ENTERGY

CALCULATION TITLE PAGE
ENGINEERING DEPARTMENT

1. GSU CALCULATION NUMBER: G13.18.14.0-178, Rev. 0

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2. CALCULATION TITLE: Ampacity Derating Factors for Thermo-Lag 330-1 Enclosures

3. SUPERSEDES:

4. OBJECTIVE OF CALCULATION: To establish the Ampacity Derating Factors (ADF) for Thermo-Lag 330-1 enclosures at River Bend Station

5. CALCULATION METHOD / ASSUMPTIONS: See Sections 2.0 and 3.0

6. SOURCES OF DATA/EQUATIONS (REFERENCES): See Section 6.0.

7. CONCLUSIONS: See Section 5.0.

8. REASON FOR REVISION (IF APPLICABLE):

9. RELATED DOCUMENTS:
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2.
3.

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1.0 PURPOSE

The purpose of this calculation is to establish the Ampacity Derating Factors (ADF) for Thermo-Lag (T-L) 330-1 enclosures at RBS. The enclosures considered are described below.

1.1 *Standard Tested Configurations*
RBS T-L tray configurations (one-hour single tray and one hour two tray stack enclosures) that are similar to configurations previously analyzed/tested by the industry for which ADFs were determined. These configurations are established as applicable to "Standard Tested Configurations" at RBS by this analysis.

1.2 *Standard Untested Configurations*
These configurations consist of two categories: RBS T-L aluminum conduit enclosures (one-hour and three-hour single conduit enclosures) and RBS T-L three-hour single tray enclosures. Configurations similar to these have been tested/analyzed by the industry. However, the results are not directly applicable to the RBS T-L configurations due to the differences in conduit material or the T-L thickness. Therefore, the ADF factors for these "Standard Untested Configurations" are established by heat transfer analysis in this calculation.

1.3 *Unique Configurations*
RBS T-L configurations for which there are no industry tested/analyzed configurations that match the RBS configurations. ADF factors for these "Unique" configurations are established by heat transfer analysis in this calculation. The unique configurations consist of multiple raceways enclosed in a common enclosures with the exception of one-hour two tray stack which is included with the "Standard Tested Configurations" discussed in paragraph 1.1 above.

2.0 METHODOLOGY AND ASSUMPTIONS

2.1 *Definitions*

The definitions given below are taken from Reference 1, Section A.2.

Ampacity, Baseline ($I_{baseline}$): The ampacity of a cable in an unwrapped raceway. $I_{baseline}$ equals the nominal ampacity, I_{nom}, times all applicable correction factors such as conductor and ambient temperature, conduit grouping, number of conductors in conduit, tray covers, etc.

Ampacity, Nominal (I_{nom}): The ampacity of a cable based on the construction of the cable (i.e., conductor size, insulation, diameter, etc.) as given in the applicable standards such as References 2 and 3.

Ampacity, Protected ($I_{protected}$): The ampacity of a cable for the raceway configuration while protected by the fire barrier.

Ampacity Derating Factor (*ADF*): The percentage reduction in measured ampacity between the unprotected configuration (baseline ampacity) and protected configuration. ADF values are calculated from:

$$ADF = \frac{I_{baseline} - I_{protected}}{I_{baseline}} x100 \qquad (1)$$

2.2 *Methodology*

The ampacity derating factors are determined by performing heat transfer analysis for the enclosures. The essential criteria is that the heat generated within the cables must be dissipated to the surrounding medium without causing the cable conductor/insulation temperature to exceed a specified temperature limit. The heat transfer relations are taken from basic heat transfer texts such as References 6, 7, 10, and 16

2.3 *Assumptions*

The calculation is based on the assumptions stated below.

2.3.1. The ampacity derating factors are for a cable with a 90°C (194°F) insulation rating in an ambient temperature of 40°C (104°F). For temperatures other than these an additional factor (Conductor and Ambient Temperature Correction Factor), as defined in Reference 1 (Section A.4.1), must be applied. This approach is consistent with accepted industry practices such as those described in References 2 (paragraph 310-15), and Reference 3 (paragraph B).

2.3.2. Thermo-Lag thickness is at the upper fabrication tolerance specified by the manufacturer. This is a conservative assumption since it increases the thermal resistance of the enclosure and results in lower ampacity.

2.3.3. Where pre-shaped half-rounds are used to wrap the individual conduits, there is an air gap (approximately 1/8 inch wide per Reference 4) between the conduit and the Thermo-Lag panel. This assumption is conservative since it results in higher thermal resistance (than a solid contact case) and lowers the ampacity.

2.3.4. The ampacity derating factors are based on a model cable fill (1KV, size 8, three conductor copper cable with rubber insulation). This approach simplifies the calculations as well as the subsequent application of the results to actual cables. The approach is justified for the following reasons:

- The calculation determines the ampacity derating factor (which reflects the percent change in the ampacity from a baseline case); it does not determine the actual ampacities for individual cables. Individual cable ampacities are determined by applying the ampacity derating factors determined here to the corresponding baseline ampacities which account for the size and the type of the cable.

- For a given raceway the governing parameter for the ampacity is the heat generation rate within the raceway. Thus, the ampacity derating factor is a measure of the reduction in the heat generation rate due to the presence of the enclosure. Since this heat generation rate is independent of the size of the cable, a model cable can be used to represent an assortment of cables.

2.3.5. Heat transfer from the sides of the tray is ignored. This assumption is conservative since it reduces the ampacity by restricting the heat transfer rate This is also consistent with the method described in Reference 5 (page 964).

2.3.6. The walls of the enclosure are assumed to be at a uniform temperature. This is a restrictive assumption for large enclosures with multiple raceways since variations in the wall temperature might exist due to localized radiation/convection effects. There are two configurations at RBS that are large enclosures; Configurations U1 shown in Figure 5.1, and Configuration U2 shown in Figure 5.2. These configurations also have large concrete walls that form part of the enclosure. Heat loss through the concrete walls are neglected per paragraph 2.3. 9 below. Therefore, any nonconservatism that might have been introduced by the uniform temperature assumption is expected to be offset by not counting the heat transfer through the concrete walls.

2.3.7. Natural convection heat transfer coefficient is calculated by assuming laminar heat transfer regime, and by choosing the width as the basis for the characteristic length. This approach reduces the calculated ampacity by reducing the convective heat transfer rate.

2.3.8. Enclosure cross section is assumed to be uniform. Where cross section varies along the enclosure, calculations are performed at a representative minimum cross sectional area. This is a conservative assumption since the ampacity decreases with decreasing area.

2.3.9 Heat transfer through concrete walls that may form part of the enclosure is not counted. This is a conservative assumption since reduced heat transfer rate reduces the ampacity.

2.3.10. For cable trays that are filled to less than one inch depth, it is assumed that the depth is one inch. This is conservative since ampacity decreases with increasing depth.

2.3.11. Raceways carrying power cables are assumed to be above the raceways carrying control and/or instrument cables. This is a common industry practice.

3.0 THEORY AND EQUATIONS

A typical enclosure that is considered in this calculation is illustrated in Figure 3.1. The enclosure is constructed from Thermo-Lag panels and encloses one or more cable trays, conduits, or combinations of them. The heat generated within each raceway (cable tray or conduit) is conducted away through the cable bed. The total heat generated by all of the raceways is dissipated into the surrounding first by radiative and convective heat transfer through the enclosure gap, then by conduction through the enclosure wall, and finally by radiation and convection from the surface of the enclosure into the surrounding area. In case of single conduits enclosed by pre-formed half round Thermo-Lag sections, there may be a small gap between the conduit wall and the Thermo-Lag material. The heat transfer model described here accounts for this gap also. The applicable equations for each stage of the heat transfer are described below. The heat generation rates and heat transfer rates are for a unit lengths (i.e., per foot) of the raceway.

3.1 Heat Generation

Heat is generated within each raceway according to:

$$q_r = 3.413[n_{cable} n_{con} I^2 R] \qquad (2)$$

where

q_r	heat generation rate per unit length of the raceway, Btu/h-ft
I	conductor current, Amperes
R	conductor resistance (ac) per unit length, ohm/ft
n_{con}	number of conductors per cable
n_{cable}	number of cables in the raceway

and

cable	subscript for cable
con	subscript for conductor
r	subscript for raceway

Equation 2 above is an extension of equation 2 of Reference 5 for a single conductor, to a raceway containing multiple cables with multiple conductors. The constant *3.413* is the conversion factor from watts to Btu/h (*h* is used to designate "hour" throughout this calculation).

The number of cables within the raceway is calculated from equation 3 below. The equation for cable trays is derived from the equation in section A.2 of Reference 1. The equation for conduits is based on the ratio of the actual cross sectional area occupied by the cables to the inside cross sectional area of the conduit.

$$n_{cable} = \frac{w_t d_t}{d^2_{cable}} \quad \textit{for cable trays}$$

$$n_{cable} = \left[\frac{d_{conduit} - 2t_{conduit}}{d_{cable}}\right]^2 \frac{percent\ fill}{100} \quad \textit{for conduits} \qquad (3)$$

where

w_t	width of the tray, ft
d_t	depth of cable fill of the tray, ft
d_{cable}	diameter of the cable, ft
$d_{conduit}$	outside diameter of the conduit, ft
$t_{conduit}$	conduit wall thickness, ft
t	subscript for "tray"
conduit	subscript for "conduit"

3.2 *Heat Transfer Through The Cable Bed*

The heat q_r generated within each raceway is conducted through the cable bed to the surface of the raceway. The equations describing the heat transfer can be derived by assuming uniform heat generation within the raceway. Cable trays are treated as long slabs of width w_t and thickness d_t. Conduits are treated as long cylinders with diameter $d_{conduit}$. This approach is conservative since it ignores the axial heat transfer along the trays or the conduits, and the lateral heat transfer toward the sides of the trays. The applicable equations are taken from Reference 7 (page 18).

$$q_r = [\frac{4k_{bed}}{d_t}]\ (2w_t)(T_n - T_r) = U_t(2w_t)(T_n - T_r) \quad \textit{for cable trays}$$

$$q_r = [\frac{4k_{bed}}{d_{conduit}}]\ (\pi d_{conduit})(T_n - T_r) = U_{conduit}(\pi d_{conduit})(T_n - T_r) \quad \textit{for conduits} \qquad (4)$$

where

k_{bed}	equivalent thermal conductivity of the cable bed, Btu/h-ft-°F
T_n	conductor temperature, °F
T_r	surface temperature of the raceway, °F

U overall heat transfer coefficient defined by the expression inside the bracket, Btu/h-ft^2-°F (the symbol *R* shown in Figure 3.1 represents the thermal resistance and which is the inverse of U)

The overall heat transfer coefficient U_t for cable trays is calculated directly using the appropriate expression in equation 4. The overall heat transfer coefficient for conduits $U_{conduit}$ is back calculated from the baseline ampacity data. This is done by calculating q_r from equation 2 and substituting the calculated value into equation 4 with the appropriate temperature terms and the conduit diameter.

3.3 *Heat Transfer from the Surface of the Raceway to The Enclosure*

The heat generated within the cable bed and arriving at the surface of the raceway is transferred to the enclosure by convection and radiation according to [Ref. 16, p.203]:

$$q_r = (h_c + h_{rad}) A_r (T_r - T_{b-in}) \tag{5}$$

where

h_c convective heat transfer coefficient, Btu/h-ft^2-°F
h_{rad} radiative heat transfer coefficient, Btu/h-ft^2-°F
A_r heat transfer area (per unit length) of the raceway, ft^2/ft
T_{b-in} inside surface temperature of the enclosure, °F
T_r surface temperature of the raceway, °F

The heat transfer area is calculated from

$$\begin{aligned} A &= 2w_t \quad \textit{for cable trays} \\ A &= \pi d_{conduit} \quad \textit{for conduits} \end{aligned} \tag{6}$$

The radiative heat transfer coefficient h_{rad} between two surfaces (surface 1 and surface 2) is determined using its general definition. Since $q = hA(T_1 - T_2)$ an equivalent radiative heat transfer coefficient can be defined as $h_{rad} = q_{rad}/A(T_1 - T_2)$ where the net radiative heat transfer q_{rad}, is given by [Ref. 16, p.203],

$$q_{rad} = \frac{\sigma[(T_1 + 460)^4 - (T_2 + 460)^4])}{\dfrac{1-\varepsilon_1}{\varepsilon_1 A_1} + \dfrac{1}{F_{12} A_1} + \dfrac{1-\varepsilon_2}{\varepsilon_2 A_2}} \tag{7}$$

Expanding the expression inside the bracket and combining with the definition for h_{rad}

$$h_{rad} = \frac{\sigma[(T_1+460)^2+(T_2+460)^2][(T_1+460)+(T_2+460)]}{\frac{1-\varepsilon_1}{\varepsilon_1}+\frac{1}{F_{12}}+\frac{1-\varepsilon_2}{\varepsilon_2}\frac{A_1}{A_2}} \tag{8}$$

where

h_{rad}	radiative heat transfer coefficient, Btu/h-ft^2-°F
ε	emissivity of the surface, dimensionless
σ	Stephan Boltzmann constant (0.1714x10^{-8} Btu/h-ft^2-°R, Ref. 16, p: 174)
A	surface area participating in radiative heat transfer, ft^2
F_{12}	shape factor, dimensionless

The equation above is applied to the radiative heat exchange between the raceway and the enclosure by assigning the subscripts as

1	subscript for the raceway
2	subscript for the enclosure inside surface

The convective heat transfer coefficient h_c is based on laminar heat transfer regime and has the following general form

$$h_c = \frac{a}{L^n}(\Delta T)^n \tag{9}$$

where L is the characteristic length, ΔT is the temperature difference, and a and n are appropriate constants as defined in Reference 6 (page 315). In this calculation the parameters a and n are chosen to produce a low (i.e., conservative) heat transfer coefficient as:

$a=0.20$
$n=1/4$

These values are consistent with the recommended values in Reference 8 (Appendix B).

The convective heat transfer is from the raceway to the air in the enclosure and then from the air to the inner surface of the enclosure. Therefore

$$q_c = A_r h_{c-re}(T_r - T_e) = A_b h_{c-eb}(T_e - T_{b-in}) = A_r h_{c-rb}(T_r - T_{b-in}) \qquad (10)$$

where

h_{c-rb}	overall convective heat transfer coefficient from the raceway to the enclosure wall, Btu/h-ft^2-°F.
h_{c-re}	convective heat transfer coefficient from the raceway to the air inside the enclosure, Btu/h-ft^2-°F.
h_{c-eb}	convective heat transfer coefficient from the air inside the enclosure to the surface of the enclosure, Btu/h-ft^2-°F.
T_e	air temperature surrounding the raceway, °F
T_{b-in}	inside surface temperature of the enclosure, °F
T_r	surface temperature of the raceway, °F
A_b	surface area of the enclosure, ft^2
A_r	surface area of the raceway, ft^2

The overall convective heat transfer coefficient h_{c-rb} is determined by eliminating the temperature terms (T_r, T_e, T_{b-in}) from equation 10. The resulting expression is compared with the conduction heat transfer coefficient across the enclosure gap and the maximum of the two is taken. The expression for h_{c-rb} is given below.

$$h_{c-rb} = Maximum\,of \left\{ \frac{h_{c-re}}{1 + (\frac{A_r}{A_b})(\frac{h_{c-re}}{h_{c-eb}})}, \frac{k_g}{t_g} \right\} \qquad (11)$$

In this equation the conduction heat transfer coefficient is given by k_g/t_g where k_g is the thermal conductivity of air in the enclosure (Btu/h-ft^2-°F) and t_g is the width of the enclosure (ft). In situations where the enclosure width is small the conduction heat transfer coefficient becomes larger than the convective heat transfer coefficient. In such cases the heat transfer coefficient is based on the conduction heat transfer coefficient. This is the case with the conduits that are protected by pre-formed half round fire barriers. In case of the cable trays the enclosure width is sufficiently large so that the heat transfer is controlled by convection.

The approach used in modeling the convective heat transfer from the raceway to the enclosure results in different air temperature (T_a) for each raceway. This is reasonable since localized effects are expected to produce temperature variation within the enclosure. The approach also assumes that each raceway interacts convectively with the full area of the enclosure. This is a somewhat restrictive assumption and conflicts to some extent with the assumption that different raceways within the same enclosure may be surrounded by different air temperature. The overall effect, however, is not expected to be significant since: (1) heat transfer mechanism is predominantly radiative rather than convective. The assumption described above applies only to the convective portion of the heat transfer; (2) Thermal resistance within the enclosure air space is only a small fraction of the overall thermal resistance of the system.

3.4 *Heat Transfer through The Enclosure*

Heat transfer through the enclosure is by conduction according to the following equations

$$\sum q_r = [\frac{k_b}{t_b}]A_b(T_{b-in} - T_{b-out}) = U_b A_b (T_{b-in} - T_{b-out}) \quad \textit{flat enclosures}$$

$$\sum q_r = [\frac{k_b}{r_b \ln \frac{r_b}{r_b - t_b}}](2\pi r_b)(T_{b-in} - T_{b-out}) = U_b (2\pi r_b)(T_{b-in} - T_{b-out}) \; \textit{cylindrical encl.} \qquad (12)$$

where

k_b thermal conductivity of the barrier, Btu/h-ft-°F
r_b outer radius of a circular enclosure (used on conduits), ft
t_b thickness of the enclosure, ft
T_{b-out} outside surface temperature of the enclosure, °F

3.5 *Heat Transfer from the enclosure to The Ambient*

Heat transfer from the enclosure to the ambient is by convection and radiation according to the following equation.

$$\sum q_r = (h_{c-ba} + h_{r-ba})A_b(T_{b-out} - T_a) \qquad (13)$$

where

h_{c-ba} convective heat transfer coefficient from the enclosure to the ambient, Btu/h-ft^2-°F
h_{r-ba} radiative heat transfer coefficient from the enclosure to the ambient, Btu/h-ft^2-°F
T_a ambient temperature, °F

The area term A_b in equations 12 and 13 above is the net external area of the enclosure per unit length. If enclosure is not in contact with nearby walls A_b is equal to the perimeter of the enclosure. If however, part of the enclosure is formed by walls then A_b is set equal to the perimeter of the enclosure minus the perimeter of the wall contact (A_w).

The heat transfer coefficients $h_{c\text{-}ba}$ and $h_{r\text{-}ba}$ are calculated from equations 8 and 9 by assigning the subscripts 1 and 2 as

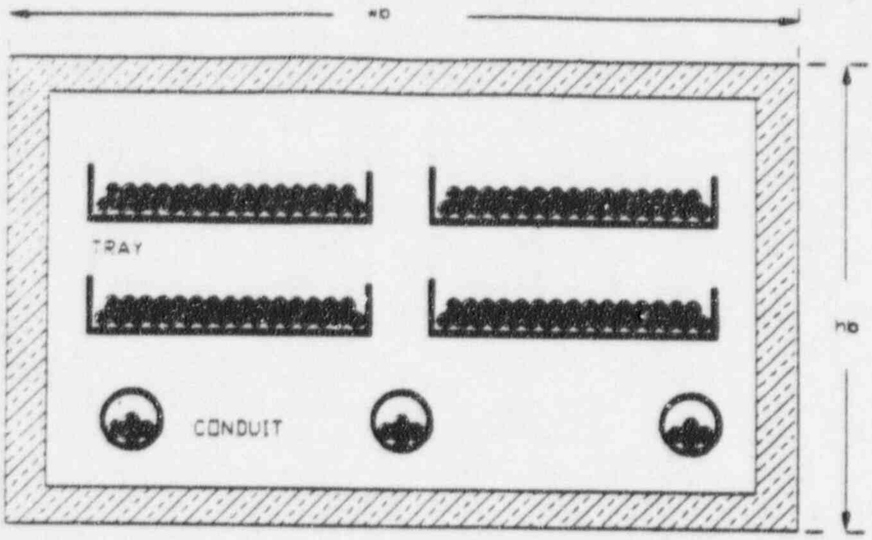
1 enclosure outside wall
2 ambient

Radiation Shape Factor (F_{12})

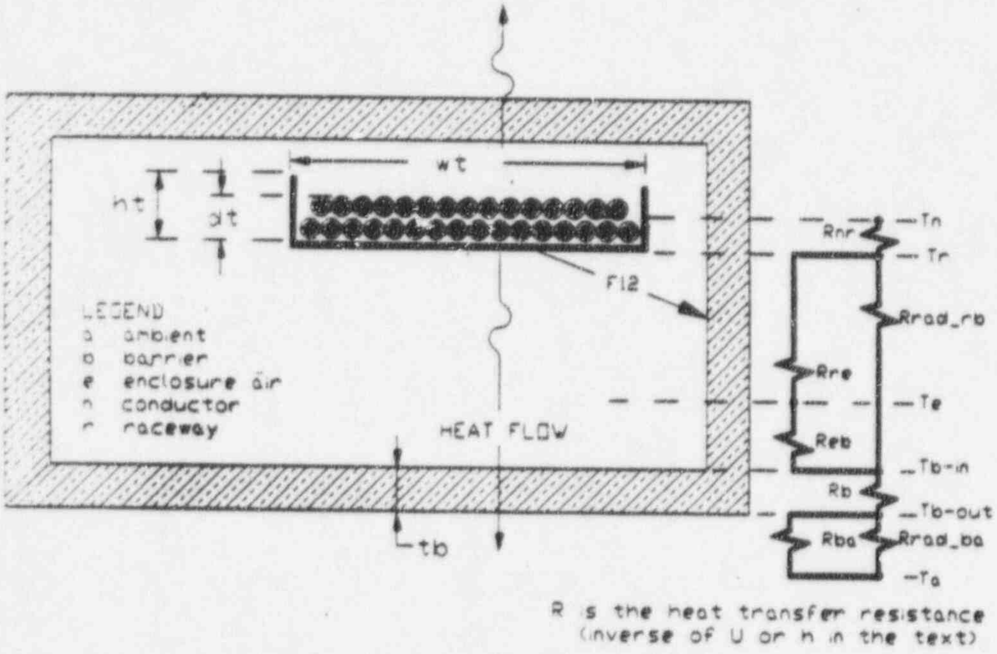
Radiation shape factor between the raceway and the enclosure is calculated as follows:

From the upper surface of the tray to the top of the enclosure:	1.0x0.5 (area ratio)
From the lower surface to the left (or right) face of the enclosure:	0.3x0.5 (area ratio)
Between two conduits at 1.25 diameter centers:	(1.0-0.15)=0.85

The shape factors are taken from configuration 2 of Reference 10 (page 15-44)for trays (corresponding to two infinitely long surfaces arranged at right angles to each other) and from configuration 7 for conduits at 1.25 diameter centers.



MULTIPLE COMMODITIES IN A COMMON FBS



R is the heat transfer resistance (inverse of U or h in the text)

Figure 3.1 Heat Transfer Model

4.0 IMPLEMENTATION

4.1 Verification of The Method

The Method described in Section 3.0 was tested against available data to establish the validity of the method. The test cases involved an unprotected 24 inch tray, a protected 36 inch tray, and a 2 inch conduit. The test cases and the comparison of the results are summarized in Table 4.1. Detailed calculations are contained in Tables 4.3 through 4.6. The calculated results bound the industry data with reasonable margins.

Table 4.1 Verification Test Results

	TEST CASE			
	Tray			*Conduit*
	Unprotected	*Protected*	*Protected*	*Protected*
Raceway Size (in)	4 x 24	4 x 36	4 x 36	2
Cable Data				
Depth (in) or fill (%)	1 in	1 in	2 in	12%
k_{bed} (Btu/h-ft-°F) [9, p: A3-8]	0.09	0.09	0.09	0.09
ε_{bed} [9, p: A3-8]	0.8	0.8	0.8	0.8
$I_{baseline}$ (Amp)	59 [3, p:309]	34 [8, Table 3-6]	22 [8, Table 3-6]	52*1.0=52 [3, p:313 and Table 1, A.4.3.2]
Enclosure Data	N/A			
Width or Dia (in)	N/A	37	37	3.375
Height (in)	N/A	6.25	6.25	N/A
t_b (in), minimum	N/A	0.625	0.625	0.75
k_b (Btu/h-ft-°F) [9, p: A3-8]	N/A	0.122	0.122	0.122
ε_b [9, p: A3-8]	N/A	0.9	0.9	0.9
Industry Data				
$I_{protected}$ (Amp)	34			
ADF (%)	N/A	36.2	30.5	6.6
	[8, Table 3-6]	[9, p: A3-9]	[9, p: A3-9]	[9, p: A4-6]
Calculated Results				
$I_{protected}$ (Amp)	31.6			
ADF (%)	N/A	37.1	35.7	9.9
Deviation	+7.1%	+2.5%	+17%	+33%

Notes:

1. All calculations are based on #8 3/C Cu cable with 0.708" diameter, 0.875 Ohm/1000 ft resistance. Thermo-Lag thickness is based on the nominal value for one-hour (existing) enclosures given in Table 4.2.
2. Deviation=100x(Calculated ADF - Industry ADF)/Industry ADF for protected raceways
3. Deviation=100x(Nominal Ampacity -Calculated Ampacity)/Nominal Ampacity for unprotected tray

Table 4.2 Enclosure Thickness for One Hour (Upgraded) [Ref. 14]

One-Hour (Upgraded) [Ref. 14]			
Enclosure			
	Conduits Less than 3" Nominal Dia.	Conduits 3" or larger Nominal Dia.	Multiple Raceways in Common Enclosure
Base Layer	1/2"(+1/4", -0")	1/2"(+1/4", -0")	5/8 " (±1/8")
Overlay	3/8"(+1/8",-1/8")	None	None
Stress Skin (Trowel Grade)	None	1/4" nominal	1/4" (see note 1 below)
Total Barrier Thickness	1 1/4" max 7/8" nominal 3/4" minimum	1" max 3/4" nominal 3/4" minimum	1" max 7/8 nominal 3/4 minimum
One-Hour (Existing) [Ref. 4] Total thickness: 0.5"+(+1/8", -0")			
Three-Hour (Existing) [Ref. 4] Total thickness: 1.0"+(+1/4", -0")			

Notes

(1) For multiple raceway enclosures the stress skin is applied over the entire surface of the enclosure. For single tray raceways the stress skin is applied along the joint interfaces approximately 4" wide on each face along the joint.

TABLE 4.3 -24 INCH TRAY /UNPROTECTED

FIRE ENCLOSURE DATA

w_b, width, (in)	1.00E+06	
h_b, height, (in)	1.00E+06	
A_b, A_w, area , ft^2	3.33E+05	0.0
ε_b, emissivity	1.00	
t_b, thickness (in)	5.00E-06	
k_b, (Btu/h-ft-°F)	1.00E+03	
F_{be}, shape factor	1.00	

TEMPERATURE DATA

T_n, conductor	194.0 F
T_e, ambient	104.0 F

HEAT TRANSFER

σ, Btu/h-ft^2-°R	1.7140E-09
C, (w-h/Btu)	0.2931
a	0.20
n	0.25

GAP DATA

k_g, Btu/h-ft-°F	0.016
t_g, in	N/A
t_g, Btu/h-ft-°F	N/A

TRAY AND CONDUIT DATA

Raceway Categories	1
Type	TRAY
ID	24" TRAY
n_r, no. of raceways	1
w_t, width *(d, dia)* , in	24.0
h_t, height *(t, thickn.)* , (in)	4.00
d_t, depth, in *(fill, %)*	1.00
ε, cable emissivity	0.80
F_{rb}, shape factor	1.00
cable size	#8 3/C Cu
d_{cable}, cable dia, (in)	0.708
n_{con}, no. of conductors	3
R, resistance, Ohm/1000ft	0.875
k_{bed}, Btu/h-ft-°F	0.090
I_{nom}, nominal amp., (Amp)	59.0

Enclosure size has been chosen intentionally very large to simulate an unprotected raceway.

Boxed entries designate the parameters over which iterations are carried out

Entries in [ ] show the equation number in Section 3.0
Entries in *(italic)* apply to conduits only

CALCULATED PARAMETERS

Raceway		
$I_{baseline}$, baseline amp., (Amp)	$\boxed{31.6}$	
n_{cable}, number of cables	48	[3]
A_r, heat transfer area, (ft^2)	4.00	[6]
q_r , (Btu/h-raceway)	429.	[2]
q, (Btu/h-category)	429.	[q_r*n_r]
U, (Btu/h-ft^2-°F)	4.32	[4k_{bed}/d in Eq. 4]
T_r, Surface Temp., (°F)	169.2	[Eq. 4]
T_e, enclosure air temp.; (°F)	$\boxed{104.0}$	
Ambient		
h_{c_re}, Btu/h-ft^2-°F	0.48	[Eq. 9]
h_{c_eb}, Btu/h-ft^2-°F	0.00	[Eq. 9]
h_{c_rb}, Btu/h-ft^2-°F	0.48	[Eq. 11]
h_{rad}, (Btu/h-f^2-°F)	1.17	[Eq. 8]
U, (Btu/h-f^2t-°F)	1.64	[h_{c-rb}+h_{rad}]
Barrier		
U_b, Btu/h-ft-°F	2.40E+09	[Eq. 12]
T_{in-b} Inside Temp., °F	$\boxed{104.0}$	
T_{b-out}, Outside Temp., °F	104.0	[Eq. 12]
h_{c-be}, Btu/h-ft^2-°F	0.00	[Eq. 9]
h_{rad}, Btu/h-f^2-°F	1.23	[Eq. 8]
U, Btu/h-f^2t-°F	1.23	[h_{c-be}+h_{rad}]
T_e, °F	104.0	[Eq. 13]

AMPACITY **31.6 Amp**

TABLE 4.4 -36 INCH TRAY -1 HR / 1"FILL

FIRE ENCLOSURE DATA

w_b, width, (in)	37.0	
h_b, height, (in)	6.25	
A_b, A_w, area , ft^2	7.2	0.0
ε_b, emissivity	0.90	
t_b, thickness (in)	0.625	
k_b (Btu/h-ft-°F)	0.122	
F_{be}, shape factor	1.00	

GAP DATA

k_g, Btu/h-ft-°F	0.016
t_g, in	N/A
h_g, Btu/h-ft^2-°	N/A

TEMPERATURE DATA

T_n, conductor	194.0 F
T_a, ambient	104.0 F

HEAT TRANSFER

σ, Btu/h-ft^2-°R	1.7140E-09
C, (w-h/Btu)	0.2931
a	0.20
n	0.25

TRAY AND CONDUIT DATA

Raceway Categories	Category 1
Type	TRAY
ID	1 HR TRAY
n_r, no. of raceways	1
w_t, width *(d, dia)*, in	36.0
h_t, height *(t, thickn.)*, (in)	4.0
d_t, depth, in *(fill, %)*	1.0
ε, cable emissivity	0.80
F_{rb}, shape factor	1.00
cable size	#8 3/C Cu
d_{cable}, cable dia, (in)	0.708
n_{con}, no. of conductors	3
R, resistance, Ohm/1000ft	0.875
k_{bed}, Btu/h-ft-°F	0.090
$I_{baseline}$, baseline amp., (Amp)	34.0

Boxed entries designate the parameters over which iterations are carried out

Entries in [ ] show the equation number in Section 3.0
Entries in *(italic)* apply to conduits only

CALCULATED PARAMETERS

Raceway		
$I_{protected}$, protected amp., (Amp)	$\boxed{21.4}$	
n_{cable}, number of cables	72	[3]
A_r, heat transfer area, (ft^2)	6.00	[6]
q_r , (Btu/h-raceway)	294.	[2]
q, (Btu/h-category)	294.	[q_r*n_r]
U, (Btu/h-ft^2-°F)	4.32	[Eq. 4]
T_r, Surface Temp., (°F)	182.6	[Eq. 4]
T_e, enclosure air temp., (°F)	$\boxed{164.1}$	
Enclosure		
h_{c_re}, Btu/h-ft^2-°F	0.32	[Eq. 9]
h_{c_eb}, Btu/h-ft^2-°F	0.30	[Eq. 9]
h_{c_rb}, Btu/h-ft^2-°F	0.17	[Eq. 11]
h_{rad}, (Btu/h-f^2-°F)	1.25	[Eq. 8]
U, (Btu/h-f^{2}t-°F)	1.42	[$h_{c\text{-}rb}$+h_{rad}]
Barrier		
U_b, Btu/h-ft-°F	2.34	[Eq. 12]
$T_{in\text{-}b}$ Inside Temp., °F	$\boxed{148.1}$	
$T_{b\text{-}out}$, Outside Temp., °F	130.7	[Eq. 12]
$h_{c\text{-}ba}$, Btu/h-ft^2-°F	0.34	[Eq. 9]
h_{rad}, Btu/h-f^2-°F	1.19	[Eq. 8]
U, Btu/h-f^{2}t-°F	1.53	[$h_{c\text{-}ba}$+h_{rad}]
T_a, °F	104.0	[Eq. 13]
ADF	37.1%	

TABLE 4.5 -36 INCH TRAY -1 HOUR/ 2" FILL

FIRE ENCLOSURE DATA

w_b, width, (in)	37.0	
h_b, height, (in)	6.25	
A_b, A_w, area , ft^2	7.2	0.0
ε_b, emissivity	0.90	
t_b, thickness (in)	0.625	
k_b, (Btu/h-ft-°F)	0.122	
F_{be}, shape factor	1.00	

GAP DATA

k_g, Btu/h-ft-°F	0.016
t_g, in	N/A
h_g, Btu/h-ft^2-°	N/A

TEMPERATURE DATA

T_n, conductor	194.0 F
T_a, ambient	104.0 F

HEAT TRANSFER

σ, Btu/h-ft^2-°R	1.7140E-09
C, (w-h/Btu)	0.2931
a	0.20
n	0.25

TRAY AND CONDUIT DATA

Raceway Categories	Category 1
Type	TRAY
ID	1 HR TRAY
n_r, no. of raceways	1
w_t, width *(d, dia)* , in	36.0
h_t, height *(t, thickn.)* , (in)	4.0
d_t, depth, in *(fill, %)*	2.0
ε, cable emissivity	0.80
F_{rb}, shape factor	1.00
cable size	#8 3/C Cu
d_{cable}, cable dia, (in)	0.708
n_{con}, no. of conductors	3
R, resistance, Ohm/1000ft	0.875
k_{bed}, Btu/h-ft-°F	0.090
$I_{baseline}$, baseline amp., (Amp)	22.0

Boxed entries designate the parameters over which iterations are carried out

Entries in [ ] show the equation number in Section 3.0
Entries in *(italic)* apply to conduits only

CALCULATED PARAMETERS

Raceway		
$I_{protected}$, protected amp., (Amp)	$\boxed{14.2}$	
n_{cable}, number of cables	144	[3]
A_r, heat transfer area, (ft^2)	6.00	[6]
q_r , (Btu/h-raceway)	258.	[2]
q, (Btu/h-category)	258.	[q_r*n_r]
U, (Btu/h-ft^2-°F)	2.16	[Eq. 4]
T_r, Surface Temp., (°F)	174.1	[Eq. 4]
T_e, enclosure air temp., (°F)	$\boxed{157.4}$	
Enclosure		
h_{c_re}, Btu/h-ft^2-°F	0.31	[Eq. 9]
h_{c_eb}, Btu/h-ft^2-°F	0.29	[Eq. 9]
h_{c_rb}, Btu/h-ft^2-°F	0.16	[Eq. 11]
h_{rad}, (Btu/h-f^2-°F)	1.21	[Eq. 8]
U, (Btu/h-f^2t-°F)	1.37	[h_{c-rb}+h_{rad}]
Barrier		
U_b, Btu/h-ft-°F	2.34	[Eq. 12]
T_{in-b} Inside Temp., °F	$\boxed{142.9}$	
T_{b-out}, Outside Temp., °F	127.6	[Eq. 12]
h_{c-be}, Btu/h-ft^2-°F	0.33	[Eq. 9]
h_{rad}, Btu/h-f^2-°F	1.18	[Eq. 8]
U, Btu/h-f^2t-°F	1.51	[h_{c-be}+h_{rad}]
T_a, °F	104.0	[Eq. 13]

ADF	35.7%

REF PAGE

TABLE 4.6 -2 INCH CONDUIT/PROTECTED

FIRE ENCLOSURE DATA

d_b, outside diameter, (in)	4.125	
h_b, height, (in)	N/A	
A_b, A_w, area , ft^2	1.08	0.00
ε_b, emissivity	0.90	
t_b, thickness (in)	0.750	
k_b, (Btu/h-ft-°F)	0.122	
F_{be}, shape factor	1.00	

GAP DATA

k_g, Btu/h-ft-°F	0.016
t_g, in	1/8
h_g, Btu/h-ft^2-°F	1.54

TEMPERATURE DATA

T_n, conductor	194.0 F
T_a, ambient	104.0 F

HEAT TRANSFER

σ, Btu/h-ft^2-°R	1.7140E-09
C, (w-h/Btu)	0.2931
a	0.20
n	0.25

TRAY AND CONDUIT DATA

Raceway Categories	Category 4
Type	CONDUIT
ID	2" CONDUIT
n_r, no. of raceways	1
w_t, width *(d, dia)*, in	2.375
h_t, height *(t, thickn.)*, (in)	0.154
d_t, depth, in *(fill, %)*	12.0
ε, cable emissivity	0.80
F_{rb}, shape factor	1.00
cable size	#8 3/C Cu
d_{cable}, cable dia, (in)	0.708
n_{con}, no. of conductors	3
R, resistance, Ohm/1000ft	0.875
k_{bed}, Btu/h-ft-°F	0.090
$I_{baseline}$, baseline amp., (Amp)	52.0

Boxed entries designate the parameters over which iterations are carried out

Entries in [ ] show the equation number in Section 3.0
Entries in *(italic)* apply to conduits only

CALCULATED PARAMETERS

Raceway		
$I_{protected}$, protected amp., (Amp)	$\boxed{46.9}$	
n_{cable}, number of cables	1	[3]
A_r, heat transfer area, (ft^2)	0.62	[6]
q_r , (Btu/h-raceway)	20.13	[2]
q, (Btu/h-category)	20.13	[q_r*n_r]
U, (Btu/h-ft^2-°F)	0.60	[Eq. 4]
T_r, Surface Temp., (°F)	140.1	[Eq. 4]
T_e, enclosure air temp., (°F)	$\boxed{133.6}$	
Enclosure		
h_{c_re}, Btu/h-ft^2-°F	3.07	[Eq. 9,11]
h_{c_eb}, Btu/h-ft^2-°F	3.07	[Eq. 9,11]
h_{c_rb}, Btu/h-ft^2-°F	1.54	[Eq. 11]
h_{rad}, (Btu/h-f^2-°F)	1.05	[Eq. 8]
U, (Btu/h-f^2t-°F)	2.59	[h_{c-rb}+h_{rad}]
Barrier		
U_b, Btu/h-ft-°F	1.57	[Eq. 12]
T_{in-b} Inside Temp., °F	$\boxed{127.4}$	
T_{b-out}, Outside Temp., °F	115.5	[Eq. 12]
h_{c-be}, Btu/h-ft^2-°F	0.48	[Eq. 9]
h_{rad}, Btu/h-f^2-°F	1.14	[Eq. 8]
U, Btu/h-f^2t-°F	1.62	[h_{c-be}+h_{rad}]
T_a, °F	104.0	[Eq. 13]

ADF 9.9%

4.2 *Application to RBS Thermo-Lag Enclosures*

The equations given in Section 3.0 are solved by iteration to determine the limiting rate of heat generation within each raceway such that the cable conductor temperature is at its specified value. The heat generation rate is then converted into an ampacity value using Equation 2. The ampacity derating factor (ADF) is defined as

$$ADF = \frac{I_{baseline} - I_{protected}}{I_{baseline}} x100 \qquad (14)$$

where $I_{baseline}$ refers to the ampacity of the cable without the fire enclosure and $I_{protected}$ refers to the ampacity of the cable in the enclosure. This approach eliminates the need for specific cable information in each individual conduit and simplifies the subsequent application of the ADFs. This approach is also consistent with the NRC method used in Reference 9 (page A3-9).

Calculations are performed using the approach as outlined below.

1. Calculate the thermal resistance of the raceway (U_t or $U_{conduit}$ in equation 4) from the raceway and the cable data. For cable trays U_t is calculated directly from the corresponding expression in equation 4. For conduits $U_{conduit}$ is back calculated from the baseline ampacity data. This is requires knowledge of the conduit surface emissivity. It has been assumed that this emissivity (for the purpose of determining $U_{conduit}$) is at the high end of the range (0.4 to 0.8) given in Reference 9, page A4-5, i.e., emissivity =0.8. This is conservative since it increases the effect of the fire barrier.

2. Assume a reasonable enclosure wall temperature corresponding to the specified cable insulation temperature and the ambient temperature. Calculate the corresponding heat transfer rate to the ambient. Calculate the raceway surface temperature and the corresponding heat generation rate within each raceway.

3. Compare the heat transfer rate to the ambient determined in step 1 to the total heat generation rate determined in step 3. The two quantities must agree within a reasonable limit.

4. Adjust the enclosure temperature and repeat steps 2 and 3 until the solution converges.

5. Calculate the current corresponding to the heat generation rate using equation 2

6. Calculate the ampacity derating factor from equation 14 above

4.3 Input Data

The input data used in the calculations are summarized below:

Ambient Temperature	40°C (104°F)

Cable

Cable Size	#8 3/C Cu, 1KV, rubber insulated
Conductor Resistance (ac)	0.875 Ohm/1000 ft [Ref. 1, Table A.4-2]
Cable Diameter	0.708 in [Ref. 3, p: 308]
Conductor Temperature	90°C (194°F)
Nominal Ampacity	59 Amp [Ref. 1, Table A.4-2] 52 Amp [Ref. 1, Table A.4-2] in conduit
Emissivity of The Cable	0.8 [Ref. 8, Appendix B]

Baseline Ampacities for Trays [Ref. 8, Table 3-6]

34.0 Amp 1" depth of cables in tray
22.0 Amp 2" depth of cables in tray

Baseline Ampacities for Conduits [Ref. 1, Table A.4.3-2]

Baseline Ampacity=Nominal Ampacity x MCF from Table A.4.3-2 of Reference 1
52.0 Amp in 2" conduit 12% (52x1.0 for three conductors or less)
41.6 Amp in 2" conduit 24% (52x 0.8 for 6 conductors)

Enclosure

Type	Thermo-Lag 330-1
Thermal Conductivity	0.09 Btu/h-ft-°F [Ref. 11], (SNL Uses 0.122, Ref. 9, p: A3-8)
Thickness	See Table 4.2
Emissivity	0.9 [Ref. 9, p: A3-8]

Conduit Data

Material	Aluminum
Schedule	Standard schedule
Emissivity	0.2 (oxidized surface, for discussion see section 4.4)

Configuration Specific Data

See Table 5.3, and Figures 5.1 through 5.4 [Data taken from Refs. 4, 13]

4.4 *Emissivity of Aluminum Conduits*

According to the SNL review the measured emissivity of the TU/CPSES conduits varied from 0.4 to 0.8 [Ref. 9, p: A4-5]. Since the TU conduits are steel whereas the RBS conduits are aluminum the measured emissivity data is not directly applicable to RBS. In this calculation a value of 0.2 has been used for the emissivity of aluminum conduits. This is considered to be a conservative value for the following reasons:

1. Industry standards [References 2, 3] does not make any distinction between aluminum and steel conduits. This implies that the baseline ampacities listed in IPCEA are bounding for steel and aluminum conduits.

2. The Neher-McGrath technical paper [Reference 15], which is the basis for the IPCEA publication P-46-526, does not discuss aluminum versus steel conduits. Regarding the emissivity it is stated on page 758 that "*The value of emissivity may be taken 0.95 for pipes, conduits or ducts, and painted or braided surfaces, and from 02. to 0.5 for lead and aluminum sheaths, depending upon whether the surface is bright or corroded.*" Reasonably assuming that surface conditions of aluminum conduits is comparable to surface condition of sheaths, the use of 0.2 emissivity for aluminum conduits is conservative.

3. Emissivity of aluminum surfaces vary from 0.03 to 0.4 depending on the surface conditions. The following is a compilation of data from various sources:

Heavily oxidized aluminum	0.20 -0.31 [Ref. 16, p: 285]
Aluminum (sand blasted)	0.40 [Ref. 10, p: 3-22]
Aluminum, oxidized	0.20 [Ref.6, p: 344]

The above data suggest that a conservative value of the emissivity for oxidized aluminum surfaces is 0.20 The emissivity for rough oxidized aluminum surfaces can be as high as 0.40.

5.0 AMPACITY DERATING FACTORS

5.1 Results

Ampacity derating factors have been determined for the configurations listed below:

1. Standard Tested Configurations (Ampacities Based on Industry Test Data)
    1.1 Single tray (1-hour)
    1.2 Two stacked trays in a common enclosure (1-hour)

2. Standard Untested Configurations (Ampacities Based on Analysis)
    1.1 Single conduit (1-hour)
    1.2 Single conduit (3-hour)
    1.3 Single trays (3-hour)

3. Unique Configurations (Ampacities Based on Analysis)
    3.1. Configuration U1: Multiple trays and conduits in a 1-hour enclosure (not upgraded)
    3.2. Configuration U2: Multiple trays and conduits in a 1-hour enclosure (not upgraded)
    3.3. Configuration U3a-h3: Two cable trays in a 3-hour enclosure
    3.4. (not upgraded)
    3.5. Configuration U3b-h3: Two cable trays in a 3-hour enclosure
    3.6. (not upgraded)
    3.7 Configuration U3a-h1: Two cable trays in a 1-hour enclosure (upgraded)
    3.8. Configuration U3b-h1: Two cable trays in a 1-hour enclosure (upgraded)

The results are summarized in Tables 5.1 through 5.3. Detailed spread sheet calculations are given in Tables 5.5 through 5.12.

Arrangement of the raceways within the enclosures for the unique configurations U1, U2, U3a-h1/h3, and U3b-h1/h3 are shown Figures 5.1 through 5.4.

Table 5.1 **Standard Tested Configurations (Ampacities Based on Industry Test Data, Ref. 9)**

Configuration	Barrier Rating	ADF(%)	
		NRC	RBS
Single Tray	1-hour	31.5 [Ref. 9, p: 15]	32
Two Tray Stack	1-hour	37.7 [Ref. 9, Cover Letter]	38

Table 5.2 **Standard Untested Configurations (Ampacities Based on Analysis)**

Configuration	Barrier Rating	ADF(%)	
Single Conduit	1-hour	21	Table 5.5 See Note 1
Single Conduit	3-hour	21	Table 5.5 See Note 2
Single Tray	3-hour	44	Table 5.6

Notes:

1. The calculated ADF value is 20% (see Table 5.5). Since Reference 9 recommends 21%, the higher value has been selected for use at RBS.

2. Three-hour conduit (existing) has the same T-L thickness as the one-hour (upgraded) T-L thickness (1.25"). Therefore it has been assigned the same ADF as the one-hour conduit (i.e., 21%)

Table 5.3 Unique Configurations (Ampacities Based on Analysis)

Configuration.	**Raceway** [Refs. 4, 13]	Size [Refs. 4, 13]	Fill [Ref. 12]	**ADF (%)**	Remarks
U1	*1*JB2072*				Configuration is shown in Figure 5.1.
1-hour	**1CK600NA1**	C-3.00	31.4%	**41**	
	1CK600NA6	C-1.50	23.6%	**37**	No credit has been taken for the heat
Figure 5.1	1CX911OA				transfer through the concrete wall.
Table 5.7	**1TK200R**	T-3x18	1.08%	**40**	
	1TH200R	T-3x18		**36**	The junction does not contain any power cable [Ref. 4].
	1TC200R	T-3x18			
	1TX200R	T-3x18			
U2	**1CK600NA7**	C-1.50	23.6	**24**	Configuration is shown in Figure 5.2
1-hour	**1CK600ND2**	C-3.00	11.9	**22**	Most restrictive portion is the East
	1TH201R	T-3x18		**28**	Leg.
Figure 5.2	1TC201R	T-3x18			
Table 5.8	1TX201R	T-3x18			No credit has been taken for the heat
	(1TC202R)	T-3x18	(Note 1]		transfer through the concrete wall.
	(1TX202R)	T-3x18			
	1TC203R	T-3x18			1TC203R, 1TX203R, 1TC204R, and
	1TX203R				1TH202R are above the vertical chase
	1TC204R	T-3x18			
	(1TH202R)	T-3x18			
U3a	**1TL012B**	T-3x30	1"	**33**	Configuration is shown in Figure 5.3.
1-hour			selected		
Figure 5.3	1TC048B	T-3x30			
Table 5.9					
U3a	**1TL012B**	T-3x30	12.1%	**38**	Configuration is shown in Figure 5.3
3-hour					
Figure 5.3	1TC048B	T-3x30			
Table 5.10					
U3b	**1TK001B**	T-3x30	12.1%	**25**	Configuration is shown in Figure 5.4
1-hour					
Figure 5.4	(TK002B)	T-3x30	20.5%		
Table 5.11	1TC047B	T-3x30			
U3b	**1TK001B**	T-3x30	12.1%	**41**	Configuration is shown in Figure 5.4
3-hour					
Figure 5.4	(TK002B)	T-3x30	20.5%		
Table 5.12	1TC047B	T-3x30			

Notes: (1) Raceways shown in parenthesis are continuation of other raceways listed.
(2) Raceways carrying power cables are shown in bold.
(3) ADF values have been rounded off upward to the next integer value

5.2 *Standard Tested Configurations*

The ampacity derating factors for standard one-hour cable tray installations at RBS (referred here as "*Standard Tested Configurations*") are based on the results of the tests performed by Texas Utilities (TU). The test results produced by TU were later adjusted by the NRC based on a study performed by Sandia National Laboratories (SNL). The ADF values applied to the standard one-hour tray configurations at RBS are based on the NRC adjusted ADF values. The ADF values are listed in Table 5.1.

Applicability of the TU tested configurations to RBS was established by a review of the configurations tested by TU and by comparing them to the tray configurations at RBS. Table 5.4 provides a summary of this comparison. Comparisons were made regarding the tray size, material, fire barrier thickness, joints, and, upgrade methods. The as designed configurations at RBS are found to be the same as the tested configurations except:

1. Cable tray sizes at RBS range from 18" to 30" whereas the tested configuration is 24"
2. The raceway material at RBS is aluminum whereas the tested raceway is steel.

Neither of these differences is important as far as the ADF values are concerned as discussed below.

Tray size
The size of the tray tested by TU represents the median tray size at RBS. Maximum variation from the tested tray size is ±6 inches. Additionally, ADF is independent of the tray size. The controlling parameter for the cable ampacity in a tray is the heat flux from the cable bed. For a given cable depth fill and cable size this parameter is independent of the width of the tray (heat generation rate and the surface area both vary linearly with the width of the tray.) Since the surface area of the fire barrier also varies linearly with the with of the tray the ampacity derating factor is independent of the width of the tray. This observation is consistent with the simulation model used by SNL to evaluate the TU test results. In reference to the results of the SNL study, it is stated on page A3-10 of Reference 9 that "...these results (ADFs) are independent of the tray width because of the assumption of true 1-dimensional behavior for these simulations."

Raceway Material

The difference between aluminum and steel, as far as their heat transfer capability is concerned, is that aluminum has a lower emissivity, lower specific heat, and higher thermal conductivity than those of steel. None of these parameters, however, is important to the cable ampacity in a tray.

1. Specific heat is not a factor since the ampacities are determined for steady state conditions.

2. For the problem under consideration thermal conductivity of the raceway material is insignificant. If anything, aluminum is a better conductor than steel which should augment the ampacity.

3. Emissivity affects the radiation heat transfer which is an important component of the heat transfer rate from the cable bed to the fire barrier. For cable trays though, the radiation is directly from the exposed surface of the cable bed to the fire barrier. Area covered by the tray rungs is only a small fraction of the effective heat transfer area of the cable bed. Therefore the ADF is determined by the emissivity of the cable rather than the emissivity of the tray material. This is consistent with the approach used by ICEA/NEMA [Ref. 8, Appendix B] which does not make a distinction between aluminum and steel trays, and the heat transfer model used by SNL to evaluate the TU test data which uses the cable emissivity rather than the tray emissivity as the basis for heat transfer calculations.

Based on the comparison of the Thermo-Lag tray tested by TU to obtain the ampacity derating factors and the standard Thermo-Lag tray installations at RBS as summarized in Table 5.4 and further discussed in the paragraphs above, the use of the ampacity derating factors given in Table 5.1 is justified.

5.3 Standard Untested Configurations

The ampacity derating factors for single conduit (both one-hour and three-hour) and single three-hour tray enclosures at RBS (referred here as "*Standard Untested Configurations*") are based on the results of the heat transfer. Although test data exists for steel conduits, this data was not used since the conduits at RBS are aluminum. Test data for three hour tray enclosures is not available. Accordingly, the ampacity derating factors for these configurations were determined by heat transfer analysis. The ADF values are listed in Table 5.2.

5.4 *Unique Configurations*

The ampacity derating factors for multiple raceways in common enclosures (referred here as "*Unique Configurations*") are based on the results of the heat transfer. The only exception to this is the two stacked tray configuration for which TU test data was applied. as discussed in paragraph 5.1. The ADF values are listed in Table 5.3.

Table 5.4 Comparison of RBS and TU Tested Tray Configurations [Ref. 14]

ATTRIBUTE	RIVER BEND STATION AS-DESIGNED CONFIGURATION	COMANCHE PEAK TESTED CONFIGURATION	TEST REFERENCES	COMMENTS
RACEWAY TYPE	*Cable Tray*	*Cable Tray*	*TUEC Scheme #AT-1 (Page 6 of Ref. 17)*	*As-Designed is the same as Tested.*
RACEWAY SIZE	*18" x 3"* *30" x 3"*	*24" x 4"*	*TUEC Scheme #AT-1 (Page 6 of Ref. 17)*	*See the discussion in paragraph 5.1 above*
RACEWAY MATERIAL	*Aluminum*	*Steel*	*TUEC Scheme #AT-1 (Page 4 of Ref. 17)*	*See the discussion paragraph 5.1 above*
BARRIER MATERIAL	*Thermo-Lag 330-1 Prefabricated V-rib Panel*	*Thermo-Lag 330-1 Prefabricated V-rib Panel*	*TUEC Scheme #AT-1 (Page 6 of Ref. 17)*	*As-Designed is the same as Tested.*
BARRIER THICKNESS	*5/8" (± 1/8")*	*5/8" (± 1/8")*	*TUEC Scheme #AT-1 (Page 9 of Ref. 17)*	*As-Designed is the same as Tested.*
JOINT TYPES	*Pre-buttered with trowel grade material*	*Pre-buttered with trowel grade material*	*TUEC Scheme #AT-1 (Page 9 of Ref. 17)*	*As-Designed is the same as Tested.*
JOINT UPGRADE METHODS	*Stress Skin, Trowel Grade, Wire, Staples*	*Stress Skin, Trowel Grade, Wire, Staples*	*TUEC Scheme #AT-1 (Page 10 of Ref. 17)*	*As-Designed is the same as Tested.*

Note: Data for River Bend Station are taken from Reference 14.

TABLE 5.5 -STANDARD ONE-HOUR CONDUIT

FIRE ENCLOSURE DATA

d_b, outside diameter, (in)	5.125	
h_b, height, (in)	N/A	
A_b, A_w, area , ft^2	1.34	0.00
ε_b, emissivity	0.90	
t_b, thickness (in)	1.25	
k_b, (Btu/h-ft-°F)	0.090	
F_{ba}, shape factor	1.00	

GAP DATA

k_g, Btu/h-ft-°F	0.016
t_g, in	1/8
h_g, Btu/h-ft^2-°F	1.54

TEMPERATURE DATA

T_n, conductor	194.0 F
T_a, ambient	104.0 F

HEAT TRANSFER

σ, Btu/h-ft^2-°R	1.714E-09
C, (w-h/Btu)	0.2931
a	0.20
n	0.25

TRAY AND CONDUIT DATA

Raceway Categories	Category 4
Type	STD/CONDUIT
ID	2" CONDUIT
n_r, no. of raceways	1
w_t, width *(d, dia)* , in	2.375
h_t, height *(t, thickn.)* , (in)	0.154
d_t, depth, in *(fill, %)*	23.5
ε, emissivity	0.20
F_{rb}, shape factor	1.00
cable size	#8 3/C Cu
d_{cable}, cable dia, (in)	0.708
n_{con}, no. of conductors	3
R, resistance, Ohm/1000ft	0.875
k_{bed}, Btu/h-ft-°F	0.090
$I_{baseline}$, baseline amp., (Amp)	41.6

Boxed entries designate the parameters over which iterations are carried out

Entries in [ ] show the equation number in Section 3.0
Entries in *(italic)* apply to conduits only

CALCULATED PARAMETERS

Raceway		
$I_{protected}$, protected amp., (Amp'	$\boxed{33.3}$	
n_{cable}, number of cables	2	[3]
A_r, heat transfer area, (ft^2)	0.62	[6]
q_r , (Btu/h-raceway)	20.	[2]
q, (Btu/h-category)	20.	[q_r*n_r]
U, (Btu/h-ft^2-°F)	0.81	[Eq. 4]
T_r, Surface Temp., (°F)	154.5	[Eq. 4]
T_e, enclosure air temp., (°F)	$\boxed{145.8}$	
Enclosure		
h_{c_re}, Btu/h-ft^2-°F	3.07	[Eq. 9,11]
h_{c_eb}, Btu/h-ft^2-°F	3.07	[Eq. 9,11]
h_{c_rb}, Btu/h-ft^2-°F	1.54	[Eq. 11]
h_{rad}, (Btu/h-f^2-°F)	0.30	[Eq. 8]
U, (Btu/h-f^{2}t-°F)	1.83	[$h_{c\text{-}rb}$+h_{rad}]
Barrier		
U_b, Btu/h-ft-°F	0.63	[Eq. 12]
$T_{in\text{-}b}$ Inside Temp., °F	$\boxed{137.0}$	
$T_{b\text{-}out}$, Outside Temp., °F	113.5	[Eq. 12]
$h_{c\text{-}ba}$, Btu/h-ft^2-°F	0.43	[Eq. 9]
h_{rad}, Btu/h-f^2-°F	1.14	[Eq. 8]
U, Btu/h-f^{2}t-°F	1.57	[$h_{c\text{-}ba}$+h_{rad}]
T_a, °F	104.0	[Eq. 13]

ADF 20.0%

TABLE 5.6 -STANDARD THREE-HOUR TRAY

FIRE ENCLOSURE DATA

w_b, width, (in)	32.5	
h_b, height, (in)	7.75	
A_b, A_w, area , ft^2	6.7	0.0
ε_b, emissivity	0.90	
t_b, thickness (in)	1.250	
k_b, (Btu/h-ft-°F)	0.090	
F_{ba}, shape factor	1.00	

GAP DATA

k_g, Btu/h-ft-°F	0.016
t_g, in	N/A
h_g, Btu/h-ft^2-°F	N/A

TEMPERATURE DATA

T_n, conductor	194.0 F
T_a, ambient	104.0 F

HEAT TRANSFER

σ, Btu/h-ft^2-°R	1.714E-09
C, (w-h/Btu)	0.2931
a	0.20
n	0.25

TRAY AND CONDUIT DATA

Raceway Categories	Category 1
Type	TRAY
ID	STD/TRAY
n_r, no. of raceways	1
w_t, width *(d, dia)*, in	30.0
h_t, height *(t, thickn.)*, (in)	4.0
d_t, depth, in *(fill, %)*	1.0
ε, cable emissivity	0.80
F_{rb}, shape factor	1.00
cable size	#8 3/C Cu
d_{cable}, cable dia, (in)	0.708
n_{con}, no. of conductors	3
R, resistance, Ohm/1000ft	0.875
k_{bed}, Btu/h-ft-°F	0.090
I_{nom}, nominal amp., (Amp)	34.0

Boxed entries designate the parameters over which iterations are carried out

Entries in [ ] show the equation number in Section 3.0
Entries in *(italic)* apply to conduits only

CALCULATED PARAMETERS

Raceway		
$I_{protected}$, protected amp., (Amp)	19.2	
n_{cable}, number of cables	60	[3]
A_r, heat transfer area, (ft^2)	5.00	[6]
q_r , (Btu/h-raceway)	198.	[2]
q, (Btu/h-category)	198.	[q_r*n_r]
U, (Btu/h-ft^2-°F)	4.32	[4k_{bed}/d in Eq. 4]
T_r, Surface Temp., (°F)	184.8	[Eq. 4]
T_e, enclosure air temp.; (°F)	169.9	
Enclosure		
h_{c_rw}, Btu/h-ft^2-°F	0.31	[Eq. 9]
h_{c_eb}, Btu/h-ft^2-°F	0.29	[Eq. 9]
h_{c_rb}, Btu/h-ft^2-°F	0.17	[Eq. 11]
h_{rad}, (Btu/h-f^2-°F)	1.30	[Eq. 8]
U, (Btu/h-f^2t-°F)	1.47	[h_{c-rb}+h_{rad}]
Barrier		
U_b, Btu/h-ft-°F	0.86	[Eq. 12]
T_{in-b} Inside Temp., °F	157.9	
T_{b-out}, Outside Temp., °F	123.7	[Eq. 12]
h_{c-bo}, Btu/h-ft^2-°F	0.33	[Eq. 9]
h_{rad}, Btu/h-f^2-°F	1.17	[Eq. 8]
U, Btu/h-f^2t-°F	1.50	[h_{c-bo}+h_{rad}]
T_a, °F	104.0	[Eq. 13]
ADF	43.5%	

TABLE 5.7 -CONFIGURATION U1

FIRE ENCLOSURE DATA

w_b, width, (in)	42.0	
h_b, height, (in)	81.00	
A_b, A_w, area , ft^2	10.3	10.3
ε_b, emissivity	0.90	
t_b, thickness (in)	0.625	
k_b, (Btu/h-ft-°F)	0.090	
F_{be}, shape factor	1.00	

GAP DATA

k_g, Btu/h-ft-°F	0.016
t_g, in	N/A
h_g, Btu/h-ft^2-°F	N/A

TEMPERATURE DATA

T_n, conductor	194.0 F
T_a, ambient	104.0 F

HEAT TRANSFER.

σ, Btu/h-ft^2-°R	1.714E-09
C, (w-h/Btu)	0.2931
a	0.20
n	0.25

TRAY AND CONDUIT DATA

Raceway Categories	Category 1	Category 2	Category 3	Category 4
Type	TRAY	TRAY	CONDUIT	CONDUIT
ID	1TH200R	1TK200R	1CK600NA1	1CK600NA6
n_r, no. of raceways	1	1	1	1
w_t, width *(d, dia)*, in	18.0	18.0	3.50	1.90
h_t, height *(t, thickn.)*, (in)	4.0	4.0	0.216	0.145
d_t, depth, in *(fill, %)*	1.0	1.0	31.4	23.6
ε, emissivity	0.80	0.80	0.20	0.20
F_{rb}, shape factor	0.80	0.60	0.85	0.70
cable size	#8 3/C Cu	#8 3/C Cu	#8 3/C Cu	#8 3/C Cu
d_{cable}, cable dia, (in)	0.708	0.708	0.708	0.708
n_{con}, no. of conductors	3	3	3	3
R, resistance, Ohm/1000ft	0.875	0.875	0.875	0.875
k_{bed}, Btu/h-ft-°F	0.090	0.090	0.090	0.090
$I_{baseline}$, baseline amp., (Amp)	34.0	34.0	36.4	52.0

CALCULATED PARAMETERS

Raceway					
$I_{protected}$, protected amp., (Amp)	22.0	20.5	21.7	33.0	
n_{cable}, number of cables	36	36	6	1	[3]
A_r, heat transfer area, (ft^2)	3.00	3.00	0.92	0.50	[6]
q_r, (Btu/h-raceway)	156.	135.	25.	12.	[2]
q, (Btu/h-category)	156.	135.	25.	12.	[q_r*n_r]
U, (Btu/h-ft^2-°F)	4.32	4.32	1.61	1.03	[Eq. 4]
T_r, Surface Temp. (°F)	182.0	183.5	177.2	170.8	[Eq. 4]
T_e, enclosure air temp., (°F)	155.7	156.2	150.4	147.8	
Enclosure					
h_{c_rs}, Btu/h-ft^2-°F	0.41	0.41	0.62	0.69	[Eq. 9]
h_{c_sb}, Btu/h-ft^2-°F	0.27	0.27	0.23	0.20	[Eq. 9]
h_{c_rb}, Btu/h-ft^2-°F	0.28	0.29	0.50	0.60	[Eq. 11]
h_{rad}, (Btu/h-ft^2-°F)	1.08	0.85	0.32	0.30	[Eq. 8]
U, (Btu/h-ft^2-°F)	1.37	1.14	0.82	0.89	[h_{c-rb}+h_{rad}]

Barrier		
U_b, Btu/h-ft-°F	1.73	[Eq. 12]
T_{in-b} Inside Temp., °F	144.0	
T_{b-out}, Outside Temp., °F	125.5	[Eq. 12]
h_{c-bs}, Btu/h-ft^2-°F	0.31	[Eq. 9]
h_{rad}, Btu/h-ft^2-°F	1.17	[Eq. 8]
U, Btu/h-ft^2-°F	1.49	[h_{c-bs}+h_{rad}]
T_a, °F	104.0	[Eq. 13]

Boxed entries designate the parameters over which iterations are carried out

Entries in [ ] show the equation number in Section 3.0

Entries in *(italic)* apply to conduits only

ADF	35.3%	39.6%	40.5%	36.5%

TABLE 5.8 - CONFIGURATION U2

FIRE ENCLOSURE DATA

w_b, width, (in)	70.0	
h_b, height, (in)	68.00	
A_b, A_c, area, ft^2	11.5	11.5
ε_b, emissivity	0.90	
t_b, thickness (in)	0.625	
k_b, (Btu/h-ft-°F)	0.090	
F_{ba}, shape factor	1.00	

GAP DATA

k_g, Btu/h-ft-°	0.016
t_g, in	N/A
h_g, Btu/h-ft^2-	N/A

TEMPERATURE DATA

T_n, conducto	194.0 F
T_a, ambient	104.0 F

HEAT TRANSFER.

σ, Btu/h-ft^2-°	1.714E-09
C, (w-h/Btu)	0.2931
a	0.20
n	0.25

TRAY AND CONDUIT DATA

Raceway Categories	Category 1	Category 2	Category 3
Type	TRAY	CONDUIT	CONDUIT
ID	1TH201R	1CK600NA7	1CK600ND2
n_r, no. of raceways	1	1	1
w_t, width *(d, dia)*, in	18.0	1.90	3.50
h_t, height *(t, thickn.)*, (in)	4.0	0.145	0.216
d_t, depth, in *(fill, %)*	1.0	23.6	12.0
ε, emissivity	0.80	0.20	0.20
F_{rb}, shape factor	0.80	0.85	0.85
cable size	#8 3/C Cu	#8 3/C Cu	#8 3/C Cu
d_{cable}, cable dia, (in)	0.708	0.708	0.708
n_{con}, no. of conductors	3	3	3
R, resistance, Ohm/1000ft	0.875	0.875	0.875
k_{bed}, Btu/h-ft-°F	0.090	0.090	0.090
$I_{baseline}$, baseline amp., (Amp)	34.0	52.0	41.6

CALCULATED PARAMETERS

Raceway				
$I_{protected}$, protected amp., (Amp)	24.7	39.9	32.5	
n_{cable}, number of cables	36	1	2	[3]
A_r, heat transfer area, (ft^2)	3.00	0.50	0.92	[6]
q_r, (Btu/h-raceway)	196.	17.	21.	[2]
q, (Btu/h-category)	196.	17.	21.	[q_r*n_r]
U, (Btu/h-ft^2-°F)	4.32	1.03	0.57	[Eq. 4]
T_r, Surface Temp., (°F)	178.9	160.0	153.3	[Eq. 4]
T_e, enclosure air temp., (°F)	154.4	134.6	134.8	
Enclosure				
h_{c_re}, Btu/h-ft^2-°F	0.40	0.71	0.56	[Eq. 9]
h_{c_eb}, Btu/h-ft^2-°F	0.29	0.19	0.19	[Eq. 9]
h_{c_rb}, Btu/h-ft^2-°F	0.29	0.61	0.45	[Eq. 11]
h_{rad}, (Btu/h-f^2-°F)	1.04	0.29	0.29	[Eq. 8]
U, (Btu/h-f^{2}t-°F)	1.34	0.90	0.74	[h_{c-rb}+h_{rad}]
Barrier				
U_b, Btu/h-ft-°F	1.73	[Eq. 12]		
T_{in-b} Inside Temp., °F	130.3			
T_{b-out}, Outside Temp., °F	118.5	[Eq. 12]		
h_{c-ba}, Btu/h-ft^2-°F	0.25	[Eq. 9, 11]		
h_{rad}, Btu/h-f^2-°F	1.15	[Eq. 8]		
U, Btu/h-f^{2}t-°F	1.40	[h_{c-ba}+h_{rad}]		
T_a, °F	104.0	[Eq. 12]		
ADF	27.4%	23.2%	21.9%	

Boxed entries designate the parameters over which iterations are carried out

Entries in [ ] show the equation number in Section 3.0

Entries in *(italic)* apply to conduits only

TABLE 5.9 -RBS CONFIGURATION U3A /ONE-HOUR

FIRE ENCLOSURE DATA

w_b, width, (in)	41.0	
h_b, height, (in)	24.00	
A_b, A_w, area , ft^2	10.8	0.0
ε_b, emissivity	0.90	
t_b, thickness (in)	0.625	
k_b, (Btu/h-ft-°F)	0.090	
F_{be}, shape factor	1.00	

GAP DATA

k_g, Btu/h-ft-°F	0.016
t_g, in	N/A
h_g, Btu/h-ft^2-°	N/A

TEMPERATURE DATA

T_n, conductor	194.0 F
T_a, ambient	104.0 F

HEAT TRANSFER

σ, Btu/h-ft^2-°R	1.714E-09
C, (w-h/Btu)	0.2931
a	0.20
n	0.25

Boxed entries designate the parameters over which iterations are carried out

Entries in [ ] show the equation number in Section 3.0

Entries in *(italic)* apply to conduits only

TRAY AND CONDUIT DATA

Raceway Categories	Category 1
Type	TRAY
ID	1TL012B
n_r, no. of raceways	1
w_t, width *(d, dia)* , in	30.0
h_t, height *(t, thickn.)* , (in)	4.0
d_t, depth, in *(fill, %)*	1.0
ε, emissivity	0.80
F_{rb}, shape factor	0.80
cable size	#8 3/C Cu
d_{cable}, cable dia, (in)	0.708
n_{con}, no. of conductors	3
R, resistance, Ohm/1000ft	0.875
k_{bod}, Btu/h-ft-°F	0.090
$I_{baseline}$, baseline amp., (Amp)	34.0

CALCULATED PARAMETERS

Raceway		
$I_{protected}$, protected amp., (Amp)	23.0	
n_{cable}, number of cables	60	[3]
A_r, heat transfer area, (ft^2)	5.00	[6]
q_r , (Btu/h-raceway)	282.	[2]
q, (Btu/h-category)	282.	[q_r*n_r]
U, (Btu/h-ft^2-°F)	4.32	[Eq. 4]
T_r, Surface Temp., (°F)	180.9	[Eq. 4]
T_e, enclosure air temp., (°F)	152.9	
Enclosure		
h_{c_re}, Btu/h-ft^2-°F	0.37	[Eq. 9]
h_{c_eb}, Btu/h-ft^2-°F	0.29	[Eq. 9]
h_{c_rb}, Btu/h-ft^2-°F	0.23	[Eq. 11]
h_{rad}, (Btu/h-f^2-°F)	1.05	[Eq. 8]
U, (Btu/h-f^{2}t-°F)	1.28	[h_{c-rb}+h_{rad}]
Barrier		
U_b, Btu/h-ft-°F	1.73	[Eq. 12]
T_{in-b} Inside Temp., °F	136.9	
T_{b-out}, Outside Temp., °F	121.8	[Eq. 12]
h_{c-ba}, Btu/h-ft^2-°F	0.30	[Eq. 9, 11]
h_{rad}, Btu/h-f^2-°F	1.16	[Eq. 8]
U, Btu/h-f^{2}t-°F	1.46	[h_{c-ba}+h_{rad}]
T_a, °F	104.0	[Eq. 12]

ADF	32.5%

TABLE 5.10 -RBS CONFIGURATION U3A /THREE-HOUR

FIRE ENCLOSURE DATA

w_b, width, (in)	41.0	
h_b, height, (in)	24.00	
A_b, A_w, area , ft^2	10.8	0.0
ε_b, emissivity	0.90	
t_b, thickness (in)	1.250	
k_b, (Btu/h-ft-°F)	0.090	
F_{be}, shape factor	1.00	

GAP DATA

k_g, Btu/h-ft-°F	0.016
t_g, in	N/A
h_g, Btu/h-ft^2-°	N/A

TEMPERATURE DATA

T_n, conductor	194.0 F
T_a, ambient	104.0 F

HEAT TRANSFER

σ, Btu/h-ft^2-°R	1.714E-09
C, (w-h/Btu)	0.2931
a	0.20
n	0.25

Boxed entries designate the parameters over which iterations are carried out

Entries in [ ] show the equation number in Section 3.0

Entries in *(italic)* apply to conduits only

TRAY AND CONDUIT DATA

Raceway Categories	Category 1
Type	TRAY
ID	1TL012B
n_r, no. of raceways	1
w_t, width *(d, dia)* , in	30.0
h_t, height *(t, thickn.)* , (in)	4.0
d_t, depth, in *(fill, %)*	1.0
ε, emissivity	0.80
F_{rb}, shape factor	0.80
cable size	#8 3/C Cu
d_{cable}, cable dia. (in)	0.708
n_{con}, no. of conductors	3
R, resistance, Ohm/1000ft	0.875
k_{bed}, Btu/h-ft-°F	0.090
$I_{baseline}$, baseline amp., (Amp)	34.0

CALCULATED PARAMETERS

Raceway		
$I_{protected}$, protected amp., (Amp)	$\boxed{21.3}$	
n_{cable}, number of cables	60	[3]
A_r, heat transfer area, (ft^2)	5.00	[6]
q_r , (Btu/h-raceway)	243.	[2]
q, (Btu/h-category)	243.	[q_r*n_r]
U, (Btu/h-ft^2-°F)	4.32	[Eq. 4]
T_r, Surface Temp., (°F)	182.8	[Eq. 4]
T_e, enclosure air temp., (°F)	$\boxed{159.0}$	
Enclosure		
h_{c_re}, Btu/h-ft^2-°F	0.35	[Eq. 9]
h_{c_eb}, Btu/h-ft^2-°F	0.28	[Eq. 9]
h_{c_rb}, Btu/h-ft^2-°F	0.22	[Eq. 11]
h_{rad}, (Btu/h-f^2-°F)	1.08	[Eq. 8]
U, (Btu/h-f^2t-°F)	1.30	[h_{c-rb}+h_{rad}]
Barrier		
U_b, Btu/h-ft-°F	0.86	[Eq. 12]
T_{b-in} Inside Temp., °F	$\boxed{145.4}$	
T_{b-out}, Outside Temp., °F	119.5	[Eq. 12]
h_{c-ba}, Btu/h-ft^2-°F	0.29	[Eq. 9]
h_{rad}, Btu/h-f^2-°F	1.15	[Eq. 8]
U, Btu/h-f^2t-°F	1.45	[h_{c-ba}+h_{rad}]
T_a, °F	104.0	[Eq. 13]

ADF 37.4%

TABLE 5.11 -RBS CONFIGURATION U3B /ONE-HOUR

FIRE ENCLOSURE DATA

w_b, width, (in)	41.0	
h_b, height, (in)	8.00	
A_b, A_w, area , ft^2	8.2	0.0
ε_b, emissivity	0.90	
t_b, thickness (in)	0.625	
k_b, (Btu/h-ft-°F)	0.090	
F_{ba}, shape factor	1.00	

TEMPERATURE DATA

T_n, conductor	194.0 F
T_a, ambient	104.0 F

HEAT TRANSFER

σ, Btu/h-ft^2-°R	1.714E-09
C, (w-h/Btu)	0.2931
a	0.20
n	0.25

GAP DATA

k_g, Btu/h-ft-°F	0.016
t_g, in	N/A
h_g, Btu/h-ft^2-°F	N/A

TRAY AND CONDUIT DATA

Raceway Categories	Category 1
Type	TRAY
ID	1TK001B
n_r, no. of raceways	1
w_t, width *(d, dia)*, in	30.0
h_t, height *(t, thickn.)*, (in)	4.0
d_t, depth, in *(fill, %)*	1.0
ε, emissivity	0.80
F_{rb}, shape factor	1.00
cable size	#8 3/C Cu
d_{cable}, cable dia, (in)	0.708
n_{con}, no. of conductors	3
R, resistance, Ohm/1000ft	0.875
k_{bed}, Btu/h-ft-°F	0.090
$I_{baseline}$, baseline amp., (Amp)	34.0

Boxed entries designate the parameters over which iterations are carried out

Entries in [ ] show the equation number in Section 3.0

Entries in *(italic)* apply to conduits only

CALCULATED PARAMETERS

Raceway		
$I_{protected}$, protected amp., (Amp)	$\boxed{22.3}$	
n_{cable}, number of cables	60	[3]
A_r, heat transfer area, (ft^2)	5.00	[6]
q_r, (Btu/h-raceway)	268.	[2]
q, (Btu/h-category)	268.	[q_r*n_r]
U, (Btu/h-ft^2-°F)	4.32	[Eq. 4]
T_r, Surface Temp., (°F)	181.6	[Eq. 4]
T_e, enclosure air temp., (°F)	$\boxed{160.3}$	
Enclosure		
h_{c_ra}, Btu/h-ft^2-°F	0.34	[Eq. 9]
h_{c_eb}, Btu/h-ft^2-°F	0.29	[Eq. 9]
h_{c_rb}, Btu/h-ft^2-°F	0.20	[Eq. 11]
h_{rad}, (Btu/h-f^2-°F)	1.26	[Eq. 8]
U, (Btu/h-f^2t-°F)	1.46	[h_{c-rb}+h_{rad}]
Barrier		
U_b, Btu/h-ft-°F	1.73	[Eq. 12]
T_{in-b} Inside Temp., °F	$\boxed{144.9}$	
T_{b-out}, Outside Temp., °F	125.9	[Eq. 12]
h_{c-ba}, Btu/h-ft^2-°F	0.32	[Eq. 9]
h_{rad}, Btu/h-f^2-°F	1.17	[Eq. 8]
U, Btu/h-f^2t-°F	1.49	[h_{c-ba}+h_{rad}]
T_a, °F	104.0	[Eq. 13]
ADF	34.3%	

TABLE 5.12 -RBS CONFIGURATION U3B /THREE-HC

FIRE ENCLOSURE DATA

w_b, width, (in)	41.0	
h_b, height, (in)	8.00	
A_b, A_w, area , ft^2	8.2	0.0
ε_b, emissivity	0.90	
t_b, thickness (in)	1.250	
k_b, (Btu/h-ft-°F)	0.090	
F_{be}, shape factor	1.00	

GAP DATA

k_g, Btu/h-ft-°F	0.016
t_g, in	N/A
h_g, Btu/h-ft^2-°F	N/A

TEMPERATURE DATA

T_n, conductor	194.0 F
T_a, ambient	104.0 F

HEAT TRANSFER

σ, Btu/h-ft^2-°R	1.714E-09
C, (w-h/Btu)	0.2931
a	0.20
n	0.25

TRAY AND CONDUIT DATA

Raceway Categories	Category 1
Type	TRAY
ID	1TK001B
n_r, no. of raceways	1
w_t, width *(d, dia)* , in	30.0
h_t, height *(t, thickn.)*, (in)	4.0
d_t, depth, in *(fill, %)*	1.0
ε, emissivity	0.80
F_{rb}, shape factor	1.00
cable size	#8 3/C Cu
d_{cable}, cable dia, (in)	0.708
n_{con}, no. of conductors	3
R, resistance, Ohm/1000ft	0.875
k_{bed}, Btu/h-ft-°F	0.090
$I_{baseline}$, baseline amp., (Amp)	34.0

Boxed entries designate the parameters over which iterations are carried out

Entries in [ ] show the equation number in Section 3.0

Entries in *(italic)* apply to conduits only

CALCULATED PARAMETERS

Raceway		
$I_{protected}$, protected amp., (Amp)	20.3	
n_{cable}, number of cables	60	[3]
A_r, heat transfer area, (ft^2)	5.00	[6]
q_r , (Btu/h-raceway)	222.	[2]
q, (Btu/h-category)	222.	[q_r*n_r]
U, (Btu/h-ft^2-°F)	4.32	[Eq. 4]
T_r, Surface Temp., (°F)	183.7	[Eq. 4]
T_e, enclosure air temp., (°F)	166.4	
Enclosure		
h_{c_re}, Btu/h-ft^2-°F	0.32	[Eq. 9]
h_{c_eb}, Btu/h-ft^2-°F	0.28	[Eq. 9]
h_{c_rb}, Btu/h-ft^2-°F	0.19	[Eq. 11]
h_{rad}, (Btu/h-ft^2-°F)	1.29	[Eq. 8]
U, (Btu/h-ft^2-°F)	1.48	[h_{c-rb}+h_{rad}]
Barrier		
U_b, Btu/h-ft-°F	0.86	[Eq. 12]
T_{in-b} Inside Temp., °F	153.9	
T_{b-out}, Outside Temp., °F	122.5	[Eq. 12]
h_{c-ba}, Btu/h-ft^2-°F	0.31	[Eq. 9]
h_{rad}, Btu/h-ft^2-°F	1.16	[Eq. 8]
U, Btu/h-ft^2-°F	1.47	[h_{c-ba}+h_{rad}]
T_a, °F	104.0	[Eq. 13]

ADF 40.2%

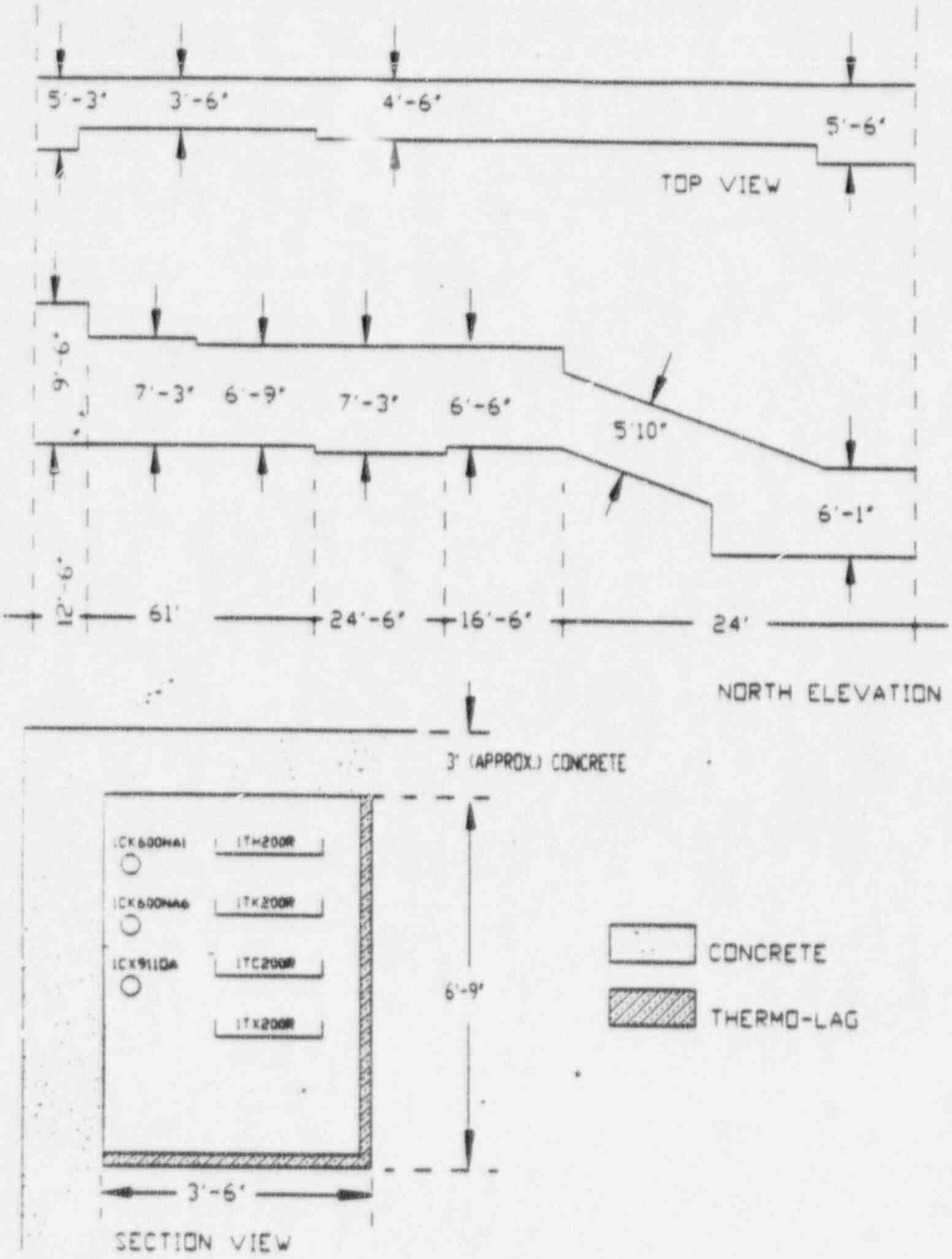


Figure 5.1 Configuration U1

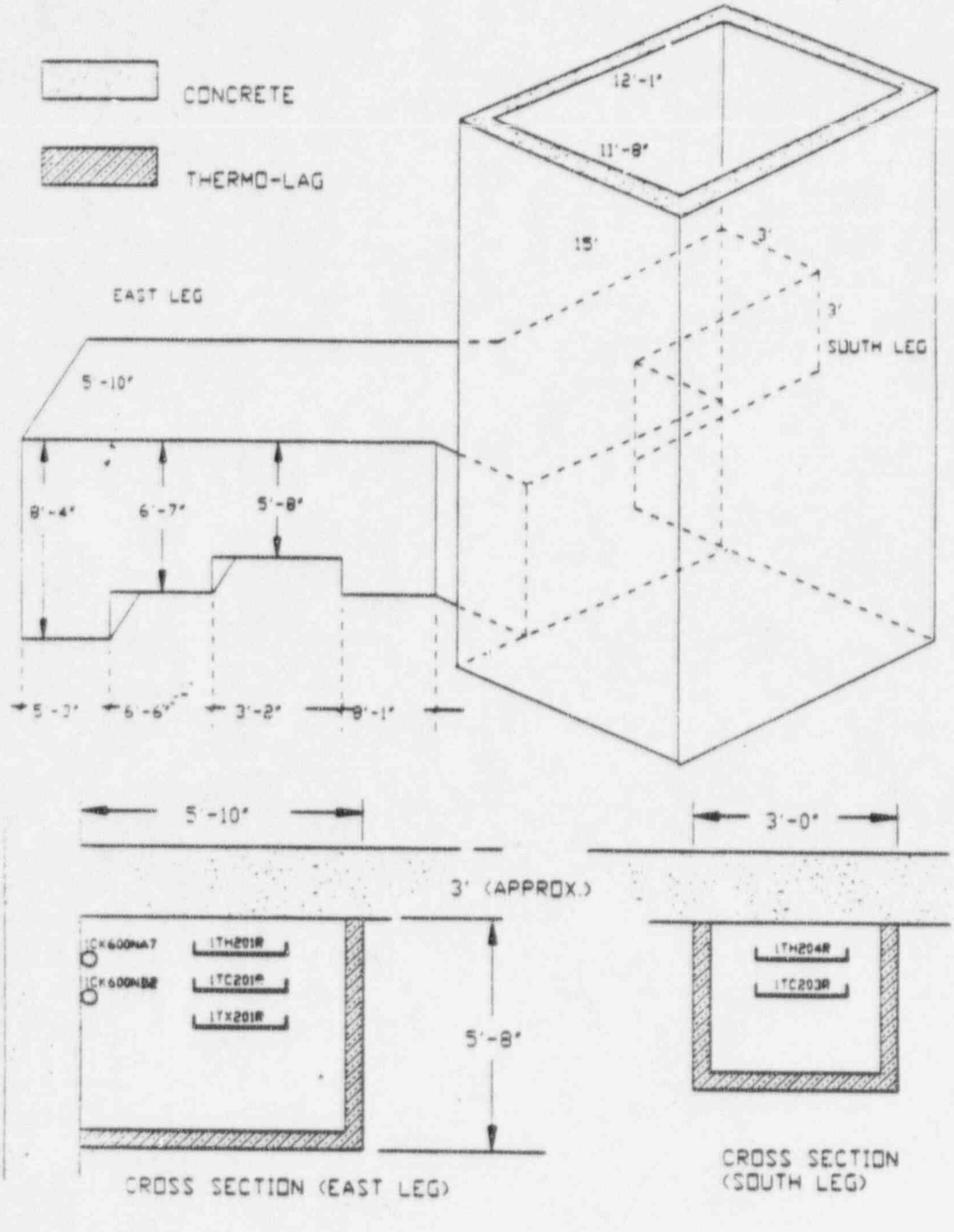


Figure 5.2 **Configuration U2**

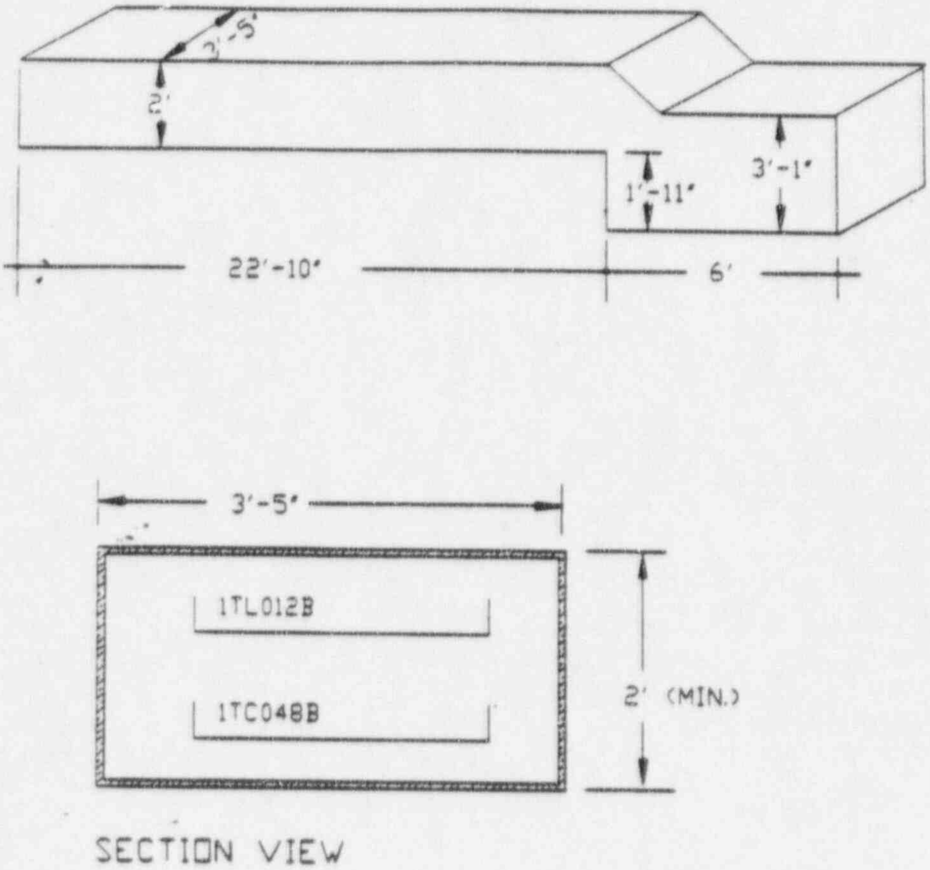
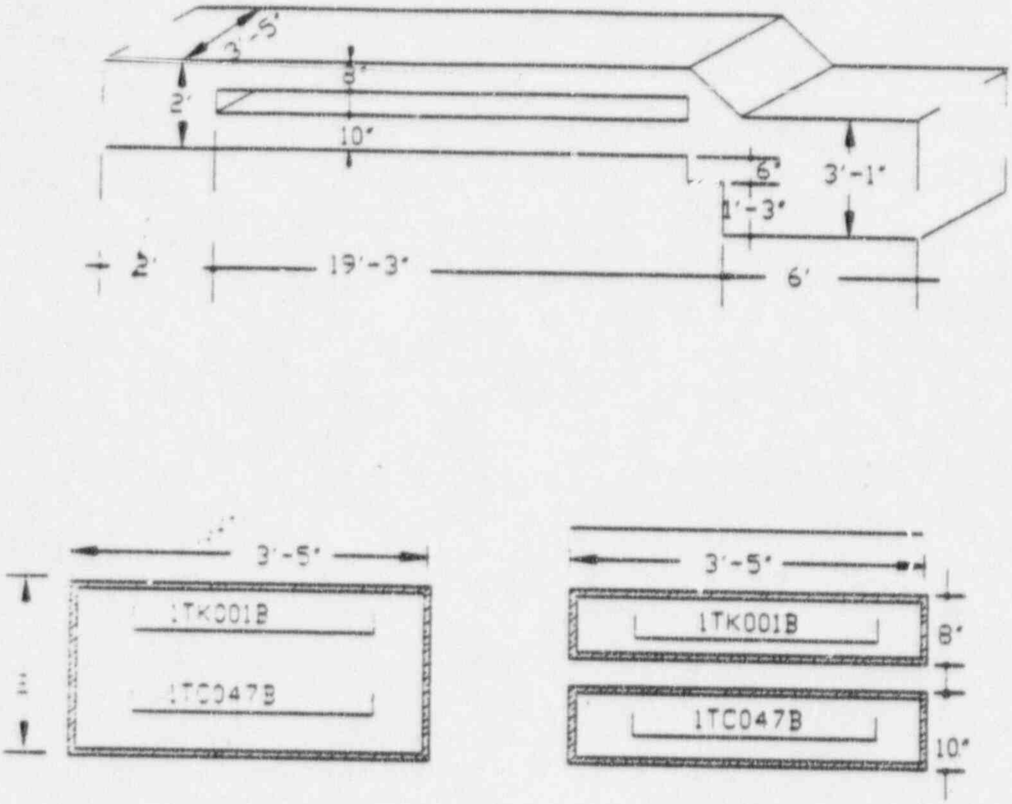


Figure 5.3: Configuration U3a-h1/h3



(LEFT END)

(CENTRAL SECTION)

Figure 5.4 **Configuration U3b-h1/h3**

6.0 REFERENCES

1. VECTRA Project Instructions Titled "*Ampacity Derating Evaluation,*" PI-0103-00203.002-101, Revision 1.

2. Early, M. W. et al, *National Electric Code Handbook*, Sixth Edition, 1993, National Fire Protection Association.

3. IEEE/IPCEA Standard S-135/P-46-426, *Power Cable ampacities: Volume I -Copper conductors and Volume II -Aluminum Conductors*, 1984.

4. Memorandum from A. Adrian (VECTRA) to T. Dogan (VECTRA) dated June 4, 1996. (Included in appendix B)

5. Stolpe, *Ampacities for Cables in randomly Filled Trays*, IEEE Transactions Paper No. 70 TP 557-PWR, April 1970.

6. Ozisik, M. N., *Basic heat Transfer*, McGraw-Hill, 1977.

7. McAdams, *Heat Transmission*, McGraw-Hill, 1954.

8. ICEA Standard Publication, *Ampacities of Cables in Open-top Cable Trays*, ICEA P-54-440 (Third Edition), NEMA WC 51-1986.

9. Safety Evaluation Report by the Office of Nuclear Reactor Regulation, *Ampacity Issues Related to Thermo-Lag Fire Barriers, Texas Utilities Electric Company, Comanche Peak Steam Electric Station, Unit 2, Docket No. 50-446*, US Nuclear Regulatory Commission, June 14, 1995.

10. Rohsenow, *Handbook of heat Transfer*, McGraw Hill, 1973.

11. Test Report by United States Testing company, Inc. dated July 1994.

12. Memorandum from L. Ester (VECTRA) to T. Dogan (VECTRA) dated 6/7/96 (Included in Appendix B)

13. Memorandum from A. Adrian (VECTRA) to T. Dogan (VECTRA) dated May 31, 1996. (Included in appendix B)

REF PAGE

14. VECTRA Report Titled "Thermo-Lag Assessment for Entergy Operations Inc., River Bend Station (640.201-795-007A), September 1996

15. Neher J. H., and M. H. McGrath, *The calculation of The Temperature Rise and Load Capability of Cable Systems*, AIEE Transactions, vol. 76, Oct. 1957, pp. 752-72.

16. Holman, J. P., *Heat Transfer*, McGraw Hill, 1963.

17. Omega Point Report Titled *"Ampacity Derating of Fire Protected Cables"* Prepared for TU Electric, Omega Point Project No. 12340-94583, 95165-95168, 95246, March 19, 1993.

ENTERGY	APPENDIX A ENTERGY OPERATIONS INCORP.	CALCULATION NUMBER	REV
		G13.18.14.0-178	0
		JBI NO.	
		PAGE A1 OF 7	

REF PAGE

APPENDIX A

CALCULATION REVIEW SHEET

ENTERGY

CALCULATION REVIEW SHEET

ENTERGY OPERATIONS INCORP.

CALCULATION NUMBER	REV
G13.18.14.0-178	0
JBI NO.	
PAGE A2 OF 7	

ITEM	CALC PAGE	COMMENT	RESPONSE RESOLUTION
		SEE PAGE A3	SEE PAGES A4 THROUGH A7

COMMENTS PREPARED BY		COMMENTS RESOLVED		RESOLUTION ACCEPTED	
REVIEWER	DATE	PREPARER	DATE	REVIEWER	DATE

ENTERGY	**CALCULATION REVIEW SHEET** ENTERGY OPERATIONS INCORP.	CALCULATION NUMBER G13.18.14.0-178 JBI NO.	REV 0
		PAGE A3 OF 7	

RBG-43119
ED-96-0268
Attachment 1
Page 1 of 1

Comments on Calculation G13.18.14.0-178 on Ampacity Derating Factors
by John Lynch, 7/22/96 Phone 504-336-6437

1 Conversation with Rudy Kerar indicate that the configurations studied are very similar to those at RBS.

2 How realistic(or conservative) is Assumption 4, regarding the types of cable considered?

3 Please provide a copy of the sheet(s) referred to for Equation 3

4 In equation 2, is I the current per cable?

5 On Page 8 - how are air gaps between cables accounted for?

6 Where is Kbed computed?

7 Equation 5 - should Tn be replaced with Tr?

8 The overall approach used is to compute the heat transfer from the conductor to the raceway, then the heat transfer from the raceway to the enclosure, then from the enclosure out. This method is straightforward, but may lead to some errors. Recent work has been done to compute an overall heat transfer coefficient from a heat source inside an enclousre to the outside, e.g. "An Experimental Study on Natural Convection Heat Transfer in an Inclined Square Enclosure Containing Heat Sources" by Lee and Gpoldstein, J. Heat Trans, May 1988., p. 345 (among others)

9 What factor of uncertainty is applied to the results of this calculation? It does not appear that there are any, although there may be uncertainties of, perhaps, + or - 30%.

10 Equation 8 - the form of the equation appears to be from one surface to an enclousre, not from one surface to another.

11 Equation 10 - See Comment 8 and please define At, Art

12 What is being used to perform the itrative calculations? The gray box described is not visible in the copy we have here.

ENTERGY

CALCULATION REVIEW SHEET
ENTERGY OPERATIONS INCORP.

CALCULATION NUMBER	REV
G13.18.14.0-178 JBI NO.	0
PAGE A4 OF 7	

Attachment I
Responses to Comments on Calculation G13.18.14.0-178
Page 1 of 3

Comments by Mr. R. Kerar

1 *Provide a comparison of the TU Comanche Peak Thermo-Lag configurations to the Thermo-Lag configurations at RBS and justify the applicability of the TU one hour Ampacity Derating Factors to RBS.*

R The comparison and justification is discussed in Section 5.2.

2. *Reference the applicable equations in the Tables of Section 4.0*

R Applicable equations are referenced in the Tables of Section 4.0 and Section 5.

General comments listed in the Attachment to R. Kerar's letter (J. Lynch).

1 *Conversation with Rudy Kerar indicate that the configurations studied are very similar to those at RBS.*

R Please see the response to Mr. Kerar's comment No. 1 above.

2 *How realistic (conservative) is assumption 4, regarding the types of cable considered ?*

R As stated in the calculation ampacity is directly related to the maximum heat that can be generated in the raceway and dissipated to the ambient without exceeding the allowable conductor (or insulation) temperature. For a given raceway and fire barrier combination this limiting heat generation rate is independent of the size of the cable. The calculation is not attempting to determine the absolute ampacity but the reduction in ampacity due to the addition of a fire barrier. This reduction in ampacity is also directly related to the reduction in the limiting heat generation rate which is independent of the cable size. Therefore, assumption 4 is a realistic assumption. It simplifies the calculation but does not affect the conservatism of the results.

3 *Please provide a copy of the sheet(s) referred to for Equation 3*

R The relevant pages of the reference document for equation are include in Appendix B to the calculation.

Attachment I
Responses to Comments on Calculation G13.18.14.0-178
Page 2 of 3

4 In equation 2, is I the current per cable?

R. "I" in Equation 2 is the current per conductor. Clarification is added to the definition in the calculation

5 On page 8 -how are air gaps between cables accounted for.

R Air gaps between the cables are accounted for in the thermal conductivity (k_{bed}) of the cable bed. This parameter is either empirically determined or back calculated from the published ampacity data.

7 *Equation 5 -should T_a be replaced by T_s?*

R What appears to be T_a in the print is actually T_{ri} (T_ri, surface temperature of the "i" th raceway). Subscript "i" has been eliminated in the calculation.

8 ......*This method is straight forward, but may lead to some errors. Recent work has been done to compute an overall heat transfer coefficient from a heat source inside an enclosure to outside, e.g. "An Experimental Study on Natural Convection Heat Transfer in an Inclined Square Enclosure Containing Heat Sources" by Lee and Goldstein, J. Heat Trans., May 1988, p. 345 (among others).*

R The method has been kept intentionally straightforward and has been based on conventional well established heat transfer principles rather than case-specific empirical equations. The configurations at RBS have two dominant features: (1) natural convection is always in parallel with radiative heat transfer which is the dominant mode of heat transfer, (2) the main heat transfer resistance is due to the Thermo-Lag enclosure. For these reasons a detailed investigation of the natural convection heat transfer as it applies to the configurations at RBS was not attempted. Instead, the parameters describing the natural convection were chosen on the conservative side.

9 What factor of uncertainty is applied to the results of this calculation? It does not appear that there are any, although there may be uncertainties of, perhaps + or - 30%.

R. There is no uncertainty factor applied to the results. The input data used for calculating the Ampacity Derating Factors are chosen on the conservative side (See assumptions 2, 3, 5, 7, 8, 9, and 10).

Attachment I
Responses to Comments on Calculation G13.18.14.0-178
Page 3 of 3

10 *Equation 8 -the form of the equation appears to be from one surface to an enclosure, not from one surface to another.*

R Equation 8 is for heat transfer from a surface to a fluid medium (or vice versa). Surface to surface heat transfer is calculated using the heat transfer coefficient defined by Equation 11.

11 *See comment 8 and define Ai, Ari.*

R A_i is the heat transfer area of the "*i*"th raceway in a common enclosure. In Equation 10 it was also shown, inadvertently, as A_{ri}. In the revised version of the calculation individual raceways are designated by the subscript "*r*" instead of "*i*".

12 *What is being used to perform the iterative calculations. The gray box described is not visible in the copy we have here.*

R. Iterations are performed over three parameters: ampacity, inside surface temperature of the barrier, and the enclosure air temperature. The Tables in Section 4.0 are revised to show the iteration parameters enclosed in solid frames.

Comments Marked up on The Calculation

- All editorial comments are incorporated except the numbers for the References.
- References (or the basis) of the equations are stated.
- Relevant pages of the references are included in Appendix B.
- Cover page is changed to Entergy cover page.

Entries in the Tables of Section 4.0 will be labeled with the applicable equation numbers. Symbols used in the Tables will be consistent with the symbols used in Section 3.0 of the calculation.

Attachment II
Responses to Comments on Calculation G13.18.14.0-178
Page 1 of 1

Derivation of Equation 11

Starting with Equation 10 and noting that it consist of three equations as follows:

$$q_c = A_r h_{c-rw}(T_r - T_a) \tag{10.1}$$

$$q_c = A_b h_{c-ab}(T_a - T_{b-in}) \tag{10.2}$$

$$\vdots$$

$$q_c = A_r h_{c-rb}(T_r - T_{b-in}) \tag{10.3}$$

rewriting these equations as

$$\frac{q_c}{A_r h_{c-rw}} = T_r - T_a \tag{10.4}$$

$$\frac{q_c}{A_b h_{c-ab}} = T_a - T_{b-in} \tag{10.5}$$

$$\frac{q_c}{A_r h_{c-rb}} = T_r - T_{b-in} \tag{10.6}$$

Adding equations 10.4 and 10.5

$$\frac{q_c}{A_r h_{c-rw}} + \frac{q_c}{A_b h_{c-ab}} = T_r - T_{b-in} \tag{10.7}$$

combining Equations 10.6 and 10.7

$$\frac{q_c}{A_r h_{c-rw}} + \frac{q_c}{A_b h_{c-ab}} = \frac{q_c}{A_r h_{c-rb}} \tag{10.8}$$

finally, Equation 11 is obtained by solving for h_{c-rb} from Equation 10.8

$$h_{c-rb} = \frac{h_{c-rw}}{1 + (\frac{A_r}{A_b})(\frac{h_{c-rw}}{h_{c-ab}})} \tag{11}$$

APPENDIX B

SELECTED REFERENCES

1. IEEE/IPCEA Standard S-135/P-46-426, *Power Cable ampacities: Volume I -Copper conductors and Volume II -Aluminum Conductors*, 1984. **[Ref. 3]**
2. Memorandum from A. Adrian (VECTRA) to T. Dogan (VECTRA) dated June 4, 1996.). **[Ref. 4]**
3. Ozisik, M. N., *Basic heat Transfer*, McGraw-Hill, 1977. **[Ref. 6]**
4. McAdams, *Heat Transmission*, McGraw-Hill, 1954. **[Ref. 7]**
5. ICEA Standard Publication, *Ampacities of Cables in Open-top Cable Trays*, ICEA P-54-440 (Third Edition), NEMA WC 51-1986. **[Ref. 8]**
6. Safety Evaluation Report by the Office of Nuclear Reactor Regulation, *Ampacity Issues Related to Thermo-Lag Fire Barriers, Texas Utilities Electric Company, Comanche Peak Steam Electric Station, Unit 2, Docket No. 50-446*, US Nuclear Regulatory Commission, June 14, 1995. **[Ref. 9]**
7. Rohsenow, *Handbook of heat Transfer*, McGraw Hill, 1973. **[Ref. 10]**
8. Memorandum from L. Ester (VECTRA) to T. Dogan (VECTRA) dated 6/7/96. **[Ref. 12]**
9. Memorandum from A. Adrian (VECTRA) to T. Dogan (VECTRA) dated May 31, 1996. **[Ref. 13]**
10. Neher J. H., and M. H. McGrath, *The calculation of The Temperature Rise and Load Capability of Cable Systems*, AIEE Transactions, vol. 76, Oct. 1957, pp. 752-72. **[Ref. 15]**
11. Holman, J. P., *Heat Transfer*, McGraw Hill, 1963. **[Ref. 16]**

IEEE S-135
IPCEA Pub. No. P-46-426

Power Cable Ampacities

Volume I—Copper Conductors

INSULATIONS:	IMPREGNATED PAPER VARNISHED CLOTH RUBBER AND THERMOPLASTIC ASBESTOS-VARNISHED CLOTH
INSTALLATIONS:	IN UNDERGROUND DUCTS BURIED DIRECTLY IN EARTH IN FREE AIR IN CONDUIT

IPCEA

Sponsored and Computed by
Insulated Power Cable Engineers Association

In Collaboration with
Insulated Conductors Committee
IEEE Power Engineering Society

Published by
Institute of Electrical and Electronics Engineers, Inc
345 East 47th St., New York, NY 10017, USA
Third Printing 1984

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                                                                  -205-

          THREE CONDUCTOR CONCENTRIC STRANDED RUBBER INSULATED CABLES IN AIR
                        ISOLATED CABLE 40 C AMBIENT AIR
                       COPPER CONDUCTOR CONCENTRIC STRAND
         VOLTAGE KV                                          VOLTAGE KV
 SIZE     1      8      15                                 1     8       15
            AMPACITY                                         DELTA TD
             CONDUCTOR TEMPERATURE 90 C INSULATION P F  .0350

    8     59
    6     79     93                                              0.18
    4    104    122                                              0.19
    2    138    159    166                                       0.21    0.49
    1    161    184    187                                       0.22    0.52

  1/0    186    211    219                                       0.23    0.54
  2/0    215    243    246                                       0.26    0.55
  3/0    249    279    283                                       0.28    0.57
  4/0    287    321    325                                       0.30    0.59

  250    320    355    359                                       0.40    0.61
  350    396    439    436                                       0.20    0.64
  500    487    530    536                                       0.29    0.68
  750    615    660    669                                       0.31    0.71
 1000    787    766    770                                       0.32    0.76


                                CABLE CONSTANTS
                  THREE CONDUCTOR RUBBER INSULATED CABLES IN AIR
                       COPPER CONDUCTOR CONCENTRIC STRAND
             SIZE     OD      WD      RI      RSD      RS      RAC

                             1 KV 75 C CONDUCTOR

                8   0.700          4.997   12.680   1.000   779.85
                6   0.809          5.010   10.620   1.000   490.32
                4   0.992          4.385    9.740   1.000   307.85
                2   1.121          4.839    8.017   1.000   194.62
                1   1.309          4.194    7.746   1.000   154.10

              1/0   1.397          3.920    7.130   1.000   121.92
              2/0   1.496          3.712    6.912   1.000    97.00
              3/0   1.600          3.513    6.180   1.000    77.20
              4/0   1.761          3.400    5.907   1.000    61.42

              250   1.927          3.422    5.537   1.000    52.19
              350   2.129          3.194    5.010   1.000    37.72
              500   2.472          3.011    4.420   1.000    27.20
              750   2.959          2.880    3.776   1.000    19.40
             1000   3.303          2.711    3.300   1.000    15.09


                             8 KV 75 C CONDUCTOR

                6   1.472   0.019   3.172    7.000   1.001   490.32
                4   1.579   0.022   2.616    6.611   1.002   307.85
                2   1.739   0.025   2.400    6.075   1.003   194.56
                1   1.821   0.028   2.316    5.822   1.004   154.00

              1/0   1.909   0.030   2.176    5.503   1.000   121.60
              2/0   2.000   0.033   2.030    5.250   1.000    96.90
              3/0   2.110   0.036   1.912    5.009   1.010    77.03
              4/0   2.275   0.039   1.796    4.771   1.013    61.27

              250   2.377   0.042   1.712    4.505   1.017    52.60
              350   2.609   0.046   1.506    4.217   1.026    37.35
              500   2.809   0.056   1.430    3.839   1.040    26.90
              750   3.320   0.066   1.290    3.370   1.064    19.12
             1000   3.602   0.075   1.222    3.055   1.086    15.46
```

THREE CONDUCTOR CONCENTRIC STRANDED RUBBER INSULATED CABLES IN CONDUIT

ISOLATED CABLE 40 C AMBIENT AIR

COPPER CONDUCTOR CONCENTRIC STRAND

CONDUCTOR TEMPERATURE 90 C INSULATION P F .0350

	AMPACITY			DELTA TD		
	VOLTAGE KV			VOLTAGE KV		
SIZE	1	8	15	1	8	15
8	52					
6	69	83				
4	91	107			0.24	
2	123	143	147		0.26	
1	141	163	167		0.27	0.66
					0.29	0.66
1/0	166	186	190			
2/0	190	212	220		0.30	0.60
3/0	218	247	251		0.32	0.72
4/0	255	280	289		0.32	0.73
					0.36	0.76
250	282	313	317			
350	340	376	386		0.36	0.79
500	429	458	475		0.37	0.82
750	526	571	569		0.39	0.85
1000	590	630	640		0.39	0.93
					0.42	0.93

CABLE CONSTANTS

THREE CONDUCTOR RUBBER INSULATED CABLES IN CONDUIT

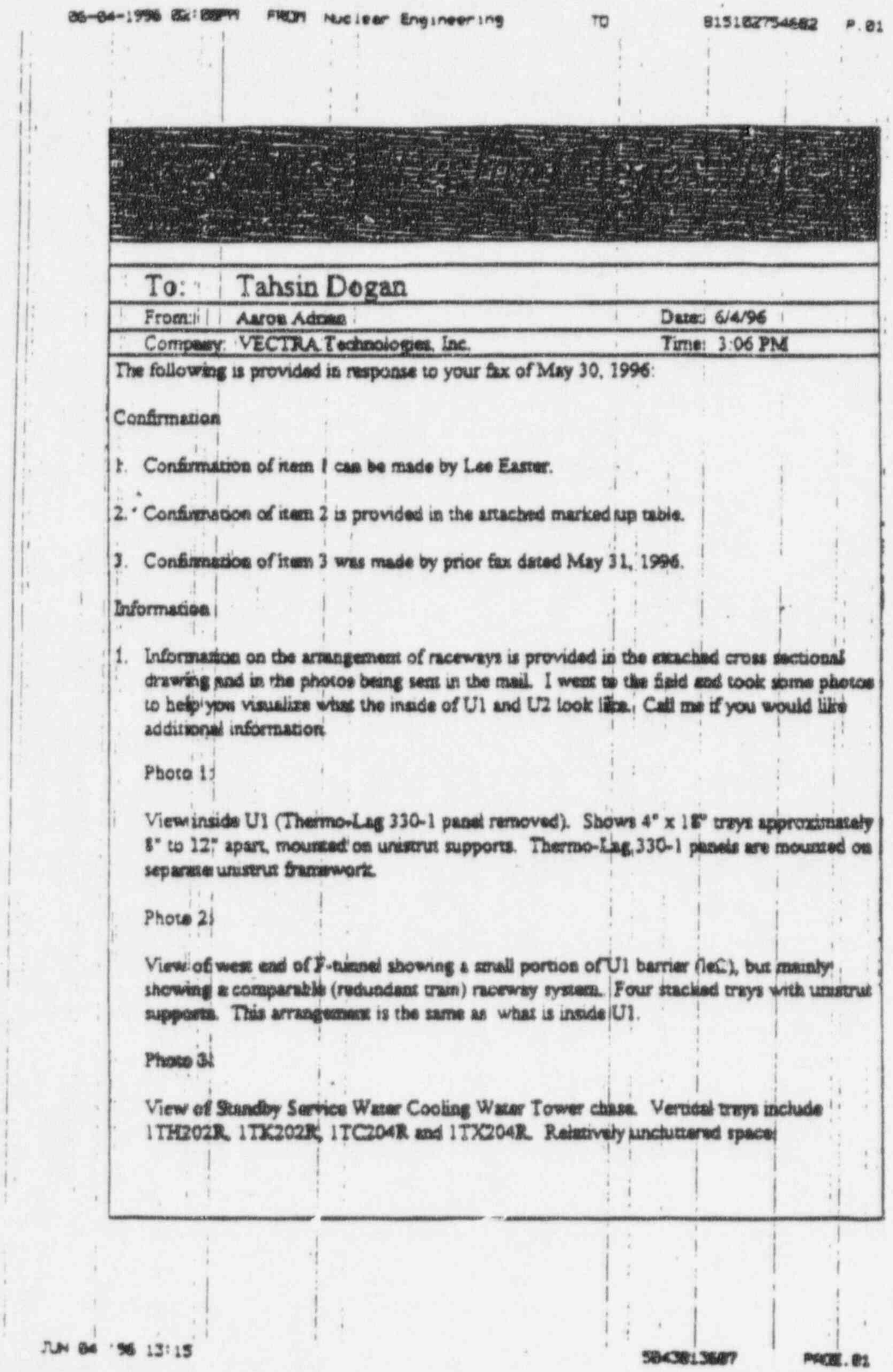
COPPER CONDUCTOR CONCENTRIC STRAND

1 KV 75 C CONDUCTOR

SIZE	OD	SD	RI	RSD *	YS	RAC
8	0.700		4.997	10.690	1.000	779.03
6	0.829		5.010	8.097	1.000	490.32
4	0.992		4.905	8.121	1.000	307.80
2	1.121		4.099	7.322	1.000	194.73
1	1.309		4.136	6.084	1.000	154.24
1/0	1.359		3.999	6.060	1.000	122.60
2/0	1.496		3.713	5.695	1.000	97.35
3/0	1.606		3.512	5.345	1.000	77.67
4/0	1.761		3.406	4.920	1.000	61.83
250	1.929		3.422	4.336	1.000	52.65
350	2.159		3.150	4.097	1.000	38.41
500	2.472		3.011	3.480	1.000	26.27
750	2.959		2.806	3.060	1.000	20.06
1000	3.303		2.711	2.760	1.000	16.80

8 KV 75 C CONDUCTOR

SIZE	OD	SD	RI	RSD *	YS	RAC
6	1.472	0.019	3.172	5.776	1.001	490.32
4	1.575	0.022	2.814	5.430	1.003	307.80
2	1.795	0.025	2.408	4.967	1.005	194.60
1	1.821	0.028	2.318	4.775	1.007	154.15
1/0	1.909	0.030	2.176	4.573	1.009	121.90
2/0	2.006	0.033	2.038	4.367	1.012	97.17
3/0	2.110	0.036	1.912	4.159	1.017	77.49
4/0	2.275	0.039	1.784	3.866	1.022	61.36
250	2.377	0.042	1.712	3.739	1.030	52.40
350	2.605	0.048	1.506	3.436	1.042	38.40
500	2.889	0.056	1.430	3.117	1.059	27.03
750	3.188	0.066	1.299	2.790	1.102	20.06
1000	3.652	0.075	1.222	2.600	1.135	17.41



06-04-1996 02:08PM FROM Nuclear Engineering TO 815182754682 P.01

To:	Tahsin Dogan		
From:	Aaron Adams	Date:	6/4/96
Company:	VECTRA Technologies, Inc.	Time:	3:06 PM

The following is provided in response to your fax of May 30, 1996:

Confirmation

1. Confirmation of item 1 can be made by Lee Easter.
2. Confirmation of item 2 is provided in the attached marked up table.
3. Confirmation of item 3 was made by prior fax dated May 31, 1996.

Information

1. Information on the arrangement of raceways is provided in the attached cross sectional drawing and in the photos being sent in the mail. I went to the field and took some photos to help you visualize what the inside of U1 and U2 look like. Call me if you would like additional information.

   Photo 1)

   View inside U1 (Thermo-Lag 330-1 panel removed). Shows 4" x 18" trays approximately 8" to 12" apart, mounted on unistrut supports. Thermo-Lag 330-1 panels are mounted on separate unistrut framework.

   Photo 2)

   View of west end of F-tunnel showing a small portion of U1 barrier (left), but mainly showing a comparable (redundant train) raceway system. Four stacked trays with unistrut supports. This arrangement is the same as what is inside U1.

   Photo 3)

   View of Standby Service Water Cooling Water Tower chase. Vertical trays include 1TH202R, 1TK202R, 1TC204R and 1TX204R. Relatively uncluttered space.

JUN 04 '96 13:15 5043813607 PAGE.01

06-04-1996 02:09PM FROM Nuclear Engineering TO 815182754682 P.02

Photo 4:

View from inside of cooling tower chase looking at the opening into U2, Thermo-Lag 330-1 encased trays (in G-tunnel). The only trays that can be seen in this area are 1TH201R, 1TC202R and 1TX202R, and the only conduits that can be seen in the Thermo-Lag 330-1 boxed area are 1CK600NM2, 1CC270NQ, 1CK600ND2, 1CK600RA7 and 1CC270NP. Note: The conduits and trays are not wrapped separately.

Photos will follow in the mail, I hope they will be helpful.

2. Information concerning material thickness was identified per telephone conversation as:
   1 hour panel = 1/2 inch + 1/8 inch/- 0 inches.
   3 hour panel = 1 inch + 1/4 inch/- 0 inches.
   1 hour preformed half round = 1/2 inch + 1/8 inch/- 0 inches.
   3 hour preformed half round = 1 inch + 1/4 inch/- 0 inches.

3. The north wall of F and G tunnels scales between 2'-6" and 3'-0" on drawing EE-37Y. Call me if more accurate information is required.

4. The Thermo-Lag 330-1 preformed half rounds are rough shaped and installation was dry mounted to the conduit so that gaps and spaces were not filled. It is reasonable to assume a maximum of 1/4 inch gap on one side of the conduit.

5. NA

6. Good question. Drawing EE-590A indicates that junction box 1*JB2072 is connected to conduit 1CX9110A which runs through the F-tunnel to junction box 1*JB2104. PDMS indicates that 1*JB2072 is located in the F-tunnel but contains no cables and has no connecting conduit. Backtracking, PDMS identifies 1*JB2104 connected to 1CX9110A connected to 1*JB0272. PDMS lists cables HNOX409 and 1CSHNOX410 in 1*JB0272. We cannot ascertain at this time number is correct but we can assume that there is only one junction box at the end o conduit, therefore, use the two cables identified above as the contents of 1*JB2072.

mounted on the wall of U1

7. Information can be provided by Lee Easter.

Thanks,

Aaron Adrian
(504) 381-4508

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06-04-1996 02:10PM FROM Nuclear Engineering TO 815182754682 P.03

Table 1 Unique Configuration

Config.	Raceway	Fire Zone	Area	Enclosure Description	EE-34Y Detail
U1 1-hour	1"JB2072 ✓ ~~1CC600NA6~~ → side 1CK600NA1 ≈ 10" WITHIN ENCLOSURE 1CK600NA6 ?' NO CONFIRMATION ~~1CK600NA1~~ Duplicated ~~1CK800NAD~~ INVALID NO. ~~1CK800NAD~~ Duplicate 1CX911OA ≈ 2' WITHIN ENCLOSURE 1TC200R ✓ 1TH200R ✓ 1TK200R ✓ 1TX200R ✓	PT1	Along North wall of Tunnel "F"	2-sided box (side & bottom) approx. 6 ft. wide x 8 ft. high x 125 ft. long	BJ, BL & See 4/12 FAX, Attach. 1, pg. 1 of 2
	1CK800NA7 ✓ 1CK600ND2 ✓ 1TC201R ✓ 1TC202R ✓ 1TC203R ✓ 1TC204R IN VERTICAL CHASE ~~1TC205R~~ AT TOP OF CHASE 1TH201R ✓ 1TH202R IN VERTICAL CHASE ~~1TH203R~~ AT TOP OF CHASE ~~1TH204R~~ AT TOP OF CHASE ~~1TH206R~~ NA 1TX201R ✓ 1TX202R ✓ 1TX203R ✓	PT1	Along North wall of Tunnel "G"	2-sided box (side & bottom) approx. 6 ft. wide x 8 ft. high x 45 ft. long	BF, BJ
U3a 3-hour	1TC048B ✓ 1TL012B ✓	C16	Trays 1TC048B & 1TL012B	See 4/2 A. Adrian FAX	BF
U3b 3-hour	1TC047B ✓ 1TK001B ✓ 1TK002B ✓	C16	Trays 1TK001B, 1TK002B and 1TC047B	See 4/2 A. Adrian FAX	BF
STD 3-hour conduit		Var.		single conduit covered with preshaped half rounds	BA
STD 3-hour tray/Jb		Var.		single tray or junction box covered with panels	

ENTERGY

APPENDIX B
ENTERGY OPERATIONS INCORP.

CALCULATION NUMBER	REV
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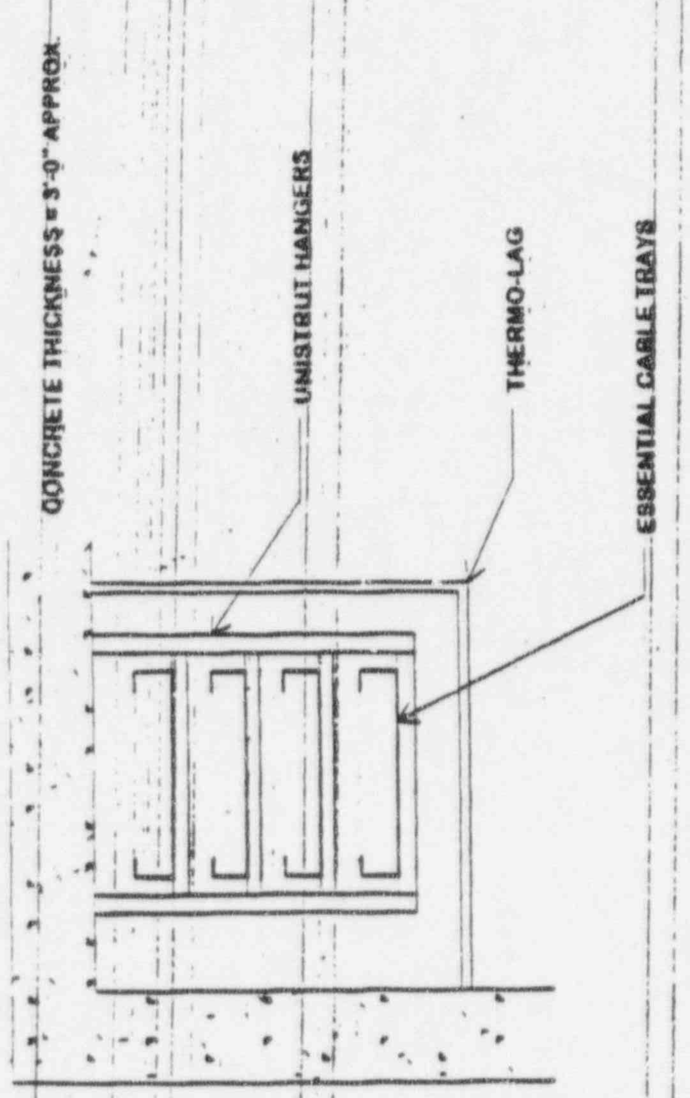

APPROXIMATELY 8 INCHE DISTANCE BETWEEN CABLE TRAYS.
UNISTRUT CABLE TRAY SUPPORTS ARE APPROXIMATELY 6 INCHES WIDE.
THERE IS APPROXIMATELY 6 INCHES OF CLEARANCE BETWEEN THE SUPPORTS AND THE THERMO-LAG MATERIAL

COMPARABLE CONSTRUCTION THCHNIQUES
ARE USED FOR ENCLOSURES U1 AND U2

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BASIC HEAT TRANSFER

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Then Eq. (1-5) is written in the form

$$q = h_r(T_1 - T_2) \tag{1-7}$$

which is analogous to Eq. (1-2) for convective heat transfer. This approximate, simple expression for radiative-heat flux given by Eq. (1-7) is applicable only if $|T_1 - T_2|/T_1 \ll 1$.

1-4 COMBINED CONVECTION AND RADIATION

When heat transfer by convection and by radiation are of the same order of magnitude and occur simultaneously, a proper analysis of heat transfer by taking into consideration the interaction between the two modes of heat transfer is a very complicated matter. On the other hand, under very restrictive conditions the heat transfer by simultaneous convection and radiation can be determined approximately by linear superposition of heat fluxes due to these two different modes of heat transfer. Consider, for example, the flow of hot combustion products at temperature T_g through a cooled duct whose walls are kept at temperature T_w. Combustion products such as CO_2, CO, and H_2O absorb and emit radiation. Therefore, the heat transfer from the gas to the channel walls is by both convection and radiation, and a proper analysis of this heat-transfer problem requires a simultaneous solution of convection and radiation problems; but this is a very complicated matter. If the radiative component of the heat flux is not very strong, the total heat flux q from the gas to the wall surface may be computed approximately by taking the sum of the convective heat flux q_c and the radiative heat flux q_r as

$$q = q_c + q_r \tag{1-8}$$

When the relations for the convective and radiative heat flux given by Eqs. (1-2) and (1-7) are introduced into Eq. (1-8) we find

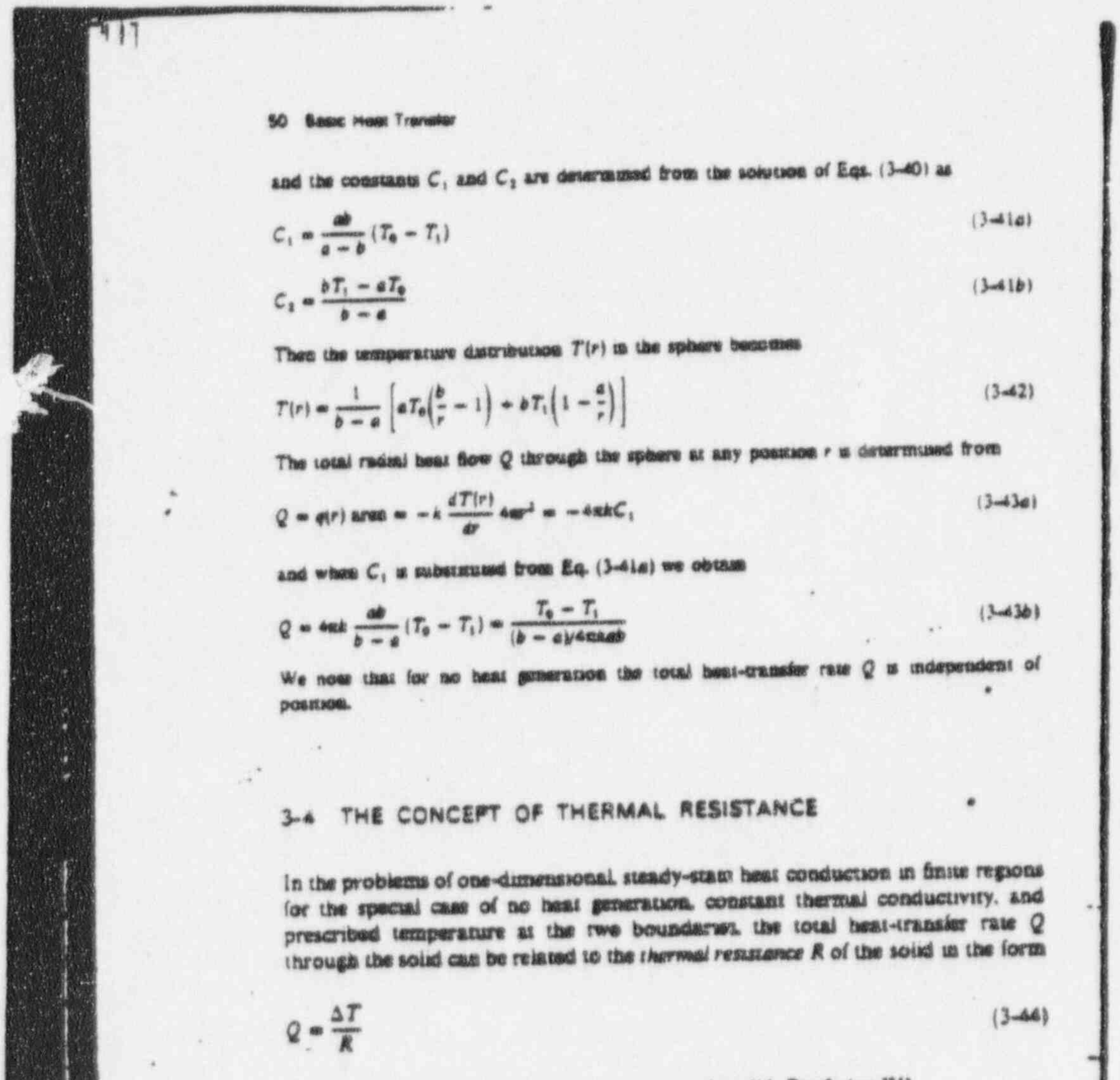
$$q = h_c(T_g - T_w) + h_r(T_g - T_w) = (h_c + h_r)(T_g - T_w)$$

or

$$q = h_{cr}(T_g - T_w) \tag{1-9a}$$

where the *combined convection and radiation heat-transfer coefficient* h_{cr} is defined as

$$h_{cr} = h_c + h_r \tag{1-9b}$$



50 Basic Heat Transfer

and the constants C_1 and C_2 are determined from the solution of Eqs. (3-40) as

$$C_1 = \frac{ab}{a-b}(T_0 - T_1) \tag{3-41a}$$

$$C_2 = \frac{bT_1 - aT_0}{b-a} \tag{3-41b}$$

Then the temperature distribution $T(r)$ in the sphere becomes

$$T(r) = \frac{1}{b-a}\left[aT_0\left(\frac{b}{r} - 1\right) + bT_1\left(1 - \frac{a}{r}\right)\right] \tag{3-42}$$

The total radial heat flow Q through the sphere at any position r is determined from

$$Q = q(r)\,\text{area} = -k\frac{dT(r)}{dr}4\pi r^2 = -4\pi k C_1 \tag{3-43a}$$

and when C_1 is substituted from Eq. (3-41a) we obtain

$$Q = 4\pi k\frac{ab}{b-a}(T_0 - T_1) = \frac{T_0 - T_1}{(b-a)/4\pi kab} \tag{3-43b}$$

We note that for no heat generation the total heat-transfer rate Q is independent of position.

3-4 THE CONCEPT OF THERMAL RESISTANCE

In the problems of one-dimensional, steady-state heat conduction in finite regions for the special case of no heat generation, constant thermal conductivity, and prescribed temperature at the two boundaries, the total heat-transfer rate Q through the solid can be related to the *thermal resistance* R of the solid in the form

$$Q = \frac{\Delta T}{R} \tag{3-44}$$

where Q = total heat-transfer rate through solid, Btu/h (or W)
ΔT = difference between temperatures of the two boundary surfaces of the region, °F (or °C)
R = thermal resistance of solid, h · °F/Btu (or °C/W)

The thermal-resistance concept is analogous to the electric-resistance concept defined by the relation

$$\text{Current} = \frac{\text{potential difference}}{\text{electric resistance}} \tag{3-45}$$

Clearly, the total heat flow Q is analogous to the electric current and the temperature difference to voltage difference. The thermal-resistance concept is used in many engineering applications. We now examine the determination of the thermal resistances of a slab, a hollow cylinder, and a hollow sphere.

Slab

Consider the one-dimensional, steady-state heat conduction through a slab in the region $0 \le x \le L$, having a constant thermal conductivity k and boundaries at $x = 0$ and $x = L$ kept at uniform temperatures T_0 and T_1, respectively. The solution of this problem was considered previously in Example 3-1, and the heat flux q was given by $q = k(T_0 - T_1)/L$. Then the total heat-transfer rate Q through an area A of the slab is given by

$$Q = Aq = Ak\,\frac{T_0 - T_1}{L} \equiv \frac{T_0 - T_1}{R_{\text{slab}}} \qquad \text{(3-46a)}$$

where the *thermal resistance of the slab* R_{slab} is defined as

$$R_{\text{slab}} = \frac{L}{Ak} \qquad \text{(3-46b)}$$

Hollow Cylinder

We now consider one-dimensional, steady-state heat conduction through a hollow cylinder in the region $a \le r \le b$, having a constant thermal conductivity k and boundaries at $r = a$ and $r = b$ kept at uniform temperatures T_0 and T_1, respectively. The total heat-transfer rate Q through the cylinder over a length H of the cylinder can be obtained from the solution of the same problem given by Eq. (3-34) as

$$Q = \frac{2\pi kH}{\ln(b/a)}(T_0 - T_1) \equiv \frac{T_0 - T_1}{R_{\text{cyl}}} \qquad \text{(3-47a)}$$

where the *thermal resistance of the cylinder* R_{cyl} is defined as

$$R_{\text{cyl}} \equiv \frac{\ln(b/a)}{2\pi Hk} \qquad \text{(3-47b)}$$

The thermal resistance given by Eq. (3-47b) is now rearranged in a form similar to that for a slab:

$$R_{\text{cyl}} = \frac{\ln(b/a)}{2\pi kH} = \frac{(b-a)\ln(2\pi bH/2\pi aH)}{(b-a)2\pi Hk} = \frac{L_{\text{cyl}}\ln(A_1/A_0)}{(A_1 - A_0)k} \equiv \frac{L_{\text{cyl}}}{A_{\text{cyl}}k} \qquad \text{(3-47c)}$$

REF	PAGE

TABLE 10.6 Simplified Equations for Free Convection to Air at Atmospheric Pressure and Moderate Temperatures†

Geometry	Characteristic Dimension, L	Type of Flow	Range of $Gr_L\,Pr$	Heat Transfer Coefficient, h_m Btu/h ft² °F ‡	Heat Transfer Coefficient, h_m W/m² °C §
Vertical plates and cylinders	Height	Laminar Turbulent	10^4 to 10^9 10^9 to 10^{13}	$h_m = 0.29(\Delta T/L)^{1/4}$ $h_m = 0.19\Delta T^{1/3}$	$h_m = 1.42(\Delta T/L)^{1/4}$ $h_m = 1.31\Delta T^{1/3}$
Horizontal cylinders	Outside diameter	Laminar Turbulent	10^4 to 10^9 10^9 to 10^{12}	$h_m = 0.27(\Delta T/L)^{1/4}$ $h_m = 0.18\Delta T^{1/3}$	$h_m = 1.32(\Delta T/L)^{1/4}$ $h_m = 1.24\Delta T^{1/3}$
Horizontal plates					
(a) Upper surface heated or lower surface cooled	As defined in the text	Laminar Turbulent	10^5 to 2×10^7 2×10^7 to 3×10^{10}	$h_m = 0.27(\Delta T/L)^{1/4}$ $h_m = 0.22\Delta T^{1/3}$	$h_m = 1.32(\Delta T/L)^{1/4}$ $h_m = 1.52\Delta T^{1/3}$
(b) Lower surface heated or upper surface cooled	As defined in the text	Laminar	3×10^5 to 3×10^{10}	$h_m = 0.12(\Delta T/L)^{1/4}$	$h_m = 0.59(\Delta T/L)^{1/4}$

† From McAdams [10].

‡ L is in feet, $\Delta T = T_w - T_\infty$ is in degrees Fahrenheit. These relations may be extended to higher or lower pressures about atmospheric pressure by multiplying by the following factors: $(P/14.7)^{1/2}$ for laminar, $(P/14.7)^{2/3}$ for turbulent, where P is in lb/in² abs.

§ L is in meters, $\Delta T = T_w - T_\infty$ is in degrees Celsius. These relations may be extended to higher or lower pressures about atmospheric pressure by multiplying by the following factors: $(P/1.0132)^{1/2}$ for laminar, $(P/1.0132)^{2/3}$ for turbulent, where P is the pressure in bars.

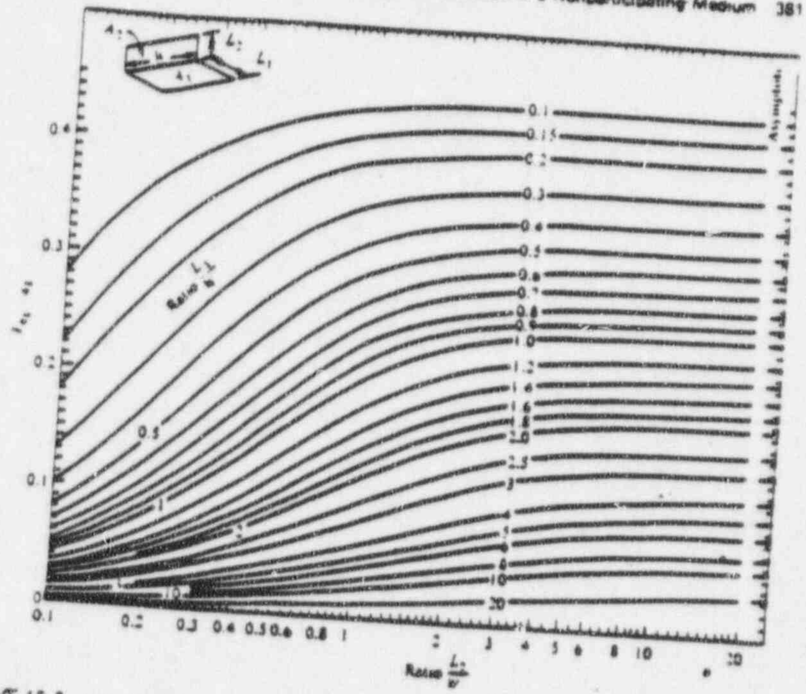


FIG. 12-3 View factor $F_{A_1-A_2}$ from a rectangular surface A_1 to a rectangular surface A_2 which are adjacent and in perpendicular planes. (From Mackey, et al. [18].)

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$$A_2 = A_3 - A_4 - A_5 - A_6 \tag{12-20}$$

Then the view factor $F_{dA_1-A_2}$ can be expressed as the algebraic sum of the view factors from dA_1 to the areas A_i ($i = 3, 4, 5, 6$) as

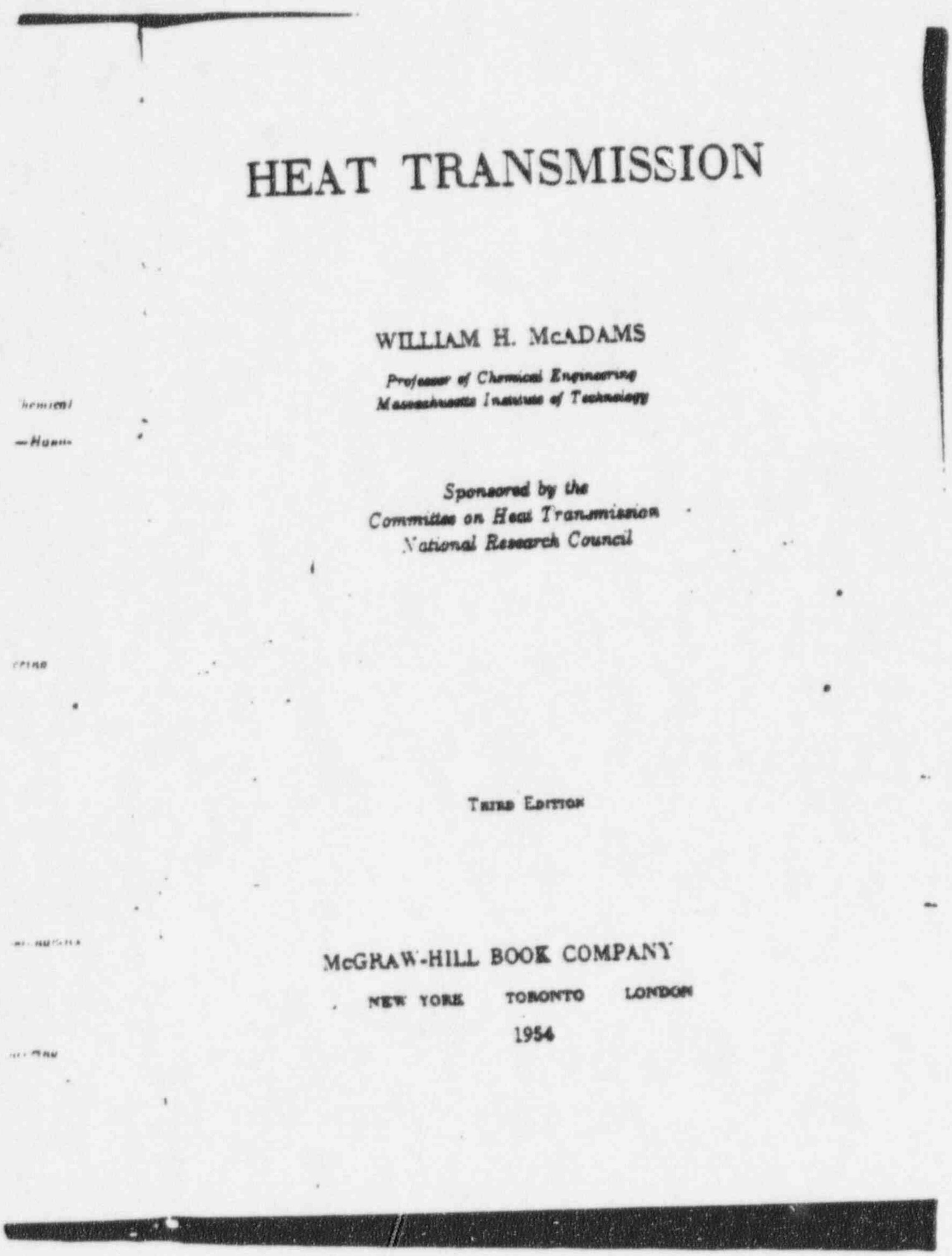
$$F_{dA_1-A_2} = F_{dA_1-A_3} - F_{dA_1-A_4} - F_{dA_1-A_5} + F_{dA_1-A_6} \tag{12-21}$$

Here the view factors on the right-hand side of this equation are obtainable from the view-factor chart given by Fig. 12-2, hence the view factor $F_{dA_1-A_2}$ is determined.

Example 12-1 Determine analytically the view factor from an elemental surface dA_1 to a circular disk A_2 of radius R which are parallel to each other and positioned at a distance L as shown in Fig. 12-7.

TABLE 11-3 Emissivities of Various Surfaces†

Material	Temperature	ε
Asbestos:		
Board	100°F	0.96
Cloth	93°C	0.90
Paper	100°F	0.93
Brick:		
Red	0-93°C	0.93
Red, rough	0-200°C	0.93-0.95
Ceramic:		
Earthenware, glazed	20°C	0.90
Earthenware, matte	20°C	0.93
Porcelain	22°C	0.92
Refractory, black	93°C	0.94
Clay, fired	158°C	0.91
Concrete, rough	0-93°C	0.94
Glass	100°F	0.90
Glass, smooth	100°F	0.94
Ice	32°F	0.92-0.96
Lacquers:		
Black	93°C	0.96
Black, on iron	0-93°C	0.875
Clear, one thin coat on tarnished copper	93°C	0.64
Clear, two coats on tarnished copper	93°C	0.7.
White	20°C	0.95
White, heavy coat on bright copper	93°C	0.93
Lampblack, 0.003 in or thicker	100°F	0.95
Marble, light-grey polished	22°C	0.93
Metals:		
Aluminum, polished	100°F	0.04
Aluminum, oxidized	100°F	0.20
Brass, polished	100°F	0.10
Brass, oxidized	100°F	0.46
Chromium, polished	100°F	0.08
Copper, polished	100°F	0.04
Copper, calorized	100°F	0.18
Copper, oxidized	100°F	0.73
Copper, black oxidized	100°F	0.87
Gold, polished	100°F	0.02
Iron, polished	100°F	0.06
Iron, oxidized	100°F	0.74
Lead, pure polished	100°F	0.05
Lead, gray, oxidized	100°F	0.28
Lead, unoxidized, rough	100°F	0.43
Mercury	100°F	0.10
Molybdenum, polished	100°F	0.06



HEAT TRANSMISSION

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Professor of Chemical Engineering
Massachusetts Institute of Technology

Sponsored by the
Committee on Heat Transmission
National Research Council

THIRD EDITION

McGRAW-HILL BOOK COMPANY
NEW YORK TORONTO LONDON
1954

Weills and Ryder[26] measured contact, or junction, coefficients h_c between metal blocks having surface temperatures t_1 and t_2:

$$h_c = \frac{q/A}{t_1 - t_2} \qquad (2\text{-}14$$

which increased with increased pressure on the blocks. For example, with rough aluminum at 300°F, h_c ranged from 500 at 0 gauge pressure to 11,000 at 3,800 pounds per square inch. At 300°F and a given pressure, h_c increased as roughness decreased. Brunot and Buckland[4] report contact coefficients for machined joints.

Cetinkale and Fishenden[6] measured contact coefficients for metal blocks of steel, brass, and aluminum ground to various degrees of roughness, with air, spindle oil, or glycerol in the voids at the junction. Pressures ranged from 19 to 800 pounds per square inch and h_c ranged from 550 to 12,500. An interesting theory was developed for predicting contact coefficients from fundamental factors.

Heat Meter. Over-all resistances for structures in service may be determined by the use of the heat meter,[16,30] which measures the temperature drop through the known resistance of the meter. By simultaneously measuring the temperature gradient through the wall itself, the thermal conductivity of the whole wall or of any layer may be measured, even though the use of the meter reduces the heat flow compared with that from the bare wall. Precautions should be taken to secure data under steady conditions. Van Dusen and Finck[22] report experimentally determined over-all thermal resistances of a number of walls and also individual resistances of the various components; in general, fairly satisfactory agreement was found between the predicted values and observed results.

UNIFORM INTERNAL GENERATION OF HEAT IN BODIES WITH HEAT DISSIPATION AT ONLY ONE SURFACE

Flat Plate. Consider a flat metal plate ideally insulated except on one surface. Heat is generated uniformly throughout the plate by a steady flow of electricity and is dissipated at the colder surface by transfer to a boiling liquid. Let q_T represent the total generation in Btu per hour. Since the generation is uniform throughout the thickness, the local heat current q_x at distance x from the adiabatic surface is

$$q_x = q_T \frac{x}{x_T} = -kA\frac{dt}{dx}$$

Integration, from $q = 0$ at $x = 0$ to $q = q_T$ at $x = x_T$, gives

$$q_T = \frac{k_m A(t_1 - t_2)}{x_T/2} \qquad (2\text{-}14a)\,*$$

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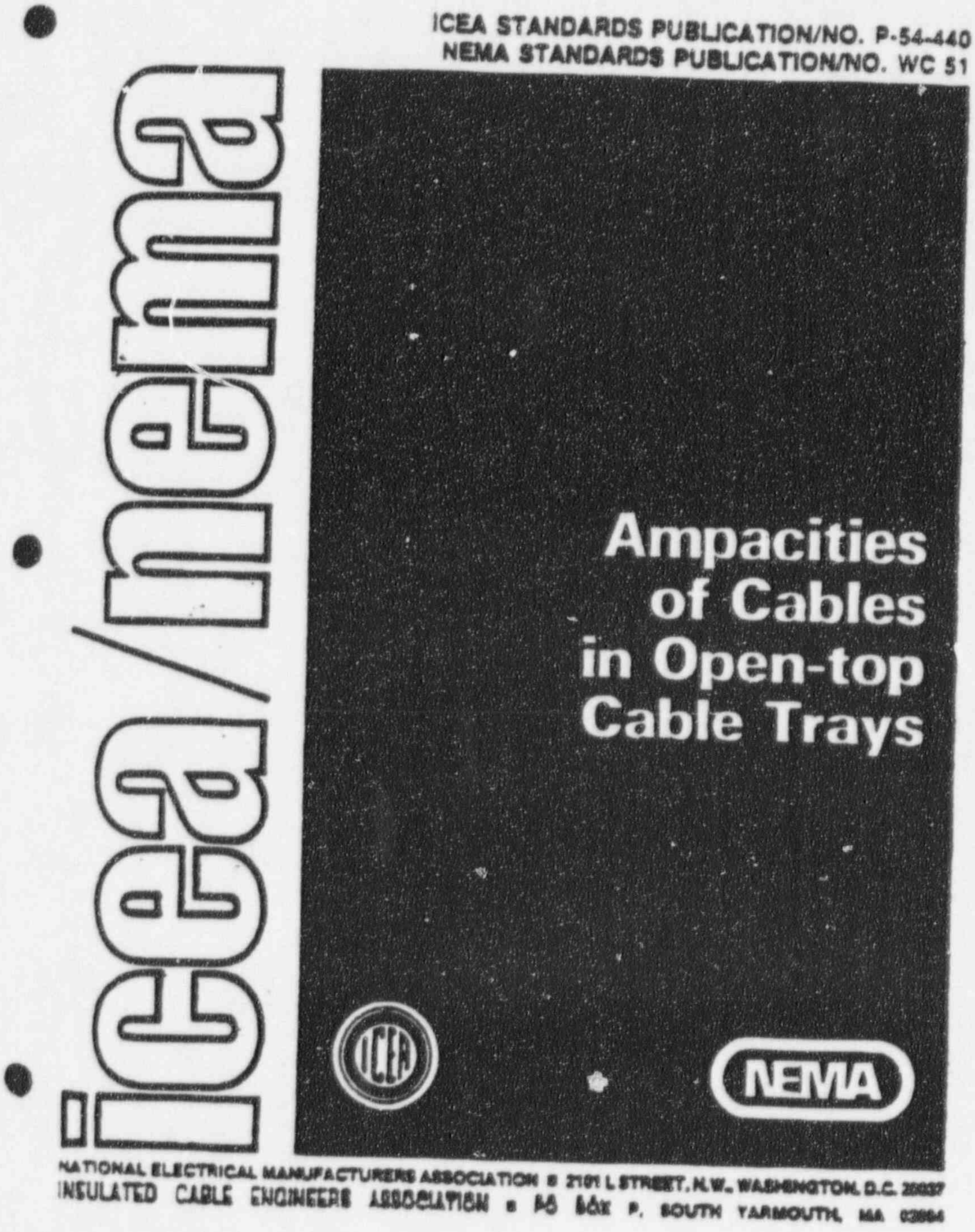

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Ampacities of Cables in Open-top Cable Trays

NATIONAL ELECTRICAL MANUFACTURERS ASSOCIATION ■ 2101 L STREET, N.W., WASHINGTON, D.C. 20037
INSULATED CABLE ENGINEERS ASSOCIATION ■ PO BOX P, SOUTH YARMOUTH, MA 02664

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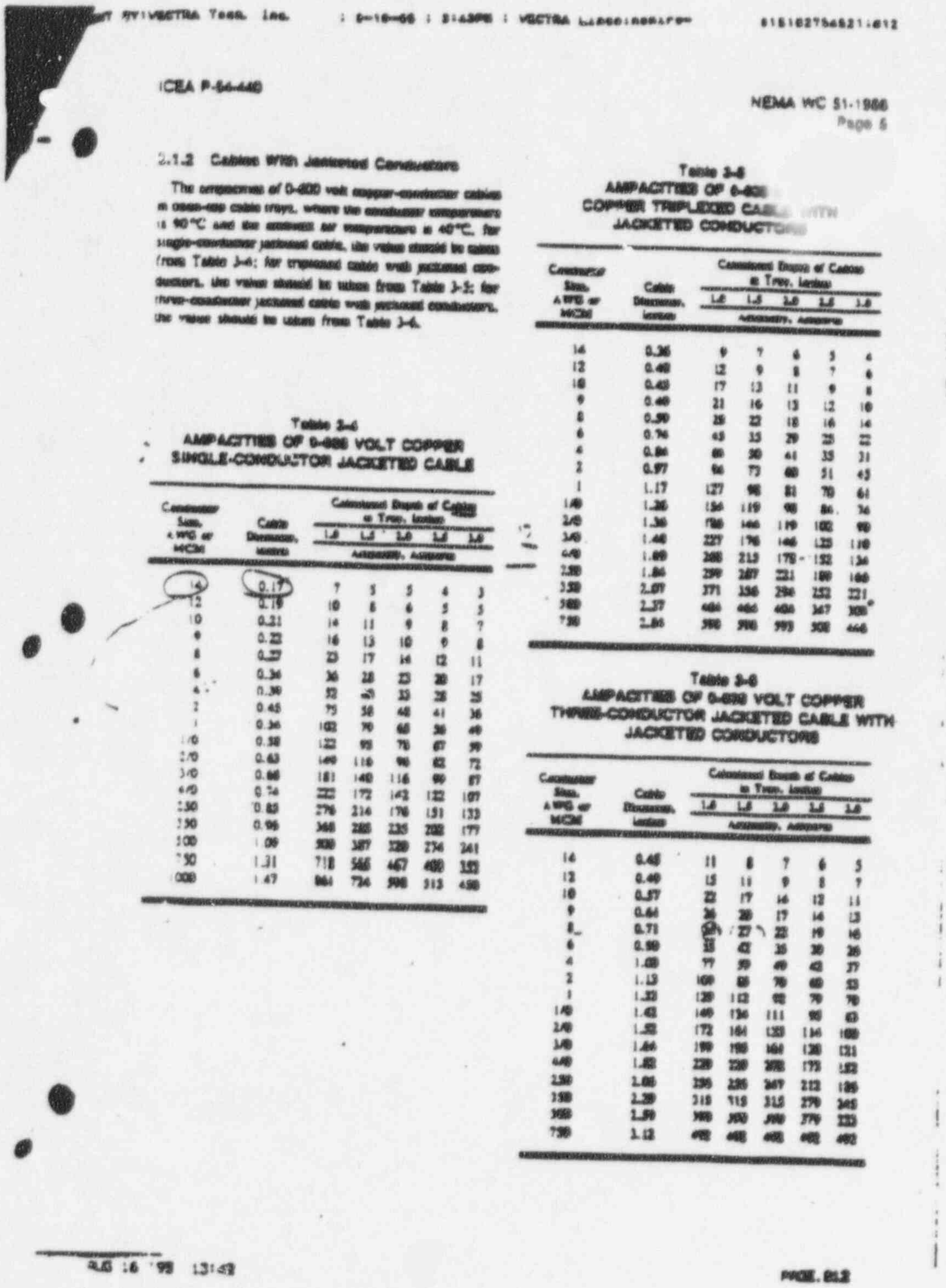

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3.1.2 Cables With Jacketed Conductors

The ampacities of 0-600 volt copper-conductor cables in open-top cable trays, where the conductor temperature is 90°C and the ambient air temperature is 40°C, for single-conductor jacketed cable, the values should be taken from Table 3-4; for triplexed cable with jacketed conductors, the values should be taken from Table 3-5; for three-conductor jacketed cable with jacketed conductors, the values should be taken from Table 3-6.

Table 3-4
AMPACITIES OF 0-600 VOLT COPPER SINGLE-CONDUCTOR JACKETED CABLE

Conductor Size, AWG or MCM	Cable Diameter, inches	Calculated Depth of Cables in Tray, inches				
		1.0	1.5	2.0	2.5	3.0
		Ampacity, Amperes				
14	0.17	7	5	5	4	3
12	0.19	10	8	6	5	5
10	0.21	14	11	9	8	7
9	0.23	16	13	10	9	8
8	0.27	23	17	14	12	11
6	0.34	36	28	23	20	17
4	0.39	52	40	33	28	25
2	0.45	75	58	48	41	36
1	0.56	102	79	65	56	49
1/0	0.58	122	95	78	67	59
2/0	0.63	149	116	96	82	72
3/0	0.68	181	140	116	99	87
4/0	0.74	222	172	142	122	107
250	0.83	276	214	176	151	133
350	0.96	368	285	235	202	177
500	1.09	500	387	320	274	241
750	1.31	718	565	467	400	353
1000	1.47	864	734	598	513	450

Table 3-5
AMPACITIES OF 0-600 COPPER TRIPLEXED CABLE WITH JACKETED CONDUCTORS

Conductor Size, AWG or MCM	Cable Diameter, inches	Calculated Depth of Cables in Tray, inches				
		1.0	1.5	2.0	2.5	3.0
		Ampacity, Amperes				
14	0.36	9	7	6	5	4
12	0.40	12	9	8	7	6
10	0.45	17	13	11	9	8
9	0.49	21	16	13	12	10
8	0.59	28	22	18	16	14
6	0.74	45	35	29	25	22
4	0.84	60	50	41	35	31
2	0.97	96	73	60	51	45
1	1.17	127	98	81	70	61
1/0	1.26	156	119	98	84	74
2/0	1.36	180	146	119	102	90
3/0	1.46	227	176	146	125	110
4/0	1.69	268	215	178	152	134
250	1.86	299	267	221	189	166
350	2.07	371	336	296	252	221
500	2.37	486	486	406	347	305
750	2.86	590	590	593	508	446

Table 3-6
AMPACITIES OF 0-600 VOLT COPPER THREE-CONDUCTOR JACKETED CABLE WITH JACKETED CONDUCTORS

Conductor Size, AWG or MCM	Cable Diameter, inches	Calculated Depth of Cables in Tray, inches				
		1.0	1.5	2.0	2.5	3.0
		Ampacity, Amperes				
14	0.45	11	8	7	6	5
12	0.49	15	11	9	8	7
10	0.57	22	17	14	12	11
9	0.64	26	20	17	14	13
8	0.71	31	27	22	19	16
6	0.90	55	42	35	30	26
4	1.03	77	59	49	42	37
2	1.13	100	80	70	60	53
1	1.33	129	112	92	79	70
1/0	1.43	149	134	111	95	83
2/0	1.52	172	164	135	116	100
3/0	1.64	199	195	164	138	121
4/0	1.82	228	228	208	175	152
250	2.05	235	235	207	212	185
350	2.29	315	315	315	270	245
500	2.59	390	390	390	379	335
750	3.12	492	492	492	492	492

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Appendix B

AMPACITY TABLES

Values Used With Stolpe's Equation

In this publication, the following values were assigned to the constants used in the formulae in Stolpe's paper, see Appendix A, Reference 1.

h = overall convection heat transfer co-efficient for the tray in (watts/ft²) /°C

$$= 0.223 \left(\frac{\Delta T}{w}\right)^{1/4}$$

= 0.101 (ΔT) ¼ (For 24-inch wide tray. The increase in ampacity using a 12-inch tray is less than 2 percent. The decrease in ampacities for widths greater than 24 inches is negligible.)

ΔT = Temperature drop through air, degrees C.
w = width of tray, inches.

σ = Stefan-Boltzmann constant in (watts/ft²)/K⁴
= 0.530×10^{-8} ✓

ϵ = effective thermal emissivity of cable mass and tray surface
= 0.8 based on open-top trays. This is the arithmetic average of the top cable surface and bottom cable and tray surface emissivities—

$$0.95 + \left(\frac{0.95 + 0.33}{2}\right) / 2 = 0.8$$

Skin effect was taken into account but not proximity effect. Shields were assumed to be open circuited; thus, shield losses were not included.

The solution to equations (4), (5), (6), and (7) given by Stolpe in Reference 1 resulted in the following values of Q for various percent tray fill and were used for calculating the ampacities given in Tables 3-1 thru 3-36 of this publication.

Q	[illegible]	d	% Tray Fill
5.923	[illegible]	1.0	33.3
3.557	2.56	1.5	50.0
2.427	[illegible]	2.0	66.6
1.784	[illegible]	2.5	83.3
1.377	[illegible]	3.0	100.0

✓

Q = Allowable heat intensity in watts/ft, per square inch of tray.
d = Calculated depth of cables in trays.

UNITED STATES
NUCLEAR REGULATORY COMMISSION
WASHINGTON, D.C. 20555-0001

SAFETY EVALUATION BY THE OFFICE OF NUCLEAR REACTOR REGULATION

AMPACITY ISSUES RELATED TO THERMO-LAG FIRE BARRIERS

TEXAS UTILITIES ELECTRIC COMPANY

COMANCHE PEAK STEAM ELECTRIC STATION, UNIT 2

DOCKET NO. 50-446

INTRODUCTION

In June 1991, the Nuclear Regulatory Commission (NRC) Special Review Team (SRT) found various areas of concern regarding the use of Thermo-Lag materials. One area of concern was the validity of the ampacity derating parameters previously established for Thermo-Lag fire barriers. The NRC issued Generic Letter 92-08, "Thermo-Lag 330-1 Fire Barriers," on December 17, 1992, to provide further information on staff concerns related to this subject. In light of the concerns raised by the SRT, during the construction of Comanche Peak Steam Electric Station (CPSES), Unit 2, Texas Utilities Electric Company (TUE/the licensee) initiated a testing program to demonstrate the acceptability of the continued use of Thermo-Lag material at CPSES, Unit 2. The licensee committed to complete the required ampacity derating tests before the first refueling cycle at CPSES, Unit 2.

The licensee conducted a series of ampacity derating tests for Thermo-Lag fire barrier configurations at Omega Point Laboratories (OPL) in San Antonio, Texas, from March 3 through March 13, 1993. The staff observed test preparation and testing from March 2 through March 7, 1993. The first test group (tests conducted from March 2 through March 3, 1993) consisted of a 3/4-inch-diameter conduit with a single 3/C #10 AWG 600-volt copper cable and a 2-inch-diameter conduit with a single 3/C #6 AWG 600-volt copper cable. The second test group (tests conducted from March 5 through March 8, 1993) consisted of a 24-inch x 4-inch cable tray filled to a depth of 2.05 inches with 3/C #6 AWG 600-volt copper cables and a free air drop (small) made of a single 3/C #6 AWG 600-volt copper cable. The final test group (tests conducted from March 10 through March 14, 1993) consisted of a 5-inch-diameter conduit first with three 1/C 750 MCM 600-volt copper cables and later four 1/C 750 MCM 600-volt copper cables and a free air drop (large) made of three 1/C 750 MCM 600-volt copper cables.

The licensee ampacity derating test methodology followed the guidance in draft Institute of Electrical and Electronics Engineers (IEEE) Standard P848, "Procedure for the Determination of the Ampacity Derating of Fire Protected

Enclosure 1

where (W_{tray}) is the width of the cable tray. This is also the same correlation used in the original version of FITCOND, and in this modified version as well, for simulating convective heat transfer from the bottom of the fire barrier enclosure to the ambient.

For heat transfer from the air to the fire barrier side panels, Equation 6 above was used except in that the distance between the two cable trays (H_{sep}) was substituted for the total external box height (H_{box}) as the characteristic length scale. In the case of the side panels, the total heat flux was again normalized to heat flux per unit area of cable tray using an area ratio consistent with Equations 8 and 4 above.

Model Input Parameters:

Using the thermal model described above, SNL performed several simulations in which a number of physical parameters were varied. These parameters were varied over a range which is expected to encompass the TUE applications based on the information provided by TUE and on SNL's knowledge of both the TUE ampacity derating program and the fire barrier fire endurance test programs. This was necessitated in that TUE has not provided concise descriptions of all aspects of the two-tray fire barrier enclosures. (Note that the need for such explicit information had not been anticipated, and hence, no requests for such extensive and explicit information were made to TUE.)

The parameters which were varied in an attempt to bound TUE's applications included the following:

- Cable Tray Width: Widths from 12" to 36" were evaluated. In general, for a given tray-to-tray spacing, wider trays will suffer a greater ampacity penalty
- Thickness of the Cable Masses: The thickness of both the upper and lower cable masses will impact the ampacity calculations. In terms of the relative derating impact, the thickness of the lower, unpowered cable mass will be more significant. SNL has investigated lower tray cable mass thicknesses from 1" to 4". The upper (powered) cable mass thickness was typically set to 3" (about the same thickness as the standard ampacity derating test tray specified in IEEE P848 drafts).
- Tray-to-Tray Spacing: TUE states in its analysis that the minimum tray-to-tray spacing encountered in two-tray enclosures is 9". In general, a closer spacing will lead to a greater ampacity impact. SNL has investigated tray-to-tray spacings ranging from 1" to 12".

A number of parameters were held constant through all of the simulations. These include:

K_{cable} = 0.09 BTU/hr-ft²-°F (based on SNL testing)
$K_{barrier}$ = 0.122 BTU/hr-ft²-°F (based on TSI data)
$t_{barrier}$ = 0.5" (1/2" Thermo-Lag barrier thickness assumed throughout)
T_{cable} = 90°C (cable hot spot temperature)
$T_{ambient}$ = 40°C (consistent with TUE analyses)
ϵ_{cable} = 0.8 (cable emissivity)
$\epsilon_{barrier}$ = 0.9 (barrier emissivity)

$x_{bot-gap}$ = 1.0" (gap to bottom barrier panel, see tray geometry discussion above)
$x_{top-gap}$ = $4.25 - x_{top-cables}$ (gap to top barrier panel, see tray geometry discussion above)
$x_{mid-gap}$ = $1 + H_{gap} - (4.25 - x_{top-cables})$ (mid-gap thickness, cables-to-cables)

Base-Case Modeling Results:

In considering the SNL analysis results presented here, it is recommended that the primary basis for comparisons be the relative change in ampacity derating predicted for a two-tray enclosure as compared to an equivalent single tray enclosure. That is, the SNL results should be primarily viewed in terms of relative changes rather than as accurate estimates of absolute derating factors for a given configuration. This is recommended for two reasons. First, only limited validation of the SNL simulation models has been possible to date. Second, the SNL simulations have neglected the effects of the Sil-Temp blanket used by TUE in it fire barrier systems for wider cable trays. Based on this second factor, SNL would expect that the thermal model results would yield lower absolute derating factor predictions than those measured in TUE's testing.

The "base cases" involve the simulation of single tray fire barrier enclosures which were calculated using the original version of FITCOND. This included a calculation of both the un-protected thermal power density and the power density assuming a normal single tray Thermo-Lag enclosure. Based on these calculations, the nominal single tray ampacity derating factors predicted by the SNL model for various depths of cable fill are given in Table 1.

Table 1: Nominal ampacity derating factors for a single tray, 1/2" Thermo-Lag fire barrier system predicted by the SNL thermal model FITCOND.

Cable Depth of Fill (in.)	Ampacity Derating Factor (%)	Ampacity Correction Factor
1	36.2	0.638
2	30.5	0.695
3	26.2	0.738
4	22.1	0.779

It is these values which form the basis for comparisons to the balance of the simulation results presented here. The remainder of the SNL simulations described here were performed using the modified version of the FITCOND program (TWOTRAY) with convection in the mid-gap region either active (best-estimate) or inactive (conservative).

interest of bounding the potential impact, this is the worst-case scenario for the assessment of conduit emissivity effects on test results.

Table 1: Worst-case derating factors for TUE tests based on "corrected" base line ampacities to account for potential variations in conduit surface emissivity.

Test Configuration:	Nominal Test ADF (%)	Worst-Case ADF (%)
3/C #10 AWG in 3/4" conduit	9.4	23.9
3/C #6 AWG in 2" conduit	6.6	21.5
4-1/C 750MCM in 5" conduit	10.7	25.0

Conduit Analysis Program Listing

The following pages provide a listing of the computer code utilized by SNL in its analysis of conduit thermal behavior. The code is not intended for general purpose utilization, and has received only minimal validation against experimental data. Its use here was primarily intended to provide for relative assessments on conduit surface emissivity effects rather than to provide predictions of actual conduit ampacity limits

Handbook of Heat Transfer

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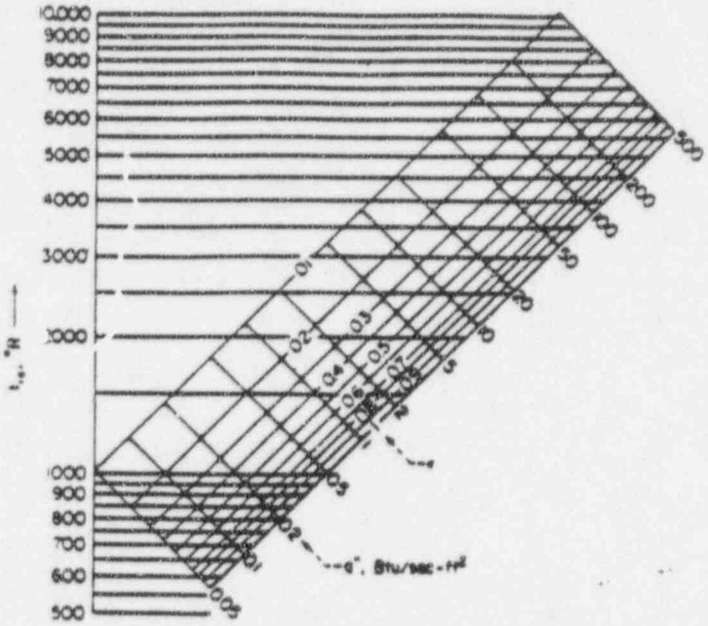

Fig. 11. Radiation equilibrium temperature (t_s = 0°R).

is thus seen to depend on not only ε alone but the ratio a_s/ϵ. Approximate values of these optical properties for typical temperature-control surfaces exposed to solar radiation [14] are listed in Table 4.

TABLE 4. Emissivity and Solar Absorptivity of Selected Surfaces

Surface (500°R)	ε	a_s	a_s/ϵ
aluminum (buffed)	0.03	0.36	12
gold (plated)	0.03	0.30	10
gold (vacuum deposited)	0.03	0.24	8
stainless steel (polished)	0.05	0.40	8
aluminum foil (dull)	0.03	0.21	7
tantalum	0.08	0.48	6
beryllium (polished)	0.09	0.49	5.5
aluminum foil (shiny)	0.04	0.20	5.0
beryllium (milled)	0.11	0.49	4.5
titanium	0.20	0.80	4.0
Rene 41	0.11	0.39	3.5
chrome	0.08	0.24	3.0
nickel	0.18	0.45	2.5
silver	0.02	0.04	2.0
aluminum (polished)	0.05	0.10	2.0
aluminum (sandblasted)	0.40	0.60	1.5
black vinyl phenolic (dull)	0.84	0.93	1.1
black silicone paint (flat)	0.81	0.89	1.1
lamp black	0.95	0.95	1.0
grey silicone paint	0.96	0.53	0.55
white silicone paint (gloss)	0.75	0.26	0.35
magnesia	0.95	0.14	0.15

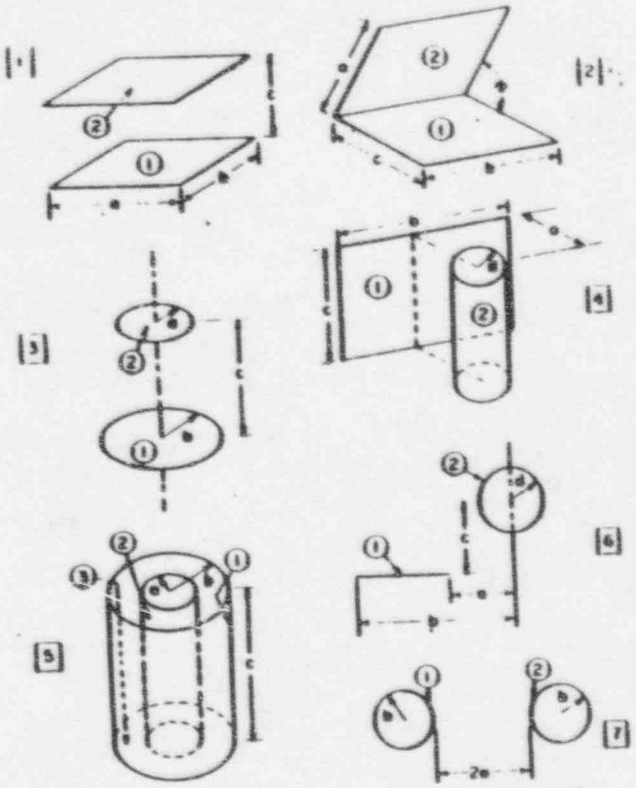

Fig. 4a. Schematic representations of configurations 1 through 7

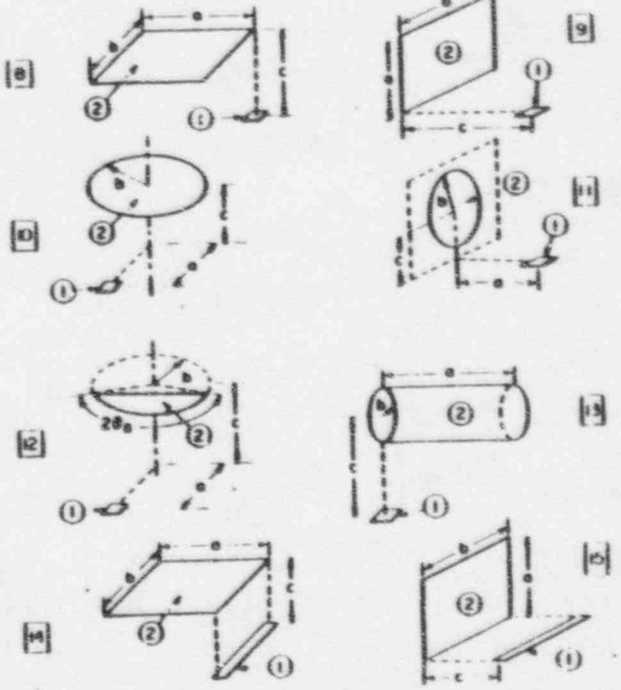

Fig. 4b. Schematic representations of configurations 8 through 15

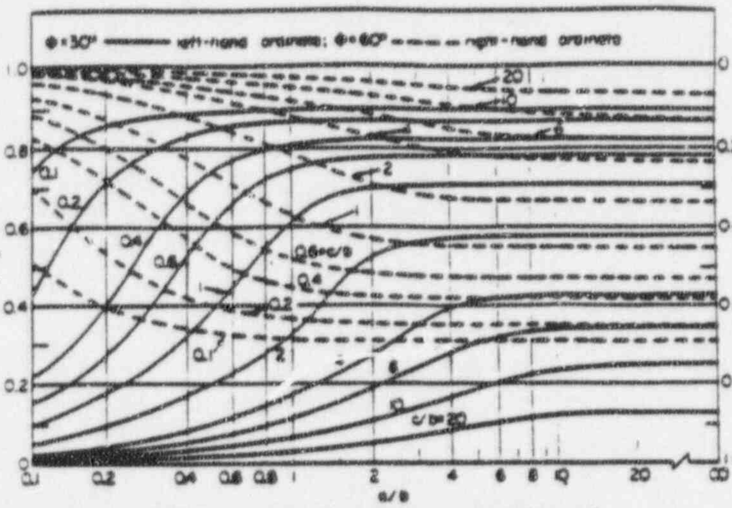

Fig. 6a. Angle factors for configuration 2, Φ = 30° and 60°.

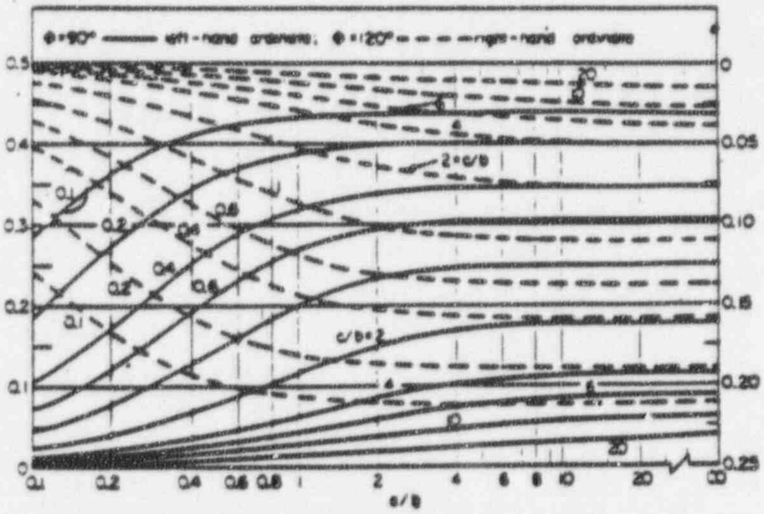

Fig. 6b. Angle factors for configuration 2, Φ = 90° and 120°.

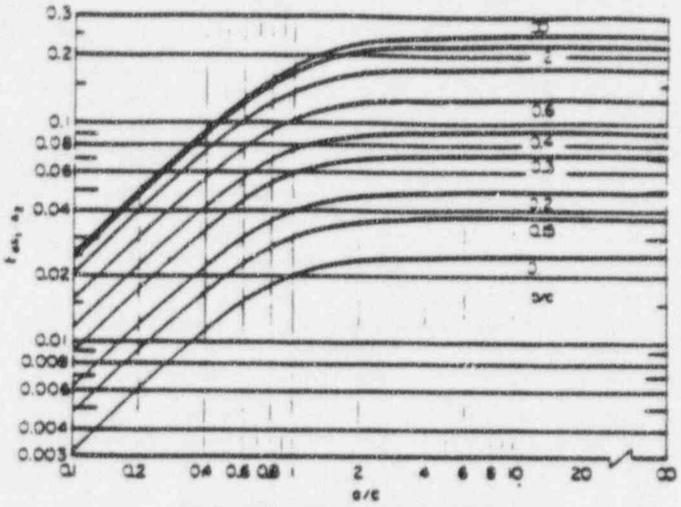

Fig. 9. Angle factors for configuration 8.

Configuration 6 $X = c/d,\ Y = a/d,\ Z = b/d$

$$F_{A_1-A_2} = \frac{1}{Z - Y}\left(\tan^{-1}\frac{Z}{X} - \tan^{-1}\frac{Y}{X}\right)$$

Configuration 7 $X = 1 + (a/b)$

$$F_{A_1-A_2} = \frac{2}{\pi}\left(\sqrt{X^2 - 1} - X + \frac{\pi}{2} - \cos^{-1}\frac{1}{X}\right)$$

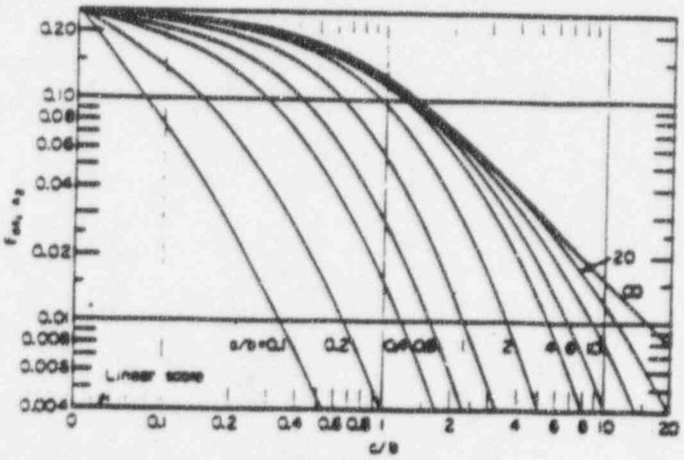

Fig. 10. Angle factors for configuration 9.

Author: Lee Easter at VECTRA-Norcross
Date: 6/7/96 2:58 PM
Priority: Urgent
Receipt Requested
TO: Tahsin Dogan at VECTRA-San_Ramon
Subject: RBS Raceway Fills

---------------------------------- Message Contents ----------------------------------

Here they are. Actual %Fill is based on cable and raceway dimensions. PDMS %Fill is based on the %Fill Limit. Let me know if you need more.

Raceway No.	PDMS %Fill	PDMS %Fill Limit	Actual %Fill
1CK600NA1	78.524	40	31.410
1CK600NA6	76.180	31	23.616
1CK600NA7	76.180	31	23.616
1CK600ND2	22.495	53	11.922
1TK200R	2.706	40	1.082
1TK001B	30.274	40	12.110
1TK002B	51.285	40	20.514

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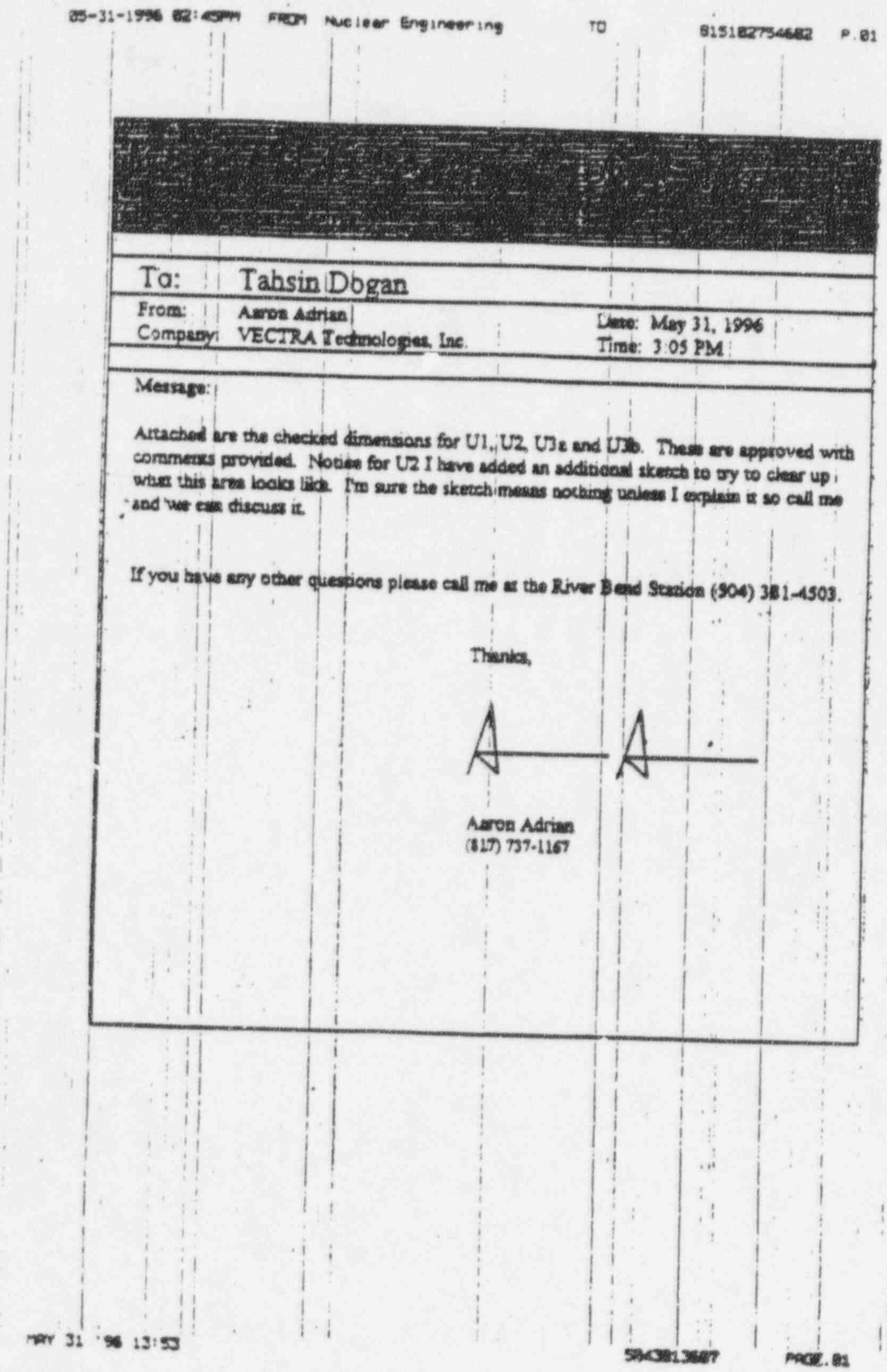


05-31-1996 02:45PM FROM Nuclear Engineering TO 815182754682 P.01

[redacted]

To: Tahsin Dogan

From: Aaron Adrian
Company: VECTRA Technologies, Inc.

Date: May 31, 1996
Time: 3:05 PM

Message:

Attached are the checked dimensions for U1, U2, U3a and U3b. These are approved with comments provided. Notice for U2 I have added an additional sketch to try to clear up what this area looks like. I'm sure the sketch means nothing unless I explain it so call me and we can discuss it.

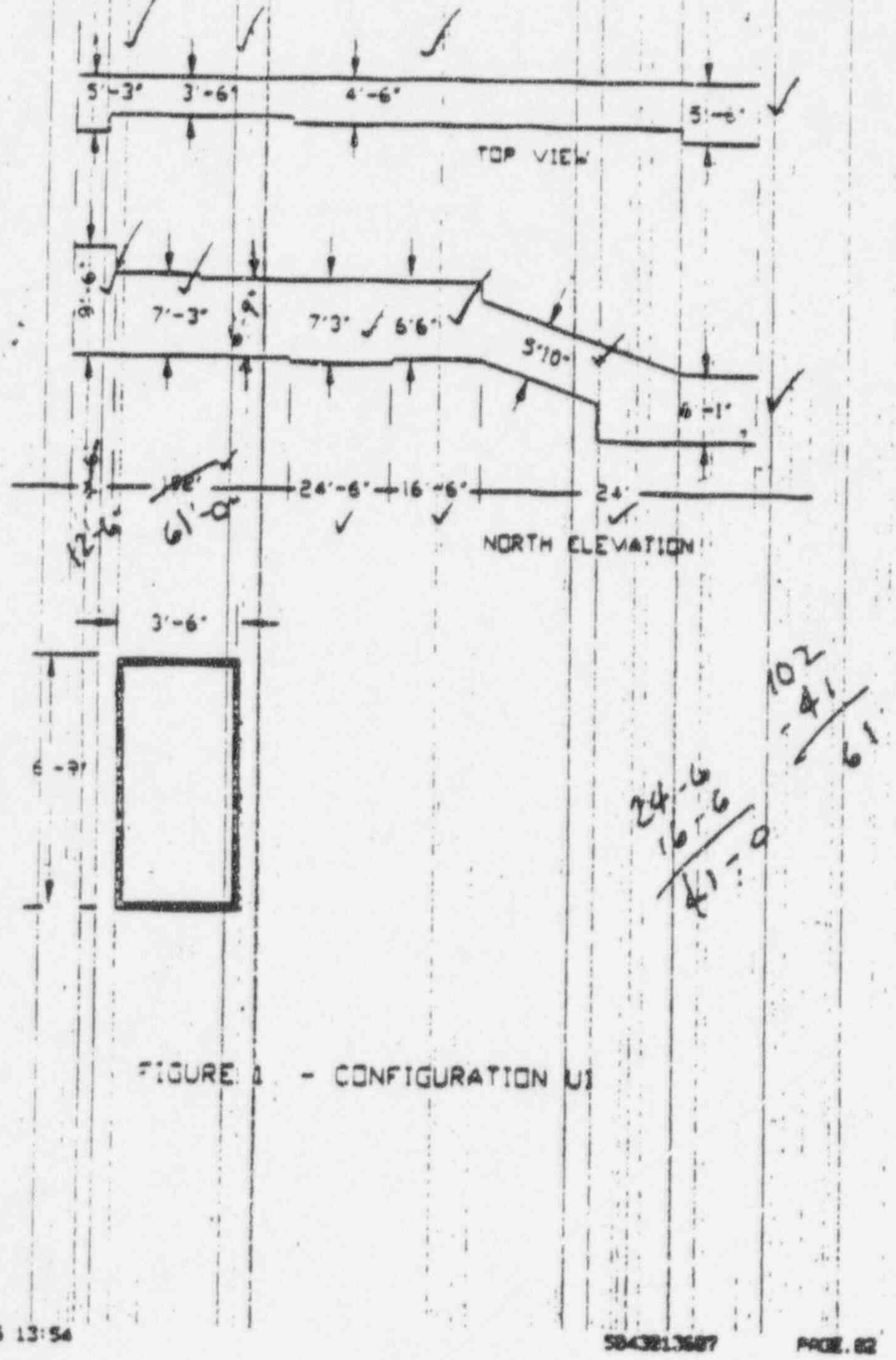
If you have any other questions please call me at the River Bend Station (504) 381-4503.

Thanks,

Aaron Adrian
(817) 737-1167

MAY 31 '96 13:53 5043813687 PAGE.01

05-31-1996 02:47PM FROM Nuclear Engineering TO 815102754682 P.02



24-6
16-6
41-0

102
-41
61

FIGURE 1 - CONFIGURATION U1

MAY 31 '96 13:54 5043213687 PAGE.02

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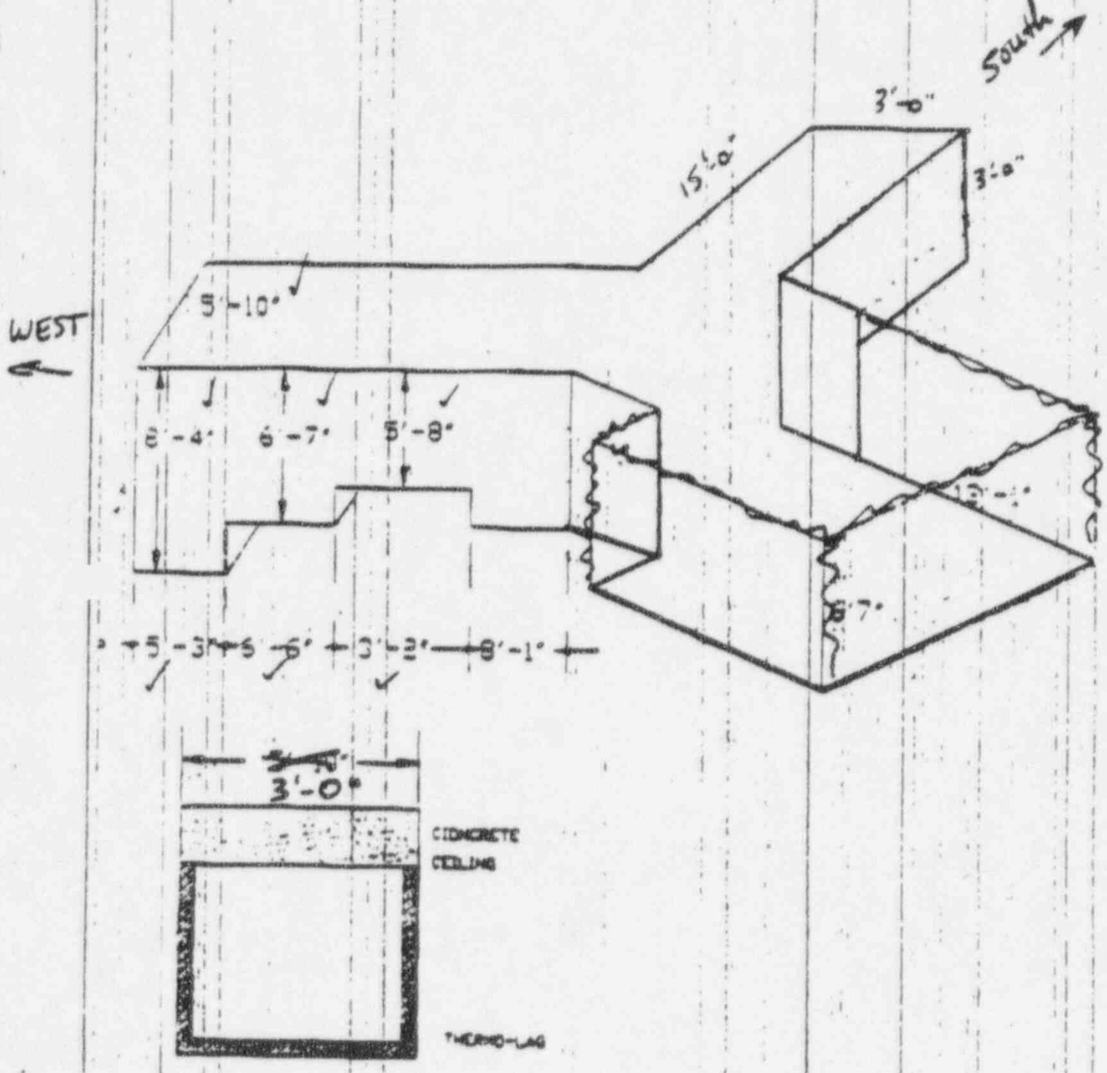

CROSS SECTION
(SOUTH LEG)

FIGURE 2 - CONFIGURATION U2

MAY 31 '96 13:55 5043813687 PAGE.03

ENTERGY	**APPENDIX B** ENTERGY OPERATIONS INCORP.	CALCULATION NUMBER G13.18.14.0-178	REV 0
		JBI NO.	
		PAGE B34 OF 45	
			REF / PAGE

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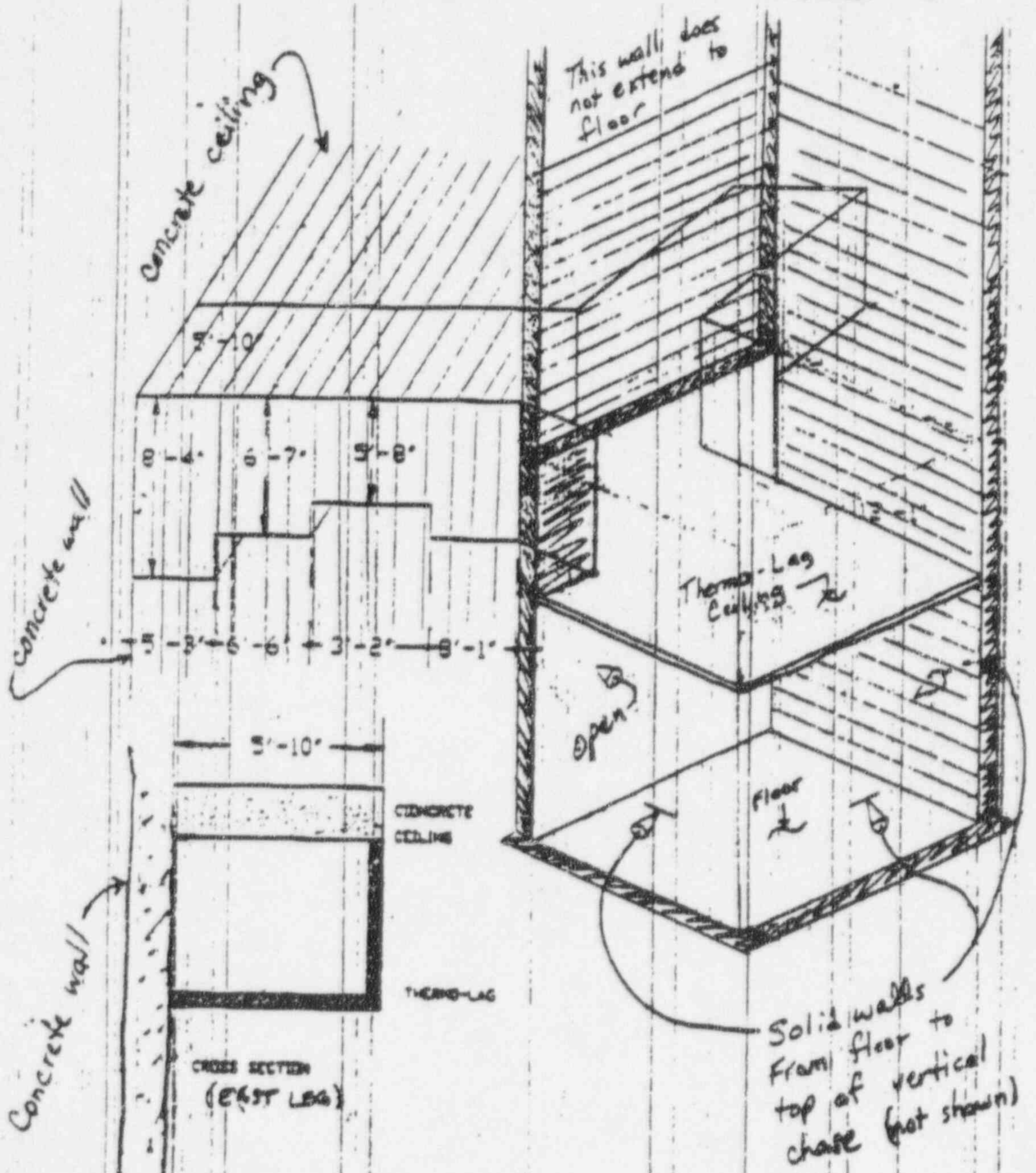

FIGURE 2 - CONFIGURATION U2

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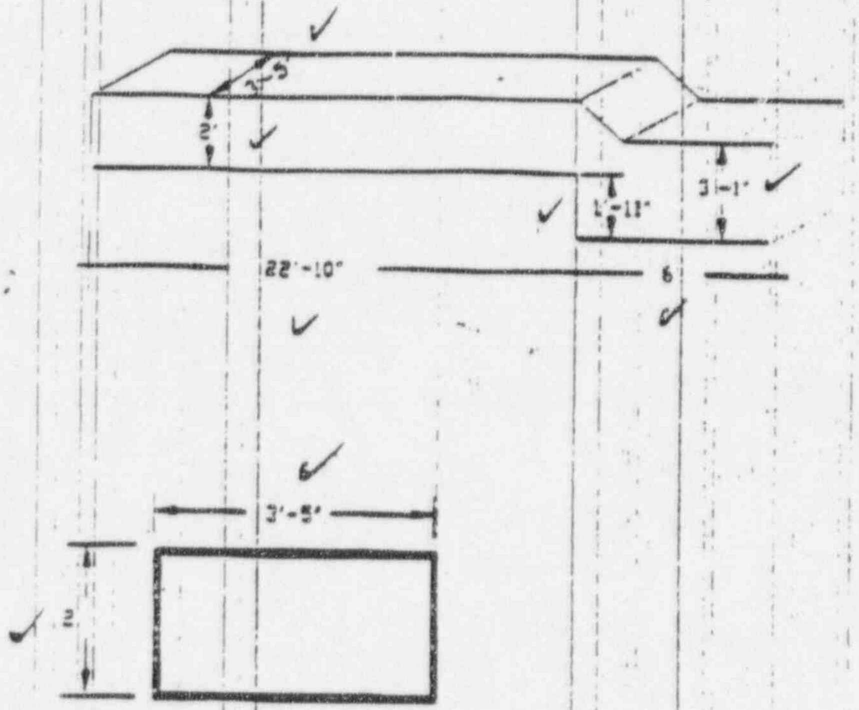

FIGURE 3a - CONFIGURATION U3a

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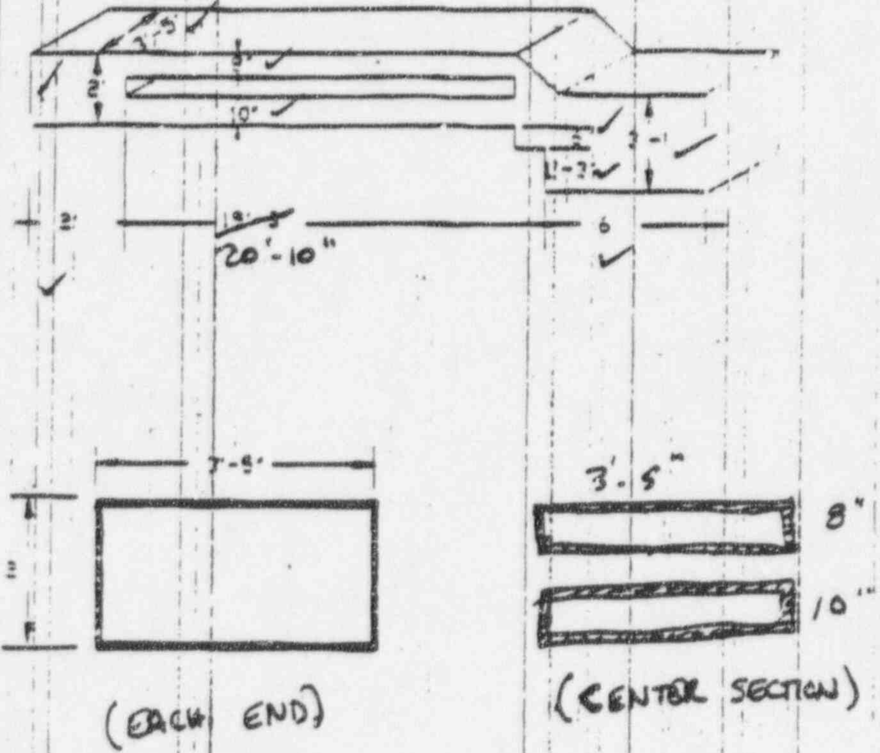


FIGURE 3b - CONFIGURATION 43a

MAY 31 '96 13:57 5043813687 PAGE.06 TOTAL P.06

given in Table I have been determined from the experimental data given in references 10 and 11.

If representative values of $T_m = 60$ C are assumed, equation 41 reduces to

$$R_{sd} = \frac{n'A'}{D_s' + B'} \text{ thermal ohm-feet} \quad (41A)$$

It should be noted that in the case of ducts, R_{sd} is calculated to the inside of the duct wall and the thermal resistance of the duct wall should be added to obtain R_{sd}.

THERMAL RESISTANCE FROM CABLES, CONDUITS, OR DUCTS SUSPENDED IN AIR

The thermal resistance R_a between cables, conduits, or ducts suspended in still air may be determined from the following expression which is developed in Appendix I.

$$R_a = \frac{12.5n'}{D_s'[(\Delta T/D_s')^{1/4} + 1.6\epsilon(1 + 0.0167T_m)]} \text{ thermal ohm-feet} \quad (42)$$

In this equation ΔT represents the difference between the cable surface temperature T_s and ambient air temperature T_a in degrees centigrade, T_m the average of these temperatures and ϵ the coefficient of emissivity of the cable surface. Assuming representative values of $T_m = 40$ and $\Delta T = 30$ C, and a range in D_s' of from 1 to 10 inches, equation 42 may be simplified to

$$R_a = \frac{9.5n'}{1 + 1.7D_s'(\epsilon + 0.41)} \text{ thermal ohm-feet} \quad (42A)$$

The value of ϵ may be taken as equal to 0.95 for pipes, conduits or ducts, and painted or braided surfaces, and from 0.2 to 0.5 for lead and aluminum sheaths, depending upon whether the surface is bright or corroded. It is interesting to note that equation 42(A) checks the IPCEA method of determining R_a very closely with $\epsilon = 0.41$ for diameters up to 3.5 inches. In the IPCEA method $R_a = 0.00411\ n'B/D_s'$ where $B = 650 + 314\ D_s'$ for

$D_s' = 0 - 1.73$ inches and $B = 1{,}200$ for larger values of D_s'

EFFECTIVE THERMAL RESISTANCE BETWEEN CABLES, DUCTS, OR PIPES, AND AMBIENT EARTH

As previously indicated, an effective thermal resistance R_e' may be employed to represent the earth portion of the thermal circuit in the case of buried cable systems. This effective thermal resistance includes the effect of loss factor and, in the case of a multicable installation, also the mutual heating effects of the other cables of the system. In the case of cables in a concrete duct bank, it is desirable to further recognize a difference between the thermal resistivity of the concrete ρ_c and the thermal resistivity of the surrounding earth ρ_e.

The thermal resistance between any point in the earth surrounding a buried cable and ambient earth is given by the expression[12]

$$R_{xe} = 0.012\rho_e \log d'/d \quad \text{thermal ohm-feet} \quad (43)$$

in which ρ_e is the thermal resistivity of the earth, d' is the distance from the image of the cable to the point P, and d is the distance from the cable center to P. From this equation and the principles discussed in references 3, 12, and 13, the following expressions may be developed, applicable to directly buried cables and to pipe-type cables.

$$R_e' = 0.012\rho n' \times \left[\log\frac{D_x}{D_e} + (LF)\log\left[\left(\frac{4L}{D_x}\right)F\right]\right] \text{ thermal ohm-feet} \quad (44)$$

in which D_x is the diameter at which the earth portion of the thermal circuit commences and n' is the number of conductors contained within D_e. The fictitious diameter D_x at which the effect of loss factor commences is a function of the diffusivity of the medium α and the length of the loss cycle.[4]

$$D_x = 1.02\sqrt{\alpha\ (\text{length of cycle in hours})} \quad \text{inches} \quad (45)$$

The empirical development of this equation is discussed in Appendix III. For a daily load cycle and a representative value of $\alpha = 2.75$ square inches per hour for earth, D_x is equal to 8.3 inches. It should be noted that the value of D_x obtained from equation 45 is applicable for pipe diameters exceeding D_x, in which case the first term of equation 44 is negative.

The factor F accounts for the mutual heating effect of the other cables of the cable system, and consists of the product of the ratios of the distance from the reference cable to the image of each of the other cables to the distance to that cable. Thus,

$$F = \left(\frac{d_{12}'}{d_{12}}\right)\left(\frac{d_{13}'}{d_{13}}\right)\cdots\left(\frac{d_{1N}'}{d_{1N}}\right)(N-1 \text{ terms}) \quad (46)$$

It will be noted that the value of F will vary depending upon which cable is selected as the reference, and the maximum conductor temperature will occur in the cable for which $4LF/D_e$ is a maximum. N refers to the number of cables or pipes, and F is equal to unity when $N = 1$.

When the cable system is contained within a concrete envelope such as a duct bank, the effect of the differing thermal resistivity of the concrete envelope is conveniently handled by first assuming that the thermal resistivity of the medium is that of concrete ρ_c throughout and then correcting that portion lying beyond the concrete envelope to the thermal resistivity of the earth ρ_e. Thus

$$R_e' = 0.012\rho_c n' \times \left[\log\frac{D_x}{D_e} + (LF)\log\left[\left(\frac{4L}{D_x}\right)F\right]\right] + 0.012(\rho_e - \rho_c)n' N(LF)G_b \text{ thermal ohm-feet} \quad (44A)$$

The geometric factor G_b as developed in Appendix II is a function of the depth to the center of the concrete enclosure L_b and its perimeter P, and may be found conveniently from Fig. 2 in terms of the ratio L_b/P and the ratio of the longest to shortest dimension of the enclosure.

For buried cable systems T_a should be taken as the ambient temperature at the depth of the hottest cable. As indicated in reference 12, the expressions used throughout this paper for the thermal resistance and temperature rise of buried cable systems are based on the hypothesis suggested by Kennelly applied in accordance with the principle of superposition. According to this hypothesis, the isothermal-heat flow field and temperature rise at any point in the soil surrounding a buried cable can be represented by the steady-state solution for the heat flow between two parallel cylinders (constituting a heat source and sink) located in a vertical plane in an infinite medium of uniform temperature and thermal resistivity with an axial separation between cylinders of twice the actual depth of burial and with source and sink respectively generating and absorbing heat at identical rates, thereby resulting in the temperature of the horizontal mid-plane between cylinders (i.e., corresponding to the surface of the earth) remaining, by symmetry, undisturbed.

The principle of superposition, as applied to the case at hand, can be stated in thermal terms as follows: If the thermal network has more than one source of temperature rise, the heat that flows at any point, or the temperature drop between any two points, is the sum of the heat flows and temperature drops at these points which would exist if each source of temperature rise were considered separately. In the case at hand, the sources of heat flow and temperature rise to be superimposed are, namely, the heat

heat
transfer

J. P. Holman

Associate Professor
Mechanical Engineering Department
Southern Methodist University

McGraw-Hill Book Company
New York San Francisco Toronto London

power (see, for example, Ref. 1).

$$E_b = \sigma T^4 \qquad (8\text{-}2)$$

Equation 8-2 is called the Stefan-Boltzmann law. E_b is the energy radiated per unit time and per unit area by the ideal radiator and σ is the Stefan-Boltzmann constant which has the value

$$\sigma = 0.1714 \times 10^{-8}\ \text{Btu/hr-ft}^2\text{-}^\circ\text{R}^4$$

when E_b is in Btu per hour per square foot, and T is in degrees Rankine. In the thermodynamic analysis the energy density is related to the energy which is radiated from a surface per unit time and per unit area. Thus, the heated interior surface of an enclosure produces a certain energy density of thermal radiation in the enclosure. We are interested in radiant exchange with surfaces, hence the reason for the expression of radiation from a surface in terms of its temperature. The subscript b in Eq. (8-2) denotes that this is the radiation from a blackbody. We call this blackbody radiation because materials which obey this law appear black to the eye; they appear black because they do not reflect any radiation. Thus, a blackbody is also considered as one which absorbs all radiation incident upon it. E_b is called the *emissive power* of a blackbody.

8-3 Radiation properties

When radiant energy strikes a material surface, part of the radiation is reflected, part is absorbed, and part is transmitted as shown in Fig. 8-2. We define the reflectivity ρ as the fraction reflected, the absorptivity α as the fraction absorbed, and the transmissivity τ as the fraction transmitted. Thus

$$\rho + \alpha + \tau = 1 \qquad (8\text{-}3)$$

Most solid bodies do not transmit thermal radiation, so that for many applied problems the transmissivity may be taken as zero. Then

$$\rho + \alpha = 1$$

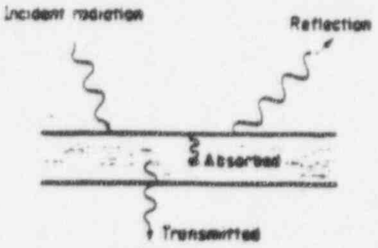


Fig. 8-2 *Sketch showing types of radiation.*

Two types of reflection phenomena may be observed when radiation strikes a surface. If the angle of incidence is equal to the angle of reflection, the reflection is called *specular*. On the other hand, when an incident the transmissivity is assumed to be zero, the reflectivity may be expressed

$$\rho = 1 - \alpha = 1 - \epsilon$$

so that

$$J = \epsilon E_b + (1 - \epsilon)G \qquad (8\text{-}26)$$

The net energy leaving the surface is the difference between the radiosity and the irradiation

$$\frac{q}{A} = J - G = \epsilon E_b + (1 - \epsilon)G - G$$

Solving for G in terms of J from Eq. (8-26),

$$q = \frac{\epsilon A}{1 - \epsilon}(E_b - J)$$

or

$$q = \frac{E_b - J}{(1 - \epsilon)/\epsilon A} \qquad (8\text{-}27)$$

At this point we introduce a very useful interpretation for Eq. (8-27). If the denominator of the right side is considered as the surface resistance to radiation heat transfer, the numerator as a potential difference, and the heat flow as the "current," then a network element could be drawn as in Fig. 8-17 to represent the physical situation. This is the first step in the network method of analysis for radiation problems.

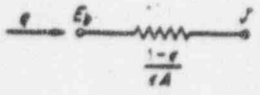


Fig. 8-17 *Element representing "surface resistance" in radiation-network method.*

Now consider the exchange of radiant energy by two surfaces A_1 and A_2. Of that total radiation which leaves surface 1, the amount that reaches surface 2 is

$$J_1 A_1 F_{12}$$

And of that total energy leaving surface 2, the amount that reaches surface 1 is

$$J_2 A_2 F_{21}$$

The net interchange between the two surfaces is

$$q_{1\text{-}2} = J_1 A_1 F_{12} - J_2 A_2 F_{21}$$

But

$$A_1 F_{12} = A_2 F_{21}$$

so that

$$q_{1\text{-}2} = (J_1 - J_2) A_1 F_{12} = (J_1 - J_2) A_2 F_{21}$$

or

$$q_{1\text{-}2} = \frac{J_1 - J_2}{1/A_1 F_{12}} \qquad (8\text{-}28)$$

We may thus construct a network element which represents Eq. (8-28) as shown in Fig. 8-18. The two network elements shown in Figs. 8-17 and 8-18 represent the essentials of the radiation-network method. To construct a network for a particular radiation heat-transfer problem we need only connect a "surface resistance" $(1-\epsilon)/\epsilon A$ to each surface and a "space resistance" $1/A_m F_{m-n}$ between the radiosity potentials. For example, two surfaces which exchange heat with each other *and nothing else* would be represented by the network shown in Fig. 8-19. In this case

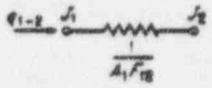


Fig. 8-18 *Element representing "space resistance" in radiation-network method.*

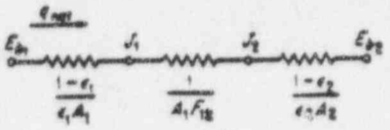


Fig. 8-19 *Radiation network for two surfaces which see each other and nothing else.*

the net heat transfer would be the overall potential difference divided by the sum of the resistances.

$$q_{net} = \frac{E_{b_1} - E_{b_2}}{\frac{1-\epsilon_1}{\epsilon_1 A_1} + \frac{1}{A_1F_{12}} + \frac{1-\epsilon_2}{\epsilon_2 A_2}} = \frac{\sigma(T_1^4 - T_2^4)}{\frac{1-\epsilon_1}{\epsilon_1 A_1} + \frac{1}{A_1F_{12}} + \frac{1-\epsilon_2}{\epsilon_2 A_2}} \qquad (8\text{-}29)$$

A three-body problem is shown in Fig. 8-20. In this case each of the bodies exchanges heat with the other two. The heat exchange between body 1 and body 2 would be

$$q_{1-2} = \frac{J_1 - J_2}{1/A_1F_{12}}$$

and that between body 1 and body 3

$$q_{1-3} = \frac{J_1 - J_3}{1/A_1F_{13}}$$

To determine the heat flows in a problem of this type, the values of the radiosities must be calculated. This may be accomplished by performing standard methods of analysis used in d-c circuit theory. The most convenient method is an application of Kirchhoff's current law to the circuit, which states that the sum of the currents entering a node is zero. Example 8-3 illustrates the use of the method for the three-body problem.

A problem which may be easily solved with the network method is that of two surfaces exchanging heat with one another, but connected by a third surface which does not exchange heat, i.e., one which is perfectly insulated. This third surface nevertheless influences the heat-transfer network is relatively easy to obtain because only two unknown potentials J_1 and J_2 need be determined to establish the various heat-flow quantities. In this case the two transmitting layers will either absorb or lose a certain quantity of energy, depending on the temperature at which they are maintained.

When no net energy is delivered to the transmitting layers, then the nodes E_{bm} and E_{bn} must be left "floating" in the analysis: and for this particular system four nodal equations would be required for a solution of the problem.

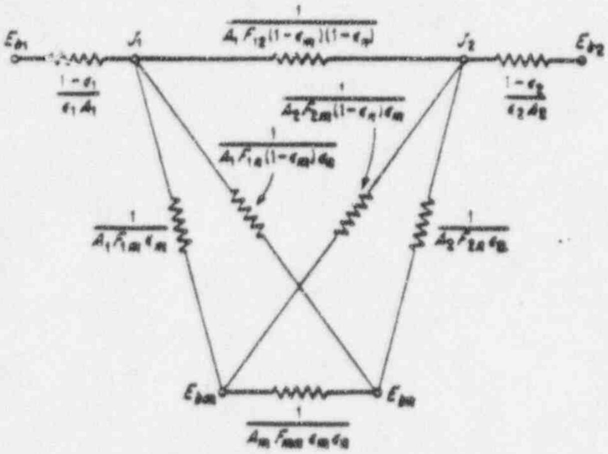


Fig. 8-33 *Total radiation network for system of Fig. 8-29.*

8-11 The radiation heat-transfer coefficient

In the development of convection heat transfer in the previous chapters we found it convenient to define a heat-transfer coefficient by

$$q_{conv} = h_{conv}A(T_w - T_\infty)$$

Since radiation heat-transfer problems are often very closely associated with convection problems and the total heat transfer by both convection and radiation is often the objective of an analysis, it is worthwhile to put both processes on a common basis by defining a radiation heat-transfer coefficient h_r as

$$q_{rad} = h_r A_1(T_1 - T_2)$$

where T_1 and T_2 are the temperatures of the two bodies exchanging heat by radiation. The total heat transfer is then the sum of the convection and radiation.

$$q = (h_c + h_r)A_1(T_w - T_\infty) \qquad (8\text{-}45)$$

if we assume that the second radiation-exchange surface is an enclosure and is at the same temperature as the fluid. For example, the heat loss by free convection and radiation from a hot steam pipe passing through a room could be calculated from Eq. (8-45).

In many instances the convection heat-transfer coefficient is not strongly dependent on temperature. However, this is not so with the radiation heat-transfer coefficient. The value of h_r, corresponding to Eq. (8-32), could be calculated from

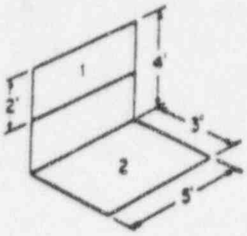
$$\frac{q}{A_1} = \frac{\sigma(T_1^4 - T_2^4)}{1/\epsilon_1 + (A_1/A_2)(1/\epsilon_2 - 1)} = h_r(T_1 - T_2)$$

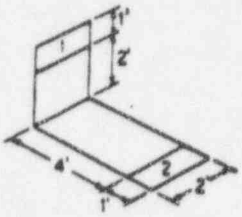
$$h_r = \frac{\sigma(T_1^2 + T_2^2)(T_1 + T_2)}{1/\epsilon_1 + (A_1/A_2)(1/\epsilon_2 - 1)} \qquad (8\text{-}46)$$

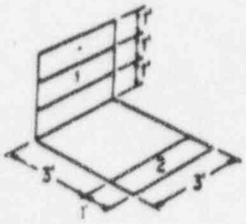
Obviously, the radiation coefficient is a very strong function of temperature.

PROBLEMS

8-1. Find the radiation shape factors F_{1-2} for the situations shown in the accompanying figures.







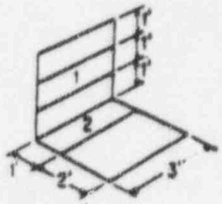
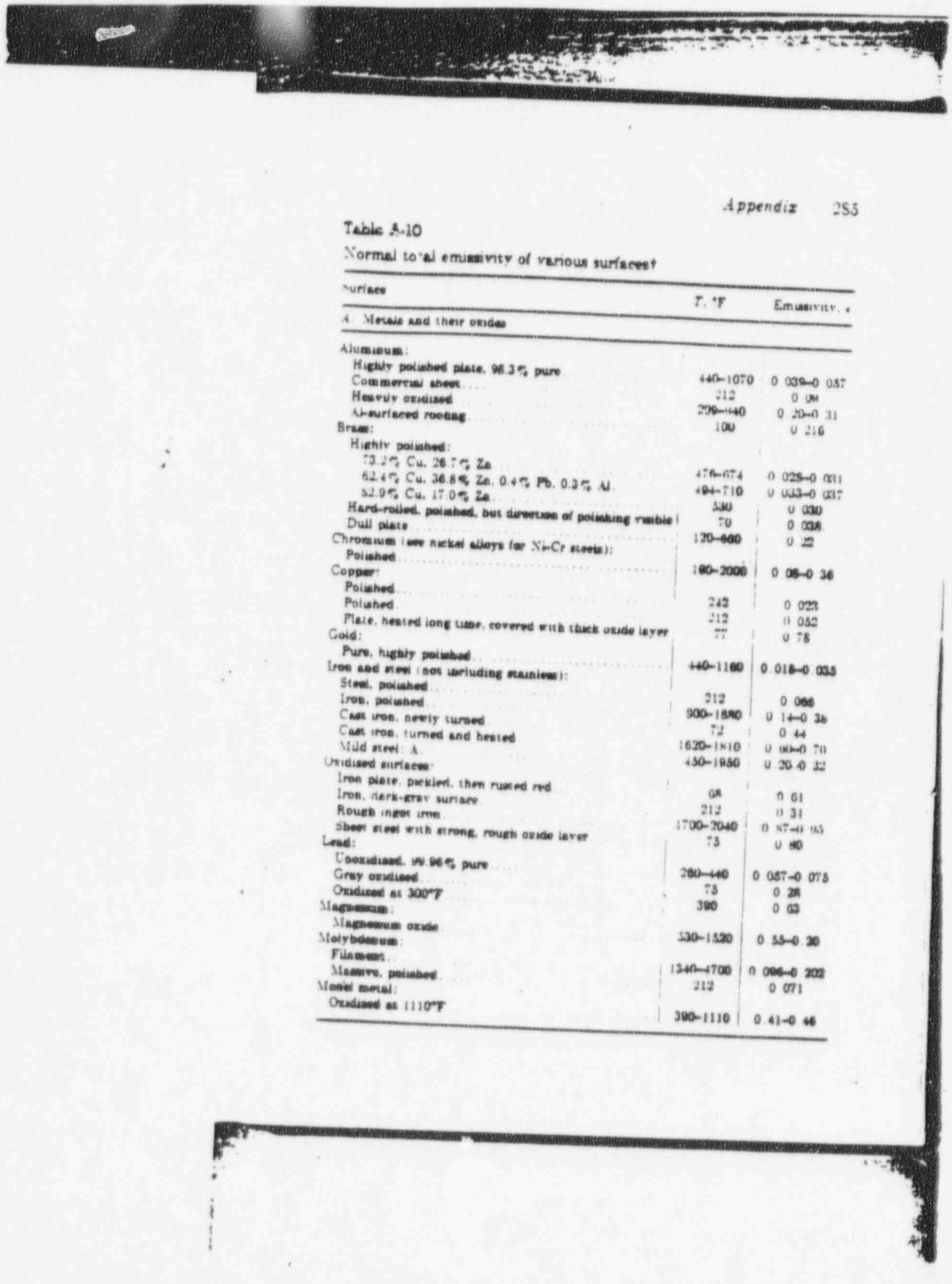


Table A-3

Properties of nonmetals†

Substance	Temperature, °F	k, Btu/hr-ft-°F
Structural and heat-resistant materials:		
Asphalt	68–132	0.43–0.44
Brick:		
Building brick, common	68	0.40
Building brick, face	....	0.76
Carborundum brick	1110	10.7
Carborundum brick	2550	6.4
Chrome brick	392	1.34
Chrome brick	1022	1.43
Chrome brick	1652	1.15
Diatomaceous earth, molded and fired	400	0.14
	1600	0.18
Fireclay brick (burnt 2426°F	932	0.60
	1472	0.82
	2012	0.63
Fireclay brick (burnt 2642°F)	932	0.74
	1472	0.79
	2012	0.81
Fireclay brick (Missouri)	392	0.58
	1112	0.85
	2552	1.02
Magnesite	400	2.2
	1200	1.6
	2200	1.1
Cement, portland	....	0.17
Cement, mortar	75	0.67
Concrete, cinder	75	0.44
Concrete, stone 1-2-4 mix	69	0.79
Glass, window	68	0.45 (av.)
Glass, borosilicate	86–167	0.63
Plaster, gypsum	70	0.28
Plaster, metal lath	70	0.27
Plaster, wood lath	70	0.16
Stone:		
Granite	....	1.0–2.3
Limestone	210–570	0.73–0.77
Marble	....	1.20–1.70
Sandstone	104	1.06
Wood (across the grain):		
Balsa, 8.8 lb/cu-ft	86	0.032
Cypress	86	0.056
Fir	75	0.063
Maple or oak	36	0.096
Yellow pine	75	0.085
White pine	86	0.065



Appendix 285

Table A-10

Normal total emissivity of various surfaces†

Surface	T, °F	Emissivity, ε
A. Metals and their oxides		
Aluminum:		
Highly polished plate, 98.3% pure	440–1070	0.039–0.057
Commercial sheet	212	0.09
Heavily oxidized	299–940	0.20–0.31
Al-surfaced roofing	100	0.216
Brass:		
Highly polished:		
73.2% Cu, 26.7% Zn	476–674	0.028–0.031
62.4% Cu, 36.8% Zn, 0.4% Pb, 0.3% Al	494–710	0.033–0.037
82.9% Cu, 17.0% Zn	530	0.030
Hard-rolled, polished, but direction of polishing visible	70	0.038
Dull plate	120–660	0.22
Chromium (see nickel alloys for Ni-Cr steels):		
Polished	100–2000	0.08–0.36
Copper:		
Polished	242	0.023
Polished	212	0.052
Plate, heated long time, covered with thick oxide layer	77	0.78
Gold:		
Pure, highly polished	440–1160	0.018–0.035
Iron and steel (not including stainless):		
Steel, polished	212	0.066
Iron, polished	900–1880	0.14–0.38
Cast iron, newly turned	72	0.44
Cast iron, turned and heated	1620–1810	0.60–0.70
Mild steel; A	450–1950	0.20–0.32
Oxidized surfaces:		
Iron plate, pickled, then rusted red	68	0.61
Iron, dark-gray surface	212	0.31
Rough ingot iron	1700–2040	0.87–0.95
Sheet steel with strong, rough oxide layer	75	0.80
Lead:		
Unoxidized, 99.96% pure	260–440	0.057–0.075
Gray oxidized	75	0.28
Oxidized at 300°F	390	0.63
Magnesium:		
Magnesium oxide	530–1520	0.55–0.20
Molybdenum:		
Filament	1340–4700	0.096–0.202
Massive, polished	212	0.071
Monel metal:		
Oxidized at 1110°F	390–1110	0.41–0.46

ATTACHMENT C

DRAFT

Calculation E-218, Revision 1

"Ampacity Verification of Cables within Raceways
Wrapped with Appendix R Fire Protection Barrier"