A Review of the River Bend Station Fire Barrier Ampacity Assessments

A Letter Report to the USNRC

Revision 0

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ENCLOSURE 2

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FORWARD

The United States Nuclear Regulatory Commission (USNRC) has solicited the support of Sandia National Laboratories (SNL) in the review of utility submittals associated with fire protection and electrical engineering. This letter report documents the results of a SNL review of a set of submittals from the River Bend Station (RBS) nuclear plant. 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 analyses performed by RBS to support an assessment of actual in-plant cable ampacities. These documents were submitted by the utility in response to USNRC Generic Letter 92-08. This work was performed as Task Order 8, Subtask 3 of USNRC JCN J2017.

1.0 INTRODUCTION

1.1 Objective

In response to USNRC Generic Letter 92-08, the River Bend Station (RBS) nuclear plant provided documentation of the utility position regarding ampacity derating factors associ. .d with its installed Thermo-Lag 330-1 fire barrier systems. The objective of t.. subtask was to review and evaluate these utility submittals. In particular, the :ubmittals included documentation of analyses intended to demonstrate that the cables at RBS are operating within acceptable ampacity limits. The relevant documents reviewed are:

- Letter, November 9, 1995, J. J. Fisicaro, Entergy Operations/RBS to the USNRC Document Control Desk, item RBG-42159, RBF1-95-0265 with attachments/enclosures as follows:

  - Attachment 1: Utility response to USNRC Request for Additional Information (RAI) of February 9, 1994.

  - Attachment 2: Utility response to USNRC Request for Additional Information (RAI) of December 28, 1994.

  - Enclosure 1: Utility Calculation E-218 with Supplements A-C and Attachments 1-13, "Ampacity Verification of Cables Within Raceways Wrapped with Appendix R Fire Protection Barrier", various dates.

SNL was requested tc review the ampacity derating aspects of these submittals under the terms of the general technical support contract JCN J-2017, Task Order 8, Subtask 3. 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.

1.2 Overview of the Utility Ampacity Derating Approach

The consideration of ampacity derating factors for fire barriers at RBS, as currently documented by the utility in the above referenced submittals, is based on an analytical assessment using available test data on the derating impact of the fire barrier systems. The bulk of the assessment is based on fairly simple, and generally conservative, calculations which begin with an assessment of the nominal ampacity limits for the cables installed at RBS including such factors as the ambient temperature, grouping of conduits, grouping of cables, and the ampacity impact of the fire barrier itself. These nominal ampacity limits are then compared to the actual in-plant cable loads. The result is an assessment of the acceptability of the in-plant ampacity loads. In general, this is considered an appropriate approach to analysis, provided that the analysis itself is properly conducted.

It must, however, be noted that the submittals are incomplete and, as they currently stand, are not sufficient to demonstrate the acceptability of the ampacity loads at RBS. In particular, the only test results cited by the utility are those performed under the sponsorship of the manufacturer Thermal Science Inc. (TSI), all of which have been discredited. Hence, these tests do not represent an appropriate basis for the utility ampacity assessment. The utility does cite that it will reevaluate its ampacity factors once the TU, or potentially other utility tests, become available. A final assessment of the utility ampacity load factors will require that such an assessment be provided.

Another factor which must also be clarified before a final assessment is possible is that the utility states that it is in the process of reviewing all of its installed fire barriers and that many of the barriers may be either abandoned in place, removed entirely, or replaced with an alternate material. This raises certain questions related to cable which might have once been protected but have since had their fire barriers removed. This issue should be resolved by the utility as will be discussed further below.

1.3 Organization of Report

This review has focussed on a technical review of the utility documentation and the utility analysis approach. Section 2 of this report provides a more thorough discussion of the utility approach to ampacity assessments. Section 3 provides a technical review of the actual calculations documented in the utility submittals. Section 4 summarizes the SNL findings and provides recommendations regarding the need for additional information to support the final assessment of the utility analyses.

2.0 OVERVIEW OF THE UTILITY APPROACH

2.1 Overview

The utility submittals are quite extensive, and document ampacity assessments for a very large number of individual cables and barriers. The utility ampacity analysis is based on a relatively straight-forward analysis approach. That is, the utility assesses the baseline limits of its installed cables using the tabulated ampacity values from ICEA P-54-440 [1] or IPCEA P-46-426 [2]. In some specific cases the NEC tables are also cited [3]. The nominal tabulated ampacities are derated by the utility to account for a range of service conditions including the local ambient temperature, cable tray depth of fill, cable size, and the fire barrier itself. This results in the development of customized ampacity tables which are applicable to the RBS cables for a range of specific installation configurations. These derated cable ampacities (or DCA's) are then compared to the actual in-plant ampacity loads. It the service load is less than the DCA then the cable is assumed to be acceptable. More general aspects of the utility analyses will be reviewed in detail in this Section of the report. A more detailed examination of certain specific aspects of the utility calculations is provided separately in Section 3 below.

2.2 Base Assumptions

There are several basic assumptions made by the utility which will significantly influence the utility analyses, and the final assessment of the adequacy of the utility submittals. The most significant of these factors are as follows:

- The utility analysis assumes that all of the cables reviewed are rated for an operating temperature of 90°C. This is a typical value for modern insulation types used in the nuclear industry.

- The utility has used an initial ambient environment temperature of 40°C for all cable ampacity assessments. However, the individual ampacity values are then adjusted to account for the "maximum ambient design temperature for each room". While such an assessment is entirely appropriate, it should be noted that the utility assessments will derive little or no conservatism from the assumed ambient temperatures. (A common source of conservatism noted in other analyses is use of a single bounding and conservative ambient temperature for all areas. The RBS analyses will only derive conservatism in this aspect of the analysis to the extent that the assumed area ambient temperatures are conservative estimates of actual in-service plant conditions.)

- The utility analysis has not considered Instrument and Control (I&C) cables as a thermal source in its ampacity calculations. Neglecting of instrument and non-continuous control cables is consistent with general practice and is considered appropriate for the assessments at RBS. However, the customized RBS ampacity limit tables include the consideration of ampacity limits for "continuous duty loading" of control cables. The utility should clarify whether or not "continuous duty" cont[illegible] cables have been included in the ampacity

derating assessments. If such cables have not be included, then supplemental analyses should be provided to cover such cables.

- Ampacity loads for cables are apparently based on actual in-plant service loads using the rated power of connected devices (as compared to breaker settings e.g.). This is generally considered an appropriate practice although the utility will derive no conservatism from this treatment. It was also noted that for the more significant ampacity loads, the calculations included consideration of at least a 10% degraded voltage operating condition.

2.3 The RBS General Analysis Methodology

In Attachment 2 of the utility submittal, as identified in Section 1.1 above, RBS has documented its general procedure for the assessment of the in-plant ampacity service loads in cables protected by Thermo-Lag fire barrier systems. This assessment is based on a fairly straight forward approach to the calculation of in-plant ampacity loads and to the evaluation of allowable ampacity limits. Simple comparison of the actual in-plant ampacity loads to derated cable ampacity (DCA) values provides an assessment of the adequacy of the service loads.

In general, the utility approach to analysis is appropriate. In particular, the approach allows for the assessment of individual cable ampacity loads in comparison to published tables of cable ampacity limits and includes the consideration of important in-plant service conditions, including the fire barrier itself, in these estimates. However, there are several points regarding the utility procedure which should be clarified or further justified. In particular:

- Attachment 2, Item 1: This item states that the analysis will focus only on "required and abandoned Thermo-Lag wrapped raceways." This implies that cables that were originally enclosed in fire barriers that were subsequently removed by the utility will not be considered. This is not an adequate basis for analysis. The fire barriers have, presumably, been in place at RBS for some years. If cables in formerly protected raceways have been operating significantly above allowable ampacity limits, then the aging of these cables would have been significantly accelerated and the cables may not have little or no remaining "life expectancy." This may prove to be particularly important for RBS because the original utility analyses were based on fire barrier ADF values which are now known to have been highly optimistic, and because even using these optimistic ADF values certain of the cables at RBS were found to have little or no additional margin available. The utility analysis should include all cables which are either currently or formerly enclosed in fire barrier wraps. For formerly protected cables, they should be shown to have either been operating within acceptable limits during the time they were protected, or alternately, an analysis of the aging of these cables during the period they were wrapped should be provided.

- Attachment 2, Items 6 and 7: The utility ampacity load calculations have included an "ampacity adjustment factor (value greater than one)" as a

multiplier on current loads (see utility Attachment 2, items 6 and 7). The basis and intent of this factor is somewhat unclear and should be clarified by the utility. In particular, the utility should describe all of the effects which are intended to be addressed by this factor, and should describe how it has been applied in specific cases. More definitive criteria for how this factor is assessed for specific cases is also needed.

- Attachment 2, Items 10: It is not clear that the utility has appropriately accounted for the impact of collocated I&C cables on the performance limits of its cables. In particular, utility Attachment 2, item 10 states that the utility will "Calculate the depth of cables in each wrapped tray (other than control cables)" and will "Use this value to determine an ampacity derating adjustment for cable depth." These statements imply that in calculating the cable tray depth of fill, collocated control cables may not have been included. It appears that the utility might be taking credit for cable load diversity through a modification of the cable tray depth of fill calculation.

  If this is a correct interpretation of the utility practice, this would be inappropriate. The mere presence of collocated cables in either a raceway would impact the ampacity limits of the other cables in the raceway regardless of their own operating status. Depth of fill calculations should include all cables in a cable tray. Even though instrument cables and non-continuous load control cables may be assumed to not provide an additional heating source, they will still act as thermal insulation isolating the other collocated cables from the ambient environment. This important effect must be accounted for, and it is not clear that the utility has done so. Clarification of the utility assumptions in this regard is needed. All of the cables present in a raceway should be included in the calculation of depth of fill, or the utility practice in this regards should be specifically justified and validated in detail.

2.4 Calculation E-218 General Methodology

The utility has also provided Calculations E-218 with three supplements and 13 attachments (see citation in Section 1.1 above). This calculation provides the specific details of the utility methodology, and the actual calculations for the protected cables. The following identifies points of the general methodology and documentation which may be inappropriate, require clarification, or require further justification. (Section 3 of this report provides a brief review of certain of the actual cable calculations.)

- Calculation E-218, Revision 0, Page 2 of 35, item 7: The calculation cites that RBS "takes credit for the guaranteed average diameters rather than guaranteed minimum cable diameters for 600 volt 'K&C' cable. This will result in slightly higher DCA's for these cable types." This assumption should be clarified. In particular, what is the difference between the guaranteed minimum diameter and average diameter? How large would the ampacity impact be if the minimum diameter is used? In general, it would be considered more appropriate to use the minimum diameter value because this would be more conservative, and the manufacturer has apparently indicated that these minimum values are not unlikely. If the impact is significant then the utility

should reassess its ampacity limits using the minimum cable diameter as the basis for analysis.

- Calculation E-218, Revision 0, Page 6 of 35, Item II-a: This item identifies five "types" of cable trays, H J L K and C. These designations should be clearly explained.

- Calculation E-218, Revision 0, Page 6 of 35, Item II-a-4: This item states that cables in "K-trays" are based on an assumed depth of fill of 1.5". This value appears again on page 22 of 35, item 1a, and in this citation E218-Attachment 3 is cited as the basis for this value. However, E218-Attachment 3 states that a depth of fill of 2.5" should be used for sizing cables in "K-trays" (see "Conclusion" on page 3 of 3 of E218-Attachment 3). This discrepancy should be resolved. In particular does a value of 1.5" bound the upper limit on depth of fill for all such trays? If not, then either an upper bound value or the actual value associated with a given case should be used.

- Calculation E-218, Revision 0, Page 8 of 35, Item 3: This item cites the IPCEA derating factors for "cable with maintained spacing". The requirements for "maintained spacing" are quite restrictive and specific (cable-to-cable gaps must be maintained at or above a minimum value, and the cable must be installed with physical restraints to maintain these gaps). The utility should explicitly justify its use of the "maintained spacing" factors by explicitly verifying that the requirements set forth in the IPCEA standard for use of these factors are in fact met in the RBS installations. Specific cases in which these factors have been applied should be identified by the utility, and each such application should be specifically evaluated as to their compliance with the "maintained spacing" criteria.

- Calculation E-218, Revision 0, Page 35 of 35, Item E: The utility has not provided any detail or results for the calculation of ampacity limits for 5kV and 15kV cables. RBS should cite the tables from which the ampacity limits for these cables are derived, and should describe the appropriate derating factors applied to the tabulated ampacities as has been done for all other cable types. Comments associated with the other cable type calculations should also be considered as applicable for the 5kV and 15kV cables as well (for example, use of the open air tables without consideration of cable tray effects (see section 3.2 below), assumptions regarding maintained spacing, etc.)

3.0 REVIEW OF SPECIFIC UTILITY ANALYSES

3.1 Overview

Included in the utility submittal are the specific calculations for a large number of individual cables. This includes the development of modified or customized tables of general cable ampacity limits, the estimation of individual cable ampacity loads, and the assessment of cable loads in comparison to the "generic" ampacity limits. This effort has not attempted to review all of these individual calculations, but rather, has "spot checked" certain of the calculations in an attempt to highlight potential shortcomings. The findings of these reviews are documented in this section.

3.2 Development of Customized General Ampacity Tables

One aspect of Calculation E218 is the development by the utility of modified generic ampacity limit tables for cables specifically used at RBS under a range of potential application conditions. That is, the utility has taken the base ampacity tables from the IPCEA or NEC standards, and has customized those tables to address the specific cables in use at RBS, the placement of those cables in a raceway system (either a conduit or cable tray), the local ambient temperature of the area, and the type of fire barrier system installed on the raceway (1hr or 3hr, conduit or cable tray system).

In general, this practice can be used to provide a more consistent and concise assessment of ampacity limits for the cables in use at a given site. These tables can be used as a simple source of estimated ampacity limits to support the cable ampacity assessments. However, there are certain aspects of the utility ampacity tables that have not been adequately addressed and that may lead to nonconservative estimates of cable ampacity limits. These questions are addressed in the following subsections.

Also noted in the review of these calculations were two potential discrepancies in one of the customized utility ampacity charts:

- Calculation E-218, Revision 0, Page 29 of 35, Item "Chart 2": There appear to be two possible discrepancies in the values cited in this chart; for the 10AWG 7/C and 12/C cables, and for the 12AWG 7/C and 9/C cables. In general, the ampacity limits should drop with an increase in the number of conductors. For all cases, except the two pairs cited, this expectation is met. The ampacity values cited in column three of this chart should be verified and the apparent discrepancies for these two cable pairs should be resolved.

3.2.1 The Customized Conduit Ampacity Tables

The RBS customized ampacity limits for cables in conduits are presented in E218 Charts 1 and 2. In developing these tables, the utility has taken the cited ampacity values from the IPCEA (or ICEA) or NEC tables for a single cable or circuit in conduit, and has derated those values to account for the local ambient temperature and for the fire barrier system installed. However, the utility has not fully accounted for

the additional derating factors which are required when a conduit contains more than three power carrying conductors.

That is, the IPCEA and NEC conduit tables are intended to address only a single cable (with up to three conductors) housed alone in a conduit. The IPCEA tables do not address any other conduit loadings. For conduits loaded with more than three conductors, typical practice is to apply the NEC cable grouping factors. While the utility cites these NEC factors in its submittal (see page 8 of 35 of E218), it has not applied them in a fully appropriate manner. In particular, the NEC handbook states in Note 8 to the ampacity tables in Article 310 that:

> "Where the number of current-carrying conductors in a raceway or cable exceeds three, the allowable ampacities shall be reduced as shown in the following table:"

A table of ampacity corrections factors (ACF) is then provided.[1] For example, if a conduit housed between 4 and 6 current carrying conductors, then an additional 20% ADF (or 80% ACF) would be applied to account for the mutual heating effects of one cable on its neighbors within the conduit. This ADF increases as the number of conductors increases.

It was noted that the utility has apparently applied these factors in reducing the ampacity limits of individual cables with more than three conductors when installed in a conduit (see page 27 of 35 of E218). However, this is not fully consistent with the intent of the NEC design practice, and does not result in the same derating effect as that intended by the standard. That is, the intent of the NEC conductor grouping factors is to account for two situations.

- first, for an individual cable which has more conductors than the cables cited in the tables, and
- second, for the installation of multiple cables in a raceway system (either a tray or conduit) where the spacing between cables is not explicitly maintained.

The utility practice has only accounted for the first part of this problem, and has ignored the second aspect, and hence, does not adequately address this factor.

It was also found that the utility has cited an older version of the NEC tables in its assessment (NEC 1984). The newer versions of the NEC tables have updated the cable conductor grouping ACF values (all versions issued since 1990). The older values included an assumption of a 50% load diversity, although this was often overlooked in ampacity calculations. The updated standards allow for their use only where load diversity can be verified (calculations under engineering supervision as per Appendix B of the NEC handbook). For general applications, a new set of values has

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[1] Recall that ADF = 1.0 - ACF

been developed which are more restrictive if the number of conductors exceeds nine. The utility should be asked to justify its use of the "50% load diversity" based factors in lieu of the general values assuming no load diversity consistent with current NEC design practice.

To illustrate, consider the first raceway cited in Attachment 1 to E218; Raceway 1CC600RB. This is cited as a raceway protected by a 1hr fire barrier, and located in an area with a 50°C ambient temperature. A comparison of the ampacity limits cited and the utility customized tables shows that this raceway is, in fact, a conduit.[2] In all, this conduit holds 6 multiconductor cables with a total of 23 individual conductors. Using the 1996 NEC handbook, an additional ADF of 55% should be applied to the tabulated ampacity limits for each and every cable in this conduit.[3] Even using the older NEC values cited by the utility, a uniform ADF of 30% should have been applied to all of these cables. In the utility practice, just two of the cables (1RCSARC300 & 301) had individual conductor grouping ADFs (of 20% and 30% respectively) applied to their ampacity limits in developing the customized ampacity tables.[4] The other four cables were either 2/C or 3/C cables, and hence, no conductor grouping ADF was applied. The overall effect is not at all equivalent. In this particular case, even if the ADF for conductor grouping is applied to the conduit as a whole, all of the cited cable loads would still remain within acceptable limits. However, the available margins would be significantly reduced.

A second example where this shortcoming may impact the results is discussed in Section 3.4 below. In that section, the supplemental calculations provided for certain conduits in which the power loads were split between two parallel power cables might also be impacted by the failure to include appropriate conductor grouping adjustment factors.

This review has not assessed all of the utility conduit calculations to determine where this factor might change the utility conclusions regarding individual cable ampacity loads. A spot check indicated that most of the conduit installed cables at RBS are either not impacted by this issue (i.e., are in conduits with 3 or fewer conductors present), or will likely have sufficient available margin to encompass this additional derating effect. Nonetheless, the utility should review all of its conduit assessments to determine how the appropriate treatment of conductor grouping ADFs would impact its overall assessment conclusions.

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[2] While the utility nomenclature is not explained, it appears that a "C" in the second slot in the raceway identifier would indicate a conduit. Similarly, a "T" in this slot would appear to indicate a cable tray, and an "I" indicates and instrumentation pipe.

[3] See NEC Handbook, 1996, page 70-196.

[4] Cable x300 is a 5/C cable and x301 is a 9/C cable, hence, different ADF values apply as per NEC

3.2.2 The Customized Ampacity Tables for Type "L" and "K" Cable Trays

In the development of its customized ampacity tables for type "L" and "K" cable trays, the utility has made certain assumptions regarding the application of the IPCEA P-46-426 open air ampacity table to cable tray installations which appear to be inappropriate. In particular:

- Calculation E-218, Revision 0, Page 24 of 35, Item "Chart 1": This item is described as a table of allowable ampacities for "L-trays". (The utility has failed to explain its nomenclature, and it is unknown what the designation "L-tray" implies. These appear to be associated with lower voltage (<600V) light power and control cables.) However, it is clear that the base ampacity values are from the ICEA P-46-426 tables for a cable located in free air with no derating factors applied.

- Calculation E-218, Revision 0, Page 6 of 35, Item II-a-4 (and pages 32 and 33 of 35, Item VII-c and "Chart 4"): These items state that for cables with "intermittent service" in type "K" trays, ampacity limits are based on IPCEA P-46-426 "without derating for spacing." That is, the IPCEA P-46-426 table values of the ampacity limits for cables in open air have been used directly to assess ampacity load limits for cables in trays with no consideration of the impact of placement in a cable tray with other cables on those limits.

The use of open air ampacity values for a general cable tray appears inappropriate. The basis for the development of these charts requires further explanation and justification. The basis for use of open air ampacity limits for cables located in a cable tray is inadequately addressed. On page 6 of 35 of E218 the utility cites an alternate calculation, E-137, as the basis for the cable sizing for "L"-trays. This calculation has not been provided for review. In effect, the utility appears to be crediting load diversity in its cable trays through application of the open air ampacity limits to diversely loaded cables in cable trays. This is a fundamental departure from accepted ampacity analysis approaches, and the reviewer knows of no precedent for this approach.

For example, in the ICEA P-54-440 tables, ampacity limits are generally established based on the cable tray depth of fill. However, the standard also establish an upper-bound limit of no more than 80% of the open air values for cables in cable trays (see Section 2.2 of the standard). The utility has not justified its use of open air ampacity limits for cables in cable trays, and the result could be non-conservative assessments of cable ampacity limits. Even for a cable with intermittent loads, the fact that is might be collocated with other cables in the same tray could mean that a significant mutual heating effect might be observed, or at the least that an insulating effect would impact the allowable cable ampacity limits. It is this type of effect which must be accounted for in the calculation of cable tray ampacity limits.

Cable ampacities for cable tray installed cables should be based on appropriate consideration of the installation details. This should include the appropriate consideration of cable tray loadings, regardless of the nature of the load placed on the

cables. If the utility is, in fact, crediting load diversity using this practice, then the utility approach must be fully detailed, justified, and validated. Alternatively, the utility should provide a reassessment of the cable ampacity limits using accepted ampacity sizing methods which include consideration of the cable tray loading conditions.

3.2.3 Estimation of Ampacity Limits for Control Cables

Control cables are treated in a similar manner to that discussed in Section 3.2.3 above (See E218 Section II.A.5). That is, non-continuous load control cable ampacity limits are derived from open air ampacity limits even though these cables might be installed in cable trays. While, in general, intermittent service control cables are excluded from the final fire barrier ampacity derating assessments, the initial sizing of such control cables is an important design consideration. This is particularly true when the cables are collocated with other continuously energized control (or power) cables. While in the final analysis it is not expected that this will prove to be a point of significant concern, the utility practice in this regard should be further justified consistent with the discussions provided above.

3.3 Calculation E218 Attachment 9 Compressor Loads

Attachment 9 to Calculation E218 documents supplemental assessments performed by RBS for four specific cables which are nominally identified as operating at least part of the time under ampacity overload conditions. Two of the four cables service certain compressor power loads. The purpose of this section is to provide a review of the calculations for these two cables.

The two compressor power cables oonsidered in this analysis are physically identical and also carry nominally identical loads (cables 1HVKBBC515 and 1HVKDBC506). Each is a 2/C #10 AWG cable, and each feeds power loads to one of two separate compressors. Each cable carries the power for the crankcase oil heater, and a seal oil pump motor for one of the two compressors. (The compressor motors themselves are apparently fed through separate cables.) Both cables are located in a common cable tray (tray 1TC043B) which is wrapped with a 3-hour Thermo-Lag fire barrier.

The initial estimate of the full load current for each cable is given as 14.35A, including consideration of a 10% undervoltage condition of operation. The ambient temperature is cited as 40°C, and the "derated cable ampacity" (or DCA) is estimated as 12.1A including the effects of the 3-hr fire barrier (assuming an ADF for the fire barrier of just 20.5%). Hence, these two cables are nominally cited as overloaded (because 14.35A > 12.1A).

Given the actual estimated maximum load and the nominal DCA cited, the utility calculates that under these load conditions the temperature of the cable may reach about 110°C. This calculation was based on a fairly simple correlation which relates the impact of current on operating temperature (this relationship derives from the IPCEA tables). The utility then cites the equipment qualification (EQ) results as

provided by the manufacturer, and calculates an expected life for this cable under conditions of continuous operation at this temperature as just under seven years.

Based on these results, the utility cites and initial conclusion that the "cable is inadequate." However, the utility continues its assessment in an attempt to demonstrate acceptability. In particular, the utility cites that the oil crankcase heater and the seal oil pump motor "rarely operate simultaneously." That is, the oil heater shuts down after some period of compressor operation and oil temperature is maintained by the excess heat of the motor operation, and the seal pump operates only periodically and then for short periods of time. The utility then states that "it is anticipated that the amount of time that both loads operate simultaneously is far less that 100 hours per year and less than 5 hours per occurrence."

Using only the load of the heater, apparently the larger and more frequent of the two loads, a modified ampacity load of 9.17A is calculated. This is within the estimated DCA of 12.1A, and hence, the utility concludes that the "cable is adequate under typical and emergency overload conditions."

There are several points of concern related to this calculation:

- As has been noted above, the utility DCA values are based on an assumed ADF for a 3-hr wrapped cable tray of just 20.5%. This value is clearly optimistic (i.e., too low) based on existing test data. A more realistic estimate of the ADF of a 3-hr barrier would be on the order of 40% (this is an estimate only and is used for illustration purposes, this value is not based on any specific test results). Use of this as an estimate of the actual ADF would have a significant impact on the utility calculations:
    - Using an ADF of 40% in the utility calculation method, the actual DCA of the cable would be estimated as 9.13A. This would be lower than the value of the full load amperage even with only the crankcase heater operating as cited in the second stage of the utility calculation (9.17A). Given this situation, and the fact that both loads can be active for at least part of the time (yielding a maximum load of the original 14.35A), there is a distinct possibility that this cable has been operating for some time at a significant overload condition (potentially at more that 150% of the nominal ampacity limit for at least part of its life).
    - If the same process used by the utility is again used to estimate the operating temperature of the cable under the conditions in which both loads are active, a temperature of 163.5°C is found.[5] This temperature would be clearly unacceptable even for short term

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[5] Note that this is only a rough estimate and is probably non-conservative, i.e., too low. In particular, the simple temperature calculation cited does not consider the increase in electrical resistance for copper at increasing temperatures. This effect would increase the cable self heating rate for a given current as temperature increases.

"overload" operations. Even very short term operation of the cable at these temperatures would severely degrade the cable's "life expectancy." Recognizing that the 40% ADF value is an estimate only, it is still considered unlikely that the utility can demonstrate that the operating conditions of these two cables are, in fact, acceptable. Operation of the crankcase heater load only might be demonstrated as an adequate operating condition, but clearly, the two loads operating simultaneously would not be considered acceptable under these conditions.

- The utility has not provided any assessment of the impact of the stated conditions of overload operation on the cable's "life expectancy." That is, the utility did provide for an assessment of life impact for the conditions of continuous operation at an overload condition, but did not provide the corresponding assessment for periodic operation at overload coupled to "normal" operation with a single device operational. Even relatively short periods of operation at a temperature exceeding the qualified life temperature of 90°C can significantly degrade the cables. The utility should provide for an assessment of life expectancy under the worst case anticipated conditions of operation.[6]

- If these cables have operated under the stated conditions for any significant length of time, then the cables may have already exceeded their rated life expectancy. Given the aging versus temperature chart cited by the utility, the estimated life expectancy of the cable operating at 165°C would be just 850 hours, or less than 36 days (this value corresponds to the conditions postulated by SNL using an ADF of 40% for the 3hr fire barrier as stated above). Even assuming the operating times cited by the utility, "far less than 100 hours per year," coupled with near continuous operation of the heater at essentially 100% of the cable ampacity limit, the cable would be aging at an effective rate of 5.7 years per actual year of plant operation.[7] Hence, the cables nominal "40 year at 90°C" life would be exceeded in about seven years.

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[6] Note that the impact of aging at different conditions of operation can be assessed in a fairly simple manner by simply summing the equivalent life impact of the various operating conditions. Also note that this assessment must also include the aging impact of the ambient environment even when the cable is not energized. That is, even at an ambient of 40°C a cable continues to age. A forthcoming DOE report on this subject should soon be available, and the anticipated distribution will include virtually every utility in the U.S. (see reference 4).

[7] This is an attempt to relate the given operating conditions to an equivalent life expectancy of 40yrs at 90°C. Assuming that the cable would last for 850 hours, or 8.5 years at 100 hours per year overload loading, is an "equivalent aging rate" of (40/8.5 = 4.7 years/year) in comparison to its 40 year qualified life at 90°C. Added to this is 1.0yrs/yr for the normal operation at 100% ampacity with the heater only operating at most times. This gives a total equivalent aging rate of 5.7yrs/yr.

The point of this admittedly course exercise is to illustrate that even if the utility were to immediately remove the fire barrier for this tray, these two cables might still be found to be unserviceable in the context of equipment qualification, and hence, might still require replacement. This, of course, assumes that the conditions cited are a relatively accurate representation of the actual ADF impact. A full assessment would require application of a well validated ADF value to this particular case, and should also include a more accurate estimate of the cable operating temperature under the overload conditions. A more accurate estimate of the actual cable power cycling behavior should also be included.

- The final justification for the acceptability of these two cables operating conditions is based in part on the manufacturer's stated overload conditions of operation. These ratings are not generally intended to cover anticipated conditions of normal operation, but rather, are intended to cover only unexpected emergency conditions of operation. For example, it would not be unexpected for a utility to cite overload conditions of operation to allow for period operation at degraded voltage conditions. However, the reliance on overload ratings as exercised by RBS is potentially inappropriate. At the least, this practice represents a fundamental departure from accepted ampacity assessment practices, and as such, should be thoroughly justified and reviewed before being accepted as a cable design practice.

Further, the utility cites a specific passage in the IEEE 242 standard as the basis for its assessment of overload conditions (para. 11.5.2(3)). A review of this section of the standard revealed no relevance whatsoever to the issue of cable overload conditions (attachment 1 to this report provides the relevant passage). It is expected that either an older version of the standard is being cited (no specific version is identified by the utility), or that the citation is in error. In the version reviewed by SNL (242-1986), Section 8.5.2 deals with overload conditions of operation and 8.5.2.3 states in part that:

> "a temperature safely reached during a fault, and maintained for only a few seconds, could cause severe life reduction if it were maintained for even a few minutes. Lower temperatures, above the rated continuous operating temperatures, can be tolerated for intermediate times."

It is suspected that this is the passage being referred to by the utility. However, this section of the standard goes on to state.

> "The continuous current, or ampacity, ratings of cable have been long established and pose no problems for protection. The greatest unknown in the cable thermal characteristic occurs in the intermediate time zone, or the transition from short-time to long-time or continuous state."

Also presented in the standard (section 8.5.2.4) is an approach to the determination of intermediate overload ratings. At the least, this assessment coupled to an assessment of the impact of overload operations on cable life expectancy should be provided by the utility. (Attachment 2 to this report provides a copy of these two passages.)

The IPCEA P-46-426 standard also addresses overload conditions of operation. In particular, Appendix III.4 states:

"Operation at the emergency overload temperatures tabulated here shall not exceed 100 hours per year. Such 100-hour overload periods shall not exceed five."

The utility should address this aspect of the IPCEA ampacity standards in its assessment of cable performance. This requirement would appear to preclude a general reliance on the overload ratings as a routine aspect of the anticipated ampacity operating conditions.

- The utility has cited a particular equipment qualification test report as the basis for its assessment of cable life expectancy calculations (Okonite report SWGS-1282-2). The copy of the cable aging chart provided in the submittal is not sufficiently clear to verify the acceptability of this calculation as a basis for the assumed cable life expectancy calculations. In particular, the utility has not cited the assumed value of the cable insulation's activation energy, nor has it cited its assumed criteria for the cable end-of-life indicator. The chart included in the submittal contains four specific curves, and the utility assessment is based on the most optimistic of these curves. While this may be the appropriate curve for the case under consideration, some explanation and justification for the particular curve chosen is needed. The utility aging calculations should either include the full EQ report, or should at the least provide sufficient information upon which to base a review of the calculations.

In a more general context, it should be noted that this is the first instance in which a citation to the IEEE 242 standard has been encountered by this reviewer in a utility ampacity assessment submittal. Hence, the overall acceptability of this design practice in the context of USNRC requirements has not yet been made. Such an assessment is also considered outside the scope of the review of this specific utility submittal because the utility has not yet invoked this particular design practice in its calculations, but rather, has simply cited a passage from that standard. Hence, it is strongly recommended that this IEEE design practice should be reviewed in detail by the USNRC and that an assessment of its acceptability as a general design practice in the context of the USNRC Equipment Qualification Program and other USNRC requirements should be made.

3.4 Review of Attachment 12 to Calculation E218

Attachment 12 to Calculation E218 documents special calculations performed for certain cables in conduits. In particular, the assessments document calculations of ampacity limits under conditions in which the power loads are split between parallel runs of cable. This calculation raises one potential concern for this specific calculation which has also been discussed in the broader context of the RBS conduit calculations in Section 3.2 above.

The initial assessment determined the allowable ampacity limit for the subject cables including the effects of the fire barrier system assuming that three conductors might be used to carry the required load. Because the ampacity limits were lower than the actual loads, the possibility of paralleling two cables for each load was considered. For the parallel power configuration, the ampacity limit determined for one (out of

three) conductor(s) is simply doubled, or alternately, the same load is assumed to apply to each of the six conductors in the parallel cables.

This practice would not be correct if the paralleled cables (all six conductors) are located in a common conduit. In particular, the IPCEA tables address only the ampacity limits of a single cable of the given type located alone in a conduit (that is, for a triplex cable it is assumed that only one such 3-conductor cable is located in the conduit). IPCEA does not address the placement of additional cables in the same conduit.

The NEC handbook includes factors which account for the number of conductors in a conduit, and requires additional derating based on the conductor count. Hence, if the cables are collocated in the same conduit, then paralleling does not necessarily double the total ampacity limit. The 1996 NEC tables would require an additional derating factor of 20% for a conduit with 4-6 current carrying conductors. If these factors are included in the calculation of ampacity limits, then the cables considered in this RBS analysis would still be found to be nominally overloaded, even in the paralleled configuration.

Consistent with the recommendations presented in Section 3.2 above, for this specific cable, the utility should be asked to clarify the following point:

> Are the paralleled cables cited, for example, in Attachment 12 to calculation E218 enclosed in a common conduit? If so, then direct application of the IPCEA tables to this configuration would be inappropriate. Cable ampacity limits should include consideration of multiple conductor derating factors such as those presented in the NEC handbook.

4.0 SUMMARY OF REVIEW FINDINGS AND RECOMMENDATIONS

4.1 Summary of Findings on the General Utility Approach and Scope

The overall ampacity assessment approach taken by the utility was generally found to be an acceptable means of resolving the ampacity derating questions. The overall methodology is basically sound, and can appropriately determine whether or not individual cables at RBS are operating within acceptable ampacity limits. The methodology provides for case specific treatment of each protected cable at RBS, and compares actual in-plant loadings to estimated ampacity limits which include the effects of various environmental factors as well as the fire barrier system itseif. The methodology is fairly straight forward in its overall implementation.

The utility approach is quite similar to a margins analysis in many regards. The primary difference is that the utility has developed customized tables of ampacity limits for its specific cable types to cover a range of potential installations, and it is in these tables of "derated cable ampacity" (DCA) limits that the utility has included the assumed ADF for the fire barrier system in the calculation. Hence, the utility draws a direct comparison between the DCA values in their customized tables, and the actual in-plant service loads.

The acceptability of this approach in the final analysis rests an assessment of whether or not the utility has compared appropriately determined in-plant ampacity service loads to estimated ampacity limits which are based on appropriate application of the base line ampacity tables, and on appropriate estimates of the fire barrier derating impact. The documentation as currently provided by the utility is insufficient to make this determination. The utility analyses of nominally overloaded cables are also considered inadequate as currently documented.

In a very fundamental sense, the utility submittals were viewed as preliminary only, and it is in this context that this review has been performed. In particular, the utility calculation of its DCA limits are currently based on now discredited TSI-sponsored tests. In fact, the values used by RBS in its assessment, for cable trays in particular, are known to be highly optimistic in comparison to the most recent test results. The utility recognizes this limitation and cites plans to review its submittal upon receipt of the TU test results.

4.2 Summary of Findings on the Overall E218 Analysis Method

Specific areas or weakness or uncertainty as related to the overall approach to ampacity assessments taken by the utility which should be addressed are:

- RBS Attachment 2, Item 1 states that the analysis will focus only on "required and abandoned Thermo-Lag wrapped raceways." This implies that cables that were originally enclosed in fire barriers that were subsequently removed by the utility will not be considered. If cables in formerly protected raceways have been operating significantly above allowable ampacity limits, then the aging of these cables would have been significantly accelerated and

the cables may have little or no remaining "life expectancy." For formerly protected cables, RBS should show that they have either been operating within acceptable limits during the time they were protected, or alternately, an analysis of the aging of these cables during the period they were wrapped should be provided.

- RBS Attachment 2, Items 6 and 7 indicates that an "ampacity adjustment factor (value greater than one)" has been applied as a multiplier on current loads (see utility Attachment 2, items 6 and 7). The basis and intent of this factor should be clarified as it is applied to the various cases considered.

- RBS Attachment 2, Items 10 states that the utility will "Calculate the depth of cables in each wrapped tray (other than control cables)" and will "Use this value to determine an ampacity derating adjustment for cable depth." These statements imply that the depth of fill calculation may not include all cables in a given tray. This aspect of the utility analysis should be clarified, and depth of fill calculations should consider all cables located in a given cable tray regardless of their function or loading.

Utility Calculation E218 and its various attachments and supplements document the actual calculations for specific cables, cable trays, and conduits. Two minor points related to the utility nomenclature used in this calculation require clarification:

- The utility uses a plant specific nomenclature to identify various classes of cable trays (types H, J, L, K, and C). This nomenclature should be explained.

- The utility submittals fail to explicitly identify raceway systems as either conduits or cable trays, and fails to describe the physical characteristics of the various raceway systems (such as tray width or conduit diameter). The utility should provide supplemental information to characterize the raceways considered in its analyses.

Several points related to the overall utility analysis methodology were also noted:

- The utility analyses are based on optimistic assumptions related to the ampacity derating impact of the fire barrier systems. Use of more realistic values in the subsequent final utility assessments is expected.

- Calculation E-218, Revision 0, Page 2 of 35, item 7: This item states that RBS "takes credit for the guaranteed average diameters rather than guaranteed minimum cable diameters for 600 volt 'K&C' cable. This will result in slightly higher DCA's for these cable types." This assumption should be clarified. In particular, what is the difference between the guaranteed minimum diameter and average diameter? How large would the ampacity impact be if the minimum diameter is used? In general, it would be considered more appropriate to use the minimum diameter value because this would be more conservative, and the manufacturer has apparently indicated that these minimum values are not unlikely. If the impact is significant then the utility

should reassess its ampacity limits using the minimum cable diameter as the basis for analysis.

- Calculation E-218, Revision 0, Page 6 of 35, Item II-a-4: This item states that cables in "K-trays" are based on an assumed depth of fill of 1.5". This value appears again on page 22 of 35, item 1a, and in this citation E218-Attachment 3 is cited as the basis for this value. However, E218-Attachment 3 states that a depth of fill of 2.5" should be used for sizing cables in "K-trays" (see "Conclusion" on page 3 of 3 of E218 Attachment 3). This discrepancy should be resolved. In particular does a value of 1.5" bound the upper limit on depth of fill for all such trays? If not, then either an upper bound value or the actual value associated with a given case should be used.

- Calculation E-218, Revision 0, Page 8 of 35, Item 3: This item cites the IPCEA derating factors for "cable with maintained spacing". The utility should explicitly justify its use of the "maintained spacing" factors by explicitly verifying that the requirements set forth in the IPCEA standard for use of these factors are in fact met in the RBS installations for which these factors have been applied. Alternatively, the utility should reassess its analyses using grouping factors for cables without maintained spacing.

- Calculation E-218, Revision 0, Page 35 of 35, Item E: The utility has not provided any detail or results for the calculation of ampacity limits for 5kV and 15kV cables. RBS should cite the tables from which the ampacity limits for these cables are derived, and should describe the appropriate derating factors applied to the tabulated ampacities as has been done for all other cable types. Comments associated with the other cable type calculations should also be considered as applicable for the 5kV and 15kV cables as well (for example, use of the open air tables without consideration of cable tray effects, assumptions regarding maintained spacing, more appropriate fire barrier ADF values etc.).

In addition, this review identified certain concerns related to the calculation of ampacity limits for cables located in conduits. In particular:

- The utility application of the NEC conductor grouping ampacity correction factors for more than three conductors in a cable or raceway is considered incomplete. In the case of conduits, the NEC correction factors should be applied to the conduit system as a whole whenever the total count of current carrying conductors exceeds three. In contrast, the utility has only applied these factors to individual multiconductor cables when the conductor count for a given cable exceeds three. This is an incomplete and nonconservative treatment. The utility analyses should be revised to fully account for the conductor count adjustment factors for all conduit systems in which the conductor count exceeds three.

- The utility has cited the 1984 version of the NEC handbook as the basis for its assumed conductor count correction factors. However, since 1990 NEC has

published an updated listing of correction factors which are more conservative for conductor counts of 10 or more. The older (1984) values included an assumption of 50% or more load diversity in the installed cables. The utility should either apply the more recent values in its corrections, or should specifically justify the applicability of the older adjustment factors on the basis of existing cable load diversity (see Appendix B of the current NEC handbook for further guidance).

Finally, certain points of potential shortcoming or uncertainty were also noted in the calculation of general cable tray ampacity limits as follows:

- Calculation E-218, Revision 0, Page 24 of 35, Item "Chart 1": This item is described as a table of allowable ampacities for "L-trays". However, it is clear that the base ampacity values are from the ICEA P-46-426 tables for a cable located in free air with no derating factors applied (this is stated in the supporting text). The use of open air ampacity values for a general cable tray appears inappropriate and must be either corrected or further justified. In particular, this practice is not consistent with accepted ampacity design practices, and hence, would require explicit and detailed justification and validation. Similar assumptions are also used for intermittent load cable in "K"-trays, and for intermittent load control cables as well. Similarly, these applications should also be explicitly justified or corrected.

- Calculation E-218, Revision 0, Page 29 of 35, Item "Chart 2": There appear to be two possible discrepancies in the values cited in this chart; for the 10AWG 7/C and 12/C cables, and for the 12AWG 7/C and 9/C cables. In general, the ampacity limits should drop with an increase in the number of conductors. For all cases, except the two pairs cited, this expectation is met. The ampacity values cited in column three of this chart should be verified and the apparent discrepancies for these two cable pairs should be resolved.

4.3 Summary of Finding on Utility Analyses for Nominally Overloaded Cables

Attachment 9 to Calculation E218 documents supplemental assessments performed by RBS for four specific cables which are nominally identified as operating at least part of the time under ampacity overload conditions. Two of the four cables service certain compressor power loads. There are several points of concern related to the supplemental assessments for these two specific cables:

- As has been noted above, the utility DCA values are based on an assumed ADF for a 3-hr wrapped cable tray of just 20.5%. Using a more realistic ADF value might well indicate that this cable has been operating for some time at a significant overload condition (potentially at more that 150% of the nominal ampacity limit for at least part of its life). Given the maximum current loads cited by the utility, and even nominal estimates of the actual fire barrier derating impact, it is considered unlikely that the operating conditions of these cables could be justified by the utility.

- If these cables have operated under the stated conditions for any significant length of time, then the cables may have already exceeded their rated life expectancy. Rough estimates performed as a part of this review indicate that these the cables may exceed their nominal "40 year at 90°C" life in as little as seven years. The utility should provide an assessment of the impact of past operations on the "life expectancy" of these cables in addition to any assessment of existing or future operating conditions.

- The final justification for the acceptability of the operating conditions of these two cables is based largely on the manufacturer's stated overload conditions of operation. These overload ratings are not generally intended to cover anticipated conditions of normal operation, but rather, are intended to cover only rarely encountered and unexpected emergency conditions of operation. Hence, reliance on overload ratings in this case is potentially inappropriate. At the least, this practice represents a fundamental departure from accepted ampacity assessment practices, and as such, should be thoroughly justified and reviewed before being accepted as a cable design practice. In particular, the utility must consider the full context of the IPCEA and IEEE overload ratings which set severe limits on these overload ratings. Significant additional justification and validation of this design practice should be provided by RBS.

- The utility cites a specific passage in the IEEE 242 standard as the basis for its assessment of overload conditions (para. 11.5.2(3)). A review of this section of the standard (1986 version) revealed no relevance whatsoever to the issue of cable overload conditions. It is expected that either an older version of the standard is being cited (no specific version is identified by the utility), or that the citation is in error. The utility should clarify its intent in citing the IEEE 242 standard.

- The utility has cited a particular equipment qualification test report as the basis for its assessment of cable life expectancy calculations (Okonite report SWGS-1282-2). Insufficient information has been provided upon which to base an assessment of the appropriateness of this correlation to the analysis. The utility aging calculations should either include the full EQ report, or should at the least provide sufficient information upon which to base a review of the calculations (for example, identify the materials evaluated in the study and their relevance to the cables at RBS, provide the assumed material activation energy, and identify the assumed end of life assessment criteria used).

4.4 The IEEE 242 Standard

In a more general context, the USNRC should note that this is the first instance in which a citation to the IEEE 242 standard has been encountered by this reviewer in a utility ampacity assessment submittal. In this case, the utility has cited only a single passage from the standard, but a brief review of this document did reveal that it has a potential for a much broader application to these types of ampacity assessments. Hence, the overall acceptability of this design practice in the context of USNRC

requirements has not yet been assessed. It is strongly recommended that this IEEE design practice should be reviewed in detail and that an assessment of its acceptability as a general design practice in the context of the USNRC Equipment Qualification Program and other USNRC requirements should be made.

4.5 Recommendations

It is recommended that the USNRC prepare an RAI to the utility. The issues identified above should be addressed in this RAI. A final assessment of the utility submittal is not possible at this time because (1) the outstanding issues identified above require clarification or other action and (2) because the utility has not utilized realistic estimates of the fire barrier ADF impact in its current assessments, a shortcoming acknowledged by RBS. For this reason, the utility submittal should be viewed as a preliminary assessment only, a status also acknowledged by the utility. It is recommended that the utility be asked to address the identified concerns as a part of its updated final analysis package.

5.0 REFERENCES

1 *Ampacities of Cables in Open-top Cable Trays*, ICEA P-54-440, NEMA WC 51, 1986.

2 *Power Cable Ampacities Volume 1 - Copper Conductors*, ICEA P-46-426, IEEE S-135-1, 1962

3 *The National Electrical Code Handbook*, NFPA. Note that the utility has cited the 1984 editions and this review has also cited the current 1996 edition.

4. Gazdzinski, R. F., et.al., *Aging Management Guideline for Commercial Nuclear Power Plants - Electrical Cable and Terminations*, SAND96-0344, Sandia National Laboratories, Albuquerque, NM, to be published by June 30, 1996. (Note: This is a forthcoming publication developed under the sponsorship of the U.S. Dept. of Energy as a part of the Plant Life Extension program. The document is in the final stages of the printing and distribution process, and should be available within 30 days or less. The distribution list includes representatives of every nuclear utility in the U.S., generally those knowledgeable in the area of cable qualification. Hence, this document should be readily available to RBS by the time the results of this review are forwarded to the utility for consideration.)