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DESIGN AND FABRICATION OF AN INTERNALLY INSULATED FILAMENT WOUND LIQUID HYDROGEN PROPELLANT TANK

by C. B. Shriver

Prepared under Contract No. NAS 3-2291 *by*
GOODYEAR AEROSPACE CORPORATION
Akron, Ohio
for

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Goodyear Aerospace Corporation

SECTION I - SUMMARY

The design and fabrication of a small internally insulated filament wound fiberglass reinforced plastic tank for liquid hydrogen use are presented. The tank consists of three main components: filament wound fiberglass shell, insulation system, and an impermeable liner. The fiberglass shell is cylindrical with dome ends, 18 inches in diameter by 36 inches overall length, and has a design maximum test pressure of 100 pound per square inch. The shell consists of S/HTS 20 end glass roving in a matrix composed of Union Carbide's No. 2256 epoxy resin and No. ZZL 0820 hardener. The insulation is located internally and consists of 4 pounds per foot density polyurethane foam encapsulated in a vacuum tight jacket of aluminum-Mylar-aluminum foil laminate. The impermeable liner consists of a similar laminate and is located inside but not attached to the insulation. The tank weight, excluding a metal fill tube is 12.25 pounds. Some basic property data for some of the materials used in the tank are also presented.

SECTION II - INTRODUCTION

The potential performance of present day liquid hydrogen (LH_2) fueled rockets can be substantially improved by reducing the weight of the fuel tank. Because of the very low density of LH_2, storage tanks are much larger than for other fuels. Thus, the need for a light weight tank structure becomes imperative. The potential weight saving possible with filament wound structures and the built in insulation possibilities prompted this program.

The program objectives were to develop and fabricate a light weight liquid propellant tank having the following structural characteristics:

1. A light weight load carrying reinforced plastic shell constructed by the filament winding process.

2. A thin impermeable liner capable of containing liquid or gaseous hydrogen.

3. An internal light weight thermal protection system employing low density plastic foam encapsulated in a vacuum tight casing.

4. The completed subscale tank was designed to contain liquid hydrogen at pressures up to 100 psi for six (6) temperature cycles.

5. The capacity of the subscale tank was to be 40 gallons.

To accomplish the objectives a concurrent two part program of materials and process development and tank fabrication was conducted as delineated in Sections III and IV of this report. The program encompassed the design, development and fabrication of a subscale filament wound liquid hydrogen tank having an internal insulation system. The completed tank was delivered to NASA, Lewis Research Center on June 6, 1963 for thermal and structural testing and evaluation.

This final report describes the work performed by Goodyear Aerospace Corporation (GAC) on National Aeronautics and Space Administration (NASA) Contract NAS 3-2291. Close technical liaison between NASA, Lewis Research Center and Goodyear Aerospace afforded decisions and solutions to many difficult problem areas. This effective coordination contributed significantly to the successful completion of the program.

SECTION III - TECHNICAL DISCUSSION

1. General

To demonstrate the feasibility of an internally insulated filament wound tank, a modified ABL 6400 pressure vessel configuration was selected for the test tank. The modifications consisted of increasing the overall length from 24" to 36" and eliminating the hub opening on one dome end as shown on Figures 1 and 2. The tank has an approximate capacity of 40 gallons.

Application of existing lightweight external insulation technology toward the development of the light weight glass-wound tank and integral insulation system posed new and different problems. Herein GAC was faced with two major problem areas:

(1) An internal insulation requirement

(2) A liner (requirement) capable of containing liquid hydrogen

The design aspects of this tank involved consideration of thermal expansion coefficients of all elements, the liner, insulation system and the structural shell. Other major considerations were the vapor tightness of insulation jackets and integrity of adhesive bonded joints at cryogenic temperatures. Detailed discussions of these and other problem areas are presented in the ensuing technical discussions of

each of the subject tank components. The major components of the tank as portrayed on GAC Dwg. 62QS614 shown in Figure 3 are:

(A) A filament wound fiberglass structural shell.

(B) A three piece insulation assembly comprised of a top dome and full neck assembly, a cylinder section assembly and a bottom dome assembly.

(C) A cryogenic liner assembly is comprised of two dome ends and cylinder section which are assembled to fit closely against the inner wall of the insulation assembly.

(D) All components of the cryogenic liner and the vacuum jackets over the foam were fabricated from thin aluminum-mylar-aluminum foil laminate and are bonded together with a polyamid-epoxy resin system developed and tested for this program.

2. Filament Wound Fiberglass Structural Shell

In the design of the structural shell the major consideration was to affect a low shell strain at the maximum test pressure of 100 psi, thereby reducing the accumulative thermal shrink and internal pressurization strains on the insulation and cryogenic liner components.

To this end, the filament wound shell is of a balanced design. It consisted of a full 360 degree longo wrap (two layers of roving) with 412 total ends per inch and four layers of circo wrap with 736 total ends per inch of S/HTS 20 end glass roving wet impregnated with Union Carbide 2256 epoxy resin. The resin hardener selected for this application was the Union Carbide, ZZL 0820, a liquid eutectic blend of aromatic amine type hardeners. The selection of this resin - hardener combination was based on a low temperature cure requirement and the excellent handling characteristics of this resin system. The low temperature cure is mandated by the low heat distortion temperature of the foam insulation.

The construction outlined above is somewhat heavier (.040" in the cylinder section) than required for the 100 psi internal pressure, however this construction is considered a practical minimum to create a tank shell sufficiently rigid to withstand handling loads. The construction as designed will withstand internal static pressures in excess of 600 psi. As shown on Figure 3 the normal polar opening and hub associated with ABL-6400 pressure vessels has been eliminated from one end of the structural shell, however a small reinforced plastic boss is provided to anchor the longo wrapped rovings and to accommodate the pressure tap protruding from the bottom insulation dome. On the opposite end of the tank, the fill neck flange has a recessed annular groove to anchor the longo wrapped rovings.

3. Internal Insulation Assembly

For optimum efficiency the thermal insulation was designed to be located on the inside of the filament wound structural shell. The major reasons for internal location were:

(1) To protect the relatively delicate insulation from damage while handling the tank.

(2) The internal insulation would provide a backup liner assembly.

To facilitate fabrication, the internal insulation is divided into three sections, namely: (1) the upper dome, (2) the cylinder section, (3) and the lower dome. Each section is comprised of polyurethane foam encased in a vacuum tight jacket of aluminum-mylar-aluminum foil laminate, hereafter designated as AMA in this report.

The foam provides a structural media for transmitting LH_2 pressure loads to the external filament wound structural shell when the pressure inside the panels is reduced by cryopumping.

The cryopumping phenomena which takes place within the foam insulation during actual storage of liquid hydrogen is beneficial to the performance of this insulation system. The reliability of this insulation system is dependent on one stringent requirement that the vacuum jackets over the foam be leak tight and remain so throughout the useful life of the insulation. To achieve the desired reliability, the vacuum jacket material was selected on the basis of previous experience. During a program conducted for NASA, Lewis Research Center on the development of a lightweight insulation system for metal tanks, the sealing reliability at cryogenic temperatures of aluminum-mylar-aluminum foil laminates was demonstrated. Also favoring the selection of this material is the formability to permit fabrication into shapes required by the insulation and liner components.

The foam insulation thickness for this tank was .50 inch and was selected to facilitate the fabrication of dome ends by foam-in-place techniques. Selection of the foam density was based upon compressive strength requirements of the foam to withstand 100 psi pressure. GAC supplied selected foam samples to NASA for determination of compressive yield stress at room temperature and -320°F. Test results in Figure 4 show foam compressive stress as a function of density and temperature. For this tank a foam density of 4.0 lb/ft^3 was selected having a compressive strength of 150 psi at liquid nitrogen temperature. The test results show an improvement in compressive strength with decrease in temperature therefore at liquid hydrogen temperatures greater than 150 psi compressive strength is expected.

The insulation is divided into three component parts due to vacuum jacket fabrication considerations. To provide dome ends vacuum jackets having a minimum of seams, it is desirable to fabricate these foil gage jackets as one piece shells. To preclude delamination of the aluminum and mylar layers in the shell, the depth of forming the sheets is limited to approximately one third the diameter. Inasmuch as the domes required for filament winding are oblate spheroids having R/H at about 1.5 it was possible to spin form the AMA shells. Spinning techniques to form these dome shells are feasible when the ratio of aluminum to mylar is approximately 2 to 1 or greater. The shells are constructed from .005" thick foil laminate comprised of .002 aluminum, .001 mylar, .002 aluminum (AMA). The dome insulation inner and outer vacuum jacket shells are sealed together at the base diameter by a .005" thick spin-formed AMA channel section bonded to the jackets. The cylinder section insulation vacuum jackets are pre-stretched .0024" thick AMA sheets fitted and bonded to the inner and outer walls of the foam cylinder. Sealing the vacuum jackets is completed at each end of the insulation cylinder by bonding spin formed .005" thick AMA channel sections to the jackets.

To increase the vapor tightness reliability of bonded seams, all the seams are designed with a .0017" AMA doubler strip bonded in place overlapping the initial seam.

An important feature incorporated in the design of this prototype tank is a glass cloth layer in the foam to vacuum jacket interface. The glass cloth is a bleeder ply incorporated to serve the following purposes:

(1) Facilitate leak checking the vacuum jackets on each of the insulation components.

(2) Permit monitoring of the pressure within the insulation during performance testing of the tank.

(3) Permit rapid detection and vacuum pumping of small leaks if they occur in the vacuum jackets during tests.

Considerable effort was expended to develop a successful technique to incorporate the dry bleeder ply in a foamed-in-place insulation domes. The foam-in-place process employs liquid resins which normally would impregnate the dry cloth that is placed against the vacuum jackets before the foam resin is poured.

Resin or foam impregnation would seriously hamper the effectiveness of the bleeder ply. To preclude the undesirable foaming resin impregnation and provide good adhesion between the bleeder cloth and foam, a sprayed in place "cocoon" was developed as a barrier media. The "cocoon" application involves the use of a polyester resin formulated to be air gun sprayed such that a tacky spider web of resin is plied upon the glass cloth bleeder to build up a thin cocoon-like skin that is impervious to the foaming resin. The tacky spider web resin adheres

to but does not permeate into the glass bleeder cloth.

To utilize the bleeder plies described above, the bleeder plies of each insulation section are connected to the adjacent sections thru four bleeder ply patches shown on the exterior of the insulation shown in Sections C-C and D-D in Figure 3. The bleeder plies of the bottom dome are vented to a pressure tap protruding from the outer vacuum jacket shown in detail A of Figure 3.

The upper insulation dome assembly is designed to incorporate a stainless seel fill neck. The inner and outer vacuum jackets are bonded to a dual flange at the base of the fill neck. A 7" long .015" wall section is provided in the fill neck stem to minimize heat leak into the tank thru the long thin wall tube section. A removable sleeve is provided to reinforce the thin wall filler neck to withstand fabrication and handling of the tank.

4. Cryogenic Liner Assembly

To provide maximum assurance of achieving a leak tight cryogenic liner and de-emphasize the importance of achieving leak tight joints between insulation components, the cryogenic liner is designed as a separate unit. As shown in Figure 3 the basic components of the cryogenic liner are a dome on each end and a cylinder section.

The dome portions are designed as spin formed .005" AMA shells similar to the insulation vacuum jackets. The cylinder section is a single sheet of .0024" prestretched AMA formed into a cylinder and joined with one longitudinal lap joint seam. Figure 3 detail E shows the method of lap joint connection between the dome ends and the cylinder section. All joints are covered with an extra layer of .0017" thick AMA tape to reinforce the joints and increase the reliability of the seal. As shown in Figure 3 detail B the upper dome is bonded to the innder vacuum jacket of the thermal insulation dome in the area of the fill neck fitting flange.

5. Adhesive Evaluation

Of prime consideration in the design of this tank was the method of joining the cryogenic liner and insulation vacuum jacket components to obtain hermetically sealed joints.

A room temperature adhesive bonding method was selected to fulfill the following requirements:

(a) Low permeability at LH_2 temperature.

(b) Cure at temperature not detrimental to the foam insulation. The desired cure temperature range if 75°F to 180°F.

(c) Ease of mixing and application to substrate.

Bond line test samples were fabricated per Figure 5 and submitted to the NASA Lewis Research Center for leak testing at LH_2 temperatures. These tests evaluated methods of surface preparation as well as adhesives. On the basis of test results reported in a proposed NASA technical memorandum, the adhesive system selected for assembly of the cryogenic liner and insulation vacuum jacket components was:

Resin Mix:	Epon 828	65 parts by weight
	Versamid 125	35 parts by weight
	Surface Preparation:	Chem-Lock treatment
	Cure:	Room Temperature (75°F) 8 hours, pressure 5 to 15 psi

6. Materials Testing and Analysis

A material test program was undertaken to determine the properties of the aluminum-mylar-aluminum laminates. Tests were conducted at both room temperature and at -300°F. Table I shows the tests that were conducted and the results of these tests. Figures 6 thru 12 show typical load strain curves recorded during these tests.

Because of the differences in the coefficient of thermal contraction for the aluminum-mylar-aluminum liner and the filament-wound fiberglass tank, the liner will shrink away from the tank upon cooling to -423°F. It was determined by NASA personnel that the liner would shrink approximately 0.0035 in/in more than the fiberglass tank. Upon pressurization the liner would then be enlarged this initial amount plus the amount the tank expands. The fiberglass tank will expand as follows upon pressurization to 100 psi:

Hoop Material Thickness = .025 inches
Radius - 8.95 inches

$$\text{Stress} = \frac{PR}{t} = \frac{100 \times 8.95}{.025} = 35{,}800 \text{ psi}$$

Modulus of Elasticity of Hoop Laminate = 6.50×10^6 psi

$$\text{Strain} = \frac{35{,}800}{6.50 \times 10^6} = .0055 \text{ inches/inch}$$

Therefore if the tank is pressurized to 100 psi after being cooled to -423°F, the liner will expand a total of 0.0035+0.0055 or 0.0090 inches/inch. As can be seen in Figure 10 a strain of approximately .0045 inches/inch causes a permanent set in the liner material of approximately .0015 inches/inch. Therefore the liner after one cycle is larger than the tank which causes the liner to wrinkle upon depressurization. Upon repressurization these wrinkles can easily crease, causing breaks in the liner. It was found from the above material tests that if the liner material is loaded to a level above its elastic limit, subsequent loadings to a lower load level produces no further permanent set (see Figures 8 and 10). Therefore it was decided to load the liner material to 25 lb/in at room temperature prior to using as a liner to keep the permanent set and therefore the wrinkles to a minimum (see Figure 12). This pre-loading and cycling did not change the ultimate strength of the material.

SECTION IV - FABRICATION

1. General

The materials and processes developed and employed in construction of the subject tank are believed to represent a major achievement toward demonstrating techniques applicable to fabrication of large flight type liquid propellant tanks. Possibly the singular exception would be the spin forming technique of forming the aluminum foil laminate dome end shells. Wherein the shells for the subject tank were spun in one piece, a larger tank may require a gore panel construction of the dome end shell and methods such as stretch forming or press forming could be utilized to form large gore panel segments which would be adhesive bonded together to complete a large dome. No difficulties are anticipated in scaling up the fabrication techniques related to the foam insulation, adhesive bonding of aluminum foil laminate, filament winding of the structural shell and leak testing of component parts and completed assembly.

All adhesive bonding noted in the ensuing fabrication discussion, will utilize the Epon 828 - Versamid 125 polyamid epoxy resin system selected from the adhesive evaluation program presented in Section III 5 of this report.

2. Mandrel

The winding mandrel for the subject tank was designed and fabricated in a manner to insure complete removal from the tank without damage to the AMA cryogenic liner and the insulation components. As shown on Figures 13 and 14 the mandrel assembly is comprised of 5 $\#/ft^3$ density polystyrene foam machined to match the inside contours of the cryogenic liner. The foam mandrel is assembled on a hollow steel shaft which is designed to transmit torque to the foam mandrel through a pair of blades, see Figure 13, that fold into the shaft during shaft and mandrel removal. A steel bushing is provided to position the fill neck fitting on the shaft as shown in Figures 14 and 15. The mandrel is designed to be removed by dissolving and washing out with safety solvents.

3. Cryogenic Liner

The cryogenic liner is comprised of three components, a dome on each end and a cylinder section. Fabrication of the liner begins with spin forming the dome shells. These shells are spun from .005" AMA which is sandwiched between two .050" thick aluminum sheets. After spinning to shape, the heavier sheets are carefully removed leaving a typical spun AMA dome shown in Figure 16.

The assembly of the cryogenic liner over the foam mandrel begins with the installation of the top dome insulation assembly on the mandrel as shown on Figure 17. On this tank the top dome of the cryogenic liner is bonded to the fill neck flange therefore it became a part of the top insulation dome assembly. The liner dome is shown protruding from the base

of the insulation on Figure 18. The assembly of the cryogenic liner is accomplished as shown on Figure 19 by placing the bottom AMA dome over the mandrel and a single sheet of pre-stretched .0024" AMA is wrapped over the mandrel and bonded with a lap joint seam at each dome end and with one longitudinal lap joint seam. Doubler strips of .0017" AMA are bonded on all seams to complete the cryogenic liner assembly. Leak tightness of the liner assembly is verified by mass spectrometer helium leak detector techniques to qualify the liner for subsequent processing of the tank.

4. Insulation Components

The insulation is divided into three component parts, (1) the top dome assembly including the filler neck tube, (2) the cylinder section insulation and (3) the bottom insulation dome including the pressure tap. Common to each of the components are the basic insulation elements.

(A) Polyurethane foam insulation

(B) Aluminum foil (AMA) vacuum jackets

(C) Glass cloth bleeder ply located on foam to vacuum jacket interface

Fabrication of the upper insulation dome assembly utilizes the foam-in-place technique developed for this program as described in Section III 3. The inner and outer vacuum jackets are spun from .005" thick AMA shown in Figure 16. The inner jacket is applied over a male plug of the foaming mold and the outer jacket is placed into the cavity of the foaming mold. The stainless steel filler neck top flange is bonded to the outer vacuum jacket and a bleeder ply of 181 glass cloth is bonded to the I.D. of the vacuum jacket as shown in Figure 20. The glass cloth to vacuum jacket bond is made with a thin film of pigmented polyamid epoxy resin painted on the aluminum foil surface and allowed to reach a tacky state before applying the 181 glass cloth layer. This method has provided an excellent bond with a minimum resin migration into the bleeder cloth. The barrier film of polyester resin is sprayed over the entire inner surface of the glass cloth and oven dried to form a skin as shown in Figure 21. Also shown is the inner vacuum jacket with the glass bleeder ply and resin barrier film applied in the same manner as described above. For clarity, the inner vacuum jacket is lifted off the male plug of the foaming mold and the bonding area of the jacket and fill neck flange are prepared for adhesive. The inner vacuum jacket was placed onto the fill neck flange and centered with a silicone rubber plug fitted into the fill neck opening as shown in Figure 22. To provide contact pressure to the bond, weight was placed on the plug and allowed to remain during the cure of bonding resin. After bonding the vacuum jackets to the fill neck flange, the male plug mold was carefully inserted into the inner jacket and secured to the female mold as shown in Figure 23. The .50" annular space between the vacuum jackets is now controlled by the plug to cavity clearance in the foaming mold. The foam resin funnel cups are placed in four places as shown in Figure 23. The entire mold and vacuum jackets

assembly is preheated to 120°F prior to pouring foam resin. A 4 #/ft^3 density foam resin formulation is mixed as follows:

100 PBW*	Plaskon PFR #5 Resin
.2 PBW	Dabco Catalyst
2 PBW	L-521 Silicone Surfactant
22 PBW	Trichloromonofluromethane Blowing Agent
110 PBW	Nacconate 1080 HM Isocyanate Prepolymer

*PBW = Parts by Weight

The foam resin mixture is divided into four parts and immediately poured into the mold with the attendant foam rise and flow out as shown on Figures 24 and 25. The foam is allowed to reach an initial cure in 30 minutes at room temperature followed by an oven post cure at 120° for 8 hours. The excess foam is trimmed away and the male plug with the part are removed from the female mold. Final trim is accomplished by sanding the foam and AMA jackets to the trim line established by the base diameter of the male mold plug. The part is then removed from the male mold and a spin formed .005" AMA channel (See Figure 26) and attendant doubler strips are bonded to the base of the insulation dome to complete thispart as shown on Figure 27. The effectiveness of the fabrication technique described above to achieve a dry bleeder ply of glass cloth between the foamed-in-place foam insulation and the AMA vacuum jacket is illustrated in Figure 28 where the outervacuum jacket has been peeled away revealing the dry glass cloth underneath.

The bottom insulation dome assembly was fabricated in a manner similar to the top insulation dome described above with exception of the processing associated with the filler neck. The inner and outer vacuum jackets prepared for foaming operation are shown on Figure 29. A completed bottom dome assembly less the doubler strips on channel bond seams is shown in Figure 30.

The cylinder section insulation is constructed from a 4 #/ft^3 density polyurethane foam cylinder that is O.D. machined to a .50" wall thickness from a 3" thick wall cylinder 30" long created by the foam-in-place technique. The heavy wall thickness is required to achieve a uniform foam density throughout a cylinder of this diameter and length. The heavy wall foam cylinder is foamed between a teflon coated mandrel and a cylindrical sheet metal shroud centered about the mandrel with approximately three inches radial clearance. The foam resin mix was as follows:

100 PBW*	Plaskon PFR #5 Resin
.2 PBW	Dabco Catalyst
2 PBW	L-521 Silicone Surfactant
15 PBW	Trichloromonofluromethane Blowing Agent
110 PBW	Nacconate 1080 HM Isocyanate Prepolymer

*PBW = Parts by Weight

The mandrel is wrapped with four plies of style 128 glass cloth having release agent sprayed over each layer. A fifth layer of style 104 cloth was applied over the 128 cloth layers. The 128 cloth serves as a bleeder to remove foam gases that would otherwise be trapped on the I.D. surface of the foam cylinder. The style 104 cloth reinforces the surface of the foam to prevent foam tear out when the bleeder plies are peeled out. Up to six attempts were made to establish the proper processing parameters of cylinder length, bleeder ply thickness and foam formulation to obtain the desired thick wall foam cylinder of sufficient length and uniform foam density. While still on the mandrel, the heavy wall foam cylinder was machined to .50" wall thickness. Figure 31 portrays the machined cylinder before final end trim. The O.D. is covered with glass cloth bleeder ply and the outer vacuum jacket of pre-stretched .0024" AMA. The I.D. has the style 181 glass cloth bleeder ply bonded to the foam. The cylinder section trimmed to length is shown on Figure 32. A .005" AMA channel, Figure 33, and .0017" doubler strips are bonded to each end of the cylinder to complete this assembly.

To verify the leak tightness of the vacuum jackets on each of the three insulation components, they were leak tested by a mass spectrometer helium leak detector technique wherein a temporary pressure tap was attached to the outer vacuum jacket and the foam volume pumped down to 25 microns by the helium leak detector roughing and diffusion pumps. A stream of helium gas was directed over the jackets with particular emphasis on the bond line seams. Any leaks were isolated and repaired before accepting the insulation components for final assembly. Figure 34 shows the cylinder section under test for leakage. On the right is a 4" Veeco vacuum station used for roughing and on the left is a Veeco MS-9 helium leak detector. Leak test setup for the upper insulation dome is shown in Figures 35 and 36. On the right is a Kinney vacuum station used for roughing and on the left is a CVC helium leak detector.

5. Assembly of Insulation on Mandrel

As previously noted, the upper insulation dome is installed on the mandrel during the assembly of the cryogenic liner per Figure 18. To complete the assembly of the insulation over the mandrel and cryogenic liner, the cylinder section insulation is slipped onto the mandrel and slid up to the top dome. The aft insulation dome is placed on the mandrel and pushed in place against the cylinder section. Circumferential splice strips of .0024" AMA and .0017" AMA doubler strips are bonded to the butt joints between the insulation components as shown on Figures 37 and 38. To interconnect the bleeder plies of each insulation component, four bleeder patches were added at each joint between cylinder and dome insulations. Each bleeder patch is comprised of a glass cloth strip overlapping a hole in each outer vacuum jacket, and a .0024" AMA cover

ply over the glass cloth. A large .0017" AMA doubler strip is bonded over each patch area as shown on Figures 37 and 38. With the addition of the bleeder patches, the entire insulation bleeder ply system is vented to the pressure tap permanently installed in the bottom insulation dome as shown on the left in Figure 38. Utilizing this pressure tap, the completed insulation assembly is leak tested as shown in Figure 39. The Veeco helium leak detector is hooked into the bottom dome pressure tap and the entire insulation assembly is evacuated via the bottom dome assembly thru the bleeder patches connecting the cylinder and dome insulation assemblies. Helium gas is sprayed over the exterior surfaces of the insulation and the leak detector monitored for indication of helium pick up. No leaks were detected in the assembly during this process. To ascertain the validity of the leak test, a small pin hole leak was punctured in the top dome at a point furthest from the aft dome pressure tap. The leak detector response was noted in approximately 14 seconds when a pressure increase and helium pick up was indicated to verify the leak testing capability of this system. The pin hole leak was repaired to complete the insulation assembly for the follow on process of wrapping the structural shell.

6. Filament Wound Structural Shell

The mandrel and insulation assembly was mounted in a turret type filament winding machine as shown in Figure 40. To insure adequate adhesion of the filament wound glass roving, the exterior surface of the entire insulation assembly was cleaned by the Chem-Lock process and primed with a brush coat of Epon 828 and Versamid 125 polyamid-epoxy resin. The resin was allowed to reach a tacky state before the longo wrap was started. To apply the longo wrap the mandrel is tilted to the wrap angle and is revolved past a fixed distributor head guiding the wet resin impregnated glass roving. At the same time the mandrel precesses about its axis to a precise indexing for a uniform distribution of the glass roving over the surface of the insulation as shown on Figure 41. The longo wrap is one complete 360 degree covering which is two layers of the S/HTS glass roving having a layer density of about 206 ends per inch of width.

The in-process application of one of four layers of circumferential wrapped rovings is shown in Figure 42. In this operation the axis of the mandrel is horizontal and the mandrel is rotating at a rate synchronized to the lateral movement of the distributor head to provide precise indexing for a uniform wrap of the wet resin impregnated glass roving onto the longo wrapped roving. The complete circo wrap is four layers of S/HTS glass rovings applied between the cylinder section transition points as shown on Figure 43.

The filament winding resin (Union Carbide 2256 epoxy resin with ZZL 0820 hardener) was partially cured under heat lamps for six hours with the mandrel rotating. The filament wound structural shell was then completely cured at a long term low temperature post cure cycle not detrimental to the foam insulation. The post cure cycle was as follows:

150°F	5 hours
170°F	2 hours
180°F	12 hours

7. Mandrel Removal

The polystyrene foam mandrel was completely removed in seven hours using 120 lbs of Trichlorethane to dissolve out the foam and an additional 65 lbs of Trichlorethane for rinse and removal of scum residue on the interior walls of the cryogenic liner. The procedure was as follows:

(a) Remove mandrel shaft lock nut and bushing from fill neck area.

(b) Pour Trichlorethane (solvent) into hollow shaft and soften the foam mandrel adjacent to shaft.

(c) Carefully pull shaft from mandrel and fill neck tube.

(d) Pour additional solvent into filler neck and slowly rotate the tank and mandrel on padded table top to distribute solvent in the mandrel. Pour off foam slush and spent solvent.

(e) Pour in fresh solvent and repeat (d) as required to completely remove all pieces of the foam mandrel.

(f) Rinse interior of tank with mixture of fresh solvent and clean cotton rags sloshed about to gently scrub the cryogenic liner free of residue and scum.

(g) Final rinse with solvent only.

The total solvent and rinse time was less than six hours and was considered of no detriment to the bonded joints of the cryogenic liner. Tests conducted on bond line samples showed no deleterious effects in 24 hours immersion in Trichlorethane solution.

8. Final Leak Tests

The completed tank assembly was tested for leak tightness of the insulation after removal of the mandrel. As shown in Figure 44 the helium detector is hooked up to the pressure tap protruding from the

bottom of the tank. The foam insulation was evacuated by the 4" Veeco vacuum station roughing pump and the Veeco MS-9 leak detector diffusion pump. Helium gas was sprayed over the exterior surfaces of the tank and the leak detector monitored for any leaks thru the exterior vacuum jackets of the insulation. Helium was also introduced to the interior of the tank thru the filler neck to check for leaks in the cryogenic liner and interior vacuum jackets of the insulation. No leaks could be detected in the cryogenic liner and insulation vacuum jackets. This was considered the final qualification test for the tank.

9. Weight Summary

The completed tank shown in Figure 45 weights 17.20 lbs. A weight breakdown is as follows:

Cryogenic Liner		.63#
Insulation Assembly		
Top Dome Assembly (includes 4.95# filler neck)	6.21	
Cylinder Section	3.64	
Bottom Dome Assembly (includes .18" pressure tap)	1.35	
	11.20	11.20
Filament Wound Structural		5.37
Total Weight		17.20#

SECTION V - CONCLUDING REMARKS

The effort described herein indicates that subscale filament wound fiberglass reinforced plastic tanks with internal encapsulated foam insulation for liquid hydrogen use can be successfully fabricated. This construction is believed to represent a significant step toward advancing the state-of-the-art of new materials for rocket propellant tanks.

TABLE I - TEST PROGRAM AND TEST RESULTS

Ultimate Tensile Strength and Modulus

Material	Test Temp	No. of Specimens	Gage Length	Specimen Direction	Average Ultimate Tensile PSI	Average Modulus PSI
.0007 Al	Room	5	4 in.	L	12,740	2.42×10^6
.001 Mylar	Temp	5	4	C	13,530	2.43×10^6
.0007 Al		5	8	L	12,770	2.66×10^6
		5	8	C	13,280	3.11×10^6
		5	12	L	12,950	3.02×10^6
		5	12	C	13,050	3.10×10^6
		5	20	L	13,610	2.99×10^6
		5	20	C	13,070	2.94×10^6
	-300°F	1	5	L	26,020	4.56×10^6
	-300°F	6	6	L	24,240	-
.002 Al	Room	5	4	L	10,500	3.76×10^6
.001 Mylar	Temp	5	20	L	10,300	5.39×10^6
.002 Al	-300°F	3	6	L	18,450	-
	-240°F	1	6	L	17,420	-

Cycling Tests

Material	Test Temp	Gage Length	Initial Load-Lb	Number of Cycles	Cycling Loads Lb
.0007 Al	Room Temp	8 in.	15	6	15
.001 Mylar		20	15	6	15
.0007 Al		20	14	5	2 at 14; 3 at 18
		8	15	6	2 at 15; 4 at 18
		20	25	4	25
		-	20	5	15
		-	25	5	15
	-300°F	6	25(RT)	1	50
		6	25(RT)	6	45
		6	50	6	40
		6	55	6	50
		5	20	6	15
.002 Al	Room Temp	20 in.	30	6	25
.001 Mylar		20	30	6	25
.002 Al		4	30	6	25
		4	30	6	25
	-300°F	6	40(RT)	6	80
	-300°F	6	40(RT)	6	70

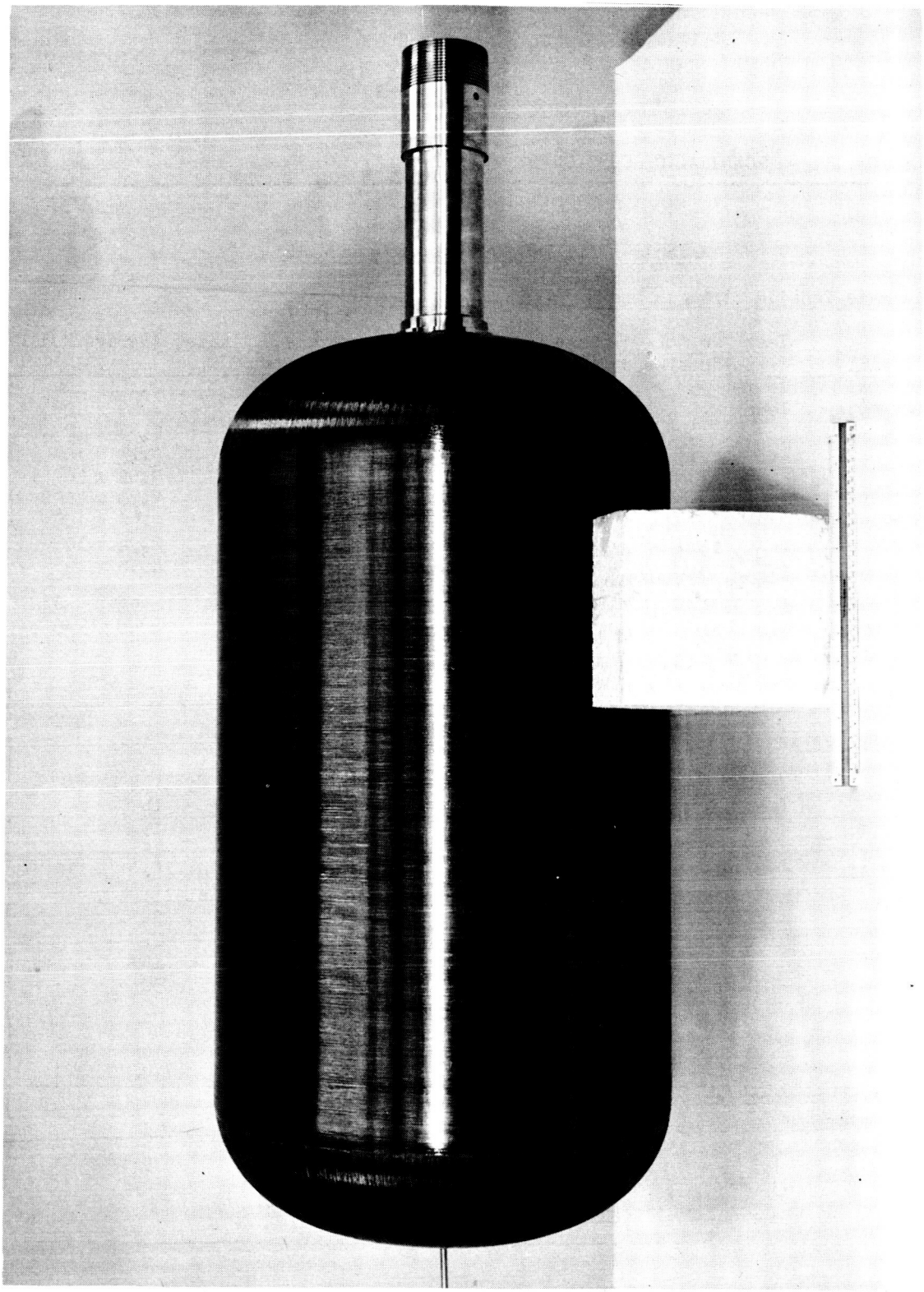


FIGURE 1 - FILAMENT WOUND LH_2 TANK - SIDE VIEW

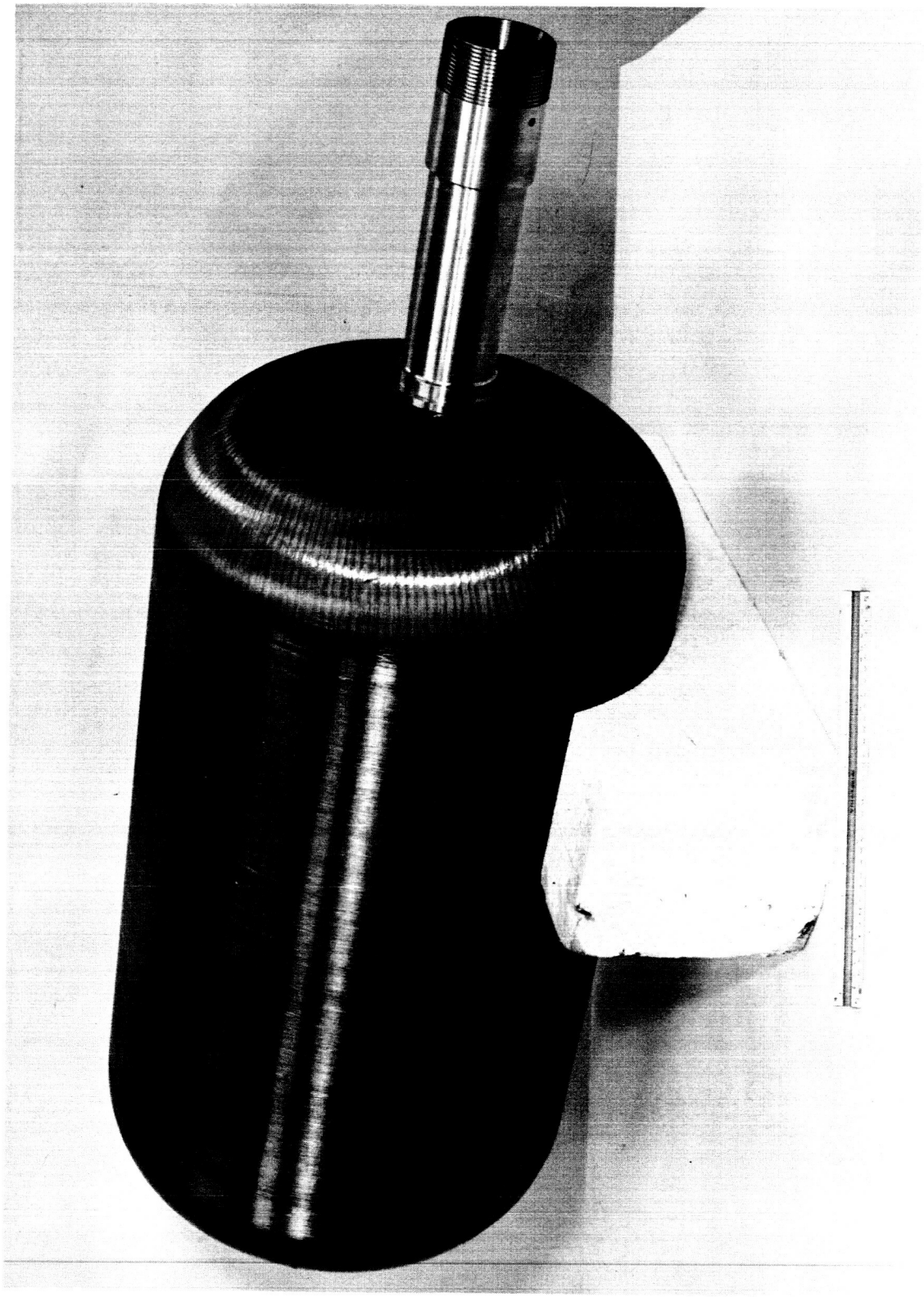


FIGURE 2 - FILAMENT WOUND LH_2 TANK - TOP END VIEW

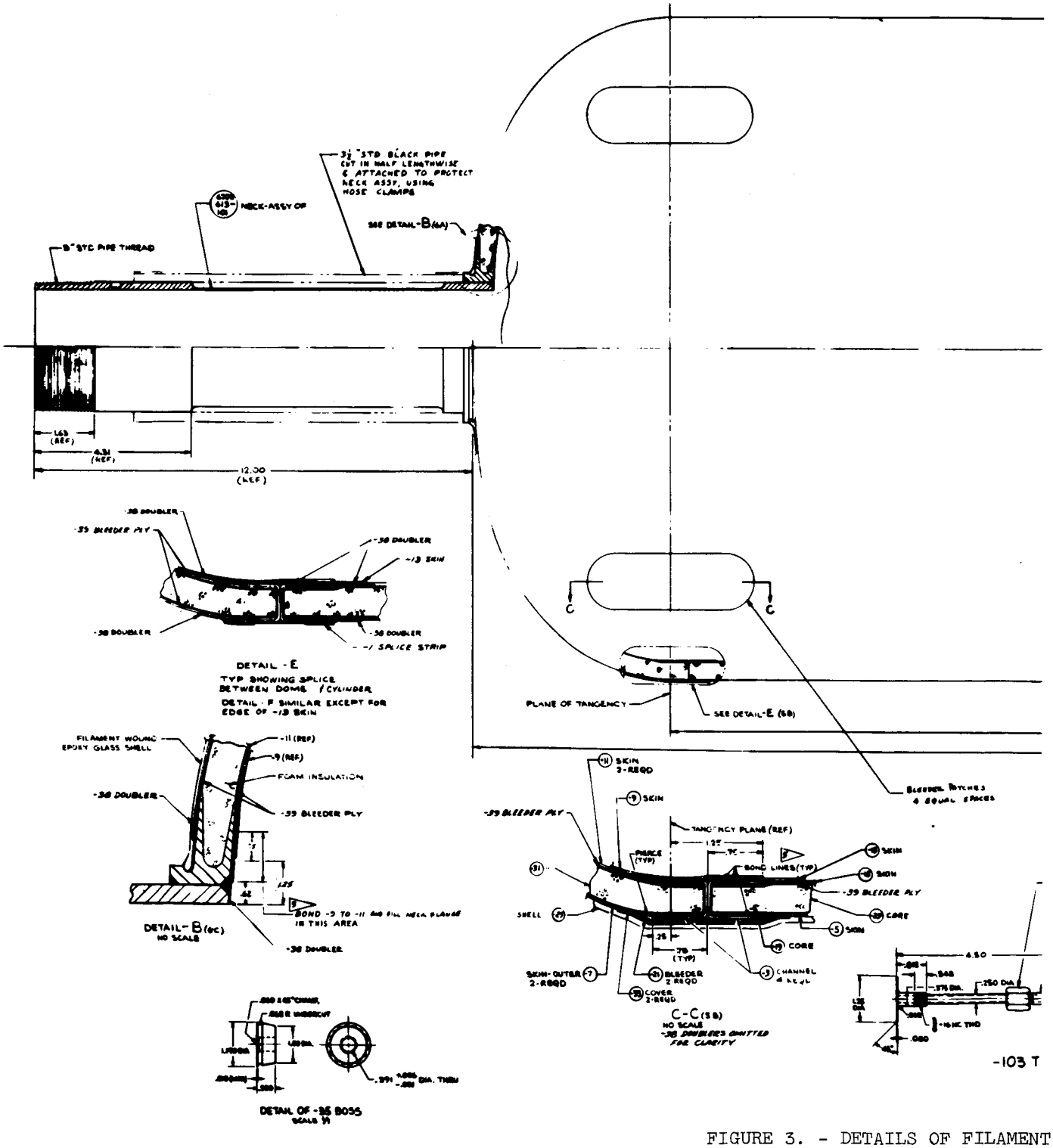
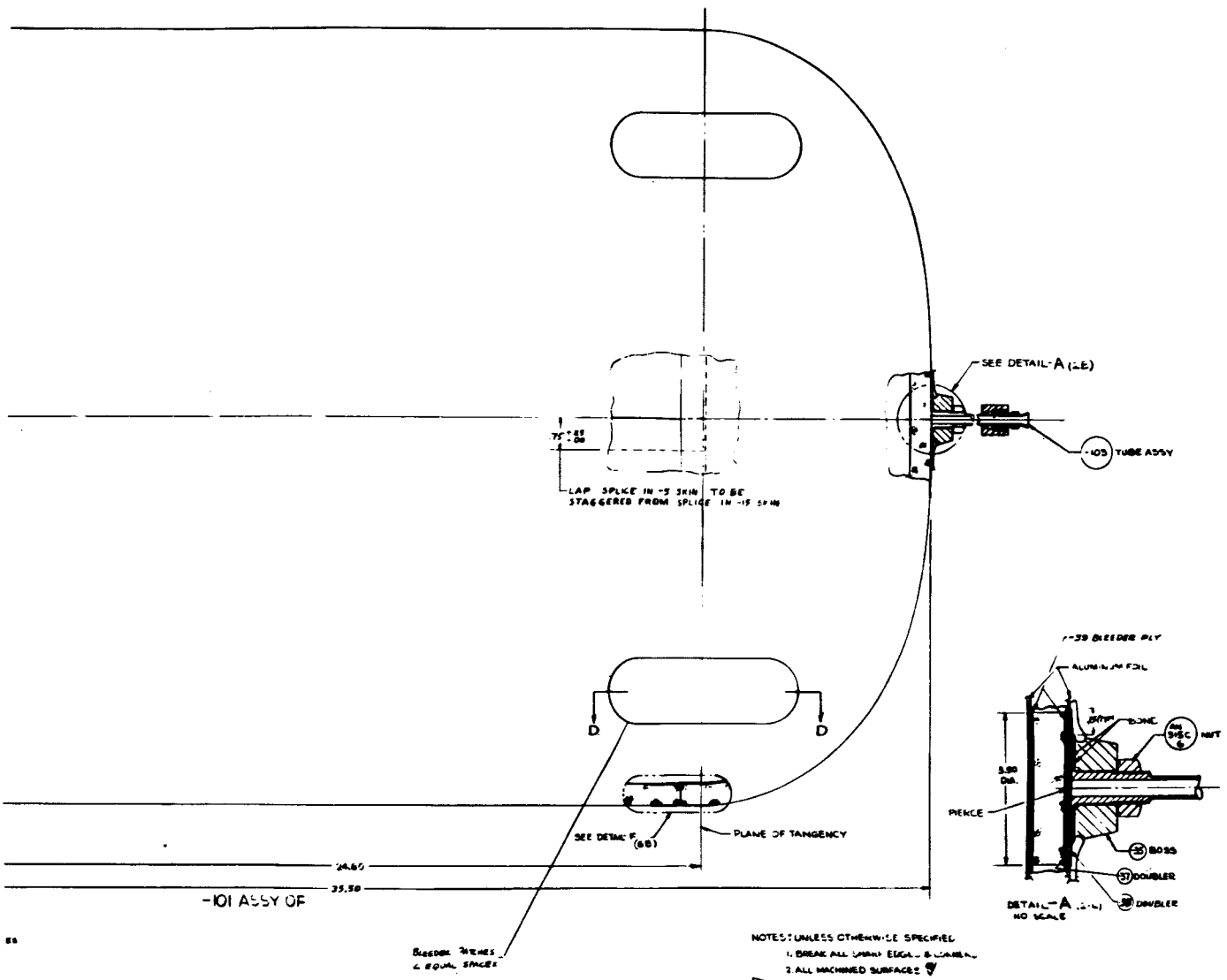
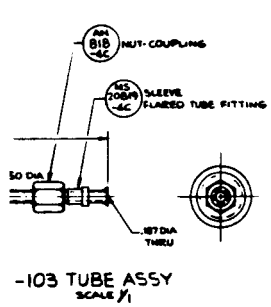


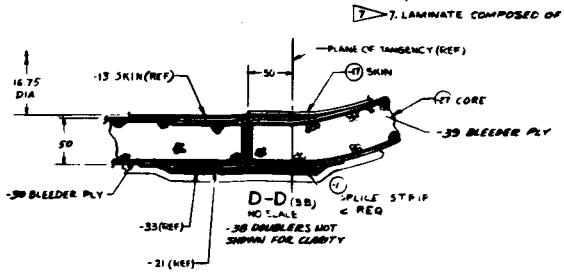
FIGURE 3. - DETAILS OF FILAMENT



NOTES: UNLESS OTHERWISE SPECIFIED
1. BREAK ALL SHARP EDGES & CORNERS
2. ALL MACHINED SURFACES
3. LAMINATE COMPOSED OF .002 AL FOIL - .001 MYLAR - .002 AL FOIL
4. LAMINATE COMPOSED OF .0007 AL FOIL - .001 MYLAR - .0007 AL FOIL
5. BONDS TO BE A POLYAMID-EPOXY RESIN SYSTEM
6. MATERIAL TO BE HIGH TENSILE STRENGTH GLASS & EPOXY RESIN - FILAMENT WOUND
7. LAMINATE COMPOSED OF .0035 AL - .001 MYLAR - .0035 AL

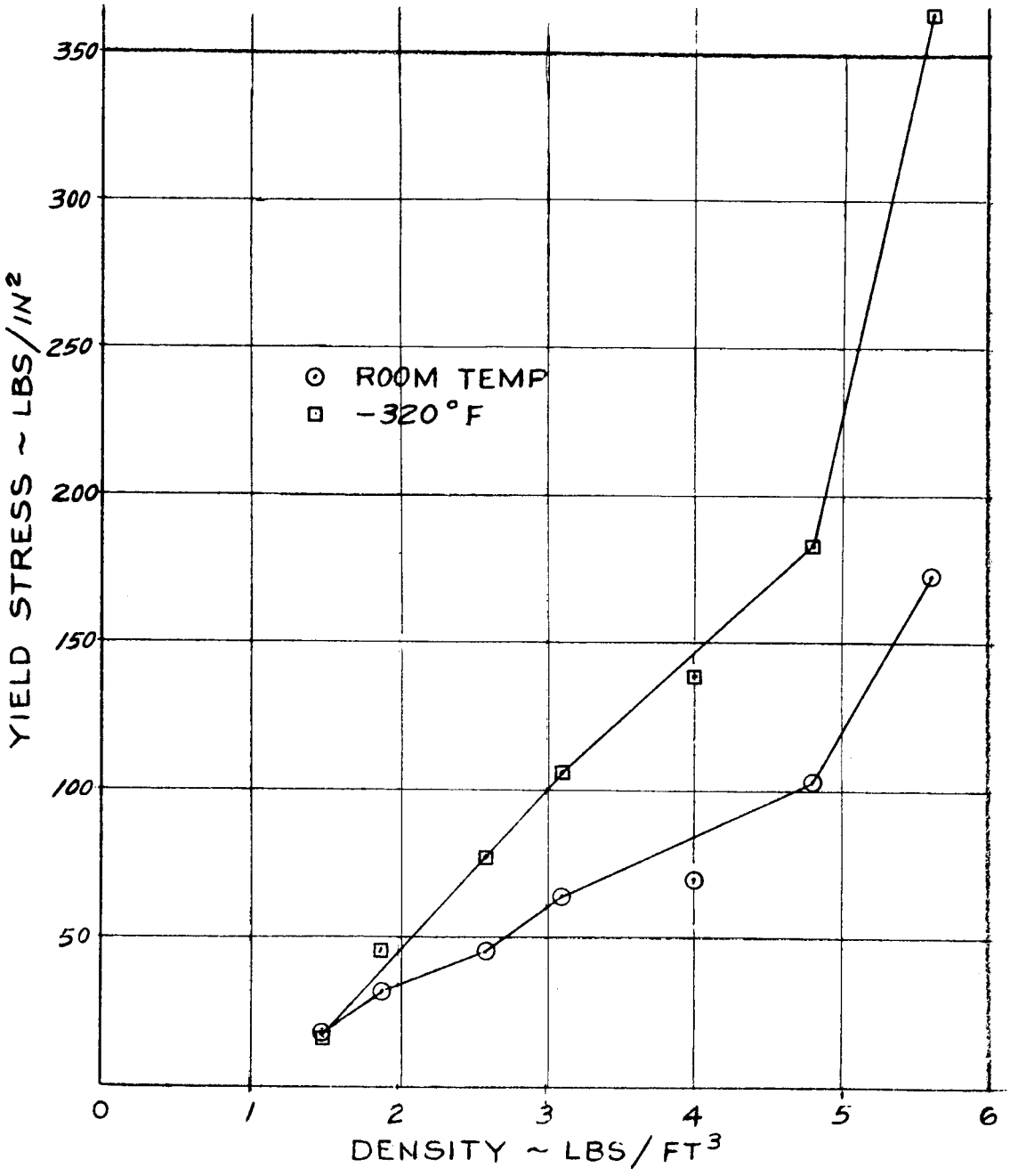


-103 TUBE ASSY
SCALE 1/1



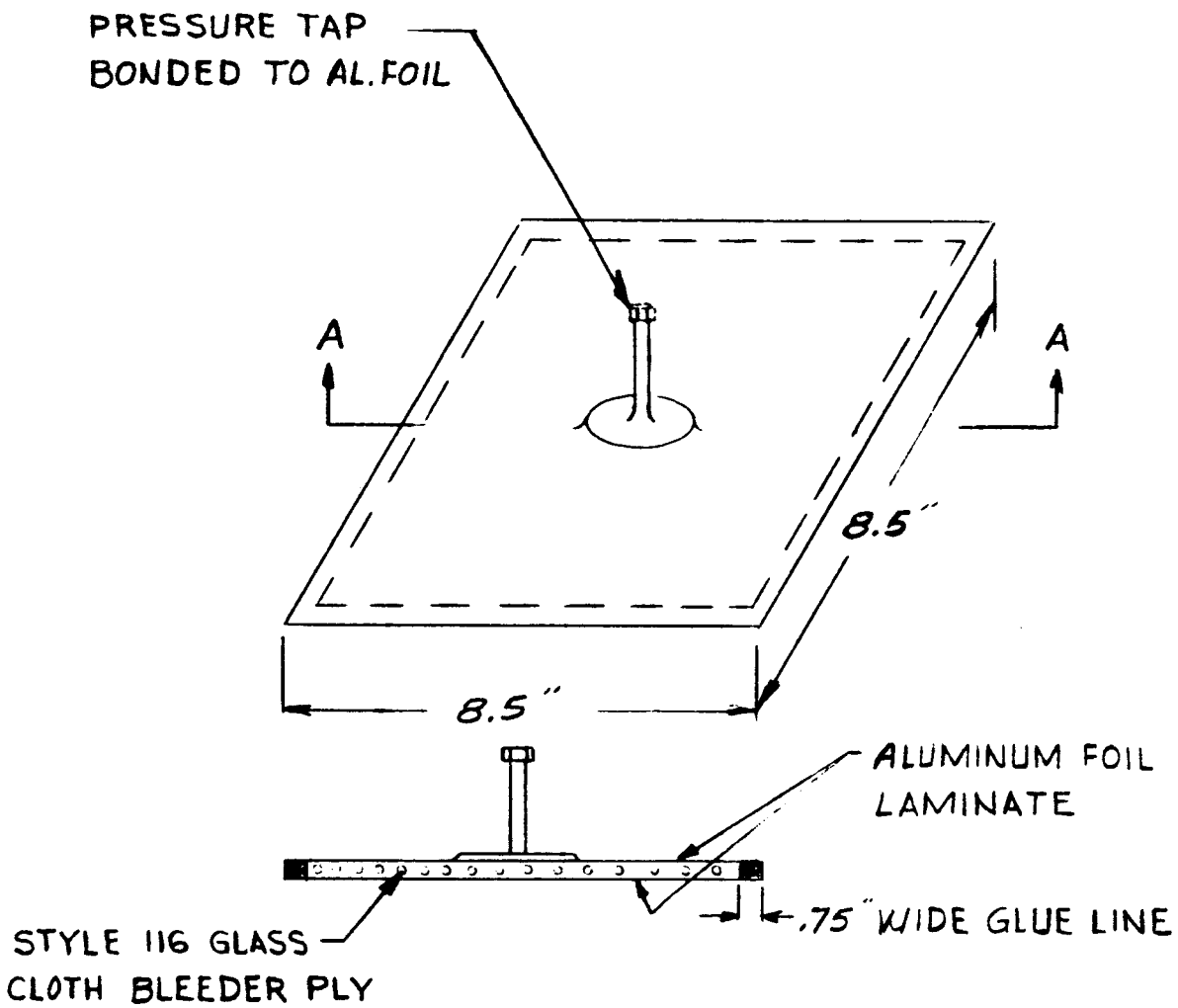
D-D (3B)
NO SCALE

-WOUND CRYOGENIC TEST TANK.



POLYURETHANE FOAM COMPRESSION TEST

FIGURE 4.



BOND LINE TEST SPECIMEN

FIG 5

TENSILE TEST

MATERIAL ~ .0007 ALUMINUM, 001 MYLAR, .0007 ALUMINUM
TEST TEMPERATURE ~ ROOM TEMPERATURE
SPECIMEN WIDTH ~ 1.0 INCH
ULTIMATE LOAD ~ 31 POUNDS

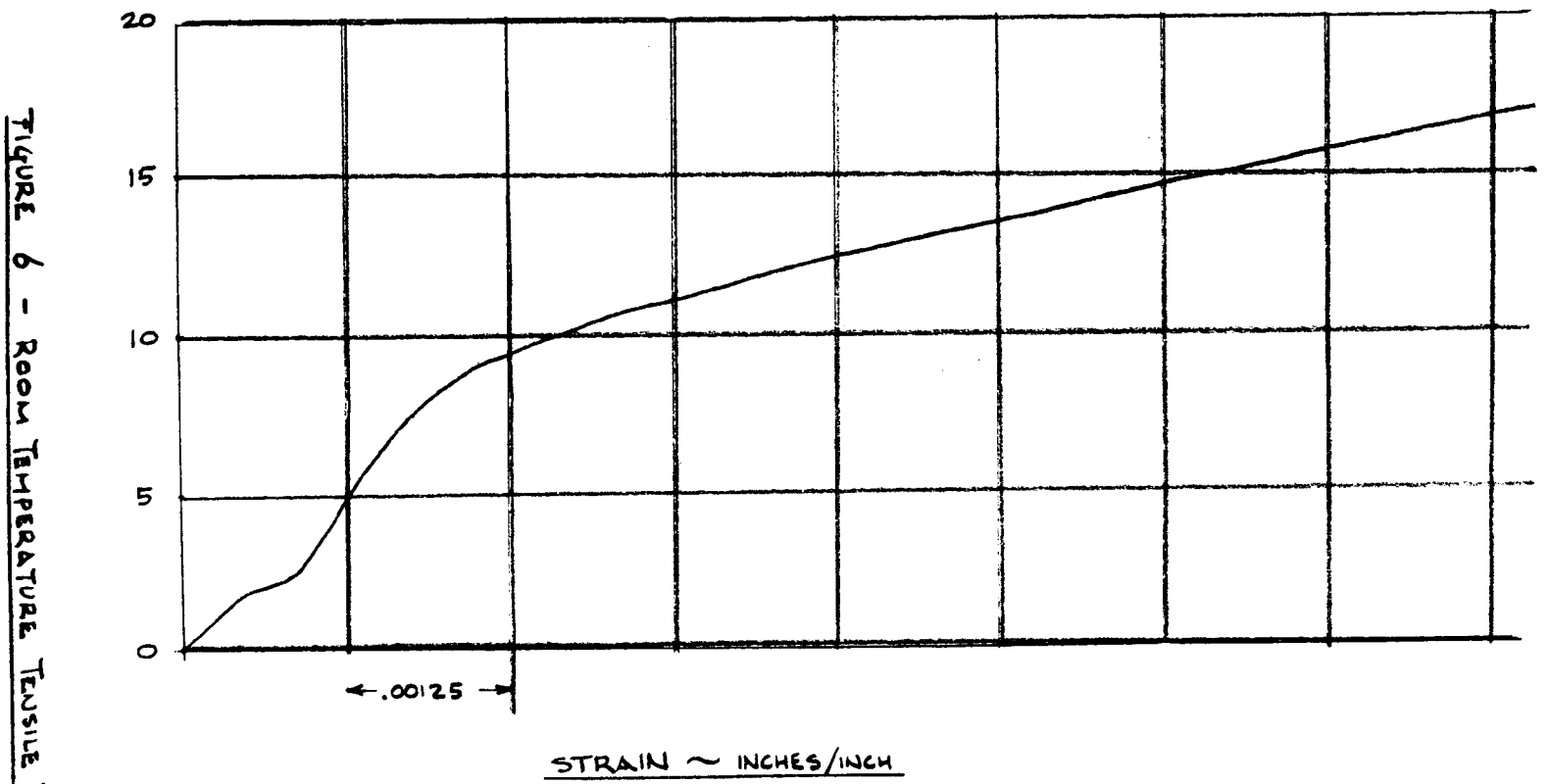


FIGURE 6 - ROOM TEMPERATURE TENSILE TEST

TENSILE CYCLING TEST

MATERIAL ~ .0007 AL, .001 MYLAR, .0007 AL
INITIAL LOAD ~ 25 LB AT R.T.
CYCLING LOAD ~ 4 CYCLES AT 25 LB AT R.T.
SPECIMEN WIDTH ~ 1.0 INCH

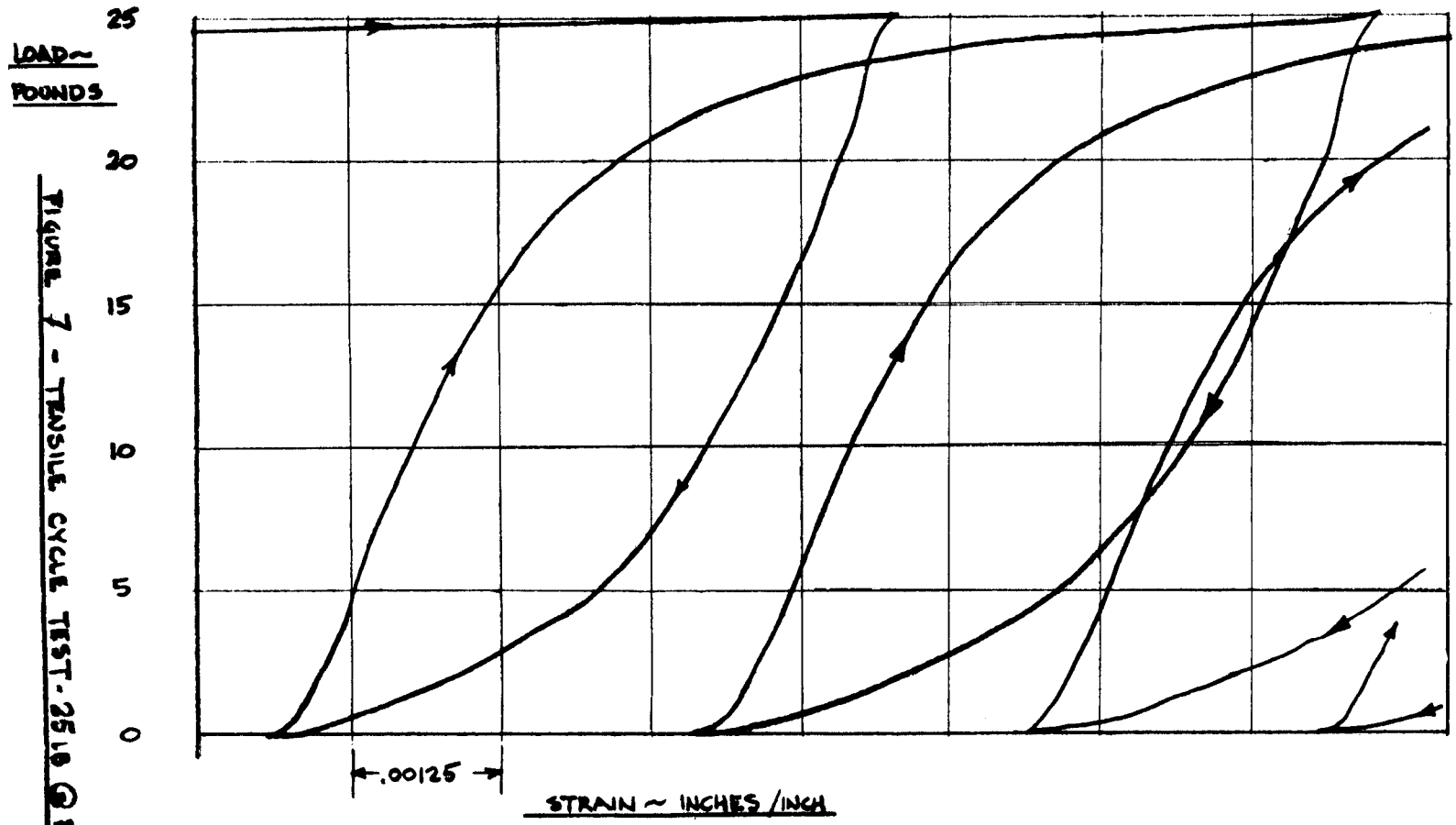


FIGURE 7 - TENSILE CYCLE TEST. 25 LB @ R.T.

TENSILE CYCLING TEST

MATERIAL - .0007 ALUMINUM, .001 MYLAR, .0007 AL
INITIAL LOAD ~ 25 LB AT R.T.
CYCLING LOAD ~ 5 CYCLES AT 15 LB AT R.T.
SPECIMEN WIDTH ~ 1.0 INCH

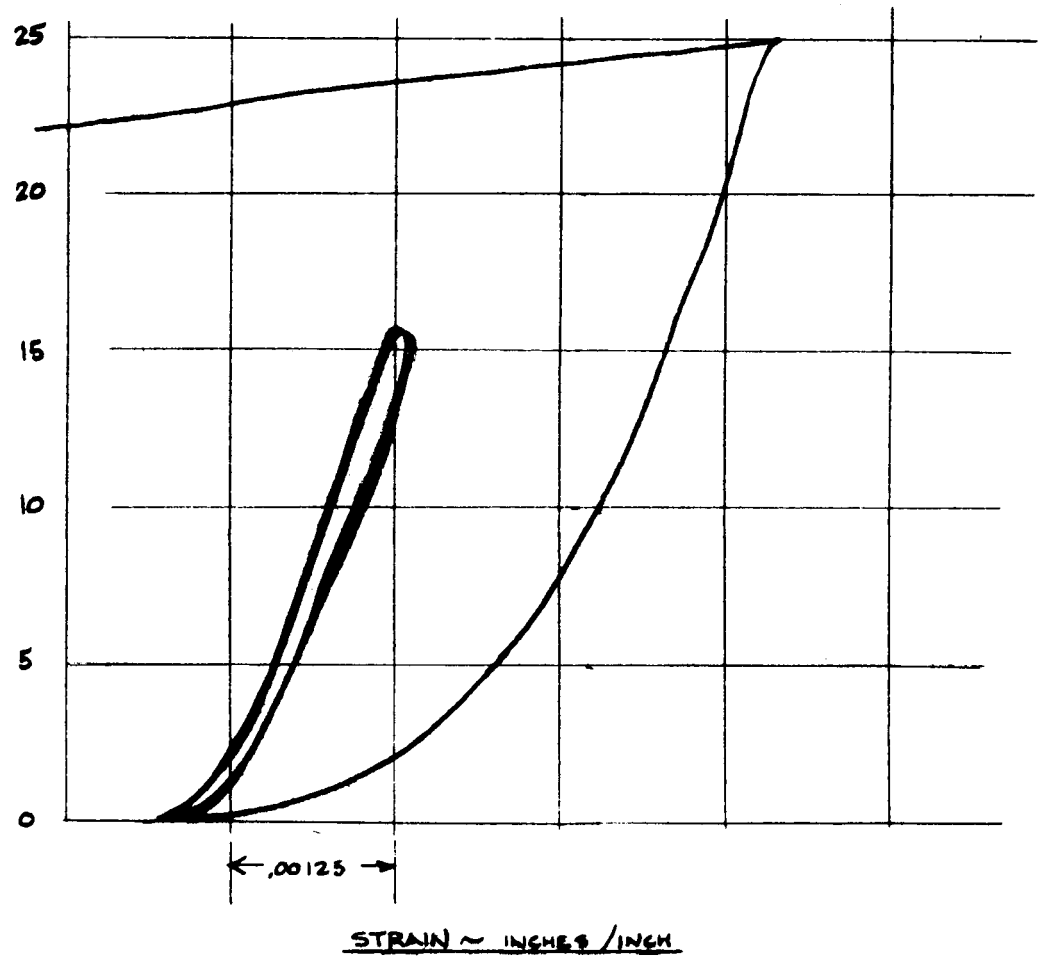


FIGURE 8 — TENSILE CYCLING TEST - 15 LB @ R.T.

TENSILE TEST

MATERIAL ~ .0007 ALUMINUM, .001 MYLAR, .0007 ALUMINUM

TEST TEMPERATURE ~ -300° F

SPECIMEN WIDTH ~ 1.0 INCH

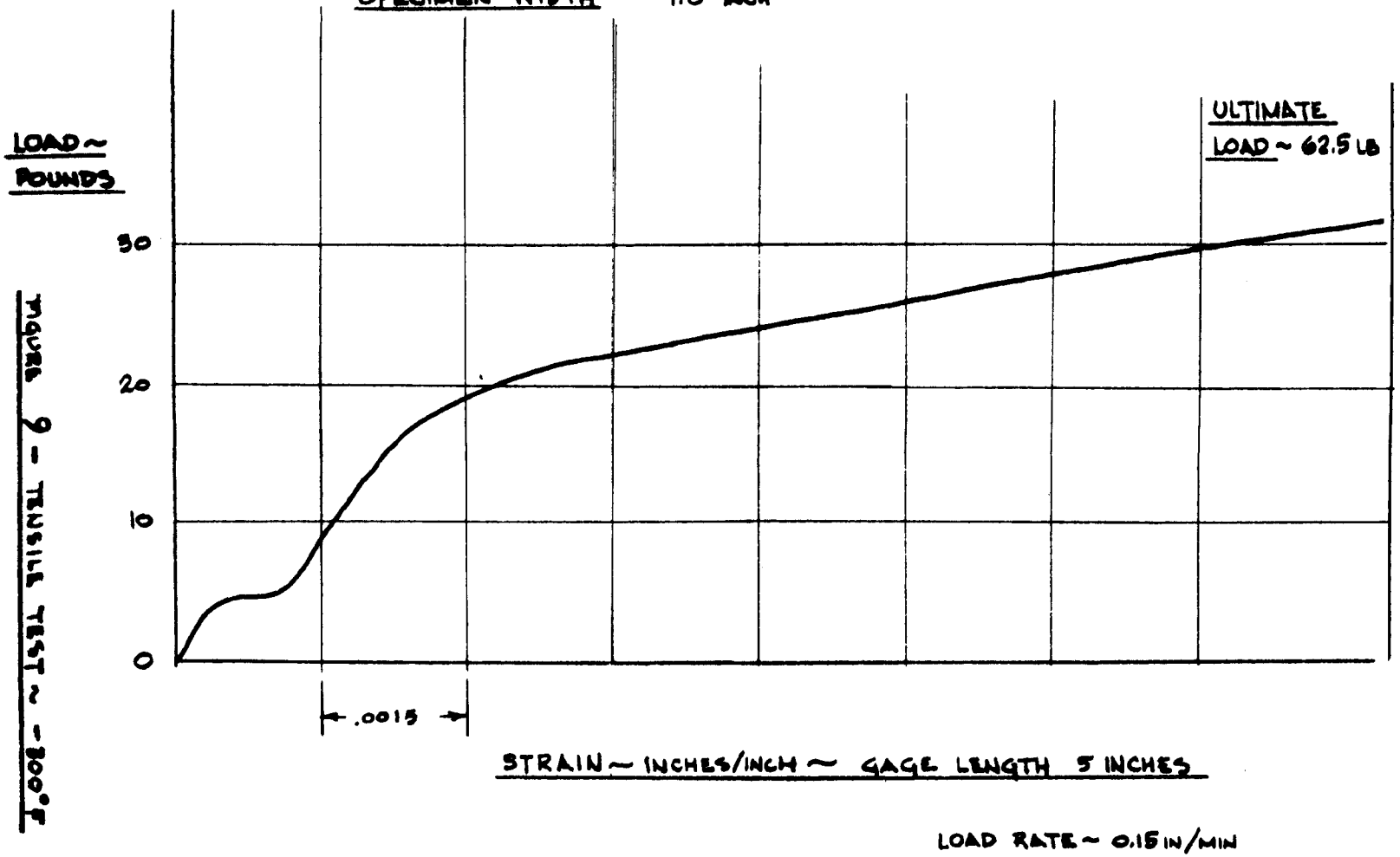


FIGURE 9 - TENSILE TEST ~ -300°F

LOAD RATE ~ 0.15 IN/MIN

TENSILE CYCLING TEST

MATERIAL ~ .0007 AL, .001 MYLAR, .0007 AL
INITIAL LOAD ~ 20 LB AT -300°F
CYCLING LOAD ~ 6 CYCLES AT 15 LB AT -300°F
SPECIMEN WIDTH ~ 1.0 INCH

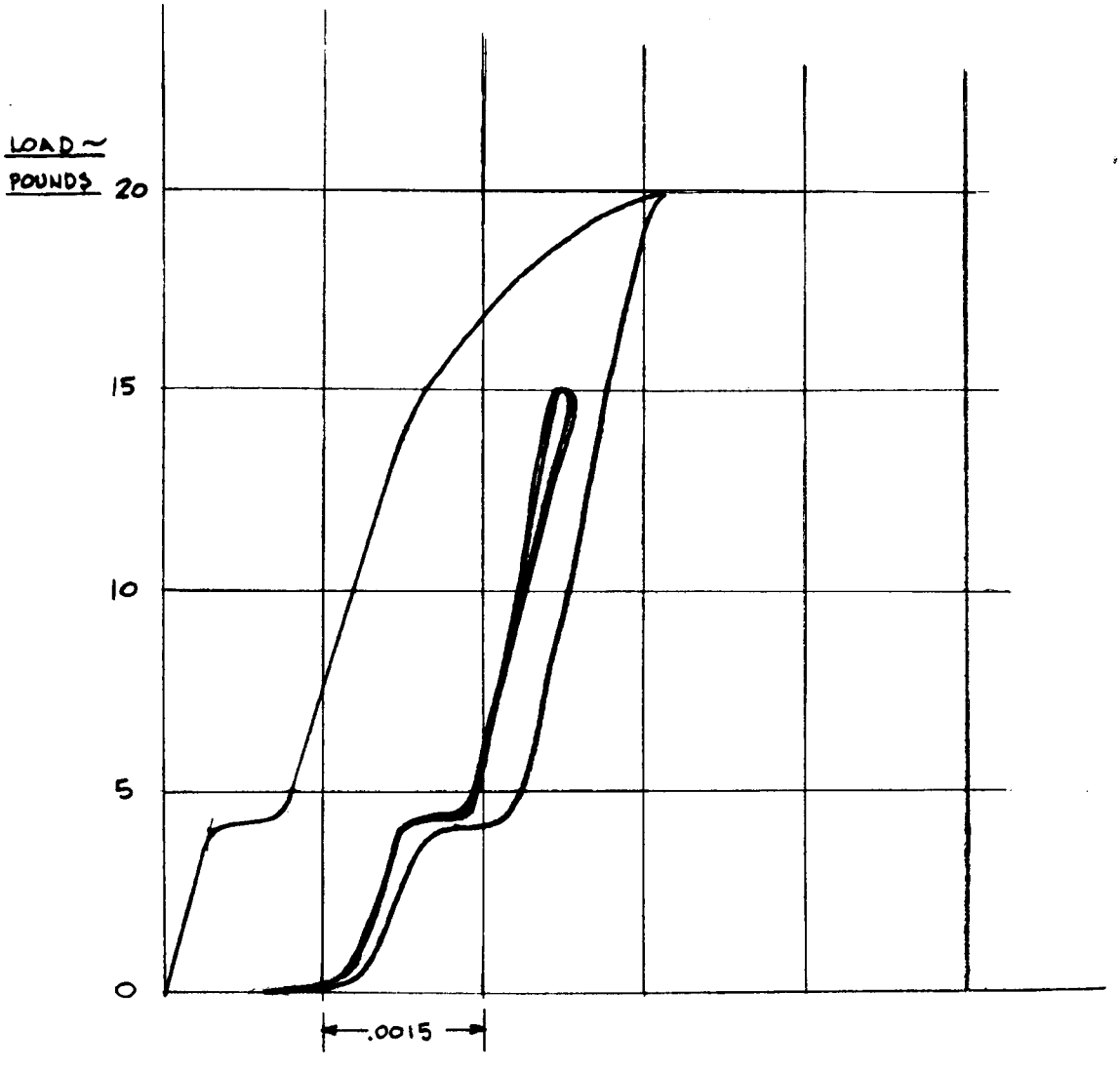


FIGURE 10 ~ TENSILE CYCLING TEST — 15 LB AT -300°F

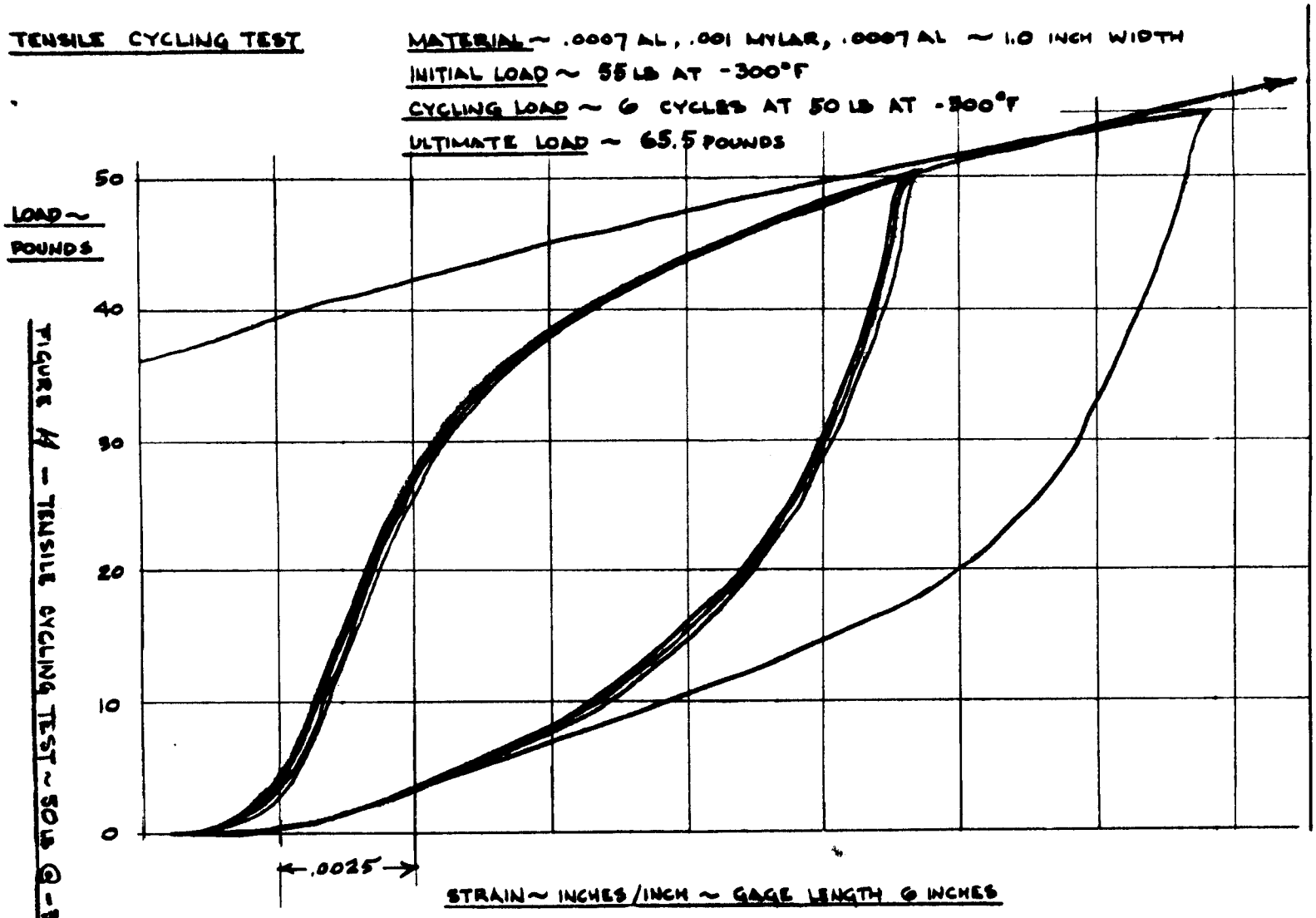


FIGURE 14 - TENSILE CYCLING TEST ~ 50 LB @ -300°F

TENSILE CYCLING TEST

MATERIAL ~ .0007 AL, .001 MYLAR, .0007 AL
INITIAL LOAD ~ 25 LB AT ROOM TEMPERATURE
CYCLING LOAD ~ 6 CYCLES AT 45 LB AT -300°F
ULTIMATE LOAD ~ 65 POUNDS
SPECIMEN WIDTH ~ 1.0 INCH

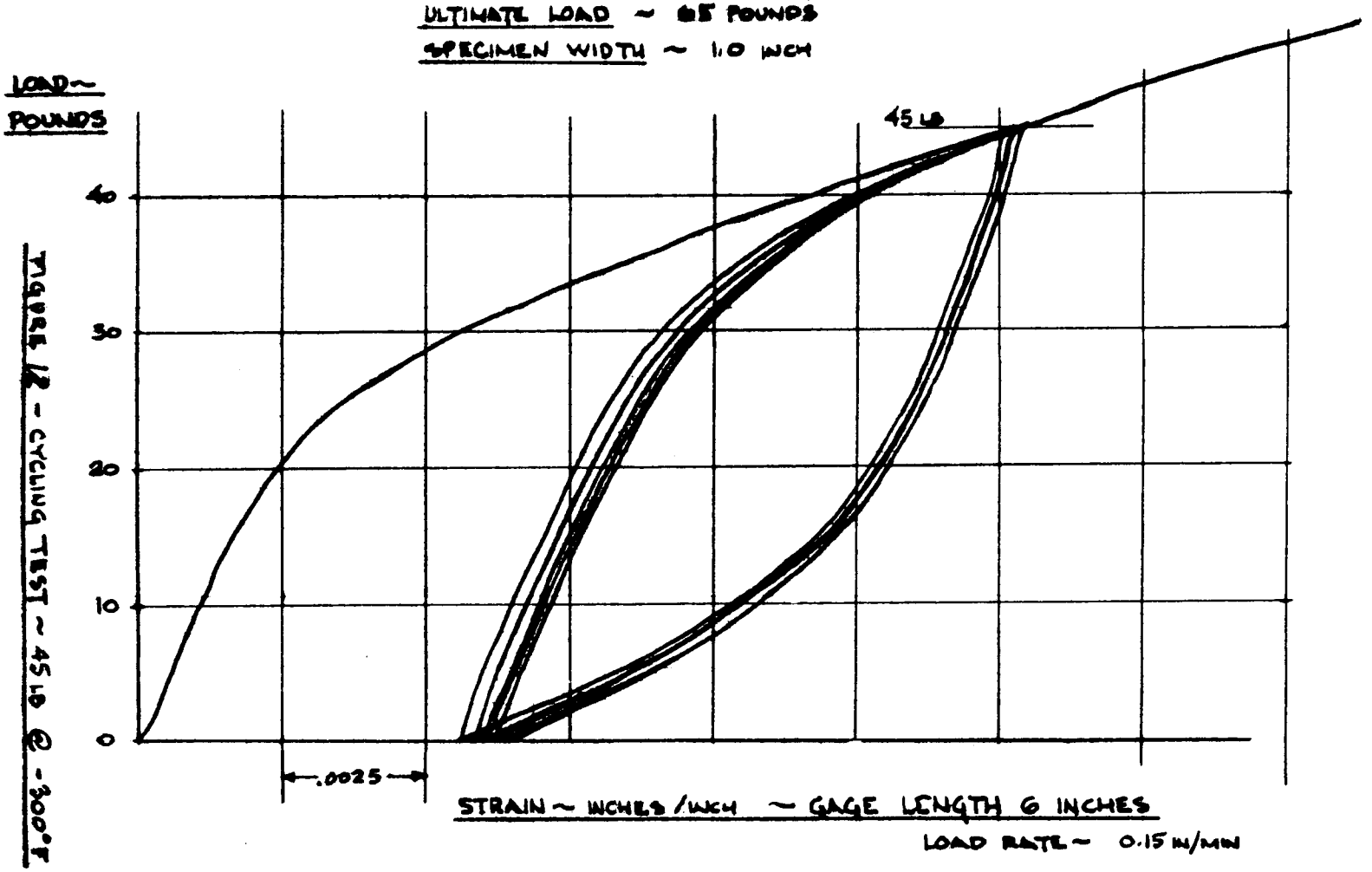


FIGURE 12 - CYCLING TEST ~ 45 LB @ -300°F

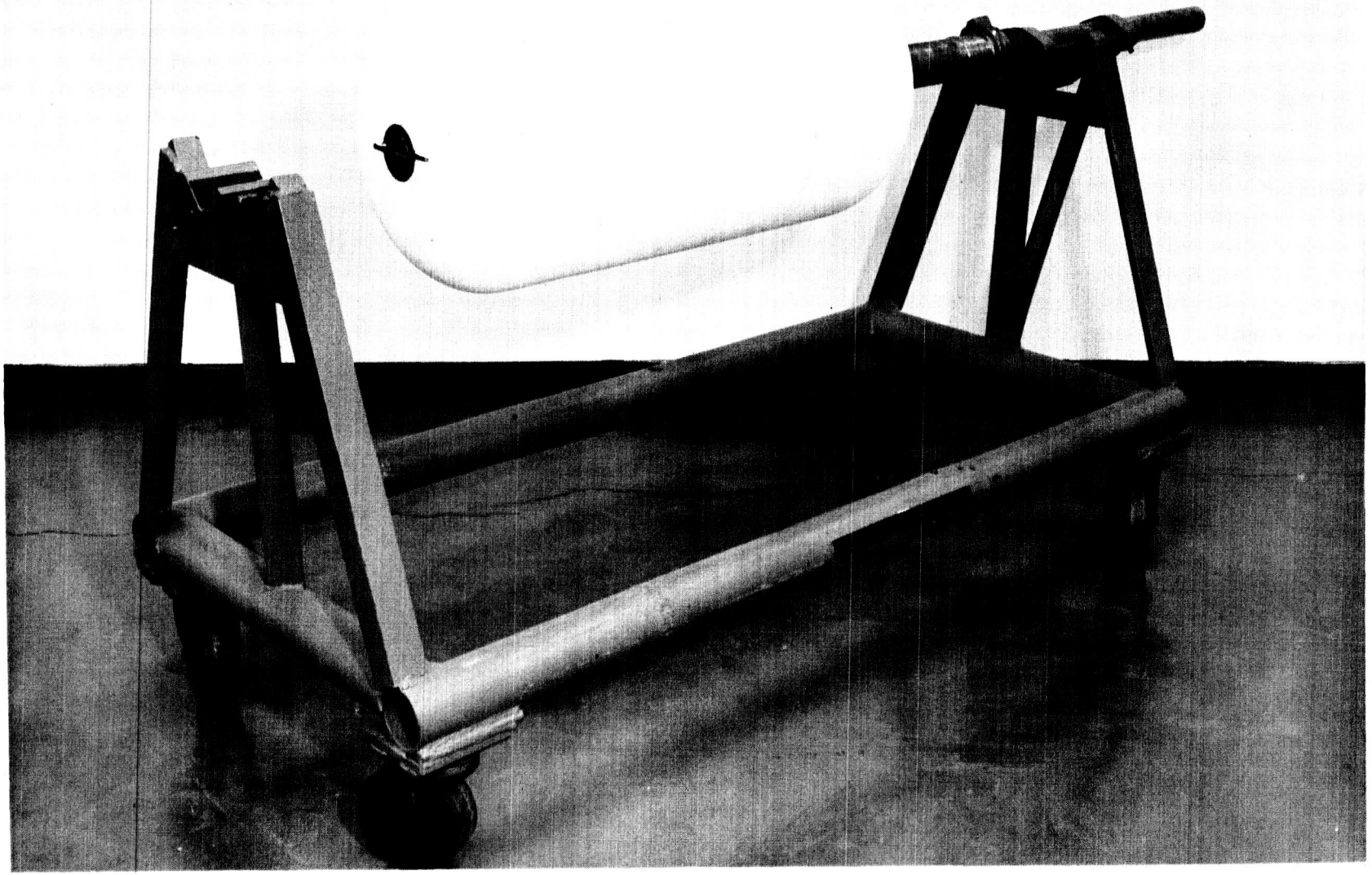


FIGURE 13 - MANDREL ASSEMBLY - BOTTOM END VIEW

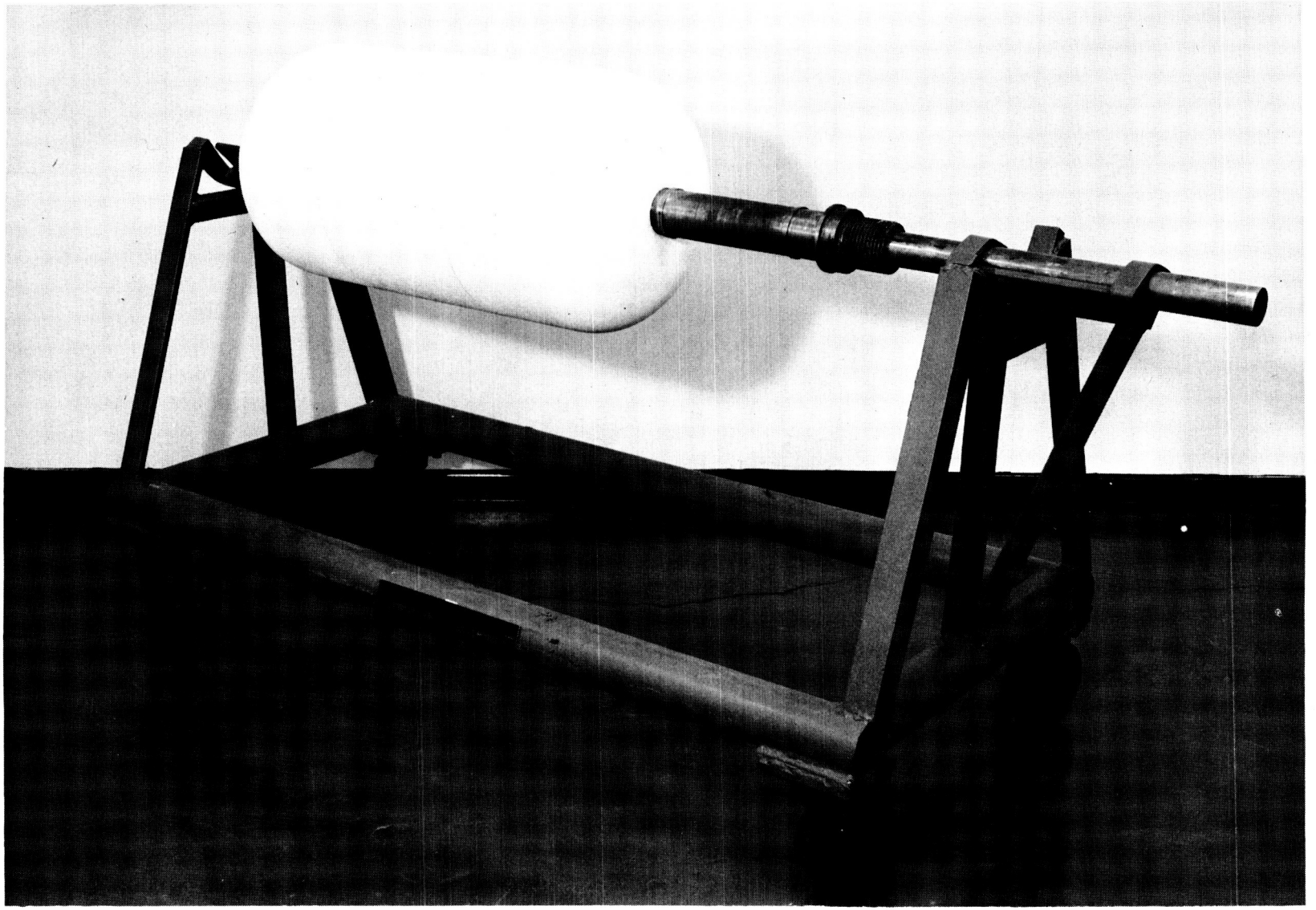


FIGURE 14 - MANDREL ASSEMBLY - TOP END VIEW

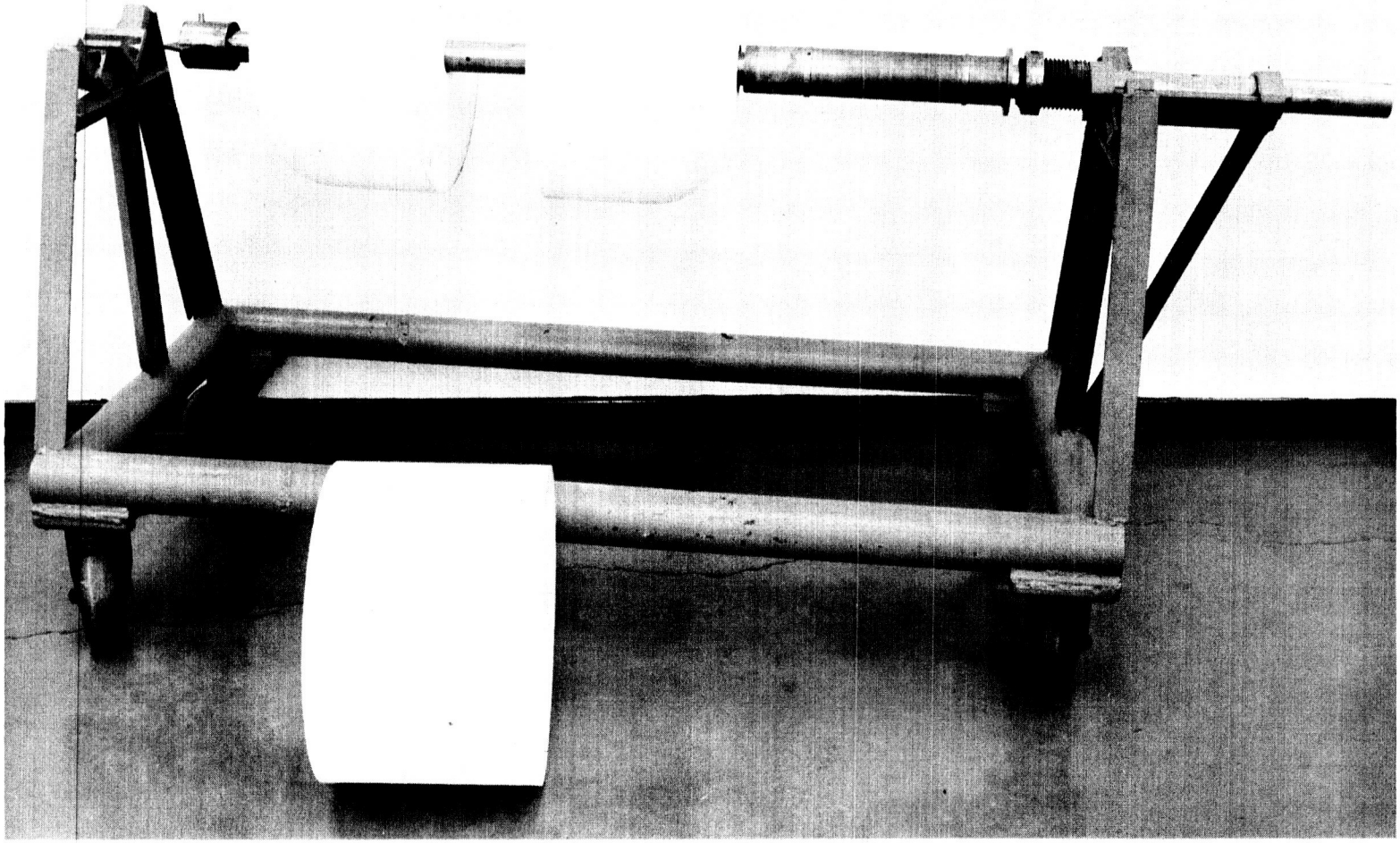


FIGURE 15 - MANDREL ASSEMBLY BREAKDOWN

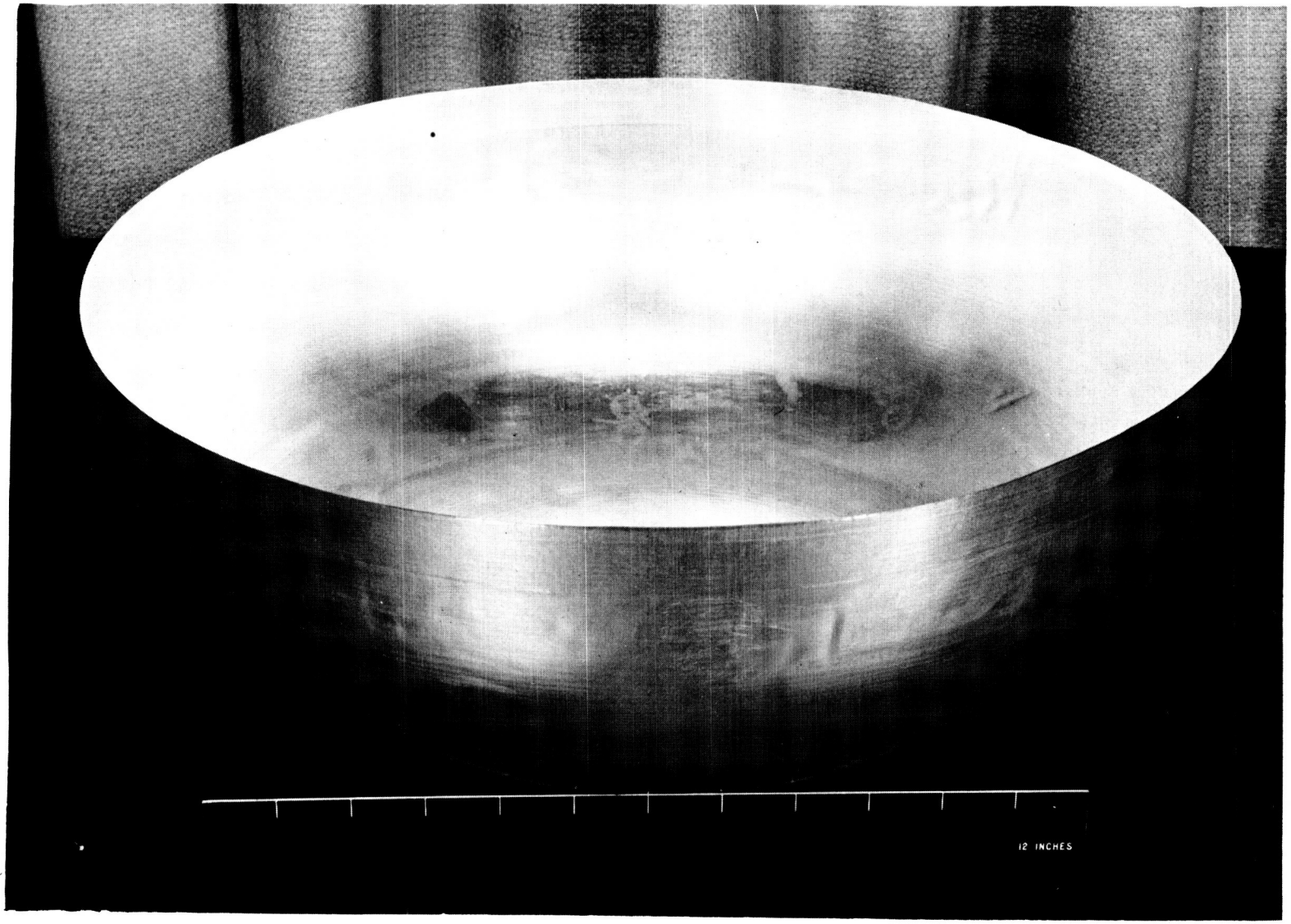


FIGURE 16 - AMA SPIN FORMED DOME

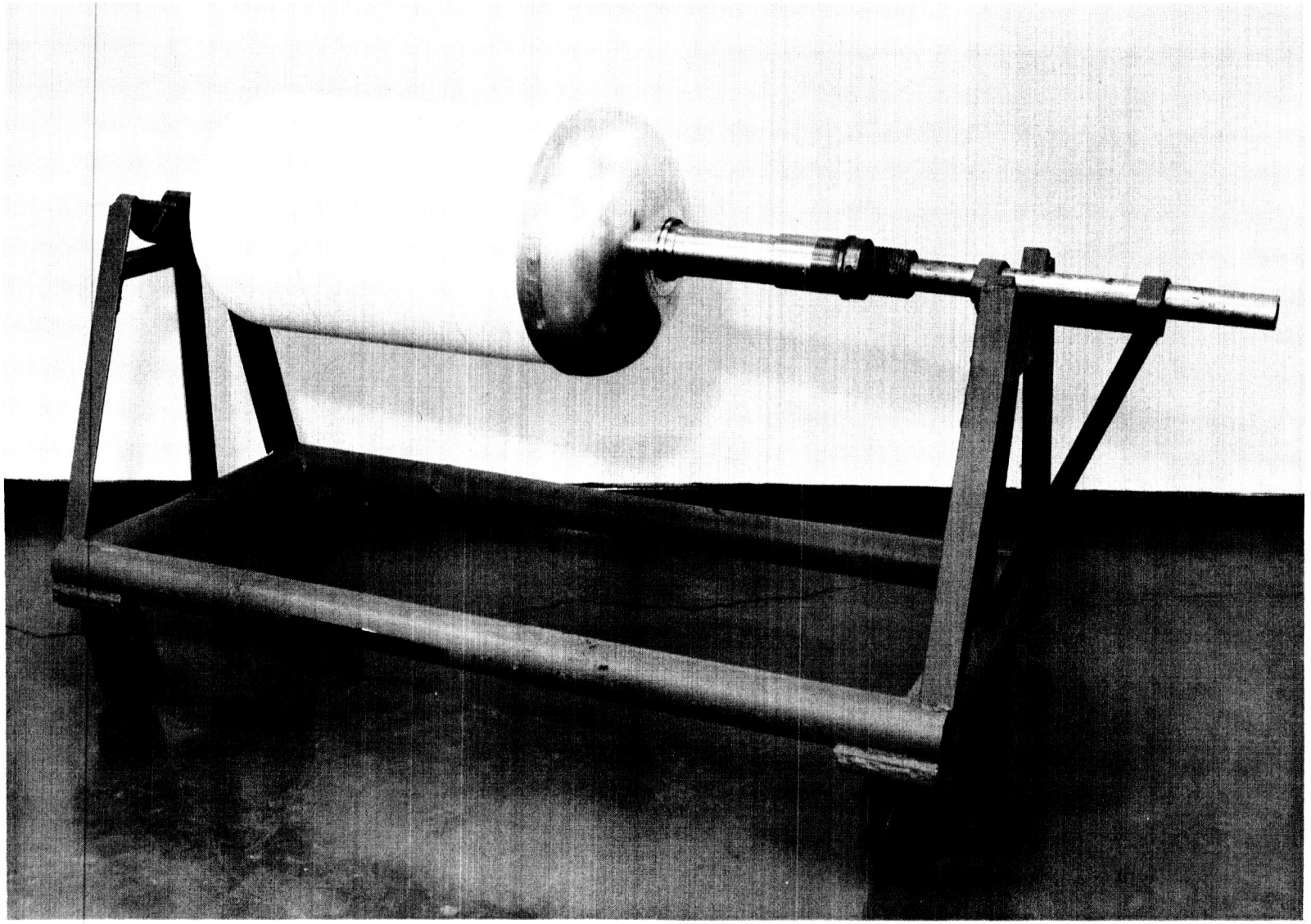


FIGURE 17 - TOP INSULATION DOME AND LINER ON MANDREL

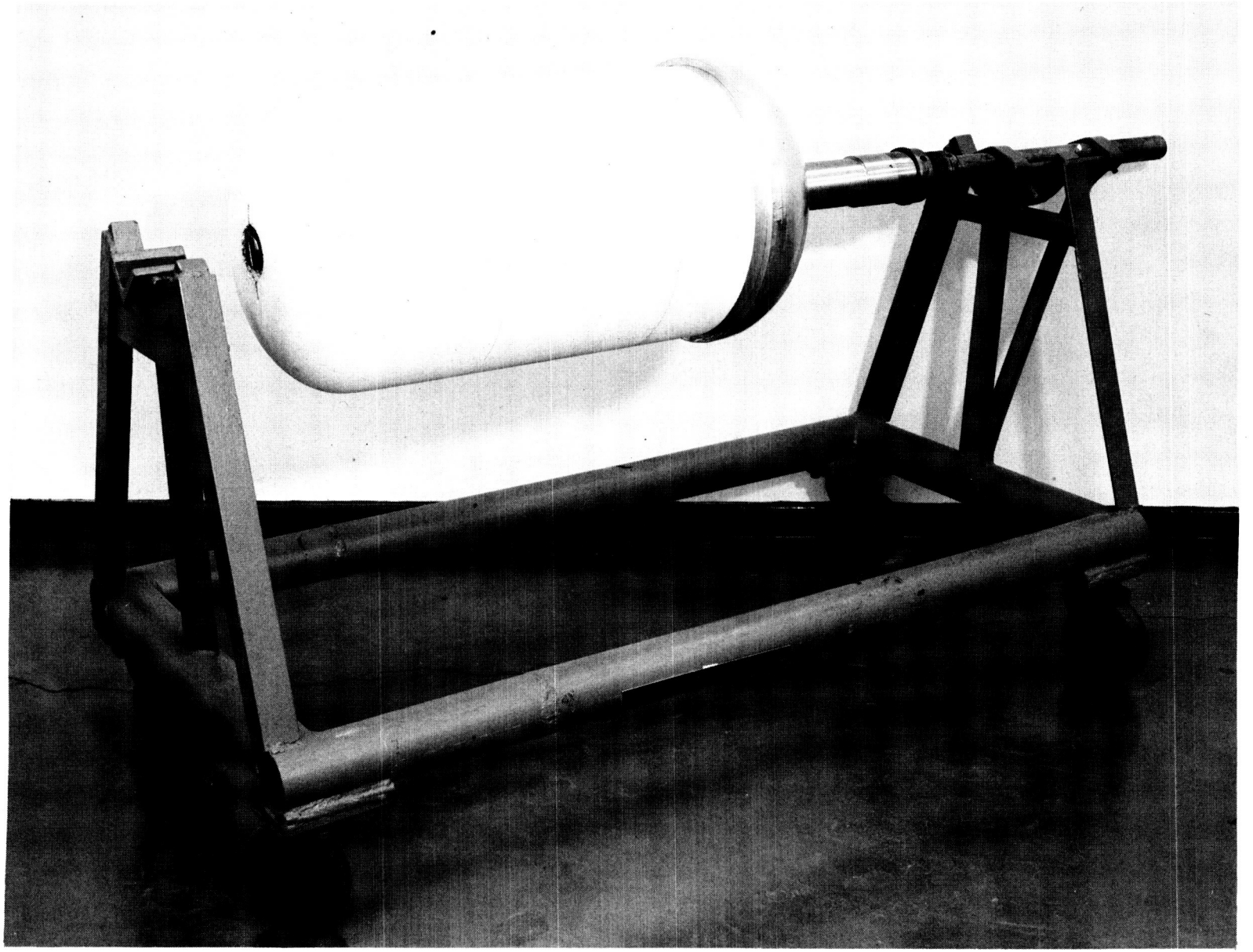


FIGURE 18 - TOP INSULATION DOME AND LINER ON MANDREL

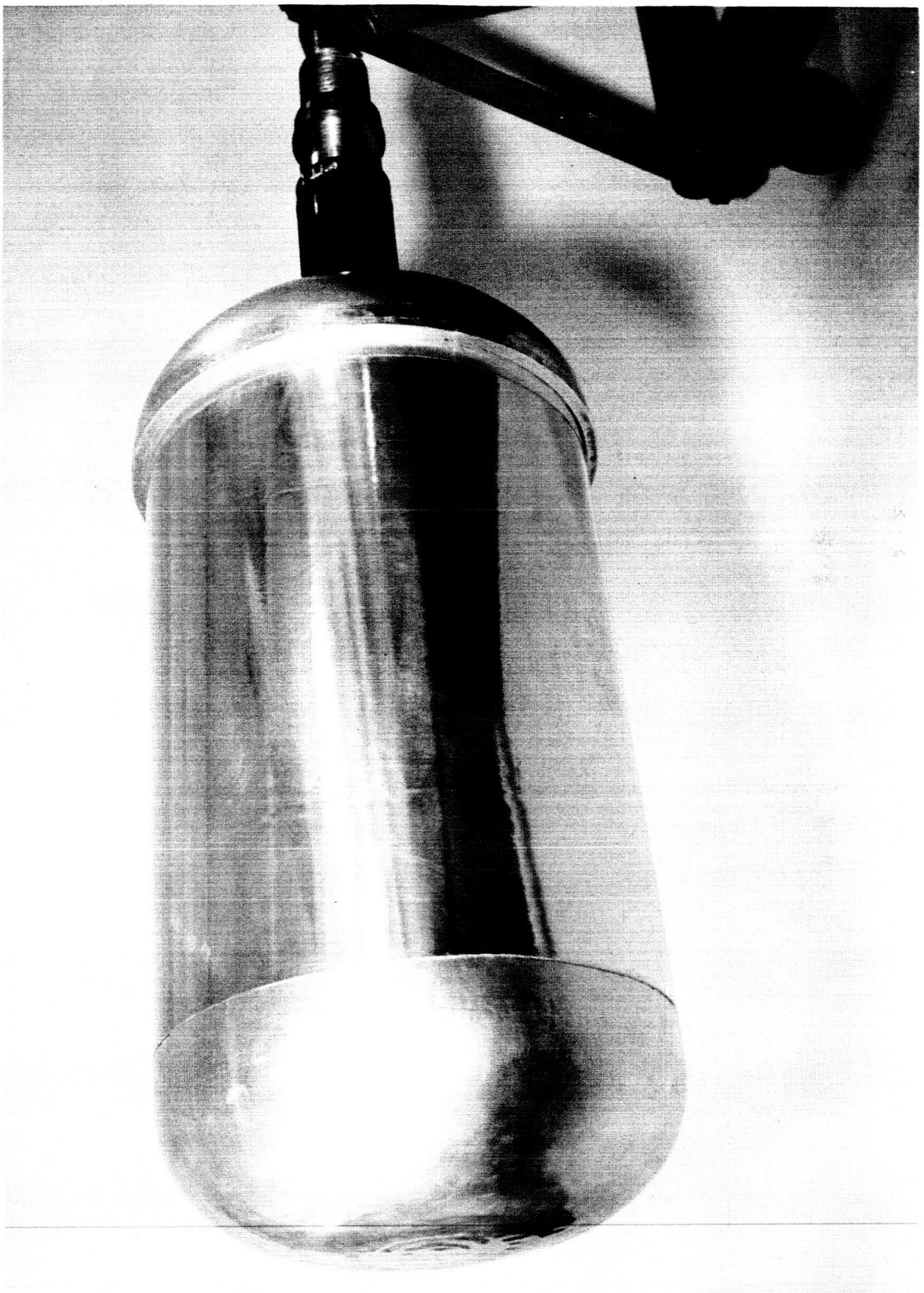


FIGURE 19 - CRYOGENIC LINER ASSEMBLY ON MANDREL

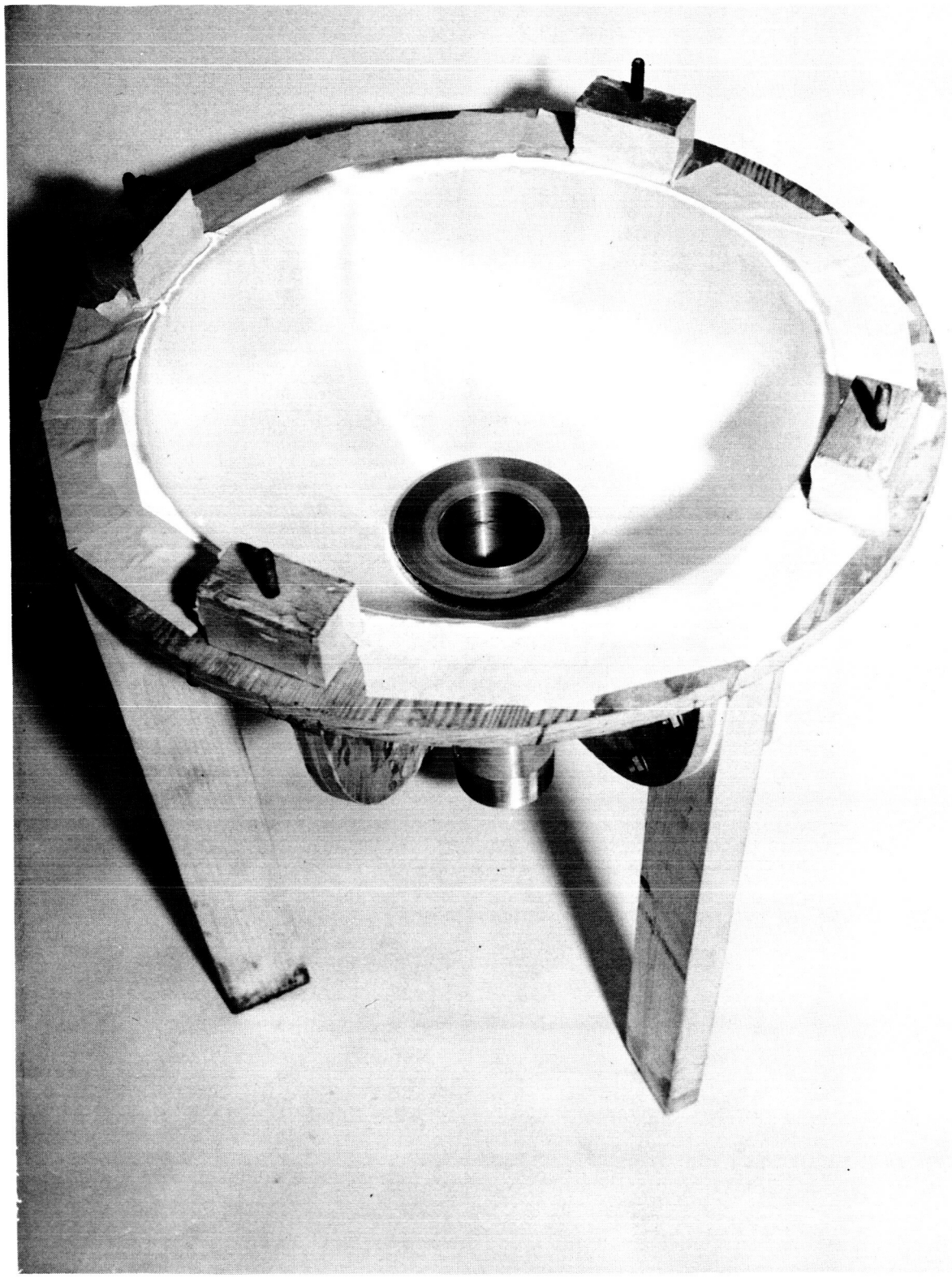


FIGURE 20 - BLEEDER PLY - OUTER VACUUM JACKET - TOP DOME INSULATION

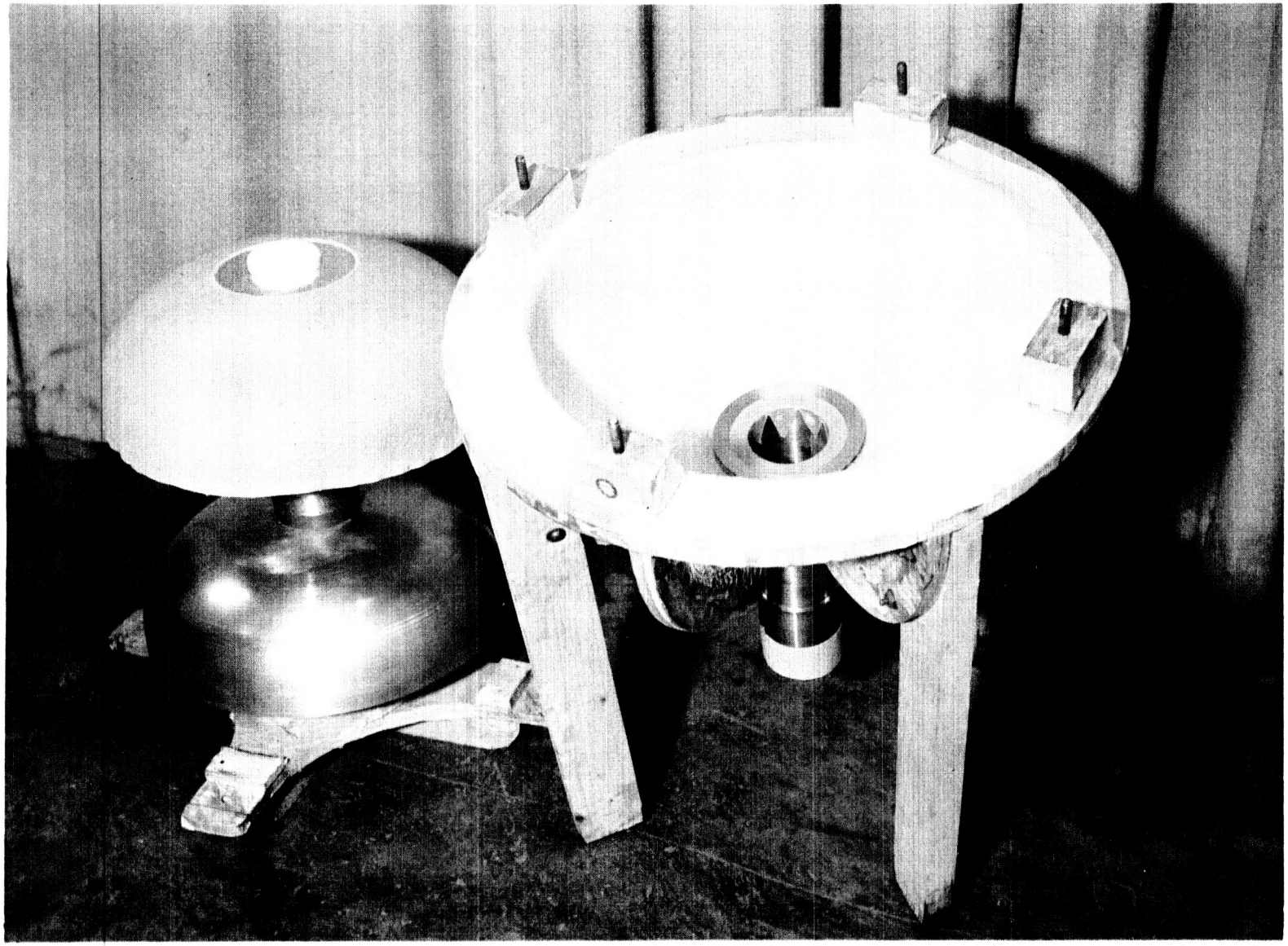


FIGURE 21 - BARRIER FILM - VACUUM JACKETS TOP DOME INSULATION

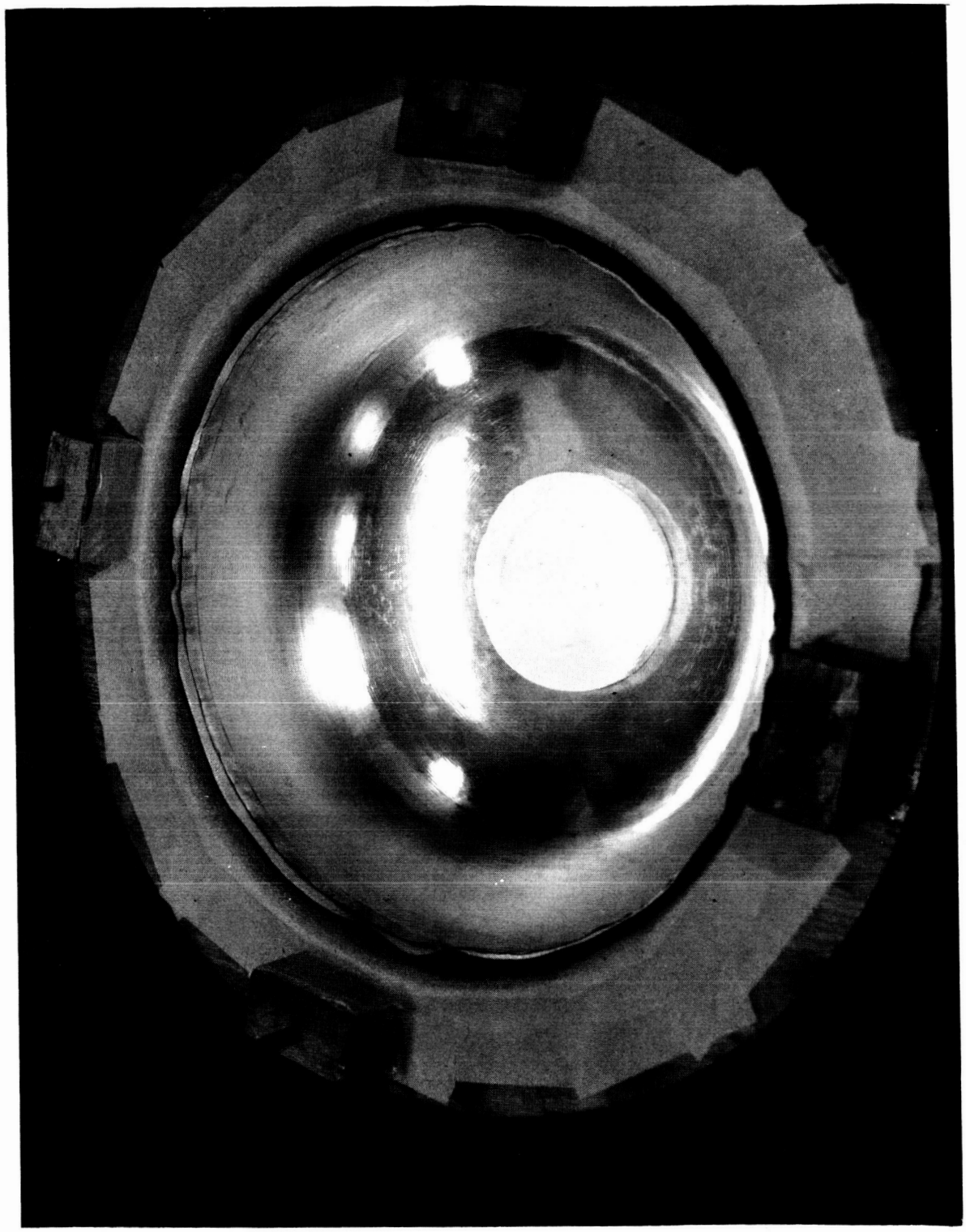


FIGURE 22- INNER VACUUM JACKET BONDING TO FILL NECK

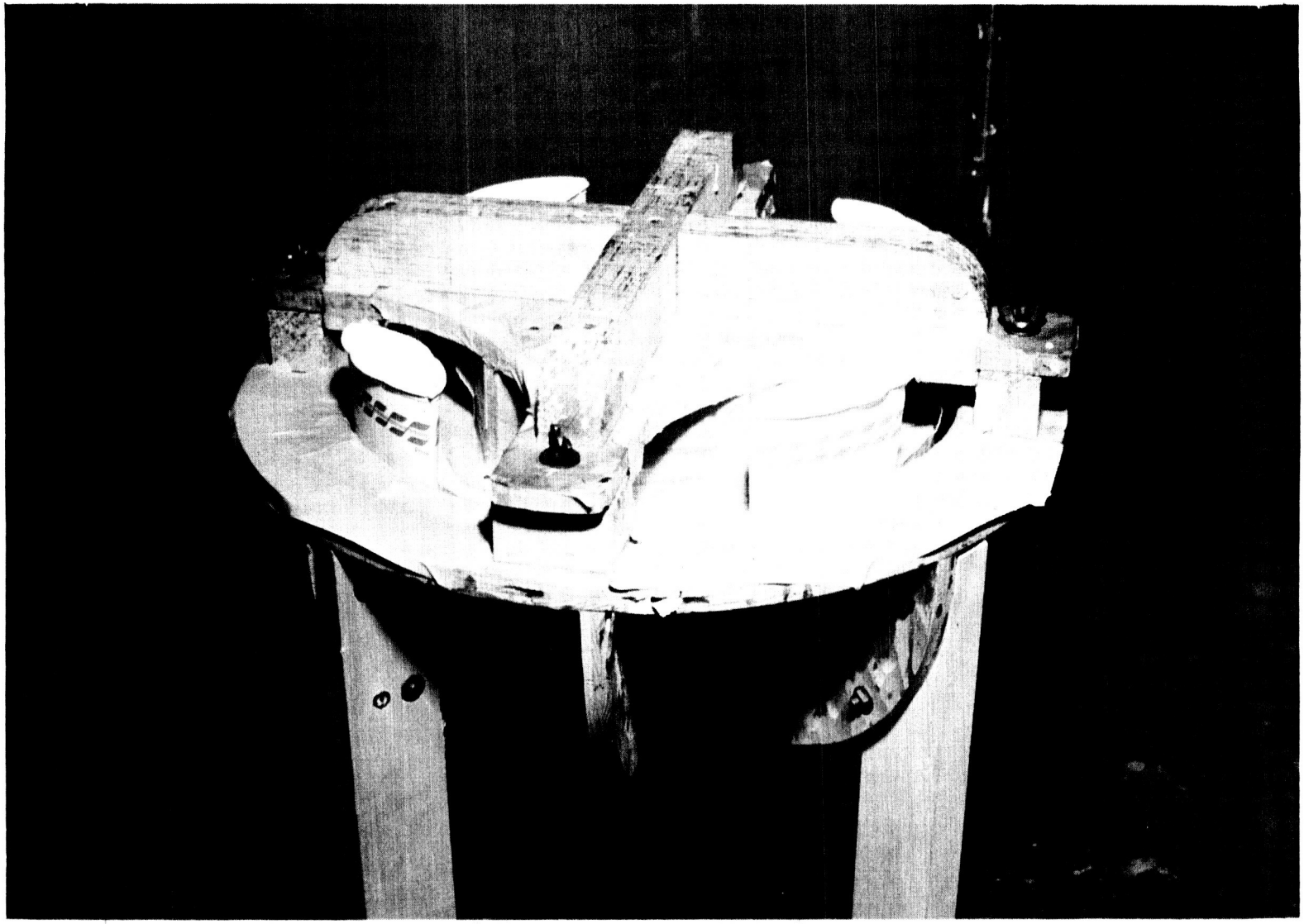


FIGURE 23 - DOME INSULATION FOAM POUR SETUP

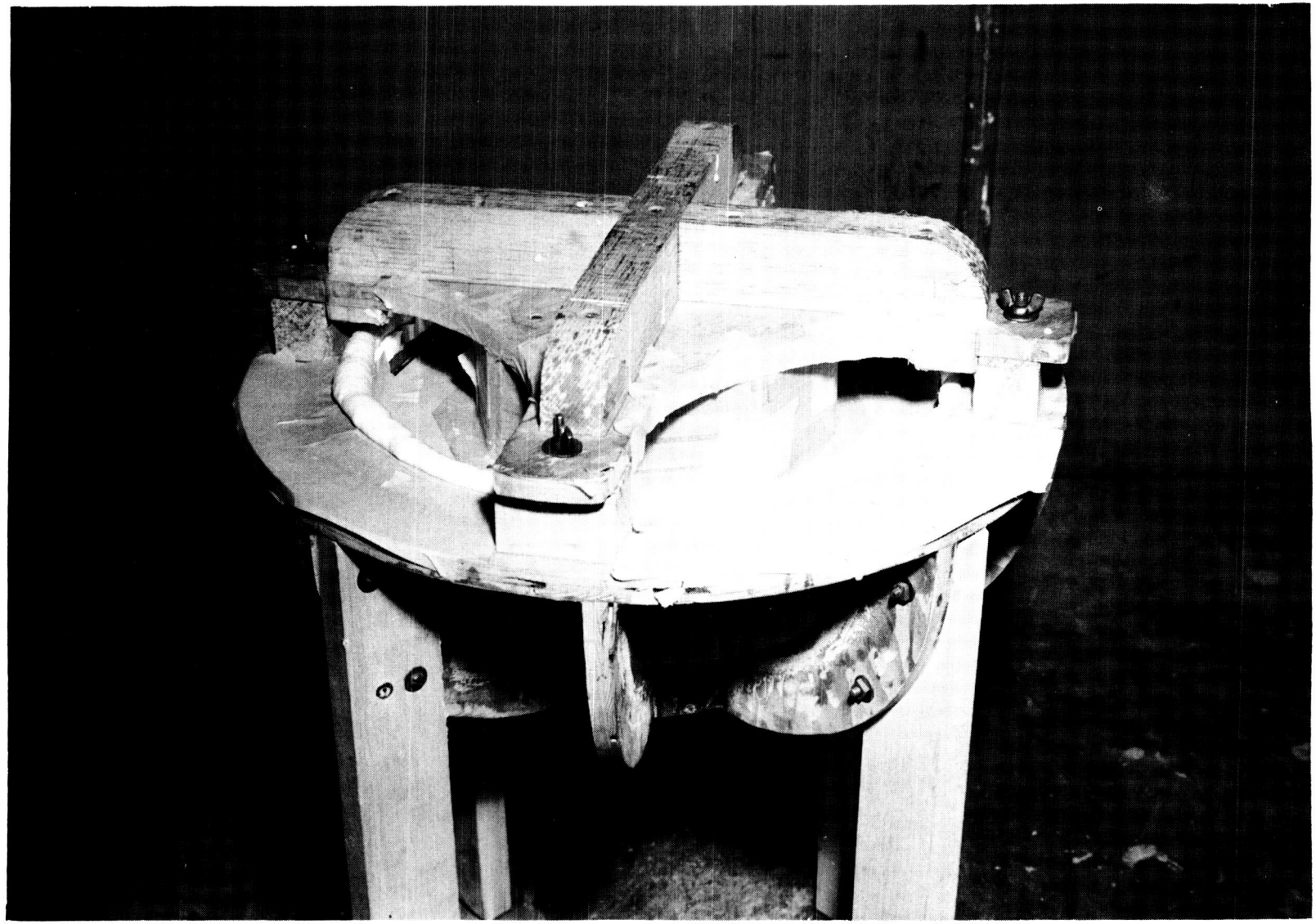


FIGURE 24 - DOME INSULATION FOAM RISE

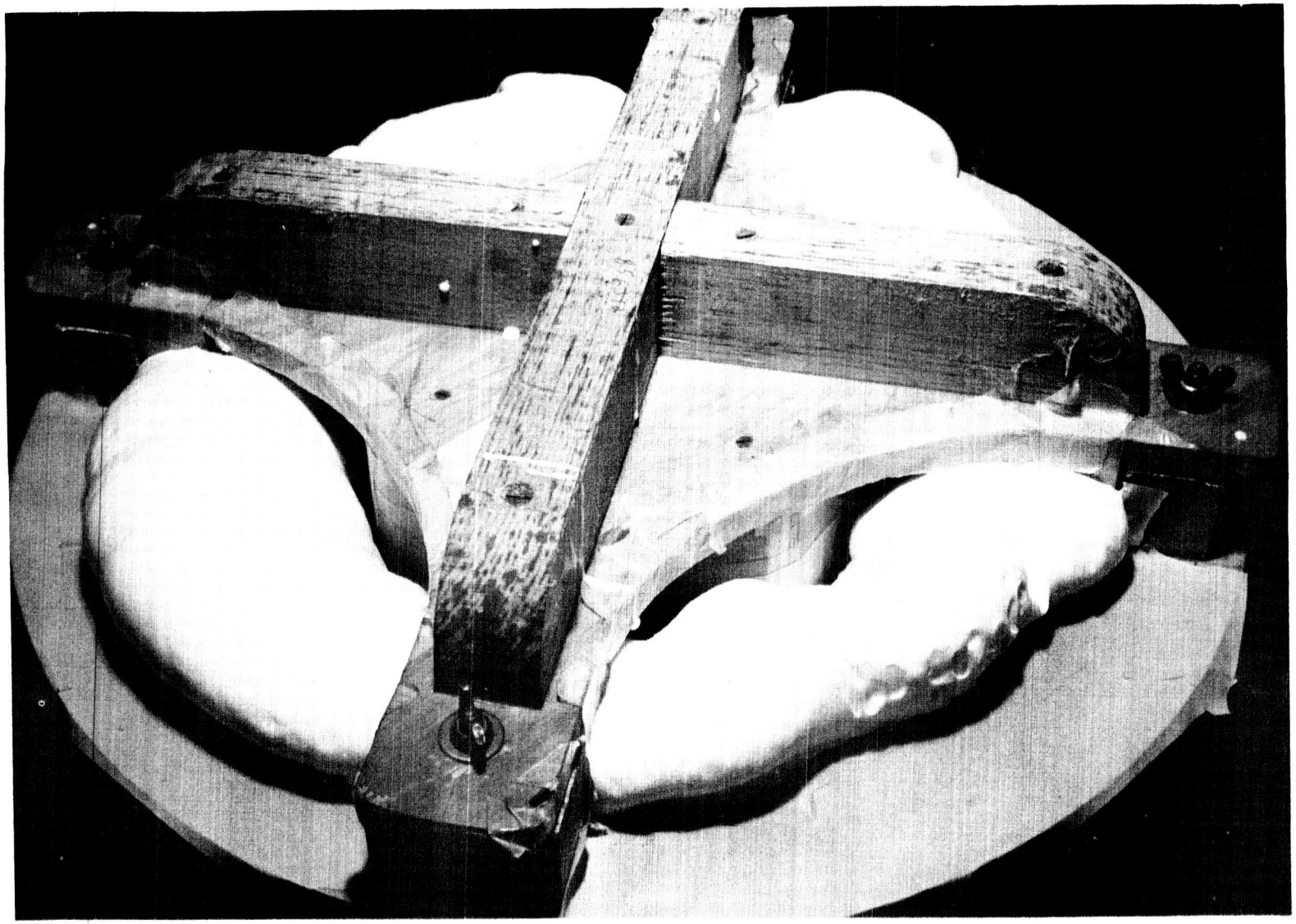


FIGURE 25 - DOME INSULATION FOAM OVERFLOW

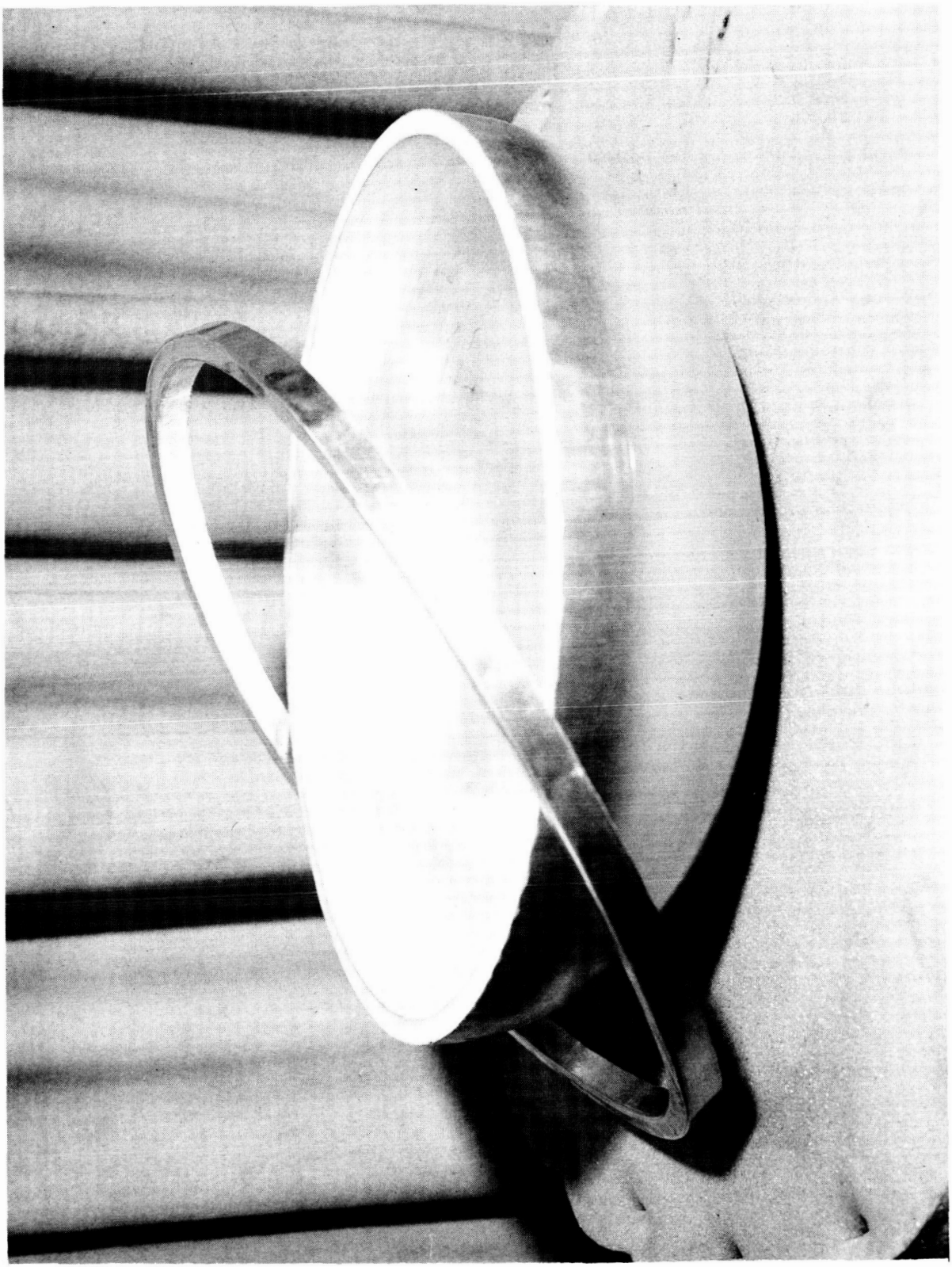


FIGURE 26 - TOP DOME INSULATION AND BASE CHANNEL

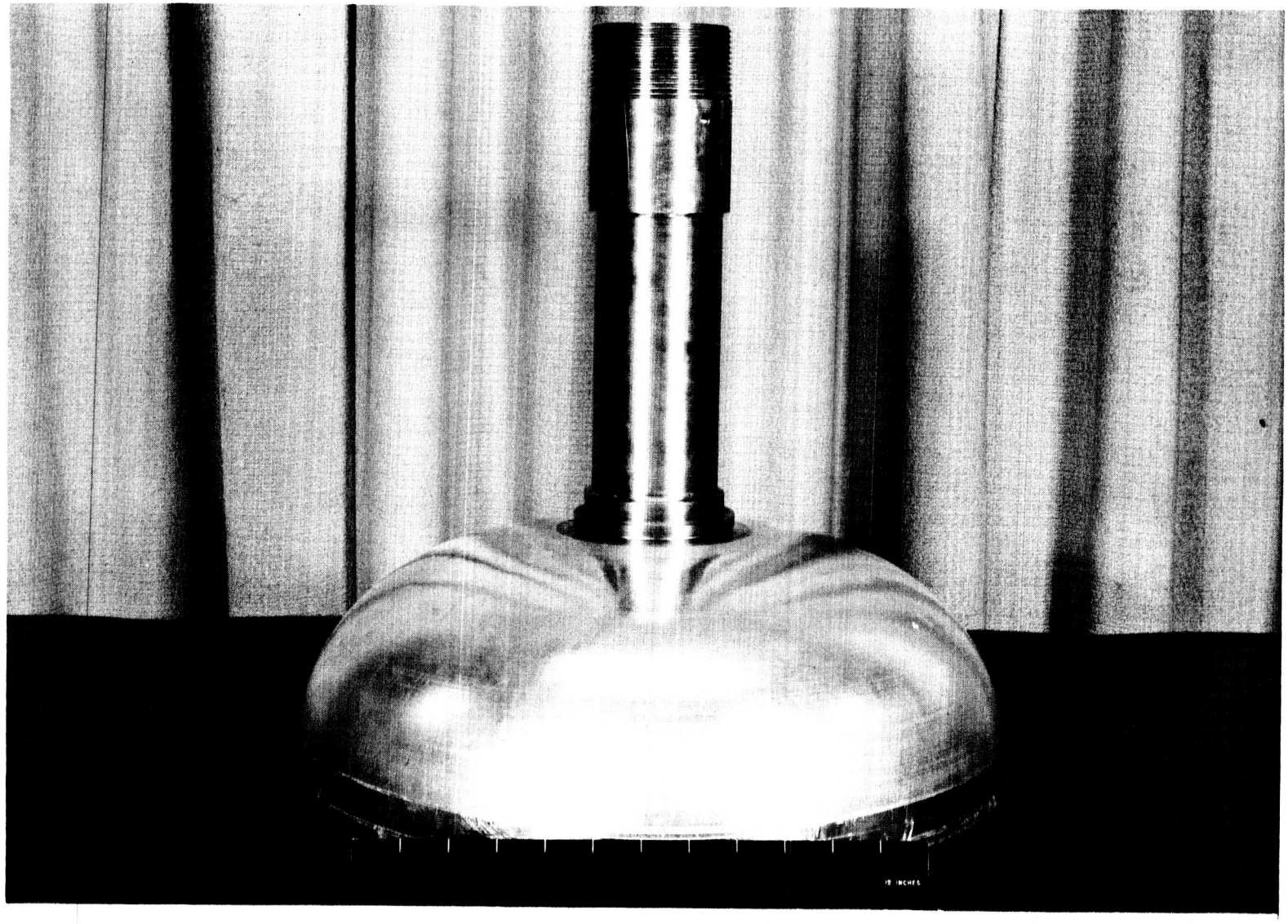


FIGURE 27 - TOP DOME INSULATION ASSEMBLY

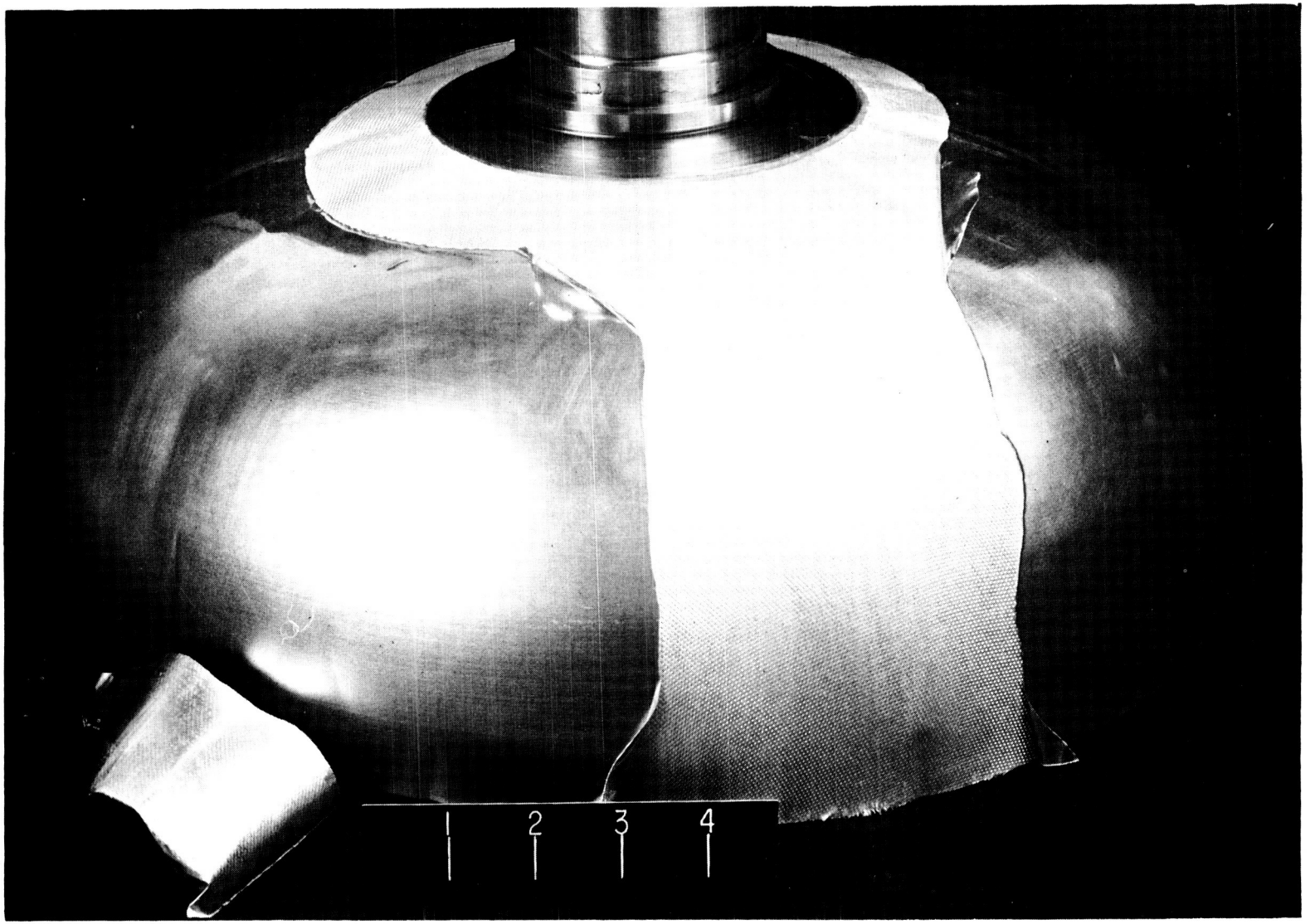


FIGURE 28 - TOP DOME INSULATION - OUTER VACUUM JACKET PEELED AWAY TO EXPOSE BLEEDER PLY

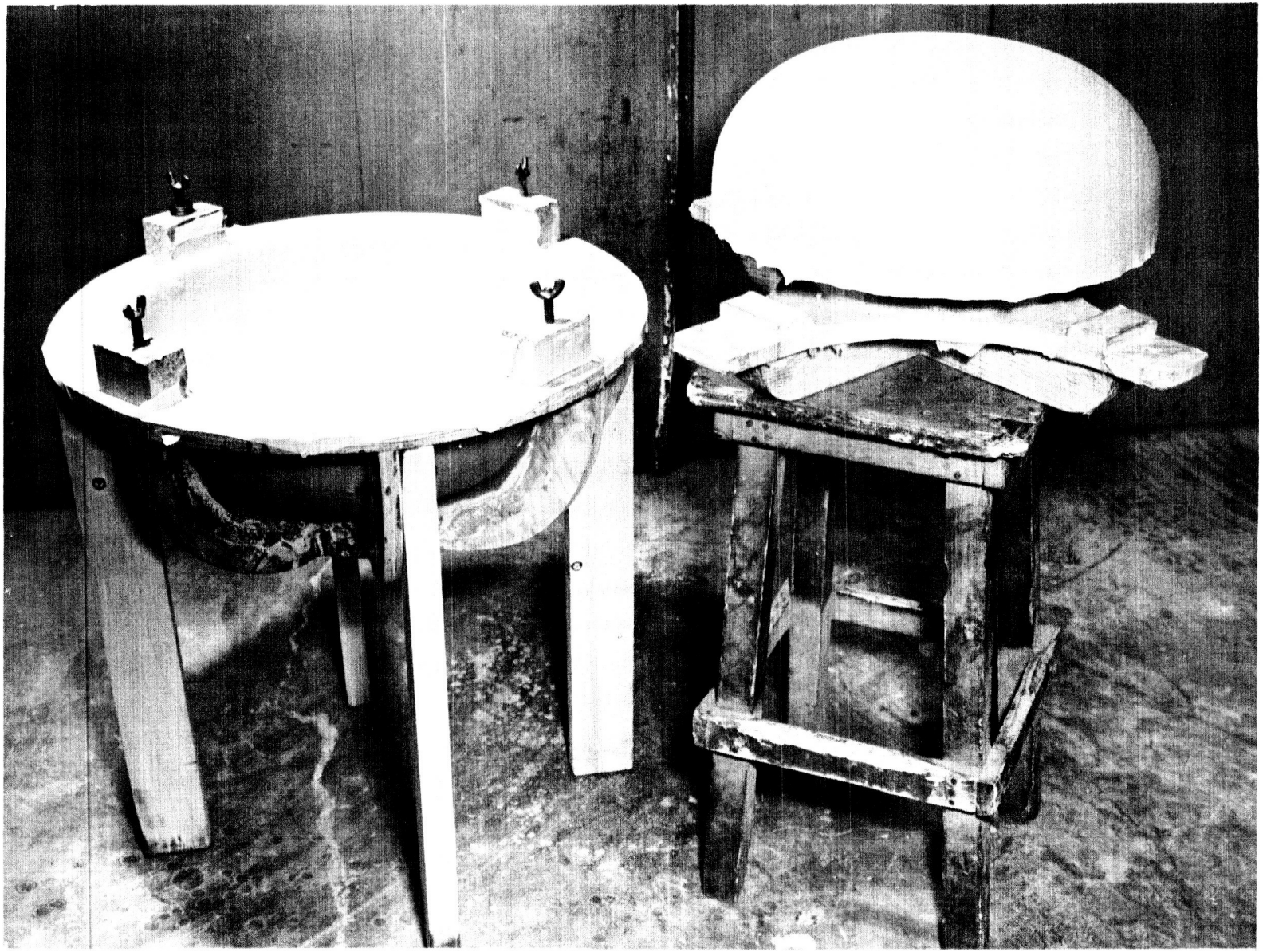


FIGURE 29 - BOTTOM INSULATION DOME - BARRIER FILM ON VACUUM JACKETS

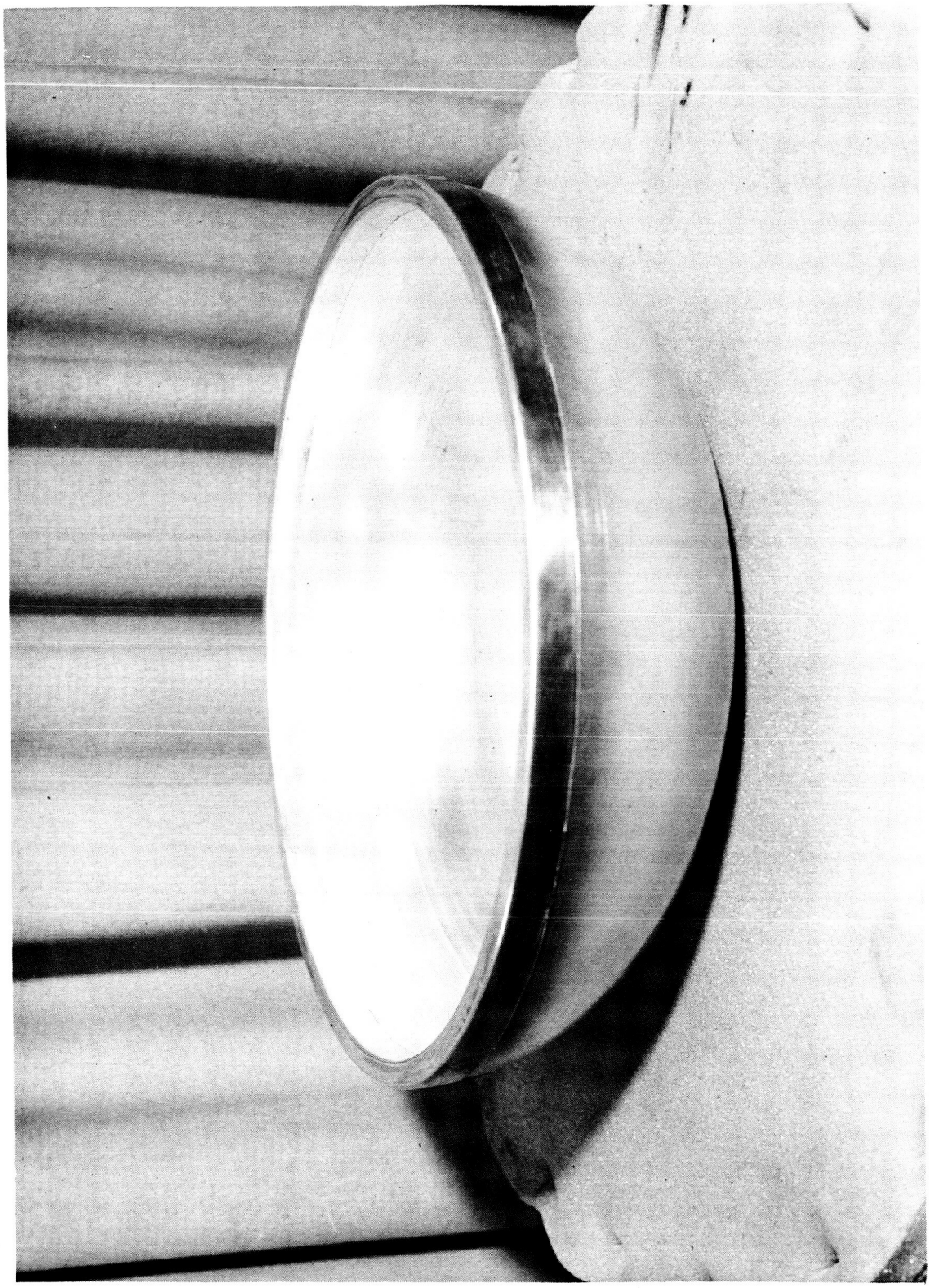


FIGURE 30 - BOTTOM INSULATION DOME ASSEMBLY

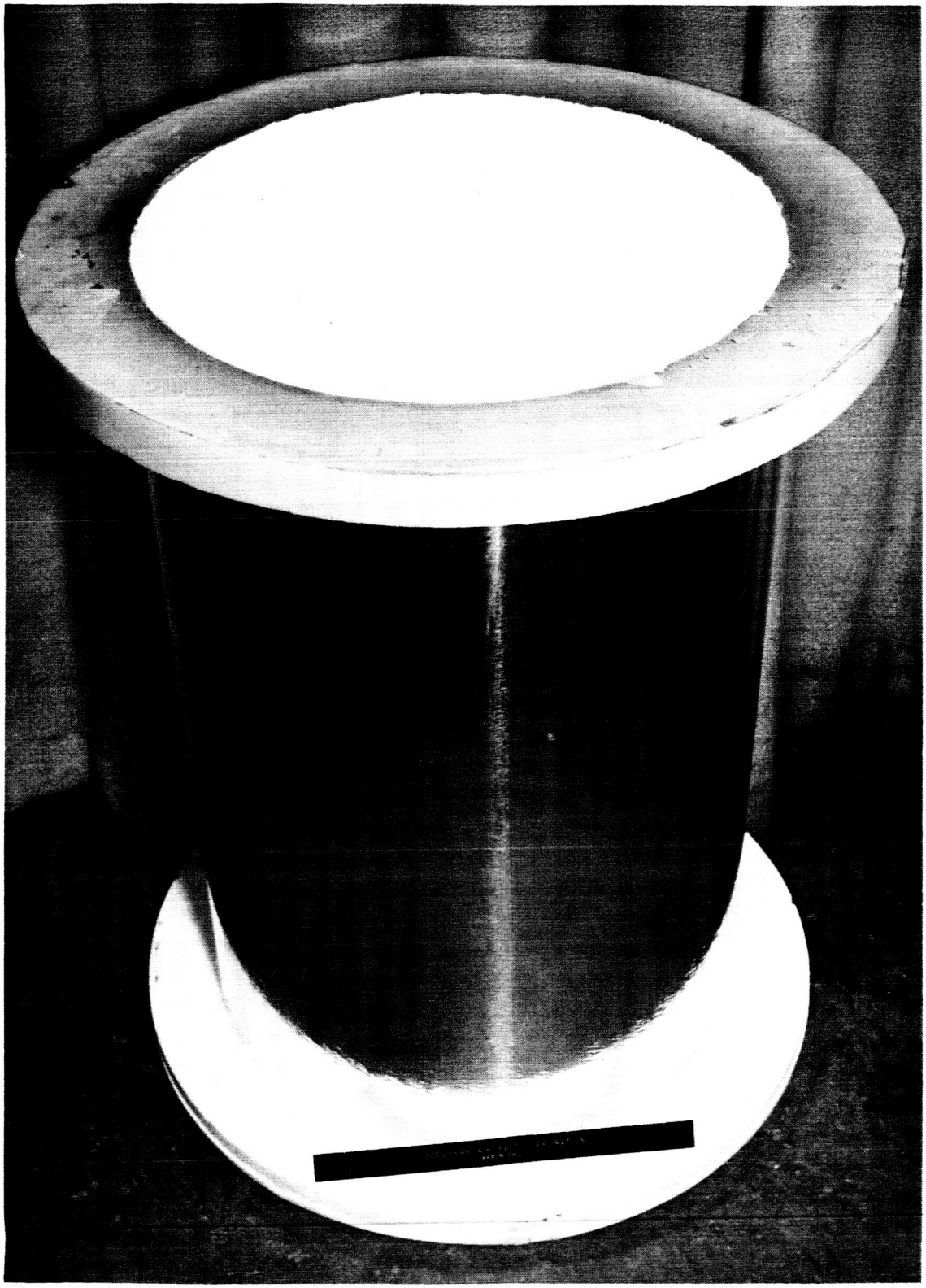


FIGURE 31 - CYLINDER SECTION INSULATION BEFORE FINAL TRIM

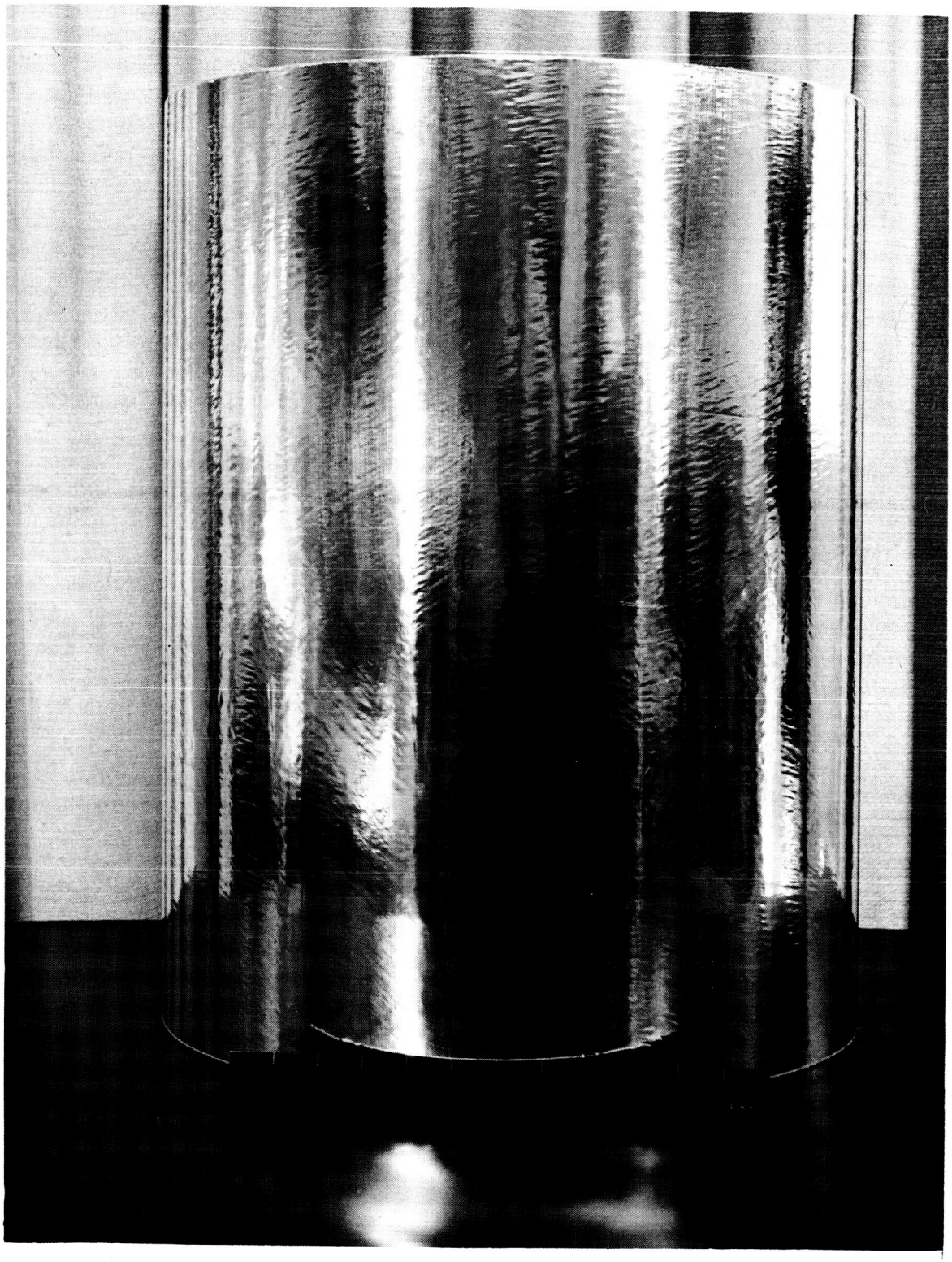


FIGURE 32 - CYLINDER SECTION INSULATION AFTER FINAL TRIM

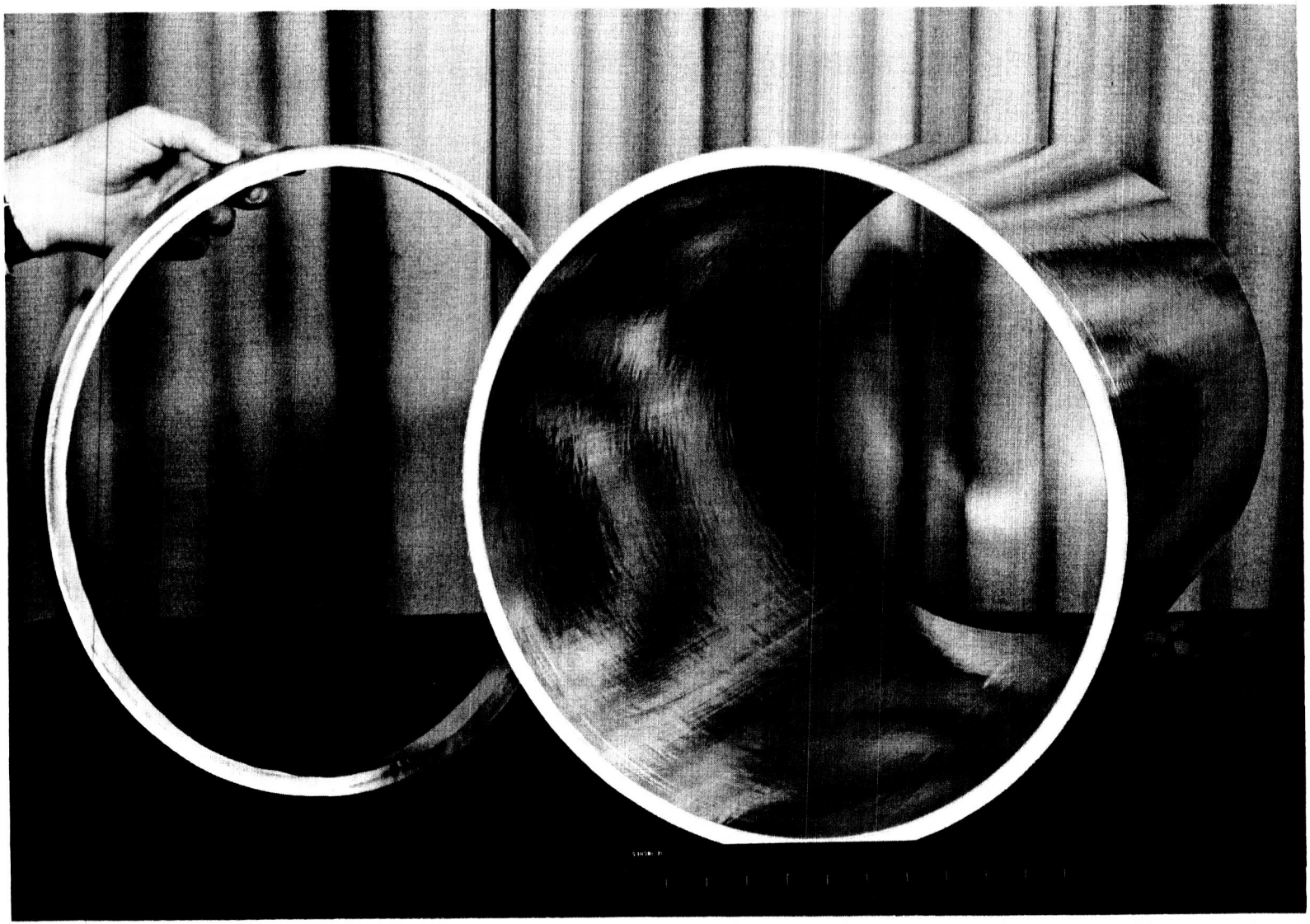


FIGURE 33 - CYLINDER SECTION INSULATION AND END CHANNEL

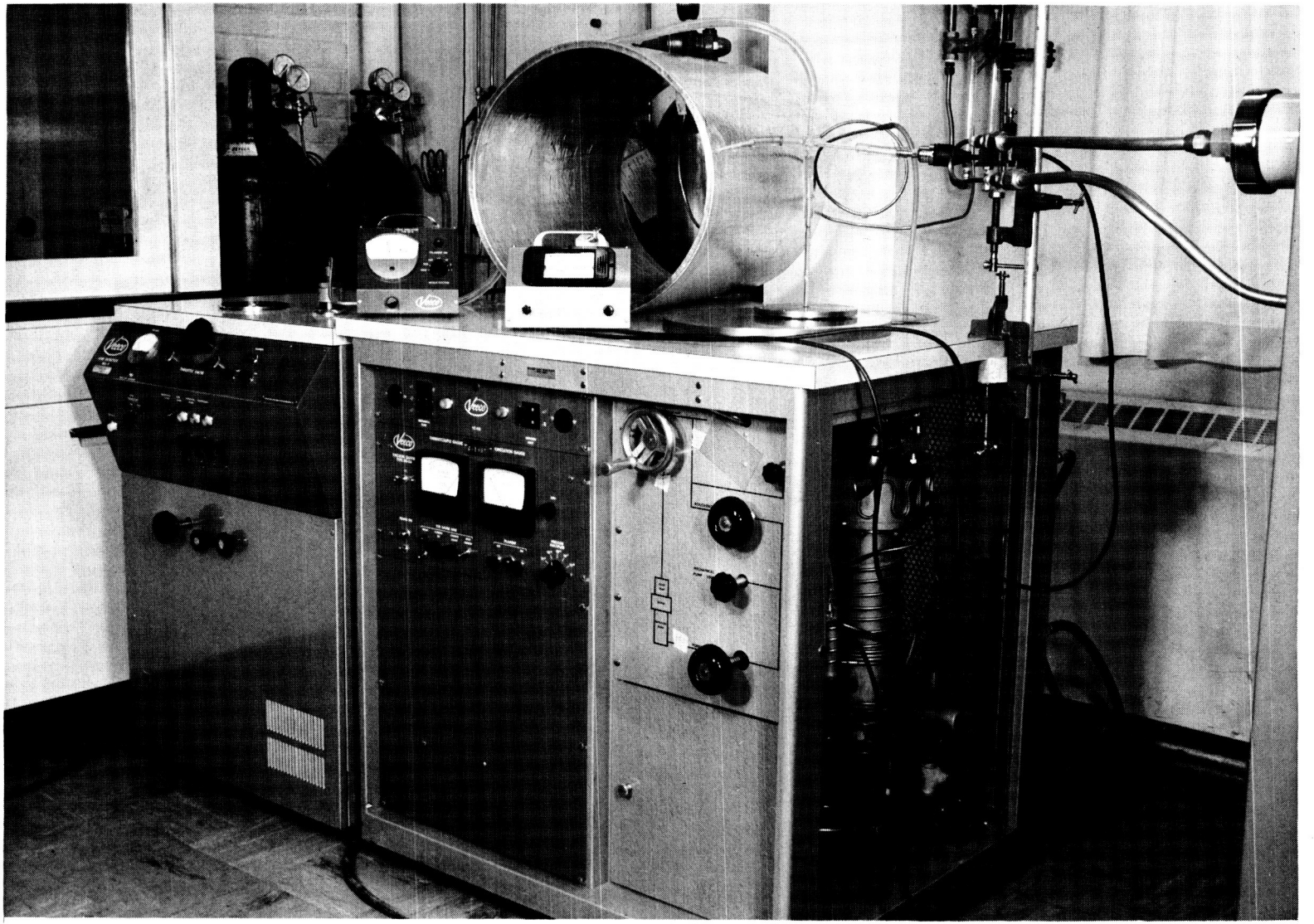


FIGURE 34 - LEAK TEST - CYLINDER SECTION INSULATION

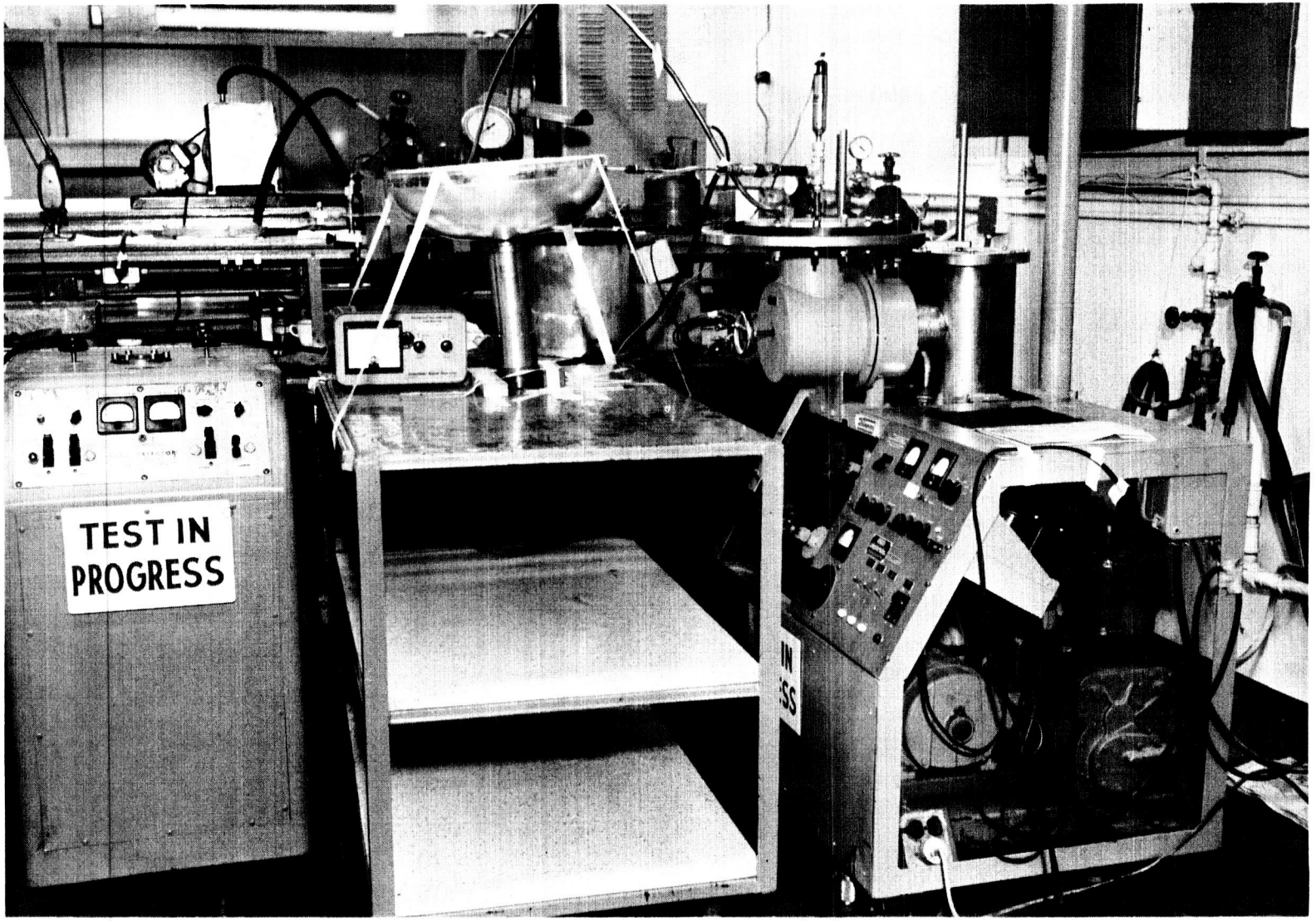


FIGURE 35 - LEAK TEST - TOP INSULATION DOME

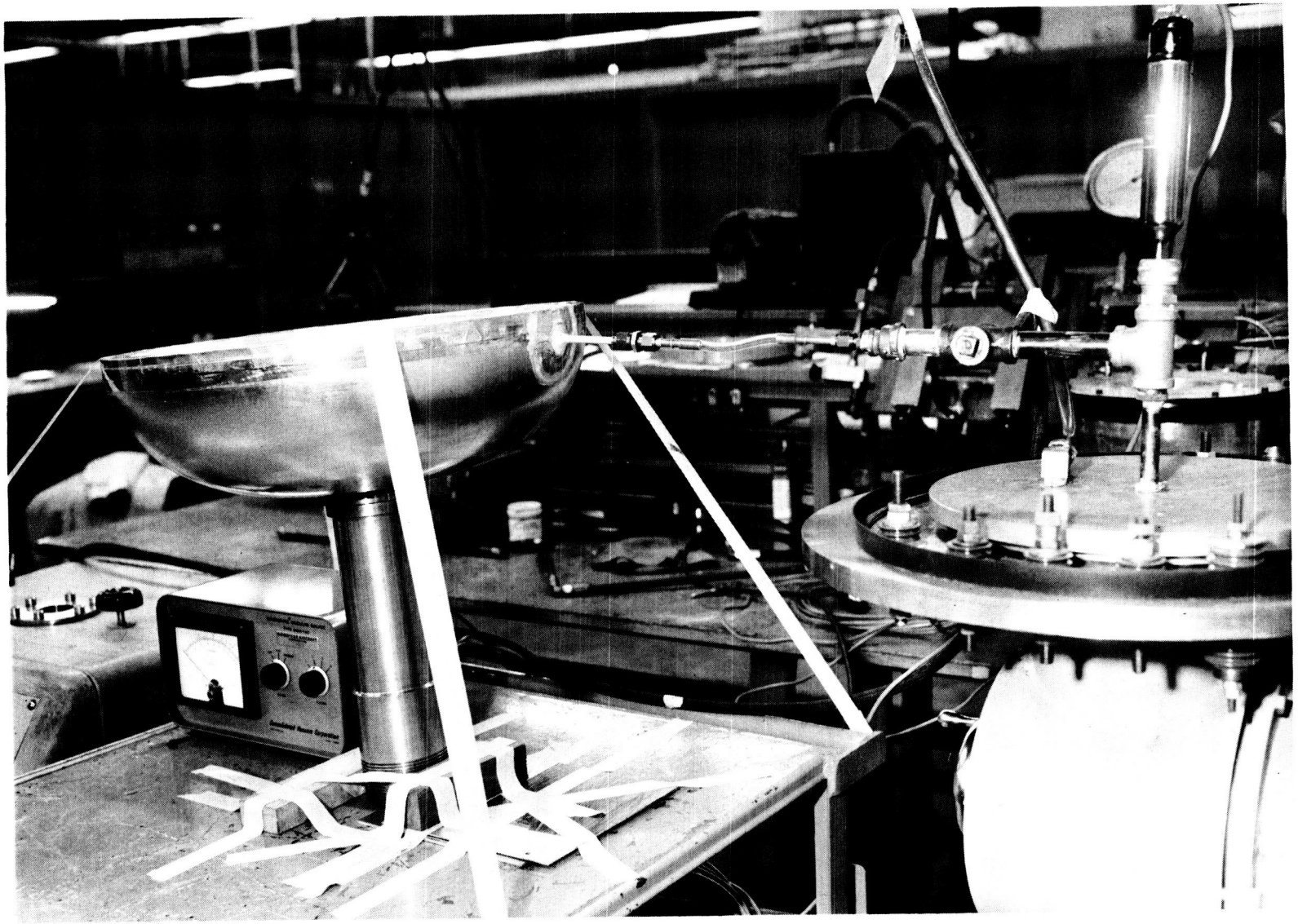


FIGURE 36 - LEAK TEST - TOP INSULATION DOME - CLOSE UP

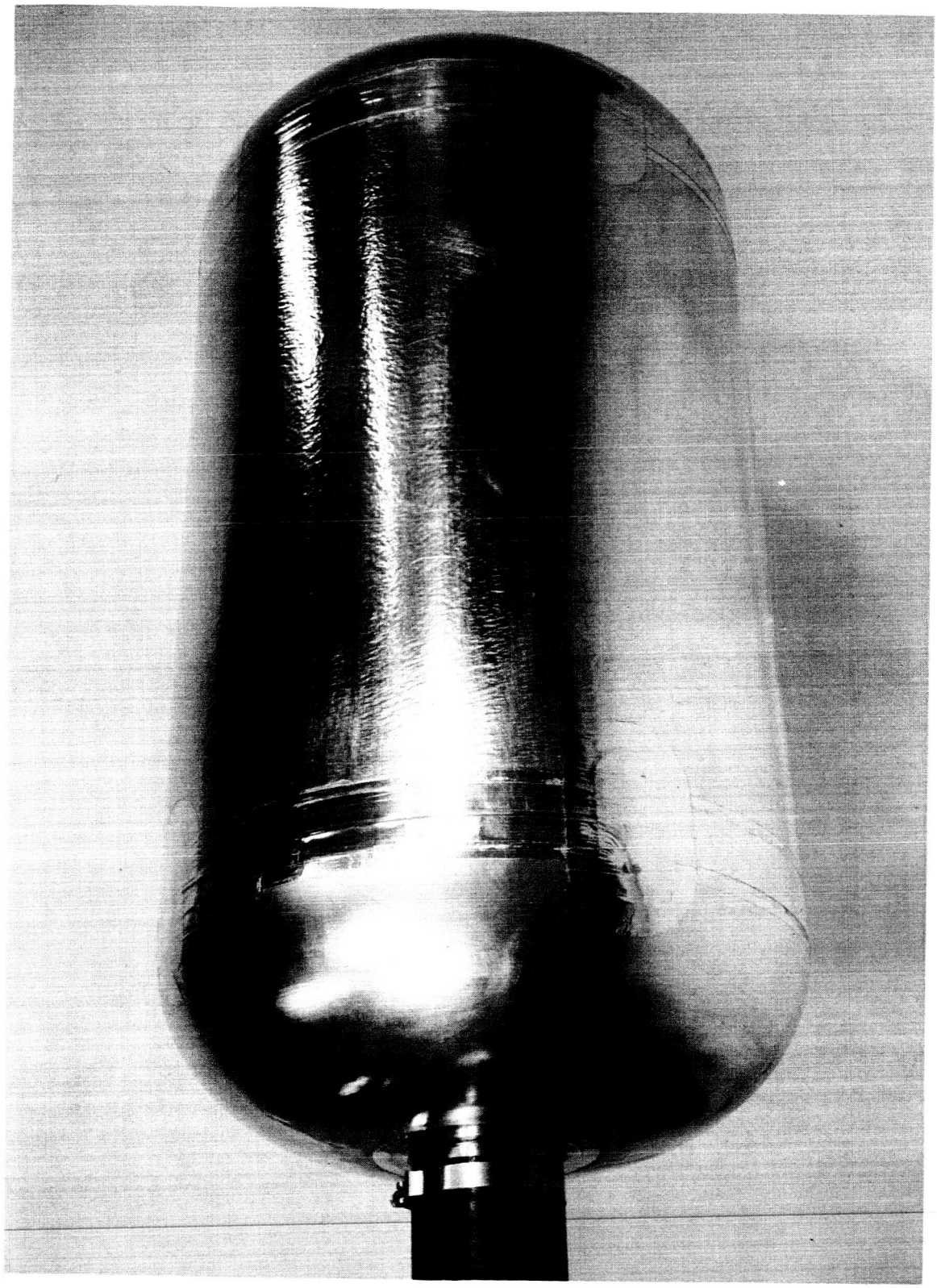


FIGURE 37 - INSULATION ASSEMBLY - VIEW OF TOP DOME END



FIGURE 38 - INSULATION ASSEMBLY - VIEW OF BOTTOM DOME END

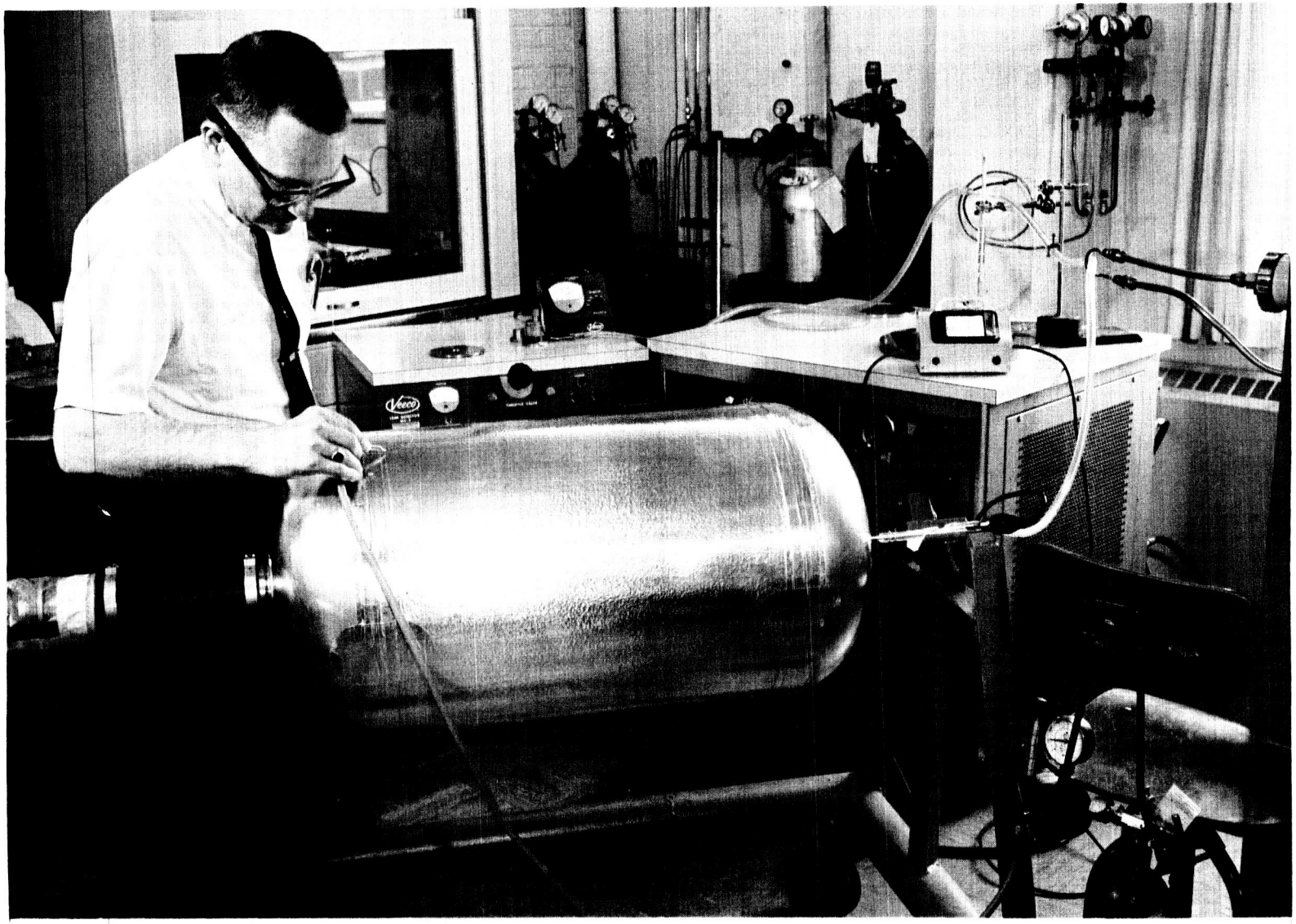


FIGURE 39 - LEAK TEST - INSULATION ASSEMBLY ON MANDREL

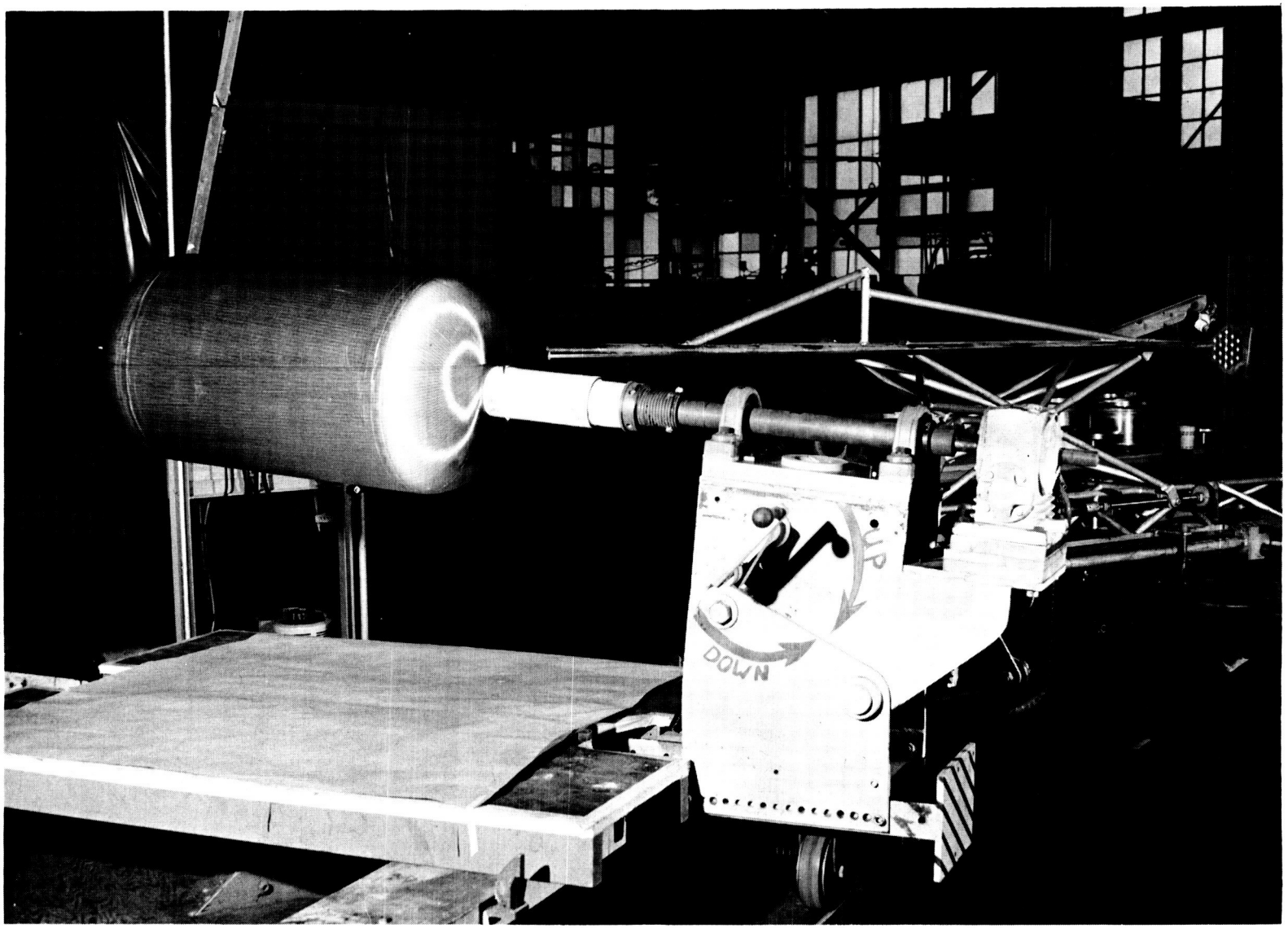


FIGURE 40 - FILAMENT WINDING MACHINE SET UP

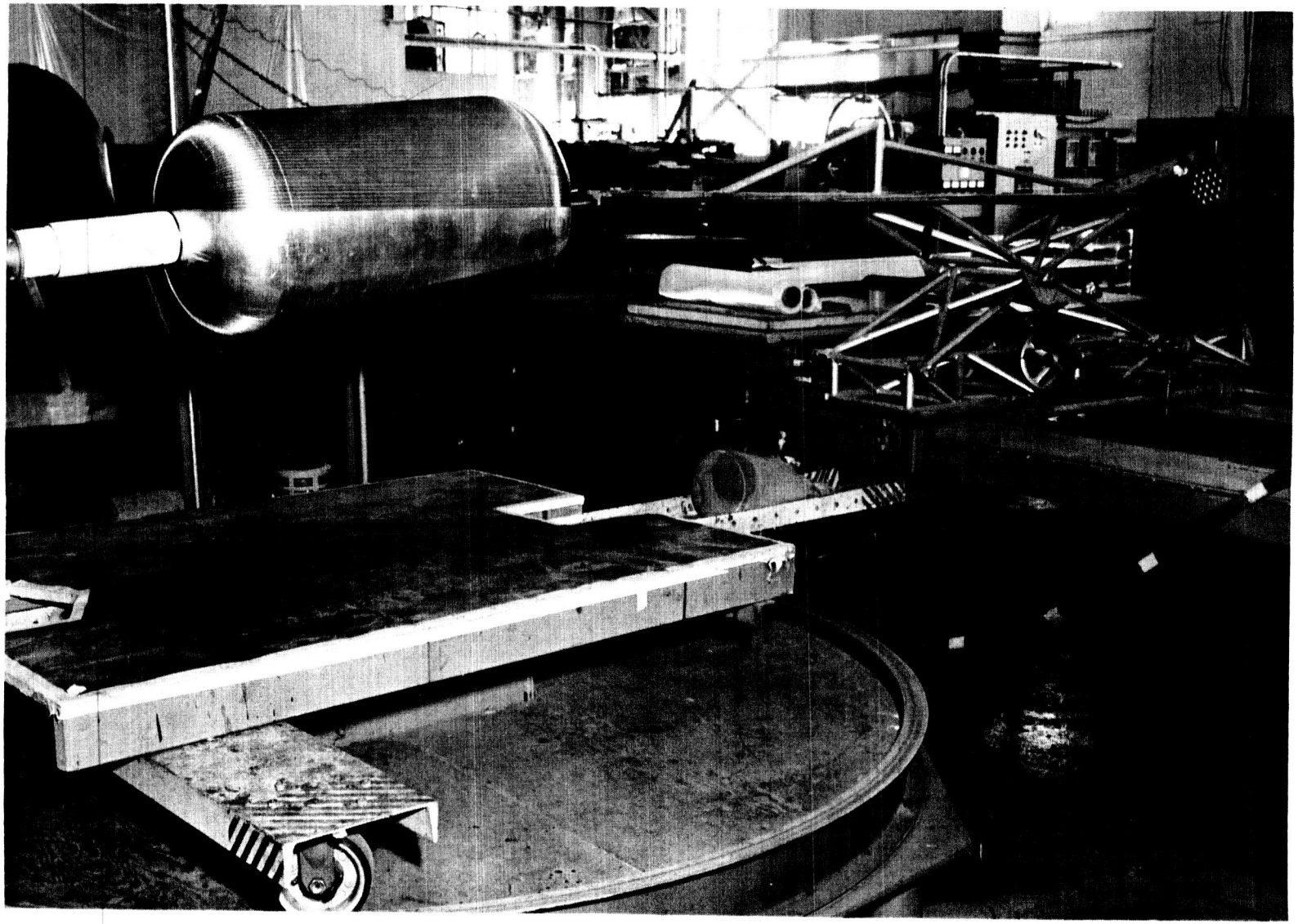


FIGURE 41 - FILAMENT WINDING LONGO WRAP OVER INSULATION

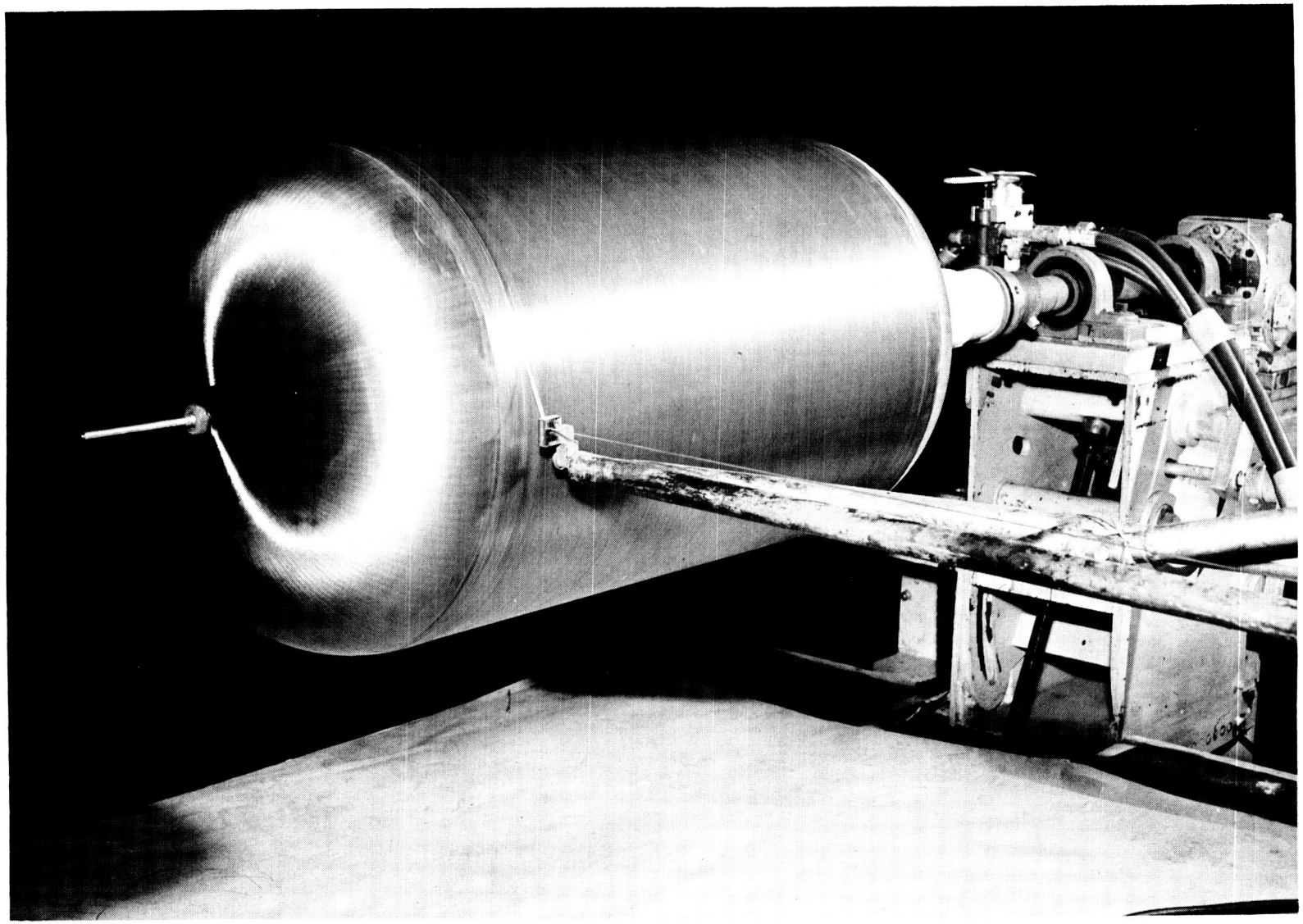


FIGURE 42 - FILAMENT WINDING CIRCO WRAPS

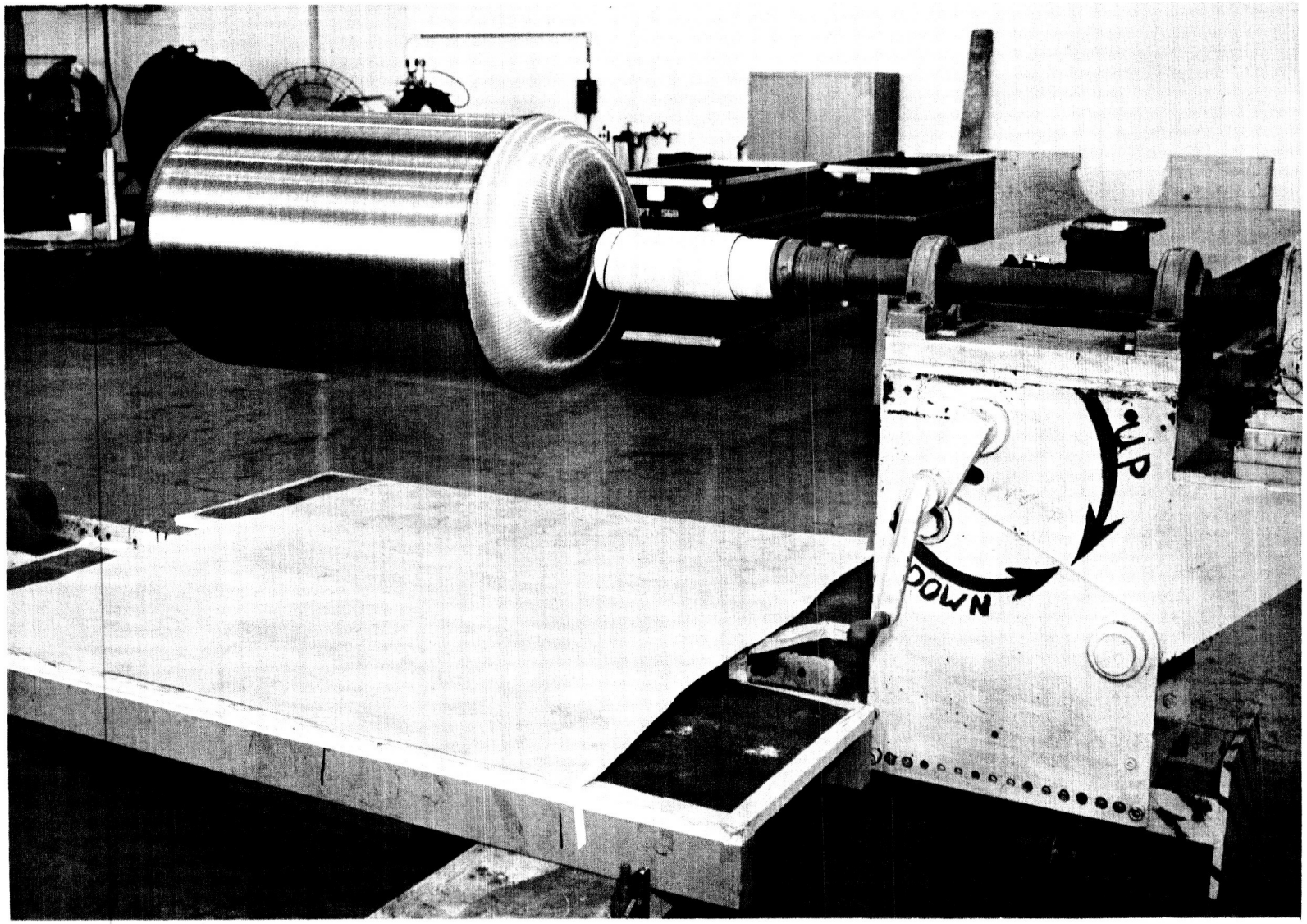


FIGURE 43 - COMPLETED FILAMENT WINDING PROCESS

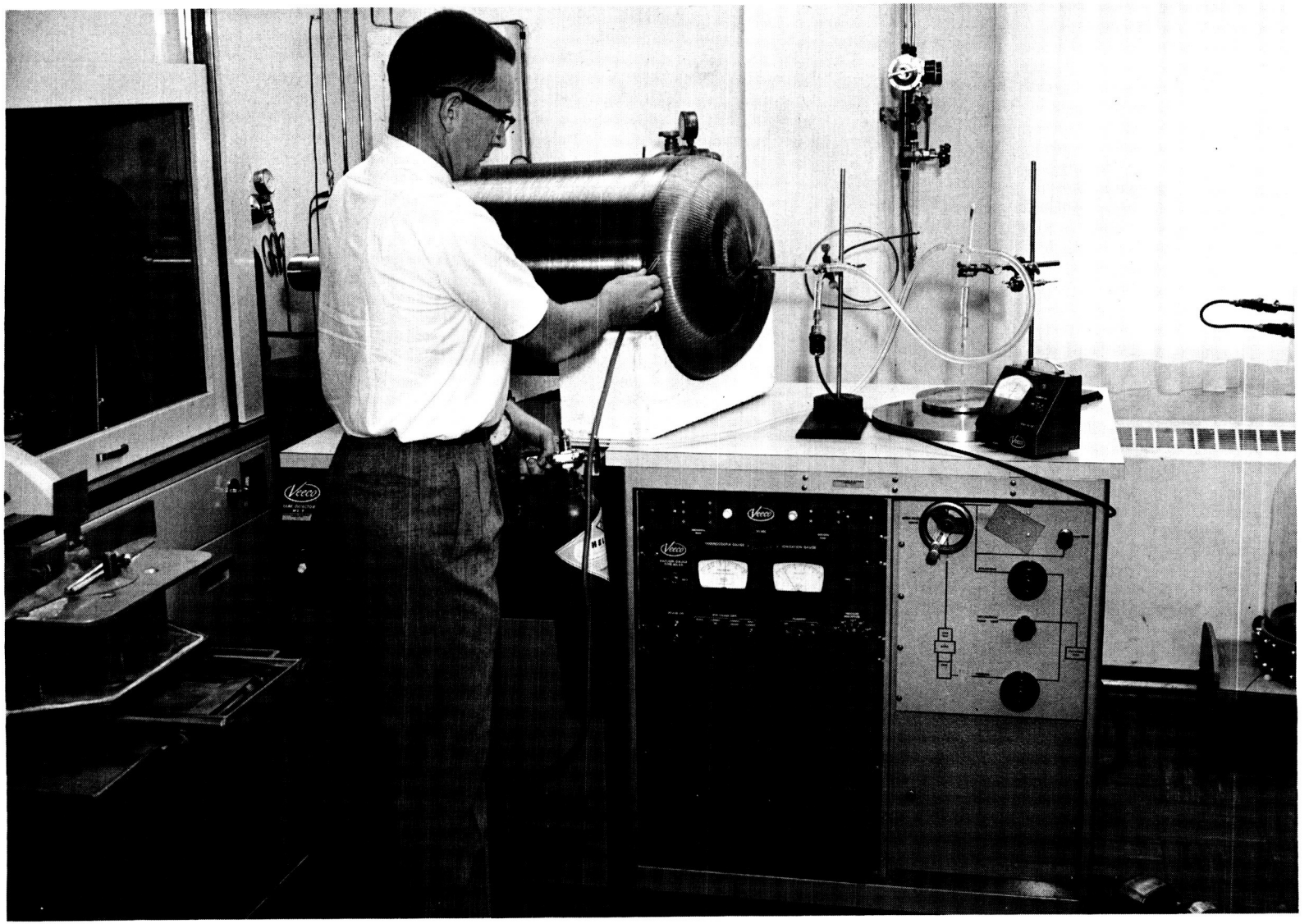


FIGURE 44 - LEAK TEST COMPLETED TANK ASSEMBLY AFTER MANDREL REMOVAL



FIGURE 45 - LIGHTWEIGHT FILAMENT WOUND LIQUID PROPELLANT TANK

NASA CONTRACTOR REPORT

DESIGN AND FABRICATION OF AN INTERNALLY INSULATED FILAMENT WOUND LIQUID HYDROGEN PROPELLANT TANK

Goodyear Aerospace Corporation

ABSTRACT

Details are presented of the design and fabrication of a subscale filament wound fiberglass reinforced plastic tank with internal encapsulated foam insulation for liquid hydrogen use. A thin laminate of aluminum-mylar-aluminum foil was used for the vacuum tight jacket around the polyurethane foam. An inner laminate served as the impermeable liner to contain the hydrogen.