CALCULATION COVER SHEET

Calculation No: PSL-BFSM-98-005

Title: Electrical Cable Ampacity Correction Factors For Thermo-Lag Fire Barriers

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1.0 Purpose/Scope

GL 92-08 (Ref. 2.1) has required FPL to review the ampacity correction factors (ACF) used for raceway with fire barriers. The ampacity correction factors were updated by calculation PTN-BFJM-96-005 and were based on testing performed at Omega Point Laboratories. The NRC in Reference 2.2 has expressed concern over the testing performed at Omega Point Laboratories; therefore, this calculation will determine applicable ampacity correction factors for St. Lucie based on testing performed at Underwriters Laboratories. This calculation will use heat transfer relationships to extrapolate the results from the tested fire barriers to thicknesses which bound the thickness of fire barrier used at the St. Lucie Plant Units 1 and 2. This calculation is intended to be a conservative extrapolation of test data based on the laws of heat transfer and not a thorough heat transfer evaluation.

2.0 References

2.1 GL-92-08, "Thermo-Lag 330-1 Fire Barriers" Dated December 17, 1992.

2.2 Second Request for Additional Information - Generic Letter 92-08 "Thermo-Lag 330-1 Fire Barriers, St. Lucie Plant Units 1 and 2 and Turkey Point Plant Units 3 and 4", (TAC NO. M82809), Dated April 23,1998 Addressed to T.F. Plunkett and signed by Fredric J. Hebdon, Director

2.3 ASHRAE Handbook, 1991 Fundamentals

2.4 NRC Safety Evaluation Addressing Thermo-Lag Related Ampacity Derating Issues for Crystal River (TAC NO. M91772), Dated November 14, 1997, Addressed to Roy A. Anderson and Signed by L. Raghaven, Project Manager

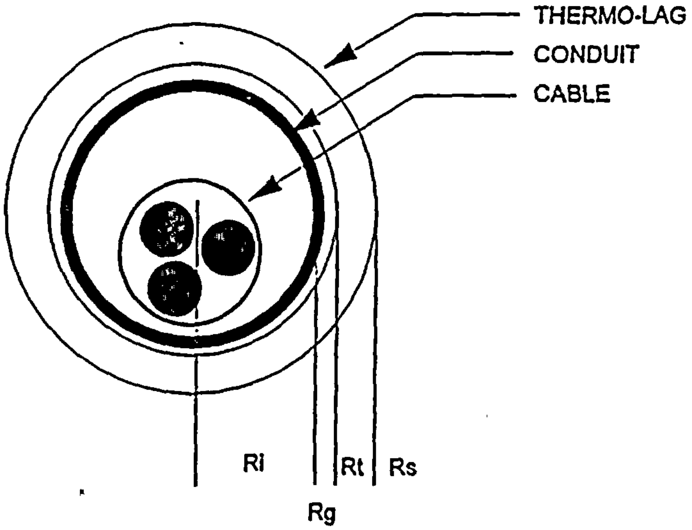
2.5 ANSI C80.1-1990, Table 2 "Dimensions and Weights of Rigid Steel Conduits"

2.6 Underwriters Laboratories, Ampacity Test Investigation of Raceway Fire Barriers for Conduit and Cable Tray Systems, Dated May 8, 1996, File NC1973, Project 95NK17030 (Note: Recorded in Passport as REPORT NC1973)

2.7. TSI Inc., Thermo-Lag 330 & 770 Thermal Properties (Included as Attachment 1)

2.8. NEMA Publication WC3-1980, Rubber-Insulated Wire and Cable for the Transmission and Distribution of Electrical Energy.

3.0 Methodology



Heat transfer will be calculated per foot of raceway length in accordance with the following relationship:

$$q = (T_c - T_a) / (R_i + R_g + R_t + R_s)$$

q	=	Rate of heat transfer from raceway
T_c	=	Temperature of conductor (90°C/194°F)
T_a	=	Ambient temperature (40°C/104°F)
R_i	=	Thermal resistance of all items within the raceway including the raceway itself
R_g	=	Thermal resistance of the air gap between the raceway and the fire barrier material
R_t	=	Thermal resistance of the fire barrier material
R_s	=	Thermal resistance at the surface of the protected or unprotected raceway

The heat transferred from the raceway under steady state conditions is essentially equal to the I^2R losses within the conductors. These heat values can be determined from the test data based on the measured current and size of conductor used.

T_c and T_a are fixed test parameters with values which are listed above.

The thermal resistance values will be determined based on test data and physical properties as follows:

R_i will be calculated from the test data for raceway without fire barrier.

R_g will be calculated from test data for raceway with a fire barrier of tested thickness.

R_t will be calculated based on the known thermal conductivity (k) for Thermo-Lag material.

R_s will be based on known physical properties and the laws of convection and radiation heat transfer.

After all of the thermal resistance values have been established, the heat transferred can be calculated for the raceway with a desired thickness of fire barrier by recalculating R_t and R_s considering the additional thickness.

Since the heat is a function of the current squared, the ampacity correction factor (ACF) will be determined by the following relationship.

$ACF = I_p/I = (q_p/q)^{1/2}$ where the subscript p refers to the protected raceway

As a test of the methodology, the test data for 1 hour fire barrier will be used to predict the ACF for the 3 hour barrier test. These results will be compared to the test data to demonstrate the conservatism of the methodology.

4.0 Assumptions/Bases

4.1 The total heat load used in the extrapolation of the ampacity correction factors associated with fire barriers will be based on the I^2R losses in the cables which will be representative of the total heat load. The testing documented in Reference 2.6 included paired sets of conductors with the same current running in opposite directions; therefore, the magnetic fields associated with this current will be effectively canceled. Generally, inductive losses are minimal in plant applications due to the practice of routing three phases of power cables in the same raceway. Inductive losses are accounted for in the ampacity rating calculations for the cables.

4.2 Surface emittance for cable, raceway, and Thermo-Lag will be assumed to be equal to 0.9. Note that a high emittance value will reduce the thermal resistance at the surface having an overall effect of maximizing the ampacity de-rating from the additional thickness of Thermo-Lag.

4.3 Heat transfer through the sides of cable tray will be assumed to be zero. This will reduce the heat transfer equation for tray to a one dimensional heat transfer equation. As the tested cable tray is relatively wide ,24", compared to the depth, 4", this test is expected to be a good approximation for all cable tray widths.

4.4 The thickness of the Thermo-Lag in the tests is assumed to be at the minimum allowable thickness specified. This thickness will provide a conservative ACF value as it maximizes the thickness of Thermo-Lag which must be added to reach the final thickness.

Conduit		
1 Hour Thermo-Lag 330-1	0.625 Inches	(Ref. 2.6 Page 6)
3 Hour Thermo-Lag 330-1	1.25 Inches	
Tray		
1 Hour Thermo-Lag 330-1	0.625 Inches	
3 Hour Thermo-Lag 330-1	1.125 Inches	

4.5 The calculation will be performed assuming the following bounding plant configurations:

Conduit With 1 Hour Barrier
Bounded by 1 to 4" Conduit
Maximum Barrier Thickness = 1-1/2"

Conduit With 3 Hour Barrier
Bounded by 1 to 4" Conduit
Maximum Barrier Thickness = 3-1/16"

Tray or Banked Conduit With 1 Hour Barrier
Bounded by 4" deep tray and 1 to 4" Banked Conduit
Maximum Barrier Thickness = 1-1/2"

Tray or Banked Conduit With 3 Hour Barrier
Bounded by 4" deep tray and 1 to 4" Banked Conduit
Maximum Barrier Thickness = 3-1/16"

Adjacent layers of fire barriers are assumed to be installed with a layer of trowel grade material creating a homogeneous thickness of Thermo-Lag material with no intervening air gaps. An exception is the 1 hour upgrade which provides a second layer of Thermo-Lag 330 applied directly on the base layer. For this case, the potential for additional thermal resistance at this interface will be ignored. The conservative assumptions relative to the Thermo-Lag thickness applied will compensate for any additional resistance at this interface.

4.6 Raceway is made of rigid steel, magnetic material, which is typical for power plant installations.

4.7 Banked conduit which is banked in a single plane can be assumed to be equivalent to cable tray. Both configurations involve a cable mass arranged in a shallow rectangular section. Both configurations involve an air gap between the cables and the fire barrier material.

4.8 The thermal resistance values for all items within the raceway and for the gap between the conduit and the Thermo-Lag material will be assumed to remain constant as additional thickness of Thermo-Lag is installed. Considering that the geometry of these areas is not changed, this approximation is reasonable.

4.9 This calculation is valid for indoor areas where the surrounding air and surface temperatures are relatively equal. Air flow around the raceway is assumed to be in the laminar flow region.

5.0 Calculation

5.1 Determination of test heat loads

Test heat loss in watts is calculated by the following equation:

$$q=I^2RN$$

q= Heat Per Foot
I= Test Current
R= Cable Resistance Per Foot
N= Number of Conductors

Raceway Size	(Conductor)	Test Current[1]	Resistance Per Foot[2]	Number of Conductors	Heat/Ft Watts	Heat/Ft BTU/Hr[3]
1"	(1-4C/#10)	30.5	.00136	4	5.06	17.27
1" w/3 Hr Barrier		31.8			5.50	18.78
4"	(12-3C/#6)	27.2	.000548	36	14.60	49.81
4" w/1 Hr Barrier		28.1			15.58	53.17
4"	(12-3C/#6)	26.0	.000548	36	13.34	45.52
4" w/3 Hr Barrier		25.3			12.63	43.10
Tray	(96-3C/#6)	28.8	.000548	288	130.91	446.78
Tray w/1 Hr Barrier		17.0			45.61	155.67
Tray	(96-3C/#6)	28.0	.000548	288	123.73	422.30
Tray w/3 Hr Barrier		16.4			42.45	144.87

1. Normalized test current is from Reference 2.6
2. Resistance per foot is from Ref. 2.8 Section 2.5, Table 2-6, Table 6-1
3. Multiply Watts by 3.413 to obtain BTU/Hr

5.2 Determination of Thermo-Lag R values (R_t)

For heat transfer through Thermo-Lag cylinder

$R = Ln(Ro/Ri)/2\pi kL$ (Ref. 2.3, Page 2.3)

Ro= Outside Radius
Ri= Inside Radius
k= Thermal Conductivity = 0.1 BTU/Hr-FT-°F (Ref. 2.7)
L= Length = 1 Ft. (Per Foot)

For heat transfer through Thermo-Lag sheet

$R = L/kA$ (Ref. 2.3, Page 2.3)
L= Thickness
k= Thermal Conductivity = 0.1 BTU/Hr-FT-°F (Ref. 2.7)
A= Surface Area

A full tabulation of the Thermo-Lag R values for the various sizes is included in the spreadsheet below.

5.3 Determination of surface R values (R_s)

The surface resistance will consider free convection and radiation heat transfer.

For free convection

$q_c = hA\Delta T$
q_c=heat transferred by convection
h = convection heat transfer coefficient
For horizontal cylinders in air $h = .27(\Delta T/L)^{.25}$ (Ref. 2.3, Page 2.12)
A = Surface Area
L = Characteristic length in feet (diameter or width)

$q_c = .27(\Delta T/L)^{.25} A\Delta T$

For radiation

$q_r = sAe(T_s^4 - T_a^4)$ (Ref. 2.3, Page 2.11)
q_r= Heat transferred by radiation
s = 1.714×10^{-9} BTU/Hr-Ft2-R^4, Boltzmann Constant
A= Surface area
e = Surface Emittance = .9 (Assumption 4.1)
T = Absolute Temperature, Rankine

$q_r = 1.714 \times 10^{-9}(.9)A(T_1^4 - T_2^4)$

For total heat transferred from the surface

$$q_s = qc + qr$$

$$q_s = .27(\Delta T/L)^{.25} A\Delta T + 1.714X10^{-9}(.9)A(T_1^4 - T_2^4)$$

$$q_s = [.27(\Delta T/L)^{.25} + 1.714X10^{-9}(.9)(T_1^4 - T_2^4)/\Delta T]A\Delta T$$

$$\Delta T/q_s = R_s = 1/\{[.27(\Delta T/L)^{.25} + 1.714X10^{-9}(.9)(T_1^4 - T_2^4)/\Delta T]A\}$$

5.4 Calculation of ACF

The ACF is calculated using a spreadsheet in accordance with the methodology described above. A description of the spreadsheet follows:

OD/W This is an input value of the conduit outside diameter or cable tray width in inches. Conduit diameters are obtained from Reference 2.5.

TH This value is the thermo-Lag thickness in inches.

ODT This is the outside diameter of the raceway with any wrap calculated from the OD and TH. For cable tray OD is not calculated because it will always be equal to W.

A The outer surface heat transfer area. Note that for cable tray, both the top and bottom areas are included. Area is calculated on the basis of a one foot length of raceway.

R_i Inside thermal resistance as defined above. The value is calculated from the test data with no wrap in accordance with the following formula. The R_i value. calculated is then used for the cases with fire barrier installed. Note that there is no Rg and Rt for this case.

$$Ri = \Delta T/q - Rs, \quad \text{Where } \Delta T = 90°F$$
(Temp drop from conductor surface to ambient)

R_g Gap thermal resistance as defined above. The value is calculated from the test data for raceway with fire barrier in accordance with the following formula. The R_g value calculated is then used for extrapolating cases with a different thickness of fire barrier.

$$Rg = \Delta T/q - (R_i + R_t + R_s), \quad \text{Where } \Delta T = 90°F$$

R_t Thermo-Lag thermal resistance. The value is calculated in accordance with the following equations which were developed above.

Conduit	$R_t = Ln(ODT/OD)/2\pi k$,	k=.1	(Ref. 2.7)
Tray	$R_t = TH/kA$,	k=.1	

R_s Surface thermal resistance is calculated in accordance with the following equations which were developed above. Note that the ΔT in this equation is between the surface and ambient and the T^4 values must be in °R. The ambient temperature used is 104°F/564°R.

$$Rs = 1/[.27((T_s-104)/ODT)^{.25} + 1.714X10^{-9}(.9)((T_s+460)^4-564^4)/(T_s-104)]A$$

T_s Surface temperature of Thermo-Lag or bare conduit. The value is determined by iteration until $q = q'$.

q Heat transferred - For test cases, the test data is used. For extrapolated cases, it is calculated as follows:

$$q = \Delta T/(R_i + R_g + R_c + R_s), \quad \text{Where } \Delta T = 90°F$$

q' Heat transferred from the surface - Calculate heat transferred from the surface as follows:

$$q = \Delta T/R_s, \quad \text{Where } \Delta T = T_s - 104°F$$

From continuity, the heat transferred from the surface is the same as the total heat transferred. In order to solve the various cases, Ts is adjusted by iteration until $q = q'$.

ACF Ampacity correction factor calculated by the following equation which was developed above.

$$ACF = (q_o/q)^{1/2}$$

RACEWAY HEAT TRANSFER AND AMPACITY DE-RATING

CONDUIT

	OD IN	TH IN	ODT IN	A SQFT	Ri BTU/HR-F	Rg BTU/HR-F	Rt BTU/HR-F	Rs BTU/HR-F	Ts F	q BTU/H	q' BTU/H	ACF
Values Extrapolated from 1" Conduit Test w/ 3 Hour Wrap												
Test Unwrapped	1.315	0	1.315	0.3443	3.891	[redacted]		1.3196	126.79	17.272	17.27	[redacted]
Test Wrapped	1.315	1.25	3.815	0.9988	3.891	-1.354	1.6952	0.5606	114.53	18.775	18.78	1.043
Extrapolated 1 HR	1.315	1.5	4.315	1.1297	3.891	-1.354	1.8912	0.5079	113.26	18.23	18.23	1.027
Extrapolated 3 HR	1.315	3.06	7.435	1.9465	3.891	-1.354	2.7571	0.3247	109.20	16.02	16.02	0.963
Values Extrapolated from 4" Conduit Test w/ 1 Hour Wrap												
Test Unwrapped	4.5	0	4.5	1.1781	1.365	[redacted]		0.4419	126.01	49.81	49.81	[redacted]
Test Wrapped	4.5	0.625	5.75	1.5053	1.365	-0.422	0.3901	0.3603	123.16	53.17	53.17	1.033
Extrapolated 1 HR	4.5	1.5	7.5	1.9635	1.365	-0.422	0.813	0.2957	116.98	43.88	43.88	0.939
Extrapolated 3 HR	4.5	3.06	10.62	2.7803	1.365	-0.422	1.3666	0.225	111.99	35.52	35.52	0.844
Predict 3 HR Test	4.5	1.25	7	1.8326	1.365	-0.422	0.7032	0.3116	118.33	45.98	45.98	0.961
Values Extrapolated from 4" Conduit Test w/ 3 Hour Wrap												
Test Unwrapped	4.5	0	4.5	1.1781	1.531	[redacted]		0.4465	124.32	45.52	45.52	[redacted]
Test Wrapped	4.5	1.25	7	1.8326	1.531	-0.459	0.7032	0.3136	117.52	43.10	43.10	0.973
Extrapolated 1 HR	4.5	1.5	7.5	1.9635	1.531	-0.459	0.813	0.2975	116.27	41.25	41.25	0.952
Extrapolated 3 HR	4.5	3.06	10.62	2.7803	1.531	-0.459	1.3666	0.2259	111.63	33.79	33.79	0.862

RACEWAY HEAT TRANSFER AND AMPACITY DE-RATING

CABLE TRAY / BANKED CONDUIT

	W IN	TH IN		A SQFT	Ri BTU/HR-F	Rg BTU/HR-F	Rt BTU/HR-F	Rs BTU/HR-F	Ts F	q BTU/H	q' BTU/H	ACF
Values Extrapolated from 4 X 24" Tray Test w/ 1 Hour Wrap												
Test Unwrapped	24	0	[redacted]	4	0.071	[redacted]	[redacted]	0.1304	162.24	446.78	446.78	[redacted]
Test Wrapped	24	0.625	[redacted]	4	0.071	0.228	0.1302	0.1492	127.22	155.67	155.67	0.590
Extrapolated 1 HR	24	1.5	[redacted]	4	0.071	0.228	0.3125	0.1534	122.06	117.70	117.70	0.513
Extrapolated 3 HR	24	3.06	[redacted]	4	0.071	0.228	0.6375	0.1585	117.03	82.21	82.21	0.429
Predict 3 HR Test	24	1.125	[redacted]	4	0.071	0.228	0.2344	0.1518	123.95	131.40	131.40	0.542
Values Extrapolated from 4 X 24" Tray Test w/ 3 Hour Wrap												
Test Unwrapped	24	0	[redacted]	4	0.082	[redacted]	[redacted]	0.1315	159.53	422.30	422.30	[redacted]
Test Wrapped	24	1.125	[redacted]	4	0.082	0.155	0.2344	0.1503	125.78	144.88	144.88	0.586
Extrapolated 1 HR	24	1.5	[redacted]	4	0.082	0.155	0.3125	0.1521	123.53	128.36	128.36	0.551
Extrapolated 3 HR	24	3.06	[redacted]	4	0.082	0.155	0.6375	0.1577	117.76	87.23	87.23	0.454

6.0 Results

The most conservative results for 1 hour and 3 hour conduit and cable tray are listed below. The less conservative values from the spreadsheet can also be used for applicable field conditions.

Item	ACF
1 HR Conduit	.94
3 HR Conduit	.84
1 HR Tray (Banked Conduit)	.51
3 HR Tray (Banked Conduit)	.43

Note that these correction factors are contingent upon the maximum thickness, installation requirements, and size limits detailed in the Assumptions/Basis.

Discussion

The calculation spreadsheet provided negative values for R_g for conduit. A negative value for thermal resistance has no real physical meaning. The negative value is a result of back calculating the resistance from test data. As the total resistance is made up of 4 components, the negative value is simply a correction for a resistance value that is excessive for one of the other components. The negative value does not interfere with the calculation because it is always added to the other components to obtain the total resistance.

When the methodology was used to predict the ACF for the tested 3 hour barriers using the test data from the 1 hour barriers, the results were as follows:

	Predicted Value	Test Value
4" Conduit w/3 hour barrier	.96	.97
Cable Tray w/3 hour barrier	.54	.59

These results demonstrate that the methodology used to extrapolate the test data provides conservative and reasonably accurate values.

TSI INC.

APPROVED FIRE BARRIERS FOR THE NUCLEAR INDUSTRY

thermo-lag® 330-1 FIRE BARRIER

MATERIAL PROPERTIES

This brochure presents the major properties of THERMO-LAG in interest for nuclear generating plant application. For additional data not presented, consult TSI.

RADIATION RESISTANCE

- 2.12 x 10^8 rads total 40 year integrated dose
- After irradiation no degradation in fire resistive properties

FIRE PROTECTIVE FEATURES

- ASTM E-84 Testing for THERMO-LAG 330-1
  - Flame Spread Rating — 5
  - Fuel Contributed Rating — 0
  - Smoke Developed Rating — 15
- ASTM E-84 Testing for THERMO-LAG Primer
  - Flame Spread Rating — 0
  - Fuel Contributed Rating — 0
  - Smoke Developed Rating — 5
- ASTM E-84 Testing for THERMO-LAG 350-2P Topcoat
  - Flame Spread Rating — 5
  - Fuel Contributed Rating — 0
  - Smoke Developed Rating — 0
- One-hour and three-hour fire endurance test in accordance with ASTM E-119, and ANI/MAERP test "ANI/MAERP Standard Fire Endurance Test Method to Qualify a Protective Envelope for Class 1E Electrical Circuits".
  - 1/2 inch THERMO-LAG rated one hour
  - 1 inch THERMO-LAG rated three hours
- ASTM E-119 hose stream test on electrical trays and conduit for one and three hour rated THERMO-LAG (2-1/2 minute hose stream application)
- ASTM E-119 fire tests for structural steel, hangers to determine required THERMO-LAG thickness for one and three hour rating

AMPACITY DERATING

Ampacity derating tests performed in accordance with IPCEA Publication Number P-54-440 (Second Edition) (to determine cable base ampacity) and NEMA Publication No. WC51-1975. The following results were obtained (for 40 percent loading):

One-Hour THERMO-LAG Barriers
- Tray — 12.5 percent derating
- Conduit — 6.8 percent derating

Three-Hour THERMO-LAG Barriers
- Tray — 17 percent derating
- Conduit — 10.9 percent derating

MECHANICAL (PHYSICAL) PROPORTIES

- Density wet — 10.5 lbs/gallon
- Density dry — 75±3 lbs/ft³
- Dry Weight 1/2 inch thickness (one-hour rated) = 3.25 lb/ft²
- Dry Weight 1 inch thickness (three-hour rated) = 6.5 lb/ft²
- Water based

Tensile strength	(75°F)	800 PSI
Shear strength	(75°F)	1100 PSI
Flexural stiffness	(75°F)	85 KSI
Flexural strength	(75°F)	2200 PSI
Bond strength	(75°F)	575 PSI
Initial Modulus	(75°F)	70 KSI

- Thermal Conductivity (Unfired, full cured) 0.1 Btu/hr ft.² °F/ft

SEISMIC PROPORTY

THERMO-LAG has been qualified by static analysis for a very conservative loading. A value of 7.5g horizontal, and 6.0g vertical acceleration, combined biaxially was used for the analysis. These values bound most nuclear generating plant seismic criteria.

THERMO-LAG® 770 FIRE BARRIER SYSTEM

PHYSICAL AND MECHANICAL PROPERTIES

Property	Nominal Value	Procedure
Sprayed Density	62 Lbs/Ft^3	ASTM D 792
Hardness	50	Shore D
Thermal Conductivity	.1 Btu-Ft / Ft^2 Hr °F	ASTM C 177
Tensile Strength	850 psi	ASTM D 638
Compressive Strength	625 psi	ASTM D 695
Flexural Strength	2500 psi	ASTM D 790
Flexural Stiffness	90 ksi	ASTM D 790
Bond Strength	700 psi @ RT	ASTM D 952
Initial Modulus	75,000 psi	ASTM D 638
Shear Strength	1,250 psi	ASTM D 732

For additional information, consult the THERMO-LAG 770 Subliming Material data sheet.

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