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AUTHORITY

AFAPL ltr, 12 Apr 1972

AFAPL-TR-66-135

GELATIN RIGIDIZED EXPANDABLE SANDWICH SOLAR ENERGY CONCENTRATORS AND SPACE SHELTERS

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G. T. SCHJELDAHL COMPANY

TECHNICAL REPORT AFAPL-TR-66-135

AUGUST 1966

AIR FORCE AERO PROPULSION LABORATORY
RESEARCH AND TECHNOLOGY DIVISION
AIR FORCE SYSTEMS COMMAND
WRIGHT-PATTERSON AIR FORCE BASE, OHIO

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900 - May 1967 - CO192 - 33-634

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RAYMOND G. NEAMAN

FOREWORD

This report was prepared, under Contract No. AF33(615)-2058, S/A 3(65-2910) by Raymond G. Reaman of G. T. Schjeldahl Company, Northfield, Minnesota. Final reports by three subcontractors, covering three subcontracted efforts, are included as part of this report. The subcontractors are Swift and Company, Chicago, Illinois; Monsanto Research Corporation, Dayton, Ohio; and GCA Corporation, Bedford, Massachusetts. The effort was initiated under:

Project Number 8170, "Aerospace Site Support Techniques",

Project Number 3145, "Dynamic Energy Conversion Technology", and

Project Number 7381, "Materials Applications".

The specific tasks were:

Task Number 817004, "Expandable and Modular Structures for Aerospace",

Task Number 314502, "Solar Dynamic Power Unit", and

Task Number 738101, "Exploratory Design and Prototype Development".

Portions of the study were supported by the Air Force Aero Propulsion Laboratory Directors Discretionary Fund.

The study was administered under the direction of the Technical Support Division and the Aerospace Power Division of the Air Force Aero Propulsion Laboratory and the Application Division of the Air Force Materials Laboratory, Research and Technology Division, Air Force Systems Command, Wright-Patterson Air Force Base, Ohio. The Air Force Project Engineers were Mr. Fred W. Forbes and Mr. Albert Olevitch. This report covers work conducted from June 7, 1965 to August 1966.

The authors wish to thank the Project Monitors, Mr. Fred W. Forbes, Mr. Albert Olevitch, 1/Lt. Anthony Zappanti, and 1/Lt. P. W. Lauderback for their assistance in scheduling the vacuum facilities for experimental work and for their suggestions and thorough acquaintance with the problems of the study. Their efforts have widened the scope of the investigation and have yielded a more useful study.

This report was submitted by the authors August 1966.

This technical report has been reviewed and is approved.

James A. McMillan, Major, USAF
Chief, Space Technology Branch
Support Technology Division

ABSTRACT

In the search for optimum materials to be used in an expandable sandwich concept of fabricating space structures, a gelatin rigidizing resin system was improved and adapted for use. It was demonstrated that this system would be desirable for use with fabric materials. The resin system is easily applied, has high strength to weight ratio, and is resistant to a space environment.

The other materials finally selected for use are completely compatible and equally resistant to a space environment.

The final items of the development program were light-weight, self-rigidizing, 10-foot diameter solar energy concentrators and 4-foot diameter cylinders, 8 feet long. Space systems considerations were an integral part of this study, with particular emphasis on much larger structure requirements.

(This abstract is subject to special export controls and each transmittal to foreign governments or foreign nationals may be made only with prior approval of the Space Technology Branch (APFT), Air Force Aero Propulsion Laboratory, Wright-Patterson AFB, Ohio 45433.)

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1.0 INTRODUCTION

The exploration of space will undoubtedly require large size solar collectors and space shelters. The need for transportation of those items into the space environment makes an expandable structure concept attractive. One concept, which was originated by Mr. F. W. Forbes and Mr. Sidney Allinikov of the Research and Technology Division, Air Force Systems Command, Wright-Patterson Air Force Base, Ohio, is based on the combination of a fabric honeycomb material with a plastic rigidizing resin system. High strength-to-weight ratios are inherent in the sandwich material and complete flexibility and packageability are available with the fabric material. A number of plastic resin systems are available for rigidization of the complete structure.

A feasibility demonstration of this concept using a polyurethane, vapor-cured resin system was conducted under Contract AF33(657)-10409 and is discussed in AFL-TDR-64-29. That work was continued under Contract AF33(615)-1243 which furthered the development and produced larger structures based on the expandable honeycomb concept. That work is discussed in AFAPL-TR-64-40, Volume I. Both of these efforts were sponsored by the Air Force Aero Propulsion Laboratory.

The feasibility of utilizing gelatin as a rigidizing media for expandable space structures was also demonstrated by Mr. Forbes and Mr. Allinikov as an Air Force in-house study. Further work by the Air Force Materials Laboratory under Contract AF33(616)-8483 produced some promising structural properties and space applicability information for gelatin. That work is discussed in ASD-TDR-63-444.

AFAPL-TR-65-84 discusses the outcome of a study which brought together the knowledge gained under earlier studies of the expandable sandwich concept and the earlier gelatin development work. That study furthered the development of the expandable honeycomb concept and demonstrated that gelatin is a useful rigidizing media for that application. This report continues the discussion by describing the work completed during this phase of the program. Particular emphasis was placed on application of results to larger space structures and to compatibilities of materials in a space environment.

2.0 OBJECTIVES

The principal objectives of this research and technology effort were as follows:

1. Optimization of gelatin, collagen, and other rigidization materials systems for expandable honeycomb structures.

2. Determination of operational characteristics of these systems under space conditions.

3. The design, fabrication, and rigidization in a vacuum environment of 10-foot diameter solar concentrators with balloon end caps.

4. The design, fabrication, rigidization in a vacuum environment, and pressure testing of 4-foot diameter by 8-foot long space cylinders.

The technology gained is directly applicable to the design of larger sapce structures.

Phase I of this contract, as reported in AFAPL-TR-65-84, found that modification of the basic gelatin resin system to produce a vapor catalyst cross-linking mechanism, and to reduce the viscosity while increasing the gelatin solids by the addition of various solvents, (other than H_2O) would only tend to reduce the final strength of the resin system. An operable resin system was established for use under Phase I of this contract. However, it was felt that this was not the optimum gelatin system, and that studies should be continued in an attempt to optimize the formulation. Swift and Company continued these studies as a subcontractor. Emphasis was placed on increased strength, faster cure times, and a plasticizer boil-off system. Additional requirements of an optimum system were that it remain in a liquid state during impregnation, be nontoxic, usable in a normal laboratory environment, be compatible with other material components in the overall composite, and compatible to a space environment. This study demonstrates, although not reaching the ultimate design goal of a 15-minute cure time, that gelatin can be used as a rigidizing resin in combination with a fabric sandwich material to produce large expandable structures suitable for space use. The search for component materials such as adhesives, and a flexible layer, to be used between the structural backing and the surface film, was continued. The selected materials also must be compatible with other components, with space, be packageable, be usable in a normal working environment, and be adaptable to larger structures. Monsanto Research Corporation, as a subcontractor, aided in this search.

The assurance that a selected design will meet the requirements imposed by performance in a space environment was approached by anticipating problems which will arise when the structure is placed in that hostile environment. The Technology Division of the GCA Corporation, as a subcontractor, helped in defining these problems.

The final reports, as submitted, by each of the three subcontracotrs are included in this report as appendices.

3.0 MATERIALS RESEARCH AND INVESTIGATION

The materials research and investigation were directed toward obtaining optimum samples of components, such as, reflective surface materials, 100 per cent reactive flexible resins, elastomeric sheets of foam, sponge, and rubber, and adhesives suitable for bonding the various components together.

3.1 REFLECTIVE SURFACE MATERIALS

A solar concentrator design study, presented later in this report, advanced the theories that postcure gelatin shrinkage, large differences in stress-strain relationships of components, and material creep were the primary causes of fabric show-through, orange peel, wrinkles, and crease separation of the Mylar from the flexible epoxy. This information pointed out the possibility of a need to substitute a material other than Mylar for the reflective surface. The materials investigated and their properties are listed in Tables 1A, 1B, and 1C.

A material similar to A-12 was selected for further investigation. This material, purchased from Arvey Corporation, Chicago, Illinois, was a laminate consisting of 0.25-mil Mylar with 0.35 mil aluminum 1100 type 0 laminated to both sides.

The material was used to fabricate 2 1/2-foot model concentrators based on the design which employs a very high modulus material that can be strain-set, thus eliminating the distortions caused by the restoring forces in the elastic region of Mylar. The concentrators fabricated using the new material did show an improvement in most of the surface irregularities, particularly in the elimination of wrinkles and crease separations.

Another material that, at first, indicated some promise as a surface film was Capran, a polyamide film. Use of Capran did not progress beyond the 2-foot diameter experimental stage.

Based on the information presented in Table 1, and on experimental results, a strain-set material, similar to A-12, was selected for use on the 10-foot diameter concentrators.

The material was modified by replacing the 0.25-mil Mylar inner layer with 0.50-mil Mylar. This increased the weight from 0.0106 lb/ft^2 to 0.0139 lb/ft^2.

The aluminum surface material used during this program was not a highly polished aluminum or a vapor deposited metalized surface, and therefore, not highly reflective. However, a polished surface laminate or a vapor deposited metalized surface is a practical solution to obtaining a brilliant surface.

3.2 100 PER CENT REACTIVE FLEXIBLE RESIN SYSTEMS

Past efforts have utilized Epon 872 x 75 and Epon Agent U epoxy resin as the flexible layer behind the reflective surface. This did not prevent surface irregularities, was not 100 per cent solids, and not 100 per

cent reactive and therefore, because of shrinkage during cure, the possible cause of some of the surface irregularities. This would imply that a 100 per cent reactive resin would eliminate shrinkage and thus improve the surface.

Two 100 per cent reactive resin systems were investigated. They were Epon 872 and Dow DER 736, and were used with B. F. Goodrich Hycar CTBNX containing a polycarbodiimide, (antioxidant PCD) manufactured by Noftone, Inc. Hycar CTBNX is a synthetic rubber polymer of butadiene and acrylonitrile. The uncured liquid has a viscosity of about 100,000 centipoises, but can be sprayed uniformly at elevated temperatures.

Neither system showed any substantial improvements over past efforts. Further investigation of 100 per cent reactive systems were discontinued in favor of a more promising flexible layer material such as foam.

3.3 FLEXIBLE LAYER

Initially much time was spent on the investigation of various elastomeric materials. Visits were made to raw material suppliers and manufacturers of the finished products to determine availability of materials in the desired weights and thickness. Information was also sought on how the various elastomers were processed and what modifications could be made to properties. The materials were obtained in working amounts for preliminary evaluation, and are shown in Table 2. As the work progressed additional material was obtained (see Table 3)

Although the thicknesses of the materials listed are not necessarily the same as would be used to fabricate the flexible layer, the samples were useful for establishing data on various joining techniques and adhesive studies. Physical and thermal properties for promising materials were accumulated from the literature on elastomeric materials and from testing. See Tables 4, 5 and 6.

There is no specific information on the effects of radiation on flexible foams available at this time. However, inferences can be made; for example, a foam material based on a urethane linkage will probably possess the same relative stability as a urethane based elastomer. See Table 6.

Some of the more promising materials were tested for vacuum stability. The tests were conducted on a 4 by 4-inch sample of each material. The samples were held at 2×10^{-5} mm Hg. for 72 hours. The results are listed in Table 7. They clearly indicate that most closed cell foams are not satisfactory for use in a vacuum because of the tendency to shrink and lose weight.

Tests also indicate that most foams, especially open cell foams, absorb liquids easily. In the case of the gelatin water solution the result is a wrinkling of the foam because of shrinking of the gelatin during cure. Attempts described later in this report to cover the foam with Mylar proved unsatisfactory. Another approach was to fill the open cell foam with RTV or similar material. This usually resulted only in an increase in weight. The

method finally selected was to block the foam with an adhesive such as Epon 872-X-75 and Epon Curing Agent U.

As the search for new materials, experimenting, and testing continued, a new foam was obtained that revealed excellent possibilities. The foam, Scott Felt 10-900, is manufactured by the Scott Paper Company. Typical properties of some of the available varieties of this foam are listed in Table 8.

All of the varieties discussed in Table 8 are made by applying heat and pressure to an open celled, flexible, 2 lb/ft^3 urethane foam until the desired degree of firmness, density and thickness is reached. Firmness 10 indicates that a 1/16-inch thick material was originally 10/16-inch thick before being compressed.

The 1/16-inch thick, 900 Series, foam material described above was found to absorb large amounts of adhesive when bonding to the Dacron structural material. As a result, a new foam was ordered and was utilized with good results. The new material, Scott Felt Grade 600, is similar to the 900 Series, but is nonreticulated; that is, the cell membranes have not been removed although it possesses some permeability to air. Typical properties of the 600 Series are shown in Table 9.

The Scott Felt Grade 10-600 foam has been used with good results on most of the 10-foot diameter solar concentrators.

Certain silicone rubber type materials have been used from time to time during this program because of their flexibility, adhesive qualities, and availability. The selection of a particular RTV has been more or less at random. However, it appears that a broad range of properties are available in the silicone rubbers. A study of these properties was made in an attempt to find a more suitable candidate for use as the flexible layer material. Table 10 is a tabulation of physical properties of RTV silicone rubbers. It shows that increased hardness is available without seriously affecting flexibility. RTV compounds with the higher hardness values were received and screened for flexible layer applicability. Use of RTV as a flexible layer was discontinued in favor of the more promising foam.

3.4 ADHESIVES

Table 11 lists the adhesives that were investigated. They were screened for apparent bond strengths, flexibility after cure, and material compatibility. Samples were cured for 24 hours before testing. Most adhesives were discarded because of incompatibility with the urethane foam, and neoprene sheets. Others were discarded because of excessive cure time, poor bond, extreme shrinkage and tackiness after cure. The remaining adhesives, their properties and use, are listed in Table 12. Bond strengths of the more promising adhesives and material combinations were tested in peel using an Instron testing machine. The results are presented in Table 13.

Epon 872-X-75 later proved to be the most useful and versatile. It was used to bond the reflective surface to the foam and to bond the structural

backing to the foam.

During the investigation an attempt was made to find the best adhesive for 1-mil Capran. Table 14 summarizes the results.

Table 15 lists some of the properties of candidate adhesive.

TABLE 1-A

PROPERTIES OF REFLECTIVE SURFACE MATERIALS

PROPERTIES	MYLAR	1100-0	A-12	TEDLAR
Chemical Type	Polyethylene teraphthalate	Aluminum	Aluminum and Mylar	PVF
Life Expectancy			10 yrs.	
Form Available	Film		Laminate	
Toxicity	None	None	None	Toxic if burned
Flammability	Slow to Self Ext.	None	Mylar Burns	
Environment Compatibility	Excellent		Excellent	
Reliability	Excellent		Excellent	
Vacuum Stability	Excellent	Excellent	Excellent	No Plasticizer
Specific Gravity	1.39	2.66	2.04	1.34
Tensile Strength psi	23,000	13,000	13,700	19,000
a. Yield Point psi	4% at 12,000 psi	5,000	3,000	2% at 6,000 psi
b. Modulus of Elasticity psi	550,000	10,000,000	2,700,000	280,000
Available Minimum Thickness, mils	0.30	.18	.75	.5
Weight lbs/ft^2/mil	0.0073	0.0140	0.0106	.008
Servicable Temperature Range				
a. High ^{o}F	300		392	225
b. Low ^{o}F	-75		-148	-100
c. Brittle Point ^{o}F				

TABLE 1-A (Cont.)

PROPERTIES OF REFLECTIVE SURFACE MATERIALS

PROPERTIES	MYLAR	1100-0	A-12	TEDLAR
Thermal				
a. K Factor Btu/(hr)(ft^2) (F/ft)	.093	128	Al 128/ft Mylar .093	
b. Coefficient of Expansion Linear in/in/$^\circ$F	1.5×10^{-5}	1.31×10^{-5}	13.1×10^{-4}	2.8×10^{-5}
c. Specific Heat cals/g/ C	.315	.22		
Radiation Characteristics				
a. Beginning of Moderate Damage ergs/gm (C)	4.4×10^{8}			4.4×10^{9}
b. Beginning of 25% Damage ergs/gm (C)	8.7×10^{9}			4.4×10^{9}
c. Stable up to	10^{11} ergs/g			
How Sealed	Heat Sensitive Adhesives		Heat + Sensitive Adhesives	Heat 5% Shrink 256 F
Aluminized Reflectivity (compared to Mylar)				

TABLE 1-B

PROPERTIES OF REFLECTIVE SURFACE MATERIALS

PROPERTIES	TEFLON	POLYETHYLENE[b]	KARDEL
Chemical Type	FEP[a]	Olefin	Polystyrene
Life Expectancy			
Form Available	Film	Film	Film
Toxicity	Toxic Decomposed	Non-toxic	
Flammability	Non-Flam.	Sl. Burn	2.0[c]
Environment Compatibility			
Reliability			
Vacuum Stability			No Plasticizer
Specific Gravity	2.15	.935-.938	1.05
Tensile Strength psi	3000	3500	9,000-10,000
a. Yield Point psi	3% 1700		
b. Modulus of Elasticity psi	70,000		450,000
Available Minimum Thickness mils	.5	.5	.75
Weight lbs/ft^2/mil	.011		
Serviceable Temperature Range			
a. High ^{o}F	400	250	
b. Low ^{o}F	-400	-100	-94
c. Brittle Point ^{o}F			
Thermal			
a. K Factor			
Btu/(hr)(ft^2)(F/ft)	.112	.193	

TABLE 1-B (cont.)

PROPERTIES OF REFLECTIVE SURFACE MATERIALS

PROPERTIES	TEFLON	POLYETHYLENE[b]	KAPTON
b. Coefficient of Expansion	4.6×10^{-5} at -100 5.8×10^{-5} at 160		
Linear in/in/°F	9.0×10^{-5} at 212	9×10^{-5}	6×10^{-5}
c. Specific Heat Cal/g/C	.25	.55	
Radiation Characteristics			
a. Beginning of Moderate Damage ergs/gm (G)	1.7×10^{6}	4.4×10^{8}	
b. Beginning of Serious Damage ergs/gm (G)	3.7×10^{6}	8.7×10^{8}	
c. Stable up to			
How Sealed	Heat 500 F	Heat 220 F	Heat 280-380 F
Aluminized Reflectivity (compared to Mylar)			

a. Fluorinated ethylene propylene

b. Typical Values

c. in/min ASTM D-635

TABLE 1-C

PROPERTIES OF REFLECTIVE SURFACE MATERIALS

PROPERTIES	CAPRAN	SURLYN	H-FILM	ACLAR 22A
Chemical Type	Polyamide	Ionomer	Polyimide	Fluorochloro Resin
Life Expectancy				
Form Available	Film	Film	Film	Film
Toxicity	Non-toxic			Non-toxic below 300 F
Flammability	Self-ext.	1.1 in/min	Chars at 800 C	None
Environment Compatibility				
Reliability				
Vacuum Stability				
Specific Gravity	1.13	.925	1.38	2.079
Tensile Strength psi	6700	5000	25,000	8,000-11,000
a. Yield Point psi	4400	1800	14,000	
b. Modulus of Elasticity psi	100,000	30,000	430,000	300,000
Available Minimum Thickness mils	1	0.5	1	.5
Weight lbs/ft^2/mil	0.006	0.0049	.007	0.011
Servicable Temperature Range				
a. High ^{o}F	200	160	300	390
b. Low ^{o}F	-100	-160	-100	-320
c. Brittle Point ^{o}F				

TABLE 1-C (cont.)

PROPERTIES OF REFLECTIVE SURFACE MATERIALS

PROPERTIES	CAPRAN	SYLVYN	H-FILM	ACLAR 22A
Thermal				
a. K Factor				
Btu/(hr)(ft^2)(F/ft)	.141	.140	.084	.128
b. Coefficient of Expansion				
Linear in/in/$^\circ$F	4.6×10^{-5}		2×10^{-5}	
c. Specific Heat Cal/g/C	.40			
Radiation Characteristics				
a. Beginning of Moderate Damage ergs/gm (C)	9.6×10^{7}		5×10^{11}	4.1×10^{8}
b. Beginning of Serious Damage ergs/gm (C)	4.7×10^{8}			
c. Stable up to				
How Sealed	Heat 390°		Heat + Adhesive	Etched Heat + Adhesive
Aluminized Reflectivity (compared to Mylar)			good	

TABLE 7

PRELIMINARY CANDIDATE FLEXIBLE LAYER MATERIALS

MATERIAL	SOURCE
15 mil GRS neoprene sheet	Atlantic India Rubber Works Chicago, Illinois
15 mil Viton sheet	DuPont, Chicago, Illinois
31 mil Hypalon sheet	DuPont, Chicago, Illinois
1/8 inch, soft neoprene sponge	Atlantic India Rubber Works Chicago, Illinois
5 mil urethane sheet	Seiberling Rubber Company Newcomerstown, Ohio
1/8 inch firm neoprene sponge	Hood Rubber Company Chicago, Illinois
1/8 inch firm vinyl sponge	W. S. Nott Company Minneapolis, Minnesota
1/4 inch butyl sponge	Hood Rubber Company Chicago, Illinois
1/16 inch silicone sheet	W. S. Nott Company Minneapolis, Minnesota

TABLE 3

CANDIDATE FLEXIBLE FOAMS

PROPERTIES	B. F. GOODRICH CO.				SCOTT PAPER CO. (Polyurethane)	
Designation	R-43	M-407	S-534	H-334		
Chemical Type	Neoprene	PVC	PVC	PVC	Polyester	Polyether
Cell Structure	Closed	Closed	Closed	Closed	Open	Open
Thickness, inches	1/8	1/8	1/8	1/16	1/8	1/16
Density, lb/ft^3	10	4	5	3 1/2	5	10

TABLE 4

PHYSICAL AND THERMAL PROPERTIES OF ELASTOMERIC MATERIALS

PROPERTIES	RUBATEX	RUBATEX	SCOTT	NOPCO	NOPCO	NOPCO
Polymer	Neoprene	Vinyl	Polyether	Polyether	Polyester	Polyester
Density lbs/ft^3	40	13	5.5-10.5	2	2	6
Cell Structure	Closed	Closed	Open	Open	Open	Open
Tensile Strength psi			20	16	35	45
Elongation per cent			50	220	450	700
Compression Set 50 per cent	30	50	10	6	6	2
Compression						
Per Cent Deflection lbs/in^2						
20			1.3-3.4			
25	90-13.0	1.5-4.0		0.5	0.55	0.65
50			2.8-7.4			
60			3.4-12			
65				0.85	0.88	1.30
Service Temperature (F)						
Low	-30	-20				
High Continuous	150	130				
High Intermittent	200	200				
Thermal Conductivity Btu/(hr)(ft^2)(F/ft)	.11					
Vacuum Stability		Poor				

TABLE 5

APPROXIMATE ORDER OF STABILITY OF COMMERCIAL POLYMERS

COMMERCIAL POLYMER	NUCLEAR ENERGY FOR APPRECIABLE DAMAGE[a] (rad)	COMMENTS
Polystyrene	10^9	Cross-links but distorts under load at 80 C
Silicone (aromatic)		Cross-links
Polyethylene		Cross-links
Epoxy	10^8	
Melamine-formaldehyde		
Urea-formaldehyde		
Mylar		
Natural Rubber (polyisoprene)		Cross-links
Silicone Elastomers (aliphatic)	10^7	Cross-links
Polypropylene		Cross-links
Polycarbonates (Lexan)		
Polyvinyl chlorides		Degrades via scission
Nylons		Cross-links
Synthetic Rubbers		
Kel-F	10^6	Degrades via scission
Polyurethanes		
Polymethacrylates		Degrades via scission
Polyacrylates		Cross-links
Teflon	10^5	Degrades via scission

(a) 23% change in a significant mechanical property

TABLE 6

EFFECT OF GAMMA RADIATION ON DAMAGE THRESHOLDS OF ELASTOMERS

RUBBER MATERIAL	BEGINNING OF MODERATE DAMAGE ergs/g C (a)	BEGINNING OF SERIOUS DAMAGE ergs/g C
Urethane	7.5×10^9	4.5×10^{10}
Natural	6×10^9	3×10^{10}
SBR	3.5×10^9	3×10^{10}
Nitrile	2×10^9	9.5×10^9
Neoprene	2×10^9	9.5×10^9
Acrylic	0.5×10^9	1×10^{10}
Silicone	8.0×10^8	6.0×10^9
Fluoroelastomers	8.0×10^8	4.0×10^9
Polysulfide	1.5×10^8	4.5×10^8
Butyl	0.5×10^8	4.0×10^8

(a) Incipient to mild damage at about $10^5 - 10^7$ ergs/g C

TABLE 7

VACUUM STABILITY OF FLEXIBLE LAYER MATERIAL

MATERIAL	DENSITY lbs/ft^3	DIMENSION CHANGE %	WEIGHT LOSS %
1/4 inch vinyl foam closed cell	10	43	1.5
1/5 inch neoprene foam closed cell	35	10	1.0
1/4 inch urethane foam open cell	.7	none	none
1/4 inch urethane foam	2	none	none
15 mil neoprene sheet	--	none	none
20 mil urethane sheet	--	none	none
1/8 inch PVC foam closed cell	4	70	19
1/8 inch neoprene foam closed cell	10	none	none
1/8 inch PVC foam closed cell	5	40	2.5
1/16 inch PVC foam closed cell	3.5	none	none
1/8 inch polyester open cell	5	none	none
1/16 inch polyester open cell	10	none	none

TABLE 8

TYPICAL PHYSICAL PROPERTIES OF SCOTT FELT GRADE 900 SERIES

Firmness	3	5	10	15
Tensile Strength psi	50-70	85-105	160-200	230-270
Per Cent Elongation at Break	300-400	250-350	250-350	200-300
Tear Strength lb/in	7-9	10-13	20-27	27-35
Vacuum Effect	none	none	none	none

TABLE 9

TYPICAL PHYSICAL PROPERTIES OF SCOTT FELT GRADE 600 SERIES

Firmness	3	5	7	10
Tensile Strength psi	.67	115	155	220
Per cent Elongation at Break	275	250	225	200
Tear Strength lb/in	9	15	20	25
Vacuum Effect	none	none	none	none
Compression-Deflection psi				
@ 25%	1	5	13	25
@ 50%	5	14	35	75
@ 66%	12	40	100	175

TABLE 10

PROPERTIES OF RTV MATERIAL

COMPOUND	SPECIFIC GRAVITY	DUROMETER HARDNESS SHORE A	TENSILE STRENGTH PSI	ELONGATION %	LINEAR SHRINKAGE %
RTV-11	1.18	45	350	180	.2-.6
RTV-20	1.35	50	450	140	.2-.6
RTV-21	1.30	50	600	130	.2-.6
RTV-30	1.45	60	850	130	.2-.6
RTV-40	1.37	55	550	120	.2-.6
RTV-41	1.30	50	450	200	.2-.6
RTV-60	1.47	60	650	110	.2-.6
RTV-77	1.33	50	500	220	.2-.6
RTV-88	1.47	60	750	160	.2-.6
RTV-511	1.18	40	350	180	.2-.6
RTV-560	1.42	60	800	160	.2-.6
RTV-577	1.35	50	450	200	.2-.6
RTV-580	1.45	60	800	120	.2-.6
RTV-102*	1.07	30	350	400	.2-.6

*The several materials in the 100 series all have similar properties; their differences are in viscosity and color.

TABLE 11

ADHESIVES INVESTIGATED

ADHESIVE	STRUCTURAL BACKING	MYLAR	ALUMINUM - TO -	NEOPRENE SHEET	URETHANE SHEET	URETHANE FOAM
Hycar 2100-X-20	X	X	X	X	X	X
Hycar CTBNX	X	X		X	X	X
Hycar 2100-X-20 Epon 828 TETA	X	X	X	X	X	X
3-M EC 1711	X	X	X	X	X	X
3-M EC 776	X	X	X	X	X	X
3-M EC 2216 B/A	X	X	X	X	X	X
RTV-60 Spray Thermolite 12 spray SS 4101 primer	X	X		X	X	X
RTV 102	X	X	X	X	X	X
RTV 340 SS-4101 primer	X	X	X	X	X	X
RTV 11	X	X	X	X	X	X
RTV 112 Thermolite 12 spray SS 4101 primer	X	X	X	X	X	X
RTV 90		X		X	X	X
Epon 872-X-75 Epoxy	X	X	X	X	X	X
Epon 823 Epoxy	X	X	X	X	X	X
Bostik 7964	X	X	X	X	X	X
Bostik 4047	X	X	X	X	X	X
Bostik 7070	X	X	X	X	X	X
Bostik 1095	X	X	X	X	X	X

TABLE 11 (cont.)

ADHESIVES INVESTIGATED

ADHESIVE	STRUCTURAL BACKING	MYLAR	ALUMINUM - TO -	NEOPRENE SHEET	URETHANE SHEET	URETHANE FOAM
Caram's 244	X	X	X	X	X	X
Swift 7347	X	X	X	X	X	X
Swift 7162	X	X	X	X	X	X
Swift 7335	X	X	X	X	X	X
Swift Y-7167	X	X	X	X	X	X
Swift 4246	X	X	X	X	X	X
Du Pont 46971+ RC 805 no heat	X	X	X	X	X	X
Du Pont 4684+ RC 805 no heat	X	X	X	X	X	X
Du Pont 5491 no heat	X	X		X	X	X
Du Pont 56012	X	X	X	X	X	X
Du Pont 46970 no heat	X	X	X	X	X	X
U.S. Rubber DC 1977	X	X	X	X	X	X
Carboline F-1	X	X	X	X	X	X
Aerobond 2010	X	X	X	X	X	X
Aerobond 2125	X	X	X	X	X	X
Aerobond 2131	X	X	X	X	X	X
Aerobond 2143-4	X	X	X			
Silastic 733	X	X	X	X	X	X
B.F.G. A-1191-B	X	X	X	X	X	X

TABLE 11 (cont.)

ADHESIVES INVESTIGATED

ADHESIVE	STRUCTURAL BACKING	MYLAR	ALUMINUM - TO -	NEOPRENE SHEET	URETHANE SHEET	URETHANE FOAM
B.F.G. A-178-B+ A-1146-B	X	X	X	X	X	X
B.F.G. A-68-B+ A-53-B	X	X	X	X	X	X
Estane 5740-X-071	X	X	X	X	X	X
Precision 6091	X	X	X	X	X	X
Vithane 200	X	X	X	X	X	X
Cyanamid PDI-1-3041	X	X	X	X	X	X
Weldwood Contact Cement	X	X	X	X	X	X

TABLE 12

PROPERTIES AND USES OF ADHESIVES

ADHESIVE	CHEMICAL TYPE	% SOLIDS IN.	TENSILE STRENGTH PSI	TEMPERATURE STABILITY	SPECIFIC GRAVITY	USE[a]
Swift 7162	GRS Nitrile	20 in Toluol+ Ketones				1, 4
Swift 4246	PV Ac.	52 in H_2O		180 F		3, 7
Du Pont 4684	Syn. rubber	28 Ketones	500-1000	300 F		1, 2, 3
RC - 805	Isocyanate					
Aerobond 2010	Epoxy	100				1,
Silastic 733	Fluoro-silicone	100	150	300 F	1.36	1, 3, 4
EFG A-68-B A-53-B	Neoprene	25 Isopropyl acetate				1, 2, 3, 4
Vithane 200	Urethane	30 DMF	5000		1.219	1, 3, 4
RTV 102	Silicone	100	350	300 F	1.07	2, 3, 5
RTV 11	Silicone	100	380	300 F	1.18	3, 4
Primer SS 4101	Tin octoate					
Bostic 7070	Urethane	21 Ketones		250 F		4
Epon 872-X-75	Epoxy	75 Xylol		250 F		3, 4
Epon 923	Epoxy			250 F		4
Estane 5740X071	Urethane	20-30 THF DMF	11,300	200 F		6

(a) Use

1. Mylar to neoprene and urethane
2. Aluminum to neoprene
3. Aluminum to urethane sheet and foam
4. Nylon to urethane foam
5. Urethane foam to urethane foam
6. Nylon to nylon
7. Dacron to Mylar

TABLE 13

ADHESIVE STRENGTH IN PEEL LBS/IN.

	MYLAR TO:			ALUMINUM TO:		NYLON TO:
ADHESIVE	NEOPRENE	URETHANE SHEET	URETHANE FOAM	NEOPRENE SHEET	URETHANE FOAM	URETHANE FOAM
Swift 7162	5 A.F.(a)		Mat.(b)		Mat.	Mat.
Du Pont 4684	4 A.F.	4 A.F.	Mat.	6 A.F.		
Aerobond 2010	Mat.		Mat.			Mat.
Silastic 733	2 A.F.		Mat.		Mat.	Mat.
BFG A-68-A-53-B	2 A.F.	8 Mat.	Mat.		Mat.	Mat.
Vithane 200	No Reading		Mat.	No Reading	Mat.	Mat.
RTV 102				45 A.F.	Mat.	
RTV 11						2 Mat.
Bostic 7070						Mat.
Epon 872-X-75	6 A.F.					Mat.
Epon 913						Mat.

(a) Adhesive Failure - AF
(b) Material Strength - Mat.

TABLE 14

SHEAR STRENGTHS OF CAPRAN LAP SEAMS

ADHESIVE	SHEAR STRENGTH LBS/IN	TYPE OF FAILURE
Du Pont 46970	6.6	Adhesive
Du Pont 4684	6.0	Adhesive
EZ 1900	4.3	Adhesive
None 400 F	7.1	Material

TABLE 15

TEMPERATURE AND RADIATION STABILITY OF CANDIDATE ADHESIVES

ADHESIVE	CHEMICAL TYPE	SERVICEABLE TEMPERATURE LIMITS °F		ABSORBED RADIATION FOR MODERATE DAMAGE
Du Pont 46971	Polyester	-75	300 F	4.4×10^6 rad
G.E. RTV 11	Silicone	-90	300 F	8.0×10^6 rad
B. F. Goodrich Estane 5740-X-071	Urethane		200 F	7.9×10^4 rad
PTP 4050	Butyl	-40	200 F	0.5×10^6 rad
Epon 872-X-75	Epoxy	-100	300 F	5.0×10^3 rad

3.5 STRUCTURAL MATERIAL

The structural material used to fabricate the solar concentrator was an all Dacron sandwich material from A. Wimpfheimer and Company, of Stonington, Connecticut. It had two faces separated by random scattered drop threads 7/8 inch long.

The structural material used to fabricate the cylinders was No. 181 fiberglass from Hess, Goldsmith and Company of New York.

Table 16 lists some of the properties of the gelatin-fabric system as compared to a urethane-fabric system.

3.6 GELATIN SOLUTION

The following paragraphs contain a description of the gelatin system as used for the Dacron and fiberglass structural materials.

3.6.1 Formulations

The gelatin formulations for the Dacron solar concentrator and the fiberglas cylinder are listed in Table 17. The formula for the concentrator is thinner because of the larger area to impregnate. The impregnation is completed while the concentrator is on the fabrication fixture in the inflated position.

A degradation of the reflective surface of the solar concentrator was traced to the highly acidic (pH 3.8) gelatin resin system which attacks the aluminum surface during and after resin impregnation. To alleviate this, the gelatin solution is neutralized with 2 per cent, per weight of resin solids, NaOH, prior to resin impregnation.

The optimum ratio of gelatin solids to fabric for the Dacron concentrator is 20/100, and for the fiberglass cylinders is 30/100.

3.6.2 Viscosity Determinations

Figure 1 presents a family of curves showing the viscosity of various gelatin solutions at temperatures from 70 to 130 F. The shaded area gives the limits for the most satisfactory conditions for vacuum impregnation and minimum resin drainage.

3.6.3 Gelatin Impregnation Studies

A series of Dacron pillows and a 24-inch concentrator composite were vacuum impregnated to determine rate of impregnation vs. gelatin solution content at 115 F. It was found that a 10-by 10-inch pillow and the 24-inch

concentrator composite became completely saturated with the 15 per cent gelatin solution within about 1-1/2 minutes, while the 25 per cent gelatin solutions required over 5 minutes for completion. Table 18 summarizes the experimental data.

The pillows were rigidized without holding tension in the material. A great deal of wrinkling occurred with the fabric-gelatin ratio of 7:3, while no wrinkling or puckering was observed on the fabrics containing only 20 parts gelatin. It was also noted that the structures with 20 parts gelatin seemed sufficiently strong for solar concentrator rigidity. Work was completed to determine optimum fabric-gelatin ratios which would result in sufficient strengths with a minimum or no fabric shrinkage.

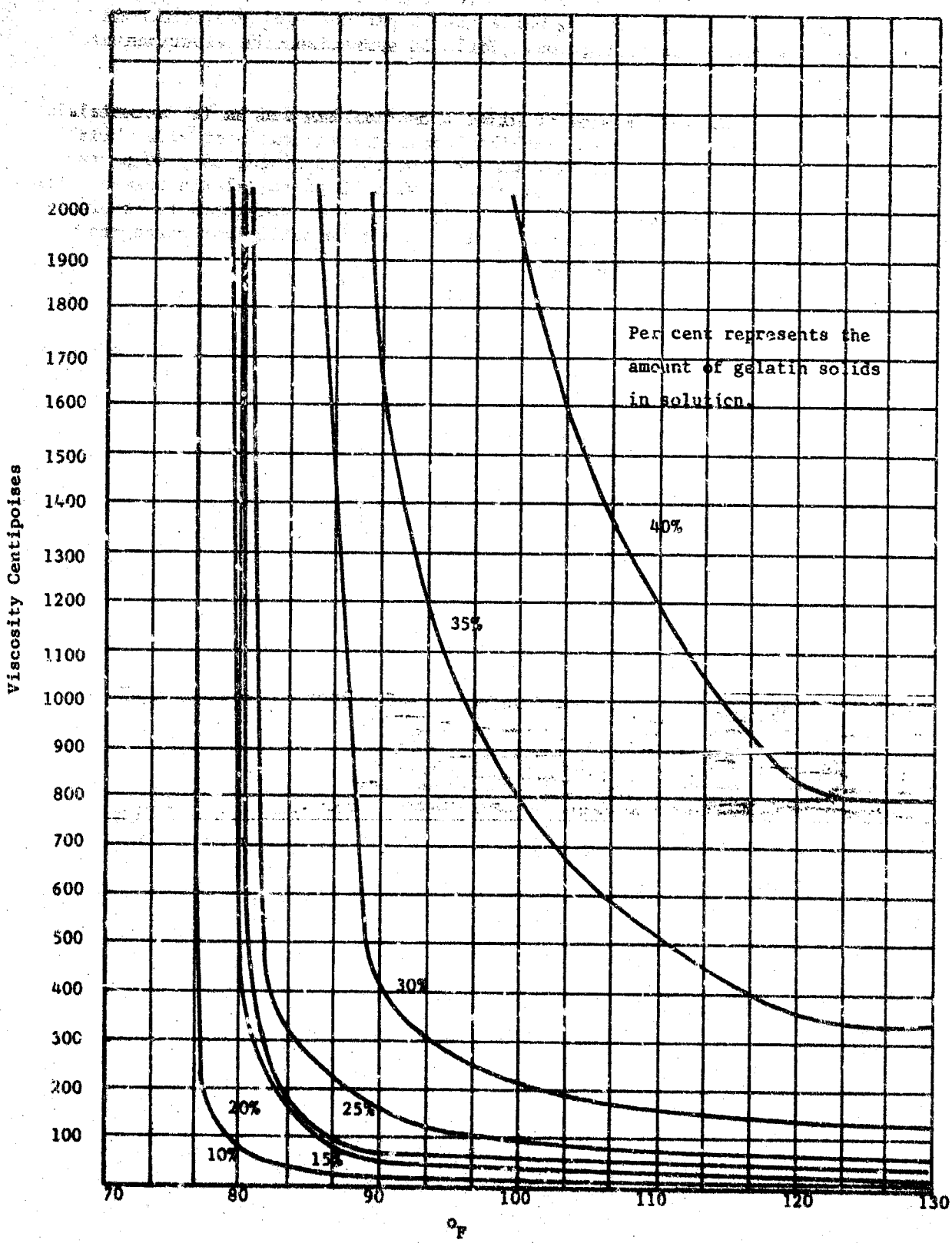


FIGURE 1 - VISCOSITY OF GELATIN SOLUTIONS VS. TEMPERATURE

TABLE 16

TYPICAL PROPERTIES OF EXPANDABLE, SELF-RIGIDIZING MATERIALS

PROPERTY*	GELATIN-FIBERGLASS	GELATIN-DACRON	URETHANE-FIBERGLASS	URETHANE-DACRON
Specific Gravity	1.7	1.3	1.5	1.4
Shelf-life	Very good	Very good	Limited	Limited
Space Environment Stability	Excellent	Very good	Good	Good
Cure Time**(hrs)	3-4	3-4	2	2
Ult. Tensile Strength (psi)	40,000	25,000	40,000	25,000
Ult. Flexural Strength (psi)	35,000	--	35,000	--
Modulus (Tensile and Flexural)(psi)	2.0×10^6	--	2.0×10^6	--
Specific Heat	.25	.30	.25	.30
Coefficient of Thermal Expansion in/in ^{o}F	2×10^{-5}	--	2×10^{-5}	--

*Based on an optimum resin/fiber ratio
**Vacuum Environment

TABLE 17

GELATIN FORMULATION FOR SOLAR CONCENTRATOR AND SPACE CYLINDER

	SOLAR CONCENTRATOR PER CENT	SPACE CYLINDER PER CENT
Gelatin Solids	12	30
Water	100	100
Benzoic Acid (1 per cent gelatin solids)	1.2	3.0
NaOH (2 per cent gelatin solids)	6.0	--

TABLE 18

GELATIN IMPREGNATION STUDIES

PARTS GELATIN	PARTS FABRIC	TIME FOR IMPREGNATION	PER CENT GELATIN IN SOLUTION	DACRON FABRIC SAMPLE
10	90	1 min.	10	10 x 10" pillow
20	80	1.5 min.	15	2 ft. collector
20	80	5 min.	25	10 x 10" pillow
30	70	5 min.	25	10 x 10" pillow

4.0 STRUCTURAL-MECHANICAL ANALYSES

A number of structural-mechanical analyses of the two structures of this contract have been completed. These investigated the dynamic, thermodynamic, structural, and materials aspects of the structures from fabrication through their operational phases.

As a part of the predeployment analysis, the structures were investigated for handling and packaging degradations, primarily during fabrication. Part of the packaging analysis was to determine critical fold radii for each of the various material components of the structures. The results of this analysis revealed that the reflective surface element is vulnerable to packaging damage.

A general deployment analysis of inflatable, folded structures was applied to the solar energy concentrator and cylindrical structures of this contract. The results of this approximate analysis showed that the solar energy concentrator structure is vulnerable to deployment failure whereas the cylindrical structure is not.

Both the solar energy concentrator and the cylindrical structures were analyzed for many operational loading conditions. In general, these structures were analyzed for pressurization loads, maneuvering loads and deflection, and thermal gradients. In addition, an approximate analysis of the natural frequency of the solar energy concentrator structure was made to determine if it could operate within reasonable vibrational limits.

The results of these structural-mechanical analyses contributed to a preliminary design of the structural element of both the solar energy concentrator and the cylinder. The sandwich fabric material of the solar energy concentrator was a one-inch thick Dacron with a random-scatter drop-thread core. A more optimum core configuration would have been a 2-inch square celled, honeycomb array. Although this material is within the state-of-the-art of the weaving industry, it was beyond the scope of this contract.

The sandwich material for the cylinder was a one-inch thick fiberglass fabric with a unidirectional, triangularly fluted core oriented from pole to pole of the hemispherical ends. The anhydrous weight of the resin-impregnated, fiberglass fabric was about 3/10 pounds per square foot.

4.1 SOLAR CONCENTRATOR

4.1.1 Stress Analysis of a Parabolic Surface of Revolution

The complete stress analysis of an operational solar collector should include the following loads:

1. Static (terrestrial handling)
2. Dynamic (Launch and maneuvering)
3. Uniform pressure (solar, aerodynamic)
4. Thermal gradients

In addition the natural frequency of the structure should be investigated. However, of all the above loading conditions, only the dynamic maneuvering loads and thermal gradients are included in this report.

There are two approaches to the solution of the stresses in a surface of revolution. A simplified approach assumes that there are only membrane direct stresses and shears available to resist the applied loading. See Figure 2 (2) below for the description of these stresses.

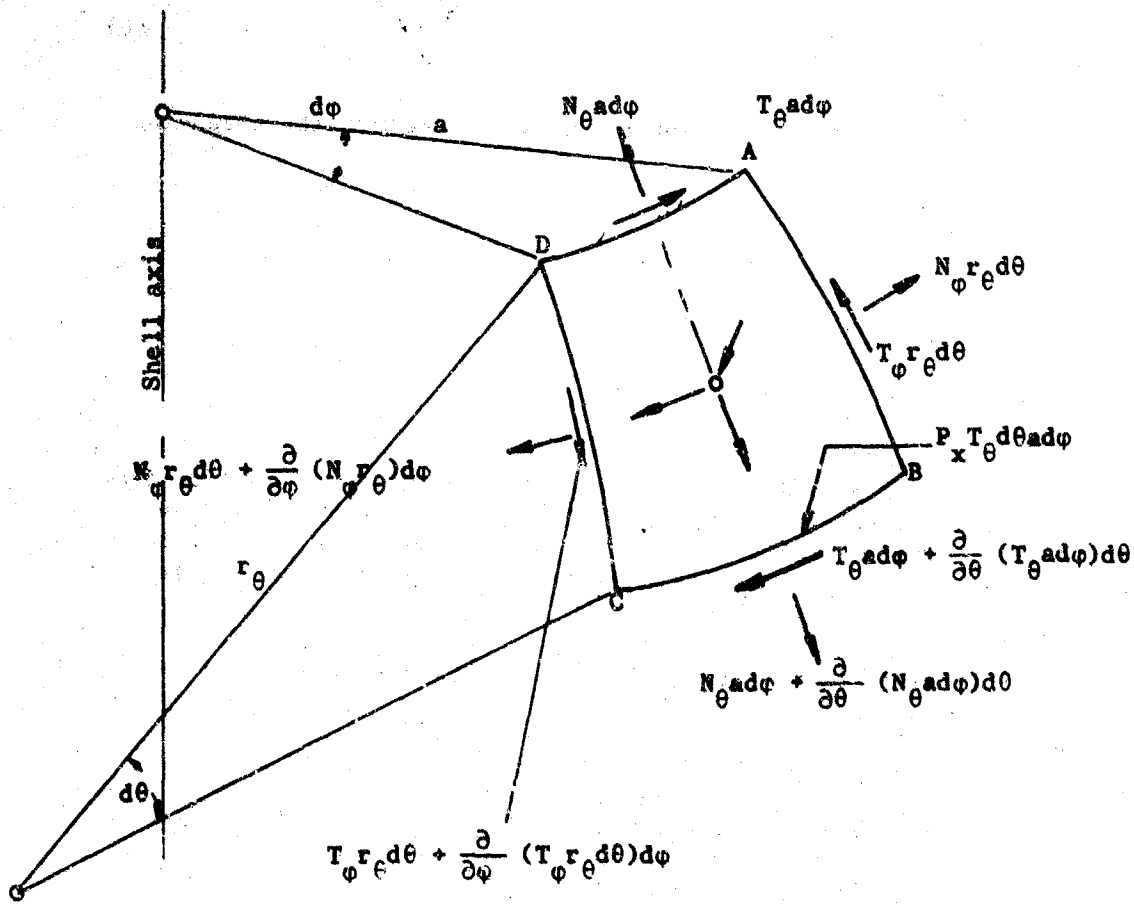


Figure 2

Elements of a Shell of Revolution Showing the Forces of the Membrane Theory

The resolution of the applied loads by the membrane stresses leads to the following set of simultaneous equations (2).

$$\frac{\partial}{\partial\theta}(N_\theta\, a \sin\theta) + \frac{\partial r}{\partial\theta} r_\theta - N_\varphi r_\theta \cos\theta + P_x r_\theta a \sin\theta = 0 \qquad (a)$$

$$\frac{\partial N_\theta}{\partial\varphi} r_\theta + \frac{\partial}{\partial\theta}(T\, a \sin\theta) + T\, r_\theta \cos\theta + P_y r_\theta r_\varphi \sin\theta = 0 \qquad (b)$$

$$N_\theta\, a + N_\varphi\, r_\theta + P_z r_\theta a = 0 \qquad (c)$$

For applied loadings of rotational symmetry, the preceding expressions reduce to:

$$\frac{\partial}{\partial\theta}(N_\theta\, a \sin\theta) - N_\varphi r_\theta \cos\theta + P_x r_\theta a \sin\theta = 0 \qquad (a')$$

$$N_\theta a + N_\varphi r_\theta + P_z r_\theta a = 0 \qquad (c')$$

Further N_θ can be solved at any circumferential section from statics, and N_φ solved from equation (c) if the normal load component (P_z) and the principal radii of curvature (r_θ and a) are known. In the following Figures 3 and 4 there are graphical solutions to the geometry and the principal radii of curvature.

The inflation stresses in a parabolic membrane can be reduced to the following.

<u>At rim:</u> $N_\theta = +.500\ pD$ (lb/inch)

$N_\varphi = +.625\ pD$ (lb/inch)

<u>At apex:</u> $N_\theta = N_\varphi = +.433\ pD$ (lb/inch)

Where p is the internal inflation pressure (psi), D is the rim diameter of the paraboloid (in.), and the + sign denotes tension. Similarly, the above expressions are correct for external pressure loadings except for a stress reversal from tensile to compressive stresses.

Unsymmetrical gravity loads (loaded at some angle (not zero) to the axis of symmetry) and the critical buckling load were investigated. The former merely involves solving the simultaneous equations (a), (b), and (c) for various directions of applied load. The solution to the stability problem is more complex and is described in paragraph 4.1.5.

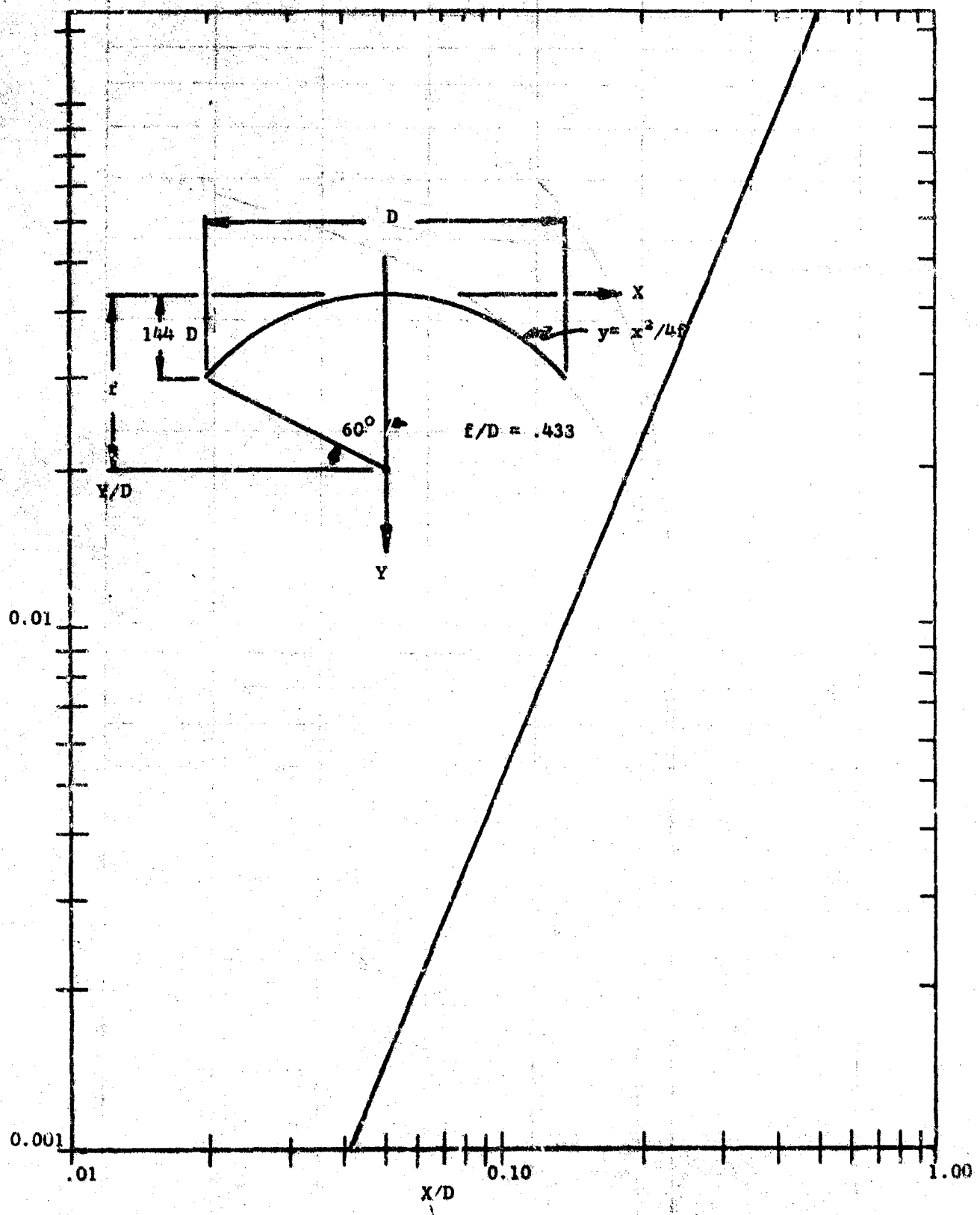


Figure 3. Parabolic Geometry

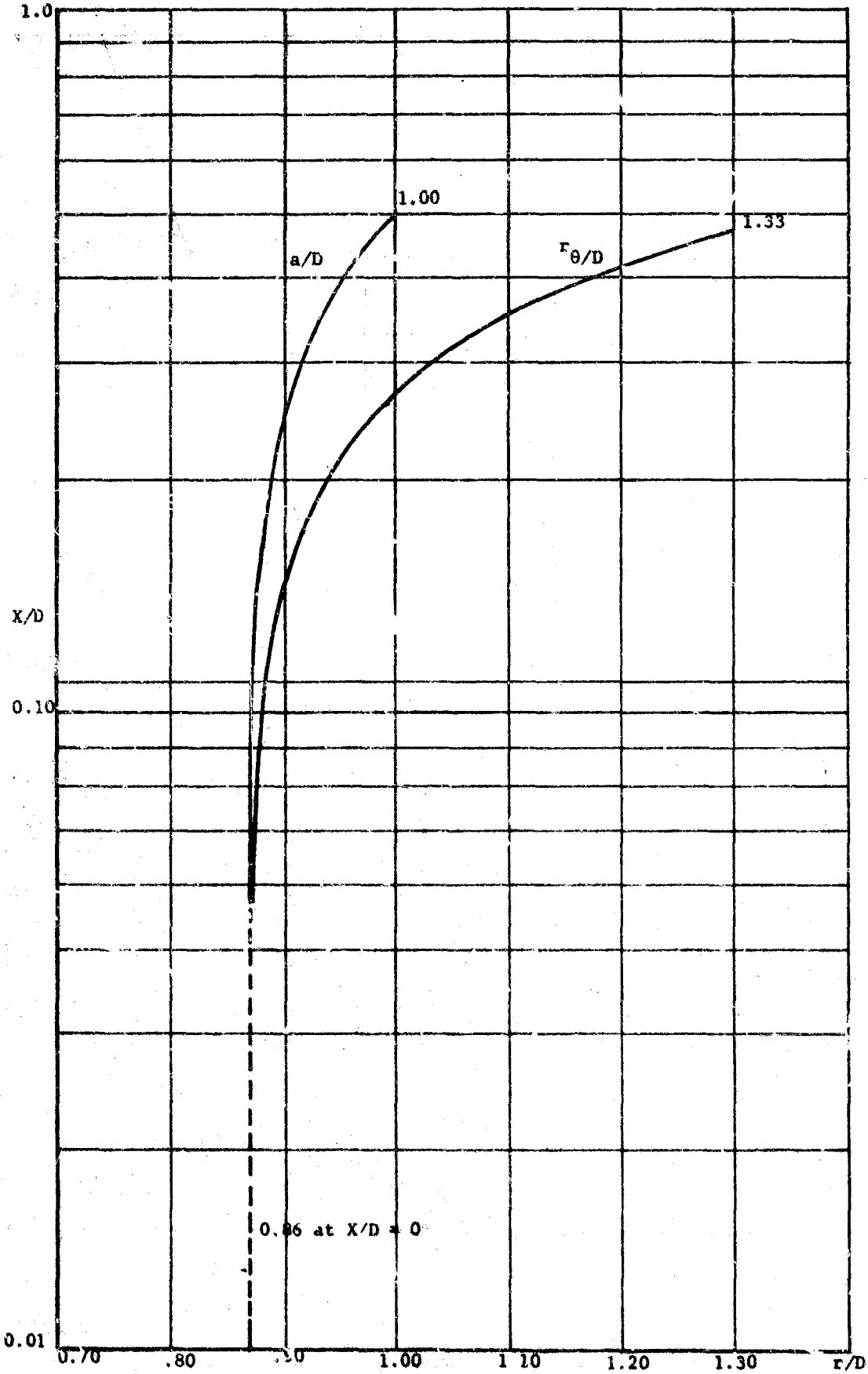
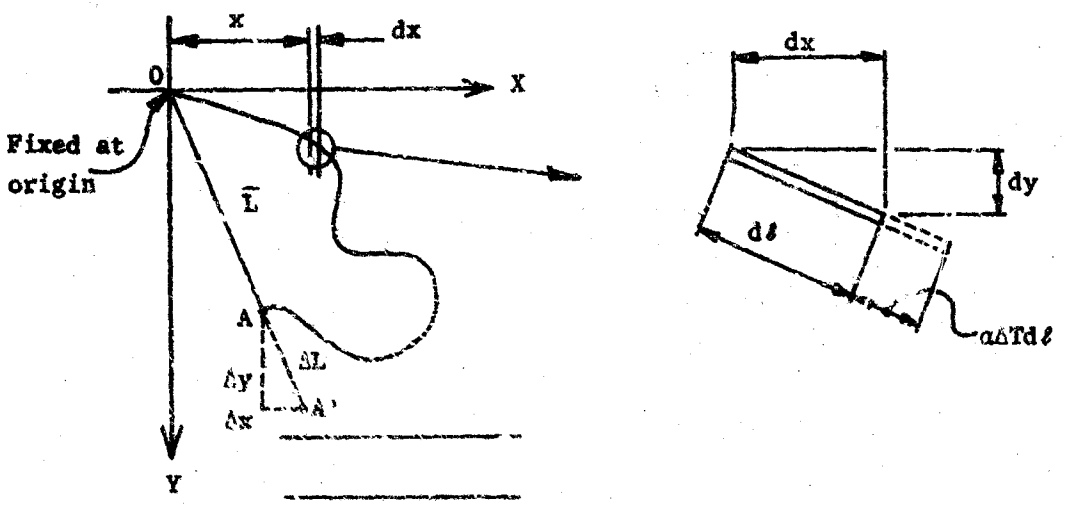


Figure 4. Parabolic Radii of Curvature

In addition to the simplified membrane approach a more exact solution which takes into account the local bending rigidity of the shell can be obtained from eight simultaneous equations involving eight unknown stresses and deflections. (1)

The solutions to these equations must involve applied loadings of rotational symmetry and thus are not as comprehensive as equations (a), (b), and (c). They do offer, however, a way to evaluate the influence of the three dimensional sandwich fabrics in reducing membrane streses and deflections.

4.1.2 Thermal Displacement of Any Curve



Consider the curve OA above having been exposed to a temperature change of ΔT. Then determine the displacement of point A to A'. The expanded view of an element of the curve enables a calculation of the X and Y displacements to be made. The X displacement is given by

$$\Delta X = \Sigma \alpha \Delta T d\ell \left(\frac{dx}{d\ell}\right)$$

$$= \int_0^{X_A} \alpha \Delta T dx = \alpha \Delta T X_A$$

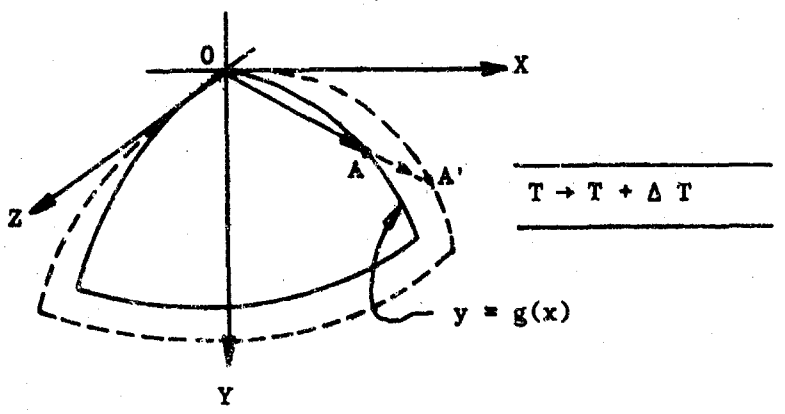
The y displacement is similarly expressed by

$$\Delta Y = \alpha \Delta T Y_A$$

(1) "Elementary Statics of Shells" Second Edition. Alf Pfluger 1961, New York City, McGraw-Hill Book Co., Inc.

Therefore ΔX and ΔY are directly proportional to the location of point A (X_A, Y_A) and independent or the shape of the curve. Also, the total displacement of point A, ΔL, is parallel to the vector $\overline{OA}$ and equal to $(\alpha\Delta T)\ (\overline{OA}) = \alpha\Delta T\overline{L}$.

4.1.3 Thermal Displacement of Any Surface of Revolution



From 4.1.2 it has been shown that the displacement of the curve $y = f(x)$ in the x-y plane is proportional only to the x and y coordinates of the curve and the temperature parameter, $\alpha\Delta T$. Thus, for any point on the curve A (X_A, Y_A), the change in location of the point due to a temperature change, ΔT, equals $X'_A = X_A\ (1 + \alpha\Delta T)$ and $Y'_A = Y_A\ (1 + \alpha\Delta T)$. Hence, the expression for the new curve $y' = g(x')$ becomes $y(1 + \alpha\Delta T) = g\left\{x\ (1 + \alpha\Delta T)\right\}$.

In the case of the parabola $y = x^2/4f$, the expression for the new curve $(y' = x'^2/4f)$ is also a parabola, $y(1 + \alpha\Delta T) = \left[x\ (1 + \alpha\Delta T)\right]^2/4f$

$$y = \left[(1 + \alpha\Delta T)x^2\right]/4f$$

Therefore, due to a uniform temperature change, ΔT, the parabola $y = x^2/4f$ becomes $y = \left(\frac{1 + \alpha\Delta T}{4f}\right) x^2$ which changes the length of the focus by $\left(\frac{1}{1 + \alpha\Delta T}\right)$.

Due to the rotational symmetry, the circumferential elongations are all directly proportional to their respective radii. Since the radius of any circumferential element is the x coordinate and since this displacement has been accounted for in deriving a new expression for the curve that generates the surface of revolution, the total thermal displacement of the surface of revolution is satisfied by the new surface of revolution $y' = g(x')$.

4.1.4 Operational Accuracy

The most important requirement of the solar energy concentrator is that it maintain the specified surface accuracy. It was expected that the concurrent gelatin development and application program would eliminate most of the surface inaccuracies due to fabrication, packaging, deployment and rigidization; thereby leaving only operational inaccuracies (or distortions) to be considered in this program.

The operational distortions of the solar energy concentrator are primarily the result of "G"-loads (maneuvering the structure) and thermal gradients. Since these forces cannot be eliminated, the resulting distortions to the solar collector cannot be eliminated. Their effect can be reduced, however, by adequately stiffening the structure and by reducing the magnitude of the thermal gradients.

In the following analysis the specified surface accuracy is translated into an equation for a rotated surface of revolution which in turn is evaluated at the rim of the surface. This ordinate minus the ordinate of the original curve, $Y_o = x^2/4f$, will be defined as the maximum allowable deflection of the rim of the solar collector.

It is assumed that the deflected surface is symmetric about the axis of rotation; therefore, this analysis is only valid for applied loadings of rotational symmetry.

The surface accuracy of the solar collector is specified thus: "The solar collector shall be accurate to within ± 1/2 degree by the tangent method over 98 per cent of the reflective surface." Therefore, the deflected surface must satisfy the following equations (refer to Figure 5).

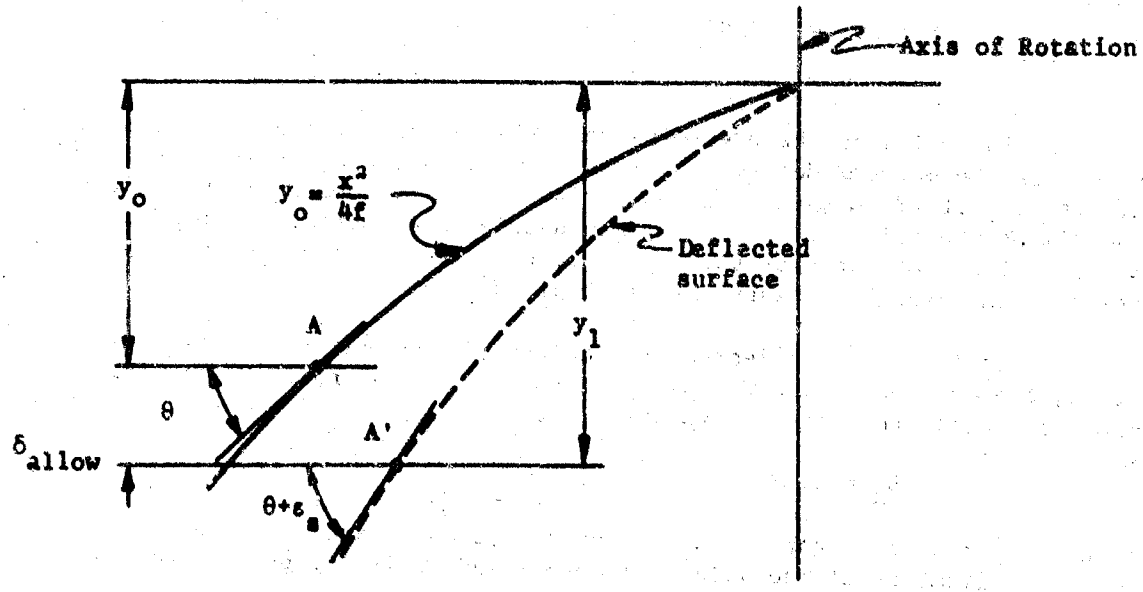


Figure 5 SURFACE ACCURACY

Since $y_o = \frac{x^2}{4f}$, $\frac{dy_o}{dx} = \frac{x}{2f}$, and $\theta = \tan^{-1} \frac{dy_o}{dx}$

therefore, $\tan \theta = \frac{dy_o}{dx} = \frac{x}{2f}$. Now, the allowable angular distortion as point A deflects to point A' = $\varepsilon_s = \frac{1}{2}^o$.

Let, $\tan \varepsilon_s = e$

Therefore, $\tan (\theta + \varepsilon_s) = \frac{x + 2fe}{2f - xe}$ from $\frac{\tan \theta + \tan \varepsilon_s}{1 - \tan \theta \tan \varepsilon_s}$

Now, $\frac{dy_1}{dx} = \tan (\theta + \varepsilon_s) = \frac{x + 2fe}{2f - xe}$

or, $y_1 = \int \left(\frac{x + 2fe}{2f - xe} \right) dx$

$$= \frac{1}{e^2} \left[2f - ex - \left(2f \ln(2f - ex) \right) \left(1 + e^2 \right) \right] + c$$

At $x = 0$, $y = 0$,

Hence $y_1 = \frac{1}{e^2} \left[(2f)(1 + e^2) \left(\ln \frac{2f}{2f - ex} \right) - ex \right]$

for $f/D = \sqrt{3}/4$, $e = \tan \frac{1}{2}^o$, and $x = D/2$ (at the rim)

$y_1 = .149204\ D$ (at the rim)

$y_o = .144338D$ (at the rim)

Therefore

$\delta_{allow} = y_1 - y_c = .00487\ D$

The value of the preceding analysis is that it provides an expression for the maximum deflection at the rim of the solar collector that is within the specified surface accuracy limitations. By comparing the deflection of the rim of the solar collector for maneuvering and thermal loadings to the allowable deflection, an expression for the required stiffness of the structure or the maximum thermal gradiant can be obtained.

If the solar collector is accelerated parallel to the axis of rotation, the maximum deflection parallel to the axis of rotation (at the rim of the solar collector) can be expressed as,

$$\delta_G = 0.78\ W_G\ D^2/Et$$

Where W_G is the unit weight of the structure due to an acceleration, "G"; D is the rim diameter of the solar collector; and Et is the product of the

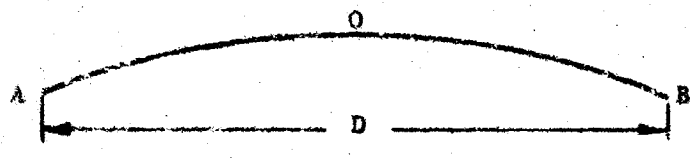
thickness and modulus of elasticity of the structural membrane of the solar collector. This expression is overly conservative for the three dimensional sandwich material of this study, but it will serve to illustrate the magnitude of the deflection problem.

Setting $\delta_G = \delta_{allow}$ results in an expression for Et of the structural membrane that will not distort the solar collector surface beyond specified limits. This expression will be defined as the stiffness product and is: $Et = 180\ W_G D$. If the total system including inflatant and end cap is limited to 40.0 pounds, W_G will equal .034 psf for a 0.1 G acceleration. Therefore, for a 10-foot diameter solar collector the stiffness product becomes 4.54 lb/inch. From this it can be seen that the stiffness product for the 10-foot solar collector need not be large to maintain the specified surface accuracy due to a 0.10 G acceleration parallel to the axis of rotation.

The problem of maintaining the specified surface accuracy because of a uniform thermal gradient can be approximately analyzed as follows. A uniform thermal gradient normal to the surface of a spherical shell will produce uniform bending moments (M) throughout the shell (wherever boundary conditions permit): $M = \frac{\alpha \Delta T EI(1 + \mu)}{t(1 - \mu^2)}$. * Since the paraboloid of this study approximates a spherical surface, the preceding expression can be used as an approximation of its thermal bending moment. Further, the unit angular distortion produced by the constant thermal bending moment would equal $\frac{dEt}{ds} = \frac{M(1 - \mu^2)}{EI} \equiv d\epsilon_T$ or, $\frac{dEt}{ds} = \frac{\alpha \Delta T(1 + \mu)}{t}$. In this expression α is the coefficient of thermal expansion, ΔT is the difference in temperatures across the surface, μ equals Poisson's ratio for the structural membrane, and t is the thickness of the membrane or in this study the depth of the sandwich material.

If the paraboloid shown in the figure below is supported at its apex, the angular thermal distortion at the rim is given by

$$\epsilon_T = \int d\epsilon_T = \int dEt = \int_0^A \frac{\alpha \Delta T(1 + \mu) ds}{t} ,$$



*Timoshenko and Woinowsky - Krieger "Theory of Plates and Shells" 2nd Edition P. 546. McGraw-Hill Book Company, Inc., New York, 1959

with $f/D = \sqrt{3}/4$ and

$$\widehat{AOB} = 1.053\ D,$$

$$\varepsilon_T = \frac{\alpha \Delta T(1 + \mu)(1.053\ D)}{2t} .$$

Since the angular thermal distortion at the rim must be less than the specified distortion,

where $\varepsilon_s \leq \pm \frac{1^\circ}{2} = \pm \frac{\pi}{360}$

then $\varepsilon_T \leq \varepsilon_s$

and $$\Delta T \leq \frac{(2)\left(\frac{\pi}{360}\right)(t)}{\alpha(1 + \mu)(1.053\ D)}$$

For a sandwich thickness, t, of 1 inch; a rim diameter, D = 120 inches; and typical α and μ values for fiberglass reinforced plastics of 2.0×10^{-5} in/in-$^\circ$F and 0.15, respectively: $\Delta T \leq \pm$ 6F.

4.1.5 Stress Analysis

Membrane shell theory can be utilized as a simplified approach to the solution of the internal stresses in the parabolic surface of revolution subjected to maneuvering ("G") loads. If the maneuvering accelerations are parallel to the axis of rotation of the solar collector, the meridional and circumferential stresses become the principal membrane stresses, since the associated shearing stresses would be zero. This is a specialized loading condition, but it will serve to illustrate the magnitude of the problem.

The expressions for the meridional stress (N_θ) and circumferential stress (N_ϕ) in a parabolic membrane which is supported at its apex and accelerated parallel to its axis of revolution, (See the notation of Figure 6) are:

$$N_\theta = \frac{W_G D}{2\sqrt{3}} \left| \frac{1.54 \cos\theta - \sec^2\theta}{1 - \cos^2\theta} \right|$$

$$N_\phi = -\frac{\sqrt{3}\, W_G D}{2} \left[1 + \frac{1}{3} \left(\frac{1.54 \cos^3\theta - 1}{1 - \cos^2\theta} \right) \right]$$

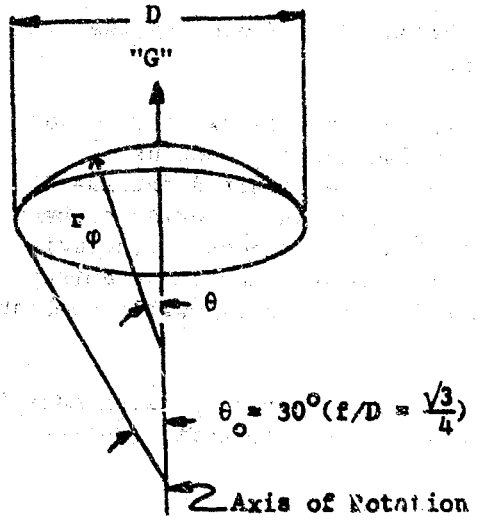


Figure 6 STRESS ANALYSIS

Where,

D = the rim diameter.

W_G = the apparent weight of the paraboloid due to an acceleration "G".

θ_o = the angle defined by a circumference of the shell and the axis of rotation.

\+ denotes accelerations directed away from the apex of the shell and tension stresses.

— denotes opposite accelerations and compressive stresses.

From these expressions, it can be noted that the stresses approach infinity as θ approaches zero; the stresses are of opposite sign throughout the shell; and there are no stress reversals. Since the magnitude of the stresses near the apex become relatively large, the size of the boom attachment flange becomes critical. In the following expressions, the meridional and circumferential membrane stresses are evaluated at the rim of a 14-inch diameter boom attachment flange, and at the outer rim of a 10-foot diameter solar collector. A 1/10 "G" load gives the 0.34 psf solar collector an apparent weight of 0.034 psf.

At the Boom Attachment Flange $\theta = 3^\circ 53'$ and,

$$N_\theta = \frac{W_G D}{2\sqrt{3}} (115) = 0.938 \text{ lb/in}$$

$$N_\varphi = -\frac{\sqrt{3}\, W_G D}{2} (33.3) = -0.967 \text{ lb/in}$$

At the Rim $\theta = 30^\circ$ and,

$$N_\theta = 0$$

$$N_\varphi = -\frac{\sqrt{3}\, W_G D}{2} (.9985) = -0.0245 \text{ lb/in}$$

The unit stresses (lb/in^2) equal the membrane stresses (lb/in.) divided by the membrane thickness.

For selecting a membrane thickness, there are three considerations--1) allowable membrane deflections, 2) available materials and thicknesses, and 3) allowable membrane stresses. An expression for the minimum stiffness product (modulus of elasticity × thickness), Et, was outlined. This expression was based on maintaining a maximum deflection at the rim of the solar collector

that would not distort the reflective surface beyond "± 1/2 deg. by the tangent method" and determined Et = 4.54 lb/in.

Dacron fabrics are readily available in very lightweight weaves and minimum thicknesses. Using a conservative value for the modulus of elasticity of Dacron and gelatin of 0.50×10^6 psi, the required thickness (t) of the parabolic membrane (based on maximum deflection criteria) becomes 9.08×10^{-6} inch. Minimum weight Dacron fabrics have thicknesses (including the rigidizing resin) of about 0.010 inch. This is many times the required thickness based upon the allowable deflection criteria, and allowable membrane stresses.

Assuming that both faces of the 0.010 inch fabric sandwich material are available to resist the preceding membrane stresses, the unit stresses at the boom attachment flange and the rim become,

At Boom Attachment Flange

$$\sigma_\theta = 0.938 \;/\; 2 \times 0.010 = +46.9 \text{ psi}$$

$$\sigma_\varphi = -0.967 \;/\; 2 \times 0.010 = -48.3 \text{ psi}$$

At Rim

$$\sigma_\theta = 0; \; \sigma_\varphi = \frac{-0.0245}{2 \times 0.010} = -1.22 \text{ psi}$$

The facings of the parabolic membrane can be assumed to be flat plate elements, simply-supported by the cell walls of the drop thread core. Using a square-celled core whose plan dimension is a (See Figure 7), the following expression can be used to relate the biaxial stresses, σ_x and σ_y, that produce buckling in a square plate to the geometry and stiffness of the plate.

$$\sigma_x m^2 + \sigma_y n^2 = \frac{\pi^2 E}{12(1-\mu^2)} \left(\frac{t}{a}\right)^2 (m^2 + n^2)^2 \; *$$

Where, m and n equal the number of half waves in the buckled plate in the x and y directions respectively,

E equals the modulus of elasticity,
μ equals Posson's ratio,
t equals the thickness of the plate,
a equals the length and width of the plate,
* denotes compression.

By letting $\sigma_e = \frac{\pi^2 E}{12(1-\mu^2)} \left(\frac{t}{a}\right)^2$, this expression reduces to,

$$\sigma_x m^2 + \sigma_y n^2 = \sigma_e (m^2 + n^2)^2$$

The number of half waves in the buckled plate must correspond to the minimum values of σ_x and σ_y. A number of plots of the above equation

*Timoshenko & Gere, "Theory of Elastic Stability" 2nd Ed. 1961, New York City, McGraw-Hill Book Co., Inc.

are shown in Figure 7. The dark interaction line ABCD is a plot of the buckling modes that result in the minimum biaxial buckling stresses on a square, flat, simply-supported plate. For $\sigma_y = \sigma_x$ to $\sigma_y = -3/7\ \sigma_x$ (ABC), the critical buckling mode is one half wave in each direction of the plate (m = 1, n = 1). At point C, the buckling mode changes to two half waves in the X direction and one half wave in the Y direction (m = 2, n = 1). This mode continues beyond $\sigma_y = -\sigma_x$ (point D) until the plot intersects a new buckling mode (m = 3, n = 1) which intercedes to change the slope of the interaction curve.

By using the interaction curve and evaluating σ_e in terms of a^2, the minimum core cell size can be determined for the minimum facing thickness of Dacron fabric and gelatin resin and the preceding membrane stresses.

$$\sigma_e = \frac{\pi^2 E}{12(1-\mu^2)} \left(\frac{t}{a}\right); \quad \mu = .15 \text{ for fiber reinforced plastics}$$

$$\sigma_e = \frac{42.0}{a^2}$$

At Boom Attachment Flange(14 inches in Diameter):

$$\sigma_\varphi \simeq \sigma_\theta = 48.3 \text{ psi}$$

From Figure 7 $\dfrac{\sigma_x}{\sigma_e} = \dfrac{-\sigma_y}{\sigma_e} = 8.33$

$$\therefore \quad \sigma_\theta = -\sigma_\varphi = (8.33)\left(\frac{42.0}{a^2}\right) = 48.3; \quad a = 2.69 \text{ in.}$$

At Rim (10 feet in Diameter):

$$\sigma_\varphi = -1.22 \text{ psi}; \quad \sigma_\theta = 0$$

From Figure 7 $\dfrac{\sigma_x}{\sigma_e} = 4; \quad \dfrac{\sigma_y}{\sigma_e} = 0$

$$\therefore \quad \sigma_\varphi = (4.0)\left(\frac{42.0}{a^2}\right) = 1.22; \quad a = 11.7 \text{ in.}$$

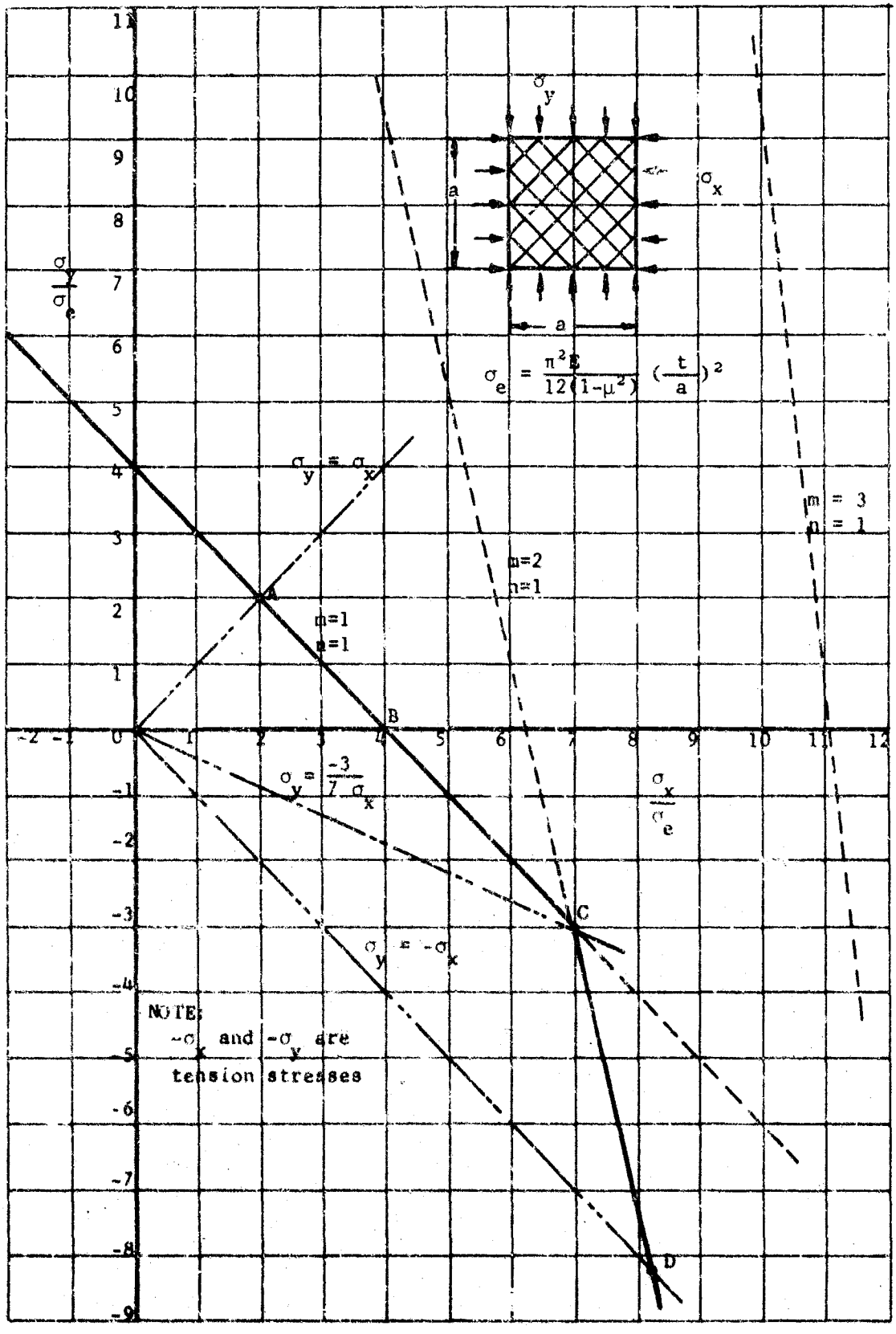


FIGURE 7 INTERACTION CURVE FOR BIAXIAL BUCKLING

From this, it can be seen that the critical core cell size is 2.69 in. If a factor of safety of 2 is applied to the membrane stress, the core cell size must be reduced to 1.90 in. A further reduction to 1.50 in will account for irregularities in the plate surface, as the theory is based on a geometrically perfect plate.

Thus, it can be seen that a Dacron fabric sandwich material with a 0.010 inch facing thickness and a 1 1/2-inch square celled honeycomb type core will satisfactorily support the 10-foot diameter solar collector of this study when subjected to a 0.10 "G" load parallel to the axis of rotation.

4.1.6 Thermal Analysis

GCA Technology Division has derived equations (in parametric form) for the thermal analysis of a 10-foot diameter solar collector. Results were used in the trade-off analysis and design. The thermal analysis study included the following; equilibrium temperature between the front and back of the concentrator, temperature-time history for a deployed concentrator, and temperature-time history of a deployed concentrator in the flexible state. Conclusions indicate the following; if some of the drop threads in the structural backing were made of aluminum, practically no gradient would exist between the front and back of the concentrator, and approximately 1 to 5 minutes are available between deployment and the time required for the entire structure to be below the freezing point of water. The complete procedures and results may be found in the GCA Technology Division report which is included as Appendix A.

4.1.7 Radiation Samples

Two four-inch samples were prepared for radiation testing. Those include two types of solar collector structural material and two types of heavier fiberglass material. They were exposed to radiation for approximately 44 hours. The test showed, in addition to an insignificant weight loss, that there was visible evidence of UV degradation in the appearence of the test samples. The irradiated surface was tinted yellow whereas the control samples retained their white appearance. Test procedure and results may be found in the GCA Technology Division report which is included as Appendix A.

4.1.8 Post Cure Distortion

An analysis showed that if nylon and gelatin are approximately the same weight in a composite and the nylon is stressed to 5000 psi during cure and then released, the composite will change dimensions by only 1/4 total per cent. That conclusion was used in the collector design.

4.1.9 Inflation Dynamics

It has been shown in a GCA Viron paper[1] that the maximum canister pressure PoM, that can be tolerated and not result in a material failure during the initial deployment cycle is as follows:

$$P_{oM} = \frac{2\,(\gamma - 1)^{h}\, f\, S}{D\;\ell_o/\ell_m - (\ell_o/\ell_m)},$$

where P_{oM} = Residual pressure inside the sphere prior to deployment,

$\gamma = c_p/c_v = 1.4$ (for air),

h = thickness of the sphere skin,

f = fractional elongation at rupture of the skin,

S = skin stress at rupture,

D = canister diameter or (diameter of expanding cylinder),

ℓ_o = dimension of sphere prior to deployment,

ℓ_m = maximum extension of sphere during deployment.

The validity of this equation is demonstrated by ECHO II results, For P_o = 10 mm Hg the sphere burst, whereas at P_o = 0.9 mm Hg it did not. The value for P_{oM} calculated from the above equation is 3 mm Hg (where h = 0.7 mil, f = 0.01, S = 5000 psi, D = 35 inches and ℓ_o/ℓ_m = 1/70).

This model assumes a cylindrical representation of the unfolding during the initial inflation. This model does not allow for the large solar collector mass, but it is a good first approximation.

Applying this equation to a test balloon of 10-foot diameter and using 1-mil Mylar with a stress of 10,000 psi and an elongation of 0.02 for a dynamic failure, yields the values for the maximum allowable residual pressure in the three specified size spheres as follows:

TABLE 19

ALLOWABLE CANISTER PRESSURES AND INFLATION TIMES

Diameter	P_{oM} (psi)	Time (Seconds)
10 ft	.40	3
20 ft	.50	4.5
100 ft	.27	18

Another item of interest shown in this table is the length of time that is required for the sphere to deploy to its largest dimension.

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1 Technical Paper On A Model For the Study of Inflation Dynamics of Spherical Satellites

4.2 Cylinder Stress Analyses

As the contract provided for the design, analysis and fabrication of expandable cylinders in addition to the solar collectors, the expandable cylinders were analyzed structurally. The following is a summary of the structural analyses of the expandable cylinder that have been completed to date. The primary load imposed upon the cylinder is that of containing an internal pressure. This applied loading has been thoroughly investigated, even to the determination of secondary shears and bending moments due to unequal radial strains in the structure.

A section of the optimized sandwich shell of the expandable cylinder is shown below. Pertinent dimensions and properties are tabulated in table 20.

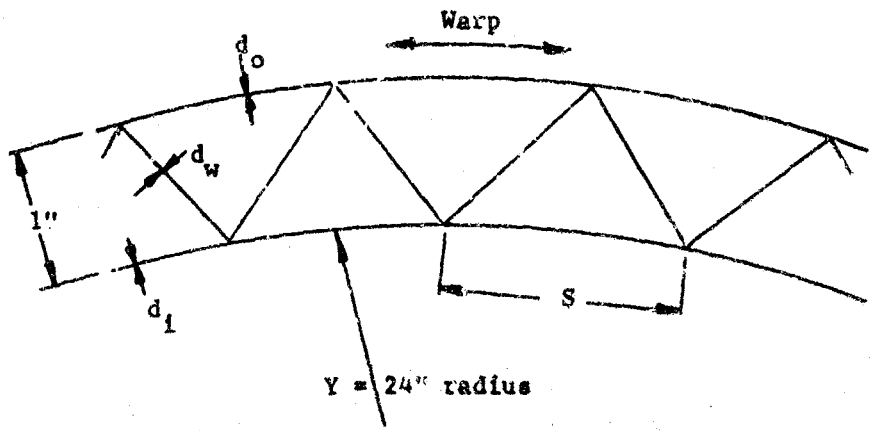


TABLE 20

DIMENSIONS AND PROPERTIES OF CYLINDER SHELL

ELEMENT	DIRECTION	YARNS	CONSTRUCTION	WEAVE	THICKNESS* WITH GELATIN	S
Outside Facing	Warp	225-1/3	60	4 shaft satin	0.010 in = d_o	1.00"
	Fill	225-1/3	60			
Web	Warp	225-1/3	38	4 shaft satin	0.008 in = d_w	
	Fill	225-1/3	38			
Inside Facing	Warp	225-2/3	38	4 shaft satin	0.012 in = d_i	
	Fill	225-1/3	38			

*Approximately ± 10%

The sandwich structure was fabricated from "E" Class Fiberglas and the flutes were oriented from pole to pole of the hemispherical ends.

An internal pressure of 7.5 psia with a factor of safety of 2 was used as the primary loading condition. It can be shown that for the truss core sandwich cylinder, approximately 40 per cent of the internal pressure stresses can be theoretically distributed to the outside facing. However, in order for the outside facing to be stressed to this level it must be circumferentially strained about 1/2 inch. Since this small strain is of the same order of magnitude as the weaving and other fabrication tolerances, the exact stress distribution between the inner and outer facings is intimately related to the degree of fabrication accuracy. In addition, if the outer facing were not fully expanded during deployment, there would be no stress distribution to it. For these reasons, the inside facing was designed to resist all of the internal pressure. The stress levels in the inside facing are as follows:

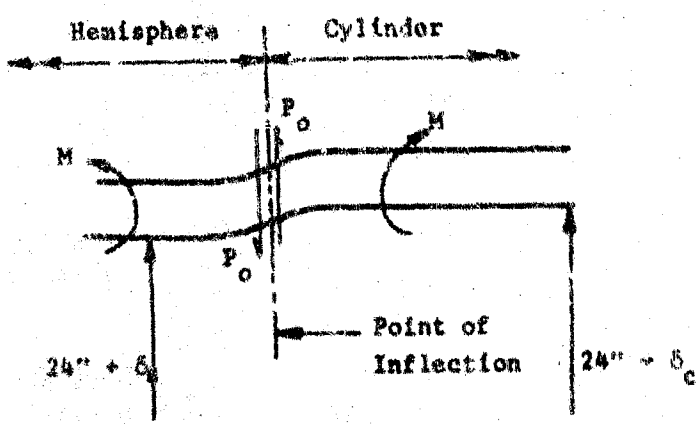
Cylinder: $N_{\theta c} = 180$ lb/in

$N_{\varphi c} = 360$ lb/in

Spherical Ends: $N_{\theta s} = 180$ lb/in

$N_{\varphi s} = 180$ lb/in

Secondary stresses are present at the juncture of the cylinder proper to the hemispherical ends due to unequal radial deflections. At this juncture, the structural sandwich shell makes a transition from the smaller deflected circumference of the hemisphere to the larger deflected circumference of the cylinder, as indicated in the drawing below.

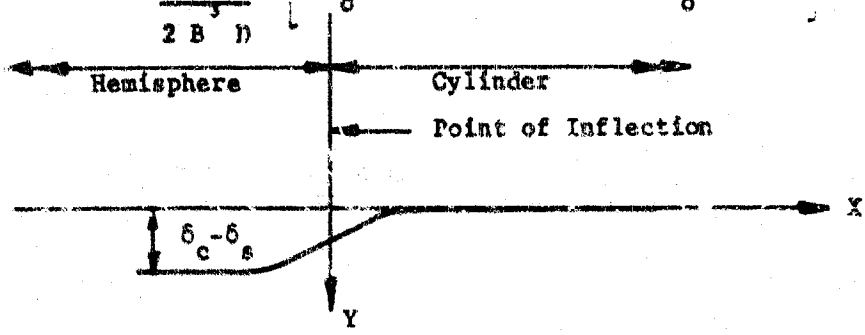


Where δ_s = Radial Deflection of spherical ends, δ_c = Radial deflection of Cylinder, P_o = Secondary shear at point of inflection, and M = secondary bending moment.

Because the sandwich shell is symmetrical about the juncture of the hemisphere and cylinder, the transition curve will undergo a point of inflection at this juncture and there will be no secondary moment, M_o, at this point. There is a secondary shear normal to the sandwich shell at P_o, which produces secondary bending moments in other parts of the shell.* These bending moments increase to a maximum at a distance = $0.6/\beta$ from the point of inflection and diminish to zero beyond this distance. In the subsequent analysis, the entire sandwich cross section is assumed to deflect radially without distorting in accordance with the initial assumption that all of the internal pressure is contained by the inside facing.

The expression for the transition curve as represented in the coordinate system below is:

$$Y = \frac{e^{-Bx}}{2B^3D}\left[BM_o\,(\text{Sin } Bx - \text{Cos } Bx) - P_o \text{ Cos } Bx\right] \quad *$$



For the symmetrical curve of the sandwich shell, $M_o = o$, and therefore

$$Y = \frac{e^{-Bx}}{2B^3D} - P_o \text{ Cos } Bx \quad .$$

Where $D = \frac{EI}{1-\mu^2}$ (Flexural Rigidity)

$$B = \sqrt[4]{\frac{Ed_i}{4Dr^2}} \quad \text{(Elastic Parameter)}$$

For the fiberglas/gelatin sandwich material of this study

$I \quad \frac{(d_i + d_o)}{2}(2)(1/2 \text{ in})^3 \quad \frac{d_i + d_o}{4} \quad 0.0035 \text{ in}^4/\text{in}$

$E \quad 2.0 \times 10^6$ psi

$\mu \quad 0.15$

$d_i \quad 0.012$ in

$r = 24$ in

*Timoshenko, Woinowsky - Krieger "Theory of Plates and Shells 2nd Ed. McGraw-Hill Book Company, Inc., New York, 1959

Therefore, $D = 1.12 \times 10^4$, $B = 0.175$.

The maximum deflection, $\delta_c - \delta_s$, is the difference between the radial deflections of the hemisphere and the cylinder. Therefore $\delta_c - \delta_s = r/Ed_i (N_{\varphi c} - N_{\varphi s}) = 0.180$ in. Since the transition curve is symmetrical about the Y - axis, the equation of the transition curve at $x = 0$ is equal to $(\delta_c - \delta_s)/2$.

Therefore, $Y_{x=o} = \frac{-Po}{2 B^3 D} = \frac{.180}{2}$; and $Po = -10.8$ lb/in.

The secondary bending moment, Mx, is equal to $(-D)(d^2y/dx^2)$

Differentiating the expression for Y as a function of Bx twice gives

$$d^2y/dx^2 = \frac{-1}{2 BD} \left[2BM_o \varphi (Bx) + 2 P_o \theta (Bx) \right]$$

Where $\varphi (Bx)$ and $\theta (Bx)$ are the functions described and plotted in Figure 8 again, since $M_o = 0$, the expression for secondary bending moment reduces to

$$Mx = \frac{+Po}{B} \left[\theta (Bx) \right].$$

From Figure 8, it is seen that $\theta (Bx)$ is a maximum at $Bx = 0.8$. Thus, the maximum secondary bending moment is equal to

$$M_s = \frac{-10.8}{.175} (0.32) = -19.8 \text{ in - lb/ in.}$$

The location of the maximum bending moment is 4.56 in from the juncture of the cylinder and the hemisphere.

The maximum bending moment, Ms, results in facing stresses of approximately 19.8 lb/in parallel to the flutes of the core.

The most severe maneuvering loading condition was investigated for its effect on the expandable cylinder. This consisted of supporting the cylinder with a 10-inch diameter boom attachment flange at one of the hemispherical poles and accelerating it 0.10 "G" perpendicular to its axis. The expandable cylinder was conservatively assumed to weigh 50 lb which resulted in a bending moment at the boom attachment flange of 240 in-lb. The maximum stress in the facing of the sandwich structure can be approximated by the following expression:

$$N_\theta = \frac{M}{\pi r_o^2} \left[1 + \frac{(n+1)}{n} \ln \frac{2 (r - r_o)}{Kr} \right] *.$$

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*Roark, Raymond J., 1954 Formulas For Stress and Strain, 3rd ed. New York City, McGraw-Hill Book Company, Inc.

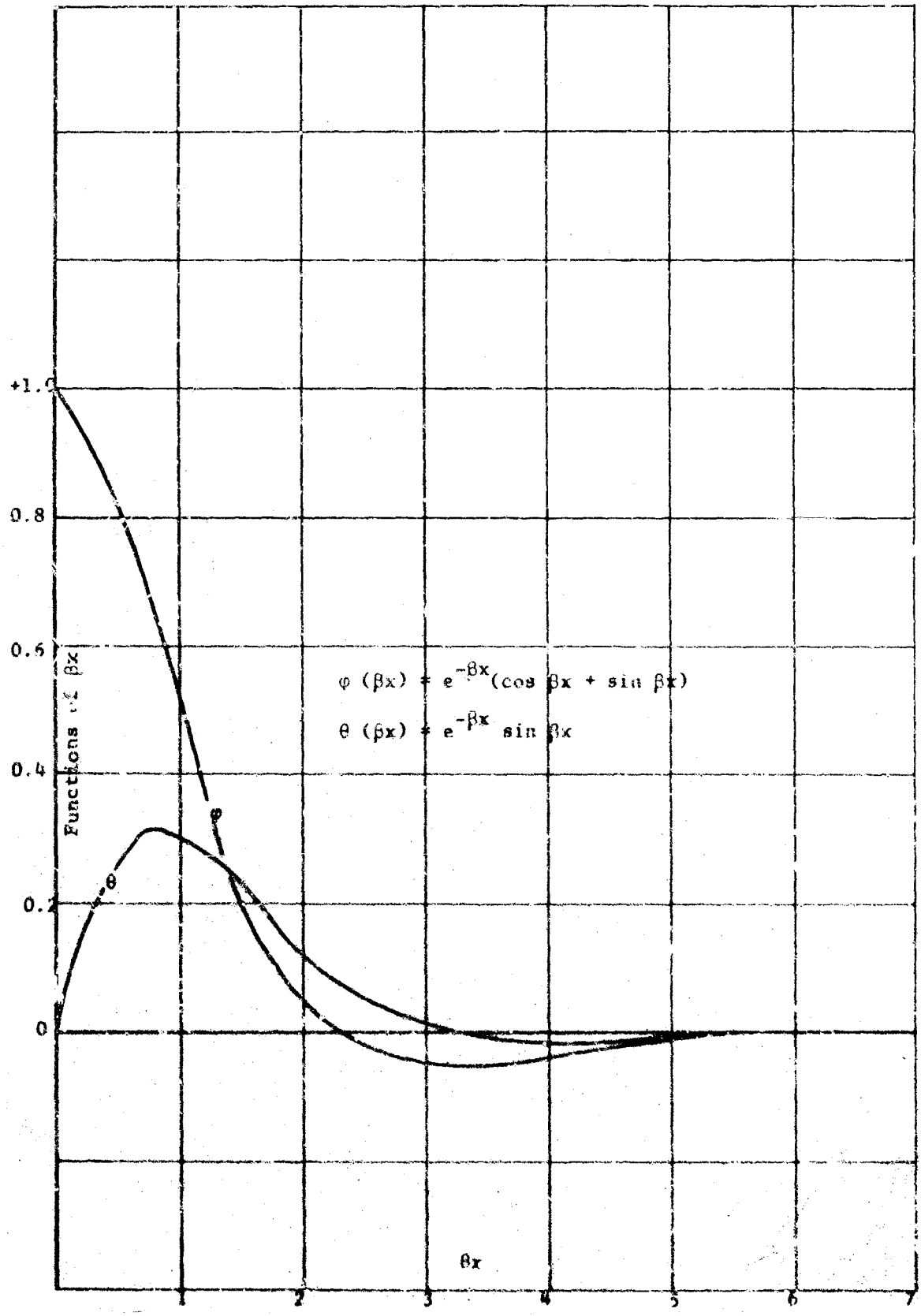


Figure 8. φ and θ Functions for Secondary Cylindrical Stresses.

Where, $M = 240$ in-lb

$r_o = 5$ in (Radius of Boom Attachment Flange)

$m = 1/u = 6.67$

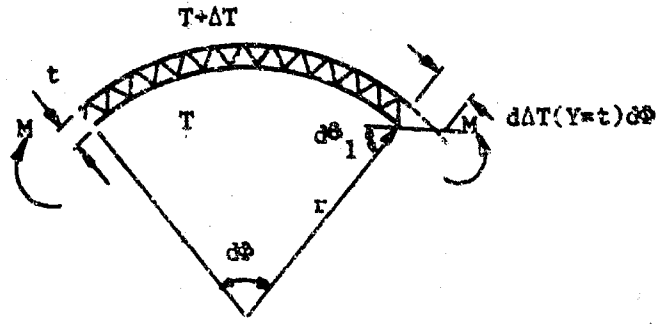
$k = .49\ r^2/(r_o + .7r)^2$

$r = 24$ in (Radius of Cylinder)

$t = 1$ in (Depth of Sandwich)

Thus, $N = 4.05$ lb/in. (Parallel to the flutes of the core).

A simplified thermal loading condition was investigated as a preliminary approach to the problem of thermal stresses in the expandable cylinder. A temperature gradient, ΔT was assumed normal to the surface of the cylinder. It was also assumed to be uniform around the cylinder. Thus a unit angular distortion, $d\theta$, would occur between the facings of a section of the cylinder if it were unrestrained. See the figure below.



Thus, $d\theta_1 = \dfrac{\alpha\Delta T\,(r + t)\,d\varphi}{t}$ and $\theta_1 = \int_0^{2\pi} d\theta_1$

$$\theta_1 = \frac{\alpha\Delta T\,(r + t)\,2\pi}{t}$$

But, the restraining moment, M, in the cylindrical shell can be equated to a unit angular distortion,

$$d\theta_2 = \frac{M\,(r + t/2)\,d\varphi}{EI}, \text{ and } \theta_2 = \int_0^{2\pi} d\theta_2 \qquad \theta_2 = \frac{M(r+t/2)2\pi}{EI}$$

Therefore, the restraining bending moment can be determined by equating $\theta_1 = \theta_2$.

And, $$M = \frac{\alpha\Delta T E I}{t}\ \frac{(r + t)}{r + t/2}$$

Where, α = Coefficient of thermal expansion $\simeq 2.0 \times 10^{-5}$ in/in -°F

$E \simeq 2.0 \times 10^{6}$ psi

$I = 0.0055$ in 4/in.

$t = 1.0$ in.

$r = 24$ in.

The stress in the facings would thus equal,

$N_{\varphi} = 0.224$ in-°F. (Perpendicular to the flutes of the core).

This expression is conservative and unrealistic since it is based on a uniform thermal gradient around the entire structure. Actually, the thermal gradient, ΔT, and the restraining moment, M, would be functions of φ and must be integrated as such in determining θ_1 and θ_2.

The facings of the fluted core, sandwich shell are essentially long, narrow simply supported, flat plate elements. The bending moments associated with the secondary stress, inertial, and thermal loadings will produce compressive loads in the thin sandwich facings which tend to buckle them at low stress levels. The critical buckling stress levels in a long, narrow rectangular plate can be expressed as follows*.

$$\sigma_{\theta} \text{ (Parallel to flutes)} = \frac{4\pi^2 E}{(12)(1-\mu^2)} \left(\frac{d_o}{S}\right)^2 = 6720 \text{ psi}$$

$$\sigma_{\varphi} \text{ (Perpendicular to flutes)} = \frac{\pi^2 E}{(12)(1-\mu^2)} \left(\frac{d_o}{S}\right)^2 = 1680 \text{ psi}$$

Where, E and μ are the same as before and

d_o = thickness of thinest facing = 0.010

S = core spacing $\sim$ 1.0 in.

Thus, the secondary, inertial, and thermal-bending-moment stresses can be compared to allowable stresses which are the critical buckling stresses reduced by a factor of safety of 2. This comparison is shown in Table 21.

*Timoshenko And Gare "Theory of Elastic Stability" 2nd Ed. McGraw-Hill Book Company, Inc., New York, 1961

TABLE 21

CYLINDER FACING STRESS

Loading Condition	Actual $=N/do$	Allowable	Remarks
Internal Pressure (Secondary Stress)	$\frac{19.8}{.01}$ = 1980 psi	3360 psi	Realistic
Maneuvering (0.10 "G")	$\frac{4.05}{.01}$ = 405 psi	3360 psi	Approximate
Thermal (T = 37 1/2F)	$\frac{8.4}{.01}$ = 840 psi	840 psi	Conservative

In summary, a fluted core sandwich configuration has been optimized for use as the structural shell of the 4 by 8 foot expandable cylinder.

A number of loading conditions were considered including internal pressure secondary stresses, maneuvering, and thermal loads. The sandwich configuration was optimized for an internal pressure of 7.5 psia, a 0.10 "G" acceleration, and a temperature differential of 37 degrees F normal to the surface of the cylinder -- all with a factor of safety of two.

The weight of the optimized sandwich shell (including 33 per cent gelatin resin) is 0.31 psf or about 30 lbs total.

5.0 MATERIALS VERIFICATION PROGRAM

A very extensive laboratory program was organized to verify the design concepts, materials, and seaming and joining methods for the solar concentrator and cylinder. Following is a general outline of the areas covered.

a. Structural-Mechanical Tests

1. Tensile Tests
2. Flexural Tests
3. Cylinder Seaming and Joining

b. Compatibility And Shelf-Life Tests

1. Qualitative Tests
2. Flexibility Tests
3. Materials Degradation, Ambient

c. Packaging Tests

1. Materials Degradation
2. Hand Folding
3. Forced Folding

d. Resin Tests

1. Cure Time Parameters
2. Shrinkage Parameters
3. "B"-Staging Parameters
4. Degree of Cure

e. Environmental Tests

1. U.V. - Vacuum Degradation
2. Electron Radiation Degradation
3. Thermal Degradation

f. Thermal Tests

1. Thermal Characteristics
2. Thermal Parameters

Some of the results are included in the Appendix.

5.1 Structural-Mechanical Tests

5.1.1 Fabric-Resin Ratio Optimization

The gelatin-fabric ratio (3:10) was optimized for maximum strength-to-weight characteristics. Gelatin and fabric composites were evaluated for tensile, flexural, and shear strengths. It was the intent of the experimental program to optimize the resin-fabric ratio for both fiberglass and Dacron. To date, however, all of the strength-to-weight optimization studies have been conducted with No 181 fiberglass fabric ("E" Glass, Volan "A" treated).

The tensile and shear test specimens were made of single ply laminates with varying gelatin contents. The flexural test specimens were made of triple ply laminates also with varying gelatin contents. All specimens were "B"-staged with formaldehyde and dried at ambient conditions. Prior to testing, the specimens were dried in a bell jar at 10 to 50 microns and room temperature for 24 hours. All specimens were tested within an hour after removal from the bell jar.

5.1.2 Tensile Tests

The results of the tensile tests are shown in Figure 9. In this figure, the ultimate tensile load (lb/in) is plotted vs the gelatin content of the test specimens. An illustration of the test specimen is also shown in Figure 9. The lower curve is a plot of the ultimate tensile loads divided by the representative weight of the sample. This curve indicates that the optimum gelatin content for maximum tensile strength-to-weight ratio is 15 per cent of the total composite weight. There was no significant change in tensile modulus at any gelatin content. The tests were made on an Instron tensile tester with a jaw separation of 0.2 in/min.

5.1.3 Flexural Tests

The results of the flexural tests are shown in Figure 10. In order to eliminate the effect of increased specimen thickness with increasing gelatin content, the ultimate bending moment has been reduced by a factor, $(t/t_o)^2$, where "t" is the specimen thickness and t_o is the 10 per cent gelatin specimen thickness. An illustration of the mid-point loading arrangement is also shown in Figure 10. Again, an optimized load curve is obtained by dividing the actual bending moment by the representative weight of the sample. This curve indicates that the optimum gelatin content for maximum flexural (i.e., compressive) strength-to-weight ratio is 40 to 45 per cent of the total composite weight. These tests were made on an Instron Tensile Tester with a jaw separation of 1.0 in/min.

5.1.4 Seaming and Joining

Three types of adhesive seams were tensile tested; Estane, vinyl

plastisol, and polyethylene. These adhesives are representative of three types of flexible adhesives; a solvent-adhesive system, a thermosetting system, and an insoluble hot-melt system. The seams were tested with a 1/4-inch, a 1/2-inch, and a 1-inch lap of No 181 fiberglas fabric. Two series were run; one at 75 F, and a second at 200 F. The results of the tests are listed in Table 22.

TABLE 22

SEAMING AND JOINING TESTS

	Average Ultimate Shear Strength For 3 Samples (lb/in)					
	75 F			200 F		
Lap Width	1"	1/2"	1/4"	1"	1/2"	1/4"
Adhesive						
Estane	M	M	M	M	M	74*
Vinyl Plastisol	M	M	M	74*	46*	44*
Polyethylene	M	M	M	85*	63*	27*

* - These samples peeled at seam.
M - Sample developed full material strength (110 to 120 lb/in).

As can be seen by the table, the only adhesive samples which maintained their 75 F strength at 200 F were the 1-inch and 1/2-inch Estane strips. More tests were conducted on the same type of seam samples, but at 0 F and -50 F. All seams maintained material strength at these temperatures.

5.2 Compatibility and Shelf-Life Tests

Test specimens were prepared, folded, packaged, and stored in an effort to initiate the experimental work in the area of shelf-life and compatibility. The specimens that were prepared would have measured the effect of packaging, storing, flexibility, and degradation on the materials and composites of this study. These packaging and shelf-life specimens were to have been periodically examined for weight loss, which would indicate loss of resin solvent, and for pressure change within the packaged specimen, which would indicate sublimation or leakage in the sealed package.

The test specimens included composite sections of the solar concentrator and of the cylinder structures. These specimens were resin impregnated and adjusted for the minimum amount of water necessary for flexible packaging conditions. The composites were folded to simulate full-size structure folding conditions. The specimens were to be visually and qualitatively examined after six months.

Test specimens of the flexible adhesives of the two structures were also prepared. The adhesive samples were Estane 5740-x-071, DuPont 46970, and Shell epoxy Epon 872x75. Test specimens to measure the tensile and flexural strengths of number 181 fiberglass and gelatin laminates after storage were also prepared. In addition, test specimens of the one-mil Mylar balloon end cap, and aluminum-Mylar-aluminum, reflective surface material were prepared for gas permeability measurements after storage.

Unfortunately, the only items to survive the move from Viron to Schjeldahl, were four impregnated samples of the solar concentrator composites. The following information, from a laboratory notebook, describes these samples.

TABLE 23

COMPATIBILITY AND SHELF LIFE OF SOLAR CONCENTRATOR COMPOSITES

Sample Number	Reflective Surface Material	Foam Material	Dry Weight (gms)	Wet Weight (gms)	Gelatin Solution Weight (gms)	Packaged Weight (Gms)
1	A-12 type	Scott Series 900 - 10	181.9	206.4	24.5	210.0
2	A-12 type	Scott Series 900 - 10	170.4	187.4	17.0	192.3
3	Mylar	Polyurethane open cell 1/8 inch thick	105.0	123.0	18.0	127.5
4	Mylar	Scott Series 900 - 10	127.3	142.2	14.9	147.9

Each sample was a 10-inch by 10-inch solar concentrator composite with random-scatter, drop-thread Dacron as backing material. The reflective surfaces showed no signs of shrinkage, crease marks from folding, or show through, except the surface of sample number 3 which had an orange-peel effect caused by the foam. All samples were folded twice, sealed in polyethylene bags, placed in a cardboard container, and stored in the laboratory store room. No record of interim examination could be found.

Table 24 describes the samples after an eight month storage period. If future shelf-life studies are undertaken the following suggestions should be considered; samples should be packaged in containers that are less permeable than polyethylene, the highly acidic (ph 3.8) gelatin resin should be neutralized with NaOH prior to impregnation (this was not done on these samples), and more complete records should be maintained. To emphasize this last suggestion, the putrification of samples number 1 and 2 was probably caused by not"B"-staging, while samples number 3 and 4 were probably "B"-

TABLE 24

AUGUST 10, 1956 EXAMINATION OF SOLAP CONCENTRATOR COMPOSITES STORED SINCE DECEMBER 28, 1965

(7 Month Storage)

					SURFACE				BACKING	
SAMPLE NUMBER	PACKAGED WT. GMS.	WEIGHT LOSS GMS.	UNFOLDING FOLD 1	FOLD 2	BLISTERING	CREASES AT FOLDS	WRINKLING	DELAMINATION	WET	PUTRID
1	193.2	17.2	Easy	Hard	Severe	Severe	Some	Between foam and reflective surface	Yes	Yes
2	174.8	17.5	Easy	Harder than sample 1	Some	Severe	Some, but less than sample 1	Between foam and reflective surface more than sample 1	Slightly	Yes
3	117.5	10.0	Easier than sample 1	Not as hard as sample 1	None	Some	None	Very little at folds between foam and backing	Very Slightly	No
4	133.5	14.4	Easier than Sample 1	Not as hard as Sample 1	None	Some	None	None	No	No

staged. No record can be found to determine if this is true. However, benzoic acid is usually added to preserve the gelatin, or "B"-staging will also act as a preservative.

It was proven, after these samples were packaged, that the acid in the gelatin reacts with the A-12 type material to form a gas which causes blisters on the surface. The blisters are actually between the aluminum and the Mylar inner layer. However, this was overcome by neutralizing the gelatin.

5.3 Packaging Tests

Tests were conducted to determine the effects of folding and packaging on the tensile strength of the fiberglass material. One ply samples of No 181 fiberglass impregnated to 30 per cent gelatin content were used. The samples were folded, and subjected to 5 psi, 10 psi, and 15 psi so that the fold and material were compressed. Three samples were run at each level with three control samples not folded. The pressure was held for 5 minutes, and the samples were unfolded and vacuum cured. Each sample was then tested for tensile strength. Table 25 lists the results.

TABLE 25

EFFECTS OF PRESSURE FOLDS ON NO. 181 FIBERGLASS MATERIAL IMPREGNATED WITH GELATIN

Pressure on Fold	Tensile Strength lb/in		
	Sample No 1	Sample No 2	Sample No 3
No Fold	400	420	400
5 psi	134	120	106
10 psi	131	106	104
15 psi	73	65	53

These tests indicated a definite degradation in the strength of the fiberglass material when it is pressure-folded. However, this test represented extreme conditions with a single fold compressed between hard surfaces. The main purpose was to compare these results with a similar test on Dacron and nylon materials.

A packaging test similar to the one described above was conducted on 4 oz/yd^2, single-ply, nylon cloth impregnated with 30 per cent gelatin. The results showed no strength degradation from folding.

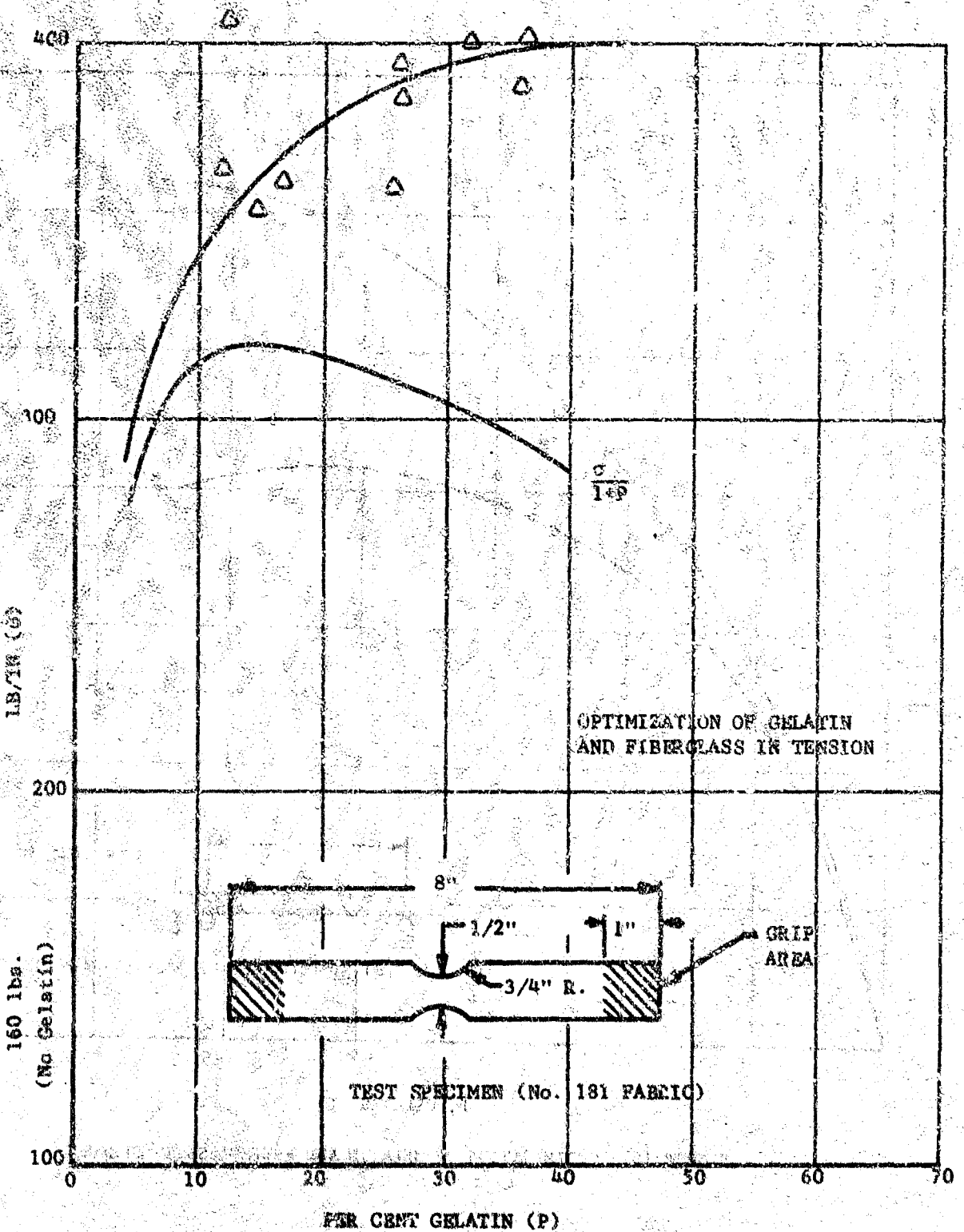


Figure 9. OPTIMIZATION OF GELATIN AND FIBERGLASS IN TENSION

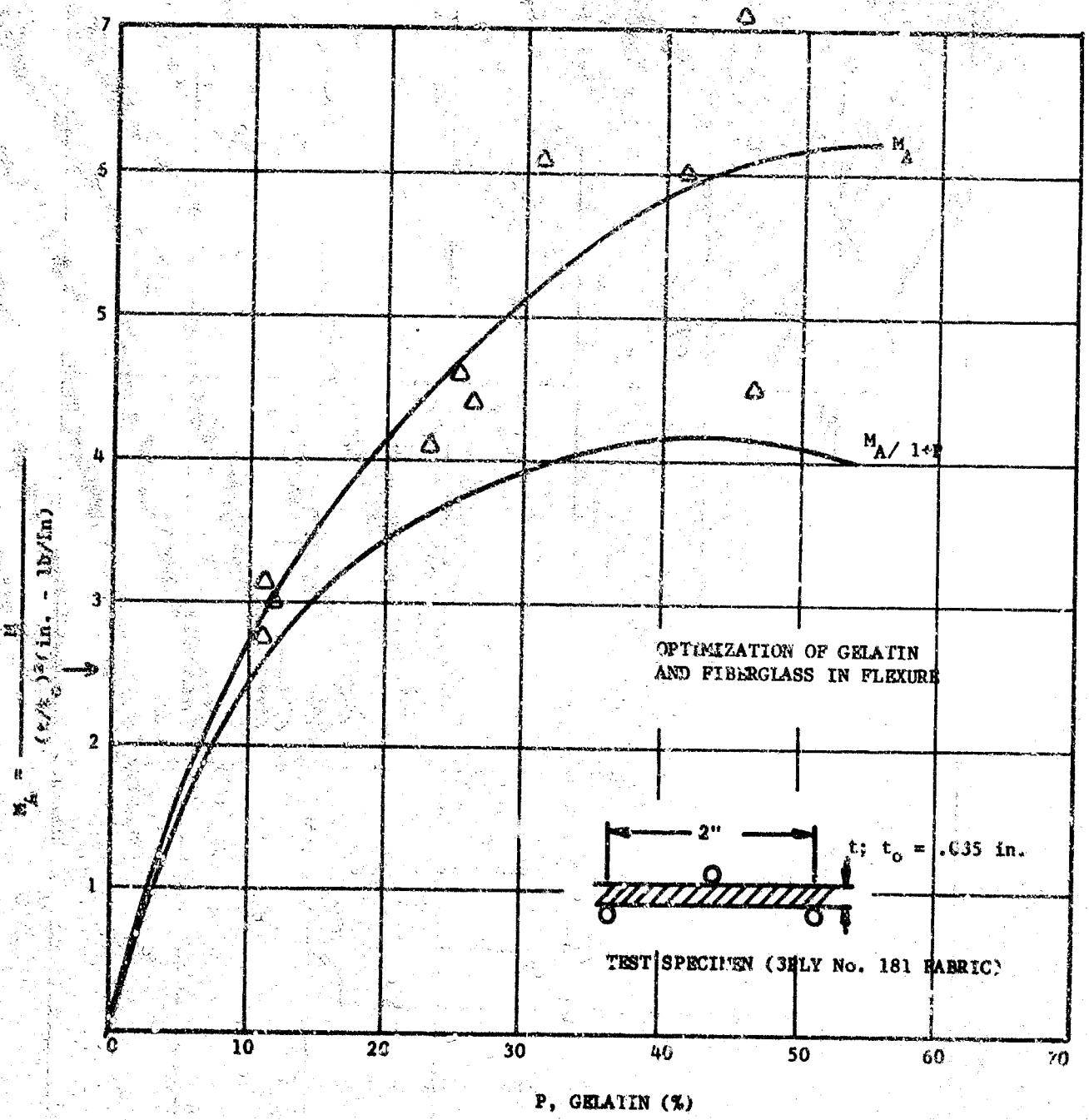


FIGURE 10 OPTIMIZATION OF GELATIN AND FIBERGLASS IN FLEXURE

5.4 Resin Tests

5.4.1 Cure Time Studies

Cure time of the gelatin material was studied in three ways. They were: (a) cure time as a function of gelatin thickness, (b) cure time as a function of the solvent-to-solid ratio and, (c) cure time as a function of the type of solvent system used.

5.4.1.1 Cure Time As A Function Of Gelatin Thickness

For this test, 3-5/8-inch diameter discs of gelatin were cast in thicknesses varying from 13 mils to 104 mils. The solvent used was water and the gelatin to water ratio was 1:1. Two samples for each thickness were cast, and the actual thicknesses and weights were measured. One set of samples was placed in one 18-inch bell jar and the other set in another bell jar. Each sample was on a spring weight scale (upper left picture in Figure 11) so that weight losses with time could be measured. The results of these tests are graphed in Figures 12 and 13 as percentage of water lost versus time in the vacuum. The conclusion was that thickness of the gelatin does have an effect on the cure time of the material as the thinner samples cured the most rapidly. The initial solvent loss is nearly the same in all samples because of flash-off of the water on the surface. However, thickness becomes a factor with time since the interior water must diffuse to the surface to evaporate.

5.4.1.2 Cure Time As A Function Of The Solid-To-Solvent Ratio

Samples for this test were also 3-5/8-inch diameter cast discs of gelatin material with water as the solvent. All samples were 100 mils thick. The percentages of solvent in the samples were 10, 15, 20, 30, 40, and 60 per cent. Again, two samples of each level were tested in the 18-inch bell jar and the weights were monitored on the spring scales. The results are shown in Figures 14 and 15 where they are graphed as percentage of the solvent lost from the material in the sample versus the time spent in the vacuum. There is no significant variation in the cure times for the various percentages of solvents.

5.4.1.3 Cure Time As A Function Of Various Solvent Systems

The six different solvent systems used in these tests are listed in Table 27. All were impregnated in No 181 fiberglas fabric. For the test the following procedure was used. The bell jar was shielded on all sides with metallized Mylar so that a standardized environment could be achieved (upper right of Figure 11). Two 4 by 5-inch samples were mounted in the bell jar, one on the spring scale and one in the center with two thermocouples imbedded in it (upper left of Figure 11). The bell jar was evacuated and weight loss and temperature constantly checked (bottom of Figure 11). The results were graphed to determine which system cured at the

greatest rate. Figure 16 is a composite of these graphs. It shows the percentage of solvent in the sample by weight versus the time in the bell jar. As can be seen by the different slopes of the curves, the 73-A system of 100 per cent methanol cured fastest and reached a greater degree of cure in less time than the other systems. The other high percentage methanol systems and the alcohol systems showed rapid cure rates, except the 75-A system was crosslinked by immersion rather than by the gaseous process. This would indicate that liquid crosslinking tends to retard the curing of the methanol systems, possibly because it penetrates the whole sample rather than just the surface.

To determine if a vacuum is a necessary condition before the gelatin system will cure, samples were tested in a dry box. The relative humidity of the box was kept below 10 per cent and the temperature at 90 F. The tests were not conclusive; however, the cure rates seem to correspond closely to the vacuum cure rates. The steep temperature drop experienced in the vacuum as the gelatin solvent was flushed off was not present.

5.5 Shrinkage of Structural Material

A series of 10 by 10-inch fluted-core, Dacron pillows were impregnated with 30 per cent gelatin-water solutions. Various tensions were held in the material during cure. Measurements of linear changes were taken at selected intervals over two weeks. The results are presented in Table 28. Tension was removed after the first 24 hours. Although there is some data scatter, the table shows that most shrinkage occurred in the material which was not in tension during cure.

5.6 B-Staging

B-Staging is a process of crosslinking the jelled gelatin resin system with formaldehyde. This causes the gelatin to remain in a solid, jelled, flexible, and non-tacky condition that cannot be dissolved or washed away by liquids such as water. A structure that has been impregnated, B-Staged, and cured (rigidized) can then be made flexible again by the addition of water or water vapor. B-Staging also produces a certain amount of memory or elastic recovery. As an example, if a fluted core structure is impregnated with gelatin, inflated to its desired shape, B-Staged, and then packaged, the structure, upon opening of the package, would tend to spring back to its original inflated shape.

The first approach to the B-staging of structures was to expose the structure to vapors from a solution of formalin and water. This method did not provide an accurate determination of the actual amount of formaldehyde used in the process. In addition, scaling up to the large structures appeared to be very difficult.

Another method of B-staging was developed that at first had promising results. The method was to add formalin directly to a gelatin-water solution and heat the mixture until it was near gelation, then impregnate the structure and rigidize it. The structure can then later be made flexible again.

The degree of B-staging attained was found to be dependent on the concentration of formalin and the time-temperature product of the resin solution. Preliminary experiments have shown that it is necessary to maintain a minimum solution temperature of 85 to 90 F to attain an appreciable amount of B-staging with any formalin concentration and over any time interval. Above 90 F, however, there is a definite correlation between the amount of formalin added and the time required for gelation of the solution.

Table 26 summarizes these experimental studies and shows the correlation between gel time, formalin concentration, and temperature. Also shown in the table are characteristics of the reflexibilized structures. An optimum formalin concentration appears to be 8 to 12 per cent of the gelatin solids.

This method proved to be unusable for large areas or large amount of packaged materials for several reasons; these were, inability to control temperature throughout the material being impregnated, the inability to definitely control pot life, and premature B-staging (before completion of impregnation).

TABLE 26

B-STAGING CHARACTERISTICS OF FORMALIN

Formalin* (Per Cent)	Pre-Impregnation Solution Temperature: 110 F Pot Life	90 F Pot Life	Reflexibilized Structures Impregnated After Adding Formalin:** 2 hrs. Tacky	Memory	Wt. Loss(%)	At Gel Point Tacky	Memory	Wt. Loss(%)
2	-	-	Yes	None	28	-		-
4	-	5 1/2 hrs	Yes	1/2 Folded	12	-		-
8	3 1/2 hrs	4 hrs	No	Unfolded, No Sepn.	5	No	Full, 1 Sec.	4
12	2 1/2 hrs	3 hrs	No	Full, 2 sec.	4	No	Full, 1 Sec.	4
16	2 hrs	2 1/2 hrs	No	Full, 2 Sec.	3	No	Full, 2 Sec.	3

* Based On Wt. Of Gelatin Solids

** Cooked At 90 F

Five-by five-inch samples of Dacron fabric with random-scattered, drop-thread cores were used as the resin substrate in the experiments. The reflexibilized characteristics were determined as follows:

Tacky.	A subjective test. Yes or no. Tacky to the touch.
Wt. Loss.	Loss of gelatin after reflexibilizing in 140 F water for 5 minutes.
Memory.	Degree of elastic recovery after folding the samples twice. One-half folded indicates that the structure unfolded only once. Unfolded, no separation, indicates that the sample unfolded twice, but there was no recovery of the drop-thread core. Full, 2 sec. indicates that the structure returned to its fully expanded shape in two seconds.

During the B-staging (exposing to vapor from a solution of formalin and water), paraformaldehyde formed in the flask containing diluted formalin solution. Paraformaldehyde is a white amorphous solid, insoluble in water and organic solvents, and dissociates into gaseous formaldehyde when heated. Because of this latter property and the fact that a direct measurement of the amount of gas evolved can be made, it was decided to attempt B-staging structures with the heated solid material.

An 18-inch fiberglass cylinder was impregnated with heated gelatin, and cooled to room temperature while inflated with air. Formaldehyde gas was then directed into the structure for 18 hours. The gelatin became non-tacky and had very good memory after being folded. The process appeared promising and further work was completed to determine the amount of solid material, and the length of time necessary to B-stage a given structure.

Two, 10-inch, two-ply cubes, fabricated from 1 layer of No 181 and 1 layer of No 402 fiberglass cloth, were vacuum impregnated with 30 per cent gelatin-H_2O solution at 130 F. The first cube was vacuum cured and then B-staged with formaldehyde and water vapor. The second cube was B-staged immediately after impregnation. Some of the water was removed from the second cube by directing air into its interior for 3 hours before introducing the formaldehyde vapors.

It appears that the procedure utilized for the second cube is more practical because it was B-staged to a packageable flexibility in about one-third of the time it took for the first cube. In addition, the necessity for first rigidizing a structure was eliminated. Starting with heated vapor can probably reduce the processing time further. It was also noted that a gelatin-water ratio of about 1:1 seemed necessary for the required degree of flexibility. The weight ratios of materials at various stages are shown in Table 29.

The second cube was folded and chilled to -20 F for one week, brought to room temperature, and vacuum cured with no apparent adverse effects.

5.6.1 B-Staging Ten-Foot Solar Energy Concentrators

A further improvement was made in the B-staging procedure which

appears to be very efficient and directly applicable to larger structures. Figure 17 depicts the apparatus employed. Paraformaldehyde and water were heated in separate containers enclosed in A. The air, saturated with water and formaldehyde, was circulated towards B by an axial-vane fan (D) of a 60-cfm capacity. The air cooled copper coils, B, act as condensers to cool the saturated air to room temperature to prevent dissolving the gelatin on the impregnated fabric. The vapors are then recirculated under the plastic film which covers the gelatin-impregnated structure, and back into the container, A. Unreacted formaldehyde vapors pass through the opening at C and are recycled. The condensate in the copper coils automatically drains back into container A. An advantage of this system was that it was self-enclosed and irritating vapors did not contact personnel. A 10-foot structure was successfully B-staged by the method described.

5.6.2 Formaldehyde Determination

A method of determining the amount of formaldehyde, used in the B-staging process, was developed. Formaldehyde reacts with aqueous potassium permanganate according to the following formula:

Side A	Side B
$2KMnO_4 + 3HCOH + H_2O$	$2MnO_2 + 3KCOOH + 2KOH$

Side A is a purple colored solution which becomes colorless when all of the permanganate has been converted to manganese dioxide by the formaldehyde. The MnO_2 is an insoluble precipitate. By knowing the initial weight of the paraformaldehyde and the amount of $KMnO_4$ in a solution, the formaldehyde which has reacted with the gelatin, plus the small amount lost to the atmosphere under the film, may be determined.

It was intended to connect the flasks containing $KMnO_4$ solution at point C, Figure 17. Should the B-staging process seem complete before a color change occurred, accurate determinations could be made, either gravimetrically (amount of precipitate) or by titration.

5.7 DEGREE OF CURE EFFECT ON STRENGTH

Tensile and flexural tests were conducted on the gelatin impregnated fiberglass fabric to determine how various degrees of cure affected the tensile and flexural strengths of the material.

5.7.1 Tensile Tests

Single ply No 181 fiberglass samples, impregnated to 27 per cent gelatin content by weight, were used in the tensile tests. The degree of cure varied from a water content of 0 to 30 per cent. The results of these tests are graphed in Figure 18 which indicates an increase of strength after a water content of 10 per cent or less is reached. More testing in the region of 20 per cent to 30 per cent water content is needed to determine if the strength levels off at the basic strength of the fiberglass.

5.7.2 Flexural Tests

Three ply samples of No 181 fiberglass impregnated to 23 per cent gelatin content by weight were used in the flexural tests. The degree of cure varied from 5 to 40 per cent water content. The results, Figure 19, show a definite increase in strength as the residual solvent approaches zero. However, more testing in the region from 15 to 30 per cent water content is needed to define the variation in strength more accurately.

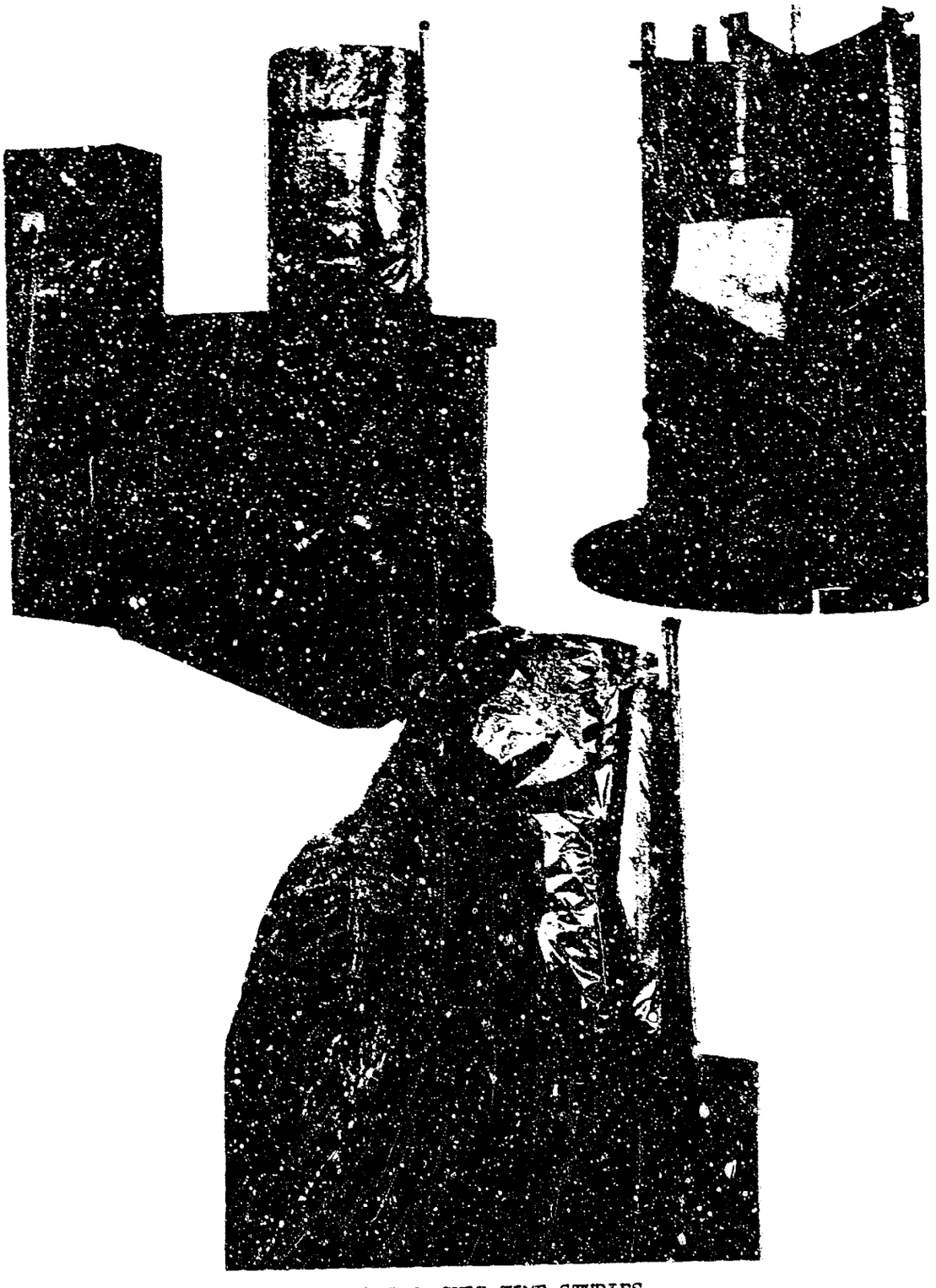


FIGURE 11 VACUUM CURE TIME STUDIES

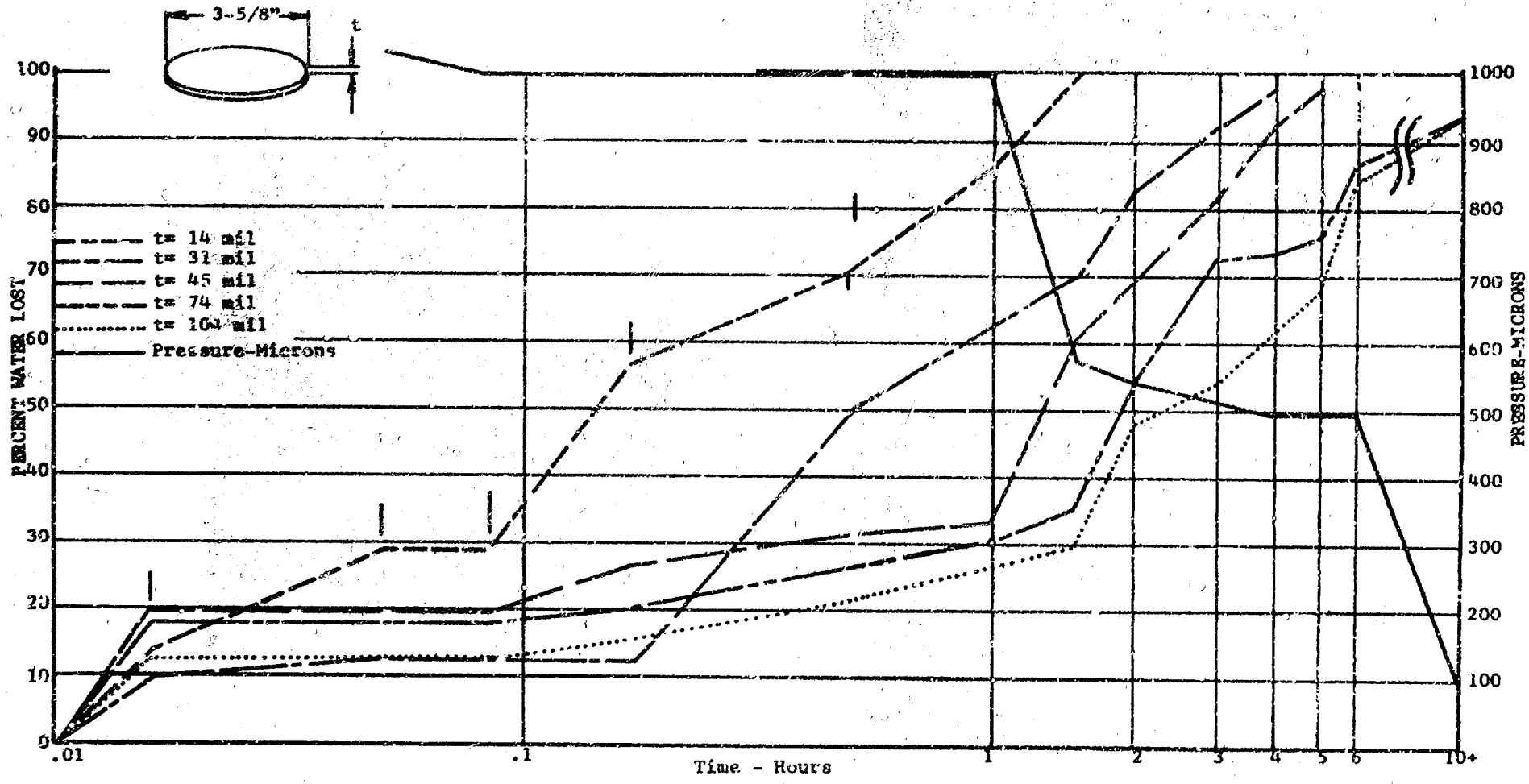


FIGURE 12 CURE TIMES AS A FUNCTION OF GELATIN THICKNESS

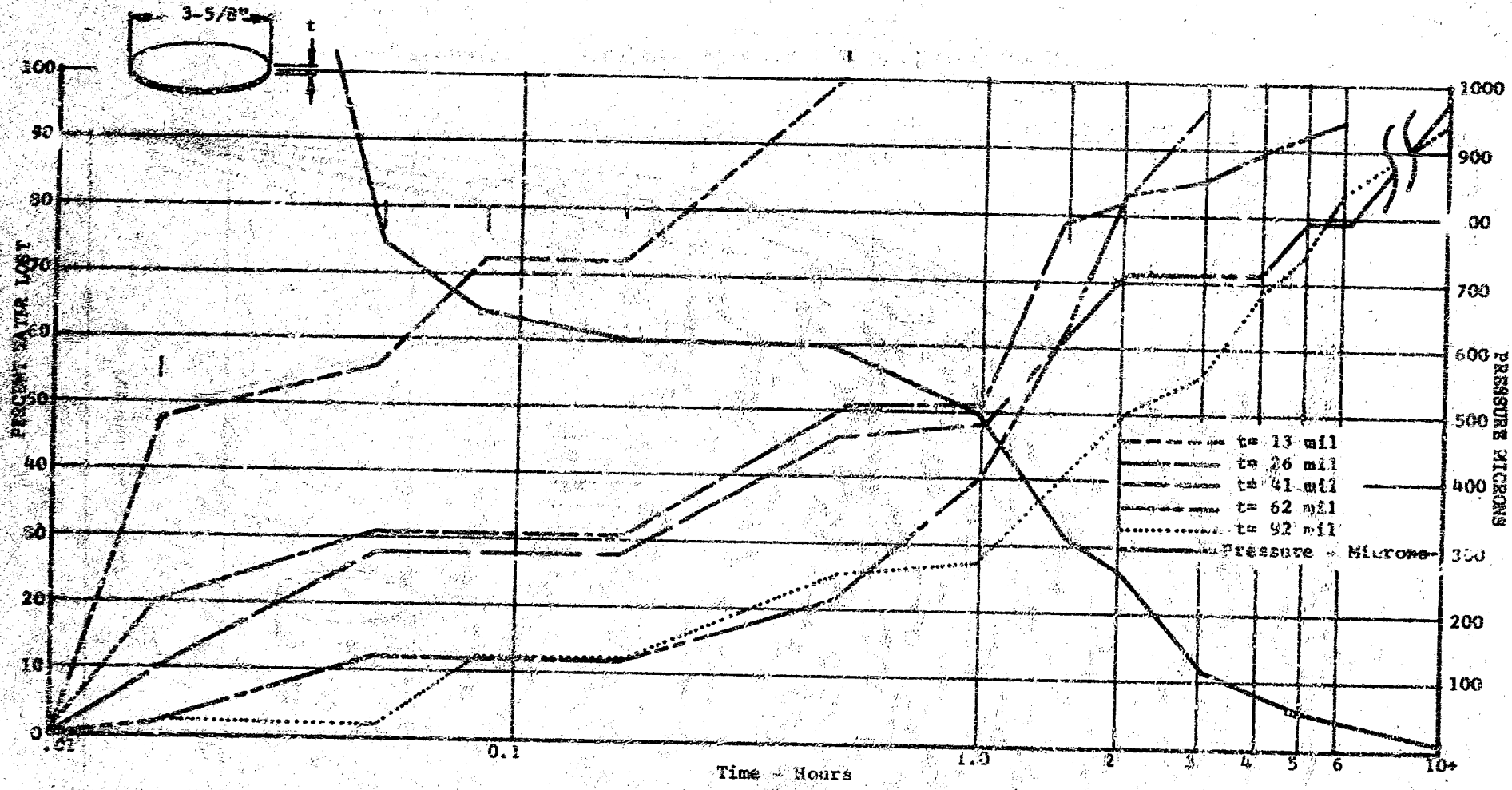


FIGURE 13 CURE TIMES AS A FUNCTION OF GELATIN THICKNESS

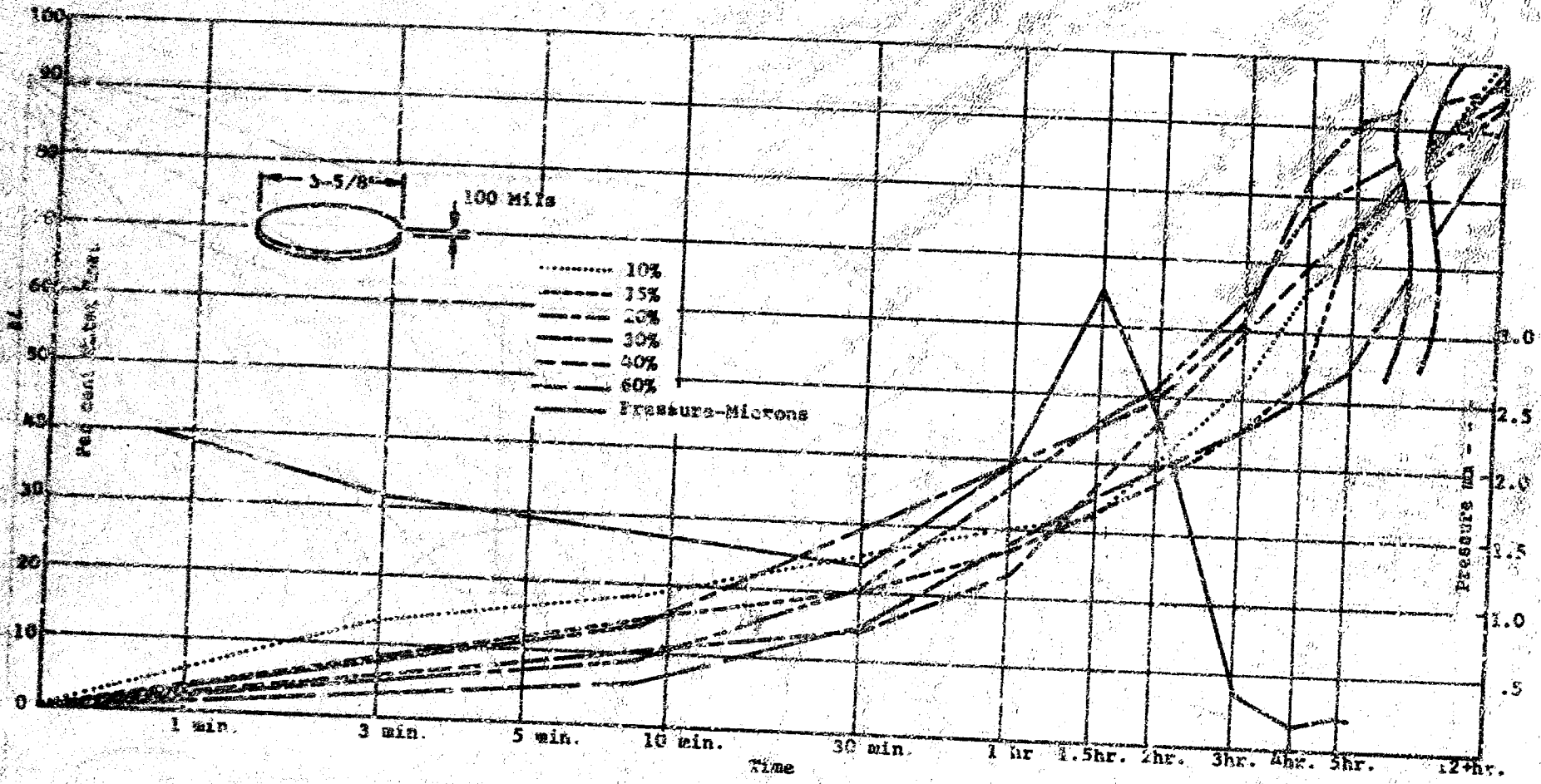


Figure 14 CURE TIMES AS A FUNCTION OF SOLVENT CONTENT

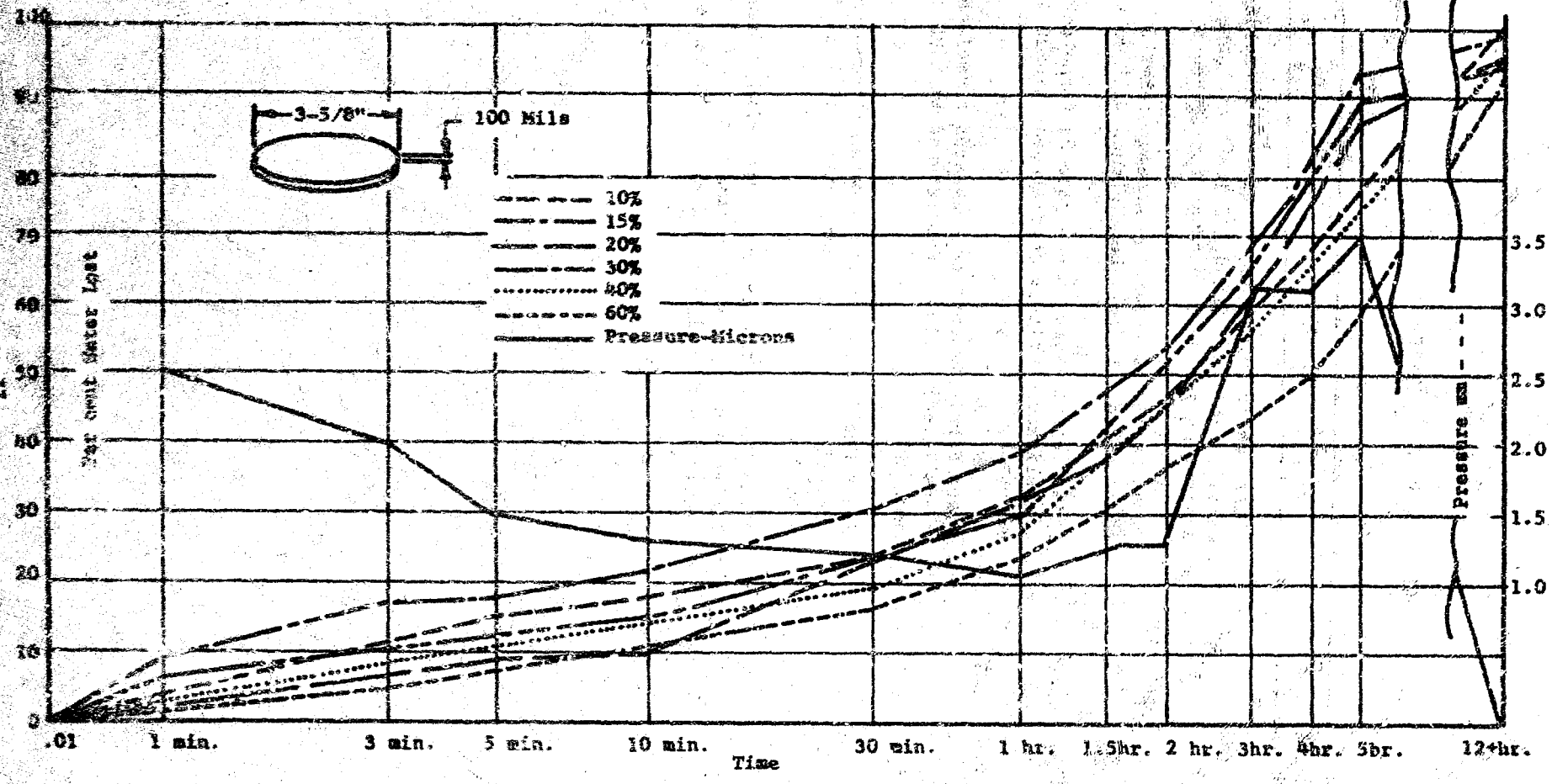


Figure 15 CURE TIMES AS A FUNCTION OF SOLVENT CONTENT

TABLE 27

GELATIN SOLVENT SYSTEMS

SYSTEM NUMBER	PROCESS
4632-73-A	Glass Fabric Impregnates - gaseous formaldehyde crosslinked - Not dried. Solvent exchanged by suspending in 100 % methanol for 16 hours.
4632-74-A	Glass Fabric Impregnate - gaseous formaldehyde crosslinked. Dried. Remoistened with water.
4632-74-B	Glass Fabric Impregnate - gaseous formaldehyde crosslinked. Dried. Remoistened with 20 % methanol.
4632-74-C	Glass Fabric Impregnate - gaseous formaldehyde crosslinked. Dried. Remoistened with 80 % methanol.
4632-74-D	Glass Fabric Impregnates - gaseous formaldehyde crosslinked. Dried. Remoistened with 80 % #30 alcohol.
4632-75-A	Glass Fabric Impregnates. Not dried. Cross-linked and dehydrated by immersion in 1 % formaldehyde in 80 % methanol for 24 hours.

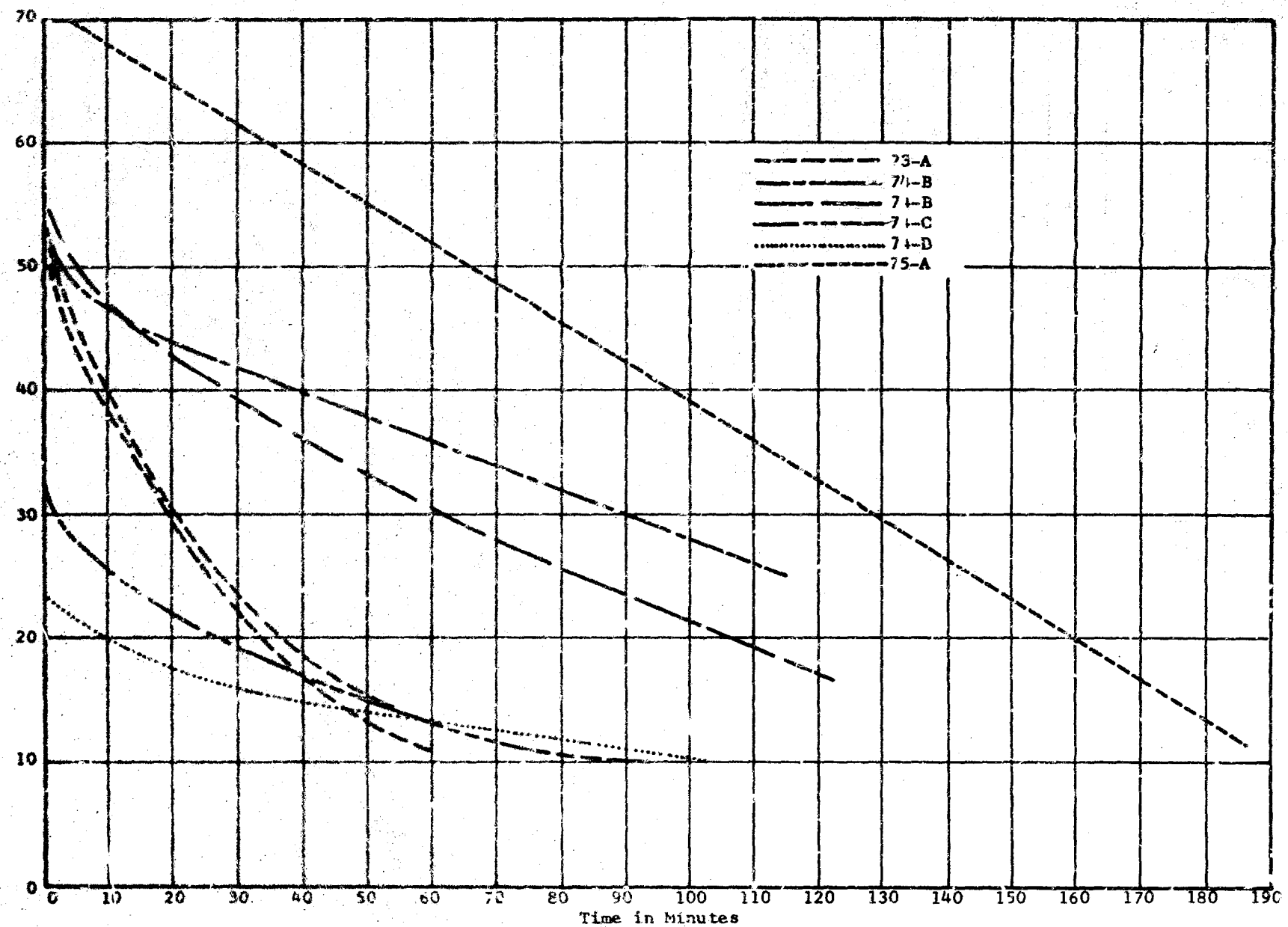


FIGURE 16 CURE RATES FOR VARIOUS SOLVENT SYSTEMS

TABLE 28

PER CENT SHRINKAGE
VS
FABRIC TENSION HELD DURING CURE

SAMPLE	1	2	3	4	5
Tension lbs/in	0.6	0.3	0.1	0.05	0
Per Cent Shrinkage Parallel to Flutes Days					
1	0.23	0.49		0.47	1.6
2	0.47				
7					
14	0.71	1.45	0.24	1.18	2.06
Per Cent Shrinkage Perpendicular to Flutes Days					
1					0.44
2	0.95	0.25			
7					
14	1.18	0.75	0.71	0.93	1.78

TABLE 39

B-STAGING AFTER VACUUM CURE
VS
AFTER GELATIN IMPREGNATION AND
WEIGHT RATIOS OF MATERIALS

	Cube 1	Cube 2
After Impregnation		
Weight Ratios		
Fabric	2.08	2.44
Gelatin	1.00	1.00
H_2O	2.57	2.53
After Vacuum Cure		
Weight Ratios		
Fabric	2.08	not
Gelatin	1.00	rigidized
H_2O	0.10	
B-Staging Time		
Aldehyde/H_2O at 40 F	17.5 hrs	5 hrs
Aldehyde/H_2O at 120 F	22.5 hrs	8 hrs
Total time to complete	40.0	13.0
After B-Staging		
Weight Ratios		
Gelatin	1.00	1.00
H_2O	.98	1.01

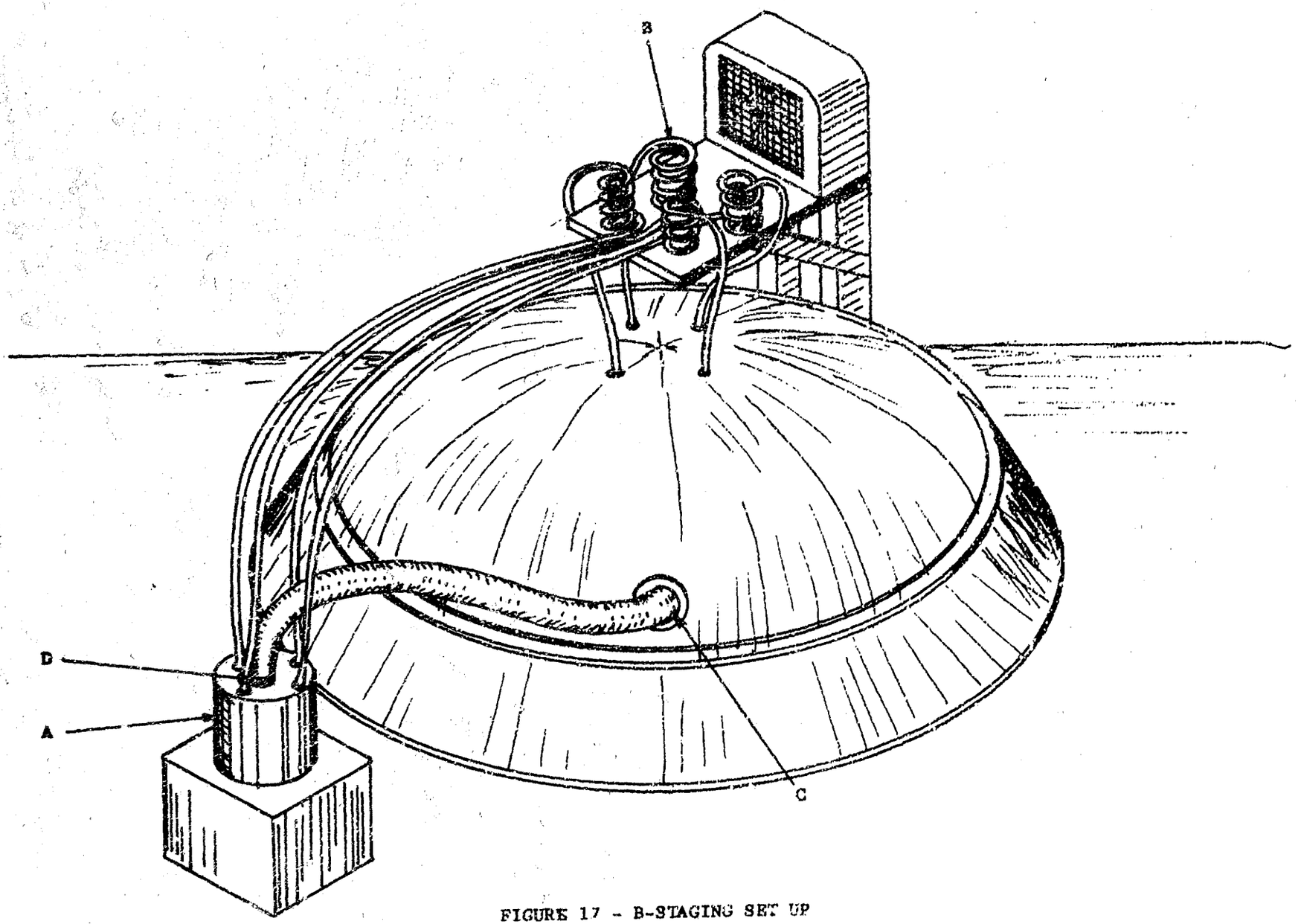


FIGURE 17 - B-STAGING SET UP

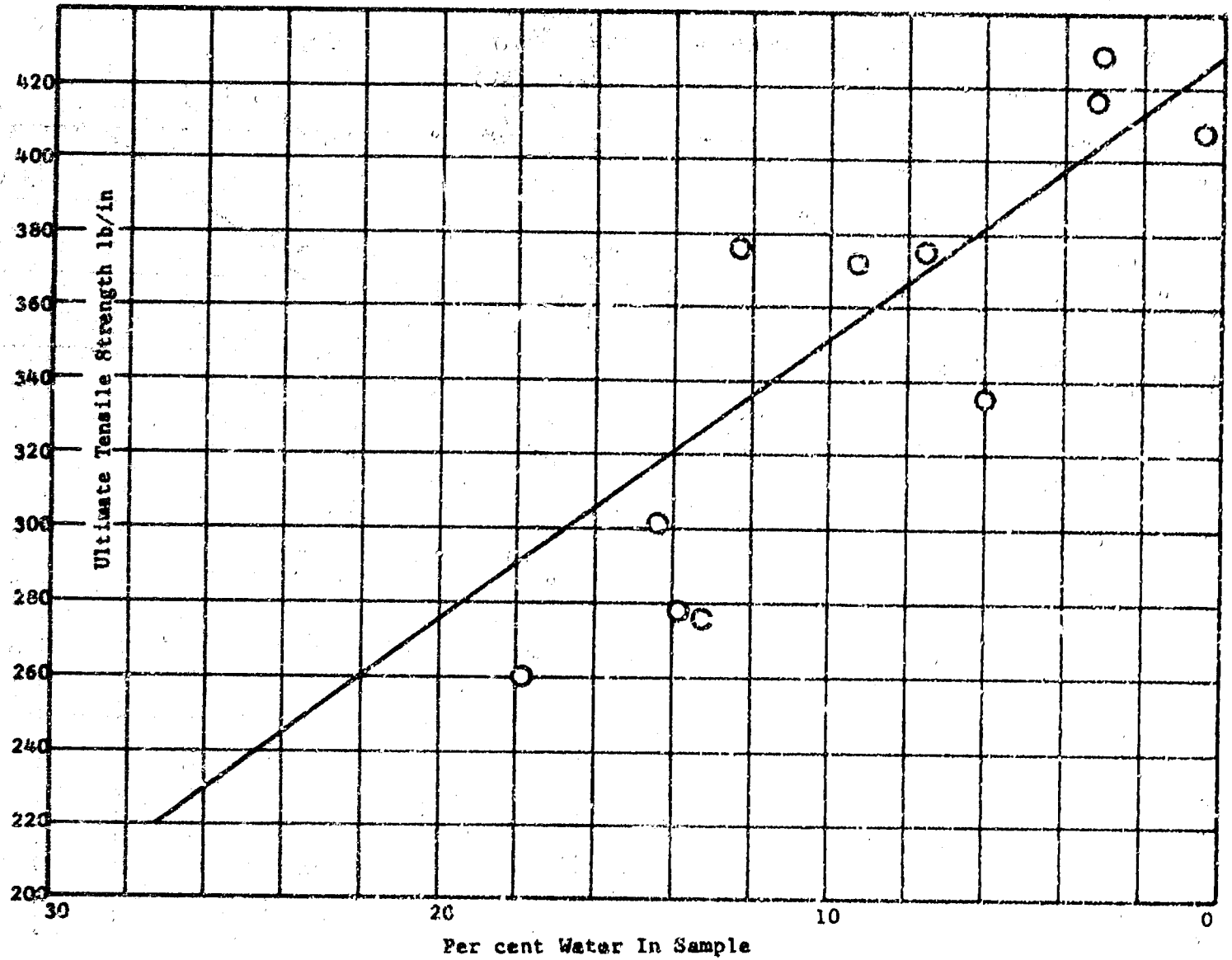


Figure 18 TENSILE STRENGTH VS. DEGREE OF CURE

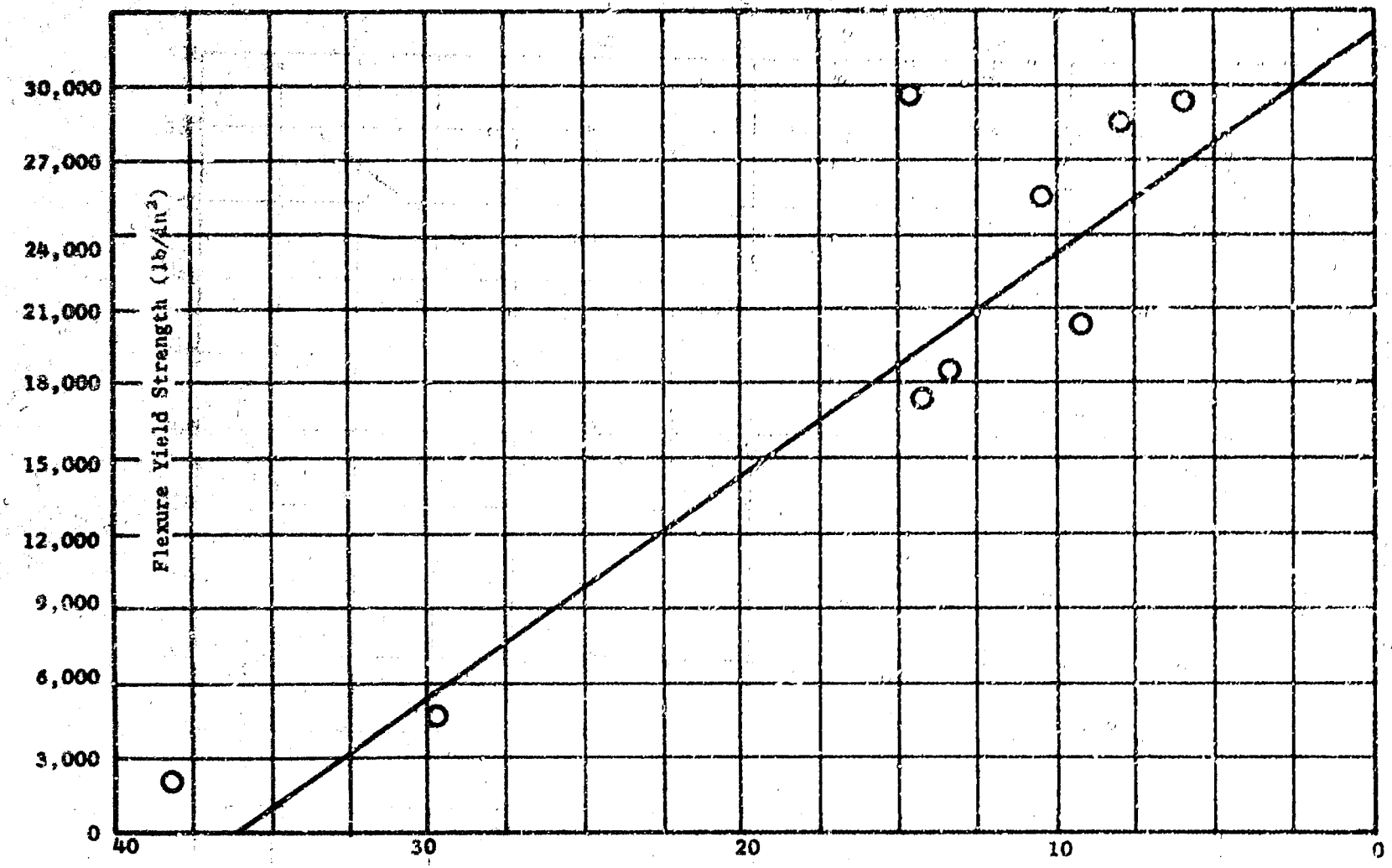
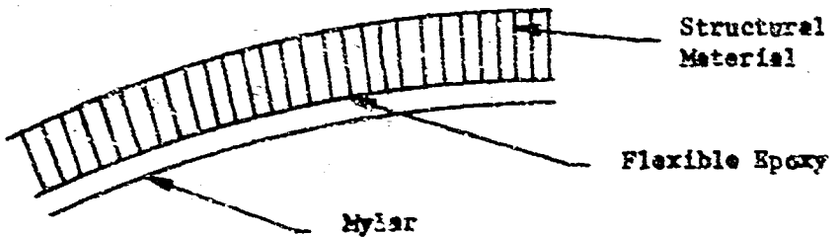


Figure 19 FLEXURAL STRENGTH VS. DEGREE OF CURE

6.0 SOLAR ENERGY CONCENTRATORS

6.1 PRELIMINARY DESIGN

The solar collector design for this study has been based entirely on the theory that only very minimum restoring forces can be tolerated in any part of the collector composite. Past efforts used Mylar, flexible epoxy, and sandwich material as shown below.



This composite was initially assembled at a Mylar skin stress of about 3,000 psi. After the composite bonding was completed, the structure was impregnated with gelatin and cured in a vacuum environment with the Mylar stressed to about 6,000 psi. Fabric show-through, orange-peel, and crease separation of the Mylar from the flexible epoxy, often resulted. A detailed analysis of the causes of these defects was made and several theories such as post-cure gelatin shrinkage, large differences in stress-strain relationships of components, and material creep were investigated.

The design which appeared most promising for development with this concept is shown in the following sketch, Figure 20.

The design is based on a nonrestoring strain-set material for the reflective surface, (high modulus material) and a stress being insured in the structural material during resin cure. Trade-off studies were made to determine the optimum materials and material characteristics to satisfy the requirements of this design. Experimental verification of theories such as "no shrink if there is a tension in the structural material during cure" were made. Refer to materials verification program.

6.2 EXPERIMENTAL SOLAR CONCENTRATORS

6.2.1 24-Inch and 28-Inch Diameter Experimental Models

Verification of the solar concentrator design was completed using 24-inch and 28-inch diameter experimental models. Fabrication techniques and procedures were developed that would have application to the 10-foot and larger diameter collectors. Work on the small experimental concentrators was kept to a minimum so that maximum effort could be placed on the material verification program and the fabrication of the 10-foot diameter concentrators.

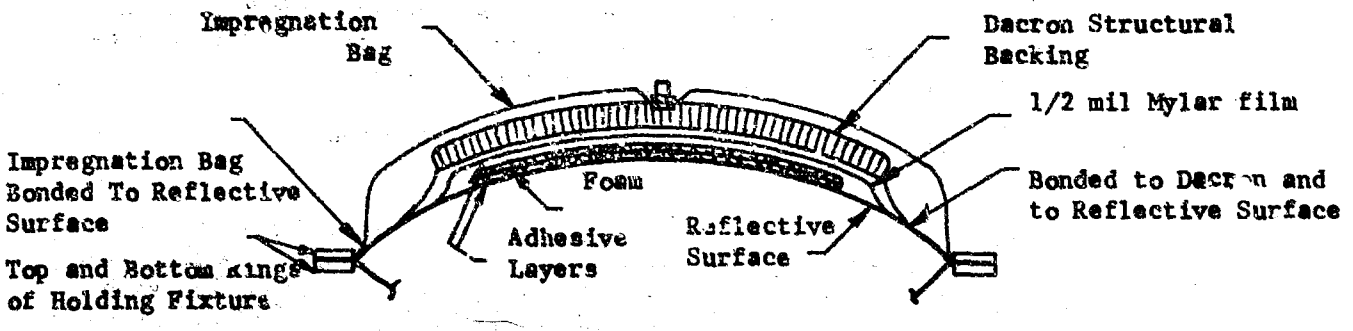
The first concentrator experiments used a single piece of reflective surface material which produced an almost flat, dish-shaped concentrator. However they provided an efficient means of developing fabrication techniques and procedures.

The result of a significant experiment, performed early in the program, is shown in Figure 21. This experiment showed the need for a flexible layer, such as foam, to block the weave show-through (orange-peel). It also showed the need for a good bond between the surface material and the flexible foam layer.

Fabrication of a solar concentrator based on results of the above experiment produced the results shown in Figure 22. The wrinkled surface shown was caused by gelatin shrinkage in the foam during cure.

The next step was to fabricate a concentrator that would effectively block the foam from absorbing the gelatin. One method, using a Mylar film, is described in detail below.

Reflective Surface: A-12 Material
Adhesive: Epon No. 872 plus Agent U
Foam: 10-lb. Polyether - open cell - 1/8-inch thick
Adhesive: Epon 872 plus curing Agent U - 50 gm brushed on foam.
Structural Backing: 1/2-mil Mylar heat sealed (DuPont 46970) to Dacron sandwich material.
Impregnation Bag: Scotchpak heat sealed (DuPont 46970) to back of surface material.



The one-piece reflective surface material was placed in a 24-inch jig and inflated to 1.2-inches water pressure. Approximately 40 gms of Epon 872 plus curing agent U was sprayed in an 18-inch circle on the back of the reflective surface. The internal pressure was removed, the top ring of the holding fixture was removed, and the one-piece, flexible-foam layer placed on the coated reflective surface. The top ring was replaced to hold the foam and surface material in place. Pressure was returned to 1.2-inches of water, and the adhesive was allowed to cure. The Dacron structural backing material was cut to size, sewn, and the 1/2-mil Mylar blocking film was cut to size. The appropriate side of both were coated with DuPont 46970, and heat sealed

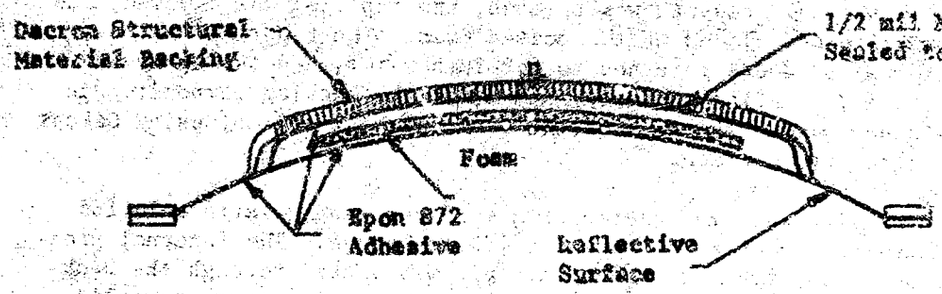
together. Approximately 50-gms of Epon 872 plus curing agent U were brushed on the foam, the internal pressure was removed, the top ring was removed, and the backing composite was placed on the coated foam. The top ring was replaced, the internal pressure returned to 1.2-inch water, and the epoxy adhesive allowed to cure. After the epoxy had cured the backing composite was trimmed 1 1/2-inches beyond the edge of the foam and heat sealed, using DuPont 46970, to the reflective surface.

The backing was impregnated with a 15 per cent gelatin solution to a resin solids content of 20-gm resin to 100-gm Dacron. The internal pressure was increased to 5 inches of water, dry air was passed through the backing to inflate and cure it. Examination of the surface after cure revealed no show-through, no wrinkles, no creases, and only a slight waviness. The results were very encouraging. Several other concentrators were fabricated, using this concept, with very good results. Figure 23 shows some of the experiments in various phases of completion. Upper left shows the dry backing, upper right shows the backing in a B-staged condition, lower left shows the reflective surface with internal pressure before cure, and lower right shows the surface after vacuum cure.

Effort was now turned to fabricating gored model concentrators in order to further develop the techniques and procedures more closely related to the larger diameter concentrators. Several methods, such as sonic welding, lap seams using DuPont 46970 heat sealed, and a butt seam using Mylar-46970-tape heat sealed, were tried in an attempt to seal the gores of the A-12 type material together. It is interesting to note that material strength was achieved with each method. The sonic welding was eliminated because it would require expensive jigs to seal the compound curves involved. The lap seam was eliminated because of hair-line leaks which could not be eliminated. The final method using Mylar tape has been used very satisfactorily on most of the experimental concentrators and on all of the demonstration items.

Two model concentrators are representative of the many fabricated during the experimental phase of the program. The first of these was built as follows:

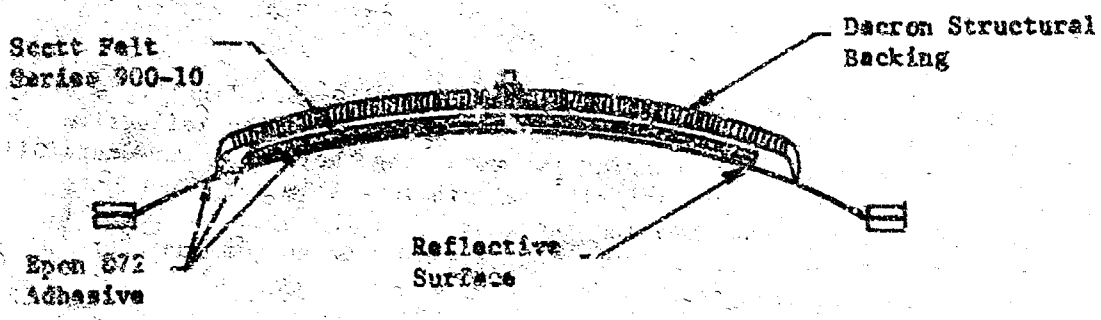
Skin: A-12 Type, Gored (16)
Adhesive: Epon 872 plus Curing Agent U - Brushed 80-gm on back of reflective surface in a 24-inch diameter.
Foam: Gored (16) butt seamed with heat sealable Estane.
Adhesive: Epon 872 plus curing Agent U - Brushed 100-gm on back of foam in a 28-inch diameter.
Backing Composite: 1/2-mil Mylar heat sealed to Dacron structural material with DuPont 46970. Mylar and Dacron material were both assembled from gores.



The reflective surface was fabricated from 16 gores of A-12 type material and Mylar tape. It was placed in the holding rings and pressurized to 3.5-inches of water during the remaining fabrication. The foam backing was fabricated from 16 gores into a single piece. This was attached to the lowering fixture, which was inflated, and the foam was lowered onto the back of the adhesive-covered reflective surface. The backing was fabricated into a single piece by sewing the 16 gores together. The Mylar was sealed to the backing one gore at a time. This assembly was attached to the lowering fixture, which was inflated, and lowered onto the adhesive covered foam. The backing, which weighed 464 gms, was impregnated with 550 gms of gelatin solution with 15 per cent solids. The internal pressure was increased to 10-inches of water during cure. The backing was inflated, and cured with dry air pressure. The backing was B-staged during cure. The reflective surface was very good except for some creases caused by the seams of the gored foam. Some delaminations also occurred between the Mylar and the foam. Several concentrators were fabricated using this basic concept, but with the following changes: the 1/2-mil Mylar was bonded directly to the foam, with either Epon 872 or DuPont 46970, and then the backing was lowered and bonded to the Mylar. This improved fabrication procedures, but not the delamination problems.

The second, of the two representative concentrators, did not use the Mylar film. It is described below:

Skin: A-12 type, gored (16)
Adhesive: Epon 872 plus curing Agent U - Brushed 80 gm. on back of reflective surface in a 24-inch diameter.
Foam: Scott Series 900-10, Gored (16) Butt seamed with DuPont 46970.
Adhesive: Epon 372 plus Curing Agent U- Brushed 120 gms on back of foam in a 28-inch diameter.
Backing: Dacron, Gored (16)



The reflective surface was fabricated, placed in the holding fixture, and pressurized to 3.5-inches of water. The foam layer was fabricated, attached to the lowering fixture, and bonded to the reflective surface. The Dacron backing was fabricated, attached to the lowering fixture, and bonded to the foam. The structural backing was impregnated to a gelatin content of 12 per cent, based on the weight of the backing. The internal pressure was increased to 10-inches of water and the backing was inflated and B-staged during cure.

The reflective surface of these models was a slight improvement over earlier experiments, however, some creases still persisted from the seams of the foam gores. There was no evidence of gelatin being absorbed by the foam. This was probably because of the excess amount of Epon 872 used to bond the backing to the foam. It should be noted that the foam layer had a tendency to wrinkle when being bonded to the reflective surface. This resulted in bubbles between the foam and the reflective surface. The wrinkles were caused by a mismatch of the two surfaces.

Several experimental concentrators were fabricated by bonding the foam gores individually to the reflective surface. However this required that the final foam gore be tailored to fit, and resulted in misalinement of reflective surface and foam gore lines.

The techniques and procedures for the first 10-foot diameter solar concentrator were derived from this experimental program. It was decided to fabricate it from a gored reflective surface of A-13 type material, a gored foam layer of Scott series 900-10, and a gored backing of Dacron, random-scattered, drop-thread material. Epon 872 x 75 epoxy plus curing agent U would be used for the adhesive to bond components together, and a lowering fixture would be utilized during this bonding operation.

6.2.2 Ten-foot Diameter Experimental Solar Concentrators

The first 10-foot diameter solar energy concentrator was assembled and rigidized with some encouraging results. The aluminum-Mylar laminate material was used for the reflective surface and the structure was fabricated on a 14-foot diameter government furnished fixture. Components were assembled and gelatin was impregnated at a low internal pressure, while a higher pressure, sufficient to set the aluminum, was employed during gelatin cure.

Figures 24 through 28 depict some of the steps and fixtures used in the construction of the unit. Figure 24 shows a fixture designed for the purpose of minimizing handling of the reflective surface material. The fixture consists of a 14-foot diameter plywood base plate with three curved wooden sections which support a gored polyethylene film. By referring to Figure 24,

it may be seen than an operator has access to an entire gore length. A strip of Teflon-coated neoprene provided a base for heat sealing the reflective surface gores together. After bonding two gores together, they were carefully moved counterclockwise over the inflated polyethylene film and a new gore positioned for sealing. When sealing the last gore, the operator brought the outer edge of the reflective surface up toward the center just far enough to allow him to reach the tip of the gore.

When the laminate material was completely assembled, it was very nearly free from fold marks. The film was then transferred to the aluminum base plate, inserted, alined with the aid of markings, and pressurized.

Figure 25 shows the gored 1/16-inch foam material ready to be bonded to the adhesive-coated reflective surface, by means of a lowering ring, equipped with a pressurized plastic envelope for providing a wrinkle and fold-free surface. Figure 26 shows the position of the lowering fixture during cure of the adhesive. The pressure envelope, and the wires used to maintain intimate contact between the surfaces being bonded, can be seen in this photo. The structural material was also bonded to the foam layer by means of the lowering ring.

Gelatin impregnation of the structural material is shown in Figure 27. Two gelatin inlet valves were provided for this structure and the results pointed to a need for larger inlets. The gelatin concentration of the impregnating solution was 12.5 per cent. The viscosity of the heated solution (120 F) seemed amenable for good fabric saturation and fairly rapid flow-out.

The rigidized concentrator, Figure 28, had a very good reflective surface. Much valuable information, learned during the fabrication of this unit, was used during the construction of the next 10-foot structure. Improvements were made in the gelatin impregnation and stress level during rigidization.

During the fabrication of the next two 10-foot diameter concentrators, it was found that the Series 900 foam took up excessive amount of adhesive, and during fabric impregnation, gelatin solution was absorbed. An attempt was made to overcome this problem by coating the gores with a thin layer of dried DuPont 46971. Although some improvement was noted, it was deemed not adequate because some gelatin absorption continued to occur. The problem was overcome, however, by selecting another foam with equal flexibility but which had not been reticulated; i.e., the cell membranes were intact. The impermeability of this material to gelatin solution was demonstrated experimentally. The foam, Scott Felt Grade 600-10, was used to construct the rest of the 10-foot structures.

When bonding the gored foam to the adhesive coated reflective surface material by means of the lowering fixture, a poor fit would often result which caused some unbonded areas. To avoid this the gores were applied to the tacky adhesive one at a time. One of the 10-foot structures was fabricated by this method with good results. The signifficance of this approach lies in its applicability to the larger structures with 20 - 50 foot diameters.

The 100 per cent reactive epoxy, used for bonding the foam to the aluminum and to the Dacron structural material, was found to degrade upon contact with the gelatin solution. The reason for this is not known, but other materials were used for this application in later experiments.

The fabrication techniques of construction of 10-foot concentrators was again modified and refined. This seemed to result in satisfactory procedures. The second of these two structures was fabricated by laying up the foam gores one at a time on the pressurized, adhesive-coated, reflective surface material. This procedure sometimes resulted in inaccuracies along the gore lines, and the last gore usually had to be specially tailored for a good fit. This particular concentrator was impregnated, and B-staging was successful. The overall reflective surface was good, but had some areas with show-through from wrinkles in the Dacron structural material, and the tailored gore lines were evident on the reflective surface.

The next two 10-foot structures were made with a modification in the gore assembly procedure. The reflective surface material and the flexible foam were first bonded together with Epon 872-X-75, and the gores were cut from the composite and sealed together with Mylar tape. After insertion and pressurizing on the 14-foot diameter base plate, a coat of Epon 875-X-75 was applied to the foam and allowed to cure. A second coat of the epoxy was used to bond the structural material, which was lowered and accurately centered by means of several weighted guide wires placed at the periphery of the lowering ring. Impregnation of the two concentrators proceeded smoothly, as did B-staging and rigidization.

Another structure was fabricated and placed on the accuracy measuring fixture as shown in Figure 29 and surface checks were made. Two close-ups (Figure 30) illustrate the smoothness and reflectivity of the structures surface.

On the basis of the favorable results obtained with the last three concentrators, it is felt that the materials and the fabrication techniques currently employed satisfy the requirements of this concept.

Figures 31 and 32 show some of 10-foot concentrators in various phases of completion, and B-staging.

6.3 ACCURACY MEASURING

Figure 33 is a schematic of a surface accuracy measuring fixture. The 12-inch diameter rotary table supports a working bench upon which is mounted an accurate optical table for positioning the collimated light source and pentaprism. The pentaprism can be positioned at any point along the optical bench, from the center of the solar collector to the outside diameter. The collimated light can, therefore, be focused on any point of the solar collector surface, and the reflected position can be read out on the central plate which contains concentric rings and angles. The solar collector is supported by three adjustable stands above the rotary table and collimated light source. The angular distortion of any point on the solar collector surface can be obtained by reading the angular and distance displacement of the reflected light and using the geometry associated with the test setup.

Two types of optical measurements were made on the collectors using the optical accuracy checker. The purpose of the first measurement was to determine the angular variation from the true parabola of the reflective surface after rigidization. The purpose of the second measurement was to determine the reflectivity of the surface and the degree of diffusion of the reflected light.

The angular accuracy, which was of the most concern in these measurements was in the plane of the parabolic curvature of the collector. A standard polar graph was set at the focal point, and measurements were made at the two, three, and four foot radii of the collector at eight positions around the circumference. The measured point was the center of the spot of light returned from the collector. Using these points, the slope angle of the parabola was determined using the following formula,

$$\varphi = 1/2 \tan^{-1} 4f \left(\frac{r + \rho}{4f^2 - r^2} \right)$$

where, φ = the measured slope angle,

f = the focal length of the parabola,

r = the radius at which the measurement was made, and

ρ = the distance between the focal point and center of the reflected image.

The mean test values at the two, three, and four foot radii respectively were -2 deg 17 min, -1 deg 1 min, and +0 deg 35 min. To determine an approximation of the average error, e, the following formula was used.

$$\bar{e} = \frac{\Sigma Ae}{A_t}$$

where, e = error at a specified radius

A = area of the concentric paraboloids at the two, three, and four foot radii

A_t = total measured area of the paraboloid

This formula resulted in an $\bar{e}$ of 1 deg 05 min.

The resultant average error is significantly less than the measured errors at the two-foot radius, because of the very large surface area at the four-foot radius where the measured error was very nearly within the specified goal of $\pm$ 1/2 degree.

To determine the extent to which light is diffused by reflection from the collector, a silicone solar cell, in conjunction with an electronic voltmeter, was used to measure the relative intensities of the light after it was reflected from the surface, and when it reached the focal point. Since the light spot at the focal point was relatively large, a mapping was made of the reflected images. The mapped area was constructed of three concentric rings,

1-inch diameter, 2.5-inch diameter, and 5-inch diameter. Since the 5-inch circle is the largest allowable area, any light falling outside this limit was considered lost.

The intensity of light immediately after reflection from the surface of the paraboloid was compared to a standard base for comparison, and was specified at 100 per cent. The incident light on the collector was measured and read out at 130 per cent by comparison. At the focal point, three types of reflected spots were measured. They were specified as good, poor, and seam reflection. This judgement was made by a visual comparison of the reflection.

Concentric circles of 1-, 2.5-, and 5-inch diameter were drawn about the focal point. In a good spot 2 per cent of the light was received in the 1-inch circle, 9 per cent between 1 and 2.5 inches and 17 per cent between 2.5 and 5 inches. In a poor spot the percentages were 1, 4 and 9; while in a seam spot, they were 1, 6 and 9 respectively.

6.4 10-Foot Diameter Solar Concentrator Demonstrations Wright-Patterson Air Force Base

6.4.1 Demonstrations Without End Caps

The first, (in what was to have been a series of five), 10-foot diameter solar concentrator was inflated and cured in a vacuum environment at Wright-Patterson Air Force Base on April 28, 1966.

The solar concentrator was impregnated with gelatin, B-staged, packaged, and shipped to Wright-Patterson Air Force Base in a packaged configuration. Figure 34 shows the packaged solar concentrator being carried into the vacuum chamber. Figure 35 shows the solar concentrator still in a B-staged flexible condition secured to a base plate. Figure 36 shows the solar concentrator in the inflated position prior to rigidization. Figure 37 shows the solar concentrator after rigidization.

A condensed version of the test record, Table 32, is included in this report. The particular interest of this record is the temperature which clearly shows the points of maximum solvent loss and ultimate point of cure.

Immediately after the chamber was entered, examination of the solar concentrator revealed that the backing was completely dry and appeared to have good inflation and cure. The reflective surface was very smooth, had little show through, but did have some wrinkling caused from packaging.

In summary, it was felt that the fabrication procedures, impregnation, and B-staging (which were the same as for the last three experimental 10-foot concentrators), were quite satisfactory, but that more time should be devoted to packaging. The test procedures and equipment worked very smoothly.

The second 10-foot diameter solar concentrator was inflated and cured in the new Air Force Aero Propulsion Laboratory Vacuum Facilities at Wright-Patterson Air Force Base on May 11, 1966. This was the first operational demonstration in the new facilities.

The solar concentrator was impregnated with gelatin, B-staged, [illegible]-packaged, and shipped to Wright-Patterson Air Force Base. There it was unpacked and secured to the base plate still in the flexible, B-staged condition.

A mirror was located under the base plate and adjusted so that the surface of the collector could be observed from a point near the instrumentation and control systems.

Included in this report is a condensed version of the test record, Table 33, and a graph, Figure 38, showing the pressure versus time in the test chamber. There are several items of interest recorded on these charts. Table 33 shows a very insignificant drop in temperature on the backing material. This would indicate a "dry box" cure instead of a vacuum cure. To verify this, Figure 38 shows the slow pump-down time (approximately 3 hours 23 minutes) from atmospheric pressure to the vapor pressure of water. This slow pump-down at the beginning of the demonstration contributed to a poor inflation of the structural backing material. The reason for the slow pump down was a small, 1/2-inch diameter, equalization system to the internal pressure area of the solar collector. Enlarging this system for any future demonstrations would eliminate this problem. Table 31 also indicates that the internal pressure of the collector was equalized to the chamber for a period of approximately 10 hours, and then increased to 3 inches of H_2O before and during the time the chamber was returning to atmospheric pressure. During this period the collector was observed to be slowly moving out of the holding fixture. To stop this, the internal pressure was opened to the chamber; however, before the pressure could equalize, the collector lifted completely off the base plate and came to rest on the on the chamber floor and wall. This action did not seriously affect the surface, or damage the solar collector. It did tear the skirt, outside the surface area, used to hold the collector to the base plate. The fixture used to hold the collector to the base plate is a rubber inner tube in a metal tube. This was the first time it had been subjected to a high vacuum or to a vacuum for such a long period of time. Obviously, the tube leaked, and when the pressure in the chamber equalled the pressure in the tube there was no longer any force holding the collector to the base plate. This should This should be corrected in future tests by connecting the inner tube to a pressure line and gage outside the chamber.

Examination of the solar concentrator, immediately after the chamber was entered, revealed that the backing was not completely inflated but that it was completely dry and cured. The reflective surface was wrinkled and had several small bubble-type delaminations, the largest about 4 to 6 inches in diameter. (See Figure 39) The concentrator was cut

into segments and shipped to Schjeldahl for an analysis of the surface. This analysis revealed that the foam backing on the reflective surface had absorbed some of the water-gelatin solution, the larger amounts being in the areas of delamination. It was also discovered that the fabrication technique for this concentrator was different than previous ones. The main difference was failure to seal the foam seams, thus allowing the gelatin solution to flow into the seams and be absorbed by the foam. This fabrication technique would not have been used for future solar concentrators.

5.5 Packaging

The first folding and packaging studies were conducted using a 1-mil, 10-foot diameter Mylar sphere with a 5-foot diameter concentrator, consisting of a gored 1/4-inch thick flexible foam, and a gored Dacron sandwich material, bonded to the sphere. This model was purposely made from thicker materials. See Figure 40.

A pleat and accordion folding method appeared to give the best results. See Figure 41. Two variations of this method were evaluated experimentally and are summarized in Table 30.

The first method pleat-folded the entire structure from pole to pole into a long narrow package, one-half the basic gore width. This configuration was in turn accordion folded into a small rectangular cube. The second method only pleat-folded the balloon end cap while the concentrator portion was folded in 1/2, 1/4, 1/8, etc. This configuration was again accordion folded (starting with the end cap) to efficient packaging proportions.

The volume was then further reduced by a factor of two by removing air from the folded package. The data in Table 30 show that the second method is more efficient. It is also attractive because it results in the least length at the folds in the reflective surface material.

TABLE 30

PACKAGING COMPARISON

Method	Folded Dimensions (Inches)	(Ft^3)	Dimensions After Air Removal (Inches)	(Ft^3)
1. All pleat folded.	17 x 14 x 6	= 0.82	17 x 14 x 3	= 0.41
2. End cap only, pleat folded.	19 x 11 x 6	= 0.72	19 x 11 x 3	= 0.36

Next a 10-foot concentrator was rigidized after first having been impregnated, B-staged, and folded. The purpose of this experiment was to learn the effects of packaging on the reflective surface material after deployment. Figure 42 shows (a) the depressurized, impregnated structure, (b) initial folding, and (c) the final folded configuration, 10-inches high by 23-inches by 28-inches. After unfolding the concentrator and rigid-

ining it, it was apparent that no delaminations had occurred, and although some fold lines were visible, the overall reflective surface was not adversely affected.

6.5.1 Definition of Contents

The critical concentrator components in the canister consist of the following materials in the given ratios:

	Parts by Weight
Fabric	3
Gelatin	2
Water	1

The gelatin-water solution is uniformly distributed throughout the entire fabric which is adhered to the reverse side of a reflective film. At 75 F, the solution is nonflowing and the combination of materials not tacky.

At 100 F, the gelatin-water solution becomes less viscous and might tend to shift. Under prolonged storage, some seepage might occur resulting in a nonhomogeneous distribution of materials.

Temperature increases will significatnly affect the vapor pressure of the water. Migration of water vapor may occur if the canister is not sufficiently tight.

If the contents reach 32 F, the water may freeze, and the solute and solvent might separate. In addition, puncture or penetration of the reflective surface and spherical end cap may result from the expansion of the water.

6.5.2 Temperature Range of Package

For the reasons stated in paragraph 3.4.5.1, recommended storage temperature limits lie between 50 F and 85 F. The optimum storage temperature is 75 F plus or minus 10 F. It is recommended that the temperature be adjusted to 75 F at the time of launch. (The resin consistency could be changed if the temperature could be anticipated.)

6.5.3 Pressure Range of Package

The ratio of water present in the canister to the canister volume (neglecting fabric and plastic films) is such that the pressure inside the evacuated canister will be determined by the vapor pressure of the water, at a given temperature.

The internal pressure of the canister must be maintained according to Table 33.

TABLE 31

PRESSURE RANGE OF CANISTER PACKAGE

Temperature F	Vapor* Pressure of Water MMHg	Required Canister Pressure MMHg
50	9.209	11.0
55	11.5	13.8
60	13.2	15.8
65	15.9	19.0
70	19.2	23.0
75	22.3	26.7
80	24.5	29.4
85	31.0	37.2
100	49.1	59.9
120	88.2	106.0

The excess pressure in column three is necessary to prevent migration within or loss of water from the composite.

6.5.4 Canister Instrumentation

In order to monitor the internal pressure and temperature of the canister, both in its packaged or crated and unpackaged or uncrated state, the necessary instrumentation must be implemented into the canister design.

Provision must be made to detach the instrumentation from the canister, prior to rocket installation.

6.5.5 Canister Internal Pressure Control

The excess canister pressure might result in an explosive opening and solar concentrator deployment, causing material damage. To minimize or limit this possibility, the canister should be instrumented to enable the astronaut, within the capsule, to adjust the pressure to a predetermined level just prior to the actual canister opening.

6.5.6 Canister Packaging or Crating

For the purpose of transferring the impregnated and folded solar concentrator composite within the canister, from Viron to the demonstration site by common carrier, it is recommended that the canister be separated from the enclosing crate with 2-inches of resilent polyurethane foam with a K factor of about 0.11. This will provide protection from shock, vibration and temperature extremes for a maximum length of time. (The foam mentioned is commonly available and provides the lowest heat transfer of any commercial shock-proofing material available.)

*Approximate

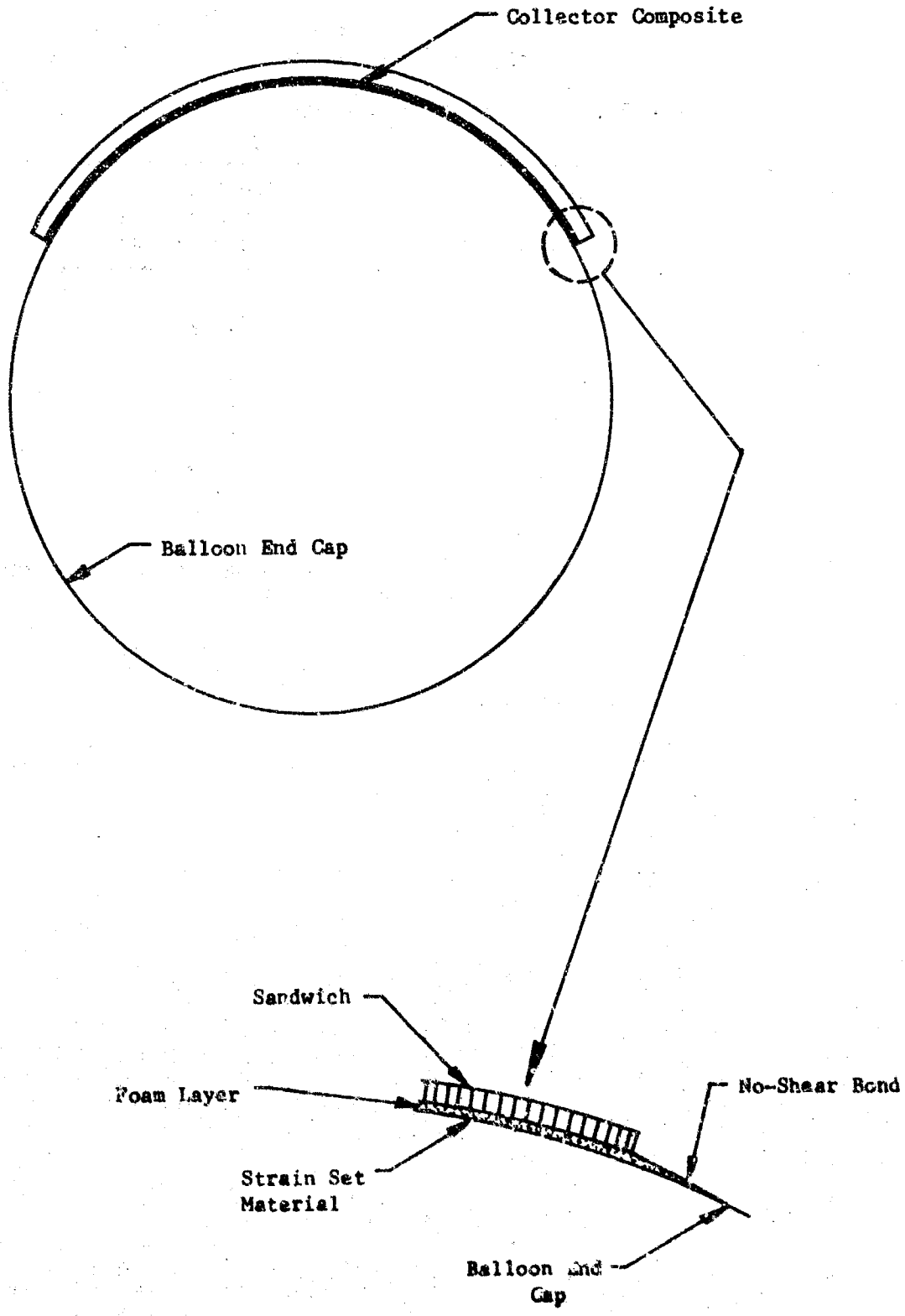
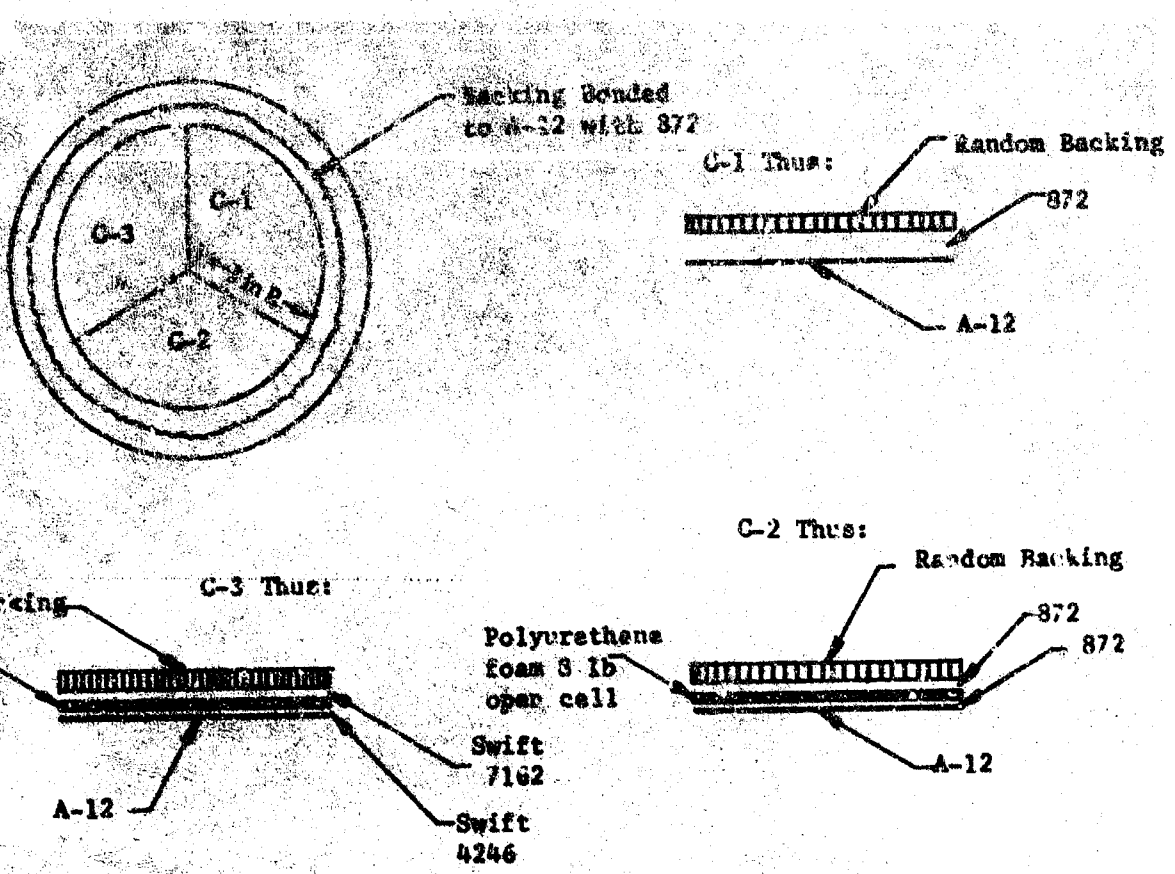


Figure 20 SOLAR COLLECTOR DESIGN



9-22

Maintained 1 inch water pressure during fabrication.

9-23

Impregnated 100 gel/100 Dacron. (Approximately 220 gm)
Held heat around collector at 190° during impregnation.

Inflated backing with air through single valve in center of backing.
Maintained 5 inch water pressure during cure.

9-24

Removed from rings.

	(Wave) Orange Peel	Wrinkles	Spider Webs	Heavy Waves from Backing	Foam A-12 Bond No. 1	Bond No. 2
C-1	Yes	Some around edges	No	Yes	----	Good
C-2	No	Yes	No	Some	Good	Good
C-3	No	Yes	Yes	Some	Poor	Good

Surface in all 3 samples - poor

Figure 21 SOLAR CONCENTRATORS COMPOSITE TEST EXPERIMENT

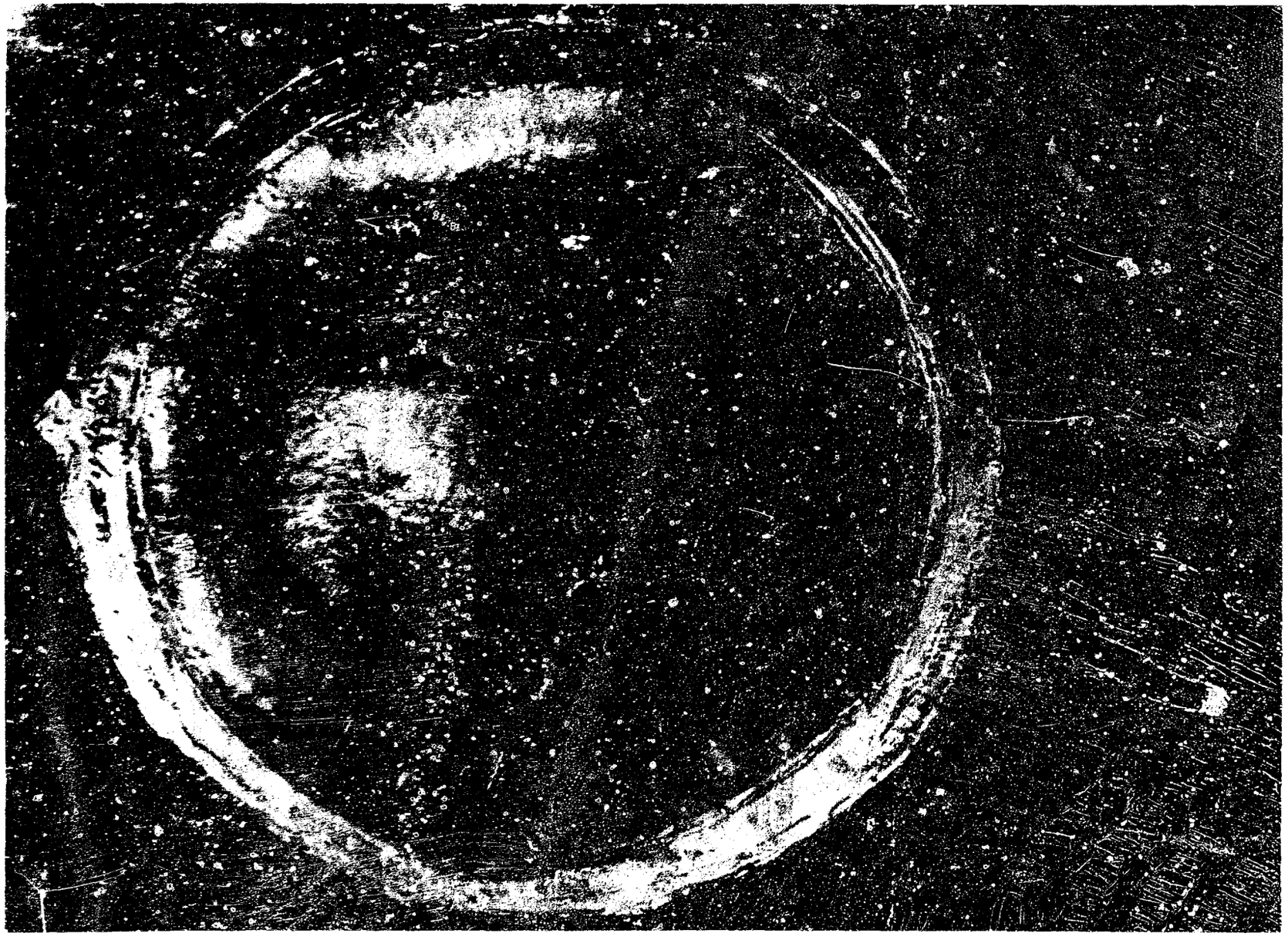


FIGURE 22 - SURFACE OF FIRST EXPERIMENTAL CONCENTRATOR

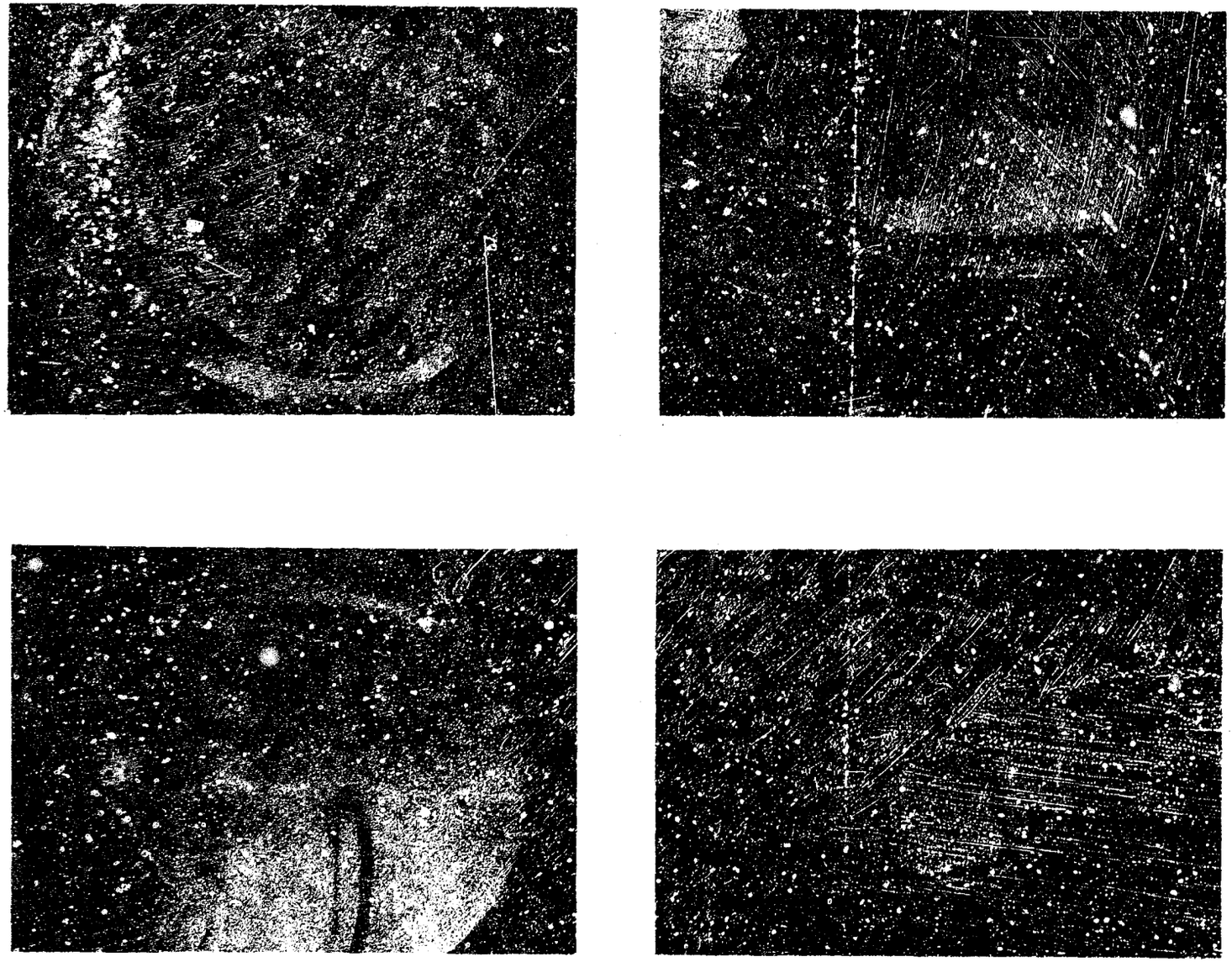


FIGURE 23 – EXPERIMENTAL CONCENTRATORS IN VARIOUS PHASES OF COMPLETION

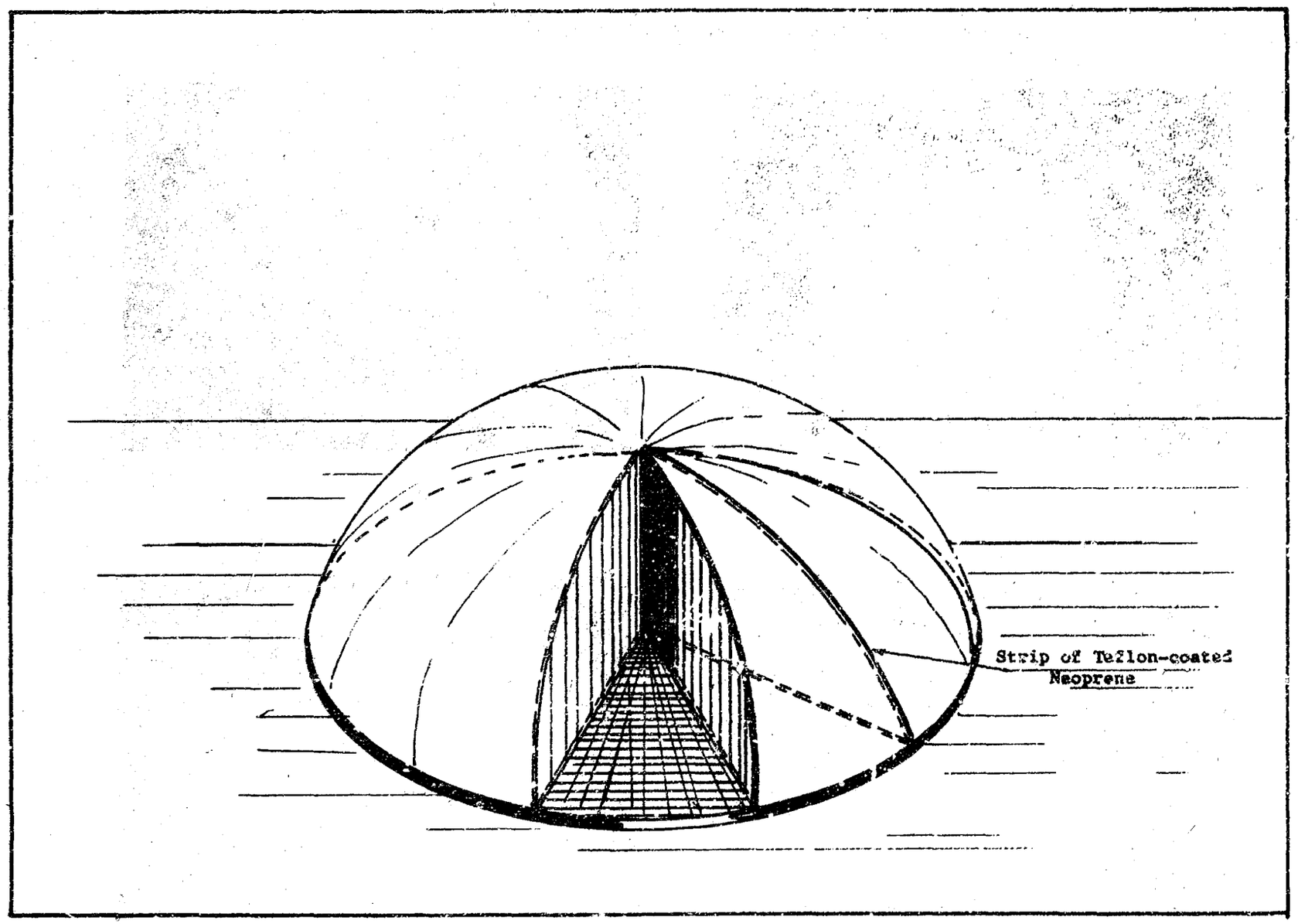


Figure 24 FIXTURE USED DURING FABRICATION OF EARLY 10-FOOT DIAMETER REFLECTIVE SURFACE

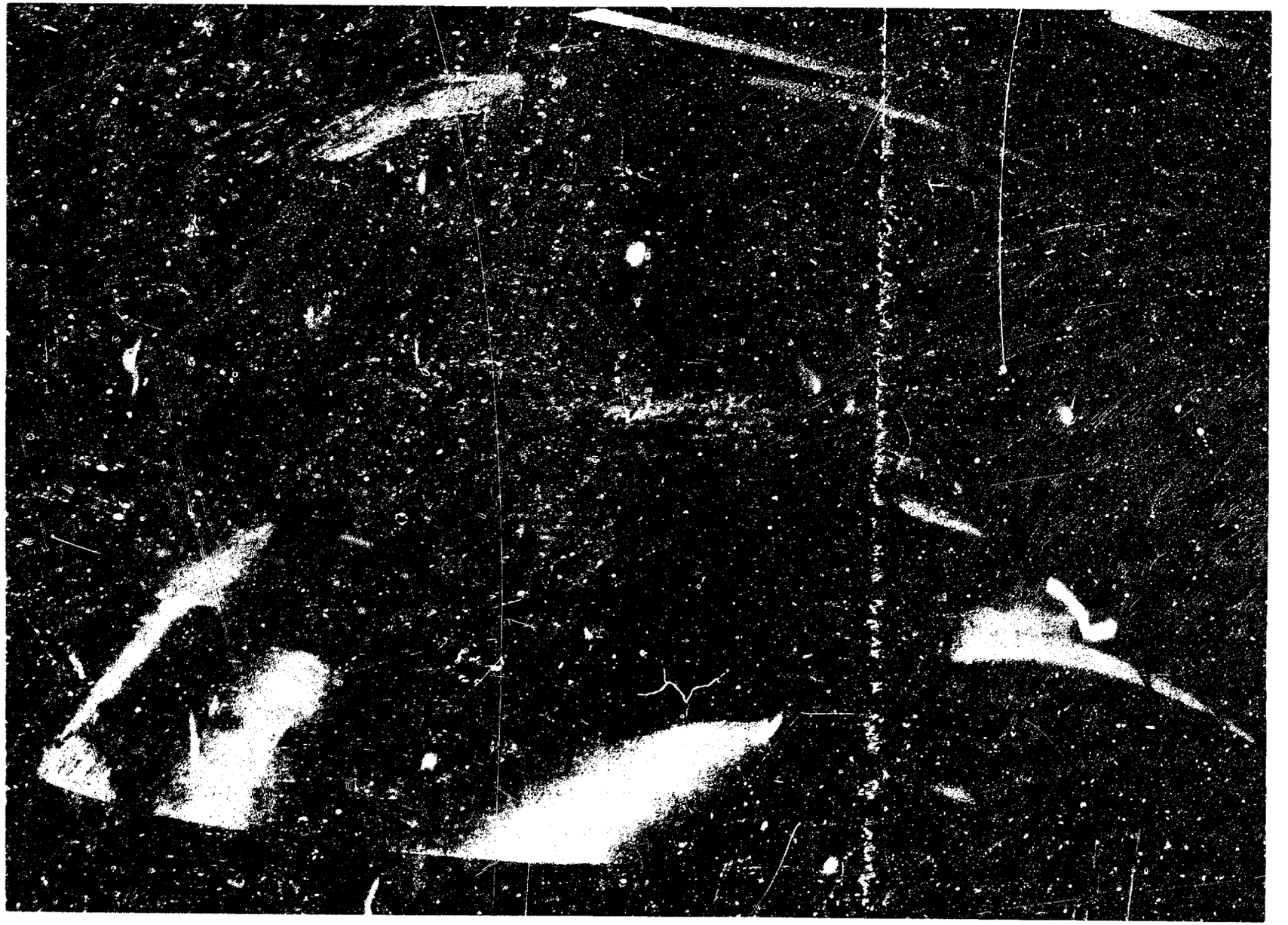


FIGURE 5 - LOWERING FOAM LAYER ONTO REFLECTIVE SURFACE FILM

FIGURE 26 - BONDING FOAM LAYER TO REFLECTIVE SURFACE FILM

FIGURE 27 - GELATIN IMPREGNATION OF STRUCTURAL BACKING

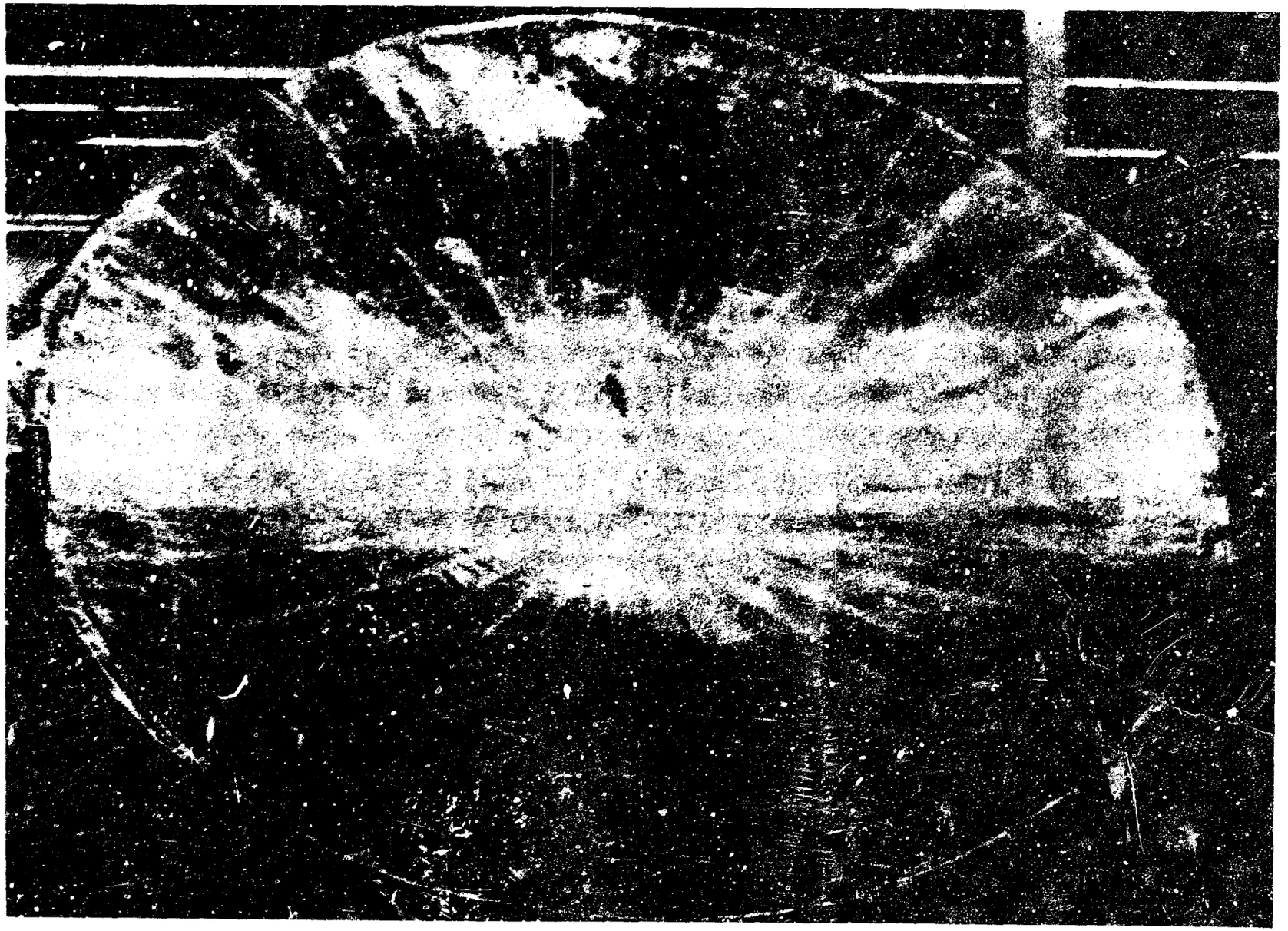


FIGURE 23 - RIGIDIZED 10-FOOT DIAMETER CONCENTRATOR

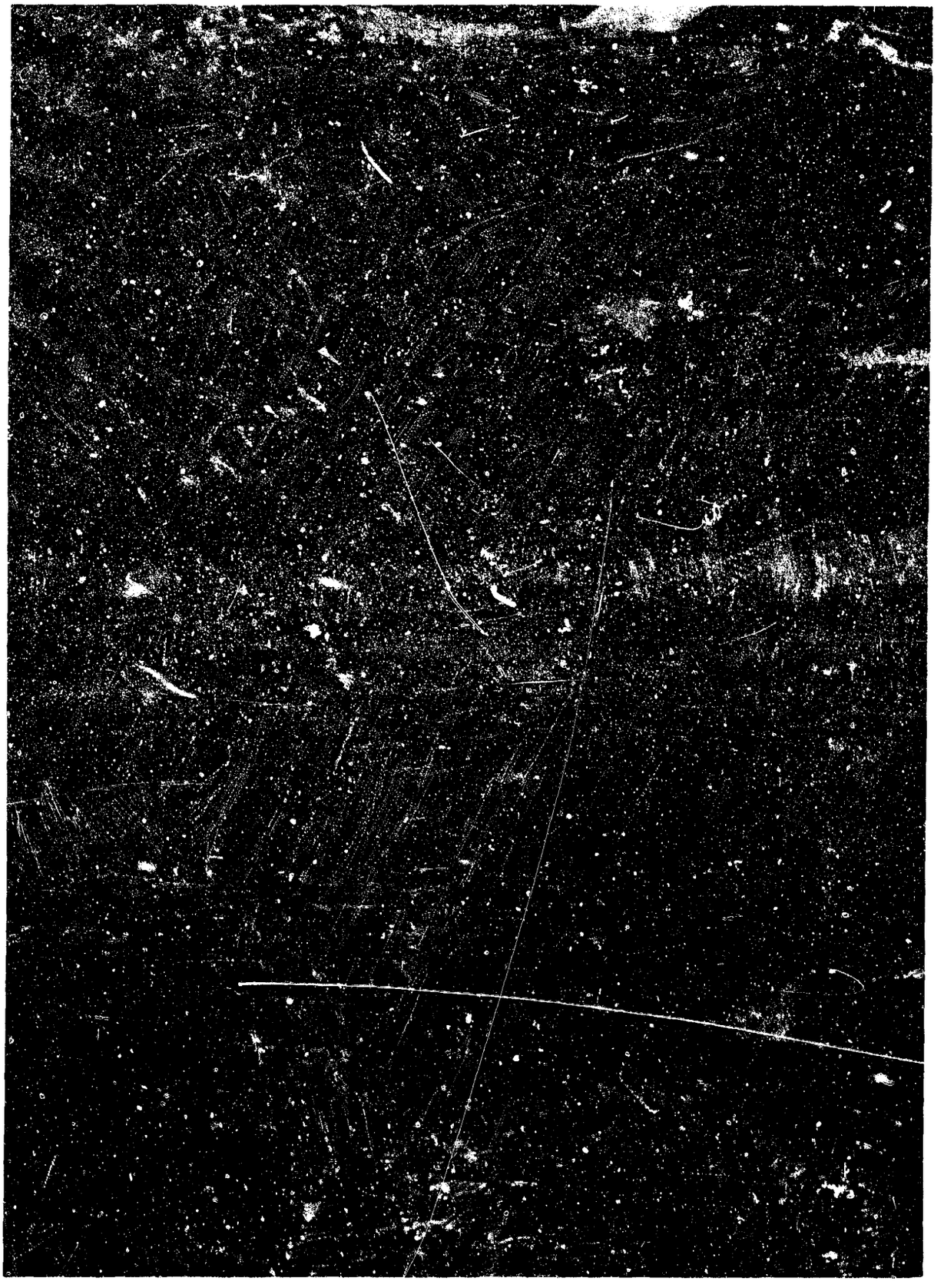


FIGURE 29 - ACCURACY MEASURING FIXTURE

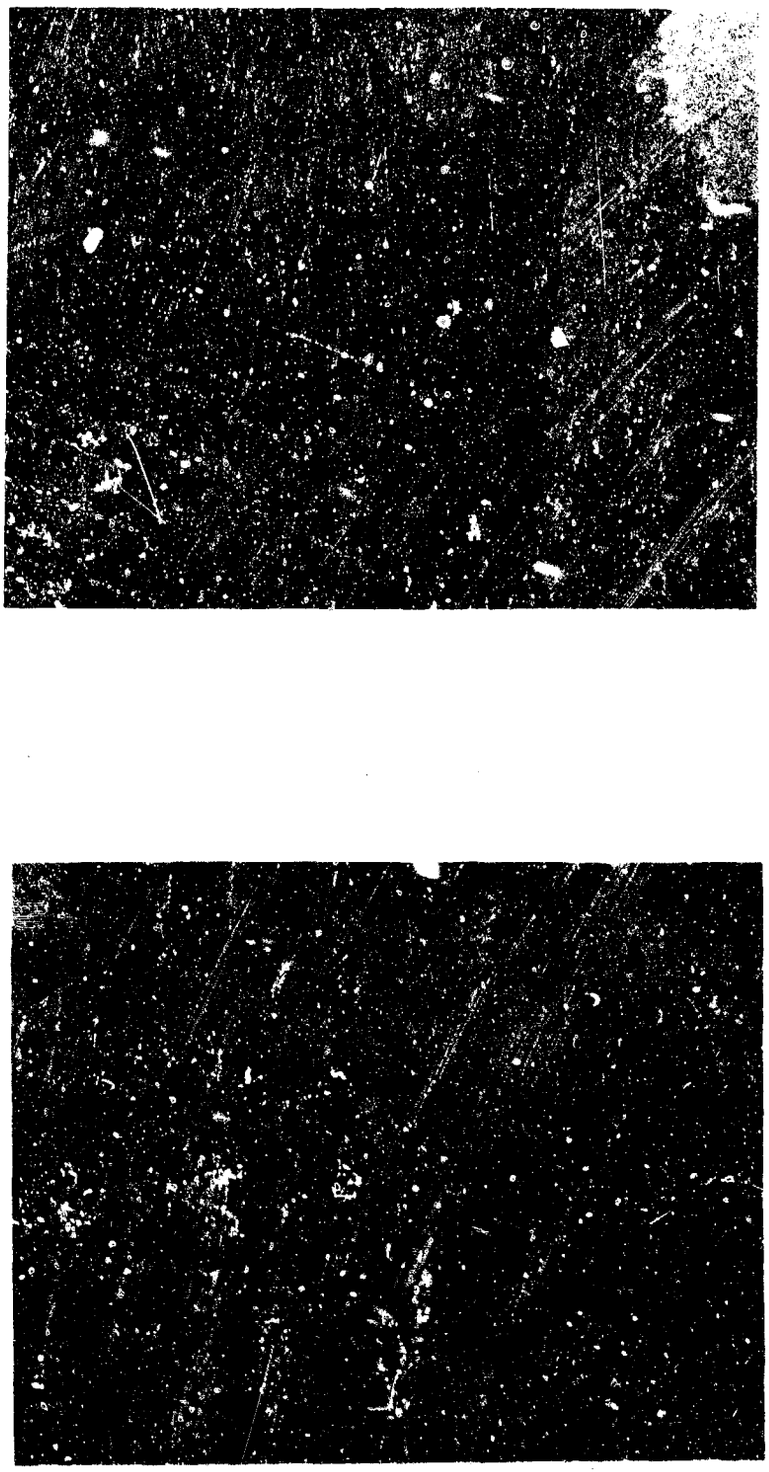


FIGURE 30 - TWO CLOSE UPS OF REFLECTIVE SURFACE

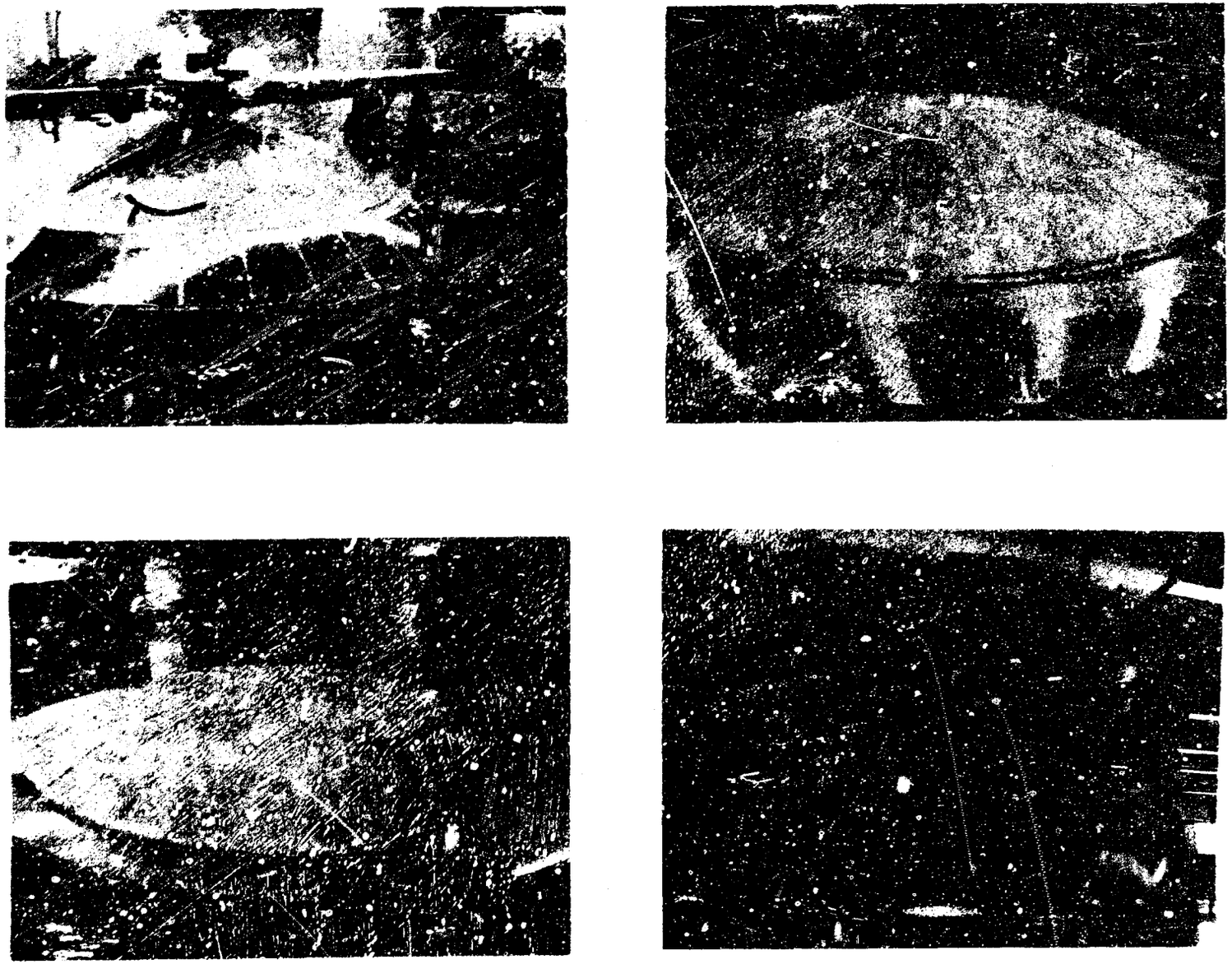


FIGURE 31 - 10-FOOT DIAMETER CONCENTRATORS IN VARIOUS PHASES OF COMPLETION

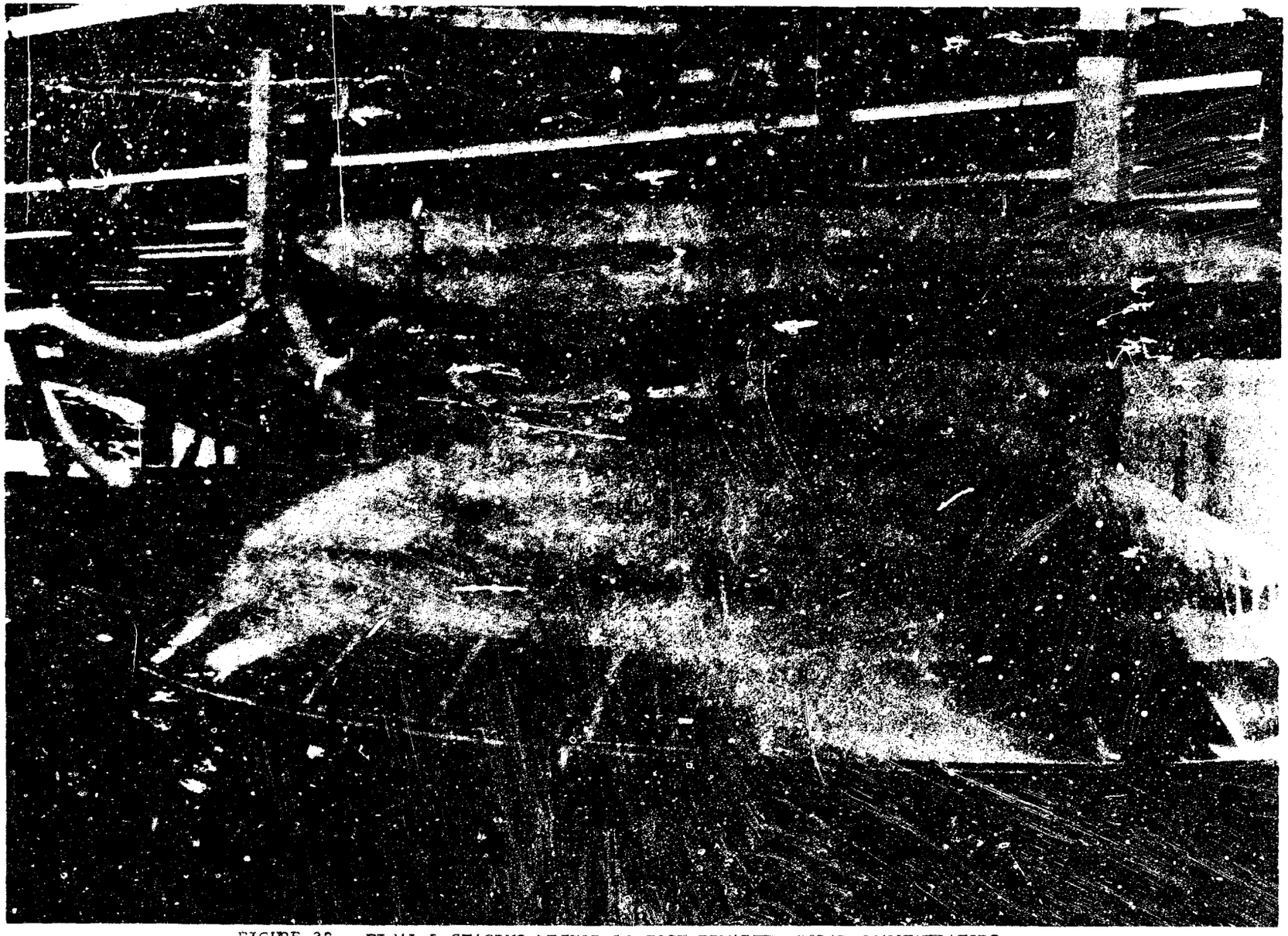


FIGURE 32 - FINAL B-STAGING METHOD 10-FOOT DIAMETER SOLAR CONCENTRATORS

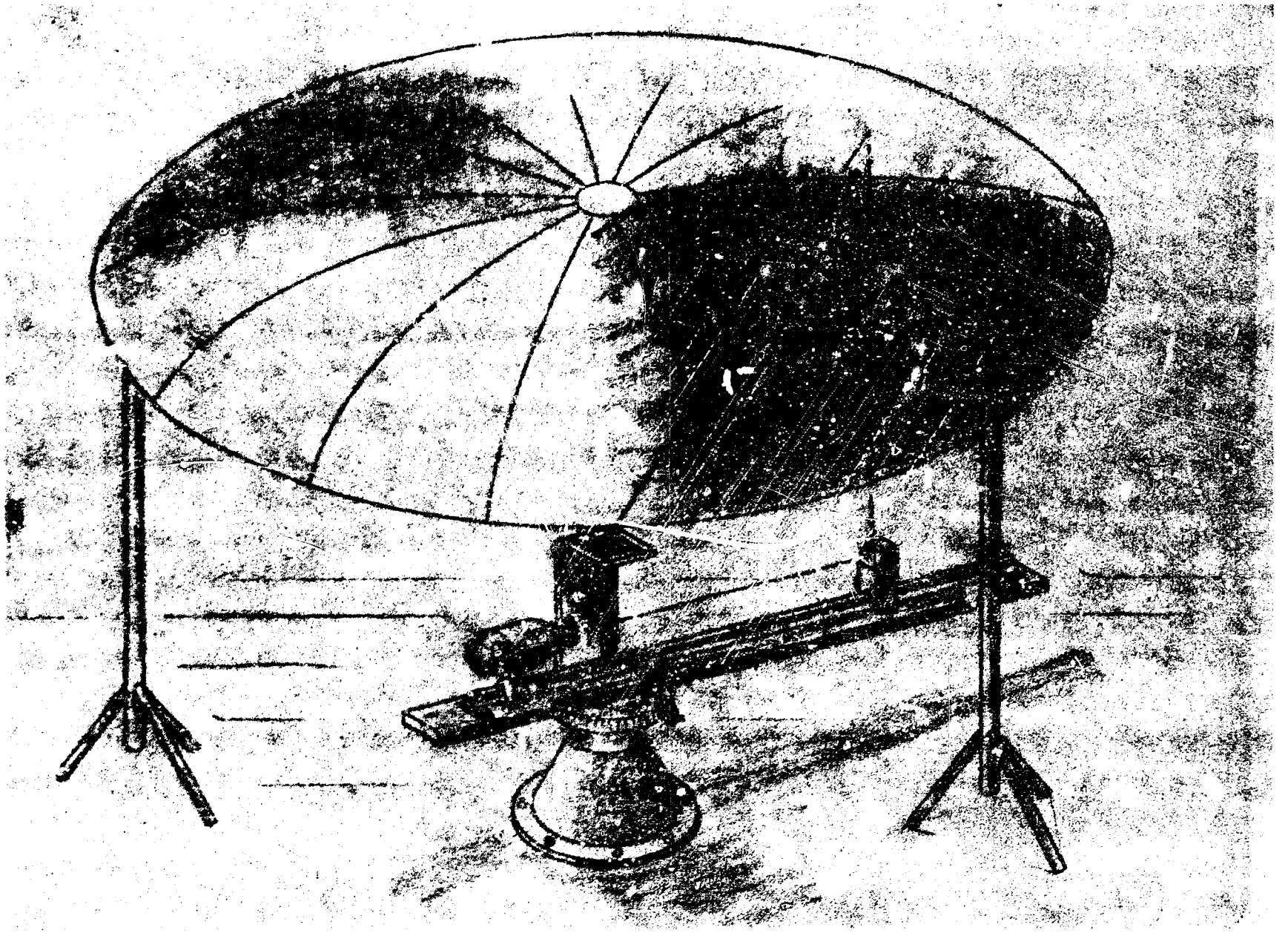


FIGURE 33 SOLAR ENERGY CONCENTRATOR ACCURACY MEASURING FIXTURE

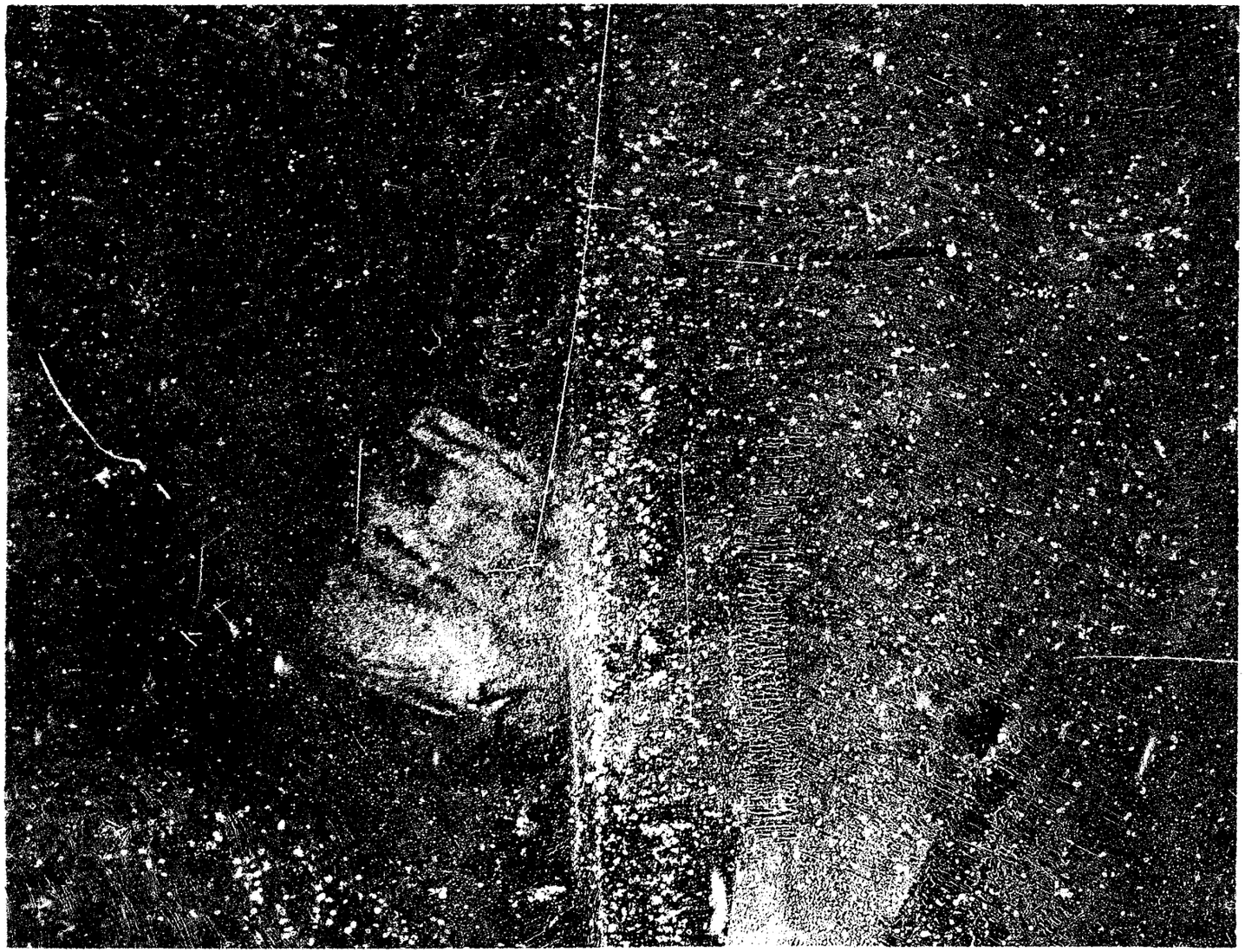


FIGURE 34 - PACKAGED SOLAR CONCENTRATOR BEING CARRIED INTO VACUUM CHAMBER

FIGURE 35 - B-STAGED FLEXIBLE SOLAR CONCENTRATOR SECURED TO BASE PLATE

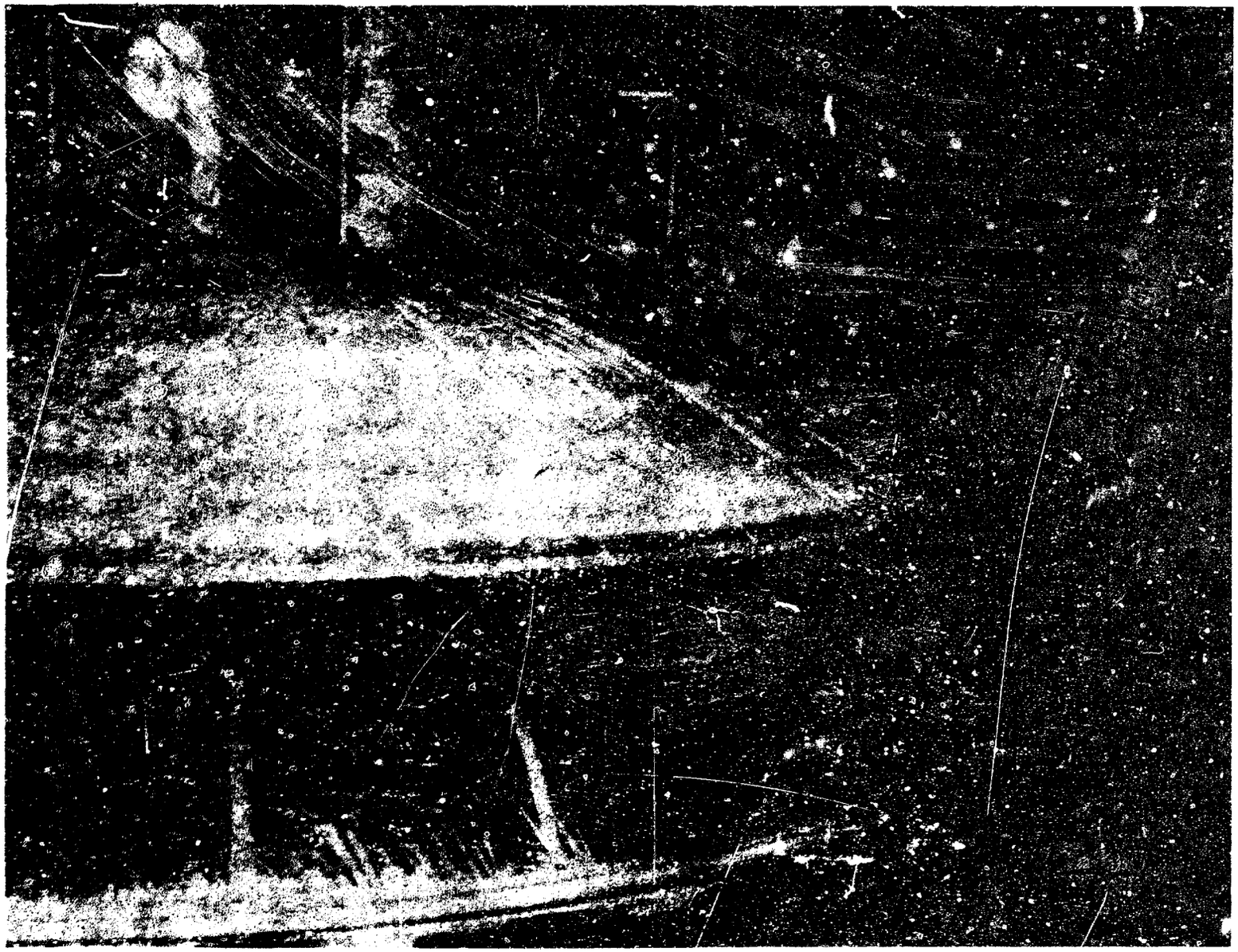
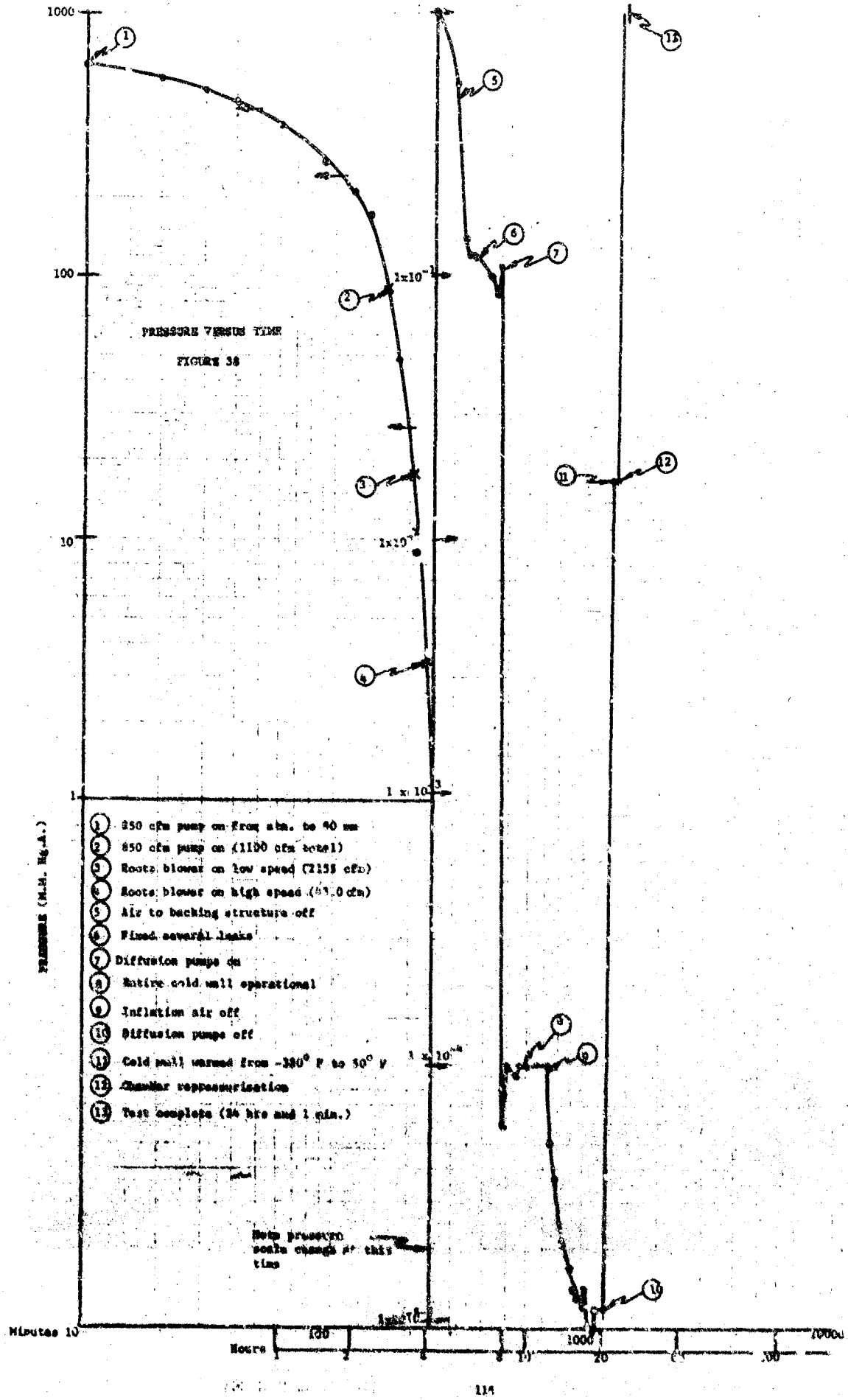


FIGURE 36 - INFLATED SOLAR CONCENTRATOR

FIGURE 37 - RIGIDIZED SOLAR CONCENTRATOR



PRESSURE VERSUS TIME

FIGURE 38

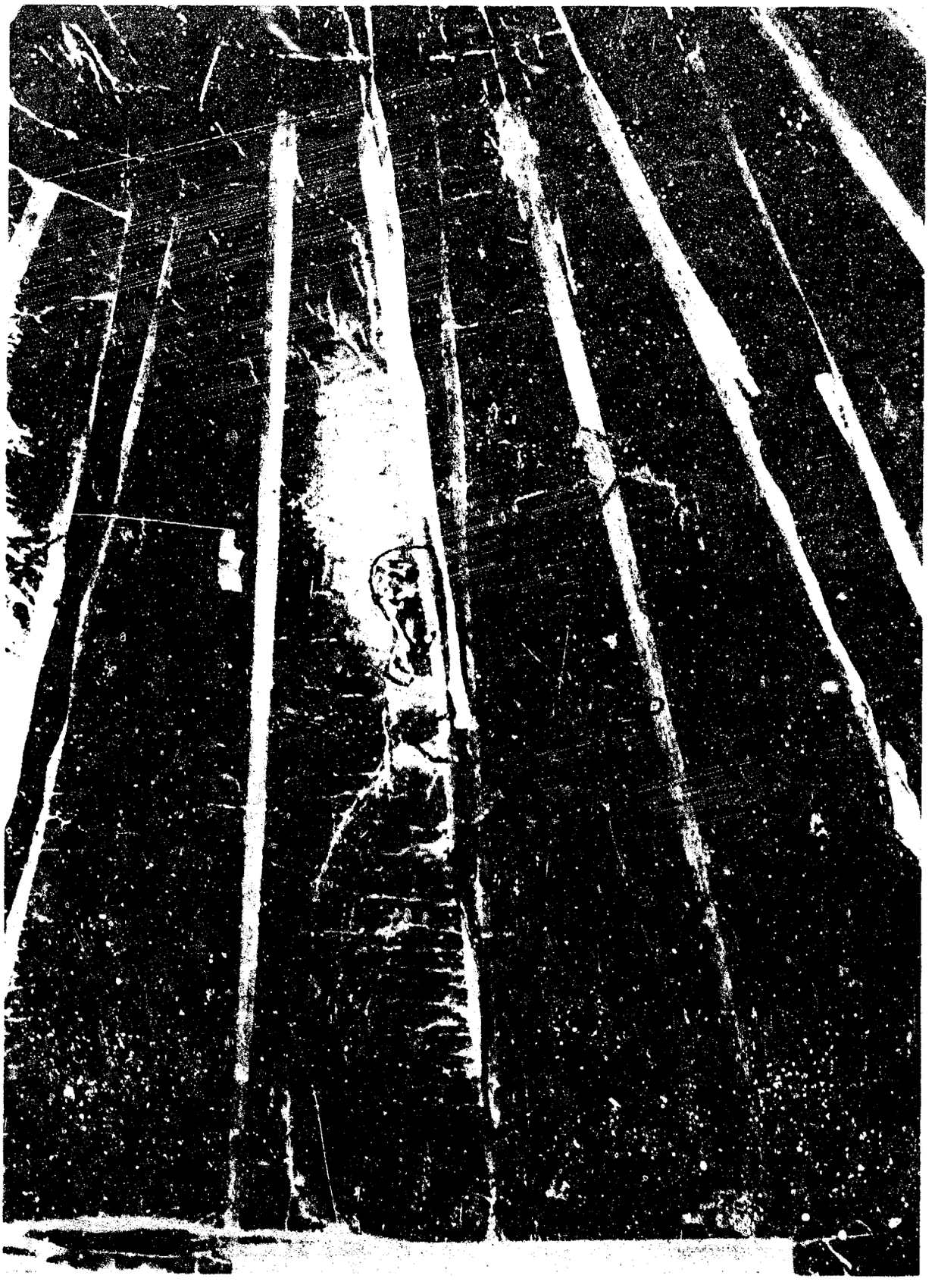


FIGURE 39 - SURFACE EFFECT OF GELATIN ABSORBED BY FOAM FOR SECOND 10-FOOT DIAMETER DEMONSTRATION

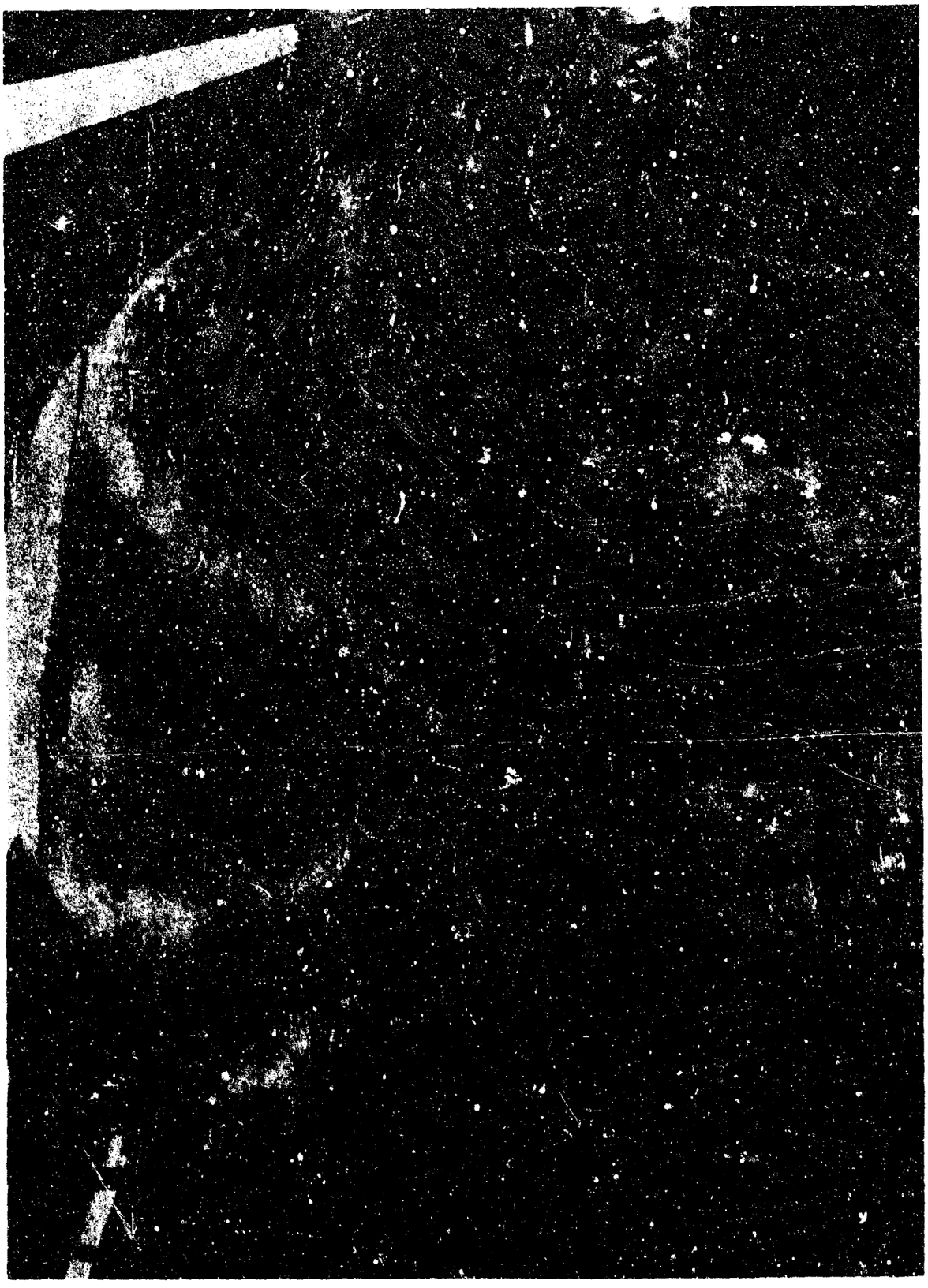


FIGURE 40 - PACKAGING MODEL INFLATED

FIGURE 41 - PACKAGING MODEL PACKAGED

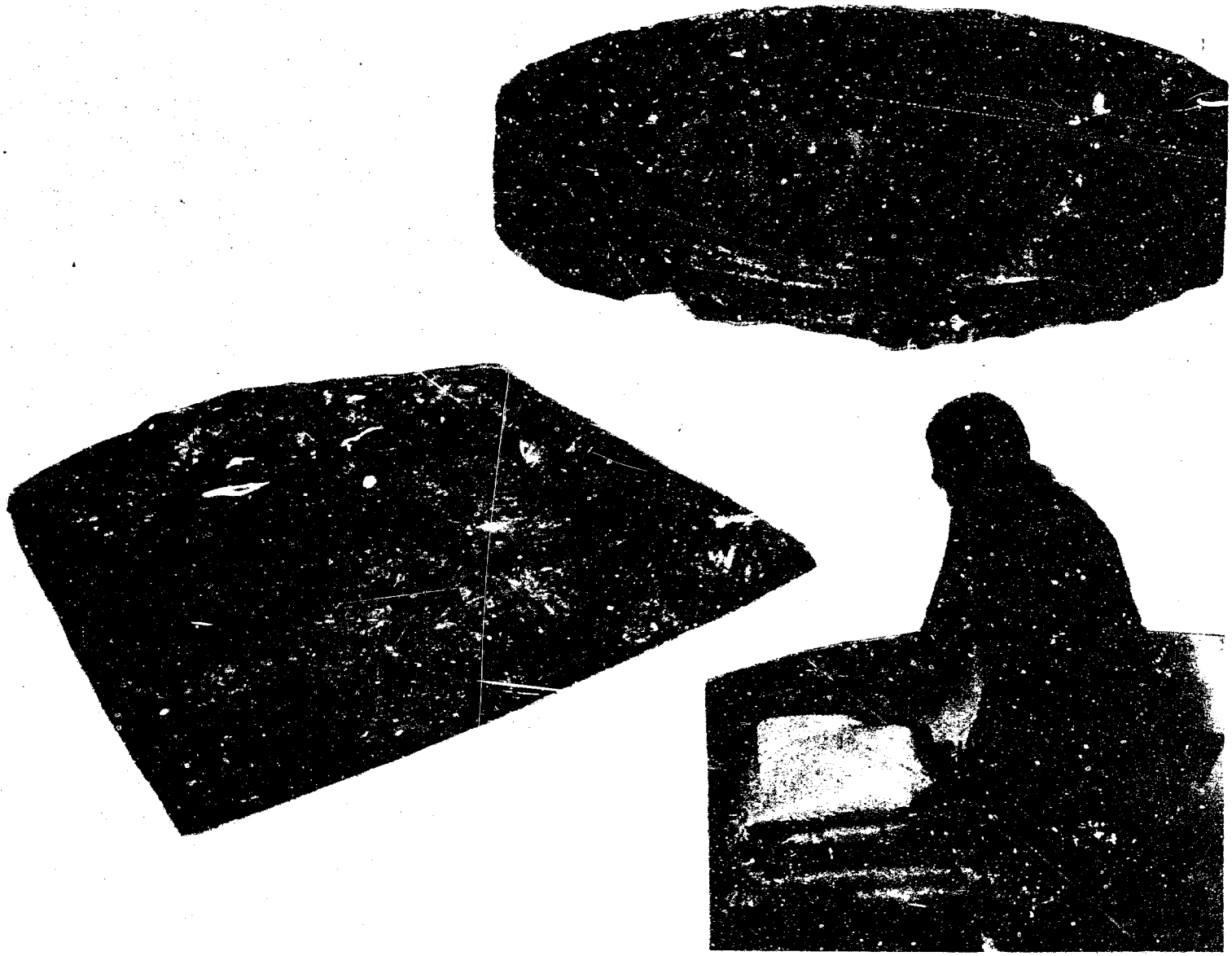


FIGURE 42 - 10-FOOT GELATIN IMPREGNATED CONCENTRATOR FOLDED FOR DEPLOYMENT AND RIGIDIZATION

TABLE 32

SAMPLE TEST RECORD

First 10-foot Diameter Solar Concentrator Demonstration

5/28/66

TIME	CHAMBER PRESSURE	INTERNAL PRESSURE	MATERIAL BACKING PRESSURE	TEMPERATURE #1 CENTER	#2 EDGE	REMARKS
						chamber temp. 72
1438						Start pumpdown - room temp. 76
1441	575 Torr	$3"H_2O$	Zero			
1444	290 Torr	$3"H_2O$	Zero	63	61	
1447	150 Torr	$3"H_2O$	Zero	58	55	
1451	13	$3"H_2O$	-			Start to inflate backing.
1455	6	$3"H_2O$	$4"H_2O$	28	27	
1456	4.75	3-3¼	4	18	25	Maximum solvent loss,
1456				15	20	low point of temperature,
1510	3.1	3.4	3.7	13	20	occurred between 1456-1510.
1514	3.1	3.4	3.7	21	20	
1518	3.0	3.4	3.7	25	20	
1523	3.0	3.4	3.7	33	21	
1527	3.2	3.5	5	41	22	
1600	3.15	3.7	4.5	59	31	
1700	3.1	3.7	4.0	69	50	
1730	3.0	3.7	4.0	70	57	#1 temp. equal to chamber temp.
1731	-	-	Zero			Shut off inflative pressure to backing.
1800	1.4	3.6	-	70	63	
1830	1.25	3.6	-	70	69	Low point in vacuum chamber.
1900	-	Zero	-	70	70	Equalized internal pressure to chamber pressure.
1918	-	Zero	-	70	70	Shut down pumps.
2000						Entered chamber.

TABLE 33

SAMPLE TEST RECORD

Second 10-foot Diameter Solar Concentrator Demonstration

May 11, 1966

DATE-TIME	CHAMBER PRESSURE	INTERNAL COLLECTOR PRESSURE	FABRIC BACKING PRESSURE	TEMPERATURE NO. 1	TEMPERATURE NO. 2	REMARKS COMMENTS
5/11 1030	ATM			59	57	No. 1 center No. 2 edge Start pump down
1035	700 mm			57.5	57	
1047	600 mm	3.25		57	53	
1053	580	3	2"	54	50	Inflate flutes to 2" H_2O
1057	540	3	2	57.5	58.5	
1200	280	3.8	2.0	53	48	Wrinkling appearing in reflective surface
1305	200	4.6	2.5	54	56	KD850 pump turned on intermittently
1335	37	3.8	2.5	57	52	Bubble appeared near edge of polar cap approx. 4" dia.
1353	15	3.7	2.3	60	53	
1410	5	3.2 and 3.6	4.5	61	51.5	
1500	21	3.6	4.1	67	57	
1530	4×10^{-1}	3.7	.5	71	59	Inflation pressure off.
1700	100u	3.5	.2	75	70	Larger bubble has receded

TABLE 33 (cont.)

DATE-TIME	CHAMBER PRESSURE	INTERNAL COLLECTOR PRESSURE	FABRIC BACKING PRESSURE	TEMPERATURE NO. 1	TEMPERATURE NO. 2	REMARKS COMMENTS
1800	100u	3.6	0	77	74	2 small bubbles approx. 1" dia. One small bubble increased 1" x 2"
1900	95u	3.8		78	76	Liquid Nit. induced into chamber
2000	82u	3.5		54	52	
2100	11	3.5		Off scale		
2130	9×10^{-5}	3		"	"	Internal pressure brought down to 3" H_2O because of leakage into chamber. 2 small bubbles have receded Temperature probably below -100 F Cold walls -250-300 F
2345	1×10^{-4}	3.0				Opened equalizer valve-will equalize pressure inside collector to chamber pressure. Thermocouples connected to readout calibrated to -75° - off scale.
0200	3.8×10^{-5}	.2				Holding .2" H_2O with equalizer valve open.

TABLE 33 (cont.)

DATE-TIME	CHAMBER PRESSURE	INTERNAL COLLECTOR PRESSURE	FABRIC BACKING PRESSURE	TEMPERATURE NO. 1	TEMPERATURE NO. 2	REMARKS COMMENTS
0600	1.6×10^{-5}					No apparent change in surface since 1900. Collector resting on base plate. Temperature check on solar collector fabric backing -212°
1000	1.3×10^{-5}					Pressure in collector returned to 3" H_2O.
						Venting chamber to ATM. Reducing pressure in collector due to apparent movement of collector out of holding fixture on base plate.
1205	100u	2"		15		Collector lifted off base plate, out of holding fixture.

7.0 SPACE SHELTERS

7.1 PRELIMINARY DESIGN

The preliminary design of the cylinder structures for this contract consists of two basic elements - rigid bulkheads at the ends and a flexible, cylindrical body. The rigid bulkheads were to be thin shell aluminum spinnings with all the appropriate fittings and details to package, deploy, and rigidize the gelatin structure.

The cylindrical body of the structure was to consist of a truss core fiberglass fabric which was to be impregnated with gelatin resin, an impermeable inner layer for internal pressure retention, and an impermeable outer layer which would have facilitated packaging, provided an on-command cure system, minimized the total weight of the system, and improved the total appearance of the structure.

By incorporating the gelatin-impregnated fiberglass fabric between two impermeable layers, a controlled system is obtained which minimizes premature drying or rigidization of the resin system in the packaged condition and facilitates the on-command cure of the system. The cure time studies that were conducted indicate that during the latter stages of the gelatin cure cycle, the rate of solvent evaporation is very low; therefore, by sealing the gelatin-impregnated fabric between two impermeable layers the initial rate of rigidization is somewhat inhibited. However, the total time that is required to completely rigidize the structure is not increased, and may even be shortened, because the controlled rate of rigidization does not result in a sharp drop in temperature in the resin-impregnated fabric.

Further cure time studies should be conducted to confirm this design feature which could be modified should it be discovered that the outer layer seriously impedes the rate of rigidization of the structure. The system is cured on command by venting the gelatin-impregnated fabric by solenoid valves whenever it is desirable to initiate rigidization. It has been found in previous studies that it is necessary to provide a substantial pressure within the flutes of the gelatin-impregnated sandwich material to insure that the flutes remain fully deployed throughout the rigidization cycle. Initially, it was felt that the vapor pressure of the solvent in the gelatin system would provide this necessary pressure; however, for the small-size structures that have been investigated, the solvent pressure is not sufficient, especially as the structure cools due to removing heat for vaporization. Therefore, on the gelatin cylinders that were studied, it has been necessary to artificially pressurize the flutes of the fabric sandwich material with air, or a bottled gas such as nitrogen. Without an impermeable outer layer on the fabric sandwich material, a large volume of air is required to pressurize the flutes of the sandwich material throughout the cure cycle because of the high permeability of the resin-impregnated fabric. With an impermeable outer layer outside of the gelatin-impregnated fabric, the auxiliary supply of pressurizing gas can be drastically reduced, since its venting will be controlled with the solenoid valve along with the venting of the water vapor from the gelatin resin.

7.2 1/2 SIZE CYLINDER

A 1/2 scale cylinder was completed for testing and to determine fabrication techniques and procedures. The wall composite was attached to the bulkhead by first epoxying the fiberglass wall and bladder to a metal ring. This ring was the same diameter and depth as the flute area of the wall composite. Part of the bulkhead was a metal retainer forming a trough around the inside of the bulkhead. This trough was filled with epoxy, and the wall composite attached to the ring lowered into the epoxy. After the epoxy cured, the cylinder was rotated and the process repeated for the other end.

This model was leak-checked by the ammonia-phenol method. No leaks were found either in the bladder or the outer facing. This indicates an improvement in fabrication procedures over cylinders completed under past contracts. The model was prepared for impregnation and cured in a 5-foot vacuum chamber. However, before the actual test could be started, it was necessary to start dismantling the chamber for shipment to its new location at G. T. Schjeldahl, Northfield, Minnesota.

Figure 43 shows the package cylinder in the vacuum chamber.

Figure 44 shows the cylinder in a deployed, inflated configuration.

In general the overall appearance of the model is very pleasing, the packagability is quite satisfactory, and no delamination of the outer facing has occurred from repeated packaging and inflating.

The cylinder has not been impregnated or cured.

FIGURE 43

PACKAGED 1/2 SIZE CYLINDER
IN VACUUM CHAMBER

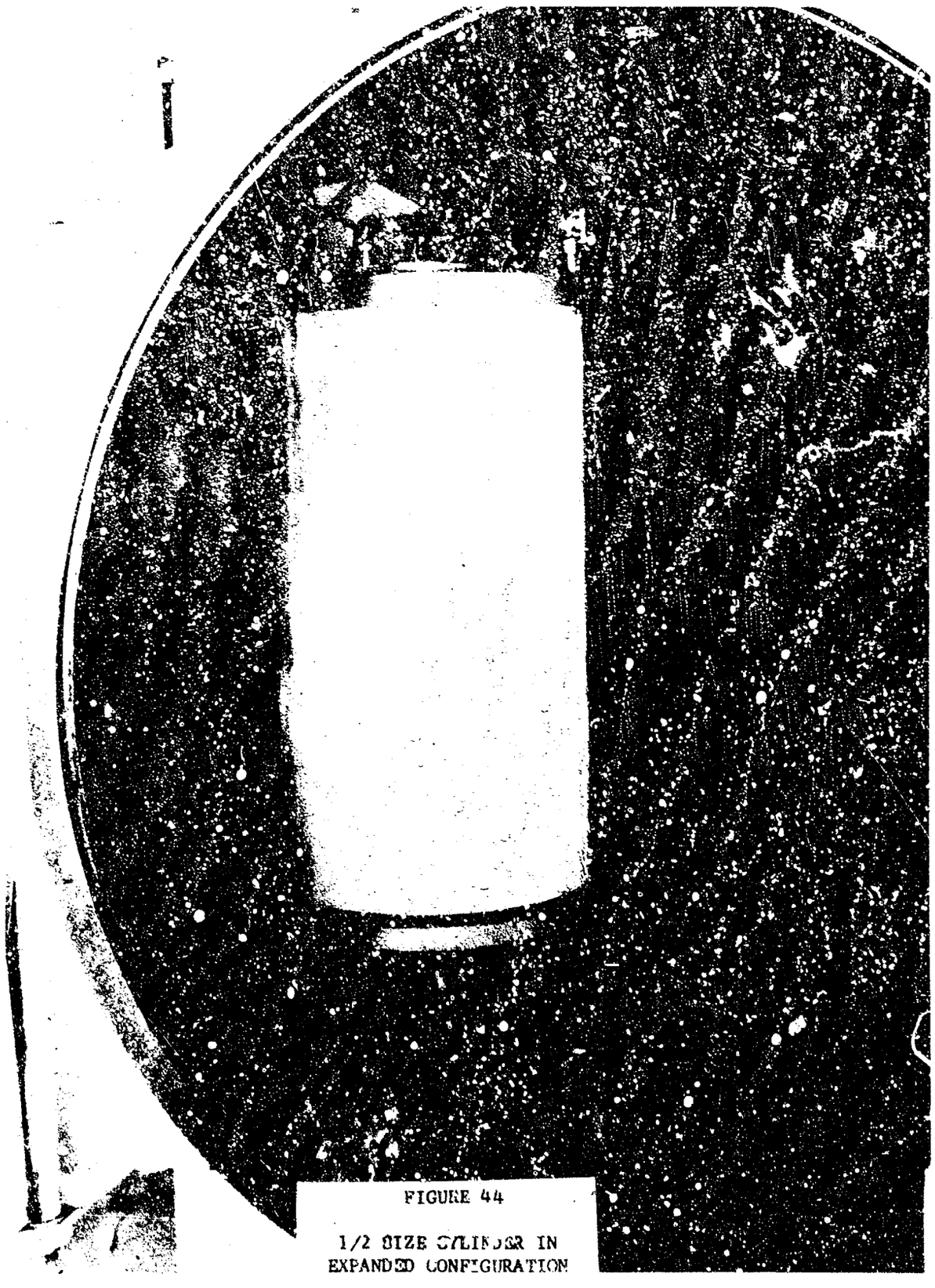


FIGURE 44

1/2 SIZE CYLINDER IN
EXPANDED CONFIGURATION

8.0 PLANS FOR DELIVERY OF FINAL DEMONSTRATION ITEMS

The original plans called for both the cylinder and the solar concentrator to be demonstrated late in August or early September. Both demonstrations were to take place during the same trip. Therefore, the vacuum chamber was designed to be used for both test articles with a minimum of revisions.

The support, electrical, instrumentation, and control systems requirements for the two demonstrations were essentially the same. The major differences were: (1) the heat source arrangement and (2) the support harness. There are only slight differences in the use of electrical circuits which would have required no change involving the vacuum chamber.

8.1 FINAL SOLAR CONCENTRATOR DELIVERY

An ellipsoid instead of a sphere was considered to erect the 10-foot diameter solar collectors, because the smaller volume and surface area of the ellipsoid would result in a lower weight, smaller packaging volume, and a smaller erection system.

For the analytical study the limitations placed on the ellipsoid were: (1) the 10-foot collector would match the ellipsoid tangentially, and (2) there would be no points of negative stress on the ellipsoid.

The following formulas were used:

For the ellipse $\frac{x^2}{a^2} + \frac{y^2}{b^2} = 1$

where, a = major semiaxis

b = minor semiaxis

For the stress $S_1 = \frac{pr_2}{2t}$, $r_1 = r_2^3 \frac{b^2}{a^4}$

$$S_2 = \frac{pr_2}{2t}\left(2 - \frac{r_2}{r_1}\right), \quad r_2 = \frac{(a^4y^2 + b^4x^2)^{1/2}}{b^2}$$

where, S_1 = meridional membrane stress

S_2 = hoop membrane stress

p = internal pressure

t = material thickness

r_1 = radius of curvature along meridian

r_2 = radius of curvature normal to meridian

To have no negative stress a/b must be $\leq \sqrt{2}$. The smallest volume ellipsoid occurred when $a/b = \sqrt{2}$. To determine the matching tangent circle, the slope of the ellipse is set equal to the slope of the parabola at the ten foot diameter.

$$\frac{dy}{dx} = \frac{bx}{a^2\left(\frac{1 - x^2}{a^2}\right)^{1/2}} = \frac{x}{2f} = \frac{1}{3} \text{ for the particular paraboloid}$$

therefore,

$$a = \frac{5\sqrt{10}}{2}$$

$$b = \frac{5\sqrt{5}}{2}$$

This determines the ellipse to be rotated as

$$2x^2 + 4y^2 = 125$$

Stress in the ellipsoid varies from 0 to 80 pounds per inch. The stress at the joint between the ellipsoid and the paraboloid is 45p. A 1/10 size model of this ellipsoid was constructed to test for edge wrinkling and distortions. The results demonstrated that a full size ellipsoid could be used with the 10-foot solar collector.

8.1.1 Canister and Spreader Plate for Use With Final Demonstration 10-Foot Diameter Solar Concentrator

The drawings for the canister, top and bottom, were completed and sent out for bids early in June. When the bids were returned it was determined that the best delivery date would be six weeks from the date of arrival of material at the fabricators. The bid was let during the last week of June. This projected the demonstration date to late August or early September.

The canister consists of two sections, a top (Drawing SD-628), and a bottom (Drawing SD-629). Both sections are fabricated of 5/16-inch aluminum alloy. The top is slightly conical in shape, measuring 35-3/4 inches in diameter at the base, 14 inches high and 30-3/4 inches in diameter at the top. The top half drops away during deployment. The bottom is a flat disk 36-1/4 inches in diameter with a 3/4-inch lip around the edge. The bottom half of the canister remains attached to the support frame during the demonstration. The instrumentation, pressurization and controls are attached to, or extend through, the bottom half of the canister. The drawings are located in Appendix D.

The bottom half of the canister is attached to the solar concentrator by bolting to a spreader plate, (Drawing SD-630). The spreader plate is an integral part of the solar concentrator, and performs several functions. During impregnation the spreader plate acts as a manifold to distribute the

gelatin. During pumpdown and cure, an attachment is secured to the spreader plate, and a temperature readout, a pressure readout, and pressure control in the structural backing material, is obtained through the spreader plate and its attachment. A pressure readout and pressure control of the inflation balloon is also obtained through the spreader plate.

The spreader plate and its attachments were fabricated by G. T. Schjeldahl.

8.1.2 Solar Concentrator Demonstration and Type of Deployment

The demonstrations were to be conducted in the Air Force Aero Propulsion Laboratory vacuum facility at Wright-Patterson Air Force Base, Dayton, Ohio.

The solar concentrator was to have been deployed on command from a packaged configuration inside a canister. Inflation of an ellipsoid balloon would have commenced as soon as the canister separated. The balloon would have shaped and held the solar concentrator in the designed configuration during the curing cycle. An external pressure source would have inflated the balloon and the structural backing material. The type of curing system intended for this structure was a plasticizer-boil-off; no additional catalyst is required.

During pump down three pressure zones, two temperature zones, and the weight loss of the test article are of interest. The pressure zones are: (1) internal pressure of the balloon, (2) pressure in the structural backing material, and pressure in the canister. The temperature zones are: (1) temperature of the structural backing material inside the canister, and (2) temperature outside the canister. After deployment, the same information is of interest except that there is obviously no pressure inside the canister.

The canister would have been supported from a load cell attached to a framework 25-feet above the chamber floor. This would allow adequate clearance for balloon inflation and for a net or other suitable device to catch half of the canister.

The ellipsoid balloon would have been deployed in a downward direction (one half of the canister falling away) with the solar collector and the other half of the canister remaining on top, still attached to the load cell. See Figure 45. Stabilizing cables would have been used between the canister and the framework. All instrumentation and control systems would have been attached to, or penetrated the canister half and spreader plate which remain on top.

Instrumentation, recorders, and system controls should be convenient to, or located in, the view port nearest the main control and operations room.

High speed motion picture coverage should be located in one of the lower view ports and if possible, from one of the view ports located on top of the chamber.

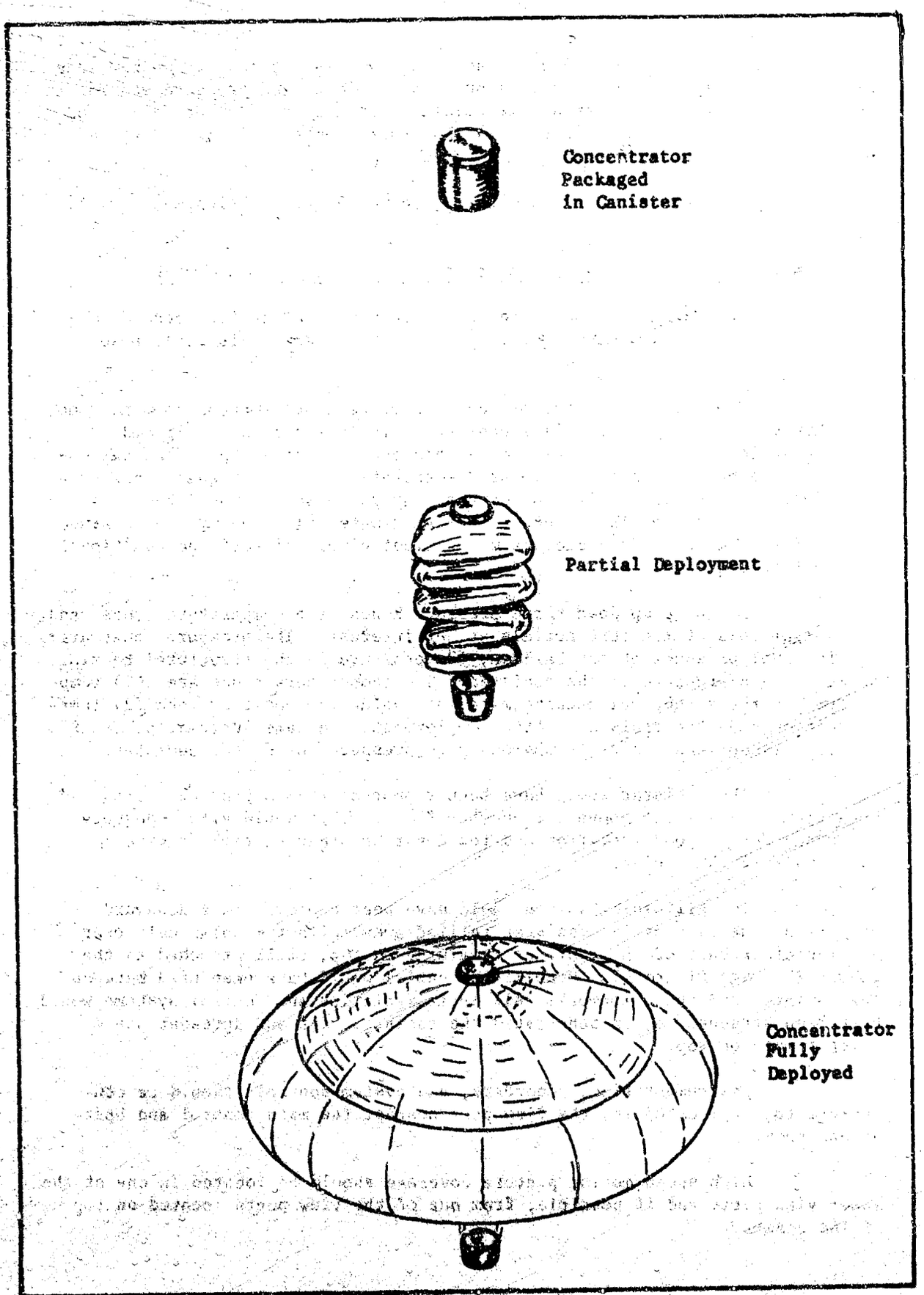


Figure 45 SOLAR CONCENTRATOR DEPLOYMENT

8.2 FINAL SPACE CYLINDER DELIVERY

8.2.1 Bulkhead-Canister for Use With Final Cylinder Demonstration

The drawings for the cylinder bulkhead-canister, top (Drawing SD-648) and bottom (Drawing SD-639), were completed, set out, and bids received at the same time as the solar concentrator. The same delivery and demonstration dates were established for the cylinder as were set up for the solar concentrator.

The cylinder bulkhead performs a double function, that is, during packaging the bulkheads serve as packaging canisters, and during and after deployment, the bulkheads remain attached to the cylinder wall and serve as end bulkheads.

The bulkheads are fabricated of an aluminum alloy and measure approximately 48-1/2 inches in diameter by 7 inches deep at their maximum point.

The instrumentation, pressurization, and controls are attached to, or through, the top bulkhead. The top bulkhead remains attached to the support frame during and after deployment.

Drawing SD-647 shows the metal ring used to assemble the fiberglass wall and bladder to the metal bulkhead.

Drawing SD-646 shows the assembly of the 48-inch diameter cylinder. The cylinder drawings are in Appendix D.

8.2.2 Cylinder Demonstration and Type of Deployment

The demonstrations were to be conducted in the Air Force Aero Propulsion Laboratory vacuum facility at Wright-Patterson Air Force Base, Dayton, Ohio.

The cylinder was to have been deployed on command from a packaged configuration inside a canister. The canister halves remain attached to the cylinder after deployment and serve as end bulkheads. An external pressure source would have inflated and held the cylinder in the designed configuration during the curing cycle. The external pressure would also have inflated the flute area of the cylinder if necessary. The type of curing system intended for this structure was a plasticized-boil-off. No additional catalyst is required.

During pump down three pressure zones, two temperature zones, and the weight loss of the test article are of interest. The pressure zones are: (1) internal pressure of the bladder, (2) pressure in the flute area of the structural wall material, and (3) pressure in the ring area of the canisters. The temperature zones are: (1) temperature in the flute area of the structural wall material, and (2) temperature outside the canister. After deployment we are interested in the same information, except there is no pressure in the ring area of the canisters.

The cylinder canister would have been supported from the same load cell used for the solar concentrator demonstration. Cables would suspend the canister 11 feet above the chamber floor. The deployed cylinder size is 4 feet in diameter by 8 feet long. Stabilizing cables would have been used between the canister and the framework. All instrumentation and control systems would have been attached to, or penetrate, the top half of the canister.

Instrumentation, recorders, and system controls should be convenient to or located in the view port nearest the main control and operation room. High speed motion picture coverage should be located in one of the lower view ports and if possible, from one of the view ports located on top of the chamber.

8.3 TERMINATION OF PLANS

The contract was terminated before the final items could be demonstrated.

9.0 CONCLUSIONS

9.1 From the gelatin studies conducted during this program, the following was concluded:

1. Attempts to chemically modify the basic gelatin formulation by means of additives to achieve increased strength, faster cure times, chemically cross-linking, and improved handling characteristics result in a decrease of physical strength.

2. A gelatin formulation suitable for vacuum impregnation at room temperature (80 F to 90 F) was developed and utilized to rigidize expandable, honeycomb-type structures by means of plasticizer boil-off.

3. To achieve significant improvements in surface accuracy, study of ways to minimize gelatin shrinkage must be undertaken.

9.2 B-Staging studies produced the following conclusions:

1. Gelatin impregnated structures can easily be B-staged by circulating paraformaldehyde vapors through the structure immediately after impregnation.

2. A B-staged, rigidized structure can be reflexibilized by circulating warm moist air through the structure, and then rerigidized without any loss of shape, gelatin, or strength.

9.3 From the various analyses, material studies, design studies, and test programs it was concluded that:

1. The structures of this program are feasible and capable of deploying and rigidizing in a space environment.

2. Techniques and procedures of this program are applicable to larger structures.

10.0 RECOMMENDATIONS

10.1 GELATIN

1. The investigation of gelatin modification should be continued.

2. A method of minimizing gelatin shrinkage during cure should be investigated.

10.2 FLEXIBLE LAYER

The flexible layer should be investigated to eliminate its tendency to cause creases in the material when packaged. However, the characteristic of eliminating show-through should not be lost in this effort.

10.3 MATERIALS VERIFICATION PROGRAM

Work in this area should be continued with emphasis on component materials, compatibility and shelf-life improvement.

10.4 GENERAL

Larger structures, utilizing gelatin as the rigidizing resin, should be fabricated to gain experience in fabricating, deploying and rigidizing these structures.

APPENDIX I

DETERMINATION OF OPTIMUM GELATIN FORMULATION FOR EXPANDABLE STRUCTURES

H. H. Young

Swift and Company

Research and Development Center

Chicago, Illinois

INTRODUCTION

The statement of work requested by Viron and the proposal submitted by Swift on May 20, 1965, were modified as a result of a meeting held with Viron's project manager, Mr. Ivan Russell. Reference to this is made in Mr. Joseph Kalinski's letter to Mr. D. G. Sullivan dated June 28, 1965.

The following individual tasks were to comprise our total effort in this research program:

1. Determination of gelatin concentration and saturation techniques for producing a saturated glass fabric comprising 67 per cent glass and 33 per cent gelatin approximately.

2. Determination of the effect of gelatin pickup upon the tensile strength of saturated No. 181 glass fabric.

3. Determination of the proper type and concentration of fluidizer or liquifier to produce a saturating solution whose viscosity will not exceed 1,500 cps at 110 F.

4. Determination of optimum techniques for crosslinking of gelatin with formaldehyde.

5. Development of optimum remoistening or reflexibilizing techniques.

6. Observations of torture and shrinkage effects after curing and drying of test specimens.

7. Study of neutral organic co-solvents and their effect upon curing rates of the moist flexible test specimens in a hard vacuum environment.

8. Study of aging characteristics of test specimens after folding and sealing in plastic envelopes.

9. Preparation of test specimens for Viron to determine desired strength characteristics.

10. Conclusions and Recommendations resulting from this experimental program and the consultation carried out in personal contacts with Messrs., Russell, Rochon, and Broz of Viron.

DETERMINATION OF OPTIMUM CONCENTRATIONS OF THE GELATIN SATURATING SOLUTION AND THE RATIO OF GELATIN PICKUP TO THE ULTIMATE TENSILE STRENGTH

Throughout the experimental work carried out in the overall study of gelatin as the saturating resin there have been numerous opinions expressed as to the optimum gelatin pickup by the fabric in order to create the strongest structure. For the most part tensile strength has been used as the criterion although full cognizance has been given to the need for rigidity as well. Preliminary work has been completed in other studies without any specific study of the importance of preparing the glass fabric prior to saturation with gelatin.

A 10 sq yd sample of No. 181 glass fabric was received from Viron August 5, 1965, and given preliminary treatment by cleaning with chromic acid, and acid cleaner (Swift's Hyscore) and an alkaline detergent based upon soap. Specimens of fabric 10 in wide and 36 in long were wound on small frames made of thin glass rods so that cleaning and rinsing could be effected in 1 liter graduated cylinders. After cleaning and thorough rinsing the cleaned fabric was air dried by hanging from clips and stored between kraft paper sheets until used.

The elimination of bubbles was the biggest problem. Experience showed that the best way to impregnate the glass fabric was to slowly lower one corner of the inclined wood frame into the gelatin, then gradually immerse that edge, then slowly tilt the assembly into the gelatin. This needs to be done slowly so as to permit the air to escape from the fabric. This air expulsion takes place much more readily from a dry fabric than from one which is wet provided the fabric is thoroughly cleaned. By keeping the pans warm and covered, the concentration can be maintained without difficulty. After a few minutes, the gelatin is skimmed, and the frame lifted slowly by one edge. If done slowly no bubble will form on the underside. It is then allowed to drain for a few seconds and then held horizontal to distribute the gelatin. The frame is turned over every few seconds to prevent drips until the natural cooling has gelled the gelatin. This can be speeded up by doing all the turning over in a cooler. The sample is air dried, cut out with a knife and used for cutting dumbells. All the scrap is used for resin pickup determination by incinceration. The frames are cleaned, dried, and reused.

Alkaline cleaners generally produced a glass surface that was wet with difficulty probably due to thin films of insoluble soaps resulting from water hardness. In the light of subsequent success with acid detergents no further effort was made to use distilled or deionized water as the gelatin solvent.

Hyscore acid cleaner, a proprietary product of Swift & Company, was compared with a standard chromic acid cleaning solution prepared by saturating concentrated sulfuric acid with chromium trioxide.

TABLE 34

LAB. NOTEBOOK NUMBER	CLEANER	SOLUTION CONCENTRATION OF GELATIN	PER CENT GELATIN PICKUP	TENSILE STRENGTH	LOAD x 2 % GELATIN PICKUP
4565-74A	Chromic Acid	20%	39.8	25900	779
4565-74B	" "	15%	23.9	26600	879
4565-74C	Hyscore Cleaner	20%	33.5	27500	917
4565-74D&F	" "	15%	26.3	36900	1160
4565-74E	" "	15% (double dip)	54.5	32000	553

In Table 34 some explanations are in order. Tensile strength determinations are calculated using a cross sectional area in the denominator. Hence, at low levels of saturation or pickup, the thickness is that of the woven thread only and the gelatin film bridging the interstices is infinitely smaller. The average thickness is unknown but definitely less than measured. As the pickup increases these depressions fill with gelatin until the whole specimen has a cross section which in fact can be measured as a rectangular area. From this it becomes apparent that the strength of the thick specimen is measured with reasonable accuracy, whereas the values for the low resin pickup specimens are invariably lower than the unknown true value.

For this reason another value which offers a means of comparison is used. This is the breaking load doubled (because specimens are 1/2 in. wide) divided by the per cent gelatin picked up. Such a figure, while arbitrary, does show a definite relationship between strength of specimen and the degree of saturation or gelatin pickup.

Although differences are not great it is obvious that the highly concentrated and corrosive chromic acid produces no improved surface over the milder acid cleaner (pH 2.5-3.0).

Before rejecting chromic acid as a cleaner for the glass fabric, two samples were washed in sequence. One was washed in Hyscore acid cleaner, rinsed and cleaned again with chromic acid. The other was cleaned in the reverse order. Results are in Table 35.

TABLE 35

LAB. NOTEBOOK NUMBER	1st CLEANER	2nd CLEANER	GELATIN CONCEN-TRATION	PER CENT GELATIN PICKUP	TENSILE STRENGTH	LOAD x 2 % GELATIN PICKUP
4632-4 A	Hyscore	Chromic Acid	25%	45.8	17920	745
4632-4 B	"	"	15	21.7	19700	1260
4632-4 D	Chromic Acid	Hyscore	25	47.3	22500	810
4632-4 E	"	"	15	24.8	22000	1045

Hyscore cleaned is to be preferred over chromic acid as a preparatory cleaning step and has been used throughout this study. Knowing that 15 per cent gelatin will diffuse through the fabric displacing the air and that 30 per cent gelatin is sufficiently fluid at 110-120 F to permit dipping, these concentrations were chosen. The fabric was washed in acid cleaner, rinsed, dried in air and tacked to the frame. The feel of the fabric was harsh as if it lacked lubricant which it, in fact, did. Care was taken not to touch the fabric anywhere except at the tacked edges. Table 36 shows the results:

TABLE 36

LAB. NOTEBOOK NUMBER	GELATIN CONCENTRATION DIP 1	DIP 2	DIP 3	DIP 4	PER CENT GELATIN PICKUP	TENSILE STRENGTH	LOAD x 2 % GELATIN PICKUP
4632-1 J	15	30			45.9	14140	527
4632-1 H	15	30	30		55.3	11470	441
4632-1 G	15	30	30	30	70.9	8200	645

It appears as if increase in resin pickup decreases the total strength and there is a strong indication that the assumed increase in strength with increased gelatin pickup is fallacious. Note Figure 46 which plots per cent gelatin pickup against twice the load divided by the per cent gelatin pickup. Also, note Figure 47, which plots the pickup against the tensile strength as measured. All points are scattered but the trend is clearly indicated, namely that increased pickup of gelatin decreases tensile strength. Of course rigidity, which is probably of equal importance, does increase sharply with thickness and hence, with gelatin pickup.

Therefore, a more thickly woven glass fabric bonded by even lesser gelatin pickup may prove to be very desirable, although admittedly not a part of this specific assignment.

Further, it is not clear that considering both stiffness and tensile strength the arbitrary selection of 30-35 per cent gelatin pickup may well be the optimum for the No. 181 glass fabric only and after acid cleaning.

Table 37 includes additional data at lower gelatin pickup levels.

TABLE 37

LAB. NOTEBOOK NO.	CONCENTRATION OF GELATIN IN SOLUTION	PER CENT GELATIN PICKUP	TENSILE STRENGTH IN LBS. PER SQUARE INCH
4632-5 A	5	6.3%	31,080 (stretched)
4632-5 C	10	15.1	31,620 (")
4632-5 D	12	19	21,292 (")
4632-5 E	15	24.8	29,220 (")
4632-5 F	20	11.9	23,615 (")

These results further confirm that the tensile strength increases with an increase in glass content. However, all samples "stretched", meaning they did not break with a snap. This indicated that the glass-gelatin system no longer acts as a unit and other properties such as stiffness are sacrificed.

It was at this point that we were requested to prepare (Sept. 10, 1965) 3-ply saturated laminates at various levels of gelatin pickup. These were prepared at levels of 22.4, 26.6, 36.3, 39.7, 45.1, 47.6, 51, and 59.7 per cent gelatin pickup, dried under tension at ambient conditions and sent to Viron for conditioning and testing. Results of Viron's tests on these specimens are not available.

SELECTION OF A SUITABLE LIQUIFIER OR FLUIDIZER TO INSURE PROPER VISCOSITY FOR SATURATION AT PRACTICAL TEMPERATURES

The following liquifying agents were investigated: urea, thiourea, ammonium thiocyanate, chloral hydrate, α-sodium naphthalene sulfonate, and β-sodium naphthalene sulfonate. These materials were tried at the 5, 10, and 20 per cent level in 25 per cent gelatin solutions at 40 C (104 F). The results of these tests have been plotted

in Figure 48. Beta sodium naphthalene sulfonate was omitted, subsequently because its limited solubility produced heterogeneous mixtures whose viscosities were without meaning.

Figure 48 shows that increased amounts of liquifier do not produce increased fluidity or decreases in viscosity. Since materials ordinarily referred to as liquifiers are actually hydrogen bond destroyers causing a drop in jelly strength, we should not expect great reductions in viscosities with these reagents. In addition, since the gelatin level is constant, any increase in liquifier takes place at the expense of an equal weight of water and this would be expected to cause some increase in viscosity.

Figure 48 further indicates that ammonium thiocyanate is the most effective liquifier but the positive slope of most of these curves indicated that the point of inflection lies somewhere below the 5 per cent level. This would then represent the minimum amount of liquifier yielding the maximum amount of reduction in the viscosities.

We studied the area below the 5 per cent liquifier level in greater detail and the results are shown in Figure 49. It is apparent that the minimum for most of the curves lies between 2 and 4 per cent level. No unexpected results were found and ammonium thiocyanate appears to be the most effective liquifier. Impregnating solutions of greater gelatin content than 25 per cent may be prepared and a viscosity study at a 30 per cent gelatin level has been made. The results so obtained are plotted in Figure 50. It is apparent that all levels except the unliquified 30 per cent gelatin sample are below the 1500 centipoise target. It would be to our advantage to use the absolute minimum necessary to achieve our objective and since the greatest amount of effect is obtained with the first 1 per cent, additional quantities, while lowering the viscosity still further, do not do enough to justify their use.

DETERMINATION OF OPTIMUM TECHNIQUES FOR CROSSLINKING THE GELATIN WITH FORMALDEHYDE AND REMOISTENING TO DESIRED FLEXIBILITY

Several procedures were evaluated including:

a. The moist saturated fabric exposed to gaseous formaldehyde at maximum humidity.

b. Spraying the formalin solution directly upon the saturated fabric.

c. Dipping.

d. Various combinations of crosslinking and remoistening to promote flexibility.

CROSSLINKING WITH FORMALDEHYDE VAPOR

The specimens were impregnated at 40 C., with 25 per cent and 30 per cent gelatin solution containing 1 per cent ammonium thiocyanate. The impregnates were handled after gelling but before drying by exposing to an atmosphere of formaldehyde, stacking them in a closed chamber over a surface of formalin (37 per cent aqueous formaldehyde). After 18 hours at 45 F in this chamber, the impregnates were dialyzed for 6 hours against ice water using the gelatin as its own membrane. Removed and air dried prior to remoistening to render flexible.

REMOISTENING BY SPRAYING

Samples of No. 181 glass fabric cleaned in "Hyscore" acid cleaner were impregnated with 25 per cent gelatin solution at 40 C while stapled to 6 in by 8 in wooden frames using the procedures outlined in our August report. After chilling some of the impregnates were air dried while others were cut out of the frames in the congealed state, wrapped in Saran and held under refrigeration until required.

In order to obtain some idea as to how rapidly a dry glass fabric-gelatin impregnate would redydrate to the desired pliability, the following experiment was carried out. A dry strip, 6 in. by 1 in. was clamped in a vertical position with the clamp at the bottom. One side of this strip was sprayed evenly with water. After ten minutes, the strip started to droop. After 20 minutes, the back side was still dry and a crease made by hand looked as if fiber fracture had taken place. After two more resprayings and 1 3/4 hours later the strip was pliable but still not tacky on the back side. This strip could not be folded and rolled without suffering any visible damage.

CONSECUTIVE REMOISTENING AND CROSSLINKING

Four 6 in. by 1 in. strips of dry impregnates were held between two clips horizontally and sprayed on one side several times over a 30-minute period followed by a formaldehyde spray over an additional 30-minute period. The samples were then folded, rolled, and heat sealed in a Mylar-Saran-polyethylene film. They are being held for stability and blocking tests. Table 33 summarizes the treatments.

TABLE 38

LAB. NO.	1st TREATMENT	2nd TREATMENT
C4632-40-B-1	30' Water	None
C4632-40-B-2	30' "	30' - 2% Formaldehyde
C4632-40-B-3	30' "	30' - 4 % "
C4632-40-B-4	30' "	30' - 8% "

COMBINED REMOISTENING-CROSSLINKING

Four samples were prepared as in the previous experiment and these were sprayed as summarized in Table 39.

TABLE 39

LAB. NO.	TREATMENT
C4632-39-A-1	Sprayed 1 hr. with water.
C4632-39-A-2	" " " 2% formaldehyde.
C4632-39-A-3	" " " 4% "
C4632-39-A-4	" " " 8% "

All samples were then folded, rolled, and sealed in the Mylar-Saran-polyethylene film for storage tests and for blocking.

CROSSLINKING OF CONCEALED FILMS

The following experiment using specimens that had only been congealed after dipping was performed. Four strips were mounted as usual and sprayed on one side with varying concentrations of aqueous formaldehyde over a 30-minute period. The summarized results are given in Table 40.

TABLE 40

LAB. NO.	TREATMENT
C4632-40-C-1	Packaged as is (control)
C4632-40-C-2	Sprayed with 2% formaldehyde
C4632-40-C-3	" " 4% "
C4632-40-C-4	" " 8% "

The treated specimens were folded, rolled, and sealed in the usual manner for storage and blocking tests.

REMOISTENING BY CONTROLLED HUMIDITY OPERATIONS

The use of relative humidities as high as 100 per cent failed to produce sufficient pliability to permit the folding of specimens without creasing and cracking. Because of the unfavorable results obtained further pursuit of this approach was abandoned.

As the impregnation solution we have used the 25 per cent gelatin solution. A multitude of samples were prepared and treated in various ways. Some of the variables tested were the length of time in formaldehyde vapor, with and without dialysis, with and without added formalin as a preservative. Table 41 summarizes the various factors:

TABLE 41

LAB. NO.	LENGTH OF TIME CROSSLINKED IN GASEOUS FORMALDEHYDE	DIALYZED 5 HOURS	FORMALIN ADDED TO PACKAGE TO PRESERVE
4632-23-D-1	1 hour	no	no
4632-23-D-2	1 hour	no	1 drop
4632-23-D-3	1 hour	yes	no
4632-23-D-4	1 hour	yes	1 drop
4632-24-E-1	3 hours	no	no
4632-24-E-2	"	no	1 drop
4632-24-E-3	"	yes	no
4632-24-E-4	"	yes	1 drop
4632-24-F-1	5 hours	no	no
4632-24-F-2	"	no	1 drop
4632-24-F-3	"	yes	no
4632-24-F-4	"	yes	1 drop
4632-24-G-1	72 hours	no	no
4632-24-G-2	"	no	1 drop
4632-24-G-3	"	yes	no
4632-24-G-4	"	yes	1 drop

All samples were stored in the sealed Mylar-Saran-polyethylene film overwraps. These samples were to provide answers to such questions as: How much time is required to adequately crosslink the resin so that it won't block? Is it possible to overdo the crosslinking step? Is dialysis really required to remove the liquifier and does it also remove the crosslinking agent? Finally, is an added preservative necessary or is the crosslinked material sufficiently stable to require no further

treatment?

All of these questions were answered after three months of aging followed by a critical examination of the specimens.

SAMPLES REHYDRATED AND CROSSLINKED BY SPRAYING

C4632-40-B1-	Musty - blocked
C4632-40-B2-	Moldy
C4632-40-B3-	Blocked at edges, otherwise acceptable
C4632-40-B4-	Slight blocking--some cracking at the folds.

Conclusion: None of these were excellent.

COMBINATION OF REMOISTENING AND CROSSLINKING BY SPRAYING

C4632-39-A-1	Moldy
C4632-39-A-2	No blocking but glass fabric ruptured at the folds
C4632-39-A-3	Some blocking, glass fabric weak at the folds
C4632-39-A-4	Stiff, glass fabric weak at the fold

None of these could be recommended.

CROSSLINKING BY SPRAYING UNDRIED IMPREGNATES

C4632-40-C-1	Blocked badly
C4632-40-C-2	Some blocking - otherwise good
C4632-40-C-3	Some blocking - otherwise good
C4632-40-C-4	Blocked - somewhat "cheesy", not good

Conclusion: Spraying of formaldehyde does not give the best properties to gelatin.

SAMPLES CROSSLINKED WITH GASEOUS FORMALDEHYDE FOR VARYING LENGTHS OF TIME

4632-23-D-1	Small amount of blocking, no spoilage, rolls up spontaneously
4632-23-D-2	Very small amount of blocking, no putrifaction slight cheesiness, could be used
4632-23-D-3	Liquified but not putried
4632-23-D-4	Perfect - no blocking, no spoilage

4632-23-E-1	No blocking - stiff - resists unfolding - somewhat cheesy - overcrosslinked
4632-23-E-2	No blocking - some slight cracking - seems less cheesy than E-1. Fair, could be used

4632-23-E-3 Liquified, sl. musty odor - unsatisfactory
4632-23-E-4 Excellent - no blocking - small amount of creasing - could be used

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4632-24-F-1 No blocking - overcrosslinked, cracked as it was unrolled
4632-24-F-2 No blocking - slightly better than F-1
4632-24-F-3 Liquified - unsatisfactory
4632-24-F-4 Liquified - unsatisfactory

4632-24-G-1 No blocking - crazes as it is unrolled - crumbly
4632-24-G-2 Same as G-1
4632-24-G-3 Crumbly - crazes as it is unrolled
4632-24-G-4 Same as G-3, also weak.

Conclusion: Ideal crosslinking time between 1 and 3 hours. Dialyzed specimens are usable at somewhat longer crosslinking time - Recommended about 1 1/2 hours in gaseous formaldehyde with no dialysis.

REPLASTICIZING WITH DILUTE FORMALIN

A number of finished impregnates were prepared from 25 per cent gelatin solution which were crosslinked in an atmosphere of formaldehyde for a period of 18 hours at 70 F. Excess formaldehyde was removed by an eight-hour dialysis in ice water. These sheets were air dried to shiny, hard impregnates. These impregnates could not be folded, even after storing in a high humidity environment but hydrated beautifully in water. A sample soaked for 10 minutes was held in air for an additional 30' and then packaged as 18A. A similar sample packaged at once after the 10' soak was labeled 18B.

Taking into consideration that these samples might not be stable to bacterial attack if moistened only with water, we have remoistened some of them with formaldehyde of different strengths. We recognize that too much formaldehyde tends to make the gelatin "cheesy" and causes strength losses. Thus, we would want to use the minimum amount required. Table 42 summarizes the test samples of the series:

TABLE 42

LAB. NO.	REMOISTENED WITH FORMALDEHYDE SOLUTION BY DIPPING FOR 20-25 MIN.
4632-25-A	Water (control)
4632-25-B	0.1% Formaldehyde
4632-25-C	0.2% "
4632-25-D	0.4% "
4632-25-E	0.8% "
4632-25-F	1.0% "
4632-25-G	1.6% "
4632-25-H	2.0% "

All samples were packaged hermetically and held for 3 months storage life.

At the end of this period the following evaluations were made:

C4632-25-A - Semi fluid - sticky not unrollable
C4632-25-B - Some blocking, some liquifaction
C4632-25-C - Some blocking, slightly sticky and tender
C4632-25-D - Fair - sharp fold broke gelatin film cheesy
C4632-25-E - Cheesy - too far crosslinked
C4632-25-F - Breaks on creasing - no good
C4632-25-G - Cheesy, no good
C4632-25-H - Very cheesy - no good

Conclusion: Remoistening with dilute formaldehyde seems to yield poor results. Not recommended.

To combine the remoistening and crosslinking steps into on operation, dry impregnates which had not been previously crosslinked were remoistened and crosslinked by soaking for 35 minutes in the formaldehyde solutions. Table 43 summarizes this series:

TABLE 43

LAB. NO.	TREATMENT (SOAKED FOR 35' IN SOLUTION THEN PACKAGED IN FILM
4632-26-A	Water (control)
4632-26-B	0.1% Formaldehyde
4632-26-C	0.2% "
4632-26-D	0.4% "
4632-26-E	0.8% "
4632-26-F	1.2% "
4632-26-G	1.6% "
4632-26-H	2.0% "

All samples were packaged and held for storage test. It is worth noting that the samples in the higher concentrations of formaldehyde were weak and crumbly and tended to be tender during the rolling up operation. This appears not to be the case when gaseous formaldehyde is used as the crosslinking agent.

No special tests investigating the interruption of the drying step short of completion were undertaken because some of the work under "dipping" covered this operation.

3 Months storage resulted in the following evaluation:

4632-26-A - Liquified - not putrid
4632-26-B - Liquified - no gell strength left
4632-26-C - Very slightly sticky, no blocking, no overcross-linking, no crazing at the folds, could be used
4632-26-D - Some blocking, cheesy, overcrosslinked
4632-26-E - Cheesy - unsatisfactory
4632-26-F - Cheesy - unsatisfactory
4632-26-G - Cheesy - exudes some surface moisture
4632-26-G - Cheesy - exudes formaldehyde vapor and excess moisture

Conclusion: Simultaneous crosslinking and remoistening is not promising.

USE OF ANTIBLOCKING AGENTS

The use of hydrophobic materials as antiblocking agents was investigated. The materials considered were white mineral oil, kerosene, and silicone oil. These were sprayed onto water plasticized gelatin-glass impregnate which had previously been crosslinked for 1 hour in an atmosphere of formaldehyde. Table 44 summarizes the results:

TABLE 44

LAB. NO.	TREATMENT
4632-41-1	No treatment (control)
4632-41-2	1 hr formaldehyde gas (control)
4632-41-3	" sprayed with kerosene on one side
4632-41-4	" sprayed with 50% mineral oil in hexane
4632-41-5	" sprayed with silicone oil-aerosol type

The specimens were packaged and held for 3 months storage life, with the following results:

4632-41-1 - Liquified
4632-41-2 - Extremely cheesy - no good
4632-41-3 - No blocking - but too cheesy
4632-41-4 - No blocking - but cheesy
4632-41-5 - Very good - no blocking - cheesy

Conclusion: All of them could be used. The cheesiness has nothing to do with agent, but does make antiblocking agent look better than it really is. We would recommend kerosene as a first choice.

OBSERVATIONS OF TORTURE AND SHRINKAGE EFFECTS DURING RIGIDATION OF SPECIMENS FLEXIBILIZED WITH VARIOUS SOLVENT SYSTEMS

A number of organic solvents having comparatively high dielectric constants for use with water were selected as remoistening media for dried impregnates of glass fabric and gelatin. The solvents chosen were methanol, ethanol, acetone, and tetrahydrofurane. All of these compounds exhibit a polarity indicating some of the solvent characteristics of water. In order to study the effect of varying the solvent-water ratio, different compositions were prepared varying from each other by 20 per cent increments. It was hoped also that these organic solvents might exert some effect upon an increase in diffusion rates, which we believe are critical in the overall rate of evaporation. Additional factors studied were the presence or absence of an ammonium thiocyanate fluidizer and the presence or absence of a dialysis purification step.

PREPARATION OF TEST SPECIMENS

Samples of No. 181 glass fabric were cleaned in Swift's "Hi Score" acid cleaner. After rinsing and drying these were impregnated while stapled to 7 in. by 9 in. pine frames using the procedures outlined in our August report. Two kinds of impregnating solutions were used, namely: 25 per cent gelatin solution in water with and without 1 per cent ammonium thiocyanate. Each of these solutions was used to impregnate five frames of glass fabric. After congealing, some of these specimens were dialyzed to remove the ammonium thiocyanate while others were not. All samples were then air dried, cut out of their frames and used to prepare test specimens. The object was to obtain up to 6 test strips of 1 in. by 6 in. plus a representative sample to be used for the resin pickup determination. This objective was achieved by trimming the panel to a 6 in. by 7 3/4 in. size and cutting in alternating manner a 6 in. by 1 in. test strips. The entire seven 1/4 in. strips were dried and ashed to determine the resin pickup while the six 1 in. strips were used for the test work.

REMOISTENING OF DRY IMPREGNATES

Remoistening was carried out in the following manner: 0, 20, 40, 60, 80, 100 per cent aqueous solutions of methanol, ethanol, acetone, and tetrahydrofurane were prepared. One strip from a set of six cut from a given panel was placed into each of the solvent levels of one particular solvent. After two hours, the specimens were removed, inspected for plasticity and packed for further testing. If a sample was pliable and did not crack or craze on creasing, it was passed for further testing. The sample was divided so as to yield two pieces, one 2 1/2 in. long, the other 3 1/2 in. long. These samples were sealed into separate Mylar-Saran-polyethylene envelopes. The smaller pieces were used for determining distortion and torture during drying while the other specimen was used to find the rate of solvent loss under high vacuum. Table 45 summarizes the treatments and the results obtained during the remoistening operation.

TABLE 45

REMOISTENING OF GLASS-GELATIN IMPREGNATES

LAB. NO.	AMMONIUM THIOCYANATE	DIALYZED	ORGANIC SOLVENT	PER CENT ORGANIC SOLVENT	RESIN PICK-UP	REMOISTENING RESULTS
4632-46-10-0	No	No	Methanol	0	49.7	Very good-curled
" " " -20	"	"	"	20	"	Very good
" " " -40	"	"	"	40	"	Very good
" " " -60	"	"	"	60	"	V.sl. sticky
" " " -80	"	"	"	80	"	O.K.
" " " -100	"	"	"	100	"	
" -45-1-0	1%	No	Methanol	0	47.3	Good-somewhat tender
" " " -20	"	"	"	20	"	Good-curled even while wet
" " " -40	"	"	"	40	"	Good
" " " -60	"	"	"	60	"	Good
" " " -80	"	"	"	80	"	Very good
" " " -100	"	"	"	100	"	Insufficiently soft
" -42-6-20	No	Yes	Methanol	20	54	Good
" " " -40	"	"	"	40	"	Poor-very swelled
" " " -60	"	"	"	60	"	Sticky
" " " -80	"	"	"	80	"	Dryish but pliable
" " " -100	"	"	"	100	"	N.G.

LAB. NO.	AMMONIUM THIOCYANATE	DIALYZED	ORGANIC SOLVENT	PER CENT ORGANIC SOLVENT	RESIN PICK-UP	REMOISTENING RESULTS
4632-45-2-0	1%	Yes	Methanol	0	45.2	Good
" " "-20	"	"	"	20	"	V.sl. sticky
" " "-40	"	"	"	40	"	Sl. sticky
" " "-60	"	"	"	60	"	" "
" " "-80	"	"	"	80	"	Dryish
" " "-100	"	"	"	100	"	Hard
4632-44-7-20	No	Yes	Ethanol	20	49.6	V.sl. sticky
" " "-40	"	"	"	40	"	Sl. sticky
" " "-60	"	"	"	60	"	" "
" " "-80	"	"	"	80	"	Good
" " "-100	"	"	"	100	"	Hardish
"-45-3-0	Yes	Yes	Ethanol	0	50.2	Good
" " "-20	"	"	"	20	"	Sl. sticky
" " "-40	"	"	"	40	"	Sticky
" " "-60	"	"	"	60	"	Sticky on handling
" " "-80	"	"	"	80	"	Dry
" " "-100	"	"	"	100	"	Incompletely softened
"-44-8-20	No	Yes	Acetone	20	48.8	Sticky
" " "-40	"	"	"	40	"	Sticky
" " "-60	"	"	"	60	"	Fair
" " "-80	"	"	"	80	"	Good
" " "-100	"	"	"	100	"	N.G.
4632-46-4-0	1%	Yes	"	0	48.7	O.K. little tender
" " "-20	"	"	"	20	"	Sticky
" " "-40	"	"	"	40	"	O.K.
" " "-60	"	"	"	60	"	O.K.
" " "-80	"	"	"	80	"	O.K.
" " "-100	"	"	"	100	"	Incomplete
4632-44-9-20	No	Yes	Tetra-hydro-furane	20	50.6	Swelled N.G.
" " "-40	"	"	"	40	"	Very sticky
" " "-60	"	"	"	60	"	Sl. sticky
" " "-80	"	"	"	80	"	Good
" " "-100	"	"	"	100	"	Hardish
" 46-3-0	1%	"	"	0	47.1	O.K.
" " "-20	"	"	"	20	"	Sticky
" " "-40	"	"	"	40	"	Very sticky
" " "-60	"	"	"	60	"	Sl. sticky
" " "-80	"	"	"	80	"	Good
" " "-100	"	"	"	100	"	Hardish

CONCLUSIONS REGARDING REMOISTENING

The effects of the various factors appear to be best discussed by taking them one at a time and eliminating those samples which performed poorly. Thus the number of samples to be discussed with the next factor is reduced and a final choice is more readily determined.

PRESENCE OF FLUIDIZER

The lack of difference between samples containing ammonium thiocyanate and those that do not when tested with methanol formulations indicate that the removal of the thiocyanate is not required.

EFFECT OF DIALYSIS

Dialysis appeared to make the gelatin film more susceptible to solvents, and tended to create a sticky surface. For this reason we would prefer to avoid a dialysis step.

NATURE OF SOLVENT

Tetrahydrofurane appeared to have strong liquifying properties. Acetone was less objectionable but retained enough liquifying properties to cause it to be rejected in favor of the two aliphatic alcohols. Comparison of methanol and theanol indicated a small advantage in favor of methanol. We would tentatively consider the use of either methanol or ethanol in the 20-40 per cent range, with or without ammonium thiocyanate but without dialysis.

DISTORTION AND TORTURE

An empirical approach was used in the evaluation of distortion and torture. Samples of remoistened specimens cut to exactly 1 in. by 2 in. size were laid flat on perforated desiccator plates. The plates were very lightly coated with a silicone oil to prevent adhesion. All the samples were then stacked in the vacuum chamber and evacuated to about 0.1 mm of mercury for six days. The samples curled to varying degrees as illustrated in Figure 51. Of the samples which curled in the short dimension some curled away from the supporting plates while others curled towards them. This indicated that contact with the supporting surface was not the predominant factor responsible for the curl. It is entirely possible that the curl is due to such uncontrolled variables as the variability of the thickness of the gelatin film or the failure of the glass fabric to be positioned precisely in the center of the film. Then too, the glass fabric appears to have two dissimilar sides. The nonhomogeneous nature of the dried surfaces of some of the samples, notably those of the lower levels of acetone

(46-4-20) and of tetrahydrofurane (46-5-20), (44-9-20) indicated that these solvents are least likely to be successful. We have thus restricted ourselves to methanol and ethanol at room level, the final choice of which is best made on the basis of the rate of solvent loss in vacuum.

RATE OF SOLVENT LOSS UNDER HIGH VACUUM

The experimental procedure used to determine the rates of solvent loss from and the change of temperature of remoistened glass fabric-gelatin impregnates is described below.

The apparatus used to determine rates of evaporation of solvents from the samples of gelatin-coated glass is shown in Figure 52. It consists of two basic parts: a high speed high vacuum system on the left hand side of the Figure 52 and an electro-balance, (Cahn R.G.) enclosed in a glass container, on the right hand side of the Figure 52. A more detailed view of the balance is shown in Figure 53.

Two samples of gelatin-coated glass, remoistened with solvent of known composition, were placed in A (see Figure 53). One of them was suspended on a glass fiber from electro-balance at B, the other attached to chromel-alumel thermocouple at C. The reference junction of thermocouple D was placed in 0 C temperature bath E.

Next the stopcock A (Figure 52) was closed, mechanical and mercury diffusion pumps turned on and the left hand side of the system evacuated to a pressure lower than 10^{-6} mm Hg. as indicated on McLeod gage B. After the initial weight of the sample was recorded on a strip chart recorder C, and temperature of the sample measured using precision potentiometer (not shown) stopcock A was opened and the balance compartment D evacuated. The loss of weight and changes in temperature were measured for about 3 hours. To determine the pressure changes in the balance compartment during the run Pirani gage F was used. To remove the residual amounts of solvent each sample was heated to approximately 95 C for 15 hours and the amount of dry gelatin in each sample determined.

The mode of operating the vacuum apparatus restricted us to two samples per 24 hour period. A sample was evacuated for three hours to determine the important points for the evaporation and temperature curves. Then the first sample was put into the bottom of the vacuum chamber and a second sample was tested for three hours. Finally, both samples were run until the following day. Thus one sample was run 24 hours and the other 20 hours. The values obtained for the final weight loss were not much lower than those of three hours. Consequently, in drawing the curves for these tests, values beyond 180 minutes have been omitted.

A study of the curves, Figures 54, 56, 58, 60, 62, and 64, showing solvent content basis gelatin plotted against time under vacuum must be considered in the light of the temperature vs., time curves, Figures 55, 57, 59, 61, 63, and 65. There are various factors which must be weighed:

a. In the methanol-water remoistened specimens those containing ammonium thiocyanate registered a much higher solvent pickup than did those containing no thiocyanate. The curves vary markedly in shape and it is fair to assume that the methanol water ratio varies rapidly because of the greater volatility of the methanol. This is further evidenced by the fact that all curves approach the same end-point namely, water as the principal residual solvent. The ammonium thiocyanate not only facilitates solvent pickup but retards solvent loss as well. This is explained by the normal hygroscopicity of the salt. It would appear that the fluidizer should not be used unless absolutely necessary since reflexibilizing procedures would have to be sharply controlled to avoid the pickup of excessive amounts of plasticizing solvent.

b. The temperature-time curves provide a significant indication as to the rate of diffusion of the solvent from the interior of the specimen to the surface where it flashes its vapor.

Examination of the temperature-time curves revealed that the samples were subject to very rapid cooling as the surface solvent was vaporized. Within a few minutes and long before more than a minor fraction of the solvent was removed, a minimum was reached. At this point any further evaporation taking place is limited by the rate at which the solvent is able to diffuse to the surface of the gelatin. This assumption is strengthened by the fact that heat from the surroundings is able to gradually raise the temperature in spite of the evaporation still taking place. That such evaporation does take place is proven by the companion chart showing the weight loss-time relationship.

Therefore, an empirical relationship appears to exist between the rate of diffusion of solvent to the surface of the laminate and the "bluntness" of the minimum point on the temperature-time curve.

Noting the attached time-temperature curves for ethanol-water and tetrahydrofuran-water systems the water alone produces the most

blunt or rounded minimum point and there is a "ripple" in the curve at the subsequent incline. We conclude from this that there is freezing of the water and hence a much slower recovery of environmental heat. This same ripple occurred in the water curve shown with the methanol curves but only when ammonium thiocyanate was present. The hump was not apparent when the thiocyanate fluidizer was eliminated. Any explanation for this variation is most difficult because of radiant heat sources which might have prevented freezing. Since no "humps or ripples" were present in any of the other curves we are forced to conclude that the broadness of the water curve minimum points are not a measure of diffusion because of freezing. The solvent mixture curves however are believed to afford an approximate picture of the diffusion rates.

From a study of all the curves made it appears that 40 per cent aqueous ethanol, 20, 40, 60, or 80 per cent aqueous methanol and 20 or 40 per cent aqueous acetone all offer distinct possibilities in the light of their diffusion and evaporation rates. Whether or not one concentration or organic solvent-water system is preferred to another will depend upon temperature minimums achieved in an extra terrestrial atmosphere.

Since the capacity of the laboratory equipment used was relatively minute as compared with the capacity of outer space, pressure could not be maintained below 10^{-3} Torr as long as any vaporization was taking place.

It was proposed that larger vacuum chambers would be necessary before the possibility of "gassing" of the solvents would be a problem. The rate of rigidization as a result of solvent loss could be measured only in a much larger chamber where hard vacuums could be maintained during solvent vaporization. The curves plotted during the study completed so far were extended to 2 or 3 hours before true rigidization took place.

Large test specimens were requested for hard vacuum testing at the prime contractor's facility and a minimum of four samples for each recommended treatment was delivered at the time of the final meeting which took place in Minneapolis, January 27, 1966. These test specimens were prepared as follows:

Swift's Superclear 6-20 gelatin was made up with distilled water to yield a 25 per cent solution. After melting and bringing to 40 C, No. 181 glass fabric cleaned with Swift's Hi-Score acid cleaner and tacked onto 5 in. by 8 in. pine frames was impregnated, congealed, and crosslinked by placing into an atmosphere or formaldehyde for 2 1/2 hours. The atmosphere of formaldehyde was that which resulted when an open surface of 37 per cent aqueous formaldehyde in a closed container was allowed to reach equilibrium with the space above it. The gelled impregnates were stacked into the container above the liquid formaldehyde solution in such a way that all surfaces were freely accessible to the vapors. After 2 1/2 hours, the frames were removed and allowed to dry. When dry the impregnates were cut out, trimmed to their final size of 5 in. by 7 in. and subjected to one of the four treatments enumerated below:

1. Remoistened with water at 20 C for 2 hours.
2. Remoistened with 20 per cent methanol (by weight) at 20 C for 2 hours.
3. Remoistened with 80 per cent methanol (by weight at 20 C for 2 hours.
4. Remoistened with 80 per cent No. 30 alcohol (by weight) at 20 C for 2 hours.

At the end of this time, the specimens were removed and wrapped in aluminum foil until they could be folded and packaged. A more detailed discussion regarding the individual series follows:

REMOISTENED WITH WATER ALONE

The remoistening operation yielded good supple sheets but two hours appeared to lead to excessive water inhibition. This in turn caused some fragility of the gelatin film. Therefore, we would consider the two hour period to be the maximum with the optimum at some shorter time period to be determined under actual application conditions. The samples were labeled 4632-74-A.

REMOISTENED WITH 20 PER CENT METHANOL

The samples remoistened well and appeared to be satisfactory. They were labeled 4632-74-B.

REMOISTENING WITH 80 PER CENT METHANOL

The samples remoistened sufficiently well so that they could be

folded. There were areas which while plastic had not yet reached equilibrium with the liquid. Such areas were lighter in color indicating less penetration of the remoistening solution. The areas around the edges were more thoroughly penetrated as indicated by their translucent appearance. These samples should be inspected carefully at a later date in order to determine if the final equilibrium state resulted in a more equitable plasticizer distribution. The samples were labeled 4632-74-C.

REMOISTENED WITH 80 PER CENT NO. 30 ALCOHOL

No. 30 alcohol is 95 per cent ethanol to which one gallon of methanol has been added for every ten gallons of ethanol. The specimens remoistened permitted folding, however, there were what appeared to be incompletely equilibriated areas. These samples after folding and packaging lost this spottiness in a few days indicating that two hours was insufficient time to permit equilibrium to be reached. No other reason was apparent as to why this formula should not prove to be acceptable. The final decision should be made on the basis of results obtained when the package is opened, unfolded, and dried. These samples were labeled 4632-74-D.

CROSSLINKING AND DEHYDRATION IN ONE STEP

We have in mind a simplified procedure resulting from the consolidation of several consecutive steps. Thus, instead of crosslinking in gaseous formaldehyde and then drying and finally remoistening with our chosen solvent mixture we would put the gelled impregnate into the methanolic formaldehyde, and at the end of the immersion period be able to withdraw a crosslinked, plasticized impregnate.

Experimentally, the following test was carried out. Four impregnates were prepared as usual and after gelling were immersed in 1 per cent formaldehyde solution made up in 80 per cent methanol. After several hours, the impregnates had swelled more than usual; after 24 hours, the impregnates were still overswelled but were not weak. These samples, 4632-75-A, were packaged for further testing. It should be pointed out that if a less plasticized material is desired, this could easily be obtained by decreasing the water content in the methanol.

CROSSLINKING FOLLOWED BY SOLVENT EXCHANGE

Taking into consideration the possibility that the above consolidation of steps is too extreme, we have investigated a two-step process where the gelled impregnate is crosslinked with formaldehyde vapor but instead of drying, the water is merely displaced with methanol. Four

replicates so prepared were labelled 4632-73-A. All samples were suitably packaged for testing in a hard vacuum at Viron.

As part of a telephone conversation with Mr. Ivan Russell, it was agreed that further studies on these specimens in high vacuum would be carried out at Viron rather than at Cook Electric as proposed in the November report.

CONCLUSIONS AND RECOMMENDATIONS

Throughout this research program certain conclusions have been drawn in the light of those process steps which seem to be required for the successful saturation of fabric structure which in turn must be expanded and rigidized in space.

These steps are listed as follows with appropriate comments as to the preferred procedures to be employed:

1. Cleaning of the fabric so as to improve the bonding with the gelatin resin system. In the case of glass fabric, an acid cleaner such as Swift's Hy-score Cleaner was satisfactory. No work has been done with nylon, Dacron, or other materials but it is assumed that some kind of cleaning to remove sizing material should be effected.

2. Saturation of the woven structure with an air free solution of gelatin in water at an elevated temperature 110-140 F. Concentrations up to 25 per cent gelatin may be used without exceeding the limit of 1500 cps. Fluidizers are optional.

3. Inflation or positioning so as to produce the desired structure and permitting the gelatin to set to a firm gel.

4. Crosslinking is effected preferably by exposure to formaldehyde vapors.

5. The structure is rigidized by drying in its final form.

6. Reflexibilized by remoistening with a suitable plasticizing solvent. Although water alone is quite satisfactory somewhat better diffusion to the surface can be effected by using co-solvents such as water soluble alcohols, or ketones. These serve as antifreeze agents and hence, greatly accelerate the flow of the volatile components to the surface of the structure for evaporation. High boiling plasticizer may well be suitable but will be much slower in reaching the desired volatile state.

7. Final packaging of the flexible structure with some excess formaldehyde to insure adequate storage life and a non-blocking agent such as kerosene or light mineral oil.

As a result of all variations studied in this program the following recommendations are made a part of this final report:

Any concentration up to 25 per cent gelatin can be used. A course grind is preferred so that the gelatin can be thoroughly moistened with cold water with a minimum of stirring. 4 to 6 mesh particle size permits thorough wetting with almost no entrapment of air. One or two hours soaking in the cold water results in complete swelling of the gelatin with no residual free water being apparent. This granular gel should not be agitated so as to avoid air entrapment with the resultant and problem of foam scum on the surface. Instead the swollen granules are melted by indirect heat without stirring until the mass is clear and fluid.

Upon completion of the saturation and while still warm the structure should be maintained in its inflated form and held in this way under a plastic hood while crosslinking is effected with formaldehyde vapor. The vapor may be generated from a fogging or atomization of commercial formalin or by introducing the formaldehyde into the air used for inflation. If possible this should be done at as high a temperature as is practical in order to permit the gelatin resin to migrate uniformly throughout the fibers before fixation with the aldehyde.

From this point on drying is effected while the structure is in its erected form and continued until the structure is rigid.

Remoistening to render flexible for packaging can be effected by water alone or aqueous solutions of methanol or ethanol to which a little formalin is added. This can be done by pumping the voids of the structure full of the solvent mixture until the desired flexibility is obtained. 80 per cent methanol or ethanol and 20 per cent water is considered optimum since the amount picked up is self limiting. Another advantage is the degree of antifreeze protection and the extremely rapid rate of rigidization.

Prior to folding for packaging the structure should be fogged with kerosene mist as an excellent lightweight volatile antiblocking lubricant.

Various modifications of this sequence have been delivered to the prime contractor in the form of 5 in. by 7 in. specimens folded and hermetically sealed in individual plastic envelopes.

FINAL MEETING WITH PRIME CONTRACTOR

On January 27, 1966, the leader of this project met with the technical personnel of the prime contractor and the final samples were delivered for further testing by Viron.

During the discussion of the various problems anticipated in the

making of the larger structures we made numerous suggestions to the Viron personnel. As a matter of record these are outlined as follows:

1. In the construction of very large solar Collectors the various segments in the shape of a "piece" of pie could be fabricated individually and bonded into final form using gelatin as the adhesive.

2. In the saturation of large shelters using the fluted fabrics in cylindrical form a practical method would comprise a dipping tank with double wall construction. The inner wall would feature a circumference equal but slightly smaller than that of the inner wall of the cylindrical shelter. The outer wall would be large enough to permit the fabric to be dropped in and expanded by means of wooden or plastic "mandrels" in the flutes after filling the annular-shaped tank with the gelatin resin the mandrels would be withdrawn slowly thereby drawing the warm solution through the fabric mesh. The saturated cylinder with fluted walls now expanded would be drawn slowly out of the tank so as to permit as much run off as desired. The remainder could be gelled rapidly by cold air as desired. The uniformity of the resin pickup could be controlled by the concentration of the gelatin solution, temperature of the solution, and rate of withdrawal from the tank. The important point is that the fluted cylinder would remain inflated during the slow removal from the annular tank. The possibility of multiple dips using less concentrated gelatin solutions should not be overlooked.

3. In the "beefing up" of saturated fabric structure thin sheets of gelatin jelly can be made up with predetermined thickness and concentration. These can be laid over any surface and penetrated by means of fusing with a heat lamp.

4. Finally, it was suggested that similar strengths can be achieved at much less weight if glass fabric were replaced by silk, wool, hair, collagen or any other protein fiber. The use of nylon and Dacron already under study make use of this density advantage.

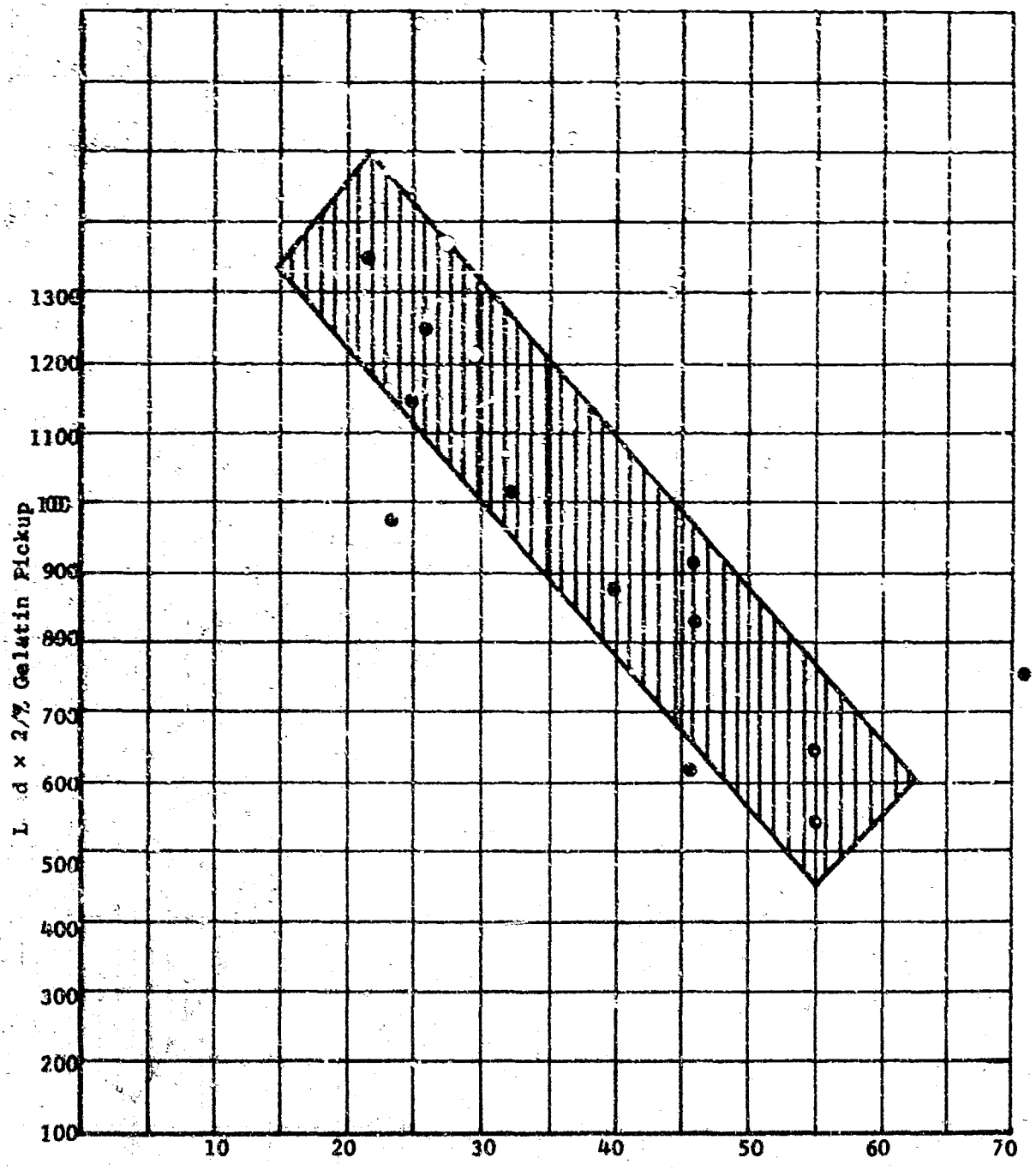

Figure 46 Twice the Load Divided by Per Cent Gelatin Pickup vs. Per Cent Gelatin Pickup.

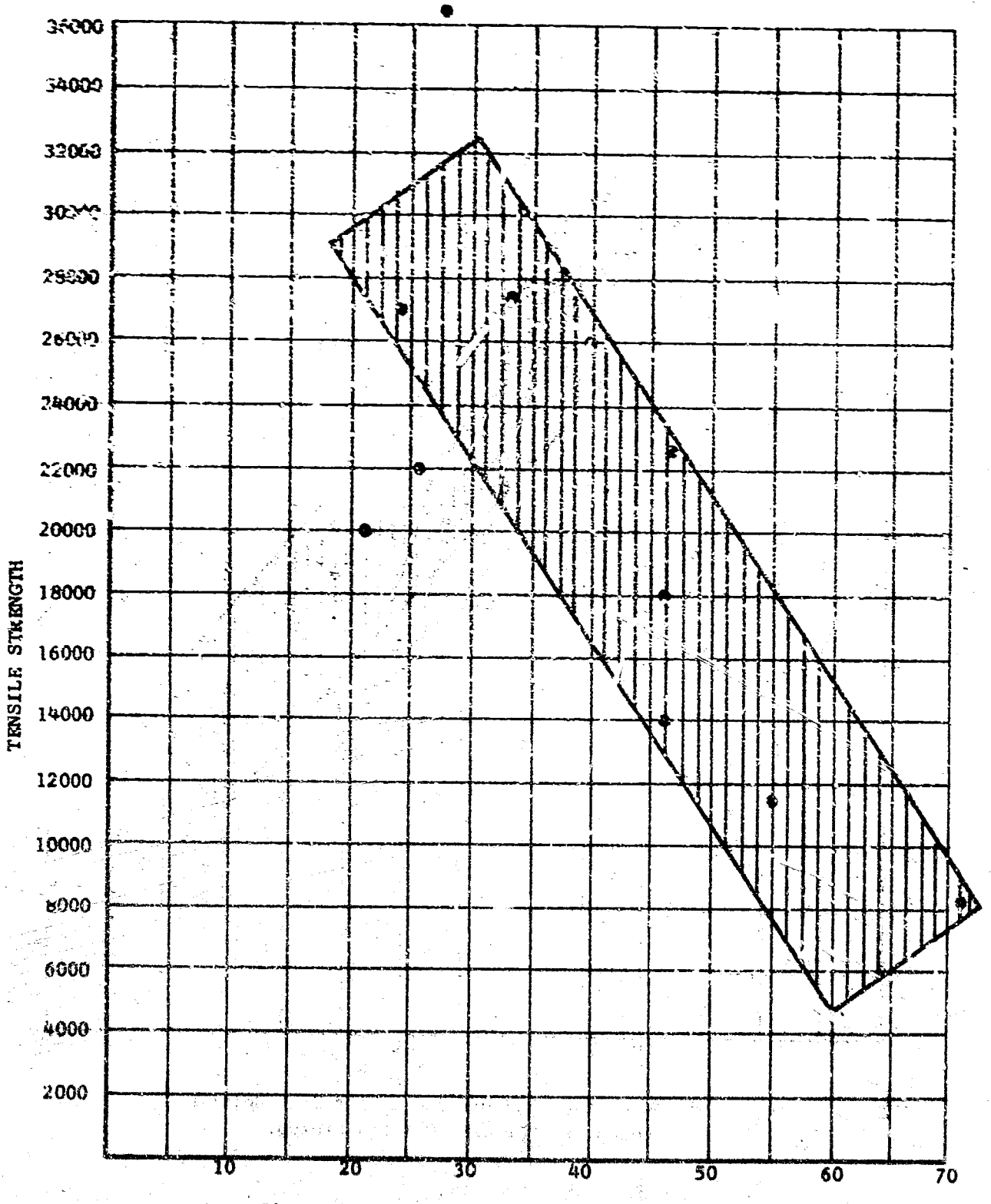

Figure 47 Tensile Strength vs. Per Cent Gelatin Pickup

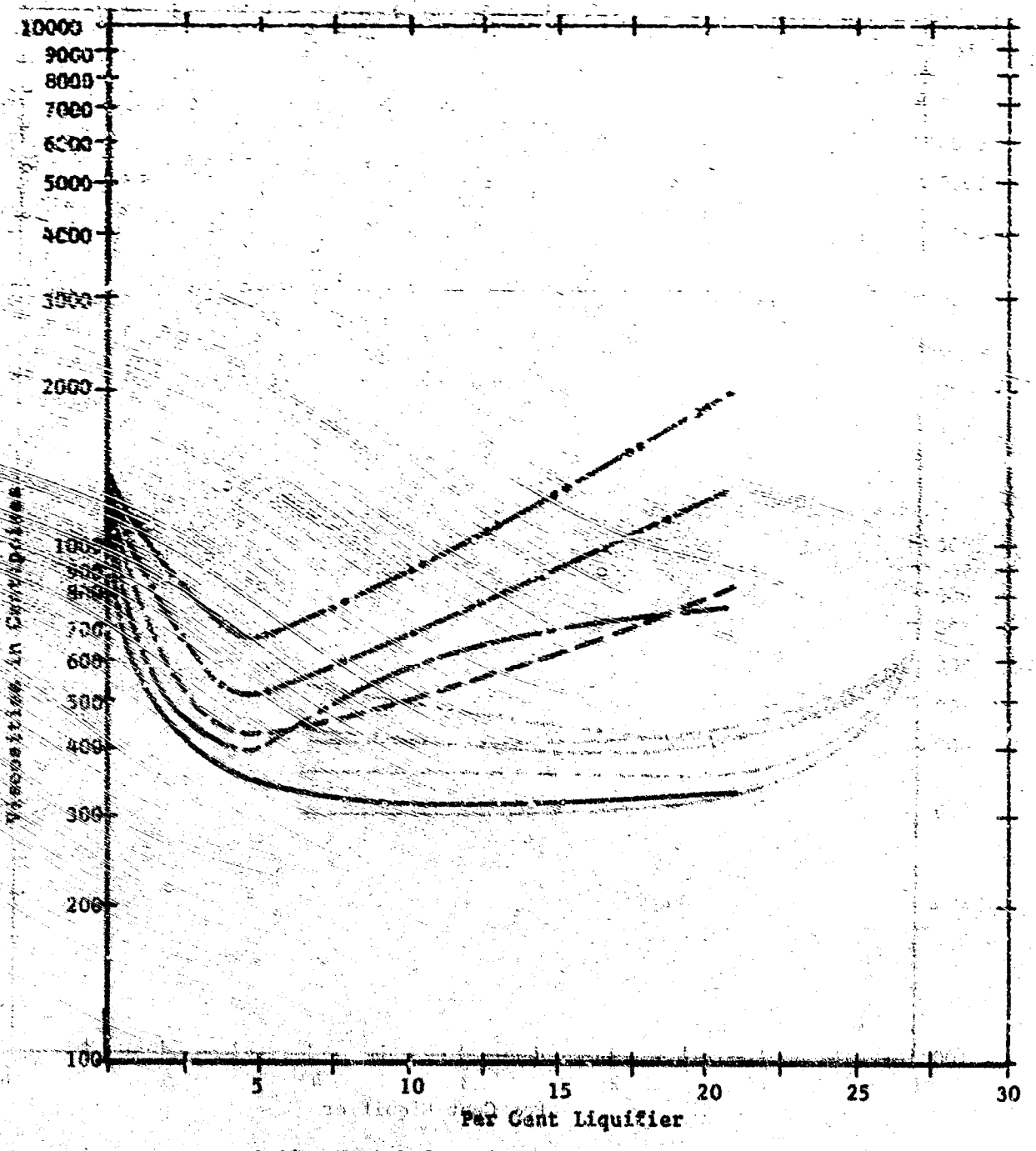

Figure 48 Viscosities of 25 Per Cent Gelatin Solutions at 40° C

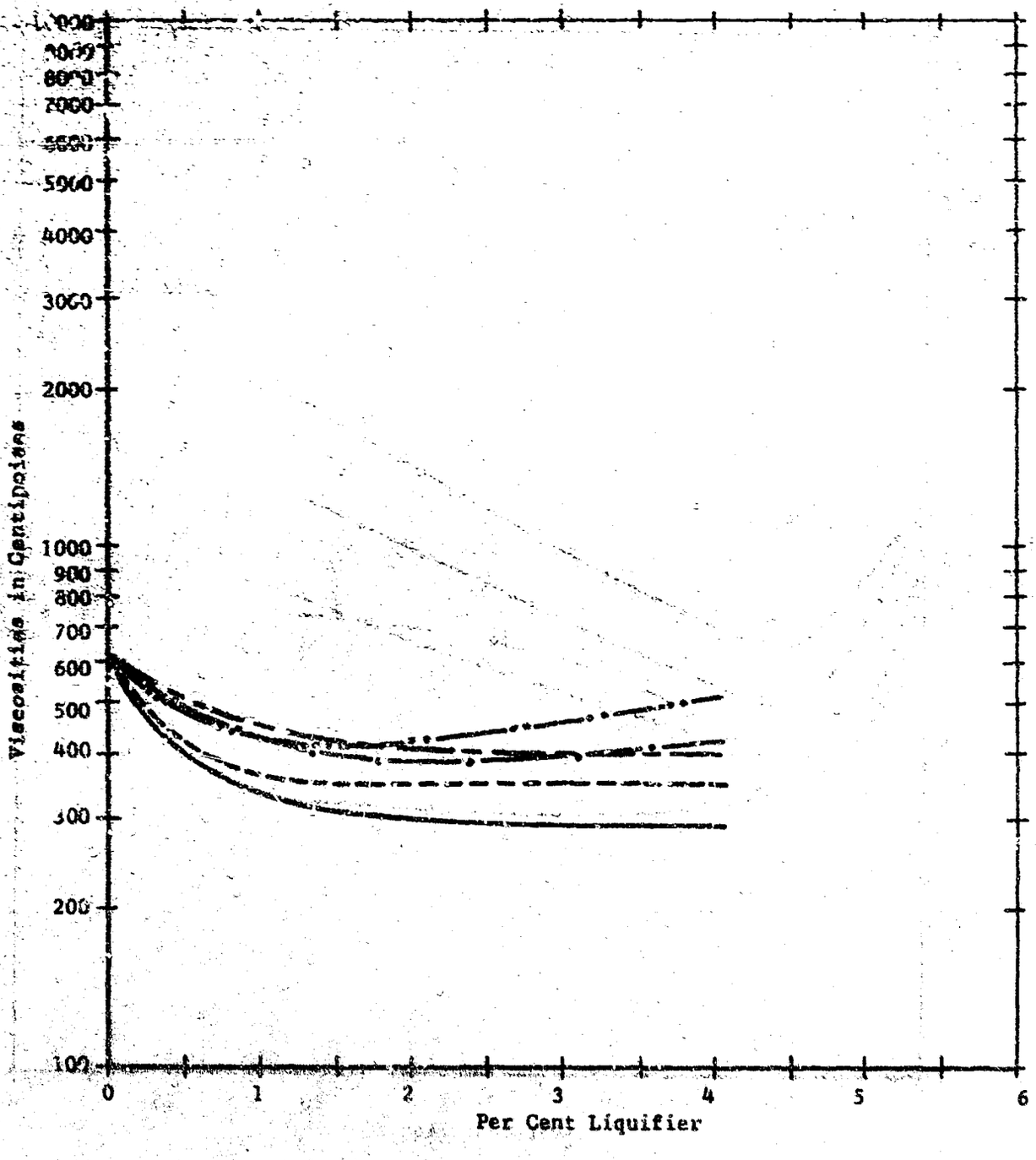

Figure 49 Viscosities of 25 Per Cent Gelatin Sol'n at 40 C with Lower Ranges of Liquifiers

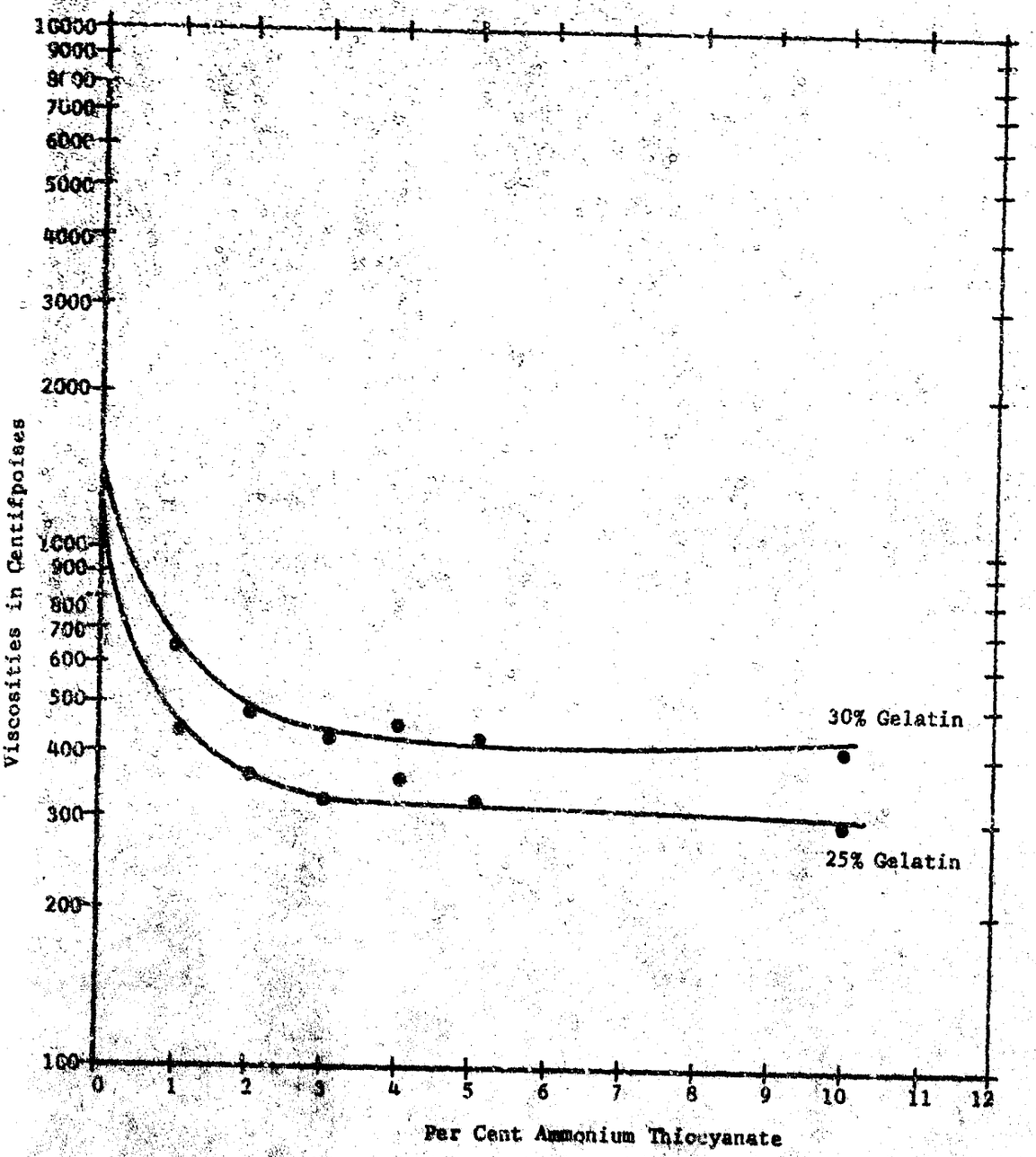

Figure 50 Viscosities of 25 and 30 Per Cent Gelatin at 40 C Using Ammonium Thiocyanate as the Liquifier

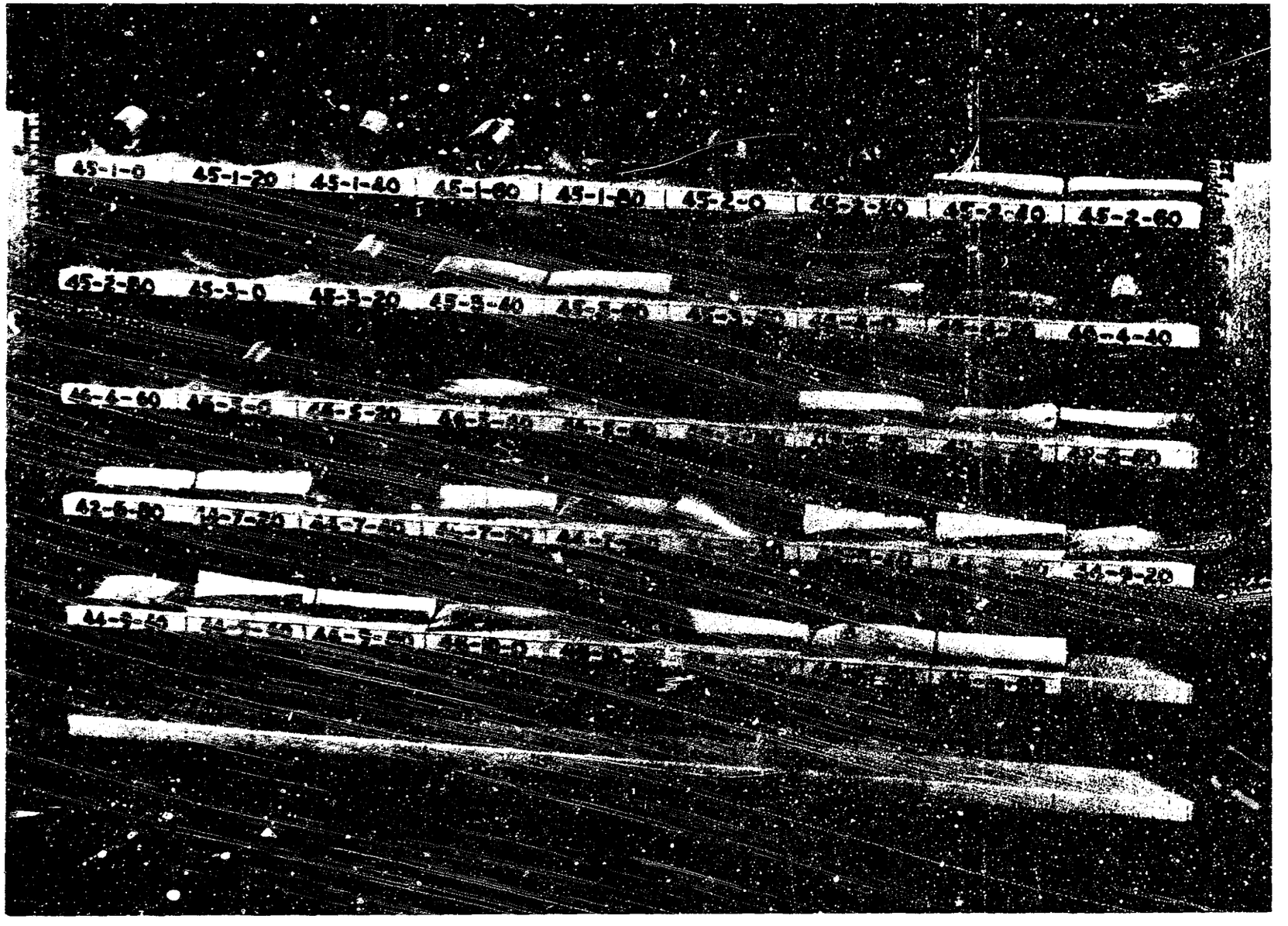

Figure 51 Distortion and Torture Test Samples

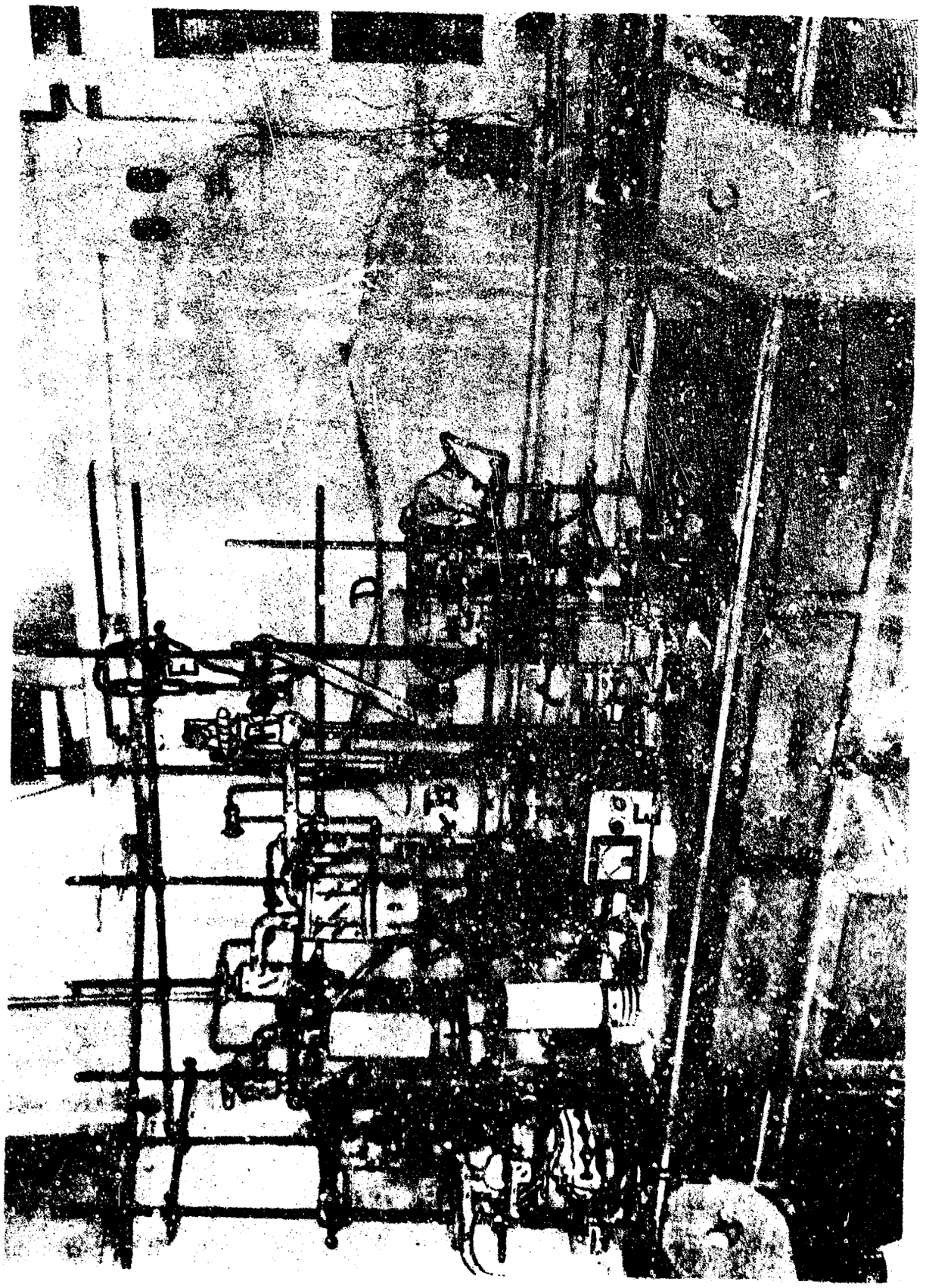

Figure 52 Evaporation Rate Apparatus

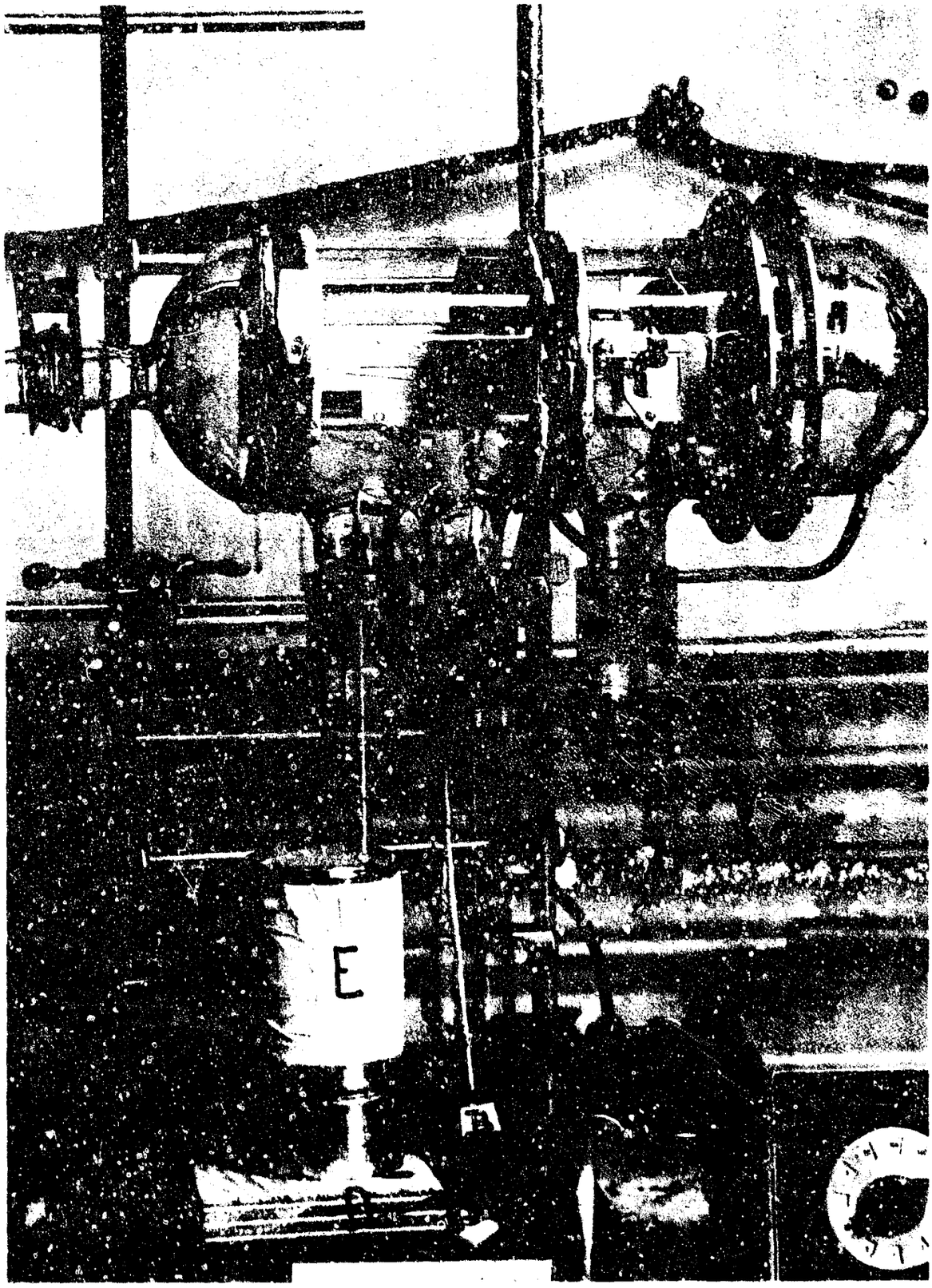

Figure 53 Detailed View of Electro-Balance

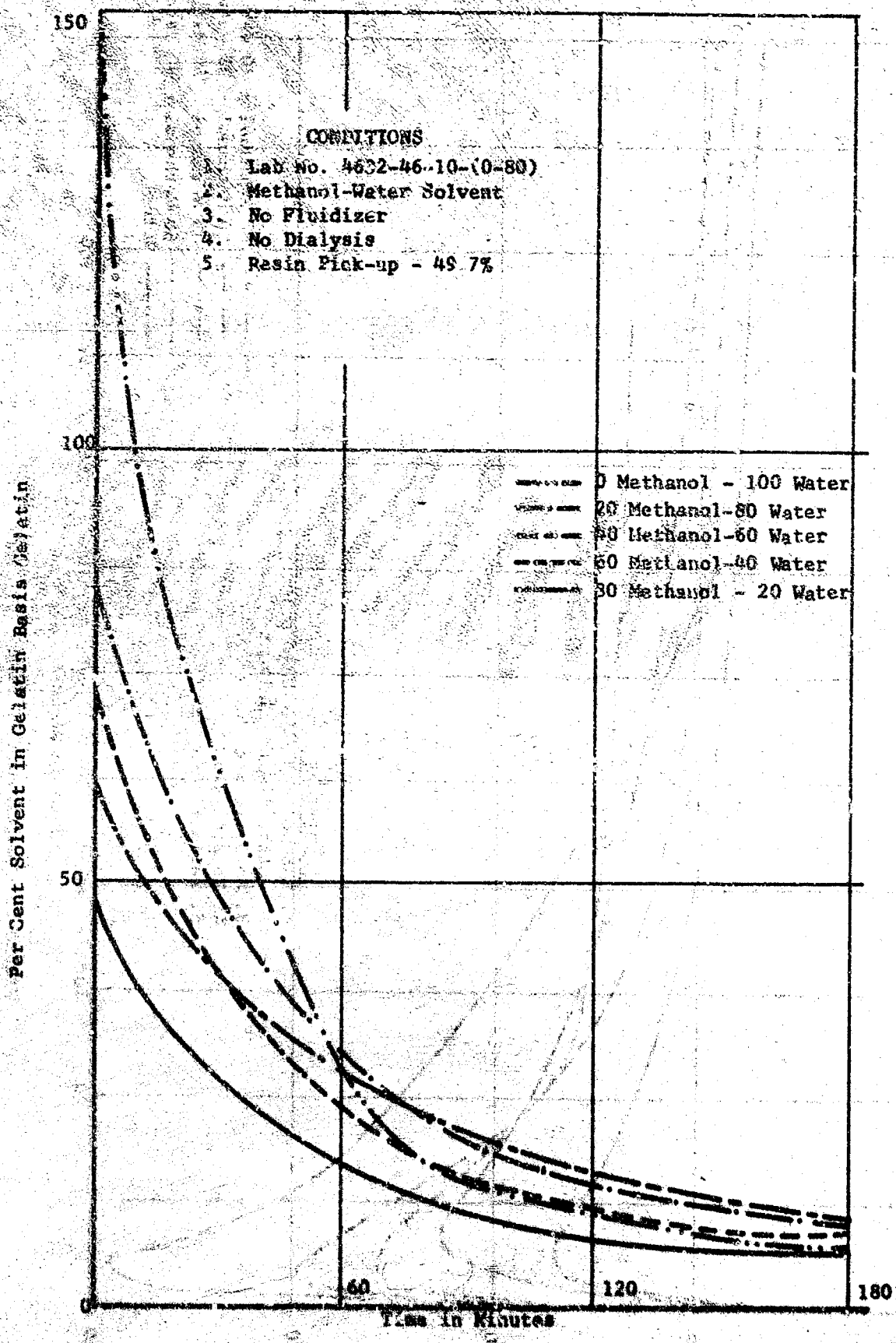

Figure 54 Solvent Content Basis Gelatin vs Time

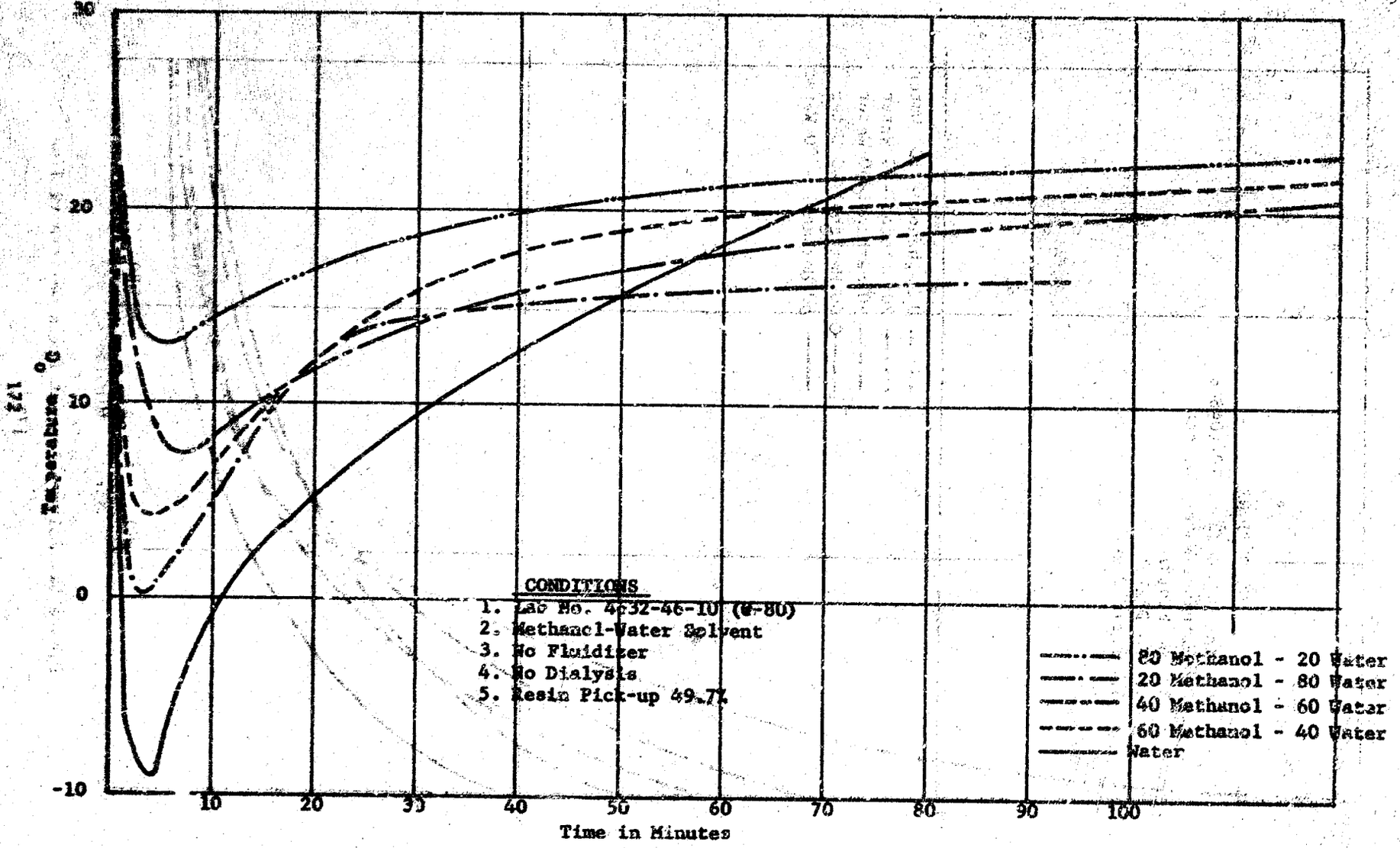

Figure 55 Temperature vs Time

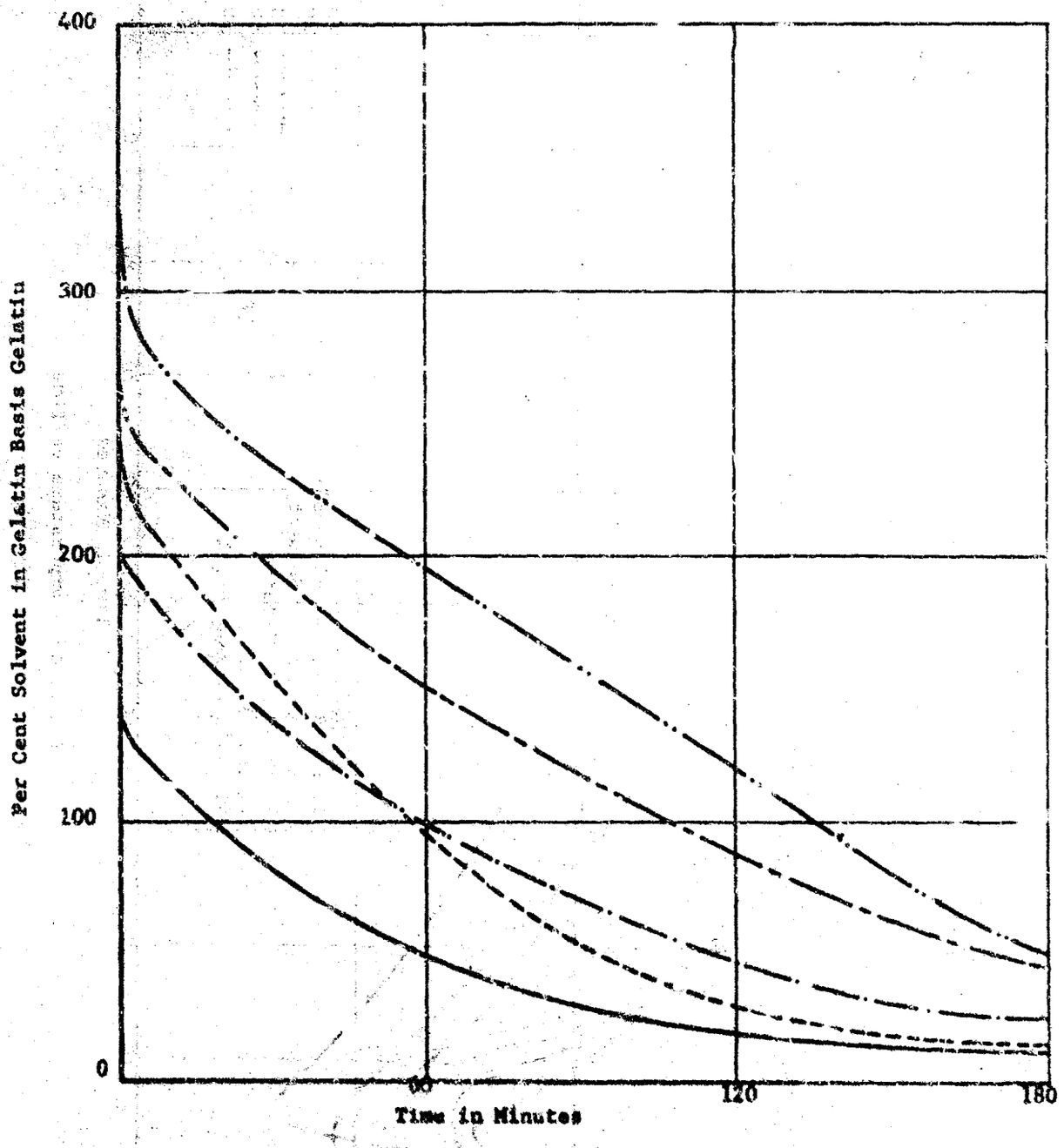

Figure 56 Solvent Content Basis Gelatin vs Time

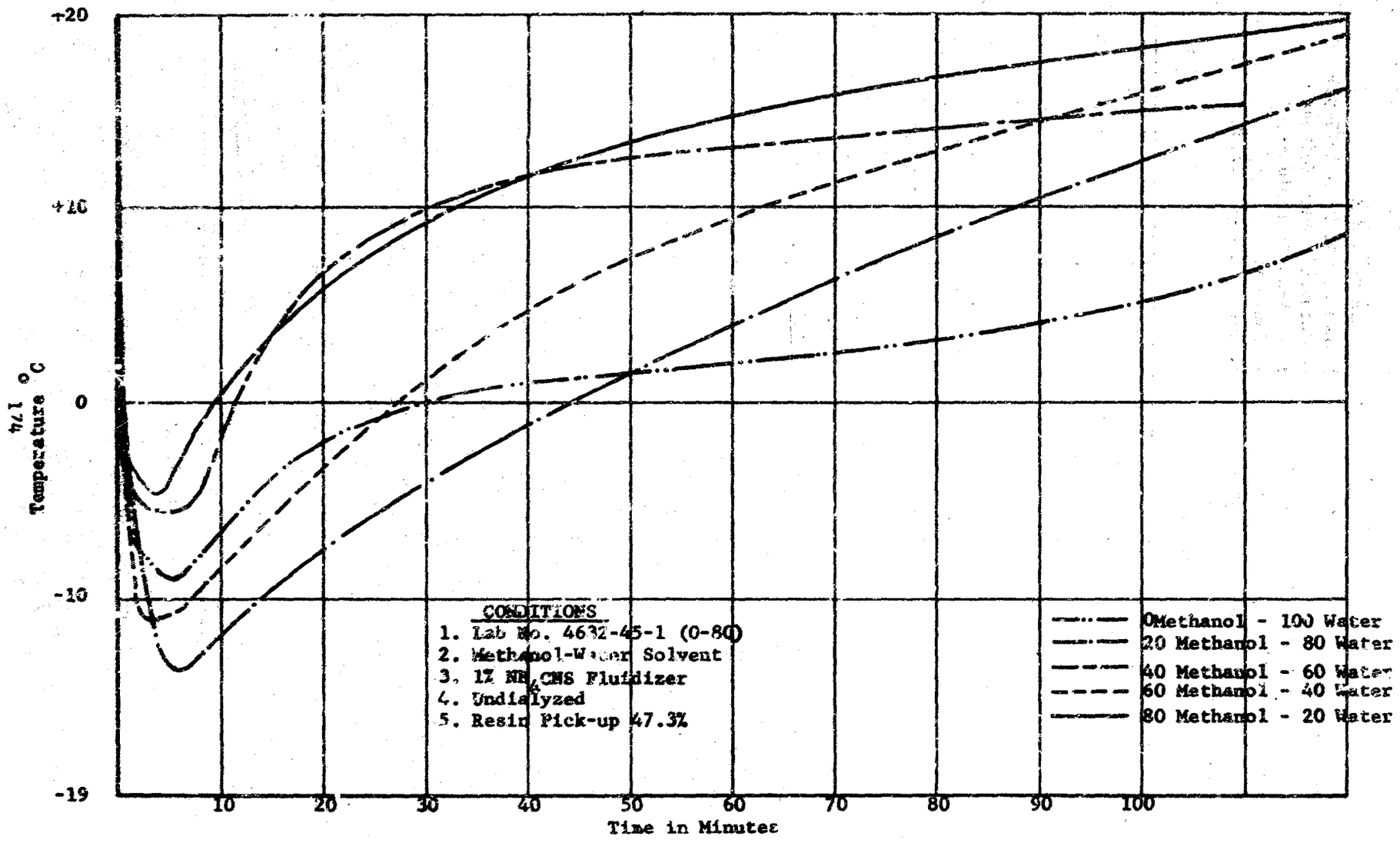

Figure 57 Temperature vs Time

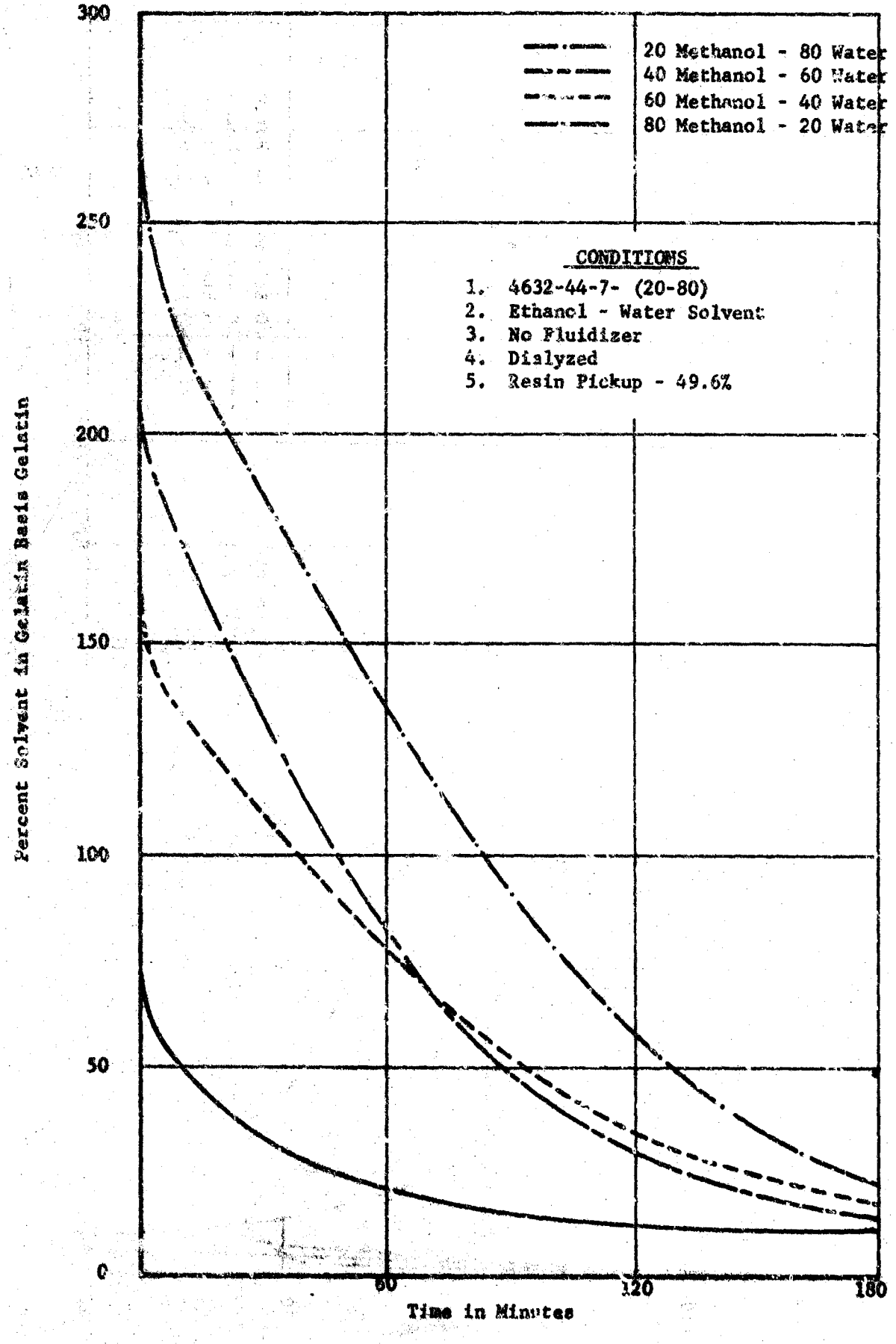

Figure 58 Solvent Content Basis Gelatin vs Time

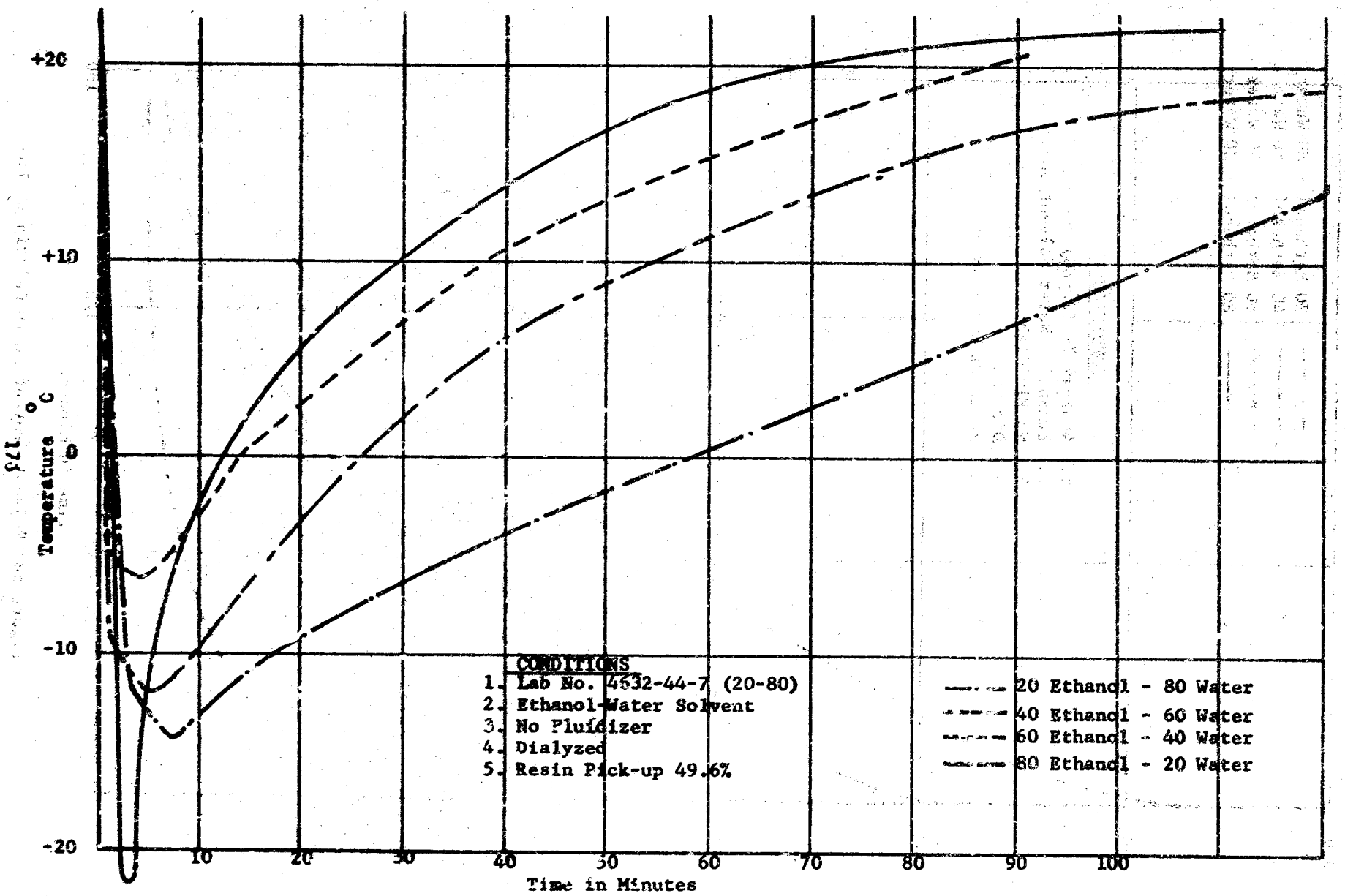

Figure 59 Temperature vs Time

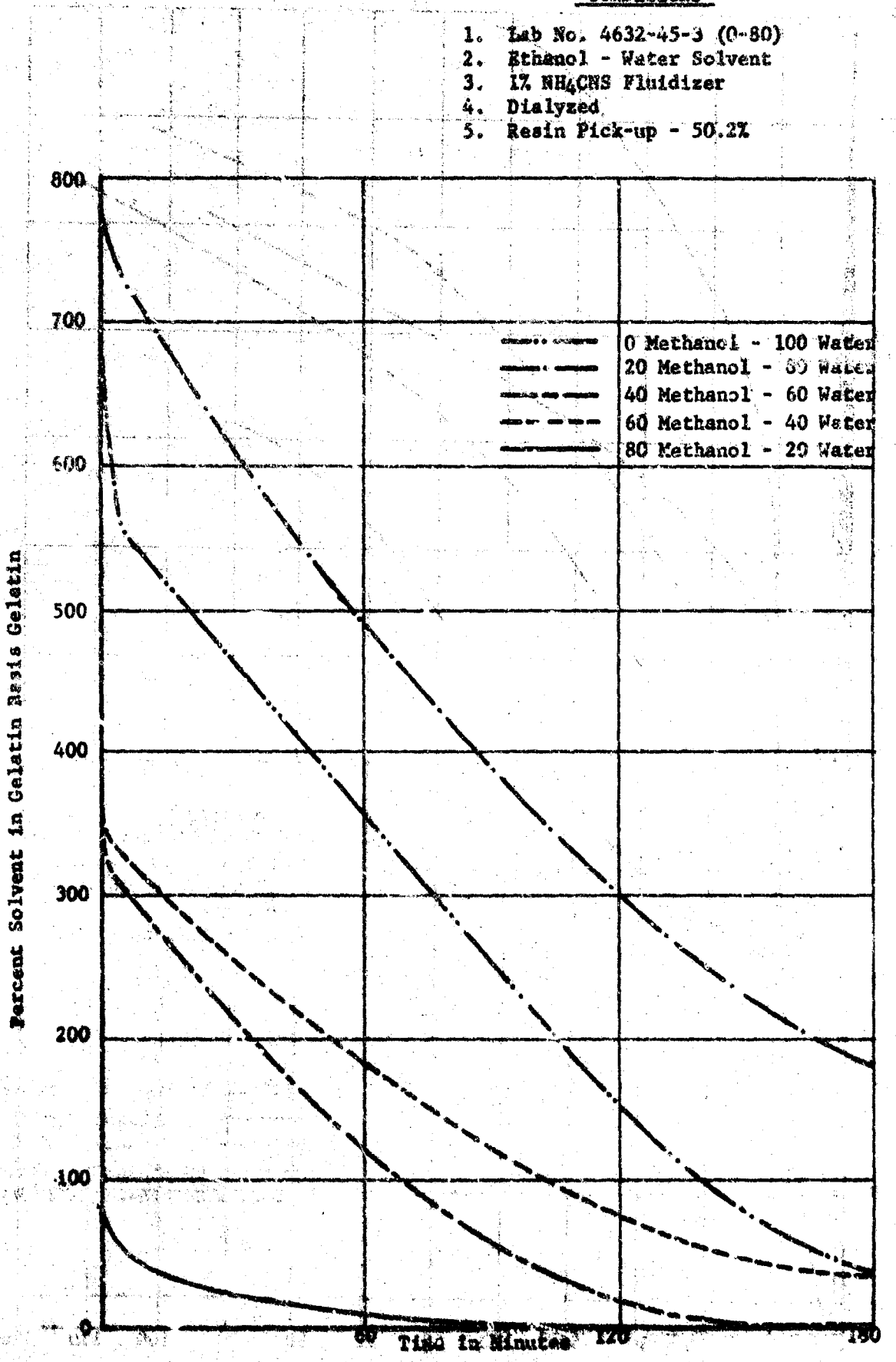

Figure 60 Solvent Content Basis Gelatin vs Time

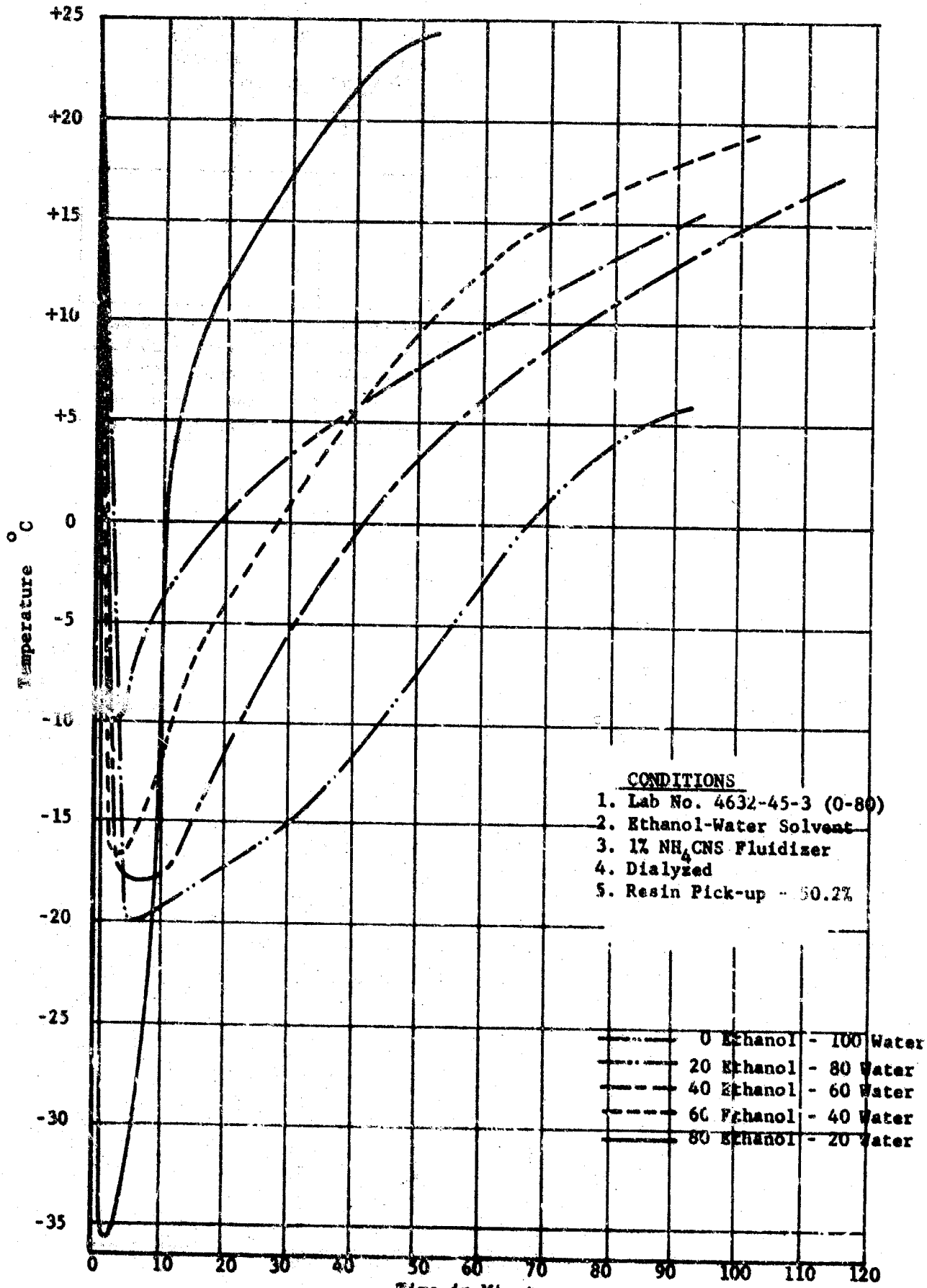

Figure 61 Temperature vs Time

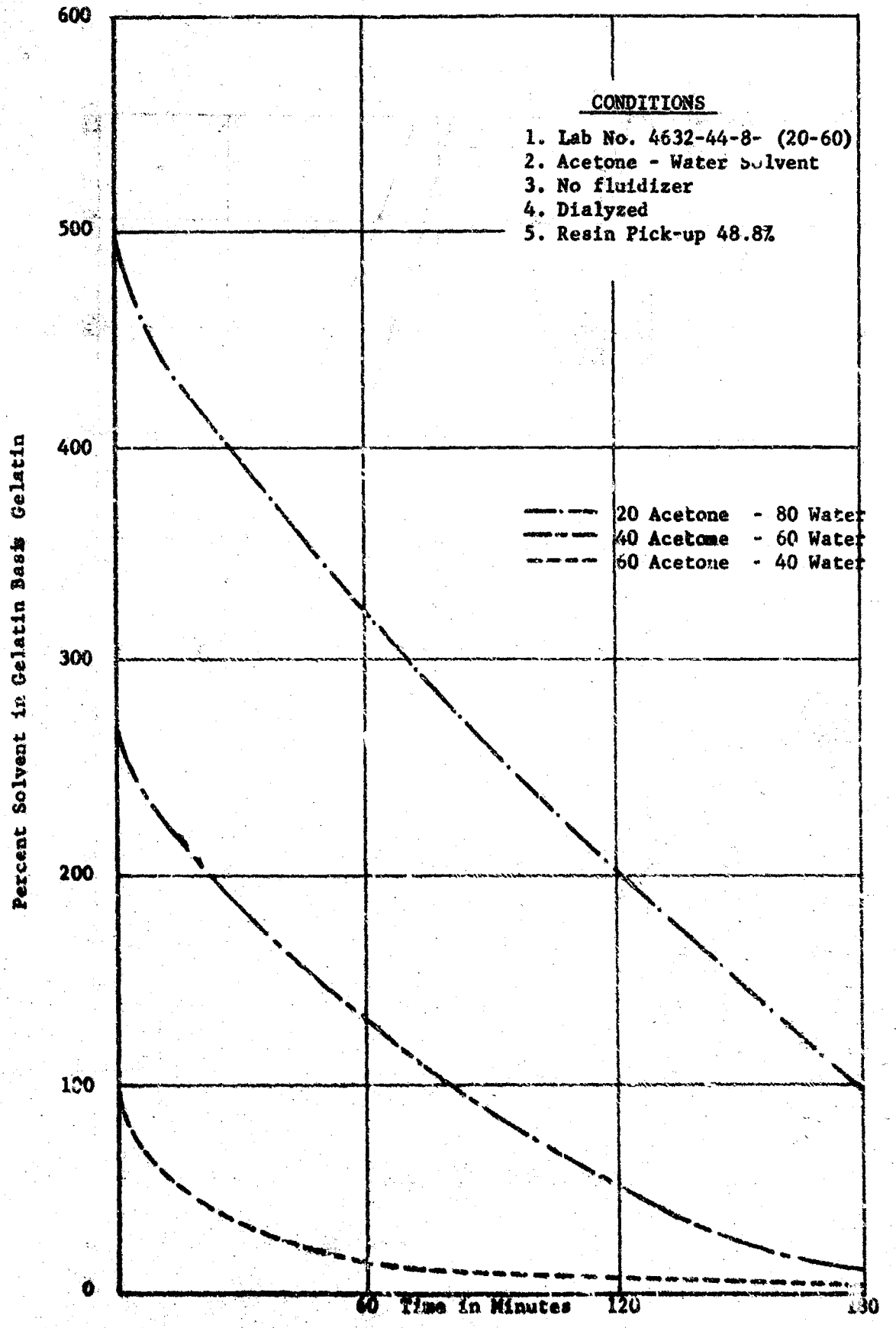

Figure 62 Solvent Content Basis Gelatin vs Time

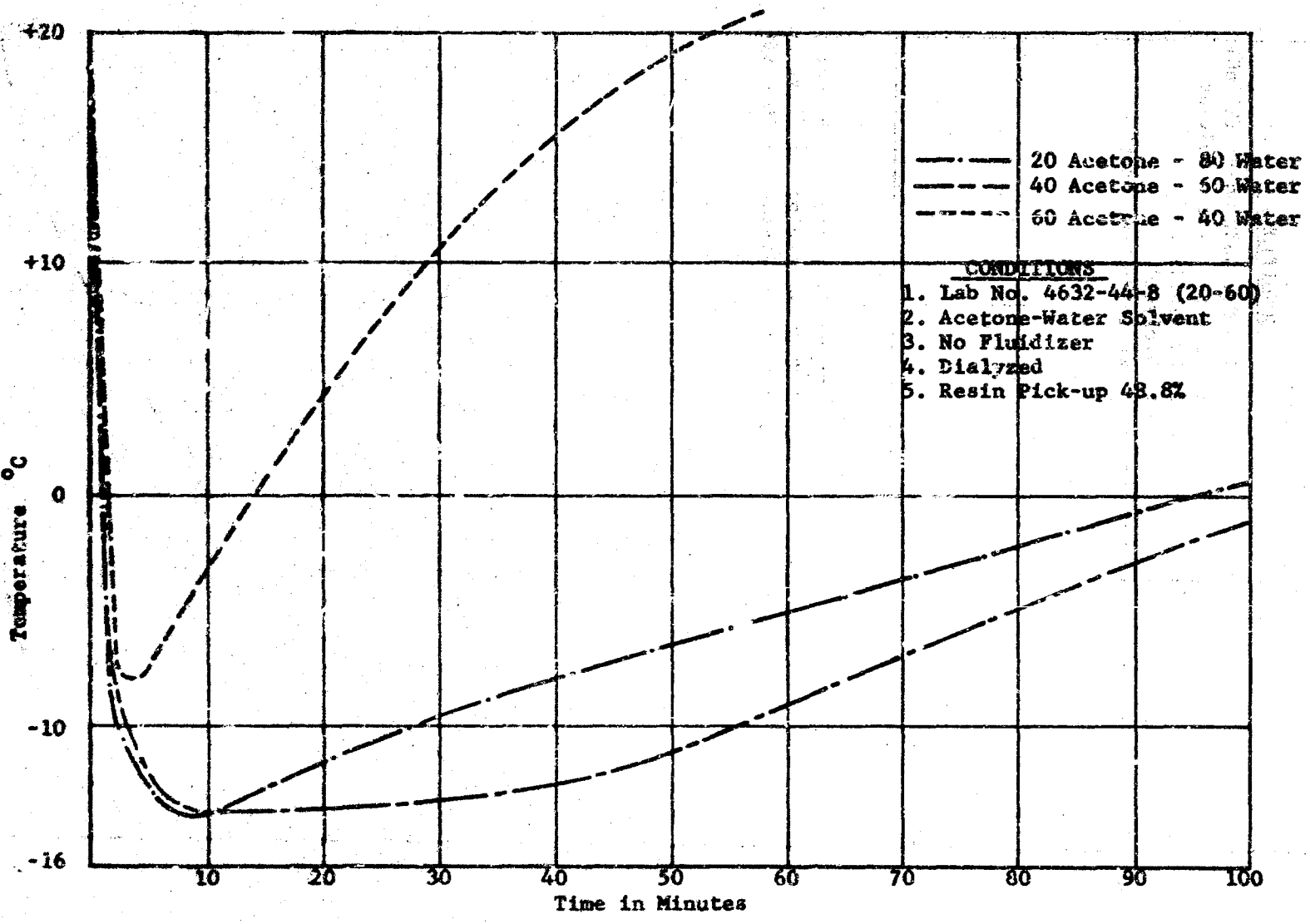

Figure 63 Temperature vs Time

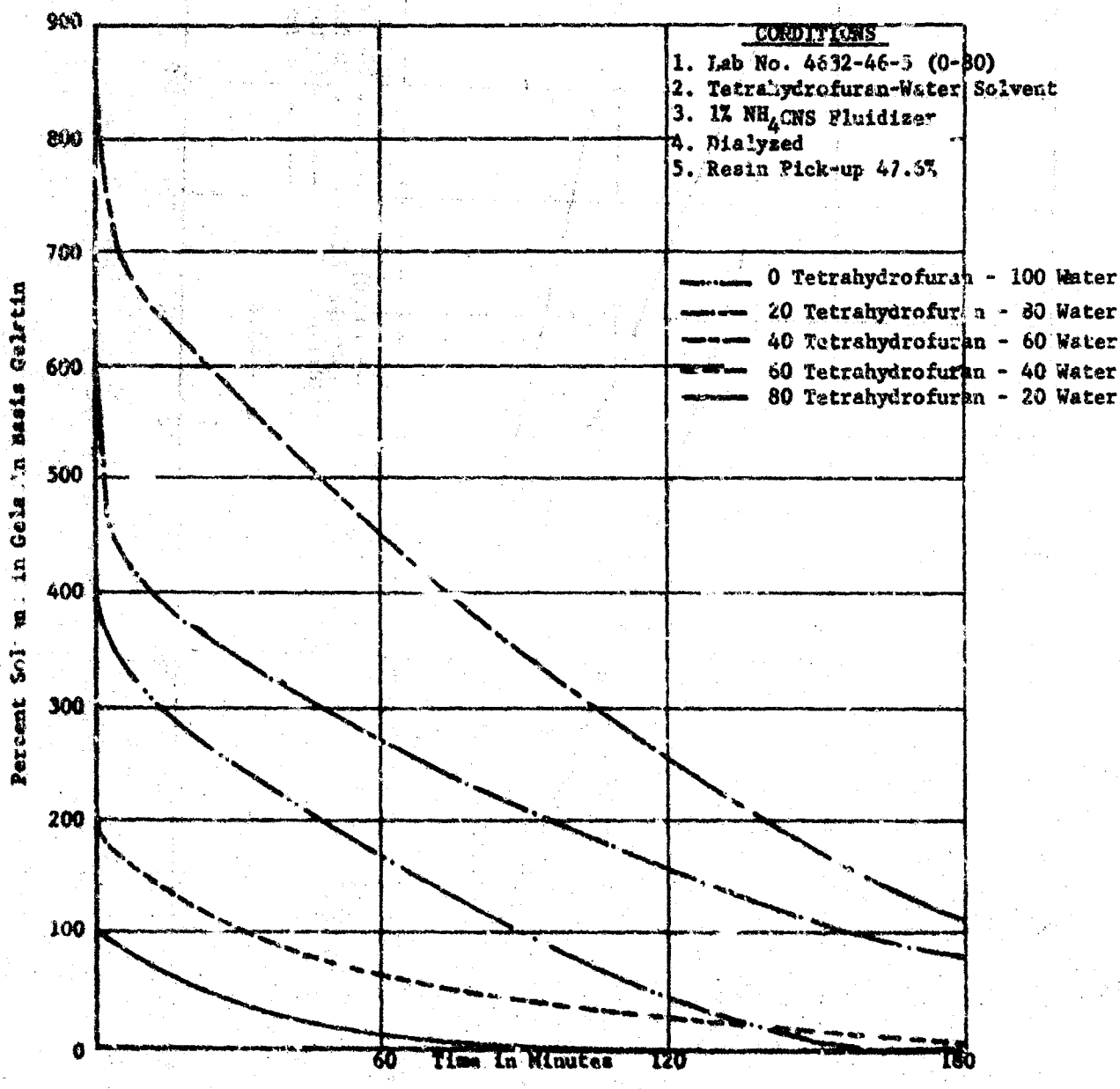

Figure 64 Solvent Content Basis Gelatin vs Time

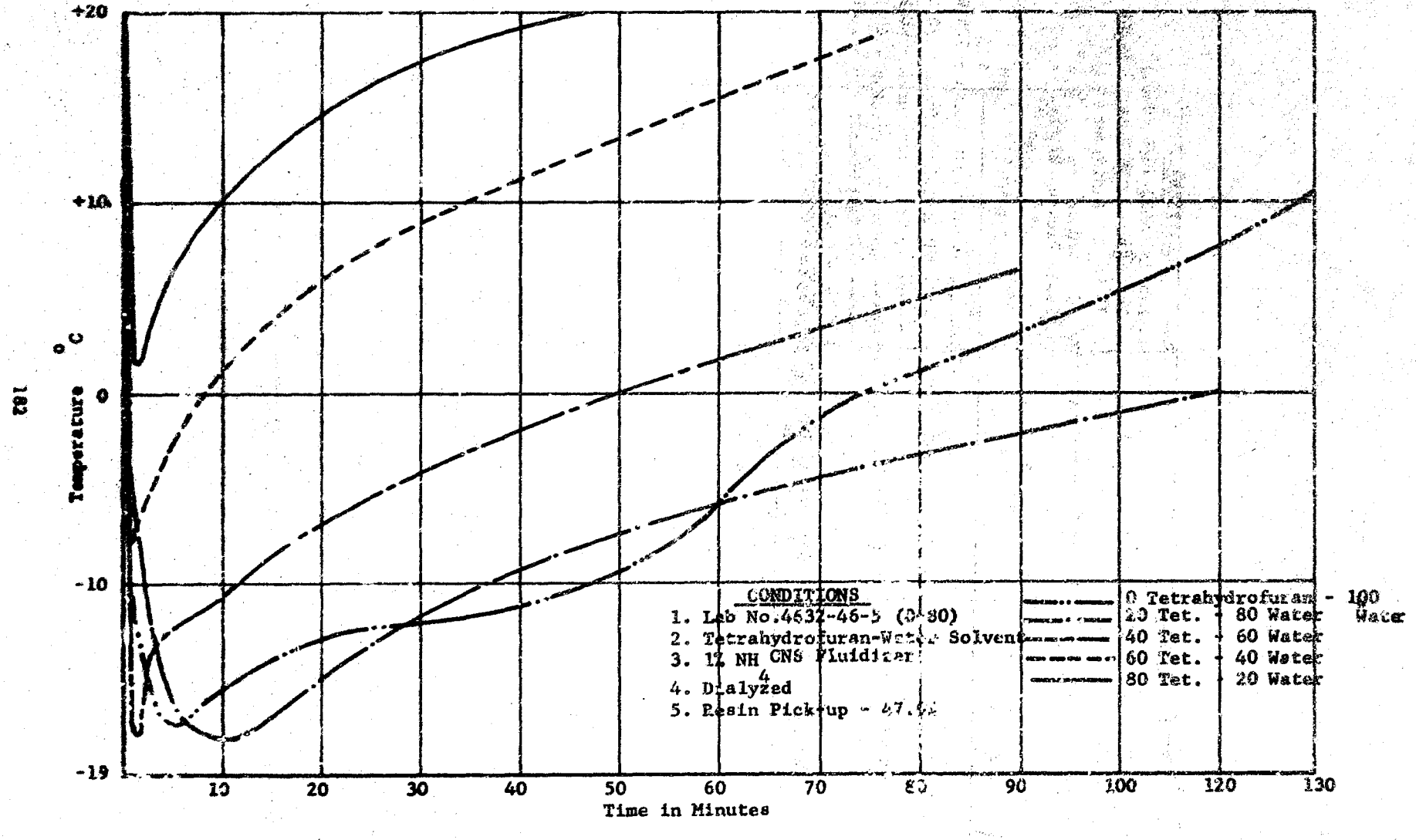

Figure 65 Temperature vs Time

APPENDIX II

ADHESIVES AND FLEXIBLE LAYER RESEARCH

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L. R. Erbaugh

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Dayton Laboratory

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I. INTRODUCTION

The principal goal of this project was to develop an adhesive layer to attach an aluminized Mylar mirror film to a supporting Dacron or nylon honeycomb fabric.

The adhesive layer must satisfy four separate functional requirements:

(1) It must adhere strongly to the Mylar film and the Dacron (or nylon) fabric.

(2) The adhesive must be flexible enough to permit folding and deployment over the prescribed temperature range (50 F to +165 F).

(3) The adhesive layer must fill in and hide the "see-through" distortion of the fabric and seams.

(4) The adhesive must not separate from the substrate or bubble in a high vacuum.

To accomplish these objectives, we investigated various types of adhesives, including silicones, epoxies, and urethanes. To further minimize the see-through problem, thin layers of flexible foam were used in combination with these adhesives. Flexible foams of relatively high modulus were obtained commercially and/or synthesized in our own laboratory. Velvet cloth was also evaluated as a possible alternate to foam to hide see-through.

A second goal was to evaluate films other than Mylar as the mirror surface. Biaxially oriented caprolactam and ethylene/vinyl acetate copolymer films were evaluated for this purpose. The strong, low-modulus ethylene/vinyl acetate film appeared to be especially promising as a possible replacement for Mylar.

II. SUMMARY

A. ADHESIVES

For ease of application, most of the compounds which are possible candidates as flexible adhesives for the solar mirror assembly are solvent-extended mixtures of polymer solutions. In those systems, the volatilization of the solvents during or following cure of the resin causes shrinkage of the adhesive layer.

In some cases, this shrinkage occurs over a period of several days and develops forces which are so strong as to greatly distort the Mylar/adhesive assembly. To avoid this shrinkage and resultant distortion, "all-solids" adhesives are much preferred.

Silicone adhesives are available in a wide variety of types and viscosities and can be cured to different degrees of hardness by several routes. They are dimensionally stable, chemically inert as cured resins, and possess good strength, elongation and excellent flexibility over a wide range of temperatures, including as low as -60 F. Some silicones adhere well to cleaned but unprimed Mylar, while others require a primer.

Many of the silicones may be solvent-thinned for easy spray application, but the preferred solvent-free materials are high viscosity and require high-pressure airless spray equipment for uniform application. The General Electric RTV 102 [illegible] lowest viscosity, one-component, all-solids silicone included [illegible]dy. It adheres to unprimed Mylar and most nearly meets the product [illegible]ements for the mirror adhesive.

As ordinarily prepared, epoxy resins are useful rigid adhesives. By proper selection of resin reactants, the epoxies can be tailored to obtain room-temperature flexible products. In most cases, these rubbery epoxies will adhere to Mylar without a primer, and their strength properties are good. However, the rubbery epoxies have the disadvantage of becoming rigid and brittle at temperatures only slightly lower than ambient.

Solvent extenders are normally necessary in application if the rubbery epoxy adhesives in order to apply them in the desired thin layers. As previously noted, use of solvent diluent causes excessive shrinkage of the adhesive layer (and resulting see-through) during and following cure.

To overcome these problems, an all-solids epoxy adhesive has been developed which is fluid when prepared and cures overnight to form a flexible rubber. This cured material may be tightly folded double at room temperature and recover totally when released. Adhesion of this resin to unprimed Mylar is excellent, and no shrinkage or distortion occurs during or following cure. This epoxy resin has much to recommend it, but it still has the limitation of poor flexibility at low temperatures (e.g., - 60 F).

Like epoxies, the physical properties of urethanes can be varied by choice of reactive resin ingredients. Unlike epoxies, urethane adhesives require a primer to adhere to Mylar film.

Nopcothanes 201 and 203 are air-curing urethanes which are easily applied due to solvent dilution. Their adhesion to Mylar is good, but shrinkage accompanies cure. An all-solids urethane which is air-curing and flexible has been studied. It does not shrink, but slow cure and adhesion remain problems.

B. FOAM AND OTHER INTERLAYERS TO MINIMIZE SEE-THROUGH

In addition to adhesives, an interlayer may be used to minimize or eliminate "see-through". If the interlayer functions as designed, it allows the perfectly formed, parabolic Mylar mirror a measure of "freedom" by introducing the possibility of shifting slightly with respect to the cloth substrate. The degree of "freedom" is dependent on the type, density, and firmness of the material. In urethane foams, the choice is quite wide--from extremely flexible, low firmness, 2 pcf open-cell commercial stock, all the way to those which are just foldable and very firm, prepared in our laboratory. Both trade and laboratory materials have been submitted to Viron for their evaluation.

Differing from foams in structural type is velvet cloth, which has much to recommend it as an interlayer. As a fabric, it is extremely flexible in every direction, but in the direction of the pile it is quite firm and incompressible.

C. MYLAR REPLACEMENT MIRROR FILMS

Because of its unique low modulus among high-strength materials, biaxially oriented ethylene/vinyl acetate is recommended as a candidate for the mirror film material.

III. DISCUSSION AND EXPERIMENTAL

A. ADHESIVES FOR MYLAR

1. Silicone Adhesives

Silicones, epoxies, and urethanes were tested as adhesives for Mylar. Each had peculiar advantages and limitations.

Silicones are available in a variety of types and viscosities and can be cured by different routes to various degrees of hardness. They adhere well to a variety of materials, are dimensionally stable, are chemically inert as cured resins, and possess good strength and elongation. Their outstanding property for this application is excellent flexibility over an extremely wide temperature range.

Two basic types of silicones were studied, one-component, or "ready-to-use", and two-component.

The "ready-to-use" included RTV 102, 103, and 112, which evolve acetic acid during cure, and DC 92-018, which does not. The RTV 112 is the lowest viscosity in this series, and DC 92-018, the highest. All these adhere well to Mylar that has been thoroughly degreased by multiple washing with organic solvents, but the cure requires several days to become tack-free and about three weeks to develop maximum strength properties. Since no primer is required for adhesion to Mylar, they are highly resistant to solvent attack.

The two-component silicones included RTV 11, which is lower in viscosity as an uncured resin, and RTV 60, which has superior cured properties. Rate of cure of both can be widely varied by choice and concentration of catalyst. Adhesion of both these resins to Mylar which has been cleaned and primed with SS-4004 is excellent. Primer application is only a slight disadvantage, and its distribution is improved by the addition of benzyl alcohol in a 1/1 ratio. Since the primer is subject to attack by organic solvents, it is, in the presence of these solvents, the weak link in the film/primer/adhesive assembly. It is not affected by water.

RTV 60 was used two ways: (a) as 100 per cent solids in which T-12 catalyst was mechanically mixed, and (b) as a spray (aerosol can in which the silicone is diluted with a hydrocarbon) with the catalyst applied as an overspray. In some cases, the overspray was applied simultaneously with the resin solution. This spray technique has the advantage of uniformity over an area, with thickness being controlled by the number of coats. It had the disadvantage of curing slowly and of shrinking as the hydrocarbon evaporated from the film. The 100 per cent solids RTV 60 was applied by spatula after catalyzing just prior to application. This method provided a much more rapid cure than the spray system, but uni-

formity of application suffered. Although not studied, high-pressure airless spray is the logical means of uniformly applying 100 per cent solids RTV 60.

RTV 11 was used only as 100 per cent solids and possessed curing characteristics similar to the all-solids RTV 60.

See Table No. 47 for data on the tests of silicones as Mylar adhesives.

2. Epoxy Adhesives

Epoxies are recognized as outstanding adhesvies in many applications. They have the advantage of being somewhat adjustable in flexibility by choice of ingredients. For use in this application, they require no primer to form a good bond with Mylar.

Many epoxy formulations are reduced in viscosity by addition of solvents for ease of application. A problem develops during cure, however, due to the evaporation of this solvent. Experiments were conducted to evaluate the extent of this problem. Rather heavy layers of resin solution (to cure to about 20 mils thick) were spread on sheets of Mylar and allowed to cure. After one day, the resin layers were dry to touch, and the films still laid flat; but by the second day, the resin layers had shrunk enough to curl the film. These assemblies were then hung on a line with free distribution of air and observed daily. Shrinkage continued for at least six days, in one case, and ten days in another. After these elapsed times, the curling ends had pulled the film to form cylinders, which prevented further change in appearance. These are Runs 43482-2, 3, in Table 48.

When a solvent-extended adhesive is used on a fabric surface, it will vary in depth, depending on the weave. At points where the resin is deepest, greatest shrinkage will occur, and "micro-dimpling" of the Mylar surface will develop as this shrinkage proceeds, due to forces developed in the adhesive itself. It thus follows that, for the solar mirror application, solvents are to be avoided in epoxy adhesives as well as in silicones if distortions of the mirror surface are to be eliminated.

Several epoxies and mixtures of epoxies were tried in order to find a solvent-free system which is fluid while uncured and flexible enough to fold after cure (see Table 48). Although not likely optimum, the best system of this series consists of 100 parts Epon 872, 100 parts D.E.R. 736, and 15.3 parts of Epon curing agent U. This resin is like varnish when first mixed and cures overnight to a flexible rubber. At room temperature, sheets as thick as 1/10 inches (0.10") may be folded double and squeezed with pliers, and still totally recover when released. The adhesion of this resin to Mylar is excellent and shows essentially no shrinkage or distortion in a 20-mil layer after one month. This epoxy system has very good low-temperature properties, but is not equal to the

silicones and, like the silicones, would likely require high-pressure airless spray for uniform application. Table 48 lists the details of the preparation of the epoxy samples.

3. Urethane Adhesives

Two approaches were tried in order to find a urethane adhesive for Mylar. In one case, Nopcothane 201 and 203 were tried. These are room-temperature air-curing varnishes diluted about 1/1 with solvents. The 201 is more flexible and adheres well to Mylar primed with Arolast 8990. The presence of solvents in these varnishes has produced erratic results. In some cases, shrinkage has accompanied cure; in others, it has been minimal or absent. This variation is not understood. The best in the series is 43488-5 (Table 48).

The other approach was an all-solids, air-curing, room-temperature urethane. It cured over several days to a flexible rubber, but had only fair adhesion to both unprimed and primed Mylar. Thus, no satisfactory urethane was found. Details of experimental work on urethane are listed in Table 48.

4. Resistance of Adhesives to Solvent Attack

The possibility of blisters forming between the adhesive and the Mylar due to contact with an organic solvent or vapor has been considered. Degree of attack by a few organic solvents likely to be encountered were studied by placing small coupons of representative laminates in bottles with varying solvents.

All adhesives or their primers are affected by organic solvents. The degree of attack varies from severe to slight, depending on the resin and solvent. The one-component silicone performed best. (See Table 49 for data).

5. Effect of Temperature on Adhesives

By American Society of Testing Materials D-1043-61T method (1), modulus of rigidity vs. temperature studies have been made of the adhesives studied in this program.

Besides providing a comparison of the various materials in their response to temperature, two items of special interest for this project were uncovered.

One is the very flexible properties associated with all the silicones, even at temperatures as low as -50 to -60 F. The other is a comparison of the resin formulated from Epon 872 x 75 (contains 25 per cent xylene), Beetle, and Epon U with the same formulation using Epon 872, which contains no xylene. The much greater flexibility of the Epon 872 x

75 containing material is due to residual xylene, which serves as a plasticizer. This is desirable at normal temperatures and pressures, but would be lost at the lower pressures of space. These data are listed in Table 46 which summarizes the curves, indicating T45000 and T670 for each adhesive. The T45000 is an arbitrary value chosen to indicate a transition from a solid to plastic material, and the T670 indicates a further transition from plastic to flexible.

TABLE 46

STIFFNESS MODULUS OF ADHESIVES

		TRANSITION FROM SOLID TO PLASTIC $T_{45,000}$	PLASTIC TO FLEXIBLE T_{670}
RTV 102		---	-58F
RTV 112		---	-54
RTV 11		---	-62
RTV 60		---	-62
Epon 872 x 75	30.0g		
Beetle 216-8	1.0		
Epon U	1.5	-38F	+46
Epon 872	22.5g		
Beetle 216-8	1.0		
Epon U	1.5	-8	+70
Epon 872	1.5g		
D.E.R. 736	1.5		
Epon U	4.6	-56	+16
Dupont Adhesive 46971		-17	+207
Nopcothane 201		-53	+9
Nopcothane 203		-26	+125

The curves giving the change of modulus with temperature are given in Figures 66 through 75.

TABLE 47

SILICONE ADHESIVES FOR MYLAR

Laboratory NBS Identification	ADHESIVE TYPE	APPLICATION	FILM TREATMENT Wash TRICLENE	XYLENE	ACETONE	OTHER	PRIMER	Adhesion Quality	OBSERVATION
43454-2	RTV11(5)	Spatula	No	No	Yes	None	None	Poor (9)	Slow cure.
43455-3	RTV11(5)	Spatula	No	No	Yes	None	None	Poor	Slow cure.
43455-2	RTV11(6)	Spatula	No	No	Yes	None	None	Poor	
43454-7	RTV11(6)	Spatula	No	No	Yes	None	SS-4004	Fair (10)	
43456-1	RTV11(6)	Spatula	Yes	No	Yes	None	SS-4004	Poor	
43455-2	RTV11(6)	Spatula	No	Yes	Yes	None	SS-4004	Good (11)	
43456-3	RTV11(6)	Spatula	No	Yes	Yes	None	None	Poor	
43458-66	RTV11(6)	Spatula	Yes	Yes	Yes	None	SS-4004	Good	
43454-1	RTV60(5)	Spray	No	No	Yes	None	None	Poor	
43455-4	RTV60(5)	Spatula	No	No	Yes	None	None	Poor	
43458-4	RTV60(5)	Spray	Yes	Yes	Yes	None	SS-4004	Good	4 days required for cure.
43458-5	RTV60(5)	Spray	Yes	Yes	Yes	None	SS-4004	Fair	3 alternating layers of resin & catalyst.
43463-4	RTV60(6)	Spatula	Yes	Yes	Yes	None	SS-4004(1)	Good	
43463-1	RTV60(6)	Spatula	Yes	Yes	Yes	Benzyl Alcohol	SS-4004(1)	Good	Benzyl Alcohol aids in distribution of primer.
43464-3	RTV60(6)	Spatula	Yes	Yes	Yes	Benzyl Alcohol	SS-4004(2)	Fair	
43464-4	RTV60(6)	Spatula	Yes	Yes	Yes	Benzyl Alcohol	None	Poor	
43476-1	RTV60(5)	Spray	Yes	Yes	Yes	Benzyl Alcohol	SS-4004(3)	Good	
43476-3	RTV60(5)	Spray	Yes	Yes	Yes	Benzyl Alcohol	SS-4004(4)	Good	
43463-2	RTV60(6)	Spatula	Yes	Yes	Yes	Methylene Chloride	SS-4004(1)	Good	
43464-2	RTV60(6)	Spatula	Yes	Yes	Yes	Methylene Chloride	SS-4004(2)	Good	
43465-5	RTV60(6)	Spatula	Yes	Yes	Yes	Methylene Chloride	None	Poor	
43463-3	RTV60(6)	Spatula	Yes	Yes	Yes	Dichloro-ethane	SS-4004	Good	
43464-6	RTV60(6)	Spatula	Yes	Yes	Yes	Dichloro-ethane	None	Poor	
43478-1	RTV112	Spatula	Yes	Yes	Yes	None	None	Good	3 days required for cure.
43478-2	RTV112	Spatula	Yes	Yes	Yes	Benzyl Alcohol	None	Good	No improvement over 43478-1.
43451-2	RTV102	Spatula	No	No	Yes	None	None	Fair	
43451-4	RTV102	Spatula	No	No	Yes	None	(7)	Good	
43457-3	RTV102	Spatula	No	Yes	Yes	None	None	Good	3 days required for cure.

TABLE 47 (Continued)

SILICONE ADHESIVES FOR MYLAR

Laboratory MRP Identification	ADHESIVE TYPE	APPLICATION	FILM TREATMENT Wash: TRICLENE	XYLENE	ACETONE	OTHER	PRIMER	Adhesion Quality	OBSERVATION
43458-3	MV103	Spatula	No	No	Yes	None	None	Good	
43451-1	DC92-018	Spatula	No	No	Yes	None	None	Poor	
43451-3	DC92-018	Spatula	No	No	Yes	None	(7)	Poor	
43451-5	DC92-018	Spatula	No	No	Yes	None	DC-4094	Poor	
43459-1	DC92-018	Spatula	Yes	Yes	Yes	None	None	Good	
43406-6	DC92-018	Spatula	Yes	Yes	Yes	None	Vinyl tri-chlorsilane (8)	Good	
43458-1	DC92-018	Spatula	Yes	Yes	Yes	Benzyl Alcohol	SS-4004	Good	
43458-2	DC92-018	Spatula	Yes	Yes	Yes	None	DC-1200	Good	

1. Applied immediately after washing.

2. Applied ½ hour after washing.

3. Two coats of primer; 1 immediately after washing, the second 16 hours later.

4. SS-4004 primer mixed 1/1 with Benzyl Alcohol.

5. T-12 catalyst applied as an overspray.

6. T-12 catalyst mixed with resin just prior to application.

7. Etched with fine sandpaper before washing.

8. 20% solution in Xylene.

9. Easily separated from substrate.

10. Peels with difficulty.

11. Can't be separated from substrate with fingernail.

TABLE 48

EPOXY, URETHANE, AND OTHER ADHESIVES FOR MYLAR

Laboratory MSF Identification	ADHESIVES Type	FILM TREATMENT Wash: Trichlene	Xylene	Acetone	Other	Primer	Adhesion Quality	Observation
43462-1	Epoxy (1)	No	No	Yes	None	None	Fair	
43462-2	Epoxy (1)	Yes	Yes	Yes	None	None	Fair	No improvement over 43462-1.
43470-	Epoxy (1)	Yes	Yes	Yes	Benzyl Alcohol	None	Good	
43482-2	Epoxy (1)	No	No	Yes	None	None	Good	Shrinkage continued more than 6 days.
43482-3	Epoxy (2)	No	No	Yes	None	None	Good	Shrinkage continued more than 10 days.
43490-1	Epoxy (3)	No	No	Yes	None	None	Poor	Did not cure on film, but did in beaker.
43495-3	Epoxy (4)	No	No	Yes	None	None	Poor	Did not cure in 2 days.
43490-3	Epoxy (5)	No	No	No	None	None	Fair	Cured better in beaker than on film.
43491-2	Epoxy (6)	No	No	No	None	None	Good	Too viscous uncured, too rigid cured.
43491-4	Epoxy (7)	No	No	Yes	None	None	Fair	No shrinkage, adhesive breaks when creased.
43495-1	Epoxy (8)	No	No	Yes	None	None	Good	Good flexibility, no shrinkage.
43484-2	Urethane (9)	Yes	Yes	Yes	Benzyl Alcohol	None	Good	Two weeks required for cure, much shrinkage.
43484-3	Urethane (9)	No	No	No	None	None	Good	Similar to 43484-2
43484-5	Urethane (10)	No	No	No	None	None	Poor	Solvent odor for 3 days, much shrinkage.
43488-6	Urethane (9)	No	No	No	None	Arolast 8990	Good	Very flexible.
46125-1	Urethane (11)	Yes	Yes	Yes	None	Arolast 8990	Fair	Over a week to cure.
43466-1	Dupont (12)	Yes	Yes	Yes	None	None	Good	Severe shrinkage of adhesive.

(1) Epon 872 x 75, 30 g; Beetle 216-8, 1 g; Epon curing agent U, 1.5 g.
(2) As (1) except added 60 wt. % Xylene.
(3) DER 732, 100 g; Triethylenetetramine, 7.5 g.
(4) Epon 828, 100 g; Epon curing agent U, 4.5 g.
(5) Epon 872, 10 g; Epon 871, 20 g; Beetle 216-8, 0.3 g; Triethylenetetramine, 1 g.
(6) Epon 872, 30 g; Epon curing agent U, 2 g.
(7) Epon 872, 15 g; DER 836, 15 g; Triethylenetetramine, 2.4 g.
(8) Epon 872, 15 g; DER 836, 15 g; curing agent U, 4.6 g.
(9) Nopcothane 201.
(10) Nopcothane 203.
(11) Multrathane F84; 50 g; Multron 34, 15.7 g.
(12) Food Grade adhesive 46971 (Product identity unknown).

TABLE 49

EFFECT OF SOLVENTS ON LAMINATE COMPONENTS

TEST MATERIAL	SOLVENTS						
	Acetone	Xylene	Chloroform	Triclene	Water	Ecthylene Chlorohydrin	Methyl Butynol
Mylar/RTV60	Prime layer destroyed	Swollen	Prime layer destroyed	Prime layer destroyed	No damage	Prime layer destroyed	Prime layer destroyed
Mylar/RTV 102	Swollen					No damage	No damage
Mylar/DC 92-018	Swollen					No damage	No damage
Mylar/Dupont 46971	Softened	No damage	Destroyed	Softened	No damage	Destroyed adhesive	Destroyed adhesive
Mylar/epoxy	Destroyed	No damage	Destroyed	Softened		Detached	Detached
Mylar/Urethane	Swollen						
Schjel-clad laminate	No damage	No damage		No damage	No damage	Destroyed	Destroyed
80 Pores/inch Urethane		Swelled		Swelled		Swelled	Swelled

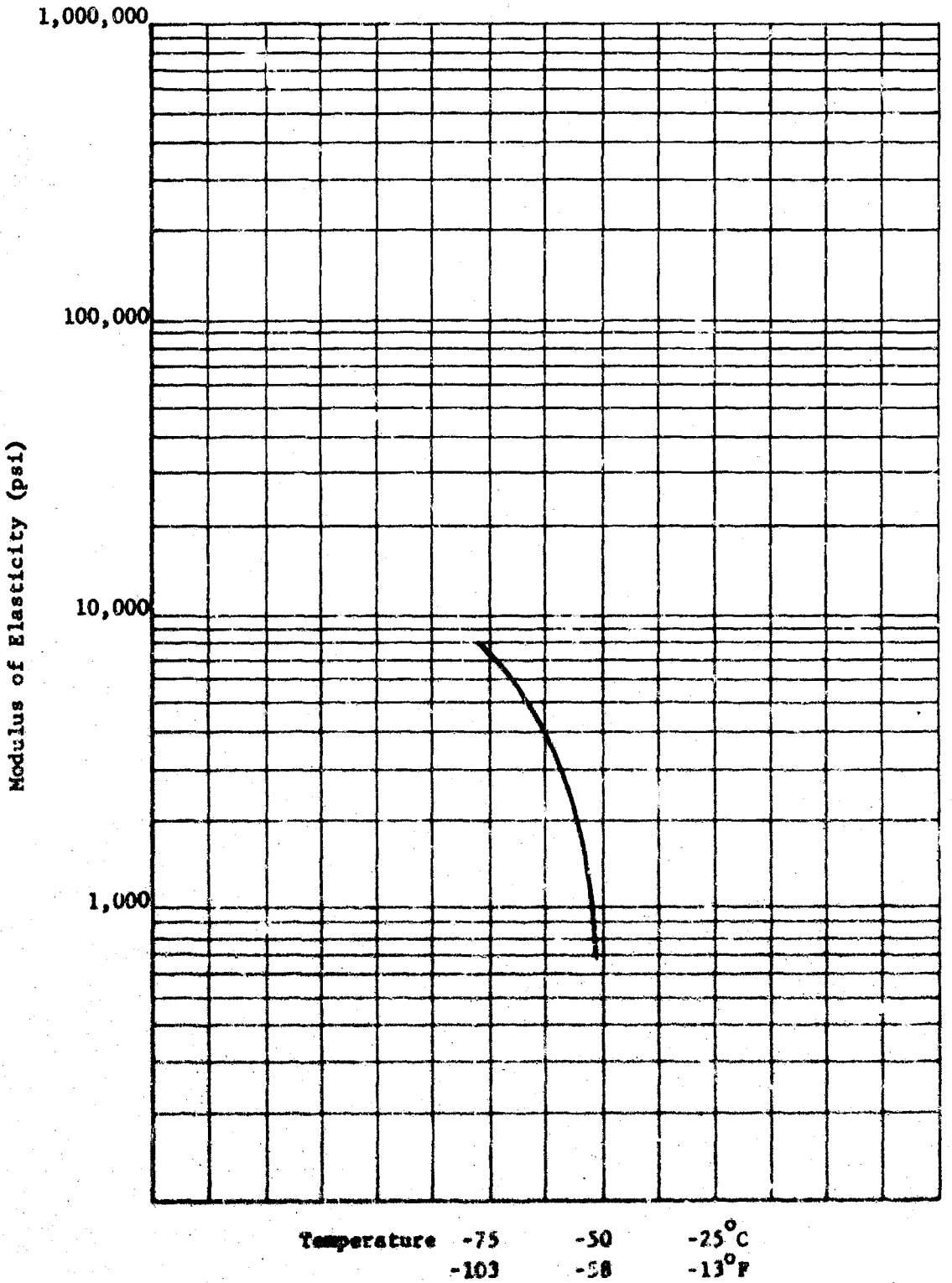

Figure 66

Change of Modulus vs Temperature

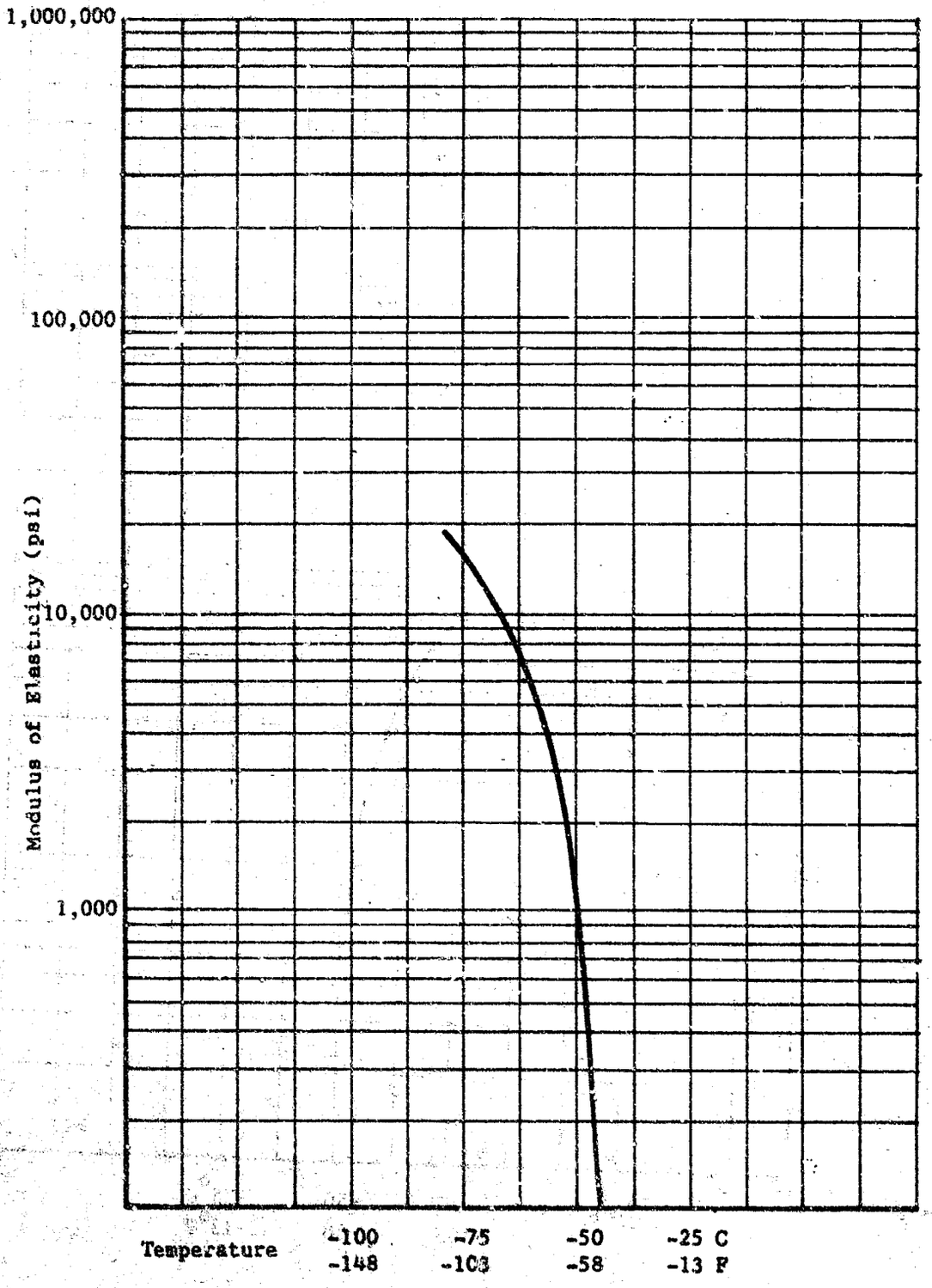

Figure 67
Change of Modulus vs Temperature

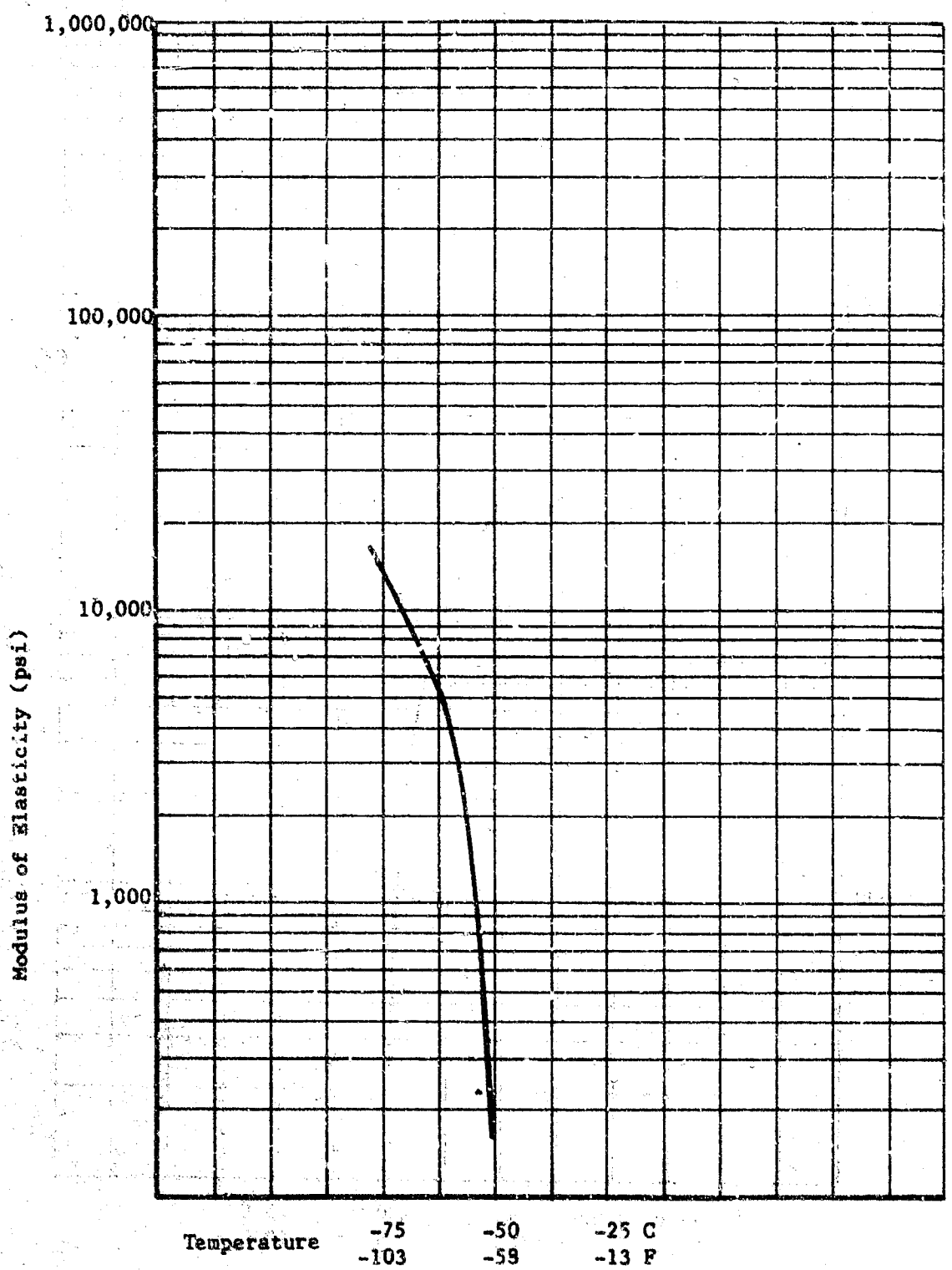

Figure 68
Change of Modulus vs Temperature

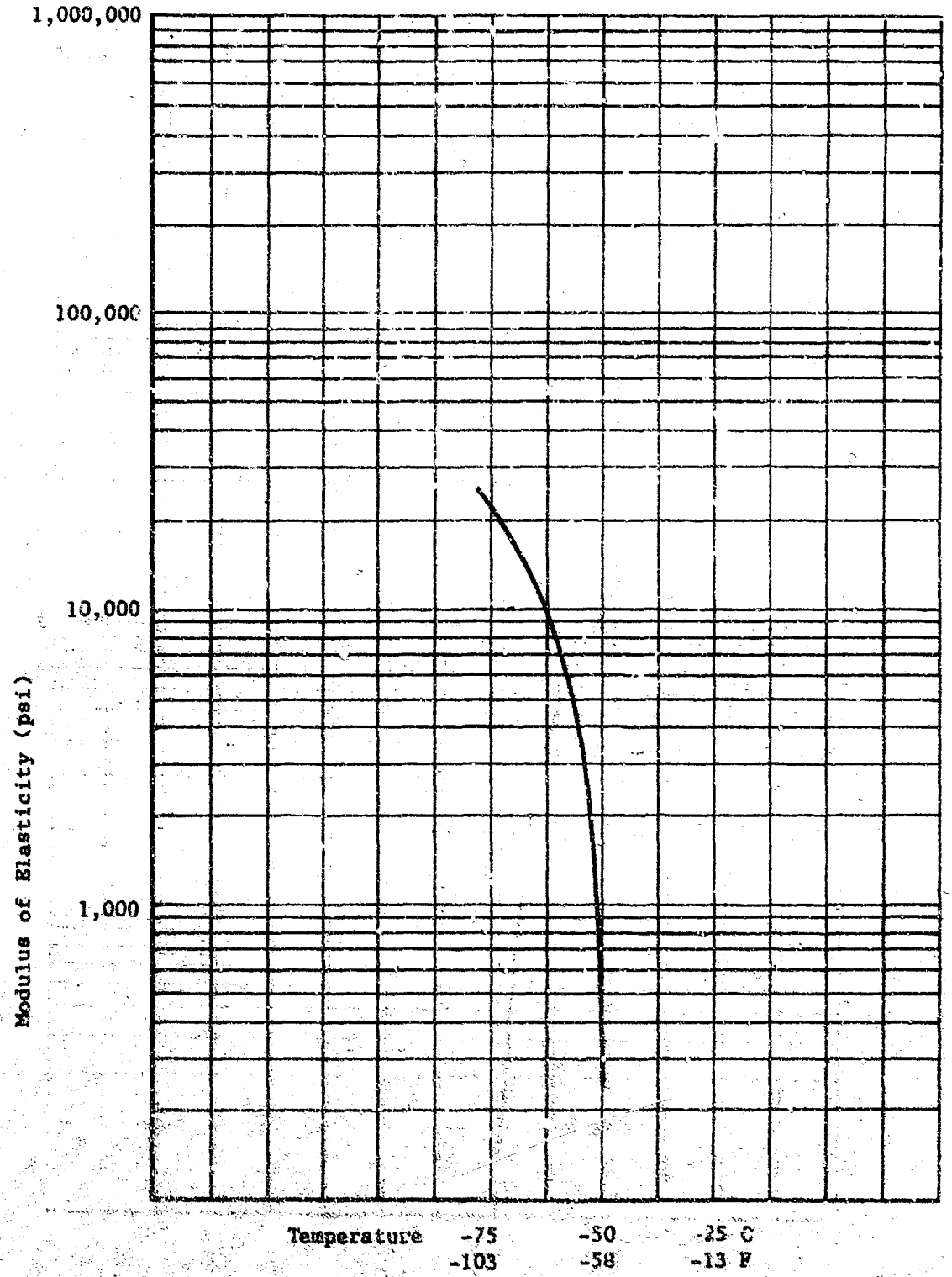

Figure 69

Change of Modulus vs Temperature

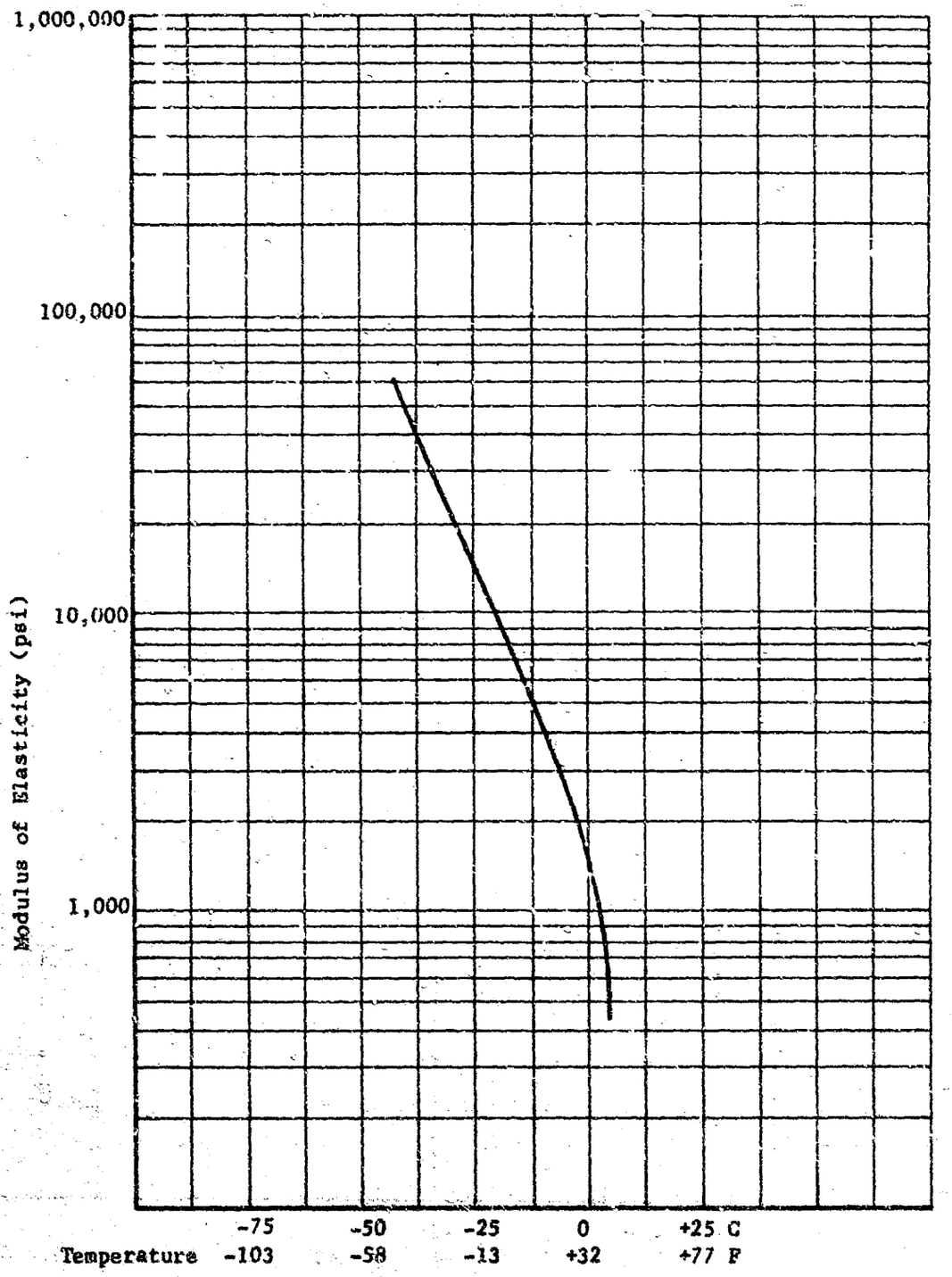

Figure 70

Change of Modulus vs Temperature

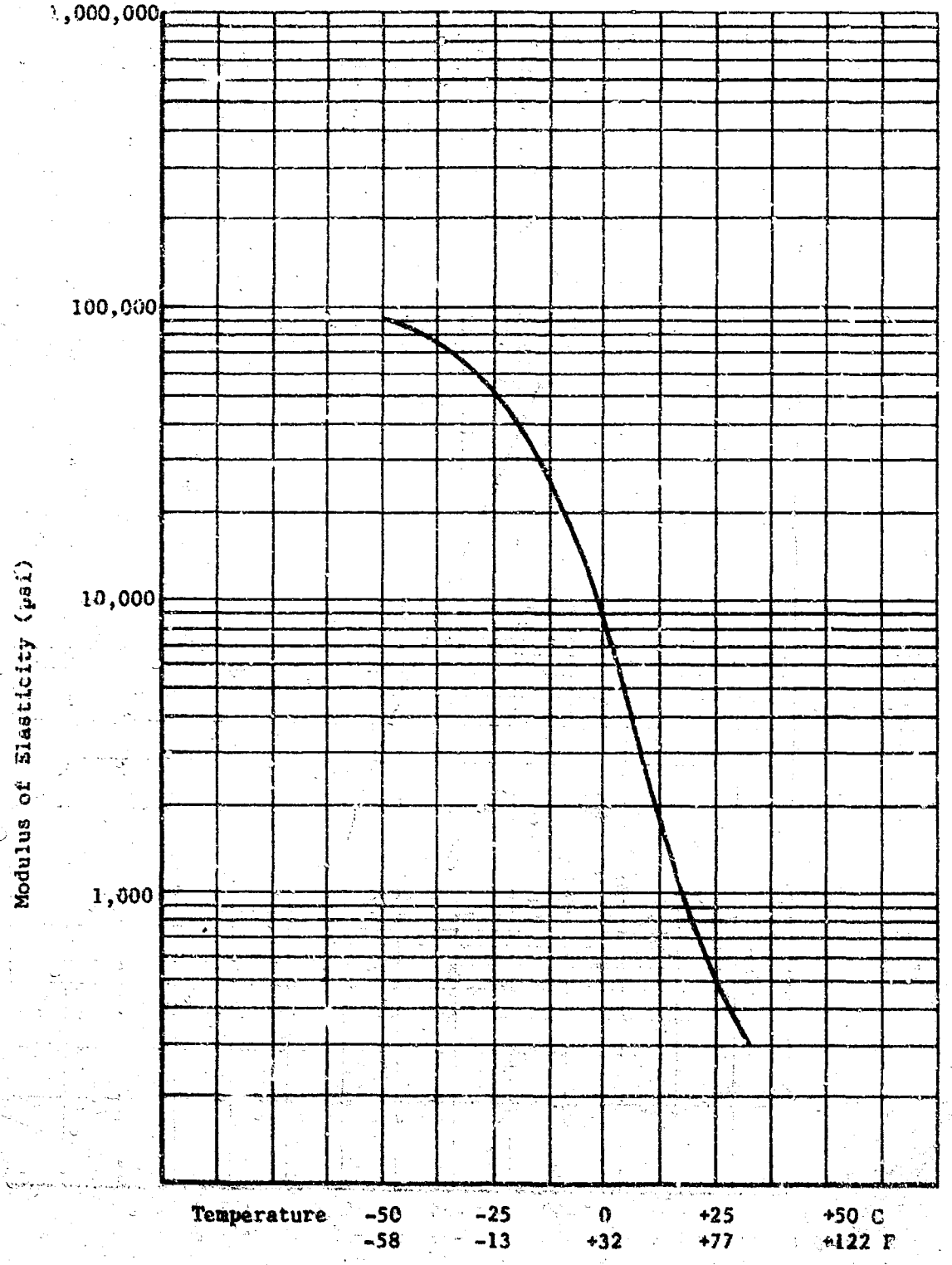

Figure 71
Change of Modulus vs Temperature

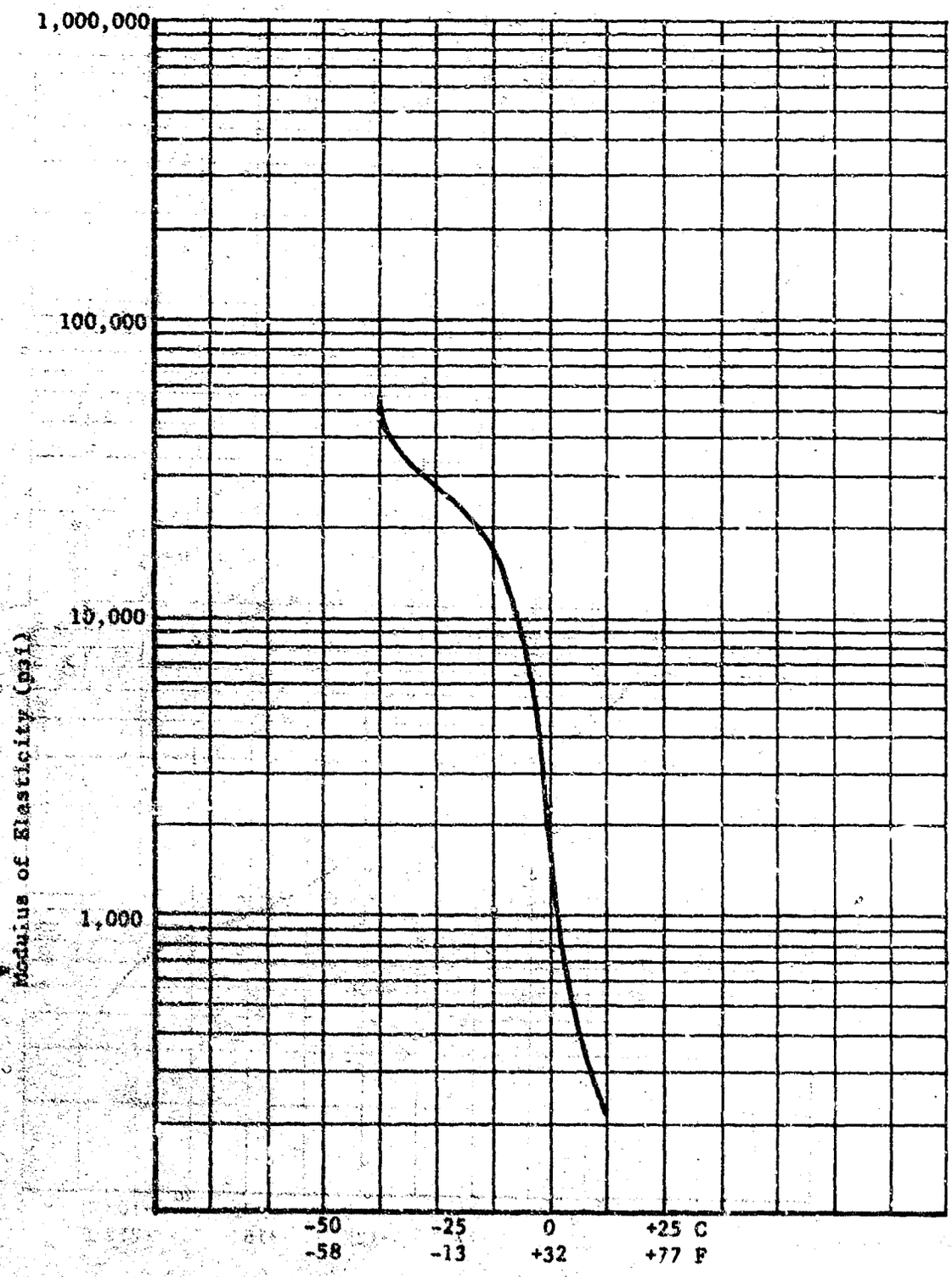

Figure 72

Change of Modulus vs Temperature

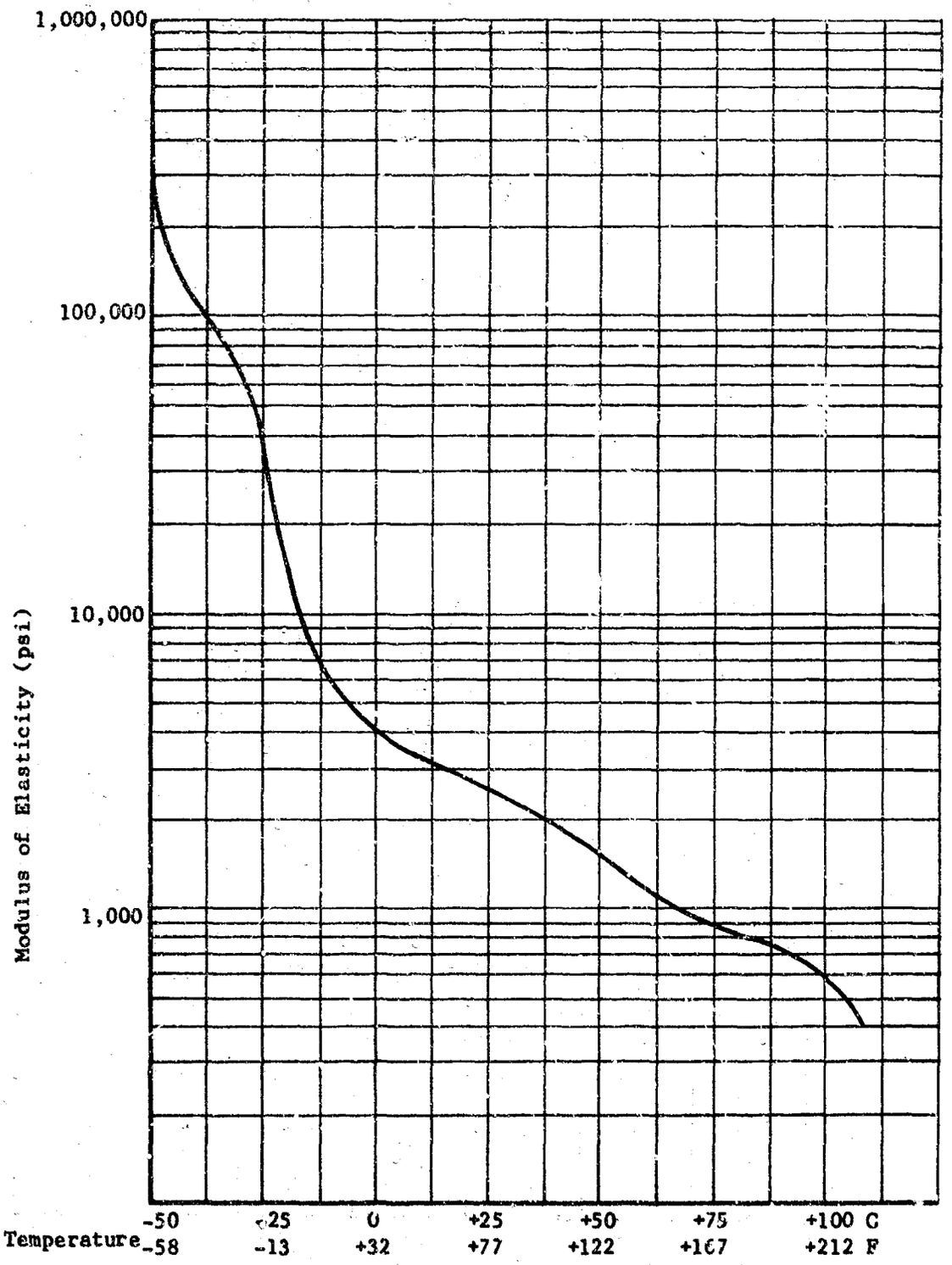

Figure 73

Change of Modulus vs Temperature

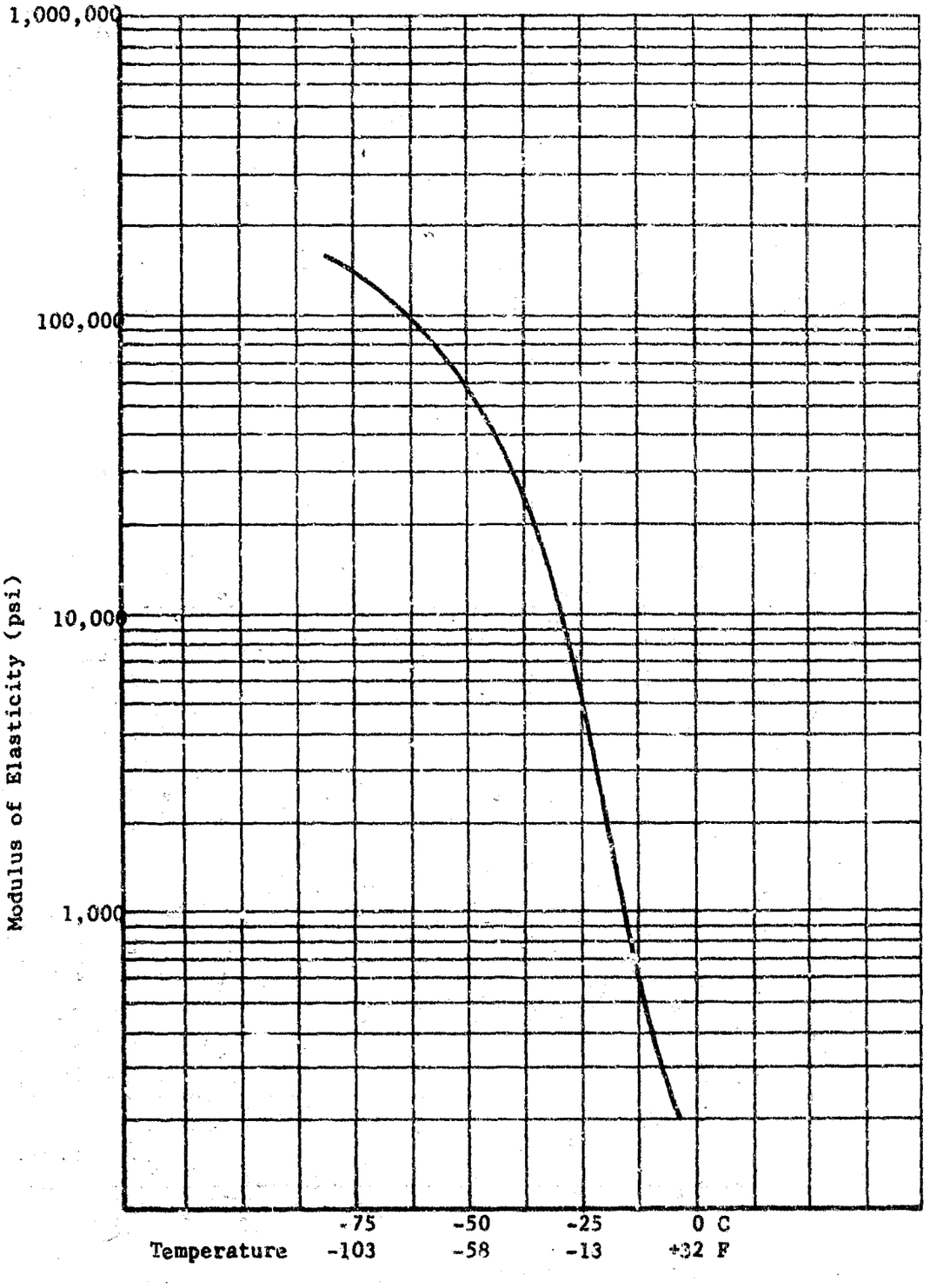

Figure 74

Change of Modulus vs Temperature

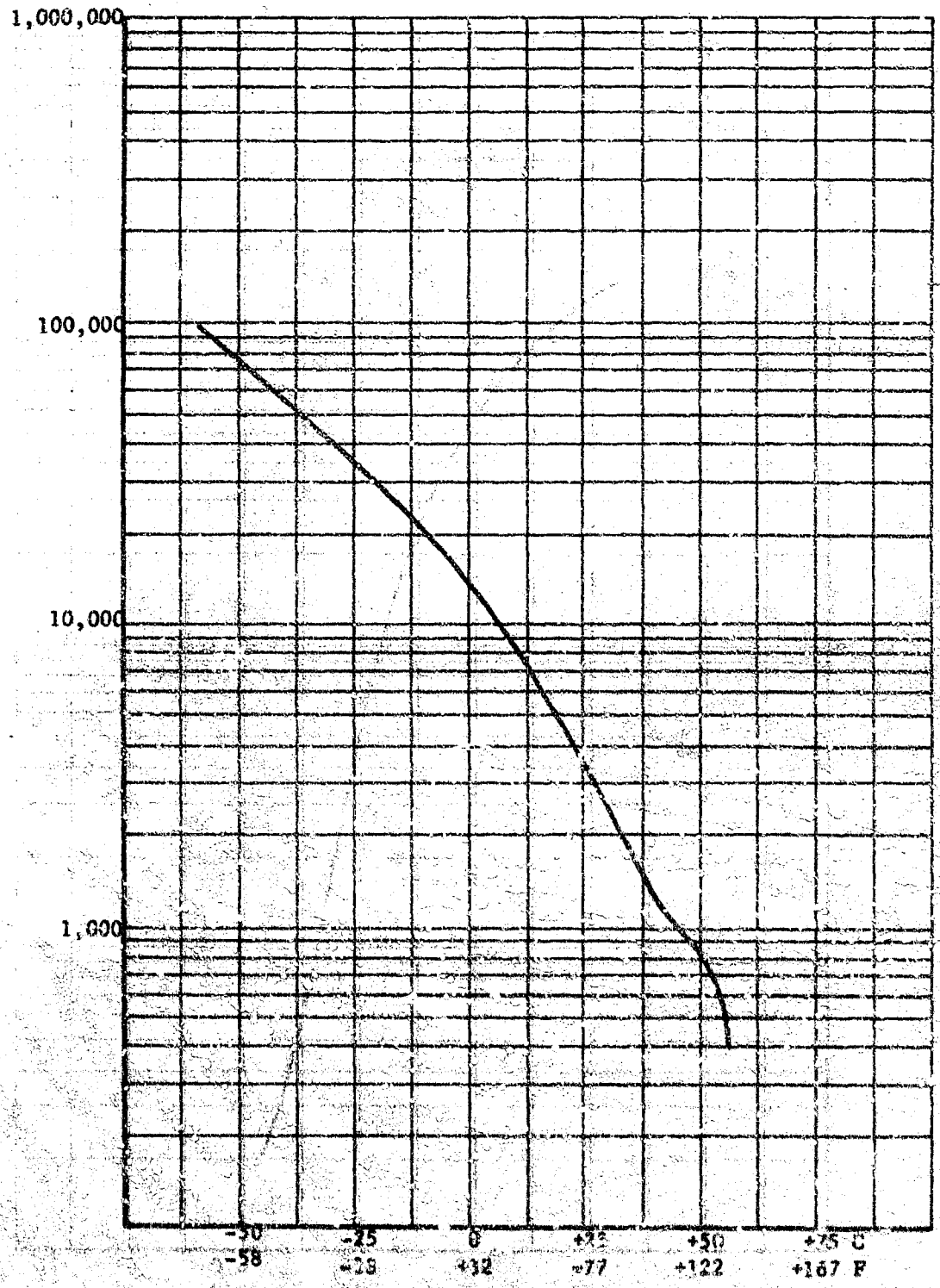

Figure 75

Change of Modulus vs Temperature

B. ADHESIVES FOR FILMS (OTHER THAN MYLAR)

Silicone adhesives were found to have fair or good adhesion to H-film, caprolactam, and biaxially oriented ethylene/vinyl acetate. No doubt, better cleaning and/or primers would have upgraded these results. (See Table 50). Flexible epoxies also formed a strong bond with unprimed ethylene/vinyl acetate.

Like Mylar, ethylene/vinyl acetate is commercially available and has such properties as high strength, ease of being aluminized, and good resistance, both to vacuum and radiation of space. But unlike Mylar, it has the unique property of low modulus. This low-modulus property appears to be a very desirable property for films intended for use in a structure which must be folded after assembly and in which the precise geometry originally built into the structure must be totally restored after deployment. For this unique property, ethylene/vinyl acetate film is suggested as a strong candidate for the mirror film in the solar collector.

C. MYLAR LAMINATE ASSEMBLIES

Laminates were prepared using 1.5-mil Mylar washed with triclene, xylene, and acetone as one element. A few had five layers: Mylar/adhesive/foam/adhesive/cloth. For expediency, we omitted a part of the layers in most of the samples. This group provided both materials for observation and an opportunity to evaluate some variations in materials and techniques. See the observations in Table 51 concerning this work.

Conclusions are as follows:

As discussed in the adhesives section, solvents in the adhesive layer present problems here. In some instances, there is gradual shrinkage of the adhesive during or following cure, resulting in curling of the laminate and "microdimpling" of the fiber surface. In other instances, the urethane foam is swelled severely by absorption of solvent during assembly with gradual return to original dimensions later and with resultant distortion.

Even though the resins are the same, the RTV 60 in which the catalyst is mechanically mixed cures about four times as fast as the aerosol-applied resin with catalyst applied as an overspray. No doubt this is due to the more intimate mixing of the catalyst in the former case.

After the laminate is folded, there is little strain, stretching and wrinkling of the Mylar when the adhesive layer is thin. In contrast, the distortion of the Mylar is excessive after folding very thick sections. It follows, therefore, that minimum thickness of the adhesive layer is a desirable goal for minimum mirror distortion due to folding.

TABLE 50

ADHESIVES FOR FILMS (OTHER THAN MYLAR)
ALL FILMS WASHED WITH ACETONE

	FILM	PRIMER	TYPE	IDENTIFICATION	ADHESION QUALITY	OBSERVATION
43453-5	H-Film	None	Silicone	DC 92-018	Poor (3)	
43453-4	H-Film	None	Silicone	RTV-102	Fair (4)	
43453-9	Caprolactam	None	Silicone	DC 92-018	Poor	
43453-8	Caprolactam	None	Silicone	RTV-102	Good (5)	
43453-7	Ethylene/Vinyl Acetate	None	Silicone	DC 92-018	Poor	
43453-6	" "	None	Silicone	RTV-102	Poor	
43493-1	" "	None	Silicone	DC 92-018	Poor	
43493-2	" "	None	Silicone	RTV-102	Fair	
43493-2A	" "	SS-4004	Silicone	RTV-102	Fair	
43493-3	" "	SS-4004	Silicone	RTV-60 (1)	Good	Snappy recovery when distorted
43493-5	" "	DC-1200	Silicone	DC 92-018	Poor	
43493-6	" "	DC-1200	Silicone	RTV-102	Poor	
43493-7	" "	DC-1200	Silicone	RTV-60 (1)	Poor	
43493-4	" "	None	Epoxy	(2)	Good	

(1). RTV-60 + T-12 catalyst mixed just prior to application.

(2). Epon 872, 15 g; D.E.R. 736, 15 g; triethylenetetramine, 2.4g.

(3). Easily separated from substrate.

(4). Peels with difficulty.

(5). Can't be separated from substrate with fingernail.

TABLE 51

LAMINATE ASSEMBLIES USING TRICLENE, XYLENE AND ACETONE WASHED 1 1/2 MIL MYLAR FILM AS ONE ELEMENT

Panel No.	Additional Sheet In Panel Assembly	Primer	Adhesive No. 1	Foam 80 Pores/Inch	Adhesive No. 2	Type	Treatment	Observation
[illegible]	No	SS-4004A	RTV60[1]	None	None	Parachute	RTV60[1]	4 days required to cure - good adhesion and surface
[illegible]	No	SS-4004A	RTV11[2]	None	None	Parachute	Acetone Washed	3 days required to cure - wavy surface
[illegible]	No	None	RTV112[3]	None	None	Spun 200	Acetone Washed	Very slow cure - Best adhesion in thinnest section
[illegible]	No	SS-4004	RTV60[2]	None	None	Spun 200	RTV60[1][4]	Poor adhesion between primed cloth and adhesive No. 1
[illegible]	No	SS-4004	RTV60[1]	None	None	Spun 200	RTV60[1][5]	Slow cure - Poor adhesion of primer to Mylar
[illegible]	Yes	SS-4004A	RTV60[1]	Yes[6]	None	None	None	Excellent adhesion
[illegible]	Yes	SS-4004A	RTV60[1]	None	None	Parachute	RTV60[1][5]	Slow cure
[illegible]	Yes	SS-4004A	RTV60[1]	Yes[6]	None	None	None	Slow cure
[illegible]	No	SS-4004A	RTV60[1]	Yes	RTV60[2]	Spun 200	None	Good cure and adhesion
[illegible]	No	None	Dupont 46971	Yes	None	None		Adhesive solvent swelled foam
[illegible]	No	None	Dupont 46971[7]	Yes[8]	None	None		Good adhesion - Foam is mottled
[illegible]	No	None	Dupont 46971[7]	Yes	Epon[9]	Spun 200		Good cure and adhesion - Semi-Rigid.
[illegible]	Yes	None	Epon[9]	Yes	None	None		Good cure and adhesion - Solvent swelled foam
[illegible]	No	None	Epon[9]	Yes	Epon[9]	Spun 200		Good cure and adhesion - Shrinkage of cloth side

(1) Alternating spray layers of RTV60 dissolved in a hydrocarbon and T-12 catalyst

(2) T-12 catalyst mixed into all volatile resin just prior to spatula application

(3) "Ready to cure" type silicone - pressed from a tube and evened with spatula

(4) Treatment applied 6 days prior to assembly

(5) Treatment applied one hour prior to assembly

(6) Foam treated with SS-4004 primer

TABLE 51 (Continued)

LAMINATE ASSEMBLIES USING TRICLENE, XYLENE AND ACETONE WASHED 1 1/2 MIL MYLARTYM AS ONE ELEMENT

Page No.	Additional Wash in Benzyl Alcohol	Primer	Adhesive No. 1	Foam 8C Pores/Inch	Adhesive No. 2	Type	Treatment	Observation
			(7) Diluted 1/1 with Triclene					
			(8) Dipped foam in adhesive					
			(9) Viron formulation based on Epon 812xT5					

D. INTERLAYER MATERIAL

If fabric "see-through" cannot be avoided by choice or development of a suitable adhesive, an interlayer of such physical form and structure as to allow the mirror film a measure of "freedom", with respect to the cloth substrate, may be needed. Several approaches were taken to find or produce this material. Table 52 describes work on interlayer materials. Two general types were tested and are discussed below:

1. Modification of Commercial Foam

Commercial 2 pfc open-cell flexible urethane 1/16 in. foam was first tried as received as an interlayer. Adhesion of the foam to either or Mylar presented no problem. However, when the adhesive was silicone, priming of the foam with SS-4004 improved adhesion. When the adhesive did not penetrate into the foam, this type material was very delicate and easily compressed. To increase resistance of the foam to compression, penetration of the adhesive into the foam was studied. This involved coating the interior of the pores with the adhesive resin. Products varied from soft, flexible materials through rubber-like stripe when heavy charges of silicones were used, all the way to semirigid tough sheets like cardboard, when epoxies were used. Also included was a similar series in which the starting foam was a 6 pcf 1/2 open-cell material. Best results were achieved when the resin solutions were diluted to about 35 per cent to 50 per cent solids. This provided good distribution, and the foams were still largely open-cell. At this concentration, there was great increase in resistance to compression with a minimum increase in weight when a rigid resin like Nopcothane 203 was used. But this approach was only partly successful, largely because of poor distribution of resin. In an open-cell foam, the entire structure is composed of posts or "struts". The goal is a uniform coating of rigid resin surrounding each strut. This goal is a uniform coating of rigid resin surrounding each strut. This goal was achieved in parts of the foam, but, in other areas, microscopic examination showed that the resin forms droplets, or even large drops sometimes at the intersection of two or more struts. This uneven distribution problem has not been solved.

2. Velvet

Velvet has been studied as a special type of "freedom" layer. Since it is composed of a sheet fabric on one face and "bristle" on the other, there is flexibility and complete freedom of movement parallel to the plane of the cloth, with maximum resistance to compression in the opposite direction. Filling of velvet with adhesives was also studied. See Table 52 covering interlayer modification.

3. Commercial Foams

Inquiry was made in the trade as to the availability of foams of not more than 8 pcf density in the flexible range, but highly resistant to

TABLE 52

INTERLAYER MODIFICATION AND ASSEMBLIES

	INTERLAYER		FILLER			
Sample Number	Material	Application	Type		Application	Observations
43468-2	Foam (6)	Rigidize Foam	Silicone	(1A)	Dip & Drain	Very heavy, like sheet of rubber
43468-2A	Foam (6)	" "	"	(1A)	" " "	" " " "
43480-6	Foam (6)	" "	"	(1B)	" " "	Very flexible, easy drape, heavy
43477-1	Foam (6)	" "	"	(1B)	" " "	Even distribution
43477-2	Foam (6)	" "	"	(1C)	" " "	Even distribution and flexible
43477-2A	Foam (6)	" "	"	(1C)	" " "	Dipped a part of 43477-2 a second time
43481-5	Foam (6)	" "	"	(1D)	" " "	Uneven deposition
43477-7	Foam (6)	" "	"	(1E)	" " "	" "
43480-1	Foam (6)	" "	"	(1F)	" " "	" "
43480-9	Foam (6)	" "	"	(1G)	" " "	" "
43480-10	Foam (6)	" "	"	(1G)	Resin spread on film, foam pressed in	Little penetration, good surface
43480-5	Foam (6)	" "	"	(1H)	Dip and Drain	Uneven deposition
43480-5A	Foam (6)	" "	"	(1I)	" " "	" "
43480-7	Foam (6)	" "	"	(1J)	Dip & Wring	Resin heavier at bottom of sheet
43480-8	Foam (6)	" "	"	(1J)	Resin pressed on film, foam pressed in	Little penetration
43477-3	Foam (6)	" "	"	(1K)	Dip & Drain	Spotty - heavy
43477-4	Foam (6)	" "	"	(1L)	" " "	Even - flexible
43477-5	Foam (6)	" "	"	(1M)	" " "	Uneven deposition
43477-6	Foam (6)	" "	"	(1M)	" " "	" " - flexible
43477A8	Foam (6)	" "	Epoxy	(5A)	" " "	" " - some flexibility
43481-1	Foam (6)	" "	"	(5B)	" " "	Stuck to substrate during cure
43481-2	Foam (6)	" "	"	(5C)	" " "	" " " "
43481-3	Foam (6)	" "	"	(5D)	" " "	Uneven deposition
43481-3	Foam (6)	" "	"	(5E)	" " "	" "
43481-4	Foam (6)	" "	"	(5F)	" " "	" "
43489-3	Foam (6)	" "	Urethane	(2A)	" " "	Increase in compressive modulus, no even distribution
43494-9	Foam (8)	" "	Epoxy	(4)	" " "	Too much resin pick-up
43494-10	Foam (8)	" "	Epoxy	(4)	" " "	Too much resin pick-up, better cure than 43494-9
43496-1	Foam (6)	" "	Urethane	(3A)	Dip & Wring	50 wt. % resin pick-up, good recovery in cured structure
43496-2	Foam (8)	" "	Urethane	(3A)	Dip & Wring	300 wt. % resin pick-up, good recovery in cured structure.
43496-3	Foam (6)	" "	Epoxy	(5)	Dip & Wring	Low resin pick-up, low rigidity
46102-1	Foam (6)	" "	Urethane	(3B)	Dip & Wring	200 wt. % resin pick-up, irregular distribution.
46102-2	Foam (7)	" "	Urethane	(3B)	Dip & Wring	200 wt. % resin pick-up. irregular distribution.
46102-3	Foam (6)	" "	Urethane	(3C)	Dip & Wring	175 wt. % resin pick-up, irregular distribution.
46102-4	Foam (6)	" "	Urethane	(3D)	Dip & Wring	175 wt. % resin pick-up, irregular distribution
46203-7	Foam (6)	" "	Urethane	(3E)	Dip & Wring	60 wt. % resin pick-up. irregular distribution
46104-1	Foam (6)	" "	Urethane	(3F)	Dip & Wring	260 wt % resin pick-up, irregular distribution
46104-2	Foam (6)	" "	Urethane	(3G)	Dip & Wring	175 wt. % resin pick-up. irregular distribution
46104-3	Foam (6)	" "	Urethane	(3H)	Dip & Wring	100 wt. % resin pick-up, irregular distribution
43488-1	Velvet	Mylar sandwich	Silicone	(1)	Spatula	Woven side next to Mylar, adhesive about 10 mil, very flexible, no show-through, no shrinkage
43488-2	Velvet	Mylar sandwich	Urethane	(2)	Spatula	"Bristle" side toward Mylar, some unevenness in resin coating.
43488-4	Velvet	Mylar sandwich	Urethane	(4)	Spatula	"Bristle" side toward Mylar, bristles not well adhered.
43485-1	Velvet	Rigidize Cloth	Urethane	(2A)	Dip & Drain	Flexible in plane of cloth, [illegible] modulus [illegible]

(Key to Previous Table)

(1A)	RTV 60 catalyzed with T-12	
(1B)	RTV 60 as 1A	1 part; Freon 11 - 1 part.
(1C)	" " " "	1 part; Freon 11 - 2 parts.
(1D)	" " " "	2 parts; Chloroform - 1 part.
(1E)	" " " "	1 part; Freon 11 - 5 parts.
(1F)	" " " "	1 part; Freon 11 - 10 parts.
(1G)	" " " "	1 part; Triclene - 1 part.
(1H)	" " " "	1 part; Triclene - 10 parts.
(1I)	" " " "	1 part; Naptha - 2 parts.
(1J)	" " " "	1 part; Xylene - 1 part.
(1K)	" 102	1 part; Freon 11 - 1 part.
(1L)	" 102 as 1K	1 part; Freon 11 - 2 parts.
(1M)	" 112	1 part; Freon 11 - 1 part.
(1N)	" 112 as 1M	1 part; Freon 11 - 2 parts.

(2) Hopcothane 201

(2A) Hopcothane 201 diluted with a 1/1 ixture of xylene and cellosolve.

(2B) 2 parts Hopcothane 201, 1 part xylene

(3) Hopcothane 203

(3A) 1 part Hopcothane 203, 1 part xylene

(3B) 2 parts Hopcothane 203, 1 part xylene

(3C) 2 parts Hopcothane 203, 1 part xylene, 0.5% DC-113

(3D) 2 parts Hopcothane 203, 1 part xylene, 1.0% DC-113

(3E) 1 part Hopcothane 203, 1 part xylene, 2 parts acetone

(3F) 4 parts Hopcothane 203, 1 part methyl ethyl ketone

(3G) 3 parts Hopcothane 203, 1 part methyl ethyl ketone

(3H) 2 parts Hopcothane 203, 1 part methyl ethyl ketone

(4) 15 g Epon 872, 15 g D.E.R. 736, 3 g triethylene-tetramine, 30 g xylene

(5) 30 g Epon 872 x 75, 1.5 g Epon curing agent U

(5A)	Epoxy as 5	1 part; Xylene - 1 part.
(5B)	Epoxy as 5	2 parts; Xylene - 1 part.
(5C)	Epoxy as 5	2 parts; Xylene - 3 parts.
(5D)	Epoxy as 5	1 part; Acetone - 1 part.
(5E)	Epoxy as 5	2 parts; Chloroform - 1 part.
(5F)	Epoxy as 5	2 parts; Chloroform - 3 parts.

(6) 2 lb. open cell urethane foa

(7) 2 lb. open cell urethane foam primed with Aroplaz 6990

(8) 6 lb. 1/2 open cell urethane foa

compression. Unfortunately, very few were found.

One outstanding material of considerable interest was located and is recommended as a candidate. It was develped for the Navy by the Westinghouse Research and Development Center at Pittsburgh, Pa.[2] to serve as a cushioning material. The foam is largely open-cell of about 8 pcf density and designed to process high resilience over a wide temperature range. While not commercial, this foam has been made in quantity by the Foam Division of Scott Paper Company of Chester, Pa., and could easily be produced by them or others, should the need develop. An interesting group of Scott products which are commercial are a series of Scott Felt Grade 900 materials. These are made by compressing 2 pcf flexible open-cell foams under heat and pressure to the desired densities and firmnesses. These provide a range of materials which are also recommended as candidates for the interlayer.

Available from Haveg Industries[3] are some polypropylene foams which are about 5 pcf density and are readily foldable and quite incompressible. Adhesives for them are not available at this time, but are being developed.

4. Laboratory Foams

From several experiments performed in our laboratory to produce materials whose properties are different from the commercial types, five samples have been selected for Viron evaluation. (See Table 53). These batch-mixed samples lack the finished appearance of machine-made foams, but provide variations in density, flexibility and firmness not otherwise available. Three are based on Adiprene-modified urethane formulations developed at Dayton: No. 5, No. 45, and No. 51. Two are from Mobay's[4] work in which they were developing a foam which is flexible at low temperature: No. 52 and No. 53. These two foams are identical in formulation, except for a trace of aluminum powder in the No. 53 to provide a high percentage of open cells and, consequently, better heat transfer.

E. REFERENCES

(1) Test developed from Article by R. F. Clash, Jr. and R. M. Berg. Industrial and Engineering Chemistry, 34, p. 1218.

(2) Morris A. Mendelsohn and others - American Chemical Society - Division of Organic Coatings and Plastics Chemistry Papers, presented at the Detroit Meeting April 1965, Vol. 25, No. 1, p. 85.

(3) Haveg Industries, Inc., Plastics Park, Wilmington, Delaware 19808.

(4) Mobay Chemical Co., Penn Lincoln Parkway West, Pittsburgh 5, Pa.

TABLE 53

EXPERIMENTAL FOAMS PREPARED DURING COURSE OF PROGRAM

No.	Polyol 1/g	Polyol 2/g	Urethane Elastomer/g	Isocyanate	Catalyst C-16/g	H_2O/g	Silicone 1/g	Silicone 2/g	Density pfc	Compression PSI	Comments
1.	LE380-120		L100- 30	MR - 134	2	3.0	DC113- 3	Y4499- 3	3.28	39.2	
2.	" - 90		" - 60	MR - 100	1	3.0	" - 3	" - 3	3.51	29.1	
3.	" - 60		" - 90	MR - 95	1	3.0	" - 3	" - 3	3.80	42.0	
3A.	" - 60		" - 90	MR - 95	1	3.0	" - 3	" - 3	6.01	44.2	
4.	" - 60	LHT34- 60	" -116	TDI- 49	1	3.0	" - 3	" - 3			Discard - Collapsed
5.	" -240	" -240	" -464	MR - 356	4	12.0	" -24	" -12	5.76	5.5	To be sent.
5A.	" - 60	" - 60	" -116	MR - 89	0.5	3.0	" - 6	" - 3			
6.	" - 60	" - 60	" -116	TDI- 49	1	3.0	" - 6	" - 3			Discard - Collapsed
7.	" - 60	" - 60	" -116	TDI- 49	1	5.0	" - 6	" - 4			Discard - Collapsed
8.	" - 52	" - 52	" -130	TDI- 53	1	4.0	" - 8	" - 3			Discard - Collapsed
9.	" - 58	" - 58	" -116	TDI- 49	1	4.6	" - 6	" - 3			Discard - Collapsed
10.	" - 58	" - 58	" -116	TDI- 49	1	4.6	" - 1	" - 3			Discard - Collapsed
11.	" - 60		L167- 60	MR - 95	1	3.0	" - 3	" - 3	2.60	20.0	
12.	" - 30		L167--80	MR - 90	1	3.0	" - 3	" - 3	7.22	73.0	
13.	" - 60		L100- 60	MR - 65	1	1.0	" - 3	" - 3	5.06	57.5	
14.	" - 90		L167- 60	MR - 97	1.5	1.5	" - 4.5	" - 4.5	4.50	51.6	
15	" - 90		L167- 55	MR - 88	1	0.5	" - 4.5	" - 4.5	3.80	165.0	
16.	" - 90		L167- 55	TDI- 49	1	0.5	" - 4.5	" - 4.5	8.03	118.0	
17.	" -135		L315- 37	TDI- 74	1	0 75	" - 6.7	" - 6.7	6.56	134.0	
18.	" - 90		L167- 60	TDI- 54	1.5	1.5	" - 4.5	" - 4.5			
19.	" - 90		L167- 60	TDI- 54	1.5	1.5	" - 4.5		4.38	45.0	
20	" - 90		L167- 60	TDI- 54	0.5	1.5	" - 4.5		4.25	47.4	
21.	" - 90		L167- 60	TDI- 50	0.5	1.5	" - 4.5		4.56	47.4	
22	" - 90		L167- 60	TDI- 58	0.5	1.5	" - 4.5		4.57	59.3	
23.	" - 90		L167- 60	TDI- 54	0.5	1.5			4.38	59.7	Not quite foldable
24.	" - 90		L167- 60	TDI- 54	0.5	1.5			9.59	183.0	Discard - Collapsed
25.	" - 90		L167- 60	TDI- 54	0.5	1.5		Y4499-2.0	11.40	232.0	Discard - Collapsed
25A.	" - 90		L167- 60	TDI- 54	0.5	1.5(1)	DC113-4.5				Discard - Collapsed(oven)
26.	" - 90		L167- 50	TDI- 45	0.5	0.5			10.40	33.0	Foldable
26A.	" - 90		L167- 60	TDI- 54	0.5	1.5(1)	" -4.5				Discard - Collapsed(oven
27.	" - 90		L100-135	TDI- 68	1.0	3.0(1)	" -4.5	" -4.5			Discard - Collapsed
28.	" - 90		L100-135	TDI- 68	1.0	3.0(1)	" -4.5				Discard-"Crevices"
29.	" -110		L167-110	TDI- 75	0.5	2.0	" -4.		5.16	42.0	
30.	" -110		L167-110	TDI- 70	0.5	1.0	" -4.0		7.21	99.0	
31.	" -110		L167-110	TDI- 65	0.5	0.5(1)	" -3.6		12.54	132.5	Brittle
32	" -110		L167-110	TDI- 70	0.5	1.0(1)	" -3.0		8.12	108.8	Not foldable
33.	" -110		L167-110	TDI- 75	0.5	1.5(1)	" -3.0	"	6.04	71.3	Not quite flexible
34.	" - 60	LHT34-60	L100-116	MR- 75	1.0	2.0(1)	" -3.0	-3.0			Discard
35.	" - 60	" -60	L100-116	MR- 75	1.0	2.0(1)	" -6.0	" -2.0			Discard
36.	" - 60	" -60	L167- 77	MR- 75	1.0	2.0(1)	" -6.0	" -2.0	8.06	9.0	Flexible
37.	" -60	" -60	L167- 77	MR- 75	1.0	2.0	" -6.0	" -2.0	5.03	6 0	Flexible
38.	LG56--170	Quadrol-30		MR-(2) 92	1.0	1.0(2)	SF1034-4.0				Discard - "Cheesy"
39.	LE380- 62	LHT34-62	L100-123	TDI- 53	1.0	5.0	Y4347-8.0	" -4.0			Springy & quick recovery
40.	" - 62	" -62	L100-125	TDI- 35	1.0	2.0	" -8.0	" -4.0			Discard - "Cheesy"
41.	" - 60	" -60	L100-116	MR- 89	1.0	3.0	" -6.0	" -3.0			Good Texture, No Strength

TABLE 53 (Continued)

EXPERIMENTAL FOAMS PREPARED DURING COURSE OF PROGRAM

No.	Polyol 1/g	Polyol 2/g	Urethane Stabilizer/g	Isocyanate	Catalyst C-16/g	H_2O/g	Silicone 1/g	Silicone 2/g	Density pcf	Compression PSI	Comments
42.	" - 60	" - 60	L100-116	TDI- 49	1.0	3.0	" -6.0	" - 3.0			Springy, like fresh bread.
42A.	" -240	" -240	L100-464	TDI- 196	4.0	12.0	" -24.0	" -12.0			Discard - Collapsed.
43.	" - 60	" - 60	L100-116	TDI- 49	1.0	3.0	" - 3.0	" - 1.5			Springy & quick recovery.
44.	" - 60	" - 60	L100-120	TDI- 50	1.2	5.0	" - 7.0	" - 3.5			Discard.
45.	" - 60	L5734- 60	L100-120	TDI- 30		3.0	" - 7.0	" - 3.5			Discard-collapsed(oven).
46.	" -240	" -240	L100-480	TDI- 200	4.8	20.0	" -28.0	" -14.0			Springy & quick recovery.
47.	" - 90		L167- 60	TDI- 54	0.5	1.5	" - 6.0	" - 3.0			Discard - Collapsed.
48.	" - 90		L167- 60	TDI- 54	0.5	1.5	" - 3.0	" - 1.5			Discard - Collapsed.
49.	" - 90		L167- 60	TDI- 54	0.5	1.5	" - 3.0	" - 1.5			Discard - Collapsed.
50.	" - 90		L167- 60	TDI- 54	1.0	1.5					Firm-just foldable.
51.	" -360		L167-240	TDI- 216	4.0	6.0					Firm-just foldable, to be sent.
52.	L056 -680	Quadrol- 30		MR- 372	12.0	4.0(3)	L5310-16.0				Springy & quick recovery, to be sent.
53.	" -680	" - 30		MR- 372	12.0	4.0(3)	" -16.0(4)				Springy & quick recovery, to be sent.

(1) Syton 200 used in place of H_2O.

(2) F-11 used as additional blowing agent. (20.0 gms)

(3) F-11 used as additional blowing agent. (64.0 gms)

(4) Alcoa No. 422 aluminum powder for cell opening (6 g added)

F. MATERIALS USED

Table 54 lists the various materials used in this program, including source, specification, and availability of these materials.

IV. CONCLUSIONS

The following conclusions were made as a result of this work:

(1) Silicone adhesives generally adhere well to Mylar, urethane foams, and nylon cloth. Adhesion is good if the surfaces of the substrates are adequately cleaned. Those silicones releasing acetic acid (RTV 100 series) do not need primers for good adhesion. Primers are needed, however, with silicones which do not release acetic acid during the curing cycle. The silicone adhesives have the advantages of being flexible at low temperatures (-50 to -60 F). The 100 per cent solids silicone systems were dimensionally quite stable. The one system (RTV 60) applied as an aerosol spray had some shrinkage during cure because of the escape of hydrocarbon solvent.

(2) Epoxies in general had good adhesion to the substrates (Mylar, foam, and nylon cloth). Epoxy systems containing solvents as viscosity reducers had poor dimensional stability. Conventional epoxies were very viscous when applied without solvents, but their dimensional stability was good. Epoxy formulations made by blending Epon 872 and D E R 736 and curing with Epon Curing Agent U had good flexibility at room temperature, but were deficient in this property at low temperatures.

(3) A limited amount of work did not produce a satisfactory urethane adhesive for use as a flexible interlayer material. Urethane varnishes showed excessive shrinkage, and a 100 per cent solids system did not have good adhesion to Mylar.

(4) Primers for Mylar are susceptible to attacks by organic solvents that may be present in the gelatin impregnating solutions. The primers tested are not affected by water.

(5) Silicone adhesives are superior to other adhesives tested in the wide temperature range over which they remain flexible (-50 to -60 F upward).

(6) Biaxially oriented ethylene/vinyl acetate (E/VA) film appears to offer certain advantages over Mylar as the mirror film for solar collectors. E/VA film is a high-strength material which has good resistance to vacuum and radiation and can be aluminized. It has the advantage of being a low-modulus material which would facilitate folding.

(7) Preparation of small test laminates showed that the presence

of solvent in the adhesive was definitely undesirable, as it caused "see-through" or dimpling. Mixing of catalyst systems with the base resin appears to be desirable over application of catalyst by overspraying the adhesive. The latter method of application does not result in adequate blending, and slow cures result. Thin layers of adhesive are more desirable than thick layers, as less distortion results in the former case on folding.

(8) Flexible urethane foams are used as the interlayer. They should be sliced into thin sections (1/16 in.).

(9) Impregnation of low-density foams (≤2 pcf) with dilute solutions of high-modulus resins to increase compressive strength is not recommended. It has been found that it is difficult to obtain uniform results.

(10) The use of velvet as a flexible interlayer appears promising.

(11) Several commercial foams which are either regular items of commerce or development materials were found which appear to be promising flexible interlayer materials. Prominent among them are the Scott Felt Grade 900 materials.

(12) Five laboratory foam formulations were developed which have promise of giving a useful flexible interlayer material.

TABLE 54

MATERIALS USED

ITEM	SOURCE OR MFG.	SPECIFICATIONS	IDENTIFICATION
Structural			
Mylar	Dupont	5 mil, 1-1/2 mil	Commercial
Ethylene/Vinyl Acetate Film	Monsanto	10 mil	Research Sample
H-Film	Dupont	2 mil	Development
Caprolactam Film	________	2 mil	[illegible] at Monsanto
Nylon Cloth	Testfabrics, Inc.	3 mil	300 [illegible]
Nylon Cloth	" " "	12 mil	Style 3542 - [illegible] Type 300
Velvet	________	60 mil	[illegible]
Urethane Foam	Merryweather Foam Co.	1/16"	2 pcf open cell
Urethane Foam	" " " "	1/16+"	6 pcf 1/2 open cell (polyester)
Silicones			
RTV 11	Gen. Electric	Two component	Silicone
RTV 60	" "	" "	"
RTV102	" "	Ready for use	"
RTV103	" "	" " "	"
RTV112	" "	" " "	"
XC92-018	Dow Corning	" " "	"
Epoxy Components			
Epon 872	Shell Chemical Co.		Epoxy
Epon 872 x 75	" " "	Epon 872 + 25% Xylene	"
Epon 871	" " "		"
Epon 828	" " "		"
Epon Curing Agent U	" " "		"
D.E.R.736	Dow Chemical Co.		"
D.E.R.732	" " "		"
Urethane & Urethane Components			
Nopcothane 201	Nopco Chemical Co.		Air drying Urethane varnish
Nopcothane 203	" " "		" " " "
Multron R4	Mobay Chemical Co.		Polyester
Multrathane F84	" " "		
PG 380	Union Carbide		Polyol
LG 56	" "		"
LHT 34	" "		"
L-100	Dupont		Urethane Elastomer
L-167	"		" "
Mondur MR	Mobay Chemical Co.		Isocyanate
TDI	" " "		" "
Miscellaneous			
46971 Adhesive	Dupont	Food Grade	Adhesive
Beetle 216-8	American Cyanamid	60% solids	Resin Solution
SS-4004	Gen. Electric	10% solids	Primer
Arolast 8991	A. D. M.	________	Primer
T-12	M & T Chemicals	________	Catalyst
C-16	Mobay Chemical Co.	________	Catalyst

APPENDIX III

THERMAL ANALYSIS AND RADIATION STUDIES

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I INTRODUCTION

In order to design a space structure properly, its behavior when deployed in the exoatmosphere must be anticipated as much as possible. This is particularly true for structures that are erected from small volumes into large areas composed of relatively thin skins. When the surface area to weight ratio is large, the interaction with the space environment is more rapid. This means that problems related to temperature or changes in temperature become important.

This report deals with thermal analysis of "dry" and "wet" solar collectors, and with the experimental evaluation of a number of test panels of solar collector material. The latter includes weight and topographical changes in a simulated solar environment.

II SOLAR COLLECTOR EQUILIBRIUM TEMPERATURES

A solar collector made up of the following elements has been proposed:

1. A reflective metallic surface attached to a thin layer of polymer.

2. The above bonded to another flexible polymer layer which in turn is bonded to

3. Polymer drop-thread cloth impregnated with a gelatin-water formulation.

When the water is removed from the above composite, a rigid structure results.

A solar collector of the above type deployed in the exoatmosphere so that the reflective surface continuously faces the sun, comes to thermal equilibrium after the water is removed.

The temperature distribution through the composite collector will be determined by the shape and the thermal-optical characteristics of the components. A thermal analysis of this collector based on a detailed accounting of the thermal, mechanical, and radiative coupling of the composite parts is a very difficult problem.

As a point of departure, the solar collector can be approximated by the model shown in Figure 75. For simplicity, it is a planar structure with its front surface normal to solar radiation at all times.

The following describes the collector:

1. Front Surface of the Collector

The important parameters on the front surface are the absorptivity and emissivity of the metallic film on polymer substrate. The flexible polymer layer followed by the cloth backing impregnated with gelatin constitutes the remainder of the front. Previous calculations have shown that only a very small temperature gradient is sustained in such a thin structure so that we have assumed that the entire front surface is characterized by a temperature T_1. In addition, an emissivity of the back part of the front surface has been designated as ϵ_2.

2. Back Surface of the Collector

The back surface is considered to be simply a surface with emissivity ϵ_3 coming to an equilibrium temperature T_3.

3. Drop-thread Coupling

In addition to a radiative exchange between the front and back surfaces of the collector, there is a thermal conductive path due to the presence of drop threads of thermal conductivity K. It is assumed that all the drop threads are perpendicular to the two surfaces so that there is no complication arising from thermal and radiative coupling.

Using this model, the following equations were obtained describing thermal balance in the collector.

1. Overall Heat Balance

$$\alpha_1 S = \sigma \epsilon_1 T_1^4 + \sigma \epsilon_3 T_3^4 \qquad (1)$$

where:

α_1 is the absorptivity of the metallic reflective surface,

S is the solar flux impinging on the front surface,

σ is the Stefan-Boltzman constant,

ϵ_1 is the emissivity of the front surface, and

ϵ_3 is the emissivity of the back surface.

2. Heat Balance in the Back Surface

An additional equation can be obtained by considering the back surface alone.

$$\frac{K}{\delta_2}(T_1 - T_3)(1 - f) + \frac{\sigma f}{\varepsilon_2^{-1} + \varepsilon_3^{-1} - 1}(T_1^4 - T_3^4) = \sigma \varepsilon_3 T_3^4 \quad (2)$$

where:

K is the thermal conductivity of the drop threads,

δ_2 is the length of the drop threads,

f is the fraction of a collector surface which is emitting radiation,

and

(1 - f) is the fraction of a collector surface which is thermally conductive (cross sectional area of the drop threads).

The second term in equation (2) represents the overall radiative exchange from the two internal surfaces or radiation absorbed by the back surface.

The solution of these equations for T_1 and T_3 for ranges of values for f, K/δ_2, S, α_1, ε_1, ε_2, and ε_3 was computerized (IBM 1620). It became apparent that considerable computer time would be needed for running through ranges for all of the above parameters. It was therefore necessary to restrict computing for chosen values of f, S and to confine the ranges of the remaining. Some of the results are shown in Table 55.

As can be seen, front and back temperature differences of 50 to 80 degrees are predicted for collectors having rather wide ranges of α_1 and the ε's, and for a K value typical of polymers such as Nylon.

If the drop threads were made of aluminum, practically no gradient would exist between the front and back of the collector. This appears to be an interesting possibility for further exploration.

III TEMPERATURE-TIME HISTORY FOR A DEPLOYED SOLAR COLLECTOR

In order to determine the time necessary to erect and rigidize a solar collector, a detailed knowledge of the energy and mass transport in and out the system is necessary. At the beginning, the collector is at a uniform temperature (probably that of the canister) and the water is distributed in proportion to the gelatin in the front, the drop-threads, and the back. The collector is brought into shape by inflation of a balloon attached to the periphery of the collector and receives a solar input depending on the transmissive properties of this end-cap. The front and edge of the collector are impervious to the passage of water vapor,

so that rigidization is accomplished by removal of the water through the back of the collector.

As the collector is exposed to the space environment a temperature difference starts to develop due to emission of radiation on the surfaces. The temperature gradient results in mass transport of water from the front part of the collector to the back; at the same time water is being removed from the collector by evaporation.

The change in temperature with time of the two surfaces depends on a consideration of both the energy and mass balance in these parts.

The following equation can be considered to represent such a condition:

1. Energy and Mass Transport of the Front

$$\left[D_c C_c + \left(D_{Hf} - \Gamma_{Hf}\,(d\tau)\right) C_H\right] \frac{dT_1}{d\tau} = \tau_1 S = \frac{\sigma f}{\varepsilon_2^{-1} + \varepsilon_3^{-1} - 1}\left(T_1^4 - T_3^4\right)$$

$$- \frac{K}{t_2}\,(T_1 - T_3)\,(1 - f) - \Delta H\,(\Gamma_{Hf})\,f + \sigma \varepsilon_1 T_1^4 \qquad (3)$$

where:

D_c is the mass/unit area of the dry front part of the collector,

C_c is the average heat capacity of the front of the collector,

D_{Hf} is the mass/unit area of the water in the wet front collector in the canister,

C_H is the heat capacity of water,

Γ_{Hf} is the flux of water vapor from the cloth in the front of the collector towards the back,

τ is the time, and

ΔH is the heat of evaporation of water.

This equation states that the change in temperature with time is directly proportional to the difference in heat inputs and outputs both from mass and energy flow and inversely proportional to the mass and heat capacity of the structure. The complication in this equation arises from a variable flux of mass from the front, i.e., $\Gamma_{Hf} = \Gamma_{Hf}(\tau)$.

2. Energy and Mass Transport of the Back

In a similar manner we can consider the energy and mass balance of the back of the collector:

$$\left[D_b C_b + \left(D_{Hb} + \Gamma_{Hf} d\tau - \Gamma_{Hb} d\tau\right) C_H\right] \frac{dT_3}{d\tau} = \frac{\sigma f}{\varepsilon_2^{-1} + \varepsilon_3^{-1} - 1} \left(T_1^4 - T_3^4\right)$$

$$+ \frac{K}{\delta_2} (T_1 - T_3)(1 - f) + \Delta H \left(\Gamma_{Hf} - \Gamma_{Hb}\right) - \sigma \varepsilon_3 T_3^4 \qquad (4)$$

where

$$\Gamma_{Hb} = \frac{a P_3}{(2\pi R T_3)^{1/2}} \qquad (5)$$

In these equations:

D_b is the mass/unit area of the back of the collector,

C_b is the heat capacity of the back,

D_{Hb} is the mass of water/unit area of the back part of the collector (wet) prior to deployment

P_3 is the vapor pressure of water at temperature T_3,

a is the coefficient of evaporation of the water from the back of the collector, and

R is the gas constant.

Several expressions were tried for Γ_{Hf} until one was found in the literature which gives the net flow of vapor between two liquid surfaces:(1)

$$\Gamma_{net} = \frac{a P_1}{(2\pi R)^{1/2} T_1^{1/2}} \left[\frac{1 - \frac{P_3}{P_1}}{1 + \left(\frac{T_3}{T_1}\right)^{1/2}}\right] \qquad (6)$$

Rewriting equation (3) and (4) in incremental form, we have:

(1) Plesset, M.S., J. Chem. Phys. 20, 799 (1952)

$$\left\{ \rho_f C_f + [D_{Hf} - \sum_i (\varphi_f \Gamma_{net} \Delta\tau)_i] C_H \right\} \left\{ \frac{\Delta T_1}{\Delta\tau} \right\}_i = \alpha_1 S - \frac{\sigma f (T_1^4 - T_3^4)}{\varepsilon_2^{-1} + \varepsilon_3^{-1} - 1}$$

$$- \frac{K}{\ell_2} (T_1 - T_3) (1 - f) - \Delta H (\varphi_f \Gamma_{net})_i - \sigma \varepsilon_1 T_1^4 \qquad (7)$$

$$\left\{ \rho_b C_b + [D_{Hb} + \sum_i (\varphi_f \Gamma_{net} \Delta\tau)_i - \sum_i (\varphi_b \Gamma_{Hb} \Delta)_i] C_H \right\} \left\{ \frac{\Delta T_3}{\Delta\tau} \right\}_i$$

$$= \frac{\sigma f (T_1^4 - T_3^4)}{\varepsilon_2^{-1} + \varepsilon_3^{-1} - 1} + \frac{K}{\ell_2} (T_1 - T_3) (1 - f) + \Delta H \left[\varphi_f \Gamma_{net} - \varphi_b \Gamma_{Hb} \right]_i$$

$$- \sigma \varepsilon_3 T_3^4 \qquad (8)$$

In these equations, φ_1 was introduced as a porosity or permeability factor, i.e. the fraction of collector area which offers no resistance to vapor flow. This factor may be a function of the gelatin concentration and the amount of water remaining at any time τ, but was assumed constant in the computations which were made.

A program was written for the 1620 IBM computer to solve the above equations for ΔT_1 and ΔT_3. To do this the time increments $\Delta\tau_i$ were chosen to yield reasonably small values for ΔT_1 and ΔT_3. In the test example described below increments from 1 to 600 seconds were used. When the solution progressed to the point where $D_{Hf} - \sum_i (\varphi_f \Gamma_{net} \Delta\tau)_i$ was close to zero, i.e. when all the water was transported from the front of the collector, the program called for an end to the summation in equation (7) but for a continuation of the $\sum_i (\varphi_b \Gamma_{Hb} \Delta\tau)_i$ term in equation (8).

When all the water has left the collector, equations (7) and (8) degenerate to the case of a dry collector coming to equilibrium from temperatures T_1 and T_3 at the time all the water has left the system.

Equations (7) and (8) can be used to calculate the temperature-time history of a collector put into various orbits. In order to do this with any significance, the position of the satellite at the time of

erection must be known. In addition, the aspect of the collector must be known as a function of time.

The computer program can be scheduled to accommodate varying values of heat input, αS, determined by the orbit parameters.

Equations (7) and (8) were solved using the following values for the material parameters: $\rho_c = 0.1$ g/cm^2, $C_c = 0.5$ cal/g/$^\circ$K, $D_{Hf} = 0.034$ g/cm^2, $\varphi_f = \varphi_b = 0.05$, $C_H = 1$ cal/g/$^\circ$K, $\alpha = 0.2$, $\varepsilon_1 = 0.2$, $f = 0.95$, $\varepsilon_2 = \varepsilon_3 = 0.5$, $K/\ell_2 = 2 \times 10^{-4}$ cal/cm^2/sec/$^\circ$K, $\Delta H = 540$ cal/g, $a = -.04$. The expressions used for the vapor pressure of water were obtained from the International Critical Tables for one range of temperature and from a two-parameter equation obtained by using the values for the lower temperature range found in the 43rd edition of the Handbook of Chemistry and Physics.

The results are shown in the actual computer readout. The two columns headed by W_f and W_b show the amount of water remaining in the front and the back at a time $\sum_i (\Delta\tau)_i$. It can be seen that in less than a minute the entire structure is below the freezing point of water. This conflicts with solar simulator experiments described below which show that it takes about five minutes for this to happen. The difference can be due to the incorrect choice of values of some of the parameters in the equations (especially φ_i) or that our deployment simulation at the very beginning was poor. In any case, it is strongly recommended that experiments be conducted to determine the transport of water from H_2O-gelatin-impregnated membranes.

IV SOLAR COLLECTOR EFFICIENCY

Before proceeding with solar collector experiments in the solar simulator chamber to measure shrinkage, distortion, etc., it was of some interest to examine the optical response of a collector. By this we mean to observe the image of reflected radiation in the focal plane.

Variations of the optical arrangement shown in Figure 76 were used. A source of light (S) is placed at the focus of a concave mirror (M) to produce a beam of parallel light. Masks and slits can be used to alter the size of the beam. The light impinges on the collector parallel to its axis and is reflected into a photometer. All of the components are clamped at points marked X on optical benches A and B. By adjusting the size of the beam and the photometer aperture, some idea of the collector efficiency could be obtained by recording the intensities of the incident and reflected beams. By placing a piece of white paper in the focal plane, one can observe the size of the circle of confusion which reflects the perfection of the collector geometry.

This procedure was used on one of the earlier collectors. It was found that with a fixed photometer position in the focal plane, the reflected intensity varied from gore to gore by almost an order of magnitude in a circle of confusion having a diameter of 2 to 3 inches. The later corresponds to ± 10 degree surface deviation.

The purpose of this measurement was to determine the magnitude of the effect of disturbing the collector both mechanically and thermally. In both instances, changes in reflected intensity were recorded, but all changes fell within the range of reflected intensities from gore to gore. It appears that higher quality reflectors are needed to evaluate the changes that would be produced in the solar simulator from thermal cycling, etc.

V TEMPERATURE-TIME HISTORY OF DEPLOYED COLLECTORS IN THE FLEXIBLE STATE

A. EXPERIMENTAL

Two solar collector panels furnished by Viron (Russel to Rosen memo, Aug. 23, 1965) were placed in the GCA Technology Division solar simulator to determine the curing cycle expected for structures actually deployed in the exoatmosphere.

Before discussing the results a description of the simulation desired and that actually achieved will be given.

It is assumed that the wet collector will be placed in a canister and kept at room temperature right up to deployment time. When the latter takes place, the inflated collector is immediately subjected to the space environment. In a solar simulator this is not quite the case. The latter is due to the time delay resulting from "priming" the chamber, i.e. pumping and filling the shrouds with liquid nitrogen. In this interval the panel temperature starts to drop due to water loss from the sample.

An encapsulation method was developed to help minimize this. The enclosure of the panel by Viron was felt to be unrealistic since water vapor egress would occur past a slit whereas in space the entire back surface of the collector is exposed at once. In addition, it was necessary to attach thermocouples to monitor temperatures. Accordingly, the plastic covering was removed after first weighing the panel to assure that the proper amount of water would be replaced just prior to sealing. A number of thermocouples were attached to the front, middle, and back of the panel. The leads were potted in between two 12 inch by 12 inch sheets of aluminum foil with Silastic rubber (see Figure 76). After adding back the water lost in handling, the panel was sealed between the foil using Histowax. The sample was then clamped to a holder mounted on an optical bench.

The opening mechanism was completed by attaching strings with weights according to Figure 77. When the carbon arc is turned on the sample, the Histowax melts and the foils are drawn away from the panels by the pully-weight system thus exposing the sample to vacuum. Some water is probably lost through the imperfect seal when pumpdown occurs.

B. RESULTS

1. Panel number one was encapsulated as indicated in Figure 77. The pumpdown was started and the shrouds filled when the chamber pressure was about one millimeter. Two cone heaters with a cylindrical parabolic reflector were turned on in an attempt to keep the back of the sample at room temperature during this process, but this was not completely effective. The arc was turned on as the filling operation was being completed. The temperature-time history is shown in Figure 78.

For the first twenty minutes or so the collector panel temperature dropped uniformly to about - 20 C whereupon the front surface temperature started to rise, the back surface temperature remaining at about -20 C. After three hours only small changes in temperature could be detected. As will be shown in the next section this does not necessarily indicate a completely cured collector. The rather steep initial drop in temperature may be partially due to imperfect encapsulation of the sample. The rise in temperature of the front is due to the loss of water and an approach to equilibrium for a dry surface.

2. Panel number two was encapsulated in the same fashion as one except that only the back or permeable part was enclosed leaving the reflective surface exposed to the environment. This prevented damage to the thin aluminum coating from water vapor, Formalin, and contact with the encapsulating foil. The temperature-time history for this panel is shown in Figure 79.

The overall shape is the same as for panel one, the differences lying in the dissimilar starting conditions. The apparent equilibrium temperatures are essentially the same. Unfortunately a guess has to be made concerning the initial thermal history since we couldn't duplicate the initial deployment expected in space with precision. The results do indicate that no more than five minutes is available for inflating a structure made from this composite since the freezing point of water is approached. The assumption made here is that the plastic parts of the collector are not below their respective glass transition temperatures, or if they are, proper inflation is still feasible. As mentioned previously, these results are not in agreement with results obtained from equations (7) and (8).

VI DEGRADATION AND TEMPERATURE MEASUREMENTS

A number of solar collector and space shelter structural material

samples were exposed to solar environment conditions in the GCA solar simulator in order to determine whether any changes occur. Included in the latter are changes in physical appearance (shape, color), weight, and thermal characteristics.

A. EXPERIMENTAL

1. Equilibrium Temperature Measurements

Copper-constantan thermocouples were attached to the front and back surfaces of a number of samples. Care was taken to insure that the thermocouple tips were imbedded in the surfaces to establish good thermal contact. Temperatures were recorded using a Leeds Northrop multipoint recorder.

2. Weight Change Measurements

Since very small weight changes were expected in these experiments, it was necessary to work out a consistent and controlled method of obtaining the weights of the samples; in addition, the measurement is complicated by the presence of gelatin which absorbs water.

The method finally adopted consisted of the following: The samples (2 in by 4 in) were placed in aluminum foil packets with one end open. These were then placed in a vacuum oven set at 60 C and evacuated for approximately fifteen hours. The oven was vented through a silica gel drying tube and the samples removed and sealed while still warm. The weights were then followed with time. The process was repeated with a more extended vacuum heating treatment of approximately fifty hours.

The samples were then mounted on a lattice work two feet in diameter corresponding to the irradiation area of the arc lamp giving one overall solar constant.

Since weight changes in the samples could take place from water loss and UV degradation, a control set of samples were masked with Plexiglas sheet. The latter effectively absorbs in the ultraviolet.

B. RESULTS

The test samples were irradiated a total of about 45 hours in the simulator with liquid nitrogen in the shrouds. In addition to the carbon arc, a 250 watt mercury-xenon was used to more closely approximate the Johnson solar distribution in the ultraviolet. The total UV flux was approximately 0.5 solar constant based on previous experience.

The temperature and weight data are summarized in Table 56.

The equilibrium temperatures were averaged over steady-state periods taken over the complete irradiation history. The samples containing larger amounts of gelatin exhibit greater differences in front and back temperatures indicating that the emissivity of the gelatin is higher than that of cloth matrix.

The weight losses in the table were obtained by subtracting the weight loss of the control from the average weight losses of the companion samples (2).

As can be seen most of the samples lost some weight but not a significant amount. The greatest weight loss occurred from the 3/8 inch Rayon - 35 gel/100 sample. This is probably due to both a higher rate of degradation and the porosity of the cloth permitting irradiation of part of the back surface.

In addition to the weight losses, there was visible evidence of UV degradation in the appearance of the test samples. The irradiated surface was tinted yellow whereas the control samples retained their white appearance.

During the irradiation, leak rates were taken with and without the radiation. On the basis of this experiment, there is definite evidence of degradation to produce noncondensables. Using the perfect gas law and an average molecular weight of 40, the rate of degradation was roughly 2×10^{-3} mg/hr/sample.

No definite changes in equilibrium temperature could be detected as a result of this color change. Without a much more extended period of irradiation, this question cannot be resolved.

Along with the color change, it was noted that the surface of the aluminized Mylar samples (5 and 6 in Table 56) were extensively wrinkled with the latter extending into the foam layer.

VII CURING OF A SOLAR COLLECTOR PANEL (NO. 1) UNDER BIAXIAL STRESS

The deployment and rigidization of a flexibilized solar collector constructed from a composite of aluminized Mylar, "flexible" Epoxy, and drop thread cloth impregnated with a solution of gelatin presents a number of questions. A critical one is related to the preservation of topographical integrity when erection in the exoatmosphere has been completed. The latter occurs when a bulk of the water has been removed. After erection, the system comes to thermal equilibrium as in the case of a collector in an equatorial orbit and thermally cycled in other orbits. In either case stresses develop in the structure which may alter the collector efficiency.

If a biaxial stress is kept in the structure during rigidization, it has been postulated that the collector will retain the shape of the

frontal layered structure, or expressed in another way that rigidization due to loss in water will have no effect on the shape of a collector when the inflation pressure is released.

An experiment described below was carried out to evaluate this notion using a reflexibilized flat panel.

A. APPARATUS

Figure 80 shows the arrangement used to place a biaxial load on one of the solar collector panels (13 in. by 13 in.) supplied by Viron. The aluminized Mylar Flexible Epoxy layer projected beyond the edge of the backing structure of gelatinized drop-thread cloth to allow clamping on four sides. A deadweight of 8 1/2 lbs was applied as indicated in the figure. This corresponds to approximately 1000 lbs/in^2 or presumably the skin stress expected from the erection and inflation of a paraboloidal collector. The weight figure was supplied by Viron as the proper one.

B. PROCEDURE

Since the emphasis in this experiment was to determine the effect of curing on shape, no attempt was made to determine thermal or water loss histories.

A wet 13 in. by 13 in. panel was clamped in the jig shown in Figure 80 and the entire assembly placed in the solar simulator. The system was pumped and liquid nitrogen introduced into the shrouds. At this time the panel was exposed to one solar constant of radiation from the carbon arc lamp. The state of the surface was observed during the water removal process and is described in Table 57.

The solar simulator was brought to room temperature and vented the day following the experiment. The sample was found to still contain an appreciable amount of water (an excess had been added to replace water lost in handling and mounting.)

The sample was kept under stress in the ambient for two additional weeks during which the surface condition was observed as the water was removed. In this time wrinkles spread through the entire surface. In addition, the panel itself became warped (approximately a radius of curvature of one foot). Finally a network of fine wrinkles appeared in the structure.

Since the curing of the test panel described above was done with rigid clamping at points A and B in Figure 80, the question of the effect of poor clamping on the sample distortion arose.

To test this a 3-mil Mylar sheet was attached to the framework as before. With the load on, the area was observed through crossed polarizers. The intersection of A and B showed some evidence of stress

concentration. The 3-mil film was replaced by a 0.5-mil sheet and the observation repeated. There was definite evidence of nonhomogeneous stress distribution. To overcome this, clamps A and B were attached to pivots as shown in the figure. In addition, cardboard spacers were used on either side of the sheet at the clamps to assure more effective clamping. With these alterations uniform stress was achieved in most of the central portion of the specimen and no serious stress concentrations at the corners were noted.

Despite the question of poor clamping, it was felt that the warping observed was due to stresses which developed during curing that exceeded the biaxial stress employed. To investigate this several experiments were carried out. These are described in the next section.

VIII WARPING OF COMPOSITE MEMBRANES

A. TESTING OF AN EPOXY LAYER ON MYLAR FOR WARPAGE

1. A 5 to 1 mixture of Hysol Resin R9-2039 and H2-3490 was applied to an 0.5-mil Mylar film under biaxial load. Upon hardening and load removal, no shrinkage or warpage was evident.

2. The above experiment was repeated with zero load with the same results.

3. The same mixture was applied to 3-mil Mylar with the same results.

These results suggested that warpage was probably due to the gelatinized part of the composite structure.

B. TESTING OF GELATIN FILMS ON MYLAR FOR WARPAGE

1. A gelatin solution was prepared and poured onto a 3-mil Mylar sheet and allowed to dry. The Mylar-gelatin combination was highly distorted.

The above was repeated twice using a much thinner application. The results were the same indicating that the linear shrinkage of gelatin is stressing the Mylar to distortion. The stresses are large enough to overcome the adhesion between the two surfaces. The latter results in delamination to relieve the shear stresses. The resulting structure is bonded only at a few spots.

2. A gelatin solution was applied to one-half of a 0.5-mil Mylar sheet which had a layer of Epoxy resin on it. Upon drying the gelatin side was curled, whereas the straight Epoxy side was unaffected.

It was apparent that the stresses due to gelatin shrinkage were greater than the capacity of the substrate to resist it.

3. Experiment 2 was repeated except that the sheet was kept in tension during both application and cure of the gelatin layer. Once again the gelatin side curled.

4. Gelatin was applied to heavy aluminum mesh placed on 3-mil Mylar film. When partly cured the composite was separated from the Mylar. Distortion was not evident until the curing progressed further. After 24 hours the composite had curled into a cone-shaped structure.

5. Gelatin applied to Nylon mesh distorted upon curing.

6. Similar results were obtained when samples were dried in a vacuum oven.

7. A cured gelatin film (distorted) was placed between two aluminum plates and flattened using a 5-lb weight. This assembly was heated in a vacuum oven at 50 C for one hour. This treatment had no effect on the films which reverted to its distorted state when the compressive load was removed.

8. Several experiments were carried out with combinations of gelatin and Eccospheres in an attempt to minimize distortion but were not successful.

These experiments emphasize the problems of distortion to be expected with structures employing gelatin.

Although it may be argued that 2 foot collectors have been prepared, it has been observed that these structures change with time. This is understandable since plastics creep under stress and there can be no argument that the front portion of a collector is under stress from cured gelatin. This is in the nature of a shear stress so that as long as the bond between gelatin and the flexible layer is strong, stress relaxation of either the gelatin or the flexible layer will occur. The latter seems to be evident in current structures.

Distortion is more evident when flat panels are studied since there is no back-stress applied to the shear stress at the gelatin-flexible layer interface. This accounts for the ability to erect a fairly decent looking paraboloid.

It has been observed that cast sheets of gelatin often dry to give a surface resembling a saddle. (The same thing happens, I believe, when you make potato chips.) This tendancy to warp in two directions is a manifestation of the principle of minimization of surface free energy and results when drying occurs on both surfaces. The phenomenon is complex and difficult to explain, but suggests that isotropic drying of gelatin would create less of a problem in terms of distortion since tension and compression stresses are distributed

on both sides of the film.

This appears to be difficult since the front surface of the collector is impervious so that the gelatin surfaces are drying on one side.

IX CURING OF A SOLAR COLLECTOR PANEL (NO. 2) UNDER BIAXIAL STRESS

The second 13 in. by 13 in. panel supplied by Viron was clamped (Figure 72) and loaded as with panel No. 1 (Section VII). It was decided to cure this panel under ambient conditions. The hole in the back of the collector was sealed with masking tape to insure homogeneous efflux of solvents.

The clamped panel was initially free from large wrinkles or distortions.

The panel was observed for approximately one week. The sample dried slowly and became wrinkled, warped, and distorted within this time.

Thus, duplicate results were obtained using the biaxial stress recommended by Viron.

The results of these tests point to the need of a generalized stress analysis for the composite structure. Such an analysis is complex but necessary and will be aided by an accumulation of mechanical property data.

Of particular interest are the creep properties of the component parts of the composite structure. It is believed that the orange peel phenomenon, wrinkles, delamination, etc., can be partially explained by stress relaxation effects.

A perusal of the Viron progress reports show a mutual cognizance of the need for studies of this type.

X SUMMARY

A mismatch of thermal, mechanical, and optical properties of the components of the composite structure representing a solar collector points out the need for a generalized stress analysis. The latter can be done by using the thermal analysis started by us, and the material properties to define the internal stress distribution expected in the cured solar collector.

The latter along with a knowledge of the bond strengths of the junctions and the creep properties of the junction components will enable one to predict the roughness of the collector surface with time as well as the change in paraboloid parameters.

The results obtained in our thermal analysis show the need for a rapid erection of the structure. If one is willing to place confidence

in the model used in our thermal analysis, it can be seen that the most effective way of diminishing the thermal gradient is to increase the overall conductivity between the two collector surfaces. A weight penalty may result, since metal fibers will probably have to replace a fraction of the Nylon drop threads.

The shrinkage of gelatin appears to be the most serious problem relative to producing a rigid distortionless collector. We made an abortive attempt to reduce shrinkage; but a greater effort is needed. Not only that, but a replacement for gelatin cannot be ruled out. It would be particularly desirable to employ a system using a nonpolar plasticizer so that more rapid curing could be effected.

The short-range effects of UV radistion on the solar collector materials studied were found to be negligible. If the back of the collector is to be exposed for extended periods in the exoatmosphere, changes in absorptivity and emissivity will probably occur judging from the color changes produced in some of the test samples.

TABLE 55

SOLAR COLLECTOR EQUILIBRIUM TEMPERATURES

$\tau = 0.95$, $\bar{s} = 3.68 \times 10^{-2}$ cal/cm^{2}sec

K/δ_2	α_1	ϵ_1	ϵ_2	ϵ_3	T_1 (°K)	T_3 (°K)
2×10^{-4}	0.1	0.1	0.1	0.1	354	299
2×10^{-4}	0.1	0.1	0.3	0.3	317	259
2×10^{-4}	0.1	0.2	0.1	0.1	310	268
2×10^{-4}	0.1	0.2	0.3	0.3	289	239
2×10^{-4}	0.1	0.2	0.5	0.5	272	225
2×10^{-4}	0.2	0.1	0.1	0.1	425	348
2×10^{-4}	0.2	0.2	0.1	0.1	371	311
2×10^{-4}	0.2	0.2	0.3	0.3	346	281
2×10^{-4}	0.2	0.2	0.5	0.5	328	265
0.2	0.1	0.1	0.1	0.1	330.0	329.9
0.2	0.1	0.2	0.1	0.1	298.2	298.1
0.2	0.1	0.2	0.3	0.3	262.3	262.3
0.2	0.2	0.1	0.1	0.1	392.5	392.3
0.2	0.2	0.2	0.1	0.1	354.6	354.4
0.2	0.2	0.2	0.3	0.3	312.3	311.9

TABLE 56

EQUILIBRIUM TEMPERATURE AND WEIGHT LOSS MEASUREMENTS

SAMPLE	EQUILIBRIUM TEMP., FRONT, °C	EQUILIBRIUM TEMP., BACK °C	% WEIGHT LOSS, (DEGRADATION)
1. 100 gal/100 Nylon	15	-3.7	0.06 ± 0.02
2. 75 gal/100 Nylon	18	-2.1	0.01 ± 0.02
3. 100 gal/100 Dacron	30	4.3	0.01 ± 0.02
4. 75 gal/100 Dacron	17.5	-4.0	-0.04 ± 0.02
5. 100 gal/100 Dacron aluminized Mylar (1 mil), Polyurethane foam	6.2	-14.3	-0.02 ± 0.01
6. 75 gal/100 Dacron aluminized Mylar (1 mil), Polyurethane foam	7.3	-4.2	0.01 ± 0.01
7. 35 gal/100, 3/8" Rayon	16.5	-8.5	0.09 ± 0.01
8. 35 gal/100, 3 ply 181 Fiberglas	0	-	0.02 ± 0.01

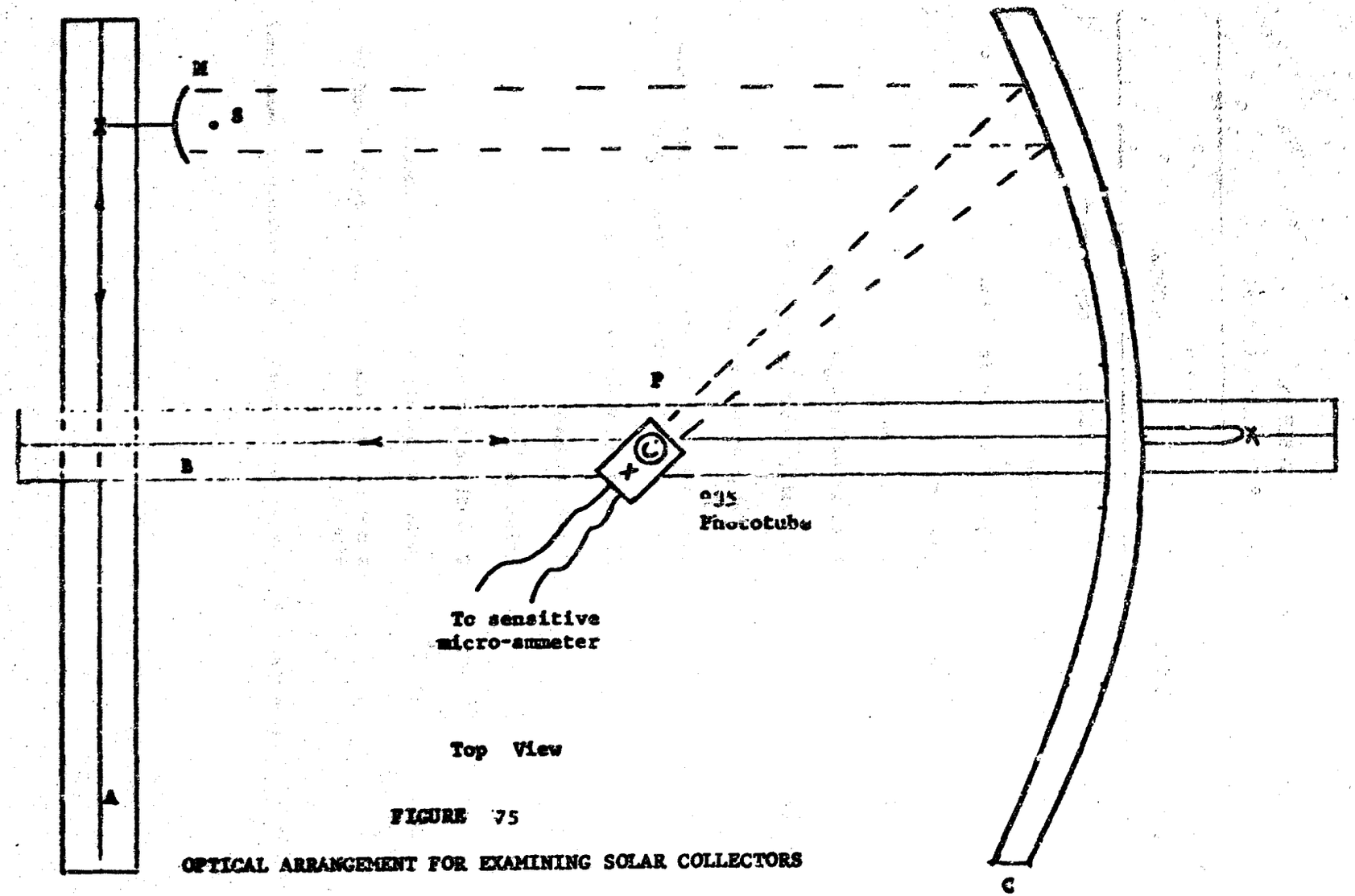
Time of Irradiation: 44 hours

Flux: One overall solar constant; ~0.3 solar constant in 2200-2700Å range.

TABLE 57

EFFECT OF CURE TIME ON SHAPE

TIME (min)	PRESSURE	REMARKS
0		Wrinkles evident in top corners
10	100-1000μ	No change
22		Liquid nitrogen in shrouds
30	40μ	Arc lamp on
35		Diffusion pump on
50		Some wrinkles appear larger
85		No change; carbons replaced
110		Wrinkles appear larger
155	9μ	Front surface distorted in one corner (where hole is situated in drop thread cloth)
180		Distortion spreading from corner
190		Carbon changed
210		Wrinkles larger
230	10^{-6} mm	Distortion increasing
260	3×10^{-6}	Corner wrinkled; rest flat and smooth
290		Arc off. No fine wrinkles evident at end of simulator run.



Top View

FIGURE 75

OPTICAL ARRANGEMENT FOR EXAMINING SOLAR COLLECTORS

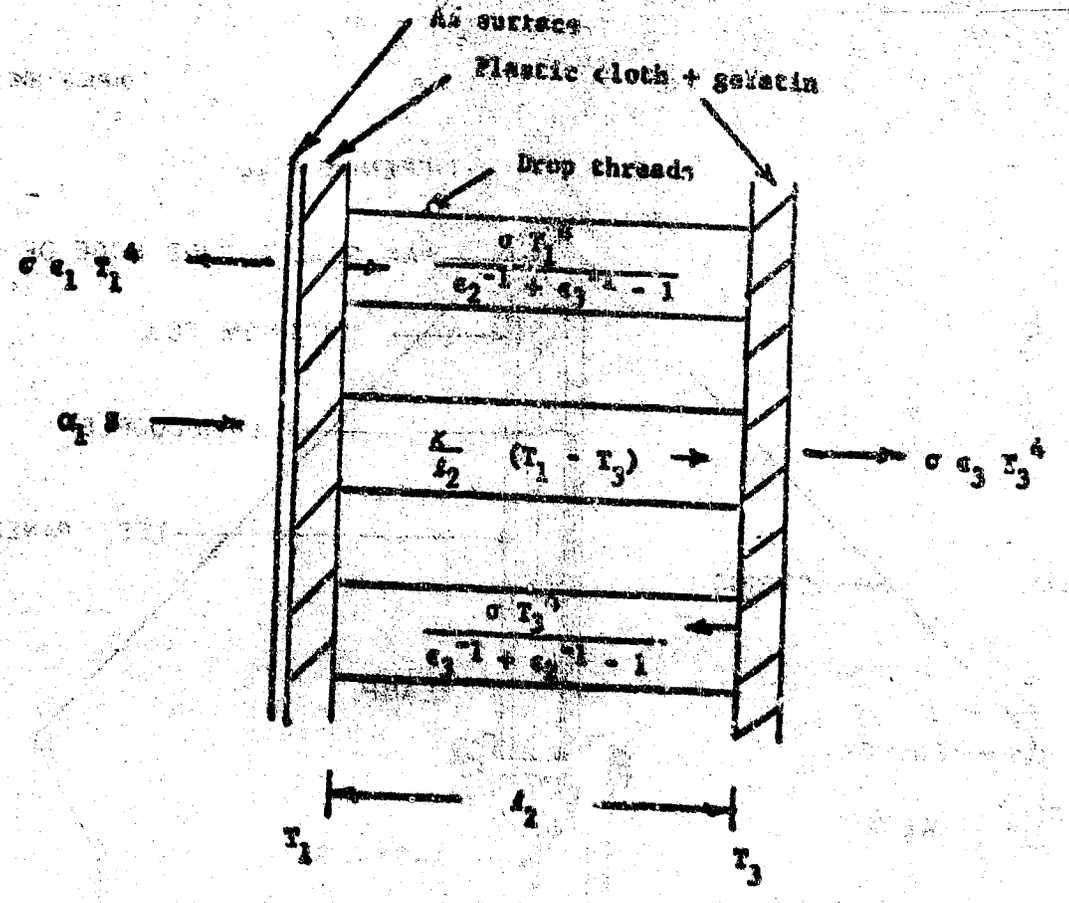


FIGURE 36

MODEL FOR SOLAR COLLECTOR

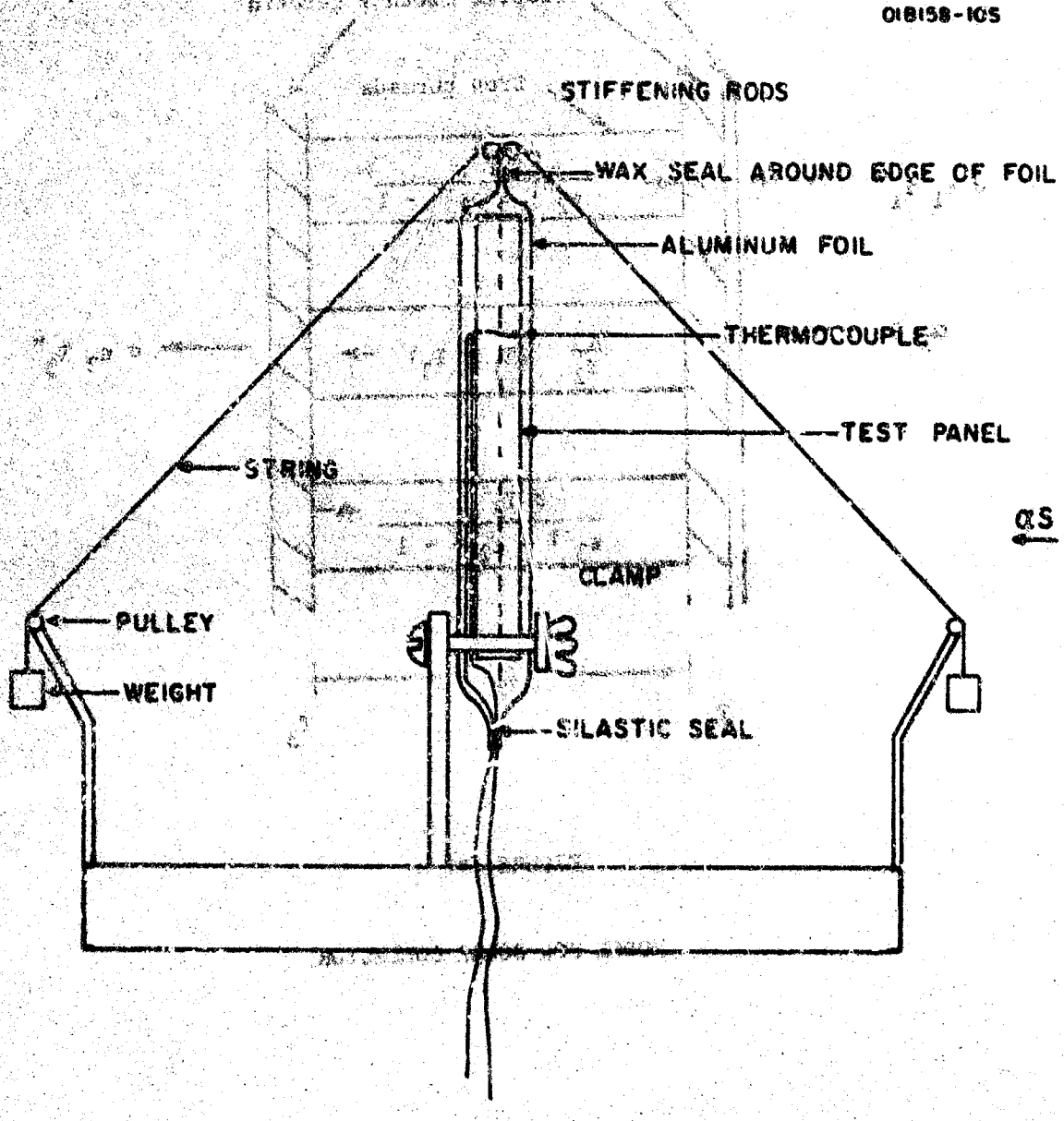


Figure 77 Panel encapsulation and deployment assembly.

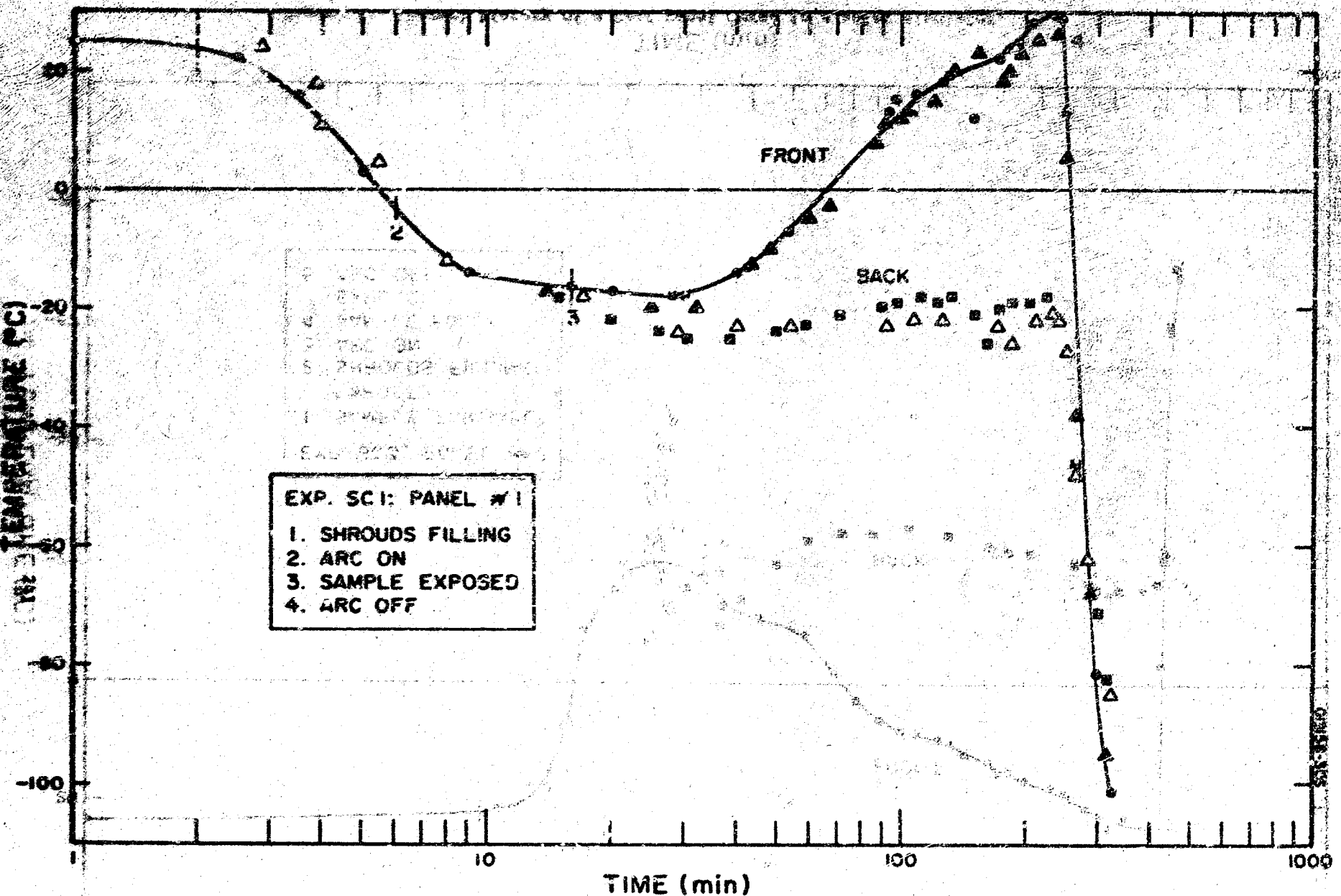


Figure 78 Thermal history of a test panel cured in a solar simulator.

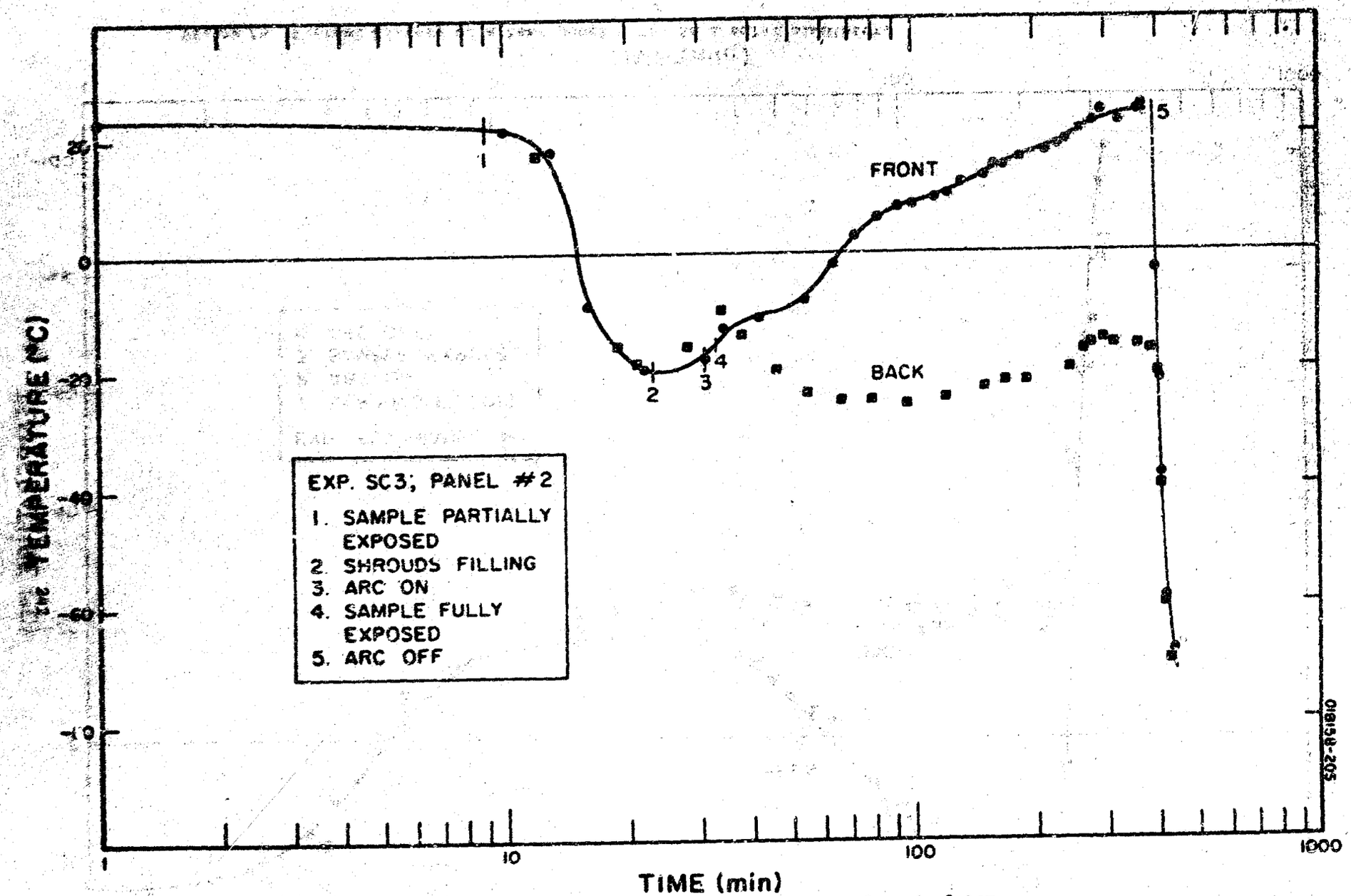


Figure 79 Thermal history of a test panel cured in a solar simulator.

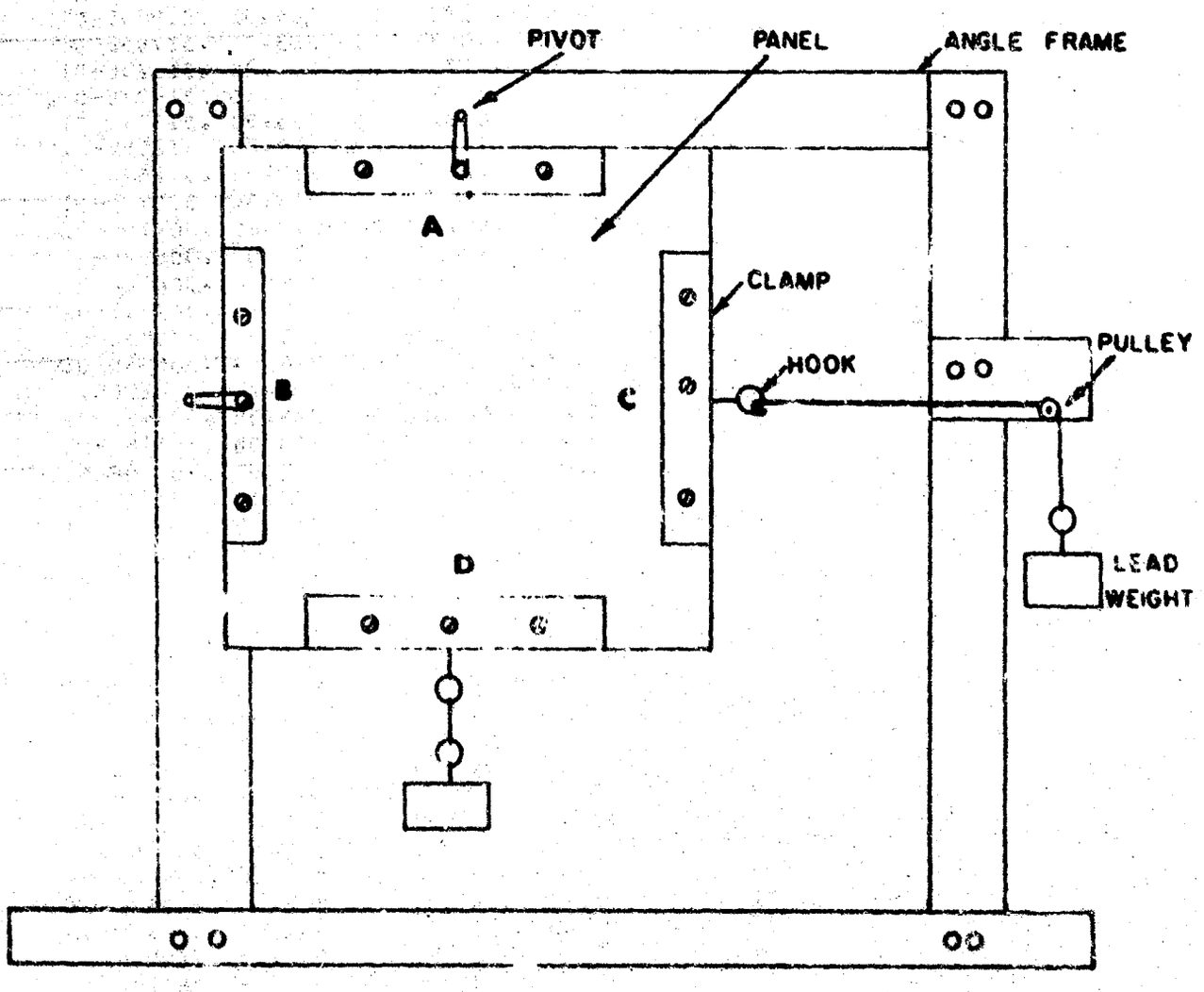


Figure 60 Assembly for Applying Biaxial Loads on Solar Collector Panels.

Computer Readout

	$\Delta\tau$ (sec.)	ΔT_1	T_1(°K)		ΔT_3	T_3 (°K)	W_b
	.700	.200	.500	.500	.100	.950	.2000E-03
	540.000	8.000	.034	.034	1.000		
1	1.0	.46488E-01	298.24	.34000E-01	.44698E 01	293.73	.33320E-01
2	1.0	-.48704E 00	297.75	.33917E-01	-.29169E 01	290.81	.32881E-01
3	1.0	-.70685E 00	297.05	.33801E-01	-.21481E 01	288.66	.32561E-01
4	1.0	-.79975E 00	296.25	.33670E-01	-.17024E 01	286.96	.32309E-01
5	1.0	-.83263E 00	295.42	.33535E-01	-.14180E 01	285.54	.32101E-01
6	1.0	-.83504E 00	294.58	.33400E-01	-.12237E 01	284.32	.31923E-01
7	1.0	-.82155E 00	293.76	.33267E-01	-.10835E 01	283.23	.31766E-01
8	1.0	-.79985E 00	292.96	.33137E-01	-.97792E 00	282.25	.31625E-01
9	1.0	-.77416E 00	292.18	.33012E-01	-.89529E 00	281.36	.31497E-01
10	1.0	-.74684E 00	291.44	.32890E-01	-.82864E 00	280.53	.31379E-01
11	1.0	-.71926E 00	290.72	.32774E-01	-.77367E 00	279.76	.31269E-01
12	1.0	-.69218E 00	290.03	.32661E-01	-.72681E 00	279.03	.31167E-01
13	1.0	-.66602E 00	289.36	.32552E-01	-.68638E 00	278.34	.31070E-01
14	1.0	-.64099E 00	288.72	.32448E-01	-.65151E 00	277.69	.30979E-01
15	1.0	-.61719E 00	288.10	.32347E-01	-.62041E 00	277.07	.30892E-01
16	1.0	-.59464E 00	287.51	.32250E-01	-.59259E 00	276.48	.30810E-01
17	1.0	-.57333E 00	286.93	.32156E-01	-.56747E 00	275.91	.30731E-01
18	1.0	-.55319E 00	286.38	.32065E-01	-.54462E 00	275.37	.30656E-01
19	1.0	-.53419E 00	285.85	.31977E-01	-.52371E 00	274.84	.30584E-01
20	1.0	-.51624E 00	285.33	.31892E-01	-.50446E 00	274.34	.30515E-01
21	1.0	-.49929E 00	284.83	.31809E-01	-.48666E 00	273.85	.30449E-01
22	1.0	-.48327E 00	284.35	.31729E-01	-.47012E 00	273.38	.30385E-01
23	1.0	-.46811E 00	283.88	.31651E-01	-.45471E 00	272.93	.30323E-01
24	1.0	-.45727E 00	283.42	.31575E-01	-.42955E 00	272.50	.30266E-01
25	1.0	-.44502E 00	282.98	.31501E-01	-.41142E 00	272.09	.30210E-01
26	1.0	-.43309E 00	282.54	.31429E-01	-.39512E 00	271.69	.30158E-01
27	1.0	-.42151E 00	282.12	.31358E-01	-.38036E 00	271.31	.30107E-01
28	1.0	-.41032E 00	281.71	.31289E-01	-.36690E 00	270.94	.30059E-01
29	1.0	-.39952E 00	281.31	.31222E-01	-.35456E 00	270.59	.30012E-01
30	1.0	-.38912E 00	280.92	.31157E-01	-.34316E 00	270.25	.29967E-01
31	1.0	-.37911E 00	280.54	.31092E-01	-.33261E 00	269.91	.29923E-01
32	1.0	-.36949E 00	280.18	.31030E-01	-.32278E 00	269.59	.29881E-01
33	1.0	-.36025E 00	279.82	.30969E-01	-.31359E 00	269.28	.29841E-01
34	1.0	-.35136E 00	279.46	.30909E-01	-.30498E 00	268.97	.29801E-01
35	10.0	-.34507E 01	276.01	.30323E-01	-.29817E 01	265.99	.29419E-01
36	10.0	-.26771E 01	273.54	.29852E-01	-.22959E 01	263.69	.29137E-01
37	10.0	-.21641E 01	271.17	.29458E-01	-.18871E 01	261.81	.28914E-01
38	10.0	-.16953E 01	269.48	.29132E-01	-.17099E 01	260.10	.28716E-01
39	10.0	-.14230E 01	268.05	.28846E-01	-.14715E 01	258.63	.28552E-01
40	10.0	-.12216E 01	266.83	.28589E-01	-.12845E 01	257.34	.28415E-01
41	10.0	-.10654E 01	265.77	.28355E-01	-.11364E 01	256.20	.28297E-01
42	10.0	-.94040E 00	264.83	.28139E-01	-.10167E 01	255.19	.28197E-01
43	10.0	-.83812E 00	263.99	.27938E-01	-.91798E 00	254.27	.28110E-01
44	10.0	-.75291E 00	263.23	.27749E-01	-.83521E 00	253.43	.28034E-01
45	10.0	-.68087E 00	262.55	.27571E-01	-.76479E 00	252.67	.27968E-01
46	10.0	-.61920E 00	261.93	.27401E-01	-.70415E 00	251.97	.27911E-01
47	10.0	-.56587E 00	261.37	.27239E-01	-.65137E 00	251.31	.27860E-01
48	10.0	-.51932E 00	260.85	.27084E-01	-.60501E 00	250.71	.27815E-01
49	10.0	-.47838E 00	260.37	.26934E-01	-.56397E 00	250.15	.27776E-01
50	10.0	-.44212E 00	259.93	.26790E-01	-.52736E 00	249.62	.27742E-01
51	10.0	-.40982E 00	259.52	.26650E-01	-.49450E 00	249.12	.27712E-01
52	10.0	-.38088E 00	259.14	.26514E-01	-.46485E 00	248.66	.27686E-01
53	10.0	-.35402E 00	258.78	.26382E-01	-.43795E 00	248.22	.27663E-01
54	10.0	-.33127E 00	258.45	.26253E-01	-.41345E 00	247.81	.27644E-01
55	10.0	-.30989E 00	258.14	.26127E-01	-.39101E 00	247.41	.27627E-01
56	10.0	-.29041E 00	257.85	.26004E-01	-.37042E 00	247.05	.27614E-01
57	10.0	-.27261E 00	257.58	.25884E-01	-.35145E 00	246.69	.27602E-01

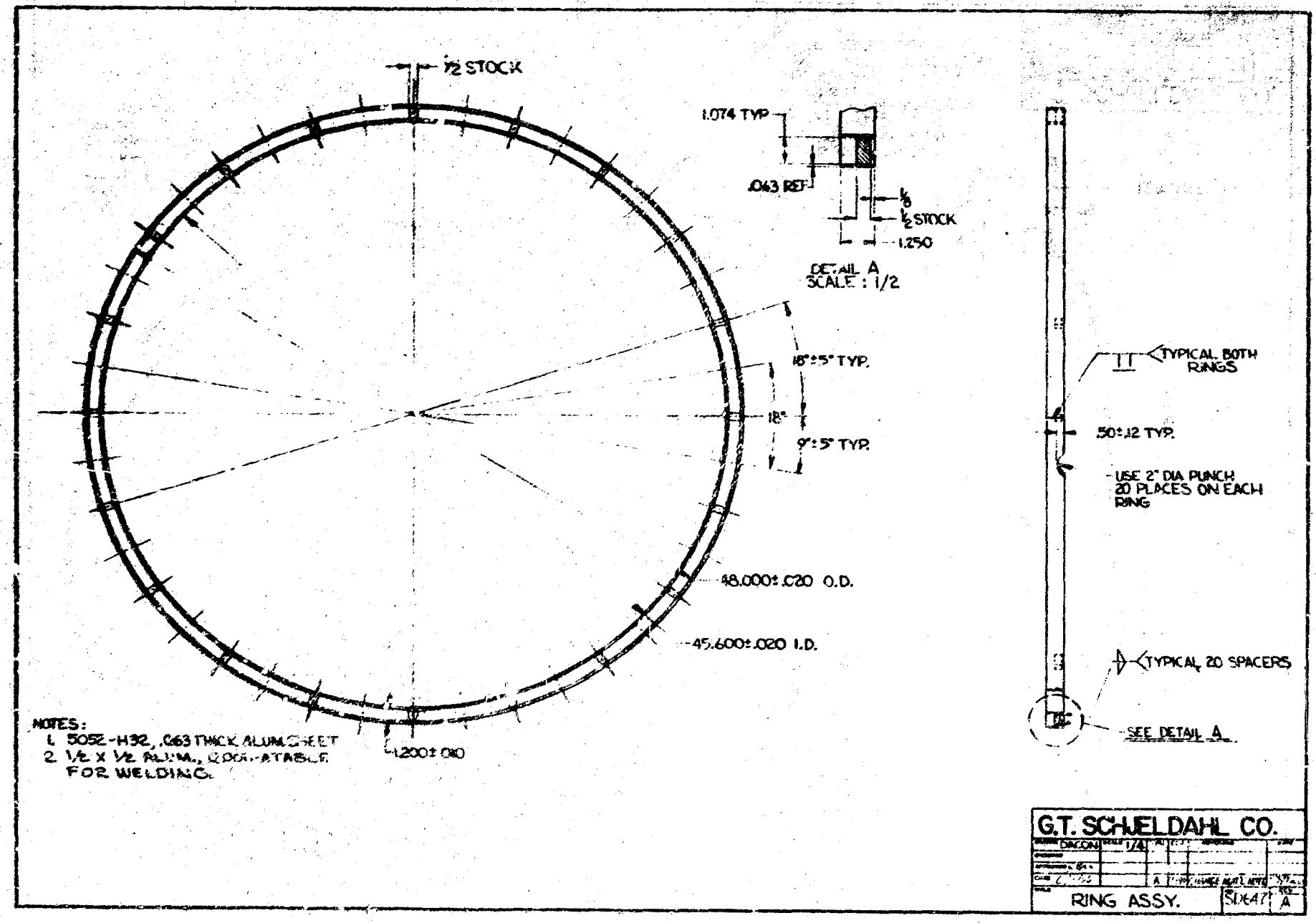
58	10.0-.25629E 00	257.32	.25766E-01-.33387E 00	246.36	.27593E-01
59	10.0-.24128E 00	257.08	.25649E-01-.31760E 00	246.04	.27586E-01
60	10.0-.22745E 00	256.85	.25535E-01-.30246E 00	245.74	.27580E-01
61	10.0-.21469E 00	256.64	.25423E-01-.28835E 00	245.45	.27577E-01
62	10.0-.20286E 00	256.44	.25312E-01-.27518E 00	245.18	.27575E-01
63	10.0-.19189E 00	256.24	.25203E-01-.26284E 00	244.91	.27575E-01
64	10.0-.18169E 00	256.06	.25095E-01-.25127E 00	244.66	.27576E-01
65	10.0-.17220E 00	255.89	.24990E-01-.24040E 00	244.42	.27578E-01
66	60.0-.98704E 00	254.90	.24357E-01-.13806E 01	243.04	.27601E-01
67	60.0-.68494E 00	254.22	.23767E-01-.10635E 01	241.98	.27662E-01
68	60.0-.50328E 00	253.72	.23302E-01-.81663E 00	241.16	.27752E-01
69	60.0-.37730E 00	253.34	.22955E-01-.63882E 00	240.52	.27864E-01
70	60.0-.28763E 00	253.05	.22720E-01-.50519E 00	240.02	.27991E-01
71	60.0-.22209E 00	252.83	.21594E-01-.40260E 00	239.62	.28130E-01
72	60.0-.17322E 00	252.66	.21074E-01-.32261E 00	239.29	.28278E-01
73	60.0-.13619E 00	252.52	.20560E-01-.25957E 00	239.03	.28434E-01
74	60.0-.10775E 00	252.41	.20050E-01-.20948E 00	238.82	.28595E-01
75	60.0-.85698E-01	252.33	.19543E-01-.16944E 00	238.65	.28761E-01
76	60.0-.68423E-01	252.26	.19039E-01-.13729E 00	238.52	.28930E-01
77	60.0-.54826E-01	252.20	.18536E-01-.11138E 00	238.41	.29103E-01
78	60.0-.44034E-01	252.16	.18035E-01-.90460E-01	238.31	.29278E-01
79	60.0-.35434E-01	252.12	.17535E-01-.73530E-01	238.24	.29455E-01
80	60.0-.28584E-01	252.09	.17036E-01-.59770E-01	238.18	.29633E-01
81	60.0-.23076E-01	252.07	.16537E-01-.48625E-01	238.13	.29813E-01
82	60.0-.18643E-01	252.05	.16040E-01-.39568E-01	238.09	.29994E-01
83	60.0-.15078E-01	252.04	.15542E-01-.32198E-01	238.06	.30176E-01
84	60.0-.12212E-01	252.03	.15046E-01-.26196E-01	238.03	.30358E-01
85	60.0-.98858E-02	252.02	.14549E-01-.21317E-01	238.01	.30541E-01
86	60.0-.80007E-02	252.01	.14053E-01-.17356E-01	238.00	.30724E-01
87	60.0-.64891E-02	252.00	.13557E-01-.14113E-01	237.98	.30908E-01
88	60.0-.52488E-02	252.00	.13061E-01-.11492E-01	237.97	.31092E-01
89	60.0-.42608E-02	251.99	.12565E-01-.93396E-02	237.96	.31277E-01
90	60.0-.34423E-02	251.99	.12069E-01-.76084E-02	237.95	.31461E-01
91	60.0-.27963E-02	251.99	.11573E-01-.61793E-02	237.95	.31646E-01
92	60.0-.22612E-02	251.98	.11078E-01-.50289E-02	237.94	.31831E-01
93	60.0-.18380E-02	251.98	.10582E-01-.40824E-02	237.94	.32016E-01
94	60.0-.14792E-02	251.98	.10087E-01-.33263E-02	237.94	.32201E-01
95	60.0-.12082E-02	251.98	.95919E-02-.26911E-02	237.93	.32386E-01
96	60.0-.97234E-03	251.98	.90965E-02-.21929E-02	237.93	.32571E-01
97	60.0-.78858E-03	251.98	.86012E-02-.17788E-02	237.93	.32756E-01
98	60.0-.64114E-03	251.98	.81058E-02-.14431E-02	237.93	.32942E-01
99	60.0-.51636E-03	251.98	.76105E-02-.11751E-02	237.93	.33127E-01
100	60.0-.41190E-03	251.98	.71151E-02-.96057E-03	237.92	.33312E-01
101	60.0-.33041E-03	251.97	.66198E-02-.77764E-03	237.92	.33497E-01
102	60.0-.27143E-03	251.97	.61245E-02-.62578E-03	237.92	.33683E-01
103	60.0-.22347E-03	251.97	.56292E-02-.50757E-03	237.92	.33868E-01
104	60.0-.18543E-03	251.97	.51339E-02-.40916E-03	237.92	.34054E-01
105	60.0-.14616E-03	251.97	.46386E-02-.33191E-03	237.92	.34239E-01
106	60.0-.11547E-03	251.97	.41433E-02-.27439E-03	237.92	.34424E-01
107	60.0-.93386E-04	251.97	.36480E-02-.22224E-03	237.92	.34610E-01
108	60.0-.73486E-04	251.97	.31527E-02-.18340E-03	237.92	.34795E-01
109	60.0-.63694E-04	251.97	.26574E-02-.14374E-03	237.92	.34981E-01
110	60.0-.61768E-04	251.97	.21621E-02-.10969E-03	237.92	.35166E-01
111	60.0-.35651E-04	251.97	.16668E-02-.10031E-03	237.92	.35352E-01
112	60.0-.37169E-04	251.97	.11716E-02-.78772E-04	237.92	.35537E-01
113	60.0-.22732E-04	251.97	.67632E-03-.67123E-04	237.92	.35723E-01
114	60.0-.39696E-04	251.97	.18103E-03-.37225E-04	237.92	.35908E-01
115	10.0-.18164E-05	251.97	.98492E-04-.80638E-05	237.92	.35939E-01
116	1.0-.24999E-06	251.97	.90237E-04-.69115E-06	237.92	.35942E-01

117	1.0-.24559E-06	251.97	.81972E-04-.69113E-06	237.92	.35945E-01
118	1.0-.24563E-06	251.97	.73727E-04-.69111E-06	237.92	.35948E-01
119	1.0-.24567E-06	251.97	.65472E-04-.69108E-06	237.92	.35951E-01
120	1.0-.24571E-06	251.97	.57217E-04-.69106E-06	237.92	.35954E-01
121	1.0-.24575E-06	251.97	.48962E-04-.69103E-06	237.92	.35957E-01
122	1.0-.24579E-06	251.97	.40707E-04-.69101E-06	237.92	.35961E-01
123	1.0-.24584E-06	251.97	.32452E-04-.69098E-06	237.92	.35964E-01
124	1.0-.24588E-06	251.97	.24197E-04-.69096E-06	237.92	.35967E-01
125	1.0-.24592E-06	251.97	.15942E-04-.69093E-06	237.92	.35970E-01
126	1.0-.24596E-06	251.97	.76870E-05-.69091E-06	237.92	.35973E-01
127	1.0 .89150E-01	252.06	.00000E-50-.51846E-01	237.87	.35976E-01
128	1.0 .89019E-01	252.15	.00000E-50-.51590E-01	237.82	.35971E-01
129	1.0 .88887E-01	252.24	.00000E-50-.51335E-01	237.77	.35966E-01
130	1.0 .88756E-01	252.33	.00000E-50-.51082E-01	237.72	.35961E-01
131	1.0 .88625E-01	252.42	.00000E-50-.50831E-01	237.66	.35956E-01
132	10.0 .88494E 00	253.30	.00000E-50-.50609E 00	237.16	.35905E-01
133	10.0 .87185E 00	254.17	.00000E-50-.48172E 00	236.68	.35858E-01
134	10.0 .85901E 00	255.03	.00000E-50-.45912E 00	236.22	.35813E-01
135	10.0 .84639E 00	255.88	.00000E-50-.43809E 00	235.78	.35770E-01
136	10.0 .83398E 00	256.71	.00000E-50-.41844E 00	235.36	.35729E-01
137	10.0 .82177E 00	257.54	.00000E-50-.40009E 00	234.96	.35689E-01
138	10.0 .80975E 00	258.35	.00000E-50-.38274E 00	234.58	.35652E-01
139	10.0 .79791E 00	259.14	.00000E-50-.36646E 00	234.21	.35616E-01
140	10.0 .78626E 00	259.93	.00000E-50-.35108E 00	233.86	.35582E-01
141	10.0 .77477E 00	260.70	.00000E-50-.33653E 00	233.52	.35548E-01
142	10.0 .76346E 00	261.47	.00000E-50-.32274E 00	233.20	.35516E-01
143	10.0 .75230E 00	262.22	.00000E-50-.30963E 00	232.89	.35485E-01
144	10.0 .74130E 00	262.96	.00000E-50-.29716E 00	232.59	.35456E-01
145	60.0 .43827E 01	267.34	.00000E-50-.17145E 01	230.88	.35283E-01
146	60.0 .39921E 01	271.34	.00000E-50-.13168E 01	229.56	.35140E-01
147	60.0 .36343E 01	274.97	.00000E-50-.10105E 01	228.55	.35017E-01
148	60.0 .33056E 01	278.28	.00000E-50-.76577E 00	227.79	.34908E-01
149	60.0 .30038E 01	281.28	.00000E-50-.56597E 00	227.22	.34808E-01
150	60.0 .27270E 01	284.01	.00000E-50-.39966E 00	226.82	.34714E-01
151	60.0 .24737E 01	286.48	.00000E-50-.26125E 00	226.56	.34625E-01
152	60.0 .22424E 01	288.72	.00000E-50-.14562E 00	226.41	.34538E-01
153	60.0 .20317E 01	290.76	.00000E-50-.49258E-01	226.37	.34453E-01
154	60.0 .18401E 01	292.60	.00000E-50 .30544E-01	226.40	.34369E-01
155	60.0 .16662E 01	294.26	.00000E-50 .95973E-01	226.49	.34284E-01
156	60.0 .15087E 01	295.77	.00000E-50 .14885E 00	226.64	.34198E-01
157	60.0 .13662E 01	297.14	.00000E-50 .19076E 00	226.83	.34111E-01
158	60.0 .12375E 01	298.37	.00000E-50 .22306E 00	227.05	.34021E-01
159	60.0 .11213E 01	299.50	.00000E-50 .24700E 00	227.30	.33929E-01
160	60.0 .10165E 01	300.51	.00000E-50 .26369E 00	227.57	.33835E-01
161	60.0 .92193E 00	301.43	.00000E-50 .27413E 00	227.84	.33738E-01
162	60.0 .83664E 00	302.27	.00000E-50 .27925E 00	228.12	.33637E-01
163	60.0 .75970E 00	303.03	.00000E-50 .27990E 00	228.40	.33533E-01
164	60.0 .69026E 00	303.72	.00000E-50 .27693E 00	228.68	.33426E-01
165	60.0 .62715E 00	304.35	.00000E-50 .27074E 00	228.95	.33315E-01
166	60.0 .57087E 00	304.92	.00000E-50 .26225E 00	229.21	.33201E-01
167	60.0 .51960E 00	305.42	.00000E-50 .25192E 00	229.46	.33085E-01
168	60.0 .47310E 00	305.91	.00000E-50 .24023E 00	229.70	.32961E-01
169	60.0 .43110E 00	306.34	.00000E-50 .22762E 00	229.93	.32837E-01
170	60.0 .39292E 00	306.74	.00000E-50 .21443E 00	230.14	.32709E-01
171	60.0 .35824E 00	307.09	.00000E-50 .20098E 00	230.34	.32578E-01
172	60.0 .32671E 00	307.42	.00000E-50 .18753E 00	230.53	.32443E-01
173	60.0 .29802E 00	307.72	.00000E-50 .17427E 00	230.71	.32306E-01
174	60.0 .27189E 00	307.99	.00000E-50 .16137E 00	230.87	.32166E-01
175	60.0 .24807E 00	308.24	.00000E-50 .14894E 00	231.02	.32024E-01

178	600.0	.22635E 00	308.47	.00000E-50	.13708E 00	231.15	.31879E-01
177	600.0	.20693E 00	308.67	.00000E-50	.12585E 00	231.28	.31732E-01
178	600.0	.18034E 01	310.36	.00000E-50	.11721E 01	232.43	.30239E-01
179	600.0	.22618E 00	310.78	.00000E-50	.42943E-01	232.49	.28536E-01
180	600.0	-.11803E-01	310.77	.00000E-50	.72507E-01	232.57	.26824E-01
181	600.0	.28800E-01	310.80	.00000E-50	-.69775E-01	232.50	.25096E-01
182	600.0	-.29986E-01	310.77	.00000E-50	.79131E-01	232.58	.23386E-01
183	600.0	.33669E-01	310.80	.00000E-50	-.92463E-01	232.48	.21659E-01
184	600.0	-.39163E-01	310.76	.00000E-50	.11216E 00	232.60	.19950E-01
185	600.0	.47295E-01	310.81	.00000E-50	-.14158E 00	232.45	.18216E-01
186	600.0	-.59438E-01	310.75	.00000E-50	.18545E 00	232.64	.16515E-01
187	600.0	.77547E-01	310.83	.00000E-50	-.25358E 00	232.39	.14775E-01
188	600.0	-.10534E 00	310.72	.00000E-50	.35931E 00	232.74	.13084E-01
189	600.0	.14906E 00	310.87	.00000E-50	-.53454E 00	232.27	.11324E-01
190	600.0	-.22063E 00	310.69	.00000E-50	.81955E 00	233.05	.96661E-02
191	600.0	.33758E 00	310.99	.00000E-50	-.13371E 01	231.69	.78409E-02
192	600.0	-.54704E 00	310.44	.00000E-50	.22036E 01	233.90	.62840E-02
193	600.0	.90301E 00	311.35	.00000E-50	-.40249E 01	229.87	.42840E-02
194	600.0	-.16267E 01	309.72	.00000E-50	.68894E 01	236.76	-.30121E-02
195	600.0	.28272E 01	312.54	.00000E-50	-.15073E 02	221.69	.27654E-03
196	600.0	-.59000E 01	306.64	.00000E-50	.22794E 02	244.48	-.20498E-03

APPENDIX IV

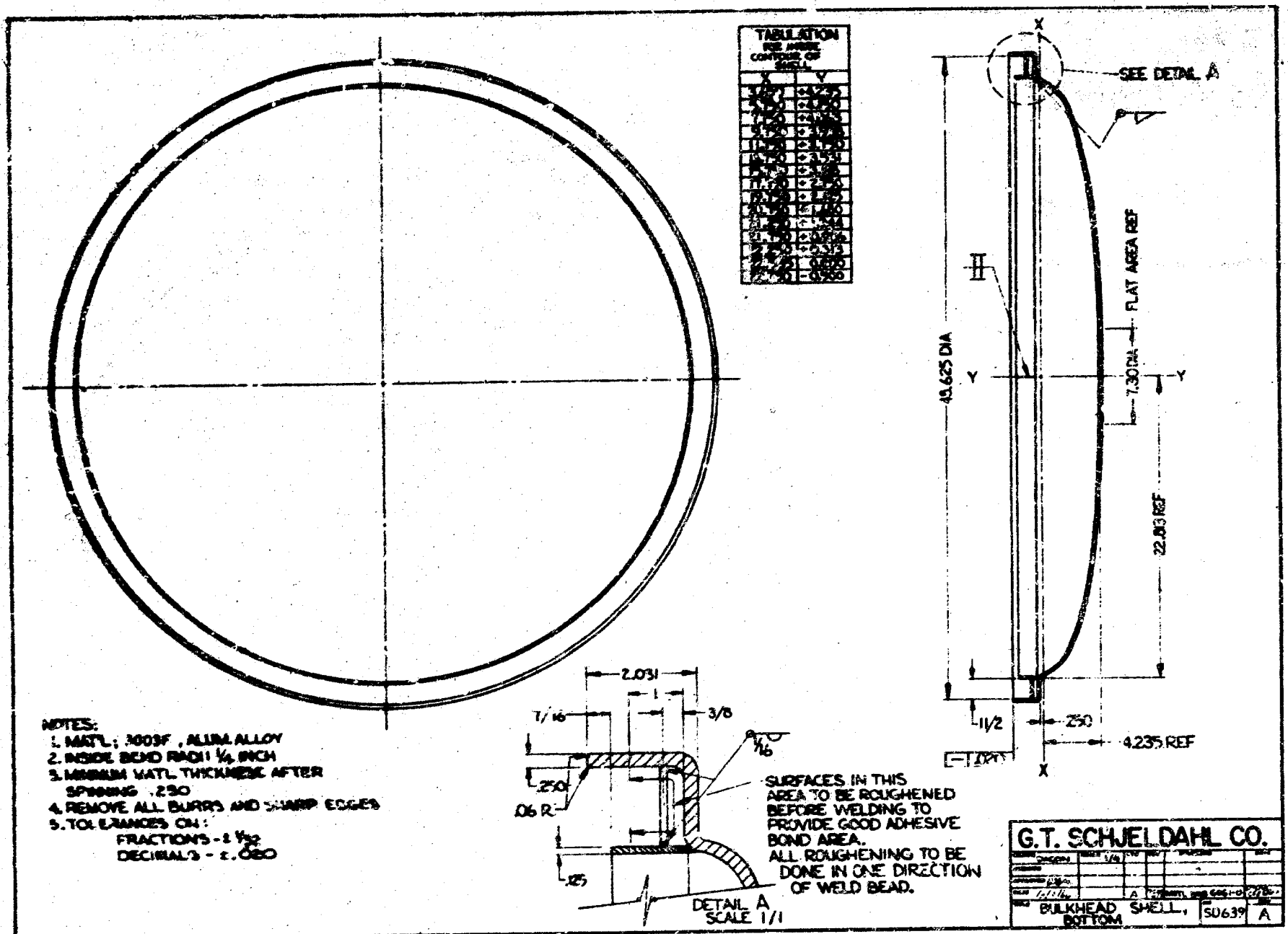
DRAWINGS OF SOLAR COLLECTOR CANISTER AND CYLINDER BULKHEADS



NOTES:
1. 5052-H32, .063 THICK ALUM SHEET
2. ½ X ½ ALUM., EQUIVALENT FOR WELDING.

G.T. SCHJELDAHL CO.

DRAWN DICON	SCALE 1/4		
RING ASSY.		SD647	REV A

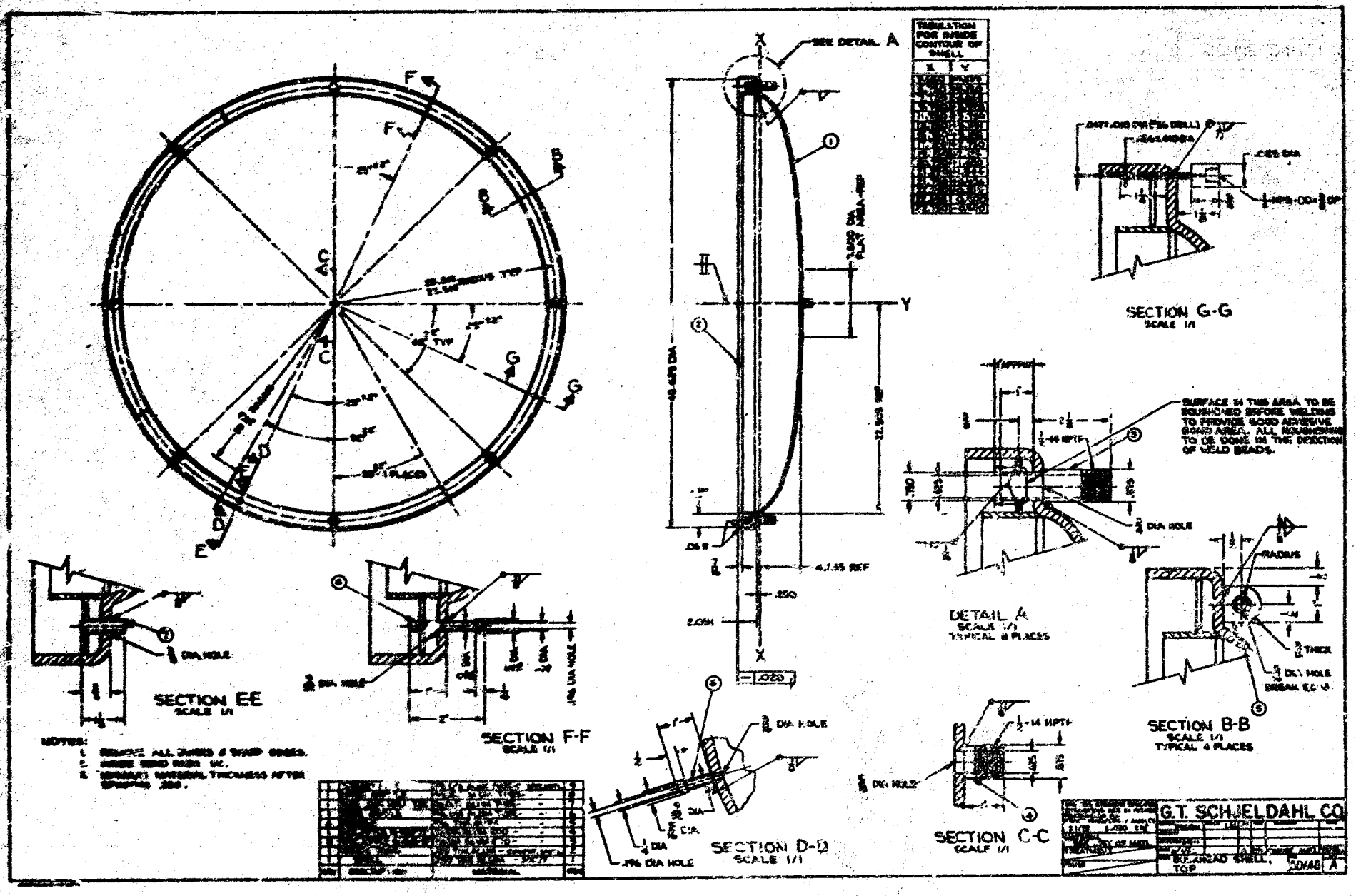


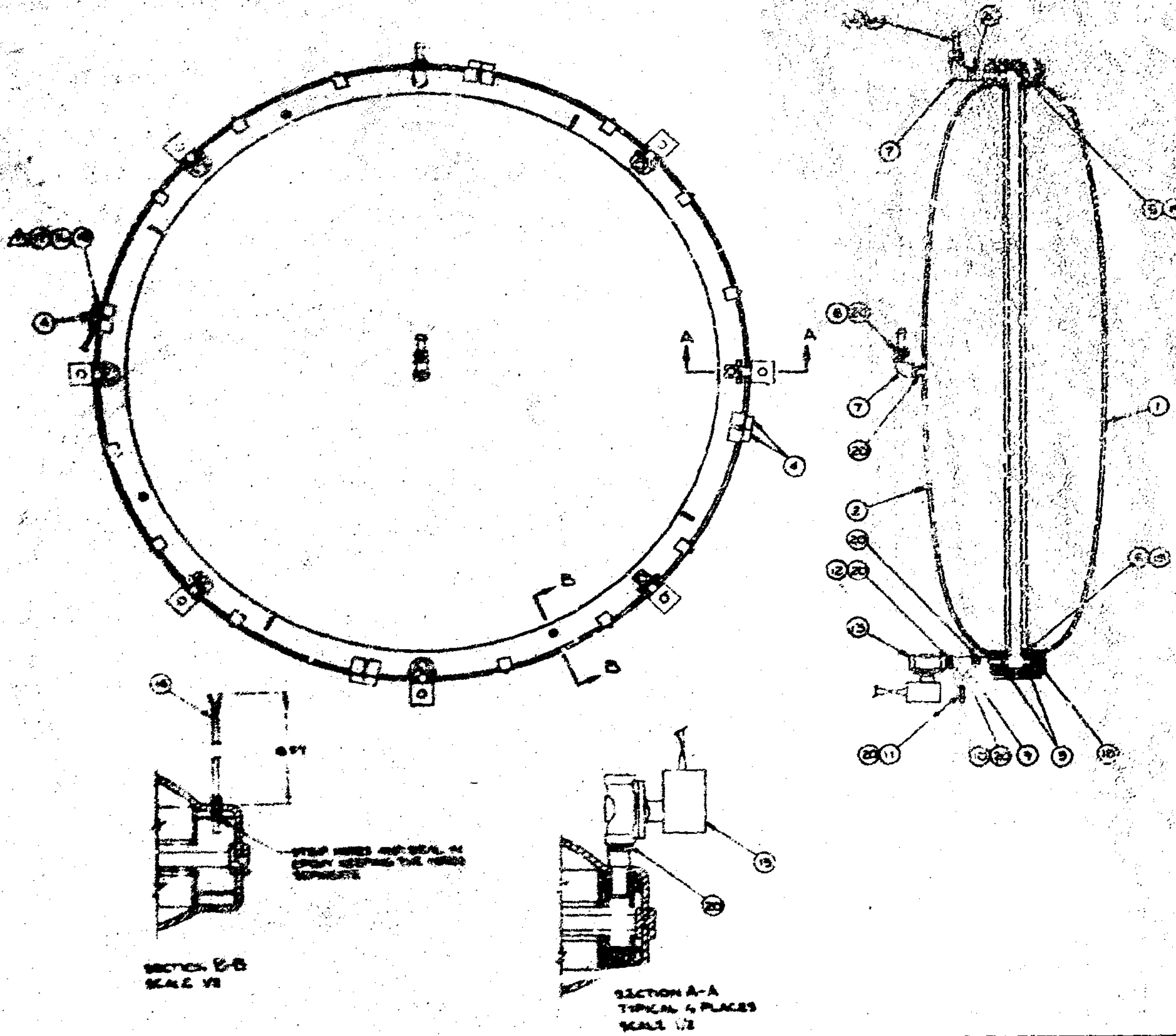
NOTES:
1. MATL.; 3003F, ALUM. ALLOY
2. INSIDE BEND RADII 1/4 INCH
3. MINIMUM MATL. THICKNESS AFTER SPINNING .230
4. REMOVE ALL BURRS AND SHARP EDGES
5. TOLERANCES ON:
   FRACTIONS - ± 1/32
   DECIMALS - ± .010

G.T. SCHJELDAHL CO.

		1/4			
		A			

BULKHEAD, SHELL, BOTTOM | SU639 | A


SEE DETAIL A
SECTION G-G
SCALE 1/1
DETAIL A
SCALE 1/1
TYPICAL 8 PLACES
SECTION B-B
SCALE 1/1
TYPICAL 4 PLACES
SECTION EE
SCALE 1/1
SECTION F-F
SCALE 1/1
SECTION D-D
SCALE 1/1
SECTION C-C
SCALE 1/1
G.T. SCHJELDAHL CO.
TOP



NOTES:
1. MAXIMUM INSTALLATION TORQUE - 3 FOOT-LBS.

QTY REQ	DESCRIPTION	PART NO.	SPECIFICATION	MATERIAL	UNIT WT	ITEM NO
[illegible]	TEFLON TAPE-DUPONT					20
[illegible]	ADHESIVE RUBBER [illegible]		CARBOLINE [illegible]			19
[illegible]	EPOXY					18
[illegible]	#10-32 [illegible] HEX NUT			ST. STEEL		17
4	#10 FLAT WASHER			ST. STEEL		16
4	#10-32 [illegible]	5903-11	[illegible] INC.			15
A/R	THERMOCOUPLE WIRE					14
7	[illegible] VALVE		[illegible]	BRONZE		13
1	1/4" CLOSE NIPPLE			BRASS		12
1	1/4" PIPE [illegible] FITTING	NK-2[illegible]	PUNCH-LOK	STEEL CAD. PLT.		11
1	[illegible] REDUC. BUSH.			BRASS		10
1	1/4" TEE			BRASS		9
2	[illegible] FITTING	[illegible]	PUNCH-LOK	STEEL CAD. PLT.		8
2	1/4" 90° ELBOW			BRASS		7
[illegible]	RUBBER CHANNEL	[illegible]	[illegible]			6
[illegible]	RUBBER [illegible]	[illegible]	[illegible]			5
4	BAND ASSY	5D648				4
2	RING ASSY	[illegible]				3
1	[illegible]	[illegible]				2
1	BULKHEAD, BOTTOM	5D639				1

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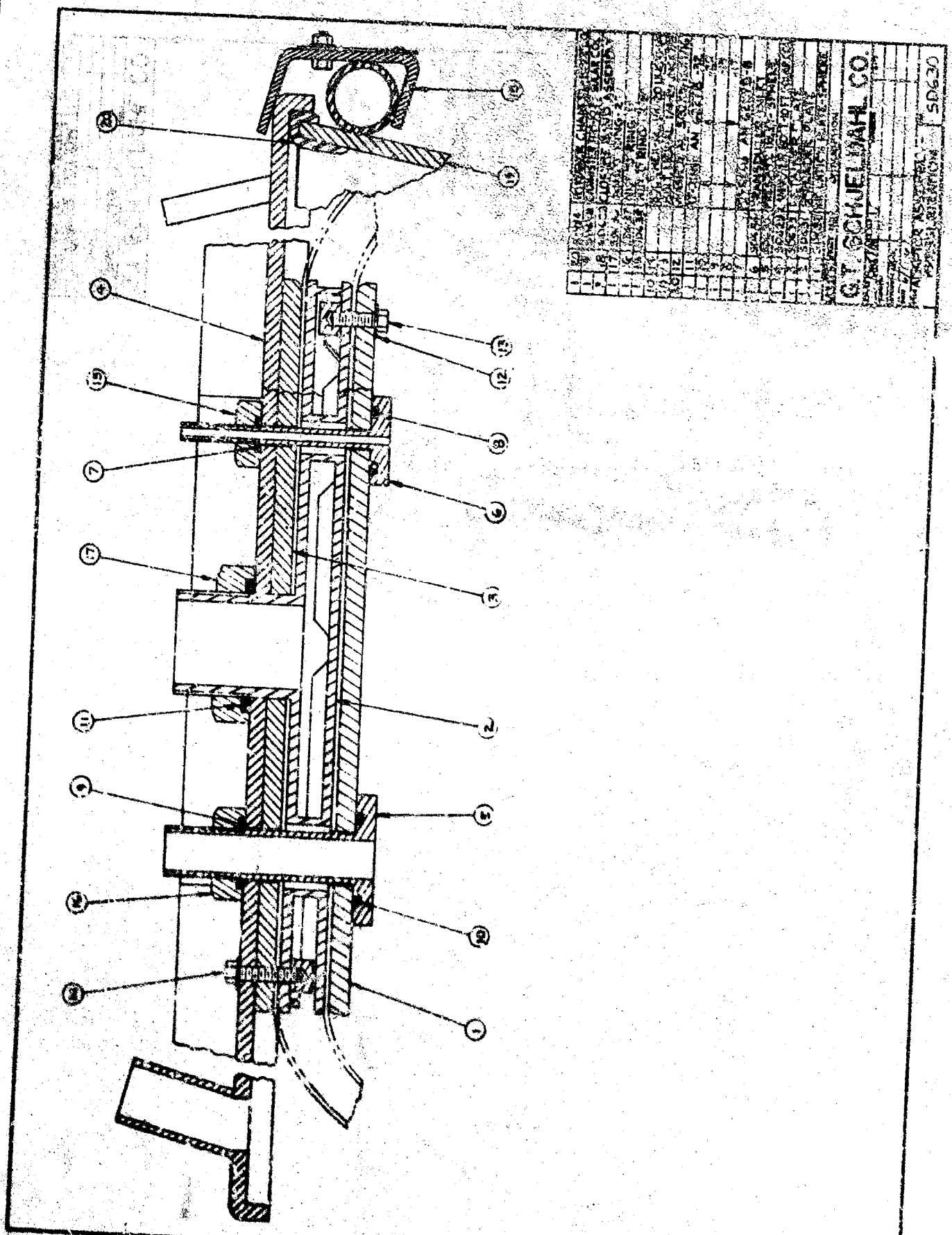
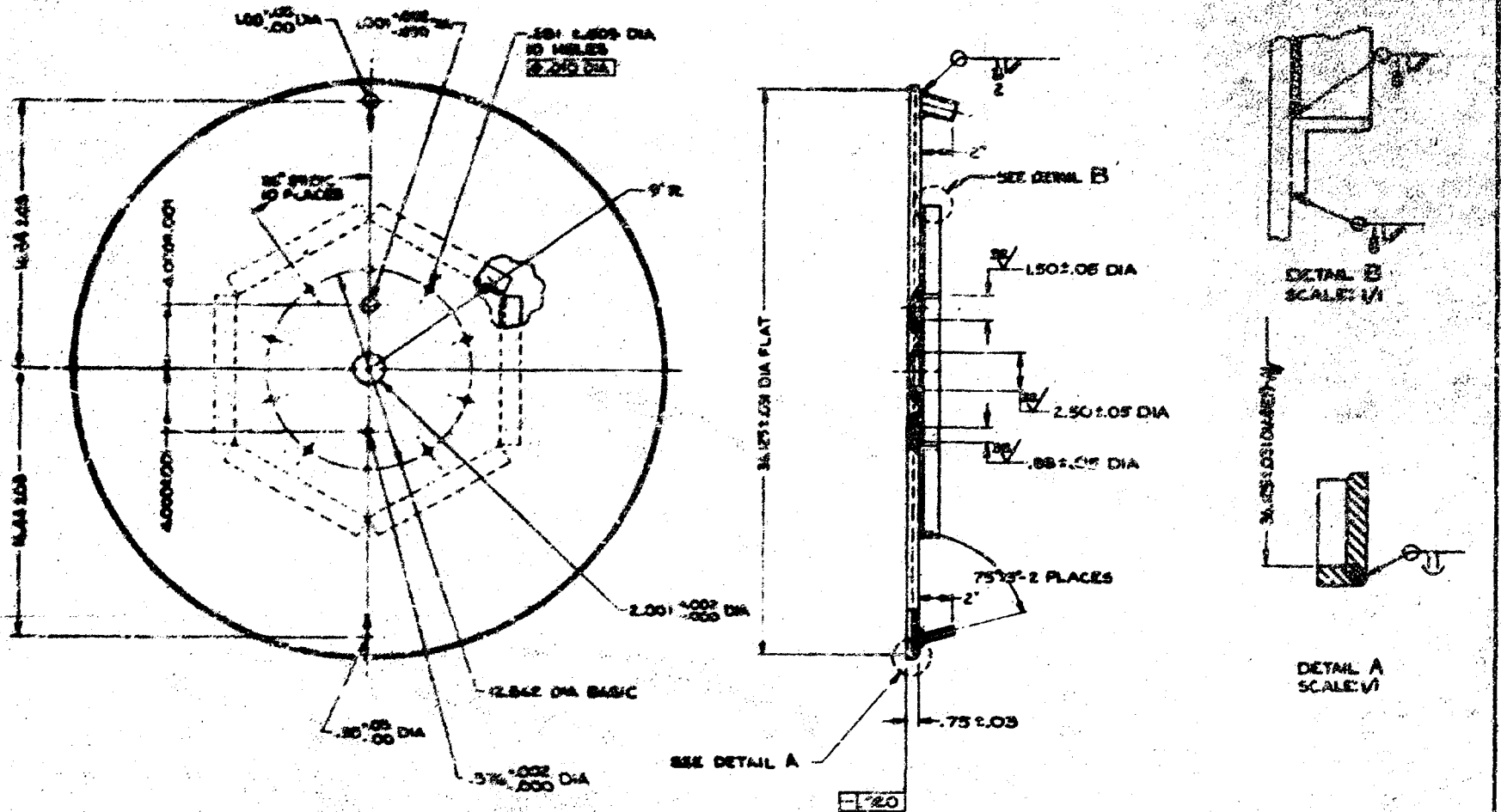
48" DIA CYLINDER ASSY | 5D646


G. T. SCHJELDAHL CO.

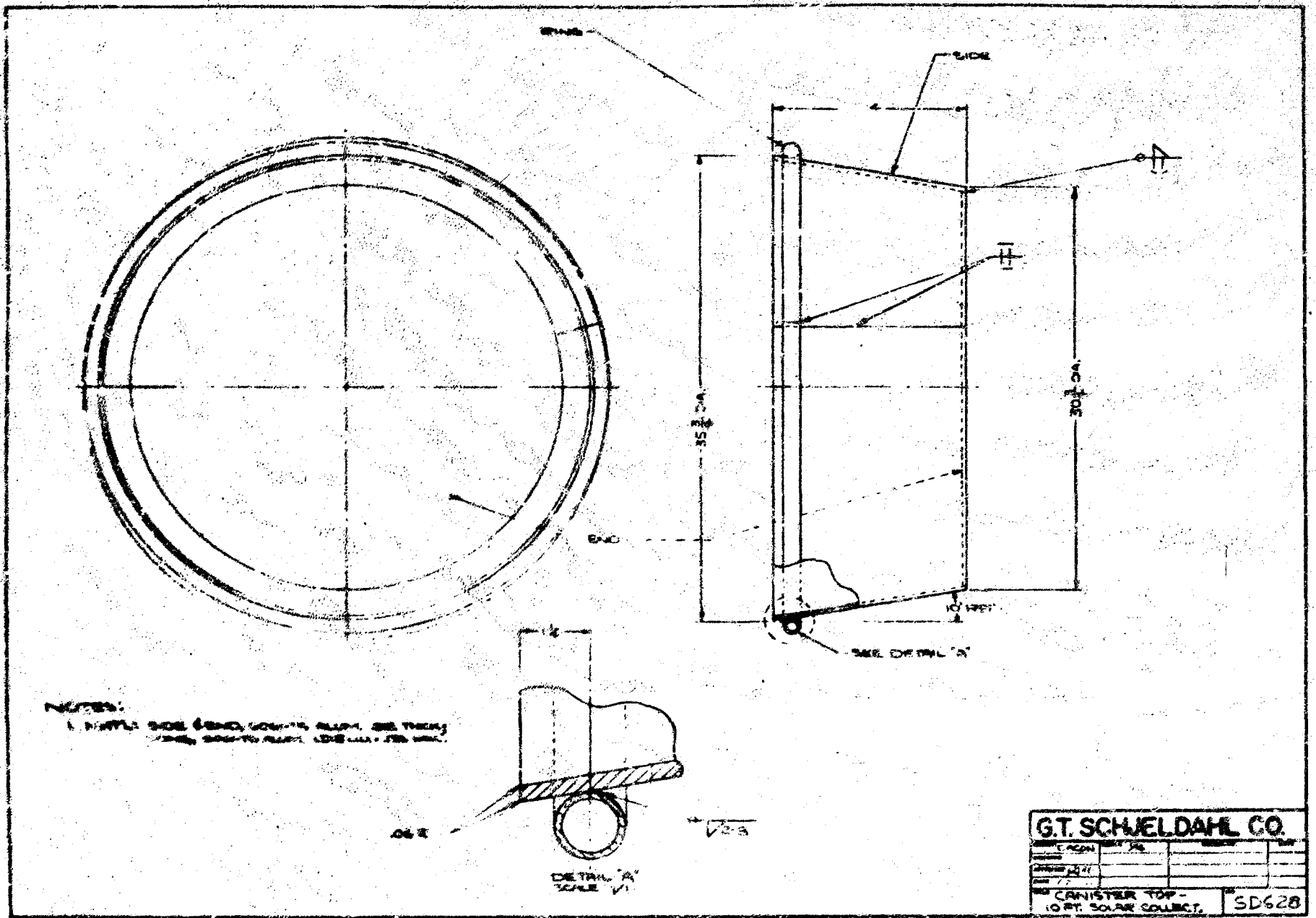


NOTES:

1. MATL: 6061-O PLATE, ALUM., .512 THICK
   6061-T6 STRONG, ALUM.-1
   1¼ O.D. x.120 WALL THICKNESS
   ½ O.D. x.065 WALL THICKNESS
   6061-T6 ANGLE, ALUM., 1¼ x 1¼ x ⅛
2. WELDS TO BE AIR TIGHT-WELDARC

G.T. SCHJELDAHL CO.

DRAWN	1/4/8		
CANISTER BOTTOM, 10 FT. SOLAR COLLECTOR			SD629



G.T. SCHUELDAHL CO.

CANISTER TOP - 10 FT. SOLAR COLLECT.

SD628

Unclassified

Security Classification

DOCUMENT CONTROL DATA - R&D

(Security classification of title, body of abstract and indexing annotation must be entered when the overall report is classified)

1. ORIGINATING ACTIVITY (Corporate author) G. T. Schjeldahl Company Northfield, Minnesota	2a. REPORT SECURITY CLASSIFICATION Unclassified 2b. GROUP

3. REPORT TITLE

Gelatin Rigidized Expandable Sandwich Solar Energy Concentrators and Space Structures

4. DESCRIPTIVE NOTES (Type of report and inclusive dates)

Final Report

5. AUTHOR(S) (Last name, first name, initial)

Neaman, Raymond G.

6. REPORT DATE	7a. TOTAL NO. OF PAGES	7b. NO. OF REFS
August 1966	274	None

8a. CONTRACT OR GRANT NO. AF 33(615)-2058 b. PROJECT NO. 8170, 3145, 7381 c. Tasks 817004, 314502, 738101 d.	9a. ORIGINATOR'S REPORT NUMBER(S) 9b. OTHER REPORT NO(S) (Any other numbers that may be assigned this report) AFAPL-TR-66-135

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11. SUPPLEMENTARY NOTES	12. SPONSORING MILITARY ACTIVITY
	Air Force Aero Propulsion Laboratory Wright-Patterson AFB, Ohio 45433

13. ABSTRACT

In the search for optimum materials to be used in an expandable sandwich concept of fabricating space structures, a gelatin rigidizing resin system was improved and adapted for use. It was demonstrated that this system would be desirable for use with fabric materials. The resin system is easily applied, has high strength to weight ratio, and is resistant to a space environment.

The other materials finally selected for use are completely compatible and equally resistant to a space environment.

The final items of the development program were lightweight, self-rigidizing, 10-foot diameter solar energy concentrators; and 4-foot diameter cylinders, 8-foot long. Space systems considerations were an integral part of this study, with particular emphasis on much larger structures requirements.

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DD FORM 1 JAN 64 1473

Unclassified

14. KEY WORDS	LINK A		LINK B		LINK C	
	ROLE	WT	ROLE	WT	ROLE	WT
Expandable	8	3				
Space Structures	8	3				
Gelatin Rigidizing Resin	8	3				
High Strength to Weight Ratio	2	3				
Resistant to Space Environment	1	1				
Space Systems Considerations			8	3		
Self-rigidizing			8	3		

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