SYSTEM: ~~EE~~ XX File EPED 4266/19G52

317682

SARGENT & LUNDY ENGINEERS

Calc. For Ampacity Derating for combination Thermo Lag 330-1 Material and Darmatt firewrap			
X	**Safety-Related**		**Non-Safety-Related**

Calc. No 4266/19G52	
Rev. 0	**Date** 3-4-94
Page 1	**of** 25

Client	Commonwealth Edison	**Prepared by** John M Leicht	**Date** 3-4-94
Project	LaSalle Units 1 and 2	**Reviewed by** Art A. Bari	**Date** 3/4/94
Proj. No.	9376-20 **Equip. No.**	**Approved by** D. A. Kolzak	**Date** 3-4-94

JUN 24 94 2 1 1 5

I. REVISION SUMMARY and REVIEW METHOD

A. Revision Summary

Revision 0 - First Issue of Calculation, Pages 1-25.
Appendix A, Pages A1-A15.

REVISION SUMMARY and REVIEW METHOD (continued)

B.METHOD OF REVIEW

QA CALCULATION REVIEW CHECKLIST
TYPE OF CALCULATION

☐ Hand-Prepared Design Calculation Only

☐ Computer-Aided Design Calculation Only

☑ Both hand-Prepared and Computer Aided Design Calculation

FOR HAND-PREPARED DESIGN CALC
(check the appropriate items)

☑ Detailed review of the original calculation.

☐ Review by an alternate, simplified or approximate method of calculation.

☐ Review of a representative sample of repetitive calculations.

☐ Review of the calculation against a similar calculation previously performed.

FOR COMPUTER-AIDED DESIGN CALC
(check the appropriate items)

☑ A review to determine if the engineering design and analysis computer program(s) used have been validated and documented and that the calculation, regardless of the program used, contains all the necessary documentation for reconstruction at a later date. (MUST BE PERFORMED)

☑ A review to verify that the computer program is suitable to the problem being analyzed. (MUST BE PERFORMED)

☑ A review to determine if the input data as specified for program execution is consistent with the design input, correctly defines the problem for the computer program algorithm and is sufficiently accurate to produce results within any numerical limitation of the program. (MUST BE PERFORMED)

☑ A review to verify that the results obtained from the program are correct and within stated assumptions and limitations of the program and are consistent with the input. (MUST BE PERFORMED)

☐ Validation documentation for temporary changes to listed programs or developmental programs or unique single application programs shall be reviewed to assure that methods used adequately validate the program for the intended application. (WHERE APPLICABLE)

REVIEWER: [signature] DATE: 3/4/94

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II. TABLE OF CONTENTS

Section	Contents	Page No.

III. PURPOSE/SCOPE

A. Purpose

The purpose of this calculation is to determine the amount of ampacity derating required for the following two firewrap configurations:

Configuration 1

- 1.23" of Darmatt firewrap material over 0.5" of Thermo Lag 330-1 material. Both materials cover the top, bottom, and sides of the tray.

Configuration 2

- 1.23" of Darmatt firewrap material over 0.5" of Thermo Lag 330-1 material. Both materials cover the bottom and sides of the tray but only the Darmatt covers the top of the tray.

B. Scope

The scope of this calculation covers power cable trays with the above described firewrap configurations. The derating factor will be based on a 40°C ambient, a 0.91 inch depth of fill, a 90°C conductor temperature, and a tray size of 4 inches high by 30 inches wide. An ambient greater than 40°C will require an additional derating factor.

IV. INPUT DATA

1. The ambient temperature is 40°C. (See III. B, Scope)

2. The cable trays are 30 inches wide. (See III. B, Scope)

3. The cable trays are 4 inches high. (See III. B, Scope)

4. The depth of fill is 0.91 inches. (See III. B, Scope)

5. The allowable heat intensity for a 0.91 inch depth of fill is 7.7 watts/ft-square inch. (Ref 1)

6. A tightly covered cable tray requires a 15 % ampacity derating. (Ref 2)

7. The emissivity of a galvanized steel surface is .23. (Ref 5)

8. The emissivity of the Darmatt surface is 0.6 (Ref 6).

9. The rated conductor temperature is 90°C. (See III. B, Scope)

10. The thermal conductivity of the Darmatt material is 0.0653 BTU/hr-ft-F @60°C. (Ref 6)

11. The Darmatt firewrap material is 1.23 inch thick. (per Ref 6, the Darmatt is 27mm,-0%,+15%, thick: 1.23" = 1.15 * 2.7cm / (2.54cm per inch))

12. The thermal conductivity of the Thermo Lag 330-1 material is .1 Btu/hr-ft-degree R (Ref 6)

13. The Stephan-Boltzman constant is equal to .1713*10^-8 Btu/hr-ft. 2-degree Rankine^4. (Ref 5)

14. The Thermo Lag 330-1 material is 0.5" thick (Ref 6).

V. ASSUMPTIONS

The effective surface area available for convection and radiation will not be increased after the fire wrap is added. This assumption accounts for the non-uniform heat flow at the corners. This assumption is conservative since the allowable heat flow will be reduced with the lower surface area, and therefore this assumption does not need to be verified.

VI. ACCEPTANCE CRITERIA

N/A

VII. METHODOLOGY

The allowable heat generation for a tightly covered cable tray is first calculated from the allowable heat intensity versus depth of fill curve for an uncovered cable tray and the required 15 % ampacity derating for a tightly covered cable tray.

This allowable heat generation for a tightly covered cable tray is then used to calculate the surface temperature of the cable tray. The difference between the rated conductor temperature and this surface temperature is then divided by the allowable heat generation for a tightly covered cable tray in order to obtain an equivalent thermal resistance from the conductor metal to the surface of the cable tray. The surface temperature of the tightly covered cable tray, TGS, is found by manually adjusting this value in the MATHCAD program below until QTGS, the calculated value of the total heat transferred from closed cable tray surface, nearly matches QCB, the allowable heat generation in a tightly covered cable tray.

Next, a composite thermal resistance of the Darmatt fire wrap and the Thermo Lag 330-1 material itself is calculated and added to the equivalent resistance from the conductor metal to the surface of the cable tray which was calculated previously.

The same formulas for the convection and radiation from the tray surface to the ambient, as modified for the higher emissivity of the Darmatt material as compared to galvanized steel, are then used to calculate the convection and radiation from the wrapped cable tray to the ambient.

The surface temperature of the wrapped cable tray, TWT, is manually adjusted using the MATHCAD program until the calculated maximum temperature of the conductor, TCCR, is nearly equal to the rated conductor temperature, TCR. The variable TCCR is calculated from the formula TCCR=TWT+QTWT*RTOT, where QTWT is the total heat transfer from the wrapped cable tray, and RTOT is the total thermal resistance from the conductor metal to the surface of the fire wrap.

Since the heat generated in the cable tray is proportional to the square of the current, the ratio of the ampacity with the cable wrap to the ampacity for the tightly covered tray is equal to the square root of the ratio of the allowable heats for each cable installation method.

METHODOLOGY (continued)

The above method is repeated but with a composite wrap resistance reflecting only the Darmatt material on the tray top.

IX. CALCULATIONS and RESULTS

A. Heat generated by the cables

Equivalent cable area

The cross sectional area of the cable tray is equal to the depth of fill times the tray width. The cross sectional area of the cable tray must be multipied by π/4 in order to obtain the equivalent cable area.

$dof := 0.91$ The depth of fill is 0.91 inches.

$w := 30$ The width of the tray is 30 inches.

$Aeq := \left(\frac{\pi}{4}\right) \cdot dof \cdot w$ Equivalent cable area

$Aeq = 21.441$ The equivalent cable area in square inches for a 0.91 inch depth of fill and a 30 inch wide cable tray.

Heat generation allowable for an uncovered cable tray

The allowable heat generation for an uncovered cable tray is found by multiplying the equivalent cable area by the allowable heat intensity as taken from calculation 4266-EAD-13. (Ref 1)

$HI := 7.7$ The allowable heat intensity in watts/ ft-square inch for a 0.91 inch depth of fill.

$QUCW := Aeq \cdot HI$ The allowable heat in watts/ft for an uncovered cable tray

$QUCW = 165.099$ The allowable heat in watts/ft for an uncovered cable tray with a 0.91 inch depth of fill.

$QUCB := \frac{QUCW}{.2929}$ The allowable heat in Btu/hr-ft for an uncovered cable tray

$QUCB = 563.669$ The allowable heat in Btu/hr-ft for an uncovered cable tray with a 0.91 inch depth of fill.

CALCULATIONS and RESULTS (continued)

From "Tests at the Braidwood Station on the Effects of Fire Stops on the Ampacity Rating of Power Cables"(Ref 2), there is a 15% derating in the conductor ampacity for a tightly covered tray. The allowable heat from the cable tray will be decreased by the square of the ampacity derating.

$QCB := (1 - .15)^2 \cdot QUCB$ The allowable heat in Btu/hr-ft for a tightly covered cable tray

$QCB = 407.251$ The allowable heat in Btu/hr-ft for a tightly covered cable tray with a 0.91 inch depth of fill

B. Temperature of the outside of a cable tray with tight covers

Radiation Formula

Radiation heat transfer is given by the following formula (Ref 3):

QR=σεA(T1^4-T2^4)

Where QR is the heat dissipated by radiation
σ=.1713*10^-8 is the Stephan-Boltzman constant (Ref 5)
ε is the surface emissivity
A is the surface area
T1 is the surface temperature
T2 is the ambient temperature

Area of radiating surface per linear foot of tray

$AT := \left(\frac{2}{12}\right) \cdot (4 + 30)$ Area in square ft/ft

$AT = 5.667$

Total radiating area for a 2.5 ft wide, 4 inch high tray

$\sigma := .1713 \cdot 10^{-8}$ Stephan-Boltzman constant in Btu/hr-ft2-R4

$\varepsilon GS := .23$ Emissivity of a galvanized steel surface

$TAC := 40$ The ambient temperature in degrees centigrade

$TAR := (TAC + 273) \cdot \frac{9}{5}$ The ambient temperature in degrees Rankine

$TAR = 563.4$ degrees Rankine

CALCULATIONS and RESULTS (continued)

$TGS := 643.915$ Iterated value of the temperature of the galvanized steel surface of the cable tray in degrees Rankine

$QRGS := \sigma \cdot \varepsilon GS \cdot AT \cdot \left(TGS^4 - TAR^4\right)$ Radiation heat transfer from the galvanized steel surface of the cable tray in Btu/hr-ft

$QRGS = 158.872$

Convection Formula

Convective heat transfer is given by the following formula (Ref 3):

QC=hA(T1-T2)

Where QC is the heat dissipated by convection
h is the convection heat transfer coefficient
A is the particular area under consideration
T1 is the surface temperature
T2 is the ambient temperature

From table 7-4 of Heat Transfer by Holman (Ref 3) the convective heat transfer coefficient for vertical planes or cylinders is h=.29(δT/L)^.25. This equation will apply to the tray sides with L equal to 4/12 feet.

$hsGS := .29 \cdot \left[\frac{TGS - TAR}{\left(\frac{4}{12}\right)}\right]^{.25}$ Convective heat transfer coefficient for the sides of the unwrapped cable tray in Btu/hr-ft2-degree F

$hsGS = 1.143$ Btu/hr-ft2-degree F

CALCULATIONS and RESULTS (continued)

$AS := 2 \cdot \left(\frac{4}{12}\right)$ Area of cable tray sides in square ft/ft

$AS = 0.667$

$QCSGS := hsGS \cdot AS \cdot (TGS - TAR)$ Convective heat transfer from the sides of the cable tray in Btu/hr-ft

$QCSGS = 61.367$ Btu/hr-ft

From table 7-4 the convective heat transfer coefficient for a heated plate facing upward is h=.27(δT/L)^.25. This equation will apply to the top of the cable tray with L equal to 2.5 feet.

$htGS := .27 \cdot \left(\frac{TGS - TAR}{2.5}\right)^{.25}$ Convective heat transfer coefficient for the top of the cable tray in Btu/hr-ft2-degree F

$htGS = 0.643$

$ATS := \frac{30}{12}$ Area of top of cable tray in square ft/ft

$ATS = 2.5$

$QCTGS := htGS \cdot ATS \cdot (TGS - TAR)$ Convective heat transfer from the top of the cable tray in Btu/hr-ft

$QCTGS = 129.469$

From table 7-4 the convective heat transfer coefficient for a heated plat facing downward is h=.12(δ/L)^.25. This equation will apply to the bottom of the cable tray with L equal to 2.5 feet.

$hbGS := .12 \cdot \left(\frac{TGS - TAR}{2.5}\right)^{.25}$ Convective heat transfer coefficient for the bottom of the cable tray in Btu/hr-ft2-degree F

$hbGS = 0.286$

CALCULATIONS and RESULTS (continued)

$AB := \frac{30}{12}$ Area of the bottom of the cable tray in square ft/ft

$AB = 2.5$

$QCBGS := hbGS \cdot AB \cdot (TGS - TAR)$ Convective heat transfer from the bottom of the cable tray in Btu/hr-ft

$QCBGS = 57.542$

$QTGS := QRGS + QCSGS + QCTGS + QCBGS$ Total heat transfer from the unwrapped cable tray in Btu/hr-ft

$QTGS = 407.25$

Since the value of QTGS matches the value for QCB, the iterated value of 643.915 degrees Rankine for the surface temperature of the cable tray is correct.

C. Thermal resistance of the cable mass and cable tray assembly up to the surface of the cable tray.

This resistance is equal to the temperature drop from the conductor to the cable tray surface divided by the allowable heat.

$TCC := 90$ Rated conductor temperature in degrees centigrade

$TCR := (TCC + 273) \cdot \frac{9}{5}$ Rated conductor temperature in degrees Rankine

$TCR = 653.4$

$RCM := \frac{TCR - TGS}{QCB}$ Thermal resistance of the cable mass in degrees Rankine-hr-ft/Btu

$RCM = 0.023$

CALCULATIONS and RESULTS (continued)

D. Thermal resistance of the Thermo Lag 330-1 material and the Darmatt firewrap with the Darmatt material covering the bottom, top, and sides of the tray

The following formula will be used to calculate the thermal resistance of the composite of the Darmatt fire wrap and the Thermo Lag material:

R=(1/k)/((e1/b1+.54)+(e2/b2+.54)+(e1/b3+.54)+(e2/b4+.54)) (Ref 4)

where k is the thermal conductivity of the Thermo Lag and e1, e2, b1, b2, b3, and b4 are constants defining the tray/wrap configuration (see attachment C)

To componsate for the lower conductivity of the the Darmatt material as compared to the Thermo Lag material, the thickness of the Darmatt material is inecreased by a factor equal to ratio of the two conductivities:

$k3301 := 0.1$ conductivity of Thermo Lag 330-1 (see IV.12)

$kDar := 0.0653$ conductivity of Darmatt (see IV.10)

$t := \frac{k3301}{kDar}$ $t = 1.531$

$e1 := 4$ $e2 := 30$ $b1 := 0.5 + 1.23 \cdot t$ $b2 := 0.5 + 1.23 \cdot t$ $b3 := 0.5 + 1.23 \cdot t$ $b4 := 0.5 + 1.23 \cdot t$

$b1 = 2.384$ $b2 = 2.384$ $b3 = 2.384$ $b4 = 2.384$

$$R_{comp} := \frac{\frac{1}{k3301}}{\left(\frac{e1}{b1} + .54\right) + \left(\frac{e2}{b2} + .54\right) + \left(\frac{e1}{b3} + .54\right) + \left(\frac{e2}{b4} + .54\right)}$$

$R_{comp} = 0.326$ Resistance of the fire wrap in degree Rankine-ft-hr/Btu

E. Total resistance of the cable mass and cable wrap

$RTOT := RCM + R_{comp}$

$RTOT = 0.349$

CALCULATIONS and RESULTS (continued)

F. Total Heat Transfered from the Wrapped Cable Tray

$\varepsilon A := .6$ Emissivity of the Darmatt firewrap

$TWT := 590.043$ Iterated value of the surface temperature of the wrapped cable tray

The increase in surface area available for convection and radiation caused by wrapping the tray will be ignored on the basis that the heat flow through the firewrap is non-uniform.

$QRWT := \sigma \cdot \varepsilon A \cdot AT \cdot \left(TWT^4 - TAR^4\right)$ Radiation heat transfer from the surface of the wrapped tray in Btu/hr-ft

$QRWT = 119.127$

$$hsWT := .29 \cdot \left[\frac{TWT - TAR}{\left(\frac{4}{12}\right)}\right]^{.25}$$

$hsWT = 0.867$

$QCSWT := hsWT \cdot AS \cdot (TWT - TAR)$ Convective heat transfer from the sides of the wrapped cable tray in Btu/hr-ft

$QCSWT = 15.402$

$$htWT := .27 \cdot \left(\frac{TWT - TAR}{2.5}\right)^{.25}$$

$htWT = 0.488$

$QCTWT := htWT \cdot ATS \cdot (TWT - TAR)$ Convective heat transfer from the top of the wrapped cable tray in Btu/hr-ft

$QCTWT = 32.494$

$$hbWT := .12 \cdot \left(\frac{TWT - TAR}{2.5}\right)^{.25}$$ $hbWT = 0.217$

CALCULATIONS and RESULTS (continued)

$QCBWT := hbWT \cdot AB \cdot (TWT - TAR)$ Convective heat transfer from the bottom of the wrapped cable tray in Btu/hr-ft

$QCBWT = 14.442$

$QTWT := QRWT + QCSWT + QCTWT + QCBWT$ Total heat transfer from the wrapped cable tray in Btu/hr-ft

$QTWT = 181.464$

$TCCR := TWT + QTWT \cdot RTOT$ Calculated maximum temperature of the conductor

$TCCR = 653.401$

Since TCCR is nearly equal to the rated conductor temperature TCR, it can be concluded that the allowable heat with a firewrap is about 181 Btu/hr-ft.

G. Ampacity Derating Factor

The ampacity derating factor is equal to the square root of the ratio of the allowable heats.

$DFDar := \sqrt{\frac{QTWT}{QUCB}}$ Ampacity derating factor for 0.5 inches of Thermo-Lag 330-1 material and a one hour firewrap using 1.23 inches of Darmatt material .

$DFDar = 0.567$

CALCULATIONS and RESULTS (continued)

H. Thermal resistance of the Thermo Lag 330-1 material and the Darmatt firewrap with the Thermo Lag material and Darmatt material covering the bottom, and sides of the tray but only the Darmatt material covering the top of the tray

The following formula will be used to calculate the thermal resistance of the composite of the Darmatt fire wrap and the Thermo Lag material:

R=(1/k)/((e1/b1+.54)+(e2/b2+.54)+(e1/b3+.54)+(e2/b4+.54)) (Ref 4)

where k is the thermal conductivity of the Thermo Lag and e1, e2, b1, b2, b3, and b4 are constants defining the tray/wrap configuration (see attachment C)

To componsate for the lower conductivity of the the Darmatt material as compared to the Thermo Lag material, the thickness of the Darmatt material is inecrease by a factor equal to ratio of the two conductivities:

$k3301 := 0.1$ conductivity of Thermo Lag 330-1 (Ref 6)

$kDar := 0.0653$ conductivity of Darmatt (Ref 6)

$t := \frac{k3301}{kDar}$ $t = 1.531$

$e1 := 4$ $e2 := 30$ $b1 := 0.5 + 1.23 \cdot t$ $b2 := 0.5 + 1.23 \cdot t$ $b3 := 0.5 + 1.23 \cdot t$ $b4 := 1.23 \cdot t$

$b1 = 2.384$ $b2 = 2.384$ $b3 = 2.384$ $b4 = 1.884$

$$R_{comp} := \frac{\frac{1}{k3301}}{\left(\frac{e1}{b1} + .54\right) + \left(\frac{e2}{b2} + .54\right) + \left(\frac{e1}{b3} + .54\right) + \left(\frac{e2}{b4} + .54\right)}$$

$R_{comp} = 0.294$ Resistance of the fire wrap in degree Rankine-ft-hr/Btu

I. Total resistance of the cable mass and cable wrap

$RTOT := RCM + R_{comp}$

$RTOT = 0.317$

CALCULATIONS and RESULTS (continued)

J. Total Heat Transfered from the Wrapped Cable Tray

$\varepsilon A := .6$ Emissivity of the Darmatt firewrap

$TWT := 591.868$ Iterated value of the surface temperature of the wrapped cable tray

The increase in surface area available for convection and radiation caused by wrapping the tray will be ignored on the basis that the heat flow through the firewrap is non-uniform.

$QRWT := \sigma \cdot \varepsilon A \cdot AT \cdot \left(TWT^4 - TAR^4\right)$ Radiation heat transfer from the surface of the wrapped tray in Btu/hr-ft

$QRWT = 127.901$

$$hsWT := .29 \cdot \left(\frac{TWT - TAR}{.5}\right)^{.25}$$

$hsWT = 0.797$

$QCSWT := hsWT \cdot AS \cdot (TWT - TAR)$ Convective heat transfer from the sides of the wrapped cable tray in Btu/hr-ft

$QCSWT = 15.119$

$$htWT := .27 \cdot \left(\frac{TWT - TAR}{2.5}\right)^{.25}$$

$htWT = 0.496$

$QCTWT := htWT \cdot ATS \cdot (TWT - TAR)$ Convective heat transfer from the top of the wrapped cable tray in Btu/hr-ft

$QCTWT = 35.299$

CALCULATIONS and RESULTS (continued)

$hbWT := .12 \cdot \left(\frac{TWT - TAR}{2.5}\right)^{.25}$ $hbWT = 0.22$

$QCBWT := hbWT \cdot AB \cdot (TWT - TAR)$ Convective heat transfer from the bottom of the wrapped cable tray in Btu/hr-ft

$QCBWT = 15.689$

$QTWT := QRWT + QCSWT + QCTWT + QCBWT$ Total heat transfer from the wrapped cable tray in Btu/hr-ft

$QTWT = 194.008$

$TCCR := TWT + QTWT \cdot RTOT$ Calculated maximum temperature of the conductor

$TCCR = 653.399$

Since TCCR is nearly equal to the rated conductor temperature TCR, it can be concluded that the allowable heat with a firewrap is about 194 Btu/hr-ft.

K. Ampacity Derating Factor

The ampacity derating factor is equal to the square root of the ratio of the allowable heats.

$DFDar := \sqrt{\frac{QTWT}{QUCB}}$ Ampacity derating factor for 0.5 inches of Thermo-Lag 330-1 material and a one hour firewrap using 1.23 inches of Darmatt material (only the Darmatt material covers the top of the tray).

$DFDar = 0.587$

X. COMPARISON of RESULTS with ACCEPTANCE CRITERIA

N/A

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XI. CONCLUSIONS

The ampacity of a cable installed in a tray with either firewrap configuration 1 or 2, as defined in the purpose, is obtained by multiplying the uncovered cable tray ampacity by 0.567 or 0.587, respectively.

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XII. RECOMMENDATIONS

N/A

XIII. REFERENCES

1. LaSalle calculation 4266-EAD-13, Rev 0, 2-8-82, entitled "Cable Tray Heat Intensity" - This reference provides the allowable heat intensity of 7.7 watts/ft-square inch which applies to a 0.91 inch depth of fill.

2. "Tests at Braidwood Station for the Effects of Fire Stops on the Ampacity Rating of Power Cables" - Haddad, Bloethe, Stolt, Lamkin, and Sykora - Proceedings of the 44th American Power Conference (1982) - This reference indicates that the ampacity derating factor for a cable tray with tight covers is .85.

3. Holman, J. P. Heat Transfer, New York: McGraw Hill Book Co, 1968 - This reference provides convection and radiation heat transfer formulas.

4. Kaminsky, D. A. (editor), Heat Transfer Data Book, Schenectady, New York, General Electric Co, 1977 - This reference provided the formula for the thermal resistance of the fire wrap.

5. Baumeister, J. (editor), Mark's Standard Handbook for Mechanical Engineers, New York, McGraw Hill Book Co, 1967 - This reference provided the emissivity values for galvanized steel and aluminum foil, and a value for the Stephan-Boltzman constant.

6. S&L DIT LS-EPED-0269, dated 2-16-94 (attached).

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XIII. COMPUTER FILE LISTING

darmatt	mcd	32263	03-04-94	2:30p	Mathcad
newcalc	wp	89099	03-04-94	4:27p	Wordperfect
readme		(**)	03-04-94	(**)	DOS Edit text file

XIV. ATTACHMENTS

A. "Tests at Braidwood Station on the Effects of Fire Stops on the Ampacity Rating of Power Cables" (Ref 2)

B. Table 7-4 of Heat Transfer by Holman (Ref 3)

C. Page 5 of Section 502.4 of the "Heat Transfer Data Book" (Ref 4)

D. Page 4-108 and 4-111 of Mark's Standard Handbook for Mechanical Engineers (Ref 5)

E. S&L DIT LS-EPED-0269 (Ref 6)

TESTS AT BRAIDWOOD STATION ON THE EFFECTS OF FIRE STOPS ON THE AMPACITY RATING OF POWER CABLES

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INTRODUCTION

A fire stop is a physical barrier constructed at a conduit or cable tray penetration through a wall or floor for the purpose of preventing the spread of a fire along the cable tray or conduit system from one area to another. The fire-stop material must completely surround and enclose the cable and tray in order to form a fire-resistant barrier. The fire-stop material surrounding the cables is required to have reasonably good insulating qualities and may therefore be expected to have a relatively high thermal resistance. Consequently, the maximum temperature of the conductor inside the fire stop is expected to be higher than the maximum temperature of the conductor outside the fire stop. The current-carrying capacity of cables passing through fire stops may, therefore, have to be reduced to prevent the maximum conductor temperature within the fire stop from exceeding the rated insulation temperature.

To investigate the impact of fire stops on the ampacity rating of cables, Sargent & Lundy and Commonwealth Edison Company conducted a series of fire-stop cable ampacity tests over a time period extending from December 1979 through September 1980. The results of these tests were used to design and verify a computer program developed to evaluate cable ampacity deratings for various fire-stop designs. This paper describes the test setup and procedures followed for the different types of tests conducted and presents the test results and the conclusions that can be drawn from these results.

TEST SETUP

The tests were conducted at the Braidwood Nuclear Station at a location where cable tray penetrations are to be installed through a three-foot concrete wall. There are eight openings in the wall for cable tray penetrations that are arranged in four horizontal layers with two openings per layer. Ten cable trays were used in the test; four of these were installed in the top two openings (two per opening) and the remaining six were installed in the bottom three layers. These cable trays were loaded with the power cables to be tested. Two additional trays were installed and left empty since in the actual installation these trays will be loaded with control cables. Each cable tray was 18-inches wide, 4-inches deep and 20-feet long. The trays were installed through the penetrations and extended 8½-feet on each side of the three-foot thick wall.

The cables used in the test were both three conductor and triplexed cables selected to have a range of conductor size and voltage ratings to allow investigating the impact of these two parameters on the thermal behavior of the cable in the fire stop and, therefore, on the cable derating. Each cable was run in a cable tray through the wall penetration and looped back in the corresponding cable tray located in the other wall penetration at the same level. This looping process was repeated a number of times until a depth of fill of approximately two inches was achieved. In the cable crossover areas, the cables were supported on plywood to reduce the heat dissipation from the cables at these locations and thereby minimize the end effect on the temperature of the cables within the trays.

Figure 1 is an elevation view of the test installation showing the location of the cable trays and the size, type and number of cables used in each tray.

The temperatures of the cable conductors and jackets and the cable trays, wall surface and room ambient were monitored using No. 20 copper-constantan thermocouples that were recorded periodically during the test by a data logger. The thermocouples measuring the conductor temperature were placed in contact with the conductors by puncturing the insulation at an angle of 30 degrees and inserting the thermocouple head so that it made contact with the conductor. The thermocouple leads were taped to secure the thermocouple in place. A total of over 400 thermocouples was used.

Thermocouples were located at cross sections along the cable of each layer similar to those shown in Figure 2. Cross sections of thermocouples were located both inside and outside the wall. At each cross section thermocouples sensed both conductor and cable tray temperatures. Figure 3 shows the locations of thermocouples used in a typical cable tray. Additional

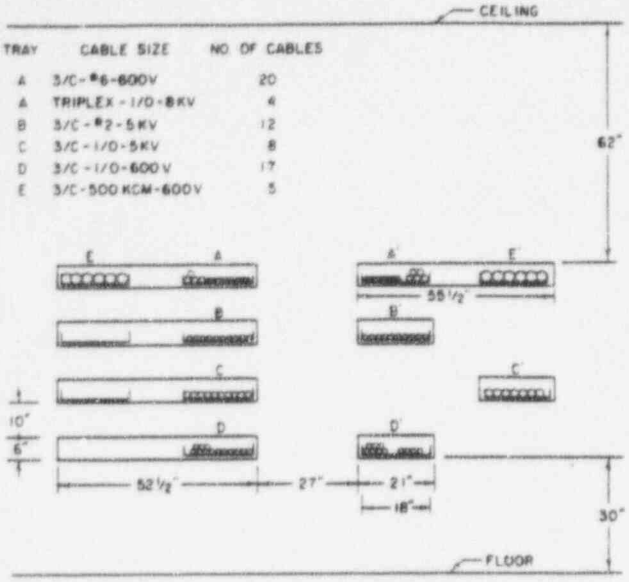

Figure 1—Elevation view of test setup.

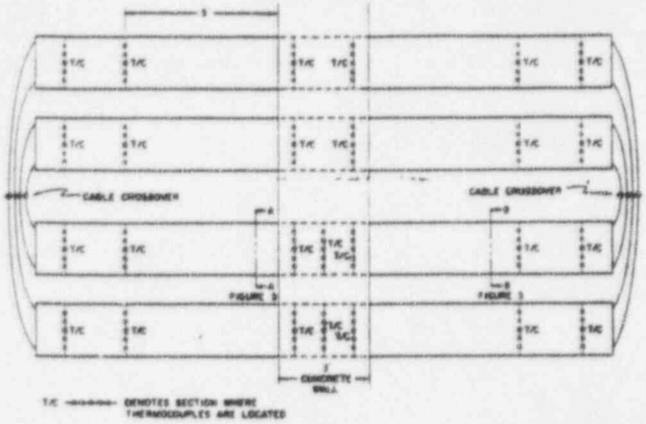

Figure 2—Top view showing thermocouple general locations.

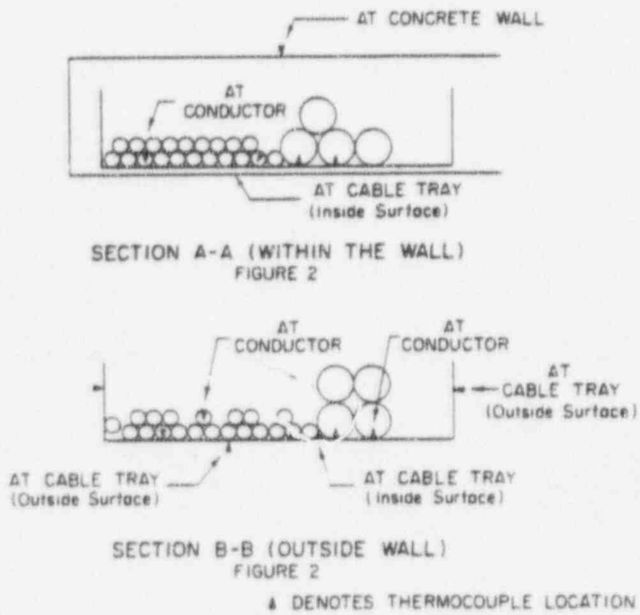

Figure 3—Representative thermocouple locations.

thermocouples were placed at different locations of the wall surface and inside the fire stop on the wall surface to sense the temperature of the concrete. The ambient temperature was sensed by thermocouples located 6 and 30 feet away from the test setup.

The test cables were energized from a manually regulated three-phase power supply. The test currents used were estimated to give a 50°C rise for cables in a cable tray in air using the Stolpe method.[1] These test currents were kept constant for all the tests conducted. In each test the cables were kept energized until all temperatures stabilized. Temperatures were recorded at hourly intervals and just prior to deenergization. Initially, the tests were run until the temperature change during a period of one hour was less than 1°C. The time required to achieve this condition varied with type of fire stop used but was usually slightly in excess of 12 hours. Later tests, however indicated that the wall temperature (and, therefore, the conductor temperature) continued to increase when the test duration was extended. Later tests were, therefore, conducted for durations exceeding 100 hours.

Figure 4 shows the test setup with the stepdown transformers in the foreground and the cable tray installation in the background.

TESTS CONDUCTED

The following is a description of the various tests conducted.

Gypsum Fire Stop—One Side Only

The first type of fire stop tested was the gypsum (Fire Code CT Gypsum) fire stop. The fire stop was installed on one side of the wall for cable trays A through E by pouring a slurry of gypsum over the cables at one side of the wall penetration. After the gypsum had set, a 6-inch section of thermalfiber (Thermalfiber CT Felt) was used to fill the opening to allow for hand application of gypsum to completely fill the wall opening. Figure 5 shows this installation. The total thickness of the fire stop in the open wall area was 9½ inches. The gypsum covered the cables over a 24-inch length in each direction.

The test was run, after allowing an initial drying period of one week, by energizing all the cables in the four layers of trays at one time and also by energizing all the cables in one layer of trays at a time. The test was terminated when the rate of rise of the cable temperature in the wall was 1.0°C per hour.

Gypsum Fire Stop—Both Sides of the Wall

This test was conducted after a second gypsum fire stop similar to the first was installed on the other side of the penetration. As in the previous test, all the cables

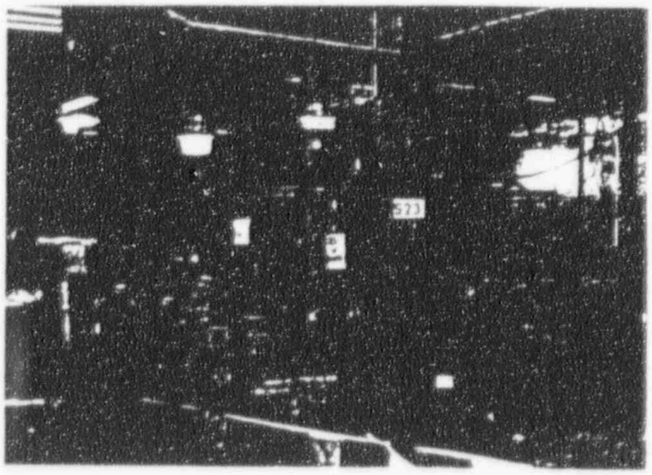

Figure 4—Test setup.

in each layer of trays were energized one layer of trays at a time and then all the cables in the four layers of trays were energized simultaneously. In each case the final temperature measurements were recorded and the test terminated when the maximum rate of rise of the cable temperature in the wall was 0.8°C per hour.

Modified Gypsum Fire Stop

A modified gypsum fire stop of a different design was tested in an attempt to reduce the impact of the fire stop on cable ampacity deratings. This fire stop consisted of a 4-inch section of thermalfiber inserted in the penetration followed by the application of a 5-inch section of gypsum. The gypsum was made into a paste rather than a slurry to make it possible to apply it within the specified thickness without flowing into the cable tray on both sides of the fire stop. The gypsum was applied flush with the concrete wall at the penetration. This fire stop was applied on only one side of the wall penetrations for cable trays A, B, D and E. The penetration for cable tray C was filled with a different type of fire stop, used for other tests.

Current was circulated through the cables for two weeks to dry the gypsum and to drive off some of the chemically combined water, leaving the gypsum partially calcined. (See paragraphs on aging under Temperature Rise Results.) The ampacity test was then first conducted with all the cables simultaneously carrying the predetermined test currents and then was repeated by energizing all the cables in one layer of cable trays at a time.

These tests were repeated after the thermal fiber in all the gypsum fire stops was removed to test the behavior of a fire stop consisting only of 5-inch thick gypsum without thermal fiber.

Silicone Fire Stops

Three different types of silicone fire stops were tested.

The 20-lb Silicone Foam Fire Stop—This fire stop was

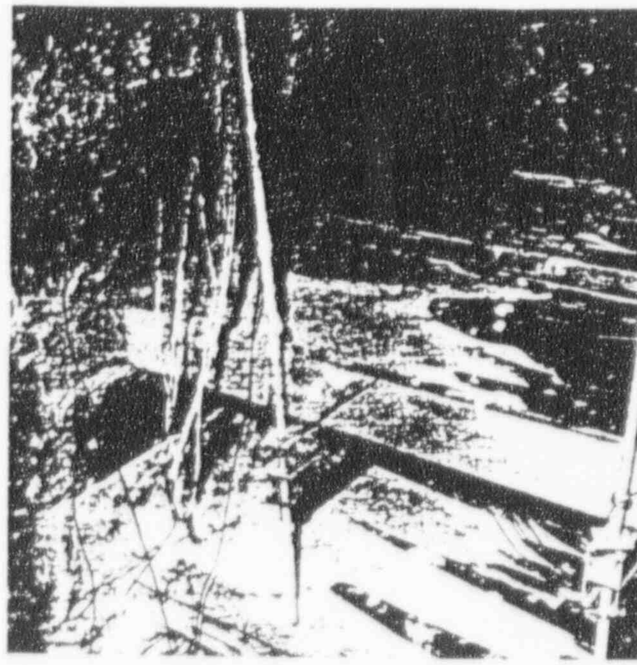

Figure 5—Fire stop installation.

installed in the penetrations for cable trays A through E. The silicone foam used had a density of 20 lb/ft^3 and was installed to a depth of 10 inches into the penetration on one side of the wall. The test was conducted with the cable in all the trays energized simultaneously and then with only the cable in the top layer of the cable trays energized. Although the duration of this test was 50 hours with all cables energized and an additional 50 hours with the top layer energized, steady-state conditions were approached but not reached. This can be attributed to the continued heat buildup in the massive structure of the concrete wall. When the fire stops were dismantled, it was observed that air pockets were trapped in the silicone.

The 80-lb Silicone Elastomer Fire Stop—The 10-inch, 20-lb silicone foam fire stops were removed and in their place silicone rubber with a density of 80 lb/ft^3 was used. These fire stops were installed in the wall penetrations for cable trays A, B, D, and E to a depth of 6 inches and in the wall penetration for cable tray C to a depth of 3 feet (completely filling the wall opening).

The test was conducted with the cable in all the trays energized simultaneously and also with only the cable in the top layer of trays energized.

As in the previous test, the presence of air pockets in the silicone was observed when the fire stops were dismantled.

The 145-lb Silicone Elastomer Fire Stop—This type of fire stop was installed in the penetrations for cable trays A through E. The silicone elastomer used had a density of 145 lb/ft^3 and was installed to a depth of 3 feet to completely fill the wall openings. The test was con-

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TABLE I
CABLE COATINGS TESTED

	Carboline	Flamastic	Gypsum	RAPCO
Conductivity, Btu/in-°F-h-ft²	3.5	2.3	0.7	0.23
Applied Thickness, in	1/16	1/16	3/8	3 Foam 3/8 Plaster

ducted with the cable in all trays energized simultaneously and also with only the caple in the top layer of trays energized.

In subsequent tests, the 145-lb silicone fire stops were left intact and their temperatures were monitored. These tests were continued for over 500 hours.

Cable Coatings

The impact of various types of cable coating on cable ampacities was also investigated. Tests were conducted on four different types of coating materials that are usually applied on cables in the tray for fire protection purposes. The four different coatings used are shown in *Table I.* Each type of cable coating was applied on the test cables in the tray section outside the wall. The temperatures of the cables before and after the application of the coating for the same test currents were recorded.

Tray Covers

The effect of covering cable trays on cable ampacity was investigated by comparing conductor temperature rise with the covers installed over the trays to the values obtained without the covers. Various types of covers were tested such as raised covers that allowed air flow and tight covers consisting of galvanized steel sheets completely covering the cable tray and sealed at both ends to prevent air flow.

Load Diversity

Tests were conducted to determine the benefits attributed to diversity of cable loading in a cable tray. This test involved just the topmost cable tray layer with only the 3/C, No. 6 600-V and the triplexed, No. 1 8-kV cables. In this test, first the No. 6 600-V cable was deenergized and the conductor temperatures of the energized No. 1/0 8-kV cable were obtained. Afterwards, the 3/C, No. 6 600-V cable was energized, the No. 1/0, 8-kV cable was deenergized, and the conductor temperatures of the No. 6, 600-V cable were obtained. These temperatures were then compared with the temperatures obtained for the same thermocouples with both cables energized simultaneously.

TEMPERATURE RISE RESULTS

Gypsum Fire Stops

The temperature readings for the first test (gypsum fire stop installed on one side of the wall) indicated that the conductor temperature rise was higher inside the wall than in the section ofcable tray far from the wall. The temperature difference ranged from 2°C to 12°C depending on conductor size and voltage rating. The difference was highest for the No. 1/0 8-kV cable and lowest for the 500 kCM and No. 1/0 600-V cables. When all the cable trays were energized simultaneously, conductor temperatures increased about 5°C both inside and outside the wall resulting in no change in the increase in conductor temperature inside the wall compared with that outside the wall.

As described earlier, at the conclusion of this test, a second identical fire stop was installed on the other side of the wall. The temperature rise due to the double-sided fire stop ranged from 7°C for the 500-kCM, 600-V cable to 16°C for the No. 1/0, 8-kV cable with only one tray layer energized at a time. When all of the tray layers were energized at once, the temperature increase inside the wall was higher, ranging from 10°C to 22°C. This demonstrated the beginning of the impact of mutual heating from the other trays in the wall. As will be discussed later, the characteristics of the gypsum changed as the tests progressed. The above results are characteristic of "fresh" gypsum. As additional testing was conducted, the gypsum "dried out" and the range of temperature rise from this fire stop reached 18°C to 31°C.

The modified gypsum fire stop described earlier was tested next. When all of the cables were energized, the temperature rise due to the fire stop ranged from 9°C for the No. 1/0 600-V cable to 28°C for the No. 1/0 8-kV cable. It should be noted that the 9°C rise was recorded for a tray at the bottom of the stack of trays, exposing it to minimum mutual heating. Removing the thermal fiber from these single-sided fire stops resulted in only a slight reduction in the fire-stop cable temperatures.

Silicone Fire Stops

The thermal conductivity of the 20-lb silicone foam first tested is 0.54 Btu/in-°F-h-ft². With all of the cables energized, this fire stop caused a temperature rise of 10°C for the No. 1/0 600-V cable to 31°C for the No 1/0 8-kV cable. This is comparable to the modified gypsum fire stop.

The thermal conductivity of the 80-lb silicone elastomer tested is 2.5 Btu/in-°F-h-ft². In the cases where the elastomer was installed to a depth of 6 inches, the temperature rise ranged from 9°C to 23°C. Where the elastomer was installed to a depth of 3 feet, the initial

temperature rise was 27°C. This increased to 33°C as the wall temperature stabilized.

The 145-lb silicone elastomer material had a thermal conductivity of 3.75 Btu/in-°F-h-ft². As the high thermal conductivity suggests, the fire stop temperature rise was the lowest of the materials tested even though the three-foot wall was filled with this elastomer. The temperature rise with all the trays energized ranged from 6°C to 12°C. After an additional 500 hours of testing, the maximum temperature rise stabilized at 19°C.

Other Test Results

The results of the cable coating tests indicate that the increase in conductor temperature with RAPCO coating applied ranged from 40°C to 80°C. This is, in our view, too excessive to make RAPCO a practical coating method for power cables. RAPCO, however, can be used for control and instrumentation cables. The "fresh" gypsum coating resulted in an average conductor temperature increase of about 7°C. Further "drying" of the gypsum coating resulted in more than doubling the temperature increase. The conductor temperature increase attributed to the Carboline and Flamastic coatings was moderate and can be ignored. The relatively high thermal conductivity and the moderate thickness of the applied coating explain the minimal impact of the Carboline and Flamastic coatings on cable ampacity. It was even observed that the application of either of these two types of coating actually resulted in a reduction, rather than an increase, in the temperature of some of the test conductors.

Tests on raised tray covers resulted in a conductor temperature increase of 5°C, while tight covers resulted in conductor temperature increases ranging from 15°C to 22°C.

The results for the load diversity test indicated 5°C to 8°C reduction in conductor maximum temperatures when the amount of heat generated in the tray is reduced in half. This is the minimum benefit that can be derived from 50 percent diversity. The maximum benefit that can be derived from 50 percent diversity with uniform distribution of unloaded cables was calculated to be 25°C. Actual installations will have a benefit ranging between these two values.

Aging of Fire-stop Material

One unexpected but explainable result of the tests was the continuing increase in the temperature rise of the gypsum fire stops.

Gypsum is a cement-like material to which water is added to make a mixture with a consistency appropriate to the method of application (spray, trowel, etc.). A drying period of three to four days is necessary for the material to reach its normal mechanical strength. During this period, most of the free moisture in the gypsum mixture is given off to the atmosphere. This process may be accelerated by heating the material.

Calcining, which is the process whereby heat drives the chemically combined water out of the gypsum, begins at about 70°C. When calcining takes place, the thermal conductivity of the gypsum decreases, making the material a better heat insulator. The calcining process is partially reversible if all of the chemically combined water has not been driven out. Also, the calcinated gypsum seems to lose some of its mechanical strength.

Preheating was done in the first tests to accelerate the drying process to remove the free water from the material so that it would not influence the ampacity test results. It was, however, noted during the first tests that the temperature in the fire stop continued to increase after the initial drying period, indicating that partial calcining was taking place. As a result of this phenomenon, instead of terminating the test when the rate of temperature rise of the cable in the wall was between .8°C and 1.0°C per hour, as in the initial tests, subsequent tests were terminated when there was no measurable rate of temperature rise.

Analysis of gypsum from the Braidwood fire stops by both the material vendor and the Commonwealth Edison Company showed that a high percentage of the chemically combined water had in fact been driven off. It should be noted, however, that the fire stops were exposed to temperature in the range of 100°C to 120°C. The temperature range the gypsum is expected to be exposed to in normal service is between 60°C and 80°C.

COMPARISON OF TEST RESULTS WITH ICEA/NEMA AMPACITIES

The ampacity of the test cables based on their measured temperatures was compared with the ampacities given in ICEA-NEMA Standards.[2] The test results show that the ICEA ampacities were conservative for the No. 6 and No. 1/0 600-V cables; agreed with the tests results for the 500-kCM 600-V cable; and were high for the medium-voltage cables. It can be concluded that ICEA can give conservative results for smaller cables or for high depth of fills where uniform cable layout can easily be achieved. However, wherever uniformity of cable layout is not maintained, the ICEA ampacities can be on the optimistic side. Since uniformity of cable layout cannot be ensured with the installation techniques normally used in power plants, we feel that no credit can be taken for the theoretical conservatism that may exist in the ICEA tables.

DERATING FACTORS

The derating for a cable system can be shown from basic heat transfer theory to be:

$$\text{Derating} = 1 - (\Delta t_1/\Delta t_2)$$

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TABLE II
AMPACITY DERATING AT FIRE STOPS (3-IN WALL, 10 TRAY PENETRATIONS)

Type of Fire Stop	Derating in Percent* Conductor Type #1/0 8 kV	#2 5 kV	#1/0 5kV	#6 600 V	#1/0 600 V	500kCM 600 V
Gypsum fire stop at both sides of wall (each 3½" gypsum-6" thermal fiber	32	30	28	30	22	26
Modified gypsum fire stop on one side of wall (5" gypsum-4" thermal fiber	22	21	—	18	8	13
10" 20-lb/ft³ silicone** fire stop on one side of wall	23	19	20	17	8	14
6" 80-lb/ft³ silicone** fire stop on one side of wall	19	15	22***	12	8	11
3' 145-lb/ft³ silicone fire stop	16	10	15	13	10	9

$$\text{*Derating (\%)} = 100\,\frac{\text{Ampacity in Tray} - \text{Ampacity in Fire Stop}}{\text{Ampacity in Tray}}$$

**These tests approached steady-state conditions but did not completely stabilize.
***This penetration had a 3' fire stop. The derating at steady-state went up to 25%.

TABLE III
AMPACITY DERATING DUE TO
CABLE COVERINGS ON AMPACITY

Application	Derating, %*
Raised pan covers	5
Tight pan covers	15
RAPCO coating (3" foam, ⅜" plaster)	40
Gypsum (⅜" thick) coating	15
Flamastic ($^1/_{16}$" thick) coating	0
Carboline ($^1/_{16}$" thick) coating	0

*Derating (%)

$$= 100\,\frac{\text{Ampacity in Tray} - \text{Ampacity With Covers or Coating}}{\text{Ampacity in Tray}}$$

where Δt_1 and Δt_2 are conductor temperature rise above ambient at the cable tray and fire stop, respectively. This formula can be used to obtain the derating due to the fire stop or coating using test data to derive the temperature rise over the ambient temperature for the cable tray outside the treated area and the rise above ambient inside the fire stop or coated area.

The calculated derating factors for the various types of fire stops tested are given in *Table II*, and the derating factors for coatings and covers are given in *Table III*.

A number of miscellaneous factors seemed to affect the amount of derating caused by the fire stop:

1. Cable Size—The smaller the conductor size, the greater the increase in temperature rise within the fire stop.
2. Cable Insulation—The greater the voltage rating of the cable and, therefore, the insulation thickness, the greater the increase in temperature rise within the fire stop.
3. Cable Layout—An even and uniform layout of cables in the tray results in lower conductor temperatures. Conversely, random cable configurations and the crowding of cables into one location in the tray results in increasing the temperature in the crowded part of the tray. However, an effort is normally made to improve the layout of the cables at the fire stop. The thermal benefits resulting from the improved cable configuration at the fire stop tend to reduce the increase in conductor temperature rise at the fire stop and, therefore, reduce the magnitude of the required derating. These benefits, although difficult to quantify, indicate a measure of conservatism in the derating factors given in *Table II* since the table is based on random cable laid both inside and outside the wall.

COMPUTER PROGRAM

Based on the temperature values measured at the various critical locations in the test setup, a computer program was developed to evaluate conductor temperature rise within fire stops by modeling the thermal characteristics and physical configuration of the wall, the fire stop, the cables, and the cable tray. The test results were used to define some of the boundary conditions in the heat flow simulation. Values calculated by the program show reasonable agreement with measured values.

The program utilized network theory and finite difference techniques to solve the heat problem. The modeling method used simulates all the available heat flow paths from the cables in the fire stop to the ambient. These paths include longitudinal heat conduction along the cable tray and the radial heat conduction through the fire stop and concrete wall. The heat is then dissipated by convection and radiation from the cable tray and concrete wall.

The computer model can evaluate the required derating for fire stops of different materials, physical di-

TABLE IV
AMPACITY DERATING AT 6" HIGH FIRE STOPS
#1/0, 5-KV CABLE

	Derating in Percent*					
	Single Tray Wall Thickness			Multiple Trays Wall Thickness		
Type Of Fire Stop	12"	24"	36"	12"	24"	36"
Gypsum fire stop at both sides of wall (each 3½" gypsum-6" thermalfiber)	—	14	20	—	20	28
Modified gypsum fire stop on one side of wall (5" gypsum-4" thermalfiber)	5	8	12	8	12	18
10" 20-lb/ft³ silicone fire stop on one side of wall	6	9	14	10	15	23
6" 80-lb/ft³ silicone fire stop on one side of wall	5	8	11	8	12	17
10" 145-lb/ft³ silicone fire stop	3	5	7	5	7	10

$$^{*}\text{Derating (\%)} = 100\,\frac{\text{Ampacity in Tray} - \text{Ampacity in Fire Stop}}{\text{Ampacity in Tray}}$$

mensions, and as installed in walls of varying thickness. *Table IV* gives the calculated results for the derating required for a No. 1/0 5-kV cable for various types of fire stops.

CABLE LOADING IN POWER PLANT INSTALLATIONS

The method of selecting cable sizes for the various loads in the power plant incorporates conservatism (design margin) that results in the selected cables actually carrying currents much lower than their rated ampacity. This design margin should be taken into consideration if derating multiplying factors are to be applied to the ampacity of cables. To determine the typical magnitude of this design margin, an investigation was made of cable sizes and their expected loading for actual power plant installations. This investigation covered three nuclear power plants and one fossil unit. The ampacity of each cable was compared with its full load current and the total heat generated by the cables within the tray was compared with the allowable heat that will result in the rated conductor temperature rise.

The results indicated that the heat generated in the cable trays is usually less than 30 percent of the heat that would result if all the conductors in the tray were carrying their rated currents. The most heavily loaded cable tray had a heat generation equal to 62 percent of its capacity. The load currents in the power cables generally ranged from 30 percent to 80 percent of cable ampacity. The increase in conductor temperature at fire stops can, therefore, be easily accommodated in most cases without exceeding rated conductor temperature.

CONCLUSIONS

The fire-stop cable ampacity tests conducted at the Braidwood Nuclear Station were very useful in helping to determine the required cable ampacity derating for a number of different types of fire stops, cable coatings, and tray covers. The test results were helpful in developing a computer program for evaluating conductor temperatures at wall penetrations.

Based on these results, it was concluded that ampacity deratings are required for cables in fire stops. Ampacity deratings encountered in the tests ranged from 8 percent to 32 percent. The required derating factors depend on conductor size and voltage rating, on the type and size of the fire stop, and on the thickness of the wall. The heaviest derating is encountered when the standard gypsum fire stop is applied to both sides of the wall.

An investigation into the design margin in cable size selection as practiced in power plant installations revealed that this margin is large enough in most cases to accommodate the required derating. It is, therefore, concluded that it is only necessary to check the cables in the heavily loaded penetrations at the final design stages to ensure that the required derating is met when taking actual cable loading into consideration.

ACKNOWLEDGMENTS

The authors wish to express their appreciation to Messrs. C. A. Mennecke, L. R. Norberg, and S. T. Rejudkowski for their efforts in support of the test setup and conducting of the field tests, and to Mr. T. M. McCauley for his contribution to the development of the computer program.

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2. Insulated Cable Engineers Association and National Electrical Manufacturers Association, "ICEA-NEMA Standards Publication Ampacities Cables in Open-Top Cable Trays," *ICEA Pub. No.* **P-54-440**, 2nd ed; *NEMA Pub. No.* **WC51-1975**.

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Table 7-4 Simplified Equations for Free Convection from Various Surfaces to Air at Atmospheric Pressure According to McAdams [4]

Surface	Laminar, $10^4 < Gr_f Pr_f < 10^9$	Turbulent, $Gr_f Pr_f > 10^9$
Vertical planes or cylinders	$h = 0.29\left(\frac{\Delta T}{L}\right)^{1/4}$	$h = 0.19(\Delta T)^{1/3}$
Horizontal cylinders	$h = 0.27\left(\frac{\Delta T}{d}\right)^{1/4}$	$h = 0.18(\Delta T)^{1/3}$
Horizontal plates:		
Heated plates facing upward or cooled plates facing downward	$h = 0.27\left(\frac{\Delta T}{L}\right)^{1/4}$ ✓	$h = 0.22(\Delta T)^{1/3}$
Heated plates facing downward or cooled plates facing upward	$h = 0.12\left(\frac{\Delta T}{L}\right)^{1/4}$ ✓	

h in Btu/hr-ft²-°F
$\Delta T = T_w - T_\infty$, °F
L = vertical or horizontal dimension, ft
d = diameter, ft

7-7 SIMPLIFIED EQUATIONS FOR AIR

Simplified equations for the heat-transfer coefficient from various surfaces to air at atmospheric pressure and moderate temperatures are given in Table 7-4.

Example 7-1

Steam at 500°F flows through a 12-in.-OD pipe which is exposed to atmospheric air at 50°F. Calculate the heat transfer per foot of length.

Solution We first determine the Grashof-Prandtl number product and then select the appropriate constants from Table 7-2 for use with Eq. (7-23). The properties of air are evaluated at the film temperature.

$$T_f = \frac{T_w + T_\infty}{2} = \frac{500 + 50}{2} = 275°\text{F}$$

$$\rho = 0.054 \text{ lb}_m/\text{ft}^3$$

$$c_p = 0.24$$

$$\mu = 1.57 \times 10^{-5} \text{ lb}_m/\text{ft-sec} = 0.0565 \text{ lb}_m/\text{ft-hr}$$

$$k = 0.0197 \text{ Btu/hr-ft-°F}$$

$$\beta = 1.36 \times 10^{-3} \text{ °F}^{-1}$$

$$Gr_d\, Pr = \frac{c_p g \beta (T_w - T_\infty)\rho^2 d^3}{k\mu}$$

$$= \frac{(0.24)(32.2)(3600)^2(1.36 \times 10^{-3})(500 - 50)(0.054)^2(1)^3}{(0.0197)(0.0565)}$$

$$= 1.60 \times 10^8$$

HOLLOW RECTANGULAR CROSS SECTION - TWO-DIMENSIONAL HEAT FLOW

Inner and Outer Surface Each at a Different Uniform Temperature
Heat Input at One Surface (The Warmer One)

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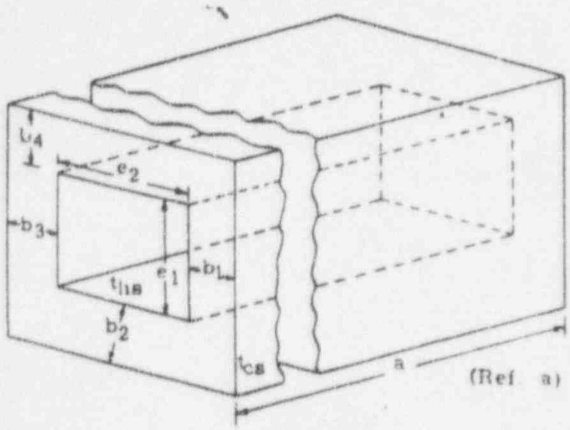
Maximum Temperature*

$t_{hs} - t_{cs} = qR$

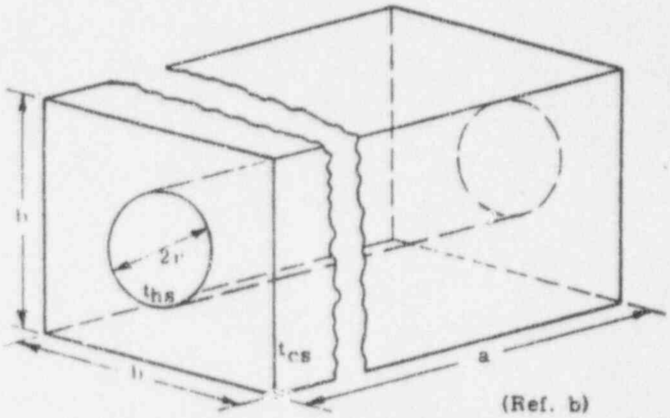
t_{hs} = temperature of hot surface

t_{cs} = temperature of cold surface

Thick Walls



(Ref. a)



(Ref. b)

$$R = \frac{1/ka}{\left(\frac{e_1}{b_1} + .54\right) + \left(\frac{e_2}{b_2} + .54\right) + \left(\frac{e_1}{b_3} + .54\right) + \left(\frac{e_2}{b_4} + .54\right)}$$

$$R = \frac{1}{2\pi ak} \ln\left(1.08 \frac{b}{2r}\right)$$

REFERENCES

a. McAdams, Heat Transmission, 2nd edition, p. 26.
b. Kutateladze, S. S., "Fundamentals of Heat Transfer," Academic Press, N. Y., 1963, p. 89.

* For symbols, see Section G502.1, p. 1, and sketches above.

RADIANT-HEAT TRANSFER

BY

Hoyt C. Hottel and Adel F. Sarofim

REFERENCES: McAdams, "Heat Transmission," 3d ed. (chap. IV by Hottel), McGraw-Hill. Jakob, "Heat Transfer," vols. I and II, Wiley. Viskanta and Grosh, Applied Mechanics Reviews, 17, 91, 1964.

A heated body loses energy continuously by radiation, at a rate dependent on the shape, the size, and, particularly, the temperature of the body. This emitted radiation is capable of passage to a distant body, where it may be absorbed, reflected, scattered, or transmitted.

Consider a pencil of radiation, defined as all the rays passing through each of two small, widely separated areas dA_1 and dA_2. The rays at dA_1 will have a solid angle of divergence $d\Omega_1$, equal to the apparent area of dA_2 (viewed from dA_1) divided by the square of the separating distance. Let the normal to dA_1 make the angle θ_1 with the pencil. The flux density q [energy/(time)(area normal to beam)] per unit solid angle of divergence is called the intensity I, and the flux dQ (energy/time) through area dA_1 (of apparent area $dA_1 \cos \theta_1$ normal to the beam) is therefore given by

$$dQ = dA_1 \cos \theta_1 \, dq_1 = I \, dA_1 \cos \theta_1 \, d\Omega_1 \qquad (1)$$

The intensity I along a pencil, in the absence of absorption or scatter, is constant (unless the beam passes into a medium of different refractive index n; $I_1/n_1^2 = I_2/n_2^2$).

The emissive power of a surface is the flux density [energy/(time)(surface area)] due to emission from it throughout a hemisphere. If the intensity I of emission from a surface is independent of the angle of emission, Eq. (1) may be used to show that the surface emissive power is πI, though the emission is throughout 2π steradians.

Black-body Radiation

Engineering calculations of thermal radiation from surfaces is best keyed to the radiation characteristics of the black body, or ideal radiator. The characteristic properties of a black body are that it absorbs all the radiation incident on its surface and that the quality and intensity of the radiation it emits are completely determined by its temperature. The total radiative flux throughout a hemisphere from a black surface of area A and absolute temperature T is given by the Stefan-Boltzmann law: $Q = A\sigma T^4$ or $q = \sigma T^4$. The Stefan-Boltzmann constant has the value 0.1713×10^{-8} Btu/(sq ft)(hr)(deg R)^4, 5.67×10^{-5} ergs/(sq cm)(sec)(deg K)^4; 5.67×10^{-8} watts/(sq m)(deg K)^4, or 1.00×10^{-8} chu/(sq ft)(hr)(deg K)^4. From the above definition of emissive power, σT^4 is the total emissive power of a black body, called E; and the intensity I_B of emission from a black body is E/π, or $\sigma T^4/\pi$.

The spectral distribution of energy flux from a black body is expressed by Planck's law

$$E_\lambda \, d\lambda = \frac{c_1 \lambda^{-5}}{e^{c_2/\lambda T} - 1} d\lambda \qquad (2)$$

wherein $E_\lambda \, d\lambda$ is the hemispherical flux density lying in the wavelength range λ to $\lambda + d\lambda$. With E_λ (called the monochromatic emissive power) in ergs/(sq cm)(cm)(sec), λ in cm, and T in deg K, the values of c_1 and c_2 are 3.74×10^{-5} erg cm^2/sec and 1.4387 cm deg K. It may be shown from Planck's law that, of the total energy flux from a

black body at any temperature, th[e] ... only on λT. Values of f versus λT

Table 1. Fraction f ... (λT ...

λT	1200	1600	1800	200[0]
f	0.002	0.020	0.039	0.0[illegible]
λT	3400	3600	3800	400[0]
f	0.362	0.404	0.443	0.4[illegible]
λT	6500	7000	7600	846[illegible]
f	0.776	0.808	0.839	0.8[illegible]

Table 1 indicates that half of bl[ack] ... [len]gth given by λT = 4107 microns ... 5426 spans half the energy. The ...

Radiative Exchan[ge]

The ratio of the total radiating p[ower] ... same temperature is called the e[mittance] ... [an]d, the emissivity), designated by ... differentiate monochromatic, direc[tional] ... from the total hemispherical value. ... [a]bsorbed is called the absorptance ... appended, the first to identify t[he] ... [id]entify the quality of the incident ra[diation] ... of a surface at temperature T_1 equ[als] ... radiation from a source at its o[wn] ... [rad]iating power is also a poor absorb[er] ... own temperature. Under practi[cal] ... [an]d absorptivity α_λ are the same. ... called gray, and $\epsilon_\lambda = \alpha_\lambda = \epsilon = \alpha$ ... [te]mperature, the total emittance or ... [wit]h its temperature.

Consider radiative exchange betw[een] ... [blac]k surroundings at T_2. The net ...

$Q_{1=2} =$ ...

[F]rom what has preceded, it is clear ...

$$\epsilon_1 = \int_0^1 \epsilon_\lambda \, df_{\lambda T_1}$$

... that ϵ_1 (or α_{12}) is the area under ... (or T_2) from Table 1. A selective ... low (high) value as λ increases. ... [surf]aces are markedly different wh[en] ... [tem]perature) and T_2 = 10800 R (e ... 0.2 for a white paint, but ϵ_1 c... ... of copper oxide on bright alum[inum] ... Although values of emittances ar[e] ... [re]al and imaginary components ... [struc]ture of the surface layer, some ... [Po]lished Metals. (1) ϵ_λ is quite ... [close]ly approximated by 0.00365 $\sqrt{}$ ... [mi]crons; at shorter wavelengths, ... in the visible (0.4–0.7μ). ϵ_λ is ... absolute temperature ($\epsilon_\lambda \propto \sqrt{T}$ ...

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7-1.0̲ nd decreases slightly with
ance is substantially proportional to
re, $\epsilon_n = 0.58T\sqrt{r_0/T_0}$, where T is in
t T_1 for radiation from a black or gray
d at the geometric mean of T_1 and T_2.

The ratio of hemispherical to normal
ittance (absorptance) varies from 1.33
very low ϵ's (α's) to about 1.03 at an
) of 0.4.

Unless extraordinary pains are taken
prevent oxidation, however, a metallic
rface may exhibit several times the
ittance or absorptance of a polished
ecimen. The emittance of iron and
eel, for example, varies widely with
gree of oxidation and roughness—clean
etallic surfaces have an emittance of
om 0.05–0.45 at ambient temperatures
0.4–0.7 at high temperatures; oxidized
d/or rough surfaces range from 0.6–0.95
low temperatures to 0.9–0.95 at high
mperatures.

Refractory Materials. Grain size and
ncentration of trace impurities are im-
rtant. (1) Most refractory materials
ve an ϵ_λ of 0.8 to 1.0 at wavelengths
yond 2 to 4 microns; ϵ_λ decreases rapidly
ward shorter wavelengths for materials
at are white in the visible but retains its
gh value for black materials such as FeO
d Cr_2O_3. Small concentrations of FeO
d Cr_2O_3 or other colored oxides can cause
arked increases in the emittance of ma
rial are normally white. ϵ_λ for
fractory materials varies little with
mperature. (2) Refractory materials
nerally have a total emittance which is
gh (0.7 to 1.0) at ambient temperatures
d decreases with increase in tempera-
re; a change from 1850 to 2850 F may
use a decrease in ϵ of one-fourth to one-
ird. (3) The emittance and absorp-
nce increase with increase in grain size
er a grain-size range of 1–200 μ. (4)
he ratio ϵ/ϵ_n of hemispherical to normal
missivity of polished surfaces varies with
fractive index from 1 at $n = 0$ to 0.92
t $n = 1.5$ (common glass) and back to
.96 at $n = 3$. (5) The ratio ϵ/ϵ_n for a
rface composed of particulate matter
hich scatters isotropically varies with
om 1 when $\epsilon = 1$ to 0.8 when $\epsilon = 0.0$
ith increase in temperature of the radia
with increase in the specimen tempera
perature of the radiation source on th
at room temperature. It will be note
d aluminum (line 13), representative
oppositely to a change in the temper

ture of the radiation source. The absorptance of surfaces for sunlight may be read from the right of Fig. 1, assuming sunlight to consist of black-body radiation from a source at 10800 R.

From Fig. 1 it is seen that, when T_2 is not too different from T_1, α_{12} may be expressed

Table 2. Emissivity of Surfaces

Surface	Temp.* deg F	Emissivity*
Metals and Their Oxides		
Aluminum:		
Highly polished	440–1070	0.039–0.057
Polished	73	0.040
Rough plate	78	0.055–0.07
Oxidized at 1110 F	390–1110	0.11–0.19
Oxide	530–1520	0.63–0.26
Alloy 75ST	75	0.10
75ST, repeated heating	450–900	0.22–0.16
Brass:		
Highly polished	497–710	0.03–0.04
Rolled plate, natural	72	0.06
Rolled, coarse-emeried	72	0.20
Oxidized at 1110 F	390–1110	0.61–0.59
Chromium	100–1000	0.08–0.26
Copper:		
Electrolytic, polished	176	0.02
Comm'l plate, polished	66	0.030
Heated at 1110 F	390–1110	0.57–0.57
Thick oxide coating	77	0.78
Cuprous oxide	1470–2010	0.66–0.54
Molten copper	1970–2330	0.16–0.13
Dow metal, cleaned, heated	430–750	0.24–0.20
Gold, highly polished	440–1160	0.02–0.40
Iron and steel:		
Pure Fe, polished	350–1800	0.05–0.37
Wrought iron, polished	100–480	0.28
Smooth sheet iron	1650–1900	0.55–0.60
Rusted plate	67	0.69
Smooth oxidized iron	260–980	0.78–0.82
Strongly oxidized	100–480	0.95
Molten iron and steel	2730–3220	0.40–0.45
Lead:		
99.96%, unoxidized	260–440	0.06–0.08
Gray oxidized	75	0.28
Oxidized at 390 F	390	0.63
Mercury, pure clean	32–212	0.09–0.12
Molybdenum filament	1340–4700	0.10–0.29
Monel metal, K5700		
Washed, abrasive soap	75	0.17
Repeated heating	450–1610	0.46–0.65
Nickel and alloys:		
Electrolytic, polished	74	0.05
Electroplated, not polished	68	0.11
Wire	368–1844	0.10–0.19
Plate, oxid. at 1110 F	390–1110	0.37–0.48
Nickel oxide	1200–2290	0.59–0.86
Copper-nickel, polished	212	0.06
Nickel-silver, polished	212	0.14
Nickelin, gray oxide	70	0.26
Nichrome wire, bright	120–1830	0.65–0.79
Nichrome wire, oxid.	120–930	0.95–0.98
ACI-HW (60Ni, 12Cr): firm black ox. coat	520–1045	0.89–0.82
Platinum, polished plate	440–2960	0.05–0.17
Silver, pure polished	440–1160	0.02–0.03
Stainless steels:		
Type 316, cleaned	75	0.28
316, repeated heating	450–1600	0.37–0.66
304, 42 hr at 980 F	420–980	0.62–0.73
310, furnace service	420–980	0.90–0.97
Allegheny #4, polished	212	0.13
Tantalum filament	2420–5430	0.194–0.33
Thorium oxide	530–1520	0.58–0.21
Tin, bright	76	0.04–0.06
Tungsten, aged filament	80–6000	0.03–0.35
Zinc, 99.1%, comm'l, polished	440–620	0.05
Galv., iron, bright	82	0.23
Galv., gray oxid.	75	0.28
Refractories, Building Materials, Paints, Misc.		
Alumina, 50μ grain size	1850–2850	0.39–0.28
Alumina-silica, cont'g	1850–2850	
0.4% Fe_2O_3		0.61–0.43
1.7% Fe_2O_3		0.73–0.62
2.9% Fe_2O_3		0.78–0.68
Al paints (vary with am't lacquer body, age)	212	0.27–0.67
Asbestos	100–700	0.93–0.95
Candle soot; lampblack-water glass	70–700	0.95 ± 0.01
Carbon plate, heated	260–1160	0.81–0.79
Oil layers:		
Lube oil, 0.01" on pol. Ni	68	0.82
Linseed, 1–2 coats on Al	68	0.56–0.57
Rubber, soft gray reclaimed	76	0.86
Misc. I: shiny black lacquer, planed oak, white enamel, serpentine, gypsum, white enamel paint, roofing paper, lime plaster, black matte shellac	70	0.87–0.91
Misc. II: glazed porcelain, white paper, fused quartz, polished marble, rough red brick, smooth glass, hard glossy rubber, flat black lacquer, water, electrographite	70	0.92–0.96

* When two temperatures and two emissivities are given they correspond, first to first and second to second, and linear interpolation is permissible.

SARGENT & LUNDY ENGINEERS

DESIGN INFORMATION TRANSMITTAL

X SAFETY-RELATED	NON-SAFETY-RELATED	DIT No. - LS-EPED-0269

Page 1 of 3

To S. Z. Haddad - 25

CLIENT Commonwealth Edison Company

STATION LaSalle UNIT(S) 1 and 2

PROJECT NO(S) 9376-020 T/C E00240

SUBJECT Calculation of Power Cable Ampacity Derating Factors for 1-Hour rated cable tray fire barriers

MODIFICATION OR DESIGN CHANGE NUMBER(S) N/A

D.A. Kalczak	EPED	D.A. Kalczak	03-16-94
PREPARER (PLEASE PRINT NAME)	DIVISION	PREPARER'S SIGNATURE	ISSUE DATE

STATUS OF INFORMATION (This information is approved for use. Design information, approved for use, that contains assumptions or is preliminary or requires further verification (review) shall be so identified.)

This information is approved for use. No further verification is required.

IDENTIFICATION OF THE SPECIFIC DESIGN INFORMATION TRANSMITTED AND PURPOSE OF ISSUE (List any supporting documents attached to DIT by its title, revision and/or issue date, and total number of pages for each supporting document.)

See Page 2

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SOURCE OF INFORMATION

Calc. No. N/A N/A (Rev. and/or date) Report No. N/A N/A (Rev. and/or date)

Other See Page 3

DISTRIBUTION

R. A. Parson - 21
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WIN 0450

Form GQ-3.17.1 Rev. 2

Task 1:

Determine the amount of ampacity derating required for a firestop configuration using a layer of Thermo-Lag 330-1 fire barrier material and a layer of Darmatt KM1 fire barrier material. The Thermo-Lag fire barrier material is currently installed over the existing power cable trays at Unit 1 routing points 163A, 164A and 165A and Unit 2 routing points 153A, 154A and 155A. The layer of Darmatt will be applied directly over the Thermo-Lag material due to difficulty in completely removing the existing Thermo-Lag from the cable trays. There will be no credit taken for the existing Thermo-Lag as a rated 1-hour fire barrier. The enveloping layer of Darmatt material will provide the required 1-hour rating. However, the impact of both fireproofing materials must be considered in evaluating power cable ampacity derating.

Task 2:

Perform a similar evaluation to Task 1 noted above, except that the existing Thermo-Lag fire barrier material will be removed from the top section of the power cable trays prior to installing the outer covering of the Darmatt material.

The derating factors calculated for Tasks 1 and 2 will be entered into the LaSalle SLICE program by EPED to evaluate the impact of the derating relative to power cable ampacity.

Cable Tray Data:
Size- 4"x30"
Type- #14 gauge galvanized steel with solid bottom
Depth of fill- 0.91"

Power Cable Data:
Surrounding Ambient Temperature- 40°C
Rated Conductor Temperature- 90°C

Thermo-Lag 330-1 Material Data:
Thickness- 0.5"
Emissivity- 0.3"
Thermal Conductivity- 0.1 BTU/hr-ft-°R

Darmatt Material Data:
Thickness- 27mm(-0%,+15%)
Emissivity- 0.6
Thermal Conductivity- 0.0653 BTU/hr-ft-°F @ 60°C mean temperature

$27mm \frac{1 inch}{25.4mm} (1.15) = 1.23''$

References:

Cable tray data was taken from Drawing 1E-0-3074B, Revision D and S&L Specification J-2560.

The Thermo-Lag material data was taken from S&L Calculation 4266/19BC31, Revision 0.

The Darmatt material data was taken from a TRANSCO PRODUCTS INC. Facsimile dated 02-14-94.

The maximum ambient temperature of 40°C is taken from the LaSalle County Station UFSAR Section 3.11.

The 90°C conductor temperature rating can be assumed.

ATTACHMENT C

Sargent & Lundy Engineers Letter, dated March 10, 1994, concerning LaSalle County Station Power Cable Ampacity Assessment

D.A. Kolczak

SARGENT & LUNDY
ENGINEERS
FOUNDED 1891
55 EAST MONROE STREET
CHICAGO, ILLINOIS 60603-5780
(312) 269-2000

SCE-07113
March 10, 1994
Project No. 9376-020

Commonwealth Edison Company
LaSalle County Nuclear Station
Units 1 and 2

Power Cable Ampacity Assessment
Engineering Support for Resolving
Regulatory Issues Related to
Thermo-Lag 330-1 Fire Barriers
Modification No.: N/A
System Code: FP
Safety-Related: Yes
WIN 0450

Mr. J. W. Gieseker
Site Engineering and Construction Manager
Commonwealth Edison Company
LaSalle County Nuclear Station
R.R. #1, P.O. Box 220
2601 North 21st Road
Marseilles, Illinois 61341

Dear Mr. Gieseker:

Sargent & Lundy has completed its power cable ampacity assessment for the affected power cable tray routing points utilizing the installation of a one-hour Darmatt KM1 fire barrier over the existing Thermo-Lag 330-1 fire barrier material.

Sargent & Lundy Calculation 4266/19G52, Revision 0, dated March 4, 1994, determined the ampacity derating required for two configurations. Configuration 1 calculated a derating factor with a one-hour rating of Darmatt firewrap material covering the existing Thermo-Lag 330-1 material over the top, bottom, and sides of the 4" x 30" power cable trays. Configuration 2 calculated a derating factor similar to configuration 1 except that the top layer of the existing Thermo-Lag 3301- material was removed. The results of this calculated determined derating factors of 0.57 and 0.59 for Configuration 1 and Configuration 2 respectively.

Mr. J. W. Gieseker
Commonwealth Edison Company

Since the derating factor of 0.57 has the greater impact upon ampacity derating, this value was entered into Sargent & Lundy Interactive Cable Engineering (SLICE) program for affected routing points 163A, 164A, 165A, 153A, 154A, and 155A. The "Cable Tray Power Cable Ampacities Selected Cables" Report S110 was generated for the affected power cable routing points. The results from this report show that the calculated ampacities for the affected power cables are greater than their respective full load currents. A copy of this report has been attached to this letter.

Therefore, the one-hour rating of Darmatt KM1 firewrap material can be applied directly over the existing Thermo-Lag 330-1 without any adverse affect upon cable ampacity derating.

If you have any questions concerning this subject, please call me at (815) 357-6761 (extension 2103).

Yours very truly,

D. A. Kolczak

D. A. Kolczak
Senior Electrical Project Engineer

DAK:slg
CECo DDL DC: C020
Attachment
Copies:

CHRON System	(1/1 via Hardcopy)
D. S. Berkman	(1/0 via CCMail)
S. Javidan	(1/0 via CCMail)
R. W. Tomala	(1/1 via Hardcopy)
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D. A. Kolczak	(1/1 via Hardcopy)

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CABLE TRAY POWER CABLE AMPACITIES - SELECTED CABLES (S110) LASALLE UNIT 1 PROJECT NO: 7705-03 03/09/94 PAGE: 1

TRAY POINT: 163A

CABLE NUMBER	PULLED STATUS	TYPE CODE	DIA-METER	AC RESIST OHMS/100FT	FL CURRENT	PROJ FLC USED	CALCULATED AMPACITY	FREE AIR AMPAC USED	FLC/ AMPACITY	EXCEED FLAG
1DG012	P	03006	1.50	0.01280000	98.0		106.06		0.92	
1DG020	P	03066	1.00	0.05130000	14.0		35.32		0.40	
1DG022	P	03066	1.00	0.05130000	14.0		35.32		0.40	
1DG037	P	02146	0.50	0.00335000	7.5	*	20.00	*	0.38	
1DG038	P	03066	1.00	0.05130000	24.0		35.32		0.68	
1DG046	P	03146	0.50	0.00335000	5.0		20.00	*	0.25	
1DG054	P	03146	0.50	0.00335000	1.9		20.00	*	0.09	
1DG232	P	03106	0.70	0.00132500	1.4		34.40	*	0.04	
1DO038	P	03146	0.50	0.00335000	6.3		20.00	*	0.32	
1DT017	P	03106	0.70	0.00132500	15.0	*	34.40	*	0.44	
1DT023	P	03106	0.70	0.00132500	15.0	*	34.40	*	0.44	
1FC022	P	03006	1.50	0.01280000	88.0		106.06		0.83	
1FC047	P	02146	0.50	0.00335000	7.5	*	20.00	*	0.38	
1RH196	P	03506	2.70	0.00275000	228.0		389.60	*	0.59	
1RH197	P	02146	0.50	0.00335000	7.5	*	20.00	*	0.38	
1RH201	P	03506	2.70	0.00275000	228.0		389.60	*	0.59	
1RH202	P	02146	0.50	0.00335000	7.5	*	20.00	*	0.38	
1VD012	P	03026	1.20	0.02030000	50.0		67.37		0.74	
1VD018	P	03146	0.50	0.00335000	4.6		20.00	*	0.23	
1VY022	P	03146	0.50	0.00335000	7.0		20.00	*	0.35	

WIDTH OF TRAY: 30.00
DEPTH OF FILL: 0.91
HEAT INTENSITY: 7.52
DERATING FACTORS:
AMBIENT: 1.00 DERATING FACTOR NOT DEFINED; STANDARD DERATING FACTOR USED
COVERS: 1.00 DERATING FACTOR NOT DEFINED; STANDARD DERATING FACTOR USED
FIRE SEAL1: 0.57
FIRE SEAL2: 1.00 DERATING FACTOR NOT DEFINED; DEFAULTS TO FACTOR FIRE SEAL1
FIRE SEAL3: 1.00 DERATING FACTOR NOT DEFINED; DEFAULTS TO FACTOR FIRE SEAL2

TRAY POINT: 164A

CABLE NUMBER	PULLED STATUS	TYPE CODE	DIA-METER	AC RESIST OHMS/100FT	FL CURRENT	PROJ FLC USED	CALCULATED AMPACITY	FREE AIR AMPAC USED	FLC/ AMPACITY	EXCEED FLAG
1DG012	P	03006	1.50	0.01280000	98.0		106.06		0.92	
1DG020	P	03066	1.00	0.05130000	14.0		35.32		0.40	
1DG022	P	03066	1.00	0.05130000	14.0		35.32		0.40	
1DG037	P	02146	0.50	0.00335000	7.5	*	20.00	*	0.38	
1DG038	P	03066	1.00	0.05130000	24.0		35.32		0.68	
1DG046	P	03146	0.50	0.00335000	5.0		20.00	*	0.25	
1DG054	P	03146	0.50	0.00335000	1.8		20.00	*	0.09	
1DG232	P	03106	0.70	0.00132500	1.4		34.40	*	0.04	

'RAY POINT: 164A CONTINUED...

1DO038	P	03146	0.50	0.00335000	6.3		20.00	*	0.32	
1DT017	P	03106	0.70	0.00132500	15.0	*	34.40	*	0.44	
1DT023	P	03106	0.70	0.00132500	15.0	*	34.40	*	0.44	
1FC022	P	03006	1.50	0.01280000	88.0		106.06		0.83	
1FC047	P	02146	0.50	0.00335000	7.5	*	20.00	*	0.38	
1RH196	P	03506	2.70	0.00275000	228.0		389.60	*	0.59	
1RH197	P	02146	0.50	0.00335000	7.5	*	20.00	*	0.38	
1RH201	P	03506	2.70	0.00275000	228.0		389.60	*	0.59	
1RH202	P	02146	0.50	0.00335000	7.5	*	20.00	*	0.38	
1VD012	P	03026	1.20	0.02030000	50.0		67.37		0.74	
1VD018	P	03146	0.50	0.00335000	4.6		20.00	*	0.23	
1VY022	P	03146	0.50	0.00335000	7.0		20.00	*	0.35	

IDTH OF TRAY: 30.00
EPTH OF FILL: 0.91
EAT INTENSITY: 7.52
ERATING FACTORS:
AMBIENT: 1.00 DERATING FACTOR NOT DEFINED; STANDARD DERATING FACTOR USED
COVERS: 1.00 DERATING FACTOR NOT DEFINED; STANDARD DERATING FACTOR USED
FIRE SEAL1: 0.57
FIRE SEAL2: 1.00 DERATING FACTOR NOT DEFINED; DEFAULTS TO FACTOR FIRE SEAL1
FIRE SEAL3: 1.00 DERATING FACTOR NOT DEFINED; DEFAULTS TO FACTOR FIRE SEAL2

'RAY POINT: 165A

CABLE NUMBER	PULLED STATUS	TYPE CODE	DIA-METER	AC RESIST OHMS/100FT	FL CURRENT	PROJ FLC USED	CALCULATED AMPACITY	FREE AIR AMPAC USED	FLC/ AMPACITY	EXCEED FLAG
1DG012	P	03006	1.50	0.01280000	98.0		106.06		0.92	
1DG020	P	03066	1.00	0.05130000	14.0		35.32		0.40	
1DG022	P	03066	1.00	0.05130000	14.0		35.32		0.40	
1DG037	P	02146	0.50	0.00335000	7.5	*	20.00	*	0.38	
1DG038	P	03066	1.00	0.05130000	24.0		35.32		0.68	
1DG046	P	03146	0.50	0.00335000	5.0		20.00	*	0.25	
1DG054	P	03146	0.50	0.00335000	1.8		20.00	*	0.09	
1DG232	P	03106	0.70	0.00132500	1.4		34.40	*	0.04	
1DO038	P	03146	0.50	0.00335000	6.3		20.00	*	0.32	
1DT017	P	03106	0.70	0.00132500	15.0	*	34.40	*	0.44	
1DT023	P	03106	0.70	0.00132500	15.0	*	34.40	*	0.44	
1FC022	P	03006	1.50	0.01280000	88.0		106.06		0.83	
1FC047	P	02146	0.50	0.00335000	7.5	*	20.00	*	0.38	
1RH196	P	-3506	2.70	0.00275000	228.0		389.60	*	0.59	
1RH197	P	02146	0.50	0.00335000	7.5	*	20.00	*	0.38	
1RH201	P	03506	2.70	0.00275000	228.0		389.60	*	0.59	
1RH202	P	02146	0.50	0.00335000	7.5	*	20.00	*	0.38	
1VD012	P	03026	1.20	0.02030000	50.0		67.37		0.74	
1VD018	P	03146	0.50	0.00335000	4.6		20.00	*	0.23	

TRAY POINT: 165A CONTINUED...

CABLE NUMBER	PULLED STATUS	TYPE CODE	DIA-METER	AC RESIST OHMS/100FT	FL CURRENT	PROJ FLC USED	CALCULATED AMPACITY	FREE AIR AMPAC USED	FLC/ AMPACITY	EXCEED FLAG
1VY022	P	03146	0.50	0.00335000	7.0		20.00	*	0.35	

WIDTH OF TRAY: 30.00
DEPTH OF FILL: 0.91
HEAT INTENSITY: 7.52
DERATING FACTORS:
AMBIENT: 1.00
COVERS: 1.00 DERATING FACTOR NOT DEFINED; STANDARD DERATING FACTOR USED
FIRE SEAL1: 0.57
FIRE SEAL2: 1.00 DERATING FACTOR NOT DEFINED; DEFAULTS TO FACTOR FIRE SEAL1
FIRE SEAL3: 1.00 DERATING FACTOR NOT DEFINED; DEFAULTS TO FACTOR FIRE SEAL2

TRAY POINT: 166A

CABLE NUMBER	PULLED STATUS	TYPE CODE	DIA-METER	AC RESIST OHMS/100FT	FL CURRENT	PROJ FLC USED	CALCULATED AMPACITY	FREE AIR AMPAC USED	FLC/ AMPACITY	EXCEED FLAG
1DG020	P	03066	1.00	0.05130000	14.0		63.20	*	0.22	
1DG022	P	03066	1.00	0.05130000	14.0		63.20	*	0.22	
1DG038	P	03066	1.00	0.05130000	24.0		63.20	*	0.38	
1DG046	P	03146	0.50	0.00335000	5.0		20.00	*	0.25	
1DG054	P	03146	0.50	0.00335000	1.8		20.00	*	0.09	
1DG232	P	03106	0.70	0.00132500	1.4		34.40	*	0.04	
1VD012	P	03026	1.20	0.02030000	50.0		110.40	*	0.45	
1VD018	P	03146	0.50	0.00335000	4.6		20.00	*	0.23	
1VY022	P	03146	0.50	0.00335000	7.0		20.00	*	0.35	

WIDTH OF TRAY: 30.00
DEPTH OF FILL: 0.20
HEAT INTENSITY: 15.40
DERATING FACTORS:
AMBIENT: 0.89
COVERS: 1.00 DERATING FACTOR NOT DEFINED; STANDARD DERATING FACTOR USED
FIRE SEAL1: 1.00 DERATING FACTOR NOT DEFINED; STANDARD DERATING FACTOR USED
FIRE SEAL2: 1.00 DERATING FACTOR NOT DEFINED; DEFAULTS TO FACTOR FIRE SEAL1
FIRE SEAL3: 1.00 DERATING FACTOR NOT DEFINED; DEFAULTS TO FACTOR FIRE SEAL2

TRAY POINT: 167A

CABLE NUMBER	PULLED STATUS	TYPE CODE	DIA-METER	AC RESIST OHMS/100FT	FL CURRENT	PROJ FLC USED	CALCULATED AMPACITY	FREE AIR AMPAC USED	FLC/ AMPACITY	EXCEED FLAG
1DG020	P	03066	1.00	0.05130000	14.0		63.20	*	0.22	
1DG022	P	03066	1.00	0.05130000	14.0		63.20	*	0.22	
1DG038	P	03066	1.00	0.05130000	24.0		63.20	*	0.38	
1DG046	P	03146	0.50	0.00335000	5.0		20.00	*	0.25	
1DG054	P	03146	0.50	0.00335000	1.8		20.00	*	0.09	

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TRAY POINT: 153A

CABLE NUMBER	PULLED STATUS	TYPE CODE	DIA-METER	AC RESIST OHMS/100FT	FL CURRENT	PROJ FLC USED	CALCULATED AMPACITY	FREE AIR AMPAC USED	FLC/ AMPACITY	EXCEED FLAG
2DG012	P	03006	1.50	0.01280000	92.0		106.06		0.87	
2DG020	P	03066	1.00	0.05130000	14.0		35.32		0.40	
2DG022	P	03066	1.00	0.05130000	14.0		35.32		0.40	
2DG037	P	02146	0.50	0.00335000	7.5	*	20.00	*	0.38	
2DG038	P	03066	1.00	0.05130000	24.0		35.32		0.68	
2DG046	P	03146	0.50	0.00335000	2.5		20.00	*	0.13	
2DG054	P	03146	0.50	0.00335000	1.8		20.00	*	0.09	
2DG232	P	03106	0.70	0.00132500	1.2		34.40	*	0.03	
2DO038	P	03146	0.50	0.00335000	6.3		20.00	*	0.32	
2DT017	P	03106	0.70	0.00132500	10.5		34.40	*	0.31	
2DT023	P	03106	0.70	0.00132500	10.5		34.40	*	0.31	
2FC022	P	03006	1.50	0.01280000	88.0		106.06		0.83	
2FC047	P	02146	0.50	0.00335000	7.5	*	20.00	*	0.38	
2RH196	P	03506	2.70	0.00275000	228.0		389.60	*	0.59	
2RH197	P	02146	0.50	0.00335000	7.5	*	20.00	*	0.38	
2RH201	P	03506	2.70	0.00275000	228.0		389.60	*	0.59	
2RH202	P	02146	0.50	0.00335000	7.5	*	20.00	*	0.38	
2VD012	P	03026	1.20	0.02030000	50.0		67.37		0.74	
2VD018	P	03146	0.50	0.00335000	4.6		20.00	*	0.23	
2VY022	P	03146	0.50	0.00335000	7.0		20.00	*	0.35	

WIDTH OF TRAY: 30.00
DEPTH OF FILL: 0.91
HEAT INTENSITY: 7.52
DERATING FACTORS:
AMBIENT: 1.00 DERATING FACTOR NOT DEFINED; STANDARD DERATING FACTOR USED
COVERS: 1.00 DERATING FACTOR NOT DEFINED; STANDARD DERATING FACTOR USED
FIRE SEAL1: 0.57
FIRE SEAL2: 1.00 DERATING FACTOR NOT DEFINED; DEFAULTS TO FACTOR FIRE SEAL1
FIRE SEAL3: 1.00 DERATING FACTOR NOT DEFINED; DEFAULTS TO FACTOR FIRE SEAL2

TRAY POINT: 154A

CABLE NUMBER	PULLED STATUS	TYPE CODE	DIA-METER	AC RESIST OHMS/100FT	FL CURRENT	PROJ FLC USED	CALCULATED AMPACITY	FREE AIR AMPAC USED	FLC/ AMPACITY	EXCEED FLAG
2DG012	P	03006	1.50	0.01280000	92.0		106.06		0.87	
2DG020	P	03066	1.00	0.05130000	14.0		35.32		0.40	
2DG022	P	03066	1.00	0.05130000	14.0		35.32		0.40	
2DG037	P	02146	0.50	0.00335000	7.5	*	20.00	*	0.38	
2DG038	P	03066	1.00	0.05130000	24.0		35.32		0.68	
2DG046	P	03146	0.50	0.00335000	2.5		20.00	*	0.13	
2DG054	P	03146	0.50	0.00335000	1.8		20.00	*	0.09	
2DG232	P	03106	0.70	0.00132500	1.2		34.40	*	0.03	

RAY POINT: 154A CONTINUED...

2DO038	P	03146	0.50	0.00335000	6.3		20.00	*	0.32	
2DT017	P	03106	0.70	0.00132500	10.5		34.40	*	0.31	
2DT023	P	03106	0.70	0.00132500	10.5		34.40	*	0.31	
2FC022	P	03006	1.50	0.01280000	88.0		106.06		0.83	
2FC047	P	02146	0.50	0.00335000	7.5	*	20.00	*	0.38	
2RH196	P	03506	2.70	0.00275000	228.0		389.60	*	0.59	
2RH197	P	02146	0.50	0.00335000	7.5	*	20.00	*	0.38	
2RH201	P	03506	2.70	0.00275000	228.0		389.60	*	0.59	
2RH202	P	02146	0.50	0.00335000	7.5	*	20.00	*	0.38	
2VD012	P	03026	1.20	0.02030000	50.0		67.37		0.74	
2VD018	P	03146	0.50	0.00335000	4.6		20.00	*	0.23	
2VY022	P	03146	0.50	0.00335000	7.0		20.00	*	0.35	

IDTH OF TRAY: 30.00
EPTH OF FILL: 0.91
EAT INTENSITY: 7.52
ERATING FACTORS:
AMBIENT: 1.00 DERATING FACTOR NOT DEFINED; STANDARD DERATING FACTOR USED
COVERS: 1.00 DERATING FACTOR NOT DEFINED; STANDARD DERATING FACTOR USED
FIRE SEAL1: 0.57
FIRE SEAL2: 1.00 DERATING FACTOR NOT DEFINED; DEFAULTS TO FACTOR FIRE SEAL1
FIRE SEAL3: 1.00 DERATING FACTOR NOT DEFINED; DEFAULTS TO FACTOR FIRE SEAL2

RAY POINT: 155A

CABLE NUMBER	PULLED STATUS	TYPE CODE	DIA-METER	AC RESIST OHMS/100FT	FL CURRENT	PROJ FLC USED	CALCULATED AMPACITY	FREE AIR AMPAC USED	FLC/ AMPACITY	EXCEED FLAG
2DG012	P	03006	1.50	0.01280000	92.0		106.06		0.87	
2DG020	P	03066	1.00	0.05130000	14.0		35.32		0.40	
2DG022	P	03066	1.00	0.05130000	14.0		35.32		0.40	
2DG037	P	02146	0.50	0.00335000	7.5	*	20.00	*	0.38	
2DG038	P	03066	1.00	0.05130000	24.0		35.32		0.68	
2DG046	P	03146	0.50	0.00335000	2.5		20.00	*	0.13	
2DG054	P	03146	0.50	0.00335000	1.8		20.00	*	0.09	
2DG232	P	03106	0.70	0.00132500	1.2		34.40	*	0.03	
2DO038	P	03146	0.50	0.00335000	6.3		20.00	*	0.32	
2DT017	P	03106	0.70	0.00132500	10.5		34.40	*	0.31	
2DT023	P	03106	0.70	0.00132500	10.5		34.40	*	0.31	
2FC022	P	03006	1.50	0.01280000	88.0		106.06		0.83	
2FC047	P	02146	0.50	0.00335000	7.5	*	20.00	*	0.38	
2RH196	P	03506	2.70	0.00275000	228.0		389.60	*	0.59	
2RH197	P	02146	0.50	0.00335000	7.5	*	20.00	*	0.38	
2RH201	P	03506	2.70	0.00275000	228.0		389.60	*	0.59	
2RH202	P	02146	0.50	0.00335000	7.5	*	20.00	*	0.38	
2VD012	P	03026	1.20	0.02030000	50.0		67.37		0.74	
2VD018	P	03146	0.50	0.00335000	4.6		20.00	*	0.23	

TRAY POINT: 155A CONTINUED...

CABLE NUMBER	PULLED STATUS	TYPE CODE	DIA-METER	AC RESIST OHMS/100FT	FL CURRENT	PROJ FLC USED	CALCULATED AMPACITY	FREE AIR AMPAC USED	FLC/ AMPACITY	EXCEED FLAG
2VY022	P	03146	0.50	0.00335000	7.0		20.00	*	0.35	

WIDTH OF TRAY: 30.00
DEPTH OF FILL: 0.91
HEAT INTENSITY: 7.52
DERATING FACTORS:
AMBIENT: 1.00 DERATING FACTOR NOT DEFINED; STANDARD DERATING FACTOR USED
COVERS: 1.00 DERATING FACTOR NOT DEFINED; STANDARD DERATING FACTOR USED
FIRE SEAL1: 0.57
FIRE SEAL2: 1.00 DERATING FACTOR NOT DEFINED; DEFAULTS TO FACTOR FIRE SEAL1
FIRE SEAL3: 1.00 DERATING FACTOR NOT DEFINED; DEFAULTS TO FACTOR FIRE SEAL2

TRAY POINT: 156A

CABLE NUMBER	PULLED STATUS	TYPE CODE	DIA-METER	AC RESIST OHMS/100FT	FL CURRENT	PROJ FLC USED	CALCULATED AMPACITY	FREE AIR AMPAC USED	FLC/ AMPACITY	EXCEED FLAG
2DG020	P	03066	1.00	0.05130000	14.0		63.20	*	0.22	
2DG022	P	03066	1.00	0.05130000	14.0		63.20	*	0.22	
2DG038	P	03066	1.00	0.05130000	24.0		63.20	*	0.38	
2DG046	P	03146	0.50	0.00335000	2.5		20.00	*	0.13	
2DG054	P	03146	0.50	0.00335000	1.8		20.00	*	0.09	
2DG232	P	03106	0.70	0.00132500	1.2		34.40	*	0.03	
2VDC12	P	03026	1.20	0.02030000	50.0		110.40	*	0.45	
2VDC18	P	03146	0.50	0.00335000	4.6		20.00	*	0.23	
2VYC22	P	03146	0.50	0.00335000	7.0		20.00	*	0.35	

WIDTH OF TRAY: 30.00
DEPTH OF FILL: 0.20
HEAT INTENSITY: 15.40
DERATING FACTORS:
AMBIENT: 0.89
COVERS: 1.00 DERATING FACTOR NOT DEFINED; STANDARD DERATING FACTOR USED
FIRE SEAL1: 1.00 DERATING FACTOR NOT DEFINED; STANDARD DERATING FACTOR USED
FIRE SEAL2: 1.00 DERATING FACTOR NOT DEFINED; DEFAULTS TO FACTOR FIRE SEAL1
FIRE SEAL3: 1.00 DERATING FACTOR NOT DEFINED; DEFAULTS TO FACTOR FIRE SEAL2

TRAY POINT: 157A

CABLE NUMBER	PULLED STATUS	TYPE CODE	DIA-METER	AC RESIST OHMS/100FT	FL CURRENT	PROJ FLC USED	CALCULATED AMPACITY	FREE AIR AMPAC USED	FLC/ AMPACITY	EXCEED FLAG
2DG020	P	03066	1.00	0.05130000	14.0		63.20	*	0.22	
2DG022	P	03066	1.00	0.05130000	14.0		63.20	*	0.22	
2DG038	P	03066	1.00	0.05130000	24.0		63.20	*	0.38	
2DG046	P	03146	0.50	0.00335000	2.5		20.00	*	0.13	
2DG054	P	03146	0.50	0.00335000	1.8		20.00	*	0.09	