CALCULATION COVER SHEET

Calculation No: PTN-BFJM-96-028

Title: Fire Barrier ACF for T-Lag 330-1/770-1 Assemblies

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1.0 Purpose/Scope

Ampacity correction factors (ACFs) were developed for Turkey Point use based on TSI Thermo-Lag (T-Lag) 330-1 material for 1-hour and 3-hour rated fire barriers (References 2.1 and 2.2). The purpose of this calculation is to develop ACF values for T-Lag 330-1 with T-Lag 770-1 overlay (330-1/770-1 composite) assemblies for 3-hour rated fire barriers for power cables.

2.0 References

2.1 Calculation PTN-BFJM-96-005, Revision 0, "Fire Barrier Ampacity Correction Factors - Extrapolation of Test Results for 3 Hour Barrier"

2.2 Evaluation JPN-PTN-SEEP-96-011, Revision 0, "Review of Ampacity Rating for Power Cables in Conduits and Trays with Thermo-Lag 330-1 Covering"

2.3 Report, "Fire Endurance and Ampacity Testing of One and Three-Hour Rated Thermo-Lag Electrical Raceway Fire Barrier Systems" (included as Attachment 1)

3.0 Methodology

The approach of Reference 2.1 was to use heat transfer analysis to extrapolate from Texas Utilities Electric test data and develop ACFs for single conduit, cable tray and banked conduit. Heat transfer was calculated per foot of raceway length as a convenient relation to the test results. The analysis was taken a step further by Reference 2.2 which evaluated power cable ampacity ratings.

This calculation begins with a similar approach to that of Reference 2.1 and evaluates the effects of augmenting existing T-Lag 330-1 material with T-Lag 770-1 material. However, this evaluation continues further by also considering the findings of Reference 2.3 to establish appropriate derating factors based on testing and to include boxes among the assembly configurations.

The analysis starts with the values calculated in Reference 2.1 for trays and conduits, then considers the ampacity effect of overlaying with T-Lag 770-1 wrap. As such, the heat transfer equation used in Reference 2.1 is revised as follows:

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

where:

- q = Rate of heat transfer from raceway
- T_c = Temperature of conductor (fixed @ 90°C/194°F)
- T_a = Ambient temperature (fixed @ 40°C/104°F)
- R_i = Thermal resistance of all items within the raceway
- R_g = Thermal resistance of the air gap between the raceway and the T-Lag
- R_t = Thermal resistance of either T-Lag 330-1 alone or with the T-Lag 770-1 overlay
- R_s = Thermal resistance at the surface of the raceway

The heat transferred from the raceway under steady-state conditions is essentially equal to the I^2R losses within the conductors. These heat transfer values were determined from the test data based on the measured current and size of conductor used, as documented in Reference 2.1.

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The thermal resistance values of R_1, R_2, R_s, and R_{t330} are also based on those determined in Reference 2.1 for 3-hour rated T-Lag 330-1 assemblies. The value for R_t with the T-Lag 770-1 overlay will be calculated assuming that the thermal conductivity for T-Lag 770-1 is the same as for T-Lag 330-1. After thermal resistance values have been established, the heat transferred can be calculated for the raceway with the 3-hour rated 330-1/770-1 composite fire barrier.

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

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

4.0 Assumptions/Bases

4.1 The effects of inductive losses in the raceway and cable sheath are negligible with respect to applying the test data to the Turkey Point configurations.

4.2 Surface emittance for cable, raceway, and T-Lag is assumed to be equal to 0.9. Note that a high emittance value will reduce the heat transfer at the surface having an overall effect of maximizing the ampacity de-rating.

4.3 Heat transfer is assumed to flow perpendicular to the surface. This allows one-dimensional analysis, is reasonable for single conduits, and is conservative for cable tray and banked conduits because no credit is taken for heat flow through box corners.

4.4 Heat transfer through the sides of cable tray is assumed to be zero. This reduces the heat transfer equation for tray to one dimension. As the tested cable tray is relatively wide (24"), this is expected to be a good approximation for all cable tray. Also, the horizontal tray configuration is more conservative than vertical in terms of reduced heat transfer, based on typical emperically developed formulae for natural convection coefficients over horizontal and vertical plane surfaces.

4.5 Convective heat transfer flow is assumed to be laminar. This is reasonable for "stagnant" rooms and conservative in outdoor areas and rooms with forced ventilation, in terms of reducing the heat transfer rate.

4.6 Pre-buttering with trowel grade T-Lag material is assumed to virtually eliminate air gaps between T-Lag layers such that interface resistance effects are negligible.

4.7 The 3-hour T-Lag 330-1 assembly is assumed to be at the 1¼" nominal thickness in accordance with the manufacturer's tolerance (± ¼"). It was judged to be excessively conservative, considering application techniques and material cost, to assume a maximum thickness of 1½".

4.8 Each layer of T-Lag 770-1 material is assumed to have a finished nominal thickness of 3/8" (including buttering). Two or more layers of wrap are assumed to be consistent with the tested configurations (Reference 2.3).

4.9 Raceway is made of rigid steel, which is typical for power plant installations.

4.10 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 and it is conservative to assume an air gap between cables in the tray and the T-Lag material.

4.11 The thermal resistance values for all items within the raceway and for the gap between the conduit and the T-Lag material are assumed to remain constant as additional thickness of T-Lag 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 T-Lag 330-1 only to raceway with composite 330-1/770-1 wrap.

4.12 The thermal conductivity of T-Lag 770-1 material is assumed to be the same as for T-Lag 330-1. This is a reasonable approximation since the two materials seem to be chemically similar. Also, based on discussion with Kent Brown (co-author of Reference 2.3), material property data provided by TSI has been inconsistent, and is considered unreliable.

4.13 The radiant heat from the sun does not adversely impact ACF values for wrapped components because the insulating effect of T-Lag reduces sun load with respect to an exposed component.

5.0 Calculation

Formulae, constants and parameter values are as presented in Reference 2.1 unless noted otherwise. Detailed calculations are performed by spreadsheet and the results presented in the table at the end of this section.

5.1 Determination of test heat loads

Test heat losses for unwrapped raceway were calculated ($q=I^2RN$) with the following results:

Raceway Size	(Conductor)	Heat/Ft BTU/Hr
¾"	(1-3C/#10)	22.6
2"	(1-3C/#6)	23.7
5"	(4-750 kCMil)	99.7
Tray	(126 -3C/#6)	382.1

5.2 Determination of Thermo-Lag R values (R_t)

For heat transfer through T-Lag cylinder:

$$R_t = ln(r_o/r_i)/2\pi kL$$

r_o = Outside Radius
r_i = Inside Radius
k_{330} = Thermal Conductivity = 0.1 BTU/Hr-FT-°F
k_{770} = Thermal Conductivity = 0.1 BTU/Hr-FT-°F
L = Length = 1 Ft. (Per Foot)

For heat transfer through T-Lag sheet:

$$R_t = l/kA$$

l = Thickness
k_{330} = Thermal Conductivity = 0.1 BTU/Hr-FT-°F
k_{770} = Thermal Conductivity = 0.1 BTU/Hr-FT-°F
A = Surface Area

5.3 Determination of surface R values (R_s)

The surface resistance considers free convection and radiation heat transfer:

$$q_s = q_c + q_r$$

q_c	=	Heat transferred by convection
q_r	=	Heat transferred by radiation

For free (laminar flow) convection:

$$q_c = hA\Delta T = 0.27(\Delta T/L)^{1/4}A\Delta T$$

h	=	Convection heat transfer coefficient: Horizontal cylinders in air $h = 0.27(\Delta T/L)^{1/4}$ Vertical planes in air $h = 0.29(\Delta T/L)^{1/4}$ Horizontal planes facing up in air $h = 0.27(\Delta T/L)^{1/4}$
A	=	Surface Area
L	=	Characteristic length in feet (diameter or width)

For radiant energy:

$$q_r = \sigma A\epsilon(T_s^4 - T_a^4)$$

σ	=	1.714×10^{-9} BTU/Hr-Ft^2-R^4, Stefan-Boltzmann Constant
A	=	Surface Area
ϵ	=	Surface Emittance = 0.9
T	=	Absolute Temperature, R (460 + °F)

For total heat transferred from the surface:

$$q_s = 0.27(\Delta T/L)^{1/4}A\Delta T + 1.714\times10^{-9}(0.9)A(T_1^4 - T_2^4)$$

$$q_s = [0.27(\Delta T/L)^{1/4} + 1.714\times10^{-9}(0.9)(T_1^4 - T_2^4)/\Delta T]A\Delta T$$

$$\Delta T/q_s = R_s = 1/\ [0.27(\Delta T/L)^{1/4} + 1.714\times10^{-9}(0.9)(T_1^4 - T_2^4)/\Delta T]A$$

5.4 Calculation of ACF

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

OD/W This is an input value of the conduit outside diameter or cable tray width. Conduit diameters were developed in Reference 2.1.

TH This value is the thermolag thickness. For each raceway size a thickness representing 330-1 wrap (TH330) only and the 770-1 wrap (TH770) is entered.

ODT This is the outside diameter of the raceway with calculated from the OD and TH. For cable tray OD is not calculated since 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 was calculated from the test data in Reference 2.1 and is not recalculated here.

Rg Gap thermal resistance as defined above. The value was calculated from the test data in Reference 2.1 and is not recalculated here.

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

Conduit	$Rt = ln(ODT/OD)/2\pi k$	$k = 0.1$
Tray	$Rt = TH/kA$	$k = 0.1$

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.

$$Rs = 1/[0.27((Ts-104)/ODT)^{1/4} + 1.714\times10^{-9}(0.9)((Ts+460)^4-564^4)/(Ts-104)]A$$

Ts Surface temperature of T-Lag, determined by iteration until q = q'.

q Heat transferred, calculated as follows:

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

q' Heat transferred from the surface, calculated as follows:

$q' = \Delta T/Rs$, 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.

$$ACF = (q_p/q)^{1/4}$$

The ampacity correction factors for 3-hour T-Lag 330-1/770-1 composite assemblies extrapolated by calculation are as follows:

Item	ACF
¾" Conduit (2 wraps)	0.84
¾" Conduit (3 wraps)	0.83
24" Tray	0.54
Banked Conduit	--

RACEWAY HEAT TRANSFER AMPACITY CORRECTION FACTORS

	OD	TH	ODT	ODT	A	Ri	Rg	Rt	Rs	Ts	q	q'	ACF
	IN	IN	IN	FT	SQFT	BTU/HR-F	BTU/HR-F	BTU/HR-F	BTU/HR-F	F	BTU/HR	BTU/HR	
3/4" CON	1.050	0.000	1.050	0.088	0.275	2.474	N/A	N/A	1.509	138.100	22.600	22.600	N/A
330-1	1.050	1.250	3.550	0.296	0.929	2.474	0.201	1.939	0.600	114.350	17.263	17.262	0.874
330/770	1.050	0.750	5.050	0.421	1.322	2.474	0.201	2.500	0.451	111.210	15.999	15.993	0.841
2" COND	2.375	0.000	2.375	0.198	0.622	2.997	N/A	N/A	0.801	122.970	23.700	23.700	N/A
330-1	2.375	1.250	4.875	0.406	1.276	2.997	0.044	1.145	0.456	112.850	19.388	19.390	0.904
330/770	2.375	0.750	6.375	0.531	1.669	2.997	0.044	1.571	0.367	110.630	18.075	18.082	0.873
5" COND	5.563	0.000	5.563	0.464	1.456	0.560	N/A	N/A	0.343	138.180	99.700	99.700	N/A
330-1	5.563	1.250	8.063	0.672	2.111	0.560	0.000	0.591	0.269	121.030	63.413	63.412	0.798
330/770	5.563	0.750	9.563	0.797	2.504	0.560	0.000	0.862	0.237	116.850	54.247	54.255	0.738
3/4" CON	1.050	0.000	1.050	0.088	0.275	2.474	N/A	N/A	1.509	138.100	22.600	22.600	N/A
330-1	1.050	1.250	3.550	0.296	0.929	2.474	0.201	1.939	0.600	114.350	17.263	17.262	0.874
3 770 LYR	1.050	1.125	5.800	0.483	1.518	2.474	0.201	2.720	0.402	110.240	15.524	15.514	0.829
	W	TH	-	-	A	Ri	Rg	Rt	Rs	Ts	q	q'	ACF
	IN	IN	-	-	SQFT	BTU/HR-F	BTU/HR-F	BTU/HR-F	BTU/HR-F	F	BTU/HR	BTU/HR	
TRAY	24.00	0.000			4.000	0.102	N/A	N/A	0.134	155.000	382.100	382.100	N/A
330-1	24.00	1.250			4.000	0.102	0.150	0.260	0.151	124.520	135.596	135.607	0.596
330/770	24.00	0.750			4.000	0.102	0.150	0.417	0.155	120.890	109.332	109.312	0.535

TVA performed ampacity tests as described in Reference 2.3. The testing was performed using an even number of conductors, pre-formed T-Lag 330-1 dry-fit to the component, and other such criteria per IEEE P-848 Draft 14. TVA identified key parameters, presented a reasonable rationale for what constitutes conservative test configurations, and maintained key parameter limits while establishing ACF values for these configurations based directly from testing.

The ampacity correction factors for 3-hour T-Lag 330-1/770-1 composite assemblies based on tested configurations are as follows:

Item	ACF
Conduit	0.87
Tray	0.52
Banked Conduit	0.74

Although actual testing of conduits produced an ACF of 0.87, TVA established a value of 0.82 as their standard to allow for variations in emissivity for different conduit materials used.

Banked conduit testing was performed in box-type configurations. The ACF value of 0.74 is appropriate for banked conduit assemblies and conservative for larger boxes. Therefore, since increasing box size increases convective cooling rate and the void fraction is larger than typically found for cable trays, an ACF value closer to that for banked conduits is reasonable for wrapped electrical boxes. Accordingly, an ACF value of 0.70 is selected for boxes.

Also, the tested configuration for 1" conduit appears to be with 3 wraps of T-Lag 770-1 material, whereas Kent Brown (co-author) indicated that only the 2-wrap configuration was used for ampacity testing. Even so, the difference in calculated values is not significant, and is conservative with respect to test values.

6.0 Results

Calculated results for conduit and cable tray are reasonably close to those established through testing. However, reliable testing automatically accounts for the myriad variables and the effects of their interactions, whereas calculated results depend on the validity of the model analyzed as well as the assumptions employed. This is particularly the case here with the assumptions for material thermal conductivity and using a conservative value for emissivity. As such, test data is considered to be a more reliable basis for determining ACF values. Since conduit testing included only 1" and 4" conduits, the calculated value is used for the 5" conduit. Therefore, the following ampacity correction factors shall be used for 3-hour rated T-Lag 330-1/770-1 composite assemblies:

Item	ACF
Conduit (≤4")	0.82
Conduit (5")	0.74
Tray	0.52
Banked Conduit	0.74
Boxes (selected)	0.70

FIRE ENDURANCE AND AMPACITY TESTING OF ONE AND THREE-HOUR RATED THERMO-LAG ELECTRICAL RACEWAY FIRE BARRIER SYSTEMS

Mark H. Salley
Senior Engineering Specialist
Tennessee Valley Authority

Kent W. Brown
Senior Electrical Engineer
Tennessee Valley Authority

ABSTRACT

The Nuclear Regulatory Commission (NRC) has determined there were deficiencies in the design, testing and installation of Thermo-Lag 330-1 Electrical Raceway Fire Barrier Systems (ERFBS). Their two primary concerns are:

- The currently installed Thermo-Lag 330-1 ERFBS may not ensure that the electrical cables are free from fire damage for the required rating and,
- The ampacity derating factors currently used for Thermo-Lag 330-1 ERFBS may not be correct.

Thermo-Lag 330-1 has been utilized in the design of the Tennessee Valley Authority's (TVA) Watts Bar (WBN), Sequoyah (SQN) and Browns Ferry (BFN) Nuclear Power Plants to protect redundant cables required for safe shutdown of the reactor in the event of a fire. Such protection is a licensing requirement per the Code of Federal Regulations, 10CFR50, Appendix R. After reviewing other available ERFBS options, TVA determined that redesign and qualification of the Thermo-Lag 330-1 systems would provide the best available ERFBS and minimize cable replacement due to ampacity effects. The resulting fire and ampacity test program developed one and three-hour rated Thermo-Lag ERFBS for cable trays, conduits, airdrops, junction boxes and other unique raceway configurations. The improved designs and installation techniques also minimized the required ampacity derating. These new designs will be used in initial installations at WBN and for upgrading other systems at other TVA Nuclear Power Plants (NPP). The TVA research and testing also provided useful input to the NRC's criterion for ERFBS fire testing and to an IEEE standard being developed which governs ERFBS ampacity testing. The TVA ampacity tests also established methodologies for use with raceway configurations which fall outside the bounds of those covered by the draft IEEE standard. Results of ampacity tests performed by Texas Utilities Electric (TU) were also compared to an existing mathematical model for cable trays which have an ERFBS installed. Modification to key parameters of that model are suggested which result in good correlation with the TU tests.

INTRODUCTION

Thermo-Lag 330-1 Electrical Raceway Fire Barrier Systems (ERFBS) have been used in the majority of United States Nuclear Power Plants as a passive fire barrier to protect redundant electrical cables and equipment required for Fire Safe Shutdown (FSSD) of the reactor. In accordance with the requirements of the Code of Federal Regulations (CFR), Title 10 Part 50, Appendix R[1], the fire barrier separating redundant FSSD cables and equipment must have a three-hour rating for areas without fixed automatic fire detection and suppression or a one-hour rating for areas with installed automatic fire detection and suppression. When Appendix R was promulgated, the majority of NPP were operating or in final stages of construction. While redundant shutdown circuits were a part of their basic design, redundant FSSD circuits were often not separated by rated fire barriers. The most cost effective backfit to meet the new requirements was to protect one of the installed redundant FSSD circuits. Areas in the NPP that have installed automatic fire detection and suppression systems rely on one-hour rated ERFBS while area without automatic systems utilize three-hour rated ERFBS. In addition to meeting the fire endurance requirements, the ERFBS could not adversely impact the ampacity derating of the cables or present an impact hazard to safety-related equipment during an earthquake.

Thermo-Lag 330-1 is a proprietary material manufactured by Thermal Science Incorporated (TSI) of St. Louis Missouri. The material is best characterized as a "subliming ablator". When exposed to elevated temperatures the material transposes from a solid into a vapor which results in heat blockage (ablative shielding/cooling). The material originated in the aerospace industry and was primarily used as a heat shield for vehicle re-entry into the atmosphere[2].

CONCERNS

Fire Protection

Beginning in August of 1991 the NRC alerted utilities to potential problems associated with Thermo-Lag 330-1 ERFBS[3]. Based upon fire testing performed by Gulf States Utilities' (GSU) River Bend Station in October 1989, deficiencies were identified in their Thermo-Lag 330-1 installation. In the GSU testing, 30-inch wide aluminum cable trays protected with 3-hour Thermo-Lag 330-1 ERFBS exceeded pass/fail temperatures and lost circuit integrity within approximately 60 minutes. Catastrophic failure and collapse of the cable tray occurred within 90 minutes. The purpose of the GSU testing was to evaluate their as-installed configurations. GSU had determined during maintenance activities that the subcontractor who installed the Thermo-Lag 330-1 had removed the "stress skin" from the fire barrier material. Stress skin is a steel wire mesh installed by the vendor as part of the fabrication of the Thermo-Lag 330-1. One-hour Thermo-Lag 330-1 has stress skin installed on the inside surface; three-hour Thermo-Lag 330-1 has stress skin installed on both the inside and outside surfaces. GSU then repeated the fire test by constructing additional assemblies in accordance with the vendors published installation manual. Similar failures occurred. The NRC continued to follow up on this subject issuing additional Information Notices[4].

Texas Utilities Electric (TU), in support of the licensing of Comanche Peak Unit 2, conducted additional fire endurance testing of one-hour Thermo-Lag 330-1 ERFBS. Based upon test failures of small conduit and large cable trays during the TU testing, the NRC issued Bulletin 92-01[5] and supplement 1[6] in June and August 1992. This Bulletin determined that Thermo-Lag 330-1, as currently installed on conduits smaller than 4-inch and cable trays larger than 14-inch wide, was unable to meet its design basis testing requirements as a rated fire barrier. This Bulletin was then followed by Generic Letter 92-08[7] in December 1992. With all the concern involving Thermo-Lag 330-1 ERFBS and independent testing being performed by utilities and the NRC the following question evolved: "What is the correct fire testing criteria?"

At the time this issue came to light the TVA was in the final stages of completing construction and licensing WBN Unit 1 located near Spring City, Tennessee. The original design of WBN utilized an ERFBS manufactured by the 3M Company. After comparing the ampacity derating factors of both 3M and Thermo-Lag 330-1, the decision was made to switch from the 3M ERFBS to Thermo-Lag 330-1 with its lower ampacity derating factors. Since WBN relies on Thermo-Lag 330-1 ERFBS, TVA then volunteered to assist the Nuclear Utilities Management And Resource Council (NUMARC) with engineering and craft personnel in performing vendor sponsored Thermo-Lag 330-1 fire testing that could be used at WBN as well as other NPPs. (Note: The Nuclear Energy Institute (NEI) is the successor organization to NUMARC). After numerous meetings and discussions with the NUMARC staff and other utilities represented on the NUMARC advisory committee, it was determined that a consensus on the appropriate fire testing methodology and acceptance criteria could not be reached in the short term required to support WBN licensing. TVA would have to proceed on its own in qualifying Thermo-Lag 330-1 as a rated ERFBS.

Cable Performance

The decision to protect the cables at WBN with an ERFBS occurred after the cables were installed in their raceways. Evaluation of the effect of the ERFBS on the installed cables was initially performed in the mid 1980s utilizing ampacity correction factors based on the results of tests conducted by or for its manufacturer, TSI. In the early 1990s Notices, Bulletins and Generic Letters from the NRC and position papers from various industry groups identified potential problems with the original ampacity tests, with the most significant concerns in the area of protected trays. A comparison of the correction factors originally utilized at TVA and those which were subsequently published is given in Table 1.

Table 1
Comparison of Ampacity Correction Factors[1] (ACF)

Configuration	Old TVA ACF[1,2]	Other Source ACF
Tray - 1 hour	0.875	0.712
Conduit - 1 hour	0.91	0.987

Note 1. ACF = Wrapped Amps / Baseline Amps
Note 2. Based on TSI sponsored testing.

A review of the early tests reveals that there was little consistency between the various protocols used for the ampacity assessment. This is not surprising given the absence at that time of an industry consensus method for the performance of such tests. Differences existed in the length of the test specimens, the control of end heating effects, the method of ambient temperature control, the size and number of cables used; the size of raceway, the location of thermocouples and the definition of equilibrium conditions. Variances in such key parameters inevitably resulted in significant differences in the derived correction factors.

In preparing for the subject test program, TVA performed a parameter by parameter review of the protocols which have been been issued since the original testing. The first, UL 1712[8] was an issued in 1984 while the second, IEEE P-848[9] was still in draft form. Based on a comparison of the key parameters, which is described in an earlier paper[10], TVA chose to utilize the draft IEEE document.

At the same time that TVA was evaluating the various methodologies, TU was preparing to perform ampacity tests. TU had also determined that the P-848 draft provided the best available guidance for the tests and had based its program on Draft 11.

Tray - Draft 11 required the use of a 4-inch x 24-inch tray filled with 12 [illegible] AWG 600 volt copper cables arranged in four layers[11]. TU barrier designs utilized a 5/8-inch layer of the Thermo-Lag 330-1 panels with a single layer of a flexible silica blanket placed over the top of the cable mass. According to TU, the blanket was added to provide additional protection for cables in highly filled trays from the heat transmitted through the barrier during the fire. Since the thermal resistivity of the silica cloth[11] is about twice that of the cable mass itself and could therefore result in some additional derating, a layer was included in the TU ampacity tests. The TU correction factor (Table 2) was therefore conservative for use at TVA's WBN plant where no silica blanket would be utilized.

Table 2
TU One-Hour Thermo-Lag 330-1 Tray

Cable Depth (in)	Tray Depth (in)	ACF
2.95	4	0.682

Conduit - The TVA and TU conduit configurations differed. Both used the same Thermo-Lag 330-1 preformed sections, however TVA procedures dictated that the interior of the barrier have a complete layer of trowelable grade Thermo-Lag 330-1 applied prior to installation. TU used a more conventional method, employing only prebuttered joints. Because of the resulting difference in fit, TVA determined to perform its own ampacity tests on conduits (using Draft 12) with the same configurations as those which were evaluated during the fire endurance testing as follows:

- a single 5/8-inch layer.
- a 3/8-inch base covered with a 3/8-inch upgrade layer.
- a 5/8-inch base covered with a 3/8-inch upgrade layer.

As permitted by Draft 12, separate conduits were used for each of these assemblies. The utilization of different conduit segments for each configuration allowed the test program to proceed at a much faster pace than if they had been conducted sequentially on the same segment, due to the 30 day cure time (for the trowelable grade material) between each test. Given that the thermal resistivity of water is fairly low, its elimination from the seams and interior prior to ampacity testing is required in order to obtain results which accurately depict the effects of the ERFBS.

Non-standard Configurations - In the early stages of the program development, it had been assumed that the configurations outlined in P-848 would envelope those which would be encountered during construction at WBN. As actual installation of the ERFBS neared, it became clear that many unique enclosures would be required. These unique enclosures fit into two broad categories. First, where the conduit-to-conduit spacing was not sufficient to permit installation of the

preformed sections, the only viable alternate was the enclosure of multiple conduits within a common ERFBS. Second, where cables in trays extended above siderails such that enclosure of individual trays was not possible it was determined that multiple trays within the same vertical stack would have to be wrapped in a common ERFBS. Therefore, given the myriad of combinations which can exist, one major component of TVA's test program became the identification of bounding test configurations for such non-standard arrangements and the development of some general rules for extrapolation of the findings.

TVA APPROACH TO RESOLUTION

Task Team

As previously stated Thermo-Lag 330-1 is used at all three TVA NPP. Since the problem was generic to more than one TVA NPP, the "ownership" of the problem resided with Corporate Engineering (CE) Chief Engineer. The first step in addressing the issue was to assemble a self-managing team of engineers to own this issue. In order to be successful the team would have to work at a fast pace, quickly overcoming any mistakes or failures[12]. At TVA, the responsibility for Fire Protection Engineering/Appendix R is assigned to the Mechanical/Nuclear Engineering Department (M/NE). Because of the potential impact on cabling and on raceway seismic integrity, the Electrical and Civil Engineering Departments, in addition to Nuclear Licensing, would play key roles in successfully resolving the issue. This is apparent since Thermo-Lag 330-1 would have to meet multiple performance criteria to be successful. Therefore, in order to address and resolve all the issues associated with Thermo-Lag 330-1, this specialized self-managing team approach was seen as the most appropriate choice. With the NRC issuance of "Request for Additional Information Regarding Generic Letter 92-08, Issued Pursuant to 10CFR50.54(f)" on December 22, 1994[13] an engineer from the CE Materials and Inspection Department was added to the team.

Fire Protection

In determining the appropriate fire test methodology and acceptance criteria for ERFBS the starting point was to perform a literature review of the available standards. TVA Engineering reviewed the NRC guidance in Generic Letter 86-10[14], ASTM E-119[15] and the American Nuclear Insurers guidance provided in "ANI/MAERP RA Standard Fire Endurance Test Method to Qualify a Protective Envelope for Class 1E Electrical Circuits"[16]. Underwriters Laboratories (UL) also had a methodology available for testing ERFBS. Their document, UL Subject 1724[17], was reviewed and determined to be the best starting point for developing the methodology. TVA decided that testing would be performed to the Standard Time/Temperature curve as used in most fire testing standards (i. e. ASTM E119).

For the TVA Phase I testing the decision was made to test the raceways without cables. In their place would be a single bare #8 AWG stranded copper conductor. This provides two benefits: first, the fire test would be conservative since there is no thermal mass of cables to act as a heat sink during the thermal exposure, and second, the testing would be independent of cable types and fills. The bare conductor is instrumented at 6 or 12-inch intervals and acts as a surrogate cable. It's thermocouples provide a profile of the temperature environment inside the raceway during the fire test. The exterior of the raceway is also instrumented with thermocouples at expected high temperature locations and 6 or 12-inch spacing thereafter. Because the ERFBS encloses the entire raceway, there is no easily definable cold side of the barrier as there is with fire wall tests. Therefore by definition, the exterior of the raceway is the cold side of the ERFBS. The test data is then interpreted as follows:

1) Since the ERFBS is installed for physical separation and functions as a fire wall, if the average temperature rise is less than 250°F (121°C) and the highest single thermocouple rise is less than 325° F (163°C) measured on the exterior of the raceway (i.e. ASTM E119 Criteria), it shall be considered rated for all types and fills of cables.

2) If the ERFBS exceeds these temperature limits, a time/temperature profile can be developed and the specific cable types then qualified in accordance with the requirements of UL 1724 Appendix B (with some enhancement).

Fire barrier testing typically includes an exposure to a hose stream to model impact, erosion and cooling effects. TVA determined that a realistic hose stream test should be performed at the end of the fire exposure.

Based on the experience of the March 22, 1975, BFN fire, the electrical raceways did not receive any severe impact force from falling objects induced by the fire. This can be attributed to the solid designed support systems used for earthquake requirements. The one-hour ERFBS will be installed in sprinkler protected areas of the plant to meet Appendix R requirements. In an actual NPP fire the ERFBS will be exposed to the mechanical impact, erosion and cooling effects of water spray from sprinkler system operation and fire brigade hose streams. Therefore, it was determined that the most appropriate hose stream test that would represent the mechanical impact, erosion and cooling effects in a TVA NPP environment would be the one and one-half inch fog nozzle test as described in NRC's NUREG 0800[18].

After the completion of the TVA phase I testing and prior to the start of Phase II, the NRC issued Supplement 1 to Generic Letter 86-10[19]. In this Supplement the NRC defined the appropriate methodology and acceptance criteria for ERFBS testing. Comparison of Supplement 1 to TVA's testing position demonstrated a great deal of similarity, the major difference being the nominal spacing of thermocouples. TVA's Phase I testing utilized UL 1724 guidance of key locations on the raceway and 12-inch spacing thereafter. Supplement 1 requires 6-inch spacing. Based upon the uniform temperature profiles developed in the Phase I, tests the difference was determined to be insignificant. Nevertheless, Phase II and III testing would utilize the 6-inch thermocouple spacing.

TVA FIRE TEST RESULTS

Phase I Fire Tests

The fire testing was divided into three phases. Phase I tested basic electrical raceways such as; conduits, junction boxes and air drops protected with one-hour ERFBS. Phase II tested cable trays and multiple conduits in a single enclosure protected with one-hour ERFBS. Phase III tested conduits and cable trays protected with three-hour ERFBS. TVA began construction of the first three Phase I test decks in the fall of 1992. In performing testing it must be recognized that Thermo-Lag 330-1 has a long lead time associated with each test. After the installation was complete (approximately one week per test deck for two craftsmen to install the ERFBS), the assemblies must cure for a minimum 30 days. This curing time is required for the trowel grade Thermo-Lag 330-1 material to dry. The first decks consisted of two each: 1-inch conduits, 5-inch conduits, and 2-inch air drops. Variations in the ERFBS design would be applied to each set. The goal was to determine the effects of conduit size on identical ERFBS. The first test was run on December 21, 1992. This test had a baseline, nominal 5/8-inch Thermo-Lag 330-1 ERFBS installed on each set of components. Additionally, the second set of components (1-inch and 5-inch conduits and 2-inch air drop) had an external layer of stress skin applied over the completed Thermo-Lag 330-1 ERFBS. The purpose of this variation was to attempt to achieve better performance as suggested by the small scale test results as reported in Information Notice 92-55[4]. This additional stress skin would also act as an external skeleton should any structural problems develop during the test. The test demonstrated that a single layer of nominal 5/8-inch Thermo-Lag 330-1 was adequate to protect the 5-inch conduit but insufficient to protect the 1-inch conduit or the 2-inch air drop for the required period of time (i.e., one hour).

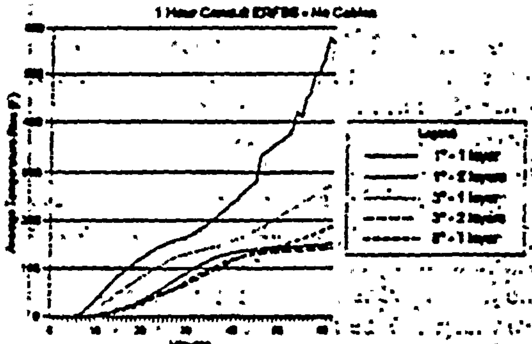
An interesting problem was discovered during some earlier testing involving anomalies with the thermocouple readings. TU was experiencing erratic temperature data in some of their tests. After some research by the laboratory (Omega Point) it was determined that when the Thermo-Lag 330-1 undergoes its subliming ablative shielding process the material saturates the fiberglass insulated thermocouple leads causing them to short. During the testing, TVA had experienced the same anomalies with fiberglass insulated thermocouple installed on earlier constructed decks. As a result of these problems, TVA switched to a Teflon PFA insulated Type 24 gage Chromel-Alumel thermocouple for all subsequent tests.

TVA continued constructing Phase I test decks and performing tests through the spring of 1993. For the first "upgrade" tests, a nominal 3/8-inch preformed section was added over the nominal 5/8-inch first layer[20]. An interesting discovery was made during the first 5/8-inch + 3/8-inch tests concerning the two layer Thermo-Lag 330-1 ERFBS performance (see Figure 1). The two layer ERFBS climbed steadily up to approximately 212°F (100°C) (ambient temperature + temperature rise). At that point the curve flattened with

only a small rise for the last 1/3 of the test. Upon disassembly it was also noted the outside layer of material was completely consumed and 1/2-inch to 3/8-inch of the inside layer was un-reacted. Based upon this test, subsequent tests were performed and qualified using a 3/8-inch + 3/8-inch ERFBS design. It is theorized that the interface resistance between the two layers coupled with the outside layer charring and stress skin maximizes the efficiency of the subliming ablative cooling on the protected electrical raceway. The graphs shown in Figure 1 were duplicated for all two layer Thermo-Lag 330-1 ERFBS installed on varying sizes of conduits. The only difference in the curves is at what time into the test the sample reaches approximately 212°F (100°C). Due to their smaller thermal mass (inertia), smaller conduits (and air drops) reach this point faster than larger conduits. Table 3 shows the TVA Thermo-Lag 330-1 ERFBS conduit designs qualified in the test program.

Figure 1

1 Hour Conduit ERFBS - No Cables



Phase I also performed tests to determine if there was any difference in thermal performance between aluminum and steel conduits protected by identical ERFBS. Steel is approximately three times heavier per equal sized conduits and aluminum has approximately twice the heat capacity. The fire test on 3-inch conduits with the same Thermo-Lag 330-1 ERFBS exposed to the same furnace heat flux demonstrated the aluminum conduits will experience slightly higher temperatures (Reference TVA Test 6.1.4).

Table 3
Thermo-Lag 330-1 Conduit System Designs

Conduit Size, Inches	Nominal Thermo-Lag 330-1 Thickness, Inches		
	5/8"	3/8" + 3/8"	3/8" + 3/8"
0.75		X	
1		X	
1.5		X	X
2		X	X
2.5		X	X
3	X	X	X
4	X		
5	X		

Note 1. Requires cable qualification.

Junction box testing demonstrated a single layer of nominal 5/8-inch Thermo-Lag 330-1 with an external layer of stainless steel stress skin and trowel grade skim coat was adequate to protect sizes ranging from 6-inch x 6-inch x 6-inch through 24-inch x 18-inch x 12-inch. Phase I also determined junction boxes with a dimension greater than 24-inch up through 48-inch x 36-inch x 12-inch can be successfully protected with a nominal 5/8-inch + 3/8-inch Thermo-Lag 330-1 ERFBS.

After the successful completion of Phase I testing, TVA entered into an agreement with the manufacturer, TSI, for the Phase II and III testing. In this arrangement TSI would provide all necessary Thermo-Lag materials and laboratory fees while TVA was responsible for providing the engineering, design, installation craft and the necessary electrical raceways. The results of this testing would be made available to any interested NPP through NEI. This arrangement would provide a "Win/Win" philosophy for the project and all parties involved[21]. In addition to the fire tests, corresponding ampacity derating would be performed on the configurations. The scope of the testing was set at seven one-hour fire tests in Phase II and two/three three-hour fire tests in Phase III.

Phase II Fire Tests

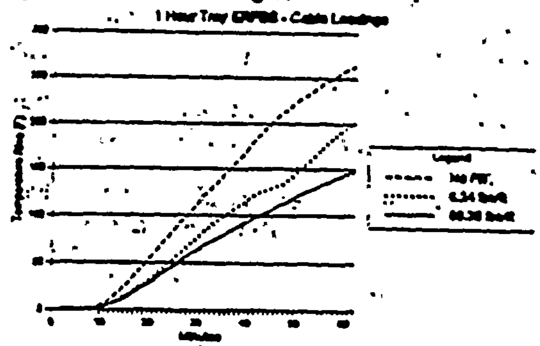
The design for the seven one-hour tests was based on existing installations at BFN and SQN in addition to the expected configurations at WBN. Based upon the success of the TVA Phase I testing, the design philosophy was to keep the "upgrades" minimal and generic as possible. The tests would also attempt to establish installation principals through bounding configurations. The "Generic TVA upgrade" consisted of adding a layer of external stainless steel stress skin with a skim coat of Thermo-Lag 330-1 trowel grade. The external stainless steel stress skin and trowel grade skim coat would:

- Provide a thermal boundary layer during the fire exposure. This will maximize the ablative shielding provided to the raceway by the nominal 5/8-inch Thermo-Lag 330-1,
- Ensures the ERFBS remains structurally intact during the dynamic process of the material subliming during the fire exposure and subsequent hose stream test, and
- Provide the necessary strength and structural integrity needed to meet seismic requirements. TVA verified this design feature in the summer of 1994 by conducting full scale shake tests at Wyle Laboratories, Huntsville, Alabama.

Cable Tray Fire Tests - The first three Phase II fire tests were dedicated to cable tray configurations. TVA Test 6.1.7 consisted of three 18-inch wide, ladder back, steel cable trays with identical upgraded ERFBS and varying cable fill. The left tray in the test deck represented a maximum filled tray (i.e. 289 4C #16 AWG [69.36 Lbs cable/ linear Ft.]). The center tray in the test deck represented a single layer filled tray (i.e. 26 4/C #16 AWG [6.24 Lbs cable/ linear Ft.]). The right tray in the test deck represented an empty tray (i.e. no cables). The results are shown in Figure 2.

The only thermocouples to exceed the acceptance criteria were the bare #8 inside the empty tray. This occurred 56 minutes into the test. The ambient temperature at the start of the test was 83°F. This dictated a maximum average temperature of 333°F at 60 minutes (ambient temperature plus 250°F allowable temperature rise). By plotting the weight of each cable tray system (i.e. the weight of the tray and cables and not including the weight of the Thermo-Lag 330-1 ERFBS which was constant for each tray) versus its temperature at 60 minutes an expression for the effect of cables can be developed.

Figure 2



The following equation is based on a "best fit" curve approach with a logarithmic relationship (i.e. result of linear regression, method of least squares).

Final Temp. = 387.9 - 86.752 *Log (Weight)

where:
Final Temp = Degrees Fahrenheit[22]
Weight = Pounds/Foot of cable tray and cables

This equation is valid for eighteen-inch cable trays protected with the TVA designed Thermo-Lag 330-1 ERFBS having cable fills ranging from 6.24 Lbs/ft up thru 69.36 Lbs/ft.

Further review was performed on the results of the single layer filled cable tray (6.24 Lbs/ft of cable) and the empty cable tray (0.0 Lbs/ft of cables). This was determined necessary since the effects of adding cables over the first layer becomes less important due to the cable insulation slowing the heat transfer to the copper conductors. Conservatively, a plot was constructed of the temperatures for the empty cable tray (0.0 Lbs/ft of cable) and the single layer cable tray (6.24 Lbs/ft of cable). The resulting linear equation given below conservatively predicts the system's thermal response at low cable fills (i.e. less than 6.24 Lbs/ft of cable).

Final Temp = 385.10 - 97756 * (Weight)

where:
Final Temp = Degrees Fahrenheit[12]
Weight = Pounds/foot of cable tray and cable

Solving this linear equation in the range of acceptable temperatures indicates that a cable tray system with a weight of 5.33 Lbs/Ft would maintain acceptable temperatures at 60 minutes. Subtracting the weight of the cable tray (4.00 Lbs) from the system yields a cable loading of 1.33 Lbs/Ft. Based on the cables used in the test (4/C #16 AWG = 0.24 Lbs/Ft) a minimum 6 cables are needed to produce acceptable temperatures (i.e. $\Delta T \leq 250°F$).

TVA Test 6.1.7 also contained a 3-inch conduit with one half protected by Thermo-Lag 330-1 and the remaining half protected by 3M M20-A. The different fire barrier materials were butted together and a layer of 3M M20-A was wrapped around the joint. The test demonstrated compatibility between the materials with no structural failures. The thermal performance during the test was representative of each unique material.

TVA Tests 6.1.8 and 6.19 demonstrated that large cable tray fittings (double-cross), vertical stack of three 18-inch trays, and two side by side 18-inch trays can successfully be protected in a single Thermo-Lag 330-1 enclosure upgraded with the TVA system. These tests were all performed with no installed cables. TVA Test 6.1.9 also demonstrated that a cable tray with a raised cover can be protected with Thermo-Lag 330-1. The test simulated a "random filled cable tray" (i.e. the cables are all located in the center of the tray with the height of the bundle above the side rail). One-inch and five-inch air drop cable bundles were also demonstrated acceptable in this test.

<u>Fire Tests of Multiple Conduits in a Single Enclosure</u>
The next four fire tests of Phase II were dedicated to multiple conduit configurations. Each assembly consisted of nominal 3/8-inch Thermo-Lag 330-1 with the Generic TVA Upgrade. TVA Test 6.1.10 demonstrated the performance of "two sided enclosures". This type enclosure is typically used where conduits are located in a corner, i.e along where the ceiling and wall meet. The conduits are enclosed on two sides by concrete and two sides by Thermo-Lag 330-1 panels attached to a Unistrut frame. Table 4 shows the average and maximum temperature rise of the assemblies. This test was performed in the horizontal position.

Table 4
Two Sided Enclosures
Standard Conduit Configurations

Configuration	Average Temperature Rise (°F)	Maximum Temperature Rise (°F)
Small Box with Two-1" Steel Conduits	25	92
Small Box Unistrut Frame	128	153
Large Box with Eight-4" AL Conduits	70	100
Large Box Unistrut Frame	158	218

TVA Test 6.1.11 demonstrated the performance of "three sided enclosures". This type enclosure is typically used where conduits are located against a wall or ceiling. The conduits are enclosed on one side by concrete and three sides by Thermo-Lag 330-1 attached to the conduits. Table 5 shows the average and maximum temperatures of the assemblies. This test was performed in the vertical position. This test also contained a large junction box (60-inch x 36-inch x 24-inch) protected with the Generic TVA Upgrade. The success of this junction box design eliminated the need for a second layer of nominal 3/8-inch Thermo-Lag 330-1 as previously determined in TVA Test 6.1.6.

Table 5
Three Sided Enclosures

Configuration	Average Temperature Rise (°F)	Maximum Temperature Rise (°F)
Seven 2" to 3" Aluminum Conduit	106	113
Two 1" Steel Conduits	118	120
Three 3" Aluminum Conduit	94	124
Large Box	138	160

TVA Test 6.1.12 demonstrated the performance of "four sided enclosures". This type enclosure is typically used where conduits are free standing. The conduits are enclosed on all four sides by Thermo-Lag 330-1 attached to the conduits. The configurations

tested were:

- A group of four 1-inch steel conduits arranged in two rows,
- A group of four 3-inch steel conduits arranged in two rows,
- A group of eight 4-inch aluminum conduits arranged in four rows of two.

Table 6 shows the average and maximum temperatures of the assemblies. This test was performed in the vertical position.

Table 6
Four Sided Enclosure

Configuration	Average Temperature Rise (°F)	Maximum Temperature Rise (°F)
Four- 1" Steel Conduit	154	172
Four-3" Steel Conduits	149	160
Eight-4" Aluminum Conduit	147	161

TVA Test 6.1.13 demonstrated the performance of "a ganged conduit enclosure". This type enclosure is used where a series of conduits are free standing and routed together. The "ganged" assembly is characterized by one section of half round preformed material installed on the outside conduits with board material spanning the distance between the two preformed sections. The conduits are enclosed on all four sides by Thermo-Lag 330-1 attached to the conduits. The tested assembly consisted of seven 4-inch steel conduits. This test also contained two 3/4-inch conduits; one steel and one aluminum. Each conduit was protected by an identical nominal 5/8-inch plus 3/8-inch Thermo-Lag 330-1 design. The 3/4-inch conduits were included to obtain a second steel verses aluminium data point. It's interesting to note that the 3/4-inch aluminum conduit had sightly lower temperatures than the steel. This is the opposite result when compared to the 3-inch conduits tested in TVA Test 6.1.4. Table 7 shows the average and maximum temperatures of the assemblies. This test was performed in the horizontal position.

Table 7
Ganged Conduits & Aluminum/Steel Comparison

Configuration	Average Temperature Rise (°F)	Maximum Temperature Rise (°F)
Seven 4" Steel Conduits	149	203
3/4" Steel Conduit	141	153
3/4" Aluminum Conduit	136	153

There were no problems with structural integrity during any of the TVA tests. This success may be attributed to three factors:

1) TVA procedures require prebuttering the entire inside surface of the sections rather than just the joints as is commonly done in the industry. This extra trowel grade Thermo-Lag 330-1 material forms a solid bond with the raceway when it cures.

2) New designs for WBN utilized a number of score and fold techniques for covering irregularly shaped objects such as condulets. This method preserves the integrity and continuity of the internal stress skin. This design attribute ensures the material will stay in place during the test.

3) As previously discussed, the Generic TVA Upgrade was installed on most assemblies.

Phase III Fire Tests

The design for the two/three three-hour tests was based on worst case existing installations in the nuclear industry. At the time the testing was planned and performed, TVA had no identified need for a three-hour ERFBS at any of our NPPs. Based upon the success of the TVA Phase I and II testing, the design philosophy was to keep the "upgrades" minimal and generic as possible. The tests would also attempt to establish installation principals through bounding configurations. All assemblies were tested without cables and in accordance with Supplement 1 to Genereic Letter 86-10. The first step was to install a "worst case" configuration on the electrical raceways

using nominal 1-1/4-inch Thermo-Lag 330-1. "Worst case" was defined as installing configurations with the lease desirable attributes. This included post-buttering and stainless steel banding 12-inches on-center. The second step was defined as "Reinforcement". In this step, areas of known weakness in the worst case design were reinforced with external stainless steel stress skin and Thermo-Lag 770-1 trowel grade material. The third step in the installation process was the "Upgrade". In this step, a new material "Thermo-Lag 770-1 Mats", manufactured by TSI, would be used. The Thermo-Lag 770-1 mats are a flexible, nominal 3/8-inch sheet material that is installed over the existing worst case Thermo-Lag 330-1 installations. The number of layers of mat applied to each raceway is given in Table 8. All layers were pre-buttered with Thermo-Lag 770-1 trowel grade and assembled using nominal 1-inch staples and 16 gage annealed stainless steel tie wire. Different assembly techniques were used on the cable trays i.e. multiple pieces vs. continuous wrapping. The final step of the installation was a skim coating of Thermo-Lag 770-1 trowel grade.

Table 8
Layers of 770-1 over baseline 330-1

Configuration	TVA Test	# Layers 770-1
12" steel ladder back cable tray	6.2.1 6.2.2	2 2
24" steel ladder back cable tray	6.2.1 6.2.2	2 2
12" x 12" x 60" junction box	6.2.1	2
1" steel conduit	6.2.2	3
2" steel conduit	6.2.2	2
5" steel conduit	6.2.2	2
2" air drop	6.2.2	2

The composite [redacted] 770-1 over 330-1 design out performed [redacted] greatest expectation. TVA Test 6.2.1 was run for 3-hours and 33-minutes. At that point the test was stopped since no one had prepared to run longer than the required three-hours. The assemblies had a large thermal margin remaining and easily passed the hose stream test. Test results are listed in Table 9.

Prior to the start of the second test it was decided to run the test until the first assembly was close to its allowable maximum average temperature rise of 250°F (121°C). TVA Test 6.2.2 was run for 4-hours and 10-minutes. The assemblies easily passed the hose stream test. Test results are listed in Table 10

Table 9 6.2.1
Results of TVA Test ~~6.1.2~~

Configuration	Ave. & Max. Temp. Rise (°F) at 3:00	Ave. & Max. Temp. Rise (°F) at 3:33
12" tray	145 Ave. 155 Max.	161 Ave. 172 Max.
24" tray	135 Ave. 145 Max.	155 Ave. 171 Max.
Junction box	138 Ave. 143 Max.	151 Ave. 158 Max.

Table 10 2
Results of TVA Test 6.~~1~~.2

Configuration	Ave. & Max. Temp. Rise (°F) at 3:00	Ave. & Max. Temp. Rise (°F) at 3:22
12" tray	144 Ave. 154 Max.	187 Ave. 208 Max.
24" tray	128 Ave. 141 Max.	172 Ave. 188 Max.
1" steel conduit	154 Ave. 170 Max.	224 Ave. 278 Max.
2" steel conduit	175 Ave. 241 Max.	246 Ave. 314 Max.
5" steel conduit	144 Ave. 166 Max.	199 Ave. 263 Max.
2" air drop	124 Ave. 131 Max.	143 Ave. 144 Max.

A third test assembly had been prepared using only the new Thermo-Lag 770-1 materials to construct the ERFBS. This test assembly served as a "Backup" in the event the previous Phase III test assemblies did not perform satisfactorily. Based on the successes of the previous two tests, this assembly was not used.

TVA ELECTRICAL TEST RESULTS

Standard Conduit Configurations

During the early TU ampacity tests, which were based on Draft 11 of P-848, it was noted that the use of three conductors connected in series resulted in excessive inductive coupling between the cables and the conduit. The resultant conduit heating and surpressed currents in their early tests led TU to add a fourth conductor to minimize the conduit effects. These findings, later supported by TVA testing, led the P-848 working group to issue draft 12, which stipulated the use of an even number of conductors.

Having witnessed a portion of the TU work, a variety of tests were performed at TVA's labs in Chattanooga, TN.

While the bulk of the details and findings of that early TVA effort were reported in our earlier paper, there were several key observations in that program which may now be updated. In the first program, because TVA had assumed that the choice of test conduits would make little difference in the determination of the final correction factor, no effort made to "match" conduit segments (i.e. select all from the same vendor). In order to confirm that repeatable results were indeed being obtained, a second 4-inch baseline conduit was prepared and tested with a variety of cable and power supply arrangements, as follows:

- 3-1/c series connected powered single phase
- 4-1/c series connected powered single phase
- 8-3/c series connected powered single phase
- 8-3/c powered three phase

A consistent 3-4% difference in the resultant correction factor was seen for the two baseline conduits. The results are shown in Table 11 for the 8-3/c cables connected single phase. Calculations for the differnt baseline conduits are labelled ACF1 and ACF2, respectively. The results of the 1-inch conduit test (where only a single baseline conduit was used) are also given in Table 11.

TVA noted that though the span of ACFs measured closely mirrored an analysis performed using classical Neher-McGrath[23] methodologies, the correction factors were well above that expected based on TSI and TU tests.

Table 11
TSI Wrapped Conduit - TVA Tests

TSI	4" ACF1 - 24/c	4" ACF2 - 24/c	1" 4/c
5/8"	1.07	1.03	0.98
1/2" + 5/8"	1.03	1	0.99
5/8" + 3/8"	1.04	1.01	0.97

While the correlation between tests conducted using the different conductor and power supply arrangements was good, the difference between the two baseline conduits was greater than is desirable for test repeatability and seemed to indicate that some conduit specific effects were still being seen.

Given the confirmation provided by the variety of configurations evaluated, TVA concluded that ACFs at or near unity were indeed possible. TVA believes that a significant contributor to this improvement was the elimination of the annular air space between the conduit outer surface and the inner surface of the Thermo-Lag. This was accomplished by the complete prebuttering of the interior of the preformed sections of Thermo-Lag prior to placing them over the conduit.

Having eliminated the air gap as described above, the additional thermal resistance from installation of the Thermo-Lag 330-1 appears to have been offset by the significant increase in the overall surface area and by the increased surface emissivity of the ERFBS compared to bare conduit.

During a literature search, it was observed that the recommended value for conduit emissivity has changed significantly over the years. When the Neher-McGrath work was performed in 1957, a value of 0.95 was utilized. In 1962, when ICEA P-46-426[24] was generated, a value of 0.82 was applied. More recently, IEEE 835[25] has utilized a value of 0.50. Discussions with those familiar with the conduit manufacturing process revealed that the change was driven by improvements in the hot-dip process and by a trend towards the use of electro-galvanized Intermediate Metal Conduit (IMC) and Electrical Metallic Tubing (EMT) in lieu of hot-dipped rigid steel conduits. Thus, it appears that the difference observed between ACF1

and ACF2 was a function of variations in the surface emissivities of the segments used in making the baseline measurements.

During the course of several test programs, TVA has measured the surface emissivities of thirty-two rigid steel and five aluminum conduits. All measurements were made with a Mikron model M80AL-2FH hand held gun. This device has a target zone of 0.25-inches at a distance of 2.0-inches. The results of those measurements are shown in Table 12. Several observations are in order. First, the emissivity of the rigid steel conduits varies over a wide range. It may be that this disparity was the result of the age of the various specimens or perhaps reflective of their respective storage conditions. In either case, the importance of "matching" conduit specimens (ie drawing from the same vendor stock or verifying emissivities) can be clearly seen. Second, the readings for steel were frequently below that assumed in IEEE 835. For aluminum, the difference is even greater. While the low emissivities will result in favorable correction factors when testing an ERFBS, the results do seems to warrant some consideration when choosing base ampacities. Since manufacturing standards do not specify an acceptable range of conduit emissivity, P-848 has been revised to require that emissivity readings be taken to facilitate informed comparison of results from different tests.

Table 12
Conduit Emissivities

Location	No. Conduit	Size & Type	Avg.
OPL	1	4" steel	0.36
OPL	11	1" steel	0.47
TVA	10	2" steel	0.86
TVA	10	0.5" steel	0.85
TVA	4	2" aluminum	0.15
TVA	[illegible]	0.5" aluminum	0.26

Three-Hour Conduits - The subsequent test program at OPL included 1-inch and 4-inch conduits wrapped with TSI's three-hour "upgrade" system as previously described. These tests were configured in compliance with Draft 14 of P-848, which included all of the lessons learned from the TU and earlier TVA efforts regarding specimen configuration and connection.

The results are given in Table 13.

Table 13
Three Hour Conduit Upgrade System

Configuration	ACF
1" - 3 hour upgrade	0.9
4" - 3 hour upgrade	0.87

Selection of TVA ACFs - Consistent with the P-848, the worst case ACF was identified for one and four inch conduits for each thickness of ERFBS. Those factors were further reduced by 5% to account for possible variations in the surface emissivities of installed conduits. The final values, which were included in TVA's internal design standard, are shown in Table 14.

Table 14
Selection of Final ACF - Conduit

Configuration	Lowest ACF	TVA Standard
5/8" - 1 hour	0.98	0.93
3/8" + 3/8" - 1 hour	0.98	0.93
1/2" + 3/8" - 1 hour	0.97	0.92
330-1/770-1 3 hour Upgrade	0.87	0.82

Non-Standard Conduit Configurations

The TVA-OPL program also included assemblies to evaluate multiple conduits encased within a common Thermo-Lag ERFBS. Two types of such enclosures may be utilized. In the former, the flat Thermo-Lag 330-1 panels are mounted directly on the surface of the conduits, with no intentional peripheral air gap. This construction will be used on all three- and four-sided boxes (the additional side of the three-sided box being provided by a concrete wall or ceiling). The second enclosure type consists of Thermo-Lag 330-1 panels attached to a Unistrut frame installed around (but not touching) the conduits. This construction will be used where the conduits to be protected are routed such that only two sides of the box will be Thermo-Lag 330-1, the other sides being concrete walls or a wall and the ceiling. The substantial heat capacity of the concrete and rebar, coupled with its low thermal resistivity

compared to Thermo-Lag 330-1, will ensure that such two- and three-sided enclosures are not the limiting cases and may be represented during testing through the use of four-sided assemblies.

There is no specific guidance for the performance of such tests in P-848. Thus, TVA first identified the key parameters regarding such arrangements and selected the variables in a manner as to ensure conservative results. Those parameters are the selection of conduit size, number of conduits (and their arrangement into rows and/or columns), conduit spacing (where multiple conduits are used) and box size (in the case of two-sided boxes on Unistrut frames). Those issues were addressed by TVA's selection in the following manner;

Enclosures Using the Conduit for Support - When enclosures are constructed of panels mounted directly to the conduit, the air gaps (between adjacent conduits) tend to vary in accordance with the enclosed conduit size. With small conduits, the correspondingly small air gaps result in the heat transfer across the gap being a function of radiation and conduction only, rather than a combination of radiation, convection and conduction. Thus, the ACF derived using "small" conduits would be conservative. In keeping with the P-848 philosophy, TVA chose to utilize 1-inch conduits since they are the smallest size in which power circuits are typically routed.

For such enclosures, surface area is lowest for low numbers of small conduits. A single conduit would provide for the lowest surface area but would not include any internal air gap since TVA's method of application is to utilize preformed sections pre-buttered with trowel grade material. While a two conduit encasement would result in an enclosed air gap, each conduit has an adjacent "end wall" from which to radiate. Thus, a set of three conduits in a row was
1x3 judged to provide the least surface area while still including a conduit which is not adjacent to one of the enclosure end walls. Such an arrangement, using 1-inch conduits, was included in the OPL testing. TVA recognized that when conduits are banked in multiple rows, an additional air gap is injected between the
2x3 rows. Thus, in order to assess that effect, an assembly was included which had a double row of three 1-inch conduits. While this arrangement leaves each row with every conduit adjacent to a radiating surface, it was felt that the likelihood of encountering three rows of ERFBS protected power conduits (which could not be individually wrapped) within a typical generating station was low.

The presence of multiple conduits in close proximity to one another (even without a barrier) results in mutual heating and the introduction of what Neher and McGrath described as an "interference temperature rise". This effect is typically accounted for through the use of a grouping factor, such as is given in P-46-426. The tendency of the effect to dominate the correction factor when many conduits are wrapped together further contributed to TVA's decision to use small conduit banks (1x3 and 2x3).

A spacing between conduits of one-half their nominal diameter was utilized. Lesser spacings would result in a greater interference temperature rise effect, as described above (and thus appear to minimize the effect of the barrier) and are not feasible below one-fourth of the nominal diameter because of the physical interference of couplings and supports and as a result of the need for tool clearances. Larger spacings would generally support individual wrapping of the conduits.

Enclosures on a Unistrut Frame - In contrast to the boxes formed by Thermo-Lag 330-1 panels in direct contact with multiple conduits (which were necessary to assess the resultant dead air spaces between conduits), enclosures constructed of panels mounted on a Unistrut frame potentially result in a large gap between the conduit surface and the inner wall of the panels. Free air exchange will exist between that larger space and the small conduit-to-conduit gaps, rendering the latter insignificant. Tests to assess the effect of the large gap and the Thermo-Lag 330-1 ERFBS were conducted using a single conduit, thus avoiding the concern for "interference temperature rise" mentioned above.

Those tests were conducted using 1-inch conduits, given that its thermal resistance to the surrounding air is higher than that of a 4-inch (due to the smaller surface area of the former). As noted earlier, this is the smallest size conduit in which power circuits are typically routed.

For a given size conduit, the minimum box size (and therefore the minimum air gap thickness) is established by the diameter of the conduit, the thickness of the

Unistrut and the gap between the conduit and the Unistrut. For a single 1-inch conduit with Thermo-Lag mounted over 1.625" P1000 Unistrut, the smallest possible box would be approximately 4.75-inch x 4.75-inch (as measured over the Unistrut). In contrast, the largest box (regardless of conduit size or numbers of conduits) which TVA anticipated was be approximately 30-inch x 30-inch. Though it was believed that the large box would facilitate better convective cooling (and therefore the better ACF), both boxes were built to provide the needed confirmation.

The final ACF for boxed conduits on a Unistrut frame would then be most conservative of the two determined by the above tests, after adjustment for the appropriate grouping factor. Consistent with IEEE P-848, both assemblies were 12 feet in length.

The results of the non-standard conduit testing are given in Table 15.

Table 15
Correction Factors - Non-Standard Conduits

Configuration	ACF
Large Unistrut box - one - 1" conduit	0.96
Small Unistrut box - one - 1" conduit	0.88
Large Unistrut box - 2x3 - 1" conduits	0.93
Direct mounted - 2x3 - 1" conduits	0.76
Direct mounted - 1x3 - 1" conduits	0.92

Standard Three-Hour Tray

The test program at OPL also included trays wrapped with a composite Thermo-Lag 330-1/770-1 three-hour upgrade system as was previously described. Those tests were configured in compliance with Draft 14 of P-848. The results are given in Table 16.

Non-Standard Tray Configurations

Constructability walkdowns at WBN had determined that not all trays could be individually wrapped consistent with the test configurations outlined in P-848. Those walkdowns had shown that electrical separations requirements would sometimes dictate the inclusion of a sheet steel top cover underneath the Thermo-Lag 330-1 or the wrapping of solid bottom trays. The same review had shown that the mounding of cables above the siderails could sometimes preclude the encasement of individual trays (necessitating the enclosure of several trays in vertical stack). In some cases, the mounding could be addressed by raising the siderails, though the effect of increasing the thickness of the air space above the cable mass would have to be evaluated. Finally, inadequate space between adjacent trays could necessiate their common enclosure.

As with the non-standard conduit configurations, there is no specific guidance for the performance of such tests in P-848. Thus, TVA identified the major variations and evaluated each to determine if additional tests were required. For those configurations which required additional testing, it was noted that only minor extension of the P-848 logic was necessary. Those issues were addressed by TVA's selection in the following manner, with the results given in Table 16:

Side-by Side - Upon review, it was determined that the results of the TU tray tests could be used to represent the common enclosure of trays which are horizontally adjacent (ie run side-by-side). This arrangement is consistent with the Stolpe model (on which tray ampacities given in ICEA P-54-440 are derived) which considers that heat is dissipated out the top and bottom surfaces only.

Solid Bottom Trays - Though the TU tests were performed on ladder type trays, it was determined that those results could also be used to represent solid bottom trays. This extension is conservative in that true solid bottom trays do not have an air gap between the bottom of the cable mass and the ERFBS barrier as a result of the presence of the tray rungs.

Covered Trays - The test program at OPL addressed the enclosure of ladder type trays over which a sheet steel cover was applied prior to the application of any barrier material. During application of the ERFBS, it had been TVA's objective to ensure that no airgap existed between the upper surface of the cover and the underside of the barrier. This was accomplished by applying trowel grade Thermo-Lag 330-1 to the top of the cover prior to installing the panels. Unfortunately, when the mastic was applied, the thin sheet steel cover sagged and more mastic was required to obtain a level surface so that no gap would exist. This process was repeated until the cumulative thickness greatly exceeded the nominal 5/8-inch. Thus, the excess depth which accumulated during its installation resulted in a

final multiplier of 0.60, well below that which had been predicted.

Vertical Stack - The tests also included a vertical stack consisting of one control and two power trays within a common Thermo-Lag 330-1 ERFBS, with the control tray on the bottom. Though a measured baseline was determined for this multiple tray arrangement, the actual ACF utilized by TVA was based on the more conservative equilibrium current for a single tray[24]. The ACF developed for the stacked triple tray arrangement will also be used for cases where the common enclosure includes two power trays without the control tray. The application of this ACF is conservative since the two tray arrangement affords more direct heat dissipation for the lower power tray than the tested three tray enclosure.

Table 16
Correction Factors - Tray
330/770

Configuration	ACF
Solid Bottom - 1hour	0.68 (note 1)
Sheet steel top cover - 1 hour	0.6
Vertical stack - 1hour	0.59
Side-by-side - 1 hour	0.68 (note 1)
Standard tray - 1 hour upgrade	0.52

Note 1. These values are by analysis, no special test performed.

Raised Siderails - During the course of preparation for the non-standard tray testing, good correlation between the TU results and a mathematical model was noted. Since the model had the ability to address the effects of raised siderails, no special testing was performed. Results of the analysis performed are given below.

Save-Engmann Model

As TVA identified the need to obtain new correction factors for wrapped trays, a survey had been conducted to determine if a proven mathematical model existed which could be used in lieu of more testing.

A literature search revealed that such a model had been proposed by Phil Save and Gary Engmann[27]. Following a review of the other applicable literature for fire protected trays, Save and Engmann suggested that the tray/fire barrier system could be divided into seven regions[28] and modelled using conventional heat transfer principles. Their analysis suggested correction factors ranging from 0.75 to 0.78 for one-hour Thermo-Lag 330-1 systems applied to tray. These values were conservative compared with the vendor's original published numbers (Table 1). However, data published since release of their paper, appeared to indicate that the model was non-conservative. Thus, in the absence of confirmatory tests, TVA's efforts turned back to identification of acceptable test methodologies.

After completion of the TU and TVA tray tests, the knowledge that additional tray configurations were likely to be encountered as the fire barrier installation process progressed at WBN, led TVA to revisit the Save-Engmann analysis. With a cable depth of 2.95-inch, the ACF established by the TU tests can readily be compared to the 3.0-inch computation in the Save-Engmann paper. The inital review, the results of which are given in Table 17, indicated that there was a significant discrepancy between the model and the TU results.

Table 17
Preliminary Comparison of ACFs

	Cable Depth (in)	Tray Depth (in)	ACF
Save-Engmann	3	4	0.78 (note 1)
TU	2.95	4	0.682

Notes: 1. As taken from Table 1 of the referenced paper.

The value of Thermo-Lag 330-1 thermal conductivity used by Save and Engmann may have been the cause of much of this variance. When the paper was prepared, they had obtained a value of thermal conductivity of 0.430 watts/(meter-°C) from TSI. Subsequently, TSI has refined their estimate of this parameter and have identified that it has a fairly strong temperature dependency. Based on the Thermo-Lag 330-1 temperature measured during the testing at OPL, a corresponding conductivity of 0.232 watts/(meter-°C) has been used in the following re-analysis.

The only other modification to the Save-Engmann model necessary for direct comparison to the TU data is the addition of a simple equation to evaluate the effect of the silica blanket. The seven distinct regions of the model were reduced by Save and Engmann to a system of two equations with two unknowns. The two

equations, Nos. 5 and 12 from their paper, have been reproduced below (definitions are given in Appendix 1). The system can be solved iteratively by first guessing a value for the two unknowns, *a* and *s*, the asymmetry of the cable mass and heat intensity, respectively. The new equation determines an effective conductivity, *km3*, of the combined mass (cables and blanket). As before, the system is solved by guessing values for the unknowns and iterating until the system converges. With these changes, and using a baseline value of *s* which corresponds to the actual baseline test current (rather than a nominal value from P-54-440), the model correlates very well with the TU tests (see Table 18).

Table 18
Comparison of Modified Save-Engmann with TU Tests.

	Cable Depth (in)	Tray Depth (in)	ACF
Modified Save-Engmann with silica cloth	2.95	4	0.67 (note 1)
Modified Save-Engmann no silica blanket	2.95	4	0.681 (note 1)
TU test with blanket	2.95	4	0.682

Note 1. Values calculated using the actual TU baseline heat intensity.

Having shown that the model favorably compares with the TU tests, the ACFs shown in Table 1 of the Save-Engmann paper can be recalculated using the modified parameters. For these standard configurations (ie no silica blanket) equation 2 is not required. The results are shown in Table 19.

One difficulty in establishing a workable model for protected raceways has been the P-848 requirement that the baseline used in determination of the ACF be empirically established. Such a requirement works a particular hardship on the development of a consistent model for use with cable trays, given the conservatisms inherent in the Stolpe model[29]. Stolpe assumes no air flow through the cable mass and his original tests included the use of a plastic sheet across the bottom of the tray to block such flow. The use of a measured baseline current as imposed by P-848 results in a loss of repeatibility since the efficiency of cable packing (and thus air flow through the mass) will vary from test to test.

As an example of that conservatism (and thus the potential variability induced by the use of a measured baseline current), the normalized current in the TVA single open top tray test was approximately 11% above the adjusted ICEA current for the same diameter and depth.

Save/Engmann equation (5)

$$s*a=\left[\frac{1.987}{w^{0.25}}*\left(\left(Tw-\frac{s*a^2}{2*km}-\frac{s*a*zb}{kzb}\right)-Ta\right)^{1.25}+sb*eob\left(\left(TKw-\frac{s*a^2}{2*km}-\frac{s*a*zb}{kzb}\right)^4-TKa^4\right)\right]$$

(1)

New equation used to evaluate the effect of the silica blanket.

$$km3=\frac{(tt-a)*km+zc*kc}{tt+zc-a}$$

(2)

Save/Engmann equation (12)

$$s\cdot(t-a)=\frac{1.917}{w^{0.25}}\cdot\left(\left[\left(Tw-Te-\frac{s\cdot(t-a)^2}{2\cdot km}-\frac{s\cdot(t-a)}{\left(\frac{k3}{d-t}\right)+4\cdot sb\cdot\left(\frac{em\cdot eu}{em+eu-0.462\cdot em\cdot eu}\right)\cdot\left(\frac{2\cdot TKw+TKe}{3}\right)^3}\right)-\frac{s\cdot(t-a)\cdot zt}{kzt}\right]^{1.25}\right) \quad (3)$$

Table 19
Save/Engmann Thermo-Lag ACFs[5]

Fill (in)	Height (in.)	TSI Barrier System: 1-hour Save/Engmann[1]	0.625"[2] Modified Analysis	3-hour Save/Engmann[3]	1.25"[2] Modified Analysis	3-hour Upgrade System[4]
1	3	0.75	0.67	0.70	0.58	0.51
	4	0.75	0.67	0.70	0.58	0.51
	5	0.75	0.67	0.70	0.58	0.51
1.5	3	0.76	0.68	0.71	0.59	0.52
	4	0.76	0.68	0.71	0.59	0.52
	5	0.76	0.68	0.71	0.59	0.52
2	3	0.76	0.70	0.71	0.62	0.54
	4	0.76	0.70	0.71	0.61	0.54
	5	0.76	0.69	0.71	0.61	0.54
2.5	3	0.76	0.71	0.72	0.63	0.55
	4	0.76	0.71	0.72	0.63	0.55
	5	0.77	0.70	0.72	0.62	0.55
3.0	4	0.78	0.72	0.73	0.64	0.57

Note 1. These factors are based on the nominal 0.30" thickness of the barrier and original Thermo-Lag conductivity.
Note 2. These factors are conservatively based on the maximum thickness (0.625") of the 1 hour barrier and the revised Thermo-Lag conductivity.
Note 3. These factors are based on the original 3-hour design.
Note 4. These factors are based on the nominal thickness of the 3-hour upgrade system.
Note 5. All entries based on nominal ICEA values of heat intensity.

The benefit of such a model is that cable sizing for a variety of configurations can be evaluated without the time and expense of testing per P-848 once confirmatory tests have been performed. Such alternate configurations might include various upgrade systems, trays with raised Thermo-Lag 330-1 side rails (to clear underlying cables which extend above the rails) and trays with removable sheet metal top or bottom covers under the ERFBS. Each case requires only simple modification of the input parameters.

In the case of an upgrade system, the thickness of the ERFBS, *zb* and *zt*, must be adjusted. Likewise, where raised siderails exist, the parameter *d* must be adjusted. Table 19 shows that such extensions typically result in an additional derating of 1% or less.

Application of a top cover or bottom requires

adjustment of the parameter *eu*, though in the case of the TVA testing, the sagging of the top cover further required the adjustment for barrier thickness.

FUTURE WORK

At this writing TVA is planning one more fire test in late 1995. This test is necessitated by differences found in circa 1985 Thermo-Lag 330-1 installed at SQN and the Thermo-Lag 330-1 materials used in the testing and installations at WBN and BFN. The anomaly was discovered while performing Thermogravimetric Analysis (TGA) and Infrared (IR) Spectroscopy in response to the NRC's request for additional information[19]. The full scale fire test will attempt to demonstrate that the minor difference in the composition of the different vintages of Thermo-Lag 330-1 will not adversely effect the performance of the ERFBS.

A calculation methodology based on the mass and size of electrical raceways (including the cable fill variables) protected with Thermo-Lag materials should be developed. An approach similar to the work performed by the American Iron and Steel Institute for structural steel protection[20] would be very useful to fire protection and electrical engineers involved in the design of Thermo-Lag ERFBS.

SUMMARY

The TVA test program has demonstrated Thermo-Lag materials, when properly designed, tested and installed are capable of providing rated one and three-hour ERFBS.

TVA ampacity test program and results have been reviewed along with a rationale for tests of multiple raceways within a common enclosure. Recent ampacity tests conducted on cables in tray by TU have been analyzed and compared with an existing thermal model. Modifications to that model have been proposed which provide good correlation with the TU results.

ACKNOWLEDGEMENTS

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Special thanks are extended to Gary Engmann of Black and Veatch for his time and patience in the discussion of his work.

APPENDIX 1 - SYMBOLS

Save-Engmann

a	distance from the bottom of the packed cable mass to a plane surface that is at the maximum temperature in the packed cable mass (meters)
s	heat generation per unit volume of packed cable mass (watts/meter^3)
em	emissivity of the packed cable mass surfaces (dimensionless)
eob	emissivity of the outside of the wrap material on the bottom of the tray (dimensionless)
eot	emissivity of the outside of the wrap material on the top of the tray (dimensionless)
eu	emissivity of the inside of the material on top of the tray side rails - tray cover, wrap material, etc. (dimensionless)
ke	thermal conductivity of air [watt/(meter-degree C)]
sb	Stefan-Boltzman constant = 5.705 * 10^{-8} [watt/(meter^2-degree K^4)
t	thickness of the packed cable mass (meter)
Te	temperature of the environment (degrees C)
Tw	temperature of the packed cable mass (degrees C)
km	thermal conductivity of the packed cable mass [watt/(meter-degree C)]
kzb	thermal conductivity of the wrap material on the bottom of the tray [watt/(meter-degree C)]
kzt	thermal conductivity of wrap material on the top of the tray [watt/(meter-degree C)]
d	loading depth of the cable tray (meters)
TKe	temperature of the environment (degrees K)
TKw	temperature of the packed cable mass (degrees K)
zb	thickness of the fire barrier material at the bottom of the tray (meters)
zt	thickness of the fire barrier material at the top of the tray (meters)
w	loading width of the cable tray (meters)
Ra	Rayleigh number (dimensionless)
Nu	Nusselt number (dimensionless)

k3 empirically derived equivalent thermal conductivity in the region between the top of the packed cable mass and the material on the top of the tray side rails - wrap, tray cover, etc. [watt/(meter-degreeC)]

Additional Parameters

kc effective thermal conductivity of the silica cloth [watt/(meter-degree C)]
zc thickness of the silica cloth (meters)
km3 effective thermal conductivity of the upper portion of the packed cable mass considering the effect of the silica cloth [watt/(meter-degree C)]
tt total thickness of the cable mass and silica cloth (meters)

APPENDIX 2 - REFERENCED TESTS

ONE HOUR FIRE TESTS

6.1.1 "Fire Endurance Test of a Thermo-Lag 330-1 Fire Protective Envelope (1-in. and 5-in. conduit configurations and 2-in. air drop configuration)", Omega Point Laboratories Project No. 11210-94554c.

6.1.2 "Fire Endurance Test of a Thermo-Lag 330-1 Fire Protective Envelope (1-in. and 5-in. conduit configurations and 2-in. air drop configuration)", Omega Point Laboratories Project No. 11210-94554a.

6.1.3 "Fire Endurance Test of a Thermo-Lag 330-1 Fire Protective Envelope (3-in., 2-in., 1-in., and 4-in. conduit configurations)", Omega Point Laboratories Project No. 11210-94943a.

6.1.4 "Fire Endurance Test of a Thermo-Lag 330-1 Fire Protective Envelope (3-in. steel, 3-in. aluminum, and 1 1/2-in. steel configurations and generic 2-in. and 4-in. tube steel support members)", Omega Point Laboratories Project No. 11210-94943b.

6.1.5 "Fire Endurance Test of a Thermo-Lag 330-1 Fire Protective Envelope (1-in., 2-in., 3-in., and 5-in. conduit and five junction boxes of varying sizes)", Omega Point Laboratories Project No. 11210-94943d.

6.1.6 "Fire Endurance Test of a Thermo-Lag 330-1 Fire Protective Envelope (large junction box and three 4-in. conduit sections)", Omega Point Laboratories Project No.11210-94943e.

6.1.7 "Fire Endurance Test of a Thermo-Lag 330-1 Fire Protective Envelope (Three 18-in. Cable Trays and a 3-in. conduit)", Omega Point Laboratories Project No. 11960-97185.

6.1.8 "Fire Endurance Test of a Thermo-Lag 330-1 Fire Protective Envelope (Special Tray Fitting With Two 18-in. Cable Tray Sections)", Omega Point Laboratories Project No.11960-97186.

6.1.9 "Fire Endurance Test of a Thermo-Lag 330-1 Fire Protective Envelope (Common Enclosure with Three 18-in. Cable Trays and Covered 18-in. Tray with 1-in. and 5-in. Air Drops)", Omega Point Laboratories Project No. 11960-97187.

6.1.10 "Fire Endurance Test of a Thermo-Lag 330-1 Fire Protective Envelope (Two Sided Multiple Conduit Enclosures and Cable Tray Support System)", Omega Point Laboratories Project No. 11960-97257.

6.1.11 "Fire Endurance Test of a Thermo-Lag 330-1 Fire Protective Envelope (Three Sided Box Enclosure Encasing Groups of Horizontal Conduits and a Large Junction Box)", Omega Point Laboratories Project No. 11960-97258.

6.1.12 "Fire Endurance Test of a Thermo-Lag 330-1 Fire Protective Envelope (Three Four Sided Box Enclosures Encasing Groups of Vertical Conduits and an Enclosure Encasing a 4-in. Conduit and a Junction Box)", Omega Point Laboratories Project No. 11960-97259.

6.1.13 "Fire Endurance Test of a Thermo-Lag 330-1 Fire Protective Envelope (Box Enclosure Encasing a Gang of Seven 4-in. Steel Conduits and Individual Enclosures on 3/4-in Aluminum and Steel Conduits)", Omega Point Laboratories Project No. 11960-97260.

THREE-HOUR FIRE TESTS

6.2.1 "Fire Endurance Test of a Thermo-Lag 330-1 Fire Protective Envelope (12-in. and 24-in. Cable Trays, and a 12-in. x 12-in. x 60-in. Junction Box)", Omega Point Laboratories Project No. 11960-97555.

6.2.2 "Fire Endurance Test of a Thermo-Lag 330-1 Fire Protective Envelope (12-in. and 24-in. Cable Trays, and 5-in., 2-in., and 1-in. Steel Conduits)", Omega Point Laboratories Project No. 11960-97553.

REFERENCES

1. Code of Federal Regulations (CFR), Title 10 Part 50, Appendix R, paragraph III.G.2.

2. A detailed discussion on the mechanics of Thermo-Lag 330-1 can be found in the NRC/NRR Official Transcript of Proceedings "Meeting with Thermal Science, Inc., to Discuss Issues Involving Thermo-Lag 330", dated October 17, 1991. NRC Public Document Room Accession Number 920205305.

3. NRC Information Notice 91-47, "Failure of Thermo-Lag Fire Barrier Material to Pass Fire Endurance Test", August 6, 1991.

4. NRC Information Notice 91-79, "Deficiencies in the Procedure for Installing Thermo-Lag Materials", December 6, 1991. NRC Information Notice 92-46, "Thermo-Lag Fire Barrier Materials Special Review Team Report Findings, Current Fire Endurance Testing, and Ampacity Calculation Errors", June 23, 1992. NRC Information Notice 92-55, "Current Fire Endurance Test Results for Thermo-Lag Fire Barrier Material", July 27, 1992. NRC Information Notice 92-82, "Results of Thermo-Lag 330-1 Combustibility Testing". NRC Information Notice 93-40, "Results of Thermo-Lag 330-1 Combustibility Testing", December 15, 1992.

5. NRC Bulletin No. 92-01, "Failure of Thermo-Lag 330 Fire Barrier Systems to Maintain Cabling in Wide Cable Trays and Small Conduits Free from Fire Damage", June 24, 1992.

6. NRC Bulletin No. 92-01, Supplement 1,"Failure of Thermo-Lag 330 Fire Barrier Systems to Perform its Specified Fire Endurance Function", August 28, 1992.

7. NRC Generic Letter 92-08, "Thermo-Lag 330-1 Fire Barriers", December 17, 1992.

8. UL Subject 1712, "Outline of Investigation for Tests for Ampacity of Insulated Electrical Conductors Installed in Fire Protective Systems", July 1984.

9. IEEE P-848, Draft IEEE Standard entitled, "Procedure for the Determination of the Ampacity Derating of Fire Protected Cables", under preparation by Task Force 12-45 of the Tests and Measurements Subcommittee of the Insulated Conductors Committee of the IEEE.

10. "Thermo-Lag Electrical Raceway Fire Barrier Systems Testing and Qualification", Mark H. Salley and Kent W. Brown, delivered at the February 1993 WATTEC conference in Knoxville, TN.

11. "Ampacity of Wrapped Cables", Keith A. Petty, IEEE paper 86 SM 398-2, IEEE Transactions on Power Delivery, volume 3, number 1, January 1988, pp 35-38.

12. Peters, T. Thriving on Chaos, Harper Collins Publishers, New York, New York, 1987.

13. NRC Request for Additional Information Regarding Generic Letter 92-08, Issued Pursuant to 10CFR50.54(f) dated December 22,1994.

14. NRC Generic Letter 86-10, "Implementation of Fire Protection Requirements", dated April 24, 1986.

15. ASTM E-119-88, "Standard Test Method for Fire Tests of Building Construction and Materials".

16. ANI/MAERP RA Guidelines for Firestop and Wrap Systems of Nuclear Facilities, Article B, Revision 0, 1987

17. Underwriters Laboratory Subject 1724, "Outline of Investigation for Fire Tests for Electrical Circuit Protective Systems", Issue number 2, August 1991.

18. NRC Standard Review Plan, NUREG-0800, Section 9.5.1, "Fire Protection Program".

19. NRC Generic Letter 86-10 Supplement 1 "Fire Endurance Test Acceptance Criteria for Fire Barrier Systems used to Separate Redundant Safe Shutdown Trains within the Same Fire Area" dated March 25, 1994

20. TVA refers to the material as nominal 5/8-inch or 3/8-inch rather than minimum 1/2-inch or 1/4-inch. This is due to TVA QA acceptance requirements. The tolerances used are 5/8-inch ± 1/8-inch and 3/8-inch ± 1/8-inch. Measurements taken during the construction of the test assemblies indicated the material was typically 5/8-inch or 3/8-inch.

21. Covey, S.R. The 7 Habits of Highly Effective People, Simons & Schuster, New York, New York, 1989.

22. The ambient starting temperature of 83°F must be used for the equations to be valid. Figure 2 has been simplified (i.e. the ambient temperature subtracted) to graphically show the allowable temperature rise (i.e. $\Delta T = 250°F$).

23. "The Calculation of the Temperature Rise and Load Capability of Cable Systems", J. H. Neher and M. H. McGrath, AIEE Transactions, volume 76, October 1957, pp 752-773.

24. ICEA P46-426, 1962 edition, entitled, "Power Cable Ampacities". Published by the Insulated Cable Engineers Association.

25. IEEE Standard 835-1994, entitled "Power Ampacity Cable Tables", dated December 1994, section 3.3.5.

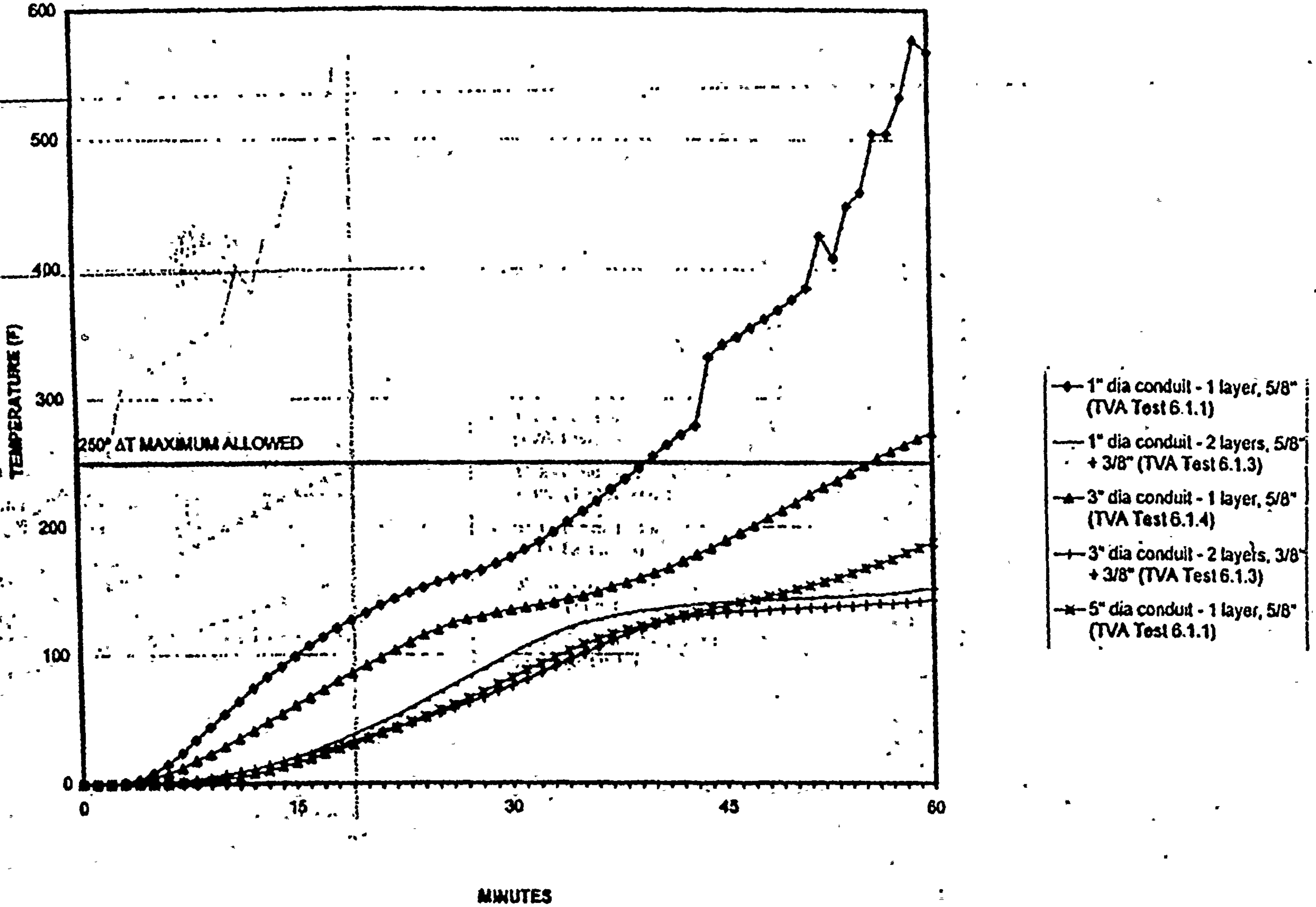
26. For a single open top tray, an equilibrium current of 29.48 amps was determined. With the triple tray vertical stack, an equilibrium current of 26.19 was measured. This 11% difference is the result of a mutual heating effect. This effect is not presently addressed by any standard. It is the author's experience that some companies apply a 5% derate to account for this effect whereas others ignore the influence of other trays in close proximity because of the significant diversity that exists in nuclear station power trays.

27. "Fire Protection Wrapped Cable Tray Ampacity", Phil Save and Gary Engmann, IEEE Transactions on Energy Conversion, volume 4, number 4, December 1989, pp 575-584.

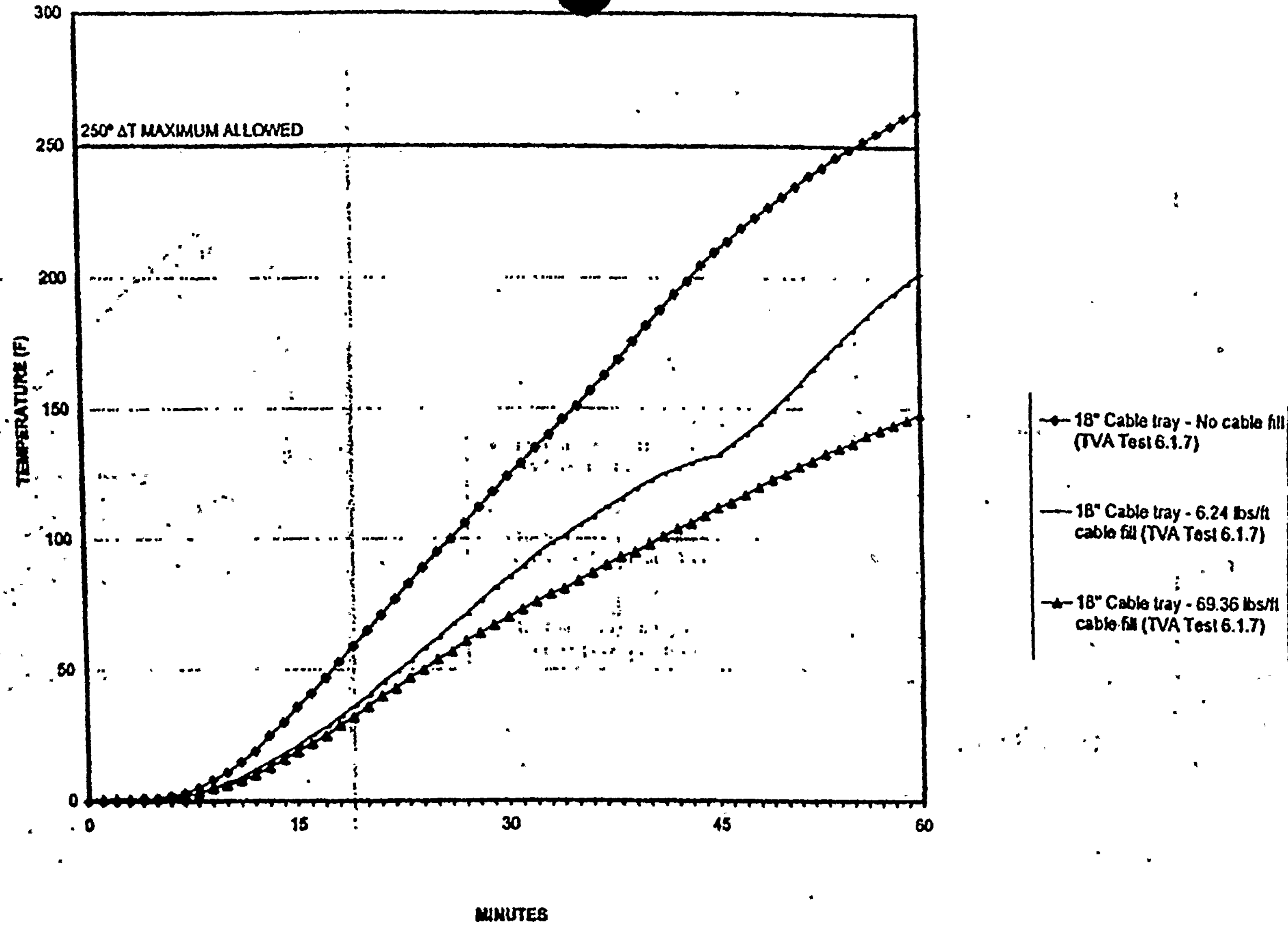
28. The seven regions of the thermal model proposed by Save and Engmann were: 1) The lower portion of the cable mass. 2) The fire wrap below the bottom of the tray. 3) The outside surface of the wrap below the bottom of the tray. 4) The upper portion of the cable mass. 5) The air space between the top of the cable mass and the fire wrap. 6) The fire wrap over the top of the tray. 7) The outside surface of the fire wrap over the top of the tray.

29. "Ampacities for Cables in Randomly Filled Trays", J. Stolpe, IEEE Transactions on Power Apparatus and Systems, Volume 90, Part 1, 1971, pp. 962-974.

30. SFPE Handbook of Fire Protection Engineering, first edition, 1988 National Fire Protection Association, Quincy, Massachusetts 02269, Chapter 3-6.



1-HOUR RATED THERMO-LAG 330-1 CONDUIT ERFBS AVERAGE INTERNAL TEMPERATURE RISE (ΔT) NO CABLE FILL



1-HOUR RATED THERMO-LAG 330-1 CABLE TRAY ERFBS
AVERAGE INTERNAL TEMPERATURE RISE (ΔT)