ENGINEERING REPORT

ON

THE THERMO-LAG 330-1 FIREPROOFING COATING THICKNESSES

REQUIRED FOR

1 AND 2 HOUR FIRE RATINGS FOR VARIOUS STRUCTURAL STEEL MEMBERS USED BY TEXAS UTILITIES SERVICES, INC.

Prepared

for

TSI, INC.

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ATTACHMENT 1 SHT 63/16
CALC NO. 0218-68-0095 R/0

ENGINEERING REPORT

ON

THE THERMO-LAG 330-1 FIREPROOFING COATING THICKNESSES

REQUIRED FOR

1 AND 3 HOUR FIRE RATINGS FOR VARIOUS STRUCTURAL STEEL

MEMBERS USED BY TEXAS UTILITIES SERVICES, INC.

I. INTRODUCTION

The purpose of this report is to present and summarize the calculated Thermo-Lag 330-1 Fireproofing Coating thicknesses for the various structural steel members that are used by Texas Utilities Services, Inc.

The fireproofing coating thicknesses have been calculated for two fire exposure times; a one (1) hour fire exposure and a three (3) hour fire exposure period. As discussed in detail in Section III of this report, the fire exposure is the commonly accepted ASTM - E - 119 Test Method. Using this Test Method, the integrated average Incident Heat Flux for a one (1) hour fire exposure is equal to 24,500 BTU/hr-ft^2, and the three (3) hour Incident Heat Flux is equal to 42,000 BTU/hr-ft^2.

In the Thermo-Lag 330-1 Fireproofing Coating thicknesses presented herein, the following structural steel member sizes and shapes, as well as the noted structural steel temperature limits were considered in the applicable heat transfer analises:

STRUCTURAL MEMBER	MAXIMUM SURFACE TEMPERATURE - °F
Square Structural Tubing	1000
Rectangular Structural Tubing	1000
Angles	1000
Channels	1000
Wide Flanges	1000
Unistrut Sections-All Types	1000

It should be recognized that the thickness of a given structural steel member significantly affects the required fireproofing coating thickness, regardless of the type of fireproofing coating used, for a given incident heat flux and fire exposure period. Hence, the thicknesses required for a Three (3) Hour Fire Rating are substantially greater than those required for a One (1) Hour Fire Rating.

The calculated fireproofing coating thicknesses reported herein are derived from Basic Engineering Data Correlations that we have developed for the Thermo-Lag 330-1 Fireproofing Coating. The experimental data sources include the results of fire testing conducted by the Underwriters' Laboratories, Factory Mutual Research, US Department of Transportation/Federal Railroad Administration, Mobil Oil Corporation, British Gas Corporation, British Petroleum Company, Shell International, and ourselves.

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CALC NO. C218-SD-11095/121

II. FIREPROOFING COATING MATERIAL TEST DATA CORRELATIONS-STRUCTURAL STEEL MEMBERS

The thermal performance characteristics of fireproofing materials such as Thermo-Lag 330-1, Thermo-Lag 290, Chartek 59, Korotherm and Pyrocrete 102 have been found to correlate as:

$$t = \text{A Function of } (T, \Delta T, W, \text{ and } F) \quad (1)$$

where t = fire/flames exposure time, minutes

T = fireproofing material thickness, inches

ΔT = allowable maximum temperature rise of the protected substrate, degrees "F"

W = effective heat capacity of the protected substrate, lbs per square foot of protected surface area

F = total incident heat flux (radiative plus convective), thousands of $BTU/HR\text{-}FT^2$.

Experimental engineering test data expressing the fire/flames exposure time as a function of the fireproofing material coating thickness, the temperature rise of the thermally protected substrate, the weight of the protected substrate and the total incident heat flux have been developed for the Thermo-Lag 330-1 Subliming Compound Fireproofing Material applied to conventional concrete, pre-stressed concrete, flat steel plates, large diameter steel plates, pipes and structural I-Beams and Angles. The range of total incident heat fluxes in these testing programs have varied from a low of 10,000 $BTU/HR\text{-}FT^2$ to a high of 100,000 $BTU/HR\text{-}FT^2$. The Thermo-Lag 330-1 dry film thicknesses have varied from a low of 0.125 inches to a high of 1.250 inches.

In this Engineering Report we are concerned only with the requirements for the fireproofing coating materials that are applied to structural steel members. The fire testing data accumulated on the Thermo-Lag 330-1 fireproofing materials applied to structural I-Beams is presented in Figure 1 in the form of,

$$t = \text{A Function of } (T)\ (\Delta T)\ (W)^{½} / (F). \quad (2)$$

As also shown by Figure 1, the Equation for the prediction of the required fireproofing material thickness applied to structural I-Beams is given as,

$$t = 1.514 \left[(T)\ (\Delta T)\ (W)^{½} / (F)\right]^{1.172} \quad (3)$$

where (W) is expressed in pounds per foot of length of the protected I-Beam.

A similar engineering test data correlation for the Thermo-Lag 330-1 fireproofing material applied to steel flat plates and pipes is presented in Figure 2. The equation for the prediction of the required fireproofing material thickness is given as,

$$t = 23.002 \left[(T)\ (\Delta T)^{0.7}\ (W)^{0.5} / (F)\right]^{1.3356} \quad (4)$$

where (W) is expressed in pounds per sq-ft for the flat plates. As noted on Figure 2,

FIGURE 1: CORRELATION OF THE THERMAL PERFORMANCE CHARACTERISTICS OF THE THERMO-LAG 330-1 FIREPROOFING COATING APPLIED TO STRUCTURAL STEEL COLUMNS

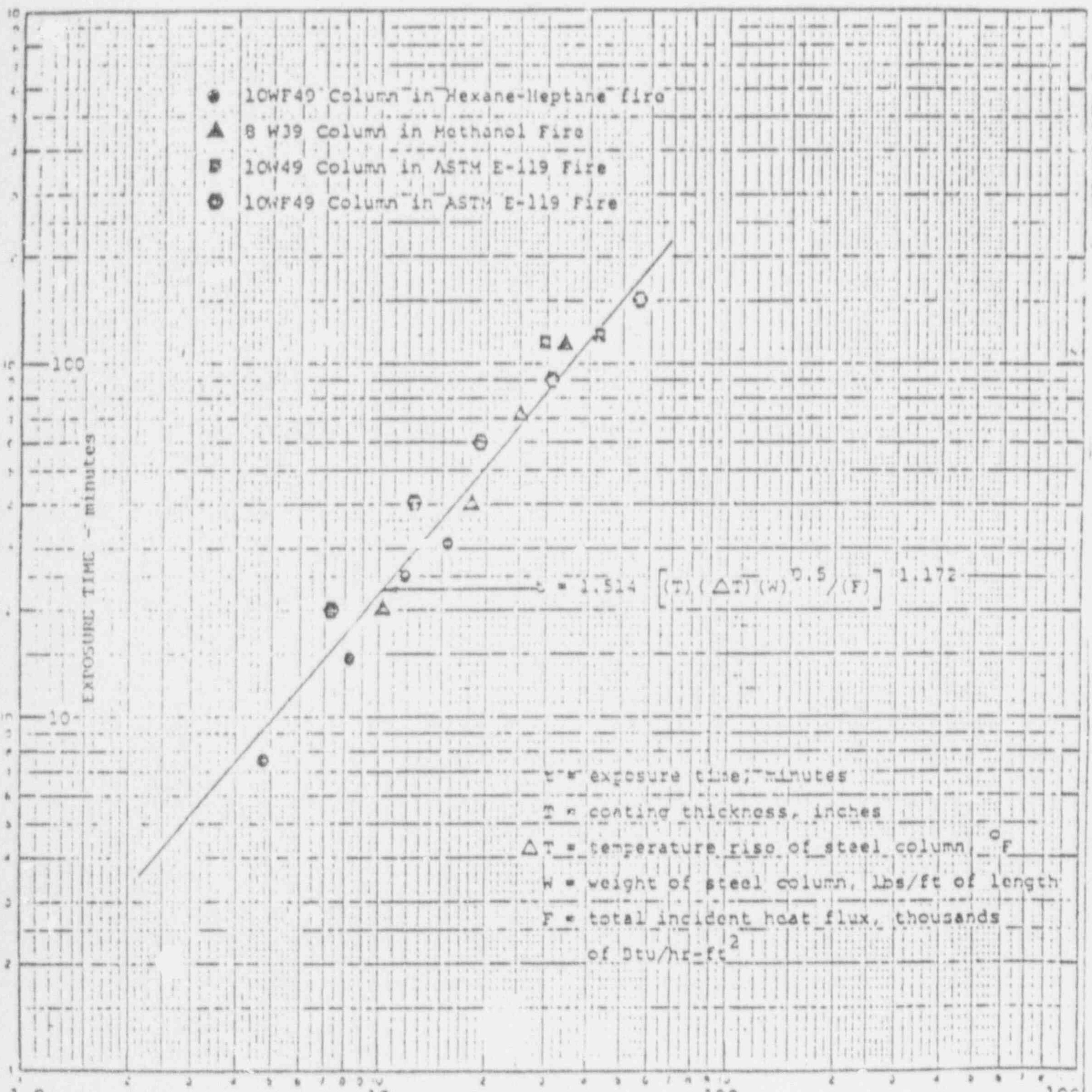

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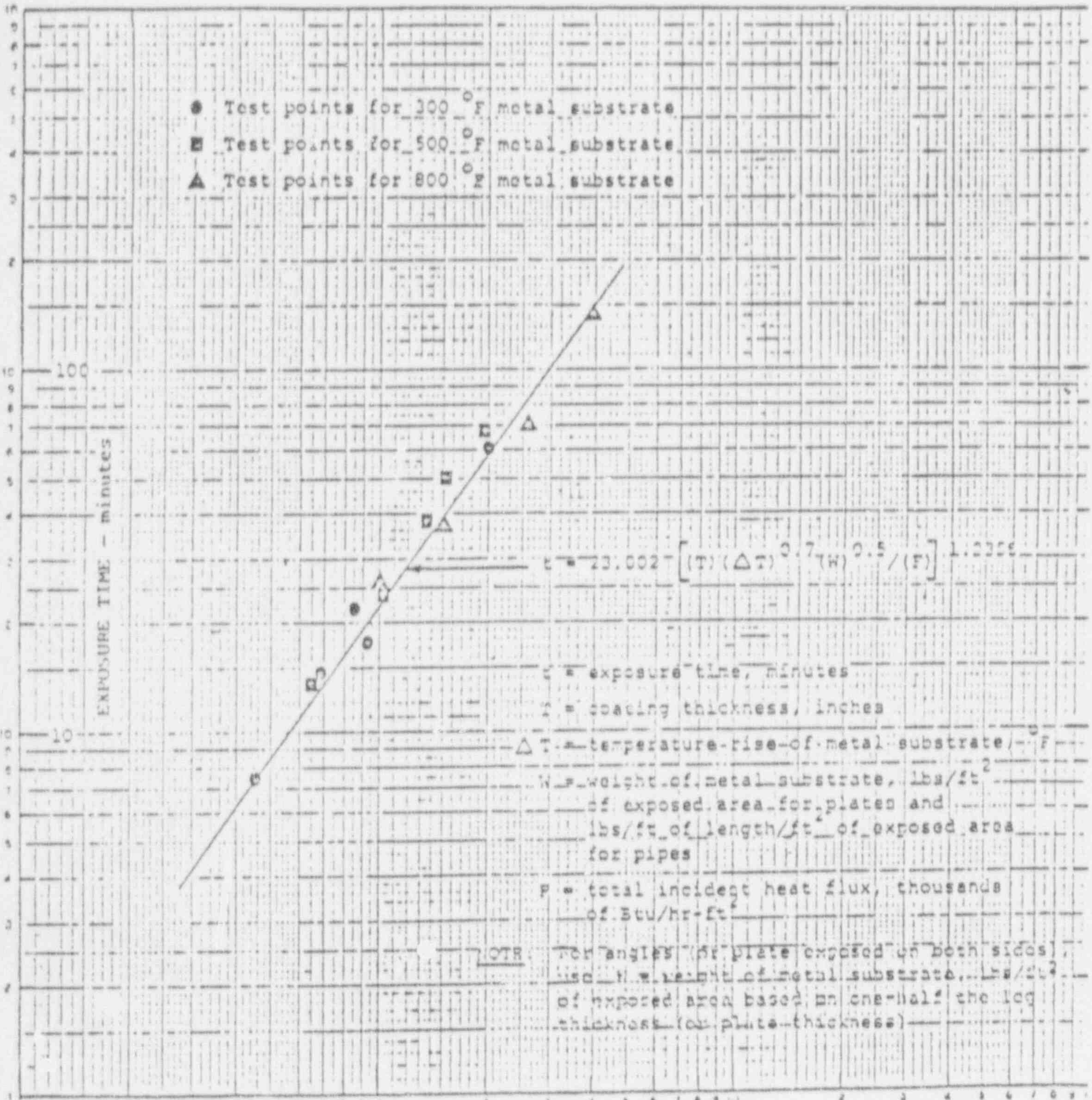
FIGURE 2: CORRELATION OF THE THERMAL PERFORMANCE CHARACTERISTICS OF THE THERMO-LAG 330-1 FIREPROOFING COATING APPLIED TO CARBON STEEL PLATES AND PIPES



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For the fireproofing thickness requirements for various structural steel Channels, Angles, Flat Plates and Unistruts, as currently utilized by the Texas Utilities Services, Inc., that are exposed to heating conditions on 'Both Sides', the factor (W) is expressed in terms of pounds per square foot of surface area using one-half the plate, section thickness, or angle thickness for calculation of the member weight per squate foot per linear foot of length.

The report reader is cautioned that the Thermo-Lag 330-1 fireproofing coating thicknesses reported herein are probably the 'minimum' fireproofing coating thicknesses that are available from the 'passive thermal coatings' which have been commercially approved. Hence, if the coating thicknesses reported herein are used, they 'will not' be applicable to other types of fireproofing coating materials. If other materials are considered, the required thickness could vary from moderate increases over the thicknesses presented herein to very large thickness increases, depending upon the specific material being considered.

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III. DETERMINATION OF THE REQUIRED FIREPROOFING COATING THICKNESS AS A FUNCTION OF THE FIRE EXPOSURE TIME PERIOD

As discussed in the INTRODUCTION to this report, both the ASTM - E - 119 Test Method and the total incident heat fluxes resulting from actual flammable liquid spill fires are widely used for the determination of the required fireproofing coating thicknesses for various structural steel members. Each of these two methods are discussed separately below.

A. ASTM - E - 119 Test Method

NOTE: For ease of reference, Appendix (E) presents a copy of the ASTM - E - 119 Test Method.

The ASTM - E - 119 Test Method utilizes a specific Time-Temperature Relationship for testing of the fire resistive capabilities of the various fireproofing coating materials. This Time-Temperature Relationship is presented in Figure 3. As shown, the Test Set-up Internal Air Temperature starts at the prevailing ambient air temperature, reaches a temperature of 1700 °F at the end of the first hour of exposure, a temperature of 1850 °F at the end of the second hour of exposure and a temperature of about 1950 °F at the end of the third hour of exposure. As such, this Time-Temperature History DOES NOT fairly represent the Time-Temperature Relationship for a typical flammable liquid hydrocarbon spill fire wherein the temperature within the flames zone may very quickly (within a few SECONDS) reach a value of 2200 °F or more depending on the specific fuel. Thus, as such the ASTM - E - 119 Test Method does not provide a uniform target incident heat flux, as would a typical hydrocarbon spill fire. For this reason, many Insurance Underwriters' require a long term (up to three hours) Fire Rating when applying the ASTM - E - 119 Test Method to hydrocarbon Processing Facilities.

However, using accepted engineering practices, the Figure 1 Time-Temperature Relationship can be converted to a Heat Flux-Time Relationship. Such a relationship for the ASTM - E - 119 Test Method is presented in Figure 4. As shown, the Time Averaged Heat Flux for the first hour of exposure is equal to 24,500 BTU/HR-FT^2, the Time Averaged Incident Heat Flux for the first two hours of fire exposure is equal to 34,500 BTU/HR-FT^2 and the Time Averaged Total Incident Heat Flux for the first three hours of fire exposure is equal to about 42,000 BTU/HR-FT^2. Using this basis of Time Averaged Incident Heat Flux, the fire resistive capabilities of a given fireproofing material to an equivalent hydrocarbon spill fire can be obtained

B. Hydrocarbon Pool Fire Total Heat Fluxes:

It MUST be emphasized that all hydrocarbon liquid spill fires DO NOT liberate the same total heating effects. As shown by Table I, different liquid hydrocarbon spill fires have very different heating effects. For example, a spill fire involving Methanol will only yield a total incident heat flux of about 12,000 BTU/HR-FT^2, while a spill fire involving LPG could yield up to 40,000 BTU/HR-FT^2 for large diameter spill fires (fire diameters in excess of 10 meters).

Since the Total Heat Flux, "F" appears as a linear term in Equations (3) and (4), it is very important to know the type of flammable liquid hydrocarbon spill fire for the determination of the required fireproofing material thickness.

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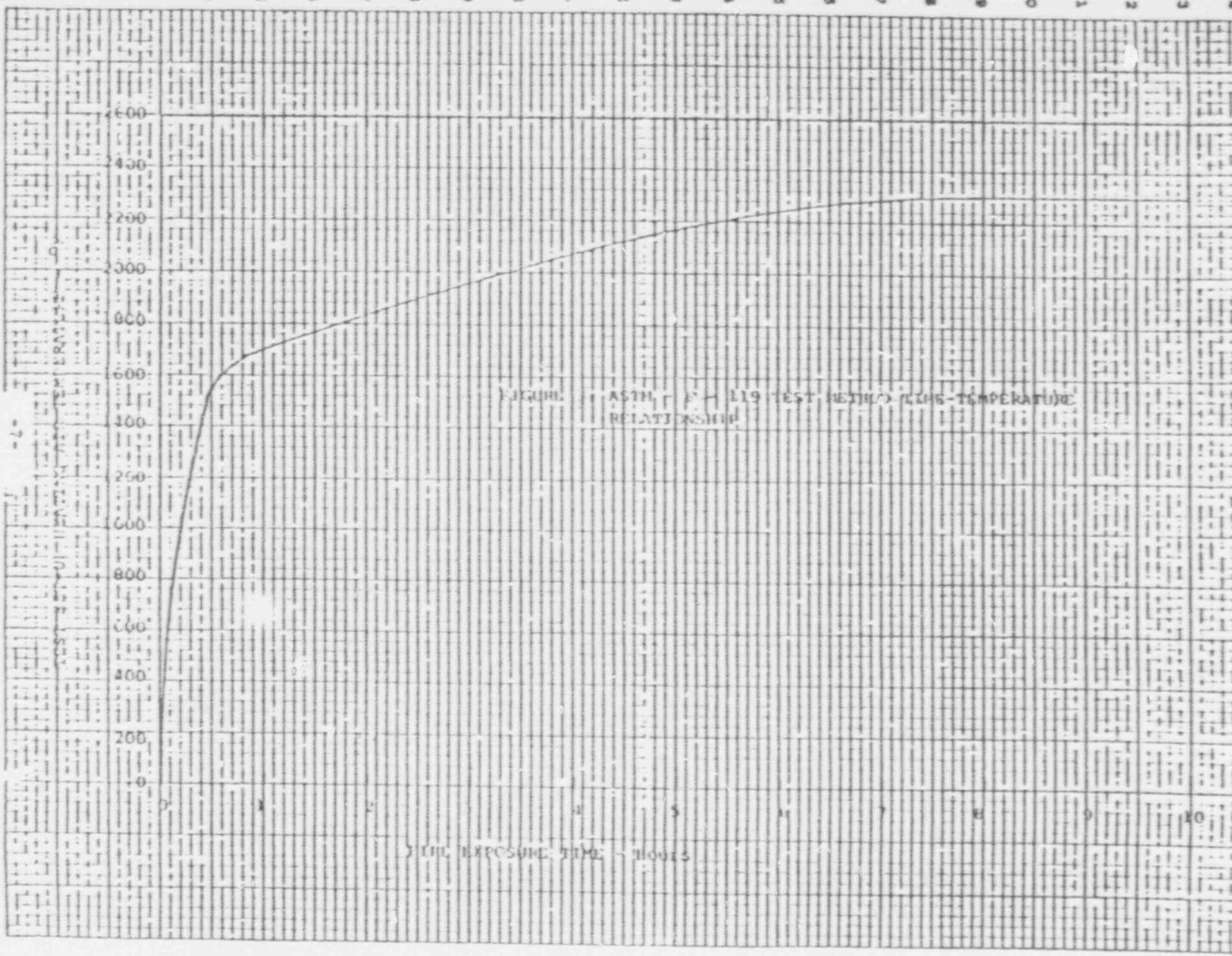

FIGURE 1 ASTM E-119 TEST METHOD TIME-TEMPERATURE RELATIONSHIP

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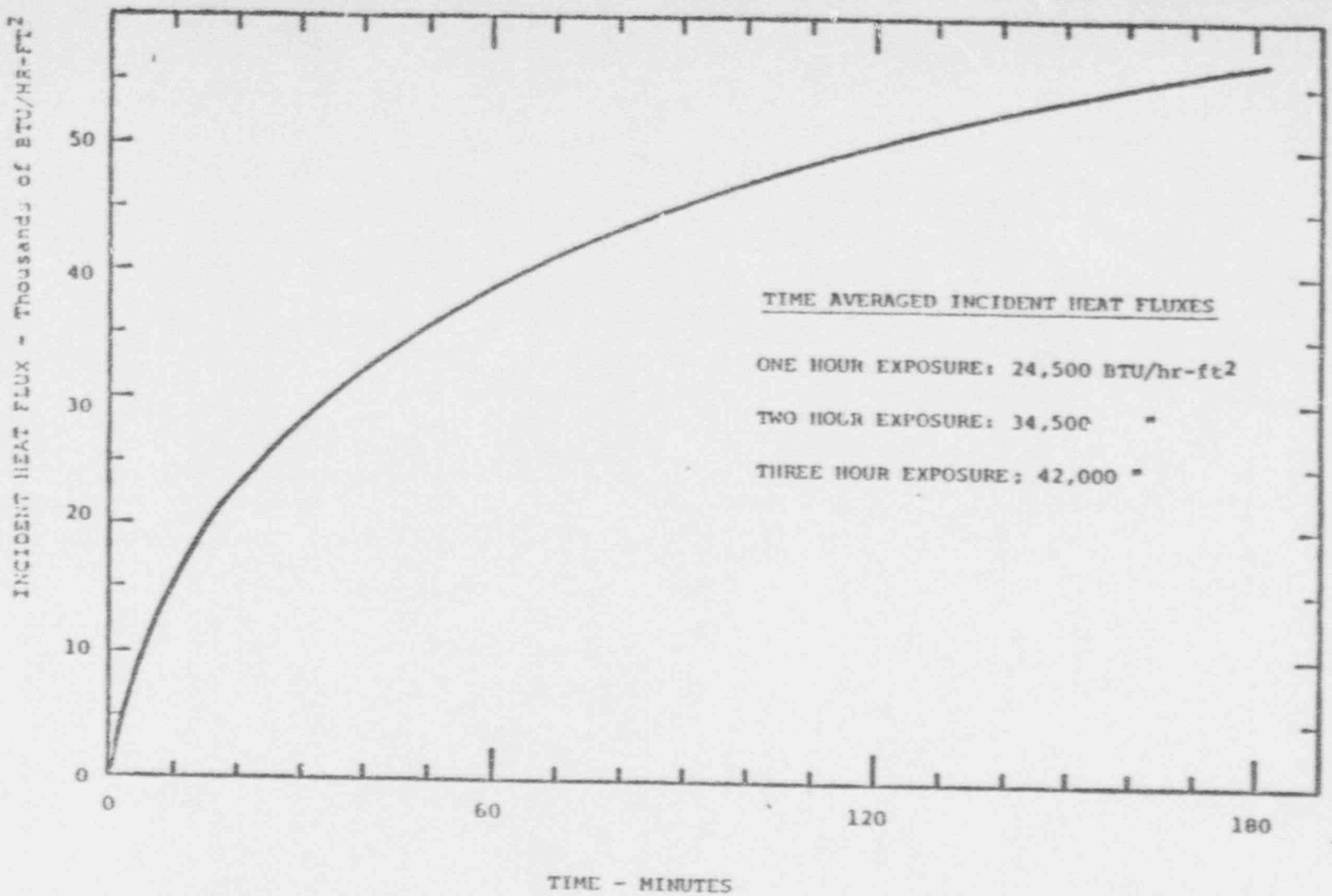

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C. Incident Heat Fluxes For Texas Utilities Services, Inc.:

In accordance with the directions from TSI, Inc., we have used the following Incident Heat Fluxes for the fireproofing coating thickness requirements as reported herein:

.. One (1) Hour Fire Rating: The One (1) Hour Fire Rating has been based upon the Incident Heat Flux Level associated with a one (1) hour exposure to the ASTM-E-119 Test Method, as shown by Figure 1. As shown, the integrated incident heat flux for one (1) hour's exposure to the ASTM-E-119 Test Method equates to 24,500 BTU/hr-ft^2.

.. Three (3) Hour Fire Rating: The Three (3) Hour Fire Rating has also been based upon the Incident Heat Flux Level associated with a three (3) hour exposure to the ASTM-E-119 Test Method, as also shown in Figure 1. As shown, the integrated incident heat flux for three (3) hour's exposure to the ASTM-E-119 Test Method equates to 42,000 BTU/hr-ft^2.

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CALC NO 0210-CS-0296

IV. STRUCTURAL STEEL MEMBER REQUIRED FIREPROOFING COATING THICKNESSES

A complete listing of the calculated Thermo-Lag 330-1 fireproofing coating thicknesses for each of the structural steel members as specified in the letter from Texas Utilities Services, Inc. to TSI, Inc., dated 9 July 1981, is presented in Appendix (A) to this report.

One (1) and Three (3) Hour Fire Rating thicknesses for Square Structural Tubing, Rectangular Structural Tubing, Angles, Channels, Wide Flange Beams and a wide variety of Unistruts are presented. The physical properties for the Unistrut Members was taken directly from "UNISTRUT, General Engineering Catalog No. 9" forwarded to TSI, Inc. by Texas Utilities Services, Inc., and reforwarded to us by TSI, Inc.

It should be emphasized that the Appendix (A) calculated Thermo-Lag 330-1 fireproofing coating material thicknesses do NOT include a 10 percent aging and weathering allowance in accordance with the long term Environmental Test Programs conducted by Underwriters' Laboratories, U.S. Army Ballistics Research Laboratories and commercial users in the Hydrocarbon (Oil and Gas) Processing Industries. To provide aging and weather allowance, coating thicknesses of Appendix (A) should be increased by 10 percent.

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ATTACHMENT 4 SHT 6.13/16
CALC NO 2215-SB-0295 R/0

APPENDIX (A)

CALCULATED THERMO-LAG 330-1 FIREPROOFING COATING THICKNESSES FOR TSI/TUSI STRUCTURAL STEEL MEMBERS

1 Hr. & 3 Hr. ASTM 119 Fireratings for Structural Steel

1 Hr. exposure: $F = 24{,}500\ \mathrm{Btu/hrft^2}$ (time-averaged)
3 Hr. exposure: $F = 42{,}000\ \mathrm{Btu/hrft^2}$ (time-averaged)

APPLICABLE CORRELATIONS FOR COATING THICKNESS:

1. Structural Beams:

$$T = \frac{F}{(\Delta T)(W)^{0.5}} \left[\frac{t}{1.514}\right]^{1/1.72}$$

2. Pipe, Tubing, Plate:

$$T = \frac{F}{(\Delta T)^{0.7}(W)^{0.5}} \left[\frac{t}{23.002}\right]^{1/1.3356}$$

I. SQUARE STRUCTURAL TUBING: $\Delta T = 1000 - 70 = 930°F$

Size	lb/ft	ft^2/ft	W(lb/ft)	Coating thickness (in.) 1-hour	3-hour
2x2x3/16	4.31	0.66	6.47	0.165	0.642
x1/4	5.40	0.66	8.10	0.147	0.574
3x3x3/16	6.86	1.00	6.86	0.160	0.623
x1/4	8.80	1.00	8.80	0.141	0.551
4x4x3/16	9.31	1.33	6.98	0.158	0.618
x1/4	12.02	1.33	9.02	0.139	0.544
x3/8	16.84	1.33	12.63	0.117	0.460
6x6x1/4	18.82	2.00	9.41	0.136	0.533
x5/16	23.02	2.00	11.51	0.123	0.481
x3/8	27.04	2.00	13.52	0.114	0.445
8x8x3/8	36.83	2.66	13.81	0.113	0.440
x1/2	47.35	2.66	17.76	0.100	0.388
10x10x1/2	60.95	3.33	18.29	0.098	0.382
x5/8	79.26	3.33	23.78	0.086	0.335

II. RECTANGULAR STRUCTURAL TUBING: $\Delta T = 1000 - 70 = 930°F$

Size	lb/ft	ft^2/ft	W(lb/ft)	Coating thickness (in.) 1-hour	3-hour
8x4x5/16	23.02	2.00	11.51	0.123	0.482
x3/8	27.04	2.00	13.52	0.114	0.444
6x4x3/8	21.94	1.66	13.16	0.115	0.450
x1/2	27.68	1.66	16.61	0.103	0.400

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III. ANGLES: $\Delta T = 1000 - 70 = 930°F$

Note: exposure to both surfaces assumed

Size	pl thk (in.) (50% leg)	W(lb/ft^2)	Coating thickness (in.) ΔT = 930°F 1-hour	3-hour
3x3x3/8	3/16	7.65	0.151	0.590
3½x3½x3/8	3/16	7.65	0.151	0.590
x1/2	1/4	10.20	0.131	0.511
4x4x3/8	3/16	7.65	0.151	0.590
x1/2	1/4	10.20	0.131	0.511
5x5x3/4	3/8	15.30	0.107	0.417
x 1	1/2	20.40	0.092	0.361
6x6x3/4	3/8	15.30	0.131	0.417
x 1	1/2	20.40	0.092	0.361
8x6x1/2	1/4	10.20	0.131	0.511
x 1	1/2	20.40	0.092	0.361
6x4x3/8	3/16	7.65	0.151	0.590
x1/2	1/4	10.20	0.131	0.511
x 1	1/2	20.40	0.092	0.361

IV. CHANNELS

Size	web thk (in.)	W(lb/ft^2) (50% web thk)	Coating thickness (in.) ΔT = 930°F 1-hour	3-hour
MC 3x7.1	0.321	6.548	0.164	0.638
C 3x4.1	0.170	3.468	225	0.817
C 4x5.4	0.180	3.672	218	0.852
x7.25	0.320	6.528	0.164	0.639
C 6x8.2	0.200	4.080	0.207	0.808
x10.5	0.314	6.406	0.165	0.646
C 8x11.5	0.220	4.488	0.197	0.771
C10x15.3	0.240	4.896	0.[illegible]	0.738

V. WIDE FLANGES: $\Delta T = 1000 - 70 = 930°F$

Size	W(lb/ft)	Coating thickness (in.) 1-hour	3-hour
W 4x13	13	0.169	0.739
W 5x16	16	0.152	0.666
x18.5	18.5	0.141	0.619
W 6x8.5	8.5	0.209	0.913
x15.5	15.5	0.155	0.676
W 8x10	10	0.192	0.842
x13	13	0.169	0.739
x15	15	0.157	0.688
x24	24	0.124	0.544
x28	28	0.115	0.503
W 10x11.5	11.5	0.179	0.785
x15	15	0.157	0.688
x29	29	0.113	0.495

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VI. UNISTRUT SECTION: $\Delta T = 1000 - 70 = 930°F$

Size	pl thk	$W(lb/ft^2)$ (50% pl thk)	Coating thickness (in.) $\Delta T = 930°F$ 1-hour	3-hour
P 1000	0.105	0.288	0.283	1.104
1001	0.105	0.288	0.283	1.104
1001 C3	0.105	0.288	0.283	1.104
1004 A	0.105	0.288	0.283	1.104
P 3000	0.105	0.288	0.283	1.104
3001	0.105	0.288	0.283	1.104
P 5000	0.105	0.288	0.283	1.104
5001	0.105	0.288	0.283	1.104