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June 2, 1995
NG-95-1223

Mr. William T. Russell, Director
Office of Nuclear Reactor Regulation
U. S. Nuclear Regulatory Commission
Attn: Document Control Desk
Mail Station P1-37
Washington, DC 20555-0001

Subject: Duane Arnold Energy Center
Docket No: 50-331
Op. License No: DPR-49
Response to NRC RAI regarding Generic Letter 92-08 "Thermo-Lag 330-1 Fire Barriers"

References: Letter from G. Kelly (NRC) to L. Liu (IES) dated February 14, 1995
Subject: DAEC RAI regarding Generic Letter 92-08

File: A-117, P-72a

Dear Mr. Russell:

In the referenced letter, your Staff requested additional information regarding Generic Letter 92-08, "Thermo-Lag 330-1 Fire Barriers." The questions pertained to the methodology used to calculate electrical cable ampacity derating in raceways encased in Thermo-Lag fire barrier material.

Question 1 of the referenced letter requested the technical basis for the electrical cable ampacity derating methodology used by the Duane Arnold Energy Center (DAEC). This methodology is detailed in Sections 1 through 3 of the Attachment to this letter.

Question 2 of the referenced letter requested the most bounding cable ampacity calculations for equipment protected by Thermo-Lag:

- The bounding calculations for cables in cable tray is given in Section 4 of the Attachment,
- The bounding calculations for cables in conduit is given in Section 5 of the Attachment,
- There are no protected cables in an air drop configuration at the DAEC.

A029 /1

Question 3 of the referenced letter requested information regarding Flexi-Blanket applications. Flexi-Blanket (i.e., Thermo-Lag 330-660) has not been used at the DAEC.

This letter contains no new commitments.

Should you have any further questions regarding this information, please contact this office.

Sincerely,

David L Wilson for

John F. Franz
Vice President, Nuclear

Attachment

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cc: L. B. Swenzinski
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DAEC Methodology
for
Evaluating Acceptability
of
Cable Ampacity
in
Fire Barrier Wrapped Raceway

1.0 Introduction/Scope

This document presents a summary of the methodology that was used to evaluate the acceptability of cable ampacity in raceway wrapped in Thermo-Lag 330-1 one-hour and three-hour fire barrier wrap at the DAEC. The methodology is valid for any fire barrier wrap provided test data is available.

2.0 Theory and Assumptions

2.1 Theory

The ampacity of a cable is dependent on the ability to radiate heat to the environs and the thermal limits of the insulating material. Fire barrier wrap reduces the ampacity of cables in wrapped raceways.

When evaluating the acceptability of an existing wrapped raceway, the maximum amount of heat that can be transmitted through the fire barrier wrap is the critical parameter. This parameter is the permissible thermal output and is identified by q.

Permissible thermal output (q) is dependent on the heat transfer characteristics of the wrapped raceway and can be determined for any fire barrier wrap by performing a two-part test. Part 1 of the test consists of a raceway in which all cables are current-loaded such that the cable temperature stabilizes near 90°C. The current through each cable, the temperature along each cable and the ambient temperature are recorded. Part 2 consists of the same raceway with cables, now wrapped in fire barrier wrap. Again all cables are current loaded such that the cable temperature stabilizes near 90°C. The same data is recorded.

From the two sets of data recorded, the thermal conductance (G) of the fire barrier wrap can be derived. From the thermal conductance, the permissible thermal output (q) can be calculated.

Lightly loaded cables are those cables where the ratio of actual current to the ampacity limit is low, highly loaded cables are those cables where that ratio is high. In the test described above, all of the cables in the raceway are loaded to the ampacity limit. This will result in a conservative permissible thermal output (q) because:

- The lightly loaded cables are theorized to act as heat sinks and may allow the highly loaded cables to be cooler than predicted by the National Electric Code (NEC) and Insulated Cable Engineers Association (ICEA) ampacity tables.

- Location of the lightly loaded cables with respect to the highly loaded cables affects the ampacity limit and may allow the highly loaded cables to be cooler than predicted by the NEC and ICEA ampacity tables.

- Reference 6.3 defines diversity as "the variation of the actual electrical load from the maximum electrical load assumed by the code." Test results in the article show that highly loaded cables in cable trays with large diversity do not reach the temperatures predicted by Reference 6.2.

To determine the acceptability of an existing raceway wrapped in fire barrier wrap, the actual power cable and load data are used to determine the actual thermal output (A_{TH}) of the raceway. If the actual thermal output (A_{TH}) is less than the permissible thermal output (q), the cables in the raceway section will not be heated to temperatures above the thermal limits of the insulating material and cable derating is not necessary.

2.2 Assumptions

This methodology adds an allowance for the heat generated by control, instrumentation and power cables associated with intermittent loads. The heat generated by all cables within wrapped raceways is conservatively taken to be 125% of the heat generated by the continuously energized power cables. The 25% additional heat load is judged to bound any cables in the raceway which are not continuously energized power cables.

The following assumptions are made for this methodology:

2.2.1 The only appreciable heat generated in the wrapped raceway section is from the continuously energized power cables.

2.2.2 Power cables associated with intermittent loads such as motor operated valves are assumed to generate no appreciable heat due to the low duty cycle and low frequency of operation. These cables are not analyzed individually, but are accounted for by the allowance described above.

2.2.3 Control cables are assumed to generate no appreciable heat due to the low current levels associated with these cables. These cables are not analyzed individually but are accounted for by the allowance described above.

2.2.4 Air inside the fire barrier wrap will be assumed to transfer heat by conduction, convection and radiation.

2.2.5 Wrapped raceways are analyzed as horizontal. This is consistent with IEEE and industry standards for cable derating. Analyzing raceways as horizontal is deemed acceptable because of the large margins (margin is defined as $\left(\frac{q - A_{TH}}{A_{TH}}\right) * 100\%$) calculated for all raceways.

2.2.6 Cable temperatures are assumed to be constant over the length of cable in the wrapped raceway.

2.2.7 Only steady state heat transfer is considered.

3.0 Methodology

3.1 Procedure for Calculating the Permissible Thermal Output (q) of a Wrapped Cable Tray Section

3.1.1 Perform Two-part test. For both sets of test data, perform the following:

3.1.1.1 Using the cable size and the cable resistance R1 at temperature T1 (baseline values provided by manufacturer), calculate the cable resistance R2 at temperature T2 (values under test conditions) per the following equation.

$$R2 = R1 * (1 + a * (T2 - T1))$$

a is the temperature coefficient of copper,
a = 0.00385 if T1 = 25°C
a = 0.00393 if T1 = 20°C

3.1.1.2 Using the number of each size cable, the cable resistance and the cable current, calculate the heat output of the tray section.

The heat output of the tray section is equal to the sum of the I^2R (current squared times the resistance of the cable) losses for all the cables in the tray section.

3.1.1.3 Using the heat output of the tray section, the cable temperature and the ambient temperature, calculate the thermal conductance (G) of the tray section using the following equation.

$$G = \frac{\text{Heat Output of the Tray Section}}{\text{Cable Temperature - Ambient Temperature}}$$

3.1.1.4 Using the thermal conductance (G), calculate the thermal resistance (H) of the tray section using the following equation.

$$H = 1/G$$

3.1.2 Using the thermal resistance of the tray section in Part 1 of the test (no wrap) and the thermal resistance of the tray section in Part 2 of the test (wrap installed), calculate the thermal resistance (H) and conductance (G) of the fire barrier wrap using the following equations.

$$H_{wrap} = H_{part2} - H_{part1}$$

$$G_{wrap} = 1/H_{wrap}$$

3.1.3 Calculate the permissible thermal output of the tray section using the following equation.

$$q = \frac{T*G_{wrap}*q_0}{T*G_{wrap} + q_0}$$

T = Difference between allowable cable temperature and ambient temperature
q_0 is the allowable watts per square foot of tray as found in Figure 1 of Reference 6.1,
q_0 = 68.7 W/ft^2 for 1" fill in a 3" deep tray
= 61.6 W/ft^2 for 1.5" fill in a 3" deep tray
= 56.1 W/ft^2 for 2" fill in a 3" deep tray
= 51.6 W/ft^2 for 2.5" fill in a 3" deep tray
= 47.8 W/ft^2 for 3" fill in a 3" deep tray
G_{wrap} as found in Section 3.1.2

The permissible thermal output of the tray section is the thermal output of the cable in the wrapped tray section that would heat the cables to the thermal limits of the insulating material.

3.2 Procedure for the Analysis of an Existing Wrapped Cable Tray Section

3.2.1 For an existing tray section, list the cables installed, the cable size and the actual or estimated load current.

3.2.2 Using the cable size, calculate the cable resistance at 90°C. Use the same equation as Section 3.1.1.1 with T2 = 90°C.

3.2.3 Using the cable resistance and the load current, calculate the actual thermal output (A_{TH}) of the tray section. The A_{TH} of the tray section is equal to the sum of the I^2R (current squared times the resistance of the cable) losses for all the cables in the tray section.

3.2.4 For conservatism, multiply the actual thermal output (A_{TH}) of the tray section by 1.25. Using this factor allows the methodology to ignore any momentarily energized power cables, instrumentation and control cables in the tray section. These cables do not add significant heat loads to the tray section, and can be accounted for by this factor.

3.2.5 Compare the actual thermal output (A_{TH}) of the tray section found by Section 3.2.4 to the permissible thermal output found by Section 3.1.3. If the actual thermal output of the tray section is less than the permissible thermal output, then the tray section requires no further action. If the actual thermal output of the tray section is greater than the permissible thermal output then further actions are required.

3.3 Procedure for Calculating the Permissible Thermal Output (q) of a Wrapped Conduit

3.3.1 Perform Two-part test. For both sets of Test Data, perform the following:

3.3.1.1 Using the cable size and the cable resistance R1 at temperature T1, calculate the cable resistance R2 at temperature T2, use the following equation.

R2 = R1 * (1 + a * (T2 - T1))

R1 is the resistance at T1, this data is taken from vendor information
R2 is the resistance at T2, T2 is the cable temperature from test data

a is the temperature coefficient of copper and
a = 0.00385 if T1 = 25°C
a = 0.00393 if T1 = 20°C

3.3.1.2 Using the number of each size cable, the cable resistance and the cable current, calculate the heat output of the conduit section.

The heat output of the conduit section is equal to the sum of the I^2R (current squared times the resistance of the cable) losses for all the cables in the conduit section.

3.3.1.3 Using the heat output of the conduit section, the cable temperature and the ambient temperature, calculate the thermal conductance (G) of the conduit section using the following equation.

$$G = \frac{\text{Heat Output of the Tray Section}}{\text{Cable Temperature - Ambient Temperature}}$$

3.3.1.4 Using the thermal conductance (G), calculate the thermal resistance (H) of the conduit section using the following equation.

$$H = 1/G$$

3.3.2 Calculate the Thermal Conductivity of the fire barrier wrap, (k), by the following equation.

$$k = \frac{\text{Thermal Conductance of wrap * Thickness of wrap in test}}{\text{Area of the wrap in test}}$$

3.3.3 Calculate Permissible Thermal Output (q).

3.3.3.1 Calculate the Temperature times the Thermal Conductance of the conduit (G_c)with the fire barrier wrap by the following equation.

$$T * G_c = \frac{2 * \pi * k * T}{\ln (d_o/d_i)}$$

d_0 = Outside fire barrier wrap diameter
d_i = Inside fire barrier wrap diameter
T = Cable Temperature - Ambient Temperature

3.3.3.2 Calculate the permissible thermal output (q) of cable inside a fire barrier wrapped conduit, by the following equation.

$$q = \frac{T * G_c * q_0}{T * G_c + q_0}$$

3.4 Procedure for the Analysis of an Existing Wrapped Conduit

3.4.1 For an existing conduit section, list the cables installed, the cable size and the actual or estimated load current.

3.4.2 Using the cable size, calculate the cable resistance at 90°C. Use the same equation of Section 3.3.1.1 with T2 = 90°C.

3.4.3 Using the cable resistance and the load current, calculate the actual thermal output (A_{TH}) of the conduit section. The A_{TH} of the conduit section is equal to the sum of the I^2R (current squared times the resistance of the cable) losses for all the cables in the conduit section.

3.4.4 Multiply the actual thermal output (A_{TH}) of the conduit section by 1.25. (If the conduit does not contain any momentarily energized power cables, instrumentation or control cables, the 25% margin need not be added.)

3.4.5 Compare the actual thermal output (A_{TH}) of the conduit section found by Section 3.4.4 to the permissible thermal output (q) found by Section 3.3.4.2. If the actual thermal output of the conduit section is less than the permissible thermal output then the conduit section requires no further action. If the actual thermal output of the conduit section is greater than the permissible thermal output then further actions are required.

3.5 Methodology Applicability

Reference 6.9 provided test data for cable trays with tray covers. The results of this methodology did not compare favorably to the results in the reference. The difference may be due to the tray cover reflecting heat back to the cable mass. Therefore, this methodology is not applicable for cables trays with tray covers installed.

The DAEC uses standard industry practices to evaluate the ampacity in cable trays with tray covers. At the DAEC, all covered cable trays with fire barrier wrap contain only instrumentation cables. Therefore, no further evaluation is needed.

3.6 Conclusion

This methodology is applicable for fire wrapped cable tray and conduit sections when appropriate testing is performed. The results of this methodology compare favorably with results in references 6.8 through 6.12.

4.0 Evaluating Acceptability of Cable Tray (2H2D) with 3-hour Fire Barrier Wrap

4.1 Test Data Analysis

4.1.1 Part 1 Test Data (Ref. 6.4):

The tray section contained the following cables and current in free air.

99 cables #8 AWG	18.87 amps
58 cables #4 AWG	38.66 amps
20 cables #2/0 AWG	114.46 amps
Average Cable Temperature	90.87°C
Ambient Temperature	47.95°C

4.1.2 Part 2 Test Data (Ref. 6.4):

The tray section with 3 hour fire barrier wrap contained the following cables and current.

99 cables #8 AWG	14.26 amps
58 cables #4 AWG	28.96 amps
20 cables #2/0 AWG	84.90 amps
Average Cable Temperature	91.67°C
Ambient Temperature	38.67°C

4.1.3 Calculate Cable Resistance for both sets of test data.

$$R2 = R1 * (1 + a * (T2 - T1))$$

	Per Vendor Information	Part 1	Part 2
	25°C	90.87°C	91.67°C
#8 AWG	0.654 Ω/1000 ft	0.820 Ω/1000 ft	0.822 Ω/1000 ft
#4 AWG	0.259 Ω/ 1000 ft	0.325 Ω/1000 ft	0.325 Ω/1000 ft
#2/0 AWG	0.0811 Ω/1000 ft	0.102 Ω/1000 ft	0.102 Ω/1000 ft

4.1.4 Calculate Heat Output.

Heat Output = $\sum I^2R$ for all cables

	Part 1	Part 2
#8 AWG	28.91 W/ft^2	16.55 W/ft^2
#4 AWG	28.17 W/ft^2	15.81 W/ft^2
#2/0 AWG	26.73 W/ft^2	14.70 W/ft^2
Total	83.81 W/ft^2	47.06 W/ft^2

4.1.5 Calculate Thermal Conduct⁻ance.

$$G = \frac{\text{Heat Output of the Tray Section}}{\text{Cable Temperature - Ambient Temperature}}$$

	Part 1	Part 2
Cable Temperature	90.87°C	91.67°C
Ambient Temperature	47.95°C	38.67°C
Heat Output	83.81 W/ft^2	47.06 W/ft^2
Thermal Conductance (G)	1.953 W/ft^2 °C	0.888 W/ft^2 °C

4.1.6 Calculate Thermal Resistance.

$H = 1/G$

	Part 1	Part 2
Thermal Resistance (H)	0.512°C ft^2/W	1.126°C ft^2/W

4.1.7 Determine Thermal Resistance of the Fire Barrier Wrap.

$$H_{wrap} = H_{part2} - H_{part1}$$

$$H_{wrap} = 1.126 - 0.512 = 0.614 \ ^\circ C\ ft^2/W$$

4.1.8 Calculate Permissible Thermal Output (q).

$$q = \frac{T*G_{wrap}*q_0}{T*G_{wrap} + q_0}$$

$$G_{wrap} = 1/H_{wrap}$$

G_{wrap}	1.629 W/ft^2°C	For 1" thick (3 hour rated) TSI 330-1 Fire Barrier Material
T	50°C	90°C (Cable Limit) - 40°C (ICEA Ambient)
q_0	61.6 W/ft^2	1.5" fill in 3" deep tray (ref. Section 3.1.3)
q	35.07 W/ft^2	

4.2 Limiting Calculation for Cable Tray 2H2D

4.2.1 Calculate Actual Thermal Output.

4.2.1.1 List Power Cables Installed, Cable Size and Load Current.

Tray Dimensions 3" deep by 18" wide
Tray wrap is the same that used in Section 4.1.2

Cable 1	3/c	# 350 MCM	247.22 amps/cable
Cable 2	3/c	# 350 MCM	247.22 amps/cable

(Note: Intermittent Load, Instrument and Control Cables are not listed here)

4.2.1.2 Calculate of Cable Resistance at 90°C.

$$R2 = R1 * (1 + a * (T2 - T1))$$

	25°C	90°C
#350 MCM	0.0311 Ω/1000 ft	0.0389 Ω/1000 ft

4.2.1.3 Calculate Actual Thermal Output.

Heat Output = $\sum I^2R$ for all cables

Cable 1	7.13 W/ft
Cable 2	7.13 W/ft
Total	14.26 W/ft

4.2.1.4 Add Conservatism to Account for Intermittent Load, Instrument and Control Cables.

$$14.26 \text{ W/ft} \times 1.25 = 17.825 \text{ W/ft}$$

4.2.2 Compare to Permissible Thermal Output.

Multiply the result of Section 4.2.1.4 by 1.5 ft since the tray section used in the test was 1 foot wide and tray 2H2D section is a 1.5 ft wide.

$$17.825 \text{ W/ft} < 35.07 \text{ W/ft}^2 * 1.5 \text{ ft}$$
$$17.825 \text{ W/ft} < 52.605 \text{ W/ft}$$

4.2.3 Conclusion: Tray section is within limit set in Section 4.1.8, no further action is required.

5.0 Evaluating Acceptability of Conduit 1C979 (4" diameter)

5.1 Test Data Analysis

5.1.1 Perform Two-Part Test to Determine G_{wrap}.

The conduit is wrapped in 3-hour TSI-330-1 Fire Barrier material. Therefore, G_{wrap} calculated in Section 4.1.4 can be used, there is no need to perform another test.

5.1.2 Calculate Allowable Temperature Rise.

Maximum Cable Operating Temperature	90°C
Ambient Temperature	40°C
Allowable Temperature Rise (T)	50°C

5.1.3 List Cables Installed and Cable Size.

			Ampacity (from NEC)
Cable 1	3/c	350 MCM	325 amps
Cable 2	2/c	#4/0 AWG	235 amps

Maximum Ampacity for a 3 conductor 350 MCM cable in conduit with a total of 5 conductors
I_1 = 325 amps * 0.91 * 0.80 = 236.6 amps/conductor

Maximum ampacity for a 2 conductor 4/0 AWG cable in conduit with a total of 5 conductors
I_2 = 235 amps * 0.91 * 0.80 = 171.1 amps/conductor

Note:
0.91 is the derating for 40°C ambient
0.80 is the derating for 4 to 6 conductors in conduit per NEC

5.1.4 Calculate Cable Resistance.

$$R2 = R1 * (1 + a * (T2 - T1))$$

	25°C	90°C
Cable 1	0.0311 Ω/1000ft	0.0389 Ω/1000ft
Cable 2	0.0509 Ω/1000ft	0.0636 Ω/1000ft

5.1.5 Calculate Heat Output (q_0).

$q_0 = 3 * I_1^2 * R_1 + 2 * I_2^2 * R_2$
$q_0 = 10.257$ W/ft

5.1.6 Calculation of Thermal Conductivity (k).

G_{wrap} = 1.629 W/ft^2 °C (from Section 4.1.4)
t = thickness of fire barrier wrap in test = 1 in
A = Area of fire barrier wrap per square foot of conduit
= 2 ft^2/ft^2

k = G_w * t / A
k = 0.0679 W/ft°C

5.1.7 Calculate Thermal Conductance of the wrapped conduit.

$$G_c = \frac{2 * \pi * k}{\ln (d_o/d_i)}$$

d_o = Outside fire barrier wrap radius = 0.270 ft
d_i = Inside fire barrier wrap radius = 0.188 ft
G_c = 1.179 W/ft °C

5.1.8 Calculate Permissible Thermal Output (q).

$$q = \frac{T*G_c*q_0}{T*G_c + q_0}$$

q = 8.74 W/ft

5.2 Limiting Calculation for Conduit 1C979

5.2.1 Calculate Actual Thermal Output.

5.2.1.1 List Cables Installed, Cable Size and Load Current.

		Actual Current Load
Cable 1	3/c 350 MCM	223.2 amps/conductor
Cable 2	2/c #4/0 AWG	48.88 amps/conductor

5.2.1.2 Calculate Cable Resistance at 90°C.

R2 = R1 * (1 = a * (T2 - T1))

	25°C	90°C
Cable 1	0.0311Ω/1000 ft	0.0389 Ω/1000 ft
Cable 2	0.0509 Ω/1000 ft	1.0636 Ω/1000 ft

5.2.1.3 Calculate of Actual Thermal Output (A_{TH}).

Heat Output = $\sum I^2R$ for all cables

Cable 1	5.814 W/ft
Cable 2	0.245 W/ft
Total	6.059 W/ft

No conservatism needed since the conduit does not contain any other cables, A_{TH} = 6.059 W/ft.

5.2.2 Compare to Permissible Thermal Output.

6.059 W/ft < 8.74 W/ft

5.2.3 Conclusion: Conduit is within limits set in Section 5.1.8, no further action Is necessary.

6.0 References

References 6.1 through 6.5 are the primary sources of information used in the development of this methodology. References 6.6 and 6.7 document the implementation of the methodology. The other references were used to insure that the methodology in this document does not conflict with other methodologies.

6.1 Derating Cables in Trays Transversing Firestops or Wrapped in Fireproofing, Oscar M. Esteves, IEEE Paper 82 JPGC 601-3

6.2 ICEA P 54-440 (Third Edition), Ampacities of Cables in Open-Top Cable Trays

6.3 Ampacity of Cables in single Open-Top Cable Trays, B. Harshe and W. Black, IEEE Transactions on Power Delivery, Vol. 9, p 1733-1739

6.4 I.T.L. Report No. 82-5-355F, dated July 1982, "Ampacity Test for 1000 Volt Power Cables in a Ladder Cable Tray Protected with a Three Hour Rated Design of Thermo-Lag 330-1 Subliming Coating Envelope System"

6.5 Calculating Heat Loss from Insulated Piping, N.P. Cheremisinoff and P.N. Cheremisinoff, Power Engineering, April 29, 1976

6.6 DAEC Calculation 294-E-001 Rev. 0, Determining If Cable Derating is Required for Cables Encased in Fireproofing

6.7 DAEC Engineering Design Guide DGC-E109 Rev. 3, Engineering Design Guide for Ampacity of Cables Routed in Tray

6.8 Ampacities for Cables in Randomly Filled Trays, J. Stolpe, IEEE Transactions on Power Apparatus and Systems, Vol. 90 p. 963-974

6.9 Ampacity of Cable in Covered Tray, Gary Engmann, IEEE Transactions on Power Apparatus and Systems, Vol. 103 p 345-352

6.10 Ampacity of Wrapped Cables, Keith Petty, IEEE Transactions on Power Delivery, Vol. 3 p 35-38

6.11 Rating Power Cables in Wrapped Cable Trays, Ajit Hiranandani, IEEE Transactions on Power Delivery, Vol. 3 p 76-82

6.12 Ampacities of Multiconductor Cables in Trays, Ralph Lee, IEEE Transactions on Power Apparatus and Systems, 1972, p 1051-1056