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PARTITIONED CENTAUR TEST TANK

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GENERAL DYNAMICS CONVAIR

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AIR FORCE ROCKET PROPULSION LABORATORY

AIR FORCE SYSTEMS COMMAND

RESEARCH AND TECHNOLOGY DIVISION

EDWARDS AIR FORCE BASE, CALIFORNIA

(147650)

FOREWORD

The Partitioned Centaur Test Tank Program was conducted by the Convair Division of General Dynamics, San Diego, California, under the sponsorship of the United States Air Force Rocket Propulsion Laboratory, Edwards Air Force Base, California. The work was performed as Project No. 3058 and Task No. 305806 under Air Force Contract No. F04611-67-C-0004 dated 15 August 1966, and covers work conducted from 15 August 1966 through 14 March 1967.

The contractor's secondary report number for this report is GDC-BNZ67-027.

This technical report has been reviewed and is approved by:

EDWARD DAHL, 1/Lt, USAF
Project Engineer, RPRPP

ABSTRACT

Presented are results of a program to modify an available Centaur tankage system for testing in the AFRPL Space Environmental Simulation Chamber to determine its thermodynamic suitability for space storability. Results of a detailed thermal analysis predict equilibrium propellant tank net heat rates of 42.09 BTU/hr for the LH_2 tank and 14.56 BTU/hr for the LN_2 tank with corresponding respective boil-off rates of 0.218 lb/hr and 0.169 lb/hr.

TABLE OF CONTENTS

PAGE

Summary viii

1. TEST ARTICLE DESCRIPTION 1

1.1 Pre-Modification 1

1.1.1 Description 1
1.1.2 Tank History 4
1.1.3 Tank Corrosion Study 9

1.2 Modifications (PCTT) 19

1.2.1 Tank Description 21
1.2.2 Adapter Description 24
1.2.3 Cover Plate Description 26
1.2.4 Insulation Description 26
1.2.5 Instrumentation Description 29

2. TEST ARTICLE FABRICATION 35

2.1 Tank Fabrication 36
2.2 Adapters and Cover Plates Fabrication 38
2.3 Insulation Fabrication 46
2.4 Instrumentation 46
2.5 Final Assembly 46

3. TEST ARTICLE DELIVERY 51

3.1 Leak Test 51
3.2 Shipping 55

4. FIELD TEST SUPPORT 60

4.1 Fill & Drain Lines 60
4.2 Instrumentation 60
4.3 Insulation 64

APPENDIX A Functional Limitations

APPENDIX B Space Environmental Thermal Analysis

APPENDIX C Recommended Test Plan

LIST OF ILLUSTRATIONS

FIGURE		PAGE
1-1	Tank Configuration (55-7542)	2
1-2	Partitioned Centaur Test Tank	20
1-3	PCTT Propellant Tank	22
1-4	PCTT Fill & Drain Lines	23
1-5	PCTT Adapters and Covers	25
1-6	PCTT Insulation Installation	27
1-7	PCTT Insulation Details	28
1-8	PCTT Instrumentation	30
1-9	PCTT Instrumentation Schematic	31
1-10	PCTT Instrumentation Junction Block	32
1-11	PCTT Hot-Wire Sensor	33
2-1	Aft Gantry Welder	39
2-2	Partitioning Bulkhead Installation	40
2-3	PCTT Basic Tank	41
2-4	PCTT Adapter Assembly	43
2-5	PCTT Adapter Ring Installation	44
2-6	Forward Adapter Assembly	45
2-7	Forward Adapter Installation	47
2-8	Aft Adapter Installation	48
2-9	Cover Plate Installation	50
3-1	PCTT Support Saddles	56
3-2	PCTT Shipping Installation	58
3-3	PCTT Transportation Pressurization Unit	59

LIST OF ILLUSTRATIONS (Continued)

FIGURE		PAGE
4-1	LH_2 Fill and Vent Line Installation	61
4-2	LO_2 Pressurization Line Installation	62
4-3	LO_2 Fill and Drain Line Installation	63
4-4	Terminal Block Installation	65
4-5	Stand-Off Band (Forward Adapter)	66
4-6	Stand-Off Band (Aft Adapter)	67
4-7	Stand-Off Ring	68
4-8	Cover Plate Insulation	69
4-9	Forward Adapter Insulation	71
4-10	Aft Adapter Insulation	72
4-11	Insulation Installation	73
4-12	Completed Insulation	74

LIST OF TABLES

TABLE		PAGE
1-1	Fatigue Tests on Simulated Tank Joints	14
1-2	Stress Corrosion Cracking Tests	15
1-3	Specimens which were Sectioned to Examine Spotwelds.	16
1-4	Sustained Loading Test	17
3-1	Leak Test Readings	54

SUMMARY

The Partitioned Centaur Test Tank program was conducted by Convair Division of General Dynamics under Air Force Contract F04611-67-C-0004.

The primary objective of this program was to modify an available Centaur tankage system (identified as end item 55-7542) for use in an AFRPL test program to determine its thermodynamic suitability for space storability.

Modifications to the Centaur tankage system consisted basically of the following:

-Cut the vehicle aft of station 219.0 and remove approximately 81 inches of constant section skin.

-Fabricate and install a new partitioning bulkhead for the hydrogen tank.

-Reweld forward bulkhead on to new constant section and install fill and vent lines, covers, etc.

-Fabricate and install two Fiberglas adapters which are 10 feet in diameter and approximately 68 inches long.

-Fabricate and install two 10 foot diameter Fiberglas cover plates.

-Fabricate and install one hot wire sensor, six platinum resistance type thermometers and approximately 52 copper constantan thermocouples.

-Super-insulate the entire vehicle with approximately 42 layers of super-temp (Dimplar) insulation.

During the course of the program, four analytical reports were generated; an informal stress analysis report, a recommended test plan, a functional limitations report and a space-environmental thermal analysis.

1. TEST ARTICLE DESCRIPTION

This section contains a description of the Centaur Test Article modified for the Partitioned Centaur Test Tank (PCTT). The section discusses the previous test program conducted on the article and the results of Convair's tank corrosion study program. Also included in Section 1, is a general description of the modifications performed during this program.

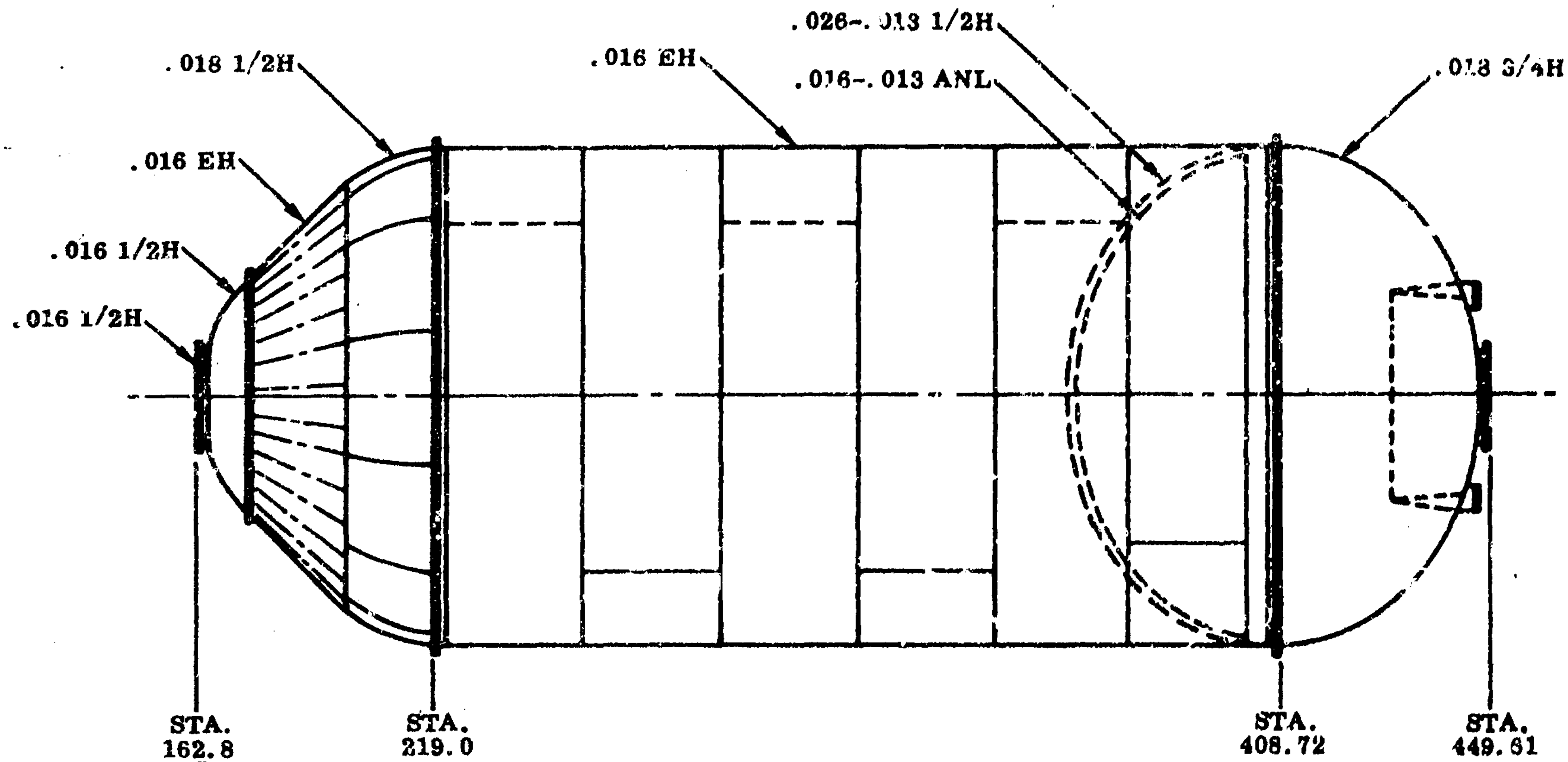
1.1 PRE-MODIFICATION

1.1.1 Description - The Centaur Test Article (Figure 1-1, end item 55-7542) used for construction of the PCTT was a 10 foot diameter, approximately 24 foot long vehicle, fabricated from thin gauge, 300 series, stainless steel material, and was pressure stabilized.

The configuration consists of two propellant tanks (liquid hydrogen and liquid oxygen) separated by a common bulkhead.

The LO_2 tank located in the aft region of the test article consists of an aft bulkhead fabricated from gore section of .018 3/4 hard 301 series stainless steel and a forward (common to the LH_2 tank) bulkhead consisting of a structural member and a non-structural member (spring bulkhead) fabricated from .026 (chem-milled to .013) 1/2 hard 301 stainless steel and .016 (chem-milled to .013) annealed stainless steel, respectively.

The LH_2 tank (Figure 1-1), located forward of the LO_2 tank consists of six cylindrical sections 10 feet in diameter and approximately 33 inches long joined at approximately the tangency point of the LO_2 tank forward bulkhead.



EH = EXTRA HARD
1/2H = HALF HARD
ANL = ANNEALED

NOTE: Station (STA.) is a dimensional reference system with a base (zero station) represented by the apex of the Centaur nose fairing and depicts the location in inches, of various points with respect to station zero.

Fig. 1-1. Centaur Tank Configuration (Un-manned)

The cylindrical skins are constructed from .016 extra hard 301 series stainless steel. Completing the LH_2 tank is a forward bulkhead consisting of two ellipsoidal skin segments fabricated from .016 1/2 hard 301 stainless steel material and a conical section of skin fabricated from .016 extra hard 301 stainless steel material.

Prominent features of the above described configuration are a LO_2 tank volume of 404.76 cubic feet and a LH_2 volume of 1247.98 cubic feet. The LO_2 tank bulkheads are an ellipsoidal shape having a major axis of 120.00 inches and a minor axis of 87.00 inches. The LH_2 tank forward bulkhead geometry consists of an ellipsoidal segment having a major axis of 120.00 inches and a minor axis of 89.90 inches, a 45° cone segment, and an ellipsoidal segment with a major axis of 70.37 inches and a minor axis of 51.04 inches.

Joining techniques on the test article were primarily resistance spotwelds and seamwelds as well as automatic machine heli-arc buttwelds. Joints involving the use of materials above the annealed hardness level using buttwelding techniques are supplemented by the use of doublers.

The 55-7542 test article was highly representative of the Centaur flight configuration for the R & D series. Certain modifications peculiar to the intended test requirements were incorporated. These changes were local in nature involving such things as attachments for incorporating ground testing requirements, instrumentation and test peculiars.

1.1.2 <u>Tank History</u> - The Centaur Test Article (end item 55-7542) has been utilized to support seven major R & D tests on the Centaur program. During the conducting of these tests, the test article was subjected to 69 pressure cycles. Peak pressures in the LH_2 tank ranged from 12.5 psig to 23 psig. LO_2 tank peak pressure ranged from 30 psig to 36.3 psig. Total time pressurized above standby pressure was 95.65 hours in the LO_2 tank and 70.97 hours in the LH_2 tank. A brief description of the areas of interest of these seven major tests is given below.

1.1.2.1 Insulation Panel Fit and Cryogenic Test (July, 1963) - The objectives of this series of tests were to:

1. Perform fit and leak check of the Centaur AC-2 configuration insulation panels.

2. Flight proof test Centaur AC-2 insulation panels under cryogenic conditions.

3. Demonstrate vehicle structural integrity.

The structural integrity of the test vehicle was demonstrated when tank pressures were raised to 36.3 psig LO_2 and 23.0 psig fuel, and helium was injected into the bulkhead cavity at 14.0 psia. This phase of testing (the proof pressure test) was held for three minutes before returning the propellant tanks to the automatic boiloff-valve conditions with LO_2 tank reseat and venting pressures of 14-17 psig, and fuel tank reseat and venting pressures of 4.5-7.5 psig.

A second series of flight proof testing was conducted on the test article in August, 1963. Three fuel tank boiloff valve lockups were performed with cycles ranging from 6.5 psig to 12.5 psig. Two pressure cycles of 23 psig in the fuel tank and 31 psig in the LO_2 tank were also conducted during this series of tests.

1.1.2.2 Centaur Fuel Boiloff Valve Lockup Test (9-21-63 to 10-14-63) - The objectives of this series of tests were as follows:

1. Determine fuel tank ullage pressure rise rate versus time.

2. Demonstrate operational characteristics of the nose fairing skirt heaters air inflatable seal.

3. Measure temperature stratification of the liquid hydrogen above station 215.0.

4. Measure external skin temperature on a dummy Centaur destruct unit and destruct unit arming switch.

5. Measure the external body temperature of the intermediate bulkhead cavity pressure transducer.

6. Determine deflection of two simulated attitude control engine brackets.

7. Evaluate a new cold hydrogen gas purge technique for the fuel tank.

During tanking test number one conducted on 9-21-63, a series of twenty-one boiloff valve lockups were accomplished. Each lockup consisted of closing the fuel boiloff valve and monitoring the fuel tank pressure rise until 27 psia was reached. The fuel boiloff valve was put in the vent position when the fuel ullage pressure reached 27 psia. The LO_2 tank pressure was maintained at 18 $\pm$ 1 psig during all lockup tests. Propellants used for all tests were liquid nitrogen in the aft tank and liquid hydrogen in the forward tank.

During tanking test number two conducted on 10-3-63, a series of sixteen fuel boiloff valve lockups were performed as described in tanking test number one, except three lockups were performed with heat applied to the forward bulkhead coverplate insulation. The nose fairing skirt heaters and the insulation panel forward seal were operated during this test.

Seventeen additional fuel boiloff valve lockup tests similar to the test set up described in tanking test number one were conducted on 10-9-63.

On 10-12-63, a two hour and twenty minute hold period was maintained on both tanks. An identical hold test was also conducted on 10-14-63.

1.1.2.3 Design Evaluation Fill and Drain Outlet Test (10-26-63) - The objectives of this series of tests were:

1. Prove the structural integrity of the Centaur propellant fill and drain outlets by loading to 100% of the design loads.

2. Determine tank wall deflection radially, and propellant fill and drain outlet deflection radially, tangentially and vertically.

On 10-26-63, the structural integrity of the fill and drain outlets was satisfactorily demonstrated with liquid nitrogen in the fuel and LO_2 tanks at 4.5 psig and 15.5 psig, respectively.

1.1.2.4 Hydrogen Peroxide and Helium Bottle Support Structure Test (11-7-63) - The objective of this test was to demonstrate the structural integrity of the hydrogen peroxide and helium bottle support system, when exposed to simulated flight limit loads.

The structural integrity of the hydrogen peroxide and helium support system was successfully demonstrated on 11-7-63 while the vehicle was tanked with liquid nitrogen in both the fuel and oxidizer tank. The fuel tank pressure was maintained at 12 psig and the oxidizer tank at 30 psig.

1.1.2.5 Centaur 3C Structural Test (3-31-64 to 4-11-64) - The objective of this series of tests was to demonstrate the structural integrity of the station 219.0 and 408.0 tank rings when subjected to simulated flight loads that occur during maximum "G" and maximum alpha "Q" conditions.

During the maximum alpha "Q" test of the 219.0 ring, liquid nitrogen was tanked into the fuel and oxidizer tanks at 19.4 psig and 32.0 psig, respectively. Axial compression loads and shear loads representing flight loading conditions at alpha "Q" were applied to the vehicle with subsequent demonstration of the integrity of the station 219.0 ring. A second maximum alpha "Q" test was conducted on the test article the same as above except tank pressures were 33 psig in the oxidizer tank and 20.5 psig in the fuel tank.

During the maximum "G" test of the 219.0 ring, liquid nitrogen was tanked into the fuel and oxidizer tanks at 20.5 psig and 33.0 psig, respectively. An axial compression load was applied to the test article and structural integrity of the station 219.0 ring was demonstrated for this flight loading condition. No shear load was imposed during this test. A maximum "G" test was conducted on the station 408.0 ring similar to that conducted on the 219.0 ring except tank pressures were 34.9 psig in the oxidizer tank and 20.5 psig in the fuel tank.

All above series tests demonstrated the structural integrity of the 219.0 and 408.0 tank rings to withstand flight loading conditions.

1.1.2.6 Centaur-Surveyor Nose Fairing Jettison Test (5-14-64 to 5-23-64) - The objective of this test was to determine whether possible ice or frozen nitrogen, between the forward bulkhead and the nose fairing, impairs separation of the nose fairing from the tank; and to determine whether nose fairing jettison causes damage to the forward tank bulkhead and station 219 ring area.

During this test, the oxidizer tank was tanked with liquid nitrogen at 30 psig and the fuel tank with liquid hydrogen at 20 psig. The nose fairing was unlatched and accelerated away from the test article with thruster bottles. Structural integrity of the test article was maintained during this series of tests.

1.1.3 Tank Corrosion Study - During the research and development phase of the Centaur program, an anomaly was detected in the resistance welding techniques used in the fabrication process of the Centaur tanks. This irregularity was discovered during the radiographic inspection of resistance welds.

Convair was directed under NASA contract NAS3-3232 to study this condition. The major objectives of this study were:

1. Determine the source and causes of spotweld corrosion.

2. Develop methods to inhibit present and future corrosion to Centaur tanks.

3. Development of acceptance standards.

4. Documentation and evaluation of data acquired for application to future corrosion problems.

To meet these objectives, it was necessary to accomplish the following tasks:

1. Re-examine X-rays and develop trend charts.

2. Provide supplementary X-ray data and integrate new data into trend charts.

3. Determine causes, effects, and means of preventing corrosion by laboratory tests and analysis.

4. Effect changes in Centaur tank fabrication standards to inhibit substances inducing corrosion.

1.1.3.1 Corrosion Origin and Formation - The irregularities discovered in the resistance spotwelds on the Centaur tank were identified and classified as corrosion pits and/or corrosion cracks. This corrosion usually appears as either pits in metal caused by corrosion, or cracks formed by corrosion combined with stress in the metal. The corrosion may result from: (1) an acid solution in contact with the metal which attacks the metal directly; (2) an electro-chemical process in which the metal is removed by galvanic action; (3) stress corrosion where the corrosion is initiated by stresses within the metal in the presence of an electrolyte.

Four distinct areas where corrosion may occur in a spotweld are:

1. Parent metal unaffected by the welding.

2. The cast structure or actual weld nugget formed by the molten metal.

3. The heat affected zone.

4. The carbide precipitate zone formed by the precipitation of chromium carbides upon cooling.

Most of the corrosion at the spotwelds begins at the carbide precipitate zone. This may be the result of intergranular corrosion resulting from sensitization. Occurring principally in austenitic stainless steel when it is heated in the range of 900 to 1400°F, sensitization results from precipitated chromium carbides at the grain boundaries, chromium depletion in zones adjacent to those boundaries, and a difference in solution potential between the center of the grains and their outer chromium zones.

The condition described previously can result in the appearance of pits and/or cracks. These cracks have been found to be both intergranular and transgranular and are similar in appearance to cracks produced by stress corrosion. They appear to originate as pits and form cracks due to stresses set up during metal cooling. The cracks could originate as micro-cracks, produced during welding operations, which were attacked and opened up by a corrosive fluid in the faying surface. This fluid may be one of the corrosive processing fluids which became trapped between the faying surfaces before or after the sheets were spotwelded. Corrosion may also have been initiated by non-corrosive solutions combining with salt or other dry corrosive elements, which settled from the atmosphere during tank build-up, forming electrolytes or corrosive solutions.

During the course of the investigation, it was discovered that certain metal marking fluids were also a possible source of corrosion initiation.

1.1.3.2 Extent and Growth of Corrosion - The fabrication process used on the Centaur tank incorporates approximately 75,000 spotwelds. Approximately 22,000 are used during the forward bulkhead build-up, approximately 24,000 are incorporated in the fabrication of the cylindrical section of the tank, and approximately 29,000 are used in the construction of the aft tank.

The aft bulkhead of the aft tank appears to show the greatest amount of corrosion. This is attributed to the aft bulkhead possessing more doublers than in other areas and, consequently, more spotwelds and more areas for collection of corrodents.

The corrosion on Centaur tanks affected a small percentage of the total spotwelds. The maximum amount of corrosion on any Centaur flight tank was 1.25 percent of all spotwelds examined, with most tanks showing corrosion of less than one percent.

Charts showing crack growth versus time were prepared and monitored for several tanks over a time period of one year. The data for these charts was collected by identifying each crack noted on the X-ray and measuring the length. This type of examination generally showed that the cracks seldom grew in length.

Charts showing the increase in total number of pits and/or cracks versus time were also prepared and monitored for a time period of one year. Results indicated that after a 4 month time period essentially no new cracks or pits were discovered.

1.1.3.3 Effects of Corrosion on Structural Capability - To determine the effects of corrosion on the load carrying capability of resistance welded structures, a test program was initiated as follows:

1. Perform stress corrosion testing on approximately 40 specimens for six months under a continuously applied load equivalent to 20,000 psi stress.

2. Corroded and non-corroded control specimens were subjected to cyclic fatigue loading equivalent to from 0 to 135,000 psi stress. Other specimens were exposed to sustained loadings equivalent to 135,000 psi stress for 16 hours followed by sustained loading equivalent to 160,000 psi stress for 16 hours. All tests were conducted at -320°F or -423°F as applicable.

Corrosion was induced into 4 inch x 4 inch welded specimens by the application of electroetch 260A together with an applied stress. Cracks and pits representative of those found in Centaur tanks were produced.

Fatigue tests of simulated tank joints were conducted at both -320°F and -423°F. These specimens were cycled for 200 cycles while subjected to a stress level from 0 to 135,000 psi, then checked for leaks. Simulated LO_2 tank joints were then cycled, (under temperature exposures of -320°F), from 0 to 160,000 psi stress levels until failure occurred; and simulated LH_2 tank joints were cycled, (under temperature exposures of -423°F), from 0 to 135,000 psi stress levels until they failed. Results of these tests are shown in Table 1-1.

Welded test specimens were tested with various corrodents and subjected to sustained loadings at the 20,000 psi stress level. The corrodents used, the resultant corrosion determined by X-ray examination, and the duration of the tests are shown in Table 1-2. None of these specimens failed under test. Sections were made of the more severely corroded specimens which, upon examination, showed the apparent cracks to be elongated pits as shown in Table 1-3.

1.1.3.4 Sustained Flight Load Test - Several simulated Centaur joint specimens were corroded and tested at simulated flight loads. This program consisted of applying a tension load equivalent to 135,000 psi for 16 hours. Three times during the test the load was reduced to zero, simulating the variation of load in flight. After the 135,000 psi exposure, the stress level was increased to 160,000 psi and sustained for 16 hours. The load was relaxed three times as before. Conditions and results of this test are presented in Table 1-4.

TABLE 1-1 FATIGUE TESTS ON SIMULATED TANK JOINTS

Code I.D.	Specimen Matl. & Gage	Specimen Conditions	Test Conditions: Stess	Test Cycles	Cycles To Failure	Test Temp. °F	Remarks
E-1	301 3/4 H .020	Corroded	135	200		-320	No leaks
			160		382		Failed on first row of spot welds
E-2		Corroded	135	200			No leaks
			160		810		Failed on first row of spot welds
E-3		Corroded	135	200			No leaks
			160		406		Failed on first row of spot welds
C-1		Uncorroded	135	200			No leaks
			160		397		Failed on first row of spot welds
C-2	301 3/4 H .020	Uncorroded	135	200		-320	No leaks
			160		406		Failed on first row of spot welds
C-3	301 XFH .016	Uncorroded	135	200		-423	No leaks
			135		413		Failed on first row of spot welds
C-4		Uncorroded	135	200			No leaks
			135		440		Failed on first row of spot welds
E-4		Corroded	135	200			No leaks
			135		371		Failed on first row of spot welds
E-5		Corroded	135	200			No leaks
			135		393		Failed on first row of spot welds
E-6	301 XFH .016	Corroded	135	200		-423	No leaks
			135		316		Failed on first row of spot welds

NOTE:

1. Specimens E-1, E-2, E-3, C-1 and C-2 were cycled 200 times at 135 ksi and leak checked; stress was then increased to 160 ksi for additional cycles as indicated.

2. Specimens C-3, C-4, E-4, E-5 and E-6, were cycled 200 times at 135 ksi and leak checked. Cycling was then continued to failure for a total number of cycles as indicated.

TABLE 1-2 STRESS CORROSION CRACKING TE

Specimen No.		Corrodent I	Corrodent II	Corrodent Application Schedule (No. of Times/Week)		Start D		
I	II			I	II	I		
A	*	2611A		Initial		9	8	
B		2611A		2		9	8	
701		2611A		Note 1		4	28	
702		2611A		Note 1		4	28	
C	*	260A		2		9	8	
718		260A		Note 1		4	28	
719		260A		Note 1		4	28	
D		E No. 1 (Initial 260A)		2		9	8	
S		E. No. 1		2		11	2	
720		E. No. 1		Note 1		4	28	
721		E. No. 1		Note 1		4	28	
722		B10		Note 1		4	28	
723		B10		Note 1		4	28	
G		Tec 901 + Mill Marking Ink		Initial		9	8	
H	*	Tec 901 + Mill Marking Ink		2		9	8	
726		Tec 901 + Mill Marking Ink		Note 1		4	28	
727		Tec 901 + Mill Marking Ink		Note 1		4	28	
I	W	Tec 901/CB MX 8-D.I. H_2O	Tech 902 + Mill Marking Ink	Initial	2	9	8	11
J		Tec 901/CB MX 8-D.I. H_2O		2		9	8	
M	U	Tec 901	Trichloroethylene	Initial	2	9	8	11
N	V	Tec 901	Tric. + Mill Marking Ink	2	2	9	8	11
O		Tec 902		2		9	8	
728		Tec 902		Note 1		4	28	
729		Tec 902		Note 1		4	28	
732		Trichloroethylene		Note 1				
734		Oxylene		Note 1				
E		Red X Bubble Fluid		Initial		9	8	
F		Red X Bubble Fluid		2		9	8	
724		Red X Bubble Fluid		Note 1		4	28	
725		Red X Bubble Fluid		Note 1		4	28	
P	*	Dykem Ink		2		9	8	
730		Dykem Ink		Note 1		4	28	
731		Dykem Ink		Note 1		4	28	
733		Monode APC Cleaner		Note 1				
K		Control (Not Cleaned)				9	8	
L	*	Magnesium Chloride (42 Wt%)		2		9	8	
7		B10		2		3	3	
8		B10A		2		4	13	

NOTE: 1. 7XX, Specimens prepared from 301 CRES 0.018 in. 3/4 H corrodent added initially and after t

3. * Indicates specimens which were sectioned. See Table 5-2 for results.

SION CRACKING TEST

ent tion le (es/Week)	Start Date				Corrodent Application Stopped				Test Terminated				Radiographic Analyses Days from Start Date (Total Corrosion Pits and Cracks)											
													I								II			
II	I		II		I		II		I		II		14	22	44	52	66	84	141		11	13	68	70
	9	8			11	13			1	27				17	49		63		64					
	9	8			10	27			10	28				28	55									
	4	28											0											
	4	28											0											
	9	8			11	13			1	27				34	49		56		64					
	4	28											0											
	4	28											0											
	9	8			11	13			1	27				29	58		61		64					
	11	2			12	1			1	27			3		14			18						
	4	28											0											
	4	28											0											
	4	28											0											
	4	28											0											
	9	8			11	13			11	13				1	4		4							
	9	8			11	13			1	27				6	12		19		19					
	4	28											0											
	4	28											0											
2	9	8	11	20			12	1	11	13	1	27		0	0		0				0		0	
	9	8			11	13			11	13				0	0		0							
2	9	8	11	18	11	13	12	1	11	13	1	27		0	0		0					0		1
2	9	8	11	18	11	13	12	1	11	13	1	27		0	0		0					0		0
	9	8			11	13					1	27		0	0		0		0					
	4	28											0											
	4	28											0											
	9	8							11	13				0	0		0	0	0					
	9	8			11	13			1	27				0	0		3		3					
	4	28											0											
	4	28											0											
	9	8			11	13			1	27				0	9		[illegible]		8					
	4	28											0											
	4	28											0											
	9	8							1	27				0	0		0		0					
	9	8			11	13			1	27				46	52		52		52					
	3	3			3	17										0			0					
	4	13			4	27							0					0						

tially and after two weeks. 2. Other specimens prepared from 301 CRES 0.010 in. XH

2

TABLE 1-3 SPECIMENS WHICH WERE SECTIONED TO EXAMINE SPOTWELDS

Code No.	Corrodent	Beginning of Test	Date of Last X-Ray to be Evaluated	Duration of Evaluation Period (Days)	Corrosion as Indicated by X-Ray		Number of Spotwelds Examined (By X-Rays)	Results From Sectioning*
					Pits	Cracks		
A	2611A Lectroetch	9/8/64	1/27/65	141	3	61	64	Sections showed only pits and elongated - pits, no cracks
C	260A Lectroetch	9/8/64	1/27/65	141	8	56	64	
H	Tec 901 + Mill marking ink	9/8/64	1/27/65	141	3	16	64	
L	Magnesium Chloride (42% by wt)	9/8/64	1/27/65	141	0	52	52	
P	Dyechem Ink	9/8/64	1/27/65	141	0	8	18	
S	E No. 1 Lectroetch	11/2/64	1/27/64	86	7	11	18	
PML 1, 2,3	2611A Lectroetch	7/29/64	10/26/64	89	17	29	204	
PML 20	260A Lectroetch	8/7/64	10/26/64	80	8	30	68	
PML 174	2611A Lectroetch	11/24/64	1/12/65	49	12	18	68	

NOTE: 1. Numbered Specimens were corroded at 100% R.H. while stressed to 20 ksi.

2. Lettered Specimens were corroded at outside air environment under no load.

3. Between one and four welds in each specimen were sectioned and examined.

TABLE 1-4 SUSTAINED LOADING TEST

Code I.D.	Specimen Matl. & Gage	Corrodent Used	Level ksi	Duration hr	** Method	Temp	Corrosion* Start 1/6/65 P	Corrosion* Start 1/6/65 C	Corrosion* Finish 1/15/65 P	Corrosion* Finish 1/15/65 C	Corrosion* Total Spots Examined	Remarks
1	EH Type 301 CRES .010	None	135 160	16 16	3 3	-320	0 0	0 0	0	0	68	Control Specimens No failure
2		None	135 160	16 16	3 3		0 0	0 0	0 0	0 0		
3		None	135 160	16 16	3 3		0	0	0	0		No failure
4		Lectroetch #260A	135 160	16 16	3 3		17	26	15	41		No failure
5		Lectroetch #260A	135 160	16 16	3 3		13	22	16	37		
6		Lectroetch #260A	135	16	3		6	22	17	26		

* Legend

P - Pits

C - Cracks (By X-ray evaluation)

**Load reduced to zero three times.

1.1.3.5 Special Test - From November 2, 1962, to December 15, 1962, special tests were conducted on the forward bulkhead of test tank 55-7534-1 in order to evaluate the structural integrity of installed plugwelds. A total of 101 pressure cycles at full flight pressures were conducted. These tests were conducted at the Convair Point Loma facility where the tank was subjected to salt air environment. Although 40 percent of the spotwelds examined showed corrosion, no failure occurred during testing. This tank was similar to flight tanks but had been subjected to considerably more load cycles and more severe corrosion.

1.1.3.6 Corrosion Study Conclusions - The following conclusions on the effects of corrosion on tank structural integrity, cause of corrosion, extent of corrosion, and methods of preventing corrosion are presented.

1. Moderate to severe corrosion causes a decrease of approximately 3% in the static strength of tank joints when tested in tension at -320°F and -423°F.

2. The fatigue strength when cycled 0 - 135,000 psi at -320°F and -423°F of such corroded joints is insensitive to moderate corrosion when compared with uncorroded specimens.

3. Based on available data, the fatigue strength (0 - 160,000 psi) at -320°F and -423°F of moderately corroded specimens is not lowered.

4. Spotweld corrosion is caused by corrosive solutions entrapped between the faying surfaces of spotwelded joints.

5. The corrosion on Centaur tanks affected a small percentage of the total spotwelds. The maximum amount was 1.25 percent of all welds examined.

6. Corrosion cracks seldom increase in length over extended time periods.

7. Application of corrosion inhibitors, such as WD-40, to all outside tank surfaces immediately following fabrication is desirable.

1.2 MODIFICATIONS (PCTT)

The Partitioned Centaur Test Tank (PCTT), Figure 1-2, article consists essentially of the following:

1. A stainless steel tankage system containing a liquid oxygen tank, an intermediate tank volume, and a forward liquid hydrogen tank.

2. A forward and aft Fiberglas adapter.

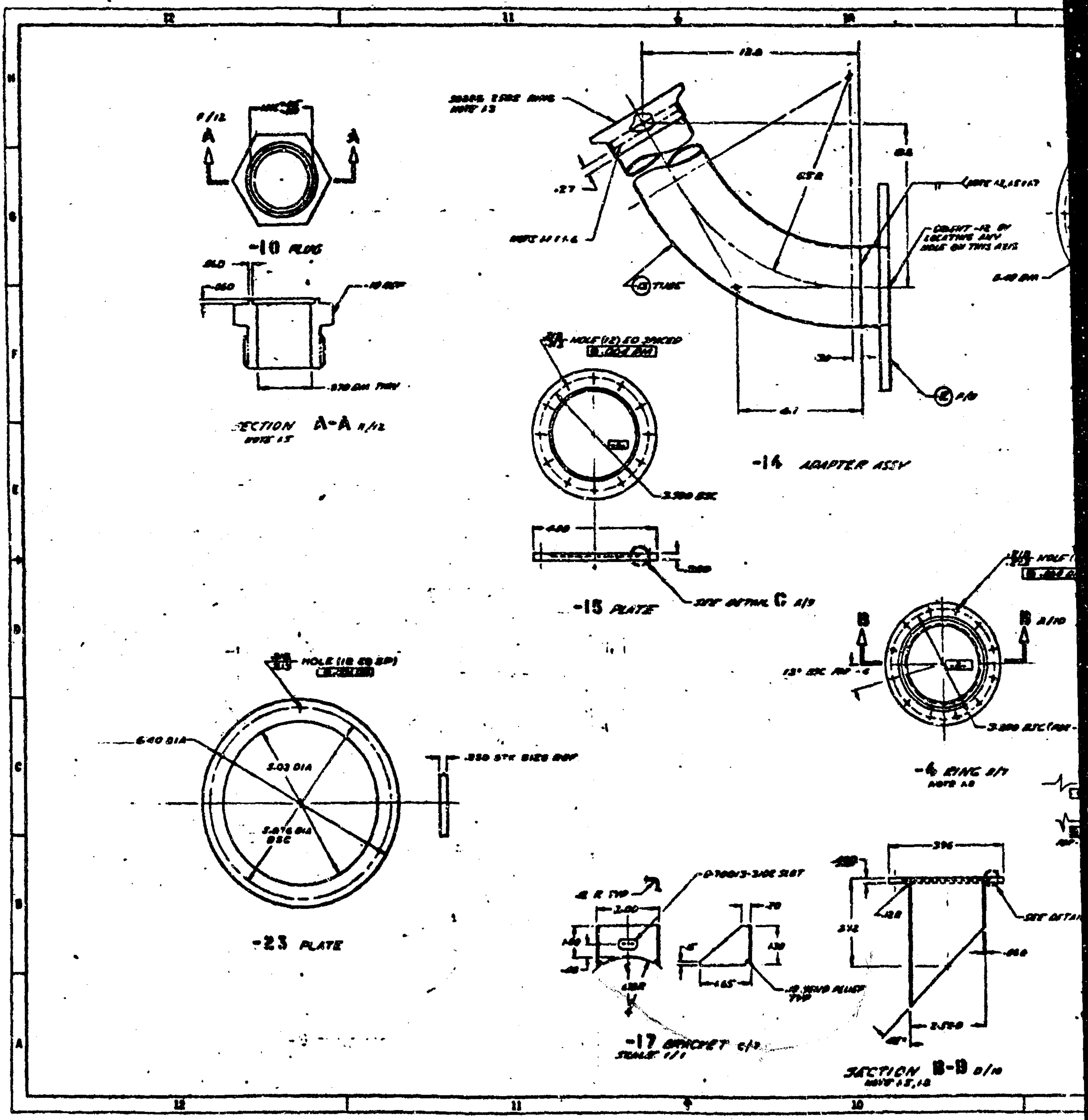
3. A forward and aft Fiberglas cover plate.

4. Propellant fill and drain lines and pressurization lines.

5. An instrumentation system.

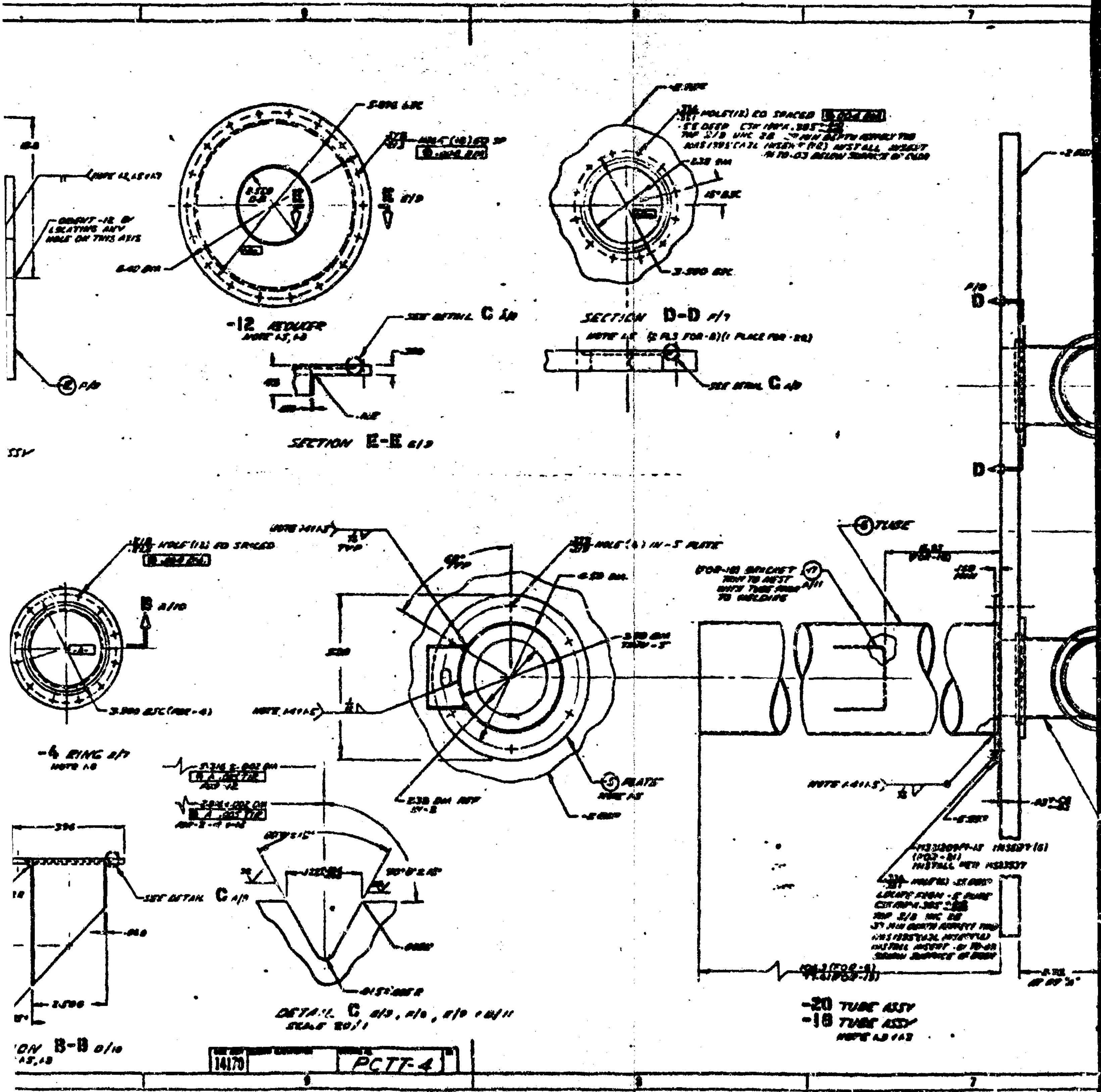
6. A thermal control (superinsulation) system.

The complete test article is 10 feet in diameter, approximately 20 feet long and has a total empty weight of approximately 3,300 pounds. The nominal volume of the LH_2 tank is 440 cubic feet and the nominal volume of the LO_2 tank is 408 cubic feet.

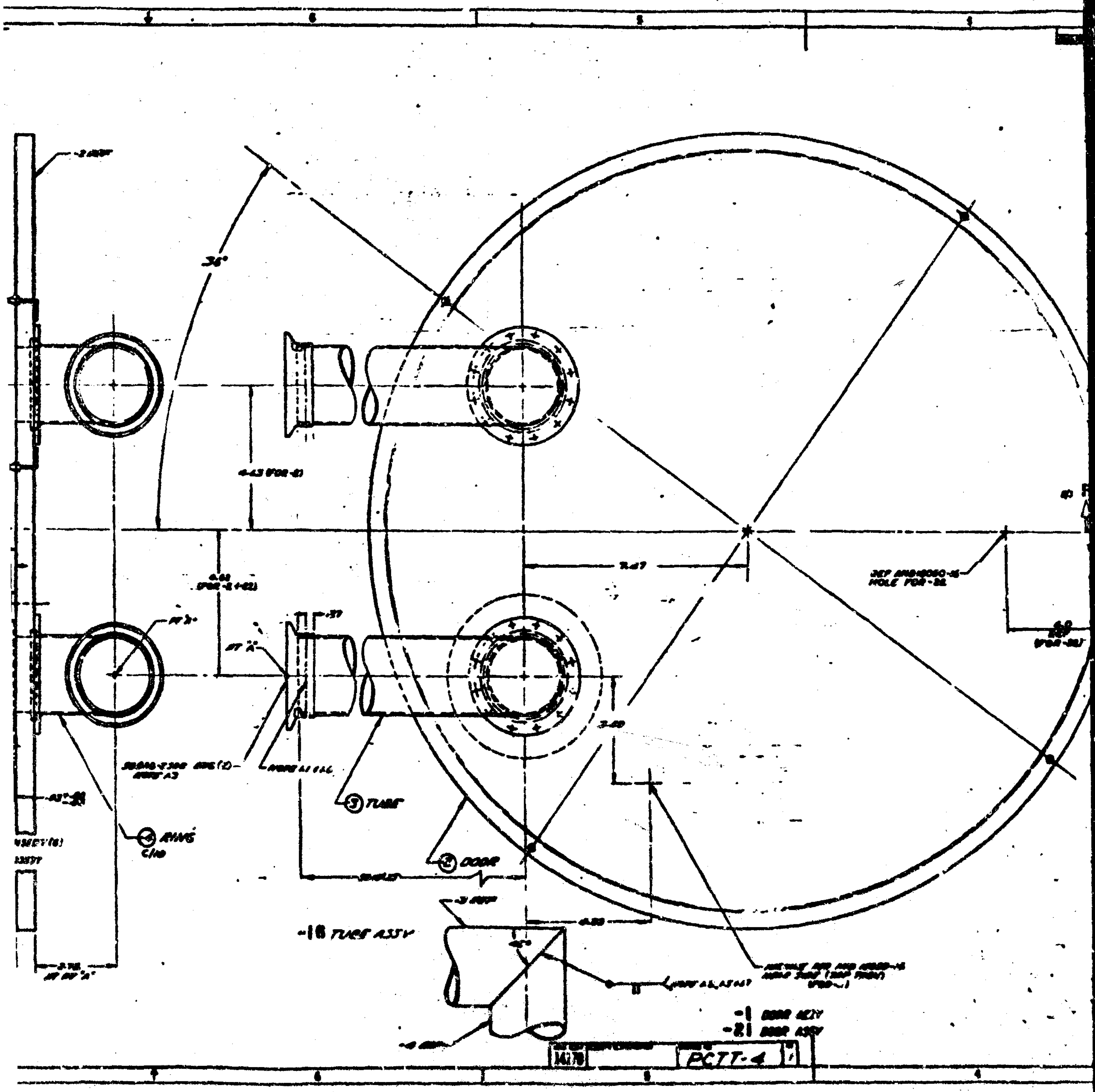


-10 PLUG
SECTION A-A
-14 ADAPTER ASSY
-15 PLATE
-23 PLATE
-4 RING
-17 BRACKET
SECTION B-B

FIG 1-4


-12 REDUCER
SECTION D-D
SEE DETAIL C
SECTION E-E
-4 RING
DETAIL C
SCALE 20/1
-20 TUBE ASSY
-18 TUBE ASSY
TUBE
PLATE
SECTION B-B
14170
PCTT-4

J



36°
4.43 (FOR -21)
7.47
REF AN810050-16 HOLE FOR -32
③ TUBE
④ RING
② DOOR
-18 TUBE ASSY
-1 DOOR ASSY
-21 DOOR ASSY
45°
14170
PCTT-4

3

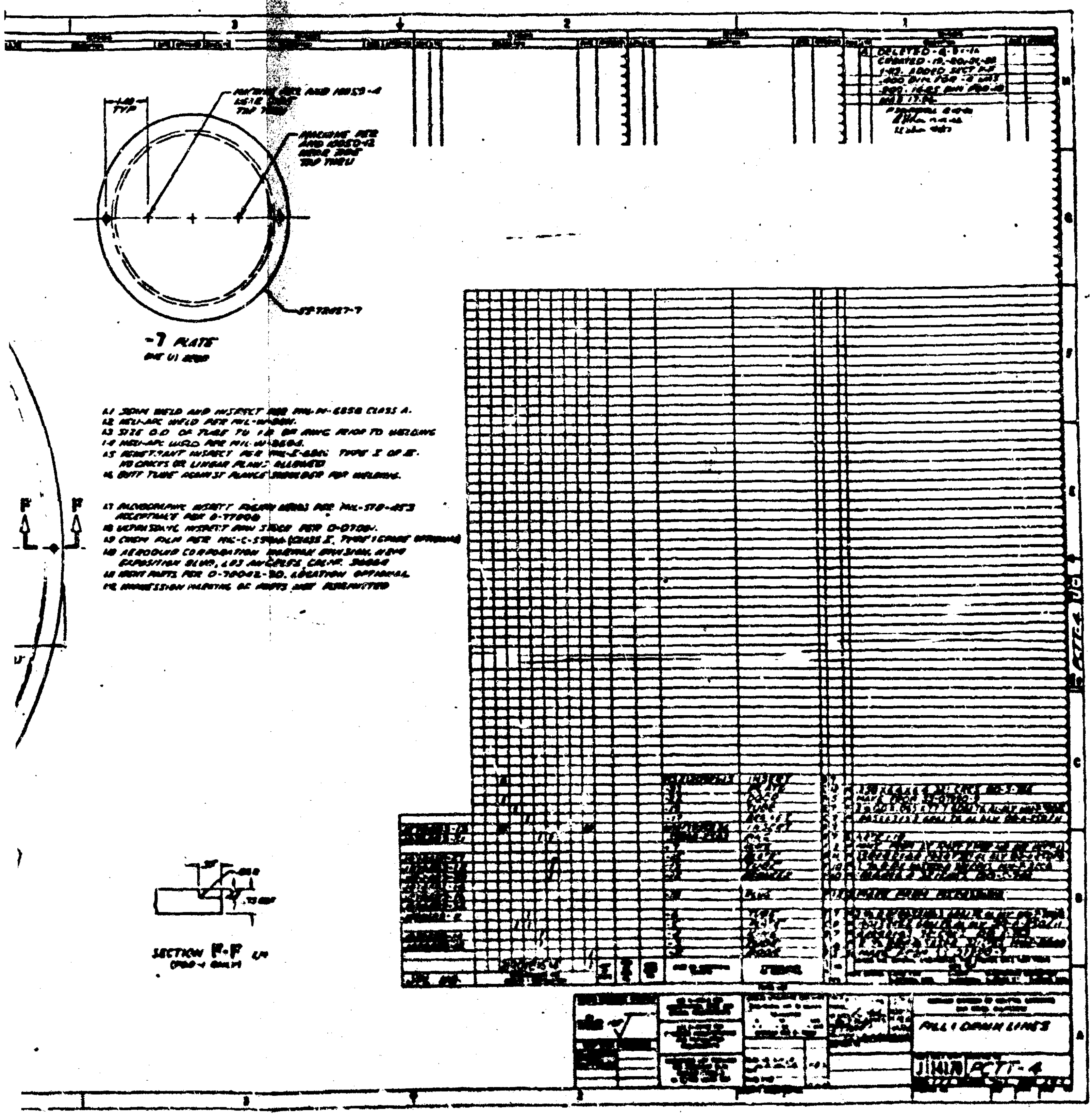


Fig. 1-2 Partitioned Centaur Test Tank

1.2.1 <u>Tank Description</u> - The Partitioned Centaur Test Tank (PCTT), Figure 1-3, is a 10 foot diameter approximately 17-1/2 foot long tankage system, designed to use thin gauge, 300 series, stainless steel material, and is pressure stabilized. The tank only weight is approximately 1,400 pounds. The LO_2 tank was not modified from its original configuration defined in Section 1.1.1. The liquid hydrogen tank and intermediate tank were formed by removing approximately four feet of cylindrical section skin and adding a new LH_2 tank aft bulkhead as shown in Figure 1-2. The new bulkhead is made from eleven .020 half hard, 301 series, stainless steel, gore sections. These gore sections are machine heli-arc buttwelded to form the completed bulkhead. Resistance spotwelding and seamwelding and machine heli-arc buttwelding are used throughout for joining techniques.

Fill and vent and pressurization lines have also been provided for in the PCTT; see Figures 1-2 and 1-4. The LH_2 tank fill and drain line consists of a 3-1/2 inch diameter, .065 gauge, standpipe made from 6061 T6 aluminum alloy internally mounted to the LH_2 tank forward cover and a 2-1/2 inch diameter, .065 gauge, 321 stainless steel outside line extending from the top of the LH_2 tank forward cover plate out through the forward adapter for a length of approximately 6 inches. Flanges at the cover plate of these lines incorporate a metal "O" ring seal and are bolted to the cover plate. A Conoseal type flange is provided for on the line which interfaces with the AFRPL facility line. The LH_2 tank pressurization line is made from 2-1/2 inch diameter, .065 gauge, 321 stainless steel material and extends from the top of the LH_2 tank cover plate, out through the forward adapter, in approximately the same radial location as the LH_2 fill and drain line. It incorporates the

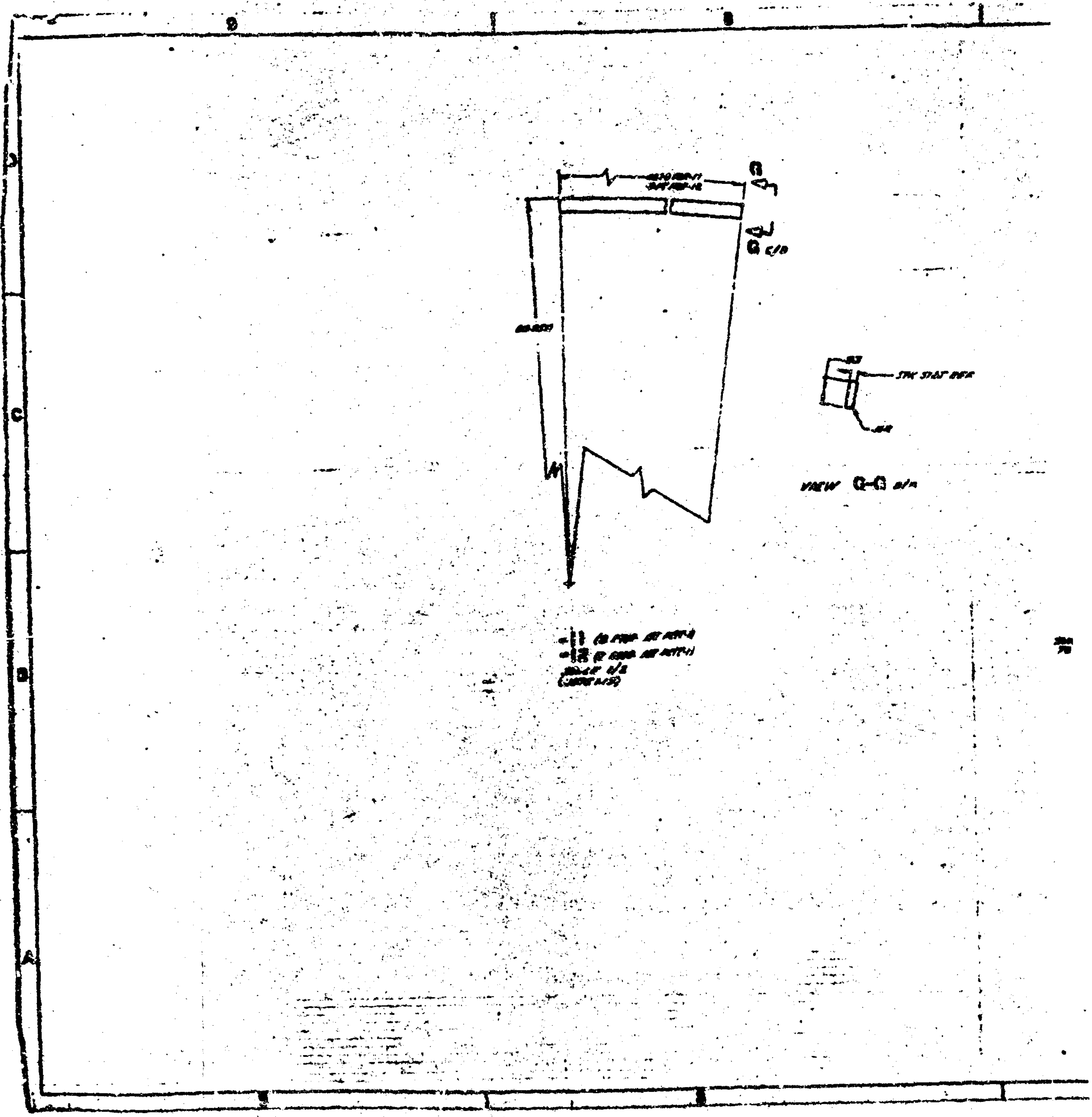
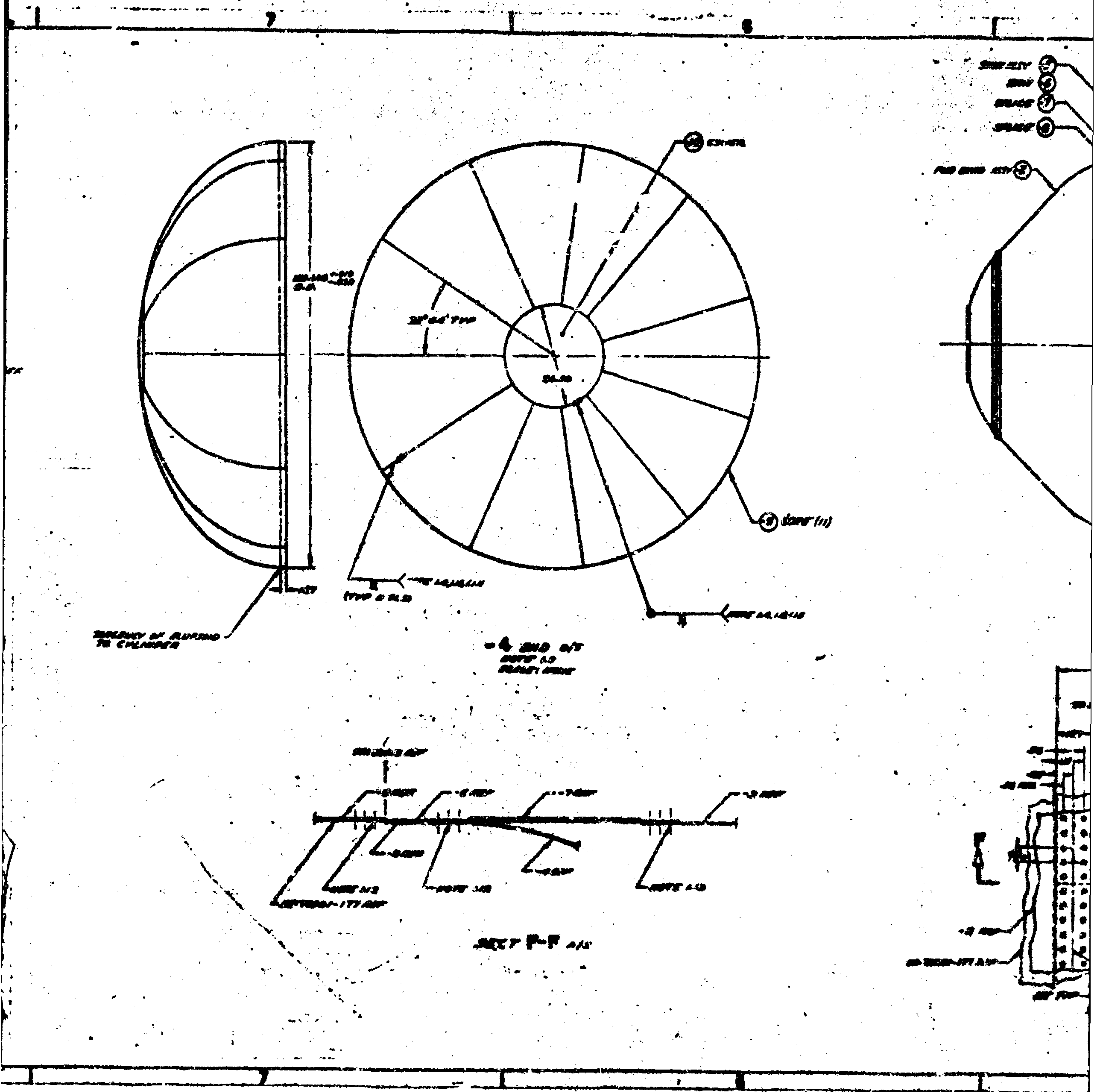
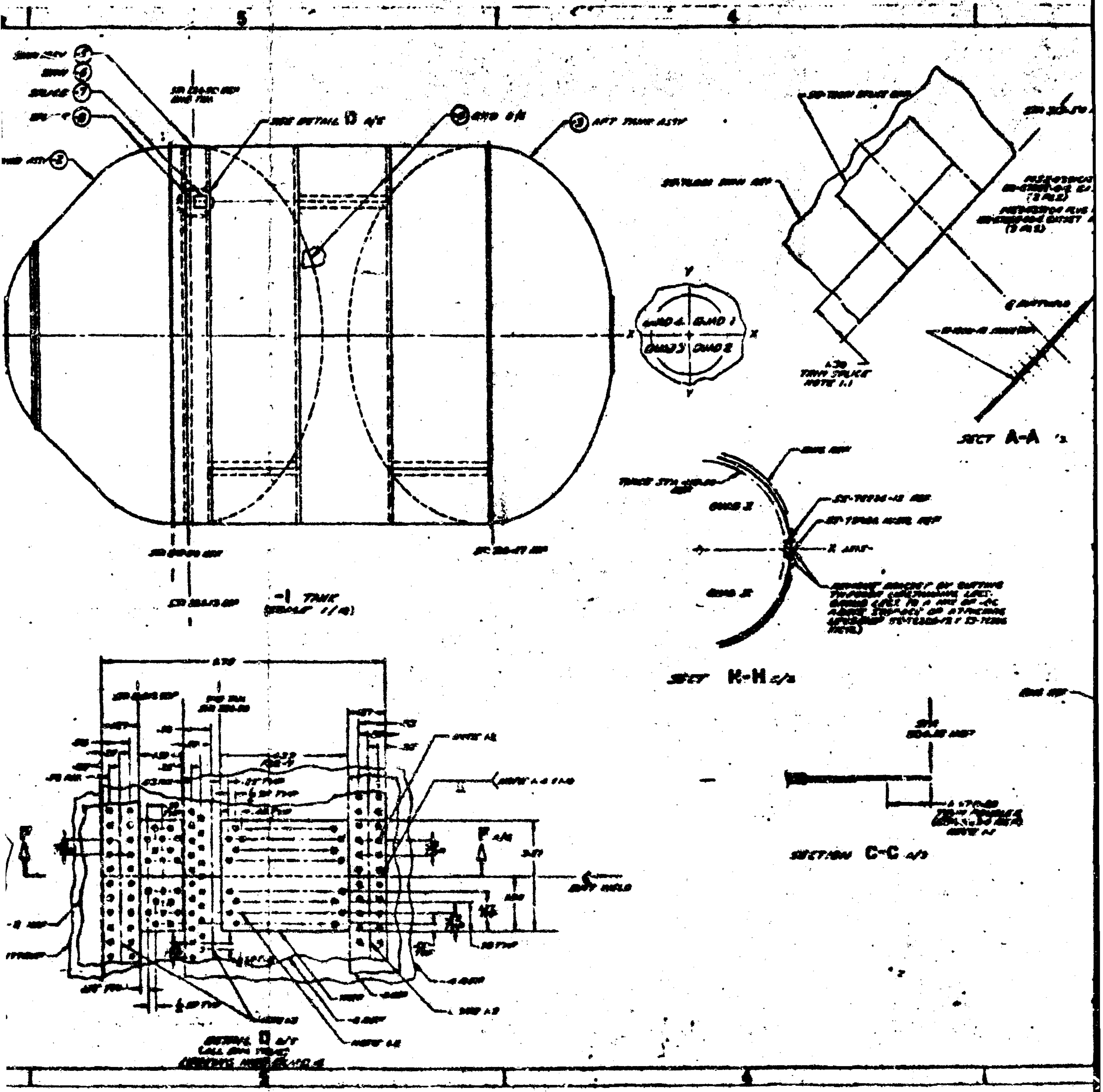


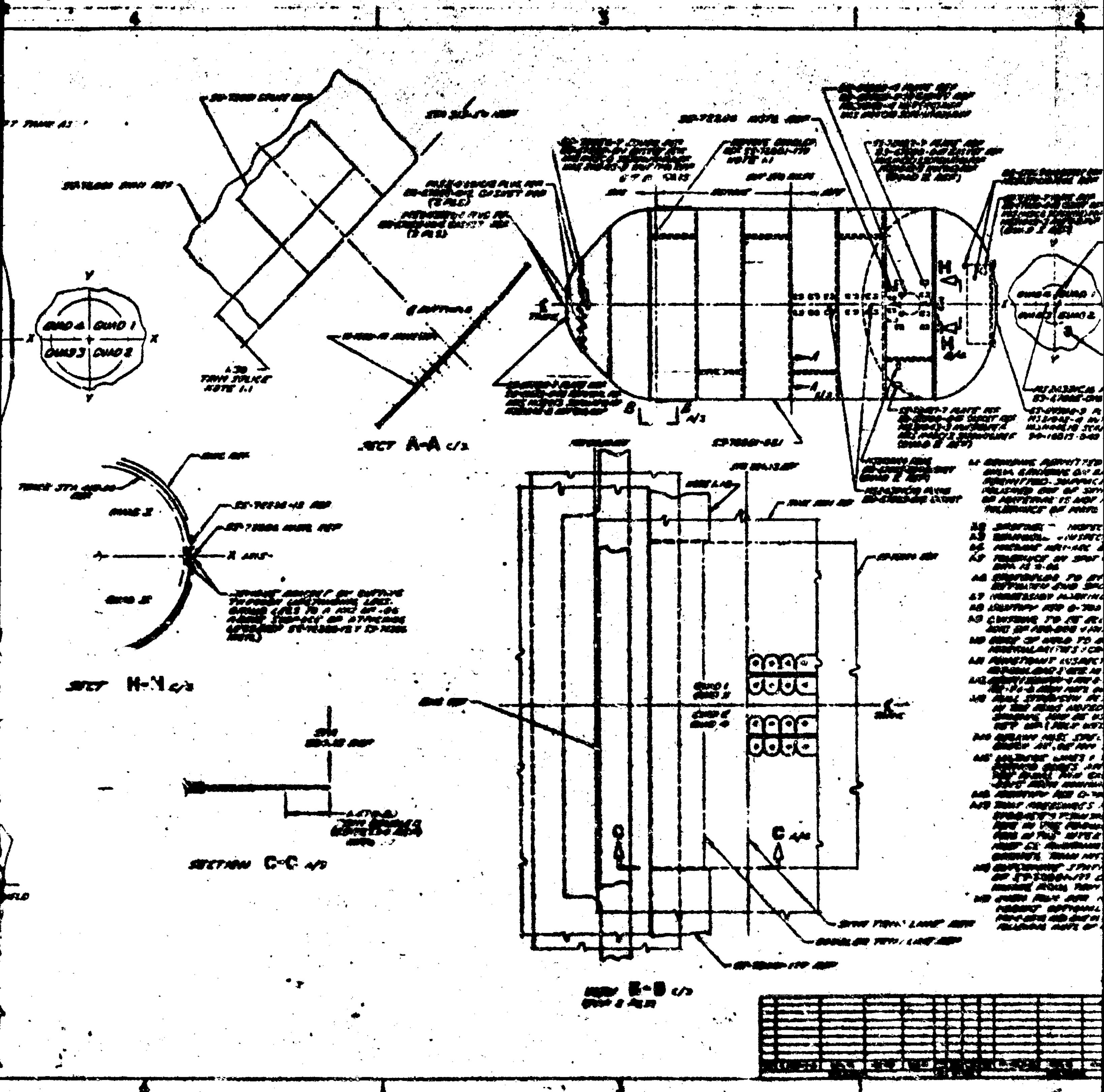
FIG 1-3



g



-1 TANK
QUAD 4
QUAD 1
QUAD 3
QUAD 2
SECT A-A
SECTION C-C



QUAD 4
QUAD 1
QUAD 3
QUAD 2
SECT A-A C/3
SECT H-H C/3
SECTION C-C A/3
VIEW B-B C/3

4

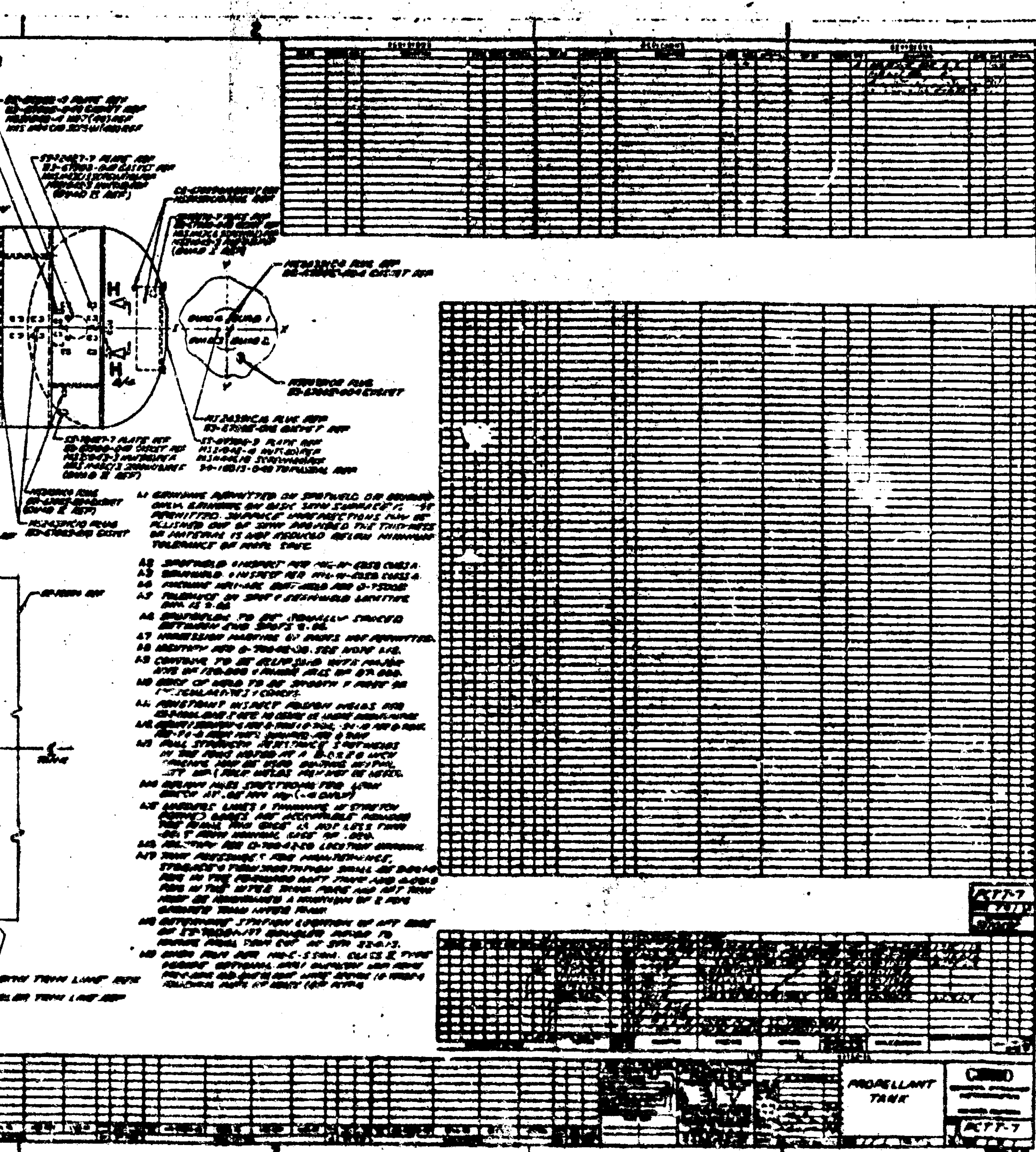


Fig. 1-3 PCTT Propellant Tank

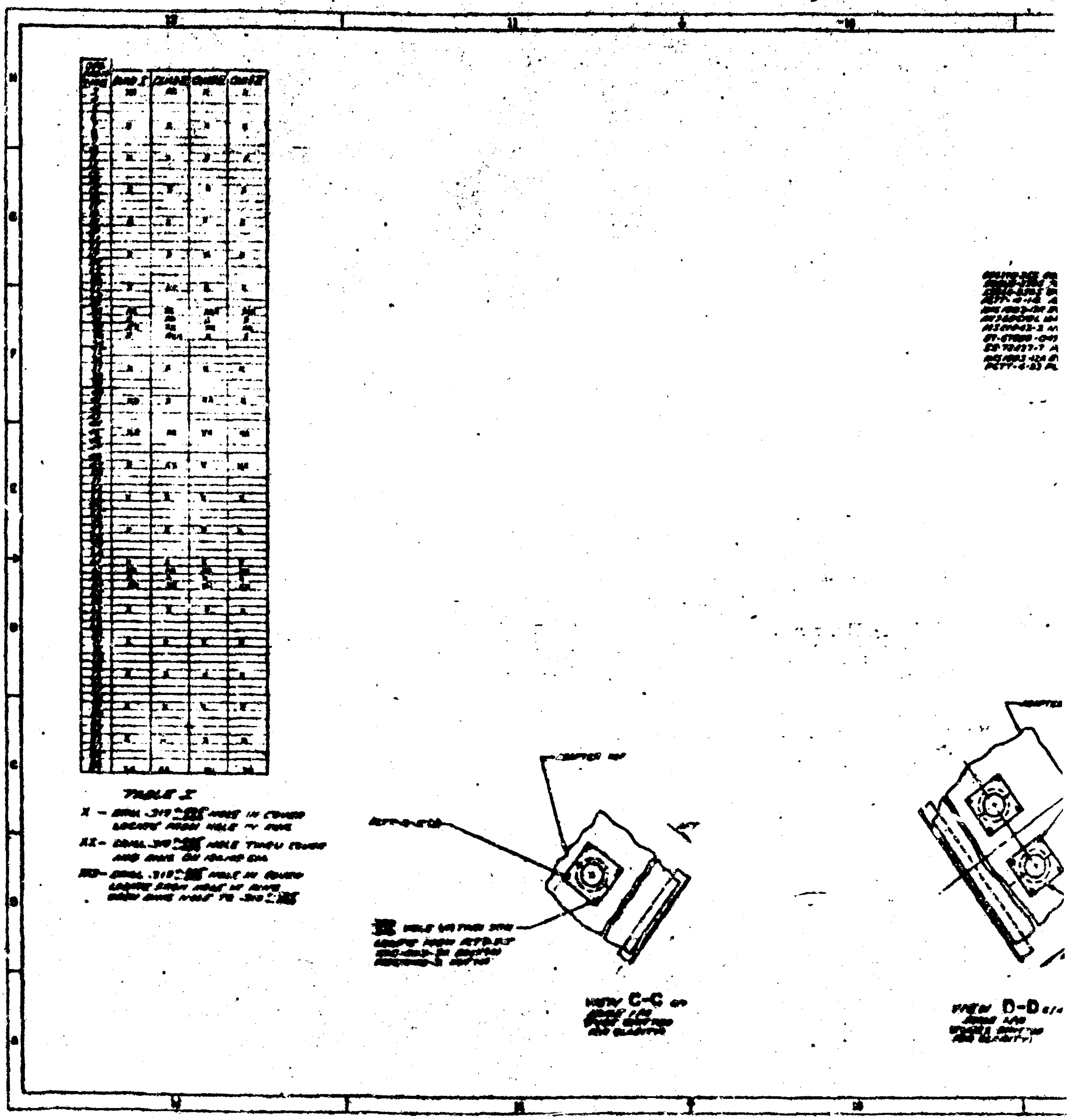
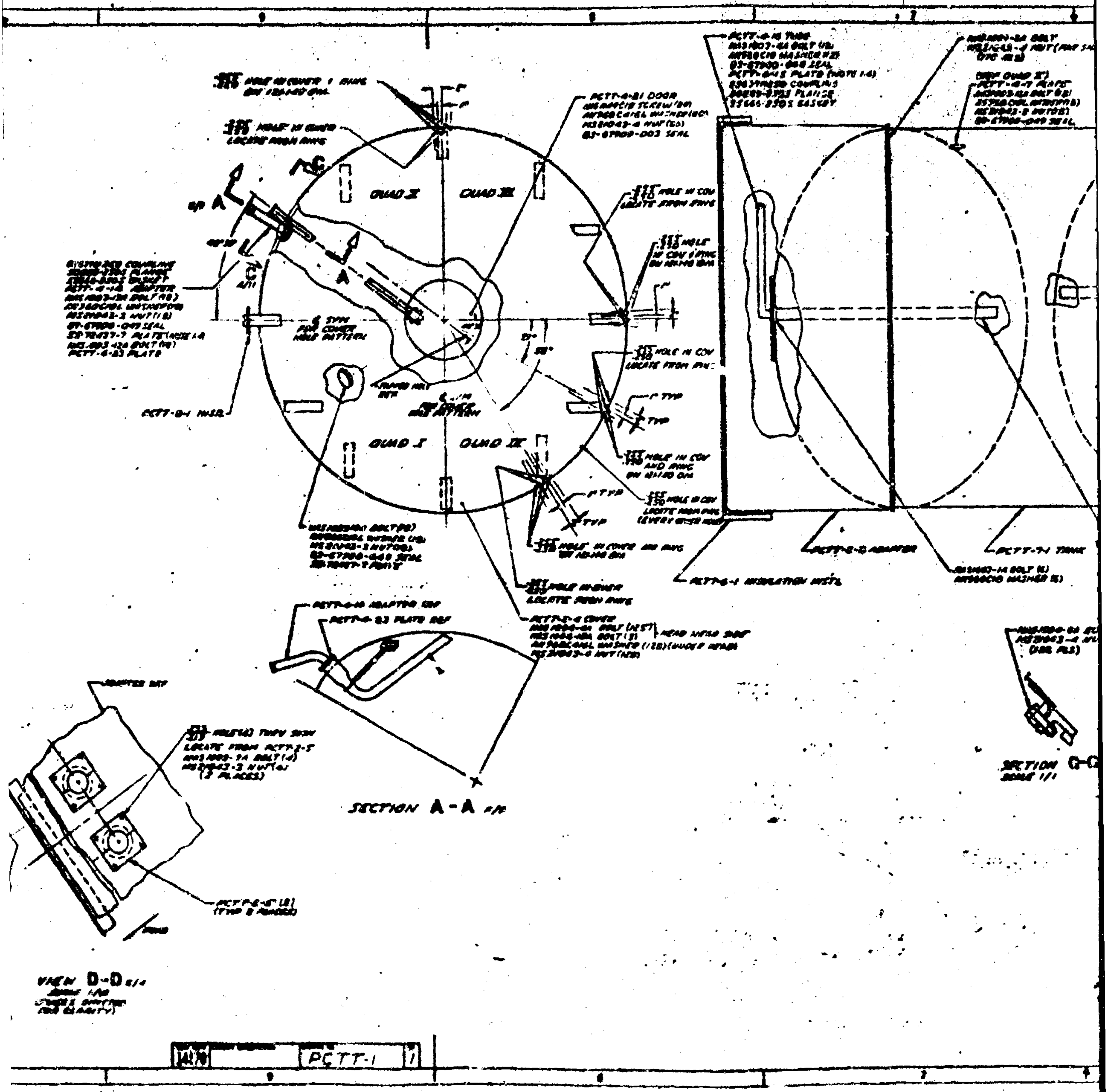
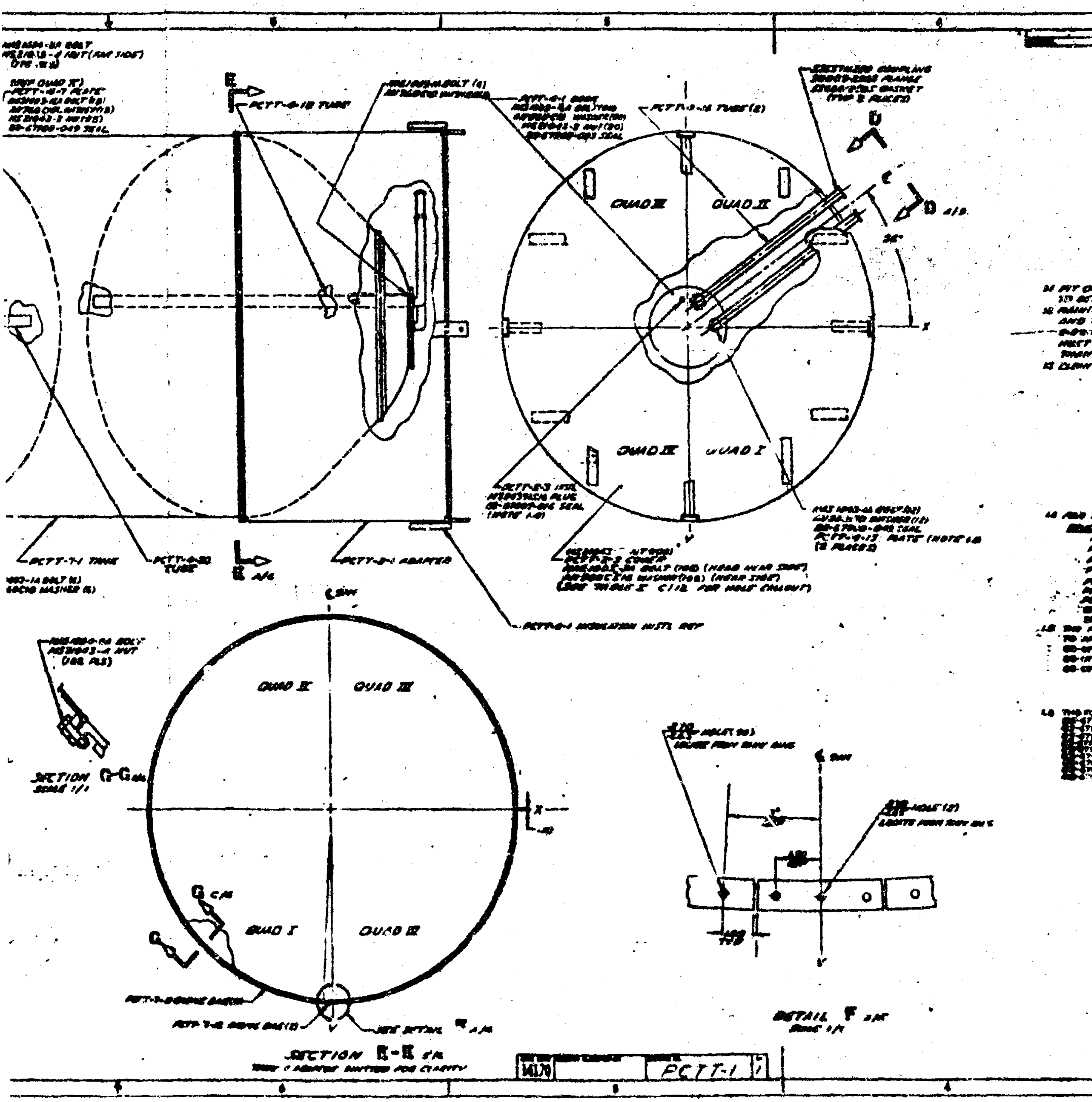
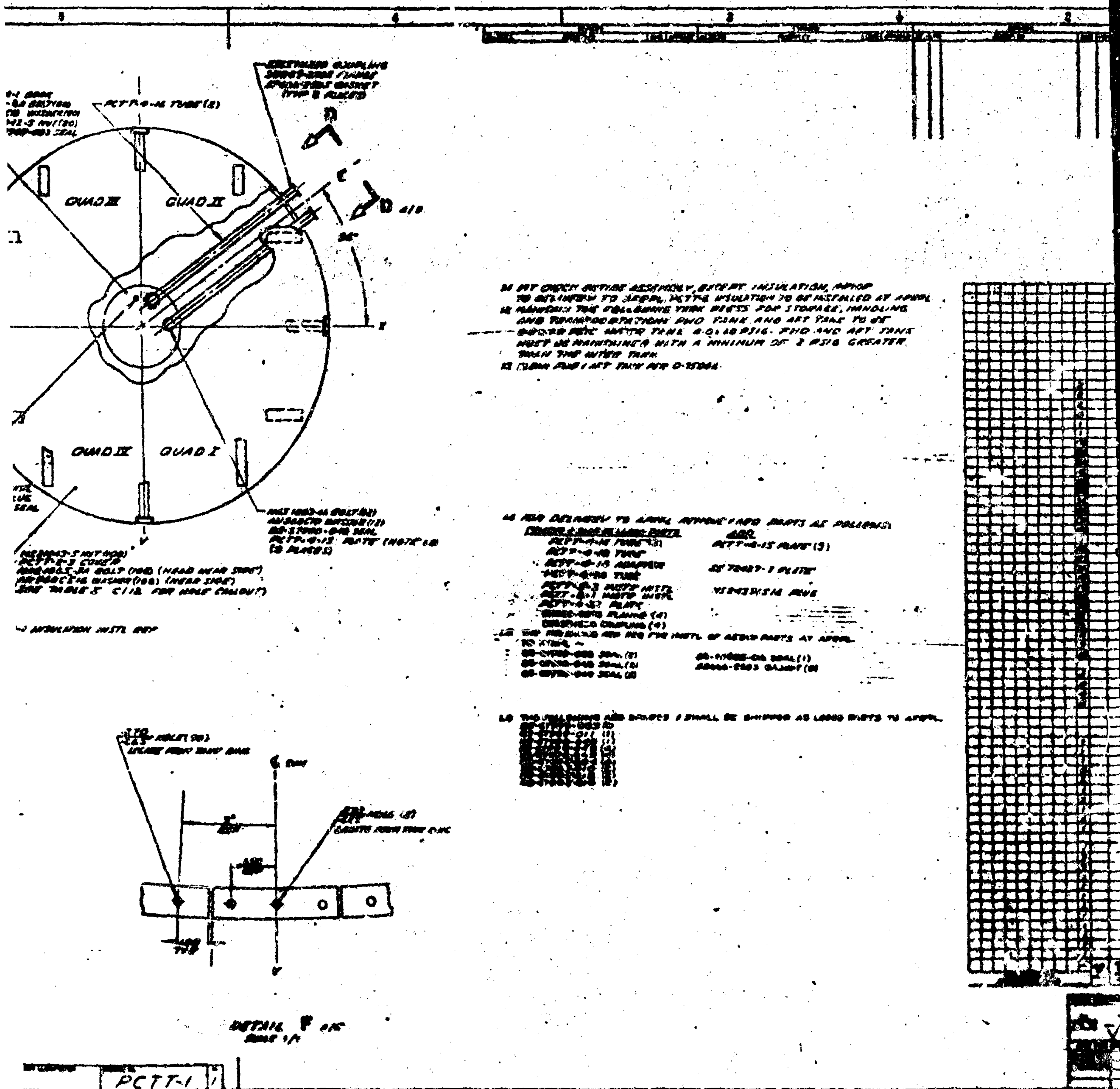


FIG 1-2


QUAD I
QUAD II
QUAD III
SECTION A-A
SECTION C-C
VIEW D-D
PCTT-1



QUAD IV
QUAD II
QUAD III
QUAD I
PCTT-1-1 TANK
PCTT-2-1 ADAPTER
PCTT-6-1 INSULATION INSTL REF
SECTION G-G
SECTION E-E
DETAIL F
14170
PCTT-1



QUAD III
QUAD II
QUAD IV
QUAD I
INSULATION, PRIOR
INSULATION TO BE INSTALLED AT
STORAGE, HANDLING
TANK AND AFT TANK TO BE
PSIG. FWD AND AFT TANK
WITH A MINIMUM OF 2 PSIG GREATER
PCTT-4-15 PLATE (3)
FLANGE (4)
COUPLING (4)
DETAIL
SCALE 1/1
PCTT-1

4

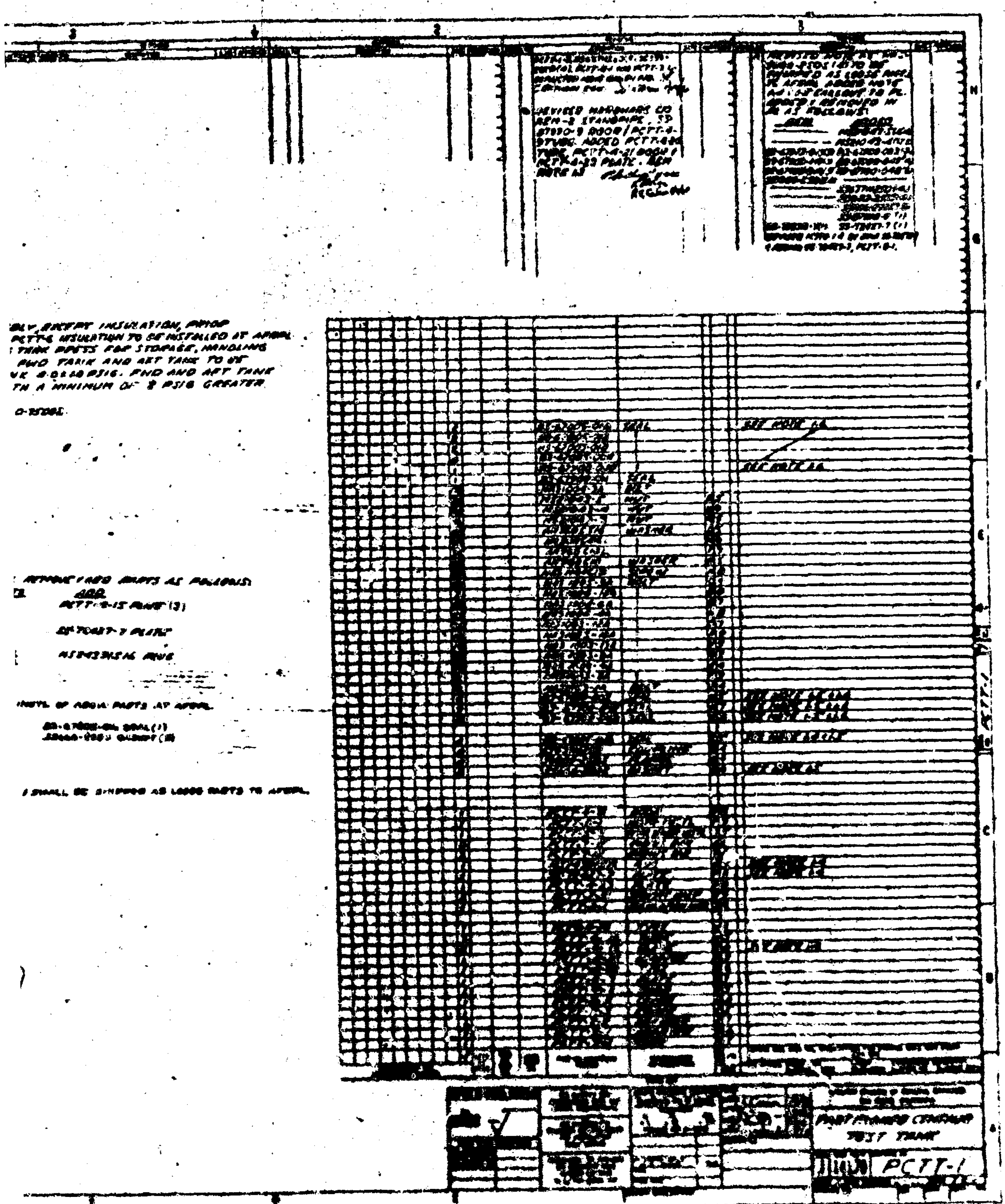
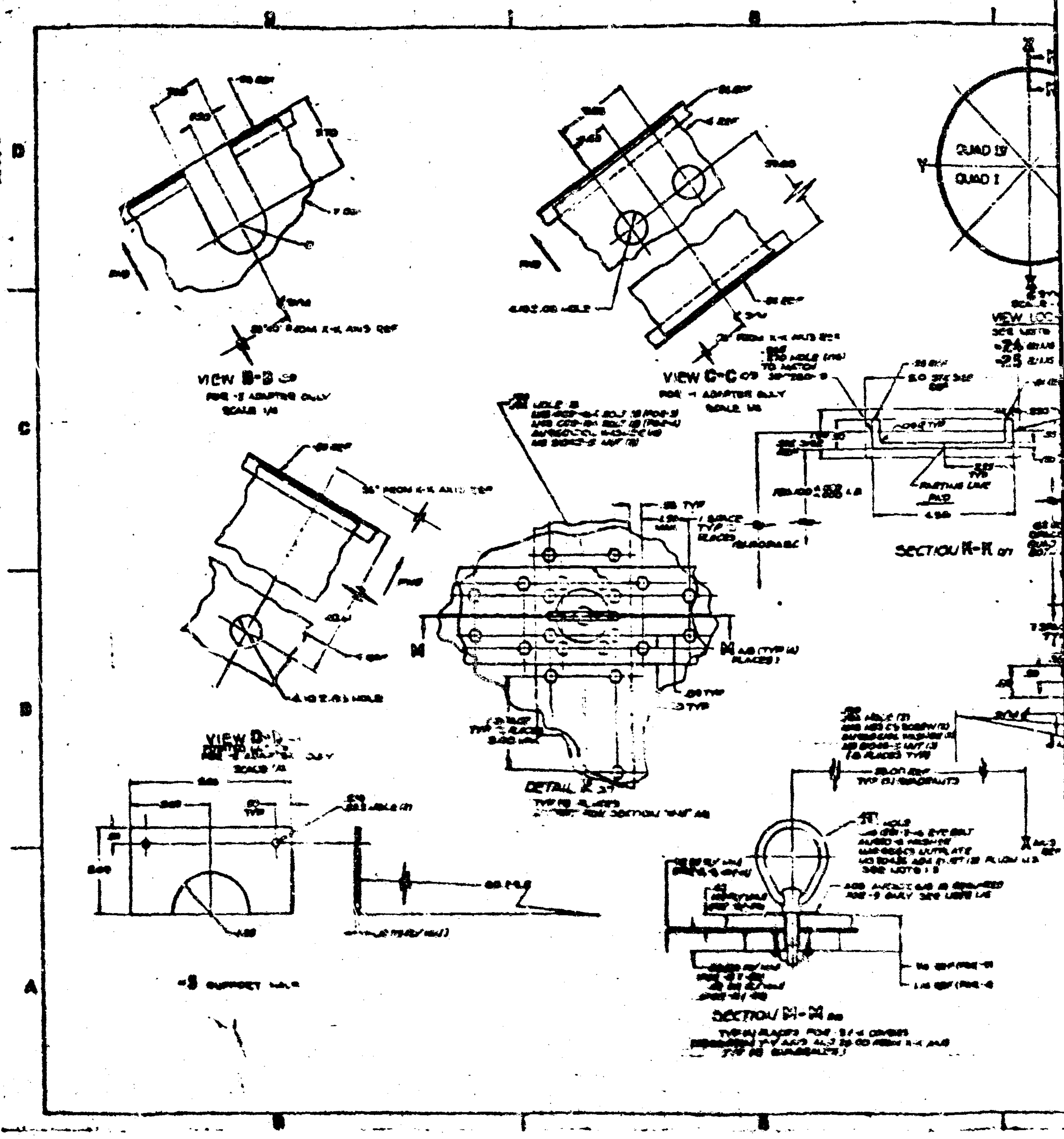


Fig. 1-4 PCTT Fill & Drain Lines

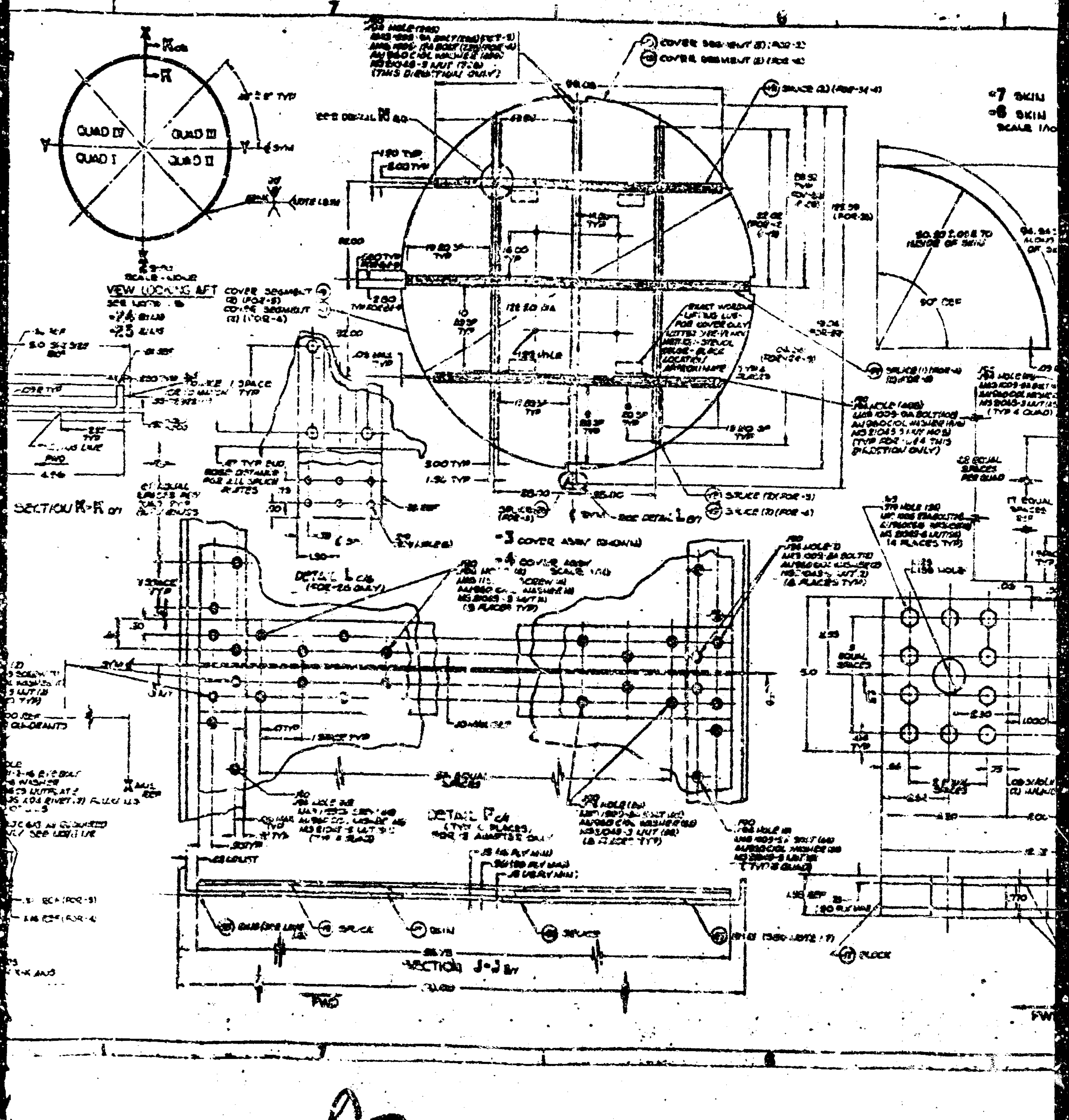
same attachment and sealing techniques as the LH_2 fill and drain line. The LO_2 tank uses the existing internal fill and drain line previously installed, without modification. Provisions have been made for incorporating a short elbow from the existing flanged outlet to the facility interface. Connections include an "O" ring, bolt-on joint at the tank flange and a Conoseal, marmon clamp arrangement at the facility interface. The LO_2 tank pressurization line is identical to the LH_2 tank fill and drain line except for the internal standpipe length.

1.2.2 Adapter Description - Forward and aft adapters, Figure 1-5, are provided as part of the Partitioned Centaur Test Tank. The adapters are used for handling the test article as well as suspending the test article from the chamber during testing. The adapters are also representative of interstage and payload adapters, thus providing for thermodynamic characteristics of this type structure and its relationship to the tankage system. The adapters also provide means for externally mounting the superinsulation.

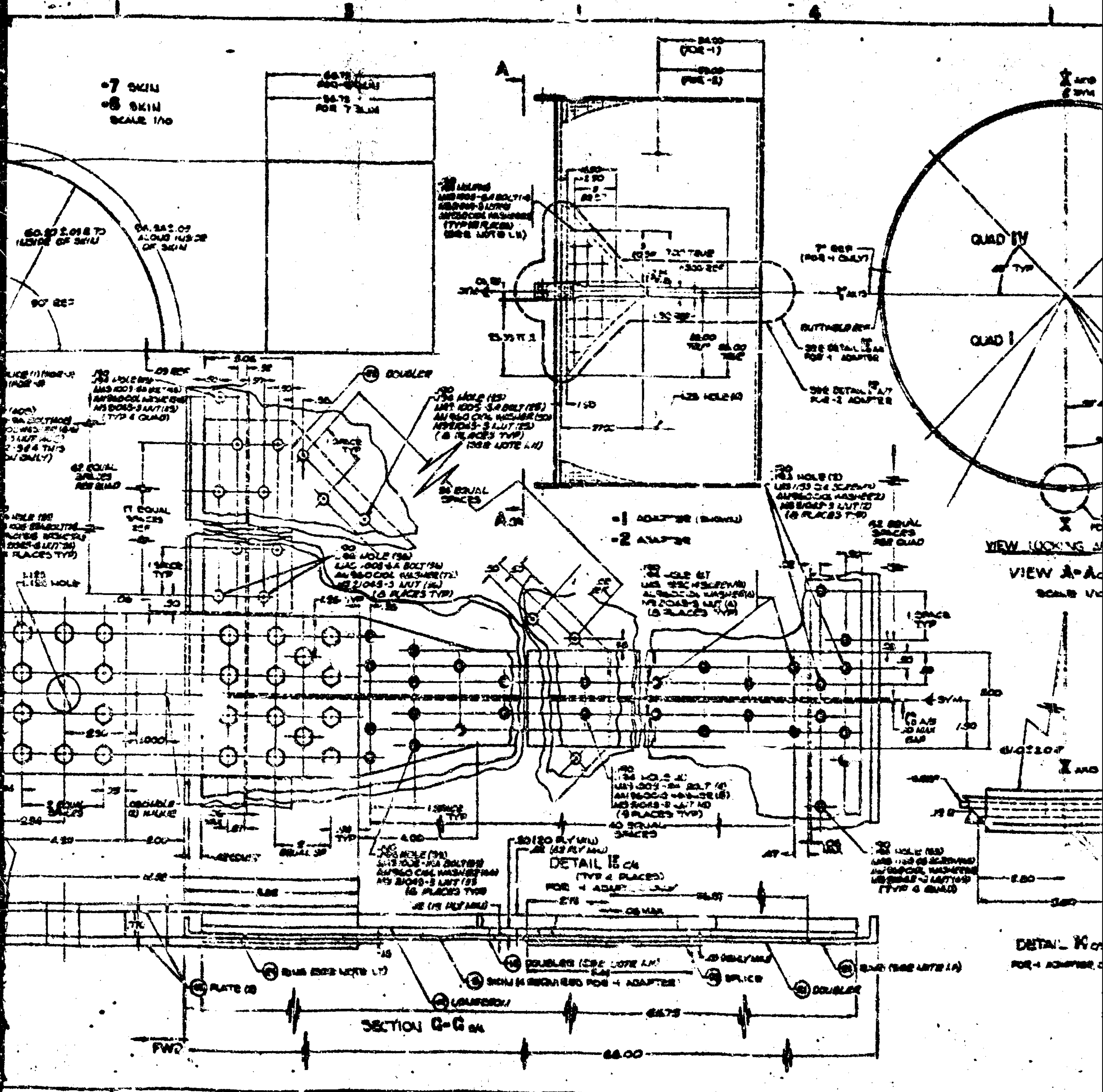
The forward adapter is 10 feet in diameter and approximately 68 inches long. The adapter is fabricated from a 20 ply minimum, glass reinforced, plastic layup, forming skin segments. Four skin segments are spliced and mechanically fastened using bolts, washers and nuts. At each end of the adapter is a 6061 aluminum alloy ring which is attached to the Fiberglas skin segments with mechanical fasteners. The forward adapter incorporates four Fiberglas lugs for mounting the entire test article in the AFRPL chamber. The aft adapter is similar to the forward adapter except it is 58 inches in length and has no attachment lugs. It also has several cutouts for propellant fill and drain lines which are different than those in the forward adapter.



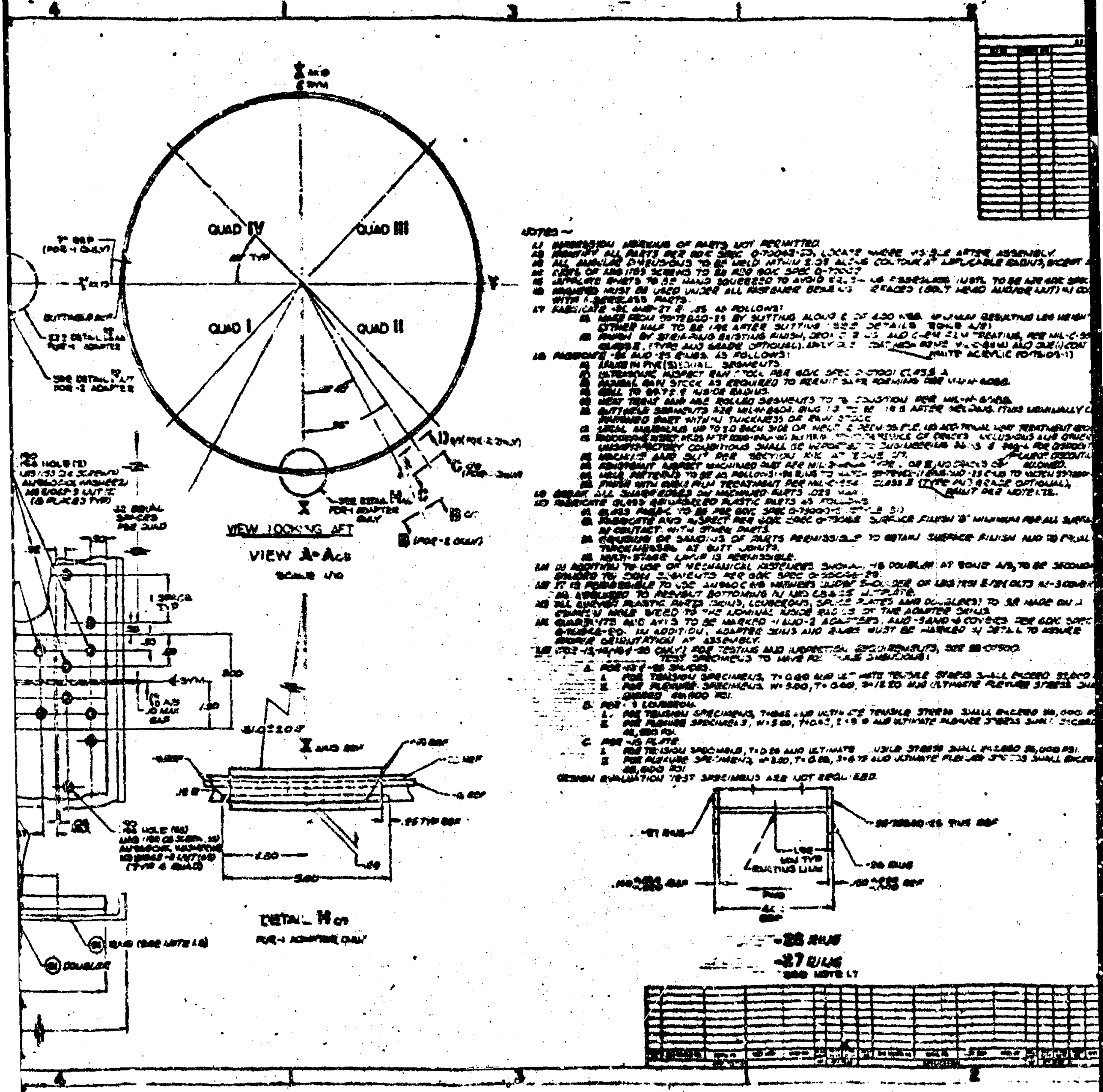
1-5



QUAD IV
QUAD III
QUAD I
QUAD II
VIEW LOOKING AFT
SECTION K-K
DETAIL L
DETAIL P
-3 COVER ASSY (SHOWN)
-4 COVER ASSY
SECTION J-J
FWD



-7 SKIN
-8 SKIN
SCALE 1/10
QUAD IV
QUAD I
VIEW A-A
DOUBLER
-1 ADAPTER (SHOWN)
-2 ADAPTER
DETAIL
SECTION G-G
FWD
66.00


QUAD IV
QUAD III
QUAD I
QUAD II
VIEW LOOKING AFT
VIEW A-A
SCALE 1/10
DETAIL H
FOR -1 ADAPTER ONLY
DOUBLER
-28 RING
-27 RING
SEE NOTE L7
NOTES ~
FABRICATE -26 AND -25 RINGS AS FOLLOWS:
MAKE IN FIVE (5) EQUAL SEGMENTS.
ULTRASONIC INSPECT RAW STOCK
ROLL TO 97.2 INSIDE RADIUS.
BREAK ALL SHARP EDGES ON MACHINED PARTS .035 MAX.
FABRICATE GLASS REINFORCED PLASTIC PARTS AS FOLLOWS:
MULTI-STAGE LAYUP IS PERMISSIBLE.
PROPER ORIENTATION AT ASSEMBLY.
DESIGN EVALUATION TEST SPECIMENS ARE NOT REQUIRED.

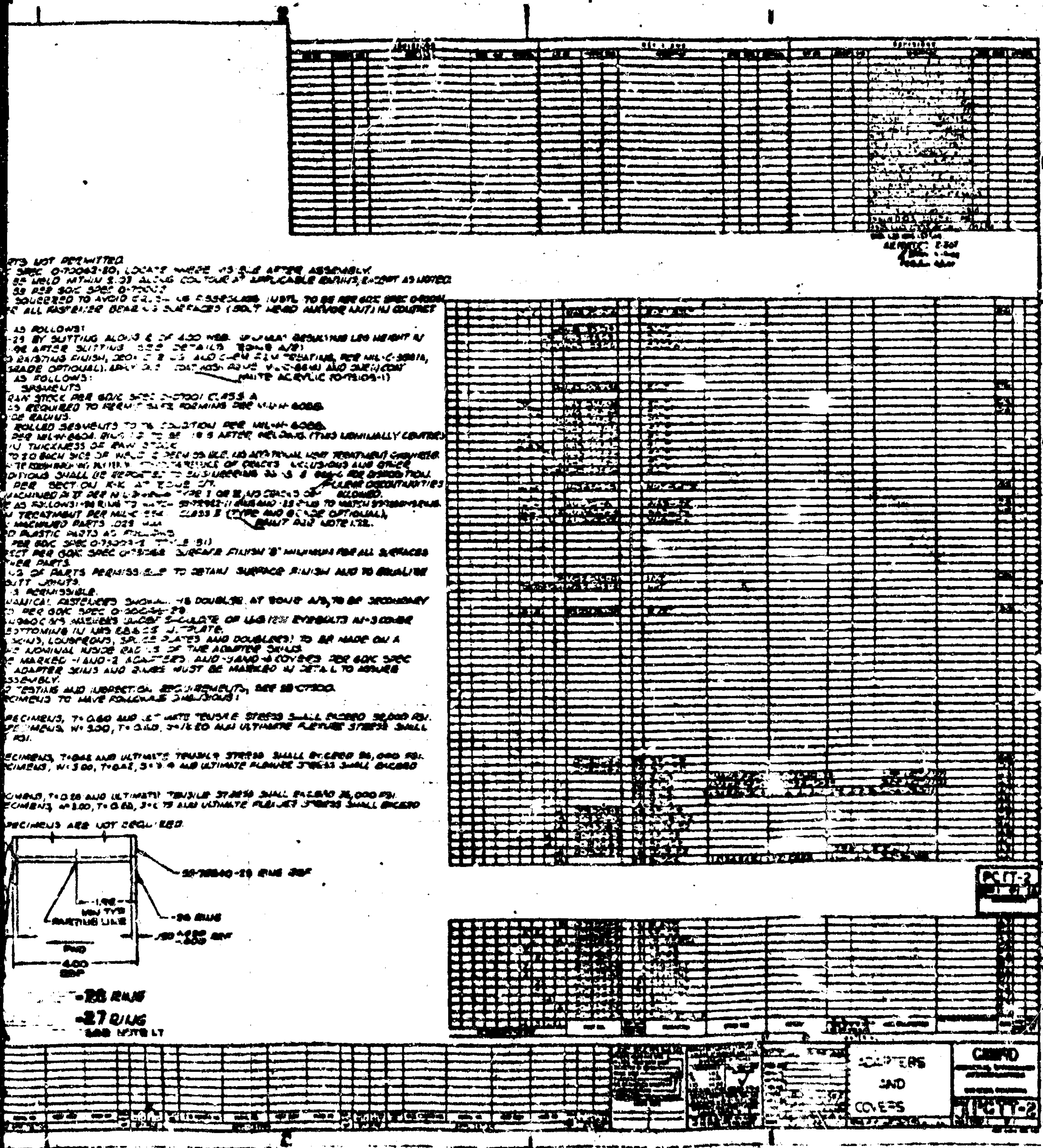
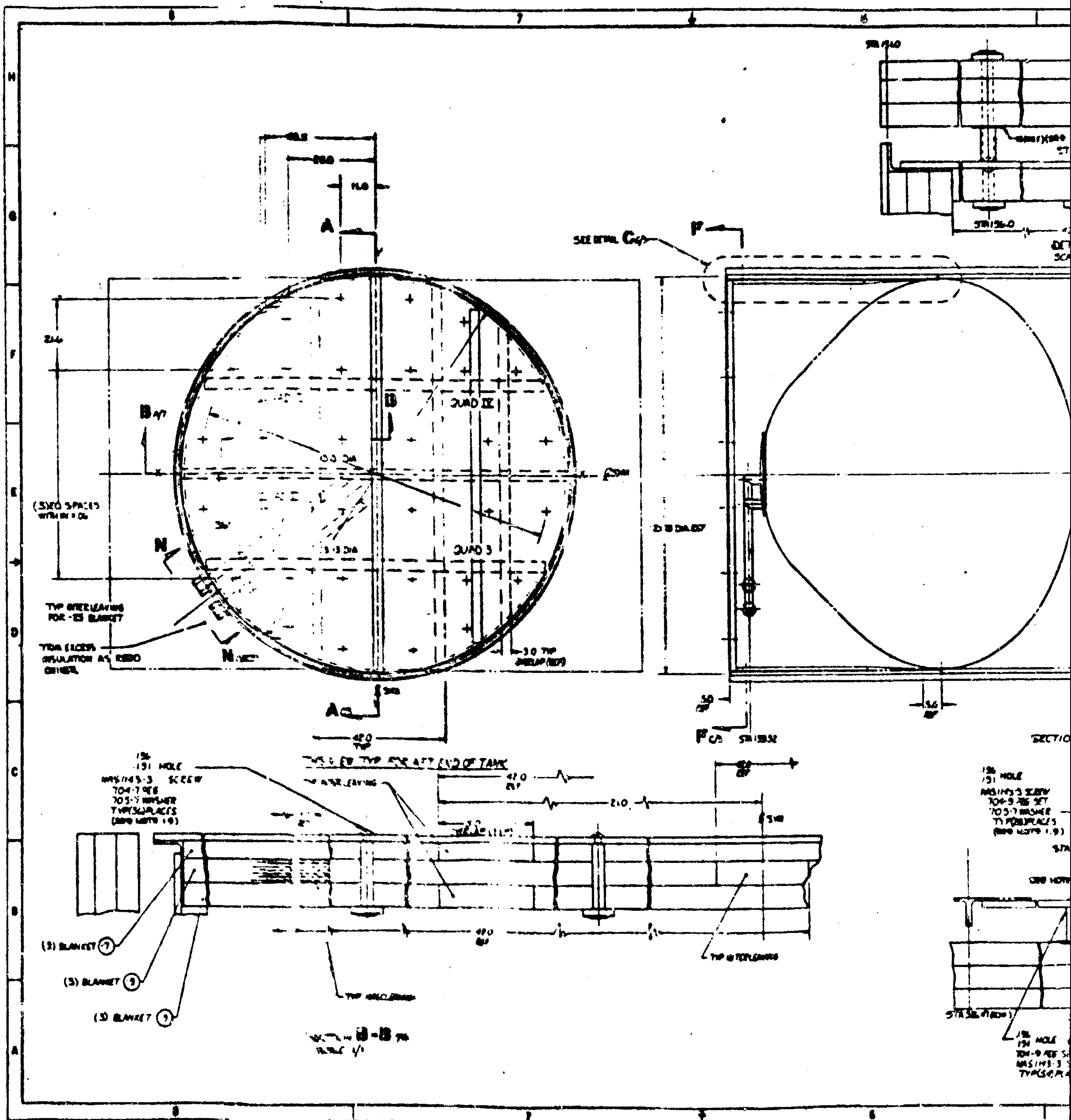


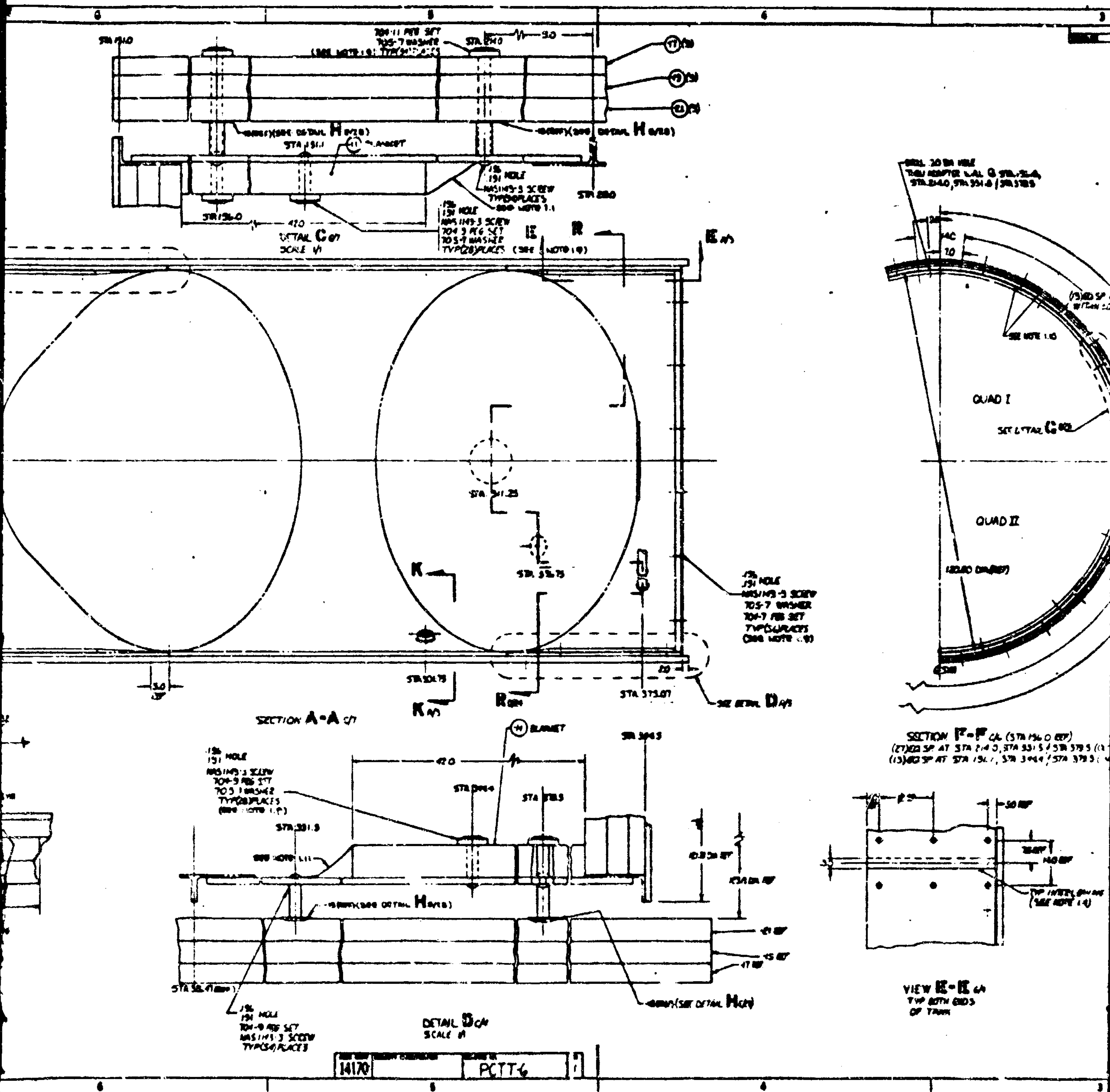
Fig. 1-5 PCTT Adapters and Covers

1.2.3 Cover Plate Description - The PCTT incorporates forward and aft cover plates, Figure 1-5, which attach to the forward and aft adapters. The cover plates are fabricated from four flat sheet segments of 12 ply, glass reinforced plastic. These four segments are spliced together with mechanical fasteners to form a 10 foot diameter circular shape. Each splice is reinforced with approximately 40 ply, glass reinforced plastic splice plates.

1.2.4 Insulation Description - The PCTT article is completely insulated with super-temp (Dimplar) superinsulation; see Figures 1-6 and 1-7. The insulation sheets are aluminized mylar, 1/2 mil thick. These sheets are used to form insulation blankets consisting of several pairs of mylar sheets. One pair uses a single layer of 1/2 mil smooth mylar aluminized on both sides and a single layer of 1/2 mil, deep-set Dimplar (mylar aluminized on both sides and processed by Super-Temp Corporation) material. The inside surface of the forward and aft adapters is insulated to a depth of approximately 42 inches with one continuous blanket containing 10 pairs of superinsulation material. These blankets are attached to the adapters by use of Fiberglas support pegs, Fiberglas felt washers, and teflon screws. Nylon monofilament line (4# test or equivalent) is laced diagonally between upper and lower support pegs for additional insulation support. The inside surface of the forward and aft cover plates are insulated with three insulation blankets for each cover. One of the three blankets consists of six pairs of superinsulation material and the other two blankets use seven pairs per blanket. Attachment methods used are the same as those used for attachment to the forward and aft adapters. The



QUAD IV
QUAD 3
THIS VIEW TYP FOR AFT END OF TANK
(3) BLANKET
SECTION


DETAIL C
SCALE 1/1
SECTION A-A
QUAD I
QUAD II
SECTION F-F
DETAIL D
SCALE 1/1
VIEW E-E
TYP BOTH ENDS OF TANK
STA 373.07
14170
PCTT-6

2

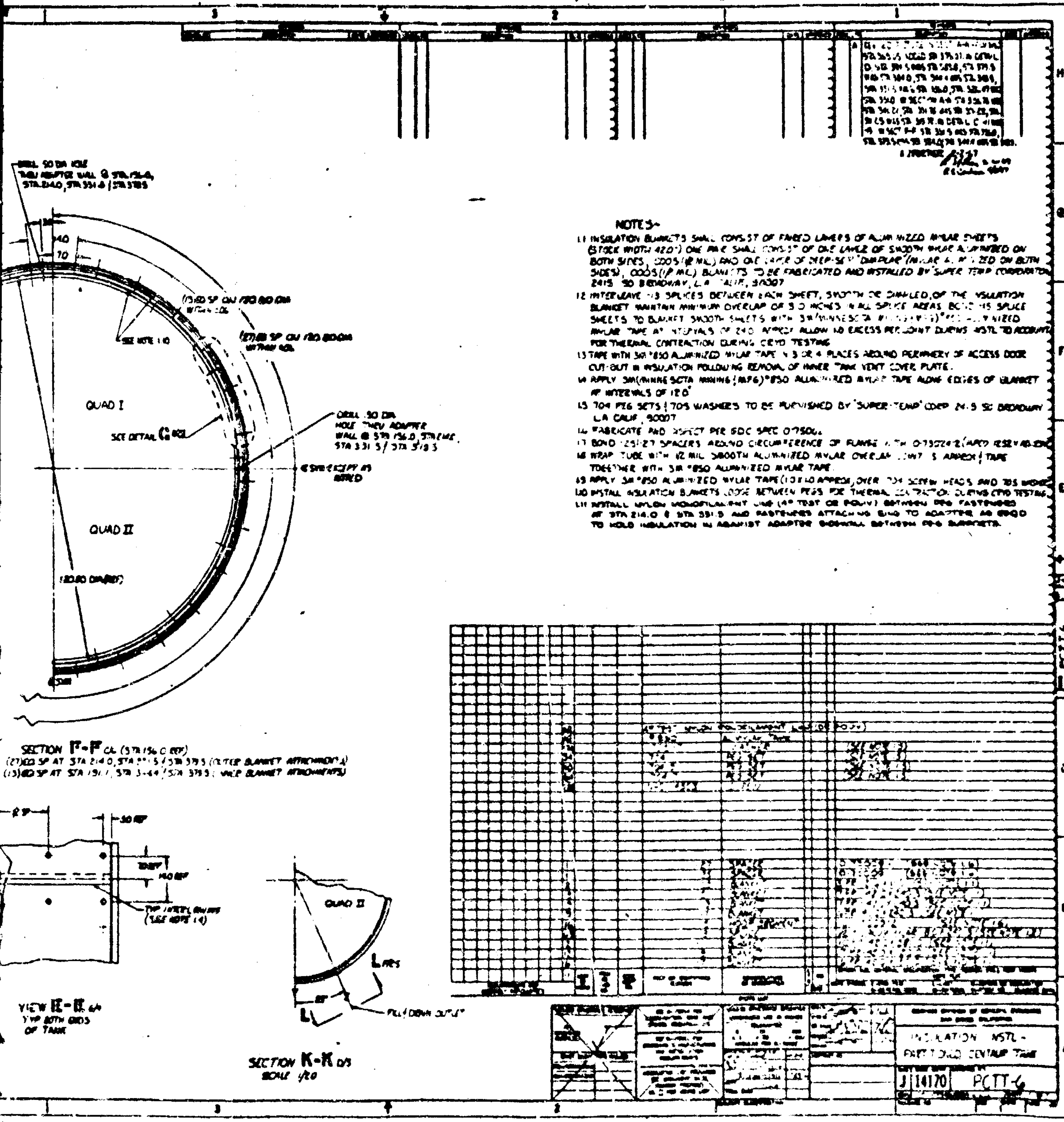
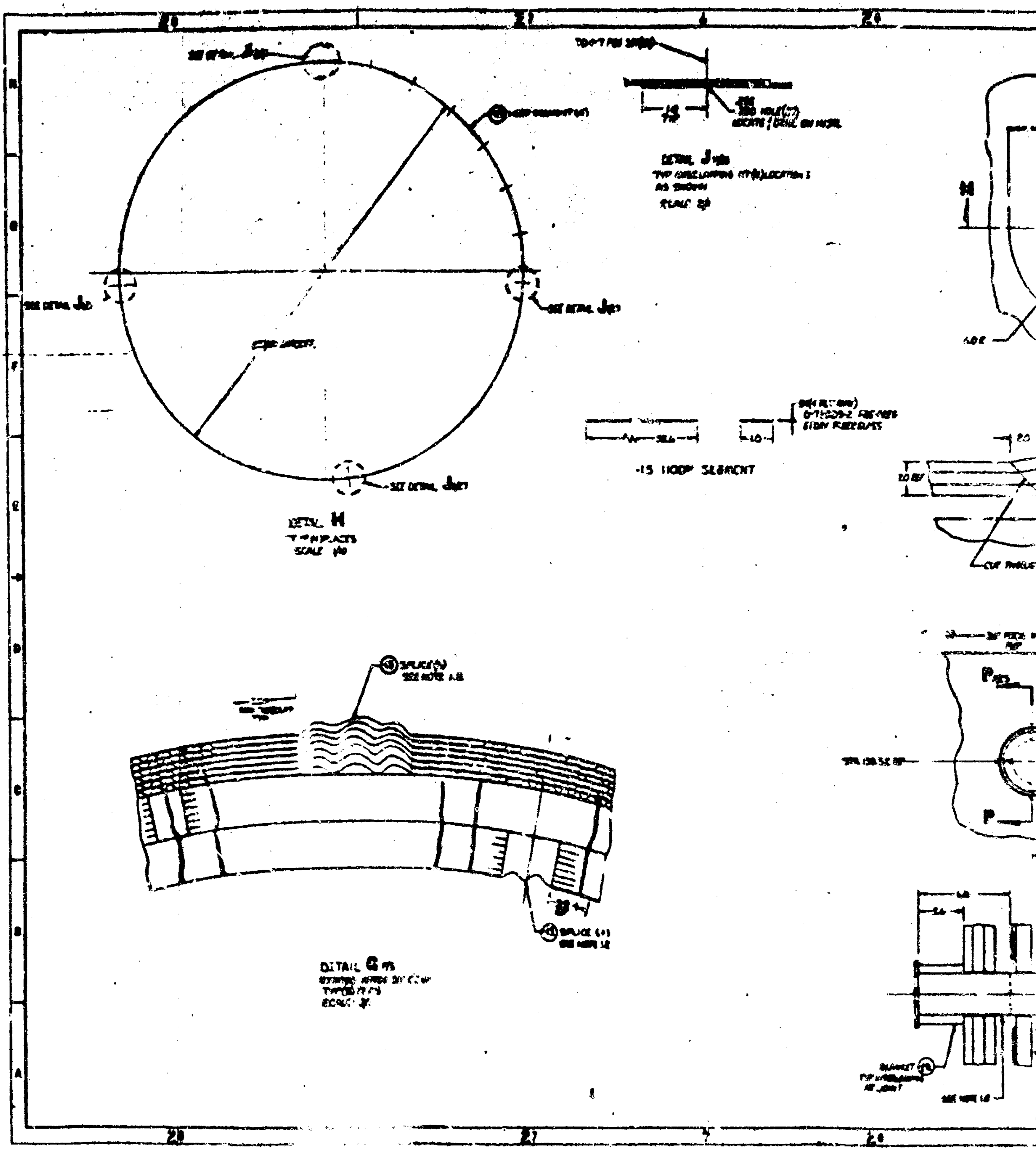
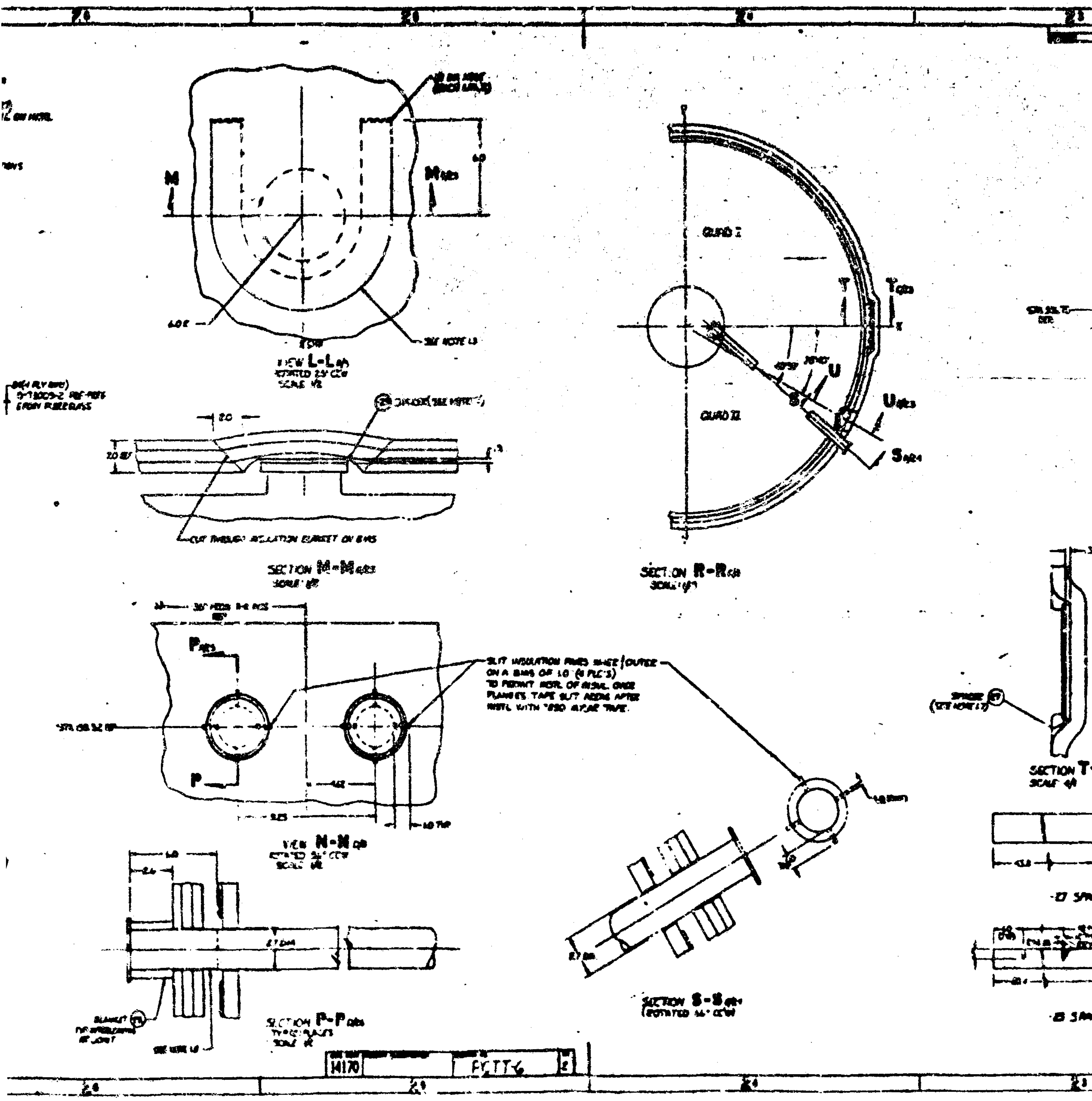


Fig. 1-6 PCTT Insulation Installation



SEE DETAIL J
DETAIL J
SCALE 2/1
DETAIL H
SCALE 1/10
-15 HOOP SEGMENT
SPLICE
DETAIL G


VIEW L-L
SEE NOTE L3
SECTION M-M
CUT THROUGH INSULATION BLANKET ON BIAS
QUAD I
QUAD II
SECTION R-R
SLIT INSULATION FIBERS SHEET (OUTER
ON A BIAS OF 1.0 (8 PLC'S)
TO PERMIT INSTL OF INSUL OVER
FLANGES. TAPE SLIT AREAS AFTER
INSTL WITH 7850 MYLAR TAPE.
VIEW N-N
SECTION P-P
SEE NOTE L3
SECTION S-S
SECTION T
14170
FY TT-6

2

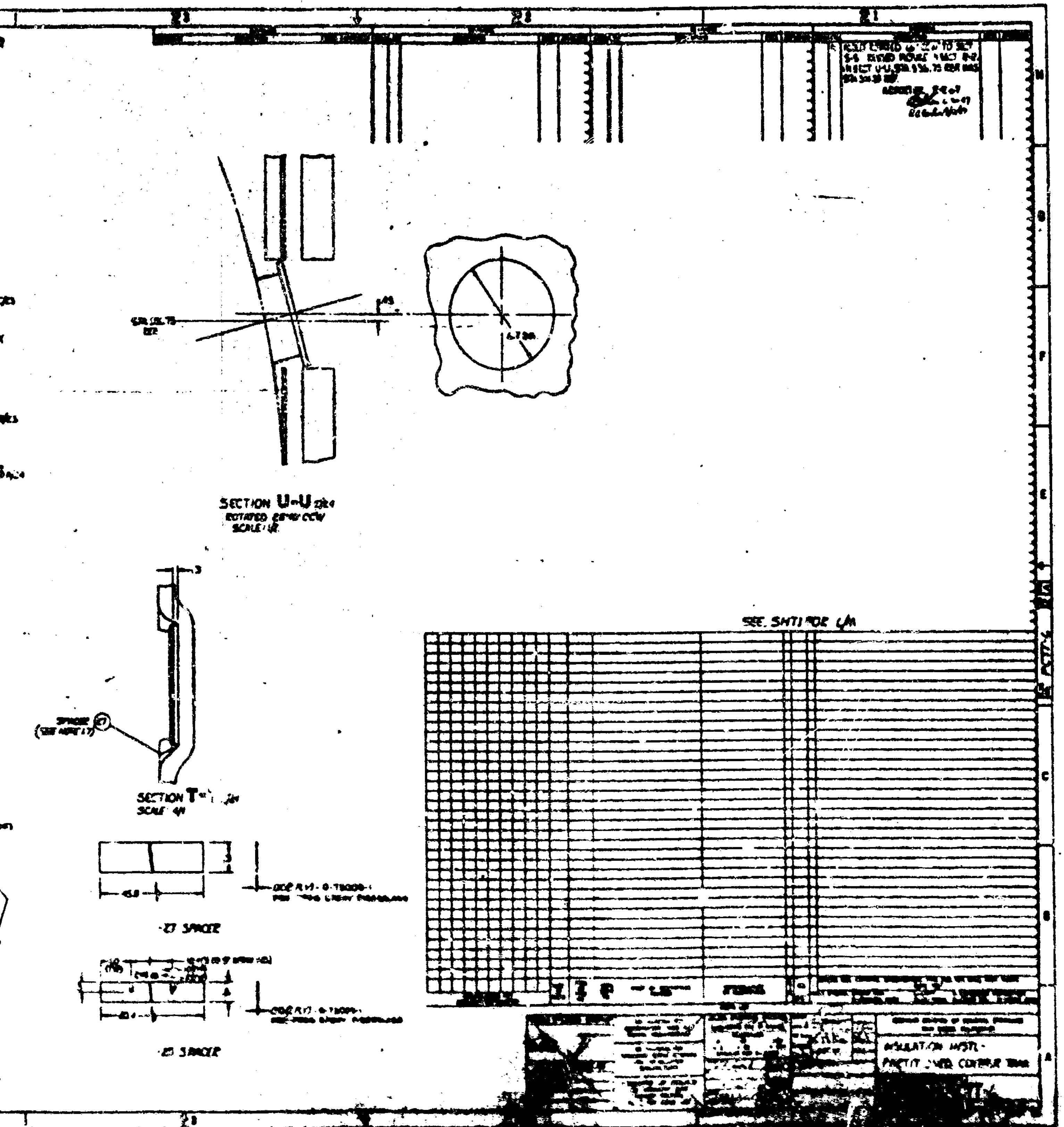

SECTION U-U
SCALE 1/1
SECTION T-T
SCALE 4/1
-27 SPACER
-25 SPACER
INSULATION MATL -

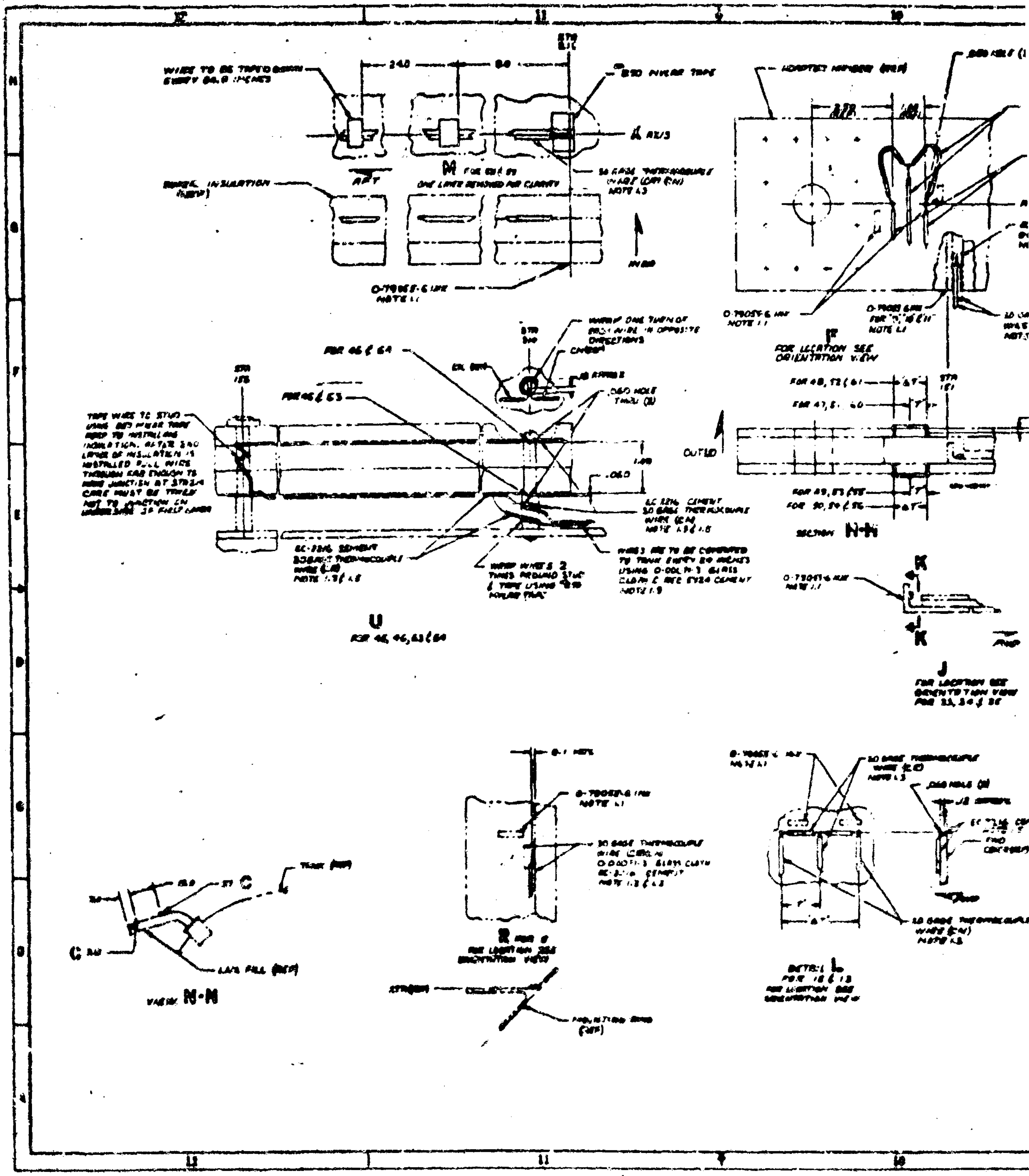
Fig. 1-9

entire outside cylindrical surface of the test article, including outside surfaces of the forward and aft adapters, is insulated. Nine separate blankets for each of three layers are used on the outside surfaces. The innermost blankets are made from six pairs of insulation and the outer two layers use seven pairs for each layer. These insulation blankets are attached to two sets of Fiberglas pegs mounted on the forward adapter and are suspended the entire length of the vehicle without additional support. A technique of interleaving smooth sheets of aluminized mylar was used for "bridging" the gaps left by the necessity to butt the insulation blankets during installation. Aluminized mylar tape was used liberally for attaching the interleaved sheets and for covering exposed screw heads and penetration areas. Fiberglas standoff rings and bands were used to reduce direct contact area of the superinsulation to the tank walls and tank outlets.

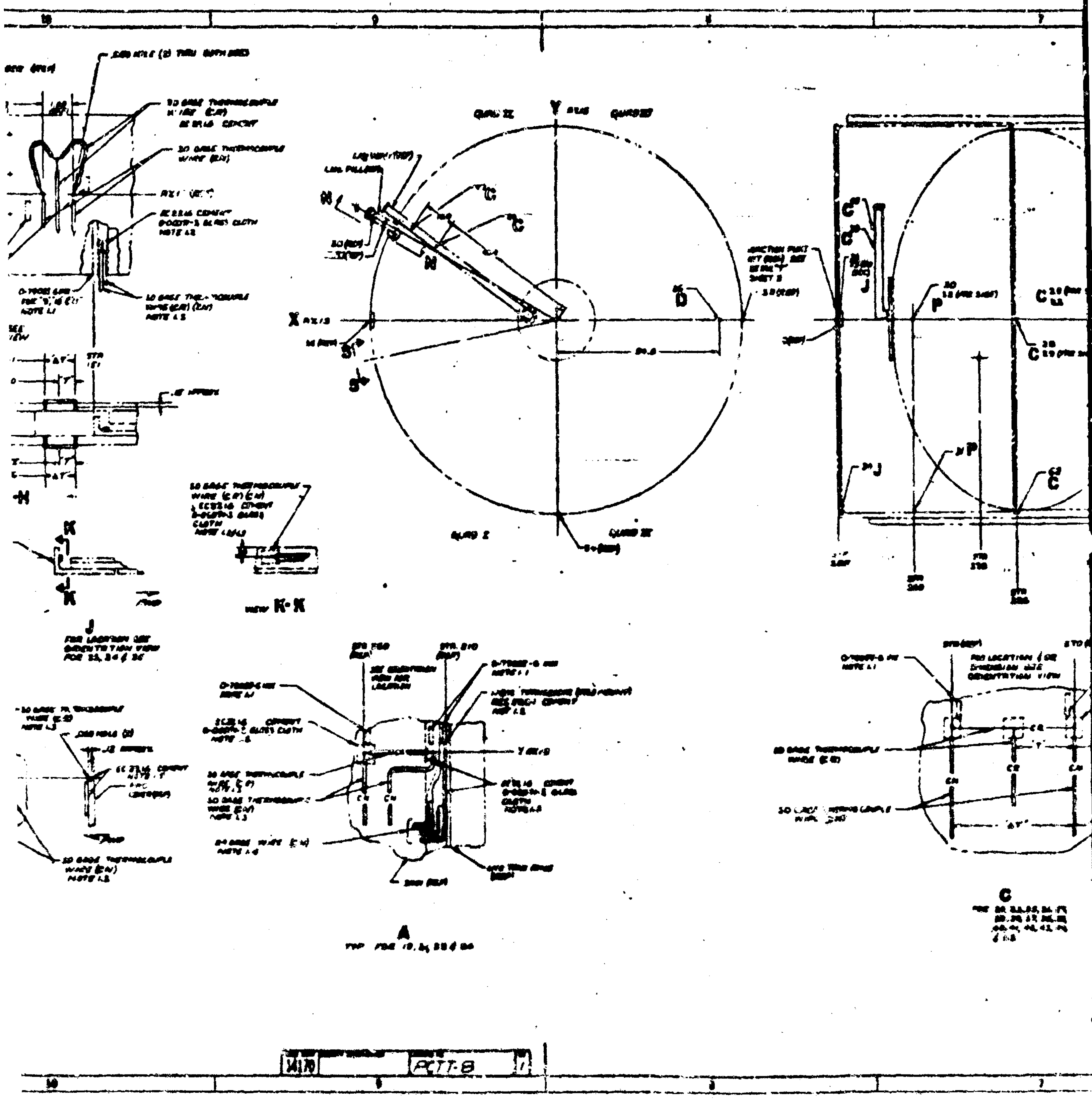
1.2.5 Instrumentation Description - The instrumentation for the PCTT, Figures 1-8, 1-9, 1-10 and 1-11, consists of one hot wire sensor, six platinum thermometers and approximately 58 constantan thermocouples

All of the thermometers and thermocouples are intended for use in assessing the individual magnitude of the heat leaks into and through the test article structure. Platinum resistance elements and chromel/constantan thermocouples are placed in strategic locations. Each thermocouple is wired with a voltage bucking that of another couple, the latter couple being shown as reference.

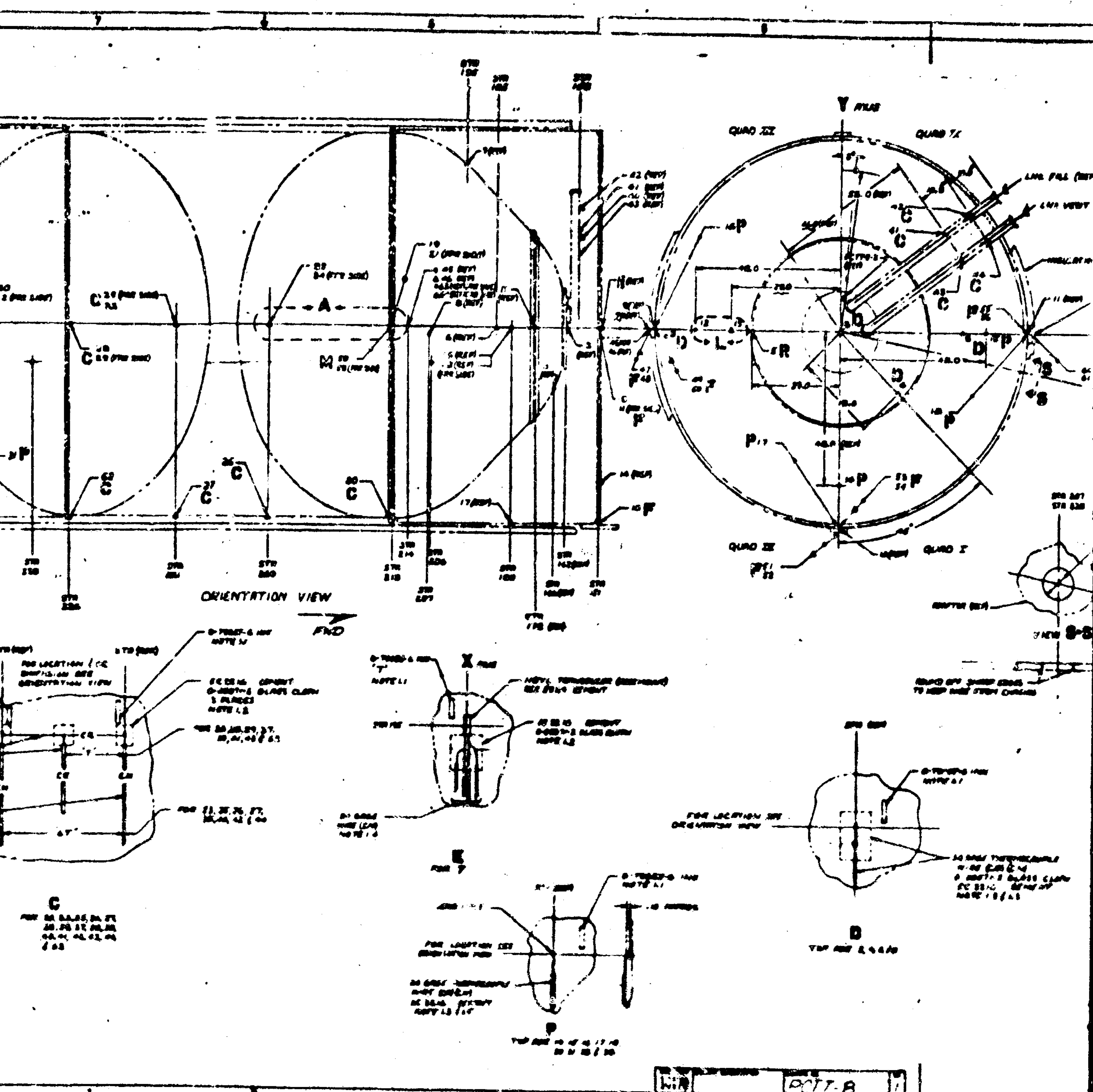
The thermometers have an ice point resistance of about 1,380 ohms. The leads connecting the thermometers to the reference junction block are of 24



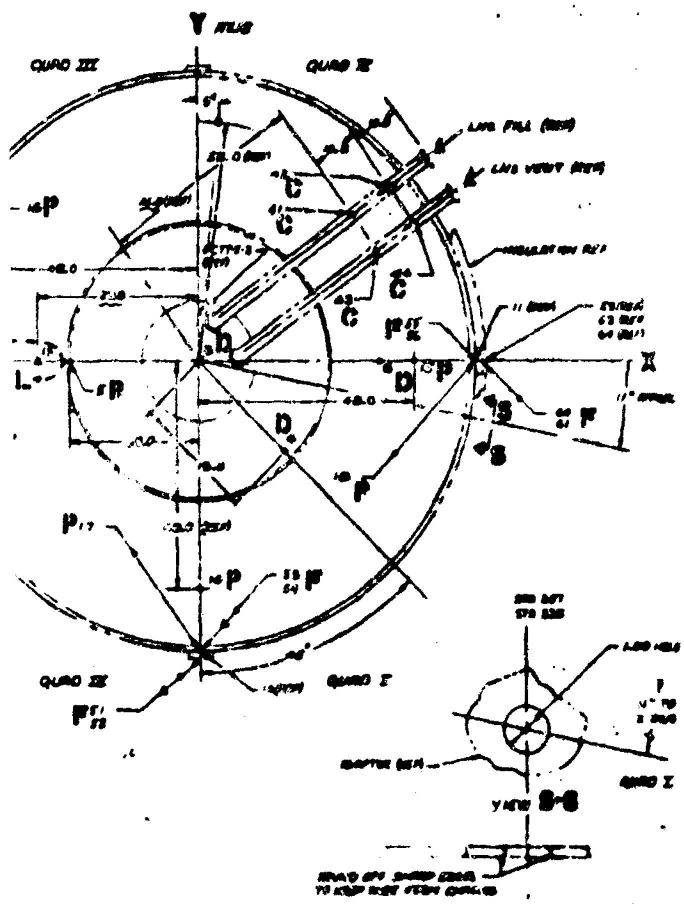
1-8



2



ORIENTATION VIEW
FWD
Y AXIS
QUAD II
QUAD IV
QUAD III
QUAD I
X AXIS
C
D
E
P
PCTT-B



NOTES~

1.1 APPLY REF DESIGNATOR APPROX .12 HIGH IN GENERAL AREA INDICATED USING C-78077-6 INK PER D-7016, AMBIENT CURE. DETAIL & ORIENTATION VIEW SHALL BE MARKED TOGETHER FOR REF DESIGNATOR.

1.2 APPLY ONE LAYER OF [illegible]-3 GLASS CLOTH UNDER THERMOCOUPLES & TRANSDUCER LEADS AS SHOWN ON F/D USING EC 2216 CEMENT. DO NOT USE GLASS CLOTH UNDER TRANSDUCER BODY. CEMENT IN PLACE USING [illegible].

1.3 FORM THERMOCOUPLE AS FOLLOWS: PLACE WIRES TOGETHER THEN SILVER BRAZE USING 0-00351, 36 BRAZING ALLOY.

1.4 SOLDER WIRE TO TRANSDUCER LEADS USING 0-00351-36 BRAZING ALLOY.

1.5 AFTER THERMOCOUPLE HAS BEEN INSERTED IN HOLE, FILL HOLE USING EC 2216 CEMENT.

1.6 ASSEMBLE [illegible] CONNECTOR PER MPS 25.33.5.

1.7 IDENTIFY WIRE WITH MARS NUMBERS & LETTERS INDICATED IN DWG (SHEET 2) USING READY LABELS.

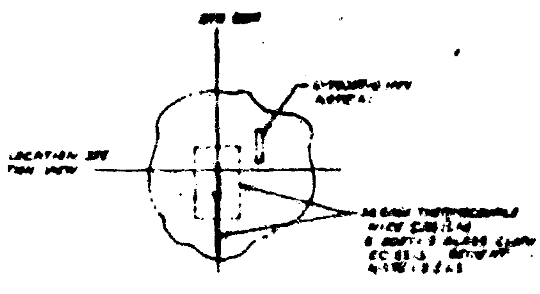
1.9 WIRES ARE TO BE CEMENTED DOWN EVERY 24 INCHES WITH A 1 INCH STRAIN RELIEF EVERY 70 INCHES AS SHOWN IN DETAIL "V". WIRES IN THE ADAPTERS WILL BE ROUTED FROM THE PICKUP POINT TO THE ONE INCH HOLE IN ADAPTER (IN QUAD I) THROUGH HOLE AND OUT UNDER THE INSULATION TO THE JUNCTION PLATE.

1.10 MAKE JUNCTION WITH WIRE INDICATED IN WIRING DIAGRAM USING 0-00351-36 BRAZING ALLOY. SLIDE INTO SLEEVING AND SHRINK PER MPS 25.83.

1.11 SYMBOLS ARE AS FOLLOWS:

- ● PLATINUM TRANSDUCER
- • THERMOCOUPLE
- ▲ DELTA "T"

1.12 WIRES WITH 2 REF DESIGNATORS TO BE INSTALLED AT LOCATION OF DESIGNATOR TO THE LEFT OF SLASH. EXAMPLE: 53/80. WIRE TO BE ROUTED TO 53.



D

TYP FOR 2, 9 & 10

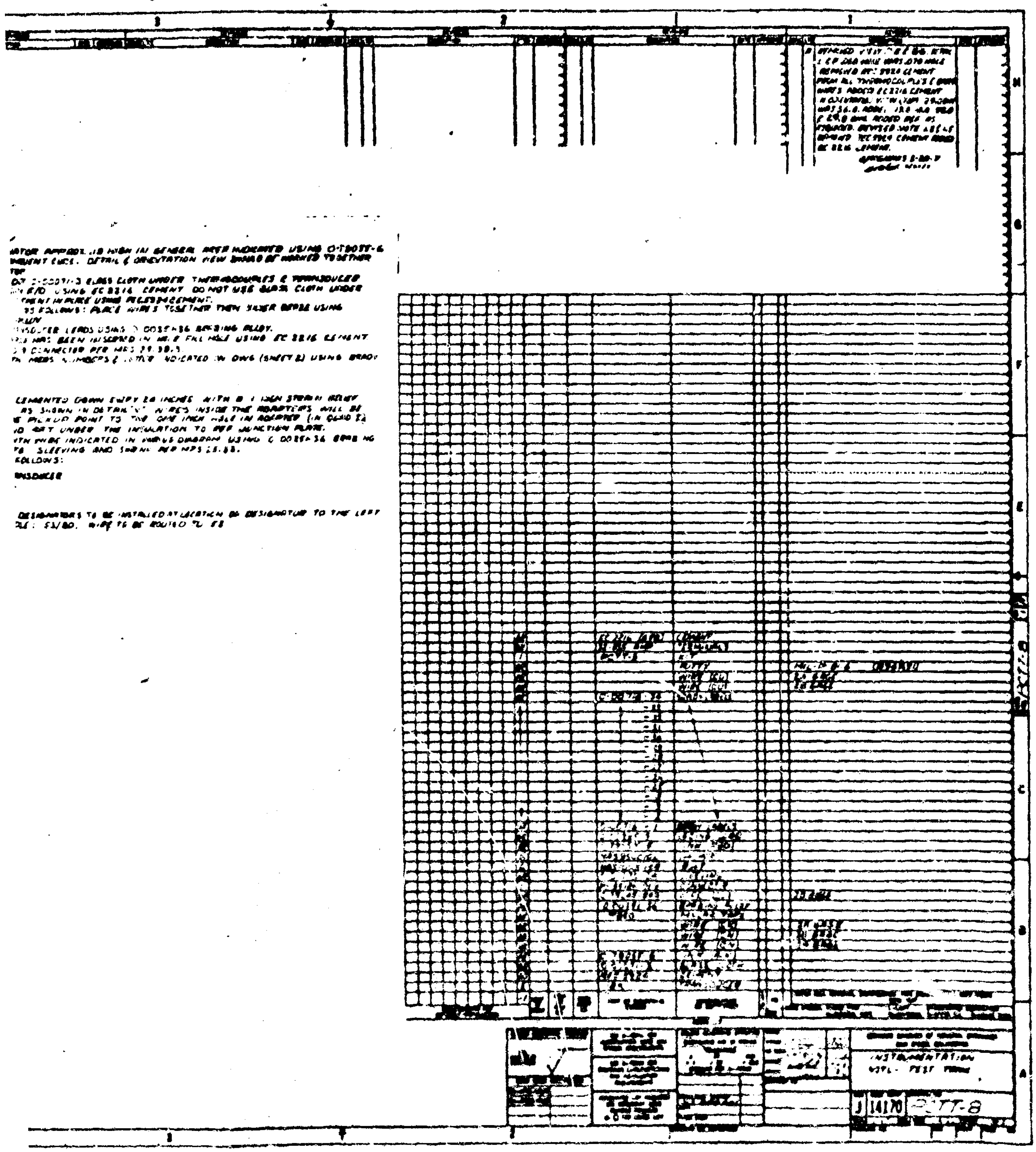
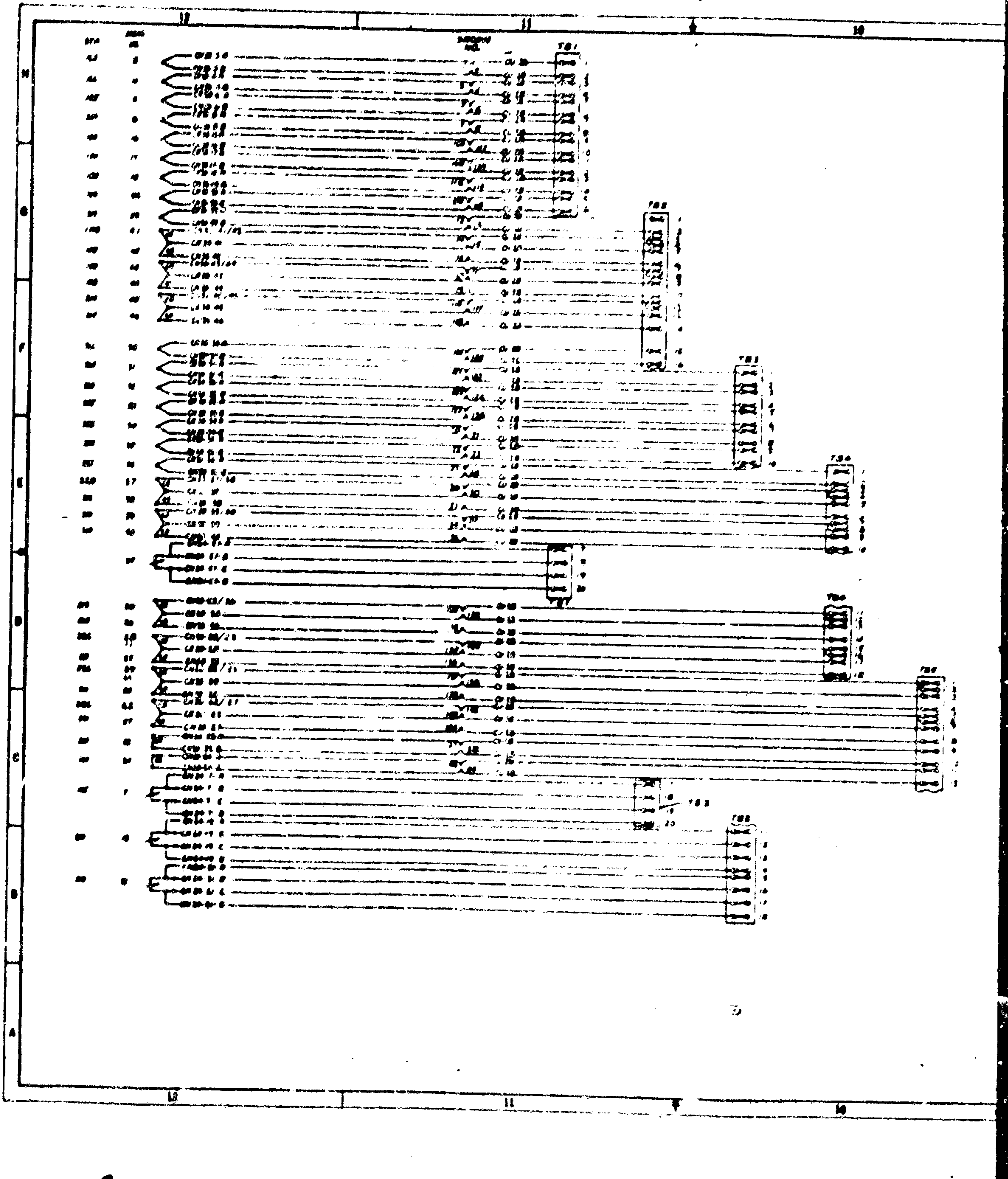


Fig. 1-8 PCTT Instrumentation



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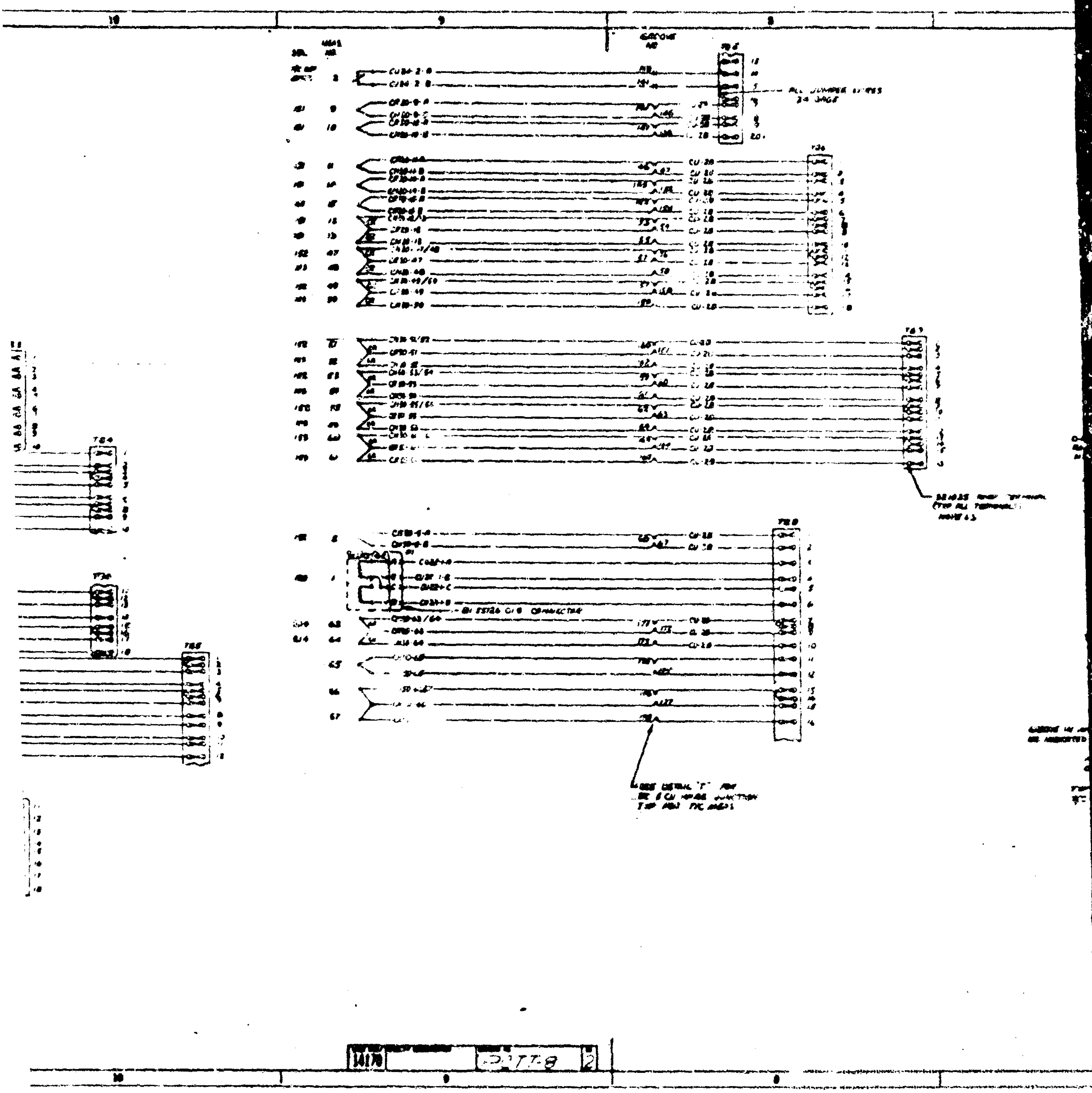

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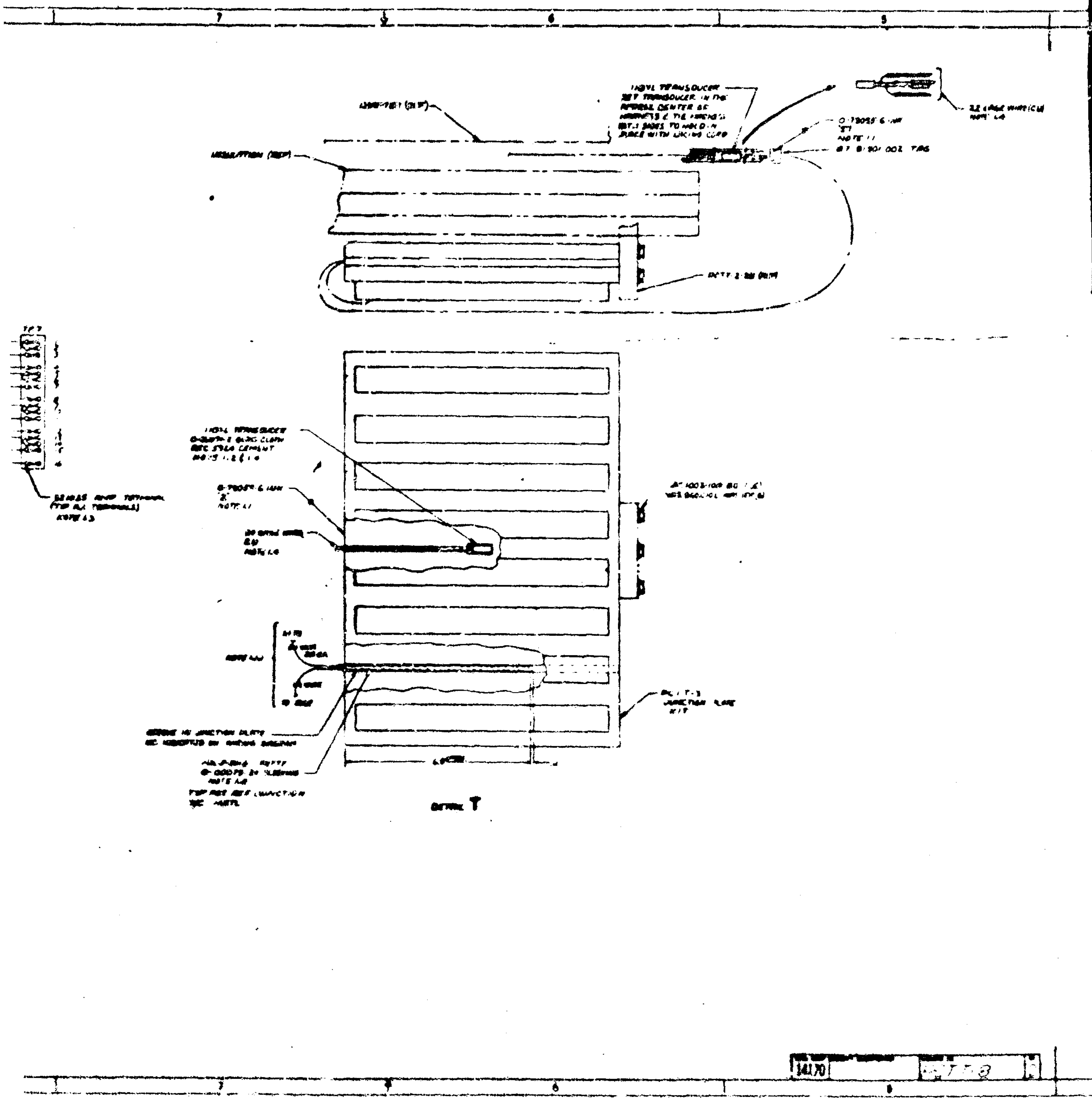
DETAIL T
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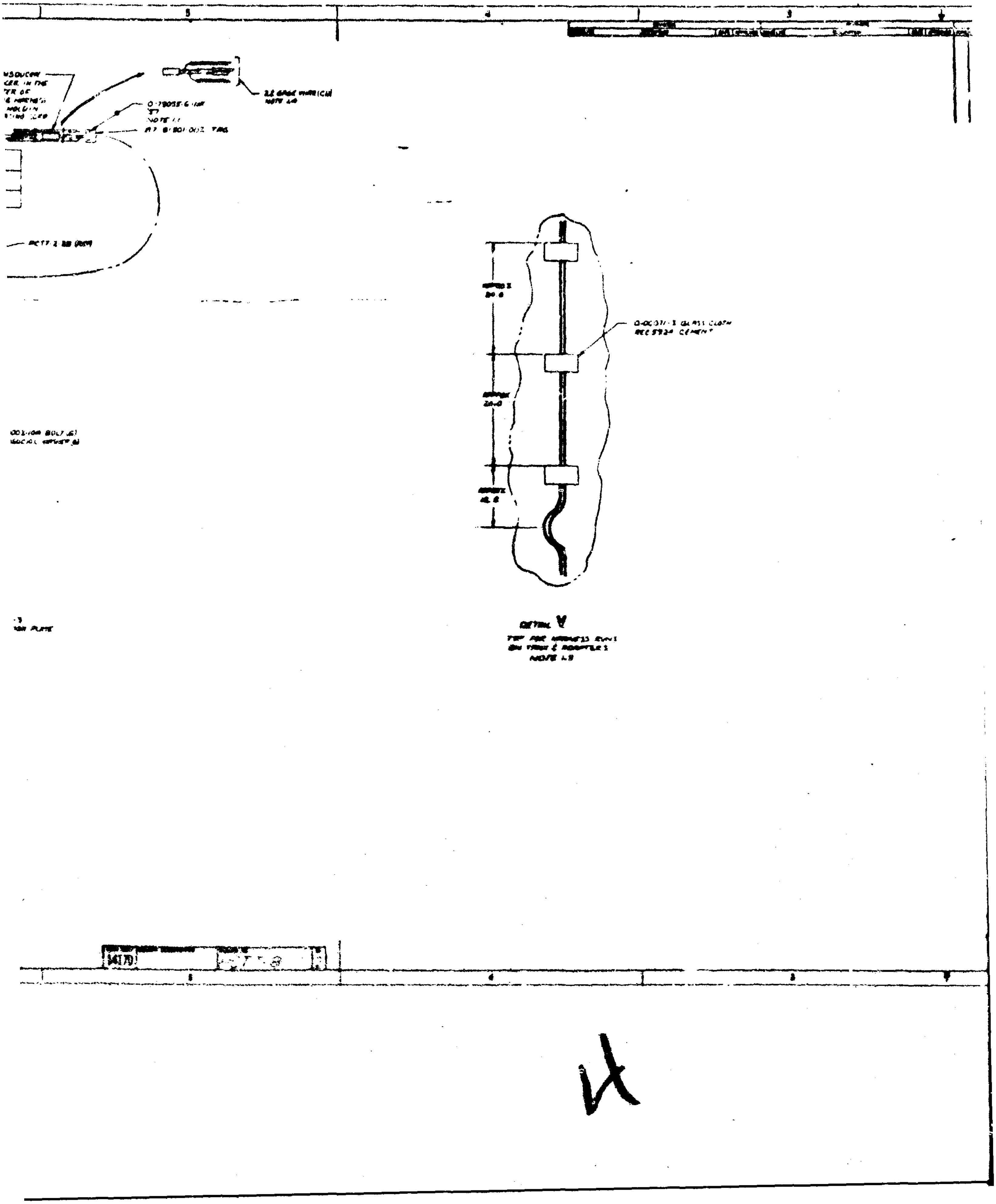

CEMENT
DETAIL V

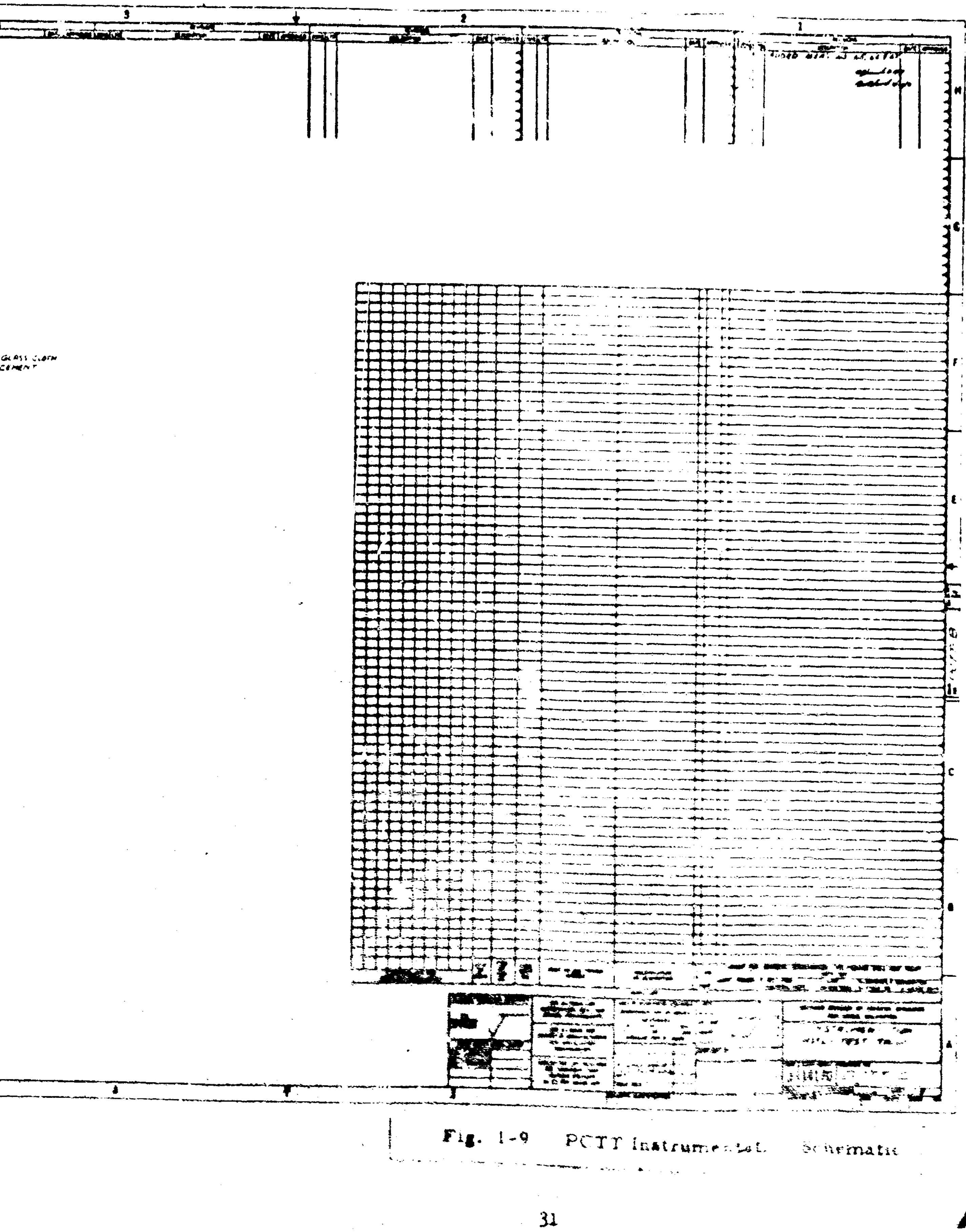

Fig. 1-9 PCTT Instrumentation Schematic

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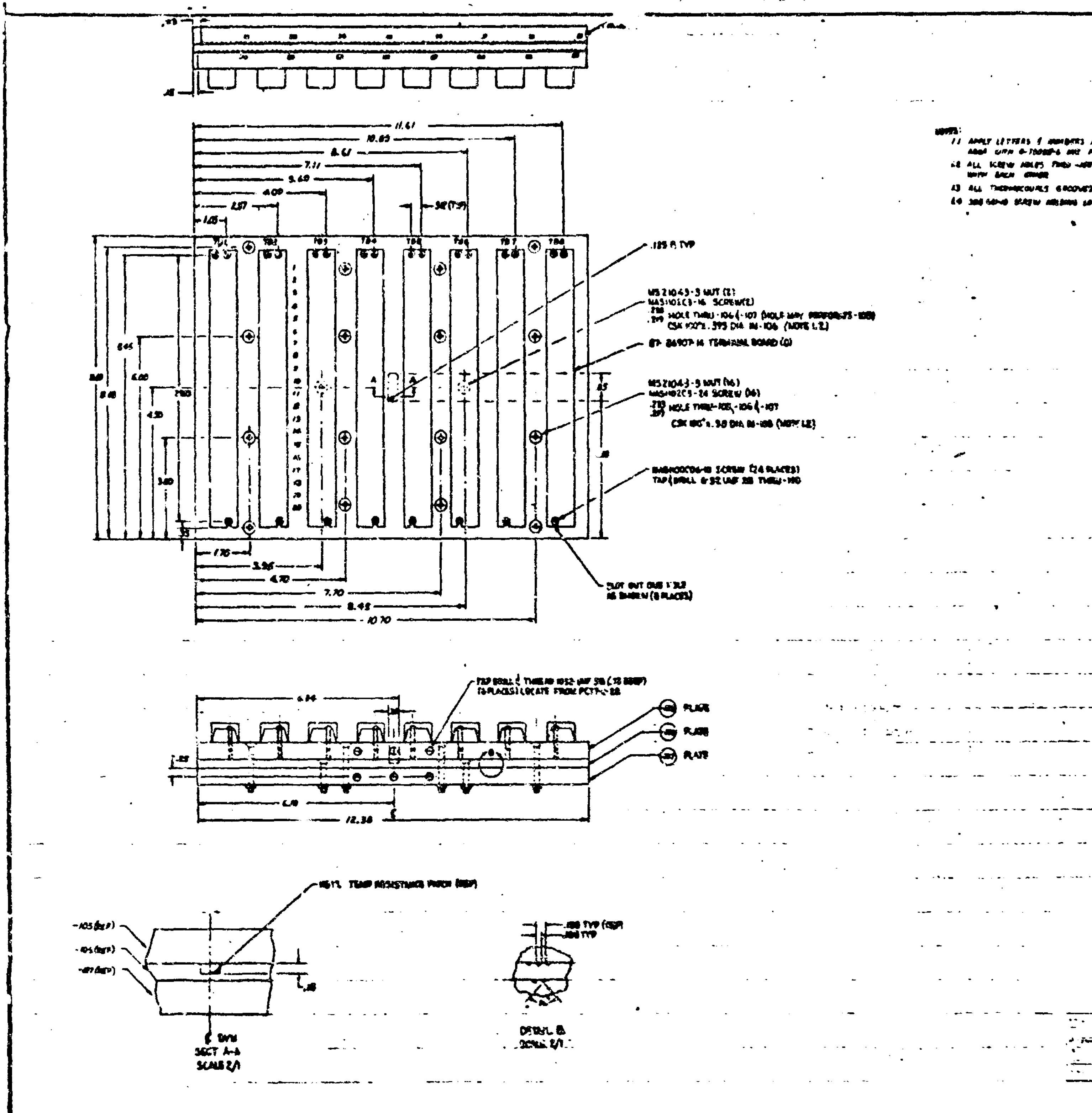

11.61
10.85
8.61
7.11
5.60
4.09
2.57
1.05
TB1
TB2
TB3
TB4
TB5
TB6
TB7
TB8
.125 R TYP
MS21043-3 NUT (2)
MS21043-3 NUT (16)
1.70
3.96
4.70
7.70
8.45
10.70
PLATE
PLATE
PLATE
6.10
12.38
SECT A-A
SCALE 2/1
DETAIL B
NOTES:

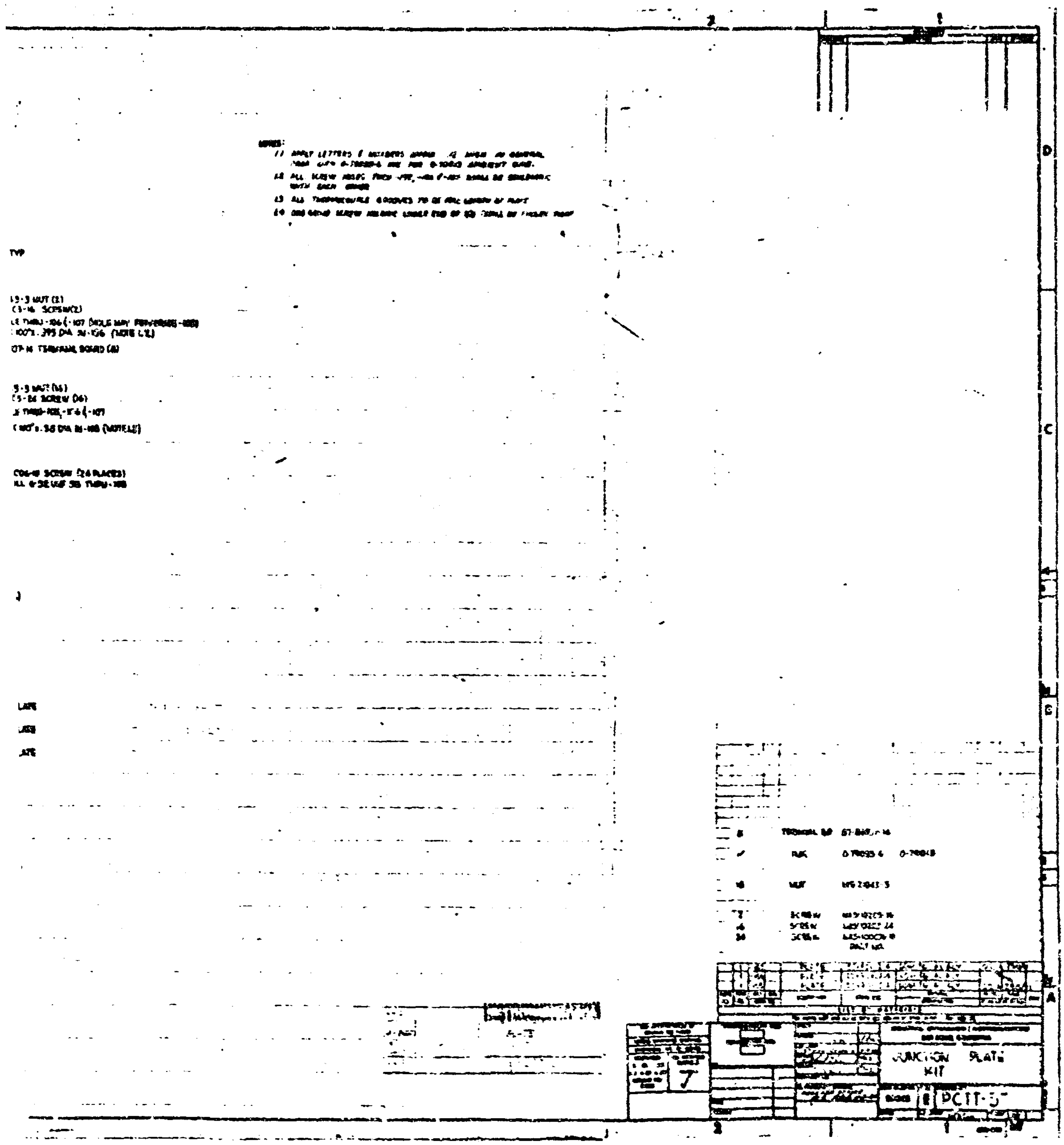

Fig. 1-10 PCTT Instrumentation Junction Block

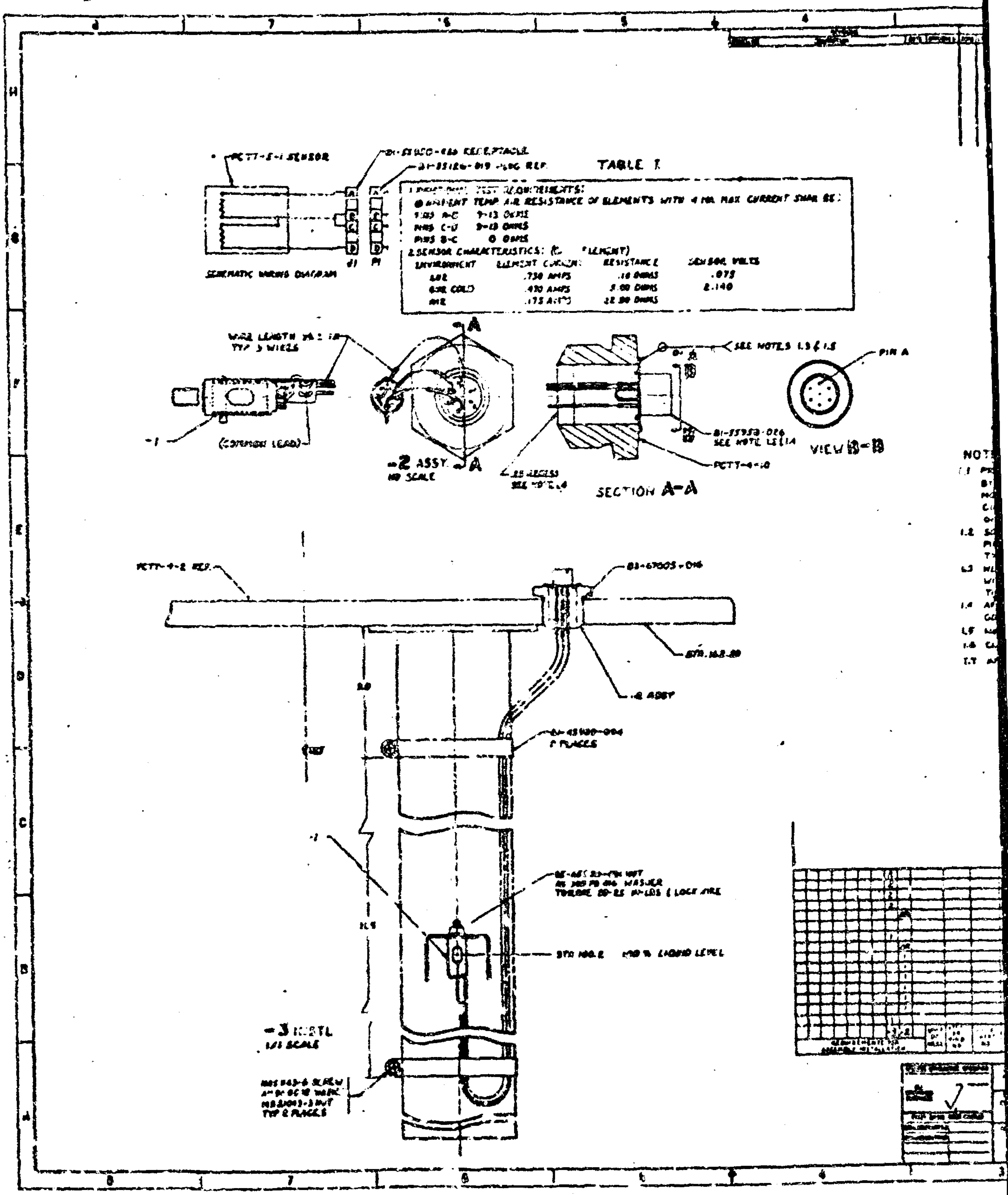
TABLE 1
SCHEMATIC WIRING DIAGRAM
(COMMON LEAD)
-2 ASSY
NO SCALE
SECTION A-A
VIEW B-B
SEE NOTES 1.3 & 1.5
PIN A
-3 INSTL
1/1 SCALE

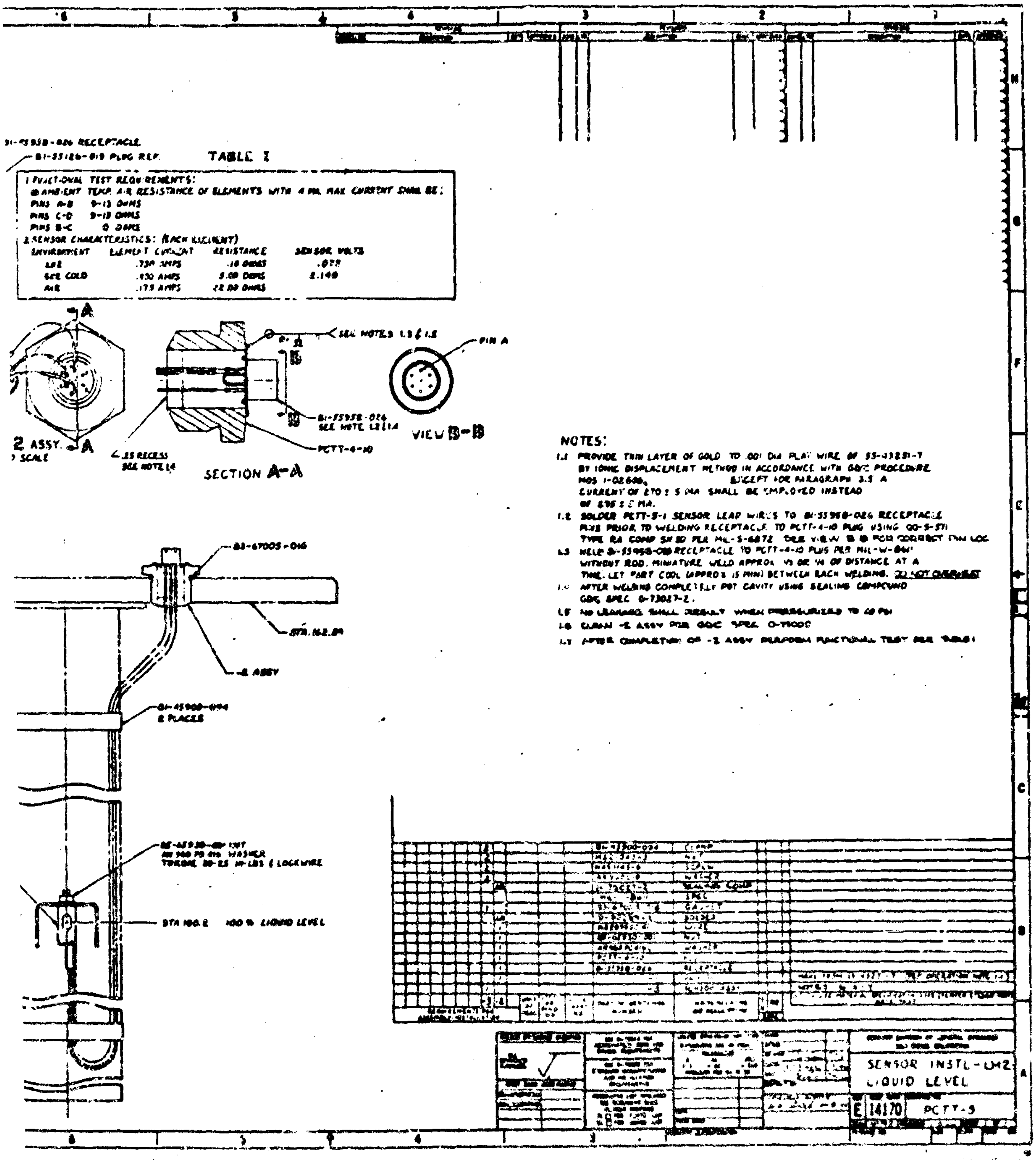

Fig. 1-11 PCTT Hot-Wire Sensor

gauge constantan and therefore of relatively high resistance, ranging up to about 40 ohms at room temperature.

Fifty-eight of the temperature measurements are made with chromel/constantan thermocouples. Thirty-nine of these are referenced to the junction block (Figure 1-10) which is expected to stabilize at about LN_2 temperature during the testing, and whose temperature is monitored by a Rosemont 118YL platinum resistance thermometer. Nineteen of the thermocouple pairs measure temperature differences between closely related points on the structure in order to assess the magnitude of the individual local heat leaks into and between the tanks.

The hot wire sensor is designed to determine liquid level in the liquid hydrogen tank during cryogenic testing. The sensor is located on the LH_2 tank fill and drain standpipe in such a manner as to detect liquid level at tank station 180.2. The liquid level sensor consists of two identical (redundant) resistance elements of one mil diameter platinum wire. A voltage applied to either or both elements (for redundant sensing) will result in a current which will vary as a function of the heat transfer characteristics of the sensor environment. The sensor power supply provides a low voltage (2.6 to 3.0V) to the sensor from a 28V dc source.

2. TEST ARTICLE FABRICATION

The Partitioned Centaur Test Tank modification and fabrication task comprised the following:

1. Cut the vehicle aft of station 219.0 and remove approximately 81 inches of constant section skin.

2. Fabricate and install a new partitioning bulkhead for the hydrogen tank.

3. Reweld forward bulkhead on to new constant section and install new fill and vent lines, covers, etc.

4. Fabricate and install two Fiberglas adapters which are 10 feet in diameter and approximately 68 inches long.

5. Fabricate and install two 10 foot diameter Fiberglas cover plates.

6. Fabricate and install one hot wire sensor, six platinum resistance type thermometers and approximately 58 chromel/constantan thermocouples.

7. Fabricate superinsulation blankets and install on vehicle.

This section of the report is devoted to the fabrication, assembly and installation tasks which were accomplished at the Convair facility in San Diego. A limited amount of final installation was accomplished at the Air Force Rocket Propulsion Laboratory by Convair personnel. This work is discussed in Section 4, Field Test Support.

2.1 TANK FABRICATION

The initial task associated with modification of the Centaur test tank into a PCTT configuration was to strip the forward bulkhead of fixed insulation and leak test the pre-modified tankage system to assure the integrity of the article to be modified. A freon leak test and a helium leak test were conducted on the test article in October 1966. The freon leak test was conducted first, using the Centaur Standard Equipment Operations Procedure 55-535.4.1 previously established for Centaur vehicles. The following is a brief description of the general requirements and procedures used during the freon testing of the LO_2 and LH_2 tanks.

1. The oxidizer tank pressure was raised to 7.5 psig, using nitrogen, and held for five minutes, after which time it was reduced to 3.7 psig.

2. The oxidizer tank pressure was then increased to 4.0 psig, using freon.

3. The oxidizer tank was then further pressurized to 5.0 psig, using nitrogen, and held for 30 minutes prior to sniffing.

4. A leak test on all seams, welds and other possible sources of leaks was then conducted, using the General Electric H-1 type sniffer.

5. The LH_2 tank pressure was then raised to 3.6 psig, using nitrogen, and held for five minutes, after which time it was reduced to 1.5 psig.

6. The LH_2 tank pressure was then increased to 1.8 psig, using freon.

7. The LH_2 tank was then further pressurized to 2.4 psig, using nitrogen, and held for 30 minutes prior to sniffing.

8. A leak test was then performed on all seams, welds, and other possible sources of leaks, using the G.E. sniffer.

Following the LO_2 and LH_2 tank test, a helium leak test was conducted on the intermediate bulkhead cavity using the Convair Equipment Operational Procedure 55-535.4.3.

A leak test consisting of 100% helium leak check of all weld areas was then conducted on the entire vehicle in accordance with the same procedure used for the freon leak testing.

The results of this series of tests showed no leaks in excess of 2.6×10^{-5} cc/sec in the weld areas. A leak in the spring bulkhead (Convair was previously aware of this leak) was observed and calculated to be 2.8×10^{-8} standard cc He/sec. After completion of the pre-modification acceptance testing, Convair proceeded with tank and tank components modification and fabrication.

The Centaur test article was installed in the major weld fixture (modified for this program) and preparations completed for cutting the cylindrical skin (thus removing the forward bulkhead) for the purpose of installing the new partitioning bulkhead, and shortening the overall length. After cutting the cylindrical skin, the forward bulkhead was placed in storage for subsequent reinstallation. Existing doublers which would cause interference with the installation of the new partitioning bulkhead were ground off.

The new partitioning bulkhead was fabricated on existing tooling using similar procedures to those used for Centaur production bulkheads, the major difference being that Centaur bulkheads are chem-milled and the partitioning bulkhead was not. Material qualification procedures followed were the same as those used on production vehicles. Quality controls were identical to production methods except no radiographic inspection was performed on weld joints. A separate bulkhead leak test was performed on the bulkhead assembly prior to installation.

In preparation for the installation of the new bulkhead, the aft section of the tank was relocated in the major weld fixture and a new short length cylindrical skin installed. The new bulkhead was then welded to the tank using the aft gantry welder. See Figures 2-1 and 2-2. Resistance spotweld and seamwelding techniques were used during this process. The forward bulkhead was then taken out of storage and reinstalled by use of the aft gantry welder to complete the basic tank modification task. See Figure 2-3 for completed tank.

Detail fabrication of the forward and aft door assemblies, the fill and drain lines, and the pressurization lines, was accomplished using standard machining and fusion welding techniques. The door assemblies were installed on the tank and the lines were prepared for shipment to AFRPL for subsequent attachment as part of the field test support task described in Section 4.

2.2 ADAPTER AND COVER PLATE FABRICATION

The fabrication technique applied to the production of the detailed parts for the forward and aft adapters and the cover plates was the typical dry layup of glass fabric, reinforced plastic laminates. This process essentially consists of preparing the layup tool, applying the designated plys, preparation for and application of the vacuum bag processing, curing the parts and

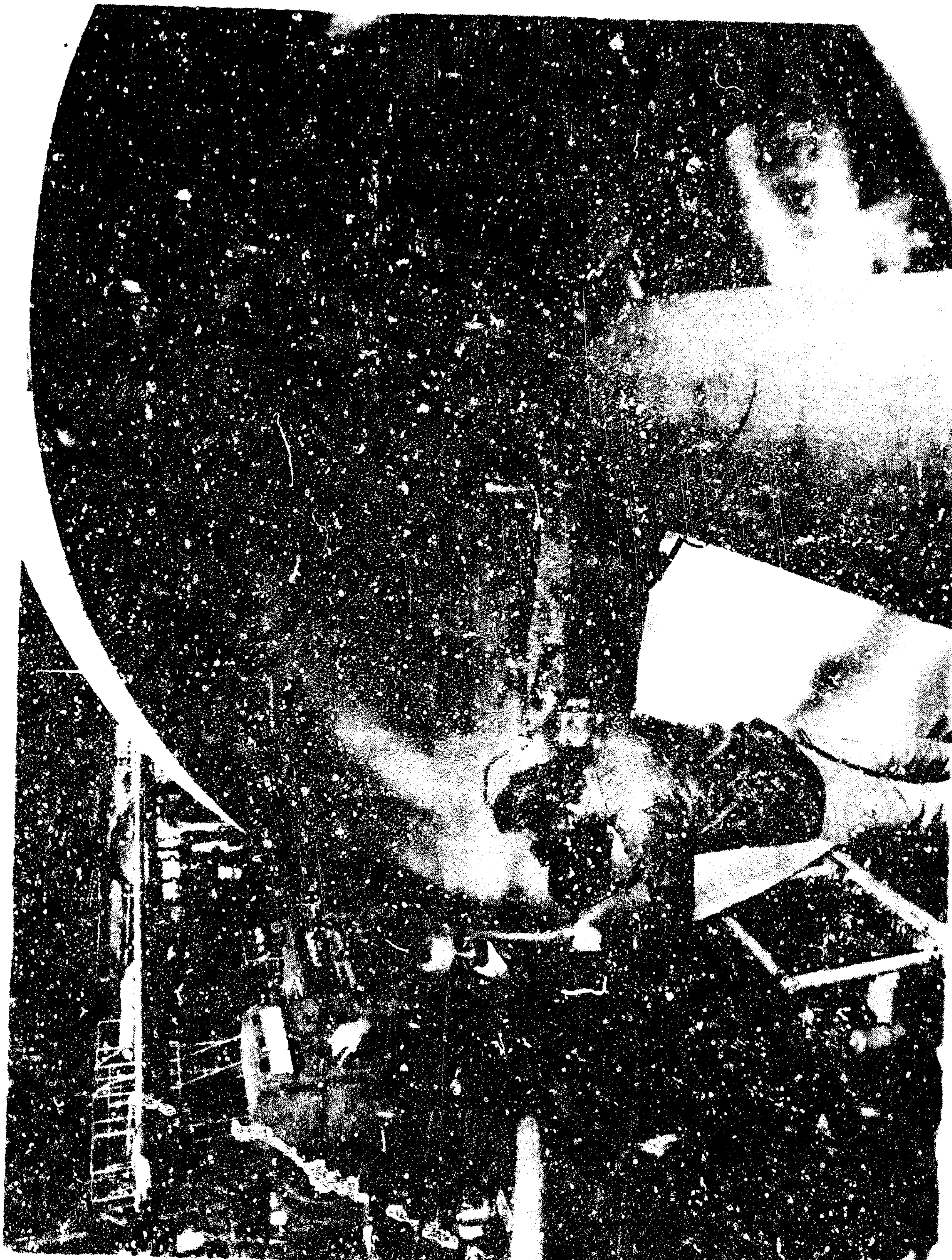

Figure 2-1 Aft Gantry Welder

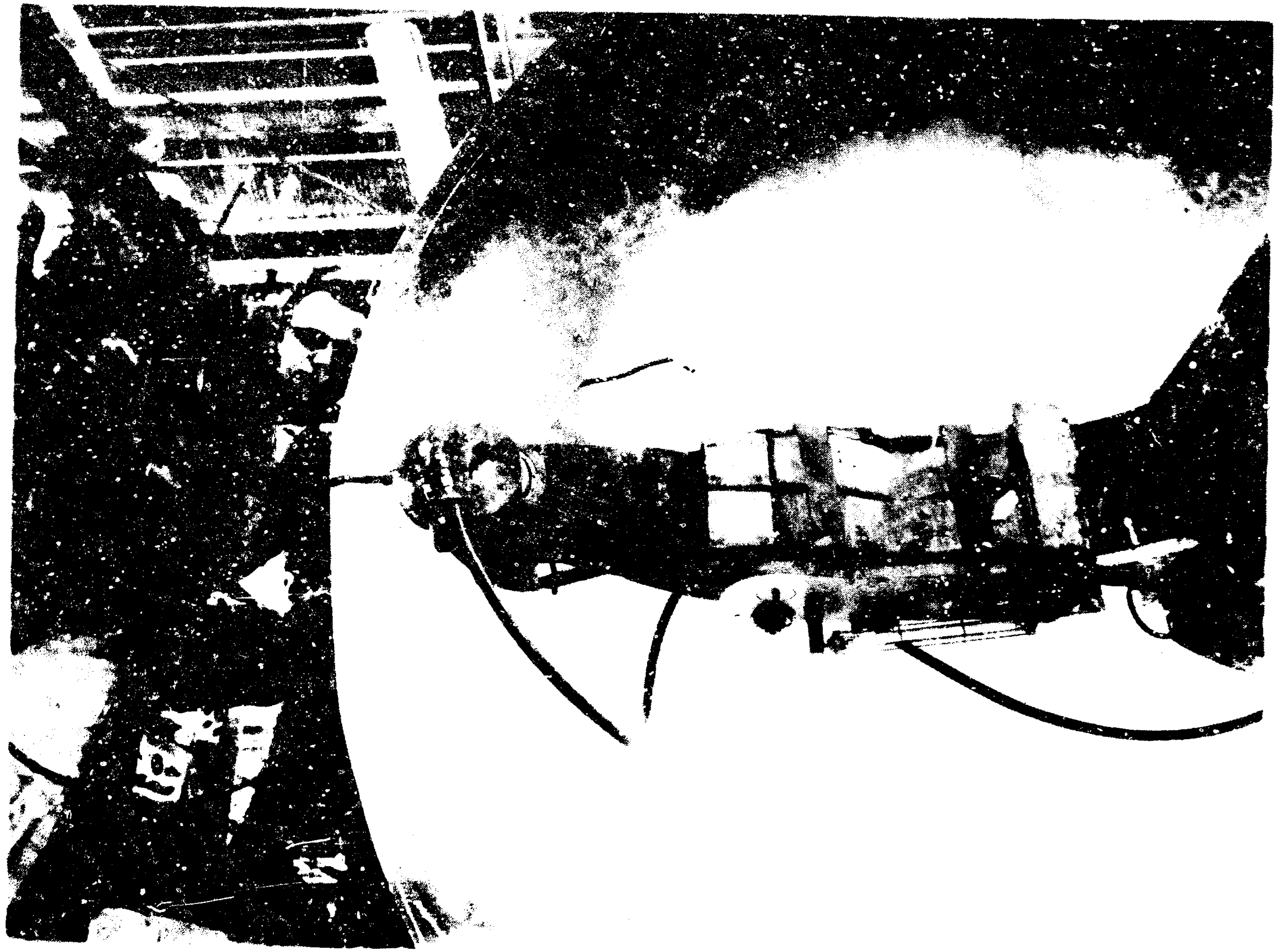

Figure 2- Partitioning Bulkhead Installation

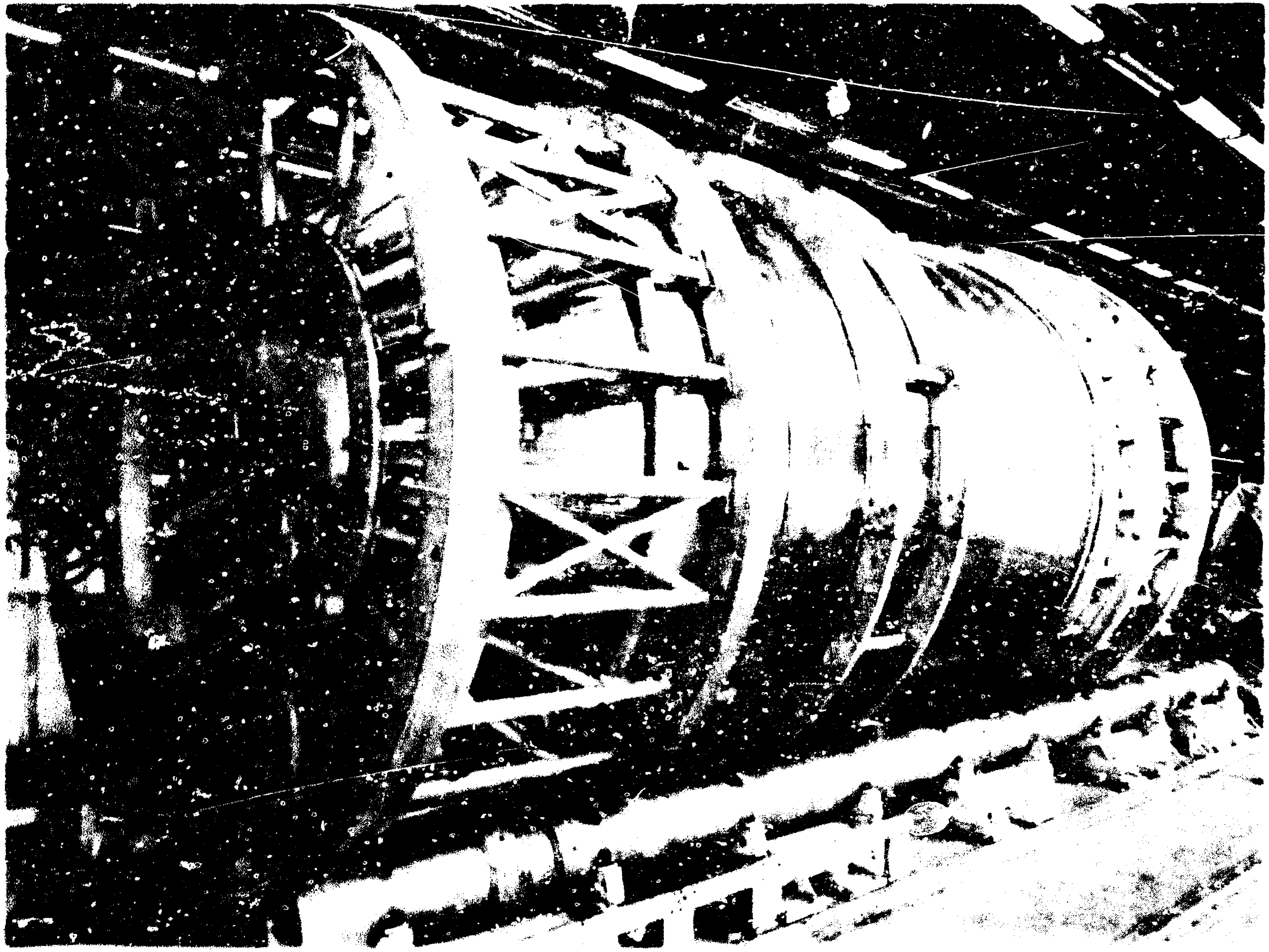

Figure 2-3 PCTT Basic Tank

trimming them to blueprint specifications.

All adapter details requiring a contour shape were fabricated from one layup tool designed and constructed for this program. Parts fabricated on this tool included the cylindrical skin quadrants, longerons, plates, doublers and splices.

All cover plate details were fabricated on aluminum flat plates. Trim and drill tools were made of template stock and wrapped to contour as required.

Two aluminum rings for each adapter were required to be fabricated for this program. The aluminum ring for the outboard end of each adapter was fabricated from an existing channel section ring provided as part of the GFP. The aluminum ring for the inboard end of each adapter was fabricated from a welded 6061 aluminum blank. The blanks were rolled to shape, solution heat treated, aged to T6 condition, fusion (tig) welded, radiographic inspected and machined to final configuration.

The forward and aft adapter were assembled by use of existing (modified) tooling as shown in Figures 2-4, 2-5 and 2-6. The entire assemblies were bolted together. The aluminum attachment rings were drilled from existing Centaur master gauge tooling to assure matching of the hole pattern established on tank mounting rings.

Cover plates were assembled using bolts, nuts and washers for all joining requirements. No special tooling was required for this assembly except for the drilling operation of holes in the cover plates for attachment to the adapters. These holes were drilled from the same available master gauge tools used to drill the adapter rings and tank attachment rings.

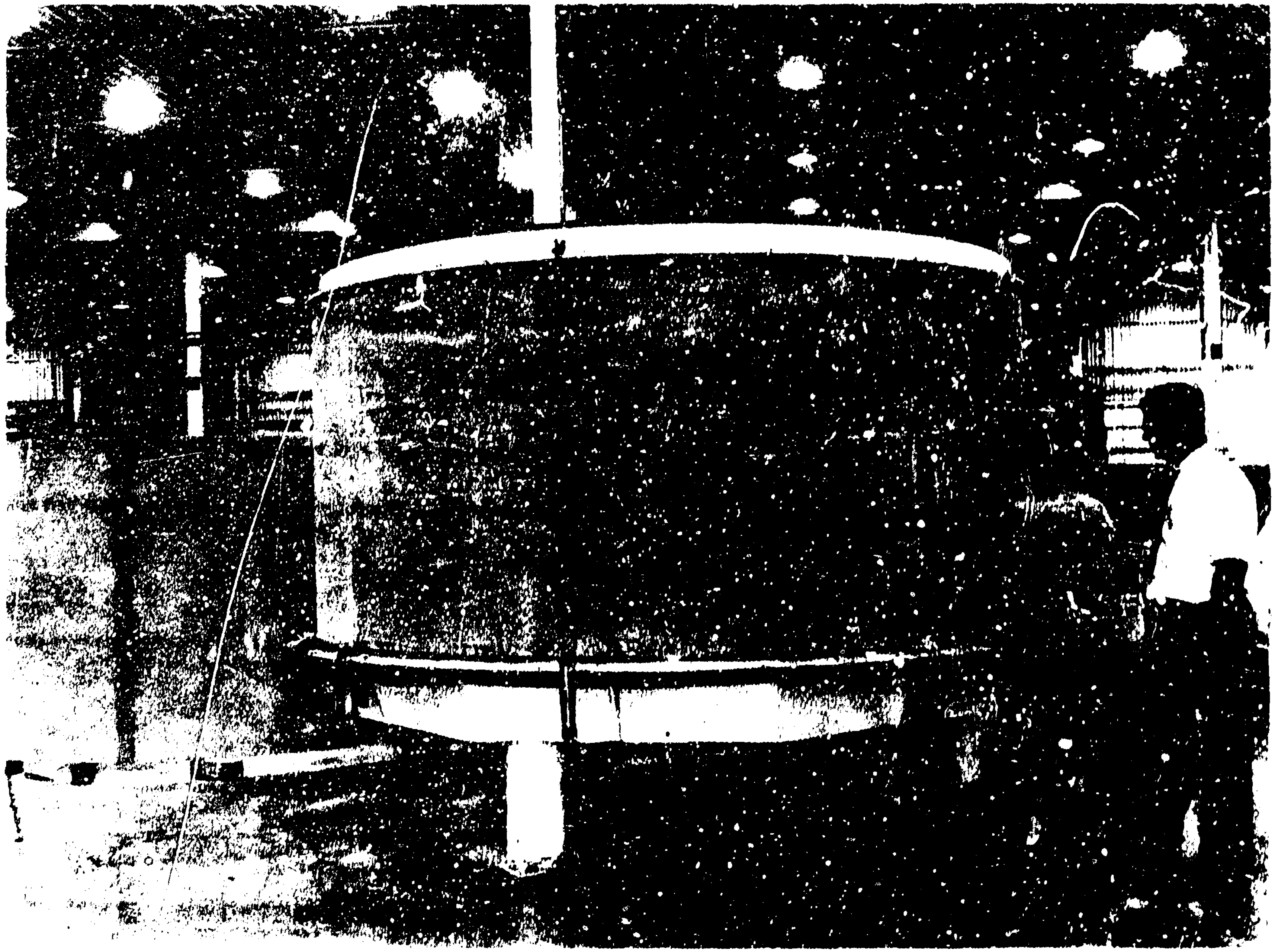

Figure 2-4 PCPT Adapter Assembly

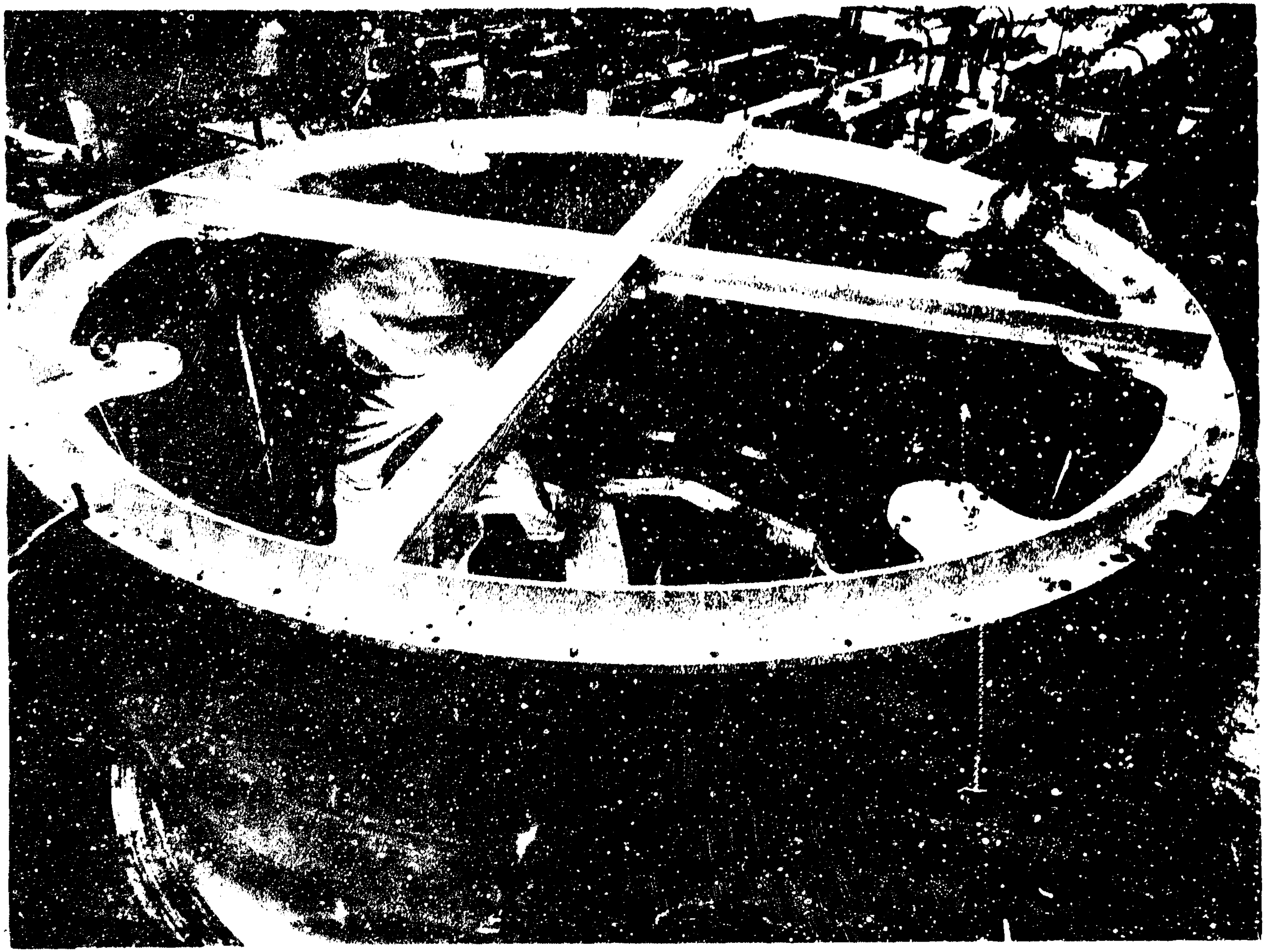

Figure 2-5 PCTT Adapter Ring Installation

Figure 2-6   Forward Adapter Assembly

2.3 INSULATION BLANKET FABRICATION

All insulation blankets were assembled by the Super-Temp Corporation in accordance with blueprints and specifications provided by Convair. The blankets were prepared by alternate stacking of a smooth aluminized mylar sheet and a "dimpled" aluminized mylar sheet until the desired buildup was obtained. All blankets were fabricated oversize and a planned trimming operation was to take place at the time of installation.

2.4 INSTRUMENTATION FABRICATION

The hot wire sensor was installed on the LH_2 fill and drain standpipe in such a manner as to indicate liquid level at tank station 180.2. Sensor lead wires were soldered to a standard receptacle which in turn was welded into a bulkhead pass-through fitting. This fitting, made from a standard MS plug, was then installed in the forward tank cover plate using a metal "O" ring for sealing. These leads were then carried to the terminal junction plate located on the aft adapter. The terminal plate and reference junction block were fabricated using standard machining techniques.

2.5 FINAL ASSEMBLY

The final assembly task at the Convair San Diego plant consisted primarily of the task of installing the forward and aft adapters and the forward and aft cover plates.

The forward and aft adapters were installed on the tank assembly while in the horizontal position. (See Figures 2-7 and 2-8.) This installation is completed by bolting the aft flange of the adapter to the tank mating ring. The forward adapter installation incorporates the use of radius blocks installed behind the tank ring.

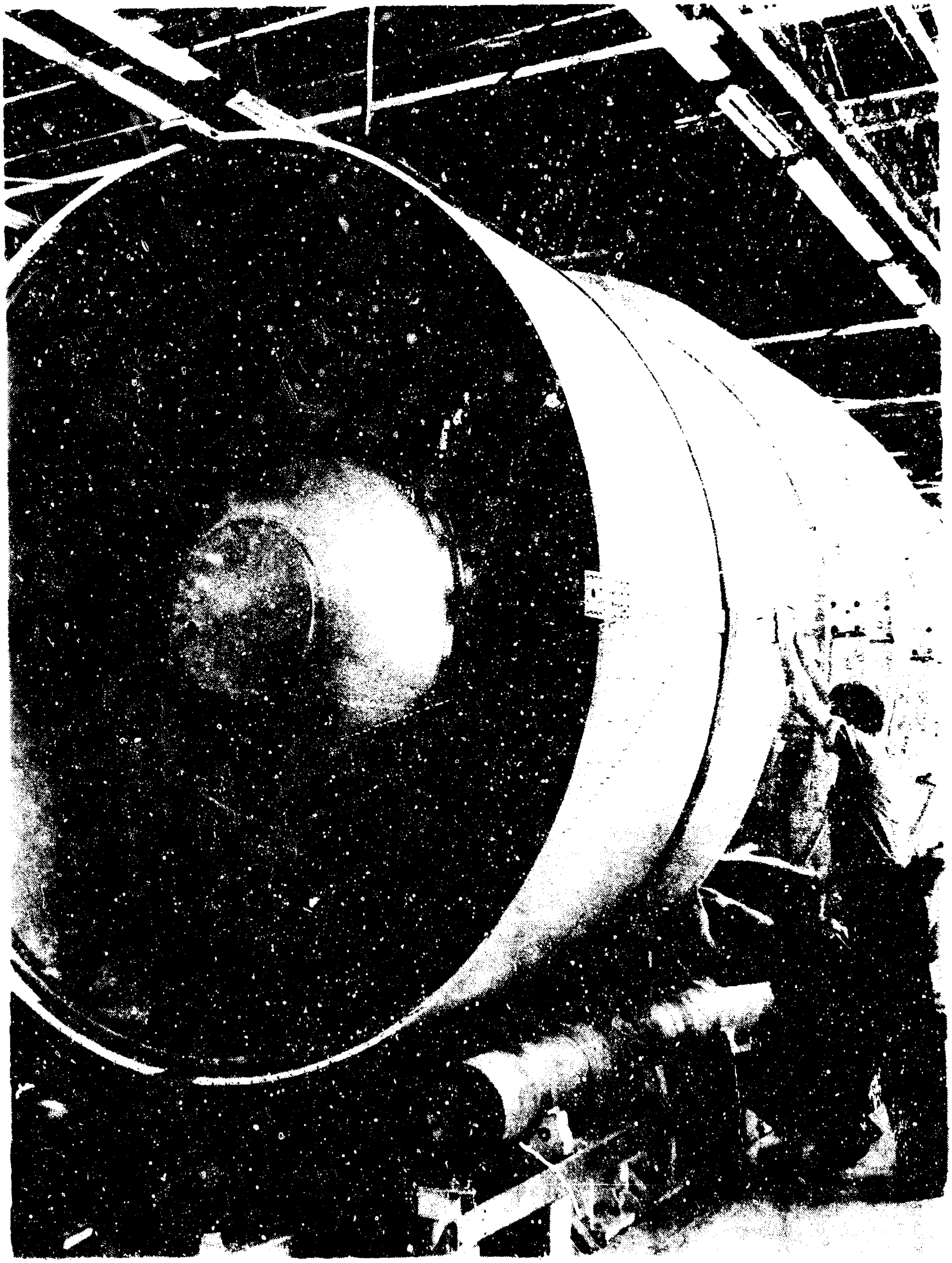

Figure 2-7 Forward Adapter Installation

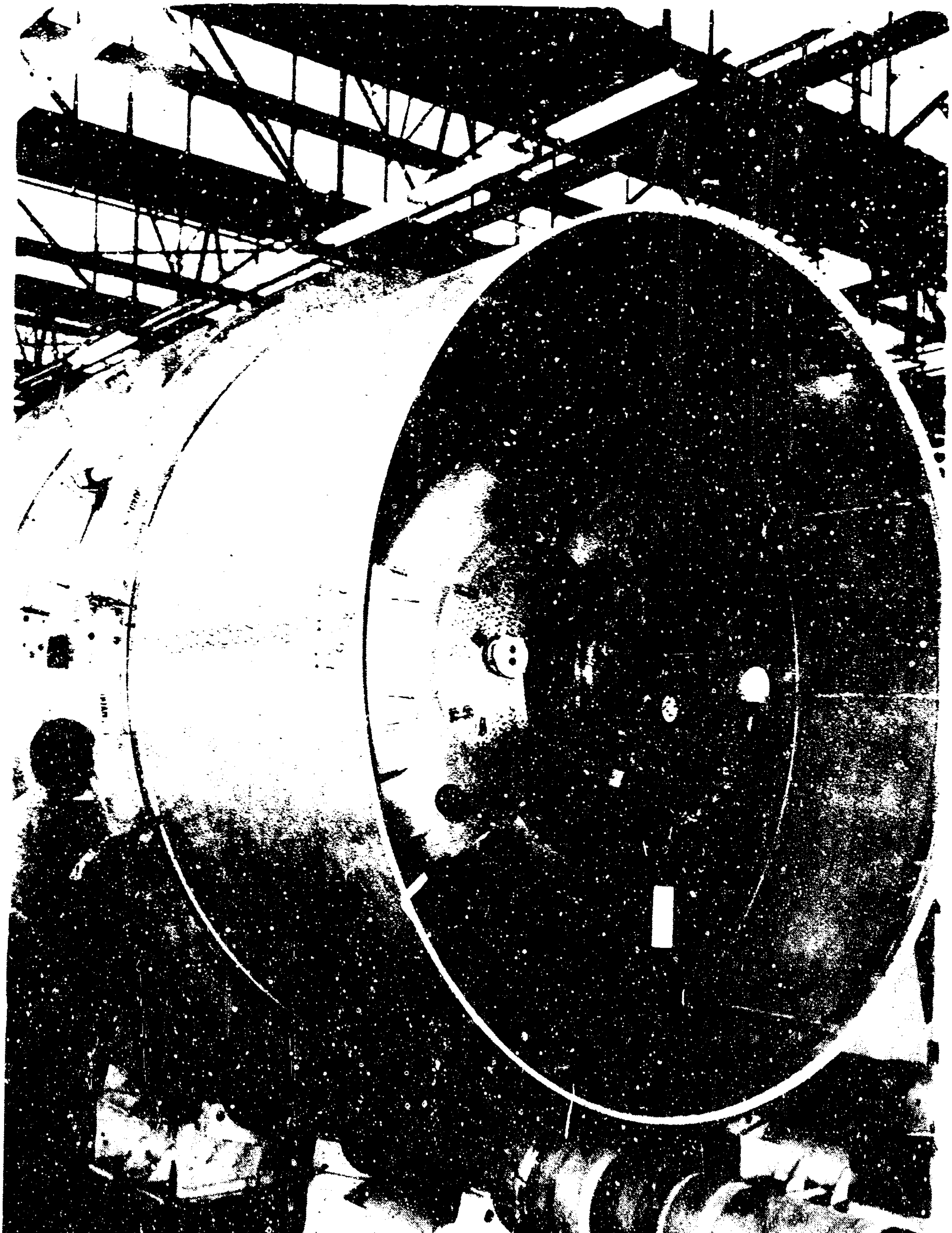

Figure 2-8 Aft Adapter Installation

The forward and aft cover plates were then installed on the outboard end of each adapter (see Figure 2-9) with bolts and nuts, thus completing the installation task. The test article was now ready for final acceptance testing at San Diego.

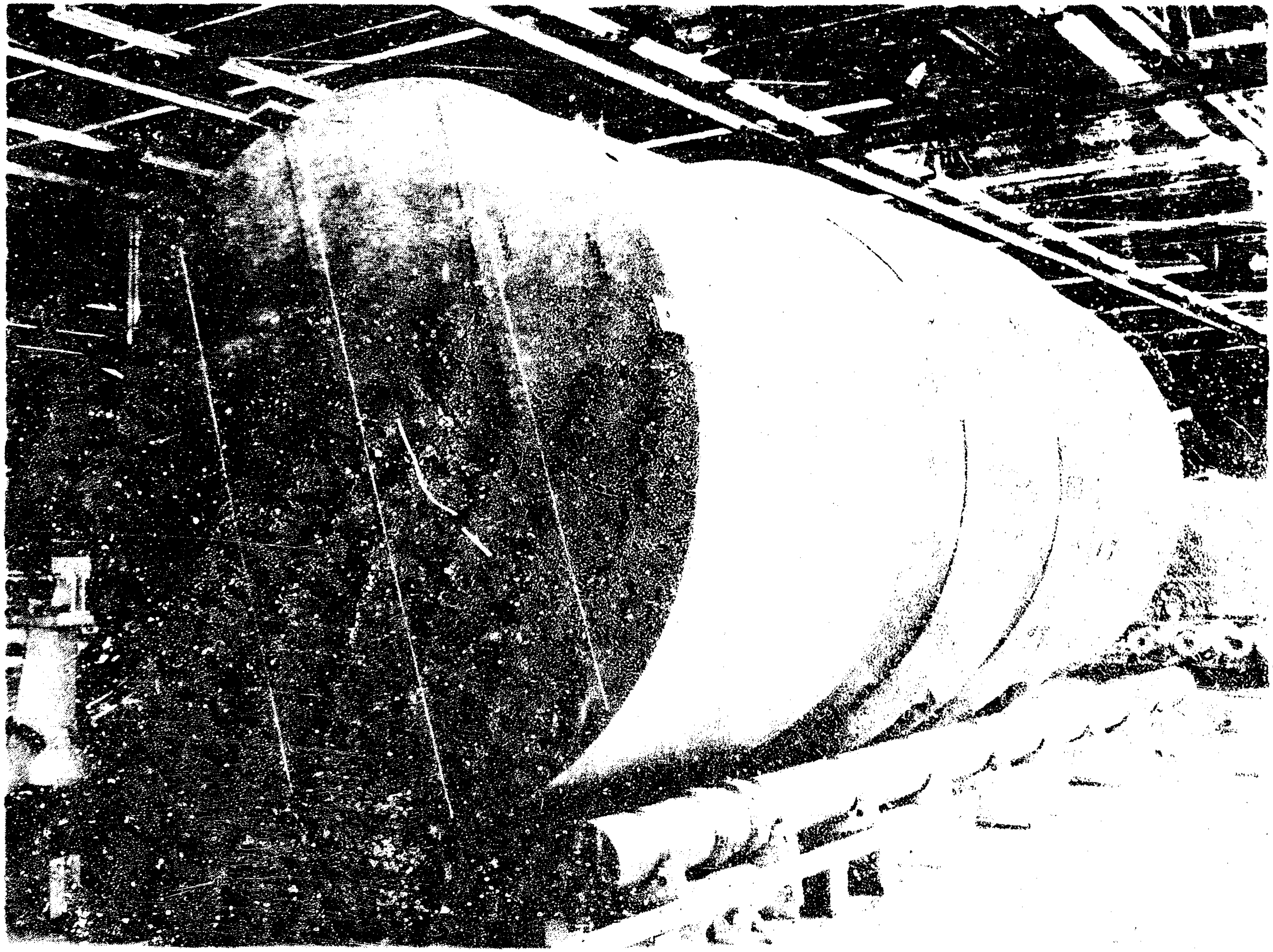

Figure 2-9 Cover Plate Installation

3. TEST ARTICLE DELIVERY

3.1 ACCEPTANCE LEAK TEST

An acceptance helium leak test of all weld areas was conducted on the PCTT prior to delivery. Detection of individual leaks greater than 2.6 x 10^{-5} cc/sec would be cause for rejection.

The following sequence of leak testing was planned and accomplished on the Partitioned Centaur Test Tank prior to delivery:

1. Pressurize the LH_2 tank and LO_2 tank with pure helium and perform a leak check on all weld areas using the Veeco leak detector in conjunction with a sniffer probe.

2. Determine the helium content in the intermediate tank and monitor for increase in concentration thus determining if the bulkheads forming the intermediate tank were satisfactory. (It was later discovered that this test was not feasible except to establish a confidence level.)

3. Pressurize the intermediate tank with pure helium and check all external weld areas for leaks using the Veeco leak detector in conjunction with the sniffer probe.

The leak testing of the LH_2 and LO_2 tanks was accomplished on January 18, 1967. Both tanks were pressurized with pure helium to approximately 8 psig and allowed to stand for 30 minutes. All welds associated with these tanks were then leak checked with the Veeco leak detector using a standard equipment operational procedure and operated by a qualified person from the inspection department. No leaks were detected with the Veeco and probe on its highest sensitivity scale.

On January 19, 1967, with the LH_2 and LO_2 tanks locked up at 7.5 psig with pure helium, nitrogen was introduced into the intermediate tank until a pressure of 3.5 psig was reached. This procedure was implemented in preparation of taking a base point (initial helium concentration) reading with the Veeco the following morning. The plan was to then take subsequent readings at four hour intervals for 24 hours to determine if the concentration changed from the base reading. If the concentration changed, it would be indicative of a leak in one of the bulkheads.

On January 20, 1967, the intermediate tank was vented to zero psig and the first reading taken with the Veeco and probe. This reading was recorded as 340 units on the Veeco. This reading and a subsequent calculation on the possible parts per million count of helium was evaluated to be excessively high for a base point reading. A nitrogen purge of the intertank was then directed by engineering. After 2 hours of nitrogen purge at a low flow rate and essentially zero pressure, a second Veeco reading was taken. This reading was recorded to be 9.9 units on a 100 scale. Further discussion in the Engineering department on the procedure being used to check the intertank disclosed that this method of testing would be inconclusive. This conclusion was based on the use of the probe in a large volume (intertank is approximately 250 cubic feet) giving dilution effects, for which the machine has no compensating capability. Because of the uncertainty of the test results with the Veeco apparatus, a decision was made to take gas samples and analyze these samples in the laboratory on a Perkin-Elmer, Model 154-D, gas chromatograph. Veeco reading would also be continued. This new procedure for leak testing the intertank was discussed with the AFRPL Project Engineer, who directed the implementation of this procedure. Convair initiated a 48 hour leak check sequence with the intent of demonstrating that no increase in helium concentration (within the limits of the test equipment) occurred in the intermediate cavity. The results of this test are shown in Table 3-1. It should be noted that the accuracy of the gas chromatograph is considered by Convair laboratory personnel to be ± 20 parts per million. The data in Table 3-1 shows that for a period of time exceeding 46 hours, the concentration did not increase with the exception of a sample taken at 6:20 p.m. on January 23, 1967. This one exception was attributed to a tank watch on the night shift inadvertently pressurizing the intertank cavity with nitrogen through a hose which was previously used for pressurizing the LH_2 and LO_2 tanks with helium.

The third phase of acceptance testing was initiated on January 26, 1967. This phase consisted of pressurizing the intertank cavity to 3.5 psig with pure helium and leak checking all external weld areas with the Veeco leak detector and sniffer probe. No leaks were detected.

Preliminary inspection of the test article was conducted on January 27, 1967, by the AFRPL Project Engineer resulting in the initial signing of the DD250 and authorization to deliver the PCTT to AFRPL.

Prior to completing the preliminary inspection on the PCTT, it was necessary to disposition an Air Force Discrepancy Report, issued by the

TABLE 3-1 LEAK TEST READINGS

DATE TIME	VEECO BACKGROUND READING	VEECO TANK READING	CHROMATOGRAPH READING	TANK PRESSURE (PSIG)	REMARKS
1-23-67					
8:09 a.m.	1.9	30.0	226 PPM	3.0	
3:00 p.m.	1.5	29.0		3.5	No gas sample
4:00 p.m.	1.4	28.0		3.5	No gas sample
5:00 p.m.	1.4	20.0		3.5	No gas sample
6:00 p.m.	1.8	19.5		3.3	No gas sample
6:20 p.m.	1.9	19.0	360 PPM	3.3	Helium possibly introduced into tank
1-24-67					
8:30 a.m.	1.9	18.0		2.9	No gas sample
10:10 a.m.	1.9	14.5	260 PPM	2.9	
1:00 p.m.	1.9	13.0		2.5	No gas sample
3:00 p.m.	1.9	14.0	274 PPM	2.3	
4:00 p.m.	1.7	6.0		2.3	No gas sample
5:00 p.m.	1.7	25.0		2.2	No gas sample
6:00 p.m.	1.7	18.0		2.1	No gas sample
1-25-67					
9:00 a.m.	2.1	13.0	237 PPM	2.1	
11:00 a.m.	1.5	13.0		2.1	No gas sample
1:00 p.m.	1.9	16.0		2.1	No gas sample
2:00 p.m.	1.9	17.0	264 PPM	2.0	
4:00 p.m.	1.3	18.0		1.9	No gas sample
5:10 p.m.	1.4	16.0	272 PPM	1.8	

DECASPRO Quality Assurance Representative. This report (67-02-3) was issued to document a previous known condition of spotweld corrosion pits and cracks discovered on test tank 55-7542-1 on September 8, 1964. The discrepancy report reflected the following information regarding the PCTT spotweld corrosion status:

- Aft bulkhead contains 316 spotwelds with corrosion pits.
- Constant skin contains 71 spotwelds with corrosion pits.
- Aft bulkhead contains 90 spotwelds with corrosion cracks.
- Constant skin contains 41 spotwelds with corrosion cracks.

This condition was previously known by Convair and was thoroughly evaluated as part of the tank corrosion study program, conducted by Convair under contracts to the NASA Lewis Research Center, discussed in Section 1.1.3 of this report.

The Air Force Discrepancy Report described above, was dispositioned to the satisfaction of the Air Force by Convair defining the appropriate functional limitations to be used in handling, transporting and testing the PCTT. These limitations are presented in Convair Report GDC-BTD66-216, "Functional Limitations of The Partitioned Centaur Test Tank".

3.2 SHIPPING

The PCTT vehicle was prepared for shipment to the AFRPL by use of a standard "low boy" trailer. The test article was supported on the trailer through the use of wood saddles bolted to the trailer bed. (See Figure 3-1.) Steel bands were then secured around the vehicle and fixed to the trailer bed as

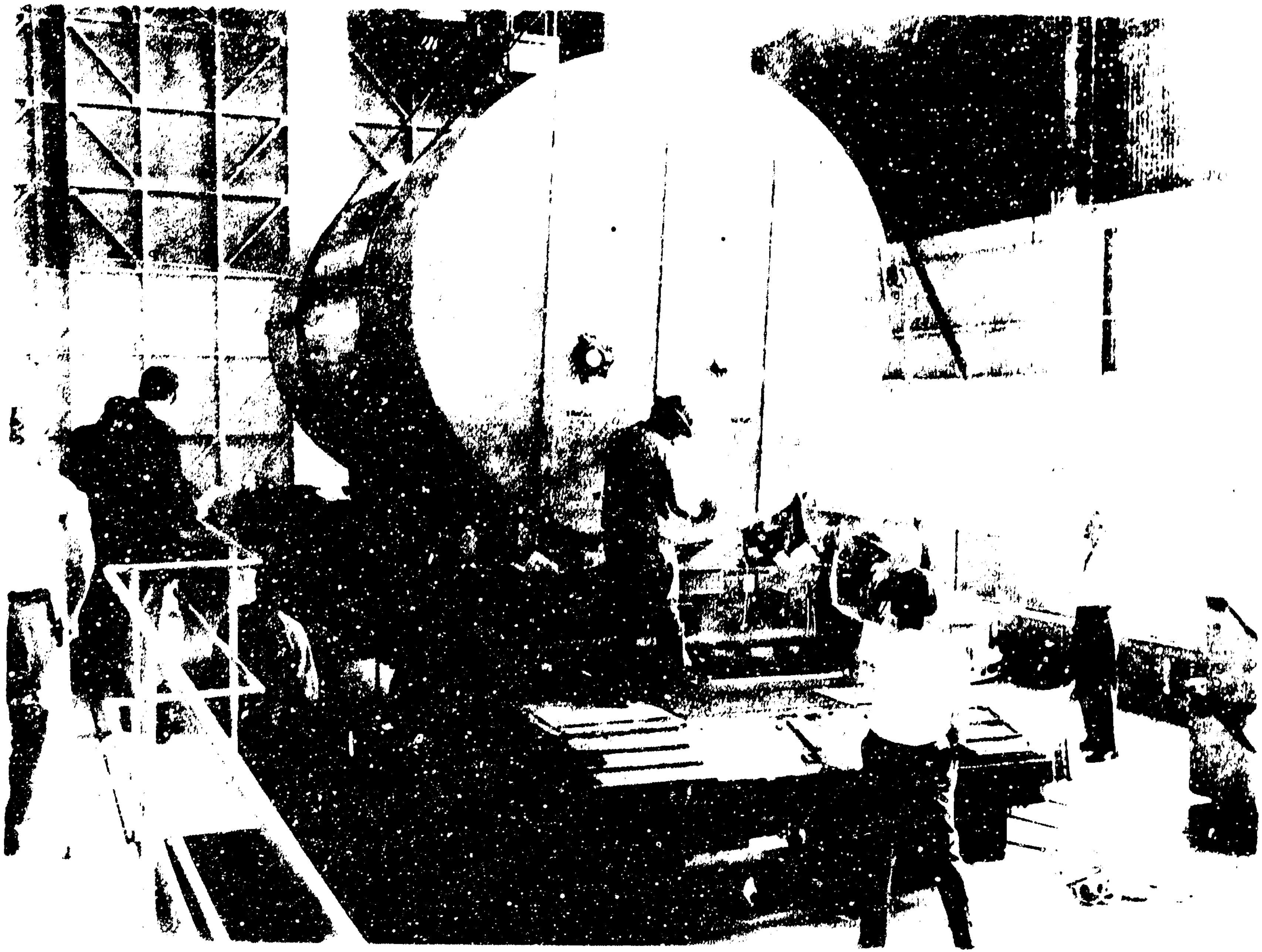

Figure 3-1 PCTT Support Saddles

shown in Figure 3-2. A Centaur transportation pressurization unit (Figure 3-3) was installed on the trailer to be used for automatically maintaining tank pressures between specified bands during transportation to AFRPL. The entire test article was shrouded with a polyethylene cover and delivery was made to the Air Force Rocket Propulsion Laboratory on January 30, 1967.

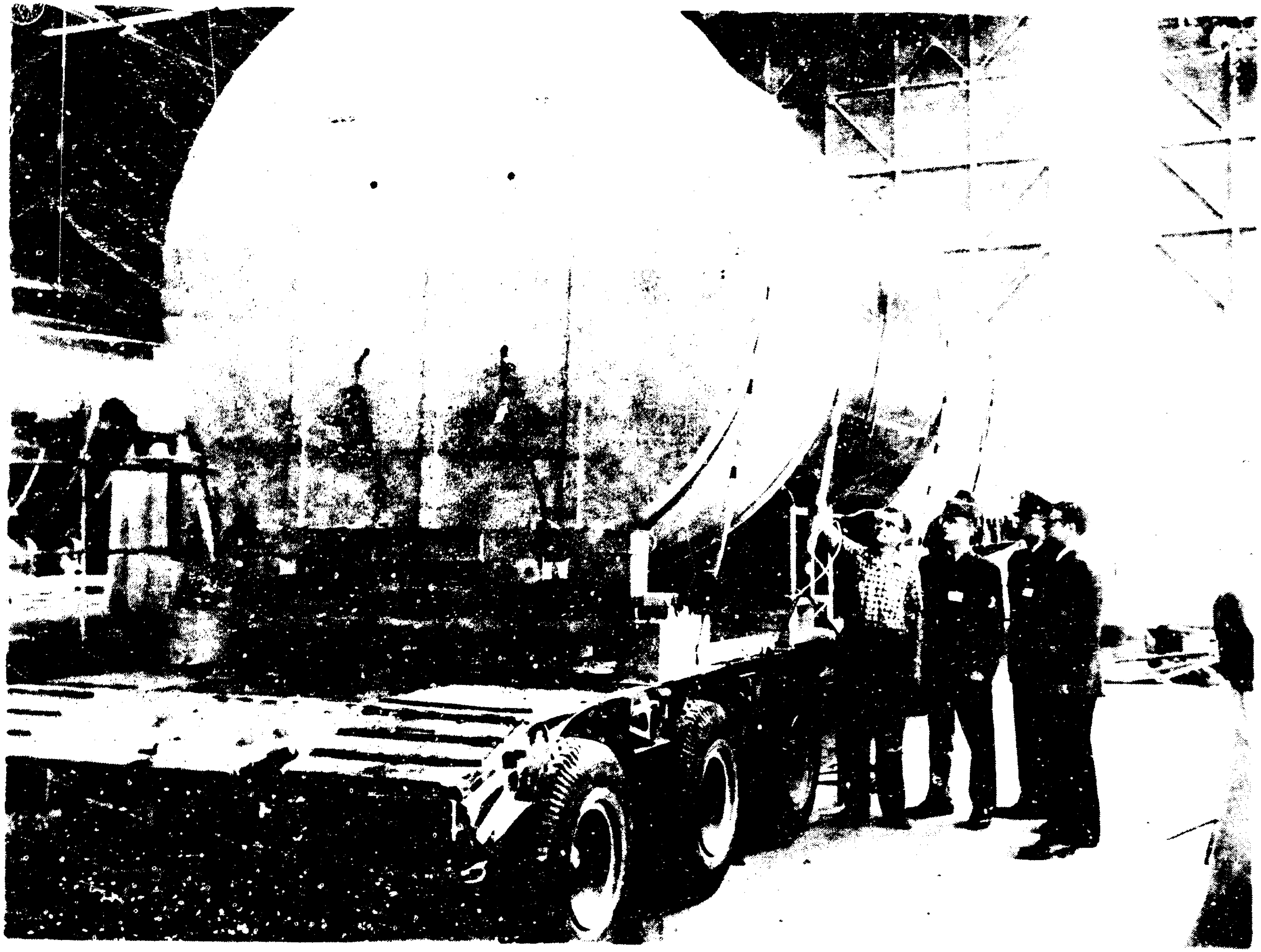

Figure 3-2 PCTT Shipping Installation

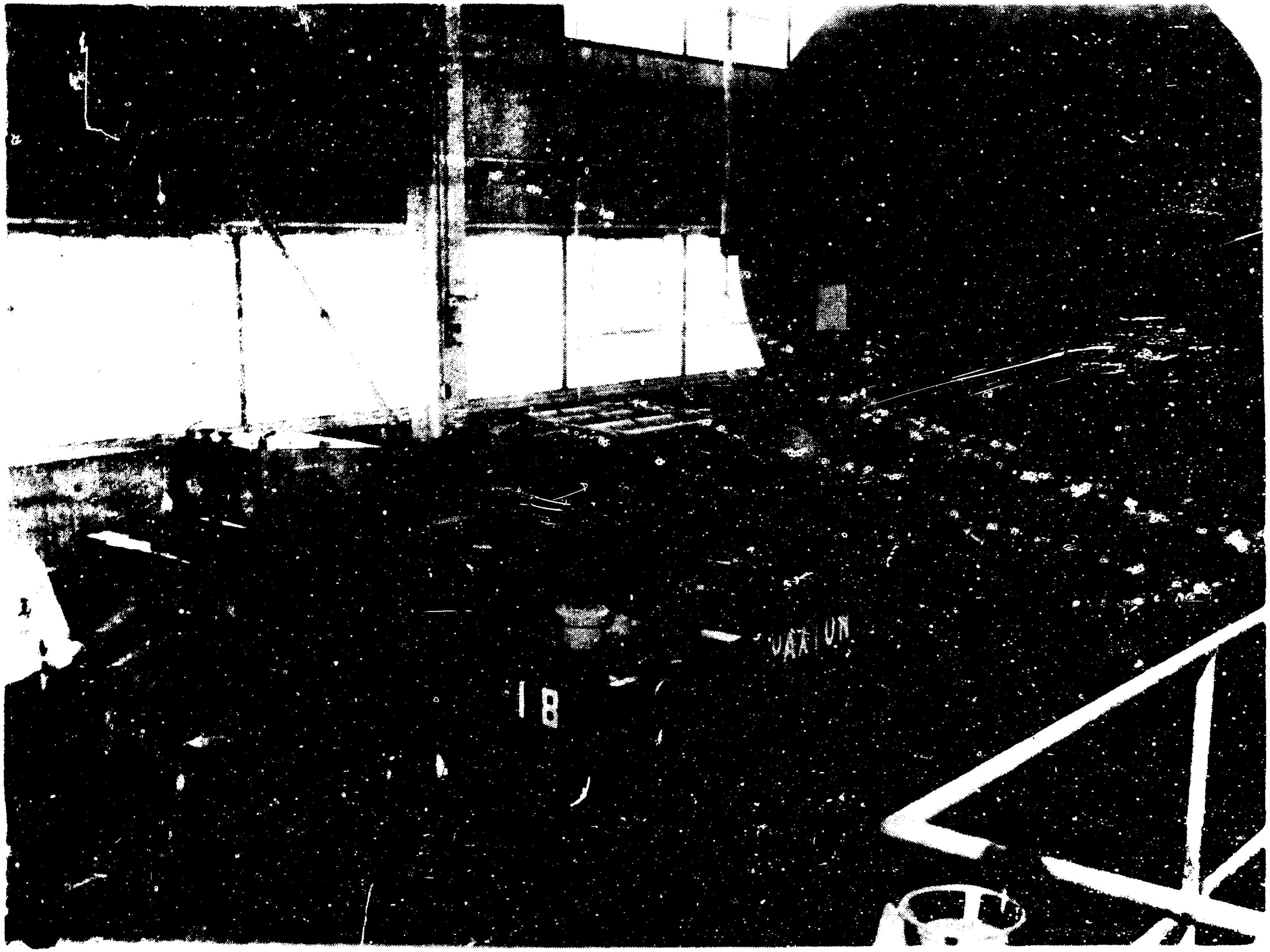

Figure 3-3 PCTT Transportation Pressurization Unit

4. FIELD TEST SUPPORT

Certain tasks on the PCTT program were of a nature that they were planned for accomplishment at the AFRPL by Convair personnel. The three major tasks of this nature were: the final installation of the fill and drain and pressurization lines, the installation of instrumentation, and the installation of the superinsulation.

4.1 FILL AND DRAIN LINES

This task consisted of installing the internal standpipe for the LH_2 fill and drain line to the inboard side of the LH_2 tank cover plate. The cover plate with standpipe attached was then reinstalled (using new metal "O" ring seal) on the tank flange and bolted together. The external LH_2 fill and drain line and LH_2 tank pressurization lines were inserted through the access holes provided in the forward adapter and then attached to the outboard side of the cover plate as shown in Figure 4-1.

The LO_2 tank pressurization standpipe and external line were installed in the same fashion as the LH_2 lines and are shown in Figure 4-2. The LO_2 fill and drain line installation consisted merely of installing a new elbow (Figure 4-3) to an existing fill and drain outlet on the LO_2 tank bulkhead.

4.2 INSTRUMENTATION

Six platinum resistance type thermometers were installed in areas of the LH_2 tank as shown in Figure 1-8. Approximately 58 constantan thermocouples were attached to designated points on the tank, adapters, cover plates, insulation mounting pegs and between insulation panels. All thermometer and thermocouple

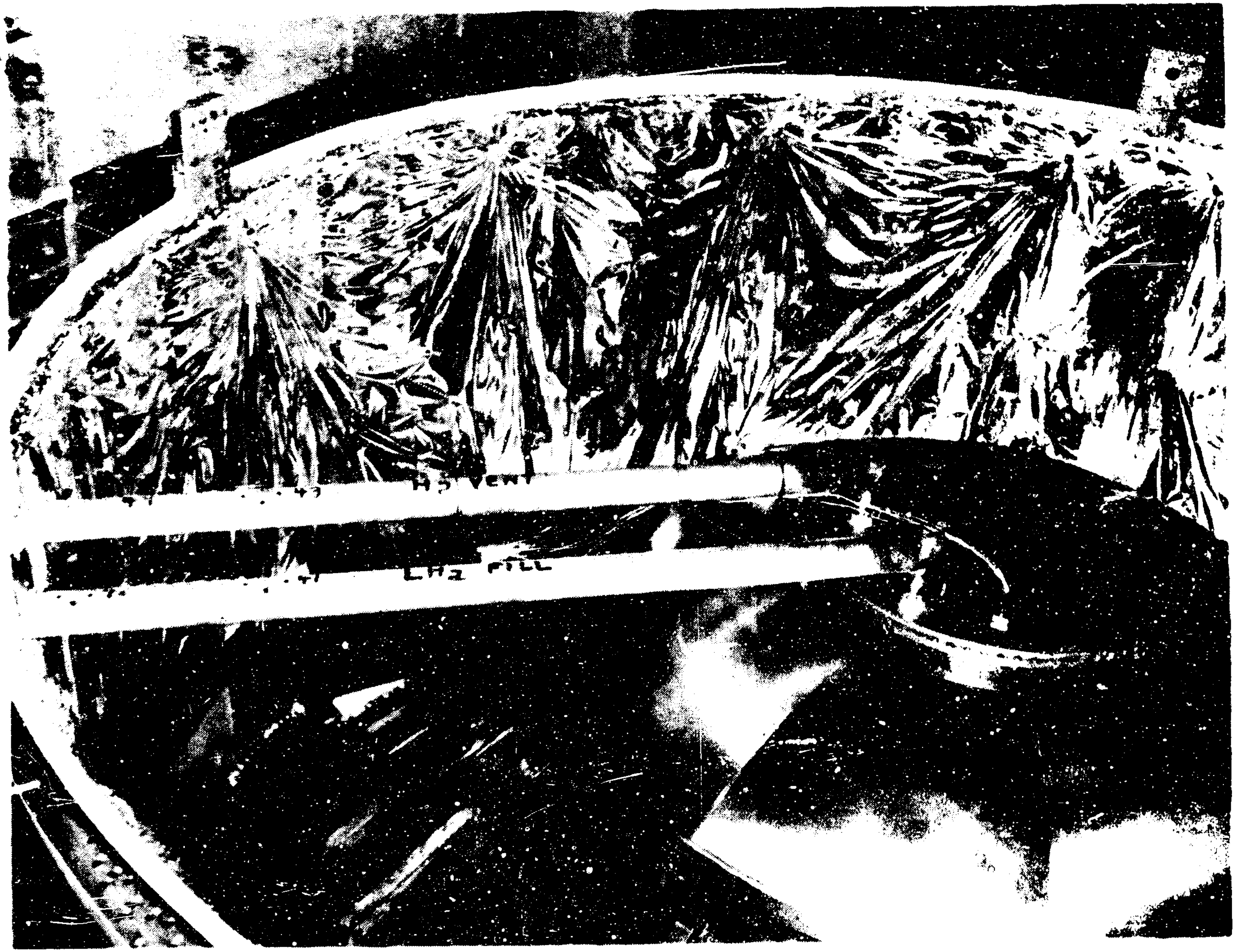

Figure 4-1 LH_2 Fill and Vent Line Installation

Figure 4-2 LO_2 Pressurization Line Installation

Figure 4-3 LO_2 Fill and Drain Line Installation leads were terminated at the terminal and reference junction block located on the aft adapter in an orderly fashion as shown in Figure 4-4.

4.3 INSULATION

Prior to the installation of the superinsulation blankets, it was necessary to install mounting pegs, stand-off bands and stand-off rings on the tank and adapters as shown in Figures 1-6 and 1-7. A typical stand-off band and mounting peg installation is shown in Figure 4-5. This installation was accomplished by first installing Fiberglas mounting pegs around the periphery of the forward adapter. Fiberglas bands were then installed on the pegs which contained a shoulder to "stand-off" the bands approximately one inch from the adapter surface. A similar installation was provided for on the aft adapter as shown in Figure 4-6. Figure 4-7 shows the installation of a Fiberglas stand-off ring epoxied to the tank outlet ring.

The task of installing the superinsulation was accomplished in three major steps: insulation of the cover plates, insulation of the adapter interiors, insulation of the exterior surface.

The insulation of the cover plates (Figure 4-8) was accomplished by installing three blankets on the entire interior surface of the forward and aft adapter cover plates. These blankets were mounted to the covers by use of Fiberglas mounting pegs, Fiberglas felt washers and teflon screws. All blanket splices were made by interleaving layers of adjacent blankets and securing the final layer with aluminized mylar tape. The blankets were then trimmed to final shape and placed in storage awaiting final installation.

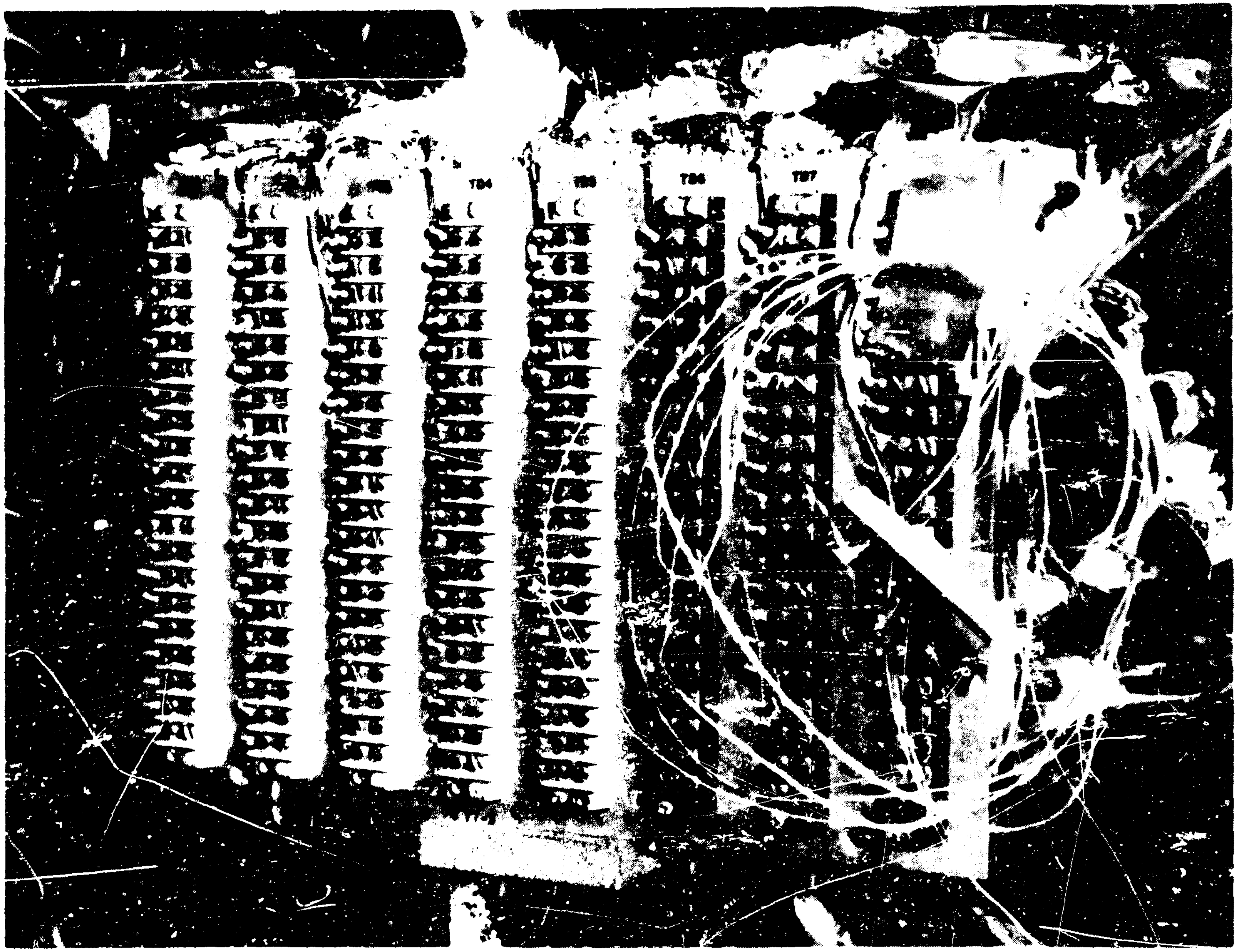

Figure 4.4 Terminal Block Installation

Figure 4-5 Stand-off Band (Forward Adapter)

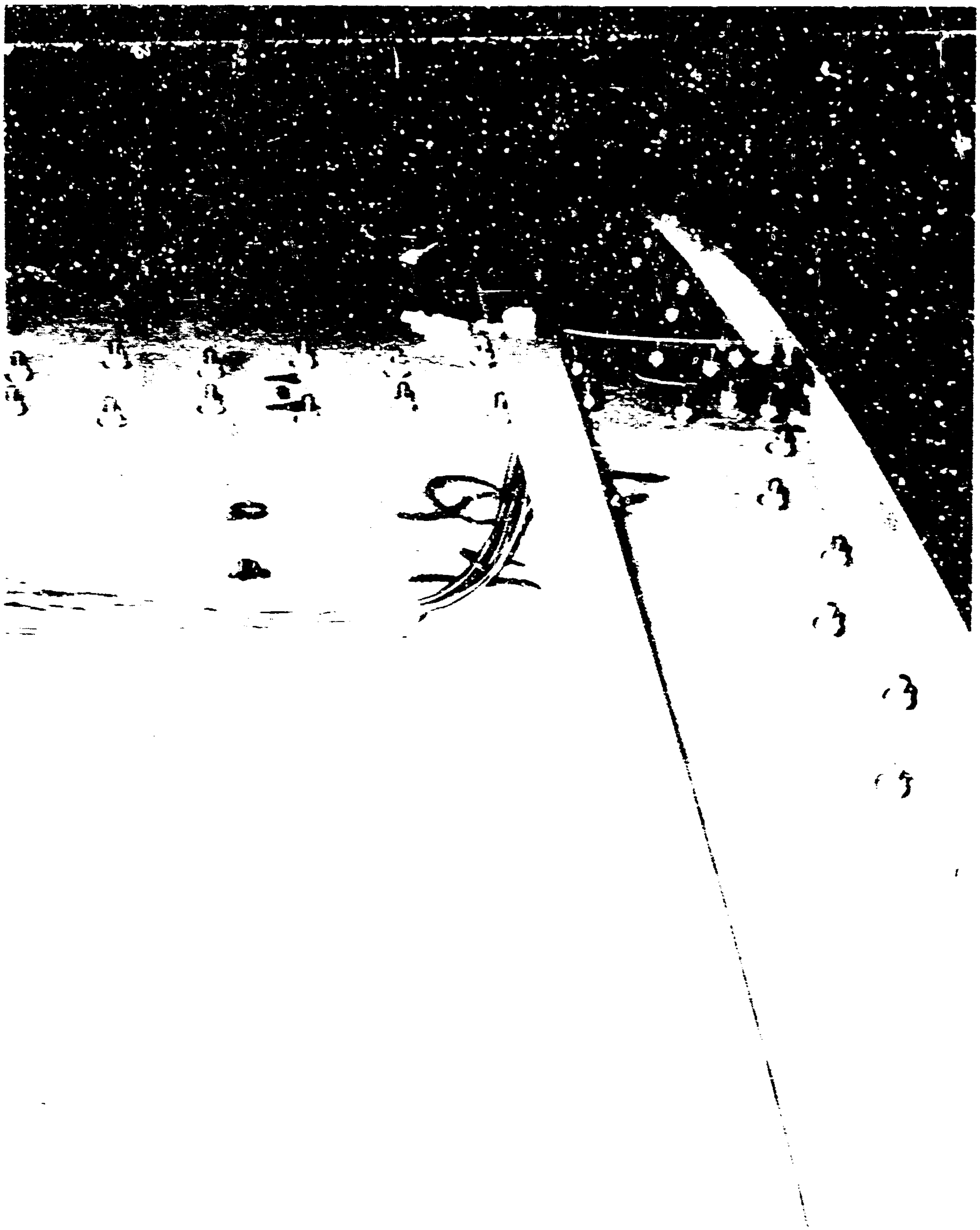

Figure 4-6 Stand-off Band (AFL Adapter)

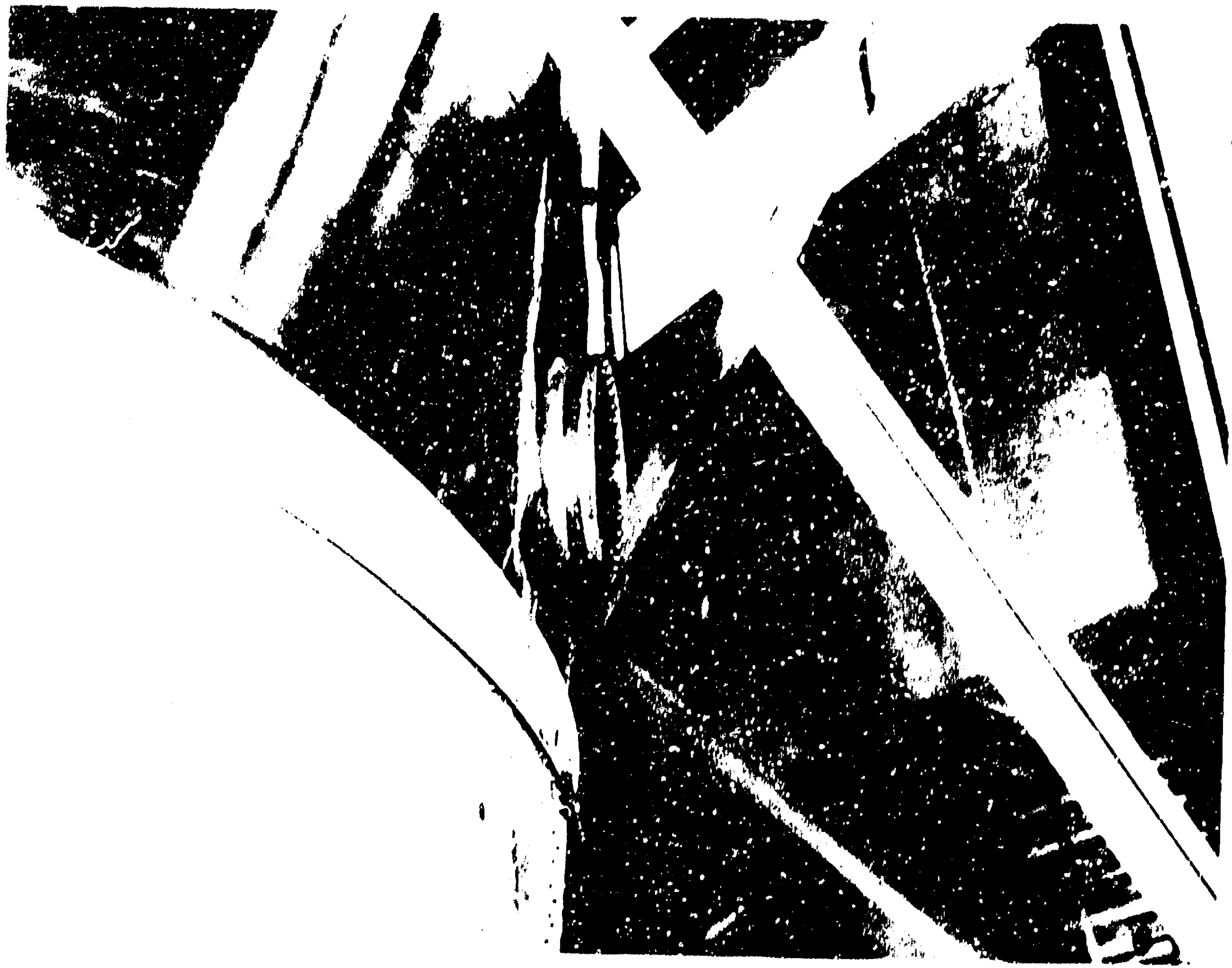

Figure 4-7 Stand-off Ring

Figure 4-8 Cover Plate Insulation

The interior surface of the forward and aft adapters was insulated with a one piece blanket mounted in a fashion as described above and shown in Figures 4-9 and 4-10.

Forty-two-inch wide insulation blankets were installed around the entire exterior surface of the tank and adapters. The buildup consisted of three blankets installed in a staggered pattern. The first layer of blankets is shown in Figure 4-11. The first and second layer of blankets was spliced with a single layer of the six-inch wide aluminized mylar sheet attached to the outside layer of each adjacent blanket with aluminized mylar tape. The final layer of blankets (Figure 4-12) was spliced with a six-inch wide aluminized mylar sheet attached to every other sheet (within the final blanket) with aluminized mylar tape.

During the final trimming operation of the superinsulation, instrumentation measurement number 46 was inadvertently cut, requiring splicing to repair.

The insulated cover plates were then installed on the forward and aft adapters. The entire test article was then wrapped with a polyethylene cover as a protective measure and delivered to the AFRPL by DD250.

Figure 4-9 Forward Adapter Insulation

Figure 4-10 Aft Adapter Insulation

Figure 4-11 Insulation Installation

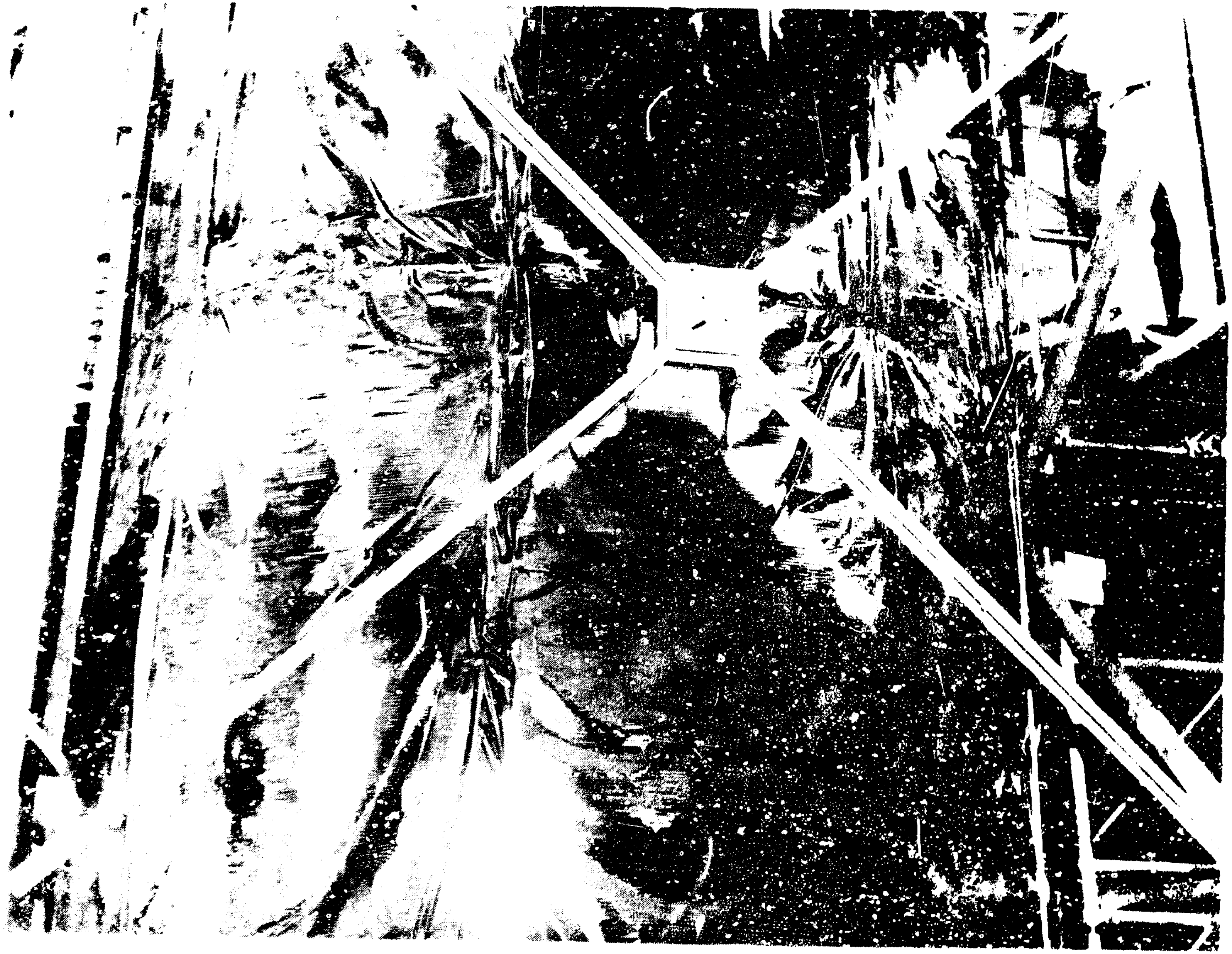

Figure 4-12 Completed Insulation

APPENDIX A

FUNCTIONAL LIMITATIONS

OF THE

PARTITIONED CENTAUR TEST TANK

FUNCTIONAL LIMITATIONS
OF THE
PARTITIONED CENTAUR TEST TANK

REPORT NUMBER GDC-BTD66-216

9 JANUARY 1967

CONTRACT NUMBER F04611-67-C-0004

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FOREWORD

This report was prepared for the Air Force Rocket Propulsion Laboratory, Edwards Air Force Base, California. It represents partial fulfillment of the Partitioned Centaur Test Tank Contract, F04611-67-C-0004.

TABLE OF CONTENTS

SECTION	TITLE	PAGE
1	INTRODUCTION	1
2	DESIGN FACTORS OF SAFETY	3
3	GROUND HANDLING AND TRANSPORTATION	5
3.1	Configuration	5
3.2	Tank Pressures	5
3.3	Ground Winds	5
3.4	Hoisting and Positioning	6
3.5	Erection	6
3.6	Transportation	9
3.7	Cover Plate Removal and Installation	11
3.8	Adapter Removal and Installation	11
3.9	Depressurization Opening, Closing, and Pressurization of Tanks	13
3.10	Propellant Fill and Vent Lines	16
3.11	Installation of Insulation	16
4	TESTING	17
4.1	Configuration	17
4.2	Tank Pressures	17
4.3	Propellant Fill and Vent Lines	18
4.4	Cryogenic Proof Test	19
4.5	Tanking and Detanking	20

SECTION 1

INTRODUCTION

The Partitioned Centaur Test Tank (PCTT) is a Flight-Weight Centaur Test Tank (55-7542) which has been modified for thermal testing at the Air Force Rocket Propulsion Laboratory (AFRPL). A sketch of the PCTT is shown in Figure 1. Modifications to the Centaur tank consist of removing a section of cylindrical tank skin, welding in a new ellipsoidal bulkhead, and rewelding the forward bulkhead to the tank. New hardware fabricated for the PCTT consists of the adapters, cover plates, propellant fill and vent lines, and superinsulation.

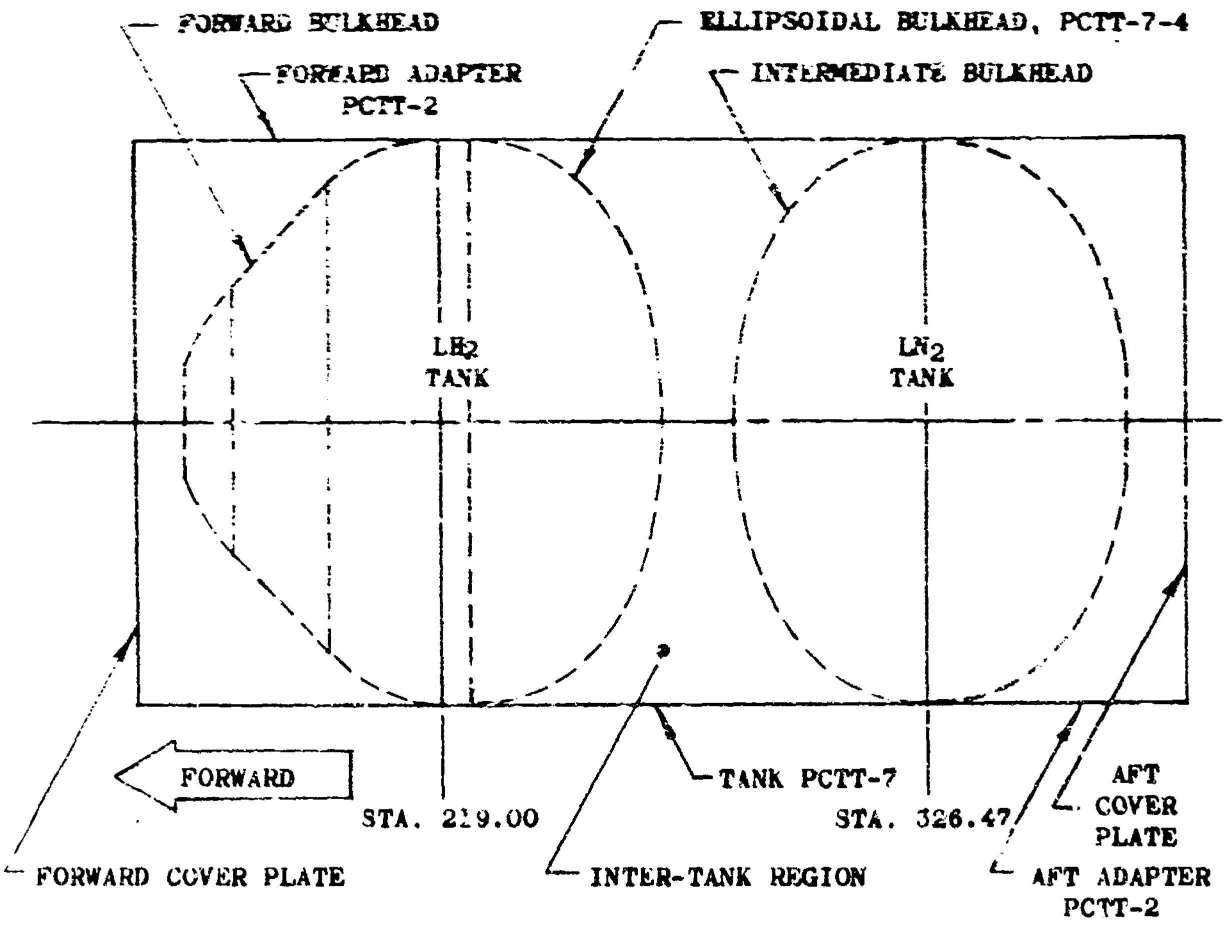

Figure 1

PCTT-1 CONFIGURATION
(PCTT-6 INSULATION OMITTED FOR CLARITY)

PREPARED BY	DATE	CHECKED BY	DATE	REVISED BY	DATE

SECTION 2

DESIGN FACTORS OF SAFETY

The PCTT is made from an existing flight weight Centaur Test Tank. Care should be used to see that all limitations set forth in this document are strictly adhered to because safety factors of a flight weight Tank are considerably less than those usually encountered in ground test equipment. Hardware which was fabricated new for the PCTT has safety factors which are consistent with Centaur ground support equipment. A list of safety factors used for the design of the major PCTT components is contained in Table 1. The safety factors are defined in the following manner:

$$\text{Limit safety factor} = \frac{\text{Limit stress}}{\text{Operating stress}}$$

$$\text{Ultimate safety factor} = \frac{\text{Ultimate stress}}{\text{Operating stress}}$$

Operating stress is defined as the stress encountered under the specified conditions of operation or use. No detrimental yielding shall occur at limit stress and no failure shall occur at ultimate stress.

Table 1

SAFETY FACTORS USED IN THE PCTT DESIGN

PART NUMBER	NAME OF PART	SAFETY FACTOR LIMIT	SAFETY FACTOR ULTIMATE
PCTT-1-2	STANDPIPE	1.00	1.50
PCTT-2-1	FORWARD ADAPTER ASSEMBLY	2.00	3.00
PCTT-2-2	AFT ADAPTER ASSEMBLY	2.00	3.00
PCTT-2-3	FORWARD COVER PLATE	2.00	3.00
PCTT-2-4	AFT COVER PLATE	2.00	3.00
PCTT-2-24	RING	1.00	1.50
PCTT-2-25	RING	1.00	1.50
PCTT-4-1	DOOR ASSEMBLY	2.00	3.00
PCTT-4-9	TUBE ASSEMBLY	2.00	3.00
PCTT-4-14	TUBE ASSEMBLY	2.00	3.00
PCTT-4-16	TUBE ASSEMBLY	2.00	3.00
PCTT-4-18	TUBE ASSEMBLY	2.00	3.00
PCTT-6-1	INSULATION ASSEMBLY	2.00	3.00
PCTT-7-1	TANK ASSEMBLY	1.00	1.25

SECTION 3

GROUND HANDLING AND TRANSPORTATION

3.1 Configuration - All routine ground handling and transportation of the PCTT shall be accomplished with the adapters and cover plates installed, and the propellant fill and vent lines (both internal and external) removed unless specified otherwise elsewhere in this procedure. Gross empty weight of the PCTT in its transportation configuration is 3200 pounds.

3.2 Tank Pressures - The tank pressures during maintenance, storage, ground handling, and transportation shall be 8.0 ± 1.0 psig in the forward and aft tank, and 4.0 ± 1.0 psig in the inter-tank region.

- CAUTION -

> The forward and aft tanks must be maintained at least 2.0 psig higher in pressure than the inter-tank region. Damage will result to the test article if this condition is not strictly observed.

During transportation from San Diego to AFRPL, the tank pressures will be automatically maintained at 8.3 to 9.8 psig in the forward and aft tanks and 4.2 to 7.2 psig in the inter-tank region by means of a Centaur Transportation Pressurization Unit. This unit gives an automatic warning signal if the tank pressures vary outside the limits set forth above.

The intermediate bulkhead boss at Sta. 324.17 (Quad. I, 3 inches from the Y-axis) shall be vented to the atmosphere at all times during maintenance, storage, ground handling, and transportation. The boss shall be protected by a four layer thickness of cheese-cloth taped in place. A plastic bag at least 9 inches long and 2 inches in diameter with both ends open shall be taped over the boss to serve as weather protection.

- CAUTION -

> The fragmentation pressure for the PCTT tank is 9.9 psig. Tank pressures shall be kept below 9.9 psig at all times when a failure would be hazardous to personnel.

3.3 Ground Winds - Erection, positioning, and hoisting of the PCTT shall be accomplished only in winds which do not exceed ten (10) MPH. The PCTT shall not be left free standing in winds (steady state plus gusts) which exceed 20 MPH.

3.4 Hoisting and Positioning - All hoisting and positioning shall be performed with a crane system having a rated load capacity of at least 4 tons. The cable from the crane shall be attached to the PCTT by means of a 4 ton capacity spreader bar system which has two cables 120.9 inches apart that attach to two diametrically opposite longerons as shown in Figure 2. A clevis or clevis-like device shall be used to connect the spreader bar cables to the PCTT so no bending or radial shear forces are induced on the longerons. The distance across the throat of the clevis shall be 2.35 to 2.40 inches. The clevis pins shall be NAS 1018 bolts made from A286 CRES. Two half inch diameter nylon taglines, 180° apart, shall be attached to the aft adapter and one man shall manage each tagline. The taglines shall be attached to the adapter by means of angles (2) which bolt to the aft adapter ring with at least 4 bolts each at a 2 inch spacing. The outstanding leg of the angle has a hole through which the tagline can be attached. The purpose of the taglines is to help damp out oscillations of the PCTT while it is being hoisted. Extremely large forces shall not be applied to the taglines.

3.5 Erection - Erection from horizontal to vertical shall be accomplished on a truck having a rotating cradle. A spreader bar (see Section 3.4) shall be used to attach the crane to the PCTT longerons at the sides of the test article as shown in Figure 3. Two padded straps located as shown in Figure 3 shall be used to tie the aft adapter to the rotation cradle. As the PCTT is slowly raised to the vertical position, the truck must be slowly moved forward to keep the hoisting cables within 10° of vertical. The base of the PCTT shall be kept in contact with the cradle, but the PCTT must be held by the crane at all times. Two taglines capable of 2000 pounds each shall be attached to the clevises (see Figure 3) to help ease the PCTT through the over center portion of rotation which occurs from approximately 55° to 80° from the horizontal position. A 2000 pound tension load shall be supplied by means of a winch or the equivalent. When the vertical position is reached, the straps may be removed and the PCTT may be raised from the truck bed. Rotation from vertical to horizontal can be accomplished by reversing the above procedure.

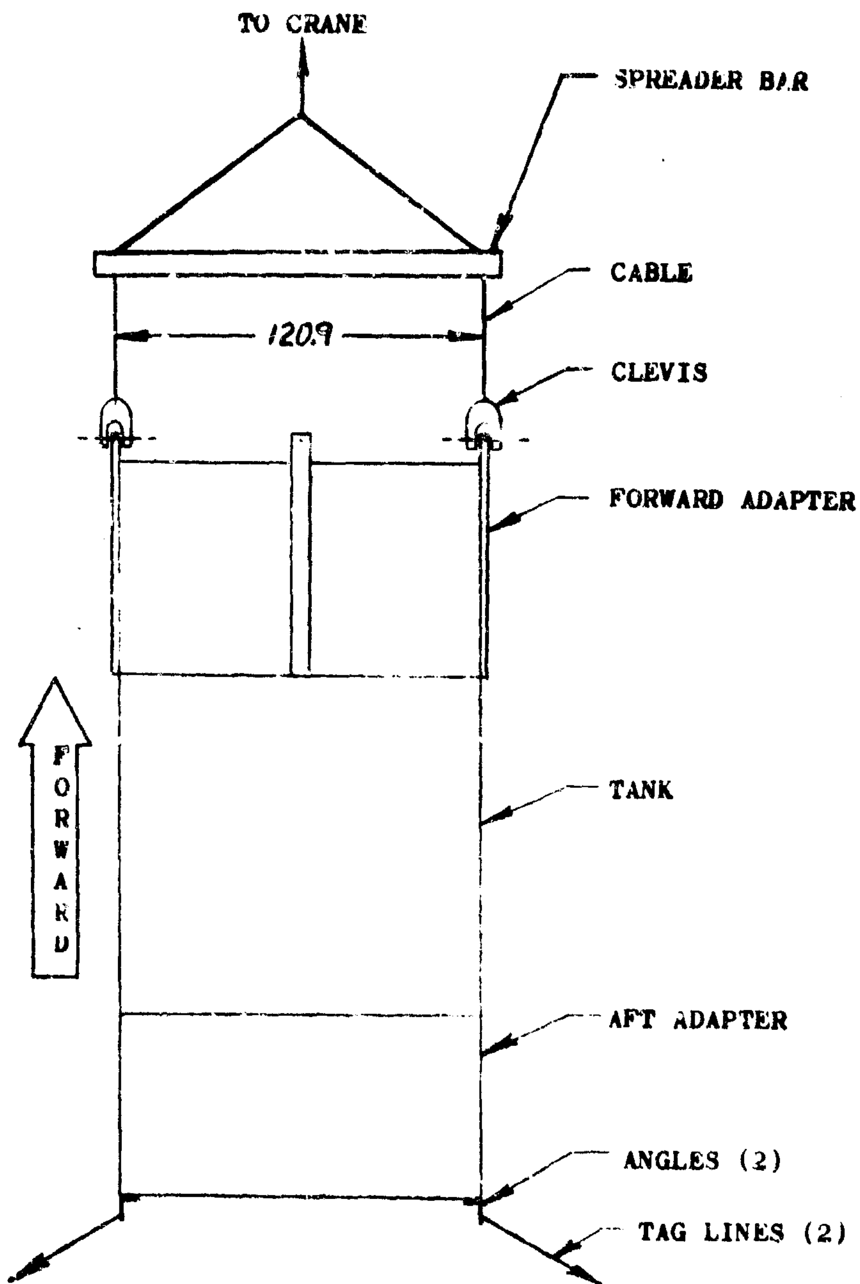

Figure 2
HOISTING SYSTEM

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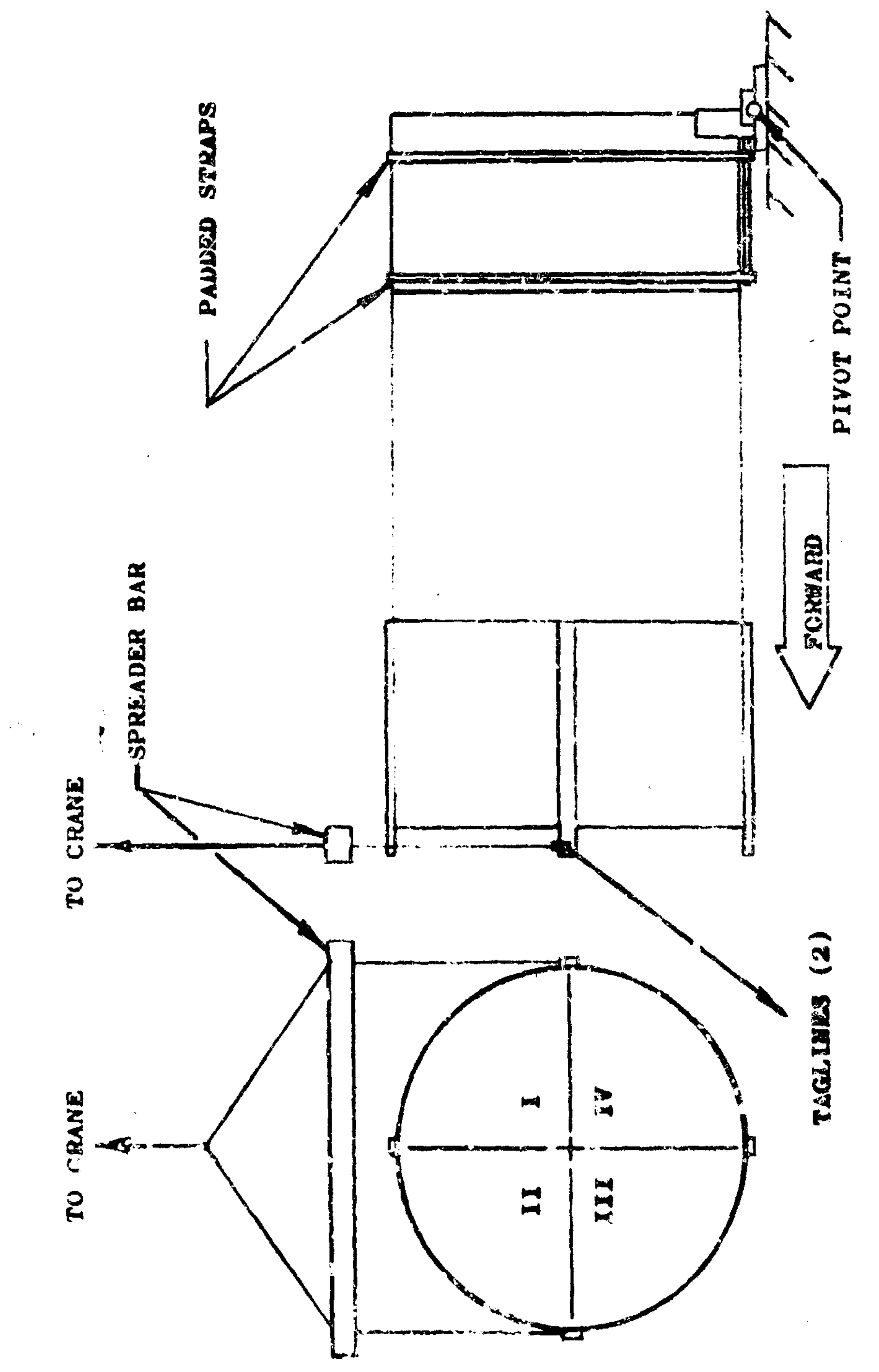


Figure 3
ERECTION FROM HORIZONTAL TO VERTICAL

3.[illegible] Transportation - Transportation of the PCTT shall be accomplished on a flat bed truck having supports located as shown in Figure 4. The 30 inch wide cradles form the main supports. These cradles shall be located as close as possible to the Sta. 219 and Sta. 328.47 rings. A minimum of 0.75 inches of wool felt padding shall be used between the cradles and the tank. Steel hold down straps, a minimum of 1.25 inches wide, shall be used at the Sta. 219 and Sta. 328.47 rings. A minimum thickness of 0.75 inches of Cargo Pak padding shall be used between the hold down straps and the tank rings. A wooden support cradle with a minimum of 1 inch of Cargo Pak padding shall be provided at Sta. 151. The rotation cradle, Douglas Part No. 1T14150-7, with a minimum of 1 inch of Cargo Pak padding shall be used as a support at Sta. 384.47. Snug but not tight 0.75 inch wide steel straps with a 1.0 inch minimum thickness of Cargo Pak padding shall be used at Sta. 151 and Sta. 384.47 to secure the adapters. Engineering representatives from Design (961-3) X2966, and Stress (961-4) X2222, shall be present during the entire loading process to insure that the PCTT is properly secured to the trailer.

- CAUTION -

The tank pressures shall be monitored continuously during transportation and kept within the limits established in Section 3.2 of this report. A minimum of four (4) K-bottles of dry nitrogen shall be provided during shipment so that tank pressures may be increased if necessary.

- WARNING -

If pressure in any tank varies outside the limits of Section 3.2, the truck must stop at once. The truck must not proceed until the pressures are restored to normal (see Section 3.2).

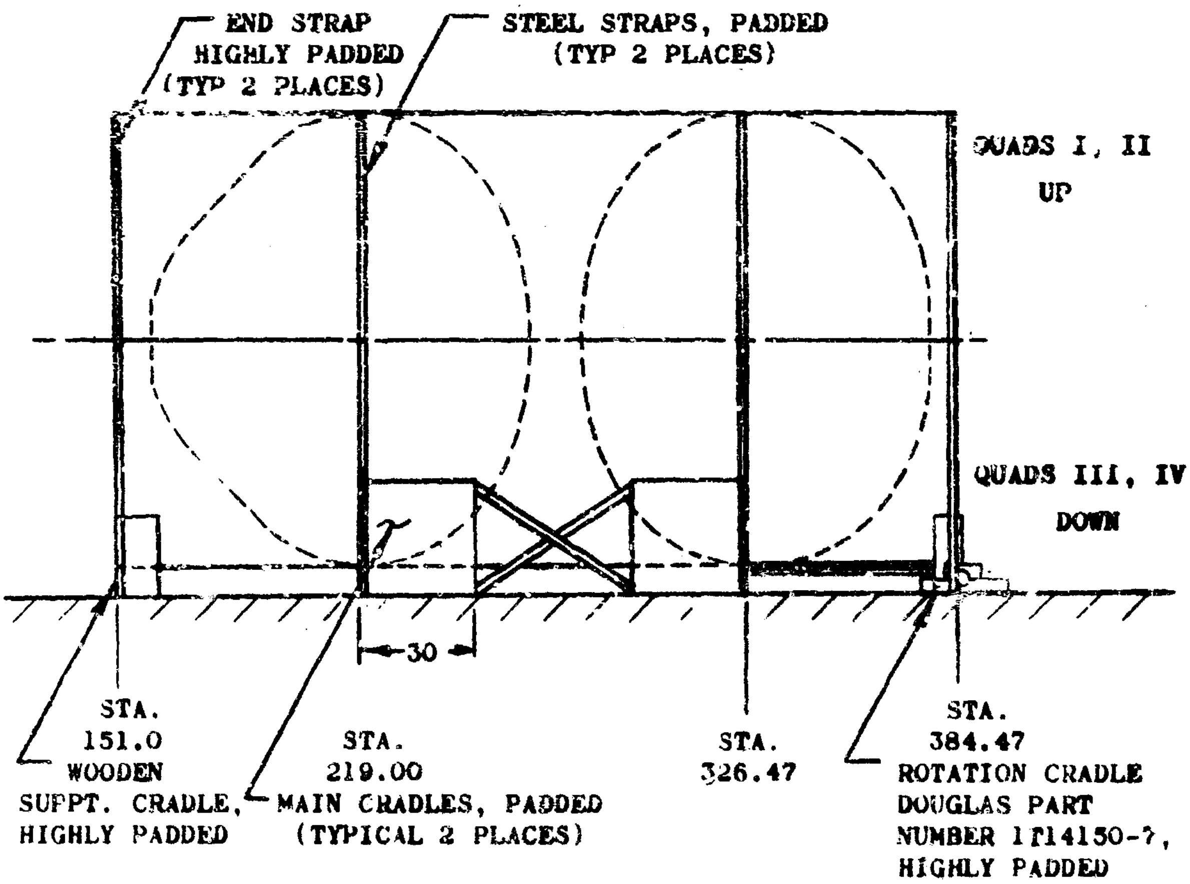


Figure 4

TRANSPORTATION SUPPORTS

PREPARED BY	DATE	CHECKED BY	DATE	REVISED BY	DATE

3.7 Adapter Cover Plate Removal and Installation - The adapter cover plates shall only be removed (or installed) with the PCTT in a vertical position. Removal of the forward cover plate shall be accomplished with the PCTT standing on the aft adapter. Attach a four cable sling to the eyebolts located on the cover as shown in Figure 5. Unbolt the cover and lift it vertically until it clears the longerons. Reverse the above procedure to install the forward cover. Torque the NAS 1005 fasteners to 100 - 140 in. lb.

Removal of the aft cover plate shall be accomplished by suspending the PCTT over some supports for the cover, unbolting the cover, and hoisting the entire PCTT, leaving the cover plate on the three supports (Figure 5). The cover plate can then be moved by a sling attached to the eyebolts as in Figure 5. Reverse the above procedure to install the aft cover. Torque the NAS 1004 fasteners to 50 - 70 in. lb.

3.8 Adapter Removal and Installation - The adapters shall only be removed when the PCTT is in the vertical position. The exterior propellant fill and vent lines must be removed per Section 3.10, the tank openings capped, and the tanks repressurized before the adapters can be removed. Removal of the forward adapter is accomplished by supporting the PCTT on the aft adapter, unbolting the forward adapter, and hoisting it vertically with the spreader bar (Section 3.4) until it clears the forward bulkhead. Two half inch nylon tag lines located 180° apart shall be attached to the aft ring of the adapter, if necessary, and one man shall manage each tagline. The taglines shall be attached in the manner of Section 3.4. Taglines are required on the adapters only when hoisting in a wind or when damage due to oscillations is possible. The adapter shall be kept vertical when it is removed from the tank. Reverse the above procedure to install the forward adapter on the tank. Torque the NAS 1004 fasteners to 50 - 70 in. lb.

Removal of the aft adapter can only be accomplished with the forward adapter installed because the PCTT shall be hoisted only through the forward adapter. Removal of the aft adapter is accomplished by supporting the PCTT on the aft adapter, unbolting the aft adapter from the tank ring, and hoisting the PCTT vertically until it clears the aft adapter. Two taglines located 180° apart shall be attached to the aft ring of the tank, if necessary, and one man shall manage each tagline. The tagline attachment method is the same as used on the forward adapter. The PCTT must remain suspended while the aft adapter is not in place. Reverse the above procedure to install the aft adapter on the tank. Torque the NAS 1004 fasteners to 50 - 70 in. lb.

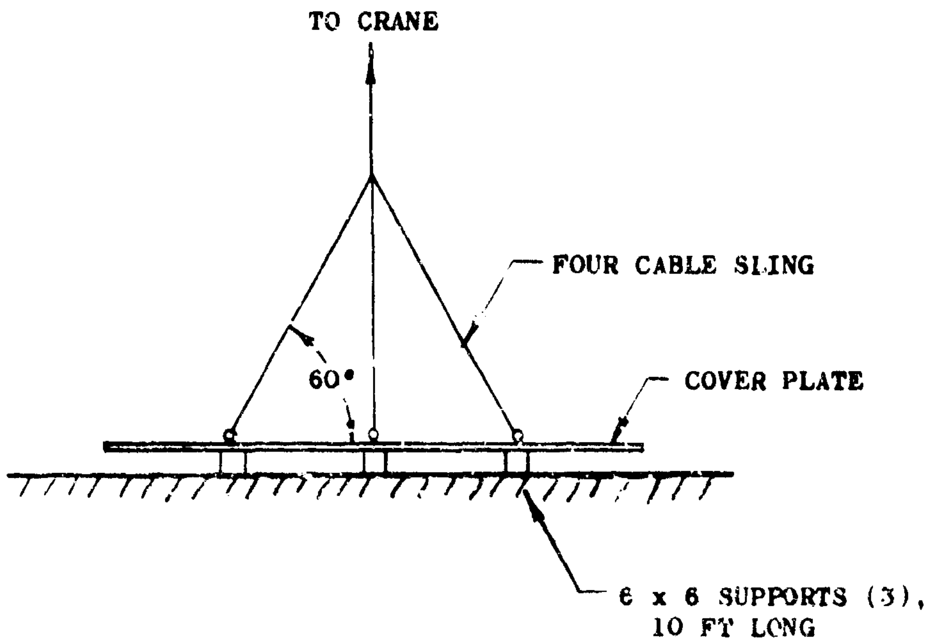


Figure 5

COVER PLATE SLING AND SUPPORTS

3.9 Depressurization, Opening, Closure, and Pressurization of Propellant Tanks -

3.9.1 Verify that the following materials and equipment are available before attempting any portion of this procedure.

1. Adequate tooling and/or engineering parts to seal all tanks and to place the PCTT in stretch by suspending it in tension.

2. Three pressure gages 0-15 psig range minimum.

3. A regulated supply of nitrogen gas per MIL-P-27401.

4. Adequate fittings, valves, adapters, and hose for use during pressurization and depressurization.

5. Cheesecloth, GDC Material No. 32 262700 (787032) or equivalent.

6. Centaur upper-stage tank log book GDC Form No. A-4083.

3.9.2 Depressurization - The depressurization sequence shall be performed in the following manner:

1. Place the PCTT in stretch by suspending it from the forward adapter per Section 3.4 and place "tanks degassed and in stretch" signs on all four sides of the tank.

2. Verify that the intermediate bulkhead is vented to the atmosphere. Protect the vent tube at Sta. 324.17 in Quad. I, 3 inches from the Y-axis with four thicknesses of cheesecloth taped in place.

3. Depressurize the inter-tank region first by removing the pressurization line at the PCTT-4-7 plate and monitoring the pressure gage until it reads zero gage pressure. Remove the PCTT-4-7 plate and cover the opening with a four layer thickness of cheesecloth taped in place. Record the actual time and place where the tank is depressurized in the tank log book

4. Depressurize the forward tank by removing the pressurization line (or plug as applicable) located at Sta. 179.0 on the X-X axis between Quads I and II.

- CAUTION -

The inter-tank region must be depressurized before the forward and/or aft tank is depressurized. Damage will result to the test article if this condition is not strictly observed.

4. Continued

Monitor the pressure gage until it reads zero. Cover the tank opening with a four-layer thickness of cheesecloth taped in place. Record the actual time and place where the tank is depressurized in the tank log book.

NOTE: The aft tank may remain pressurized when the forward tank is depressurized, however, the inter-tank region must be depressurized first.

5. Depressurize the aft tank by removing the pressurization line (or plug as applicable) located on the aft door on the X-X axis between Quads III and IV.

- CAUTION -

The inter-tank region must be depressurized before the forward and/or aft tank is depressurized. Damage will result to the test article if this condition is not strictly observed.

Monitor the pressure gage until it reads zero. Cover the tank opening wit a four-layer thickness of cheesecloth taped in place. Record the actual time and place where the tank is depressurized in the tank log book.

NOTE: The forward tank may remain pressurized when the aft tank is depressurized, however, the inter-tank region must be depressurized first.

3.9.3 Opening Forward or Aft Tank - Before opening any tank it must be depressurized in the manner of Section 3.9.2. The forward and/or aft tank may then be opened by removing the fill and vent pipes if installed, and the bolts around the periphery of the door. Care shall be used when the internal pipes, PCTT-4-18 and PCTT-4-20, are installed on the door to insure that they do not hit the tank walls as the doors are removed.

- WARNING -

The tanks are pressurized with nitrogen gas. Personnel should not attempt to enter the tanks until the tanks have been purged and it is verified that the oxygen content is normal.

Until the tanks are purged, a sign shall be taped next to the opening with the following words: "Caution, Tank Not Purged, Do Not Enter". After the tanks are properly purged, a continuous supply of fresh air shall be blown into the tank while personnel are inside. Personnel entering the tank shall be supported from the outside by means of a bosun's chair or other suitable device.

- CAUTION -

The depressurized tank skin is not capable of supporting personnel or equipment. Extreme care should be used when entering the tank to avoid local loads on the tank skin.

3.9.4 Closing Forward or Aft Tank - Every time the door is removed, the torus seal, 83-67973-040, shall be replaced with a new seal. The door shall be bolted in place with the bolts torqued to the following limits:

Forward door: NAS 1003 bolts, 20 - 25 in. lb.

Aft door: NAS 1144 screws, 50 - 70 in. lb.

Care shall be used when the internal pipes, PCTT-4-18 and PCTT-4-20 are installed on the door to insure that they do not hit the tank walls as the doors are installed.

3.9.5 Pressurization - Reverse the procedure of Section 3.9.2 to pressurize the tanks.

- CAUTION -

Pressurize both the forward and aft tanks before pressurizing the inter-tank region.

Tank pressures shall be in accordance with Section 3.2. Leak check all fittings on the forward and aft tanks before pressurizing the inter-tank region. Leak check the fittings on the inter-tank region after it is pressurized.

3.10 Propellant Fill and Vent Lines - During all phases of transportation the propellant fill and vent lines, PCTT-4-16 (3), PCTT-4-18, PCTT-4-14, and PCTT-4-20, must be removed from the PCTT and shipped separately. The lines shall be installed (or removed) with the PCTT vertical and depressurized per Section 3.9 just prior to installation in the test facility. The forward and aft cover plates must be removed per Section 3.7 to install the fill and vent lines, PCTT-4, and a portion of the insulation PCTT-6. All of the fill and vent lines shall be installed with NAS 1003 bolts torqued to 20 - 25 in. lb. After installing the propellant lines, install the PCTT-2-5 support halves on the adapters.

Care should be used to avoid loading the fill and vent pipes during ground handling and installation of the PCTT in the test facility. Load limitations on the pipes are listed in Section 4.3 of this report.

3.11 Insulation Installation - The PCTT-6 superinsulation for the PCTT shall be installed on the test article after the fill and vent lines and appropriate instrumentation have been installed. The PCTT shall be in the vertical position when the insulation is installed. A portion of the insulation must be installed while the cover plates are removed to install the pipes, see Section 3.10.

SECTION 4

TESTING

4.1 Configuration - The PCTT shall be put in its test configuration just prior to installation in the test facility. Test configuration includes the adapters, cover plates, fill and vent pipes, and super-insulation. The PCTT shall be supported by suspending it in tension from the longerons at the forward end of the forward adapter. Maximum empty weight of the PCTT in its test configuration is 3500 pounds. Maximum gross weight of 25,000 pounds occurs with the forward tank full of LN_2 and the aft tank empty. Gross weight with LH_2 forward and LN_2 aft is 24,300 pounds.

4.2 Tank Pressures - During installation (or removal) of the PCTT in the test facility, the tank pressures shall be maintained per Section 3.2.

During tanking, testing, and detanking, the intermediate bulkhead cavity shall be kept evacuated by a vacuum pump running continuously.

After installation of the PCTT in the test facility, the inter-tank region shall be vented to the altitude chamber as per Section 3.9.

During tanking, testing, and detanking, the gas pressure in the forward (LH_2) and aft (LN_2) tanks shall not exceed 20.0 psia. When LN_2 is in the forward tank, its maximum gas pressure shall be 20.0 psia. The pressure in the forward and aft tanks shall always be maintained a minimum of 4.0 psi higher than the pressure in the inter-tank region and/or test facility. The tanks shall be pressurized through the vent lines during tanking, testing, and detanking.

The rate of chamber evacuation (or repressurization) shall be monitored so that the differential pressure across the adapter walls does not exceed 0.02 psid. Visual surveillance of the superinsulation shall be provided during facility evacuation to verify that it is outgassing properly. A slower than normal pumpdown may be required to keep from damaging the insulation.

- CAUTION

> The fragmentation pressure of the PCTT tank is 9.9 psig. Tank pressures shall be kept below 9.9 psig at all times when a failure would be hazardous to personnel.

4.3 Propellant Fill and Vent Lines - The PCTT fill and vent lines are cantilevered from the propellant tanks. The lines receive some support at the adapter wall. Allowable loads which may be applied to the ends of the fill and vent lines are given by the interaction equations which follow:

4.3.1 LH_2 fill and vent pipes, PCTT-4-16.

$$\frac{M(IN.LB.)}{1500} + \frac{P(LB.)}{75} \leq 1 \text{ (SEE FIGURE 6)}$$

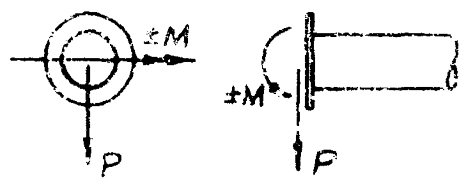


Figure 6

LOAD DIRECTIONS, PCTT-4-16, FORWARD

4.3.2 LN_2 vent pipe, PCTT-4-16.

$$\frac{M(IN.LB.)}{2000} + \frac{P(LB.)}{75} \leq 1 \text{ (SEE FIGURE 7)}$$

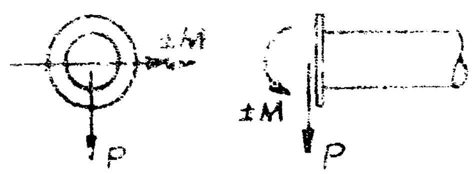


Figure 7

LOAD DIRECTIONS, PCTT-4-16, AFT

4.3.3 LN_2 fill pipe, PCTT-4-14.

$$\frac{M(IN.LB.)}{950} + \frac{P(LB.)}{65} \leq 1 \text{ (SEE FIGURE 8)}$$

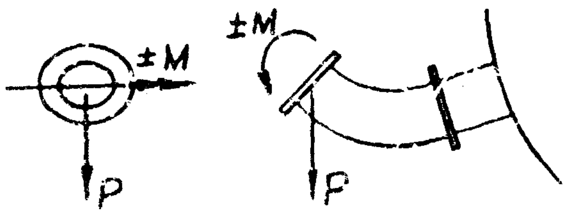


Figure 8

LOAD DIRECTIONS, PCTT-4-14

4.3.4 Thermal Deflections of Pipes - The propellant fill and vent pipes will deflect relative to the test facility when cryogenics are tanked in the PCTT. Thermal deflection relative to the point of support at the top of the longerons is equal to or less than:

PCTT-4-16, $\Delta_{LH_2\ Tank}$ = ± 0.15 inches

PCTT-4-16, $\Delta_{LN_2\ Tank}$ = ± 0.65 inches

PCTT-4-14, Δ = ± 0.65 inches

Design of the facility lines shall incorporate provisions to allow the above deflections without exceeding the allowable pipe loads of the preceding section.

4.4 Cryogenic Proof Test - A cryogenic proof test of the reworked forward tank shall be performed with LN_2 before testing is performed with LH_2. The tanking level shall not exceed Sta. 180.2. The aft tank shall be empty during this test. Maximum pressure in the forward tank shall not exceed 20.0 psia when it contains LN_2. Chill the tank per Section 4.5 before tanking LN_2. A minimum differential pressure of 4.0 psid shall be maintained across the tank wall when it contains LN_2.

- CAUTION -

When LN is in the forward tank the aft tank shall be empty of liquids. Failure to observe this limitation may cause damage to the test article.

4.4 Continued

- CAUTION -

LH_2 shall not at any time be put in the aft (LN_2) tank. Failure to observe this limitation may cause damage to the test article.

4.5 Tanking and Detanking - The forward (LH_2) tank shall always be tanked first and detanked last. The forward tank shall be chilled by cracking the LH_2 fill valve and letting cold H_2 (or N_2) gas into the tank for a period of twenty minutes before opening the valve wide and filling the tank with LH_2 (or LN_2). Tank pressures during tanking shall be in accordance with Section 4.2. The LH_2 level in the forward tank shall not exceed Sta. 180.2. Thirty minutes shall be allowed between completion of LH_2 tanking and beginning LN_2 tanking in the aft tank, however, during this time the aft tank shall be chilled by cracking the LN_2 fill valve and letting cold N_2 gas into the tank. The LN_2 level in the aft tank shall not exceed Sta. 294.

- CAUTION -

LH_2 shall not at any time be put in the aft tank. Failure to observe this limitation may cause damage to the test article.

Nominal tank volumes versus station are shown in Figure 9 and 10.

Figure 9
NOMINAL FWD. TANK VOLUME VS. STATION

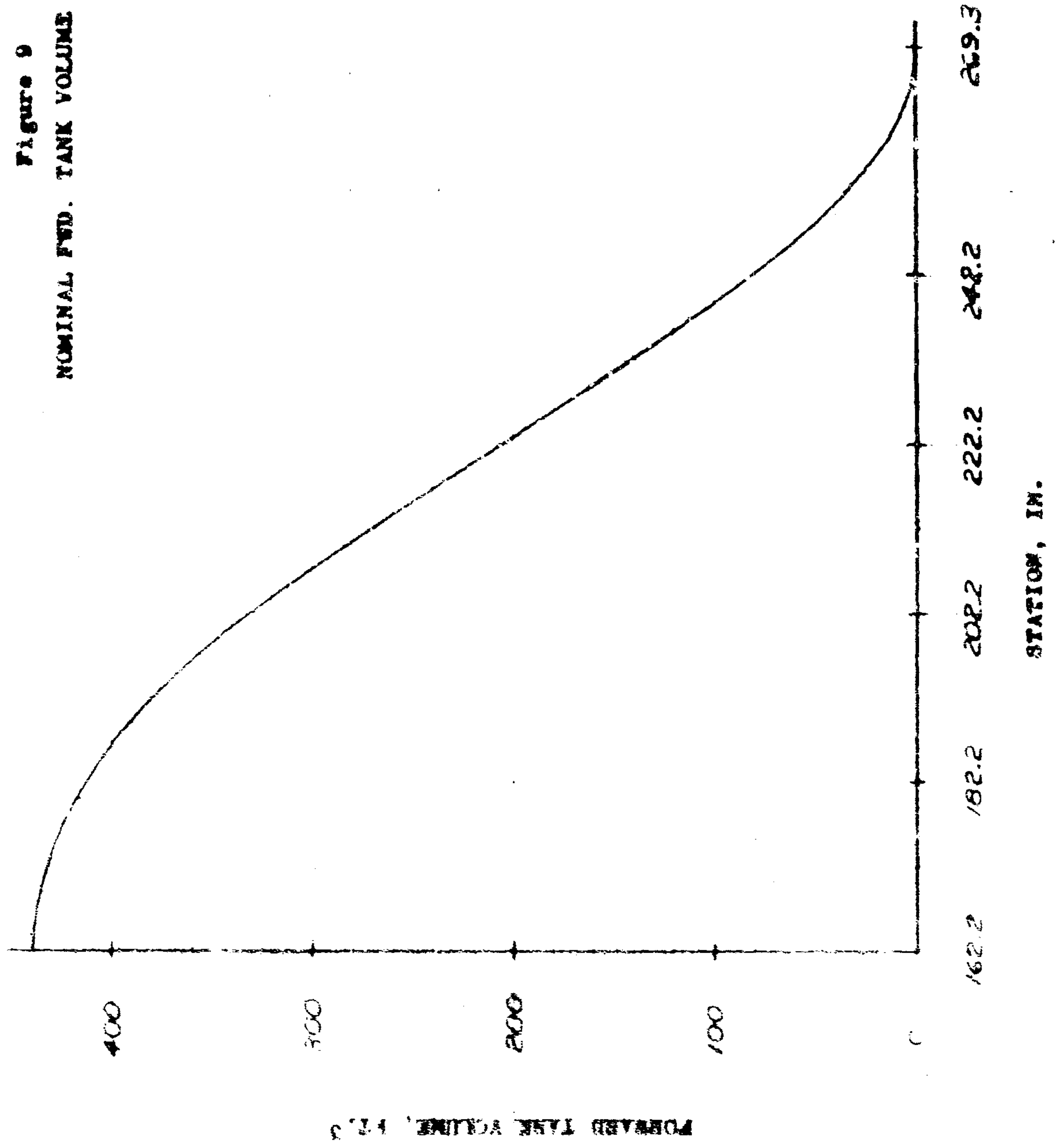
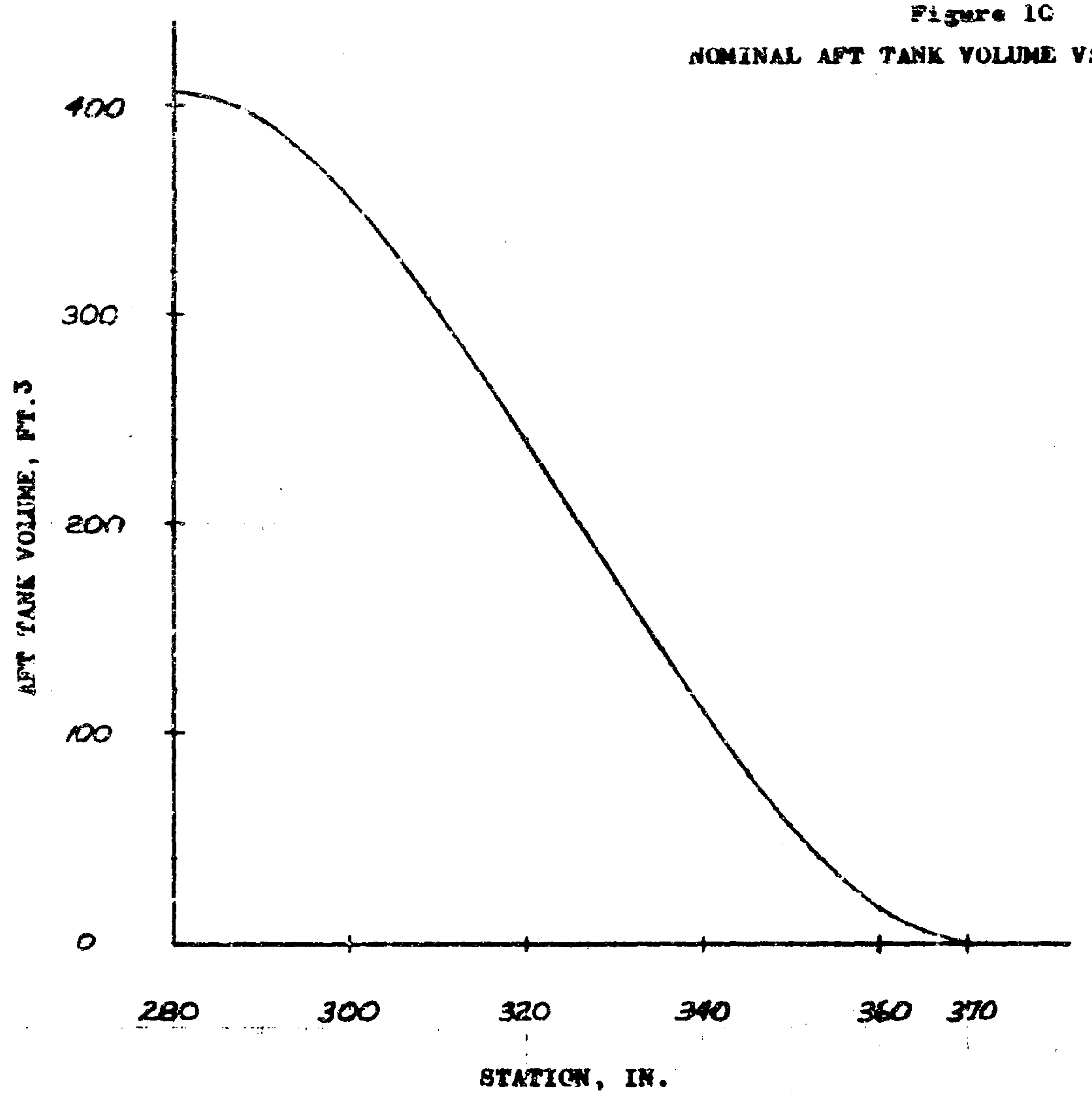


Figure 1C

NOMINAL AFT TANK VOLUME VS. STATION



APPENDIX B

SPACE-ENVIRONMENTAL THERMAL ANALYSIS

OF THE

PARTITIONED CENTAUR TEST TANK

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GENERAL DYNAMICS
Convair Division

SPACE-ENVIRONMENTAL THERMAL ANALYSIS

OF THE

PARTITIONED CENTAUR TEST TANK

Contract No. F04611-67-C-0004

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FOREWORD

The Partitioned Centaur Test Tank (PCTT) thermal analysis of this report has been performed in accordance with the provisions of Contract No. F0461-67-C-0004. The report includes detailed predicted temperature distributions, resulting tank net heat rates, and propellant boil-off rates for the PCTT under simulated space-environmental conditions in the Space Environment Simulation Facility Chamber of the Air Force Rocket Propulsion Laboratory at Edwards Rocket Site.

TABLE OF CONTENTS

	Page
FOREWORD	i
TABLE OF CONTENTS	ii
LIST OF ILLUSTRATIONS	iii
LIST OF TABLES	vi
LIST OF SYMBOLS	vii
SUMMARY	1
INTRODUCTION	2
1. DISCUSSION	3
1.1. PCTT Thermal Control Design	3
1.1.1. General Configuration	3
1.1.2. Super Insulation Configuration	3
1.2. PCTT Analytical Procedures	4
1.2.1. Assumed Space-Environmental Simulation	4
1.2.2. The PCTT Thermal Model	6
1.3 Resulting Predicted PCTT Thermal Control Performance For Hard Vacuum	8
1.3.1. PCTT Temperature Profiles	8
1.3.2. PCTT Propellant Heat Rates	8
2. CONCLUSIONS AND RECOMMENDATIONS	13
2.1. Interpretation and Limitations	13
2.2. Correspondence to PCTT Test Article	14
REFERENCES	15

LIST OF ILLUSTRATIONS

Figure Number	Title	Page Number
1.	Partitioned Centaur Test Tank as Positioned in AFRPL Space Environment Simulation Chamber	16
2.	PCTT Super Insulation Detail	17
3a.	PCTT Thermal Model: Cover, Ring, and Hanger Detail	18
3b.	PCTT Thermal Model: LH_2 Tank/Adapter Interface	19
3c.	PCTT Thermal Model: LN_2 Tank/Adapter Interface	20
3d.	PCTT Thermal Model: Typical Intertank Location	21
3e.	PCTT Thermal Model: Typical Forward or Aft Adapter Location	22
3f.	PCTT Thermal Model: Radiative Exchange Factors ($\mathcal{F}$) Forward Adapter and Cover to LH_2 Tank	23
3g.	PCTT Thermal Model: Forward Adapter Cylindrical Wall Radiative Exchange Factors ($\mathcal{F}$)	24
3h.	PCTT Thermal Model: Radiative Exchange Factors ($\mathcal{F}$) from PCTT Forward Adapter to Cover	25
3j.	PCTT Thermal Model: Intertank Section Radiative Exchange Factors ($\mathcal{F}$) to LH_2 and LN_2 Tank	26
3k.	PCTT Thermal Model: Intertank Cylindrical Wall Radiative Exchange Factors ($\mathcal{F}$)	27
4.	PCTT Thermal Model Analytical Data Stations	28
5.	PCTT Forward Adapter Ring Temperature, Data Station 1	29
6.	PCTT Temperatures, Data Station 2	30
7.	PCTT Temperatures, Data Station 3	31
8.	PCTT Temperatures, Data Station 4	32
9.	PCTT Temperatures, Data Station 5	33

LIST OF ILLUSTRATIONS (Continued)

Figure Number	Title	Page Number
10.	PCTT Temperatures, Data Station 6	34
11.	PCTT Temperatures, Data Station 7	35
12.	PCTT Temperatures, Data Station 8	36
13.	PCTT Temperatures, Data Station 9	37
14.	PCTT Temperatures, Data Station 10	38
15.	PCTT Temperatures, Data Station 11	39
16.	PCTT Temperatures, Data Station 12	40
17.	PCTT Temperatures, Data Station 13	41
18.	PCTT Temperatures, Data Station 14	42
19.	PCTT Temperatures, Data Station 15	43
20.	PCTT Temperatures, Data Station 16	44
21.	PCTT Aft Adapter Ring Temperature, Data Station 17	45
22.	PCTT Temperatures, Data Station 18	46
23.	PCTT Temperatures, Data Station 19	47
24.	PCTT Temperatures, Data Station 20	48
25.	PCTT Temperatures, Data Station 21	49
26.	PCTT Temperatures, Data Station 22	50
27.	PCTT Temperatures, Data Station 23	51
28.	PCTT Forward Adapter Temperatures vs Data Station	52
29.	PCTT Intertank Section Temperatures vs Data Station	53
30.	PCTT Aft Adapter Temperatures vs Data Station	54
31.	PCTT LH_2 Tank Heat Rates, Forward Cover, Stations 18, 19 and 20	55

LIST OF ILLUSTRATIONS (Continued)

Figure Number	Title	Page Number
32.	PCTT LH_2 Tank Radiation Heat Rates, Forward Adapter, Stations 2, 3 and 4	56
33.	PCTT LH_2 Tank Radiation Heat Rate, Station 5	57
34.	PCTT LH_2 and LN_2 Tank Radiation Heat Rates, Intertank Section, Stations 6 through 13	58
35.	PCTT LN_2 Tank Radiation Heat Rates, Aft Adapter, Stations 14, 15 and 16	59
36.	PCTT LN_2 Tank Radiation Heat Rates, Aft Cover, Stations 21, 22 and 23	60
37.	PCTT LH_2 Tank Sidewall Radiation Heat Rate Distribution	61
38.	PCTT LN_2 Tank Sidewall Radiation Heat Rate Distribution	62
39.	PCTT Penetration and Structure Conduction Heat Leak Summary	63

LIST OF TABLES

Table		Page
I	PCTT Super Insulation Configuration Summary	5
II	PCTT Penetration Thermal Data	10
III	PCTT Total Heat Rate Summary	12

LIST OF SYMBOLS

Symbol	Definition
A	Area, ft^2
Q	Heat Rate, Btu/Hr
T	Temperature, °R
$\mathcal{F}$	Radiative Exchange Factor, Dimensionless
ϵ	Emissivity, Dimensionless
σ	Stefan-Boltzmann Constant, 0.1714×10^{-8} Btu/Hr-Ft^2-°R^4

Subscripts

a, b	Surface differentiation
i	Inner surface
n	Number of layers
o	Outer surface
1	Flat mylar surface
2	Dimpled mylar surface

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SUMMARY

Results of a detailed thermal analysis are presented for the Partitioned Centaur Test Tank (PCTT), a space-environmental cryogenic storage test article employing Dimplar super insulation. The analysis of this report is based on the simulated space-environmental conditions of the AFRPL vacuum test facility including hard vacuum, LN_2 cold wall, and quartz lamp radiation source, assuming the PCTT to be fully tanked in accordance with stress limitations and in thermal equilibrium. Detailed PCTT temperature distributions and heat transfer rates were predicted on the basis of the simulated space-environmental flux distribution prescribed for AFRPL PCTT testing in the test document of Reference 1. Applications of the analytical predictions to the anticipated test procedure and the ensuing post-test evaluation of the PCTT thermal control performance are discussed. Predicted equilibrium propellant tank net heat rates corresponding to the Reference 1 PCTT incident heating rates are 42.09 Btu/hr for the LH_2 tank and 14.56 Btu/hr for the LN_2 tank, with corresponding respective boil-off rates of 0.218 lb/hr and 0.169 lb/hr.

INTRODUCTION

Future space missions require storage of high-energy cryogenic propellants in propulsion system tankage during long space coast. Evaluation of the potential space-environmental cryogenic storage capabilities of tank thermal control systems employing super insulation is necessarily predicated on the ability to demonstrate thermal control performance. The Partitioned Centaur Test Tank provides a full-scale test article with an LH_2-filled fuel tank and an LN_2-filled oxidizer tank designed to accommodate a practical evaluation of a Dimplar super insulation system under simulated space thermal vacuum conditions. Interpretation of the resulting thermal test data must in turn be supported by detailed analysis of the actual test article.

1. DISCUSSION

1.1. Partitioned Centaur Test Tank Thermal Control Design

1.1.1 General Configuration. The Partitioned Centaur Test Tank (PCTT) conforms in all essential details to the configuration described in Reference 2, in which the partitioned tank assembly is provided fore and aft with cylindrical fiberglass adapters, each having a stiffened fiberglass cover. The entire test article is suspended in the Air Force Rocket Propulsion Laboratory (AFRPL) Space Environment Simulation Facility (SESF) vacuum chamber by means of four hanger assemblies. The forward and aft adapters are provided with circumferential aluminum rings (angle sections) to which the respective covers are mounted. Simulated space heating is provided by banks of quartz lamps, positioned to distribute a controlled heat flux over half of the external cylindrical surface area. Propellant tank fill and drain ducts, vent ducts, and instrumentation leads emerge on the side of the vehicle not irradiated by the lamps.

1.1.2. Super Insulation Configuration.

1.1.2.1. The Dimplar super insulation, positioned as noted in Figure 1, is installed in overlapping "blankets". Each "blanket" consists of a specified number of "pairs" of Dimplar layers, where a "pair" corresponds to a single layer of flat Dimplar, plus a single dimpled layer. The external super insulation is suspended by means of teflon pegs which are the sole physical contact between the external insulation and the PCTT adapter. The aft adapter pegs do not penetrate the external super insulation but support two fiberglass rings (Stations 336 and 384) which, in turn, maintain physical separation of the external insulation blankets and the aft adapter. The internal surfaces of the forward and aft adapters and covers are provided with additional Dimplar blankets which are in direct contact with the respective adapter/cover internal surfaces. A summary of the super insulation and teflon peg configuration is presented in Table I. A 26-inch section of the forward adapter inner surface, adjacent to the LH_2 tank is uninsulated. A 16-inch section of the aft adapter inner surface is similarly uninsulated.

1.1.2.2. The super insulation and peg mounting characteristics are detailed in the sketches of Figure 2. A typical blanket section is shown in Figure 2a. As noted in Figure 2b, the individual blankets are 42 inches wide, and the method of staggering the blankets circumferentially is shown in Figure 2c. As the cylindrical diameter increases with succeeding insulation layers, a progressively increasing V-shaped gap occurs between mating blankets, as shown in Figures 2b and 2d. This gap is closed by means of two Dimplar strips on the inner blanket and seven Dimplar strips on the outer blanket. The external strips are secured by means of aluminized mylar tape to provide a continuous exterior surface. The teflon mounting pegs and a typical mounting detail are presented in Figures 2e and 2f.

1.2. PCTT Analytical Procedures

1.2.1. Assumed Space-Environmental Simulation. As noted in Reference 1, the simulated space-environmental incident heat input prescribed for PCTT thermal testing yields a surface absorbed heat distribution which corresponds to the local absorbed solar energy distribution over a cylindrically configured vehicle in a deep space environment with vehicle centerline oriented normal to the vehicle-sun vector. Absorbed heat rate for the actual flight vehicle is accordingly predicated on assumed solar absorptivity and emissivity values of 0.3 and 0.91, respectively. The appropriate space vehicle incident heat flux distribution is detailed in Appendix A of Reference 1. As noted in the latter study, this heat flux distribution combines with the above vehicle surface radiative characteristics in rendering a unique

TABLE I

PCTT SUPER INSULATION CONFIGURATION SUMMARY

PCTT Item	Number of Blankets	Dimpler "Pairs" Per Blanket	Support Peg Configuration
Outer Sidewalls	3	7, 7 & 6	27 pegs, Sta. 156* 27 pegs, Sta. 214 27 pegs, Sta. 336 27 pegs, Sta. 384
Inner Forward Adapter	1	10	27 pegs, Sta. 156 28 pegs, Sta. 191
Inner Aft Adapter	1	10	27 pegs, Sta. 336 28 pegs, Sta. 384.9
Forward & Aft Covers	3	7, 7, & 6	32 pegs (ea.) evenly distributed

* Station numbers represent longitudinal inches

vehicle external surface equilibrium circumferential temperature distribution, also presented in Appendix A of Reference 1. This temperature distribution which considers reradiation to a deep space environment was accordingly employed as an external cylindrical surface temperature boundary in the analysis of this study, and will be seen as curve (a) of Figures 7 through 20. A thermally black radiative heat sink at 150°R (LN_2 cold-wall) was assumed to be the radiative boundary conditions for the external surfaces of the forward and aft covers as well as the unirradiated half of the cylindrical side. An external cover emittance of 0.8 was employed, corresponding approximately to unpainted fiberglass.

1.2.2. The PCTT Thermal Model.

1.2.2.1. Data obtained in Convair calorimetric testing of Dimplar insulation was employed in formulating the following expression for heat rate through n layers of Dimplar:

$$\frac{Q}{A} = \frac{(T_o^4 - T_i^4)}{(n-1)\left(\frac{1}{\epsilon_2} + \frac{1}{\epsilon_1} - 1\right)} + \frac{T_o - T_i}{(n-1)(\mathcal{f}(R))}$$

in which T_o and T_i are outer and inner surface temperatures, ϵ_2 is the flat layer emittance (0.04), ϵ_1 is the dimpled layer emittance (.07), and $\mathcal{f}(R)$ is an empirically-determined thermal resistance factor, 47.4 for 10 pair-layers of Dimplar per inch. The respective emittance values are based on measurements obtained in the Convair Space-Physics Laboratory. The overall heat rate is thus seen to combine a radiation term and a conduction term, and the above expression was employed throughout the analysis.

1.2.2.2. The PCTT test article was numerically represented in terms of an elaborate thermal model of the analogous electrical type, incorporating a total of 661 temperature nodes and 4230 conductive and radiative resistors. The complete test article is shown in Figure 4, in which it is seen that the PCTT was numerically represented in terms of seventeen (17) cylindrical section data stations, and (6) cover section data stations. Each of the cylindrical stations contained ten (10) circumferential incremental area segments, each in turn containing an appropriate composite array of nodes related to that area segment. Both adapter covers were divided into three (3) annular regions, each containing ten (10) equal area segments, with each segment, in turn, containing a composite nodal array. The areas of the surface nodes are tabulated in Figure 4. Each propellant tank was represented by a single heat sink node of appropriate temperature and surface area.

1.2.2.3. Typical thermal model local geometrical and thermophysical characteristics are detailed showing the nodal array for each of the major composite structure configurations in Figures 3a through 3e. Internal radiation exchange parameters were obtained in a separate preliminary numerical study. Conventional methods were first employed in determining the appropriate geometric configuration factors. Pertinent configuration factors and surface emittances were then supplied as input to an analysis employing the classical Oppenheim method of determining radiation exchange factors. These radiation exchange factors ($\mathcal{F}$) are summarized graphically in Figures 3f through 3k as functions of test article station. Thus it is possible to represent the net radiative heat transfer from a given surface (a) to a neighboring surface (b) as

$$Q_{ab} = A_a \mathcal{F}_{ab}(T_a^4 - T_b^4) = - A_b \mathcal{F}_{ba}(T_b^4 - T_a^4)$$

where

$$A_a \mathcal{F}_{ab} = A_b \mathcal{F}_{ba}$$

1.2.2.4. It is of interest to note the effect of the uninsulated portion of the inner adapter surfaces on the resulting factors (Figures 3f and 3g). The uninsulated adapter surface was assumed to have an emittance of 0.8, corresponding to unpainted fiberglass. The resulting effect on wall-to-tank radiative heat rate will be seen in the following section. The emittance of the super insulation inner surface was assumed to be the measured value of 0.04, as noted earlier, and the 301 stainless steel tank surface emittance was assumed to be 0.175.

1.3. Resulting Predicted PCTT Thermal Control Performance for Hard Vacuum (10^{-5} TORR)

1.3.1. PCTT Temperature Profiles.

1.3.1.1. Equilibrium temperatures throughout the PCTT test article assuming tanked conditions and hard vacuum (10^{-5} TORR) are presented in Figures 5 through 30. Figures 5 through 21 show temperature profiles in planes normal to the vehicle major axis. Temperatures presented for data stations 1 and 17 are for the forward and aft aluminum adapter rings. Forward and aft cover temperatures are presented in Figures 22 through 27. Thermal symmetry permits complete presentation of the cover temperatures in terms of three transverse data stations each. It will be noted that in each case, the three data stations are coincident at the center of the cover.

1.3.1.2. Lengthwise temperature profiles are presented in Figures 28, 29 and 30, respectively, for the forward fiberglass adapter, the cylindrical intertank section, and the aft fiberglass adapter. It is seen that considerably elevated local structural temperatures occur on the heated side of the vehicle. Maximum temperatures of 330°R, 186°R, and 342°R correspond respectively to the forward adapter, the intertank section, and the aft adapter.

1.3.2. PCTT Propellant Heat Rates.

1.3.2.1. Tank heating rates from each of the data stations (stations 1 and 17 are not applicable) are presented in Figures 31 through 36.

It should be noted that the sidewall radiation heat rates (stations 2 through 16) are local fluxes presented in Btu/hr-ft^2. These data are integrated circumferentially and presented in Figures 37 and 38 as average sidewall heat rate in Btu/hr-ft^2 vs data station.

1.3.2.2. As seen in Figures 37 and 38, the relative contributions of the uninsulated, unpainted adapter sections to tank radiative heat rate (data stations 4 and 14) are significant. Of further significance is the LH_2 tank heat rate at data station 5, a short, cylindrical tank section which is not afforded the added shielding of the adapter or the intertank cylindrical wall. It will be of interest to briefly consult Figure 39, noting the LH_2 tank conduction from the fiberglass adapter (1.8 Btu/hr), and the correspondingly greater conduction from the steel intertank section (7.47 Btu/hr). Conversely, it is seen that the intertank section radiation from station 6 (0.005 Btu/hr-ft^2, or approximately 0.16 Btu/hr) is markedly less than the adapter radiative heat rate from station 4 (0.143 Btu/hr-ft^2, or approximately 8.40 Btu/hr). It should be remembered that a decrease in the latter value would accompany incorporation of a low-emittance adapter surface. However, the above comparison tends to suggest the desirability of radiation-conduction trade-off studies in the thermal design of cryogenic tank adapters.

1.3.2.3. Thermal data and resulting predictions for penetration heat leaks (exclusive of adapter and intertank section conduction) are presented in Table II. All penetrations emerge from the test article at a shadowed-side location with respect to the heat source. Thermally controlled facility valves are installed in each fill and drain duct, approximately two (2) feet outboard of the test article. These valves are radiatively shielded from the test article surfaces by local LN_2 cold walls, but provide temperature boundaries of approximately 400°R for duct conduction and internal duct radiation. All other penetration

TABLE II

PCTT PENETRATION THERMAL DATA

Penetration Description	Temperature Boundary, °R	Radiation, Btu/hr	Conduction, Btu/hr	Total Heat Leak, Btu/hr
LH_2 Fill & Drain 304 Stainless Steel, 7' x 2.5" x .049"	400°R	1.43	0.88	2.31
LH_2 Vent Duct, 304 Stainless Steel, 5' x 3"D x .049"	140°R	0.04	0.26	0.30
LH_2 Instrumentation, (213" long) Constantan 8 x 30 GA. 12 x 24 GA. Chromel 8 x 30 GA. Copper 4 x 24 GA.	140°R	----	0.10	0.10
LH_2 Tank Total	----	1.47	1.24	2.71
LN_2 Fill & Drain 304 Stainless Steel, 2' x 2.5"D x .049"	400°R	1.40	2.12	3.52
LN_2 Tank Total	----	1.40	2.12	3.52

boundaries were assumed to be at chamber cold wall temperature, or 140°R. Thus, the fill and drain duct is the only external penetration measurably affecting the LN_2 tank at equilibrium conditions. The instrumentation leads converge at a terminal board mounted at the bottom, rear of the aft adapter. As noted, the terminal board was assumed to reach an equilibrium temperature of 140°R. Internal duct radiation was predicated in all cases on the duct cross-sectional area and an effective emittance of 1.0. The combined penetration heat rates (including adapter and intertank section conduction) are presented and summarized in Figure 39. The test article support hangers, considered not irradiated by the lamp banks and therefore found to contribute a net loss of heat from the forward adapter, were conservatively omitted from the penetration summary.

1.3.2.4. Total equilibrium heat rates to the PCTT LH_2 and LN_2 tanks are summarized in Table III. The respective sidewall radiation heat rates were obtained by integrating the heat distribution curves of Figures 37 and 38, while the adapter cover radiation and direct radiation between tanks were obtained directly from numerical output from the thermal model. As seen in Table III, based on the AFRPL vacuum facility environmental conditions of 1.2.1., above, the respective total equilibrium heat rates are 42.09 Btu/hr to the LH_2 tank and 14.56 Btu/hr to the LN_2 tank. Total predicted boil-off rates are thus 0.218 lb/hr of LH_2 and 0.169 lb/hr of LN_2.

TABLE III

FCTT TOTAL HEAT RATE SUMMARY

HEAT SOURCE	LH_2 TANK HEATING BTU/HR	LN_2 TANK HEATING BTU/HR
Radiation, Cover Inner Surface		
Forward Cover (Fig. 31)	1.16	
Aft Cover (Fig. 36)		0.85
Radiation, Sidewall Inner Surface (Figs. 37 and 38)	25.10	10.17
Radiation Between Tanks	3.85	-3.85
Penetrations & Structure Conduction (Fig. 39)	11.98	7.39
Total Heat Rate (Btu/hr)	42.09	14.56
Total Boil-off Rate, (lb/hr)	0.218	0.169

2. CONCLUSIONS AND RECOMMENDATIONS

2.1 Interpretation and Limitations

2.1.1. The analysis of this report is predicated on successful achievement of the thermal control design objectives of the FCTT test article. An obvious objective of the test program is evaluation of the practical capabilities of the FCTT thermal control design concepts. The performance predictions of this report should thus be considered representative of a theoretical optimum configuration. It is therefore useful to enumerate the specific items of possible departure from the assumptions of this report.

2.1.1.1. The heat rates and temperatures of this document correspond to equilibrium simulated space-environmental conditions, including a hard vacuum of at least 10^{-5} TORR. This presumes a) a sufficient duration of complete vehicle childown, and b) complete out-gassing of the super insulation. The former may require a transient period of the order of 24 hours, and the latter may conceivably continue for periods of ten (10) to one hundred (100) hours. Tank leakage could effectively retard the outgassing process.

2.1.1.2. Super insulation edge losses were not considered in the analysis of this report. The accumulated areas between matching blankets of Dimplar would be a relatively insignificant portion of the total FCTT surface area. However, edgewise radiative heating of the blankets at these locations and at the support peg locations could, in the aggregate, significantly impair the insulation efficiency. As noted, evaluation of this effect is a test objective.

2.1.1.3. Heat leaks from external penetrations are not expected to contribute significant error after childown to equilibrium conditions. As noted earlier, all penetrations emerge to an effective cold wall environment, the thermally controlled fill and drain valves being the sole exception. However, a significant transient in penetration childown can be expected.

2.2. Correspondence to the PCTT Test Article

The detailed temperature distributions presented in this report are considered a practical requisite for a thorough evaluation of the PCTT measurement data. Measured PCTT boil-off rates which exceed the corresponding predicted values would be indicative of a departure from the intended thermal control performance objective. Comparison of the respective temperature distributions would be a practical requirement for isolating the specific causative thermal control characteristic. It is further suggested that post-test modification of the thermal model of this report as required to accomplish an analytical fit of the test data would be highly desirable for detailed evaluation of all aspects of the PCTT thermal control design.

REFERENCES

1. Jennings, R. W., "Recommended Test Plan, Partitioned Centaur Test Tank", Convair Report GDC-BTD67-011, January, 1967.

2. Report No. GDC-PIN66-106A, PR30587609, "A Proposal to Design and Fabricate a Partitioned Centaur Test Tank", 24 May 1966.

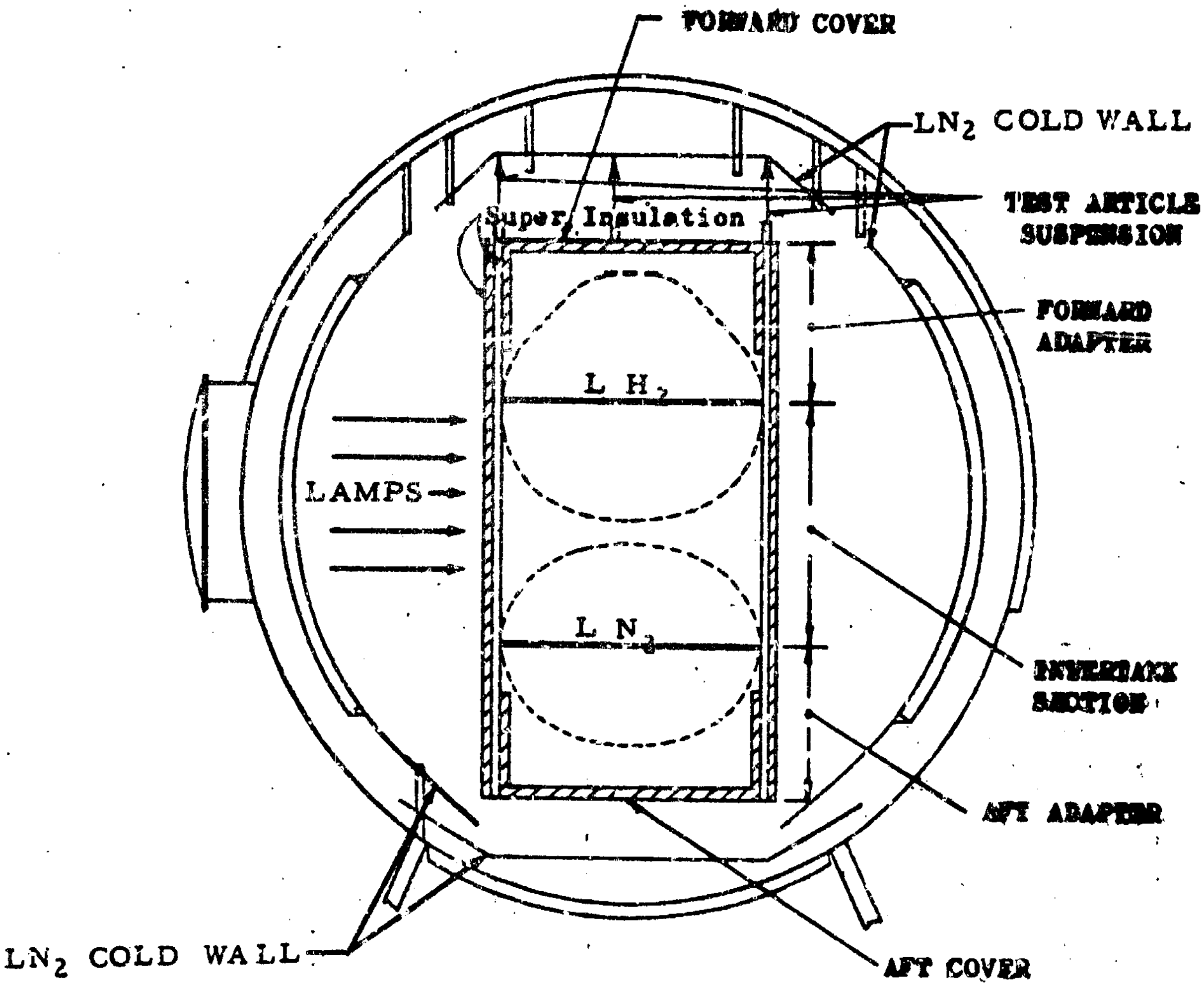


FIG. 1. PCTT AS POSITIONED IN AFRPL SESF CHAMBER

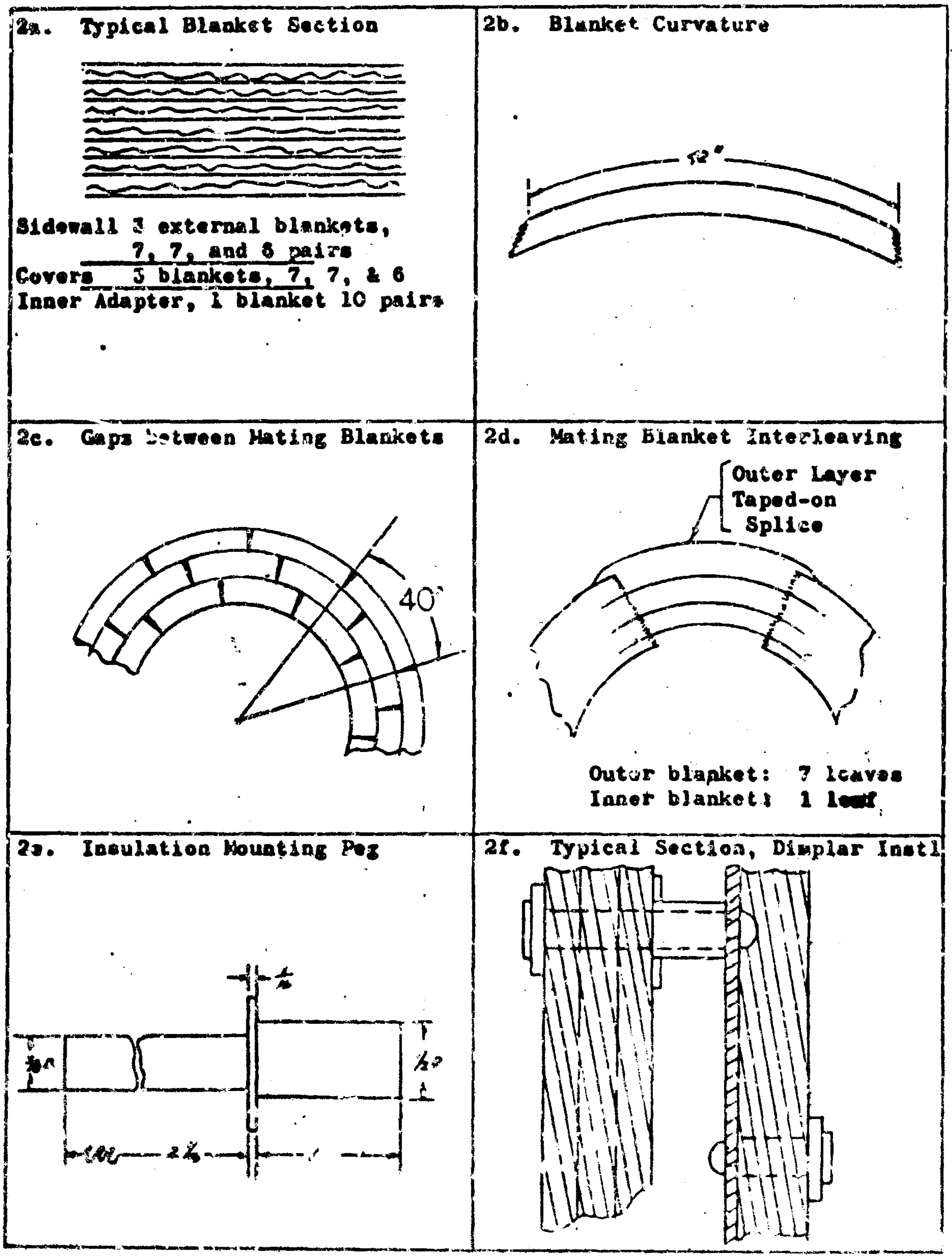
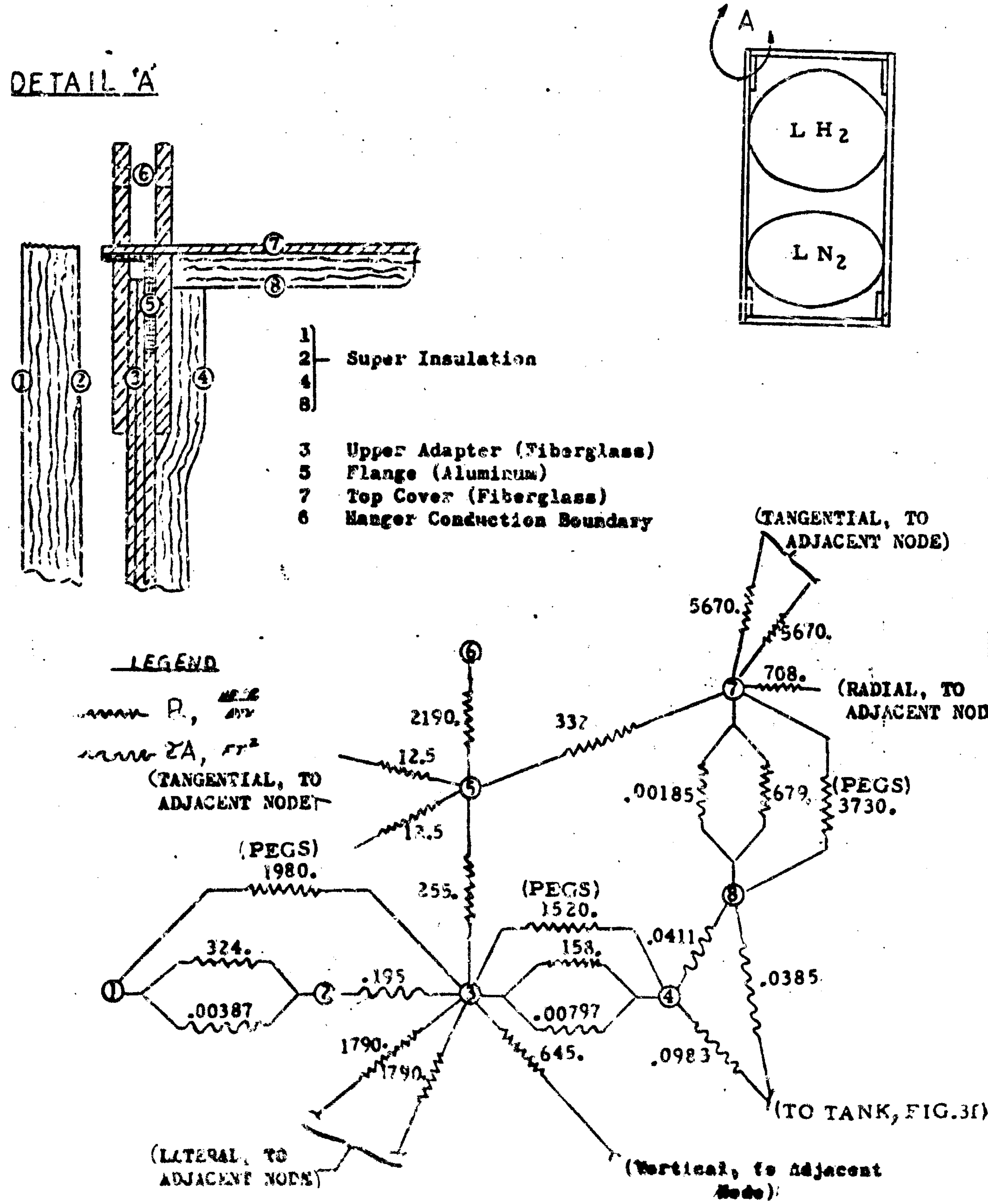


FIG. 2 PCTT SUPER INSULATION DETAIL



Note: Aft Cover Model is similar, less Node 6 .

FIG. 3e. PCTT THERMAL MODEL: COVER, RING, AND HANGER DETAIL

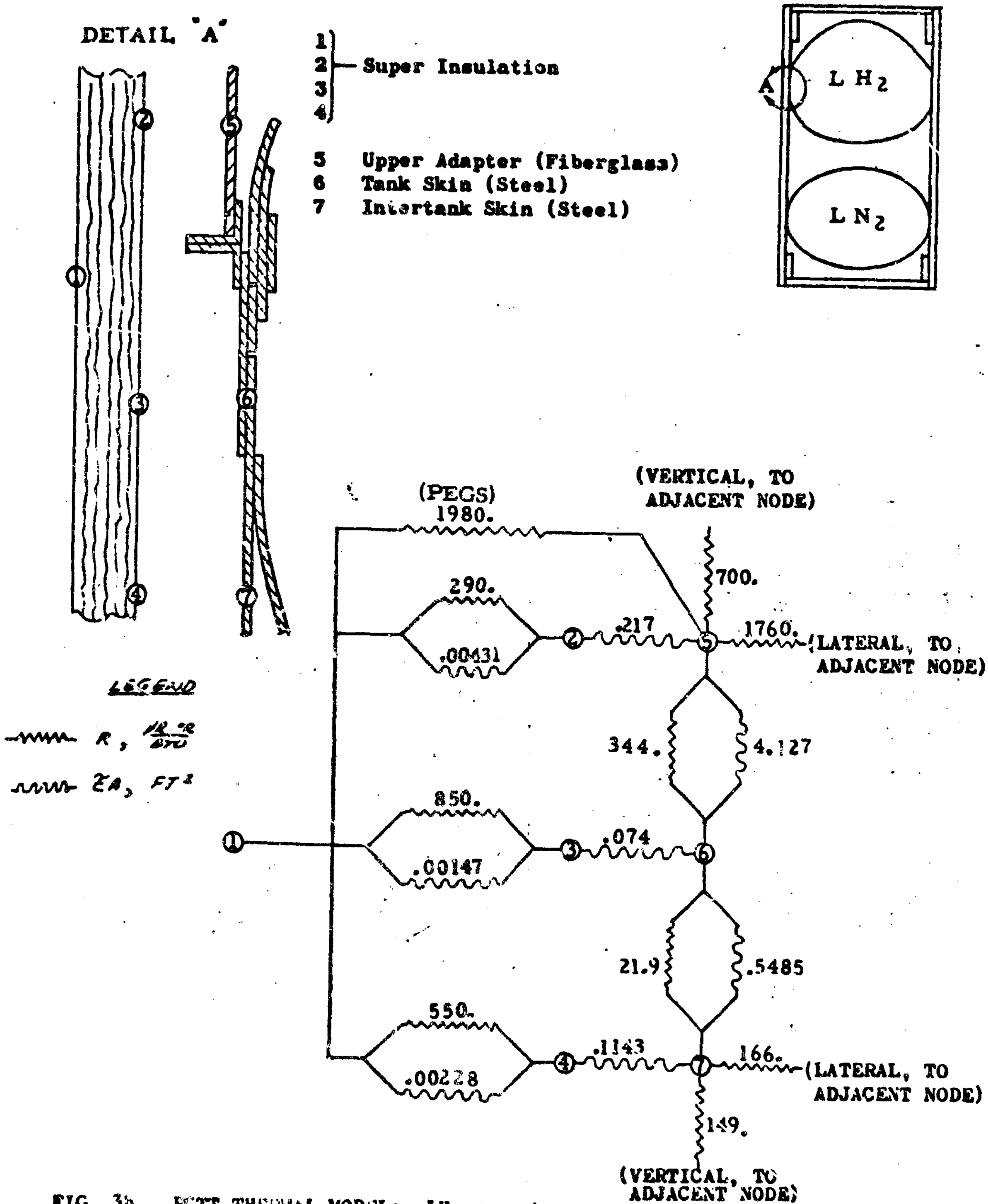


FIG. 3b. FCTT THERMAL MODEL: LH_2 TANK/ADAPTER INTERFACE

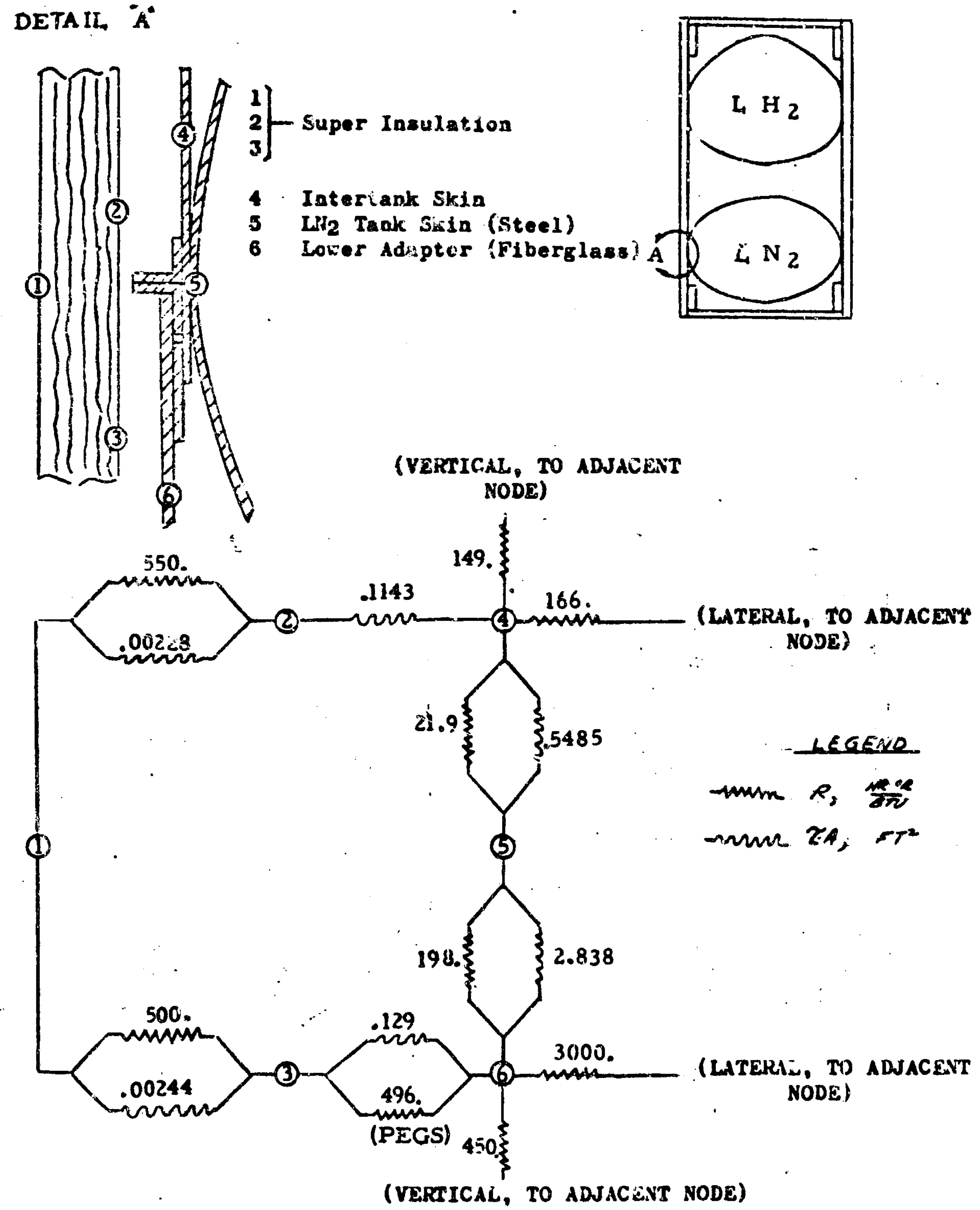


FIG. 3c. PCTT THERMAL MODEL: LN_2 TANK/ADAPTER INTERFACE

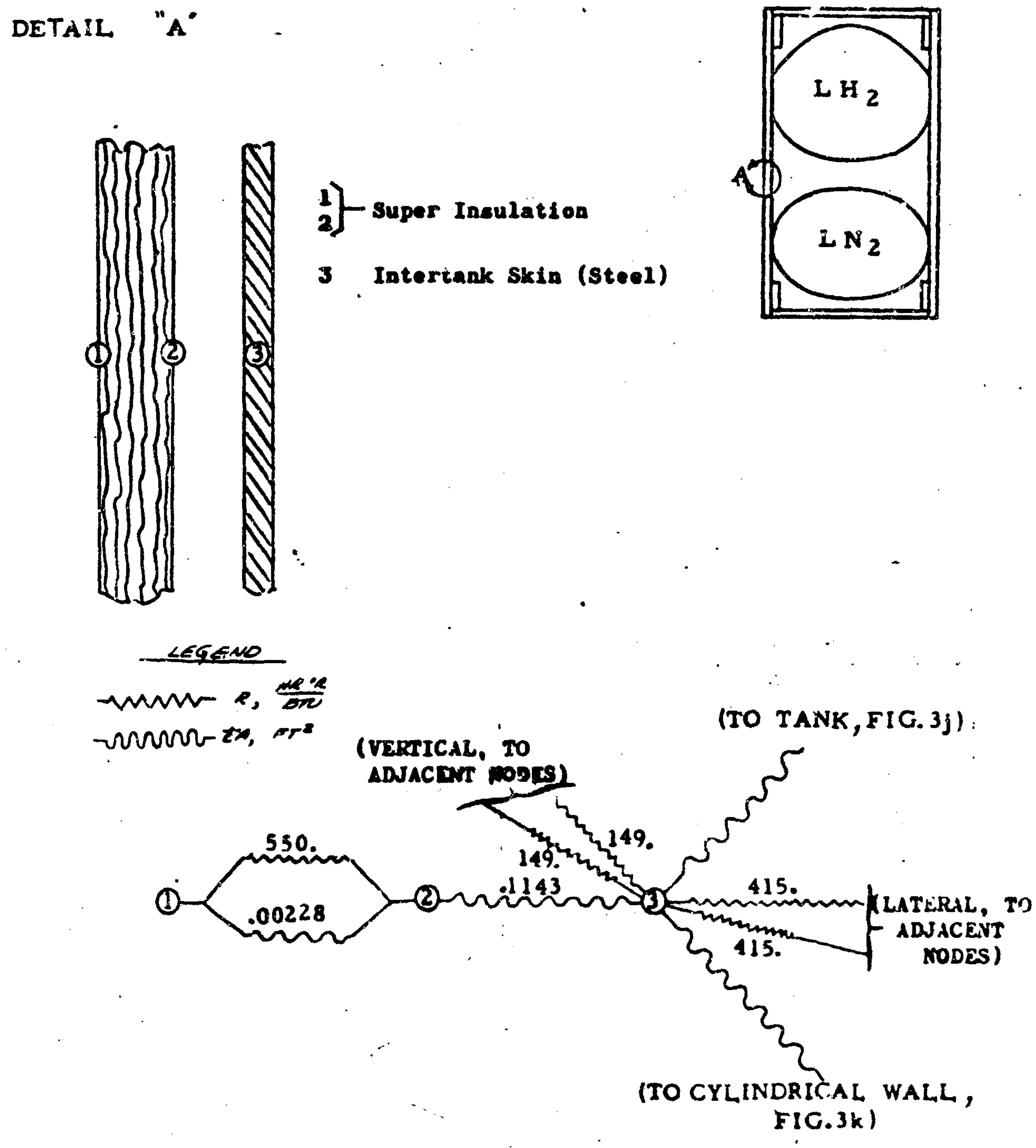
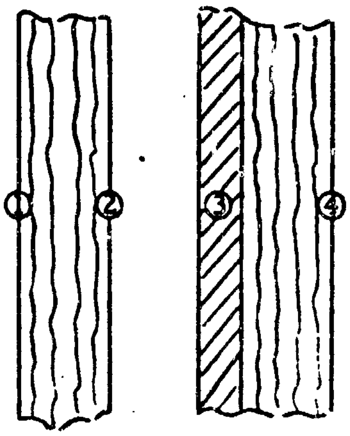


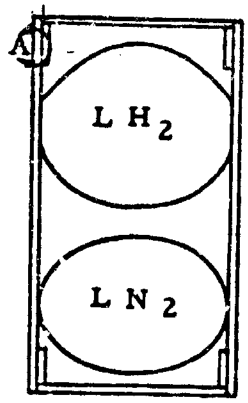
FIG. 3d. PCTT THERMAL MODEL: TYPICAL INTERTANK LOCATION

DETAIL "A"



1, 2, 4 — Super Insulation

3 Upper Adapter Skin (Fiberglass)



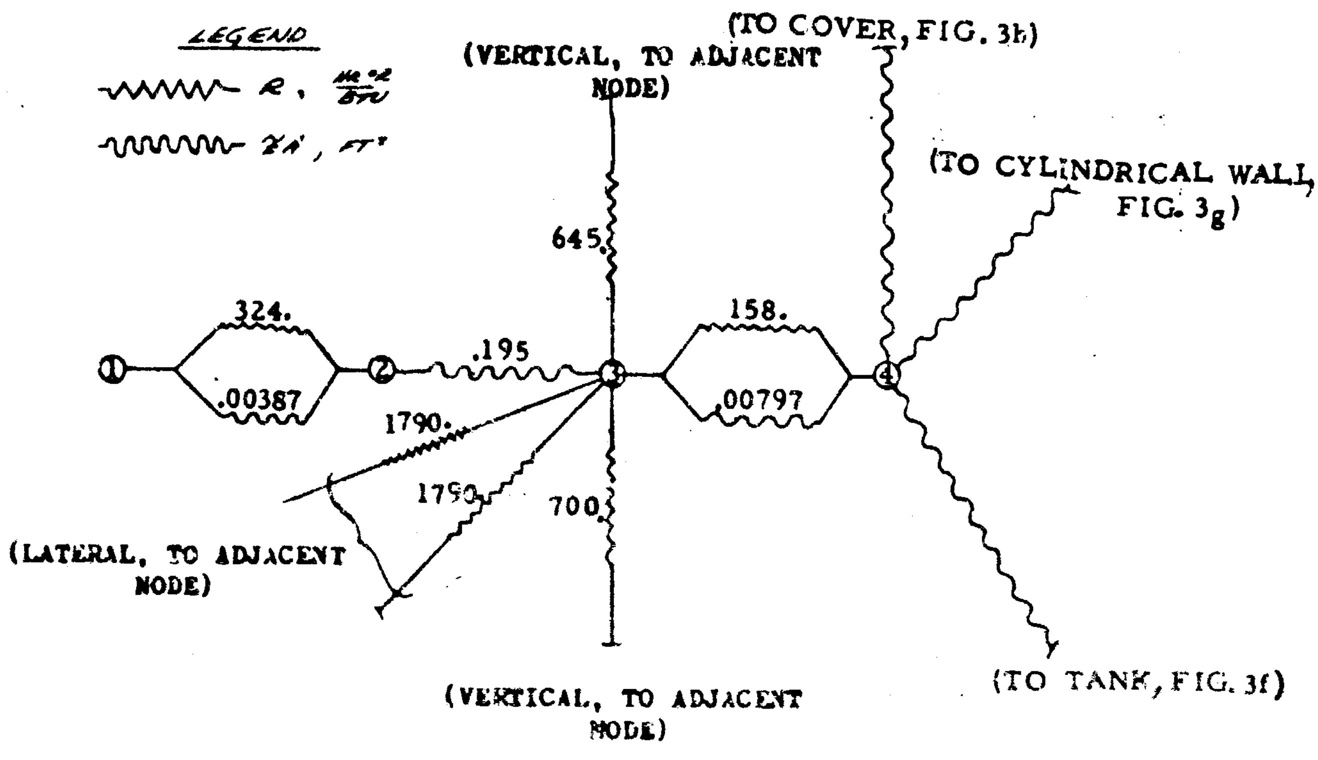


FIG. 3e. PCTT THERMAL MODEL: TYPICAL FORWARD OR AFT ADAPTER LOCATION

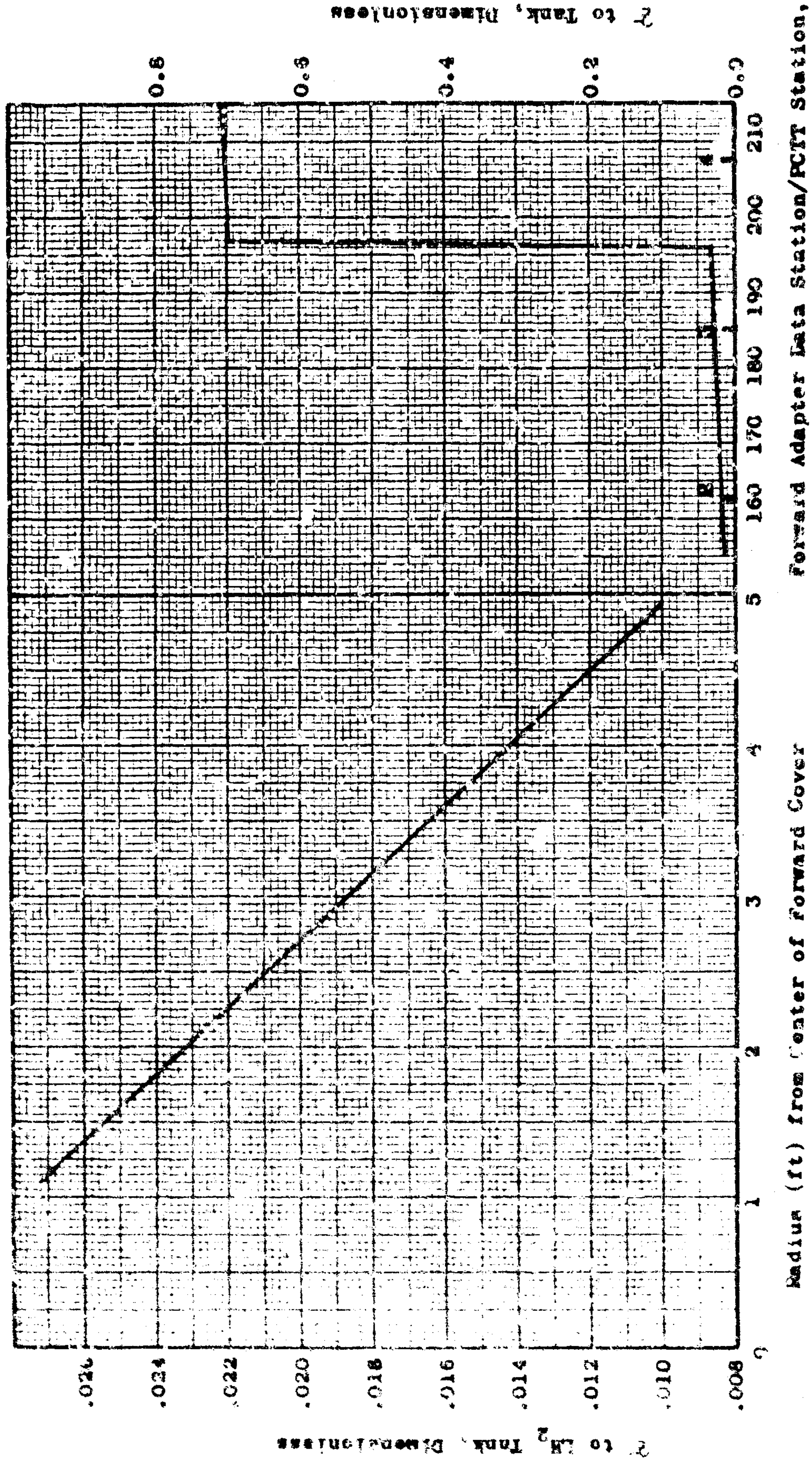


FIG. 3f. PCTT THERMAL MODEL: RADIATIVE EXCHANGE FACTORS ($\mathcal{F}$), FORWARD ADAPTER AND COVER TO LH_2 TANK.

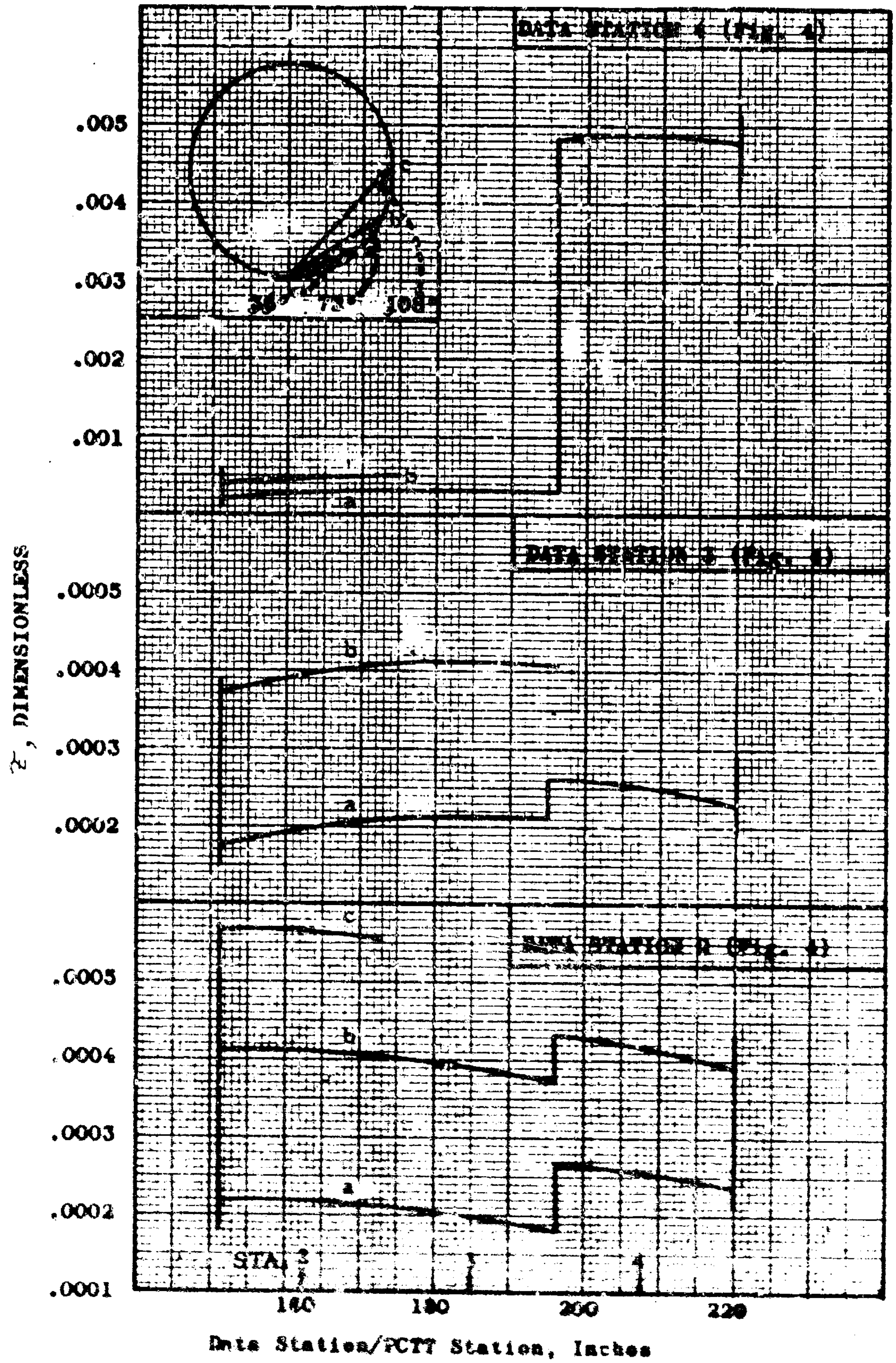


FIG. 3g. PCTT THERMAL MODEL: FORWARD ADAPTER CYLINDRICAL WALL RADIATIVE EXCHANGE FACTORS (τ)

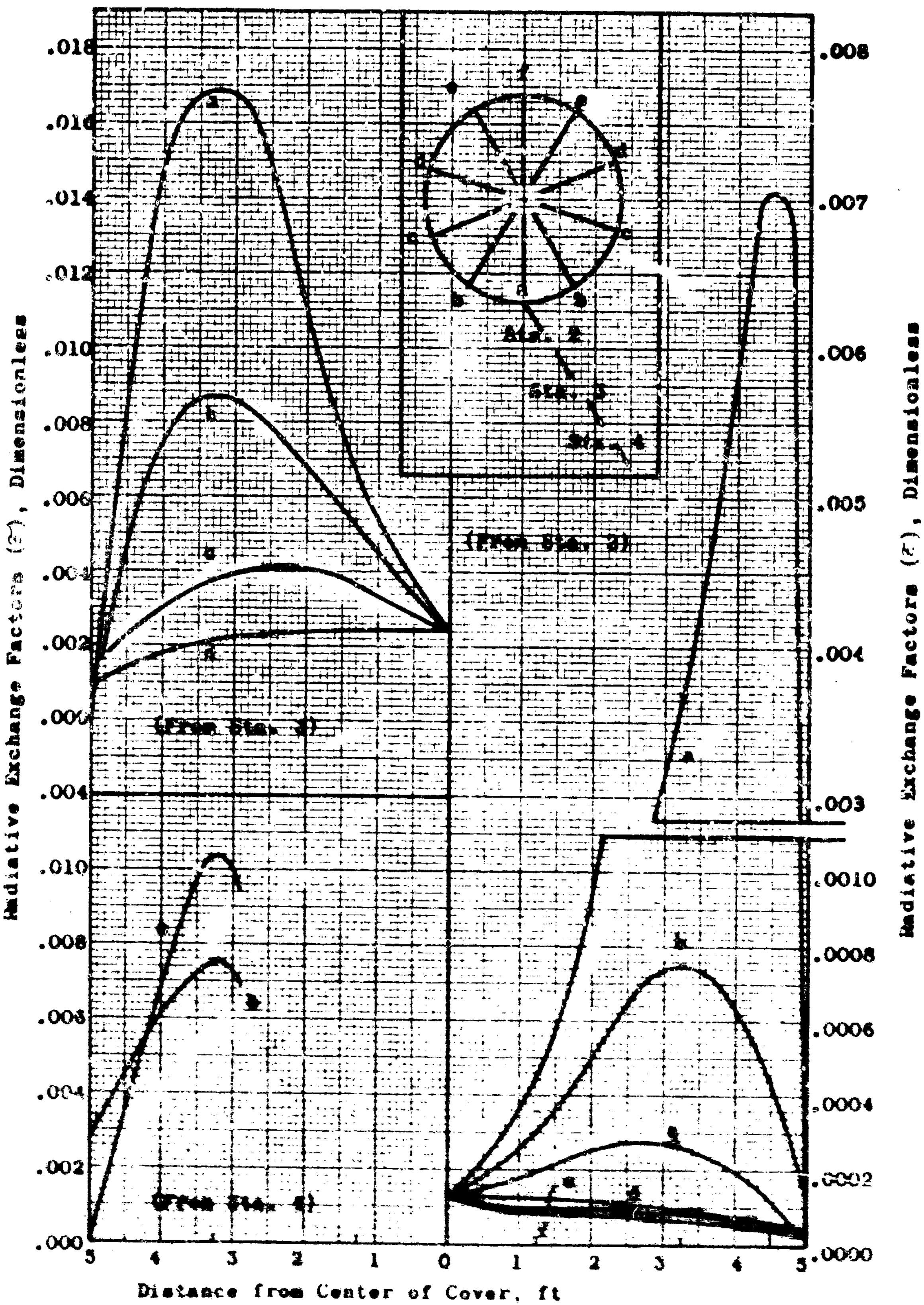


FIG. 3h. PCTT THERMAL MODEL: RADIATIVE EXCHANGE FACTORS (ℱ) FROM FORWARD ADAPTER TO COVER

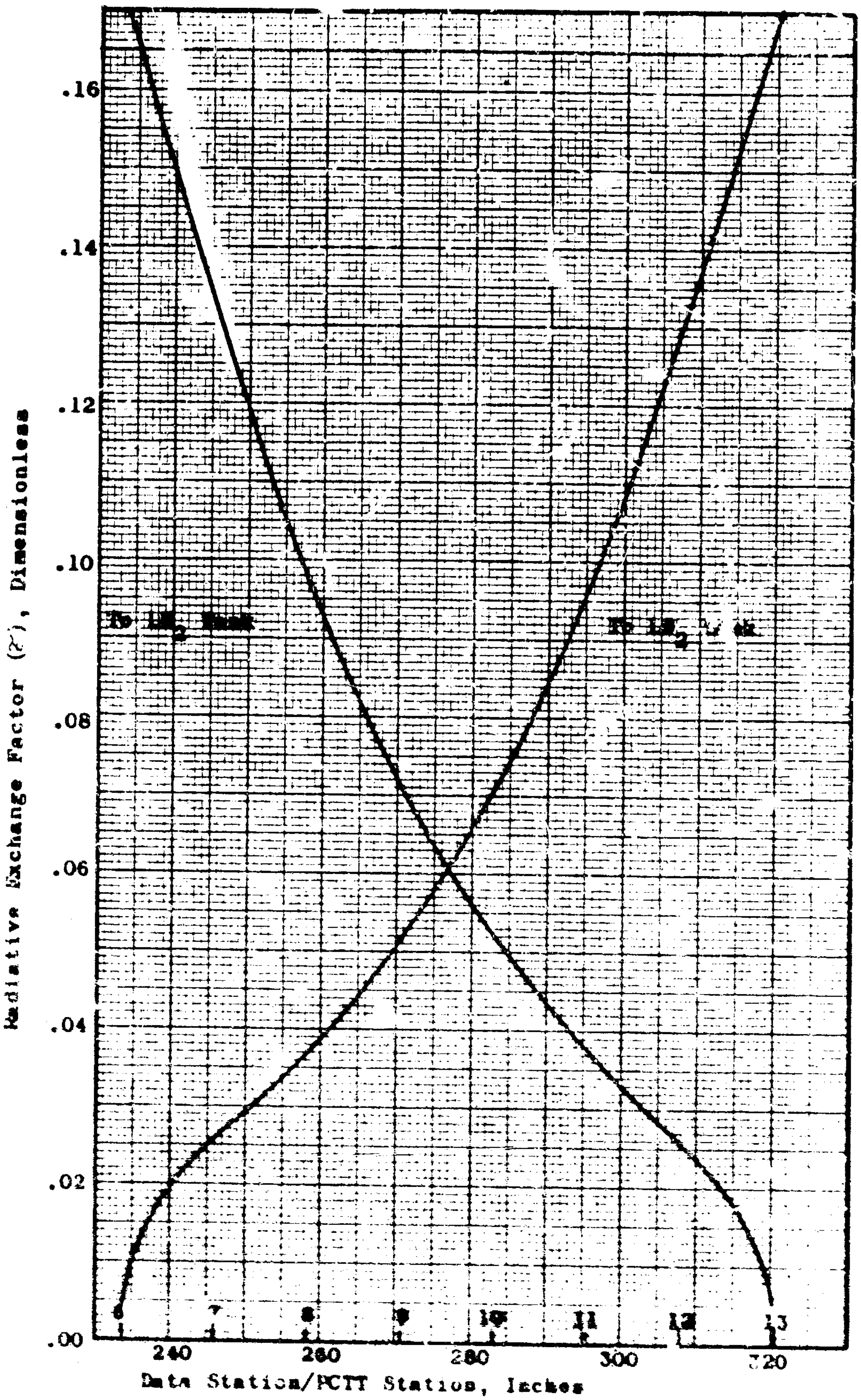


FIG. 3j. PCTT THERMAL MODEL: INTERTANK SECTION RADIATIVE EXCHANGE FACTORS ($\mathcal{F}$) TO LH_2 TANK AND LN_2 TANK

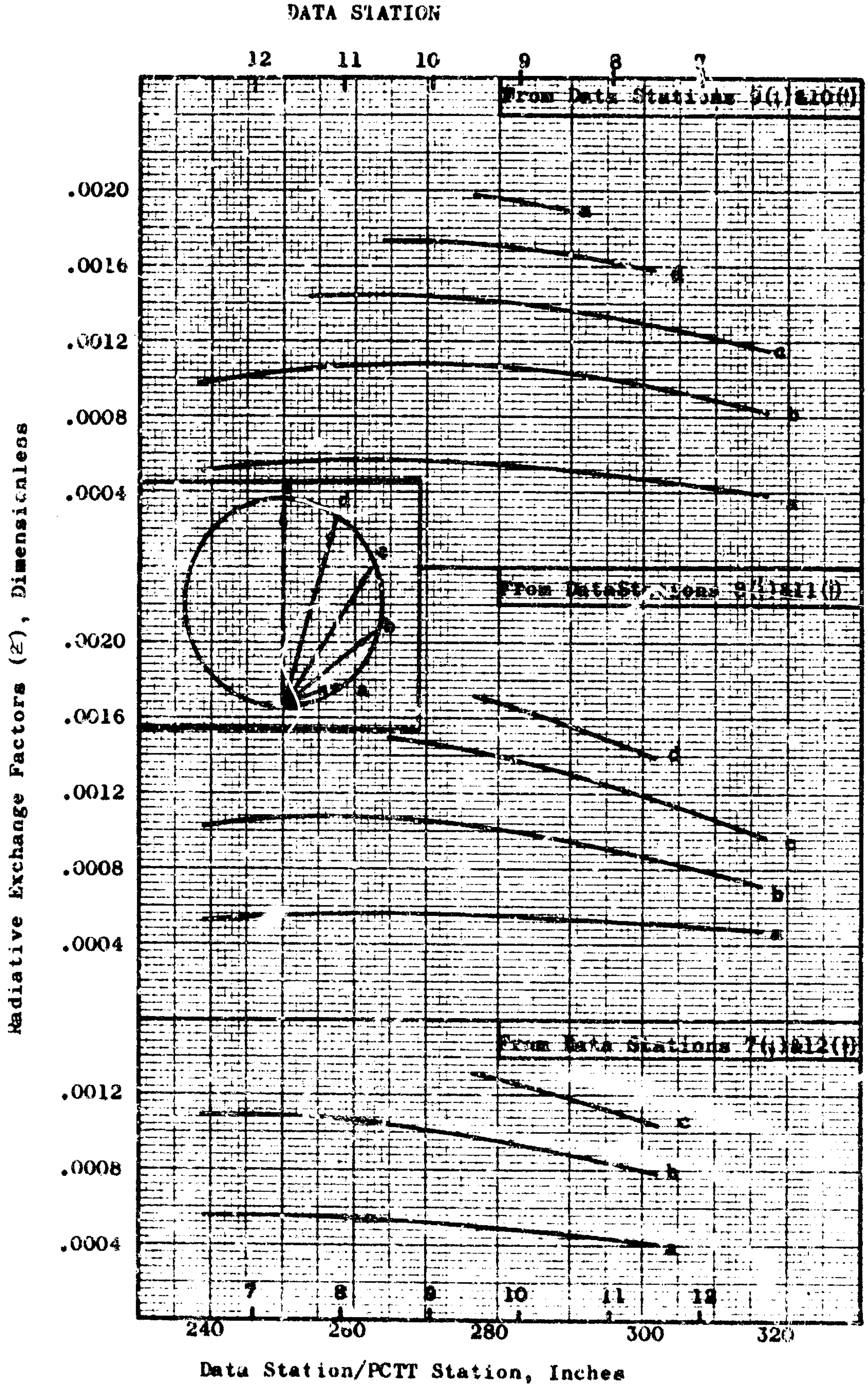
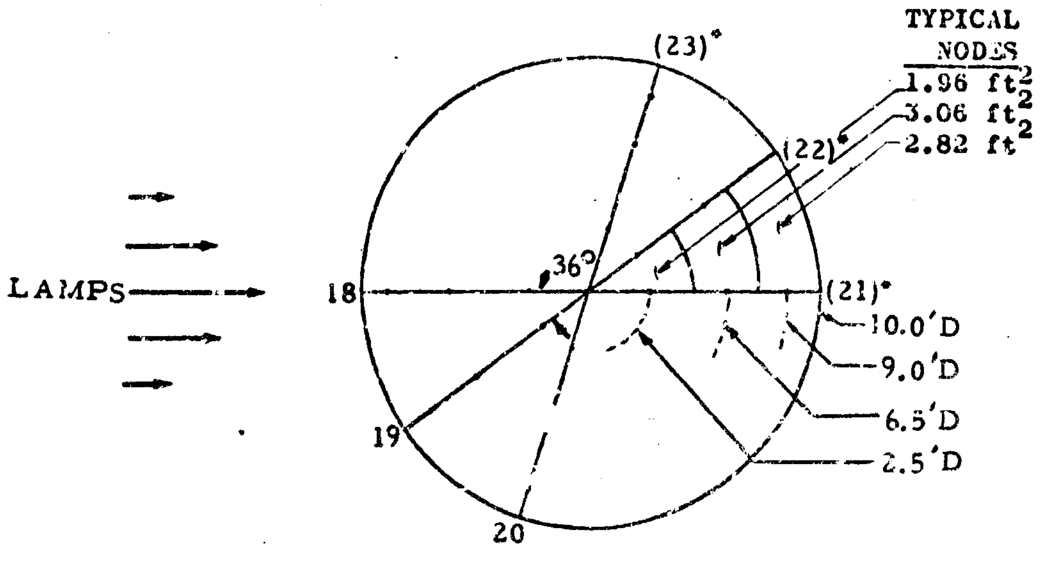


FIG. 3k. PCTT THERMAL MODEL: INTERTANK CYLINDRICAL WALL RADIATIVE EXCHANGE FACTORS



DATA STATION	NODE AREA, ft^2	PCTT STATION, IN.
1	----	151.00
2	5.83	162.75
3	5.83	185.00
4	5.83	207.25
5	2.09	223.23
6	3.24	233.66
7	3.24	246.04
8	3.24	258.41
9	3.24	270.79
10	3.24	283.16
11	3.24	295.54
12	3.24	307.91
13	3.24	320.29
14	3.20	333.22
15	5.83	350.47
16	5.83	372.72
17	----	384.47

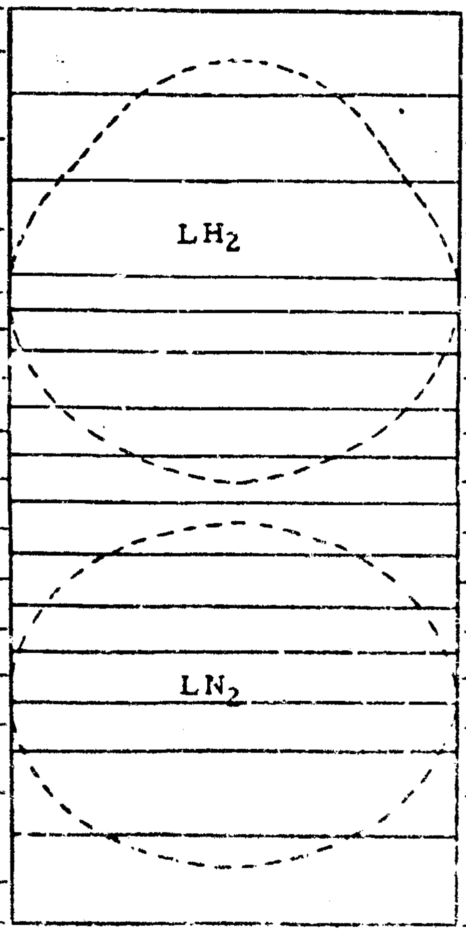


FIG. 4. PCTT THERMAL MODEL ANALYTICAL DATA STATIONS

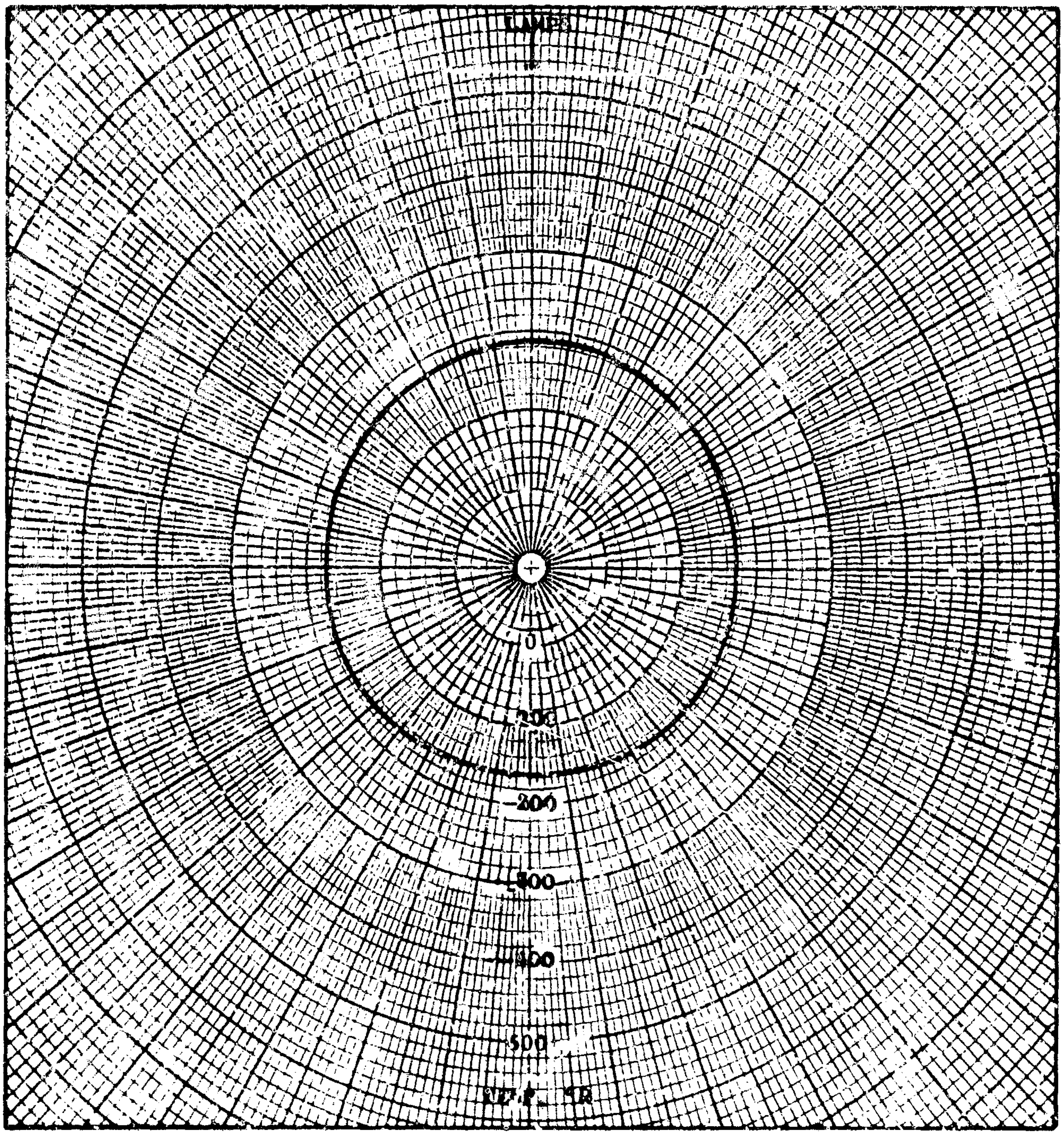
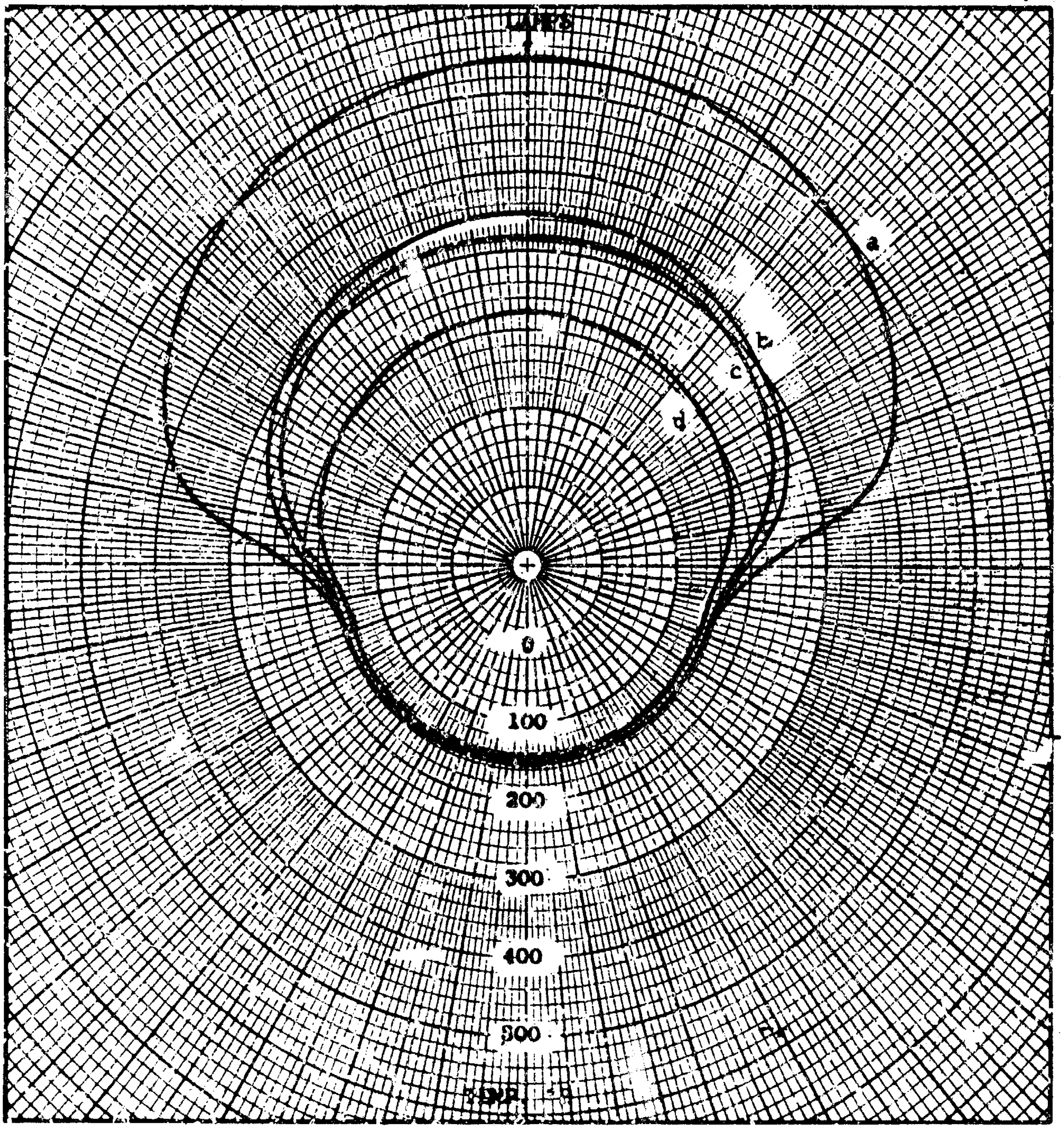
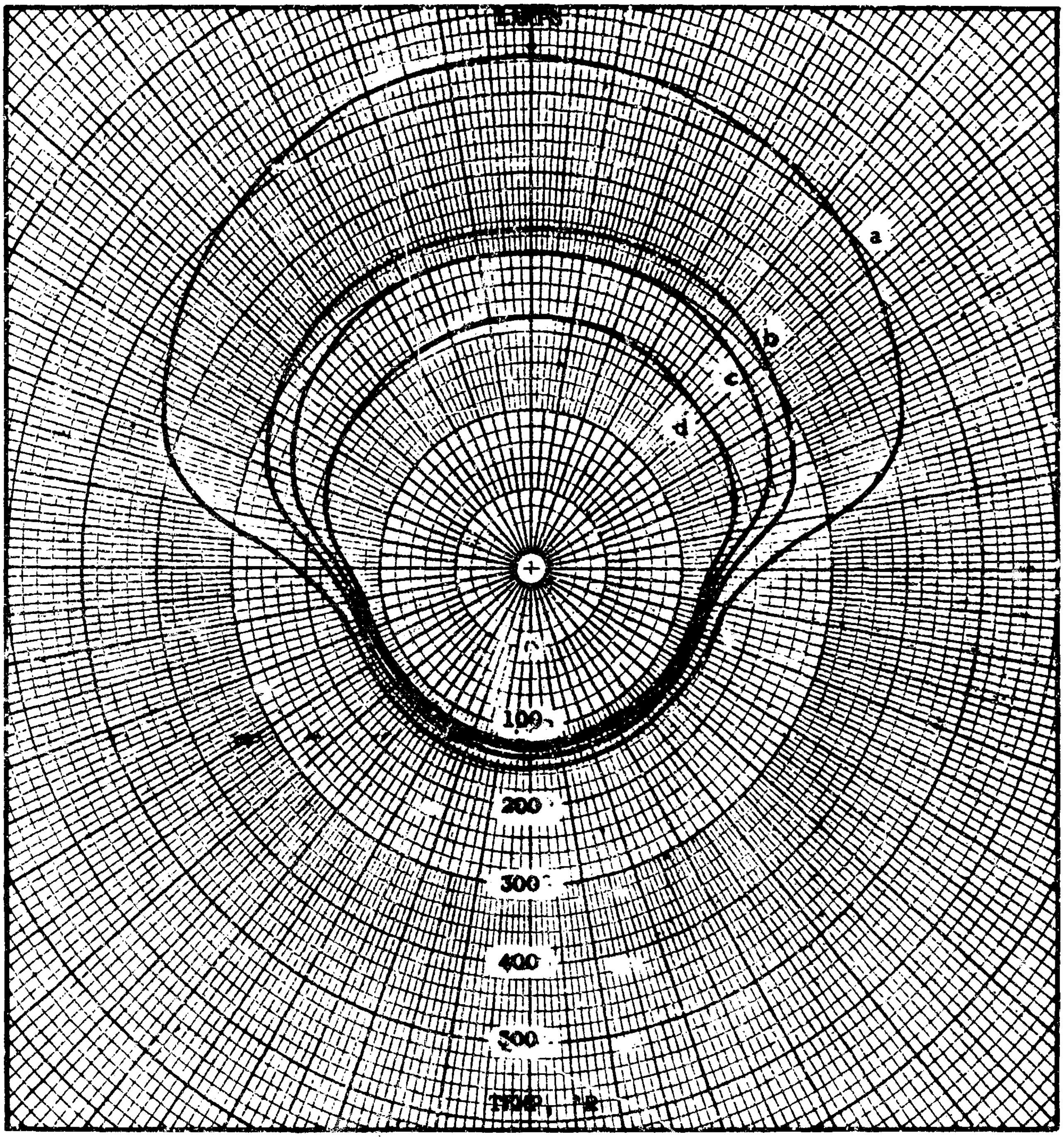


FIG. 5. PCTT FORWARD ADAPTER RING TEMPERATURE, DATA STATION 1



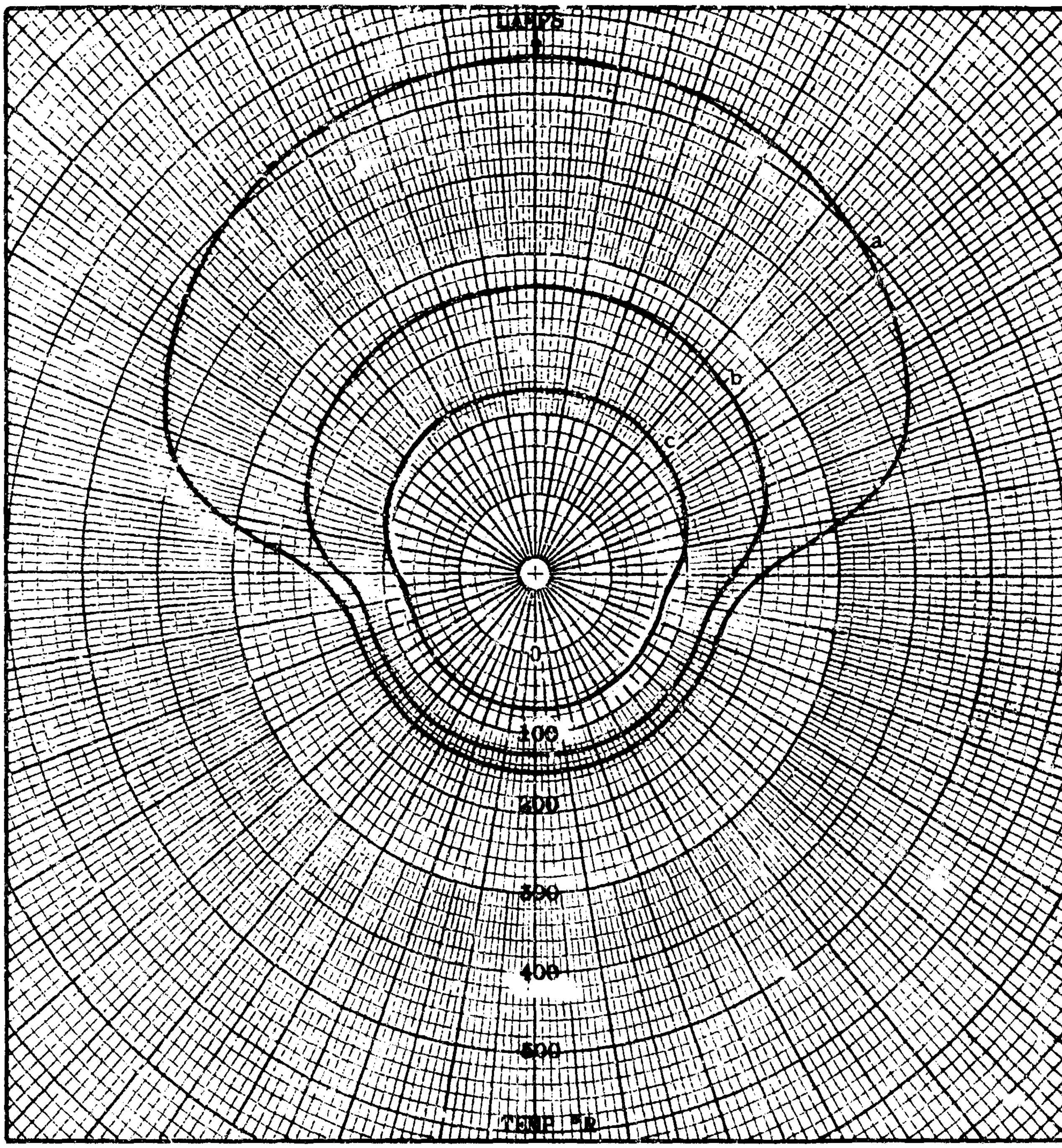
a. Outer Super Insulation, Outer Surface
b. Outer Super Insulation, Inner Surface
c. Fiberglass Adapter
d. Inner Super Insulation, Inner Surface

FIG. 6. PCTT TEMPERATURES, DATA STATION 2



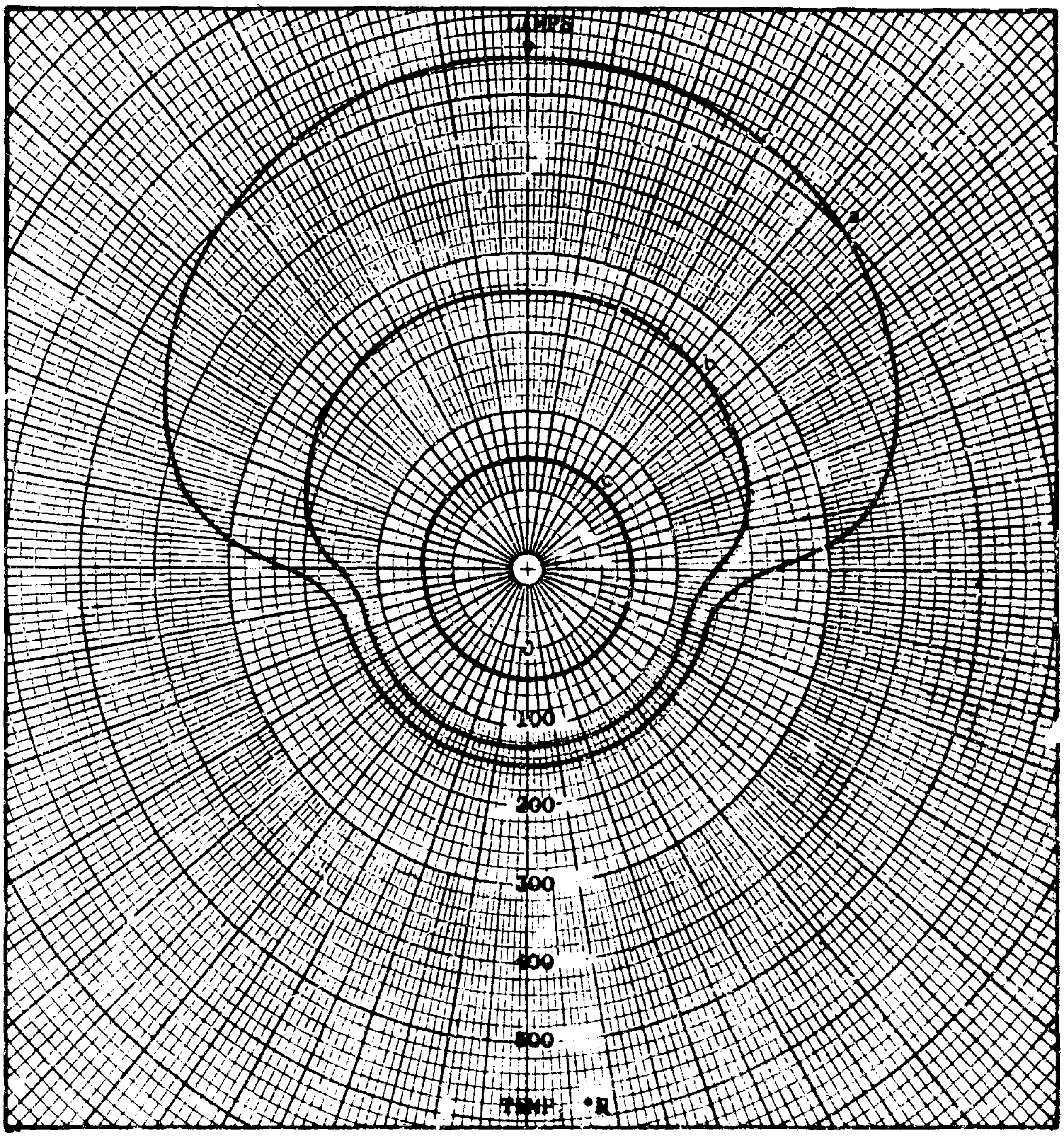
a. Outer Super Insulation, Outer Surface
b. Outer Super Insulation, Inner Surface
c. Fiberglass Adapter
d. Inner Super Insulation, Inner Surface

FIG. 7. PCTT TEMPERATURES, DATA STATION 3



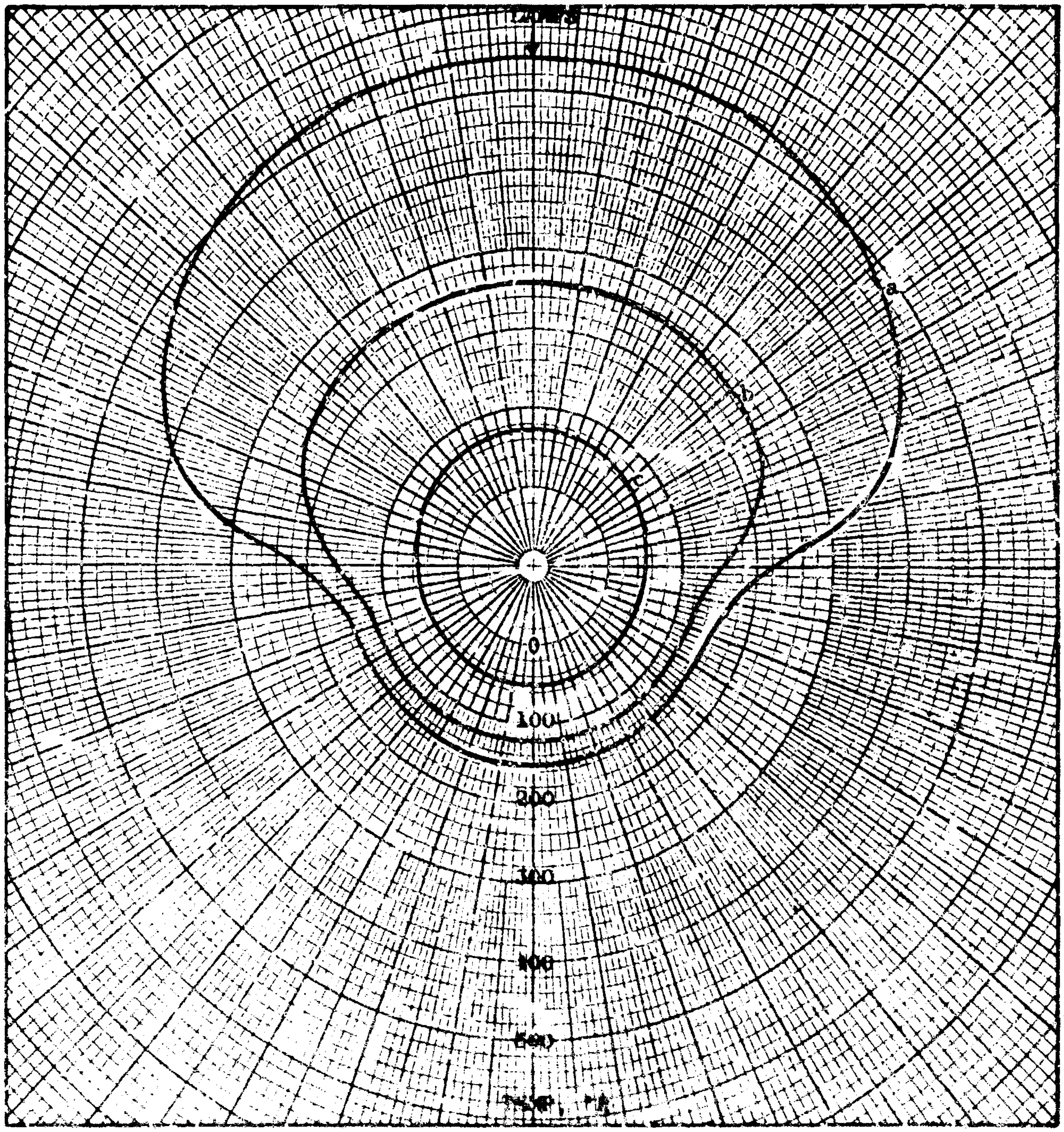
a. Outer Super Insulation, Outer Surface
b. Outer Super Insulation, Inner Surface
c. Fiberglass Adapter

FIG. 8. PCTT TEMPERATURES, DATA STATION 4



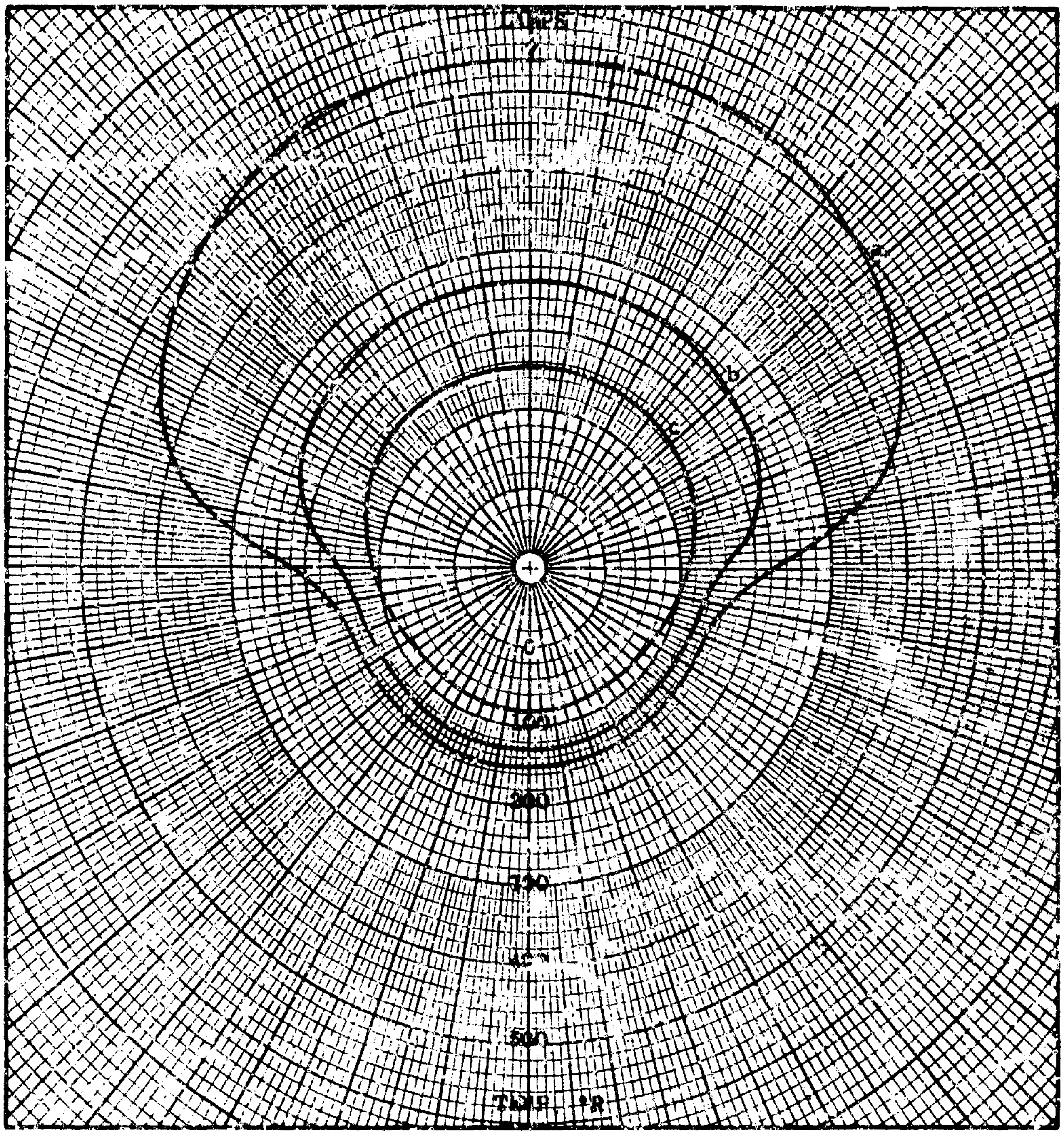
a. Super Insulation Outer Surface
b. Super Insul tion Inner Surface
c. LH_2 Tank Skin

FIG. 9. PCTT TEMPERATURES, DATA STATION 5



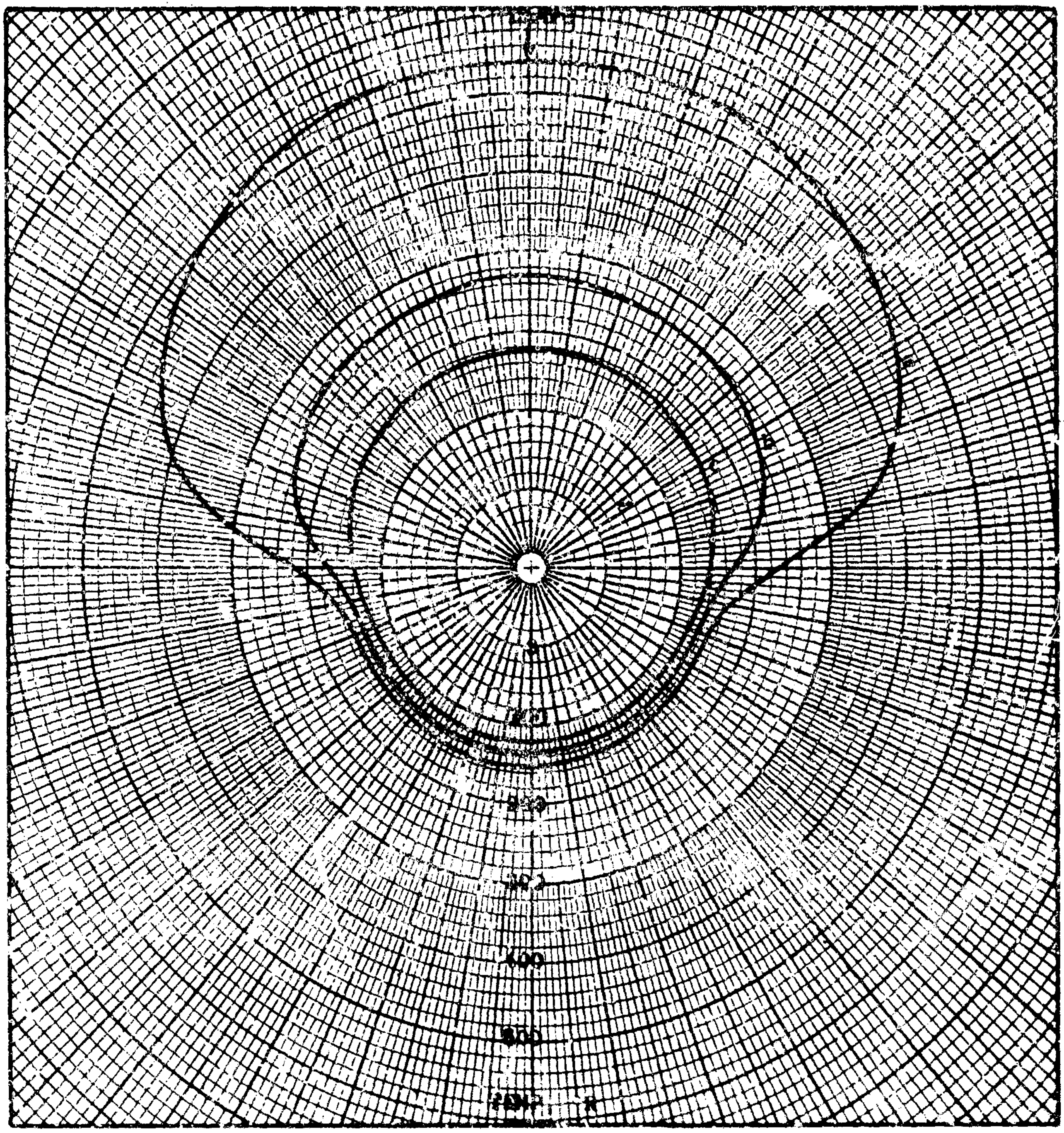
a. Super Insulation Outer Surface
b. Super Insulation Inner Surface
c. Intertank Section Skin

FIG. 10. [illegible] TEMPERATURES, DATA STATION 6



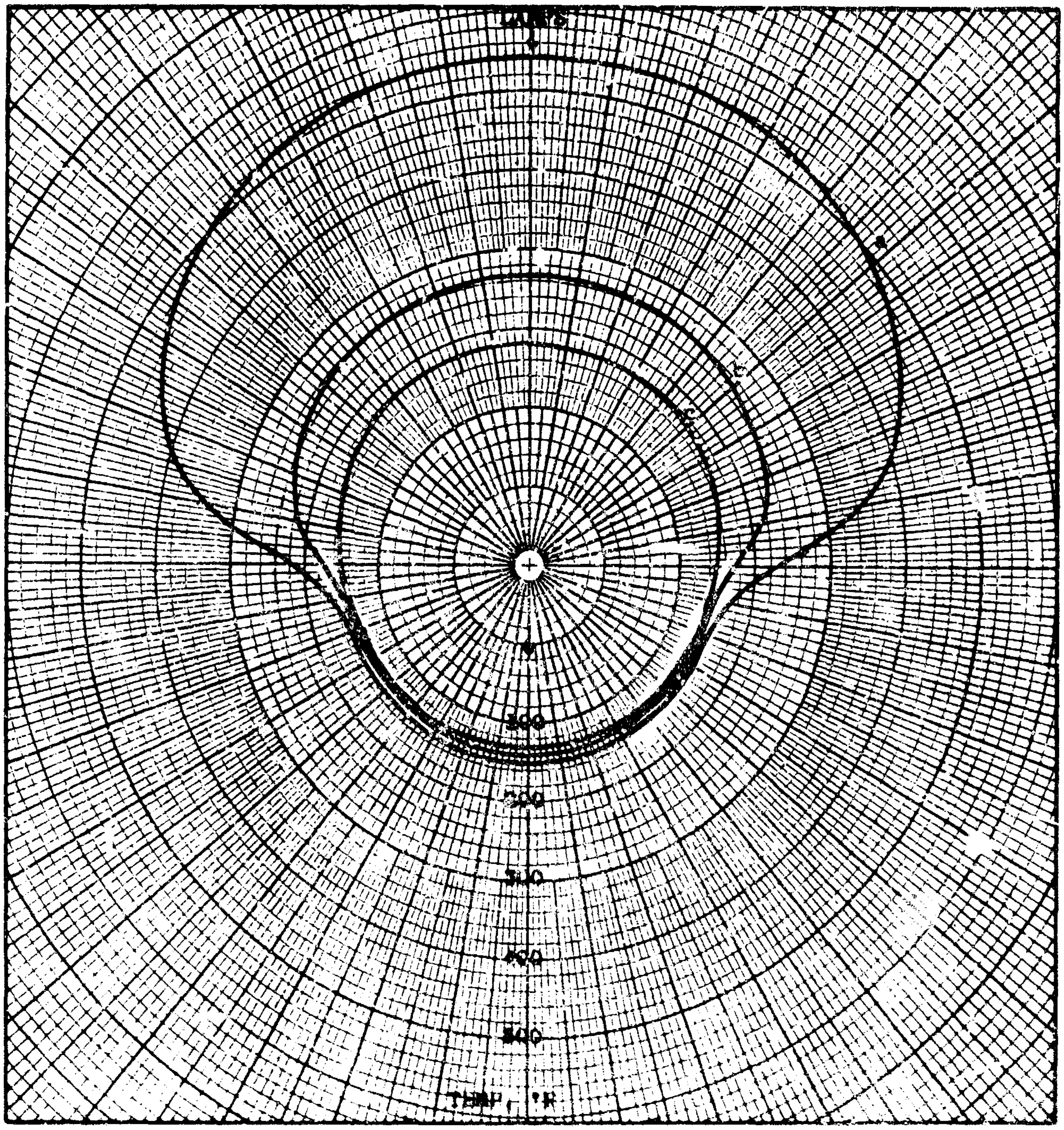
a. Super Insulation Outer Surface
b. Super Insulation Inner Surface
c. Intertank Section Skin

FIG. 11. PCTT TEMPERATURES, DATA STATION 7



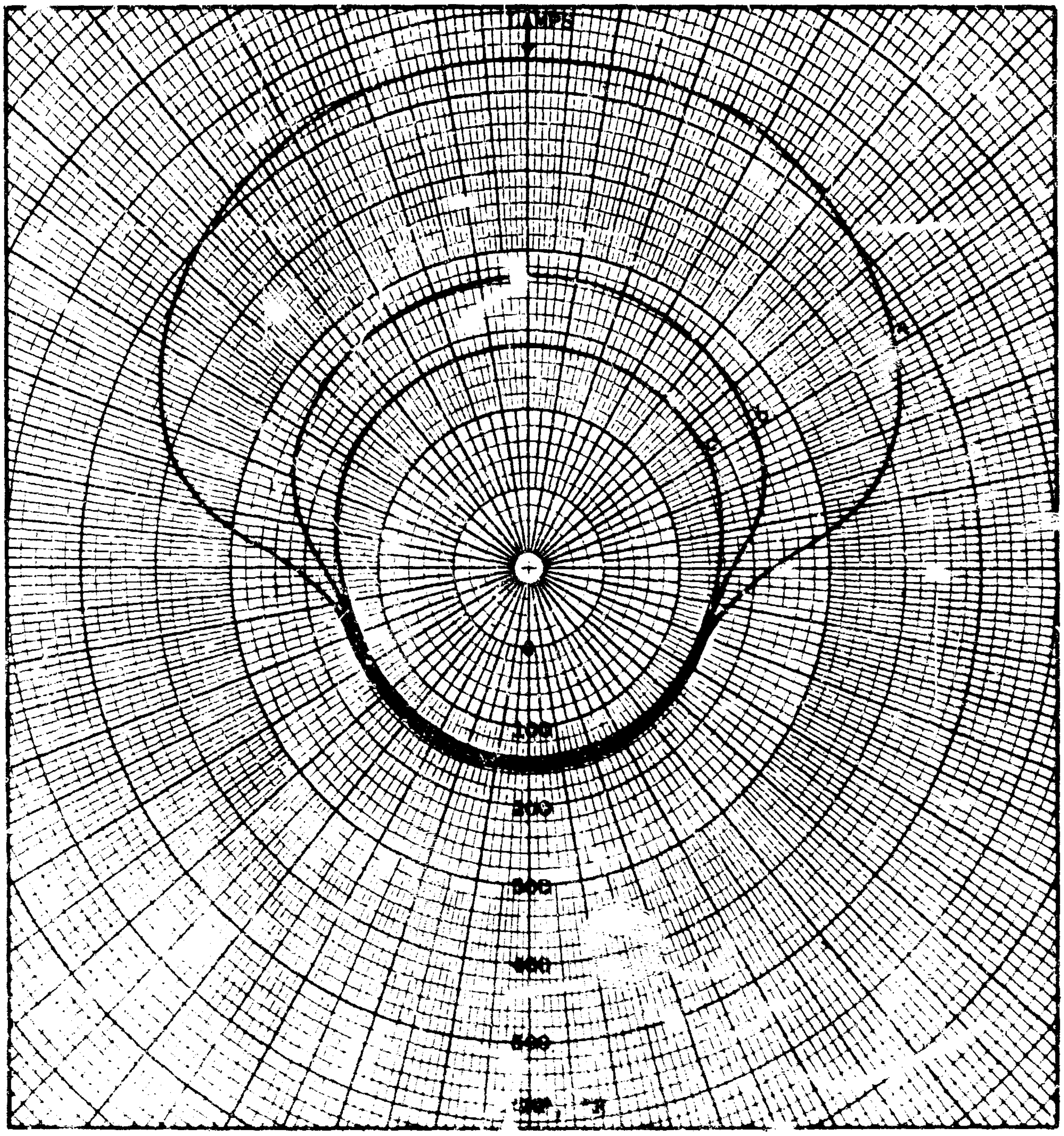
a. Super Insulation Outer Surface
b. Super Insulation Inner Surface
c. Intertank Section Skin

FIG. 12. PCTT TEMPERATURES, DATA STATION 8



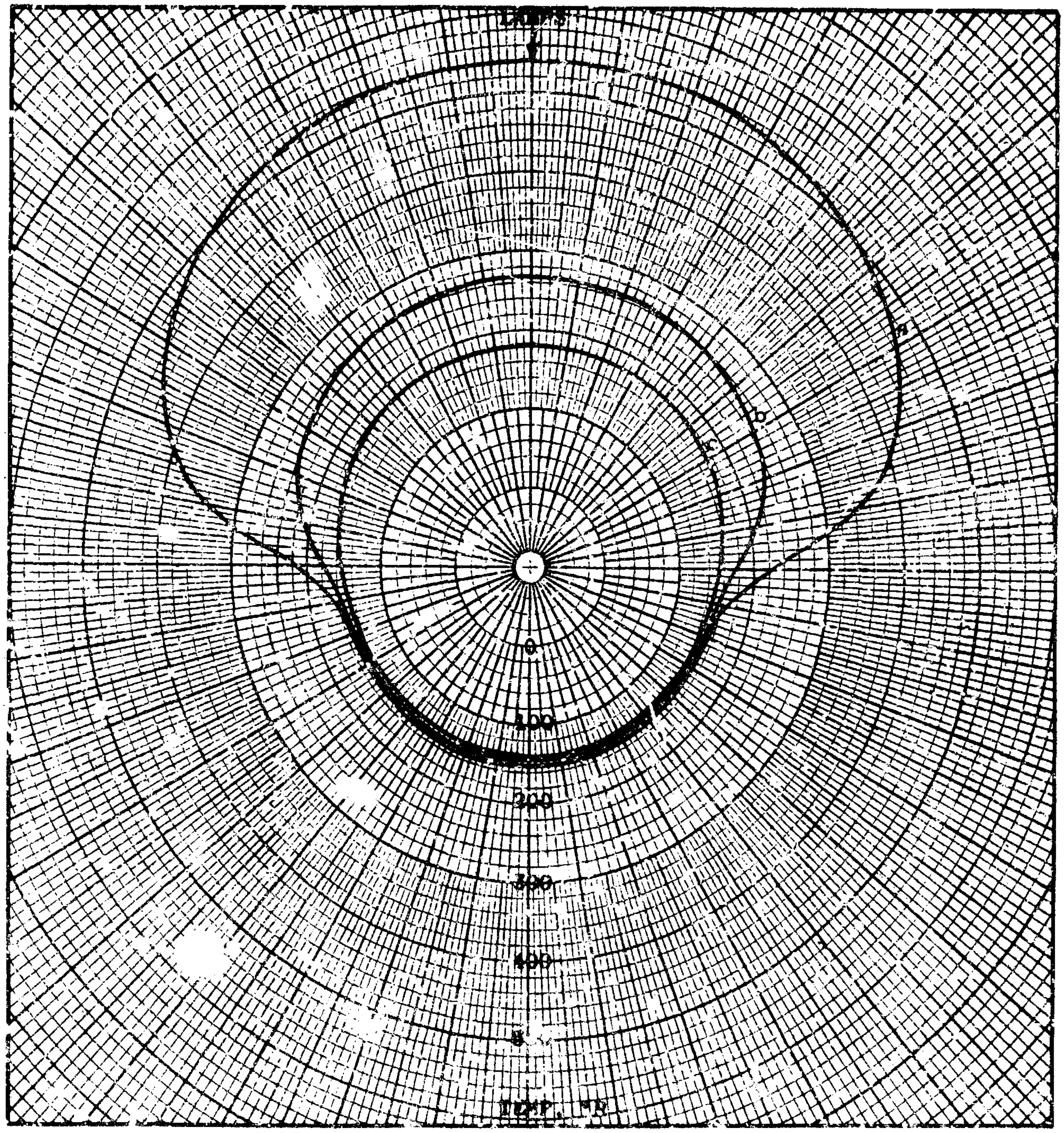
a. Super Insulation Outer Surface
b. Super Insulation Inner Surface
c. Intertank Section Skin

FIG. 13. PCTT TEMPERATURES, DATA STATION 9



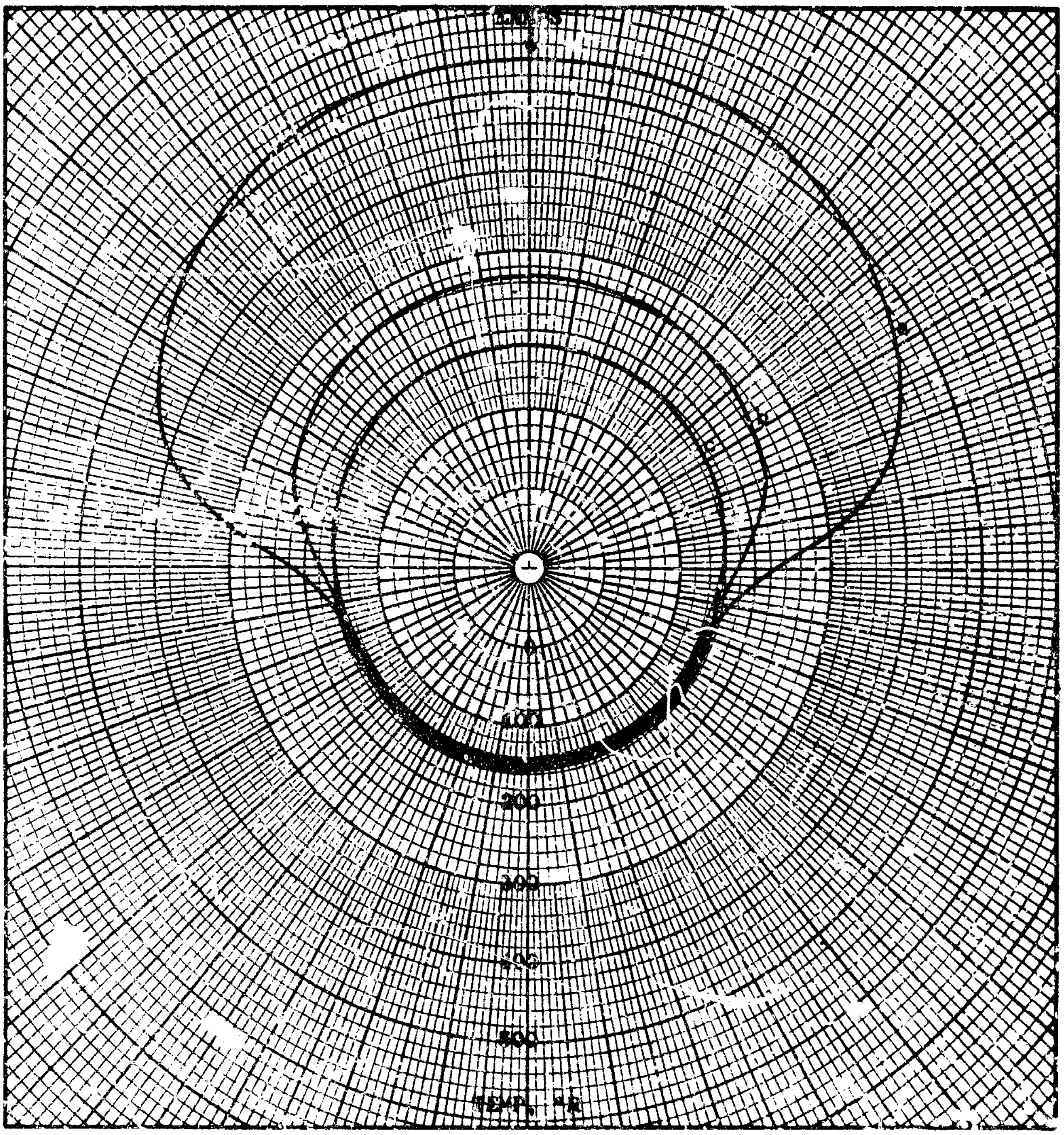
a. Super Insulation Outer Surface
b. Super Insulation Inner Surface
c. Intertank Section Skin

FIG. 14. PCTT TEMPERATURES, DATA STATION 10



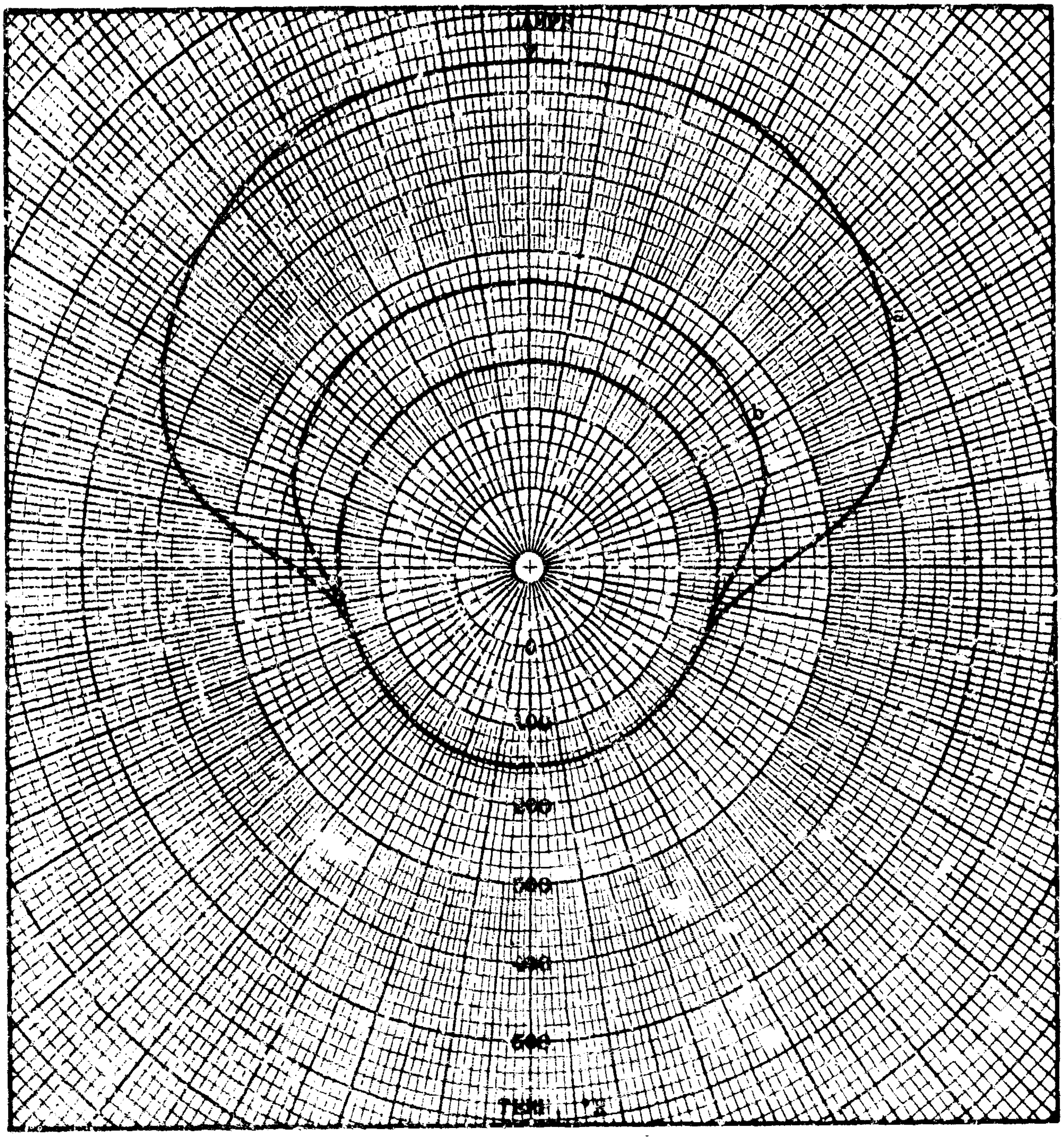
a. Super Insulation Outer Surface
b. Super Insulation Inner Surface
c. Intertank Section Skin

FIG. 15. PCTT TEMPERATURES, DATA STATION 11



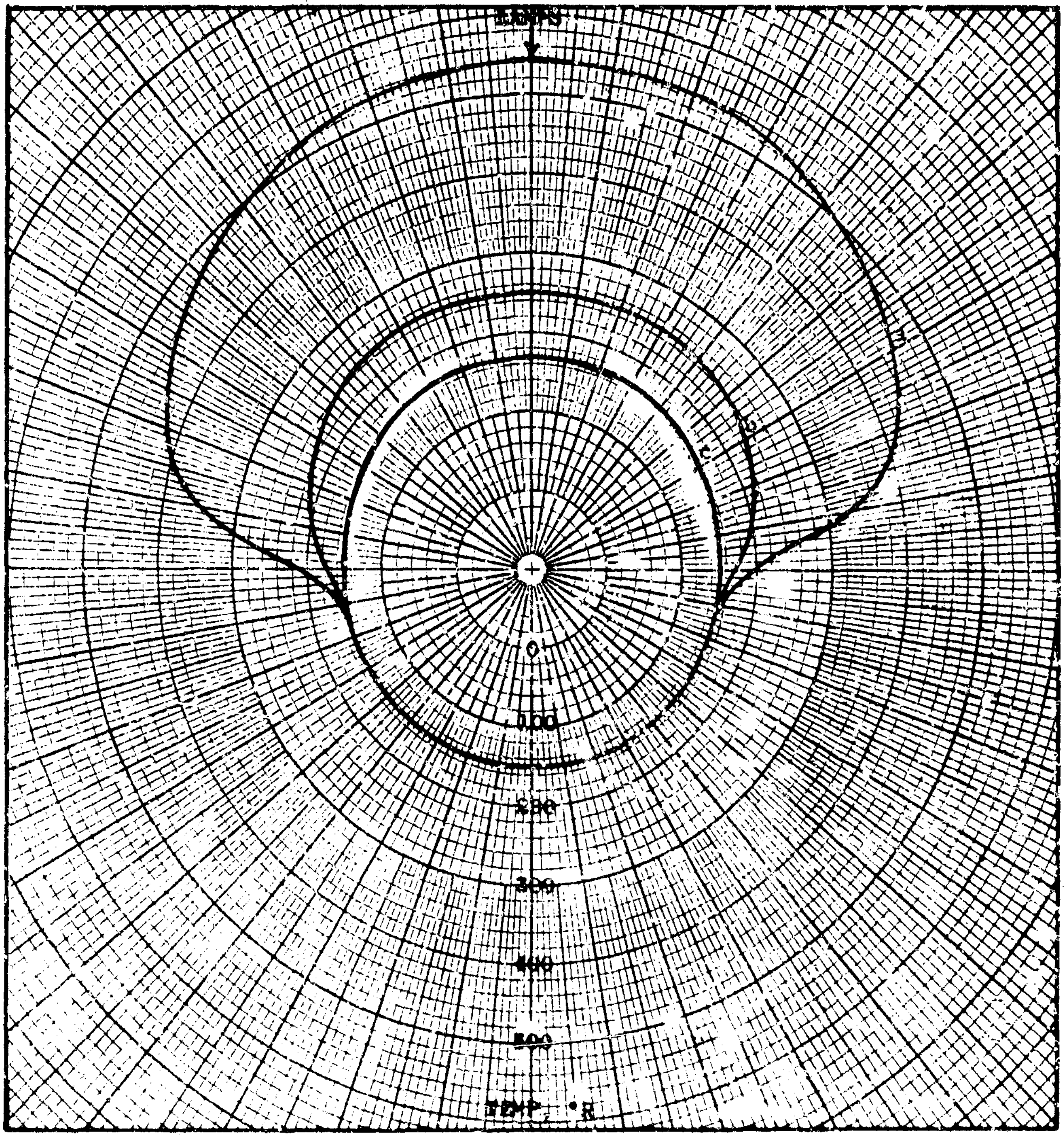
a. Super Insulation Outer Surface
b. Super Insulation Inner Surface
c. Intertank Section Skin

FIG. 16. PCTT TEMPERATURES, DATA STATION 12



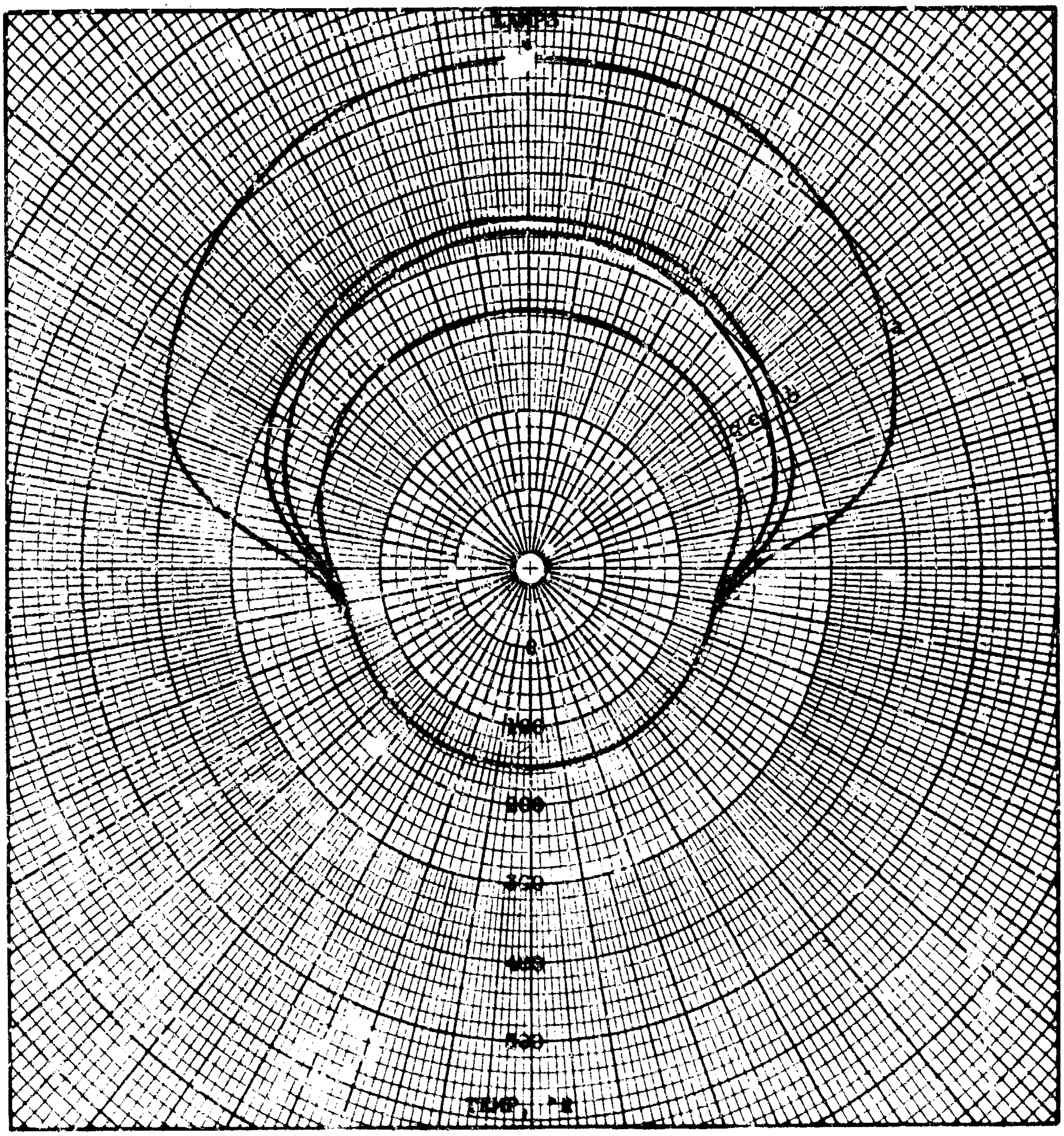
a. Super Insulation Outer Surface
b. Super Insulation Inner Surface
c. Intertank Section Skin

FIG. 17. FCTT TEMPERATURES, DATA STATION 13



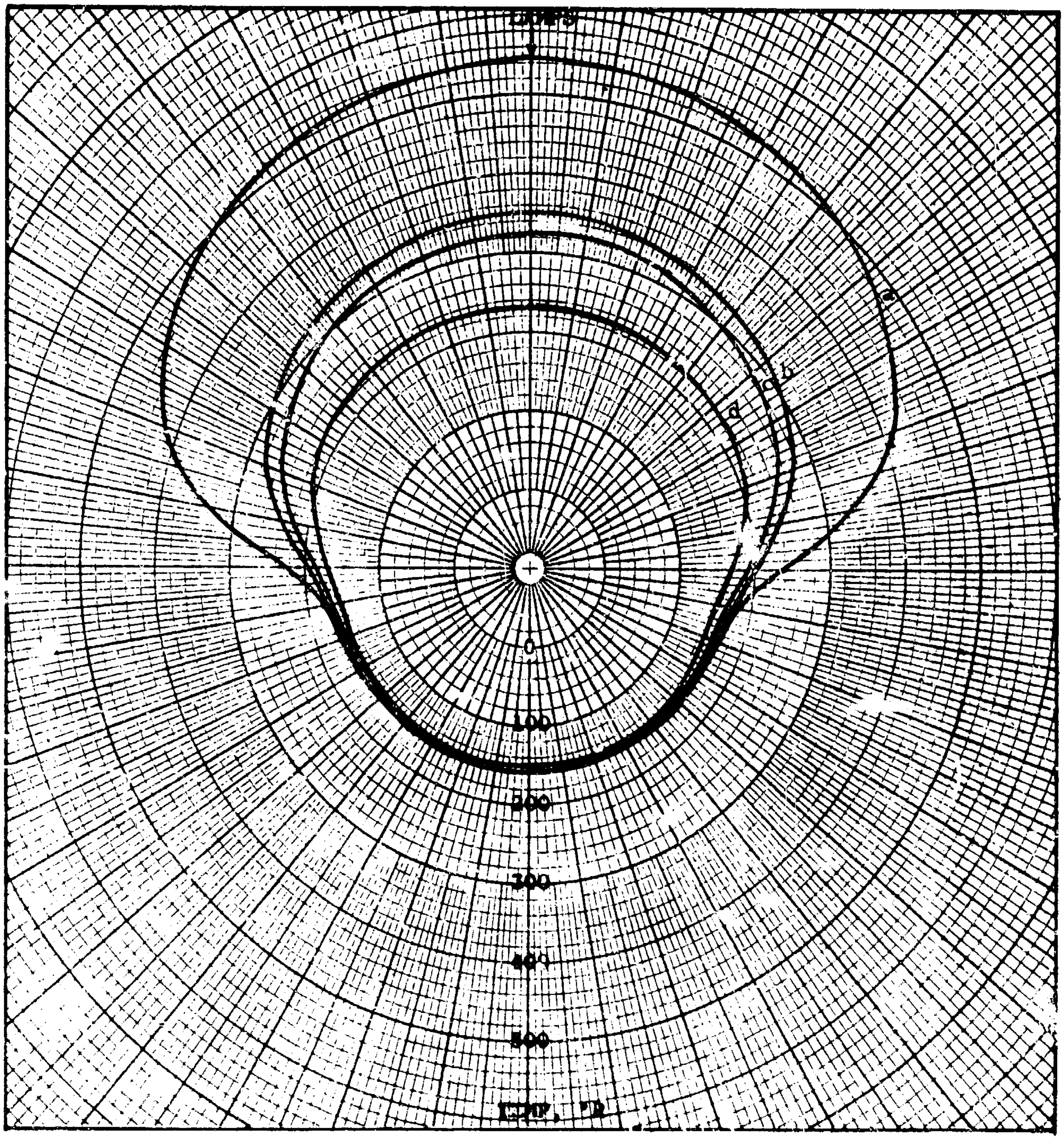
a. Outer Super Insulation, Outer Surface
b. Outer Super Insulation, Inner Surface
c. Fiberglass Adapter

FIG. 18. PCTT TEMPERATURES, DATA STATION 14



a. Outer Super Insulation, Outer Surface
b. Outer Super Insulation, Inner Surface
c. Fiberglass Adapter
d. Inner Super Insulation, Inner Surface

FIG. 19. PCTT TEMPERATURES, DATA STATION 15



a. Outer Super Insulation, Outer Surface
b. Outer Super Insulation, Inner Surface
c. Fiberglass Adapter
d. Inner Super Insulation, Inner Surface

FIG. 20. PCTT TEMPERATURES, DATA STATION 16

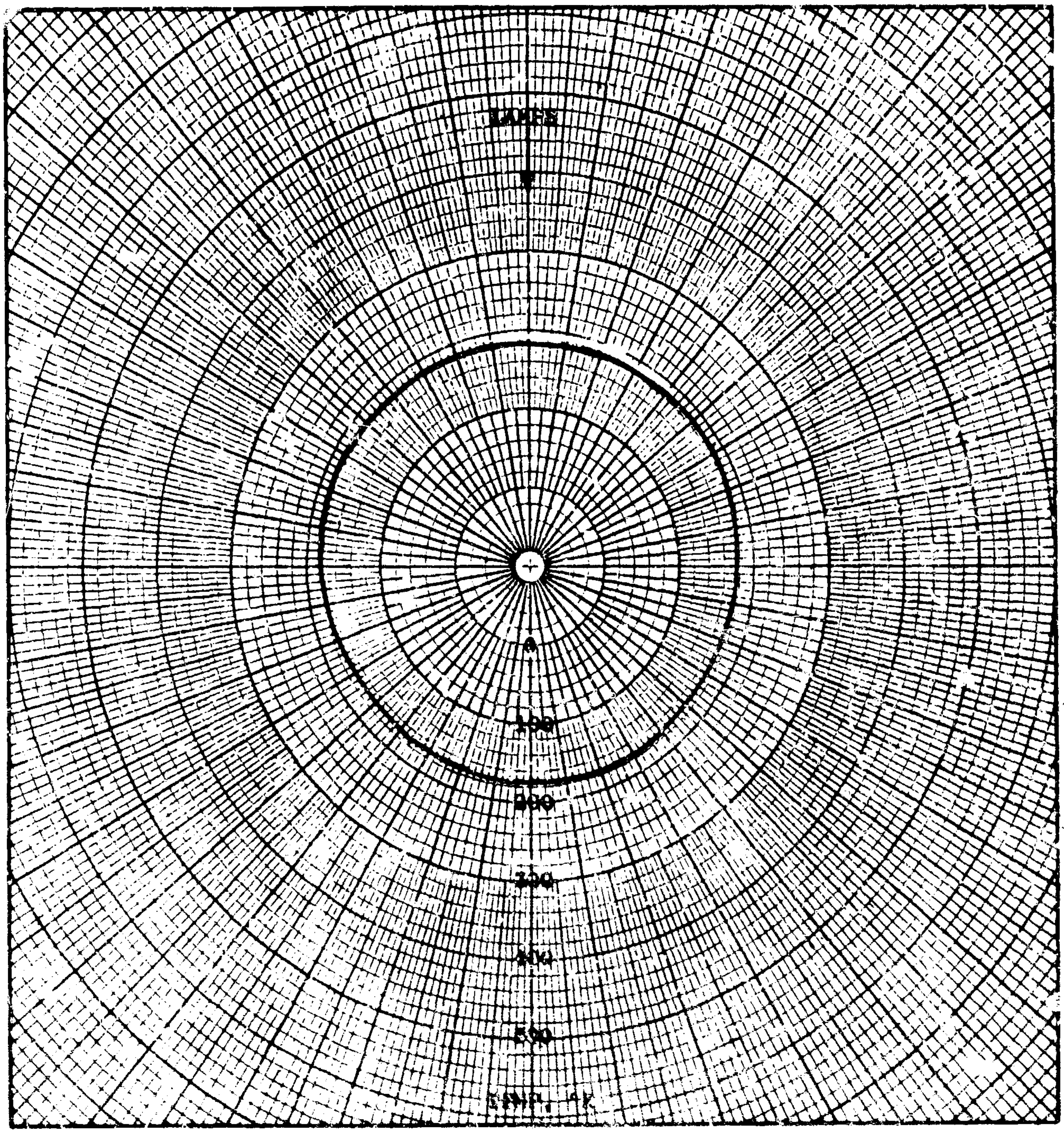


FIG. 21. PCTT AFT ADAPTER RING TEMPERATURE, DATA STATION 17

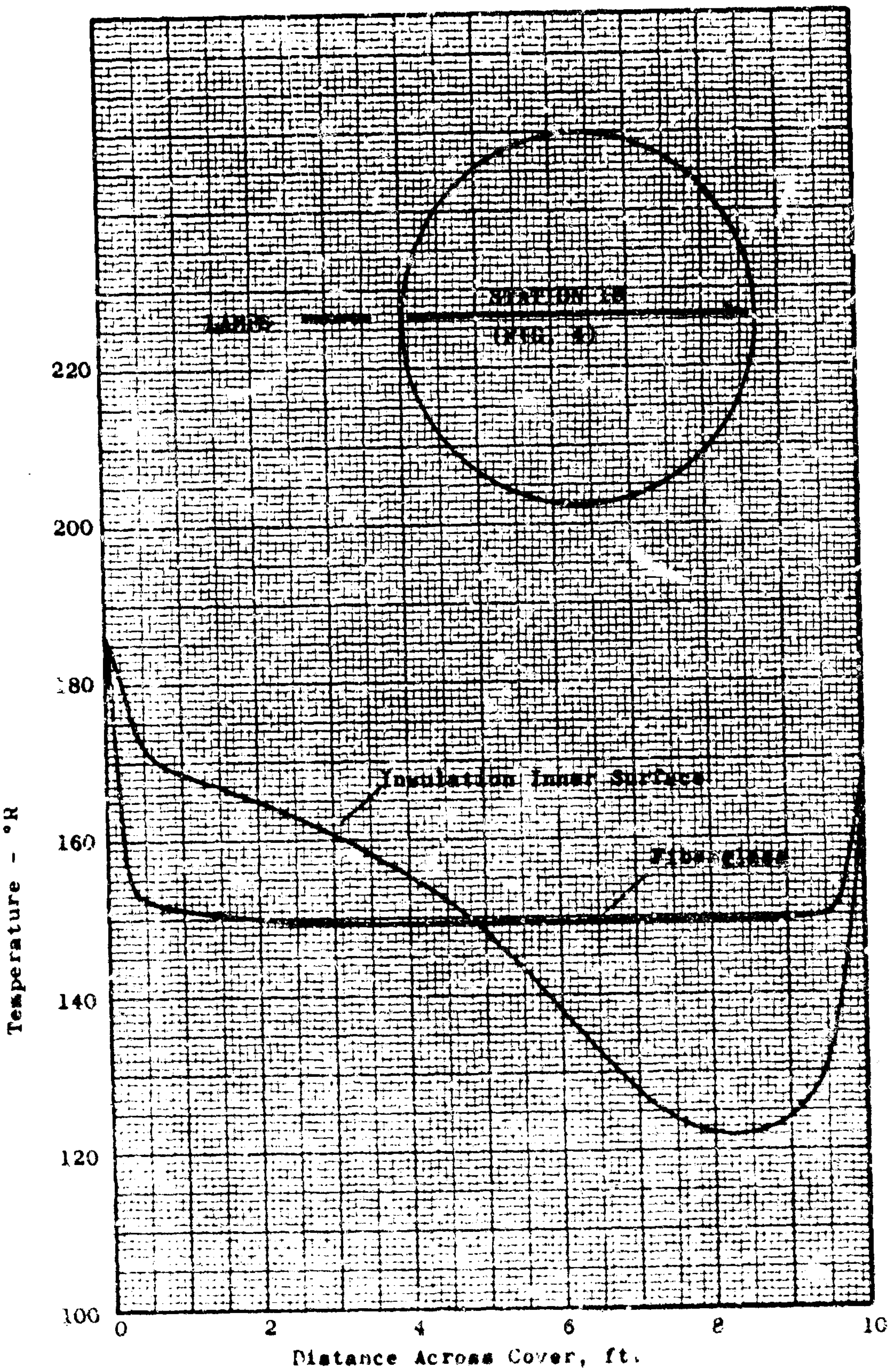
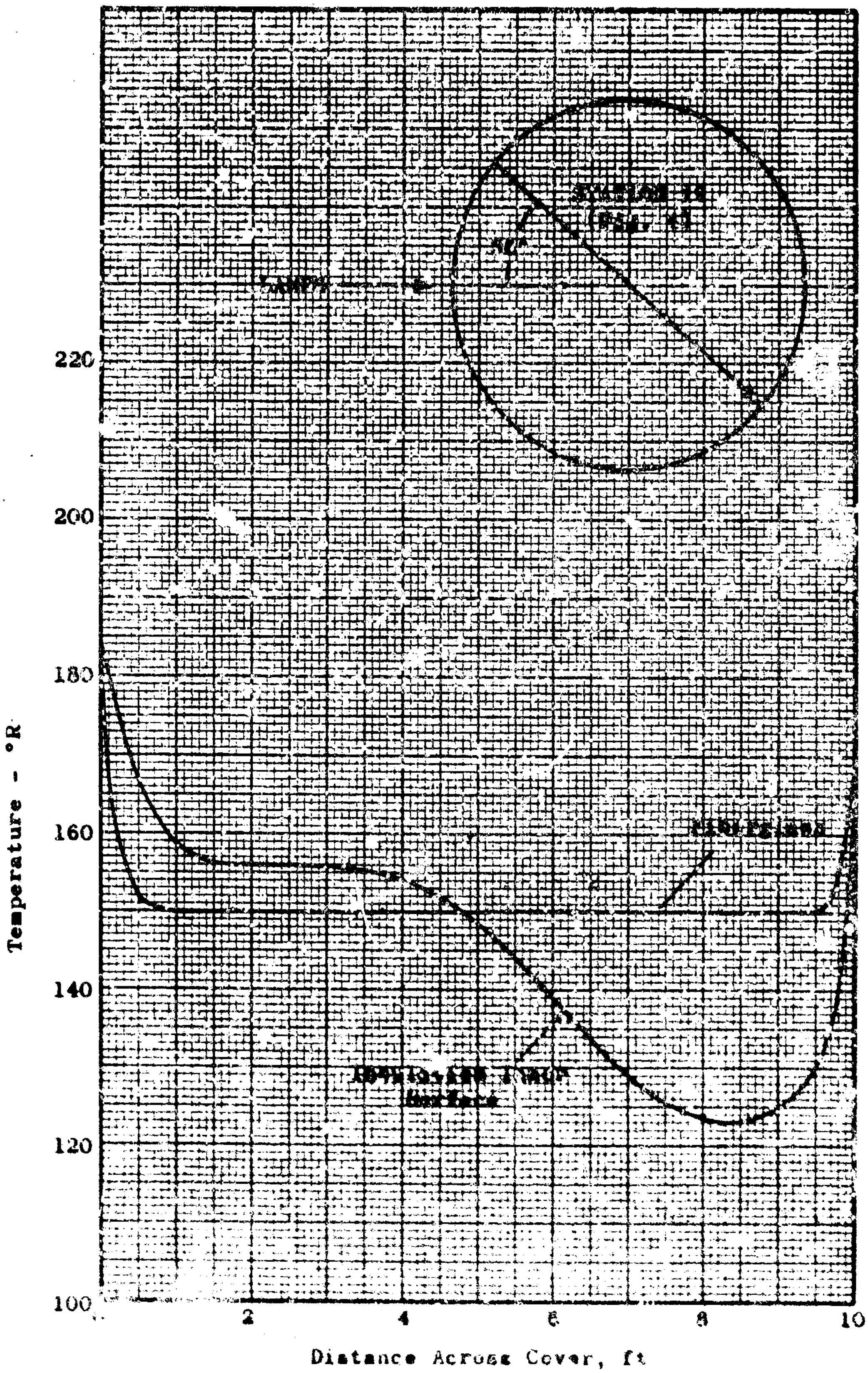


FIG. 22. PCTT TEMPERATURES, DATA STATION 18



... PCTT TEMPERATURES, DATA STATION 19

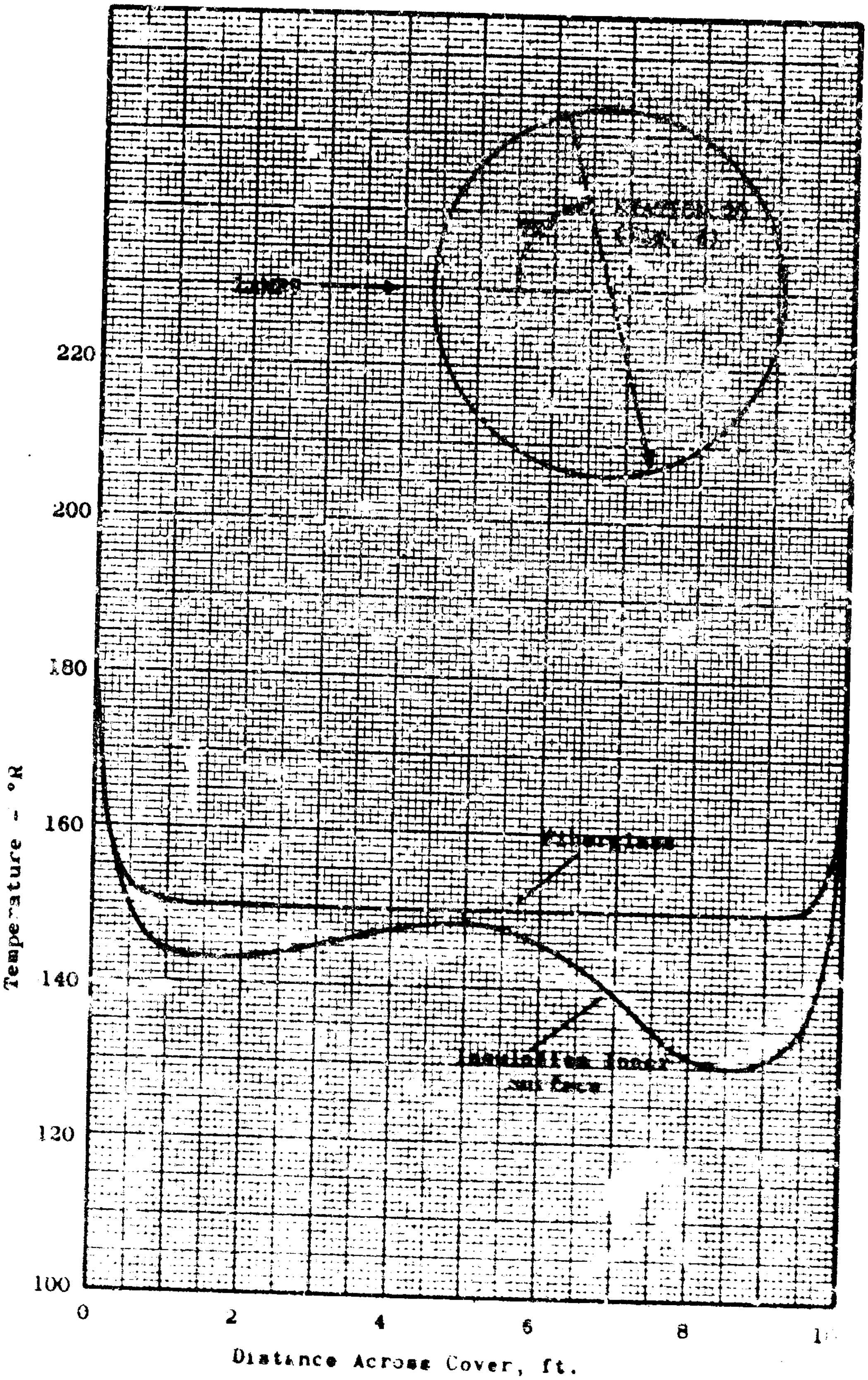


FIG. 24. PCTT TEMPERATURES, DATA STATION 20

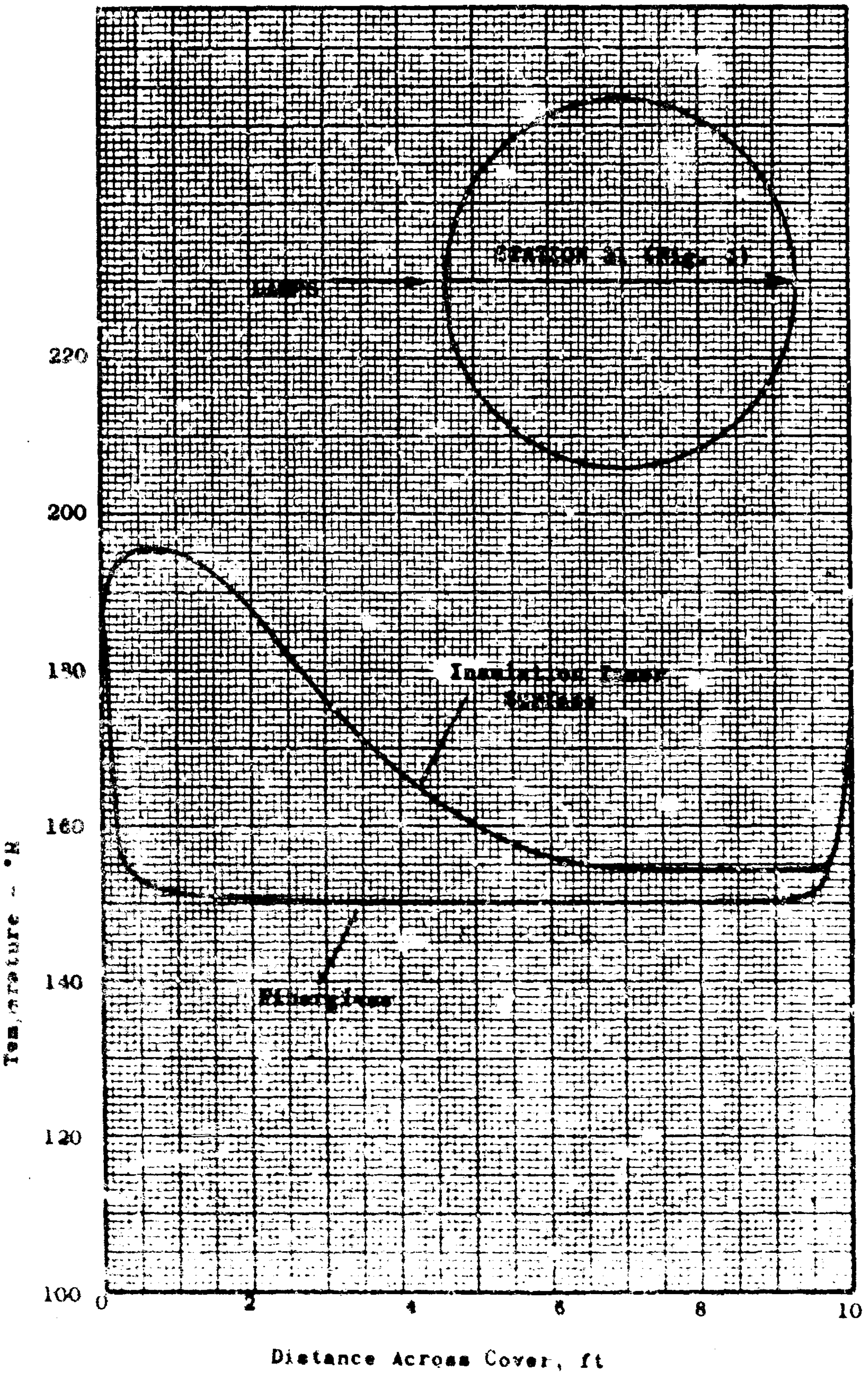


FIG. 25. PUTT TEMPERATURES, DATA STATION 21

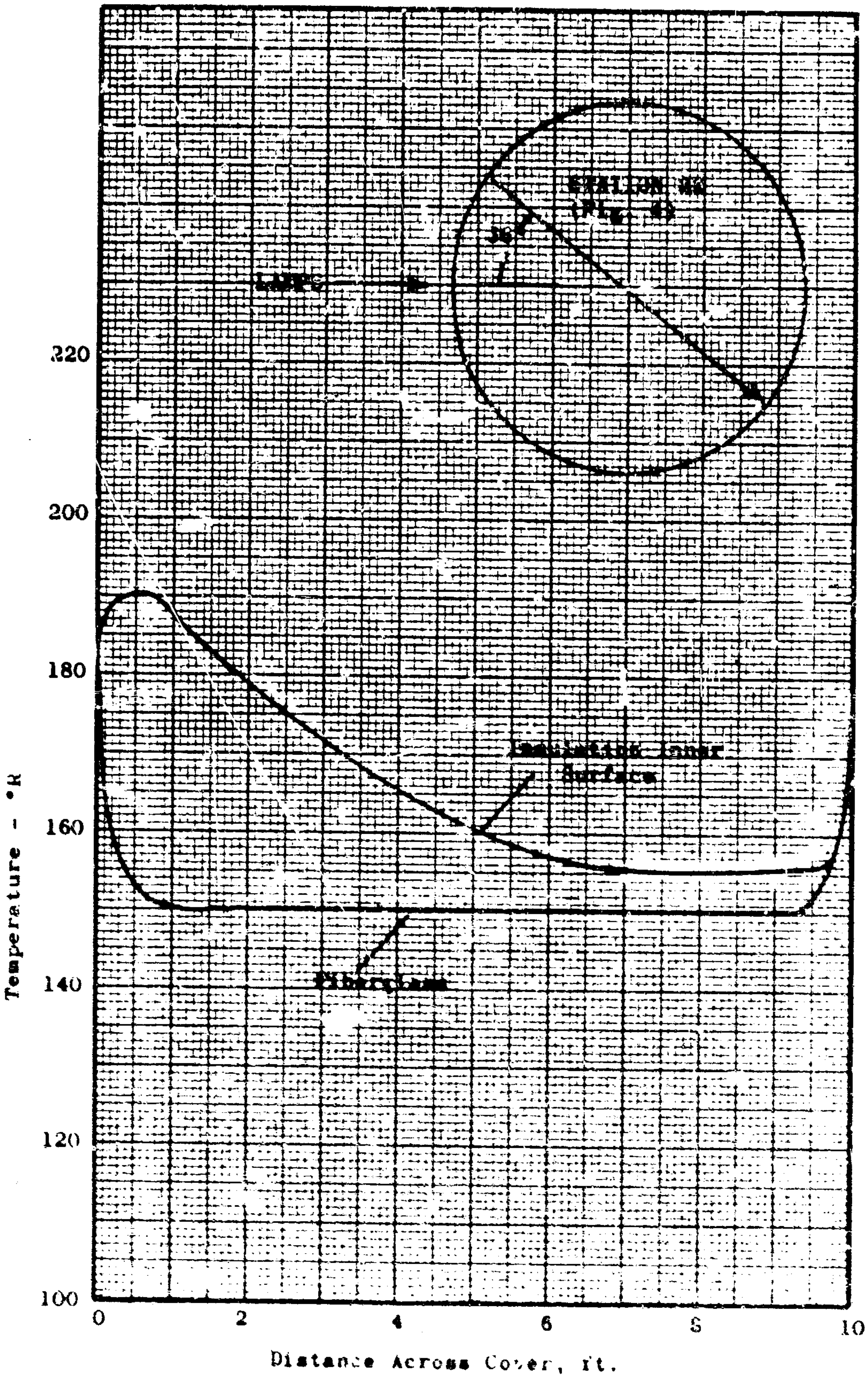


FIG. 26. PCTT TEMPERATURES, DATA STATION 22

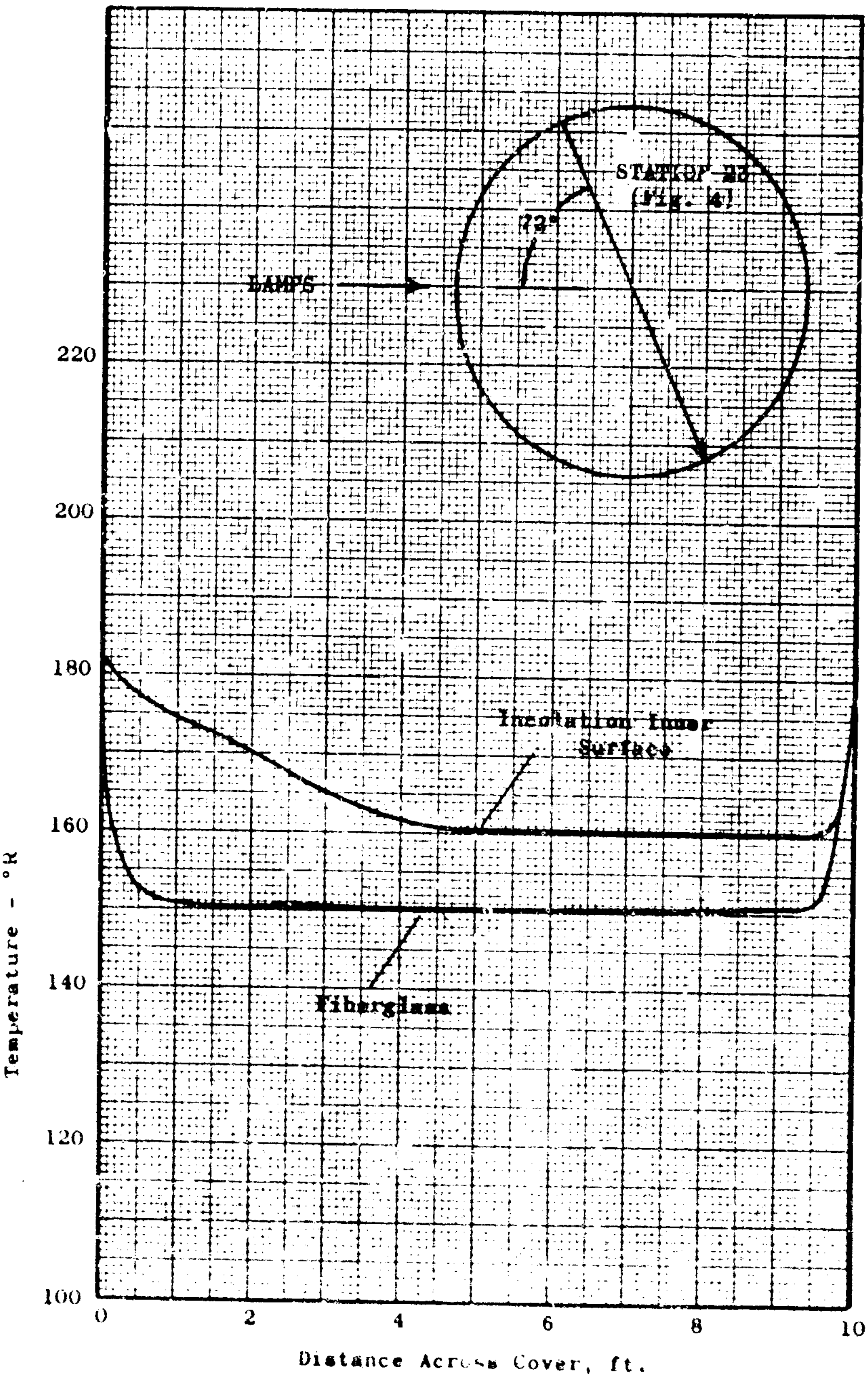


FIG. 27. PCTT TEMPERATURES, DATA STATION 23

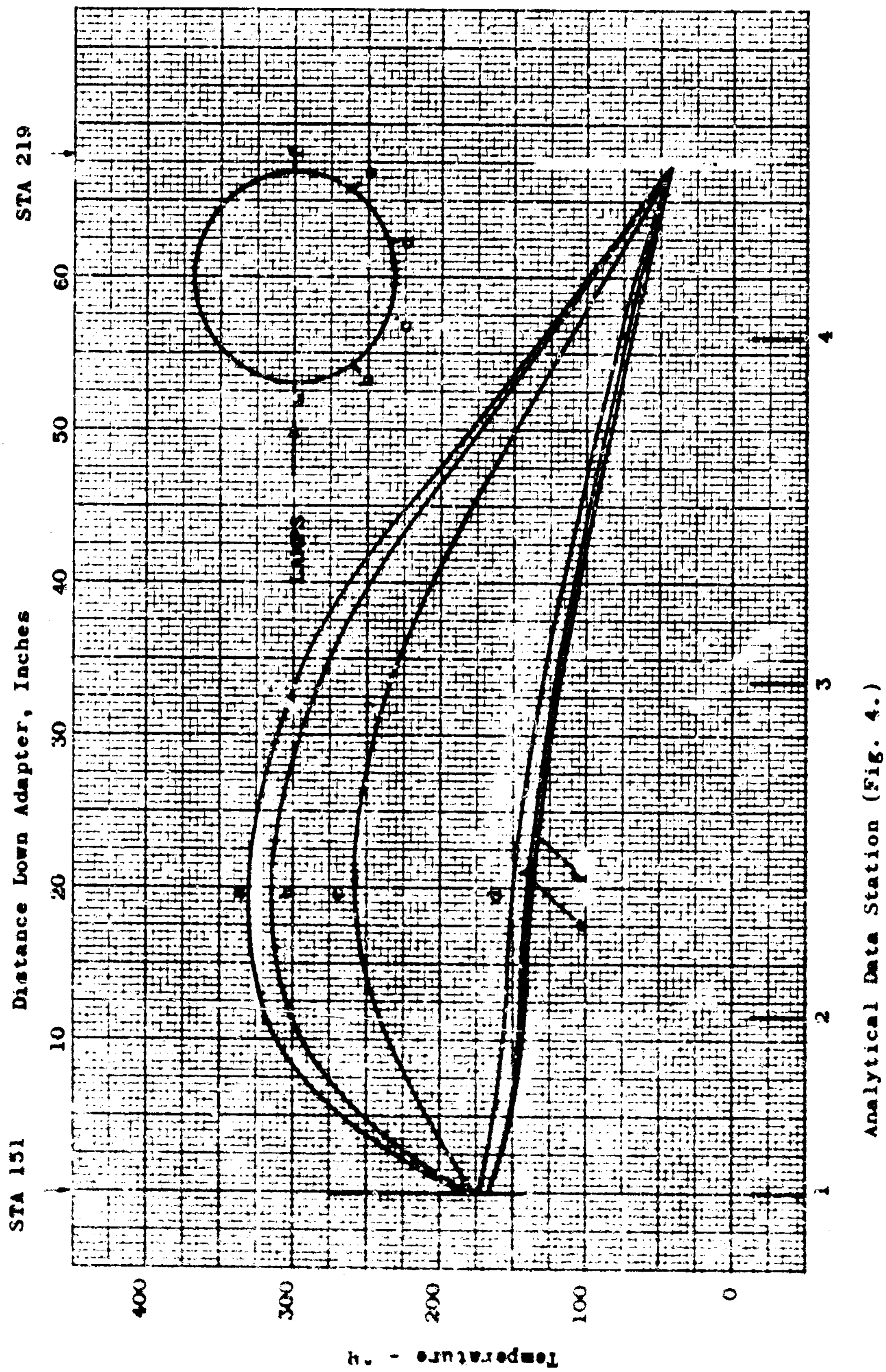


FIG. 28. PCTT FORWARD ADAPTER TEMPERATURES VS DATA STATION

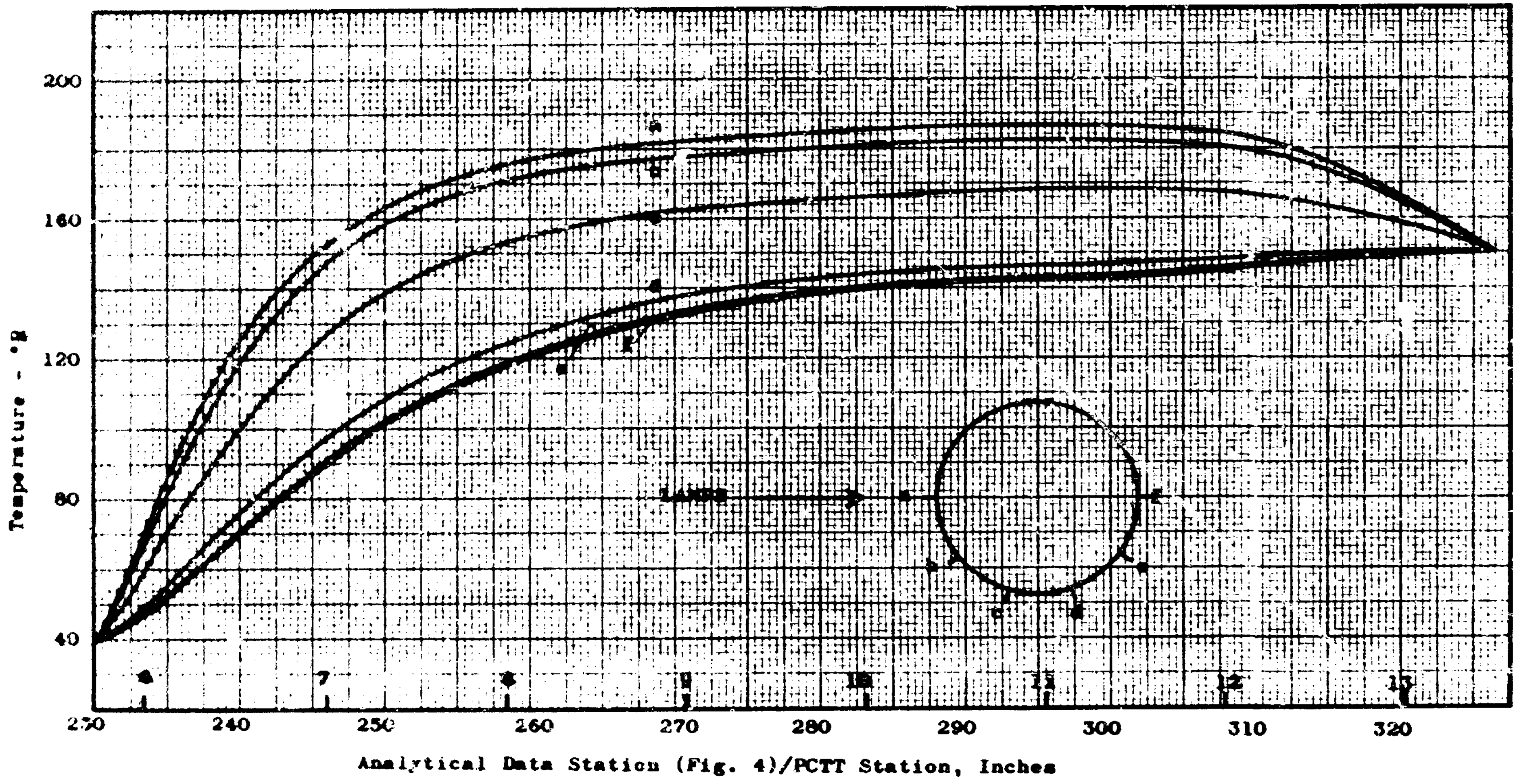


FIG. 29. PCTT INTERTANK SECTION TEMPERATURES VS DATA STATION

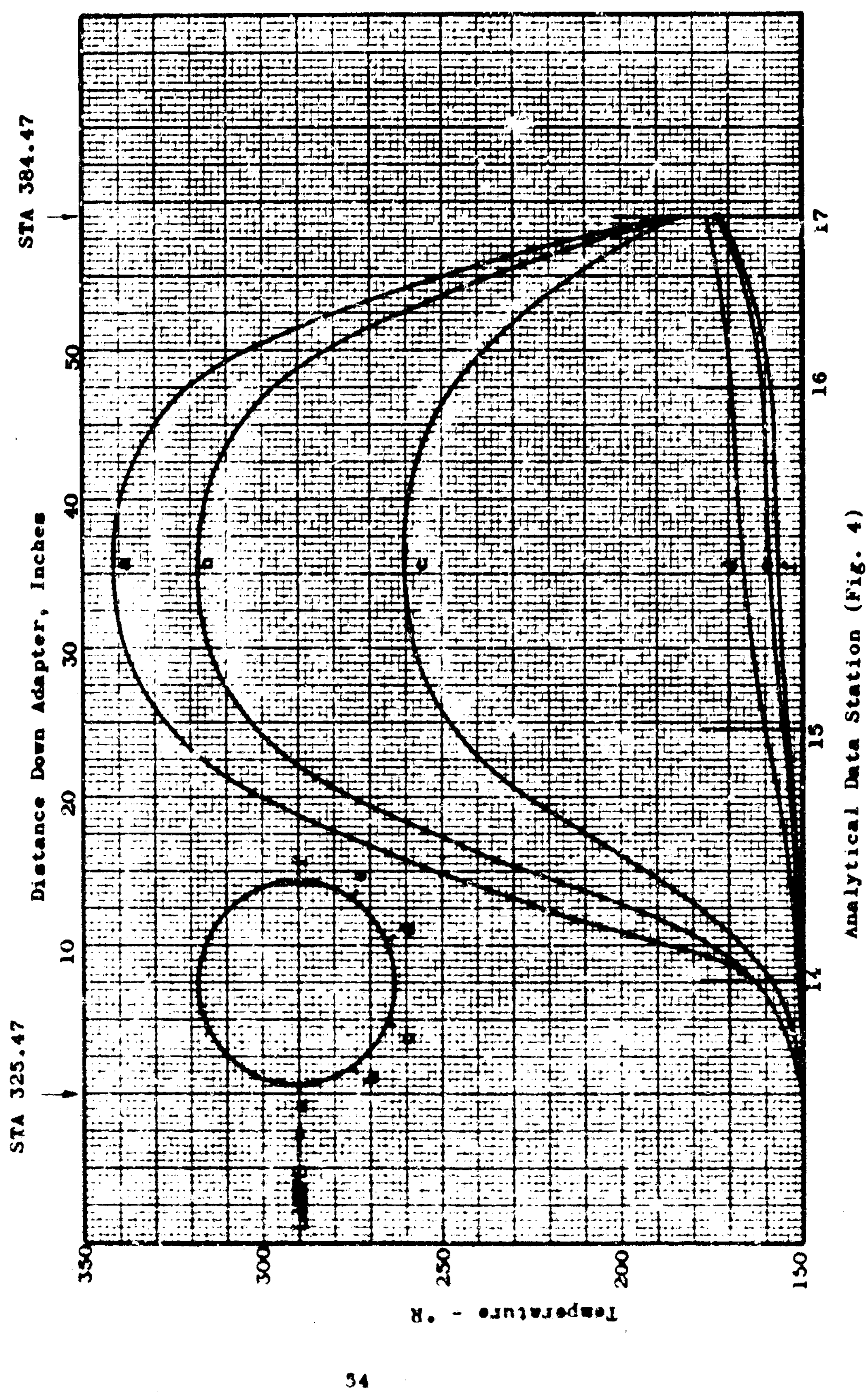


FIG. 30. PCTT AFT ADAPTER TEMPERATURES VS DATA STATION

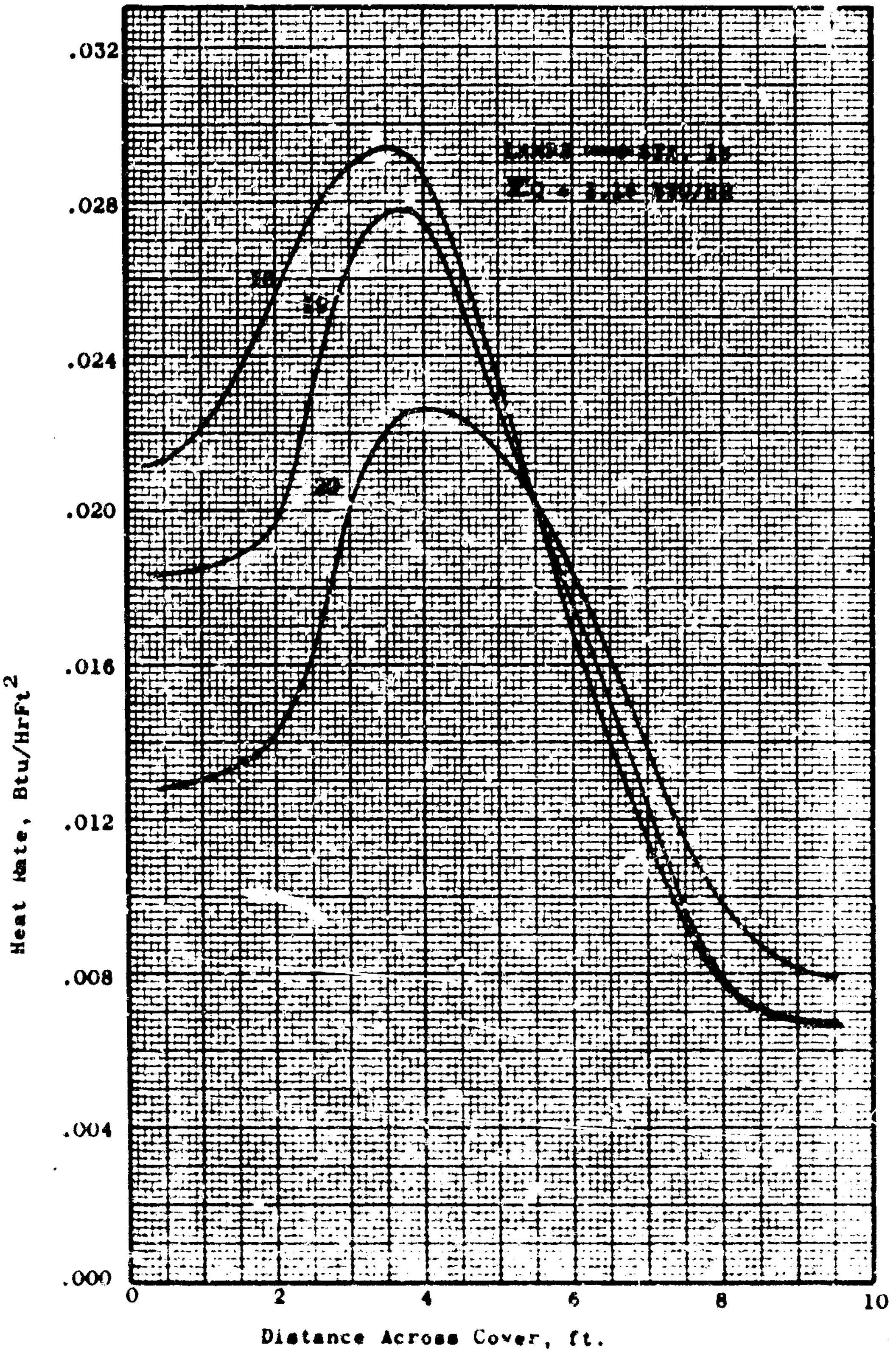


FIG. 31. PCTT LH_2 TANK HEAT RATES, FORWARD COVER, STATIONS 18, 19 AND 20

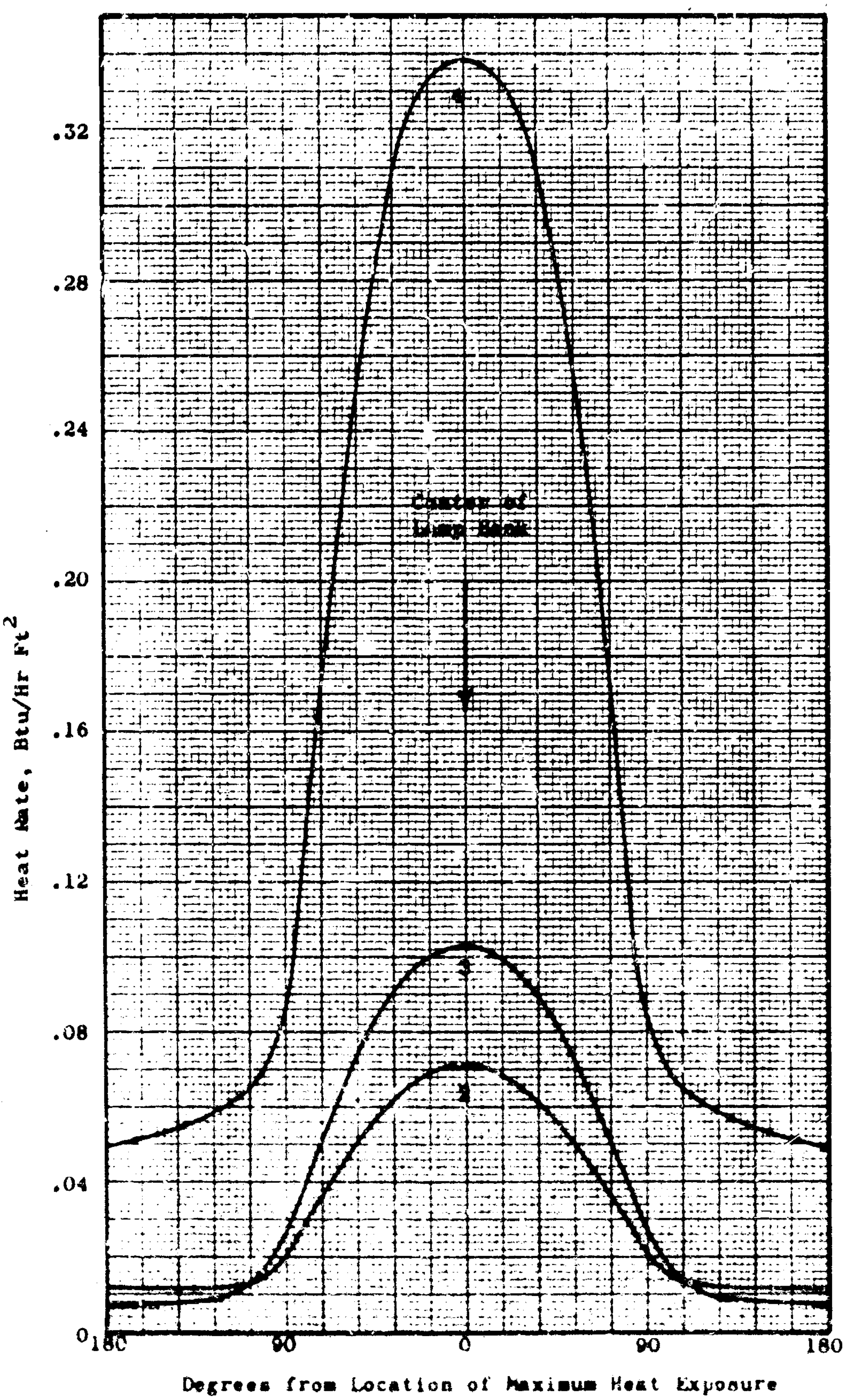


FIG. 32. PCTF LH_2 TANK RADIATION HEAT RATES, FORWARD ADAPTER, STATIONS 2, 3 AND 4.

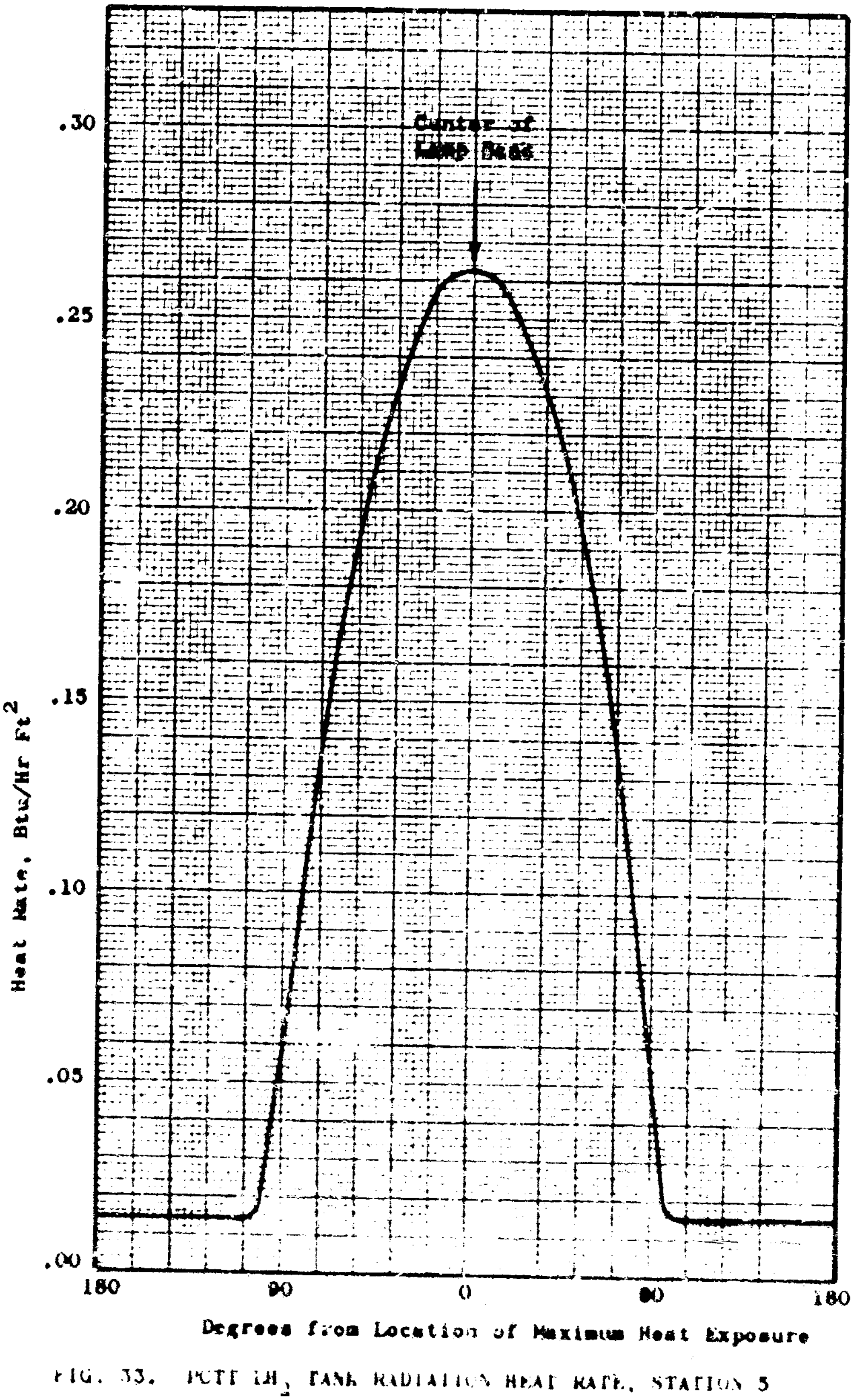


FIG. 33. PCTF LH_2 TANK RADIATION HEAT RATE, STATION 5

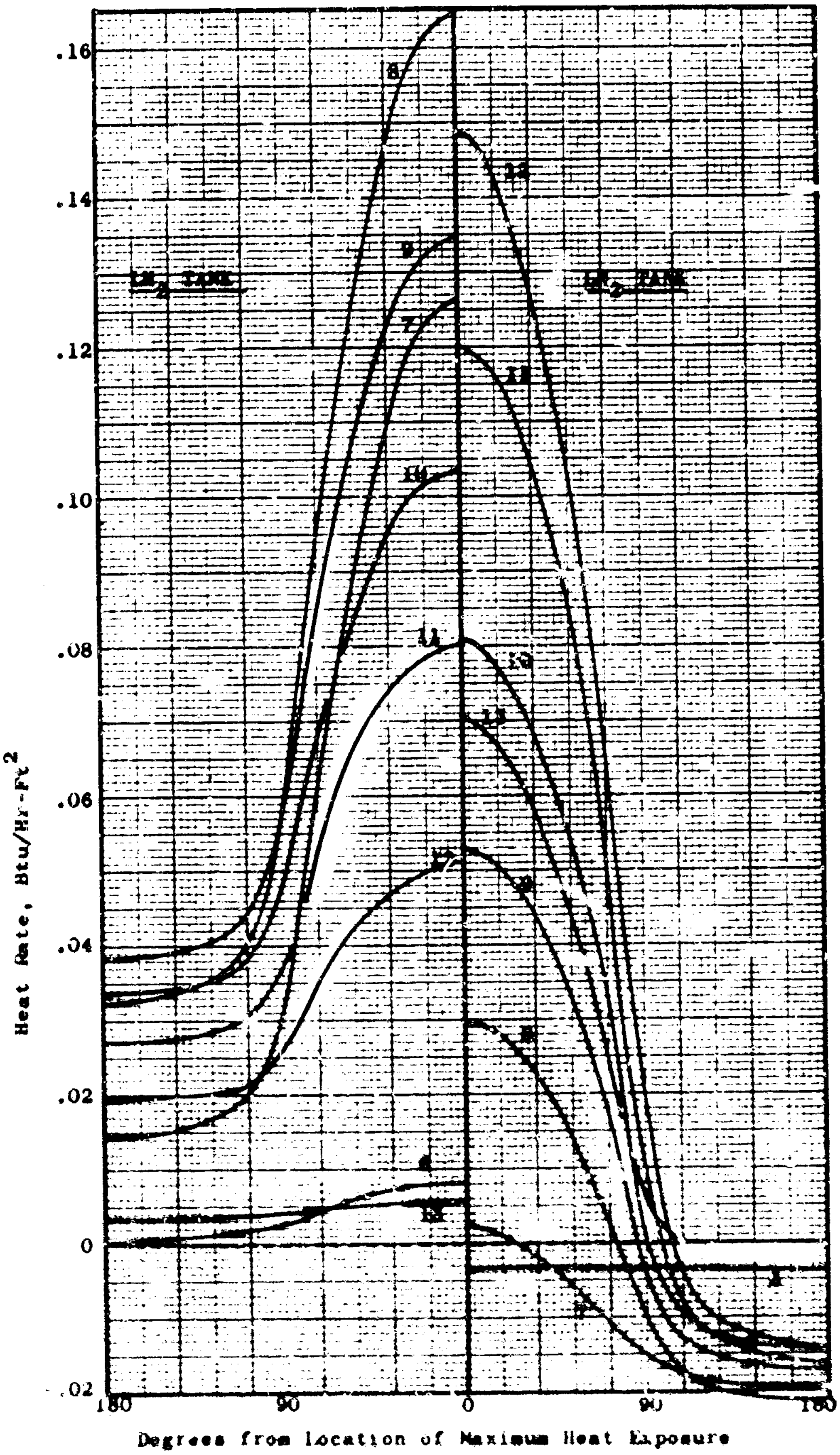


FIG. 34. FCTT LH_2 & LN_2 TANK RADIATION HEAT RATES, INTERTANK SECTION, STATIONS 6 THROUGH 13.

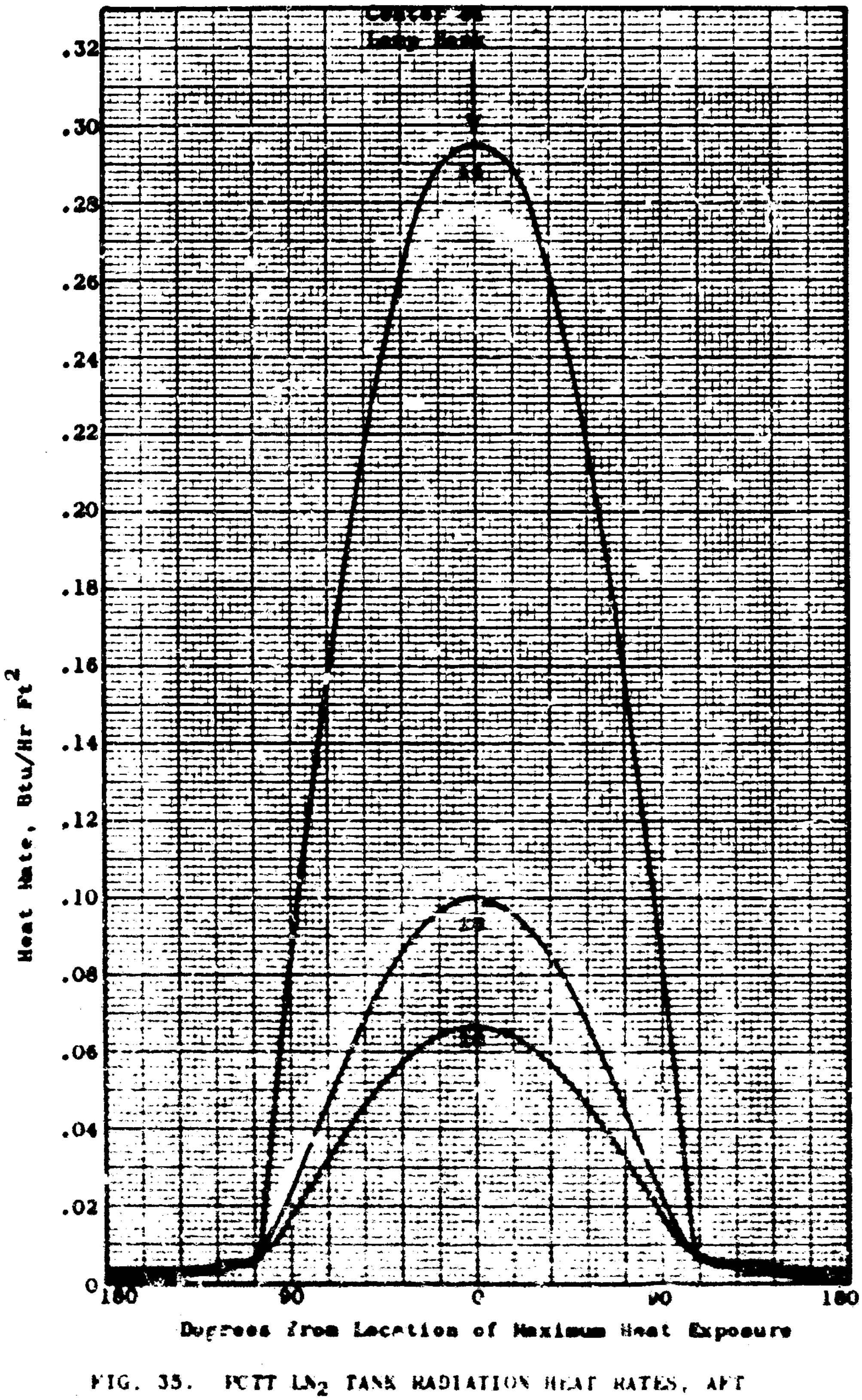


FIG. 35. FCTT LN_2 TANK RADIATION HEAT RATES, AFT ADAPTER, STATIONS 14, 15 AND 16

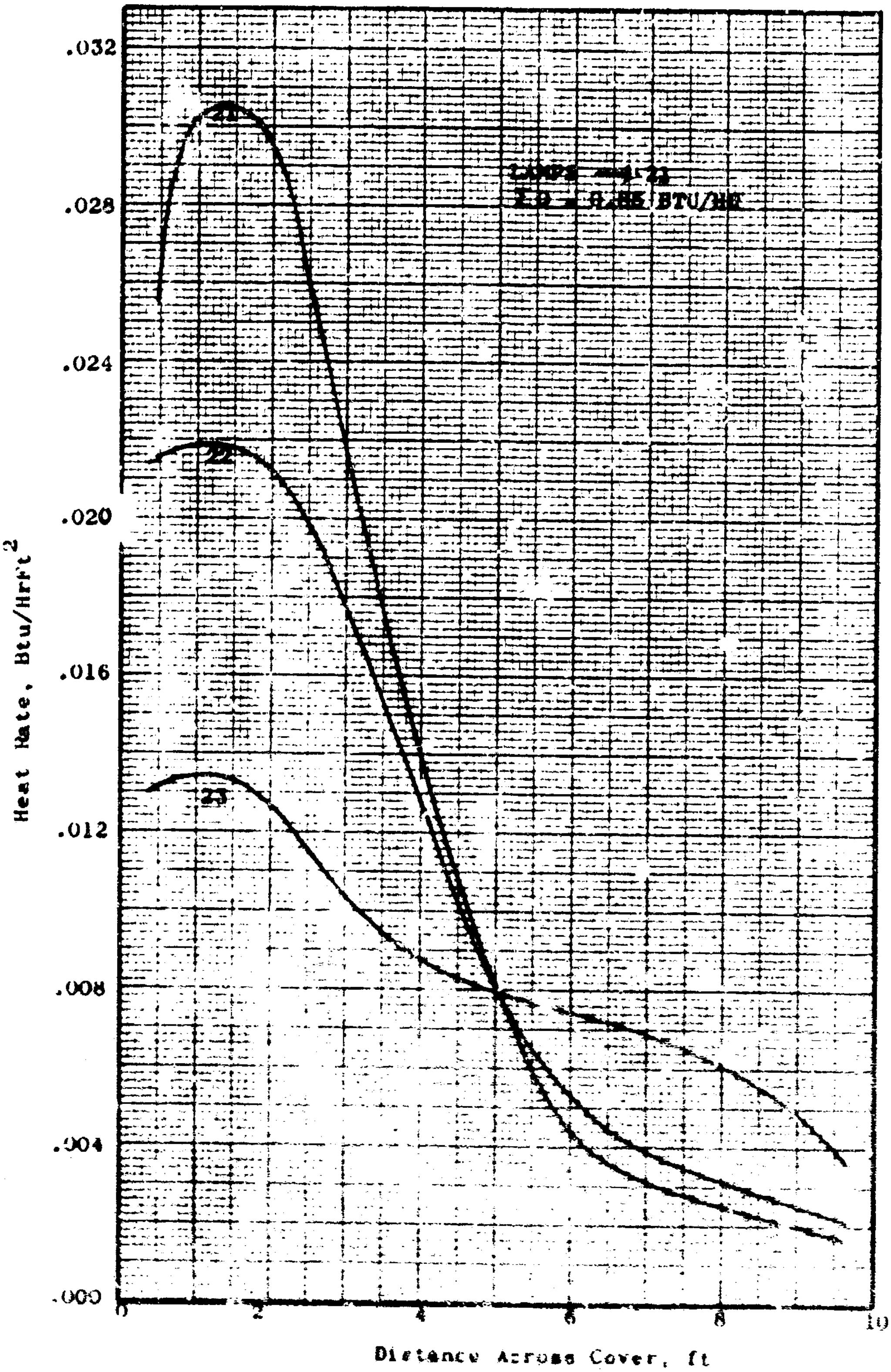


FIG. 36. PCTF LN_2 TANK HEAT RATES, AFT COVER, STATIONS 21, 22 AND 23

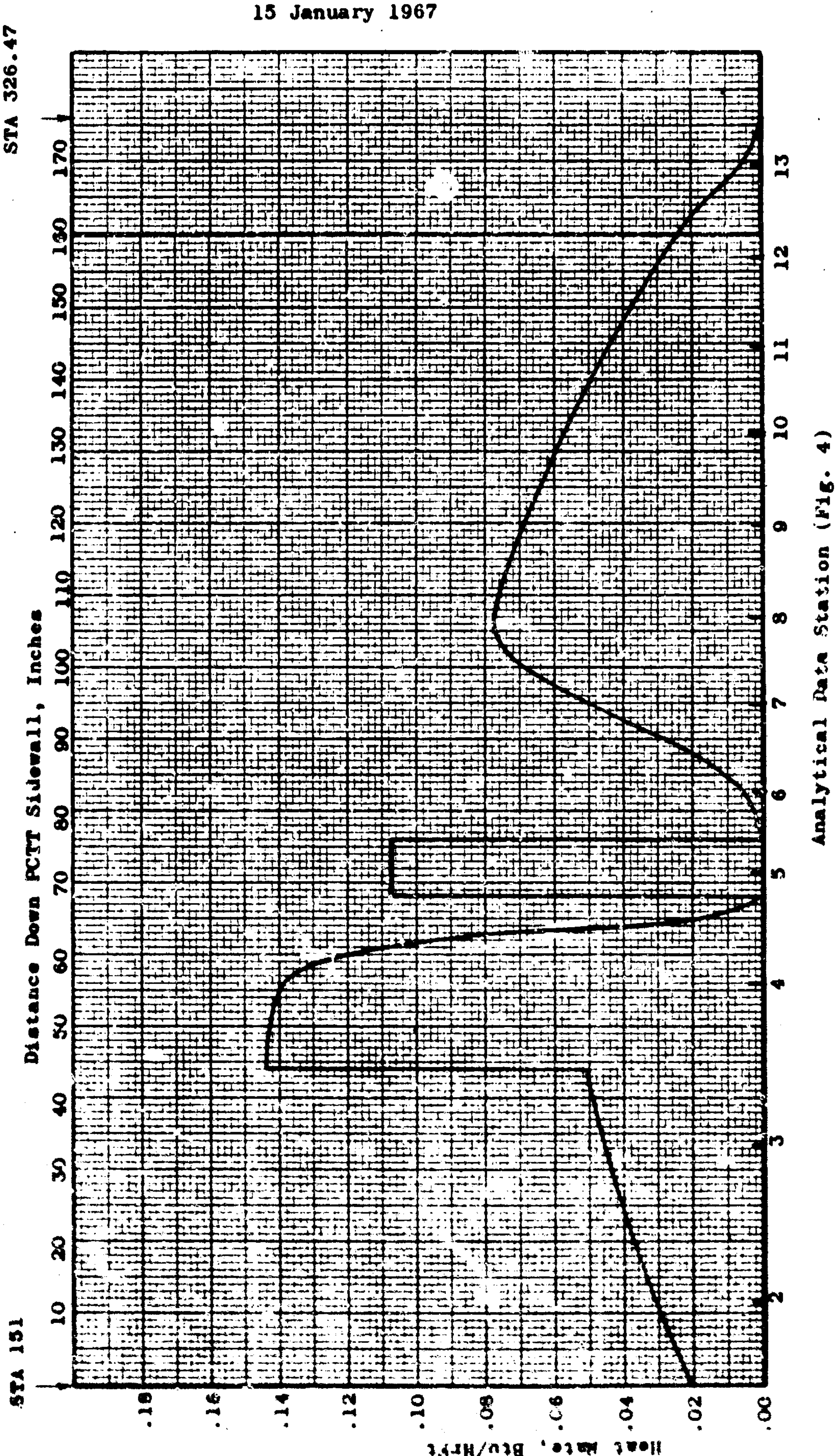


FIG. 37. PCTT LH_2 TANK SIDEWALL RADIATION HEAT RATE DISTRIBUTION

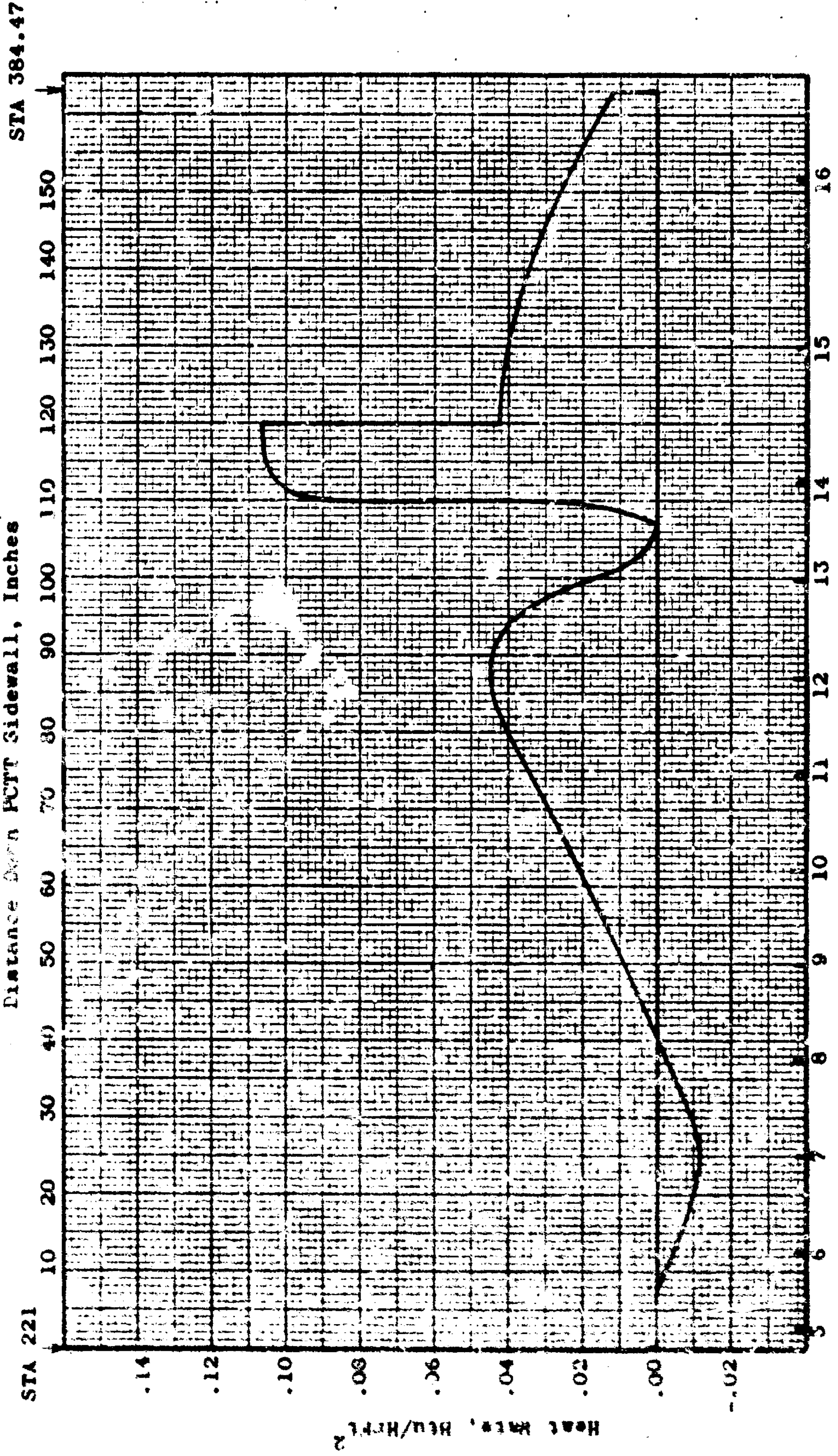
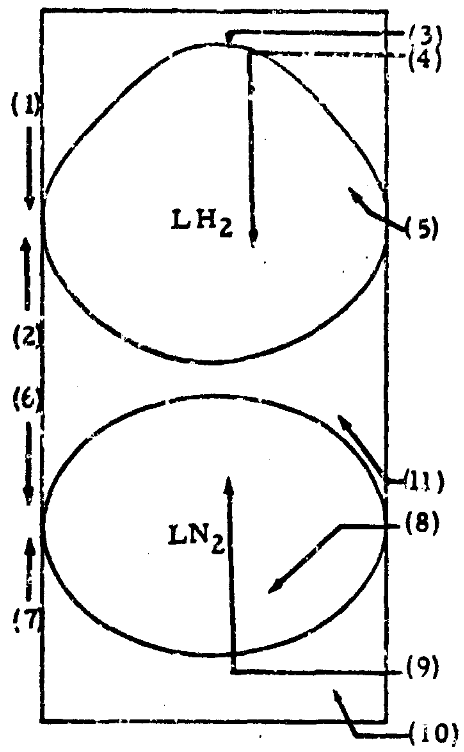


FIG. 33. PCTT LN_2 TANK SIDEWALL RADIATION HEAT RATE DISTRIBUTION



LH2 TANK PENETRATION HEAT LEAK, BTU/HR

1	Conduction, Forward Adapter.	1.80
2	Conduction, Intertank Section. . . .	7.47
3	Vent Duct.	0.30
4	Fill & Drain Duct.	2.31
5	Instrumentation Leads.	0.10
	LH_2 Tank, Penetration Total	11.98

LN2 TANK PENETRATION HEAT LEAK, BTU/HR

6	Conduction, Intertank Section. . . .	2.67
7	Conduction, Aft Adapter.	1.20
8	Fill & Drain Duct.	3.52
9	Vent Duct	0.00
10	Instrumentation Leads.	0.00
11	Intermediate Bulkhead Vacuum Line. .	0.00
	LN_2 Tank, Penetration Total	7.39

FIG. 39. PCTT PENETRATION & STRUCTURE CONDUCTION HEAT LEAK SUMMARY

APPENDIX C

RECOMMENDED TEST PLAN

FOR THE

PARTITIONED CENTAUR TEST TANK

REPORT NO. GDC-BTD67-011

DATE 24 January 1967

NO. OF PAGES

GENERAL DYNAMICS
Convair Division

RECOMMENDED TEST PLAN FOR PARTITIONED CENTAUR TEST TANK

Contract No. F04611-67-C-0004

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GDC-BTD67-011

24 January 1967

FOREWORD

This report contains the General Dynamics/Convair (GD/C) recommended test plan for the Partitioned Centaur Test Tank (PCTT) designed and fabricated for the Air Force Rocket Propulsion Laboratory (AFRPL), Edwards Rocket Site, per Air Force Contract F04611-67-C-0004. The report includes test objectives, test conditions, recommended general procedures, and suggested areas of evaluation after testing.

TABLE OF CONTENTS

	Page
FOREWORD	i
TABLE OF CONTENTS	ii
LIST OF ILLUSTRATIONS	vi
LIST OF TABLES	vi
SUMMARY	1
INTRODUCTION	2
1.0 TEST OBJECTIVES AND LIMITATIONS	3
1.1 Objectives	3
1.2 Limitations	3
2.0 TEST ARTICLE AND FACILITY REQUIREMENTS	4
2.1 General Dynamics Convair Partitioned Centaur Test Tank (PCTT)	4
2.1.1 Modified Centaur Test Tank	4
2.1.2 Test Article Adapters and Covers	4
2.1.3 Dimplar Cryogenic Insulation	4
2.1.4 Insulation Penetrations	5
2.1.5 Comparison to Actual Flight Vehicle	6
2.2 Air Force Rocket Propulsion Laboratory Facility Requirements	6
2.2.1 Chamber Configuration	6
2.2.2 Column Supports and Crossmember	6
2.2.3 Local Cold Wall Installations	6
2.2.4 Bulkhead Vacuum	7
2.2.5 Television Camera Coverage	7
2.2.6 Facility Heat Source	7

TABLE OF CONTENTS (Continued)

Page

2.2.7 Heat Flux Monitoring Facilities 7

2.2.8 Facility Penetration Lines. 8

2.2.9 Penetration Calibration 8

2.2.10 Facility Vent System Capability 8

3.0 INSTRUMENTATION. 9

3.1 Description of General Dynamics/Convair Instrumentation Provisions. 9

3.1.1 LH_2 Level Sensor-Measurement #1. 9

3.1.2 Platinum Resistance Transducers-Measurements #2, 7, 19, 21 and 57 9

3.1.3 Thermocouples. 10

3.1.4 Measurement List 10

3.1.5 Data Reduction Requirements. 11

3.2 Air Force Rocket Propulsion Laboratory Instrumentation Provisions. 12

3.2.1 Propellant Tank Pressure Sensors 12

3.2.2 Penetration Temperature Measurements 12

3.2.3 Chamber Pressure and Cold Wall Instrumentation . 12

3.2.4 Chamber Safety Instrumentation 13

3.2.5 Measurement Recording Equipment. 13

3.2.6 Facility Wiring. 13

3.2.7 Test Article Television Camera Provisions. . . . 13

3.2.8 Heat Source Monitoring Sensors 13

3.2.9 Cryogenic Boil-off Instrumentation 13

3.2.10 Instrumentation Calibration. 13

TABLE OF CONTENTS (Continued)

Page

4.0 TEST PROCEDURAL REQUIREMENTS. 14

4.1 Pretest Requirements 14

4.1.1 Test Article Preliminaries. 14

4.1.2 Test Facility Preliminaries 14

4.2 Thermal Testing. 15

4.2.1 Chamber Pumpdown. 15

4.2.2 Childown and Tanking 16

4.2.3 Data Acquisition. 17

4.3 Recommended Tests During Test Article Tanking. 19

4.3.1 Space Environment Simulation-Sunlit 19

4.3.2 Space Environment Simulation-Shaded Coast 19

4.3.3 Testing for Chamber Pressure Effects on Heat Transfer. 20

4.3.4 Testing for Residual Helium Effects on Insulation. 20

4.3.5 LH_2 Tank Lock-up Tests. 21

4.4 Detanking and Post-test Checkouts. 21

4.4.1 LN_2 Tank Detanking. 21

4.4.2 LH_2 Tank Detanking. 21

4.4.3 LH_2 Tank Decontamination. 21

4.5 Data Evaluation. 21

4.5.1 Temperature Distribution. 22

4.5.2 Heat Transfer Rate Distribution 22

4.5.3 Insulation Penetrations 22

4.5.4 Reduced Insulation Efficiency Due to Residual Gas. 22

4.5.5 Dimplar Insulation. 23

TABLE OF CONTENTS (Continued)

Page

5.0 SUGGESTED FUTURE TEST CAPABILITY OF TEST ARTICLE 23

5.1 Purge Systems 23

5.2 Other Insulations 23

5.3 Tank Pressurization Systems 23

5.4 Alternate Fluid Systems 24

5.5 Alternate Structural Components 24

5.6 Propellant Line Disconnect Systems. 24

5.7 Propellant Dynamics Investigations. 24

5.8 New Tanking Concepts. 24

5.9 Propellant Stratification Studies 25

5.10 Alternate or Variable Space Heating Rates 25

REFERENCES. 26

APPENDIX A - Air Force Rocket Propulsion Laboratory (AFRPL) Thermal Support Requirements for Partitioned Centaur Test Tank (PCTT) a-1

APPENDIX B - PCTT LH_2 Level Sensor. b-1

LIST OF ILLUSTRATIONS

Figure		Page
1	Partitioned Centaur Test Tank Positioned in AFRPL Space Environment Simulation Chamber	29
2	PCTT Measurement Locations	30
A-1	Incident Solar Energy Distribution	a-4
A-2	Insulation Surface Temperature	a-4
A-3a	Heat Flux Measuring Disk Configuration	a-5
A-3b	Aluminized Mylar Application to Disks	a-5
A-3c	Typical Heat Sensor Line	a-5
B-1	LH_2 Level Sensor Characteristic Curves	b-5
B-2	Sensor Power Supply	b-6
B-3	Sensor Power Supply Schematic Diagram	b-7
B-4	LH_2 Level Sensor Test Set-up	b-8

LIST OF TABLES

Table		Page
I	PCTT Instrumentation Measurement List	27

SUMMARY

The General Dynamics/Convair Partitioned Centaur Test Tank article, to which this recommended test plan applies, is a flight-weight, flight-similar tankage system enclosed in a thermal envelope of Dimplar multi-layered cryogenic insulation. The test plan encompasses test article and facility test requirements in addition to test procedures. Included in the test plan are recommended general test objectives and limitations, description of the test article and its interface with the facility vacuum chamber, test article and chamber instrumentation description, test procedural requirements, and suggested future test capability of the tankage system. This test requirements document compiles general and detailed guidelines which can be incorporated directly in preparation of a detailed test procedure by the Air Force Rocket Propulsion Laboratory. The information contained herein was derived from General Dynamics/Convair experience in similar testing and vacuum chamber operations.

INTRODUCTION

Future spacecraft performance requirements suggest that sophisticated high-performance rocket propulsion systems be incorporated as launch vehicle upper stages. Increased mission complexities lead to requirements for added upper-stage versatility, such that various combinations of intermittent powered flight and extended space coast operation may be accommodated. Utilization of upper stages of this type, employing cryogenic propellant for maximum performance, presents a major problem of long-term storage of cryogenic propellant in the space environment.

The purpose of the Partitioned Centaur Test Tank (PCTT) Program, as initially proposed in Reference 2, is to utilize existing tankage to provide a flight-size, flight-similar test article for space thermal/vacuum testing by the Air Force Rocket Propulsion Laboratory (AFRPL). Of further interest is the practical evaluation of the multilayer insulation concept as a method of achieving long-term cryogenic storage in the space environment.

Thermal studies conducted prior to and leading to the preparation of this report are available in Reference 1.

1.0 TEST OBJECTIVES AND LIMITATIONS

1.1 Objectives

The objectives of the test are:

1) To determine the total fuel and oxidizer boil-off for the Partitioned Centaur Test Tank configuration during simulated space environments.

2) To determine, insofar as procedural limitations permit, the heat transfer rate breakdown through the major elements of the thermodynamic system, i.e., insulation, structural penetrations and fluid duct penetrations.

3) To determine the thermal control performance effects of the non-tank structure of the vehicle comprising the forward and aft adapters and the intertank structure.

4) To determine the overall thermal performance of the Dimplar multilayer evacuated insulation, including evaluation of the effects of the mounting pegs.

5) To determine the venting and outgassing characteristics of the insulation system and the resulting influence on thermal control performance.

6) To determine the effect of chamber pressure level on the thermal performance of the insulation.

1.2 Limitations

It was originally proposed (Reference 2) to satisfy an objective of determining the heat flow between the fuel (LH_2) and oxidizer (LN_2) tanks by techniques involving tanking of fuel in the oxidizer tank. Structural and other limitations now preclude this, and tanking LN_2 in the fuel tank is similarly not feasible. The intertank heat rate must therefore be assessed by a less direct method involving computation of the heat flux from measured temperatures as part of the post-test analytical tank.

2.0 TEST ARTICLE AND FACILITY REQUIREMENTS

2.1 The General Dynamics/Convair Partitioned Centaur Test Tank (PCTT)

2.1.1 Modified Centaur Test Tank. The PCTT article, Figure 1, has been fabricated from a Centaur flight-weight test tank with the addition of an ellipsoidal bulkhead, forward and aft cylindrical adapters, end covers, and Dimplar super insulation. Fill, drain, vent and vacuum lines were added. The Centaur tank alteration consisted of removing approximately 112 inches of hydrogen tank cylindrical skin, adding a new aft bulkhead to form a forward stub hydrogen tank, and adding a short new cylindrical skin section to join the modified forward tank to the remaining aft tank. Tank details are shown on General Dynamics/Convair drawing PCTT-7.

2.1.2 Test Article Adapters and Covers. The forward and aft adapters have been fabricated from fiberglass and are designed to support the test article during storage, handling, and transportation, and to facilitate vertical suspension while testing. Provisions are made for attaching the forward adapter to the vacuum chamber structure, and suspending the test article from the top during tanking and testing. Both forward and aft adapters are enclosed with a fiberglass cover. The PCTT adapters and covers are detailed in General Dynamics/Convair drawing PCTT-2.

2.1.3 Dimplar Cryogenic Insulation. The Dimplar cryogenic insulation consists of a stack of alternate radiation shields of flat aluminized mylar and dimpled aluminized mylar with the dimpling providing the shield separation. The combination of a flat sheet and a dimpled sheet is a pair-layer. The Dimplar insulation will be mounted by means of fiberglass pegs positioned around the forward adapter in two rows of 27 pegs each, as recommended by the insulation subcontractor. There is no insulation attachment directly to the tank; all insulation is supported by the adaptors and cover plates. Two stand-off fiberglass hoops around the aft adapter hold the insulation away from the test article skin at the aft end.

The insulation creates a thermal boundary envelope and is comprised of three blanket thicknesses on the external cylindrical surface and on the inner cover surfaces. The insulation consists of two 7-pair layer blankets and one 6-pair-layer blanket yielding a total of 20 pair-layers. In addition, one 10-pair-layer was added to the internal surface of each adapter, beginning at the cover and extending toward the tank-adapter interfaces, for a distance of 42 inches from the cover. General Dynamics/Convair drawing PCTT-6 details the Dimplar insulation installation.

2.1.4 <u>Insulation Penetrations</u>. The insulation penetrations are comprised of the following:

1) two rows of 27 fiberglass pegs each around the forward adapter.

2) one liquid hydrogen and one liquid nitrogen fill and drain line which are 2.5 inch OD, 0.065 inch thick 321 CRES tubing, extending approximately 3 inches and 18 inches outside the insulation to the flange terminations for the liquid hydrogen and liquid nitrogen tanks, respectively.

3) one hydrogen and one nitrogen vent line formed of 2.5 inch OD, 0.065 inch thick 321 CRES tubing, extending approximately 3 inches outside the insulation to the flange terminations.

4) an intermediate bulkhead vacuum line boss which is connected to a facility vacuum line, assumed to be approximately 0.25 inch ID 304 stainless steel tubing.

5) approximately 134 instrumentation leads.

2.1.5 Comparison to Actual Flight Vehicle. The Partitioned Centaur Test Tank article is thermodynamically and, in a measure, geometrically comparable to a flight vehicle tank system in a space coast condition. However, the insulation coverage would have to be modified extensively to accommodate the requirements for pre-launch conditions and for protection during launch.

2.2 Air Force Rocket Propulsion Laboratory Facility Requirements

2.2.1 Chamber Configuration. The test is to be conducted in the altitude chamber of the Space Environmental Simulation Facility located at the Air Force Rocket Propulsion Laboratory at Edwards Rocket Site. The chamber is capable of maintaining pressures at 10^{-6} torr or less, while accommodating leak rates of 0.3 torr-liters/sec. In addition, the chamber incorporates a thermally black, liquid nitrogen cold wall for space simulation, and is capable of supplying a maximum of 596 Btu/hr-ft^2 (175 watts/ft^2) infra-red radiant energy for solar simulation.

2.2.2 Column Supports and Crossmember. The PCTT article will be installed in the vacuum chamber by means of four column supports. Cross member beams spanning the opposing columns provide four attach points from which the test article will hang by pins through four strap hangers mounted to the top of the forward adapter.

2.2.3 Local Cold Wall Installations. AFRPL will supply two local cold walls, one between each of the fill and drain valves and the PCTT side. The local cold walls should effectively shield the PCTT from valve assembly radiation.

2.2.4 Bulkhead Vacuum. A vacuum pump must be connected to the forward LN_2 tank bulkhead pressure tap in order to maintain an evacuated insulation bulkhead during chamber pumpdown and testing. This will insure that if gases leak into the bulkhead insulation cavity, the bulkhead will not reverse and rupture upon returning the chamber to ambient conditions.

2.2.5 Television Camera Coverage. Television camera coverage during chamber pumpdown, testing, and return to ambient conditions must be provided. Continual surveillance must be maintained during periods of chamber pressure transients in order to recognize and avoid possible onset of insulation "ballooning" and/or collapse with subsequent tearing. Coverage of the entire cylindrical surface is recommended. However, should coverage be limited, the cameras should be placed so that the maximum temperature point (center of the irradiated surface) can be examined from the standpoint of overheating. The camera position should then be adjusted such that the field of view would reach as much of the cold side of the test article as possible.

2.2.6 Facility Heat Source. AFRPL will provide a sufficient number of verticle heat lamp lines around one-half of the circumference of the PCTT to provide the insulation surface temperature distribution shown in Figure A-2 of Appendix A. The temperature distribution is also discussed in Appendix A. The heat lamps should be capable of providing a radiant energy level at the article insulation surface of zero to 442 Btu/hr-ft^2 (0-130 watts/ft^2). The portion of the test article circumference chosen shall be located such that the fill and drain lines as well as vent lines are not irradiated. The forward and aft most lamps shall be positioned such that they irradiate no closer than 4 inches to the forward or aft edge of the PCTT side insulation.

2.2.7 Heat Flux Monitoring Facilities. AFRPL shall provide disk heat source monitoring facilities as described in Appendix A. One heat sensor line should be provided and located very near the insulation surface for each lamp line provided.

2.2.8 Facility Penetration Lines. The facility-supplied fill/drain and vent lines which are not yet designed, will be connected to the GD/C insulation penetration stubs (see Article 2.1.4) by flanges. At least the terminating two (2) feet of the facility fill and drain lines should be rigid ducting, assumed for analysis to be 2.5 inch ID, 0.049 inch thick 304 stainless steel, connecting the fill and drain valves to the tank fill and drain stubs. At least the terminating two (2) feet of the facility vent lines connecting to the tank stubs should be rigid ducting assumed for analysis to be 3.0 inch ID (requires an increaser from 2½ inch ID to 3 inch ID), 0.049 inch thick, 304 stainless steel. The entire liquid nitrogen tank forward bulkhead vacuum line is assumed to be 0.25 inch ID, 304 stainless steel tubing.

2.2.9 Penetration Calibration. Before connection of the fill and drain, vent, and vacuum lines is accomplished, facility-supplied lines must be carefully measured as to inside and outside diameter, and distance between temperature measurements (see 3.2.2). The dimensions, as well as information describing the type of line material or alloy, must be recorded. These lines (approximately the terminal two feet) will be bracketed with two temperature measurements, described in paragraph 3.2.2. Ideally, line sections between measurements should be of constant crossection, and as nearly straight as possible. Any departure from the assumed dimensions and materials of paragraph 2.2.8 above should be carefully noted.

2.2.10 Facility Vent System Capability. The facility-supplied vent system and associated flow measuring devices shall be capable of venting and measuring boil-off rates from the LH_2 and LN_2 tanks of 0.003 to 30 and 0.0025 to 80 pounds per minute, respectively. The facility vent system design for each tank shall limit pressure drop from tank to ambient to 3 psi.

3.0 INSTRUMENTATION

3.1 Description of General Dynamics/Convair Instrumentation Provisions

All of the instrumentation supplied with the Partitioned Centaur Test Tank measure temperature. Some of the elements are intended for use in controlling test operations such as tank fill and drain sequences; nearly all are intended for use in assessing the individual magnitude of the heat leaks into and through the tank structure. Platinum resistance elements and chromel/constantan thermocouples are placed in strategic locations. Each thermocouple is wired with a voltage bucking that of another couple, the latter couple being shown as "Reference" in the Measurement List of Table 1. Instrumentation sensor locations are shown in Figure 2.

3.1.1. LH_2 Level Sensor-Measurement #1. This system is described in Appendix B. It is intended for use in tanking and topping LH_2.

3.1.2 Platinum Resistance Transducers-Measurements #2, 7, 19, 21 and 57. These units have an ice point resistance of about 1380 ohms. Calibration data for each unit is supplied by Rosemount and will be identified by measurement number and turned over to the test personnel.

The leads connecting measurements #7, 19, 21 and 57 to the Junction Block are of 24 gage constantan and therefore of relatively high resistance, ranging up to about 40 ohms at room temperature. The constantan was selected because of its low thermal conductivity and because its electrical resistance is nearly invariant with temperature. Taking into account that the leads will be chilled to the LN_2/LH_2 temperature region, it may be assumed that their test condition resistance will be 4% lower than their room temperature resistance. The room temperature lead resistance can and should be measured in available pairs, and used (with the suitable 4% allowance) in calibrating the R.E.C. bridges in the instrument room.

For the calibration, it is recommended that each bridge be unplugged and the combined lead resistances measured at the socket through pins D to F and N to R. The bridge ZERO ADJUST and SPAN ADJUST screws may then be set by connecting the bridge to its Voltage Supply, Indicator, and a five resistor network simulating the transducer and leads. The four lead simulators should approximate the lead resistance. The transducer simulator must be accurate--well within the transducer or bridge specifications.

3.1.3 Thermocouples. Fifty-eight of the sixty-four measurements are made with chromel-constantan thermocouples. Thirty-nine of these are referenced to the PCTT-3 Junction Block which is expected to stabilize at about LN_2 temperature during the testing, and whose temperature is monitored by a Rosemount 118YL platinum resistance thermometer. Nineteen of the thermocouple pairs measure temperature differences between closely related points on the structure in order to assess the magnitude of the individual local heat leaks into and between the tanks.

3.1.4 Measurement List. Certain ground rule definitions will be helpful in the interpretation and use of Table 1. Column One indicates the measurement number. Column Two shows the measurements to which the Column One thermocouple measurements are referenced. The Column One measurements not showing a reference number in Column Two are platinum resistance transducers. Column Three shows the terminal board number to which the Column One measurements are connected. In Column Four, the comma indicates wires terminating together. The dash separates terminals (or pairs) representing the two sides of a measurement. For the thermocouples, the first screw listed will be positive relative to the second when the measurement point is warmer than the reference point. Columns Five through Seven give the PCTT quandrant, station, and radial distance from center line (inches) of the measurement location. Column Eight gives the nomenclature or description of the measurement. Instrumentation locations and reference junction block/terminal board configuration are detailed in General Dynamics/Convair drawing PCTT-8.

3.1.5 Data Reduction Requirements

3.1.5.1 LH_2 Level Sensor. Reduction of the platinum wire LH_2 level sensor data will be on a GO/NO-GO basis as indicated in Appendix B.

3.1.5.2 Platinum Resistance Transducers. Platinum resistance thermometer data reduction should be based on the transducer calibration data furnished, as noted above.

3.1.5.3 Thermocouples. Thermocouple data reduction should be based on the calibration tables which will be generated and furnished by Convair on the basis of the early test data. These tables will list the thermocouple voltages vs temperature in one degree increments from zero to three hundred degrees Kelvin. Data reduction will then consist of the following operations:

(1) Find the reference junction temperature.

(2) Look up the reference junction voltage (in the tables to be furnished).

(3) Read the Measurement Voltage and add it algebraically to the Reference Voltage, obtaining Result Voltage.

(4) Look up the temperature corresponding to this Result Voltage. This is the temperature at the measurement location.

3.1.5.4 Thermocouple Tables. The following data should be obtained early in the test for Measurements 6, 8 and 20 under simultaneous conditions of LH_2 tank venting, heat lamps on, and LH_2 level above measurement location:

1) Measurement Number
2) Date
3) Time
4) Ref. Junction Temp. (M'sm'nt No. 2) (°K)
5) H_2 ullage pressure (psia)
6) Electrical output (polarity per 3.1.4) (Microvolts)

This data should be forwarded to Convair for preparation of the corrected Thermocouple Calibration Table(s).

3.2 Air Force Rocket Propulsion Laboratory Instrumentation Provisions

3.2.1 Propellant Tank Pressure Sensors. A minimum of one tank pressure sensor shall be provided in each tank fill and drain line. The sensor should be located between the fill and drain valve and the PCTT fill and drain line stub. They should be as close as practical to the tank stub but located in a straight section of line at least 5 diameters downstream of bends and discontinuities in the duct inner wall. The sensors should be capable of sensing and recording at least 0 to 30 psia. It should be noted here that the maximum allowable tank pressure for both tanks is 20 psia, as stipulated in the Functional Limitation Report of Reference 3.

3.2.2 Penetration Temperature Measurements. AFRPL shall install two thermocouples on each tank plumbing penetration. To be included are the two fill and drain lines, the two vent lines, and the forward LN_2 tank bulkhead vacuum line. The sensors are to be located approximately two feet apart on a hard section of each line near the PCTT stubs, and the provisions of 2.2.9 above must be adhered to. The measurements must be capable of measuring 35° to 400°R ± 1% on the liquid hydrogen tank lines, and 125° to 400°R ± 1% on the liquid nitrogen tank lines.

3.2.3 Chamber Pressure and Cold Wall Instrumentation. The vacuum chamber pressure and cold wall temperatures shall be monitored and recorded continually during pumpdown and testing.

3.2.4 Chamber Safety Instrumentation. AFRPL shall provide sufficient instrumentation to determine chamber malfunctions leading to test abort procedures, such as loss of chamber pressure or loss of cold wall.

3.2.5 Measurement Recording Equipment. The measurement and recording equipment supplied by AFRPL shall be capable of monitoring and recording measurements consistent with the schedule of paragraph 4.2.3.1 below.

3.2.6 Facility Wiring. Wiring from the Junction Block to the Instrument Room should be reasonably heavy copper, e.g. 20 gage. The thermocouple wiring should not connect to the Facility Reference Junctions. The four wires from each platinum thermometer should connect through to the Instrument Room.

3.2.7 Test Article Television Camera Provisions. AFRPL will provide test article television camera coverage during chamber pressure transients and testing. Recommended coverage is discussed in paragraph 2.2.5.

3.2.8 Heat Source Monitoring Sensors. Heat flux sensing instrumentation is to be designed per Appendix A and paragraph 2.2.7. Heat flux sensing disk thermocouple instrumentation should be capable of recording temperatures from 150° to 700°R ± 1%.

3.2.9 Cryogenic Boil-off Instrumentation. The AFRPL boil-off instrumentation is assumed to be four wet-gas meters arranged such that the test conductor may place one or all in use as the boil-off requirements dictate. The recommended overall variable ranges for the LH_2 and LN_2 tanks are 0.002 to 30 and 0.0025 to 80 pounds per minute, respectively.

3.2.10 Instrumentation Calibration. AFRPL instrumentation and recording equipment should be calibrated. Calibration curves for the GD/C supplied thermocouples will be generated after early test data is available, and supplied to AFRPL personnel.

4.0 TEST PROCEDURAL REQUIREMENTS

4.1 Pre-Test Requirements

4.1.1 Test Article Preliminaires.

4.1.1.1 Circuitry. Check all electrical connections for proper circuitry and integrity. Appropriate portions of this inspection should be completed prior to insulation application.

4.1.1.2 Compartment Vents. Inspect the intertank space vent port to insure port cap plates have been removed. Inspect the forward and aft adapters to verify at least 1.5 square inches of gas vent area each.

4.1.1.3 Propellant Transfer Lines. Check all valves and propellant ducting for operation and structural integrity.

4.1.1.4 LH_2 Tank Decontamination. Decontaminate the LH_2 tank and tankage system to remove condensable gases by flowing dry helium gas through the lines and tank until at least three complete tank volumes have been displaced and the dew point of the emerging gas is at or below -140°F. This process should require approximately 55 minutes at a helium flow rate of 25 cfm.

4.1.1.5 LN_2 Tank Decontamination. Flow dry GN_2 through the LN_2 tank system until the dew point of the emerging gas is at or below -120°F.

4.1.2 Test Facility Preliminaries.

4.1.2.1 Chamber Operation. Inspect and functionally check all chamber valves, pumps, cold traps, instrumentation, and facility-supplied equipment.

4.1.2.2 Special Electrical Systems. Provide sufficient electrical power internally to the chamber to operate camera systems and heat lamp sources. The lamp source power supply should be capable of adjusting the lamp radiant energy output to provide heat flux sensing disk temperatures of 85°F with cold wall and 200°F without cold wall. The incident energy required to produce these temperatures will be approximately 42 Btu/Hr-Ft^2 (12.5 Watts/Ft^2) while the chamber pressure is at 10^{-4} torr or below. Much higher flux levels may be required to produce the required sensor temperatures at higher chamber pressures. Extreme caution should be exercised to insure that the insulation temperature does not exceed 200°F. It is recommended that the heat flux sensor temperatures be recorded and monitored visually during lamp activation.

4.1.2.3 Instrumentation. Check facility supplied instrumentation for continuity and recording equipment for proper operation.

4.2 Thermal Testing

4.2.1 Chamber Pumpdown.

4.2.1.1 Heat Flux During Pumpdown. Actuate all lamp lines with power dissipations sufficient to provide heat flux sensing disk temperatures of 200°F maximum. This procedure will facilitate Dimplar insulation venting and outgassing.

4.2.1.2 Rough Pumping. Rough pump chamber per facility procedure. Do not exceed pumping rate of approximately 1 psi (52torr) per minute. Initiate cold wall filling with LN_2 at the appropriate chamber pressure (approximately 1 torr).

4.2.1.3 Test Article Outgassing. Continue chamber pumpdown to a pressure of 10^{-4} torr. Hold the chamber pressure at 10^{-4} torr to facilitate outgassing of the test system which may continue for as much as 50 hours. The heat lamp power dissipations may be cycled 30 minutes on and 30 minutes off during the hold period. The 200°F heat flux sensor temperature may be retained. Caution should be exercised in monitoring the disk temperatures since varying chamber parameters necessitate frequent lamp adjustment.

4.2.1.4 Final Pumpdown. Complete chamber pumpdown to 10^{-6} torr with the heat lamp lines off. Chilling of the LH_2 tank (paragraph 4.2.2) may commence during the final pumpdown. It is essential that the cold wall remain full during testing to provide a stable simulation of the space heat sink properties, which is particularly critical on the non-irradiated areas of the test tank. Should the loss of chamber vacuum or loss of cold wall occur during testing, the incident heat flux must be immediately terminated and LH_2 detanking begun. If the cold wall is operating properly, and outside air has not entered the chamber, the LN_2 may be retained in the LN_2 tank until it is determined if corrective action will allow continuance of the test. If, however, outside air has entered the chamber, LN_2 must also be detanked and the test terminated for insulation inspection. In either case, if the chamber pressure has changed at a rate exceeding 1 psi per minute, the insulation and adapters should be inspected for tears or cracks.

4.2.2 Childown and Tanking.

4.2.2.1 General. The chilldown and tanking of the test article is subject to stress limitations per PCTT Functional Limitations Report, Reference 3. The procedures below reflect these requirements.

4.2.2.2 LH_2 Tank Chilldown. Crack the LH_2 fill valve and chill the LH_2 tank for a minimum of 20 minutes.

4.2.2.3 LH_2 Tanking. Fill the LH_2 tank, limiting fill rate to a value allowing no greater than a 3 psi tank pressure increase above ambient pressure during tanking. Reduce fill rate to approximately

50 gal/min as the liquid level approaches the 100% level sensor as determined from LH_2 tank forward bulkhead temperature sensors, particularly Measurement #7, and facility fill procedures. Close the LH_2 tank fill valve and hold the test article in this configuration for 30 minutes, allowing tank childown.

4.2.2.4 LN_2 Tank Childown and Tanking. During the 30-minute LH_2 tanked hold, crack the LN_2 tank fill valve to initiate LN_2 tank childown. Tank LN_2 at a rate allowing a tank pressure increase no greater than 3 psi above ambient pressure. Reduce fill rate to approximately 50 gal/min as the liquid level approaches the 100% level, as determined from LN_2 tank ring temperature sensor (Measurement #28) and facility fill procedures.

4.2.2.5 Heat Lamp Source During Testing. Energize heat lamps to produce the temperature distribution shown in Figure A-2 of Appendix A, as indicated by the heat flux sensing disks. The maximum energy required at the point in the center of the irradiated half of the circumference is approximately 42 Btu/Hr-Ft^2 (12.5 Watts/Ft^2) when chamber pressure is less than 10^{-5} torr. The sensors should be monitored and recorded continually while the heat lamps are activated to ensure that insulation overheating does not occur.

4.2.2.6 Topping. The LH_2 tank should be topped at the completion of LN_2 tank filling, and thereafter, only when 200 pounds of boil-off have been recorded.

4.2.3 Data Acquisition.

4.2.3.1 Measurement Sensing Rates. Data acquisition is required for the full duration of the tests of Section 4.3. Continuous strip recording and visual monitoring is required for the following measurements:

1) LH_2 and LN_2 (an AFRPL installation) level sensor output

2) boil-off rates

3) tank and chamber pressures

4) one tank ring measurement on each tank

5) one LH_2 tank forward bulkhead measurement (Measurement #7)

6) instrumentation junction block temperature

7) heat flux sensors.

Exceptions to this are the level sensors which need be recorded only during activation for level sensing purposes. Acquisition and recording rates for all other measurements should be consistent with the following schedule:

During chamber pumpdown	- 1 sample every 15 minutes
During tank chilldown	- 1 sample every 5 minutes
During tank filling	- 1 sample every 1 minute
During tank cold soak	- 1 sample every 5 minutes
During space simulation test	- 1 sample every 30 minutes

4.2.3.2 Heat Flux Sensors. It is recommended that the heat flux sensor output be monitored visually and continually adjusted to provide the sensor circumferential temperature distribution per Figure A-2 of Appendix A.

4.2.3.3 Chamber Environment. The vacuum chamber pressure and cold wall temperature should be visually monitored as well as recorded. Should the cold wall temperature or the chamber pressure increase to the point where it is deemed necessary to proceed with chamber abort procedures, tank abort precautions of paragraph (4.2.1.4) should be consulted.

4.2.3.4 Boil-off Measurement. Boil-off measurements taken during steady state should be made over extended periods of time of approximately 2 to 3 hours. Measurement periods should commence at least one hour after topping, as topping may upset equilibrium conditions.

4.2.3.5 Test Duration. After propellant tanks have been filled, approximately 50 hours will be required to reach steady-state thermal conditions. Steady-state conditions will be defined as the time required for all temperature measurements to be stabilized to the extent that their variance is no more than 5°F per 5-hour period.

4.3 Recommended Tests During Test Article Tanking

The above recommended test procedures imply that but one test article tanking need be accomplished. During this tanking, however, a series of four tests is recommended. The test conditions and test requirements are outlined below. After each test, the tanks should be topped before proceeding to the next.

4.3.1 Space Environment Simulation-Sunlit. These conditions were described above as an integral part of the test procedures.

4.3.2 Space Environment Simulation-Shaded Coast. The shaded coast conditions are identical to the sunlit test condition, with the exception that the heat lamps remain off during space simulation. At the conclusion of the sunlit test, the test conductor may proceed directly to the shaded coast test by simply turning the heat lamps off, topping the propellant tanks, and allowing the tanks to come to equilibrium temperature conditions. If LN_2 boil-off decreases to an immeasurable rate, intermittent complete closure of the LN_2 vent may be required to avoid back pumping. Tank (line) pressure must be maintained within allowable limits as outlined in Reference 3, as a limiting shaded coast simulation condition.

4.3.3 Testing for Chamber Pressure Effects on Heat Transfer. Upon completion of the shaded coast test and tank topping, the chamber pressure should be increased by shutting off the diffusion pumps and returning the chamber to a steady pressure of 10^{-2} torr readmitting air to the chamber, if necessary. The heat lamps should then be turned on and adjusted to produce the flux sensing disk temperature distribution of Figure A-2 of Appendix A. It should be noted here that a considerably greater lamp power distribution may be required than was used in the sunlit test, due to the increased conduction through the insulation. When the system is allowed to come to steady-state conditions in this configuration, valuable basic information will be obtained on super insulation efficiency under conditions of degraded vacuum. An additional objective here will be to determine if the hydrogen tank will allow pressures in the 10^{-2} torr range without cryopumping to lower pressures, thereby determining the maximum chamber pressures allowable for future hydrogen filled tank testing.

4.3.4 Testing for Residual Helium Effects on Insulation. A flight-rated vehicle of this type would necessarily require that the insulation be helium purged while in the tanked condition prior to launch. It would then be of interest to determine the increase in heat leak to the propellant tanks under the conditions of insulation helium contamination. Since venting within the insulation occurs rapidly in the continuum regime but slowly in the free molecule regime, the heat leak due to residual helium may be important during long-term cryogenic storage in space.

This test may be continued from the high pressure air test by pumping the chamber down to 10^{-5} torr, topping the tanks, and readmitting helium to the chamber to a pressure of about 10 torr. Caution should be taken here to insure that the chamber pressure gauges are calibrated to read helium pressures and correction factors are available. The chamber should then be pumped down to 10^{-5} torr and the test article allowed to reach steady-state conditions.

4.3.5 LH_2 Tank Lock-up Tests. If the AFRPL provides a boil-off valve on the tank vent lines, GD/C recommends that a liquid hydrogen tank lock-up be accomplished after steady-state conditions have been attained on both the sunlit and shaded coast tests. The hydrogen tank pressure should be carefully recorded continually during such a lock-up. It should be cautioned that the tank pressure must not be allowed to increase to a value greater than 20 psia. Care should also be taken to insure that the hydrogen vent valve is hydrogen qualified to sufficient extent to preclude the possibility of freezing of the valve in the locked position. Alternate procedures such as rapid detanking must be provided for, should valve freezing occur.

4.4 Detanking and Post-Test Checkouts

4.4.1 LN_2 Tank Detanking. The LN_2 tank must be detanked first per Stress Limitations Report, GD/C-BTD66-216 (Reference 3). Detank LN_2 and blow ambient temperature GN_2 into the tank at about 25 cfm to remove residual LN_2. This process will require approximately four hours and should be continued until the temperatures of the purge gas and vent gas are equal. The tank pressure should be monitored to insure 20 psia is not exceeded.

4.4.2 LH_2 Tank Detanking. The LH_2 tank may be detanked after initiation of the LN_2 tank purge. All heat lamps may be energized to produce the 85°F temperature on the irradiated half of the test article circumference to increase residual boil-off.

4.4.3 LH_2 Tank Decontamination. Blow ambient temperature helium into the LH_2 tank and fill and drain line for about one hour at approximately 25 cfm to remove residual LH_2 and decontaminate the LH_2 tank. Test the LH_2 tank vent gas products to insure no hydrogen remains in the tank before terminating purge. Carefully monitor tank pressure to insure 20 psia is not exceeded.

4.5 Data Evaluation

4.5.1 Temperature Distributions. Temperature distributions of forward and aft covers, forward and aft adapters, intertank space, and insulation may be compared with the analysis of Reference 1. Comparison here will allow preparation of a thermal map of the test article which would be useful in the future structural design of similar vehicles.

4.5.2 Heat Transfer Rate Distribution. Direct measurement of the heat transfer rate through or between various major elements of the test article is not possible. The less direct method of correlating the thermal temperature map from above with the thermo-physical data for the structure and the analysis of Reference 1 may be incorporated to prepare a heat transfer map of the heat leaks through and between the overall test article thermal envelope boundaries. This model may be checked for accuracy by comparison with the actual boil-off rates during testing after accounting for the heat leaks from the insulation penetrations.

4.5.3 Insulation Penetrations. Determine the heat transfer rate through each of the insulation penetrations by examining the temperatures of the facility-supplied penetration instrumentation (paragraph 3.2.2) in conjunction with the penetration calibrations of paragraph 2.2.8.

4.5.4 Reduced Insulation Efficiency Due to Residual Gas. Evaluate the increase in the overall heat transfer rate through the insulation between the hard vacuum (10^{-6} torr) sunlit test, and the increased air and helium pressure tests. The difference in heat transfer rates is the measure of the insulation degradation at higher pressures. The helium heat transfer evaluation test is also a measure of the insulation venting characteristics during a simulated flight. Future upper stages employing liquid hydrogen will typically have their insulations purged with helium prior to launch which necessitates insulation venting and outgassing of helium during early coast phases.

4.5.5 Dimplar Insulation. Evaluate the overall Dimplar cryogenic insulation system, along with peg application method, for use on flight vehicles. Compare analytical heat transfer rate prediction equations of Reference 1 with test resultant boil-off data. Determine the percentage heat leak through the insulation due to the mounting pegs.

5.0 SUGGESTED FUTURE TEST CAPABILITY OF TEST ARTICLE

Below is a list of proposed future test capabilities of the test article. Modifications would be required in varying degrees for incorporation of any or all of the items.

5.1 Purge Systems

The test article may be used as a convenient tankage system for the testing of tank or insulation purge systems and/or procedures.

5.2 Other Insulations

The complete test procedures outlined here may be carried out again utilizing different insulations or methods of application. Suggested insulations are General Dynamics/Convair Superfloc super insulation, NRC-2, and a Linde SI series insulation.

5.3 Tank Pressurization Systems

The test article may be used to simulate a flight-weight vehicle under one-g forces utilizing various methods of tank pressurization during simulated pre-launch and flight (engine run and coast) conditions. The propellants may be pumped out at various rates to simulate propellant depletion during engine run. Caution should be exercised to limit tank pressures to 20 psia maximum.

5.4 Alternate Fluid Systems

Different propellants may be examined for space storage suitability by testing in the PCTT test article. By removing the tank insulation and applying different space-rated thermal control coatings, the article may be used to test the space-storage properties of the non-cryogenic propellants. The Functional Stress Limitations Report, Reference 3, should be consulted for propellant mass limitations.

5.5 Alternate Structural Components

By the installation of various fill and drain or vent valves and associated tubing, the article may be used to test their capability and reliability with respect to flight-type vehicles. Vehicle modifications may be made to test the suitability of new structural components in the space environment, e.g. bulkheads, brackets, and vent lines.

5.6 Propellant Line Disconnect Systems

Fill and drain line disconnect systems are required on all flight vehicles of this type in order to disconnect propellant lines at lift off and provide thermal insulation at the termination of the airborne line. The test article may be used to determine the suitability of such systems and the thermal efficiency of insulation penetrations after disconnect.

5.7 Propellant Dynamics Investigations

The test article may be re-instrumented to evaluate propellant behavior during tanking. When coupled with a source of vibration, the article may be used in low acceleration 1-g simulation testing.

5.8 New Tanking Concepts

The partitioned tank concept allows the consideration of the inter-tank cavity being utilised as an additional fuel tank. The test article may be utilized as a test tank to determine the feasibility of this concept.

5.9 Propellant Stratification Studies

Under steady-state conditions the test article may be used to provide data on propellant stratification. This test may be conducted in conjunction with the various insulation tests recommended in paragraph 5.2.

5.10 Alternate or Variable Space Heating Rates

Alternate or variable space heating rates could be incorporated to provide a detailed simulation of space heating conditions which would be more realistic than the constant heat flux levels utilized in this report. Various periods of sun orientation and/or maneuvers could be incorporated. Varying heat rates would require a more flexible vent system capability.

REFERENCES:

1. Jennings, R. W., O'Neill, R. F., "Space-Environmental Thermal Analysis of the Centaur Partitioned Test Tank", GDC-BTD67-006, 15 January 1967.

2. Convair Division of General Dynamics, A Proposal to Design and Fabricate a Partitioned Centaur Test Tank", GDC PIN 66-106A, dated 24 May 1966.

3. Carlson, R. E., "Functional Limitations of the Partitioned Centaur Test Tank", GDC-BTD66-216, dated 9 January 1967.

TABLE 1

PCTT MEASUREMENT LIST

Meas. No.	Ref.	Term Bd	Terminal Screw No.	Location Quad.	Location Sta.	Location Rad.	Description
1	--	8	3-4, 5-6		180		LH_2 100% L/V Det.
2	--	5	13, 14-15, 16	I-II			Ref Junction Block
3	2	1	1-2	℄	162	0	LH_2 Tank Lid
4	2	1	3-4	I,45°	166	19	LH_2 Tank Top Bulkhead
5	2	8	1-2	III-IV	172	29	LH_2 Tank Top Bulkhead
6	2	1	5-6	I-II	185	40	LH_2 Tank Top Bulkhead
7	--	2	17, 18-19, 20	II-III	195	50	LH_2 Tank Top Bulkhead
8	2	1	7-8	III-IV	207	58	LH_2 Tank Top Bulkhead
9	2	5	17-18	III-IV	151	62	Top Ring
10	2	5	19-20	IV-I	151	62	Top Ring
11	2	5	1-2	I-II	151	62	Top Ring
12	2	6	9-8	III-IV	151	48	Top Cover
13	12	6	7-10	III-IV	151	36	Top Cover
14	2	6	3-4	IV-I	151	48	Top Cover
15	2	6	5-6	I-II	151	48	Top Cover
16	2	1	9-10	III-IV	180	60	Upper Adapter
17	2	1	11-12	IV-I	180	60	Upper Adapter
18	2	1	13-14	I-II	180	60	Upper Adapter
19	--	3	11, 12-13, 14	III-IV	219	60	LH_2 Tank Ring
20	2	4	13-12	IV-I	219	60	LH_2 Tank Ring
21	--	3	15, 16-17, 18	I-II	219	60	LH_2 Tank Ring
22	19	5	9-10	III-IV	260	60	Cyl. Tank Skin
23	28	4	15-18	III-IV	291	60	Cyl. Tank Skin
24	21	5	11-12	I-II	260	60	Cyl. Tank Skin
25	29	5	1-4	I-II	291	60	Cyl. Tank Skin
26	20	4	11-14	IV-I	260	60	Cyl. Tank Skin
27	62	5	5-8	IV-I	291	60	Cyl. Tank Skin
28	2	4	17-16	III-IV	326	60	LN_2 Tank Ring
29	2	5	3-2	I-II	326	60	LN_2 Tank Ring
30	2	2	15-16	III-IV	360	60	Bot Adapter
31	2	3	1-2	IV-I	360	60	Bot Adapter
32	2	3	3-4	I-II	360	60	Bot Adapter
33	2	3	5-6	III-IV	385	60	Bot Ring
34	2	3	7-8	IV-I	385	60	Bot Ring
35	2	3	9-10	I-II	385	60	Bot Ring
36	2	4	1-2	III-IV	385	54	Bot Cover
37	2	4	5-4	II	330	72	LN_2 Fill
38	37	4	3-6	II	323	73	LN_2 Fill
39	2	4	9-8	II	375	46	N_2 Vent
40	39	4	7-10	II	375	56	N_2 Vent

TABLE 1

PCTT MEASUREMENT LIST (Contd.)

Meas. No.	Ref.	Term Bd	Terminal Screw No.	Location Quad.	Sta.	Rad	Description
41	2	2	5-4	II	158	46	LH_2 Fill
42	41	2	3-6	II	158	56	LH_2 Fill
43	2	2	9-8	II	158	46	H_2 Vent
44	43	2	7-10	II	158	56	H_2 Vent
45	2	2	13-12	III-IV	214	63	Dimplar Peg
46	45	2	11-14	III-IV	214	64	Dimplar Peg
47	2	6	13-12	III-IV	150	61	Hanger
48	47	6	11-14	III-IV	149	61	Hanger
49	2	6	17-16	III-IV	150	62	Hanger
50	49	6	15-18	III-IV	149	62	Hanger
51	2	7	3-2	IV-I	150	61	Hanger
52	51	7	1-4	IV-I	149	61	Hanger
53	2	7	7-6	IV-I	150	62	Hanger
54	53	7	5-8	IV-I	149	62	Hanger
55	2	7	11-10	I-II	150	62	Hanger
56	55	7	9-12	I-II	149	62	Hanger
57	--	1	17, 18-19, 20				Wiring Harness
58	2	1	15-16	III-IV	219	65	Super Insulation
59	2	2	1-2	I-II	219	65	Super Insulation
60	2	7	15-14	I-II	150	61	Hanger
61	60	7	13-16	I-II	149	61	Hanger
62	2	5	7-6	IV-I	326	80	LN_2 Tank Ring
63	2	8	9-8	I-II	214	63	Dimplar Peg
64	63	8	7-10	I-II	214	64	Dimplar Peg

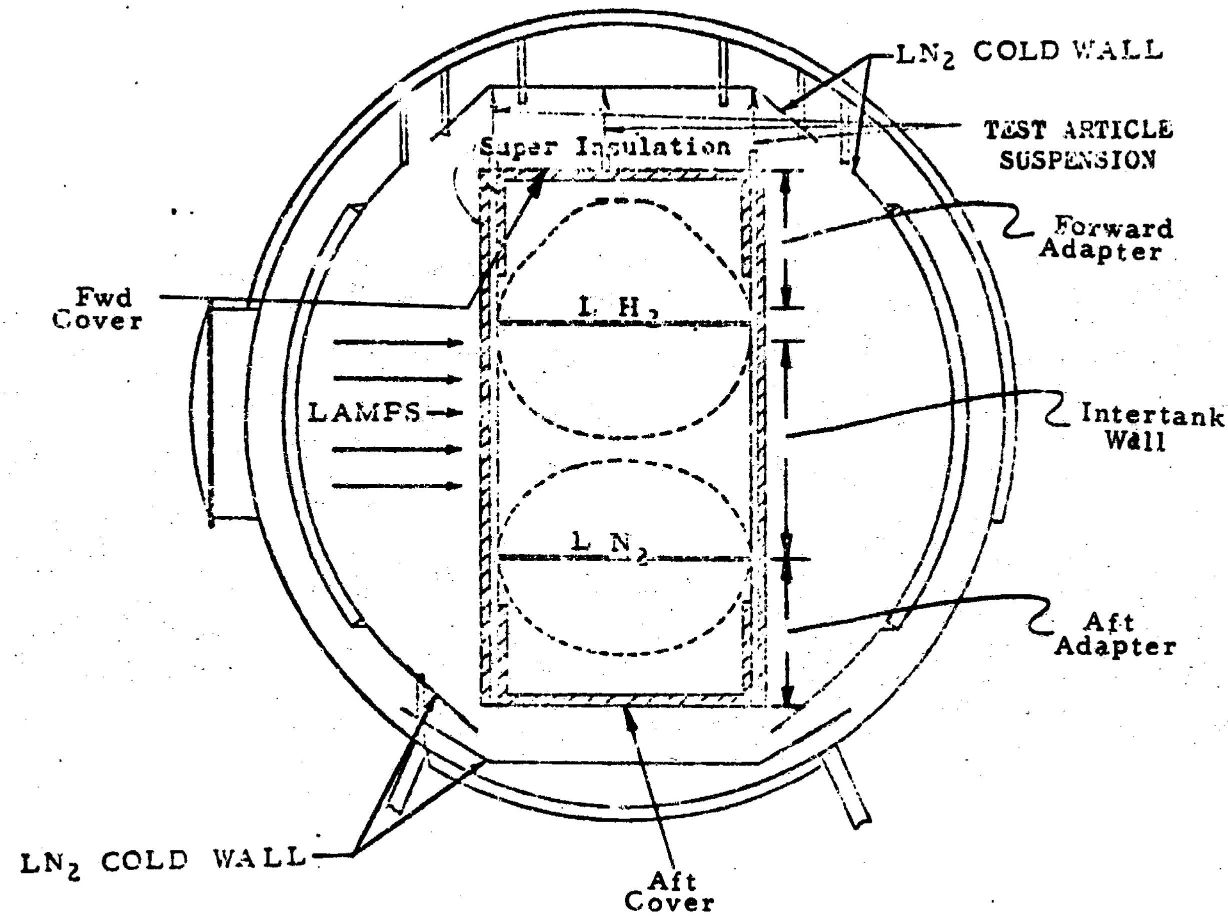


FIG. 1. PCPT POSITIONED IN AFRPL SESF CHAMBER

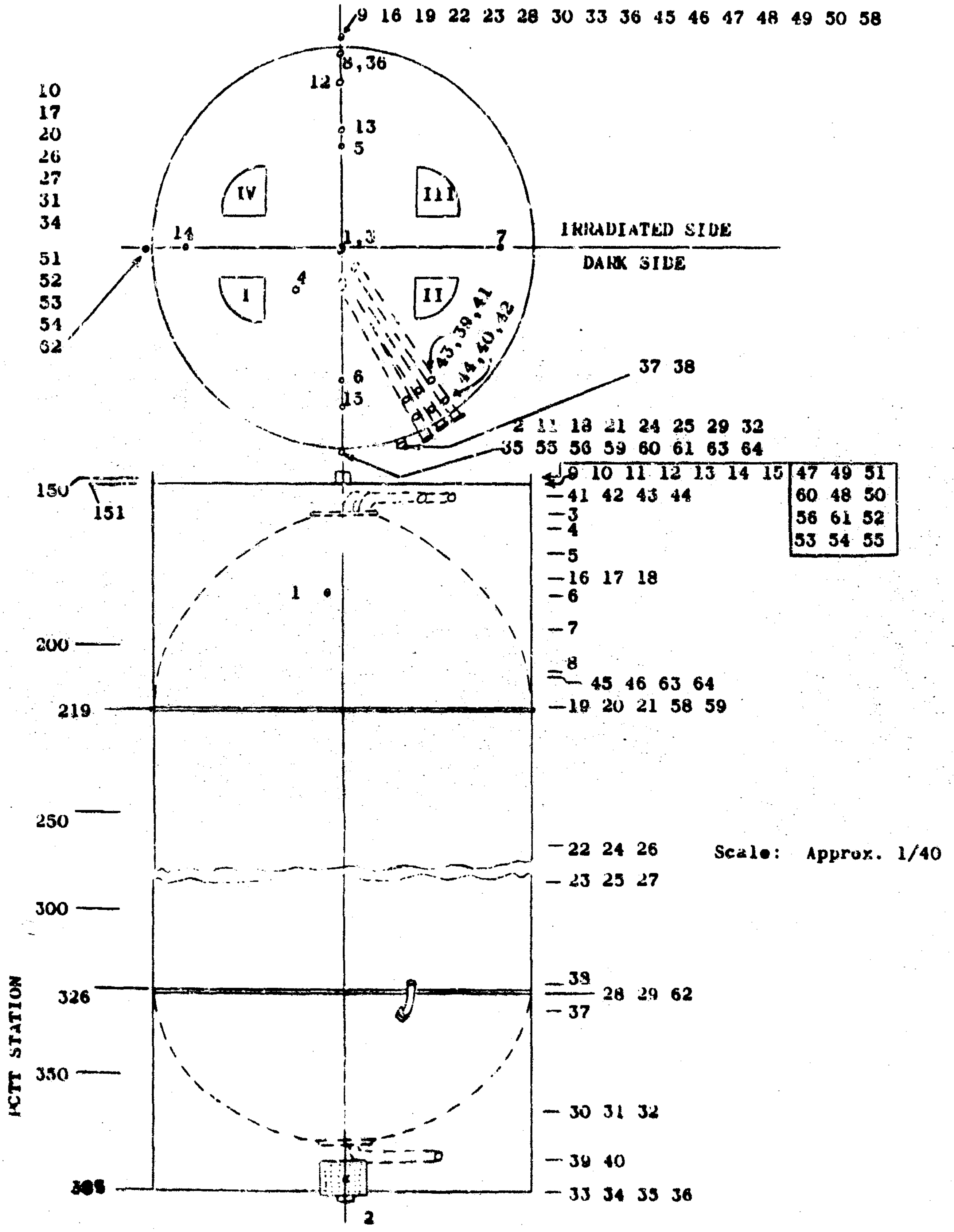


FIG. 2. PCTT MEASUREMENT LOCATIONS

APPENDIX A

Air Force Rocket Propulsion Laboratory (AFRPL) Thermal Support Requirements for Partitioned Centaur Test Tank (PCTT)

To provide a realistic space heat transfer simulation, the following recommendations are made for controlling and monitoring the radiant source incident energy and the heat leaks to the propellants through the facility/tank interfaces:

1. Flux Measurement

1.1 A cylindrically configured vehicle in a deep space environment, if oriented with the vehicle center-line normal to the vehicle-sun vector, would be subjected to a local incident solar energy distribution as presented in Figure A-1. To minimize surface temperatures and resulting tank heating, a practical requirement for the external vehicle surfaces would be a minimum α/ϵ ratio. Resulting surface temperature distribution would be similar to that of Figure A-2, which assumes α and ϵ values of 0.3 and 0.91, respectively. However, the incident heat flux of Figure A-1 would have a radiative spectral distribution corresponding to a solar source of energy.

1.2 The AFRPL facility energy source has a spectral energy distribution which is shifted to the infra-red. In order to insure that an equivalent solar energy distribution is obtained on the PCTT, the test energy distribution must be measured. A practical heat flux measurement solution must consist of a flux measuring scheme which will;

1.2.1 Give an accurate indication of Dimplar surface temperature.

1.2.2 Not alter or otherwise compromise necessary insulation structural surface characteristics.

APPENDIX A (Contd.)

1.2.3 Provide basis for lamp adjustment such that Figure A-2 temperature profile can be achieved.

1.3 Valid surface temperature control and measurement presents the following practical requirements:

1.3.1 Measurement device must incorporate sufficient thermal mass to assure actual existence of indicated temperature level. This would be subject to serious doubt, for example, were a thermocouple attached directly to the very thin Dimplar surface layer.

1.3.2 Measurement device must have an α/ϵ ratio equal to that of Dimplar.

1.4 A suggested flux measurement procedure involves mapping of the test article surface with thin copper disks approximately one inch in diameter and 0.010 inches thick. Disks should be instrumented with copper-constantan leads forming an effective thermocouple, as noted in Figure A-3a. The disks and leads must then have flat sheets of Dimplar bonded to both sides per Figure A-3b, and mounted in vertical lines as shown in Figure A-3c, very near the insulation skin.

2. Suggested Lamp Positions

2.1 Install five vertical lines of lamps around one half of the circumference of the PCTT, and adjust lamp intensities to provide measurement device temperatures consistent with Figure A-2. The circumference chosen should be located such that the fill and drain lines as well as vent lines are not irradiated.

2.2 Position the forward-most lamp in each line such that the impingement area is no closer than 4 inches to the forward edge of the PCTT side insulation.

APPENDIX A (Contd.)

3. Provide local, thermally black cold walls between the PCTT fill and drain valves and PCTT insulation skin.

4. Instrument each fill and drain line between the fill and drain valve and the PCTT with two thermocouples each, located approximately 24 inches apart. Each vent line should be instrumented similarly just outboard of the PCTT vent line stubs. All measurements should be located on relatively straight sections of line having a constant cross-sectional geometry.

5. Current assumptions for the facility interface fill and drain lines include a 24-inch length of 2.5 in ID, 0.049 in 304SS ducting from the fill and drain valves to the PCTT stubs. The valves are assumed to have a temperature of -65°F, and a cold wall between the valve and PCTT is assumed. The vent lines are assumed to be 3.0 in ID, 0.049 in thick 304SS.

6. Pressure sensing and boil-off measuring capabilities for both tanks is assumed available within the chamber instrumentations facilities. Pressure sensing instrumentation should be located in both vent lines as near as feasible to the PCTT vent line stubs.

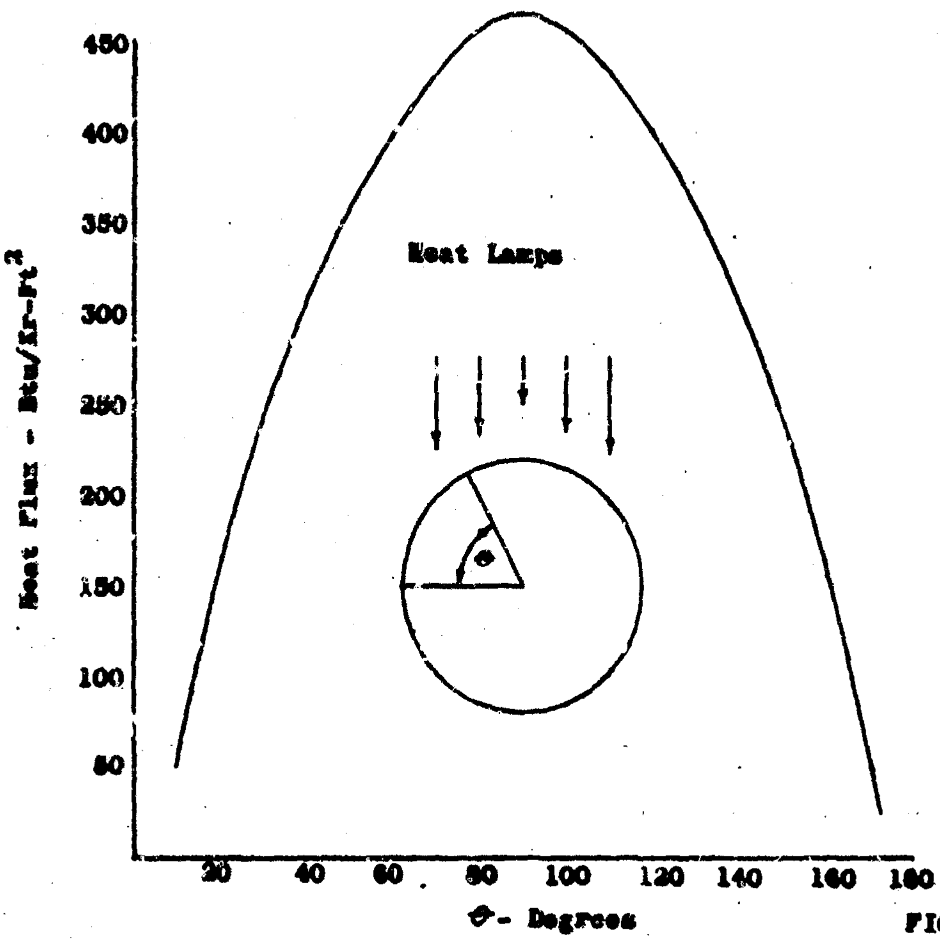


FIGURE A-1

INCIDENT SOLAR ENERGY DISTRIBUTION

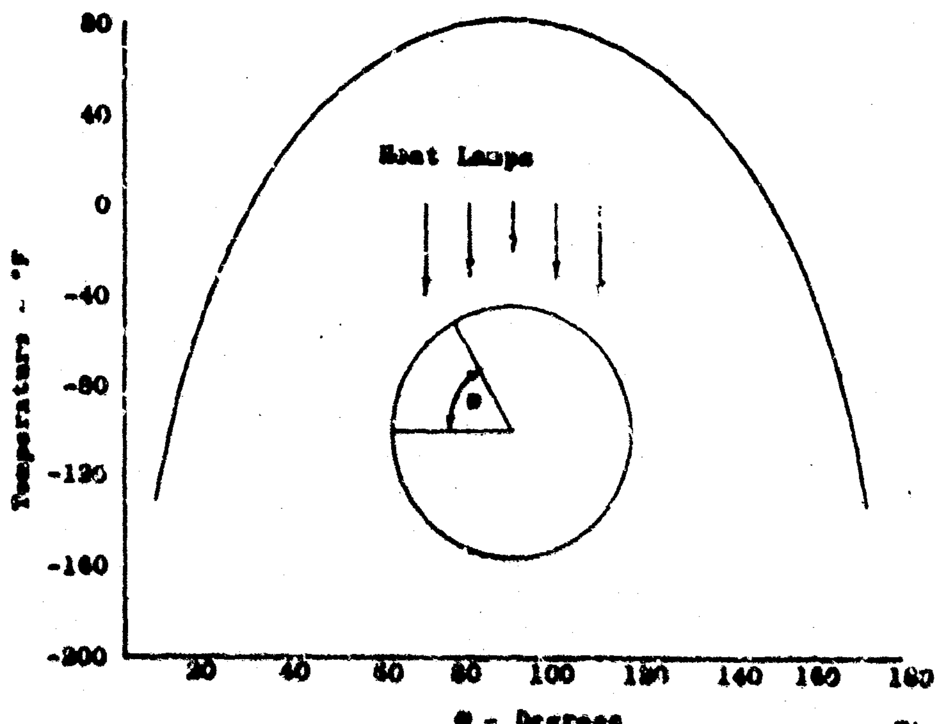


Figure A-2

INSULATION SURFACE TEMPERATURE

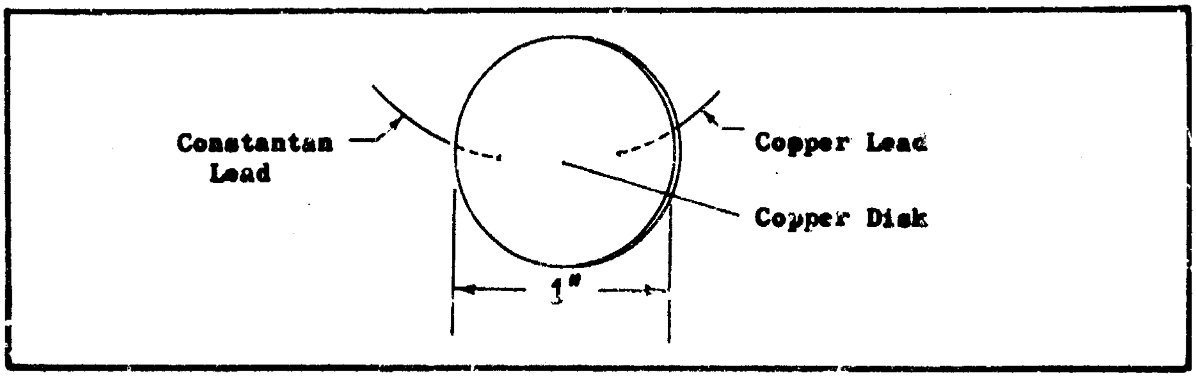


FIG. A-3a HEAT FLUX MEASURING DISK CONFIGURATION

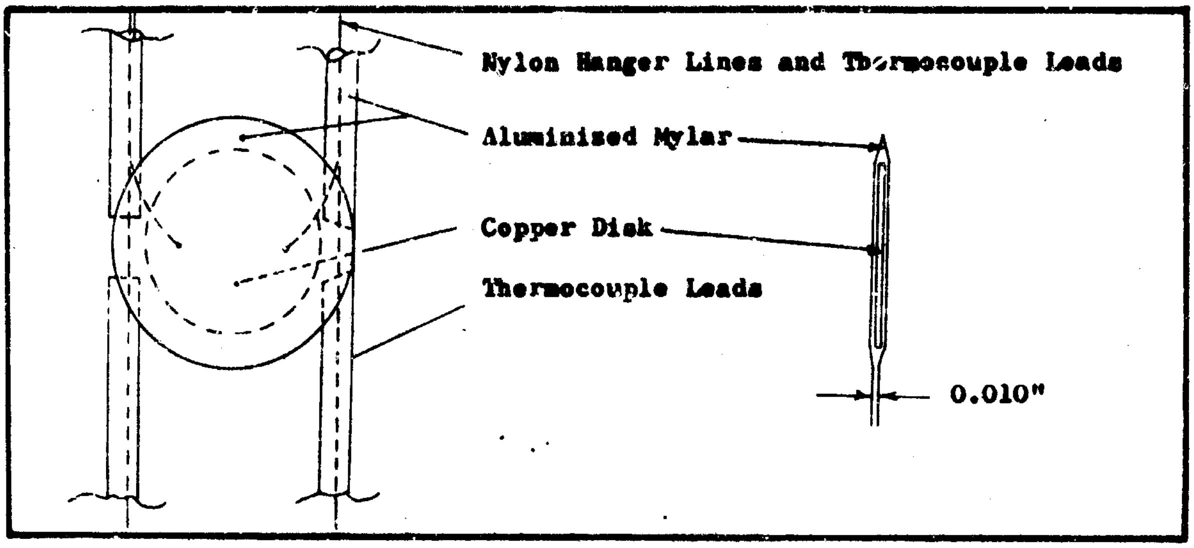


FIG. A-3b ALUMINIZED MYLAR APPLICATION TO DISK

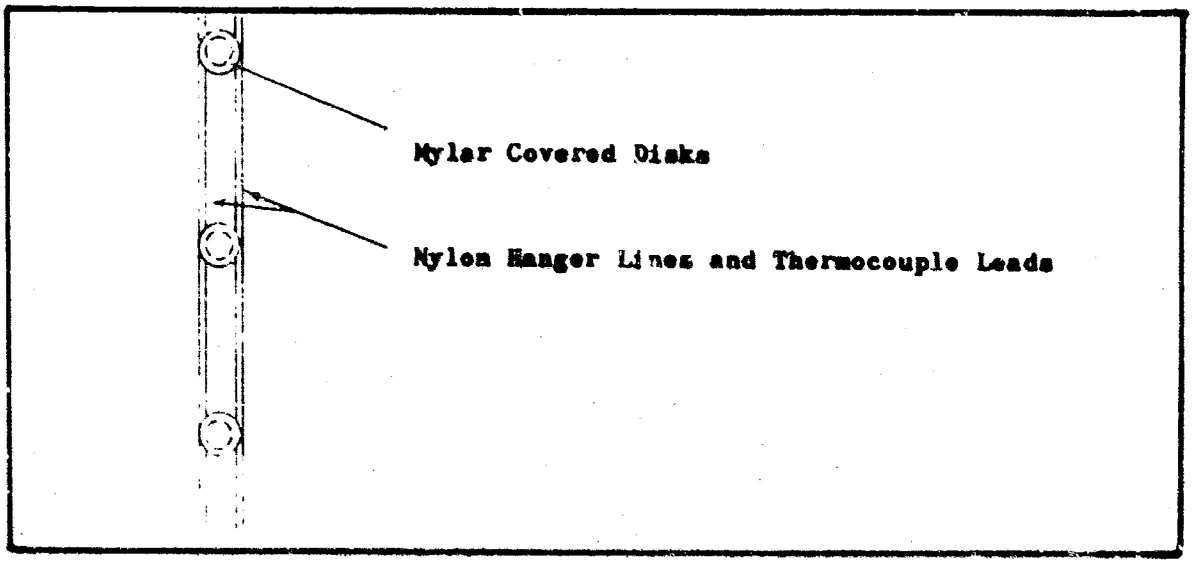


FIG. A-3c TYPICAL HEAT SENSOR LINE

APPENDIX B

PCTT LH_2 Level Sensor

The following is a description of the system which will indicate the liquid/gas interface at the 100% level of liquid hydrogen in the Partitioned Centaur Test Tank during tanking operations.

1.0 DESCRIPTION

1.1 Level Sensor

The LH_2 Level Sensor consists of two identical (redundant) resistance elements of one-mil diameter platinum wire. The sensor assembly is installed in the vehicle per General Dynamics/Convair drawing PCTT-5, and is positioned for direct contact with the liquid at 100% of desired level. A voltage applied to either or both elements (for redundant sensing) will result in a current which will vary as a function of the heat transfer characteristics of the sensor environment.

The sensor circuit characteristic curves are shown in Figure B-1. Intersection of the loading curves ("COLD GH_2", "LH_2 NUCLEATE BOILING", "ROOM TEMP GH_2") with the "COMPENSATED POWER SUPPLY LINE" defines the current and voltage drop of the sensor element in its normal working environment. Note that the load line intersects "LH_2 NUCLEATE BOILING" curve but not the "LH_2 FILM BOILING". It is therefore expected the sensor element will exhibit the characteristics of the "NUCLEATE BOILING" curve, i.e. lower voltage drop. (Film boiling would be encountered with the sensor operated at a higher power level.

1.2 Sensor Power Supply (Figures B-2 and B-3)

The sensor power supply provides a low voltage (2.6 to 3.0 v) to the sensor from a 28 VDC source (See Figure B-1 output curve.) It consists of two identical zener diode/transistor circuits (one for each of the two sensor elements.) Switches to break input and output circuits and ammeter jacks are provided. With both sections operating, approximately 30 watts of heat maximum must be dissipated.

APPENDIX B (Contd.)

2.0 SYSTEM OPERATION

2.1 Measurement and Indication

Sensing the arrival of LH_2 during filling operations can be accomplished by one of several methods, e.g. measure current to sensor or voltage drop across sensor. The following outlines the considerations for the voltage drop method.

It is suggested that one element of the sensor be active and the second element retained as a backup should the first element fail. The power supply should be located adjacent to the vehicle (at terminal rack external to chamber) and provided with means to remotely control the activation of the sensor during tanking operations.

For maximum sensitivity of measurement of the voltage drop, tapping into the circuit should be made close to the level sensor which avoids as much as possible the influence of voltage drop in the lines (the unused sensor circuit which carries no current would be employed for one leg). The sensor voltage drop can be displayed remotely in the blockhouse on meter or recorder. A "dry" indication is a reading which exceeds 0.5 volts. "LH_2" at the sensor would indicate less than 0.5 volts.

2.2 Operating Procedure

To provide the desired current to the sensor it is necessary to determine the value of the compensating resistor to be inserted in series with the interconnecting cable loop resistance. This is accomplished by the following method: (See Figure B-4 for test set-up)

APPENDIX B (Contd.)

a. At the instrumentation junction block, short terminals 3 and 4.

b. Remove shorting bar of the sensor power supply and insert D.C. ammeter (0-1 amp).

c. Connect in series a resistance decade or 2-watt variable resistor (4 ohms max. in one-tenth ohm steps).

d. Adjust the resistance to obtain 660 ma.

e. Replace the test resistor with a fixed value and recheck current: the exact current is not critical (the load line will vary accordingly at the intersection with the ordinate of Figure B-1). Remove the jumper at the instrumentation junction block.

This completes the operating circuit preparation.

Note: The circuit interconnect wiring was shorted at the instrumentation junction block terminals, therefore the loop resistance of the vehicle cable was ignored. This could introduce appreciable error except that the copper wire, during tanking operations, will approach cryogenic temperatures and attain minimum resistance (approximately 10% or less of ambient wire resistance).

2.3 Safety

The platinum sensor element attains a temperature which could ignite a detonable gas except for a deposited gold coating. This increases the ignition temperature from less than 700°F to approximately 1700°F by providing a barrier to the catalytic

APPENDIX B (Contd.)

2.3 Safety (Contd.)

effect of platinum. To assure a satisfactory gold coating, the sensor is tested in a detonable mixture of GH_2/air with 270 ma current per GD/C Drawing PCTT-5. In this circuit, the current is limited to approximately 175 ma in GH_2/air. For safety, however, a double protection should be provided by having the sensor deactivated and therefore cold when it may be exposed to a fuel/oxidant mixture.

The following procedure shall be followed in employing this sensor for tanking indication:

a. By remote control, activate sensor current only when LH_2 is present, i.e. after some LH_2 has been transferred to the vehicle.

b. Upon completion of tanking (100% full), deactivate circuit.

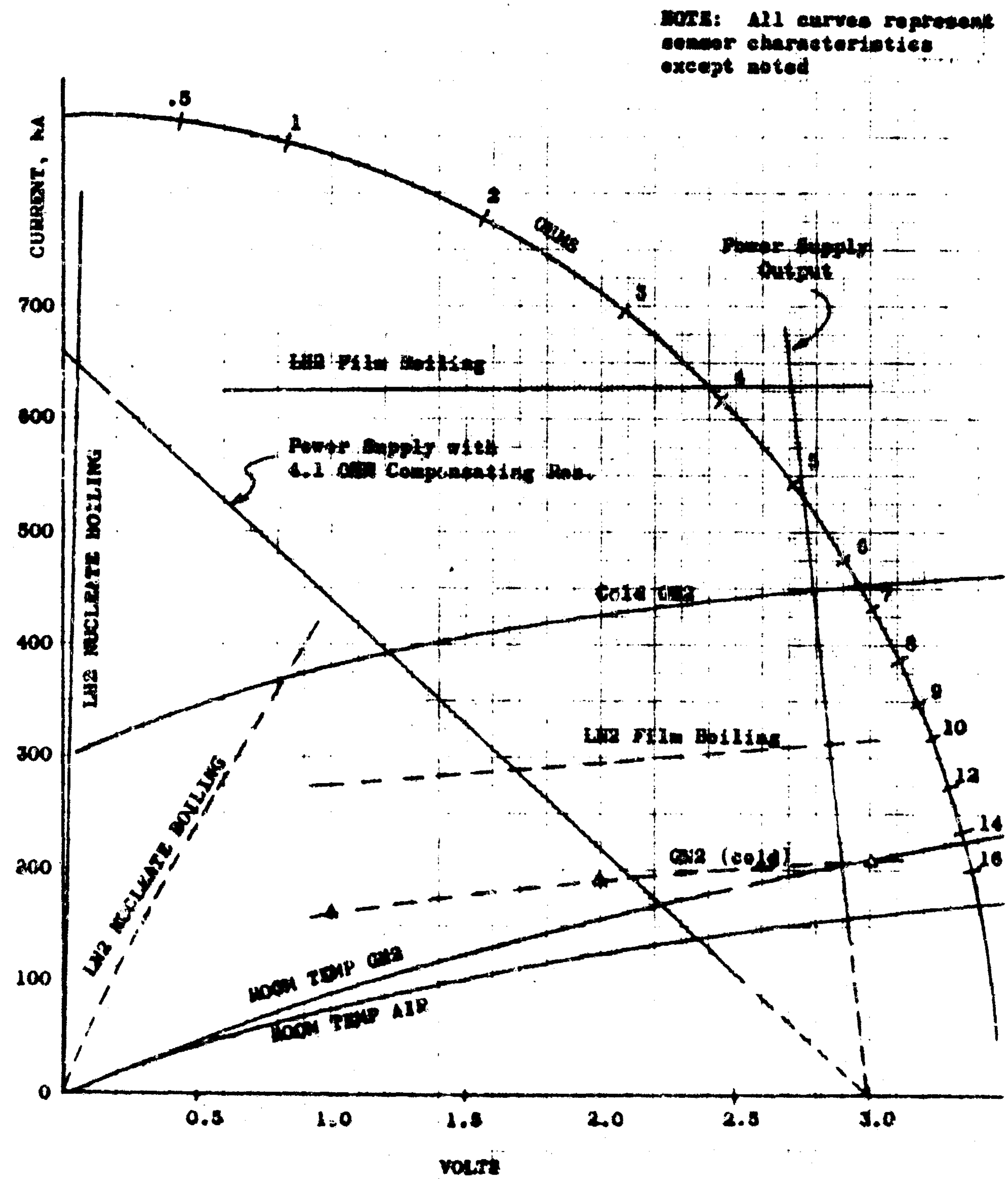


FIG. B-1 LH_2 LEVEL SENSOR CHARACTERISTIC CURVES

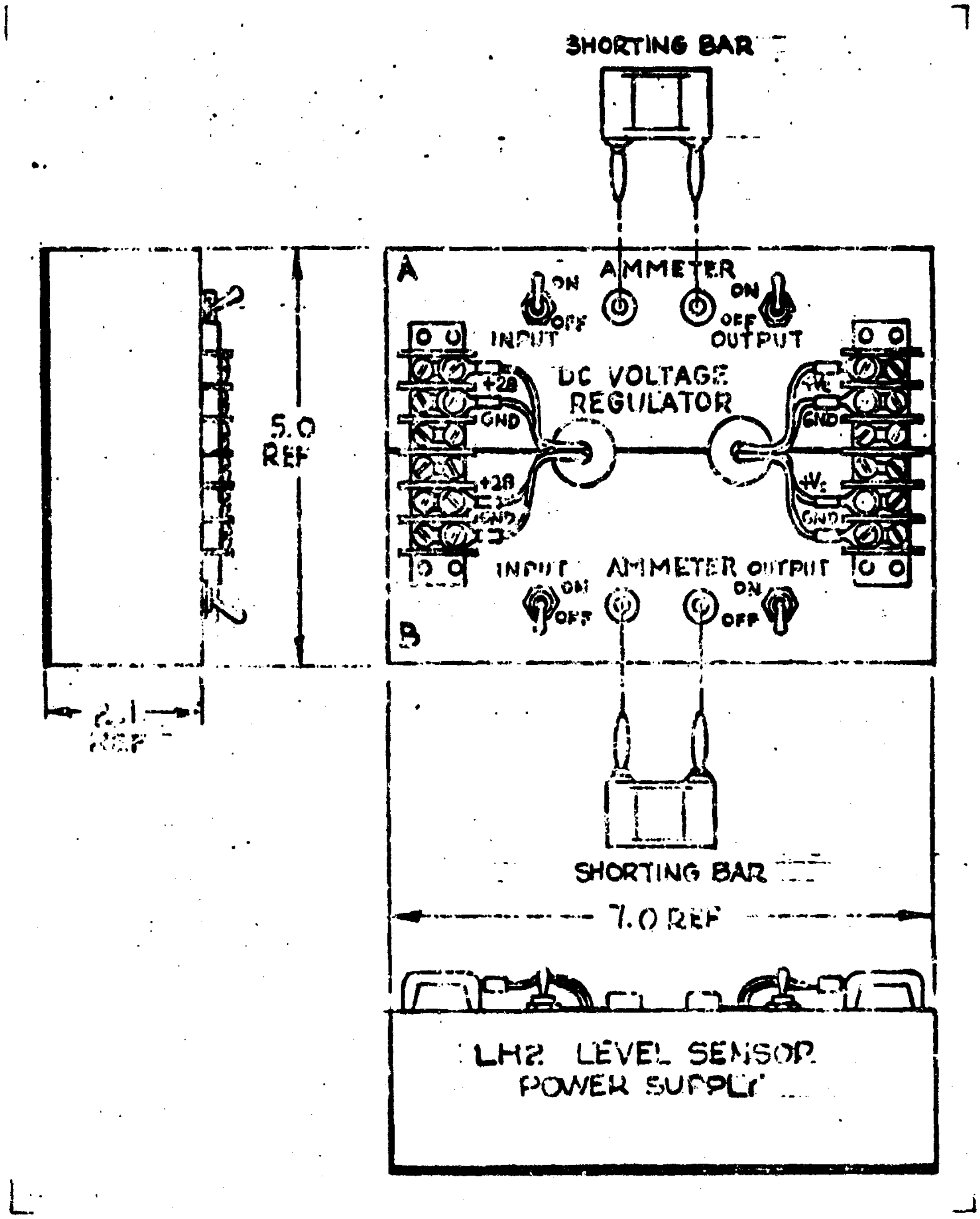
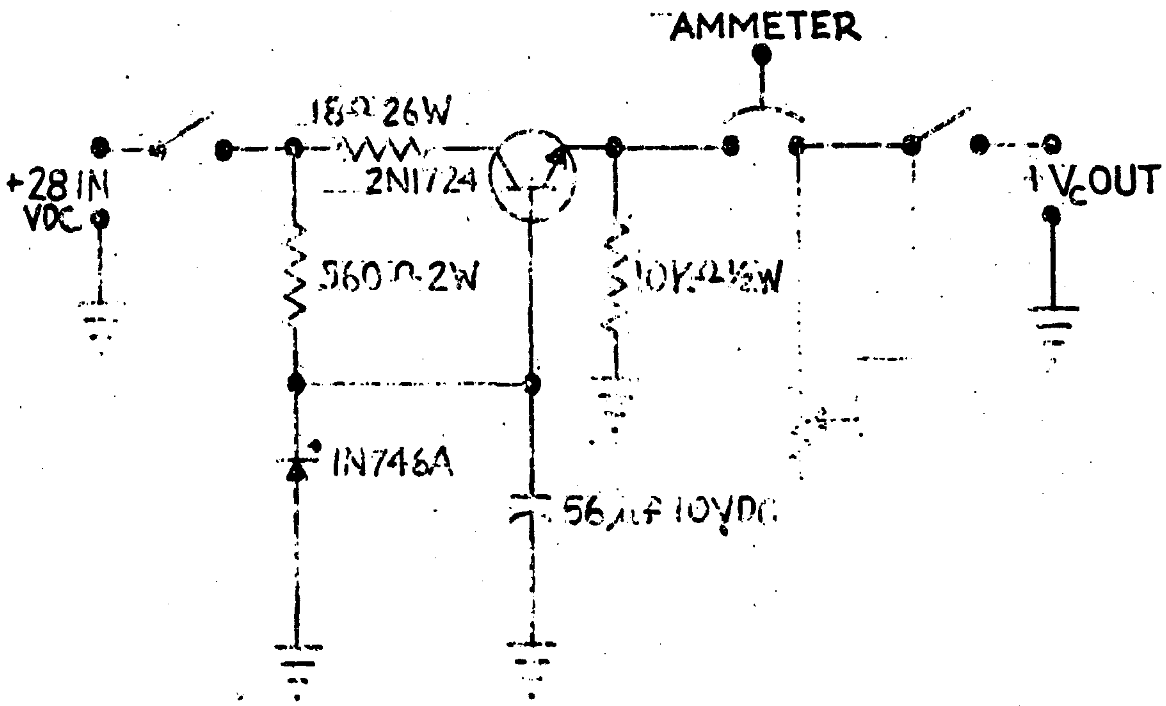
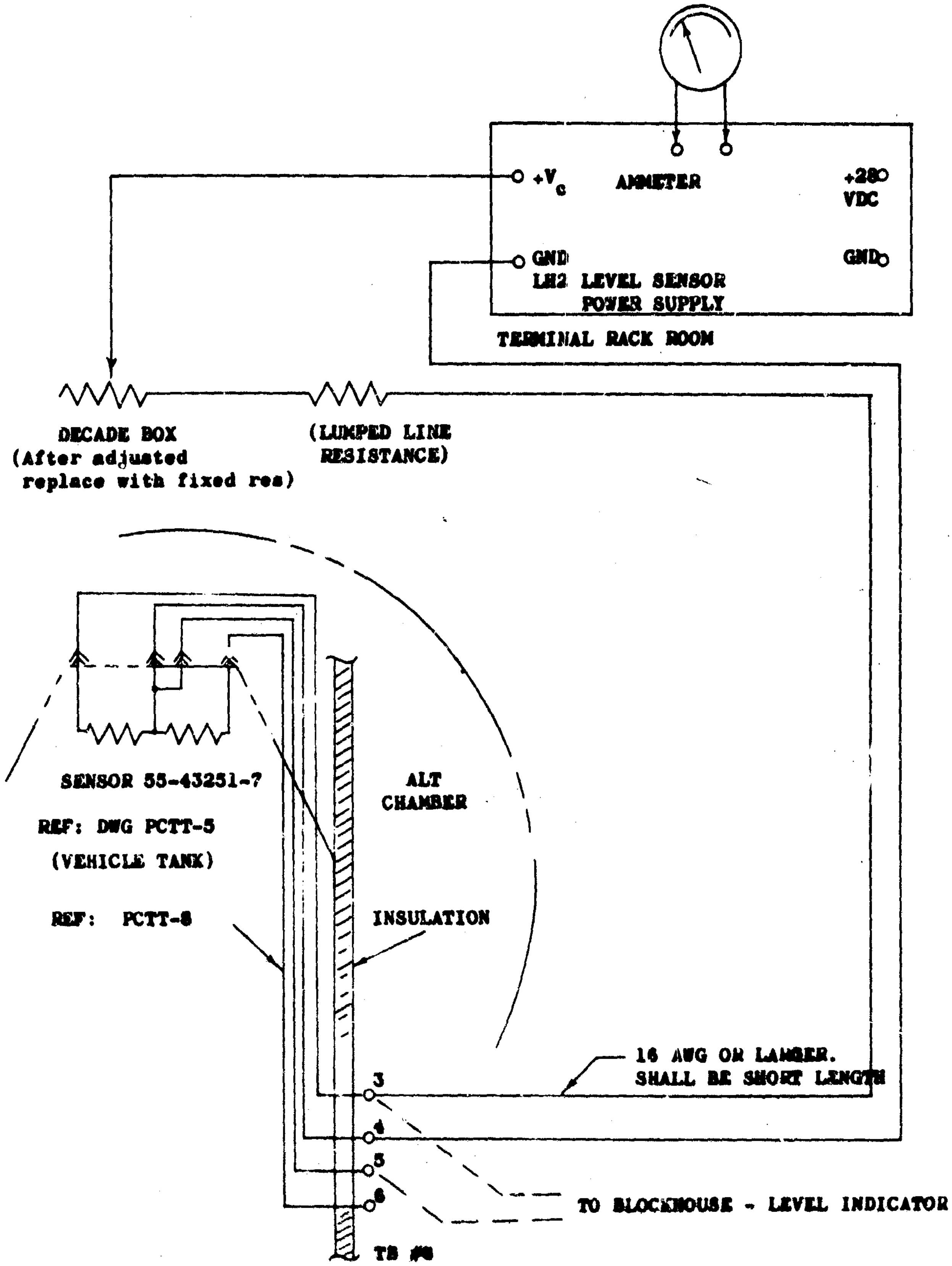


FIG. B-3 SENSOR POWER SUPPLY



THIS SCHEMATIC TYPICAL FOR BOTH SECTIONS (A&B) OF THE LIQUID LEVEL SENSOR CONTROL UNIT

FIG. B-3 SENSOR POWER SUPPLY SCHEMATIC DIAGRAM



LH2 LEVEL SENSOR TEST SET-UP FIGURE B-4

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13. ABSTRACT

Presented are results of a program to modify an available Centaur tankage system for testing in the Air Force Rocket Propulsion Laboratory Space Environmental Simulation Chamber to determine its thermodynamic suitability for space storability. Results of a detailed thermal analysis predict equilibrium propellant tank net heat rates of 42.09 BTU/hr for the LH_2 tank and 14.56 BTU/hr for the LN_2 tank with corresponding respective boil-off rates of 0.218 lb/hr and 0.169 lb/hr.

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