cable. That is, the large thermal mass of the power cable could have easily absorbed enough heat so as to prevent damage to those thermocouples which were installed in intimate contact with the power cable itself, while those thermocouples installed on the much smaller 8AWG conductor would not have been afforded that same level of protection. Given this understanding, SNL recommends that the cable surface temperature data be accepted as indicative of the actual cable behavior.

However, this situation also illustrates the critical role played by the massive size of the power cable. The failure of the more exposed 8AWG thermocouples and the survival X of the power cable thermocouples clearly indicates that the heat absorbing capacity of the power cable itself significantly influenced the results for these two test articles. That is, it is apparent that the power cables did, in fact, absorb very large quantities of heat during the exposure. Had the same barrier configuration been installed on a cable of smaller diameter, much sharper rises in cable temperature would likely have been experienced. Hence, it is recommended that the results for these two test articles should <u>in no case</u> be extrapolated so as to justify the installation of a similar barrier system for the protection of cable sizes smaller than those tested; namely, 750 MCM. If this barrier system is to be applied to cables of smaller diameter, then these installations should be specifically validated by supplemental testing.

compared to the USNRC acceptance criteria of 1.0E6. When the impact of cable self-heating effects are included in the analysis of power cable performance the predicted composite cable IR drops to 1.55E3.

Following the SNL recommended evaluation procedure, the single point hot-spot cable behavior is considered. An analysis of the hot-spot power cable behavior including cable self-heating effects (Case 2 from Table 3.2 for this test article) predicts a hot-spot IR of just 6.0E1 Ω-1000ft. This is well below the recommended SNL threshold value of 1.0E3 Ω-1000ft for the hot-spot IR.

It should also be noted that this test demonstrated vary large variations in point-to-point cable temperature measurements. In the area immediately surrounding the hot-spot, a point-to-point variation of as much as 158°F was noted for the power cable. Note that this represents the variation in measured cable surface temperature over a 6" segment of the cable. Given this very large variation, the actual hot-spot temperature must be considered highly uncertain (higher temperatures than those measured may well have been experienced). Hence, a very large uncertainty regarding the hot-spot IR exists.

range

X

It is recommended that this test article should not be accepted. This recommendation is based on:

- Unacceptable composite cable IR values for all cables
- Unacceptable hot-spot cable IR values for all cables
- Excessive uncertainty regarding the adequacy of the hot-spot characterization

6.2.2 Test Scheme 9-3, 2" Conduit Test Article

The estimated composite performance of the control cable in this test exceeded the USNRC basic performance acceptance criteria of 1.0E6 Ω-1000ft. However, both the power and instrument cables in this test article failed to achieve this level of performance.

In considering the cable hot-spot behavior, the predicted IR values for both the control and instrumentation cables (see Case 1 analysis results in Table 3.2) were well above the SNL recommended acceptance criteria of 1.0E3 Ω-1000ft. However, the hot-spot performance analysis for the power cable, including the effects of cable self-heating, predicted an IR value of 5.61E2 (see Case 2 analysis in Table 3.2). This value fails to achieve the recommended SNL acceptance criteria.

It should also be noted that this test demonstrated a pronounced variation in point-to-point cable temperature measurements. In the vicinity of the hot-spot, a point-to-point variation of as much as 224°F over a length of just 6" was noted for the power cable (TC channels 96 and 97). Given this very large variation, the actual hot-spot temperature must be considered highly uncertain (higher temperatures than those measured may well have been experienced). Hence, the ultimate performance of the power cable cannot be accurately assessed.

Omega Point Laboratories

Finally, as discussed in Section 5.3 above, the initial SNL reviews for this test article had noted that significant areas of full Thermo-Lag material burn-through were noted in the post-test inspections performed by TUE as documented in the test report for this X
observation violated test article. This ~~was considered in excess of~~ the acceptance criteria established by the X
USNRC in its letter of 10/29/92. The implications of extensive material burn-through have not been addressed by TUE.
wi

It is recommended that this test article should not be accepted. This recommendation is based on:

- Unacceptable composite cable IR values for all cables
- Unacceptable hot-spot cable IR values for the power cable when cable self-heating effects are considered
- Excessive uncertainty regarding the adequacy of the hot-spot characterization for the power cable in particular
- Extensive regions of full barrier material burn through noted during the post-test examinations

6.2.3 Test Scheme 11-2, 1½" Air Drop Test Article

The predicted composite performance of the cables in this article met the USNRC basic IR acceptance criteria of 1.0E6 Ω-1000ft. In fact, this included calculations finding X based on the measured cable temperatures, power cable performance including self-heating effects, and the temperatures measured on the bare 8AWG conductor. While it was noted in the test report that certain of the thermocouple lead wires running through this section of the test assembly were melted during the exposure, no further evidence of any material burn-through nor excessive point-to-point temperature variation were noted.

It recommended that this test article should be accepted.

6.2.4 Test Scheme 11-2, 2" Air Drop Test Article

The estimated composite performance of the control and instrumentation cables met the USNRC IR acceptance criteria of 1.0E6 Ω-1000ft even when only the hot-spot behavior is considered. However, the estimated composite performance of the power cable in this article was close to an order of magnitude below the USNRC acceptance criteria even in the absence of cable self-heating effects. (the best-estimate of cable performance neglecting self-heating effects was 1.1E5 as compared to the USNRC acceptance criteria of 1.0E6).

In the consideration of the hot-spot IR behavior of the power cable an IR value of 2.78E2 was obtained when the effects of cable self-heating are included in the analysis (see Case 2 analysis in Table 3.2). This is well below the SNL recommended acceptance criteria of 1.0E3 Ω-1000ft.

The poor performance of the power cable can be attributed directly to the hot-spot behavior. The peak measured temperature for this cable was 439°F as compared to the next highest reading of 321°F for an adjacent thermocouple. This test article also demonstrated very high point-to-point variation in measured temperatures with a variation from the hot spot to the second adjacent measurement point (6" away) of temperature rendered 225°F. This wide variation implies that the hot-spot may not have been well characterized and renders even the hot-spot analysis of questionable validity. X It is not X possible to provide an accurate estimate of the actual hot-spot temperature for this test given this very wide variability between adjacent measurement points.

Further evidence that the hot-spot was not well characterized was also demonstrated in Omega Point Laboratories the post-test examinations. For this test assembly it was noted by TUE that 5 X thermocouple lead wires were melted in the center section of this test article. In the test photographs of these failed thermocouples provided in the report, the thermocouple X leads appear to have been charred over a short segment of their length (perhaps on the order of 2" or less). Further, the test report states that a "localized surface char" was identified on the power cable in this same area of the article. As noted previously, charring is an indication of actual combustion within the test article. Such evidence of combustion would appear to violate the intent of the ASTM testing standard, and represents a degree of damage beyond that nominally identified by the USNRC as potentially acceptable (e.g., jacket swelling, hardening, or discoloration). This localized charring also is indicative of the actual cable hot spot, and this charring appears to have occurred between two measurement points.

Based on these insights it appears that this test assembly likely suffered an actual or near burn-through of the fire barrier at a point adjacent to the power cable. Temperatures in the immediate vicinity of this location were high enough to melt, and possible char, the thermocouple lead wires, and to char (burn) the surface of the adjacent power cable. The power cable also experienced surface temperatures over a which leads very localized segment well in excess of those experienced by the balance of the test article leading to a very poor estimated cable IR performance. X

It is recommended that this test article should not be accepted. This recommendation is based on:

- Unacceptable composite cable IR value for the power cable
- Unacceptable hot-spot cable IR values for the power cable
- Excessive uncertainty regarding the adequacy of the hot-spot characterization for the power cable
- Charring of the cable insulation in the immediate vicinity of the hot-spot

6.2.5 Test Scheme 11-4, Box Assembly Test Article

The estimated composite performance of all of the cables in both trays of this test article met the basic USNRC acceptance criteria of 1.0E6 Ω-1000ft. This estimate included calculations based on both the measured cable surface temperatures and the cable tray side rail temperatures. No other evidence of localized hot-spots or other barrier integrity problems were noted for this test article. X

It is recommended that this test article should be accepted.

6.2.6 Test Scheme 11-5, 24" Center Cable Tray Test Article

None of the cables in this test article met the basic USNRC acceptance criteria when the composite cable performance assessments ~~are~~ were considered (see Case 1 analyses in Table 3.3). X However, when the hot-spot cable IR performance is considered, each of the three cables ~~meets~~ met the SNL recommended criteria (see the Case 1 and 2 analyses in Table 3.2). X This assessment includes the consideration of cable self-heating effects for the power cable.

Note that no evidence of excessive point-to-point variation in temperatures was noted for this test article. X Rather, the cable surface temperatures were relatively uniform, and only slightly in excess of values which would have yielded acceptable composite cable IR values.

It is recommended that this test article should be accepted.

6.2.7 Test Scheme 13-2, 12" Cable Tray Test Article

The composite analyses performed for both the power and control cables in this test article met the USNRC IR acceptance criteria based on measured cable surface temperatures (see the Case 1 analyses in Table 3.3). The instrument cable fell slightly below this criteria. When the hot-spot performance is considered, all of the cables performed in excess of the recommended SNL IR acceptance criteria (see the Case 1 and 2 analyses in Table 3.2). No evidence of pronounced localized cable heating effects were noted for this test article.

It is recommended that this test article should be accepted.

6.2.8 Test Scheme 13-2, 2" Conduit Test Article

All of the cables in this test article meet the USNRC cable IR performance criteria based on the actual measured cable temperatures. No other evidence of pronounced localized heating of the cables was noted for this test article

It is recommended that this test article should be accepted.

6.2.9 Test Scheme 15-2, Front Power Cable Test Article

observations regarding

The composite IR performance of the power cable in this test article was acceptable in comparison to the USNRC acceptance criteria, even when the effects of cable self-heating were included in the analysis. However, SNL had previously raised concerns regarding the observation of melted thermocouples within this test article, and the resulting uncertainty regarding the accuracy of temperature measurements. As discussed in Section 5.4 above, these concerns have been addressed in part, but not in full. In particular, while the melted thermocouples were not associated with the power cable surface temperature measurements, they do provide evidence that the very large size and large thermal mass of the power cable significantly influenced the test results. Hence, it is considered inappropriate to extrapolate the results of this test to similar configurations which involve cables of smaller size. X

It is recommended that this test article should be accepted, but only for applications involving cables 750MCM and larger.

6.2.10 Test Scheme 15-2, Rear Power Cable Test Article

The estimated composite cable IR values for this power cable failed to meet the USNRC acceptance criteria, even in the absence of self-heating effects (the best-estimate IR performance during the test was 3.00E5 as compared to the acceptance value of 1E6). When the hot-spot cable IR performance is (was) considered, an IR value of 1.68E3 Ω-1000ft is (was) obtained including the effects of cable self heating. This ~~does~~ value meet the SNL recommended acceptance criteria. X X

One potential point of concern which does remain is that a significant variation in point-to-point cable temperatures was noted in the test data. The peak variation was about 90°F over a distance of 6" adjacent to the hot-spot. This variation is indicative of potentially marginal performance, especially given the very large size of the cable which would normally be expected to mitigate local heating effects through lateral heat conduction. X

Also note that in prior reviews SNL had expressed concern (concerns) regarding the reliability of temperature measurements in light of the observed melting of certain of the thermocouple lead wires. The utility statements in this regards (see Section 5.4 above) are considered sufficient to justify reliance on the measured cable surface temperatures. However, as discussed in Section 5.4 above, this test article should not be extrapolated so as to justify a similar installation for smaller cable sizes. X

Of the tests reviewed, this is the one test article concluded which is considered most difficult to judge. However, in the final analysis, SNL concludes that the combined conservatisms which arise as a result of the cable IR versus temperature correlation, the inherent nature of the hot-spot analysis method, and the recommended hot-spot IR acceptance criteria provides sufficient margin so as to justify acceptance of this test article based on the hot-spot analysis results. X