FOR INFORMATION ONLY

CALCULATION TITLE SHEET

12400 E. IMPERIAL HWY.
NORWALK, CALIFORNIA

OJECT ANPP(PVNGS) JOB NO. 10407-002 DISCIPLINE ELEC

JBJECT POWER CABLE AMPACITIES FILE NO. E.12.01, E.19

CALC. NO. 13EC-PA-210

ORIGINATOR SIG. [illegible] DATE 6-9-75 QUALITY CLASSIF. Q

CHECKER SIG. [illegible] J. Cairella DATE 6/26/75 NO. LAST PAGE 19 △4

P.E. STAMP IF REQ'D

ORIGINAL ISSUE

	NAME	ACTION REQ'D	DATE	SIGNATURE
GROUP LEADER	J. L. CAIRELLA	REVIEW	9/29/75	J. Cairella
EGS	P. Y. HATAGO	"	10/3/75	Paul Hatago
SPECIALIST				
CHIEF	R. ZWEIGLER	APPROVAL	12/1/75	R. Zweigler
OTHER				

RECORD OF REVISIONS

NO.	REVISION	DATE	ENG.	CKR.	EGL	EGS	SPEC.	CHIEF
△1	Added cable ampacity table for 60C ambient temp, PAGES 1, 4, 5, 14, 15	1-30-76	[illegible]	Y.S.	[illegible]	[illegible]	—	ZED
△2	CONDUCTOR SIZE #12 IS DELETED FROM TABLES 1, 4 & 7 PAGES 16, 17 REV	7-23-76	Y.S.	[illegible]	[illegible]	CM	—	ZED
△3	ADDED TABLE OF CONTENTS & REVISED PAGE NO'S	10-5-77	Y.S.	YMJ	[illegible]	CM	—	ZED
△4	UPDATED PER VENDOR DATA	1-25-83	KHN	DC	VK	[illegible]	[illegible]	RC
△5	MODIFIED SECTIONS III A, III B, III C, III D, II B, PP. 1, 2, 3-7; ADDED NOTE I	7-12-84	ECL	JM	NY	[illegible]	[illegible]	RC
△								

△5 NOTE I:

THIS CALCULATION IS NOT USED AS A REFERENCE BY OTHER CALCULATIONS. SHOULD THIS CALCULATION BE USED AS A REFERENCE BY ANOTHER CALCULATION, THEN THIS PAGE SHOULD BE REVISED TO INDICATE THE REFERENCING CALCULATION.

NOTICE

APS ACKNOWLEDGES THAT THESE DESIGN CALCULATIONS ARE ONLY AN ISOLATED PART OF THE COMPLETE DESIGN FOR THE SYSTEM THEY CONCERN, AND ARE SUBJECT TO BEING TAKEN OUT OF CONTEXT, MISINTERPRETED OR MISCONSTRUED IF USED WITHOUT BECHTEL POWER CORPORATION'S DIRECT PARTICIPATION.

PF-6346 (10407) 2/84

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LAO 0513 8-73

CALC. NO. 13-EC-PA-210

SIGNATURE David Chang DATE 1/14/83

CHECKED VA DATE 1/17/83

PROJECT ANPP (PVNGS)

JOB NO. 10407-002

SUBJECT POWER CABLE AMPACITIES

SHEET 1 OF 19 SHEETS △4

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PROJECT ANPP (PVNGS) JOB NO. 10407-002

SUBJECT POWER CABLE AMPACITIES SHEET 2 OF 19 SHEETS △4

I. STATEMENT OF PROBLEM

THE PURPOSE OF THIS CALCULATION IS TO ESTABLISH AMPACITIES OF CABLES FOR 480V, 4.16KV, AND 13.8KV POWER CIRCUITS IN EXPOSED CONDUITS, UNDERGROUND DUCTBANKS, OPEN-TOP CABLE TRAYS & EMBEDDED CONDUITS. AMPACITY TABLES DEVELOPED SHALL BE USED AS THE BASIS TO SIZE ALL POWER CABLES.

II. CRITERIA

A. OPERATING TEMPERATURES (REF. IV A, SECT 4.3)

1. CONDUCTOR 90°C
2. AMBIENT EARTH 30°C (ASSUMED PER REF. D, PAGE XVI, SECT 7d)
3. AMBIENT AIR 60°C (FOR CABLE ROUTED IN THE DG BLDG & ALL CLASS 1E CABLES)
50°C (FOR ALL NON-CLASS 1E CABLE EXCEPT FOR CABLES R[illegible]ED IN DG BLDG.)

△5 B. ALL CABLES SHALL BE CAPABLE OF CARRYING 125 PERCENT OF RATED FULL LOAD CURRENT CONTINUOUSLY. (EXCEPT THOSE CIRCUITS LISTED IN THE DESIGN CRIT MANUAL [SECTION 4.3.3.1.).

C. VOLTAGE DROP (REF IV A, SECT 4.3.3.1.D)

△ CABLES SHALL BE SIZED SO THAT THE VOLTAGE DROP WILL NOT EXCEED THE PERMISSIBLE VALUES SPECIFIED IN REF. IV A. THIS CONDITION SHALL BE VERIFIED THRU AC VOLTAGE DROP CALCULATION (CALC NO. 13-EC-PH-100).

D. SHORT CIRCUIT DUTY

1. THE CONDUCTOR TEMPERATURE AFTER A SHORT CIRCUIT (ASSUMING RATED CONDUCTOR TEMPERATURE PRIOR TO THE SHORT CIRCUIT) SHALL NOT EXCEED 250°C (REFERENCE IV A, SECT 4.3.3.4). △

2. THE MAXIMUM SHORT CIRCUIT CURRENT AND PROTECTION PLUS CIRCUIT BREAKER CLEARING TIME WILL DETERMINE THE MINIMUM SIZE OF CABLE WHICH CAN BE USED (REF: CALC 13-EC-PH-100).

E. OVERLOAD OPERATION

THE EMERGENCY OPERATION AT THE OVERLOAD TEMPERATURE OF THE CONDUCTOR (130°C FOR CROSS-LINKED POLYETHELENE AND EPR) SHALL NOT OCCUR MORE THAN FIVE TIMES DURING THE LIFE OF THE PLANT, NOR MORE THAN 100 HOURS PER YEAR (REF: IV A, SECT 4.3.3.5) △

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F. AMPACITY FOR 5KV SHIELDED + NONSHIELDED CABLES ARE ASSUMED EQUAL.

G. THE FOLLOWING TABLE OUTLINES THE PROPOSED CABLE USUAGE:

VOLTAGE CLASS	CONDUIT	UNDERGROUND DUCTS	TRAY
600 V	3/C CABLE #10 TO #2, JACKETED	SAME	SAME
	1/C CABLE # 8 AND LARGER, JACKETED	SAME	SAME
5 KV	1/C, SHIELDED	SAME	3/C, ARMORED, NONSHIELDED + JACKETED
15 KV	1/C, SHIELDED	SAME	3/C, ARMORED, SHIELDED, + JACKETED.

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III. ASSUMPTIONS AND DETAIL CALCULATION BASIS

A. CABLE IN EXPOSED CONDUITS (SEE TABLES 1, 2, 3)

1. AMBIENT TEMPERATURE — AMPACITIES FOR 40°C AMBIENT IN REF. IV. D. TABLES ARE DERATED FOR 50°C AND 60°C AMBIENT CONDITIONS BASED ON THE FORMULA (5a) SHOWN ON PAGE III OF IPCEA P46-426. WHICH IS,

$$I' = I\sqrt{\frac{Tc' - Ta' - \text{DELTA } TD'}{Tc - Ta - \text{DELTA } TD}}$$

I' = NEW CURRENT RATING AT 50°C AMBIENT OR 60°C AMBIENT.
I = ORIGINAL CURRENT RATING AT 40°C AMBIENT.
Tc' = NEW CONDUCTOR TEMPERATURE = Tc = 90°C
Tc = ORIGINAL CONDUCTOR TEMPERATURE = 90°C
Ta' = NEW AMBIENT TEMPERATURE
Ta = ORIGINAL AMBIENT TEMPERATURE = 40°C
DELTA TD = DELTA TD' = DIELECTRIC TEMP. LOSSES (FROM IPCEA TABLES)

2. MORE THAN ONE CONDUIT DIAMETER SPACING BETWEEN ADJACENT CONDUITS IS USED AS THE BASIS FOR AMPACITY CALCULATION. WHEN THIS SPACING IS NOT GREATER THAN THE CONDUIT DIAMETER OR LESS THAN 1/4 OF THE CONDUIT DIAMETER THEN FACTORS SHOWN ON TABLE IX ON PAGE II OF REF. IV D SHOULD BE CONSIDERED.

3. FOR MORE THAN 3/C IN A CONDUIT, THE FOLLOWING TABLE SHOULD BE USED FOR DERATING, (REF: NEC 1978, NOTE X TO TABLE 310-16 THR 310-19)

NO. OF CONDUCTORS	DERATING FACTOR
4 – 6	0.80
7 – 24	0.70
25 – 42	0.60
43 & OVER	0.50

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4. AMPACITIES FOR 600V, 3/C#10 CABLE ARE EXTRAPOLATED FROM OTHER 3/C CABLES.

5. FOR CONDUITS IN AIR WITH THERMAL INSULATION WRAP, REF. IV C SHOULD BE USED AS THE BASIS FOR AMPACITY CALCULATION.

6. 1 KV CABLE INSULATION FOR 600V CABLE & 8KV INSULATION FOR 5KV CABLE.

7. INSULATION POWER FACTOR 0.035 (REF. IV D, PAGE III).

8. AMPACITY VALUES CALCULATED FOR 1/C CABLES ARE BASED ON 3-1/C CABLES PER CONDUIT. THE AMPACITY OF 3-1/C IS ASSUMED EQUAL TO TRIPLEX CABLE VALUES.

B. CABLES IN UNDERGROUND DUCTS (SEE TABLES 4,5,6)

1. AMBIENT TEMPERATURE — AMPACITIES FOR 20°C AMBIENT EARTH IN REF. IV D ARE DERATED FOR 30°C AMBIENT EARTH BASED ON FORMULA SHOWN ON PAGE 4, SECT III A.1.

2. AMPACITY VALUES CALCULATED FOR SINGLE CONDUCTOR CABLES ARE BASED ON 3-1/C CABLES PER DUCT. THE AMPACITY OF 3-1/C IS ASSUMED EQUAL TO TRIPLEX CABLE VALUES (REF IV B, PAGE 7).

3. DUCTBANKS WILL BE USED UP TO 9 DUCTS IN A BANK. FOR DUCTS MORE THAN 9 IN THE BANK, EXTRAPOLATION OF TABLES 4, 5 & 6 (PAGES 13-15) IS NECESSARY (REF. IV B, PAGE 9, PARA. 3.3.1.c)

4. ACTUAL SOIL DATA IS BEING MONITORED. THIS CALC. USES AN EARTH THERMAL RESISTIVITY OF RHO = 90, WHICH IS RECOMMENDED BY IPCEA P46-426. A DCP # AOE-NA-032 IS BEING IMPLEMENTED TO GATHER ACTUAL RHO VALUES.

5. 100% LOAD FACTOR (LF) IS USED FOR ALL CABLES.

6. FOR 600V 3/C #10 CABLE AMPACITY IS EXTRAPOLATED FROM OTHER 3/C CABLES.

△5 C. CABLE IN OPEN-TOP CABLE TRAYS (SEE TABLES 7, 8, 9)

1. ~~FOR 5 & 15KV CABLES ICEA P54-440 DOES NOT GIVE AMPACITY VALUES FOR TYPES OF CABLES USED ON ANPP THEREFORE~~ AMPACITY VALUES FROM IPCEA P46-426, PAGE 309 FOR CABLES IN AIR SHALL BE USED. FOR 600V CABLES, AMPACITIES ARE BASED ON ICEA P54-440 TABLES 3 & 4 SHOWN ON PAGES iii & iv RESPECTIVELY.

2. AMBIENT TEMPERATURE — FOR 5 & 15KV CABLES, AMBIENT TEMPERATURES O[illegible]C & 60°C ARE DERATED BASED ON THE FORMULA SHOWN ON PAGE 4. FOR 600V CABLES, DERATING FACTORS ARE BASED ON TABLE SHOWN ON PAGE i OF REF. E AND FORMULA SHOWN ON PAGE 4, SECT III.A.1. (WHERE DELTA TD = 0 FOR THE CABLES OF CONCERN) △5

3. 100% LOAD FACTOR (LF) ARE USED FOR ALL CABLES.

4. 600V CABLE AMPACITY TABLE CALCULATED IS BASED ON RANDOM FILLED OPEN-TOP CABLE TRAYS.

5. FOR RANDOM FILLED CABLE IN TRAYS UNDER FOLLOWING CONDITIONS, REF. C SHOULD BE USED AS THE BASIS FOR AMPACITY CALCULATION.
   - a. WITH SOLID TRAY COVERS
   - b. PASSING THRU 3 HOUR RATED FIRE STOPS.
   - c. WITH A SOLID TRAY COVER ABUTTING TO A 3 HOUR RATED FIRE STOP.
   - d. WITH 1" OF 8PCF THERMAL INSULATION WRAP FOR "EXPOSURE FIRES".
   - e. WITH 2" OF 8PCF THERMAL INSULATION WRAP FOR "EXPOSURE FI[illegible]

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6. 5 & 15 KV AMPACITY TABLES ARE CALCULATED BASED ON CABLE INSTALLATION WITH MAINTAINED SPACING OF MORE THAN 1 CABLE DIAMETER APART. IN THE CASE WHERE MAINTAINED CABLE SPACING IS FROM 1/4 TO 1 CABLE DIAMETER THEN DERATING FACTORS SHOWN ON TABLE VIII, PAGE V, REF.IV.D SHOULD BE USED.

7. FOR 600V CABLES, EQUIVALENT CABLE DEPTH IS CALCULATED USING THE METHOD DESCRIBED ON PAGE 17 OF REF IV B. WHICH IS,

EFFECTIVE DEPTH OF TRAY = 3"
PERCENT FILL OF TRAY = 30%

(30% X 3") / 0.7854 = 1.15" ⟶ EQUIVALENT CABLE DEPTH.

8. FOR RANDOM FILLED CABLES, MANUFACTURER'S CABLE OD DATA SHOWN ON REF. F & G AND THE FOLLOWING EQUATION ARE USED TO CALCULATE CABLE AMPACITIES,

$$I_x = \frac{d_x}{d_o} I_o \quad \text{(REF: ICEA P54-440, PAGE i)}$$

WHERE I_o = AMPACITY FOR CABLE DIAMETER d_o FROM TABLES.
I_x = AMPACITY FOR CABLE DIAMETER d_x.

9. FOR CABLES WITH DIFFERENT NUMBER OF CONDUCTORS THAN THOSE USED IN ICEA TABLES, AMPACITY SHALL BE CALCULATED BASED ON THE FOLLOWING EQUATION:

$$I_x' = \frac{d_x'}{d_o'} I_o' \sqrt{\frac{3}{n_x}} \quad \text{(REF: ICEA P54-440 PAGE ii)}$$

WHERE I_o' = AMPACITY FOR 3/C CABLE FROM TABLES.
I_x' = AMPACITY FOR CABLE HAVING n_x CONDUCTORS.
d_x' = DIAMETER OF CABLE HAVING n_x CONDUCTORS
d_o' = DIAMETER OF 3/C CABLE FROM TABLE.

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D. CABLES IN EMBEDDED CONDUITS

△5 AMPACITY FOR CABLE IN EMBEDDED CONDUIT CAN BE CONSIDERED THE SAME AS IN UNDERGROUND DUCTS, PROVIDED THAT THE SAME CONFIGURATION RESTRAINTS ARE IMPOSED. FOR CONFIGURATIONS OTHER THAN AS SHOWN IN REFERENCE IV D, EXTRAPOLATION OF VALUES SHALL BE PERFORMED PER SECTION III. B. 3 OF THIS CALCULATION.

E. DIFFERENT PARAMETERS

△5 FOR PARAMETERS DIFFERENT THAN THE ONES SHOWN IN TABLES 1 THROUGH 9, THE CABLE AMPACITIES SHALL BE MODIFIED AS INDICATED IN SECTIONS III A, III B, AND III C OF THIS CALCULATION.

IV. REFERENCES

A. ANPP DESIGN CRITERIA MANUAL, ELECTRICAL GENERAL DESIGN CRITERIA, PART II SECT. 4.3.

B. BECHTEL TPO DESIGN GUIDE , SECTION 2.6.4.

C. BECHTEL LAPD ELECTRICAL BULLETIN NO. 20 — REV.1, TPO DESIGN GUIDE E2.6.4, DATED 2/3/81.

D. IPCEA PUB. NO. P-46-426, VOL I (SECOND PRINTING, 1978), POWER CABLE AMPACITY FOR COPPER CONDUCTORS IN CONDUITS, UNDERGROUND DUCTS, FREE AIR AND BURIED DIRECTLY IN EARTH.

E. ICEA PUB. NO. P54-440 (SECOND EDITION) INCLUDING REV. 2, AUG 1979. — AMPACITY FOR CABLES IN OPEN TOP CABLE TRAYS.

F. APPENDIX 5B , SPEC. EM058 , REV. 6.

G. APPENDIX 5B , SPEC EM058A , REV 2.

H. NATIONAL ELECTRICAL CODE , 1978.

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TABLE 1. 600 V - POWER CABLE AMPACITY
IN CONDUIT
1/C & 3/C CABLES, 50C AND 60C AMBIENT
AIR, 90C COND. TEMP.

	CONDUCTOR SIZE, AWG (KCMIL)	AMPACITY AMPS 50C AMB. AIR	AMPACITY AMPS 60C AMB. AIR
③	3/C # 10	35	30
①	8	47	40
	6	62	53
	4	81	70
	2	110	95
②	1/C # 8	49	42
	6	67	58
	4	87	75
	2/0	182	158
	4/0	249	215
	350	343	297
	500	427	369

△4

NOTES: ① IPCEA P46-426, PAGE 313 COLUMN FOR 1KV CABLE.
② IPCEA P46-426, PAGE 264 COLUMN FOR 1KV CABLE.
③ EXTRAPOLATED VALUES, SEE FIG. 1 ON PAGE 18.

△4

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SUBJECT POWER CABLE AMPACITIES SHEET 11 OF 19 SHEETS 4

TABLE 2. 5KV POWER CABLE AMPACITY IN CONDUIT
1/C CABLES
50 C AND 60 C AMBIENT AIR
90 C CONDUCTOR TEMP.

CONDUCTOR SIZE AWG (KCMIL)	AMPACITY (AMPS) 50C AMB. AIR	AMPACITY (AMPS) 60C AMB. AIR
① # 4/0	256	222
250 KCMIL	281	243
350	346	299
500	423	365
750	517	447

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NOTE: ① IPCEA P46-426, PAGE 264 COL. FOR 8KV CABLE.

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TABLE 3. 15 KV POWER CABLE AMPACITIES IN CONDUIT

1/C CABLE

50C AMBIENT AIR

90 C CONDUCTOR TEMP.

CONDUCTOR SIZE AWG (, KCMIL)	AMPACITY (AMPS) 50°C AMB. AIR
① 4/0	263
250 KCMIL	294
350	352
500	429
750	525

NOTE : ① IPCEA P46-426 , PAGE 264. | ⚠4

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TABLE 4. 600V - POWER CABLE AMPACITY
IN DUCT BANK
1/C & 3/C CABLES, 30C AMBIENT
EARTH, 90C COND. TEMP.

		CONDUCTOR SIZE, AWG (KCMIL)	NUMBER OF 3 PHASE CIRCUITS (ONE PER DUCT)			
			1	3	6	9
③	3/C #	10	44	39	34	31
①		8	55	49	43	40
		6	72	64	56	51
		4	94	82	71	66
		2	123	107	91	84
②	1/C #	8	59	52	44	42
		6	79	68	57	54
		4	103	88	74	69
		2/0	204	169	139	127
		4/0	268	219	179	163
		350	358	290	233	212
		500	436	348	279	253

4

4

NOTES: ① IPCEA P46-426, PAGE 289, RHO 90, 100LF FOR 1KV CABLE.
② IPCEA P46-426, PAGE 240, RHO 90, 100LF FOR 1KV TRIPLEX CABLE.
③ EXTRAPOLATED FIGURES, SEE FIG. 2 PAGE 19.

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TABLE 5. 5 KV POWER CABLE AMPACITY IN DUCT BANK
30C AMBIENT EARTH
90C CONDUCTOR TEMP.
1/C CABLES

CONDUCTOR SIZE AWG (KCMIL)	NUMBER OF THREE PHASE CIRCUITS (ONE PER DUCT)			
	1	3	6	9
① # 4/0	270	219	178	161
250 KCMIL	294	240	193	175
350	357	286	228	207
500	430	340	270	244
750	523	409	322	289

4

NOTE : ① IPCEA P46-426, PAGE 241, RHO 90, 100LF FOR 8KV TRIPLEX CABLE.

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TABLE 6. 15 KV POWER CABLE AMPACITIES IN DUCT BANK
30 C AMBIENT EARTH
90 C CONDUCTOR TEMP
1/C CABLES

CONDUCTOR AWG (KCMIL)	NUMBER OF THREE PHASE CIRCUITS (ONE PER DUCT)			
	1	3	6	9
① # 4/0	273	220	175	158
250 KCMIL	299	239	191	172
350	358	284	225	203
500	430	338	265	238
750	522	405	316	282

△4

△4 NOTE: ① IPCEA P46-426, PAGE 242, RHO 90, 100 LF FOR 15KV TRIPLEX CABLE.

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TABLE 7. 600 VOLT POWER CABLE AMPACITY IN TRAY
40C, 50C AND 60C AMBIENT; 90C CONDUCTOR TEMP
1/C & 3/C JACKETED CABLE W/ NONJACKETED COND.
30% FILL IN A 3' TRAY

4

O.D. (IN.) ③	CONDUCTOR SIZE AWG (KCMIL)	AMPACITY (AMPS) 1.15" DEPTH OF CABLE IN TRAY 50C AMBIENT &	40C	AMPACITY (AMPS) 1.15" DEPTH OF CABLE IN TRAY 60C AMBIENT AIR
.53 (R) 3/C #	10 ①	17	18	14
.705 (B)	8	29	32	25
.8 (R)	6	41	45	35
.96 (R)	4	62	69	53
1.09 (R)	2	89	98	76
.276 (R) 1/C #	8 ②	19	21	17
.323 (R)	6	29	32	25
.39 (B)	4	43	48	37
.65 (B)	2/0	129	143	111
.77 (B)	4/0	194	215	167
.97 (B)	350	312	347	268
1.115 (B)	500	429	477	369

4

NOTES: ① ICEA P54-440, PAGE iii TABLE 3. AMPACITY FOR 1.15" CABLE DEPTH IN TRAY IS INTERPOLATED FROM THE TABLE.

② ICEA P54-440, PAGE iv TABLE 4. AMPACITY FOR 1.15" CABLE DEPTH IN TRAY IS INTERPOLATED FROM THE TABLE.

③ OD VALUES ARE GUARANTEED MAXIMUM OD VALUES BY VENDOR (SPEC. EM058 + EM058A, APPENDIX 5B). SINCE BOTH BRAND REX AND ROCKBESTOS SUPPLIED CABLES FOR ANPP USE, THE SMALLER OF THE TWO OD'S ARE CHOSEN AS BASIS FOR CALCULATION.

B - BRAND REX

R - ROCKBESTOS

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TABLE 8. 5 KV POWER CABLE AMPACITY IN TRAY

50C AND 60C AMBIENT, 90C CONDUCTOR TEMP
3/C JACKETED CABLE

CONDUCTOR SIZE AWG (KCMIL)	AMPACITIES (AMPS) 50C AMBIENT AIR	AMPACITIES (AMPS) 60C AMBIENT AIR
① # 4/0	287	248
250 KCMIL	317	275
350	389	336
500	479	414
750	597	516

TABLE 9. 15 KV POWER CABLE AMPACITY IN TRAY

50C AMBIENT, 90C CONDUCTOR TEMP
3/C JACKETED CABLE

CONDUCTOR SIZE AWG (KCMIL)	AMPACITIES (AMPS) 50C AMB. AIR
② # 4/0	290
250 KCMIL	321
350	391
500	479
750	597

NOTE: ① IPCEA P46-426, P.309 FOR 8KV CABLE IN AIR.
② IPCEA P46-426, P.309 FOR 15KV CABLE IN AIR. 4

K+E LOGARITHMIC 3 x 5 CYCLES KEUFFEL & ESSER CO.

46 7520

FIG 1

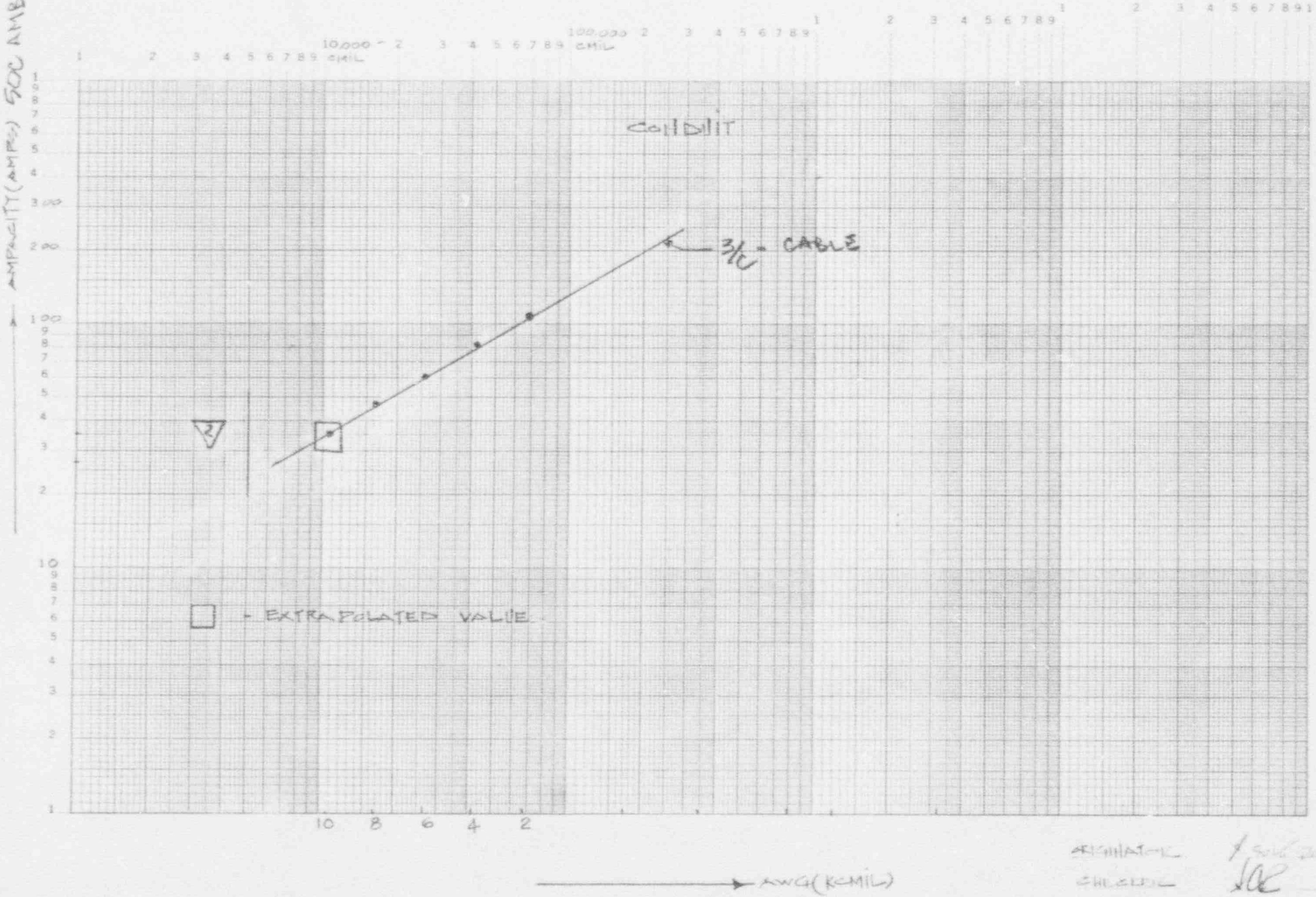

FIG. 1.

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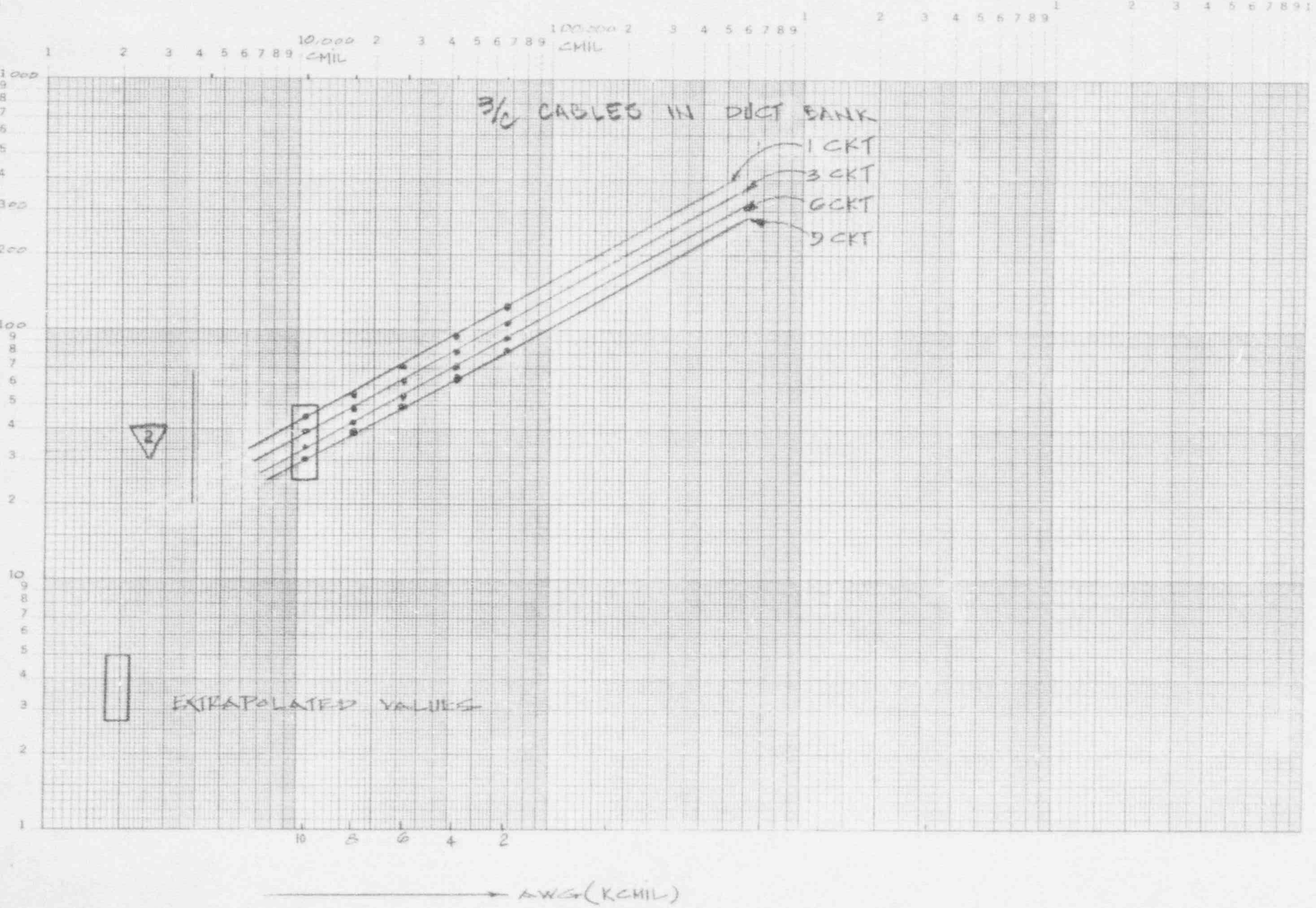
FIG 2



FIG

ORIGINATOR

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ENCLOSURE 5

APS INTRODUCTION AND BECHTEL MEMORANDUM IOM-E-13521 DATED FEBRUARY 18, 1987

The following is provided to clarify the calculation method used by Bechtel in memorandum IOM-E-13521, dated February 18, 1987.

Purpose

The calculations in Table 1 establishes that the Watts/ft method is conservative, resulting in heat dissipation values less than the resulting Watts/ft values calculated based on the U.L. test results. The calculations are based on overfilled tray since U.L. loaded the test trays to approximately 61% where as the Bechtel design limit is 30%.

Although Bechtel did not use the Watts/ft method for determining the derating of Thermolag (it is based on a 12.5% derating specified in T.P.O. E2.6.4), it is shown that the Watts/ft calculation of overfilled and uncovered tray, calculated in accordance with 13-EC-ZA-300, is more conservative than the calculated result derived from the data provided in the U.L. report for overfilled and uncovered tray. Similarily, the Watts/ft calculation of overfilled and covered tray is more conservative than the U.L. based calculated result for Thermolag covered tray. In fact, even the result above for overfilled uncovered tray, based on 13-E-ZA-300, is more conservative than the results of the U.L. based calculation for Thermolag covered tray.

U.L. based thermolag, overfilled dissipation:	49.1 W/ft
13-EC-ZA-300 based overfilled, uncovered:	35.5 W/ft
13-EC-ZA-300 based overfilled, covered:	26 W/ft

The above results establish that the 13-EC-ZA-300 Watts/ft method for covered tray provides conservative results, even for thermolag covered trays. It was then used as the basis for Tables 2,3, and 4 to compare the Watts/ft of thermolag coverd trays, calculated in 13-EC-ZA-300, to the maximum heat dissipation levels for covered tray. These maximum levels are established in 13-EC-ZA-300, especially Attachment E.

Table 1

The following equation is used in Table 1 for determining the Watts/ft from the U.L. data.

$$\frac{\frac{I^2 \cdot R}{\text{conductor}} \cdot \text{\# of conductors}}{\text{total length of conductors}} = \frac{\frac{\text{Watts}}{\text{conductor}} \cdot \text{\# cables} \cdot \frac{\text{conductors}}{\text{cable}}}{\text{total length of conductors}}$$

$$= \frac{\text{Watts}}{\text{ft}}$$

The depth of cable fill in the tray for the U.L. report is determined based on the following:

$$\frac{\text{\# of cables} \cdot \text{cross sectional area of cable } (\text{in})^2}{\text{tray width}} = \frac{\text{\# cables} \cdot (\text{cable diameter})^2 \frac{\pi}{4}}{\text{tray width}}$$

= depth of fill in tray

KN
please send a copy to TOM Ballweg

Bechtel Western Power Corporation

Interoffice Memorandum

To R. A. Schmitter

Subject Bechtel Job 10407
Derating of Cables
PIR LA 86-22

Copies to J. Aguilar
V. Karrian
J. E. Mahlmeister
R. R. Stiens
All w/enclosures

File No. D.4.32.3

Date February 18, 1987
IOM-E-13521 MOC-453836

From C. M. Herbst

Of Engineering

At BWPC Ext 5150

FOR INF[illegible] ONLY

The results of the formal test reports covering the recently conducted Ampacity Tests by Underwriters Laboratories using TSI 330 (Thermo-lag) material were reviewed by project engineering, and as a result we are revising our "action taken" statement to PIR LA 86-22 as follows:

ACTION TAKEN:

The fireproofing material used at PVNGS is Thermo-lag 330-1. The cable derating calculation was based on a Thermo-lag derating factor of 12.5% which was given in TPO Design Guide E2.6.4, Rev. 1. Since all power cables were sized to at least 125% of full load currents, there was sufficient margin to compensate for the 12.5% derating and no additional cable derating was taken. The PVNGS cable derating calculation was based on information at the time of issue and was approved by the Chief Engineer.

Since no additional cable derating was taken for Thermolagged cable trays, the U.L. test results were compared to the cable derating calculation (13-EC-ZA-300) for trays overfilled, covered or passing through firestops.

Table 1 shows the comparison between the U.L. test report and calc. 13-EC-ZA-300. The U.L. test configuration of 71-3/C#6 cables in a tray is equivalent to 2.323 inches depth fill or 60.8% fill which is an overfill tray condition (allowable is 1.15" depth or 30% fill of a 3" power tray).

Based on the 2.323" depth fill, PVNGS derating calc. 13-EC-ZA-300 has more conservative derating values as compared to the U.L. test results as shown on Table 1 (at 40°C ambient temperature, 62.6% better for overfilled open trays and 47% better for Thermo-lagged overfilled trays).

After the comparison of the U.L. test data and the 13-EC-ZA-300 calc., a review of Thermo-lagged cable trays in Units 1, 2, and 3 was done using EE580 reports [Enclosure (2) outlines the procedures used to track Thermo-lagged raceways in the EE580 program]. Tables 2 through 4 in Enclosure (1) list the Thermo-lagged trays and their calculated watts/ft and allowable watts/ft as documented in calc. 13-EC-ZA-300. The calculated watts/ft values are all below the allowable for covered trays. No overfilled tray conditions exist.

Based on the above study and investigation, the derating factors of 28% for one-hour protective system and 31% for a three-hour protective system has no safety impact on the PVNGS project. The project's current cable derating calculation 13-EC-ZA-300, which is by watts per foot method has more conservative values than the U.L. test results.

C. M. Herbst

CMH:JSF:eg

Enclosure: (1) Tables Listing the Thermo-lagged Trays
(3 pages, 1 copy)
(2) Procedures to Track Thermo-lagged Raceways
(1 page, 1 copy)

Written Response Required: NO

ENCLOSURE 1

PROJECT ANPP/PVNGS
JOB NO. 10407
SUBJECT CALC. 13-EC-ZA-300 CABLE DERATING VERIFICATION
SHEET NO. 1 OF 3

REV	ORIGINATOR	DATE	CHECKER	DATE	REV	ORIGINATOR	DATE	CHECKER	DATE
△	F. CHEN	2-7-87			△				
△					△				

COMPARISON:

TABLE 1

CONDITION	① PIR LA-86-22 U.L. TEST REPORT	② CALC. BASIS ** (13-EC-ZA-300)	COMPARISION
OVERFILLED W/O TRAY COVER, W/O THERMAL LAG 40°C	$\frac{32.1^2 \times 1.287 \times 71 \times 3}{2980} = 94.8$ W/FT	$71.67 \times \frac{1.15}{2.323^*} = 35.5$ W/FT	$\frac{(1)-(2)}{(1)} \times 100 = 62.6\%$
OVERFILLED WITH 1HR THERMAL LAG (TESTING) 40°C OR OVERFILLED WITH TRAY COVERED (CALCULATION) 40°C	$\frac{23.1^2 \times 1.287 \times 71 \times 3}{2980} = 49.1$ W/FT	$52.56 \times \frac{1.15}{2.323^*} = 26$ W/FT	$\frac{(1)-(2)}{(1)} \times 100 = 47\%$

* DEPTH OF CABLE IN THE TRAY OF U.L. TEST REPORT

$$\frac{71 \times 1^2 \times \frac{\pi}{4}}{24} = 2.323''$$

$$\left(\frac{2.323 \times \pi}{4 \times 3} = 60.8\% \text{ FILL} \right)$$

** USE THIS CALC. BASIS VALUE TO REVIEW ALL CIRCUITS PROTECTED OF FIRE BY WRAPPED THERMAL LAG AS SHOWN ON THE TABLE 2, 3 & 4

BECHTEL

ENCLOSURE 1

SIGNATURE J. S. Fuentes DATE 2-09-87 CHECKED ______ DATE ______
PROJECT ANPP / PVNGS 1, 2 & 3 JOB NO. ______
SUBJECT CALC. 13-EC-ZA-300 CABLE DERATING VERIFICATION SHEET 2 OF 3 SHEETS

TABLE 2

THERMOLAGGED TRAYS IN UNIT 1 PER EE 580

TRAY I.D.	TOTAL * WATTS/FT	ALLOWABLE WATTS/FT **	REMARKS
1EZA1CATGAJ	4.92	31.97	
1EZA1DCTKBC	1.07	31.97	
1EZA1DCTKBD	1.07	31.97	
1EZA1DCTKBE	1.07	31.97	
1EZA1DCTKBF	1.07	31.97	
1EZA1DCTKBG	1.07	31.97	
1EZA1DCTKBH	1.07	31.97	
1EZA1DCTKBJ	1.07	31.97	
1EZA1DCTKBL	1.27	31.97	

TABLE 3

THERMOLAGGED TRAY IN UNIT 3 PER EE 580

TRAY I.D.	TOTAL WATTS/FT.*	ALLOWABLE WATTS/FT.**	REMARKS
3EZA1DCTKBL	1.07	31.97	U1 VALUE

* CALCULATION
** TABLE SH. 6 OF 18
(TRAY W/SOLID COVER W/O OVERFILLED)

LAO 0513 6-73

ENCLOSURE 1

SIGNATURE J. S. FUENTES DATE 2-09-87 CHECKED ________ DATE ________
PROJECT ANPP / PVNGS 1, 2 & 3 JOB NO. ________
SUBJECT CALC. 13-EC-ZA-300 CABLE DERATING VERIFICATION SHEET 3 OF 3 SHEETS

TABLE 4.

THERMOLAGGED TRAYS IN UNIT 2 PER EE 580

TRAY I.D.	TOTAL WATTS/FT *	ALLOWABLE WATTS/FT **	REMARKS
2EZA1BNTKAD	16.84	42.57	NON-1E
2EZA1CATGAJ	4.92	31.97	U1 VALUE
2EZA1CATKBA	1.07	31.97	
2EZA1CATKBC	1.07	31.97	
2EZA1DATFBA	1.874	31.97	U1 VALUE
2EZA1DATKBA	5.428	31.97	
2EZA1DCTKBF	0.136	31.97	
2EZA1DCTKBG	0.136	31.97	
2EZA1DCTKBK	0.136	31.97	
2EZA2ANTFAA	19.49	42.57	
2EZA2ANTFAF	19.49	42.57	
2EZA2ANTFBB	13.76	42.57	
2EZA2CNTAAD	0.72	42.57	USED NTAAA VALUE
2EZA2CNTFAP	17.65	42.57	
2EZA2CNTFAQ	24.24	42.57	
2EZA2CNTKFB	11.18	42.57	U1 VALUE
2EZA3ANTKAV	5.42	42.57	

ENCLOSURE 2

PROCEDURE:

Raceways wrapped with Thermo-lag to comply with Appendix "R" requirements are shown on Appendix "R" drawings and tracked in the EE580 program.

Raceways wrapped with Thermo-lag to comply with Reg. Guide 1.75 are determined in a case-by-case basis by the field engineer and documented via an FCR and in addition are tracked in the EE580 program.

EE580 tracking of wrapped raceways is accomplished by assigning a unique secondary status (G7) control characteristic value of "WP" (wrapped) to the raceway when the Appendix "R" drawing is issued and/or when review and approval of the FCR is completed by the home office engineering.

UNDERWRITERS LABORATORIES INC.
[illegible]

an independent, not-for-profit organization testing for public safety

January 21, 1987

FOR INFORMATION ONLY

Thermal Science, Inc.
Mr. Rubin Feldman, President
2200 Cassens Drive
St. Louis, MO 63026

Our Reference: Project 86NK23826, File R6802

Subject: Special Services Investigation Of Ampacity Ratings For Power Cables In Steel Conduits And In Open-Ladder Cable Trays With Field-Applied Enclosures

Dear Mr. Feldman:

The following is a Letter Report summarizing the details and results of the ampacity investigation conducted at our Northbrook Testing Station. The sole purpose of this investigation was to develop information which you intend to use to determine if the ampacity derating caused by the field-applied enclosures meet the requirements of Bechtel Power Corporation for use at the South Texas Project Nuclear Power Plant. It is understood that the information developed as a result of the investigation described herein is to be submitted only to Bechtel Power Corporation.

In no event shall Underwriters Laboratories be responsible to anyone for whatever use or nonuse is made of the information contained in this Letter Report and in no event shall Underwriters Laboratories, its employees, or its agents incur any obligation or liability for damages, including, but not limited to, consequential damages, arising out of or in connection with the use, or inability to use, the information contained in this Letter Report.

The issuance of this Letter Report in no way implies Listing, Classification or other Recognition by UL and does not authorize the use of UL Listing or Classification Markings or any other reference to Underwriters Laboratories Inc. on or in connection with the product or system.

THERMAL SCIENCE, INC. AND ITS EMPLOYEES AND AGENTS SHALL HAVE NO OBLIGATION OR LIABILITY FOR DAMAGES, INCLUDING BUT NOT LIMITED TO CONSEQUENTIAL DAMAGES ARISING OUT OF OR IN CONNECTION WITH THE USE, OR INABILITY TO USE, THE INFORMATION INCLUDED IN THIS REPORT.

FOR INFORMATION ONLY

DESCRIPTION

MATERIALS:

The following is a description of the materials used in the test investigation.

Cable Tray - The nominal 24 in. wide open-ladder galvanized cable tray consisted of nominal 4 in. deep siderail members with ribbed and vented rungs. The rungs were spaced 12 in. OC. The loading depth of the cable tray was 3-5/8 in. The cable tray, manufactured by MP Husky Corp., Greenville, South Carolina and designated Type S9J-24-144 VENTRAY, was supplied in a nominal 12 ft length. The cable tray was purchased by Houston Lighting and Power Company, Wadsworth, Texas under their Customer Order No. CF28294.

Steel Conduit - The nominal 4 in. diameter rigid galvanized steel conduit had an outside diameter of 4.500 in., and an inside diameter of 4.026 in. and a wall thickness of 0.237 in. Two nominal 10 ft lengths of conduit were purchased locally and connected together using a threaded steel coupling. After assembly, one conduit was cut to provide an overall conduit length of 12 ft, 0 in. Each length of conduit bore the UL Listing Mark.

Cables - The 3-conductor No. 6 AWG power cable was marked "THE OKONITE CO PLT #7 OKONITE VFR POWER CABLE 3CDR 6 AWG CU 2000V 90C RA-306 1979." Each of the three stranded conductors consisted of seven 0.060 in. diameter tinned copper strands. The outside diameter of each insulated and jacketed conductor was 0.340 in. The outside diameter of the cable was 1.000 in.

The reel of cable was shipped from the South Texas Project (Shipping Notice 5813 dated August 29, 1986). The reel of cable bore the following information imprinted on aluminum plates:

BECHTEL REEL
RA306 503

P.O. 35-1197-8046-POC2
B&R ITEM NO. 9 - VIOLET
SOUTH TEXAS PROJECT
THE OKONITE CO.
CUSTOMER REEL RA-306503
2100 FT QC 23588B3
CLASS 1E

3/C 6 7X CC-2000V
.055 OKONITE-.030 OKOLON
.080 OKOLON
F.O. 07-2597-1
SEQ FTG T.7010108
B.7008008

Enclosure - A total of six different enclosure materials were supplied by Thermal Science, Inc. for inclusion in the ampacity investigation. The four enclosure materials used on the cable tray sample were each supplied in sheets and were identified by the manufacturer as being:

1. THERMO-LAG 330 Prefabricated Panels
   Regular Density - Nominal Thickness: 1/2 in.
   Color - Off White

2. THERMO-LAG 330 Prefabricated Panels
   Regular Density - Nominal Thickness: 1 in.
   Color - Off White

3. THERMO-LAG 330 Prefabricated Panels
   Low Density - Nominal Thickness: 1/2 in.

4. THERMO-LAG 330 Prefabricated Panels
   Low Density - Nominal Thickness: 1 in.
   Color - Charcoal Grey

The two enclosure materials used on the conduit sample were preformed sections split in half, longitudinally, and were identified by the manufacturer as being:

1. THERMO-LAG 330 Preshaped Conduit Sections
   Regular Density - Nominal Thickness: 1/2 in.
   Color - Off White

2. THERMO-LAG 330 Preshaped Conduit Sections
   Regular Density - Nominal Thickness: 1/2 in.
   Color - Off White

Small samples of each material were obtained by representatives of Bechtel Power Corporation and Houston Lighting & Power Company.

Joint Sealant Material - The material used to cover the joint openings of the various enclosures on the cable tray and conduit samples was supplied by Thermal Science Inc. and was identified by the manufacturer as being "THERMO-LAG 330-1 Trowel Grade." The material was supplied in a 5 gal plastic pail.

Banding Straps - The stainless steel banding straps were 1/2 in. wide by 0.020 in. thick. The 13/16 in. long by 0.605 in. wide winged-sleeve cinch clips used in conjunction with the banding straps were formed of 0.028 in. thick stainless steel. The steel strapping and clips were manufactured by Childers Products Co., Cleveland, OH.

Corner Angles - The corner angles used in conjunction with the stainless steel banding straps on the cable tray sample consisted of nominal 2 in. lengths of nominal 2 by 2 by 0.046 in. thick stainless steel angle.

Tie Wire - The stainless steel tie wire used in conjunction with the 1/2 in. thick panels on the cable tray sample had a diameter of 0.030 in.

CONSTRUCTION OF TEST ASSEMBLIES:

The cable tray and conduit samples, with cables, were assembled by members of the technical staff of Underwriters Laboratories Inc. under the supervision of the engineering staff of Underwriters Laboratories Inc. The various enclosures were installed by workmen in the employ of the submittor under the supervision of representatives from Bechtel Power Corporation and Houston Lighting and Power Company. The installation was also witnessed by members of the engineering staff of Underwriters Laboratories Inc.

The nominal 12 ft long cable tray was supported 18 in. from each of its ends by a nominal 5 ft long H-shaped Type P1001 steel Unistrut channel. A nominal 3 by 25 by 1 in. thick piece of ceramic fiber blanket insulation was placed atop the Unistrut channel beneath the cable tray in order to provide a thermal break.

The cables were installed in the nominal 12 ft long cable tray as shown in ILL. 1. The first (bottom) layer consisted of 24 runs of cable looped back-and-forth in the cable tray with each loop of cable extending approximately 8 to 12 in. beyond the cable tray end. Each cable was secured to the cable tray rungs with No. 16 SWG steel wire ties spaced 12 to 24 in. OC. The second layer consisted of 23 runs of cable looped back-and-forth in the cable tray and secured to the cable tray rungs using No. 16 SWG steel wire ties. The third (top) layer consisted of 24 runs of cable looped back-and-forth in the cable tray without attachment.

The first and second layers of cable in the cable tray system were installed using a continuous length of cable. The third layer of cable was installed in one continuous length with the three conductors of the third layer length spliced to the three corresponding conductors of the second layer length using split-bolt connectors in conjunction with multiple wraps of PVC electrical tape insulation. The three conductors of the spliced cable were then wired in series in such a manner as to represent a single No. 6 AWG conductor having a total length in the tray of approximately 2980 ft. The measured resistance of the No. 6 AWG conductor was 1.287 ohms.

The cables were installed in the nominal 12 ft long steel conduit adjacent to the cable tray as shown in ILL. 2. Seven cables, each 14 ft long, were tightly bundled together using nylon ties and were inserted in the steel conduit system such that 1 ft projected from each of its open ends. After installation in the steel conduit, the individual conductors were wired in series using split-bolt connectors in conjunction with PVC electrical tape which resulted in a single No. 6 AWG conductor having an overall length of approximately 294 ft.

The four enclosure configurations for the cable tray sample were each installed in essentially the same manner. The general installation details for the four cable tray enclosures are shown in ILLS. 3, 4 and 5.

The two enclosure configurations for the conduit sample were each installed in essentially the same manner. The two halves of the preformed panel sections were installed about the conduit with the longitudinal seams oriented at the 3 o'clock and 9 o'clock positions. Adjacent 3 ft lengths of the preformed panel sections were butted together. The pairs of preformed panel sections were secured to the conduit sample with stainless steel banding straps located at each end of each 3 ft long section and maximum 12 in. OC along the length of the conduit sample. After completion of the banding installation, the longitudinal seams and end seams were covered with the joint sealant material.

A piece of glass fiber insulation was placed beneath the enclosed conduit sample at each support channel location to afford a thermal break.

As a final step in the installation of the protective enclosure on each test sample, the ends of the cables projecting 8 to 12 in. from each end of each system were wrapped with glass fiber insulation covered with PVC duct tape.

TEST RECORD

AMPACITY TESTS:

SAMPLES

The ampacity tests were conducted on the cable tray and conduit configurations described previously in this Letter Report under "Construction of Test Assemblies."

METHOD

For each test of the cable tray configuration, 53 fusion-welded No. 24 gauge chromel-alumel (Type K) thermocouples were used to measure temperatures. Thirty-six of the thermocouples were located on the copper conductors of the cables, as shown in ILL. 1. To obtain accurate conductor temperature readings, a slit was made in the cable jacket and insulation materials, and the thermocouple was inserted in the slit, in contact with the copper conductor. To ensure that the thermocouple remained in intimate contact with the copper conductor, the strands of the conductor were spread apart, the beaded tip of the thermocouple was inserted between the strands and the copper strands were released, thereby locking the beaded thermocouple tip in place. The slit in the cable jacket was then sealed with multiple wraps of PVC electrical tape. The remaining thermocouples were used to measure the ambient temperature of the test enclosure and the top surface temperature of the cable tray protective system, as shown in ILL. 1.

Thirty fusion-welded No. 24 gauge chromel-alumel (Type K) thermocouples were used during the conduit ampacity tests to measure temperatures. Twelve of the thermocouples were located on the copper conductors of the cables, as shown in ILL. 2. To obtain accurate conductor temperature readings, a slit was made in the cable jacket and insulation materials and the thermocouple was inserted in the slit, in contact with the copper conductor. To ensure intimate contact with the copper conductor, the strands of the copper conductor were spread apart, the beaded tip of the thermocouple was inserted between the strands and the strands were released, thereby locking the thermocouple tip in place. The slit in the cable jacket material was then sealed with multiple wraps of PVC electrical tape. The remaining thermocouples were used to measure the ambient temperature of the test enclosure and the temperatures of the top and bottom surfaces of the conduit or conduit protective materials, as shown in ILL. 2.

Testing was performed using house current in combination with a variable load bank. For each configuration, one end of the series-wired No. 6 AWG cable conductor was connected to 115 V ac house current protected with a 110 A fuse. The return leg of the series-wired No. 6 AWG cable conductor passed through a 0.1-101 A variable load bank. The current was measured using an ammeter shunted from the load bank.

The thermocouple wire used for each test configuration was purchased from Claud S. Gordon, Richmond, Illinois, and was designated K24-2-305, Type K.

The data logger used to measure and record the temperature data for each test configuration was a Fluke 2285B Data Logger (UL Asset No. 85 1075, Serial No. 3910000).

The analog ammeter used to measure the current for each test configuration was manufactured by Yokogawa Electric Works, Ltd., Tokyo, Japan (UL Instrument No. 97836M).

The calibration records for the data logger and ammeter are on file at Underwriters Laboratories Inc.

The ampacity tests were each conducted in a draft-free enclosure having inside dimensions of 7 ft, 6 in. wide by 15 ft, 6 in. long by 5 ft, 10-1/2 in. high. The floor, ceiling, walls and door were each insulated. A 240 V, 2100 W heater was mounted on the inside surface of the insulated door, 4 ft above the floor of the enclosure, to supplement heating of the enclosure as required. The heater was mounted at an angle such that its heat was directed upward with no direct radiation onto the test sample. The radiant heater was provided with a Variac to allow manual control of the heater output. A small exhaust fan was located in the ceiling at the center of the enclosure to exhaust heat from the room as needed. In addition, a nominal 8 by 12 in. shuttered opening was provided in each corner of the ceiling to vent heat, as necessary, through natural convection. To prevent movement of air across the test samples with the exhaust fan in use, a nominal 4 by 8 ft sheet of plywood was suspended approximately 8 in. below the ceiling of the enclosure, centered under the exhaust fan outlet.

The cable tray and conduit "baseline" ampacity tests and the ampacity tests on the various cable tray and conduit configurations were all performed using the same procedure. For each test, the sample was installed in the draft-free enclosure and the cable circuit was electrically loaded with current at 110 V ac. The load on the cable circuit was adjusted to the value necessary to attain a steady-state temperature of 90°C ± 0.4°C as measured on the hottest cable conductor at the center section of thermocouples (Thermocouple Nos. 13 through 24 on the cable tray sample and Thermocouple Nos. 2, 5, 8 and 11 on the conduit samples). During each ampacity test, the ambient temperature within the enclosure, as determined from Thermocouple No. 0 (average of three thermocouples wired in parallel) was maintained at 40 ± 0.3°C using the radiant heater, ceiling vents and/or exhaust fan, as necessary.

For each ampacity test, approximately 15 min time was allowed to elapse after the final electrical current adjustments were made to ensure that the cable conductor temperatures were stabilized. Upon reaching and maintaining the steady-state temperature of 90°C ± 0.4°C over the 15 min time period, the electrical current was recorded and the temperatures of each thermocouple in the test set up were measured and recorded at 1 min intervals for a 60 min time period. During the 60 min time period, the electrical current was monitored to ensure that it did not change.

RESULTS

The temperature data from each test is on file at Underwriters Laboratories Inc. in Northbrook, Illinois. The results of the ampacity tests are summarized in the following table:

Ampacity Test Configuration	Ambient Temperature, °C		Maximum Conductor Temperature, °C		T.C. No.	Current, A
	Start	60 min	Start	60 min		
Cable tray without protective enclosure (Baseline)	40.3	40.1	90.3	90.3	16	32.1
Cable tray with regular density 1/2 in. thick panel enclosure	40.0	40.0	90.0	90.3	17	23.1
Cable tray with regular density 1 in. thick panel enclosure	40.1	40.0	90.2	90.1	18	22.1
Cable tray with low density 1/2 in. thick panel enclosure	40.0	40.2	90.2	90.1	17	21.7
Cable tray with low density 1 in. thick panel enclosure	40.3	40.2	90.4	90.3	19	19.5
Conduit without protective enclosure (Baseline)	40.1	40.2	90.2	90.2	2	34.1
Conduit with regular density 1/2 in. thick preform panels	40.2	40.2	90.1	90.1	2	34.8
Conduit with regular density 1 in. thick preform panels	40.1	39.9	90.1	90.2	2	30.9

For each of the ampacity tests, a representative of the Bechtel Power Corporation made the determination as to when the ampacity test sample had reached a steady-state condition. One or more representatives of Thermal Science, Inc. was also present for each of the ampacity tests.

Very truly yours,

Mark T. Fava

MARK T. FAVA
Laboratory Assistant
Fire Protection Department

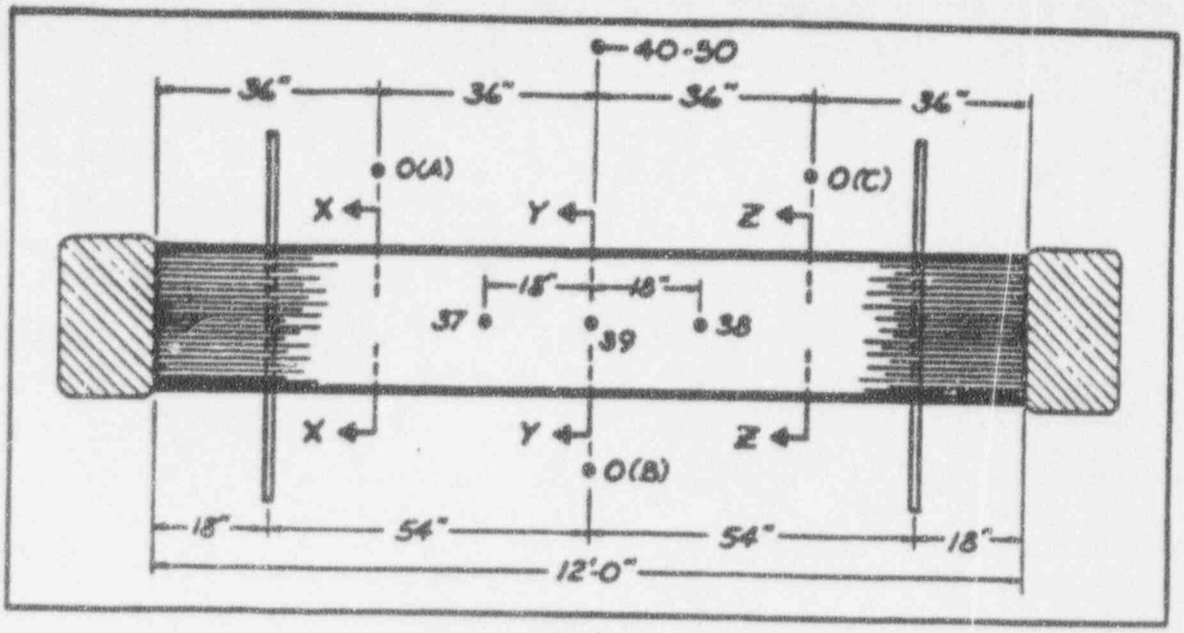
C. J. JOHNSON
Senior Engineering Associate
Fire Protection Department

Reviewed by:

K D Rhodes

K. D. RHODES
Engineering Group Leader
Fire Protection Department

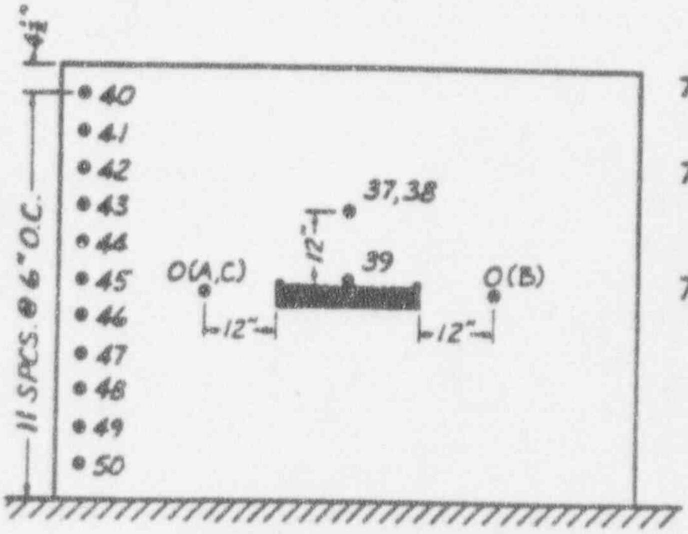
CJJ:gz
GZ5:2



PLAN

T.C. NO. 0, CONSISTING OF 3 T.C.'s WIRED IN PARALLEL, USED FOR AMBIENT TEMPERATURE DETERMINATION. THE 3 T.C.'s (A, B & C) WERE LOCATED 12" FROM CABLE TRAY OR PROTECTIVE ENCLOSURE @ PLANE OF CABLE TRAY MIDHEIGHT.

T.C. NOS. 1-36 ON CU CNDR. OF 3/C-6AWG CABLES.

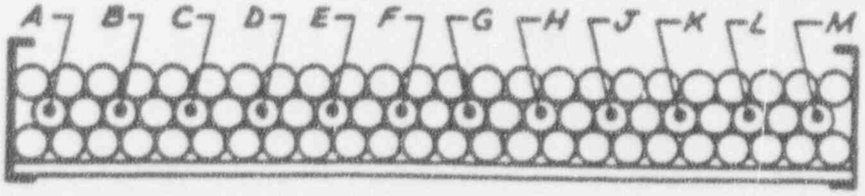


ELEVATION(END VIEW)

T.C. NOS. 37 & 38 LOCATED 12" ABOVE CABLES OR PROTECTIVE ENCLOSUR

T.C. NO. 39 LOCATED ON TOP SURFACE OF CABLE FILL OR PROTECTIVE ENCLOSURE

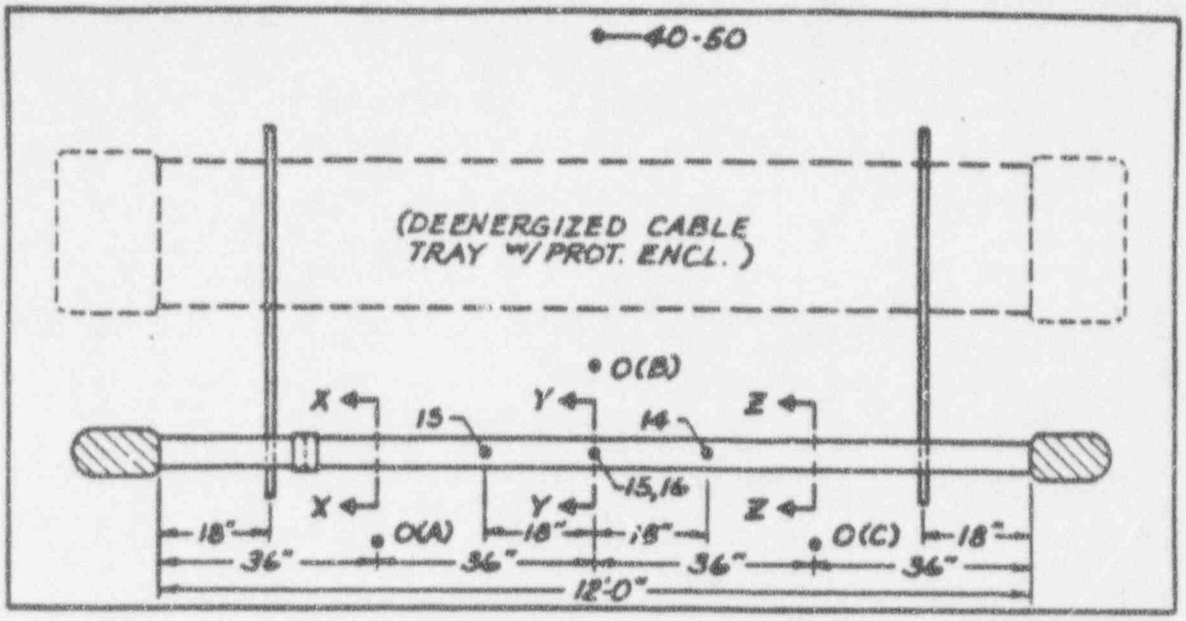
T.C. NOS. 40-50 LOCATE IN AIR APPROX. 4" FROM WALL OF TES ENCLOSURE.



TRAY SECT.	THERMOCOUPLE NOS.											
	A	B	C	D	E	F	G	H	J	K	L	M
X-X	1	2	3	4	5	6	7	8	9	10	11	12
Y-Y	13	14	15	16	17	18	19	20	21	22	23	24
Z-Z	25	26	27	28	29	30	31	32	33	34	35	36

THERMOCOUPLE LOCATIONS

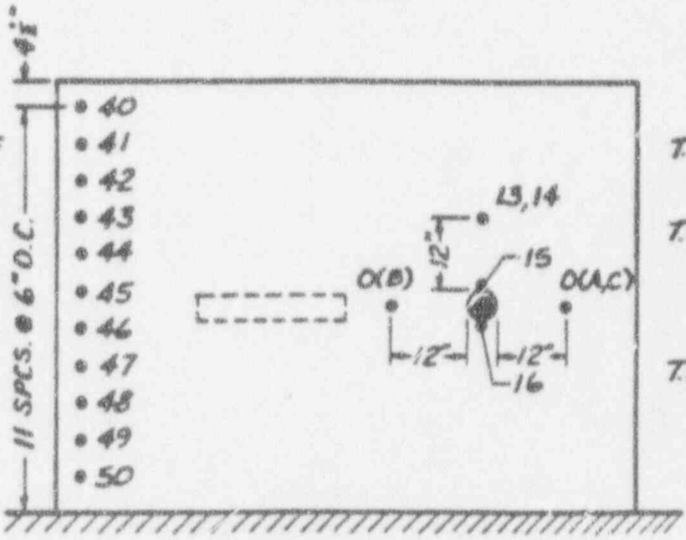
R6802
ILL. 1



PLAN

T.C. NO. 0, CONSISTING OF 3 T.C.'s WIRED IN PARALLEL, USED FOR AMBIENT TEMPERATURE DETERMINATION. THE 3 T.C.'s (A, B & C) WERE LOCATED 12" FROM CONDUIT OR PROTECTIVE ENCLOSURE @ PLANE OF CONDUIT MIDHEIGHT.

T.C. NOS. 1-12 ON COPPER CONDUCTOR OF 3/C-6AWG CABLE.

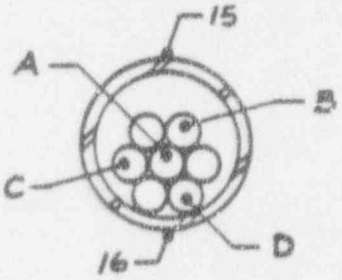


T.C. NOS. 13 & 14 LOCATE
12" ABOVE CONDUIT O
PROTECTIVE ENCLOSUR

T.C. NOS. 15 & 16 LOCATED ON TOP & BOTTOM SURFACES, RESPECTIVELY, OF CONDUIT OR PROTECTIVE ENCLOSURE

T.C. NOS. 40-50 LOCATE IN AIR APPROX. 4" FR WALL OF TEST ENCLOSURE.

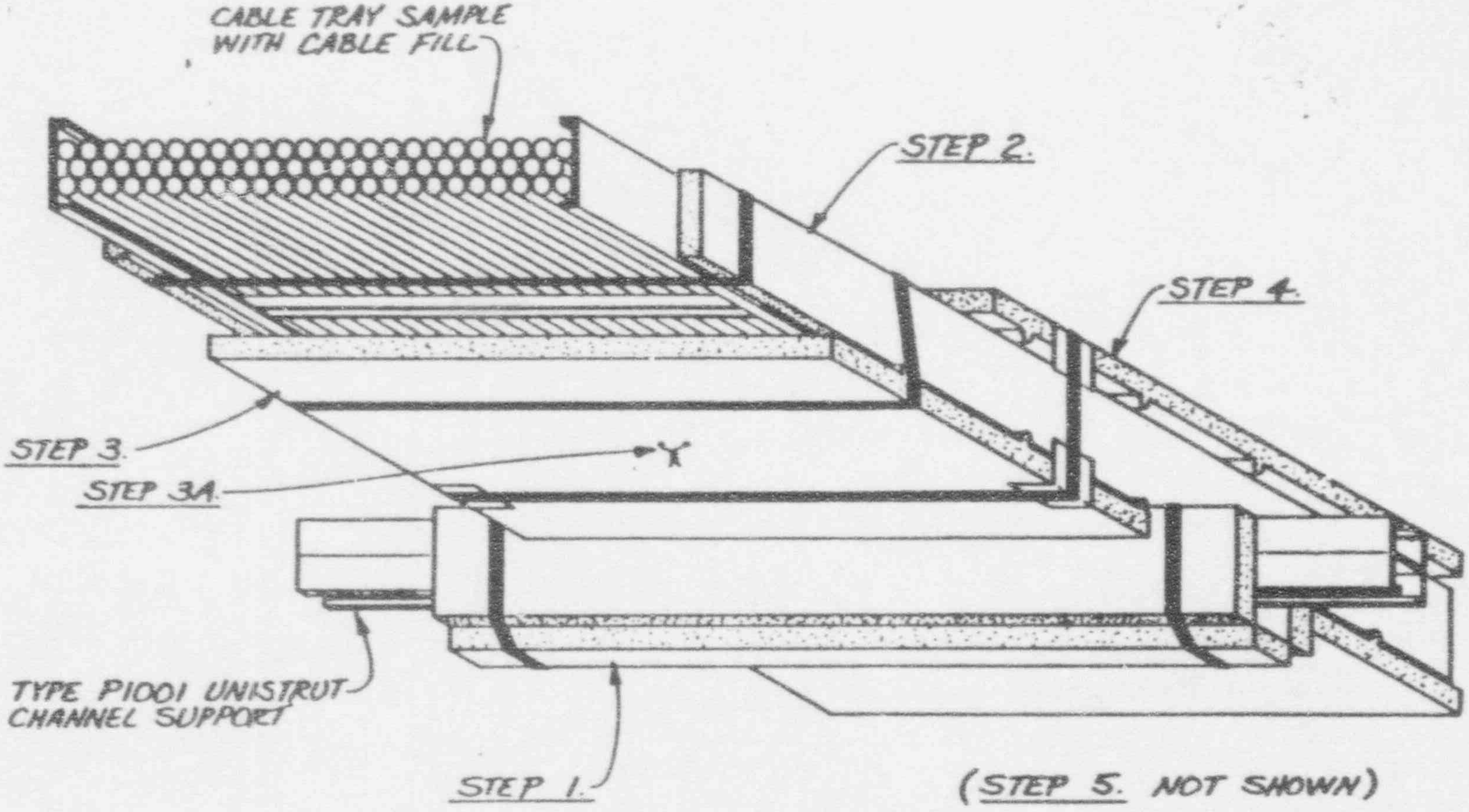
ELEVATION (END VIEW)



COND'T. SECT.	T.C. NOS.			
	A	B	C	D
X-X	1	4	7	10
Y-Y	2	5	8	11
Z-Z	3	6	9	12

THERMOCOUPLE LOCATIONS

R6802
ILL. 2



TYPICAL INSTALLATION DETAILS
FOR CABLE TRAY ENCLOSURES
(SEE ILLS. 4 & 5 FOR DESCRIPTIVE TEXT OF STEPS 1-5)

R6802
ILL. 3

TYPICAL INSTALLATION DETAILS FOR CABLE TRAY ENCLOSURES

1. The Type P1001 Unistrut support channels were each covered on the bottom and sides with a "U"-shaped section formed by slitting a nominal 10 by 38 in. panel with a razor knife and folding as shown. The "U"-shaped panel sections were each secured to the support channels with a stainless steel banding strap on each side of the cable tray.

2. The cable tray siderails were covered using four nominal 4-1/2 in. wide by 6 ft long sections of panel. The bottom edge of each panel was notched approximately 1/2 in. at the support channel locations such that its top edge was flush with the top of the cable tray siderail. Pairs of siderail cover panels were secured in place with stainless steel banding straps passing around cable tray. Each 6 ft long pair of siderail cover panels was secured by a banding strap near its center and near each end. For configurations using 1/2 in. thick panels, the ribbed surface of the siderail cover panels was placed against the cable tray siderails (flat surface exposed). For configurations using 1 in. thick panels, the flat surface of the siderail cover panels was placed against the cable tray siderails (ribbed surface exposed).

3. The panel sections on the underside of the cable tray were cut to extend 1/4 to 3/4 in. beyond the siderail cover panels on both sides of the cable tray. Sections of panel, with the ribbed surface toward the cable tray (flat surface exposed), were secured to the underside of the cable tray with stainless steel banding straps passing around the cable tray and spaced 18 to 24 in. OC.

3A. For configurations employing the 1/2 in. thick regular or low density panels, the panel sections on the underside of the cable tray were additionally supported along the longitudinal centerline of the cable tray using stainless steel tie wires. At each rung location (12 in. OC), two holes were pierced through the 1/2 in. thick panel using a Phillips screwdriver. A length of wire was passed around the rung of the cable tray with its two ends extending through the pierced holes in the panel. The panel was then pushed against the underside of the cable tray and was secured in place by twisting the ends of the tie wire together using multiple tight twists.

4. The nominal 6 ft long panel sections on the top of the cable tray were cut to the same width as the bottom panels and were placed atop the cable tray with the ribbed surface against the cable tray (flat surface exposed). The panel sections were secured to the cable tray using stainless steel banding straps in conjunction with stainless steel corner protector angles at each corner with the bands spaced 12 to 18 in. OC.

R6802
ILL 4

5. The openings along the top and bottom of each cable tray siderail panel, formed by the ribs of the top and bottom panel sections, were covered with a thin coating of trowel-grade joint sealant. No attempt was made to fill the openings through the thickness of the siderail panels. The seams of the top, side and bottom panel sections at the center of the cable tray sample were also covered with a thin coating of the joint sealant.

R6802
ILL. 5

ENCLOSURE 6

AMPACITIES FOR CABLES IN RANDOMLY FILLED TRAYS

AMPACITIES FOR CABLES IN RANDOMLY FILLED TRAYS

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ABSTRACT

The allowable current which may be carried by a given conductor size cable has been thoroughly investigated in almost every conceivable type of cable installation. One area which has not had much attention up to now is the allowable current which can be carried by cables in cable trays, or troughs. This paper presents a completely general method for calculating the ampacities of cables in cable trays; it has been derived from elementary heat transfer theory and amply verified with many full-scale tests. The method shows that currently published ampacities for small cables in highly filled trays must be reduced, but the large cable ampacities can be safely increased.

INTRODUCTION

In the studies which have been made on the current carrying ability of electric power cables, the most simple case of one cable operating in air has been expanded to multiple cables in a conduit,[1] multiple cables or conduits in stacked banks,[2] and several cables pulled into steel raceways.[3] The results of these studies are incorporated to various extents in both the AIEE-IPCEA Power Cable Ampacities and the National Electric Code.

The ampacities, or derating factors, which have been determined so far are for cables which are in some form of an orderly arrangement; a further simplification which has been easily justified in the past is all the conductors considered were the same size. Unfortunately, this simplifying treatment cannot be justified when considering ampacities of randomly arranged cables in trays.

A typical cable tray installation which is found in the electric power generation and distribution industry can be visualized as a 3-inch deep 24-inch wide metal trough containing anywhere from 20 to 400 randomly arranged single or multi-conductor power and control cables ranging in size from #12 AWG to 750 MCM. This array of cables is usually secured along the cable tray with some ties to prevent the cables already in the tray from shifting if additional cables should be pulled into the tray. During construction as cables are secured in the tray, group by group, they can become packed together tight enough that air is unable to circulate through the mass of cables. With the physical ties and the normal vibration which is present in most plants, even many of the initially loose cable arrays can be expected to settle and thus become more or less restricting to air flow.

Several other variables tend to complicate the determination of ampacities of cables in trays. Some of the more apparent ones are the fullness of a tray, diversity of loading of cables in a tray, determining the location of the hottest spot over the tray cross-section, and the amount of power cable (which generates heat) in proportion to the amount of control cable (which generates negligible heat) in a tray. All the above variables can be, and are accounted for in the method described herein.

PROBLEM DEFINITION

The first of many variables to be examined is the extent to which the cables in any tray are packed. It is apparent that cables in a very loose arrangement are essentially immersed in air which can freely flow through the vacant space in a tray. As the space between cables is reduced, by packing cables closer together, free flow of air through the pack is gradually restricted. Taking this to the point where adjacent cables are touching each other on all sides, the continuous free space between cables becomes practically nonexistent and only small air pockets remain between the cables.

Applying this reasoning to heat flow from cables in a cable tray we see that a loose packing is desirable since air can naturally flow around each cable. The heat will then rise out of the pack and be replaced with cooler air from the bottom. When cables become tightly packed, there is no air flow through the bundle, and thus heat cannot be carried out of the bundle by natural air flow. In fact, the only way for heat to flow out of the tight bundle is by heat conduction through the conglomeration of cable conductors, insulation, and air pockets.

Cable ampacities in randomly filled trays must be based on the assumption that cables are tightly packed and that we cannot depend on heat being carried out of the bundle by air flowing through it. Without question, this tightly packed condition does not exist in every cable tray, but it does randomly occur often enough that, for safety, each cable tray must be designed as though it was going to be tightly packed. It is not even necessary that the entire cable tray be tightly packed, since a packed width of only about three inches is sufficient to produce a hot spot in an otherwise cool tray.

With the criterion of tight cable packing established, it is then required to determine how the heat generation is distributed in the tray cross-section. The many cable sizes possible, both single and multi-conductor, and each carrying a different current apparently makes it quite difficult to place allowable currents on such a heterogeneous mixture. However, looking at the problem from the standpoint that we do not want any hot spots in the cable tray, the problem can be solved.

Hot spots in a thermal system are produced by locally intense heat sources; thus, in every area of the cable tray we must eliminate such conditions. In other words, the heat generated in every area of a cable tray cross-section must be uniform. This is the key to the entire problem of ampacities for randomly arranged cables in cable trays, and the concept of uniform heat generation cannot be overemphasized.

Consider Figure 1 showing a hypothetical slice of area from a typical, tightly packed cable tray. The heat intensity within each unit area, expressed in watts/ft. per square inch of cross-sectional area, must be constant all the way down to the smallest unit area inside the tray, which is the smallest cable in the tray. We therefore place ampacities of cables, such as shown in Figure 1, in proportion to the overall cross-sectional area of the individual cables, including the conductor and insulation.

If we know the allowable heat intensity for a given cable tray, we can immediately place ampacities on every cable in the tray

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by knowing the cross-sectional area of each composite cable. Thus, the problem now remains to establish the allowable heat intensity for various cable tray configurations.

The reasoning presented thus far is significantly different from that used for cable tray ratings we now use. To show this, consider a large cable tray randomly filled with, say 300 tightly packed 600 volt cables of assorted sizes. According to the ratings published so far, every cable in this tray must be derated to 50% of the ampacity for a 3-conductor cable in air.[4,5,6,7] Figure 2 shows that seven single conductor #12 cables can occupy about the same area in the tray as one 4/0 cable. Comparing the heat which is generated within the equal areas of cables it can be seen that three to four times more heat is produced in the bundle of seven #12 cables as in a single #4/0 cable, even though the two configurations occupy the same area in the filled tray. This effect is exactly what we want to eliminate in a cable tray installation because it is possible to get bundles of small cables which produce locally intense heat sources and result in hot spots within the cable tray cross-section.

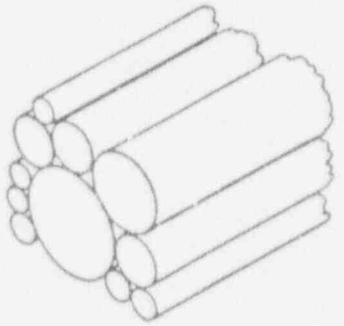


Fig. 1. Cross-section slice from a randomly arranged, closely packed cable tray.

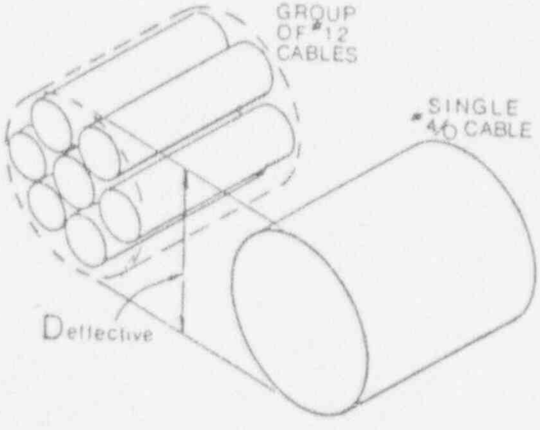


Fig. 2. Physical size comparison of typical rubber insulated cables.

This comparison can be made over and over with the present ampacities for cables in trays. The result is that small conductor size cables are allowed to "work" harder than the large size cables when they are all placed in a common random tray. Actually, all cables should be worked uniformly by coming to the same operating temperature in the tray.

ANALYTICAL MODEL

Whenever cable ampacities can be established with calculations, instead of an empirical approach, a better understanding of the overall heat transfer mechanism is possible. A simple analytical solution to the heat transfer from the general, hypothetical cable tray in Figure 3 has been made, and some rather subtle findings from the analysis will be pointed out.

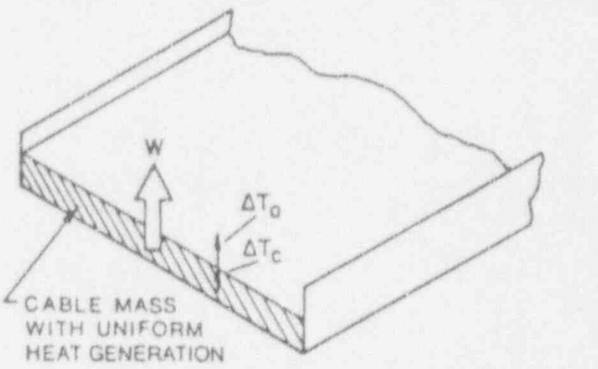


Fig. 3. Simplified analytical model for heat transfer from a tightly packed cable tray containing all power cable.

Before proceeding with the analysis, two additional conditions must be specified. The first condition is cables in any tray must be installed at a constant, or uniform, depth. This is to prevent cables from being heaped on one side of a tray with a resulting vacant space on the other side. The second condition is to assume, at first, that all the cables in the tray are power cables which will uniformly generate heat throughout the tray. These conditions allow the random mixture of cable to be treated as a homogeneous rectangular mass with uniform heat generation.

The task now is to simply find the allowable heat intensity (Q) for trays containing variable amounts of cable. Once we find the heat intensity, the heat which can be generated by each individual conductor (q) can be calculated from

$$q = \frac{QA}{n} \tag{1}$$

where n = number of conductors in cable

A = cross-sectional area of the n-conductor cable

Q = allowable heat per unit area generated in the tray

and, of course,

$$q = I^2R \tag{2}$$

where

I = maximum allowable current for a conductor

R = a.c. resistance of conductor at the maximum operating temperature of the insulation material in the cable tray.

Heat generated in any tightly packed cable tray must pass through two media: 1) the cable mass, and 2) the air immediately around the tray. Since heat flows through the media there is a resulting temperature drop in each, as shown in Figure 3, ΔT_c through the cables and ΔT_a through the air.

To determine the total amount of heat (W) which can be dissipated by a cable tray in an ambient temperature (T_a), and maintain its highest temperature at or below the operating temperature (T_m) of the cable insulation in the tray, we must limit the system temperature drop (ΔT) to

$$\Delta T = T_m - T_a \tag{3}$$

The system temperature drop is the sum of the drop through the packed cable mass (ΔT_c) and the drop through the air (ΔT_a) around the cable tray.

Therefore

$$\Delta T = \Delta T_c + \Delta T_a \tag{4}$$

The drop through the cable mass (ΔT_c) can be obtained from the equation given by Holman[8] for a rectangular slab with uniform internal heat generation.

$$\Delta T_c = \frac{W\rho d}{8w} \tag{5}$$

where ρ = effective thermal resistivity of cable mass
d = depth of cable mass
w = width of cable mass and tray
W = the total heat generated in the tray per unit length

Equation (5) is specifically for one dimensional heat flow out the top and bottom of the tray and it ignores any heat flow out the sides of the tray. This is a realistic simplification which is accurate for 6-inch and wider cable trays.

The temperature drop through the air (ΔT_a) is obtained from a heat balance between convection and radiation heat flow. Using basic equations from McAdams[9] we find

$$W = hA_s\Delta T_a + \sigma A_s\epsilon[T_c4 - T_a^4] \tag{6}$$

where $hA_s\Delta T_a$ = the heat loss from the tray due to convection
$\sigma A_s\epsilon[T_c^4 - T_a^4]$ = the heat loss from the tray due to radiation
and h = overall convection heat transfer coefficient for tray
A_s = surface area of cable mass per unit tray length
σ = Stefan–Boltzmann constant
ϵ = effective thermal emissivity of cable mass and tray surface
T_c = average cable mass surface temperature

The three equations (4), (5), and (6) have three unknowns and they can be solved to get the total allowable heat which can be generated in a cable tray (W). Since equation (6) is quite non-linear, the solution to the three equations must be obtained by iteration; thus, for general application the solution for W is done most easily on a computer.

Having the total heat generated in the cable tray, the heat generation per unit area is simply

$$Q = \frac{W}{(d)(w)} \tag{7}$$

The ampacity of each cable in the tray is finally determined with equations (1) & (2).

THEORETICAL RESULTS

The solution to equations (4), (5), and (6) for W and several degrees of cable tray fill will result in curves similar to those shown in Figure 4. It is seen that as the cable tray percent fill increases, the allowable heat intensity decreases due to greater temperature drop in the tightly packed cable mass. Figure 4 was made for an effective thermal resistivity of the cable mass being 400°C-cm/watt; and the test results to be presented later show this value to be valid for either rubber or polyethylene insulated cables which are tightly packed.

At this point we must define cable tray percent fill as the sum of the cross-sectional areas of all cables in the tray (including conductor, insulation, and jacket) divided by the total available cross-sectional area in the cable tray (width times height). It can be seen that a cable tray which is packed as tight as possible and level across the top is filled to about 75%, because about 25% of the tray area is void area between the circular cables. From the above percent tray fill definition it is apparent that a 6-inch deep tray with 20% fill has the same depth of packed cable as a 3-inch deep tray with 40% fill.

In applying equations (1) and (2) to get the ampacity of specific conductor sizes in a given cable tray, an interesting observation can be made. The cable ampacity (1) is given by

$$I = \sqrt{\frac{QA}{nR}} \tag{8}$$

and substituting for the circular cross-sectional area of each cable (A) we get

$$I = \frac{D}{2}\sqrt{\frac{Q\pi}{nR}} \tag{9}$$

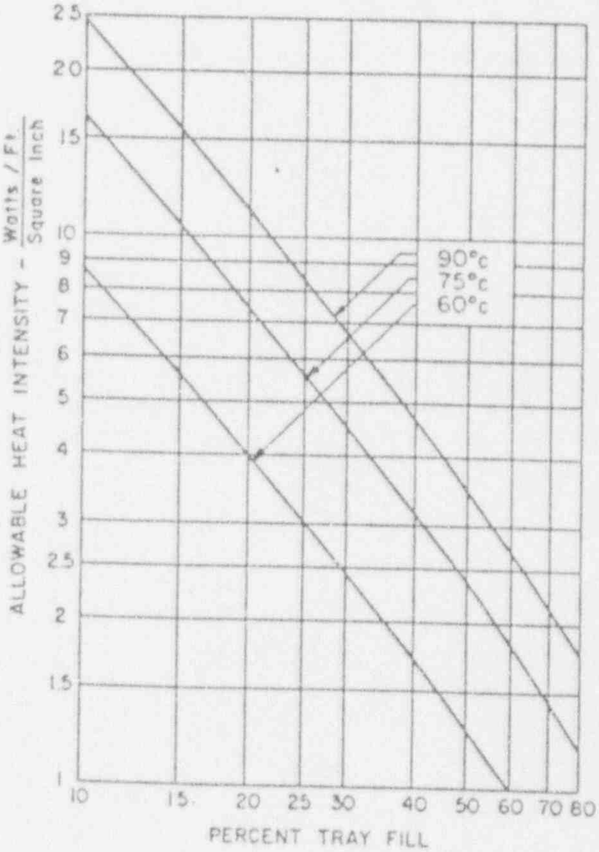


Fig. 4. Allowable heat intensity (Q) to maintain rubber-like or polyethylene cables at the specified temperature in 3-inches deep by 24-inches wide trays operating in a 40° C ambient.

It is seen that the ampacity of a cable is directly proportional to its overall diameter (D). Thus, increasing the insulation thickness on a given conductor increases its diameter and thus increases its ampacity when installed in a cable tray, for a given percent tray fill and the same temperature limits.

Here it must be pointed out that the ampacities of the bulky rubber insulated cables in trays are not at all the same as ampacities for the small crosslinked polyethylene insulated cables with very thin insulations. For example, a number 12 AWG rubber insulated cable with a diameter of .24 inches may have an allowable heat intensity (from Figure 4) to give an ampacity of 24 amps; the same conductor insulated with crosslinked polyethylene would have a diameter of only about .16 inches and therefore, from equation (9), an ampacity of 16 amps. It thus becomes necessary to distinguish between thin wall and thick wall insulated cables; throughout this paper, reference to polyethylene cable implies thin wall insulation and rubber implies thick wall insulation.

The above difference in ampacity comes from the fact that for a given percent tray fill, more crosslinked polyethylene (thin wall) insulated *conductors* can be packed into the tray than rubber (thick wall) insulated *conductors*. Since the total amount of heat which may be generated in the tray must remain constant, the heat per conductor must be less for the small diameter cables than for the large ones.

With the allowable heat intensities from Figure 4 and using them in equation (9), the ampacities of several cable sizes and percent tray fills can be obtained. The results are shown in Figure 5, which is a graphical ampacity table for typical single conductor rubber insulated copper conductors installed in 3-inch by 24-inch cable trays. For comparison, the presently published ampacities for the same type cable are also plotted; they are for the assumed case of maximum derating which is for 43 or more conductors in the tray, and thus are 50% of the ampacity of a three conductor cable in air.

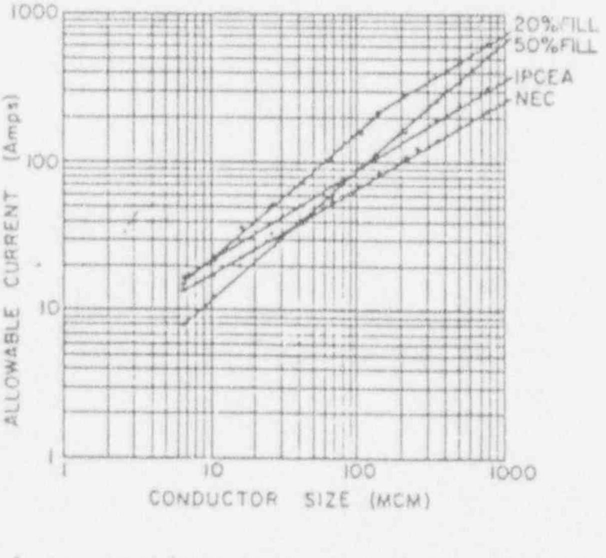


Fig. 5. Ampacities of typical rubber insulated copper cables in 3" x 24" trays as determined by this study and compared with IPCEA and NEC values for trays containing more than 43 conductors. 90° C operating temperature in a 40° C ambient

This graphical comparison, along with test results presented later, makes it quite clear that the present ampacities for trays with high percent fills are too high for small conductor sizes, while being too low for the large conductor sizes. Note that for the thin wall XLP insulated cables, the ampacities are even lower than for the thick wall rubber cables, and the safety of the present ampacities would be even more questionable.

This point is made to supplement one of the favorable properties of the small diameter XLP cables. Specifically, more XLP cables can be installed in a cable tray than other kinds of insulated cables, and thus there is economy in using fewer cable trays. Along with being able to install more cables in a tray it is essential that the thin wall cables carry less current than the heavier insulated cables. If this is not done, there will be overheating of the XLP cables and the accelerated loss of cable life resulting in premature cable failures.

The best observation to be made from the theory is related to heat generation in cable trays being in proportion to the cross-sectional area of each cable. A somewhat evident justification for this requirement can be seen from the following reasoning.

The most elementary equation describing convection heat flow is

$$q = hA_s\Delta T$$

where h is the convection heat transfer coefficient, A_s is the surface area convecting heat to the air, and ΔT is temperature difference between the cable surface and the ambient air. The basic equation for conduction heat transfer is

$$q = kA_c\frac{\Delta T}{\Delta x}$$

where k is the thermal conductivity of the heat conducting medium, A_c is the cross-sectional area through which heat flows, and ΔT is the temperature drop over a distance Δx in the direction of heat flow. Note that convection heat flow is proportional to surface area while conduction heat flow is proportional to cross-sectional area. Since conduction is the governing method of heat flow within a tightly packed cable mass, we should be concerned with cross-sectional areas of cables rather than peripheral or surface areas.

TEST PROCEDURE

Five different cable tray arrangements have been thoroughly tested in order to determine the heat transfer properties of each arrangement. Two of the tests involved randomly arranged cables of various sizes in 24-inch wide trays and three tests were performed on 12-inch wide trays with only one cable size in the tray. Table I summarizes the various tests which were performed and Figure 6 shows the overall test setup.

TABLE I - Summary of Tests Conducted to Support Analytical Results

TRAY SIZE	PERCENT FILL	CABLE SIZES TESTED	INSULATION TYPE	
3"x24"	20	#12 to 4/0	Rubber	thick wall
3"x24"	55	#12 to 4/0	Rubber	
3"x12"	40	3/C-#12	Rubber	
3"x12"	40	3/C-#12	XLP	thin wall
3"x12"	50	1/C-500	XLP	

Some details of the testing which were common to all tests can be seen from Figure 6. 600 volt rated copper conductor cables were laid in a 24-foot long cable tray and temperatures were measured at three different tray cross sections; one was in the mid-length of the tray and two others at the quarter lengths. In many cases cables extended out both ends of the tray in order to make-up connections more easily. To insure that there was no heat flow from the tray center out the ends of the tray, a ring of fiberglass building insulation was wrapped around the cables at each end of the tray. This served to make a short hot spot at each end where the cables ran about 5°C hotter than the cables inside the tray, and thus no heat could flow out the tray ends.

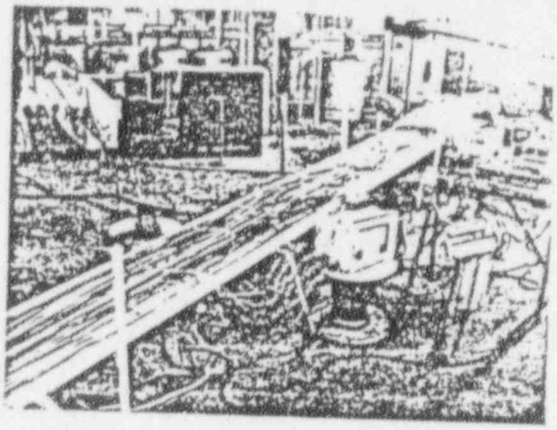


Fig. 6. *Overall view of test area showing 24-ft. long cable tray, loading transformers on right, and thermocouple recorder in the center.*

All testing was conducted with single phase 60 hertz alternating current. Other investigations[3] have shown that essentially no difference exists between three phase and single phase test results. Thus, test current was applied to each conductor size by passing it through a long continuous length of wire folded back and forth in the tray the required number of times to get the proper quantity of cable in each test tray. The voltage applied to the cable was only enough to overcome the electrical impedance of the long continuous wire.

Temperatures produced by the test currents were measured with No. 20 AWG iron-constantan thermocouples connected to a 24 point thermocouple recorder. Calibration of each thermocouple was checked against a standard thermometer by comparing thermocouple readings at room temperature and in boiling water. The deviation was less than 1°C from the known temperatures in every case. The thermocouples were placed on the test cables by making a narrow slit in the insulation just wide enough to accept the twisted end of the thermocouple, thus embedding it in the cable insulation. This permits accurate measurement of the maximum temperature in a cable tray, provided thermocouples are placed on the side of cables at the mid-depth of the packed cable mass.

Finally, in order to closely pack the cables in each tested tray, plastic tie-straps about 0.2-inch wide were used where required. The tie-straps were generally passed through one of the ventilating holes in the tray bottom, over the cables to be held down, and back through the tray bottom and secured.

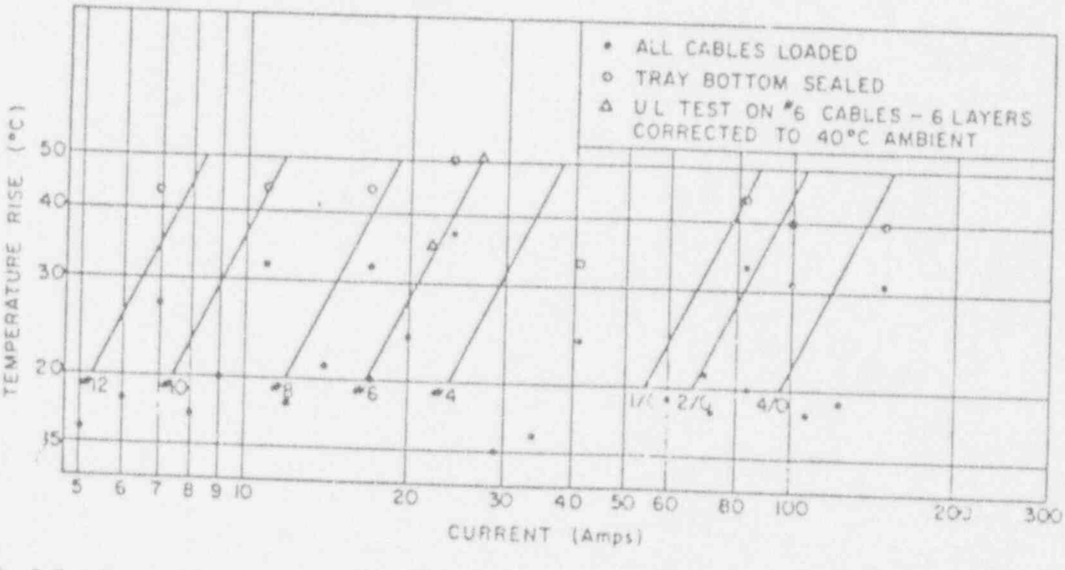


Fig. 7. Test Results for the 55 Percent Fill 24-inch Wide Tray Containing the Following Thick Wall Insulated Cables

CABLE SIZE	OUTSIDE DIAMETER	QUANTITY IN TRAY
#12	.25"	78
10	.27"	9
8	.36"	17
6	.40"	43
4	.45"	8
1/0	.65"	6
2/0	.70"	3
4/0	.80"	6
Multi-Conductor #12		To Fill Tray to 55 Percent

TEST RESULTS

The data from each heating test is summarized in Figures 7 through 11. In each figure the theoretical steady state temperature rise for the indicated cable sizes is drawn as a solid line and has been obtained from the allowable heat intensities in Figure 4. The theoretical ampacities are all based on an average cable mass thermal resistivity of 400°C-cm/watt. Test data is indicated by the plotted points.

The first test which was run to establish the validity of this method was on the 55% filled tray. Figure 7 shows an appreciable amount of data scatter which can be attributed to air flow through the tray. But it must be noted that when a sheet of .003-inch thickness polyethylene was placed under the tray to seal the ventilating holes in its bottom, the temperatures came up to the calculated values, as shown by the open data points. The reason for the air flow through the tray is that when it was assembled, all the cables were first laid loosely in the tray and then later tied down. This sequence did not effectively form trapped air pockets in the areas where thermocouples were placed. Subsequent test trays were assembled by placing and tying a large handful of cables at a time, which is more representative of how cables are installed in the field. Note that even though the majority of cables in the 55% filled tray ran cooler than calcuated, there was a group of No. 6 AWG cables within the tray which did reach the calculated maximum temperature. This points out the fact that all cables in a randomly arranged tray cannot be expected to have the most thermally adverse environment, but some of them will.

The set of triangle points in Figure 7 is data taken from an unpublished report made by the Underwriters' Laboratories Incorporated in October 1957. The report is substantially the basis for the cable tray derating factors published thus far for trays in which cable spacing is not maintained. The two triangle points are taken directly from Figure 2 of the U.L. report, and are for a 6-inch wide tray filled with six even layers of single conductor No. 6 rubber insulated cable. The correlation between the U.L. test data and the theoretical calculations is remarkable.

The data in Figure 8 for the 20% filled tray shows much less scatter than the 55% data, with the majority of the points being nearly coincident with the calculated values. All the cables came up to the predicted temperatures since care was taken to lay the cables close enough to prevent air movement through the cable mass. It is important to note that the temperatures in the 20% filled tray remained essentially constant when a layer of polyethylene sheet was placed on the tray bottom.

Possibly the most important information which came directly from the data is in reference to diversity within the tray. The triangle points plotted for the No. 6, 1/0, and 4/0 cables are for only those three cable sizes carrying current, and the No. 12, 10, 8, 4, and 2/0 cables being unloaded. The No. 6 cables ran about 15°C cooler than when all cables were energized but the 4/0 cable only ran 1°C cooler.

It is from this experimental finding that it appears to be unwise to increase cable ampacities on the basis of diversity. The cables in the above diversity test were separated by about 6-inches of "dead"

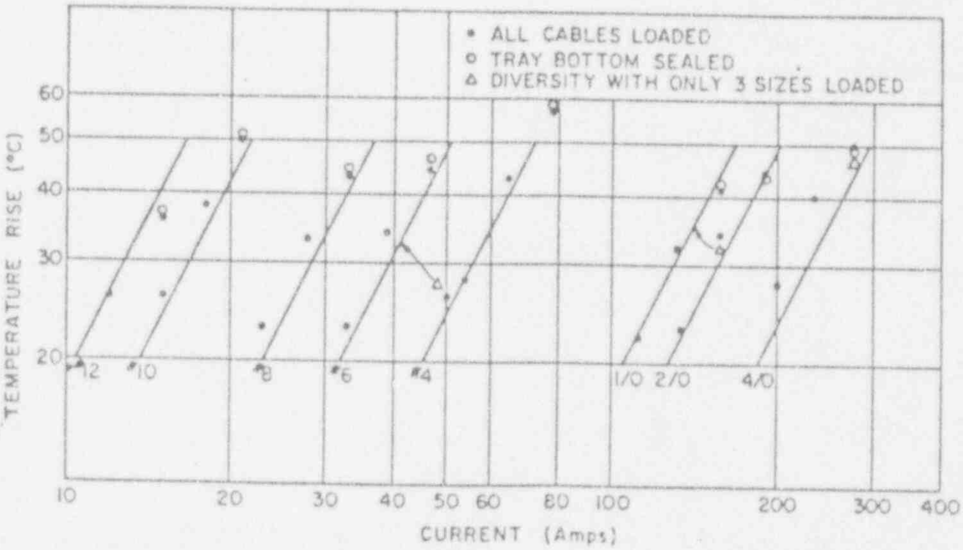


Fig. 8. Test Results for the 20 Percent Fill 24-inch Wide Tray Containing the Following Thick Wall Insulated Cables.

CABLE SIZE	OUTSIDE DIAMETER	QUANTITY IN TRAY
#12	.25"	14
10	.27"	6
8	.36"	6
6	.40"	10
4	.45"	8
1/0	.65"	6
2/0	.70"	3
4/0	.80"	6
Multi-Conductor #12		To Fill Tray to 20 Percent

cable, but it is conceivable that the No. 6 cables could be placed adjacent to, or between, some 4/0 cables. If the cables in this configuration had increased ampacities based on assumed diversity, there would undoubtedly be a local hot spot in the cable tray. Thus, it seems impossible to apply a general increase in the ampacities of smaller cables due to diversity because there is no general way to assure that small cables would remain separated from large cables in randomly filled trays.

Figure 9 shows results for two different tests on trays with 40% fill, one with 3/C-12 thick wall rubber insulated cable and the other with thin wall XLP insulated cable contained within a neoprene jacket. The same total amount of heat was generated within each cable tray, but the smaller diameter cables generated less heat per conductor because there were more small cables in the tray. This shows that all 3/C-12 cables do not have the same ampacity when installed in trays, and for a given tray fill the smaller the cable diameter the lower its cable tray ampacity, in accordance with equation (9).

It is interesting to note that in the tests producing 50°C rise in Figure 9, the two thermocouples closest to the tray sides only ran 2 to 3°C cooler than the other five in the tray. With the vertical temperature gradient through the cable mass being on the order of 15°C, it is quite evident that most of the heat in a cable tray flows vertically, rather than horizontally, as assumed in equation (5). From the above finding, it becomes clear that cable ampacities developed with this method are valid for trays 6-inches or more in width.

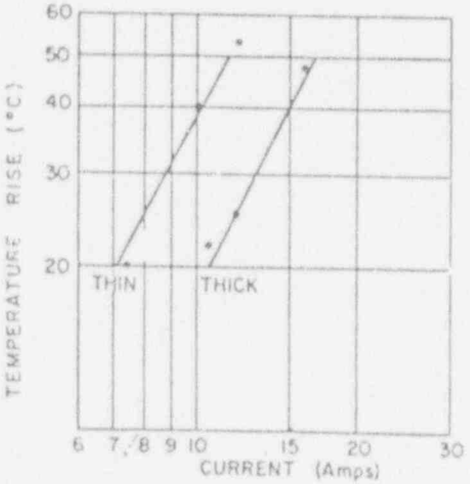
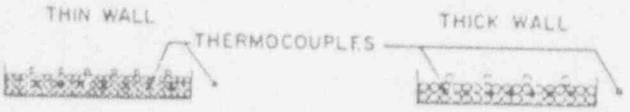


Fig. 9. Test results for 12-inch wide trays filled to 40 percent containing thick wall and thin wall insulated 3/C-#12 cables as shown below:



Cable O.D. – .475"
Quantity – 81

Cable O.D. – .70"
Quantity – 38

The final test was run on single conductor 500 MCM thin wall XLP insulated cable. Figure 10 shows excellent agreement between calculated and test ampacities for the XLP cables. Although the results are for a 12-inch wide tray, a 24-inch wide tray would respond the same if twice the number of cables would be in it. Using the present derating factors for more than 43 conductors in the tray (46 in this case) one-half of the three conductor cable ampacity would result; this would be one-half of either 487 amps. or 365 amps. depending on whether IPCEA or National Electric Code respectively is used. Both of these values are significantly less than the 324 ampere ampacity which comes from calculations and testing on the 50% fill tray.

Figure 10 also shows excellent correlation between calculated and tested ampacities for only one tightly packed layer of twelve cables, which is a 26% fill. This example again shows that the present derating factors for cables in trays are much too low for the large cables installed in wide trays.

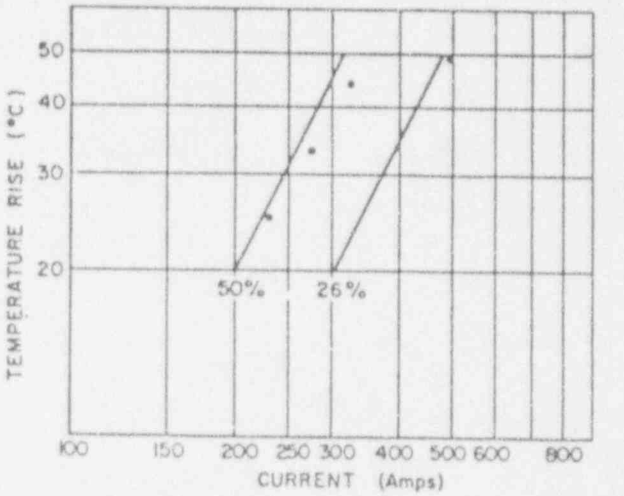
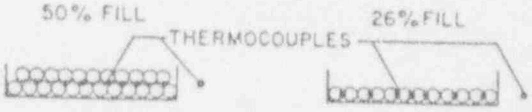


Fig. 10. Test results for the 500 MCM thin wall insulated cables in 12-inch wide trays filled to 50 percent and 26 percent as shown below:



Cable O.D. – 1.01"
Quantity – 23

Cable O.D. – 1.01"
Quantity – 12

One last example of this same idea can be taken directly from the data of the unpublished Underwriters' Laboratories report, which is the basis for the present derating factors for cables in trays. Figure 11 shows calculated ampacities for rubber insulated, single conductor 500 MCM cables in a 30% fill tray and a 60% fill tray. In both cases the data from Figure 4 of the U.L. report shows the cable ampacity to be even greater than the calculated ampacity. The reason that the cables ran cooler in the test is most likely due to air flow through the tray because of air gaps between the cables.

All the results presented thus far are for cable trays which have achieved steady state thermal equilibrium. Figure 12 shows that it requires about six hours for a cable tray to reach steady state conditions, whether it is filled to 20 or 40%. These results can be used to calculate transient ampacities of cables in trays which may see loading for, say, only one hour at a time. This would be possible, of course, only if all the cables in the tray were loaded and unloaded simultaneously, and if a precise knowledge of the maximum loading duration could be assured.

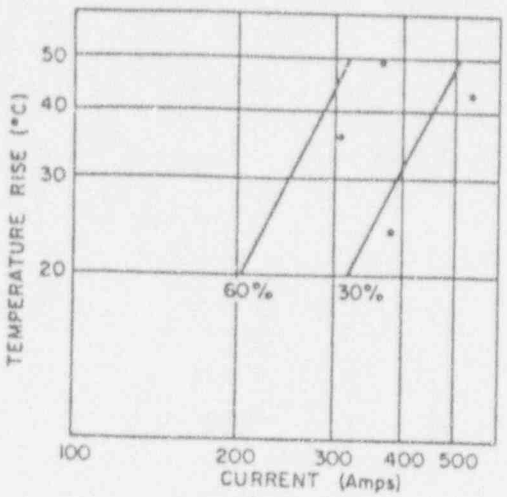


Fig. 11. Underwriters' Laboratories test results for a 24-inch wide tray containing one and two layers of 1/C-500 MCM rubber-like cable with an assumed overall diameter of 1.16 inches.

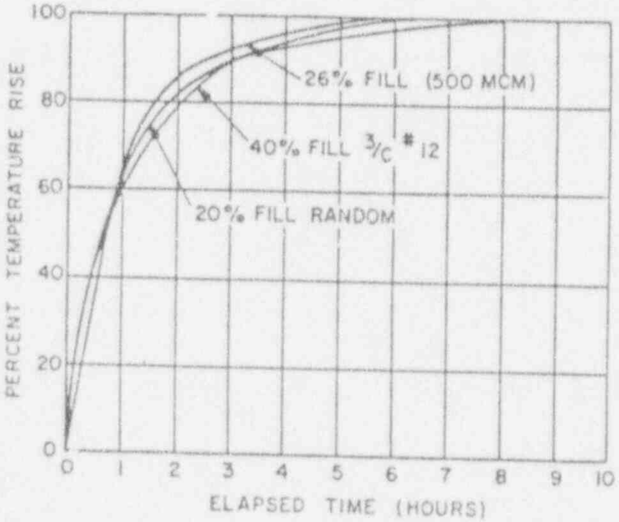


Fig. 12. Temperature response of three different cable tray assemblies.

DISCUSSION

It is seen that the ampacities of randomly arranged, tightly packed cables in trays can be calculated with about 5% error. The method is safe for any number of cables in a tray as long as they are packed to a uniform depth across the tray. (It should be noted that this is a condition which is easy to inspect as construction progresses in the field.) Although this method was developed and tested for many 600 volt class cables in a tray, it also yields realistic ampacities for 4 kV class cables mixed with low voltage cable.

To apply this method and form a workable ampacity table, some precautions must be observed. Figure 4 is the most general way to present cable tray ampacities but it is awkward to use since heat intensities must be converted to ampacity for a given cable diameter with equation (9). This has been done in Table II for 20, 40, and 60% filled trays containing typical diameter XLP and rubber insulated cables. For actual cables which may have a different diameter, the actual ampacity is obtained from the simple proportion,

$$\frac{I_{actual}}{D_{actual}} = \frac{I_{typical}}{D_{typical}} \qquad (10)$$

Another precaution can best be explained by visualizing a tray with many small cables and three 750 MCM cables. When the tray is filled to a uniform depth up to the top of the large cables (about 31%) the criterion for the theory is fulfilled. But if a tray would contain the three 750 MCM cables and enough remaining small cable to bring the fill to only about 15%, the large cables would stand about twice as high as the small cables, and the theory would not be satisfied. Using Figure 4 for a 15% tray fill would assume a uniform depth and would effectively flatten the large cables into a rectangular shape, rather than circular shape. The calculated ampacity would then be for a "rectangular cable" of 750 MCM cross section which would be meaningless.

For the above reason a limitation must be made that unless specifically engineered, no cable in any tightly packed cable tray shall be allowed to carry a current greater than that of the same size three-conductor cable in air operating at the same temperature limits. This is because it turns out that one layer of tightly packed single conductor cable has about the same ampacity as that of a three conductor cable given in reference 5.

It must also be made clear that the percent fills used in this paper are specifically for 3-inch deep trays only. The tray width is variable without error, but a 3-inch deep tray with 30% fill would only have half the depth of cable in it as a 6-inch deep tray with the same percent fill. Obviously, for the same percent fill the 6-inch deep tray would run much hotter than the 3-inch deep tray because heat would have to flow through twice as much packed cable. Thus, to simplify the application of this method, percent fill is best figured by dividing the total area of cable in a tray by the area available in the same width but 3-inch deep tray, even if the tray to be used would be other than 3-inches deep.

The results presented in this paper are for open trays without any cover. In locations where covers must be used, the Underwriters' Laboratories found that open cable tray ampacities must be reduced by about 4 to 5%. Since covered cable trays are usually found outdoors where they may be exposed to the sun's radiation, care should be taken in specifying the ambient temperature for outdoor trays. Specifically, ambient temperature for a cable tray is the highest temperature which will be reached in the tray due to all external heat sources except the I^2R heat from the cables within the tray.

This definition of ambient temperature can be useful for a first approximation in handling cases of mutual heating of several trays stacked in a vertical row. The extent to which lower trays will affect trays above them will depend on how much total heat is generated within each tray. For trays containing both power and control cable, the effect of mutual heating will usually be much less than with trays containing all power cable. An ambient increase of about 5 to 10°C for moderate and extreme cases respectively, would probably be the simplest way to account for mutual heating, if necessary.

The last observation to be made involves the idea of determining some "optimum" percent tray fill. Figure 5 and Table II show that cable ampacity drops off significantly when going from low to high percent tray fills. Combining this with the fact that the cost of installing a tray is usually less than just one large copper conductor which would lay in the tray, in some cases it may be poor economy to fill trays more than one cable deep. This would vary with each installation and would be primarily dependent on the available head room in a particular area of a plant. But in each case, an optimum tray fill would probably exist.

TABLE II

Ampacities for Copper Cables in 3-inch Deep Cable Trays,
90°C Operating Temperature in a 40°C Ambient

Conductor	Typical Cable Outside Diameter		Ampacity for Each Conductor					
			20% Fill		40% Fill		60% Fill	
Size	Rubber	XLP	Rubber	XLP	Rubber	XLP	Rubber	XLP
1/C-14	.22	.17	11	9	7	6	5	4
3/C-14	.57	.46	17	13	11	9	8	7
1/C-12	.24	.19	15	12	10	8	7	6
3/C-12	.62	.51	23	19	15	12	11	9
1/C-10	.26	.22	21	18	13	11	10	9
3/C-10	.69	.57	32	26	21	17	16	13
1/C- 8	.36	.28	37	28	24	18	18	14
3/C- 8	.94	74	50	43	36	28	27	21
1/C- 6	.40	.32	51	41	33	26	25	20
3/C- 6	1.00	.82	60	60	48	39	26	30
1/C- 4	.45	.37	72	60	47	38	35	29
3/C- 4	1.15	.93	80	80	69	56	52	42
1/C- 2	.51	.43	104	87	67	56	51	43
3/C- 2	1.28	1.07	105	105	97	81	73	61
1/C-1/0	.65	.54	167	139	108	89	81	68
1/C-2/0	.70	.59	202	170	130	110	98	83
1/C-4/0	.80	.69	287	252	188	162	142	123
1/C-250	.92	.77	320	304	234	196	177	148
1/C-350	1.03	.88	394	394	310	265	235	201
1/C-500	1.16	1.01	487	487	419	365	317	276
1/C-750	1.38	1.24	615	615	610	548	461	415

Notes: 1) Ampacities are for any width tray filled to a uniform depth.
1) A 6" deep tray with 20% fill has the same ampacities as a 3" tray with 40% fill.
3) Correction for different ambient or different operating temperature is done by the established IPCEA methods in reference 5.
4) The above ampacities are specifically for the cable diameters shown; account for deviations with equation 10.

CONCLUSIONS

It has been demonstrated that the temperatures produced in tightly packed cable trays can be predicted with good accuracy, and ampacities can be calculated for randomly arranged cables packed to a uniform depth across a tray. Cables are permitted to generate heat in proportion to their individual cross-sectional areas, and thus cable ampacity is directly proportional to each cable diameter.

The derating factors published thus far for cables in trays can lead to serious overheating on small conductor sizes while resulting in significantly underloaded large conductor sizes. Even though the previously published derating factors have distinct limitations, the unpublished basic data which was used to form the factors agrees very well with ampacities calculated in this report.

A simple table of derating factors which can be applied to existing ampacity tables to get cable tray ampacities seems impossible. Table II is about the only way to simplify ampacities of cables in trays, and it can be expanded for different tray fills with Figure 4 or for different temperature limits with the methods described in reference 5.

The ampacities in Table II are consistent with derating factors for cables with maintained spacing in that a logical transition is made from a closely spaced cable tray ampacity to a higher ampacity once cables are separated to about one-fourth diameter.

A surprising finding which has been made is that typical rubber insulated cables have significantly higher ampacities than typical crosslinked polyethylene cables when packed in trays. This seems contradictory to what would be first expected, but a closer analysis shows that more XLP cables can be placed in a given tray because they are smaller in diameter. Therefore, the heat per conductor must be less for the XLP insulated cables to keep the total heat generation within a given tray constant.

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NOMENCLATURE

A = cross-sectional area of a single or multiconductor cable including conductor, insulation, and jacket in (in^2).

A_s = surface area of cable tray per unit length in $(ft^2)/ft$.

D = the overall diameter of a cable in inches.

d = depth of packed cable mass in a tray in inches.

h = overall convection heat transfer coefficient for the cable tray in $(watts/ft^2)/°C$.

I = the ampacity, or maximum allowable current for a conductor in amperes.

n = the number of conductors in a cable.

Q = the allowable uniform heat per unit area which can be generated within a cable tray in $(watts/ft)/in^2$.

q = the heat generated by each conductor in a tray in watts/ft.

R = the a.c. resistance of a conductor at the operating temperature of the insulation material in the cable tray in ohms.

ΔT = the total temperature drop from the hottest point in the tray to ambient in °C.

ΔT_c = the temperature drop through the packed cable mass in °C.

ΔT_a = the temperature drop through the air surrounding the cable tray in °C.

T_a = the ambient temperature of the tray due to all heat sources outside the cable tray in °C.

T_s = average cable mass surface temperature in °C.

T_m = the maximum operating temperature of the cable insulation in the tray in °C.

W = the total amount of heat which is generated in a cable tray in watts/ft.

w = width of packed cable mass or tray in inches.

ϵ = the effective thermal emissivity of the packed cable mass and tray (dimensionless).

ρ = the effective thermal resistivity of the packed cable mass in (°C-ft)/watt.

σ = Stefan-Boltzmann constant in $(watts/ft^2)/°K^4$.

Discussion

Marshall Morris (Consolidated Edison Company of New York, New York, N.Y. 10003): The author is to be commended for a very ingenious solution to a complex problem. Where applicable, Table II gives a quick and convenient method for rating such groups of cables. However, practical considerations do not usually result in the uniform distribution of watts throughout the mass of the cables which is assumed by the author. In our experience many of the circuits have little or no load while a few key circuits may be heavily loaded. The IPCEA method takes this into account by giving recognition to load diversity in establishing their factors. The author's statement, "that it appears to be unwise to increase cable ampacities on the basis of diversity" is a good rule for conservative design, although there are many cases when the application of diversity would seem to be justified.

I would suggest that load diversity could be incorporated into the author's method by adjusting the value of percent fill used in the calculations. This could be done very simply by interpolation in Table II. The proper value to use would be a matter of judgment depending on the relative location of the heavily-loaded and lightly-loaded cables.

Manuscript received July 10, 1970.

Ralph H. Lee (E. I. Du Pont de Nemours and Company, Inc., Wilmington, Del.): The author has performed a highly commendable service to our technology in demonstrating that cables in trays perform thermally in a manner quite different from that in raceways. Recognition of this fact should be the starting point for adoption of rational derating factors for cables in trays and realistic loading of trays. It is fair to say that illogical derating factors have been responsible for many users' neglect of derating. This, with the absence of realistic application rules, has caused much of the malfunctions of tray systems in power use. The San Onofre case is a prime example of this.

While we agree in general with the author, on the basis of interim results of a test we have in progress there are a few points of disagreement. First is the author's assumption that the transverse thermal conductance of all cable sizes is the same (400°C cm watt).

In larger sizes the conductor-to-insulation ratio is greater, also there are fewer but larger air spaces. Both of these factors would logically impose a resistance factor which is lower for the large sizes, greater for smaller sizes. The ratio of small to large cables in a tray would markedly affect the over-all thermal resistivity, making any constant factor either over-conservative for the fills of mostly large cable or over-liberal and dangerous if the fill is mostly small cables.

Second, the variability of heat generation between the sizes, per unit cross section, is recognized by the author in connection with his Figure 2. In this, seven #12 3 C cables are shown to generate 3 to 4 times the heat of one #4 0 3 C cable having the same cross section area. This fact, however, is subsequently not considered by the author, apparently on the theory that this would be equalized through the thermal conduction of the fill. Departure of observed

Manuscript received July 28, 1970.

data from theoretical calculations, for larger percentage fill, may be due to this and the previous point.

Third, in Figure 7, the author's observed data for cable temperatures (unsealed) fall well below the theoretical lines (except #6 ga.). Calculations of the ratio of heat loss, at rated current, to the surface area of 3/C cables shows #6 ga. to be the most heavily loaded of all sizes, in terms of wattage per unit surface area. The 1968 NEC ratings permit its surface thermal loading to 44% higher than #12 ga. and 76% higher than #4/0 and 500 MCM. It is significant that the author's data for #6 conductors show its temperature rise at rated current to be highest of all sizes tested.

In our tests (using cables of only one size for each test) for #6 and #2 ga. results agree rather well with the author's observations. In Figure 1 for #2 ga., our 23.7% fill falls well between the author's #1/0 and #4, 20% fill data. Also our #2 ga. 47.4% fill data is intermediate between the author's #1/0 and #4, 55% fill data. The general slopes, likewise, agree rather well.

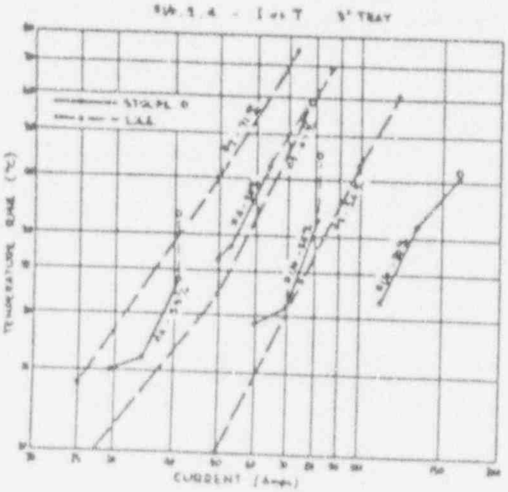

Fig. 1.

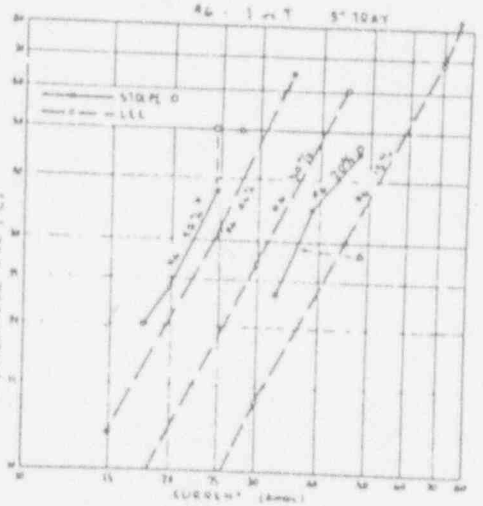

Fig. 2

In Figure 2, for #6 ga., our data for 15, 30 and 40% fill agree quite well with that of the author. They are, however, considerably higher than the UL 20% data, although agreeing rather well with the UL 55% fill point.

In Figure 3, for #12 ga., our data indicates considerably greater temperature rise for like fill than the author's data, our 26.3% fill indicating temperature rises averaging 77% greater than that of the author for 20% fill. This is believed due to the condition outlined in the first comment, that fills of smaller cables have higher thermal resistivity than those of larger average gage.

Where the bulk of the conductors or cables are of the smaller variety, it appears that the derating factor needs to be greater than where the installation consists of average or large-sized cables.

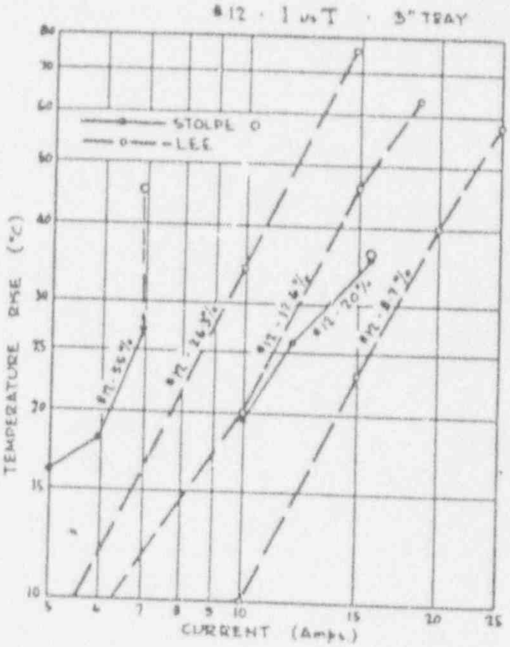

Fig. 3

Unavoidably, our tests all utilize 3/C type THWN conductors with over-all vinyl jacket, this cable type is the one approved for tray use for more than 3 conductors, and is typical of our general installations. The author's data is largely based on thicker insulation, and principally for single conductors rather than 3/C cables. He indicates that multiple conductor cables in tray have inherently higher ampacity, but that conductors with thin insulation have reduced ampacity. The rather good agreement of his data with ours appears to indicate that the ampacity increase for multiple conductor cabling and the decrease for thin insulation are approximately equal.

The good agreement should lend credence to the author's observations, in contrast to the theoretical lines, especially those shown in his Figure 7.

Fourth, the premise of a uniform level of tray fill is not compatible with the use of a few very large cables (e.g., 3/C 500 MCM) such that the top of these is much above the height of the balance of the tray fill. Likewise, the concept of percentage fill of trays is at variance with a fundamental definition of trays, i.e., a cable support, not a raceway. Variation in tray side height is basically for the purpose of spanning inter-support distances, or increasing the weight to be supported, rather than for containment. As the author's results indicate, the degree of derating required when the depth of fill reaches about 2" is so serious that additional trays and lower fills are economically justified. The concept of average fill depth, rather than per cent fill, has greater flexibility, and since it appears to be the basic criterion, should receive precedence.

Fifth, we would caution users that tray is not intended or recommended for use with single-conductor wires or cables, especially the smaller sizes. As its formal name "Continuous Rigid Cable Supports" indicates, tray should be used only with cables incorporating a protective covering of some type over the individual conductor insulation. Many failures and some fires have been initiated from destruction of the relatively thin insulation of single conductors in trays in common with larger cables. The mechanical rigors of installation, and irregularities of the inner surfaces of trays greatly exceed those of conduit, for which single-conductor insulation is intended. For tray service, a mechanical jacket or protective sheath is most useful, and is required by the National Electrical Code. In our own experience, with over 600 miles of tray in service, the only conductor failures have occurred where small single-conductors were inadvertently installed in trays with larger cables.

Sixth, our own interim results, and apparently those of the author indicate a uniform ratio of temperature rise to watts loss per unit plan area of the tray, for tray fill excluding through-ventilation.

By this criterion, the derating for a 3" fill would logically be such that the I^2R loss would be no more than that of a 1" fill in the same tray. So current derating would be inversely proportional to the square root of the fill depth. While derating by this means would be too complicated for direct use, it would be possible to factor it into a derating table considering cable dimensions and actual heat loss of the range of wire sizes.

J. Stolpe: I would like to thank Mr. Morris and Mr. Lee for their discussions of the paper. They have raised some interesting and valid points regarding the method of calculating ampacities for cables in randomly filled trays. Mr. Morris is absolutely correct in stating that there are many cases when the application of diversity would seem to be justified. The difference between the IPCEA treatment and the one herein is the IPCEA ratings assume that diversity always exists, and that control and power cables are uniformly spaced throughout a cable tray. This is generally a very optimistic assumption.

It seems that better judgment would dictate general ampacities assuming that diversity does not generally exist, because all it takes is two large conductor, heavily loaded circuits located side-by-side in a tray to produce a local hot spot in the tray cross-section. If these two circuits were the only power circuits in a tray filled to, say, 40 percent, it would be possible to account for diversity in determining the ampacity of each circuit. This is only if the engineer is absolutely sure the cables will not be bunched together when they are finally placed in the tray.

In cases where only a few power cables are in a highly filled tray, it may be feasible to partition the tray so the power and control cables would be isolated. Thus, all the control cables could be heaped together without danger of any heating whatsoever, and the power cables could then be placed in the remainder of the tray, at a relatively shallow depth. The ampacity of each power cable would be determined from the percent fill of the side of the tray which contained the power cable only.

Mr. Lee has made the valid observation that the effective thermal resistivity of large conductor size cables is less than that of the small conductor size. The value of 400°C-cm/watt was chosen to fit the case where large and small cables are intermixed at random. In special cases, as with diversity, ampacities of large cables can be calculated using lower values of effective thermal resistivity if the engineer is absolutely sure of all relevant parameters. But for general ampacity tables, the value chosen will work the best because it accounts for the case where a large conductor cable is surrounded by many small cables in a tray.

The comment that the variability of heat generation is treated in Figure 2 and is subsequently not considered in the paper is rather discouraging, and indicates that the whole point to the uniform heat generation concept has been missed. The calculated ampacities in this paper are all based on the requirement that the heat per unit area of every cable size in the tray is the same, for a given percent tray fill. This can be easily checked in Table II by calculating the I^2R for each cable and dividing by the respective cable cross-sectional area. For example, the 3/C-#4 and 1/C-500 rubber insulated cables have about the same cable diameters of 1.15" and 1.16" respectively, and thus they occupy the same approximate total area in a cable tray. Using the ampacities for 40 percent tray fill, shown in Table II, the following identical heat generation in each cable is obtained

$$3/C\text{-}\#4 = 3 \times (69)^2 \, (336 \, \mu\Omega/\mathrm{ft}) = 4.8 \text{ watts/ft}$$

$$1/C\text{-}500 = 1 \times (419)^2 \, (27.8 \, \mu\Omega/\mathrm{ft}) = 4.87 \text{ watts/ft}$$

The slight discrepancy is due to the larger cross-sectional area of the 500 KCM cable.

This point can be further emphasized from the fact, as will be shown later, that cable ampacities can be calculated from Figure 4 and equation (8) or (9). For a tray with a given percent fill, Figure 4 shows the Allowable Uniform Heat Generation for any cable size in the tray. This constant value is then used in equation (8) or (9) to arrive at an ampacity for each conductor size in the tray. Since all ampacities for a given percent tray fill are based on one uniform heat per unit area, the situation shown in Figure 2 is not only corrected, but it is impossible to occur with the method developed in this paper.

The reason for the poor correlation between the unsealed tray data and the calculations in Figure 7 is due to the manner in which the tray was assembled, as explained in the paper. Every ampacity in the tray was pre-calculated on the basis of uniform heat generation for each cable size, and the 1/C-#6 cables ran hottest because all 48 of them were located together. The air happened to be more effectively trapped in that particular portion of the tray. The fact that the NEC permits the #6 cables to generate more heat per unit surface area than other conductor sizes had nothing to do with the test results in Figure 7, because the test currents were calculated without any reference whatsoever to the NEC. Actually, heat per unit surface area is not as good an indication of cable loading in randomly filled trays as the heat per unit cross-sectional area.

The data which Mr. Lee has obtained is most valuable, and it serves to point out the difficulty which can be encountered if an adequate theory is not used in its evaluation. Mr. Lee has tried comparing 3/C cable data with 1/C cable data, and this generally cannot be done. He has also compared data from thin wall insulated cables with data from thick wall insulated cables, without taking into account that the larger the cable diameter the higher its ampacity will be, for a given conductor size.

The ampacities of the cables tested by Mr. Lee can all be calculated. Using Figure 4 of the paper to find the Allowable Heat Intensity (Q) corresponding to each percent fill labeled in his Figures 1-3, each cable ampacity is calculated with equation (9). The diameters of the cables tested by Mr. Lee were obtained from private correspondence to be:

3/C - #12 – .38" O.D.
3/C - #6 – .69" O.D.
3/C - #2 – 1.01" O.D.

A sample calculation for the ampacity of the 3/C-#12 cables which filled the tray to 26.3 percent proceeds as follows, assuming a 90°C conductor in a 40°C ambient, or 50°C rise.

$$\text{From Figure 4, } Q = 7.9 \, \frac{\text{watts/ft}}{\text{in}^2}$$

$$\text{From equation (9)} \quad I = \frac{.38 \text{ in.}}{2} \sqrt{\frac{3.14 \times 7.9 \, \frac{\text{watts/ft}}{\text{in}^2}}{3 \times 2160 \mu\Omega/\text{ft}}}$$

$$I = 11.8 \text{ amps}$$

This ampacity compares very nicely with the intersection of the 50°C rise coordinate and the 26.3% fill line in Figure 3 of the discussion, which is approximately 12 amperes. Similar calculations for all the tests conducted by Mr. Lee are shown in Table III, and they are compared with measured ampacities. The agreement is very good when all the subtle details are taken into account.

TABLE III

Comparison of Lee Data and Calculations

Conductor Size	Percent Tray Fill	Measured Ampacity From Graph		Calculated Ampacity
3/C-#12	8.7	23	Fig. 3	23
3/C-#12	17.6	16		15
3/C-#12	26.3	12		12
3/C-#6	15	59	Fig. 2	60
3/C-#6	30	41		40
3/C-#6	46	32		30
3/C-#2	24	110	Fig. 1	106
3/C-#2	47	73		69
3/C-#2	71	57		51

The matter of how to generally describe how much cable is in a cable tray is debatable, and a common agreement is not easily

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obtained. Every means with which the author is familiar has advantages as well as disadvantages, and whatever convention is finally adopted by the industry should be adaptable to the method developed herein. Percent fill was chosen as the gauge for quantity of cable in a tray for this study because it is accepted by the majority of tray users, to which the author has knowledge.

The problem of large cables protruding above the average depth of a tray fill is accounted for by limiting the maximum ampacity of any cable in a tray to that corresponding to the 1 layer percent fill of the particular cable size. A cable size which would result in a 25 percent fill for 1 layer in a tray, would have the same ampacity when installed in all trays of less than 25 percent fill, and it would suffer a loss in ampacity only when installed in trays filled to more than 25 percent. This restriction applies to single-conductor, as well as multi-conductor, cables which are installed in randomly filled trays.

The sixth point made by Mr. Lee is that for a given width tray, the total watts per foot of tray length should be the same regardless of the percent tray fill. That is, if a tray filled to 20 percent can generate a total of 70 watts/ft of length and just bring the hottest conductor in the tray up to its rated temperature, then the same tray filled to 40 or even 60 percent can also generate a total of 70 watts/ft, but the heat generated per cable must be reduced proportionately. This observation holds with fairly good accuracy.

Strictly speaking, for a given amount of heat generation in a given width cable tray, the temperature rise of the outer surface is constant with all percent tray fills; but the temperature rise through the cable mass is directly proportional to the depth of the cable mass, as described by equation (5). Therefore, as the percent tray fill increases, the temperature rise through the packed cable mass increases relative to the temperature rise of the tray outer surface, for a given amount of total heat generation. Thus, in determining cable ampacities, it is necessary to reduce the total heat generation in a tray as its percent fill is increased.

The amount of total heat reduction can be seen by taking Allowable Heat Intensities from Figure 4 for various percent tray fills and multiplying them by the cable area in the tray for each percent fill. Doing this for a 12 inch width tray yields the results shown in Table IV. For small changes in percent tray fill Mr. Lee's observation is good, but it does not hold for large changes in percent fill. Analyzing his data in a similar manner yields results similar to Table IV.

TABLE IV

Comparison of Total Tray Heat (W) with Various Percent Tray Fills
(12" Width x 3" Depth, Effective $\rho = 400^\circ$C-cm/watt)

Percent Tray Fill	Allowable Heat Intensity	Cable Area In Tray	Total Tray Heat
10	24.7 $\frac{\text{watts/ft.}}{\text{in}^2}$	3.6 in.^{2}	89 watts/
20	11.1	7.2	80 tray ft.
30	6.7	10.8	72
40	4.6	14.4	66
50	3.4	18.0	61
60	2.7	21.6	58
70	2.1	25.2	53
80	1.7	28.8	49

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Mr. Stolpe is a member of the Pacific Coast Electrical Association.

ENCLOSURE 2

CALCULATION 13-EC-ZA-300 REVISION 3