A Review of the Duane Arnold Energy Center Analysis of Fire Barrier Ampacity Derating Factors

A Letter Report to the USNRC

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

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

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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 Duane Arnold Energy Center (DAEC). These submittals deal with the issues of Thermo-Lag 330-1 fire barrier fire endurance assessments and the assessment of ampacity loads for protected cable trays and conduits. These documents were submitted by the utility in response to USNRC Generic Letter 92-08 and in response to a subsequent USNRC Request for Additional Information (RAI). This review has considered only those portions of the utility submittal directly related to the issue of ampacity derating. This work was performed as Task Order 9, Subtask 1 of USNRC JCN J2017.

1.0 INTRODUCTION

1.1 Objective

In response to USNRC Generic Letter 92-08, the Duane Arnold Energy Center (DAEC) provided documentation of the utility position regarding both the fire endurance rating and ampacity derating factors associated with its installed fire barrier systems. The objective of this review was to assess the adequacy of those portions of the utility submittal related to the issue of fire barrier ampacity derating factors. In particular, the submittals included documentation of an analytical methodology used to assess the adequacy of in-plant cable ampacity factors for its various Appendix R cable tray and conduit fire barrier systems. Also included were sample calculations for one cable tray and for one conduit.

The submittals reviewed were documented in an initial response to Generic Letter 92-08 provided by the utility and in a subsequent utility response to a USNRC Request for Additional Information (RAI). The relevant documents reviewed are:

- Letter, February 14, 1994 (item NG-94-0563), J. F. Franz, DAEC, to L. J. Callan, USNRC, (with enclosures).

- Letter, June 2, 1995 (item NG-95-1223), J. F. Franz, DAEC to W. T. Russell, USNRC (with one attachment).

SNL was requested to review these submittals under the terms of the general technical support contract JCN J-2017, Task Order 9, Subtask 1. This letter report documents the initial results of this review. The intent of this review was to provide support to the USNRC in determining the adequacy of the utility submittals, and in the potential development of a supplemental RAI. Based on the results of this review, it is recommended that such a request be pursued.

1.2 Overview of the Utility Ampacity Derating Approach

The consideration of ampacity derating factors for fire barriers at DAEC is based on an analytical method with limited validation through available experimental data. The utility has noted that it plans to update its analyses once the results of the NEI Thermo-Lag ampacity derating test program become available. No testing has apparently been performed by the utility, and at the current time, no such testing is planned.

For its assessment of ampacity derating, the utility has examined each cable tray or conduit which is both protected by a fire barrier system and houses at least one continuously energized power cable. The DAEC method is basically a variation of the methodology commonly referred to as the "Watts/ft" method. The analysis follows a simple two-step process:

Step 1: For each tray or conduit, the actual total heat load (due to cable resistance heating effects) is calculated based on the actual operating conditions

2.0 THE BASIS FOR UTILITY ANALYSIS

2.1 Overview

The DAEC methodology is apparently based on a paper presented by Esteves, then of Bechtel Power Corp., in 1982 (utility reference 6.1) and republished by IEEE in 1983 [1]. However, while the basic methods used by Esteves are valid for the purposes to which he put them, the use of this methodology in the manner employed by DAEC is not appropriate.

In particular, Esteves performed some simple analyses of the pioneering cable ampacity work of Stolpe [2]. Esteves' interest was in estimating the anticipated ampacity impact of fire barriers and fire penetration seals. His work was based on very simple models of the supplemental impact of a fire barrier (or fire stop) on heat transfer in a cable tray of the type tested by Stolpe. Using these simple calculations, Esteves estimated the ampacity derating impact for certain specific fire barrier systems.

Inherent in Esteves' work is the base assumption that the cable tray and cable loadings remained fixed as per the Stolpe tests. The utility's extension of Esteves' work to the assessment of cable ampacity adequacy for actual cable trays is incomplete and inappropriate because it violates this inherent assumption. The following sections outline the DAEC analysis methodology and identify its limitations. The basis for the SNL finding that this methodology is inadequate and inappropriate to the problem of cable ampacity derating assessments is also provided. In particular, the inherent inability of this method to assess individual cable ampacity limits is discussed in detail.

2.2 Premiss of Total Heat Rejection Capacity

The ampacity derating assessment methodology employed by DAEC is based on an evaluation of the actual in-plant overall heat load for specific cable trays and conduits. The approach is largely analytical, although certain critical parameters in the analyses are based on limited test results as available to the utility through public test reports. No supplemental testing by the utility has been performed, and at the current time, no such testing is apparently planned. The utility does cite that once the NEI test results become available, a review of the ampacity calculations will be performed.

In order to understand the utility analyses, it is critical to recognize that the utility has not applied ampacity derating factors directly to individual cables. Rather, the utility has analyzed cable trays and conduits as composite systems. In effect, the ampacity derating factor is applied to the overall heat load of the system rather than to the ampacity of individual cables within the system. That is, the utility analyses assume that so long as the total thermal load for the cable tray or conduit as a system is within allowable limits, then one can conclude that the individual cables within that tray or conduit are all operating at acceptable limits. As will be noted below, this is not a valid assumption.

associated with each "continuously energized power cable." That is, the heat load introduced by each individual cable is calculated and then the individual loads are summed to obtain the overall heat load for a given tray or conduit. Each individual cable heat load is calculated based on the actual in-plant current load and the cable's resistance per foot of length. The overall heat load is presented as the Watts of heat generated per linear foot of cable tray. (Hence, this approach is often called the "Watts/ft" method.)

Step 2: Once these overall in-plant heat loads have been calculated, they are compared to the estimated "permissible thermal output" for a tray or conduit. In the case of DAEC the "permissible" load is calculated based on a combination of one TSI/ITL test set and tabulated ampacity values. So long as the actual heat load of the tray (or conduit) does not approach the heat rejection capacity of the generic tray (or conduit), then the ampacity of the protected cables is considered acceptable.

The basic premiss of the DAEC submittal appears to be that the acceptability of ampacity loads placed on individual in-plant cables can be demonstrated by showing that the total in-plant heat load for the overall physical system housing the cable does not exceed the estimated total heat rejection capacity of that physical system. SNL takes issue with this assumption. That is, as discussed further below, the "Watts/ft" method is insufficient in and of itself to demonstrate the adequacy of individual cable ampacity factors.

1.3 Organization of Report

This review has focussed on an assessment of the acceptability of the utility ampacity derating analyses and on a review of the two specific case examples provided by the utility. Section 2 presents a review of the basic utility analysis methodology and identifies the technical shortcomings and concerns regarding the utility application of this methodology. Section 3 provides a review of the two sample calculations provided by the utility and identifies concerns associated with certain aspects of these analyses. It is expected that additional technical evaluations for each of the cases cited by the utility will be required to complete the assessments, and hence, these reviews were limited to identification of potential problem areas, rather than to detailed case examinations. Section 4 summarizes the SNL recommendations regarding the need for additional information to support the final assessment of the utility analyses.

To begin the analysis the utility must estimate the "permissible thermal output" of the subject tray or conduit. As a part of this step, the thermal impact of the fire barrier system on heat transfer behavior must be calculated. For DAEC a single TSI/ITL ampacity derating test set from 1982 is used as the basis for this assessment. The "permissible thermal output" is then calculated by mathematically imposing this heat transfer effect onto the tabulated ampacity values for a given cable tray or conduit system. That is, the tablulated ampacity values correspond to a given heat generation rate, and this heat load is reduced mathematically to account for the added thermal effects of the fire barrier. For the cable trays the generic power density values derived by Stolpe for a densely packed and uniformly powered cable tray are used, and for conduits, the tabulated ampacity limits for the actual installed cables are used.

The next step is to calculate the actual heat load of a given cable tray or conduit as a whole. This calculation is based on a simple "I^2R" resistance heating calculation applied to each of the individual "continuously energized power cables." The individual cable heating loads are summed and are normalized to a "W/ft" basis. Note that in the case of DAEC an additional multiplier of 1.25 on the calculated actual heat load is applied to account for potential intermittent loads.

The final assessment is then based on a simple and direct comparison of the actual total in-plant heat load for the tray or conduit to the estimated "permissible thermal output" (also expressed in terms of "W/ft"). Provided that the total actual heat load of the cable tray or conduit as a whole is lower than the estimated maximum allowable heat load, then the ampacities of the individual cables are considered acceptable.

2.3 Limitations to the DAEC Methodology

The methodology used by DAEC is fundamentally limited and is incapable of providing any assessment of the operating limits of any individual cable. The DAEC total heat rejection capacity analysis methodology only provides an assessment of the overall behavior of the protected tray or conduit, and provides no assessment of the behavior of individual cables within that system.

The total thermal load estimates, at best, correlate only with an average temperature inside the protected envelope. However, even this correlation will only hold true if both the physical and electrical cable loading conditions in the generic tests are similar to those of the specific application (i.e., a dense mass of uniformly loaded cables). The method fails to consider the potential for a localized hot spot to develop in the vicinity of an individual powered cable, particularly in the case of a highly diverse cable tray in which only a very few cables are actually energized. In the analysis of ampacity it is the hot-spot behavior, not the average temperature behavior, which drives the problem. Hence, this method provides no assurance that any given individual cable will not be overloaded to the point of damage. Such a situation could easily arrise without the overall "permissible thermal output" limitation being exceeded.

One way to illustrate this flaw in the methodology is to consider a hypothetical cable tray with just one single power cable inside of it. If the cable were housed in a 12"

wide cable tray, then a given ampacity limit could be calculated based on the "permissible thermal output" of a 12" tray. If this same cable were then moved to a 48" cable tray, according to the "Watts/ft" method a four-fold increase in the "permissible thermal output" would result. The thermal output of a cable increases as the square of current, and hence, a two-fold increase in the allowable ampacity limit would also result. If this "logic" is carried out further, any amperage could be justified for any cable provided the tray holding the cable were sufficiently wide. Clearly this is contrary to common sense, and to the fundamentals of heat transfer behavior.

The DAEC analyses do not address this fundamental methodological limitation, and provide no assessment of the anticipated behavior of individual cables. Therefore, the utility analyses have not demonstrated that the ampacity values associated with any given cable are within acceptable limits. The analyses as presented by the utility are incomplete because they have only provided an assessment of the overall thermal behavior of their cable trays and conduits. The utility must provide supplemental analyses to ensure that individual cable ampacities remain within acceptable limits, including consideration of the impact of the fire barrier system on the published ampacity limits for those cables. The "permissible thermal output" or "Watts/ft" method is simply not adequate to assessing this question.

In addition to the fundamental shortcomings of the methodology, there are also certain additional concerns which were identified during this review. In particular, the methodology provides no mechanism for including consideration of the following parameters, each of which can be expected to significantly impact both individual cable ampacity limits and overall cable system heat rejection capacities:

- Cable Loading Effects: The DAEC analysis methodology does not consider the impact of cable loading on the allowable heat loads except to the extent that Stolpe's work does address different cable depths of fill. In general, the "Watts/ft" method assumes that cable loading effects are largely irrelevant to the overall heat rejection capacity of the cable tray or conduit system. It is expected that the total tray heat rejection capacity would be dependent on various factors, especially including the power density within the cable mass. These factors should be accounted for in the methodology, or it should be demonstrated that these factors are not important to the analysis.

- Cable Diversity Effects: The DAEC analysis method provides for no significant treatment of cable diversity effects on the total allowable heat loads. All of the available ampacity tests cited by DAEC are based on cable trays in which all of the cables are powered uniformly (note that even though the TSI/ITL tests involved three cable sizes, the power to each cable was set so as to maintain a uniform power density across the tray). In actual applications cable trays will contain a mixture of loaded and unloaded cables. In general, one typically assumes that diversity will introduce more margin into the cable design. This is true so long as one is considering the behavior of individual cables. However, one must recall that the "Watts/ft" method is only providing an assessment of the overall behavior of the cable tray as a system. The

"Watts/ft" methodology would clearly lead to erroneous results for cases involving diverse loads.

Consider, for example, two cases involving a cable tray loaded with 50 power cables (an arbitrary number). In the first case, we assume that all 50 of the cables are powered uniformly. In the second case, we will assume that only a single cable is powered. The "Watts/ft" methodology would assume that the overall heat rejection capacity for these two cases would be identical. Hence, in effect, the heat load generated by the one cable which is powered in both cases could increase by a factor of 50 from case 1 to case 2, and still remain within the same overall heat load. This would imply a 7-fold increase in the ampacity of that cable from case 1 to case 2. (Heating load is proportional to the square of current so the "allowable" current increase would be given by the square root of 50, or 7.07 times the case 1 ampacity.) This is clearly unrealistic. As the power of the one cable were increased a limit would quickly be reached beyond which the insulating effects of the surrounding unpowered cables would increase the powered cable temperature beyond its operating limits (90°C). The "Watts/ft" methodology in and of itself would conclude that each of these two cases was equally acceptable.

The total overall heat rejection capacity of the cable tray as a system would very likely be reduced in cases involving diverse cable loads, even though the ampacity of the individual cables which are powered could be increased due to diversity arguments. The "Watts/ft" method as employed by DAEC simply contains no mechanism for assessing this effect.

2.4 Extrapolation of Experimental Results

Additional concern regarding the utility analysis methodology derives from the fact that the utility has extrapolated a rather limited data base to all of their applications. It would appear that the extrapolation of the experimental results has been performed without adequate technical justification or validation. Without further technical justification, the utility extrapolation basis is questioned. Two specific areas of concern are identified here.

First, in the DAEC calculations, a single ampacity test set (one clad and one base line test) is used to characterize the added insulation effect of the fire barrier system, and this value is assumed to remain fixed for all subsequent configurations. That is one experiment is used to characterize the additional insulating effect for all cable trays, and the same experiment is used to characterize the effect for all conduits as well. This treatment fails to recognize that there are many important factors which contribute to the barrier's overall impact. In particular, as the cable loading changes, and as diversity in cable power levels is introduced, changes in both the convective and radiative behaviors within the cable tray are expected. These factors are not considered in the DAEC calculations.

A second concern arises when the assumed base line allowable heat loads are considered. In the DAEC analysis, these values are taken directly from Esteves [1] who in turn calculated them based on Stolpe's work [2]. The assumption that these values will apply to any tray as a function only of the fill depth is inappropriate. In

particular, Stolpe's original work powered all of the cables in the test tray equally so that the heat generation was distributed evenly throughout the tray. In reality, and in particular in the DAEC cases, the cable power loads are highly diverse. The utility has stated that unpowered cables will act as a heat sink acting to cool other nearby powered cable. This is incorrect in the steady state condition. In fact, the surrounding unpowered cables will act as thermal insulation causing an increase in the temperature of the energized cables as compared to the case of a cable in open air or alone in a cable tray. In addition, the cable loading and power distributions will directly impact both the surface area and surface temperature of the cable mass. These will in turn directly impact the rates of both radiative and convective heat transfer away from the cables. The DAEC method fails to account for these factors.

It should be noted that the DAEC application of the "Watts/ft" method is somewhat different from that which has been observed elsewhere (see for example the SNL review of ampacity derating submittals from Palo Verde, 9/27/94, and the Bechtel engineering design guide upon which the Palo Verde analyses were based). In other applications the "permissible thermal load" has been based directly on that which was actually measured in an ampacity test for the clad test article. In the DAEC submittal, the "permissible thermal loads" for the clad case are based on adjustment of the "permissible thermal loads" allowed in the base cable ampacity tables (as reported by Esteves for cable trays and based on the NEC tables for conduits). The ampacity experiments are used only to assess the additional impact of the fire barrier on the thermal resistance between the cables and the environment. Given that there is generally considered to be some margin of conservatism in the base ampacity tables, the DAEC approach would be the more conservative. (Note that in the specific cable tray calculation cited by DAEC this did in fact prove true as discussed in Section 3 below.)

2.5 Validation of the "Watts/ft" Method

The utility has provided no direct results for the validation of the overall methodology used in its analyses. Even given the methodology limitations as outlined above, some validation of the method should be demonstrated. A statement is made (in section 3.6) that the "results of this methodology compare favorably with results in references 6.8 through 6.12." However, no details of these comparisons are provided.

2.6 Basis for Identification of Continuously Energized Power Cables

In performing its calculations, the utility has only considered "continuously energized power cables" as sources of heat for the protected envelopes. Hence, only trays containing such cables have been considered, all other cables in the tray are considered to add no heat to the envelope, and trays with no such cables have not been analyzed. It is not clear that this assumption as implemented by the utility is appropriate.

In general, SNL does not take exception to the assumption that control and instrumentation cables will contribute no significant heat to the envelope. The exclusion of cables for items such as MOV's which would generally only be activated

for very short periods of time is also an appropriate assumption. However, it is not clear what basis was used to identify "continuously energized power cables."

The concern here is whether or not all modes of plant operation were considered in this process. If only normal operation at full power is considered, the contribution of power cables associated with systems run during other modes of operation may have been overlooked. For example, during shutdown an entirely different set of power cables might be in operation than those active during power operations. For some barrier envelopes, this may represent the limiting condition of operation, particularly if an envelope contains no power cables energized during normal operations. Also, during certain emergency situations cables which are normally deenergized might be energized for extended periods (i.e. hours or days). One such example would be diesel generator power feed cables which might only be called upon in the event of a loss of off-site power. It appears that such cables would not have been considered in the utility analysis.

It is recommended that the utility be asked to provide additional detail regarding the nature of the cables housed in each of the fire barrier systems, to describe the process by which "continuously energized power cables" were identified, and to explain the manner in which various modes of plant operation were factored into the analysis.

2.7 Summary of Methodology Limitations and Concerns

The DAEC analysis methodology is considered inherently inadequate to demonstrate the acceptability of ampacity loading factors for the cables installed at DAEC. In particular, the methodology provides for no assessment of the ampacity limits for any given individual cable. This is an inherent limitation of the DAEC method which cannot easily be corrected. The utility states that it will reassess the analyses based on the results of data expected to be forthcoming from NEI. This would not address the fundamental shortcomings in the DAEC analysis methodology which have been identified. Even given newer data, the method will still not be capable of assessing the ampacity performance of individual cables as is needed.

It was also noted that the utility has not provided a sufficient discussion to determine whether or not adequate consideration has been given to all cables which might represent contributors to a cable tray's heat load. SNL does not take exception to the exclusion from the heat load analysis of control and instrumentation cables, nor that of power cables to intermittent devices such as MOV's. However, it is unclear whether or not all possible modes of plant operation have been considered, including situations involving plant shutdown, startup, and emergency response procedures (such as loss of off-site power) which might be active for extended periods.

Certain other concerns related to the extrapolation of limited experimental data to all of the DAEC cables and conduits were also raised. However, given the fundamental limitations and shortcomings in the overall DAEC methodology, these concerns are considered of secondary importance.

3.0 A BRIEF REVIEW OF THE SPECIFIC CASES CITED BY DAEC

3.1 Overview

The utility submittal has included two specific example analyses, one for a cable tray and one for a conduit. The primary focus of this review was placed on the overall methodology, in large part because the overall methodology was considered inherently deficient. However, this section discusses certain issues associated with the individual calculations which were identified during a review of those calculations. In general it was found that insufficient information has been provided by the utility to perform a complete review of the calculations. Those areas in which additional information is needed to support a thorough review are identified below.

3.2 Example Analysis for Cable Tray 2H2D

The first example given by the utility is for cable tray 2H2D. This tray apparently contains just two "continuously energized power cables." Each cable is a 3-conductor 350 MCM cable carrying 247.22 amps per conductor.

The analysis begins by considering the heat load determined experimentally for a 12" wide cable tray as reported in a Thermal Science Inc. report from 1982 (TSI/ITL report 82-5-355F). The test data (the measure currents and temperatures) are used to estimate the added thermal resistance effect of the fire barrier. Then the "permissible thermal output" for a protected tray is estimated by mathematically "adding" this calculated barrier resistance to the base line tray tests performed by Stolpe in his pioneering work on cable tray ampacity. The "permissible" heat load calculated by the utility is 52.6 W/ft for the 18" wide DAEC cable tray.

It should be noted that in one respect this approach is more conservative than other potential approaches which might be taken in the Watts/ft method. In particular, the "permissible" heat loads calculated by DAEC are based on Stolpe's base line values of the cable tray heating effect rather than on the measured heat loads from the actual clad ampacity test of the TSI test set. In this case, the heat loads reported by Stolpe were significantly lower than those reported in the TSI/ITL base line test; Stolpe load of 61.6 W/ft^2 as compared to the TSI/ITL test value of 83.81 W/ft^2. Hence, the utility analysis is conservative in this regard.

The utility then turns to the actual cable tray under analysis. The heat load for each of the two "continuously energized power cables" is calculated. The total heat load is multiplied by a factor of 1.25 to "add conservatism to account for intermittent load..." Using the actual in-plant cable currents, an "actual" heat load of 17.8 W/ft is calculated for this tray. The "permissible" and "actual" heat loads are then compared. Since the actual heat load is the smaller, 17.8 as compared to 52.6, it is concluded that "no further action is required."

On the surface, this analysis would indicate that this tray has significant available margin. That is, the "actual" heat load is less than 34% of the "permissible" heat load. However, this indication of significant apparent margin is very misleading. As noted

above, it is SNL's finding that this analysis has not demonstrated that these cables are operating within acceptable ampacity limits. To illustrate the basis for this finding consider that the ICEA P-54-440 "Ampacity of Cables in Open-top Cable Trays" gives the ampacity limit for a 3-conductor 350 MCM cable in a tray of 1.5" depth of fill as 315 amps.[1] The DAEC cables are carrying 247.22 amps. Hence, even without a more detailed analysis, one could conclude that there is a nominal ampacity margin of at least 21.5% available for these cables in the absence of any barrier systems. However, it is this same margin which must encompass the fire barrier ampacity derating effect. Based on the available data ampacity derating factors for a three hour Thermo-Lag fire barrier system should be on the order of 35% or more (depending on the barrier configuration).[2] Hence, the nominal available ampacity margin is not sufficient to cover the estimated generic ampacity derating impact and further analyses of the DAEC cable ampacities are needed.

Recognize that this very simple comparison has not considered the various factors which the utility might wish to consider in a more thorough analysis. It should not be concluded on the basis of this comparison that the DAEC ampacity factors are not sufficient. Rather, this comparison simply highlights the fact that the Watts/ft method is insufficient to assess the ampacity limits of individual cables. For example, the utility might wish to credit diversity arguments for providing some added margin given that only two of the cables in the tray are continuously energized. Other mitigating factors may also come into play. These factors might contribute to an assessment that a larger ampacity margin is avaiable for these cables. In any case, the utility analysis must consider the current carrying capacity of the individual cables, not just the cable tray as a whole.

There is also a second way to illustrate the basic concern being raised by SNL in this review. Consider that the utility estimate of the "permissible thermal output" for this cable tray was 52.6 W/ft. If this number is divided by 1.25 (consistent with the utility approach of multiplying the actual loads by 1.25 for conservatism) a value of 42.1 W/ft is obtained. This means that each of the individual conductors in the two, three-conductor continuously energized power cables could carry 1/6 of this thermal load, or approximately 7 W/ft, and still the tray could remain within the overall "permissible thermal output." Using the electrical resistance value for copper (as per the utility analysis) this would correspond to a current in each conductor of 424 amps. This means that any value of current lower than 424 amps would mean that the actual thermal load would be lower than the estimated "permissible thermal load" and

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[1] This value is the same in Tables 3-6, 3-9 and 3-12 of the standard so the voltage rating of the cable, normally a consideration in the ampacity analysis, is not a factor in this case.

[2] This value is based on the minimum ampacity derating estimate identified in the SNL/USNRC tests documented in SAND94-0146 [3]. Note that the ampacity values derived from those tests are not considered appropriate for use in the evaluation of actual cable tray application due to problems with the test article configuration. The SAND94-0146 results are cited as rough estimates of the anticipated impact only.

according to the utility method "no further action is needed." Note that this value, 424 amps, is 134% of the open tray ampacity limit of 315 amps published in the ICEA tables for this cable and this depth of cable tray fill. Under any circumstances these ampacity levels would be considered unacceptable for this cable. This hypothetical example clearly illustrates the fundamental shortcoming and inadequacy of the "Watts/ft" method.

Another point of concern regarding this example analysis is the fact that the utility is basing its analysis on one test performed by the manufacturer, TSI, which has since been discredited. The manufacturer's test cited by DAEC has been the focus of various concerns related to the configuration of the test articles, the acceptability of the test methods, and the processing of the test results. In particular, these early TSI ampacity tests were not performed consistent with current testing practices. The use of this test, or indeed any of the TSI tests for which significant technical concerns have been raised, as the basis for current cable ampacity assessments is considered inappropriate. The utility should be asked to cite an ampacity test which is based on currently accepted test practices (for example the IEEE P848 draft standard) and which encompasses the configurations of the 3-hr fire barrier systems in use at DAEC (for example single 1" versus double 1/2" layer systems of the appropriate material density and thickness).

3.3 Example Analysis for Conduit 1C979

The utility has provided one example of its ampacity derating analysis of conduits by presenting the calculation for Conduit 1C979. In certain respects the DAEC conduit analysis method is more reasonable than is the corresponding DAEC cable tray method. However, the conduit analysis method still fails to consider the appropriateness of ampacity values for the individual cables being examined. Hence, the method is not considered an appropriate basis of analysis, and is not considered adequate to justify the ampacity factors for the cables installed at DAEC.

There is one fundamental difference in the approach to analysis which results in the finding that the conduit analyses are more reasonable that the tray analyses. Recall that in the cable tray analysis the "permissible thermal load" was estimated based on Stolpe's tests in which the cable tray was heavily loaded and a uniform current was applied to all of the cables present (this creates a uniform "power density" which is the foundation of the Stolpe ampacity load values). It was then assumed that this same "permissible thermal load" could be applied directly to the case of a tray with just two "continuously energized power cables." With just two active cables in an 18" wide tray the condition of uniform power density is clearly violated, and the extrapolation must be considered inappropriate. In contrast, for conduits DAEC has estimated the "permissible thermal load" using tabulated NEC ampacity limits for the cables actually installed in the subject conduit. While this may seem a minor point, it is actually a fundamental difference in analysis approach.

Returning to the utility example, the conduit 1C979 is described as housing just two cables; one 3-conductor 350 MCM and one 2-conductor #4/0 cable. Based on the NEC ampacity tables, the allowable ampacity limit for each cable in the absence of a

fire barrier is calculated (236.6 and 171.1 amps per conductor respectively). This leads to an estimated permissible thermal output for the unprotected conduit of 10.257 W/ft (see steps 5.1.3 - 5.1.5).

The utility has not justified the underlying assumptions which drive the next analysis steps (steps 5.1.6 and 5.1.7). In step 5.1.6 the utility makes the basic assumption that the thermal impact of the fire barrier system for the conduit can be based on the test results obtained for the 12" cable tray cited previously (the value is taken directly from step 4.1.4 of the cable tray analysis). That is, the same TSI/ITL cable tray ampacity test cited in its cable tray example is used to assess the added thermal impact of the fire barrier for a conduit as well. This assumption has not been justified by the utility, and is of questionable merit. The fundamental thermal configuration is significantly different for cables in cable trays and those in conduits. The direct application of a value obtained in a cable tray experiment to a conduit analysis must be justified.

It would also appear that the utility has made an error in its calculations. In particular, in steps 5.1.6 and 5.1.7 the utility has apparently adjusted the nominal fire barrier thermal conductance value to account for the circular geometry of the conduit in comparison to the rectangular geometry of the cable tray. This correction does not appear to have been properly performed. The utility method makes an inherent assumption that all of the fire barrier effect is related to added thermal resistance due to conduction heat transfer through the fire barrier material. This is reflected in the manner by which the utility estimates the thermal conductivity of the fire barrier material (step 5.1.6), and then calculates an equivalent thermal conductance for an annular region of 1" thickness (step 5.1.7). This ignores the fact that much of the barrier's thermal effect is related to degradation in the radiative "access" of the cables to the ambient and to interruption of the convective heat transfer process. This conversion appears inappropriate.

In step 5.1.8 the modified "permissible thermal output" is calculated as 8.74 W/ft. Note that give this value, and the unprotected conduit heat output of 10.275 W/ft (from step 5.1.5) it is quite straight-forward to determine the effective ampacity derating factor being estimated for the protected conduit. Recall that the heat load is proportional to the square of current. Hence, the effective ampacity <u>correction</u> factor (ACF) can be calculated as:

$$ACF = \sqrt{\frac{q_{clad}}{q_{bare}}} = \sqrt{\frac{8.74}{10.257}} = 0.923$$

and the ampacity <u>derating</u> factor (ADF) is then given as:

$$ADF = (1.0 - ACF) = .077 = 7.7\%$$

Hence, while a rather round-about approach to the problem has been taken, the net effect of the utility conduit analysis is to assume that the ampacity derating impact of

its 3-hr conduit fire barrier systems is 7.7%. Given that the conduit is still analyzed as a system this means that so long as the cables as a group have an average of at least 7.7% margin in comparison to the NEC conduit ampacity limits, the conduit will be judged by DAEC to be acceptable. Note that this ADF value will change for each conduit analyzed because the base thermal loads will change.

In its subsequent analysis, the utility considers the actual ampacity loads for each of the two cables under analysis, and compares the actual heat load to the estimated "permissible thermal output." Because the actual is less than the "permissible," the conduit is judged acceptable.

It is interesting to note that the actual cable ampacities cited by the utility for these two cables are 223.2 and 48.88 amps per conductor for the 350 MCM and #4/0 cables respectively. Hence, in comparison to the NEC base conduit ampacity limits cited in step 5.1.3 (236.6 and 171.1 amps respectively), these two cables have an available margin of 5.7% and 71.4% respectively. In the case of the 4/0 cable, the available margin of 71.4% would clearly be well within even the most conservative Thermo-Lag conduit ADF values noted to date. However, for the 350 MCM cable, the available margin of 5.7% might not cover the potential ampacity derating impact of the fire barrier system. Even tests of one-hour conduit barriers have resulted in ADF values of this magnitude or greater (see for example the Texas Utilities test results).

In summary, the utility conduit analysis has again failed to consider the actual performance of each of the individual cables in comparison to published ampacity limits. Rather, because the conduit is analyzed as a system, in effect, the 350 MCM cable is able to "borrow" some of the available margin from the #4/0 cable without justification. In some senses, the "Watts/ft" methodology as applied by DAEC to conduits is more reasonable than the same methodology as applied to cable trays. This is because the conduit analysis makes more direct use of the ampacity limits of the actual cables under analysis in its estimation of the "permissible thermal output" than does the cable tray analysis. However, the methodology still fails to consider the behavior of each individual cable in comparison to the ampacity limits of that cable in the presence of the fire barrier system.

4.0 SUMMARY OF REVIEW FINDINGS

The SNL review has assessed the general methodology employed by DAEC in its evaluation of cable ampacity factors, and has examined the two specific case examples provided by the utility. Based on this review, SNL finds that the methodology employed by DAEC in its evaluation of cable ampacity factors is inherently inadequate to demonstrate that individual cable ampacity factors are within acceptable limits.

The DAEC method is, in effect, a variation of the methodology often referred to as the "Watts/ft" method. The fundamental shortcoming of this method is that it only provides a general assessment of the overall heat load for a cable tray or conduit as a whole. No assessment of the individual cable operating conditions is provided. In fact, the methodology might indicate a significant apparent ampacity margin available when the cables within the system are actually operating well above acceptable ampacity limits. The DAEC analyses are considered incomplete, and are not adequate to demonstrate the existence of appropriate cable ampacity factors.

It was also noted that, at least for the two example cased provided by DAEC, only a limited margin was apparently incorporated into the design and selection of the cables used at DAEC. In particular, the one cable tray case provided by the utility indicated a nominal available ampacity margin of approximately 21.5% for the two cables in the tray under analysis (before consideration is given to the fire barrier impact). In the case of the conduit analysis, one of the two cables cited by the utility had an available margin of just 5.7% (again, before consideration of the fire barrier impact). The ampacity derating impact of the 3-hour fire barriers in use at DAEC could easily exceed these nominal margins, and hence, further analysis of the DAEC cable ampacities is clearly needed.

It was also noted that the level of detail provided with regards to the identification of individual cable characteristics was insufficient to support a complete review of the utility analyses. In particular, the utility has considered ampacity only for those cables identified as "continuously energized power cables." The basis for identifying such cables has not been provided by the utility (for example, have all modes of power operation been considered, and has the potential operation of various backup, emergency, and shutdown systems for extended time periods been considered). It is recommended that the utility be asked to provide a listing of all affected power cables which includes identification of the physical characteristics of each cable (size, insulation type, voltage rating, etc.) in addition to the actual in-plant ampacity factors. Without this information, the individual cable heat load calculations cannot be reviewed in detail.

In addition to these findings related to the general applicability and acceptability of the overall utility method, SNL has also identified certain more specific concerns associated with the example analyses provided by the utility. With regards to the example cable tray analysis, SNL noted the following concerns:

- The DAEC analysis of cable trays is based entirely on a single fire barrier ampacity test set (one base line and one clad test) performed by

TSI/ITL in 1982. The manufacturer tests of this vintage have been the subject of significant criticism related to the test article configuration, the test procedures utilized, and the analysis of the test data. Use of these tests as the basis for current evaluation of ampacity factors is considered inappropriate and in conflict with the intent of the Generic Letter 92-08.

- The utility has assumed that the heat rejection behavior of a densely packed cable tray with uniform current loads (the Stolpe tests) is identical to that of a diverse cable tray with just two "continuously energized power cables." This assumption has not been justified, and is considered inappropriate.

- The example cable tray analysis has provided no direct comparison of the actual cable ampacity values to accepted standard ampacity limits (tabulated ampacities). The utility should provide a direct assessment of the ampacity impact of the fire barrier system on the tabulated ampacity values for specific cables in use at DAEC.

In the case of the conduit analyses, four fundamental areas of concern were noted:

- The thermal effects of the fire barrier on the conduits is assumed to be identical to the impact of the fire barrier on cable trays. This assumption is not justified and as applied by DAEC appears to yield potentially non-conservative results. Conduits and cable trays involve fundamentally different heat transfer behaviors. The assumption that the impact of a fire barrier will be the same for both items is considered inappropriate.

- The conversion by DAEC of the fire barrier thermal impact from a rectangular to a radial geometry is performed in an inappropriate manner. The DAEC conversion inherently assumes that thermal conduction through the fire barrier is the predominant mechanism contributing to the fire barriers insulating effect. However, both radiative and convective heat transfer are critical aspects of the barrier's thermal effects. The DAEC methodology does not consider these effects. The DAEC conversion needs to be justified, or it needs to be demonstrated that this conversion is conservative.

- Based on the DAEC methodology, an effective ADF of 7.7% for the example conduit has been calculated. Based on the available test results for conduits, this value may not be sufficient to cover the ADF effect of a 3-hour Thermo-Lag fire barrier system (even some 1-hour Thermo-Lag conduit systems have resulted in ADF values higher than this). Hence, the combination of inappropriate extrapolation of test results, and inappropriate geometric conversions appears to have resulted in a non-conservative estimate of the fire barrier impact. The utility should reconsider its assessments based on actual derating tests for three-hour conduit fire barriers of the type and configuration used at DAEC.

As in the case of the cable tray analysis, the DAEC methodology fails to consider the performance of individual cables in comparison to accepted ampacity performance limits, including the impact of the fire barrier system. Rather, the cables are analyzed only as a composite system, and non-conservative results can easily be obtained.

5.0 REFERENCES

1. Esteves, Oscar M., "Derating Cables in Trays Traversing Firestops or Wrapped in Fireproofing," IEEE Transactions on Power Apparatus and Systems, Vol. PAS-102, No. 6, June 1983, Pgs 1478-1481.

2. Stolpe, J., "Apacities for Cables in Randomly Filled Trays," IEEE Transactions on Power Apparatus and Systems, Vol. PAS-90, May 1972, Pgs 962-973.

3. Nowlen, S. P., *An Evaluation of the Fire Barrier System Thermo-Lag 330-1*, Sandia National Laboratories, SAND94-0146, September 1994.

CABLE DERATING PRACTICE

Verified

ATTACHMENT 1(b)

No.	DATE	REVISIONS	BY	CH'K	AP
	10-29-84	Revised Derating of Covered Tray	GAR	EL	[illegible]
	5-11-83	General Revision	GAR	EL	[illegible]
	7-7-75	ISSUED AS A TPO DESIGN GUIDE	MR	KDB	[illegible]

ORIGIN ELECTRICAL SFPD BPC	BECHTEL — Cable Derating Practice	JOB No. STANDARD
		DESIGN GUIDE
		E.2.6.4
		SHEET 1 OF 27

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REVISION 2

SUMMARY OF REVISIONS

1. General editing of entire document.

2. Changed "ventilated" cable trays to "open top" cable trays throughout to conform to ICEA.

3. Paragraph 3.6.4; Deleted section on derating 6% for solid tray covers, added reference to paragraphs 3.7, 3.8, 3.9 where 3.9 is a new section titled "Additional Derating for Cables Routed in Open Top Tray with Solid Covers".

4. Paragraph 3.6.6, b); Deleted derating for solid tray covers from sample calculation.

5. Added notations that tray covers should be removed prior to applying firestop materials or enclosing raceway with fire protecting material.

6. Paragraph 3.8; Revised to include derating for a 3-hour fire rating for Thermo-Lag. General revision to separate discussion of Thermo-Lag and ceramic fiber blankets.

7. Renumbered "3.9 General Precautions" to "3.10 General Precautions".

1. SUBJECT

Cable Derating Practice

2. PURPOSE

To establish a design guide to determine cable ampacity ratings for cable directly buried, in underground ducts, embedded and exposed conduits, and in open top cable trays. (For industrial projects and utility buildings not included in the power block, the National Electrical Code should be used for ampacity values and calculational methods).

3. DESIGN GUIDE

3.1 General

The following is to set forth a definite and uniform procedure to determine cable ampacity ratings. It encompasses various types of cable installation, namely:

a) Underground

1) Directly buried

2) In ducts

b) In Conduit

1) Embedded in slabs or walls

2) Exposed Conduit

c) In Cable Trays

1) With Maintained Cable Spacing

2) Random Fill of Cables in Tray

Publication No. P-46-426 of the ICEA contains tabulated ampacities for a variety of cable voltage classes, thermal ratings, and installations, and provides the basic ampacities for cases a), b), and c)1) above. Two volumes comprise this publication. Volume 1 deals with copper conductors and contains an Introduction and Appendices applicable to both volumes. Volume 2 contains ampacity tables for aluminum conductors.

Sections II.D.2 and 3. of the Introduction Section in Volume 1 of the above publication set forth a method for calculating ampacities for case c)2)-Cable tray installations with random

iii. This section has been superseded by a newer ICEA publication, Publication No. P-54-440 "Ampacities for Cables in Open Top Trays." The latter should be used exclusively since the older method, as set forth in Sections D.2 and 3., is in error.

If shielded medium voltage power cables are installed so that individual conductors are not symmetrically disposed, circulating currents in the insulation shields of the cables may reach a magnitude where the thermal effect of the I^2R factor requires derating of the cable conductor. Wherever such cases occur, a third ICEA publication, Publication No. P-53-426, "Ampacities Including Effect of Shield Losses for Single Conductor Solid Dielectric Power Cable 15kV through 35kV," should be consulted. The title could be misleading in that this effect applies at other voltages as well. Whenever shielded power cables are installed with individual conductors in a non-symmetrical arrangement, these effects should be investigated and either taken into account if the losses are significant, or steps should be taken to eliminate the circulating shield current. (See Design Guide E-2.6.5 "Power Cable Shielding and Shield Grounding")

This design guide contains sample ampacity calculations. Although these are primarily based on copper conductors, the same procedures and considerations are applicable to aluminum.

3.1.1 It is important to remember that current-carrying capacity, voltage regulation, and short-circuit capacity of cables must be considered independently in order to assure proper selection of cable sizes with various types of insulations, voltage classes, and modes of installation.

3.1.2 Although it is not specifically called for in the Introduction Section of Volume 1 of P-46-426 (nor elsewhere in this standard), combining circuit "sets" of power cables in the same conduit or underground duct requires that the tabulated ampacity be reduced (derated) accordingly. The derating effects of mutual heating is addressed in other sections of the Introduction -- derating for adjacent conduits in air or in concrete-encased duct banks, etc.

Since the methods set forth in Section II.D.2 and II.D.3 of the P-46-426 Introduction (including Table VIII) have been superseded (and should be crossed out in all copies of the standard presently in use), the table is reproduced in this Design Guide in Section 3.5.1.

3.1.3 Ampacity calculations for underground cables, whether run in duct banks or directly buried, can be rapidly and conveniently made by means of a privately developed computer program now available at some Bechtel offices.

card-programmable calculator, and a printer auxiliary unit.

It calculates ampacities for cables in a large number of ducts or cable groups, with complete flexibility regarding duct size, spacing, and bank configuration. Where some cables are loaded to less than their permissible ampacity, this reduction in mutual heating is taken into account to permit higher loading of other cables in the particular run. Consult with your local office Chief Electrical Engineer's staff regarding possible use of this program.

When this program is available, it is recommended for use instead of the methods set forth in Sections 3.2 and 3.3.

3.2 Direct Burial Cable

3.2.1 Types of directly buried cable configurations with typical dimensions as per ICEA Pub. No. P-46-426 are shown in Figures 1, 2 and 3. Final detail with respect to trenching and backfill are to be supplied by the project.

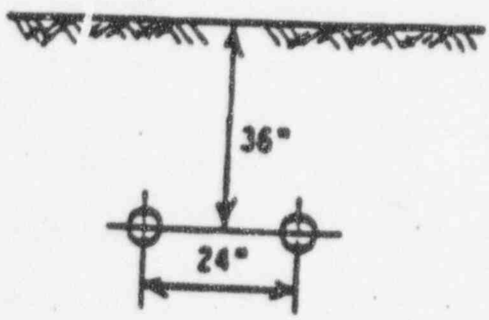

Figure 1 - Buried 3/C Cables

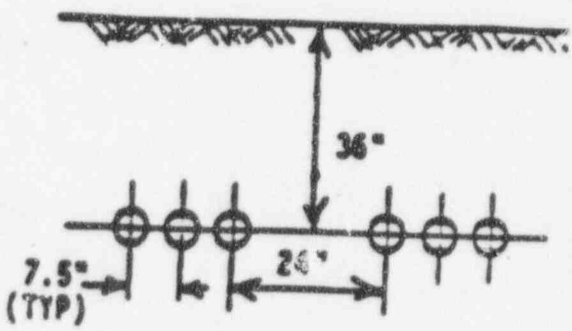

Figure 2 - Buried 1/C Cables

* Note that the arrangement in Figure 2 may cause significant shield losses if shielded cables are used and shields are grounded at more than one point.

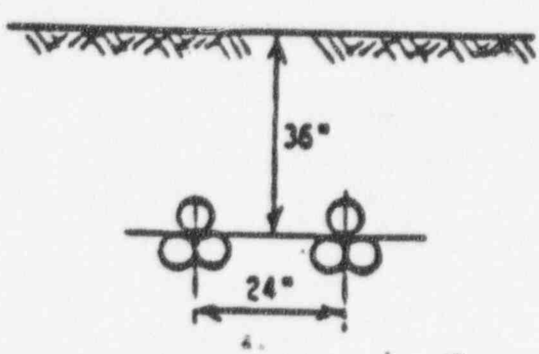

Figure 3 - Buried Triplex Cable

3.2.2 Information required to enter ICEA Pub. No. P-46-426 for Direct Burial Cable:

a) Cable Description (e.g. 1/C, 3/C, or Triplex)

b) Cable Operating Voltage (e.g. 1kV, 8kV, 15kV, or 25kV)

c) Cable Insulation (e.g. Rubber or Thermoplastic, Varnished Cloth, Paper, LP Gas or Oil-Filled)

d) Conductor Temperature (e.g. 60, 65, 70, 75, 80, 85 or 90C)

e) The ampacity values tabulated in ICEA for direct burial cable are for an ambient earth temperature of 20°C. Adjustments must be made for ambient earth temperatures which are substantially different from this. A frequently used guideline is to assume the 20°C ambient for "Northern US" locations and 30°C for "Southern US" locations. While this approach may suffice for feeders in which ampacity margin factors offset the importance of this item, important or critically loaded underground cable systems should utilize testing or other methods (per EEI "Underground Systems Reference Book" - Chapter 10). An important precaution in this regard is to ensure that cable trenches or duct banks are not affected by close proximity to other underground systems creating a higher-than-normal earth ambient. An example of this might be the installation of a cable run from the power block to the intake station or cooling tower in the same excavation with the circulating water discharge line.

If ambient earth temperatures above 20°C are encountered, one method of derating the cables is to lower the conductor operating temperature by the same amount as the increase in ambient temerature (e.g. to find the ampacity of cable with conductor temperature of 90°C and an ambient temperature of 30°C, find the ampacity of a cable with 80°C conductor temperature and a 20°C ambient temperature which can be read directly from the tables).

f) Load Factor:

Ampacities are tabulated for 30, 50, 75 and 100% load factors. These are indicated as 30LF, 50LF, 75LF, and 100LF. It is recommended that 100LF be used for all calculations involved with generating station applications.

g) Earth Thermal Resistivity:

ICEA Pub. No. P-46-426 ampacities are tabulated for in-earth thermal resistivity, RHO, in degree

centigrade-centimeters per watt, for RHO-60, RHO-90, and RHO-120. Procedures are given for interpolation and extrapolation, if other than indicated values of RHO are encountered. ICEA recommends that RHO-90 be used when earth thermal resistivity is not known. However, in the instances of major cable installations, where engineering judgement and economics dictate, we should determine RHO as closely as possible. Some of the factors which must be considered are: type of soil, type of backfill, moisture content of soil, depth below surface, and presence of nearby concrete slabs or structures. In addition, the "baking" of the soil by the current-carrying conductors can cause RHO to change (for the worse) with time. Two reference articles on this subject are: "Rapid Measurement of Thermal Resistivity of Soil" by V. V. Mason and M. Kurtz, AIEE Transactions, Vol. 71, 1952, page 570; "Soil Thermal Resistivity Measured Simply and Accurately" by John Stolpe, IEEE Transactions Vol. PAS-89, Number 2, February 1970, page 297.

3.2.3 Sample Calculation:

Given: Directly Buried Cable; 3-1/C; 4.16kV, Rubber Insulated, Conductor Temperature 90°C, Ambient Earth Temperature 30°C.

Find: Ampacities for 2/0, 4/0, and 500 kcmil at 100LF.

Solution: ICEA Pub. No. P-46-426 ampacities of directly buried cable are tabulated for 20°C Ambient Earth Temperature. To maintain same temperature difference between conductor and earth, use a conductor temperature of 80°C.

ICEA Pub. No. P-46-426 index page iii refers to table on page 202.

Wire Size	Ampacity	
2/0	303	
4/0	393	RHO-90, 100LF, 1 Circuit, 8kV
500 kcmil	629	

3.3 Cables in Underground Ducts

3.3.1 Type of duct configurations and typical dimensions as per ICEA Pub. No. P-46-426 for 5" duct are shown in Figures 4, 5, 6 and 7. Duct bank overall dimensions are approximate, to give minimum 3" encasement coverage:

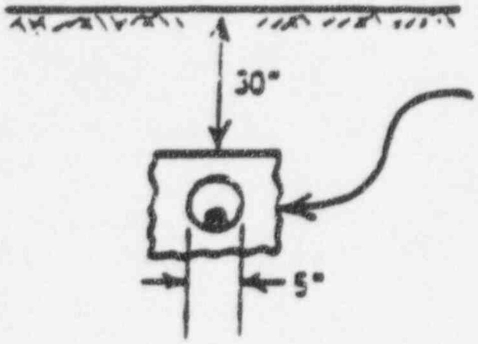

Figure 4
11.5" by 11.5" overall
Duct Bank

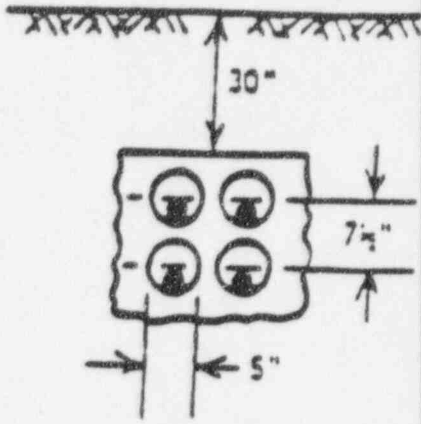

Figure 5
19" by 19" overall
Duck Bank

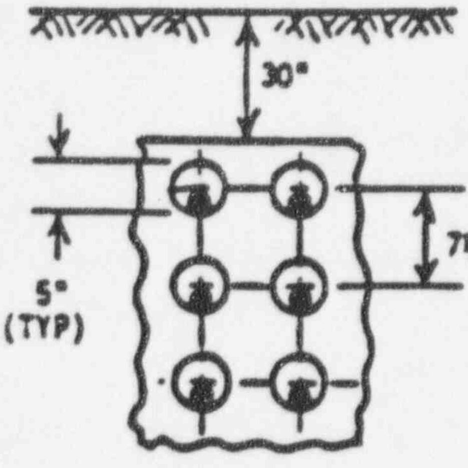

Figure 6
19" by 26.3" overall
Duct Bank

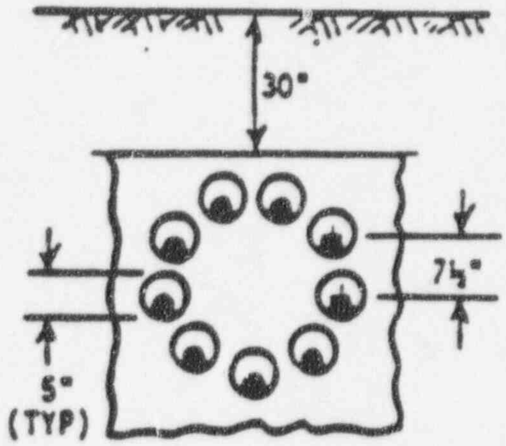

Figure 7
33.4" by 33.4" overall
(Not a feasible design)

Notes:

a) Cable in individual duct can be 1/C, 3/C or Triplex. To find ampacity, use the appropriate ICEA Pub. No. P-46-426 table. If 3-1/C cables are used per duct, the table for Triplex Cable is recommended for use.

b) For any normal duct bank configuration, phase and conductor imbalances will result if multiple paralleled cables for each phase are installed each in a separate duct. To preclude this, paralleled runs of cable should be designed with all three phases installed in each of multiple ducts (3/C, triplex, or 3-1/C), with sizes and lengths of all cable matched. For large loads, such as the secondary connections for station service transformers, this may require several more (smaller) conductors per phase but compares favorably from a cost viewpoint and avoids a possibly serious problem. If for some reason paralleled single 1/C cables per duct must be used, the individual ducts should be transposed at intervals along the duct run to balance the impedances of the three phases - a slow and expensive duct installation method. Another way is to symmetrically arrange the ducts as shown in the Underground Systems Reference Book, Figure 10-39, arrangements 4,5,6,7, 8 and 16.

c) If cable sizes larger than tabulated in ICEA are required or more than nine occupied ducts per bank are required, extrapolation of ICEA Pub. No. P-46-426 tables may be considered. It is recommended that the extrapolation, either ampacity versus cable size or ampacity versus number of ducts in bank, be done on log-log paper since an approximate straight line will be obtained. As with any extrapoltion, this method is limited - the further the extrapolation, the lower the accuracy. For duct bank arrangements other than those shown in P-46-426, extrapolation should be limited to smaller duct banks with not more than two, or at most three, layers of power conduits. Beyond this, the Neher-McGrath analysis should be applied, manually, if necessary, or preferably by means of the EE-700 (ME-80) computer program. If duct banks are run in parallel, the normal ampacity tables must be further derated. The derating will never be more severe than:

Distance Between Nearest Ducts	Depth of Burial of Lowest Ducts	Also Applies to Any Ratio of Distance/Depth	Additional Derating for All Cables In Both Duct Bank
1 ft	3 ft	1/3	0.79
2 ft	3 ft	2/3	0.87
3 ft	3 ft	1	0.91
4 ft	3 ft	1-1/3	0.94
5 ft	3 ft	1-2/3	0.95

When a horizontal separation of 6 ft or greater is maintained, the mutual heating effect of adjacent duct banks can be safely ignored.

d) In particular situations where the available tables and extrapolations are inadequate, the general equations for ampacity, as stated in ICEA Pub. No. P-53-426, Section F.4, are recommended as the best available approach.

e) Information required to enter ICEA Pub. No. P-46-426 Tables for Cable in Underground Duct is the same as that required for Direct Burial Cables, see Section 3.2.2.

f) When 1/C cable installations are designed, care must be exercised to avoid placement of steel or other magnetic material between or around conductors.

g) Tabulated ampacities apply only to a single cable or single set of cables in each duct bank conduit. Where additional circuits are installed in the same conduit, the ampacity factors tabulated at the end of Section 3.5.1 must be applied.

3.3.2 Sample Calculation:

Given: Underground Duct Installation; 13.8kV Rubber Insulated Cables; Conductor Temperature 90°C; Ambient Earth Temperature 20°C; 1600A (full load current requirements).

Find: Size, number and configuration of cables required.

Solution: a) First consider 3-1/C or 1 Triplex per duct in order to obtain balanced currents in each individual phase.

b) ICEA Pub. No. P-46-426, index page iv refers to the Table on page 242 for Triplex for the given conditions stated above.

c) We see the 3 Triplex will not carry the current for the maximum size tabulated. However, 6 Triplex will give the required ampacity (i.e. 500 kcmil, RHO-90, 100LF ampacity is 288; 6 x 288 = 1728 which is greater than the 1600A required).

d) If duct size will permit triplexed cable of larger sizes, interpolation of the tabulated data indicates that 4-750 kcmil will be marginally satisfactory and 6-1000 kcmil will provide a conservative application.

e) Note that the tabulated data for triplexed cables applies to corresponding sizes of 3-1/C cables installed in a duct.

3.4 Cables in Conduit Embedded

3.4.1 Types of Embedded Conduit Installation:

Embedded conduit refers to conduit in concrete slabs and walls. Normal configurations of conduit in underground duct installations are illustrated in Section 3.3.1. All provisions of Section 3.3.1 are equally applicable to embedded conduit.

3.4.2 Information required to enter IPCEA Tables for Cable in Embedded Conduit:

a) The ampacity of cable in embedded conduit should be taken from the ICEA P-46-426 tables for similar cables in underground duct. The same data set forth in Section 3.2.2 for entering the tables for direct burial cable is required for cable in embedded conduit.

b) It is recommended that RHO-60 be used for cables in embedded conduit (RHO-60 is typical for "hardrock" structural grade concrete).

c) An ambient temperature of greater than 20°C is frequently the case for embedded conduit in a power or industrial plant (i.e. conduit in a concrete slab with a heated room above and below may have ambient temperature 40°C or greater). Thus, it will be necessary in most cases to derate the ampacities given in ICEA Pub. No. P-46-426 for cable in underground duct, since these ampacities are for an ambient temperature of 20°C. The procedure outlined in 3.2.2e may be used to derate for ambient temperature greater than 20°C, or the ampacities may be found for an ambient temperature of 20°C and then derated by the equation shown below.

$$I' = I\sqrt{\frac{T_c - T_a'}{T_c - T_a}}$$ where

I' = derated ampacity (amperes)

I = ampacity tabulated for T_c and T_a (amperes)

T_c = rated continuous conductor temperature (°C)

T_a = tabulated ambient temperature (20°C)

T_a' = actual ambient temperature (°C)

3.5 Cable in Conduit Exposed

3.5.1 Information required to enter ICEA Pub. No. P-46-426 Tables for Cable in Conduit is the same as set forth in Section 3.2.2 a, b, c, and d for directly buried cables.

Consult the index of ICEA Pub. No. P-46-426 for tabulated ampacities for triplexed or three conductor cables in isolated conduit. Note that the tabulations are based on an ambient air temperature of 40°C. If ambient air temperatures higher than 40°C are encountered, then one of the same derating procedures outlined in 3.4.2c should be followed.

Note that tabulated ampacities are for a single three conductor or triplexed cable in an isolated conduit. If more conductors are in the same conduit and concurrently loaded, the following ampacity factors (100% ampacity MINUS the percentage derating) must be applied:

Total Number of Conductors	Ampacity Factor
3	1.00
4-6	0.80
7-9	0.70
10-24*	0.70
25-42*	0.60
43 & up*	0.50

*Includes the effects of load diversity.

Where a fourth conductor is included as the neutral in 3 Phase 4 Wire systems, the neutral is not counted as a current carrying conductor and no derating is required.

Where nominal load diversity cannot reasonably be assumed, an appropriate Ampacity Factor can be calculated using the methods set forth in Appendix 1 of the Neher-McGrath paper, "The Calculation of the Temperature Rise and Load Capability of Cable Systems." The matter should be reviewed with the office Chief Electrical Engineer.

Note: When derating approaches 30%, an alternative cable routing or raceway arrangement should be considered.

3.5.2 Derating Factors for Cables in Exposed Groups of Conduits in Air:

a) If the vertical and horizontal spacing between surfaces of conduits grouped on racks or other supports equals or exceeds the outside diameter of the conduits, the ampacities for cables in isolated conduits in air should be used without derating.

b) Table I shows ampacity factors by which ampacities tabulated for cables in isolated conduit in air should be multiplied where conduits are grouped more closely than outlined in a) above. The table is based on separation between adjacent conduit exterior surfaces not less than one fourth of the outside diameter of the larger of the two adjacent conduits, (d/4). THIS SHOULD BE CAREFULLY NOTED IN PROJECT RACEWAY INSTALLATION "NOTES AND DETAILS." If separations are less than these minima, a complex heat transfer calculation is required to accurately determine ampacity.

TABLE 1

CABLES IN CONDUIT, AMPACITY FACTORS

Number Vertically	Number Horizontally					
	1	2	3	4	5	6
1	1.00	0.94	0.91	0.88	0.87	0.86
2	0.92	0.87	0.84	0.81	0.80	0.79
3	0.85	0.81	0.78	0.76	0.75	0.74
4	0.82	0.78	0.74	0.73	0.72	0.72
5	0.80	0.76	0.72	0.71	0.70	0.70
6	0.79	0.75	0.71	0.70	0.69	0.68

3.5.3 Sample Calculation:

Given: Conduit installation in air of 3 vertical and 4 horizontal conduits, each conduit separated by 1/2 conduit diameter; 3/C, 600V, rubber insulated; conductor temperature 85°C; ambient air temperature 40°C.

Find: Ampacities for #4 AWG and #6 AWG cables.

Solution: ICEA Pub. No. P-46-426, index page V refers to table on page 312 for isolated conduit.

Size of Each Cable	Ampacity in Isolated Conduit		Ampacity Factor		Ampacity in Grouped Conduit
#4	87	x	0.76	=	66
#6	66	x	0.76	=	50.2

3.6 Cables in Open Top Cable Tray

3.6.1 Cable may be installed in tray with "maintained spacing" or randomly pulled or laid in the tray. In the maintained spacing method, cable spacers of plastic, impregnated wood, or porcelain are inserted to maintain a selected vertical and horizontal spacing dimension between adjacent cables in the tray. Rows of such spacers are installed in the tray at intervals, depending on the stiffness of the cables involved, sufficient to ensure that the design spacing is effectively "maintained". The labor required to do this type of installation is many times that required to install the same cables randomly in the same tray. It can only be economically justified for large, important feeders involving comparitively heavy electrical loads. The offsetting benefit is substantially higher ampacity. It is suggested that cable duct be considered whenever conditions are such that maintained spacing appears to be a desirable option.

3.6.2 If cable duct is selected, the ampacity used should comply with the recommendations of the cable duct manufacturer. If field-fabricated maintained spacing is to be used and the spacing is maintained to exceed the full cable diameter, the ampacity will be the same as for the same cable isolated in air. For maintained spacing from 1 diameter (cable o.d.) to 1/4 diameter, apply the ampacity factors tabulated in Table VII on page V of Volume 1- (Copper), of the ICEA ampacity tables (P-46-426) to the ampacities tabulated in the book(s) for isolated cable in air.

3.6.3 For power circuits in tray other than the major, heavily loaded runs which justify the expense of maintained spacing, the method used is "random spacing" or "random tray fill". Sections II.D.2 and 3 on page V of ICEA P-46-426 describe a method for determining ampacities for this condition, using Table VIII from these same sections, but the results are unsuitable for our applications and SHOULD NOT BE USED. The correct reference is ICEA Pub. No. P-54-440 (NEMA WC-51) entitled "Ampacities - Cables in Open-Top Cable Trays".

3.6.4 Ampacities for power cables installed in trays without maintained spacing should be based on the methods and data contained in ICEA Pub. No. P-54-440. The ampacity tables in this publication are generally based on the calculated depth

of cables in trays carefully packed to approximate maximum cable density-of-installation, considering this as the "worst case basis" for conservative design. The tables are further based on 100% load factor and no diversity. As the title indicates, the tables are based on "Open-Top Trays". The effects of tray covers, fire protecting material wraps, or routing of tray through firestops require derating to the ampacities as determined from ICEA P54-440. The additional derating required for each is covered in the following sections:

- 3.7 Additonal Derating for Tray Cables Transiting Firestops
- 3.8 Additonal Derating for Cable Trays or Conduits Enclosed in Fire Protecting Material
- 3.9 Additional Derating for Cables Routed in Open Top Tray with Solid Covers.

3.6.5 <u>Scope of ICEA Ampacity Tables for Cable Tray</u>

a) Data is tabulated for single conductor, triplexed, and three conductor cables. For multiconductor power cable other than three conductor, a conversion formula is provided in the Introduction section of the Tables.

b) Data is tabulated based on the overall cable sizes (outside diameters) corresponding to the more common cable constructions. Since cable ampacity in random-fill trays generally varies directly as the cable outside diameter (other factors being equal), a simple proportion multiplier enables determination of ampacities for outside diameters other than those tabulated for given conductor sizes. A special case occurs where cable o.d. equals or exceeds the design basis depth of fill. In these cases, cables can be laid parallel in the tray, one layer deep. Ampacity will be as tabulated for depth corresponding to cable o.d. regardless of percent fill or exact cable "size".

c) Ampacities are tabulated for four different voltage classes, 0-600V., 601-2,000V., 2,001-5,000V., and 15,000V. Ampacities for nominal 8kV class may be determined by applying the sizing (cable overall o.d.) correction described in b) (above) to the ampacity tabulated for corresponding conductor sizes for 5,000V. class cable. (While this is not precise or theoretically true, the resulting error will be negligible.)

d) Tabulations are based on cables rated for 90°C maximum continuous conductor temperature operation and 40°C maximum ambient air temperature. Correction coefficients for each of these factors are tabulated in the Introduction section of the Tables.

e) The ampacities are tabulated on the basis of "depth" of cables in the tray with "depth" defined in the Introduction section of the Tables as follows:

$$\text{Depth} = \frac{n_1 d_1^2 + n_2 d_2^2 + \ldots . n_n d_n^2}{\text{Width of Tray}} \text{ where}$$

$d_1, d_2, \quad d_n$ = Overall o.d. of different cable sizes, and

$n_1, n_2, \quad n_n$ = Number of cables of each corresponding diameter
All units are in inches.

Our usual method of calculating tray fill is to select a percentage of the usable cross section area of the tray under consideration, then to determine how many cables of various cross section areas can be accommodated in that percentage of the tray. For this, we use the actual cross section area of the cables, and since these are (usually) circular, we multiply $d^2 \times \pi/4$ for each cable o.d. Using the notations of the Introduction section of the Tables, our "depth" would be:

$$\text{Depth} = \frac{n_1 d_1^2 (\frac{\pi}{4}) + n_2 d_2^2 (\frac{\pi}{4}) + \ldots n_n d_n^2 (\frac{\pi}{4})}{\text{Width of Tray}}$$

$$= \frac{(n_1 d_1^2 + n_2 d_2^2 + \ldots\ldots n_n d_n^2)(\frac{\pi}{4})}{\text{Width of Tray}}$$

Note that our method differs from that on which the tables are based by our inclusion of the factor $\pi/4$.

Because of this difference, our calculated depth must be divided by $\pi/4$ (or 0.7854) to be consistent with the definition of "depth" on which the Tables are based. (Some find it easier to multiply our calculated depth by the reciprocal of $\pi/4$, or 1.273).

3.6.6 <u>Use of the Tables</u>

A frequent practice is to select trays for random fill with power cable which have a usable tray depth of 3 inches and to design for a 30 percent fill. (While the same tray usable depth is very widely used in the power industry, both of these parameters are selected arbitrarily. The 30% fill figure

Note that this is for a cable outside diameter of 0.45" where ours is 0.53". Recall from 3.6.5 b) of this Design Guide that, ignoring other parameters, ampacity is directly proportional to cable overall o.d.:

$$I_{cable} = \frac{d_{cable}}{d_{table}} \times I_{table}$$

$$= \frac{0.53}{0.45} \times 78A \text{ (as calculated thus far)}$$

$$= 1.18 \times 78A$$

$$= 92 \text{ Amperes}$$

b) Given: Horizontal tray, 3" usable depth, 2/C #4 AWG copper conductor 600V. cable of unjacketed "singles," 90°C conductor temperature rating, 40°C ambient air temperature, cable fillers added to make cable round in section with overall o.d. of 0.75". Cables are installed with random lay.

Find: Ampacity for 40% fill

Solution: Depth of cable for 40% fill

$$= (3" \times 0.40) \div \pi/4$$

$$= 1.2" \div 0.7854$$

$$= 1.53"$$

(For practical purposes, the last 0.03" depth can be ignored and tabulated data for 1.5" depth can be used without interpolation). Enter Table 3 and note the ampacity for 1.5" depth #4 AWG 3/C:

= 49 Amperes

Note that no corrections need be made for either ambient air temperatures or conductor temperature rating. However, we must correct for a different number of conductors and for a different cable o.d. These corrections can be made in one step utilizing the equation shown in the upper left corner of page ii of the tables:

$$I'_x = \frac{d'}{d'_o} \times I_o \sqrt{\frac{3}{n_x}}$$

$$= \frac{0.75"}{0.83"*} \times 49A \sqrt{\frac{3}{2}}$$ *From Table 3

$$= 0.905 \times 49A \times 1.225$$

$$= 54.3A.$$

supposedly represents filling the tray, using random cable pulling or laying of cables into the tray, to the point where covers may be installed wherever desired without particular difficulty. Many others take 40% as approximating "complete" tray fill. So far, neither figure has been claimed to represent a "cost-effective" optimum.)

SAMPLE CALCULATIONS

a) Given: Horizontal tray, 3" usable depth, 1/C #2 AWG jacketed, 600V, copper conductor cable, 0.53" o.d., air ambient temperature-50°C, insulation rated for 125°C conductor temperature, random fill.

Find: Ampacity at 30% tray fill.

Solution: "Depth" of cable @ 30% fill:

$$= (3" \times 30\%) \div \pi/4$$
$$= (3" \times 0.3) \div 0.7854$$
$$= 1.15$$

Enter Tables ICEA Pub. No. P-54-440 Table 4. Use straight line interpolation to interpolate between ampacities tabulated for #2 AWG @ 1.0" depth (75A.) and 1.5" depth (58A.)

$$I_{1.15} = I_{1.0} - \frac{1.15 - 1.0}{1.5 - 1.0} \times (I_{1.0} - I_{1.5})$$
$$= 75A - 0.3 \times (75A. - 58A.)$$
$$= 75A. - 5.1A.$$
$$= 70 \text{ Amperes}$$

Note that this ampacity is for 40°C ambient air, where ours is 50°C. Refer to page i right hand column "Correction for Ambient Temperature" - for 50°C ambient, multiply the above result by 0.90:

$$= 0.90 \times 70A. = 63A.$$

Note that this ampacity is for 90°C rated conductor temperature where ours is 125°C. Refer to same page, same column "Correction for Conductor Temperature" - for 125°C conductor temperature multiply our above result by 1.24:

$$= 1.24 \times 63A. = 78A.$$

c) Given: Horizontal tray, 4" usable depth, 1/C #1/0 AWG aluminum conductor 8kV nominal rating shielded cable, 0.97" o.d., 90°C conductor rating, 40°C ambient, open top randomly filled tray.

Find: Ampacity at 30% fill

Solution: Depth of cable for 30% fill

$= (4" \times 30\%) \div \pi/4$

$= 1.53"$ Again for practical purposes we can omit interpolation for the 0.03" incremental depth.

$= 1.5"$

Enter Table 29 for 1/0 AWG conductor and 1.5" cable depth:

$I_{1.5} = 94A.$ for 5kV cable w/0.72" o.d.

(Assume that the voltage class difference between 5kV and 8kV has negligible ampacity effect and make correction only for difference in o.d's.):

$$I_{cable} = \frac{d_{cable}}{d_{table}} \times I_{table}$$

$$= \frac{0.97}{0.72} \times 94A$$

$$= 126.6A.$$

$$= 127 \text{ Amperes}$$

d) Given: Horizontal tray, 3" usable depth, 1/C 1,000 kcm copper conductor 15kV shielded cables 2.13" o.d., 90°C conductor rating 40°C ambient open top randomly filled tray.

Find: Ampacity at 30% fill

Solution: Depth of cable for 30% fill

$= (3" \times 0.30) \div \pi/4$

$= 1.15"$

Note that the cable diameter exceeds the prescribed depth of fill. The cables can, however, be laid in the tray in a single layer. The ampacity may be calculated as described in the second paragraph under Section B "Use of Tables" on page "i" of P-54-440. It may more readily be looked up directly in this standard by entering Table 33 for 1,000 kcmil conductor size:

I = 833A

Where the cable o.d. exceeds the prescribed depth, the ampacity is 80% of the ampacity of the same cable in free air, as tabulated in P-46-426. It is therefore independent of the cable o.d., so no correction need be made for the difference between the actual o.d. (2.15") vs. the tabulated o.d. (1.90").

3.7 Additional Derating for Tray Cables Transitting Firestops

Many of the firestops commonly used for sealing wall and floor openings for tray cable passage make use of a flame-retardant thermal insulating material such as silicone foam. Any solid or ventilated tray covers should be removed prior to forming the firestop.

Several manufacturers or installers of this type of material claim that the use of their product or method does not require derating of enclosed power cables. They base these claims on data from tests, including one or two in which the cables were loaded to the full P-54-440 ampacity, without the firestop hot-spot temperature exceeding 90°C.

According to Stolpe, whose analyses and testing are the basis for P-54-440, 90°C hot spots will only occur where a number of cables are packed together - a typical "worst case" to use as a design basis. Commenting on his own test results, Stolpe stated, "Note that even though the majority of cables -- ran cooler than calculated, there was a group of cables -- that did reach the calculated temperature. This points out the fact that all cables in a randomly filled tray cannot be expected to have the most thermally adverse environment, but some of them will." Stolpe also demonstrated that ampacity should not be increased because of diversity (i.e., some or many of the cables in the tray are only lightly loaded or are completely unloaded).

Because of these facts, good engineering practice requires that when thermal insulating material is used as a firestop, additional derating must be considered and applied when necessary.

The Los Angeles Power Division performed a series of tests in 1980 to determine the thermal effect of two different types of firestops on tray cables. One type represented the BISCO firestop comprised of a 9" thickness of 17 lb/ft^3 density silicone foam. The other was the minimum thickness BPC firestop comprised of two layers of 1/2" Marinite with a 3-1/4" thick layer of 17 lb/ft^3 density silicone foam between, plus Flamemastic coating on the cables on each exposed face of the firestop.

Although the hot-spot temperature of the BPC firestop was slightly lower, the conclusions were that either type required a nominal incremental (additional) derating of 15%. It should also be noted that in the opening test group in this series, as in Stolpe's tests, hot-spot temperatures for trays without firestops or ceramic fiber blanket wrapping were found with virtually no thermal margin when all cables were continuously loaded to their P-54-440 ampacities. Summarizing, these tests show that cables transitting either of these typical minimum firestops should be given an additional derating of 15%. (i.e., a tray cable with P-54-440 ampacity of 100 amperes for open top tray should be derated to 85 amperes if it passes through a firestop).

Another approach that can be used is to analyse the I^2R heat gain (in watts) for a one foot length of tray. This is done by the following method:

A. Take dc resistance for ONE foot of each individual stranded conductor from a cable engineering handbook such as Okonite Cable Engineering Data Booklet, Table 1-3 (tinned conductors where appropriate).

B. Convert "A" to ac (where appropriate), by multiplying by the factors tabulated in Okonite Data booklet, Table 1-5.

C. Multiply each value by 1.25 to convert R tabulated for 25°C to 90°C maximum conductor temperature (1.258 for aluminum conductor).

D. Multiply each "C" value by the SQUARE of the current corresponding to the actual full load of the device being served. Short time intermittent loads (such as MOV operator motor loads), or loads that only occur during abnormally lightly loaded conditions, can be ignored.

E. Add all of these "watts per foot" (of tray).

F. The total wattage for each 6" increment of tray width should be 24.5 Watts @ 40°C or less to ensure hot-spot conductor temperatures less than 90°C within the firestop.

BECHTEL

Example:

70 - 3/C #12 awg cables are routed in a 12" wide tray with each circuit loaded to 9.5 amps/phase. Can a 9" thick silicone foam firestop be installed in the tray without creating hot-spot internal temperatures >90°C?

R (each cable) $1.71 \times 10^{-3} \times 1.25 = 0.00215$ (No dc/ac correction required)

I^2 (each cable) $= 9.5^2 = 90.25$

I^2R (each conductor) $= 90.25 \times 0.00215 = 0.1940375$

I^2R total $= 0.1940375 \times 70 \times 3 = 40.75$

Maximum permissible watts for 12" w. tray = $2 \times 24.5 = 49.0$ watts

$40.75 < 49.0$ watts

Therefore the firestop hot-spot is less than 90°C

CAUTION: Since "watts per foot" or "watts per foot per unit width" correlates with AVERAGE temperatures, each such case should be analyzed to ensure against hot-spots. If many of the cables are lightly loaded, one or a few small cables can be overloaded to the point of damage without the "watts per (square) foot" limitation being exceeded. The analysis should verify that the cables are evenly distributed in the fire stop. The review should be based on reasonable values of watts per linear foot per unit of cross-sectional area of each of the cables of interest.

Some firestops use silicone not as a foam but as a solid elastomer, either unfilled or filled with granular metallic lead for resistance to radioactivity. Because in its normal state it has thermal conductivity much greater than that of foam, it dissipates the internally-generated heat of the cable such that no ampacity derating is required in the 4" to 12" thicknesses of normal firestops. Even with these materials, derating may be required in substantially thicker sections such as those sometimes used for radiation barrier seals. These materials pyrolize when exposed to fire, and the resulting "char" is a good thermal insulator, thereby enabling the material to fulfill its function as a firestop.

3.8 Additional Derating for Cable Trays or Conduits Enclosed in Fire Protecting Material

In order to protect cable from damage by fire, cable trays and conduits are sometimes enclosed in fire protecting material. Among the first such materials to be used was ceramic fiber blanket material such as Kaowool or Cera-blanket. Its incombustibility and very low thermal conductivity makes it effective for protecting control, instrumentation, and communications type cables. However, the second characteristic makes it generally unsuitable for power cables, at least as a design basis.

Another fire protection covering for trays or conduits is a plaster-like material named Thermo-Lag 330-1. In addition to being easier to install and much more durable than ceramic fiber blanket, the derating required for power cables is more reasonable due to a much higher thermal conductivity.

CAUTION: Fire protecting materials should not be used inconjunction with solid or ventilated type cable tray covers on power tray. If used together, the cable would have to be derated for both the tray covers and the fire protecting materials.

3.8.1 Derating Required When Using Thermo-Lag 330-1

When fire protection material is required on trays containing power cable, Thermo-Lag 330-1 is preferred over ceramic fiber blanket materials as the cable derating is substantially less for Thermo-Lag. Based on ASTM E-119 fire tests of Thermo-Lag 330-1, 1/2" thickness will provide a 1 hour fire rating and 1" thickness will provide a 3 hour fire rating. Ampacity tests have shown that 1/2" thickness of Thermo-Lag requires that power cable be derated 12.5% for cable tray and 7.6% for conduit. Tests using 1" thickness have shown that a derating of 17% is required for cable tray.

Since tests of conduit with 1" thickness of Thermo-Lag were not conducted, the derating for power cable in conduit is estimated to be 10.5% based on the 36% increase in the derating shown between the 1/2" and 1" thicknesses which were tested on cable tray.

3.8.2 Derating Required When Using Ceramic Fiber Blankets

In 1980, the Los Angeles Power Division conducted tests of ceramic fiber blankets (Cera-Blanket). These tests indicated a requried derating of 73% (2.28 watts per foot allowable dissipation per 6" width of tray) if two 1" thick layers are

used, or 64% (4.4 watts per foot per 6" width of tray) if a single 1" thick layer is used for wrapping cable trays. For wrapping conduits, these tests indicated a maximum permissible watts per (linear) foot of conduit internal heat generation of 5.98 for 4" conduit with a single 1" layer wrap.

For the three 250 kcmil cables involved in the testing, this represents a derating of 33.3% from the actual measured ampacity for the similar "unwrapped" conduit condition.

Since only a single case was tested, it was necessary to calculate the maximum permissible watts per foot of internal heat generation for other sizes of conduit and other thickness of thermal insulation wrapping. A fairly detailed mathematical model was developed and the calculations performed for various trade sizes of conduit, each wrapped with one 1" thick layer of ceramic fiber blanket. Conclusions were as follows:

Conduit Size (RS, IMT, or EMT)	Maximum Allowable Internal Heat (I^2R) Watts/Ft.*
1"	3.28
1-1/2"	3.88
2"	4.30
2-1/2"	4.70
3"	5.18
3-1/2"	5.54
4"	5.88
5"	6.53
6"	7.11

Where one or two power circuits are installed in a wrapped conduit, these limits can be directly applied without exceeding the cable rating(s). Where three or more power circuits are installed in the same common conduit, two separate criteria must be applied, as follows:

(1) The sum of the I^2R losses* of all of the insulated conductors shall not exceed the tabulated Watts per foot tabulated above, and

(2) No insulated conductor may be loaded to more than its ampacity tabulated in ICEA P-46-426 for isolated conduit in air derated for the total number of current-carrying conductors in accordance with Table VIII of the Introduction to Volume I (Copper) of P-46-426, and reproduced in this Design Guide in Section 3.5.1

*Use the method set forth in the latter part of Section 3.7 of this Design Guide, steps "A" through "E".

3.9 <u>Additional Derating for Cables Routed in Open Top Tray with Solid Covers</u>

Solid metal tray covers are often used on cable tray to provide mechanical protection and prevent the accumulation of debris. Nuclear power plant projects may consider the use of solid tray covers to address the separation criteria in Regulation Guide 1.75.

Ampacity tests conducted in 1980, by the Los Angeles Power Division indicated that a derating of 27% is required for solid metal covers mounted directly on the tray sills. The test consisted of a tray with a 12 foot long solid metal cover mounted directly on the tray sills with a 1/8" opening at each end. For the configuration tested, a maximum allowable dissipation of 17.25 watts per linear foot for each 6" increment of tray width was determined. Subsequent to the LAPD tests, IEEE paper No. 83 SM 305-0 presented test results indicating that a 25%-30% derating should be used for solid metal covers. The test configuration for the IEEE paper was a 24" wide tray with a 24 foot long solid cover mounted on the tray sills.

The use of solid covers on tray containing power cable should be avoided when it is practical and feasible to provide an economical layout routing the trays in areas not requiring covers. Realizing this is not always possible, projects which utilize solid metal tray covers for debris protection should consider means other than mounting the covers directly on the tray sills. Instead of covers mounted directly on the tray sills, covers or shields supported above the trays can be used with no additional derating for power cables if a minimum of 4" clear space is maintained between the tray sill and the cover. When adequate protection can be provided by a shield or cover suspended above the tray, (supported a long or beneath walkways, etc.) this also has the advantage that cable may be added at some future time without incurring the cost of removing covers.

When solid tray covers greater than six (6) feet in length are utilized on power trays and are mounted directly on the tray sills, the ICEA ampacities should be derated 27%. Current Bechtel practice for cable sizing and selection is such that the 27% derating for solid tray covers may not require larger conductors. Based on an analysis of current SFPD projects, cable sizing and selection has been sufficiently conservative as to not require larger conductors to compensate for the additional derating for solid tray covers.

Prior to applying the 27% derating for solid tray covers, the following items should be considered:

a) Cables feeding motors are sized based on 125% of motor full load current which provides a 25% margin over rated full load. Most motors are selected as the next larger "trade size" over the horsepower requirements of the driven equipment which provides additional margin. Mechanical equipment selection is also based on "worst case" conditions rather than normal operating conditions. Briefly, motor feeders usually have a margin greater than 27% above the actual motor load current.

b) Some motors are not continuous duty motors such as motor operated valves, cycling sump pumps, etc. and do not contribute to heating of cables in a covered tray (ie., ICEA tables are based on all cables at 100% load with no diversity).

c) Cables feeding load centers, motor control centers and power panels in power generating stations are usually sized large enough to be capable of handling the full ampacity rating of the bus. It is recommended that this criteria be used to size such feeders as this permits the addition of loads throughout the life of the plant as long as sufficient transformer capacity is available. This technique typically results in cable ampacity margins greater than 27% above the actual load currents.

In summary, the use of solid tray covers mounted directly on the sills of power tray should be avoided. When specifically required, solid tray covers may be installed directly on the sills of power trays (without concern) as long as proper design techniques were employed in sizing the power cables.

<u>CAUTION</u>: When selecting the size of cable feeders to panels that are dedicated to loads which are all simultaneously energized, special care must be taken to assure that the conductors are of adequate size, and that all derating factors have been considered. Panels which are dedicated to loads such as unit heaters, HVAC equipment and freeze protection are typical of those which require special attention in selecting the proper cable size.

3.10 General Precautions

The consequence of overloading power cables insulated with the high quality thermosetting elastomers generally used in our industry is a reduction in full service life expectancy rather than sudden catastrophic failure during startup. Even a seriously overloaded cable may function for many years before failing.

However, good engineering demands thoughtfulness and care in performing these calculations. The relationship between conductor temperature and cable life expectancy is exponential rather than linear, so that small overtemperatures over an extended period of time can seriously shorten cable life. Premature approach to the end-of-service-life condition due to thermal aging of cables is considered by the USNRC as providing the potential for common-mode failure of class 1E circuits under accident conditions.

Probably the highest possibility of future problems in this regard is improper evaluation (or estimation) of the actual cable environment from the point of view of ambient temperature. The "standard" procedure is to find the nominal high ambient areas from the Plant Facilities group on the project, design for that, and consider the problem solved. There are many tight or isolated areas in an operating plant through which cables are routed where the temperatures substantially exceed the HVAC design figures. These hot-spot areas should not necessarily establish the limits for design of the whole plant, but cables traversing these areas should be derated accordingly on a special case basis or their premature failure should be anticipated. Raceway layouts should be reviewed and checked against piping and equipment layout to minimize hot-spot exposures or verify that power cables in the area have been derated to be conservative.

Our ampacities for cable in tray are based on "percentage fill" of the usable cross sectional area of a tray, but it has been proven that the controlling factor for fully loaded cables in tray is the <u>depth</u>. Our usual practice of 30% fill in 3" deep tray converts to 1.15" depth per ICEA Pub. No. P-54-440 (See preceding Sample Calculation 3.6.6 a). Our design basis is conservative only if the cables are spread across the width of the tray in a reasonably uniform manner. Project "cable installation notes and details" should point out to the installers the possible hazard of cable piling up in the trays (especially on inside corners of tray bend fittings) and making the actual depth be 3", for example, for a fraction of the usable width of the tray.

We should also be aware that our own electrical equipment may create a serious heat problem. If power cable trays are routed one above another, the upward convection from the lower tray(s) will create a higher temperature ambient for the upper one(s). The upward convection "exhaust" air from a class H insulated load center (AA or FA rated) transformer creates an ambient exceeding the total temperature capability of our "standard" cables - the cables would overheat at <u>zero</u> ampacity. Such areas should be carefully avoided in raceway layout (conduit or tray) or special ventilation provided.

Solar radiant heating can also seriously affect the ampacity of cables if their rating is not to be exceeded. In most cases, natural breeze or forced air circulation substantially reduces the affect, but consideration should be given to both indoor and outdoor cable runs in tray or conduit where solar exposure is substantial and possibly accentuated by restricted ventilation. One method of dealing with the problem is to provide sunshields of sheet metal or other suitable paneling. Another approach is to determine the maximum estimated temperature for an enclosed area in direct sunlight (or uninsulated attic temperature) from project plant facilities engineers and derate the cable for operation in this higher ambient. A method of directly calculating the required additional derating is set forth in the Neher-McGrath Paper "The Calculation of the Temperature Rise and Load Capability of Cable Systems" on page 759 under "Aerial Cables". To complete the calculation outlined therein, it is helpful to refer to the "Method of Calculation" section on page IV of the Introduction to ICEA Pub. No. P-46-426 and utilize the values in Table IV of that section.

4.0 REFERENCES

4.1 "The Calculation of the Temperature Rise and the Load Capability of Cable Systems", J. H. Neher and M. H. McGrath; AIEE Transactions, Part III, Volume 76, October 1957.

4.2 "Ampacities for Cables in Randomly Filled Trays", J. Stolpe; IEEE Transactions Paper No. 70 TP 557-PWR, April 1970.

4.3 "Engineering Data - Copper and Aluminum Conductor Electrical Cables" - Okonite Company's Bulletin EHB-81.

4.4 "Ampacity of Cable in Covered Tray", G. Engmann; IEEE Paper No. 83 SM 305-0, Presented at the IEEE/PES 1983 Summer Meeting in Los Angeles, May 1983.

SP-E26402

DOCUMENT NAME: G:\DUANEARN\DUA85547.RAI

ORIGINATOR NAME: G. Kelly

SECRETARY NAME:

SUBJECT: DUANE ARNOLD ENERGY CENTER - REQUEST FOR ADDITIONAL INFORMATION (RAI) ON THE DUANE ARNOLD ENERGY CENTER THERMO-LAG RELATED AMPACITY DERATING ISSUES (TAC NO. M85547)

	NAME	DATE
1.	D. Foster-Curseen	________
2.	G. Kelly	________
3.	Secretary - Dispatch	

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