SUPER INSULATION SYSTEMS FOR CRYOGENIC TEST TANK

FINAL REPORT

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NATIONAL AERONAUTICS & SPACE ADMINISTRATION
GEORGE C. MARSHALL SPACE FLIGHT CENTER
HUNTSVILLE, ALABAMA 35812

Prepared by:

C. R. Lindquist
Linde Division
Huntsville, Alabama - 35801

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UNION CARBIDE

UNION CARBIDE CORPORATION
LINDE DIVISION
CRYOGENIC PRODUCTS DEPARTMENT

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1.0 INTRODUCTION AND SUMMARY:

1.1 Background:

Long term space storage of cryogenic fluids, particularly hydrogen, necessitates the development of high quality insulation systems. Linde Division of Union Carbide Corporation has developed such a concept consisting of alternate layers of radiation shields and fibrous spacers maintained in a high vacuum environment for commercial applications and has utilized such systems in commercial containers. In order to develop the means of applying this technology to aerospace tankage and to train NASA personnel in the techniques involved, Linde entered into Contract NAS 8-11740 with NASA Marshall Space Flight Center.

In a typical commercial application the required vacuum environment is maintained within a rigid metal vacuum casing. This prevents air in-leakage so that vacuum can be maintained for periods up to ten years, and also prevents any compression of the insulation materials. For flight applications, however, weight considerations preclude the use of a heavy casing so that a light weight flexible jacket is preferred. This approach allows a bearing pressure of one atmosphere on the insulation system during the relatively short ground hold period, but when this pressure is removed during space flight, the insulation system thermal performance will approach the ideal for these Super Insulation systems. Thus, a combination of good ground hold condition with near optimum space performance is effected without the evacuation problem attached to purged systems.

Prior to embarking on this program, the compressed insulation concept had been tested on several occasions. These included in-house funded efforts by Linde as well as contracts NAS 3-2165 and NAS 8-11041 under NASA funding. While most of these programs did not provide sufficient data for thorough analysis of the insulation performance in space because of high extraneous heat sources of poor vacuum several conclusions could be reached. Most importantly, the in-space performance appeared to be very attractive if the problem of maintaining vacuum without undue restriction of the insulation recovery could be solved. It was also apparent that some application concepts which were applicable to commercial tankage would not apply for cases where the insulation would be compressed for long periods of time.

The current program's purpose was to develop the necessary technology to utilize existing materials for Super Insulated space tankage, to train NASA personnel in the manufacturing techniques involved and to demonstrate the ground hold and space flight performance of such a system applied to a NASA provided 105-inch diameter tank.

This Final Report for Contract NAS 8-11740 describes the development work performed in conjunction with this program as well as performance data previously determined by Linde in in-house funded development programs. The application techniques employed and the test results utilizing a 105 inch diameter tank are described.

1.2 RESULTS

As conducted, this program can be divided into several phases: development test, design, application and test of the 105-inch diameter test tank. The more important results are presented here with details in the sections which follow.

After surveying several available candidate flexible laminate materials for the vacuum jacket over the insulation, a laminate of 1 mil Mylar - 0.8 mil lead - 1 mil Mylar was found to be satisfactory. It was shown that this material both as received and after severe flexing demonstrated a helium gas permeability of less than $5 \times 10^{-10} ft^3 \cdot ft^2$ atmos. consistently. This was considered acceptable for the evacuated insulation system as well as for a gas purged insulation.

It was also found that this jacket laminate is readily formed into curved geometries (such as hemispheres for bulkhead jackets) by evacuating into a female die. The bulkhead jackets for the 105-inch diameter test tank were formed in this manner.

Schjeldahl GT-200 liquid adhesive was found to be satisfactory for joining with a heat sealer where the joint would never be subjected to cryogenic temperatures. It was also useful for patching damaged areas of the jacket. DuPont Adiprene L-100 adhesive was found to be satisfactory for making joints between the jacket material and the tank wall subjected to cryogenic temperatures. This feature was necessary for the original design of the 105-inch diameter test tank, although the "cold joint" was eliminated in the system finally tested. Armstrong A-12 adhesive was found useful for repairing minute vacuum leaks.

Previous data were surveyed and tests were conducted to determine the vacuum conductance and outgassing characteristics of the Super Insulation system material. Preprocessing by heating at 300°F for 30 hours is recommended for the materials prior to application. The completed insulation system should be heated to 200°F during evacuation to hasten outgassing and to reactivate the Molecular Sieve. An evacuation time of less than fifty hours to 100 microns Hg were predicted for the 105-inch tank provided the materials were outgassed and no leaks were present. Actual experience bore out this prediction after vacuum leaks had been repaired. It was found advisable to perforate the radiation shields under the vacuum gauge and evacuation ports. Several methods of perforating were investigated.

Analysis indicated that the insulation system would be self supporting (i.e. would not telescope or come apart) if each individual radiation shield were made a structural entity by taping it together with adhesive tape. While this envelope method of support appeared satisfactory to withstand boost acceleration loads, a spring loaded cinch band support system was designed as a backup. This, however, was not used because it was not considered necessary and because of the additional complexity.

Small scale thermal tests were conducted to permit prediction of the thermal performance of the 105-inch diameter test tank. The small scale tests indicated a thermal conductivity of 3.5×10^{-5} Btu/hr-ft°F at a layer density of 95 layers/inch could be achieved. However, these tests did not simulate the long term compression and rigors of handling and repair to which the 105-inch diameter tank was subjected.

An insulation system, the details of which are described in Appendix 1, was designed for the 105-inch diameter test tank. The radiation shields (aluminum foil) and spacers (106 Dexiglas paper) were spiral wrapped onto the cylindrical portion of the tank. Bands of aluminum foil and fiberglass paper were used to control layer density. Circular discs of both materials were used for the bulkheads and were interleaved with the cylindrical insulation. Individual layers were bonded together with adhesive tape. The penetrations were spiral wrapped with two inch wide strips of aluminum foil and fiberglass paper. Gaps were filled with opacified paper.

The cylindrical portion of the vacuum jacket was formed of flat sections bonded together and wrapped around the tank as described above. The bulkheads were vacuum formed to a hemispherical shape. The penetrations were covered by rigid metal jackets joined to the flexible jacket by O-ring seals. As originally designed, the flexible jacket was bonded to the tank wall around the manhole and a separate vacuum panel was installed over it to permit access to the tank. However, a hydrogen leak under the manhole blew off the insulation during simulated environment testing and this feature was abandoned.

Because of vacuum leaks, primarily from mechanical components such as O-ring seals, solder joints, weld joints, etc. rather than from the flexible jacket, evacuation proved to be an extremely tedious task. It is quite likely that moisture in the insulation and on the Molecular Sieve contributed to the problem. It was discovered that in areas of high stress such as where compression of the insulation near the rigid penetration jackets stretched the flexible jacket, delamination occurred. The area under the jacket had to be built up with fiberglass spacer material.

Four tests in the space environment on the 105-inch diameter test tank were conducted and the data are summarized and compared with the predicted results below:

Test No. C-012	29	30	31	34	Predicted
Precondition In-sulation)	Evacuated	Ambient Helium Purge	High Temp. Helium Purge	High Temp. Helium Purge	Evacuated
Vented Boiloff (#/hr.)	1.8	2.0	0.9	1.2	1.0
Total Flowrate (#/hr.)	1.8	2.0	6.0	7.7	1.0
Fill Line	Closed	Closed	Leaking	Leaking	Closed
Apparent Layer Density (Layers/inch)	120	125	-	-	95
Apparent Thickness (Inches)	0.59	0.56	-	-	0.78
Apparent Thermal Conductivity (Btu/hr-ft°R)	7.3×10^{-5}	8×10^{-5}	-	-	3.5×10^{-5}

It will be noted that good data were obtained from the first two tests with the insulation pre-evacuated and with the ambient temperature helium gas purge prior to the test. It was felt that better vacuum conditions might be obtained if warm helium gas were used to drive off any residual moisture. However, in two attempts to conduct that test, the fill valve was found to be leaking, and the data are included only for completeness and no conclusions are drawn from these latter two tests.

Data were obtained from two ground hold tests resulting in boiloff rates of 33 lbs/hr and 32 lbs/hr, considerably higher than the predicted rate of 22.5 lbs/hr. Apparently due to a high residual gas pressure although creep in the insulation thickness may also have contributed. The measured value of thermal conductivity was thus about 70×10^{-5} Btu/hr-ft°R.

1.3 CONCLUSIONS AND RECOMMENDATIONS

1.3.1 General

The concept of alternate layer Super Insulation for long term storage of cryogenic propellants in space is attractive from the thermal performance standpoint.

A lighter weight system could be achieved by replacing the aluminum foil radiation shields with an aluminized plastic.

Further development of spacer materials should be conducted to achieve less degradation due to compression and to achieve better handling properties.

The fabrication techniques employed for the 105-inch diameter tank are feasible although expensive. Improvements can be made with minor degradation of performance.

1.3.2 Preevacuated Systems

Flexible vacuum jacket manufacture is feasible, but greater ruggedness is desirable. Areas of high stress must be avoided.

A preevacuated insulation system can be utilized, but must be limited to small tankage because of the difficulties of evacuation and leak detection.

The measured performance of a preevacuated system in the ground hold condition is better than the predicted performance of a helium purged system.

1.3.3 Purged Systems

A purged insulation system is easier to fabricate and is as effective in space as a preevacuated system, but it suffers from the added complexity of purging and venting.

2.0 THEORETICAL ANALYSIS AND REVIEW OF THE STATE OF THE ART:

When this program was initiated, a wealth of unpublished technical information regarding multilayer Super Insulations had been developed during Linde in-house funded development programs. These had been directed primarily toward ground tankage which was never intended to involve compression of the insulation materials. In addition, some experience was available from Linde and NASA funded insulation development programs regarding systems similar to the one being investigated here. From time to time as specific problems arose and this program was redirected, rather extensive surveys of these data were conducted and reported. Although most of this information can be classed as non-subject data, it is included here to bring the reader up to date with the state of the art, and to provide a clearer understanding of the data obtained in this program and its application to the 105-inch diameter test tank insulation system design.

Four specific problem areas were included in this review and analysis. These were: the thermal performance of the insulation system after relaxation of the external compressive loading, support of the insulation when it is uncompressed, vacuum integrity and thermal effects of the flexible jacket, and pretreatment and evacuation criteria for the insulation materials.

2.1 Thermal Performance of Linde Super Insulation:

The most commonly used of the Linde Super Insulations, and the one for which the greatest amount of technical data and fabrication experience is available is that system consisting of aluminum foil radiation shields and 2-mil fiberglass paper spacers. While it is fully realized that these materials are by no means optimum for this application which requires compression and relaxation of the insulation under atmospheric loading, it has been chosen for this application because of the availability of the data necessary for performance prediction and fabrication. This system for commercial applications has been designated Linde SI-62.

During in-house funded development programs, Linde has determined the thermal conductivity of SI-62 as a function of initial layer density by a number of methods. These data, both experimental and calculated are shown on Figure 1. These do not include any effect of compression cycling. Late data by independent investigators essentially corroborate these data.

Considerable scatter of data will be noted in the results obtained with flat plate testers at layer densities below 120 layers/inch which corresponds to a thermal conductivity of 5×10^{-5} Btu/hr-ft-°R. This may be attributed to edge effects inherent with a flat plate calorimeter such as radiation between the radiation shields of the sample and the wall of the test chamber. The minimum layer density point for the flat plate test data at a layer density of 95 layers/inch corresponds to the minimum layer density obtainable for these materials layered up in a stack so as to be compressed only under their own weight. The data presented in Figure 1 agrees quite well with predictions for cylindrical calorimeters at low layer density (less than 120 layers/inch) and for flat plate calorimeters at high layer density (above 120 layers/inch).

2.1.1 Effects of Compression - Relaxation Cycling:

In order to determine the effects of compression of Super Insulation by a one atmosphere load, followed by relaxation of that load, Linde constructed the apparatus shown schematically in Figure 2. This small scale apparatus consisted of an inner vessel 7 inches in diameter and about two feet long onto which the insulation

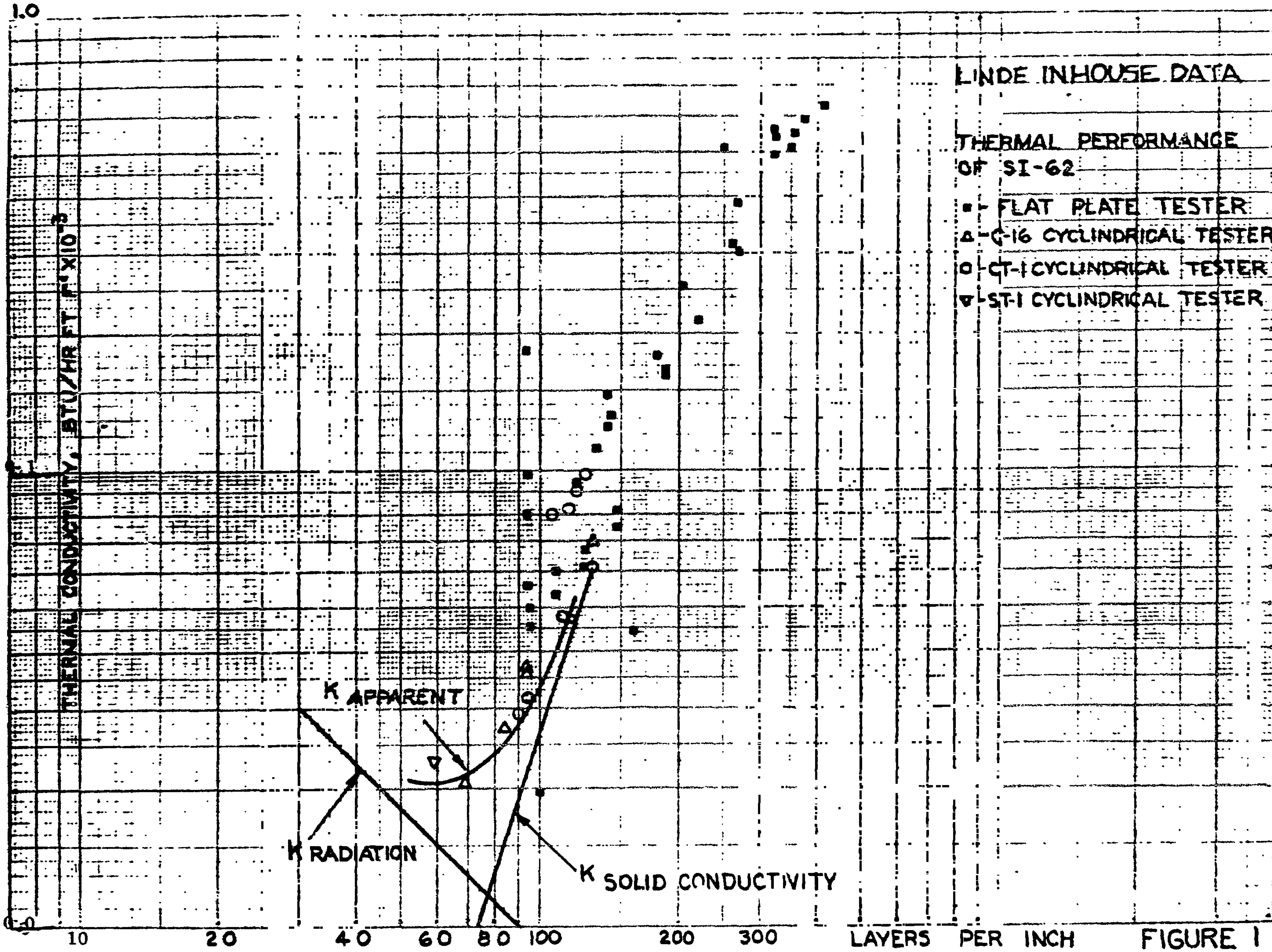

LINDE INHOUSE DATA
THERMAL PERFORMANCE OF SI-62
■ - FLAT PLATE TESTER
△ - C-16 CYCLINDRICAL TESTER
○ - CT-1 CYCLINDRICAL TESTER
▽ - ST-1 CYCLINDRICAL TESTER
THERMAL CONDUCTIVITY, BTU/HR FT F° X10^{-3}
1.0
0.1
0.0
10
20
40
60
80
100
200
300
LAYERS PER INCH
K APPARENT
K RADIATION
K SOLID CONDUCTIVITY

FIGURE 1

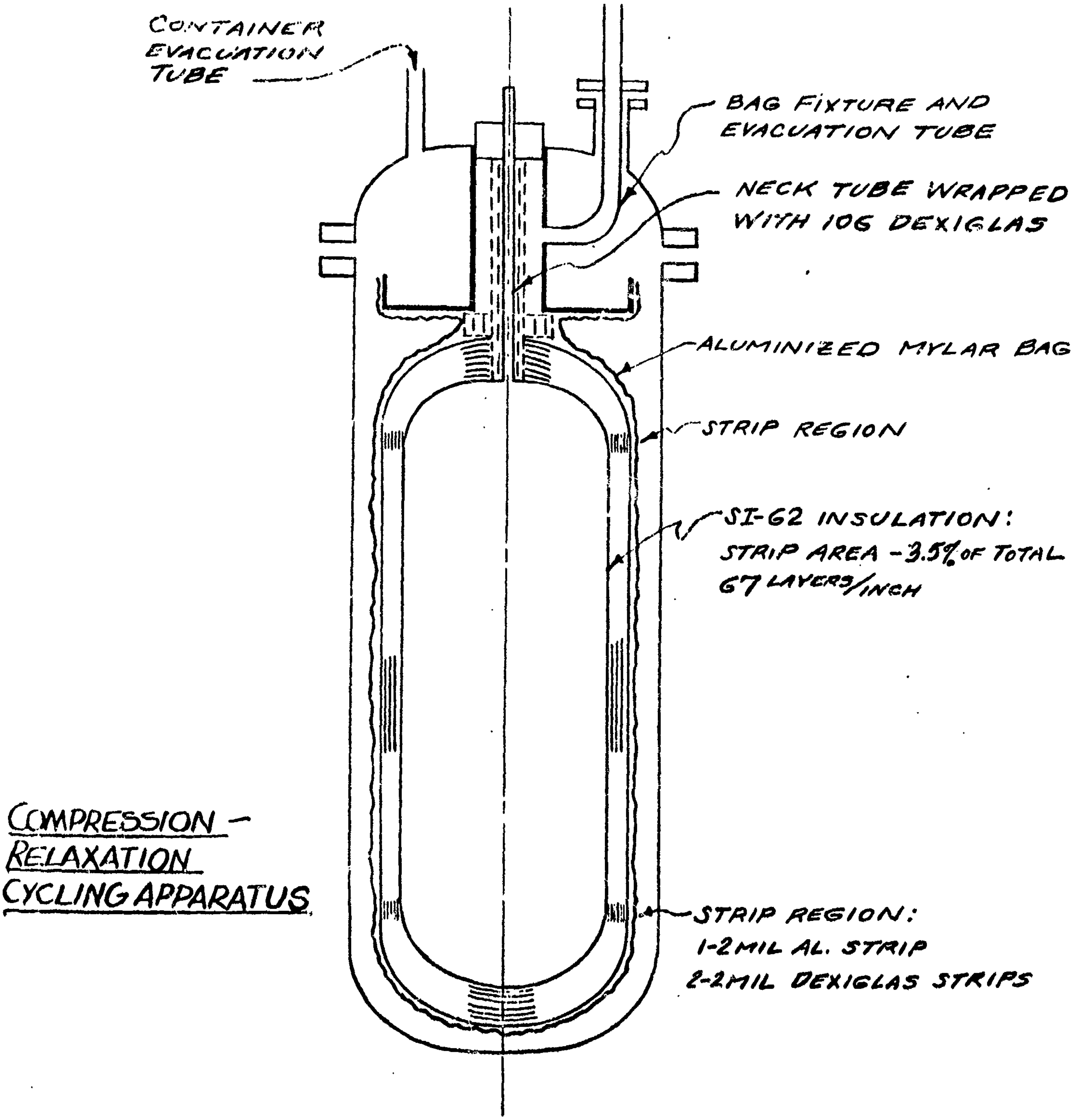

CONTAINER EVACUATION TUBE
BAG FIXTURE AND EVACUATION TUBE
NECK TUBE WRAPPED WITH 106 DEXIGLAS
ALUMINIZED MYLAR BAG
STRIP REGION
SI-62 INSULATION: STRIP AREA -3.5% OF TOTAL 67 LAYERS/INCH
COMPRESSION - RELAXATION CYCLING APPARATUS
STRIP REGION: 1-2 MIL AL. STRIP 2-2 MIL DEXIGLAS STRIPS

FIGURE 2

TABLE I

RESULTS OF SMALL SCALE COMPRESSION - RELAXATION TESTS

Run Number		70	83
Initial Layer Density		92.5	139
Initial Thickness		0.4"	0.61"
Heat flux before compression (Btu/hr-ft²)	(Q_1/A)	0.28	0.29
Heat flux after recovery (Btu/hr-ft²)	(Q_2/A)	0.29	0.31
Thermal recovery	(Q_2/Q_1)	1.04	1.06

was wrapped. The insulation was encased in a light, flexible plastic jacket and the apparatus inserted in a vacuum chamber with provision for evacuating the insulation and the chamber separately. Typical test data are shown on Table 1. Heat flux measured after compression cycling varied by only a few percent from that experienced before compression. Although the apparatus did not permit monitoring of layer density variations during cycling, it is estimated that the final layer density was in the order of 100 to 130 layers per inch.

Linde next demonstrated the feasibility of the compressed insulation concept in hydrogen service utilizing a 10-foot long tester available under another in-house funded program. High heat in-leakage at the ends precluded measurement of the system, thermal performance in the relaxed condition, but layer density as a function of bearing pressure was obtained as shown in Figure 3 and reported in "Advances in Cryogenic Engineering, Volume 8." The insulation was initially applied at a density of 110 layers per inch and it recovered to 152 layers per inch repeatedly. This high recovered layer density is attributable in part at least to permanent wrinkles in the heavy Mylar-aluminum-Mylar laminate jacket material.

Another large scale apparatus was insulated by Linde and tested by NASA, Lewis Research Center. This particular program was partially NASA funded and was reported in "Advances in Cryogenic Engineering, Volume 9." The test results and a schematic diagram are shown in Figure 4. The thermal performance obtained could be explained by an insulation interstitial pressure of 5 microns Mercury which was quite likely under the test conditions.

From these tests, one may conclude that the insulation layer density after compression cycling will be higher than originally applied, but that the heat flux will not be seriously increased. This anomaly may be explained by a shift in the solid conduction versus layer density curve shown on Figure 1 caused by yielding of the fibers under compression and a change in contact resistance between the spacer and radiation shields. Further testing is required to measure and verify these effects.

2.1.2 Spacer Development:

The results of Linde in-house development tests were explored during this program to determine if a spacer material other than the 2-mil unbonded fiberglass paper were available within the state of the art, and about which enough data and experience were available to permit its recommendation for the 105-inch diameter test tank on the basis of physical recovery after compression cycling. Variables of interest for this application include thickness of spacer, size of fiber, fiber material, fiber orientation, and binder contact and type.

In general, a thicker spacer than the nominal 2 mil would have a higher radiation component of thermal conductivity, but its recovery characteristics might be improved. This variable is discussed in section 3.3 below. Two mils is the thinnest producible paper using Number 106 fibers without resort to a binder which might increase out-gassing problems and increase solid conduction. Man-made fibers offer better structural properties than fiberglass but tend to increase outgassing.

The following is a listing of some spacer materials tested by Linde with pertinent comments regarding each:

1. Dull Viscose Rayon - open weave sheet composed of rayon fibers with a binder. This material is difficult to evacuate because of outgassing of

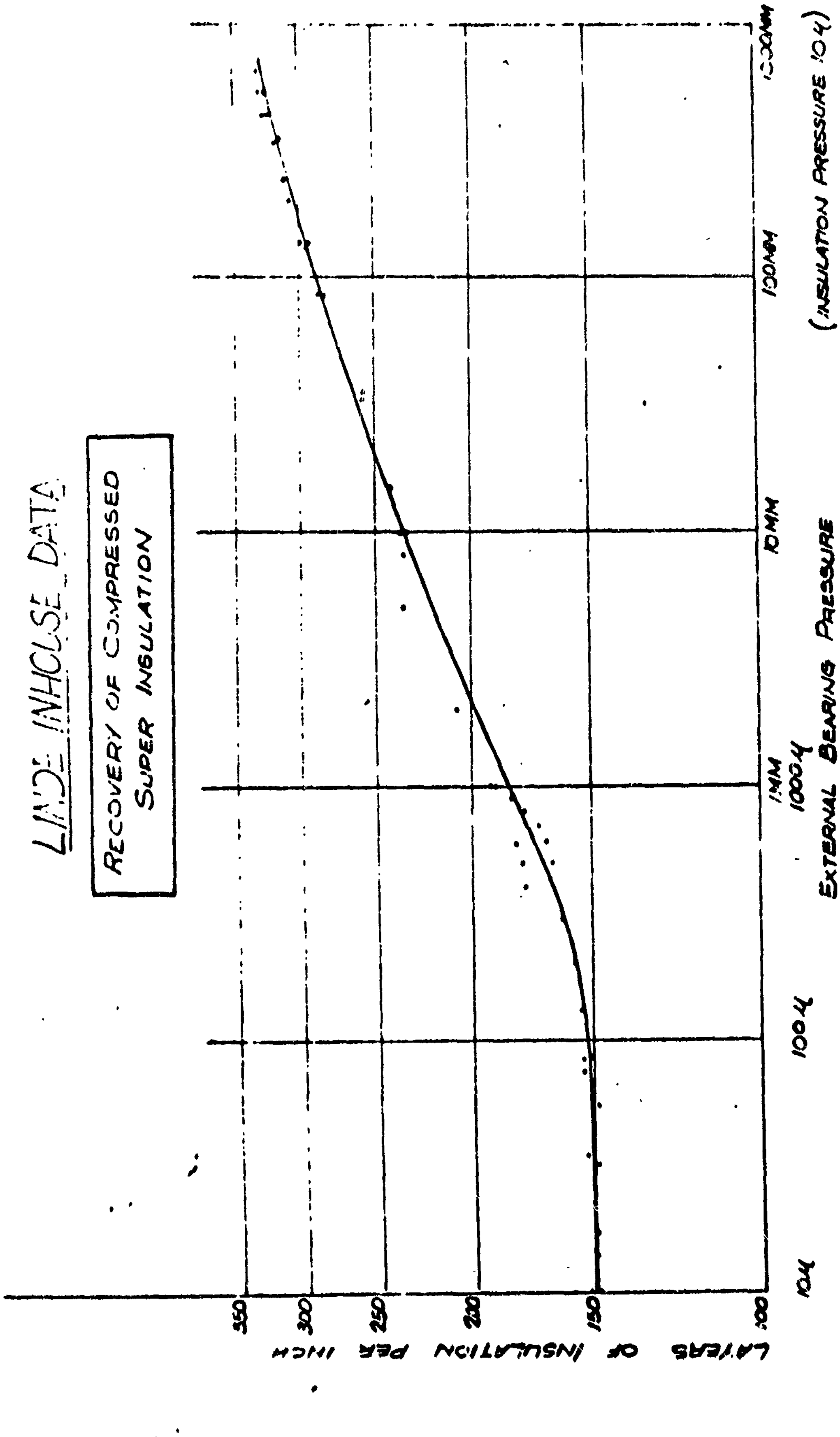
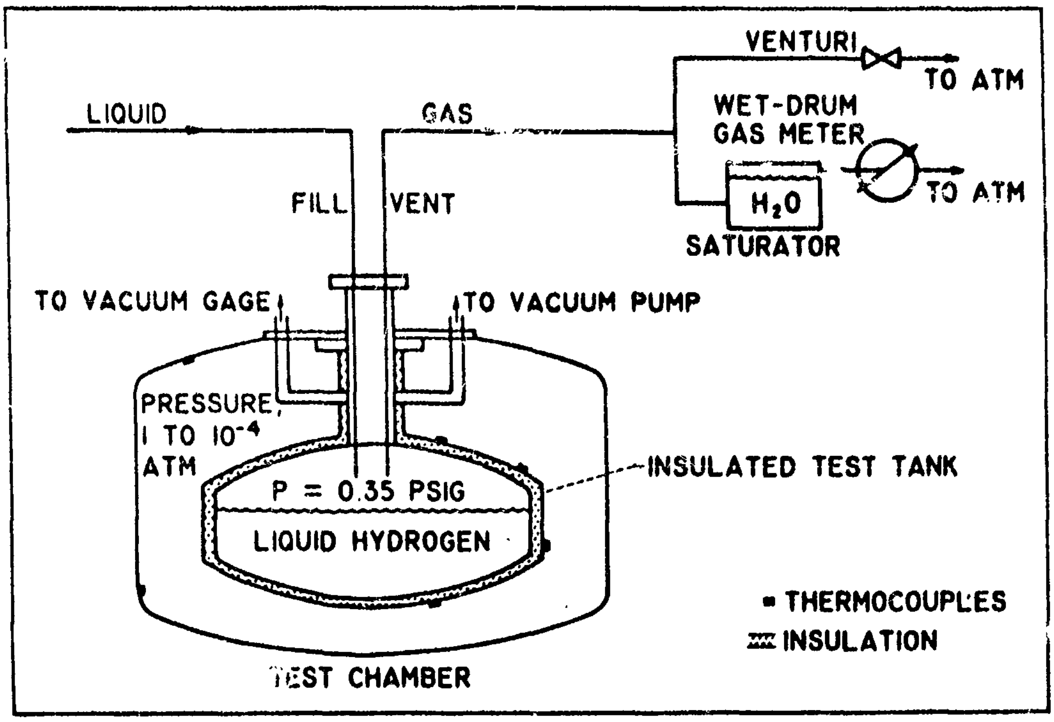

LINDE INHOUSE DATA
RECOVERY OF COMPRESSED SUPER INSULATION
LAYERS OF INSULATION PER INCH
100
150
200
250
300
350
10μ
100μ
1MM 1000μ
10MM
100MM
1000MM
EXTERNAL BEARING PRESSURE
(INSULATION PRESSURE 10μ)

Figure 3



Test apparatus.

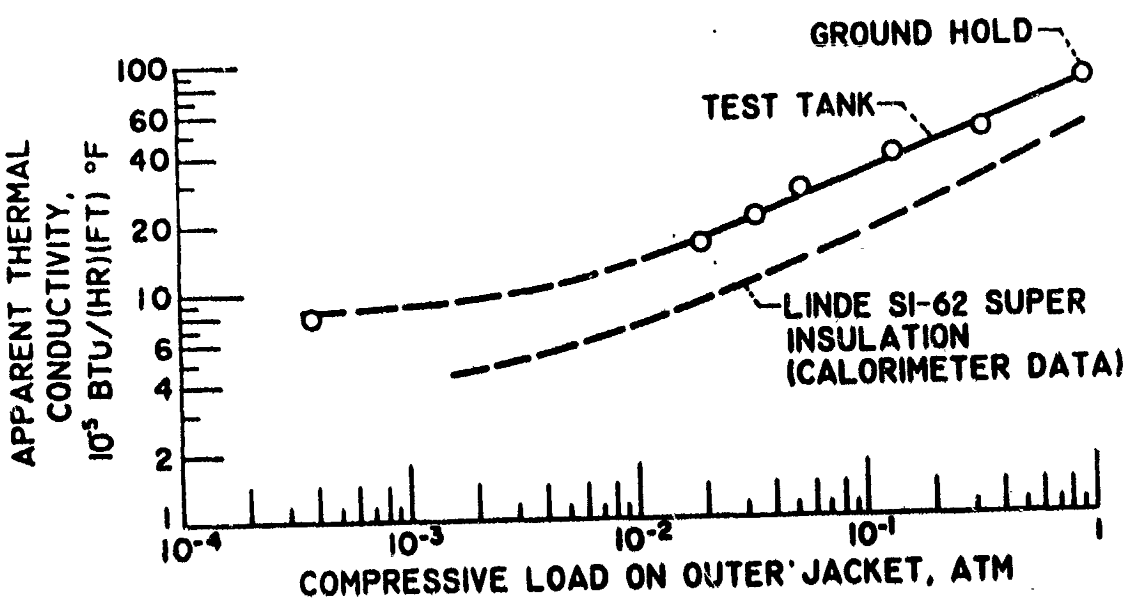


Fig. 4. - Apparent thermal conductivity as a function of compressive load on insulation.

the binder and is not compatible with oxygen. Its thermal performance when used with aluminum foil radiation shields is comparable to the 106 Fiberglass paper.

2. Dacron-Rayon Blend sheet composed of equal quantities of the two materials. Its thermal conductivity when used with aluminum foils was determined to be 5.5 x 10^{-5} Btu/hr-ft-°R.

3. Continuous weave Rayon - A thermal conductivity of 2.5 x 10^{-5} Btu/hr-ft-°R was measured using aluminum foil radiation shields.

4. Nylon - has a moisture adsorption an order of magnitude higher than Dacron which would make evacuation difficult.

Available data at the time indicated that of the commercial spacer materials, the 106 fiberglass paper would be adequate.

2.2 Insulation Support:

Although the Super Insulation system is completely encased within its flexible jacket, and thus is constrained from slipping off the tank under acceleration loads, it must be supported to prevent telescoping axially or sagging within the confines of the jacket. Either effect would cause compression and, hence, deteriorated performance over extensive areas of the insulation.

In order to maintain the desired layer density and prevent telescoping or sagging during manufacture, banded areas consisting of extra glass, paper, and heavy aluminum bands are wrapped with the insulation and held at a predetermined tension. When the insulation is compressed upon evacuation, however, the spacer material will creep, and this tension will be relaxed. Alternate support methods were, therefore, investigated.

From the standpoint of thermal performance, structural integrity of the insulation is best obtained by limiting compressed areas of the insulation to the smallest area possible. Account must also be taken of creep in the insulation material after long durations of compression. These considerations suggest a spring mechanism which will maintain compression in the banded areas of the tank as the tank cools down to liquid hydrogen temperature and the insulation is compressed by the atmosphere. Two such methods were investigated: spring loaded cinch bands and radial springs attached to a metal band. Designs for both approaches are shown in Figure 5. For reasons discussed below, cinch bands were recommended for the 105-inch diameter tank.

A more desirable system of support which does away with springs altogether has been termed the envelope method. In this method, the aluminum foil radiation shields are made integrally self-supporting by taping adjacent rolls of foil together as they are wrapped on the tank. Calculations supported by adhesive tape to aluminum strength tests indicate that only a small amount of tape would be required to hold the foils together, and that the glass would be self-supporting between the foils by friction in the band and overlap regions. The simplicity of this concept and its freedom from vibration problems and localized compression make it particularly desirable. It has been employed on the 105-inch tank design, but additional testing is needed on a large tank under conditions of high acceleration before it can be relied upon as the sole means of insulation support.

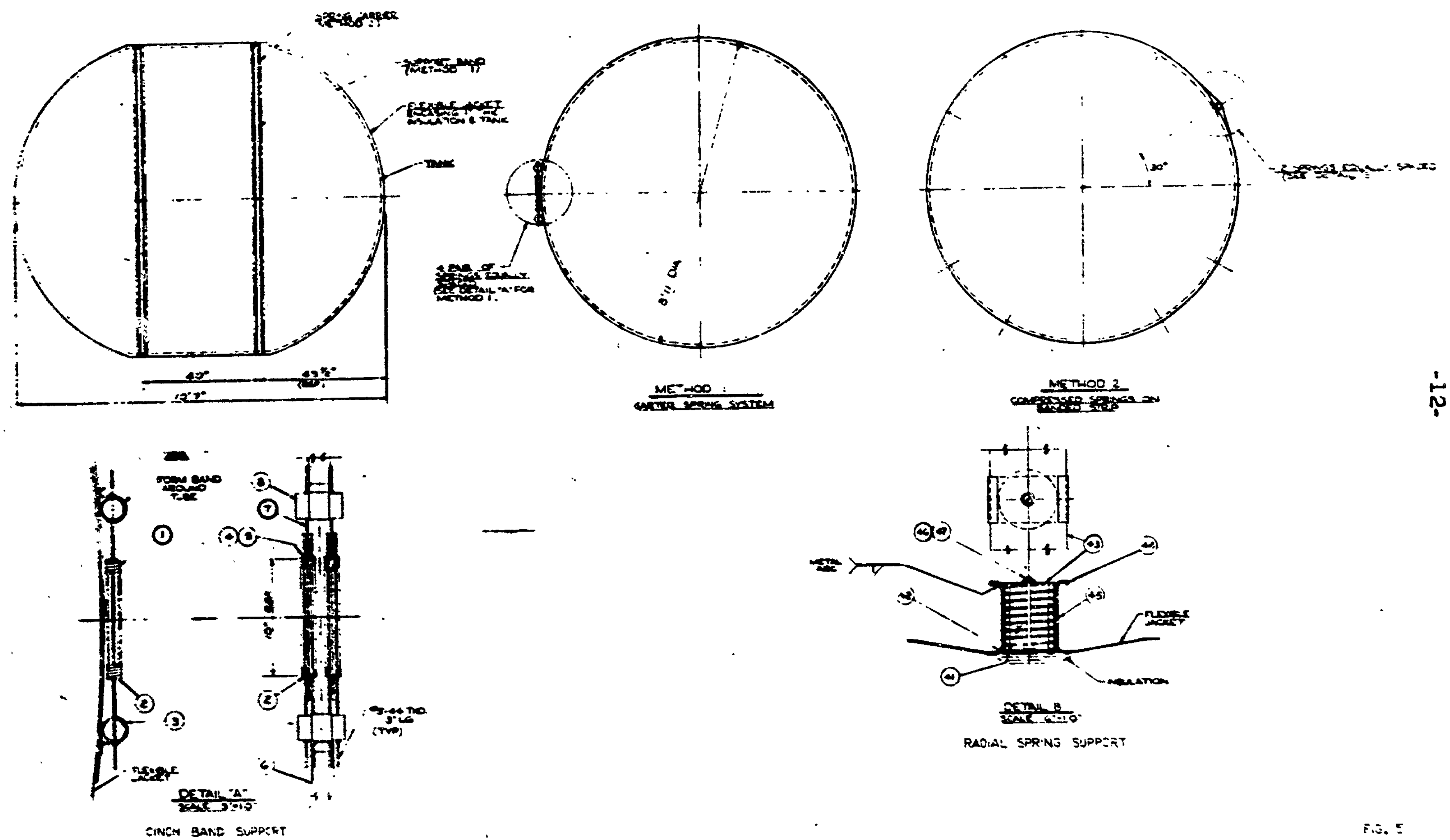

SUPPORT BAND (METHOD 1)
FLEXIBLE JACKET ENCLOSING THE INSULATION & TANK
TANK
49"
49 ½"
12'7"
4 PAIR OF SPRINGS EQUALLY SPACED SEE DETAIL "A" FOR METHOD 1.
METHOD 1
GARTER SPRING SYSTEM
METHOD 2
COMPRESSED SPRINGS ON BANDED STRIP
30°
FORM BAND AROUND TUBE
FLEXIBLE JACKET
DETAIL "A"
CINCH BAND SUPPORT
METAL
FLEXIBLE JACKET
INSULATION
DETAIL B
RADIAL SPRING SUPPORT

FIG. 5

2.2.1 Cinch Band Support:

The design of the cinch bands used for the 105-inch diameter tank is based on the premise that the bands must be spring loaded to a degree that the bands will maintain sufficient compression of the insulation that it cannot telescope when the inner tank has contracted when cooled to liquid hydrogen temperature and the spacer material has crept to the point where it has zero thickness (an obviously conservative assumption). The final design consists of four pairs of compression loaded springs located ninety degrees apart over both of the banded areas of the 105-inch tank. (See Figure 6) Dynamic considerations led to the recommendation of this method as preferred to the radial spring concept described below. The following calculations describe this design.

The weight of insulation and spring system is 188 lbs. The pressure under the band required to hold on the insulation under a 6 G load:

$$P = \frac{WG}{\mu A} = \frac{188\ (6)}{0.35\ (2)\pi(105)\ 1.75} = 2.8 \text{ psi}$$

Force required in cinch band:

$$F = Prt = 2.8\ (\frac{105}{2})\ 1.75 = 257 \text{ lb.}$$

Assuming 100 per cent creep (insulation thickness goes to zero) and allowing for thermal contraction of the tank, a circumferential change of 3.88 inches will result. Assuming a spring constant of 20 lbs/in, an additional initial loading of 78 lbs. will be needed for a total initial force of 335 lbs.

The spring system consists of 4 pairs of springs located 90 degrees apart on the tank.

For springs in series:

$$\frac{1}{K_T} = \frac{1}{K_P} + \frac{1}{K_P} + \frac{1}{K_P} + \frac{1}{K_P}$$

where K_T = total equivalent spring constant
K_P = equivalent K of a pair of springs
$\therefore$ $K_P = 4\ K_T = 4\ (20) = 80$ lb/in.
K_S = K of each spring $= \frac{80}{2} = 40$ lbs/in.

The total deflection Y of each compression spring is 16.75 inches.

Assuming a 1 inch diameter:

$$\text{The wire diameter} = \left[\frac{8FDK}{\pi S_D}\right]^{1/3} = \left[\frac{8(\frac{335}{2})\ 1\ (1.2)}{\pi 80{,}000}\right]^{1/3} = 0.1855 \text{ in.}$$

$$\text{And the number of active coils} = \frac{YGd^4}{8\ FD^3} = \frac{16.75\ (11.5)\ 10^6\ (0.1855)^4}{8(\frac{335}{2})\ 1^3} = 171 = i$$

The solid length = $(i + 8)\ d$ = 33.2 in. total length.

If standard spring diameter wire is used with d = 0.1920 in., the stress induced in the wire would be 73,000 psi and the number of active coils would be 50 coils/spring. The actual solid height is now 10 in.

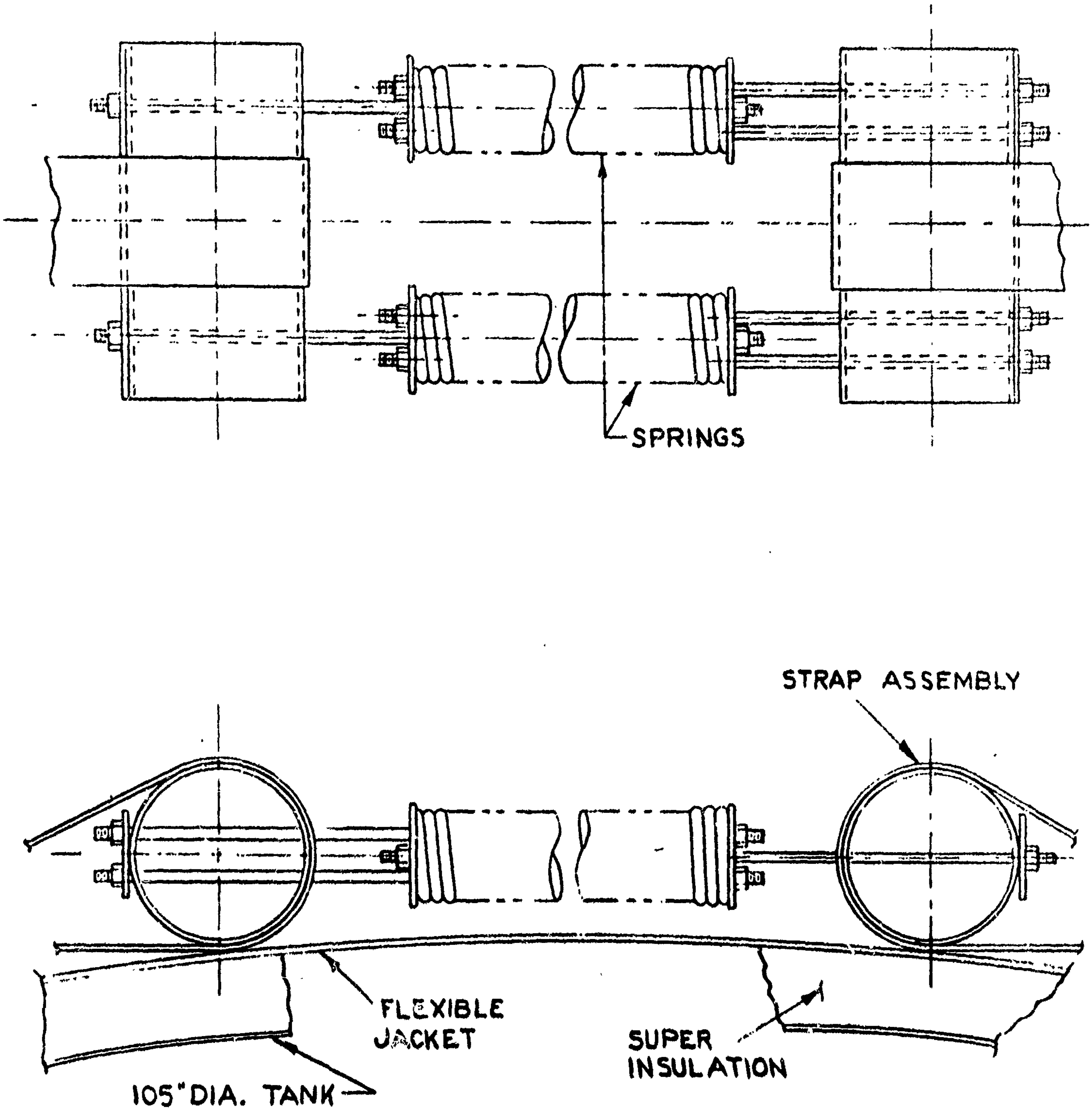


FIGURE 6
CINCH BAND SPRING SYSTEM DESIGN

The natural frequency $= 8.84 \sqrt{\frac{K_s}{W_s}} = 8.84 \sqrt{\frac{40}{1.323}} = 48.5$ vps

$W_s = \frac{\pi}{4} (0.1920)^2 \pi (1)\ 52\ (0.28) = 1.323$ lb.

Results (compression spring used in tension, Figure 6):

D = 1 in.
d = 0.1920 in.
active coils = 50
K = 40 lb/in.
solid height = 10 in.
maximum force = 168 lb.
minimum force = 129 lb.
material: oil tempered spring steel U.S. 120,000 psi

Dynamic tests of the cinch spring configuration shown in Figure 6 were conducted for NASA by Wyle Laboratories, Huntsville, Alabama under the conditions listed in Table 2. No damage to the insulation or the spring system was incurred.

2.2.2 Radial Spring Support:

The concept of radial springs located over the banded areas of the tank insulation and connected by a spring carrier band as shown in Figure 5 has been applied to large commercial tankage subjected to high acceleration loading. This concept was analyzed for the 105-inch diameter tank, but consideration of the effects of the springs when subjected to the dynamic environment of the Saturn launch profile caused it to be discarded. The radial spring design was as follows:

Major spring diameter - 2 inches
Spring wire diameter - 9.2253 inches
Active coils - 9
Spring constant - 54 pounds/inch
Solid height - 2.4 inches
Maximum force (insulation fully recovered) - 159 pounds
Minimum force (insulation compressed) - 144.5 pounds
Spring material - oil tempered spring steel, yield strength 120,000 psi
Locate springs 30 degrees apart over insulation bands.

2.2.3 Envelope Method:

The envelope support method consists of making each layer of aluminum and glass a self-supporting entity which is strong enough to hang suspended from its own top head. In the case of the aluminum, this would be done by attaching adhesive tape at all joints in a given radiation shield. The glass would be supported at discrete areas bulked by the addition of excess spacer material, such as was originally proposed for banded insulation. Tests have shown that the glass paper is strong enough to support itself and that only a small amount of tape is necessary to support the aluminum sheets.

Weight of one layer of 1/4-mil aluminum foil:

$W = 300\ (144)\ 0.25\ (10^{-3})\ 0.1 = 1.08$ lb.

TABLE 2

DYNAMIC TESTS - CINCH BAND SPRING SUPPORT SYSTEM

Test	Frequency	Range	Notes
Sine Wave Sweep	5-20 cps	0.05" DA	Scan at 0.67 octaves
	20-155 cps	1.0 g peak	per minute, duration
	155-220 cps	0.0008" DA	ten minutes
	220-2000 cps	2.0 g peak	
Random	20-100 cps	6 db/octave	Duration - ten
	100-700 cps	0.05 g2/cps	minutes

Force required under a 6 G load:

$F = WG = 1.08\ (6) = 6.48$ lb.

By referring to Figure 7, it can be seen that one piece of 3/4 in. wide Scotch No. 600 tape with 4 in. of overlap would support this load.

Weight of one layer of 106 glass paper

$$W = 1.6\ \frac{\text{grams}}{\text{ft}^2}\left[\frac{300}{454}\right] = 1.06 \text{ lb.}$$

Force required under a 6 G load

$F = WG = 1.06\ (6) = 6.36$ lb.

The strength of 106 glass paper was experimentally found to be about 0.230 lb/in of width in the circumferential direction of the roll and about 0.082 lb/in of width in the longitudinal direction of the roll. Since the longitudinal direction is the one of interest, about 6.36 over 0.082 = 77.5 inches of circumference would be required to support each layer of 106 glass paper under a 6 G load. Since this is less (by a factor of 4) than the circumference of the tank, it is considered adequate.

The friction force available to hold adjacent layers of 106 glass paper is, assuming the wrapping pressure is 0.055 psi and the overlap is one inch:

$$F = PA\mu = 0.055\ (\pi 105)\ 1\ (0.35) = 6.36 \text{ lb.}$$

Since this force must only support the lower half of each layer (the top half being supported by the top head), a safety factor of two results and is considered adequate. Additional support is provided to the spacer material by the radiation shields.

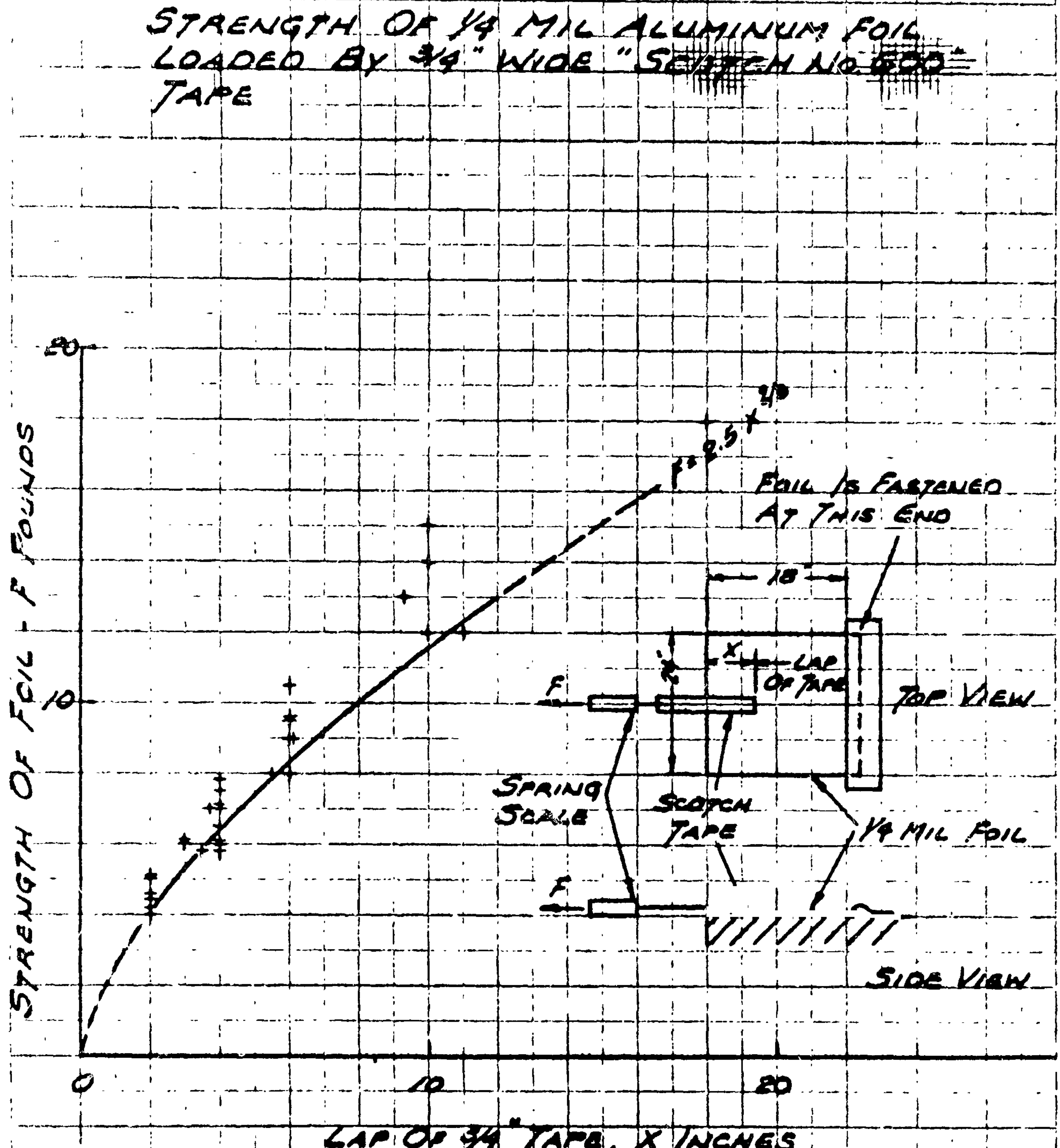
2.3 Flexible Jacket:

Attainment and maintenance of a suitable degree of vacuum is inherent to the success of any Super Insulation system. This aerospace insulation concept adds the further restraints that the jacket be able to flex down onto the insulation as it is evacuated, and then recover its shape to such a degree that the insulation performance is not hampered when the vehicle leaves the atmosphere. Light weight, too, is important.

These requirements suggest a plastic, metallized plastic, or plastic-metal foil laminate for the vacuum jacket. The requirement of flexibility suggests a thin materi[illegible] while the requirement of low permeability seems to be opposing. An investigatic[illegible] commercially available material was undertaken to find a material which would [illegible] in a suitable compromise between requirements.

2.3.1 Requir[illegible]nts:

The purpose of the vacuum jacket is to maintain vacuum on the launch pad from the time the evacuation equipment is cut off until lift-off. It was determined that a period of fifteen hours vacuum hold time is acceptable. The leakage rate then becomes a function of the amount of adsorbent and the allowable pressure level at lift-off. In order to enhance evacuation and be conservative, a permeability after flexing of less than 10^{-9} ft^{3}He/hr.-ft^2 was taken as the goal. A plot of permeability versus overall helium leakage rate for the 105-inch diameter tank



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TONAWANDA, N. Y.

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FIGURE 7

is shown in Figure 8 for comparison. The various properties of interest in surveying the available materials are listed below.

2.3.1.1 Permeability:

The flow of gases through a continuous pin-hole free plastic film is by permeation. In this process, the gas is dissolved in the film material on the high pressure side, is driven through the film by concentration gradient, and then comes out of solution on the low pressure side. The phenomenon may be described as

$$G = p \frac{A \Delta P}{t}$$

where G is flow rate in $ft.^3/hr.$
A is cross sectional area in $ft.^2$
Δ P is pressure difference in atmospheres
t is film thickness in mils
p is permeability in $ft.^3$-mil/$ft.^2$-hr.-atmos.

The permeability, p, is a strong function of the gas involved and the temperature. For purposes of evaluation, since the driving pressure force for this application will always be one atmosphere, and the film thickness will always be only a few mils, these units may be ignored in the evaluation. Similarly, the flexible jacket will be at near ambient temperature, and helium gas permeability is higher than that of other gases and convenient for test purposes, room temperature helium gas permeability may be accepted as the standard.

In theory, "permeability" through a plastic film - metal foil laminate is a combination of true permeation through the film material, and viscous or molecular flow through pin holes in the metal foil depending on the pressure level at the foil. For purposes of evaluation, it is sufficiently accurate, however, to evaluate laminates in the same manner as described above for films.

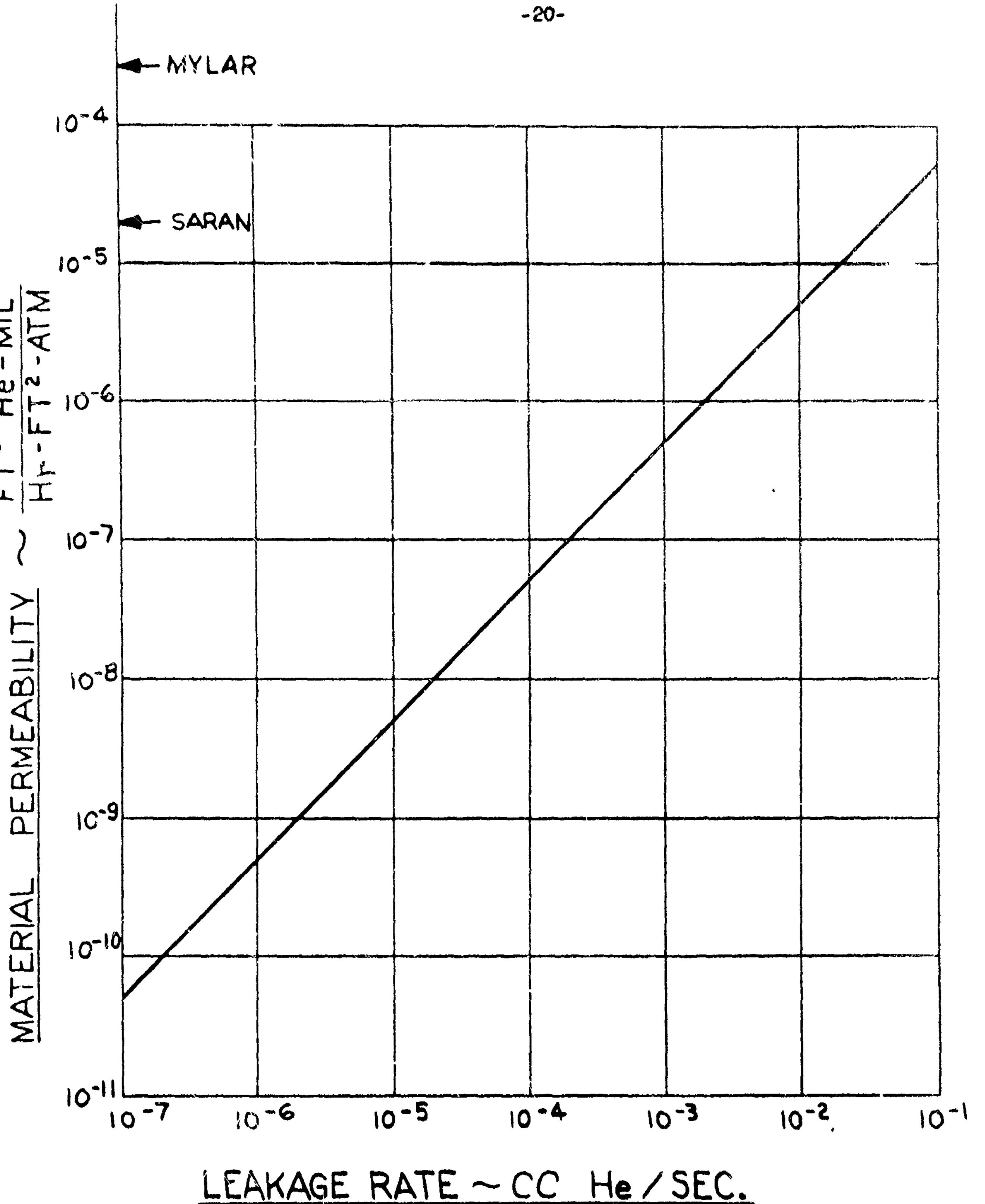
2.3.1.2 Strength and Flexibility:

Recovery of the insulation requires that the jacket material return to its original shape when the compressive load is removed without keeping a permanent set at the wrinkles. No data were available to indicate this property. In order to compare film and laminate candidates, therefore, it was necessary to employ an apparatus to induce wrinkles and measure the degree of recovery for comparable data between candidates. Permeability testing after flexure was also necessary, particularly for laminates to measure the degree of pin hole leaks induced. These tests are described below.

Other data of interest include tensile and flexural strength at room temperature and cryogenic temperature as well as cryogenic temperature flexibility. These are necessary to assess the material's ability to withstand stresses as around attachments to penetrations as well as the ability to withstand handling during manufacture and use.

2.3.1.3 Joinability:

Any practical vacuum jacket will be formed of more than one section and thus there will always exist a need for making vacuum tight joints. Preferrably, these joints should be made with a room temperature curing adhesive. However, techniques are available for heat sealing, and tooling for this purpose can be developed.



PERMEABILITY vs EQUIVALENT LEAKAGE
105 INCH TANK

FIGURE 8

In many cases, it will be necessary to join the flexible jacket to metal boundaries with a joint that has a certain amount of structural strength. Where available, such data have been included for adhesives.

2.3.1.4 Other Considerations:

Since there is always the possibility of liquid air running over the vacuum jacket, air condensing within the insulation in the case of a jacket or joint rupture, and liquid oxygen spills, liquid oxygen compatability is a desirable property. Data on outgassing is also important from the standpoint of vacuum attainment. In any aerospace application, weight is important, but in this case it may become secondary to other considerations since overall system weight reduction is the important goal.

Only available materials were considered since the program concept and schedule precluded the development of new films or laminates. The charts indicate the form in which the various candidate materials can be obtained commercially.

2.3.2 Material Evaluation:

Data for a number of available films, laminates, and adhesives are shown on the candidate charts of Table 3. These data have been taken from a myriad of sources including Linde in-house development tests and commercial literature and, therefore, are comparable only in order of magnitude in many cases. Review of the data, however, will indicate that plastic films alone would be too permeable to be attractive for this application. At the time these charts were prepared data were not available for metalized films, but the apparent superiority of laminates made them more attractive for further study considering schedule and budget restrictions.

The test program for jacket material selection is described in Section 3.1.1 below.

2.4 Super Insulation Evacuation:

Of equal importance with achieving a vacuum tight flexible jacket is the attainment and maintenance of the desired degree of vacuum within a reasonable time span. Attainment depends upon the flow of gases through the insulation materials and outgassing of these materials. Maintenance is achieved by the inclusion of adsorbent material within the vacuum system to adsorb in-leakage.

2.4.1 Available Experimental Data:

In the past, Linde, in in-house funded programs, has determined much of the information necessary to predict the vacuum performance of Super Insulation. Verification of these data by system test conducted during this program and application of the data to the design of the 105-inch diameter tank are included in later sections of this report.

2.4.1.1 Insulation Permeability:

In order to achieve vacuum, flow of the interstitial gas through a rather tortuous path through the fiberglass spacer material as it is compressed must be maintainted. For the viscous flow regime, the flow may be calculated by means of the D'Arcy equation:

$$V = \frac{a}{\mu}\frac{dp}{dx}$$

TABLE 3

CANDIDATE CHART

Films

MATERIAL	(Polyester) MYLAR	(Polyvinyl Floride) TEDLAR	POLYETHYLENE	(FEP Fluoro-carbon) TEFLON	(Polyamide) NYLON	POLYCARBONATE	POLYPROPYLENE	(Polyester) TERA FILM	H FILM	(Polyvinylidene-chloride) SARAN	(Fluohalo-carbon) ACLAR	(Polytrifluoro-chloroethylene) KEL-F
Weight, lb/ft^3	87	86	58	135	71	74	56				130	145
Availability	Rolls to 72 in. width	Rolls to 48 in. width	Rolls to 80 in. width	Rolls to 35 in. width	Rolls to 60 in. width	Rolls to 40 in. width	Rolls to 60 in. width		Exc.		Rolls	Rolls to 20 in. width
Thermal Conductivity Btu/hr-ft°R	-	0.073	0.194	0 .146	0.142	0.073	0.068				0.146	0.146
Cryogenic Temperature Flexibility	Exc.	Exc.	Poor	Good	P[illegible]r	Fair	Poor		Exc.		Good	Good
Outgassing	Good		Good	Good					Good		Good	Good
Liquid Oxygen Compatibility	Poor	Poor	Poor	Good	Poor	Fair	Poor		Poor		Good	Good
Liquid Hydrogen Compatibility	Good	Fair	Poor	Good	Poor	Fair	Poor		Fair		Good	Good
Weathering	Good	Good	Good	Exc.	Poor	Good	Exc.		Exc.		Exc.	Exc.
Flexural Strength lb/in^2		16000	6000		13000	12000			Good	6000		9000
Tensile strength lb/in^2	23000	8000	3000	3000	12000	9000	9000			4000+		5000
Joinability												
Adhesive joint	Yes	Yes	Yes but limited adhesive	Surface etching required	Yes	Yes	Yes					Surface treatment required
Heat sealed joint	No	Yes, also ultrasonic	Yes, also ultrasonic	Yes	Yes, also ultrasonic	Yes, also ultrasonic	Yes, also ultrasonic				Yes	
Operating Temperature	to 420°F		to 250°F	to 525°F	to 450°F		to 300°F				to 420°F	
Permeability $\frac{ft^3 \times 10^{-5} mil}{hr\ ft^2\ Atm.}$												Low
Helium	35.4	31.8	150.0	1410.0	-	-	162.0			13.2	70.0	
Hydrogen	21.2	12.3							42.4	6.0		
Nitrogen	0.212	0.053	29.0	76.	.354	5.9	6.8	1.37		.034		
Oxygen	0.635	0.635	90.0	208.	1.35	26.6	22.0	4.52		.42		
Carbon Dioxide	3.4	2.34	310.0	60.	3.3	33.4	67.5	12.33		1.29		
Air at 25°C	1.29											
Water Permeability $\frac{gram\ mil}{hr\ ft^2}$ at 100°F, 90% RH	.102	.166	.064	.028			.042	.108		.012		

TABLE 3

CANDIDATE CHART

Material	LAMINATES: Aluminum Mylar Laminate 1/4-mil Mylar-1/4-mil Al-1/4-mil Mylar	Alumiseal 1/2-mil Mylar 1-mil Al-1/2-mil Mylar	Lead - Mylar Laminate 1-mil Mylar-8-mil Pb-1-mil Mylar	Aluminized Mylar 2-mil Mylar Vapor Deposited Al.	Aluminized Mylar 1-mil Mylar Vapor Deposited Al, 500 A Thick	ADHESIVES: Schjeldahl GT-301 Polyester Adhesive	Schjeldahl GT-030 Polyester Adhesive	TEFLON	Epoxy Polyamides NARMCO 3135-7111	Epoxy Polyamides 3 M SC 1469	Dupont 46971	Schjeldahl Adhesive
Weight, lb/ft^3	114.	127.5	264									
Availability	Rolls	Rolls	Rolls			Rolls	Rolls	Rolls				
Cryogenic Temperature Flexibility	Good	Good	Exc.	Good		Good	Good	Good				
Outgassing	Good	Good	Good	Good								
Liquid Oxygen Compatibility	Fair	Fair	Fair	Fair		Good	Good	Good				
Liquid Hydrogen Compatibility	Good	Good	Good	Good		Poor	Poor	Good				
Weathering	Good	Good	Good	Good		Fair	Fair	Good				
Durability	Exc.	Exc.	Exc.	Exc.								
Joinability												
Adhesive Joint	Yes	Yes	Yes	Yes								
Heat Seal Joint	Yes	Yes	Yes	Yes		Yes	Yes	Yes				
Permeability $\frac{ft^3 \times 10^{-5}\ mil}{hr\text{-}ft^2\ atm}$												
Helium		.15	.055	1.83								
Hydrogen					.57							
Air Lap Joined 72 hr at 10^{-4} mm hg											.81	
Air Butt Joined 72 hr at 10^{-4} mm hg												.74
Sealability (Ease of Repair)						Good	Good	Poor				
Joint Flexibility						Good	Good	Good				
Cold Joinability						Good	Good	Good				
Shear Strength Tests												
302 SS to 4-mil Tedlar 1 in. wide joint, 1 in. lap												
at 75°F, psi									1170	1100		
at -423°F, psi										1030		
302 SS to 5-mil Mylar 1 in. wide joint, 1 in. lap												
at 75°F, psi									1300	200		
at -423°F, psi									1170	1200		

where V is apparent velocity, ft./hr.
a is permeability of the porous material, $ft.^2$
μ is fluid viscosity, $lb.-hr./ft.^2$
$\frac{dp}{dx}$ is pressure gradiant, $lb./ft.^2/ft.$

Permeability as defined here is not to be confused with permeability as a rate of diffusion used to describe passage of gas through plastic films. As used here, permeability is a property only of the pourous medium, and is independent of the fluid considered. The customary unit of permeability is the D'Arcy defined as 1 D'Arcy = $1.026 \times 10^{-11} ft.^2$

The absolute value of permeability through the spacer material is dependent upon fiber size, fiber orientation, fiber spacing, and any binder included. Experience has indicated that it is independent of temperature within the limits of experimental accuracy.

The viscous flow permeability of the 2-mil glass spacer has been measured experimentally during Linde in-house programs at three layer densities:

Layer Density	Permeability
60 layers/inch	1540 D'Arcys
80	560
100	256

By plotting these data on log-log paper, one finds that the points fall on a straight line which would be expected from viscous flow theory. The data may then be extrapolated to the 330 layers/inch corresponding to compressed insulation, and a value of 3.6 D'Arcys is determined.

Data are available for the molecular and transition flow regines only at 88 layers/inch. These are shown on Figure 9 for the system of 2-mil fiberglass spacers and aluminum radiation shields for the range 15 to 2000 microns of mercury. One would expect this conductance to vary inversly as the cube of the layer density.

2.4.1.2 Outgassing of Materials:

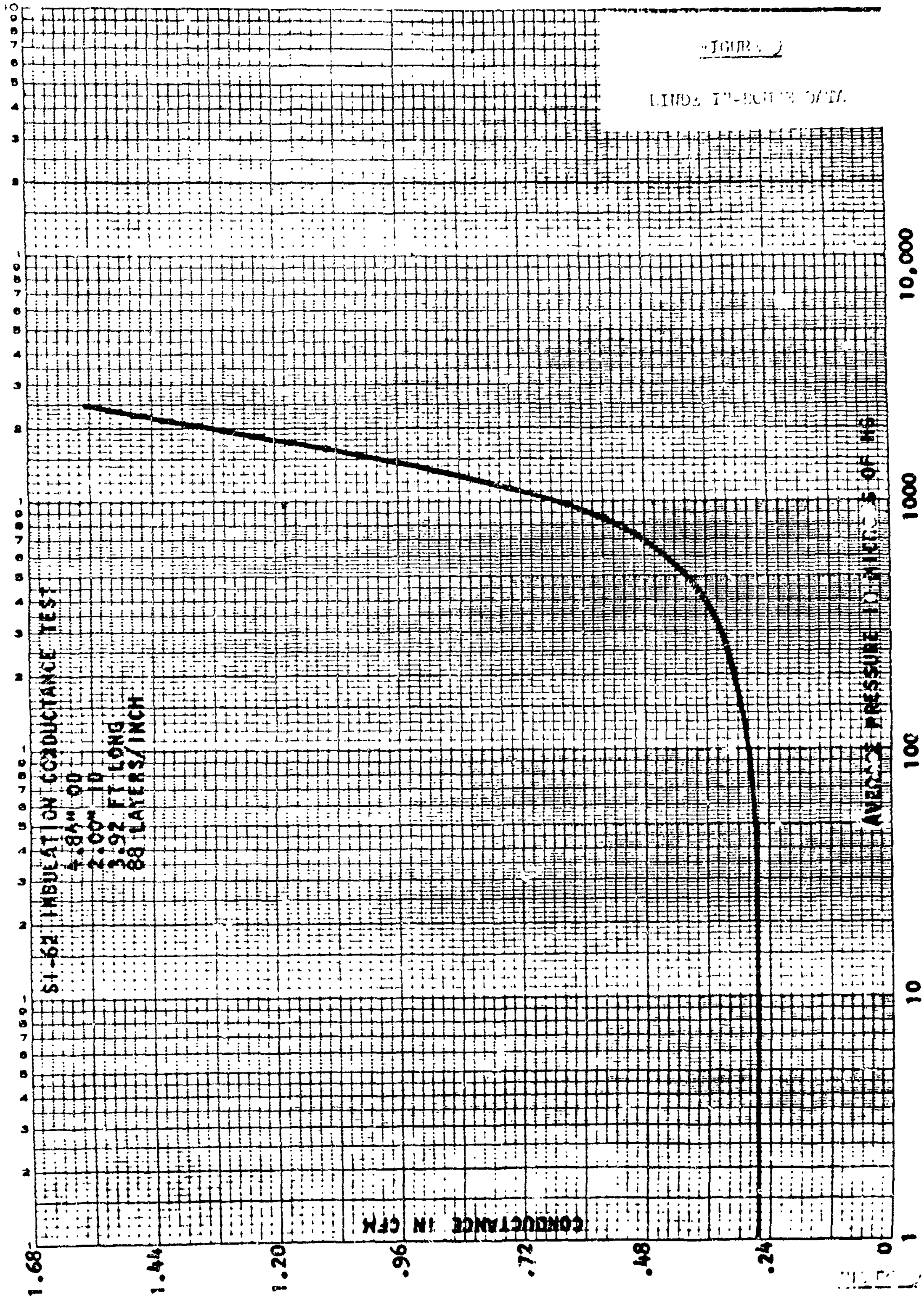
The total outgassing of the fiberglass spacer and aluminum foil have been determined by Linde and are shown on Figure 10. The tests conducted with the glass fiber paper showed relatively high outgassing rates at first indicating gas lightly held on the surface which is easily removed during rough pumpdown. From the curve, it can be seen that this represents the largest part of the volume of gas involved.

The tests of the 1/4-mil aluminum foil show similar characteristics although the total outgassing is much less since surface area per square foot is involved.

The outgassing of the adhesive tape used in applying Super Insulation was determined under the present program and the results are reported in Section 3.2.3 below compared with glass and aluminum outgassing data.

2.4.2 Adsorbent Trap Design Criteria:

Cryogenic containers are equipped with Molecular Sieve adsorbent traps to pump gases evolved from the surface of materials in the vacuum space after evacuation and to remove gases leaking into the vacuum space. When Molecular Sieves are cooled


S1-62 INSULATION CONDUCTANCE TEST
4.84" OD
2.00" ID
3.92 FT LONG
88 LAYERS/INCH
CONDUCTANCE IN CFM
1.68
1.44
1.20
.96
.72
.48
.24
0
1
10
100
1000
10,000
PRESSURE
OF HG

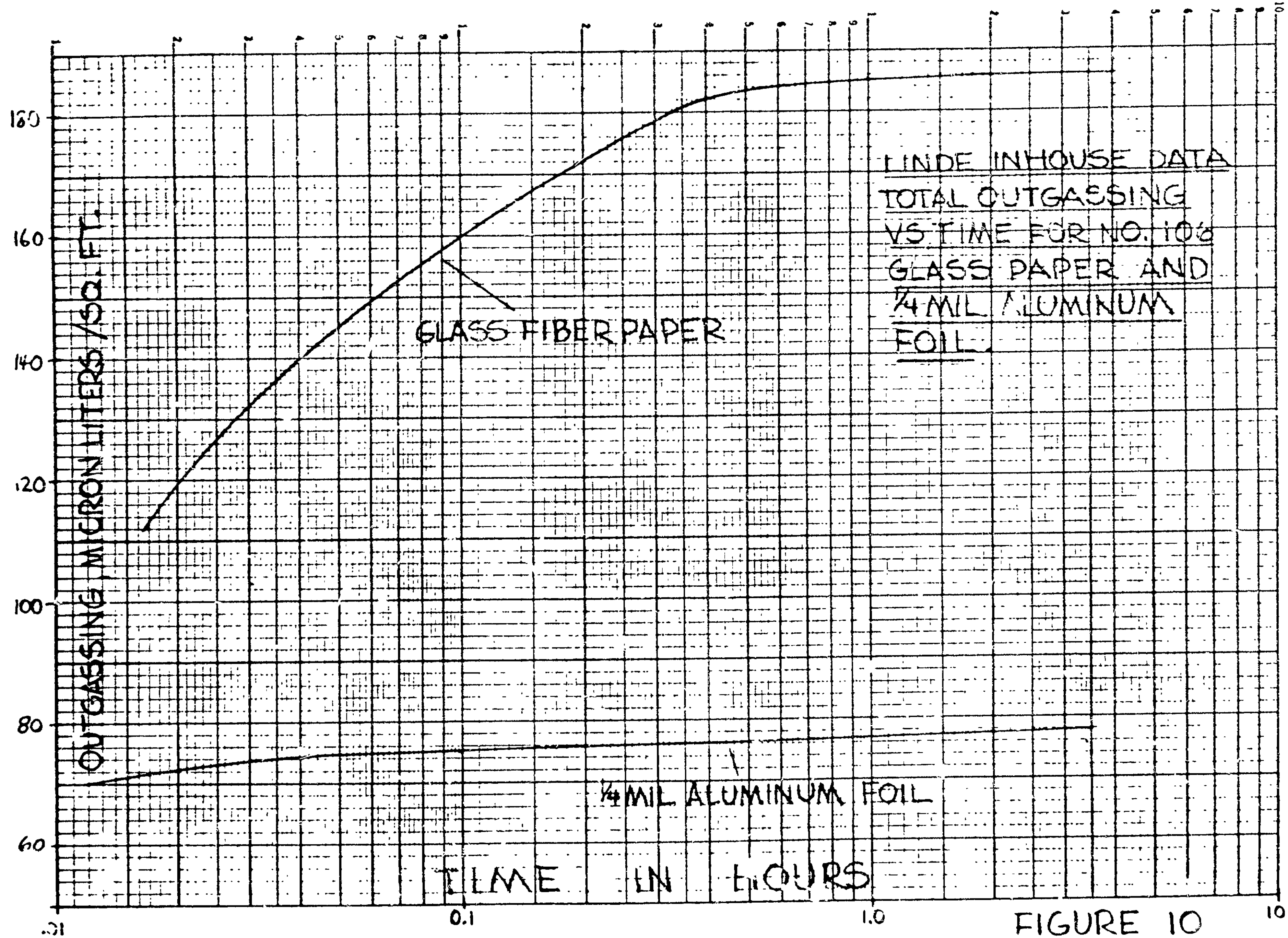

LINDE INHOUSE DATA
TOTAL OUTGASSING
VS TIME FOR NO. 106
GLASS PAPER AND
¼ MIL ALUMINUM
FOIL
GLASS FIBER PAPER
¼ MIL ALUMINUM FOIL
OUTGASSING, MICRON LITERS / SQ. FT.
180
160
140
120
100
80
60
TIME IN HOURS
.01
0.1
1.0
10

FIGURE 10

to cryogenic temperature, they have a high capacity for adsorbing gases. Knowing the total gas in-leakage to the vacuum space, vacuum level and service time requirements, the amount of Molecular Sieve needed can be calculated.

Molecular Sieves strongly adsorb water from the atmosphere at atmospheric temperature and the effect of this adsorbed water is to decrease the sieve pumping speed and adsorptive capacity. Since a certain atmospheric exposure time will exist during sieve trap installation, an activation procedure must be formulated to remove adsorbed water.

To insure that the Molecular Sieve adsorbent used for the 105-inch diameter vessel will function properly after installation, the following criteria have been established.

1. For effective use as an adsorbent, dry Molecular Sieve containing a maximum of two weight per cent water should be obtained after activation. Molecular Sieve moisture loadings of up to 15.7 weight per cent of water have been reported after prolonged exposure to the atmosphere. Experiments have indicated that it is difficult to activate below the two per cent water level and that moisture loadings up to two per cent do not materially effect the performance of the sieve.

2. The activation cycle required to reduce the water content from six per cent to two per cent would consist of heating to 300°F for 12 hours under vacuum. This cycle is based on a system pumping speed of .28 liters per second and a one pound quantity of sieve. An upper moisture limit of six per cent was used in the analysis because Molecular Sieve isotherms become non-linear and do not obey Henry's Law at higher moisture loadings. The time required to lower the moisture content from 15.7 to 6 per cent has been found by experience to be less than that required to activate the sieve from six per cent to two per cent moisture. To be conservative, an equal time is assumed and a total activation period of 24 hours is recommended.

Heating of the sieve can be accomplished by circulating preheated air or nitrogen through the container. Preheating of the gas can be accomplished by passing it through an electrical resistance type heater.

3. The total quantity of Molecular Sieve to be used will depend on the vacuum jacket permeability, ground hold time, and required vacuum level. The quantity of Molecular Sieve required will be calculated conservatively on the basis of five per cent by weight water after activation. At a pressure level of 10^{-4} Torr the adsorptive capacity of 5-A Molecular Sieve for nitrogen is decreased by about 29 per cent if the moisture content is increased from two to five per cent by weight of water.

4. The quantity of Molecular Sieve required for adsorption can be calculated conservatively based on an assumed moisture loading after activation of five weight per cent of the sieve.

5. Pretreatment of the insulation, that is, baking out at 300°F for 24 to 30 hours is recommended to reduce moisture loading on the sieve.

6. The sieve trap should be attached to the container at the last convenient time in the insulation application process to avoid unnecessary exposure to air.

7. The insulation should be perforated over the area of the sieve trap with 1/32 inch diameter holes on 1 inch centers and an evacuation port located directly over this area.

8. Since the adsorptive capacity of Molecular Sieve is higher at low temperature, the sieve trap should be attached to the bottom of the container to insure cryogenic temperature.

3.0 DEVELOPMENT TEST PROGRAMS:

With the exception of the test results obtained from contract NAS 3-2165 for the effects of compression and relaxation of a Super Insulation system, all of the data reported in Section 2 were obtained from Linde in-house funded programs. They have been reported here to form a base of technology from which the development efforts under contract NAS 8-11740 could proceed. This section will describe those development tests. Each of the tests described was conducted at Linde's Engineering Department Laboratory at Tonawanda, New York.

Review of the reported data clearly indicates that two areas needed additional development: thermal performance of the insulation system after relaxation of the atmospheric compression, and achievement and maintenance of a satisfactory residual gas pressure within the insulation system. The small scale thermal tests also served to prove out the vacuum criteria and flexible jacket concepts for application to the 105" tank at MSFC.

3.1 Flexible Vacuum Jacket Development:

In order to be effective as a flexible vacuum jacket for this application, the material (including joints) must be lightweight and flexible enough to permit maximum physical relaxation of the insulation system, and yet have a permeability in the order of $1 \times 10^{-9} ft^3/hr\text{-}ft^2$. Once the laminate material has been chosen, further development testing is needed to learn how to join the laminate material to the tank at cryogenic temperatures and to itself, as well as how to form it into the contour of the insulation, and to repair any damage caused by inordinately rough handling.

3.1.1 Permeability And Recovery Of Flexible Vacuum Jacket Materials:

An evaluation of the pertinent property data for candidate jacket materials was presented in Section 2.3 above. It was decided that helium gas permeability and physical recovery of the candidate materials when applied over a Super Insulation system were the most important characteristics of the materials to be evaluated, and a test program to measure these variables was conducted. The specific candidates and results are shown in Table 4. Because of the limited time and funding available, no laminates of plastic with vacuum deposited metal were considered in this program.

These results indicate that the lead-Mylar has the lowest permeability and best recovery of all the laminates tested. Results of previous Linde in-house tests indicate that this material can withstand over 1500 flexing cycles at -320°F before leaks occur. As a result of these tests and extensive prior experience with the material in in-house commercial development and pilot scale programs, Linde recommended that lead-Mylar be used for the flexible vacuum jacket.

The apparatus for determining permeability consisted of a sample chamber comprised of two flanges with the sample to be tested between them and sealed with a double O-ring seal (Figure 11). Helium gas at one atmosphere is fed to the high pressure side and the low pressure side is evacuated through a helium mass spectrometer. Flow through the sample is then compared with a standard leak. The helium mass spectrometer used is a Veeco Leak Detector, Model No. MS-9AB, with a maximum sensitivity of 10^{-9} std. cc of helium per second.

In order to evaluate the restricting characteristics of the candidate materials, a cylindrical tester (7 in. O.D. by 24 in. long) was fabricated (Figure 12). The tester was wrapped with 70 layers of SI-62 and covered with two 1/2-inch wide bulking strips in the insulation. The initial compressed and recovered thicknesses were measured. The recovered thickness was measured both with and without the flexible jacket covering the insulation to determine if the jacket was restricting insulation recovery.

The results of these tests indicate that a relatively thick plastic film and metal foil are required. Other desirable characteristics of the laminate are:

1. That the metal be self-annealing at ambient temperature,* thereby preventing work hardening from flexing to cause pinhole leaks.

2. That the plastic film be thick enough to have a relatively large radius of curvature at folded areas, thereby preventing sharp discontinuities in the metal foil upon flexing.

3.1.2 Hand Joining And Repair:

The fabrication of the flexible jackets for the small scale thermal tests has indicated the necessity of being able to make vacuum tight joints for the closing seams of the installed jacket and to have a method of sealing small leaks that are found in the jacket after installation.

A portable heat sealer with a six-inch jaw was obtained and modified to provide a cooling cycle. This sealer was used to make the head joints on the vacuum-formed jacket for the small scale thermal tester. Small leaks in the closing joint were sealed with a solution of Armstrong A-12 epoxy and chlorothene.

Tests indicate that these methods of hand sealing seams and sealing small leaks are satisfactory for the present jacket design using vacuum formed lead-Mylar. It is recommended that the lead-Mylar be examined for pinhole leaks prior to fabrication. When such holes are found they are to be examined to determine if the pinhole is in just the lead or in both the lead and the Mylar. If a piece of the laminate has a hole through both the lead and the Mylar, it must be discarded for a new piece.

Previous experience had shown that when sealing lead-Mylar to itself it is necessary that the joint be made under pressure with a controlled heating and cooling cycle. For this reason, the portable heat sealer was modified to incorporate a cooling cycle (Figure 13). The present sealing cycle for this sealer and lead-Mylar is to seal under 40 psig pressure with twenty seconds heating and ten seconds cooling.

Small leaks were successfully sealed by applying a 20-80 solution of Armstrong A-12 two-part epoxy adhesive and chlorothene solvent liberally over the leaking area. Curing was accomplished by blowing hot air at about 120°F over this area for about one hour.

---

* Recrystallization temperature of lead is 25°F and of pure aluminum is 175°F.

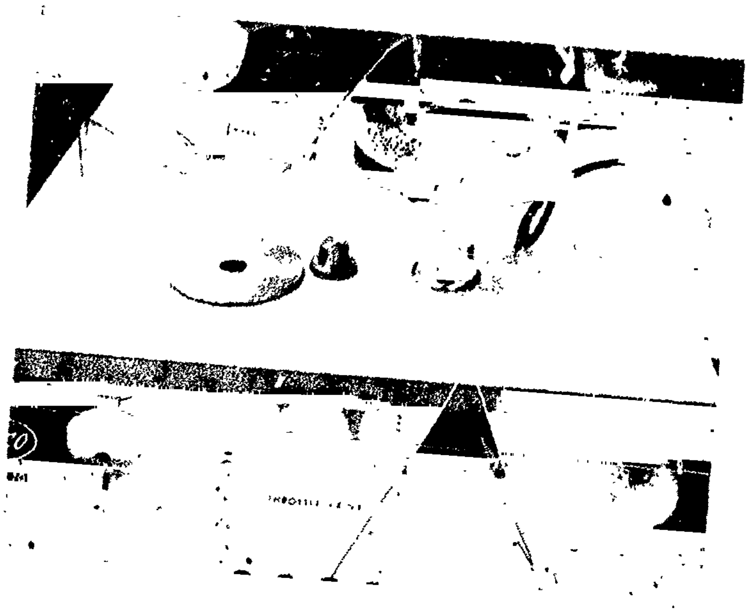
TABLE 4

PERMEABILITY & RECOVERY OF FLEXIBLE VACUUM JACKET MATERIALS

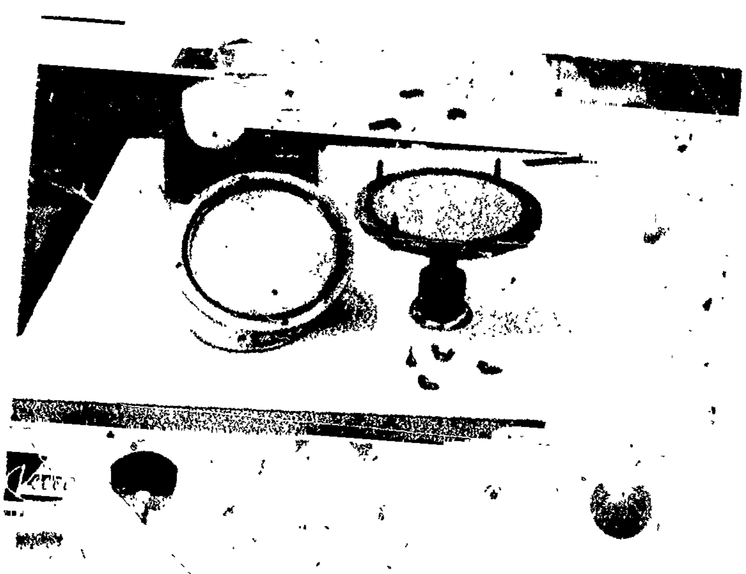
Sample	Composition	Permeability, ft^3 He/hr-ft^2-atm. As-Received	Permeability, ft^3 He/hr-ft^2-atm. Flexed
1	1 mil Mylar - 0.8 mil Pb - 1 mil Mylar	$<5 \times 10^{-10}$	$<5 \times 10^{-10}$
2	1/2 mil Tedlar - 1/4 mil Al - 1/2 mil Tedlar	3.3×10^{-9}	7.3×10^{-9}
3	1/2 mil Mylar - 1 mil Al - 1/2 mil Mylar	$<5 \times 10^{-10}$	2.4×10^{-8}
4	1/4 mil Mylar - 1/4 mil Al - 1/4 mil Mylar	1.9×10^{-8}	2.6×10^{-8}
5	1/2 mil Aclar - 1/4 mil Al - 1/2 mil Aclar	2.2×10^{-8}	1.4×10^{-7}

RECOVERY OF FLEXIBLE VACUUM JACKET AND SUPER INSULATION

	No Bulking Strips		Two 1/2-Inch Bulking Strips				
Thickness of 70 Layers Of SI-62 Inches	4 Aluminum - Mylar	1 Lead-Mylar	1 Lead-Mylar	2 Aluminum-Tedlar	3 Alumiseal	4 Aluminum-Mylar	5 Aluminum-Aclar
initial	0.969	0.844	1.021	1.062	1.017	0.953	0.969
compressed	0.203	0.219	0.266	0.209	0.250	0.288	0.250
recovered with jacket	0.656	0.794	0.806	0.844	0.641	0.750	0.637
recovered without jacket	0.484	0.606	0.688	0.844	0.938	0.625	0.781
Layer density, layers/inch							
initial	72	83	69	66	69	74	72
compressed	344	320	264	334	280	307	280
recovered with jacket	107	88	87	83	109	93	113
recovered without jacket	124	116	102	83	75	112	89



PERMEABILITY TESTER

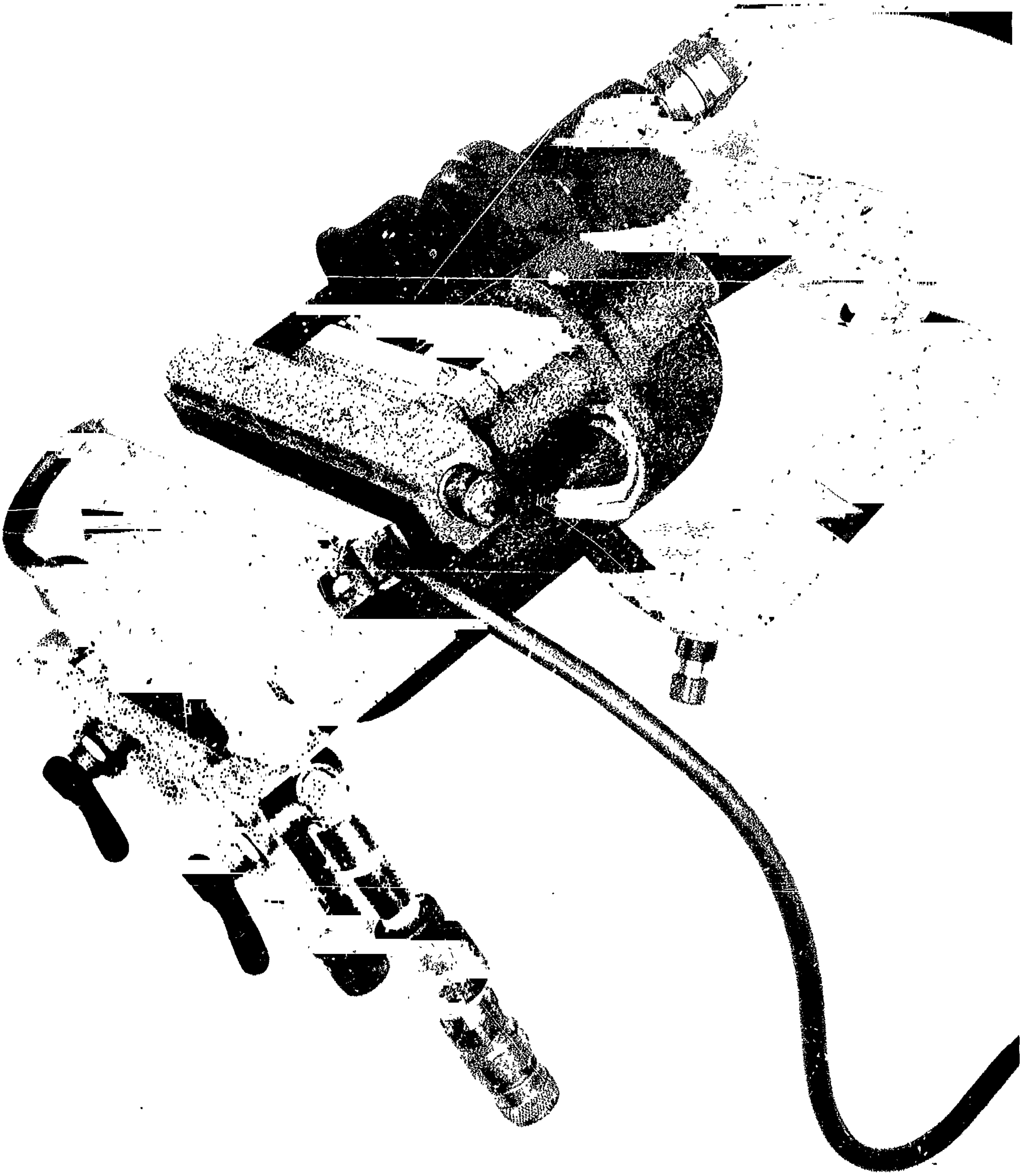


EXPLODED VIEW PERMEABILITY TESTER

FIGURE 11

FIGURE 12

FLEXURE TYPE TESTER



Portable Heat Sealer

FIGURE 13

3.1.3 Forming Techniques:

Experience in the past has indicated that vacuum leakage of jacket materials and recovery of the insulation problems are often attributable to areas of severe wrinkles in the jacket. This could be reduced materially if the jacket could be made preformed to the contour of double curved sections of the tank. Early small-scale tests indicated the lead-Mylar laminate material could be formed at about 200°F into an evacuated female die. Cooling to room temperature held spring-back to within tolerable limits. Tests were conducted on seven-inch diameter specimens drawn to two-inch depth and the permeability of the formed material measured to be less than $5 \times 10^{-5} ft^3/hr\text{-}ft^2$. Tests with samples containing lap joints were also conducted with success. This method was, therefore, recommended for the forming of the heads for the 105-inch diameter tank jacket. When the technique was first attempted on a large scale, however, a failure in an adhesive joint occurred, and additional tensile and model die tests were recommended before any more large scale draws were attempted.

Tensile tests of lead-Mylar laminate joints were conducted with the Dillon tensile tester previously used in lap and tee joint evaluation. The tester was modified by the addition of a heating jacket so that joint pull tests could be conducted at elevated temperature. A thermocouple was attached to the laminate sample to monitor temperature. Sample joints were made by sealing two sections of lead-Mylar laminate with Schjeldahl G. T. 100 tape in the 48-inch hot jaw sealer.

A total of 25 pull tests were made. The samples to be tested were clamped between the jaws of the tester with the bottom jaw moving down at constant rate until failure occurred. The top jaw is connected to a pressure transducer, the output of which is converted to pounds force and recorded. The tests were conducted at temperatures ranging from 70°F to 200°F and at pull rates of 1.1 inch per minute and 1.9 inch per minute.

In all cases tensile failure occurred in the parent material rather than shear failure at the joint. Joint creep did not occur at ambient temperature and did not become significantly noticeable until a temperature of 135°F was reached. At 180°F joint creep was pronounced but failure still occurred in the parent material. Sample elongation averaged approximately 35 per cent at a yield of about 30 pounds per inch with no clear trend based on temperature or rate of pull.

The forming die used for these tests was the 17-3/4-inch diameter form previously used to form laminate head caps for the small-scale thermal recovery tests, described in Section 3.3 below. Modification to the die included deepening from 4 inches to 5.34 inches and contouring the spherical radius to 10.3 inches by the addition of polyurethane foam. These changes made this die geometrically similar to the one to be used for the 105-inch diameter tank.

A total of 11 flat laminate blanks were formed. Seven blanks were fabricated with two lap joint seams geometrically similar to the 114-inch diameter blank to be used for the 105-inch diameter tank. Three blanks were fabricated with a lap joint in the center to evaluate the maximum elongation of 21.3 per cent and one blank without seams was used for the initial draw. Forming times of 1 minute, 10 minutes, and 30 minutes were used and forming temperatures were 70°F, 120°F, and 153°F. Table 5 summarizes the results of the testing. Springback is defined as:

$$\% \text{ Springback} = \frac{D_1 - D_2}{D_1} (100)$$

where: D_1 = maximum depth of draw, 5.34 inches

D_2 = recovered depth of head after release of vacuum, inches

This test series indicated that per cent springback decreased with increased forming temperature but that slight joint creep was noted in every case at elevated temperature except Sample 2. There seems to be no correlation between delamination or material failure and drawing temperature or rate. A possible explanation for the laminate failures is that slight cracks or nicks in the laminate would weaken the Mylar at this point and result in a tear when subjected to vacuum forming. The cracks or nicks could be the results of normal handling during formation of the blanks or could be incurred during initial lamination of the lead and Mylar.

Since the large surface area of a 114-inch diameter blank could present a great potential area for nicks or tears, it was decided, for increased reliability, to redesign the blank so that per cent elongation would be decreased.

Also, since joint creep was encountered at elevated forming temperature, it was decided to form at ambient temperature to increase joint reliability.

A conically shaped laminate blank was designed so that the apex just contacted the center of the forming die and its perimeter equalled that of the die. Based on the geometry of the die, an elongation of 5.9 per cent of the cone slant height would be experienced. The laminate cone was formed by cutting out a wedge from a flat blank and sealing the edges of the wedge together with the 48-inch heat sealer to form a cone.

Four heads were drawn, three of which contained two lap joints geometrically similar to the blanks to be used for the 105-inch diameter tank. One blank without lap joints was used for the initial draw. The forming procedure consisted of evacuation at room temperature over a 10-minute period to simulate MSFC drawing capability and placing the formed head, still in the die and under vacuum, into an oven at elevated temperature.

One head was cured in the oven for 1-1/2 hours at 150°F and another for 1-1/2 hours at 180°F. No joint creep was noted in either case and each head was well contoured to the mold after release of vacuum. Springback in each case was about 5.5 per cent. Since the higher temperature curing did not improve the head configuration, curing at 150°F was recommended.

Three conically shaped blanks, 114 inches in diameter with a slant height of 55 inches, were fabricated for the 105-inch diameter test tank at MSFC. Based on the dimensions and the spherical radius of the

TABLE 5

VACUUM FORMING DEVELOPMENT

FORMING TIME

1 MINUTE	10 MINUTES	30 MINUTES
SAMPLE 1 - No seams. Forming temperature - 70°F. Springback - 12.8%. Delamination of parent, material over 2" diameter.	SAMPLE 8 - One seam. Forming temperature - 120°F. Laminate ruptured suddenly. Failure.	SAMPLE 5 - One seam. Forming temperature - 120°F. Springback - 7%. Slight joint creep. Delamination of parent material over a section one inch long by 1/4-inch wide.
SAMPLE 2 - Two seams Forming temperature - 121°F. Springback - 10.5% Successful forming.	SAMPLE 9 - Two seams. Forming temperature - 70°F. Springback - 13.9% Two pinholes delaminations of parent material	SAMPLE 6 - Two seams. Forming temperature - 120°F. Springback - 12.8%. Slight joint creep.
SAMPLE 3 - Two seams. Forming temperature - 153°F. Laminate ruptured suddenly. Failure.	SAMPLE 10 - Two seams. Forming temperature - 70°F. Laminate ruptured suddenly. Failure.	
SAMPLE 4 - One seam. Forming temperature - 153°F. Springback - 5.8%. Slight joint creep.	SAMPLE 11 - Two seams. Forming temperature - 70°F. Springback - 15.1%. Successful forming.	
SAMPLE 7 - Two seams. Forming temperature - 70°F. Springback - 16.4%. Successful forming.		

head, 55.8 inches, an elongation of 3.3 per cent of the cone slant height would be experienced.

The equipment used to form flanges on cylindrical sections of lead-Mylar is shown in Figure 14. It consisted of an inner metal support cylinder, an outer ring clamp, and a small hand iron. The method of forming the flange is to heat and hand stretch about one to two inches of circumferential length at a time. This procedure is continued around the periphery of the cylinder until the desired flange is obtained.

3.1.4 Cold Joint Development:

In the area around the manhole, the flexible jacket must be attached to the aluminum tank as the 105-inch diameter tank is designed. This joint must be capable of withstanding temperature cycling between room temperature and liquid hydrogen temperature without losing its vacuum integrity. It was not the intent of this program to develop new joining techniques, but available concepts were investigated and two were tested. These were a mechanical O-ring and an adhesive joint. Both were successfully temperature cycled, but the latter was recommended on the basis of simplicity and reliability.

3.1.4.1 Mechanical O-ring Cold Joint:

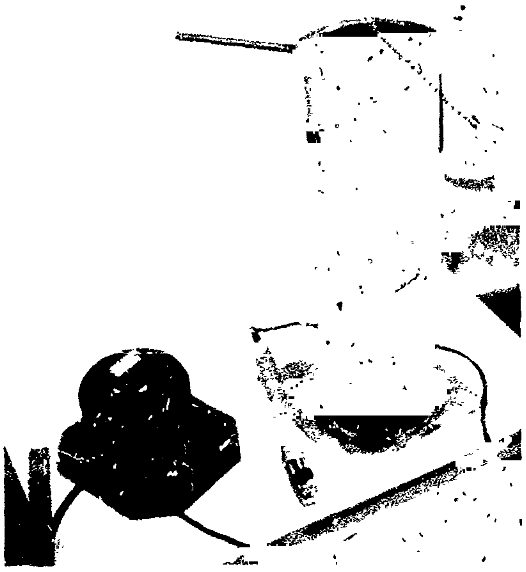
A tester with an O-ring joint, sixteen inches in diameter, was designed and fabricated as shown in Figure 15. The tester was assembled, evacuated at room temperature, and the insulation vacuum level allowed to settle out. At this time, the tester was filled with liquid nitrogen and the pressure in the insulation monitored. This test was followed by a liquid hydrogen test. Both Teflon and Viton-A O-rings were selected for testing.

A warm vacuum joint could not be achieved with the Teflon O-ring; however, the Viton-A O-ring did effect a vacuum seal at ambient and both liquid nitrogen and liquid hydrogen temperatures.

The tester was cycled successfully three times with liquid nitrogen and twice with liquid hydrogen. The longest liquid hydrogen test was about five hours. A thermocouple located in the upper flange indicated a temperature of -255°F for the liquid nitrogen tests and a temperature of -358°F for the liquid hydrogen tests.

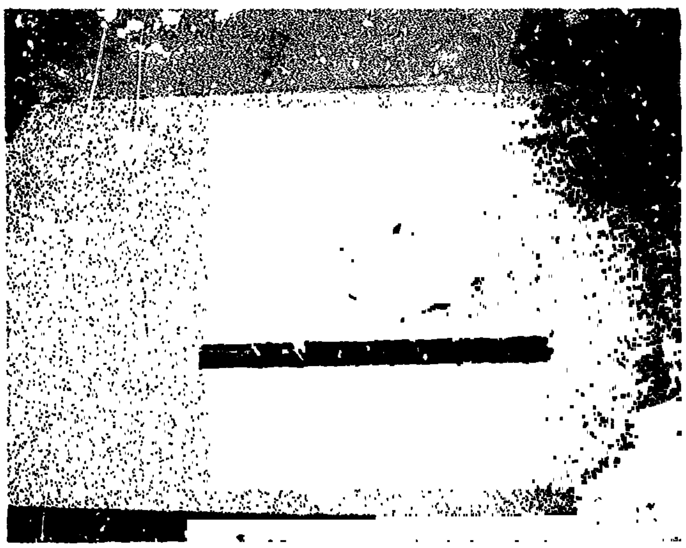
The top and bottom flanges were aluminum and the machine screws were stainless steel. Vacuum failure occurred in both the liquid nitrogen and liquid hydrogen tests when the tightening torque of the machine screws were less than forty inch-pounds.

The tester was so designed that the O-ring groove volume is only 85% of the O-ring volume. Therefore, when the machine screws are tightened to forty to sixty inch-pounds, the upper flange warps. This warpage insures intimate contact between the O-ring and the upper flange during the transient thermal contraction period, thereby effecting a vacuum tight system.



Apparatus

Method



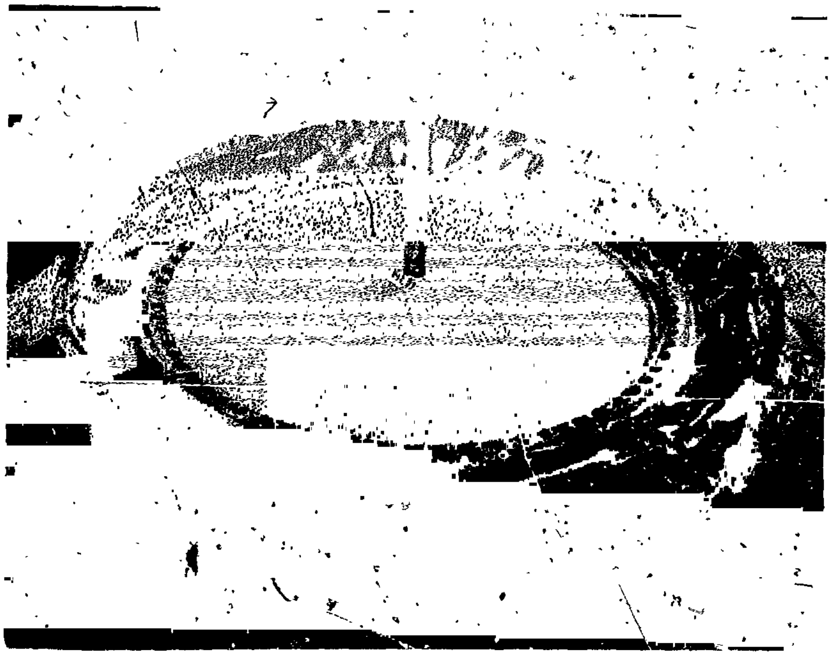
6-3/4 in. Diameter

17-3/4 in. Diameter

FIGURE 14

Hand-Forming Flanges

Top View



O-Ring Flange

Bottom View

VEECO Coupling

Evacuation Port

Pressure Tap

FIGURE 15

Cold Joint Tester

Although this method provides a vacuum joint, its reliability is questionable. Indeterminate variables include: creep of the O-ring material, the amount of the tightening torque attributable to friction, the force on the O-ring after cooldown, and the predictability of flange warpage resulting from tightening the machine screws. Also, after the O-ring groove is machined into a flange, this flange must be welded into place, thus introducing heat warpage.

3.1.4.2 Adhesive Cold Joint:

The adhesive joint designed for this application was about twenty-one inches in diameter and one inch wide. The adhesive used was a polyurethane, Dupont Adiprene L-100. The test procedure was the same as for the mechanical O-ring cold joint tester. The adhesive joint tester is shown evacuated and filled with liquid nitrogen in Figure 16. This adhesive effected a vacuum seal at ambient and both liquid nitrogen and liquid hydrogen temperatures.

The adhesive joint was cycled successfully, once with liquid nitrogen and five times with liquid hydrogen. The longest liquid hydrogen test was over 5-1/2 hours. A thermocouple located at the joint indicated a temperature of -295°F for the liquid nitrogen test and -423°F for the liquid hydrogen tests.

It was observed, after the tests were completed, that the adhesive has very high tensile and shear strengths at ambient conditions. The glue line thickness varied from 1.8 to 13.2 mils with the average thickness being 5.5 mils.

The test joint was prepared by cleaning the aluminum and the Mylar surfaces with methyl ethyl ketone and drying thoroughly with paper towels. The aluminum surface was etched for five minutes in a solution of sulfuric acid (ten parts by weight), sodium dichromate (four parts by weight), and deionized water (thirty parts by weight). The etchant was then rinsed from the aluminum surface with deionized water and the surface thoroughly dried with paper towels.

The Adiprene adhesive (100 parts of Adiprene L-100 resin with 12.5 parts of Moca curing agent) was brushed on the aluminum surface as evenly as possible. The lead-Mylar laminate was then placed over the adhesive.

The joint was cured by applying 2 psi pressure to the joint area for twenty-four hours. NOTE: The 2 psi pressure was obtained by supporting the test fixture at the joint area and adding weights to the tester. Uniform distribution of the force was achieved by placing a semi-rigid polystyrene foam sheet between the joint and the support fixture to accommodate irregularities and warpage between the mating parts. The joint was then cured for twenty-four hours at room temperature and ambient pressure and for twenty-four hours at 160°F and ambient pressure.

3.2 Vacuum Acquisition:

For satisfactory thermal performance, Super Insulation systems must be maintained at a residual gas pressure of about 0.1 micron Hg when

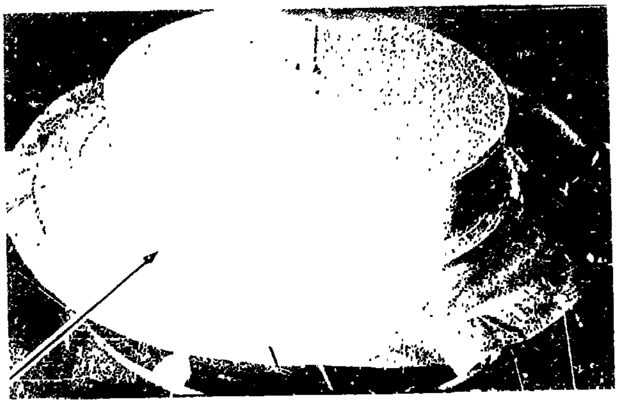


FIGURE 16A

Top View

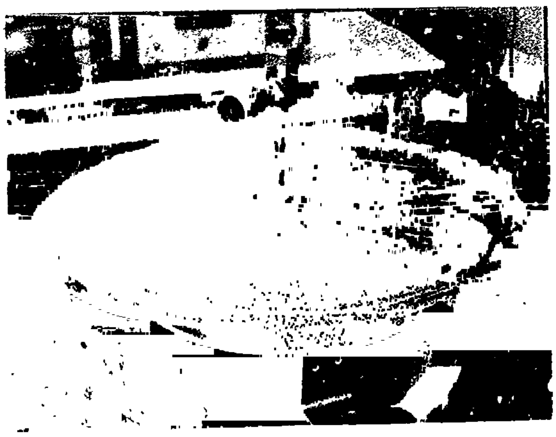


FIGURE 16B

Bottom View

FIGURE 16C - FILLED WITH LIQUID NITROGEN

Adiprene L-100 Adhesive Cold Joint

at their operating temperature. To be practical from the manufacturing point of view, the required degree of vacuum must be obtained within a reasonable period of time (several days). Since the experience gained with the 70 inch tank under contract NAS 8-11041, which was plagued with vacuum leaks in the flexible jacket, proved that this was one of the most critical areas involved in achieving a satisfactory demonstration of the Super Insulation concept, considerable emphasis has been placed on this problem. The tests and analysis described here indicate that a satisfactory vacuum can be obtained with proper design and careful techniques to avoid leaks.

3.2.1 Evacuation Of Compressed Super Insulation:

In order to establish a means of predicting the time needed to evacuate a Super Insulation system encased within a flexible jacket, a theoretical analysis was undertaken. The analysis was then verified by test and the results presented as a vacuum pressure time history.

Data was recorded for pressures down to 52 microns of mercury in a 4 ft. square sample of SI-62. Approximately 44 hours of pumping were required to attain this degree of vacuum. The theoretical analysis indicates that 28 hours of pumping would be required. The difference is attributable to outgassing of the materials in the vacuum space. At 70 microns the overall leak rate through the flexible jacket and connections was about 1.1 x 10^{-7} cc of air per second. The settle out pressure after 65 hours was 57 microns.

The experimental results indicate that it is possible to predict the length of time necessary to evacuate compressed Super Insulation to below 100 microns of mercury. The results also indicate the attractiveness of the lead-Mylar laminat for the flexible vacuum jacket since it did not develop pinhole leaks as did previous aluminum-Mylar jackets. The merits of perforating the insulation under the evacuation port were also shown since it previously proved impossible to evacuate an unperforated sample.

3.2.1.1 Theoretical Analysis:

The theoretical evacuation time can be determined from fluid flow equations, continuity equations, and the equation of state. The theoretical evacuation was considered in four steps:

1. Initial compression of the insulation.
2. Removal of noncondensibles.
3. Removal of condensibles.
4. Final evacuation in the molecular flow regime.

Considering these four steps, the following equation for time to evacuate an insulation system has been derived.

$$t = \frac{V_o^{4.55}}{S_o} \left[\frac{V^{-3.55}}{-3.55} \right]_{V_A}^{V_o} + \frac{V_A P_A}{S_A} \left[\frac{1}{-P} \right]_{P_B}^{P_A} + \frac{m}{P^s{}_B}$$

$$+ \frac{V_c}{S_D} \ln \left. \frac{P}{\left(\frac{S_c}{P_c}\right) P + S_P} \right]_{P_D}^{P_c}$$

where: t = time, hours
V = insulation volume, ft^3

$$S = \text{conductance} = P_2 \frac{a}{\mu} \frac{2\pi h}{\ln \frac{r_2}{r_1}},\ ft^3/hr$$

P = pressure, pounds/ft^2
a = permeability, ft^2
μ = viscosity, lb-hr/ft^2
h = insulation thickness, ft
r = radial distance to evacuation port, ft

and the subscrips refer to the event corresponding to Figure 17

This analysis was employed to predict the time to evacuate a panel of Super Insulation, four feet square and seventy layers thick. The prediction and experimental data are compared on Figure 17.

3.2.1.2 Evacuation Test:

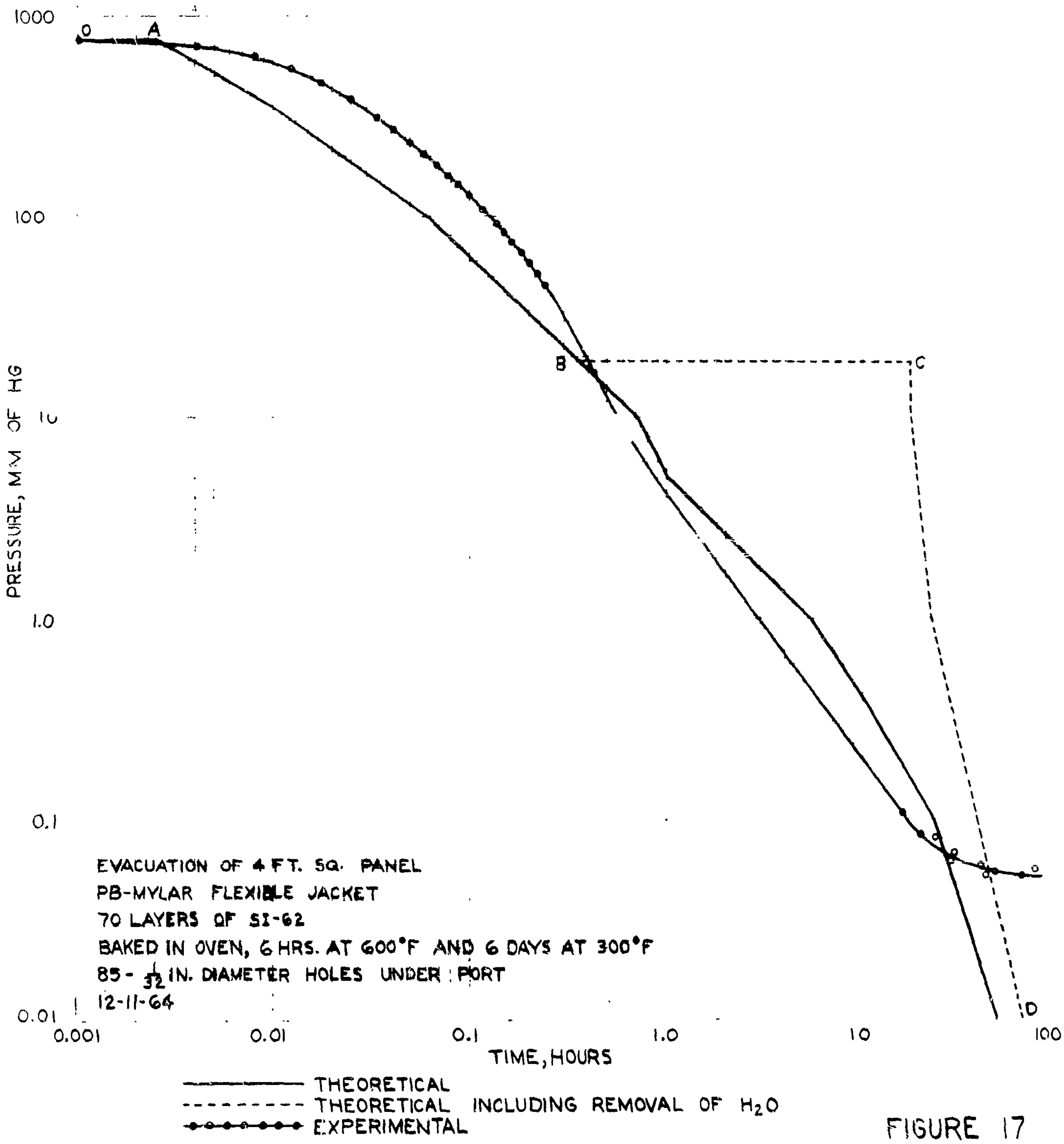
The sample that was evacuated is shown in Figure 18. It consists of 70 layers of SI-62, perforated with 85-1/32-inch diameter holes under the evacuation port and covered with the lead-Mylar laminate as the flexible vacuum jacket. The area under the thermocouple gauge was also perforated. The SI-62 was pretreated by being baked in an oven for six hours at 600°F and six days at 300°F.

The experimental results are in close agreement with the theoretical analysis. Figure 17 shows the theoretical evacuation curves for both pretreated and as-received insulation samples. The dotted portion of the curve represents the as-received sample where water vapor is being removed from B to C. Since the tested sample has been baked in an oven for six hours at 600°F and for six days at 300°F, the time required to go from point B to point C was negligible.

The experimental curve began to deviate from the theoretical one below 70 μ of Hg. The limiting value reached was between 50 and 60 μ of Hg. This can be attributed to the outgassing characteristics of SI-62 at these low pressures. The volume of outgassing obtained at 10 μ Hg for the glass paper is 128 μ liters/ft^2 and for the aluminum foil 13 μ liters/ft^2. For the size sample tested, this amounts to a total of 316,000 micron-liters. Since the throughput of the pump is very low in this range, it is recommended that the sample be heated to encourage more rapid outgassing.

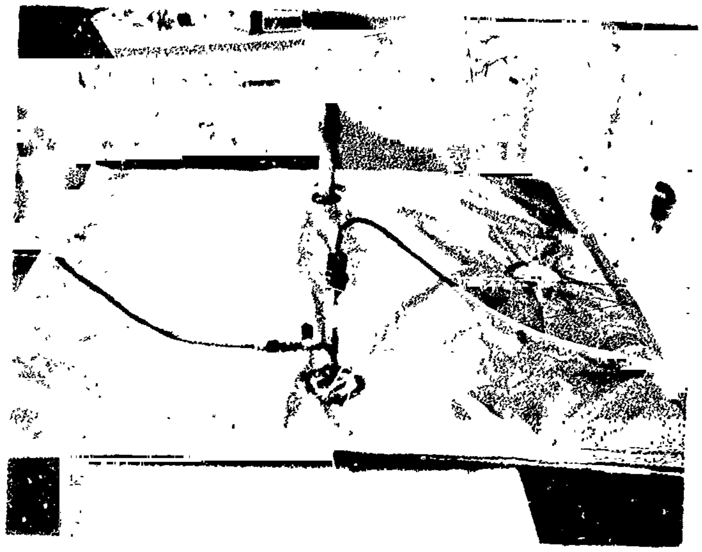
3.2.1.3 Evacuation of 105-Inch Diameter Tank:

Evacuation of the 105-inch diameter test tank can theoretically be accomplished to a level of 100 microns of mercury in about two days (Figure 19), as determined by the same analysis. This assumes that the evacuation ports are located at the four pipes located on the periphery for the cylindrical portion of the tank, and that the insulation material has been pretreated by baking to remove the water vapor. The molecular flow



1000
100
10
1.0
0.1
0.01
PRESSURE, MM OF HG
0.001
0.01
0.1
1.0
10
100
TIME, HOURS
O
A
B
C
D
EVACUATION OF 4 FT. SQ. PANEL
PB-MYLAR FLEXIBLE JACKET
70 LAYERS OF SI-62
BAKED IN OVEN, 6 HRS. AT 600°F AND 6 DAYS AT 300°F
85 - 1/32 IN. DIAMETER HOLES UNDER PORT
12-11-64
THEORETICAL
THEORETICAL INCLUDING REMOVAL OF H2O
EXPERIMENTAL

FIGURE 17



Before Evacuation

After Evacuation

FIGURE 18

EVACUATION SAMPLE

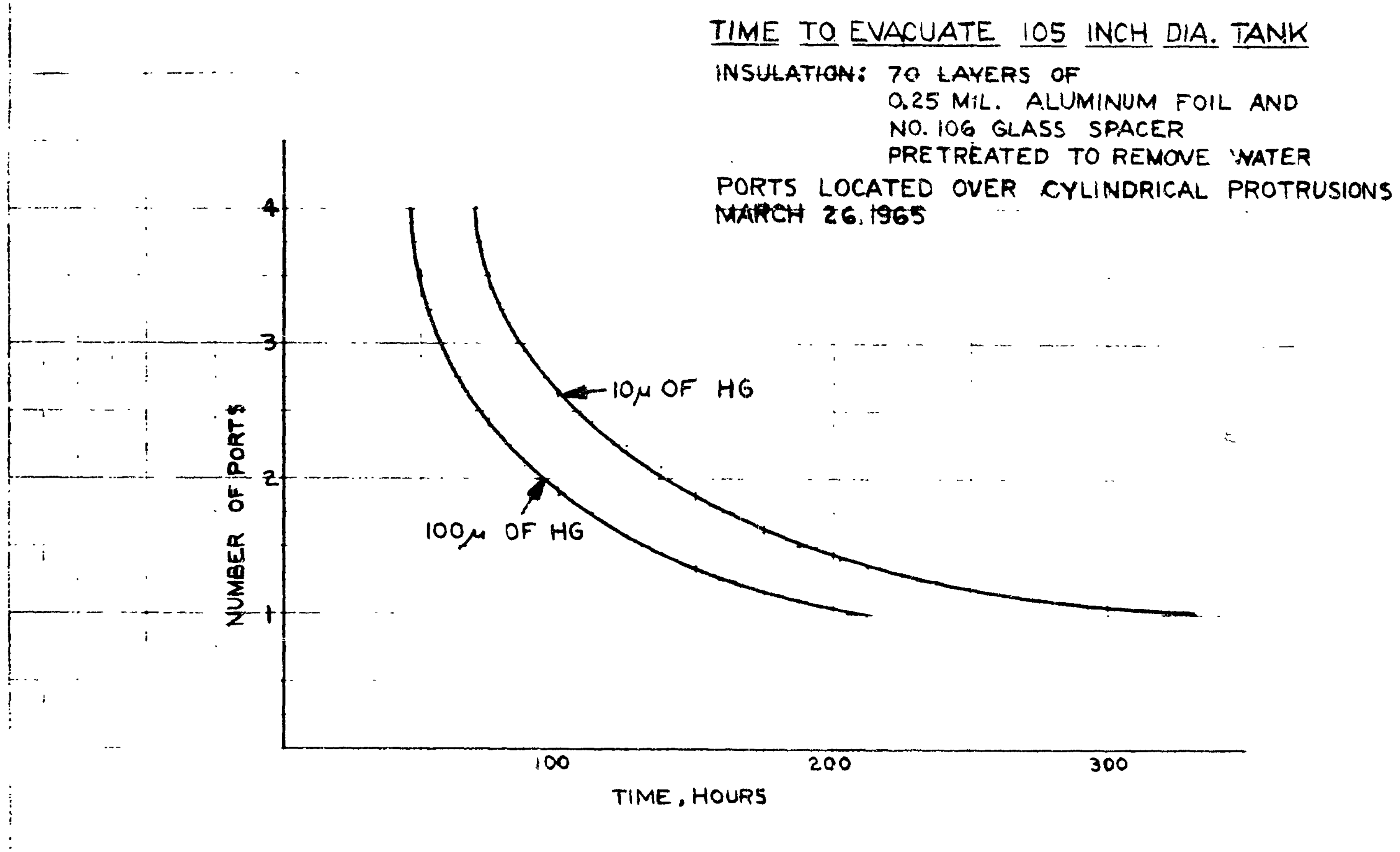

TIME TO EVACUATE 105 INCH DIA. TANK
INSULATION: 70 LAYERS OF
0.25 MIL. ALUMINUM FOIL AND
NO. 106 GLASS SPACER
PRETREATED TO REMOVE WATER
PORTS LOCATED OVER CYLINDRICAL PROTRUSIONS
MARCH 26, 1965
10μ OF HG
100μ OF HG
NUMBER OF PORTS
1
2
3
4
100
200
300
TIME, HOURS

FIGURE 19

conductance for this system is 0.09 cfh. As discussed above, the time required to evacuate the insulation to 100 microns of mercury with these four evacuation ports, and assuming that leakage is insignificant, is 45.7 hours.

3.2.2 Moisture Content Of No. 106 Glass Paper:

Past experience has shown that the removal of water vapor from a compressed Super Insulation system is a major problem. Since the No. 106 glass paper spacer will adsorb water vapor to a much greater extent than the aluminum foil radiation shield, it was believed necessary to establish pretreatment criteria for the glass paper. A test was conducted in which a roll of No. 106 glass paper was dried in a forced air furnace at 300°F. Approximately 31 hours of heating was required to reduce the moisture content from 0.0038 lb. water/lb. glass to essentially zero.

In order to allow a safety factor for the drying of glass paper stored in high humidity areas and having a higher initial moisture content, it is recommended that the drying time be extended to sixty hours.

In order to determine the rate of moisture adsorption of No. 106 glass paper, two samples were first dried and then exposed to the air. After a week's exposure in a room with a relative humidity of 36 per cent, Sample 1 contained 0.00104 lb-water/lb-glass while Sample 2 contained 0.000675 lb-water/lb-glass.

The sampling procedure consisted of removing a representative sample from the 28-inch long roll and weighing on an analytical balance. Sampling was effected by boring into the roll with a one-inch diameter cork bore. In this manner a representative sample consisting of material from the outermost to innermost layers was obtained. Sample weight was on the order of six grams.

The test procedure consisted of removing and weighing a sample of the glass paper roll prior to placing the roll in the furnace. This sample was designated Sample 1 and placed in the furnace along with the glass paper roll at 300°F. After approximately 6.5 hours, the glass paper roll and Sample 1 were removed from the furnace and Sample 2 taken from the insulation. Samples 1 and 2 were weighed on an analytical balance with Sample 1 showing an expected decrease in weight as a result of moisture removal. Samples 1 and 2 and the glass paper roll were then replaced in the furnace. The insulation samples were transferred from the furnace to the analytical balance in plastic bags filled with dry nitrogen to avoid moisture adsorption from the air.

This procedure was repeated until the weight of four samples taken over a 31-hour period remained constant during heating.

Moisture content of the glass paper is plotted as a function of the drying time in Figure 20.

In order to determine the rate of moisture adsorption of No. 106 glass paper, two samples were first dried in a furnace at 300°F for forty-eight hours. Moisture adsorption was calculated from the progressive increase

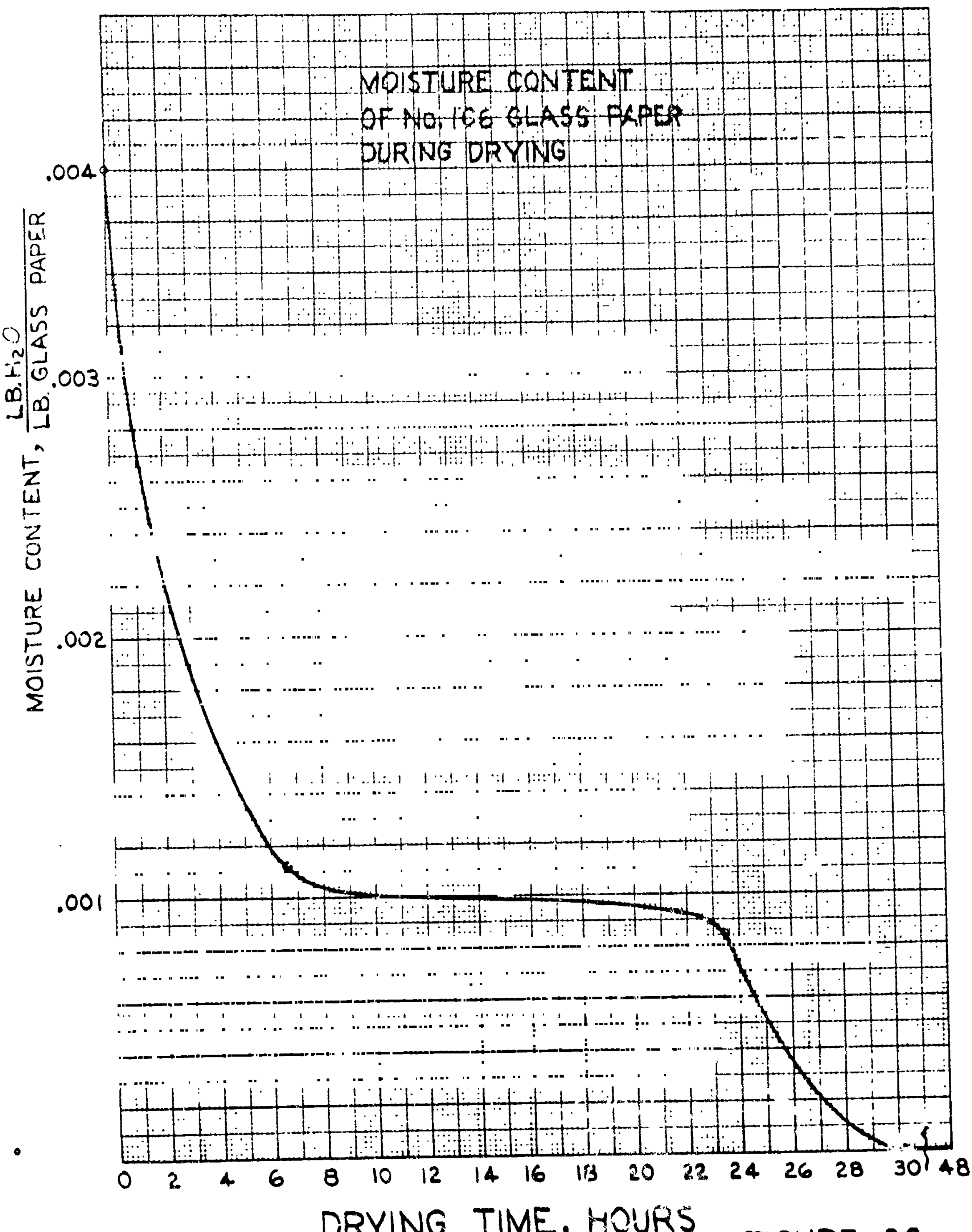

MOISTURE CONTENT
OF No. 106 GLASS PAPER
DURING DRYING
MOISTURE CONTENT, LB. H2O / LB. GLASS PAPER
.004
.003
.002
.001
0
2
4
6
8
10
12
14
16
18
20
22
24
26
28
30
48
DRYING TIME, HOURS

FIGURE 20

in weight of the samples after exposure to the air. Figure 21 shows a plot of moisture content as a function of exposure time for a one-week period. After one week's exposure, in a room with an average relative humidity of 36 per cent, Sample 1 contained 0.00104 lb-water/lb-glass and Sample 2 seemed to level off at 0.000675 lb-water/lb-glass.

The difference in moisture adsorption of the two samples may be due to incomplete initial drying of Sample 2 or an initial unrecorded moisture pickup of Sample 2.

3.2.3 Materials Outgassing:

Concern has often been expressed regarding the quantity of outgassing that will occur with a compressed Super Insulation system, and the effect it will have on the evacuation time and adsorbent requirements. The outgassing of the fiberglass and aluminum have already been reported in Section 2.4 based on Linde in-house tests, but no data were available for the Scotch brand adhesive tape used to maintain the structural integrity of the insulation. Since organic materials are involved, a quantitative comparison of the tape glass, and aluminum outgassing characteristics was deemed necessary.

The total outgassing versus time for the three materials at room temperature is shown in Figure 22. It will be noted that the data for the glass and aluminum are somewhat lower, but in the same order of magnitude as those data previously determined. A variation of this amount in the data is certainly to be expected since outgassing is such a strong function of the past history of the test sample.

The data indicate a total outgassing of $3.4 \mu ft^3/ft^2$ for the number 106 figerglass paper and $1.3 \mu ft^3/ft^2$ for the 1/4-mil aluminum foil. This compares with a figure of $86 \mu ft^3/ft^2$ for the adhesive tape. Since this absolute value is so low, and since there is relatively such a small area of tape installed in the insulation system, it can be concluded that the effects of outgassing of the tape would not be serious.

3.2.4 Radiation Shield Perforation:

Consideration of the low gas conductance of compressed Super Insulation has given rise to the suggestion that the radiation shields be perforated to permit flow of gas perpendicular to them. For a minimum of thermal degradation and ease of application, any perforations should be clean to prevent thermal short circuits, have negligible effect on layer density or foil tensile strength, and be compatible with existing tooling. Six possible methods were investigated.

3.2.4.1 Roller Perforator:

The recommended method would be to install a roller with sharp pins or nails protruding from it between the foil roll and the tank being insulated. While alignment and density control (tension is required on the foil) present problems in practice, this method has been successfully used in commercial applications. Tooling for this operation is shown in Figure 23.

MOISTURE ADSORPTION
OF No. 106 GLASS PAPER

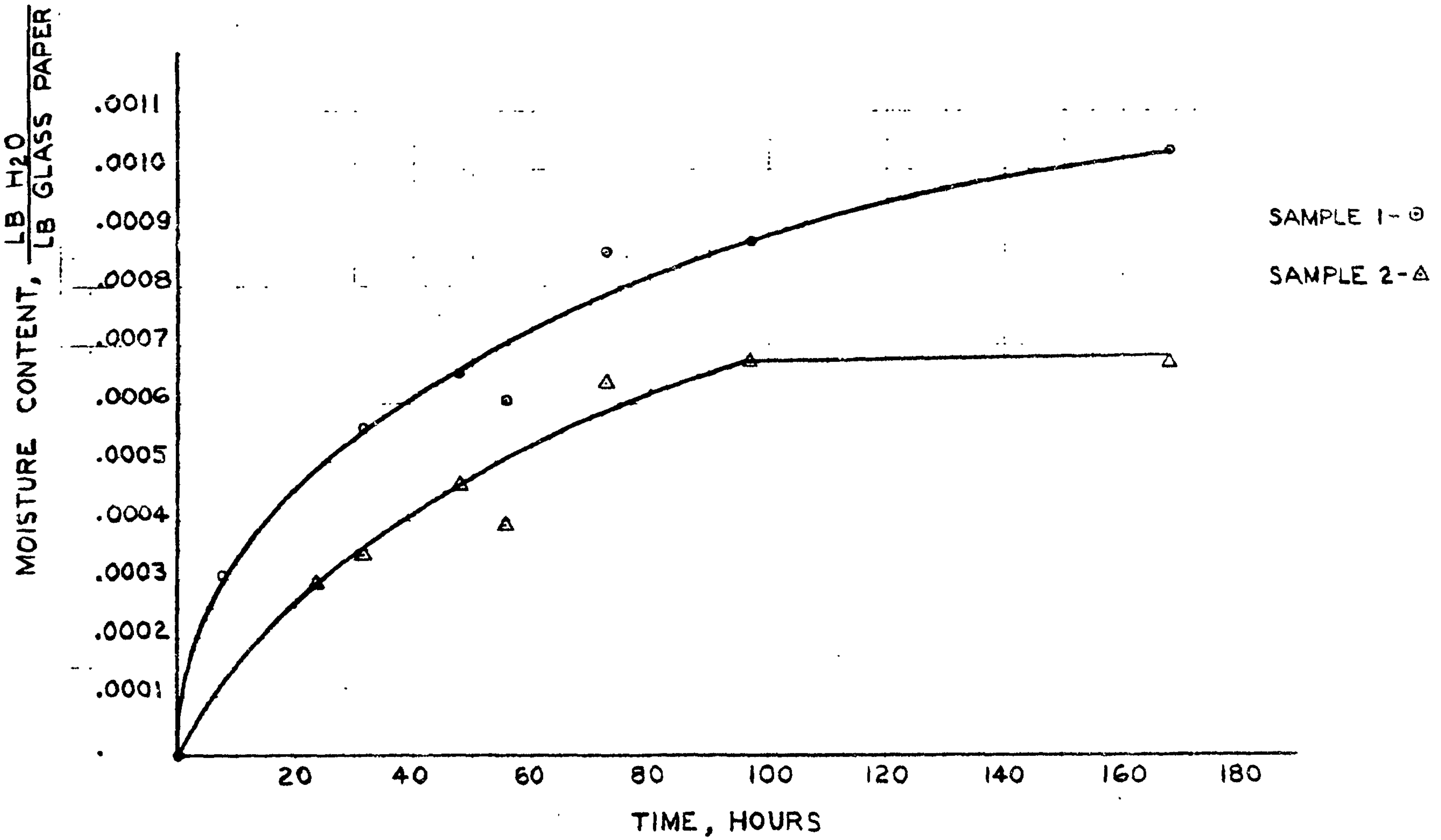


FIGURE 21

TOTAL OUTGASSING vs TIME AT AMBIENT TEMPERATURE

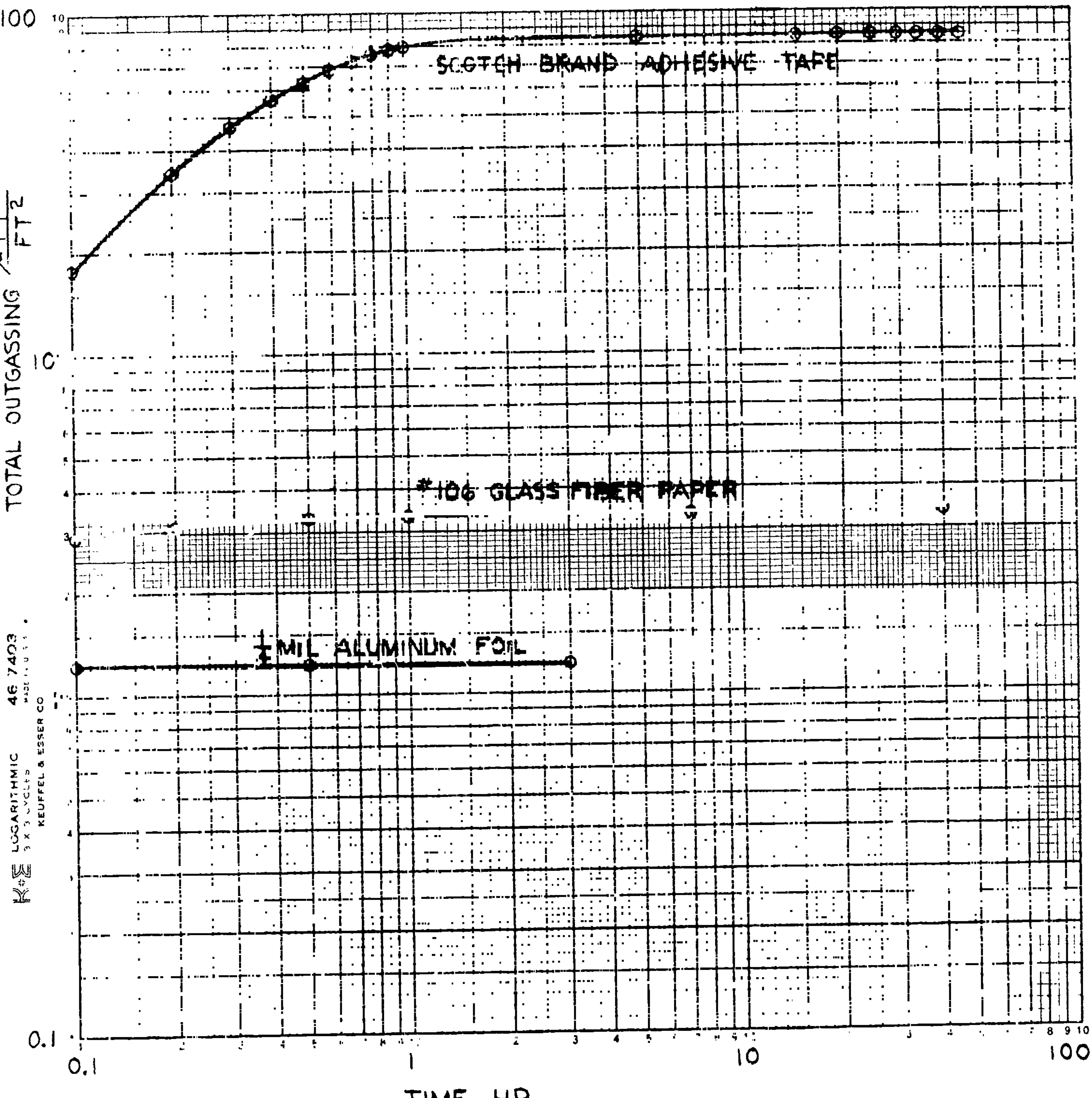
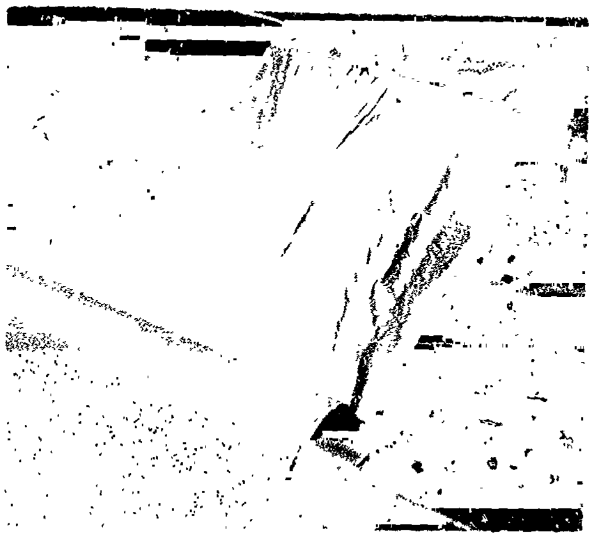


FIGURE 22

A

Foil Passing Over Perforator
Bottom View



B

Foil Passing Over Perforator
Top View

FIGURE 23

Linde Protrusion Perforator

Some of the jagged edges could be avoided by cutting small slits in the foils by means of razor edges in the roller perpendicular to its axis. Excessive tool dulling and tearing of the foils might become troublesome, however.

3.2.4.2 Puncturing After Installation:

Puncturing the insulation after it has been installed is the simplest method of perforating, but care must be exercised to prevent thermal short circuits between shields. A 1/32 - inch diameter pointed needle is recommended for this operation, and because of the likelihood of shorts, it should only be used in localized areas such as over the adsorbent trap.

3.2.4.3 Burning With An Electric Spark:

A bench scale test was conducted by passing the aluminum foil between two electrodes and attempting to vaporize the foil by an electric spark. Because of the high thermal conductivity of the foil, the heat was carried away from the area of the hole, excessive voltages were needed, and the material was physically weakened. Tooling would also be expensive and complicated, so the method has been discarded.

3.2.4.4 Punching By Air Jet:

An attempt was made to perforate a foil by aiming a jet of air at it. Ragged holes resulted, and since tooling would be expensive if the method were developed, it too, was discarded from further consideration.

3.2.4.5 Mechanically Punched Individual Holes:

A cam actuated device to bring sharp pins down onto the foil as it is being wrapped on the tank punctures uniform holes, but the edges are about as ragged as those formed by the roller perforator, and since the tooling would be more complex than the roller, no further consideration was given.

3.2.4.6 Ground Perforations:

Passing the foil between two small grinding wheels during application was considered as a means of removing metal without leaving ragged edges. The very stringent dimensional tolerances to cause the wheels to just come in contact within the 0.00025 inch thickness of the foil, however, make the method impractical.

3.3 Thermal Recovery Test Program:

One of the prime objectives of this overall program was to demonstrate the feasibility of the multi-layer Super Insulation concept, pre-evacuated so that it is compressed during the ground hold phase of the mission, but achieving performance approaching that of uncompressed Super Insulation as the compressive load is relaxed. The importance of achieving and maintaining good vacuum to a satisfactory test has already been pointed out, but the degree with which the insulation system can approach optimum performance after compression is also basic.

That the concept of pre-evacuated insulation was attractive for further development had been indicated by the Linde in-house tests described above. Those tests had been conducted on a very small scale with a thin plastic jacket which apparently did not hamper thermal recovery, and the insulation was initially applied at greater than optimum density. A development test program was therefore undertaken to determine the degree with which insulation system would approach optimum performance after compression, the effects of cycling the compressive load, and the effects of the lead-Mylar vacuum jacket. As a correlary, this testing also served to check out the vacuum jacket manufacturing techniques proposed for the full scale tank.

One of the ground rules associated with this program was that only materials within the state of the art were to be employed for purposes of the feasibility demonstration. For this reason, most emphasis in the recovery test program was devoted to the number 106 fiberglass spacer and 1/4 mil aluminum foil which has been designated Linde SI-62. This system has been the most widely applied in commercial cryogenic service, and considerable data were available. In addition, one test series was conducted with a heavier fiberglass paper nominally ten mils thick.

3.3.1 Summary Of Results:

The apparatus employed for the recovery tests consisted of a cylindrical vessel with ellipsoidal heads. It was 15-1/2 inches in diameter and 42-1/2 inches long. This inner vessel was placed inside a bell jar so equipped that the insulation when encased in its flexible jacket could be evacuated separately from the bell jar. Vacuum pressure, liquid nitrogen evaporation rate, and temperatures were monitored.

Seventy layers of SI-62 were applied to the test container at a nominal thickness of one inch - approximately optimum density for this system. The heat leak for this system was predicted to be 1.97 Btu/hr based on actual insulation thickness.

The test results with the SI-62 system are shown in Table 6. A base run was conducted without a flexible jacket for correlation with the predictions. A heat leak of 1.85 Btu/hr (corresponding to a thermal conductivity of 2.05×10^{-5} Btu/hr-ft-°R) over the cylindrical test area was measured which was within the ten per cent accuracy desired.

A "loose jacket" was fabricated in the form of a right cylinder with flat ends and installed over the insulation. Lead-Mylar laminate was used for the jacket. Two cycles of compression and relaxation were made with the heat leak measured as 3.19 and 3.64 Btu/hr respectively The apparatus was disassembled to permit thickness measurements and to determine the effects of wrinkling on the insulation. Immediately upon removal of the jacket a thickness of 0.72" was measured for the cylindrical portion of the insulation. The best estimate of thermal conductivity after two compressions was 2.73×10^{-5} Btu/hr-ft-°R which is quite low for the estimated layer density of 97 layers/inch reported previously. The unjacketed test was repeated and a conductivity of 2.34×10^{-5} Btu/hr-ft-°R at a layer density of 80 layers

TABLE 6

SMALL SCALE RECOVERY TESTS

NO. 106 GLASS PAPER

EVENT	Q EXPERIMENTAL, BTU/HR.	Q THEORETICAL, BTU/HR.	THERMAL CONDUCTIVITY, BTU/HR. FT. R° X 10-5	CYLINDRICAL SECTION LAYER DENSITY, LAYERS/INCH	CYLINDRICAL SECTION THICKNESS, INCHES
UNCOMPRESSED INSULATION					
THEORETICAL HEAT LEAK.		1.97	2.15	70	1
THERMAL TEST.	1.85				
RATIOED THERMAL CONDUCTIVITY.			2.02		
JACKET NO. 1 INSTALLED					
RECOVERED THERMAL TEST AFTER 1 COMPRESSION.	3.19				
RECOVERED THERMAL TEST AFTER 2 COMPRESSIONS.	3.64				
JACKET NO. 1 REMOVED					
INSULATION THICKNESS.				97	.72
THEORETICAL HEAT LEAK.		2.86	2.15		
RATIOED THERMAL CONDUCTIVITY.			2.73		
UNJACKETED THERMAL TEST.	2.71				
INSULATION THICKNESS AFTER THERMAL TEST.				80	.875
THEORETICAL HEAT LEAK.		2.49	2.15		
RATIOED THERMAL CONDUCTIVITY.			2.34		
JACKET NO. 2 INSTALLED					
COMPRESSED INSULATION THEORETICAL HEAT LEAK.		143.70	50		
THERMAL TEST.	174.50				
RECOVERED THERMAL TEST AFTER 5 COMPRESSIONS.	6.58*				
RECOVERED THERMAL TEST AFTER 7 COMPRESSIONS.	7.34*				
RECOVERED THERMAL TEST AFTER 10 COMPRESSIONS.	7.10*				
JACKET NO. 2 REMOVED					
INSULATION THICKNESS.				114	.62
THEORETICAL HEAT LEAK.		3.21	2.15		
RATIOED THERMAL CONDUCTIVITY			4.40		
UNJACKETED THERMAL TEST NECKTUBE SLEEVE ATTACHED.	4.95				
INSULATION THICKNESS AFTER THERMAL TEST.				79	.89
UNJACKETED THERMAL TEST NECKTUBE SLEEVE REMOVED.	3.75				
INSULATION THICKNESS AFTER THERMAL TEST.				78	.895
THEORETICAL HEAT LEAK.		2.65	2.15		
RATIOED THERMAL CONDUCTIVITY.			3.04		

* CORRECTED FOR HEAT LEAK CHARGEABLE TO THE NECK SLEEVE.

per inch was obtained. Severe wrinkling of the insulation was noted in the area of the knuckles around the heads. This was apparently due to the loose fitting jacket, and it was decided to fabricate a new jacket with formed heads, vacuum stretched to mate more closely with the contour of the insulation. It was felt to be more important to get an estimate of the effects of a greater number of compressions on the insulation than to demonstrate any better performance that might have been achievable by reinsulating to reduce the wrinkling due to excessive jacket deformation.

After installation of the new jacket, eight more compression-relaxation cycles were conducted with NER tests conducted after 5, 7, and 10 cycles. Some error in these measurements was introduced because of the manner in which the neck tube jacket was installed, but after removal of the jacket and measurement of this effect, it was conservatively estimated that the thermal conductivity after ten compression cycles was 4.4×10^{-5} Btu/hr-ft-°R at a layer density of 114 layers per inch. Inspection of the insulation in the area around the neck tube indicated that there was still some degree of thermal shorting in the area, so that this value is considered to be high, but it does demonstrate the feasibility of the system.

Whenever the flexible vacuum jacket was removed and heat transfer measured without the jacket, a lower thermal conductivity was measured. This is attributable to "fluffing" of the insulation caused by flow of air out of the insulation during evacuation, and secondarily by the time effects on expansion of the insulation and some compression due to the jacket.

Some conclusions can be reached from these tests:

1. Design values of thermal conductivity of 3.5×10^{-5} Btu/hr-ft-°R at a layer density of about 95 layers/inch are reasonable for SI-62 systems. These figures are based upon an estimate of the effects of the small-scale tester on wrinkling of the insulation, the effects of the loose fitting jacket, and the effects of damage caused by the neck tube jacket.

2. Additional test work is needed to find a better spacer material, to evaluate the application of double aluminized Mylar as a radiation shield material for these systems and to evaluate the effects of applied layer density.

3. The fabrication and repair techniques employed are applicable to the 105-inch diameter test tank.

In an effort to find a system which would exhibit more predictable recovery characteristics and less physical deformation, an insulation system consisting of ten-mil thick fiberglass spacer and aluminum foil was tested on the same apparatus. The same procecures were employed, and the results are summarized in Table 7 with a comparison with the two-mil spacer. Since the effects of build-up in the knuckle areas and overall layer density were not available, the comparison is limited to average heat flux measurements, and estimates of the K value. It may be concluded, however, that the thicker

TABLE 7

TEST RESULTS - THERMAL PERFORMANCE OF 10 MIL AND 2 MIL THICK SPACER

Test	10 MIL			2 MIL		
	$\frac{Q}{A}$	k	t	$\frac{Q}{A}$	k	t
	Btu/hr.ft^2	Btu/hr.ft°R x 10^{-5}	Inches	Btu/hr.ft^2	Btu/hr.ft°R x 10^{-5}	Inches
Before Jacket Application	0.214	4.42	0.99	0.127	2.73	1.01
Vacuum Jacket installed, insulation compressed 1 atm.	9.35	53.5	0.275	11.9	54.1	0.212
Recovery from 1 atm. compression-1st cycle	1.05	15.9	0.725	0.22	3.38	0.72
Recovery after 10th cycle	0.99	15.1	0.725	0.489	6.44	0.616
Jacket removed	--	--	--	0.258	4.91	0.89

spacer system exhibits a higher initial thermal conductivity and is more seriously degraded by compression than is the system utilizing the two mil paper. It has the advantages of easier installation and less dimensional deformation, however. Because of its poorer thermal performance, it was not recommended for the 105-inch test tank.

3.3.2 Insulation Design And Application, 2-Mil Paper Spacer:

A spirally-wrapped cylindrical insulation section 41-1/2 inches in length was selected. This length allowed coverage of the cylindrical section and a 3-inch extension at each bulkhead for interleaving of head disks.

Two 3/4-inch bulking strips of No. 106 fiberglass paper located 24 inches apart on the tank center were selected to maintain the specified layer density, 70 layers per inch.

Necktube insulation consisted of 10 layers of SI-62 applied helically with each succeeding layer extending 1-1/4 inch above the layer beneath it. An overall insulated length of 13 inches was obtained. The helically-wrapped insulation system was selected because it is easily applied and closely approaches the thermal performance of the ideal case that would be achieved by temperature matching layers of insulation to the necktube.

For insulation of the cylindrical section the insulation rolls and bulking strips were positioned as shown in Figure 24. One 24-inch and one 50-inch wide aluminum foil was used in the insulation in order to simulate the two rolls of aluminum foil that would be used in insulation of the 105-inch diameter tank. As the two aluminum foil rolls were spiraled on the tank each layer was taped together with two, four-inch long, 1/4-inch wide pieces of Scotch brand adhesive tape to simulate the envelope method of insulation support. Tape application areas were indexed approximately ten degrees on each layer to prevent local buildup.

The 24-inch aluminum foil roll was positioned to overlap the 50-inch roll by 1/2-inch leaving an excess of 32 inches which was trimmed away with an electric carving knife. This operation is shown in Figure 25.

Insulation thickness measurements taken after the cylindrical wrap varied from 7/8 to 1-5/16 inches.

Upon completion of the cylindrical wrap the vessel was removed from the wrapping machine and placed with the necktube down in a stand. Figure 26 shows the vessel in the stand prior to bottom head disk application. The bulkhead was then insulated by folding down cylindrical insulation layers and interleaving and taping to the head disks.

The vessel was then turned 180 degrees and supported on several layers of polyurethane foam in a holding frame to avoid any local loading of the insulated bottom head.

Cylindrical Wrap

FIGURE 24

Trimming Excess Insulation With Electric Knife

FIGURE 25

Vessel in Stand Before Bottom Head Disking

FIGURE 26

A copper-constantan thermocouple was attached to the base of the necktube. Insulation was next applied for a length of 13 inches measured from the bottom of the necktube.

To permit installation over the necktube and avoid short-circuiting on the necktube each head disk had a one-inch diameter hole cut in the center. Top head insulation was accomplished in the same manner as the bottom head. Thickness measurements taken on the center circular portion and at the bulked knuckle overlap areas varied from 1-3/4 inch to 1-29/32 inch.

A thermal analysis was made of the insulated tank before the initial normal evaporation rate test was made. This analysis was based on the actual insulation thickness measurements and the known thermal conductivity-layer density relationship. Since the actual data to be presented from testing will be the thermal conductivity of the insulation on the cylindrical section of the tank, it is important to assess the heat leak of such areas as the bulkheads, overlapped bulked areas, bulking strip areas, and necktube heat leak recovery. Total calculated heat leak amounted to 1.97 Btu/hr. Table 8 lists the breakdown of the total heat leak.

3.3.3 Test Apparatus:

The test apparatus is shown schematically in Figure 27. The vacuum container used in these experiments was a 20-inch O.D. carbon steel bell jar approximately 6 feet in height. The top head of the bell jar is flanged for quick assembly and disassembly. Six 1/2-inch diameter Veeco couplings were welded in place circumferentially around the bell jar to contain 1/8-inch diameter rods used to measure physical recovery on the insulation. Vacuum seal of the measuring probes is effected by inserting hollow glass tubes into the Veeco couplings. Because of wrinkling of the jacket, the thickness measurements exhibited too much scatter to be of any value. Two 3-inch diameter view ports are also installed on the bell jar.

Gaseous nitrogen evolved from the test vessel first passes through an orifice flow meter for instantaneous measurement, then through an absolute pressure maintenance system to eliminate the effects of atmospheric pressure variations and finally through a wet drum displacement meter. The wet drum meter was used to obtain total flow over a measured time period and was the prime measure of evaporation rate. The absolute pressure maintenance system consisted of an absolute pressure transmitter, absolute pressure controller, and throttling valve. Accuracy of the system is one millimeter of mercury pressure. Barometric pressure measurements were noted with a recording barometer.

3.3.4 "Loose Jacket" Tests:

In order to establish a base point for optimum insulation performance an uncompressed insulation NER* test was conducted without the flexible vacuum jacket installed. Because of outgassing and leakage problems with the bell jar, approximately one week elasped before equilibrium was attained.

*NER = normal evaporation rate

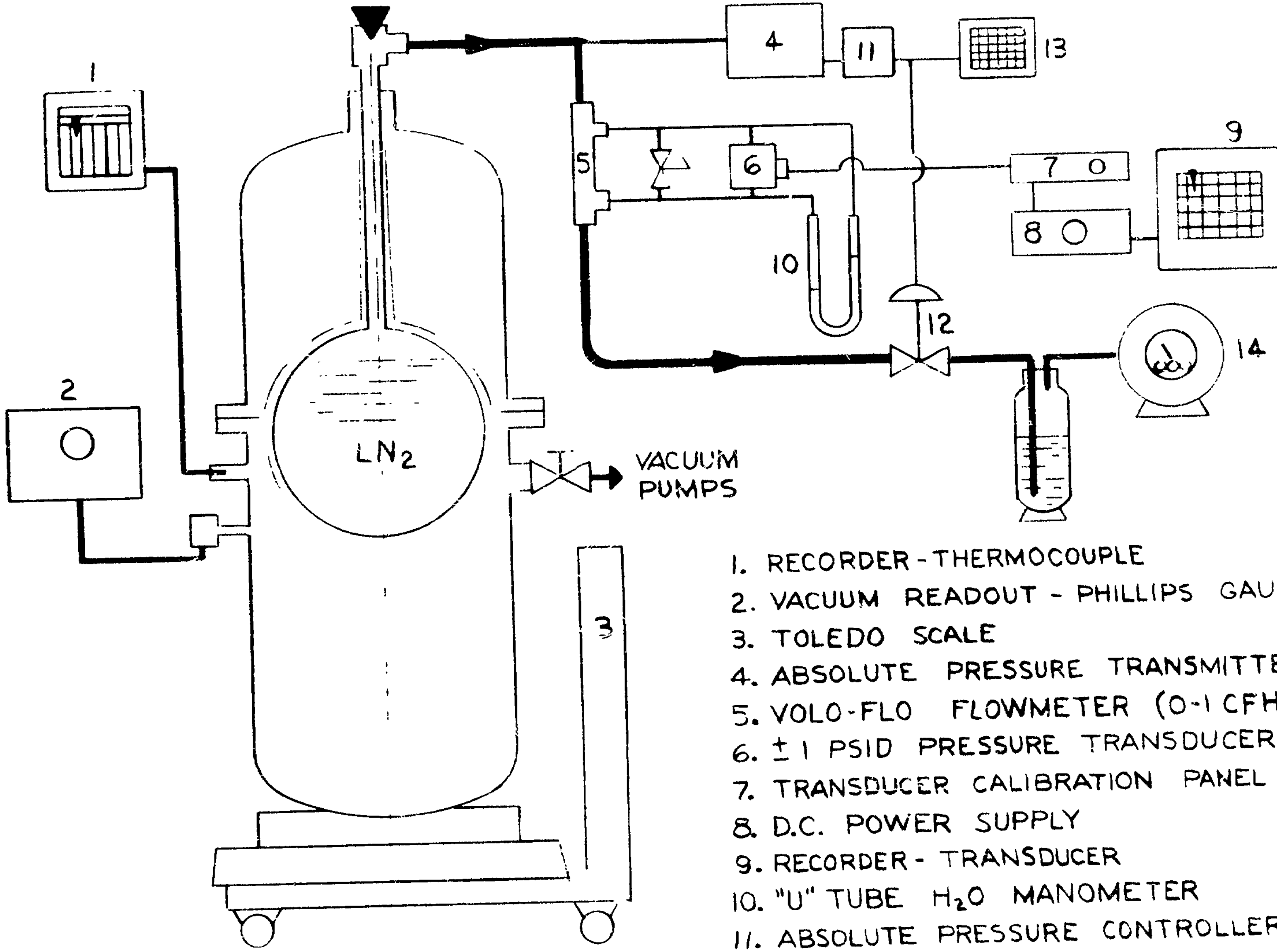
TABLE 8

UNCOMPRESSED INSULATION HEAT TRANSFER RECOVERY TESTER

SUMMARY

Head Areas	Btu/hr
Center circular	.069
Bulked knuckle	.393
Cylindrical Section	
Bulked Areas	.193
Cylindrical Portion	1.225
Necktube	.065
Thermocouple	.018
Necktube Filler Joint	.006
Total:	1.969 Btu/hr

TEST APPARATUS AND INSTRUMENTATION



1. RECORDER - THERMOCOUPLE
2. VACUUM READOUT - PHILLIPS GAUGE
3. TOLEDO SCALE
4. ABSOLUTE PRESSURE TRANSMITTER
5. VOLO-FLO FLOWMETER (0-1 CFH)
6. ± 1 PSID PRESSURE TRANSDUCER
7. TRANSDUCER CALIBRATION PANEL
8. D.C. POWER SUPPLY
9. RECORDER - TRANSDUCER
10. "U" TUBE H_2O MANOMETER
11. ABSOLUTE PRESSURE CONTROLLER
12. CONTROL VALVE
13. RECORDER, ABS. PRESSURE
14. WET DRUM FLOW METER

FIG. 27

Total heat leak of the vessel was 1.85 Btu/hr. This experimental heat leak compares well with the 1.97 Btu/hr predicted from insulation thickness measurements and is within the 10 per cent accuracy anticipated for the calculations.

Vacuum level during the test was .03 microns of mercury.

Temperature at the base of the necktube was -319°F. as measured by the thermocouple.

3.3.4.1 Compressed Test Number 1:

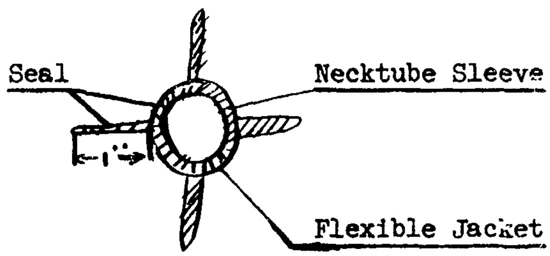
After the uncompressed insulation NER test was completed, the test tank was removed from the bell jar and the lead-Mylar vacuum jacket installed.

The cylindrical portion of the flexible jacket was fabricated by forming a section of lead-Mylar laminate 35-1/2-inch by 59 inches into a cylinder and heat sealing to itself. A one-inch overlap was provided. Sealing was accomplished on the 48-inch hot jaw sealer.

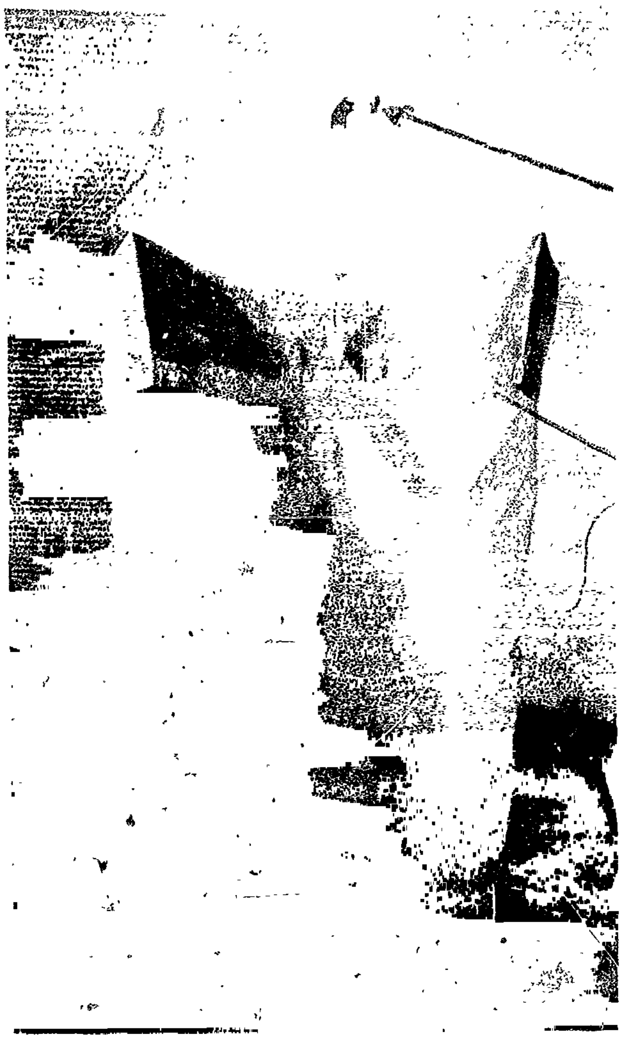
The bottom head cap was formed from a sheet of lead-Mylar laminate 27-1/2 inches square with 5-5/8 inch squares cut out of the corners to permit folding over and sealing to themselves with the hand iron. A pressure measurement fitting was attached to the bottom head cap by hand sealing the flexible jacket to the flange. A lap joint, sealed with the hand iron on the bench was employed to join the bottom head cap to the cylindrical section.

Figure 28 shows the cylindrical section with bottom head cap and pressure fitting attached. The completed sub-assembly was then slipped over the insulated vessel for top head cap and necktube jacket installation. The top head cap was formed in the same manner as the bottom head cap and joined to the cylindrical jacket section on the insulated tank with the hand sealing iron.

The necktube flexible jacket section was formed from a laminate cylinder, 2-3/16 in. in diameter and 15-1/2 in. long. It was attached to a 5/8-inch diameter sleeve at the top of the necktube by folding the laminate together to form four one-inch long leaves. Each leaf was sealed to itself and to the necktube sleeve as shown below:



The necktube jacket was attached to the head cap jacket by means of a flanged piece of aluminum tubing serving as a transition piece. The necktube jacket and head cap jacket were sealed to the transition piece with the hand sealer.



BOTTOM HEAD CAP JOINED TO CYLINDRICAL JACKET SECTION

FIGURE 28

The necktube jacket was designed with excess material so that movement could occur to allow for compression of the top head insulation under the transition piece when the insulation system was evacuated. This necktube jacket flexibility was accomplished by inserting glass paper around the transition joint.

An evacuation port consisting of a 1-1/8-inch diameter copper tube attached to a 3-inch diameter flange was attached to the top head cap by sealing the jacket to the flange with the hand iron.

The compressed insulation test procedure consisted of inserting the jacketed vessel into the bell jar and evacuating both insulation and bell jar, care being taken to avoid either compression of the insulation or an internal differential pressure against the jacket. Dry nitrogen gas was then bled into the bell jar compressing the insulation. Several vacuum leaks appeared in the area around the bottom head vacuum gauge and at top and bottom head cap lap joints and the insulation pressure rose immediately. Full physical compression of the insulation was effected but it was impossible to conduct a thermal test with the insulation compressed. In order to maintain the test schedule, leak detection and repair of the jacket was not undertaken and a recovered thermal test was begun.

3.3.4.2 Recovered Test No. 1:

The test tank with the insulation compressed was placed in the bell jar, the bell jar re-evacuated and the vessel filled with liquid nitrogen. A pressure level of 0.025 microns in the insulation and 0.06 microns in the bell jar was attained with dynamic pumping during the test.

Temperature at the base of the necktube was -318.5°F. as measured by the thermocouple.

Total heat leak was calculated to be 3.19 Btu/hr. This result showed the complete thermal recovery was not attained, possibly due to incomplete physical recovery due to local effects of the jacket. Since the accurate thickness measurements of the recovered insulation required to calculate a recovered k would involve removing the flexible jacket it was decided to run a second compression-recovery cycle to determine the effect of cycling on thermal performance.

3.3.4.3 Compressed Test No. 2:

The liquid nitrogen was dumped from the vessel, the vacuum was broken with dry nitrogen and the jacketed test vessel removed from the bell jar.

Several vacuum leaks were found in the bulkhead to cylindrical section lap joints, bottom bulkhead vacuum gauge and a cylindrical section area that was abraded by rubbing on the side of the bell jar when the test vessel was inserted into and removed from the bell jar. No leakage was found in the longitudinal seam of the cylindrical section, the only seam made with heating and cooling under controlled pressure on the hot jaw sealer.

Repair techniques consisted of applying lead-Mylar laminate patches, sealed with Schjeldahl GT-100 liquid resin and the hand iron, to larger leak areas and painting small leaks with Armstrong A-12 epoxy diluted with chlorethene solvent.

In order to maintain the test schedule, complete jacket leakage was not eliminated and a compressed thermal test was not run. Complete physical compression of the insulation was attained, however.

3.3.4.4 Recovered Test No. 2:

The jacketed vessel was returned to the bell jar and a second recovered thermal test was run. Pressure level in the bell jar was 0.04 microns and 0.01 micron in the insulation volume.

Jacket temperature was measured by iron-constantan thermocouples attached to the top head and cylindrical section. Top head jacket temperature was 62.5°F and cylindrical jacket temperature was 73.5°F. The temperature difference is attributed to the higher thermal conductivity value experienced for the head insulation because of wrinkling. Since the thermal conductivity of the jacket material parallel to the insulation is not as high as that of the aluminum radiation shields, it is expected that higher temperature gradients would exist on the jacket than on layers of the insulation itself.

The total heat leak was found to be 3.64 Btu/hr somewhat higher than the 3.19 Btu/hr heat leak attained with the first recovery test.

In order to investigate the cause of the degradation of thermal performance the apparatus was removed from the bell jar and the flexible jacket removed at the conclusion of the second recovered test. Wrinkling of the flexible jacket caused a permanent set to develop in the knuckle sections of the bulkheads, where head disks and cylindrical insulation are overlapped, and longitudinally in the cylindrical section. The loose jacket design apparently allowed the excess jacket material to grasp and wrinkle portions of the insulation during compression. The further degradation of the thermal performance after the second compression may be due to: wrinkling and setting of the insulation due to the jacket design or a degradation of the insulation that occurs with repeated cycling or a combination of both effects.

Figure 29 shows the insulation with the jacket removed after the second compression recovery cycle.

Insulation thickness measurements showed that complete physical recovery of the insulation was not attained. A thermal analysis of the insulation was made based on the new thickness measurements. Theoretical heat leak was calculated to be 5.97 Btu/hr nearly 65 per cent greater than the experimental heat leak of 3.64 Btu/hr. The theoretical heat leak was then recalculated, this time based on the original uncompressed thermal conductivity values and the actual measured insulation thickness. This time the theoretical heat leak amounted to 2.86 Btu/hr, some 27 per cent less than the experimental value. These calculations indicate that the apparent thermal conductivity of the insulation is not so significantly degraded by

Unjacketed Insulation After Two Compressions

FIGURE 29

compression but that the increase in overall heat leak is due to the decrease in insulation thickness (incomplete physical recovery). It would appear that the entire thermal conductivity versus layer density curve has shifted in the direction of higher layer density and the thermal performance of an insulation system that has been compressed and recovered cannot be calculated with accuracy from uncompressed thermal conductivity versus density values.

An apparent thermal conductivity of 2.4 x 10^{-5} Btu/hr-ft°R was obtained for the cylindrical or test portion of the insulation by ratioing theoretical to experimental heat leaks.

In order to further investigate thermal recovery an NER test was conducted with the jacket removed.

3.3.4.5. Unjacketed NER Test:

The insulated test tank was returned to the bell jar and an NER test conducted. Pressure level in the bell jar was 0.04 microns.

Temperature of the outer layer of insulation was measured with iron-constantan thermocouples attached to the top head and cylindrical portion. The temperature of the top head was 72°F and the cylindrical portion 74°F. This temperature gradient is attributed to the higher thermal conductivity of the wrinkled head insulation and is much less than the jacket temperature gradient of 11°F measured during Recovered Test 2. This is attributed to the thermal conductivity of the aluminum foil, parallel to the insulation, being much greater than that of the jacket material thus tending to establish an isotherm.

Total heat leak was found to be 2.71 Btu/hr, about 13.4 per cent less than the 3.64 Btu/hr obtained during Recovered Test 2.

Insulation thickness measurements made on the insulation after the test, showed that the insulation had further recovered physically. A possible explanation for the further physical recovery is that when a vacuum is created around the outer layer of unjacketed insulation a pressure gradient is created through the insulation to the innermost layer which is still at atmospheric pressure. This driving force may tend to expand the insulation. Another possibility is that further recovery of the insulation with time has taken place.

A thermal analysis of the insulation was made based on the known k versus N data and the actual thickness measurements. The heat leak was calculated to be 4.14 Btu/hr. The theoretical heat leak was then re-calculated based on the original uncompressed thermal conductivity values and the measured thickness values. A heat leak of 2.49 Btu/hr was obtained which correlates rather well with the experimental value.

An apparent thermal conductivity of 2.2 x 10^{-5} Btu/hr-ft°R was obtained for the cylindrical or test portion of the insulation by ratioing theoretical to experimental heat leak.

3.3.5 "Tailored Jacket" Tests:

The same insulation was used in this second test series.

It was the objective of this second test series to further investigate the effect of compression cycling on insulation performance, to fabricate a vacuum-type lead-Mylar vacuum jacket and to conduct a thermal test of the compressed insulation.

Examination of the insulation after the first test series showed that the wrinkling around the knuckle areas apparently was not severe enough to warrant reinsulation of the test apparatus. Furthermore, the experience gained from a greater number of compression recovery cycles would be more valuable than any improvement in the thermal performance of the insulation that would be gained by reinsulating. Since the most critical problem involved in the flexible jacketed Super Insulation concept is the maintenance of vacuum integrity, particular emphasis was placed on this problem during these tests.

The lead-Mylar vacuum jacket was fabricated in three parts. The heads were vacuum-formed by pressing into a female mold at elevated temperature with flanges formed around the circumference into a tee joint to mate with the cylindrical jacket portion. The cylindrical jacket section was fabricated by forming a section of lead-Mylar 39-1/2 inches by 57-3/4 inches into a cylinder and heat sealing to itself. Sealing was accomplished with the 48-inch hot jaw sealer and the ends of the cylindrical portion were heat-joined to form a tee joint for mating with the head caps. Figure 30 shows the cylindrical section and bottom head cap prior to joining.

Since the results of the first test series showed that vacuum jacket seams made with heating and cooling under controlled pressure were much more reliable than seams made with a hand iron, a portable heat sealer with a six inch jaw was obtained and modified to provide a cooling cycle. This device was used to join the cylindrical jacket section to the head caps. Sealing of the two jacket penetrations, a connection for the Phillip's vacuum gauge at the bottom and a Type 304 stainless steel necktube sleeve at the top, was accomplished with bolted O-ring flange connections. It was felt that a more reliable vacuum joint could be achieved with O-ring flanges than could be obtained by sealing the vacuum jacket to a metal surface with a hand iron. Figure 31 shows the necktube sleeve with O-ring flanges.

The bottom flange of the necktube sleeve was designed to compress the insulation to about 1/2 inch in order to prevent the flexible jacket from being drawn under the flange and damaged during evacuation. During fabrication, however, the sleeve was inadvertently installed so that the insulation was compressed to 1/4 of an inch.

Before jacket installation, a 15-mil thick Glass Fiber paper layer was taped over the insulation. This was installed to enhance leak detection and experience proved it to be quite satisfactory.

Figure 32 shows the jacketed test tank before evacuation.

FIGURE 30

Cylindrical Jacket Section and Head Cap

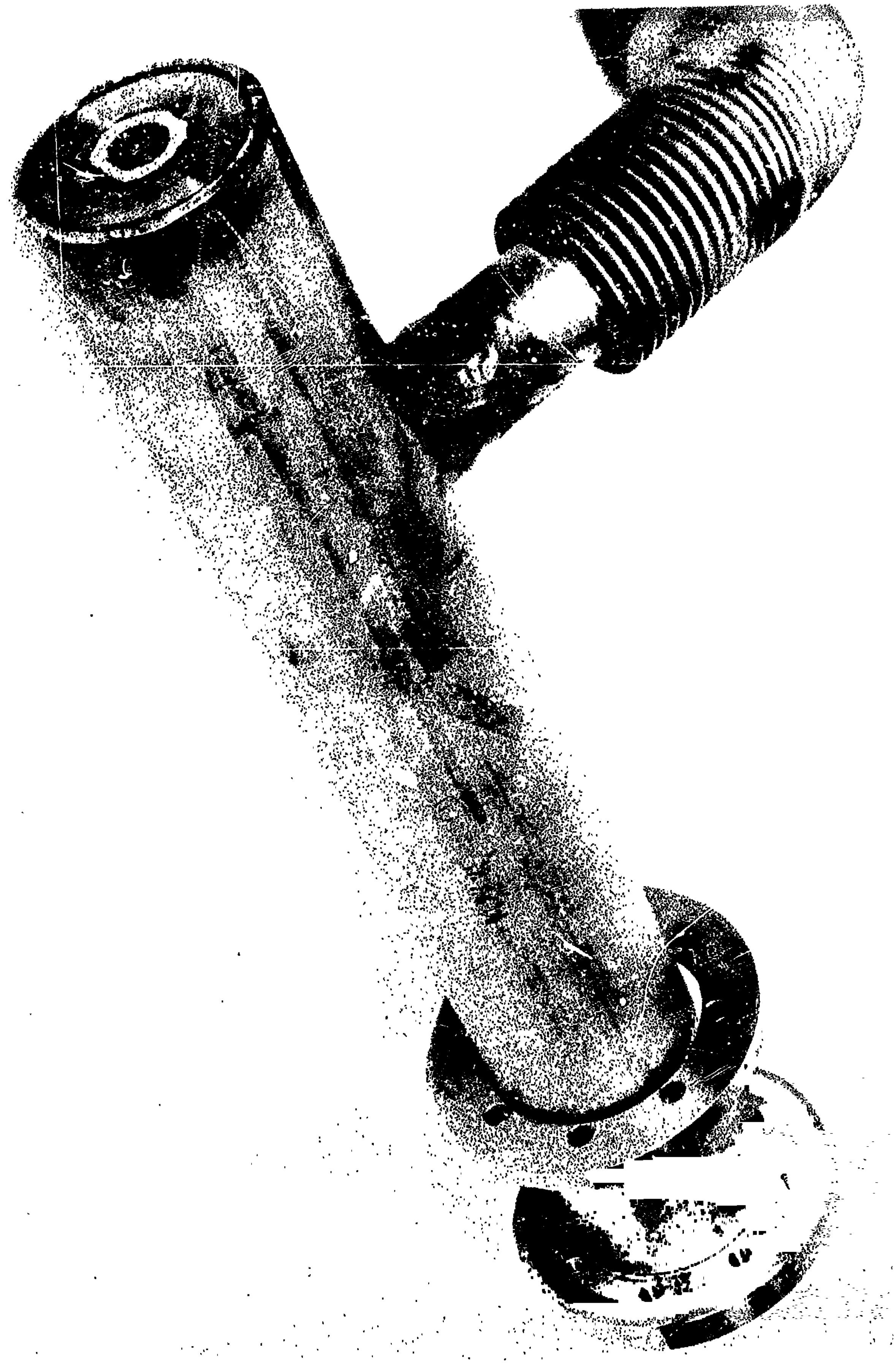


FIGURE 31

Necktube Vacuum Jacket

FIGURE 32

Jacketed Vessel Before Evacuation

The jacketed apparatus was evacuated outside of the bell jar to facilitate leak detection and permit observation of the compressed insulation system.

Figure 33 shows the evacuated apparatus with the insulation compressed. Leak detection with a mass spectrometer disclosed several small leaks in the bottom head cap to cylindrical section tee joint. Sealing was accomplished by painting with a 20-80 solution of Armstrong A-12, two-part epoxy adhesive and chlorothene solvent. After bake-out, the pressure in the jacketed insulation settled out to 70 microns after 2-1/2 hours.

The insulation system was blanked off from the vacuum pump and the vessel filled with liquid nitrogen. Pressure measured with the Phillip's gauge at the bottom of the insulation system was 30 microns, and at the evacuation port, 0.8 microns. Dynamic pumping was resumed and the pressure level fell to 0.001 microns at the evacuation port and 0.07 microns at the bottom head. This pressure reduction is attributed to cryopumping of condensibles when the vessel was filled with liquid nitrogen and removal of non-condensibles when dynamic pumping was resumed.

The insulation system was again blanked off from the vacuum pump and a settle-out pressure, 0.12 microns, was measured at the evacuation port and insulation bottom. An NER test was conducted, and total heat leak was calculated from the evaporation rate.

Total heat leak amounted to 174.5 Btu/hr. compared with a theoretical value of 143.7 Btu/hr. The 21 per cent difference between experimental and theoretical heat leak values is attributed to assumptions made in the layer densities of the compressed insulation at the bulked knuckle sections in the theoretical calculations and the effects of compression at the necktube jacket.

The test apparatus with the insulation still compressed was installed in the bell jar and the bell jar evacuated.

A series of six more compression recovery cycles were conducted. This amounted to a total of ten insulation compressions when the compressions of the first test series are included.

The cycling procedure consisting of filling the evacuated and compressed vessel with liquid nitrogen while in the bell jar, evacuating the bell jar to achieve recovery and then recompressing by admitting dry nitrogen gas to the bell jar. During testing, insulation pressure, bell jar pressure, evaporation rate, and ambient temperature and pressure were recorded. Figure 34 shows the test results plotted as insulation heat flux and bell jar pressure as a function of time after compression and during recovery. Approximately 22 hours were required after compression before the heat flux stabilized, although the most significant recovery took place in the first six hours.

An NER test conducted on the recovered insulation, after the fifth cycle, for a 35 hour period, disclosed a heat leak of 7.8 Btu/hr.

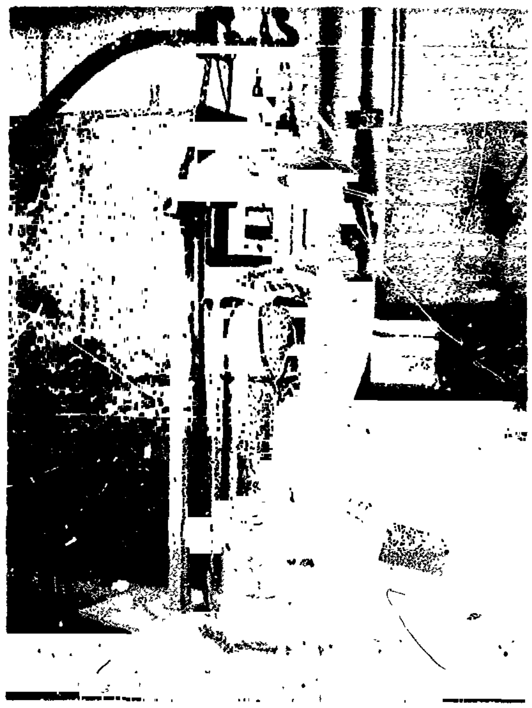


FIGURE 33

Jacketed Test Vessel After Evacuation

INSULATION HEAT FLUX AND BELL JAR PRESSURE DURING RECOVERY

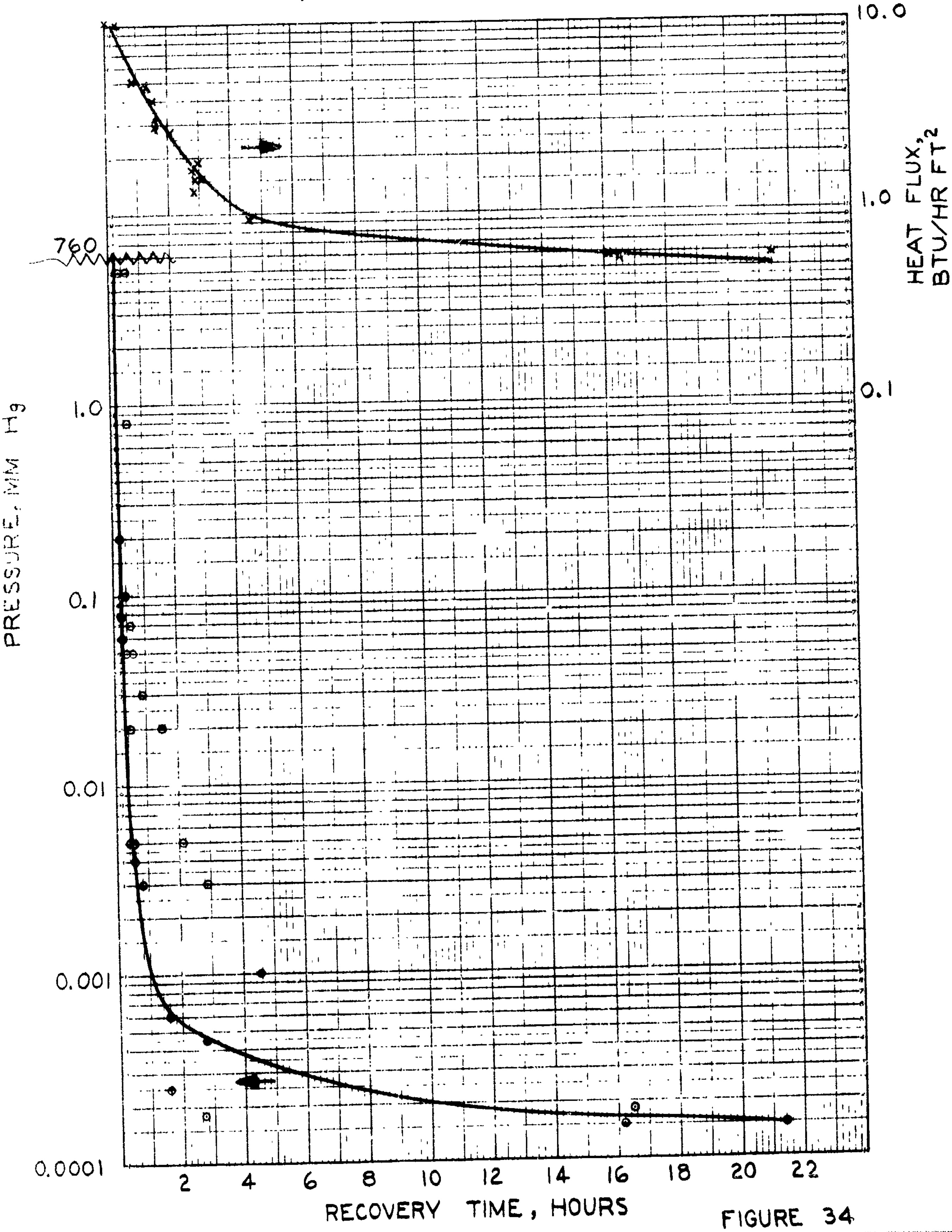


FIGURE 34

Later tests showed that 1.2 Btu/hr. of this heat leak can be attributed to the necktube sleeve, making the heat leak chargeable to the insulation in this case 6.6 Btu/hr. NER tests conducted for approximately 15 hour periods at the conclusion of compression cycles seven and ten disclosed heat leaks of 7.3 and 7.1 Btu/hr. respectively. The heat leaks reached in these 15 hour periods do not represent thermal equilibrium because of the short time period, and since the heat leak after ten compressions was less than that after seven compressions, it is believed that overall insulation performance was not degraded from that of the fifth cycle.

At the conclusion of the tenth recovery cycle, the apparatus was removed from the bell jar and the flexible jacket removed. Inspection of the insulation disclosed that compression of the jacket had caused additional wrinkling to occur in the knuckle areas and in the cylindrical section, Figure 35. Insulation thickness measurements made after the jacket removal showed the insulation had not completely recovered physically; the cylindrical or test portion was now 0.62 inches thick (114 layers per inch). The degradation of insulation performance is, therefore, attributed to wrinkling of the insulation at sharp radii of curvature sections (knuckle areas) where the jacket grasped the insulation and incomplete physical recovery.

The unjacketed vessel with the necktube sleeve still attached was returned to the bell jar and an NER test conducted. Total heat leak was found to be 4.95 Btu/hr. Insulation thickness measurements made after the test showed that the insulation had recovered further physically. The cylindrical portion was now at 0.89 inches (78 layers per inch).

An explanation for the further physical recovery is that when a vacuum is created around the outer layer of insulation, a pressure gradient is created which tends to expand the insulation.

The necktube sleeve was removed and another NER test was conducted. The heat leak was found to be 3.75 Btu/hr. indicating that at least 1.2 Btu/hr. of the total heat leak is chargeable to the necktube sleeve. Insulation thickness measurements showed a slight further recovery. The cylindrical portion was now 0.895 inches thick (79 layers per inch). Inspection of the insulation under the necktube sleeve showed that it was possible for radiation shield shorting to have occurred in the head disk insulation around the necktube. For about the first ten layers of head disk insulation, radiation shields overlapped the spacer material by about 1/4 inch and if compressed, as would be the case with the necktube sleeve in place, would touch and thermally short.

3.3.6 Ten Mil Paper Spacer Tests:

The thermal recovery test results for the system 10-mil fiberglass paper spacer and 1/4-mil aluminum foil radiation shields were summarized in Table 7. The test results are presented in terms of heat flux for the various tests conducted, and a comparison is included with the results obtained with the nominally 2-mil thick paper spacer. A total of ten compression recovery cycles were employed. It will be seen that on the basis of the heat flux, the 2-mil thick paper offers better thermal performance in space. It is recommended, however, that additional tests

Insulation After Jacket Removal

FIGURE 35

be performed with these and other spacer material candidates, preferably in conjunction with double aluminized Mylar as a radiation shield material in order to get a better understanding of the problems involved and also to achieve a more optimum practical system.

Since the insulation application, the test procedures, and apparatus employed for this phase of the program were the same as those described above, these will not be repeated here. Forty layers of insulation were applied without bands. Layer density was maintained by tension on the aluminum rolls.

In applying the insulation, it seemed that the 10 mil spacer was about as easy to handle as was the 2-mil paper although it does seem to have much greater strength. The fact that roughly half as many layers are used would make insulation application much less laborious.

The initial thermal performance test conducted prior to application of the flexible jacket resulted in a thermal conductivity of between 4 and 5 x 10^{-5} Btu/hr-ft°R. This apparently represents a value close to the optimum for this system (forty layers per inch wrapping density) and is about 10 to 20% lower than expected. At forty layers per inch, the density is 7.5 pounds per cubic foot. On the basis of the conductivity-density product, the performance of this system is poorer than the 2-mil spacer-aluminum system by a factor of more than 3. After jacketing and compression cycling, the thermal performance was degraded by a factor of 3.5 or greater degradation than had previously been experienced with the 2 mil-thick paper. The conductivity values are based on the insulation thickness measured after removal of the jacket which value is highly suspect since the effects of compression due to the jacket and the time involved are removed. This value, therefore, should be viewed with suspicion.

Because this spacer material is less compressible and more rigid than is the thinner material, the heat flux with the jacket under a one atmosphere compressive load was only 136 Btu/hr with an insulation thickness of 0.275 inch. Compared with a measured heat flux of 174.5 Btu/hr at an actual thickness of about .21 inch for the 2-mil system, it is seen that this heavier spacer has an advantage in heat flux for the ground-hold period because of its greater thickness. The conductivity is the same for either system. The compressed insulation system is shown in Figure 36. Figure 37 is a plot of layer density versus compressive pressure for the 10-mil spacer. Equivalent data for the 2 mil spacer is included for comparison.

These curves were determined from a flat plate pneumatic powered tester and should be interpreted only as a direct comparison of the two spacer systems as tested on this flat plate apparatus. The absolute values of thickness under zero load conditions, as shown, are not indicative of values obtained on actual cylindrical vessels.

The degree of degradation in thermal performance of the 10 mil spacer is somewhat surprising since the material seems quite strong and resilient in handling, which would lead one to suspect that its dimensional and thermal repeatability would be quite good. At this point, the available data do not permit a thorough evaluation of the physical process, but

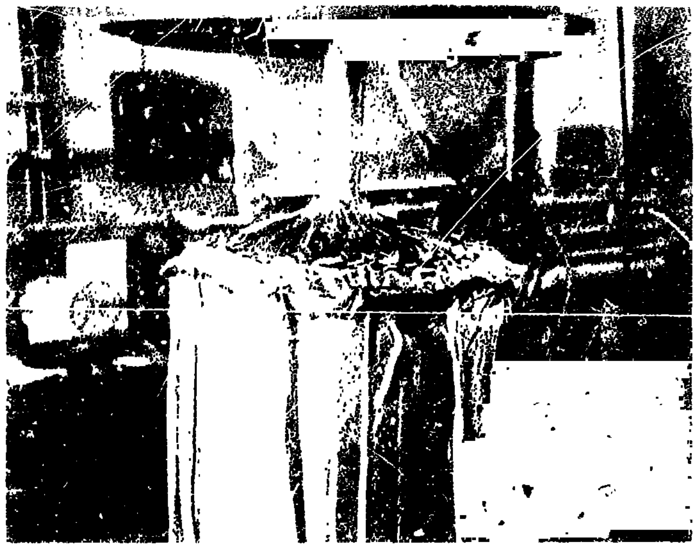
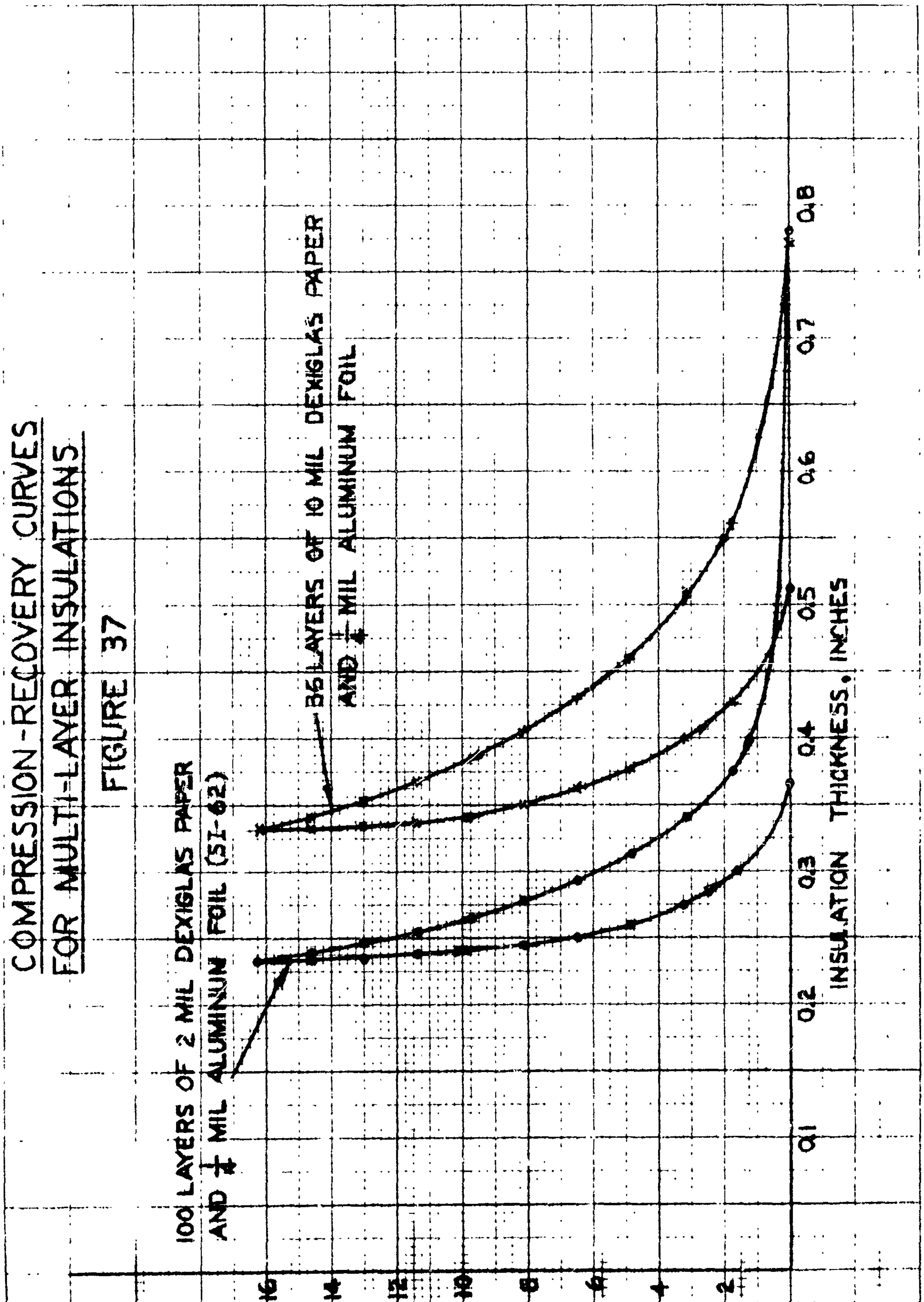


FIGURE 36
NECKTUBE SLEEVE

FIGURE 36B
CYLINDRICAL PORTION

Jacketed Test Vessel After Evacuation
Insulated With 10 Mil Dexiglas Paper


COMPRESSION-RECOVERY CURVES
FOR MULTI-LAYER INSULATIONS
FIGURE 37
100 LAYERS OF 2 MIL DEXIGLAS PAPER
AND 1/4 MIL ALUMINUM FOIL (SI-62)
35 LAYERS OF 10 MIL DEXIGLAS PAPER
AND 1/4 MIL ALUMINUM FOIL
COMPRESSION LOAD, PSI
16
14
12
10
8
6
4
2
0.1
0.2
0.3
0.4
0.5
0.6
0.7
0.8
INSULATION THICKNESS, INCHES

two related theories have been proposed to explain this performance. Banding was employed with the 2 mil-spacer system, but not for the 10-mil. Although these bands are located about two feet apart, they may have enough influence to obtain better thermal recovery. The other thought is that the greater resilience of the 10-mil paper may make it tend to recover physical dimensions better, but permanent set in the aluminum foils may tend to exert a compressive pressure on the spacer. This compressive pressure effect would oppose any inherent improvement in contact resistance that might be experienced in repeated compression recovery cycles. Additional development work will be necessary to evaluate the potential validity of these and other theories to permit rational explanation of the phenomenon and optimization of a system.

Review of the performance of the 10-mil thick system and comparison with the previous data indicates that while this material has the advantage of better dimensional stability during compression cycling, its poor thermal performance and heavier weight appear to make it less suited to this application than the thinner material. It was, therefore, recommended that 2-mil thick paper be utilized for the 105-inch tank and that additional efforts be exercised to find a more optimum material.

Removal of the flexible jacket and repetition of the thermal test was not deemed meaningful since it was noted earlier in the program that evacuation of the gas-filled insulation tends to inflate the layers somewhat, reducing the layer density and resulting in lower heat leak than would be experienced in the actual case.

4.0 PREDICTED PERFORMANCE OF 105-INCH DIAMETER TANK:

The design drawings for the NASA provided 105-inch diameter tank insulation system are attached as Appendix A. This section will describe the thermal analysis and summarize the predicted performance of the system. The following table lists a breakdown of the various contributions to the heat in-leakage to the tank as designed.

TABLE 9

PREDICTED PERFORMANCE -- 105-INCH DIAMETER TEST TANK*

	In Space Uncompressed	Ground Hold Compressed	Rigid Jacket Weight
Basic Insulation	83.5 Btu/hr	4150 Btu/hr	
Support Bands	12.7	45	
Total Thru Insulation:	96.2 Btu/hr	4195 Btu/hr	
Fill Line	17.0	17.0	5.42 lbs.
Vent Line	9.5	3.6	5.42
Instrument Line	18.3	18.3	5.42
Dummy Line	17.0	17.0	5.42
Struts (2 x 16.2)	32.4	32.4	20.0
A-Frame	7.1	7.1	21.91
Cold Jacket Joint	23.0	23.0	
Total Discontinuities:	124.3 Btu/hr	118.4 Btu/hr	
Total Heat Leak	220.5 Btu/hr	4313 Btu/hr	

It will be noted that the heat leak attributable to the insulation system itself is roughly equal to the heat leak through the various discontinuities during the in-space condition, which is a desirable design proportioning.

The weights included in Table 1 include the vacuum jackets, flange assemblies, and the rigid connection between the vacuum jacket and the member being insulated. The weights do not include weight of the insulation nor weight of the discontinuity itself. The evacuation connections are assumed to be self-supporting members attached merely for tests which would not necessarily be on a flight article, therefore, they too are excluded.

4.1 Insulation Heat Transfer:

As has been pointed out previously, it was decided to insulate the 105-inch tank with seventy layers of 2-mil number 106 fiberglass paper and 1/4-mil aluminum foil radiation shields at an applied layer density of

*In actual test of the 105-inch diameter tank, the cold joint was removed.

70 layers/inch. Further development is needed to determine a more desirable spacer-radiation shield combination for this application, and to determine the optimum applied layer density to achieve best performance after compression-relaxation cycling. The small scale development testing reported in section 3.4 above indicate that a thermal conductivity of 3.5×10^{-5} Btu/hr-ft-°R and a relaxed layer density of 95 layers per inch are reasonable to expect for this system after cycling. For an area of 300 ft^2 and a temperature difference of 493°R, the heat flow through the insulation is, then,

$$q = \frac{KA(T_1-T_2)}{x} = \frac{3.5 \times 10^{-5} \times 300 \times 493 \times 12}{70/95} = 83.5 \text{ Btu/hr}$$

for the case when the insulation is recovered in space.

During ground hold when the insulation is compressed, the thermal conductivity is 50×10^{-5} Btu/hr-ft-°R and the layer density is compressed to 330 layers per inch. The heat leak then becomes

$$q = \frac{KA(T_1-T_2)}{x} = \frac{50 \times 10^{-5} \times 300 \times 493 \times 12}{70/330} = 4150 \text{ Btu/hr}$$

Double filler bands are installed at two locations on the cylindrical portion of the insulation to affect support and layer density control during application of the insulation. As-applied, this results in a layer density of 210 layers per inch and a thermal conductivity of 22×10^{-5} Btu/hr-ft-°R for the space condition. Since this is above the relaxed density measured by test, no degradation is anticipated in this performance. During ground hold, this will compress to a layer density of 330 layer per inch and a corresponding conductivity of 50×10^{-5} Btu/hr-ft-°R. band width of 2-1/8 inches, the contribution to heat transfer for [illegible] band areas is 12.7 Btu/hr with the insulation uncompressed, and 45 Btu/hr for the insulation compressed.

4.2 Discontinuity Design:

Based on flexible jacket development work it was concluded that the vacuum integrity and reliability of the 105-inch diameter tank with a single vacuum casing could be increased considerably by the use of rigid jackets over the piping, struts, and A-frame with a minimum sacrifice in weight. A rigid vacuum jacket on the small-scale test apparatus and attached to the flexible lead-Mylar jacket by means of a bolted O-ring connection. The O-ring flange compresses the insulation to a density of 140 layers per inch in order to prevent the flexible vacuum jacket from being drawn under the flange and thereby damaged.

In order to enhance evacuation of the insulation system with a very small weight penalty, an evacuation connection was installed at each piping discontinuity and at the bottom over the adsorbent trap. Opacified paper was employed to prevent thermal interaction between the discontinuities and the basic tank insulation.

Helically-wrapped strips of insulation were used on the piping, the struts, and the A-frame support rod. Alternate layers of radiation shields and fibrous spacer were used in the first two cases while strips of opacified paper were used in the latter.

4.2.1 Piping:

It was assumed that the pipes could be insulated for a distance of 13.5 inches. Calculation of the heat leak through this insulated portion of the pipe is a fin problem wherein the fin is insulated and placed in a hot well. The equation for the solution to this problem is as follows:

$$Q/Q_o = m\,L\,\coth\,(m\,L)$$

$$\text{where } m^2 = \frac{k_a\,c/2}{k\,A}$$

- k = conductivity of support material = 6.42 Btu/hr-ft-°R
- c = circumference of support = 0.785 ft.
- t = insulation thickness = 0.012 ft.
- A = cross-sectional area of support = $3.83 \times 10^{-3} + 7.6 \times 10^{-5} n$
- L = length of support = 1.125 ft.
- k_a = apparent conductivity of insulation = 2.64×10^{-5} Btu/hr-ft-°R
- n = number of layers of insulation = 10
- Q/Q_o = ratio of total heat flow to conductive heat flow = 1.03

The insulation was helically-wrapped in the form of 2-1/4-inch wide strips of glass and 2-inch wide strips of .25 mil aluminum foil helically-wrapped concurrently. This is done to extend the heat flow path through the aluminum foil from the warm end to the cold. In order to further reduce heat flow along the foils, the cold layers are not extended as far up the pipes toward the warm end as are those on the outside. Also, at the connection to the cold tank the insulation is tapered. Ten layers of helically-wrapped insulation are satisfactory for this application. The heat leak due to the solid conduction plus the contribution of the insulation is 13.5 Btu/hr.

To connect the pipe insulation with the basic tank alternate layer insulation, opacified paper was used. Where it is uncompressed the leak is .03 Btu/hr and where it is compressed under the vacuum jacket flange, it is .16 Btu/hr based on thermal conductivity values 28.8×10^{-5} and 14×10^{-5} Btu/hr-ft-°R respectively. The opacified paper was initially installed in the form of annular disks at a density of 150 layers per inch for one inch of thickness. Under the flange this compresses to 300 layers per inch.

Radiation through the pipes was also considered. While the effective emissivity of the warm end and the cold end of the pipes is a matter of conjecture, a factor of .5 was used based upon the recommendation of NASA CR-54190, "Design and Optimization of Space Thermal Protection for Cryogens-Analytical Techniques and Results," by Jacques M. Bonneville. The radiation in each pipe was calculated to be 3.31 Btu/hr.

It has been assumed that the instrumentation line and the dummy line are evacuated so that convection is no problem in them. An additional heat leak of 1.23 Btu/hr due to conduction will be experienced through the four instrumentation lines.

Since the vent line will always be open, there will be refrigeration recovered from the effluent gases. This effect reduces the solid conduction through this line by 56% for the insulation uncompressed and 99% when the insulation is compressed.

4.2.2 Struts:

The analysis of the thermal performance for the struts is essentially the same as that for the piping. Here the conduction down each strut considered as a fin in a hot well is 14.94 Btu/hr. In the compressed area of opacified paper under the flange, the heat leak is 1.11 Btu/hr. In the uncompressed annular area it is .08 Btu/hr.

4.2.3 A-Frame:

For analysis purposes it has been assumed that the aluminum portion of the A-frame is entirely at liquid hydrogen temperature. This assumption while conservative is quite realistic since the resistance to heat flow through the A-frame is many orders of magnitude lower than it is either through the insulation or through the titanium load rod. One-half inch (75 layers) of opacified paper was chosen to insulate this portion. It is most simple to install at five layers at a time in the form of blankets and will result in a heat leak of 1.71 Btu/hr. Where the A-frame attaches to the tank opacified paper was again used extending out to the inside of the O-ring flange. This area contributes 0.5 Btu/hr. The load-bearing portion of the insulation was constructed by interleaving an annular disk of paper in the same shape and width as the flange and butting up against the already installed band for each layer of insulation. The excess paper was held in place by adhesive tape. The heat leak in this support area is 3.49 Btu/hr.

The thermal analysis of the load rod was conducted in the same manner as that described above. However, because of the small rod diameter, and low thermal conductance, 2-inch wide strips of opacified paper were helically wrapped on to the load rod to replace the alternate layer helically-wrapped insulation. The heat leak down this rod is 1.76 Btu/hr.

4.2.4 Cold Jacket Joint:

In the area around the manhole cover, where the flexible jacket is attached to the tank wall, the jacket forms a direct heat short to the tank. Since the same is true for the insulation panel covering the manhole cover, a double thickness of the laminate must be considered in the thermal analysis. The thermal conductivity of lead based on data contained in the N.B.S. Compendium is 22.2 Btu/hr-ft-°R between 20°K and 200°K. For the annulus 36 inches outside and 24 inches inside diameter, the heat leak is thus 23 Btu/hr.

5.0 APPLICATION:

Application of the Super Insulation system and the flexible jacket to the NASA provided 105-inch diameter tank is described in detail on the drawings attached as Appendix I. This section will be devoted to a brief description of the procedures and recommendations for improvement.

5.1 Insulation Application:

The 105-inch diameter test tank is shown in Figure 38. The tank is supported by the two struts shown in the photograph and an A-frame located just below the upper girth weld on the opposite side. Four piping penetrations are provided; fill and drain line, vent line, instrumentation line, and dummy. The first two are visible in the photograph. At the time of insulation, stub ends of each pipe consisting of aluminum to stainless steel transition joints were installed. Figure 38 shows the tank installed in the hydrotest facility in its vertical position which is its test position. The water line can be seen passing through the manhole cover.

5.1.1 Cylindrical Wrap:

In order to apply the insulation to the cylindrical portion of the tank, it was installed with its axis horizontal in a wrapping fixture. The drive was attached to the bolt circle for the manhole cover as shown in Figure 39. The other end was supported by a spider ring shown in Figure 40.

Two rolls of aluminum foil (visible in Figure 39) and two rolls of fiberglass paper were located on opposite sides of the tank and wrapped on simultaneously. Also shown are the two bands consisting of two thicknesses of spacer material and one band of 2-mil aluminum which were rolled into the insulation. These were installed to maintain layer density and to provide support during insulation application and are located next to the girth welds.

It was originally intended that the holes in the insulation for the piping penetrations would be trepanned by sharpened cylindrical cutters located over the dissimilar metal joints. However, because the overlap in the two aluminum rolls occurred at the same place, it was found necessary to cut each hole individually during wrapping. This required two additional men. Tape was applied on either side of the penetrations in the aluminum foil to prevent tearing and effect the envelope support. If rolls of aluminum of the size needed to provide sufficient overlap on the ends and still keep the overlap area away from the penetrations can be obtained, it is recommended that the trepanning method be further evaluated.

The actual rolls of aluminum foil used had been damaged in handling and storage so that numerous tears started where the edges had been bruised. This necessitated frequent stopping of the wrapping operation, and consequent relaxation of the band tension. Near the end of the wrapping process, the lower band snapped causing an unkown degree of relaxation in that band. It was found that, although the air pressure to the band brakes had been kept constant, the tension had about doubled therby causing the failure. The tooling should be examined to determine the reason for this increase in braking force. Since the as-applied layer density after wrapping was adequately close to the desired 70 layers per inch however, the resulting band tension was considered satisfactory.

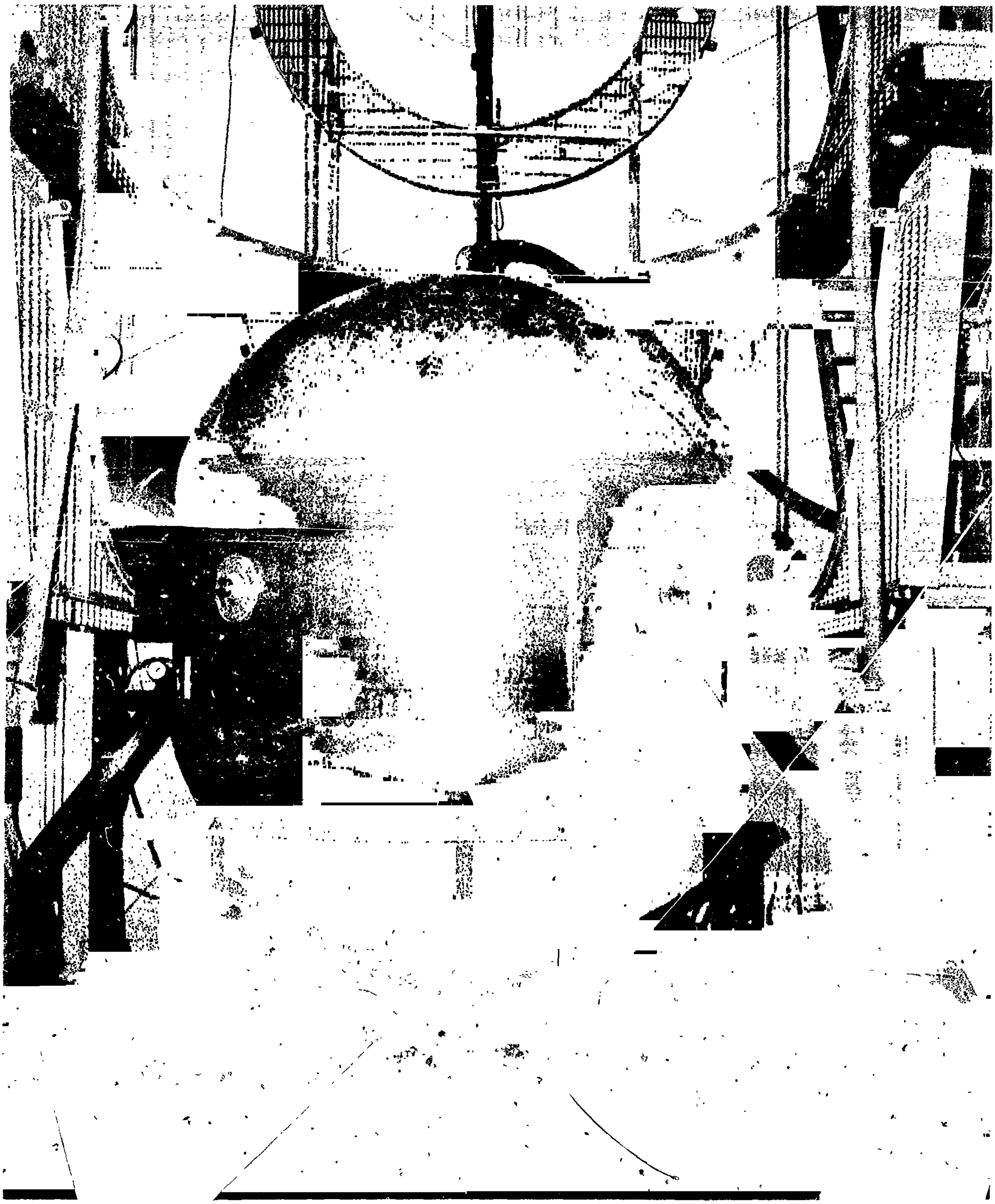


FIGURE 38

105-INCH DIAMETER TEST TANK

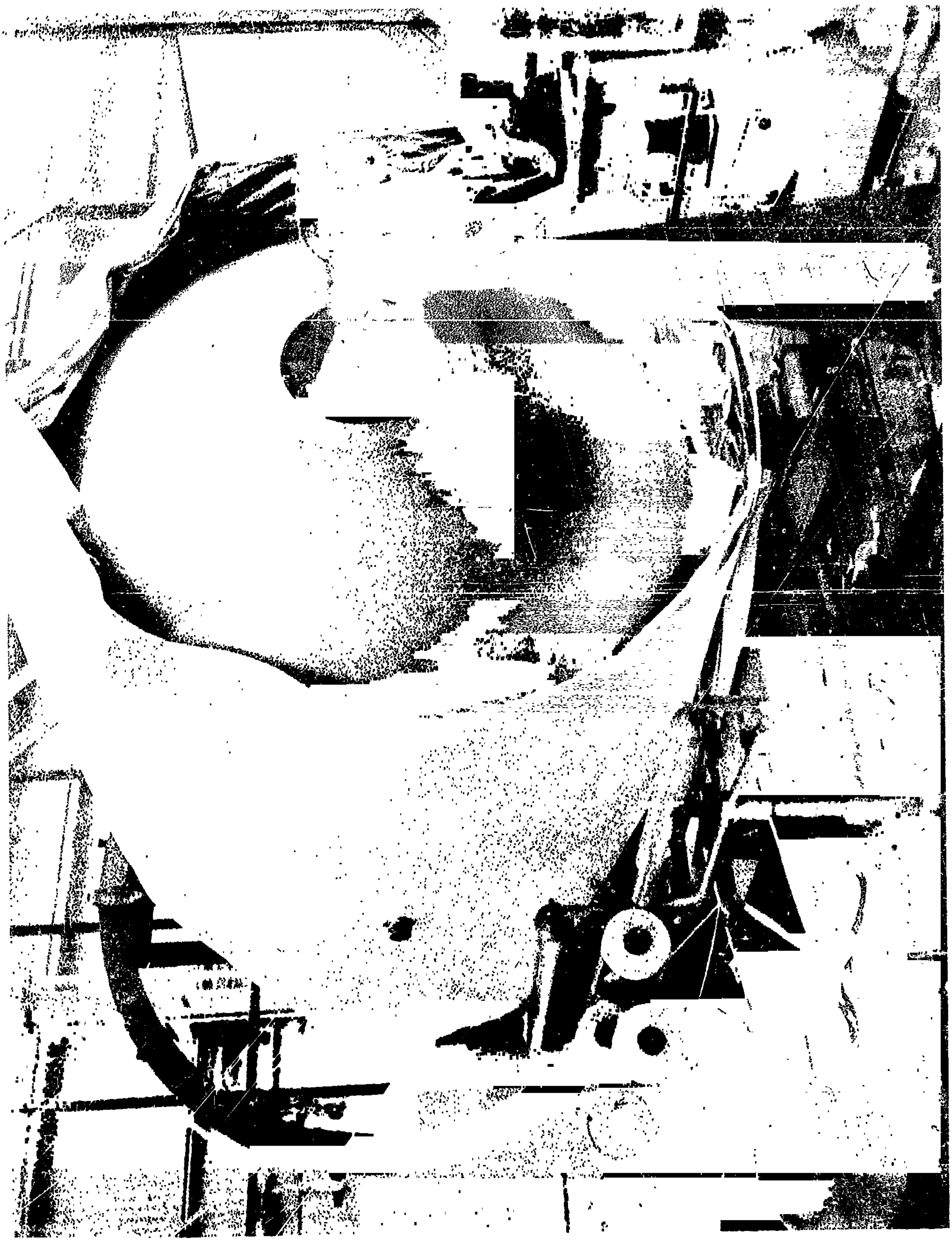


FIGURE 39 - CYLINDRICAL WRAP - TOP END

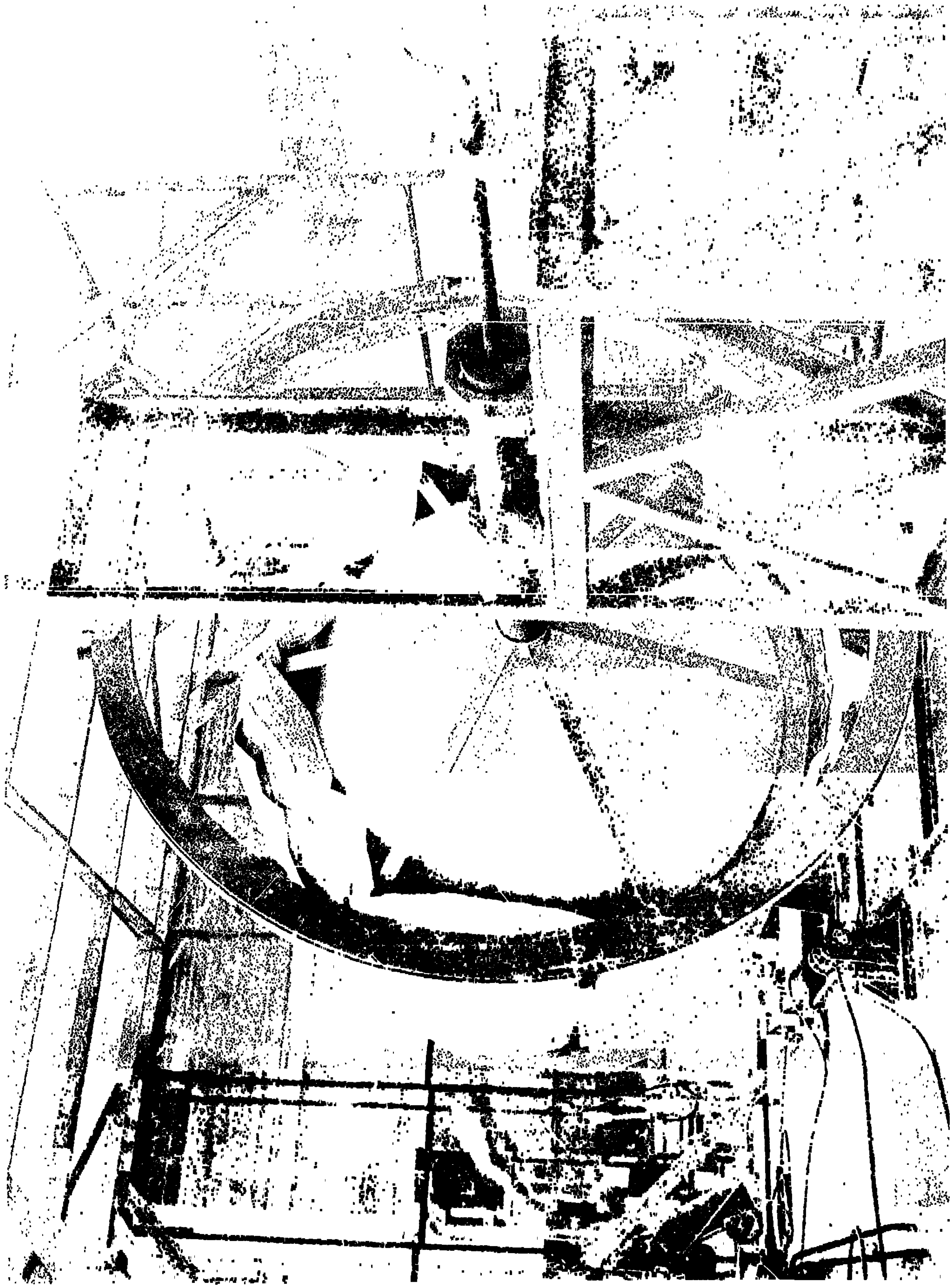


FIGURE 40 - BOTTOM END SUPPORT

The details of the aluminum, glass, and band tooling are shown in Figures 41 and 42.

The overbanging insulation at the bulkheads should be supported by a cylinder of cardboard taped to the heads during the cylindrical wrap to prevent damage to the material. At the time of this operation, however, no suitable material for this purpose could be located. As an expedient, the spider ring was relied upon to provide support on the bottom end, and a triangle of cardboard cushioned by folded paper as shown in Figure 43 on the top end. While the resulting damage did not effect the insulation thermal performance, pinholes in the foil and glass did make interleaving of the head discs more difficult, and the use of a continuous cylinder on each end is recommended for any future operations of this kind.

5.1.2 Bulkhead Insulation:

After completion of the cylindrical wrap, a tooling ring was slipped over the insulation and attached to the tapped holes around the piping penetrations as shown in Figure 44. This ring was supported on adjustable rollers on the floor. The spider ring attached to the lower bulkhead was then removed. Some trouble was experienced with binding between the tooling ring and the supporting rollers, but this has been attributed to misalignment and can be corrected.

For the lower bulkhead, a 96-inch diameter blanket of 70 layers of insulation was prepared and applied one layer at a time. As shown in Figure 45, each of these head discs was taped to the corresponding overlap area of the cylindrical insulation. The tank was indexed in rotation while this operation was taking place so that the work could always be done at the top of the tank. As each layer was applied the overlap area was smoothed at hand. White gloves were worn to limit contamination of the insulation and to prevent tearing. Only very limited bulking resulted in this area as shown in Figures 46 and 47.

After the first head disc had been applied to the lower bulkhead, a hole was cut over the opening in the Molecular Sieve trap, and the trap was filled. The hole was then repaired with adhesive tape. This was done to reduce the moisture loading on the Molecular Sieve.

Since provision had to be made for the manhole in insulating the top bulkhead, and since the fixture drive apparatus was installed to support and rotate the tank during the operation, it was found most convenient to split each layer through its centerline and apply the discs one half at a time. It was also found necessary to tape each foil to the tank at the center. This tape was later cut to avoid any impairment of the thermal performance. (The effect of this tape without cutting would have been less than one Btu/hour, and after cutting is negligible). Figure 48 shows the completed top bulkhead insulation, and Figure 49 shows a detail of the area around the manhole before the tape was cut. Again only limited buildup in thickness resulted.

5.1.3 Insulation Repair:

While adjusting the support rollers under the tank, a hole was

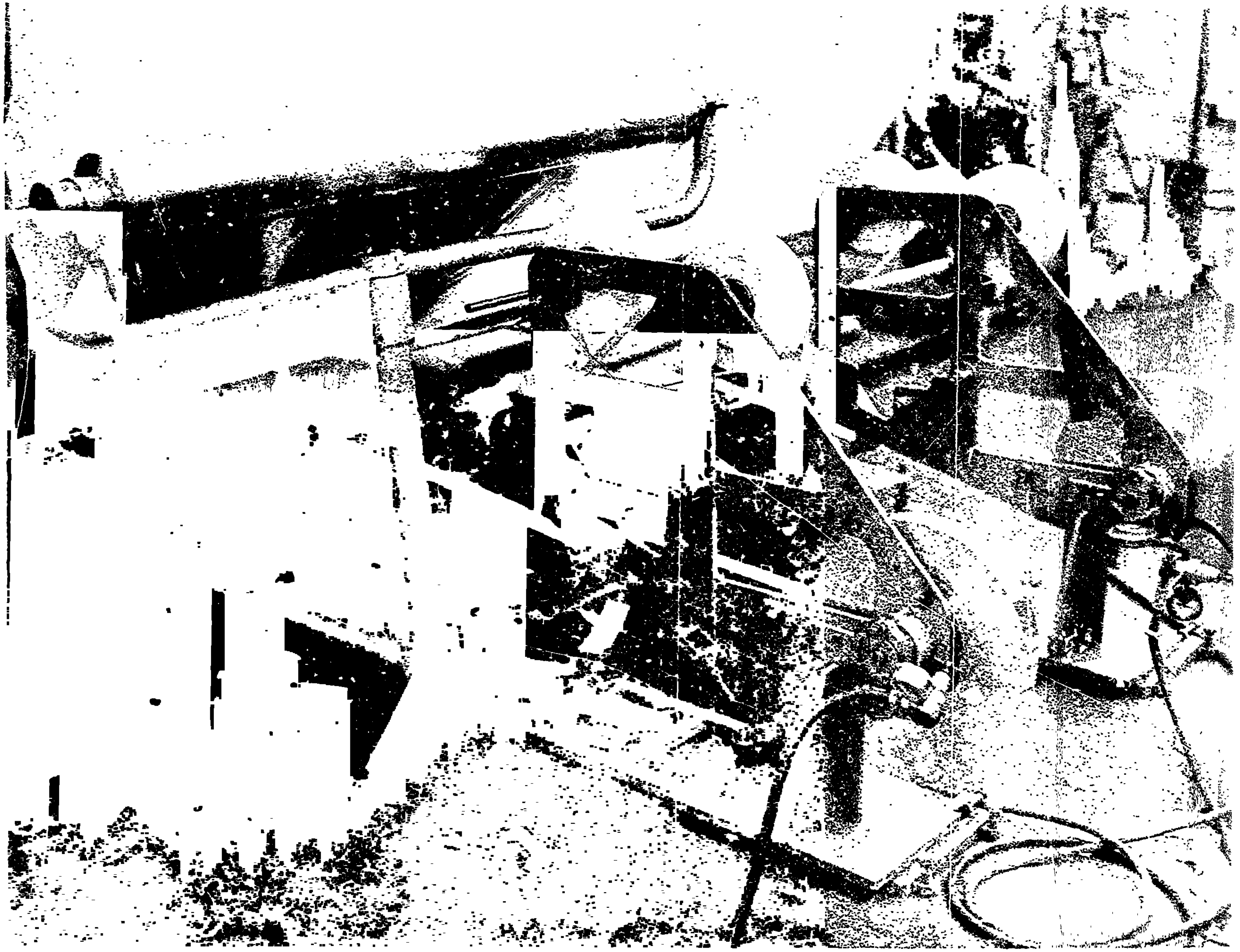


FIGURE 41 - ALUMINUM FOIL AND TENSION BAND APPARATUS

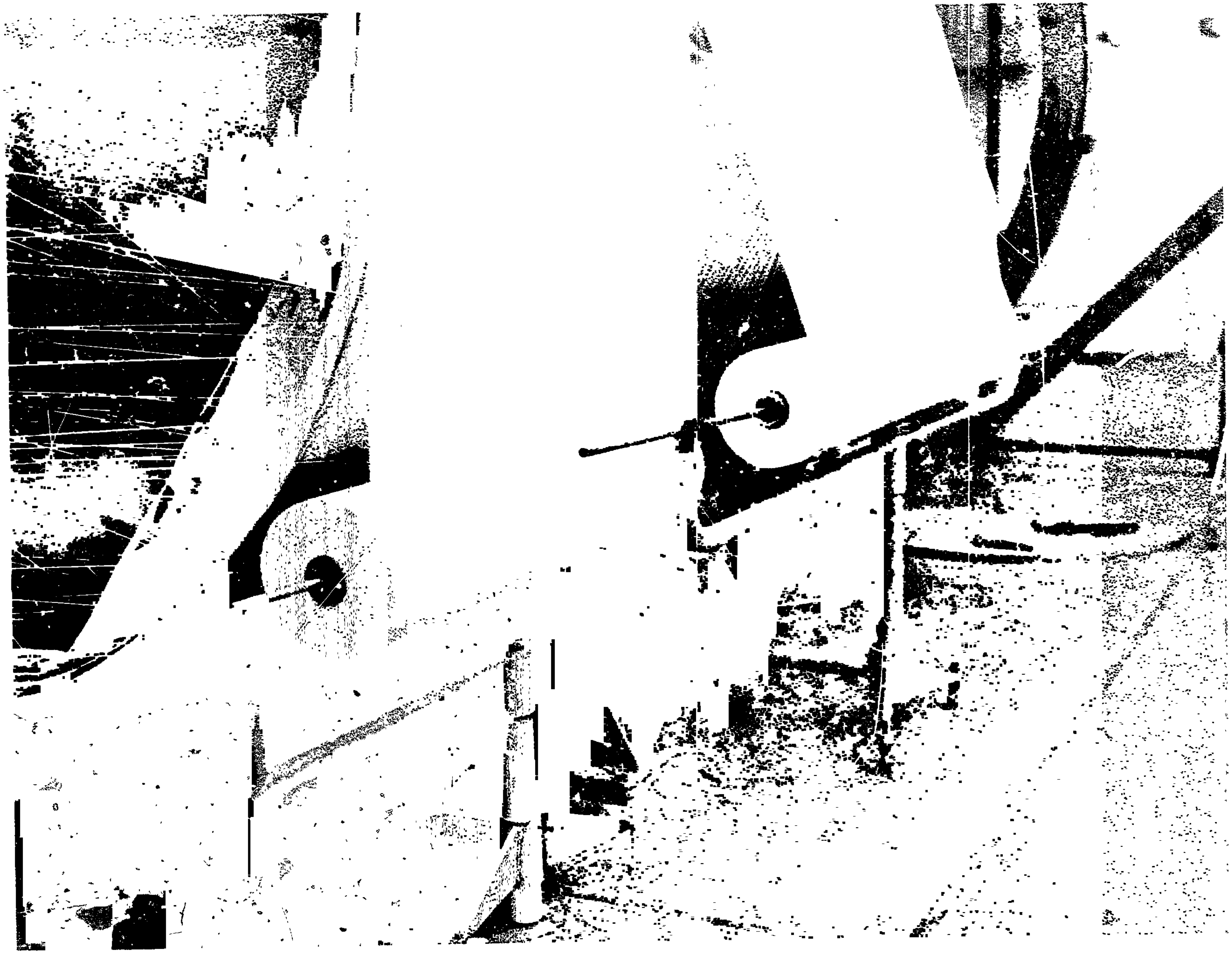


FIGURE 42 - FIBERGLASS PAPER WINDING APPARATUS

FIGURE 43 - CARDBOARD SUPPORT FOR OVERHANDING INSULATION

FIGURE 44 - SUPPORT RING INSTALLATION

FIGURE 45 - APPLICATION OF BOTTOM BULKHEAD DISCS

FIGURE 46 - COMPLETED INSULATION OF LOWER BULKHEAD

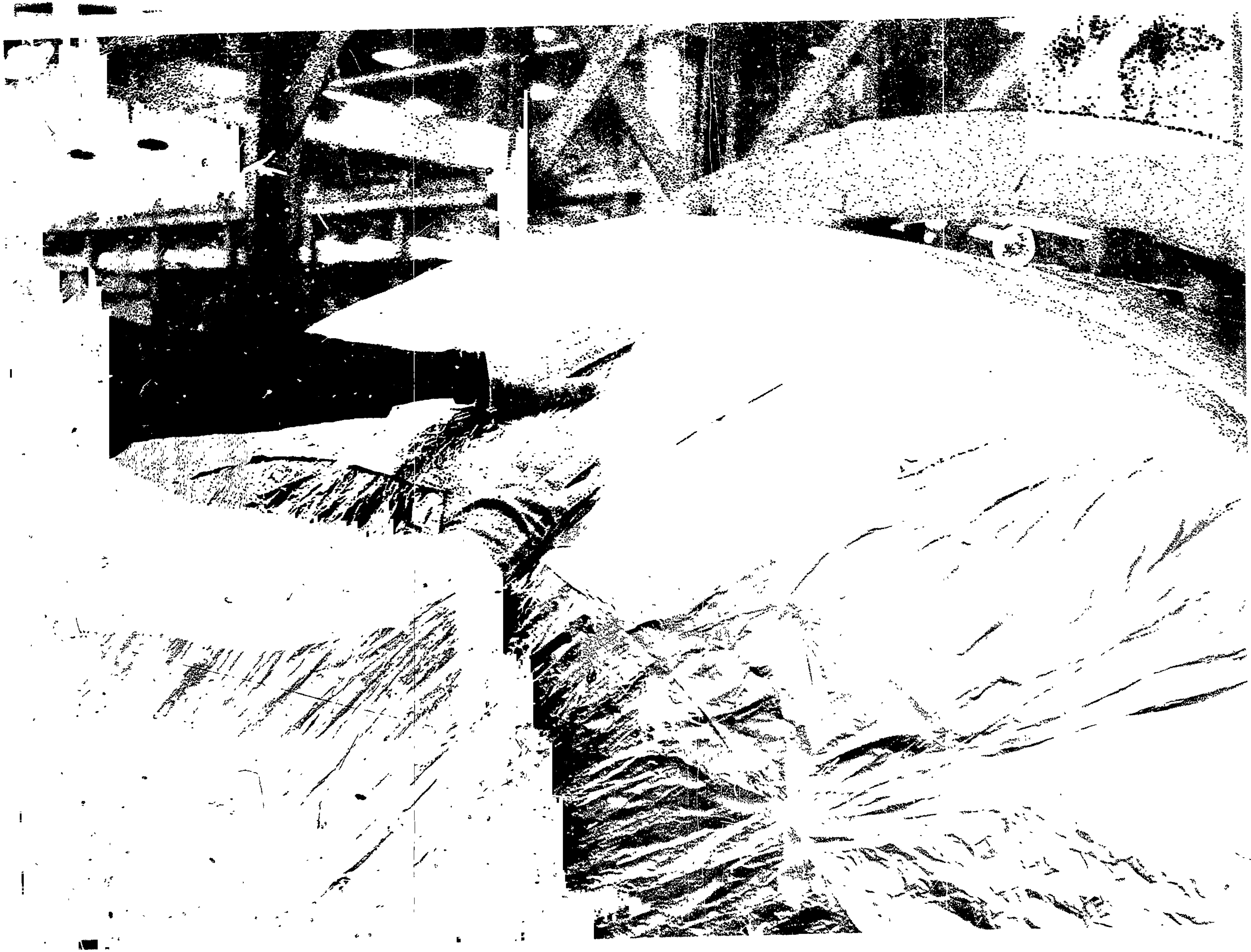


FIGURE 47 - DETAIL OF LOWER BULKHEAD INSULATION

FIGURE 48 - COMPLETED INSULATION OF TOP BULKHEAD

FIGURE 49

INSULATION AROUND MANHOLE

inadvertantly punched in the outer layers of insulation about midway between the bands. To affect repair, an X-shaped cut was made in the insulation, one layer at a time. It was found that the damage went down about twenty layers deep. Cross shaped pieces of fiberglass were then installed in each layer to prevent shorting between adjacent radiation shields as shown in Figure 50. The radiation shields were taped back together.

5.1.4 Penetration Insulation:

The original intent was to fill the void between the cylindrical insulation and the helically wrapped insulation on the penetrations with opacified paper. The holes in the cylindrical insulation, however, were cut with an electric carving knife resulting in a ragged cut with very significant shorting between radiation shields as shown in Figure 51. To prevent this effect, appropriate blanks of opacified paper were cut and interleaved with the cylindrical insulation. While this operation was time consuming, it was felt necessary to eliminate an area of doubtful insulation performance. Interleaving of these blanks around the strut is shown in Figure 52.

The piping and struts were insulated with ten layers of insulating material applied two layers at a time in strips two inches wide helically wrapped along the penetrating member. This is shown in Figure 53.

The A-frame was insulated with blankets of opacified paper precut to the proper shape and applied five layers at a time. The load rod was helically wrapped with opacified paper because of its small diameter. The completed insulation is shown in Figure 54.

5.1.5 Insulation Layer Density:

The as-applied layer density is shown on Table 10. The location of these measurements is shown on Figure 55.

The insulation density as applied was remarkably uniform considering the difficulties experienced in stopping and starting the wrapping tooling because of tears in the foil, and the large head sheets that had to be interleaved. Bulking was limited to only a small area in the overlap regions of the heads. The bulking on the upper head was somewhat less than that on the lower head probably because of the location of the manhole and the attachment of the insulation at that point.

The area of insulation around the Molecular Sieve trap was perforated with a sharp needle when the layer density measurements were taken.

FIGURE 50

INSULATION REPAIR

FIGURE 51

PENETRATION HOLES IN INSULATION

FIGURE 52

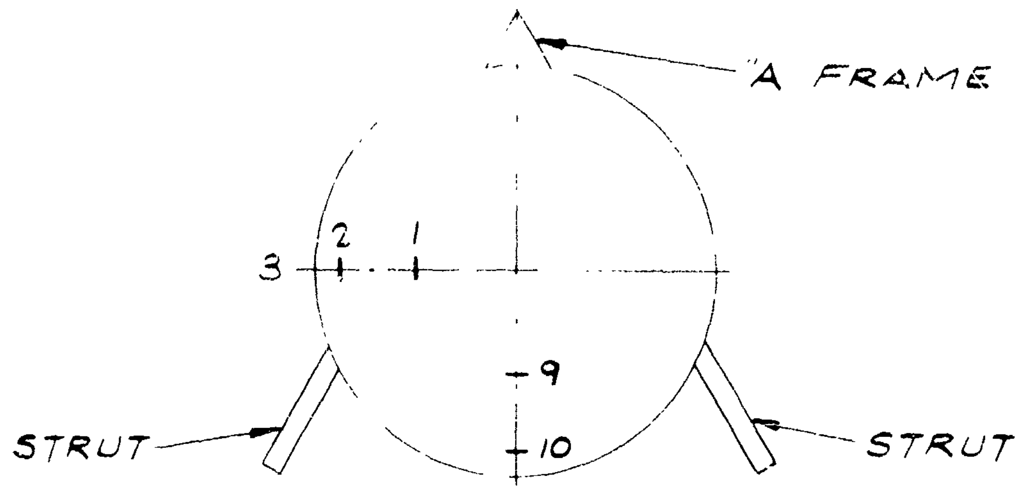
INTERLEAVING OPACIFIED PAPER AROUND STRUT

FIGURE 53

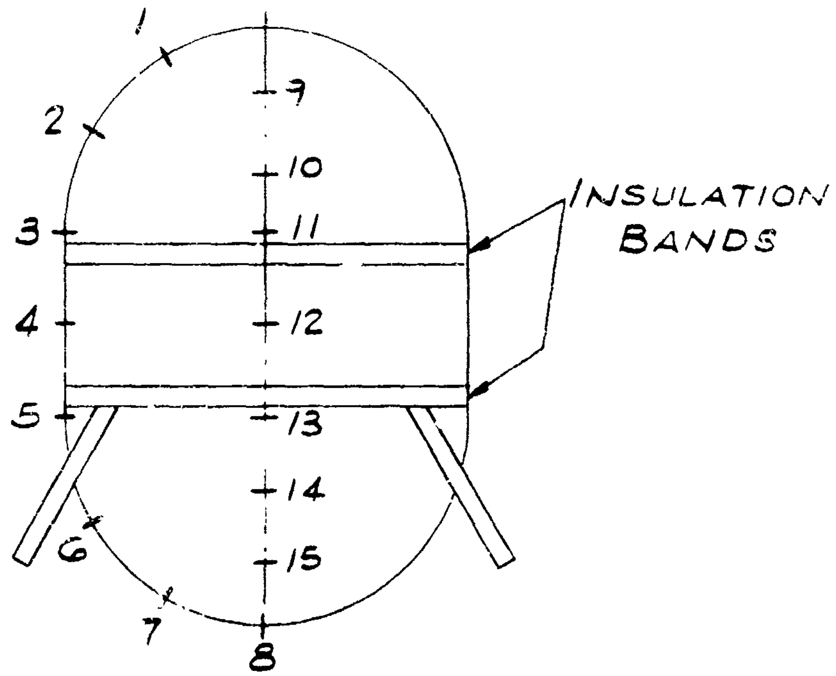
INTERLEAVING OPACIFIED PAPER AROUND PIPE

FIGURE 54

COMPLETED STRUT INTERLEAVING



PLAN VIEW



ELEVATION

LOCATION OF INSULATION DENSITY MEASUREMENTS

(SEE TABLE 10 FOR DATA)

FIGURE 55

TABLE 10

AS-APPLIED INSULATION DENSITY MEASUREMENTS
(See Figure 55 For Locations)

Location	Thickness	Location	Thickness
1	1-1/8"	9	1-1/16"
2	2-3/16"	10	2-1/8"
3	1-1/16"	11	1-1/16"
4	7/8"	12	1-1/16"
5	1-1/16"	13	7/8"
6	2-1/2"	14	2-3/8"
7	1-7/8"	15	2-1/8"
8	7/8"		

5.2 Flexible Jacket

After the insulation system had been applied to the 105 inch diameter tank a single layer of 10 mil thick fiberglass paper was applied over the entire tank insulation. This was done in order to facilitate evacuation under the compressed jacket.

A 105 inch diameter bulkhead was modified to provide the tooling for vacuum forming of the bulkhead jackets. A 114 inch diameter flange was welded to the bulhead and a neoprene gasket glued to that flange. The evacuation port was installed at the bottom. The bulkhead was lined with fiberglass cloth to preclude penetrating the jacket material with specks of dirt. It was found that absolute cleanliness was mandatory.

Lead Mylar blanks in the form of double cones were fabricated of flat material. These were leakchecked visually by placing a light behind them and any pinholes that were noted were patched. For vacuum forming, each blank, 114 inches at its base diameter, was installed in the vacuum forming fixture with the apex touching the evacuation port. The blanks had previously been fabricated using Schjeldahl GT 100 adhesive cured in a water-cooled heat sealer. The blanks were supported around the edges by a neoprene faced ring held in place by a number of "C" clamps. It was found that a small vacuum leak existed at the apex of the cone in each case and it was necessary to pour a small amount of water in the cone to facilitate its evacuation. After the blanks had been stretched by vacuum forming in about 10 to 15 minutes the entire form still under vacuum was baked in an oven at 170°F for one hour. The material itself reached a temperature of 140°F. Upon removing the apparatus from the oven and breaking back the vacuum there was a slight springback noted. There was minor wrinkling at the edges which was easily smoothed with a hand iron.

Three bulkhead insulation jackets were formed. A cutout was made at the apex of one for the manhole cover and a second for an evacuation port at the bottom of the tank. The third was kept as a spare. Figure 56 shows the top bulkhead jacket installed over the insulation of the 105 inch diameter tank. The line formed by the edge of the die in vacuum forming is clearly evident. The radius of curvature of the jacket, because it was formed in a 105 inch diameter die is smaller than the outside diameter of the installed insulation. Larger tooling would be built if more than one tank were to be insulated. However the general shape conforms to the insulation and the minor amount of wrinkling resulting from this discrepancy was not felt to be serious.

The cylindrical part of the tank was jacketed using five pieces of lead Mylar cut out for the penetrations. One of these is seen hanging on the left hand side of the tank in Figure 56. The vertical seams were made as lap joints by folding over the jacket material and sealing the joints with the water cooled six inch heat sealer. The circumferential dimension was purposely made two inches over size in order to account for the heat sealing operation. A completed joint is shown in Figure 57. Because of the folding over operation to get the joint into the heat sealer jaws and prior to evacuation it will be noted that each joint formed a lip. Again the resulting wrinkling was not considered serious.

T joints were made between the bulkhead jackets and the cylindrical portion. This operation is shown in the photograph of Figure 58 where the six inch long water cooled heat sealer is being used to cure this joint. Two passes were made for all joints to assure vacuum integrity. All joints were made with Schjedahl GT 100 adhesive.

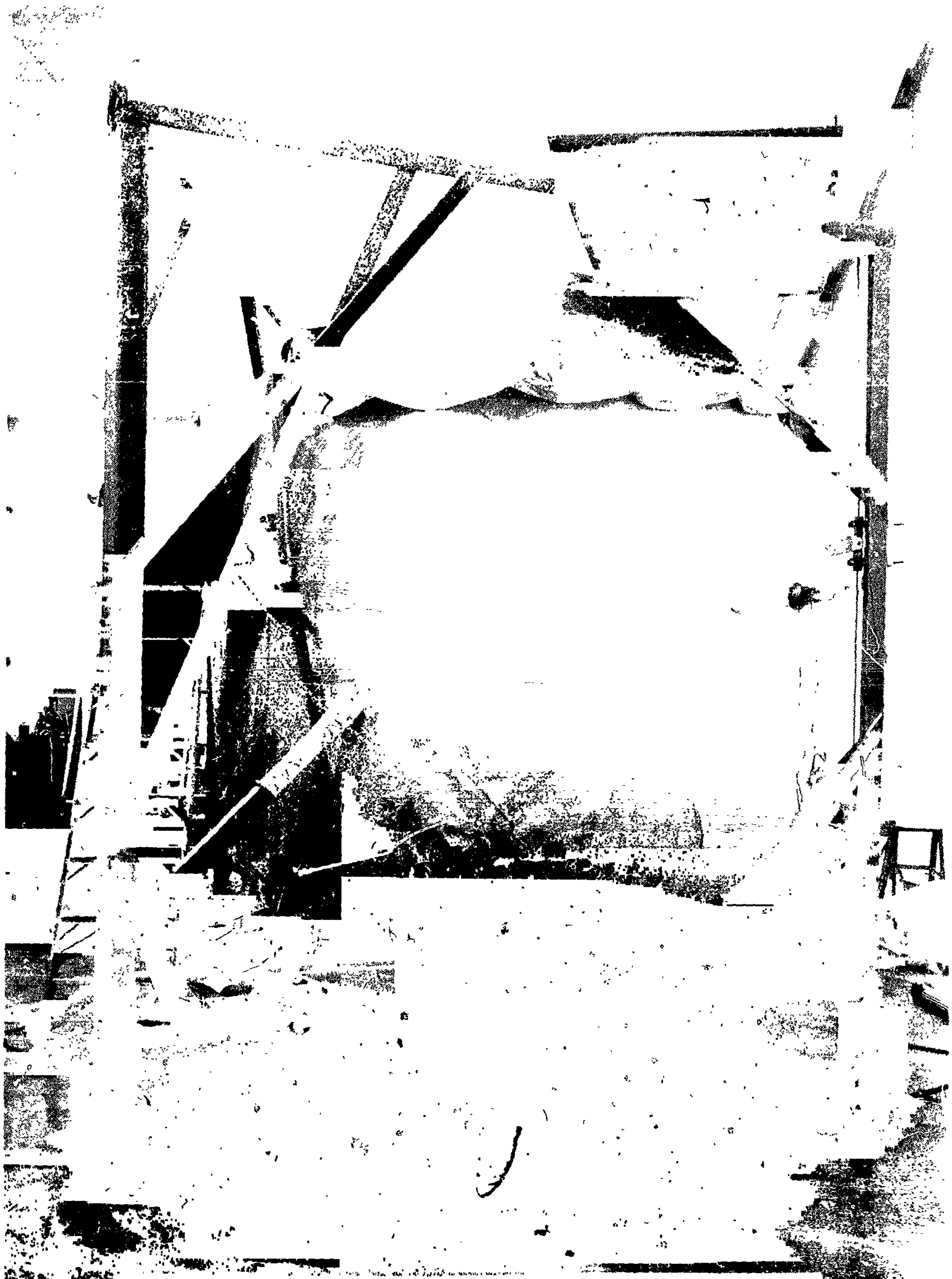


FIGURE 56 - Top Bulkhead Jacket Installed on 105" Test Tank

FIGURE 58 - Heat Sealing Tee Joint on Jacket

While the jacket was being assembled a tear developed around one of the penetrations. This was caused by the weight of the jacket material hanging on the penetration and should be eliminated during future operations by better support of the jacket material until the insulation system is evacuated. The tear was easily repaired with a patch, heatsealed in place with a hand iron.

In order to simplify the jacket design rigid metal vacuum jackets were designed and fabricated for each of the penetrations (piping, struts and A frame). Figure 59 shows an insulated strut ready for the application of its jacket. An 'O' ring seal was used to connect the rigid vacuum jacket to the flexible bag and also to connect it to the plate shown on the warm end of the strut. Figure 60 shows one of the piping penetrations with its jacket in place and with the bolted 'O' ring connections tightened. Figure 61 shows the completed jacket in the evacuated condition and shows some of the various penetrations. The A frame is indicated on the right hand side of the tank and a strut on the lower left hand side. Two piping penetrations are visible.

In order to permit access to the inside of the tank a separate insulation panel was provided for the manhole cover area. The top bulkhead jacket was cut away to the outside diameter of the manhole cover. This jacket was bonded to the tank itself with NARMCO 7343/7139 adhesive. The aluminum tank wall in that area was etched prior to bonding. This joint, with some wrinkling evident, is shown in Figure 62. The joint was cured by means of weights placed on top of a wooden weight ring which had been neoprene faced. The wrinkling did not cause detectible vacuum leaks.

The installed manhole insulation panel is shown in Figure 63. An evacuation/gauge port was attached to this panel. The joint between the manhole insulation panel and the basic tank insulation was made by NARMCO 7343 adhesive using a fiberglass cloth reinforcement. After several applications this proved to be leaktight.

5.3 Evacuation, Leak Detection and Repair

Evacuation and leak detection of the flexible jacketed insulation system proved to be an extremely time consuming and tedious process because of the apparent poor gaseous conduction and because of gas leakage into the vacuum space. Because of this, the evacuation rate within the insulation was very slow. A number of leaks were found in the jacket primarily due to pinholes and scratches. These were repaired by Armstrong A-12 or Goodyear G207 adhesive; however, most of the leakage problems were in areas other than the jacket itself such as faulty O-Ring installations, leaking bellows, etc. When all of the major leaks had been repaired it was found that the system could be pumped down from one atmosphere to the hundreds of microns residual gas pressure range in a few hours as was predicted.

The evacuation and leak detection apparatus is shown with the 105 inch diameter test tank in the evacuated condition in Figure 64. A Veeco MS 9 Leak Detector was employed. When the residual gas pressure was high, a mixture of helium and air was used and the leak detector was connected in parallel with the vacuum pump through the tee shown. Four evacuation ports at the penetrations were employed with a separate evacuation port in the bottom head and in the manhole cover (not shown in photograph). A plenum chamber was included in the evacuation system.

The evacuation process was probably further complicated by residual moisture in the molecular sieve trap although it is impossible to estimate the extent of this complication. An air heater, shown in Figure 65, was used to

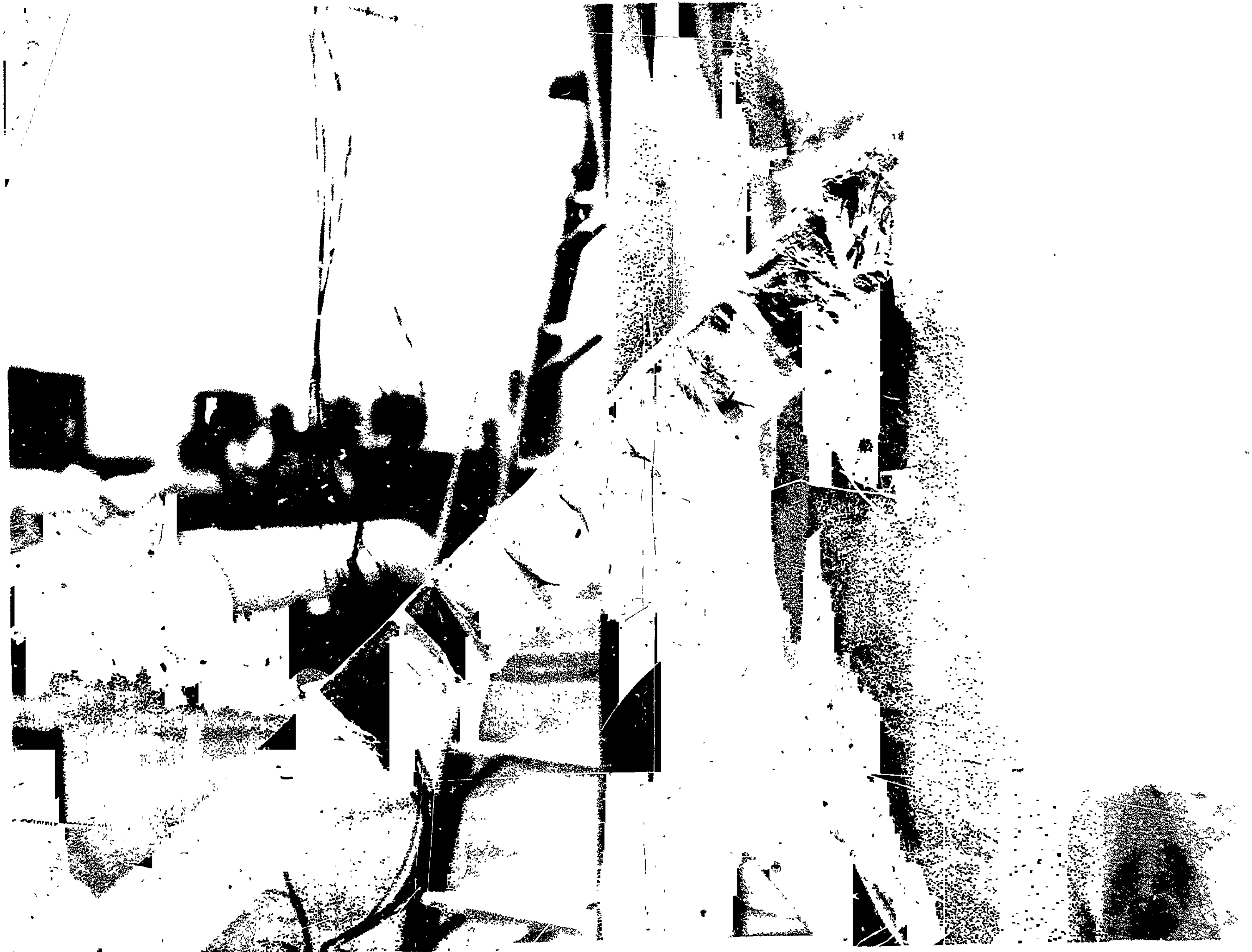


FIGURE 5 - [illegible]

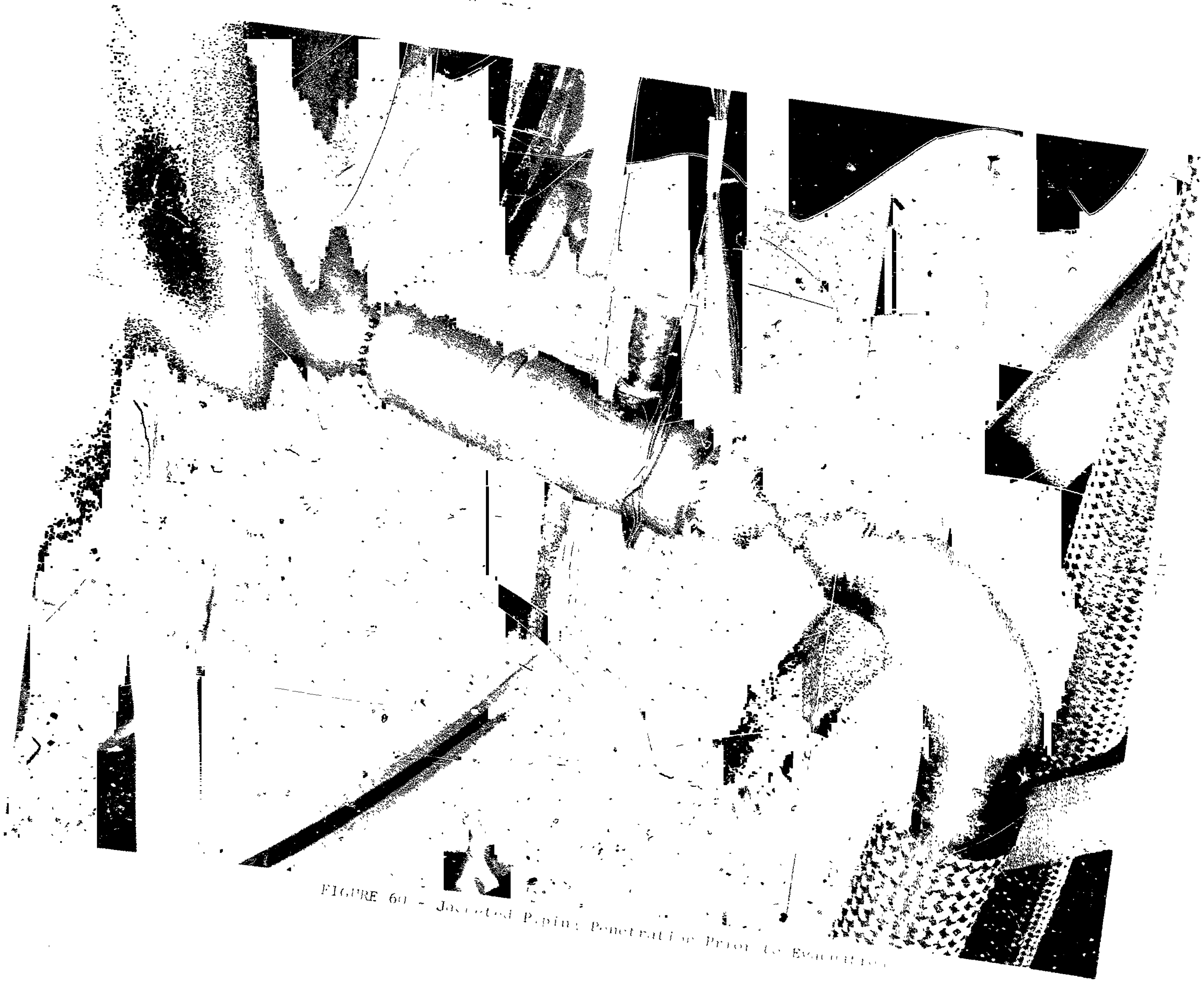


FIGURE 60 - Jacketed Piping Penetration Prior to Evacuation

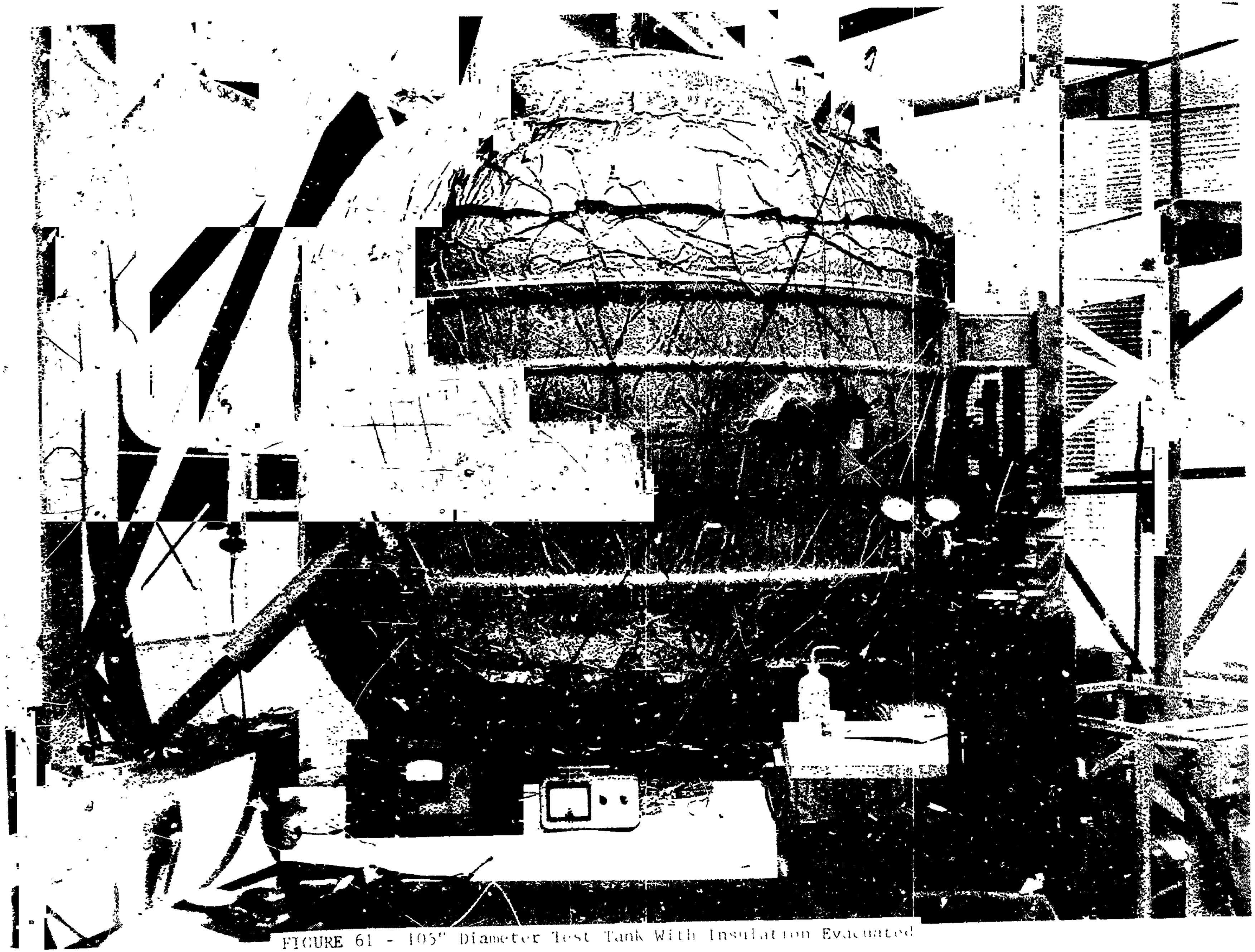


FIGURE 61 - 105" Diameter Test Tank With Insulation Evacuated

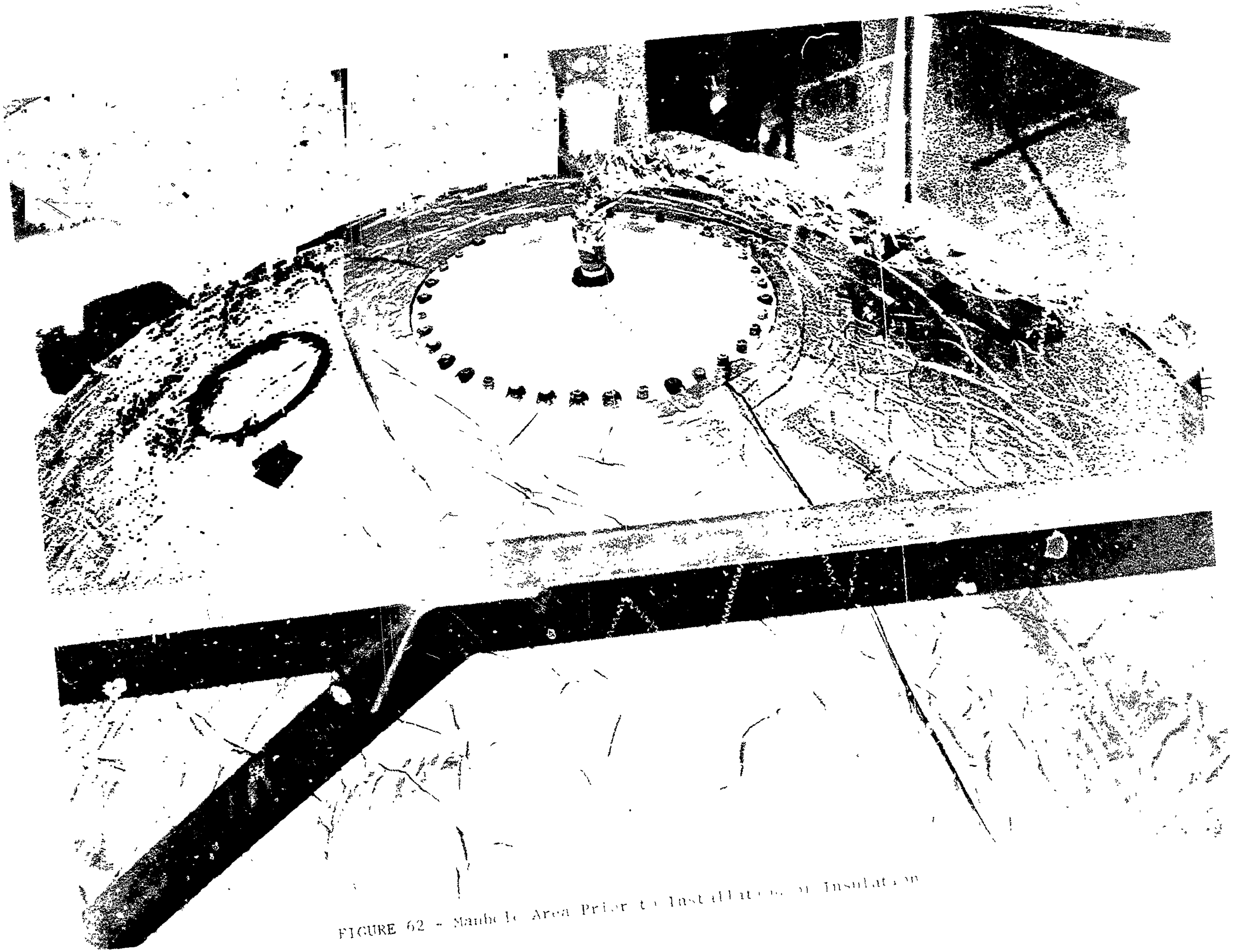


FIGURE 62 - Manhole Area Prior to Installation of Insulation

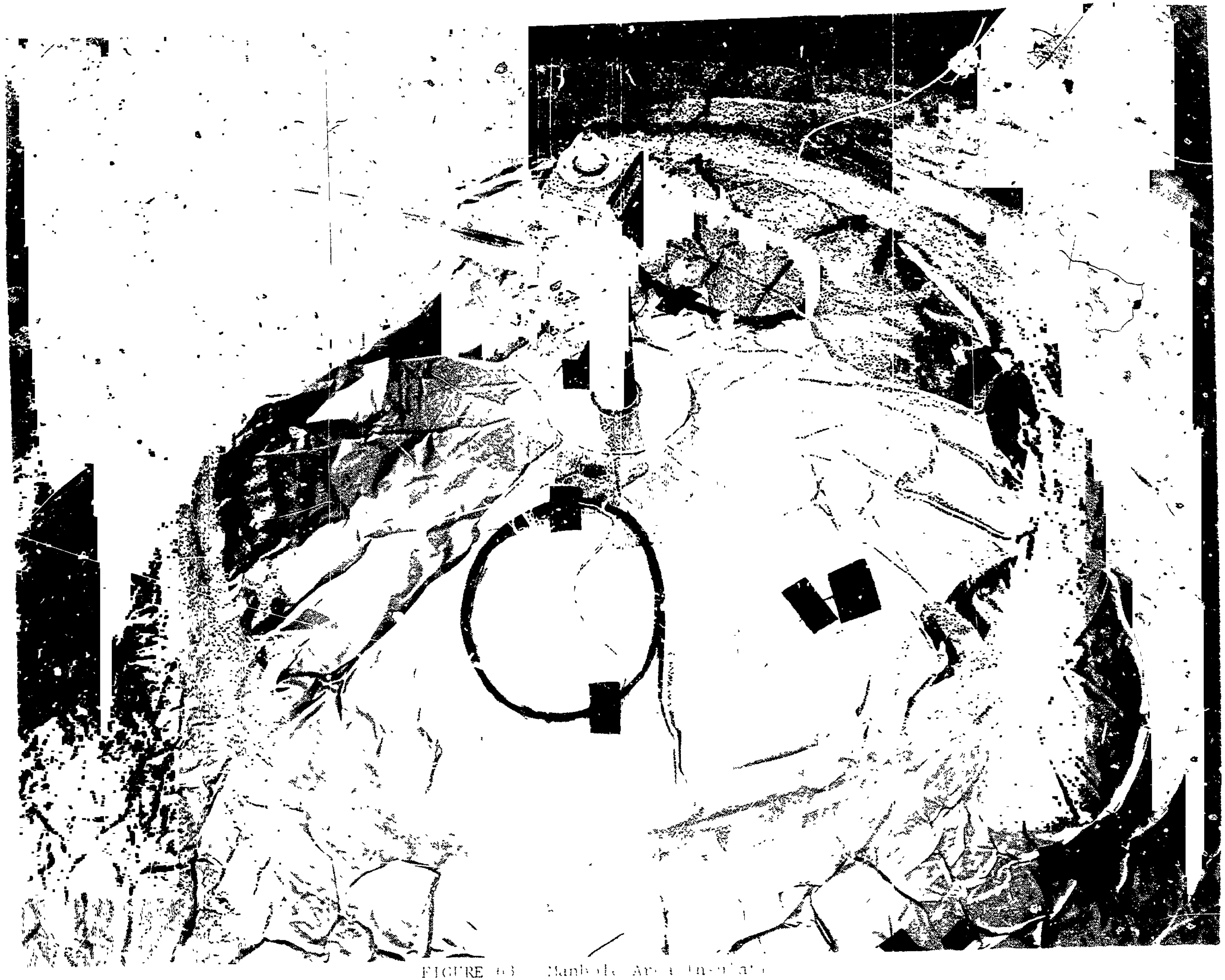


FIGURE 63 Manhole Area Insulation

FIGURE 64 - 105" Diameter Test Tank Evacuation and Leak Detection System

FIGURE 65 - Air Heater for Tank Purge

purge the tank itself and elevate the temperature of the sieve trap to drive off the water. However, the actual inside temperature of the tank could not be elevated safely to more than 130°F. This temperature is marginally adequate to dry the sieve bed after it had been exposed to the atmosphere for about four months from the time the sieve was installed until the evacuation procedure was begun.

For leak detection an area of the tank jacket was covered with a plastic film taped in place. The area between this film and the jacket itself was then purged with helium and the insulation was evacuated either with a leak detector in parallel with the vacuum pumping system if the pressure was high or later when the residual gas pressure was low enough directly through the leak detector. If a helium indication was sensed by the leak detector, a smaller portion of the area initially "bagged" was covered as shown in Figure 66. Using this procedure at elevated pressures (in the millimeter range) with the helium leak detector in parallel with the vacuum pump and with mixtures of helium and air a very poor sensitivity resulted and only the largest leaks could be discovered. Later when the pressure was down in the micron range, better resolution was experienced with only the leak detector pumping on the insulation space. Another problem was caused by the poor gas conductance through the compressed insulation. When a leak was discovered, helium would permeate through the insulation material and take a considerable length of time to be purged out through the vacuum pumping system. This made leak detection a very tedious matter.

One significant problem that was encountered and solved was delamination of the jacket material in stressed areas. This occurred in the A frame area where the insulation compressed at the edges of the rigid jacket causing the jacket material to stretch and delaminate. The same problem occurred around the strut installations. The problem was solved by backfilling the insulation with dry nitrogen and opening the damaged connection. Fiberglass material was stuffed in behind the jacket which permanently compressed the insulation locally and provided support for the flexible vacuum jacket. The delamination was repaired by injecting adhesive between the Mylar film and the lead foil. This was cured by means of a hand iron. After the repair, when the insulation space was evacuated, wrinkling in this area was also relieved by means of a hand iron. In future work, this problem must be faced and any areas of potential stress of the jacket material must be considered in the design.

When the leak detection phase was completed and the test tank was ready for installation in the vacuum chamber a hole was inadvertently gouged in the jacket penetrating the insulation as shown in Figure 67. In order to effect repair, the damaged insulation was cut out by a circular knife and a plug of fiberglass installed as shown in Figures 68 and 69. No effort was made to interleave the insulation since such a small area was involved. A patch was then ironed on over the jacket as shown in Figure 70 and the insulation re-evacuated.

Another serious mishap occurred during the first attempted altitude test. There was hydrogen gas leakage around the manhole cover seal at the top of the tank under the insulation. The resulting over-pressure under the manhole cover insulation tore the jacket apart and damaged a number of layers of insulation as can be seen in Figure 71. In order to make a more reliable system, a doubler was welded around the manhole cover to preclude leakage in that area. New insulation materials were interleaved over the top bulkhead replacing the original separate manhole cover panel. This new interleaving caused a buildup in thickness of the insulation in that area. As a result the

FIGURE 66 - Leak Detection Procedure

FIGURE 67 - Insulation Damage

FIGURE 68 - Insulation Cut-Out

FIGURE 69 - Insulation Repair Plug

FIGURE 70 - Jacket Patch Repair

FIGURE 71 - Insulation Damage

bulkhead jacket was too small and a gusset had to be added between the bulkhead jacket and the cylindrical jacket. This double seam is visible in Figure 72. A tee joint was made in the manhole cover area as can be seen in Figure 73. The resulting system eliminated the manhole cover insulation panel and the cold joint between the jacket material and the tank. There was thus one single insulation system for the entire tank with a common vacuum.

FIGURE 72 - Side View of Insulated Tank After Repair

FIGURE 73 - Manhole Cover Area After Repair.

6.0 LARGE SCALE TEST

6.1 Facility Description

All tests were conducted at NASA Marshall Space Flight Center Test Laboratory High Vacuum Chamber. The facility basically consists of a 15' diameter by 20' high stainless steel vacuum chamber with associated vacuum pumping and liquid hydrogen handling systems depicted in Figure 74. The chamber is made in two parts; the chamber proper and a flanged dome. The test tank attaches to the dome along with the necessary support hardware as shown in Figure 75. This module concept facilitates tank and component attachment while the dome is in place over the storage bay portion of the test facility. Structurally the stand is designed in two equal bays; the bay which permanently houses the vacuum chamber and the storage bay in which the test apparatus connections are made. The stand is divided into four different levels. On the lower level the vacuum pumping system is located on a concrete support pad. The second level provides access to the vacuum chamber sidewall penetration flanges and the test tank lower half when in the storage bay. The third level also provides access to the chamber sidewall and the upper test tank when in the storage bay. The fourth or top level allows access to the chamber dome. At this level the hydrogen fill and the hardware connections are made to the dome after attaching the test hardware.

The vacuum pumping system includes four 50,000 liter per second defusion pumps, a 5,000 cubic ft. per minute Roots blower and a 500 cubic ft. per minute roughing pump. At atmospheric pressure the roughing pump begins the chamber pump down, pumping the 3,500 cubic foot chamber in about two hours to ten millimeters of mercury. At this pressure the Roots blower automatically starts and continues to pump the chamber down to the low micron pressure range in about 45 minutes when the diffusion pumps are turned on. The diffusion pumps which take approximately one hour to reach peak pumping speed then continue to pump the chamber down into the 10^{-7} millimeter mercury range with the chamber clean, dry and empty.

Liquid nitrogen is fed into the test tank by a three inch vacuum jacketed fill line which enters the chamber through the dome. The hydrogen vent gases are allowed to escape through a 3" vent line except during those periods when the boiloff is being metered by venting the vent gases through a flowmetering system situated in parallel to the 3" vent. This system has 8 flowmeters mounted in parallel which measure the boiloff rate. The vent line has a 34 psig safety bursting disk which protects the system from overpressurization. Hydrogen is supplied to the tankage by either a 7,800 or 12,000 gallon trailer with remote tanking capability which allows liquid transfer while all personnel are in a safety barricaded area.

Figure 76 shows the test tank attached to the domed head of the chamber ready for admission to the chamber. The insulation is evacuated and compressed.

The instrumentation output during these tests included 150 channels of information, of which 100 were temperatures, 30 pressure measurements, 8 flows, 19 combustible gas detectors, and 12 liquid level and miscellaneous measurements (see Figures 77 through 84). All temperature measurements with the exception of 13 internal liquid measurements and 11 external skin measurements utilized copper constantan thermocouples referenced to liquid nitrogen temperatures. The 24 internal and skin measurements utilized Rosemont temperature bulbs. All pressure measurements with the exception of the vacuum gaging utilized Statham strain gage transducers. The eight flowmeters used were situated in a parallel manifold. Seven of these meters were Cox turbine type flowmeters, while the eighth was a Cox rotometer. The range capability of these meters gave a span from 3/4 to 250 ACFM. A heat exchanger, in series with the flowmeter manifold, maintained

HIGH VACUUM TEST FACILITY

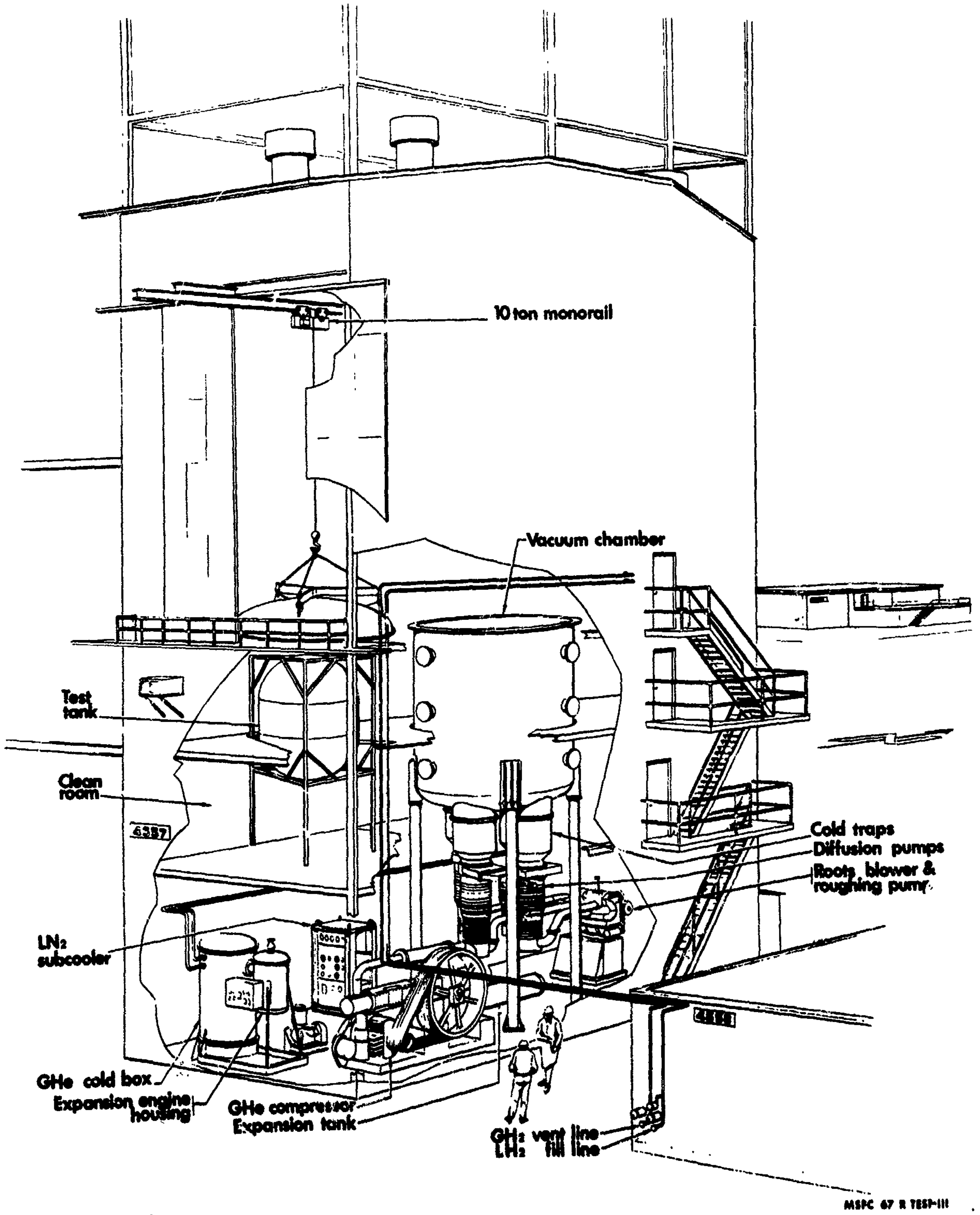


FIGURE 74

FIGURE 75 - Test Tank Support in Test Chamber

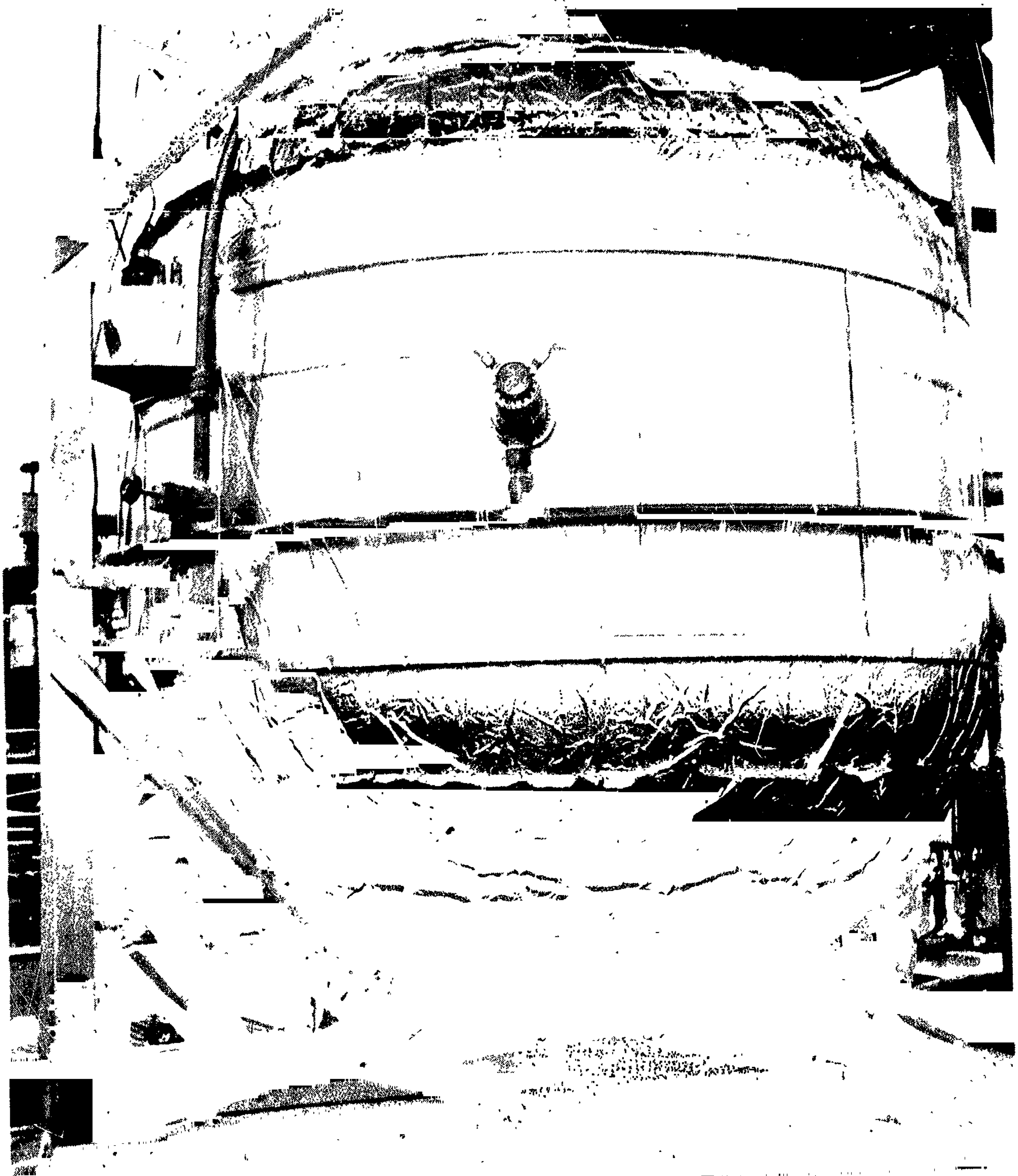
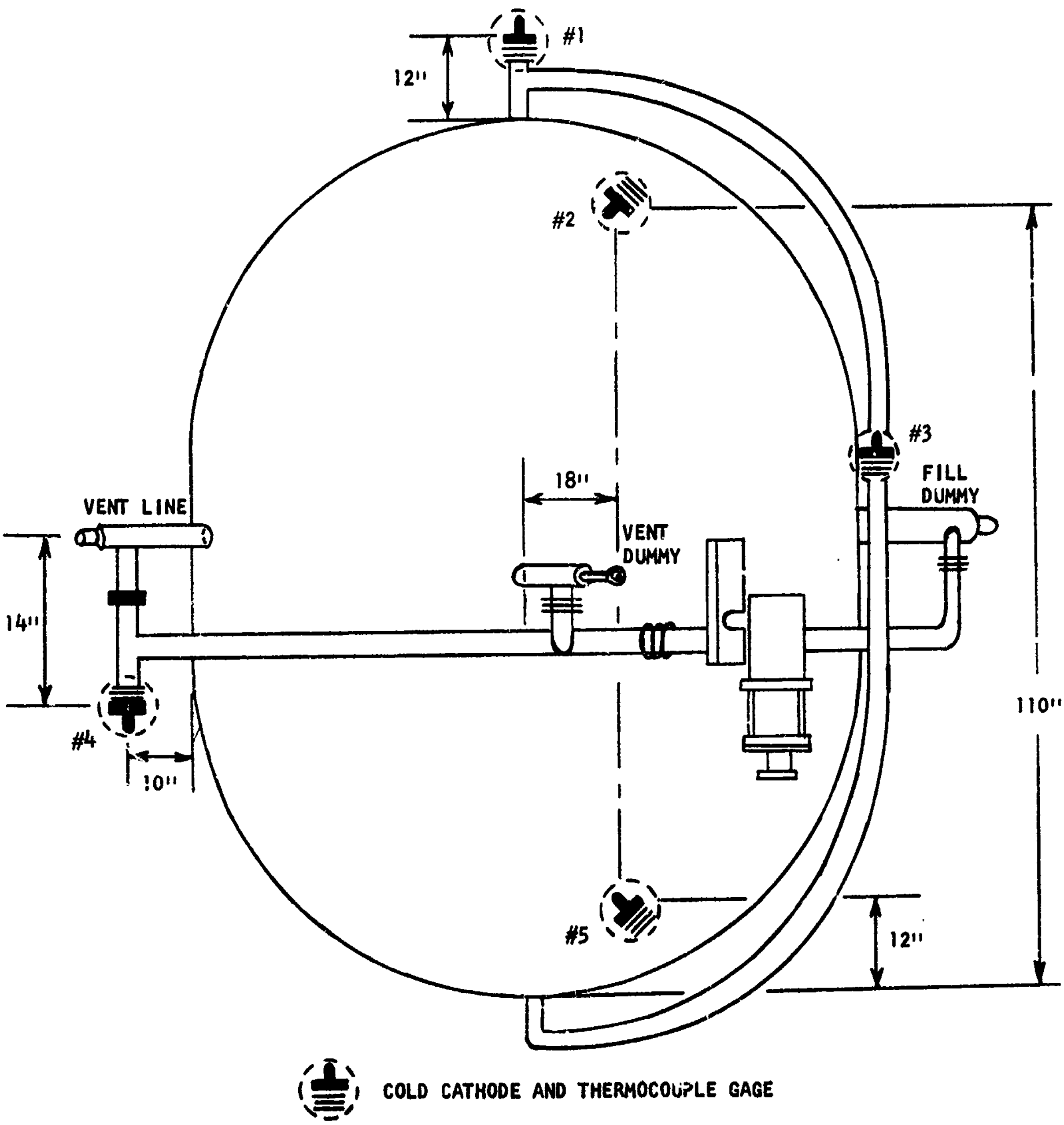


FIGURE 76 - Test Tank Ready for Admission to the Vacuum Chamber



SIDE VIEW

FIGURE 77 - Tank insulation Pressure Measurements

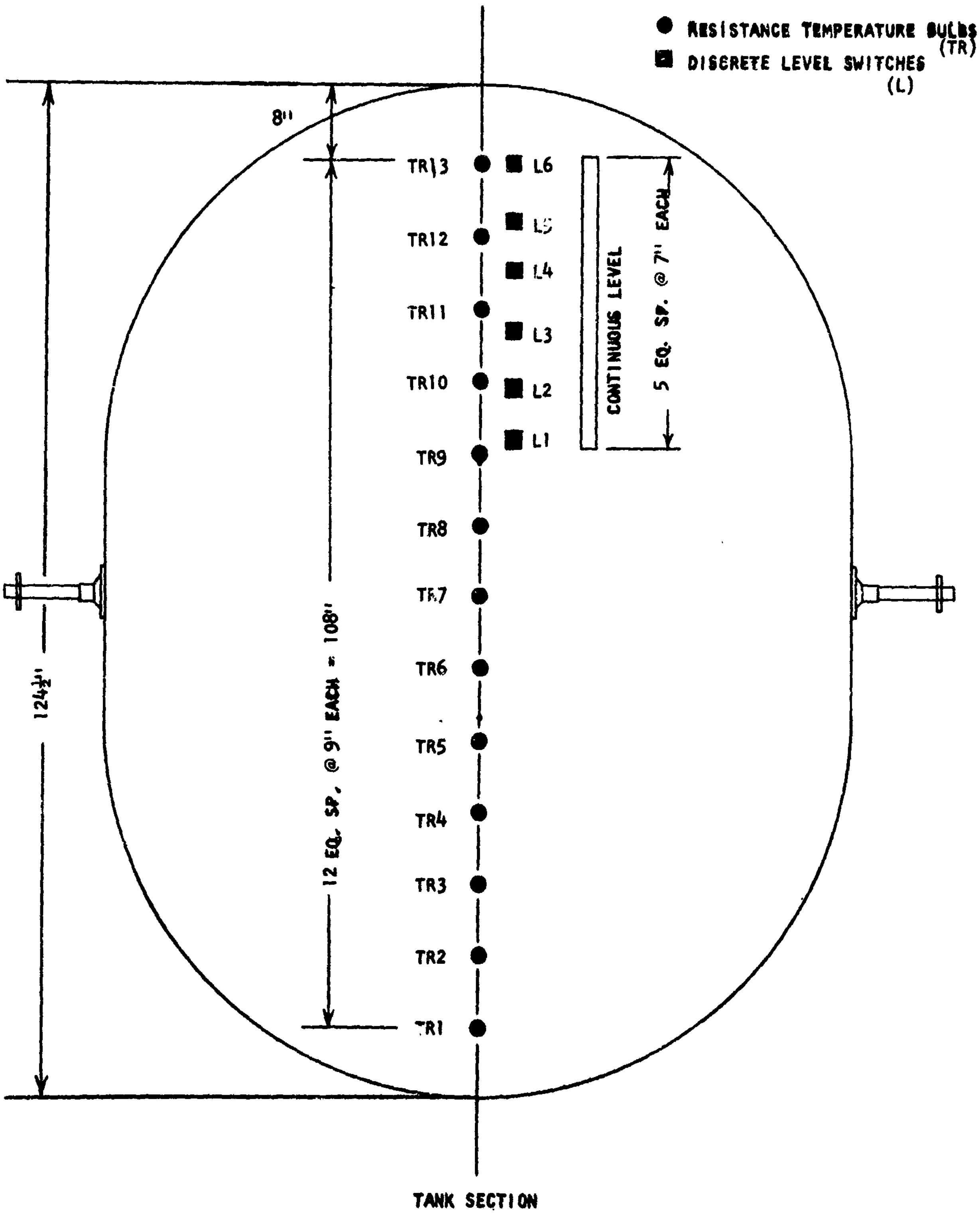


FIGURE 78 - Internal Tank Instrumentation

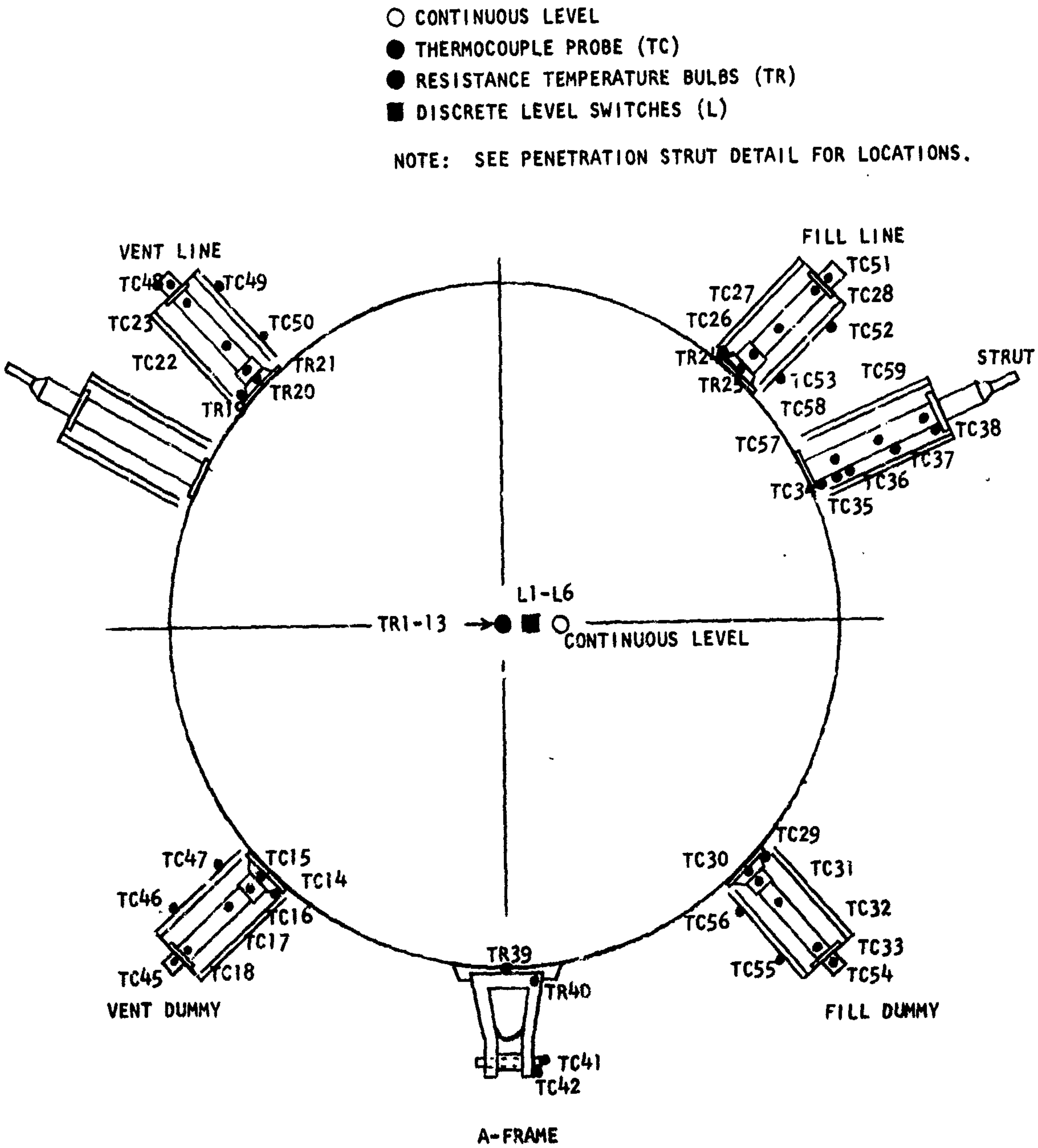
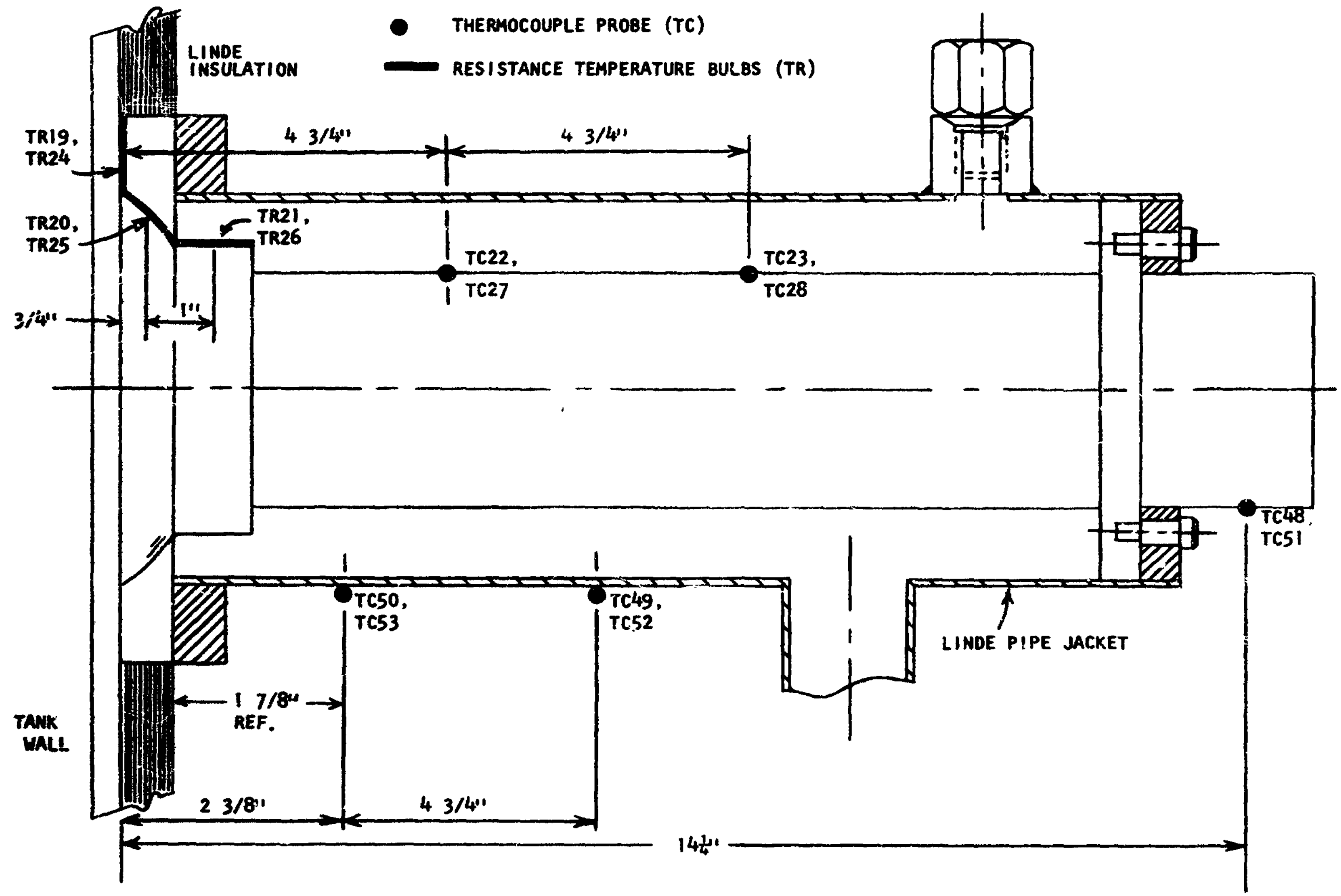


FIGURE 79 - Penetration, Support Strut and A-Frame Instrumentation

FIGURE 80 - FILL AND VENT LINE PENETRATION INSTRUMENTATION



NOTE: TC22 IS ON VENT, AND TC27 IS ON FILL (I.E., UPPER NUMBERS ON VENT AND LOWER NUMBERS ON FILL).

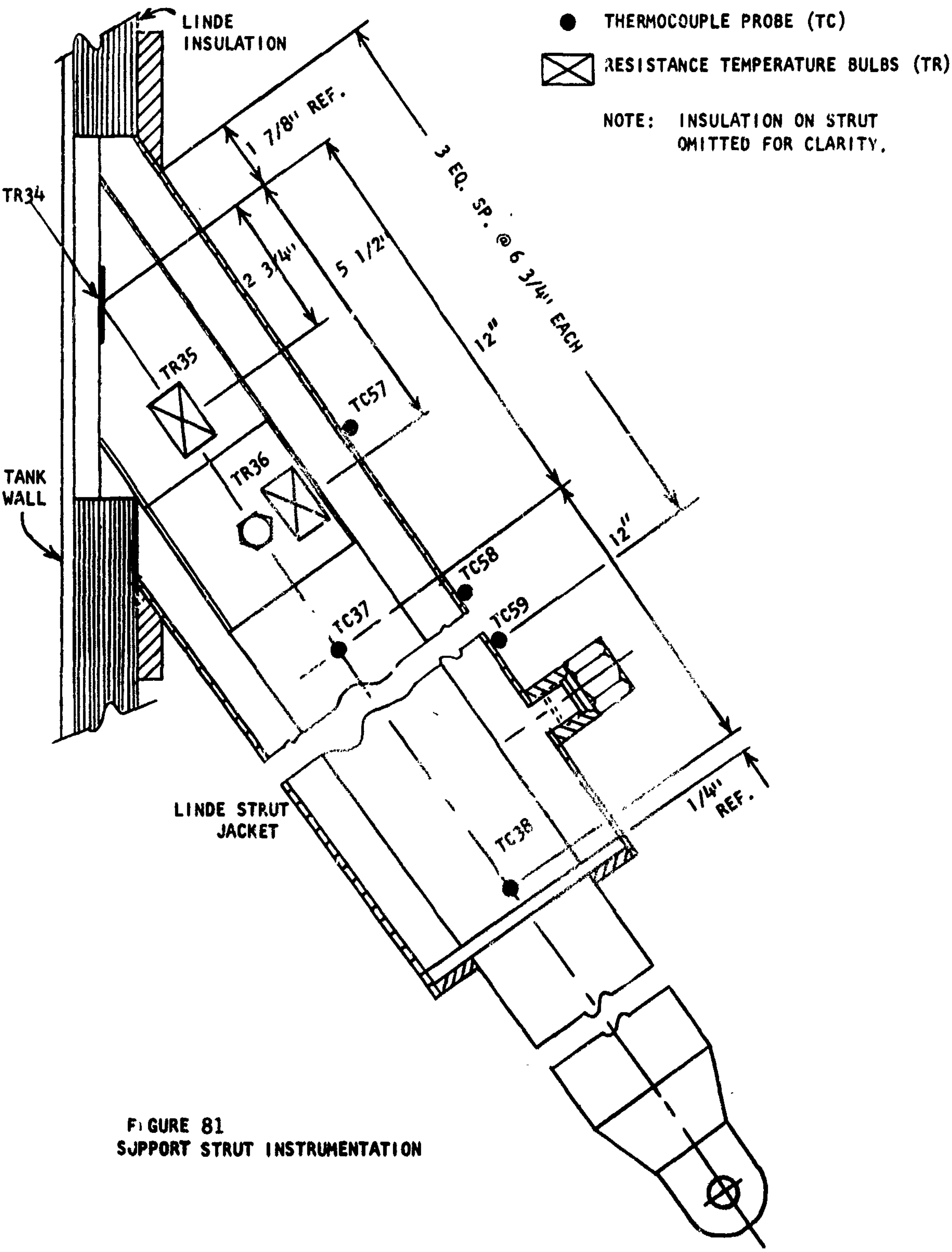


FIGURE 81
SUPPORT STRUT INSTRUMENTATION

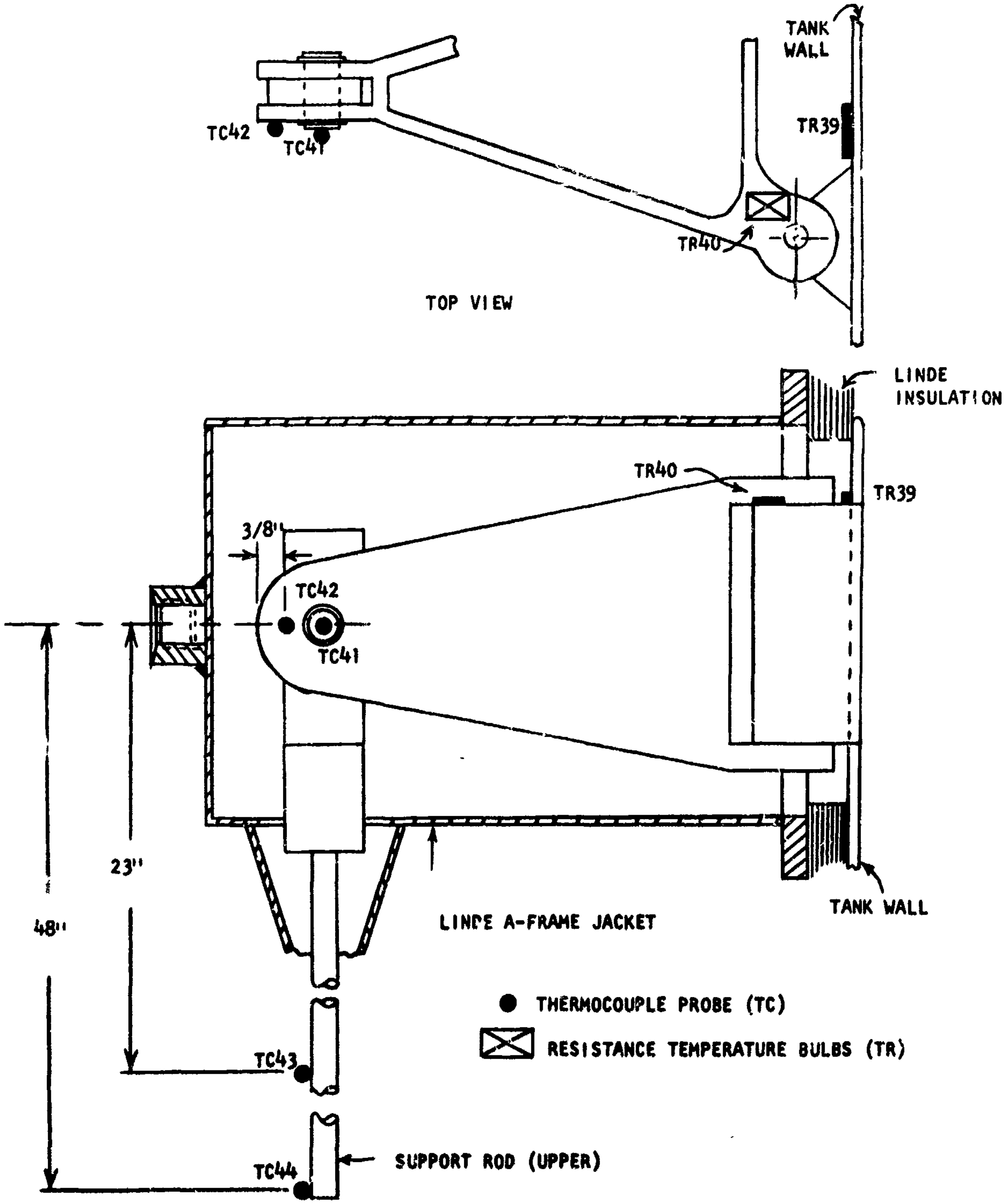
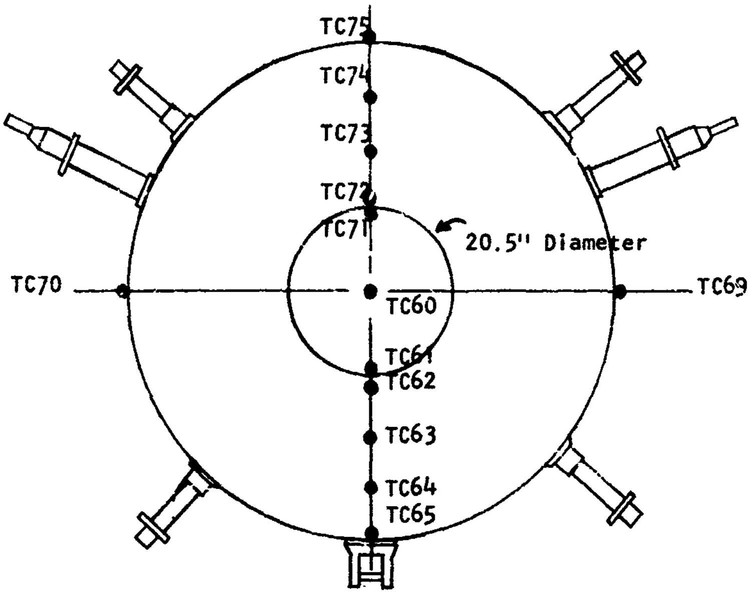
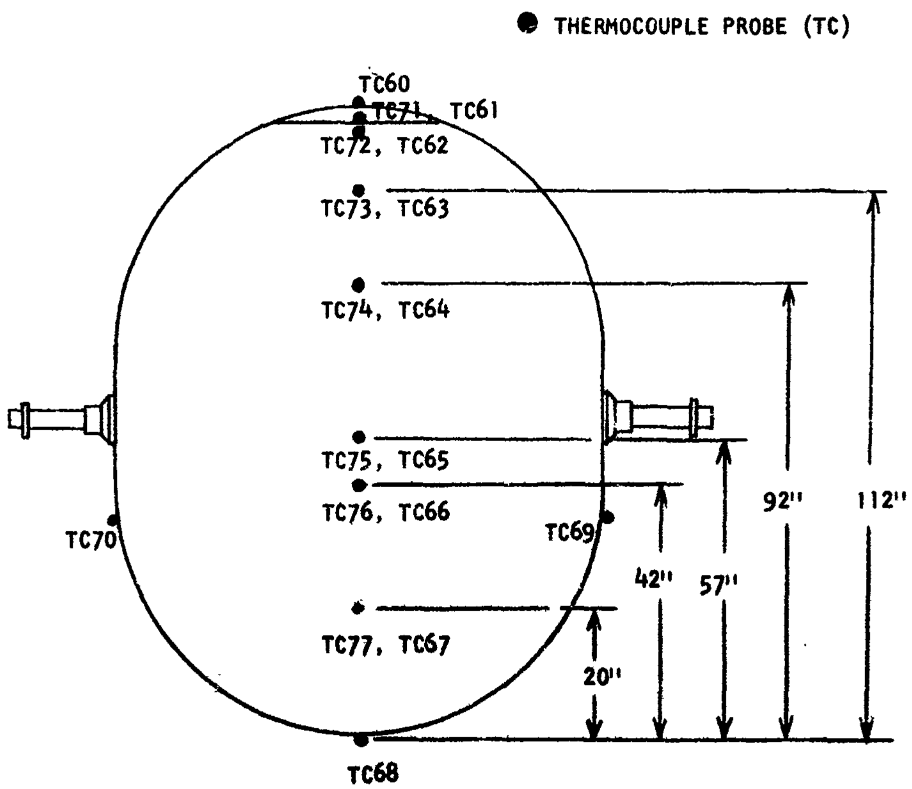


FIGURE 82 - A-FRAME INSTRUMENTATION

FIGURE 83 - EXTERNAL JACKET INSTRUMENTATION



TOP VIEW



SIDE VIEW

INTERFACE AND CHAMBER INSTRUMENTATION

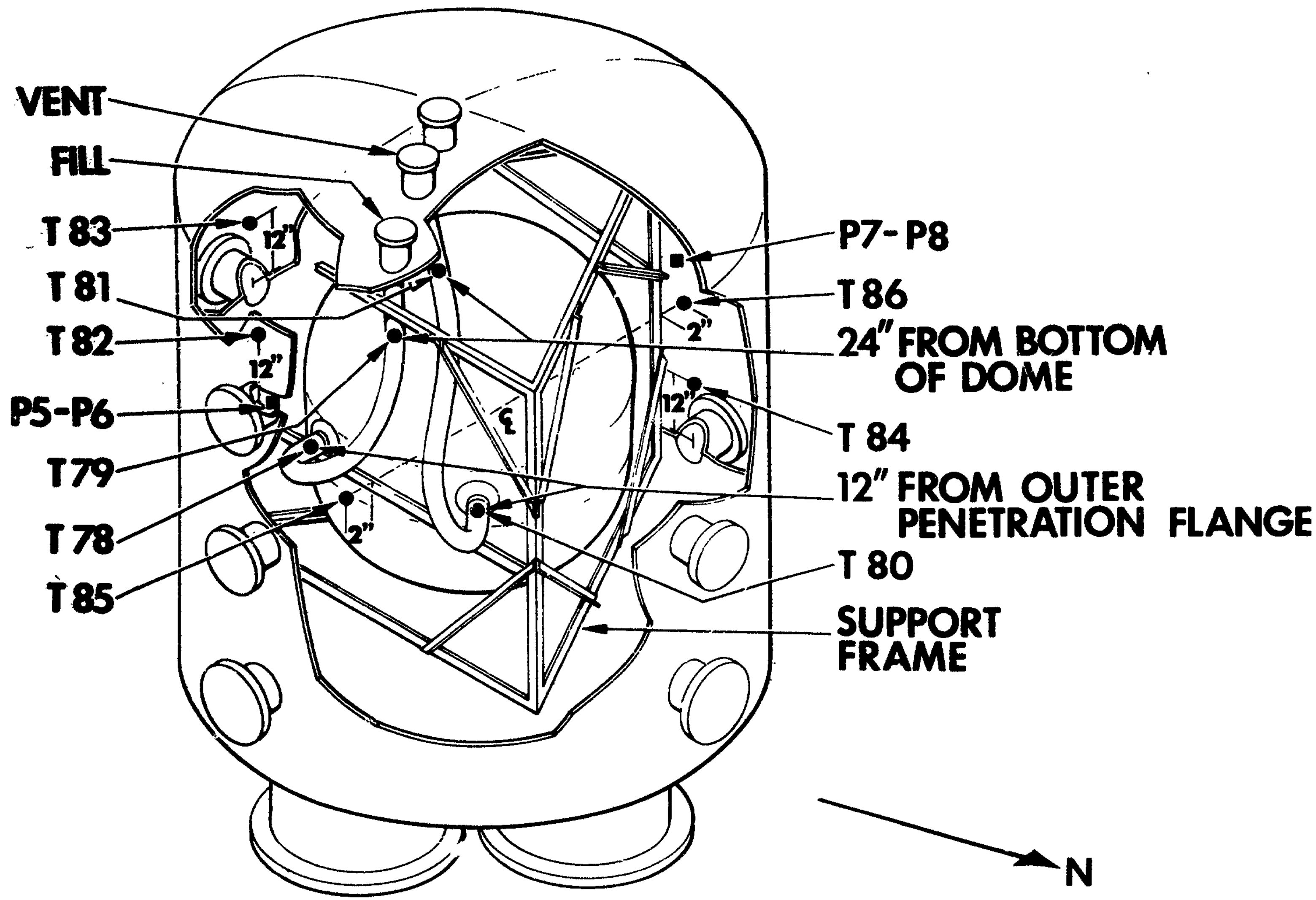


FIGURE 84

the boiloff gas at a nominal temperature of 80°F during all tests. General Monitor combustible gas detectors monitored the hydrogen gas level and were set to sound an audible alarm at 2 per cent hydrogen by volume.

The insulation pressures were measured by using National Research Corporation (NRC) type 521 thermocouple gages in the 1 mm Hg to 1×10^{-3} mm Hg range; NRC 524 cold cathode gages were used in the 1×10^{-3} to 1×10^{-6} mm Hg range. A remote vacuum pressure monitoring system assembled by the Cook Vacuum Company was used to measure chamber pressure at two chamber positions. This chamber system used NRC 553 hot filament ionization gages and NRC 530 alphatron gages operating in the 1×10^{-3} to 1×10^{-9} mm Hg and atmosphere to 1×10^{-3} mm Hg ranges, respectively.

6.2 TEST RESULTS

6.2.1 Large Scale Test Program Objectives

The primary objective of the large scale test program of the insulated 105 inch diameter test tank was to determine the performance of a Linde insulation system at altitude which system was representative of a realistic space hydrogen tank. Secondary objectives included determination of the insulation performance during the ground hold phase; the effects of heat leaks through the various penetrations; the pressure level obtainable within the insulation and the effects of purging with ambient temperature and elevated temperature helium gas on ultimate insulation performance.

6.2.2 Ground Hold Test

Two ground hold tests were conducted: one with the tank in the vacuum chamber and vacuum chamber filled with dry nitrogen gas but vented to the atmosphere and the second with the tank mounted outside the chamber in an ambient air environment. Boiloff rates of 33 lbs/hr. and 32 lbs/hr. respectively were measured. This is considerably higher than the predicted value of 22.5 lbs/hr. for the ground hold condition. The temperature and pressure data for the first of these tests is shown in Figures 85 and 86. It will be noted that the pressures during the first test were in the range of one millimeter throughout the test until time 170 minutes when a large leak developed in the vacuum jacket. This high pressure explains the high boiloff rate. In the second ground hold test, no such leak was found but it is probable that fairly high pressures were experienced also.

6.2.3 Altitude Tests

A total of four tests were conducted with the insulated test tank in the chamber and the chamber evacuated to simulate long term altitude performance. The results of these tests are tabulated in Table 11 and the pertinent available data shown in Figures 87 through 95.

In the first test (C-012-29) the insulation was initially evacuated and maintained in that condition throughout the test. The chamber was purged with dry nitrogen and evacuated to a pressure of about .05 microns. A total boiloff of about 1.8 lbs/hr. was measured by the flowmetering apparatus. When adjustments are made for heat leak effects of penetrations, a thermal performance described as K/X of 1.65×10^{-3} BTU/hr.ft.sq.°R is noted. This compares with a predicted value of 0.6×10^{-3} BTU/hr.ft.sq.°R. Unfortunately the capacitance device for measuring the position of the vacuum jacket was inoperative during these tests and therefore the thickness of the insulation can only be estimated by means of the thermal performance measurements. Assuming that the thermal conductivity - layer density relationship shown in Figure 1 and the results of small scale tests apply the apparent layer density for this test was 133 layers/inch (a thickness of 0.53 inches) and the thermal conductivity was 7.3×10^{-5} BTU/hr.ft.°R. Such performance seems realistic considering the fact that the insulation had been cycled between zero and one atmosphere on numerous occasions and was compressed for the most part over a 18 month period prior to the test. This fact coupled with the effects of repair of the insulation around the top of the bulkhead and other repairs would be expected to cause a thermal conductivity higher than predicted.

It was next desired to determine the effects on long term performance of purging the insulation system with ambient temperature helium gas prior to the hydrogen fill (Test C-012-30). The performance data obtained as shown in Table 11 indicate that little significant difference in thermal performance was

TABLE 11

SUMMARY OF LARGE SCALE TEST RESULTS*

Test No. C-012-	29	30	31	34
Precondition Insulation	Evacuated	Ambient Helium	High Temp. Helium	High Temp. Helium
Precondition Chamber	Nitrogen	Air Helium	Helium	Helium
Boiloff Rate (Vented) (#/hr.)	1.8	2.0	0.9	1.2
Total Flowrate (#/hr.)	1.8	2.0	6.0	7.7
Fill Line	Closed	Closed	Leaking	Leaking
Jacket Surface Temp.(°F)	33	37	35	-
Chamber Wall Temp. (°F)	44	46	45	-
Insulation Pressure (μ Hg)	0.45	0.35	0.50	8.0
Chamber Pressure (μ Hg)	0.05	0.05	0.05	0.05
Ullage Pressure (psig)	0.8	0.9	-	0.7
Apparent k/x (BTU/hr.ft.^{2}°R) (Predicted value = 0.6×10^{-3})	1.65×10^{-3}	1.9×10^{-3}		
Apparent Layer Density (Layers/Inch)	120	125		
Apparent Thickness (Inches)	0.59	0.56		
Apparent Thermal Conductivity (BTU/hr.ft.°R)	7.3×10^{-5}	8×10^{-5}		

*See Table 9, page 82, for a breakdown of the predicted results. Note that the cold joint was not employed during these tests so that the contribution due to discontinuities should be 101.3 Btu/hr. and the total predicted heat leak should be 197.5 Btu/hr (1.0 lbs/hr).

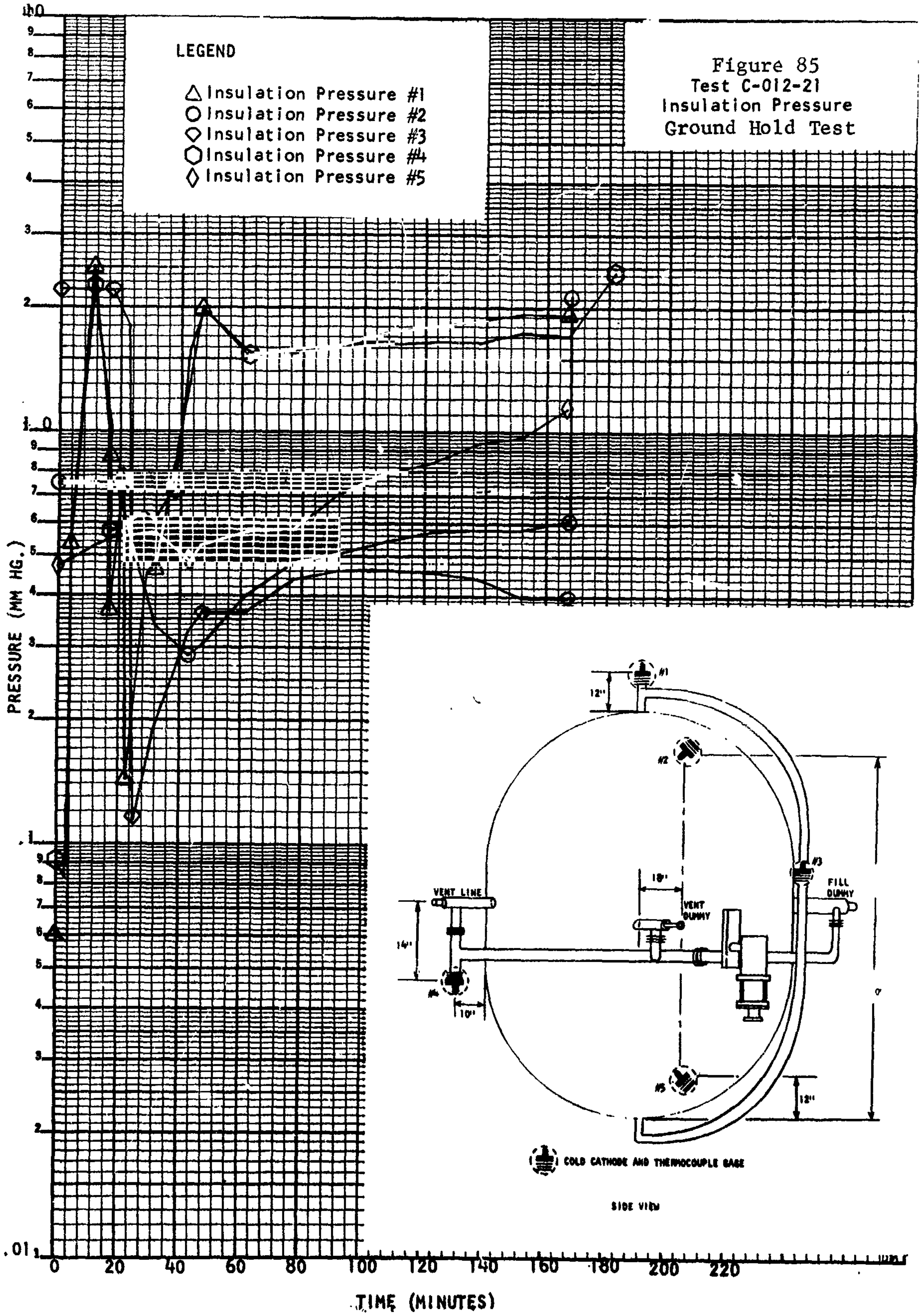


Figure 85
Test C-012-21
Insulation Pressure
Ground Hold Test

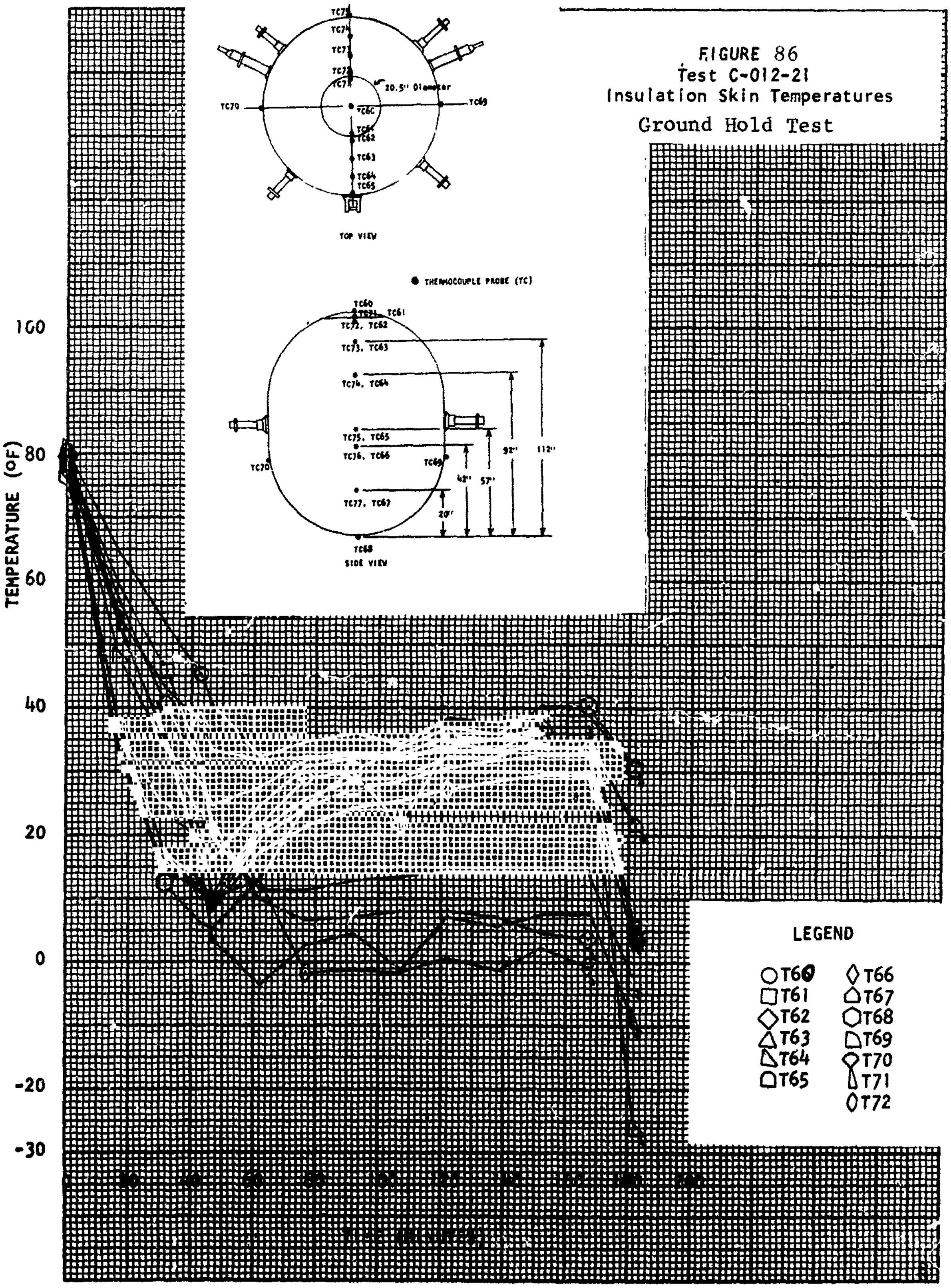


FIGURE 86
Test C-012-21
Insulation Skin Temperatures
Ground Hold Test

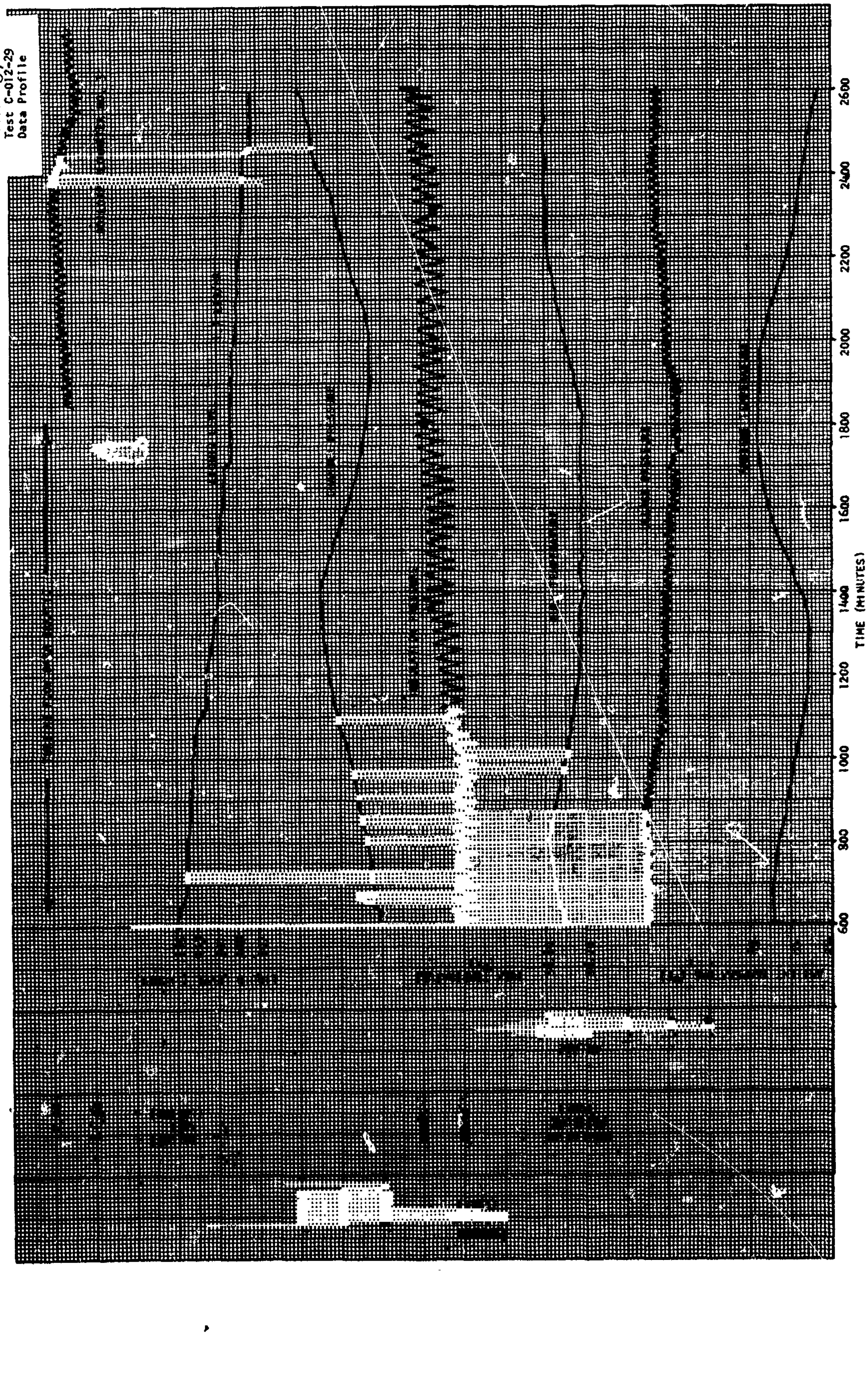


FIGURE 87
Test C-012-29
Data Profile

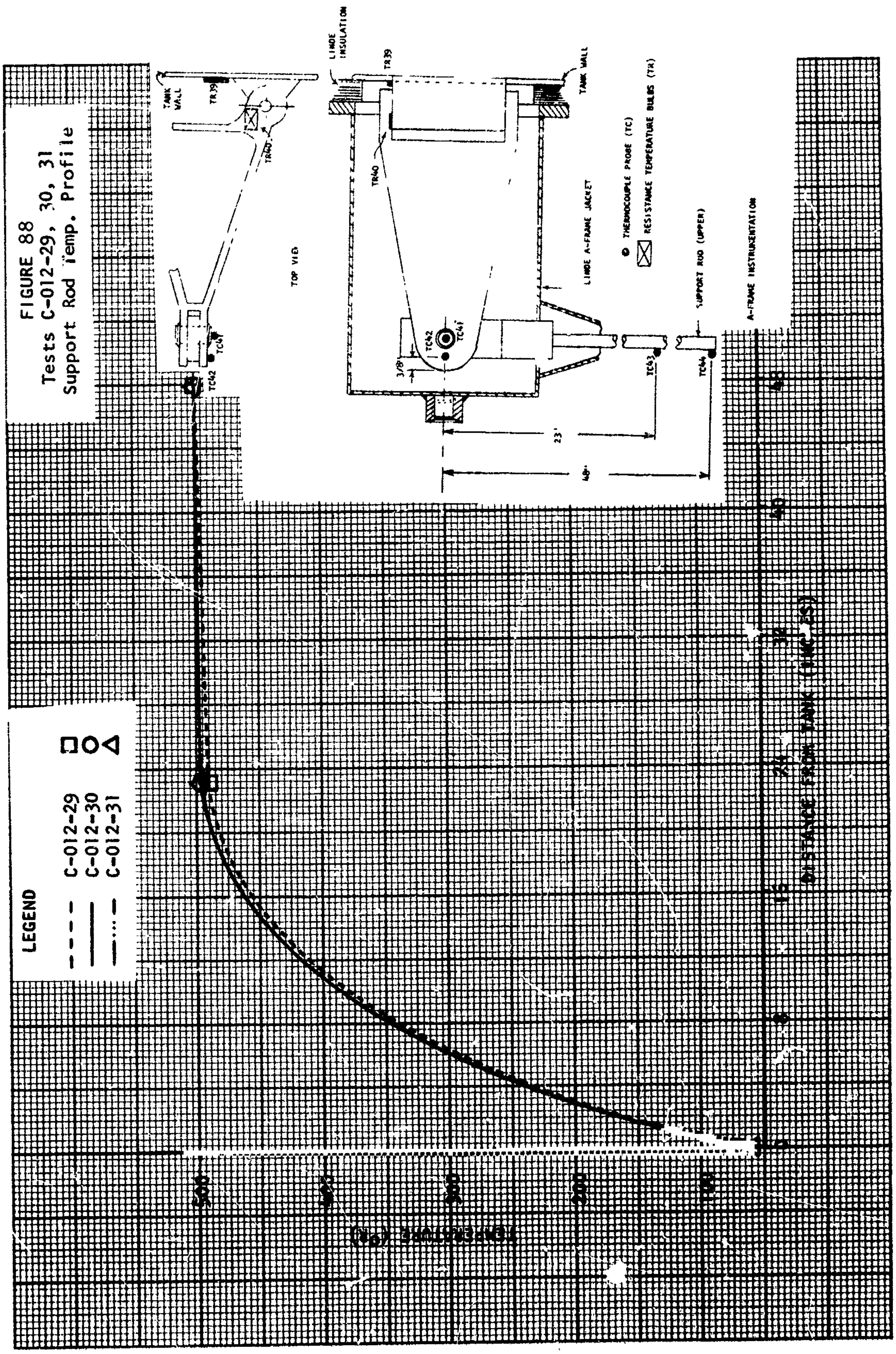


FIGURE 88
Tests C-012-29, 30, 31
Support Rod Temp. Profile

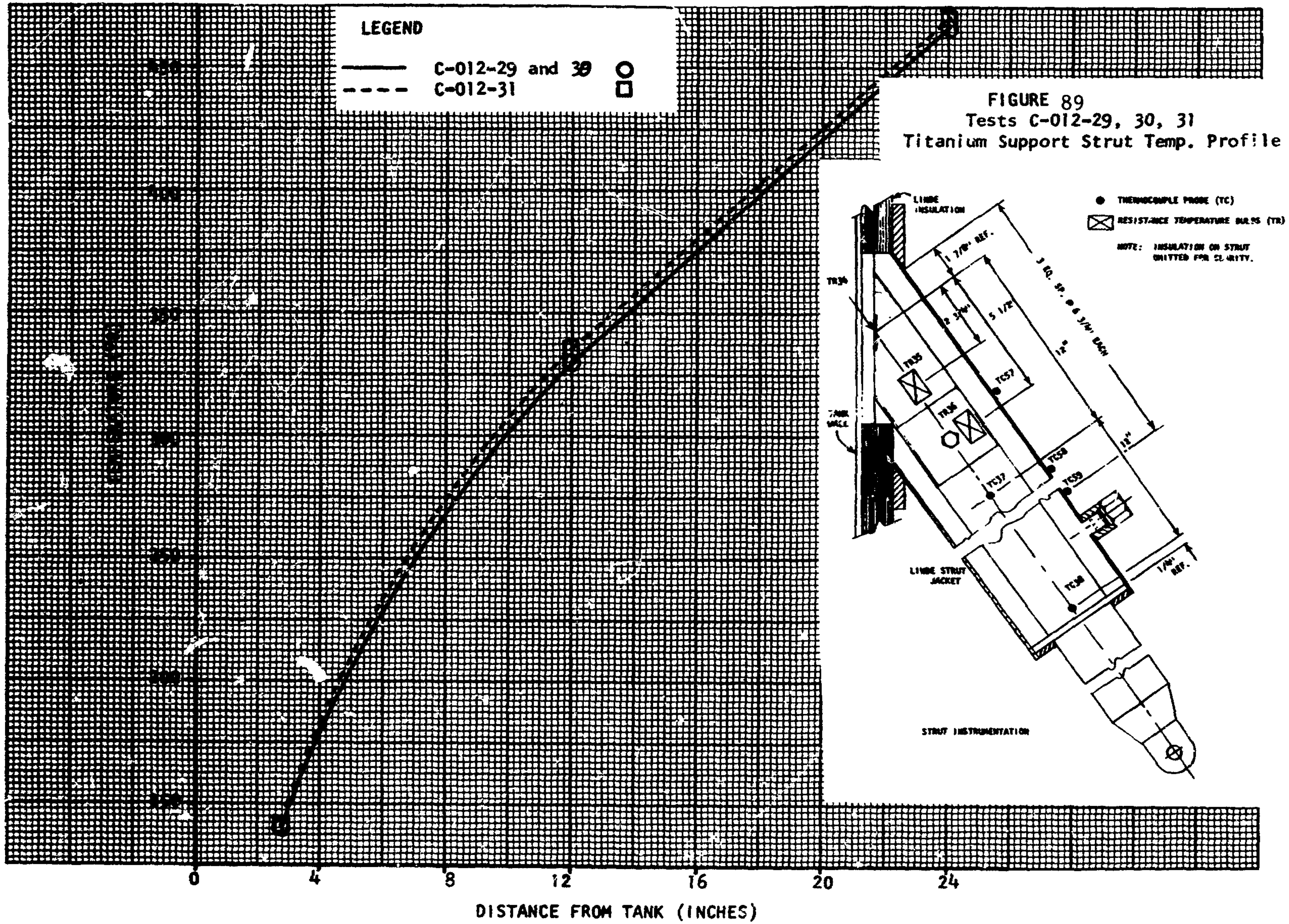


FIGURE 89
Tests C-012-29, 30, 31
Titanium Support Strut Temp. Profile

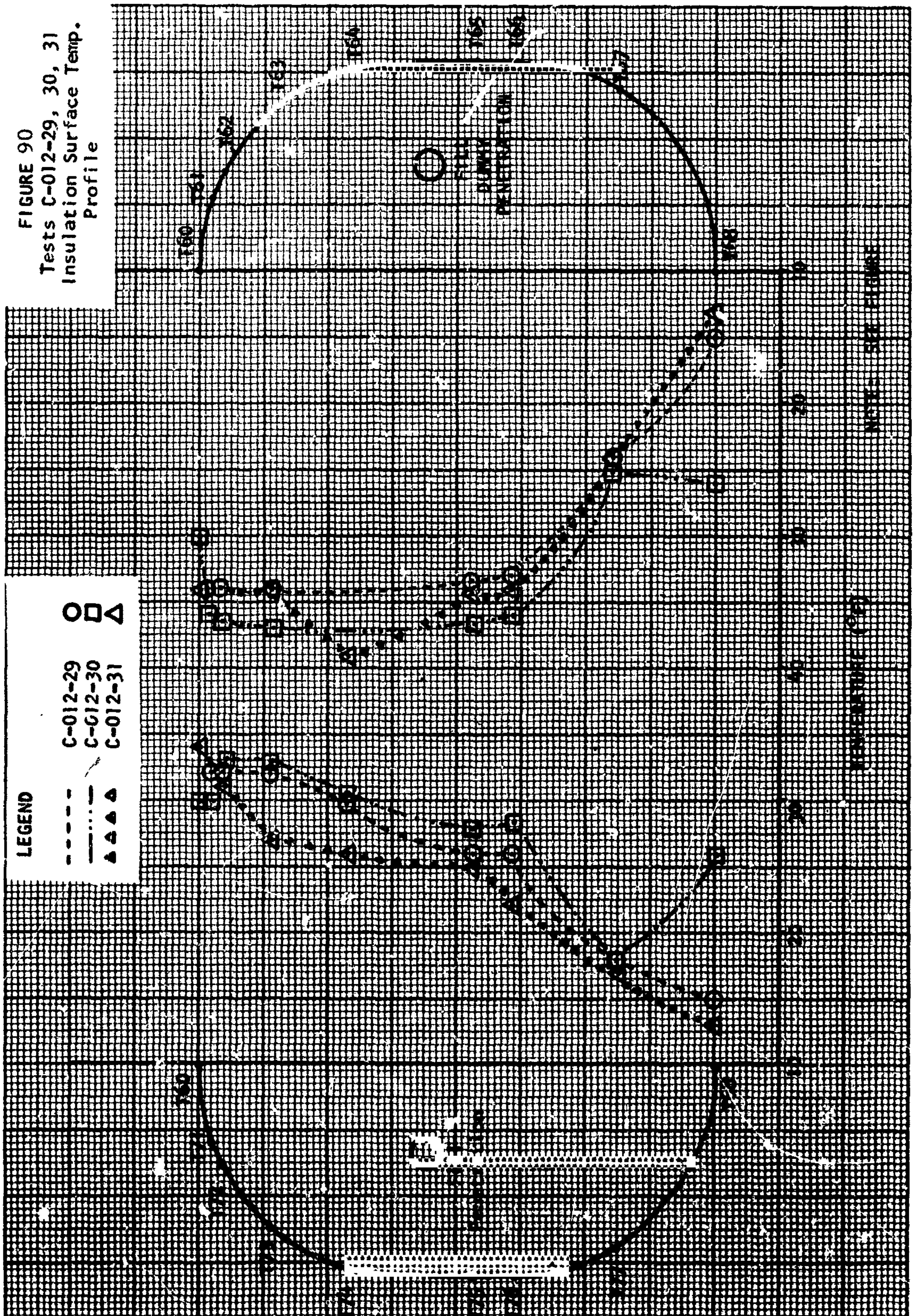


FIGURE 90
Tests C-012-29, 30, 31
Insulation Surface Temp.
Profile

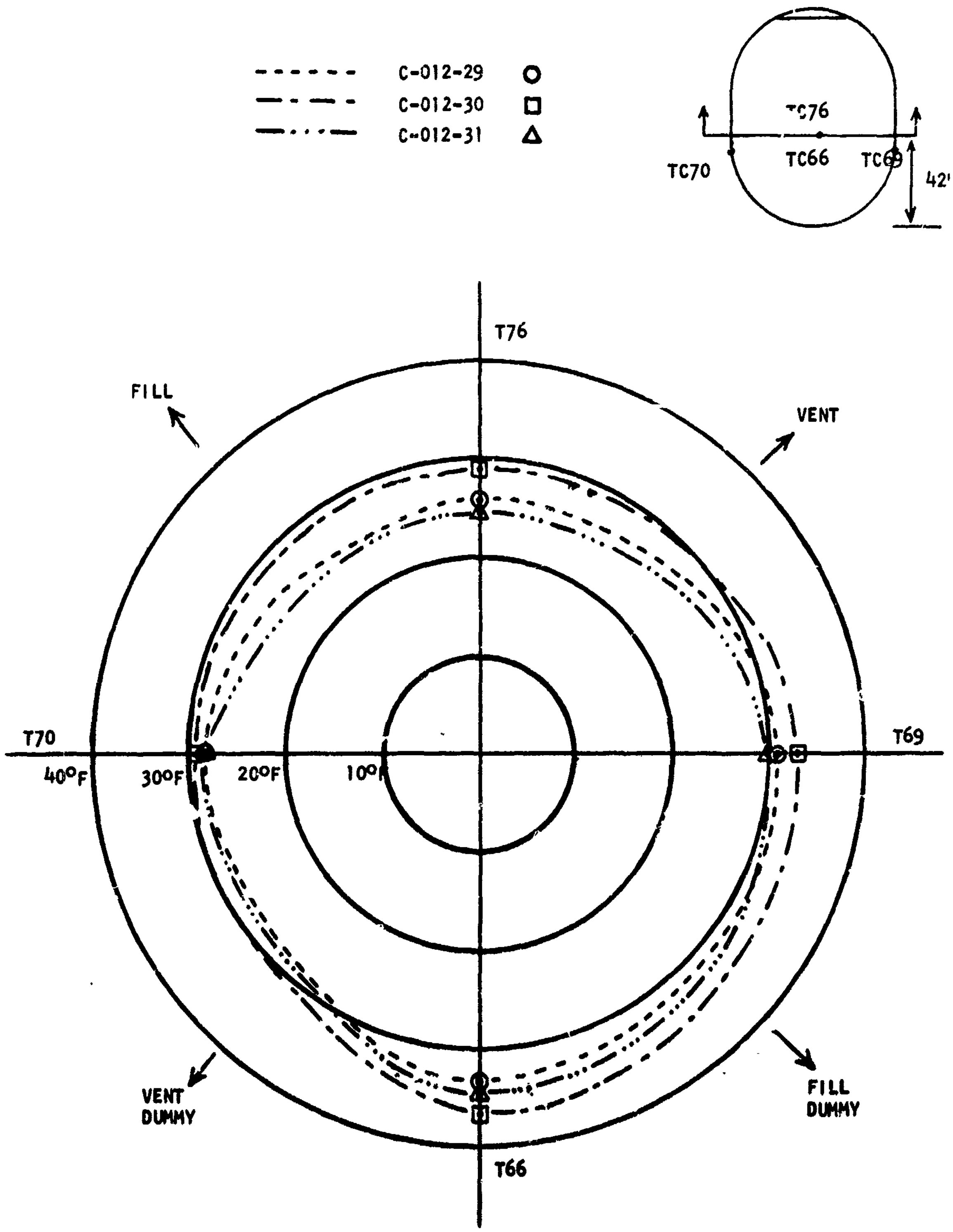


FIGURE 91 CIRCUMFERENTIAL SURFACE TEMP. PROFILE OF INSULATION BETWEEN 42 AND 40 INCH LEVEL (FROM BOTTOM)

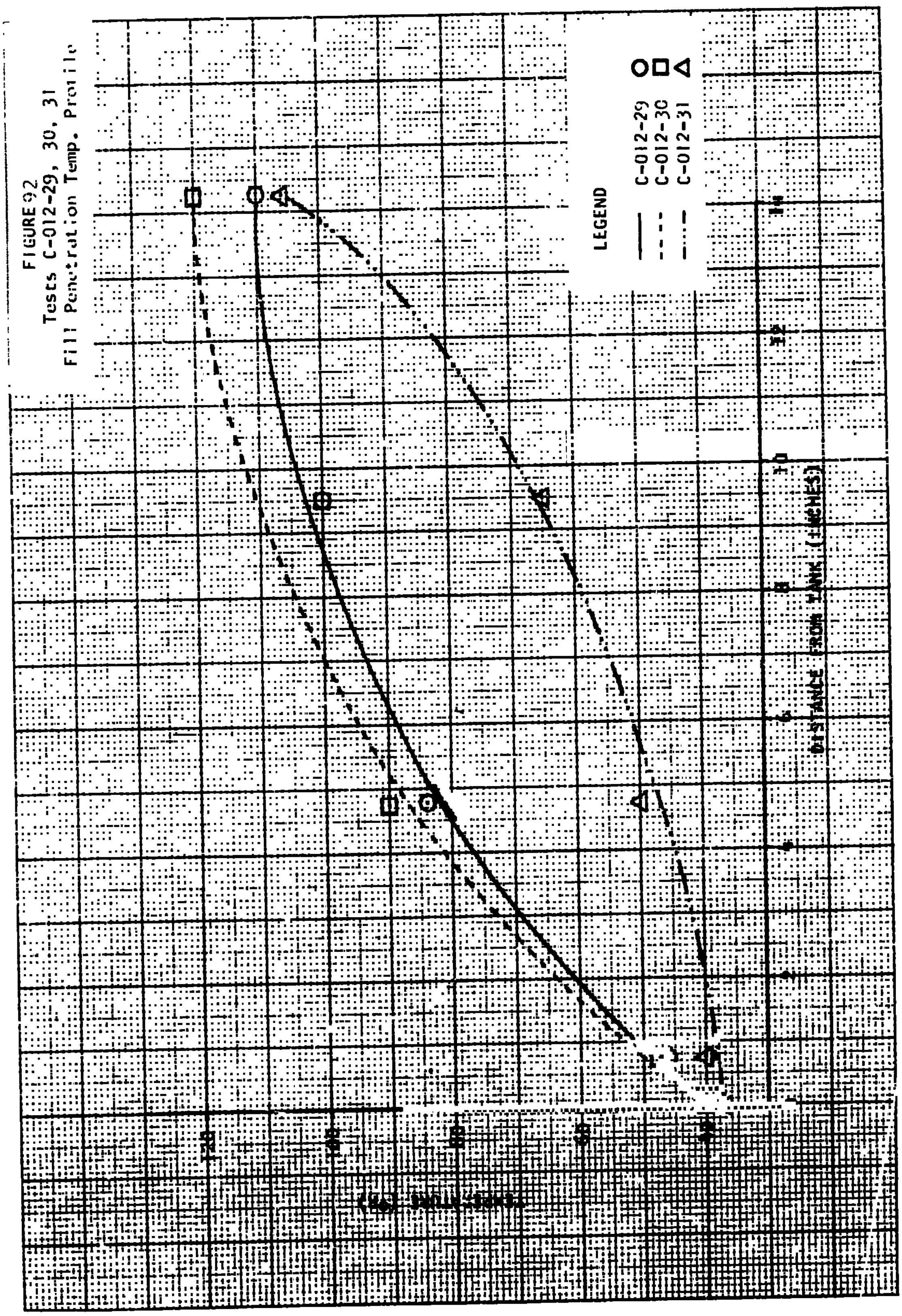


FIGURE 92
Tests C-012-29, 30, 31
Fill Penetration Temp. Profile

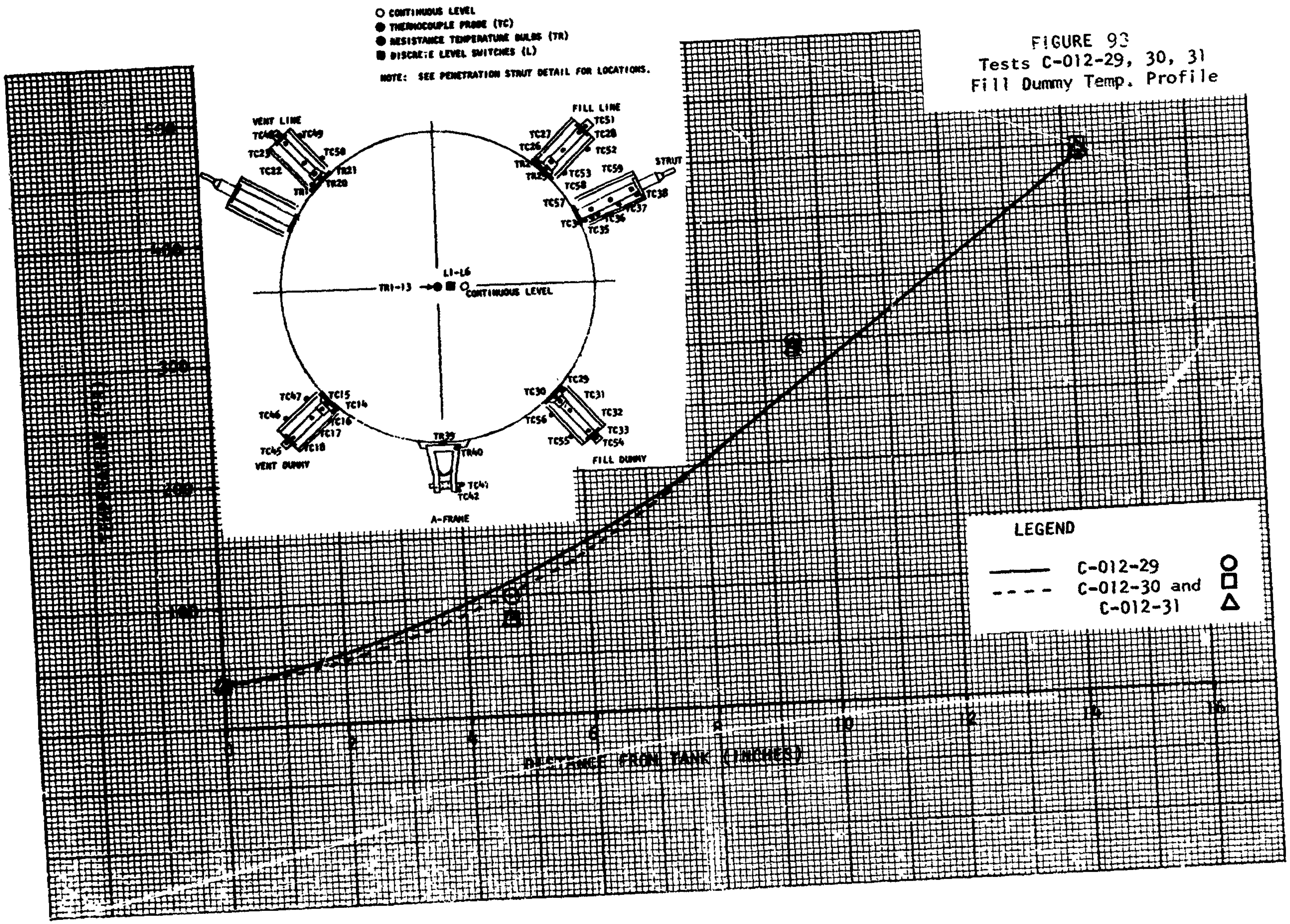


FIGURE 93
Tests C-012-29, 30, 31
Fill Dummy Temp. Profile

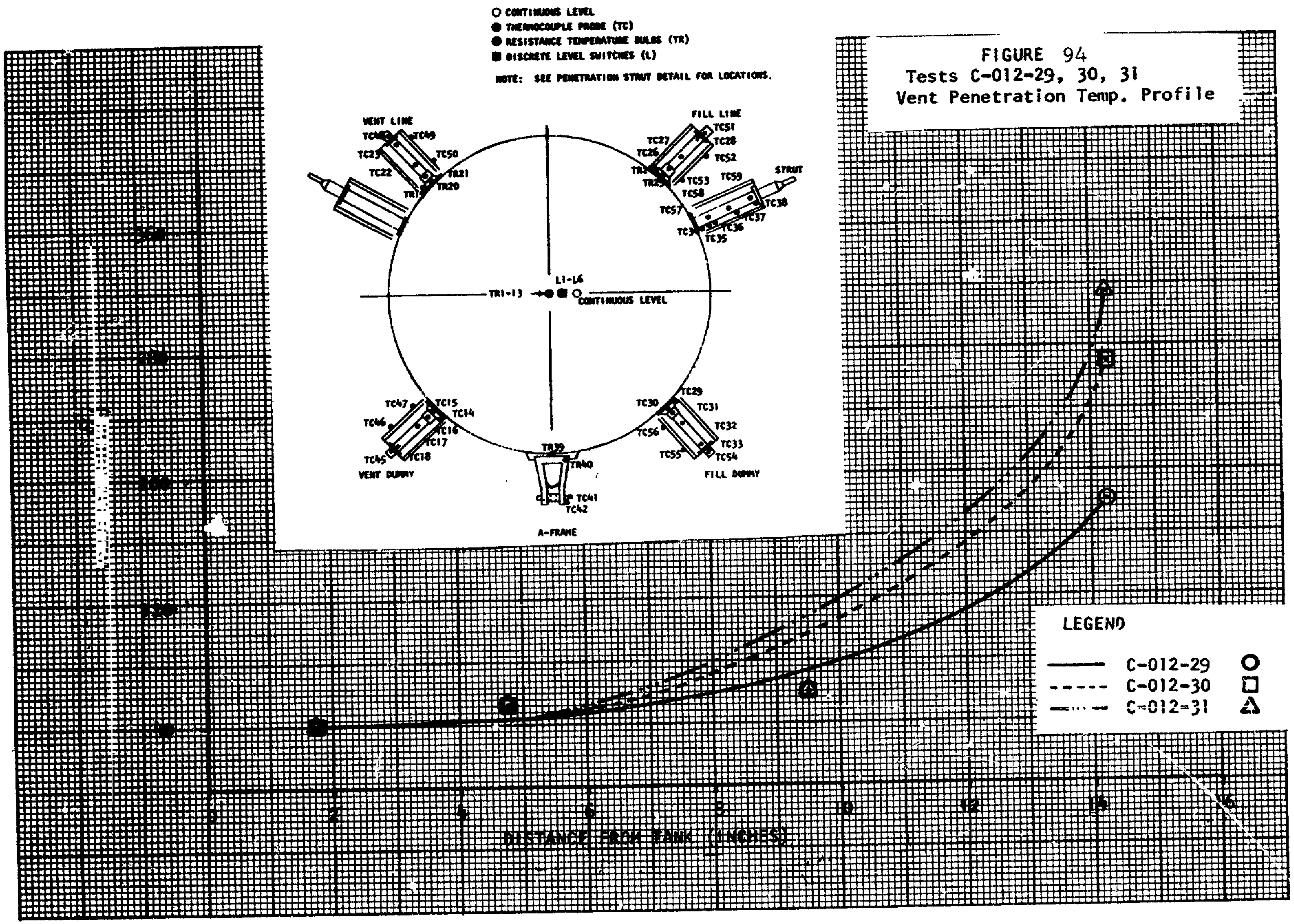


FIGURE 94
Tests C-012-29, 30, 31
Vent Penetration Temp. Profile

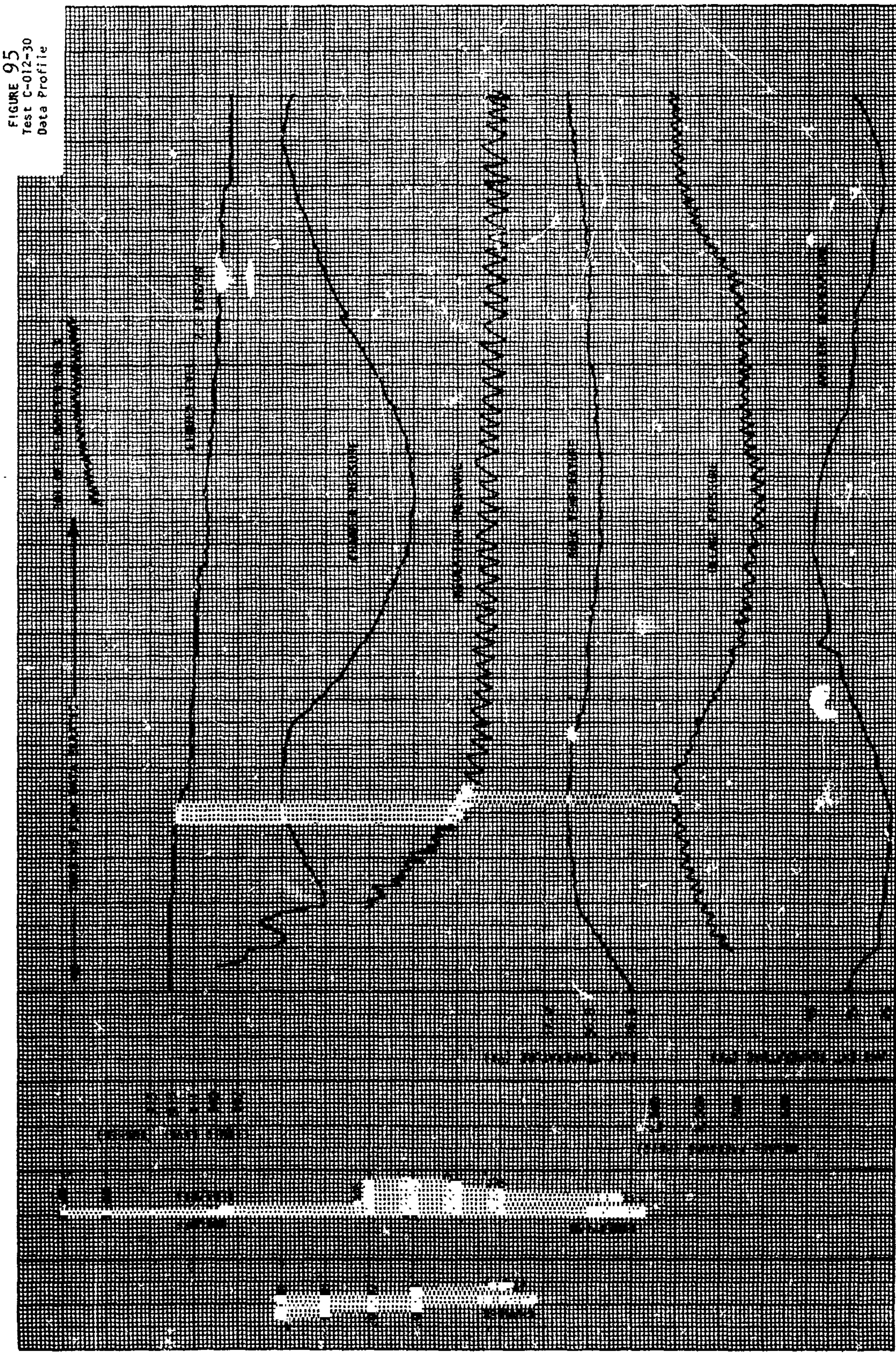


FIGURE 95
Test C-012-30
Data Profile

obtained. This is to be expected because the data were taken some 2,000 minutes into the test (as was true of the previous test also), well after the helium gas had been pumped out of the insulation space. Since the results are so similar, it can be concluded that little or no "fluffing" action resulted from the purge and a recovered insulation thickness and apparent thermal conductivity similar to that experienced previously resulted.

The third test was conducted to determine the effects, if any, of purging the insulation system with elevated temperature helium gas (250°F). During this test however difficulty was experienced with the fill valve located in the liquid line inside the test tank. It was determined that this valve did not seat properly and was leaking. Because of this leaky valve, a total flow rate of 6#/hr. of hydrogen was experienced based on the liquid level measurements; however, only about 1#/hr. of this flow actually went through the turbine metering system. As shown in Table 11, if one assumes that the turbine meters are measuring all of the boiloff gas and if these data are adjusted to account for the change in heat leakage through the fill line and the rapid change in ullage due to the leakage, a thermal performance much better than experienced previously would be surmised. However, as noted in the tabulated data, the surface temperatures of the insulation do not indicate a performance much different than that which had been previously experienced. It must therefore be concluded that most of the change in apparent performance is due to boiloff gases being entrained within the effluent liquid. The temperature profile of the fill penetration shown in Figure 92 does verify the existence of liquid hydrogen in the filling line during the test. It is therefore felt that the thermal performance of the insulation during this test was not significantly different than the previous tests and no effect can be attributed to the high temperature helium purge.

Because of the problems experienced with the fill and drain valve, the high temperature helium purge test was repeated and essentially the same data resulted with the valve leaking once again. The somewhat higher total flow and flow through the vent meters may be attributable to the higher insulation vacuum pressure. Again, however, no definitive conclusions can be reached regarding the effect of the high temperature purge.

Referring to the simplified test flow schematic shown in Figure 96 with the fill valve No. 3 leaking and the fill bleed valve No. 2 open, one would expect that the majority of the flow from the tank would be caused by gravity head to flow through the fill line, vaporize and bypass the metering system as was actually experienced. However, it was also noted that with the same condition except with the fill bleed valve closed, an increase in total boiloff resulted. This is probably due to a percolating effect within the fill line but there is no data to prove this point.

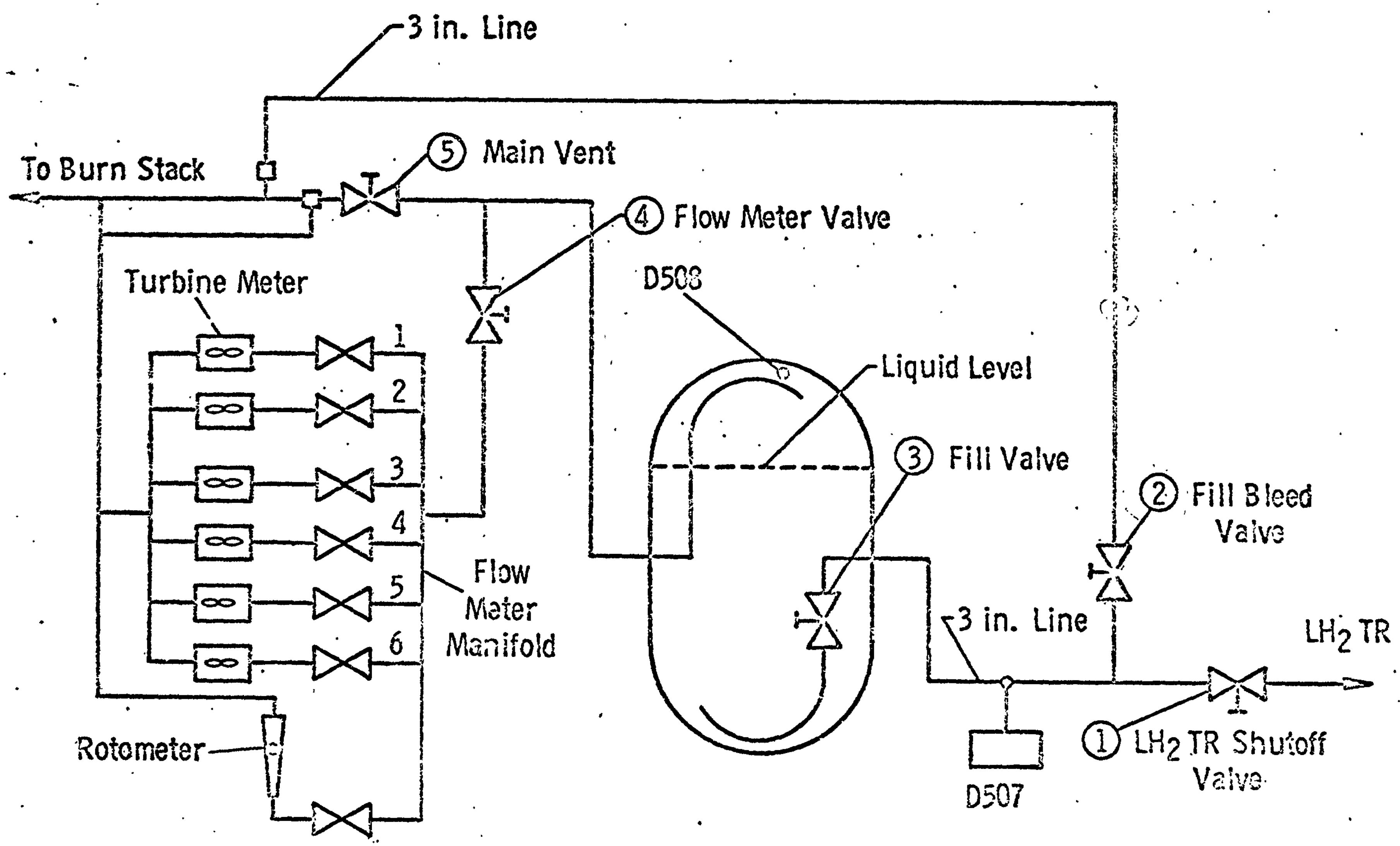
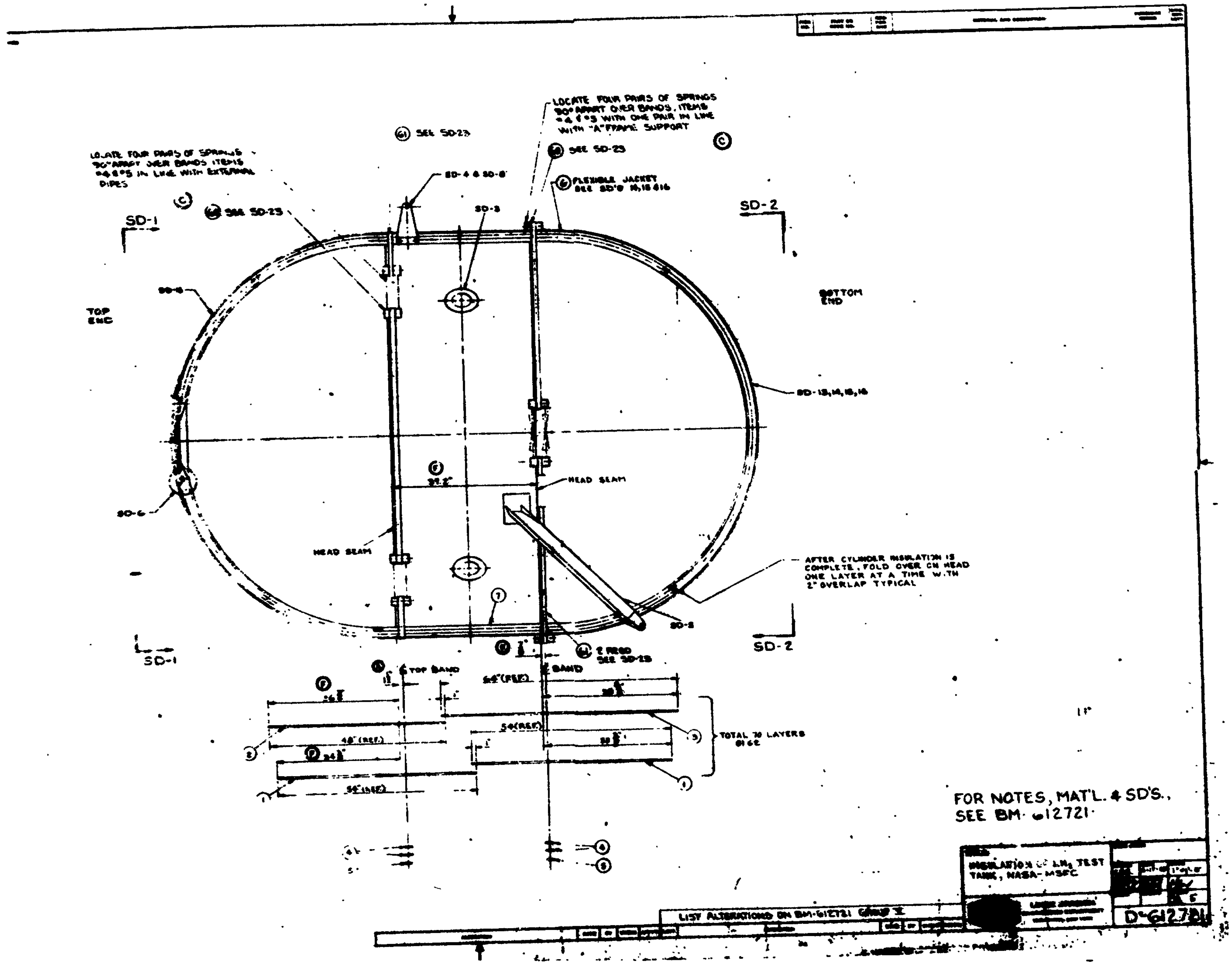


FIGURE 96
SIMPLIFIED FLOW SCHEMATIC

APPENDIX I

Design Drawings for 105 inch Diameter Test Tank


LOCATE FOUR PAIRS OF SPRINGS 90° APART OVER BANDS, ITEMS #4 & #5 WITH ONE PAIR IN LINE WITH "A" FRAME SUPPORT
LOCATE FOUR PAIRS OF SPRINGS 90° APART OVER BANDS ITEMS #4 & #5 IN LINE WITH EXTERNAL PIPES
SEE SD-23
FLEXIBLE JACKET SEE SD'S 10,15 & 16
SD-4 & SD-8
SD-3
SD-1
SD-2
TOP END
BOTTOM END
SD-13,14,15,16
SD-6
HEAD SEAM
AFTER CYLINDER INSULATION IS COMPLETE, FOLD OVER ON HEAD ONE LAYER AT A TIME WITH 2" OVERLAP TYPICAL
TOP BAND
BAND
TOTAL 70 LAYERS
FOR NOTES, MAT'L. & SD'S., SEE BM-612721
INSULATION OF LH2 TEST TANK, NASA-MSFC
LIST ALTERATIONS ON BM-612721
D-612721

GROUP LISTING	SYMBOL	GROUP INDEX	NO. OF SHEETS
NOTES	N	I	14
BILL OF MATERIALS	BM	II	5
FABRICATION DETAILS	-	III	-
ASSEMBLY DETAILS	SD	IV	23
ALTERATIONS	R	V	1
		TOTAL	43

NOTES:

A. VESSEL PREPARATION

1. INSTALL VALVE IN WRAPPING FIXTURE.

2. INSPECT VESSEL FOR SHARP PROTRUSIONS WHICH MIGHT RESULT IN INSULATION DAMAGE. REMOVE WHERE NECESSARY.

3. INSPECT VESSEL ALIGNMENT IN WRAPPING FIXTURE.

4. CLEAN VESSEL OF GREASE, DIRT, ETC. USING ACETONE FOLLOWED BY AN AIR DRY.

(F) 6. THE ENTIRE VESSEL AND ANY EXPOSED INSULATION SEGMENTS SUCH AS HEAD DISKS SHOULD BE COVERED WITH A LIGHT PLASTIC SHEET AT THE END OF EACH DAY TO PREVENT CONTAMINATION FROM DIRT.

B. PREPARATION OF HEAD INSULATION SEGMENT

1. REMOVE THE FOIL (ITEM 1) AND GLASS ROLLS (ITEMS 2 & 3, & 27) FROM THEIR BOXES. EXTREME CARE MUST BE TAKEN NOT TO DAMAGE THE ROLLS, ESPECIALLY THE FOIL.

(F) 2. PLACE THE GLASS FIBER ROLLS IN A VACUUM FURNACE AND DRY AT 300°F FOR SIXTY HOURS TO REMOVE WATER VAPOR.

3. ASSEMBLE MOUNTING SHAFTS TO BOTH ALUMINUM AND GLASS ROLLS USING EXTREME CARE NOT TO DAMAGE INSULATION MATERIAL. TWO FOILS AND ONE GLASS ROLL REQUIRED.

   NOTE: ALWAYS STORE FOIL AND GLASS IN THEIR SHIPPING CONTAINERS WHEN NOT IN USE.

4. POSITION GLASS ROLL AND FIXTURE CENTERED ALONG THE LENGTH OF ONE SIDE OF THE VESSEL.

SYMBOL	TITLE	WORK ORDER	FIRST USED ON
N	INSULATION OF LH_2 TEST TANK, NASA-MSFC DWG. D-612721	BY / DATE	SCALE
RETYPED 1-27-66	LINDE DIVISION ENGINEERING DEPARTMENT TONAWANDA, NEW YORK	CHK'D WOD / APPV'D NCG CRL	GROUP / SHEET / SHEETS: F — BM-612721

5. POSITION TWO FOIL ROLLS AND FIXTURES ON THE OPPOSITE SIDE AND ALIGN ROLLS SO AS TO GIVE A TWO INCH OVERLAP ON THE FOIL.

6. ATTACH A LIFTING ROD, TWO INCH ALUMINUM PIPE TEN FEET LONG, TO THE TANK AT THE WELD SEAMS WITH CELLULOSE TAPE, ITEM 9.

7. TAPE FOIL ROLLS, (ITEM 1) TO A DUMMY CONTAINER, ROTATE FOR APPROXIMATELY 1-1/2 TURNS, TAPE ON THE GLASS (ITEM 27) AND PROCEED WITH ROLLING ON A NINETY LAYER BLANKET (20 SPARE LAYERS) AT 1 TO 3 RPM'S (ADJUSTING THE SPEED TO MAINTAIN TENSION ON THE FOIL ROLLS (ITEM 1).

8. DURING WRAPPING, TAPE FOIL OVERLAP SEAM AT 24 INCH INTERVALS TO HOLD FOIL TOGETHER DURING HEAD DISK CUTTING AND APPLICATION.

9. AFTER COMPLETING WRAPPING, CUT GLASS AND FOIL AND TAPE ENDS TO PREVENT UNROLLING. ROTATE TANK UNTIL THE LIFTING ROD IS ON THE TOP.

10. SLIT THE INSULATION BLANKET LONGITUDINALLY AT THE BOTTOM. A SHARP ELECTRIC CARVING KNIFE MAY BE USED. REMOVE THE INSULATION (F) WITH THE LIFTING ROD AND LAY FLAT ON A SMOOTH WORK TABLE.

11. CUT OUT TOP AND BOTTOM HEAD DISKS AND MANHOLE COVER DISKS, AS PER SD'S 1, 2 AND 9. AN ELECTRIC CARVING KNIFE MAY BE USED.

C. CYLINDRICAL PORTION INSULATION

(F) 2. TRIM ONE FULL GLASS ROLL (ITEM 3) TO A 64 INCH WIDTH. SAVE THE REMAINING PORTION. THE GLASS ROLL CAN BE EFFICIENTLY CUT ON A BAND SAW BUT THE BLADE AND SAW ROLLS SHOULD BE CLEANED WITH ACETONE TO REMOVE ANY GREASE OR OIL BEFORE USE.

3. ASSEMBLE GLASS ROLLS (ITEMS 2 AND 3) AND FOIL ROLLS (ITEM 1) AND SUPPORT FIXTURES PER SD-17. ASSEMBLE GLASS ROLLS (ITEM 4) AND FOIL ROLLS (ITEM 5) IN BANDING FIXTURES PER SD-17.

4. POSITION GLASS SUPPORT FIXTURES AND FOIL SUPPORT FIXTURES AND BAND FIXTURES PER SD-17 AND INSULATION DRAWING D-612721.

5. SET ALUMINUM FOIL BANDS (ITEM 5) TENSION TO 22 POUNDS BY PULLING ON THE BAND AT A CONSTANT SPEED WITH A SPRING SCALE WHILE ADJUSTING BAND AIR BRAKES. CAREFULLY ALIGN FOIL AND GLASS SUPPORT FIXTURES BY LEVELING FIXTURES AND MAKING SURE THEY ARE PARALLEL WITH THE VESSEL. SECURE ALL LOCK NUTS AND SET SCREWS ON THE SUPPORT FIXTURES TO AVOID ANY MOVEMENT DURING WRAPPING.

6. PAINT FIVE FOOT SECTIONS OF THE BANDS AND CORRESPONDING VESSEL CIRCUMFERENCE WITH ADHESIVE (ITEM 8) AND ALLOW TO DRY FOR (15) MINUTES. FIRMLY ROLL THE BANDS ONTO THE TANK WITH A ROLLER APPROXIMATELY TWO INCHES WIDE. ROTATE THE TANK MAKING ANY ALIGNMENT ADJUSTMENTS UNTIL THE BANDS HAVE TRACKED FOR ONE COMPLETE TURN.

7. MARK THE BAND TRACK LOCATIONS ON THE TANK, REMOVE THE ROLLED BANDING WITH ACETONE AND REATTACH BANDS TO TANK, PER STEP 5.

8. AT THIS TIME, ESTABLISH LOCATIONS ON THE TANK HEAD TO LOCATE THE PROTRUSION CUTOUTS AFTER THE VESSEL IS INSULATED.

9. TAPE (ITEM 9) FOIL ROLLS (ITEM 1) TO TANK AND ROTATE FOR 1-1/2 TURNS. TAPE (ITEM 9) THE GLASS ROLLS (ITEMS 2 AND 3) TO ALUMINUM FOIL (ITEM 1). TAPE (ITEM 9) THE GLASS ROLLS (ITEM 4) TO THE ALUMINUM BANDS (ITEM 5). PROCEED WITH CYLINDRICAL WRAPPING.

(F) 10. WHILE WRAPPING, CUT FOIL AND GLASS WITH INSULATION CUTTING TOOL (SD-21) SEPARATELY AS THE MATERIAL COMES IN CONTACT WITH THE TRANSITION JOINTS. TAPE FOIL OVERLAP ON EITHER SIDE OF THE CUTOUT WITH ITEM 9.

11. EVERY 10 LAYERS, MEASURE THICKNESS OF INSULATION. ADJUST BAND TENSION TO TERMINATE 70 LAYERS AT ONE INCH THICKNESS.

12. IF A VARIATION IN BAND TENSION IS REQUIRED TO MAINTAIN REQUIRED LAYER DENSITY, THE ADJUSTMENT SHOULD BE MADE GRADUALLY WHILE THE TANK IS ROTATING.

13. MAINTAIN CLOSE CHECK ON BAND WIDTH SO THAT TOTAL TRACKING VARIATION IS PLUS OR MINUS ONE-QUARTER INCH.

14. DO NOT REVERSE ROTATION OF TANK WHILE INSULATING.

15. ALWAYS MAINTAIN TENSION ON THE ALUMINUM BANDS.

16. UPON COMPLETION OF 70 LAYERS, CUT GLASS ROLLS (ITEMS 2, 3, & 4) AND TAPE TO PREVENT UNWRAPPING. DO NOT CUT ALUMINUM ROLLS OR BANDS.

17. MAKE 1-1/2 TURNS, CUT FOIL ROLL (ITEM 1) ONLY AND TAPE (ITEM 9) TO OUTSIDE LAYER OF ALUMINUM FOIL.

(D) 18. PAINT FIVE FEET OF EACH ALUMINUM BAND (ITEM 5) AND CORRESPONDING CIRCUMFERENTIAL SECTION OF PRECEEDING BAND LAYER WITH ADHESIVE, (ITEM 8) AND ALLOW TO DRY FOR FIFTEEN MINUTES.

19. ROTATE THE TANK TO APPLY THE PAINTED BANDS (ITEM 5) UNDER TENSION.

20. ALLOW ADHESIVE TO SET FOR ONE HOUR, BUT MAINTAIN BAND TENSION AT ALL TIMES WHILE SO DOING.

21. AFTER ADHESIVE HAS SET, CUT BANDS AT TANK AND TAPE (ITEM 9) TO PRECEEDING BAND LAYER.

22. AFTER INSULATION OF CYLINDRICAL PORTION IS COMPLETED, LOCATE PROTRUSION CUTOUTS FROM REFERENCE POINTS ON TANK HEAD.

23. CUT OUT PROTRUSION HOLES IN INSULATION AS PER SD-3, 4, 5 & 8.

D. BOTTOM HEAD INSULATION

1. REMOVE WRAPPING FIXTURE FROM HEAD AND SUPPORT TANK FOR HEAD DISK APPLICATION.

(F)

2. PLACE HEAD DISKS ON A CONVENIENT TABLE.

3. PER SD-7, ATTACH THE MOLECULAR SIEVE CONTAINER, (ITEM 11) TO THE TANK AND FILL WITH 100 GRAMS OF MOLECULAR SIEVE (ITEM 12) AFTER THE FIRST LAYER OF INSULATION IS IN PLACE.

4. INTERLEAVE HEAD DISKS TO CYLINDRICAL INSULATION, APPLY TAPE (ITEM 9) AS NEEDED. CARE MUST BE TAKEN THAT ALTERNATE LAYERS OF FOIL DO NOT CONTACT EACH OTHER.

5. AFTER HEAD DISKS ARE INSTALLED, COVER HEAD WITH FINAL DISK OF FOIL ONLY.

E. TOP HEAD INSULATION

(F)

1. PLACE HEAD DISKS, CUT PER SD-1 ON A CONVENIENT TABLE.

2. INTERLEAVE HEAD DISKS TO CYLINDRICAL INSULATION BEGINNING WITH DISKS WITH 23-1/2 DIAMETER HOLES. APPLY TAPE (ITEM 9) AS NEEDED. CARE MUST BE TAKEN THAT ALTERNATE LAYERS OF FOIL DO NOT CONTACT EACH OTHER.

3. AFTER HEAD DISKS ARE INSTALLED, COVER HEAD WITH FINAL LAYER OF FOIL ONLY.

F. MANHOLE COVER INSULATION PANEL

1. USING C CLAMPS, CLAMP A 38 INCH DIAMETER DISK OF LEAD MYLAR, (ITEM 6) BETWEEN ITEMS 25 AND 28 WITH CLAMPS SPACED ABOUT TWO INCHES APART.

SYMBOL	TITLE	WORK ORDER	FIRST USED ON		
N		BY	DATE	SCALE	LATEST ALT. LET.
		CHK'D WDD	GROUP 1	SHEET 4	SHEETS	F

LINDE DIVISION
ENGINEERING DEPARTMENT
TONAWANDA, NEW YORK

APPV'D NCG CRL

BM-612721

2. EVACUATE UNDERSIDE OF DISK.

(F) 3. WHEN THE LEAD MYLAR (ITEM 6) HAS STRETCHED TO THE BOTTOM OF THE FORM, HEAT TO 150°F IN AN OVEN FOR 1 HOUR.

4. BREAK BACK THE VACUUM AND UNCLAMP THE FORMED DISK.

5. REPEAT STEPS 1 THROUGH 4 FOR A SECOND DISK OF LEAD MYLAR, (ITEM 6).

6. CUT A 1-3/4 INCH DIAMETER HOLE IN THE CENTER OF ONE OF THE DISKS FOR AN EVACUATION PORT.

7. USING LIQUID ADHESIVE (ITEM 57) HEAT SEAL THE EVACUATION PORT, (ITEMS 51 AND 52) TO THE INSIDE SURFACE OF THE LEAD MYLAR DISK USING HAND IRON PER SD-9.

8. CUT DISKS OF ITEMS 1 AND 27 AS INDICATED ON SD-9.

9. SUPPORT THE LEAD MYLAR DISK CONTAINING THE EVACUATION PORT AND LAY IN 70 LAYERS OF ITEMS 1 AND 27 AS INDICATED ON SD-9.

10. APPLY SCHJELDAHL GT-100 LIQUID ADHESIVE (ITEM 57) TO THE FLANGE AREA AND TO THE MATING FLANGE AREA OF THE OTHER LEAD MYLAR DISK.

11. ALLOW THE JOINT TO DRY FOR ONE HOUR.

12. PLACE THE TWO DISKS TOGETHER AND SEAL WITH THE PORTABLE HOT JAW HEAT SEALER. THE SEALING CYCLE WILL CONSIST OF THE APPLICATION OF 40 PSI JAW PRESSURE FOR SIXTY SECONDS. THE SIXTY SECOND PERIOD IS DIVIDED INTO TWENTY SECONDS OF HEATING AT 275°F AND FORTY SECONDS OF COOLING BY PASSING COOLING WATER THROUGH THE HOT JAW JACKET.

G. INSULATION OF PIPING

1. AFTER THE CYLINDRICAL AND HEAD INSULATIONS HAVE BEEN COMPLETED, CUT A 4-1/2 INCH DIAMETER HOLE AROUND EACH OF THE FOUR PIPING PROTRUSIONS WITHAN ELECTRIC CARVING KNIFE, AND CUT FOUR SLITS TO PERMIT FOLDING BACK THE SURROUNDING INSULATION.

(F) 2. INTERLEAVE OPACIFIED PAPER (ITEM 37) OVER EACH RADIATION SHIELD. UNDER THE END OF EACH CUT SLIP A SMALL PIECE OF FIBERGLASS PAPER (ITEM 2) TAKE CARE TO AVOID CONTACT BETWEEN RADIATION SHIELDS. IF NECESSARY TAPE (ITEM 9) FOIL TO OPACIFIED PAPER, BUT DO NOT HAVE TAPE CROSS SEPARATOR MATERIAL.

3. HELICALLY WRAP TEN LAYERS OF ITEM 54 ON EACH PIPE PER SD-3. BEGIN THE FIRST LAYER AT THE TANK SURFACE AND HELICALLY WRAP IT TO A LENGTH OF 9 INCHES. BEGIN THE SECOND LAYER AT THE TANK SURFACE AND HELICALLY WRAP IT TO A LENGTH OF 9-1/2 INCHES. BEGIN EACH LAYER AT THE TANK SURFACE AND HELICALLY WRAP IT 1/2 INCH FARTHER SO THAT THE TENTH LAYER TERMINATES 13-1/2 INCHES FROM THE TANK'S SURFACE. APPLY CELLULOSE TAPE (ITEM 9) AS REQUIRED TO HOLD IN PLACE. SEE SECTION H, NOTE 3.

H. INSULATION OF STRUTS

1. CUT TWO 8-1/4 INCH BY 7-1/8 INCH HOLES IN THE CYLINDRICAL INSULATION FOR THE STRUTS WITH THE LONGEST DIMENSIONS PARALLEL TO TANK AXIS PER SD-5.

(F) 2. INTERLEAVE OPACIFIED PAPER (ITEM 37) OVER EACH RADIATION SHIELD. UNDER THE END OF EACH CUT SLIP A SMALL PIECE OF FIBERGLASS PAPER (ITEM 2) TAKE CARE TO AVOID CONTACT BETWEEN RADIATION SHIELDS. IF NECESSARY TAPE (ITEM 9) FOIL TO OPACIFIED PAPER, BUT DO NOT HAVE TAPE CROSS SEPARATOR MATERIAL.

3. HELICALLY WRAP TEN LAYERS OF ITEM 54 ON EACH STRUT PER SD-5.

BEGIN THE SECOND LAYER AT THE TANK SURFACE AND HELICALLY WRAP IT TO A LENGTH OF EIGHT INCHES. BEGIN EACH LAYER AT THE TANK SURFACE AND HELICALLY WRAP IT TWO INCHES FARTHER SO THAT THE TENTH LAYER ENDS 24 INCHES FROM THE TANK SURFACE. APPLY CELLULOSE TAPE (ITEM 9) AS REQUIRED TO HOLD IN PLACE.

I. INSULATION OF "A" FRAME

(F) 1. CUT A HOLE 10 INCHES BY 18 INCHES IN THE CYLINDRICAL INSULATION WITH AN ELECTRIC CARVING KNIFE WITH THE SMALLEST DIMENSION PARALLEL TO THE LONGITUDINAL TANK AXIS.

2. INTERLEAVE 140 LAYERS, OF OPACIFIED PAPER (ITEM 37) AROUND THE 10" X 18" A-FRAME CUTOUT. THESE LAYERS PROVIDE BEARING SURFACE FOR THE A-FRAME BOX (ITEM 40).

4. APPLY 25 LAYERS OF OPACIFIED PAPER (ITEM 37) ON A-FRAME BY SPIRALLY WRAPPING A STRIP APPROXIMATELY 13-1/2 INCHES WIDE LONGITUDINALLY AROUND THE A-FRAME. FOLD TOP OF EACH LAYER OVER TO INSULATE TOP OF A-FRAME. APPLY CELLULOSE TAPE, (ITEM 9) AS REQUIRED TO HOLD IN PLACE.

5. HELICALLY WRAP 15 LAYERS OF SLURRY PAPER, (ITEM 37) CUT TO 2" WIDTH ON THE A-FRAME SUPPORT ROD, PER SD-4.

BEGIN THE FIRST LAYER WHERE THE ROD IS ATTACHED TO THE A-FRAME AND HELICALLY WRAP IT TO A LENGTH OF 12 INCHES. BEGIN EACH ADDITIONAL LAYER AT THE SAME POINT AND HELICALLY WRAP IT TO A LENGTH OF 12 INCHES. APPLY CELLULOSE TAPE, (ITEM 9) AS REQUIRED.

J. FLEXIBLE JACKET FABRICATION AND INSTALLATION

1. INSTALL ONE LAYER OF 10 MIL DEXIGLAS PAPER, (ITEM 10) ON THE INSULATED TANK BEFORE INSTALLATION OF FLEXIBLE JACKET. APPLY TAPE (ITEM 9) AS REQUIRED TO HOLD IN PLACE.

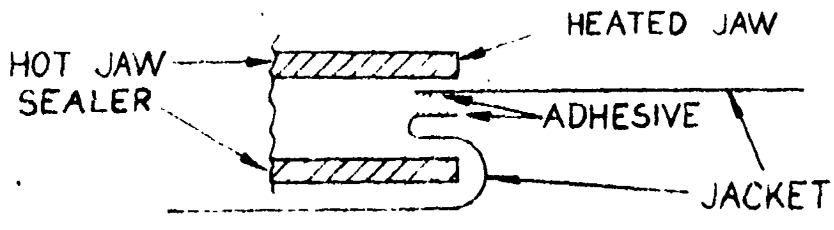
2. INSTALL RIGID VACUUM JACKETS ON PIPING AND STRUTS PER SD'S 3 AND 5.

3. FABRICATE THE FLEXIBLE JACKET SECTIONS (ITEM 6) PER SD'S 13, 14, 15, 16 AND 22. INSTALL THE TWO FLEXIBLE JACKET SECTIONS, (ITEM 6) OF SD-22 ON THE TANK PER SD-19. ONE JACKET SECTION REQUIRED FOR EACH LOWER SUPPORT STRUT. ASSEMBLY O-RING FLANGES PER SD-5 WITH MACHINE SCREWS (ITEM 53) TO HOLD JACKET SECTIONS IN PLACE.

4. INSTALL THE TWO FLEXIBLE JACKET SECTIONS (ITEM 6) OF SD-14 ON THE TANK PER SD-19. ONE JACKET SECTION REQUIRED FOR EACH CYLINDRICAL PIPE CONTAINED BETWEEN THE TWO LOWER SUPPORT STRUTS. ASSEMBLE "O" RING FLANGES, SD-3, WITH MACHINE SCREWS (ITEM 17) TO HOLD JACKET SECTIONS IN PLACE.

5. HEAT SEAL ADJACENT JACKET SECTIONS OF SD-14 TO EACH OTHER AND TO JACKET SECTIONS OF SD-22 TO FORM LAP JOINTS PER SD-19.

6. FORM HEAT SEAL LAP JOINTS BY APPLYING SCHJELDAHL GT-100 LIQUID ADHESIVE (ITEM 57) TO ONE INCH STRIPS OF EACH SECTION TO BE JOINED. ALLOW TO DRY FOR ONE HOUR; THEN FOLD ONE SECTION UNDER THE OTHER AND SEAL WITH A HOT JAW SEALER AS SHOWN BELOW.



SYMBOL	TITLE	WORK ORDER		FIRST USED ON	
N		BY	DATE	SCALE	CAT'G'Y ALT. LETT.
		CHK'D WDD	GROUP 1	SHEET 1	SHEETS
	LINDE DIVISION ENGINEERING DEPARTMENT TONAWANDA, NEW YORK	APP'D NCG CRL	BM-612721		

J. 6. CONT.

THE HEATED JAW OF THE HOT JAW SEALER MUST BE APPLIED TO THE JOINT AS SHOWN IN THE SKETCH. SEALING PROCEDURE IS THE SAME AS DESCRIBED IN SECTION F, NOTE 12.

7. INSTALL FLEXIBLE JACKET SECTIONS (ITEM 6) OF SD-16 ON THE TANK PER SD-19. ONE JACKET SECTION REQUIRED FOR EACH REMAINING CYLINDRICAL PIPE. ASSEMBLE O-RING FLANGES, SD-3, WITH MACHINE SCREWS, (ITEM 17) TO HOLD JACKET SECTIONS IN PLACE. HEAT SEAL JACKET SECTIONS TO THOSE OF SD-22 ALREADY ON THE TANK PER SD-19.

8. HEAT SEAL SECTIONS TOGETHER TO FORM LAP JOINTS PER NOTE 6 OF THIS SECTION.

9. INSTALL FLEXIBLE JACKET SECTION OF SD-15 ON THE TANK PER SD-19.

NOTE: FLEXIBLE JACKET (ITEM 6) MUST BE ASSEMBLED TO A-FRAME BOX ASSEMBLY (ITEM 40) OF SD-8, BEFORE INSTALLATION ON TANK. HEAT SEAL JACKET SECTION OF SD-15 TO JACKET SECTIONS SD-16 PER SD-19.

10. HEAT SEAL SECTIONS TOGETHER TO FORM LAP JOINTS PER NOTE 6 OF THIS SECTION.

11. INSTALL SUPPORT ROD VACUUM JACKET PER SD-12.

12. RIGIDLY SUPPORT TOP END OF CYLINDRICAL FLEXIBLE JACKET WITH CLAMPING FIXTURE PER SD-20. BEND THE TWO INCH SECTION OF FLEXIBLE JACKET EXTENDING PAST THE CLAMPING FIXTURE OUTWARD OVER THE CLAMPING FIXTURE AND PERMANENTLY FORM IT INTO A 90° ANGLE BY PASSING A HOT HAND IRON OVER IT.

13. REPEAT STEP 12 FOR THE BOTTOM END OF THE CYLINDRICAL FLEXIBLE JACKET.

14. CUT AWAY PLASTIC SHEET COVERING MANHOLE OPENING SECTION A, NOTE 5-C, LEAVING SECTION OVER CLEANED JOINT INTACT.

15. LIFT REMAINING PLASTIC SHEET COVER AND VISUALLY INSPECT CLEANED JOINT AREA. IF JOINT IS SATISFACTORY, REMOVE REMAINDER OF PLASTIC COVER.

16. CLEAN MANHOLE FLANGE FOR ADHESIVE JOINTS.

(F)

A. PER SD-6 WIPE THE TANK SURFACE CLEAN WITH METHYL-ETHYL KETONE.

B. PREPARE ETCHING SOLUTION COMPOSED OF THE FOLLOWING:

SULFURIC ACID	10 PARTS BY WEIGHT
SODIUM DICHROMATE	4 PARTS BY WEIGHT
DEIONIZED WATER	30 PARTS BY WEIGHT

MIX SUFFICIENT CAB-O-SIL OR BARIUM SULFATE WITH THE ETCHING SOLUTION TO FORM A PASTE THAT WILL NOT FLOW FROM THE SURFACE. APPLY THE ETCHING PASTE TO THE ALUMINUM SURFACE AND LEAVE THE ETCHANT IN CONTACT WITH THE SURFACE ABOUT FORTY MINUTES STIRRING OCCASIONALLY.

C. RINSE THE ETCHANT FROM THE METAL SURFACE WITH DEIONIZED WATER AND DRY THROUGHLY. COVER THE ETCHED SURFACE WITH A LIGHT PLASTIC SHEET 24-1/2" DIAMETER AND TAPE SECURELY TO THE TANK TO PREVENT CONTAMINATION FROM DIRT. DO NOT TAPE DIRECTLY TO ETCHED SURFACE.

17. INSTALL TOP HEAD FLEXIBLE JACKET SECTION SD-13 ON TANK PER SD-19.

18. PREPARE ADIPRENE L-100 ADHESIVE (ITEM 13) BY MIXING 100 PARTS OF ADIPRENE L-100 RESIN WITH 12.5 PARTS OF MOCA CURING AGENT. APPLY THE ADHESIVE (ITEM 13) TO THE TANK PER SD-13 AT A THICKNESS OF 0.007 INCHES.

19. WIPE THE FLEXIBLE JACKET SECTION TO BE JOINED TO THE TANK WITH METHYL-ETHYL KETONE AND ATTACH TO THE ADIPRENE ADHESIVE JOINT AND CURE BY ONE OF THE FOLLOWING CYCLES:

CYCLE A -

STEP 1 - CURE 24 HOURS UNDER 2 PSI PRESSURE. INSTALL ANNULAR RING 21 INCH DIAMETER BY 23 INCH DIAMETER OF POLYSTYRENE FOAM SHEET (ITEM 59). INSTALL COLD JOINT CURING FIXTURE, DWG. A-612947 OVER ANNULAR RING. LOAD CURING FIXTURE WITH 140# WEIGHT TO ACHIEVE 2 PSI PRESSURE.

CYCLE A - (CONT.)

STEP 2 - REMOVE CURING FIXTURE AND CURE 24 HOURS AT ROOM TEMPERATURE AND AMBIENT PRESSURE.

STEP 3 - CURE 24 HOURS AT 160°F.

ALTERNATE CYCLE B -

STEP 1 - CURE 24 HOURS UNDER 2 PSI PRESSURE AS IN CYCLE A.

STEP 2 - REMOVE CURING FIXTURE AND CURE SEVEN DAYS AT AMBIENT PRESSURE AND TEMPERATURE

20. APPLY SCHJELDAHL GT-100 LIQUID RESIN (ITEM 57) TO THE FLANGE AREAS OF THE TOP HEAD AND THE CYLINDRICAL PORTION. ALLOW THE ADHESIVE TO DRY FOR ABOUT ONE HOUR.

21. USING THE PORTABLE HEATER SEALER, MAKE A TEE JOINT BETWEEN THE TOP HEAD JACKET AND THE CYLINDRICAL PORTION. USE THE HEAT SEALING CYCLE OF NOTE 12 SECTION "F".

22. REPEAT STEPS 17, 20 AND 21 FOR THE BOTTOM HEAD FLEXIBLE JACKET.

23. INSTALL MANHOLE COVER INSULATION, SD-9, PER SD-19.

24. ATTACH ANNULAR RING OF ADIPRENE INPREGNATED NYLON CLOTH, (ITEMS 13 AND 23) TO FORM A LAP JOINT WITH MANHOLE COVER JACKET AND TOP HEAD JACKET PER SD-6 AND MSFC SPECIFICATIONS.

K. EVACUATION PROCEDURE

1. PURGE THE INSIDE OF THE 105" DIAMETER TANK WITH AIR OR NITROGEN AT 175°F, FOR 24 HOURS PRIOR TO STARTING EVACUATION AND CONTINUE PURGE THROUGHOUT THE EVACUATION.

2. COMPRESSION OF THE FLEXIBLE VACUUM JACKET, ITEM 6.

A. THROTTLE THE PUMP AT ONLY ONE EVACUATION PORT TO MAINTAIN NO MORE THAN 50 MM HG/MIN. EVACUATION RATE.

B. PUMP UNTIL THE PRESSURE IN THE INSULATION HAS DECREASED APPROXIMATELY 50 MM HG.

3. REMOVAL OF NON-CONDENSIBLES

PUMP AT ALL FOUR EVACUATION PORTS AT MINIMUM MANIFOLD PRESSURE TO DECREASE THE PRESSURE IN THE FLEXIBLE JACKETED SYSTEM TO THE 20 TO 30 MM HG. RANGE.

4. REMOVAL OF WATER VAPOR NOT PREVIOUSLY BAKED OUT

PUMP AT MINIMUM MANIFOLD PRESSURE TO REMOVE THE WATER VAPOR.

5. FINAL EVAUCATION

PUMP AT MINIMUM MANIFOLD PRESSURE TO EVACUATE TO APPROXIMATELY 0.1 MM HG.

L. LEAK LOCATION PROCEDURE FOR THE FLEXIBLE JACKET

THESE PROCEDURES SHOULD BE USED IN CONJUNCTION WITH THE OPERATION AND MAINTENANCE INSTRUCTIONS IN THE LEAK DETECTOR MANUAL.

1. PUT VALVE IN SYSTEM.

2. PLUG HOSE ABOVE VALVE

LEAK TEST VALVE STEM AND TUBE CONNECTIONS, HOSE FITTINGS, COMPOUND GAUGE AND FITTINGS.

PUMP TO AS LOW A PRESSURE AS POSSIBLE.

OPEN INLET VALVE INTO DIATRON TEST CHAMBER UNTIL CHAMBER PRESSURE REACHES 1 TO 2 X 10-4 MM HG.

3. CONNECT HOSE ABOVE VALVE TO TANK.

4. PUMP DOWN IN ACCORDANCE WITH PUMPDOWN INSTRUCTIONS.

5. DURING PUMPDOWN, ROUGH LEAK TEST THE FLEXIBLE JACKET.

START AT THE TOP (HELIUM FLOWS DISTINCTLY UPWARD BECAUSE OF ITS LIGHT WEIGHT RELATIVE TO AIR).

PAY PRIMARY ATTENTION TO JOINTS, ESPECIALLY THOSE WITH CREASES BUT ALSO JET HELIUM OVER THE OPEN AREAS OF THE CASING.

5. (CONT.)

USE BRIEF JETS OF HELIUM ONTO THE AREA IN QUESTION WITH THE JET TIPPED UPWARD INSOFAR AS POSSIBLE. AFTER EACH BRIEF JET ONTO THE CASING RELEASE THE JET BUTTON AND PULL THE JET UP AND AWAY FROM THE TANK.

6. WHEN HELIUM BACKGROUND BUILDS TO OVER 60 PER CENT OF THE 10 SCALE AT 1 X 10^{-4}, JET DRY NITROGEN GAS ONTO ALL SUSPECTED LEAK AREAS TO REDUCE BACKGROUND.

7. WHEN LEAKS ARE LOCATED, REPAIR IMMEDIATELY BY APPLYING A 20-80 SOLUTION OF ARMSTRONG A-12 TWO PART, EPOXY ADHESIVE, ITEM 56 AND CHLOROTHENE SOLVENT LIBERALLY.

8. AS LEAKS ARE REPAIRED AND THE VACUUM PRESSURE DECREASES, THE TESTING SYSTEM WILL BECOME MORE SENSITIVE. THUS, RETEST OF PREVIOUSLY TESTED AREAS MAY BE USED FOR MORE SENSITIVE OR MORE ACCURATE LOCATION OF LEAKS.

M. FINAL LEAK TEST - 105 IN. FLEXIBLE JACKETED TANK

I. REQUIREMENTS FOR INITIATING FINAL TEST

1. VACUUM - VACUUM LEVEL LESS THAN 5000 μ HG., PREFERABLY LESS THAN 2000 μ HG.

2. EQUIPMENT

A. HELIUM MASS SPECTROMETER LEAK DETECTOR.

B. CALIBRATED LEAK (10^{-9} TO 10^{-6} STP CC/SEC. RANGE)

C. ENVELOPE TO SURROUND TANK - PREFERABLY MINIMUM VOLUME FOR HELIUM GAS CONSERVATION.

II TEST PROCEDURE

NOTE - THE PROCEDURES FOR STARTUP, MAINTENANCE, AND OPERATION OF THE LEAK DETECTOR ARE NOT WITHIN THE SCOPE OF THIS LEAK TEST PROCEDURE. LEAK DETECTOR STARTUP, MAINTENANCE, AND OPERATION SHOULD BE PERFORMED ACCORDING TO THE MANUALS SUPPLIED WITH THE LEAK DETECTOR AND OTHER PROCEDURES AS REQUIRED.

1. STARTUP AND PEAK THE DETECTOR.

2. RECORD THE SCALE READING OF THE CALIBRATED LEAK.

3. TEST THE GAS IN THE VOLUME UNDER THE JACKET TO DETERMINE A ZERO REFERENCE MOLE PER CENT HELIUM. (IF NECESSARY, A HIGH HELIUM BACKGROUND MAY BE ZEROED OUT ELECTRONICALLY. THIS IS NOT GENERALLY RECOMMENDED BECAUSE OF CONTROL PROBLEMS.)

A. OPEN THE THROTTLE VALVE TO THE DIATRON CHAMBER OF THE MASS SPECTROMETER SUFFICIENT TO MAINTAIN 1.0 X 10^{-4} MM HG. IN THIS MANIFOLD.

B. READ AND RECORD THE NEEDLE DEFLECTION. (FOR PURPOSES OF COMPARISON, FULL SCALE ON THE X1 SCALE MAY BE TAKEN AS ONE UNIT, THUS FULL SCALE ON THE X3 WILL BE 3 UNITS, FULL SCALE ON THE X10 WILL BE 10, ETC.) THIS READING WILL BE THE ZERO READING FOR THE FINAL LEAK TEST.

4. CLOSE ALL PUMPS OFF FROM THE VACUUM VOLUME.

5. FILL THE BAG SURROUNDING THE FLEXIBLE JACKET WITH HELIUM GAS. RECORD THE TIME THAT THE FILLING IS INITIATED AND THE TIME THE BAG IS FILLED WITH HELIUM, I.E. HELIUM SURROUNDS THE FLEXIBLE JACKET.

6. FOR 12 MINUTES AT TWO MINUTE INTERVALS:

A. OPEN THE 105 IN. TANK VACUUM SYSTEM SHUT OFF VALVE.

B. OPEN THROTTLE VALVE INTO THE DIATRON TO 1 X 10^{-4} MM HG. MANIFOLD PRESSURE.

C. WAIT 30 SECONDS.

D. RECORD INDICATOR READING.

E. RECORD TANK PRESSURE.

F. CLOSE THROTTLE VALVE AND 105 IN. TANK VACUUM SYSTEM SHUT OFF VALVE.

7. OPEN VALVES TO PUMPING SYSTEM.

N. INSTALLATION OF INSULATION SUPPORT SPRINGS.

1. AFTER THE FLEXIBLE JACKET HAS BEEN EVACUATED AND LEAK TESTED INSTALL THE TOP SUPPORT SPRING SYSTEM AS PER D-612721 AND SD-23.

2. WRAP TWO LAYERS OF ITEM 6, 3" WIDE OVER THE INSULATION BAND, ITEM 4 & 5.

3. LOCATE THE FOUR PAIRS OF SPRINGS 90° APART OVER THE INSULATION BANDS, ITEM 4 & 5, IN LINE WITH THE EXTERNAL PIPES AND WITH THE NARROW STRAP ASSEMBLY, ITEM 61., PLACED OVER THE UPPER FLANGE OF THE "A" FRAME BOX ASSEMBLY, ITEM 40.

4. COMPRESS ONE PAIR OF SPRINGS TO 42 LBS. TENSION.

5. COMPRESS THE OPPOSITE (180° AROUND THE TANK) PAIR OF SPRINGS TO 84 LBS. TENSION.

6. COMPRESS ONE OF THE OTHER PAIRS OF SPRINGS TO 126 LBS. TENSION.

7. COMPRESS THE OPPOSITE PAIR OF SPRINGS TO 168 LBS. TENSION.

8. CARE MUST BE TAKEN NOT TO TEAR OR PUNCTURE THE FLEXIBLE JACKET.

9. REPEAT STEPS 1 AND 2 FOR THE BOTTOM SUPPORT SPRING SYSTEM.

10. FOR THIS SYSTEM LOCATE THE FOUR PAIRS OF SPRINGS 90° APART OVER THE INSULATION BAND ITEMS 4 & 5, WITH ONE PAIR IN LINE WITH THE "A" FROME BOX ASSEMBLY, ITEM 40.

11. LOCATE THE TWO NARROW STRAP ASSEMBLIES, ITEM 61, OPPOSITE THE TWO STRUTS.

12. REPEAT STEPS 4 THRU 8.

SYMBOL	TITLE	BY	DAT	USED ON	SCALE	LATEST ALT. LETT.
N		CHK'D. WDO	GROUP 1	SHEET 14	SHEETS	
	UNION CARBIDE LINDE DIVISION ENGINEERING DEPARTMENT TONAWANDA, NEW YORK	APP'D NCG CRL	BM-612721			

ITEM NO.	PART OR CODE NO.	REQ. FOR ONE	MATERIAL AND DESCRIPTION	PURCHASE ORDER	DWG. REV. LETT.
1		2 ROLLS	FOIL, 0.00025" THK., X 54" WIDE, PLAIN, SOFT ANNEALED, AA-1145-0 ALUMINUM, 100# ROLL COILED ON 3" I.D. NON-RETURNABLE REEL		
2		1 ROLL	#106 MICRO GLASS FIBRE PAPER, ON 3" DIA. CORE, 48" WIDE, THICKNESS OF PAPER TO BE CONTROLLED AS CLOSE TO 2 MILS AND WEIGHT AS CLOSE TO 1.4 GRAMS PER SQ. FT. AS POSSIBLE, MAXIMUM ACCEPTABLE THICKNESS 3 MILS, MAXIMUM ACCEPTABLE WEIGHT 2.1 GRAMS PER SQ. FT., C.H. DEXTER & SON INC., WINDSOR LOCKS, CONN.		
3		1 ROLL	#106 MICRO GLASS FIBRE PAPER, ON 3" DIA. CORE, 84" WIDE, THICKNESS OF PAPER TO BE CONTROLLED AS CLOSE TO 2 MILS AND WEIGHT AS CLOSE TO 1.4 GRAMS PER SQ. FT. AS POSSIBLE, MAXIMUM ACCEPTABLE THICKNESS 3 MILS, MAXIMUM ACCEPTABLE WEIGHT 2.1 GRAMS PER SQ. FT., 64" WIDE, C.H. DEXTER & SON INC., WINDSOR LOCKS, CONN.		
4		8 ROLLS	#106 MICRO GLASS FIBRE PAPER, ON 3" DIA. CORE, 2-1/8" WIDE AND APPROXIMATELY 10" O.D., THICKNESS OF PAPER TO BE CONTROLLED AS CLOSE AS POSSIBLE TO 2 MILS AND WEIGHT AS CLOSE TO 1.4 GRAMS PER SQ. FT. AS POSSIBLE MAX. ACCEPTABLE THICKNESS 3 MILS, MAX. ACCEPTABLE WEIGHT 2.1 GRAMS PER SQ. FT., C.H. DEXTER & SON INC., WINDSOR LOCKS, CONN.		
5		2 ROLLS	ALUMINUM FOIL, 0.002" THICK, 1-3/4" WIDTH, PLAIN AA-1145-H-19 ALLOY, COILED ON 3" I.D., STEEL CORE, 63 LB. OF ALUMINUM FOIL PER ROLL		
6			LAMINATE 1 MIL MYLAR - 0.8 MIL LEAD - 1 MIL MYLAR X 56 INCHES WIDE, LEAD THK. 0.8 MIL ±10%, NO GAPS BETWEEN SEAMS, LEAD ALLOY - 4-1/2% TIN, 3% ANTIMONY, 92-1/2" LEAD; G.T. SCHJELDAHL CO., NORTHFIELD, MINNESOTA		
7		1	105" DIA. LIQUID CONTAINER - NASA-MSFC		
8		1 PT.	3M ADHESIVE EC-2210 MINNESOTA MINING & MFG. CO., ST. PAUL, MINNESOTA		
9		24 ROLLS	TAPE, 3/4" WIDE, SCOTCH CELLULOSE, TRANSPARENT, 1296" PER ROLL MINNESOTA MINING & MFG. CO., ST. PAUL, MINNESOTA		

SYMBOL	TITLE	WORK ORDER	FIRST USED ON
BM	INSULATION OF LH_2 TEST TANK, NASA-MSFC		

BY	DATE	SCALE	LATEST ALT. LETT.
C.P.B.	5-17-65		

CHK'D	GROUP	SHEET	SHEETS
[illegible]	II	1	5

UNION CARBIDE

LINDE DIVISION
ENGINEERING DEPARTMENT
TONAWANDA, NEW YORK

APP'D: [illegible]

BM-612721

ITEM NO.	PART OR CODE NO.	REQ. FOR ONE	MATERIAL AND DESCRIPTION	PURCHASE ORDER	DWG. REV. LETT.
10		100 FT.	DEXIGLAS PAPER, 50" WIDE ROLL, 0.0105" THK. ±.0008" UNDER 8 PSI, 1/2 TO 3/4 MICRON FIBERS 85% BOROSILICATE GLASS, 0.0121, ±0.0012 LBS/SQ. FT., C.H. DEXTER & SON INC.		
11	C-612823	1	MOLECULAR SIEVE CONTAINER		
12		100 GRAMS	#5A MOLECULAR SIEVE, 1/16" DIA. PELLETS UNION CARBIDE CORPORATION, 270 PARK AVENUE, NEW YORK 17, NEW YORK		
13		1 PT.	ADIPRENE L-100 ADHESIVE E.I. DUPONT DE NEMOURS & CO., INC. WILMINGTON, DEL.		A
14	B-612651	4	TUBE ASSEMBLY, PIPE JACKET		
15		~~1~~	~~GODDARD "O" RING COUPLING #S-38P OR EQUIV.~~		
16	A-612653	4	FLANGE, PIPE JACKET, UPPER		
17		2/16	MACHINE SCREW, ROUND HD., #10-24 AM. STD. COPPER SILICON BRONZE MS-90, 7/16" LG.		
18		4	"O" RING, 5.359" I.D. X 0.139" WALL X 5.637" O.D., VITON "A", PARKER #2-253		E
19	A-612840	4	FLANGE ADAPTER, PIPE JACKET		
20		2	"O" RING 4.234" I.D. X 0.139" WALL X 4.512" O.D. VITON "A", PARKER #2-244		E
21	B-612869	2	STRUT JACKET ASSEMBLY		
22	A-612659	2	FLANGE, STRUT JACKET, UPPER		
23		1	TWO PLY NYLON CLOTH, SN69ES, TYPE 2, MIL-C-4479 WELLINGTON SEARS, ATLANTA, GA.		
24		2	"O" RING, 11.484" I.D. X 0.139" WALL, X 11.762" O.D. VITON "A", PARKER #2-277		
25	A-612830	1	MANHOLE EVACUATION FORM		
26	~~A-612824~~	~~1~~	~~SIEVE PLUG~~ 1		F

SYMBOL	TITLE	WORK ORDER	FIRST USED ON
BM			

BY	DATE	SCALE			LATEST ALT. LETT.
C.F.B.	6-17-65				F
CHK'D	J.P.K.	GROUP II	SHEET 2	SHEETS	
APP'D	[signature]	BM-612721			

UNION CARBIDE

LINDE DIVISION
ENGINEERING DEPARTMENT
TONAWANDA, NEW YORK

ITEM NO.	PART OR CODE NO.	REQ. FOR ONE	MATERIAL AND DESCRIPTION	PURCHASE ORDER	DWG. REV LETT.
27		1 ROLL	#106 MICRO GLASS FIBRE PAPER, ON 3" DIA. CORE IN 50 LB. ROLLS, 84" WIDE, THICKNESS OF PAPER TO BE CONTROLLED AS CLOSE TO 2 MILS AND WEIGHT AS CLOSE TO 1.4 GRAMS PER SQ. FT. AS POSSIBLE MAXIMUM ACCEPTABLE THICKNESS 3 MILS, MAXIMUM ACCEPTABLE WEIGHT 2.1 GRAMS PER SQ. FT., C.H. DEXTER & SON INC., WINDSOR LOCKS, CONN.		
28		1	PLATE, 1/4" THK., 38" O.D. X 35" I.D., ALUMINUM		
29		16	MACHINE SCREW, ROUND HD., #10-24 AM. STD. STAINLESS STEEL, 5/16" LG.		
30		1	"O" RING, 3.359" I.D. X 0.139" WALL X 3.637" O.D. VITON "A", PARKER #2-237		
31	B-612944	1	SUPPORT ROD JACKET ASSEMBLY		
32	~~B-612878~~	~~1~~	~~BELLOWS ASSEMBLY~~		
33	~~A-612668~~	~~1~~	~~FLANGE SUPPORT ROD JACKET, UPPER~~		
34		~~2~~	~~HEXCEL MYLAR HONEYCOMB, 2.75" THK. X 8.50" X 6.62"~~		C
35		~~1~~	~~HEXCEL MYLAR HONEYCOMB, .87" THK. X 11.00" X 5.70"~~		C
36		2	FACE SHEET, .008" THK. X 11.00" X 5.70", 5456 ALUMINUM		
37		1 ROLL	30% ALUMINUM OPACIFIED PAPER, 2.5 GRAMS/FT^2 IN ROLLS 24" WIDE, 1000 LINEAR FT. PER ROLL ON 3" DIA., CORE, C.H. DEXTER & SON INC., WINDSOR LOCKS, CONN.		A F
38		1	"O" RING, 16.955" I.D. X 0.210" WALL X 17.375" O.D., VITON "A", PARKER #2-386		E
39	B-612692	1	FLANGE "A" FRAME		
40	C-612693	1	BOX ASSEMBLY "A" FRAME		
41		~~1~~	~~HEXCEL MYLAR HONEYCOMB, 5.70" THK. X 9.00" X 1.75"~~		C

SYMBOL: BM | TITLE: | WORK ORDER: | FIRST USED ON:

BY: C.P.B. DATE: 6-17-65 | SCALE: | LATEST ALT. LETT.: F

CHK'D: J.P.K. | GROUP: II | SHEET: 3 | SHEETS:

APP'D: [signature]

UNION CARBIDE — LINDE DIVISION, ENGINEERING DEPARTMENT, TONAWANDA, NEW YORK

BM-612721

ITEM NO.	PART OR CODE NO.	REQ. FOR ONE	MATERIAL AND DESCRIPTION	PURCHASE ORDER	DWG. REV. LETT.
42		~~4~~	~~HEXCEL MYLAR HONEYCOMB, .38" THK. X 4.13" X 1.30"~~		C
43		74	MACHINE SCREW, ROUND HD., #10-24 AM. STD. STAINLESS STEEL, 7/16" LG.		
44		4	FACE SHEET, .008" THK. X 4.13" X 1.30" 5456 ALUMINUM		
45		1	FACE SHEET, .008" THK. X 12.00" X 11.00" 5456 ALUMINUM		
46		~~4~~	~~HEXCEL MYLAR HONEYCOMB, 1.60" THK. X 2.50" X 1.80"~~		C
47		4	"O" RING, 3.859" I.D. X 0.139" WALL X 4.137" O.D., VITON "A", PARKER #2-241		
48	A-612839	2	FLANGE ADAPTER, STRUT JACKET		
49		~~1~~	~~SHEET, 1/8" THK., SINTERED BRONZE 6" DIA.~~		F
50		~~1~~	~~PIPE, 3/8" SCH. 40, (0.091" WALL), AA-3003-18 ALUMINUM, 3" LG.~~		F
51		1	TUBE, 1-5/8" O.D. COPPER, 5" LG.		
52		1	SHEET, #25 STUBS GA. (0.020"), 4" DIA., COPPER		
53		96	MACHINE SCREW, ROUND HD., #10-24 AM. STD. STAINLESS STEEL, ½" LG.		
54	C-543634	11 ROLLS	DOUBLE LAYER SI-62, 3" WIDE		F
55		~~1~~	~~GOODARD O-RING COUPLING #S-38P OR EQUIV.~~		
56		1 PT.	ARMSTRONG A-12, TWO PART EPOXY ADHESIVE ARMSTRONG PRODUCTS CO. WARSAW, IND.		
57		1 PT.	SCHJELDAHL GT-100 LIQUID RESIN ADHESIVE G.T. SCHJELDAHL, NORTHFIELD, MINN.		
58	A-612947	1	COLD JOINT CURING FIXTURE.		
59		1	POLYSTYRENE FOAM SHEET, NOMINAL 1/8" THK., 23 ½" O.D. X 20½" I.D. GILMAN BROS. CORP., GILMAN, CONN.		A

SYMBOL	TITLE	WORK ORDER	FIRST USED ON
BM			

BY: C.T.B. DATE: 6-17-65 | SCALE | LATEST ALT. LETT.: F

CHK'D: [illegible] | GROUP: II | SHEET: 4 | SHEETS

APP'V'D: [illegible]

UNION CARBIDE

LINDE DIVISION
ENGINEERING DEPARTMENT
TONAWANDA, NEW YORK

BM-612721

ITEM NO.	PART OR CODE NO.	REQ. FOR ONE	MATERIAL AND DESCRIPTION	PURCHASE ORDER	DWG. REV. LETT.
60	B-612990	5	STRAP ASSEMBLY		C
61	B-612991	3	STRAP ASSEMBLY		C
62	A-612986	32	SPRING STOP		C
63	A-612987	8	STRIP		C
64	A-612988	8	STRIP		C
65	A-612989	64	ROD		C
66	A-612992	16	SPRING, COMPRESSION		C
67	A-612993	1	BAND GUIDE		C
68	A-612994	1	BAND GUIDE		C
69	A-612995	1	ADAPTER, "A" FRAME		C
70	A-612996	2	ADAPTER, STRUT		C
71		128	HEX NUT, #10-32 ELASTIC STOP NUT, STEEL ESNA CORP.		C

SYMBOL	TITLE	WORK ORDER	FIRST USED ON
BM			

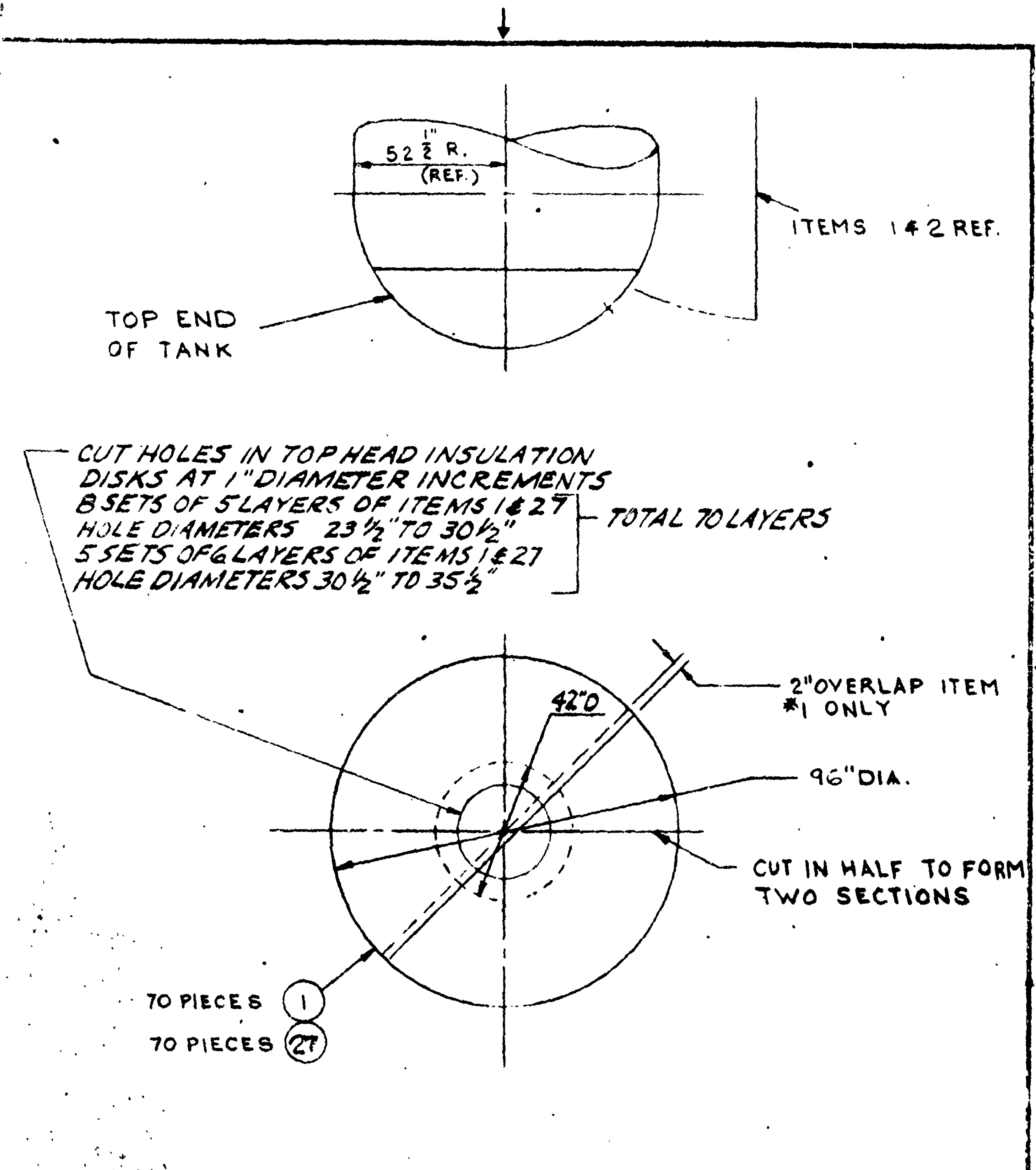
BY	DATE	SCALE	LATEST ALT. LETT.
WFL	6-29-65	—	C

CHK'D	GROUP	SHEET	SHEETS
J.V.K.	II	5	5

APP'D: [illegible]

UNION CARBIDE — LINDE DIVISION, ENGINEERING DEPARTMENT, TONAWANDA, NEW YORK

BM-612721

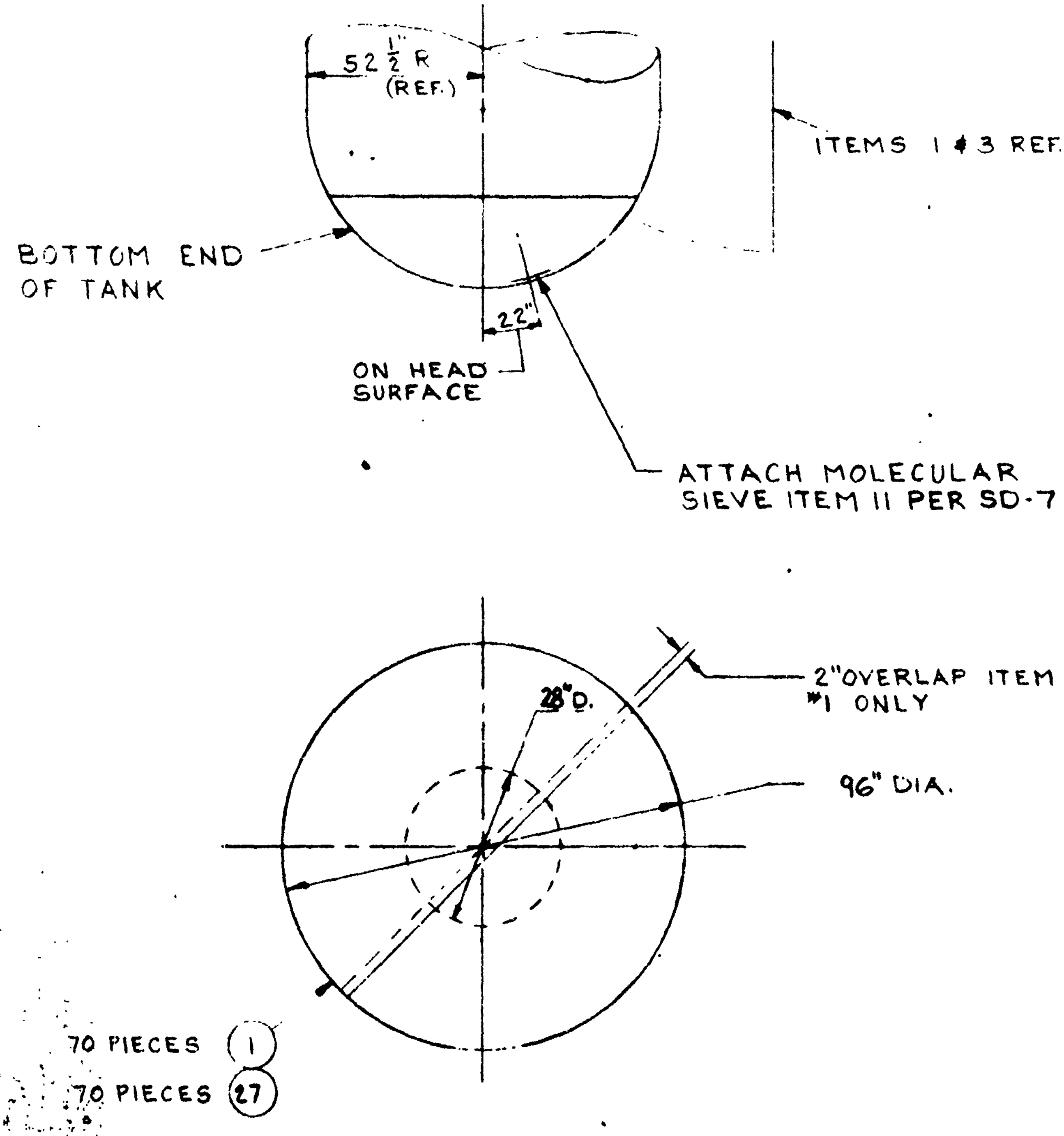


SYMBOL	TITLE	WORK ORDER			FIRST USED ON
SD-1	HEAD INSULATION TOP END	BY C.P.B. DATE 5-20-65	SCALE —		—
		CHK'D J.R.K.	GROUP IV	SHEET 1	SHEETS 22
		LATEST ALT. LETT.	F		

UNION CARBIDE — LINDE DIVISION, ENGINEERING DEPARTMENT, TONAWANDA, NEW YORK

APPR'D: [signature]

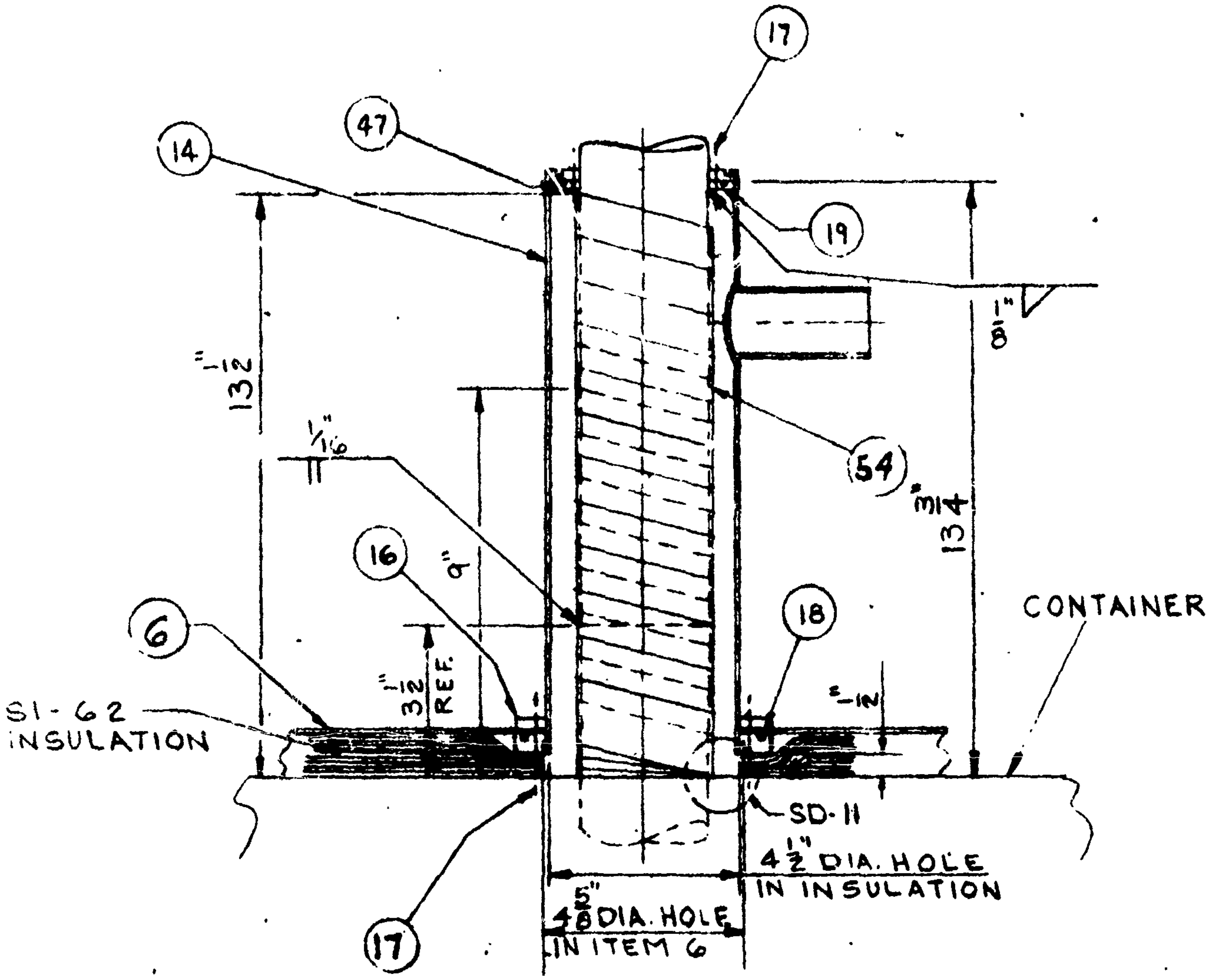
BM-612721



SYMBOL	TITLE		
SD-2	HEAD INSULATION BOTTOM END		USED ON
BY: C.P.B.	DATE: 5-28-65	SCALE	LATEST ALT. LETT.: F
CHK'D	GROUP: IV	SHEET: 2	SHEETS: –
APP'V'D	BM-612721		

UNION CARBIDE

LINDE DIVISION
ENGINEERING DEPARTMENT
TONAWANDA, NEW YORK



SYMBOL	TITLE	WORK ORDER	FIRST USED ON
SD-3	PIPE JACKET INSULATION		

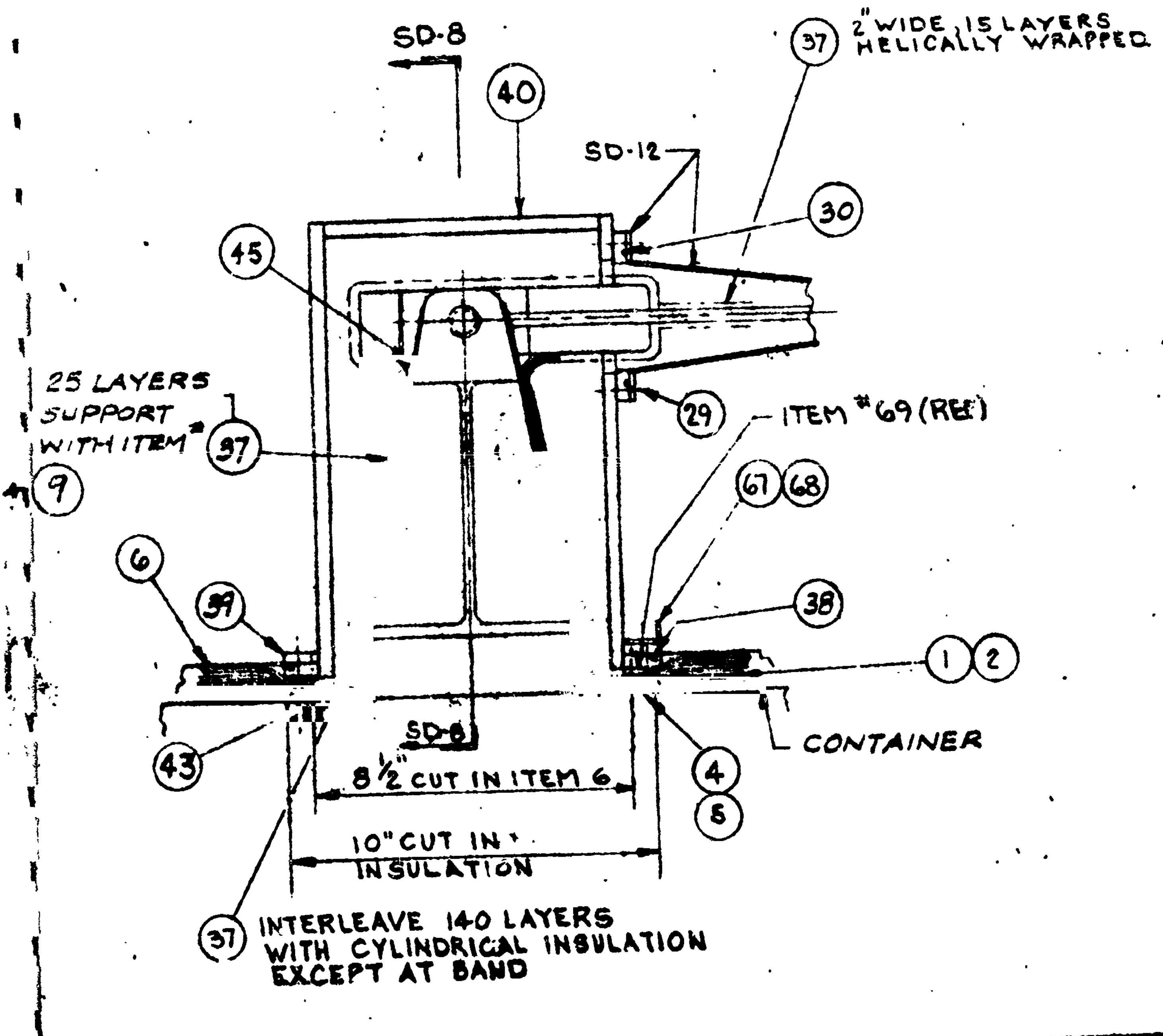
BY C.P.B. DATE 6-7-65 SCALE

CHK'D J.R.K. GROUP IV SHEET 3 SHEETS — LATEST ALT. LETT. F

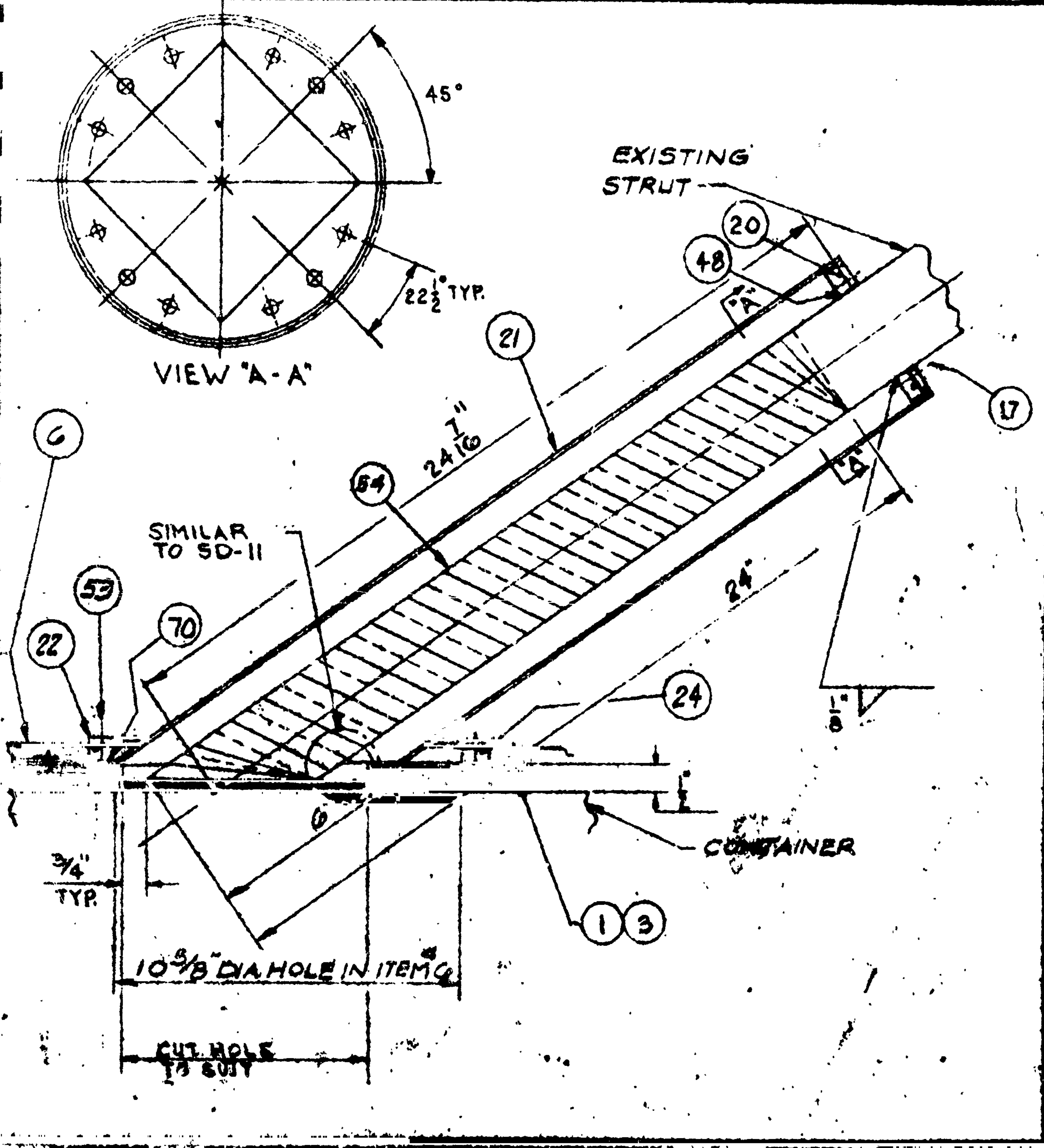
APP'D

UNION CARBIDE
LINDE DIVISION
ENGINEERING DEPARTMENT
TONAWANDA, NEW YORK

BM-61272



SYMBOL	TITLE	WORK ORDER		FIRST USED ON		
SD-4	"A" FRAME INSULATION	BY TVD	DATE 6-10-65	SCALE —		LATEST ALT. LETT. F
		CHK'D J.R.K	GROUP IV	SKETCH 4	SHEETS —	
	LINDE DIVISION ENGINEERING DEPARTMENT TONAWANDA, NEW YORK	APPR'D [signature]	BM-612721			

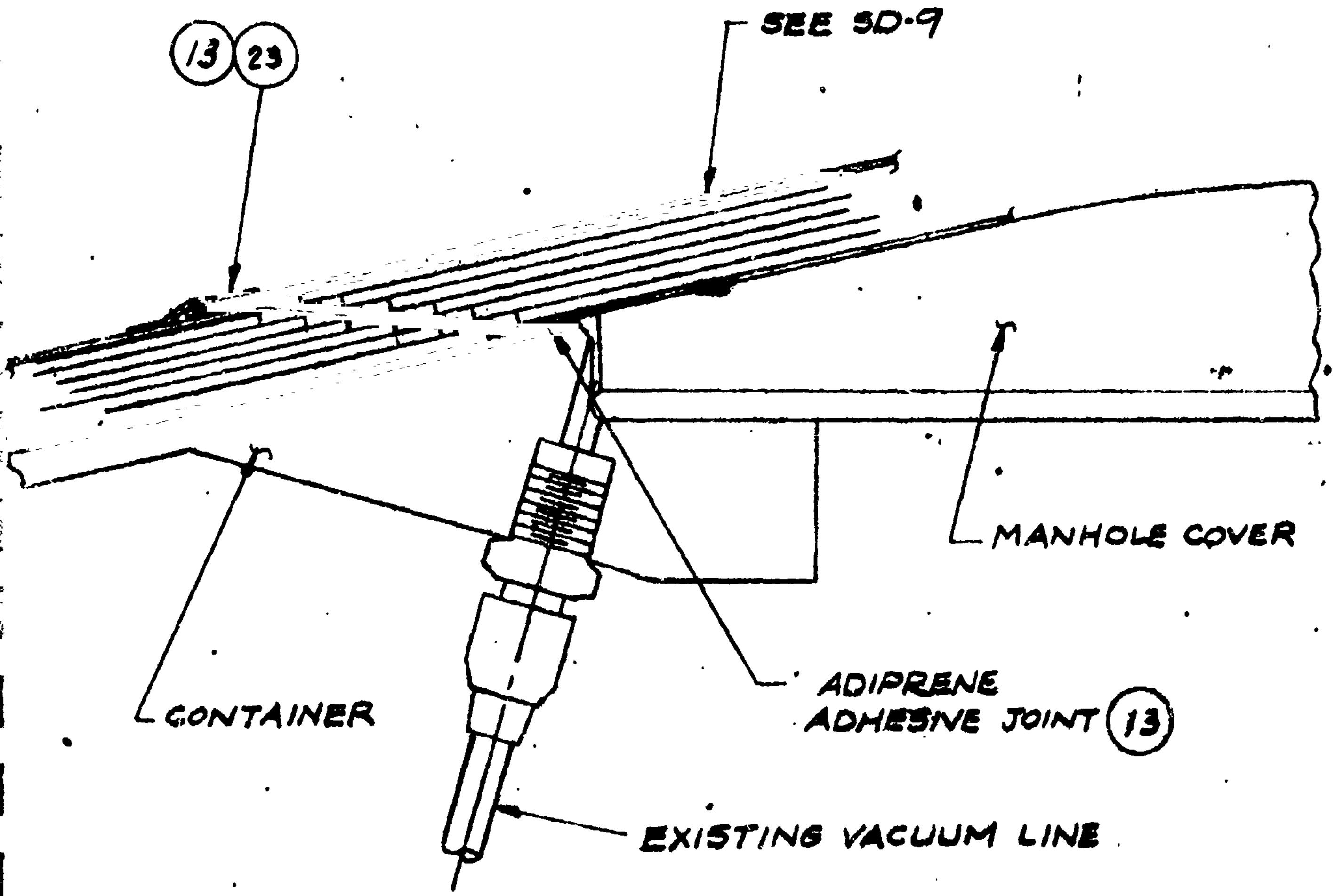


SD-5

STRUT JACKET INSULATION

LINDE DIVISION
ENGINEERING DEPARTMENT
TONAWANDA, NEW YORK

BY TVD	DATE 6-7-65	[redacted]	—	F
J.R.K.	GROUP IV	SHEET 3	SHEETS —	
APPD MKW	BM-612T21			



SD-6

FLEXIBLE JACKET
APPLICATION AT MANHOLE

BY TWD DATE 6-10-68

SCALE —

CHK'D J.P.K.

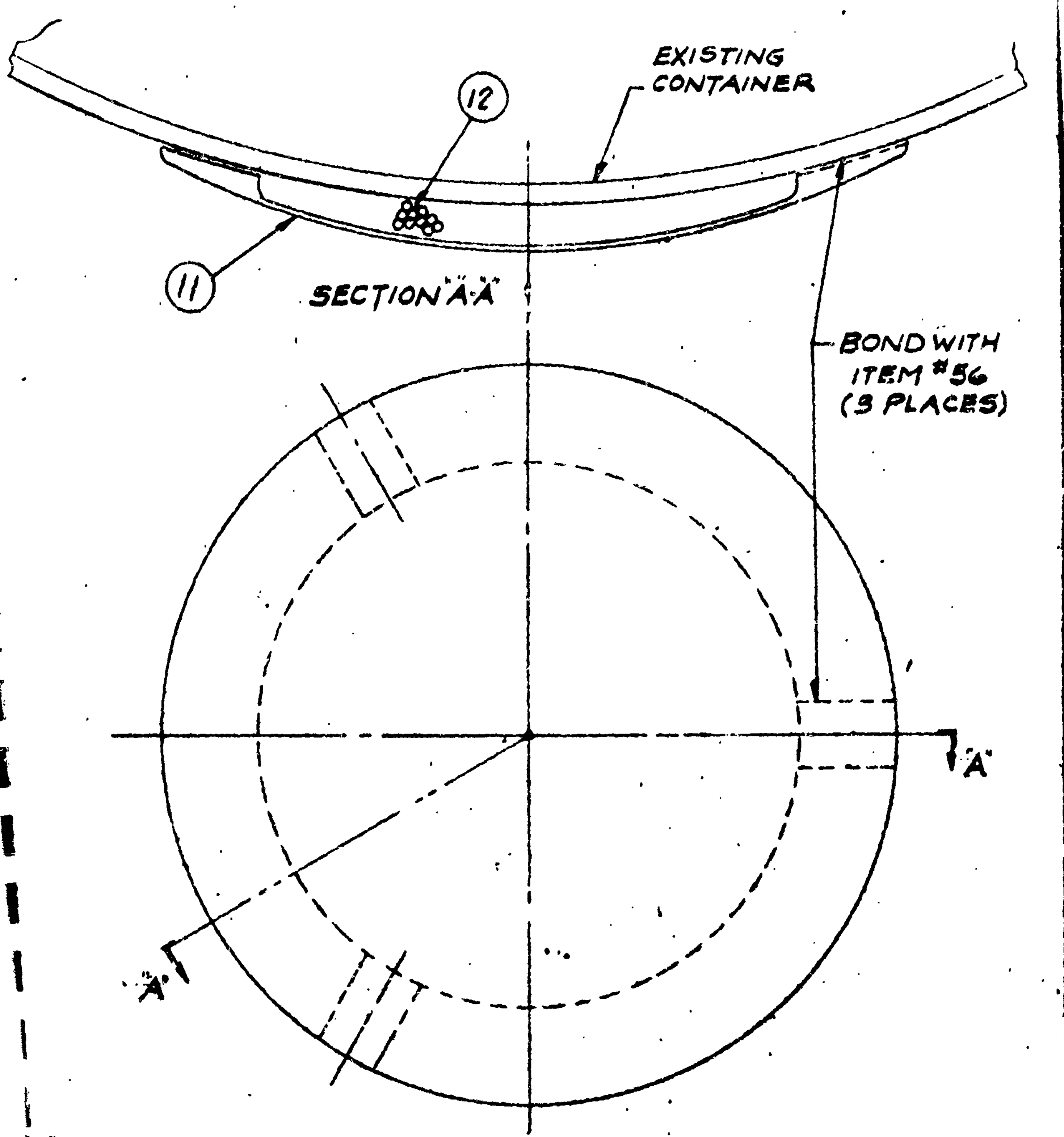
GROUP IV

SHEET 6

SHEETS -

LINDE DIVISION
ENGINEERING DEPARTMENT
TONAWANDA, NEW YORK

BM-612721



SD-7

MOLECULAR SIEVE
INSTALLATION

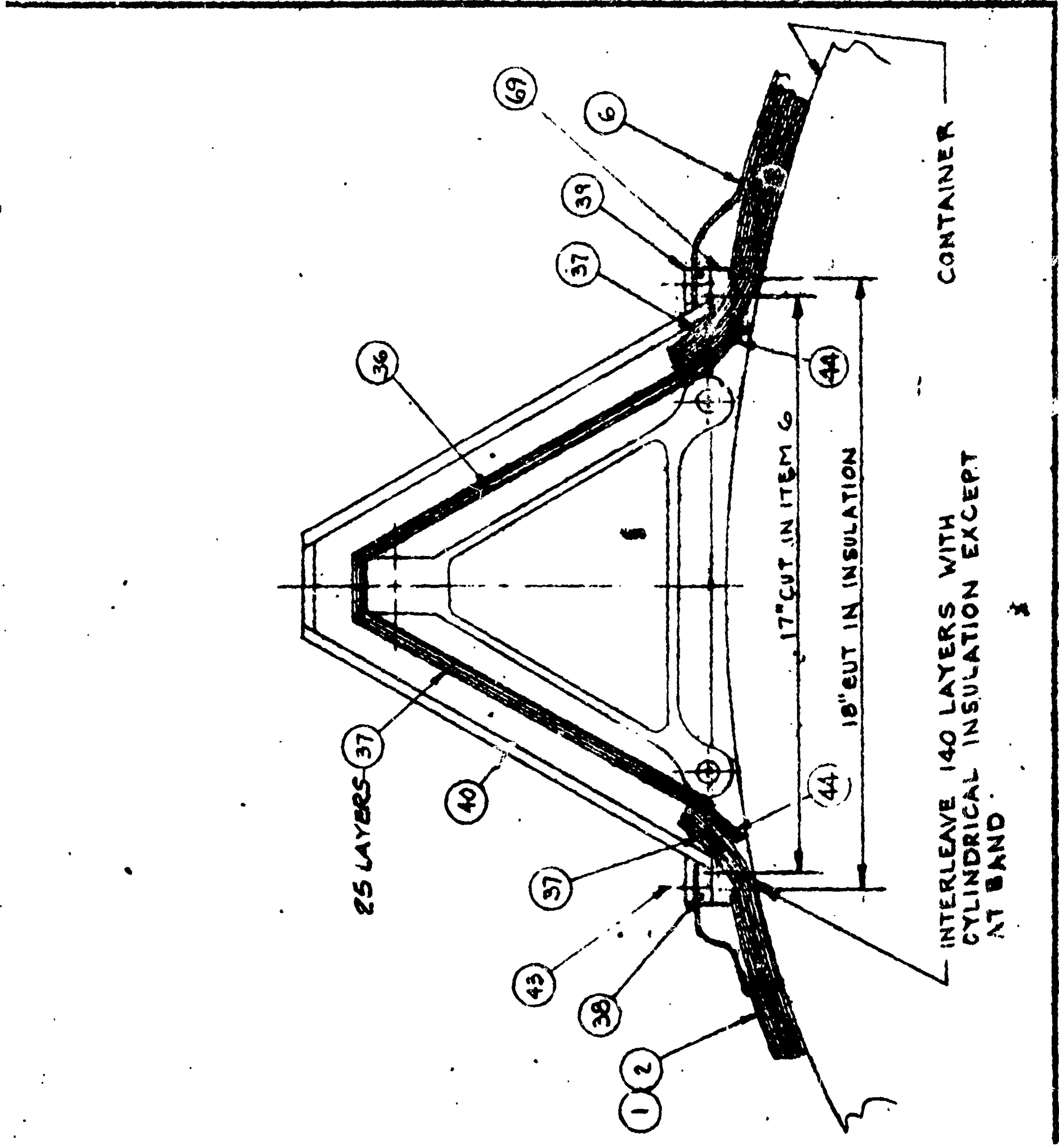
6-8-68

J.R.K.

LINDE DIVISION
ENGINEERING DEPARTMENT
TONAWANDA, NEW YORK

F

BM-612721



STUDY SD-8

TITLE "A" FRAME INSULATION

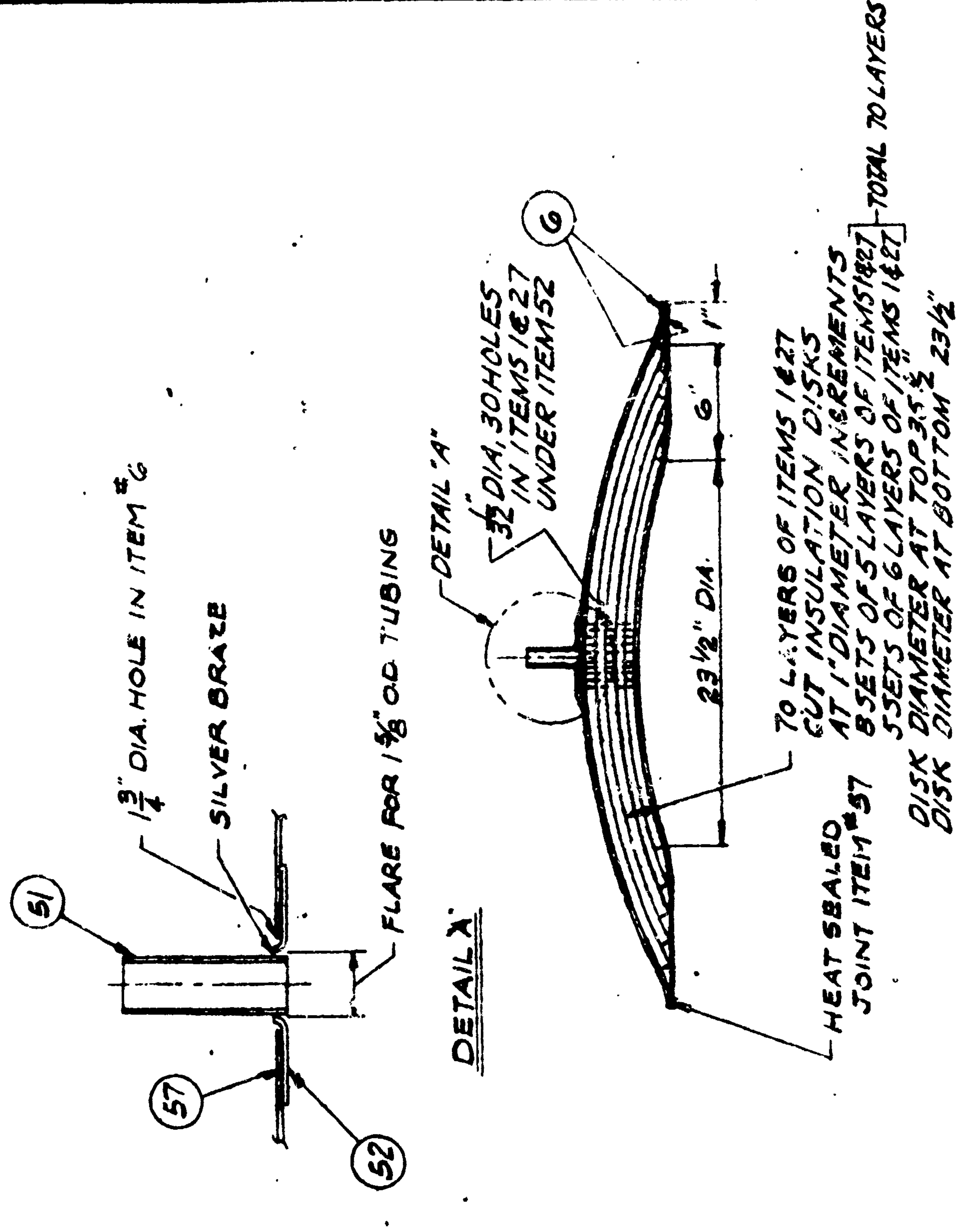
BY C.P.B. DATE 6-10-65

GROUP IV SHEET 8 SHEETS -

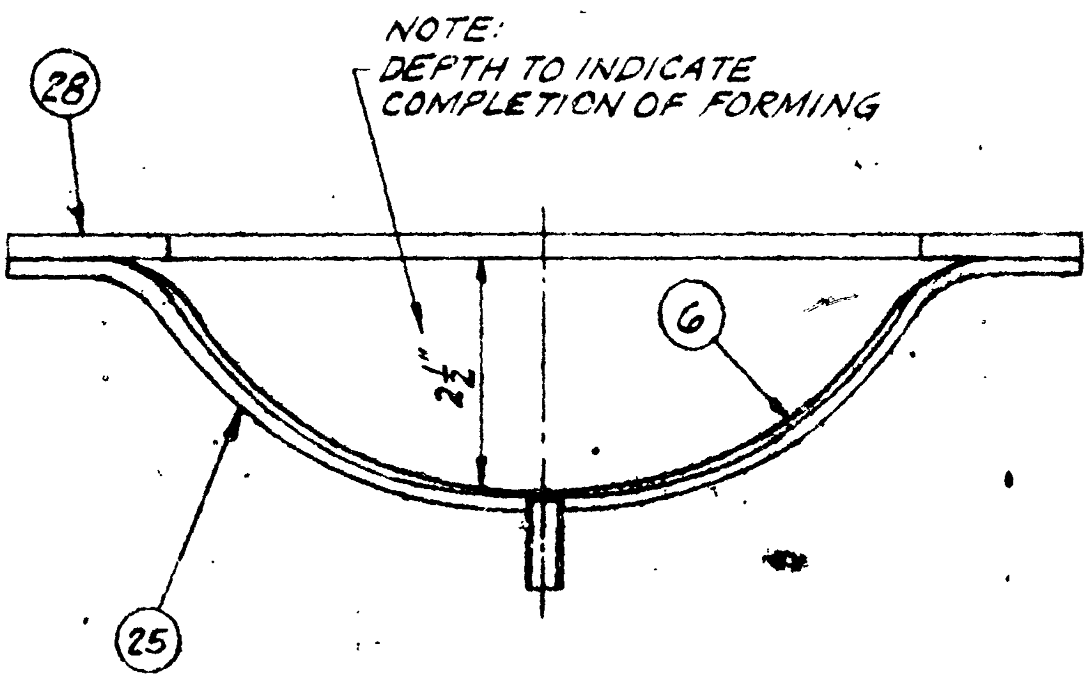
F

BM-612721

LINDE DIVISION
ENGINEERING DEPARTMENT
TONAWANDA, NEW YORK

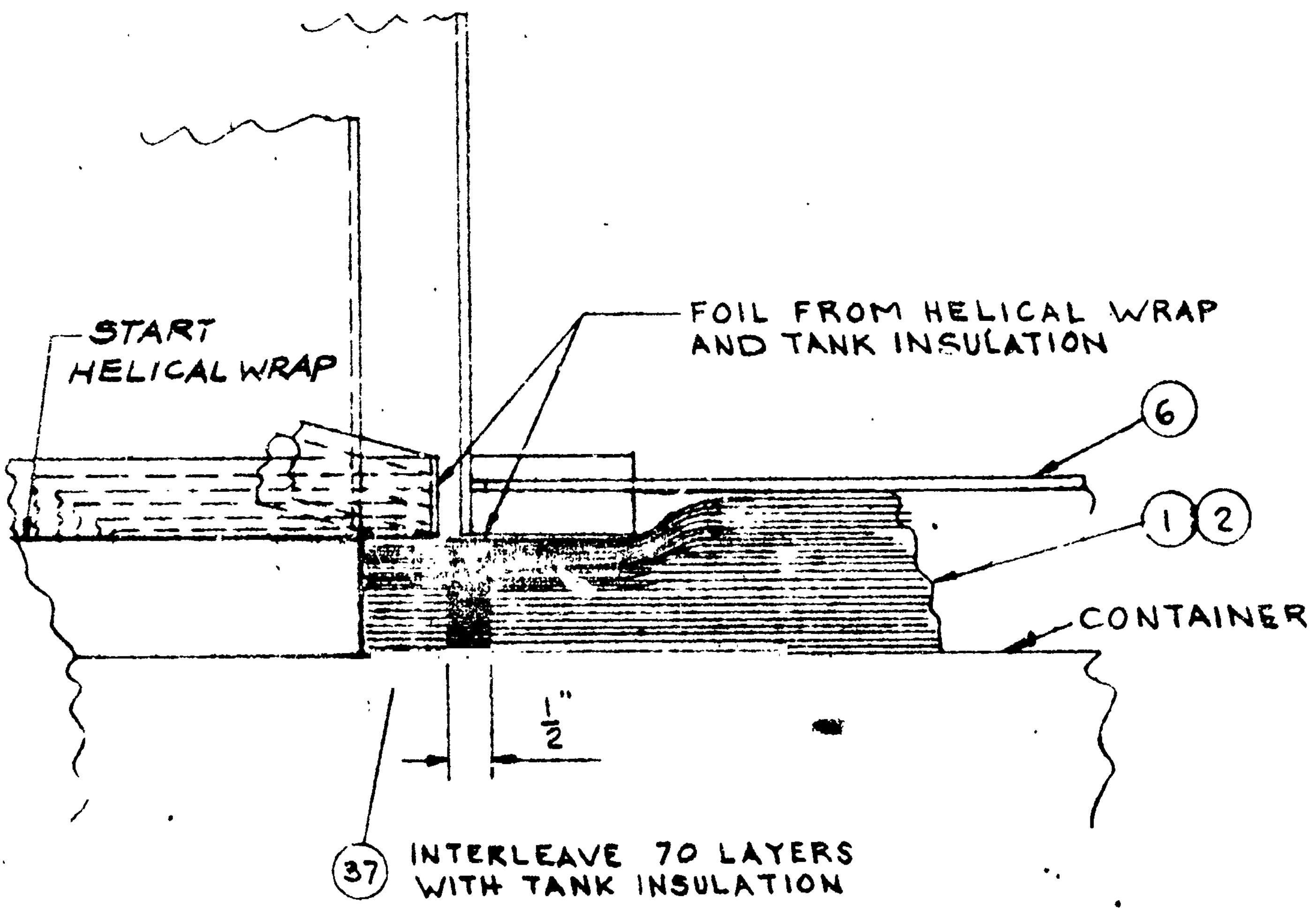


SYMBOL	TITLE	JOB ORDER	FIRST USED ON	
SD-9	MANHOLE COVER INSULATION	BY TVD DATE 6-1-65	SCALE —	
		CHK'D JRK GROUP IV	SHEET 9	SHEETS –
	LINDE DIVISION ENGINEERING DEPARTMENT TONAWANDA, NEW YORK	APPROVED [signature]	BM-612721	

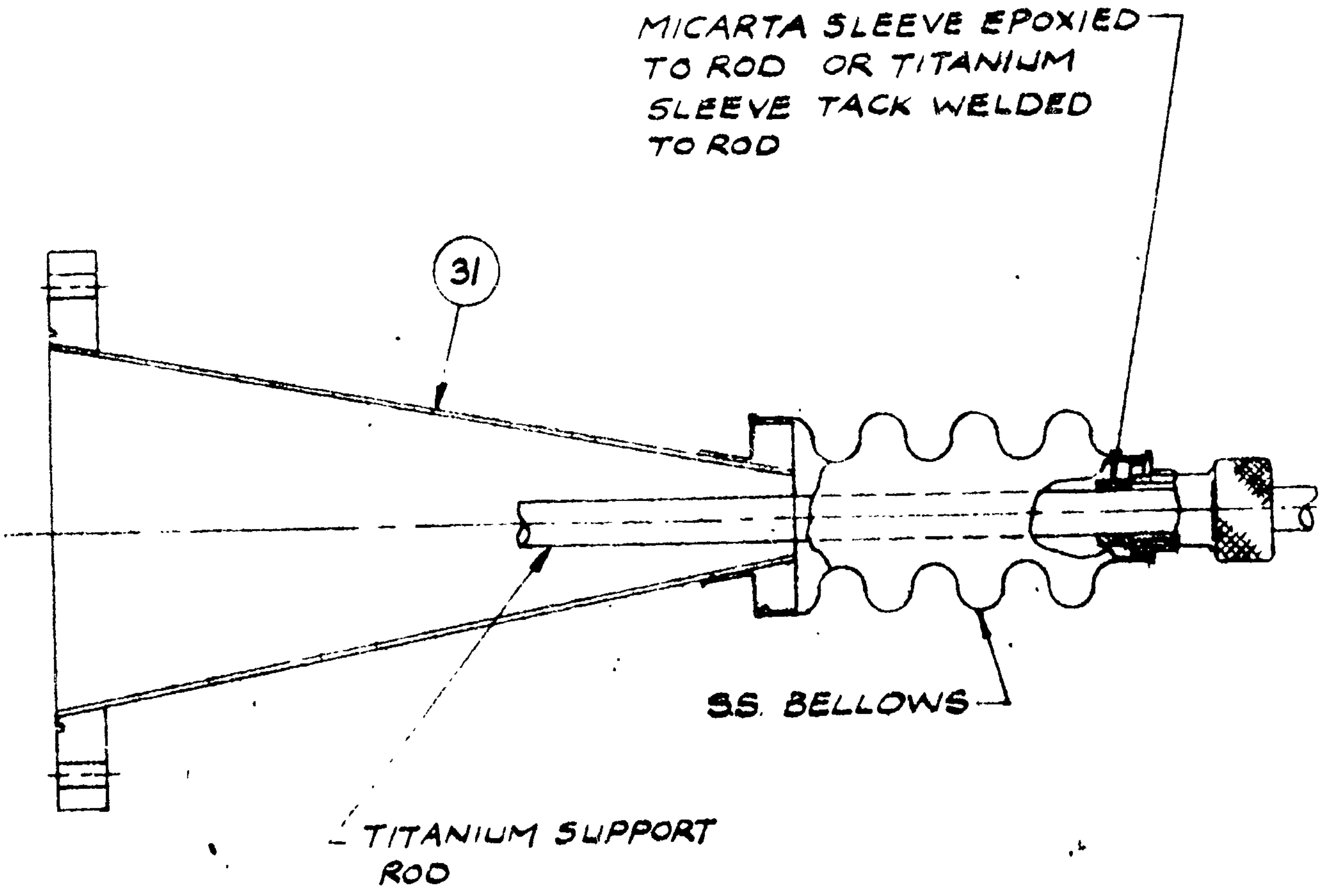


SD-10	VACUUM FORMING MANHOLE COVER-FLEXIBLE JACKET					
		BY: TVO	DATE: 6-9-65	SCALE: –		F
		J.R.K.	XV	10	–	
	LINDE DIVISION ENGINEERING DEPARTMENT TONAWANDA, NEW YORK		BM-612721			

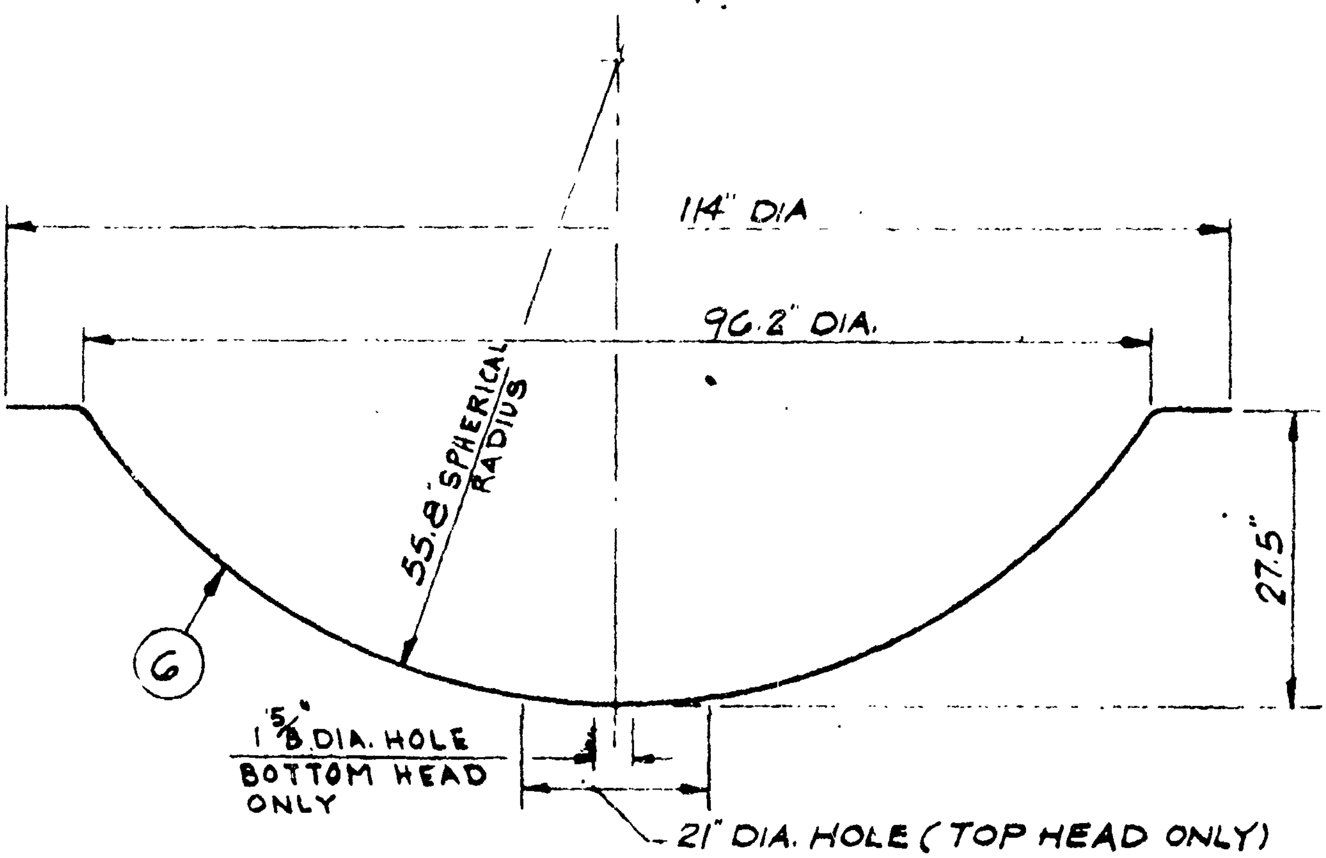
4



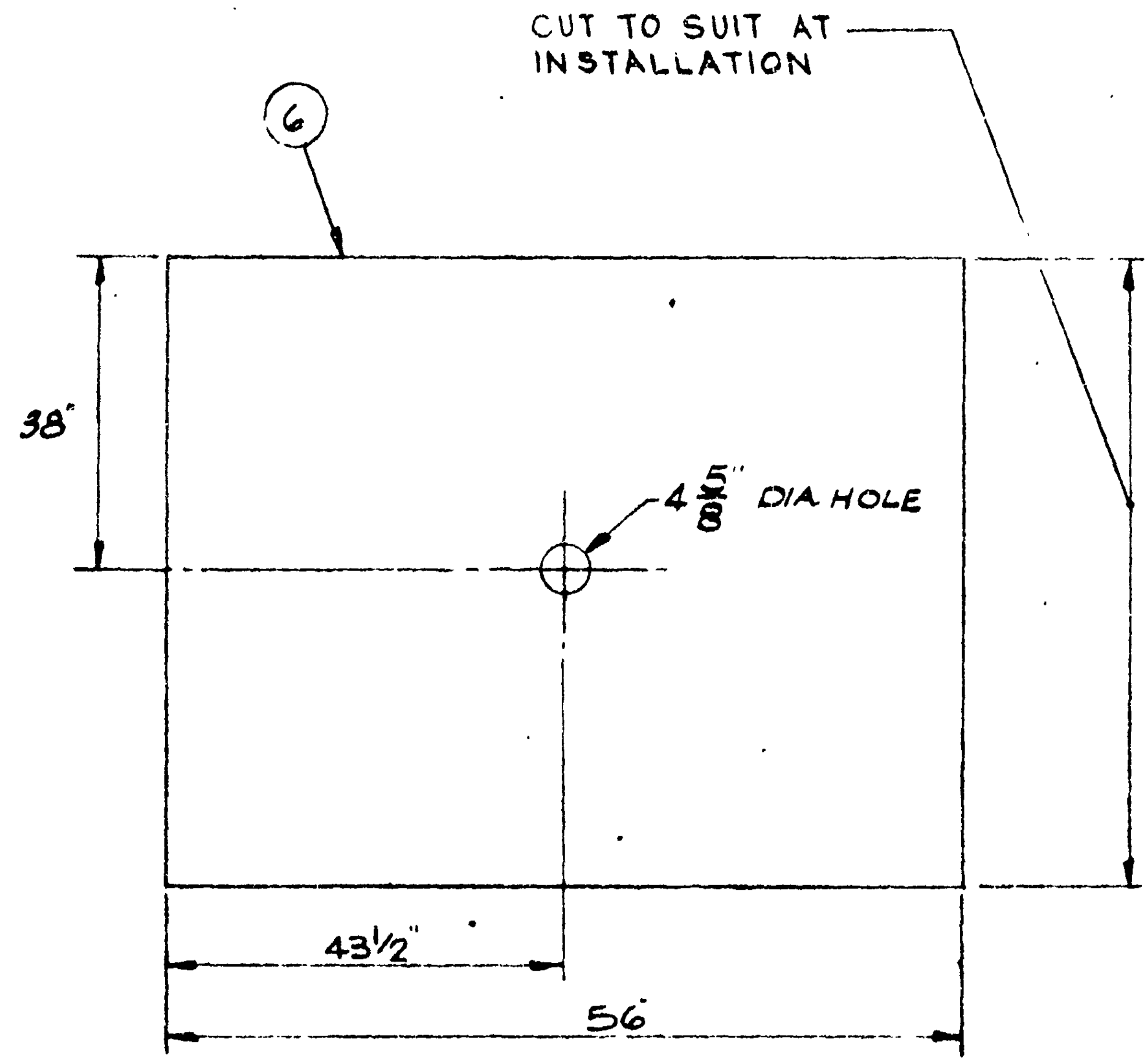
SYMBOL	TITLE	WORK ORDER		FIRST USED ON		
D-11	HELICAL WRAPPING ON PIPES & STRUTS	BY C.P.B.	DATE 6-10-65	SCALE		CHANGE ALT. LETT.
		CHK'D J.R.K.	GROUP IV	SHEET 11	SHEETS —	F
	LINDE DIVISION ENGINEERING DEPARTMENT TONAWANDA, NEW YORK	APP'D	BM-612721			



SYMBOL	TITLE	WORK ORDER	FIRST USED ON	
SD-12	SUPPORT ROD		—	
		BY: TVD DATE: 6-11-65	SCALE: —	LATEST ALT. LETT.
		CHK'D: J.R.K. GROUP: IV	SHEET: 12 SHEETS: —	
	LINDE DIVISION ENGINEERING DEPARTMENT TONAWANDA, NEW YORK	APP'D: [signature]	BM-612721	

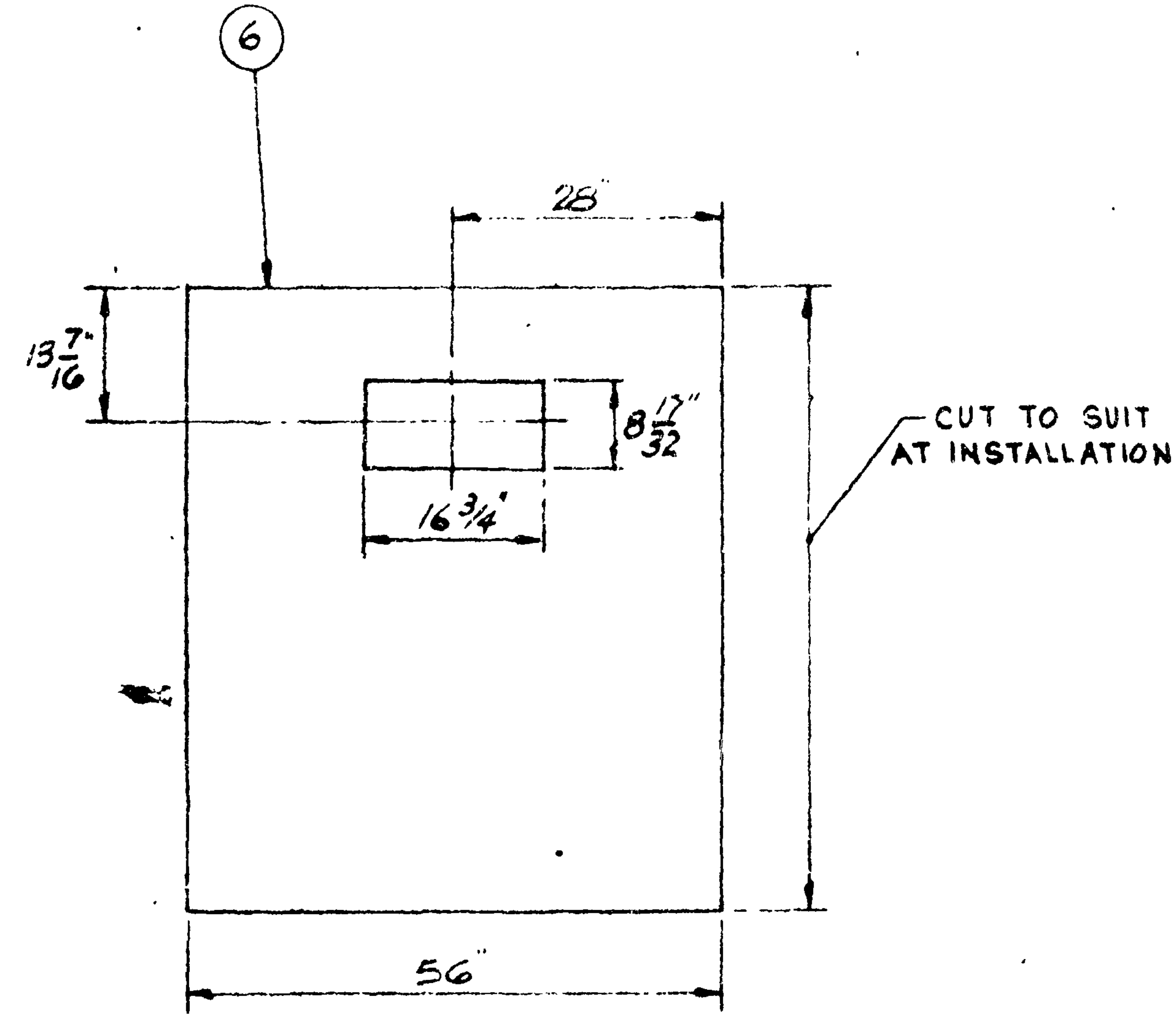


SYMBOL: SD-13	TITLE: VACUUM FORMED TOP & BOTTOM HEADS	WORK ORDER		FIRST USED ON: —		
		BY: TVD	DATE: 6-11-65	SCALE: —		LATEST ALT. LETT.: F
	LINDE DIVISION ENGINEERING DEPARTMENT TONAWANDA, NEW YORK	CHK'D: J.R.K.	GROUP: IV	SHEET: 13	SHEETS: —	
		APP'D	BM-612721			

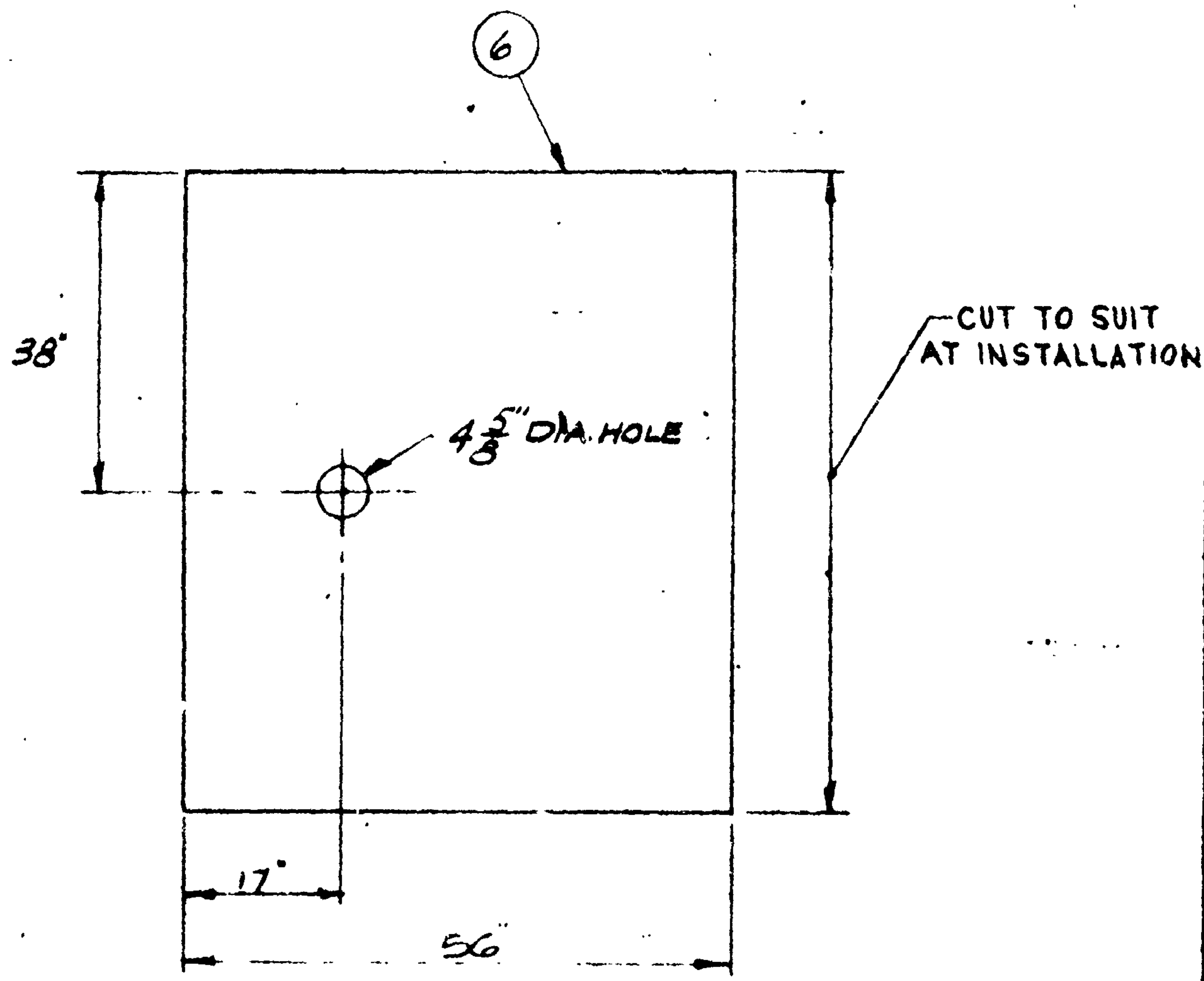


2 REQ'D.

SYMBOL: SD-14	TITLE: FLEXIBLE JACKET CYLINDRICAL SECTION	WORK ORDER	FIRST USED ON: —		
		BY: TVD DATE: 6-11-65	SCALE: —		LATEST ALT. LETT.: F
		ENG'D: JRK.	GROUP: IV	SHEET: 14	SHEETS: —
LINDE DIVISION ENGINEERING DEPARTMENT TONAWANDA, NEW YORK		APP'D	BM-612721		

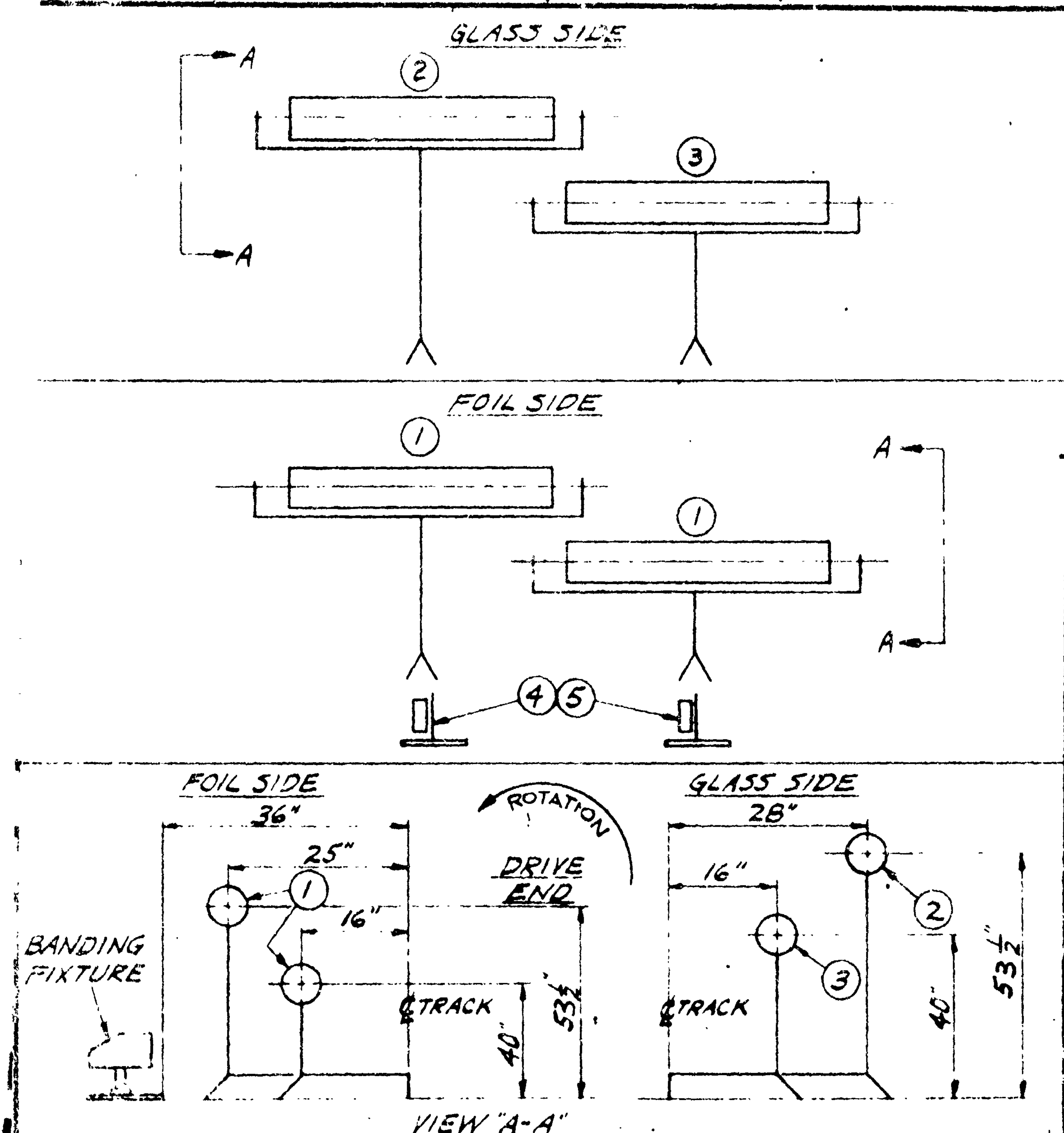


SYMBOL	TITLE	WORK ORDER		FIRST USED ON		
SD-15	FLEXIBLE JACKET CYLINDRICAL SECTION	BY TYD	DATE 6-11-65	SCALE —		LATEST ALT. LETT.
		CHK'D QRK	GROUP IV	SHEET 15	SHEETS —	F
	UNION CARBIDE · LINDE DIVISION ENGINEERING DEPARTMENT TONAWANDA, NEW YORK	APP'D		BM-612721		

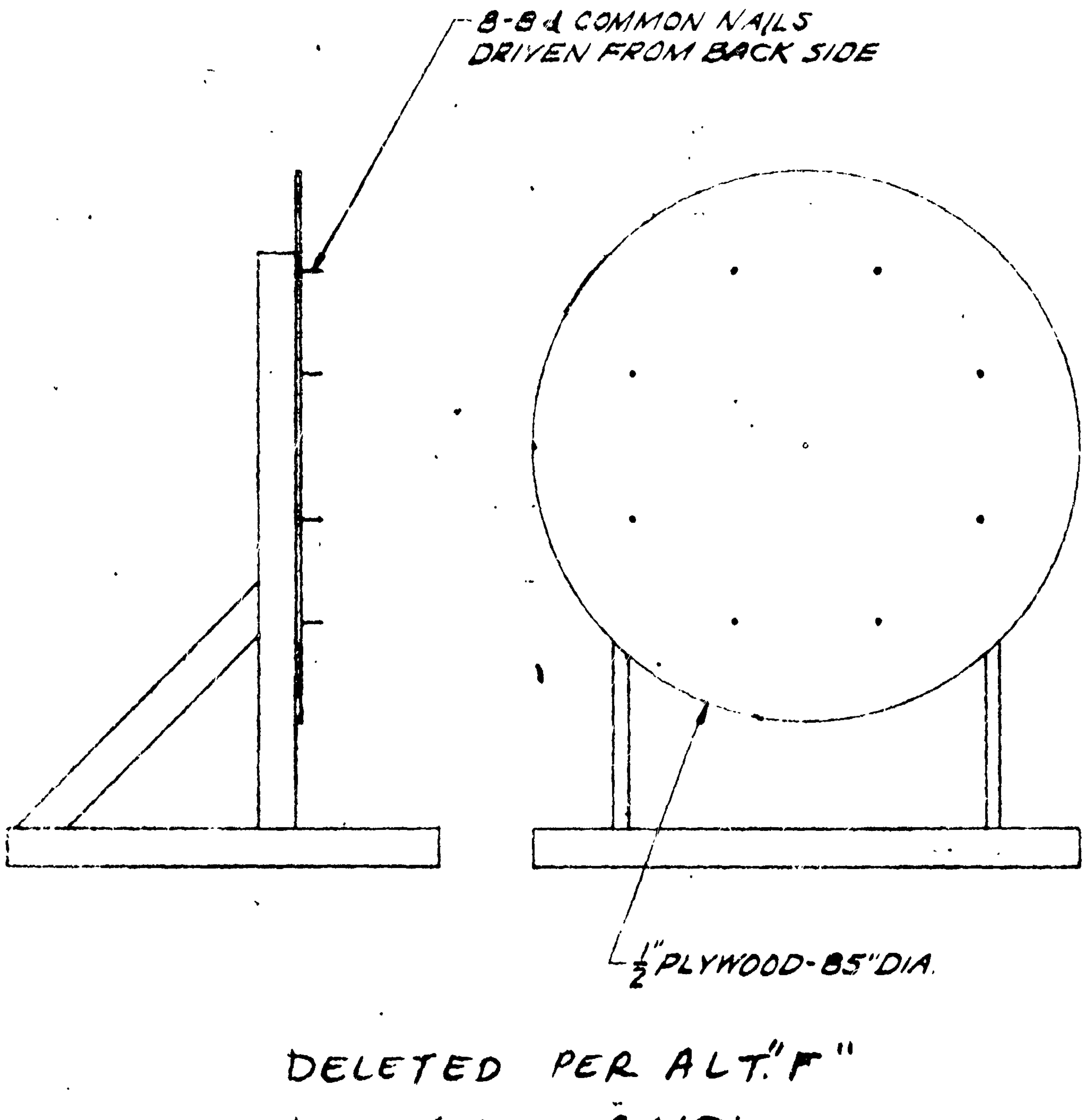


2 REQ'D

SYMBOL	TITLE	WORK ORDER		FIRST USED ON		
SD-16	FLEXIBLE JACKET CYLINDRICAL SECTION	BY TVD	DATE 6-11-65	SCALE —		LATEST ALT. LETT.
		CHK'D J.R.K.	GROUP IV	SHEET 16	SHEETS —	F
	LINDE DIVISION ENGINEERING DEPARTMENT TONAWANDA, NEW YORK	APP'D [illegible]	BM-61272			

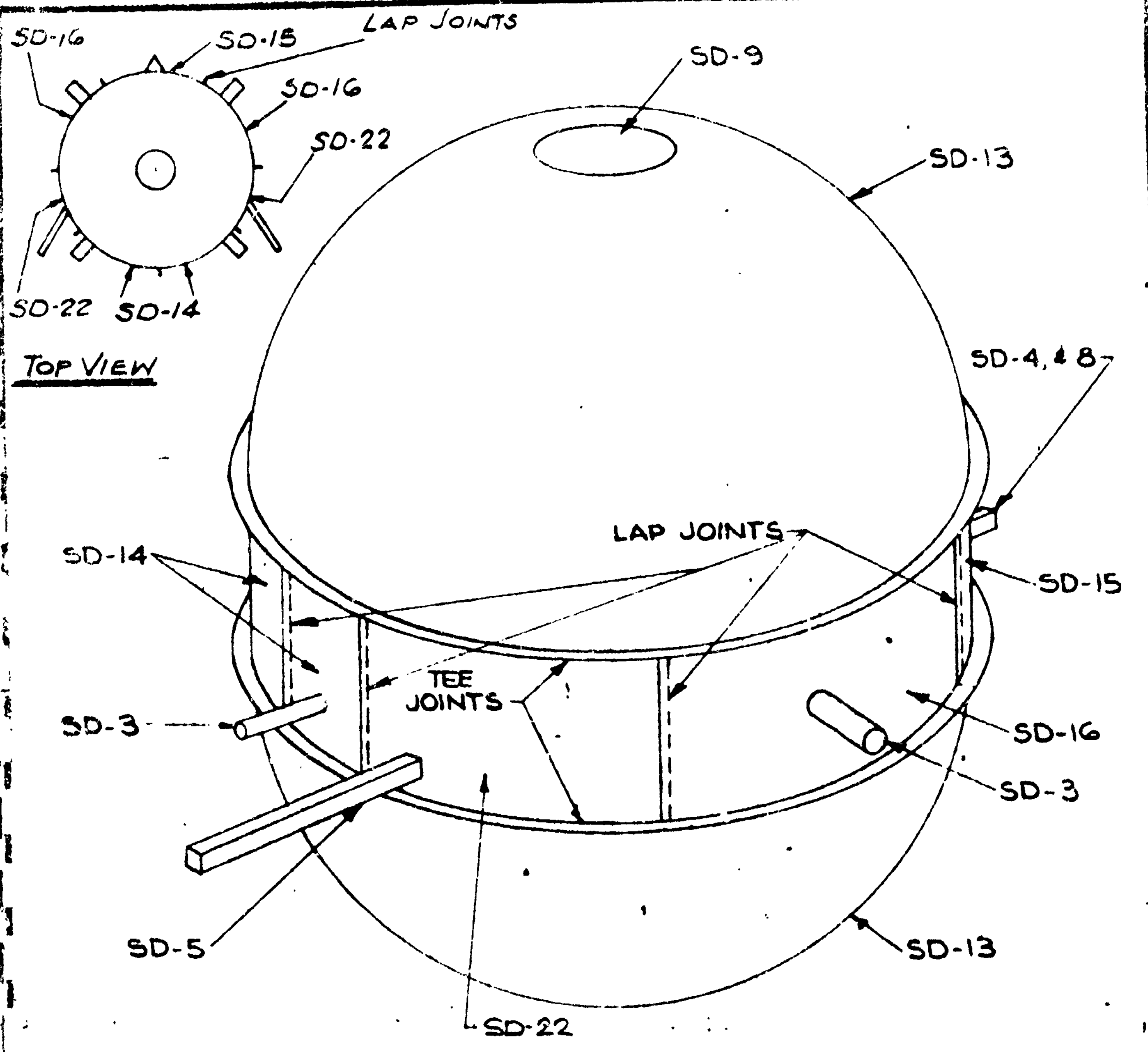


SYMBOL	TITLE	WORK ORDER	FIRST USED ON	
SD-17	SET UP FOR WRAPPING	BY MES DATE 6-17-65	SCALE —	LATEST ALT. LETT
		CHK'D JRK	GROUP IV	SHEET 17 / SHEETS —
	LINDE DIVISION ENGINEERING DEPARTMENT TONAWANDA, NEW YORK	APPV'D [signature]	BM612721	



DELETED PER ALT. "F"
1-25-66 C. BALDI

SYMBOL	TITLE	WORK ORDER	FIRST USED ON	
SD-18	HEAD INSULATION	BY MES DATE 6-17-65	SCALE —	
		CHK'D J.S.K.	GROUP IV	SHEET 18
UNION CARBIDE — LINDE DIVISION ENGINEERING DEPARTMENT TONAWANDA, NEW YORK		APP'D	BM-61272	

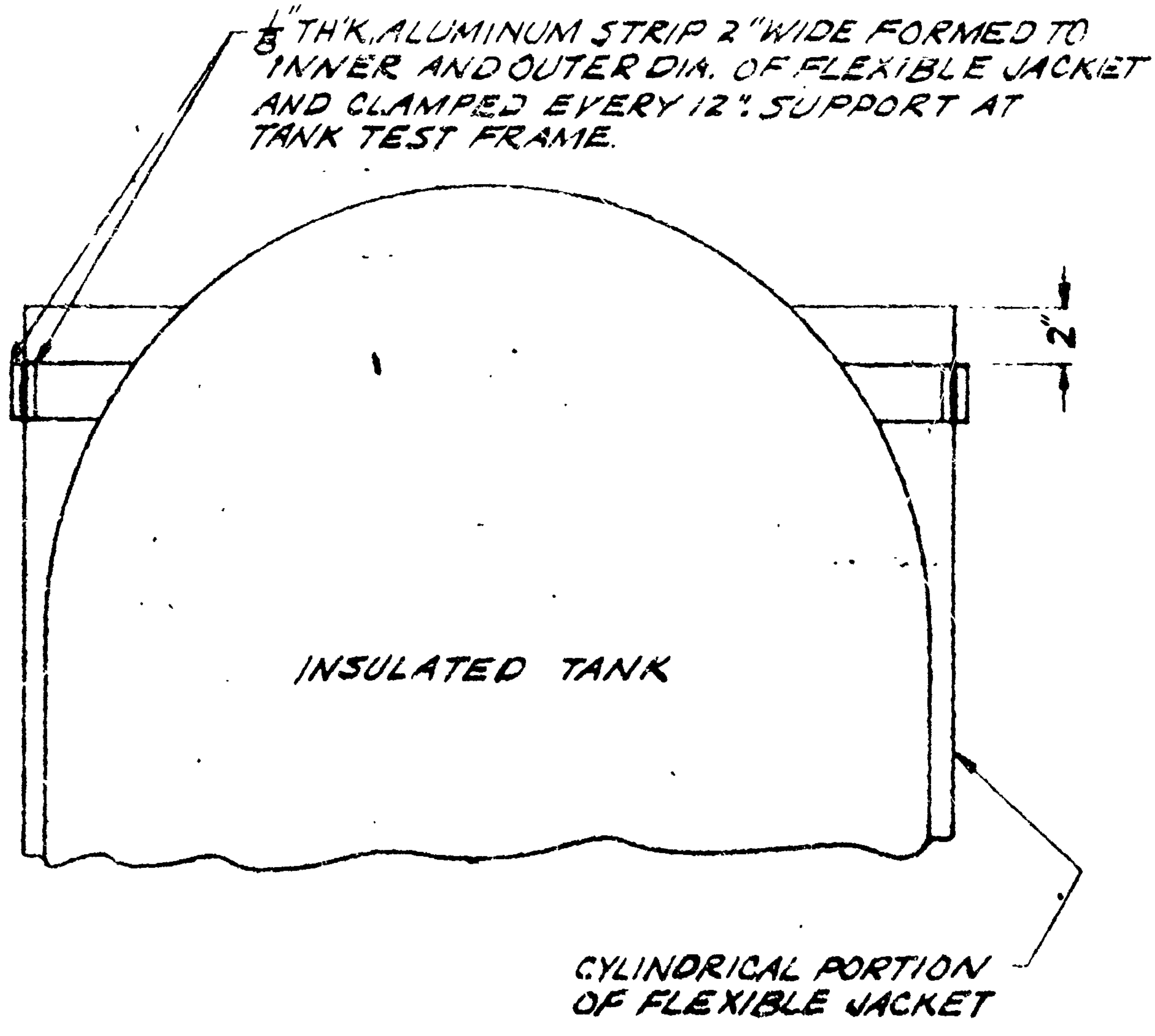


SYMBOL	TITLE	WORK ORDER	FIRST USED ON	
SD-19	FLEXIBLE JACKET ASSEMBLY	BY REH DATE 6-18-65	SCALE	LATEST ALT. LETT.
		CHK'D	GROUP IV / SHEET 19 / SHEETS —	E

LINDE DIVISION
ENGINEERING DEPARTMENT
TONAWANDA, NEW YORK

APP'D

BM-612721



SYMBOL: SD-20

TITLE: FLEXIBLE JACKET FLANGING PROCEDURE

BY: MES DATE: 6-18-65

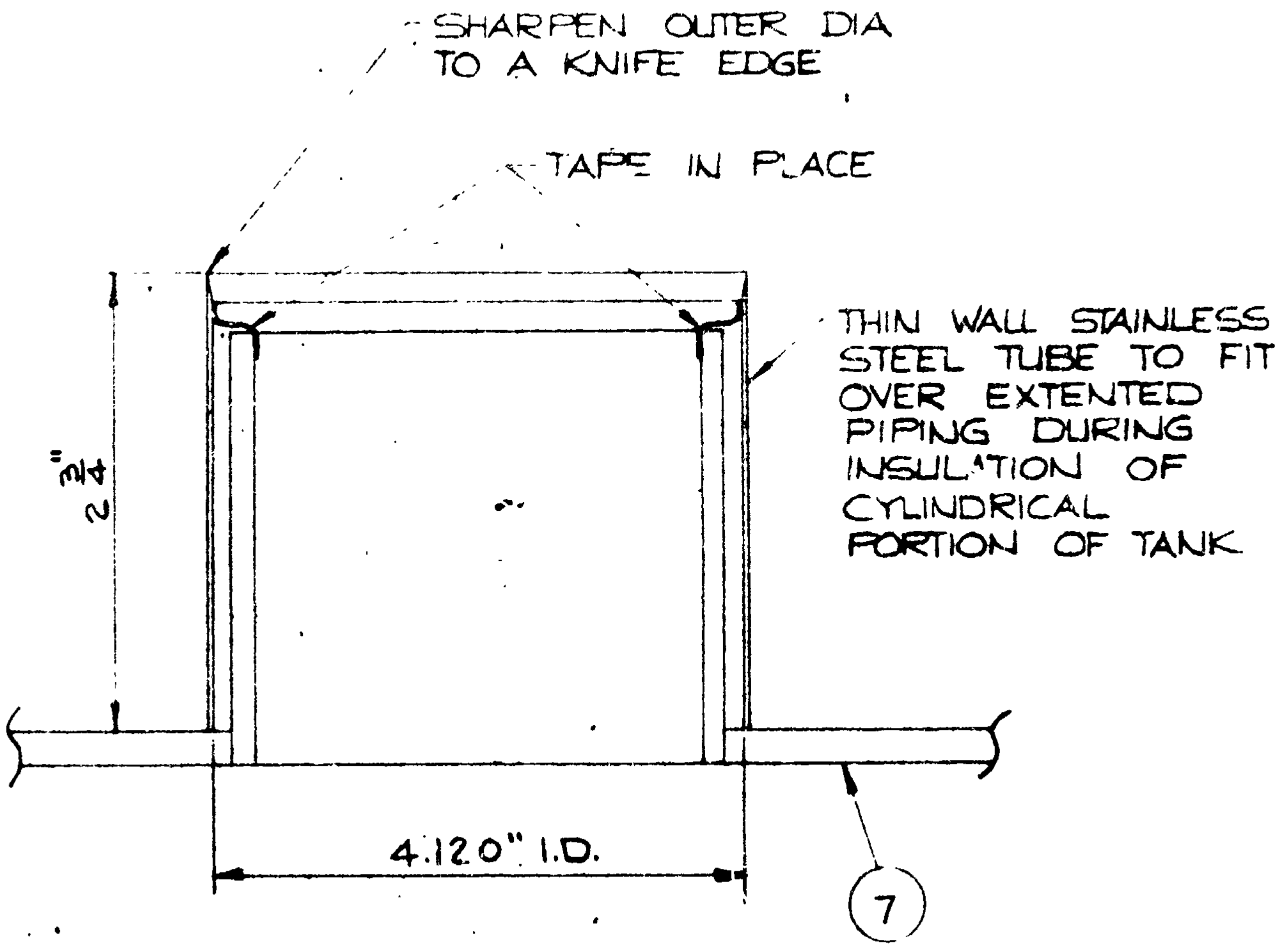
CHK'D: JPK

GROUP: IV

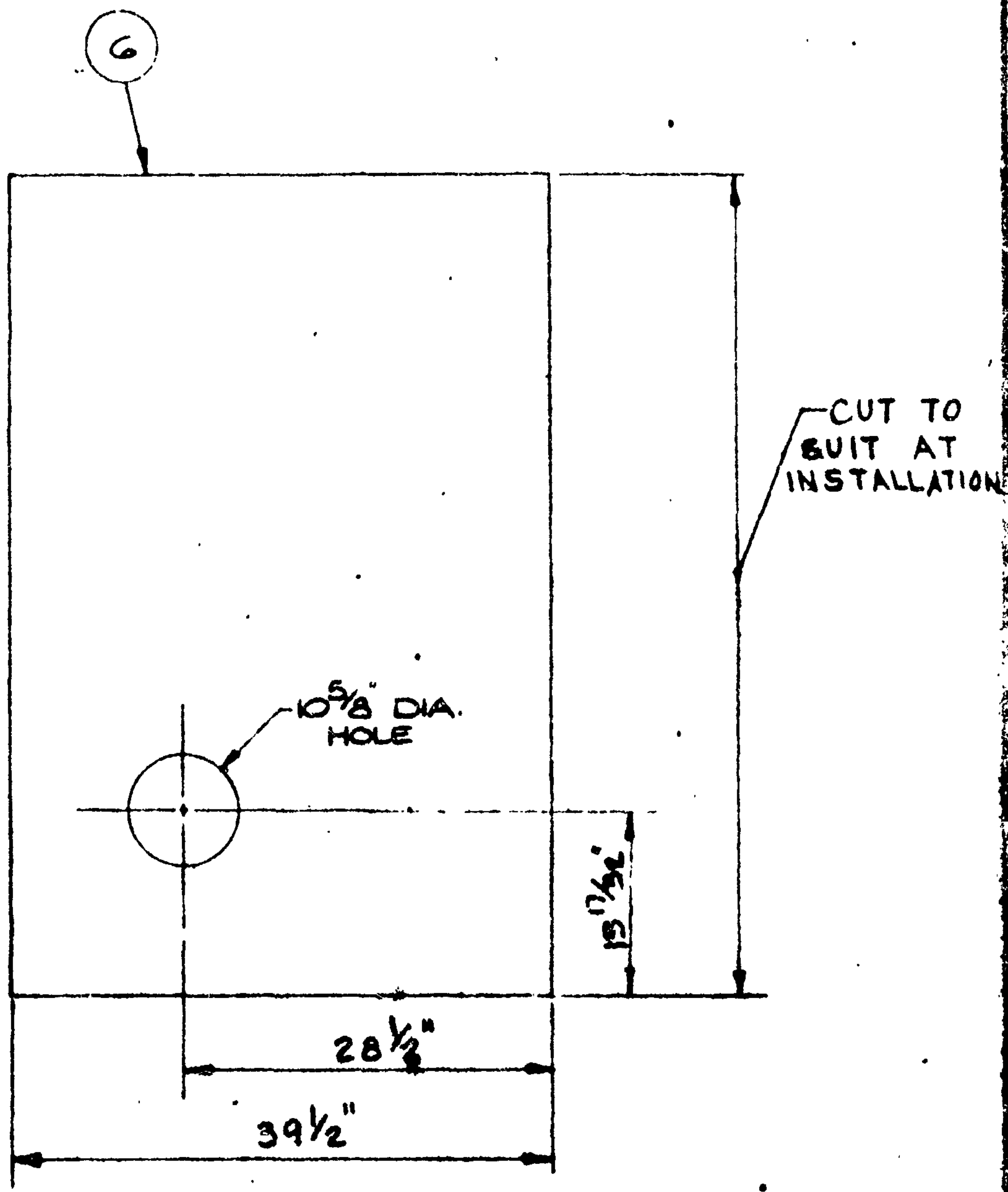
SHEET: 20

BM-612721

LINDE DIVISION
ENGINEERING DEPARTMENT
TONAWANDA, NEW YORK

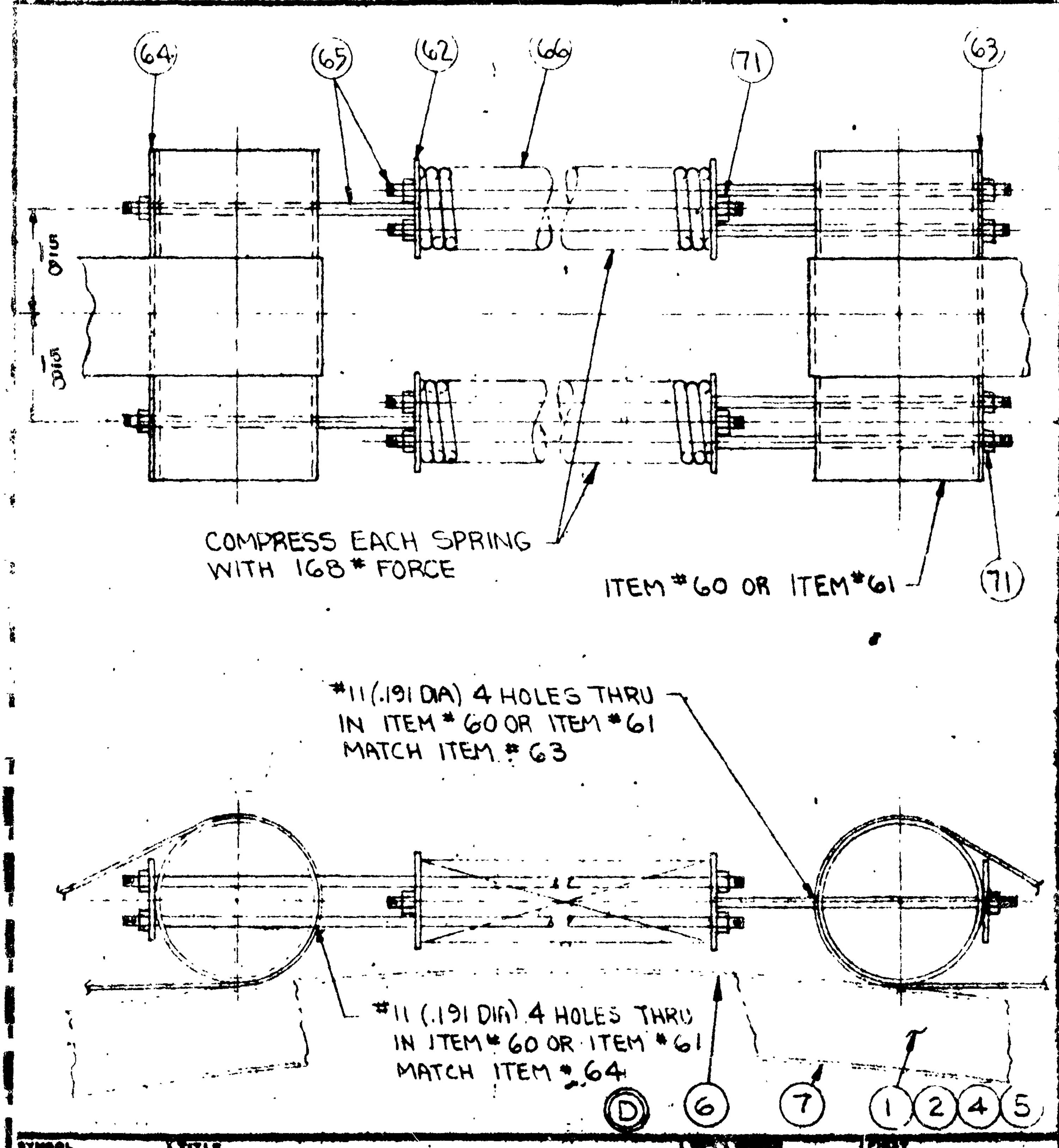


SYMBOL	TITLE	WORK ORDER	FIRST USED ON
SD-21	TOOLING FOR CYLINDRICAL WRAPPING OF INSULATION	BY LJM DATE 6-29-65	SCALE
		CHK'D SH-IV	SHEET 21, SHEETS —, F
	LINDE DIVISION ENGINEERING DEPARTMENT TONAWANDA, NEW YORK	APP'D	BM-612721



2 REQ'D.

SYMBOL	TITLE				
SD-22	FLEXIBLE JACKET CYLINDRICAL SECTION	LJM 6-22-65	—		
	LINDE DIVISION ENGINEERING DEPARTMENT TONAWANDA, NEW YORK	IV	22		F
		BM-612721			



SYMBOL	TITLE			
SD-23	INSULATION RETAINING BAND ASSY	BY WFL	DATE 6-29	
		CHK'D JPK	GROUP IV	23
	LINDE DIVISION ENGINEERING DEPARTMENT TONAWANDA, NEW YORK	APP'D		BM-612721

LETT	ALTERATION	DATE	BY	CHK'D	APPV'D
A	REVISED SD'S 4,5,8,&9; RELOCATED BANDS 4&5 FROM HEAD SEAM TO 1½" FROM SEAM. ITEM 13 WAS "NARMCO MAT'LS. DIV."; ITEM 37 WAS .25 GRAMS. ADDED ITEM 59	6-22-65	C.P.B.	[illegible]	[illegible]
B	REVISED SD'S 13,14,15,16,19; ADDED SD'S 21,22 & NOTES.	6-23-65	LM	[illegible]	[illegible]
C	ON FACE DWG ADDED ITEMS 60 & 61 & LOC NOTE. SD-4, REMOVED ITEMS 34, 35, 41 & 46. ADDED ITEMS 61, 68 & 69 REF. SD-5 ADDED ITEM 70. SD 8, REMOVED ITEMS 34, 35, 41 & 42, ADDED ITEM 69. ADDED SD-23 IN BM, REMOVED ITEMS 34, 35, 41, 42 & 46, ADDED ITEMS 60 TO 71 INCL.	6-29-65	NJF	[illegible]	[illegible]
D	REVISED SD'S-5 & 23. NOTE C-18 WAS FOR FORTY MINUTES. REMOVED NOTE I-3.	7-7-65	JLW	[illegible]	NCA
E	ITEM 18 WAS 5.234" I.D. X 5.512" O.D. PARKER # 2-237, ITEM 20 WAS 4.959" I.D. X 4.657" O.D., ITEM 58 WAS 17.955" I.D. X 18.375" O.D. PARKER # 2-387	8-2-65	PDB	[illegible]	[illegible]
F	RETYPED NOTES, & REV THE FOLLOWING: GROUP I SHEET 1 - REMOVED NOTE 5 AND ADDED TO SECTION J AS NOTE 16. SHEET 1 - B SECTION REV NOTE 2. SHEET 2 - B SECTION REV NOTES 10 & 11. C SECTION REMOVED NOTE 1. SHEET 3 - REV. NOTE 10. SHEET 4 - SECTION D REV. NOTES 1, 2 & 3 SECTION E REV. NOTE 1. SHEET 5 - SECTION F REV. NOTES 2, 3 & 4. SECTION G REV. NOTES 1, 2 & 3. SHEET 6 - SECTION H REV. NOTES 1, 2 & 4. SECTION I REV. NOTE 1 & 2. SHEET 9 - SECTION J REV. NOTE 16. REMOVED ITEMS 26, 49 & 50 SUBSTITUTED "OPACIFIED" FOR "SLURRY" IN ITEM 37; ITEM 54 WAS 1 ROLL REQUIRED. REVISED SD'S: 1, 2, 3, 4, 5, 7, 8, 10, 11, 13, 14, 15, 16, 21 & 22. DELETED: SD-18. DWG.: 39.2 DIM. WAS 40.2; 36-3/8" WAS 35-3/8"; 34-3/8" WAS 33-3/8"; ADD D 7/8" DIM. BETWEEN BAND & HEAD SEAM.	1-28-66 2/1/66	NJD C.P.B.	NJD WDD	[illegible]

SYMBOL	TITLE	WORK ORDER	FIRST USED ON
R			

BY	DATE	SCALE	LATEST ALT. LETT.
C.P.B.	6-22-65		F

CHK'D	GROUP	SHEET	SHEETS
[illegible]	V	1	

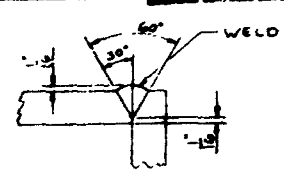
UNION CARBIDE

LINDE DIVISION
ENGINEERING DEPARTMENT
TONAWANDA, NEW YORK

APPV'D: [illegible]

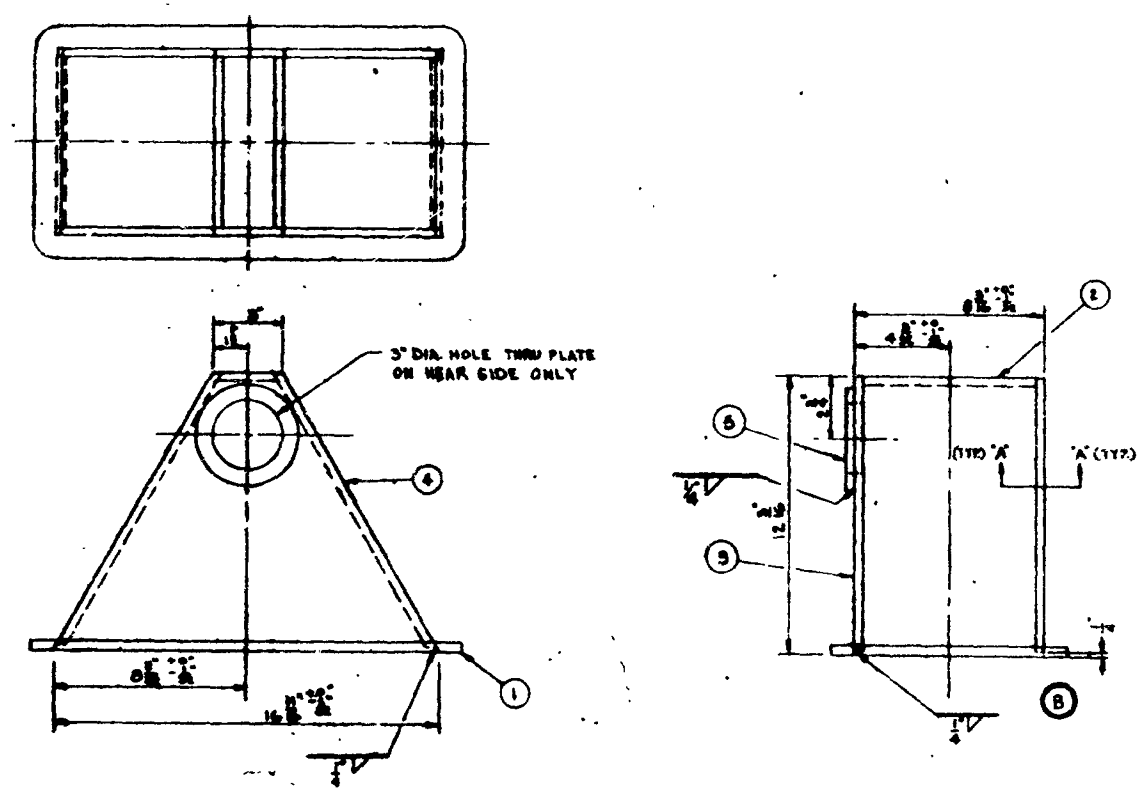
BM-612721

D-612721



SECTION "A-A"
SCALE: 12" = 1'-0"

ITEM NO	REQ FOR ONE	PART OR CODE NO	MATERIAL AND DESCRIPTION		DWG REF
1	1	B-612691	FLANGE, "A" FRAME, LOWER		A
2	1		PLATE, 3/8 THK 5456 H321 ALUMINUM		
3	2		PLATE, 3/8 THK, 5456 H321 ALUMINUM		
4	2		PLATE, 3/8 THK, 5456 H321 ALUMINUM		
5	1	A-612667	FLANGE, SUPPORT ROD JACKET, LOWER		



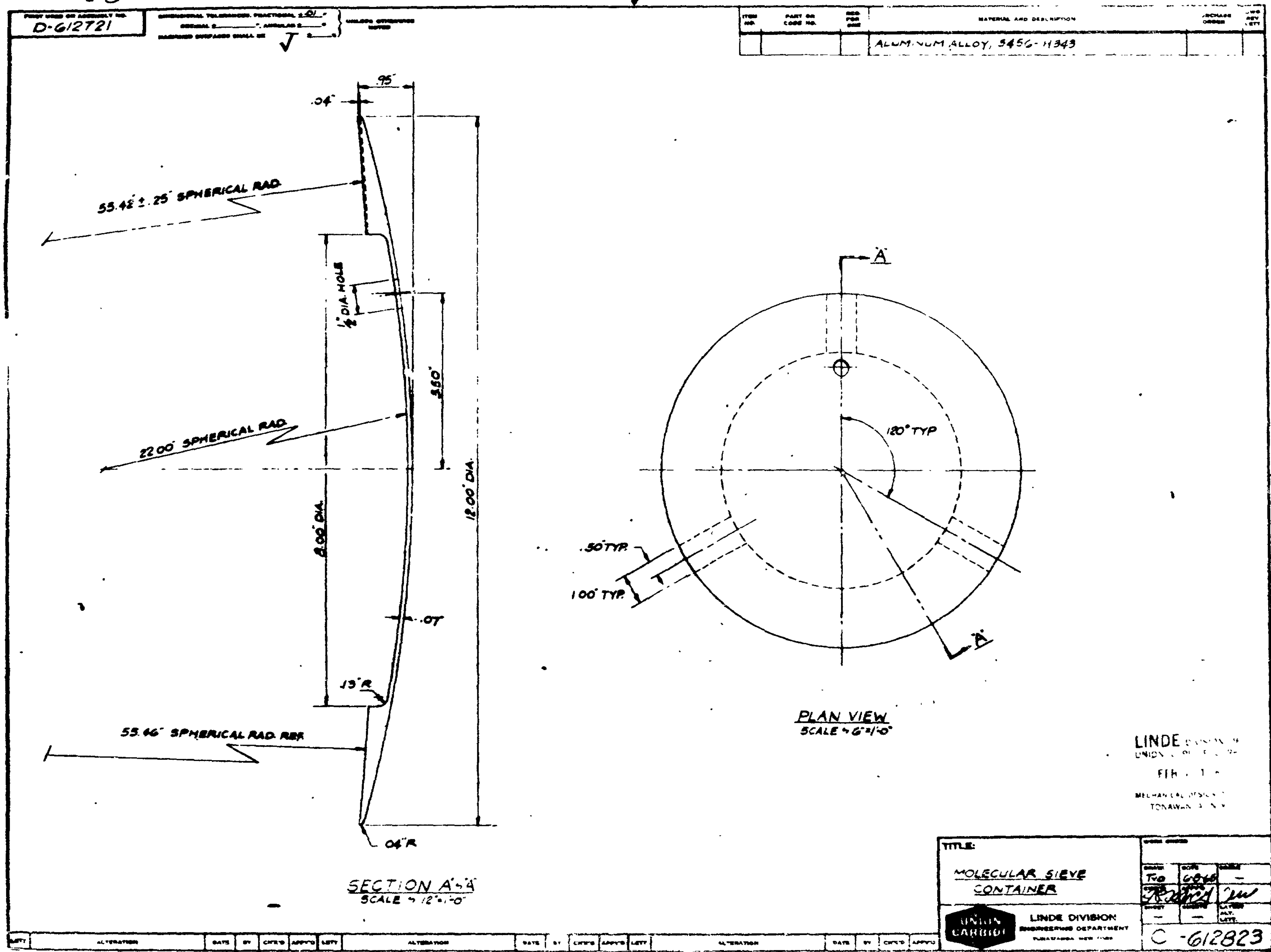
NOTE:
ALL WELDING TO BE HELIARC USING AA-5556 ROD.

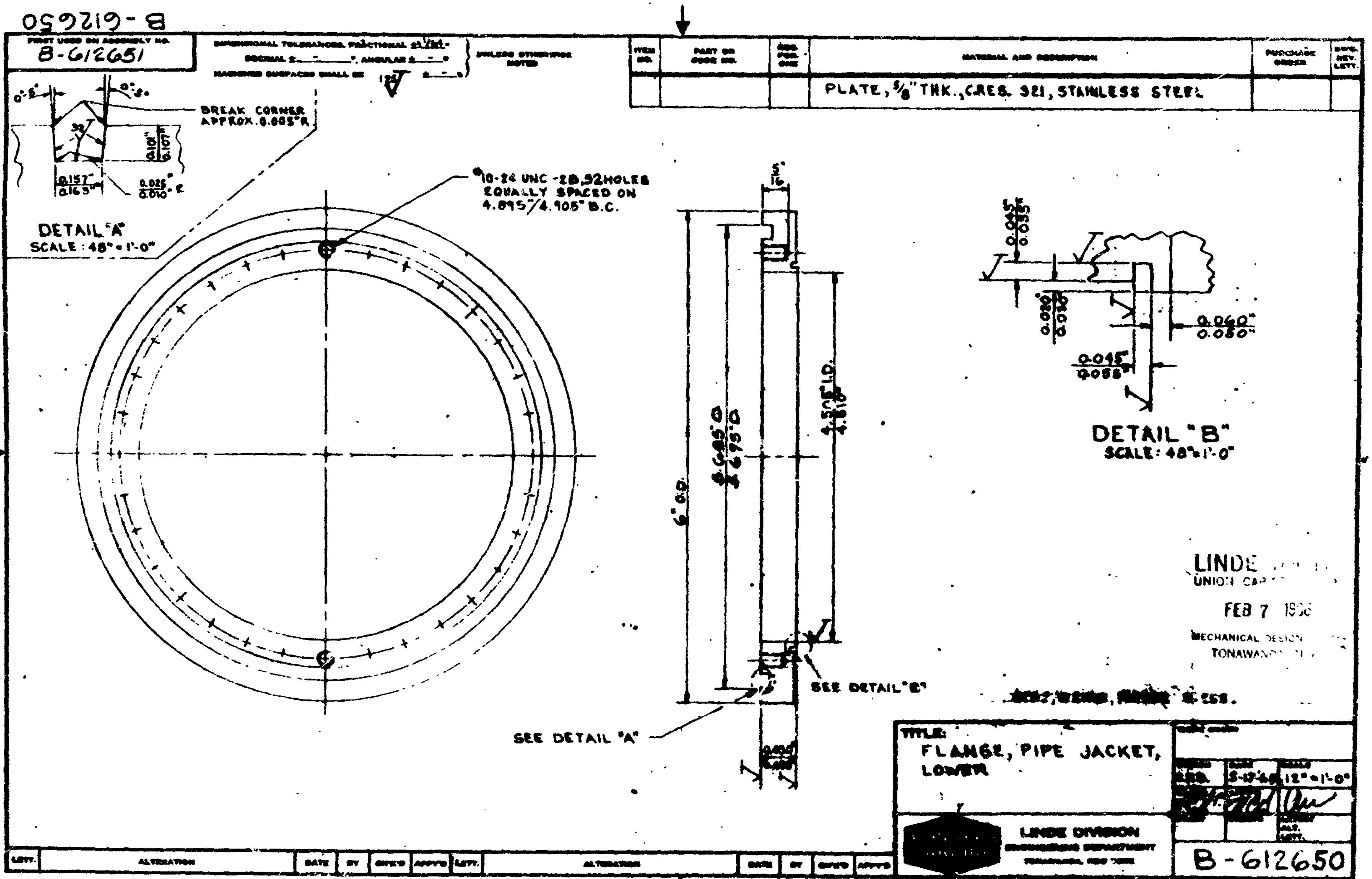
BOX ASSEMBLY "A" FRAME

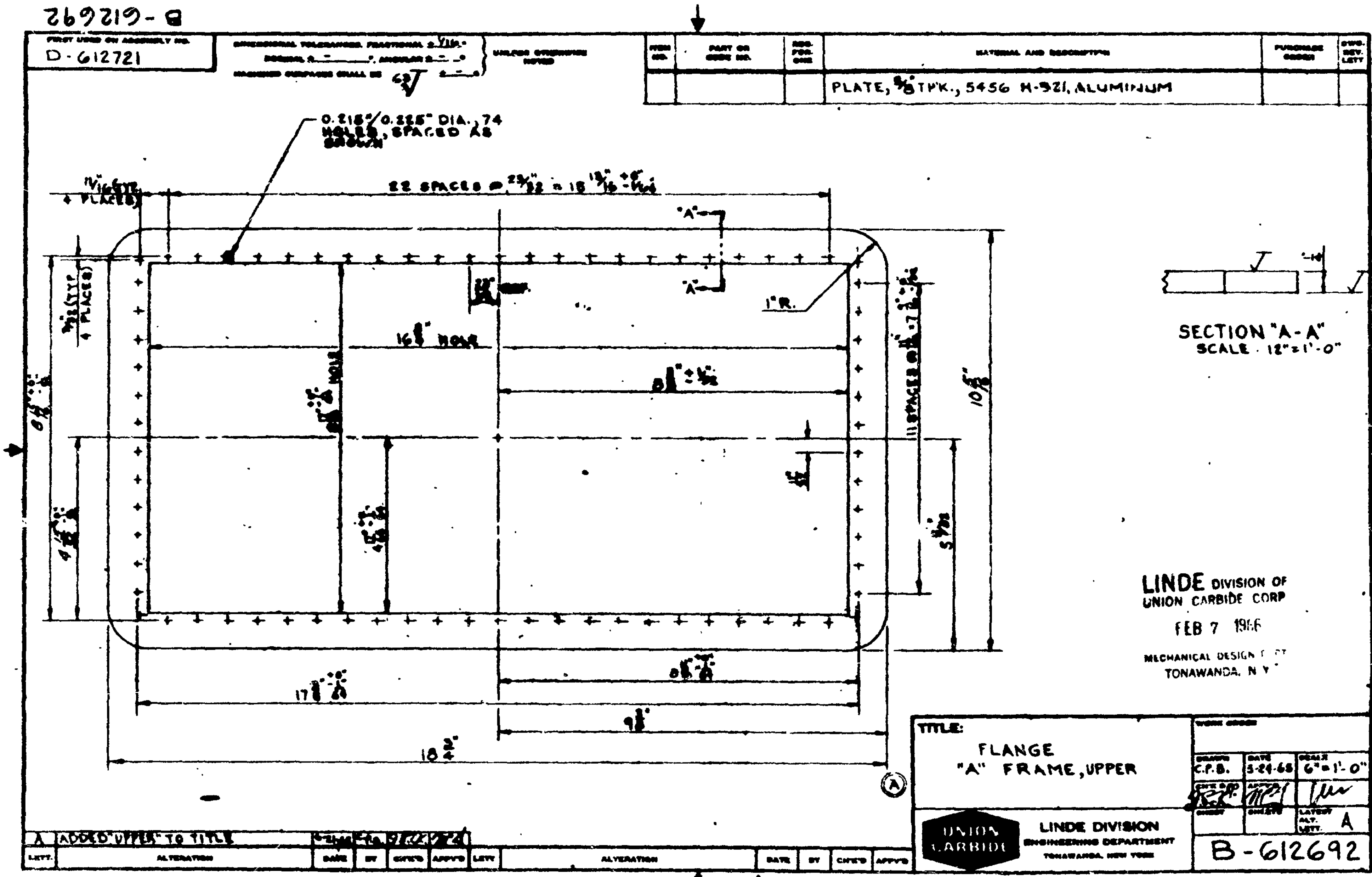
LINDE COMPANY

C-612[illegible]

B	[illegible]
A	CORRECTED TITLE OF ITEM 1


D-612721
ALUMINUM ALLOY, 5456-H343
.95"
.04"
55.42" ± .25" SPHERICAL RAD.
1/4" DIA. HOLE
3.50"
22.00" SPHERICAL RAD.
8.00" DIA.
18.00" DIA.
.07"
.13" R
55.46" SPHERICAL RAD. REF.
.04" R
SECTION A-A
SCALE ½ 12"=1'-0"
A
A
120° TYP
.50" TYP.
1.00" TYP.
PLAN VIEW
SCALE ½ 6"=1'-0"
LINDE
TITLE:
MOLECULAR SIEVE
CONTAINER
UNION CARBIDE
LINDE DIVISION
ENGINEERING DEPARTMENT
C-612823

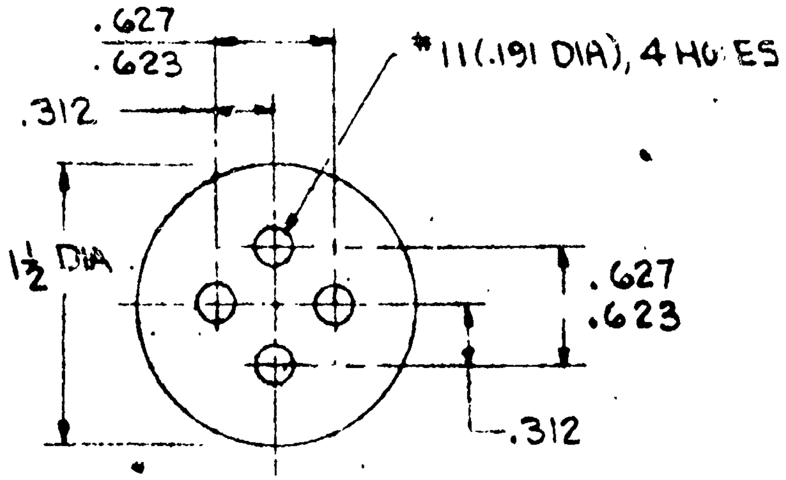

B-612650
FIRST USED ON ASSEMBLY NO.
B-612651
PLATE, 5/8" THK., CRES. 321, STAINLESS STEEL
BREAK CORNER APPROX. 0.005" R
DETAIL "A" SCALE: 48" = 1'-0"
10-24 UNC-2B, 32 HOLES EQUALLY SPACED ON 4.895/4.905" B.C.
5/16"
6" O.D.
5.685" D
5.695" D
4.505" I.D.
4.510"
SEE DETAIL "A"
SEE DETAIL "B"
DETAIL "B" SCALE: 48" = 1'-0"
0.045"
0.035
0.020"
0.030
0.060"
0.050"
0.045"
0.055"
LINDE
UNION CAR
FEB 7 1966
MECHANICAL DESIGN
TONAWANDA
TITLE:
FLANGE, PIPE JACKET, LOWER
LINDE DIVISION
ENGINEERING DEPARTMENT
TONAWANDA, NEW YORK
12" = 1'-0"
B-612650
ALTERATION
DATE
BY
CHK'D
APP'D
LETT.



B-612692
D-612721
PLATE, 5/8 THK., 5456 H-321, ALUMINUM
0.215/0.225" DIA., 74 HOLES, SPACED AS SHOWN
22 SPACES
11 SPACES
16 HOLE
1" R.
"A"
SECTION "A-A"
SCALE 12"=1'-0"
LINDE DIVISION OF UNION CARBIDE CORP
FEB 7 1966
TONAWANDA, N.Y.
TITLE:
FLANGE
"A" FRAME, UPPER
C.P.B.
5-24-65
6"=1'-0"
A
UNION CARBIDE
LINDE DIVISION
ENGINEERING DEPARTMENT
TONAWANDA, NEW YORK
B-612692
A ADDED UPPER TO TITLE
ALTERATION

LETT	ALTERATION	BY	CHK'D	DATE	APPV'D	LETT	ALTERATION	BY	CHK'D	DATE	APPV'D

DIMENSIONAL TOLERANCES, FRACTIONAL ± 1/32 "
DECIMAL ± .015 " ANGULAR ± ____ °.
MACHINED SURFACES SHALL BE √ ± ____ %.
UNLESS OTHERWISE NOTED



MATERIAL:
SHEET #11 SS GA (.125) TYPE 304 STAINLESS STEEL, 1½ × 1½.

SYMBOL	TITLE	WORK ORDER	FIRST USED ON
	SPRING STOP		D-612721.

BY	DATE	SCALE	LATEST ALT. LETT.
WR		12" = 1'-0"	

CHK'D	GROUP	SHEET	SHEETS
	-	-	-

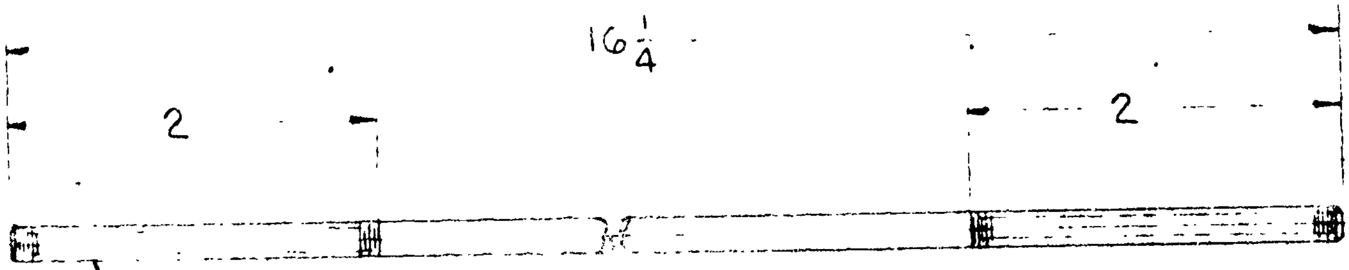
APPV'D

LINDE DIVISION
ENGINEERING DEPARTMENT
TONAWANDA, NEW YORK

A-612986

LETT	ALTERATION	BY	CHK'D	DATE	APPV'D	LETT	ALTERATION	BY	CHK'D	DATE	APPV'D

DIMENSIONAL TOLERANCES, FRACTIONAL ± 1/16"
DECIMAL ± ______ " ANGULAR ± ______ °
MACHINED SURFACES SHALL BE √ ± ______ %
UNLESS OTHERWISE NOTED



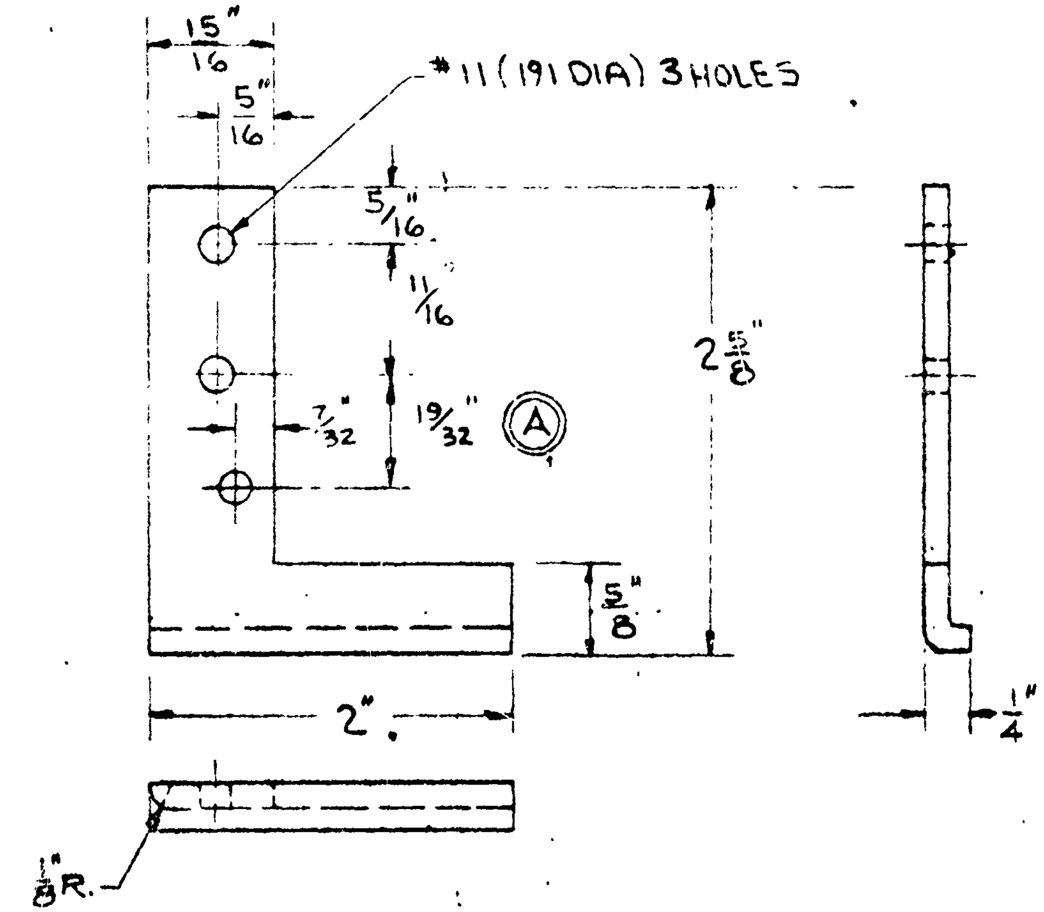
THREAD #10-32 UNF-3A
TYP [illegible]H ENDS

MATERIAL
3/16 DIA., ANNEALED & COLD DRAWN, AISI TYPE 304
STAINLESS STEEL, 16 1/4" LG

SYMBOL	TITLE	WORK ORDER	FIRST USED ON D61272
	ROD	BY WFL DATE	SCALE 12" = 1'-0"
		CHK'D [illegible]	GROUP / SHEET / SHEETS
	UNION CARBIDE — LINDE DIVISION, ENGINEERING DEPARTMENT, TONAWANDA, NEW YORK	APPV'D [illegible]	A-612989

LETT	ALTERATION	BY	CHK'D	DATE	APPV'D
A	MATERIAL WAS 2"×2⅞" ADDED ONE #11 (.191") HOLE, 5/8" DIM. WAS ½", 2 5/8" DIM. WAS 2½" & TOLERANCE WAS 1/16".	JLW	[illegible]	7-7-65	[illegible]

DIMENSIONAL TOLERANCES, FRACTIONAL ± 1/32"
DECIMAL ± ____ " ANGULAR ± ____ °.
MACHINED SURFACES SHALL BE √ ± ____ %.
UNLESS OTHERWISE NOTED



MATERIAL:

(A) SHEET #11 SS GA (.125" THICK) TYPE 304 STAINLESS STEEL, 2" × 2 5/8"

LINDE [illegible]
UNION CARB[illegible]
FEB 7 1966
MECHANICAL [illegible]
TONAWANDA, N.Y.

SYMBOL	TITLE	WORK ORDER	FIRST USED ON
	BAND GUIDE		D-612721

BY	DATE	SCALE	CAT.
WFL		12" = 1'-0"	

CHK'D	GROUP	SHEET	SHEETS
[illegible]			A

UNION CARBIDE

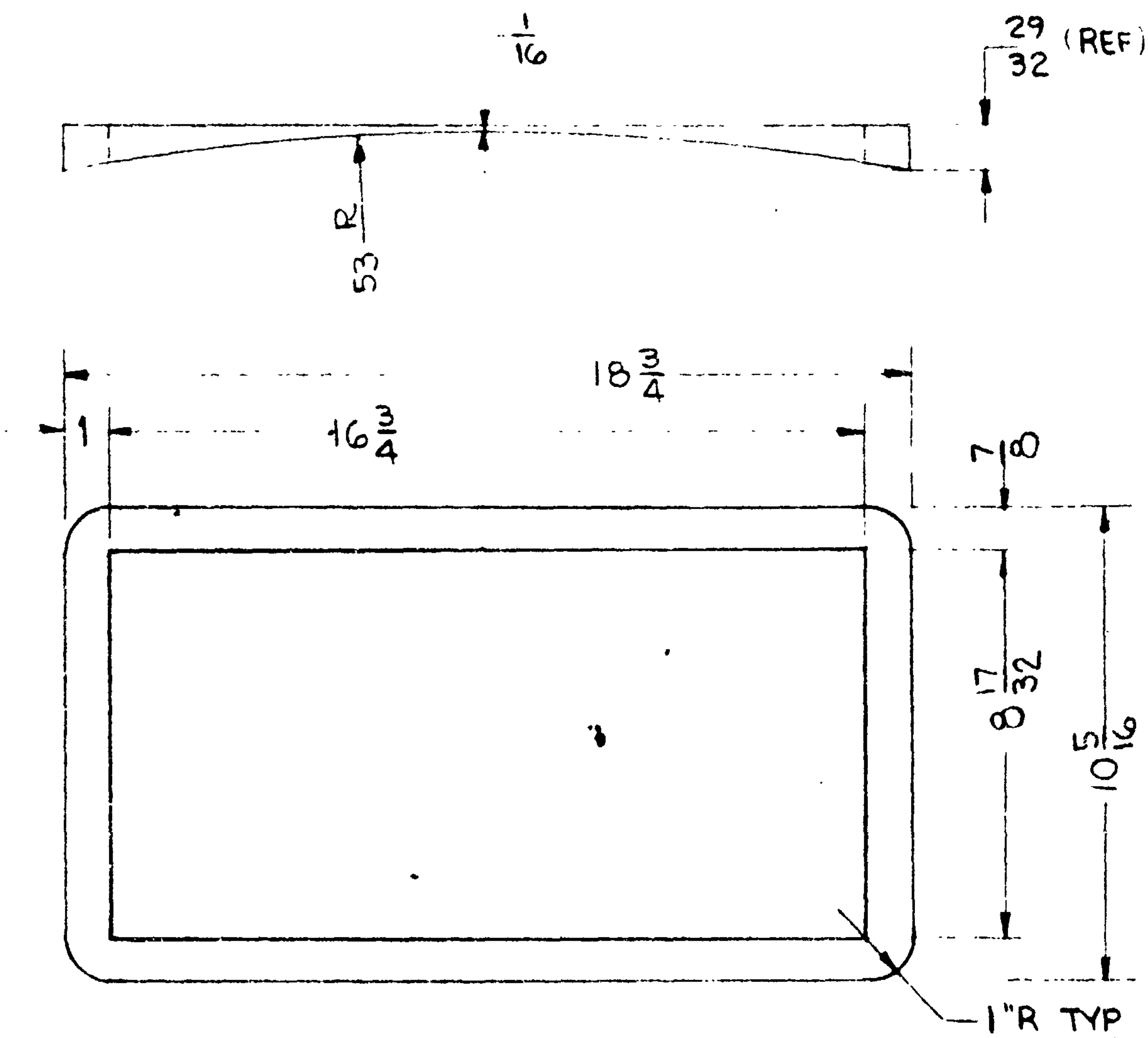
LINDE DIVISION
ENGINEERING DEPARTMENT
TONAWANDA, NEW YORK

APPV'D [illegible]

A-612994

LETT.	ALTERATION	BY	CHK'D	DATE	APPV'D	LETT.	ALTERATION	BY	CHK'D	DATE	APPV'D

DIMENSIONAL TOLERANCES, FRACTIONAL ± 1/32"
DECIMAL ± ____" ANGULAR ± ____°.
MACHINED SURFACES SHALL BE 250√ ± ____%.
UNLESS OTHERWISE NOTED



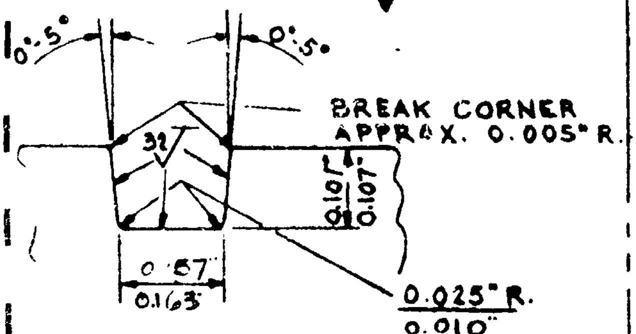
MATERIAL:
PLATE, 1" THK ALUMINUM AA5456-H321, 10 5/16 x 18 3/4 LG

MSDL	TITLE	WORK ORDER	FIRST USED ON D-612721		
	ADAPTER, "A" FRAME	BY WFL · DATE	SCALE 3" = 1'-0"		LATEST ALT. LETT.
		CHK'D	GROUP	SHEET	SHEETS
UNION CARBIDE	LINDE DIVISION ENGINEERING DEPARTMENT TONAWANDA, NEW YORK	APPV'D	A-612995		

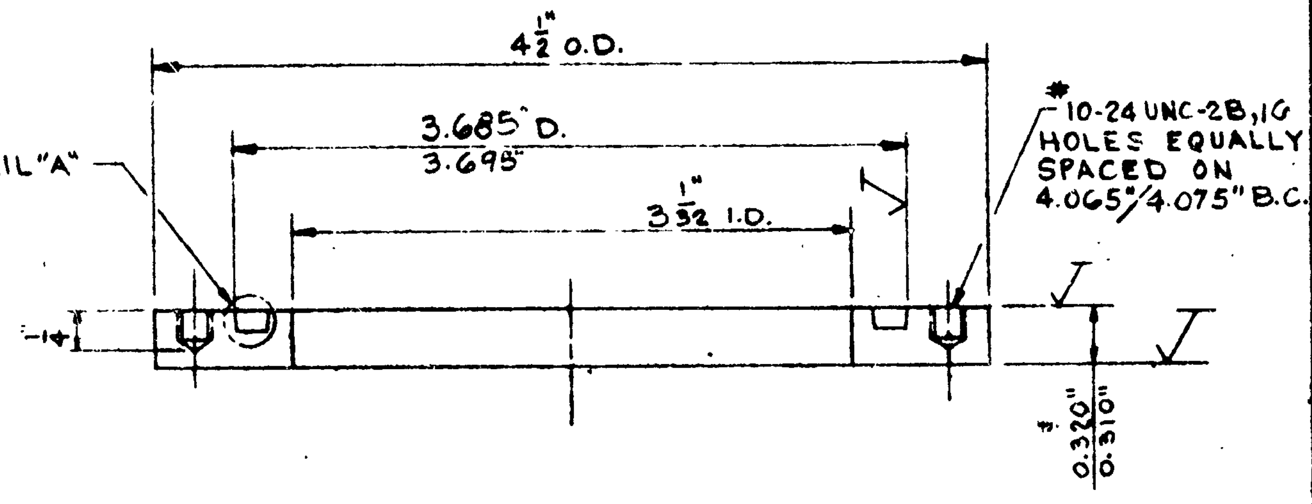
LETT	ALTERATION	BY	CHK'D	DATE	APPV'D	LETT	ALTERATION	BY	CHK'D	DATE	APPV'D

612667

DIMENSIONAL TOLERANCES, FRACTIONAL ± 1/64 "
DECIMAL ± – " ANGULAR ± – °.
MACHINED SURFACES SHALL BE 125 ± – %.
UNLESS OTHERWISE NOTED



DETAIL "A"
SCALE: 48" = 1'-0"



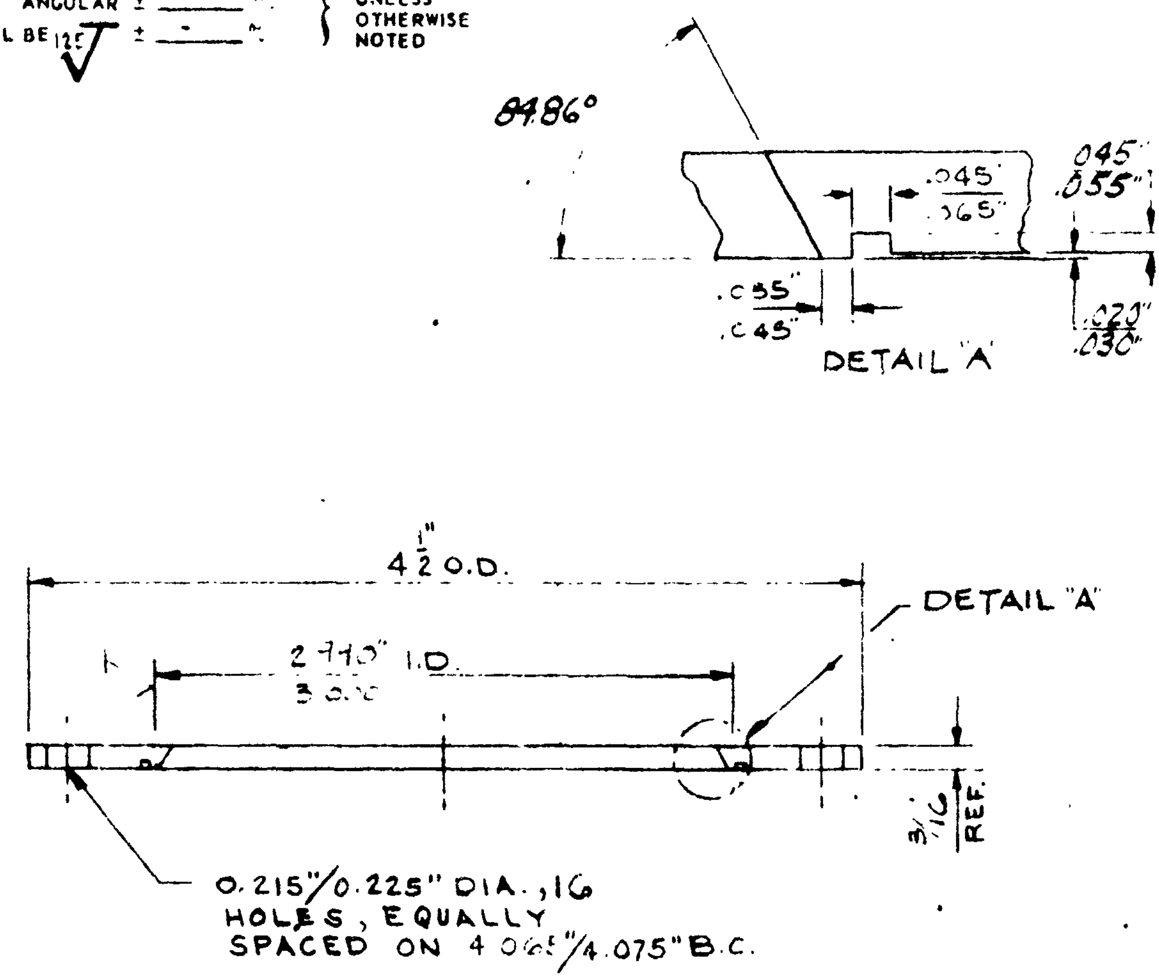
MATERIAL:
PLATE, 1/2" THK., 5456 ALUMINUM

REF: O RING, PARKER 2-237

SYMBOL	TITLE	USED ON	C-612693
	FLANGE SUPPORT ROD JACKET, LOWER	BY C.P.D. DATE 8-20-65	SCALE 12" = 1'-0"
UNION CARBIDE	LINDE DIVISION ENGINEERING DEPARTMENT TONAWANDA, NEW YORK	CHK'D / APPV'D	A-612667

LETT.	ALTERATION	BY	CHK'D	DATE	APPV'D	LETT.	ALTERATION	BY	CHK'D	DATE	APPV'D

DIMENSIONAL TOLERANCES, FRACTIONAL ± 1/64 "
DECIMAL ± — " ANGULAR ± — °
MACHINED SURFACES SHALL BE 125 ± —
UNLESS OTHERWISE NOTED



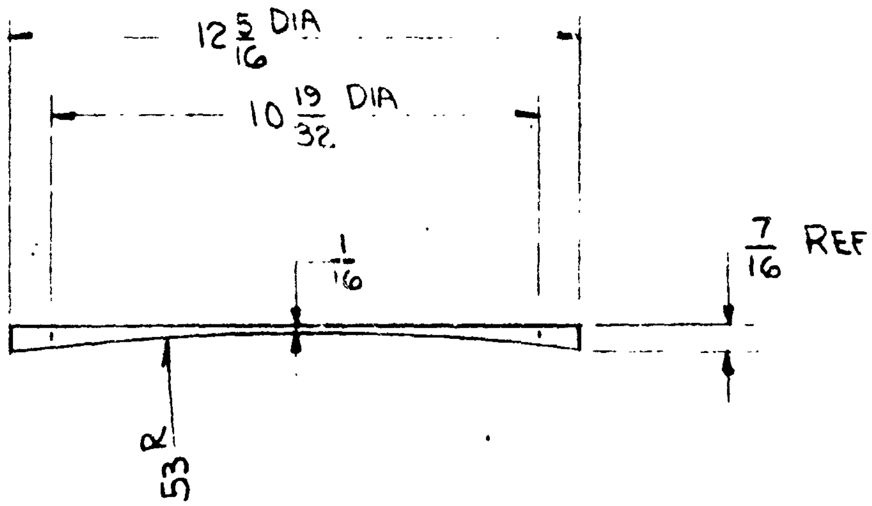
MATERIAL:
PLATE, 3/16" THK., C.RES., TYPE 321 STAINLESS STEEL

SYMBOL	TITLE	WORK ORDER		FIRST USED ON D-612721	
	FLANGE SUPPORT ROD JACKET, UPPER	BY C.P.B. DATE 5-20-65	SCALE 12" = 1'-0"		LATEST ALT. LETT.
		CHK'D R.P.K.	GROUP	SHEET	SHEETS
UNION CARBIDE	LINDE DIVISION ENGINEERING DEPARTMENT TONAWANDA, NEW YORK	APPV'D	A-612668		

LETT	ALTERATION	BY	CHK'D	DATE	APPV'D	LETT	ALTERATION	BY	CHK'D	DATE	APPV'D

612996

DIMENSIONAL TOLERANCES, FRACTIONAL ± 1/32 "
DECIMAL ± ____ " ANGULAR ± ____ °.
MACHINED SURFACES SHALL BE 250√ ± ____ %.
UNLESS OTHERWISE NOTED



MATERIAL:
PLATE: 5/8 THICK ALUMINUM, AA 5456-H321, 12 5/16 × 12 5/16

SYMBOL	TITLE	WORK ORDER	FIRST USED ON
	ADAPTER - STRUT		D-612721

BY	DATE	SCALE	LATEST ALT. LETT.
WFL		3" = 1'-0"	

CHK'D	GROUP	SHEET	SHEETS
J.R.R.			

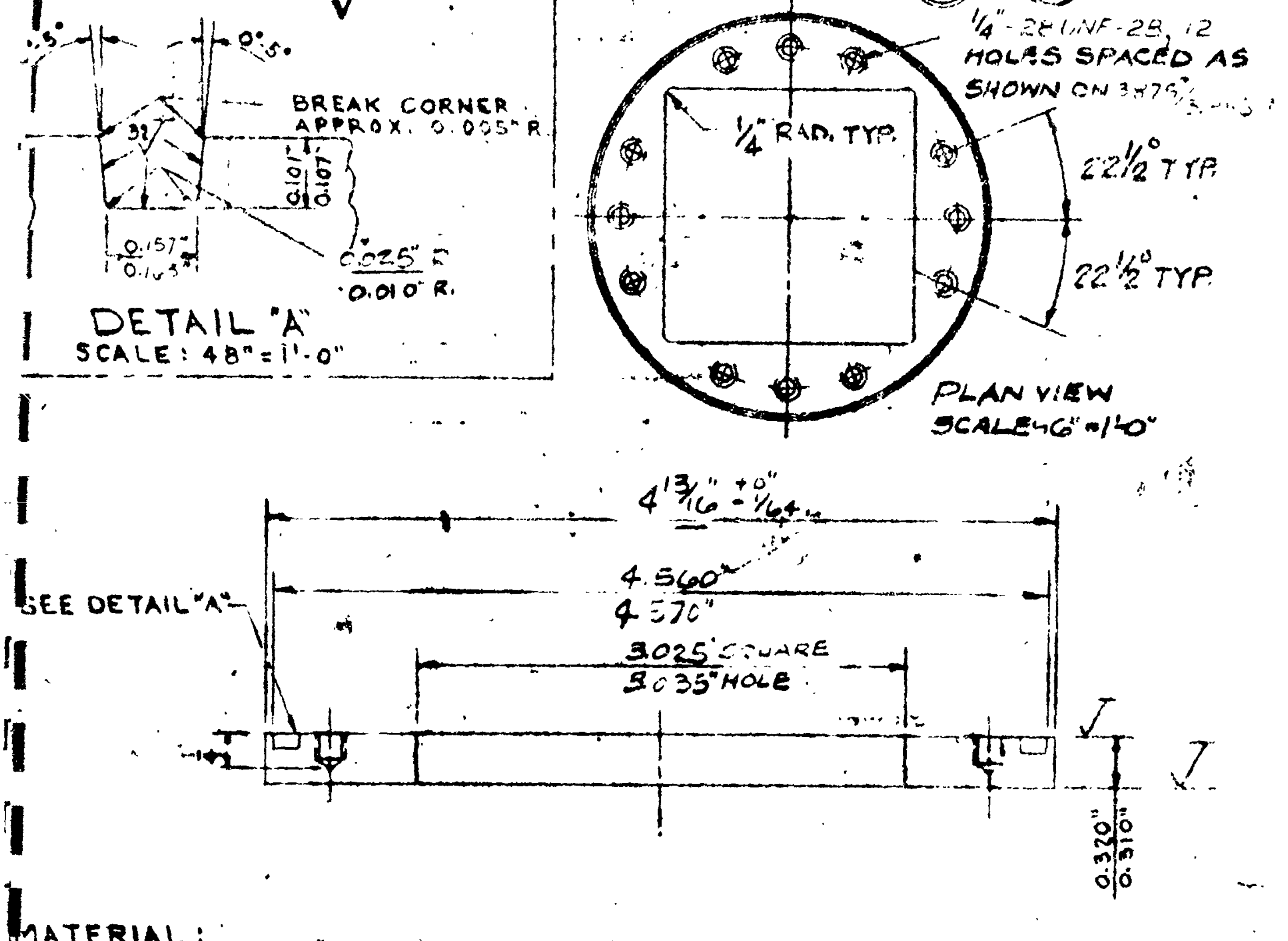
APPV'D: [illegible]

A-612996

UNION CARBIDE
LINDE DIVISION
ENGINEERING DEPARTMENT
TONAWANDA, NEW YORK

ALTERATION	BY	CHK'D	DATE	APP'V'D	LETT
1/4"-28UNF-2B HOLES WERE #10-24 UNC-2B	R.T.P.	N.J.D.	[illegible]	[illegible]	[illegible]
#10-24UNC-2B HOLES WERE .3"/.275" DIA. HOLES	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]

DIMENSIONAL TOLERANCES, FRACTIONAL ± 1/64"
DECIMAL ± — ANGULAR ± —
MACHINED SURFACES SHALL BE 125 ± —
UNLESS OTHERWISE NOTED



MATERIAL:
PLATE, 1/2" THK., 6Al-4V TITANIUM ALLOY

REF. O-RING, PARKER 2-244.

SYMBOL	TITLE	WORK ORDER	FIRST USED ON
	FLANGE ADAPTOR STRUT JACKET		[illegible]

BY	DATE	SCALE	LATEST ALT. LETT.
T.V.D	6-10-65	12" = 1'-0"	B

CHK'D	GROUP	SHEET	SHEETS
[illegible]	—	—	—

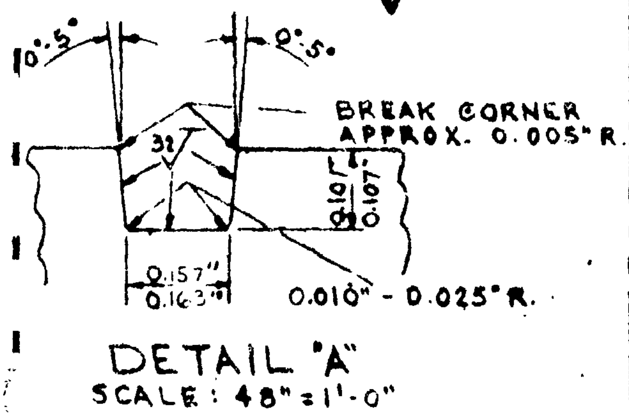
APP'V'D: [illegible]

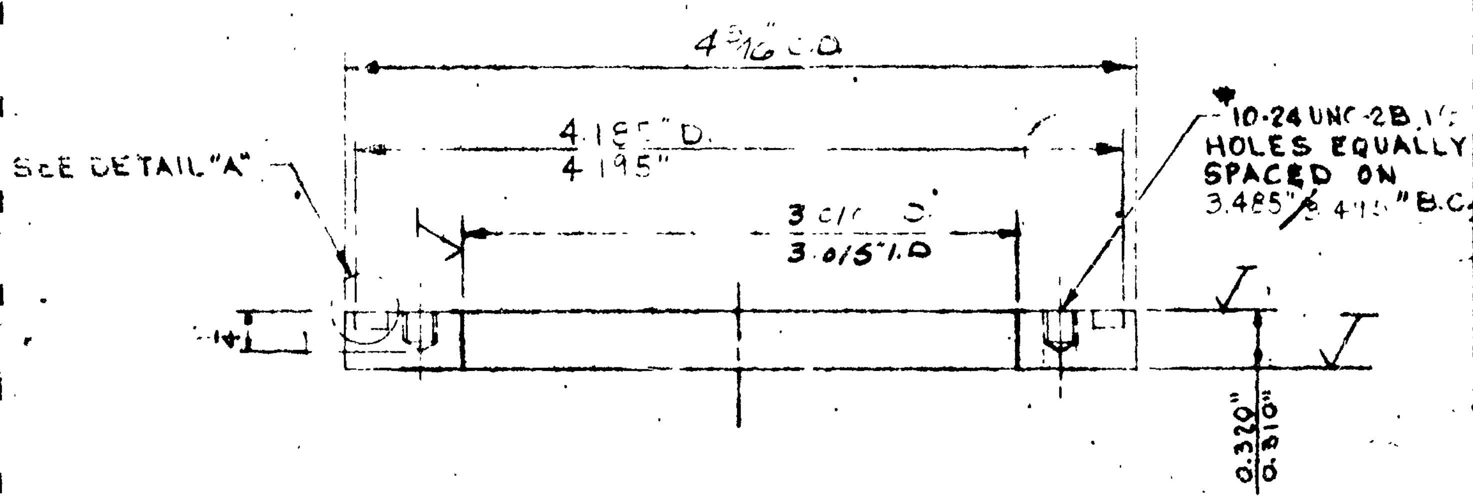
UNION CARBIDE
LINDE DIVISION
ENGINEERING DEPARTMENT
TONAWANDA, NEW YORK

A-61[illegible]

LETT.	ALTERATION	BY	CHK'D	DATE	APPV'D	LETT.	ALTERATION	BY	CHK'D	DATE	APPV'D

DIMENSIONAL TOLERANCES, FRACTIONAL ± 1/64 "
DECIMAL ± — " ANGULAR ± — °
MACHINED SURFACES SHALL BE 125 ± — % } UNLESS OTHERWISE NOTED





MATERIAL:
PLATE, 1/2" THK., CRES 321 STAINLESS STEEL.

REF.: O RING, PARKER 2-241

SYMBOL	TITLE	WORK ORDER	FIRST USED ON
	FLANGE ADAPTER PIPE JACKET		

BY	DATE	SCALE	LATEST ALT. LETT.
TVD	6-10-65	12" = 1'-0"	

CHK'D	GROUP	SHEET	SHEETS
J.P.R.	—	—	—

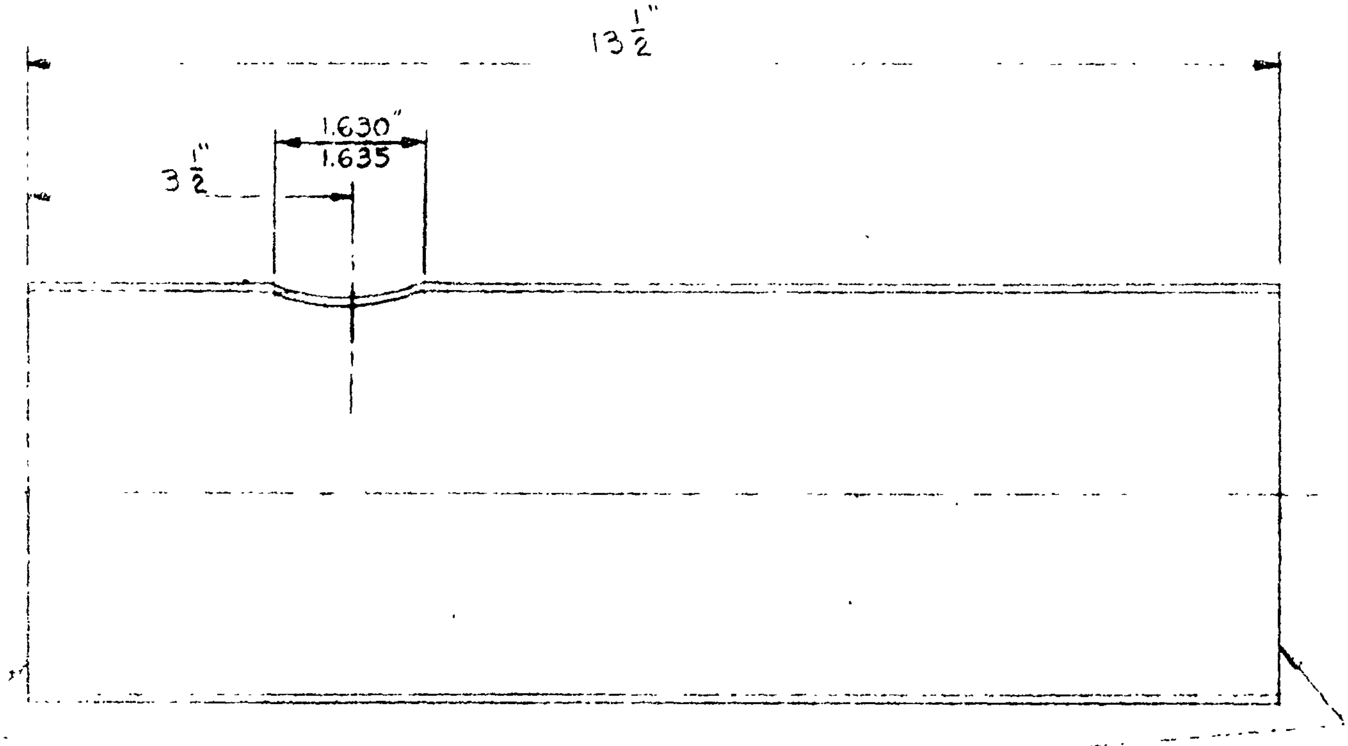
APPV'D: MPM

UNION CARBIDE
LINDE DIVISION
ENGINEERING DEPARTMENT
TONAWANDA, NEW YORK

A-612840

LETT	ALTERATION	BY	CHK'D	DATE	APPV'D	LETT	ALTERATION	BY	CHK'D	DATE	APPV'D
A	... HOLE WAS ... D.A HOLE	BTP	N.U.D. W.D.D	25-66	M.T.						

DIMENSIONAL TOLERANCES, FRACTIONAL ± 1/16"
DECIMAL ± — " ANGULAR ± — °
MACHINED SURFACES SHALL BE √ ± — " } UNLESS OTHERWISE NOTED



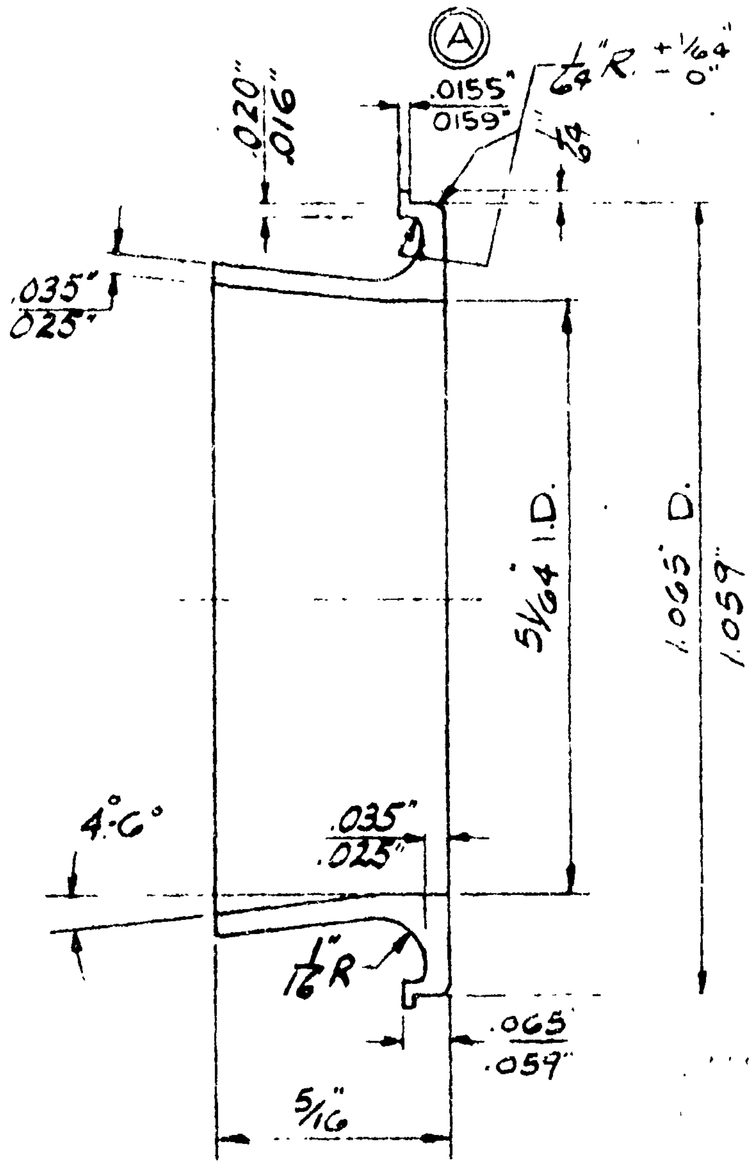
SQUARE ENDS

MATERIAL:
TUBING, 4 1/2" O.D. × #18 BW GA. (0.049" WALL), CRES 321, STAINLESS STEEL

SYMBOL	TITLE	WORK ORDER		FIRST USED ON B-61265	
	TUBE, 4 1/2" O.D., PIPE JACKET	BY C.P.B. DATE 5-17-65	SCALE 6" = 1'-0"		LATEST ALT. LETT.
		CHK'D J.R.K.	GROUP	SHEET	SHEETS	A
	UNION CARBIDE — LINDE DIVISION, ENGINEERING DEPARTMENT, TONAWANDA, NEW YORK	APP'D M.R.H.	A-612651		

LETT	ALTERATION	BY	CHK'D	DATE	APPV'D	LETT	ALTERATION	BY	CHK'D	DATE	APPV'D
A	.0155"-.0159" WAS 1/64" ADDED +1/64 -0 TO 1/64 R.	JLW	[illegible]	7-7-65	[illegible]						

DIMENSIONAL TOLERANCES, FRACTIONAL ± 1/64"
DECIMAL ± — " ANGULAR ± — °
MACHINED SURFACES SHALL BE √ ± — % } UNLESS OTHERWISE NOTED



MATERIAL:

STAINLESS STEEL

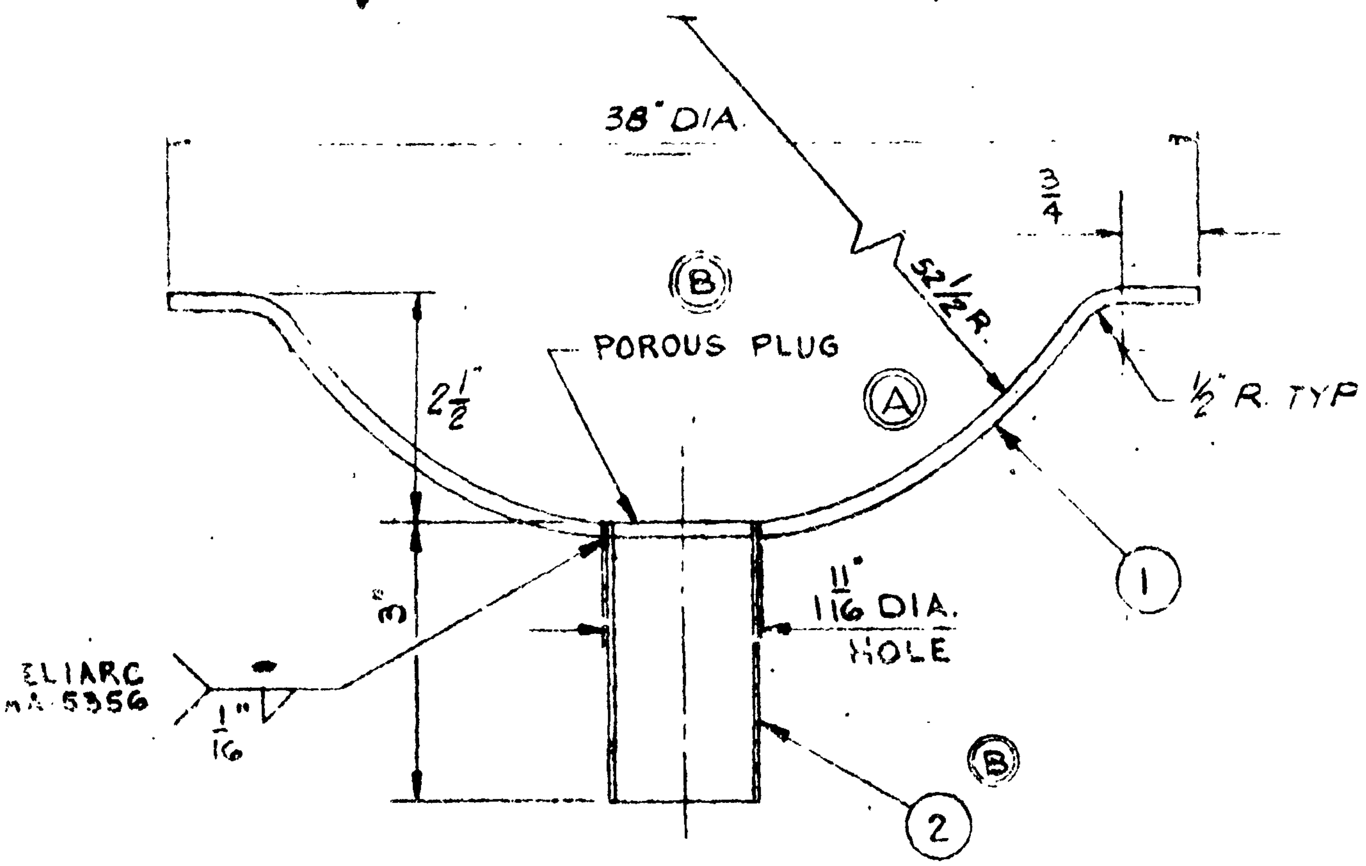
SYMBOL	TITLE	WORK ORDER	USED ON B-612878
	BELLOWS, ADAPTER	BY TVD DATE 6-15-65; CHK'D [illegible]; APPV'D [illegible]	SCALE 48" = 1'-0"; GROUP —; SHEET —; SHEETS —; LATEST ALT. LETT. A

UNION CARBIDE
LINDE DIVISION
ENGINEERING DEPARTMENT
TONAWANDA, NEW YORK

A-612879

ALTERATION	BY	CHK'D	DATE	APPV'D	LETT	ALTERATION	BY	CHK'D	DATE	APPV'D
ADDED ITEM 2 & POROUS PLUG; REMOVED ½" D. HOLE, .55" I.D. & 1" ± ½ R AT BOTTOM. PART WAS FORMED WITH SQUARE BENDS	C.P.B.	R.J.D. W.O.D.	1-26-66							
ADDED 1" ± ½" R.	JLW		7-7-65							

DIMENSIONAL TOLERANCES, FRACTIONAL ± 1/8 "
DECIMAL ± ______ " ANGULAR ± ______ "
MACHINED SURFACES SHALL BE √ ± ______ °
UNLESS OTHERWISE NOTED



MATERIAL:

(1) 9/16" THK., AA-3003-H14 ALUMINUM

(B) (2) TUBING, 1 5/8" O.D. × (0.058" WALL), 6061-T6 ALUMINUM

MODEL	TITLE	WORK ORDER	FIRST USED ON
	MANHOLE INSULATION PANEL EVACUATION FORM		D-612721

BY	DATE	SCALE	LATEST ALT. LETT.
TVD	6-9-65	6" = 1'-0"	B

CHK'D	GROUP	SHEET	SHEETS
J.R.K.	—	—	—

APPV'D

UNION CARBIDE

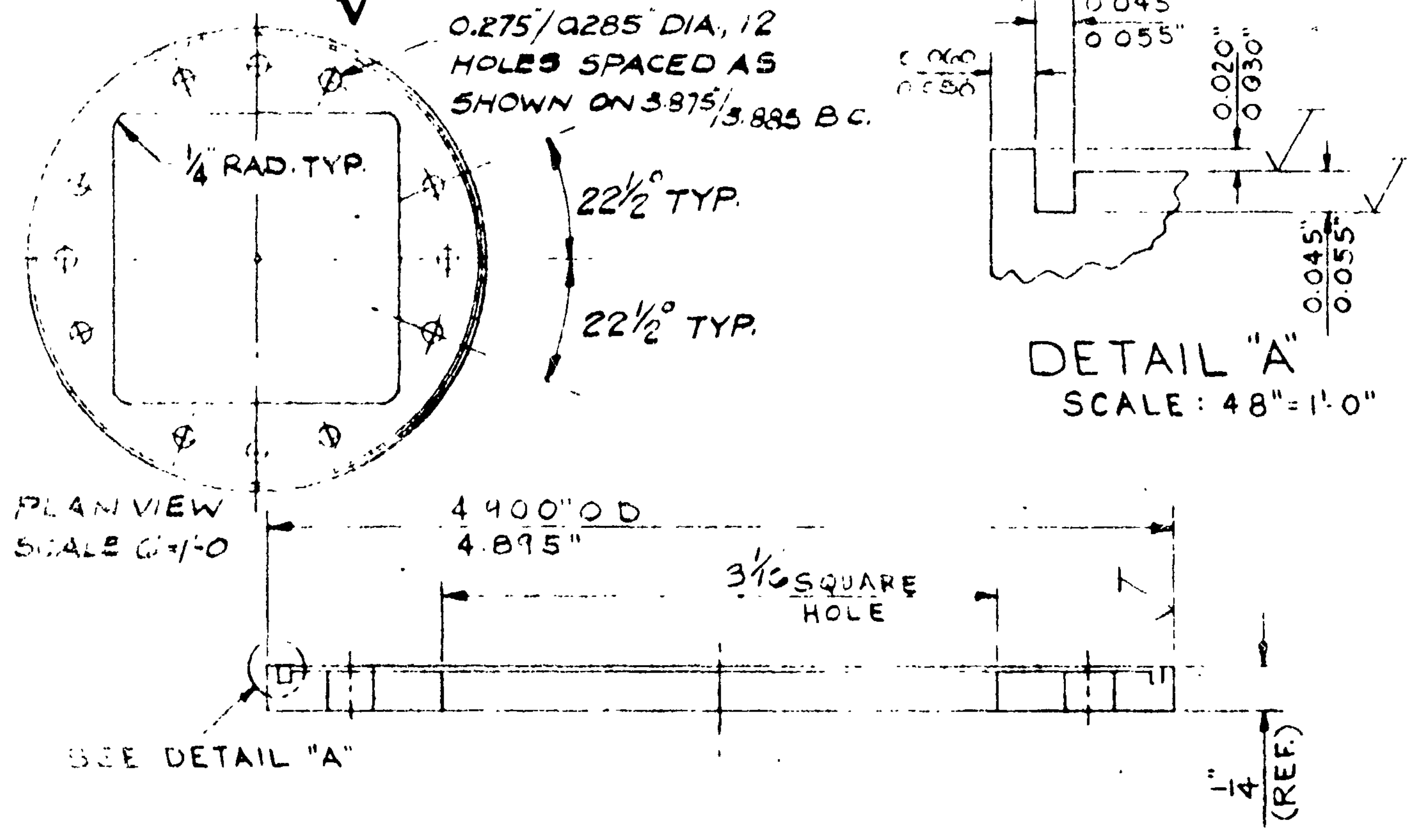
LINDE DIVISION
ENGINEERING DEPARTMENT
TONAWANDA, NEW YORK

A-612830

LETT	ALTERATION	BY	CHK'D	DATE	APPV'D
A	0.275/0.285 DIA. WAS 0.215/0.225	RTP	HJD. WDD	1/25/66	

LETT	ALTERATION	BY	CHK'D	DATE	APPV'D

DIMENSIONAL TOLERANCES, FRACTIONAL ± 1/64"
DECIMAL ± —" ANGULAR ± —°
MACHINED SURFACES SHALL BE 125 √ ± —
UNLESS OTHERWISE NOTED



MATERIAL:
PLATE, 1/4" TH'K., 5456-H321 ALUMINUM.

SYMBOL	TITLE	WORK ORDER	FIRST USED ON
	TUBE SUPPORT, STRUT JACKET		B-612869

BY	DATE	SCALE	LATEST ALT. LETT.
C.P.B.	5-19-65	12" = 1'-0"	A

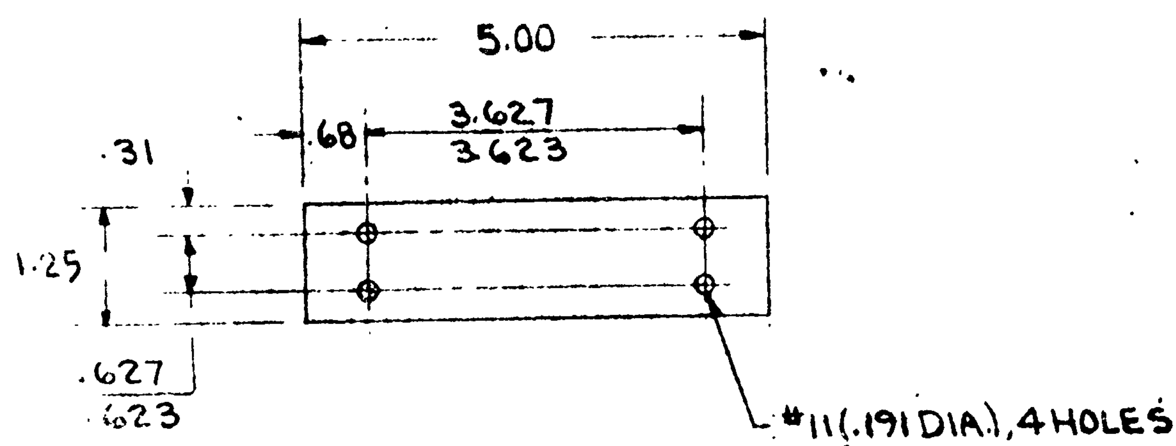
CHK'D	GROUP	SHEET	SHEETS
BP / J.P.K.			

UNION CARBIDE
LINDE DIVISION
ENGINEERING DEPARTMENT
TONAWANDA, NEW YORK

A-612657

LETT.	ALTERATION	BY	CHK'D	DATE	APPV'D	LETT.	ALTERATION	BY	CHK'D	DATE	APPV'D

DIMENSIONAL TOLERANCES, FRACTIONAL ± ____"
DECIMAL ± .03 " ANGULAR ± ____°.
MACHINED SURFACES SHALL BE √ ± ____%.
UNLESS OTHERWISE NOTED



MATERIAL:
SHEET #16 SS GA (.063 THICK) TYPE 304 STAINLESS STEEL, 1 1/4 × 5.

SYMBOL	TITLE	WORK ORDER	FIRST USED ON	
	STRIP			D-612721

BY	DATE	SCALE	LATEST ALT. LETT.
WFL		6" = 1'-0"	

CHK'D: [illegible]
APPV'D: [illegible]

GROUP | SHEET | SHEETS

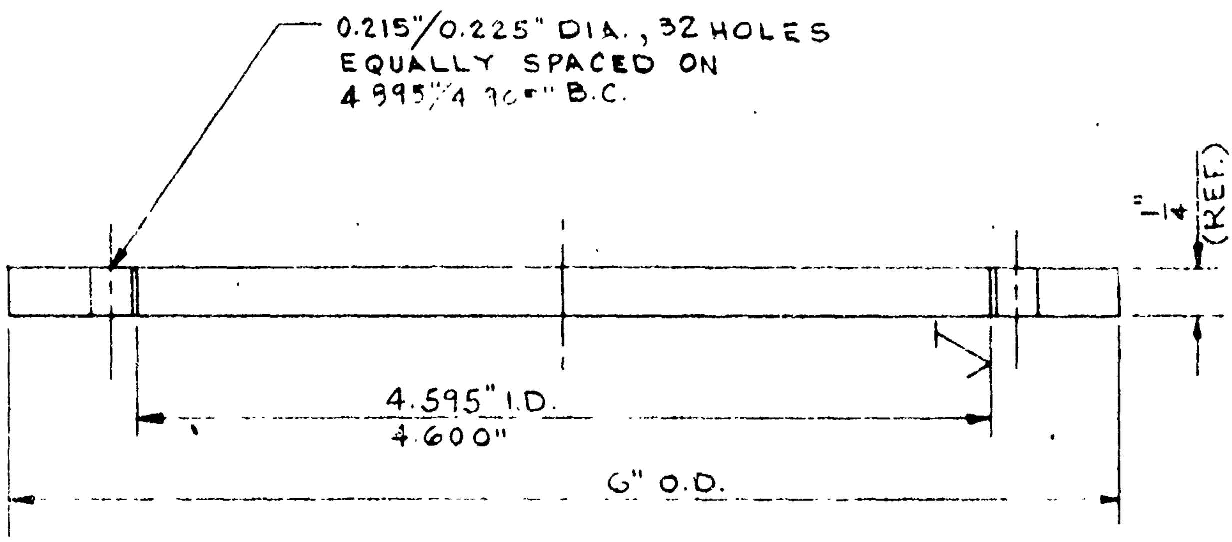
UNION CARBIDE
LINDE DIVISION
ENGINEERING DEPARTMENT
TONAWANDA, NEW YORK

A-612988

LETT	ALTERATION	BY	CHK'D	DATE	APPV'D	LETT	ALTERATION	BY	CHK'D	DATE	APPV'D

DIMENSIONAL TOLERANCES, FRACTIONAL ± 1/64"
DECIMAL ± - " ANGULAR ± - °
MACHINED SURFACES SHALL BE 125√ ± - %

UNLESS OTHERWISE NOTED



MATERIAL:
PLATE, 1/4" THK., CRES 321, STAINLESS STEEL

SYMBOL	TITLE	WORK ORDER	FIRST USED ON
	FLANGE, PIPE JACKET, UPPER		D-612721

BY	DATE	SCALE	LATEST ALT. LETT
C.P.B.	5-17-65	12" = 1'-0"	

UNION CARBIDE

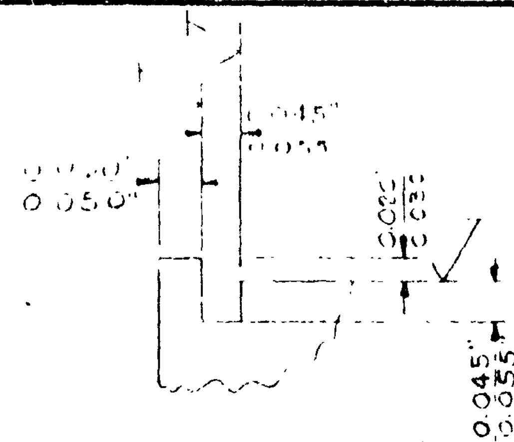
LINDE DIVISION
ENGINEERING DEPARTMENT
TONAWANDA, NEW YORK

CHK'D | APPV'D | GROUP | SHEET | SHEETS

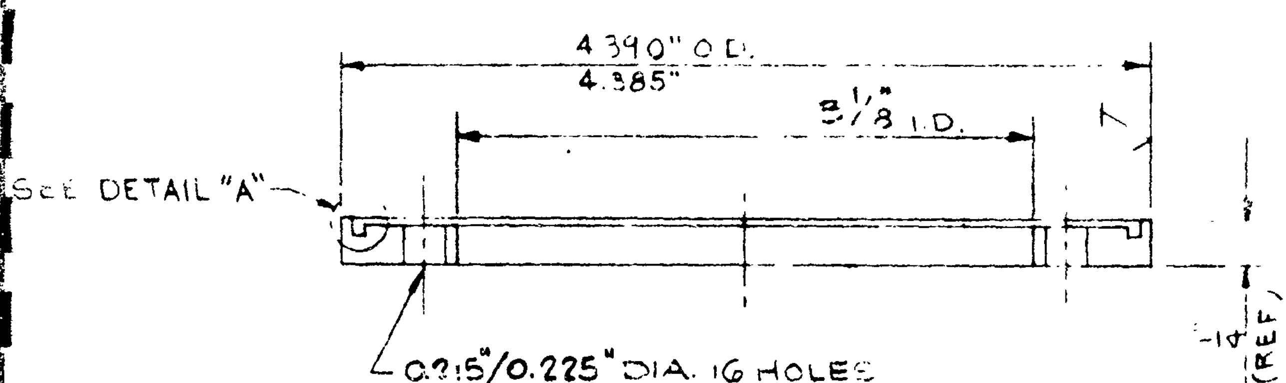
A-612653

LETT	ALTERATION	BY	CHK'D	DATE	APPV'D	LETT	ALTERATION	BY	CHK'D	DATE	APPV'D

DIMENSIONAL TOLERANCES, FRACTIONAL ± 1/64 "
DECIMAL ± — " ANGULAR ± — °
MACHINED SURFACES SHALL BE 125 ± — °
UNLESS OTHERWISE NOTED



DETAIL "A"
SCALE: 48"=1'-0"



MATERIAL:
PLATE, 1/4" THK., CRES 321, STAINLESS STEEL

SYMBOL	TITLE	WORK ORDER	FIRST USED ON
	TUBE SUPPORT, PIPE JACKET		B-612651

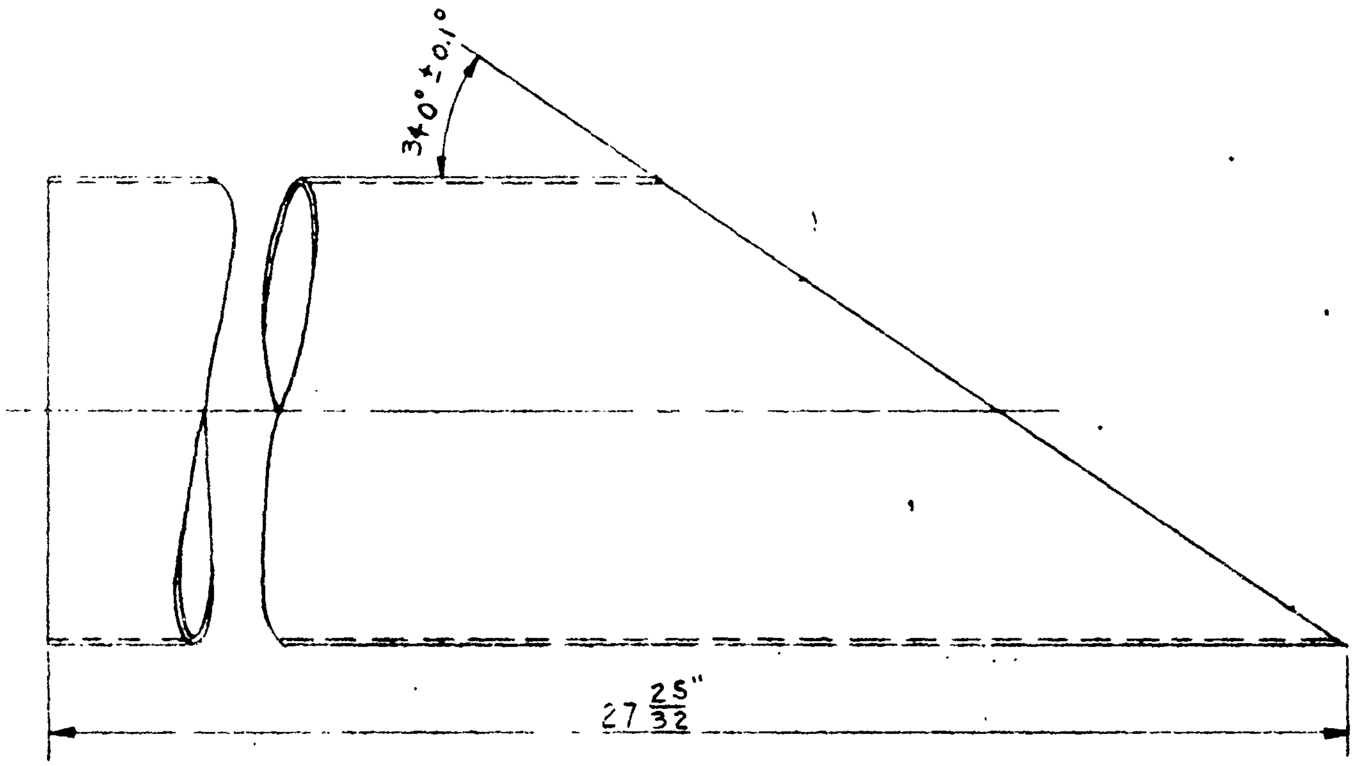
BY C.P.B. DATE 5-18-65 | SCALE 12" = 1'-0" | LATEST ALT. LETT
CHK'D | GROUP | SHEET | SHEETS
APPV'D

UNION CARBIDE
LINDE DIVISION
ENGINEERING DEPARTMENT
TONAWANDA, NEW YORK

A-612656

LETT	ALTERATION	BY	CHK'D	DATE	APPV'D	LETT	ALTERATION	BY	CHK'D	DATE	APPV'D

DIMENSIONAL TOLERANCES, FRACTIONAL ± 1/64 "
DECIMAL ± - " ANGULAR ± - "
MACHINED SURFACES SHALL BE √ ± - "
UNLESS OTHERWISE NOTED



MATERIAL:
TUBING, 5" O.D. × #18 B.W. GA (0.049" WALL)
ALUMINUM 5456-H321

SYMBOL	TITLE	WORK ORDER	FIRST USED ON
	TUBE, 5" O.D., STRUT JACKET		B-612869

BY	DATE	SCALE	LATEST ALT. LETT.
C.P.B.	5-19-65	6" = 1'-0"	

CHK'D	GROUP	SHEET	SHEETS
J.R.K.			

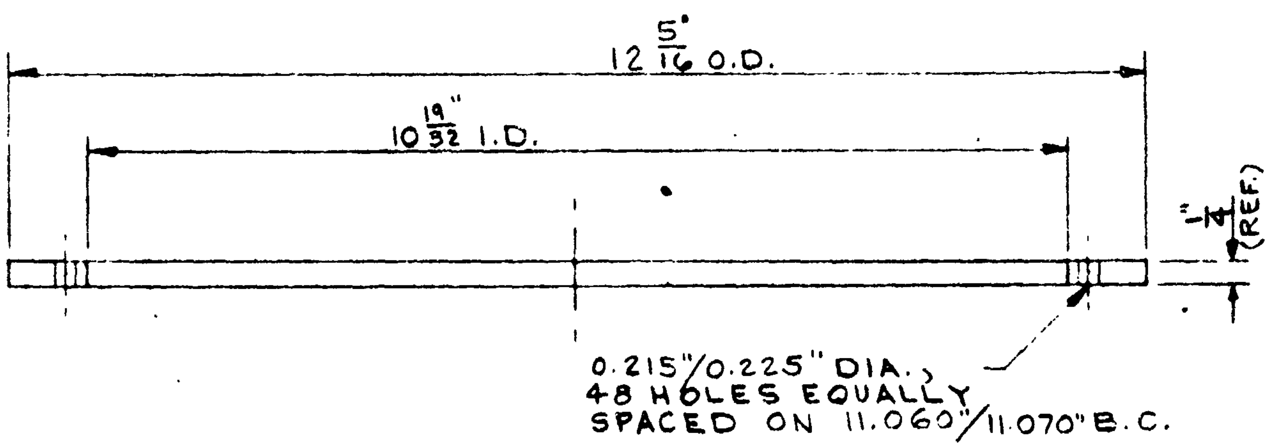
APPV'D: [illegible]

UNION CARBIDE
LINDE DIVISION
ENGINEERING DEPARTMENT
TONAWANDA, NEW YORK

A-612658

LETT	ALTERATION	BY	CHK'D	DATE	APPV'D	LETT	ALTERATION	BY	CHK'D	DATE	APPV'D

DIMENSIONAL TOLERANCES, FRACTIONAL ± 1/64 "
DECIMAL ± - " ANGULAR ± - °.
MACHINED SURFACES SHALL BE √ ± - °.
UNLESS OTHERWISE NOTED



MATERIAL:
PLATE, 1/4" TH'K., 5456-H321 ALUMINUM

SYMBOL	TITLE	WORK ORDER	FIRST USED ON
	FLANGE, STRUT JACKET. UPPER		D-612721

BY	DATE	SCALE	LATEST ALT. LETT.
C.P.B.	5-19-65	6" = 1'-0"	

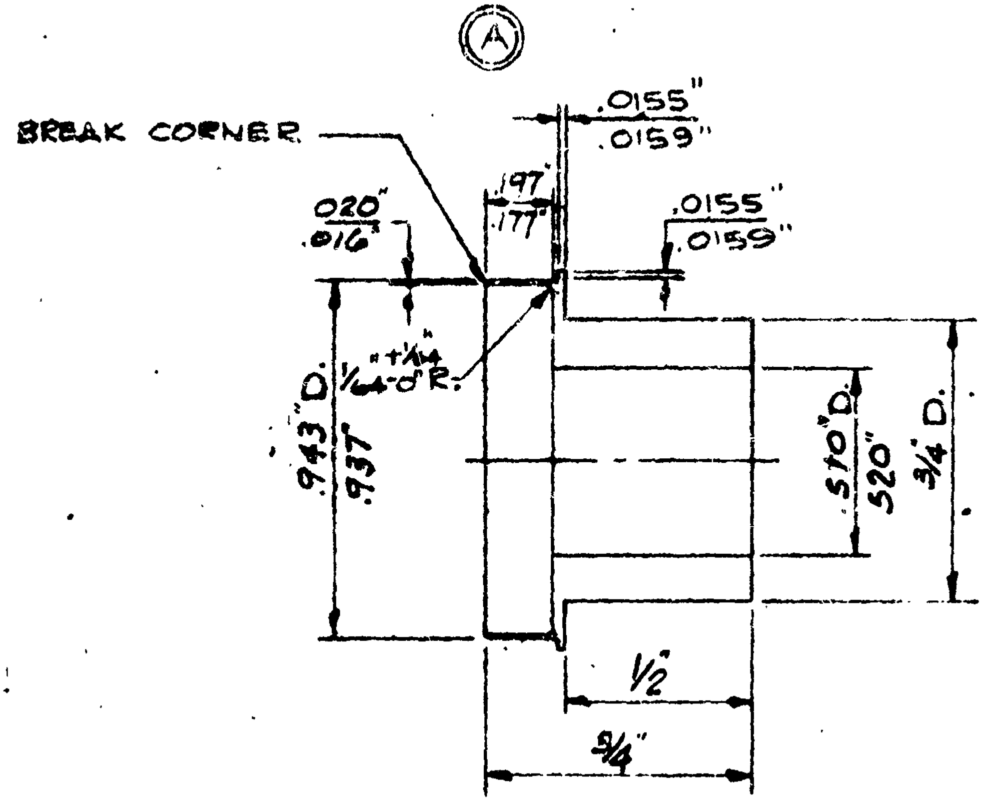
CHK'D: [signature] APP'D: [signature] GROUP SHEET SHEETS

UNION CARBIDE
LINDE DIVISION
ENGINEERING DEPARTMENT
TONAWANDA, NEW YORK

A-612659

LETT.	ALTERATION	BY	CHK'D	DATE	APPV'D	LETT.	ALTERATION	BY	CHK'D	DATE	APPV'D
	ADDED NOTE - BREAK CORNER, .0155/.0159 WAS 1/64 & ADDED +1/64 -0 TO 1/64 R.	JLW	JRK	7-7-65	MCA						

DIMENSIONAL TOLERANCES, FRACTIONAL ± 1/64 " DECIMAL ± — " ANGULAR ± — °. MACHINED SURFACES SHALL BE √ ± — %. UNLESS OTHERWISE NOTED



MATERIAL:

STAINLESS STEEL

SYMBOL	TITLE	WORK ORDER	FIRST USED ON
	BELLOWS, CONNECTOR		B-612878

BY	DATE	SCALE	LATEST ALT. LETT.
TVD	6-14-65	24"=1'-0"	A

CHK'D	GROUP	SHEET	SHEETS
JRK	—	—	—

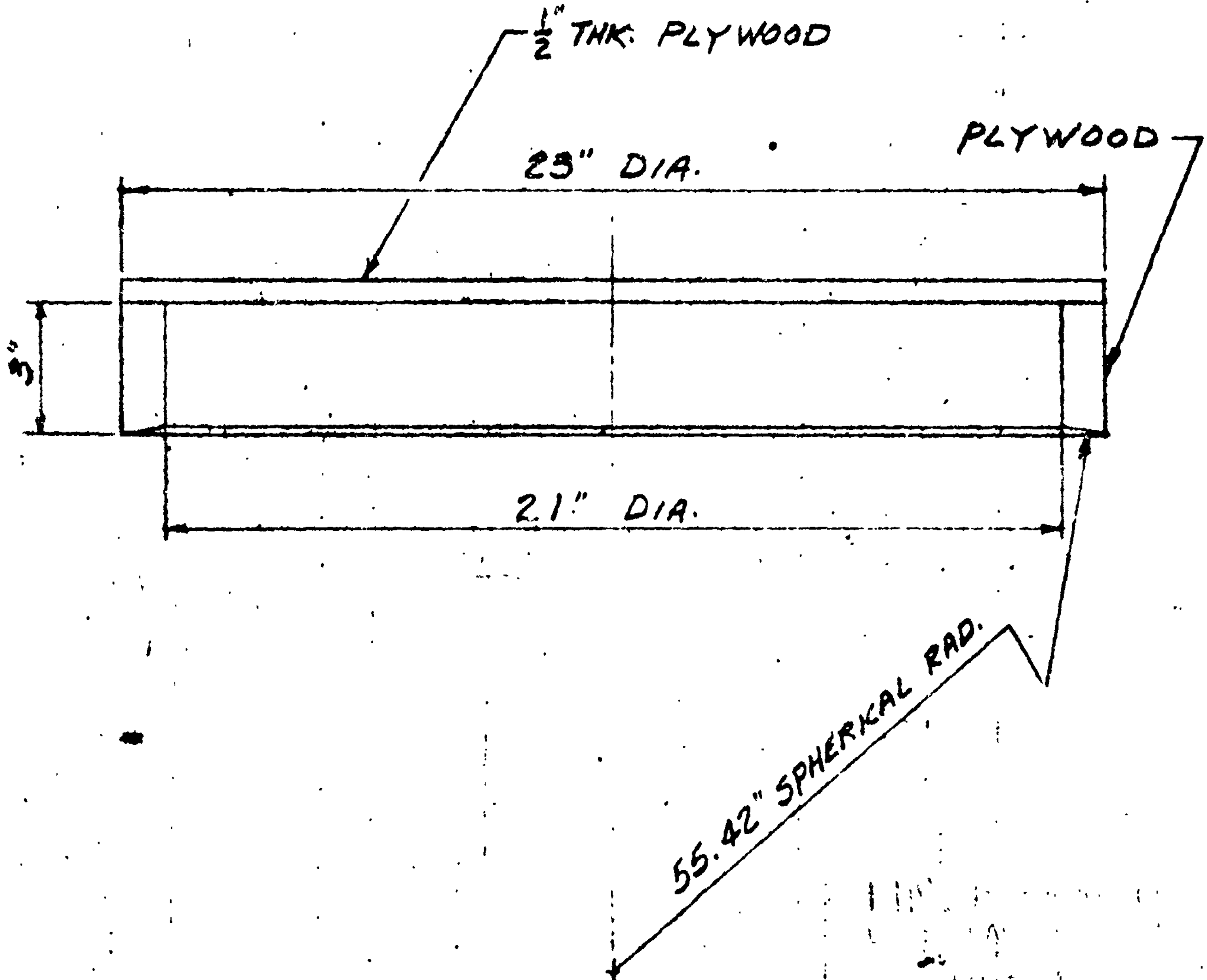
APPV'D: MCA

UNION CARBIDE — LINDE DIVISION, ENGINEERING DEPARTMENT, TONAWANDA, NEW YORK

A-612880

SYMBOL	ALTERATION	BY	CHK'D	DATE	APPV'D	LETT	ALTERATION	BY	CHK'D	DATE	APPV'D

DIMENSIONAL TOLERANCES, FRACTIONAL ± ______"
DECIMAL ± ______" ANGULAR ± ______°.
MACHINED SURFACES SHALL BE √ ± ______%.
} UNLESS OTHERWISE NOTED



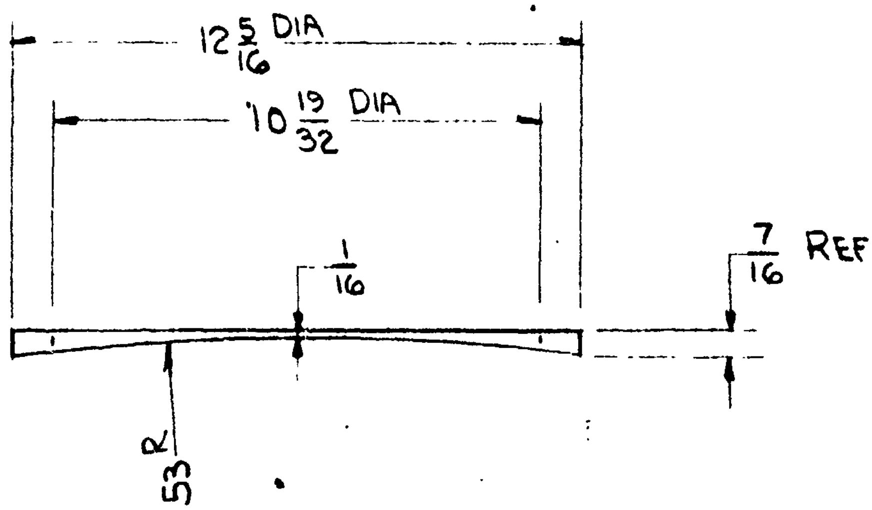
TITLE	WORK ORDER	FIRST USED ON D-612721
COLD JOINT CURING FIXTURE	BY C.S.R. DATE 6-18-65	SCALE 3" = 1'-0"
	CHK'D	
	APPV'D	

UNION CARBIDE — LINDE DIVISION ENGINEERING DEPARTMENT TONAWANDA, NEW YORK

A-612947

LETT.	ALTERATION	BY	CHK'D	DATE	APPV'D	LETT.	ALTERATION	BY	CHK'D	DATE	APPV'D

DIMENSIONAL TOLERANCES, FRACTIONAL ± 1/32 "
DECIMAL ± ____ " ANGULAR ± ____ °.
MACHINED SURFACES SHALL BE 250√ ± ____ %.
UNLESS OTHERWISE NOTED



MATERIAL:
PLATE: 5/8 THICK ALUMINUM, AA 5456-H321, 12 5/16 × 12 5/16

SYMBOL	TITLE	WORK ORDER	FIRST USED ON
	ADAPTER - STRUT		D-612721

BY	DATE	SCALE	LATEST ALT. LETT.
WFL		3" = 1'-0"	

CHK'D	GROUP	SHEET	SHEETS
[illegible]			

APPV'D: [illegible]

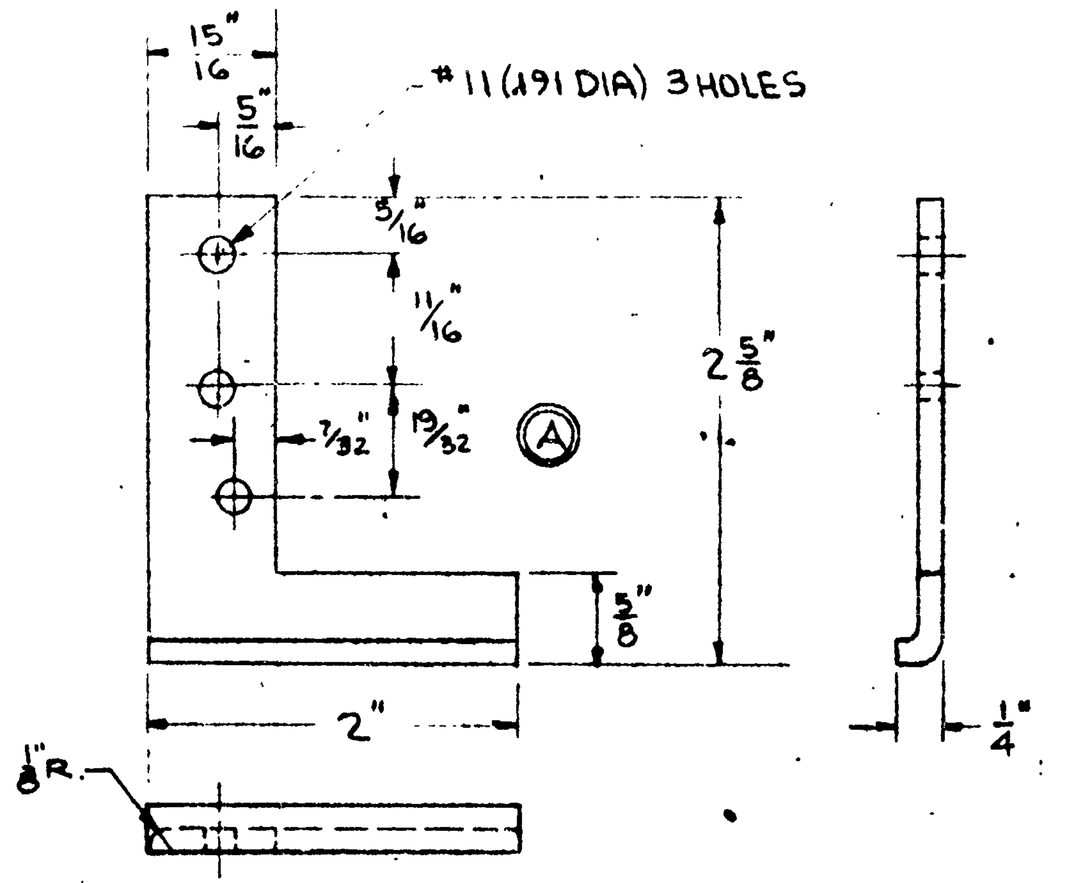
A-612996

UNION CARBIDE
LINDE DIVISION
ENGINEERING DEPARTMENT
TONAWANDA, NEW YORK

LETT.	ALTERATION	BY	CHK'D	DATE	APP'V'D
A	ADDED ONE #11 (.191") HOLE. 5/8" DIA. WAS 1/2", 2 5/8 DIM. WAS 2 1/2 & TOLERANCE WAS 1/16"	JLW	J.R.K.	7-7-65	REL

LETT.	ALTERATION	BY	CHK'D	DATE	APP'V'D

DIMENSIONAL TOLERANCES, FRACTIONAL ± 1/32"
DECIMAL ± ____" ANGULAR ± ____°
MACHINED SURFACES SHALL BE √ ± ____%
UNLESS OTHERWISE NOTED



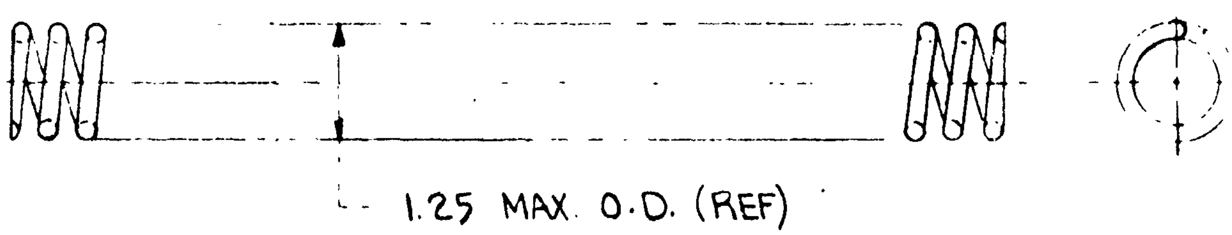
MATERIAL:

(A) SHEET #11 SS GA (.125" THICK) TYPE 304 STAINLESS STEEL, 2" x 2 5/8"

TITLE					
BAND GUIDE	USED ON	D-612721			
	BY: NFL	DATE	SCALE: 12" = 1'-0"		LATEST ALT. LETT.: A
	CHK'D: J.R.K.		GROUP	SHEET	SHEETS
UNION CARBIDE — LINDE DIVISION, ENGINEERING DEPARTMENT, TONAWANDA, NEW YORK	APP'V'D: [illegible]		A-612993		

LETT.	ALTERATION	BY	CHK'D	DATE	APPV'D	LETT.	ALTERATION	BY	CHK'D	DATE	APPV'D

DIMENSIONAL TOLERANCES, FRACTIONAL ± ______"
DECIMAL ± ______" ANGULAR ± ______°
MACHINED SURFACES SHALL BE √ ± ______"
UNLESS OTHERWISE NOTED



MATERIAL:

1.25 MAX. O.D., 0.192 DIA WIRE, 50 ACTIVE COILS
FORCE OF SOLID HEIGHT 168 #, COMPRESSED
LENGTH .10". TENSILE STRENGTH 120,000 PSI
K = 40 LB/IN. ENDS GROUND SQUARE
OIL TEMPERED SPRING STEEL.

SYMBOL	TITLE	WORK ORDER	FIRST USED ON
	SPRING, COMPRESSION		D-612721

BY	DATE	SCALE	LATEST ALT. LETT.
WFL		6" = 1'-0"	

CHK'D	GROUP	SHEET	SHEETS
[illegible]			

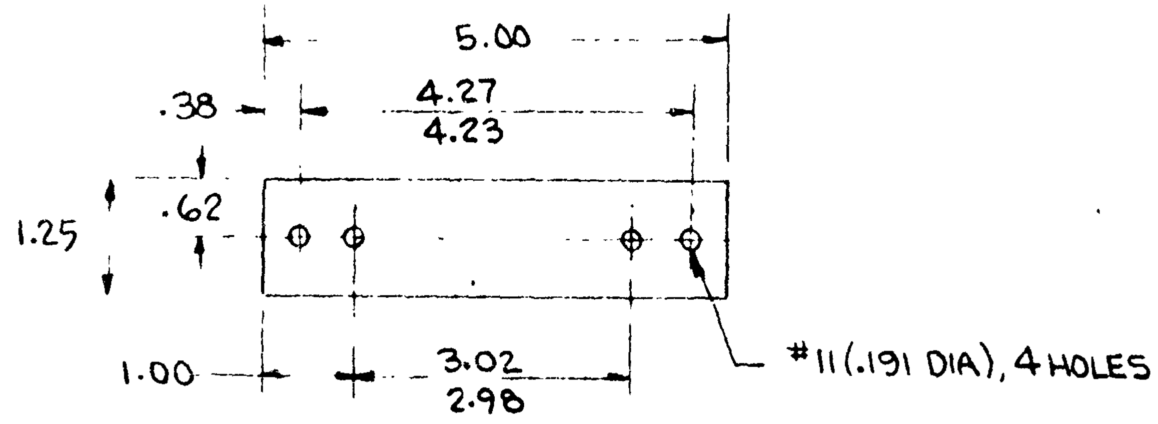
APPV'D [illegible]

UNION CARBIDE
LINDE DIVISION
ENGINEERING DEPARTMENT
TONAWANDA, NEW YORK

A-612992

LETT.	ALTERATION	BY	CHK'D	DATE	APPV'D	LETT.	ALTERATION	BY	CHK'D	DATE	APPV'D

DIMENSIONAL TOLERANCES, FRACTIONAL ± ___"
DECIMAL ± .03 " ANGULAR ± ___°.
MACHINED SURFACES SHALL BE √ ± ___°.
UNLESS OTHERWISE NOTED



MATERIAL:
SHEET, #16 SS GA (.063 THK) TYPE 304, STAINLESS STEEL, 1¼ × 5.

SYMBOL	TITLE	WORK ORD #	FIRST USED ON
	STRIP		D-612721

BY	DATE	SCALE	LATEST ALT. LETT.
WFL		6" = 1'-0"	

CHK'D	GROUP	SHEET	SHEETS
[illegible signature]	—	—	—

APPV'D: [signature]

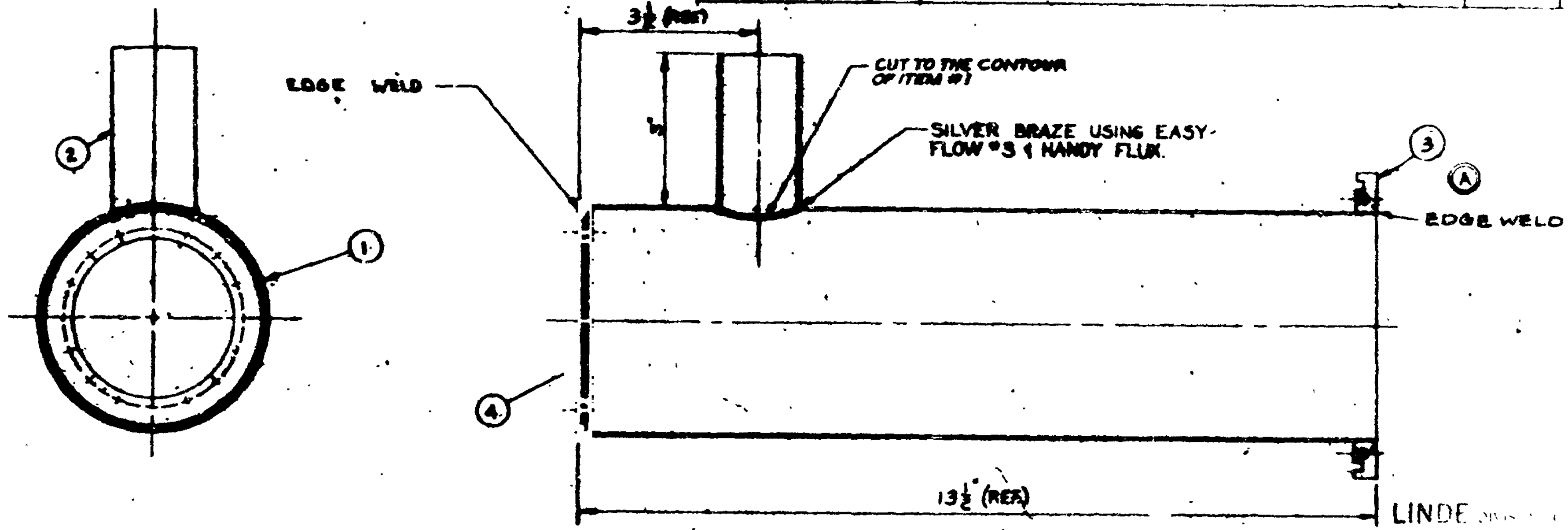
UNION CARBIDE
LINDE DIVISION
ENGINEERING DEPARTMENT
TONAWANDA, NEW YORK

A-612987

B-612651

D-612781

ITEM NO.	PART OR DWG NO.	REQ. PER ONE	MATERIAL AND DESCRIPTION	PURCHASE ORDER	REV. LTR
1	A-612654	1	TUBE, 4 1/2" O.D., PIPE JACKET		A
2		1	TUBING, 1 5/8" O.D. × 0.060" WALL, HARD CLASS "L" COPPER, 3 1/4 LG		A B
3	B-612650	1	FLANGE, PIPE JACKET, LOWER		
4	A-612656	1	TUBE SUPPORT, PIPE JACKET		



NOTE:
ALL WELDING TO BE HELIARC,
USING ER

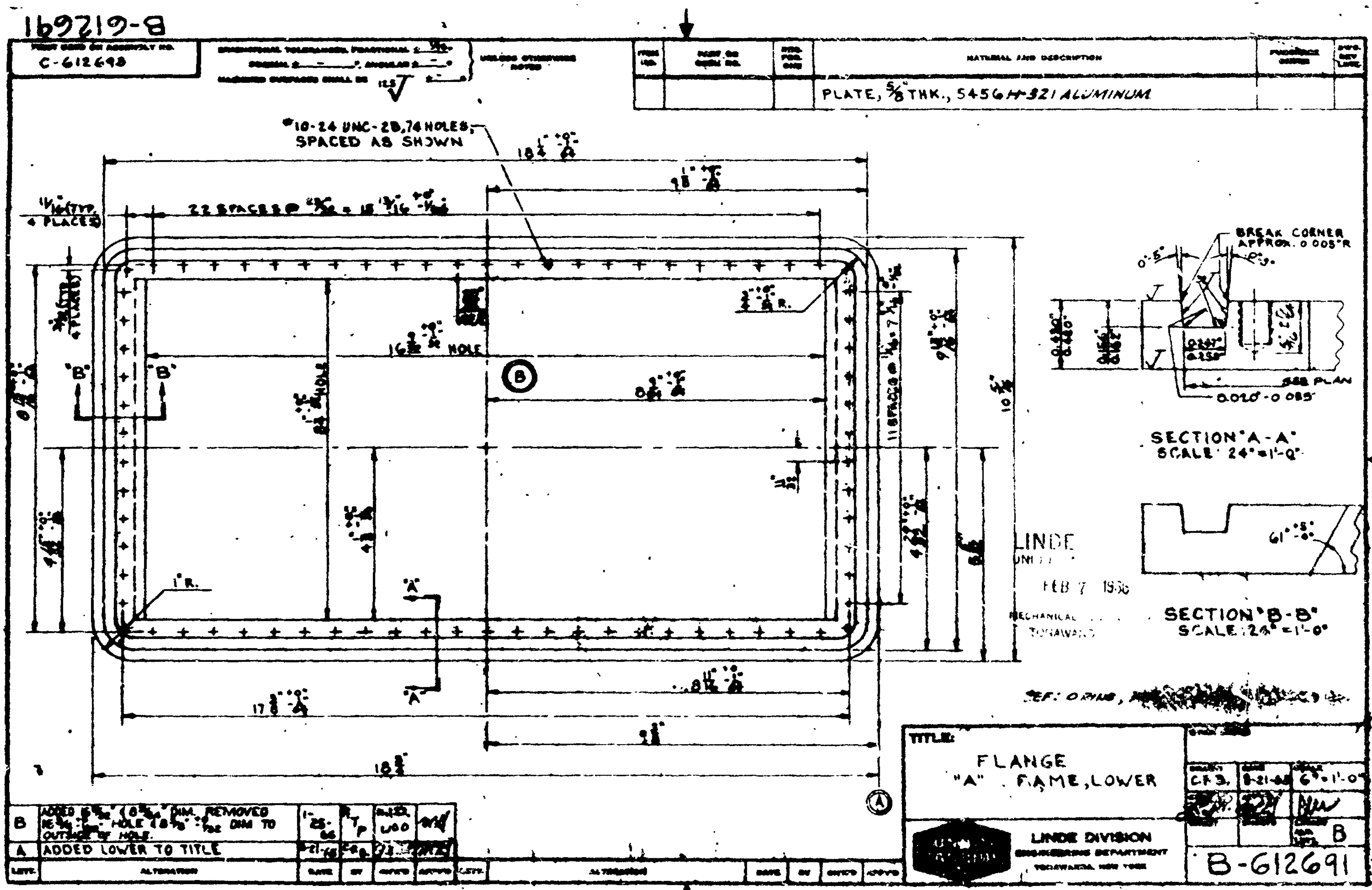
REV.	ALTERATION	DATE	BY	CHK'D	APP'D
B	ITEM 2 WAS A-612653				
A	CORRECTED: TITLES ITEMS 1 & 2, & PICTURE OF ITEM 3				

TITLE: TUBE ASSEMBLY, PIPE JACKET

LINDE DIVISION
ENGINEERING DEPARTMENT
TONAWANDA, NEW YORK

DRAWN: C.P.B. DATE: 3-11-66 SCALE: 6"=1'-0"
REV. LTR. B

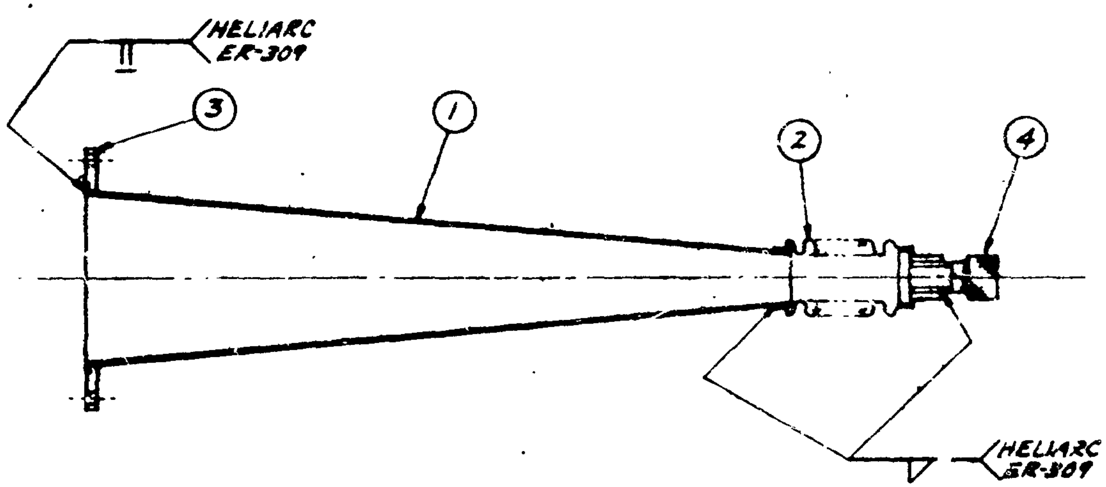
B-612651


B-612691
C-612693
PLATE, 5/8" THK., 5456-H321 ALUMINUM
#10-24 UNC-2B, 74 HOLES, SPACED AS SHOWN
22 SPACES
HOLE
SECTION "A-A"
SCALE: 24" = 1'-0"
SECTION "B-B"
SCALE: 24" = 1'-0"
BREAK CORNER APPROX. 0.005" R
SEE PLAN
0.020-0.085
LINDE
FEB 7 1966
TONAWANDA
TITLE:
FLANGE
"A" FRAME, LOWER
LINDE DIVISION
ENGINEERING DEPARTMENT
TONAWANDA, NEW YORK
B-612691
ADDED LOWER TO TITLE
ALTERATION

B-612944

D-612721

ITEM NO.	PART OR DWG NO.	REQ. PER ASSY	MATERIAL AND DESCRIPTION	PURCHASE ORDER	DWG. CHG. LETT.
1	A-612669	1	CONE SUPPORT ROD JACKET		-
2	B-612878	1	BELLOWS ASSEMBLY		
3	A-612668	1	FLANGE, SUPPORT ROD JACKET, UPPER		
4		1	GOODARD O-RING COUPLING #S-38P OR EQUIVALENT		



LINDE
FEB

TITLE:
SUPPORT ROD
JACKET ASSEMBLY

LINDE DIVISION

HES
6"=1'-0"

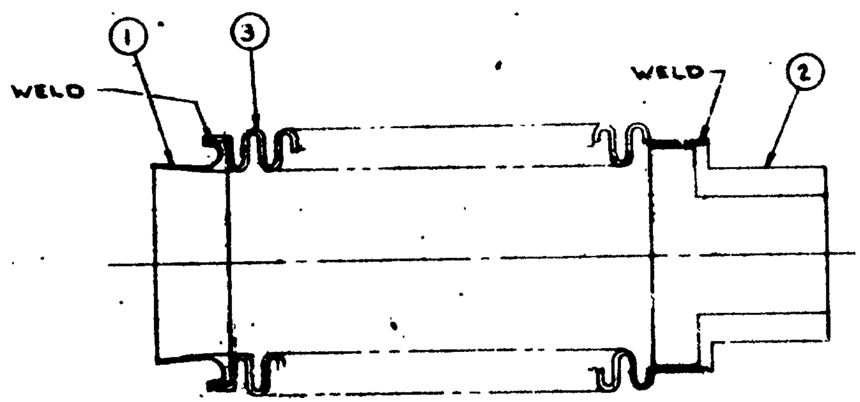
E-612944

B-612878

FIRST USED ON ASSEMBLY NO. D-612721

DIMENSIONAL TOLERANCES, FRACTIONAL ± , DECIMAL ± , ANGULAR ± , MACHINED SURFACES SHALL BE √ UNLESS OTHERWISE NOTED

ITEM NO.	PART OR CODE NO.	REQ. PER ONE	MATERIAL AND DESCRIPTION	PURCHASE ORDER	DWG REV LETT
1	A-612879	1	BELLOWS ADAPTER		A
2	A-612880	1	BELLOWS CONNECTOR		A
3		1	BELLOWS, 3/4" x 1 7/8 NOMINAL (51/64" ID x 1 5/32 OD) 0.005 THK WALL, 13 ACTIVE CONVOLUTIONS ONE PLY STAINLESS STEEL NO C 10003 EXTENDED ... NECK ENDS, MOTION OF BELLOWS TO BE ± 3/16" LATERAL AND ± 1/16" AXIAL, TO BE USED IN VACUUM SERVICE AT AMBIENT TEMPERATURE, LEAK TEST TO 10^{-7} cc/sec OF HELIUM, FLEXONIC, BARTLETT, ILLINOIS		B



LINDE DIVISION OF UNION CARBIDE CORP.

LETT.	ALTERATION	DATE	BY	CHK'D	APPV'D
B	ADDED TO ITEM 3: MOTION DIMS. & LEAK TEST. 13 CONVOLUTIONS WERE 15 CONVOLUTIONS	6-28-[illegible]			
A	ITEM 1 WAS ADAPTER, ITEM 2 WAS CONNECTOR				

TITLE: BELLOWS ASSEMBLY

UNION CARBIDE — LINDE DIVISION, ENGINEERING DEPARTMENT, TONAWANDA, NEW YORK

DRAWN: C.P.B. DATE: 6-15-64 SCALE: 24"=1'0"

LATEST ALT. LETT.: A

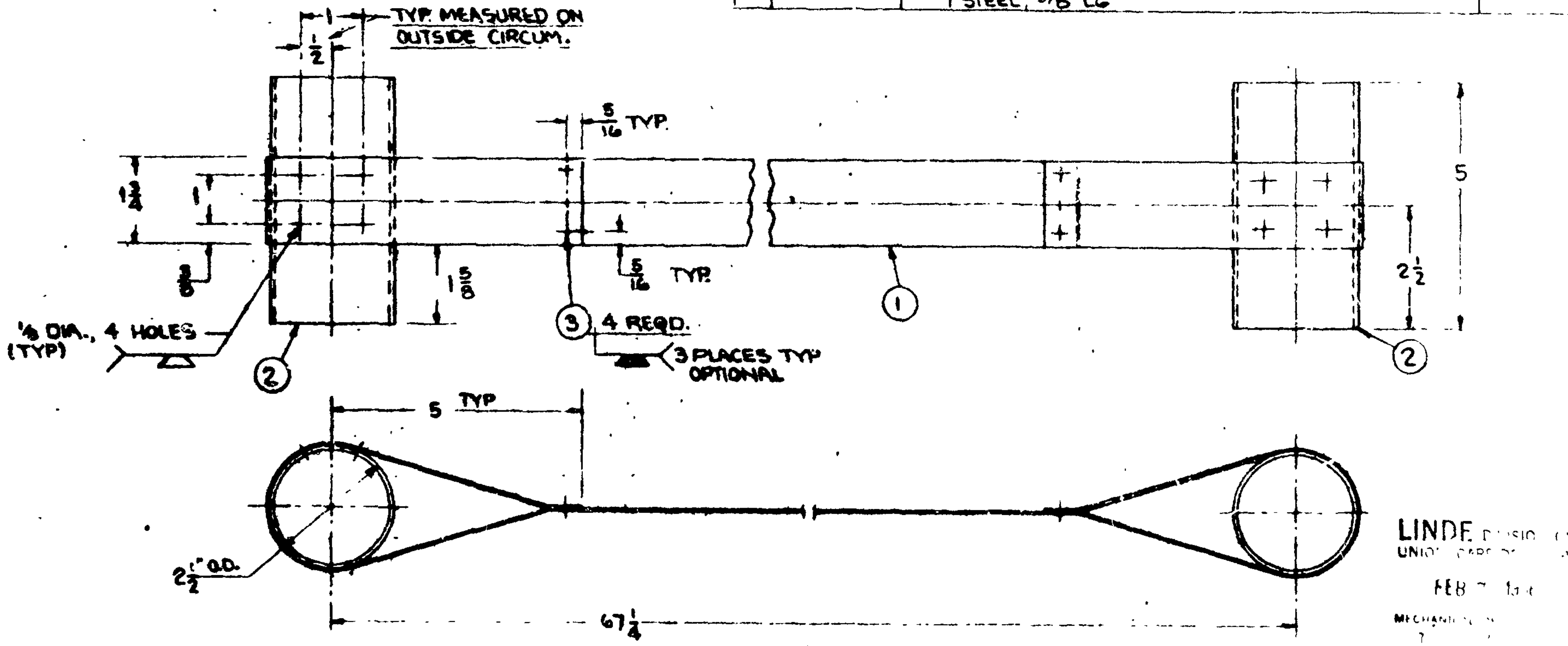
B-612878

066219-G

FIRST USED ON ASSEMBLY NO. D-612721

DIMENSIONAL TOLERANCES, FRACTIONAL ± 1/16", DECIMAL ± ___, ANGULAR ± ___° } UNLESS OTHERWISE NOTED
MACHINED SURFACES SHALL BE √

ITEM NO.	PART OR CODE NO.	NO. FOR ONE	MATERIAL AND DESCRIPTION	PURCHASE ORDER	DWG REV LETT
1		1	SHEET #16 SS GA(.062) TYPE 304 STAINLESS STEEL, 1 3/4 × 90		
2		2	TUBING SEAMLESS, 2 1/2" O.D. × #14 BW GA (.083 WALL) TP-304 STAINLESS STEEL, 5 LG		
3		4	RIVET ROUND HEAD, 1/8" DIA, 18-8 STAINLESS STEEL, 3/8" LG		



LINDE DIVISION
UNION CARBIDE
FEB 7 19..
MECHANICAL

LETT.	ALTERATION	DATE	BY	CHK'D	APPV'D	LETT.	ALTERATION	DATE	BY	CHK'D	APPV'D

TITLE: STRAP ASSEMBLY

UNION CARBIDE — LINDE DIVISION, ENGINEERING DEPARTMENT, TONAWANDA, NEW YORK

WORK ORDER		
DRAWN: WFL	DATE	SCALE: 6" = 1'-0"
CHK'D	APPV'D	
SHEET	SHEETS	CATEGORY / ALT. LETT.

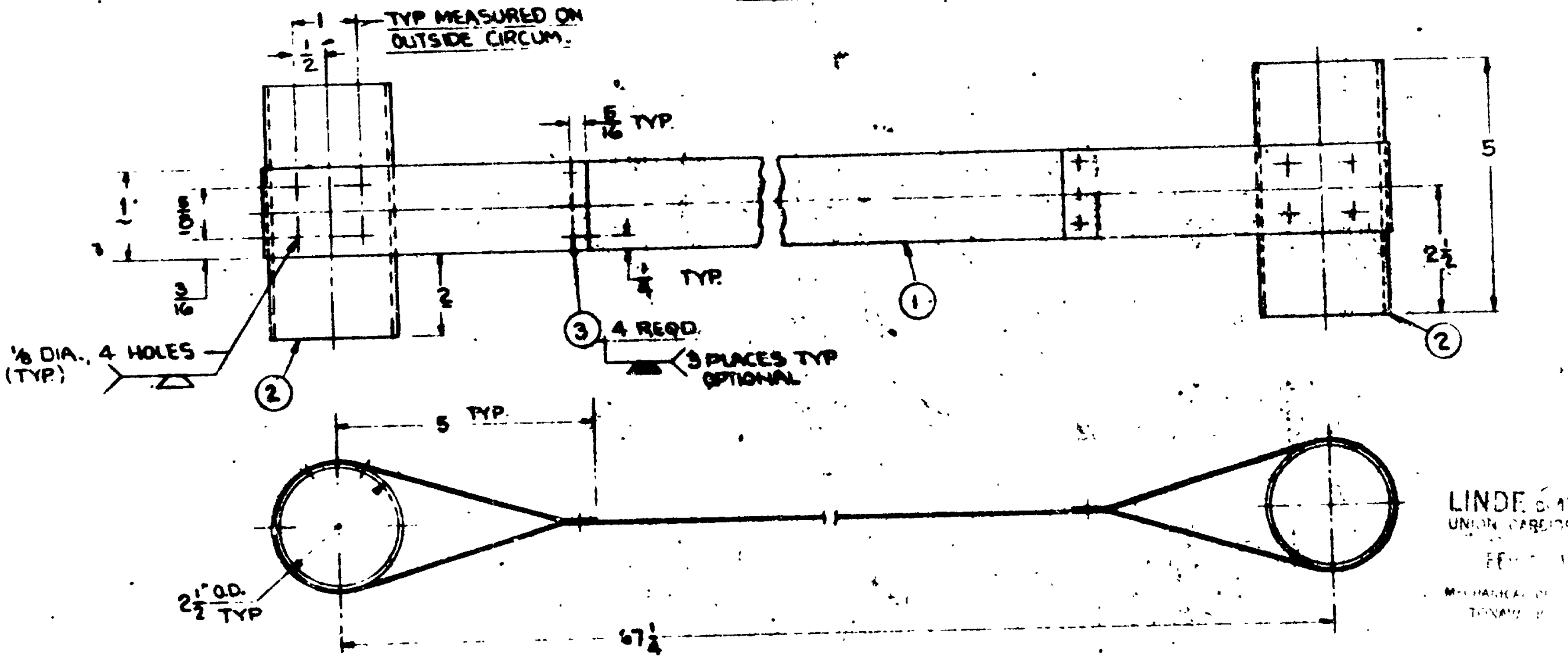
B-612990

166219-8

D-612721

DIMENSIONAL TOLERANCES: FRACTIONAL ± 1/16 — UNLESS OTHERWISE NOTED

ITEM NO.	PART OR CODE NO.	REQ. PER. UNIT	MATERIAL AND DESCRIPTION	PURCHASE ORDER	DWG. REV. LETT.
1		1	SHEET #16 SS GA(.063) TYPE 304 STAINLESS STEEL 1 x 90		
2		2	TUBING SEAMLESS, 2½" O.D. × #14 BW GA (.083 WALL) TP 304 STAINLESS STEEL, 5 LG		
3		4	RIVET ROUND HEAD 1/8" DIA, 18-8 STAINLESS STEEL 3/8" LG.		



TITLE: STRAP ASSEMBLY

SCALE 6" = 1'-0"

DRAWN WFL

LINDE DIVISION
ENGINEERING DEPARTMENT
TONAWANDA NEW YORK

UNION CARBIDE

B 612991

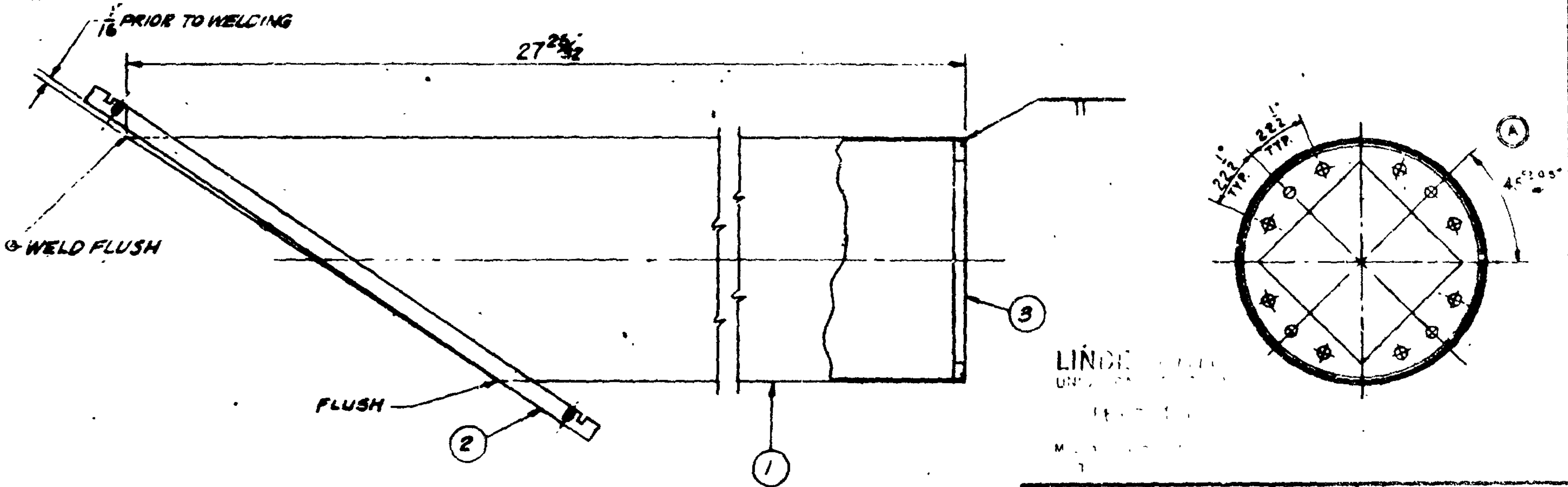
LETT	ALTERATION	DATE	BY	CHK'D	APPV'D	LETT	ALTERATION	DATE	BY	CHK'D	APPV'D

B -612869

FIRST USED ON ASSEMBLY NO. D-612721

DIMENSIONAL TOLERANCES: FRACTIONAL ± 1/64", DECIMAL ± ____, ANGULAR ± ____°; MACHINED SURFACES SHALL BE √; UNLESS OTHERWISE NOTED

ITEM NO.	PART OR CODE NO.	REQ. PER. ONE	MATERIAL AND DESCRIPTION	PURCHASE ORDER	DWG. REV LETT
1	A-612658	1	TUBE, 5" O.D., STRUT JACKET		
2	B-612652	1	FLANGE, STRUT JACKET, LOWER		
3	A-612657	1	TUBE SUPPORT, STRUT JACKET		



LETT.	ALTERATION	DATE	BY	CHK'D	APPV'D
A	ROTATED ITEM 3, 45°				

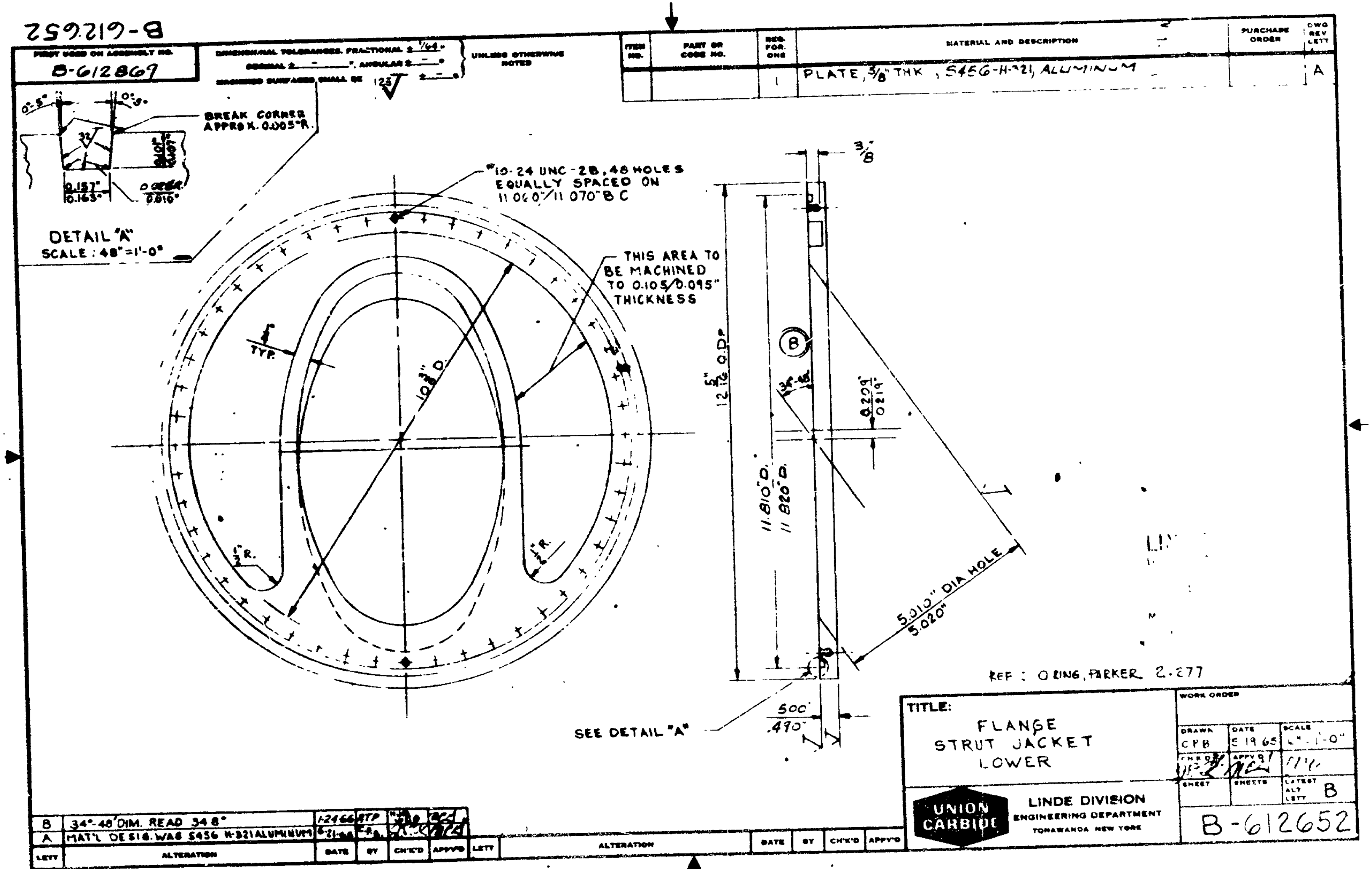
TITLE: STRUT JACKET ASSEMBLY

UNION CARBIDE — LINDE DIVISION, ENGINEERING DEPARTMENT, TONAWANDA, NEW YORK

DRAWN: TVD; DATE: 6-14-68; SCALE: 6"=1'-0"

SHEET: —; SHEETS: —; LATEST ALT. LETT.: A

B -612869


B-612652
FIRST USED ON ASSEMBLY NO. B-612869
DIMENSIONAL TOLERANCES, FRACTIONAL ± 1/64"
MACHINED SURFACES SHALL BE 125
UNLESS OTHERWISE NOTED
ITEM NO.
PART OR CODE NO.
REQ. FOR ONE
MATERIAL AND DESCRIPTION
1
PLATE, 3/8" THK, 5456-H321, ALUMINUM
PURCHASE ORDER
DWG REV LETT
A
BREAK CORNER APPROX. 0.005" R.
0.157" / 0.163"
DETAIL "A"
SCALE: 48" = 1'-0"
#10-24 UNC-2B, 48 HOLES EQUALLY SPACED ON 11.060"/11.070" B C
THIS AREA TO BE MACHINED TO 0.105/0.095" THICKNESS
TYP.
10 3/8" D
1/2" R.
3/8"
12 1/2" O.D.
11.810" D.
11.820" D.
0.209" / 0.219"
34°-48'
5.010" / 5.020" DIA HOLE
.500" / .490"
SEE DETAIL "A"
REF: O RING, PARKER 2-277
B | 34°-48' DIM. READ 34.8° | 1-24-66 | RTP
A | MAT'L DESIG. WAS 5456 H-321 ALUMINUM
LETT | ALTERATION | DATE | BY | CH'K'D | APPV'D
TITLE: FLANGE STRUT JACKET LOWER
UNION CARBIDE
LINDE DIVISION
ENGINEERING DEPARTMENT
TONAWANDA NEW YORK
WORK ORDER
DRAWN CPB
DATE 5-19-65
SCALE
LATEST ALT LETT B
B-612652