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Gentlemen:

In the Matter of)
Tennessee Valley Authority)

Docket Nos. 50-260

BROWNS FERRY NUCLEAR PLANT (BFN) UNIT 2 - ELECTRICAL CABLE AMPACITY (TAC NO. 62260) - RESPONSE TO NRC QUESTIONS FROM FEBRUARY 2, 1989 MEETING

A meeting was held on February 2, 1989, with the NRC staff and consultants to discuss BFN's electrical cable ampacity program. During this meeting several questions were raised concerning TVA's evaluation methodology and application of the diversity concept. TVA's response to those questions is contained in the enclosed attachments 1, 2, and 3 to this letter and provides the information required for the staff to complete their review and safety evaluation of the BFN electrical cable ampacity program.

If you have any questions, please telephone Patrick P. Carier, Site Licensing, BFN, at (205) 729-3570.

Very truly yours,

TENNESSEE VALLEY AUTHORITY

W. J. Ray for

R. Gridley, Manager
Nuclear Licensing and
Regulatory Affairs

Enclosure
cc: See page 2

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MAR 17 1989

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NRC question:

The TVA program characterizes the current vs temperature relationship for a cable within a tray system with diversity using an exponential relationship in lieu of a square-law. What is the basis for this selection?

TVA Response:

BACKGROUND

For a single cable in free air the temperature rise is directly proportional to the square of the imposed current. Figure 1 is a graphic representation of this relationship.

Insulated Cable Engineers Association (ICEA) standard P 46-426, "Power Cable Ampacities, Volume 1 - Copper Conductors" recognizes this relationship and couples it with a temperature correction factor for the conductor material to derive the following equation;

$$\frac{I'}{I}^{2} = \frac{(Tc' - Ta)\ (234.5 + Tc)}{(Tc - Ta)\ (234.5 + Tc')}$$

where;

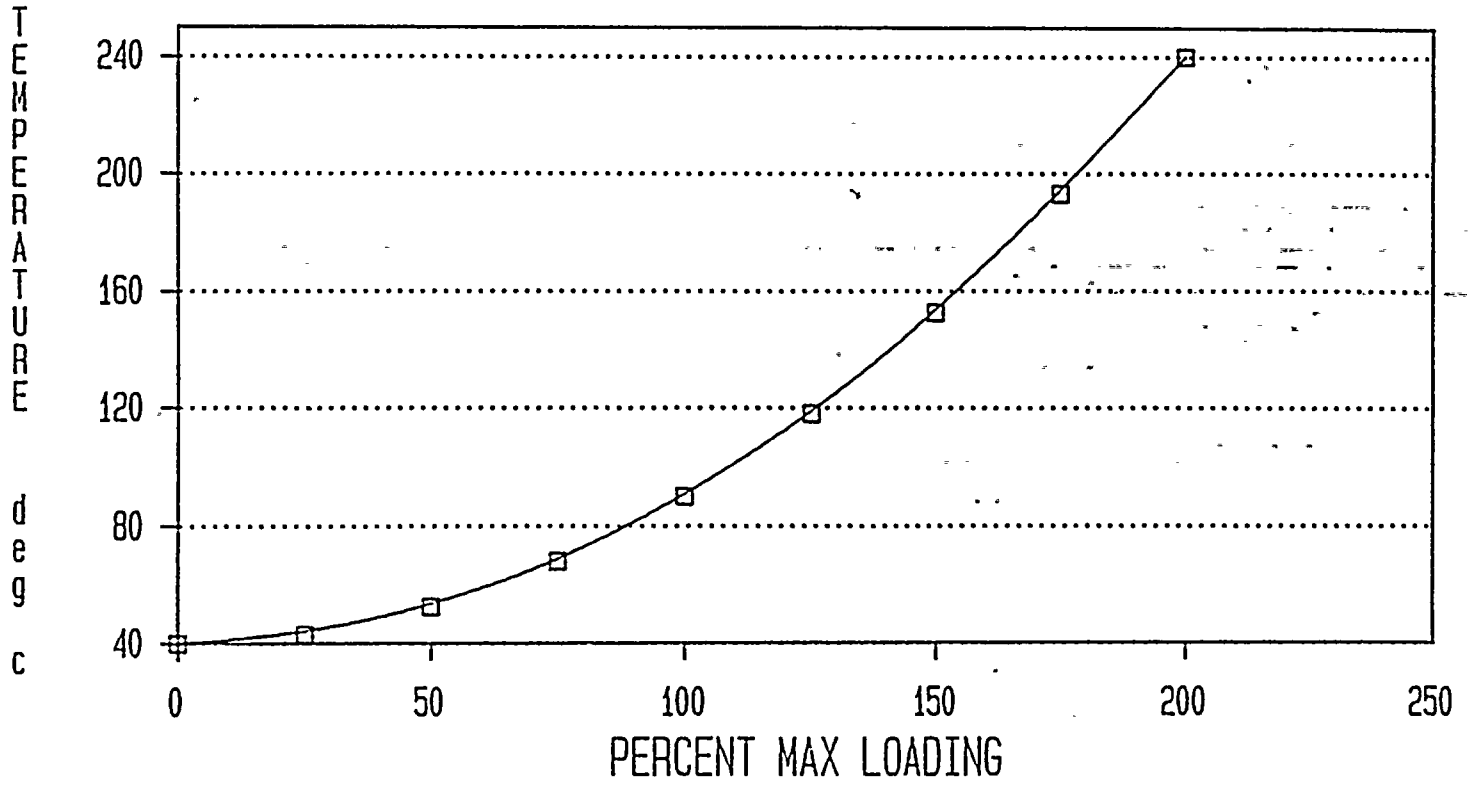
Ta = ambient temperature
Tc = conductor temperature produced when current I flows
Tc' = conductor temperature produced when current I' flows
I = the current which is known to produce Tc
I' = the new current which produces a new conductor temperature Tc'

This standard applies the equation to cables in a variety of configurations (conduits, ducts, free air). In addition, ICEA standard P 54-440 extends its use to cable tray based upon several simplifying assumptions which are applicable to Stolpe's model but would not be valid in a tray with diversity. In particular, the limiting factor is a requirement for uniform heat generation within the cable mass. For trays, this requirement is satisfied only by the Stolpe model with uniform loading. For example, if a cable installed in a tray is loaded to one-half of its ampacity rating for a fully loaded tray, its temperature rise would be one-quarter of its rated rise, provided that all of the other cables in the tray are also uniformly loaded to one-half of their rated ampacity.

In contrast, when diversity exists within a tray system without a hot-spot, changing the current on only one cable would still result in a reduction in that cable's temperature but not as much as when all of the cables in the tray are varied uniformly.

FIGURE 1

ICEA-NEMA TEMPERATURE CURVE



If the loading on a cable "X" in the middle of a tray is lowered from rated to one-half rated, while holding load constant on the remainder of the cables, the resultant temperature rise above ambient on "X" will no longer be just one-quarter of its rated rise. Instead, a rise of somewhat greater than one-quarter will be anticipated due to the influence of the constant heat from the surrounding cables. Likewise, if the current of cable "X" was raised to 1.2 times rated (while holding all other cables constant) a rise of 1.44 times rated would not be expected. Instead, since the heat produced in cable "X" will be partially shared with the cooler cables in the system a rise of less than 1.44 times rated would be anticipated.

DISCUSSION

If exact cable locations were known it would be possible to determine specific temperatures through the use of conventional heat transfer analysis. However, since exact locations within a randomly filled tray system are rarely known (or knowable) a temperature estimate is made.

Starting with the above ICEA formula, certain intuitive adjustments have been made to reflect the fact that as the current in cable "X" varies from its rated value, the slope of the temperature rise versus current curve will be less in a tray with diversity than without diversity. The exact nature of the curve in a tray with diversity is a function of the actual current on the conductor under consideration (i.e., its own I^2R) and a function of the amount of diversity which exists within the tray system.

The relationship can be more clearly seen by considering limiting conditions. If all of the cables on a tray are loaded to their rated values and the current on "X" is reduced, little change in the actual temperature on "X" would be expected due to the lack of significant heat capacity margin. As described in the February 2nd presentation and in the diversity technical manual, a minimum temperature is established for any given tray system. That is the temperature which would exist on a cable even if de-energized in a tray of the same size, generating the same amount of heat but in a uniform (i.e., Stolpe model) manner. For the postulated condition the calculated temperature rise would remain constant for values of I actual from zero amperes to almost I rated. This is shown in Figure 2.

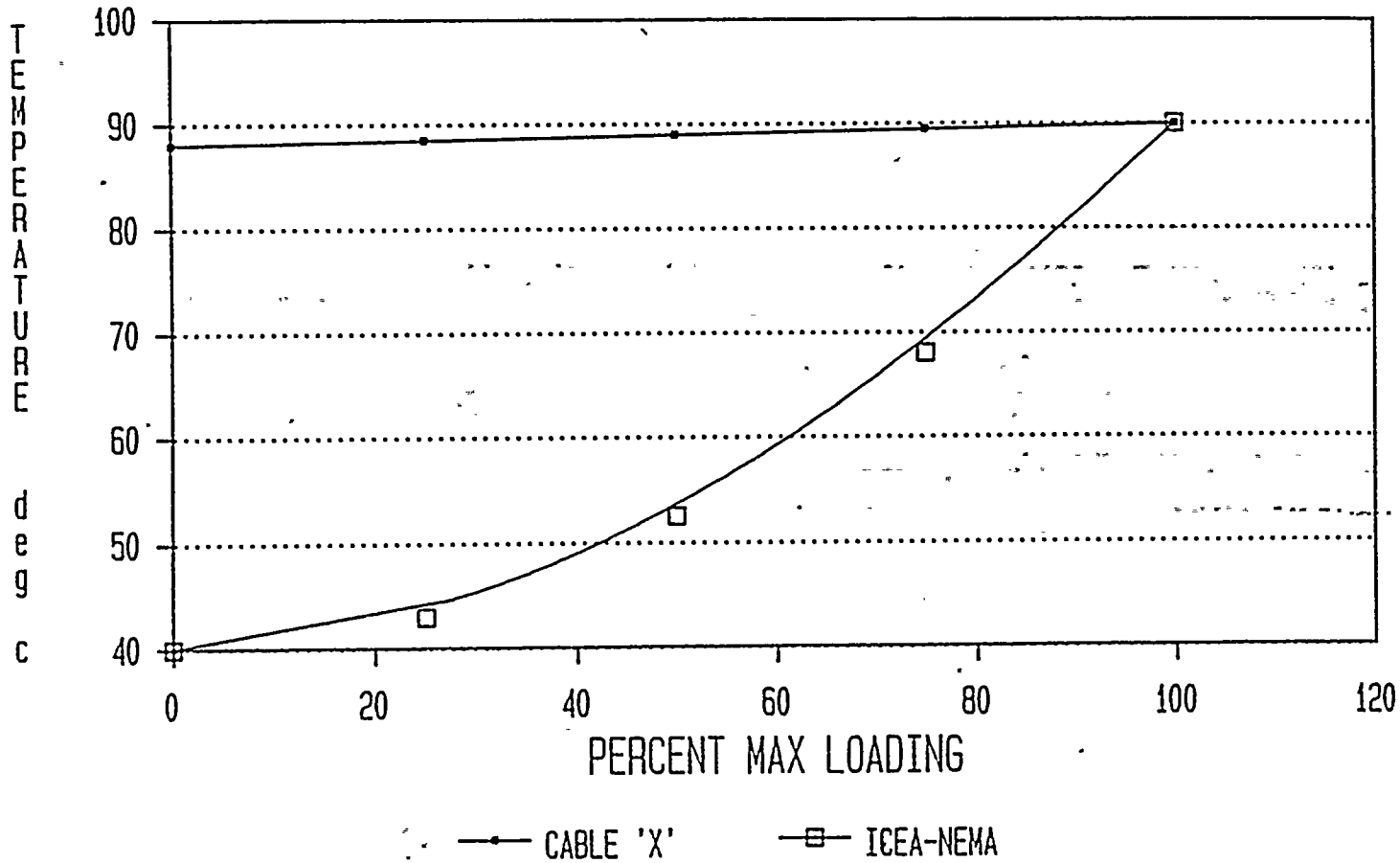
At the opposite extreme would be the case where all conductors in the same tray are de-energized except cable "X". In this case when the current on "X" is reduced to zero amperes, all cables including "X" would be at ambient. Such a tray has the maximum margin possible.

Since the shape of the current/temperature curve for any given cable is a function of its own current and the diversity within the entire tray, a variety of relationships with widely dissimilar appearance can be expected, as the zero current intercept on the examples show.

In order to show the conservatism of the diversity model, an analysis of a tray system using both diversity and HEATING6 has been performed. In this analysis the loads on 10 conductors grouped in the middle of the tray have been varied uniformly while keeping the loads on an additional 110 conductors constant.

FIGURE 2

ICEA-NEMA vs. MIN. DIVERSITY CABLE TEMP



(TYPICAL)

Several comments regarding the model are in order. First, the lower limit (based on a Stolpe uniform heat generation) can be readily identified since the reduction in current below 50 percent resulted in no significant lowering of the calculated temperature. Additionally, it was necessary to vary the current over a rather large cross sectional area. Changing currents over a small cross sectional area would demonstrate minimal variation in expected or calculated temperature (similar to Figure 2) and poorly demonstrate the current/temperature relationship.

CONCLUSION

Figures 3 and 4 show a plot of the temperatures calculated by both HEATING6 and diversity over the range of loading for the 10 conductors. Exact values are given in tables 1 and 2. Figure 3 shows the peak temperatures within the 10 conductors and figure 4 is a plot of the hottest temperatures calculated in the balance of the conductors as a function of the loading on the 10 "hot-spot" conductors.

As expected, the results shown demonstrate the conservatism of the diversity model and the acceptability of the exponential relationship for trays with diversity.

FIGURE 3
EFFECTS OF VARIABLE LOADING

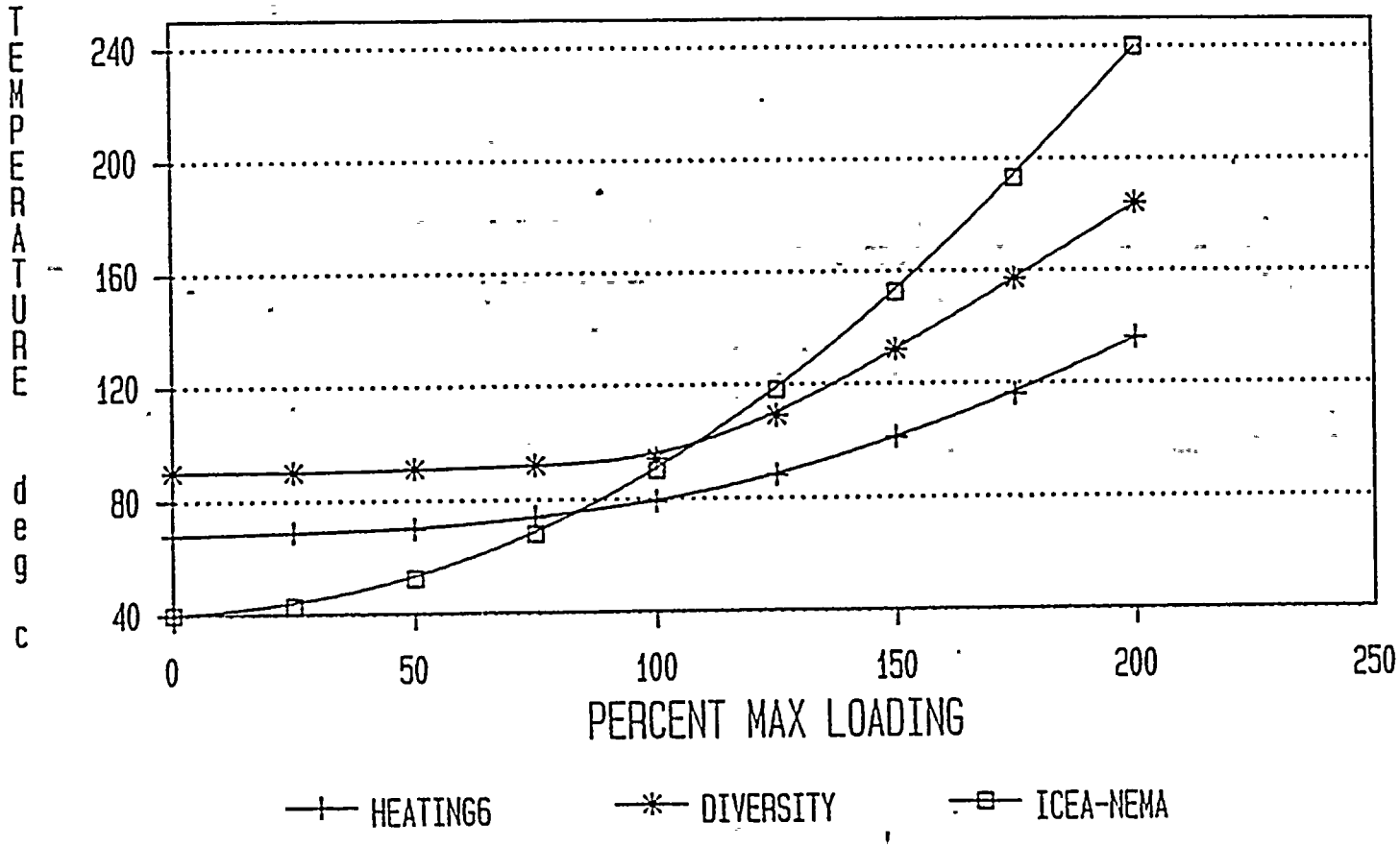
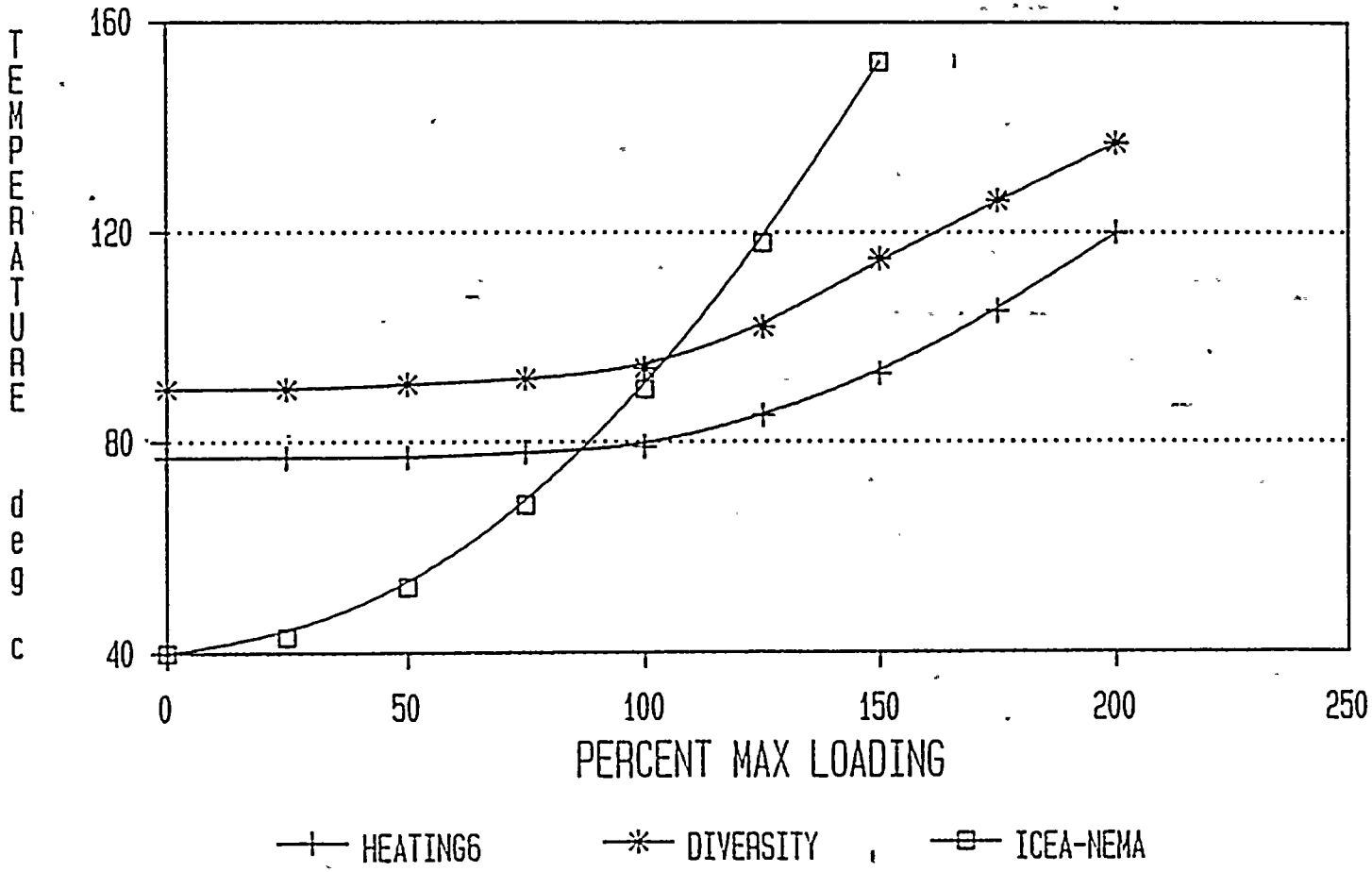


FIGURE 4 - MAX TEMPERATURE OF CONSTANTLY LOADED CABLES AT VARIOUS HOT SPOT LOADS



Variable Load Amps	Variable Load % Allowable	Variable Load, °C HEATING6	Variable Load, °C Diversity
0	0	68	90
17.5	25	69	90
35	50	70	91
52.5	75	74	93
70	100	79	95
87.5	125	88	109
105	150	101	132
122	175	116	157
140	200	136	184

TABLE 1

Effects of variable load on 10-1/0 AWG, 600 VAC conductors in a tray with other loads held constant

Variable Load %	Constant Load Amps	Constant Load, °C HEATING6	Constant Load, °C Diversity
0	70	77	90
25	70	77	90
50	70	77	91
75	70	78	93
100	70	79	95
125	70	85	102
150	70	93	115
175	70	105	126
200	70	120	137

TABLE 2

Maximum temperature of 110-1/0 AWG 600 VAC conductors held at a constant load as a function of load changes to 10-1/10 AWG conductors in the center of the tray

NRC question:

The TVA ampacity program has defined a "critical hot-spot area" as being 2.4 in^2. What is the basis for the selection of this value?

TVA Response:

BACKGROUND

Cable ampacities in trays are selected to maintain the temperature of each cable at or below its thermal rating. A hot-spot exists if there is an area in the tray whose temperature is higher than anticipated when the cable ampacity was selected. By Stolpe's method for determining ampacities, all cables in the tray are assumed to be fully loaded, so that a hot-spot cannot be produced unless some cables carry current in excess of their fully loaded tray ampacity. However, if the ampacity of a cable were increased on the basis of loading diversity alone, a hot-spot might be produced by unanticipated bundling together of installed cables such that heat dissipation is not as good as was expected. For this reason, the ampacity estimate provided by the cable tray diversity program is not based solely on load diversity, but also considers the sizes and quantities of overloaded cables and the magnitude of those overloads.

DISCUSSION

Stolpe cautioned against the general application of diversity on the basis of tests which showed that a local hot-spot could be produced by as few as two, large conductor, heavily loaded circuits located side-by-side in a tray. The two heavily loaded "circuits" included in Stolpe's tests consisted of a total of six-1/C 4/0 AWG cables each with a diameter of 0.80 inch. Thus, these cables combined to form a cross-sectional area of 3.016 square inches. On this basis, and using a conservatism factor of 1.25, TVA has chosen a hot-spot critical area of 2.4 square inches of overloaded cable area. A hot-spot critical area is considered to exist whenever at least the specified amount of overloaded cables are in the tray. This is conservative because the likelihood is small that in a randomly filled tray the specified amount of overloaded cables would all be in a tightly packed bundle unless, either the total cable area in a tray is relatively small, or for typically full trays, the amount of overloaded cables in the tray well exceeds the specified area. In either case the program will assign little or no diversity to these extremes due to the lack of heat capacity margin.

In order to demonstrate the adequacy of the selection of the 2.4 in^2 critical hot-spot area two trays have been modeled using both diversity and HEATING6. One tray contains four layers of densely packed cables. A hot-spot is produced in the middle two rows with a layer of partially loaded cables both above and below the hot mass. This is representative of a hot-spot buried within a typical tray. The second model is of a single layer tray covered both above and below by one-half inch of Flamemastic. In this tray the hot-spot has its greatest width (i.e., greatest distance from the center of the hot-spot to a cold cable).

In the first tray the hot-spot is a tightly bundled group of 10-1/0 AWG conductors in the center of the tray. This results in a hot-spot area of 2.54 in^2 . The cables are loaded in accordance with Table 3. Those conductors in the hot-spot area were loaded to twice their rated allowable current. The surrounding cables were loaded to one-half of their rated allowable (i.e., one-quarter of their rated watts). This results in the high degree of diversity within a typically loaded tray necessary to test the adequacy of the hot-spot criteria.

In the latter tray, the hot-spot consisted of 10-1/0 AWG conductors spread across a single layer, centered in the tray and coated as described earlier. As above, this results in a 2.54 in^2 hot-spot. The cables are loaded in accordance with Table 4. Those conductors in the hot-spot were loaded to 80% of their free air value with the surrounding cables loaded to one-half of their allowable (i.e., one-quarter of their rated watts). This fill and loading was chosen to provide a high degree of diversity necessary to test the adequacy of the model for a tray with a hot-spot area of significant width.

CONCLUSION

The results of both the HEATING6 and diversity analysis are presented in Tables 3 and 4 for the respective trays. A graphical comparison of the data is shown in Figure 5.

In both cases the adequacy of TVA's model and criteria is established. From the data it can be seen that regardless of the configuration of the hot-spot evaluated, the TVA diversity analysis always produced more conservative temperatures than did HEATING6. This conclusion was valid for both the overloaded conductors and for conductors outside of the hot-spot area. The HEATING6 values shown for conductors outside of the hot-spot area actually represent the highest temperature calculated at the interface between hot and cold cables (i.e., jacket-to-jacket interface). Peak insulation temperature outside of the hot-spot area would be even less.

In conclusion having evaluated trays with significant diversity and highly overloaded hot-spot areas we have been able to demonstrate that the diversity program includes adequate margin to ensure that a cable evaluated as a "pass" by this method would likewise be found acceptable using conventional heat transfer theory. From this we conclude that TVA's hot-spot criteria is both reasonable and conservative.

Size AWG	No. of Conductors	Load, Amps	HEATING6 °C	Diversity °C
1/0	10	140	117	180
1/0	110	35	96	110

Table 3

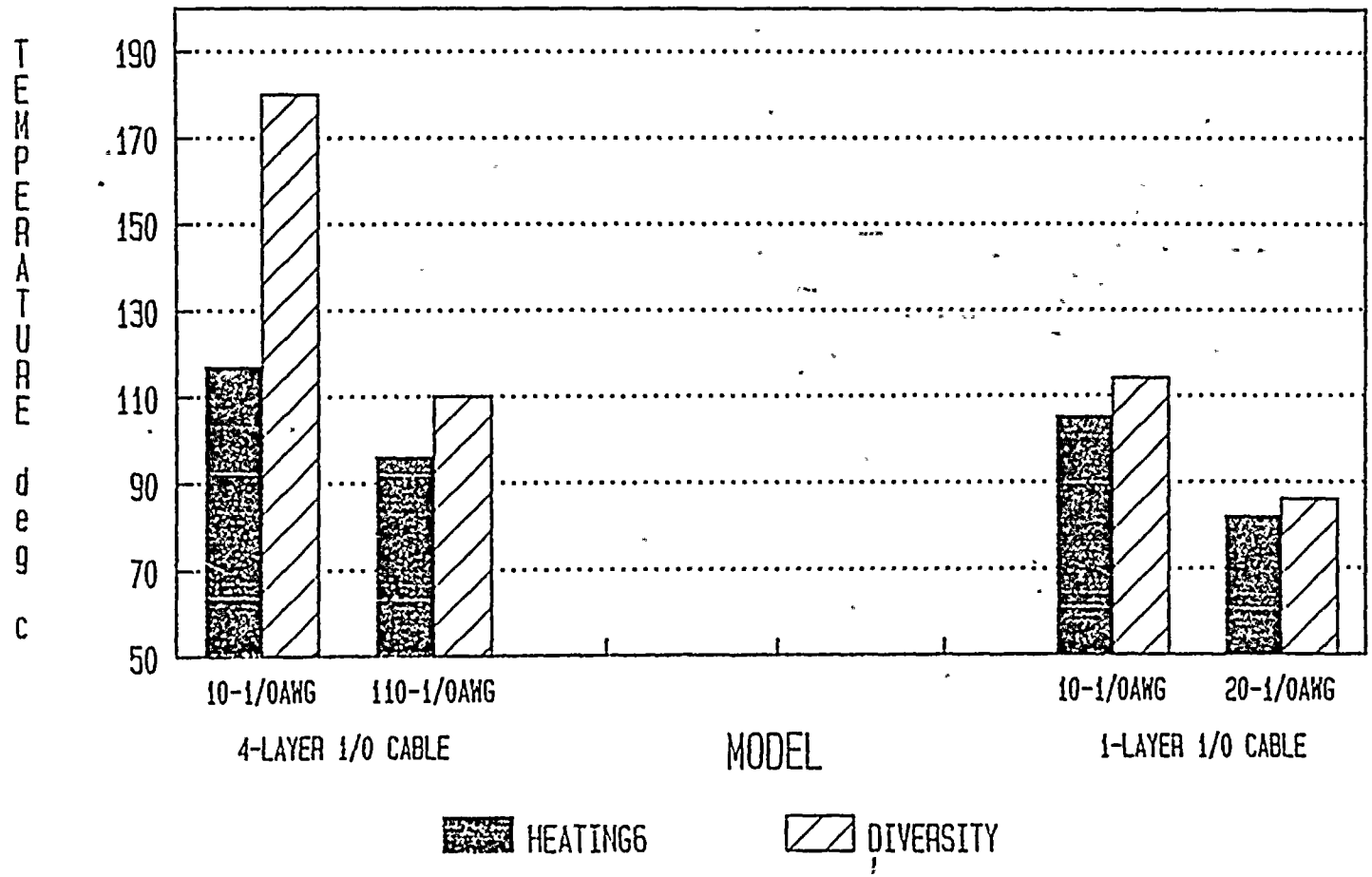
Comparison of HEATING6 and diversity calculations for a tray with a densely packed hot-spot surrounded by lightly loaded cables

Size AWG	No. of Conductors	Load, Amps	HEATING6 °C	Diversity °C
1/0	10	206	105	114
1/0	20	76.5	82	86

Table 4

Comparison of HEATING6 and diversity calculations for a single layer tray coated with Flamemastic containing a hot-spot surrounded by lightly loaded cables

FIGURE 5 - HOT SPOT MODELS
HEATING6 vs. DIVERSITY



MAXIMUM TEMPERATURES

NRC question:

Tests conducted by John Stolpe and documented in his 1970 paper, "Ampacities For Cables in Randomly Filled Trays" do not seem to support the theory that diversity exists, whereas TVA conducted tests do. Stolpe's test used conductors as large as 4/0 AWG in contrast to TVA's which used only 1/0 AWG. Had TVA's tests utilized larger conductors would the results still support the conclusion that diversity exists?

TVA Response:

BACKGROUND

In the method of sizing cables developed by Stolpe the basic underlying principle invoked in order to assure than no cable exceeded its rated temperature was that of uniform heat generation. This concept results in cable ampacities being derived in direct proportion to the cross-sectional area of the subject conductor.

In the development of its diversity approach, TVA began with the Stolpe model and made adjustments to account for the phenomena expected in a tray with diversity but retained the sensitivity to cross-sectional area. Further considerations for conductor size are developed for overloaded cables. Under ideal conditions all cables would have an actual heat intensity, q actual, (actual watts divided by cross-sectional area) less than their Stolpe heat intensity, q100, (allowable watts divided by cross-sectional area). A deviation from ideal conditions is measured by the amount by which a cable's q actual exceeds q100, and the size of the cable relative to the total area in the tray. Therefore, a relatively large diameter cable that is overloaded will reduce delta q (q100-q actual) more than will a relatively small diameter cable. Of course, if the small diameter cable is sufficiently overloaded it can reduce delta q just as much as a less overloaded large diameter cable would. The overall effect on delta q results from the summation of all the individual cable deviations above the ideal (rated) conditions.

In other words the "differences" which could be postulated had the diversity testing been undertaken with larger conductors have been anticipated and are included in the mathematical model.

In the tests conducted by Stolpe two configurations were examined. In the first case, a tray with a variety of conductor sizes was loaded using the Stolpe approach to sizing (i.e., uniform heat generation). In the latter case only 3 of the 9 conductor size groupings were loaded, the remainder being de-energized. The results of those two runs are as shown in Tables 5 and 6 in the columns labeled, Stolpe temperature.

DISCUSSION

In order to demonstrate the adequacy of the TVA diversity approach for trays containing larger conductor sizes we have modeled the Stolpe trays and compared our calculations with his tests. In addition, in order to show the sensitivity of our model for the larger conductor sizes we have evaluated the Stolpe tray with small overloads on the 4/0 AWG conductors.

Stolpe's tests were performed on 24 inch wide trays, whereas BFN trays, where diversity has been applied, are limited to 18 inches. This is a significant point for the following reason. In a tray of moderate width the bulk of the underloaded cables may be considered as contributing to the available margin. However, as tray width is increased, only a portion of this "cold mass" could be considered unless exact cable locations are known. This limitation exists since as tray width grows so does the mean distance between underloaded cables and any given overloaded cable.

In order to demonstrate the adequacy of our model for use with 18" tray systems we have, configured a "modified Stolpe tray." This tray has the same depth (and therefore the same allowable Stolpe ampacities) but is only 18 inches in width. In keeping with Stolpe's approach we have adjusted the number of multiconductor No. 12 cables to achieve the desired fill.

The comparison of Stolpe's baseline tray and the TVA baseline tray is shown in Table 5. We have utilized a load current of 72 amps on the 4 AWG conductors. According to table II in Stolpe's paper this is the value which should produce no more than a 50°C rise in a 40°C ambient in a 20% filled 24 inch wide tray. However as Figure 8 of his paper shows, Stolpe actually measured about a 57°C rise, indicating that the actual load current during the test was higher than 72 amps. Unfortunately, the graph in Figure 8 does not allow one to precisely determine the applied current or the resulting temperatures.

The comparison of Stolpe's diversity tray and the TVA "modified Stolpe diversity tray" is shown in Table 6. In the TVA tray the same fill has been utilized as above with the same number of load bearing conductors (6, 1/0 and 4/0 AWG) as were included in Stolpe's original tray. As can be seen the peak temperatures calculated are either equal to or well in excess of those values measured by Stolpe as shown in his Figure 8.

Finally in order to show the sensitivity of our model to overloads on the 4/0 conductors several additional calculations have been performed. In each of these the load current on the No. 6 and the 1/0 AWG has been held constant at 37 and 167 amps respectively. The load on the 4/0 AWG conductors has been increased and the resulting temperatures noted in Table 7. The results are as expected. A five percent increase in the 4/0 AWG load current produces a temperature rise of 4°C above the 87°C value shown in Stolpe's Figure 8. If all loads in the tray were varied uniformly, the square-law relationship would predict a 5°C rise. Given the diversity within the "modified Stolpe tray" the calculated 4°C rise appears accurate and reasonable.

CONCLUSION

In the above discussion it has been established that the TVA diversity model is sensitive to conductor size. As a result any "differences" which might be anticipated if testing were conducted using larger (or smaller) conductors have been properly accounted for.

In addition, both Stolpe's baseline and diversity trays have been modeled and the calculations yielded temperatures greater than or equal to his measured values.

Finally, using the model of Stolpe's diversity tray, the current on the 4/0 AWG conductors was increased beyond full load. The calculated temperature on the 4/0 AWG conductors was shown to begin increasing with only a two percent increase in current and rise almost as quickly as would be projected by the ICEA-NEMA square-law.

The above demonstrates the adequacy of the TVA analysis for large conductor sizes.

Cable Size AWG	Quantity Stolpe 24"	Stolpe Load Amps	Quantity TVA (3) 18"	TVA Load Amps	Stolpe Temp (4) °C	TVA Diversity Temp °C
1/C-12	14	15	14	15	77	95
1/C-10	6	21	6	21	91	95
1/C-8	6	37	6	37	84	95
1/C-6	10	51	10	51	86	95
1/C-4	8	72	8	72	97(1)	95
1/C-1/0	6	167	6	167	81	95
1/C-2/0	3	202	3	202	85	95
1/C-4/0	6	287	6	287	87	95
3/C 12	13(2)	23	1	23	--	95

Table 5

Comparison of Stolpe's 24" tray baseline test results to TVA's 18" "modified Stolpe tray" baseline diversity calculations

(1) See paragraph 4 of discussion.

(2) Exact quantity not specified in Stolpe's paper. Quantity chosen to achieve desired fill.

(3). Quantity of de-energized conductors chosen to achieve depth equivalent to Stolpe's tray

(4) From figure 8 of Stolpe's paper.

Cable Size AWG	Quantity Stolpe 24"	Stolpe Load Amps	Quantity TVA (2) 18"	TVA Load Amps	Stolpe Temp °C (3)	TVA Diversity Temp °C
1/C-12	14	--	14	--	--	83
1/C-10	6	--	6	--	--	83
1/C-8	6	--	6	--	--	83
1/C-6	10	37	10	37	67	87
1/C-4	8	--	8	--	--	83
1/C-1/0	6	167	6	167	72	87
1/C-2/0	3	--	3	--	--	83
1/C-4/0	6	287	6	287	87	87
3/C-12	13(1)	--	1	--	--	83

Table 6

Comparison of Stolpe's 24" tray diversity test results to TVA's 18" "modified Stolpe" tray diversity calculations

(1) Exact quantity not specified in the Stolpe paper. Quantity chosen to achieve desired fill.

(2) Quantity of de-energized conductors chosen to achieve depth equivalent to Stolpe's tray.

(3) From figure 8 of Stolpe's paper.

Cable Size AWG	Quantity TVA Tray	Temperature (°C) As A Function of 4/0 Loading (3)					
		4/0 100%	4/0 101%	4/0 102%	4/0 103%	4/0 104%	4/0 105%
1/C-12	14	83	83	84	85	85	86
1/C-10	6	83	83	84	85	85	86
1/C-8	6	83	83	84	85	85	86
1/C-6(1)	10	87	87	88	88	89	90
1/C-4	8	83	83	84	85	85	86
1/C-1/0(2)	6	87	87	88	88	89	90
1/C-2/0	3	83	83	84	85	85	86
1/C-4/0	6	87	87	88	89	90	91
3/C-12	1	83	83	84	85	85	86

(1) Load held constant at 37 amps.

(2) Load held constant at 167 amps.

(3) All sizes except 6, 1/0 and 4/0 AWG de-energized

Table 7

Conductor temperature in TVA's "modified Stolpe tray" as a function of 4/0 AWG loading