UNDERWRITERS LABORATORIES INC.
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an independent, not-for-profit organization testing for public safety

File R8758
Project 78NK5345

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REPORT

on

CABLE RACEWAY PROTECTION SYSTEMS FIRE TEST INVESTIGATION

Babcock & Wilcox
Augusta, Georgia

G E N E R A L

INTRODUCTION:

Concern has been expressed by the Nuclear Regulatory Commission (NRC) for the protection of the circuit integrity of power and control cables in the event of a fire within a nuclear power generating station. Specifically, protection of the redundant control circuits is of interest. In the event of a fire, although control circuits may become inoperative, the protected redundant control circuits should retain their electrical integrity.

The purpose of this investigation was to obtain information on the performance of certain electrical raceway systems protected by ceramic fiber blanket insulation, and perlite-cement insulation, when subjected to a controlled fire exposure. The data obtained are intended for use only by Georgia Power and the Bechtel Corporation for submission only to the Nuclear Regulatory Commission.

The investigation consisted of witnessing four fire tests at the facility of Babcock & Wilcox in Augusta, Georgia. Each test was conducted with one protected cable tray and one protected conduit system as shown in ILLS. 5-8. Each tray was filled with various sizes and types of cables. However, only one size and type of cable was installed into each conduit. All cables were installed forming several circuits to which a low voltage, low current load was applied. Each cable circuit was monitored and the time at which failure (i.e., shorting between conductors, or ground) occurred for each circuit was recorded. Each test varied in fire exposure duration. Details of the installation and test observations and results are recorded herein.

LJP/KWH:plh

D E S C R I P T I O N

TEST APPARATUS:

The test furnace employed was a catenary type kiln furnace with a chamber area for the test sample of approximately 36 in. wide, 36 in. deep and 31 in. maximum height, as shown in ILL. 1. Two burners located as shown in ILL. 1 provided the flame source for the furnace.

Furnace operation consisted of mixing natural gas and combustion air (supplied at about 0.6 in. H_2O pressure) within the burner nozzle. The flame length during normal furnace operation was approximately 18 in. Due to the opposing burning configuration, the hot gases and convective heat swirled upward to the top of the furnace. Combustion products were vented by natural draft through small holes in the fire brick furnace floor and into a vertical stack which was ducted to the outside.

An approximate 24 in. wide by 24 in. high opening was formed into the front and rear fire brick walls of the furnace to accommodate the sample raceways.

TEST SPECIMENS:

Cables - The cables used in this investigation were stranded copper conductors which varied in size and the number of conductors per cable. Both Okolon conductor insulation/Okolon cable jacket, and polyethylene conductor insulation/polyvinyl chloride cable jacket cables were tested. The identification of the cable materials was on the basis of the information provided by the test sponsor. The cable sizes and their identification code for test purposes are shown in Table I.

TABLE I

Cable Description

Identification	Cable Size: Number Of Conductors	Cable Size: Conductor Gauge (AWG)	Cable Size: Cross Section Diameter, In.	Cable Material: Conductor Insulation/ Conductor Jacket	Cable Material: Cable Jacket
B1-9	1	9	0.275	Okolon	Okolon
C-19	7	14	0.625	Okolon	Okolon
C-22	19	12	0.965	Okolon	Okolon
C-23	2	12	0.513	Okolon	Okolon
C-24	4	12	0.611	Okolon	Okolon
C-25	7	12	0.725	Okolon	Okolon
C-26	9	12	0.937	Okolon	Okolon
C-27	12	12	1.008	Okolon	Okolon
C-33	4	12	0.934	Okolon	Okolon
+M7-9	7	6	0.935	PE/PVC	PVC

+ - Copper sheathed cable.

Cable Trays - Two types of cable trays were employed in this investigation. In Tests 1 and 4, steel fluted back cable trays were used. The trays were 12 ft long and 18-1/8 in. wide. The tray side channels were 4 in. deep with 3/4 in. flanges, and fabricated from 0.070 in. thick galvanized steel. The 0.055 in. thick galvanized steel fluted back was 15/16 in. deep and formed with 3 in. wide crests and 1 in. wide valleys, with each flute spaced 6 in. O.C. The backing was secured to the side channels with spot welds, and installed with the flutes running perpendicular to the side channels. Also, 5/8 in. diameter, 18 in. long galvanized steel rods were welded 48 in. O.C. to the side channels for additional support.

In the remaining two tests, aluminum open ladder type cable trays were employed. The trays were 12 ft long and 17-3/4 in. wide. The side channels were 4 in. deep with 3/4 in. flanges, and 0.087 in. thick. The U-shaped rungs were 1 in. wide with 1 in. legs and 1/4 in. flanges, and were 0.087 in. thick. The ladder rungs were spaced 9 in. O C with each rung welded to each side channel.

Conduit - In two tests 10 ft long, 4 in. diameter schedule 40 galvanized steel pipe with 0.215 in. thick walls was used as rigid metal conduit raceway. In the remaining tests, 4 in. ID diameter aluminum pipe with 0.188 in. thick walls was employed.

Insulation - The insulation installed about the cable tray and conduit raceways (except in Test No. 4) was a 1 in. thick, 9.4 pcf ceramic fiber blanket designated as "Kaowool". The insulation installed about the conduit raceway in Test No. 4 was a 1-1/2 in. thick, 11.8 pcf rigid perlite-cement material designated as "Kaotemp".

Insulation Fasteners - Various different devices were used to temporarily and permanently fasten the insulation about the raceways. One inch wide Scotchgard filament adhesive tape was used to temporarily secure various pieces of the ceramic fiber blanket prior to installation of the permanent fasteners. U-shaped steel brackets of various configurations shown in ILLS. 2 and 2A, which were manufctured from 0.131 in. thick, 1-1/2 in. wide galvanized steel, were used as permanent fasteners about the cable tray insulation.

The conduit Kaowool insulation was permanently fastened with steel bands. Two types of steel bands were employed. A Type 316 stainless steel band (1/2 in. wide, 0.036 in. thick), and a coated steel band (3/4 in. wide, 0.031 in. thick) were used with their appropriate buckles and installed with the recommended banding tool.

The conduit Kaotemp insulation was fastened with No. 16 SWG (0.062 in. diameter) steel wire.

CONSTRUCTION OF RACEWAY SYSTEMS:

One cable tray and one conduit system were investigated in each test. Various types and number of cable lengths were installed into the cable trays, and one size and one type of cable was installed into the conduits as shown in ILL. 3 and as outlined in Table II.

All cables were cut into either 24 or 48 ft lengths. The 24 ft lengths were installed by routing the cable down the length of the tray, bending it at midlength and then routing it back to the end of the tray. The 48 ft cable lengths were installed similarly. However, these cables were routed down the length of the trays four times in lieu of two. Therefore, one 24 or 48 ft length of cable was considered as two or four 12 ft lengths of cable within the tray, and usually comprised one circuit as shown in Table II. One 24 ft length of cable was installed in a similar fashion into each conduit tested and comprised one circuit.

The cables were installed in two layers within the tray. The general pattern for cable installation is shown in ILL. 3A.

TABLE II - CABLE LOADING

	Test No. 1		Test No. 2		Test No. 3		Test No. 4	
Circuit No.	Cable Code	Number of 12 Ft Lengths	Cable Code	Number of 12 Ft Lengths	Cable Code	Number of 12 Ft Lengths	Cable Code	Number of 12 Ft Lengths
1	C-19	2	C-19	2	C-19	2	C-19	4
2	C-22	2	C-23	4	C-23	4	C-24	2
3	C-23	4	C-24	2	C-24	2	C-24	2
4	C-24	2	C-24	2	C-24	2	C-24	2
5	C-24	2	C-24	2	C-24	2	C-24	2
6	C-24	2	C-25	2	C-25	2	C-25	2
7	C-25	2	C-24	2	C-25	2	C-25	2
8	C-25	2	C-26	2	C-26	2	C-26	2
9	C-26	2	C-27	2	C-27	2	C-27	2
10	C-27	2	C-33	2	C-33	2	C-33	2
11	C-33	2	C-33	2	C-33	2	C-33	2
12	C-33	2	C-33	2	C-33	2	C-33	2
13	C-33	2	C-33	2	C-33	2	C-33	2
14	C-33	2	M7-9	2	M7-9	2	M7-9	2
15	M7-9	2	M7-9	2	M7-9	2	M7-9	2
16	M7-9	2	M7-9	4	M7-9	4	M7-9	2
17+	M7-9	2	M7-9	2	M7-9	2	M7-9	2
18-20++	B1-9	2	B1-9	2	B1-9	2	B1-9	2

\+ - Cable installed inside of conduit.

++ - One conductor cable. However, three circuits (two single phase and ground) were constructed by connection to single strands.

Each cable tray was wrapped with insulation as shown in ILLS. 5-8. The insulation was installed with overlaps and staggered joints. Initially, one piece of Kaowool approximately 18 in. wide by 78 in. long was cut and placed on top of the cables within the tray. Two pieces of Kaowool were then wrapped side by side around the tray forming one layer. The ends of each piece were overlapped and the common side between pieces butted. Adhesive tape was wrapped randomly around each piece to temporarily secure the insulation.

In Tests 1, 2 and 3, two pieces were then wrapped side by side around the tray to form a second insulation layer. The width of the Kaowool pieces was different than that of the first layer so as to provide an offset between the location of the butt joint in the first and second layers. The ends of each piece were overlapped with the overlap staggered between the first and second layers. Adhesive tape was then randomly wrapped about each piece to temporarily secure the insulation. Details of the insulation installation for Tests 1-3 are shown in ILLS. 5-7.

In Test 4, in lieu of installing a complete second layer of insulation, a 4 in. wide strip of insulation was placed over the first layer butt joint which was located at the midpoint of the tray. The ends of the strip were overlapped 6-1/4 in. and the piece temporarily secured with tape. Additionally, strips were installed outside the furnace chamber near the ends of the insulation. Brackets were installed over these 4 in. strips. Details of the insulation installation for Test 4 are shown in ILL. 8.

After the insulation wrapping for the tray was completed, brackets were fastened about the insulated trays. The locations of these brackets are shown in ILLS. 5-8. The brackets were fastened by tightening the bracket bolt and thereby clamping the insulation into place.

Kaowool insulation was installed in two layers about the conduit in Tests 1-3. Two pieces of Kaowool were wrapped side by side around the conduit forming one layer. The ends of each piece were angle cut and butted with each other or overlapped approximately 3 in. The common side between pieces was butted. Adhesive tape was wrapped randomly around each piece to temporarily secure the layer. Two pieces were then installed similarly forming a second layer. The width of the pieces differed from that of the first layer so as to provide an offset between the location of the butt joint in the first and second layers. The ends of each piece were angle cut and butted or overlapped with the joint or overlap staggered between the first and second layers. Adhesive tape was then used to temporarily fasten the outer layer.

Steel bands were then tightened about the insulation located as shown in ILLS. 5-7. The bands were installed with the banding tool recommended by the band manufacturer. The bands were tightened compressing the insulation.

In Test 4, Kaotemp insulation was installed about the conduit. Two 26-3/4 in. wide pieces of Kaotemp were installed with their common side butted at the midpoint of the conduit. The insulation was secured with steel wire ties twist tied and located as shown in ILL. 8.

LJP/KWH:plh

T E S T R E C O R D

The four fire tests were conducted in accordance with the following test method and observed performance is described below.

METHOD

One cable tray and one conduit system were inserted through the furnace chamber as shown in ILL. 9 for each test. The conduit was supported by pipe hangers located outside and approximately 2 in. away from the front and rear surface of the furnace. The cable tray was supported by the furance walls and an independent stand outside of the furnace chamber. Location of the raceways within the furnace is shown in ILL. 9. The remaining furnace opening about the specimens was filled with Kaowool, the ends of the conduit stuffed with Kaowool, and space between the cables filled with fire brick dust.

Eight Type K thermocouples were installed in various locations as shown in ILLS. 10, 12, 14 and 16. One Type B thermocouple was used to monitor the furnace temperature and was located approximately 1 to 2 in. above the tray along the centerline of the furnace, 15 in. from the rear furnace wall.

The furnace was controlled by feedback from the furnace thermocouple. It was planned that the measured furnace temperature for each test be in accordance with the standard temperature-time curve as described in ASTM E119 "Fire Tests Of Building Construction Materials."

Power (220 v) was supplied to each cable circuit as shown in ILL. 4. One circuit breaker was installed for each circuit. Circuit integrity was monitored by visual observation of incandescent light bulbs. Two light bulbs were provided for each circuit as shown in ILLS. 4 and 9A. The lights were connected in parallel so as to provide one back-up bulb for each circuit in case of failure of the light bulb filament.

At the initiation of each test, all circuits were energized. Upon failure of a circuit (i.e., short circuit), the circuit breaker tripped and the light bulbs for that circuit were de-energized. Since there were no furnace windows, visual observation of the furnace fire and exposed surfaces of the specimens was not possible.

Throughout each test, temperature measurements and times at which failures of circuits (monitoring light board) occurred were recorded.

RESULTS

Furnace Temperatures - The furnace temperature as measured by the one Type B thermocouple for each test are shown in ILLS. 11, 13, 15 and 17.

Temperatures - The temperatures within and on the cable tray, and within the conduit for each test are shown in ILLS. 11, 13, 15 and 17.

Circuit Failure - The times at which circuit failure occurred are presented for each test in Tables III-VI.

Post Test Observations - In general, the ceramic insulation appeared to have a brown char near each joint. The Okolon cable jacket material changed to white ash while the PVC cable jacket material decomposed exposing the copper sheath and leaving a black residue char. The general appearance of the insulation and cables after the test is shown in ILLS. 18 and 19.

LJP/KWH

S U M M A R Y

In consideration of the character of the investigation, the foregoing Report is to be construed as information only and should not be regarded as conveying any conclusion or recommendations on the part of Underwriters Labortories Inc. regarding the acceptability of the construction or performance of the product for recognition by any code or standard or for any other purpose.

In general, small scale tests individually do not represent all factors associated with fire performance under actual field conditions. Accordingly, these test results may not be generally applicable. The suitability of this test method for predicting full scale performance presently has not been determined by the Laboratories.

Based upon time to first circuit failure, the protection systems of Tests 1, 3 and 4 provided greater than 30 min of fire resistance when subjected to a fire exposure as described herein.

Based upon time of circuit failures, the tray protection systems with two complete layers of insulation protection (except Test 2) provided 11 to 21 min more resistance against fire than the Test 4 tray protection system with only one complete insulation layer.

Since Test 2 differed from Test 3 only by the location of tray insulation fasteners, the fastening method employed in Test 3 provided 50 min more protection than the fastening method employed in Test 2.

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LJP/RLP/KWH:plh

TABLE III

Circuit Failure Test No. 1

Circuit No.	Time of Failure, Min/Sec Into Test
1	51:00
20	56:00
11	57:00
19	58:30
3	58:30
18	61:00
17	65:00
5	67:00
4	69:30
2	70:00
8	70:00
6	70:00
15	70:00
7	70:00
12	75:00
Test Terminated	77:00

TABLE IV

Circuit Failure Test No. 2

Circuit No.	Time of Failure, Min/Sec Into Test
2	11:30
5	11:40
7	12:30
8	13:20
6	13:35
9	14:00
3	14:45
11	14:50
1	17:30
4	18:30
10	22:15
14	26:00
Test Terminated	30:00

TABLE V

Circuit Failure Test No. 3

Circuit No.	Time of Failure, Min/Sec Into Test
1	61:30
16	62:00
19	65:10
2	66:00
20	67:30
5	68:30
3	69:25
4	70:20
18	71:20
Test Terminated	73:00

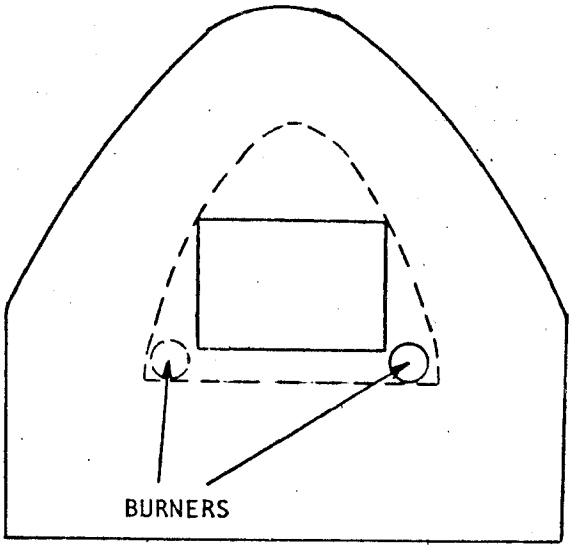
TABLE VI

Circuit Failure Test No. 4

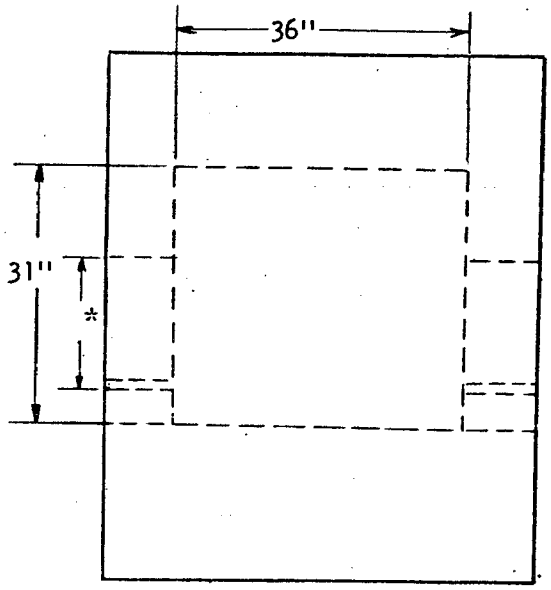
Circuit No.	Time of Failure, Min/Sec Into Test
1	40:00
20	46:00
19	46:30
17	48:18
9	50:38
15	52:00
16	53:00
2	53:17
18	54:09
6	57:30
4	58:07
3	58:30
14	59:32
Test Terminated	60:00

I L L U S T R A T I O N S

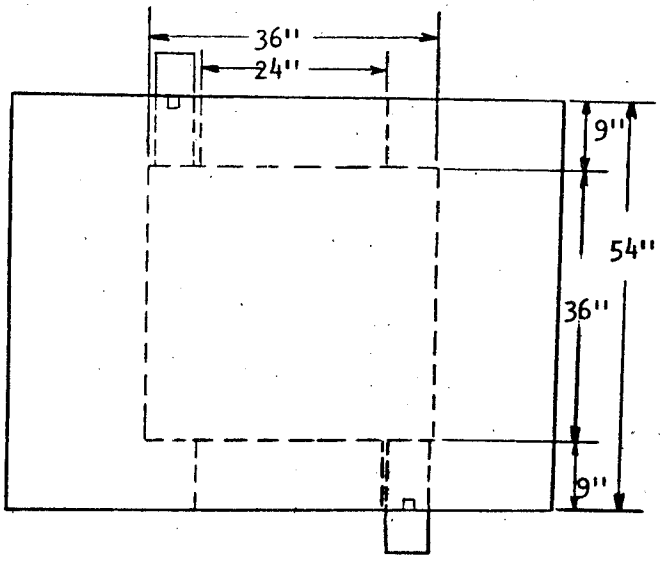
FURNACE



FRONT



SIDE



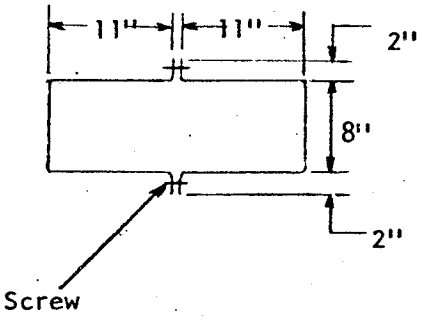
TOP

* Vary between 18" _ 24"

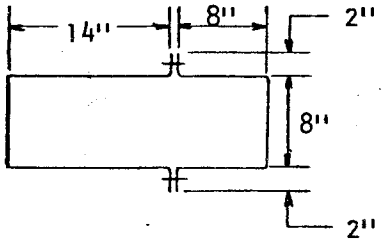
ILL.1
R 8758

BRACKETS

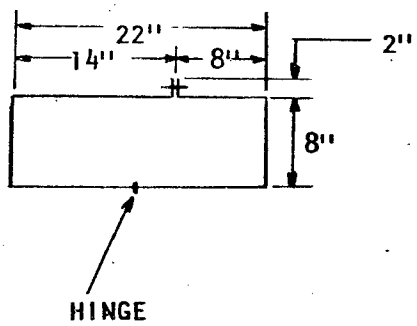
TEST 1



Test 2



TEST 3 & 4



All brackets formed from 1-1/2" wide, 0.130 in thick steel. Brackets tightened with 1/4" x 1" machine screws and 1/4" hex nut.

ILL.2
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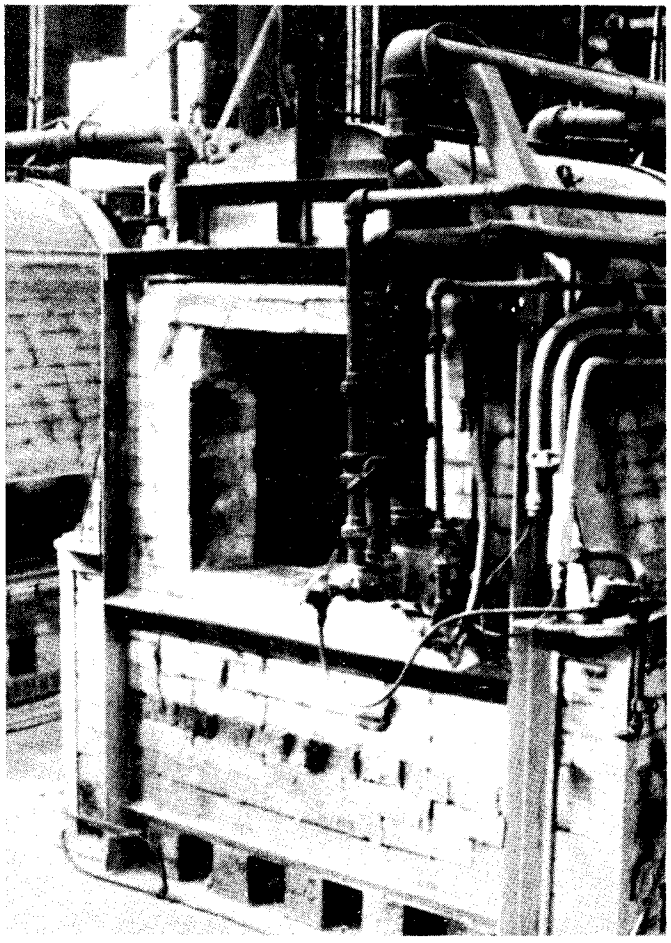
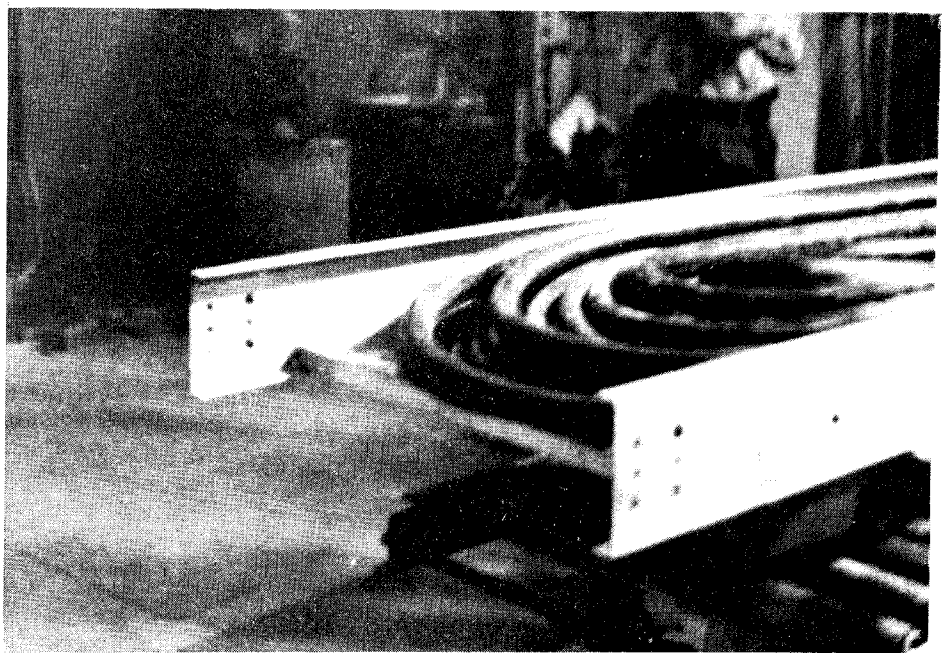
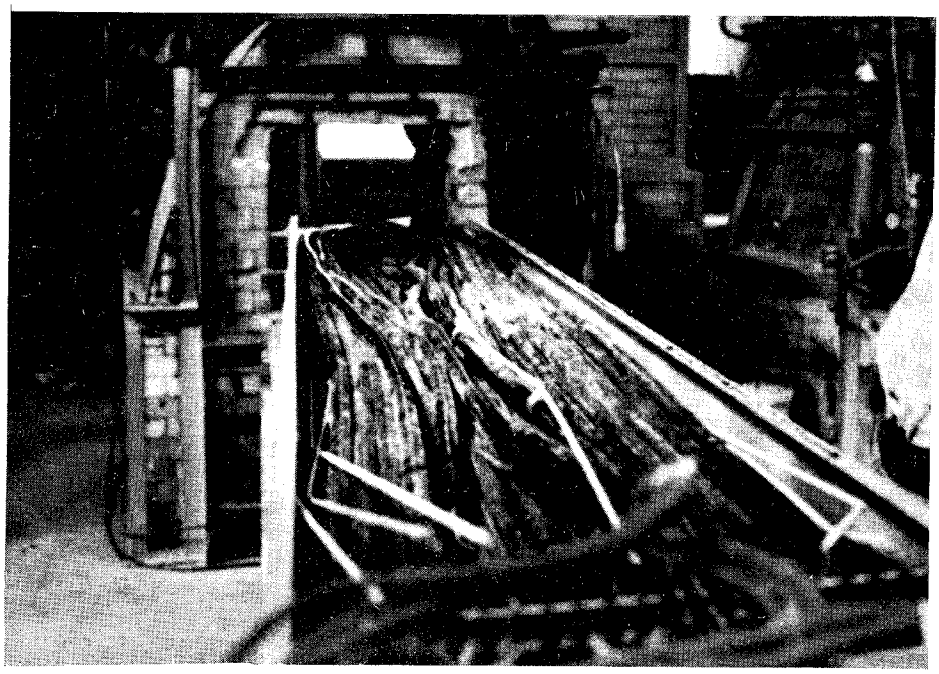


FURNACE
FRONT VIEW C78-11388

CABLE INSTALLATION





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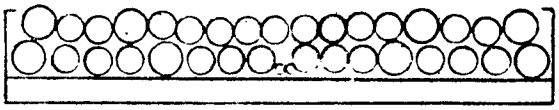
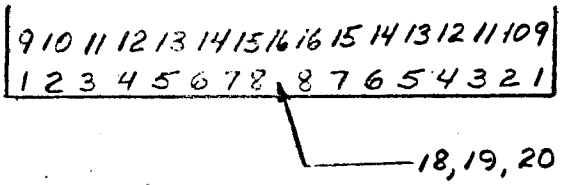
Ill. 3

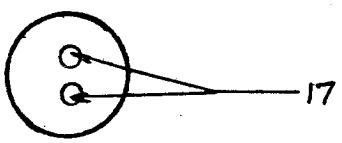
GENERAL CIRCUIT LOCATIONS



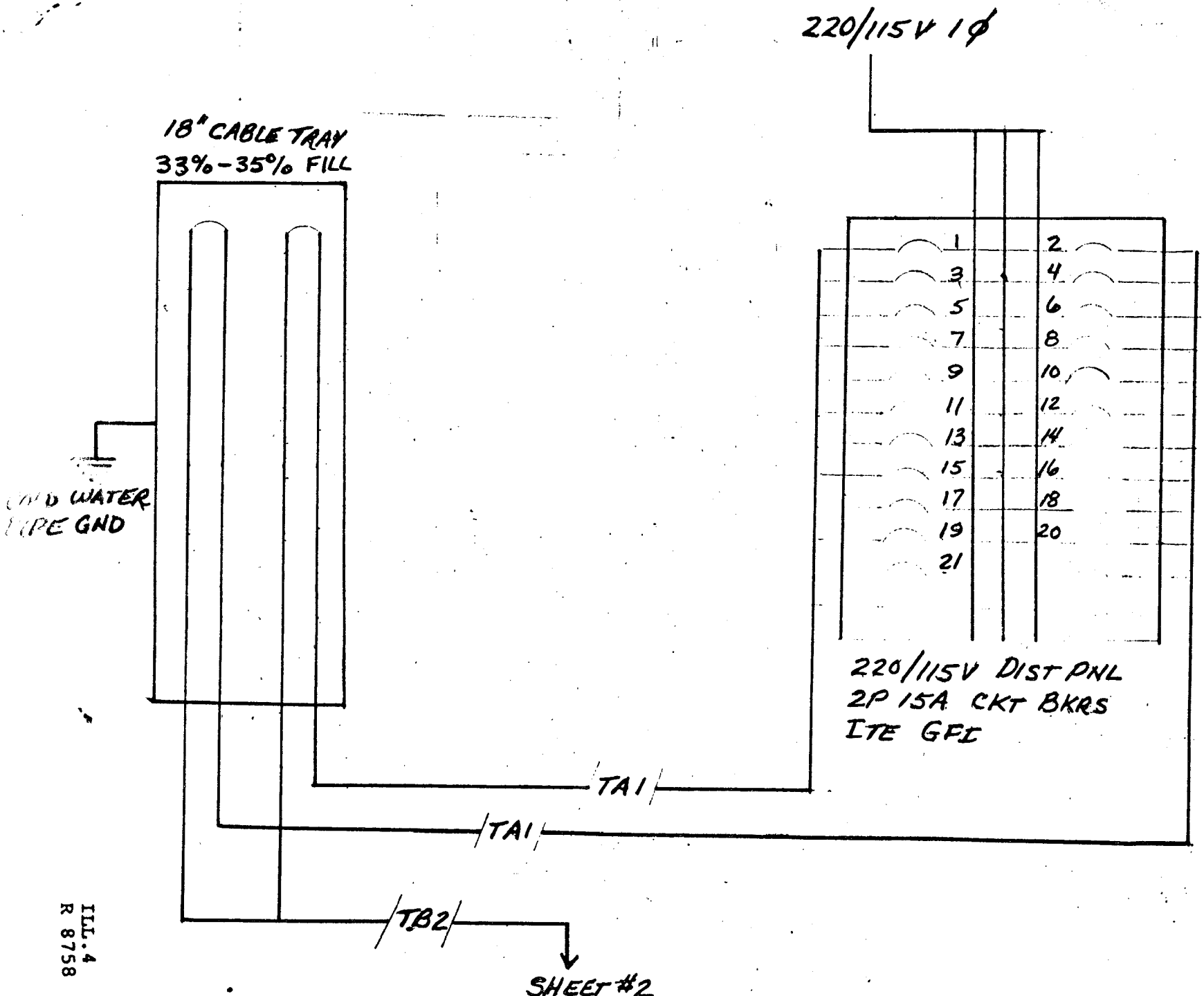
CABLE TRAY CROSS SECTION



CORRESPONDING CIRCUIT NUMBER



CONDUIT CIRCUIT


220/115V 1ϕ
18" CABLE TRAY
33%-35% FILL
COLD WATER
PIPE GND
1
2
3
4
5
6
7
8
9
10
11
12
13
14
15
16
17
18
19
20
21
220/115V DIST PNL
2P 15A CKT BKRS
ITE GFI
TA1
TA1
TB2
SHEET #2

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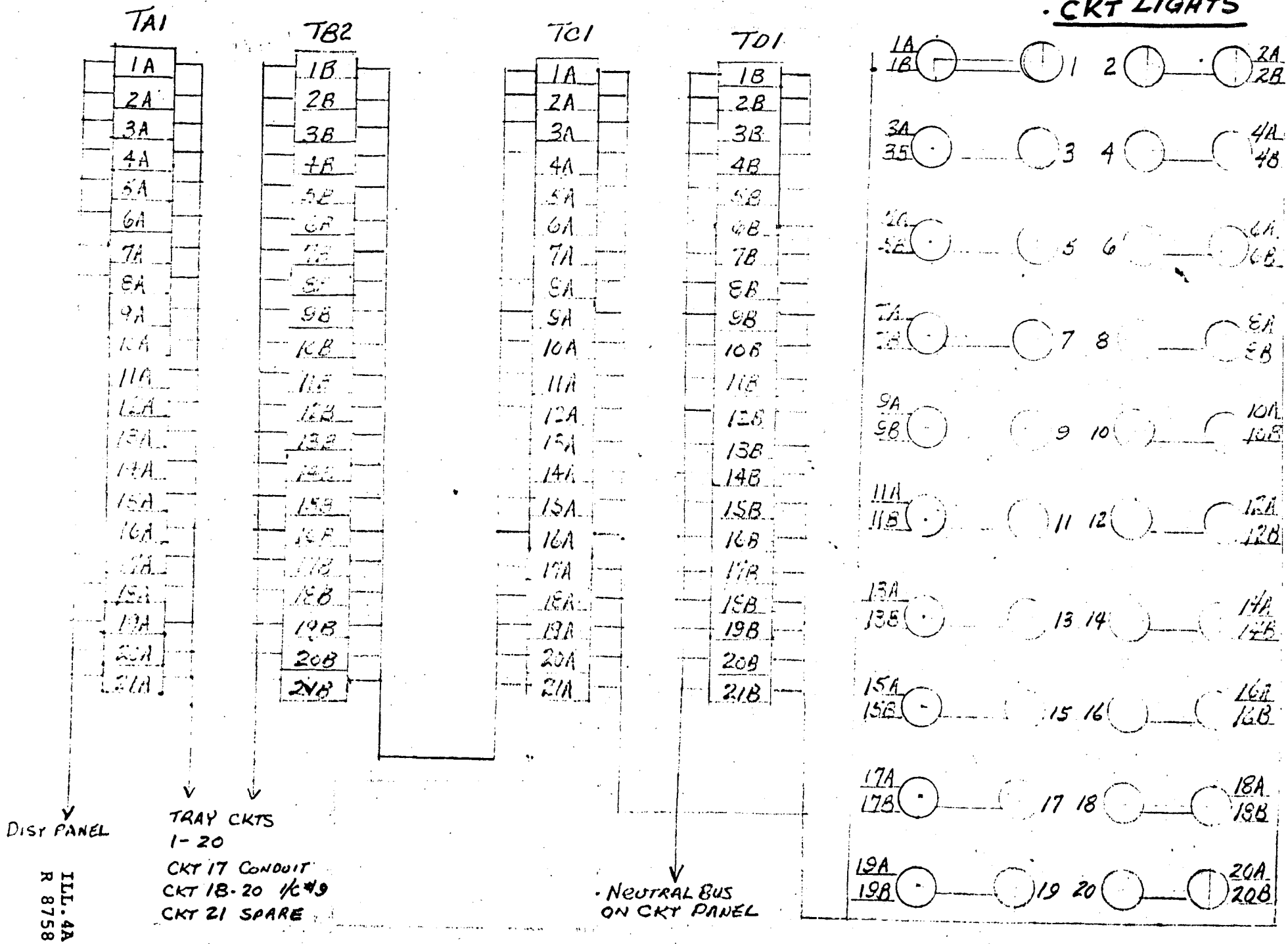
TA1
TB2
TC1
TD1
1A
2A
3A
4A
5A
6A
7A
8A
9A
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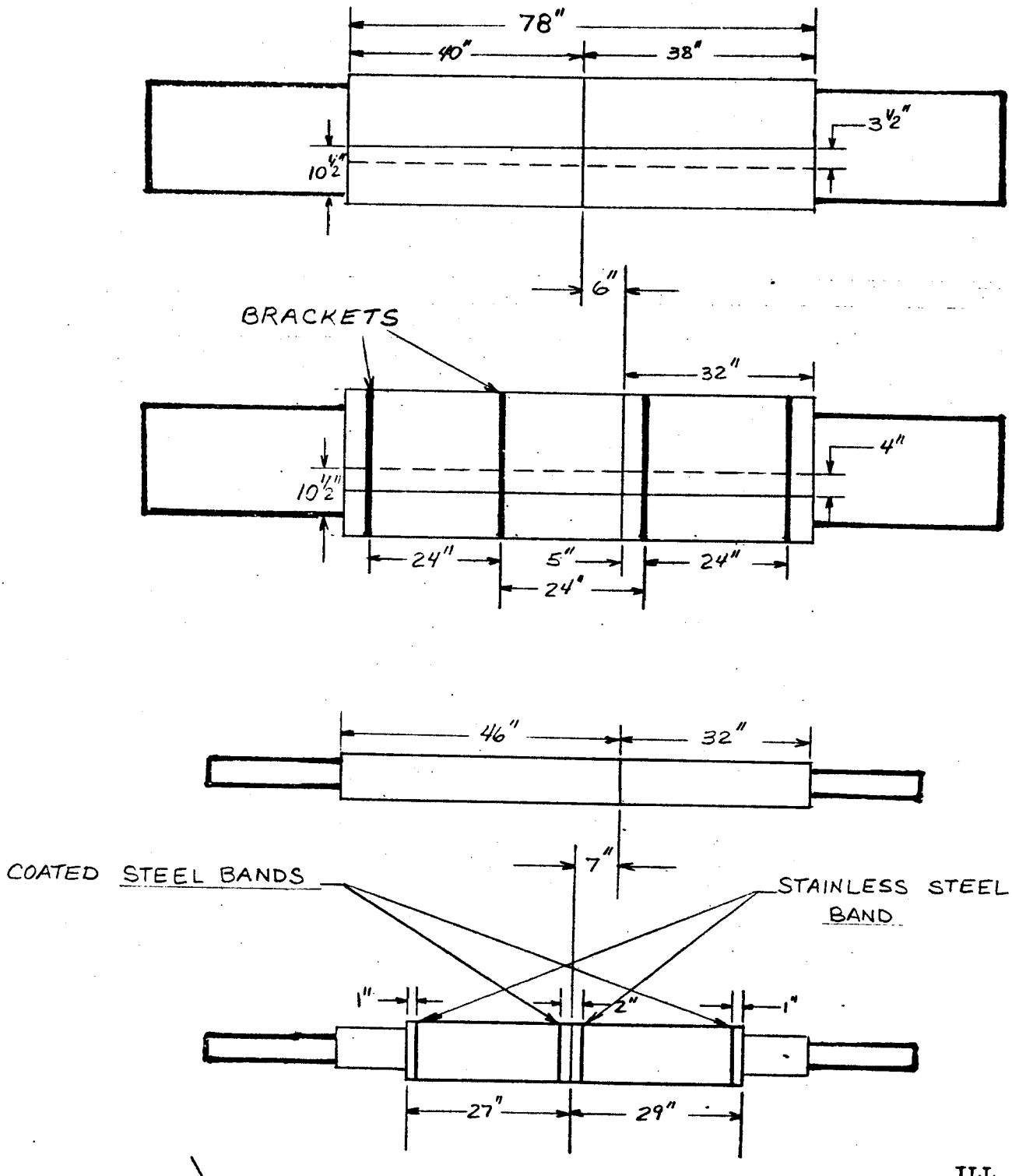
13A
14A
15A
16A
17A
18A
19A
20A
21A
1B
2B
3B
4B
5B
6B
7B
8B
9B
10B
11B
12B
13B
14B
15B
16B
17B
18B
19B
20B
21B
· CKT LIGHTS
1A 1B
1 2
2A 2B
3A 3B
3 4
4A 4B
5A 5B
5 6
6A 6B
7A 7B
7 8
8A 8B
9A 9B
9 10
10A 10B
11A 11B
11 12
12A 12B
13A 13B
13 14
14A 14B
15A 15B
15 16
16A 16B
17A 17B
17 18
18A 18B
19A 19B
19 20
20A 20B
DIST PANEL
TRAY CKTS
1 - 20
CKT 17 CONDUIT
CKT 18 - 20 1/C #9
CKT 21 SPARE
· NEUTRAL BUS
ON CKT PANEL
ILL. 4A
R 8758

INSULATION CONSTRUCTION
TEST 1

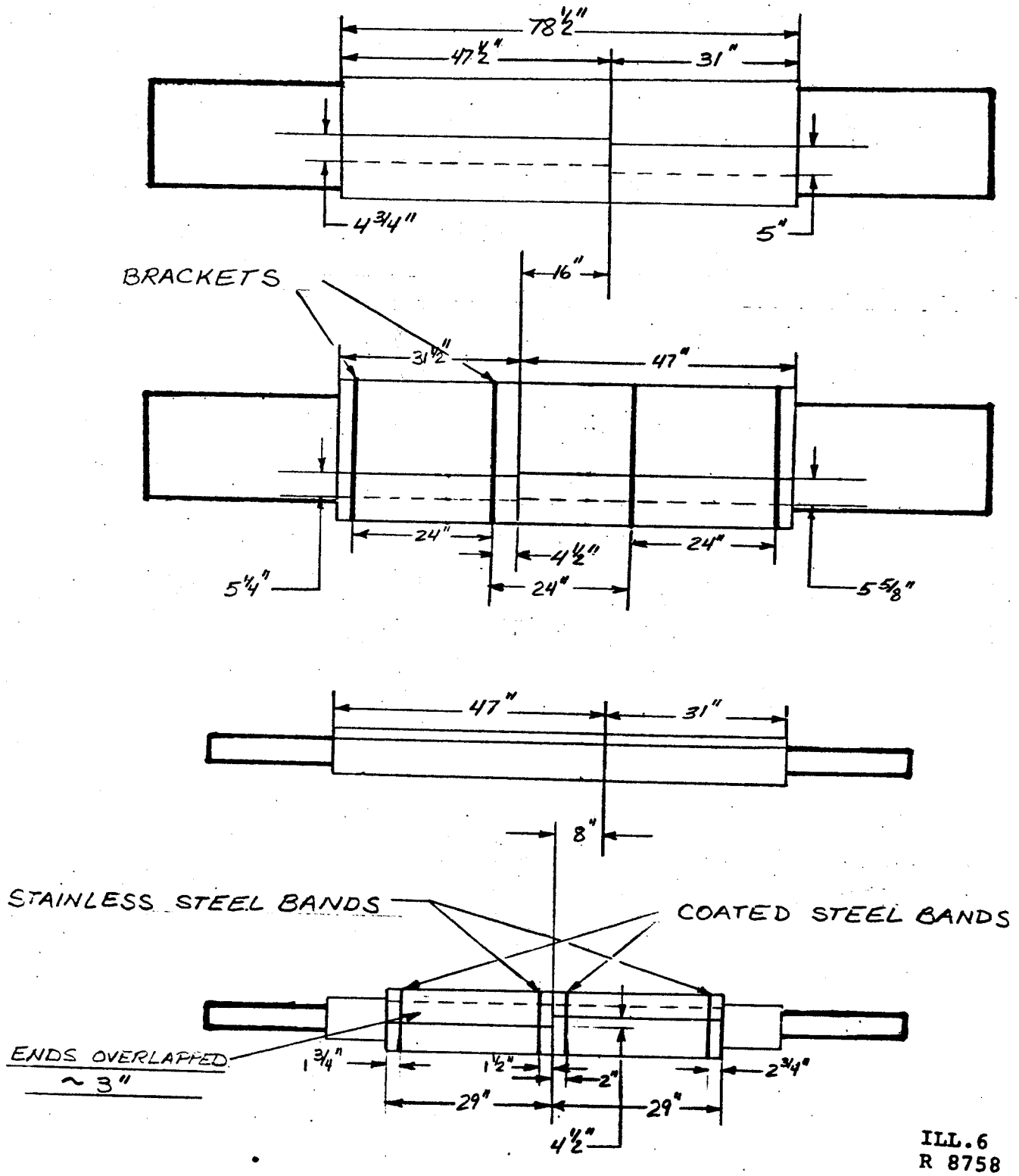


ILL.5
R 8758

BUTT JOINT OF EACH PIECE ANGLE CUT TO PROVIDE AN OVERLAP

INSULATION CONSTRUCTION

TEST 2



ILL.6
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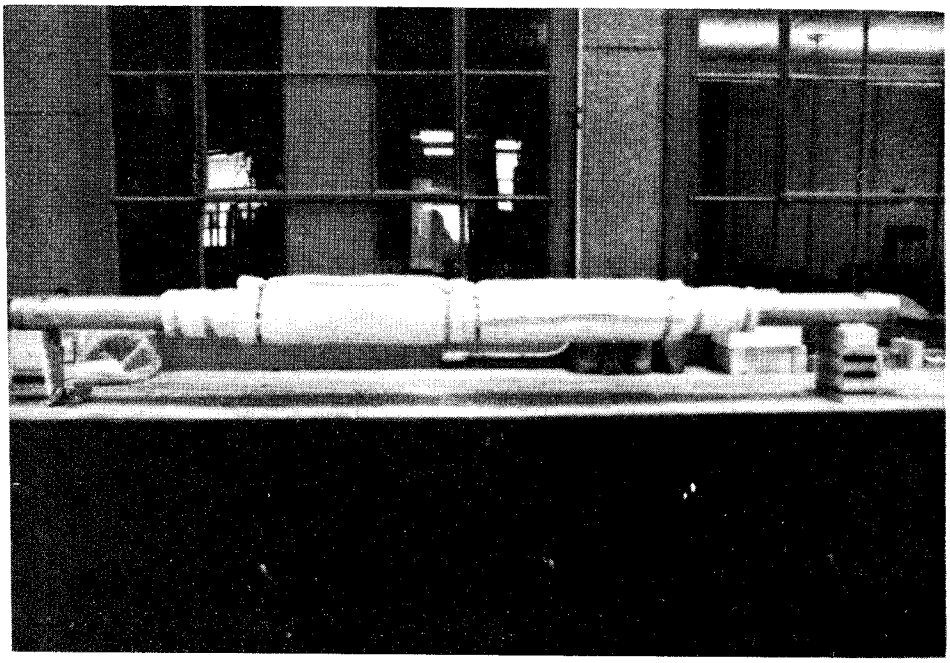
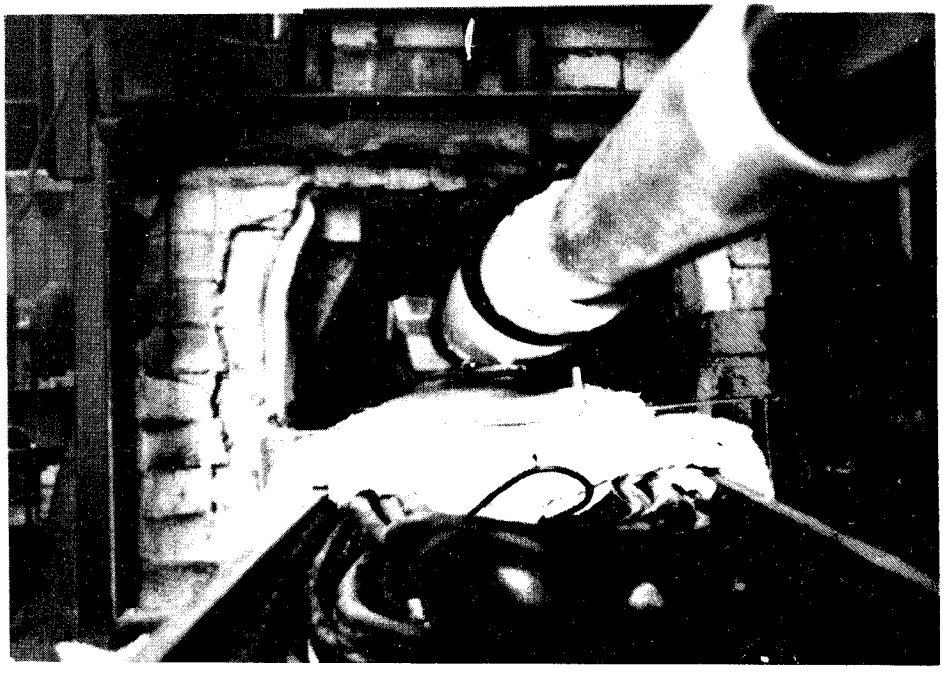
INSULATION CONSTRUCTION APPEARANCE
TEST 2
CONDUIT PROTECTION



CABLE TRAY PROTECTION



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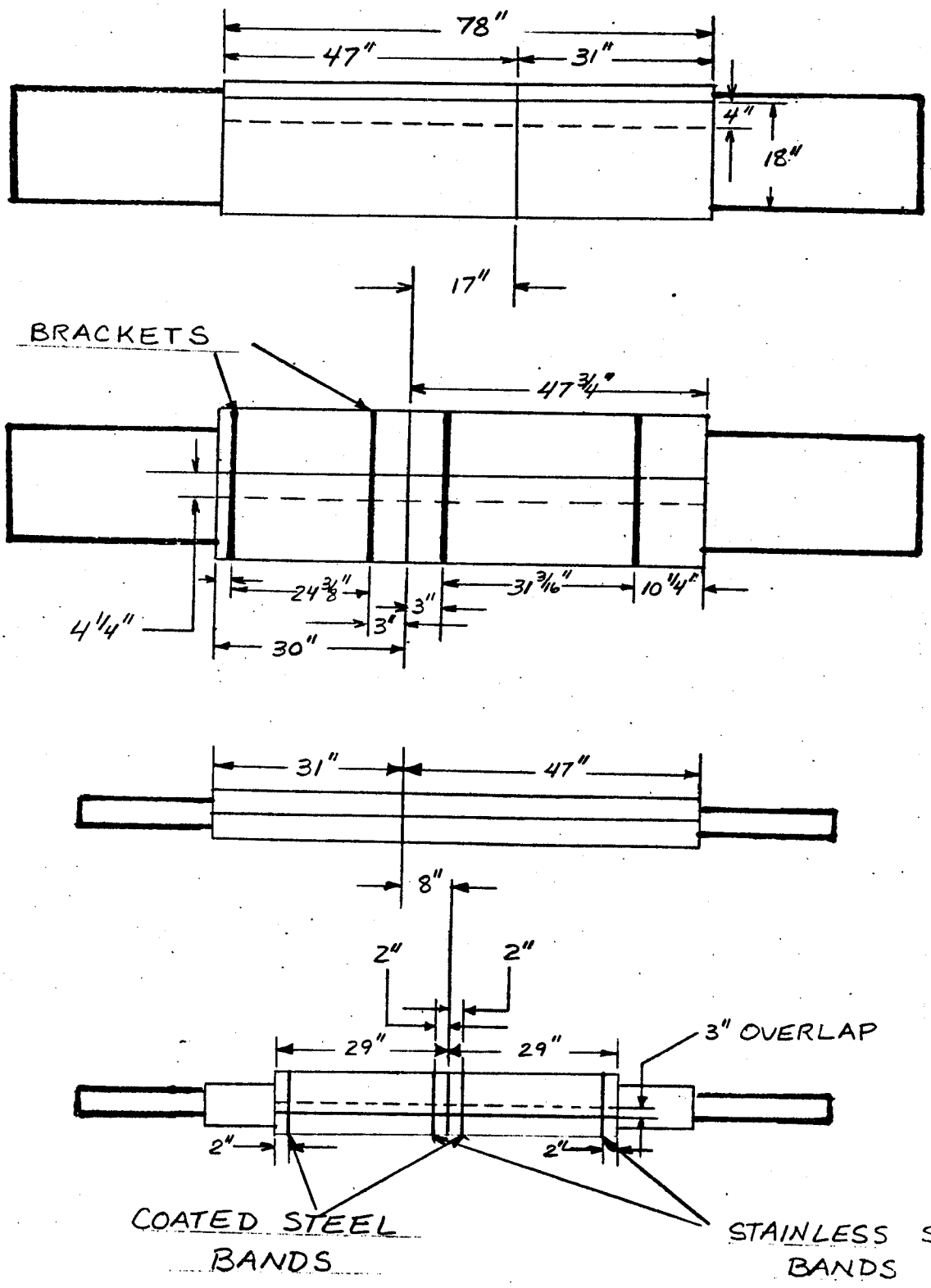
Ill. 6A

C78-11386

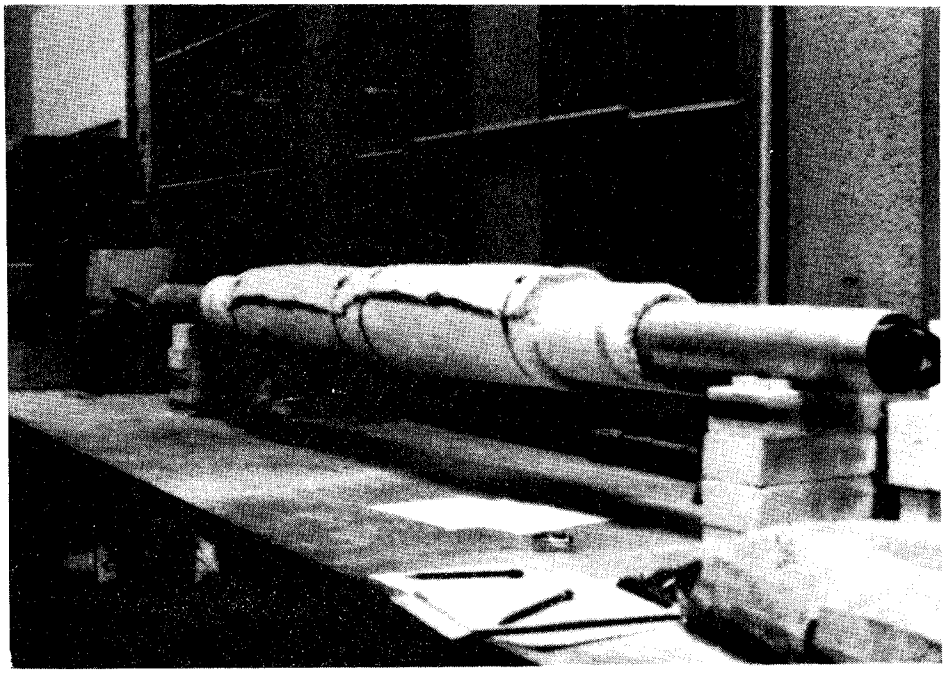
INSULATION CONSTRUCTION

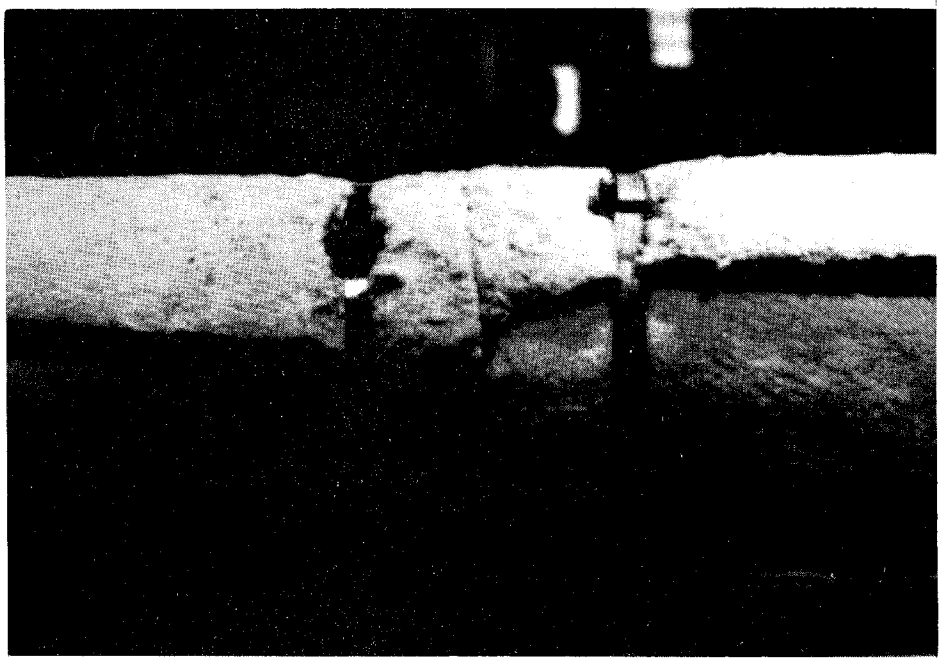
TEST 3



ILL.7
R 8758

CONDUIT INSULATION CONSTRUCTION APPEARANCE
TEST 3

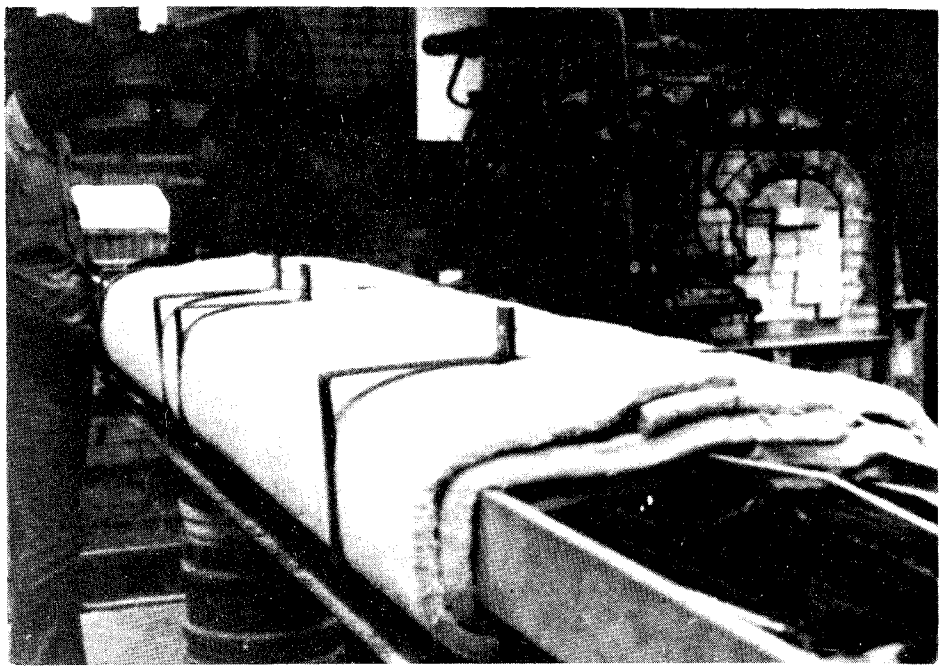


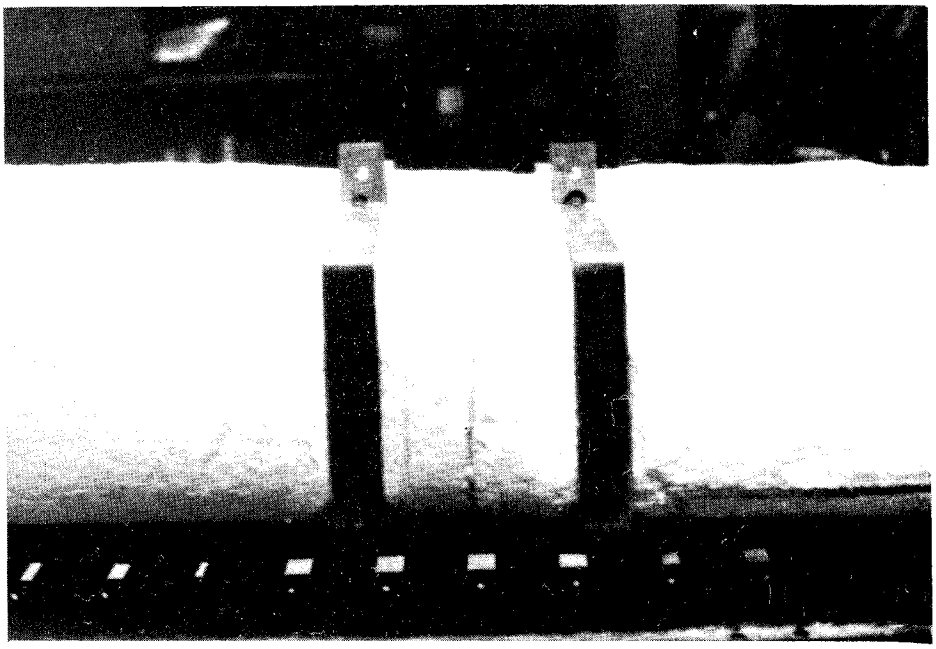


C78-11385

R8758
Ill. 7A

TRAY INSULATION CONSTRUCTION APPEARANCE
TEST 3

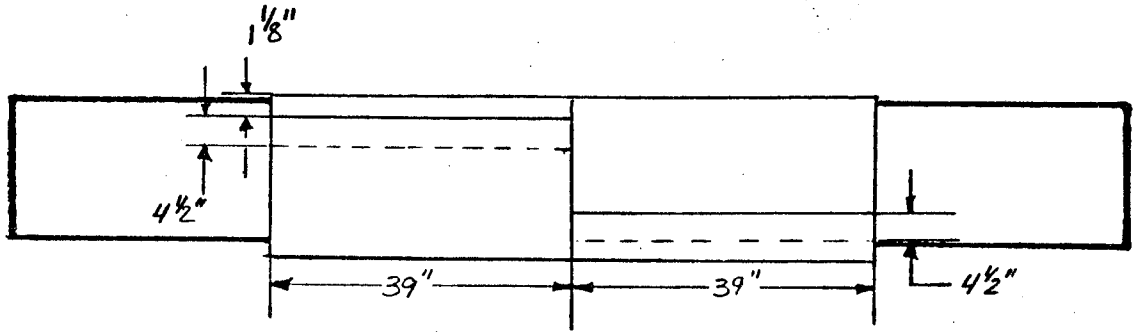


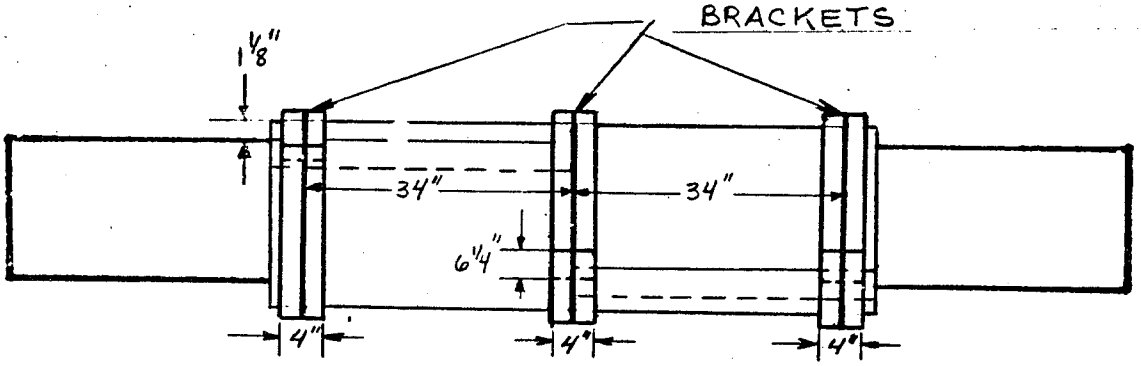


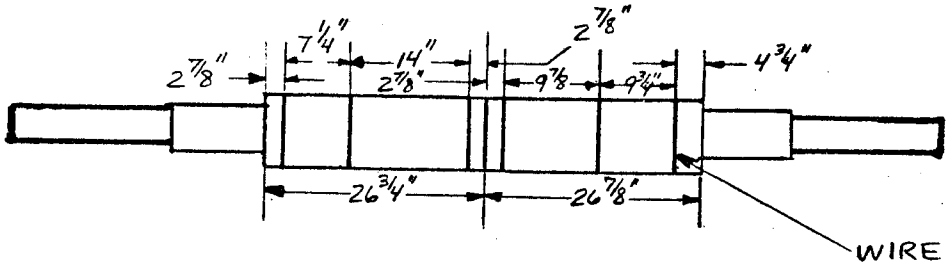
C78-11384

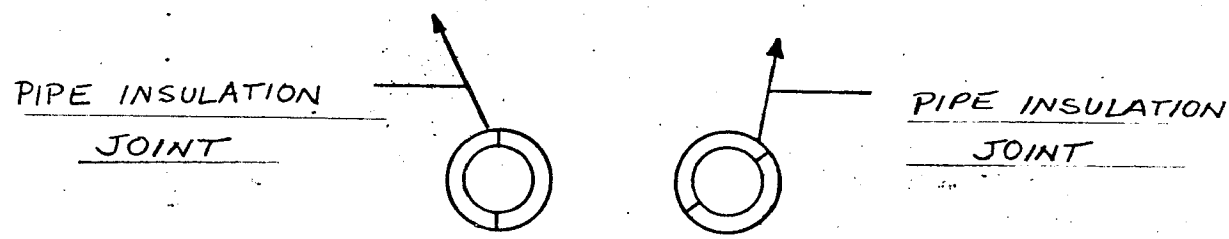
R8758
Ill. 7B

INSULATION CONSTRUCTION
TEST 4



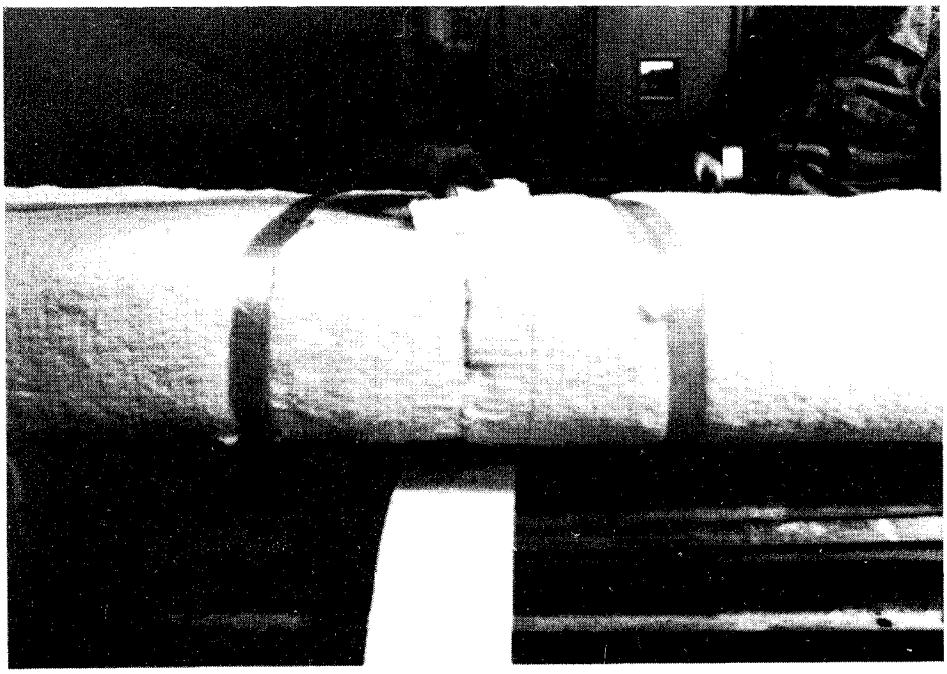


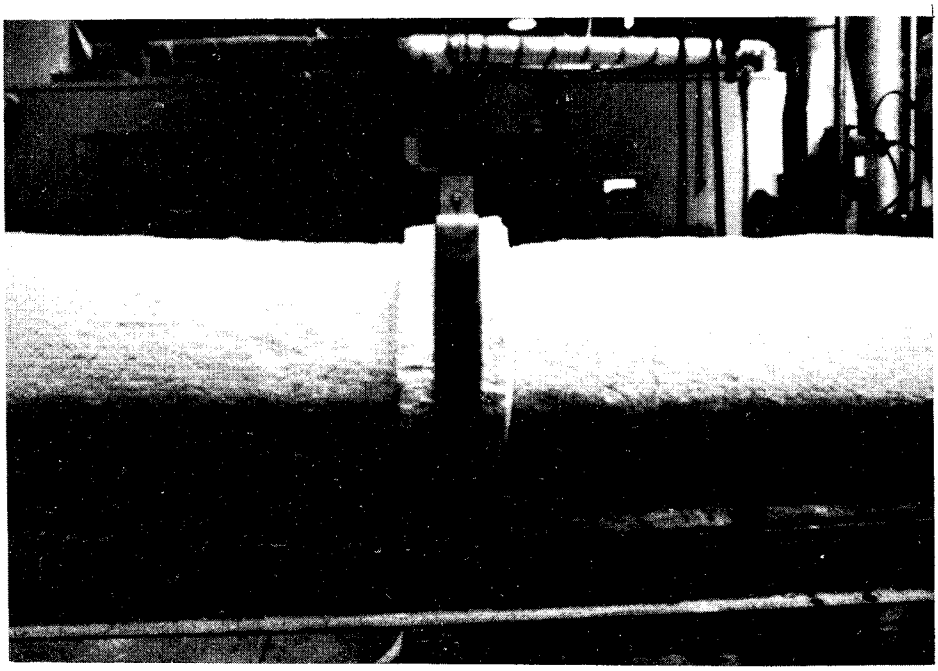




ILL. 8
R 8758

TRAY INSULATION CONSTRUCTION APPEARANCE
TEST 4

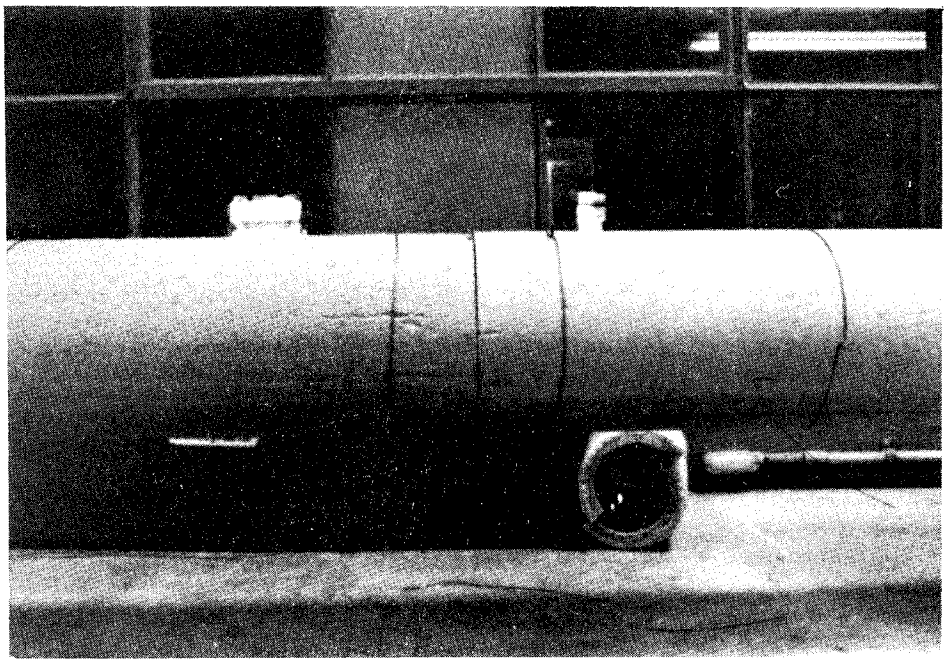


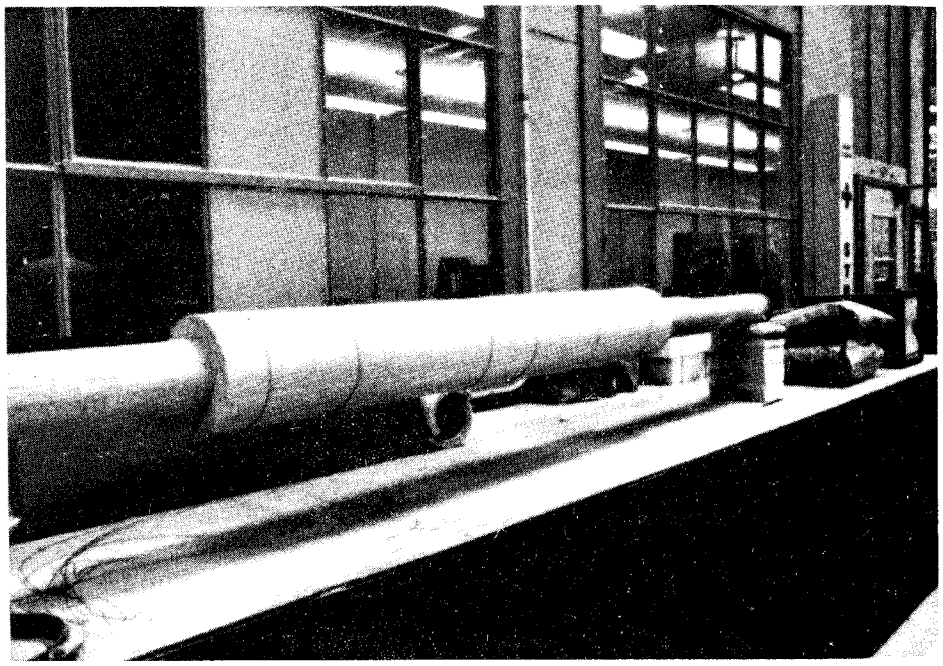


C78-11383

R8758
Ill. 8A

CONDUIT INSULATION CONSTRUCTION
TEST 4

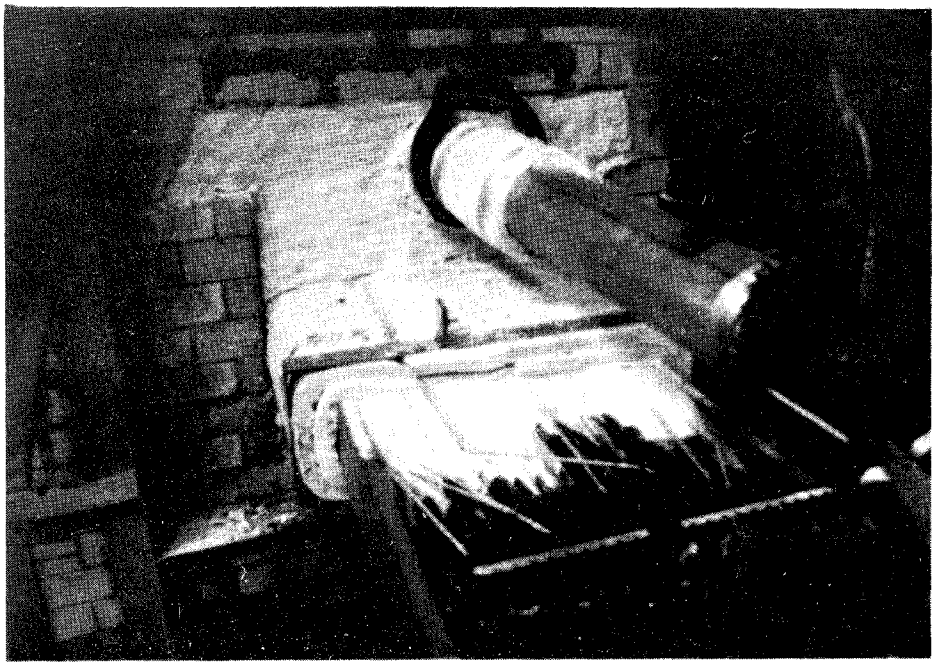


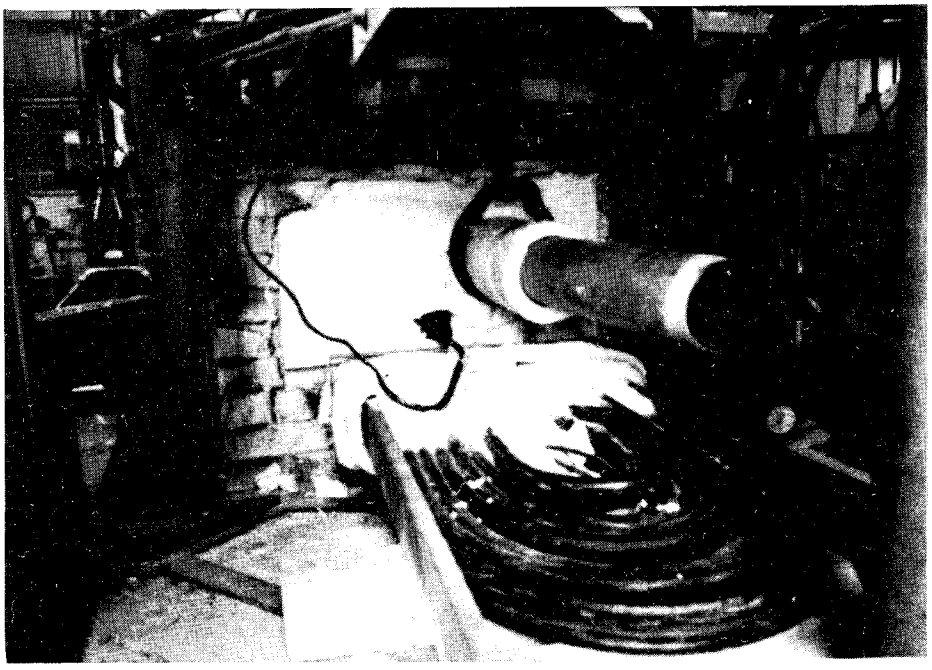


C78-11382

R8758
Ill. 8B

INSTALLATION INTO
FURNACE

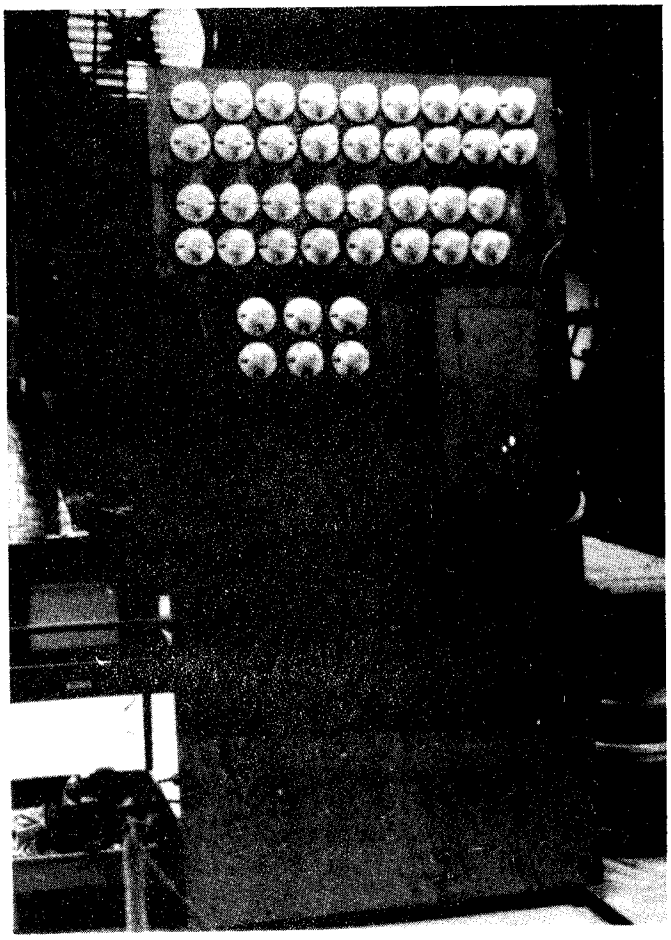




C78-11381

R8758
Ill. 9

CIRCUIT LIGHT BOARD

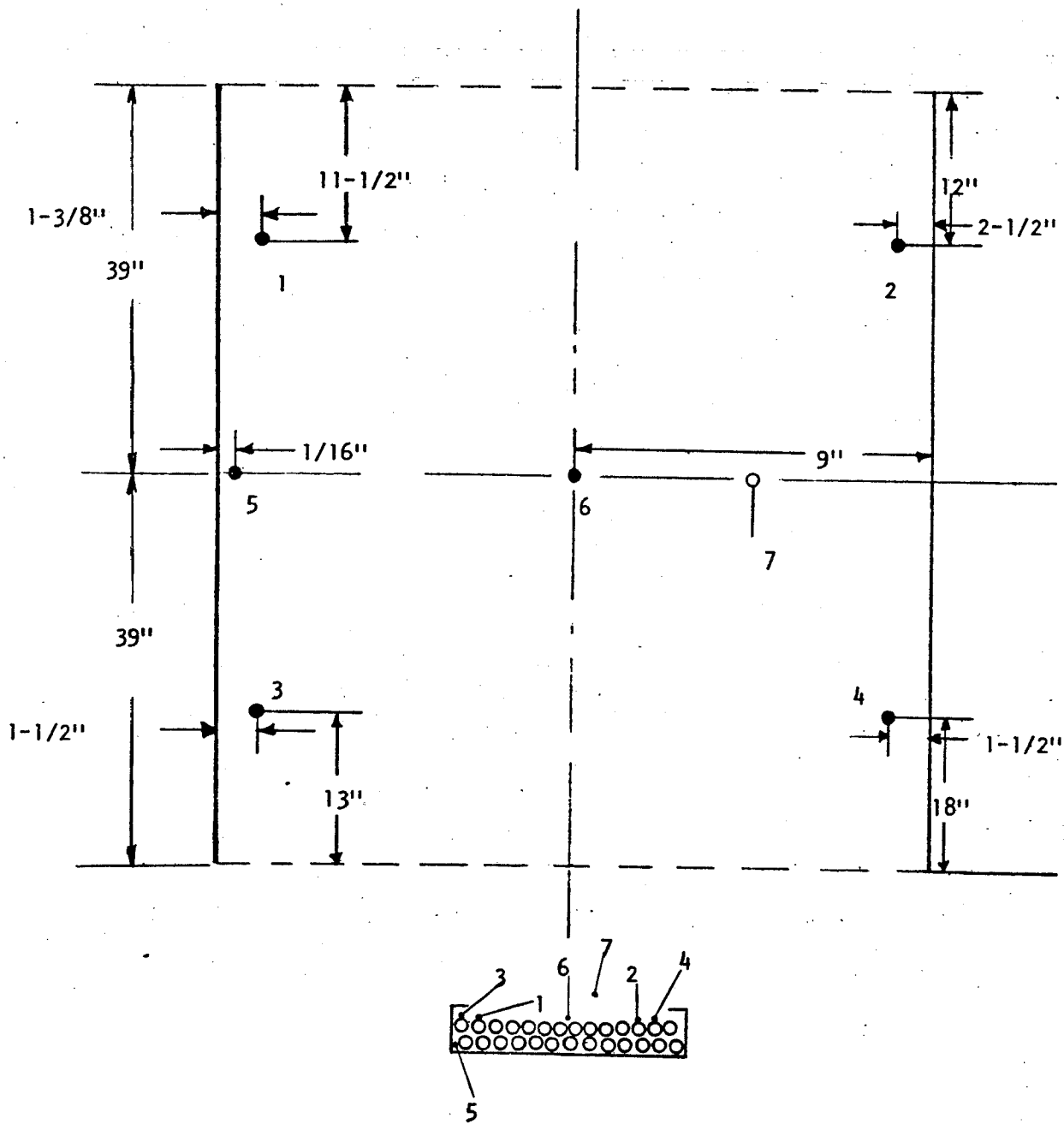


C78-11380

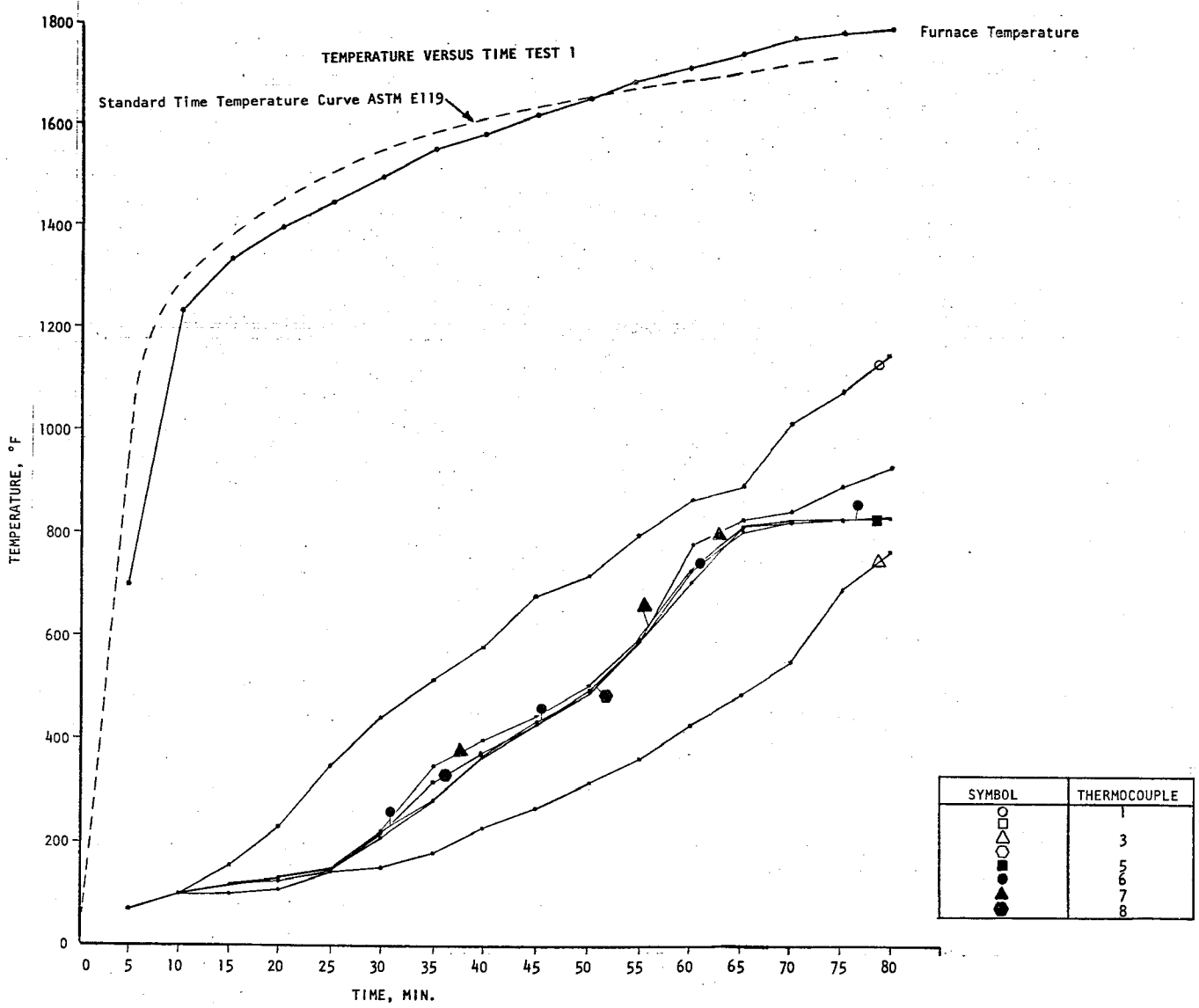
R8758
Ill. 9A

CABLE TRAY and CONDUIT THERMOCOUPLE LOCATIONS

TEST 1



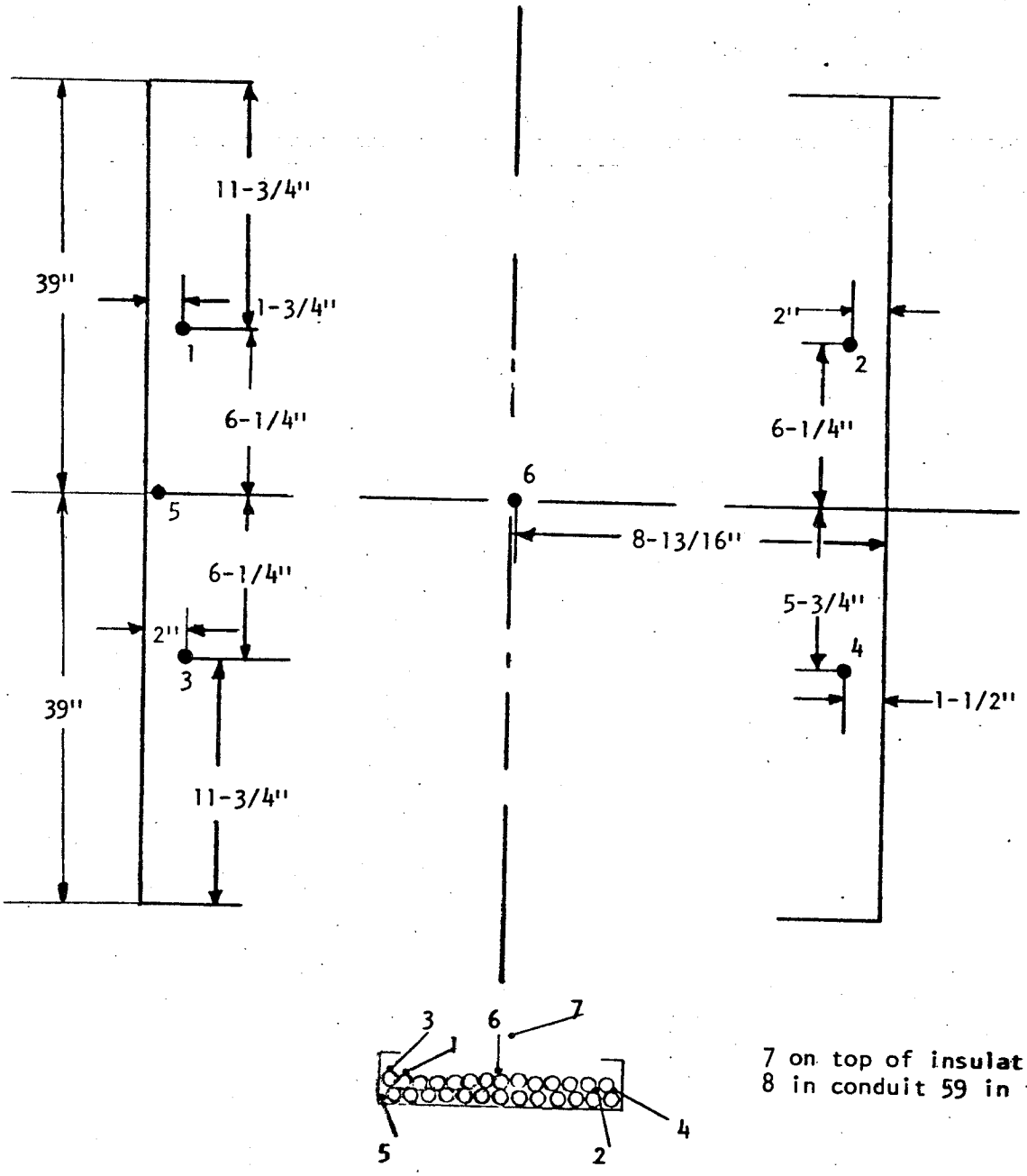
ILL.10
R 8758


TEMPERATURE VERSUS TIME TEST 1
Standard Time Temperature Curve ASTM E119
Furnace Temperature
TEMPERATURE, °F
TIME, MIN.
1800
1600
1400
1200
1000
800
600
400
200
0
0 5 10 15 20 25 30 35 40 45 50 55 60 65 70 75 80
SYMBOL
THERMOCOUPLE
1
3
5
6
7
8

ILL.11
R 8758

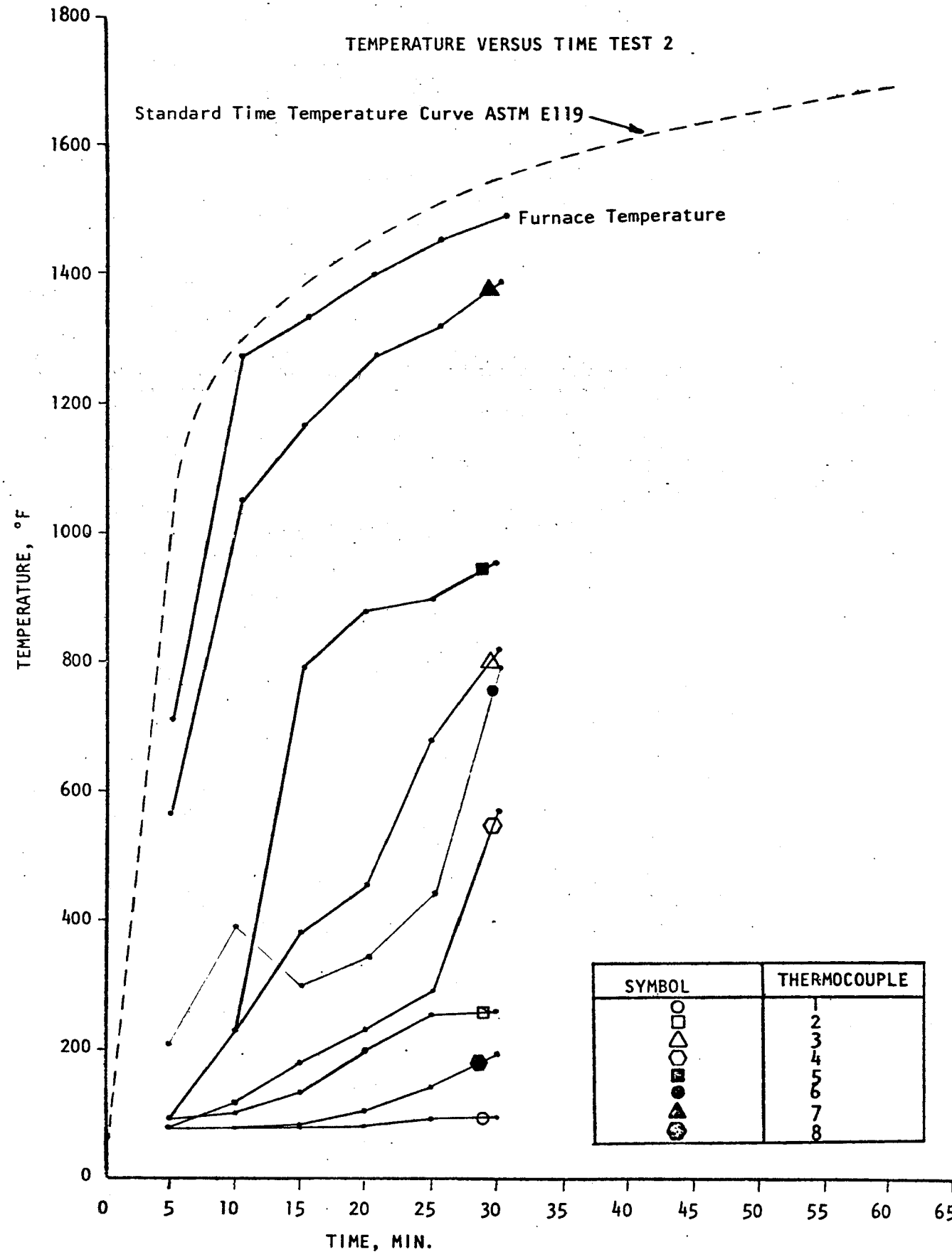
CABLE TRAY and CONDUIT THERMOCOUPLE LOCATION

TEST 2



7 on top of insulation
8 in conduit 59 in from end

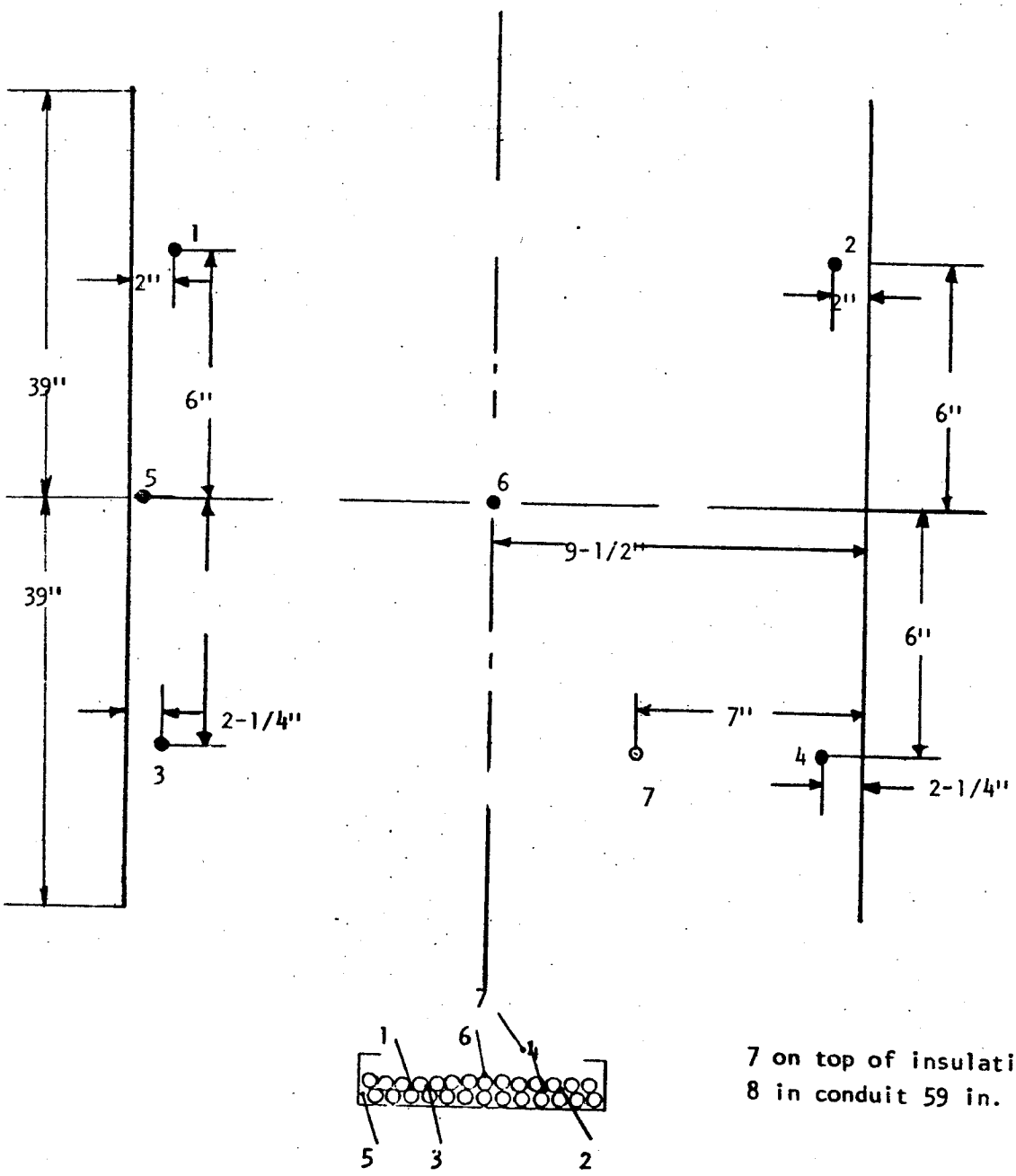
ILL.12
R 8758


TEMPERATURE VERSUS TIME TEST 2
Standard Time Temperature Curve ASTM E119
Furnace Temperature
TEMPERATURE, °F
1800
1600
1400
1200
1000
800
600
400
200
0
0
5
10
15
20
25
30
35
40
45
50
55
60
TIME, MIN.
SYMBOL
THERMOCOUPLE
1
2
3
4
5
6
7
8

ILL.13
R 8758

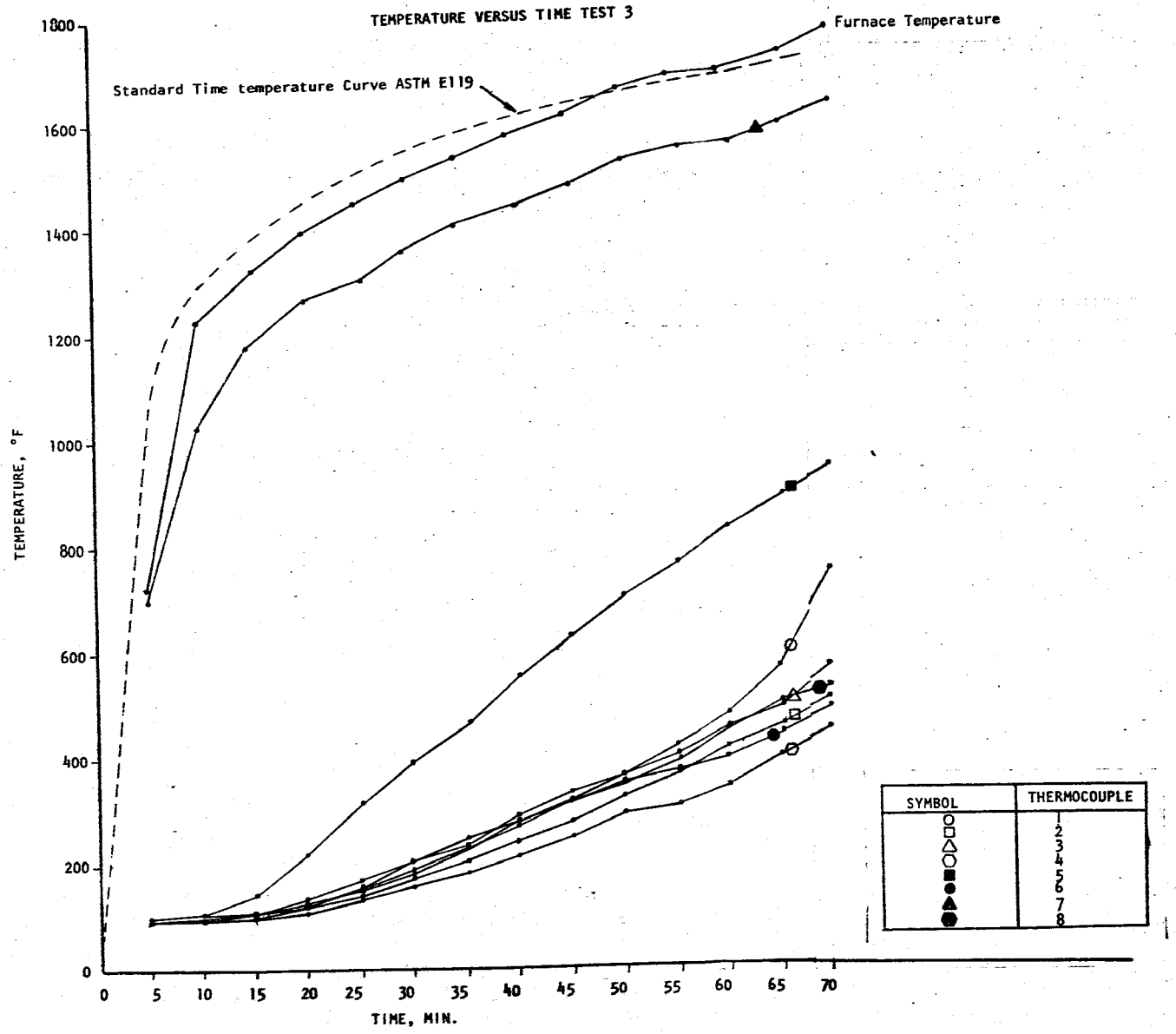
CABLE TRAY and CONDUIT THERMOCOUPLE LOCATION

TEST 3



7 on top of insulation
8 in conduit 59 in. from end

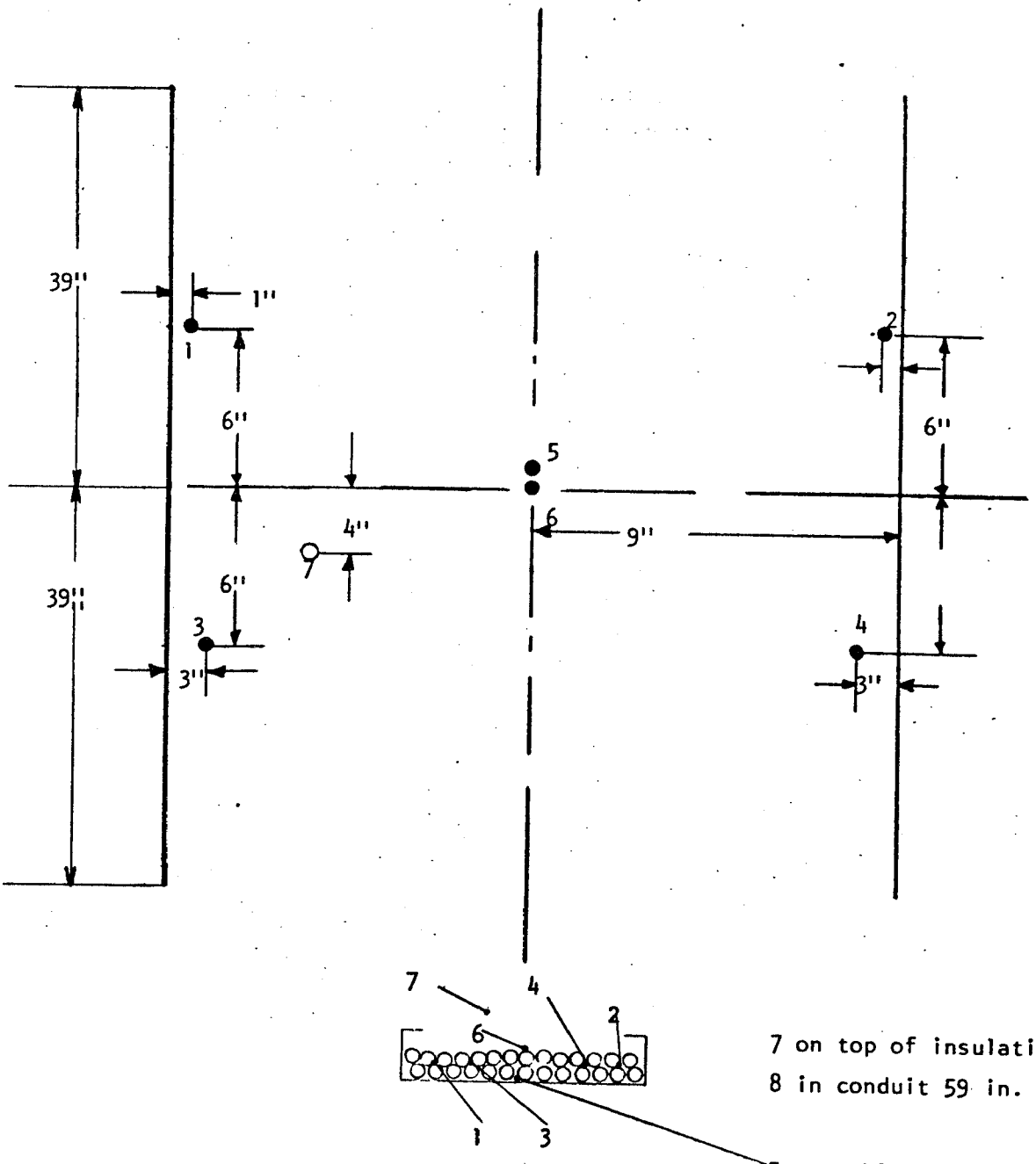
ILL.14
R 8758


TEMPERATURE VERSUS TIME TEST 3
Furnace Temperature
Standard Time temperature Curve ASTM E119
TEMPERATURE, °F
1800
1600
1400
1200
1000
800
600
400
200
0
0 5 10 15 20 25 30 35 40 45 50 55 60 65 70
TIME, MIN.
SYMBOL
THERMOCOUPLE
1
2
3
4
5
6
7
8

ILL.15
R 8758

CABLE TRAY nad CONDUIT THERMOCOUPLE LOCATION

TEST 4

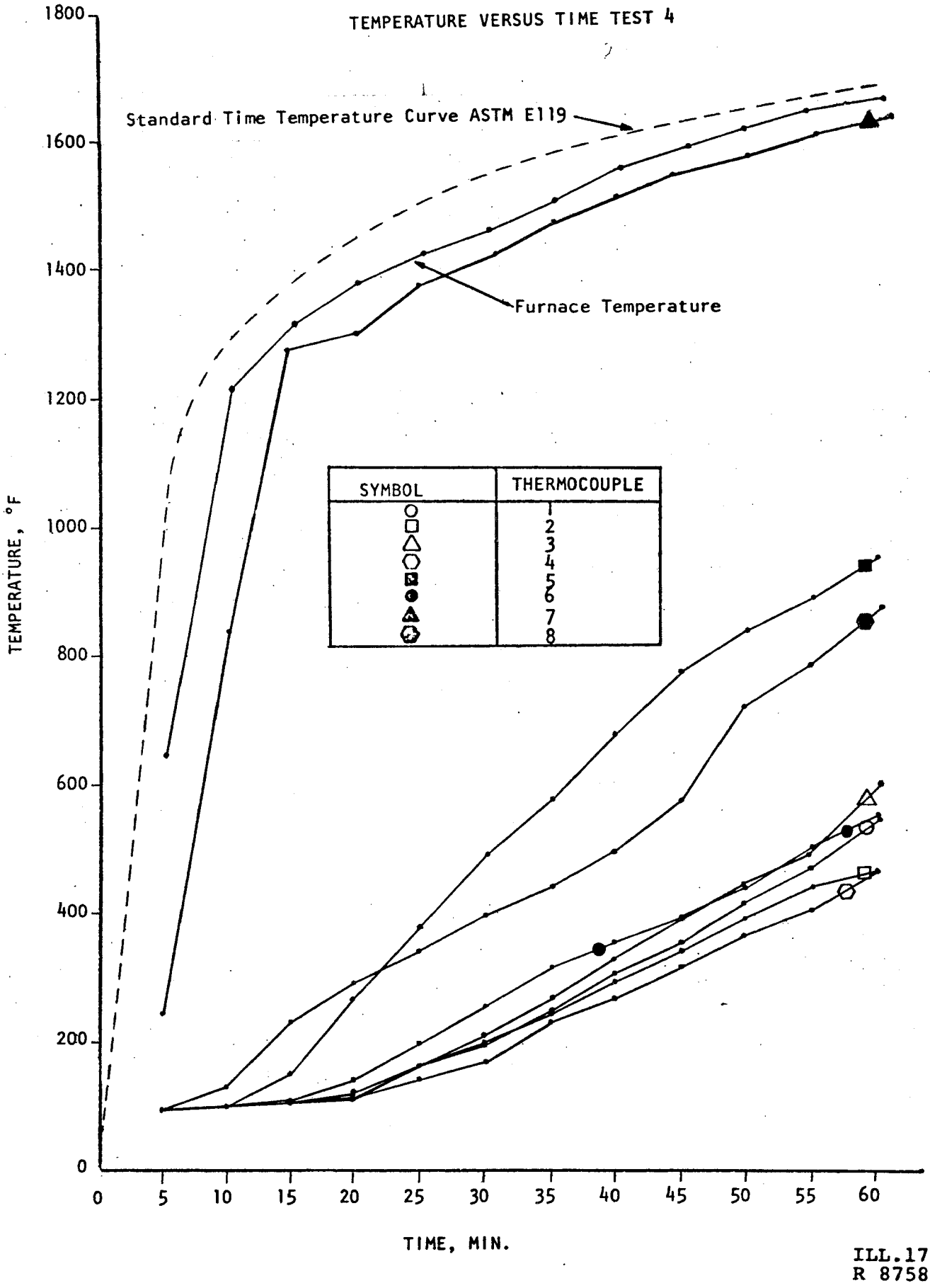


7 on top of insulation

8 in conduit 59 in. from end.

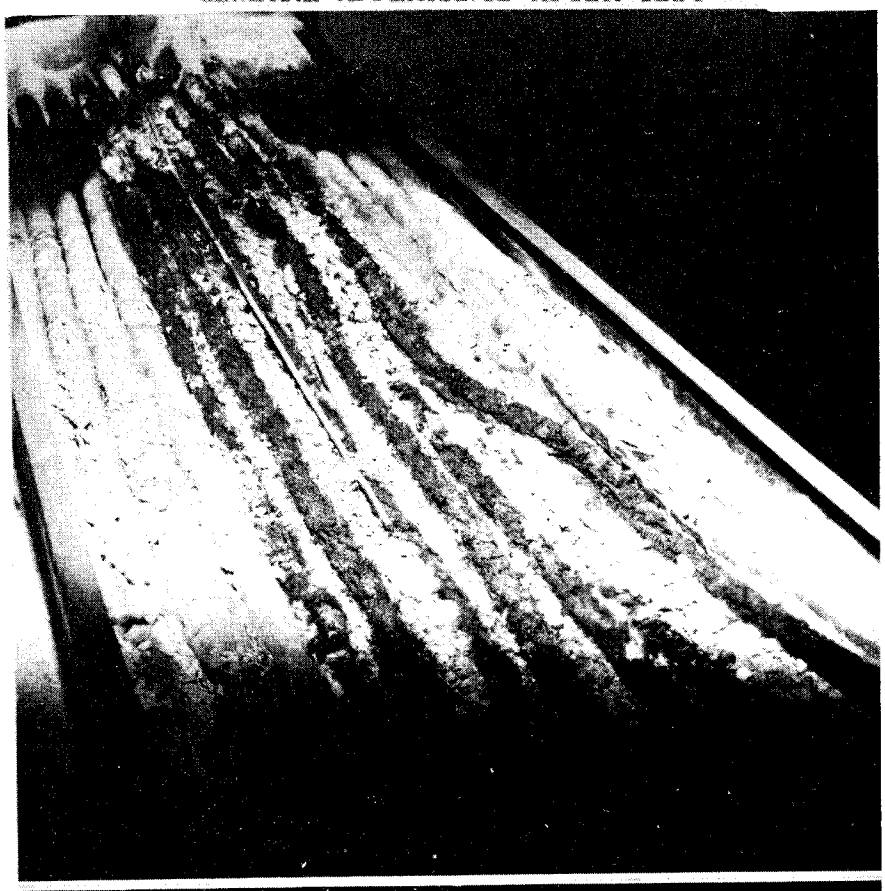
5 on cable tray back center of crest.

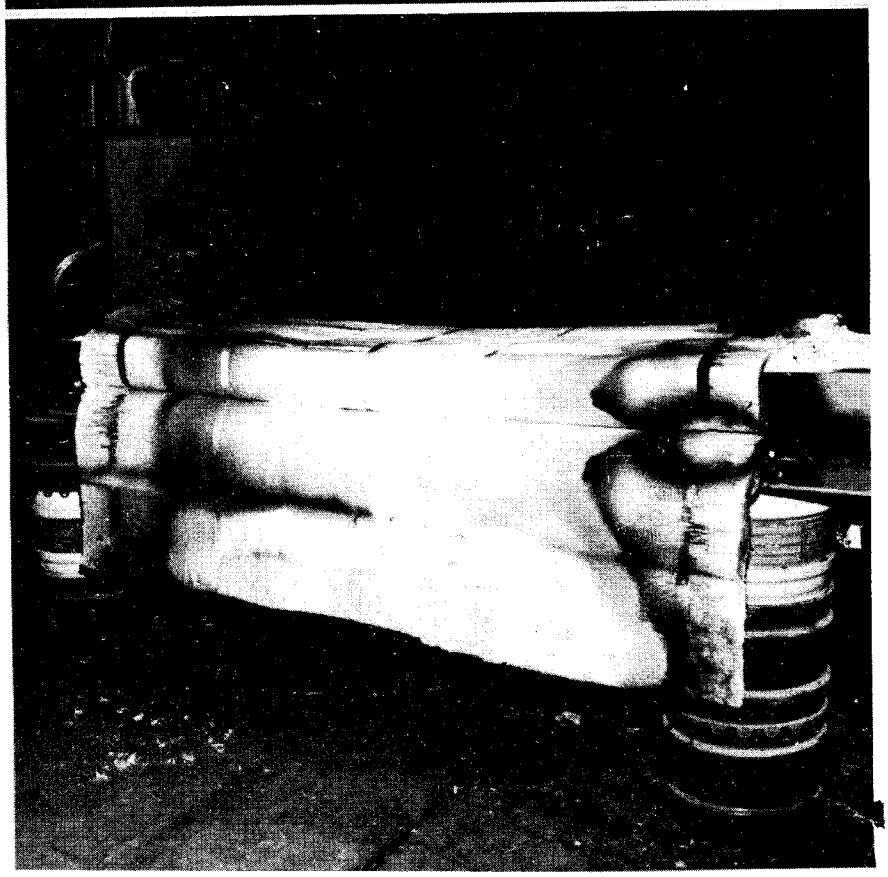
ILL.16
R 8758


TEMPERATURE VERSUS TIME TEST 4
Standard Time Temperature Curve ASTM E119
Furnace Temperature
SYMBOL
THERMOCOUPLE
1
2
3
4
5
6
7
8
TEMPERATURE, °F
1800
1600
1400
1200
1000
800
600
400
200
0
0
5
10
15
20
25
30
35
40
45
50
55
60
TIME, MIN.

ILL.17
R 8758

GENERAL APPEARANCE AFTER TEST

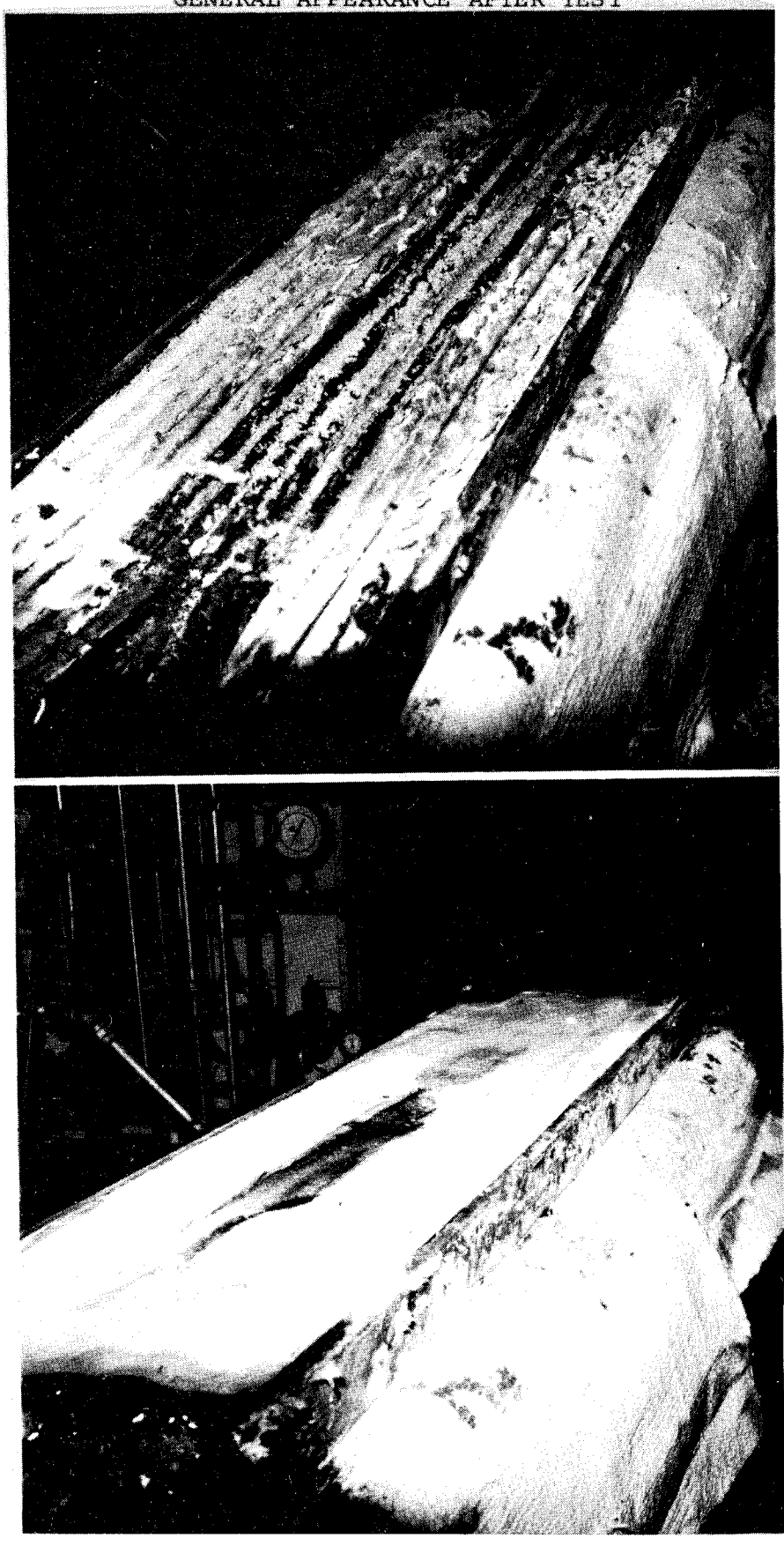




R8758
Ill. 18

C78-11379

GENERAL APPEARANCE AFTER TEST



C78-11378

R8758
Ill. 19