CALCULATION COVER SHEET

Calculation No: PTN-BFJM-96-005

Title: Fire Barrier Ampacity Correction Factors - Extrapolation of Test Results for 3 Hour Barrier

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REVISIONS

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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 will be based on testing performed at Omega Point Laboratories for Texas Utilities Comanche Peak Plant. The testing included conduit and cable tray with a 1 Hour fire barrier installed. This calculation will use heat transfer calculations to extrapolate the results from the 1 hour barrier tests to three hour rated barriers used at the Turkey Point and St. Lucie Plants.

2.0 References

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

2.2 Omega Point Lab Test Report # 12340-94583,95165,95168,95246, "Electrical Test to Determine the Ampacity Derating of a Protective Envelope for Class 1E Electrical Conduits" (Included as Attachment 1)

2.3 ASHRAE Handbook, 1991 Fundamentals

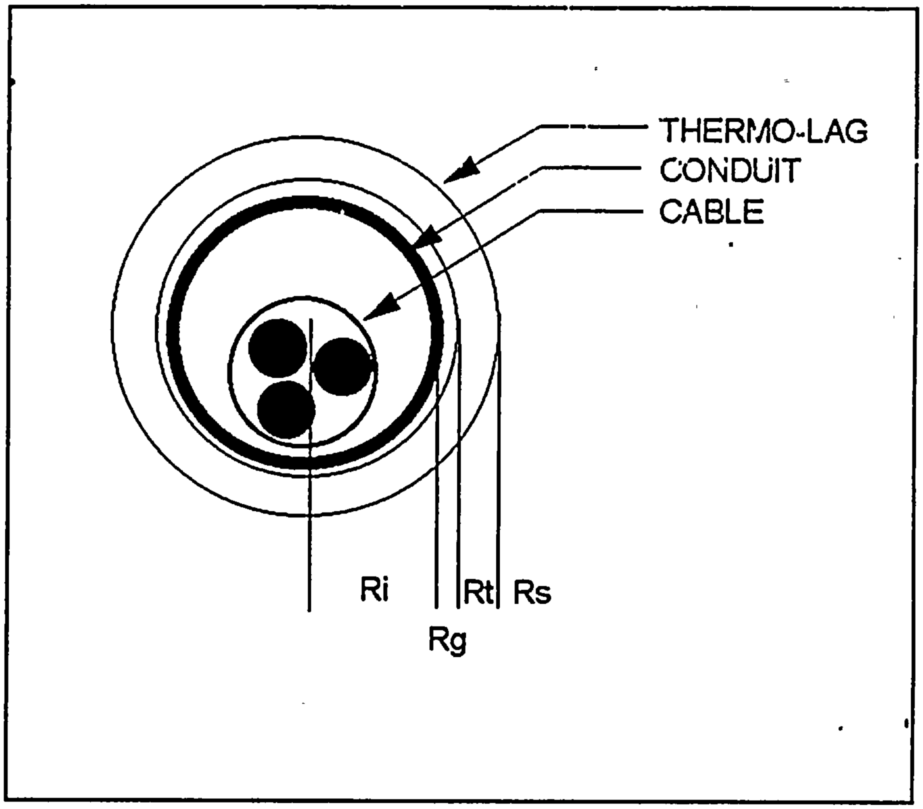
2.4 NRC Safety Evaluation of Ampacity Issues Related to Thermo-Lag Fire Barriers at Comanche Peak Steam Electric Station, Unit 2 (TAC No. M8599) Dated June 14,1995.

2.5 ANSI C80.1-1990, Table 2 "Dimensions and Weights of Rigid Steel Conduits" (Included as Attachment 2)

2.6 Ebasco Calculation EC-096, "Cable Ampacity And Voltage Drop Calculation" (Included as Attachment 3)

2.7. TSI Inc., Thermolag 330-1 Thermal Properties (Included as Attachment 4)

3.0 Methodology



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

$$q = (Tc-Ta) / (Ri + Rg + Rt + Rs)$$

q	=	Rate of heat transfer from raceway
Tc	=	Temperature of conductor (90°C/194°F)
Ta	=	Ambient temperature (40°C/104°F)
Ri	=	Thermal resistance of all items within the raceway including the raceway itself
Rg	=	Thermal resistance of the air gap between the raceway and the fire barrier material
Rt	=	Thermal resistance of the fire barrier material
Rs	=	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.

Tc and Ta are fixed test parameters with values which are listed above.

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

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

Rg will be calculated from the test data for raceway with a 1 hour barrier

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

Rs will be based on known physical properties considering 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 the three hour barrier.

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

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

4.0 Assumptions/Bases

4.1 The effect of inductive losses in the raceway and cable sheath will be negligible with respect to applying the test data to the Turkey Point and St. Lucie configurations.

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.

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", this is expected to be a good approximation for all cable tray.

4.4 One hour Thermo-Lag fire barrier will be assumed to be at the minimum thickness of 1/2" (1/4" for overlay where used). This thickness will provide a conservative value when calculating the R value for the gap between the raceway and the barrier.

4.5 Three hour Thermo-Lag fire barrier will be assumed to be at the nominal thickness in accordance with the manufacture's tolerance, 1-1/4 inches. This thickness will provide a conservative result when calculating the heat transferred with the three hour barrier, as the value of the initial 1 hour wrap was minimized. It was judged to be unrealistically conservative to go to the maximum thickness tolerance of 1.5 inches.

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 Thermolag material will be assumed to remain constant as additional thickness of Thermolag is installed. Considering that the geometry of these areas is not changed, this approximation is reasonable for the purpose of extrapolating the thermal resistance from raceway with 1 hour wrap to raceway with 3 hour wrap.

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 (Conductor) Size	Test Current[1]	Resistance Per Foot[2]	Number of Conductors	Heat/Ft Watts	Heat/Ft BTU/Hr[3]
3/4 (1-3C/#10)	39.6	.001404	3	6.61	22.6
3/4 Wrapped	35.9			5.43	18.5
2 (1-3C/#6)	64.5	.000555	3	6.93	23.7
2 Wrapped	60.2			6.03	20.6
5 (4-750 kCMil)	571	.0000224	4	29.21	99.7
5 Wrapped	510			23.30	79.5
Tray (126 -3C/#6)	23.1	.000555	378	111.9	382.1
Tray Wrapped	15.8			52.4	178.7

1. Current is from Reference 2.2
2. Resistance per foot is from Ref. 2.6
3. Multiply Watts by 3.413 to obtain BTU/Hr .

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5.2 Determination of Thermo-Lag R values (R_t)

For heat transfer through Thermo-Lag cylinder

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

R_o= Outside Radius
R_i= 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

$q_r = \sigma A\epsilon(T_s^4 - T_a^4)$ (Ref. 2.3, Page 2.11)
q_r= Heat transferred by radiation
σ = 1.714X10^{-9} BTU/Hr-Ft^2-R^4, Boltzmann Constant
A= Surface area
ϵ = Surface Emittance = .9 (Assumption 4.1)
T = Absolute Temperature, Rankine

$q_r = 1.714X10^{-9}(.9)A(T_1^4 - T_2^4)$

For total heat transferred from the surface

$q_s = q_c + q_r$

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

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

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

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. Conduit diameters are obtained from Reference 2.5.

TH This value is the thermolag thickness. For each raceway size a thickness representing no wrap, 1 Hr wrap, and 3 Hr wrap is entered.

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 raceway both the top and bottom areas are included. Area is calculated on the basis of a one foot length of raceway.

Ri Inside thermal resistance as defined above. The value is calculated from the test data with no wrap in accordance with the following formula. The Ri value calculated is then used for the cases with 1 Hr and 3 Hr wrap. Note that there is no Rg and Rt for this case.

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

Rg Gap thermal resistance as defined above. The value is calculated from the test data with 1 Hr wrap in accordance with the following formula. The Rg value calculated is then used for the case with 3 Hr wrap.

$Rg = \Delta T/q - (Ri + Rt + Rs)$, Where $\Delta T = 90°F$

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

Conduit $Rt = Ln(ODT/OD)/2\pi k$, $k = .1$ (Ref. 2.7)

Tray $Rt = TH/kA$, $K = .1$

Rs 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.

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

Ts Surface temperature of Thermo-Lag or bare conduit. The value is determined by iteration until q = q′.

q Heat transferred - For no wrap or 1 Hr wrap the value from the test data is used. For 3 Hr wrap calculate as follows:

$$q = \Delta T/(Ri + Rg + Rt + Rs), \quad \text{Where } \Delta T = 90°F$$

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

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

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.

$$ACF = \sqrt{(q_p/q)}$$

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
1.05	0	1.05	0.2749	2.474	[redacted]		1.5088	138.10	22.60	22.60	N/A
1.05	0.75	2.55	0.6676	2.474	0.201	1.4122	0.7782	118.40	18.50	18.50	0.905
1.05	1.25	3.55	0.9294	2.474	0.201	1.9388	0.5996	114.35	17.27	17.27	0.874
2.375	0	2.375	0.6218	2.997	[redacted]		0.8006	122.97	23.70	23.70	N/A
2.375	0.75	3.875	1.0145	2.997	0.044	0.7791	0.5484	115.30	20.60	20.60	0.932
2.375	1.25	4.875	1.2763	2.997	0.044	1.1445	0.4564	112.85	19.39	19.39	0.904
5.563	1E-19	5.563	1.4564	0.560	[redacted]		0.3428	138.18	99.70	99.70	N/A
5.563	0.5	6.563	1.7182	0.560	0.000	0.2631	0.3094	128.60	79.50	79.50	0.893
5.563	1.25	8.063	2.1109	0.560	0.000	0.5907	0.2686	121.04	63.43	63.43	0.798

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
24	0	[redacted]	4	0.102	[redacted]		0.1335	155.00	382.10	382.10	N/A
24	0.500	[redacted]	4	0.102	0.150	0.1042	0.147	130.27	178.70	178.70	0.684
24	1.25	[redacted]	4	0.102	0.150	0.2604	0.1513	124.50	135.50	135.50	0.595

6.0 Results

The ampacity correction factors for 1 Hr Thermo-Lag from testing and 3 hour Thermo-Lag extrapolated by calculation are as follows.

Item	ACF	
	1 Hr	3 Hr
Conduit	.89	.80
Tray (Banked Conduit)	.69	.60

AMPACITY DERATING OF FIRE PROTECTED CABLES

Project No. 12340-94583,95165-95168,95246

ELECTRICAL TEST TO DETERMINE THE AMPACITY DERATING OF A PROTECTIVE ENVELOPE FOR CLASS 1E ELECTRICAL CIRCUITS

March 19, 1993

Prepared For:

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ABSTRACT

Three conduit assemblies, two air drop assemblies, and one cable tray assembly, clad with Thermo-Lag® materials as described herein, were evaluated in accordance with the Texas Utilities Electric TEST PLAN, Rev. 4, yielding the following ampacity derating values:

TEST ITEM	PERCENT DERATING
3C/#10 in 3/4" Conduit	9.34
3C/#6 in 2" Conduit	6.67
3C/#6 in Air Drop	21.2
24" Cable Tray	31.6
750 kCMil in Air Drop	31.8
4/C 750 kCMil in 5" Conduit)	10.7

The details, procedures and observations reported herein are correct and true within the limits of sound engineering practice. All specimens and test sample assemblies were produced, installed and tested under the surveillance of either Texas Utilities' or the testing laboratory's Quality Assurance Program. This report describes the analysis of distinct assemblies and includes descriptions of the test procedure followed, the assemblies tested, and all results obtained. All test data are on file and remain available for review by authorized persons.

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INTRODUCTION

A Fire Protective Envelope protects electrical components from the effects of fire. In doing so, it will reduce the inflow of energy into the system and maintain the internal temperature below maximum limits. These limits will ensure that the cable systems remain functional during a fire, and allow operators to maintain control of systems required for fire safe shutdown.

The addition of a Fire Protective Envelope on a cable system will not only protect the contained cable from elevated temperatures associated with a fire, but will impede the heat dissipation associated with cable operation. The evaluation described herein will yield an accurate and realistic value for the ampacity derating of cables when a Fire Protective Envelope is installed on the cable system.

TEST PROCEDURE

This entire test program was performed in accordance with Texas Utilities Electric TEST PLAN, Rev. 4, which has been included in Appendix B. The specific details of this project will be found in that document.

TEST ENCLOSURE

The ampacity test enclosure was constructed of steel stud walls and ceiling with a minimum of 1 in. of polystyrene insulation lining the interior of the room. The overall dimensions of the test enclosure were 20 ft. x 18 ft. x 8 ft. An entry door was provided in one wall and an observation window was placed in an adjacent wall. The wall with the observation window was made to be removable to facilitate easier location of test articles. Four 1.5 kW heaters were disposed about the room to regulate ambient conditions. Two of the heaters were variable from outside of the test enclosure via connection to standard laboratory variable transformers. Located directly behind each heater was a 24 in. box fan to gently stir the air and more evenly distribute the heat. A total of nine thermocouples were suspended from the ceiling and positioned in the horizontal plane of the test items, 12 in. away from various test items to monitor the ambient room temperatures. Two stanchions were erected to support the test articles. Each stanchion consisted of a length of 2 in. square steel tubing supported at several points by an A-frame leg. A length of 2 in. x 4 in. wood stud was affixed to the top surface of each stanchion.

In the case of all but the 5 in. conduit, the test article with the fire protective system installed was tested first. Once the system had attained equilibrium and all final measurements had been taken, the fire protective barrier was removed from the system (in the case of the air drop assemblies and the cable tray assembly) or the instrumented cable was removed from the clad conduit and inserted into a similarly constructed, bare conduit.

THERMOCOUPLES

Temperatures on the cable conductors within the conduit and air drop assemblies were measured with Type T, 24 gauge, Copper-Constantan electrically welded thermocouples formed from Copper and Constantan wires of "special limits of error (±0.5°C)," and covered with Teflon FEP® insulation. Temperatures on the cable conductors within the cable tray assembly were measured with Type K, 24 gauge, Chromel-Alumel electrically welded thermocouples formed from Chromel and Alumel wires of "special limits of error (±1.1°C)," and covered with braided fiberglass insulation. All thermocouple wire was calibrated to ±0.5°C.

DATA ACQUISITION SYSTEM

The outputs of the test article thermocouples and room control thermocouples were monitored by a data acquisition system consisting of a John Fluke Mfg. Co. Model HELIOS I 2289A Computer Front End, and an Apple Computer Co. Macintosh Classic microcomputer. The Computer Front End was connected to the RS422 Serial Interface Port of the Macintosh. The computer was programmed in Microsoft BASIC to command the HELIOS unit to sample the data input lines, receive and convert data into a digital format, and to manipulate the data for display on screen, the hard copy printout, and saving to hard disk. The computer program determined, and displayed, the average temperatures at each of the three positions on each test article. The rate of change of temperature for the average of the thermocouples located in the center portion of the test article was then calculated. All individual data points and calculated values were saved on hard disk at one minute intervals. A record of individual location temperatures, maximum temperatures and rates of change of temperatures was printed at five minute intervals. All test data is presented in Appendix F: TEST DATA.

CURRENT CONTROL SYSTEM

The current flow through the test articles was regulated using process control type devices. The available voltage for any test control circuit was 208 Vac single phase. A Silicon Controlled Rectifier (SCR) device (Halmar Robicon Group Model No. 140P-FK2-CL) was used to vary the voltage available to the primary side of a step-down transformer between 0 Vac and 208 Vac in proportion to a 4-20 mA control input. The test article was connected to the secondary side of the step-down transformer. A proportional-integral-derivative process controller (Honeywell Universal Digital Controller Model No. UDC 3002-0-000-1-00-XXXX) was responsible for generating the 4-20 mA signal fed to the SCR device, based on a voltage feedback loop. A current transformer (Flex-Core Model No. 58-151, 150:5

or 76-102, 1000:5 ratio; input amps:output amps) was fitted to one lead of the test article to monitor the current flow through the conductor. The output of the current transformer was connected to a current transducer (Flex-Core Model No. CT5-005A) with a mA to mV converter (Flex-Core Model No. LRB-10000) to produce a 0-10 Vdc signal proportional to a 0-150 A or 0-1000 A current span in the sample conductor. This 0-10 Vdc signal is used as the "process variable" in the feedback loop to the controller. In essence, the above circuitry made up a constant-current device, insensitive to line voltage changes.

The current in any given system was driven to a level high enough to bring the conductor to 90°C as quickly as possible by increasing the output signal of the process controller via keypad commands. As the conductor temperature approached 90°C, the current level was reduced and the test article was given time to respond to current changes before another adjustment was made to the current. During this time period, the controller was turned to "automatic" control and the "process variable set point" (the voltage output from the current transformer that represents the current level at which the controller will maintain the system) was adjusted to the same value as the displayed process variable (the controller varies its output in order the maintain the process variable at the level indicated by the set point).

This process of adjusting the controller output (and the control variable set point) and waiting for the system to stabilize (about 1/2 hour to about 2 hours, depending upon the nature of the system) was continued until the temperature parameters of the test article were within the specified limits. The controller was allowed to operate the system for a minimum of three hours. If, at the end of three hours, the system was still within the bounds of all specifications, a final current and voltage measurement were taken and the system was deemed to be in equilibrium.

FINAL CURRENT MEASUREMENT

All final current measurements were performed using ammeters supplied and calibrated by Texas Utilities Electric. These ammeter used were manufactured by James Biddle Co. and identified as Biddle Instruments Digital Clamp-On RMS Volt-Ammeter, Cat. No. 278001 (TU Electric ID No. IC-1029 and IC-1030). Measurements recorded for test items containing 3C/#10 AWG of 3C/#6 AWG cable were taken with the ammeter ID No. IC-1030. Current measurements recorded for test items containing 750 kCMil cable were taken with the ammeter ID No. IC-1029. Calibration documentation for these devices can be found in Appendix G: Quality Assurance.

TEST ASSEMBLIES

TEST ITEMS (GENERAL)

The conduit materials used in the test were provided by Texas Utilities , and are representative of those installed at CPSES.

Cable tray materials used in this test were purchased by Omega Point Laboratories from B-Line Systems, Inc. (Cat. No. 248P0924144). The following table provides pertinent data on the cable tray material used:

ATTRIBUTE	DIMENSION
Side rail thickness	0.048 in.
Rung thickness	18 GA
Rung spacing	9 in. o.c.
Rung dimensions	1-5/8 in. w x 13/16 in. h x 3/8 in. leg

Cable tray straight sections consisted of ASTM A446, GR A, pre-galvanized steel, ASTM A525.

All test items (with the exception of the cable tray assembly) were constructed from materials extracted from TU Electric's Comanche Peak Steam Electric Station stock material storage areas in accordance with existing site procedures.

Electrical cables used in this test (with the exception of the cable tray assembly) consisted of cables supplied by TU Electric and taken from CPSES inventory. Cables used in these tests were as follows:

CABLE TYPE	CABLE FUNCTION	DESCRIPTION	DIAMETER (in.)	CROSS-SECTIONAL AREA (in^2)
W-020	Power	3C/#6 AWG 600v.	0.980	0.754
W-026	Power	3C/#10 AWG 600v.	0.617	0.299
W-008	Power	1/C 750 kCMil. 600v.	1.290	1.307
XHHW	Power	3C/#6 AWG 600v.	0.750	0.442

The diameters and cross-sectional areas listed herein represent the Laboratory's average of ten measurements of each cable type.

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Thermo-Lag® 330-1 Materials

Thermo-Lag® materials were procured from Thermal Science, Inc. (TSI), St. Louis, MO. The Thermo-Lag® materials were extracted from CPSES stock and were representative of materials installed in the plant. Each one hour rated Thermo-Lag® 330-1 V-Ribbed Panel is 1/2 in. thick (nominal) x 48 in. wide x 78 in. long, with stress skin monolithically adhered to the panel on one face. Each panel was received with 350 Topcoat factory applied. Each 330-1 Pre-Shaped Conduit Section is 36 in. long. Two thicknesses of conduit section materials were used, 1/2 in. thick (nominal) and 1/4 in. thick (nominal) "overlay" sections, both with stress skin monolithically adhered to the surface installed facing the protected conduit. The 330-1 conduit materials were also received with 350 Topcoat factory applied. Other materials supplied by TSI were 330-1 Trowel (bulk) Grade Subliming Compound (used to pre-caulk all joints and seams on the cable tray and conduit assemblies), 330-660 Flexi-Blanket Material used to wrap the cable air drop assemblies, 330-660 Trowel (bulk) Grade Material (used to pre-caulk all seams on the cable air drop assemblies), 330-69 Stress Skin Material (used to reinforce joints on the cable tray assembly) and 350 Topcoat (two part water-based mixture). All Thermo-Lag® materials were measured, saw cut and installed onto the respective test assembly by Peak Seals craft personnel using approved CPSES drawings, procedures and specifications. Installations were inspected by CPSES-certified quality control inspectors.

Other Materials

Other commercial grade products used were: 1/2 in. wide x 0.020 in. thick, type 304 stainless steel rolled-edge banding straps with wing seals; 16 to 18 GA stainless steel tie wire; and, 0.010 in. stainless steel sheet metal.

TEST ITEMS

Scheme #AC-1

The assembly consisted of a 3/4 in. conduit through which was pulled a single three conductor cable (W-026, 3C/#10 AWG, 600V). The total cable length used for this test item was 60 ft. The three separate conductors within the cable were connected into a single series circuit. The current source was then connected to the two free cable ends. Two conduits were prepared for testing; one clad and one bare - for baseline testing.

Scheme #AC-4

The assembly consisted of a 2 in. conduit through which was pulled a single three conductor cable (W-020, 3C/#6 AWG, 600V). The total cable length used for this test item was 60 ft. The three separate conductors within the cable were connected into a single series circuit. The current source was then connected to the two free cable ends. Two conduits were prepared for testing; one clad and one bare - for baseline testing.

Scheme #AC-5

The assembly consisted of a 5 in. conduit through which was pulled four separate single conductor cables (W-008, 1/C 750 kCMil, 600V). The total cable length used for this test item was 88 ft. The four separate conductors were connected into a single series circuit. The current source was then connected to the two free cable ends. Two conduits were prepared for testing; one clad and one bare - for baseline testing.

Scheme #AA 1-1

The assembly consisted of a single three conductor cable (W-020, 3C/#6 AWG, 600V) representing an air drop assembly. The total cable length used for this test item was 60 ft. The three separate conductors within the cable were connected into a single series circuit. The current source was then connected to the two free cable ends. The cable was clad and allowed to cure. The material was then removed to perform the baseline testing.

Scheme #AA 4-2

The assembly consisted of three separate single conductor cables (W-008, 1/C 750 kCMil, 600V) representing an air drop assembly. The total cable length used for this test item was 88 ft. The three separate conductors were connected into a single series circuit. The current source was then connected to the two free cable ends. The cable was clad and allowed to cure. The material was then removed to perform the baseline testing.

Scheme #AT-1

The assembly consisted of a 24 in. wide x 4 in. deep cable tray assembly into which was laid 126 passes of single three conductor cable (3C/#6 AWG, TC XHHW CDRS, 600 Volt). The total cable length used for this test item was 1720 ft. The three separate conductors within the cable were connected into a single series circuit and the current source was then connected to the two free cable ends. The cable tray assembly was clad and allowed to cure. The material was then removed to perform the baseline testing.

ELECTRICAL CABLES

The internal cross-sectional areas for the conduits are as follows:

CONDUIT SIZE (INCHES)	ACTUAL CONDUIT I.D. (INCHES)	CROSS-SECTIONAL AREA (in^2)
3/4	0.824	0.533
2	2.067	3.356
5	5.047	20.006

The usable cross-sectional area of the cable tray was (3 in. deep x 24 in. wide) 72 square inches.

The table below shows the cable types used in each test article, the number of each cable installed, the total cross-sectional area of each cable type and the percent of the total available area taken up by cable in each test article.

3/4 in. CONDUIT

CABLE TYPE	NUMBER PRESENT	CROSS-SECTIONAL AREA (in^2)	% OF TOTAL AREA
W-026	1	0.299	56.10

2 in. CONDUIT

CABLE TYPE	NUMBER PRESENT	CROSS-SECTIONAL AREA (in^2)	% OF TOTAL AREA
W-020	1	0.754	22.47

5 in. CONDUIT

CABLE TYPE	NUMBER PRESENT	CROSS-SECTIONAL AREA (in^2)	% OF TOTAL AREA
W-008	4	5.228	26.13

24 IN. CABLE TRAY

CABLE TYPE	NUMBER PRESENT	CROSS-SECTIONAL AREA (in^2)	% OF TOTAL AREA
3C/#6	126	55.665	77.31

THERMOCOUPLE PLACEMENT

24 gauge, Type T, Copper-Constantan electrically welded thermocouples (Special Limits of Error: ±0.5°C, purchased with lot traceability and calibration certifications) were attached in nine places within each conduit or air drop assembly, by slicing through the outer jacket of the cable (down to bare conductor) and placing the thermojunction in direct contact with the top surface of the cable conductor and covering the slit with a double wrap of glass fiber reinforced electrical tape (Glass Cloth Electrical Tape, Class "B" Insulation, 1/2 in. wide, 3M Corporation, Item No. 27) for a minimum distance of 3-1/2 inches. Thirty-nine 24 gauge, Type K, Chromel-Alumel electrically welded thermocouples (Special Limits of Error: ±1.1°C, purchased with lot traceability) were similarly secured to the cables within the cable tray assembly. A representative sample of the thermocouple wire used in the cable tray test article was calibrated after the test procedure.

One thermocouple was located on each of the three conductors in each system (except the cable tray and 5 in. conduit having four conductors) at the mid-point of the assembly, and at both ends of the assembly (36 in. left and right of mid-point). The 5 in. conduit having four conductors was similarly instrumented, however, the fourth conductor had no thermocouples installed. The cable tray assembly was instrumented with a total of thirty-nine thermocouples (thirteen located at the mid-point of the cable tray, thirteen located 36 in. to the left and 36 in. to the right of mid-point) located within the second and third layer of cables.

THERMO-LAG® INSTALLATION HIGHLIGHTS

Thermo-Lag® materials were installed in accordance with the instructions contained in the CPSES Site Procedures referenced in Test Plan, Rev. 4. Short abstracts of the installation are included herein to clarify specific details.

Thermo-Lag® 330-1 Pre-Shaped Conduit Sections (1/2 in. nom. thickness)

This material was used to construct the 3/4 in., 2 in. and 5 in. diameter raceway design protective envelopes.

Thermo-Lag® 330-1 Pre-Shaped Conduit Sections (1/4 in. nom. thickness)

This material was used as an overlay on the 3/4 in. and 2 in. diameter raceway design protective envelopes.

Thermo-Lag® 330-1 V-ribbed Panels (1/2 in, nom. thickness)

This material was used to construct the cable tray protective envelope.

Thermo-Lag® 330-1 Subliming Trowel Grade Material

This material was used to pre-caulk all joints, seams and upgraded areas between pre-shaped sections.

Thermo-Lag® 330-660 Flexi-Blanket

This material was used to construct the cable air drop protective envelopes.

Thermo-Lag® 330-660 Subliming Trowel Grade Material

This material was used to pre-caulk all joints and seams between 330-660 Flexi-Blanket material and all joints of 330-66- Flexi-Blanket.

Application Methods

Each rigid conduit assembly was clad with Thermo-Lag® 330-1 1/2 in. (nominal) thick Pre-Shaped Conduit Section Material. All joints and seams were pre-caulked with 330-1 Trowel Grade Material. The sections installed on the 5 in. diameter conduit were secured using stainless steel banding material. The sections installed on the 3/4 in. and the 2 in. diameter conduits were secured using stainless steel tie wire. After being clad with 1/2 in. thick 330-1 Pre-Shaped Conduit Sections, 1/4 in. thick (nominal) Pre-Shaped Conduit Section ("overlay") Material was installed on the 3/4 in. and the 2 in. diameter conduits. All joints and seams were pre-caulked with 330-1 Trowel Grade Material and then secured using stainless steel banding. Finally, Thermo-Lag® 350 Topcoat was applied over areas where the 330-1 Trowel Grade Material had been applied following a 72 hour (minimum cure time).

The entire cable tray system was clad with Thermo-Lag® 330-1 1/2 in. (nominal) V-Ribbed Panel Material. To prevent sagging of the top panels, the cable tray was pre-banded using stainless steel banding. Al joints and seams of the protective envelope were pre-caulked with 330-1 Trowel Grade Material and secured with stainless steel bands spaced at 12 in, intervals.

During construction of the cable tray protective envelope, several areas of the envelope were reinforced with combinations of stainless steel wire, Thermo-Lag® 330-1 Trowel Grade Material and Thermo-Lag® 330-69 Stress Skin which was secured with staples. The areas reinforced included butt joints between panels on the bottom surface of the envelope and the longitudinal seams where the top and bottom panels overlap panel pieces installed at the tray side rails.

The butt joints between panels on the bottom surface were "stitched" with stainless steel tie wires on 5 in. centers. A thin layer of 330-1 Trowel Grade Material (approximately 3/16 in. thick) was next applied extending 5 in. on each side of the butt joints. Stress skin was cut and wrapped circumferentially around the envelope to overlap the butt joints by 5 in. on each side. The stress skin was worked into the trowel grade layer and secured in place with staples and stainless steel tie wire. A skim coat of 330-1 Trowel Grade Material, approximately 1/16 in. thick, was then applied over the stress skin and the tie wires.

To reinforce the longitudinal seams at the side rails, a 3/16 in. thick layer of 330-1 Trowel Grade Material was applied over the panels installed at the side rails and extending 5 in. towards the middle of the tray and both the top and bottom surfaces. Stress skin was cut and formed into a squared, U-shaped configuration which was placed over the sides and onto the top and bottom surfaces for a 5 in. distance. The stress skin was worked into the trowel grade layer and secured in place with staples and stainless steel tie wire. A skim coat of 330-1 Trowel Grade Material, approximately 1/16 in. thick, was then applied over the stress skin and tie wires.

Finally, Thermo-Lag® 350 Topcoat was applied over all areas where 330-1 Trowel Grade Material had been applied following a 72 hour (minimum) cure time.

Each cable air drop assembly was clad with three complete wraps of Thermo-Lag® 330-660 Flexi-Blanket Material. An overlap of 2 in. - 4 in. was maintained for each wrap. The overlap area of each wrap was pre-caulked with Thermo-Lag® 330-660 Trowel Grade Material and secured with stainless steel bands spaced on 6 in. centers. The overlap areas were positioned 180° from one another.

TEST RESULTS

The completed test specimens were placed in the Laboratory's test enclosure and the thermocouples connected to the data acquisition system and their outputs verified. The tests were conducted from March 2, 1993, to March 14, 1993, by Herbert W. Stansberry II, project manager, with the following persons present at various times:

Renaldo Jenkins	-	USNRC
Dick Wilson	-	USNRC
Bill Rodgers	-	USNRC
John White	-	TU Electric
Chester Pruett	-	TU Electric (Fluor-Daniel Corporation)
Melvin Quick	-	TU Electric (Stone & Webster Engineering)
Kent Brown	-	TVA
Deggary N. Priest	-	Omega Point Laboratories, Inc.
Kerry Hitchcock	-	Omega Point Laboratories, Inc.
Connie Humphry	-	Omega Point Laboratories, Inc.
Laudencio Castanon	-	Omega Point Laboratories, Inc.

TEST ITEM	EQU. VOLTAGE (VOLTS)	EQU. CURRENT (AMPS)	EQU. TEMP (°C)	ROOM TEMP (°C)	CORRECTED CURRENT (AMPS)	PERCENT DERATING
3C/#10 in 3/4" Conduit (base)	11.9	39.4	89.8	40.3	39.6	9.34
3C/#10 in 3/4" Conduit (clad)	11.0	36.0	89.4	39.3	35.9	
3C/#6 in 2" Conduit (base)	9.96	64.6	90.5	40.3	64.5	6.67
3C/#6 in 2" Conduit (clad)	9.15	60.2	89.1	39.3	60.2	
3C/#6 in Air Drop (base)	10.9	94.0	89.9	39.5	93.6	21.2
3C/#6 in Air Drop (clad)	8.12	74.0	90.9	40.5	73.8	
3C/#6 in 24" Cable Tray (base)	46.5	23.2	89.8	39.5	23.1	31.6
3C/#6 in 24" Cable Tray (clad)	27.2	15.9	90.3	39.9	15.8	

TEST ITEM	EQU. VOLTAGE (VOLTS)	EQU. CURRENT (AMPS)	EQU. TEMP (°C)	ROOM TEMP (°C)	CORRECTED CURRENT (AMPS)	PERCENT DERATING
750 kCMil in Air Drop (base)	5.21	785	89.5	40.2	790	31.8
750 kCMil in Air Drop (clad)	3.62	540	90.0	39.9	539	
4/C 750 kCMil in 5" Conduit (base)	2.19	567	89.4	40.2	571	10.7
4/C 750 kCMil in 5" Conduit (clad)	2.08	509	90.0	40.2	510	

The equilibrium current values are single-point measurements performed after the system was at equilibrium and the change in current was very low. The Equ. Temp (equilibrium conductor temperature at the hottest location), and the Room Temp are reported as 60 minute average values. The Corrected Current values are those calculated in accordance with P 848/D12 IEEE Standard Procedure for the Determination of the Ampacity Derating of Fire Protected Cables*, which corrects these current values to a room temperature of 40°C and a conductor temperature of 90°C.

* $$I' = I\sqrt{\frac{(Tc' - Ta') \times (\alpha + Tc)}{(Tc - Ta) \times (\alpha + Tc')}}$$

where

I	test current at equilibrium, amperes	
Tc	hottest conductor temperature at center at equilibrium, °C	
Ta	measured enclosure ambient temperature, °C	
I'	normalized current, amperes	
Tc'	normalized conductor temperature	= 90°C
Ta'	normalized ambient temperature	= 40°C
α	234.5 for copper	

OMEGA POINT LABORATORIES

Table 2 – Dimensions and weights of rigid steel conduit

Nominal or trade size of conduit in	Customary inch-pound units: Nominal inside diameter in	Outside diameter in	Nominal wall thickness in	Length without coupling ft and in	Minimum weight of ten unit lengths with couplings attached lb	Metric units: Nominal inside diameter mm	Outside diameter mm	Nominal wall thickness mm	Length without coupling meters	Minimum weight of ten unit lengths with couplings attached kg
3/8	0.493	0.675	0.091	9'11 -1/2"	51.5	12.5	17.1	2.31	3.04	23.36
1/2	0.632	0.840	0.104	9'11 -1/4"	79.0	16.1	21.3	2.64	3.03	35.83
3/4	0.836	1.050	0.107	9'11 -1/4"	105.0	21.2	26.7	2.72	3.03	47.63
1	1.063	1.315	0.126	9'11"	153.0	27.0	33.4	3.20	3.02	69.40
1 -1/4	1.394	1.660	0.133	9'11"	201.0	35.4	42.2	3.38	3.02	91.17
1 -1/2	1.624	1.900	0.138	9'11"	249.0	41.2	48.3	3.51	3.02	112.95
2	2.083	2.375	0.146	9'11"	332.0	52.9	60.3	3.71	3.02	150.60
2 -1/2	2.489	2.875	0.193	9'10 -1/2"	527.0	63.2	73.0	4.90	3.01	239.05
3	3.090	3.500	0.205	9'10 -1/2"	682.6	78.5	88.9	5.21	3.01	309.63
3 -1/2	3.570	4.000	0.215	9'10 -1/4"	831.0	90.7	101.6	5.46	3.00	376.94
4	4.050	4.500	0.225	9'10 -1/4"	972.3	102.9	114.3	5.72	3.00	441.04
5	5.073	5.563	0.245	9'10"	1313.6	128.9	141.3	6.22	3.00	595.85
6	6.093	6.625	0.266	9'10"	1745.3	154.8	168.3	6.76	3.00	791.67

NOTE – Applicable tolerances:

Length: ± 1/4 in (± 6.35 mm) (without coupling)

Outside diameter
for trade sizes 3/8 in through 2 in: ± 0.015 in (± 0.38 mm)
for trade sizes 2-1/2 in through 4 in: ± 0.025 in (± 0.64 mm)
for trade sizes 5 and 6 in: ±1%

Wall thickness: See 7.3.

EBASCO SERVICES INCORPORATED

CALCULATION EC-0[illegible]

BY CHS DATE 6-29-90 REVISION 1 SHEET 2 OF 23

CHKD. BY DS DATE 6/29/90 OFS NO. 8612.301 DEPT NO. 562

CLIENT FLORIDA POWER & LIGHT COMPANY

PROJECT TURKEY POINT PLANT - UNITS 3 & 4

SUBJECT CABLE AMPACITY AND VOLTAGE DROP CALCULATION

TABLE 7.2.2.1

CONDUCTOR dc RESISTANCES AT @25°C AND 90°C

Conductor Size	dc r (at 25°C) ohms/1000' Single Conductor	3/c or Triplex (1/c x 1.04)	dc r (at 90°C) ohms/1000' Single Conductor	3/c or Triplex
#12 AWG	1.72	1.789	1.72 x 1.25 = 2.15	1.789 x 1.25 = 2.236
#10 AWG	1.08	1.123	1.08 x 1.25 = 1.35	1.123 x 1.25 = 1.404
#8 AWG	0.679	0.706	0.679 x 1.25 = 0.849	0.706 x 1.25 = 0.883
#6 AWG	0.427	0.444	0.427 x 1.25 = 0.534	0.444 x 1.25 = 0.555
#4 AWG	0.269	0.280	0.269 x 1.25 = 0.336	0.280 x 1.25 = 0.350
#2 AWG	0.169	0.176	0.169 x 1.25 = 0.211	0.176 x 1.25 = 0.220
#1/0 AWG	0.106	0.110	0.106 x 1.25 = 0.133	0.110 x 1.25 = 0.138
#2/0 AWG	0.0843	0.0877	0.0843 x 1.25 = 0.105	0.877 x 1.25 = 0.110
#4/0 AWG	0.0525	0.0546	0.0525 x 1.25 = 0.0656	0.0546 x 1.25 = 0.0683
#250 kcmil	0.0449	0.0467	0.0449 x 1.25 = 0.0561	0.0467 x 1.25 = 0.0584
#350 kcmil	0.0320	0.0333	0.0320 x 1.25 = 0.040	0.0333 x 1.25 = 0.0416
#500 kcmil	0.0222	0.0231	0.0222 x 1.25 = 0.0278	0.0231 x 1.25 = 0.0289
#750 kcmil	0.0148	0.0154	0.0148 x 1.25 = 0.0185	
#1000 kcmil	0.0111	0.0115	0.0111 x 1.25 = 0.0139	
#1250 kcmil	0.00888	0.00924	0.00888 x 1.25 = 0.0111	

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CLIENT FLORIDA POWER & LIGHT COMPANY

PROJECT TURKEY POINT PLANT - UNITS 3 & 4

SUBJECT CABLE AMPACITY AND VOLTAGE DROP CALCULATION

TABLE 7.2.2.2a

CONDUCTOR AC/DC RESISTANCE RATIOS
AND AC RESISTANCES AT 90°C (SINGLE CONDUCTOR)

Conductor Size	AC/DC Resistance Ratio Non-Magnetic	AC/DC Resistance Ratio Magnetic	AC Resistance at 90°C Single Conductor Non Magnetic	AC Resistance at 90°C Single Conductor Magnetic
#12 AWG	1.0	1.0	2.15 x 1.0 = 2.15	2.15 x 1.0 = 2.15
#10 AWG	1.0	1.0	1.35 x 1.0 = 1.35	1.35 x 1.0 = 1.35
#8 AWG	1.0	1.0	0.849x 1.0 = 0.849	0.849x 1.0 = 0.849
#6 AWG	1.0	1.0	0.534x 1.0 = 0.534	0.534x 1.0 = 0.534
#4 AWG	1.0	1.0	0.336x 1.0 = 0.336	0.336x 1.0 = 0.336
#2 AWG	1.0	1.01	0.211x 1.0 = 0.211	0.211x 1.01= 0.213
#1/0 AWG	1.001	1.02	0.133x1.001= 0.133	0.133x 1.02= 0.136
#2/0 AWG	1.001	1.03	0.105x1.001= 0.105	0.105x 1.03= 0.108
#4/0 AWG	1.004	1.05	0.0656x1.004= 0.0659	0.0656x1.05= 0.0689
#250 kcmil	1.005	1.06	0.0561x1.005= 0.0564	0.0561x1.06= 0.0595
#350 kcmil	1.009	1.08	0.0400x1.009= 0.0404	0.0400x1.08= 0.0432
#500 kcmil	1.018	1.13	0.0278x1.018=0.0283	0.0278x1.13= 0.0314
#750 kcmil	1.039	1.21	0.0185x1.039=0.0192	0.0185x1.21= 0.0224
#1000kcmil	1.067	1.30	0.0139x1.067=0.0148	0.0139x1.3 = 0.0181
#1250kcmil	1.102	1.41	0.0111x1.102=0.0122	0.0111x1.41= 0.0157

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EBASCO SERVICES INCORPORATED

BY CHS DATE 6-29-90 REVISION 1 SHEET 4 OF 23

CHKD. BY DS DATE 6/29/90 OFS NO. 8612.301 DEPT NO. 562

CLIENT FLORIDA POWER & LIGHT COMPANY

PROJECT TURKEY POINT PLANT - UNITS 3 & 4

SUBJECT CABLE AMPACITY AND VOLTAGE DROP CALCULATION

TABLE 7.2.2.2b

CONDUCTOR AC RESISTANCES AT 90°C (3/C OR TRIPLEX)

(See Table 7.2.2.2a for ac/dc resistance ratios)

Conductor Size	AC Resistance at 90°C 3/C or Triplex Non Magnetic	Magnetic
#12 AWG	2.236 x 1.0 = 2.236	2.236 x 1.0 = 2.236
#10 AWG	1.404 x 1.0 = 1.404	1.404 x 1.0 = 1.404
#8 AWG	0.883 x 1.0 = 0.883	0.883 x 1.0 = 0.883
#6 AWG	0.555 x 1.0 = 0.555	0.555 x 1.0 = 0.555
#4 AWG	0.350 x 1.0 = 0.350	0.350 x 1.0 = 0.350
#2 AWG	0.220 x 1.0 = 0.220	0.220 x 1.01= 0.222
#1/0 AWG	0.138 x 1.001=0.138	0.138 x 1.02= 0.141
#2/0 AWG	0.110 x 1.001=0.110	0.110 x 1.03= 0.113
#4/0 AWG	0.0683x 1.004=0.0686	0.0683x 1.05= 0.0720
#250 kcmil	0.0584x 1.005=0.0587	0.0584x 1.06= 0.0619
#350 kcmil	0.0416x 1.009=0.0420	0.0416x 1.08= 0.0449
#500 kcmil	0.0289x 1.018=0.0294	0.0289x 1.13= 0.0327

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 nour 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.

— Storage Conditions
above 32°F and below 100°F
— Asbestoes free
— Non-toxic

CHEMICAL RESISTANCE OF THERMO-LAG 330-1

- — Water
- — Sulfuric acid — 10 percent solution
- — Hydrochloric acid — 10 percent solution
- — Sodium hydroxide — 10 percent solution
- — Sodium chloride — 5 percent solution
- — Acetic acid
- — Kerosene
- — Anhydrous Ammonia
- — LNG
- — LPG
- — Methanol

CHEMICAL RESISTANCE OF THERMO-LAG 350-2P TOPCOAT

— Frequent Contact

- — Alkali solutions
- — Salt solutions
- — Alcohols
- — Aliphatic hydrocarbons
- — Aromatic hydrocarbons

— Occasional Contact

- — Fresh water
- — Waste water
- — Mineral oils
- — Vegetable oils
- — Organic acids
- — Mineral acids
- — Oxidizing agents
- — Ketones

- — High humidity
- — Industrial atmosphere (CO_2 — SO_2 mix)
- — Salt spray

— Interior Environmental Conditions

- — High humidity
- — CO_2 — SO_2 atmosphere mix
- — Chlorine

Results: Service life of at least 40 years

TSI

TSI, Inc.
3260 Brannon Ave.
St. Louis, Mo. 63139
• (314) 352-8422
• Telex: 44-2384
• Telex: 20-9901

VI 10204

AMPACITY DERATING OF FIRE PROTECTED CABLES

Project No. 12340-94583,95165-95168,95246

ELECTRICAL TEST TO DETERMINE THE AMPACITY DERATING OF A PROTECTIVE ENVELOPE FOR CLASS 1E ELECTRICAL CIRCUITS

March 19, 1993

Prepared For:

TU Electric
COMANCHE PEAK STEAM ELECTRIC STATION
P.O. Box 1002
Glen Rose, Texas 76043-1002

E RECEIVED OCT 20 1993

OMEGA POINT LABORATORIES

ABSTRACT

Three conduit assemblies, two air drop assemblies, and one cable tray assembly, clad with Thermo-Lag® materials as described herein, were evaluated in accordance with the Texas Utilities Electric TEST PLAN, Rev. 4, yielding the following ampacity derating values:

TEST ITEM	PERCENT DERATING
3C/#10 in 3/4" Conduit	9.34
3C/#6 in 2" Conduit	6.67
3C/#6 in Air Drop	21.2
24" Cable Tray	31.6
750 kCMil in Air Drop	31.8
4/C 750 kCMil in 5" Conduit)	10.7

The details, procedures and observations reported herein are correct and true within the limits of sound engineering practice. All specimens and test sample assemblies were produced, installed and tested under the surveillance of either Texas Utilities' or the testing laboratory's Quality Assurance Program. This report describes the analysis of distinct assemblies and includes descriptions of the test procedure followed, the assemblies tested, and all results obtained. All test data are on file and remain available for review by authorized persons.

Herbert W. Stansberry II
Project Manager

Date: 4/20/93

Constance A. Humphrey
Manager, QA Dept.

Date: 4/20/93

Deggary N. Priest
President

Date: 4/20/93

OMEGA POINT LABORATORIES

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OMEGA POINT LABORATORIES

INTRODUCTION

A Fire Protective Envelope protects electrical components from the effects of fire. In doing so, it will reduce the inflow of energy into the system and maintain the internal temperature below maximum limits. These limits will ensure that the cable systems remain functional during a fire, and allow operators to maintain control of systems required for fire safe shutdown.

The addition of a Fire Protective Envelope on a cable system will not only protect the contained cable from elevated temperatures associated with a fire, but will impede the heat dissipation associated with cable operation. The evaluation described herein will yield an accurate and realistic value for the ampacity derating of cables when a Fire Protective Envelope is installed on the cable system.

TEST PROCEDURE

This entire test program was performed in accordance with Texas Utilities Electric TEST PLAN, Rev. 4, which has been included in Appendix B. The specific details of this project will be found in that document.

TEST ENCLOSURE

The ampacity test enclosure was constructed of steel stud walls and ceiling with a minimum of 1 in. of polystyrene insulation lining the interior of the room. The overall dimensions of the test enclosure were 20 ft. x 18 ft. x 8 ft. An entry door was provided in one wall and an observation window was placed in an adjacent wall. The wall with the observation window was made to be removable to facilitate easier location of test articles. Four 1.5 kW heaters were disposed about the room to regulate ambient conditions. Two of the heaters were variable from outside of the test enclosure via connection to standard laboratory variable transformers. Located directly behind each heater was a 24 in. box fan to gently stir the air and more evenly distribute the heat. A total of nine thermocouples were suspended from the ceiling and positioned in the horizontal plane of the test items, 12 in. away from various test items to monitor the ambient room temperatures. Two stanchions were erected to support the test articles. Each stanchion consisted of a length of 2 in. square steel tubing supported at several points by an A-frame leg. A length of 2 in. x 4 in. wood stud was affixed to the top surface of each stanchion.

In the case of all but the 5 in. conduit, the test article with the fire protective system installed was tested first. Once the system had attained equilibrium and all final measurements had been taken, the fire protective barrier was removed from the system (in the case of the air drop assemblies and the cable tray assembly) or the instrumented cable was removed from the clad conduit and inserted into a similarly constructed, bare conduit.

THERMOCOUPLES

Temperatures on the cable conductors within the conduit and air drop assemblies were measured with Type T, 24 gauge, Copper-Constantan electrically welded thermocouples formed from Copper and Constantan wires of "special limits of error (±0.5°C)," and covered with Teflon FEP® insulation. Temperatures on the cable conductors within the cable tray assembly were measured with Type K, 24 gauge, Chromel-Alumel electrically welded thermocouples formed from Chromel and Alumel wires of "special limits of error (±1.1°C)," and covered with braided fiberglass insulation. All thermocouple wire was calibrated to ±0.5°C.

DATA ACQUISITION SYSTEM

The outputs of the test article thermocouples and room control thermocouples were monitored by a data acquisition system consisting of a John Fluke Mfg. Co. Model HELIOS I 2289A Computer Front End, and an Apple Computer Co. Macintosh Classic microcomputer. The Computer Front End was connected to the RS422 Serial Interface Port of the Macintosh. The computer was programmed in Microsoft BASIC to command the HELIOS unit to sample the data input lines, receive and convert data into a digital format, and to manipulate the data for display on screen, the hard copy printout, and saving to hard disk. The computer program determined, and displayed, the average temperatures at each of the three positions on each test article. The rate of change of temperature for the average of the thermocouples located in the center portion of the test article was then calculated. All individual data points and calculated values were saved on hard disk at one minute intervals. A record of individual location temperatures, maximum temperatures and rates of change of temperatures was printed at five minute intervals. All test data is presented in Appendix F: TEST DATA.

CURRENT CONTROL SYSTEM

The current flow through the test articles was regulated using process control type devices. The available voltage for any test control circuit was 208 Vac single phase. A Silicon Controlled Rectifier (SCR) device (Halmar Robicon Group Model No. 140P-FK2-CL) was used to vary the voltage available to the primary side of a step-down transformer between 0 Vac and 208 Vac in proportion to a 4-20 mA control input. The test article was connected to the secondary side of the step-down transformer. A proportional-integral-derivative process controller (Honeywell Universal Digital Controller Model No. UDC 3002-0-000-1-00-XXXX) was responsible for generating the 4-20 mA signal fed to the SCR device, based on a voltage feedback loop. A current transformer (Flex-Core Model No. 58-151, 150:5

or 76-102, 1000:5 ratio; input amps:output amps) was fitted to one lead of the test article to monitor the current flow through the conductor. The output of the current transformer was connected to a current transducer (Flex-Core Model No. CT5-005A) with a mA to mV converter (Flex-Core Model No. LRB-10000) to produce a 0-10 Vdc signal proportional to a 0-150 A or 0-1000 A current span in the sample conductor. This 0-10 Vdc signal is used as the "process variable" in the feedback loop to the controller. In essence, the above circuitry made up a constant-current device, insensitive to line voltage changes.

The current in any given system was driven to a level high enough to bring the conductor to 90°C as quickly as possible by increasing the output signal of the process controller via keypad commands. As the conductor temperature approached 90°C, the current level was reduced and the test article was given time to respond to current changes before another adjustment was made to the current. During this time period, the controller was turned to "automatic" control and the "process variable set point" (the voltage output from the current transformer that represents the current level at which the controller will maintain the system) was adjusted to the same value as the displayed process variable (the controller varies its output in order the maintain the process variable at the level indicated by the set point).

This process of adjusting the controller output (and the control variable set point) and waiting for the system to stabilize (about 1/2 hour to about 2 hours, depending upon the nature of the system) was continued until the temperature parameters of the test article were within the specified limits. The controller was allowed to operate the system for a minimum of three hours. If, at the end of three hours, the system was still within the bounds of all specifications, a final current and voltage measurement were taken and the system was deemed to be in equilibrium.

FINAL CURRENT MEASUREMENT

All final current measurements were performed using ammeters supplied and calibrated by Texas Utilities Electric. These ammeter used were manufactured by James Biddle Co. and identified as Biddle Instruments Digital Clamp-On RMS Volt-Ammeter, Cat. No. 278001 (TU Electric ID No. IC-1029 and IC-1030). Measurements recorded for test items containing 3C/#10 AWG of 3C/#6 AWG cable were taken with the ammeter ID No. IC-1030. Current measurements recorded for test items containing 750 kCMil cable were taken with the ammeter ID No. IC-1029. Calibration documentation for these devices can be found in Appendix G: Quality Assurance.

TEST ASSEMBLIES

TEST ITEMS (GENERAL)

The conduit materials used in the test were provided by Texas Utilities , and are representative of those installed at CPSES.

Cable tray materials used in this test were purchased by Omega Point Laboratories from B-Line Systems, Inc. (Cat. No. 248P0924144). The following table provides pertinent data on the cable tray material used:

ATTRIBUTE	DIMENSION
Side rail thickness	0.048 in.
Rung thickness	18 GA
Rung spacing	9 in. o.c.
Rung dimensions	1-5/8 in. w x 13/16 in. h x 3/8 in. leg

Cable tray straight sections consisted of ASTM A446, GR A, pre-galvanized steel, ASTM A525.

All test items (with the exception of the cable tray assembly) were constructed from materials extracted from TU Electric's Comanche Peak Steam Electric Station stock material storage areas in accordance with existing site procedures.

Electrical cables used in this test (with the exception of the cable tray assembly) consisted of cables supplied by TU Electric and taken from CPSES inventory. Cables used in these tests were as follows:

CABLE TYPE	CABLE FUNCTION	DESCRIPTION	DIAMETER (in.)	CROSS-SECTIONAL AREA (in^2)
W-020	Power	3C/#6 AWG 600v.	0.980	0.754
W-026	Power	3C/#10 AWG 600v.	0.617	0.299
W-008	Power	1/C 750 kCMil. 600v.	1.290	1.307
XHHW	Power	3C/#6 AWG 600v.	0.750	0.442

The diameters and cross-sectional areas listed herein represent the Laboratory's average of ten measurements of each cable type.

OMEGA POINT LABORATORIES

Thermo-Lag® 330-1 Materials

Thermo-Lag® materials were procured from Thermal Science, Inc. (TSI), St. Louis, MO. The Thermo-Lag® materials were extracted from CPSES stock and were representative of materials installed in the plant. Each one hour rated Thermo-Lag® 330-1 V-Ribbed Panel is 1/2 in. thick (nominal) x 48 in. wide x 78 in. long, with stress skin monolithically adhered to the panel on one face. Each panel was received with 350 Topcoat factory applied. Each 330-1 Pre-Shaped Conduit Section is 36 in. long. Two thicknesses of conduit section materials were used, 1/2 in. thick (nominal) and 1/4 in. thick (nominal) "overlay" sections, both with stress skin monolithically adhered to the surface installed facing the protected conduit. The 330-1 conduit materials were also received with 350 Topcoat factory applied. Other materials supplied by TSI were 330-1 Trowel (bulk) Grade Subliming Compound (used to pre-caulk all joints and seams on the cable tray and conduit assemblies), 330-660 Flexi-Blanket Material used to wrap the cable air drop assemblies, 330-660 Trowel (bulk) Grade Material (used to pre-caulk all seams on the cable air drop assemblies), 330-69 Stress Skin Material (used to reinforce joints on the cable tray assembly) and 350 Topcoat (two part water-based mixture). All Thermo-Lag® materials were measured, saw cut and installed onto the respective test assembly by Peak Seals craft personnel using approved CPSES drawings, procedures and specifications. Installations were inspected by CPSES-certified quality control inspectors.

Other Materials

Other commercial grade products used were: 1/2 in. wide x 0.020 in. thick, type 304 stainless steel rolled-edge banding straps with wing seals; 16 to 18 GA stainless steel tie wire; and, 0.010 in. stainless steel sheet metal.

TEST ITEMS

Scheme #AC-1

The assembly consisted of a 3/4 in. conduit through which was pulled a single three conductor cable (W-026, 3C/#10 AWG, 600V). The total cable length used for this test item was 60 ft. The three separate conductors within the cable were connected into a single series circuit. The current source was then connected to the two free cable ends. Two conduits were prepared for testing; one clad and one bare - for baseline testing.

Scheme #AC-4

The assembly consisted of a 2 in. conduit through which was pulled a single three conductor cable (W-020, 3C/#6 AWG, 600V). The total cable length used for this test item was 60 ft. The three separate conductors within the cable were connected into a single series circuit. The current source was then connected to the two free cable ends. Two conduits were prepared for testing; one clad and one bare - for baseline testing.

Scheme #AC-5

The assembly consisted of a 5 in. conduit through which was pulled four separate single conductor cables (W-008, 1/C 750 kCMil, 600V). The total cable length used for this test item was 88 ft. The four separate conductors were connected into a single series circuit. The current source was then connected to the two free cable ends. Two conduits were prepared for testing; one clad and one bare - for baseline testing.

Scheme #AA 1-1

The assembly consisted of a single three conductor cable (W-020, 3C/#6 AWG, 600V) representing an air drop assembly. The total cable length used for this test item was 60 ft. The three separate conductors within the cable were connected into a single series circuit. The current source was then connected to the two free cable ends. The cable was clad and allowed to cure. The material was then removed to perform the baseline testing.

Scheme #AA 4-2

The assembly consisted of three separate single conductor cables (W-008, 1/C 750 kCMil, 600V) representing an air drop assembly. The total cable length used for this test item was 88 ft. The three separate conductors were connected into a single series circuit. The current source was then connected to the two free cable ends. The cable was clad and allowed to cure. The material was then removed to perform the baseline testing.

Scheme #AT-1

The assembly consisted of a 24 in. wide x 4 in. deep cable tray assembly into which was laid 126 passes of single three conductor cable (3C/#6 AWG, TC XHHW CDRS, 600 Volt). The total cable length used for this test item was 1720 ft. The three separate conductors within the cable were connected into a single series circuit and the current source was then connected to the two free cable ends. The cable tray assembly was clad and allowed to cure. The material was then removed to perform the baseline testing.

ELECTRICAL CABLES

The internal cross-sectional areas for the conduits are as follows:

CONDUIT SIZE (INCHES)	ACTUAL CONDUIT I.D. (INCHES)	CROSS-SECTIONAL AREA (in^2)
3/4	0.824	0.533
2	2.067	3.356
5	5.047	20.006

The usable cross-sectional area of the cable tray was (3 in. deep x 24 in. wide) 72 square inches.

The table below shows the cable types used in each test article, the number of each cable installed, the total cross-sectional area of each cable type and the percent of the total available area taken up by cable in each test article.

3/4 in. CONDUIT

CABLE TYPE	NUMBER PRESENT	CROSS-SECTIONAL AREA (in^2)	% OF TOTAL AREA
W-026	1	0.299	56.10

2 in. CONDUIT

CABLE TYPE	NUMBER PRESENT	CROSS-SECTIONAL AREA (in^2)	% OF TOTAL AREA
W-020	1	0.754	22.47

5 in. CONDUIT

CABLE TYPE	NUMBER PRESENT	CROSS-SECTIONAL AREA (in^2)	% OF TOTAL AREA
W-008	4	5.228	26.13

24 IN. CABLE TRAY

CABLE TYPE	NUMBER PRESENT	CROSS-SECTIONAL AREA (in^2)	% OF TOTAL AREA
3C/#6	126	55.665	77.31

THERMOCOUPLE PLACEMENT

24 gauge, Type T, Copper-Constantan electrically welded thermocouples (Special Limits of Error: ±0.5°C, purchased with lot traceability and calibration certifications) were attached in nine places within each conduit or air drop assembly, by slicing through the outer jacket of the cable (down to bare conductor) and placing the thermojunction in direct contact with the top surface of the cable conductor and covering the slit with a double wrap of glass fiber reinforced electrical tape (Glass Cloth Electrical Tape, Class "B" Insulation, 1/2 in. wide, 3M Corporation, Item No. 27) for a minimum distance of 3-1/2 inches. Thirty-nine 24 gauge, Type K, Chromel-Alumel electrically welded thermocouples (Special Limits of Error: ±1.1°C, purchased with lot traceability) were similarly secured to the cables within the cable tray assembly. A representative sample of the thermocouple wire used in the cable tray test article was calibrated after the test procedure.

One thermocouple was located on each of the three conductors in each system (except the cable tray and 5 in. conduit having four conductors) at the mid-point of the assembly, and at both ends of the assembly (36 in. left and right of mid-point). The 5 in. conduit having four conductors was similarly instrumented, however, the fourth conductor had no thermocouples installed. The cable tray assembly was instrumented with a total of thirty-nine thermocouples (thirteen located at the mid-point of the cable tray, thirteen located 36 in. to the left and 36 in. to the right of mid-point) located within the second and third layer of cables.

THERMO-LAG® INSTALLATION HIGHLIGHTS

Thermo-Lag® materials were installed in accordance with the instructions contained in the CPSES Site Procedures referenced in Test Plan, Rev. 4. Short abstracts of the installation are included herein to clarify specific details.

Thermo-Lag® 330-1 Pre-Shaped Conduit Sections (1/2 in. nom. thickness)

This material was used to construct the 3/4 in., 2 in. and 5 in. diameter raceway design protective envelopes.

Thermo-Lag® 330-1 Pre-Shaped Conduit Sections (1/4 in. nom. thickness)

This material was used as an overlay on the 3/4 in. and 2 in. diameter raceway design protective envelopes.

Thermo-Lag® 330-1 V-ribbed Panels (1/2 in, nom. thickness)

This material was used to construct the cable tray protective envelope.

Thermo-Lag® 330-1 Subliming Trowel Grade Material

This material was used to pre-caulk all joints, seams and upgraded areas between pre-shaped sections.

Thermo-Lag® 330-660 Flexi-Blanket

This material was used to construct the cable air drop protective envelopes.

Thermo-Lag® 330-660 Subliming Trowel Grade Material

This material was used to pre-caulk all joints and seams between 330-660 Flexi-Blanket material and all joints of 330-66- Flexi-Blanket.

Application Methods

Each rigid conduit assembly was clad with Thermo-Lag® 330-1 1/2 in. (nominal) thick Pre-Shaped Conduit Section Material. All joints and seams were pre-caulked with 330-1 Trowel Grade Material. The sections installed on the 5 in. diameter conduit were secured using stainless steel banding material. The sections installed on the 3/4 in. and the 2 in. diameter conduits were secured using stainless steel tie wire. After being clad with 1/2 in. thick 330-1 Pre-Shaped Conduit Sections, 1/4 in. thick (nominal) Pre-Shaped Conduit Section ("overlay") Material was installed on the 3/4 in. and the 2 in. diameter conduits. All joints and seams were pre-caulked with 330-1 Trowel Grade Material and then secured using stainless steel banding. Finally, Thermo-Lag® 350 Topcoat was applied over areas where the 330-1 Trowel Grade Material had been applied following a 72 hour (minimum cure time).

The entire cable tray system was clad with Thermo-Lag® 330-1 1/2 in. (nominal) V-Ribbed Panel Material. To prevent sagging of the top panels, the cable tray was pre-banded using stainless steel banding. Al joints and seams of the protective envelope were pre-caulked with 330-1 Trowel Grade Material and secured with stainless steel bands spaced at 12 in, intervals.

During construction of the cable tray protective envelope, several areas of the envelope were reinforced with combinations of stainless steel wire, Thermo-Lag® 330-1 Trowel Grade Material and Thermo-Lag® 330-69 Stress Skin which was secured with staples. The areas reinforced included butt joints between panels on the bottom surface of the envelope and the longitudinal seams where the top and bottom panels overlap panel pieces installed at the tray side rails.

The butt joints between panels on the bottom surface were "stitched" with stainless steel tie wires on 5 in. centers. A thin layer of 330-1 Trowel Grade Material (approximately 3/16 in. thick) was next applied extending 5 in. on each side of the butt joints. Stress skin was cut and wrapped circumferentially around the envelope to overlap the butt joints by 5 in. on each side. The stress skin was worked into the trowel grade layer and secured in place with staples and stainless steel tie wire. A skim coat of 330-1 Trowel Grade Material, approximately 1/16 in. thick, was then applied over the stress skin and the tie wires.

To reinforce the longitudinal seams at the side rails, a 3/16 in. thick layer of 330-1 Trowel Grade Material was applied over the panels installed at the side rails and extending 5 in. towards the middle of the tray and both the top and bottom surfaces. Stress skin was cut and formed into a squared, U-shaped configuration which was placed over the sides and onto the top and bottom surfaces for a 5 in. distance. The stress skin was worked into the trowel grade layer and secured in place with staples and stainless steel tie wire. A skim coat of 330-1 Trowel Grade Material, approximately 1/16 in. thick, was then applied over the stress skin and tie wires.

Finally, Thermo-Lag® 350 Topcoat was applied over all areas where 330-1 Trowel Grade Material had been applied following a 72 hour (minimum) cure time.

Each cable air drop assembly was clad with three complete wraps of Thermo-Lag® 330-660 Flexi-Blanket Material. An overlap of 2 in. - 4 in. was maintained for each wrap. The overlap area of each wrap was pre-caulked with Thermo-Lag® 330-660 Trowel Grade Material and secured with stainless steel bands spaced on 6 in. centers. The overlap areas were positioned 180° from one another.

TEST RESULTS

The completed test specimens were placed in the Laboratory's test enclosure and the thermocouples connected to the data acquisition system and their outputs verified. The tests were conducted from March 2, 1993, to March 14, 1993, by Herbert W. Stansberry II, project manager, with the following persons present at various times:

OMEGA POINT LABORATORIES

Renaldo Jenkins	-	USNRC
Dick Wilson	-	USNRC
Bill Rodgers	-	USNRC
John White	-	TU Electric
Chester Pruett	-	TU Electric (Fluor-Daniel Corporation)
Melvin Quick	-	TU Electric (Stone & Webster Engineering)
Kent Brown	-	TVA
Deggary N. Priest	-	Omega Point Laboratories, Inc.
Kerry Hitchcock	-	Omega Point Laboratories, Inc.
Connie Humphry	-	Omega Point Laboratories, Inc.
Laudencio Castanon	-	Omega Point Laboratories, Inc.

TEST ITEM	EQU. VOLTAGE (VOLTS)	EQU. CURRENT (AMPS)	EQU. TEMP (°C)	ROOM TEMP (°C)	CORRECTED CURRENT (AMPS)	PERCENT DERATING
3C/#10 in 3/4" Conduit (base)	11.9	39.4	89.8	40.3	39.6	9.34
3C/#10 in 3/4" Conduit (clad)	11.0	36.0	89.4	39.3	35.9	
3C/#6 in 2" Conduit (base)	9.96	64.6	90.5	40.3	64.5	6.67
3C/#6 in 2" Conduit (clad)	9.15	60.2	89.1	39.3	60.2	
3C/#6 in Air Drop (base)	10.9	94.0	89.9	39.5	93.6	21.2
3C/#6 in Air Drop (clad)	8.12	74.0	90.9	40.5	73.8	
3C/#6 in 24" Cable Tray (base)	46.5	23.2	89.8	39.5	23.1	31.6
3C/#6 in 24" Cable Tray (clad)	27.2	15.9	90.3	39.9	15.8	

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TEST ITEM	EQU. VOLTAGE (VOLTS)	EQU. CURRENT (AMPS)	EQU. TEMP (°C)	ROOM TEMP (°C)	CORRECTED CURRENT (AMPS)	PERCENT DERATING
750 kCMil in Air Drop (base)	5.21	785	89.5	40.2	790	31.8
750 kCMil in Air Drop (clad)	3.62	540	90.0	39.9	539	
4/C 750 kCMil in 5" Conduit (base)	2.19	567	89.4	40.2	571	10.7
4/C 750 kCMil in 5" Conduit (clad)	2.08	509	90.0	40.2	510	

The equilibrium current values are single-point measurements performed after the system was at equilibrium and the change in current was very low. The Equ. Temp (equilibrium conductor temperature at the hottest location), and the Room Temp are reported as 60 minute average values. The Corrected Current values are those calculated in accordance with P 848/D12 IEEE Standard Procedure for the Determination of the Ampacity Derating of Fire Protected Cables*, which corrects these current values to a room temperature of 40°C and a conductor temperature of 90°C.

* $$I' = I\sqrt{\frac{(Tc' - Ta') \times (\alpha + Tc)}{(Tc - Ta) \times (\alpha + Tc')}}$$

where

I	test current at equilibrium, amperes	
Tc	hottest conductor temperature at center at equilibrium, °C	
Ta	measured enclosure ambient temperature, °C	
I'	normalized current, amperes	
Tc'	normalized conductor temperature	= 90°C
Ta'	normalized ambient temperature	= 40°C
α	234.5 for copper	

OMEGA POINT LABORATORIES

Table 2 – Dimensions and weights of rigid steel conduit

Nominal or trade size of conduit in	Customary inch-pound units: Nominal inside diameter in	Outside diameter in	Nominal wall thickness in	Length without coupling ft and in	Minimum weight of ten unit lengths with couplings attached lb	Metric units: Nominal inside diameter mm	Outside diameter mm	Nominal wall thickness mm	Length without coupling meters	Minimum weight of ten unit lengths with couplings attached kg
3/8	0.493	0.675	0.091	9'11 -1/2"	51.5	12.5	17.1	2.31	3.04	23.36
1/2	0.632	0.840	0.104	9'11 -1/4"	79.0	16.1	21.3	2.64	3.03	35.83
3/4	0.836	1.050	0.107	9'11 -1/4"	105.0	21.2	26.7	2.72	3.03	47.63
1	1.063	1.315	0.126	9'11"	153.0	27.0	33.4	3.20	3.02	69.40
1 -1/4	1.394	1.660	0.133	9'11"	201.0	35.4	42.2	3.38	3.02	91.17
1 -1/2	1.624	1.900	0.138	9'11"	249.0	41.2	48.3	3.51	3.02	112.95
2	2.083	2.375	0.146	9'11"	332.0	52.9	60.3	3.71	3.02	150.60
2 -1/2	2.489	2.875	0.193	9'10 -1/2"	527.0	63.2	73.0	4.90	3.01	239.05
3	3.090	3.500	0.205	9'10 -1/2"	682.6	78.5	88.9	5.21	3.01	309.63
3 -1/2	3.570	4.000	0.215	9'10 -1/4"	831.0	90.7	101.6	5.46	3.00	376.94
4	4.050	4.500	0.225	9'10 -1/4"	972.3	102.9	114.3	5.72	3.00	441.04
5	5.073	5.563	0.245	9'10"	1313.6	128.9	141.3	6.22	3.00	595.85
6	6.093	6.625	0.266	9'10"	1745.3	154.8	168.3	6.76	3.00	791.67

NOTE – Applicable tolerances:

Length: ± 1/4 in (± 6.35 mm) (without coupling)

Outside diameter
for trade sizes 3/8 in through 2 in: ± 0.015 in (± 0.38 mm)
for trade sizes 2-1/2 in through 4 in: ± 0.025 in (± 0.64 mm)
for trade sizes 5 and 6 in: ±1%

Wall thickness: See 7.3.

EBASCO SERVICES INCORPORATED

CALCULATION EC-0__

BY CHS DATE 6-29-90 REVISION 1 SHEET 2 OF 23

CHKD. BY [signature] DATE 6/29/90 OFS NO. 8612.301 DEPT NO. 562

CLIENT FLORIDA POWER & LIGHT COMPANY

PROJECT TURKEY POINT PLANT - UNITS 3 & 4

SUBJECT CABLE AMPACITY AND VOLTAGE DROP CALCULATION

TABLE 7.2.2.1

CONDUCTOR dc RESISTANCES AT @25°C AND 90°C

Conductor Size	dc r (at 25°C) ohms/1000' Single Conductor	3/c or Triplex (1/c x 1.04)	dc r (at 90°C) ohms/1000' Single Conductor	3/c or Triplex
#12 AWG	1.72	1.789	1.72 x 1.25 = 2.15	1.789 x 1.25 = 2.236
#10 AWG	1.08	1.123	1.08 x 1.25 = 1.35	1.123 x 1.25 = 1.404
#8 AWG	0.679	0.706	0.679 x 1.25 = 0.849	0.706 x 1.25 = 0.883
#6 AWG	0.427	0.444	0.427 x 1.25 = 0.534	0.444 x 1.25 = 0.555
#4 AWG	0.269	0.280	0.269 x 1.25 = 0.336	0.280 x 1.25 = 0.350
#2 AWG	0.169	0.176	0.169 x 1.25 = 0.211	0.176 x 1.25 = 0.220
#1/0 AWG	0.106	0.110	0.106 x 1.25 = 0.133	0.110 x 1.25 = 0.138
#2/0 AWG	0.0843	0.0877	0.0843 x 1.25 = 0.105	0.877 x 1.25 = 0.110
#4/0 AWG	0.0525	0.0546	0.0525 x 1.25 = 0.0656	0.0546 x 1.25 = 0.0683
#250 kcmil	0.0449	0.0467	0.0449 x 1.25 = 0.0561	0.0467 x 1.25 = 0.0584
#350 kcmil	0.0320	0.0333	0.0320 x 1.25 = 0.040	0.0333 x 1.25 = 0.0416
#500 kcmil	0.0222	0.0231	0.0222 x 1.25 = 0.0278	0.0231 x 1.25 = 0.0289
#750 kcmil	0.0148	0.0154	0.0148 x 1.25 = 0.0185	
#1000 kcmil	0.0111	0.0115	0.0111 x 1.25 = 0.0139	
#1250 kcmil	0.00888	0.00924	0.00888 x 1.25 = 0.0111	

BY CHS DATE 6-29-90 REVISION 1

CHKD. BY DS DATE 6/29/90 OFS NO. 8612.301 DEPT NO. 562

CLIENT FLORIDA POWER & LIGHT COMPANY

PROJECT TURKEY POINT PLANT - UNITS 3 & 4

SUBJECT CABLE AMPACITY AND VOLTAGE DROP CALCULATION

TABLE 7.2.2.2a

CONDUCTOR AC/DC RESISTANCE RATIOS
AND AC RESISTANCES AT 90°C (SINGLE CONDUCTOR)

Conductor Size	AC/DC Resistance Ratio Non-Magnetic	AC/DC Resistance Ratio Magnetic	AC Resistance at 90°C Single Conductor Non Magnetic	AC Resistance at 90°C Single Conductor Magnetic
#12 AWG	1.0	1.0	2.15 x 1.0 = 2.15	2.15 x 1.0 = 2.15
#10 AWG	1.0	1.0	1.35 x 1.0 = 1.35	1.35 x 1.0 = 1.35
#8 AWG	1.0	1.0	0.849x 1.0 = 0.849	0.849x 1.0 = 0.849
#6 AWG	1.0	1.0	0.534x 1.0 = 0.534	0.534x 1.0 = 0.534
#4 AWG	1.0	1.0	0.336x 1.0 = 0.336	0.336x 1.0 = 0.336
#2 AWG	1.0	1.01	0.211x 1.0 = 0.211	0.211x 1.01= 0.213
#1/0 AWG	1.001	1.02	0.133x1.001= 0.133	0.133x 1.02= 0.136
#2/0 AWG	1.001	1.03	0.105x1.001= 0.105	0.105x 1.03= 0.108
#4/0 AWG	1.004	1.05	0.0656x1.004= 0.0659	0.0656x1.05= 0.0689
#250 kcmil	1.005	1.06	0.0561x1.005= 0.0564	0.0561x1.06= 0.0595
#350 kcmil	1.009	1.08	0.0400x1.009= 0.0404	0.0400x1.08= 0.0432
#500 kcmil	1.018	1.13	0.0278x1.018=0.0283	0.0278x1.13= 0.0314
#750 kcmil	1.039	1.21	0.0185x1.039=0.0192	0.0185x1.21= 0.0224
#1000kcmil	1.067	1.30	0.0139x1.067=0.0148	0.0139x1.3 = 0.0181
#1250kcmil	1.102	1.41	0.0111x1.102=0.0122	0.0111x1.41= 0.0157

EBASCO SERVICES INCORPORATED

BY CHS DATE 6-29-90 REVISION 1 SHEET 4 OF 23

CHKD. BY DS DATE 6/29/90 OFS NO. 8612.301 DEPT NO. 562

CLIENT FLORIDA POWER & LIGHT COMPANY

PROJECT TURKEY POINT PLANT - UNITS 3 & 4

SUBJECT CABLE AMPACITY AND VOLTAGE DROP CALCULATION

TABLE 7.2.2.2b

CONDUCTOR AC RESISTANCES AT 90°C (3/C OR TRIPLEX)

(See Table 7.2.2.2a for ac/dc resistance ratios)

Conductor Size	AC Resistance at 90°C 3/C or Triplex Non Magnetic	Magnetic
#12 AWG	2.236 x 1.0 = 2.236	2.236 x 1.0 = 2.236
#10 AWG	1.404 x 1.0 = 1.404	1.404 x 1.0 = 1.404
#8 AWG	0.883 x 1.0 = 0.883	0.883 x 1.0 = 0.883
#6 AWG	0.555 x 1.0 = 0.555	0.555 x 1.0 = 0.555
#4 AWG	0.350 x 1.0 = 0.350	0.350 x 1.0 = 0.350
#2 AWG	0.220 x 1.0 = 0.220	0.220 x 1.01= 0.222
#1/0 AWG	0.138 x 1.001=0.138	0.138 x 1.02= 0.141
#2/0 AWG	0.110 x 1.001=0.110	0.110 x 1.03= 0.113
#4/0 AWG	0.0683x 1.004=0.0686	0.0683x 1.05= 0.0720
#250 kcmil	0.0584x 1.005=0.0587	0.0584x 1.06= 0.0619
#350 kcmil	0.0416x 1.009=0.0420	0.0416x 1.08= 0.0449
#500 kcmil	0.0289x 1.018=0.0294	0.0289x 1.13= 0.0327

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/ft^3

— Dry Weight 1/2 inch thickness (one-hour rated) = 3.25 lb/ft^2

— Dry Weight 1 inch thickness (three-hour rated) = 6.5 lb/ft^2

— 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.

— Shelf Life (Bulk) 6 months
— Storage Conditions above 32°F and below 100°F
— Asbestoes free
— Non-toxic

CHEMICAL RESISTANCE OF THERMO-LAG 330-1

— Water
— Sulfuric acid — 10 percent solution
— Hydrochloric acid — 10 percent solution
— Sodium hydroxide — 10 percent solution
— Sodium chloride — 5 percent solution
— Acetic acid
— Kerosene
— Anhydrous Ammonia
— LNG
— LPG
— Methanol

CHEMICAL RESISTANCE OF THERMO-LAG 350-2P TOPCOAT

— Frequent Contact
  — Alkali solutions
  — Salt solutions
  — Alcohols
  — Aliphatic hydrocarbons
  — Aromatic hydrocarbons
— Occasional Contact
  — Fresh water
  — Waste water
  — Mineral oils
  — Vegetable oils
  — Organic acids
  — Mineral acids
  — Oxidizing agents
  — Ketones

— Exterior Environmental Conditions
  — High humidity
  — Industrial atmosphere (CO_2 — SO_2 mix)
  — Salt spray
— Interior Environmental Conditions
  — High humidity
  — CO_2 — SO_2 atmosphere mix
  — Chlorine

Results: Service life of at least 40 years

PTN-BFJM-96-005
ATTACHMENT 4
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