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DEVELOPMENT OF MANUFACTURING TECHNIQUES FOR APPLICATION OF HIGH PERFORMANCE CRYOGENIC INSULATION

D2-109005-1

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SCOPE

This document specifies the process requirements and manufacturing procedures for the system component fabrication, insulation fabrication, insulation installation, preconditioning, and insulation quality maintenance of the thermal protection system for a 200-inch diameter Torus Tank (Drawing 15-A-X-1100).

When specified on the Engineering Drawing SK11-041071, all applicable manufacturing and quality control shall comply with the requirements of this document.

The Engineering Drawing SK11-041071 shall take precedence over this document in case a conflict arises.

FOREWORD

This final report represents the results of an 18-week design and manufacturing analysis conducted between June 21, 1967 and October 28, 1967, for the George C. Marshall Space Flight Center, National Aeronautics and Space Administration. The work was accomplished under Contract NAS8-21172. Mr. I.C. Yates, Manufacturing Engineering Laboratory, was the technical monitor.

The study was performed by The Boeing Company, Missiles and Information Systems Division, Manufacturing Development Section. Program Manager was Mr. C.L. Lofgren. Mr. D.E. Gieseking was technical advisor and Mr. D.H. Bartlett was responsible for the designs, thermal, and structural analyses. Technical participants were D.K. Zimmerman, D.L. Barclay, and Q. Ruonavaara.

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1.0 INTRODUCTION

This report details the performance of The Boeing Company in the design study and development related to the development of manufacturing techniques for insulating an existing 200-inch diameter Torus Tank detailed in MSFC Drawings 15-A-X-1101, 15-A-X-1103, and 15-A-X-1110.

The design criteria for the high performance insulation system was that it have a thermal conductivity of 5×10^{-5} Btu/hr.-ft.-°R, a density of 1.5 pounds per cubic foot, a thickness of 5 to 6 inches, and good manufacturing producibility and repeatibility. The system was required to withstand the acoustic, vibration, and acceleration loads typical of the Saturn V vehicle.

The result of the program is a detailed high performance insulation design and manufacturing plan for the Torus Tank.

2.0 SUMMARY

This final report represents the detailed results of a 18-week design and manufacturing fabrication plan for application of high performance multilayer insulation to a 200-inch diameter Torus Tank. The initial investigation phase consisted of a preliminary design and manufacturing analysis of all applicable insulation systems which would fulfill the specified requirements of the program.

Most of the insulation systems considered were those with which there was first-hand knowledge of fabrication and handling characteristics as well as thermal and physical properties. The insulation materials were narrowed to three groups for consideration in the detailed design and fabrication development program Phase II. The spacers consisted of silk or nylon netting, rigid polyurethane foam, and sliced 3/4-inch cell Mylar honeycomb were alternately interleaved with reflective shields of perforated aluminized mylar. These materials satisfied the detailed design requirements in Phase II of the program.

The most desirable insulation concept for Phase II involved detailment of the preliminary design, structural analysis of critical members, and a thermal analysis of the selected design. A comprehensive manufacturing plan was constructed for the insulation system components and contained all major tooling and their applications.

The final result of the program is a detailed insulation system design which includes a purge system, system components, and the system application to the vessel. The manufacturing plan provides sufficiently detailed fabrication and installation instructions for the application of the insulation system to the 200-inch diameter Torus Tank.

Preliminary study revealed that the purge system and purge bag assembly study in depth was beyond the scope of this program. The particular design shown in the report text is one of many which should be studied to optimize purging systems.

3.0 INITIAL INVESTIGATION

The preliminary work on this phase was a compilation of the insulation materials, purge systems, outgassing methods, and components which when combined would fulfill the requirements of the program. (See Figures 1, 2, 3, and 4.)

Figure 1 lists all the insulation materials considered for use in the program. Their availability, insulation performance, and fabrication characteristics are shown in detail. Since this work was done, the availability of the materials has changed and some are no longer available. A secondary, but critical factor, is the cost of the materials which have increased greatly since the initial work was conducted on the Boeing Company funded research.

Figure 2 lists all the possible insulation application methods, their complexities, thermal performance, compatibility, and density control.

Figure 3 lists the insulation support and attachment methods which were evaluated in the preliminary phase of the program.

Figure 4 presents the preconditioning and purge system evaluation in tabular form.

Of all basic insulation materials evaluated, only four met the requirements of the program. NRC-2 insulation was discarded because of poor density control especially in 5-inch thicknesses. Silk net, with the foam strip grid, was discarded because of fabrication difficulty. Mylar honeycomb in thin slices became the basic spacer material with sliced foam or nylon net as additional choices. Each material was interleaved with perforated aluminized Mylar. However, since the initial study was performed, it was discovered that 3/4-inch cell mylar was no longer available from any source.

Two separate designs were prepared. The first design incorporated a sump fairing which changed the inconsistent geometry of the sump into smooth lines. It proposed gas venting normal to the insulation layers where the purge gas was supplied to the purge bag adjacent to the tank. The insulation system proposed used consistent size panels of alternate layers of perforated reflective shields and any of the space materials selected.

The second design did not attempt to alter the tank geometry. The insulation system utilized unperforated reflectors and a purge system parallel to the insulation layers. Because of the inconsistent sump geometry, the insulation system required fabrication of a large number of different layer segments per layer and a good records system to keep them catalogued.

The first system was selected for detailing of the design, structural and thermal analysis, and weights estimate. The manufacturing and tooling plans proposed for the preliminary design and analysis were expanded for the secondary phase of the program.

INSULATION MA

NUMBER	INSULATION CONCEPT			MATERIALS AVAILABILITY		EVACUATION PATH	IN	
	SPACER MATERIAL	ALUMINIZED MYLAR RADIATION SHIELDS					THERMAL CONDUCTIVITY BTU/FT-HR-°R	D L
		PERFORATED	UN-PERFORATED	SPACER	SHIELD			
1	NYLON NET	X		Comm. avail.		Normal to layers	1.24×10^{-5}	
2	POLYESTER SCRIM (FORTREL)	X		Requires special mill run		Normal to layers	1.53×10^{-5}	
3	MULTIPLE (2 OR 3) SILK NETS	X		Comm. avail.		Normal to layers	3.63×10^{-5}	
4	SILK NET WITH BONDED FOAM STRIPS		X	Fab. from comm. avail. matls		Lateral (required evacuation joints)	3.58×10^{-5}	
5	SLICED 3/4" CELL MYLAR HONEYCOMB	X		Comm. avail. in 1" thick		Normal to layers	4.99×10^{-5}	
6	SLICED POLYURETHANE FOAM	X		Comm. avail (limited sources)		Normal to layers	3.36×10^{-5}	
7	NRC-2 (NO SPACER)		X	Comm. avail.		Lateral (requires evacuation joints)	1.58×10^{-5}	
8	DIMPLAR		X	Comm. avail.		Lateral (requires evacuation joints)		

F

ATERIALS EVALUATION

ISULATION THERMAL PERFORMANCE				FABRICATION CHARACTERISTICS			
ENSITY B/FT^3	THERMAL COND.X DENSITY	EFFECT OF COMPACTION	OUTGASSING CHARACTERISTICS	STRENGTH	JOINING	DRAPE	EASE OF HANDLING
3.46	4.29 x 10^{-5}	Good recovery	Large amt of absorbed water is released	Very high	Tape does not stick well to net, sewing best	Fair	Good
2.15	3.28 x 10^{-5}	No data	Very little outgassing	Strong fibers strength dep. on weave	Probably same as nylon net	Should be good	Poor for type tested, when weaved it should be good
1.39	5.05 x 10^{-5}	Should have good recovery	Should be similar to nylon net	Very high	Probably same as nylon net	Should be fair	Good
0.74	2.65 x 10^{-5}	Least increase in heat flow, good recovery	-	High	Probably same as nylon net	Should be fair	Good
1.29 (0.045" MHC)	6.44 x 10^{-5}	Least deflection good recovery	Very little outgassing	High, but stretches under uniaxial loads	Should be sewed or tied	Good	Good
1.86	6.25 x 10^{-5}	Good recovery	(Could be high no data)	Adequate	Sewing or taping acceptable	Poor	Fair
1.32	2.09 x 10^{-5}	Large deflections poor recovery	Should have very little outgassing	High, but performance is easily degraded	Tape makes strong point	Good	Fair
		No data	Should have very little outgassing	High, but stretches under uniaxial loads	Tape or sewing	Fair shield mat'l may be stiff	Good

IGURE 1

LAY-UP METHOD EVAL

NUMBER		LAY-UP METHOD	LAYER DENSITY CONTROL	COMPATIBLE CONCEPT: PURGE AND PRECONDITIONING SYSTEM	COMPATIBLE CONCEPT: INSU SUPP ATTA
1	LAY-UP ON TANK	LAYER-BY-LAYER INSTALLATION, STAGGERED LAP JOINTS	Poor	Gas purging the assembled insulation appears only possible method. Purging provisions must be built into insulation assembly	Lay-up makes s attachm provisio to insta at butt joints th and par applica
2	LAY-UP ON TANK	LAYER-BY-LAYER INSTALLATION IN-LINE BUTT OR SCARF JOINTS	Probably somewhat better than 1		
3	LAY-UP ON TANK	SPIRAL WINDING	Good for simpler geometry, probably more difficult on torus		
4	LAY-UP ON TANK	SHINGLES	Adequate, except shingles require support on tank bottom		
5	PREFABRICATED PANELS	FULL THICKNESS PANELS, IN-LINE BUTT OR SCARF JOINT	6" thickness may produce wrinkling	Panel purging or evacuation and back filling is possible as well as purging the assembled insulation. The latter requires purging provisions built into the assembly	All con applica Threads penetra entire t providir support panel a
6	PREFABRICATED PANELS	FULL THICKNESS PANELS, STEPPED BUTT JOINTS	Same as 5		
7	PREFABRICATED PANELS	MULTIPLE STACKED PANELS, IN-LINE LAP JOINTS	Degraded in lap areas		All cor applica transfe thread difficu with fu panels
8	PREFABRICATED PANELS	MULTIPLE STACKED PANELS, STAGGERED LAP JOINTS	Same as 7		
9	PREFABRICATED PANELS	MULTIPLE STACKED PANELS, IN-LINE BUTT JOINTS	Good		
10	PREFABRICATED PANELS	MULTIPLE STACKED PANELS, STAGGERED BUTT JOINTS	Good		
11	PREFABRICATED PANELS	MULTIPLE STACKED PANELS, RANDOM BUTT JOINTS, ONE PANEL SIZE PER LAYER	Good		

FIG

UATION

S LATION ORTS & CHMENTS	THERMAL PERFORMANCE	MANUFACTURING COMPLEXITY TOOLING	TOLERANCES	REMARKS
	No joint losses but degraded by poor density control	Graduated cutting templates	No problem can trim on assembly	
on tank upport and ent ns difficult ll, except or scarf reads s not ble	Significant joint losses	Graduated cutting templates	Close tolerances required on joint gap	
	Simultaneous application of shield and spacer results in minor degradation. Shields conduct directly to tank, degradation depends on shingle length	Winding machine	No problem	Not compatible with conical support, uneven thickness develop
		Few cutting templates required	No problem	
cepts ble. can e the ickness, g best over the ea	Significant joint losses	Lay-up jig, edge trim template	Close tolerances required on joint gap	
	Better than in-line butt joint	Lay-up jig, templates required for stepped joint	Close tolerances required on joint gap	
	Probably somewhat better than butt joint	Graduated lay-up jigs, edge trim	No problem	
cepts ble, but of loads more t than ll thickness	Joint losses depend on number of panels stacked. Should be good	Same as 7	No problem	
	Significant joint losses	Same as 7	Close tolerances required on joint gap	
	Better than in-line butt joint	Same as 7, but a stagger template is req'd	No problem	
	Somewhat better than 9 and 10	Same as 7, but less control required	No problem	

URE 2

INSULATION SUPPORTS AN

NUMBER	SUPPORT & ATTACHMENT CONCEPT	PURPOSE	APPLICABLE AREAS	THERMAL EFFICIENCY
1	THREADS NORMAL TO LAYERS	MULTILAYER POSITIONING	Entire insulation area	Adequate although the heat flow could become significant for close spacing
2	DIAGONAL THREADS	MULTILAYER POSITIONING	Entire insulation area	Adequate although the heat flow could become significant for close spacing
3	DROP THREADS	MULTILAYER POSITIONING	Lower half of tank surface	
4	THREADS WITH SPACERS	MULTILAYER POSITIONING	Same as 1, 2, 3	
5	RIGID POSTS WITH SPACERS	MULTILAYER POSITIONING	Entire insulation area	Very poor
6	RESTRAINT BANDS	MULTILAYER POSITIONING	Radial wrap around cross section	Poor, local compaction can greatly increase heat flow
7	"HULA HOOP"	MULTILAYER POSITIONING	Toward center from cross-section center-line	No degradation except due to attachment
8	"PAJAMA STRING"	MULTILAYER POSITIONING	Toward center from cross-section center-line	No degradation except due to attachment
9	PANEL EDGE LACING	ATTACHMENT TO TANK	Warm end of conical support tank surface	Lacing provides direct heat short to tank
10	CLOTH GRID	ATTACHMENT TO TANK	Entire tank surface	No degradation
11	FISH NET (OVER OUTSIDE OF INSULATION)	ATTACHMENT TO TANK	Entire tank surface	No direct heat short
12	DRILLED HOLES	ATTACHMENT TO TANK	Conical support and sump fairing	Some slight degradation due to radiation window
13	ADHESIVE TAPE	ATTACHMENT TO TANK	Entire insulation area	Tape at panel edges provide heat short
14	VELCRO FASTENERS	ATTACHMENT TO TANK	Entire insulation area	No degradation
15	CEMENTED BUTTONS	ATTACHMENT TO TANK	Entire insulation area	No degradation

FIGU

D ATTACHMENT EVALUATION

LOAD CARRYING CAPABILITY			INSTALLATION COMPLEXITY
INTER-LAYER SHEAR	COMPACTION	LAYER SEPARATION	
Poor	Poor	Good	Relative simple - although threads must be tied to inner supports first
Poor	Poor	Good	More complex - threads probably fed thru blanket and assembly, tied to inside first
Poor	Poor	Good	Same as 1
Poor	Fair	Good	Location of spacers for diagonal threads may be difficult
Good	Good	Good	Relatively simple
Good	Poor, causes compaction	Good	Simple
Good	Good	Good	Simple
Good	Good	Good	Simple
Good	Poor, probably causes some compaction	Fair	Requires holes or attachment clips on insulated structure
Poor, between tanks & grid	N. A.	N. A.	Relatively simple
Shear capacity provided by ties or posts	Poor	Poor	Relatively simple since netting would be applied over insulation
Good with post-type fasteners	Good with posts and spacers	Good with posts and spacers	Producing holes in multilayer appears difficult without shorting adjacent radiation shields
Poor, difficult to attach all layers	Poor at panel edges	Poor at panel edges	Simple
Good at attachment surface	N. A.	N. A.	Simple
Good at attachment surface	Poor, when used with ties	N. A.	Somewhat difficult to locate buttons under multilayer

RE 3

PRECONDITIONING, PURGE, AN

NUMBER	SYSTEM CONCEPT	PRECONDITIONING EFFICIENCY	FACILITIES REQUIRED	S
1	PRECONDITIONED SEALED PANELS A. EVACUATED AND BACK FILLED	High	Vacuum chamber, heat sources, impermeable jackets and remote valving system	D pe of m st co co m co pu
	B. GAS PURGED	High with hot gas purge	Heated gas source, impermeable jackets	D pe of m st co co co m co pu
2	TANK INSTALLED INSULATION PRECONDITIONING A. EVACUATED AND BACK FILLED	High	Large vacuum chamber, heat sources, impermeable jacket and remote valving system	D pe o m st c c m c p
	B. GAS PURGED	High	Heated gas source, impermeable jacket	D p o m st c c m c p

FIG

D EVACUATION SYSTEM EVALUATION

STORAGE LIFE	LAUNCH EVACUATION EFFICIENCY	THERMAL EFFICIENCY	WEIGHT	MANUFACTURING COMPLEXITY
epends on ermeability f jacket aterial and orage onditions ould aintain onstant urge	Fair - depends on successful rupture of jacket or ventilating system	Fair - depending on evacuation rate	High - due to encapsulating jackets and possible vent manifolding	Complicated - following evacuation encapsulated insulation blankets must be back filled and sealed remotely (inside a chamber)
epends on ermeability f jacket aterial and orage onditions ould aintain onstant urge	Fair - depends on successful rupture of jacket or ventilating system	Fair - depending on evacuation rate	High - due to encapsulating jackets and possible vent manifolding	Relatively simple if continuous purging not required
epends on ermeability f jacket aterial and orage onditions ould aintain onstant urge	Good - entire insulation vented at one time	Good - due to rapid venting possibilities	Moderate - only one encapsulating jacket required	Complicated - large vacuum chamber and remote valving system required
epends on ermeability f jacket aterial and orage onditions ould aintain onstant urge	Good - entire insulation vented at one time	Good - due to rapid venting possibilities	Moderate to high - purge system must form integral part of flight system	Somewhat complicated by need for purging system beneath insulation

GURE 4

4.0 DESIGN AND ANALYSIS

4.1 Detailed Design

A multilayer insulation thermal protection system was designed for a 200-inch O.D. toroidal liquid hydrogen tank. No specific mission was defined, therefore, selection of an insulation thickness was arbitrary. A value of five inches was chosen as being representative of future requirements for long term space storage.

The multilayer system was required to have a thermal conductivity of 5×10^{-5} Btu-ft/ft^2-hr-°R or less and a maximum density of approximately 1.5 pounds/cubic foot. Based on available flat panel thermal conductivity data several insulation systems shown in Figure 5 met these requirements. Some of these were:

1) 1/4 mil aluminized mylar radiation shields with sliced polyurethane foam spacers;
2) 1/4 mil aluminized mylar radiation shields with 0.007-inch nylon netting spacers;
3) 1/4 mil aluminized mylar radiation shields with sliced 3/4-inch cell Mylar honeycomb spacers.

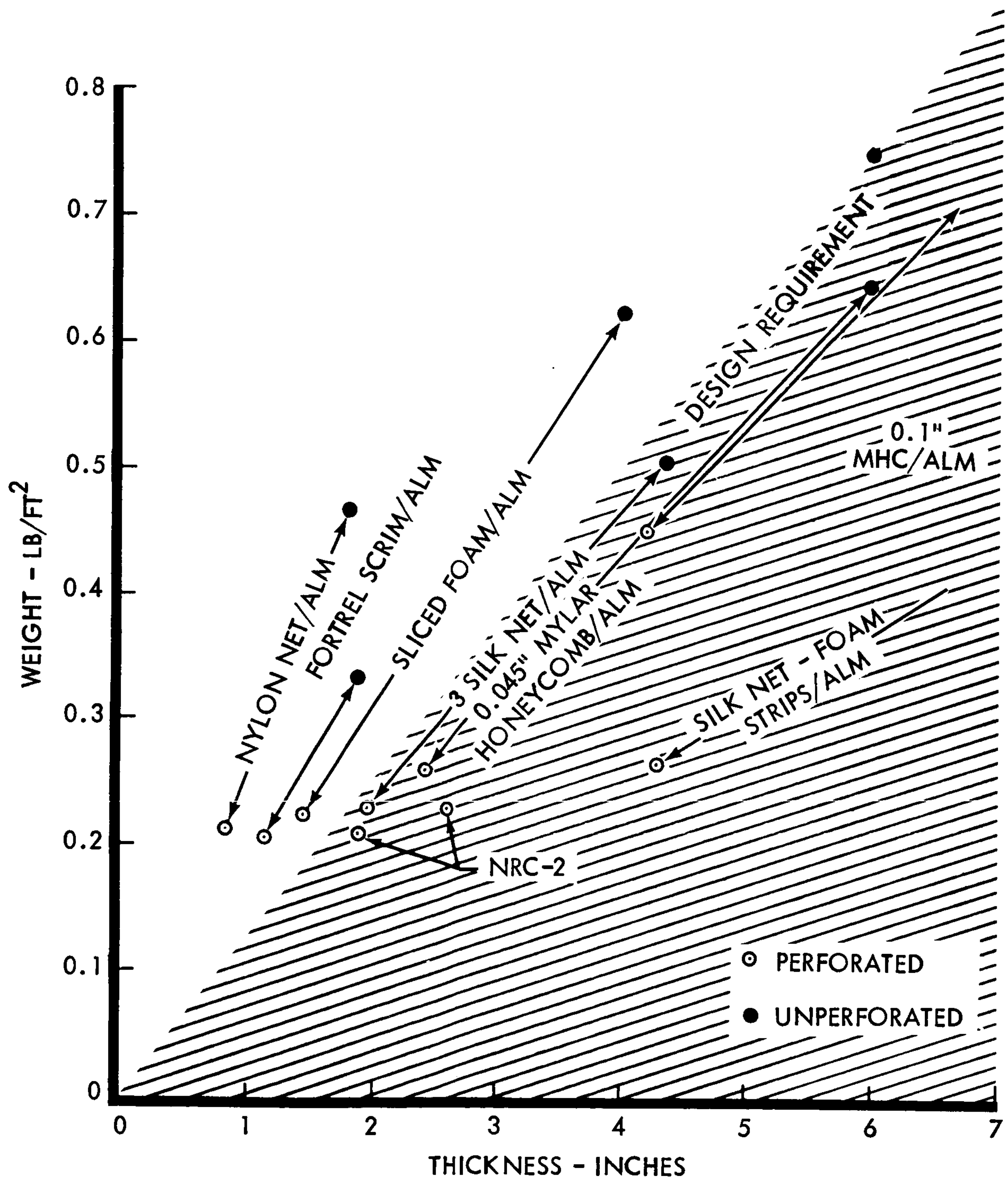
The last concept required the least labor for a 5-inch-thick insulation because optimum thermal performance was obtained with approximately 15 radiation shields per inch, as opposed to a greater number required for the other systems. Also this concept demonstrated good handling characteristics and reasonable resistance to compaction.

Aluminized mylar radiation shields for the design were perforated with 0.040-inch diameter holes on 0.30-inch centers. Previous pressure decay tests had indicated that radial venting paths were of significant value in rapid pressure reduction of a helium gas purged insulation system. Other pressure decay tests showed that a hot (200°F) helium gas purge considerably reduced the evacuation time. The design of the insulation system then was prepared with provision for rapid evacuation and preconditioning with a hot gas purge system. An external purge control system which rapidly vents purge gasses by rupture or through manifold exhaust ports is a necessary part of this type of multilayer insulation system. However, the design of the external system was determined to be beyond the scope of study for this program.

The insulation system for the Torus Tank was designed to withstand steady state acceleration loads. The design limit load factors were:

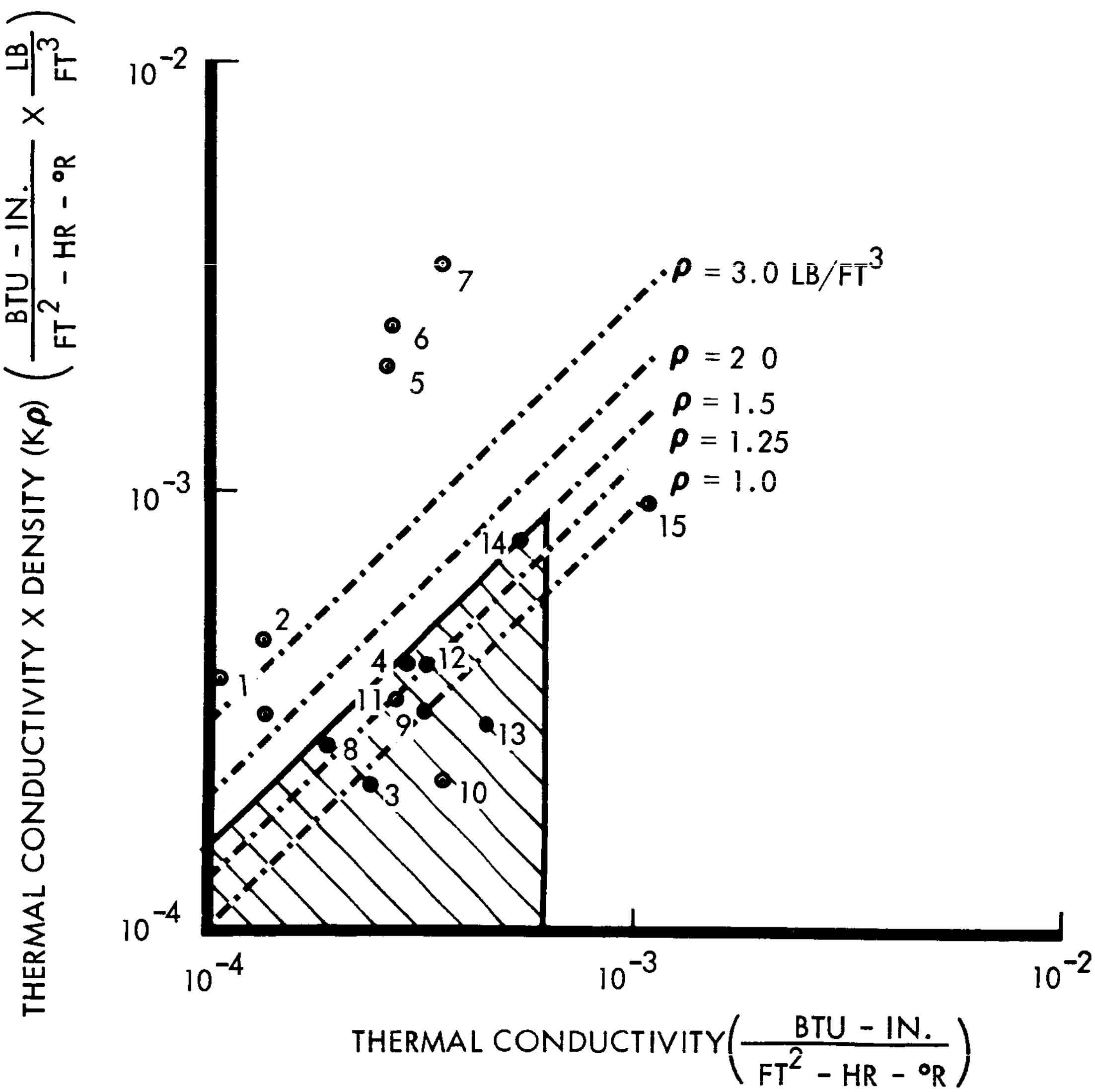
1) 5.0G vertical downward;
2) 1.5G vertical upward;
3) 0.5G lateral.

A factor of safety of 1.4 was applied to these to obtain design ultimate loads.



INSULATION PROPERTIES

FIGURE 5



SHIELDS ARE ALUMINIZED MYLAR UNLESS OTHERWISE NOTED

HOT FACE . = 70°F
COLD FACE TEMP. = -320°F

1. Nylon Net
2. 2 Nylon Net/Layer
3. Micro Fibers Web/Alum. Foil
4. Sliced 3/4" Cell Mylar Honeycomb
5. 3 Mil Dexiglass/Alum. Foil
6. 5 Mil Dexiglass/Alum. Foil
7. 10 Mil Dexiglass/Alum. Foil
8. Sliced Polyurethane Foam
9. Sliced Foam + Foam Grid
10. Silk Net + Foam Strips
11. 3 Silk Net/Layer
12. 2 Silk Net/Layer
13. NRC-2
14. Dimplar
15. Dimplar (Deep Set Dimples)
16. Fortrel Scrim

EFFECT OF DENSITY ON THERMAL CONDUCTIVITY

FIGURE 5a

Design details of the insulation system are shown in sheets 1 through 5 of Drawing SK11-041071. When assembled, the insulation system consists of an upper and a lower half. The lower half is comprised of pie shaped panels each one-inch thick which extend from the outside to the inside diameter of the Torus. Panels are butt joined and the joints are staggered to minimize radiation heat transfer. The panels are suspended from the conical support on the outside and from a dual hoop arrangement mounted slightly above the inner diameter of the tank. Intermediate supports are provided in the form of rigid fiberglass studs at two locations along the length of the panel. These studs have the capacity to carry insulation side loads as well as a portion of the total panel vertical loads. The lower contour of the tank is irregular because of the tapered sump. Rather than varying panel shape and length to account for the sump taper it was decided to fabricate and attach a sump fairing of fiberglass reinforced plastic. The addition of this fairing produced a tank contour which is uniform around the entire circumference and allows design of identical panels. To further simplify panel fabrication, a standard width was selected.

Since the circumference changed as insulation thickness varied, one "make-up" panel was required for each of the five layers. This panel was intended to be hand fit and would account for tolerance build up during assembly.

The upper half of the insulation system is also composed of pie-shaped panels each one-inch thick. These panels also extend from the cone support to the hoop support. Negative acceleration required the addition of fiberglass studs spaced along the top of the tank. Curved channel members attached to the studs are used to contain the insulation and carry loads to the studs. The outboard ends of these channels are attached to a circular ring which prevents rotation. The insulation is also tied to fiberglass reinforced plastic trays in the Y-ring area with thread. These ties hold the insulation to the required curvature in this area.

For each of assembly and handling, each one-inch-thick insulation panel is completely enclosed in nylon netting and tied together with thread and buttons. The threads prevent lateral shifting of insulation layers. The encapsulating nylon net is used to attach the insulation blankets to the hoop support and the cone support.

Insulation panels are cut out as required at the manholes and the encapsulating nylon net sewed to match the cut out. A separate insulation cover is designed to fit over each manhole so that access to the inside of the tank is possible. The insulation cover is assembled with filler layers in the center to account for the varying height of tank insulation around the periphery of the manhole. The cover is held together with nylon netting and thread ties. Velcro tape is used around the edges of the cover assembly to attach to the tank insulation.

Fiberglass studs are of two types. One type is a one-piece stud with a bonded aluminum pad at the base. These studs are used in locations where it is possible to bring the insulation panels down directly over the studs. In those locations where the panel is wrapped around the tank and slipped over a stud it is necessary to design a segmented support which could be assembled as insulation of the tank progressed. It is planned to assemble this type of support with an adhesive and a bolt. Upon completion of the insulation assembly the adhesive would be allowed to cure and then the bolt removed, increasing the thermal isolation capability of the support.

In all cases where bonded parts are to be exposed to cryogenic temperatures, a polyurethane adhesive is employed. The adhesive cure cycle is three days at 75°F and is selected to avoid possible overaging of the tank material. If a more rapid cure is desired, a slightly elevated temperature could be used. The selection and means of obtaining the required temperature should be coordinated with MSFC materials personnel.

A heated helium purge gas distribution system was designed for installation against the tank surface. The function of this system is to precondition insulation materials prior to launch. Depending on final design of the purge system this distribution system could be used continuously prior to launch or used only once to precondition prior to filling of the tank. Since the purge system could possibly be used while exposed to cryogenic temperatures a suitable film material would be mylar, Teflon, or possibly nylon. Nylon is preferred because it can be readily heat sealed. Fabrication of a mylar purge bag would require the use of adhesive thus complicating the assembly job. The purge system is designed to provide an even distribution of gas over the entire inner surface of the insulation. The purge system consists of an envelope of 2-mil films sealed over perforated tubes and then sealed into separate channels. The outer 2-mil film would be perforated to supply the gas to the insulation. The perforated tubes would be attached to supply lines which feed from a location near each manhole cover. The design shown on the drawings is intended only to supply and distribute the purge gas to the insulation and as such is an open system, i.e., the gas is exhausted to the atmosphere. It may be possible to combine such a system with an external purge bag, thus, providing a means of collecting the purge gas to be cleaned and reused in the preconditioning cycle.

4.2 Structural and Thermal Analysis

Structural analysis of the insulation support system was based on the assumption that insulation loads could be transferred by the layers into the support studs or through the thread ties to the outer nylon net layers and in turn to support clips or hoops. Test data is needed to determine the edgewise load capacity of a thick blanket of multilayer. The design drawing shows an adhesive backed reinforcing washer located at each support stud, however it is believed difficult to locate this reinforcement when producing the hole in the layers.

The support studs were analyzed as cantilever beams. Peel loading at the edge of the flat base was a critical design condition and dictated the size of the base. Shear stresses in the adhesive joint under acceleration loading was 4 psi for a typical stud. Hoop support brackets were designed to be bonded to the tank. The calculated shear stress in this joint at ultimate load was approximately 170 psi. The bond joint of sump fairing to tank is continuous around the periphery of the fairing, consequently adhesive shear stresses in this joint were minimal.

Deflections of the fiberglass studs attached to the sump fairing were found to be prohibitively high without some form of fairing stiffener. As a result, channel shaped members were designed to be bonded to the sump fairing on the inside behind each stud. These were sized to minimize deflections.

A portion of the insulation panel inertia load was carried by the nylon net webbing between inner and outer support hoops. The design ultimate load was 3.5 pounds/inch of netting circumference. No data was available on netting strength so a simple tensile test was conducted. The results of the test are shown in Figure 6. Six layers of net were selected for design, thus providing an ample margin of safety.

The heat leaks to the hydrogen tank are summarized in Figure 7 for two multilayer insulation materials. These are:

1) Perforated aluminized mylar separated by nylon net;

2) Perforated aluminized mylar separated by sliced mylar honeycomb.

The heat transferred to the tank through the undisturbed multilayer insulation under evacuated conditions consists of radiation and solid conduction components. A basic "calorimeter" heat leak through the insulation is determined for the ideal conditions of no perforations, no insulation disturbances such as local compaction or penetrations, and no butt joints in the insulation layup. The estimated actual performance in zero "g" with no perforations is taken as two times the basic "calorimeter" value to take into account local disturbances in the insulation. The perforations in the radiation shields mainly effect the radiation component of the insulation heat transfer. This is particularly evident when comparing the heat flow due to perforations for the nylon net and mylar honeycomb in Figure 7. Due to the greater spacing between aluminized mylar layers with the mylar honeycomb spacer each perforation hole "views" a greater area of adjacent layers, hence the radiation heat transfer component of the total heat flow increases.

Heat leaks through the studs, the support web, and the threads have been treated as conventional heat conduction problems. The thermal design of the insulation layup in the vicinity of the fiberglass tank support involves several considerations. Foremost is the attempt at providing an uninterrupted transition of the insulation from the tank to the tank support. This involves continuing the undisturbed tank insulation layup as far as possible into the tank — tank support junction. The insulation turning radius from the tank to the tank support is made as small as possible without causing buckling or compaction of the layers. Also of importance is the fairing out of the multilayer insulation thickness on the fiberglass tank support toward the warm end of the support. The local thickness of the insulation on the tank support is sized in such a manner as to minimize the mismatch in temperature distributions through the insulation and along the support member. In addition, the heat flow in the insulation parallel to the support at the warm end becomes increasingly normal to the support toward the cold end. This is an extremely complex two-dimensional heat transfer problem and is not dealt with in detail in this analysis.

The principal heat leak to the manhole cover occurs in the multilayer insulation layers in the immediate proximity of the cover insulation —tank insulation junction. This is due to high parallel conductivity of the multilayer insulation and is particularly important for the multilayer insulation with nylon net separators as can be seen in Figure 7, hence, the overlap of the tank insulation by the manhole cover insulation blanket is designed so as to maximize the parallel conduction path in the multilayer insulation. In addition, the tank insulation is not permitted to terminate against the manhole cover, rather a fiberglass insulation collar around the bulkhead is employed.

NYLON NET - TENSILE TEST RESULTS

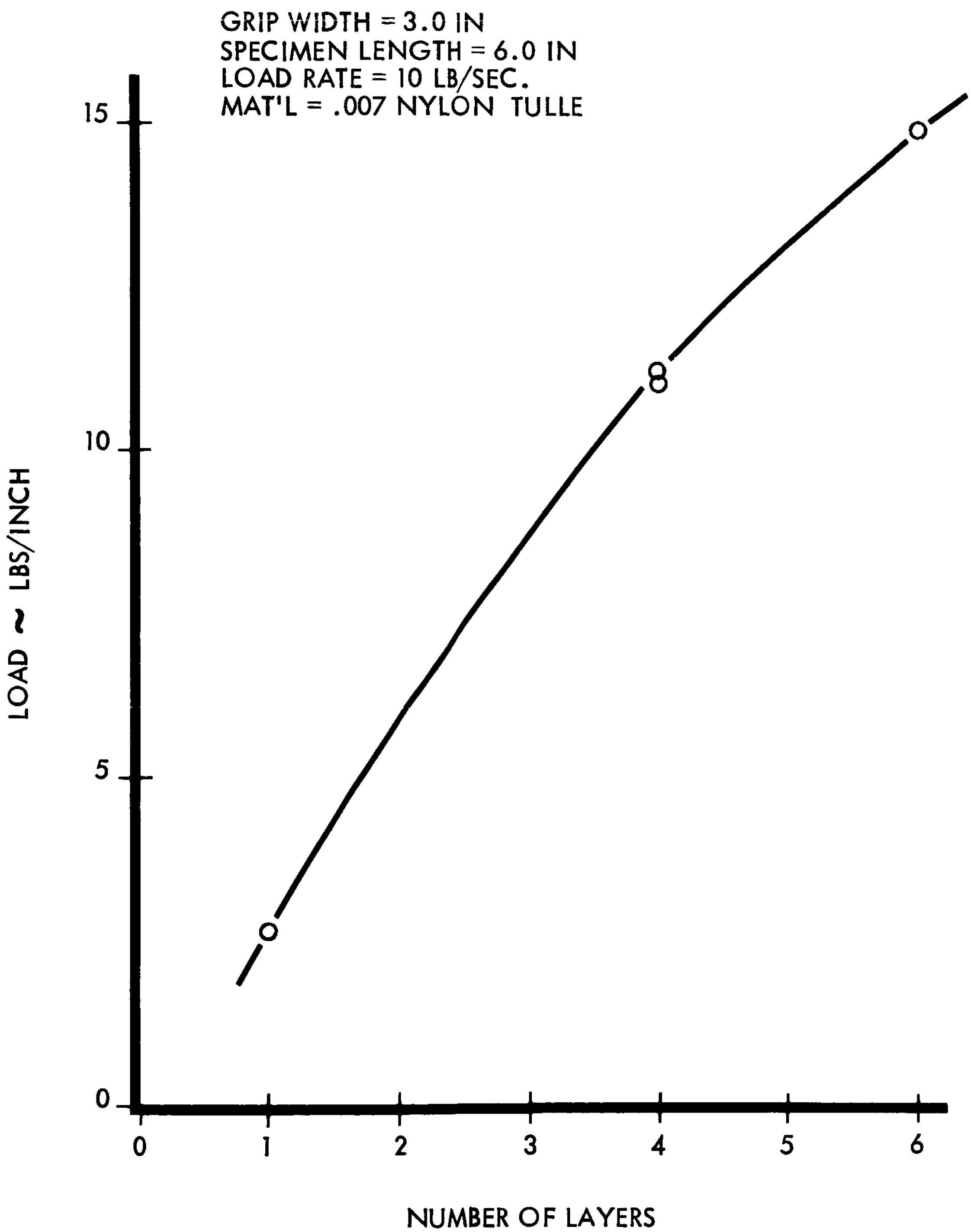


FIGURE 6

HEAT LEAK SUMMARY

	HEAT FLOW (BTU / HR)	
SPACER MAT'L	NYLON NET	MYLAR HONEYCOMB
ESTIMATED ACTUAL PERFORMANCE IN ZERO "G", NO PERFORATIONS	10.4	30.4
PERFORATIONS IN RADIATION SHIELD	6.0	22.0
STUDS	8.9	8.9
SUPPORT WEB	0.2	0.2
THREAD TIES	0.3	0.3
TANK SUPPORT	10.0	10.0
MANHOLE INSULATION	5.0	1.0
TOTALS	40.8	73.2

FIGURE 7

4.3

Weights Analysis

A weight summarization for the design is tabulated below. Insulation weights were calculated using the flat panel density of aluminized mylar and sliced mylar honeycomb. This density is 1.42 lb/ft^3.

	Pounds
Multilayer Insulation	480
Fiberglass Filler (1.5 lb/ft^3)	20
Hoop Support (2)	4
Fiberglass Trays (24)	2
Fiberglass Sump Fairing	36
Channel Supports for Sump Fairing	40
Upper Insulation Blanket Radial Retainer Assembly	13
Purge Tubing and Bag	26
Total	621
5% for Bolts, Adhesive, Thread, and Miscellaneous	31
Total	652

5.0 MANUFACTURING PLAN AND TOOLING REQUIREMENTS

Components of the insulation and thermal protection system have been detailed in Drawing SK11-041071, sheets 1 to 5 on pages 48 to 52 of this document. The following pages detail the fabrication processes which compose the manufacturing plan for each item of the system and the tools required for application of each.

5.1 Fiberglass Component Fabrication and Installation

5.1.1 Fiberglass Component Fabrication (See Figures 8 through 11)

1) Fabricate mandrel of plaster or hydrocal.
2) Apply three coats parting lacquer onto mandrel.
3) Apply Johnson's traffic wax on mandrel in layup area.
4) Apply light coat of RAM 225 mold release over traffic wax.
5) Insert reinforcement strips in mandrel.
6) Lay up a 2-ply prepreg laminate. Fiber direction oriented to radius direction. The prepreg laminate will bond to the reinforcement strips.
7) Cover laminate with perforated teflon - TFE 2-mil film.
8) Install fiberglass or Osnaburg cloth edge bleeder around periphery of part.
9) Apply vacuum sealant No. 5230-1 (Fiber Resin Corporation) to edge of tool.
10) Attach vacuum bleeder line.
11) Attach vacuum blanket (mylar or nylon) composite layup shown in Figure 8.
12) Apply vacuum pressure and checks for leaks.
13) Cure in air circulating oven at 250°F for 4 hours plus 2 hours at 300°F.
14) Cool to room temperature.
15) Remove part from tool and trim to trim line.
16) Drill as required by Drawing SK11-041071.
17) Part number package and store.

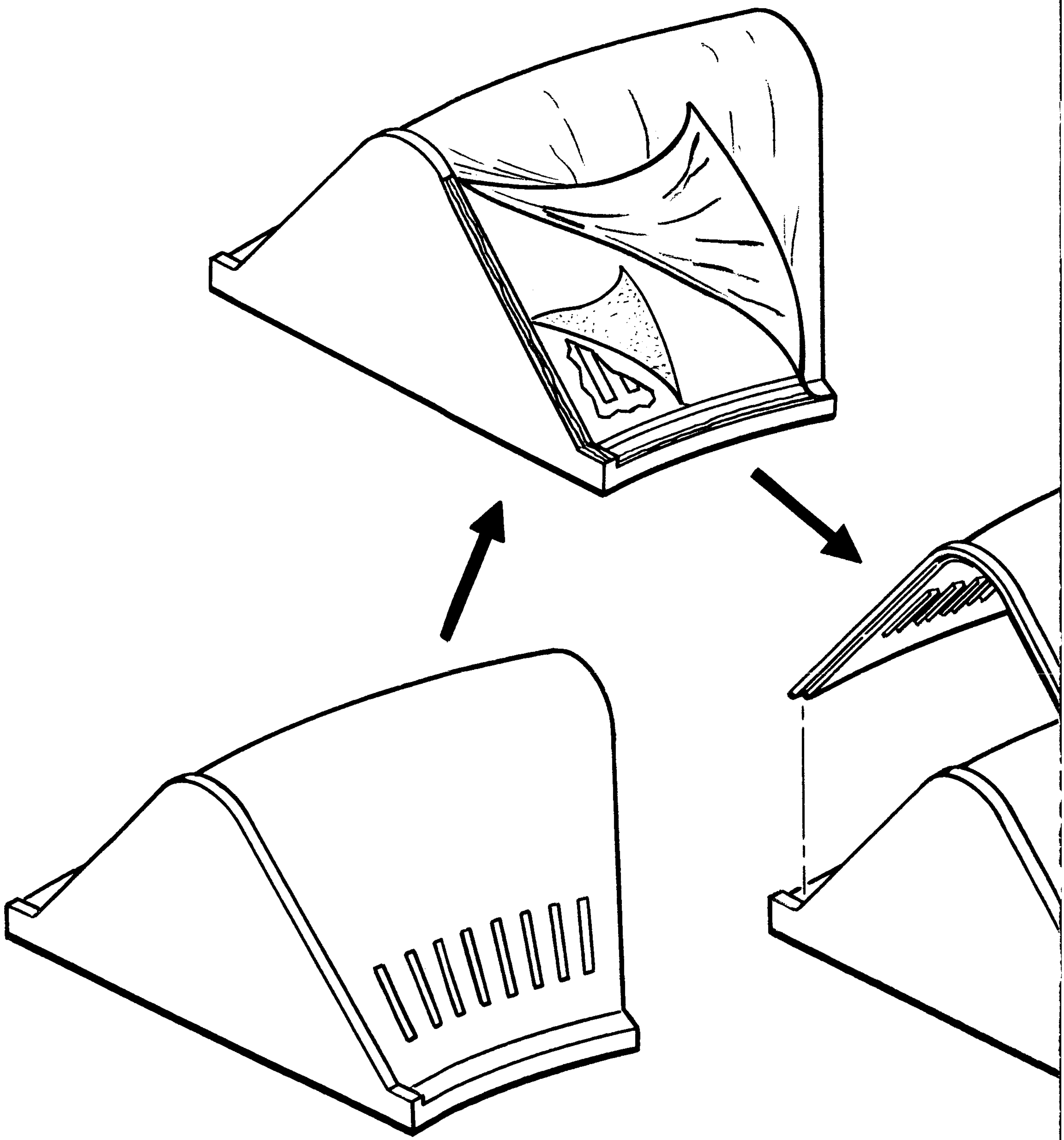
5.1.2 Facilities

Air circulating oven 6 ft x 8 ft x 6 ft, capable of control from 70°F to 400°F is required.

5.1.3 Sump Fairing Installation (See Figure 12)

1) Abrade the tank locally in the fairing bond area with abrasive. Clean with methyl ethyl ketone or acetone.
2) Using double-backed tape, attach a thin metal positioning strip at the fairing bond line. Spray each positioning strip with teflon release agent prior to application to the tank surface.
3) Position sump fairing vacuum positioning tool on the major and minor attach points and connect to plant air.

SUMP FAIRING FA



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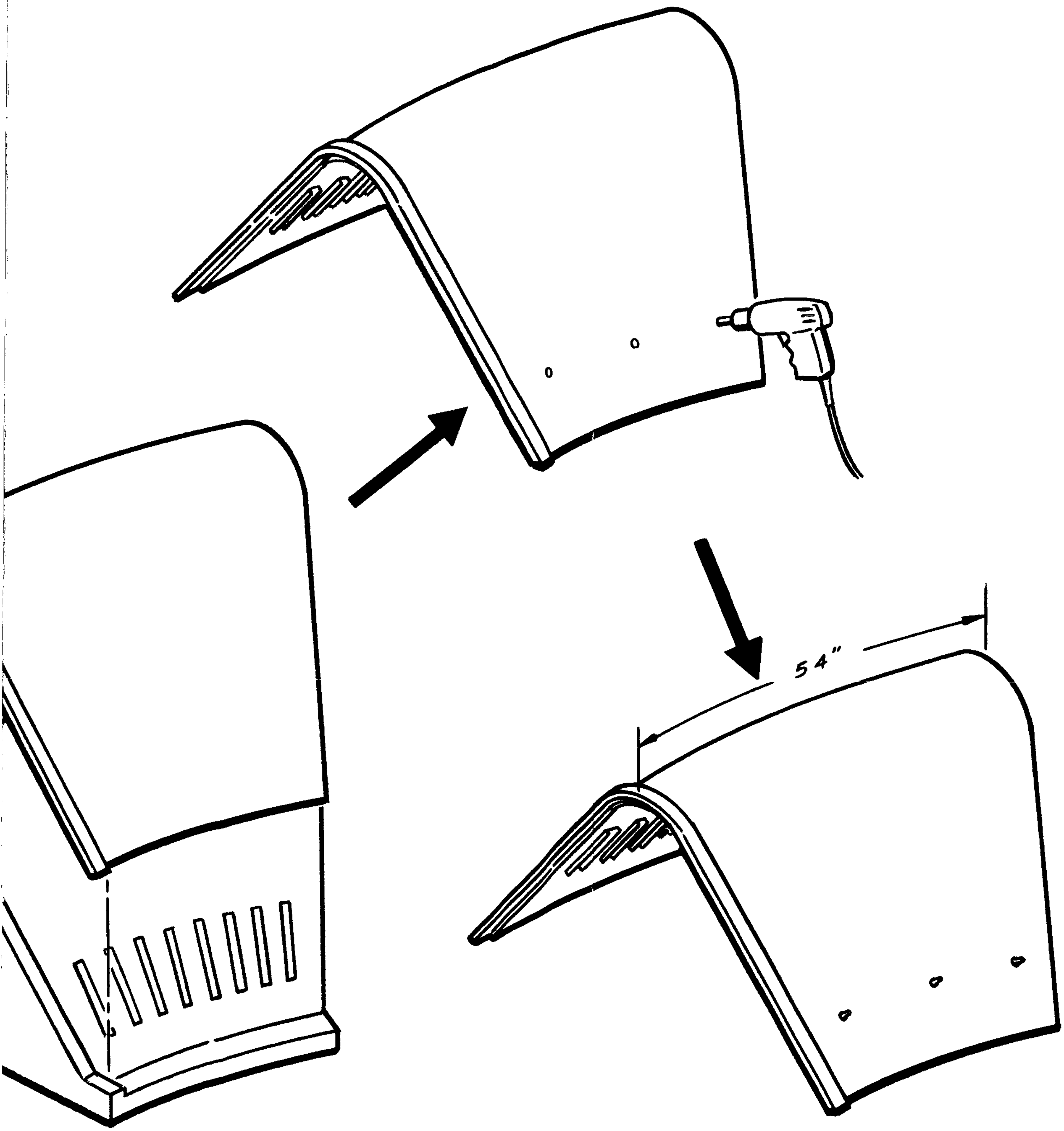


URE 8

Y-RING FAIRING FABRICATION

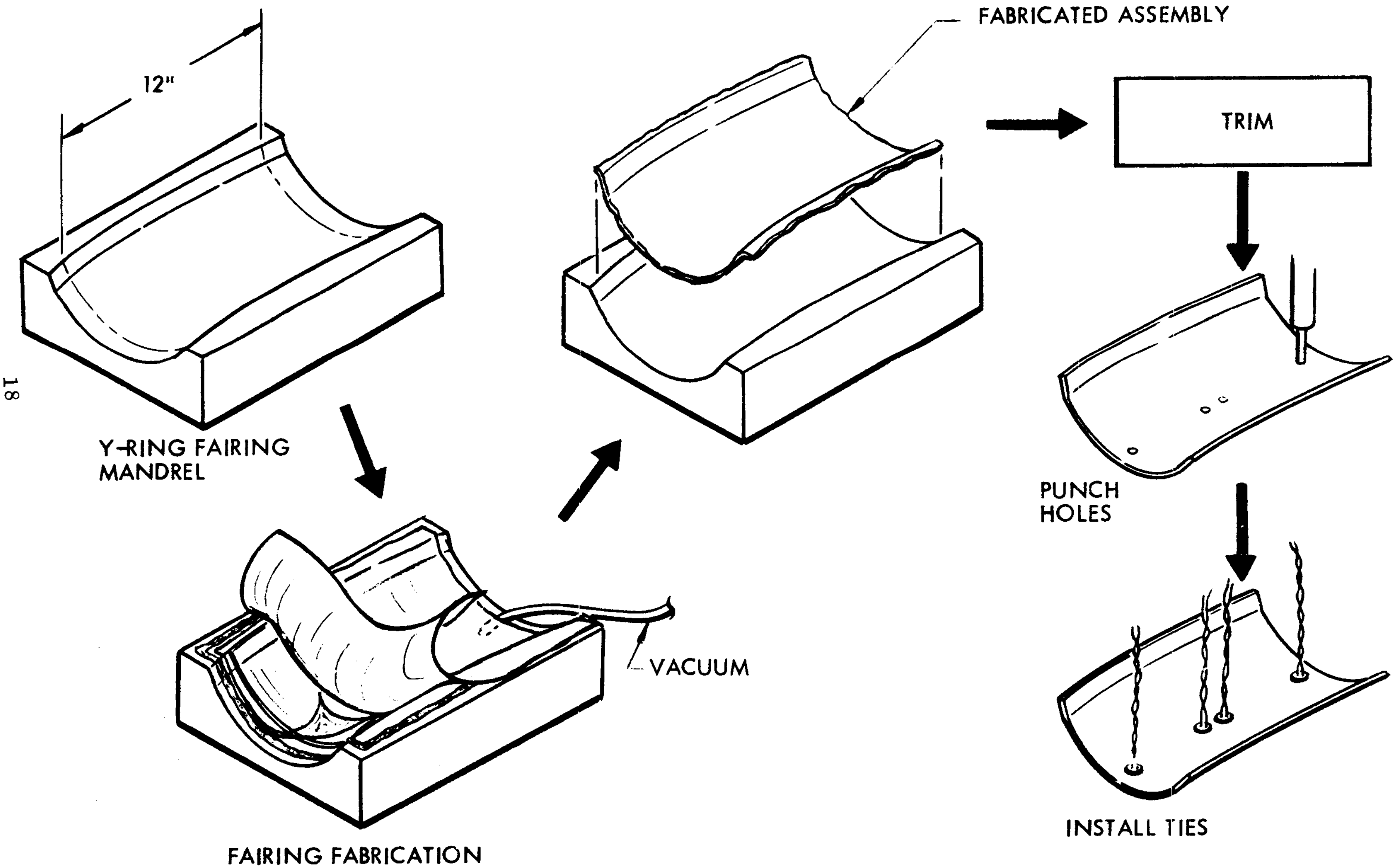
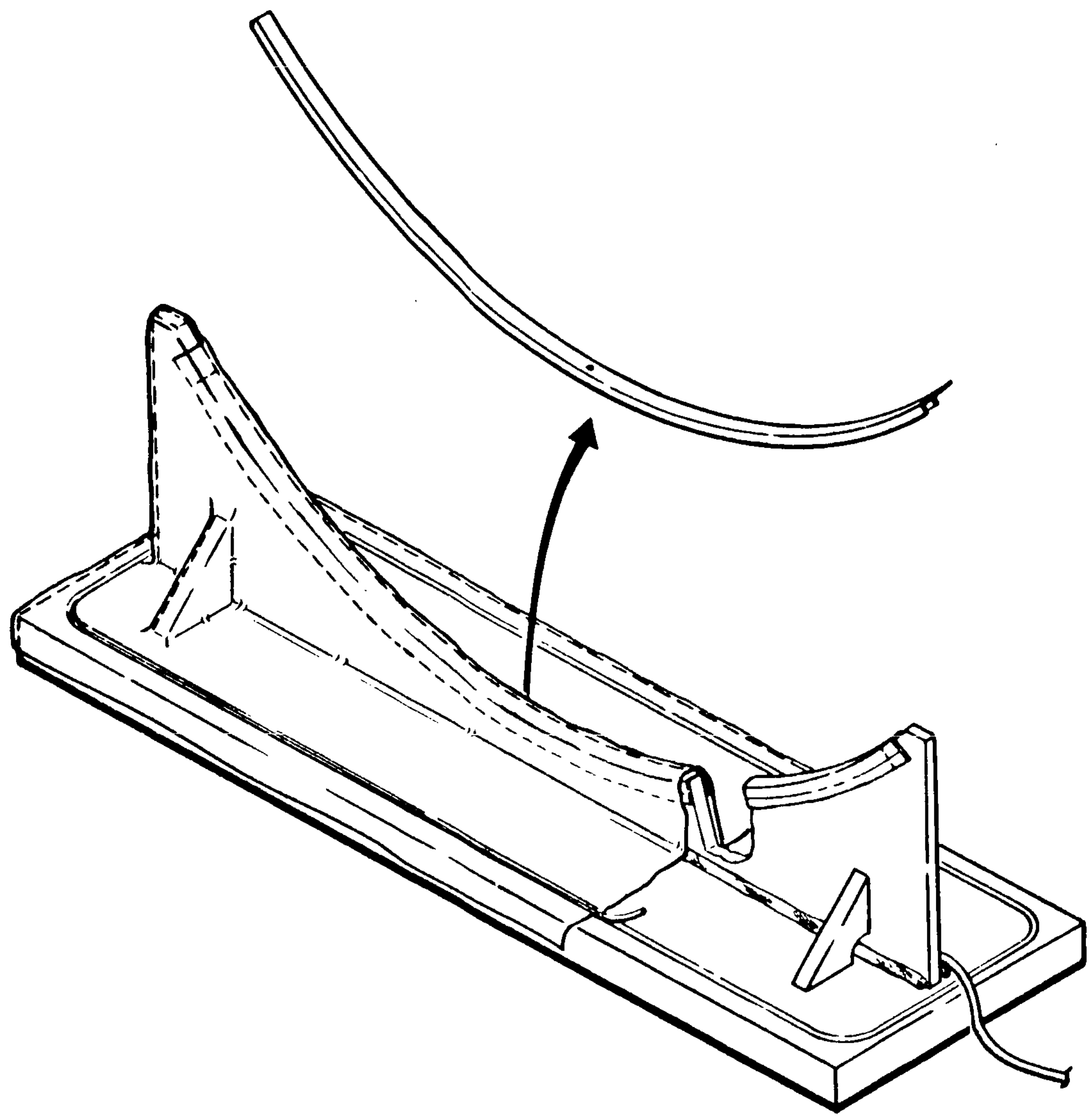
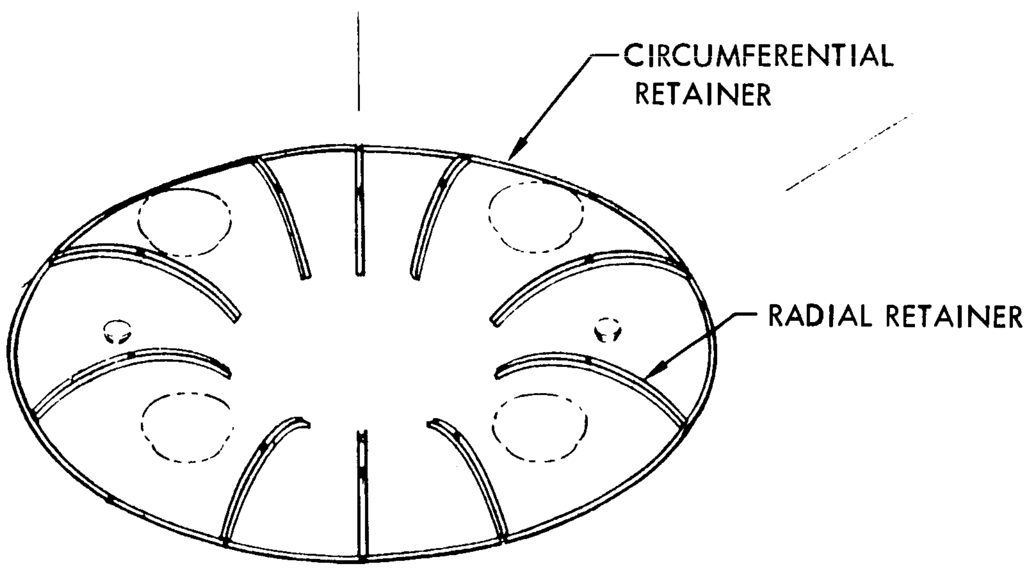


FIGURE 9



INSULATION RETAINER FABRICATION

FIGURE 10



ASSEMBLED INSULATION RETAINER

FIGURE 11

SUMP FAIRING INSTALLATION

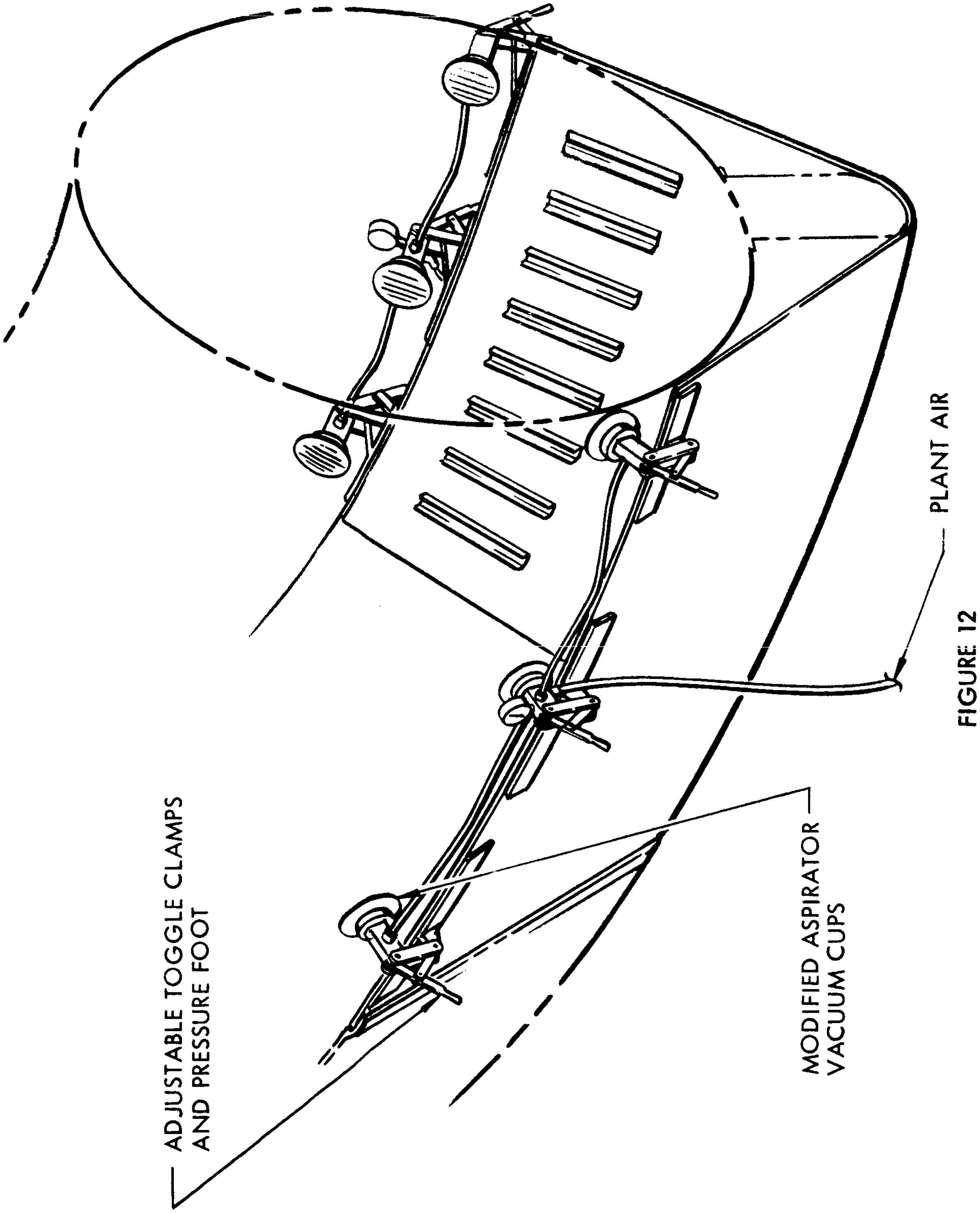


FIGURE 12

4) Apply Narmco 7343 adhesive to the bond area on the tank surface and insert a section of the sump fairing.

5) Apply pressure to the fairing tank bond area by tightening the pressure shoe screws on the vacuum fixture.

6) Allow to cure for 24 hours with pressure applied. The vacuum fixture may then be removed for an additional 36-hour cure.

7) It is recommended that two sections be applied at the same time. Narmco 7343 adhesive should be used to bond adjacent segments in the overlap area.

5.1.4 Sump Fairing Tooling

The vacuum fixture shown on the following page is fabricated of air-asperated vacuum cups which were modified with a pressure shoe which is adjusted for pressure by turning the adjustment screw clockwise. Three individual units will be required to bond the major width of the fairing and two units will be required for the minor width. The individual units for the major and minor widths may use plant air connected in series.

Enough units should be made available so that two segments can be bonded at the same time.

5.1.5 Y-Ring Fairing Installation (See Figure 13)

1) Abrade the tank locally in the area of attachment and clean locally with methyl ethyl ketone or acetone.

2) Install positioning strips on the tank and skirt bond lines.

3) Position and attach fairing bonding tools on the skirt attach ring.

4) Apply Narmco 7343 adhesive on the fairing segment and position the fairing bonding tool.

5) Apply pressure to both bonded surfaces by tightening and adjusting the toggle clamps on the tool.

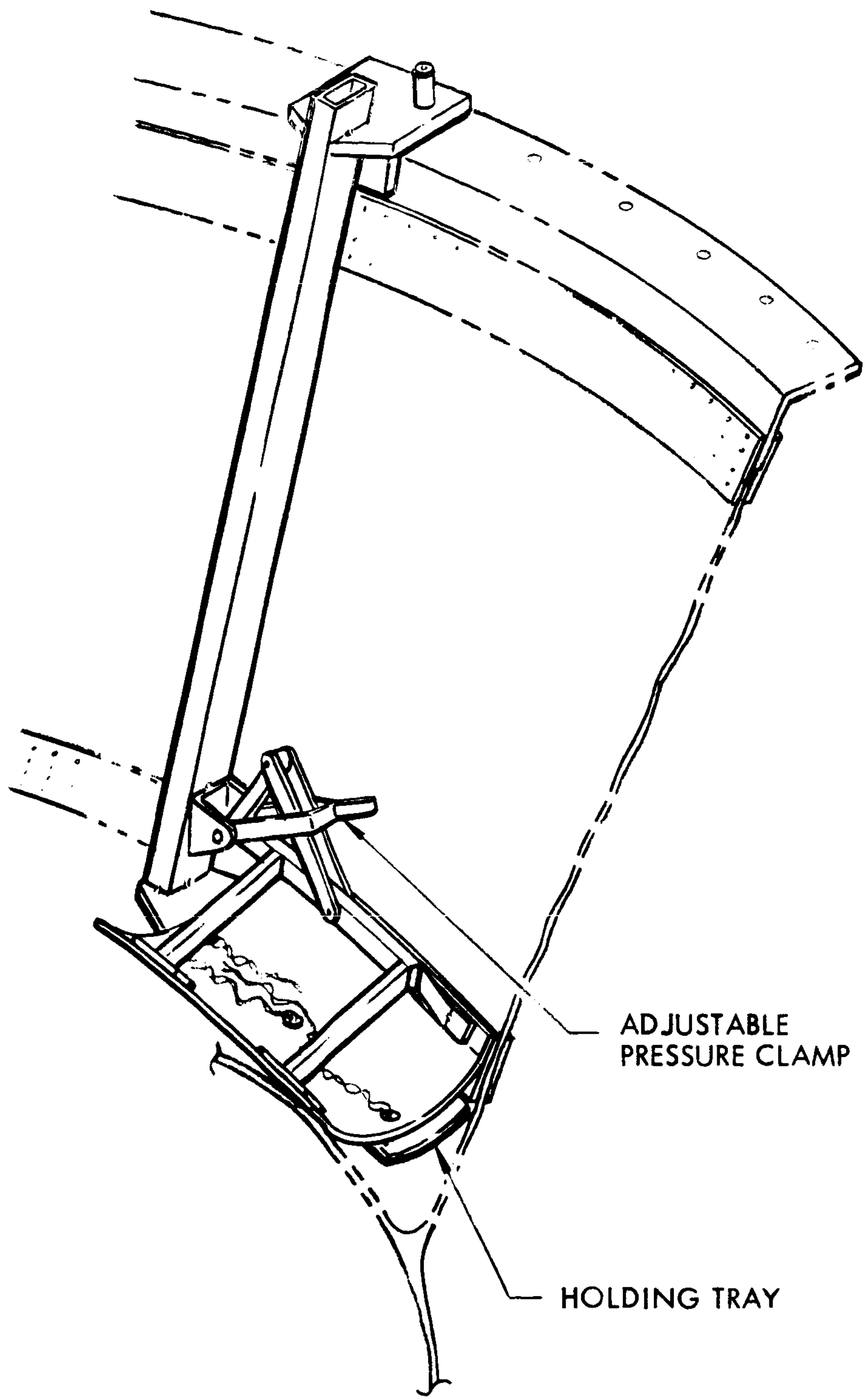
6) Maintain pressure on the fairing bonded surfaces for 24 hours at ambient temperature cure. The bonding tools may then be removed and reused.

7) Cure adhesive an additional 48 hours at room temperature before applying external loads to the fairing.

5.1.6 Y-Ring Tooling

The Y-ring bonding tool shown on page 23 consists of a positioning bar which attaches to the support flange of the skirt. This positions the tool in the desired depth and attitude. Attached to the lower portion of the positioning bar is a tray which holds the part in a position for bonding. Above this tray is a member which supports four toggle clamps which can be adjusted when applying the required contact pressure for bonding.

Two units of this type should be fabricated.



Y-RING FAIRING INSTALLATION

FIGURE 13

5.2 Double Tube Attach Clips (See Figure 14)

5.2.1 Fabrication of the Double Tube Attach Clips

1) Procure aluminum sheet material;
2) Brake-form both parts to configuration per Drawing SK11-041071;
3) Saw the formed segment to achieve 0.70 inch with parts;
4) Deburr both segments of the assembly;
5) Drill per Drawing SK11-041071;
6) Install nut plates by riveting;
7) Clean part number, package, and store in sets.

5.2.2 Fabrication of the Positioning Tool

1) Brake material to size;
2) Brake (1) in half;
3) Combine and saw out slot to accommodate clip as shown in Figure 14;
4) Install double-backed tape and spray completed assembly with teflon release agent;
5) Store.

5.2.3 Double Tube Assembly Attach Clips Installation

1) Abrade the tank surface locally with abrasive and reclean locally with acetone or methyl ethyl ketone.
2) Install bonding positioning tools, per sketch on page 25 for the hoop attachment brackets , Drawing SK11-041071, sheet 1, using double-backed tape. Spray each positioning tool with teflon release agent before application of the tank.
3) Apply Narmco 7343 adhesive to clips and insert in the positioning tools.
4) Apply tape from the tank surface across the positioned clips to the tank surface for contact bonding pressure as shown in sketch on page 25.
5) Cure at room temperature per Drawing SK11-041071, sheet 1.

5.3 Insulation Clips (See Figure 15)

5.3.1 Fabrication

1) Procure aluminum flat stock 0.040-inch thick;
2) Fabricate male-female tool steel matching dies to punch out the insulation clip flat pattern;
3) Punch insulation clip blanks (quantity to be determined);
4) Drill two 0.10-inch diameter holes in each clip. Stack drilling of the blanks will reduce flow-time and labor costs;

HOOP SUPPORT SEQUENCE

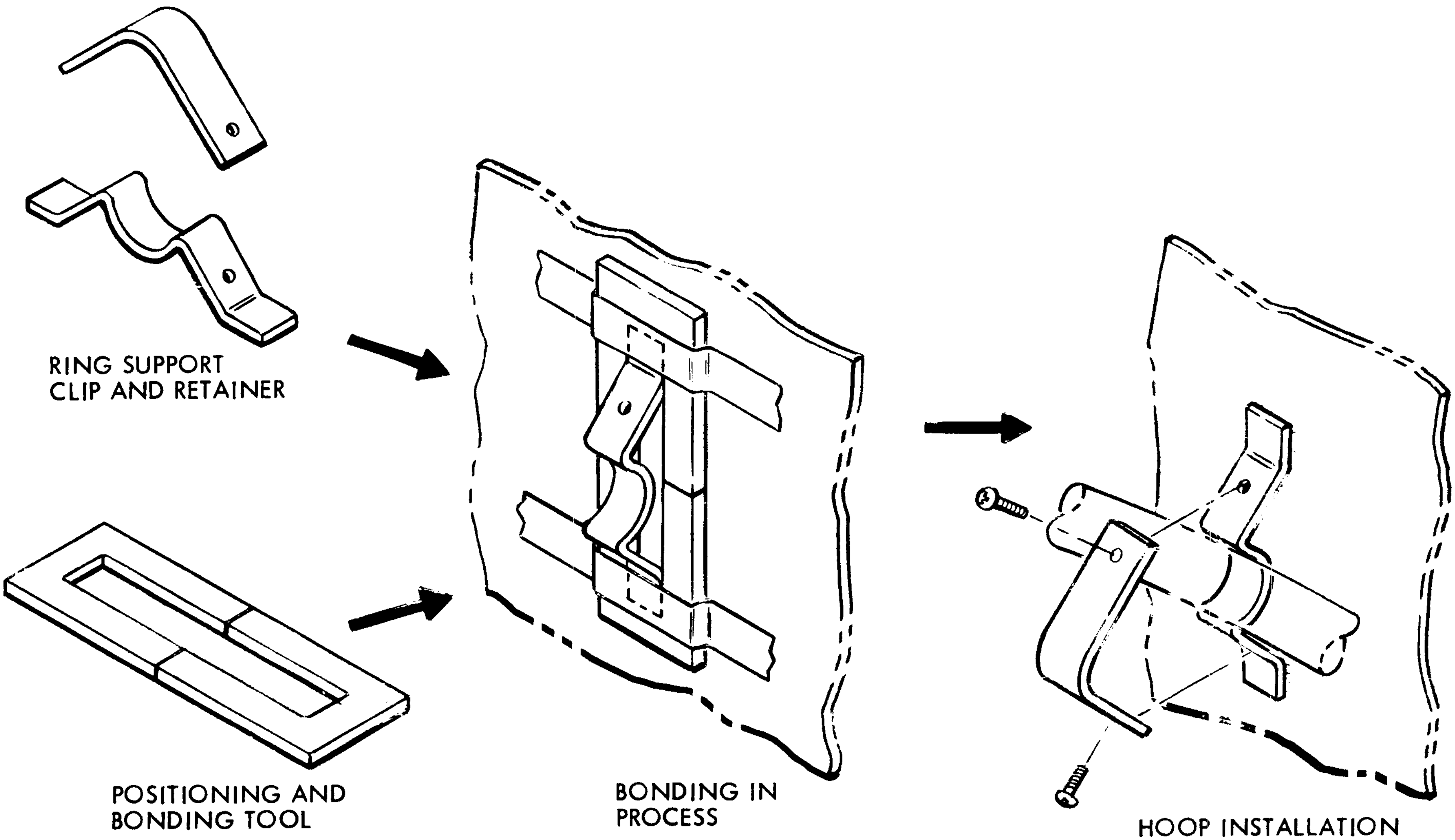


FIGURE 14

INSULATION CLIP FABRICATION AND INSTALLATION

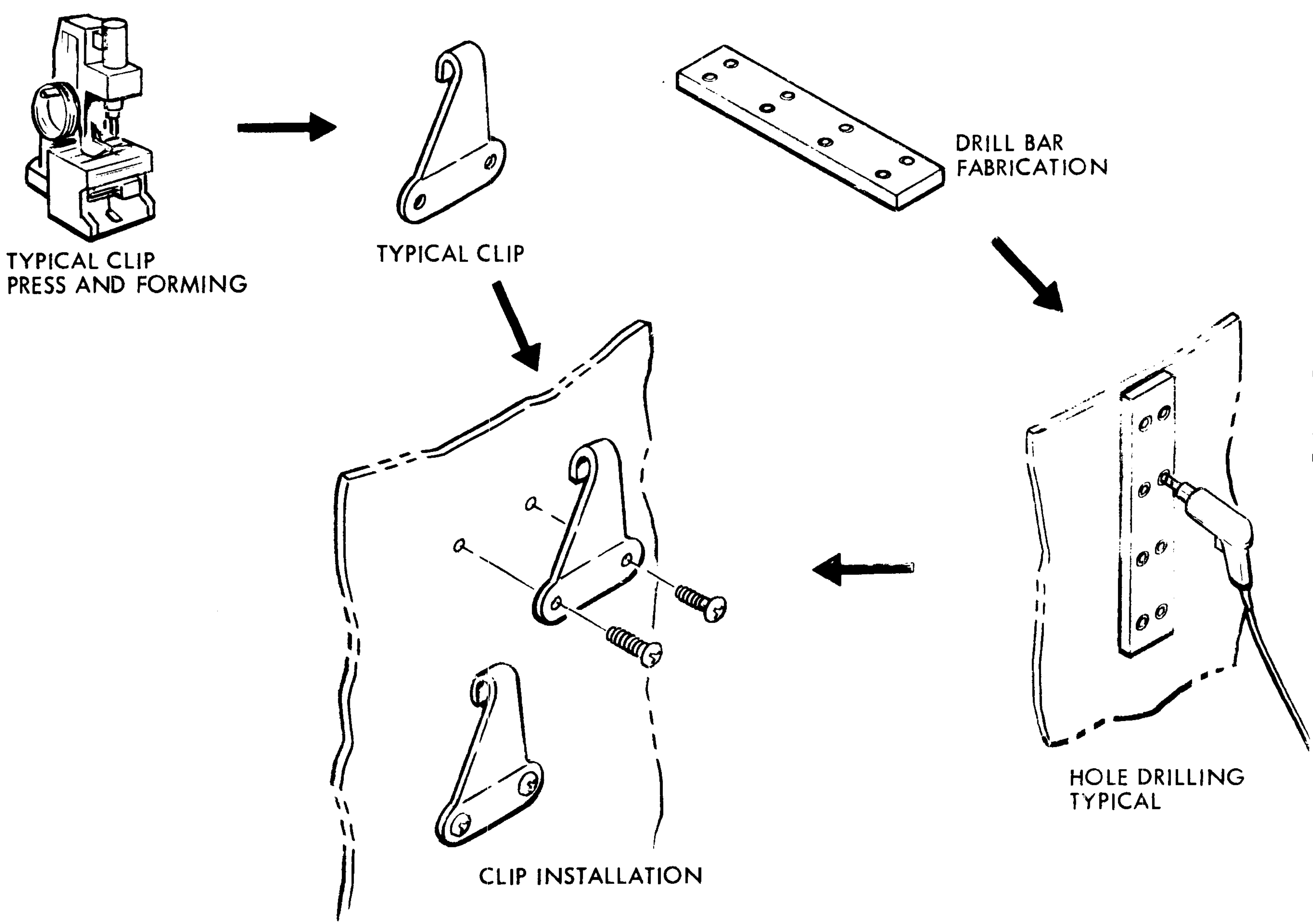


FIGURE 15

5) Bend clip tip around a 0.1-inch steel dowel form tool;

6) Deburr, clean, package, label, and store.

5.3.2 Installation

1) Fabricate drill bar of mild steel with tool steel drill bushings with the spacings specified in Drawing SK11-041071, sheet 3. Use the lower skirt splice plate as the reference point.

2) Position drill bar on skirt.

3) Drill all holes using portable high speed drilling equipment.

4) Repeat Steps 2) and 3) until all holes have been developed.

5) Position two clips and bolt through skirt using No. 2-64UNF-3A CRES bolt and nut. Repeat until all clips are secured.

5.4 Insulation Buttons (See Figure 16)

5.4.1 Fabrication

1) Purchase or draw from stores the 0.025-inch thick nylon or fiberglass flat sheet material;

2) Punch out 0.50-inch diameter buttons;

3) Stack drill holes for thread;

4) Insert threat and needle and tie in place for bonded insulation buttons;

5) DO NOT insert thread for insulation panel ties.

An alternate method is to fabricate a thin spike nylon stud then mate this with a small grip cap button.

5.4.2 Installation

Method A — Fabricate the locating and bonding tools.

1) Acquire flat stock;

2) Brake or saw to size;

3) Punch hole in center to accommodate button;

4) Saw into two equal parts;

5) Clean and deburr;

6) Apply double-backed tape to the back;

7) Spray exposed surfaces of tool with teflon release agent;

8) Part number and store.

Method B

1) Abrade the tank locally with abrasive and clean with acetone or methyl ethyl ketone ;

BUTTON FABRICATION AND INSTALLATION

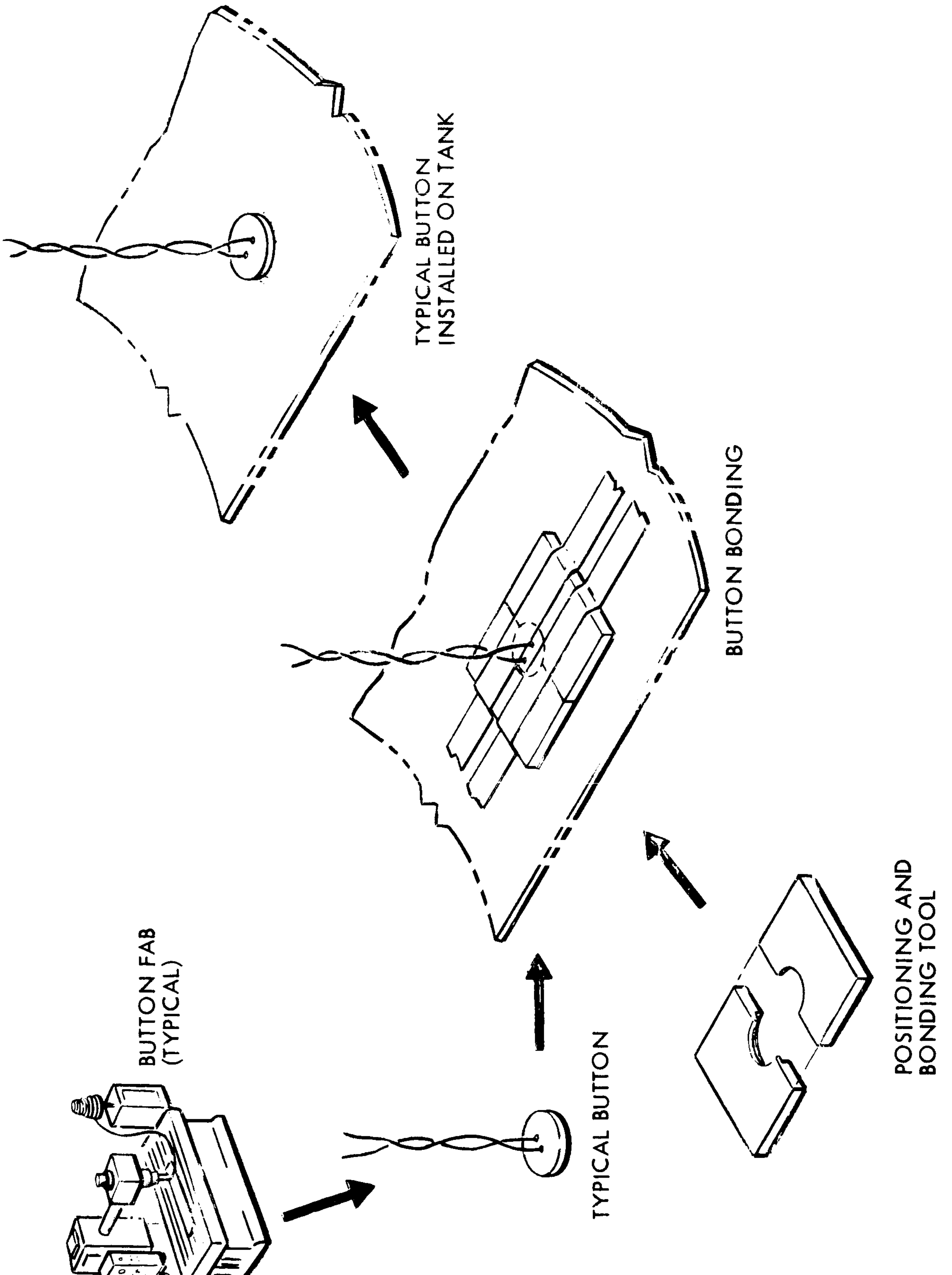


FIGURE 16

2) Install the bonding-positioning tools using double-backed tape spaced per Drawing SK11-041071. Spray each positioning tool with teflon release agent before applying to the tank;

3) Apply Narmco 7343 to the buttons and insert in the positioning tools;

4) For contact bonding pressure as shown in sketch on page 30 tape across tool and button assembly from tank surface to tank surface;

5) Allow to cure for 24 hours at room temperature. Positioning tools may then be removed and repositioned for additional button applications;

6) Allow Narmco 7343 to cure an additional 48 hours at room temperature for maximum strength.

5.5 Insulation Studs (See Figure 17)

5.5.1 Fabrication

1) Fabricate nut plates and bonding studs per Drawing SK11-041071, sheet 1;

2) Fabricate studs and retainers of fiberglass or nylon stock;

3) Fabricate positioning and bonding tool of any metal.

5.5.2 Installation

1) Position the bonding tools per Drawing SK11-041071 and attach to the tank using double-backed tape. Spray each tool with teflon release agent before applying to the tank.

2) Apply Narmco 7343 adhesive to the studs and insert in the bonding tools.

3) Tape across the studs and bonding fixture from tank surface to tank surface to obtain bonding contact pressure.

4) Allow to room temperature cure for 48 hours before applying structural loads to the studs.

5) Remove positioning and bonding tools any time after 24 hours.

5.6 Double Hoop Assembly (See Figure 18)

5.6.1 Fabrication

1) Procure material;

2) Mechanically roll two tubes to the diameters specified on the Drawing SK11-041071;

3) Tungsten inert gas weld the tubes to form two hoops;

4) Wrap hoops with fiberglass cloth or six layers of nylon net 0.007-inch fiber diameter, per Drawing SK11-041071;

5) Machine sew netting around the tube with nylon thread, per Drawing SK11-041071;

6) Protective wrap in plastic film and store.

STUD FABRICATION AND INSTALLATION

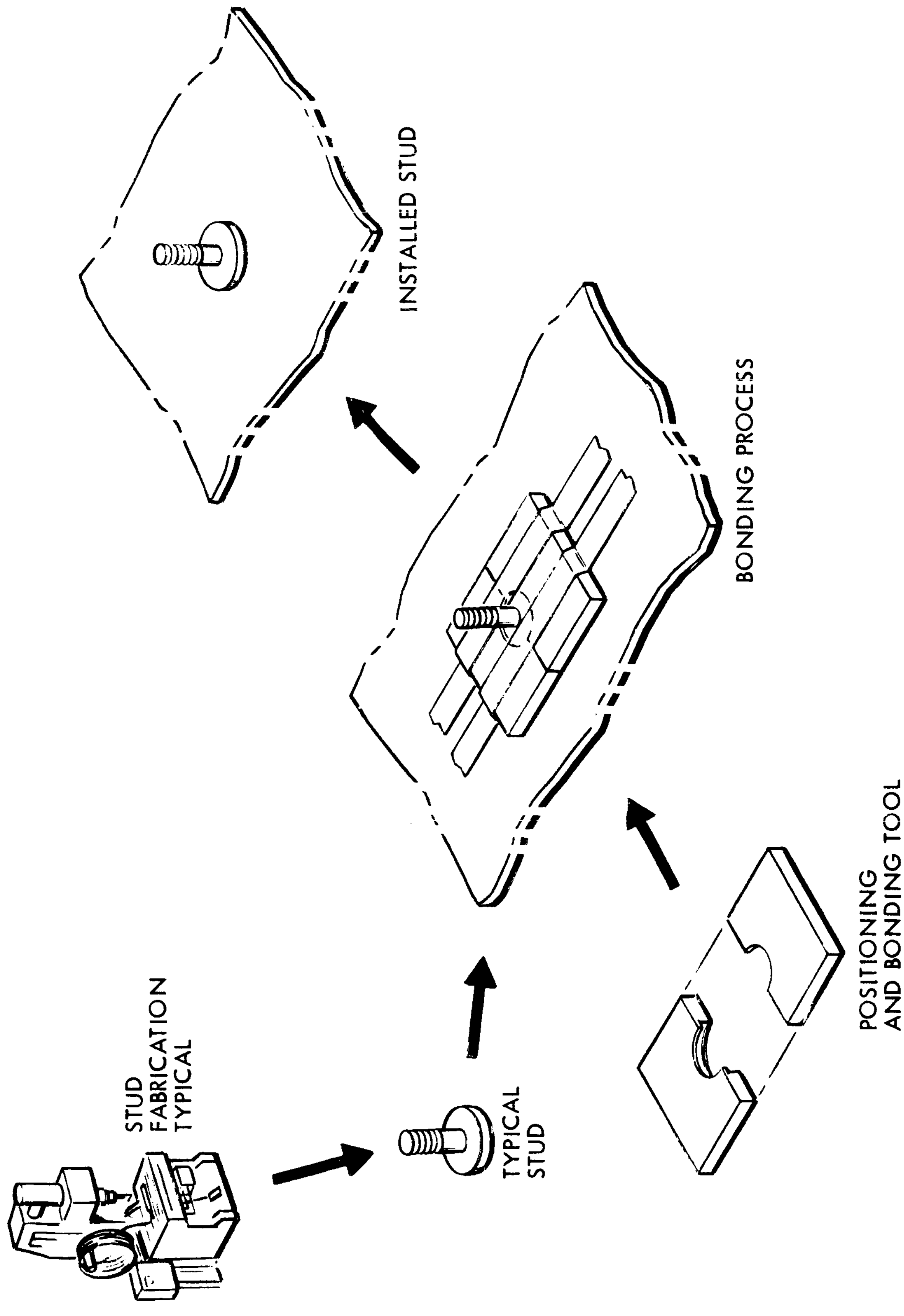


FIGURE 17

DOUBLE HOOP ASSEMBLY

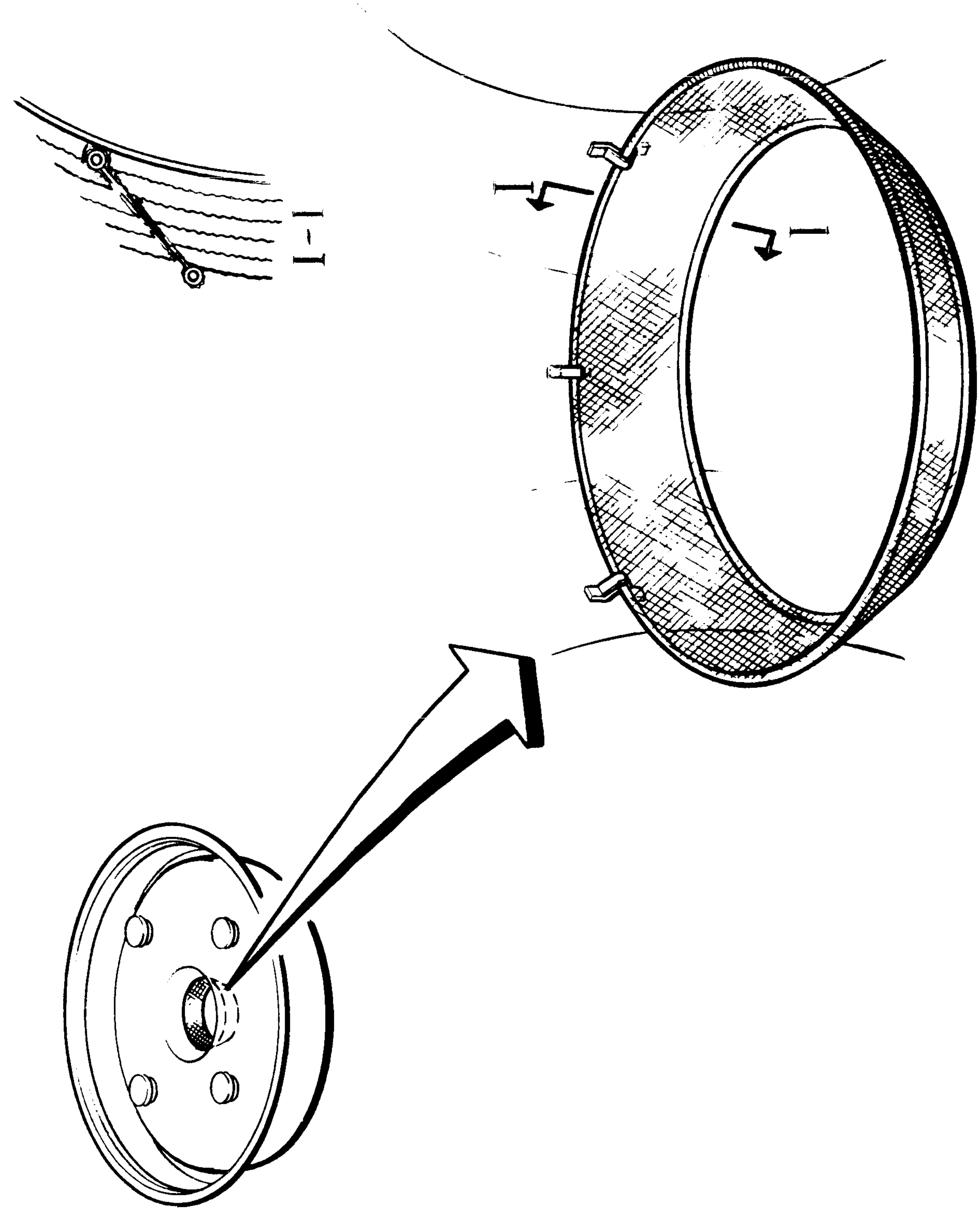


FIGURE 18

5.6.2 Installation

1) Remove retainer section from each hoop clip;
2) Position the hoop in the clips;
3) Slit the netting with a sharp instrument to allow replacement of the retainers to each hoop;
4) Repair netting by hand sewing as required on installation.

5.7 Purge System

The purge system is the largest undefined area in the insulation system. The system presented in the following text is one of many which must be considered in a broad developmental program.

5.7.1 Torus Tank Preparation (See Figures 19 through 22)

1) Install lifting harness in tank skirt ring lifting lugs;
2) Remove attach bolts;
3) Lift tank free from the support cone and insert in insulation support;
4) Install insulation bridge and center support tool;
5) Clean all external surfaces of the tank with diacetone alcohol or methyl ethyl ketone and lint free wipes;
6) After cleaning, blanket the tank with a plastic covering until insulation installation.

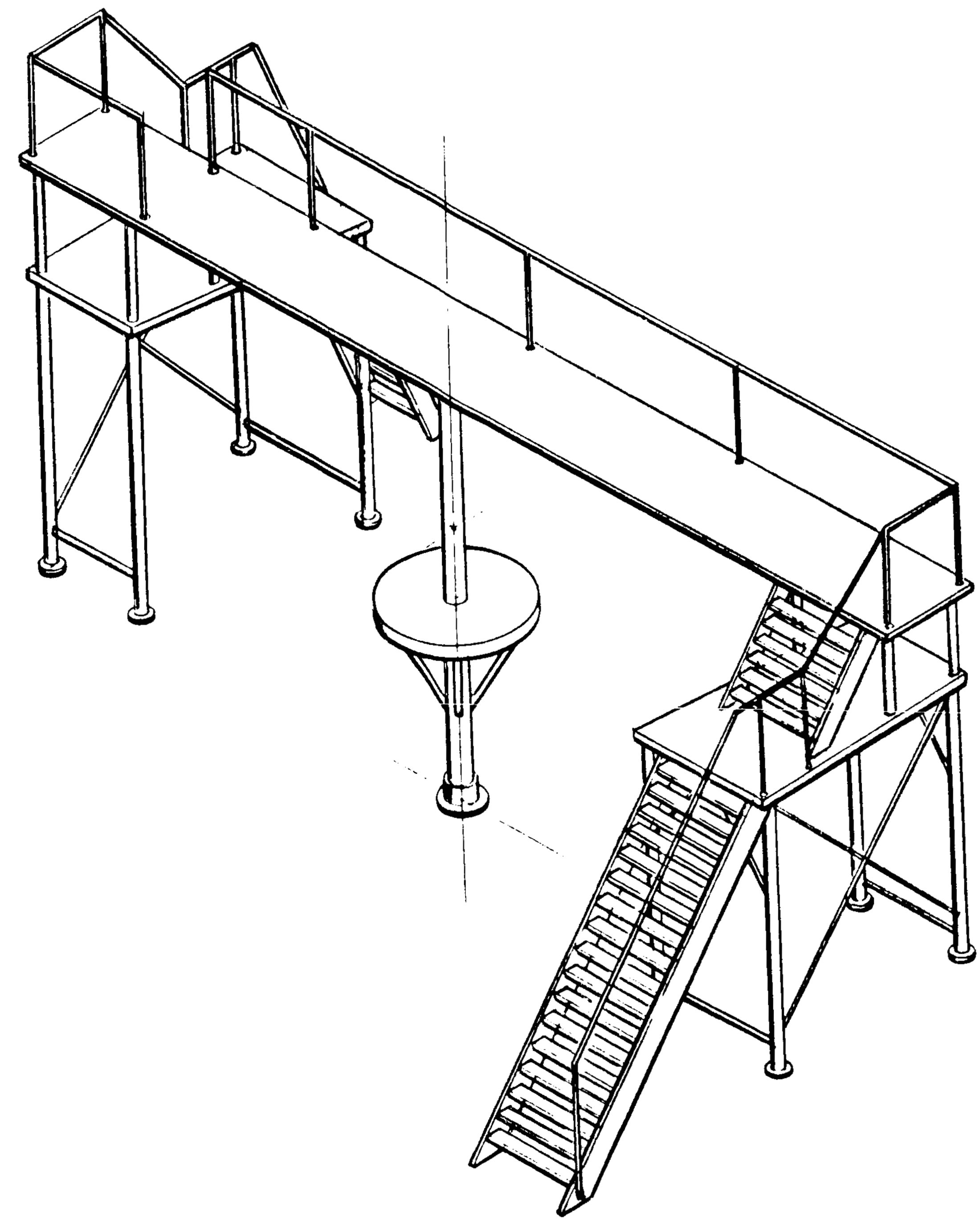
5.7.2 Fabrication

The purge system is composed of eight segments with seven sealed units per segment.

1) Procure film nylon or mylar (perforated and unperforated) per Drawing SK11-041071;
2) Fabricate shop aid templates for cutting and sealing the system to the configuration designed in Drawing SK11-041071, sheet 5;
3) Cut film using the templates;
4) Use a hot sealing iron and seal all joints per Drawing SK11-041071, sheet 5. If mylar film is used, GT100 will be required for joining and sealing;
5) Fabricate feed tubes from purge gas supply source to purge bags;
6) Install purchased nylon tees at the junction of the purge feed tubes and the purge bags.

5.7.3 Installations

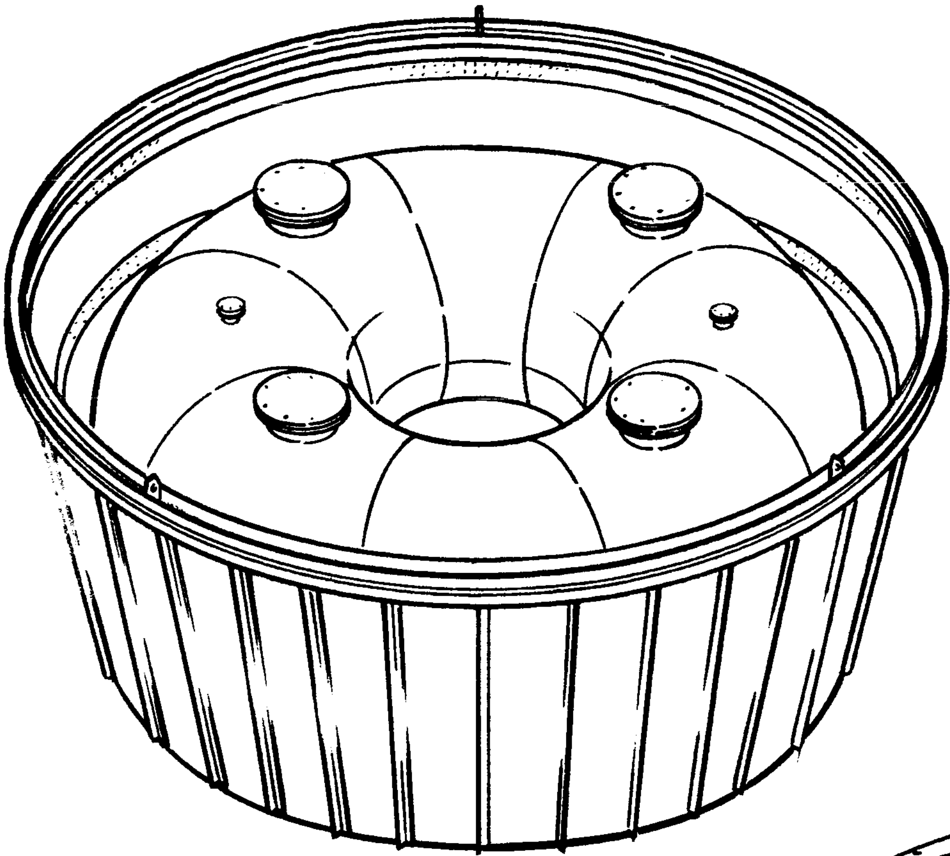
1) Tack bond the segments of each quarter to the tank using spots of contact adhesive to hold them in place;



INSTALLATION STAND

FIGURE 19

TANK PREPARATIO



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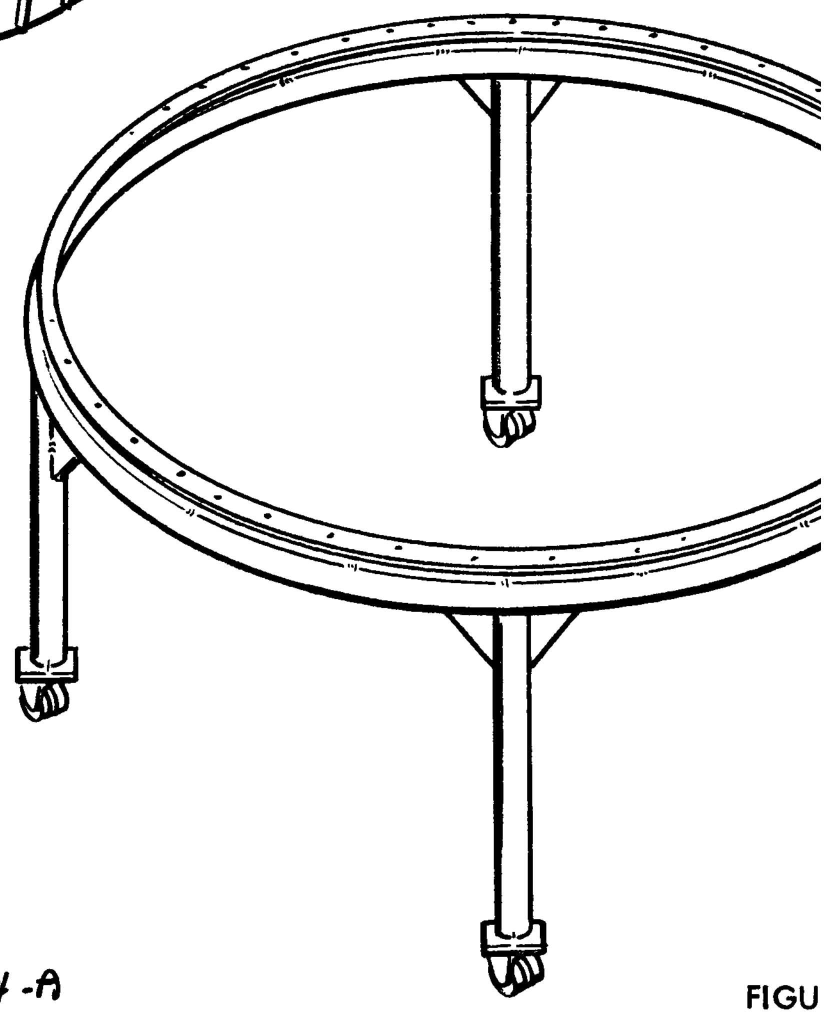

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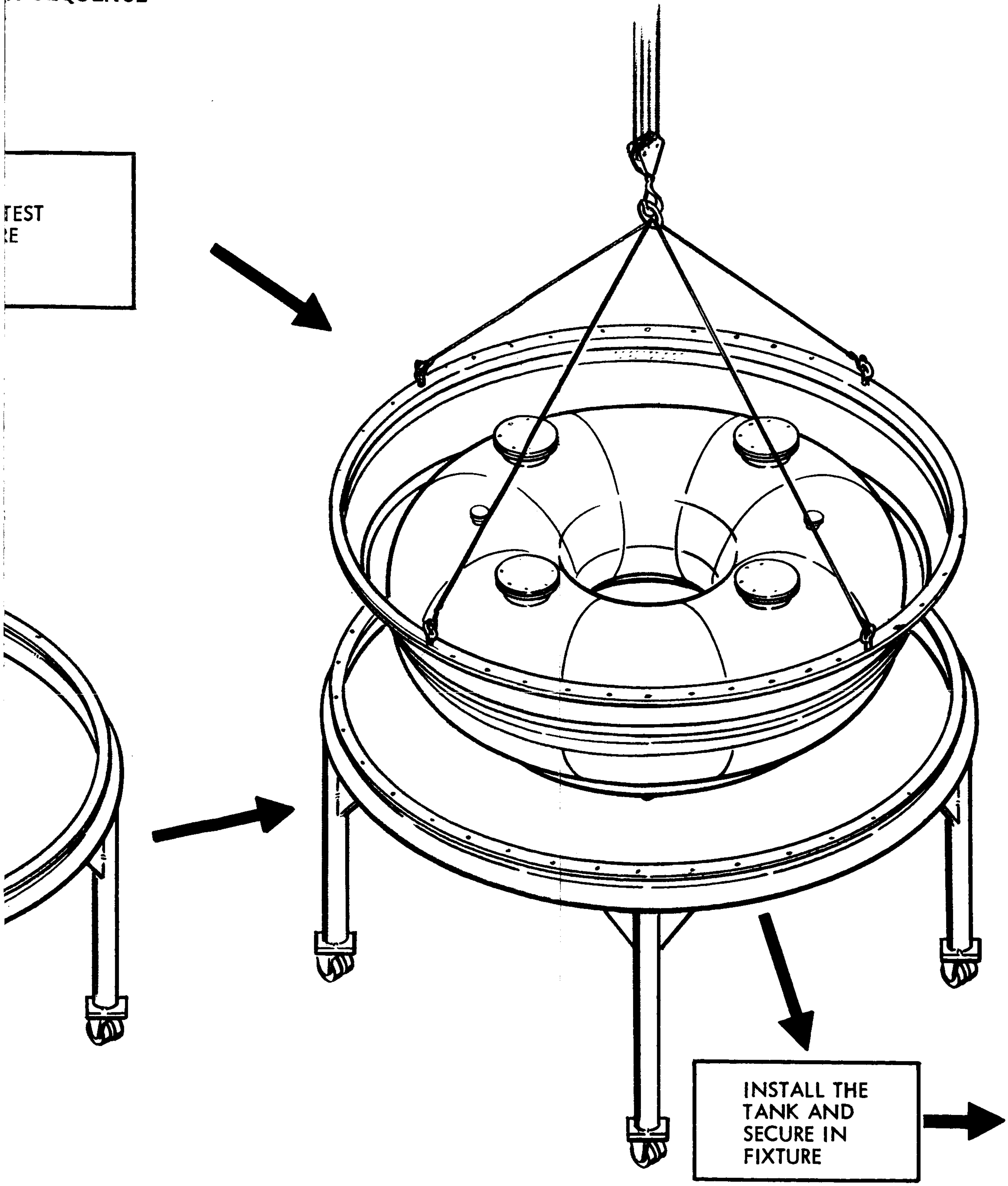

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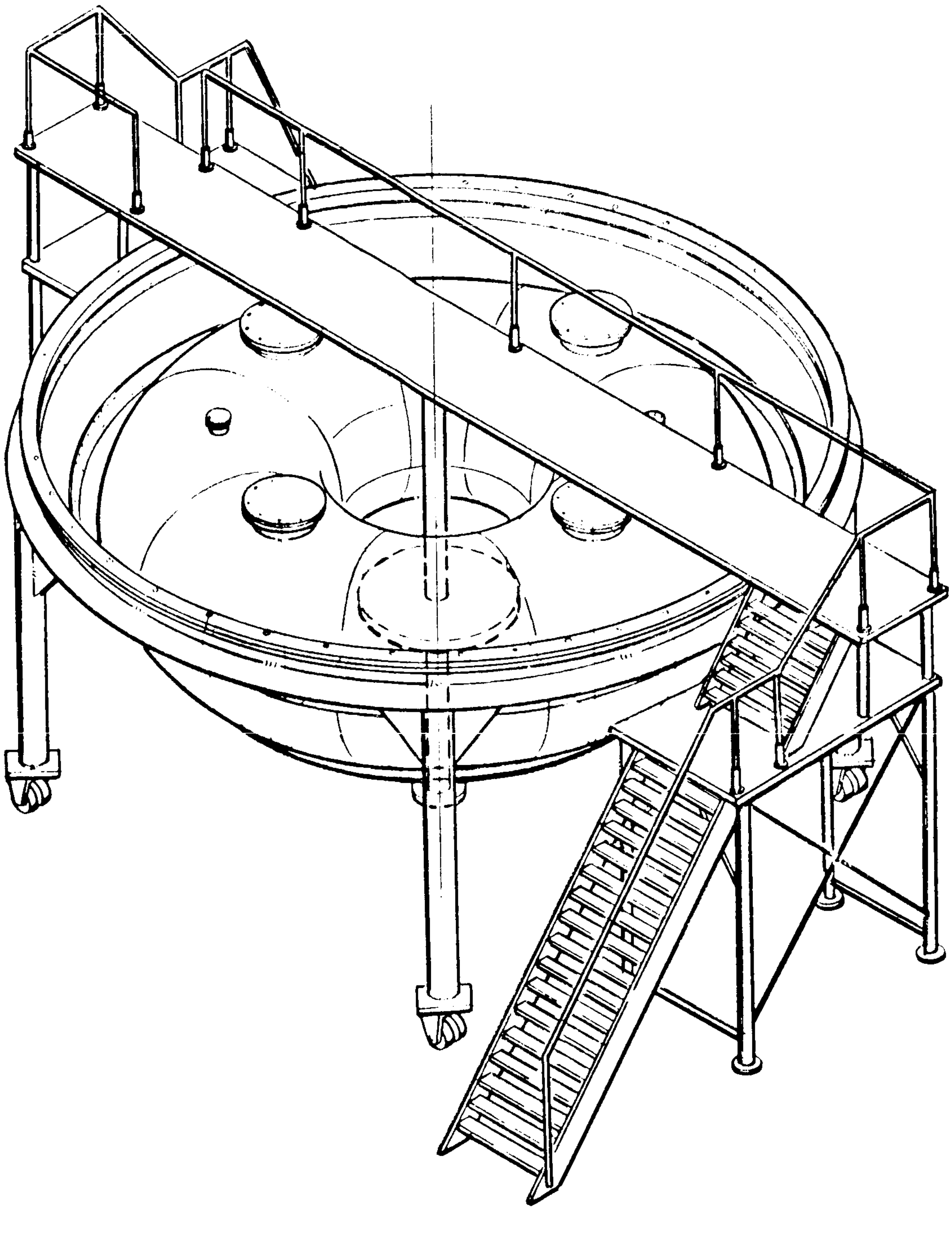
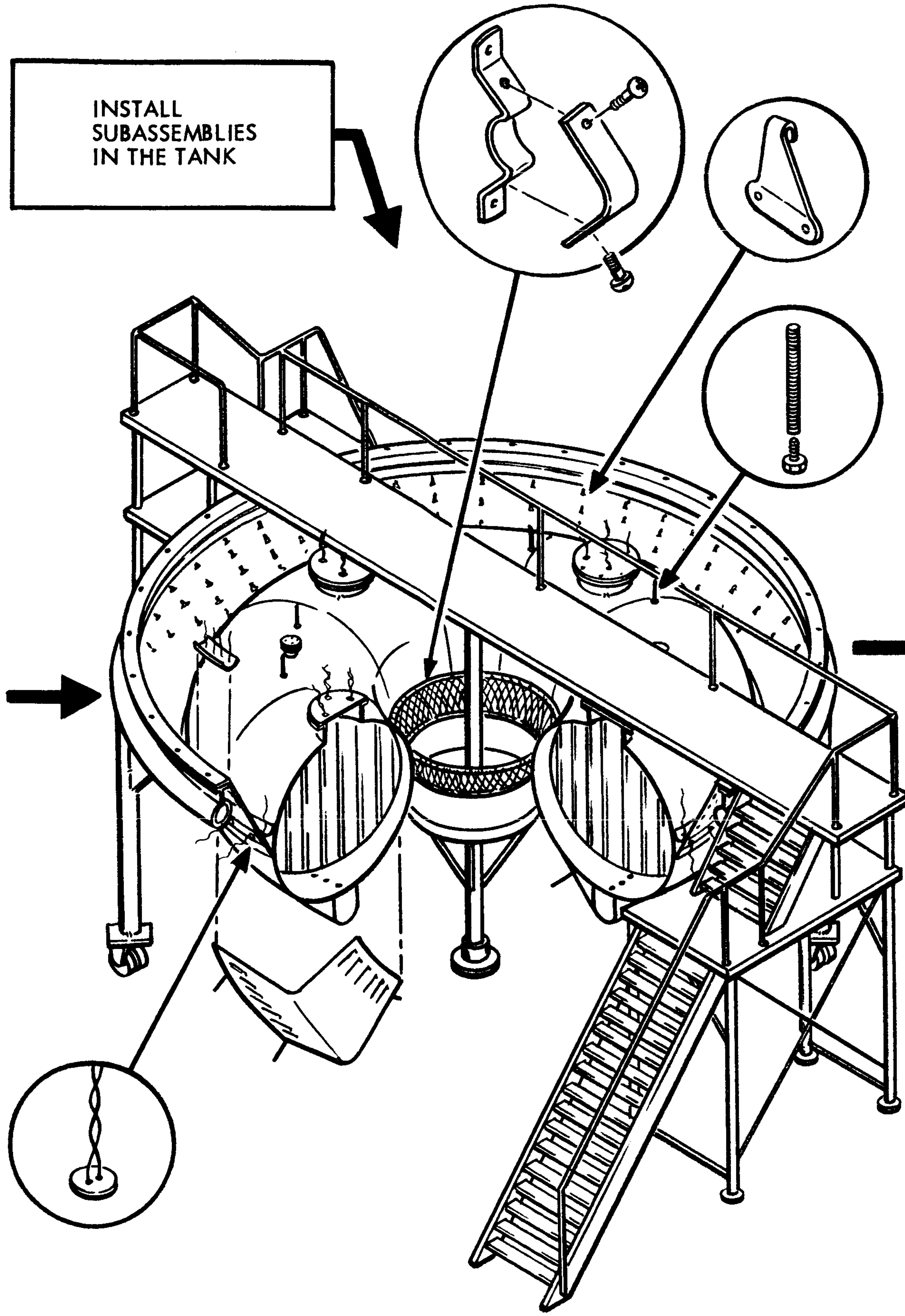


PRE - INSULATION ASSEMBLY

FIGURE 21

INSULATIO

INSTALL SUBASSEMBLIES IN THE TANK



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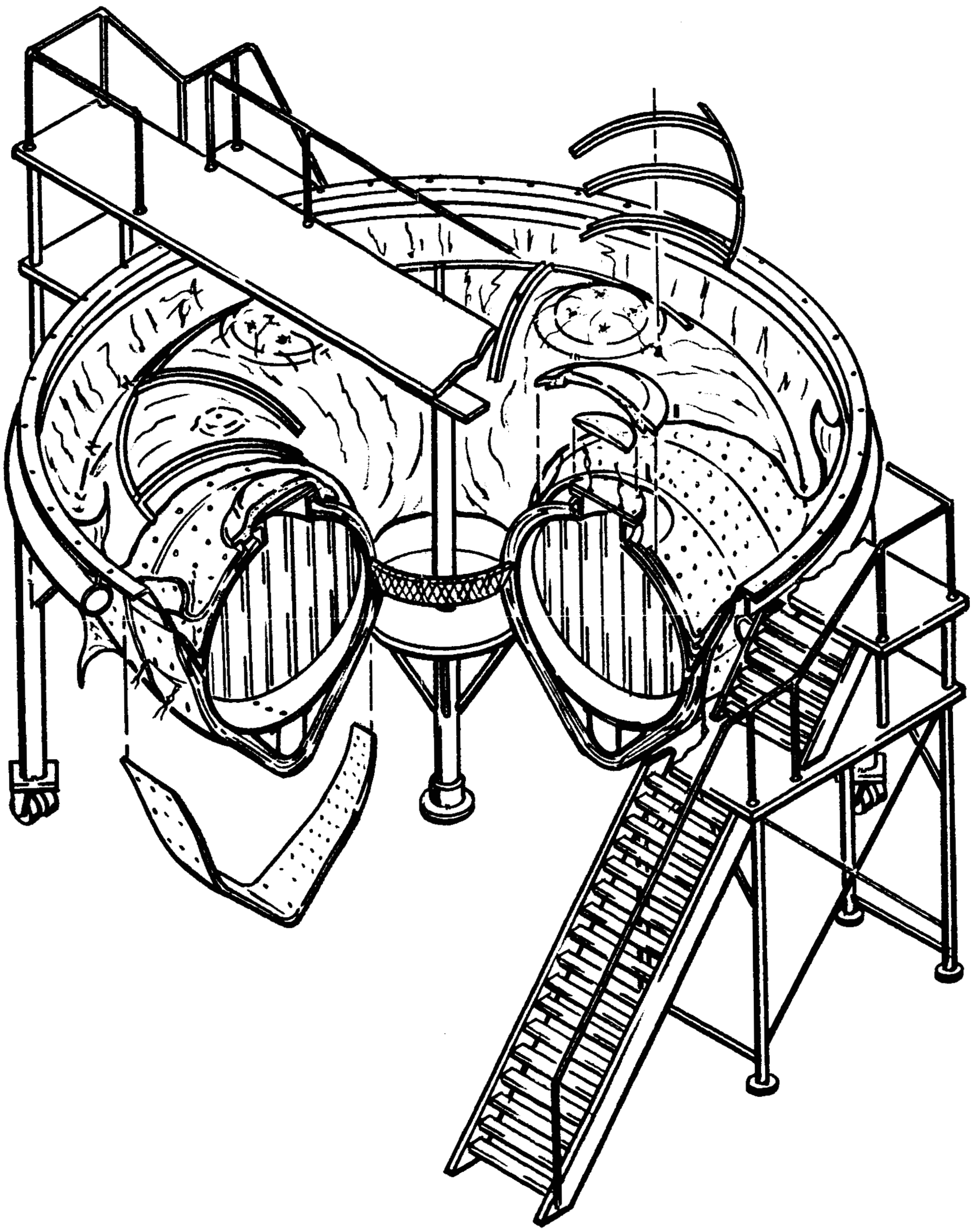


IGURE 22

2) Seal adjacent gores to each other using a hot iron. (The purge system should now resemble a complete blanket on the tank.);

3) Route the purge feed tubes to the top of the tank and continue to the manholes of each segment;

4) Connect the purge feed tubes to a central supply manifold after the insulation has been installed.

5.7.4 Facilities

A purge gas recirculation unit will be required. This unit will purify spent purge gas, reheat it to purging temperatures, and recirculate it back into the purge manifold system for another cycle.

5.8 Insulation System

5.8.1 Materials and Tooling

5.8.1.1 Materials —

1) Mylar honeycomb 3/4-inch cell size by 0.003-inch wall thickness by 0.040- x 40- x 96-inch sheets. Can be secured from Hexcel Products, Inc., Berkley, California or American Cynamid, Seattle, Washington.

2) Rigid freon or carbon dioxide blown polyurethane foam 0.025 ±0.015-inch thick. Size of sheet unknown - prefer 40 by 96 inch. Supplier: Union Carbide Company - any office.

3) Nylon tulle 0.007-inch thick by 50-inches wide by 50 yards (material bolt size). Catalog No. 36H1008, Supplier: Sears Roebuck and Company. (This is the only source of supply for this particular nylon net.)

4) Perforated double aluminized mylar, Type C, 0.00025-inch thick by 4-feet wide. Minimum of 1200 A deposited aluminum on each side. Perforations 0.04 ±0.010-inch diameter on 0.30-inch centers.

   Film to be secured from G. T. Schjeldahl, Northfield, Minnesota or any vacuum plating firm. Perforations from Perforation Specialists, 351 West 35th Street, New York.

5) Mylar film, Type A 0.001-inch thick from DuPont or any available source.

6) GT100 tape, 1/2-inch wide from G. T. Schjeldahl, Northfield, Minnesota.

7) Thread - nylon or dacron from any supplier.

5.8.1.2 Cutting Templates — Two cutting templates are required for each layer of insulation and should be approximately 0.040-inch thick of template stock. It is recommended that cardboard units be first fabricated and tooling test conducted before fabricating the metal templates.

5.8.1.3 Cutting Table and Cutter — Fabricate table to a convenient working height. Cover with a durable surface such as rubber or plastic castable.

The cutter should be a fabric cutter using a blade without teeth and extremely sharp. It should be supported from above and referenced to the table top.

5.8.1.4 Assembly Fixture — The assembly fixture is where alternate layers are built up into a full thickness insulation panel while cutting the tapes for the fiberglass skirt area.

The template is adjustable so that each insulation set of layers can be cut at a given length without affecting the layers previously cut.

Two of the assembly tools are necessary; one for the top five layers and one for the bottom five layers.

5.8.1.5 Button Assembly Fixture — Following assembly of the insulation blanket and prior to sewing the nylon tulle, the subassembly is transferred to a convenient height table where the buttons and ties (alternate nylon stud) are applied through the insulation blanket. This act helps to stabilize and locate the insulation for sewing.

This tool consists of a punched table top in the pattern of the buttons, which allows working above and below the panel, at the same time.

5.8.1.6 Sewing Table and Machine — The sewing table should be of a convenient size, i.e., 14 by 20 feet and of any smooth surface with the machine positioned approximately as shown in Figure 23. The machine should be any industrial model with a foot treadle actuator.

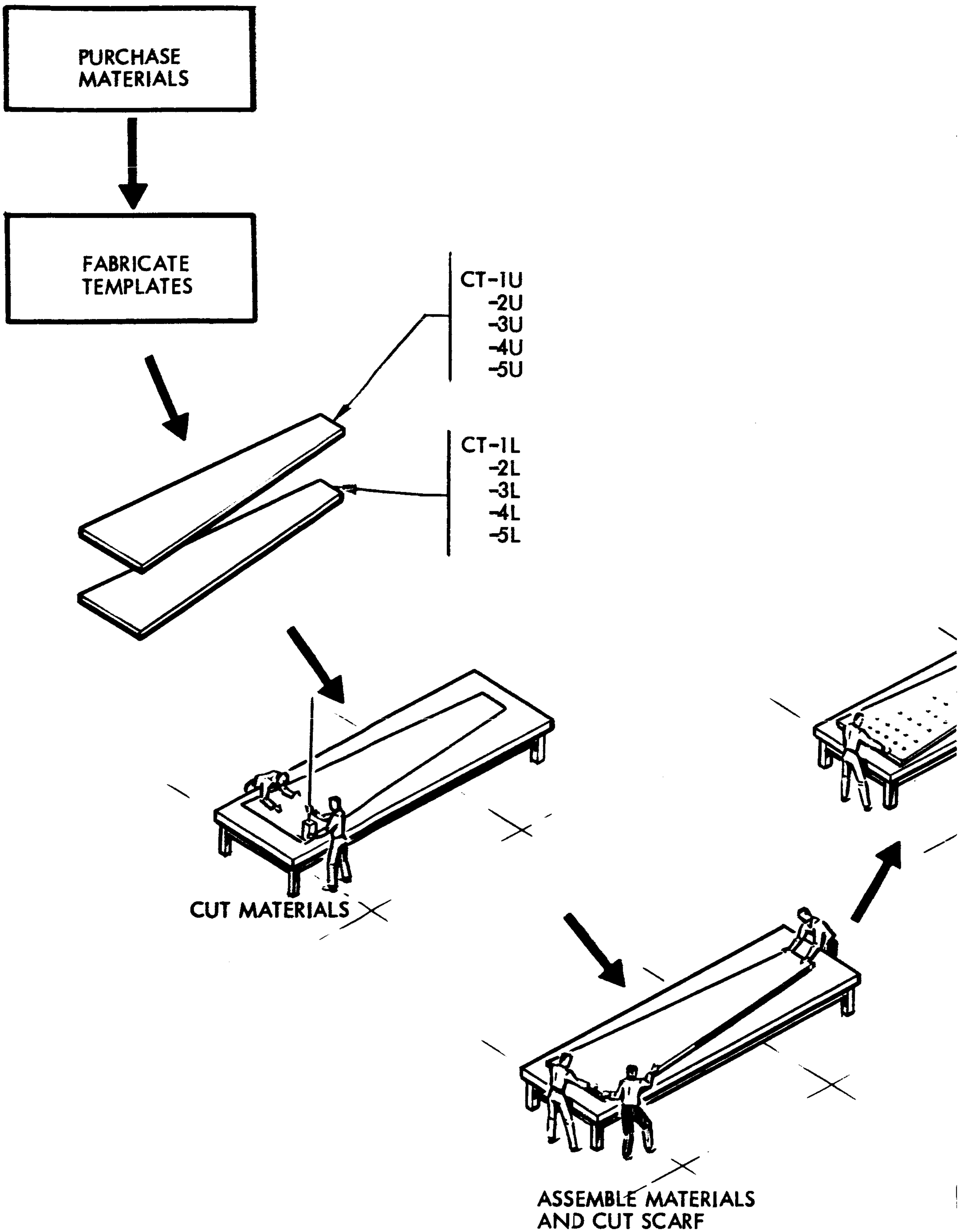
5.8.1.7 Insulation Storage Racks — Insulation storage racks can be of any metal or wood capable of supporting the insulation layers. They should be mobile, approximately 14 feet by 14 feet wide by 6 feet high and easily encloseable in plastic film for soil protection.

5.8.2 Insulation Panel Fabrication (See Figures 23 and 24)

NOTE: Assemble insulation in limited access low hydrocarbon room only. Shop personnel shall wear white gloves, hair covering, and smocks.

1) Cut mylar honeycomb for first layer blanket using cutting fixture CT-1L.
2) Cut aluminized mylar for first layer blanket using cutting fixture CT-1L.
3) Cut two layers of nylon netting using cutting fixture CT-1L.
4) Position one layer of nylon netting on fabrication fixture FF-1L.
5) Apply alternate layers of aluminized mylar and mylar honeycomb until 15 layers of each are applied.
6) Position another layer of nylon net over the insulation panel.
7) Install buttons and ties through the panel at each location indicated on the assembly tool AT-1L.
8) Machine sew all edges of the panel. Sew in nylon tape reinforcing to the wide end of the insulation panel.
9) Store in storage racks (tool ST-1L). Identify and seal with plastic film for dust protection.

INSULATION FABRICA



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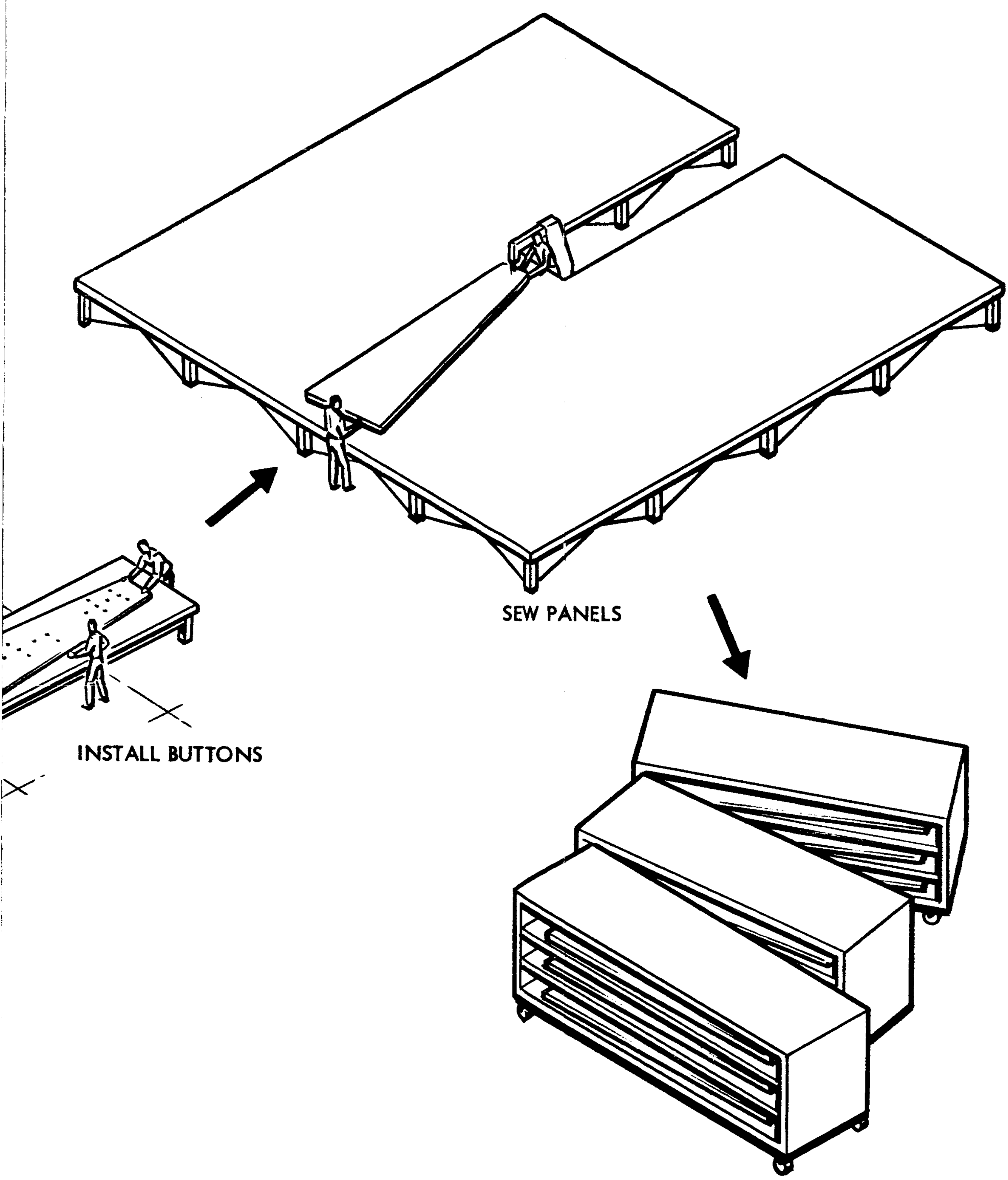


GURE 23

ASSEMBLY AND SCARF CUTTING FIXTURE

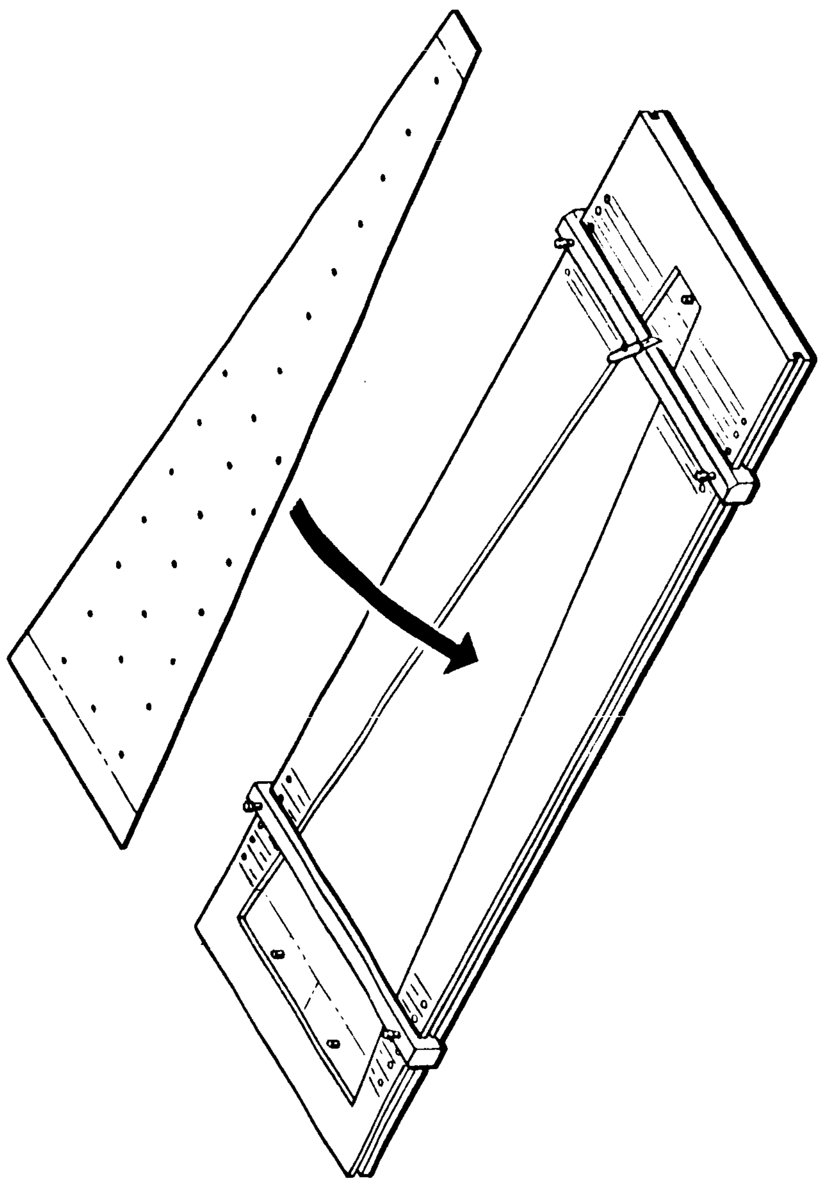


FIGURE 24

10) Repeat Steps 1) through 9) until 18 panels and 2 spares are fabricated.

11) Repeat Steps 1) through 10) using the cutting and assembly tools designated for that insulation blanket layer.

12) Repeat Steps 1) through 10) using the cutting and assembly tools designated for each insulation blanket layer of the upper tank insulation assembly.

5.8.3 Insulation Installation (See Figure 25)

1) Remove insulation from storage room for first layer of insulation.

2) Open storage cart(s) for access to the insulation.

3) Attach a blanket to the lower insulation attachment clips.

4) Rotate the panel to conform to the tank wall.

   a) Insert thread fastener through the panel at the appropriate point.

   b) Press panel against insulation support stud on the fairing.

   c) Withdraw panel from the tank surface and penetrate the indented mark with a hot iron.

      NOTE: The iron should be blunt, of 0.30-inch diameter and be heated and controlled at 450°F. This iron will burn through all layers of insulation and both net surfaces to provide a smooth hole.

      For nylon net, use a cork punch for hole development.

   d) Insert burned hole over the support stud and fasten in place using a retaining die.

5) Rotate panel under the sump and repeat Steps b), c), and d).

6) Fasten end of the insulation panel to the double hoop netting by sewing with nylon thread.

   NOTE: Trimming of the panel may be required to secure a proper fit. If this is necessary, open and fold back the net covering, then cut insulation layers back to the required dimensions and restitch the nylon net covering by hand.

7) Place adjacent blankets of insulation designated for the first layer and fasten per Steps 3) through 5) until all panels are in place.

8) Tack-sew adjacent panels to each, per Drawing SK11-041071.

9) If the full panels do not meet to form a continuous blanket, cut a splice blanket gore to the dimensions required to fill the gap.

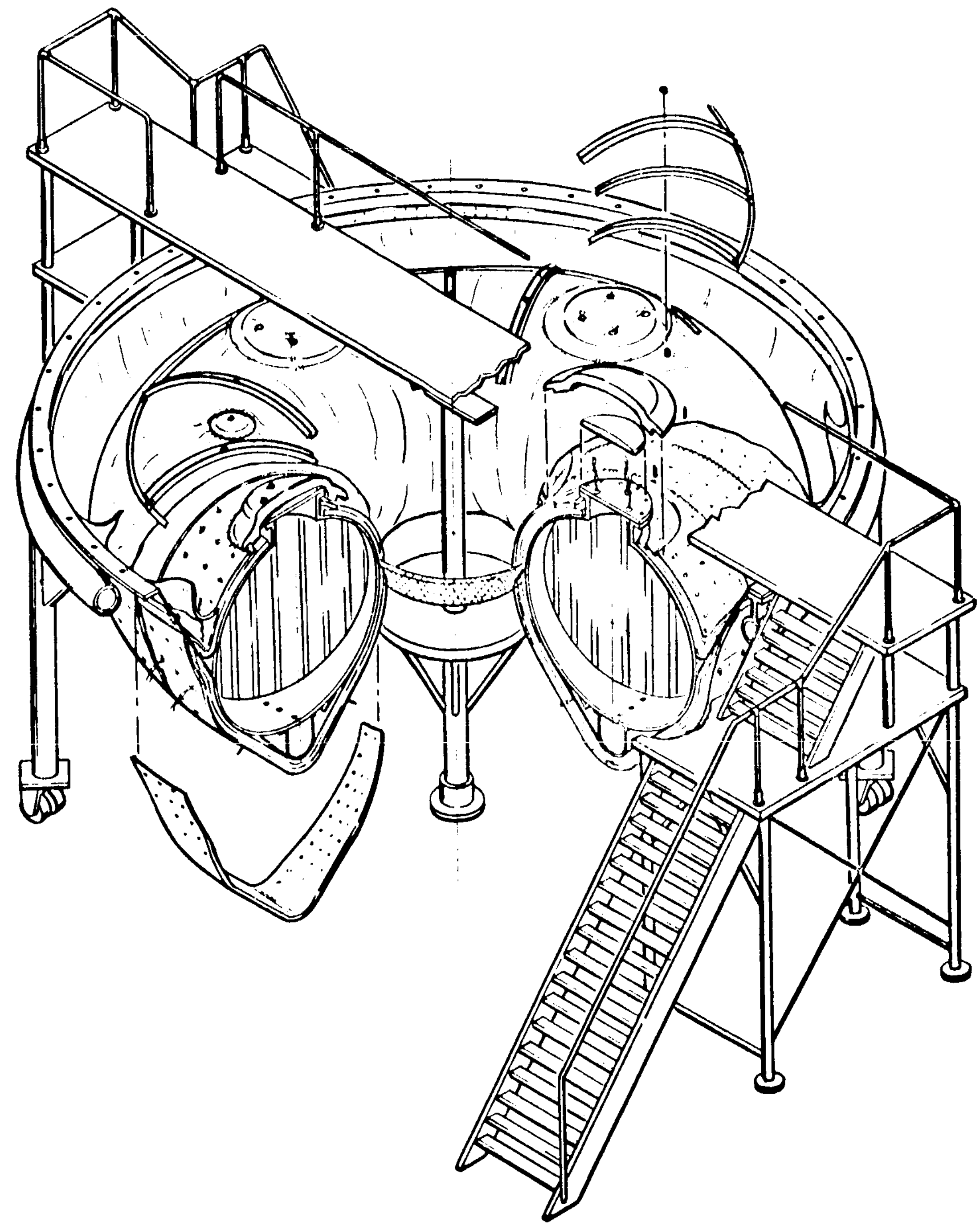
10) Remove cart(s) from storage room for upper tank insulation of first layer.

11) Fasten a gore panel to the lower attach clips on the fiberglass skirt.

12) Mold the insulation to conform to the crotch fairing using gentle hand pressure and insert the hold-down threads through the blanket gore.

13) Position over stud at top of tank; mark by gently pressing on the point of the stud and melt with the same iron described in Step c).

14) Position the holed gore on the stud and install the retainer.



INSULATION ASSEMBLY

FIGURE 25

15) Sew the blanket gore end to the double hoop netting.

NOTE: The blanket may be trimmed to dimension and resewn.

16) Place adjacent gores and attach per Steps 11) through 15).

17) Tack-sew adjacent gores per Drawing SK11-041071.

18) If a gap remains after all panels are in place, splice panels shall be cut, sewn, and placed to fill the gap.

19) Proceed to No. 2 layer on the bottom half.

20) Displace the panels from the first layer per Drawing SK11-041071.

NOTE: This spacing is critical.

21) Apply No. 2 layer on the bottom half, per Steps 3) through 6).

22) Proceed to No. 2 layer on top half.

23) Displace the panels from the first layer, per Drawing SK11-041071.

NOTE: This spacing is critical.

24) Apply No. 2 layer on the top half, per Steps 11) through 16).

25) Alternate layers, top and bottom, until all five layers are applied.

26) The manhole insulation conflict shall be resolved on installation by marking the portion to be removed; removing the net covering locally, cutting away insulation and resewing nylon net over cut area.

27) Insulation of the manhole cover shall be fabricated and installed to fit after the insulation blanket layers are applied.

28) Install the 1-mil polyethylene purge bag fabricated of gores and heat sealed together.

29) Install insulation retainers on the top portion of the tank, per Drawing SK11-041071.

5.9 Protection System

5.9.1 Fabrication and Installation

1) Procure plastic (mylar, polyethylene, or PVC).

2) Cut gore patterns for the film covering using the No. 5 blanket insulation cutting templates CT-U5 and CT-L5.

3) Join adjacent gores by heat sealing with a hot iron (tape adhesive Schjeldahl GT-100 or equivalent is required to seal mylar film.

4) Fabricate the upper and lower half units separately for handling purposes.

5) Bond the upper half unit to the fiberglass tank support skirt.

6) Bond the lower half unit to the fiberglass tank support on the outside.

7) Join the upper and lower film half sections near the double hoop assembly joint by heat sealing.

8) Make cut outs in the film macket for vent protrusions and the manholes covers.

9) Form manhole covers of gored plastic film.

10) Use double-backed tape to hold manhole film covers in place.

11) Reinforce and/or seal protrusions through the film bag by heat sealing a doubler segment adjacent to or over these areas.

5.10 Field Repairs

5.10.1 Repairs to the Purge Bag Protection System

1) Remove damaged area from the film cover.

2) Cut a film section to completely cover the area removed.

3) Heat seal film patch in place.

NOTE: Mylar film requires a film adhesive (Schjeldahl GT-100 or equivalent).

A back-up of rubber covered aluminum is required to heat seal the film and protect the underlying insulation.

5.10.2 Repairs to the Insulation System

1) Remove the purge bag in the damaged area.

2) Remove the damaged insulation gore segments from the tank.

3) Procure spare gores packaged in plastic film for soil protection from storage area.

4) Remove gores from plastic packaging.

5) Install replacement gores by attaching and sewing in place.

6) Repair film per Steps 2) and 3).

6.0 TOOLING LIST

7.0 CONCLUSIONS

A comprehensive manufacturing plan was developed for fabrication and application of high performance thermal insulation to the 200-inch diameter Torus Tank.

A detailed design of the insulation system was developed which met the requirements of the program. Thermal, structural, and weights analysis were conducted on the system.

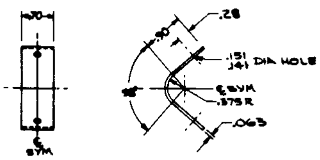
Fabrication, tooling, and installation plans were developed and documented for the detailed insulation system.

Further development is required in the areas of purge systems and outer purge covers. The units presented in this document do not attempt to define these areas.

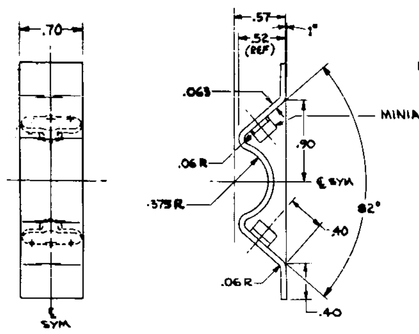
8.0 REFERENCES

MSFC Drawings:

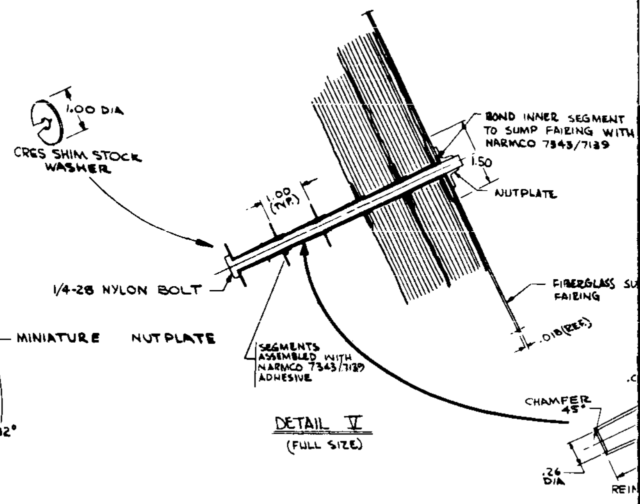
1) 15-A-X-1100
2) 15-A-X-1101
3) 15-A-X-1103
4) 15-A-X-1110



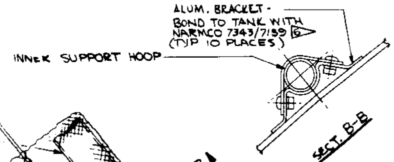
DETAIL — INNER SUPPORT HOOP ATTACH BRACKET COVER FULL SCALE

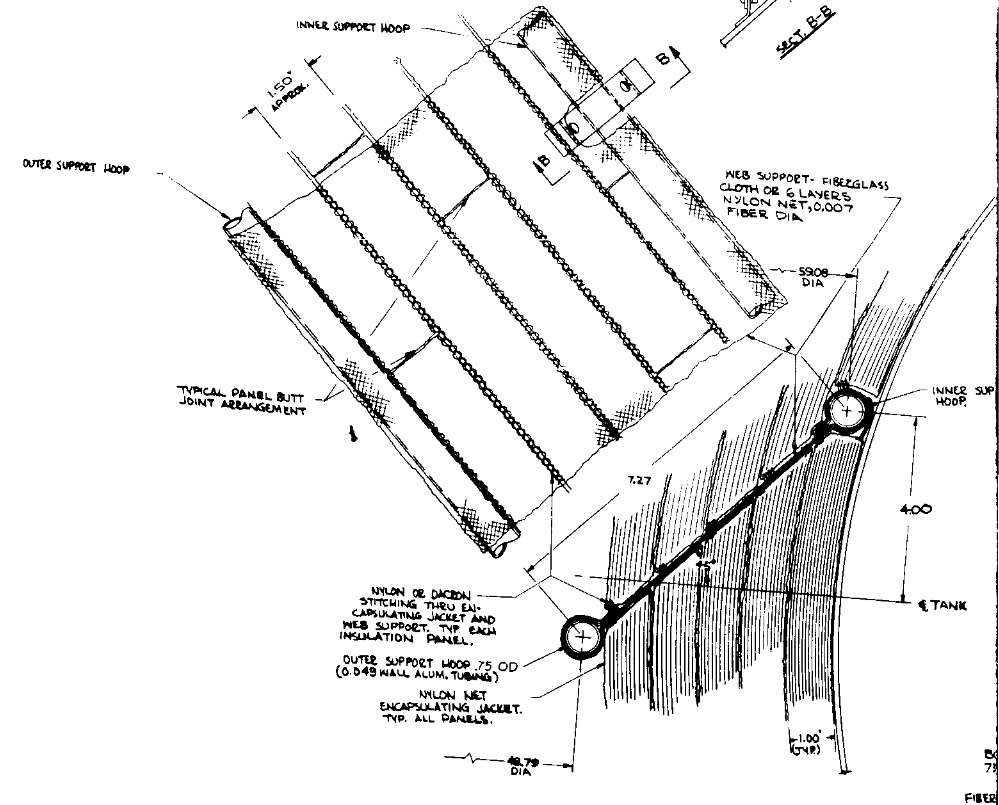


DETAIL — INNER SUPPORT HOOP ATTACH BRACKET, SCALE = 2:1
MATL: 6061-O ALUM.

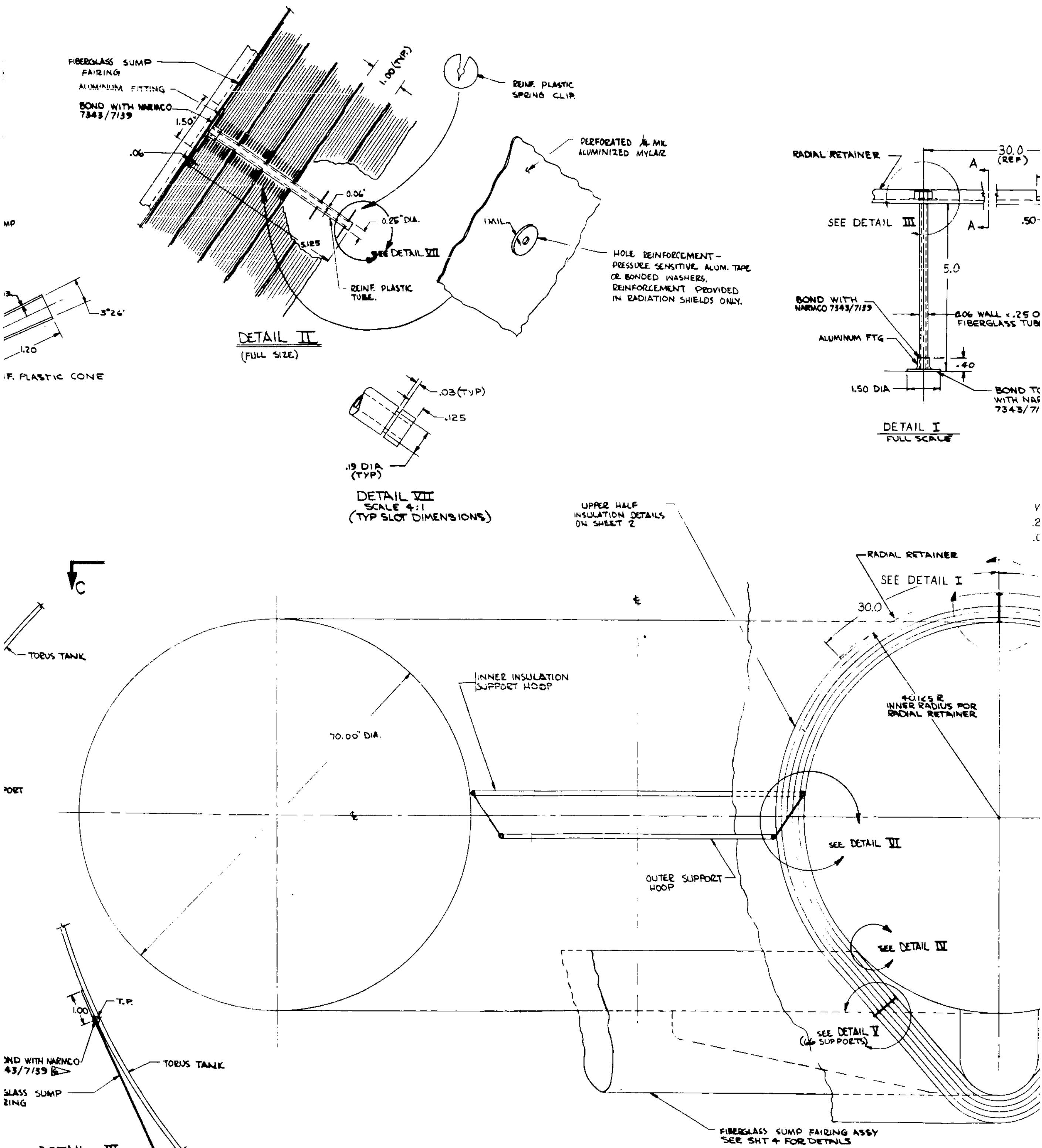


DETAIL V
(FULL SIZE)

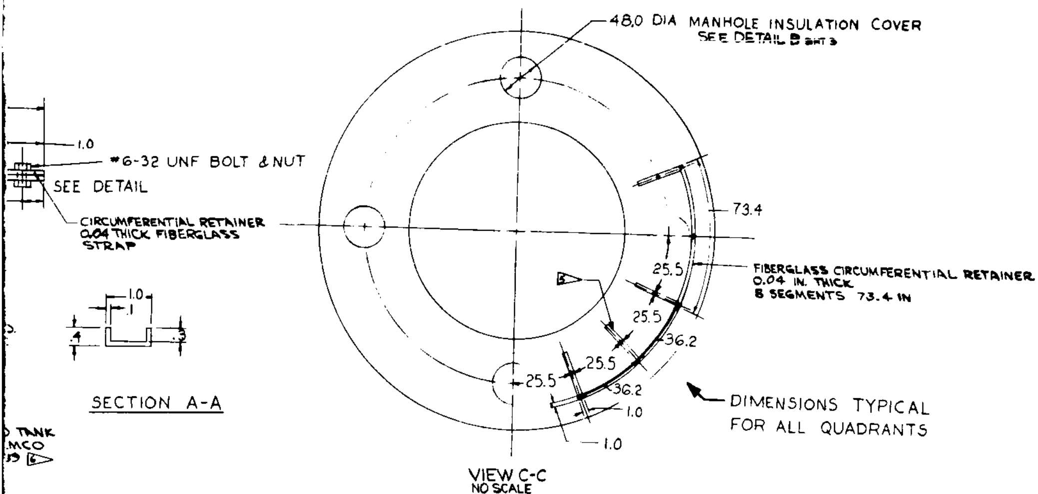


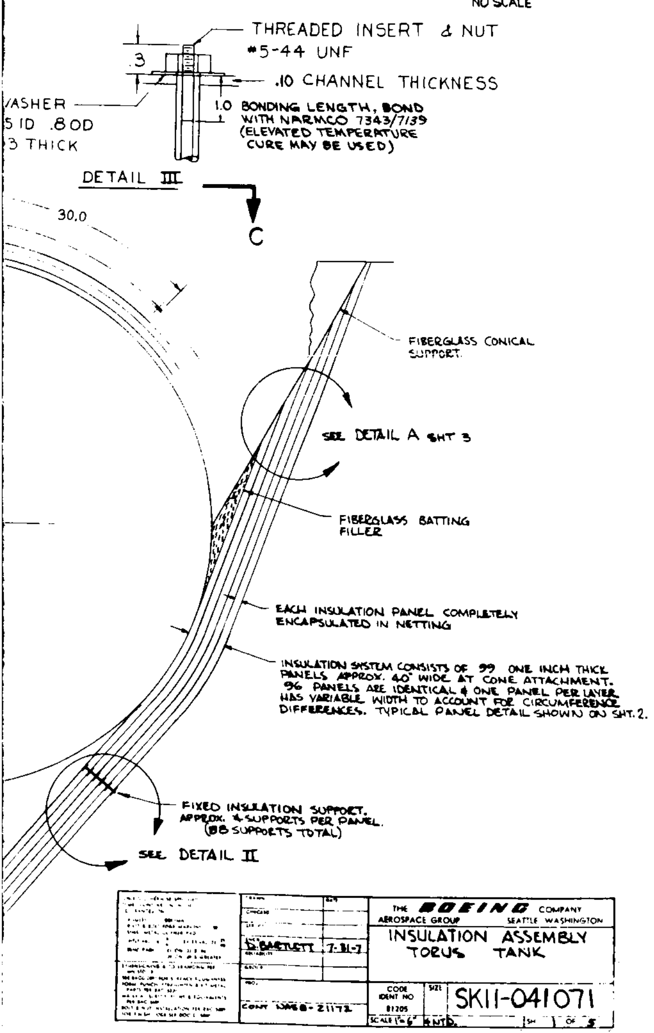


DETAIL VI
(FULL SIZE)



TORUS TANK INSULATION ASSY
SCALE: 1"=6"





NOTES:

1. INSULATION PANELS COVERING LOWER HALF OF TANK TO BE INSTALLED FIRST.

2. TYPICAL SHIELD & SPACER MAT'LS TO BE:

   SHIELDS

   1/4 MIL ALUMINIZED BOTH SIDES MYLAR PERFORATED WITH .040 DIA. HOLES ON .30" CTRS.

   SPACERS

   .007" NYLON NET OR
   .020 SLICED FOAM OR
   SLICED 3/4" CELL MYLAR HONEYCOMB

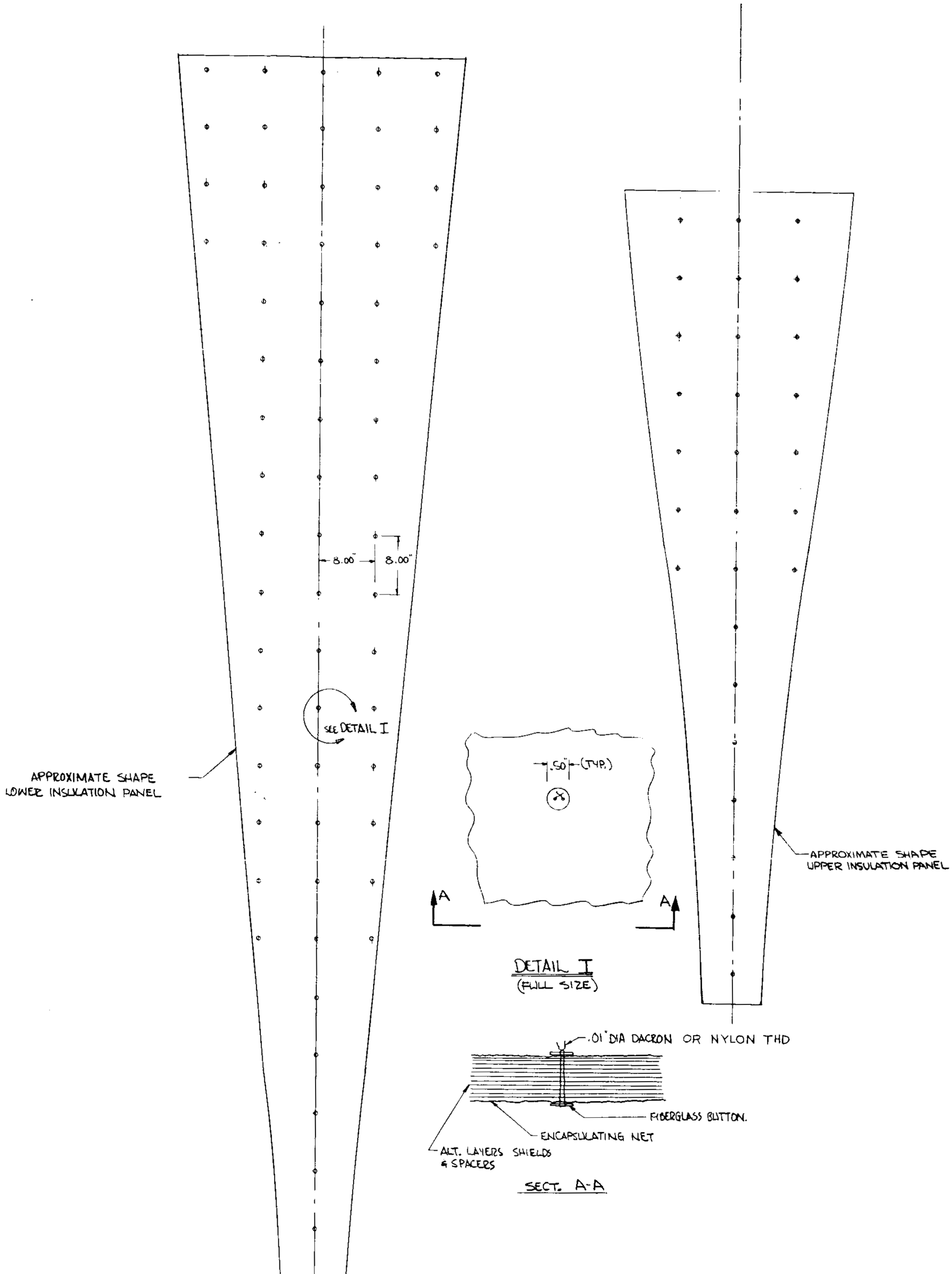
3. PRECONDITIONING: 200°F HELIUM PURGE THRU PURGING SYSTEM. IT WILL BE NECESSARY TO CONTAIN THE ASSEMBLED INSULATION IN A PURGE BAG WITH PROVISION FOR VENTING WHILE PRECONDITIONING AND SEALING OFF FOR STORAGE WITH HELIUM IN THE INSULATION. A LAUNCH VENTING SYSTEM WILL BE NECESSARY.

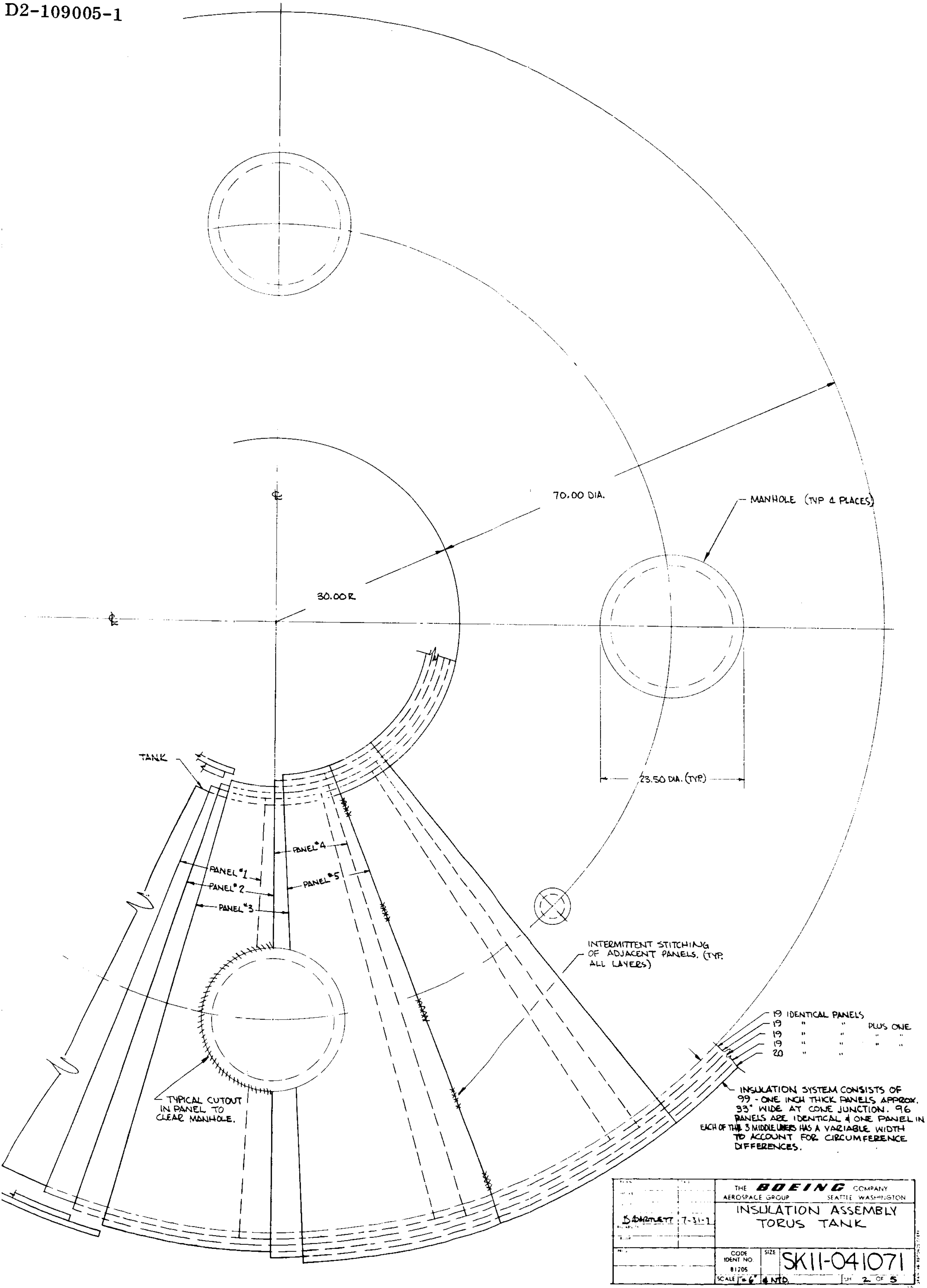
4. TYPICAL ENCAPSULATING MAT'L.:

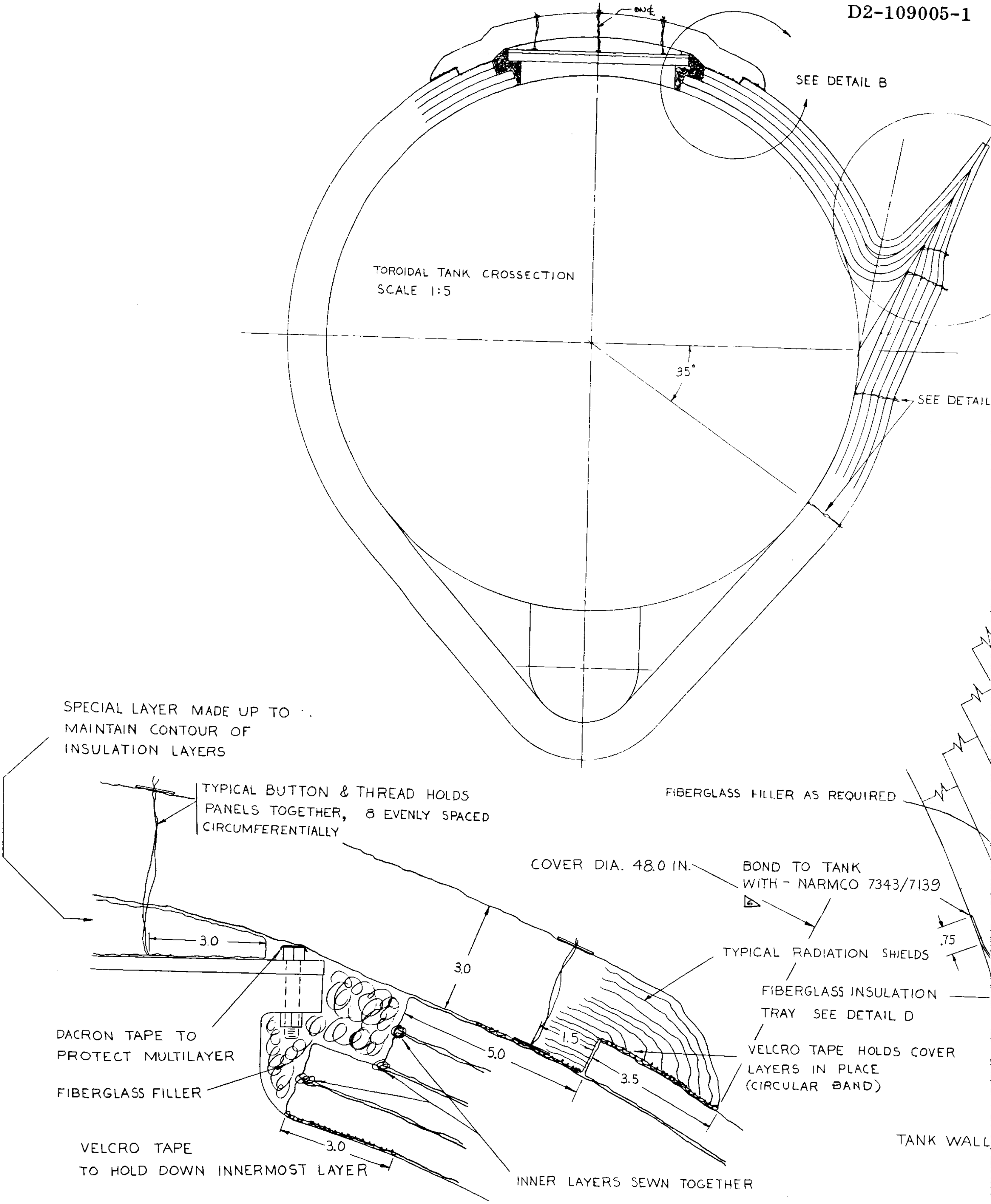
   NYLON NET OR
   SILK NET

5 THIS RADIAL RETAINER IS TO BE ROTATED 5° CLOCKWISE TO CLEAR VENT FITTING IN TWO LOCATIONS, 180° APART & CIRCUMFERENTIAL RETAINER MUST BE DRILLED TO FIT ROTATED RADIAL RETAINER.

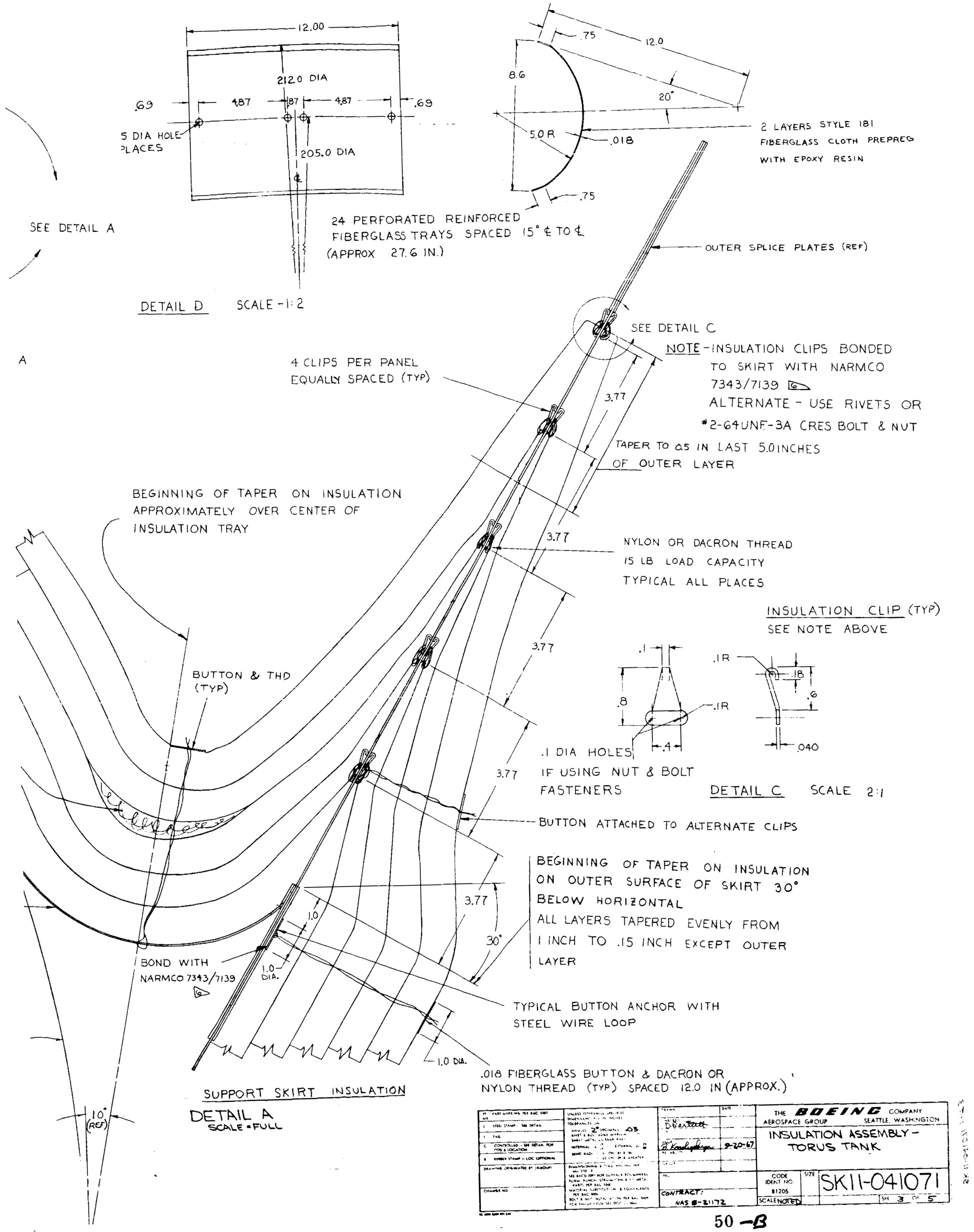
6 CURE 3 DAYS AT 75°F. PREPARE ALUMINUM & FIBERGLASS SURFACES BY LIGHT SANDING, CLEAN WITH MEK.

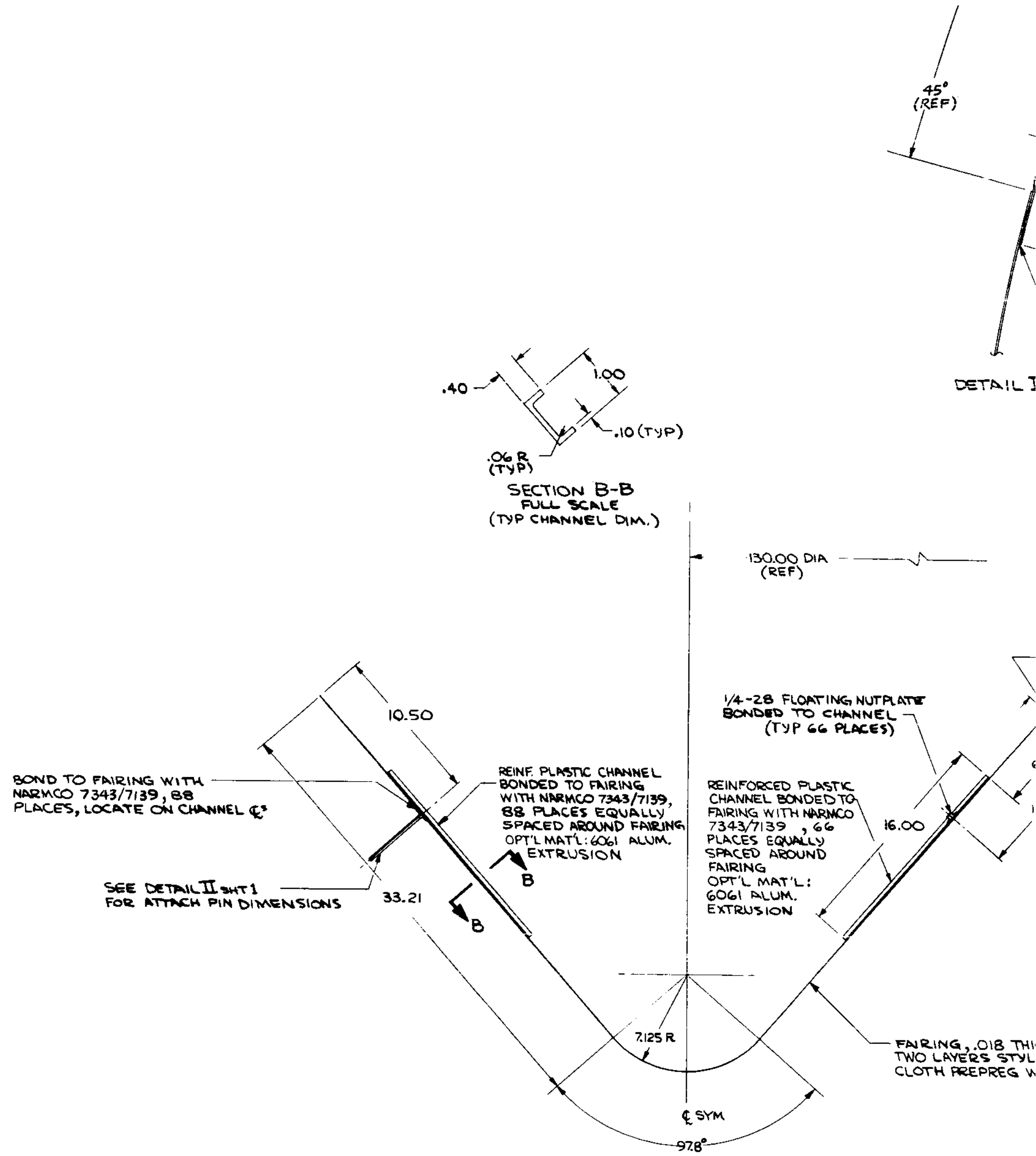

8.00"
8.00"
SEE DETAIL I
APPROXIMATE SHAPE
LOWER INSULATION PANEL
.50" (TYP.)
A
A
DETAIL I
(FULL SIZE)
APPROXIMATE SHAPE
UPPER INSULATION PANEL
.01" DIA DACRON OR NYLON THD
FIBERGLASS BUTTON.
ENCAPSULATING NET
ALT. LAYERS SHIELDS & SPACERS
SECT. A-A


70.00 DIA.
MANHOLE (TYP 4 PLACES)
30.00 R
23.50 DIA. (TYP.)
TANK
PANEL #1
PANEL #2
PANEL #3
PANEL #4
PANEL #5
INTERMITTENT STITCHING OF ADJACENT PANELS. (TYP. ALL LAYERS)
TYPICAL CUTOUT IN PANEL TO CLEAR MANHOLE.
19 IDENTICAL PANELS
19 " " PLUS ONE
19 " " " "
19 " " " "
20 " "
INSULATION SYSTEM CONSISTS OF 99 - ONE INCH THICK PANELS APPROX. 33" WIDE AT CONE JUNCTION. 96 PANELS ARE IDENTICAL & ONE PANEL IN EACH OF THE 3 MIDDLE LINERS HAS A VARIABLE WIDTH TO ACCOUNT FOR CIRCUMFERENCE DIFFERENCES.
THE BOEING COMPANY
AEROSPACE GROUP SEATTLE WASHINGTON
INSULATION ASSEMBLY
TORUS TANK
B. BARTLETT 7-31-1
CODE IDENT NO. 81205
SIZE
SK11-041071
SCALE 1" = 6" & NTD.
SH 2 OF 5

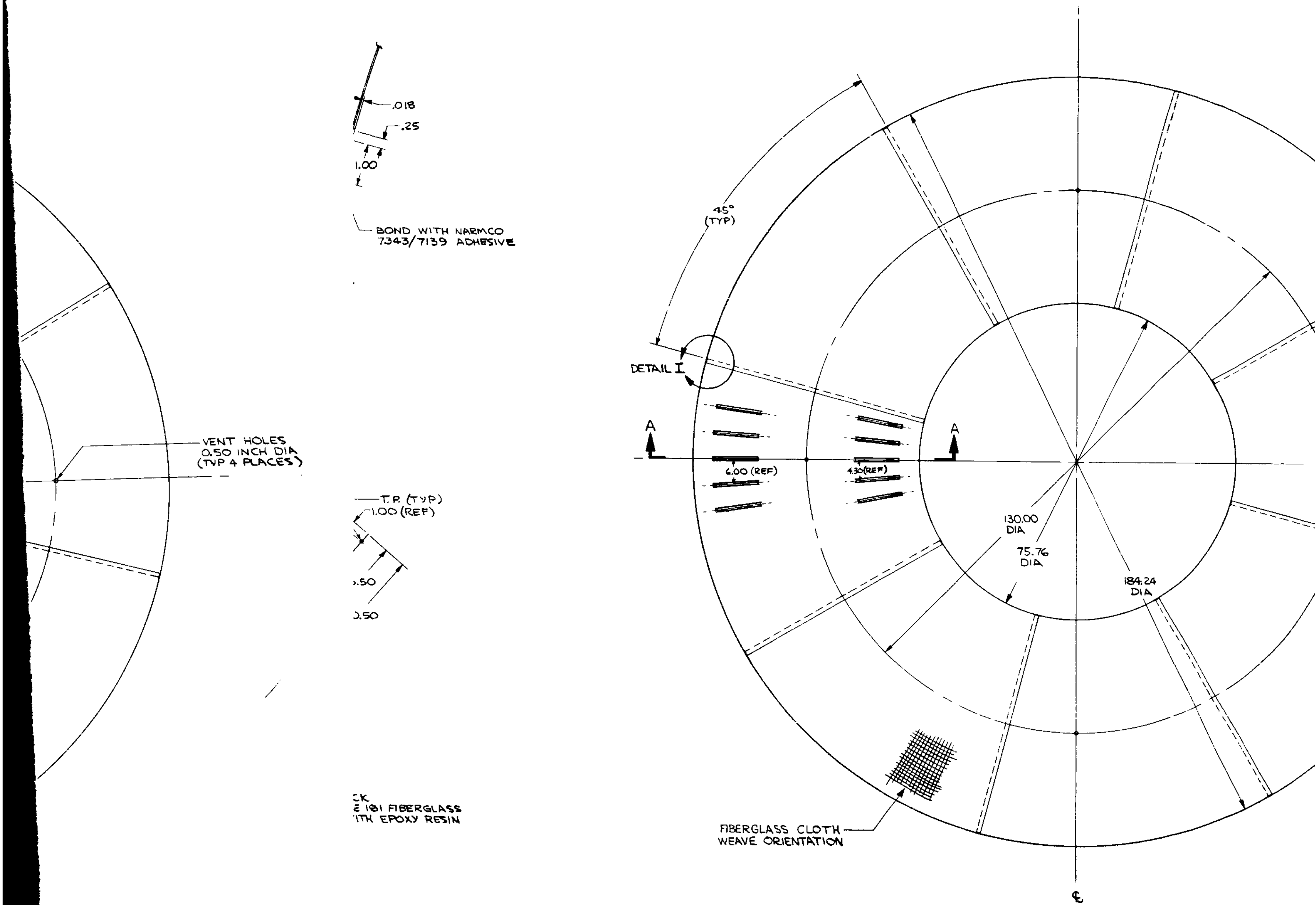


DETAIL B SCALE - FULL

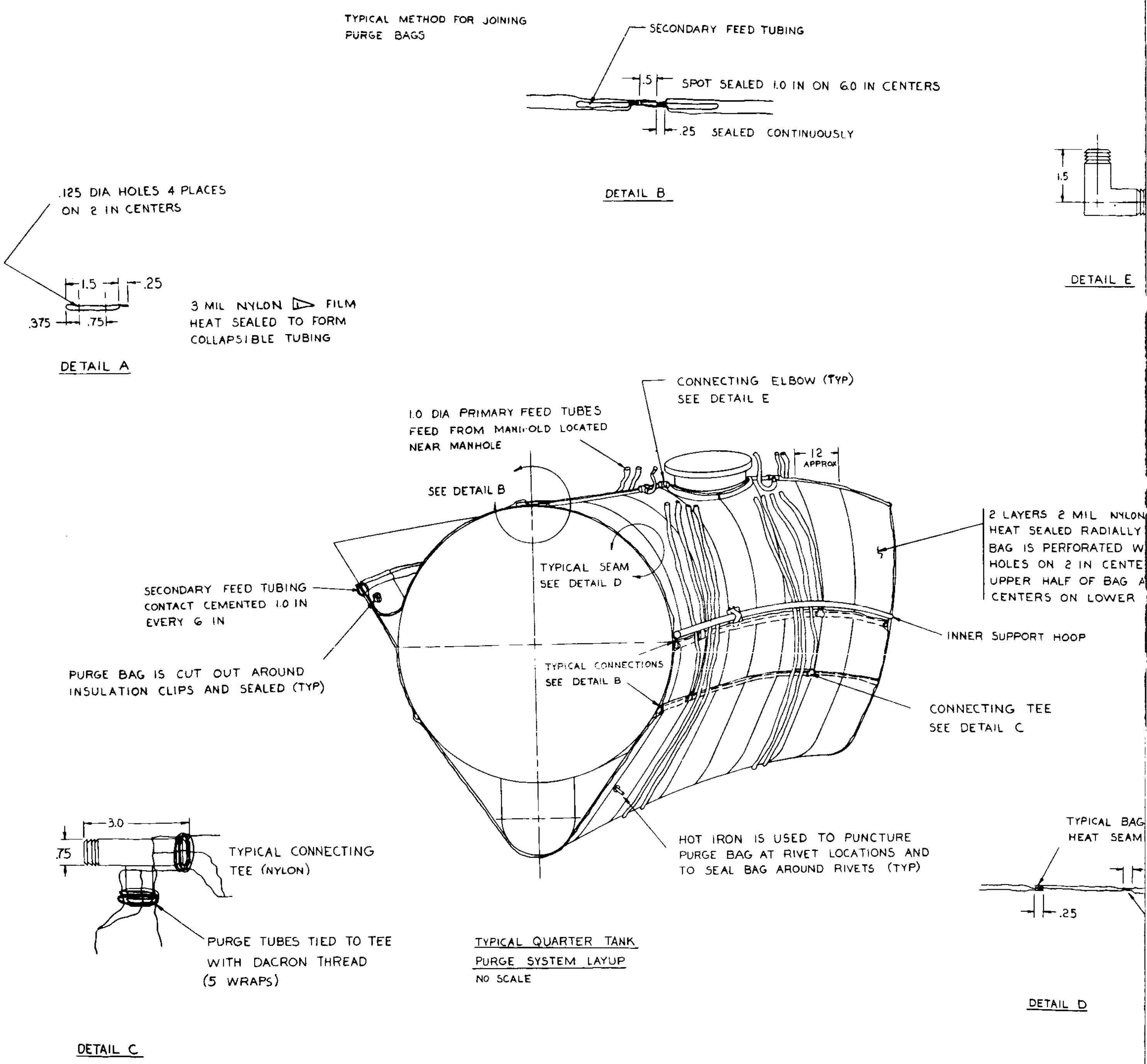

12.00
212.0 DIA
.69
4.87
.87
4.87
.69
5 DIA HOLE
PLACES
205.0 DIA
℄
.75
12.0
8.6
20°
5.0 R
.018
.75
2 LAYERS STYLE 181 FIBERGLASS CLOTH PREPREG WITH EPOXY RESIN
24 PERFORATED REINFORCED FIBERGLASS TRAYS SPACED 15° ℄ TO ℄ (APPROX 27.6 IN.)
OUTER SPLICE PLATES (REF)
SEE DETAIL A
DETAIL D SCALE - 1:2
A
SEE DETAIL C
NOTE - INSULATION CLIPS BONDED TO SKIRT WITH NARMCO 7343/7139
ALTERNATE - USE RIVETS OR #2-64UNF-3A CRES BOLT & NUT
4 CLIPS PER PANEL EQUALLY SPACED (TYP)
3.77
TAPER TO .05 IN LAST 5.0 INCHES OF OUTER LAYER
BEGINNING OF TAPER ON INSULATION APPROXIMATELY OVER CENTER OF INSULATION TRAY
3.77
NYLON OR DACRON THREAD 15 LB LOAD CAPACITY TYPICAL ALL PLACES
INSULATION CLIP (TYP)
SEE NOTE ABOVE
3.77
.1
.1R
.18
.6
.8
.1R
.4
.040
BUTTON & THD (TYP)
.1 DIA HOLES IF USING NUT & BOLT FASTENERS
3.77
DETAIL C SCALE 2:1
BUTTON ATTACHED TO ALTERNATE CLIPS
BEGINNING OF TAPER ON INSULATION ON OUTER SURFACE OF SKIRT 30° BELOW HORIZONTAL
ALL LAYERS TAPERED EVENLY FROM 1 INCH TO .15 INCH EXCEPT OUTER LAYER
3.77
1.0
30°
BOND WITH NARMCO 7343/7139
1.0 DIA.
TYPICAL BUTTON ANCHOR WITH STEEL WIRE LOOP
1.0 DIA.
.018 FIBERGLASS BUTTON & DACRON OR NYLON THREAD (TYP) SPACED 12.0 IN (APPROX.)
SUPPORT SKIRT INSULATION
DETAIL A
SCALE = FULL
10° (REF)
THE BOEING COMPANY
AEROSPACE GROUP SEATTLE, WASHINGTON
INSULATION ASSEMBLY - TORUS TANK
9-20-67
CONTRACT: NAS 8-21172
CODE IDENT NO 81205
SK11-041071
SCALE NOTED
SH 3 OF 5

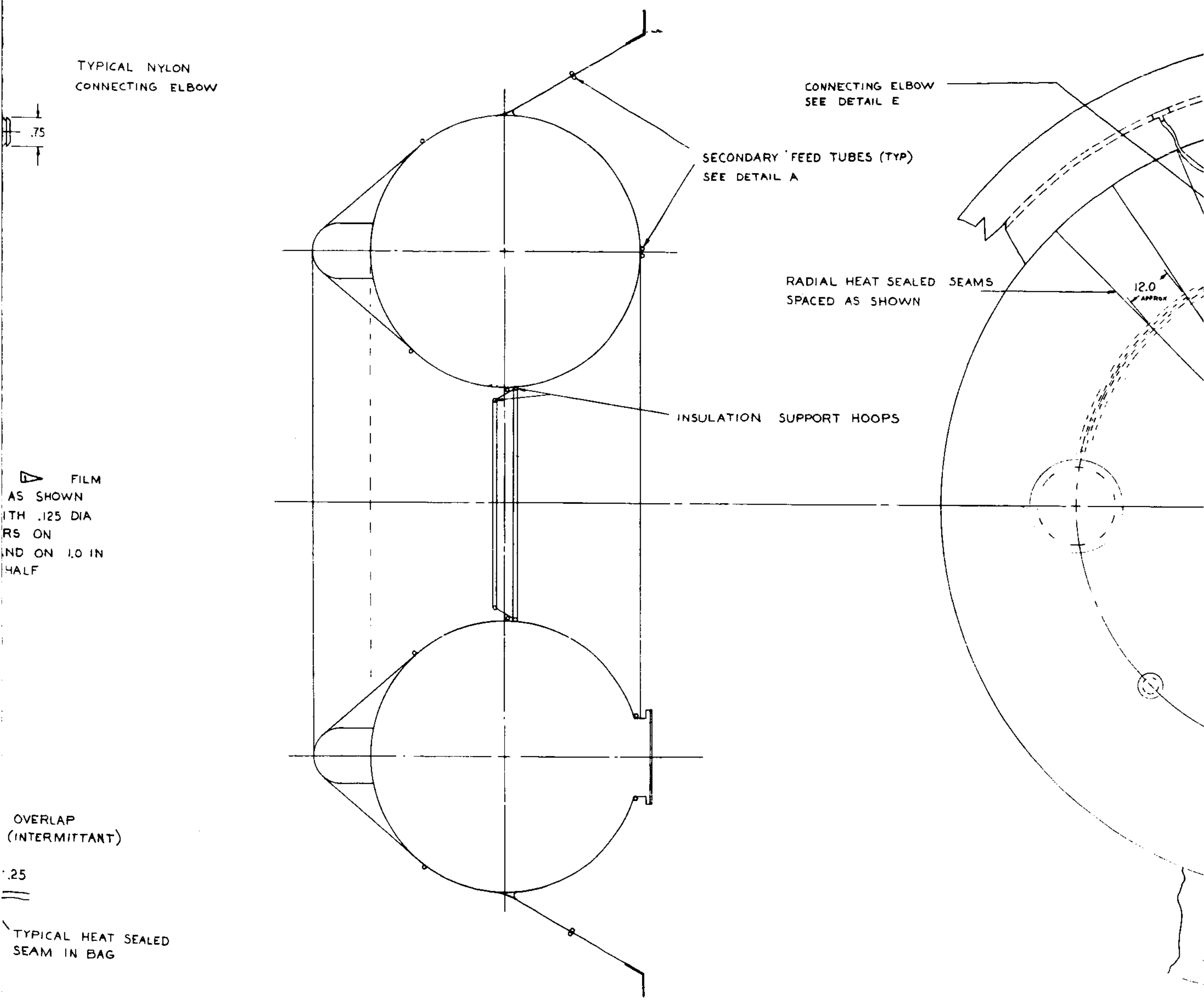


SECTION A-A
SCALE = 1/4

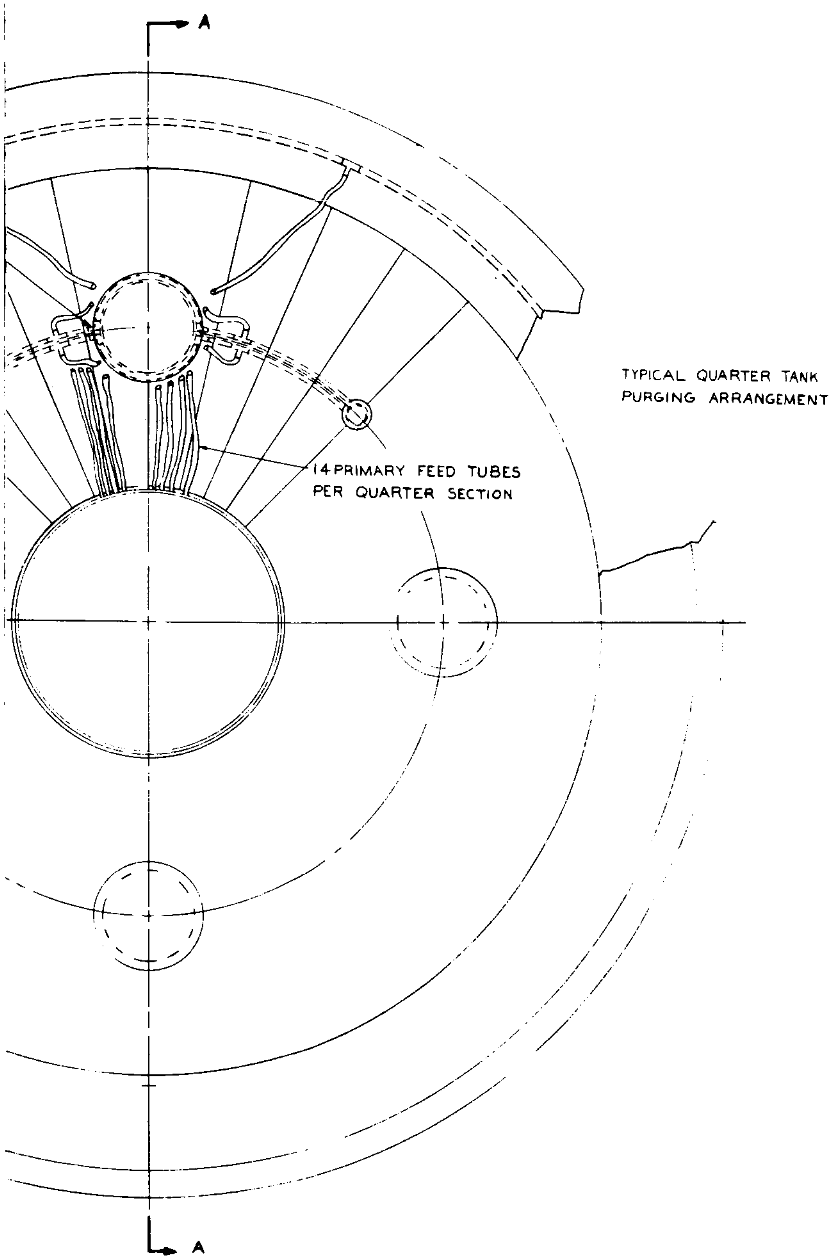


FIBERGLASS SUMP FAIRING ASSY
SCALE = 1/10


TYPICAL METHOD FOR JOINING PURGE BAGS
SECONDARY FEED TUBING
.5
SPOT SEALED 1.0 IN ON 6.0 IN CENTERS
.25 SEALED CONTINUOUSLY
DETAIL B
1.5
DETAIL E
.125 DIA HOLES 4 PLACES ON 2 IN CENTERS
1.5
.25
.375
.75
3 MIL NYLON FILM HEAT SEALED TO FORM COLLAPSIBLE TUBING
DETAIL A
CONNECTING ELBOW (TYP) SEE DETAIL E
1.0 DIA PRIMARY FEED TUBES FEED FROM MANIFOLD LOCATED NEAR MANHOLE
12 APPROX
SEE DETAIL B
TYPICAL SEAM SEE DETAIL D
SECONDARY FEED TUBING CONTACT CEMENTED 1.0 IN EVERY 6 IN
INNER SUPPORT HOOP
PURGE BAG IS CUT OUT AROUND INSULATION CLIPS AND SEALED (TYP)
TYPICAL CONNECTIONS SEE DETAIL B
CONNECTING TEE SEE DETAIL C
3.0
.75
TYPICAL CONNECTING TEE (NYLON)
HOT IRON IS USED TO PUNCTURE PURGE BAG AT RIVET LOCATIONS AND TO SEAL BAG AROUND RIVETS (TYP)
PURGE TUBES TIED TO TEE WITH DACRON THREAD (5 WRAPS)
TYPICAL QUARTER TANK PURGE SYSTEM LAYUP
NO SCALE
.25
DETAIL D
DETAIL C



SECTION A-A
SHOWING LOCATIONS OF
SECONDARY FEED TUBES



TORUS TANK PURGE SYSTEM ASSEMBLY

PLAN VIEW

1 ALTERNATE: FEP OR MYLAR FILM. SELECTION OF FILM MATL IS DEPENDANT ON DEVELOPMENT OF SEALING TECHNIQUES AND RELATIVE COST OF BONDED OR HEAT SEALED SEAMS.

THE BOEING COMPANY
AEROSPACE GROUP SEATTLE, WASHINGTON

INSULATION ASSEMBLY-TORUS TANK

CONTRACT: NAS 8-21172

CODE IDENT NO. 81205

SK11-041071