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FINAL REPORT

MATERIALS TECHNOLOGY ADVANCEMENT PROGRAM

FOR

EXPANDABLE MANNED SPACE STRUCTURES

CASE FILE
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By Kenneth L. Cordier and William B. Cross

Goodyear Aerospace Corporation
Akron, Ohio

for

Langley Research Center
Langley Station, Hampton, Va.

NATIONAL AERONAUTICS AND SPACE ADMINISTRATION

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GOODYEAR AEROSPACE CORPORATION
Akron, Ohio

for Langley Research Center

NATIONAL AERONAUTICS AND SPACE ADMINISTRATION

FOREWORD

This report was prepared by Goodyear Aerospace Corporation (GAC), Akron, Ohio, under NASA-LRC Contract NAS 1-9112. The contractor's number for this report is GER-14774.

The work was administered under the direction of the NASA-LRC Space Systems Research Division. Mr. Charles I. Tynan, Jr. of the Life Support Branch, Habitable Structures Unit, was the program director for the NASA-LRC.

This effort was started in May 1969 and concluded in February 1970. The program was directed by the Space Systems and Analytics Division, managed by Mr. S. J. Pipitone of GAC.

This program was a group effort headed by Mr. L. Jurich, program manager of the Astronautics Programs Department, assisted by K. L. Cordier, project engineer; W. B. Cross and S. Blate, materials technology; Dr. C. E. Welling, staff materials consultant; D. S. Kimes, composite materials laboratory; J. J. Meola, thermal control analysis; M. L. Lahr, quality assurance analysis; D. A. Neman, contract administration; and R. L. Hall, engineering administration.

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CONTENTS

	Page
FOREWORD	ii
SUMMARY.	1
INTRODUCTION	1
TECHNICAL DISCUSSION	4
Candidate Materials Section.	4
General.	4
Candidate Materials Selection Criteria	4
Candidate Materials Search	5
Polymer Materials Review	6
Candidate Materials Screening Tests and Composites Development	12
General.	12
Individual Materials Screening Tests	13
Mechanical Properties.	19
Development of a Flame/Gas Barrier Subcomposite.	34
NASA-WSTF Laboratory Tests	54
Four Element Composite Wall Concepts	58
Composite Materials Qualification Tests (4-Element).	69
General.	69
Flammability	69
Packageability	73
Micrometeoroid Impact Tests.	79
Thermal Vacuum Exposure.	79
Effluent Gas Analysis.	79
Ply Adhesion	79
Thermal Shock Test	79
Tensile Stress-Strain Properties	82
Taber Abrasion	82
Tear Resistance.	87
Puncture Resistance.	92
Humidity Test Effects.	92
Fungus Resistance.	96
Blocking Resistance.	98
Solar Absorptance and Infrared Emittance Measurements. . .	98
Fabrication Techniques Development	101
General.	101
Definition of Fabrication Task	101
Analysis of Utility of Candidate Materials	106
Advanced Total Composite Wall Construction	112
Definition of Structure Fabrication Techniques (Fabrica- tion Logic).	113
Thermal Control System Analysis.	122
General.	122

	Page
Quasi-Passive Thermal Control Concept.	123
Active Thermal Control Material Concept.	123
Experimental Test Results.	124
Summary.	129
Inspection and Quality Assurance Analysis.	132
Method of Inspection	132
Implementation of Quality Assurance System	133
CONCLUSIONS AND RECOMMENDATIONS.	136
REFERENCES	139
DISTRIBUTION LIST.	188

Appendix

A	Form Letter SP-6975 and Mailing List	143
B	Form Letter SP-6918 and Mailing List	149
C	Listing - Category A Usage Materials (COMAT)	153
D	Bibliography	157
E	Processing Instructions.	163
F	NASA-MSC Micrometeoroid Test Results	183

ILLUSTRATIONS

Figure		Page
1	Existing Technology.	2
2	Elastic Recovery Materials Technique	3
3	Work Flow Chart for Primary Screening Tests.	15
4	Work Flow Chart for Characterization and Screening Tests	15
5	Tensile Load vs Elongation Curves for 81677 Beta Glass Fabric at Various Temperatures - Warp.	21
6	Tensile Load vs Elongation Curves for 81677 Beta Glass Fabric at Various Temperatures - Fill.	21
7	Tensile Load vs Elongation Curves for 1-Mil Aclar 33c at Various Temperatures.	22
8	Tensile Load vs Elongation Curves for 1-Mil Kapton at Various Temperatures	22
9	Tensile Load vs Elongation Curves for 1/2-Mil 1100-O Al Foil at Various Temperatures	23
10	Tensile Load vs Elongation Curves for 1-Mil 1100-O Al Foil at Various Temperatures	23
11	Tensile Stress vs Elongation Curves for C-100-28 Refrasil Cloth at Various Temperatures - Warp.	24
12	Tensile Loading vs Elongation Curves for 5-Mil Thick Mosites #1066 Fluorel Adhesive at Various Temperatures .	24
13	Compressive Stress vs Percent Compression Curves for Mosites #1062-C Fluorel Sponge at Various Temperatures .	26
14	Compressive Stress vs Percent Compression Curves for Raybestos Manhattan RL-2060 Sponge at Various Temperatures	26
15	Typical Compressive Load vs Percent Compression for Litoflex K20 Asbestos Foam for Various Temperatures. . .	26

Figure		Page
16	Effect of Temperature on Strength of 1-Mil Aclar 33c Film	28
17	Effect of Temperature on Strength of 1-Mil Kapton Film .	28
18	Effect of Temperature on Strength of Litoflex K20 Asbestos Foam.	29
19	Effect of Temperature on Strength of 12.8 lbs/ft ³ Mosites #1062-C Fluorel Sponge	29
20	Effect of Temperature on Strength of 15.1 lbs/ft ³ Mosites #1062-C Fluorel Sponge	30
21	Effect of Temperature on Strength of Raybestos Manhattan RL 2060 Fluorel Sponge	30
22	Effect of Temperature on 5-Mil Thick Mosites #1066 Fluorel Adhesive	31
23	Candidate Flame/Gas Barrier Subcomposites Investigated (Sheet 1).	37
	(Sheet 2).	38
24	Comparison of Damage Produced by Tissue Paper and Silicone Igniters.	39
25	GAC Upward Propagation Flammability Test in 100 Percent Oxygen at 6.2 psia	40
26	Various XPB Subcomposites After GAC Upward Propagation Flammability Testing	42
27	Diaphragm Flammability Test Apparatus.	44
28	Diaphragm Flammability Test in 100 Percent Oxygen at 6.2 psia	45
29	Various Flame/Gas Barrier Subcomposites After Diaphragm Flammability Test (Sheet 1).	48
	(Sheet 2).	49
	(Sheet 3).	50
30	Typical Temperature vs Time Curve Obtained During Diaphragm Flammability Testing	51

Figure		Page
31	TGA and DTA Curves for Mosites #1066 Fluorel Adhesive. .	59
32	TGA and DTA Curves for 81677 Beta Fabric	59
33	TGA and DTA Curves for Aclar 33c Film,	60
34	TGA and DTA Curves for Mosites #1062-C Fluorel Sponge. .	60
35	TGA and DTA Curves for XPB-10 Subcomposite	61
36	TGA and DTA Curves for 1/2-Mil Kapton Film	61
37	TGA and DTA Curves for Litoflex K20 Asbestos Foam. . . .	62
38	TGA and DTA Curves for C-100-28 Refrasil Fabric.	62
39	TGA and DTA Curves for XPB-14A	63
40	TGA and DTA Curves for A1-4 White SE Polyester Foam. . .	63
41	TGA and DTA Curves for AD917 Vitel Adhesive.	64
42	Various XTC Specimens After Damaged Flame/Gas Barrier Test	70
43	XTC-6 Wall Composite After Diaphragm Flammability Test .	74
44	Outer Cover Temperature vs Time Curves Obtained During Diaphragm Flammability Testing	74
45	Effect of Temperature on Deployment Characteristics of XTC-4 Wall Composite (With Outer Cover and Asbestos Foam Layer Removed).	76
46	Effect of Temperature on Deployment Characteristics of XTC-6 Wall Composite	76
47	Ultimate Elongation vs Characteristics for Mosites #1062-C Fluorel Sponge	78
48	XTC-4, XTC-6 and Thermal Blanket Specimens Supplied to NASA-MSC for Micrometeoroid Impact Testing	80
49	Tensile Load vs Elongation Curves for XPB-14A Subcomposite at Various Temperatures.	83

Figure		Page
50	Effect of Temperature on Strength of XPB-1 ⁴ A Subcomposite	83
51	Typical Stress Strain Curve for Twisted 3-Strand 0.0035 Diameter Chromel R Configuration.	84
52	Typical Tensile Load vs Elongation Curve for Super- Insulation at 75°F	84
53	Taber Tester	85
54	Effect of Various Numbers of Taber Abrasion Cycles on XPB-1 ⁴ A Subcomposite Material.	86
55	Weight Loss vs Taber Abrasion Cycles Curves for XPB-1 ⁴ A Subcomposite	88
56	Weight Loss vs Taber Abrasion Cycles Curves for XOC-2 Subcomposite	88
57	Effect of Various Numbers of Taber Abrasion Cycles on XOC-2 Subcomposite	89
58	Puncture-Propagation of Tear Tester.	90
59	Puncture Resistance Test Sequence.	94
60	Humidity and Temperature Cycles as a Function of Time MIL-STD-810B, Method 507, Procedure 1.	97
61	Blocking Test Apparatus.	99
62	Advanced Composite Wall Constructions (Sheet 1). (Sheet 2). (Sheet 3).	102 103 104
63	Candidate Lunar Shelter Total Wall Composite and Components Supplied to NASA-LRC.	105
64	Recommended Composite Wall Materials	107
65	Recommended Flame/Gas Barrier Subcomposite (XPB-1 ⁴ A) . .	109
66	Compound Curvature Development	116
67	Near-Earth Micrometeoroid Environment.	120
68	Outer Cover of Composite Wall.	120

Figure		Page
69	Guarded Hot Plate Test Setup	125
70	Guarded Hot Plate Assembly	125
71	Thermocouple Locations	126
72	Guarded Hot Tube Thermal Conductivity Test Setup . . .	130
73	Recommended Total Composite Wall Heat Transfer Rates .	131

TABLES

Table		Page
I	Results of GAC Upward Propagation Flammability Tests in 6.2 psia 100% Oxygen on Candidate Single Layer Materials.	17
II	Summary of Weight Loss in Vacuum Tests	19
III	Tensile Test Specimen.	20
IV	Summary of Measured T_g Values.	27
V	Oxygen Permeability Measurements Obtained on Candidate Gas Barrier Materials.	33
VI	Summary of Candidate Flame/Gas Barrier Subcomposites Investigation (2 pages).	35
VII	Results of GAC Upward Propagation Flammability Tests in 6.2 psia 100% Oxygen on Candidate Flame/Gas Barrier Subcomposites.	41
VIII	Results of Diaphragm Flammability Tests in 6.2 psia 100% Oxygen on Candidate Flame/Gas Barrier Subcomposites	47
IX	Summary of Test Results Obtained on Materials Supplied to NASA-WSTF for Evaluation.	57
X	Summary of Candidate Structural Layers Investigated. .	65

Table		Page
XI	Summary of Candidate Micrometeoroid Barrier Subcomposites Investigated	66
XII	Summary of Candidate Outer Cover Subcomposites Investigated	67
XIII	Summary of Candidate Total Wall Composites Investigated.	68
XIV	Basis for Candidate Subcomposite and Total Wall Composite Elimination.	71
XV	Summary of Qualification Tests Performed on Final Candidates	72
XVI	Results of Compression Set Tests 2-Inch - Litoflex K20 Asbestos Foam Compressed 75%	75
XVII	Summary of Ply Adhesion Test Data.	81
XVIII	Test Data and Results for Resistance to Puncture-Propagation of Tear.	93
XIX	Summary of Puncture Resistance Tests	95
XX	Fungus Resistance Test Results	97
XXI	Solar Absorptance Test Data Sheet.	100
XXII	Comparative Advantages and Limitations - Proposed Micrometeoroid Barrier Wall Construction	113
XXIII	Thermal Conductivity Test Data	127

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(FINAL REPORT)

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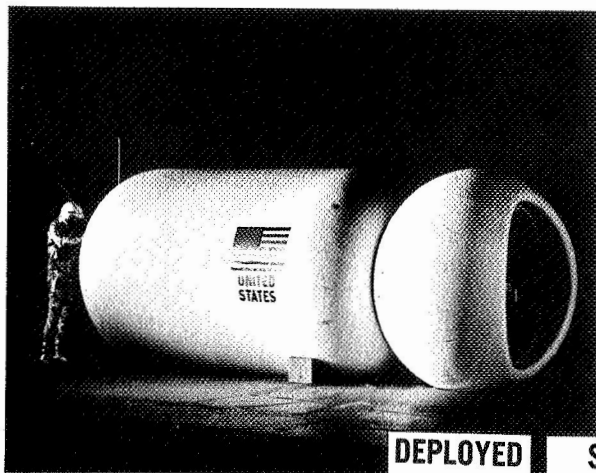
SUMMARY

Existing materials technology for expandable structures has been applied to full-scale models of airlocks, space station modules, and lunar shelters. These models, which successfully demonstrated design requirements for packaging, leak rates, and structural integrity, did not utilize nonflammable materials and hence were not compatible with an oxygen pressurized internal environment. This report documents the results of an extensive materials screening effort and selection process, fabrication of composite materials, qualification testing and a definition of construction techniques required for "flight quality" mission hardware. As a result of the development program, promising designs of fire-resistant composite wall structures were evolved for expandable manned space structures.

INTRODUCTION

The materials approach used up to this time in the design of expandable structures for manned space structure applications is based on a four-layer composite material. This composite consists of an unstressed inner layer functioning as a pressure bladder (XPB) for gas retention, a structural layer (XTL) which carries the transmitted pressure loads, a micrometeoroid barrier (XMB) which prevents penetration of the pressure bladder by high velocity particles, and an outer cover (XOC) which encapsulates the total material composite (XTC) and provides a smooth surface for the application of thermal control coatings.

The existing technology (Figure 1) for expandable structure materials is represented by the combined technologies of the Air Force D-21 Expandable Airlock Experiment (Contract F33615-67-C-1380) and the NASA-LRC Lunar Shelter (Contract NAS1-4277) and Moby Dick (Contract NAS1-6673) structures, developed by Goodyear Aerospace. Figure 2 depicts this development, showing a diagram of the four-layer elastic recovery materials concept. Compatibility with an O₂ pressurized environment, and hence nonflammability of the materials under orbital environment conditions, was not provided in these structures, but as a result of the newly developed nonflammable materials techniques in this program, would be provided on future manned space structures.

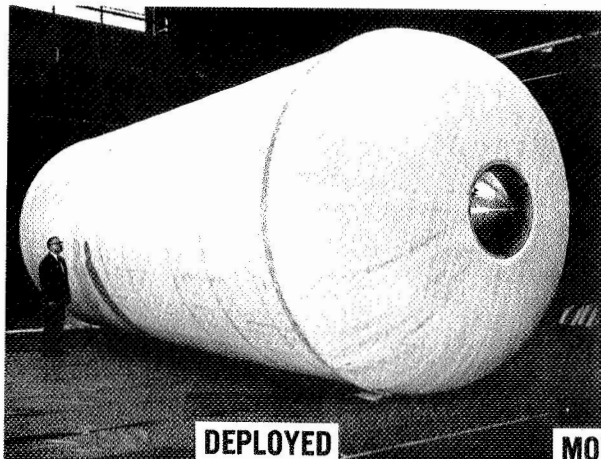


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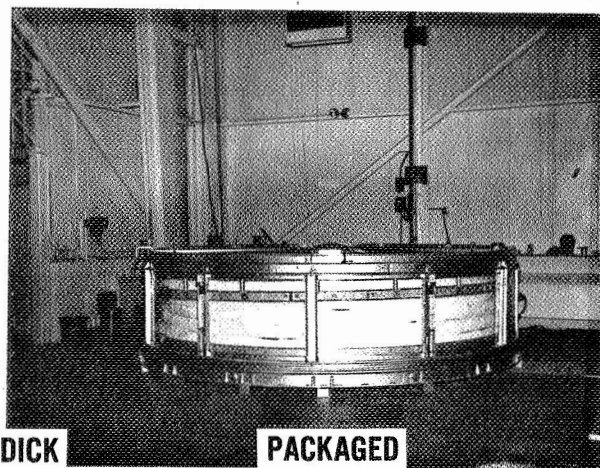


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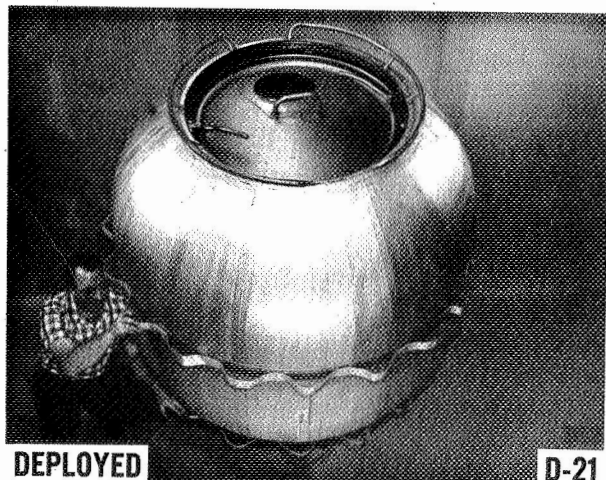


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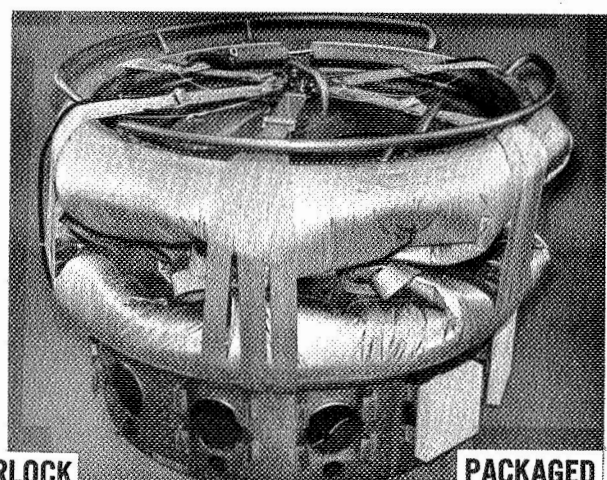


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D-21 AIRLOCK



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Figure 1. Existing Technology

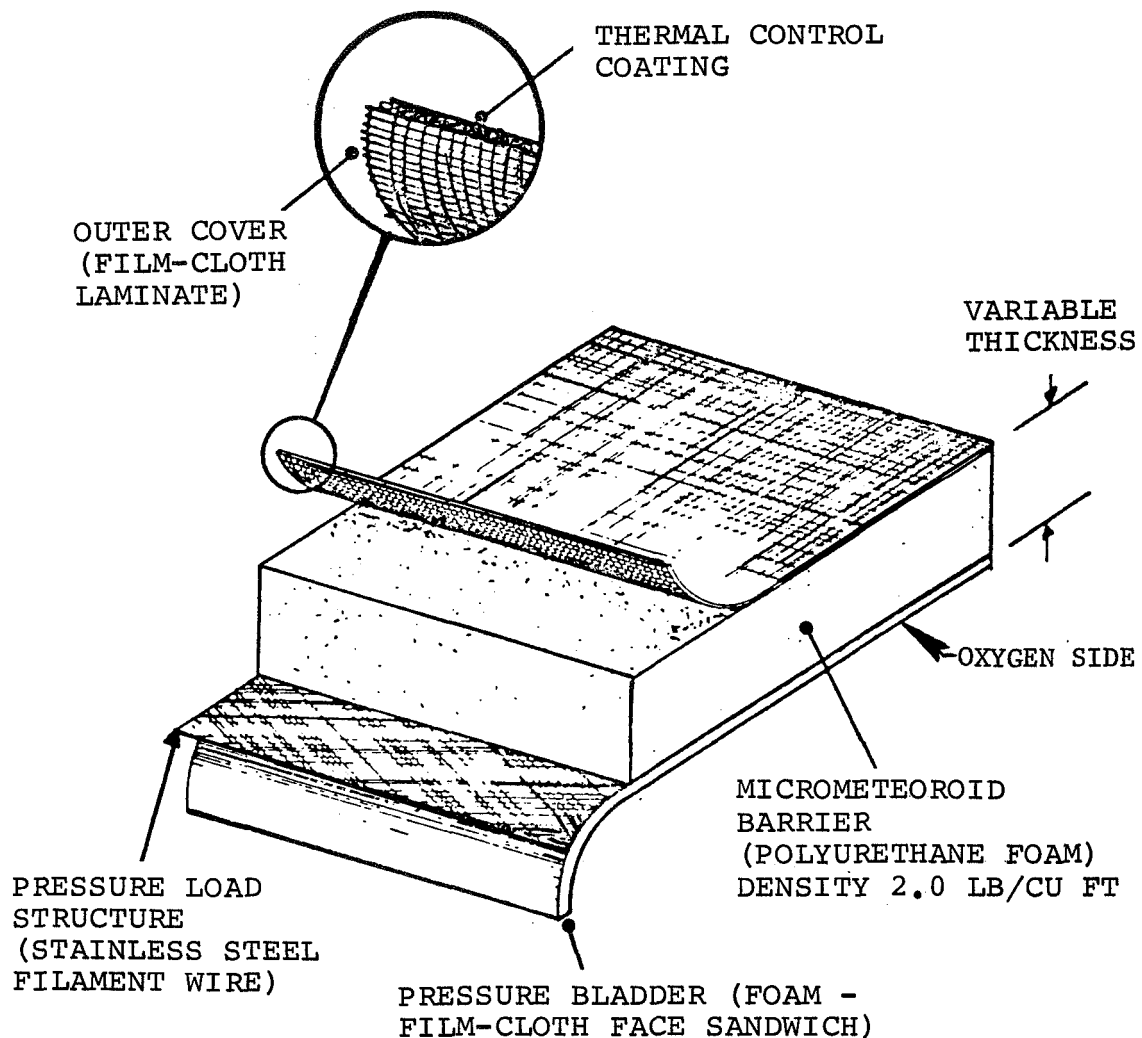


Figure 2. Elastic Recovery Materials Technique

This program was initiated to meet new and current requirements that expandable type manned space structures be compatible with an oxygen pressurized environment.

The objective of this program was to upgrade the development of expandable structures materials to a level where the technology could be applied to the fabrication of "Flight Quality" hardware, specifically a habitable type lunar personnel shelter. This objective was approached within the concept of a four-layer materials composite (pressure bladder, structural layer, micrometeoroid barrier, and outer cover) previously developed in the existing technology. (Figure 1). Specifically, the effort was achieved in two ways, primarily by upgrading the development of the four-layer materials composite relative to the

flammability hazard, and secondly, by establishing practical fabrication techniques logic for translating the materials technology into a space-qualified structure.

The general approach to the investigation was based on the use of experimentally obtained information and NASA technical guidelines and specifications for the evaluation of manned spacecraft materials. The program was conducted in the following phases:

- Task I - Conduct candidate materials section and screening.
- Task II - Conduct composite materials fabrication and qualification testing.
- Task III - Define fabrication techniques, thermal control system design, and quality assurance requirements.

The scope of the subject effort should provide the technology needed to successfully apply expandable structures techniques to meet current and future requirements for manned space mission applications, specifically habitable type lunar personal shelters and other expandable type structures such as airlocks and modular space stations.

TECHNICAL DISCUSSION

Candidate Materials Selection

General. - A screening study for the selection of candidate individual materials with potential low burning rates in a 100 percent oxygen atmosphere was conducted in the Task I Phase. NASA guidelines and recommendations were used as the basis for candidate materials selection criteria. The program started with an extensive search for nonflammable type materials through an industry survey and literature review. Quantities of candidate materials were subsequently obtained for screening tests which lead to a final selection of composite elements for a 4-element composite wall structure.

Candidate Materials Selection Criteria. - The order of significance of the evaluation factors as related to the candidate materials section, were applied in the following order.

- (1) Crew Safety (In accordance with Reference 1)
 - Flammability
 - Toxic Hazards

- (2) Mission Success
 - (a) Ground Environment (In accordance with Reference 2)
 - Humidity effects
 - Effects of temperature extremes
 - Fungus resistance
 - (b) Space Environment (In accordance with Reference 3)
 - Mechanical properties
 - Thermal conductivity
 - Gas tightness
 - Micrometeoroid impact protection
 - Packageability

(3) Mass Properties Efficiency

Candidate Materials Search. -

Industry Survey: An extensive industry wide search was initiated early in the program seeking new or improved materials potentially nonflammable in a 6.2 psia, 100 percent oxygen atmosphere. Sixty-seven letters were sent to industrial concerns regarding these materials with twenty-two responses being received. The form letter and complete mailing list sent to these concerns are shown in Appendix A. Significant information on promising new materials was obtained as a result of the survey, however, due to availability, preliminary development status, fabrication or cost considerations the utilization of these materials in this effort was limited; except for the vendor data received from HITCO concerning their Refrasil cloth. This cloth is used in the flame barrier of the pressure bladder subcomposite (XPB-14A).

Appendix B lists a second group of organizations to which a letter was mailed regarding Category A type usage materials taken from Reference 4. These materials and suppliers were selected from Appendix C, which lists all of the Category A tested materials which were reported to be nonburning. Appendix C was compiled by GAC in the course of a page by page review of the COMAT* listed in Reference 4. Thirteen replies were received from vendors in response to specific inquiries regarding COMAT listings of Category A usage materials. The most promising materials to come out of the survey at that time, as possible candidates for elements in a composite materials construction, were:

Films - Aclar 33c	Elastomers-Fluorel Raybestos Manhattan
- Kapton	L-3203-6
Fabrics - Beta Glass	Adhesives-Fluorel Mosites #1066
- Refrasil (Silica)	
Foams - Fluorel Mosites	Fibers - Chromel R
#1062-C	- Stainless Steel
- Asbestos Litoflex	- Rene' 41
K20	Foils - Aluminum

*Characteristics of Materials

Approximately 100 NASA-White Sand Test Facility (WSTF) test reports of Category A usage materials were received from NASA-MSC during the survey and reviewed for flame propagation and, in some cases, gas analysis and odor information.

Many of the candidate Category A usage materials, investigated mainly on the basis of the results published in the COMAT list (Reference 4) were found to be flammable when tested in the GAC screening test program. Category A defines materials toxicity and flammability characteristics required for major exposed materials usage in a crew bay atmosphere (Reference 1). It was found that the results of flammability tests on individual materials can often differ with a slight change in processing, thickness, post cure, etc., although they may be acceptable when used in a composite construction.

Another useful reference used during the screen program (Reference 5) placed primary emphasis on the effects of material thickness on the degree of flammability. Reference 6 which concerned materials screened for flammability and outgassing was used. However, these documents contained only a few materials which have been assigned a Category A usage.

In addition, Appendix D provided many references which were referred to throughout the materials screening and selection portion of the program and provided useful sources of information during the study.

Polymer Materials Review. - A literature review of the newer types of polymers, particularly those having known or predicted high temperature stability, was carried out. Particular use was made of four review articles, two from American and two from European sources (References 7 through 10).

Relatively little information has been published regarding the behavior of new polymers in tests for flammability in an oxygen atmosphere.

In the absence of such specific information, it is believed that the best basis for prediction of flammability characteristics (as a guide to selection of materials for direct test evaluation) lies in observations of thermal stability as measured by thermogravimetric analysis (TGA) in air, and by retention of strength properties during or after exposure to elevated temperatures in air. Such observations are often a part of the preliminary evaluation of synthesis products at the laboratory stage and are usually reported. In general, no information is to be found in the polymer synthesis and development literature on the improvements in flammability characteristics that may result from compounding with flame retardants and inert fillers or the effect of physical configuration.

Information on availability, fabrication procedures, and cost has been developed for some of the materials considered. In some cases one or more of these latter factors are highly unfavorable in the context of the present program. Only Item 1 (PBI) and Item 8 (PI) of the following group appears to be of definite interest, for possible rigid structure applications, such as terminal end rings or hatches.

The following summarizes the information gained from the literature survey:

(1) Polybenzimidazole (PBI)

As a fabric, this polymer would not ignite in 6 psia oxygen, employing spark ignition (Reference 11). Modifications incorporating a terephthalate, as well as isophthalate substructure, are available as a laminating resin (Imidite 1850) and as an adhesive (Imidite 850) (Reference 9).

Further information on commercially available (in pilot quantities) forms of PBI produced by the Whittaker Corp. has been obtained. Imidite 1850 laminating resin and a prepregged cloth are available. Certain configurations of laminates are understood to have passed a 6 psia oxygen flammability test. Release of volatiles in cure may give rise to problems of laminate porosity---it is not clear whether this may effect flammability, but porosity does unfavorably effect strength retention in air at elevated temperatures. Present cost of Imidite 1850 resin is of the order of \$100/lb. Imidite 850 resin, produced for adhesive applications, may not possess sufficient flexibility after cure for expandable structure applications.

(2) Poly (bisbenzimidazobenzophenanthroline) (BBB).

This polymer originated at the Air Force Materials Laboratory and is believed to have been fabricated into fiber only, to date. Its oxidative stability permits determination of zero strength temperature in air to be about 700° C (Reference 12). Less than 10% weight loss is experienced up to 625° C in a TGA run in air at a heating rate of 15° C/min (Reference 13). Thus its TGA stability is outstanding.

(3) Perfluoroalkylene Triazine Polymers

Synthesis of reactants and of the polymers is in the laboratory stage period. However, property determinations on small quantities of cross-linked and filled materials (which are elastomers) indicate, in oxygen bomb tests, a degree of non-flammability about equal to some samples of poly (tetrafluorethylene).

Thermal stability is good in contact with some metals and suffers greatly with the presence of other metals. Certain useful cross-linking catalysts would appear likely to reduce oxidative stability. The multi-step synthesis of polymer and poor availability of needed perfluorinated monomers make a lengthy development program likely. Development is being carried on by Hooker Development Corporation (Reference 14).

(4) Polyquinoxalines (References 15 through 21)

Whittaker Corp. is pursuing the development of this polymer type, of which the present cost is about \$100/lb. Production potential for laminates considered nonflammable in oxygen is believed to be good. Molding qualities may be superior to those of PBI. Apparently initial decomposition temperature in air is somewhat higher than for PBI.

(5) Polybenzothiazole (References 22 through 24)

With initial decomposition temperature in air is still higher than that of polyquinoxaline, this polymer may have some potential. Furthermore, weight loss of only 6 percent to 600° C in TGA run in air at 3.2° C/min. is most impressive. However, its extremely high glass transition temperature ($>600^{\circ}$ C) renders it unresponsive for fabrication. Since the initial announcement concerning its original synthesis, very little has been published. Reference 24 mentions a "modified PBT with a prepolymer soluble in dimethyl acetamide" that is identified as AF-R2506. The source is not identified.

(6) Fluorinated Polyurethanes (Reference 25)

The synthesis of perfluorinated alkyl and aryl diisocyanates and of highly fluorinated polyether polyols, which has been achieved in recent years, opens the way to production of polyurethanes containing very little hydrogen in the structures. Such structures might be predicted to resemble Teflon in resistance to oxidation. Further, there should be the possibility of covering a range of physical properties from soft elastomers to tough solids. The difficulties in synthesizing suitable fluorinated monomers appear to have greatly limited development; fluorinated monomer costs are still upwards of one hundred dollars per pound. No definite information on the stability of the materials in gaseous oxygen atmospheres or against LOX has been obtained, but indications seem unfavorable. It may be presumed that the unavoidable residual hydrogen in a fluorinated polyurethane limits its resistance to oxidation.

(7) Polyhydrazides - Polyoxadiazoles

Aromatic polyhydrazides are soluble, tractable materials that undergo cyclization on heating to give polymers containing alternating aromatic ring segments and oxadiazole rings. The final molecular structures are generally infusible and insoluble in most solvents. While thermogravimetric analysis (TGA) runs in air indicate good stability, Frazer and Memeger of duPont (Reference 26) indicate that some few aromatic poly oxadiazoles copoly (oxadiazole-thiadiazole) materials were "flammable". One material was said to be nonflammable and this was ascribed to phosphorous containing impurities left in the material from synthesis -- apparently the low level of physical properties exhibited by the nonflammable material made it of no interest.

Gibbs et al (Reference 27) have reported unsuccessful attempts to synthesize a theoretically desirable true ladder-type polymer which was named polyhydrazide.

(8) Polyimide Resins and Foam (PI)

Although polyimides are noted for thermal stability, no instances of representative resins demonstrating nonflammability have been noted. However, Monsanto has stated that PI resin-glass laminates have demonstrated nonflammability in 100 percent oxygen environment with an unspecified limitation on maximum resin content. Their recommendation for such usage is Skybond RS-6228.

Monsanto is also developing foamable polyimide compositions, supplied in powder form, that are cured to essentially open cell foams. These are stated to be flammable in oxygen and nonflammable in air. In view of the rigid plastic character (high glass transition temperature) of PI resins, production of a flexible foam incorporating sufficient inert filler to reduce oxygen flammability may be some time away.

(9) Various Ladder Polymers (References 28 through 31)

Ladder polymers are those with two strands of chemical bonds running through the molecular chain. Semi-ladder types are those with recurring interruptions in one or the other strand. A good ladder structure should possess enhanced thermal stability because molecular scission would require breaking both strands at the same time. However, there appears to be only a partial correlation between thermal stability and oxidative stability as indicated by the reports of recent work in three laboratories. DeWinter (Reference 28) suggests that structural imperfections in ladder polymers afford points for oxidative attack and lower the thermo-oxidative stability.

Okada and Marvel (Reference 29) in a study of ladder and partial ladder aromatic polymers containing quinoxaline and thiazine or oxazine recurring units found the polymers very difficult to burn completely for chemical analysis. However, no evidence of extremely good resistance to partial oxidation was reported.

Bell and Jewell (Reference 30) have reported on work with a class of polymers termed polyimidazopyrrolones or "Pyrones". TGA data suggest a degree of oxidative stability comparable to some polyimides.

Stille et al (Reference 31) reported on attempted synthesis of various ladder structures. Oxidative stability as judged by TGA in air was again comparable to polyimides at best.

(10) Silazane Polymers

N. Platzer (Reference 24) stated that polysilazanes show promise as elastomers and for high temperature coatings.

(11) Cordelan Fiber

A copolymer of polyvinyl alcohol and polyvinyl chloride termed Cordelan (Cordela?) (Reference 32) has reached commercial status in Japan. It is claimed to be nonflammable, presumably in air. There seems little likelihood that it would prove nonflammable in an oxygen environment.

(12) Phosphonitrilic Fluoroelastomers

These materials appear to be in the early development stages, and furthermore are subject to practical limitations of high cost and difficult synthesis of suitable fluorinated intermediates. Suppliers of these materials are Horizons, Inc. and El Monte Chemical Co.

(13) Thermally-Treated Polymers

It should be noted that controlled pyrolysis in air or inert atmospheres of certain polymers, particularly in fiber form, has been found to alter molecular structure and to reduce susceptibility to further oxidative attack while in some cases retaining useful physical properties. Such processing of polyacrylonitrile results in a material known as black Orlon and is the first step in some processes for production of carbon/graphite fibers.

Hirsch and Holsten (Reference 33) reported such treatments (pyrolysis in air at 300-375° C) of aromatic polyamide fibers and fabrics to yield products with an appreciable fraction of their original mechanical strength. The products did not support combustion nor fuse when subsequently heated in a Meker burner flame.

GAC has also found that Nomex cloth when heated a few hours at approximately 350° C. in air becomes incombustible in a Meker burner flame. It does however lose weight and strength in the flame.

Some similarities are seen with an experimental fabric designated X410 produced by Monsanto. This material possesses useful room temperature physical properties and again is noncombustible in a Meker flame. However, it is reported by Monsanto to be flammable in an oxygen atmosphere. A sample of X-400 was found to be much more combustible.

(14) Flame Retardants

Some preliminary laboratory evaluation work was accomplished with commercially available cellulose sponge (air-dry density of 4 lb/ft³ as received). It is, of course, a moderately rigid structure that is readily plasticized by water, becoming extremely flexible and undergoing marked expansion on wetting. It appears that 20 percent water (on dry sponge weight) is sufficient to plasticize, although the relationship between dimensions and water content would indicate poor dimensional stability for structures.

Flammability tests have been made on a few samples of sponge impregnated with varying amounts of dibasic ammonium phosphate, $(\text{NH}_4)_2\text{HPO}_4$. A sample containing 49 weight percent of the phosphate salt burned quite slowly in a test with a silicone igniter, but was definitely not self-extinguishing. On the other hand, a sample containing 59 weight percent ammonium salt suffered considerable charring with the silicone igniter before self-extinguishing. Another sample containing 74 weight percent ammonium salt charred slightly and some surface bubbling, presumably decomposition of the ammonium salt, was observed.

Further work would be required to evaluate the importance of such variables as the additives said to be present in the commercial sponge and the composition of the ammonium phosphate. Still other variables are the migration of the phosphate salt to sponge surfaces during drying after impregnation and plasticizing water requirement for the phosphate salt-impregnated sponge.

Qualitative x-ray and spectrographic inspections of samples of a flameproof paper (Tech Representation, Inc. 034-1/034-1 and Chemstrand Research Center coated X-400 fabric) indicates the presence of an antimony compound. The use of antimony oxide with chlorine containing resins to confer fire retardancy is a known art, but there is an indication that antimony may improve materials already having low intrinsic combustibility.

Candidate Materials Screening Tests and Composites Development

General. - Upon completion of the candidate materials selection phase of the program, a quantity of candidate materials for lunar shelter composite structure application was obtained for screening tests. The approach used was to conduct the candidate materials screening test program in accordance with Reference 1. The screening tests for individual materials were conducted in accordance with Reference 1 Category A screening tests logic, whereby material applications are unlimited with respect to ignition source and amount. The order of importance and criteria of the Category A tests requirements are as follows:

<u>Test No.</u>	<u>Criteria</u>
(1) Upward Propagation Flammability Edge Tests in 6.2 Psia-O ₂	Self-Extinguishing < 0.5 inches
(2) Flash and Fire Point	> 450° F
(6) Determine-Total Organics Offgassing and Carbon Monoxide	$\leq 100 \mu\text{gm/gm}$ $\leq 25 \mu\text{gm/gm}$
(7) Odor	Average Score < 2.5
Thermogravimetric Analysis (TGA)	Max. Initial Weight Loss Temp. > 450° F
Differential Thermal Analysis (DTA)	Max. Exotherm Temp. > 450°F

The usual sequence was to first conduct GAC laboratory upward propagation flammability tests of individual candidate materials and, if evaluation of results indicated acceptability, proceed with the additional tests. If evaluation of the results indicated that an individual material was conditionally acceptable, the usual practice was to incorporate the candidate material as a composite element, such as in the flame/gas barrier construction. Several materials were considered unacceptable as individual materials with regard to passing the upward propagation edge tests, but were found acceptable when used in a composite construction due to the effects of variation in thickness and processing.

Approximately 39 individual materials (plastic films, fabrics and elastomeric foams, sheet and adhesives) were investigated in GAC laboratory upward propagation edge tests in a 6.2 psi 100% oxygen environment. Of these materials only the glass fabrics and asbestos foam passed the Category A upward propagation flammability tests. Several plastic films (Aclar and Kapton) and Fluorel type elastomers were considered acceptable when used in a composite construction. Of the candidate metallic forms tested, Chromel R wire and aluminum foil passed the Category A flammability criteria.

As the development proceeded with the selection and screening of candidate individual materials, conceptual designs evolved for a flame/gas barrier (designated XPB) subcomposite construction utilizing the candidate individual materials.

The criteria for composite materials screening tests were based on Reference 1 specification test requirements logic where materials are categorized primarily by functional application. In the case of the candidate lunar shelter type composite wall materials, the end item flight configuration is categorized as the "worst case" category (Reference 1). This category applies to an assembly of nonmetallic materials, one or more of which were utilized based on deviations to the Category A individual materials screening tests requirements.

For the "worst case" exposure requirements, a special GAC diaphragm test was designed to verify any effects of fire and its propagation paths on the candidate lunar shelter composite wall materials. This was accomplished by simulating the crew bay configuration in regard to oxygen atmosphere, pressure differential, possible ignition source, and geometrical boundaries.

Individual Materials Screening Tests. -

General: During the materials screening phase, candidate films, foils, foams, elastomers and adhesives were purchased and evaluated to establish their suitability for use in a lunar shelter. Testing was performed to establish:

- (1) Flammability characteristics in 100 percent oxygen at 6.2 psia.
- (2) Weight loss in vacuum.
- (3) Differential Thermal Analysis (DTA) and Thermogravimetric Analysis (TGA) performance.
- (4) Odor characteristics.
- (5) CO and organic compound offgassing characteristics.
- (6) Mechanical properties; such as, stress-strain, low temperature behavior, adhesion, etc.
- (7) Oxygen permeability.

The results of these tests were then analyzed to establish if candidate materials met or exceeded NASA Category A requirements (Reference 1) and other baseline contractual requirements supplied by NASA-LRC.

Since flammability characteristics are a prime area of consideration for any material located within the cabin atmosphere, it was thought essential that this property should be the first to be evaluated during the screening process.

Although the literature (References 4 and 6) contains considerable data on the flammability of materials in oxygen, it is generally agreed that these data should be only used as a guide to selection since the results often change significantly with a slight decrease in thickness, processing, cleaning, post cure, etc. This particular fact was shown to be true in the course of this program as several of the materials thought to be nonflammable in 100 percent oxygen at 6.2 psia by suppliers were found to be highly flammable in the form tested. Usually it was found that the manufacturer's optimism was based on prior testing performed on similar composition materials of greater thicknesses or materials which had been applied to thick metal substrates to facilitate testing. Seldom could a supplier provide details as to the physical dimensions of the sample that was tested and found to be nonburning. Generally the supplier did not perform the test and could, therefore, only provide limited information received from customers who carried out their own evaluations. Few manufacturers appear to have undertaken testing in a 100 percent oxygen environment.

The normal sequence for screening the candidate materials is contained in Figure 3. After obtaining a quantity of a candidate material a sample was subjected to an upward propagation flammability test in 100 percent oxygen at 6.2 psia in GAC's laboratory facility. Material found to be nonburning or self-extinguishing within 0.5 inch or less after extinguishing of the ignitor (Category A Requirements) was then further evaluated as outlined in Figure 4.

In some cases materials which exhibited slow burn characteristics or those thought to be the best available in a particular class; e.g., film, foam, etc., were conditionally accepted for additional screening efforts. This conditional acceptance was justified on the basis that these materials would be incorporated into a composite having protective nonburning outer layers, and that the composite would be required to pass the upward propagation flammability test. These composites were of the flame/gas barrier type, and their development is covered in details in the section of this report entitled "Development of a Flame/Gas Barrier Subcomposite".

Upward Propagation Flammability Tests: To accelerate candidate selection and to gain a better understanding of the variables which control material flammability, GAC assembled laboratory equipment to evaluate the upward burning characteristics of candidate materials in a 6.2 psia 100 percent oxygen environment.

Initially, the test equipment and procedures were selected only on the basis of the ease in obtaining relative flammability information for screening purposes. These tests were not intended to replace the more comprehensive upward propagation rate test required for Category A certification by NASA. With this in mind, early GAC laboratory tests were conducted using a small strip of material $3/4 \times 3-1/2$ inches wide. In addition, a special test fixture was constructed which permitted

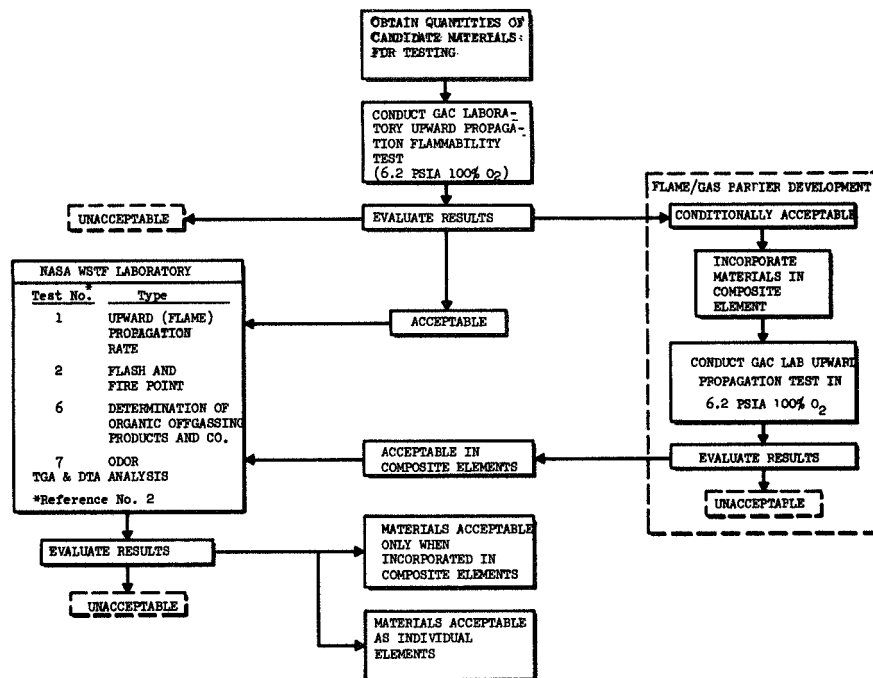


Figure 3. Work Flow Chart for Primary Screening Tests

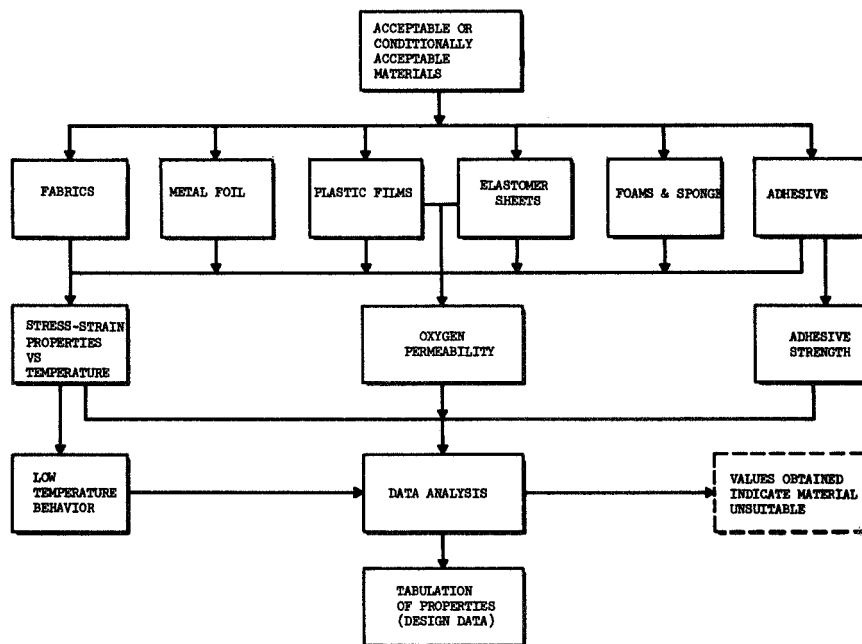


Figure 4. Work Flow Chart for Characterization and Screening Tests

two samples to be tested and compared at the same time. The ignitor used for these tests consisted of a heated Nichrome wire wrapped in a 1 x 2-inch piece of tissue paper.

This test procedure was found to be satisfactory and considerable test data were obtained using this method. However, as the screening efforts continued it was decided that three significant changes should be introduced so that the procedure conformed more closely to that used for NASA Category A qualification. These changes were:

- (1) The initial specimen size was increased to $2\frac{1}{2}$ x 5 inches to conform to MSC-D-NA-0002 test specification for upward flame propagation rate tests.
- (2) The vertical sides of the $2\frac{1}{2}$ x 5-inch specimen were clamped a distance of $1/4$ inch between sheets of heavy aluminum to closely simulate the standard NASA sample holding method.
- (3) A 0.22-inch diameter x 1.25-inch long silicone rubber ignitor fabricated in accordance with the procedure outlined in MSC-D-NA-0002 was used in place of the tissue paper ignitor.

It was observed that changing the sample size did not appear to effect the results. However, clamping the edges instead of the top of the specimen did affect the results obtained on multilayer materials, in that by clamping, the edges could not easily delaminate during the heating and burning process. Thus, a multilayer specimen might burn completely when its edges are not clamped, and be self-extinguishing when clamped. Although the tissue paper ignitor provided an effective means for igniting a specimen, the silicone ignitor was adopted since it conformed to the current NASA testing specification. This ignitor supplied considerably greater heat energy than the tissue paper, and thus thermally degraded a nonburning or self-extinguishing specimen to a much greater degree. Because of the high flame and long time burn duration, it is difficult to establish any true burn rate for a material under test. Therefore, for this evaluation GAC has only reported the condition of the specimen after testing. It can be concluded that in the case of a self-extinguishing sample considerably less damage would be reported had the ignition source been removed.

A summary of the results obtained by GAC on candidate single layer materials using both of these testing procedures is presented in Table I.

Table I provides a summary of the type of material, source, thickness tested, sample size and mounting, ignitor type and results of the test. An examination of the results shows that of the 45 tests reported, five were self-extinguishing, and in nine no ignition resulted. However, all of the materials

TABLE I. RESULTS OF GAC UPWARD PROPAGATION FLAMMABILITY TESTS IN 6.2 PSIA
100% OXYGEN ON CANDIDATE SINGLE LAYER MATERIALS

Material	Manufacturer or Source	Approx. Thickness In.	Test Variables			Observations
			Sample Size, In.	Ignitor Type*	Sample Mounting**	
<u>Films</u>						
Aclar 33c Film	Allied Chem. Corp.	0.001	2 1/2 x 5	TP	EC	Very fast burn
Kapton Film	E.I. dupont de Nemours and Co.	0.001	2 1/2 x 5	↑	↑	Very fast burn
Mylar Film	↑	0.001	2 1/2 x 5			Very fast burn
Mylar Film (Aluminized)		0.001	2 1/2 x 5			Very fast burn
Saran Film		0.001	2 1/2 x 5			Very fast burn
Teflon, FEP Film		0.003	2 1/2 x 5			Fast burn
XRP Film	E.I. dupont de Nemours and Co.	0.0025	2 1/2 x 5	↓	EC	Slow burn
XRP Film		0.005	2 1/2 x 5			Very slow burn
<u>Coated and Uncoated Fabric</u>						
Fluorel (L-3203-6) Coated on X410 cloth	Raybestos-Manhattan, Inc.	0.011	3/4 x 3 1/2		TC	Very fast burn
x400 Cloth with 3310-46-6/FRGL-8 Coating	Chemstrand Research Ctr	0.016	2 1/2 x 5		EC	Fast burn
Fluorel (No.1076 Elastomer) on Beta Glass	NASA-MSC	0.025	3/4 x 3 1/2		TC	Fast burn
Viton 238-26-1 coated Beta Glass	E. I. dupont de Nemours and Co.	0.005	3/4 x 3 1/2		↑	Fast burn
Fluorel Coated Beta Glass No. RL-3520	Raybestos-Manhattan, Inc.	0.005	3/4 x 3 1/2			Slow burn
Fluorel Coated on Stainless Steel Cloth	Raybestos-Manhattan, Inc.	0.012	3/4 x 3 1/2			Slow burn
Fluorel (L-3203-6) Coated on asbestos Cloth	Raybestos-Manhattan, Inc.	0.017	3/4 x 3 1/2			Self-Extinguishing in about 1-1/2 inches
Fluorel(RL-3489-1 RE-FSET)Coated Beta Glass	Raybestos-Manhattan, Inc.	0.008	3/4 x 3 1/2		TC	Self-Entinguishing in about 1-1/2 inches
Fiberglass Cloth 116/Volan A	J. P. Stevens and Company	0.003	2 1/2 x 5		EC	No ignition
Beta Cloth X4484 (Teflon coated yarn)	Owens/Corning	0.007	2 1/2 x 5		↑	Melted in ignition area but did not ignite
Asbestos Cloth (L-69-54 Nematex)	Raybestos-Manhattan, Inc.	0.021	2 1/2 x 5	TP		No ignition
René 41 Cloth (0.0016 1 strand 200 x 200) cleaned in MEK	Unique Wire Co.	0.003	2 1/2 x 5	SE		No ignition
Durette Cloth	Chemstrand Research Ctr	0.016	2 1/2 x 5	TP	EC	Fast burn
<u>Foams (Sponge)</u>						
Diammonium Phosphate Impregnated Scott Foam	GAC	0.500	2 1/2 x 5		TC	Very fast burn
Fluorel Sponge RL-2060	Raybestos-Manhattan, Inc.	0.100	3/4 x 3 1/2		↑	Very fast burn
Fluorel Sponge RL-2060	Raybestos-Manhattan, Inc.	0.050	3/4 x 3 1/2		↑	Very fast burn
Fluorel Sponge RL-2060	Raybestos, Manhattan, Inc.	0.150	3/4 x 3 1/2		↑	Fast burn
Fluorel Sponge L-3622-3	Raybestos-Manhattan, Inc.	0.150	3/4 x 3 1/2		↑	Fast burn
Fluorel Sponge # 1062-C	Mosites Rubber Co.	0.050	3/4 x 3 1/2		↑	Fast burn
Fluorel Sponge # 1062-C	Mosites Rubber Co.	0.050	2 1/2 x 5	TP	↑	Fast burn
Impregnated Cellulose Sponge (49% wt Diammonium Phosphate)	GAC	0.500	2 1/2 x 5	SE		Slow burn
Fluorel Sponge L-3622-2	Raybestos-Manhattan, Inc.	0.150	3/4 x 3 1/2	TP	↑	Very slow burn
LITOFLEX Asbestos Foam KG-25	Rex Asbestwerke (Germany)	0.800	3/4 x 3 1/2	TP		Red glow combustion
Cellulose Sponge (treat)	NASA-MSC	0.500	2 1/2 x 5	SE		Very slow burn
Cellulose Sponge (untreated)	NASA-MSC	0.500	2 1/2 x 5	↑	TC	Very slow burn
Compressed Cellulose Sponge (untreated)	NASA-MSC	0.500	2 1/2 x 5		EC	Very very slow burn
Compressed Cellulose Sponge (treated)	NASA-MSC	0.500	2 1/2 x 5		EC	Extremely slow burn
Impregnated Cellulose Sponge (74 wt % Diammonium Phosphate)	GAC	0.500	2 1/2 x 5		TC	Self-extinguishing in about 1.7 inches
Impregnated Cellulose Sponge (59 wt % Diammonium Phosphate)	GAC	0.500	2 1/2 x 5			Self-extinguishing in about 2.7 inches
LITOFLEX Asbestos Foam K20	Rex Asbestwerke (Germany)	0.900	3/4 x 3 1/2	SE		No ignition
Fluorel Sponge # 1062-C	Mosites Rubber Co.	0.250	3/4 x 3 1/2	TP	TC	No ignition
<u>Elastomers</u>						
Fluorel Elastomer L-3203-6 (Uncured)	Raybestos-Manhattan, Inc.	0.021	3/4 x 3 1/2		TC	Slow burn
Fluorel Elastomer L-3203-6 (Cured)	Raybestos-Manhattan, Inc.	0.014	3/4 x 3 1/2		↑	Slow burn
Fluorel Elastomer L-3203-6 (Cured)	Raybestos-Manhattan, Inc.	0.075	3/4 x 3 1/2			No ignition
Fluorel Elastomer # 1059	Mosites Rubber Co.	0.070	3/4 x 3 1/2		TC	No ignition
<u>Adhesives</u>						
Fluorel Adhesive # 1066 (coated on 1 mil Al Foil)	Mosites Rubber Co.	0.003	2 1/2 x 5		EC	Self extinguishing
Fluorel Adhesive RL-3788 (coated on 1 mil Al Foil)	Raybestos-Manhattan, Inc.	0.003	2 1/2 x 5	TP	EC	No ignition

- * TP indicates 1 x 2 inch tissue paper ignitor
SE indicates 0.22 in. dia. x 1.25 in. silicone elastomer ignitor
** EC indicates sample was mounted by clamping two side edges
TC indicates sample was mounted by clamping top edge

reported as self-extinguishing exceeded the maximum allowable burn length of 0.5 inch called for in Category A requirements. Of the nine no-ignition samples tested, five were inorganic, glass (fiberglass), asbestos or metal, and would not be expected to burn. The remaining four, 0.25-inch thick #1062-C Fluorel sponge, 0.075-inch thick L-3203-6 Fluorel sheet, 0.070-inch thick #1059 Fluorel sheet and 0.003-inch thick RL-3788 Fluorel adhesive coated on 1 mil aluminum foil, all of which are Fluorel, appear to demonstrate the inherent flame resistance of this compound. Further examination of the data in Table I, however, reveals that with the exception of RL-3788 adhesive, all of the above materials ignite and are completely consumed when their thickness is reduced. The RL-3788 adhesive data was obtained with a tissue paper ignitor. When the test was repeated at NASA-WSTF using the standard silicone ignitor the material burned.

The results of the GAC study indicate that with the exception of fiberglass, asbestos, and metal cloth, no single layer material was found which, when used in approximate thicknesses required, would be capable of passing the NASA-Category A requirements for flammability. These results were presented to NASA-LRC with a recommendation that the concept of a flame/gas barrier be incorporated into the framework of this study. This would eliminate the requirement that each material be required to pass the Category A test and permit the development of a gas barrier system composed of nonburning and slow burning rate materials that, when laminated together, would pass the Category A upward propagation flammability test requirement. This idea met with acceptance and was incorporated into the framework of the contract.

Vacuum Weight Loss Behavior: To augment candidate materials screening, the vacuum weight loss behavior of two Fluorel sponge materials and two Fluorel adhesives was determined. Tests were performed using an Ainsworth vacuum balance unit. The specimen temperature was maintained at approximately 75° F, and the percentage of weight loss for each sample was determined following a 24-hour exposure at a pressure of approximately 5×10^{-6} mm Hg.

The results of these tests are presented in Table II and, for the most part, the weight loss experienced was very low and within the 0.5 percent considered acceptable. One interesting observation made during the testing was that, after the sponge materials had been in a vacuum for several hours and then returned to atmospheric conditions, it distorted considerably.

The distortion disappeared after several hours exposure to atmospheric pressure. This behavior was apparently due to the loss of air in each closed cell of the sponge while under vacuum and the resulting collapse of the cell walls as atmospheric pressure was applied.

TABLE II. SUMMARY OF WEIGHT LOSS IN VACUUM TESTS

Material	Weight Loss*, %
Raybestos Manhattan RL-2060 Sponge	0.0522
Mosites #1062-C Sponge	0.278
Mosites #1066 Adhesive on 1-Mil Foil	No Change
Raybestos Manhattan RL-3788 Adhesive on 1-Mil Foil	0.0705

*After 24 hrs at 75° F

Mechanical Properties. -

Stress-Strain vs Temperature: Tests to determine the stress-strain properties of each candidate material were conducted on a Instron testing machine. Tensile tests were conducted in accordance with ASTM-D1682 Procedures. Compressive tests were conducted on sponge and foam specimens in accordance with GAC specifications. Both test procedures were established for the purpose of screening expandable structures materials and obtaining additional design information.

The tensile tests used to generate the stress-strain data are described in the following paragraphs.

Fifteen tests of six different materials were conducted at each of eleven temperatures. Table III describes the materials and lists the quantity tested at each temperature.

In cases where an excessive amount of scatter appeared between the test points, an additional specimen was pulled. For the most part the data was repeatable. Each tensile test was conducted on an Instron testing machine using a crosshead speed of 2 inches per minute. Since a 4-inch specimen gage length was used, strain rates of 50 percent (of gage length) per minute were achieved. The Instron chart was programmed to produce stress vs time curves

TABLE III. TENSILE TEST SPECIMEN

Material	Code	No. of Test Specimen/Temp.	Type of Tensile Specimen (1 in. x 7 in.)
<u>Cloth</u>			
Refrasil	C-100-28	2 Warp	Ravel Strip
Beta	81667	2 Warp	Ravel Strip
Beta	81667	1 Fill	Ravel Strip
<u>Film</u>			
Aclar	33c (1 mil)	2 M.D.*	Cut Strip
Kapton	Al. one side (1 mil)	2 M.D.*	Cut Strip
Mosites	#1066 Adhesive	2 **	Cut Strip
<u>Foil</u>			
Aluminum	1100-0 (1/2 mil)	2 M.D.*	Cut Strip
Aluminum	1100-0 (1 mil)	2 M.D.*	Cut Strip

* Denotes machine direction

** Sprayed adhesive on a release sheet

with slopes no greater than 60° or less than 30°. This was accomplished by programming two chart speeds and two full-scale stress values into the recorder, one set for the high modulus materials and the other for the low modulus materials. By applying the tensile conversion factor (F_T) from the following equation, the time units were converted into elongation units.

$$F_T = \frac{(\text{Cross Head Speed}) (100\%)}{(\text{Chart Speed}) (\text{Gauge Length})}$$

where:

F_T = Percent elongation per inch of chart paper.

Plots of the tensile load vs elongation at various temperature curves appear in Figures 5 through 12.

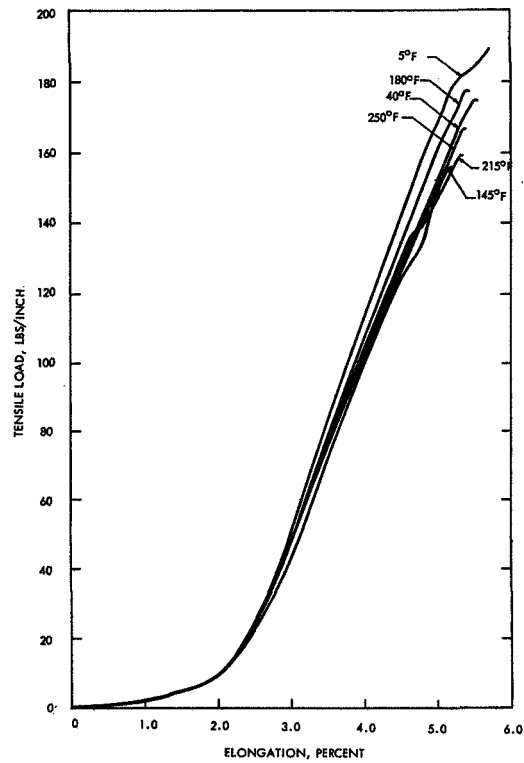


Figure 5. Tensile Load vs Elongation Curves for 81677 Beta Glass Fabric at Various Temperatures - Warp.

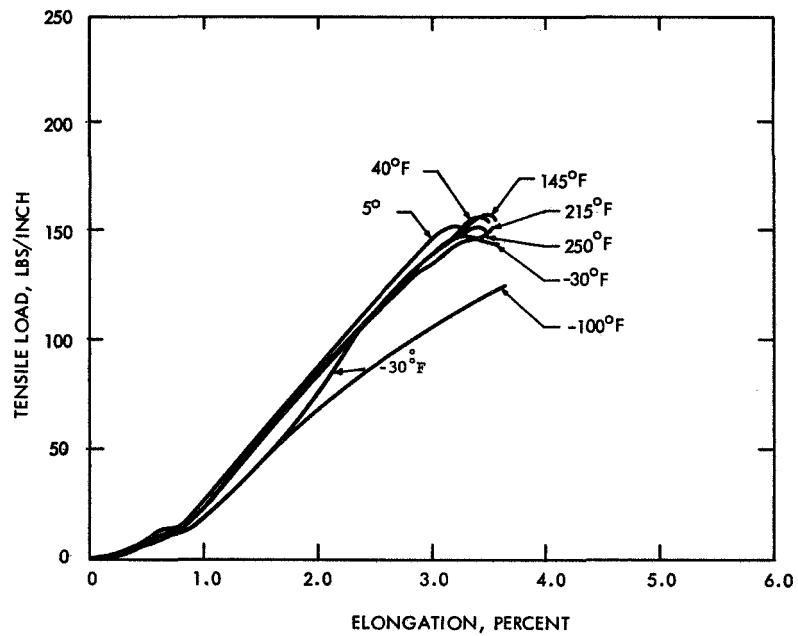


Figure 6. Tensile Load vs Elongation Curves for 81677 Beta Glass Fabric at Various Temperatures - Fill.

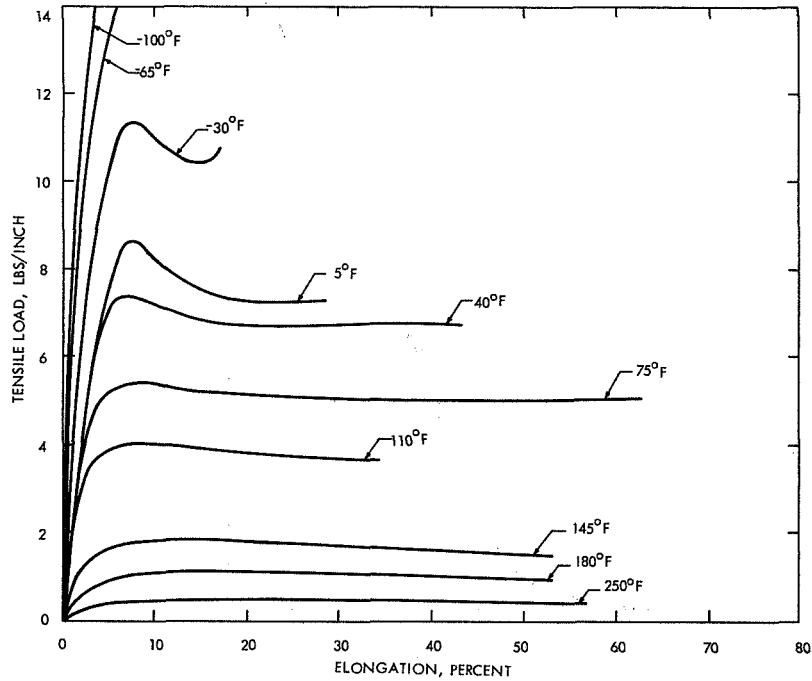


Figure 7. Tensile Load vs Elongation Curves for 1-Mil Aclar 33c at Various Temperatures.

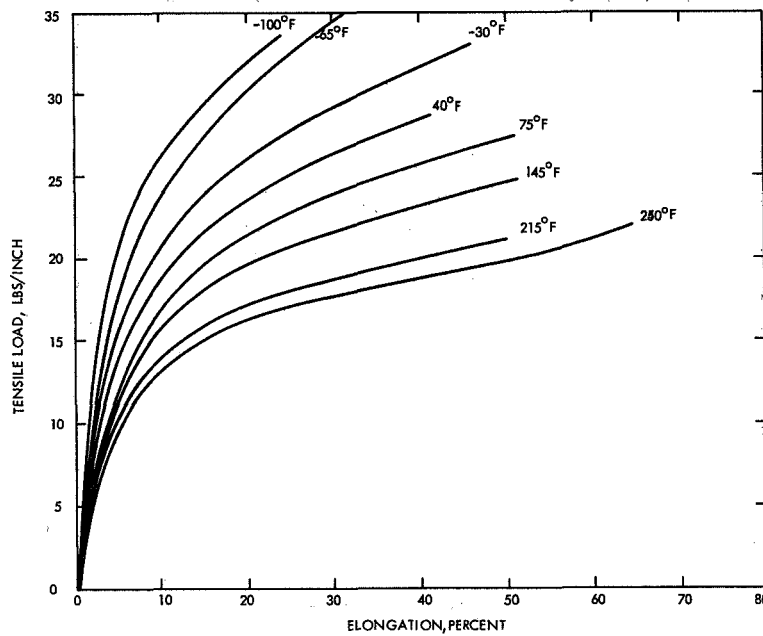


Figure 8. Tensile Load vs Elongation Curves for 1-Mil Kapton at Various Temperatures.

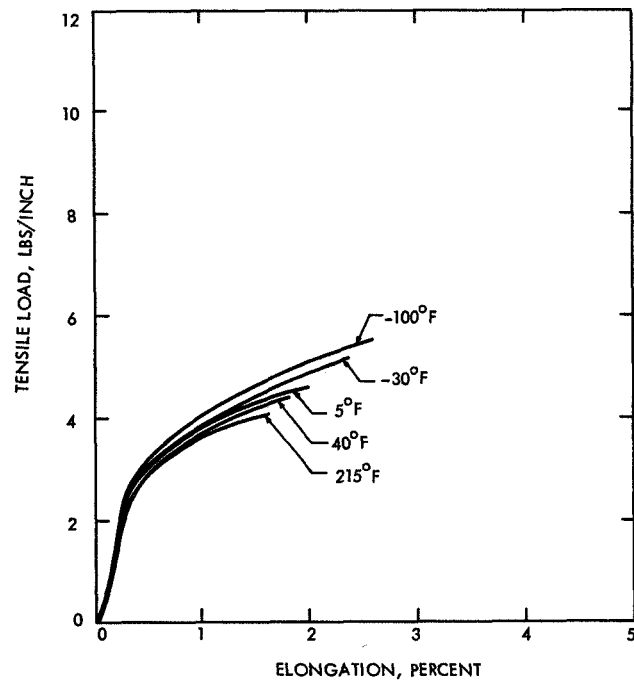


Figure 9. Tensile Load vs Elongation Curves for 1/2-Mil 1100-O Al Foil at Various Temperatures.

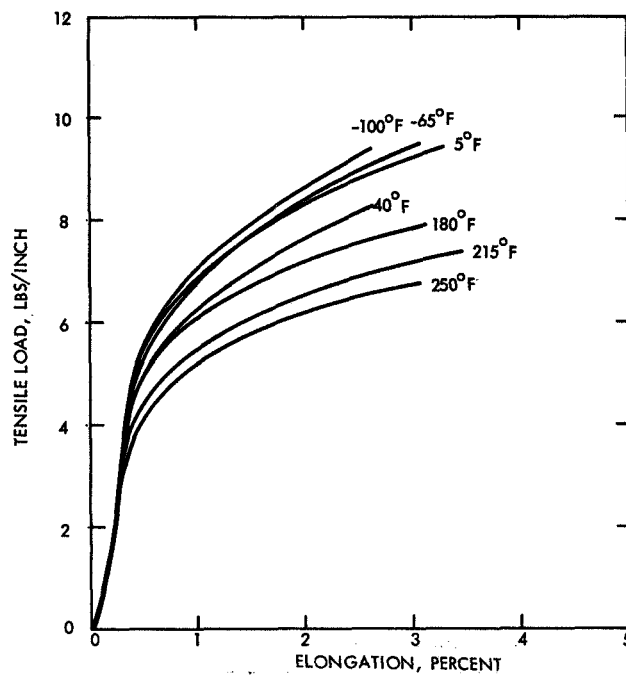


Figure 10. Tensile Load vs Elongation Curves for 1-Mil 1100-O Al Foil at Various Temperatures.

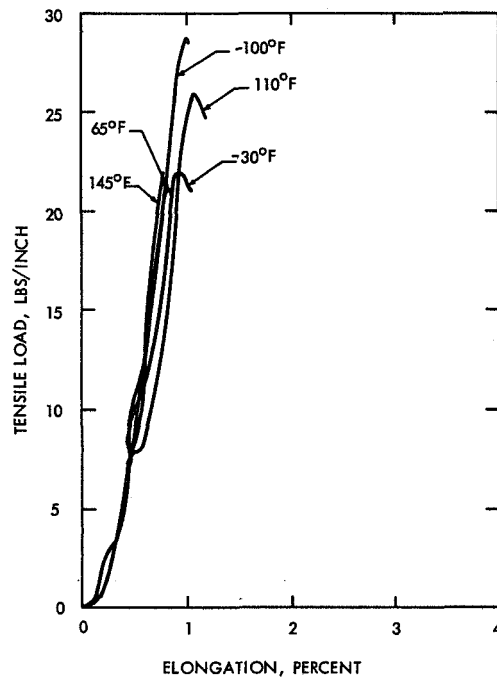


Figure 11. Tensile Stress vs Elongation Curves for C-100-28 Refrasil Cloth at Various Temperatures - Warp.

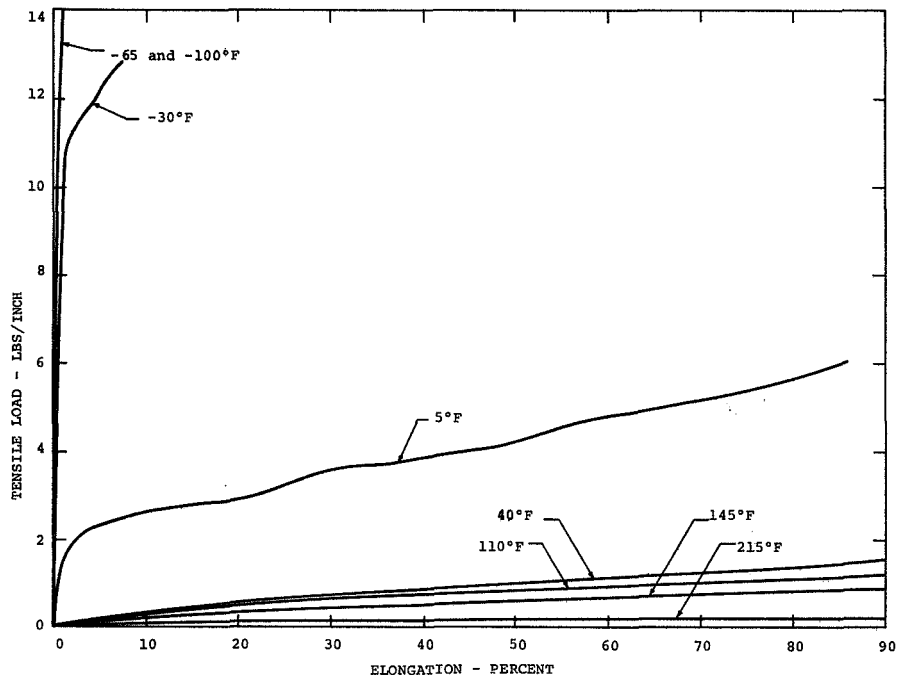


Figure 12. Tensile Loading vs Elongation Curves for 5-Mil Thick Mosites # 1066 Fluorel Adhesive at Various Temperatures.

Compressive tests were conducted on the Mosites #1062-C and Raybestos Manhattan RL-2060 Fluorel sponge using one set of parameters, while the Asbestos Litoflex K20 foam was tested using another set of parameters. The two sponges were candidates for use as a layer in a pressure bladder 50 mils thick and an abrasion layer 100 mils thick to be used in the XTC-6 composite. The Litoflex K20 asbestos foam was a candidate micrometeoroid barrier, two inches thick, to be used in the XMB-4 subcomposite. The testing was conducted over a range of temperatures from -100 to 250° F.

The 2 x 2-inch Fluorel specimens were placed in the compression cage of the Instron machine and compressed twenty-five percent of their initial thickness (4 plies of Mosites #1062-C at approximately 65 mils per ply and 3 plies of Raybestos Manhattan RL 2060 at approximately 94 mils per ply). The Litoflex K20 foam was compressed to 75 percent of its initial thickness.

To obtain an adequate slope ($45^\circ \pm 15^\circ$) to the Instron charts, a drive speed of 2 inches per minute was used for the Fluorel sponges. The area compensator was also used on the Instron during the compression testing. Its purpose was to convert the compressive force into a pressure load having units-pounds per square inch. The K20 asbestos foam utilized a chart speed of 50 inches per minute.

The compressive conversion factor (F_C) was calculated as:

$$F_C = \frac{(\text{Crosshead speed})}{(\text{Chart speed})} \frac{100\%}{(\text{Initial Thickness})}$$

where:

$$F_C = \text{Percent compression per inch of chart paper}$$

This factor then was applied to the Instron charts converting them to Compressive Stress vs Percent Compression.

The compressive stress vs elongation curves are presented in Figures 13 through 15.

Low Temperature Effects Study: To obtain a better knowledge and to clearly illustrate the effect of temperature on strength characteristics of single layer candidate materials, previous stress-strain data obtained at various temperatures (-100° F to 250° F) were analyzed. From these data, plots of tensile load, at a pre-selected strain level, as a function of sample temperature were constructed.

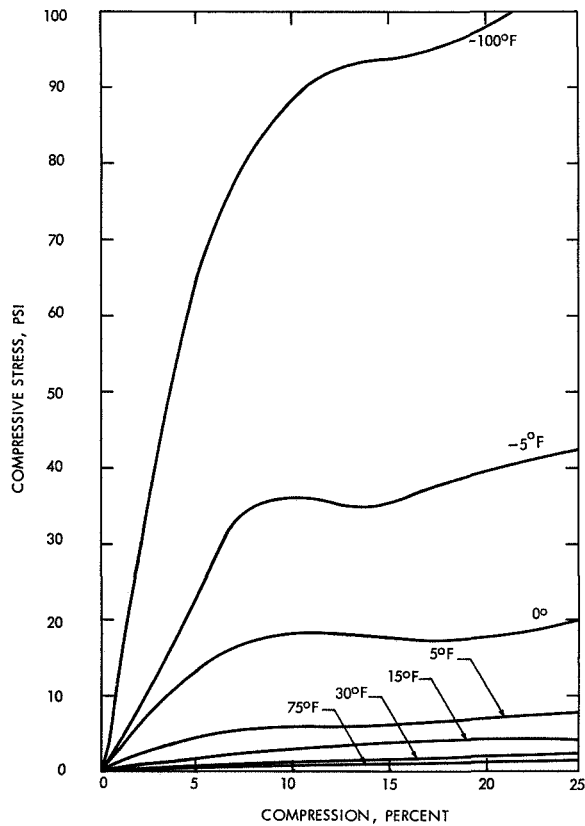


Figure 13. Compressive Stress vs Percent Compression Curves for Mosites #1062-C Fluorel Sponge at Various Temperatures

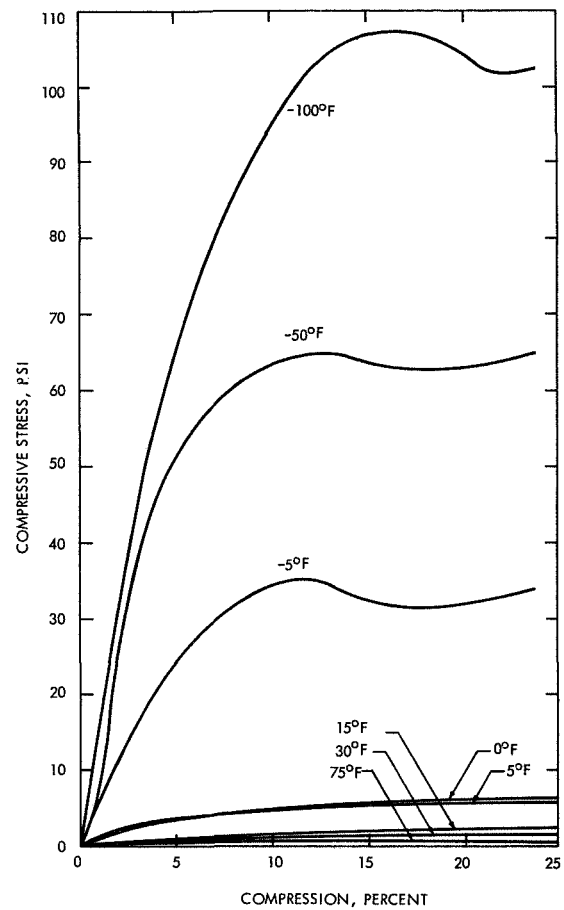


Figure 14. Compressive Stress vs Percent Compression Curves for Raybestos Manhattan No. RL-2060 Sponge at Various Temperatures

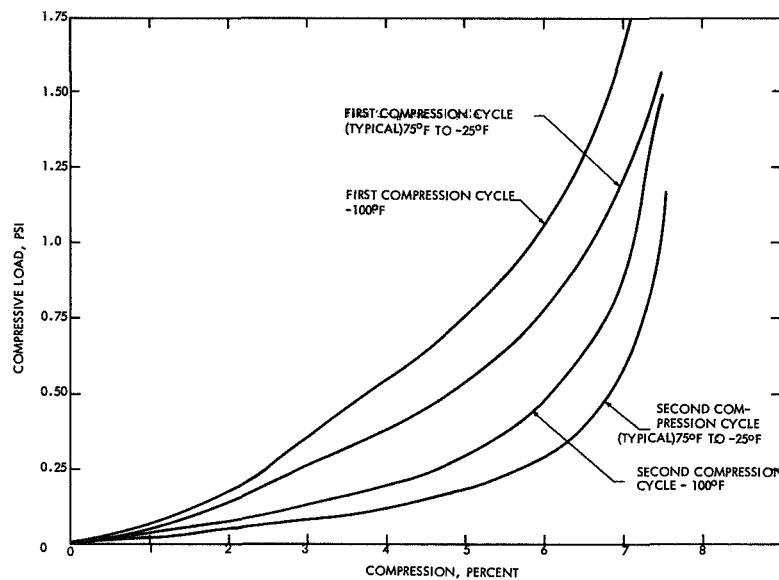


Figure 15. Typical Compressive Load vs Percent Compression for Litoflex K20 Asbestos Foam for Various Temperatures

These curves are presented in Figures 16 through 22. A review of the curves obtained for Aclar 33c, Kapton, and K20 asbestos foam, shows a gradual continuous increase in strength as the temperature of the material is reduced to -100° F. This behavior is often referred to as a simple temperature effect. In the case of the Mosites #1062-C Fluorel sponge, Raybestos Manhattan RL-2060 Fluorel sponge, and the Mosites #1066 Fluorel adhesive, the curves show a gradual characteristic increase to a point where further reduction in temperature brings about a very sharp increase in strength due to a change in modulus of the material. This change results from a sudden (second order) transition which is referred to as the "glass transition" (T_g); since it describes a point below which molecular motion necessary for rubber elasticity ceases and the material begins to taken on properties normally associated with glass. To determine approximate "glass transition" (T_g) temperature of each of the Fluorel materials tested, the slopes of the strength vs temperature curves in the change region were extended to an intercept point as shown in Figure 19. This intercept point is taken as the T_g temperature point.

A summary of the T_g points obtained by the above procedure is presented in Table IV.

TABLE IV. SUMMARY OF MEASURED T_g VALUES

Material	Approximate Glass Transition (T_g), ° F
Mosites #1062-C Fluorel Sponge 12.8 lbs/ft ³	4
Mosites #1062-C Fluorel Sponge 15.1 lbs/ft ³	19
Raybestos Manhattan RL-2060 Fluorel Sponge	0
Mosites #1066 Fluorel Adhesive	12

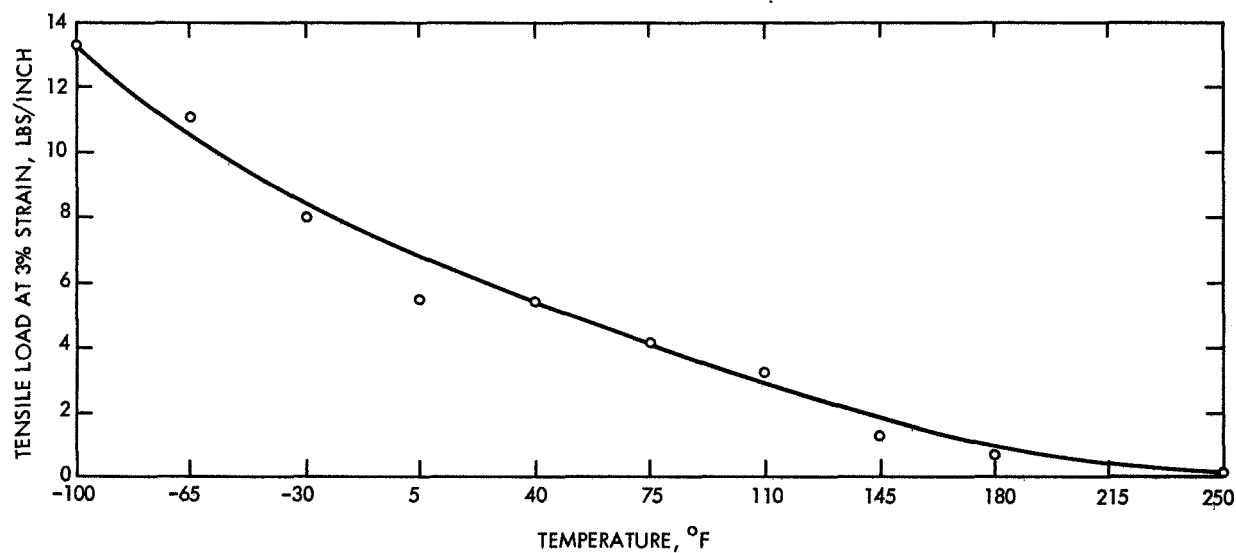


Figure 16. Effect of Temperature on Strength of 1-Mil Aclar 33c Film

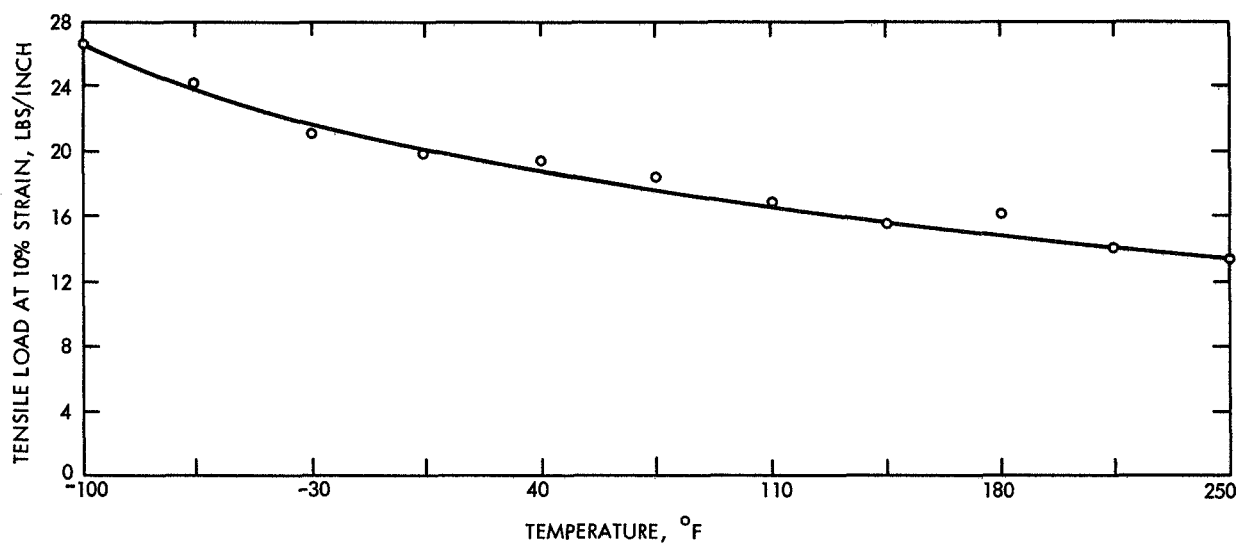


Figure 17. Effect of Temperature on Strength of 1-Mil Kapton Film

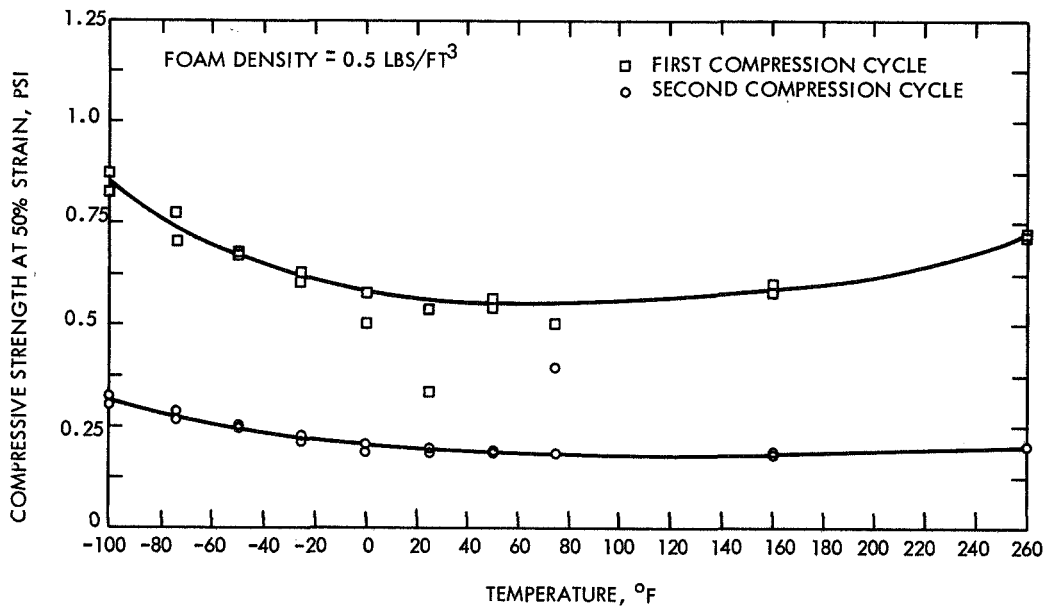


Figure 18. Effect of Temperature on Strength of Litoflex K20 Asbestos Foam

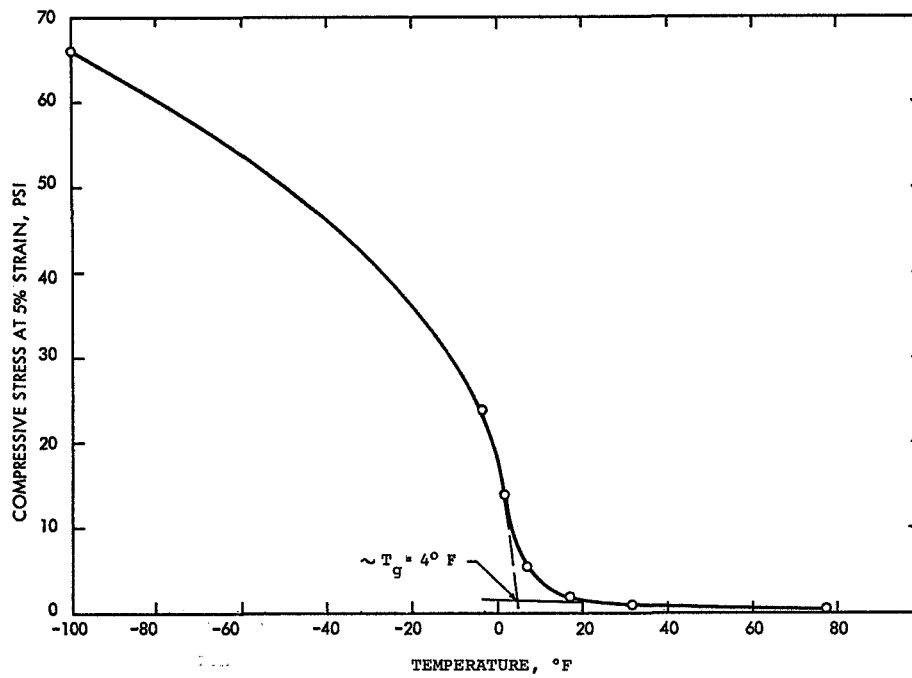


Figure 19. Effect of Temperature on Strength of 12.8 lbs/ft³ Mosites #1062-C Fluorel Sponge

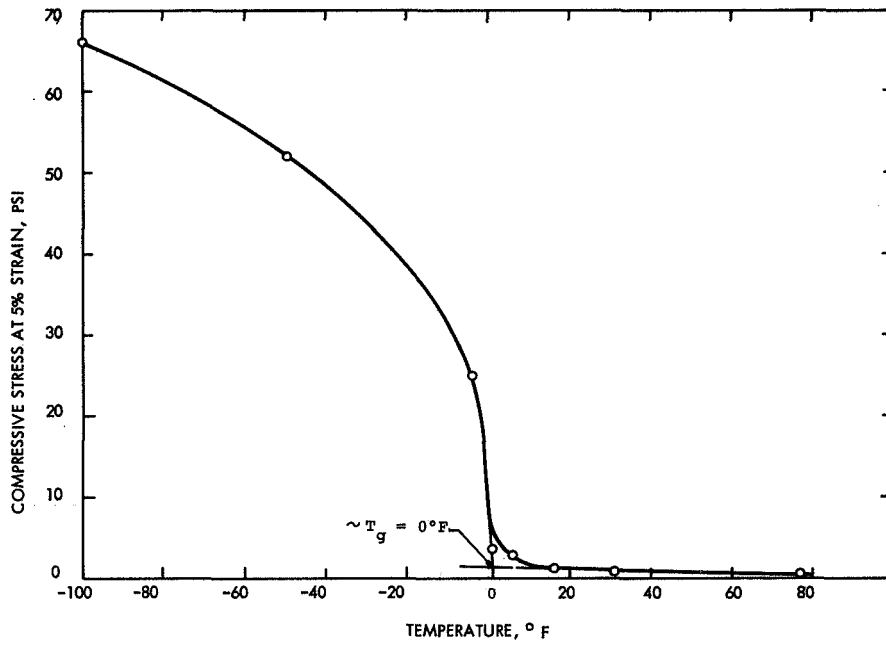


Figure 20. Effect of Temperature on Strength of 15.1 lbs/ft³ Mosites #1062-C Fluorel Sponge

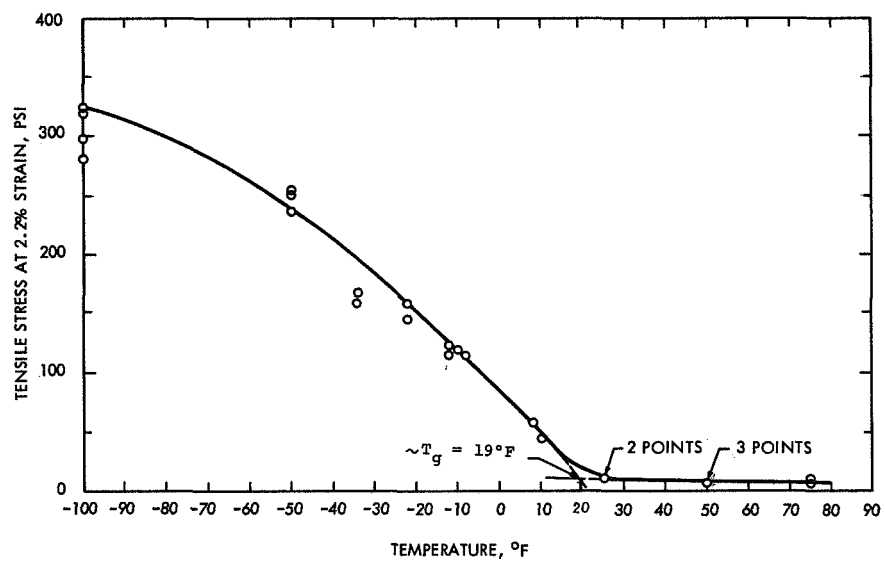


Figure 21. Effect of Temperature on Strength of Raybestos Manhattan RL-2060 Fluorel Sponge

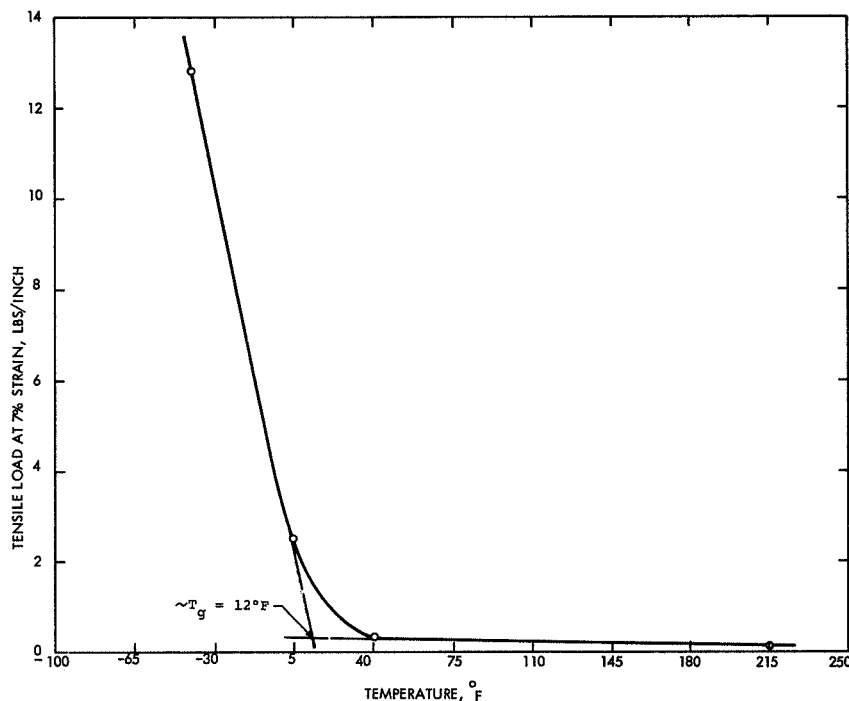


Figure 22. Effect of Temperature on 5-Mil Thick Mosites #1066 Fluorel Adhesive

Examination of Table IV shows that, in general, the T_g of the Fluorel materials occurs at a high temperature level. Therefore, care must be taken in their application to ensure that temperatures below the T_g levels, assigned to each type, will not be imposed at a time when the material must function as an elastomer. It can be shown by examination of the stress-strain curves that plastic properties prevail somewhat below the "glass transition" (T_g). Thus, these materials have direct application where rubber-like properties are not required. It is important, however, to realize that at a much lower temperature the material becomes brittle and will shatter on sudden bending or impact.

Oxygen Permeability: Oxygen permeability of various gas barrier materials was measured at approximately 74°F on Dow gas transmission cells in accordance with ASTM D-1434-66 procedures. The thickness of each material was taken as the average of 10 measurements made over the surface of the disc.

The Dow cell arrangement measures permeability on the basis of volume-pressure increase. One side of the sample under test is exposed to a vacuum of approximately 10^{-3} mm Hg, and the other side is exposed to the test gas. For normal operation a pressure of 1 atmosphere across the test specimen is used.

Prior to the admission of the test gas, both sides of the specimen are evacuated. After the cell manometer system has been evacuated, mercury is

dumped from the reservoir into the manometer legs. The test gas is then admitted into the high-pressure side of the system. With this partial pressure difference existing across the specimen, there is a transmission of gas. Along with the transmission, there exists a pressure rise in the lower pressure chamber, which can be measured by the drop of mercury in the capillary tube. This pressure change is recorded as a function of time. By use of the formula that is provided with each instrument, permeability may then be calculated.

Table V records the results obtained on aluminized and non-aluminized Kapton, Dupont XRP, Aclar 33c, and Teflon FEP films, and Mosites #1072 Fluorel Elastomer.

Aluminized Kapton was found to have the lowest permeability of all the material tested. The extremely low values obtained are attributed to the presence of the several hundred Angstroms thick aluminum layer, which added little to the weight of the material but greatly reduced permeability. Aclar 33c and Dupont XRP films measurements indicated both to be high impermeable. Teflon FEP film and Fluorel elastomer recorded high values; the highest being Teflon FEP film.

TABLE V: OXYGEN PERMEABILITY MEASUREMENTS OBTAINED
ON CANDIDATE GAS BARRIER MATERIALS

Material	Thickness Mils	O ₂ Transmission Rate* cc/m ² -24 hr - atm	O ₂ Permeability* cc-mil/m ² -24 hr-atm (Avg)
Kapton Film (Aluminized)	1.0	3.6 3.8 2.2 <u>3.2</u> Average	3.2
Kapton Film	0.5	251.0 251.0 288.0 <u>263.3</u> Average	131.5
DuPont XRP Film	2.5	12.0 14.5 12.0 <u>12.83</u> Average	32.1
Aclar 33c Film	1.0	66.0 28.0 16.0 <u>36.7</u> Average	36.7
Teflon FEP Film	1.0	5,878 4,941 5,104 <u>5,307</u> Average	5,307
Fluorel Elastomer Sheet Mosites #1072	20	69.4 66.7 <u>67.9</u> Average	1,358

* At a temperature of 74° F

Development of a Flame/Gas Barrier Subcomposite. -

Concepts Evaluated: After considerable investigation during the materials screening phase, it became increasingly apparent that presently available thin layer adhesives, plastic films, elastomeric sheets, and sponge materials would not pass the NASA Category A flammability requirements. In an attempt to utilize available low burning rate materials and still provide a satisfactory, safe, and packageable lunar shelter, a suggestion was made to NASA that a flame resistant outer layer system be employed with available burnable gas barrier materials to provide protection for flammable elements. This suggestion was accepted and work was initiated on development of a flame/gas barrier subcomposite.

During the course of the work, 22 candidate flame/gas barrier subcomposite (designated XPB-1 through 22) were fabricated and tested. A complete description of each candidate is presented in Table VI and Figure 23, Sheets 1 and 2.

Subcomposite flame/gas barrier systems were evaluated on the basis of:

- (1) Upward flame propagation in 100% oxygen at 6.2 psia test results.
- (2) Special diaphragm flammability in 100% oxygen at 6.2 psia test results.

Details of these tests are covered in the following paragraphs.

Upward Propagation Flammability Tests: The upward propagation flammability testing was conducted in a manner similar to that described previously for the single layer materials. With the exception of a few initial tests, the standard $2\frac{1}{2}$ -inch x 5-inch test specimen was used. The subcomposites were clamped in a vertical holder, exposing a 2-inch width, and placed in the test chamber. The chamber was evacuated to 1000 microns Hg and back-filled with gaseous oxygen to 6.2 psia. The chamber exceeded the minimum volume to sample weight of 12 liters per gram specified by NASA in MSC-D-NA-0002. A 1 x 2-inch piece of tissue paper was initially used as the ignitor. This ignitor was later replaced by the standard NASA 0.22-inch diameter x 1.25-inches long silicone rubber ignitor. A comparison of the extent of the damage caused by the two ignitor types on a typical candidate flame/gas barrier subcomposite, XPB-4 is shown in Figure 24.

Photographs of a typical test sequence performed on the XPB-14 subcomposite is shown in Figure 25.

A summary of the test results obtained on all candidates is provided in Table VII. Photographs of various specimens after test are shown in Figure 26. Examination of the results indicates that with the exception of XPB-2, XPB-3,

TABLE VI. SUMMARY OF CANDIDATE FLAME/GAS BARRIER SUBCOMPOSITES INVESTIGATED

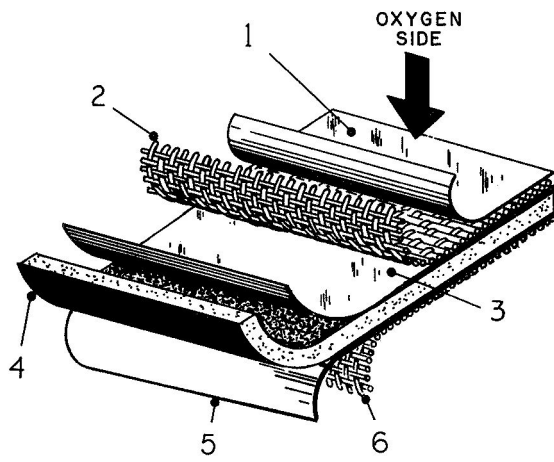
DESIGNATION	GENERAL CONSTRUCTION	DESCRIPTION OF LAYERS								Adhesive	Calculated Weight lbs/ft ²
		1	2	3	4	5	6	7	8		
XPB-1	FIGURE 23, VIEW A	0.0003" 1100-0 Aluminum Foil	116 Fiberglass Cloth, Volan A Finish	0.001" Aclar 33c Film	0.050" Raybestos Manhatten RL-2060 Fluorel Sponge (a)	0.001 Aclar 33c Film	116 Fiberglass Cloth, Volan A Finish	—	—	0.001" Mosites No. 1066 Fluorel Adhesive	0.167
XPB-2		0.0003" 1100-0 Aluminum Foil	116 Fiberglass Cloth, Volan A Finish	0.001" Aclar 33c Film	0.050" Mosites No. 1062-C Fluorel Sponge (b)	0.001 Aclar 33c Film	116 Fiberglass Cloth, Volan A Finish	—	—	0.001" Dow Corning Silicone Adhesive Type 281 Catalyzed	0.153
XPB-3		0.0003" 1100-0 Aluminum Foil	116 Fiberglass Cloth, Volan A Finish	0.001" Aclar 33c Film	0.050" Mosites No. 1062-C Fluorel Sponge (b)	0.001 Aclar 33c Film	116 Fiberglass Cloth, Volan A Finish	—	—	0.001" Mosites No. 1066 Fluorel Adhesive	0.174
XPB-4	FIGURE 23, VIEW B	0.001" 1100-0 Aluminum Foil	116 Fiberglass Cloth, Volan A Finish	0.001" Aclar 33c Film	0.050" Mosites No. 1062-C Fluorel Sponge (b)	0.001 Aclar 33c Film	116 Fiberglass Cloth, Volan A Finish	0.001" 1100-0 Aluminum Foil	—	0.001" Mosites No. 1066 Fluorel Adhesive	0.207
XPB-5		0.0003 1100-0 Aluminum Foil	A4787 Stern & Stern Nylon Fabric 8.2 oz/yd ²	0.001" (Bi-Laminate) Capran 77c Nylon Film	063" Rubatex R-481-T EPT ₂ Foam 0.085 lb/ft ³	0.001" Capran 77c Nylon Film	A4787 Stern & Stern Nylon Fabric 8.2 oz/yd ²	0.001" 1100 0 Aluminum Foil	—	0.001" Good-year AD917 Polyester Adhesive	0.198
XPB-6		0.001" 1100-0 Aluminum Foil	116 Fiberglass Cloth, Volan A Finish	0.001" Aclar 33c Film	0.050" Mosites No. 1062-C Fluorel Sponge	0.001 Aclar 33c Film	116 Fiberglass Cloth, Volan A Finish	0.001" 1100-0 Aluminum Foil	—	0.001" Dupont 238-86-1 Viton Adhesive	0.207
XPB-7	FIGURE 23, VIEW C	0.001" 1100-0 Aluminum Foil	81677 Beta Glass Cloth	0.001" Aclar 33c Film	0.050" Mosites No. 1062-C Fluorel Sponge	0.001 Aclar 33c Film	81677 Beta Glass Cloth	0.001" 1100-0 Aluminum Foil	Rene' 41 Cloth 0.0016" 1 Strand 200x200 (c)	0.001" Mosites No. 1066 Fluorel Adhesive	0.252
XPB-8		0.0005" 1100-0 Aluminum Foil	81677 Beta Glass Cloth	0.001" Aclar 33c Film	0.050" Mosites No. 1062-C Fluorel Sponge	0.001 Aclar 33c Film	81677 Beta Glass Cloth	0.0005" 1100-0 Aluminum Foil	Rene' 41 Cloth 0.0016" 1 Strand 200x200 (c)	0.001" Mosites No. 1066 Fluorel Adhesive	0.238
XPB-9	FIGURE 23, VIEW D	0.001" 1100-0 Aluminum Foil	81677 Beta Glass Cloth	0.001" Aclar 33c Film	0.050" Mosites No. 1062-C Fluorel Sponge	0.001 Aclar 33c Film	81677 Beta Glass Cloth	0.001" 1100-0 Aluminum Foil	—	0.001" Raybestos Manhattan RL-3788 Adhesive	0.207
XPB-10		0.001" 1100-0 Aluminum Foil	81677 Beta Glass Cloth	0.001" Aclar 33c Film	0.050" Mosites No. 1062-C Fluorel Sponge	0.001 Aclar 33c Film	81677 Beta Glass Cloth	0.001" 1100-0 Aluminum Foil	—	0.001" Mosites No. 1066 Fluorel Adhesive	0.207
XPB-11	FIGURE 23, VIEW D	0.0005" 1100-0 Aluminum Foil	1700 Uniroyal Asbestos Cloth 13 oz/yd .0248" thick	0.001" 1100-0 Aluminum Foil	0.001 Aclar 33c Film	0.050" Mosites No. 1062-C Fluorel Sponge	81677 Beta Glass Cloth	0.001" Aclar 33c Film	0.001" 1100-0 Aluminum Foil	0.001" Mosites No. 1066 Fluorel Adhesive	0.292
XPB-12		0.0005" 1100-0 Aluminum Foil	C-100-28 Hitco Refrasil Cloth 0.014" thick 10.5 oz/yd ²	0.001" 1100-0 Aluminum Foil	0.001 Aclar 33c Film	0.050" Mosites No. 1062-C Fluorel Sponge	81677 Beta Glass Cloth	0.001" Aclar 33c Film	0.001" 1100-0 Aluminum Foil	0.001" Mosites No. 1066 Fluorel Adhesive	0.275

TABLE VI. SUMMARY OF CANDIDATE FLAME/GAS BARRIER SUBCOMPOSITES INVESTIGATED (CONT)

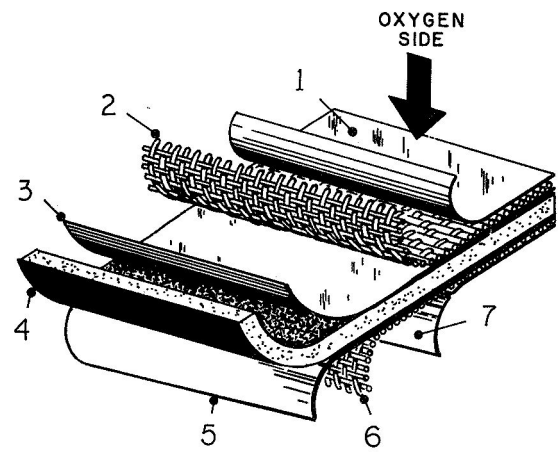
DESIGNATION	GENERAL CONSTRUCTION	DESCRIPTION OF LAYERS								Adhesive	Calculated Weight, lbs/ft ²
		1	2	3	4	5	6	7	8		
XPB-13	FIGURE 23, VIEW D	0.0005" 1100-0 Aluminum Foil	7 oz/yd ² Novatex Asbestos Cloth	0.001" 1100-0 Aluminum Foil	0.001" Aclar 33c Film	0.050" Mosites No. 1062-C Fluorel Sponge	81677 Beta Glass Cloth	0.001" Aclar 33c Film	0.001" 1100-0 Aluminum Foil	0.001" Mosites No. 1066 Fluorel Adhesive	0.251
XPB-14		0.0005" 1100-0 Aluminum Foil	C-100-28 Hitco Refrasil Cloth	0.001" 1100-0 Aluminum Foil	0.001" Kapton Film	0.050" Mosites No. 1062-C Fluorel Sponge	81677 Beta Glass Cloth	0.001" Aclar 33c Film	0.001" 1100-0 Aluminum Foil	0.001" Mosites No. 1066 Fluorel Adhesive	0.271
XPB-14A	FIGURE 23, VIEW E	0.0005" 1100-0 Aluminum Foil	C-100-28 Hitco Refrasil Cloth	0.001" 1100-0 Aluminum Foil	0.001" Kapton Film	0.050" Mosites No. 1062-C Fluorel Sponge	81677 Beta Glass Cloth	0.001" Aclar 33c Film	0.001" 1100-0 Aluminum Foil	0.001" Mosites No. 1066 Fluorel Adhesive	0.271
XPB-15	FIGURE 23, VIEW D	0.0005" 1100-0 Aluminum Foil	C-100-28 Hitco Refrasil Cloth	0.001" 1100-0 Aluminum Foil	0.001" Kapton Film	0.050" Mosites No. 1062-C Fluorel Sponge	81677 Beta Glass Cloth	0.001" Aclar 33c Film	0.001" 1100-0 Aluminum Foil	0.001" Raybestos Manhattan RL-3788 Adhesive	0.271
XPB-16	FIGURE 23, VIEW F	0.0005" 1100-0 Aluminum Foil	C-100-28 Hitco Refrasil Cloth	0.001" 1100-0 Aluminum Foil	0.010" Raybestos Manhattan L-3203-6 Sheet	0.001" 1100-0 Aluminum Foil	—	—	—	0.001" Raybestos Manhattan RL-3788 Adhesive	0.328
XPB-17	FIGURE 23, VIEW G	6.18 oz/yd ² 4484 Beta Glass Cloth Woven From Teflon Coated Yarn	0.017" Mosites No. 1076 Fluorel Sheet	—	—	—	—	—	—	None	0.206
XPB-18	FIGURE 23, VIEW H	6.18 oz/yd ² 4484 Beta Glass Cloth Woven From Teflon Coated Yarn	0.136" Mosites No. 1062 Fluorel Sponge	0.017" Mosites No. 1076 Fluorel Sheet	—	—	—	—	—	None	0.350
XPB-19	FIGURE 23, VIEW G	6.18 oz/yd ² 4484 Beta Glass Cloth Woven From Teflon Coated Yarn	0.12" Raybestos Manhattan L-3217-1 Fluorel Sheet	—	—	—	—	—	—	None	0.157
XPB-20		6.18 oz/yd ² 4484 Beta Glass Cloth Woven From Teflon Coated Yarn	0.010" Raybestos Manhattan L-3203-6 Fluorel Sheet	—	—	—	—	—	—	None	0.139
XPB-21	FIGURE 23, VIEW H	6.18 oz/yd ² 4484 Beta Glass Cloth Woven From Teflon Coated Yarn	0.155" Mosites No. 1062 Fluorel Sponge	0.010" Raybestos Manhattan L-3203-6 Fluorel Sponge	—	—	—	—	—	None	0.303
XPB-22	FIGURE 23, VIEW I	Fiberglass (Beta) Cloth 6.4 oz/yd ²	0.001" Aluminum Foil	Asbestos Cloth 12.4 oz/yd ²	Asbestos Cloth 12.4 oz/yd ²	0.001" Aluminum Foil	Fiberglass (Beta) Cloth 6.4 oz/yd ²	0.017" Mosites No. 1076 Fluorel Sheet	—	None	0.451

(a) Raybestos-Manhattan Sponge No. RL 2060 Density = 11 lbs/ft³(b) Mosites Sponge #1062-C Density = 13 lbs/ft³

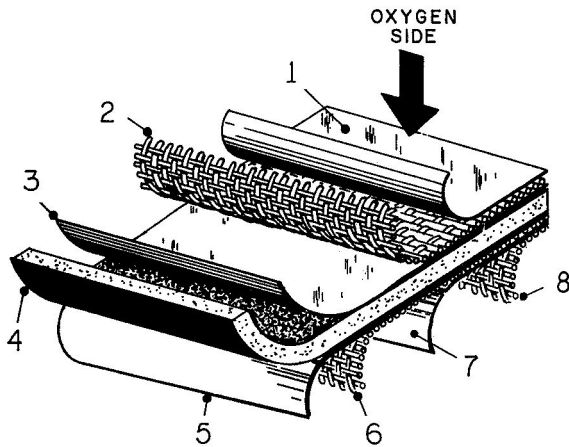
(c) Wire Mesh Added only for the purpose of simulating structural layer during diaphragm flammability testing.



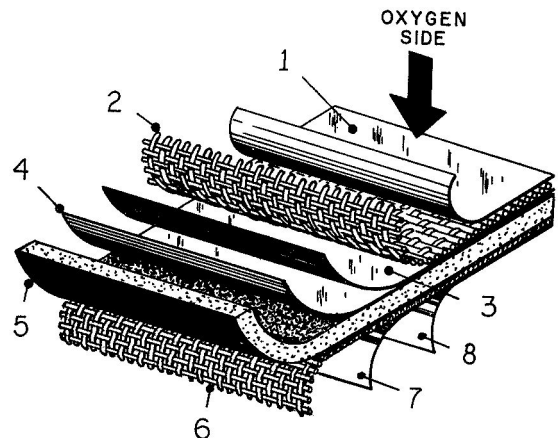
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(VIEW A)



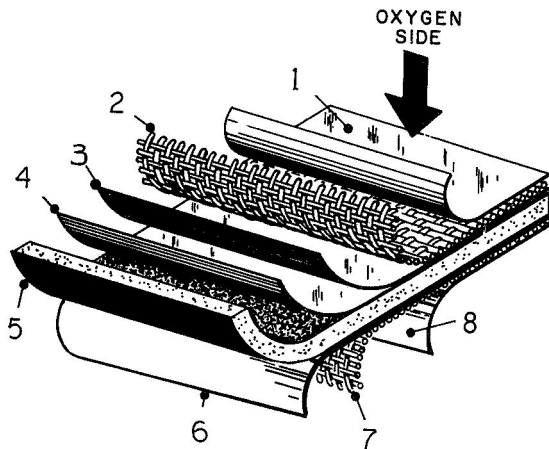
XPB-4-5-6-9-10
(VIEW B)



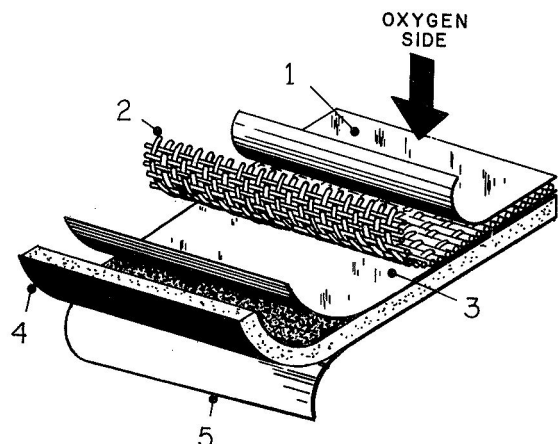
XPB-7-8
(VIEW C)



XPB-11-12-13-14-15
(VIEW D)

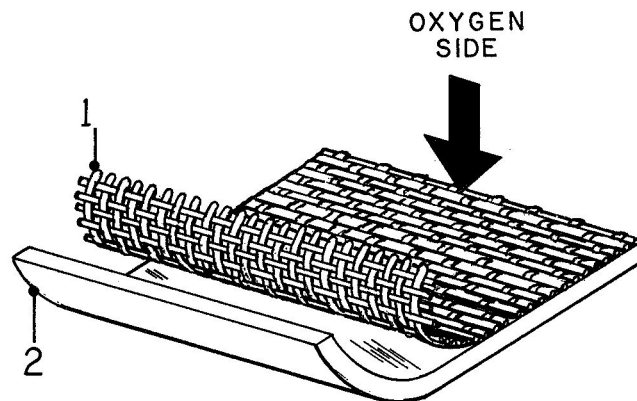


XPB-14A
(VIEW E)

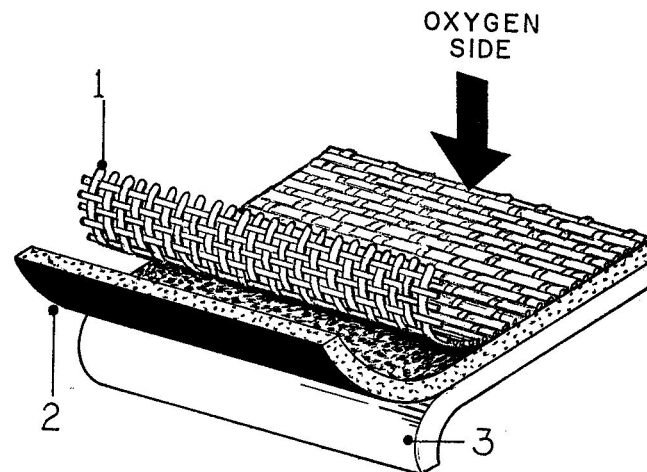


XPB-16
(VIEW F)

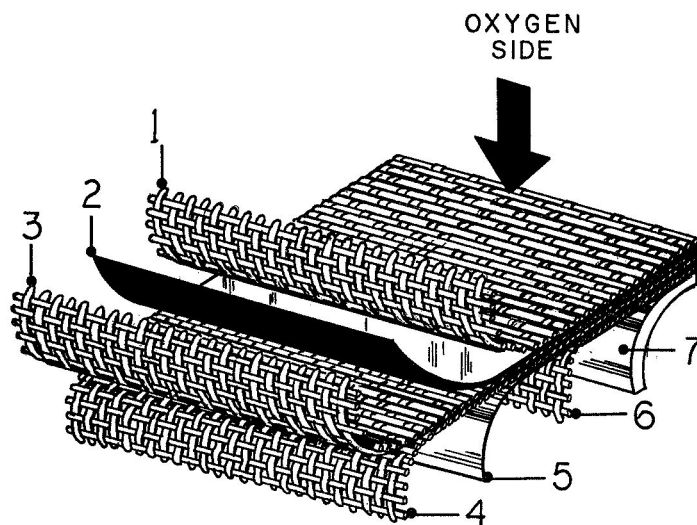
Figure 23. Candidate Flame/Gas Barrier Subcomposites Investigated (Sheet 1)



XPB-17-19-20
(VIEW G)

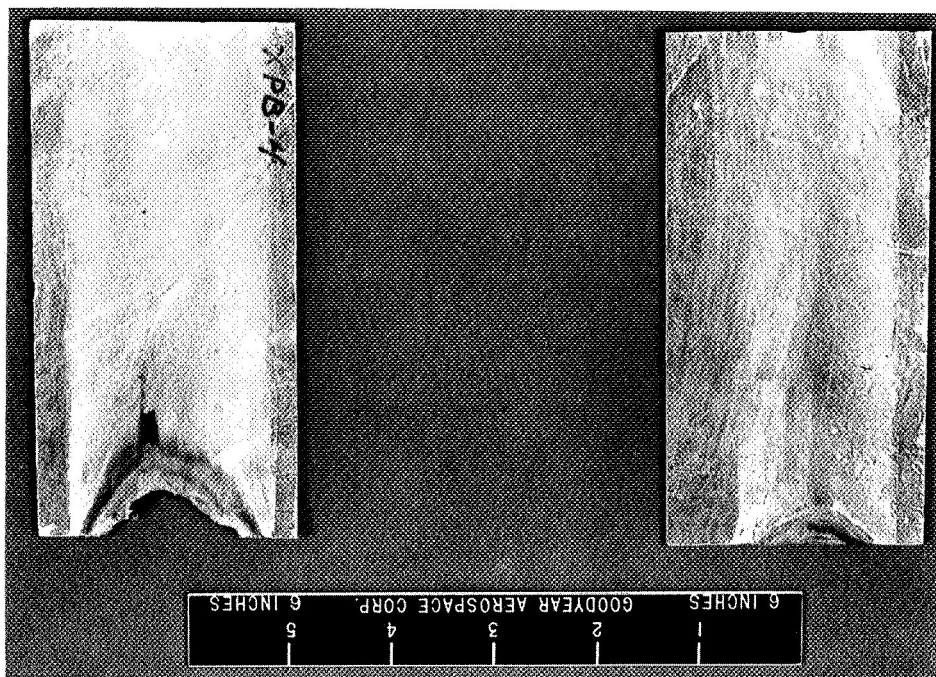


XPB-18-21
(VIEW H)



XPB-22
(VIEW I)

Figure 23. Candidate Flame/Gas Barrier Subcomposites Investigated (Sheet 2)



XPB-4
Tissue Paper Igniter

XPB-4
Silicone Igniter

Figure 24. Comparison of Damage Produced by Tissue Paper and Silicone Igniters

XPB-5 and XPB-6, all subcomposites met the acceptance requirements of Category A since all were found to be highly self-extinguishing. It was found that with the addition of a single layer of foil, XPB-2 and XPB-3 would also pass the self-extinguishing requirement.

Early tests on subcomposites showed the importance of the method in which the sample was held during testing. Specimens which were held in a vertical position by clamping the top edge were found to delaminate and burn, however, edge clamping prevented delamination and greatly increased resistance to burning.

As experimental studies continued, it was soon realized that by applying the protective outer layer concept to materials having low burn rate characteristics, a pressure bladder subcomposite could be developed that would pass the upward flame propagation rate requirements.

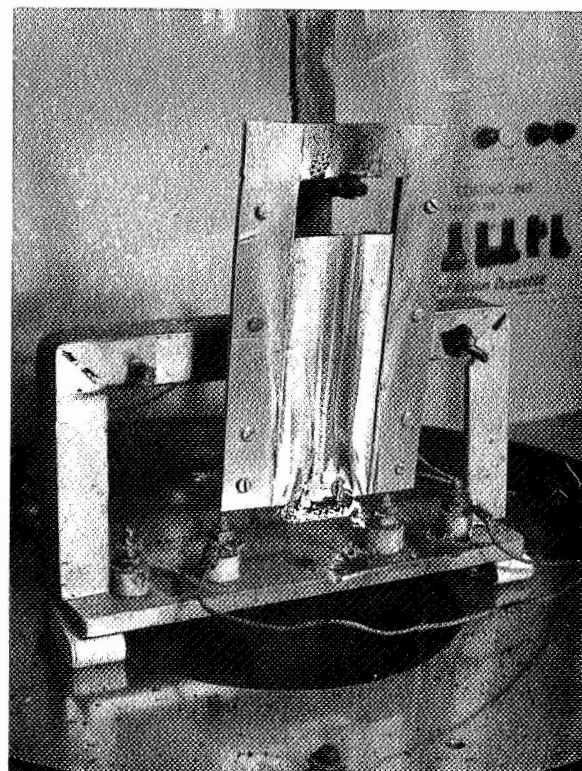
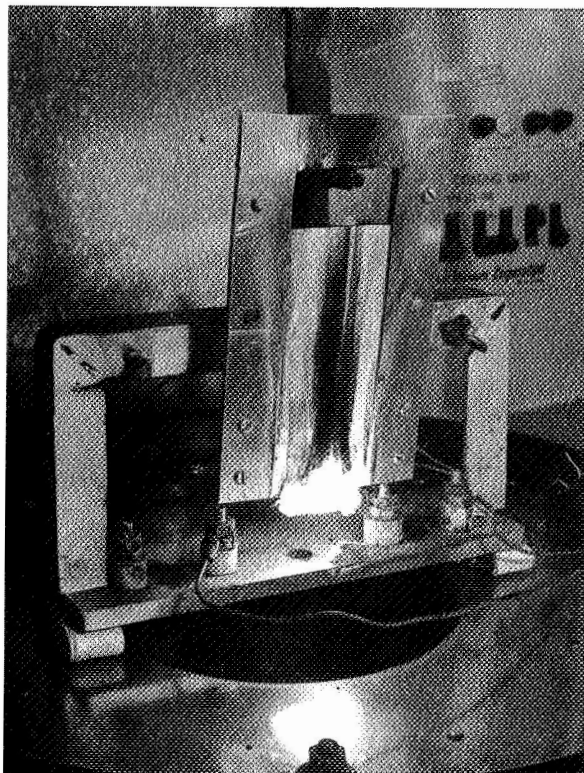
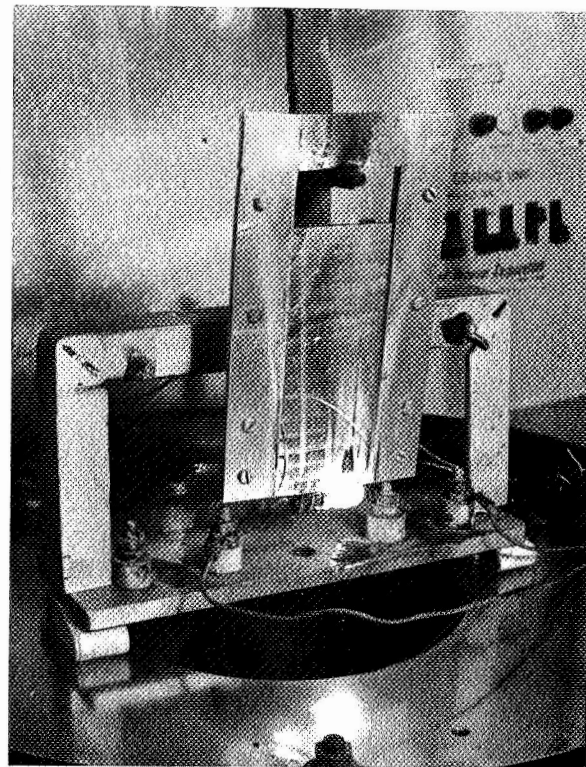
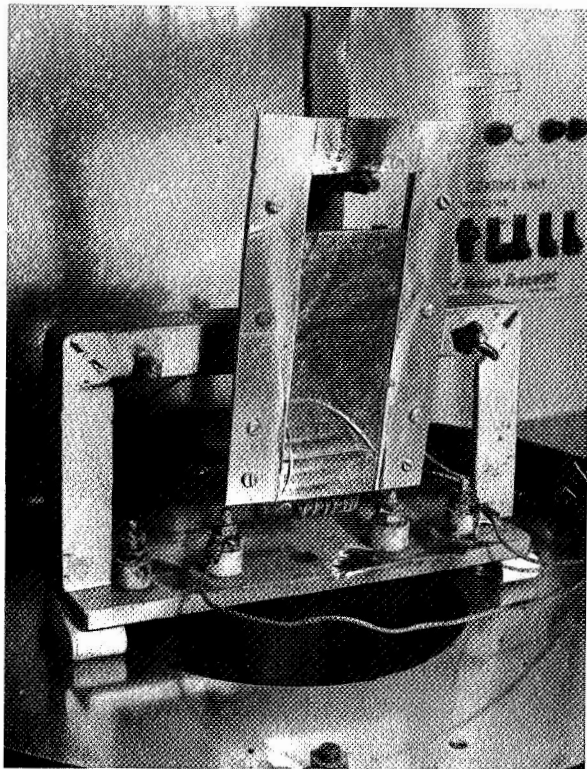


Figure 25. GAC Upward Propagation Flammability Test in 100 Percent Oxygen at 6.2 psia.

TABLE VII. RESULTS OF GAC UPWARD PROPAGATION FLAMMABILITY TESTS IN 6.2 PSIG
100% OXYGEN ON CANDIDATE FLAME/GAS BARRIER SUBCOMPOSITES

Material	Approx. Thickness In.	Test Variables			Results	
		Sample Size, In.	Ignitor Type*	Sample Mounting**	Observations	Max. Height of Thermal Damage Inch ****
XPB-2	0.075	3/4x3-1/2	TP	TC	Fast Burn	
XPB-2 on 1-mil Al Foil	0.076	2-1/2x5	TP	EC	***	0.3
XPB-3	0.050	3/4x3-1/2	TP	TC	Slow burn	
XPB-3	0.050	2-1/2x5	TP	EC	Fast burn	
XPB-3 on 1-mil Al Foil	0.051	3/4x3-1/2	TP	TC	Slow burn	
XPB-3 on 1-mil Al Foil	0.051	3/4x3-1/2	TP	EC	***	0.1
XPB-3 on 1-mil Al Foil	0.051	2-1/2x5	TP	EC	***	0.1
XPB-3 on 20-mil Al Sheet	0.070	3/4x3-1/2	TP	EC	***	0.1
XPB-4 (Run 1)	0.075	2-1/2x5	TP	EC	***	0.2
XPB-4 (Run 2)	0.060	2-1/2x5	SE	EC	***	0.5
XPB-5	0.065		TP		Fast burn	
XPB-6	0.065		TP		Burned inner core	
XPB-7	0.075		SE		***	0.8
XPB-8 (Run 1)	0.065				***	1.7
XPB-8 (Run 2)	0.065				***	1.7
XPB-8 (Run 3)	0.065				***	1.7
XPB-8 (Run 4)	0.065				***	1.7
XPB-9	0.050				***	0.6
XPB-10 (Run 1)	0.065				***	0.7
XPB-10 (Run 2)	0.065				***	0.7
XPB-10 (Run 3)	0.075				***	0.6
XPB-10 (Run 4)	0.075				***	0.6
XPB-10 (Run 5)	0.065				***	0.7
XPB-10 (Run 6)	0.070				***	0.6
XPB-11	0.090				***	0.5
XPB-12 (Run 1)	0.080				***	0.5
XPB-12 (Run 2)	0.075				***	0.4
XPB-13	0.080				***	0.5
XPB-14 (Run 1)	0.075				***	0.8
XPB-14 (Run 2)	0.075				***	0.8
XPB-14 (Run 3)	0.075				***	0.8
XPB-14 (Run 4)	0.075	2-1/2x5	SE	EC	***	0.8

*TP indicates 1 x 2 inch tissue paper ignitor

SE indicates 0.22 in. dia. x 1.25 in. silicone elastomer ignitor

** TC indicates sample was mounted by clamping top edge

EC indicates sample was mounted by clamping two side edges

*** Ignited but self-extinguished after burning 0.5 inches or less
after extinguishment of ignitor

**** Values indicated include thermal damage caused by ignitor burn
along with any self-sustained combustion after ignitor extinguishment

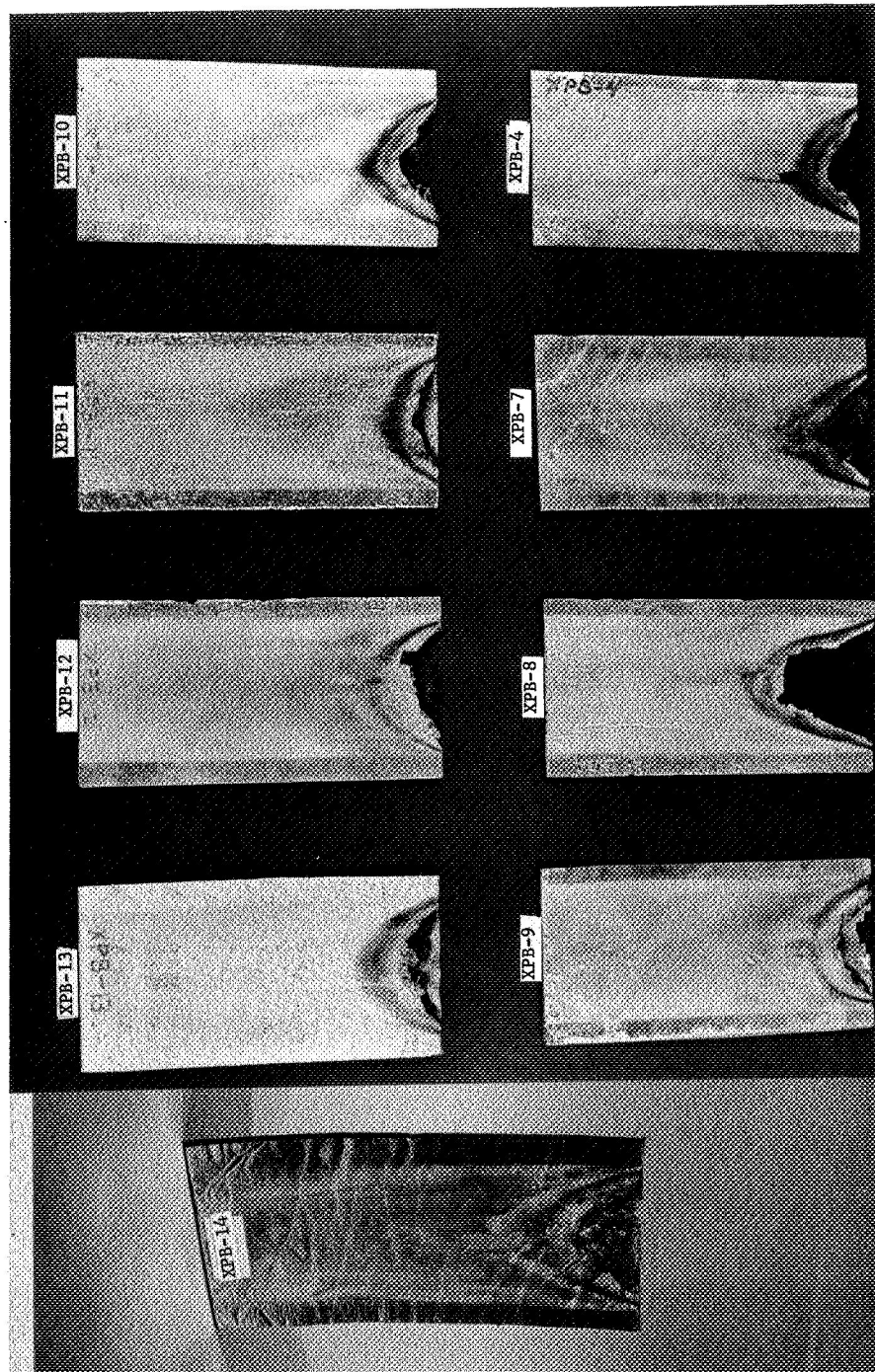


Figure 26. Various XPB Subcomposites After GAC Upward Propagation Flammability Testing

While passage of this requirement is mandatory, it provided little insight into what might happen should a sizable fire develop next to the surface of the flame/gas barrier. The need for more information in this area prompted the development of this special diaphragm flammability test; details of which are described in the section of this report entitled "Pressurized Diaphragm Flammability Test". Much of design-evaluation and redesign-reevaluation efforts leading to a highly successful flame/gas barrier system was based on a combination of upward flammability and diaphragm flammability testing.

Pressurized Diaphragm Flammability Tests: During the development and screening of candidate flame/gas barrier subcomposites the need for an oxygen flammability test to simulate the flammability hazard conditions expected in actual usage was realized. In an attempt to meet this need, GAC developed a special test method which proved to be highly successful as an adjunct to the upward propagation flammability test effort.

To perform this test, a 6.5-inch diameter specimen of a candidate flame/gas barrier material, backed up with a structural layer, is clamped in the double bell jar apparatus (Figure 27). A standard NASA silicone rubber igniter is then installed, in the center of the specimen, 1/16-inch from the surface of the material.

Thermocouples are installed to monitor flame temperature and temperature of the backside of the structural layer and pressure in both chambers is then lowered to 1000 microns Hg pressure. The two chambers are then isolated from each other and the chamber containing the igniter is backfilled with gaseous oxygen to a pressure of 6.2 psia.

Actual testing of the specimen is initiated by passing sufficient current through the Nichrome wire igniter holder, to ignite the silicone rubber insert, and record flame and structural layer temperatures. Failure of the gas barrier is indicated by a fast increase in pressure in the vacuum-side chamber.

Following the test, specimens are removed and carefully inspected to determine the extent of the flame damage. The temperature/time profiles obtained during the test are inspected to ensure that satisfactory igniter temperature was reached during the test and to document the maximum temperature seen by the structural layer during the test.

Normally photographs of the samples under test were not taken. A small window in the protective screen was provided, however, so that motion picture and still picture coverage of certain tests could be accomplished, as desired.

Photographs showing a typical test being performed on a candidate flame/gas barrier (XPB-10) are presented in Figure 28.

A complete tabulation of the diaphragm test results obtained on various experimental flame/gas barrier subcomposites are presented in Table VIII. Photographs of the specimens taken after test are presented in Figure 29. Typical structural layer temperature vs time curves are presented in Figure 30.

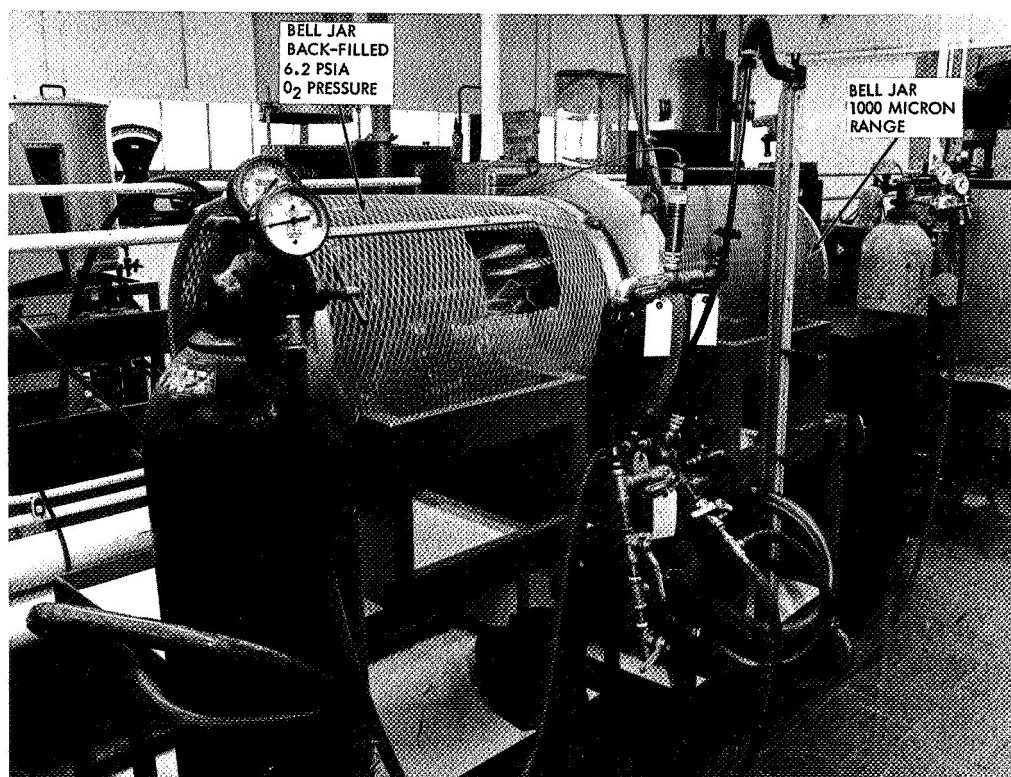
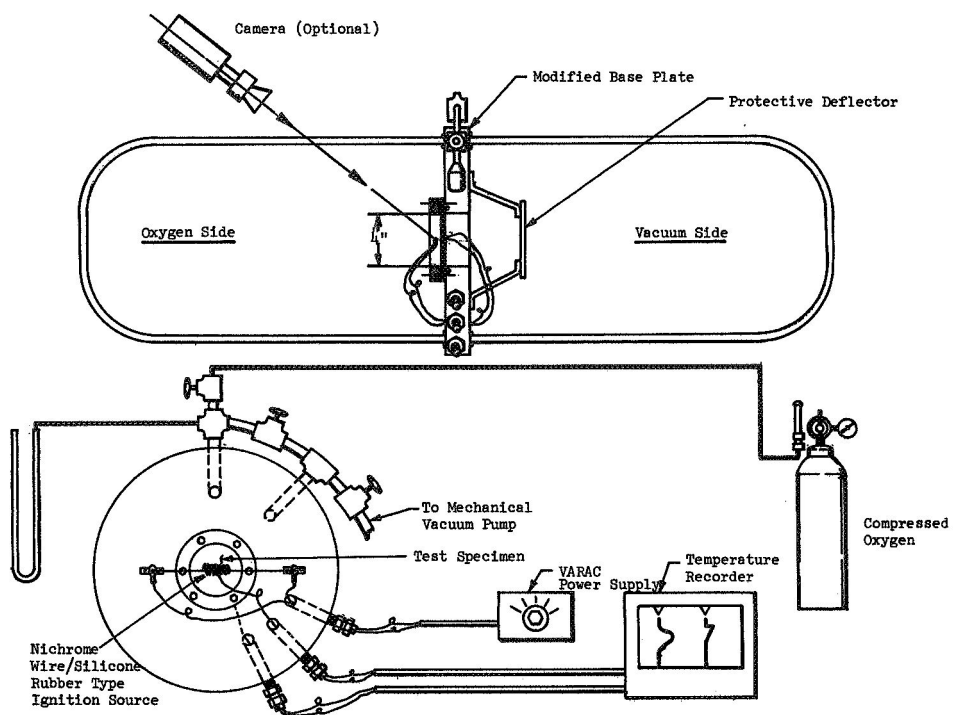


Figure 27. Diaphragm Flammability Test Apparatus

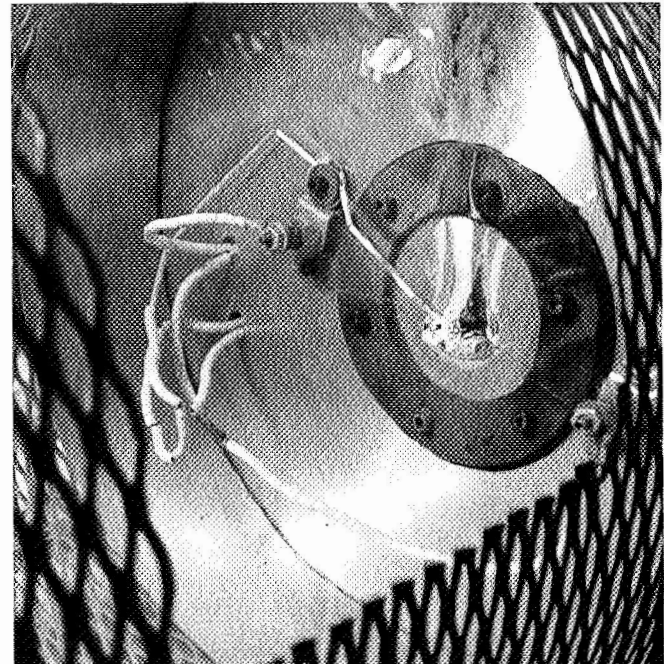
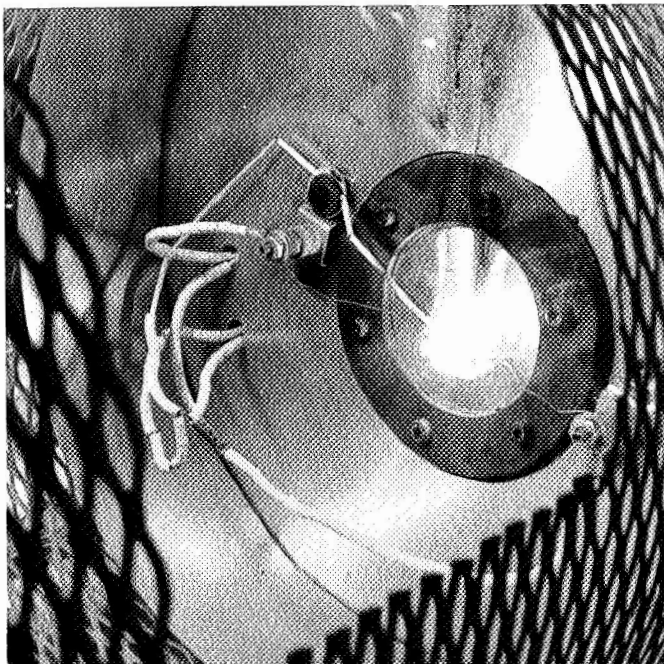
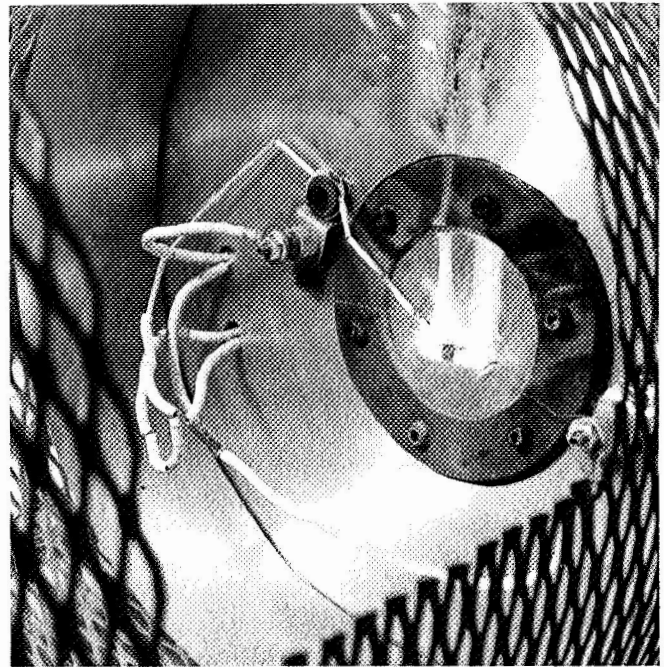
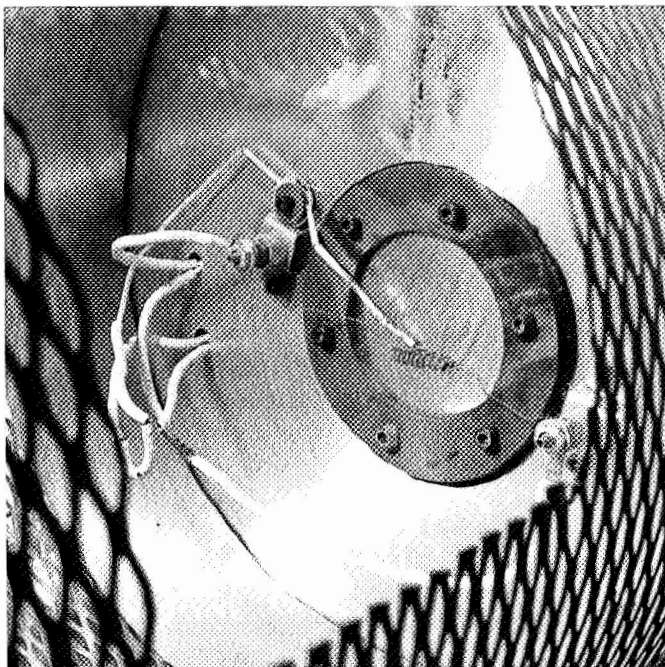


Figure 28. Diaphragm Flammability Test in 100 Percent Oxygen at 6.2 Psia

Analysis of the data obtained shows that of all the subcomposites tested, XPB-7, XPB-8, XPB-10, XPB-12, XPB-13, XPB-17, XPB-18, XPB-19, XPB-20, and XPB-21 experienced extensive damage. However, XPB-7, XPB-8, XPB-10, and XPB-13 did continue to maintain a gas seal because the back foil layer was not destroyed. Those displaying the best flame damage resistance were XPB-11, XPB-14, and XPB-16.

The XPB-22 subcomposite showed excellent resistance to thermal damage; however, since the plies are not laminated together, it would be difficult to incorporate this system into walls of a packageable lunar shelter. Also, since the flammable Fluorel sheet is not bonded tightly to the protective layer, the chances of a fire propagating in this layer are increased. In this form the material would not pass the NASA Category A upward flame propagation rate test.

Of those considered acceptable, XPB-14 was selected as the best overall candidate. This material was retested using two silicone igniters and, although considerably more heat energy was applied, it still maintained good integrity with damage extending only through the second aluminum foil layer. However, considerable discoloration and some delamination of the Kapton next to the second foil layer was noted.

A specimen of XPB-14A was also evaluated by NASA-MSC in their special flame impingement test apparatus. This test, developed by NASA-MSC, Crew Systems Division, consists of impinging a controlled temperature natural gas flame upon a horizontally positioned specimen. The test is performed in a minimum 95 percent oxygen atmosphere at various pressures. Details and results of the XPB-14A test are as follows:

Test No.:	CSD PLN 3362
Date:	12-4-69
Pretest Flame Temperature:	1800°F
Test Atmosphere:	95% Oxygen at 6.2 psia
Top Layer Temperature:	240°F after 2 minutes
Condition of Specimen after 2 Minute Test:	
	Bottom aluminum layer melted away.
	The top layer was not damaged.

Study and Elimination of Solvent Entrapment Problems: In the development of a subcomposite pressure bladder, requirements were established for acceptable low offgassing of organic vapors and carbon monoxide based on Test No. 6, Reference 1.

During the course of the development effort, two subcomposites, XPB-10 and XPB-14A, along with their individual components, were supplied to NASA-WSTF for evaluation under Test No. 6 of Reference 1.

The results of these tests (discussed in detail in the "Materials Qualification" section) showed that the individual components used in XPB-10 and XPB-14A exhibited very low and acceptable offgassing. The subcomposites, however, both exhibited unacceptably high offgassing of organic vapors.

TABLE VIII. RESULTS OF DIAPHRAGM FLAMMABILITY TESTS IN 6.2 PSIA
100% OXYGEN ON CANDIDATE FLAME/GAS BARRIER SUBCOMPOSITES

Material	Manufacturer or Source	Approx. Thickness Inch	Ignitor Type	Approx. Surface Burn Area, Sq. In.	Burn Depth
XPB-7	GAC	0.075	SE*	2.2	Through all but backside 1-mil foil layer
XPB-8		0.065		2.7	Through all but backside 1-mil foil layer
XPB-10		0.065		1.5	Through all but backside 1-mil foil layer
XPB-10		0.065		0.7	Through all but backside 1-mil foil layer
XPB-10		0.075		2.5	Through all but backside 1-mil foil layer
XPB-10		0.075		2.1	Through all but backside 1-mil foil layer
XPB-10		0.070		2.5	Through all but backside 1-mil foil layer
XPB-11		0.090		1.0	Through outside foil layer only
XPB-12		0.080		1.5	Through 2nd foil layer
XPB-12		0.075		1.3	Through 2nd foil layer
XPB-12		0.075		1.5	Through 2nd plastic film layer
XPB-12		0.075		1.5	Through 2nd foil layer
XPB-13		0.080		2.4	Through all but backside 1-mil foil layer
XPB-14		0.075		1.2	Through outside foil layer only
XPB-14		0.075		1.2	Through outside foil layer only
XPB-14		0.075		1.2	Through outside foil layer only
XPB-14		0.075	SE*	1.2	Through outside foil layer only
XPB-14		0.075	SE**	2.7	Very small hole thru 2nd foil layer
XPB-16	GAC	0.034	SE*	1.6	Through outside foil layer only
XPB-16		0.034		1.4	Through outside foil layer only
XPB-17		0.032		***	Burned through all layers
XPB-18		0.150		***	Burned through all layers
XPB-19		0.020		***	Burned through all layers
XPB-20		0.017		***	Burned through all layers
XPB-21		0.166		***	Burned through all layers
XPB-22		0.061		-	Outside Beta Glass Melted Slightly
XPB-22		0.061	SE*	-	Outside Beta Glass Melted Slightly
XPB-22	NASA-MSC	0.061	SE*	-	Outside Beta Glass Melted Slightly

* SE indicates 0.22 in. dia. x 1.25 in. silicone elastomer ignitor

** Two silicone ignitors used

*** Specimen was extinguished with Nitrogen because of excessive burning

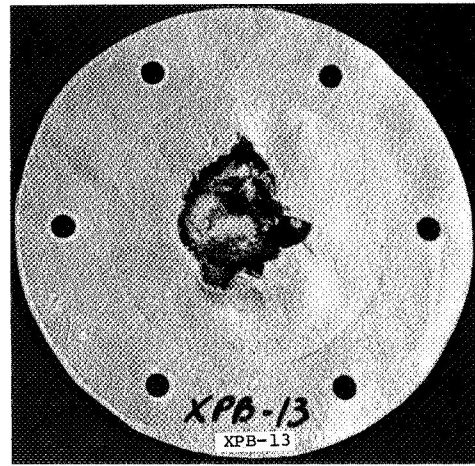
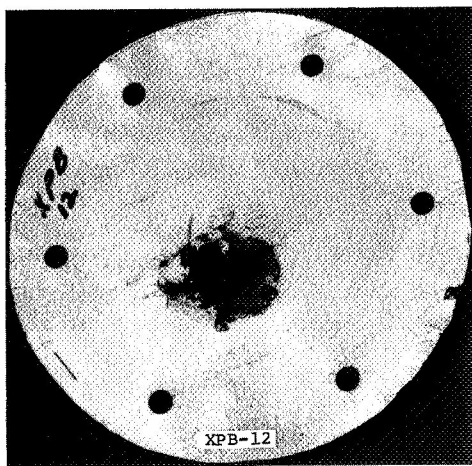
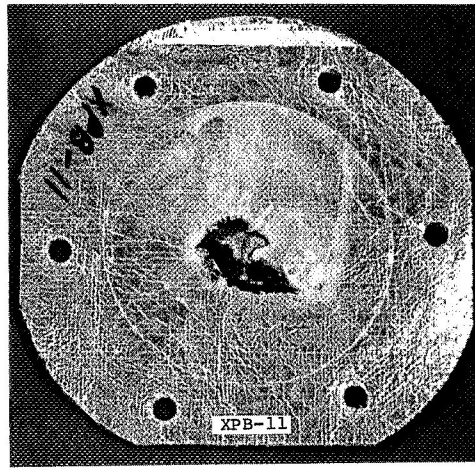
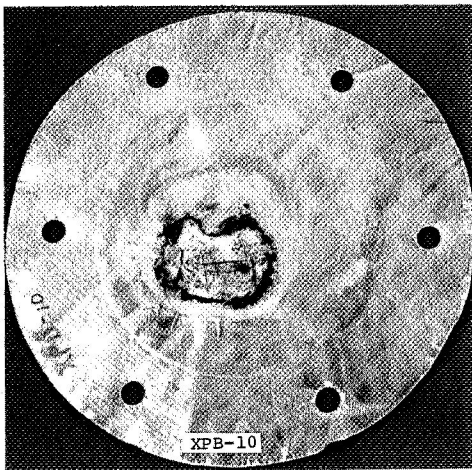
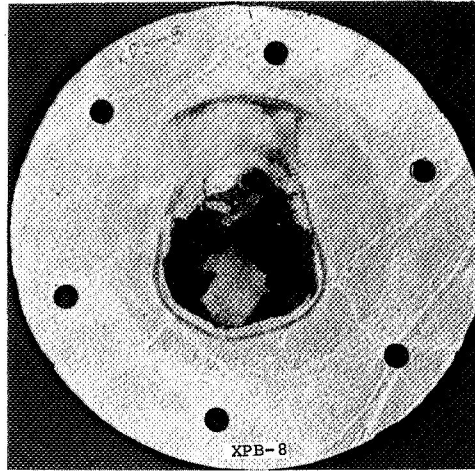
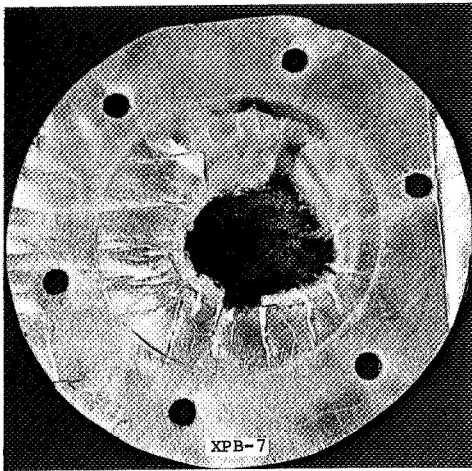


Figure 29. Various Flame/Gas Barrier Subcomposites After Diaphragm Flammability Test (Sheet 1 of 3)

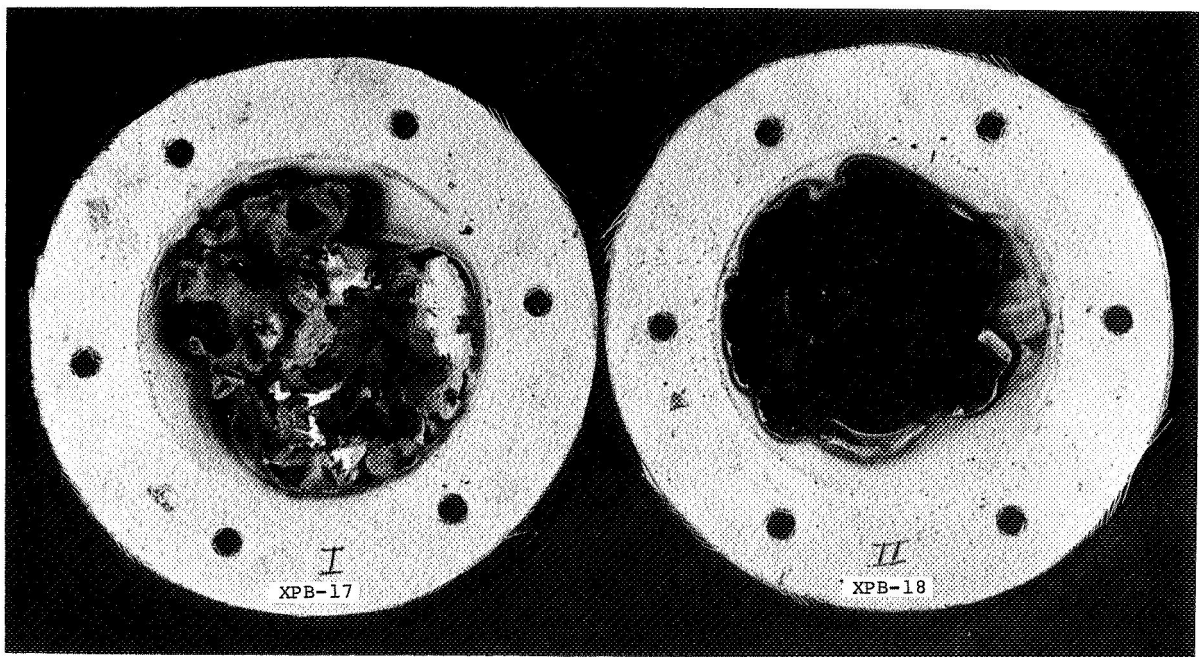
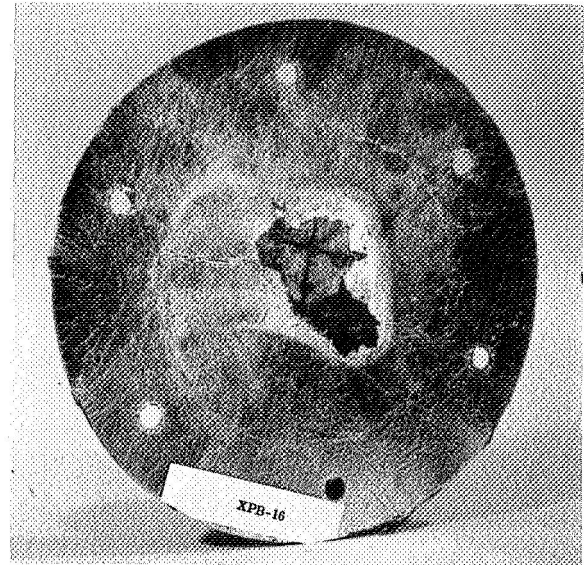
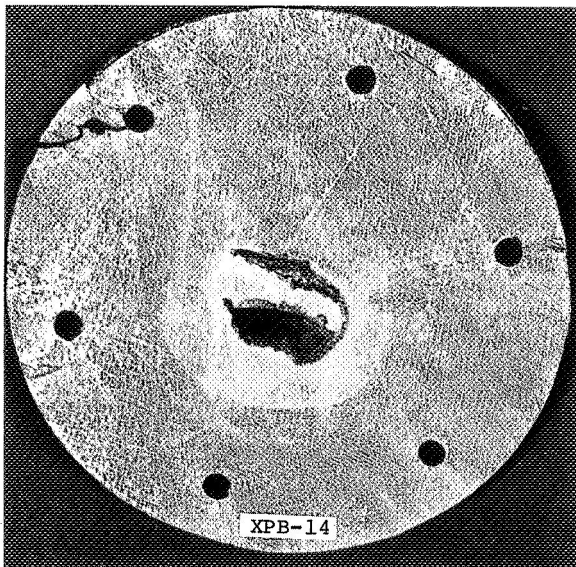


Figure 29. Various Flame/Gas Barrier Subcomposites After Diaphragm Flammability Test (Sheet 2 of 3)

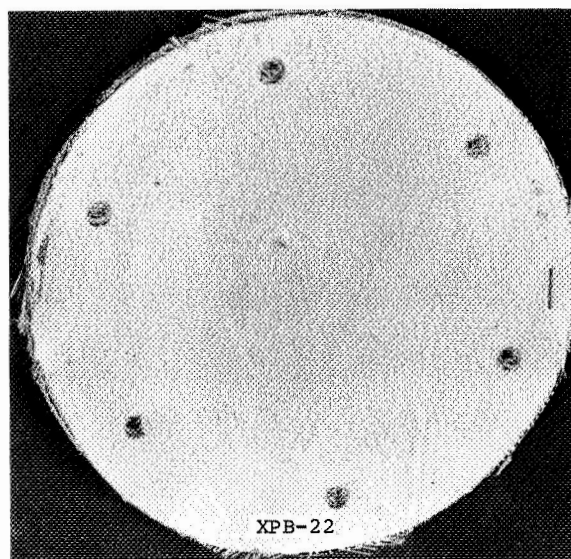
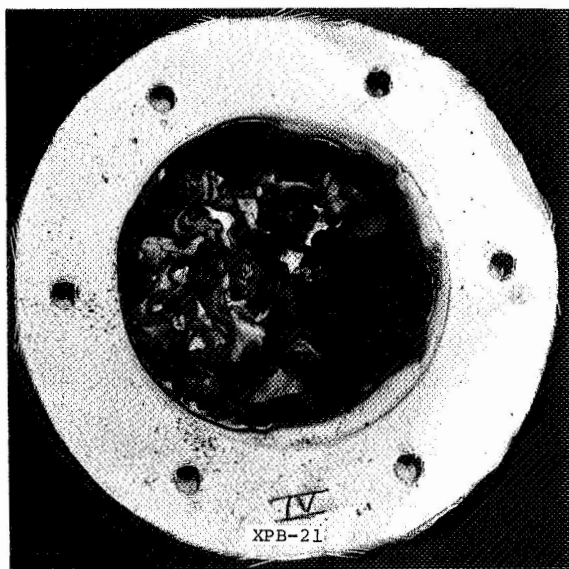
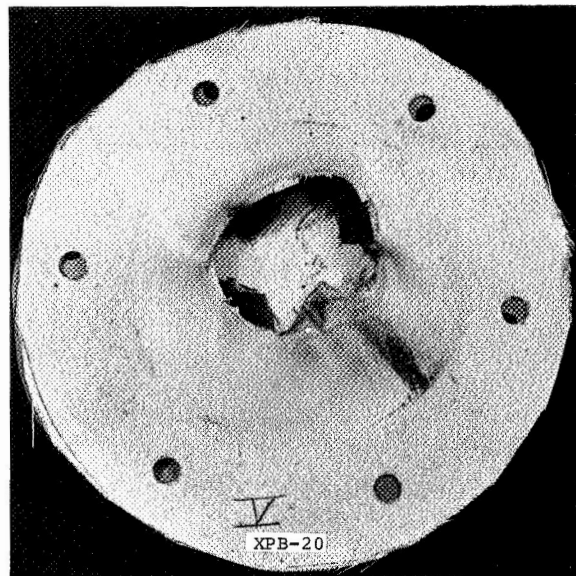
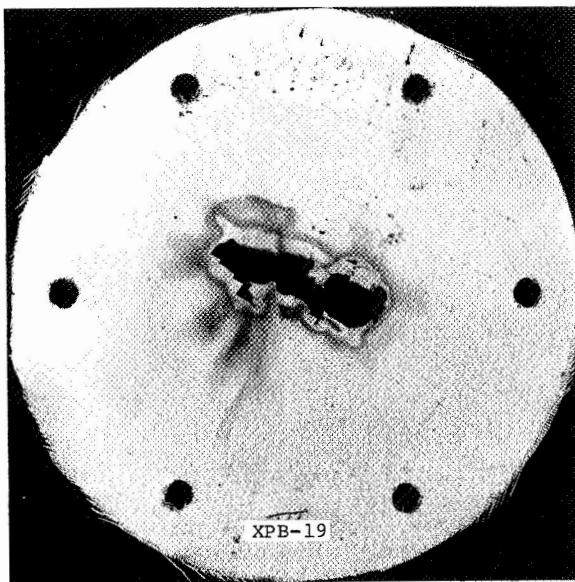
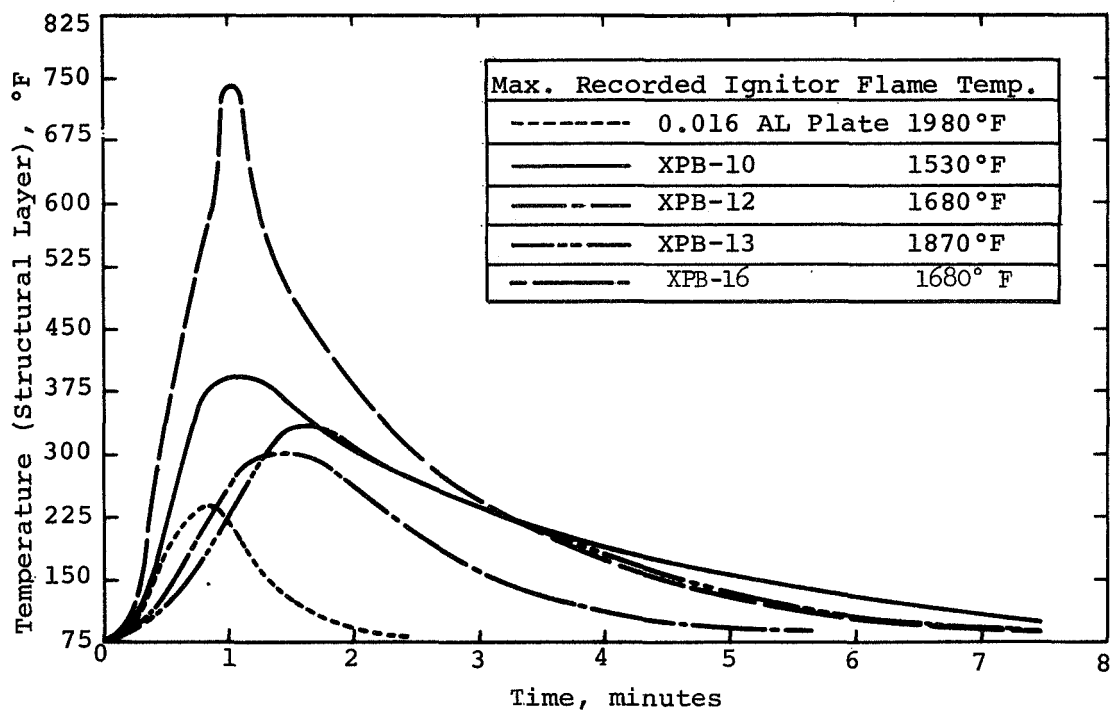


Figure 29. Various Flame/Gas Barrier Subcomposites After Diaphragm Flammability Test (Sheet 3 of 3)



(a)

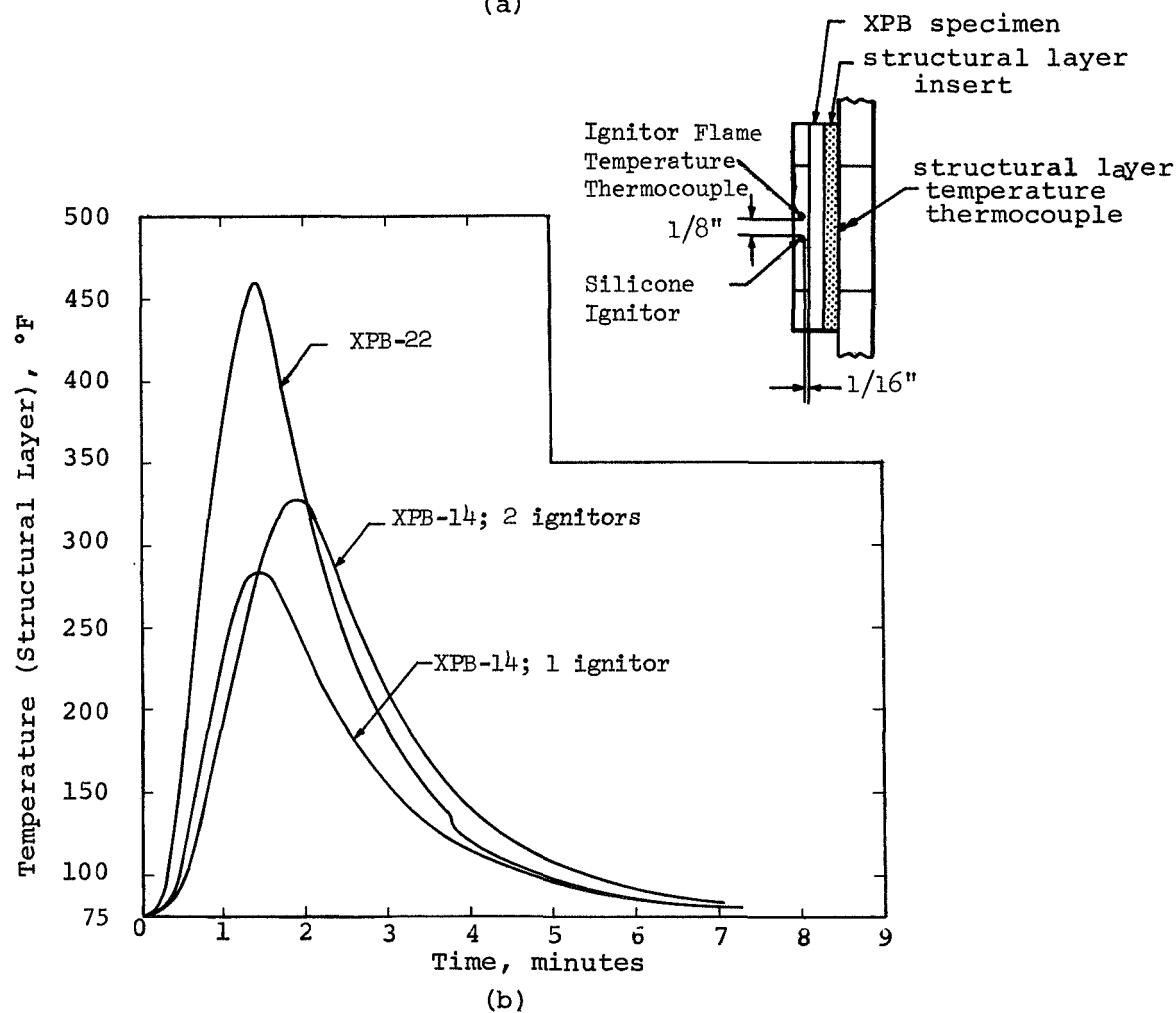


Figure 30. Typical Temperature vs Time Curves Obtained During Diaphragm Flammability Testing

Because the subcomposites carried an additional potential for offgassing in the form of possible solvent residuals from the Mosites adhesive (a solution of Fluorel polymer in methylethylketone) employed in bonding the various components of the subcomposite, the results pointed clearly to the presence of solvent residuals.

Confirmation of the presence of solvent residuals was then obtained by gas chromatographic examination of a 1-mil gas sample drawn from within the Fluorel sponge layer of the subcomposite with a hypodermic syringe. The analysis showed two organic vapors present, namely methylethylketone and toluene. The methylethylketone is the solvent contained in the Mosites adhesive, as purchased, and toluene had been used for dilution of the adhesive for spray application.

At this point it appeared that a modification of the fabrication procedures would be necessary to reduce solvent offgassing while retaining the very satisfactory low level of carbon monoxide offgassing.

In an attempt to eliminate solvent entrapment two modifications to the normal fabrication process for XPB-14A were evaluated.

The first process modification evaluated consisted of discontinuing the use of toluene in the Mosites #1066 adhesive and eliminating the application of adhesive to the sponge layer. Using this procedure, adhesive was sprayed only on the component to be bonded to the sponge. The laminate was then assembled and laminated according to the normal XPB-14A procedure. Subcomposite material produced by this method retained good bond strength and the same general physical characteristics as XPB-14A. Material produced by this modified method was designated XPB-14A-1.

The second process modification consisted of discontinuing the use of toluene in the Mosites #1066 adhesive and applying heat (150°F for 1 hour) to the sponge layer after spray application of the adhesive. This pretreatment, prior to the conventional lamination step, was to "boil-off" the solvent. Specimens prepared in this manner were designated XPB-14A-2 and retained the physical characteristics of XPB-14A, the only difference being a lower solvent residue.

The improvement (reduction) in offgassing effected by the fabrication process changes was preliminarily evaluated inhouse in advance of sending a further subcomposite to WSTF. The test method and equipment employed are briefly described as follows:

1. Preliminary Offgassing Observations on XPB-14A-1 and XPB-14A-2 Subcomposites

Apparatus:

Bomb. An aluminum bomb, provided with an aluminum foil-gasketed bolted head, was employed for the extended offgassing sample exposures. Gas samples were withdrawn from the bomb through a

demountable silicone rubber septum with a syringe. The septum was not exposed to the bomb contents except during sampling periods.

Gas Chromatography. A Varian Model 90-P3 chromatograph with a hot wire detector and a 10-foot x 1/4-inch column packaged with SE-30 on chromasorb was employed for the most part. With approximately 28 ml/minute helium flow rate and 200 ma bridge current, sensitivity was ample both for the 260 ppm n-hexane in nitrogen (Matheson) calibration standard and for offgas samples. It was felt that a sufficiently accurate transfer from a standardization on n-hexane to an analysis of methylethylketone could be made with an empirical correlation of relative response factors (Reference 34). A few check analyses were made with a Varian 600D chromatograph again using a helium carrier, SE-3D on chromasorb in a 5-foot x 1/8-inch column and hydrogen flame ionization detector. Standardization was again with the n-hexane/nitrogen calibration mixture and correlation with methylethylketone was viewed as straightforward because of the known nearly constant response per weight of carbon exhibited by a hydrogen flame ionization detector. Therefore, the HFID analyses were regarded as affording a reliable cross check on the assumptions made in the calibration of the hot wire detector.

Conditions for Offgassing. With a bomb volume of 2.25 liters, sample weights of 12 to 12.5 grams of each subcomposite material were taken, one sample per run. After purging the bomb with a hot air gun, the bomb was further purged with a nitrogen stream, the sample inserted, the bomb closed, and then placed in a mechanical circulation hot air oven controlled at 155°F. At variable times, a 5 milliliter or smaller sample was withdrawn from the bomb and subjected to gas chromatographic analysis.

2. Analysis for Offgassed Methylethylketone

Analyses with a hot wire detector were as follows:

XPB-14A-1 Subcomposite Material Run No. 1

Run was lost through experimental difficulties

XPB-14A-1 Subcomposite Material Run No. 2 (new sample)

Anal. #2 at 67.5 hours heating at 155°F detected

15 µg methylethylketone/gram of subcomposite

Anal. #3 at 69.5 hours; 22 µg/gram of subcomposite

Anal. #5 at 97 hours; 13 µg/gram of subcomposite

Anal. #6 at 97.5 hours; 20 µg/gram of subcomposite

(Analyses #1 and #4 were quite low and discarded as probably not being representative because of hypo-needle plugging.)

XPB-14A-2 Subcomposite Material Run No. 1

Analysis #1 at 22.5 hours; 32 μ g methylethylketone/
gram of subcomposite

Analysis #2 at 23.5 hours; 35 μ g methylethylketone/
gram of subcomposite

Since it appeared that subcomposite XPB-14A-2 represents
a less desirable fabrication process than that used for
XPB-14A-1, the offgassing test on XPB-14A-2 was dis-
continued.

NASA-WSTF Laboratory Tests. -

Test Procedures: Selected single layer materials and flame/gas barrier
subcomposites were supplied to NASA-WSTF Laboratory for comprehensive evalua-
tion in accordance with Category A requirements described in Reference 1.

The tests performed were as follows:

- (1) Upward Propagation Rate - Test No. 1
- (2) Flash and Fire Point - Test No. 3
- (3) Carbon Monoxide and Offgassing Products Determination -
Test No. 6
- (4) Odor Test - No. 7
- (5) DTA and TGA Analysis - Special Test

A complete description of the test procedures is contained in Reference 1
while a brief description is included here for convenience.

- (1) Upward Propagation Rate - A $2\frac{1}{2}$ x 5-inch sample is mounted in a
vertical position in a 100 percent oxygen 6.2 psia environment.
An attempt is then made to ignite the sample using a silicone
rubber igniter. This test is similar to that used in the GAC
screening tests.

Materials are considered acceptable for Category A if they:

- (a) do not ignite
- (b) ignite but self-extinguish after burning 0.5 inch
or less after extinguishment of the igniter and do
not spark, sputter, or drip flaming particles.

- (2) Flash and Fire Point - The material is installed in a special test apparatus containing an atmosphere of 100 percent oxygen at 6.2 psia. The sample is then heated at a constant rate of 25°F/min. and examined for ignition at the end of each 25°F rise by applying an electrical spark.

To be acceptable, materials:

- (a) must not evolve vapors which produce a visible flash at a temperature less than 400°F
 - (b) must not show evidence of charring or self-sustained combustion at a temperature less than 450°F.
- (3) Carbon Monoxide and Offgassing Products Determination - A sample is placed in a tight container containing a 100 percent oxygen atmosphere and heated to 155°F for 72 hours. The atmosphere within the container is then examined to determine the carbon monoxide level and total organic offgassing products level.

Materials are judged acceptable if they produce levels that do not exceed 100 micrograms of total organics per gram of sample and 25 micrograms of carbon monoxide per gram of sample when tested in accordance with required procedures.

- (4) Odor Test - Materials are heated in a test chamber at 155°F for 72 hours in an oxygen atmosphere. Following the oven treatment, known volumes of the atmosphere in the container are removed and diluted with fresh oxygen in the following proportions:
- (a) One part sample atmosphere to 29 parts of test gas
 - (b) One part sample atmosphere to 9 parts of test gas
 - (c) No dilution, or as drawn from the container

The prepared test samples are supplied to a ten member panel for evaluation on the basis of the following scale:

<u>Member Rating</u>	<u>Test Conductor's Rating</u>
Undetectable	0
Barely detectable	1
Easily detectable	2
Objectionable	3
Irritating	4

Materials are considered acceptable if an average ten member panel score is 2.5 or lower. Scores above 2.5 at any dilution signifies that the material failed.

- (5) DTA and TGA Analysis - Differential thermal analysis (DTA) and thermogravimetric analysis (TGA) tests were performed on the materials, in 100 percent oxygen at a pressure of 320 Torr, as an adjunct to the required Category A tests. DTA tests involve the continuous comparison of temperatures of a reference material and a sample as they are both heated at a uniform rate. From the direction of deviation in temperature between the sample and the reference, it is possible to establish if the physical or chemical transformation responsible is exothermic or endothermic. TGA measures the weight of the sample as it is heated at a uniform rate. Examination of both DTA and TGA curves obtained on a particular sample show whether a loss of weight accompanies an endothermic or exothermic change. Therefore, the TGA can greatly assist in the interpretation of the DTA results. Together DTA and TGA curves provide a very useful tool for establishing the characteristics and stability of a material.

Results and Discussion: The results of the WSTF Laboratory tests are tabulated in Table IX. A discussion of the results is as follows:

Upward Flame Propagation Rate: The #1066 Fluorel adhesive, RL-3788 Fluorel adhesive, 1-mil Aclar 33c film, 50-mil #1062-C Fluorel sponge, 0.5 mil Kapton film, Al-4 polyester foam, and AD 917 Vitel adhesive burned and failed to pass Category A requirements. These tests agreed with the preliminary evaluation tests run in GAC's laboratory. Results obtained on 81677 Beta fabric, XPB-10 subcomposite, Litoflex K20 asbestos foam, C-100-28 Refrasil and XPB-14A sub-composite show that these materials will not support combustion, thus meeting the Category A requirements.

Odor: All materials submitted were scored lower than the maximum allowable value of 2.5, and therefore have an acceptable odor rating.

Carbon Monoxide and Total Organic Offgassing: All materials supplied were found to have acceptable carbon monoxide levels. Moreover, each was found to yield considerably less than the maximum 25 $\mu\text{g/g}$ allowable. Total organic offgassing levels were considerably less than the allowable 100 $\mu\text{g/g}$ in all but the XPB-10, XPB-14A (initial specimen), and AD917 Vitel adhesive. The high values obtained for the XPB subcomposites were traced to solvent entrapment and were eliminated through processing changes. (Details are discussed in the section of this report entitled "Study and Elimination of Solvent Entrapment Problems.") Proof that the solvent entrapment problem was overcome was obtained by retesting XPB-14A-1. This sample was manufactured using improved methods and passed with a low 15 $\mu\text{g/g}$ value.

TABLE IX

SUMMARY OF TEST RESULTS OBTAINED ON MATERIALS SUPPLIED TO NASA-WSTF FOR EVALUATION

Material	Thick- ness, In	Manufacturer Or Source	Upward Flame Propagation Rate In (a)		Odor Test (a)		
			100% Oxygen at 6.2 psia		Max. Allow. Score-2,5		
			Propagation Rate, in/sec	Observations	(A)	(B)	(C)
Mosites #1066 Fluorel Adhesive	(b) 0.002	Mosites Rubber Company, Inc.	3.68	Burned with orange flame	0.2	0.1	0.9
RL-3788 Fluorel Adhesive	(b) 0.002	Raybestos Manhattan Inc.	0.88	Burned with orange flame	0.2	0.3	1.3
81677 Beta Fabric	0.007	J. P. Stevens & Co., Inc.	0.00	Melting in immediate area of Igniter	0.2	0.4	1.0
Aclar 33c Film	0.001	Allied Chemical Co.	3.32	Burned with orange flame	0.3	0.4	0.8
Mosites #1062-C Fluorel Sponge	0.050	Mosites Rubber Company, Inc.	0.390	Burned with orange flame	0.0	0.4	1.6
XPB-10 Composite	0.065	Goodyear Aero- space Corp.	0.00	Failed to support combustion	0.1	0.5	1.6
Kapton Film	0.0005	E.I. duPont de Nemours & Co., Inc.	3.59	Burned with orange flame	0.1	0.0	0.4
Lito Flex K20 Asbestos Foam	0.75	Rex Asbestwerke Schabisch Hall, West Germany	0.00	Failed to support combustion	0.2	0.3	1.2
C-100-28 Refrasil	0.014	Hitco	0.00	Failed to support combustion	0.1	0.0	0.4
XPB-14A Composite	0.070	Goodyear Aero- space Corp.	0.00	Failed to sustain combustion	0.2	0.4	1.3
Al-4 White Se Polyester Foam	1.00	Merryweather Foam Latex Co.	50.00	Burned with orange flame	0.2	0.4	1.4
AD 917 Vitel Adhesive	(c) 0.002	Goodyear Tire & Rubber Co.	2.73	Burned with orange flame	0.2	0.1	0.5
XPB-14A-1(d) Composite	0.070	Goodyear Aero- space Corp.					

Material	Carbon (a)	Total (a)	Flash and (a)	DTA Temp of Max. Exotherm, °C	TGA			MSC Test Report Number
	Monoxide, µgm/gm Max. Allow. 25.0	Organics, µgm/gm Max. Allow. 100.0	Fire Point Temperature Min. Allow. 450°F		Temp of Max Endo- therm, °C	Temp of Initial Wt Loss, °C	Wt, Change, %	
Mosites #1066 Fluorel Adhesive	2.5	1.6	None to 315°C No visible change	290	None	255	0.6	2300
RL-3788 Fluorel Adhesive	0.9	1.7			None			2301
81677 Beta Fabric	1.3	0.4	None to 315°C	> 315	None	260	0.7	2302
Aclar 33c Film	1.3	13.0	None to 315°C	> 315	210	> 315	0.1	2303
Mosites #1062-C Fluorel Sponge	0.8	13.0	None to 315°C No visible change	> 315	None	300	1.1	2304
XPB-10 Composite	4.6	571.0	None to 315°C No visible change	> 315	None	245	1.2	2305
Kapton Film	2.5	5.8	None to 315°C No visible change	> 315	None	80	0.6	2349
Lito Flex K20 Asbestos Foam	4.5	15.0	None to 315°C No visible change	> 315	None	75	3.8	2350
C-100-28 Refrasil	0.8	0.5	None to 315°C No visible change	> 315	90	<25	4.6	2351
XPB-14A Composite	0.9	102.0	None to 315°C	> 315	None	160	1.1	2352
Al-4 White Se Polyester Foam	0.8	1.5	No visible change Flash Point, 271°C No fire point to 315°C	280	80	90	15.4	2353
AD 917 Vitel Adhesive	1.4	1,867.0	Flash point, 294°C No fire point to 315°C	> 315	None	90	5.8	2354
XPB-14A-1(d) Composite	1.3	15.0						2382

- (a) Tested in accordance with MSC-D-NA-0002
 (b) Applied to one side of 0.001" thick aluminum foil
 (c) Applied to two sides of 0.001" thick aluminum foil
 (d) XPB-14A-1 Same as XPB-14A except processed for
 minimum adhesive solvent entrapment

- (A) 1-part sample atmos. to 29-parts O₂
 (B) 1-part sample atmos. to 9-parts O₂
 (C) No dilution

Flash and Fire Point Temperature: All materials exceeded the minimum requirements for passage of the flash and fire test. Since no fire points were reached to 600°F (315°C) in any of the materials, good stability was shown. However, flash points were reached below 600°F in the Al-4 polyester foam and AD917 Vitel adhesive. Since they appear to be degrading, care should be exercised in their use.

DTA and TGA: Differential Thermal Analysis (DTA) and Thermogravimetric Analysis (TGA) thermograms for each material studied are presented in Figures 31 through 41.

A summary of the significant temperature points found in the data is contained in Table IX. In general, the curves tend to support the flash and fire point test results. One unexpected result was that obtained on C-100-28 Refrasil fabric (Figure 38). This data shows a maximum endotherm point at approximately 90°C. This behavior is probably caused by evaporation of a low molecular compound which may have been added during weaving. Since the normal procedure is to bake out the fabric at 400°F prior to using it in manufacturing, this behavior will not occur in the subcomposite. Figures 40 and 41 clearly show the initiation of thermal degradation.

Four-Element Composite Wall Concepts. -

Description of Candidate Elements and Total Wall Composites: Using the results of the materials screening and flame/gas barrier subcomposite development studies, efforts were directed toward establishing several four-element composite wall structures (XTC). Each wall concept was composed of the following main elements:

- (1) Flame/gas barrier (XPB)
- (2) Structural layer (XTL)
- (3) Micrometeoroid barrier (XMB)
- (4) Outer cover (XOC)

To make the selection as broadly based as possible, consideration was given to several candidates in each of the four-element categories. Finally, candidate total wall composites were designed by combining acceptable elements from each category.

A complete description of the various candidate main element systems considered are found in Tables VI, X, XI and XII.

Several candidate wall systems, obtained by combining the various elements, were studied and presented to NASA for consideration and selection of the two best candidates for final qualification. The candidate wall systems proposed,

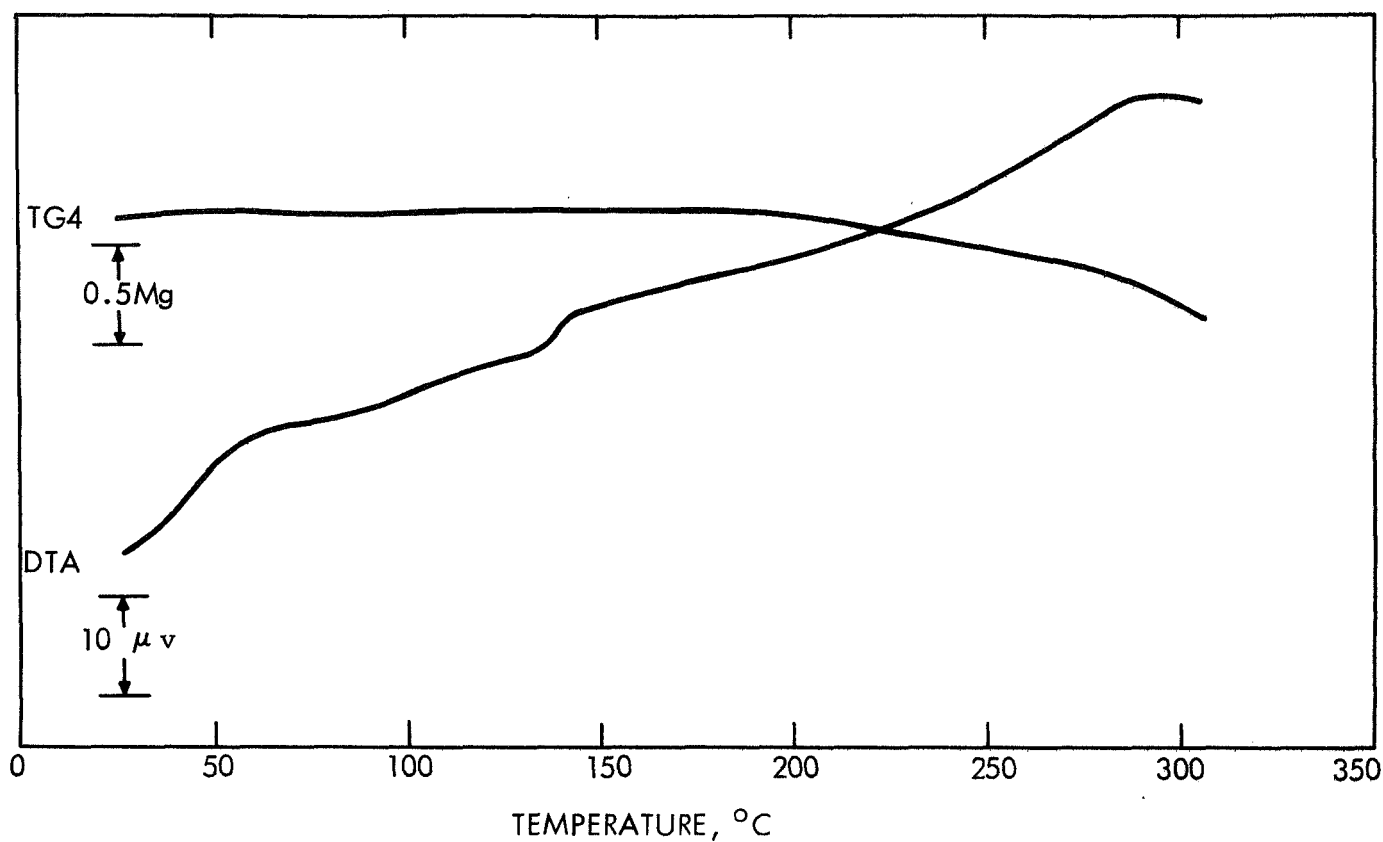


Figure 31. TGA and DTA Curves For Mosites #1066 Fluorel Adhesive.

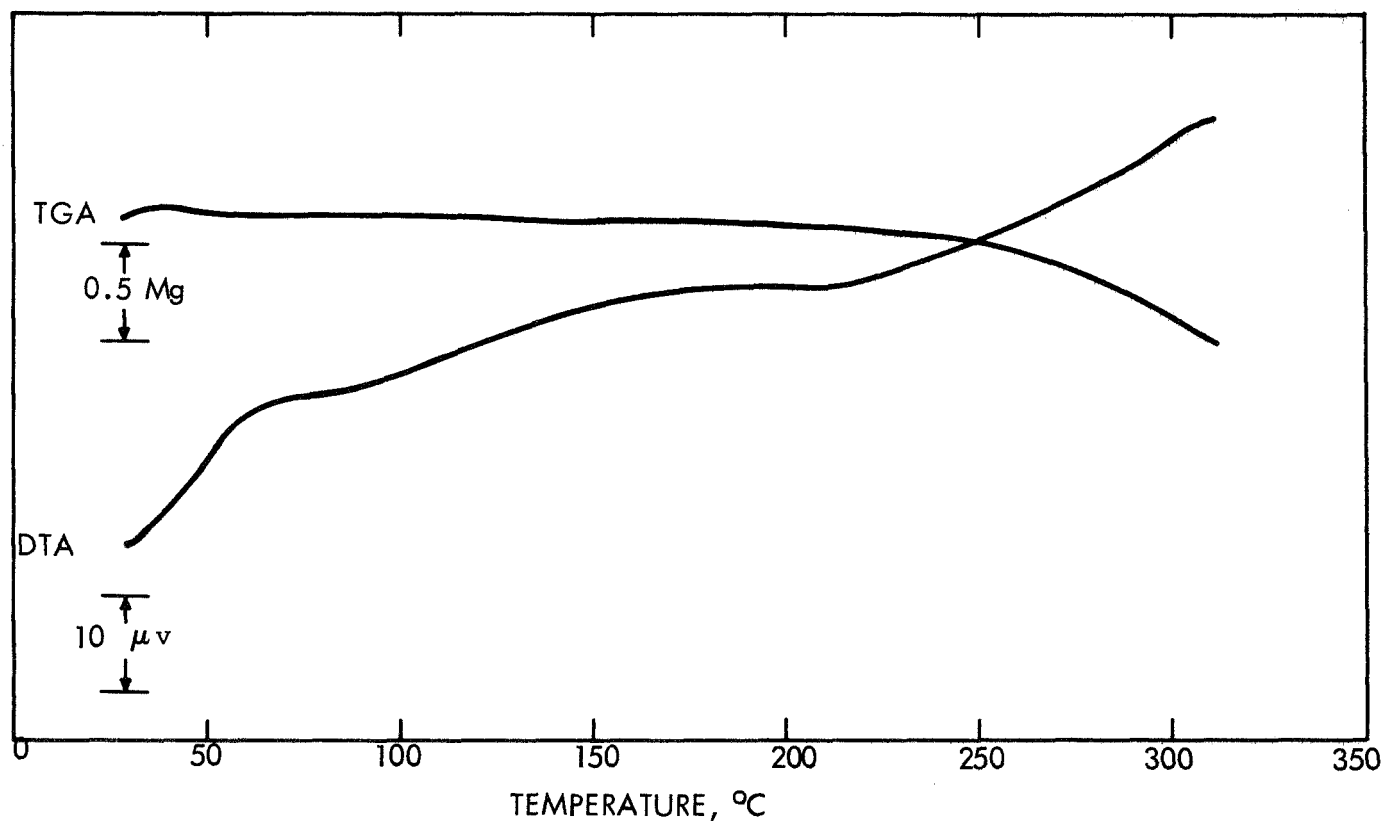


Figure 32. TGA and DTA Curves For 81677 Beta Fabric.

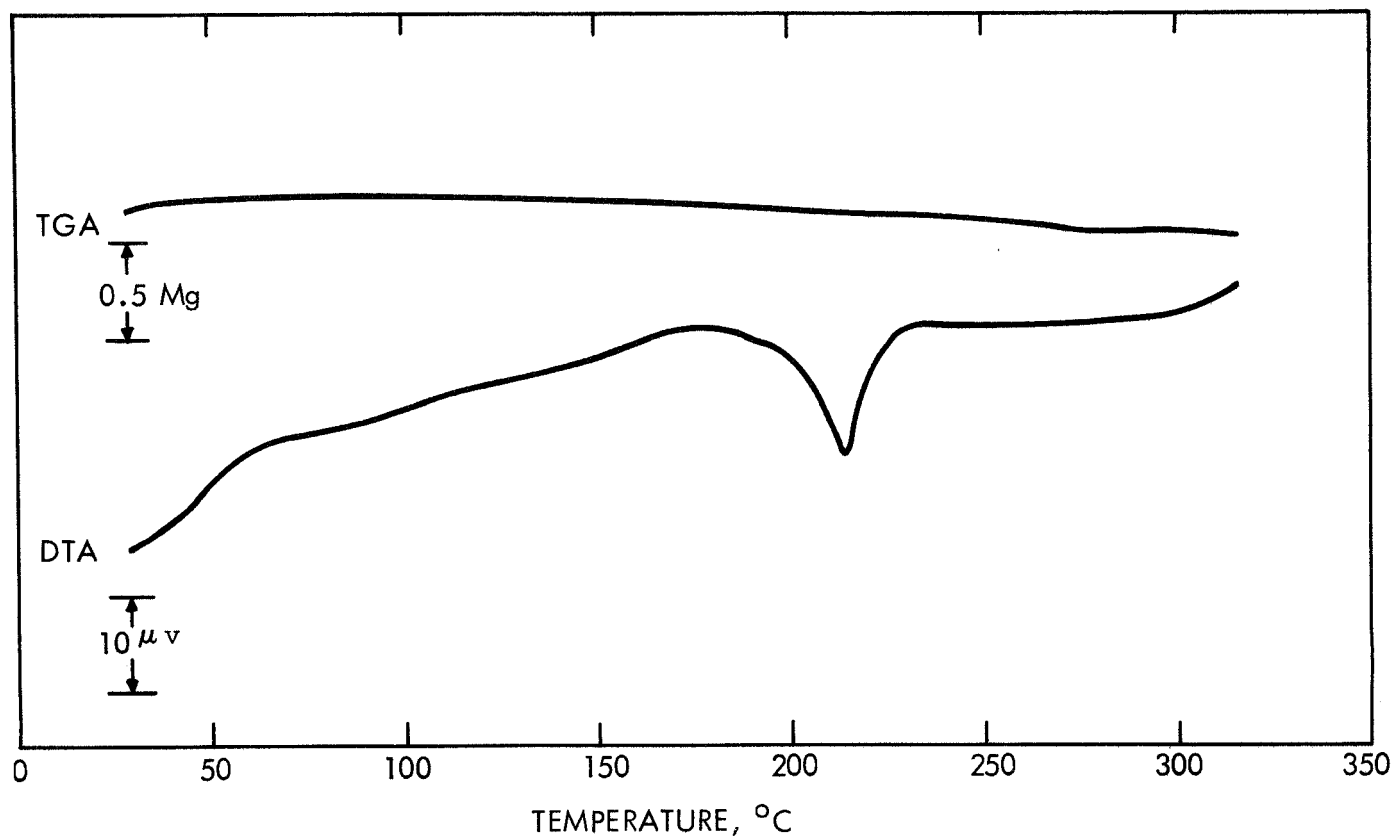


Figure 33. TGA and DTA Curves For Aclar 33c Film

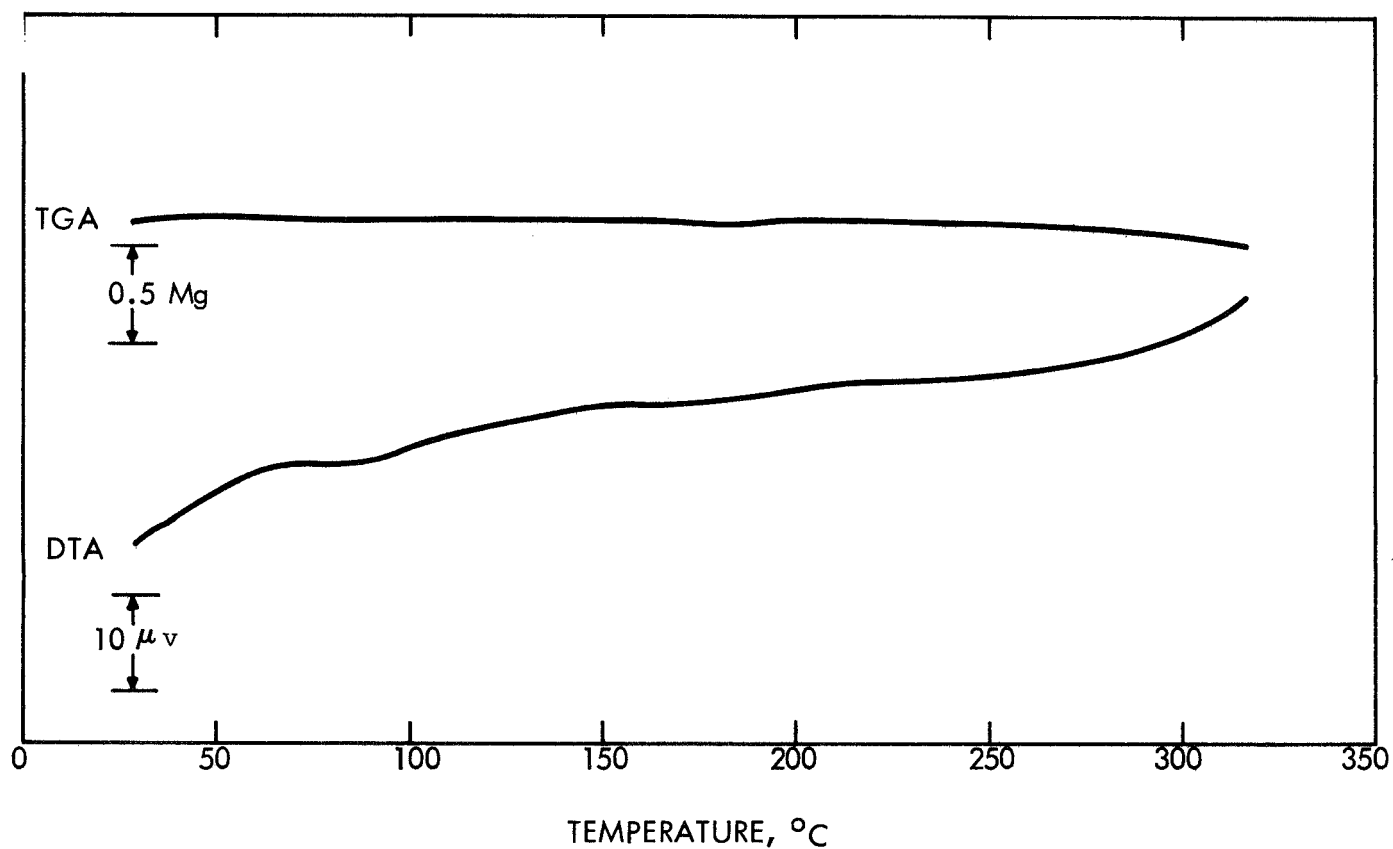


Figure 34. TGA and DTA Curves For Mosites #1062-C Fluorel Sponge.

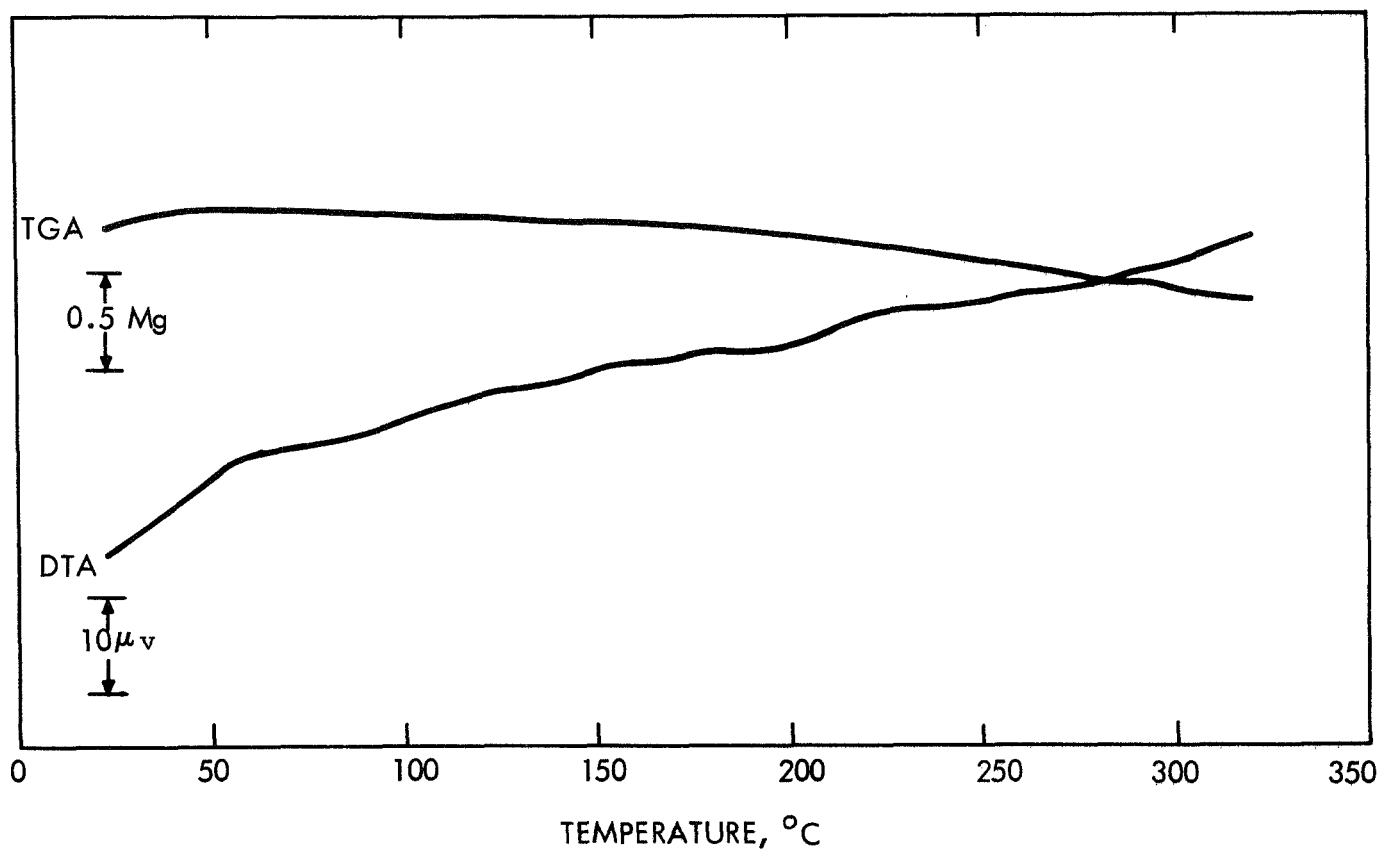


Figure 35. TGA and DTA Curves For XPB-10

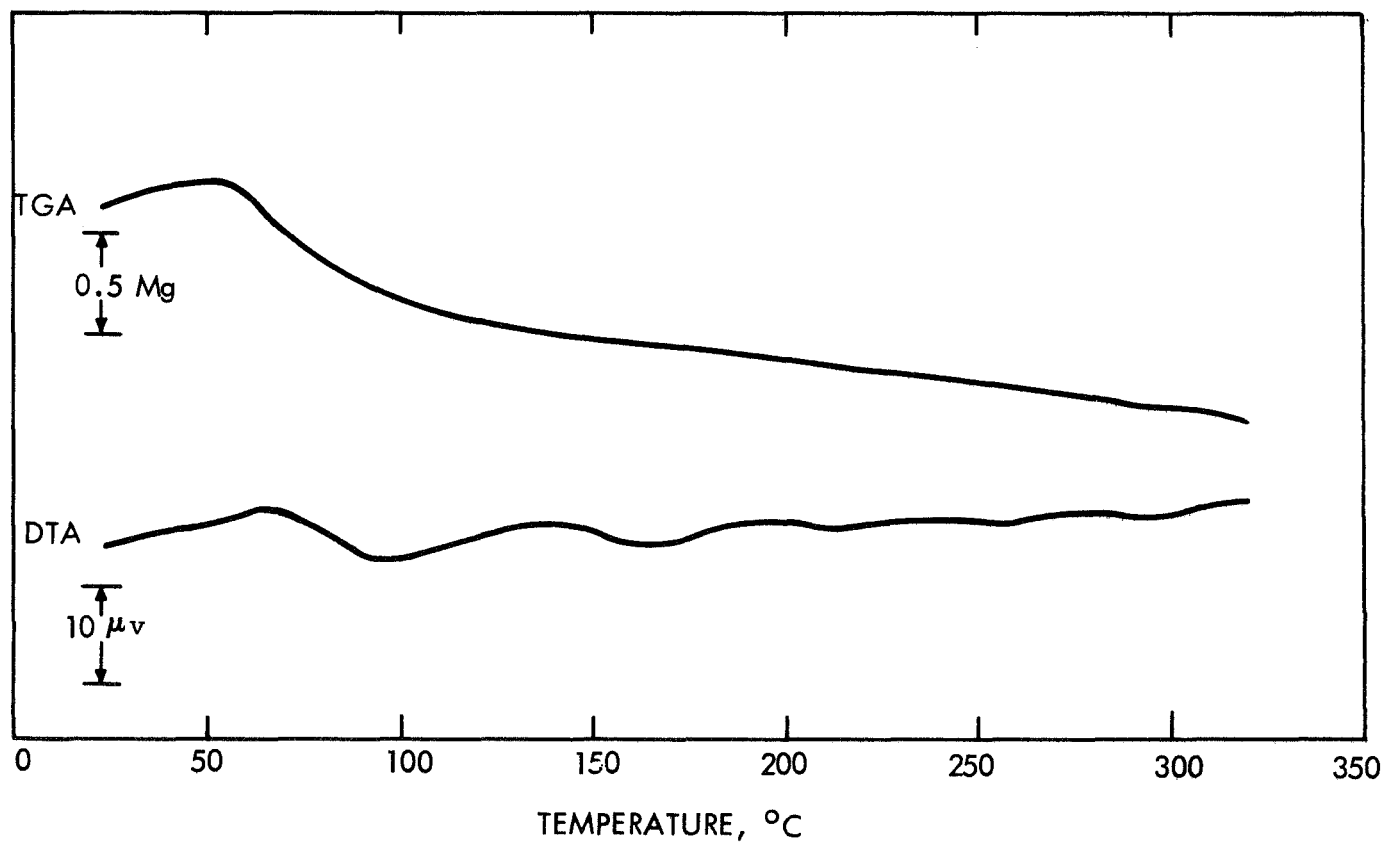


Figure 36. TGA and DTA Curves For 1/2-Mil Kapton Film

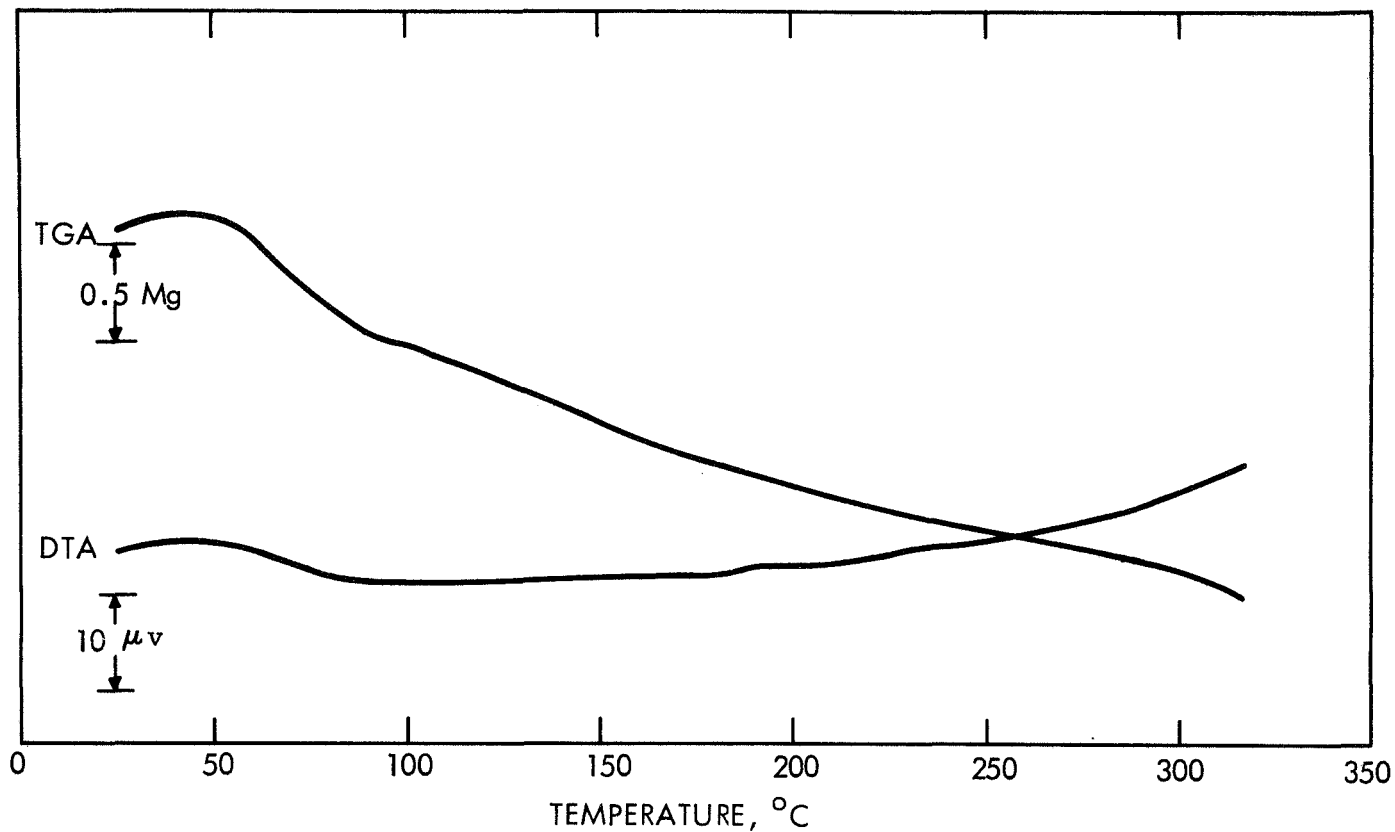


Figure 37. TGA and DTA Curves For Litoflex K20 Asbestos Foam

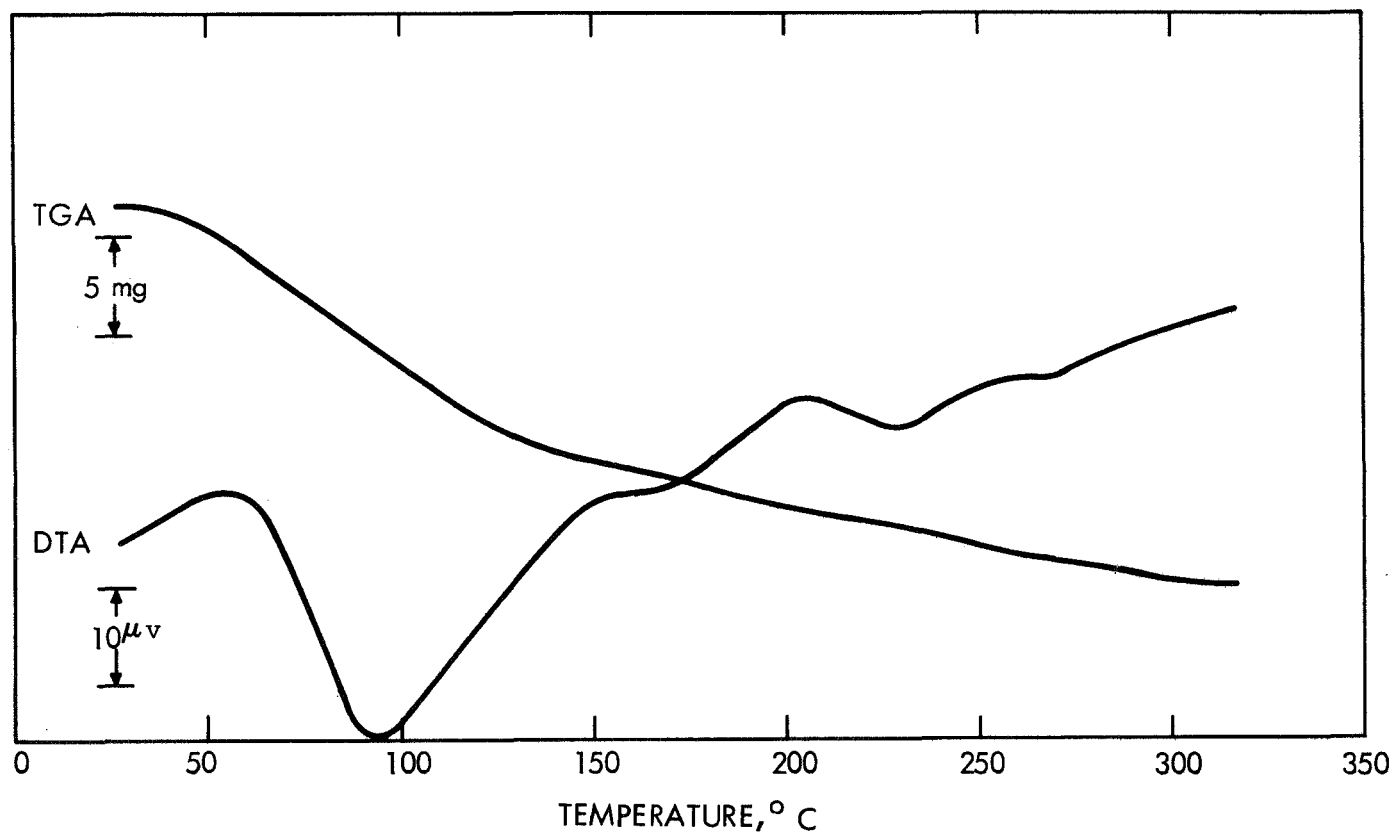


Figure 38. TGA and DTA Curves For C-100-28 Refrasil Fabric

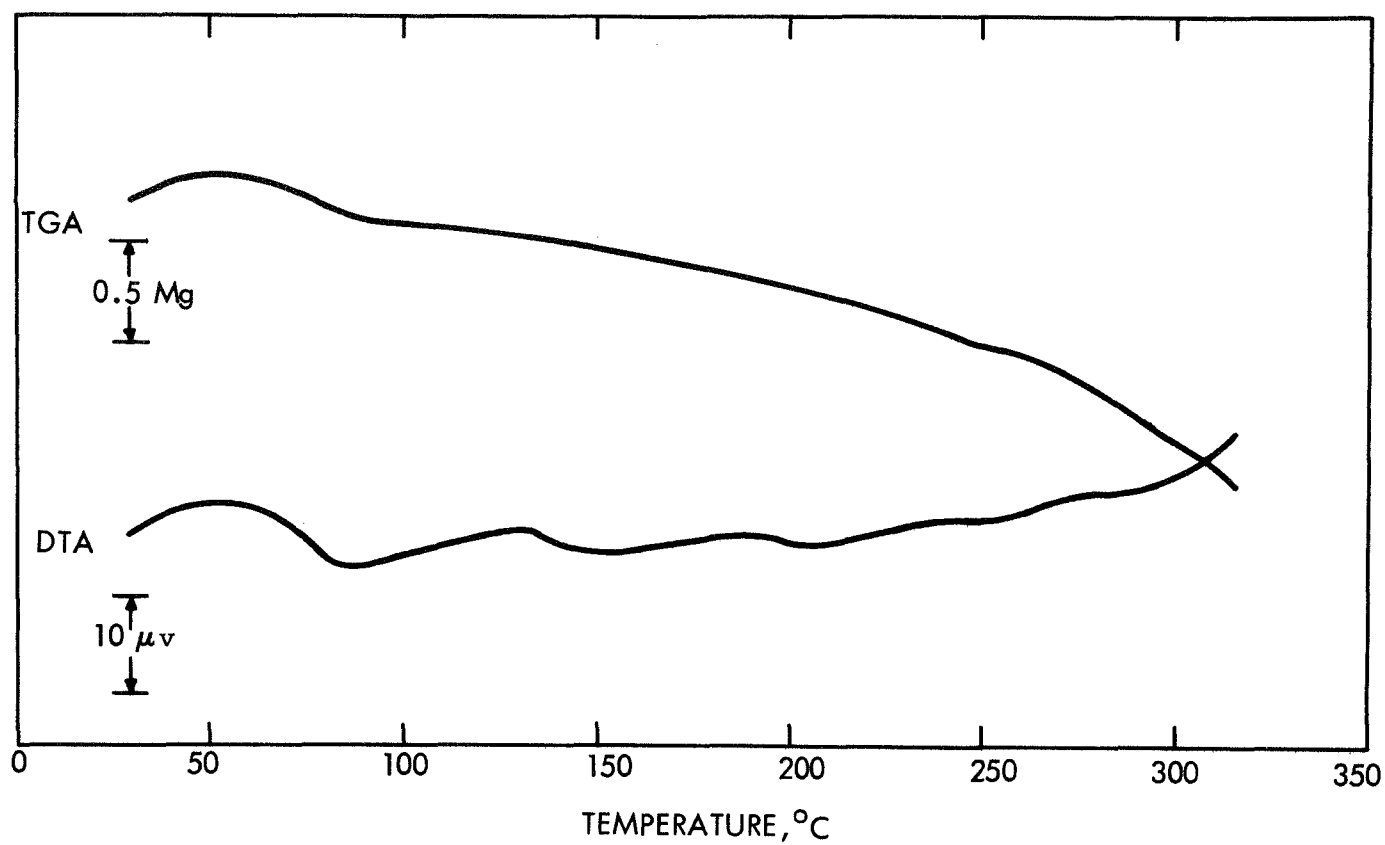


Figure 39. TGA and DTA Curves For XPB-14A

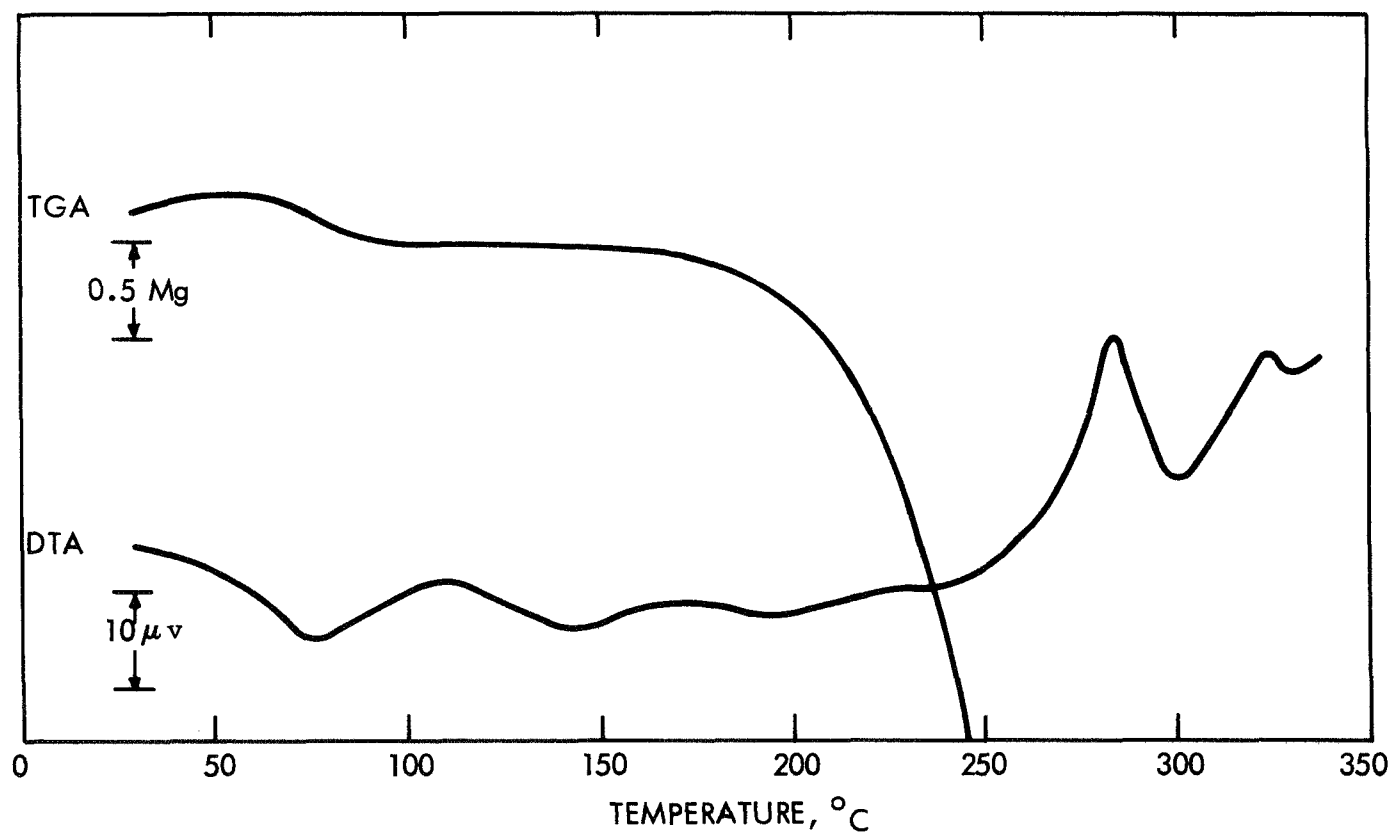


Figure 40. TGA and DTA Curves For AJ-4 White SE Polyester Foam

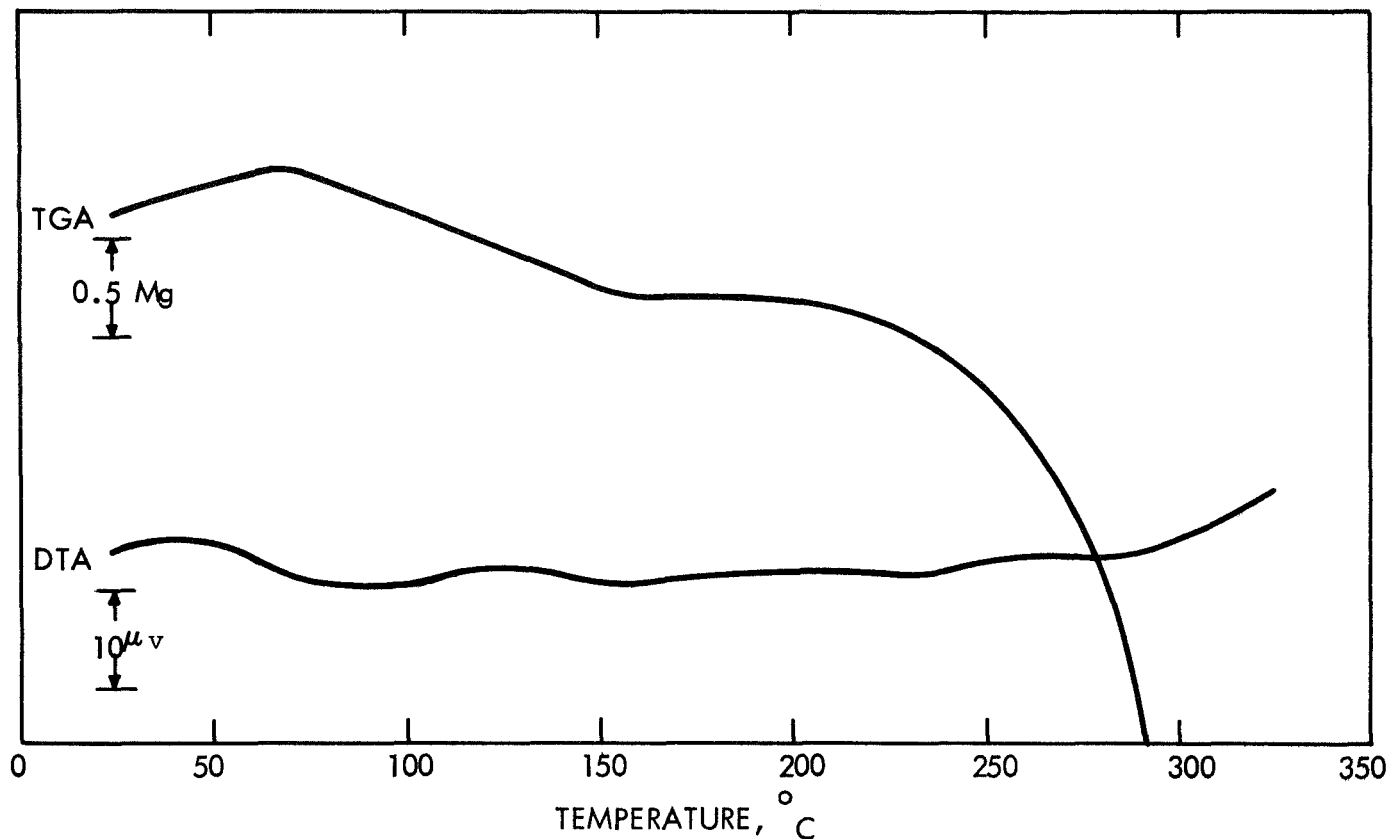


Figure 41. TGA and DTA Curves for AD 917 Vitel Adhesive

designated XTC-1 through 5, are described in Table XIII. The XTC-6, also described, was suggested by NASA-LRC personnel and incorporated later in the program. The XTC-6 differs from the others in that it does not have a full micrometeoroid protection system incorporated into the wall. For further protection, an outer layer of "bumper" material must be installed several inches from the wall in the form of a "pup tent" over the lunar shelter.

Diaphragm Flammability Tests on Total Wall Composites with Flame/Gas Barrier Punctured: As can be seen by reviewing Table XI several materials which burn in 100 percent oxygen at 6.2 psia were considered as satisfactory candidates for the micrometeoroid barrier. Their selection was tentatively justified on the basis that only one nonburnable foam was available, and since they were to be located outside of the cabin area, the requirement for use of only Category A materials might be eliminated.

To further prove that in the event of a fire inside the structure no increased hazard would be imposed by the flammable foam, a series of special diaphragm flammability tests were conducted on the wall composite. These tests were designed to establish that the outer layer of burnable material exposed to a high vacuum would not ignite and propagate even if a small hole developed in the flame/gas barrier and structural layer and oxygen rich burning gasses were impinged upon the burnable material.

TABLE X. SUMMARY OF CANDIDATE STRUCTURAL LAYERS INVESTIGATED

Designation*	Description of Layers			Adhesive	Calculated Weight, lbs/ft ²
	Ply 1	Ply 2	Ply 3		
XSL-1	Yarn: 3 filaments of 0.0036 inch diameter 302 stainless steel wire; full hard interlaced with one strand of 200 denier Taslan Construction: 16 yarns/inch; perpendicular to hoop direction wrapped 70° clockwise of hoop	Yarn: Same as Ply 1 Construction: 16 yarns/inch; perpendicular to hoop direction wrapped 70° counterclockwise to hoop	Yarn: Same as Ply 1 Construction: 34 yarns/inch parallel to hoop. Wrapped in hoop direction	Goodyear AD917 (Polyester)	0.152
XSL-2	Same as above	Same as above	Same as above	Mosites #1066 (Fluorel)	0.161
XSL-3	Yarn: 3 filaments of Chromel R Wire 0.0035 inch wire interlaced same as above Construction: Same as above	Yarn: Same as XSL-3, Ply 1 Construction: Same as above	Yarn: Same as XSL-3, Ply 1 Construction: Same as above	Mosites #1066 (Fluorel)	0.175

*Candidate structural layer systems are denoted by the letters XSL.

TABLE XI. SUMMARY OF CANDIDATE MICROMETEOROID BARRIER SUBCOMPOSITES INVESTIGATED

Designation *	Description	Adhesive	Calculated Weight lb/ft ³
XMB-1	Al-4 White SE Flexible Polyester Foam 2 inches thick. Density 2 lbs/ft ³	None	.334
XMB-2	A structure composed of a five-sided element having four walls 0.18 in. thick spaced 2.5 inch on center lines and bonded on a 0.25 inch thick bottom. Overall height 2.0 in. Structure fabricated from 1.3 lbs/ft ³ Mosites #1062-C Fluorel Sponge.	Mosites #1066 (Fluorel)	.531
XMB-3	A composite of 29 plies of 0.068 inch polyurethane foam with a ply of 0.0005 inch aluminized Mylar between each ply of foam. Composite held in place with thread.	None	.434
XMB-4	Litoflex K20 Asbestos Foam 2 inches thick. Density 0.5 lb/ft ³ .	None	.083
XMB-5	55-Nitinol ^{**} wire (15-20mils) preformed wire. Bottom taped to a base of film cloth, Aclar/Fiberglass (Bonded to 0.25 inch of Fluorel sponge. Top taped directly to outer cover.	Mosites #1066 (Fluorel)	.436

*Candidate Micrometeoroid barrier subcomposites are denoted by the letters XMB.

**55-Nitinol designates a generic class of shape-recoverable alloys ranging in composition from about 52 to 56 weight percent Nickel, balance Titanium. For details, see NASA CR-1433.

TABLE XII. SUMMARY OF CANDIDATE OUTER COVER SUBCOMPOSITES INVESTIGATED

Designation*	Description of Layers			Adhesive	Calculated Weight lbs/ft ²
	Ply 1	Ply 2	Ply 3		
XOC-1	Bilaminate of 2 plies of 1/2 mil Capran, nylon film	Nylon cloth 0.82 oz/yd ² Stern & Stern Pattern A4787	Dow 92-007 White Thermal Control Paint - 4 mil thick 0.047 #/ft ²	Goodyear AD 917 (Polyester)	0.064
XOC-2	1 Mil Aclar Film	Fiberglass 116 Volan A Finish	Same as above	Mosites #1066 (Fluorel)	0.090

* Candidate Outer Cover Subcomposites are denoted by the letters XOC.

TABLE XIII. SUMMARY OF CANDIDATE TOTAL WALL COMPOSITES INVESTIGATED

Designation	General Construction	Flame/Gas Barrier	Structural Layer	Micrometeoroid Barrier	Outer Cover	Adhesive	Calculated Weight, lbs/ft ²
XTC-1	Figure 62. Sheet 1	XPB-14A	XSL-1	XMB-1	XOC-1	Goodyear AD917 (Polyester)	0.843
XTC-2	Figure 62. Sheet 1	XPB-14A	XSL-3	XMB-2	XOC-2	Mosites #1066 (Fluorel)	1.097
XTC-3	Figure 62. Sheet 2	XPB-14A	XSL-3	XMB-3	XOC-2		1.000
XTC-4	Figure 62. Sheet 2	XPB-14A	XSL-3	XMB-4	XOC-2		0.649
XTC-5	Figure 62. Sheet 3	XPB-14A	XSL-3	XMB-5	XOC-2		1.002
XTC-6	Figure 62. Sheet 3	XPB-14A	XSL-3	*	XOC-2	Mosites #1066 (Fluorel)	0.674
* 0.10 inch Mosites #1062-C Fluorel Sponge included for abrasion protection, and partial micrometeoroid protection.							

The tests were conducted on XTC-1, XTC-2, XTC-3, and XTC-4. The procedures were the same as those outlined under the flame/gas barrier development section with the exception that a small 1/8-inch diameter hole was punched in the center of the test specimen through the flame/gas barrier and structural layer. In order to prevent leakage prior to ignition, a layer of masking tape was placed over the hole. This material quickly burned away as soon as ignition of the igniter took place and provided an opening through which the burning igniter gasses and oxygen were drawn.

Examination of the samples during and following testing indicated that damage was limited to an area directly in contact with the hot gas plume which extended from the opening in the wall. This limited damage, however, resulted only so long as the vacuum was maintained or oxygen pressure buildup was maintained below 2 psia in walls where polyester foam was used. In the case of XTC-4, higher oxygen back pressures did not increase damage. The extent of damage which occurs when these conditions are met can be seen in the photograph taken of the samples after testing (Figure 42).

Selection of Final Wall Designs for Qualification: Final wall designs were selected on the basis of considerable information and test data gathered during the course of the program. The final wall design concepts selected by NASA for qualification were XTC-4 and XTC-6. An attempt is made in Table XIV to provide the primary basis for elimination of the various candidate elements and total composites which were considered earlier. Other considerations, such as ease of fabrication and cost, were also used as the basis for selection and are discussed further in this report in the subsection entitled "Definition of Structure Fabrication Techniques (Fabrication Logic)".

Composite Materials Qualification Tests (4-Element)

General. - The two selected total wall composites, XTC-4 and XTC-6, were subjected to a series of tests selected for qualifying them for "flight" unit applications. A summary of the tests performed as part of this qualification phase is presented in Table XV.

Flammability. -

Upward Flame Propagation Rate: As indicated in Table XV, it is considered essential that the XPB-14A flame/gas barrier subcomposite meet the requirements of MSC-D-NA-0002, Test No. 1, Upward Propagation Rate Test conducted in 100 percent oxygen at 6.2 psia. Tests conducted during the screen development phase by GAC (Table VII) and NASA-WSTF (Table IX) certified that the composite self-extinguished after extinguishment of the igniter in considerably less distance than the allowable 0.5 inch.

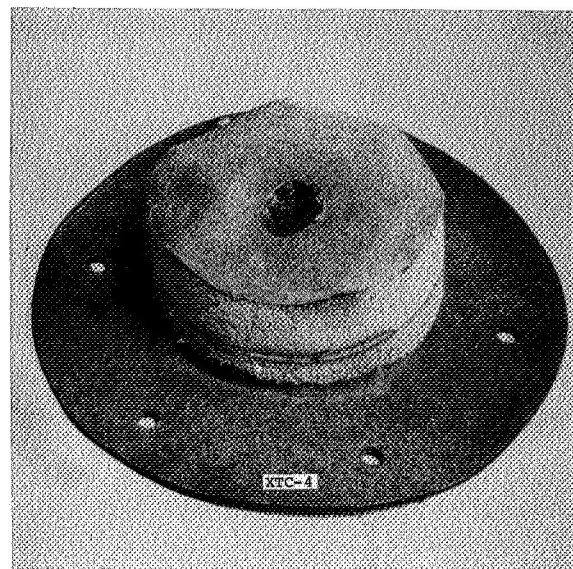
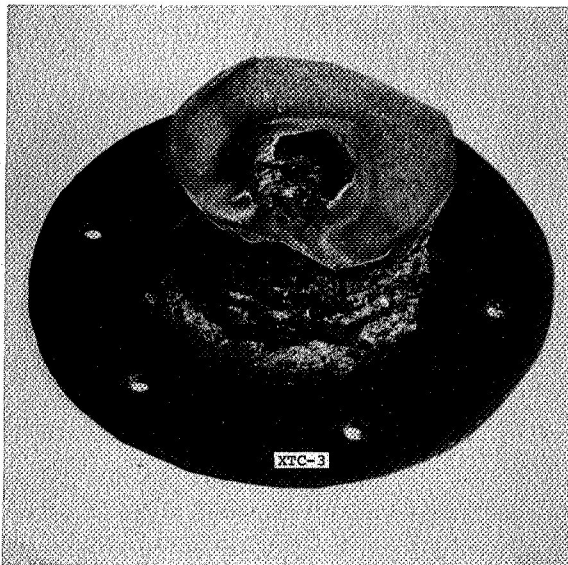
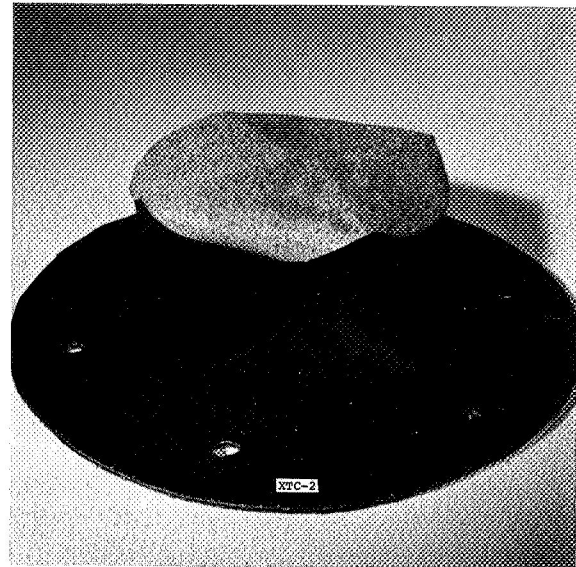
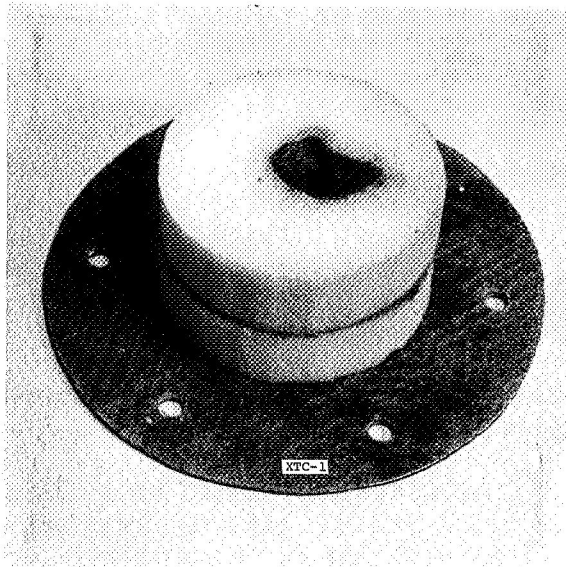


Figure 42. Various XTC Specimens After Damaged Flame/Gas Barrier Test

TABLE XIV. BASIS FOR CANDIDATE SUBCOMPOSITE AND TOTAL WALL COMPOSITE ELIMINATION

Candidate		Primary Reason For Elimination As Candidate	Failed Upward Propagation Flammability Test	Failed Diaphragm Flammability Test	Slightly Heavier Than XPB-12 and Less Abrasion Resistant	Thicker Outer Aluminum Foil Layer Required	Heavy; Providing Only Single Gas Barrier Layer	Heavy; Good Flame Barrier But No Bond Between Plies Provided	Rearrangement of Plies Six and Seven Thought Desirable	Adhesive System Not Found Superior to #1066 Mosites	Highly Flammable Adhesive System	Stainless Steel Wire Considered Less Flame Resistant than Chromel R	Flammable in 100% Oxygen at 6.2 psia	Higher Degree of Flammability Than XOC-2	Eliminated In Favor of XTC-4 and XTC-6	Selected for Qualification
Flame/Gas Barrier	XPB-1		x													
	-2		x													
	-3		x													
	-4															
	-5		x													
	-6		x													
	-7			x												
	-8			x												
	-9			x												
	-10			x												
	-11				x											
	-12					x										
	-13			x												
	-14							x								
	-14A															x
	-15									x						
	-16							x								
	-17			x												
	-18			x												
	-19			x												
	-20			x												
	-21			x												
XPB-22								x								
Structural Layer	XSL-1										x					
	XSL-2											x				
	XSL-3															x
Micrometeoroid Barrier	XMB-1												x(a)			
	XMB-2												x			
	XMB-3												x(a)			
	XMB-4															x
	XMB-5												x			
Outer Cover	XOC-1													x		
	XOC-2															x
Total Wall Composite	XTC-1														x(b)	
	XTC-2														x(b)	
	XTC-3														x(b)	
	XTC-4															x
	XTC-5														x(b)	
	XTC-6															x

(a) Flammable in 100% Oxygen at 6.2 psia. However, considered to be acceptable since located outside cabin interior.

(b) See page 112 and Table XXII for additional information.

TABLE XV. SUMMARY OF QUALIFICATION TESTS PERFORMED ON FINAL CANDIDATES

Component Test	Flame/Gas Barrier, XPB-14A	Structural Layer, XSL-3	Micromet- eoroid Barrier, XMB-4	Outer Cover, XOC-2	Total Wall Composite,		Super-Insulation Blanket
					XTC-4	XTC-6	
1. Flammability 100% Oxygen at 6.2 psia a. Upward flame Propagation Test b. GAC Diaphragm Flammability Test	X X					X	(1)
2. Packageability a. Elastic Recovery; 75% compression for 30 days at 160°F b. Effect of Temperature on deployment force; -100°F to 75°F c. Single fold test; ability to unfold after 7 days at 160°F d. Effect of repeated creasing on gas impermeability			X		X X	X X X	(2)
3. Micrometeoroid Impact NASA-MSC-LRC Test					X (20 6"x6" specimens supplied to NASA)	X (20 6"x6" specimens supplied to NASA)	X (20 6"x6" specimens supplied to NASA)
4. Thermal/Vacuum Exposure; 5x10 ⁻⁶ mm Hg, 48 hours at 160°F	X						
5. Effluent Gas Analysis a. Odor b. CO c. Total Organics	X X X						
6. Ply Adhesion	X					X	
7. Effect of Thermal Shock; -320° F to 250° F					X	X	
8. Stress-Strain Properties -100°F to 250°F	X	X single strand @ 75°F	X				X
9. Taber Abrasion	X			X			
10. Tear Resistance	X						X
11. Puncture Resistance	X	X combined with flame gas/barrier				X	
12. Humidity Resistance					X	X	
13. Fungus Resistance					X	X(3)	
14. Blocking Resistance				X			
15. Solar Absorptance and Infrared Emittance Properties				X			
16. Thermal Conductivity					X	X	X
(1) Super-insulation blanket burns in 100% Oxygen at 6.2 psia - not required to pass Category A Test							
(2) Super-insulation considered very packageable - no problems anticipated in this area							
(3) Same material as used in XTC-6 evaluated							

GAC Diaphragm Flammability Test: In addition to successfully passing the upward flame propagation rate test, the XPB-14A flame/gas barrier, which is an essential element in both XTC-4 and XTC-6 wall composites, was required to pass GAC's Special Diaphragm Flammability Test. This test was described in detail in the section of this report entitled "Special Pressurized Diaphragm Tests". Data from several tests conducted under the screening phase on XPB-14 are reported in Table VIII. Results indicated that the material displayed excellent resistance to thermal damage.

Diaphragm flammability testing of the total wall was also undertaken for qualification purposes. Since the XTC-4 wall contains the same flame/gas barrier and structural layer elements as the XTC-6, only the XTC-6 was tested. Three identical specimens of XTC-6 were tested in accordance with standard procedures. Inspection of the specimens following testing indicated that damage was largely confined to the outer foil layer. Some discoloration of the Kapton layer was noted, but it remained gas tight. These results agreed with those obtained for the XPB-14 flame/gas barrier when tested alone.

Photographs of the samples following testing are shown in Figure 43. The outer cover temperature vs time curves, along with the measured maximum igniter flame temperature obtained during the tests, are presented in Figure 44.

Packageability. -

General: A series of tests were performed to establish that selected composite materials could satisfactorily undergo packaging and deployment. Also these tests were performed to gain additional insight into the temperature range over which the unit could be stored and deployed.

Elastic Recovery: The recovery after compression properties of Litoflex K20, Asbestos foam (XMB-4) was measured. Two-inch cube samples were compressed 75 percent and held for 7, 21, and 30 days at temperatures of 75°F and 160°F. Following each time period, the specimens were released and the time period required for 100 percent recovery was determined. The results of these tests are presented in Table XVI. Examination of the results indicate that the material displays excellent recovery characteristics.

Effect of Cold Temperature on Deployment: As demonstrated during the materials screening phase, the Fluorel sponge and adhesive elements in the XTC-4 and XTC-6 wall undergo transformation (T_g) at low temperatures which drastically increases modulus and reduces elongation properties. While this behavior is undesirable, it is inherent in the material and must be taken into consideration when considering deployment of the structure.

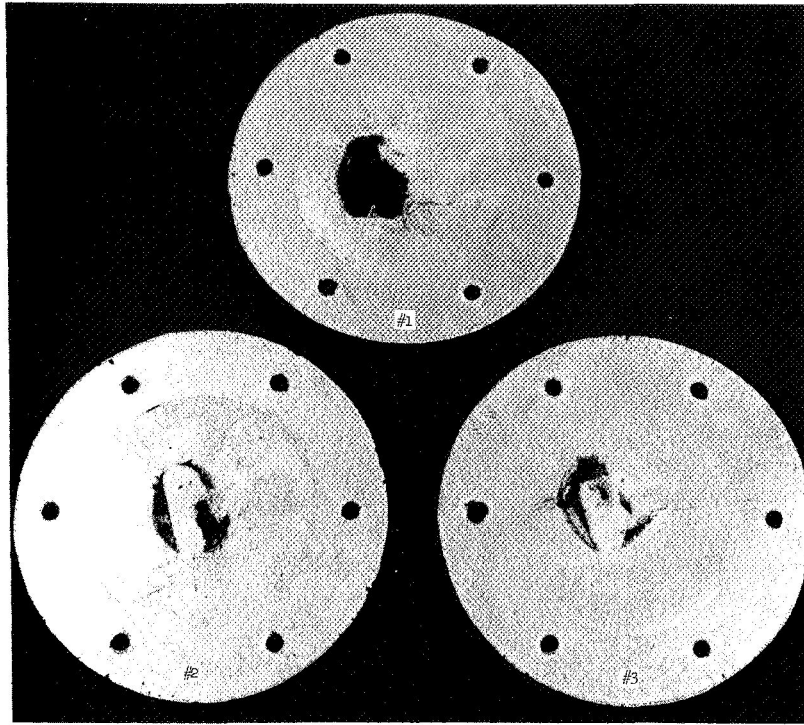


Figure 43. XTC-6 Wall Composite After Diaphragm Flammability Test

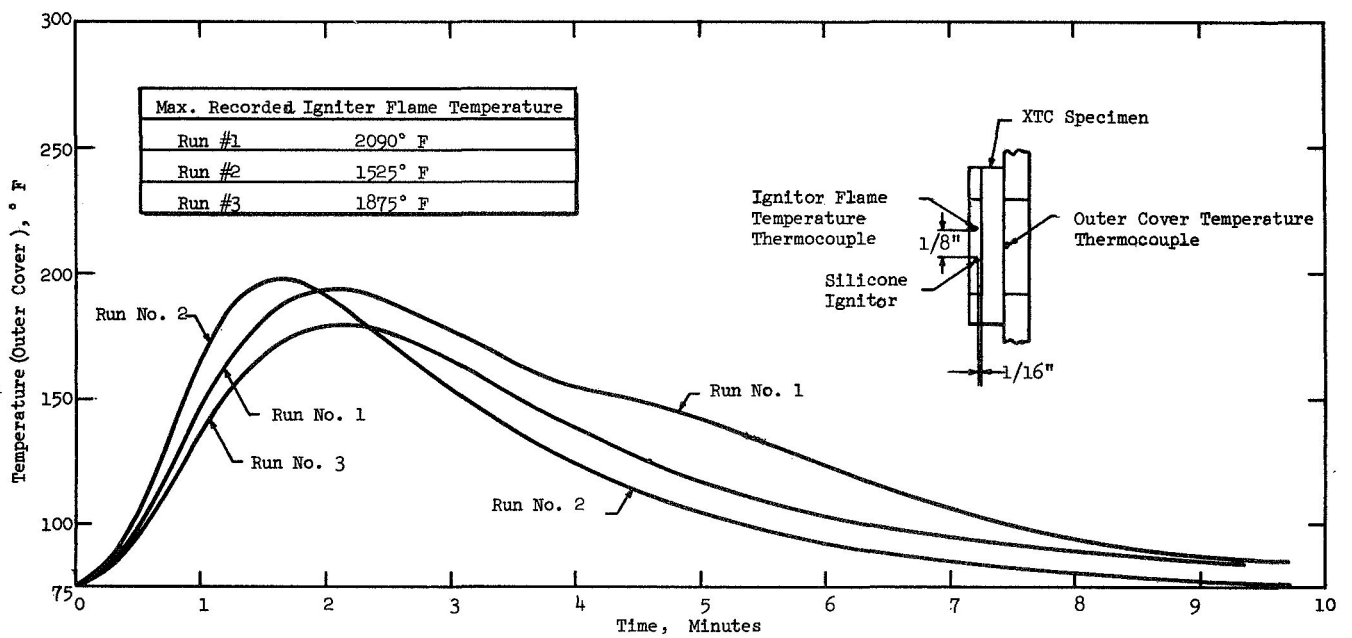


Figure 44. Outer Cover Temperature vs Time Curves Obtained During Diaphragm Flammability Testing

TABLE XVI: RESULTS OF COMPRESSION SET TESTS 2-INCH
LITOFLEX K20 ASBESTOS FOAM COMPRESSED 75%

Storage Time, Days	Storage Temp., °F	Degree of Recovery, %	Time Required for Recovery, Min.
7	160	100	5
7	75	100	<0.1
21	160	100	8
21	75	100	<0.1
30	160	100	15
30	75	100	<0.2

To evaluate the effect of temperature on deployment, two-inch wide specimens of XTC-4 (asbestos foam and outer cover removed for convenience in testing since properties of these materials are not affected by temperature) and XTC-6 were folded as shown in Figure 45. The samples were then placed in an Instron testing machine equipped with a temperature controlled oven and tested using a crosshead speed of 10 in./min. Using this procedure, the force required for deployment was determined as a function of degree of deployment for various temperature levels. A separate sample was used for each temperature condition.

The data obtained is presented in Figures 45 and 46. Examination of these results indicates that at 75°F both XTC-4 and XTC-6 wall materials are highly self-deployable requiring about 1 lb/inch to bring the sample to its straight configuration. As was expected when the temperature is reduced both wall materials tend to lose their self-deployment characteristics. By examination of Figures 44 and 45 the degree of self-deployment for any test temperature can be determined. In addition, the curves reveal the temperature at which the wall material becomes "frozen" and loses its tendency to self-deploy. At

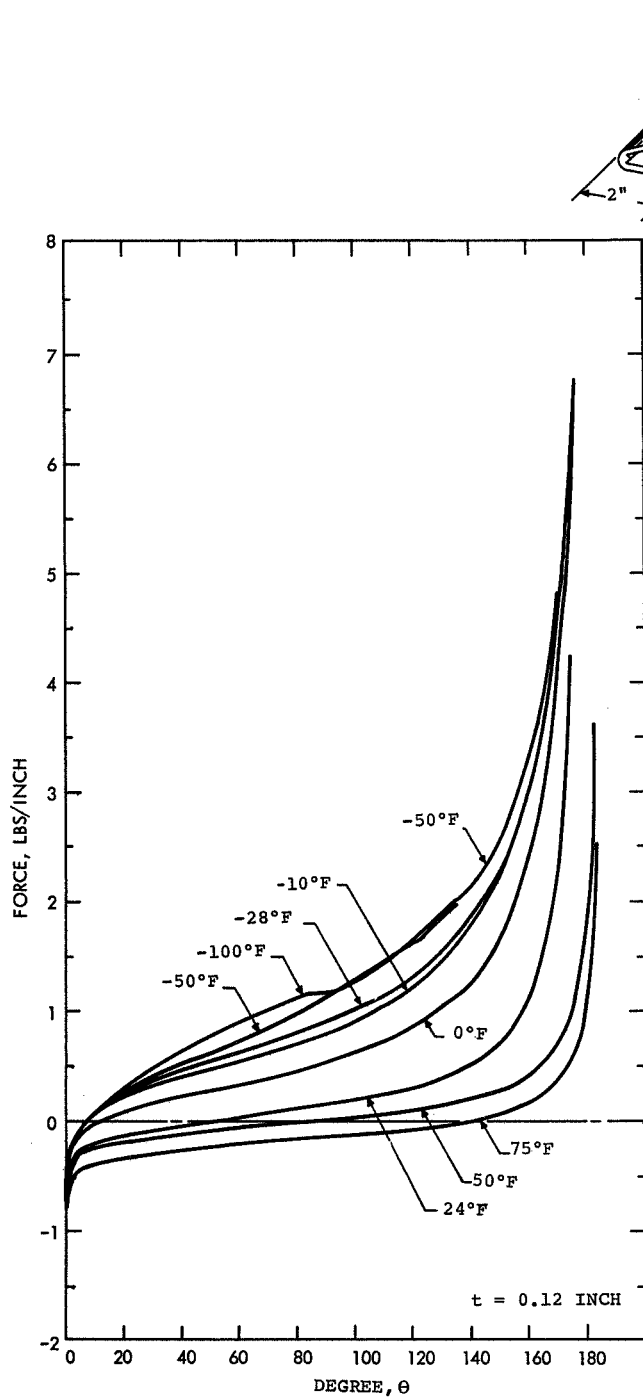


Figure 45. Effect of Temperature on Deployment Characteristics of XTC-4 Wall Composite (with Outer Cover and Asbestos Foam Layer Removed)

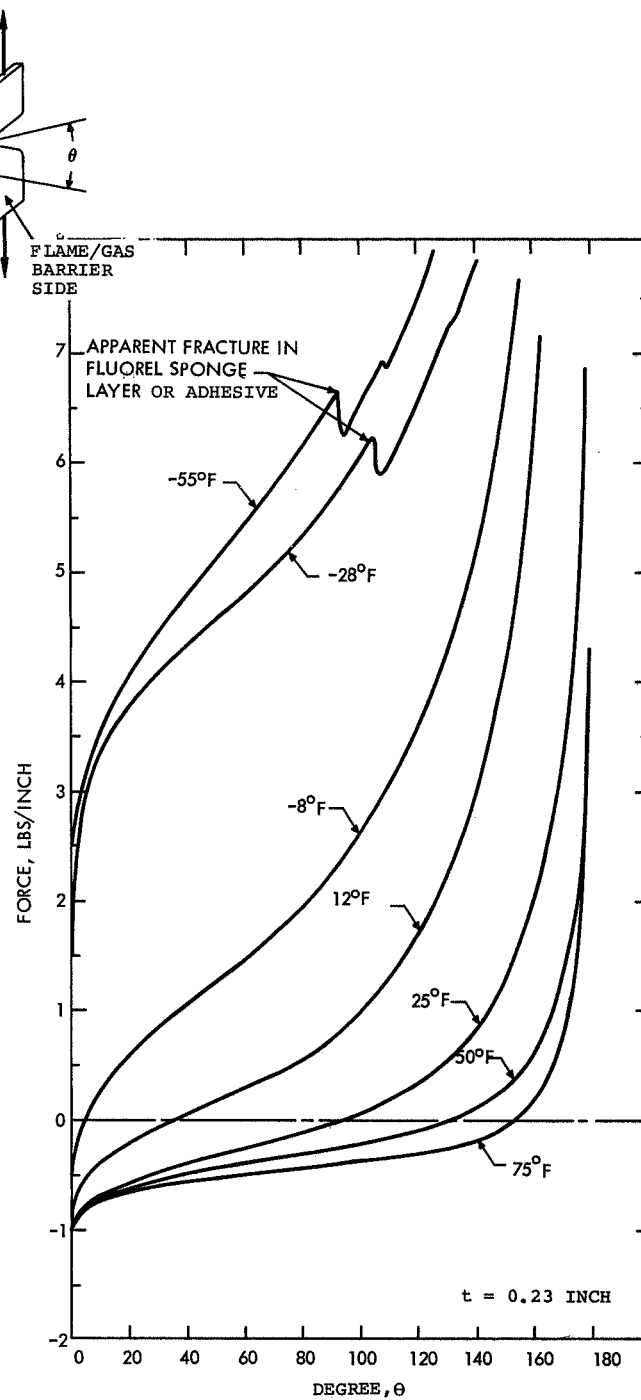


Figure 46. Effect of Temperature on Deployment Characteristics of XTC-6 Wall Composite

the "frozen" point deployment forces increases sharply and complete deployment is marked by possible fracture of the Fluorel adhesive and sponge materials. This behavior is clearly seen in curves for the XTC-6 wall and to a lesser degree in the XTC-4 curves.

Since the Fluorel sponge (Mosites #1062-C) is largely responsible for increase in stiffness as the temperature is lowered, examination of a plot of ultimate elongation characteristics as a function of temperature for this material appears to be in order. This data presented in Figure 47 was obtained from stress-strain measurements made during the screening phase. Because of the inherent nonuniformity of the sponge considerable scatter is present in the data. Because of this scatter upper and lower limits have been assigned to make the data more useful. Thus, it is assumed that for any one temperature average ultimate elongation values will vary about ± 12 to 15 percent as shown in Figure 47.

In attempting to assign some reasonable lower temperature limit for deployment of a structure fabricated from XTC-4 or XTC-6, consideration must first be given to determining what degree of strain will be imposed on the sponge during deployment. Since different degrees of strain will occur at various double-fold points, creases, etc., a nominal arbitrary value of 20 percent was selected for purposes of assigning temperature limit values. Using this strain value and Figure 47, it can be seen that cracking of the foam would not take place above -5°F . It may, however, occur between -5°F and -43°F and would fail if deployed below -43°F . Based on this reasoning, it is suggested that temperatures of -5°F or above should be provided for deployment if at all possible. Also, additional packaging and deployment tests, beyond the scope of the present effort, should be performed on a three-dimensional structure to establish minimum allowable temperature for both XTC-4 and XTC-6 wall materials.

Single Fold Test: Eight 2-inch wide x 14-inch long specimens of XTC-4 and XTC-6 composite were folded over on themselves along a line located at the mid-part of their length. Four from each group were folded with the outer cover exposed, and four were folded with the pressure bladder exposed. The specimens were then clamped between metal plates so that they were compressed to approximately $1/2$ -inch total thickness.

Following this preparation, two specimens from each group were exposed to 75°F and 160°F for 7 days. At the end of this period, the samples were examined to determine if blocking or degradation resulting from the tight packaging had taken place. Careful examination showed little blocking and no apparent degradation.

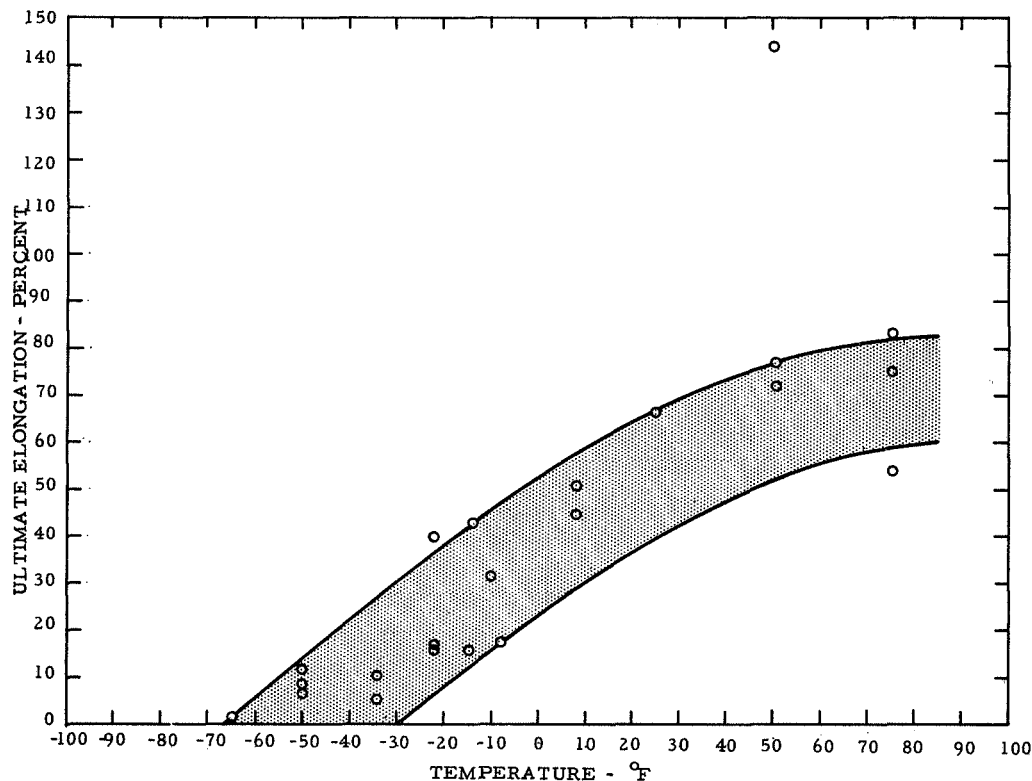


Figure 47. Ultimate Elongation vs Temperature Characteristics for Mosites #1062-C Fluorel Sponge

Effect of Repeated Creasing on Gas Impermeability: A foldability test was conducted on the XTC-6 composite without the outer cover. This test was to evaluate the packageability of the laminate.

Three specimens, 5-5/8 inches in diameter, were tested. The specimens were folded in half, and another fold was placed across the first. The specimen, now quartered, was placed under a 75-pound weight (6.2 psi compression crease load) for thirty seconds. The fold test was repeated five times and the permeability of helium was measured through the specimen. The test, conducted in the Cambridge Permeameter, was to determine whether or not the pressure bladder had ruptured. The total test saw each specimen exposed to thirty folds with permeability checks after each set of five.

The test results indicated that the outer aluminum foil of the flame/gas barrier fractured after five cycles, and bare yarns of the Refrasil cloth were exposed at ten cycles. After fifteen cycles, broken yarns of the Refrasil were evident. However, even after thirty flex cycles, the permeability tests on the composite showed no measurable leak.

Micrometeoroid Impact Tests. - Twenty 6 x 6-inch specimens of XTC-4 and XTC-6 wall composite and the super-insulation blanket material was supplied to NASA-MSC for micrometeoroid impact tests (see Figure 48).

Test data are included herein as Appendix F.

Thermal Vacuum Exposure. - Two 5 x 10-inch specimens of the XPB-14A flame/gas barrier subcomposite were installed in a special high vacuum oven system and maintained at a temperature of approximately 157°F for 48 hours under a vacuum of approximately 6×10^{-6} mm Hg.

Visual inspection of the specimen after exposure indicated that no delamination or other significant changes had taken place.

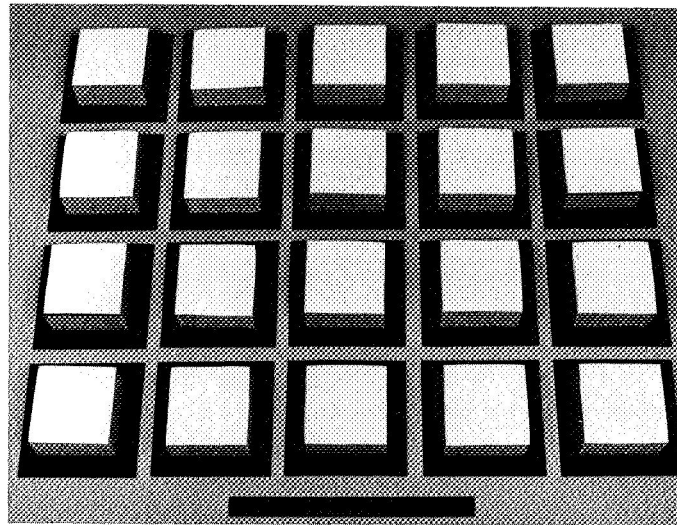
Effluent Gas Analysis. - XPB-14A specimens, processed using improved fabrication procedures (XPB-14A-1 Table IX), were tested by NASA-WSTF. These specimens successfully passed Test No. 6, Determination of Organic Offgassing Products and Carbon Monoxide, Reference 1.

Ply Adhesion. - Ply adhesion tests were conducted on the XTC-6 composite structure in accordance with Federal Test Method Standard 191 (5950).

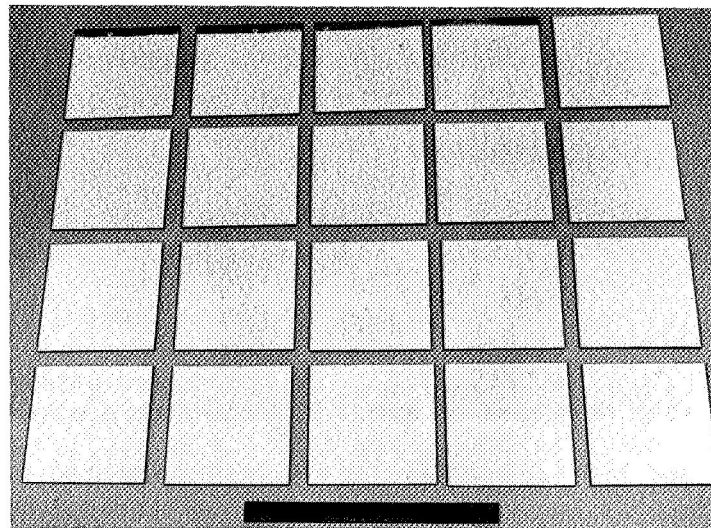
The specimens tested were two inches by twelve inches, and were peeled in an Instron testing machine at a rate of 12 inches a minute. The average of three specimens are shown in Table XVII. Of the eleven layers of adhesive, values of adhesion were obtained on six. Ply adhesion measurements could not be obtained between the 1/2-mil aluminum foil and Refrasil because the adhesive force was greater than the tear values of the foil. Kapton to Beta Cloth, and Beta Cloth to aluminum foil, values could not be determined because the Beta cloth frayed. Peel tests between the structural layer and the sponge resulted in tearing of the sponge. Also, measured values could not be obtained between Aclar film and 116 fiberglass in the outer cover because each test attempt resulted in the tearing of the film.

Thermal Shock Test. - The thermal shock test was conducted on the XTC-4 and XTC-6 specimens simultaneously. The purpose was to determine if sudden temperature changes have any effect on either delamination of the structure or damage to the individual plies.

The specimens were two inches wide by twelve inches long. The XTC-4 specimen had a thermocouple mounted in the foam. The XTC-4 specimen was attached to the XTC-6 specimen. A recorder was used in conjunction with the thermocouple to record temperatures within the limits of -100°F to 400°F.



XTC-4



XTC-6



Thermal Blanket

Figure 48. XTC-4, XTC-6, and Thermal Blanket Specimens Supplied to NASA-MSC for Micrometeoroid Impact Testing

TABLE XVII. SUMMARY OF PLY ADHESION TEST DATA

Element	Ply Identification	Mean Ply Adhesion lbs/inch
XPB-14	Aluminum Foil - 1/2 Mil	*
	Refrasil C-100-28	0.70
	Aluminum Foil - 1 Mil	1.45
	Aclar Film - 1 Mil	0.89
	Mosites Sponge - 50 Mils	1.47
	Kapton Film - 1 Mil	*
	Beta Cloth	0.85
	Aluminum Foil	1.27
	XSL-2	3 Plies of Chromel R Wire
Abrasion Layer	Fluorel Sponge - 100 Mils	0.68
XOC-2	11 Aclar Film	*
	12 Volan A 116 Fiberglass	
* Test data could not be obtained because film or foil tore, or fabric element frayed		

The test consisted of immersing the specimen in liquid nitrogen until boiling stopped. At this point the temperature of the specimens stabilized at the same temperature as the liquid nitrogen, -320°F. The specimens were removed from the liquid nitrogen and allowed to drain for one minute in a horizontal position. The samples were then placed in a Missimers oven set at 275°F. After 5 minutes the temperature rose above -100°F at which point the temperature was recorded until the specimen reached 250°F. The total cycle time was close to 15 minutes. Ten cycles were conducted.

Visual observation of the specimens revealed that:

- (1) The two-inch thick K20 Asbestos foam in the XTC-4 remained extremely flexible at -320°F . It acted much like a sponge, filling up with liquid nitrogen requiring a one minute drain time after each soak.
- (2) No delamination was evident in either the XTC-4 or XTC-6, nor was there any apparent damage to the outer plies or thermal control coating.
- (3) The 0.10-inch thick Fluorel sponge stiffened considerably in the XTC-6 configuration at -320°F .

Tensile Stress-Strain Properties. - Stress-strain data was obtained for the following:

- (1) XPB-14A Flame/gas barrier
- (2) Stranded Chromel R Wire
- (3) Thermal Blanket

The stress vs strain data generated for the XPB-14A was obtained using the same methods and temperature as described in the Tensile Stress Strain Screening Tests Section of this report. The curves are presented in Figure 49.

These data were then used to plot a curve of tensile strength at 3 percent strain vs temperature in order to more clearly define the effect of lowering temperature. This curve is presented in Figure 50. It can be seen from these data that lowering the temperature from 250°F to -100°F produces about a 60 percent increase in strength.

The Stranded Chromel R wire was tested at room temperature in the Instron machine. A gauge length of 10 inches and a load rate of 0.1 inches per minute was used. The test results are shown in Figure 51.

The super-insulation blanket was tested in tension. Two-inch wide specimens with a four-inch gauge length were pulled at a rate of 2 inches per minute. The results are presented in Figure 52.

Taber Abrasion. - Taber abrasion tests were conducted on the oxygen pressure side of XPB-14A and on the thermal coating side of XOC-2. The purpose of this test was to evaluate the durability of the material when the specimens were submitted to a rotary rubbing action under controlled conditions of pressure and abrasive action. Figure 53 is an illustration of the Taber Tester.

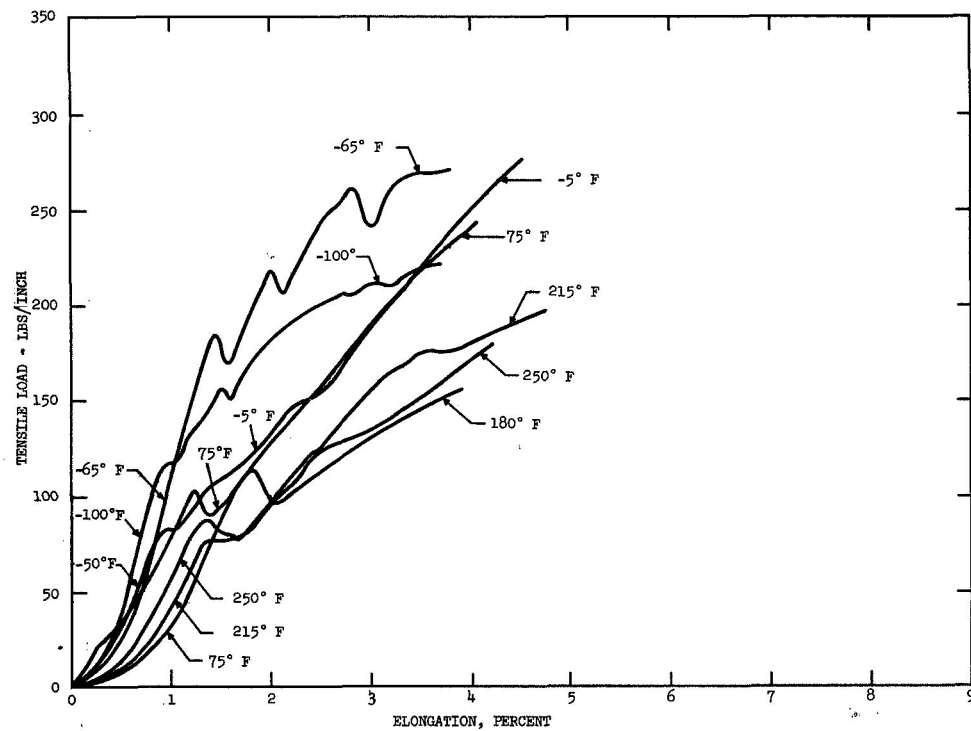


Figure 49. Tensile Load vs Elongation Curves for XPB-14A Subcomposite at Various Temperatures

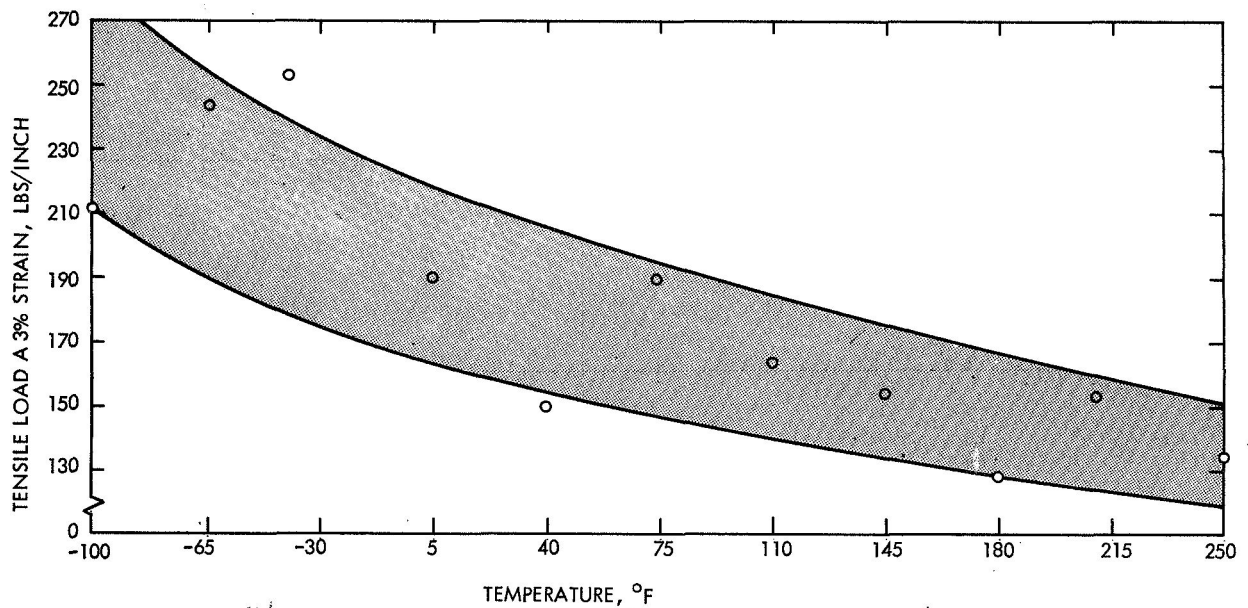


Figure 50. Effect of Temperature on Strength of XPB-14A Subcomposite

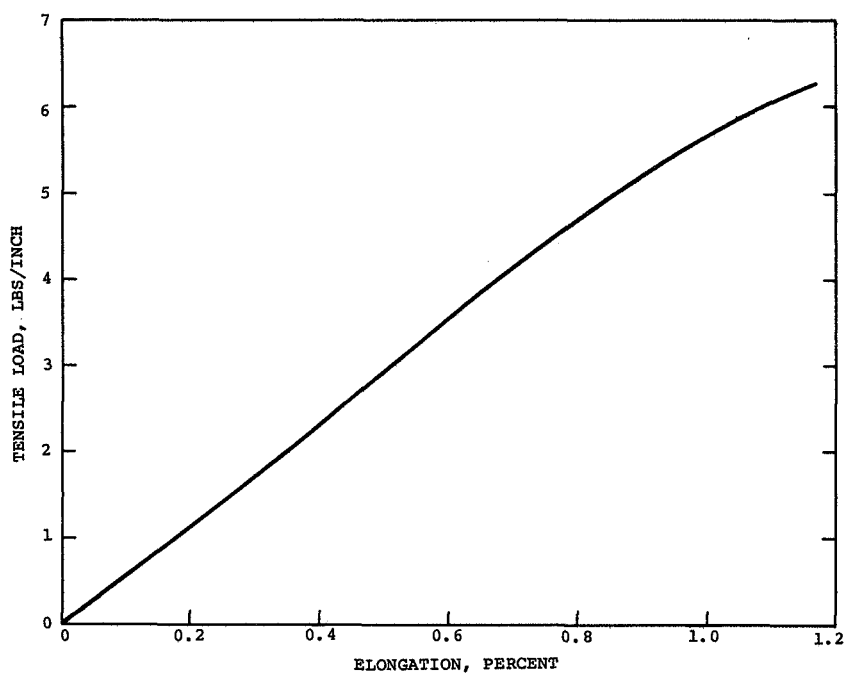


Figure 51. Typical Stress Strain Curve for Twisted 3-Strand 0.0035 Diameter Chromel R Configuration

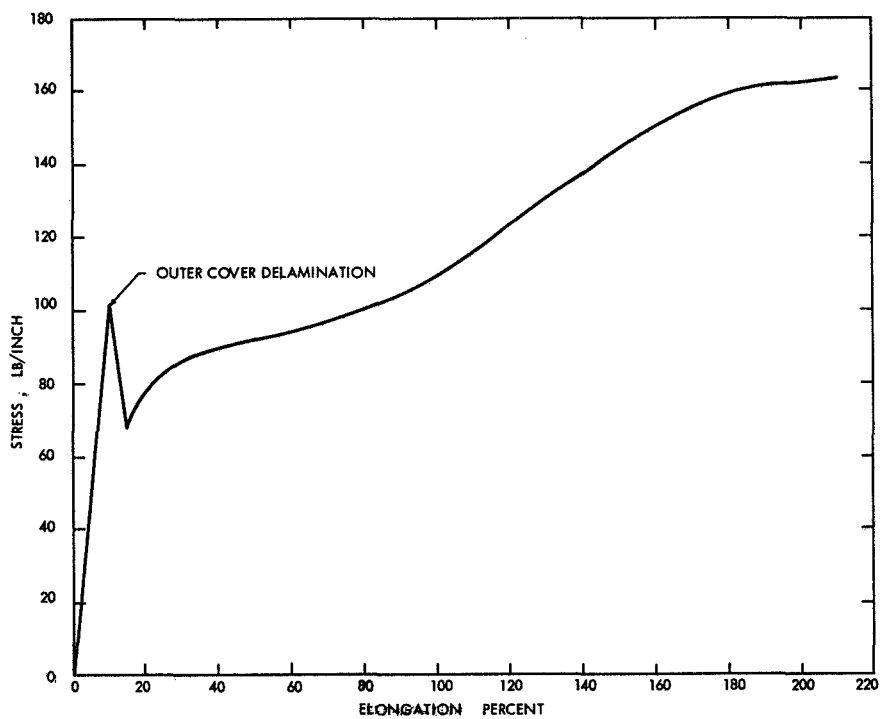


Figure 52. Typical Tensile Load vs Elongation Curve for Super-Insulation at 75°F

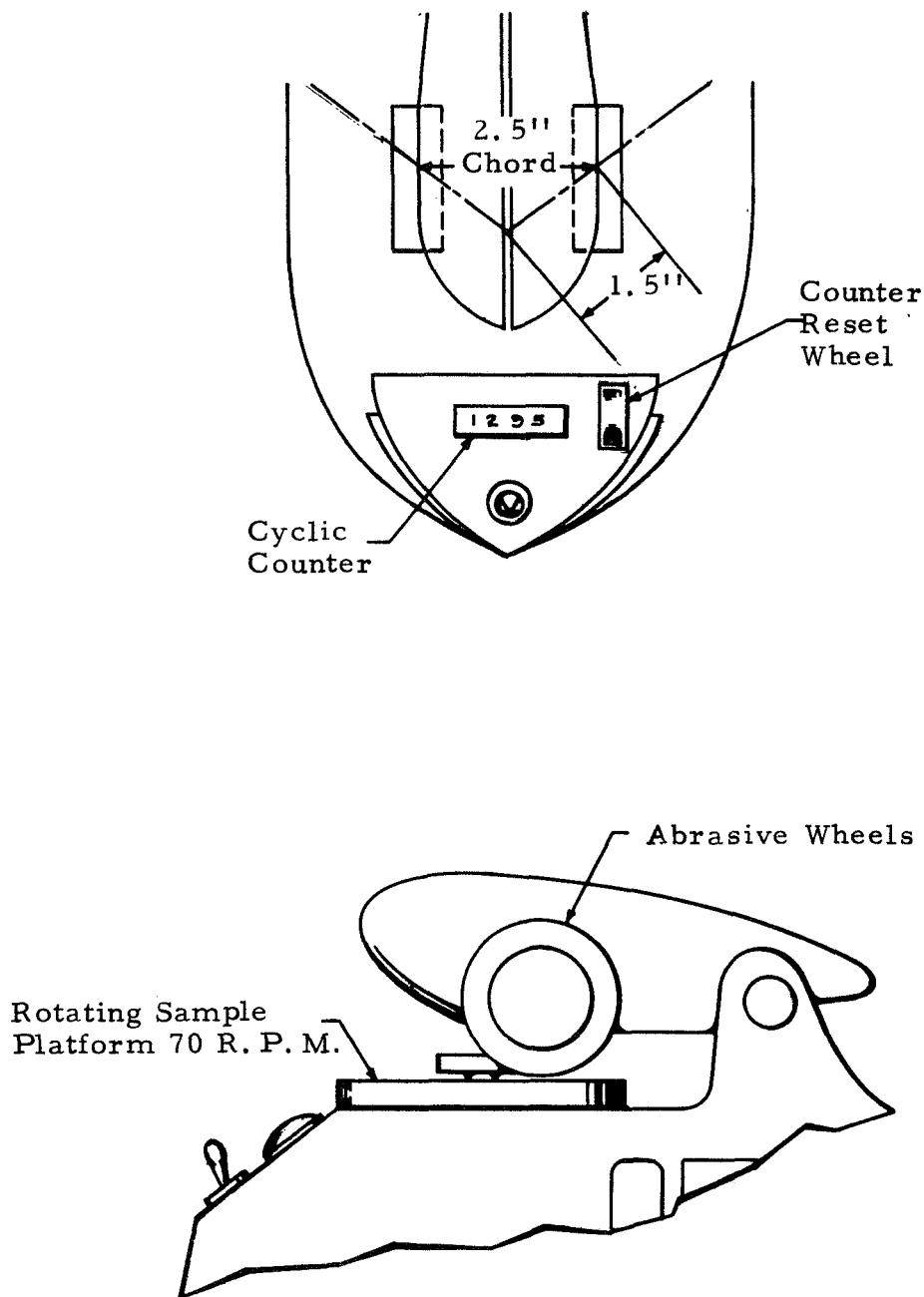
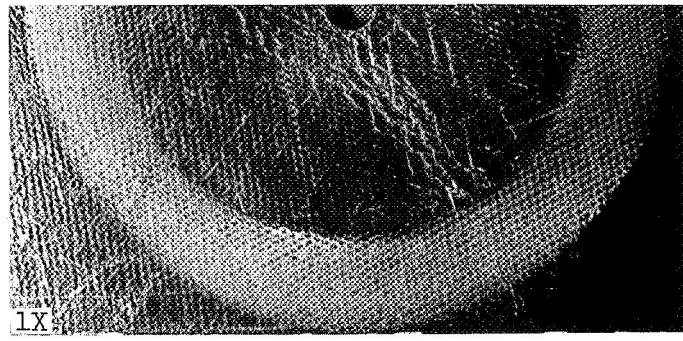
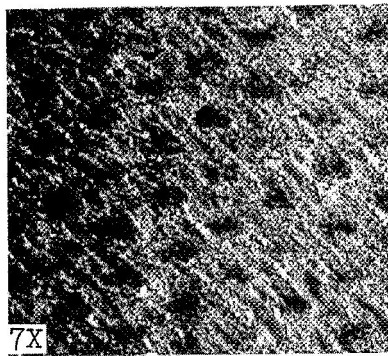
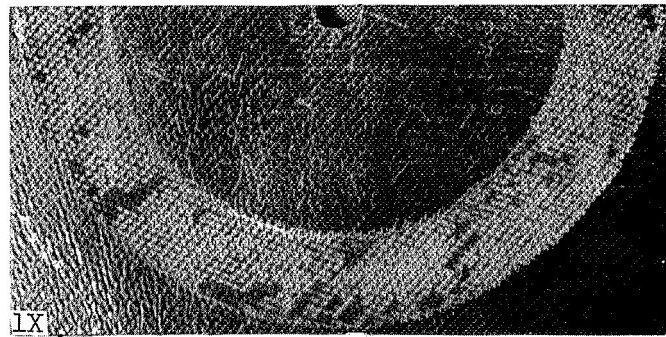
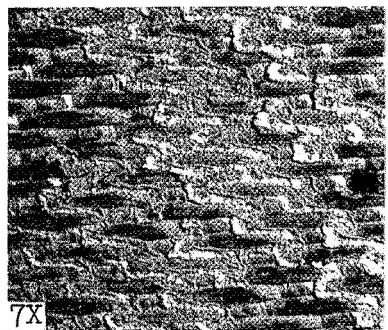


Figure 53. Taber Tester

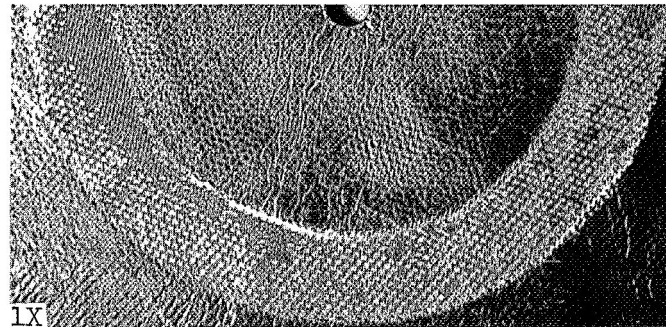
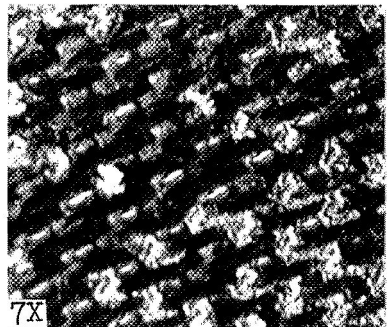
The test procedure for the XPB-14A was to first weigh the specimen and then place it on the rotating platform of the Taber tester. The abrasion wheels were lowered onto the specimen and the platform was rotated at 70 RPM for approximately 1000 cycles, at which time the specimen was reweighed. The sequence was repeated, and photographs were taken of the specimens after every 2000 cycles. These photographs are shown in Figure 54.



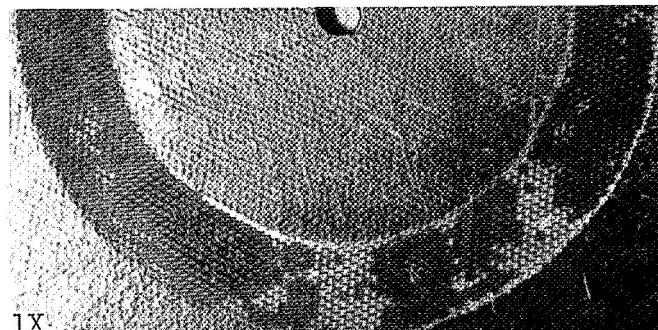
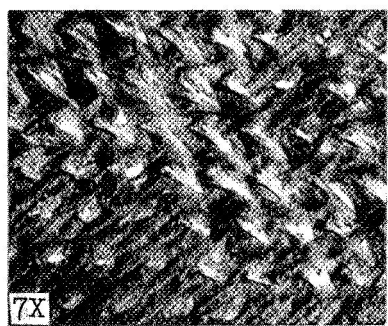
After 2000 cycles



After 4000 Cycles



After 6000 Cycles



After 8000 Cycles

Figure 54 Effect of Various Numbers of Taber Abrasion Cycles on XPB-14A Subcomposite Material

Two tests were conducted on the XPB-14A. The first utilized a CS 10 wheel with a 125 gram weight, and the other used a CS 17 wheel with a 500 gram weight. Two samples were used for each test. The test data were reported as weight loss vs number of abrasion cycles. The original weight of each specimen was used to calculate a weight per unit area. Using this value, a calculation was made to determine the weight of the 1/2-inch wide tracking area of each specimen. This weight was reported as the 100 percent value in each curve shown in Figure 55. The weight loss was converted into percent and plotted against the number of abrasion cycles. In the case of the XPB-14A the unit weight of the 1/2-mil aluminum foil was calculated as 2.7 percent of the subcomposite weight and was marked on the curves of Figure 55. As the abrasion cycles wore through the aluminum at the 2.7 percent datum line into the Refrasil the slope of the curve increased noticeably. The other point of interest was the minute difference in the test results using the CS 10 wheel and 125 gram load vs using CS 17 wheel and 500 gram load.

The procedure for the abrasion test conducted on the thermal control coating of the XOC-2 laminate was similar to the XPB-14A. The specimens were weighed before and after every 3000 cycles. Before each weighing, these specimens were washed and baked in an oven for 15 minutes. The data are presented in Figure 56 in the same manner as that described for the XPB-14A tests. Photographs of the tests are presented in Figure 57. The thermal control coating performed impressively in that it lost only 23.5 percent of the 53 percent, or less than half of the total coating weight after 12,000 cycles.

Tear Resistance. - The resistance to "Puncture-Propagation of Tear" was measured by NASA-LRC. A Puncture-Propagation Tear Tester, Model 83-5, manufactured by Testing Machines, Inc., Amityville, New York, was used in accordance with ASTM Standard D2582-67.

The materials tested were XPB-14A (Table VI) and the super-insulation. The specimens were cut in a rectangular shape approximately 8 inches in the direction of tear and were conditioned at $73.4 \pm 3.4^{\circ}\text{F}$ and 50 percent ± 5 percent relative humidity in accordance with Procedure A of ASTM Method D618 prior to testing.

The Model 83-5 tester (Figure 58), consists of:

- (1) Carriages of different weights, each with a sharp-pointed probe
- (2) Test stand
- (3) Carriage release mechanism
- (4) Calibrated scale

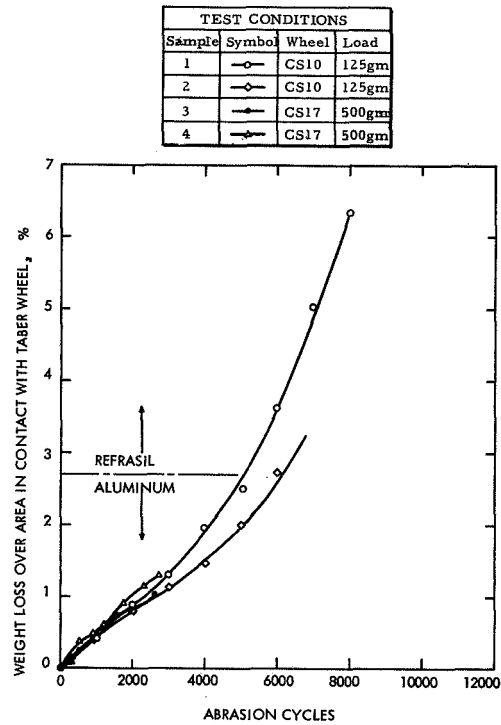


Figure 55. Weight Loss vs Taber Abrasion Cycles Curves for XPB-14A Subcomposite

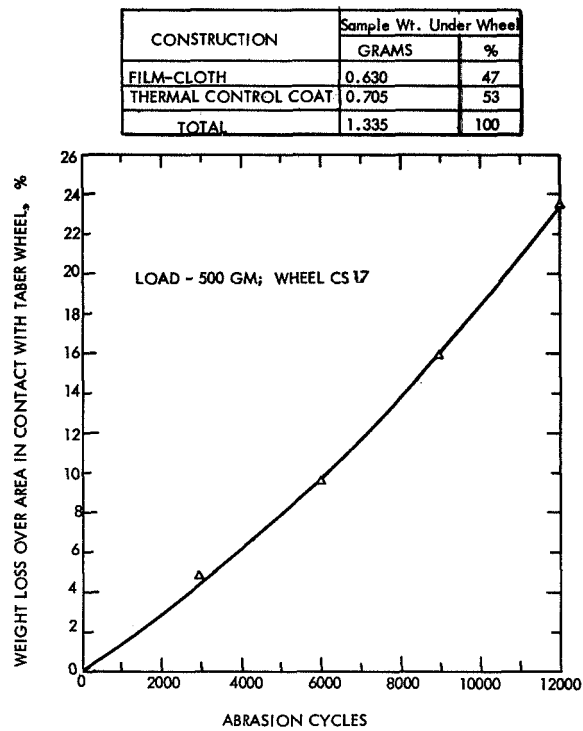
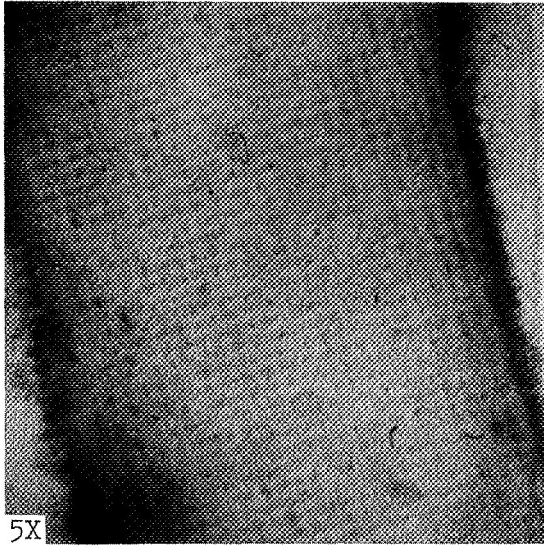
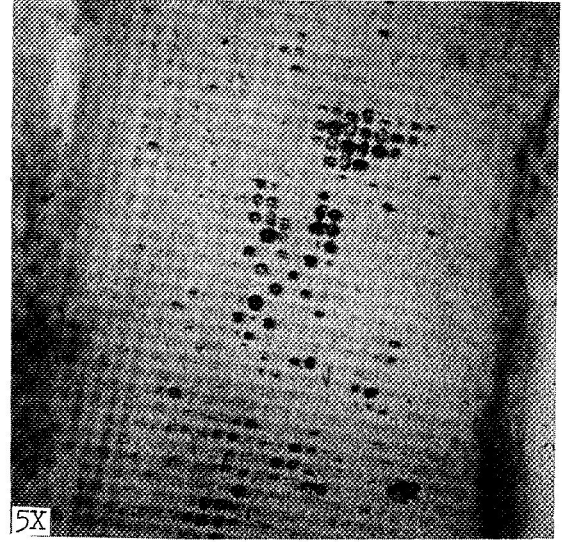


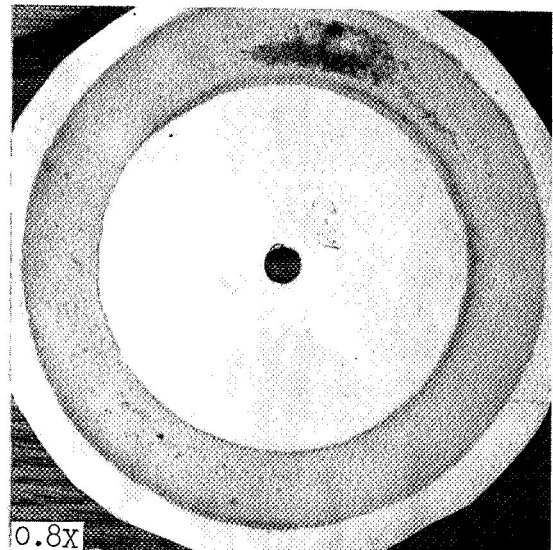
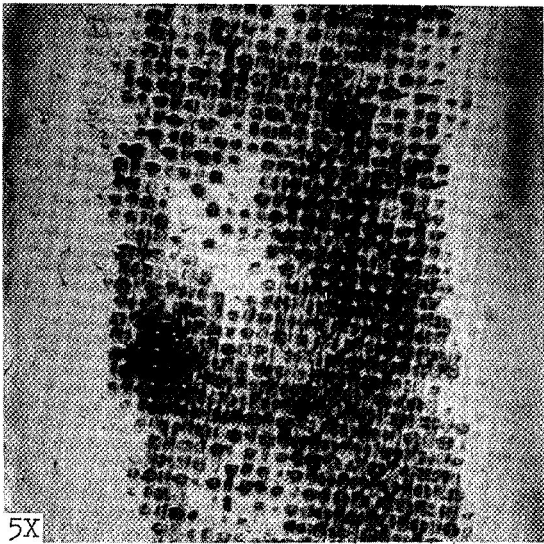
Figure 56. Weight Loss vs Taber Abrasion Cycles Curves for XOC-2 Subcomposite



After 6000 Cycles



After 9000 Cycles



After 12,000 Cycles

Figure 57 Effect of Various Numbers of Taber Abrasion Cycles on XOC-2 Subcomposite

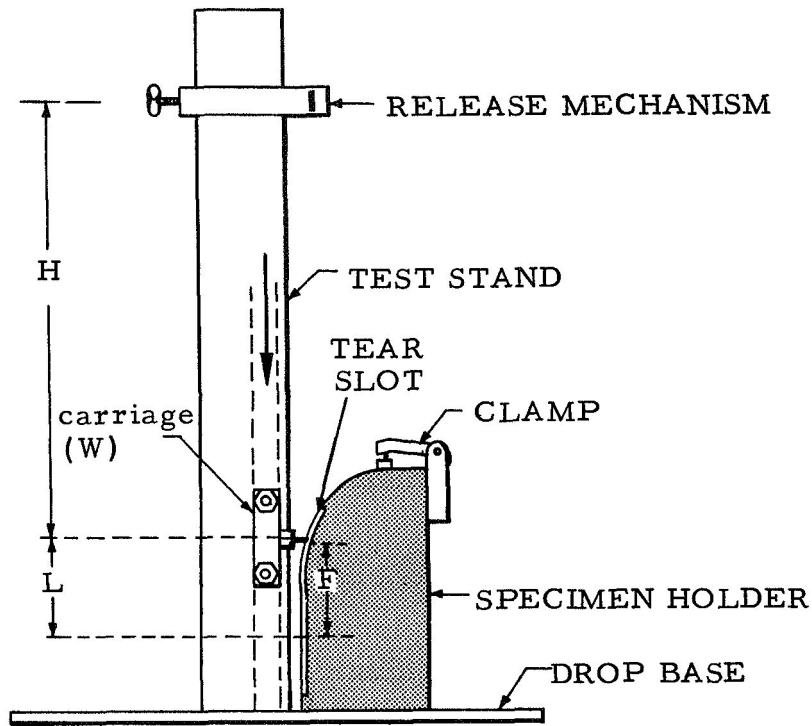


Figure 58. Puncture-Propagation of Tear Tester

- (5) Curved specimen holder with a tear slot and five clamps
- (6) Drop base with a guide channel to accommodate the carriage wheels
- (7) Spirit level to level base

The test procedure was to attach the carriage to the carriage release mechanism at the top of the test stand. The specimen is then inserted on the curved specimen holder and clamped into position. After the carriage is released, it falls a distance (H), 20.0 inches, before the carriage probe contacts the specimen. The tear length (L) is the distance in which the carriage comes to rest after contact with the specimen. Reference 35 requires (L) to be within the limits of 1.57 inches (4 cm) and a maximum in which the carriage does not bottom-out against the drop base. This is accomplished by selecting the proper weighted carriage by means of trial and error. The probe on each carriage is identical and is fabricated from a 0.125 inch diameter drill rod. One end is a truncated cone with a short base diameter of 0.016 inches and an included angle of 30 degrees. This configuration allows the body of the probe to propagate most of the tear.

The number of tears per specimen is dependent upon the width of specimen. A minimum of one inch must exist between tears for valid results.

The resistance to tear propagation is calculated by equating the potential energy of the system to the work required to bring the system to rest which is:

$$\text{Potential Energy} = \text{Arresting Work}$$

$$W(L + H) = FL$$

where:

W = Weight of carriage, lbs

L = Length of tear, inches

H = Height of drop to point of initial tear, inches

F = Force exerted by probe to propagate tear, lbs

To solve for F results in the following:

$$F = \frac{WH}{L} + W$$

In order to prevent reporting significantly different values due to the use of different carriages, the tests are normalized to the one pound carriage. This is accomplished by adding the Normalizing Factor (N_F) to the equation:

$$F = \frac{WH}{L} + W + N_F$$

The following is a sample calculation representing the third test run of the XPB-14A material.

Normalizing Force Data Obtained from Figure A-1 (Ref. 33)

Carriage Weight		Normalizing Factor	
Pounds	Kilograms	Kilograms	Pounds
1	0.4536	0.000	0.000
2	0.9072	-1.3891	-3.062
3	1.3608	-2.8677	-6.322

$$F = \frac{W \times H}{L} + W + N_F$$

$$F = \frac{(3.0 \text{ lbs})(20 \text{ inches})}{(2.053 \text{ inches})} + 3.00 \text{ lbs} - 6.322 \text{ lbs}$$

$$F = 25.900 \text{ lbs}$$

It should be noted that the XPB-14A had two valid tests in either the MD or XM direction of fabrication, and one valid test in the other. The directions were not identified. The test data indicated a difference of 15 percent between the two directions.

Table XVIII is a tabulation of the test data and results.

Puncture Resistance. - Puncture tests were conducted on the following materials:

- (1) XPB-14A
- (2) XPB-16
- (3) XPB-5 plus XSL-1
- (4) XPB-14 plus XSL-1
- (5) XTC-6

The procedure for the puncture tests were similar to the one described in Reference 36. The specimens, 6.5 inches diameter, were clamped in a specially fabricated puncture fixture such that 4.5 inches of the diameter was exposed. Next the fixture was placed on the compression cell of an Instron test machine. A Phillips Head screw driver, No. 4 point, was mounted to the Instron's crosshead. The crosshead was operated at a rate of 10 inches per minute. Figure 59 illustrates the test set up, before puncture and after puncture. The test results are reported in Table XIX.

Humidity Test Effects. - An environmental humidity test was conducted on XTC-4 and XTC-6 in accordance with MIL-STD-810B Method 507, Procedure I.

The purpose of the humidity test was to determine the resistance of the candidate XTC composites to the effects of exposure to a warm, highly humid atmosphere. The procedure which follows is an accelerated environmental test.

TABLE XVIII. TEST DATA AND RESULTS FOR RESISTANCE
TO PUNCTURE-PROPAGATION OF TEAR

Material	NASA Run No.	Carriage Weight (W) lbs	Drop Height (H) inches	Tear Length (L) inches	Tear Propagation Force (F) lbs
XPB-14A	3	3	20	2.047	25.9
XPB-14A	5	3	20	<u>1.811</u>	<u>32.7</u>
				Avg 1.979	Avg 29.3
XPB-14A	6*	3	20	2.160	24.9
Super- Insulation Blanket	1	2	20	3.031	12.064
Super- Insulation Blanket	2	2	20	2.913	12.599
Super- Insulation Blanket	3	2	20	2.362	15.803
Super- Insulation Blanket	4	2	20	3.189	11.413
				<u>Avg 2.874</u>	<u>Avg 12.599</u>

* Test was conducted on specimen perpendicular to Runs 3 and 5

The XTC samples were 12 inches x 12 inches with XOC-1 used as an edge closure bonded around the four sides. The purpose of the edge closure was to seal the specimens such that the inner pressure side and the outer cover only would be directly exposed to the humidity test as in the case of the Lunar Shelter.

The specimens were placed in the test chamber under ambient conditions. The internal chamber temperature was gradually raised to 160°F and the relative humidity (RH) to 95 percent over a period of two hours. The 95 percent RH and

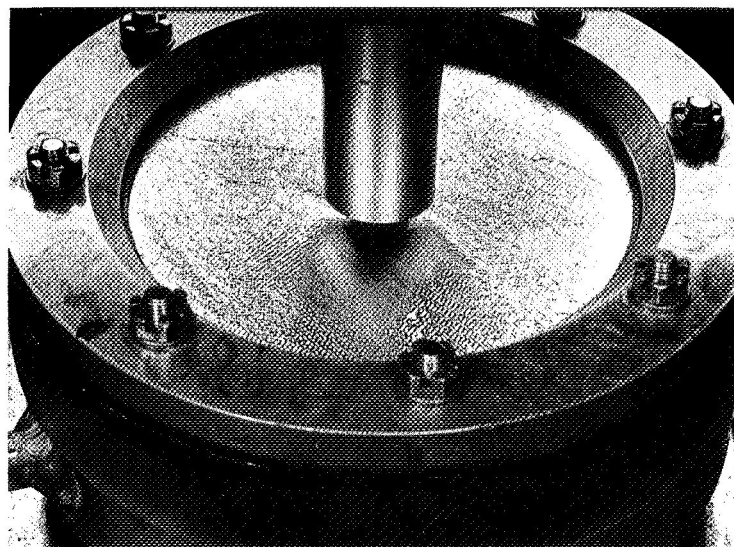
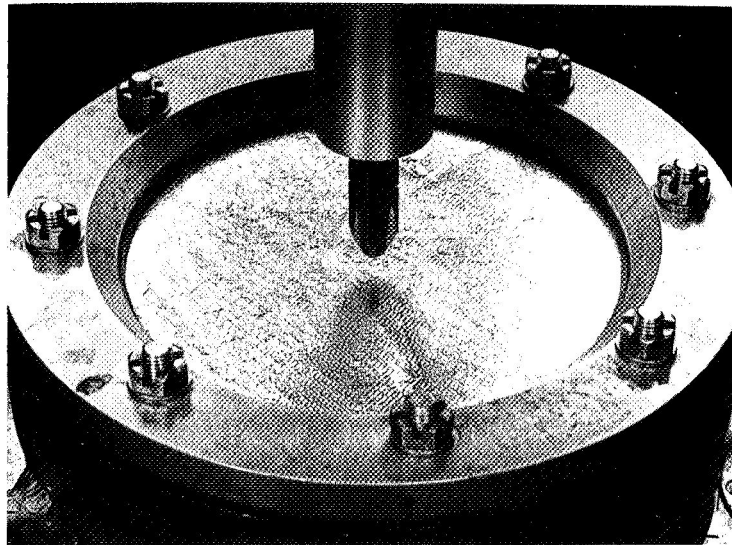
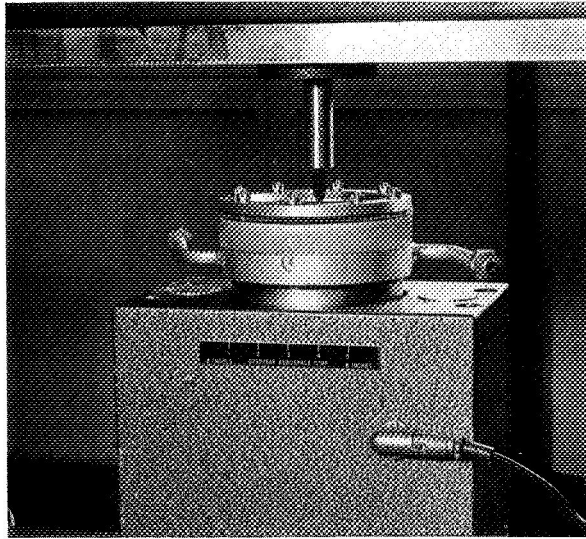


Figure 59 Puncture Resistance Test Sequence

TABLE XIX. SUMMARY OF PUNCTURE RESISTANCE TESTS

<u>Material Type and Designation</u>	<u>Puncture Load[*], Lbs</u>
Flame/Gas Barrier	
XPB-14	30.0
XPB-14	27.0
XPB-14	29.2
XPB-14	30.5
XPB-14	27.2
XPB-14	28.1
Average	<u>28.7</u>
XPB-16	13.0
XPB-16	15.7
Average	<u>14.4</u>
Flame/Gas Barrier + Structural Layer	
XPB-5 + XSL-1	49.0
XPB-5 + XSL-1	54.5
XPB-5 + XSL-1	53.0
Average	<u>52.2</u>
XPB-14 + XSL-1	68.0
XPB-14 + XSL-1	68.2
XPB-14 + XSL-1	73.5
XPB-14 + XSL-1	72.3
Average	<u>70.5</u>
XPB-15 + XSL-1	70.3
XPB-15 + XSL-1	71.5
Average	<u>70.9</u>
Total Wall Composite	
XTC-6	66.5
XTC-6	67.5
XTC-6	68.5
Average	<u>67.5</u>

* Punctured from flame/gas barrier side except in the case of XTC-6 which was punctured from outer cover side.

160°F exposure was maintained for six hours. The next step was to reduce the temperature to 82°F while keeping the RH at 85 percent or above. The 78°F drop was completed over a 16 hour period thus completing the 24-hour cycle. A total of 10 cycles were conducted on the samples. The cycle description is presented in Figure 60.

Upon completion of the test, the specimens were examined. An end closure in each specimen was cut for an internal view of the structure. The visual inspections before and after testing revealed no indications of failures after the removal from the test chamber.

Fungus Resistance. - The fungus test was conducted on XTC-1, XTC-2, XTC-3 and XTC-4 in accordance with MIL-STD-810B, Method 508.

The purpose of the fungus test was to determine the resistance of the XTC composite materials to fungi and to determine if such composite materials are adversely affected by fungi under conditions favorable for their development, namely high humidity, warm atmosphere, and the presence of inorganic salts.

One one-inch square specimen from each XTC composite was tested. In addition, a number of known susceptible substrates were inoculated along with the test items to ensure that proper conditions were present in the incubation chamber to promote fungus growth.

The test included exposing the test specimens and controls to the following five fungi in accordance with MIL-STD-810B, Method 508.

Aspergillus niger

Aspergillus flavus

Aspergillus versicolor

Pencillium Funiculosum

Chaetomium globosum

The test and control items were mounted in the test chamber and pre-conditioned for four hours at 84°F and 95 percent relative humidity. The items were then sprayed with the mixed fungus spore suspension. Immediately after the inoculation, the 28 day incubation period followed. After 14 days the items were inspected. Since the control specimens showed an abundant growth of fungus, the test was continued. The test results are shown in Table XX.

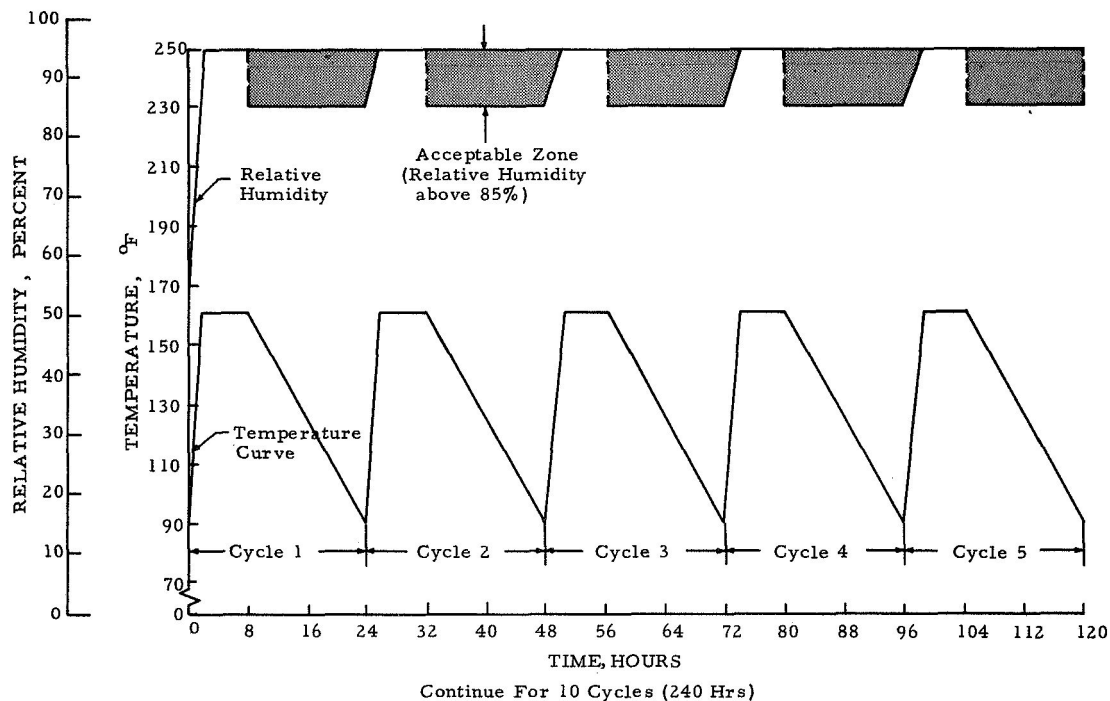


Figure 60. Humidity and Temperature Cycles as a Function of Time MIL-STD-810B, Method 507, Procedure 1

Table XX. Fungus Resistance Test Results

<u>Sample Designation</u>	<u>Results (After 4 Weeks)</u>					
XTC-1	Traces of growth less than 10%					
XTC-2	"	"	"	"	"	"
XTC-3	"	"	"	"	"	"
XTC-4	"	"	"	"	"	"

Comments

All specimens showed sparse fungal growth on foam and cover surfaces. However, microscopic examination showed no deterioration, corrosion or visible change other than partial delamination of the cover on XTC-1. This delamination did not appear to be due to fungal growth -- more likely it is a result of the high humidity.

Blocking Resistance. - The blocking test was conducted to determine if the thermal conductive coating on the XOC-2 material would adhere to itself during the packaged state.

Six samples were prepared, and under a compressive load of 5.0 pounds per square inch, were exposed to 160°F. Three samples were removed after 48 hours and examined. The remaining samples were removed and examined after 168 hours.

Test Results: Within a half hour after removing both heat and pressure, the samples separated of their own accord. No tendency for blocking after cooling was evident nor was any damage to the thermal control coating observed.

Apparatus: The test apparatus is shown in Figure 61. Two blocking fixtures with three samples each were placed in an air circulating oven and tested as described earlier.

Solar Absorptance and Infrared Emittance Measurements. - The solar absorptance measurements of the XTC-6 white thermal control coating was determined using a Beckman Model DK-2 Spectrophotometer with a Model 24500 Diffuse Reflectance Attachment. The test consisted of measuring the spectral reflectance of the specimen at ambient temperature and pressure in the wavelength range from 0.30 to 2.4 microns. The solar absorptance (α_s) was computed from the relationship:

$$\alpha_s = 1 - \frac{\left[\sum_{\lambda=1}^{20} \rho_{\lambda} \Delta \lambda \right]}{20}$$

where: ρ_{λ} = specimen reflectance at 20 equal solar energy wavelength intervals

The infrared emittance (ϵ) of the XTC-6 coating was determined at 75°F using a Lion Research Corp. Model 25-B Emisometer. The emisometer is an infrared detection system which is used to compare the radiation emitted by the test specimen to that emitted by a material of known emittance (Parson's black paint where $\epsilon = 0.97$). The scale of the instrument meter is graduated for direct emittance readings.

A summary of the test results is presented in Table XXI. Results of the tests are as follows:

$$\frac{\alpha_s}{\epsilon} = \frac{0.18}{0.77} = 0.22$$

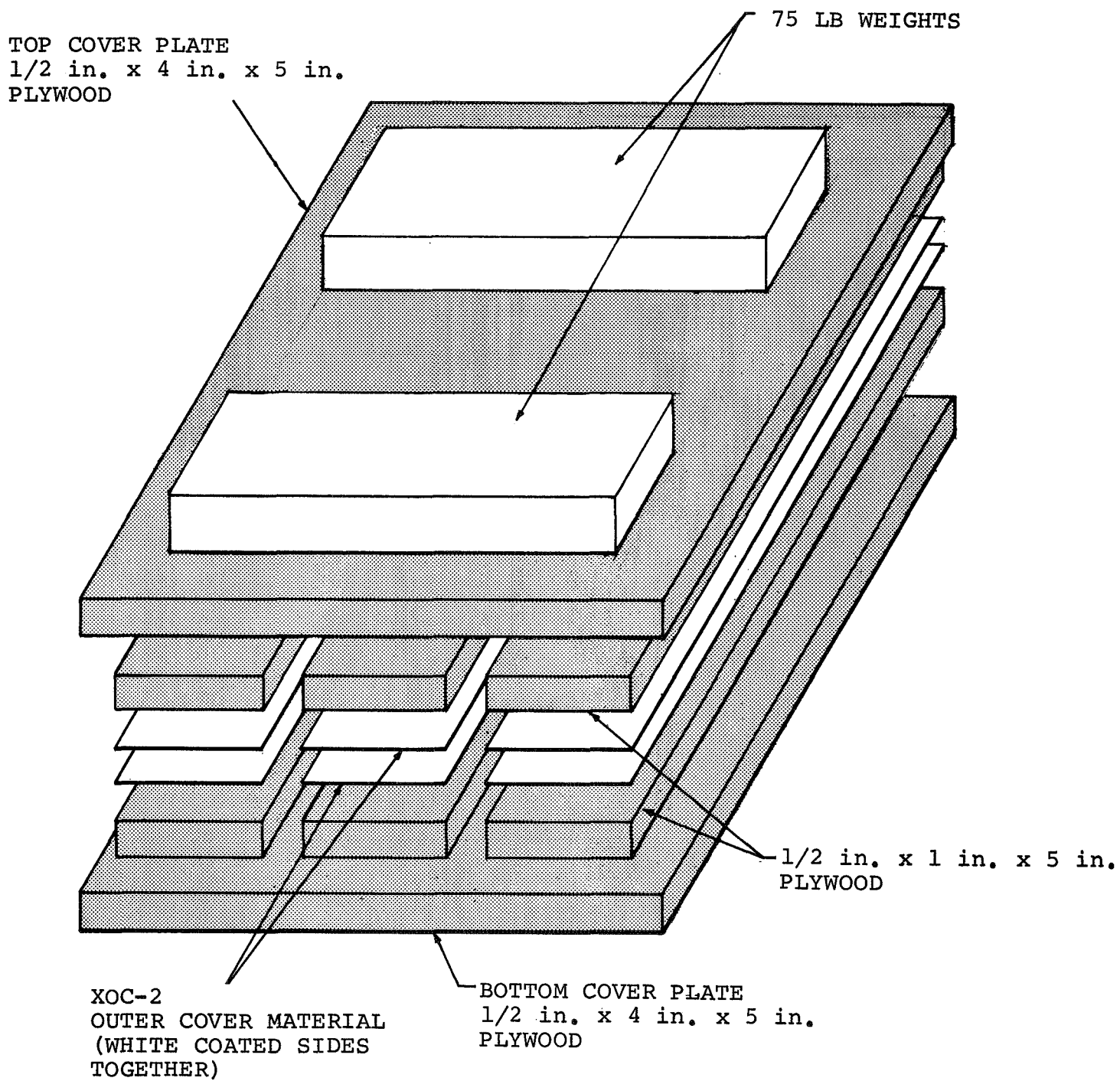


Figure 61. Blocking Test Apparatus

TABLE XXI. SOLAR ABSORPTANCE TEST DATA SHEET

Specimen Number: XTC-6
 Specimen Material: White Thermal Control Coating Tested 1-8-70

Wavelength (Microns)	Measured Reflectance		Absolute Reflectance	
	Specimen	Reference	Specimen	Reference
0.3370	0.0800	0.9400	0.0813	0.9550
0.3990	0.2600	0.9600	0.2600	0.9600
0.4410	0.9200	0.9650	0.9248	0.9700
0.4740	0.9300	0.9700	0.9300	0.9700
0.5060	0.9300	0.9750	0.9252	0.9700
0.5400	0.9350	0.9800	0.9255	0.9700
0.5750	0.9400	0.9800	0.9304	0.9700
0.6130	0.9450	0.9800	0.9354	0.9700
0.6530	0.9500	0.9850	0.9355	0.9700
0.6980	0.9500	0.9850	0.9355	0.9700
0.7480	0.9500	0.9850	0.9355	0.9700
0.8050	0.9500	0.9850	0.9355	0.9700
0.8710	0.9450	0.9850	0.9210	0.9600
0.9490	0.9450	0.9900	0.9164	0.9600
1.0400	0.9400	0.9900	0.9096	0.9580
1.1500	0.9150	0.9950	0.8810	0.9580
1.2900	0.9150	0.9950	0.8736	0.9500
1.5000	0.8850	0.9950	0.8450	0.9500
1.8500	0.8050	0.9950	0.7670	0.9480
2.4000	0.5350	0.9900	0.5096	0.9430

Specimen Solar Absorptance: 0.1861

Specimen Emittance: 0.7700

Fabrication Techniques Development

General. - As the materials screening phase of the program was completed, it became obvious that the fabrication technique processes would be completely interdependent with the materials selection in translating the final upgraded materials into "flight quality" hardware. Therefore, based on the results of the Task I materials screening phase, candidate individual materials were selected for application in a total composite wall construction incorporating the flame gas barrier subcomposite, structural layer, micrometeoroid barrier, and outer cover with thermal control coating. Six variations of a total composite wall design were fabricated at the end of the Task I phase and submitted for NASA-LRC consideration. As shown in Figure 62 these were XTC-1, XTC-2, XTC-3, XTC-4, XTC-5 and XTC-6.

After evaluation of the six advanced total composite wall constructions, XTC-4 and XTC-6 were mutually selected by NASA-LRC and GAC as the candidate total composites for evaluation in the Task II Qualification Test Program and application to a lunar shelter structure.

The process development of XTC-4 and XTC-6 total composites proceeded in an orderly step-by-step program during this phase, and a quantity of XTC-4 and XTC-6 samples were manufactured for qualification testing and as deliverable items under the contract to NASA-LRC. Photographs of these samples are shown in Figure 63.

Definition of Fabrication Task. - Utilizing the results of the materials screening and composite materials fabrication effort, a study was conducted to define the fabrication logic required to produce a full scale lunar shelter.

The sequence for the various tasks required in the fabrication process are:

- (1) A rigid foam mandrel required for geometry control.
- (2) Fabrication and assembly of the pressure bladder subcomponents.
- (3) Application of the filament-wound structural layer.
- (4) Installation of a flexible micrometeorite barrier.

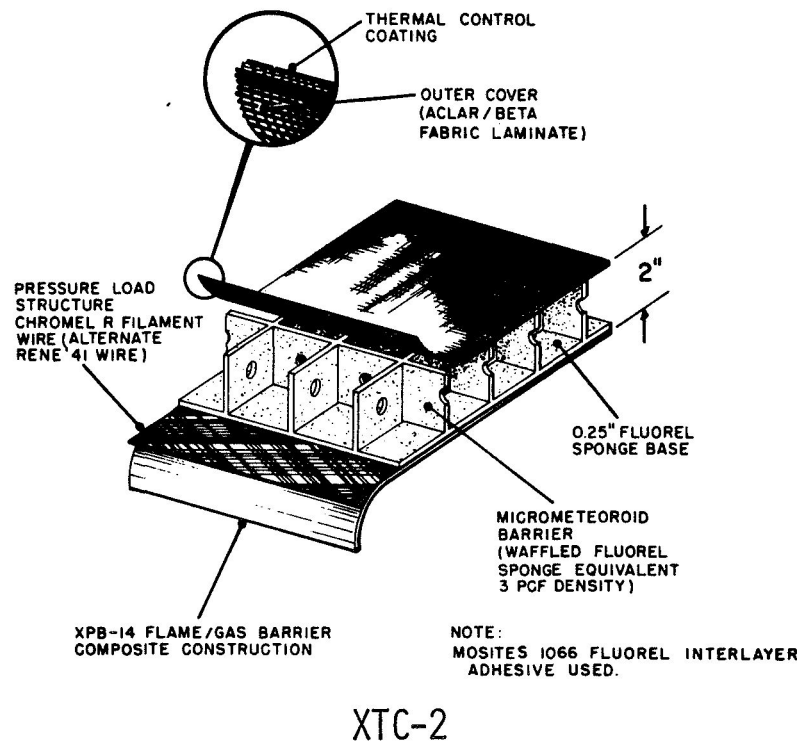
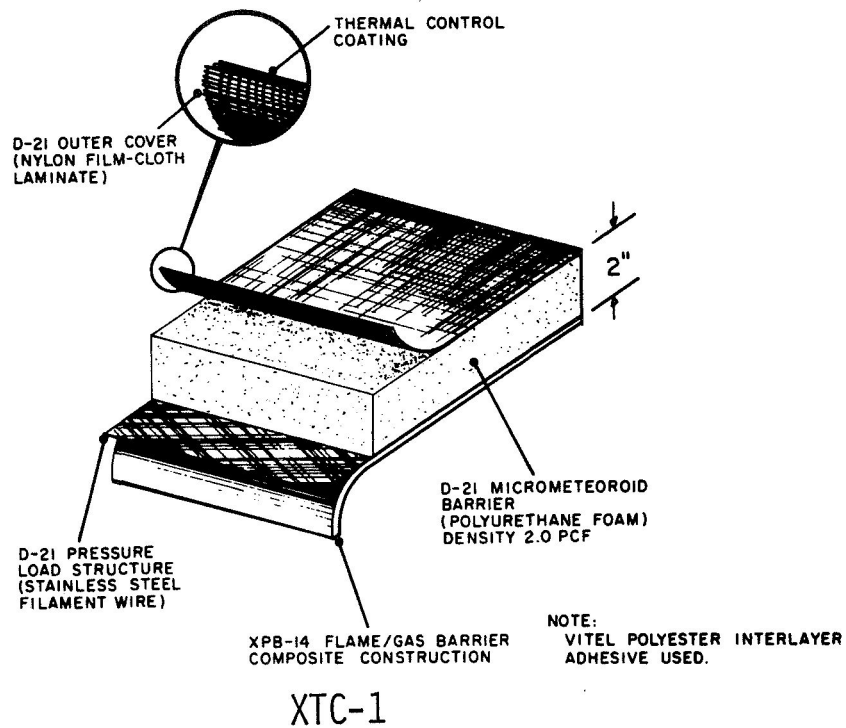
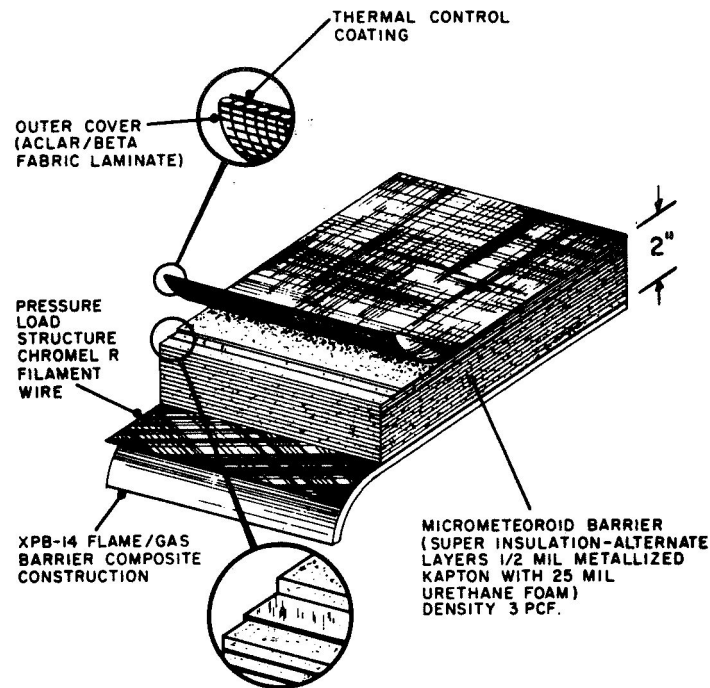
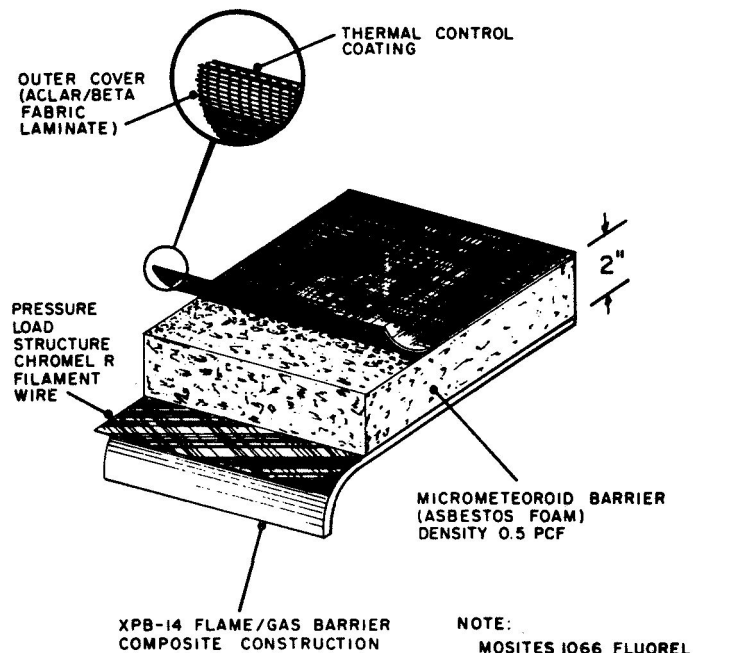


Figure 62. Advanced Composite Wall Constructions (Sheet 1)



NOTE:
MOSITES 1066 FLUOREL INTERLAYER ADHESIVE USED.

XTC -3



XTC-4

Figure 62. Advanced Composite Wall Constructions (Sheet 2)

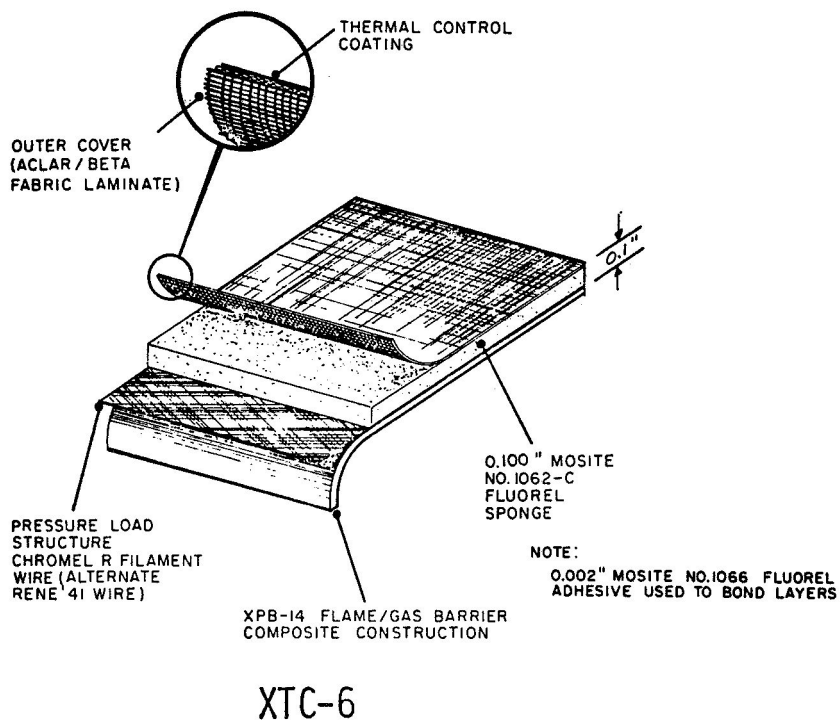
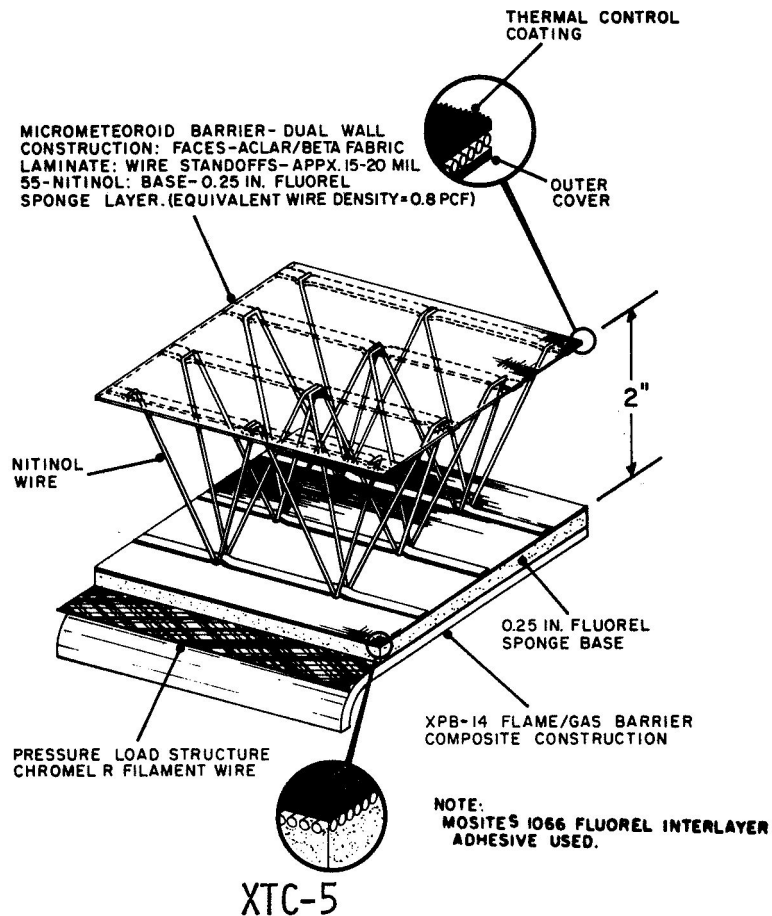
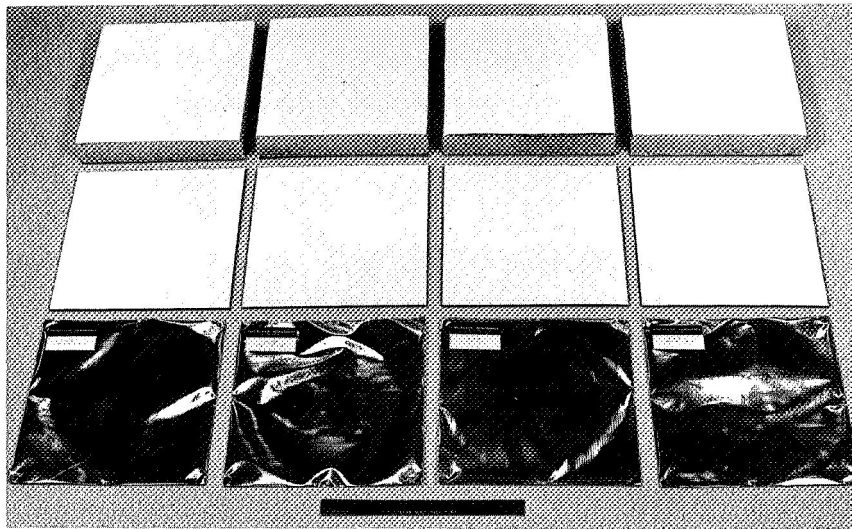


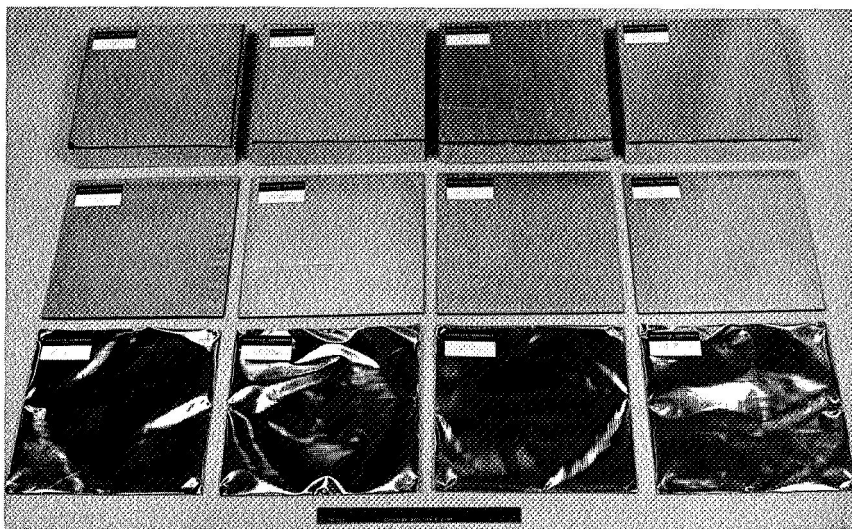
Figure 62. Advanced Composite Wall Constructions (Sheet 3)



XTC-4

XTC-6

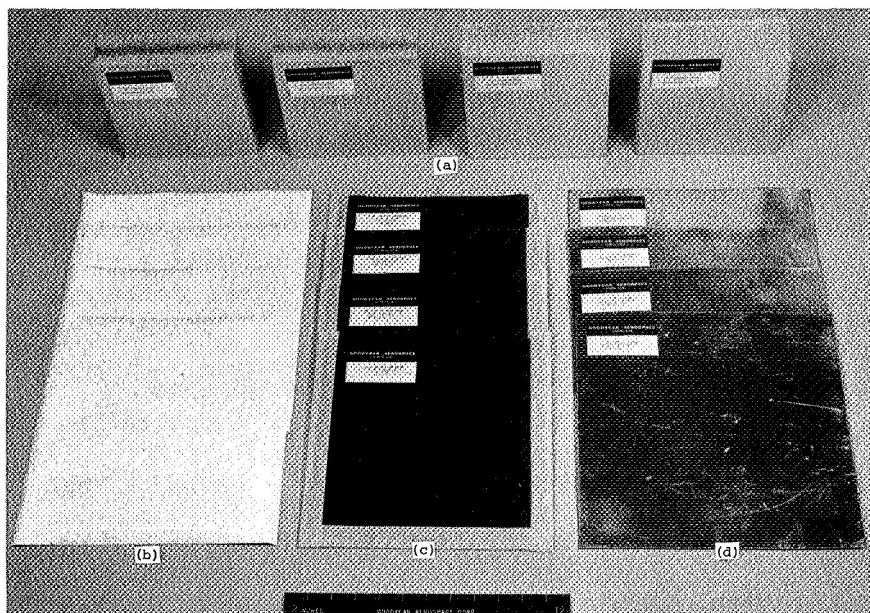
Thermal Blanket



XTC-4

XTC-6

Thermal Blanket



(a) XMB-4

(b) XOC-2

(c) XSL-3

(d) XPB-14A

Figure 63 Candidate Lunar Shelter Total Wall Composite and Components Supplied to NASA-LRC

- (5) Forming and bonding of the outer cover.
- (6) Application of a thermal coating on the outer cover.
- (7) Fabrication of a thermal blanket.

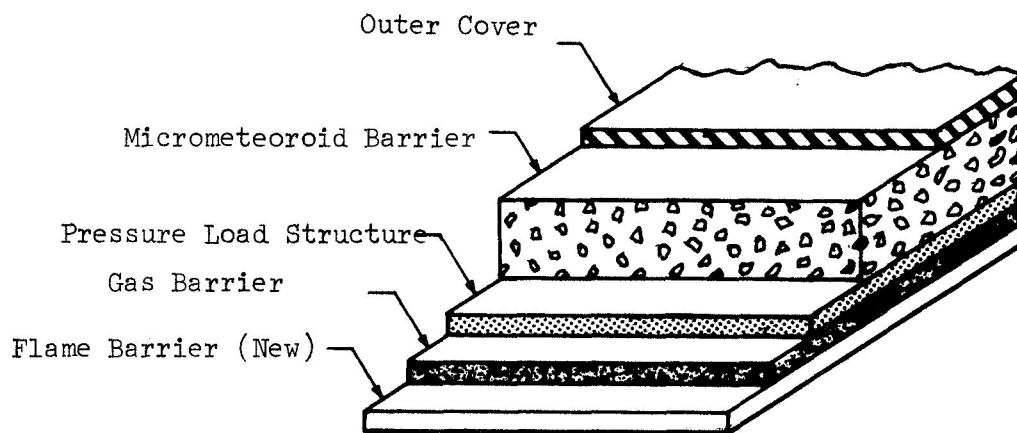
Definition and development of fabrication logic utilizing experience gained in the development and assembly of laboratory samples, should result in the ultimate goal of transforming this technique into full scale models.

Analysis of Utility of Candidate Materials. - Early program efforts involved screening various candidate materials oriented toward the selection of nonflammable materials that were compatible with fabrication technique studies for expandable structures. This portion of the contract effort covered development work which was very basic and which had to be resolved, prior to working with composites containing all of the components.

It soon became apparent that adhesion of component layers was not only dependent upon adhesive composition, but also on application techniques and coating thickness. None of the adhesives tested were of a suitable viscosity for application in the as-received condition.

Solvent systems were required which effected application characteristics and also the final quality of the laminated composite. In order to minimize the amount of residual organics in the final composite laminate, it was desirable to apply a minimum of adhesive solution to the fabric and Fluorel sponge rubber components. The means of making seams and edge closure techniques also had to be compatible with the limitations imposed by Fluorel elastomers. Joining or lamination of the numerous gores of material in the proposed composite structure was an important area for investigation. The adhesive bonds must be strong enough to transfer the deployment and erection loads and constructed so that there is no stiffness that may adversely effect folding or packaging. Figure 64 illustrates the type of materials selected as a result of these early fabrication studies.

Special Tooling: Processing, developed on laboratory samples of composite materials, requires a minimum cure temperature of 280°F. This elevated temperature cure dictates that a special high-temperature foam be utilized for full-size construction mandrels. A study was initiated to select a suitable high-temperature stable foam for the mandrels.



Recommended Material Forms (Nonmetallic)

<u>Films</u>	<u>Fabric</u>	<u>Foams</u>	<u>Elastomers</u>	<u>Adhesives</u>
Aclar 33C	Beta Glass	Fluorel (1062-C)	Fluorel (L-3203-6)	Fluorel (1066)
Kapton	Silica (Refrasil)	Asbestos (K20)		

Recommended Material Forms (Metallic)

<u>Fibers</u>	<u>Foils</u>
Chromel R	Aluminum
Rene '41	
Stainless Steel	

Recommended Solvent

Methylethylketone

Figure 64. Recommended Composite Wall Materials

During the laboratory sample phase sixteen variations of composite flame gas barrier types of construction were fabricated for evaluation. Description of variations in the multiple-ply lay-up construction and processing is shown in Appendix E, pages 164 through 181.

One problem area encountered in processing with the Fluorel type adhesive was that Mosites adhesive would not adhere to the smooth "as-received" surface of the Aclar 33c film or aluminum foil. Solvent cleaning of these surfaces would not provide an adequate bond. The film and foil were lightly sanded with No. 400 sandpaper. This improved the bond but weakened the material. Finally, scouring powder was used with water and a soft cloth. This removed the smooth finish of the Aclar film and aluminum foil and provided a good bonding surface without damage to the material.

To eliminate any effect of sizing or filler material, the fiberglass cloth and Fluorel sponge was placed in a 400°F circulating air oven for 24 hours prior to the beginning of fabrication. Various combinations of cure schedules were evaluated for the multiple-ply subcomposite constructions as shown in Appendix E, pages 164 through 181.

As new candidate materials were received, fabrication continued and through an orderly step-by-step analysis of candidates, the fabrication procedure for XPB-14A was selected as the most promising candidate. Figure 65 illustrates the composition of XPB-14A.

Total Wall Composite Fabrication Procedures: The general fabrication procedures that were developed for multiple-layer wall constructions are outlined as follows:

(A) Flame/Gas Barrier Subcomposite Fabrication.

(1) Pretreatment of Materials

(a) Refrasil C-100-28 - Fabric

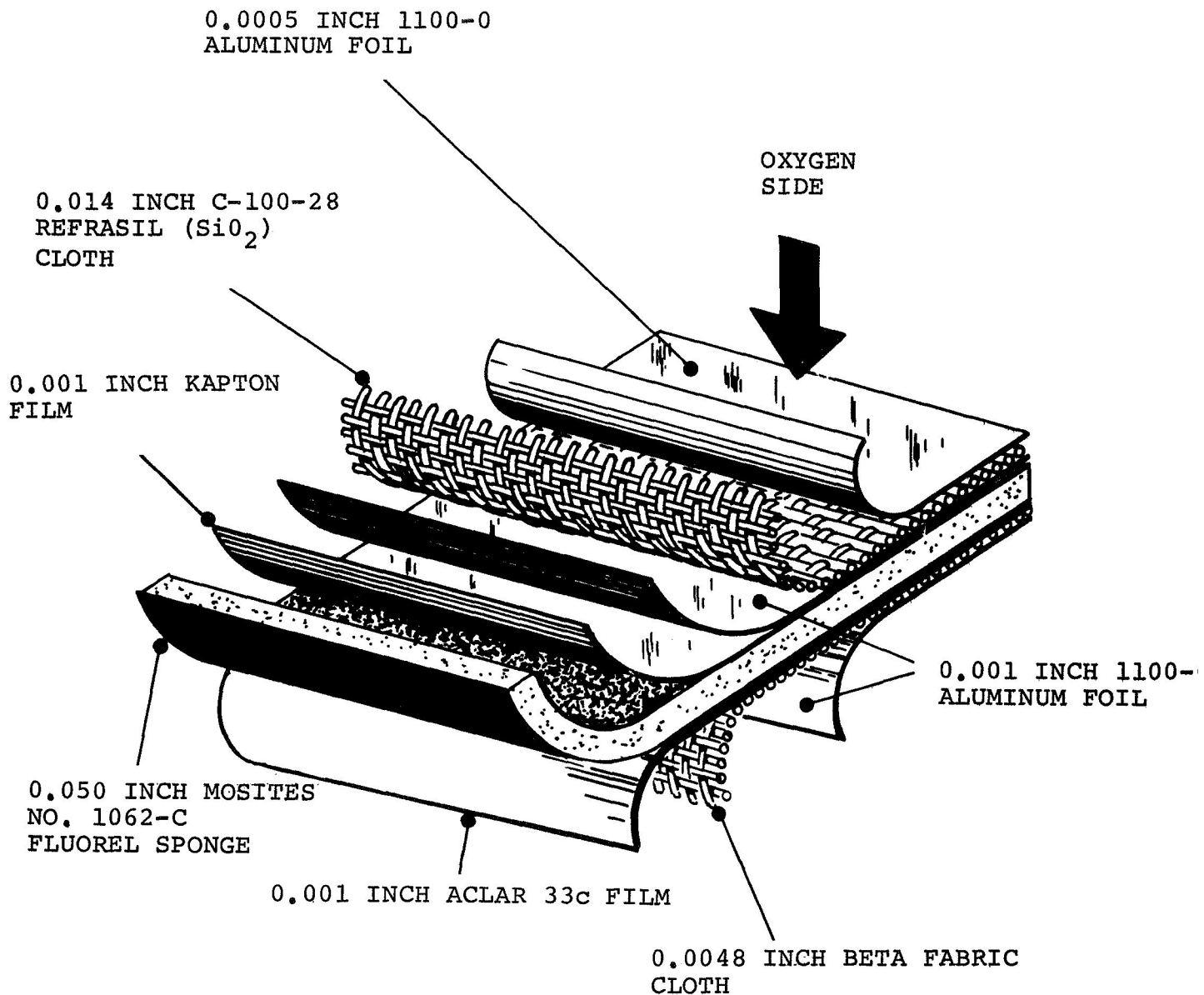
Mosites 1062-C - Sponge

Betaglas 81677 - Fabric

Placed trimmed material on individual flat trays in electric air circulating oven and heat at 400°F for 24 hours.

(b) Fluorel Sponge

Both Mosites and Raybestos-Manhattan Fluorel type sponge were evaluated for the pressure bladder construction. Since 0.25 inch foam thickness was the minimum thickness available, the 0.050 inch thickness required for sample construction was obtained by machine slitting.



NOTE:

0.002 INCH MOSITES NO. 1066 FLUOREL
ADHESIVE USED TO BOND LAYERS

Figure 65. Recommended Flame/Gas Barrier Subcomposite
(XPB-14A)

- (c) Aclar 33c - Film
Kapton - Film
Aluminum Foil
Scour both surfaces of this material very lightly, using a damp flannel cloth and household scouring powder. Solvent wipe all surfaces with methylethylketone (MEK) solution.
 - (d) Store pretreated materials between cellophane film until needed.
- (2) Lamination of Sub-composite (XPB-14A)
- (a) Remove Mosites #1066 adhesive from storage in deep freeze and allow adhesive to return to room temperature.
 - (b) Prepare adhesive spray mix by blending 50% by weight of Mosites #1066 adhesive with 50% by weight of methylethylketone.
 - (c) Apply Mosites #1066 adhesive spray mix to face of each mating surface that is to be bonded. Four coats are to be sprayed by alternately spraying in a horizontal and vertical direction. This results in a total adhesive thickness varying between one and two mils.
- NOTE: No adhesive to be sprayed on the Mosites Fluorel sponge rubber since it was determined that excess solvents are trapped in the foam cells. The foam is assembled uncoated. Adequate bond is achieved to its adhesive-coated mating surface during lamination.
- (d) The adhesive coated materials are placed in an air-circulating oven and dried for 1 hour at 150°F in order to remove solvent residue.
 - (e) Assemble adhesive-coated materials on a flat plate, beginning with the 0.0005 aluminum foil and continue in sequence.
 - (f) Cover assembly with perforated FEP film. Place bleeder cloth over FEP film and vacuum bag with nylon film.
 - (g) Apply 5 inches of vacuum to assembly and heat-cure a minimum of 16 hours at 280°F.

- (B) Structural Layer Fabrication. - The lunar shelter structural layer was fabricated using filament winding techniques. Fabrication processing was directed toward the stranding of a wicking material (Taslan) into the basic structural filament material (Chromel R wire). Interlayer bonding of the filaments was achieved with Mosites #1066 Fluorel adhesive.

Six panels, 29 inches wide x 58 inches long, were fabricated on an 18-inch diameter steel mandrel. The materials used in fabricating the panels were:

3-strand 0.0035 inch diameter Chromel R Wire

200 denier Rayon type Taslan Yarn

Mosites #1066 Fluorel Adhesive

The following procedure was used for filament winding 29-inch x 58-inch development panels for subsequent lay-up in the 12-inch x 12-inch total composite samples:

- (1) Mount 18-inch diameter steel mandrel in winding machine at approximately 30° angle for longitudinal wrapping.
- (2) Program filament winding machine to lay 16 longitudinal filaments per inch.
- (3) Install 3 spools of 3 strand Chromel R wire and 3 spools of Taslan Yarn on winding creel. Strand each wire and Taslan filament through Mosites #1066 adhesive bath and guides to winding bath.
- (4) Cover steel mandrel with FEP film to provide separator and prevent bonding of filaments to mandrel.
- (5) Proceed to filament wind two layers of longitudinal filaments on mandrel. During winding operations, spray Mosites #1066 adhesive onto the previously-wound layer to increase bond between layers. The spray adhesive is applied just ahead of the winding path.
- (6) The hoop structural layer is then applied in a single layer of 34 strands-per-inch.
- (7) During the winding of the longitudinal and hoop structural layers the winding adhesive level in the bath is maintained to ensure that filaments are adequately coated during winding operations.

- (8) The assembly is then vacuum bagged and cured for 16 hours at 300°F.

Process instructions and a record of the amount of materials used for filament wound panel is shown in Appendix E, page 182.

The average weight for a cured filament wound panel 29 inches x 58 inches is 940 grams.

Advanced Total Composite Wall Construction. - At the conclusion of the Task I Phase, GAC established and fabricated samples of five concepts for assembling the selected materials into a four-element composite wall structure. (Figure 62).

Composite sample XTC-1 was based on combining existing micrometeorite barrier technology developed for the D-21 airlock program with the XPB-14A pressure bladder developed on this program.

Composite sample XTC-2 represents a concept that incorporates the flame proof characteristics of the Mosites #1062-C Fluorel sponge. The waffle patterned sponge was a little stiff and heavy. It would create some difficulty in obtaining the desired packaging ratios for the total composite.

Composite sample XTC-3 represents a concept for combining the micro-meteorite function with a super-insulation. Although this sample has some desirable features it would be difficult to obtain the desired packaging ratio with this material.

Composite sample XTC-4 appears to be the most promising of the total composite samples. It contains all of the desired features for advanced composite materials. By combining the asbestos foam micrometeorite barrier with the filament wound structure and the XPB-14A bladder a structure is obtained which is flame-proof and also meets packaging criteria.

Composite XTC-5 is a concept wherein the micrometeorite barrier would be self-expanding. This is based on the use of a preformed Nitinol wire standoff which would deploy, due to a rise in temperature, when the structure is exposed to the sun.

After evaluation of the various advantages, disadvantages, and complexities shown in Table XXII for the five advanced total composite wall constructions, XTC-4 was mutually agreed upon by GAC and NASA-LRC for evaluation in the Task II Qualification Testing phase, and application to a lunar shelter structure. A companion total composite wall construction identified as XTC-6 was also selected by NASA-LRC for evaluation.

TABLE XXII. COMPARATIVE ADVANTAGES AND LIMITATIONS -
PROPOSED MICROMETEOROID BARRIER WALL
CONSTRUCTION

Requirement	Advanced Total Composite Wall Construction				
	No. 1	No. 2	No. 3	No. 4	No. 5
Ease of Fabrication	1	4	4	3	5
Resistance to Damage	1	2	2	4	2
Flame Resistance *	5	3	5	1	2
Minimum Cost	1	5	4	2	5
Mass Efficiency	2	4	4	1	3
Ease of Packaging	3	3	3	1	1
Total Rating	13	21	22	12	18

*Based on overall flame resistance on micrometeoroid wall material.
Other elements have equal flame resistance.

Key to Ratings:

(1) Excellent	(3) Good	(5) Poor
(2) Very Good	(4) Fair	

Definition of Structure Fabrication Techniques (Fabrication Logic)

Based on the results of the materials screening and composite materials process development, the following fabrication techniques were established for structure fabrication processing of the lunar shelter composite wall structure (XTC-4 and/or XTC-6):

(1) Manufacturing Geometry Control (Tooling)

- (a) Fabricate plaster model conforming to geometry configuration of desired structure.
- (b) Cast high temperature fiberglass mandrel mold from plaster model.
- (c) Fabricate high temperature fiberglass mold suitable for vacuum stretch forming of gored material for composite.
- (d) Fabricate high temperature 6 lb density foam mandrel from fiberglass mold. The foam mandrel is subsequently dug-out after lay-up construction is completed.

Foam is to be used as a mandrel with repeated exposures to 280°F and 5 inches Hg vacuum, and must remain stable within 0.040 inches across a 36-inch diameter span.

The first foam system tested, Vultafoam R9-45 was considered borderline at the outset but was tested because of availability. It was tested at two densities, 3.7 and 5.5 lbs/ft³. After six exposure cycles of ambient to 280°F (maintained at temperature approximately 90 minutes) and 5 inches Hg vacuum the foam "grew" 0.040 inches across an 11-inch span. This foam system value is questionable.

The second foam system tested was Upjohn CPR 32-10. This is designated a high temperature foam by the manufacturer. A 5.9 lbs/ft³ specimen was cycled 5 times between ambient and 300°F at 5 inches Hg vacuum. Its maximum change was 0.020 inch over an 11-inch span. This system appears to resist the temperature cycling much better than Vultafoam R9-45 and is considered acceptable for the mandrel application.

(2) Flame/Gas Barrier Subcomposite Fabrication (XPB-14A)

This section establishes the general procedure for laminating the multiple-ply flame/gas barrier subcomposite. This subcomposite construction provides a flame barrier and a triple-seal gas barrier protection while transmitting the gas pressure load to the structural layer. As this subcomposite fabrication technique has been very successful as used by GAC in building structures for the existing technology previously described, it was chosen for this upgraded materials development program over other techniques, such as integral molding, spray applications, etc.

(a) Lay-up construction and compound curvature development:

The subcomposite shall be constructed layer by layer as shown in Figure 65. Compound curvature development during this program indicated that the total composite could be assembled on a mandrel. The technique developed was based on the tailoring and performing of individual gores for the various plies. Contour control and uniformity of the total composite requires optimum pattern shapes and good shop practice in overlapping and bonding of the seams. The total structure is laminated ply by ply with each individual ply being curved in sequence. Figure 66 illustrates a compound curvature sample of the XPB-14A bladder.

NOTE: The foil and fabric layers shall be laminated and preformed as a subassembly part.

(b) Cementing Procedures:

CAUTION: Conduct Cementing in Well Ventilated Area.

Surface Preparation:

If necessary to remove dust, lint, or greast spots from surfaces to be cemented, use cloth dampened with acetone.

Adhesive Mixing Instructions:

<u>Parts by weight</u>	<u>Material</u>
1 part	Mosites #1066
1 part	Methylethylketone (MEK)

Use only thoroughly mixed and freshly made adhesive. Store adhesive at 32°F or below, when not in use.

Adhesive Application:

For adhesive coating on fabric, film, Fluorel sheet, structural layer, foil and asbestos micrometeoroid barrier, conventional paint spray gun equipment shall be used to apply adhesive.

Number of Coats:

Apply four spray coats to each surface to be bonded.

NOTE: Do not spray any adhesive on Fluorel sponge surfaces.

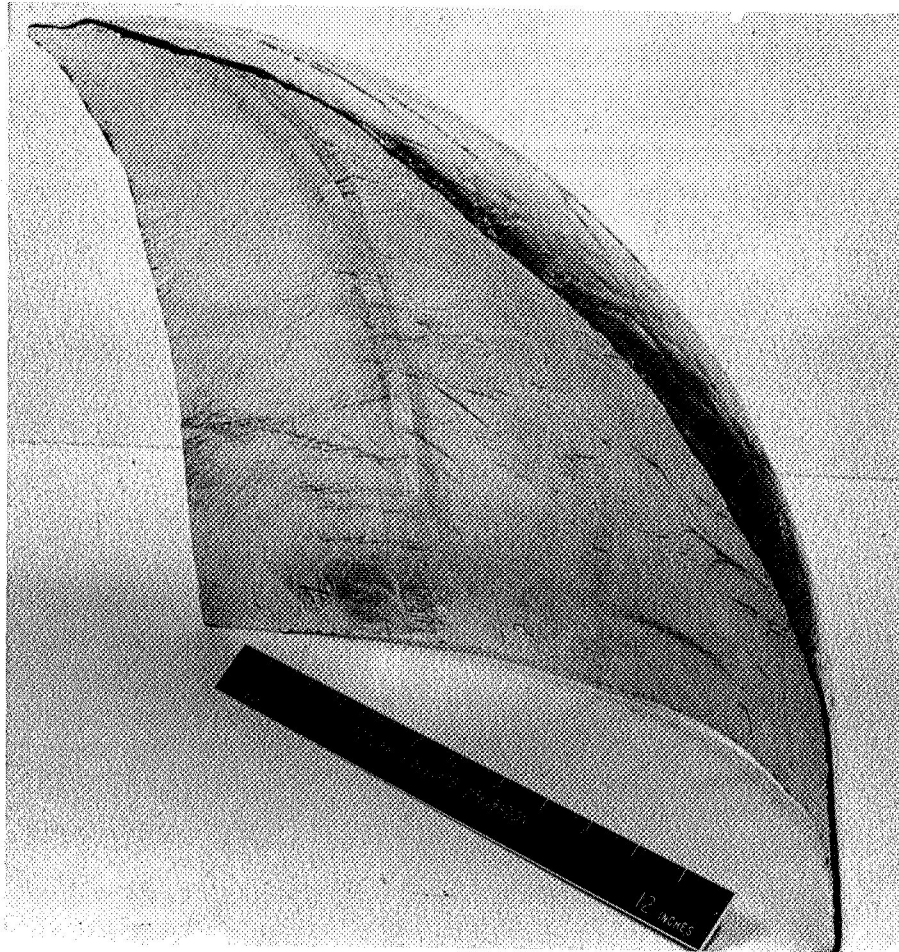


Figure 66. Compound Curvature Development

Drying:

Allow each coat of cement to dry past the tack-free stage before applying the next coat. Judgment and drying conditions determine the length of time after the last coat of adhesive is applied before joining surfaces.

Curing:

Vacuum bag curing shall be used for laminating all interply layers.

The vacuum bag lay-up shall be made with FEP film, bleeder cloth and bagged with nylon film.

All vacuum bagged parts shall be cured a minimum of 16 hours at 280°F and 4 to 5 in. Hg pressure.

(c) Attachment to terminal end rings

Cement interface of pressure bladder to terminal end rings as follows:

Clean area to be bonded with acetone dampened cloth.

Apply a thin coat of Dow 1200 primer to the aluminum surfaces. Air dry primer a minimum of 60 minutes.

Lay a continuous film of Dow 92024 silicone adhesive to the primed metal surfaces. Immediately roll down pressure bladder on terminal ring.

Cure - Allow a minimum of seven days room temperature curing.

(d) Atmosphere Conditions

Cementing procedures shall be conducted within the following atmospheric conditions.

Relative Humidity	55 percent maximum
-------------------	--------------------

Temperature	70-90°F
-------------	---------

(3) Filament Winding Adhesive Procedure (Structural Layer Fabrication):

- (a) This section establishes the wet winding procedure necessary for binder action and proper filament positioning of the structural layer.

(b) Layup Construction

For the structural layer, a strand of three 0.00035 inch Chromel R wires interlaced with one 200 denier Taslan rayon yarn is used for the specified winding pattern (number of hoop and longitudinal filaments per inch). The filaments are wet wound with Mosites #1066-C adhesive so as to provide the necessary binder for proper filament positioning through the wicking action of the rayon yarn. The last circumferential end filament is rigidly bonded to the adjacent wires with epoxy adhesive, while the longitudinal filaments at hatch and port openings are bonded with epoxy adhesive to its respective end fittings.

(c) Surface Preparation

If necessary to remove dust, lint or grease spots from surfaces to be cemented, use cloth dampened with acetone.

Mixing Instructions

Parts by weight	Material
1 part	Mosites #1066
1 part	Methylethylketone

Use only thoroughly mixed and freshly-made adhesive. Store adhesive at 32°F or below when not in use.

Application

For cement prime coating on fabric substrate, conventional paint spray gun equipment shall be used to apply cement.

For filament wet winding resin pick-up, run filament strands over pan fed pick-up roll coater.

For epoxy cement coating on filament terminal ends, a brush shall be used to flow the cement on as uniformly as possible.

Curing

Vacuum bag completed filament wound layer with a layer of perforated FEP film, No. 128 fiberglass bleeder cloth and nylon bag film. The vacuum bagged part shall be cured a minimum of 16 hours at 280°F and 4 to 5 in. Hg pressure.

(4) Micrometeoroid Barrier Development

For the existing technology materials concept, protection from micrometeoroid penetration is provided by a layer of flexible polyether foam. Based on hypervelocity particle impact tests conducted at the micrometeoroid testing facility at Wright-Patterson AFB and at the Arnold Engineering Development Center (AEDC), flexible foam with a 1.0 lb/cu ft density has been found to be a suitable barrier material. The tests at Wright-Patterson were conducted with a particle that had an average mass of 0.005 g, traveling at 27,000 fps. The test results indicated that this particle size was a critical mass for penetrating a 2-inch thickness of foam. Both series of tests indicate that a foam barrier of 1 lb/cu ft density has the same effectiveness as a single sheet of aluminum with 15 times the mass per unit area.

Figure 67 shows the Air Force near-earth micrometeoroid environment spectrum in terms of particle mass and accumulative particle flux. When the test results are correlated with single-sheet aluminum penetration theory, the critical penetrating flux level is about 5.23×10^{-7} particles/sq ft-day for a 2-inch thickness of foam. By relating the critical flux, the exposed surface area of a structural design, the mission time, and single-sheet penetration theory to each other, the probability of zero penetration for various barrier thicknesses can be determined.

In this development program, the density of the foam barrier has been decreased from 1 to 1/2 lb/cu ft to provide a nonflammable material. Even though the material density is decreased, the effectiveness of the material as a barrier to particle penetration is not expected to change. Thus the material provides equivalent penetration protection for equivalent thickness, independent of material density.

The same lay-up and cementing procedures previously described for the Flame/Gas Barrier Subcomposite Fabrication was utilized in the total composite lay-up of XTC-4 construction with asbestos foam micrometeoroid barrier. Very good inter-ply bonding adhesion while maintaining the bumper-main wall stand-off separation distance and compression recovery was demonstrated in the qualification test program.

Hypervelocity particle impact tests for both XTC-4 and XTC-6 total composites are currently being conducted at the NASA-MSC Meteoroid Science Branch testing facility, and the tests results will be attached as an appendix to this report when completed.

(5) Outer Cover Layer and Thermal Coating Development

The construction of the outer layer is shown in Figure 68. Since the outer cover encapsulates the composite wall, it serves as an aid in packaging the structure prior to launch. By a vacuum technique, the wall thickness can be compressed from the fully expanded thickness to about 3/8 inch, suitable for folding and subsequent packaging.

Various thermal coatings, either vacuum deposited or spray painted, may be applied to the surface of the outer cover. The purpose of the thermal coating is to maintain material temperatures within acceptable limits during full solar flux. Maximum temperatures are limited to about 300°F; minimum temperatures will be limited by the emissivity of the coating, the thermal conductance of the composite wall, and the heat capacity of the structure. A computer program is necessary to evaluate various coatings, as well as factors relative to orbital inclination, orbital altitude, and orientation of a structure with respect to the earth. The objective of such a program is to establish temperature gradients of the composite wall. These gradients

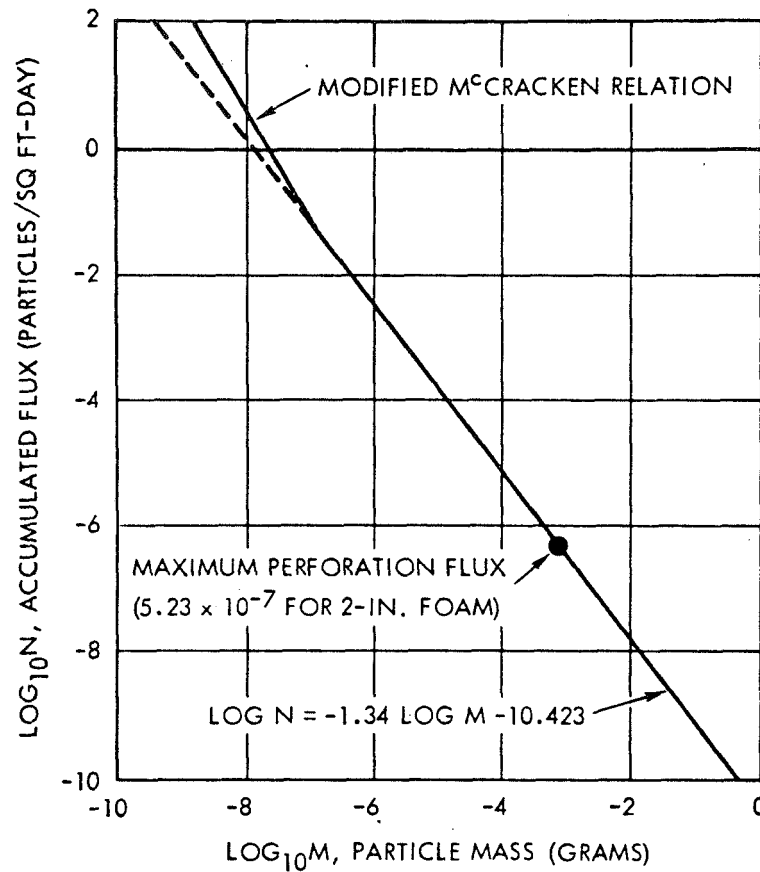
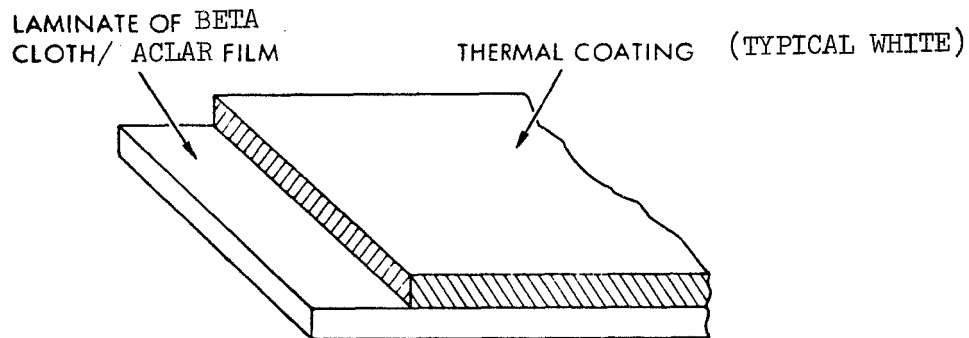


Figure 67. Near-Earth Micrometeoroid Environment



ITEM	WEIGHT (LB/SQ FT)
FILM CLOTH LAMINATE	0.043
THERMAL COATING (WHITE)	0.049
TOTAL	0.092

Figure 68. Outer Cover of Composite Wall

are in turn used to establish minimum and maximum temperatures and permit the correlation of material thermal characteristics with the expected temperature extremes.

A typical white thermal control coating (TiO_2 pigment in silicone resin) as related to a lunar shelter passive thermal control system, was selected for total composite sample (XTC-4 and XTC-6) evaluation in the qualification test program.

The same lay-up and cementing procedures as previously described in paragraph (2) was also used for laminating the Aclar Film-Beta Cloth sub-composite and subsequent bonding to the micrometeoroid barrier substrate: Very good inter-ply bonding adhesion was also demonstrated by the qualification test program for this fabrication technique.

The following painting procedures were used for application of the thermal control coating:

- (a) This process defines the procedure for application of Dow Corning 92-007 thermal control coating (T.C.C.) to the external outer cover.
- (b) Surface Preparation - Prior to the application of the T.C.C., wipe surfaces with acetone dampened rag. Apply a thin film of D-C 4094 primer to surfaces (do not flood) and air dry 30 minutes.
- (c) Mixing Instructions - Mix 4 parts D-C 92-007 paint to 1 part Heptane. Mix by adding the solvent to 92-007 and shaking in closed container until thoroughly mixed.
- (d) Spray Application - Use conventional paint spray gun equipment and manufacturer's recommended combination of nozzle, tip and gun. Apply a smooth coat with target dry film thickness of 4.5 mils.
- (e) Drying and Curing - Unless otherwise specified, allow coated surfaces to air-dry at room temperature for a minimum of 16 hours, before handling, at which time non-porous gloves must be worn and a minimum contact pressure applied. Allow five days minimum air drying before packaging.

Optical properties (α_s/ϵ) for the DC 92-007 white thermal control coating as applied to the outer cover layer were measured in the qualification test program.

Thermal Control System Analysis

General. - The extreme temperatures encountered in the lunar environment (+250 to -300°F) will necessarily impose a strong influence on the design of the lunar structure. Requirements for heat transfer between the inner and outer surface of the composite wall structure are related to the magnitude of external and internal heat loads. Studies directed towards the definition of thermal control for lunar shelter missions have indicated the requirements for heat transfer range from low values for low temperature environments and low internal heat loads to high values for high temperature environments and high internal heat loads. Consequently, two different thermal control system concepts were analyzed for the program, defined as quasi-passive and active.

Quasi-passive: - This system will use the shelter as a space radiator for rejecting the internal generated heat loads. The system will consist of two entities that will control the internal environment to approximately ambient temperatures. First, to moderate the adverse temperature effect of the 250°F lunar surface on the shelter, a reflective "mat" is employed that covers the lunar surface adjacent to the shelter, thus creating an artificial surface with a much lower temperature. Second, a movable blanket of super-insulation is provided which may be positional to cover or partially cover the shelter to any degree desired. This regulates the amount of thermal energy that the shelter can dissipate and in turn control the internal temperature. This system provides a simple quasi-passive method of thermal control embodying simplicity of design and reliable operation.

Active: - This system will require some type of external heat exchanger where the internal heat energy as well as the penetrated energy through the shelter walls must be dissipated. An evaporative or radiative type can be used depending on the choice of design. In the cold mode protection, a system similar to the quasi-passive can be employed to keep the heating requirements to a minimum.

As the method of achieving heat transfer is completely interdependent with the fabrication technique task of the program, this thermal control analysis effort deals primarily with determining heat transfer rates as related to total composites XTC-4 and XTC-6 mutually selected by NASA-LRC and GAC as the most promising candidate structures.

The two thermal control systems and the approach for achieving the desired thermal control for both systems with respect to their material requirements will be discussed in the following paragraphs.

Quasi-Passive Thermal Control Concept.

High Temperature Environment: - This type of system will require a maximum type of high thermal conducting material to allow for heat rejection. Previous studies (Reference 37) indicate that a typical shelter heat load will be approximately 3000 BTU'S/Hr and the ration area will be approximately 300 ft². These studies have also shown that a zinc-oxide pigment in a silicone resin will give the desired optical properties to yield low external surface temperatures ($\epsilon_s = 84$; $\alpha_s = 0.21$). Based on these values, a conductance value ($\frac{K}{X}$) of 0.75 BTU'S/Hr - ft² °F is indicated to maintain an internal wall temperature of 75°F. This heat transfer rate is approximately achieved with total composite XTC-6, whereby the wall structure is thin enough to permit the desirable heat energy rejection.

Low Temperature Environment: - Thermal protection during the lunar night cycle can be accomplished by the use of a high performance or super-insulation type blanket. This insulation is very efficient in vacuum type environments and a thermal conductivity value of 5×10^{-5} BTU'S/Hr-ft °F has been attained on cryogenic protective systems. The thickness requirements can be extremely small, less than 0.10 inches, based on the heat loads and area requirements stated in the Experimental Results Section.

The insulation proposed for the blanket will consist of alternate layers of 1/4 mil, aluminized both sides, Mylar and 10⁴ glass cloth spacers (11 layers of Mylar and 10 layers of cloth). A typical sample was constructed and tested to obtain thermal conductivity values in a vacuum. The results obtained were: $K = 3.16 \times 10^{-5}$ BTU'S/Hr-Ft-°F for a sample thickness of 0.12 inches. It can be seen that the thickness requirements are not controlled by the thermal requirements but rather by the minimum thickness to maintain structural requirements. A description of the test and test procedures employed is discussed in the Experimental Results Section. The cold mode protection for the XTC-6 total composite wall is thus obtained with use of the super-insulation blanket.

Active Thermal Control Material Concept.

High Temperature Environment: - The material requirements for the active type system is not as stringent as for the passive type. This type will act as a structural material with little or no requirement for heat rejection. As mentioned previously the internally generated heat energy will be rejected by some active type system. Any heat energy rejected through the wall structure will be an added advantage and will relieve the heat rejection system

by this amount. However, this system will have the capability of rejecting the total heat load. The heat transfer rate achieved by total composite XTC-4 would thus be applicable with the active thermal control material concept. The results of thermal conductivity test procedures for XTC-4 are discussed in the Experimental Results Section.

Low Temperature Environment: - The material requirements for the active low temperature environment is the same as that described previously for the quasi-passive low temperature environment. The cold mode protection for the XTC-4 total composite wall is also obtained with use of the super-insulation blanket.

Experimental Test Results.

Total Composites XTC-4 and XTC-6: - The purpose of these tests was to determine the thermal conductivity of the two types of lunar shelter total composite wall materials in a high vacuum environment. The specimens used for these tests were constructed as shown in Figure 62.

Test Equipment and Procedures: - These tests were performed using the guarded hot plate set up shown in Figures 69 and 70. The tests consisted of measuring the heat flow through the central six-inch diameter portions of the two nine-inch diameter specimens. Radial heat losses were minimized by maintaining the specimen temperatures in the guard ring area the same as those in the central area and wrapping the edge of the specimens with a low thermal conductivity multilayer insulation ($K = 3.5 \times 10^{-5}$ BTU-In/Ft² Hr°F).

The gas barrier side of the test specimens were bonded to the guarded hot plate using Vitel adhesive to minimize thermal contact resistance. The thermocouples for monitoring specimen temperatures were located as shown in Figure 71. Each test was conducted for four hours after temperature equilibrium was achieved.

Test Results: - A summary of the test results are presented in Table XXIII. These results indicate that the thermal conductivity of the XTC-4 and XTC-6 specimens were 0.44 and 0.17 BTU-In/Ft²-Hr°F, respectively.

Data Analysis: - The results of the thermal conductivity test must be corrected to allow for edge effects. In order to conduct very accurate tests, the thickness to diameter ratio should be extremely small to alleviate the heat losses through the exposed edges. Even though the edges are covered with a high performance type insulation the exposed area is sufficiently large to allow a

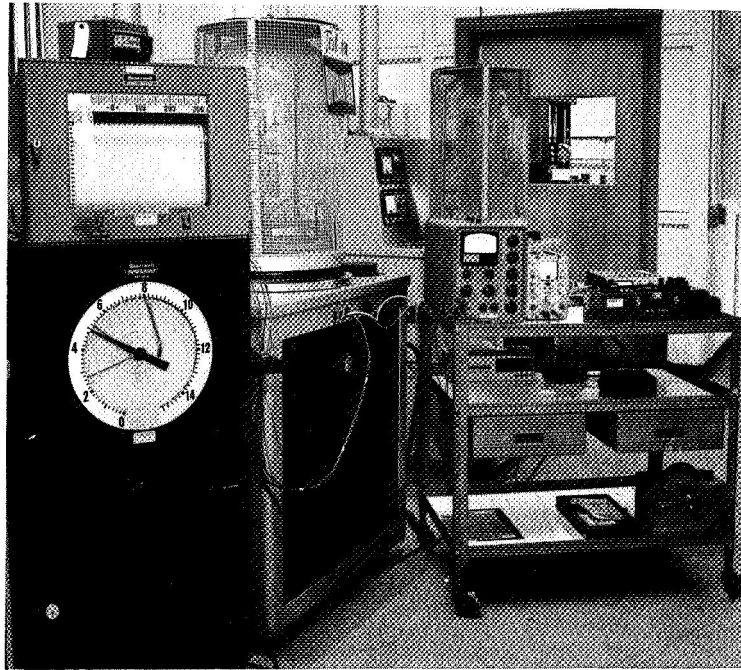


Figure 69. Guarded Hot Plate Test Set-Up

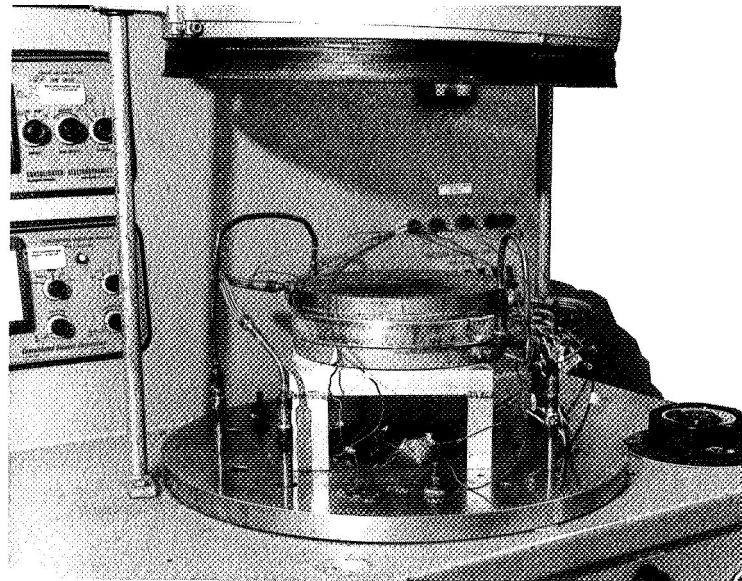


Figure 70. Guarded Hot Plate Assembly

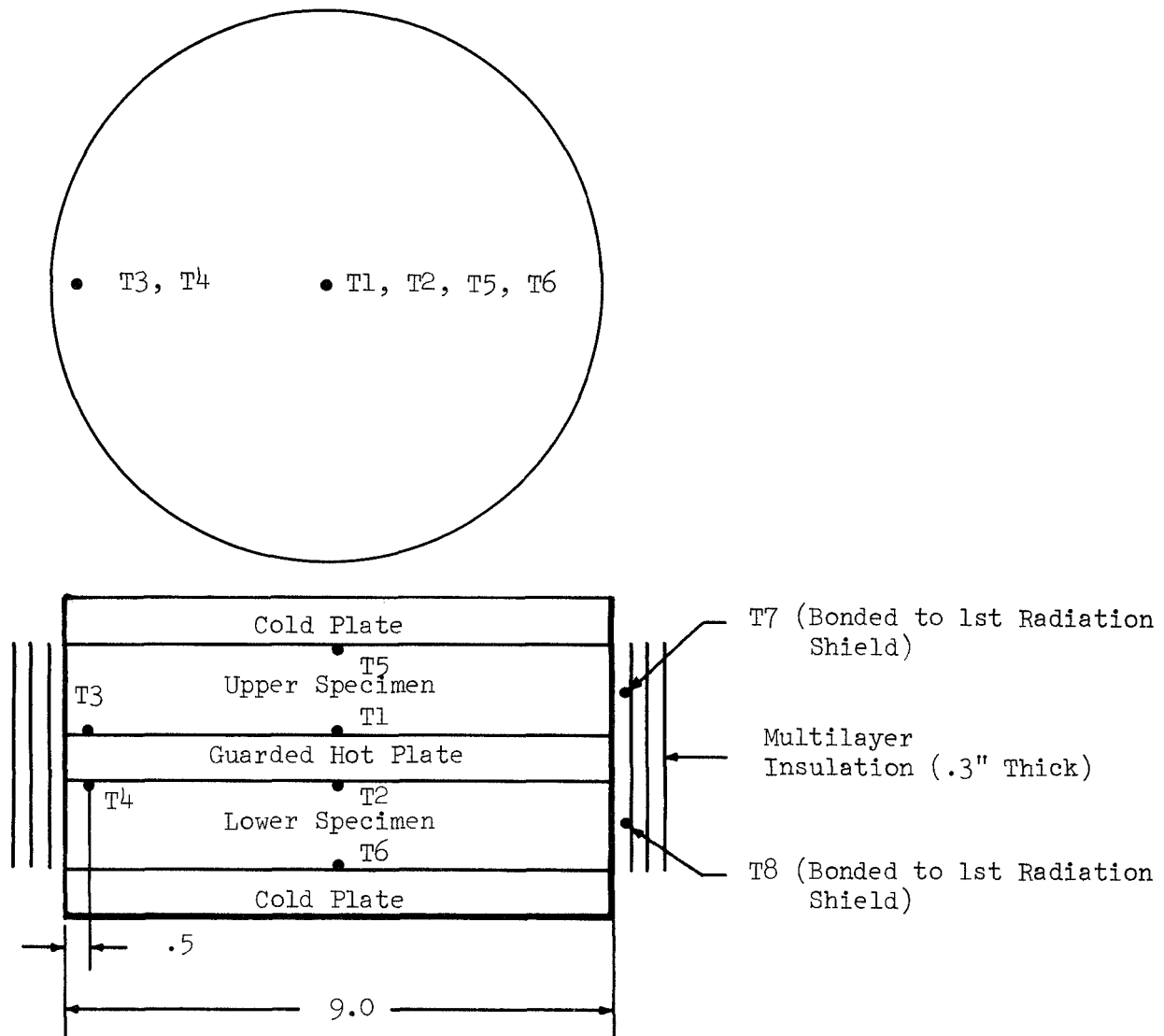


Figure 71. Thermocouple Locations

large percentage of the applied energy to escape through the edge surfaces. Sample XTC-6 was thin enough where the losses were negligible but XTC-4 was thick enough where these losses must be accounted for. The loss area can be determined by:

$$A = \frac{H d t}{144} = \frac{\pi 9.0 \cdot 4.6}{144} = 0.903 \text{ Ft}^2$$

The super-insulation is very effective as long as the heat losses are across the insulation but this effectiveness is decreased when the edges are

TABLE XXIII. THERMAL CONDUCTIVITY TEST DATA

Specimen			Central Heater		Temperatures ° F								K	Chamber Pressure (MM Hg)
No.	Construction	Thickness (Inches)	V	I	T1	T2	T3	T4	T5	T6	T7	T8		
XTC-4	Per Fig. 62	2.3	12.460	0.160	164	164	164	164	112	112	125	140	0.44	2×10^{-5}
XTC-6	Per Fig. 62	0.25	31.10	0.400	150	155	155	155	65	59	127	110	0.17	1×10^{-5}

NOTES:

$$(1) \quad K = \frac{(5) (V) (I) (t)}{\Delta T}$$

Where: K = Specimen thermal conductivity (BTU-In/ft²-Hr °F)

B = Central heater voltage (volts)

I = Central heater current (amperes)

t = Specimen thickness (inches)

$$\Delta T = \text{Temperature gradient} = \frac{[(T_1 + T_2) - (T_5 + T_6)]}{2}$$

(2) Thermocouple locations are shown in Figure 71.

exposed. GAC's past experience with this type of insulation has determined the degradation of this type insulation to be a function of length to thickness ratio for various emittance values of the exposed edges. For this particular case the thermal conductivity will be increased by a factor of five due to the edge losses (degradation factor of 5). The edge losses can be determined by:

$$Q_{\text{EDGE}} = \frac{(K) (D F) (A) (\Delta T)}{(X)}$$

where:

D F = degradation factor (5)

X = insulation thickness (ft)

K = insulation thermal conductivity (BTU'S/Hr-Ft-°F)

ΔT = average temperature difference across insulation

or:

$$Q = \frac{(3.5 \times 10^{-5}) (5.0) (0.903)}{(0.30/12)} (132 - 70)$$

$$Q = 0.391 \text{ BTU'S/Hr or } 0.114 \text{ Watts}$$

The basic equation for determining the thermal conductivity is:

$$K = \frac{(5.0) (V) (I) (t)}{(\Delta T)}$$

which is derived for the manufacturer's equipment. This equation can be modified to fit this requirement by:

$$K = \frac{(5.0) (V.I - \text{Losses})}{\Delta T}$$

$$K = \frac{(5.0) (2.00 - 0.114) 2.25}{52}$$

$$K = 0.409 \text{ BTU'S-Inch/Hr-Ft}^\circ\text{F}$$

Super Insulation Blanket: - The purpose of this test was to determine the thermal conductivity of a multilayer insulation blanket consisting of eleven layers of aluminized 1/4 mil Mylar and ten layers of 104 glass cloth spacers with each layer individually wrapped on the cylindrical calorimeter.

Test Procedure: - The thermal conductivity test was conducted on this specimen. As shown in Figure 72 this test consisted of measuring the power input and temperature gradients across the electrically heated specimen under thermal equilibrium conditions.

Test Results: The data was reduced in accordance with:

$$K = \frac{0.834}{\Delta T} (V) (I) \log \frac{(0.94 + t)}{0.94}$$

where:

K = thermal conductivity (BTU/Hr-Ft°F)

V = specimen heater voltage (Volts)

I = specimen heater current (Amps)

t = specimen thickness (Inches)

$$\Delta T = 0.50 (T_5 + T_6 - T_{11} - T_{12})$$

The results obtained from the tests were:

t = 0.12 inches

K = 3.16×10^{-5} BTU'S/Hr-Ft-°F

Summary. - The maximum and minimum limits of varying the heat transfer rates available with each of the recommended total composite wall concepts are shown in Figure 73.

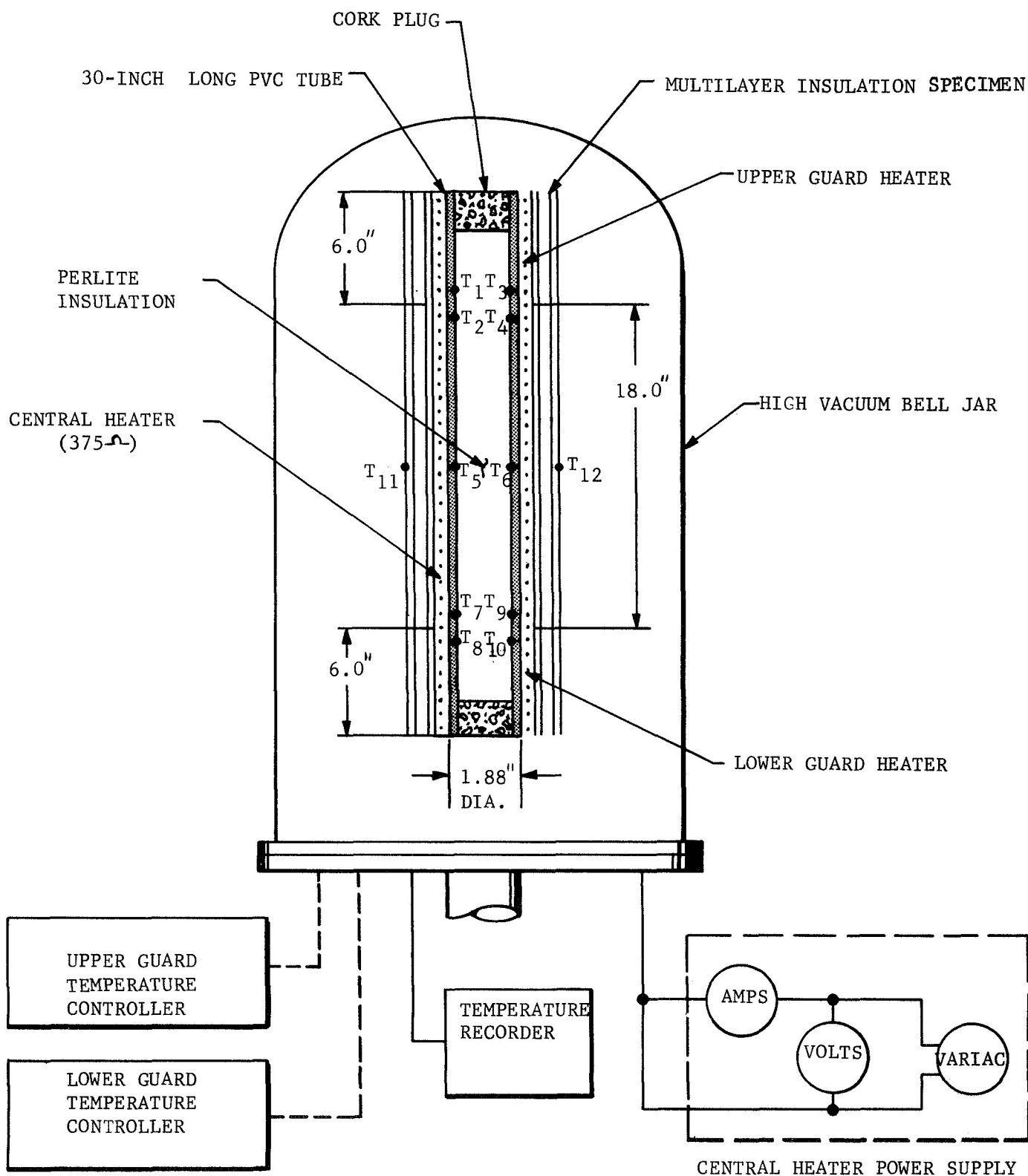
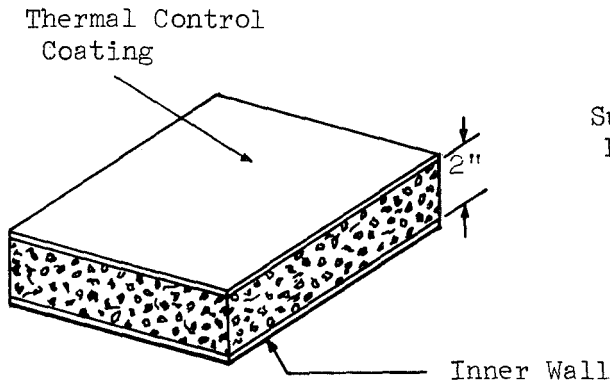
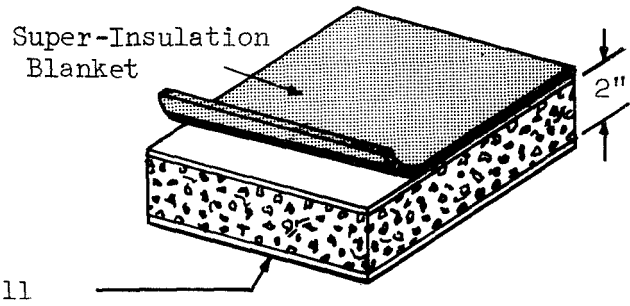


Figure 72. Guarded Hot Tube Thermal Conductivity Test Setup .

XTC-4

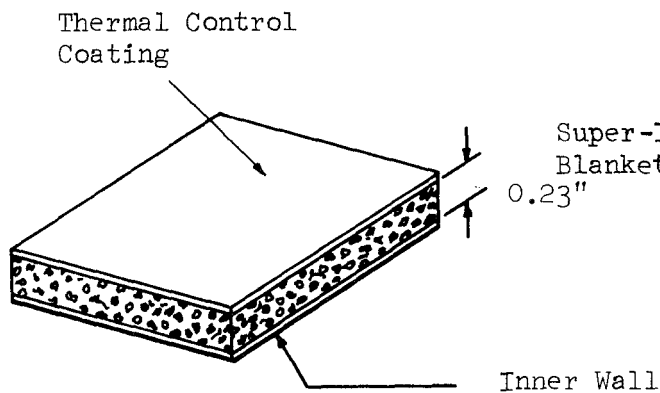


Maximum
 $K/X = .178 \text{ BTU's/Hr-Ft}^2 \text{ } ^\circ\text{F}$

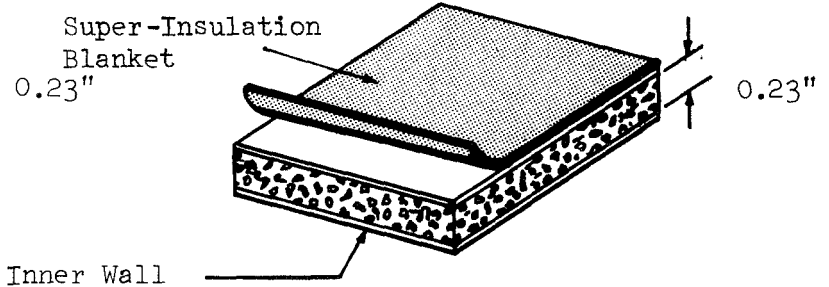


Minimum
 $K/X = 3.16 \times 10^{-3} \text{ BTU's/Hr-Ft}^2 \text{ } ^\circ\text{F}$

XTC-6



Maximum
 $K/X = .680 \text{ BTU's/Hr-Ft}^2 \text{ } ^\circ\text{F}$



Minimum
 $K/X = 3.16 \times 10^{-3} \text{ BTU's/Hr-Ft}^2 \text{ } ^\circ\text{F}$

Figure 73. Recommended Total Composite Wall Heat Transfer Rates

Inspection and Quality Assurance Analysis

Method of Inspection. - The items to be considered as basic check points by Quality Assurance Inspection in the fabrication of a Lunar Shelter using the XTC-4 or XTC-6 total composite wall construction are:

- (1) Verification of stock inspection of each basic material used in the composite material
- (2) Certification of all materials to an approved specification
- (3) Peel tensile samples of each new lot or batch of adhesive and each combination of materials to meet Engineering established criteria
- (4) Quality integrated processes for defining the step by step verification of the ply by ply mandrel and winding construction
- (5) Composite material of the same construction and fabrication as the production material for tests such as permeability, tensile and flexibility
- (6) Composite samples sprayed with thermal coating at the same time as the Shelter to be tested for coating adhesion and optical properties
- (7) The final assembled Lunar Shelter subjected to a leak test and manometer readings compared to established leak rates
- (8) Each Lunar Shelter subjected to a proof pressure test and examined for degradation.
Each Lunar Shelter subjected to one packaging and one deployment cycle to verify packaging ability and configuration
- (9) Final visual inspection and verification of all previous operations
- (10) Conformance recorded in log format

Implementation of Quality Assurance System. - A finalized Quality Assurance Plan should be generated and submitted for approval. This plan would cover all phases of the Lunar Shelter program including detailed procedures on how procurement and receiving is controlled; how complete in-house fabrication cycle is monitored and controlled; how principles of statistical analysis and variation are implemented; how manufacturing processes, procedures and testing instructions are measured and controlled; how detection of nonconforming supplies and the immediate and effective corrective actions are controlled and, how the overall quality program is implemented by an effective management organization with definite documented responsibilities.

A general summary Quality Assurance Plan for the Lunar Shelter program which meets the requirements of NASA Specification NPC 200-2 are included in the following paragraphs.

Change Control: - All documentation such as drawings, specifications, processes, manufacturing and operating instructions, procurement documents, test specifications and related documentation should all be released thru the Program Director's office.

Drawing and Specification Review: - Quality Assurance should jointly perform a design review with the Reliability Engineering group. All specifications or documentation which has any relationship to quality should receive Quality Engineering approval prior to release.

Quality Engineering should participate in all qualification testing performed on materials or assemblies for the Lunar Shelters.

Control of Procured Material: - Material obtained from suppliers for use in the Lunar Shelters should be controlled as specified in NPC 200-3. The suppliers should be required to maintain an effective and economical quality control system in conjunction with their other functions.

Suppliers should be required to:

- (1) Prepare and maintain a written inspection plan applicable to the work being accomplished. This plan should be approved by the Quality Assurance organization.
- (2) Certify that all articles are fabricated, inspected and tested to the latest applicable drawings and that records are available for audit to substantiate these certifications.

- (3) Show that their suppliers exercise adequate quality controls and maintain records of these controls.
- (4) Receive prior approval of all special processes employed by Quality Assurance.
- (5) Maintain a system for control of nonconforming materials, including identification and segregation of defective material.
- (6) Maintain a calibration system in accordance with MIL-C-4562A for all equipment used for acceptance of material to be used in the Lunar Shelter.
- (7) Receive prior approval of all sampling plans before use.
- (8) Maintain packaging, preservation and shipping requirements to the level required by the purchase order.
- (9) Maintain a system which will ensure proper and timely corrective action.
- (10) Be subject to periodic audits by Quality Assurance.

Procurement sources should be established through the results of a survey team or through past performance records as maintained by the Supplier Quality Assurance organization.

The Supplier's Quality Assurance organization should review and approve all purchase orders and other documents pertaining to a supplier's work. Quality Assurance should ensure that all requirements pertaining to quality would be passed on to the supplier by means of the purchase order.

Source inspection should be as required by the Supplier's Quality Assurance organization. Factors such as tests which can only be performed at the supplier's plant, processes which should be monitored or attributes which cannot be checked at the receiving level should be considered in establishing the need for source inspection. Government source inspection should be determined by NASA.

Receiving Inspection should inspect incoming materials, parts, assemblies and components, including packaging and preservation of these materials, for compliance with purchase order requirements. Supplier chemical and physical reports, supplier certifications and government source inspection documents should be reviewed for conformance to purchase order requirements and to NPC 200-3.

All items received should be clearly identified by part number and purchase order number. These identifications should remain with the material through processing. Traceability should be maintained through these identifications.

Inspection and control of GFP should be outlined in the contractor's Quality Assurance Procedures Manual.

All fabrication should be controlled by quality integrated processing approved by Quality Engineering. Supplementary instructions on values to be observed, standards to be maintained, details of end item inspection and records to be maintained should be issued by Quality Planning.

Methods for controlling nonconforming material and the formation of a Material Review Board should be outlined in the contractor's Quality Assurance Procedures Manual. This system should meet the requirements of NPC 200-2.

Inspection, measuring, test equipment, inspection stamps, preservation, packaging, handling, storage and shipping necessary to ensure compliance to NPC 200-2 should be outlined in detail in the contractor's Quality Assurance Procedures Manual.

Statistical planning and analysis procedures should be used where they are advantageous and economical in maintaining required controls and where the quantities are great enough for sampling. Sampling should meet MIL-STD-105 requirements as directed by Quality Planning.

Certification of personnel for special processes used in the Lunar Shelter should be maintained by Quality Audit. Training requirements and sessions should be established for special processes.

Quality Audit should provide periodic review of procedures and product on the Lunar Shelter program. Deficiencies or violations in the Quality Assurance system should be reported and corrective action required.

All documentation derived from the Quality Assurance system should be kept on file in the Quality Records section and should be available for review.

CONCLUSIONS AND RECOMMENDATIONS

As a result of the logically phased development program of candidate materials selection and screening tests and qualification testing of total composites, very promising conceptual designs for composite wall structures were evolved applicable to expandable space structures. Two concepts of total composite wall construction are recommended, identified as XTC-4 and XTC-6 (Figure 9). In composite XTC-4, the micrometeoroid barrier is provided as a built-in "layer" of the total composite, and in composite XTC-6, the primary micrometeoroid barrier is provided exterior to the expandable structure, such as a "pup tent" overlay.

Although the primary objective in the program was to upgrade expandable type materials relative to the flammability hazard as applied to the fabrication of composite wall structures, many of the materials that were found acceptable for the total composites could also serve as candidates for other space structure material categories; e.g., curtains and bunks or other flexible type material furnishings. Also, other candidate materials evaluated in the survey such as the FBI polymer could provide a nonflammable rigid type resin-fabric laminate where required for terminal end rings, hatches or other rigid structural applications.

On the basis of the results of the candidate materials selection and screening test effort, it is concluded that presently there are no available plastic films, flexible adhesives, or thin gage elastomers that will satisfactorily meet the Category A Upward (Flame) Propagation Rate Test requirements.

Extensive development and test efforts conducted during the program have shown that it is feasible to construct the major subcomposite of the wall system, such as the flame/gas barrier, from a combination of nonflammable materials and materials with slow, in oxygen, burn rates in such a manner that the component will pass an upward flame propagation test. It has also been shown that considerable improvement in resistance to fire and heat damage is obtained through the use of a 3-layer "flame barrier" element. This element, consisting of bonded aluminum foil/Refrasil cloth/aluminum foil proved to be the best of the several investigated. Due to the high melting point of the Refrasil cloth and the heat sink characteristics of the aluminum foil the system affords excellent shielding for only a small additional weight.

In view of the excellent performance of the "flame barrier", it is possible that this concept might be applied to other design areas such as, aircraft, diving chambers, test chambers, etc.

While a large number of standard NASA tests were applied during the evaluation, it was felt that due to the unique characteristic of expandable shelters, a special test should be conducted to simulate what would happen if a sizable fire developed next to the surface of the shelter wall. This test, referred to as a Pressurized Diaphragm Flammability Test, proved highly informative and greatly assisted in the development of finally selected XPB-14A flame/gas barrier design. It is recommended that this system, or one similar, be adopted by NASA to evaluate future expandable structure wall materials.

The low temperature deployment is now considered to be the most critical requirement for any expandable type space structure. The cold temperature behavior of the selected total composites XTC-4 and XTC-6 was investigated during the qualification test phase of the program. A special fold test conducted on total composite specimens XTC-4 and XTC-6, indicated they would have a satisfactory low temperature deployment capability to -5°F and with possible deployment capability extending to a maximum of -43°F . It is recommended that further investigation of low temperature deployment capability of the XTC-4 or XTC-6 total composites be investigated in the form of a three-dimensional expandable structure, so as to narrow down the critical deployment temperature range.

Compatibility of the selected XTC-4 and XTC-6 total composite materials was also resolved with the other interdependent areas of fabrication processes, thermal control heat transfer, and quality assurance implementation. A step-by-step specific fabrication process is defined in enough detail to produce an expandable structure of "flight hardware" quality. The magnitude of maximum and minimum limits of heat transfer attainable with each of the XTC-4 and XTC-6 total composites is expected to provide most ranges of heat transfer anticipated for future space mission structural design requirements. A method of inspection and quality assurance program is defined in detail for implementation with the fabrication process for production of a "flight hardware" quality space structure.

As a result of program achievements, an updated expandable structure technology is now available for manned space mission applications such as auxiliary space station structures, airlocks, lunar shelters, or other space structure applications that require expansion in one piece from a small package into a larger dimension. Furthermore, while the strength-to-weight ratio comparison of expandable vs conventional hard structures are nearly equal, significant weight savings can be made with the expandable structure design. This is due to the expandable structures low packaging volume resulting in smaller drag area exposed during the launch phase with correspondingly smaller shroud area and structural loads.

This program herein was initially Phase I of a proposed two-phase effort of development. Phase II was proposed as practical application of the Phase I effort, to be demonstrated by the fabrication and test of a "second generation" space structure of "flight hardware" quality. As the Phase I materials technology and advancement has been successfully completed in this program effort, it is strongly recommended that the Phase II "flight quality" hardware program for a representative type expandable structure be implemented at the earliest possible date, so as to provide a solid technology for the development of mission-oriented space hardware.

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APPENDIX A

FORM LETTER SP-6975 AND MAILING LIST

GOODYEAR AEROSPACE

CORPORATION

AKRON, OHIO 44315

June 4, 1969
In Reply Please Refer
to Letter SP-6975

Gentlemen:

Goodyear Aerospace Corporation, under NASA Contract NAS 1-9112 is presently engaged in an industry wide canvass to seek out new or improved nonflammable*, flexible materials in the form of elastomers, fabrics, foams and adhesives for use in multi-walled expandable lunar personnel shelter systems. It is hoped that through this survey new and perhaps little known materials, which may still be in the stages of development will become known to us and made available for testing and consideration as a candidate material.

If you have materials of the type described above which you feel might meet the nonflammable* requirement and should be considered, please supply us with any data you might have, and a sample if available.

Since we are required to select candidate materials early in the program, a prompt reply would be greatly appreciated.

Thank you for your interest in this matter.

Sincerely yours,

GOODYEAR AEROSPACE CORPORATION

WBC/bg

*Nonflammable in 100 percent oxygen, 5 psia environment

1. Adam Spence Company
3856 Park Avenue
Edison, N. J.
2. Allaco Products, Incorporated
130 Wood Road
Braintree, Massachusetts 02184
3. Allied Chemical Corporation
Plastics Division
Box 365
Morristown, New Jersey 07960
4. American Cyanamid Company
Rubber Chemicals Department
Bound Brook, New Jersey 08805
5. Armstrong Products Company
P. O. Box 657
Warsaw, Indiana 46580
6. Atlas Chemical Industries, Inc.
Concord Pk. and New Murphy Rd.
Wilmington, Delaware 19899
7. Avisun Corporation
21 S. Twelfth Street
Philadelphia, Pennsylvania 19107
8. B.F. Goodrich Chemical Company
3135 Euclid Avenue
Cleveland, Ohio 44115
9. B.F. Goodrich Industrial
Products Company
500 South Main Street
Akron, Ohio 44318
10. Borden, Incorporated
Chemical Division
350 Madison Avenue
New York, New York 10017
11. The Budd Company
Polychem Division
70 South Chapel Street
Newark, Delaware 19711
12. Brunswick Corporation
Technical Products Division
1700 Messler Street
Muskegon, Michigan 49443
13. Celanese Plastics Company
550 Broad Street
Newark, New Jersey 07102
14. Chemplast Incorporated
150 Dey Road
Wayne, New Jersey 07470
15. Chicago Rubber Company
651 Market Street
Waukegan, Illinois 60085
16. Coast Manufacturing
P. O. Box 71
Livermore, California
17. 3M Company
3M Center
St. Paul, Minnesota 55101
18. Connecticut Hard Rubber Company
407 East Street
New Haven, Connecticut 06509
19. CPR Division, Upjohn Company
555 Alaska Avenue
Torrance, California 90503
20. Diamond Alkali Chemicals
300 Union Commerce Building
Cleveland, Ohio 44114
21. Dow Chemical Company
Midland, Michigan 48640
22. Dow Corning Corporation
Midland, Michigan 48641
23. Dynatech Corp.
17 Tudor
Cambridge, Mass. 02139

24. Eastman Chemical Products, Inc.
P. O. Box 431
Kingsport, Tennessee 37662
25. E. I. duPont de Nemours & Company
1007 Market Street
Wilmington, Delaware 19898
26. Emerson and Cuming Incorporated
869 Washington Street
Canton, Massachusetts 02021
27. Enjay Chemical Company
60 West 49 Street
New York, New York 10020
28. Epoxylite Corporation
1428 N. Tyler Avenue
South El Monte, California 91733
29. F. H. Maloney Company
P. O. Box 287
Houston, Texas 77001
30. Ferro Corporation
Cordo Division
34 Smith Street
Norwalk, Connecticut 06851
31. GAF Corporation
Industrial Products Division
Glenville Station
Greenwich, Connecticut 06830
32. Gates Engineering Division
Glidden Company
100 South West Street
P. O. Box 1711
Wilmington, Delaware 19899
33. General Electric Company
Chemical Materials Dept. 1
Plastics Avenue
Pittsfield, Massachusetts
34. General Electric Company
Silicone Products Department
Waterford, New York 12188
35. General Tire and Rubber Company
Chemical Plastics
1708 Englewood Avenue
Akron, Ohio 44309
36. Haveg Industries, Inc.
Reinhold Aerospace Division
12827 E. Imperial Highway
Sante Fe Springs, Calif. 90670
37. Hitco
1600 West 135 Street
Gardena, California 90249
38. Hooker Chemical Corporation
Durez Plastics Division
1967 Wolck Road
North Tonawanda, New York 14120
39. International Latex and
Chemical Corp.
P. O. Drawer K
Dover, Delaware 19901
40. Isochem Resins Company
Cook Street
Lincoln, Rhode Island 02865
41. Johns-Mansville
22 East 40 Street
New York, New York 10016
42. Marbon Chemical Division
Borg-Warner Corporation
P.O. Box 68
Washington, West Virginia 26181
43. Mereco Products Division
Metachem Resins Corporation
530 Wellington Avenue
Granston, Rhode Island 02910
44. Miller-Stephenson Chemical Company
Rt. 7, 16 Sugar Hollow Road
Danbury, Connecticut 06810
45. Mobay Chemical Company
Penn Lincoln Parkway
West Pittsburgh, Pennsylvania 15205

46. Monsanto Company
800 N. Lindbergh Blvd.
St. Louis, Missouri 63166
47. Mosites Rubber Company, Inc.
P. O. Box 2115
Fort Worth, Texas
48. M and T Chemicals, Inc.
Rahway, New Jersey 07065
49. Multi-Flex Seals, Incorporated
1170 Commerce Avenue
Bronx, New York 10462
50. National Vulcanized Fibre
Corporation
Maryland Avenue & Beech Street
Wilmington, Delaware 19899
51. Pennsalt Chemicals Corporation
3 Penn Center
Philadelphia, Pennsylvania 19102
52. Pittsburgh Plate Glass Company
Coatings and Resins Division
225 Belleville Avenue
Bloomfield, New Jersey 07003
53. Polycast Corporation
69 Southfield Avenue
Stamford, Connecticut 06904
54. Raybestos-Manhattan, Inc.
61 Willett Street
Passaic, New Jersey 07055
55. Raychem Corporation
Rayclad Tubes, Incorporated
300 Constitution Drive
Menlo Park, California 94061
56. R. E. Darling Company
P. O. Box 666
Gaithersburg, Maryland 20760
57. Reeves Brothers, Incorporated
Vulcan Division
1071 Avenue of the Americas
New York, New York 10018
58. Rohm and Haas Company
Plastics Department
Independence Hall
West Philadelphia, Pennsylvania 19105
59. Southern Research Institute
2000 9th Ave. South
Birmingham, Ala.
60. Stauffer Chemicals
Special Products Department
380 Madison Avenue
New York, New York 10017
61. Thiokol Chemical Corporation
Chemical Division
P. O. Box 1296
Trenton, New Jersey 08607
62. Union Carbide Corporation
Chemicals and Plastics Group
270 Park Avenue
New York, New York 10017
63. Uniroyal, Incorporated
1230 Avenue of the Americas
New York, New York 10020
64. United Products Company
3000 E. State Blvd.
Ft. Wayne, Indiana 46805
65. Virginia-Carolina Chemicals Corp.
Third and Jefferson Avenue
West Norfolk, Virginia 23703
66. Witco Chemical Organics Div.
277 Park Avenue
New York, New York 10017
67. Wyandotte Chemical Corporation
1532 Biddle Avenue
Wyandotte, Michigan 48192

APPENDIX B

FORM LETTER SP-6918 AND MAILING LIST

GOODYEAR AEROSPACE

CORPORATION

AKRON, OHIO 44315

June 5, 1969
In replying, please
refer to SP-6918

Gentlemen:

We have listed below certain of your company's products which especially interest us, and which we would like to consider further as candidate materials in our development effort (under NASA Contract NAS1-9112) of a nonflammable*, flexible, multi-layered wall for an expandable lunar personnel shelter.

Material

Designation

We would appreciate receiving any data you may have on these materials, and also samples, if available. Since our area of interest includes nonflammable* elastomers, fabrics, foams and adhesives, you may wish to call attention to and include information on other of your products which have thus far escaped our notice.

Since we are scheduled to select candidate materials early in our program a prompt reply would be greatly appreciated.

Thank you for your cooperation.

Sincerely,

GOODYEAR AEROSPACE CORPORATION

- | | |
|--|---|
| 1. American Felt
Glenville, Conn. | 12. 3M Co.
St. Paul, Minn. |
| 2. Arno Adhesive Tapes
Michigan City, Indiana | 13. Mosites Rubber Co.
Ft. Worth, Texas |
| 3. Bjorksten Research Lab.
Madison, Wis. | 14. Owens-Corning Fiberglas
New York, New York |
| 4. Cadillac Plastics and Chemicals
Detroit, Mich. | 15. Owens-Illinois Glass
Toledo, Ohio |
| 5. Chemplast Inc.
Wayne, N. Y. | 16. Raybestos-Manhattan
Passaic, N. J. |
| 6. Emerson and Cuming
Canton, Mass. | 17. Rex Asbestwerke
Stuttgart, Germany |
| 7. Fabric Research Labs.
Dedham, Mass. | 18. Samson Cordage Works
Boston, Mass. |
| 8. Gates Engineering Division
Glidden Co.
Wilmington, Del. | 19. Sterling Packing and Gasket
Houston, Texas |
| 9. Grumman Aircr. Eng. Corp.
Bethpage, N. Y. | 20. Taylor Corp.
Valley Forge, Pa. |
| 10. Hitco
Gardena, Calif. | 21. Thiokol Chemical
Trenton, N. J. |
| 11. Johns-Mansville
N. Y., N. Y. | 22. Uniroyal Textile Div.
Winnsboro, S. C. |

APPENDIX C

LISTING - CATEGORY A USAGE MATERIALS (COMAT)

LISTING - CATEGORY "A" USAGE MATERIALS (COMAT)*

GENERIC ID	MANUFACTURER	MFGRS DESIGNATION	PROPG RATE	CHMB PRES	ODOR	C.O.	TOTAL ORGAN.	FLAM IND.	TEST REPORT NO.
ADHES, LIQUID, ACRYLIC, PMMA, CAST, 2	CADDILLAC PLAST/CHEM	PS-30	.000	16.5				H	67-0810
ADHES, LIQUID, FLUOROELAST	MOSITES, G.A. FT. WORTH	1066 ADHESIVE	.000	16.5				H	68-0934
ADHES, LIQUID, FLUOROELAST	RAYBESTOS-MANHATTAN	FLUOREL 1-3203-6	.000	16.5				H	68-0936
ADHES, LIQUID, FLUOROELAST, BETA FL	RAYBESTOS-MANHATTAN	1-3203 ADHESIVE/BETA	.000	16.5				H	68-0936
COATG, CHLOROFLUORO ELAST, EXPTL	GATES ENGINEERING CO	GACO FR-88G-2	.020	6.2				H	PLN-719
COATG, CONFORMAL	GRUMMAN A/C ENG CORP	MELCOAT 2 COATING SYSTEM	.000	5.0	13.0	20.0	0011	H	AA-2.7.0
COATG, CONFORMAL, SILICONE, RESINOUS	OWENS-ILLINOIS GLASS	GLASS RESIN	.000	16.5				H	PLN-862
COATG, CONFORMAL, SILICONE, RESINOUS	OWENS-ILLINOIS GLASS	907 (.3-.4 MIL)	.000	16.5				H	PLN-370/371
COATG, CTFE, FILLED	GATES ENGINEERING CO	FR86J1/KV19139/RX7132		5.0				H	68-0914
COATG, CTFE, FILLED	GATES ENGINEERING CO	FR86J/KV19139/RX7370	.000	16.5				H	68-0898
COATG, CTFE, FILLED	GATES ENGINEERING CO	KV 19139/RX 7370 ON ALUM	.000	16.5				H	68-0897
COATG, CTFE, FILLED	GATES ENGINEERING CO	KV 19139/RX 7751 ON ALUM	.000	16.5				H	68-0917
COATG, CTFE, FILLED	GATES ENGINEERING CO	KV 19139/RX 7751 ON SST	.000	16.5				H	68-0916
COATG, CTFE, FILLED	GATES ENGINEERING CO	KV 19139/RX 7890 ON ALUM	.000	16.5				H	68-0900
COATG, CTFE, FILLED	GATES ENGINEERING CO	KV 19139/RX 7890 SST	.000	16.5				H	68-0903
COATG, CTFE, FILLED	GATES ENGINEERING CO	KV 19139/1530 ON SST	.000	16.5				H	68-0908
COATG, CTFE, FILLED	GATES ENGINEERING CO	KV 19139/1560 ON ALUM	.000	16.5				H	68-0912
COATG, CTFE, FILLED	GATES ENGINEERING CO	KV 19139/1560 ON SST	.000	16.5				H	68-0911
COATG, CTFE, FILLED	GATES ENGINEERING CO	KV 19139/462 ON SST	.000	16.5				H	68-0904
COATG, CTFE, FILLED	GATES ENGINEERING CO	KV 19139/462 ON ALUM	.000	16.5				H	68-0902
COATG, PAINT	3-M ST PAUL	NEXTEL 101-C10	.000	5.0	26 0	99 0	0144	H	AA-2.8.0
COATG, PAINT, ALKYD	18537	ENAMEL 36 2231 ES 5695	.000	16.5				H	67-0764
COATG, PAINT, ALKYD, DAP	18537	382231 ES 595	.000	16.5				H	67-0764
COATG, PAINT, CTFE, FILLED	NASA MSC, CSO	PLN-1131C	.000	16.5				H	67-0849
COATG, TEMP CONTROL, EPOXY, ALUMINUM	3-M ST PAUL	ND1002289	.000	16.5				H	67-0806
COMPOUND POTTING, EPOXY, 2 PART	EMERSON & CUMING INC	STYCAST 1266 A/B	.000	16.5				H	68-1006
CORD, FIBER, GLASS, TFE	SAMSON CORDAGE WORKS	FIBERGLASS-TFE COATD CRD	.000	5.0	14	17.9	.0037	H	AA-10.34.0
FABRIC, ASBESTOS	US RUBBER/TEXTILE DV	D67-505-IWF	.000	16.5				H	68-0888
FABRIC, BETA FIBER	OWENS-CORNING FIBGLS	GF104 KMIT BETA	.000	16.5				H	20747-245
FABRIC, BETA FIBER	OWENS-CORNING FIBGLS	4190B F-017A FINISH	.000	6.2				H	AA-10.31.0
FABRIC, BETA FIBER, TREATED	OWENS-CORNING FIBGLS	FLAG ON 4065 BETA	.000	16.5				H	68-0925
FABRIC, BETA FIBER, TREATED	OWENS-CORNING FIBGLS	NASA EMBLEM ON 4065 BETA	.000	16.5				H	68-0924
FABRIC, COATING/IMPREG, BETA FIBER	THIOKOL CHEM. CORP	41908 FAB/CNR COAT	.000	16.5				H	20747-223
FABRIC, COAT/IMPREG	THIOKOL CHEM CORP	41190/41100/CNR		16.5				H	67-0734
FABRIC, COAT/IMPREG	THIOKOL CHEM CORP	41190/CNR	.000	16.5				H	67-0740
FABRIC, COAT/IMPREG, BETA FIBER, CT	GATES ENGINEERING CO	FR86J/RV19139/1530	.000	16.5				H	68-0909
FABRIC, COAT/IMPREG, BETA FIBER, CT	GATES ENGINEERING CO	KV 19139/RX 7370 ON 4190	.000	16.5				H	68-0896
FABRIC, COAT/IMPREG, BETA FIBER, CT	GATES ENGINEERING CO	KV 19139/1580 ON 4190	.000	16.5				H	68-0193
FABRIC, COAT/IMPREG, BETA FIBER, CT	GATES ENGINEERING CO	KV 19139/462 ON 4190	.000	16.5				H	68-0901
FABRIC, COAT/IMPREG, BETA FIBER, CT	NASA MSC, CSD	PLN-1133B	.000	16.5				H	67-0830
FABRIC, COAT/IMPREG, FLUOROSILICON	NASA MSC, CSD	PLN-667	.000	16.5				H	PLN-667
FABRIC, COAT/IMPREG, TFE, PTFE RESI	OWENS-CORNING FIBGLS	FABRIC 4484, RMF	.000	16.5				H	68-0990
FABRIC, FELT, TFE	AMERICAN FELT CO	TF2050	.000	6.2				H	67-0730
FABRIC, FELT, TFE	E I DUPONT CO INC	ARMALON PDX 7550	.000	6.2				H	20747-179A
FABRIC, FELT, TFE	E I DUPONT CO INC	PDX-7550-B WHITE	.000	6.2				H	67-0731
FABRIC, NYLON, AROMATIC, TREATED	90022	NOMEX/APEX 462	.000	XX.X				H	67-0844

TABLE I LISTING - CATEGORY "A" USAGE MATERIALS (COMAT)* (Continued)

GENERIC ID	MANUFACTURER	MFGRS DESIGNATION	PROPO RATE	CHMB PRES	ODOR	C.O.	TOTAL ORGAN.	FLAM IND	TEST REPORT NO.
FABRIC, OPEN, WEAVE, PRI, FLUOROELAS	FABRIC RESEARCH LAB	FRI-397-25	.000	16.5				H	PLN-1081
FABRIC, PE TEREPHTHALATE, TREATED	90022	NOMEX, STEEL/APEX 462	.000	XX.X				H	67-0847
FOAM, FLEX, OPEN CELL, CARBOXYNITRO	THIOKOL CHEM CORP	CNR FOAM	.000	16.5				H	20747-200
FOAM, FLUOROELAST	RAYBESTOS-MANHATTAN	1-3161-7	.000	16.5				H	PLN-627
FOAM, METALLIC, ALUMINUM	BJORK	ALUMINUM FOAM 35	.000	16.5				[H]	20747-221
FOAM, RIGID, CLOS CELL, GLASS	O8869	FOAM-GLAS	.000	16.5				H	68-0939A
INSUL, SILICONE, GLASS FIBER	HITCO	TG 15,000 15HRS900F	.000	16.5				H	20747-157A & B
INSUL, SILICONE, GLASS FIBER	HITCO	TG 15,000 15HRS900F	.000	6.2				H	20747-142
INSUL, SILICONE, GLASS FIBER	HITCO	TG 15,000 16HRS900FLOOOF	.000	16.5				H	2047-143
INSUL, THERM, ASBESTOS	O88869	UNIBESTOS	.000	16.5				H	68-0937A
INSUL, THERM, COMPOS, GLASS FIBER	JOHNS-MANSVILLE PROD	DYNAQUARTZ 10/FT ³ DENSITY	.000	5.0	10.0	10.7	0000	H	AA-10.33.0
INSUL, THERM, COMPOS, GLASS FIBER, LL	HITCO	E GLASS, TG 15,000 (3/8)	.000	16.5				H	20747-169
INSUL, THERM, COMPOS, SILICA, FIBER	JOHNS-MANSVILLE PROD	MICROQUARTZ FELT	.000	5.0	6.0	21.1	0000	H	AA-10.35.0
INSUL, THERM, COMPOS, SILICONE, CARB	HITCO	TG 15,000/LADICOTE NRC	.000	6.2				H	20747-151 & 152
INSUL, THERM, COMPOS, SILICONE, CARB	HITCO	TG 15,000/LADICOTE NRC	.000	16.5				H	20747-151 & 152
INSUL, THERM, GLASS FIBER	O8869	TEMP-MAT	.000	16.5				H	68-0939A
INSUL, THERM, SILICONE	DARLING, R F CO INC	REDAR FL-300 0.075 IN TH	.000	16.5				H	PLN-934
INSUL, THERM, ALUMINUM	JOHNS-MANSVILLE NH	TYPE 475E	.000	6.2				H	67-0861
LAM, GLASS FIBER BASE, AMINO, MFIA	TAYLOR CORP	GLASS LAMINATE GRADE G-9	.000	16.5				H	20747-146
LAM, GLASS FIBER BASE, PHENOLIC COP	23736	MINOLTA	.000	6.2				H	68-0828
LAM, GLASS FIBER BASE, SILICONE, RE	OWENS-ILLINOIS GLASS	650/FGLASS/181	.000	6.5				H	PLN-859
LAM, GLASS FIBER BASE, SILICONE, RE	OWENS-ILLINOIS GLASS	650/FGLASS/181	.000	16.5				H	PLN-859
LAM, PREPREG, PHENOLIC (PF)	WESTERN BACKING	AC 7581 TYL/FINISH S-920	.000	6.2				H	20747-173A
LAM, PREPREG, PHENOLIC (PF)	WESTERN BACKING	AC 7581 TYL/FINISH S-920	.000	6.2				H	20747-184A & 20747-185A
MISC, CHLOROPRENE (CR)	STERLING PACK & GASK	NEOPRENE DIAPHRAGM MATL	.000	12.3				H	67-0508
PLASTIC	OWENS-CORNING FIBGLS	FABRIC 4484, RMF	.000	16.5				H	68-0990
PLASTIC, CTFE	3-M ST PAUL	KEL-F-81, GR 3,6060	.000	6.2				H	HS7-024
PLASTIC, CTFE	3-M ST PAUL	KEL-F-81, GR 3,6060	.000	16.5				H	HS7-024
RUBBER, FLUOROELAST	MOSITES, G.A. FT WORTH	FLUOREL 1059 .088 IN	.000	16.5				H	68-0930
RUBBER, FLUOROELAST	MOSITES, G.A. FT WORTH	FLUOREL 1061.1 .13 IN	.000	6.2				H	68-0931
RUBBER, FLUOROELAST	MOSITES, G.A. FT WORTH	FLUOREL 10678 .125 IN	.000	6.2				H	68-0932
RUBBER, FLUOROELAST	MOSITES, G.A. FT WORTH	FLUOREL 1071 .075 IN	.000	16.5				H	68-1003
RUBBER, FLUOROELAST	MOSITES, G.A. FT WORTH	1061D .125 IN	.000	16.5				H	68-0948
RUBBER, FLUOROELAST	MOSITES, G.A. FT WORTH	1061K .125 IN	.000	16.5				H	68-0949
RUBBER, FLUOROELAST	RAYBESTOS-MANHATTAN	1-3203-11	.000	6.2				H	68-0919
RUBBER, FLUOROELAST	3-M ST PAUL	10-19-S 0.060 IN THICK	.000	16.5				H	PLN-1090
RUBBER, FLUOROSILICONE RUB., EXPTL	RAYBESTOS-MANHATTAN	3236-10/202	.000	16.5				H	PLN-1072
SHEET, PLASTIC, TFE, PTFE RESIN	PORT PLASTICS	TEFLON TFE .25	.000	6.2				H	68-1017
SHEET, RUBBER, FLUOROELAST	MOSITES, G.A. FT WORTH	FLUOREL 1061D	.000	16.5				H	68-0948A
SHEET, RUBBER, FLUOROELAST	RAYBESTOS-MANHATTAN	FLUOREL 1-3322-2	.000	16.5				H	68-0987
SHEET, RUBBER, FLUOROELAST	RAYBESTOS-MANHATTAN	FLUOREL 1-3322-5	.000	16.5				H	68-0986
SHEET, RUBBER, FLUOROELAST	RAYBESTOS-MANHATTAN	1-3203-11	.000	16.5				H	PLN-931
SHEET, RUBBER, FLUOROELAST	3-M ST PAUL	1-2231	.000	16.5				H	PLN-922
SHEET, RUBBER, FLUOROELAST	3-M ST PAUL	1-2233	.000	16.5				H	PLN-921
SHEET, RUBBER, FLUOROELAST	3-M ST PAUL	10-19B	.000	16.5				H	PLN-919
SHEET, RUBBER, FLUOROELAST	3-M ST PAUL	10-19C	.000	16.5				H	PLN-920
SHEET, RUBBER, FLUOROELAST	3-M ST PAUL	10-19E	.000	16.5				H	PLN-916
SHEET, RUBBER, FLUOROELAST	3-M ST PAUL	10-19G	.000	16.5				H	PLN-917
SHEET, RUBBER, FLUOROELAST	3-M ST PAUL	1-3203-6	.000	16.5				H	PLN-1077
SHEET, RUBBER, FLUOROELAST, ASBESTO	RAYBESTOS-MANHATTAN	10-19A	.000	16.5				H	PLN-913
SHEET, RUBBER, FLUOROELAST, FXPTL	3-M ST PAUL	10-27-A 0.060 IN	.000	16.5				H	PLN-937
SHEET, RUBBER, FLUOROELAST, FXPTL	3-M ST PAUL	10-27-B 0.060 IN	.000	16.5				H	PLN-936
SHEET, RUBBER, FLUOROELAST, FXPTL	3-M ST PAUL	TAPE 360	.000	XX.X				H	PLN-1095
TAPE, ADHES, SURF, GLASS FIBER, RUBB	3-M ST PAUL	TAPE 62	.000	16.5				H	68-1009
TAPE, ADHES, SURF, TFE, PTFE RESIN, S	3-M ST PAUL	CH30	.000	16.5				H	20747-215
TAPE, ADHES, SURF, ALUMINUM	ARNO ADHESIVE TAPES	CHEMFLUOR TFE INSUL TAPE	.000	6.2				H	68-1010
TAPE, TFE, PTFE RESIN	CHEMPLAST INC								

* (REF: MSC-NA-D-68-1, REV. C, FEB. 28, 1969)

APPENDIX D

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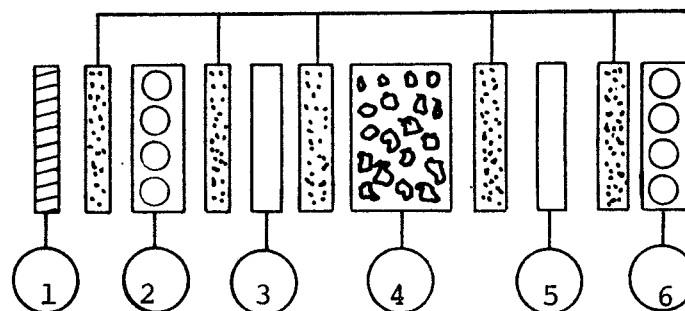
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Helium with Nitrogen for use in Diving Atmospheres, by
Gerhard A. Cook, et al, Linde Division Union Carbide Corp.
(AD-651583) March 31, 1967.
33. Proceedings of Fire Hazards and Extinguishment Conference,
ASFC - Brooks AF Base, 23 May 1967, AMD-TR-67-2, (AD-664584)
34. The Effect of Silicone and Tissue Paper Igniters on Flame
Propagation Rate, by David L. Pippen, NASA-WSTF, TR-MIS-003,
September 15, 1969
35. Combustion Safety in Diving Atmospheres, Second Summary
Report, by Victor A. Dorr and Heinz R. Schreiner, Ocean
Systems, Inc., (ONR Contract No. N00014-66-60149) May 1969
36. Flame Impingement Testing in the Crew Systems Division,
by Materials Development Lab, Supporting Development Branch,
Crew Systems Division, NASA-MSD

APPENDIX E

PROCESSING INSTRUCTIONS

EXPERIMENTAL SAMPLE NO. XPB - 1



ADHESIVE

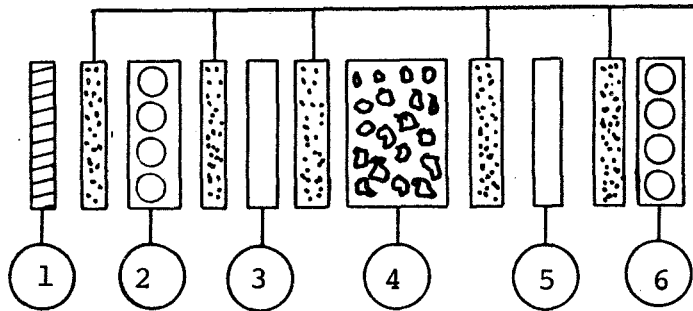
TYPE Fluorel

Mosites #1066

LOT NO. _____

LAYER NO	DESCRIPTION	MATERIAL TYPE	THICKNESS, MILS	PRE-TREATMENT	SPECIAL INSTRUCTIONS
1	Foil	Aluminum 1100-0	0.33	Scour	Vacuum Bag Cure: 8 hrs @ 280°F 5" Hg
2	Fabric	116 Fiberglass Volan A Finish	-		
3	Plastic Film	Aclar Film 33c	1.00	Scour	
4	Sponge	Raybestos Manhattan R.L. - 2060	50.00		
5	Plastic Film	Aclar 33c	1.00		
6	Fabric	116 Fiberglass Volan A Finish	-		

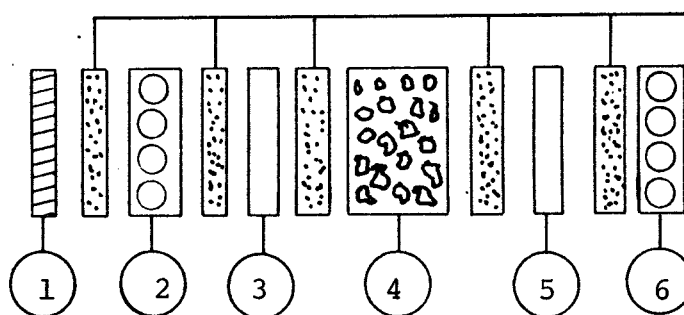
EXPERIMENTAL SAMPLE NO. XPB - 2



ADHESIVE
TYPE <u>DC-281</u>
Catalyzed
LOT NO. _____

LAYER NO	DESCRIPTION	MATERIAL TYPE	THICKNESS, MILS	PRE-TREATMENT	SPECIAL INSTRUCTIONS
1	Foil	Aluminum - 1100-0	0.33	Scour	Cure: Use vacuum bag method of assembly Cure 8 hrs @ 120°F Post cure 1 hr @ 250°F
2	Fabric	116 Fiberglass Volan A Finish		Heat for 24 hrs @ 400°F	
3	Plastic Film	Aclar 33c	1	Scour	
4	Foam	Fluorel Sponge Mosites 1062C	50	Heat for 24 hrs @ 400°F	
5	Plastic Film	Aclar 33c	1	Scour	
6	Fabric	116 Fiberglass Volan A Finish	-	Heat for 24 hrs @ 400°F	

EXPERIMENTAL SAMPLE NO. XPB - 3



ADHESIVE

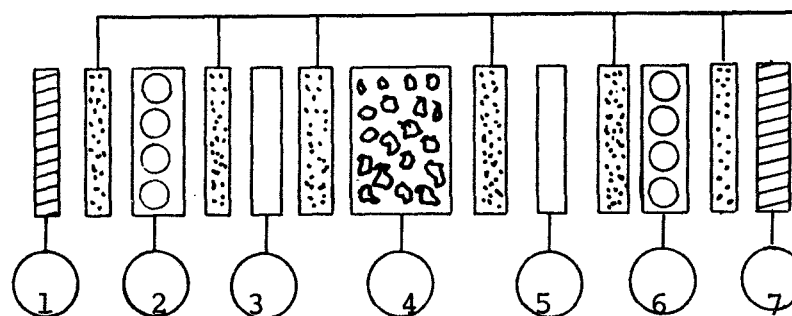
TYPE Fluorel

Mosites #1066

LOT NO. _____

LAYER NO	DESCRIPTION	MATERIAL TYPE	THICKNESS, MILS	PRE-TREATMENT	SPECIAL INSTRUCTIONS
1	Foil	Aluminum - 1100-0	0.33	Scour	Use vacuum bag method of assembly Cure at 250°F for 24 hrs
2	Fabric	116 Fiberglass Volan A Finish	-	Heat treat at 400°F for 24 hrs	
3	Plastic Film	Aclar 33c	1.0	Scour	
4	Foam	Mosites 1062C	50	Heat treat at 400°F for 24 hrs	
5	Plastic Film	Aclar 33c	1.0	Scour	
6	Fabric	116 Fiberglass Volan A Finish	-	Heat treat at 400°F for 24 hrs	

EXPERIMENTAL SAMPLE NO. XPB - 4



ADHESIVE

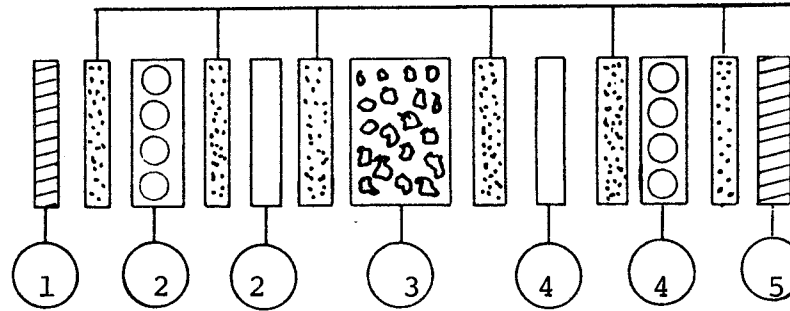
TYPE Fluorel

Mosites #1066

LOT NO. _____

LAYER NO.	DESCRIPTION	MATERIAL TYPE	THICKNESS, MILS	PRE-TREATMENT	SPECIAL INSTRUCTIONS
1	Foil	Aluminum 1100-0	1 Mil	Scour	Use vacuum bag method of assembly Cure at 240°F for 24 hrs.
2	Fabric	116 Fiberglass Volan A Finish	1 Ply	Heat treat at 400°F for 24 hr.	
3	Plastic Film	Aclar 33c	1 Mil	Scour	
4	Foam	Mosites 1062C	50	Heat treat at 400°F for 24 hr.	
5	Plastic Film	Aclar 33c	1 Mil	Scour	
6	Fabric	116 Fiberglass Volan A Finish	1 Ply	Heat treat at 400°F for 24 hr.	
7	Foil	Aluminum - 1100-0	1 Mil	Scour	

EXPERIMENTAL SAMPLE NO. XPB - 5 (D-21)



ADHESIVE

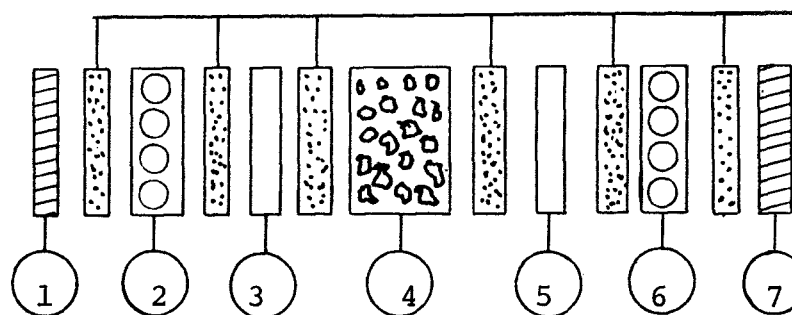
TYPE Vitel

AD-917

LOT NO. _____

LAYER NO.	DESCRIPTION	MATERIAL TYPE	THICKNESS, MILS	PRE-TREATMENT	SPECIAL INSTRUCTIONS
1	Foil	Aluminum 1100-0	.3	Anodized	Vacuum bag 5" Y cure @ 120°F for 48 hrs
2	Film Cloth	Nylon	1 Ply		
3	EPT Foam	Rubber	50 Mils	Prime with 1 coat 1473C	
4	Film Cloth	Nylon	1 Ply		
5	Foil	Aluminum 1100-0	1 Mil		

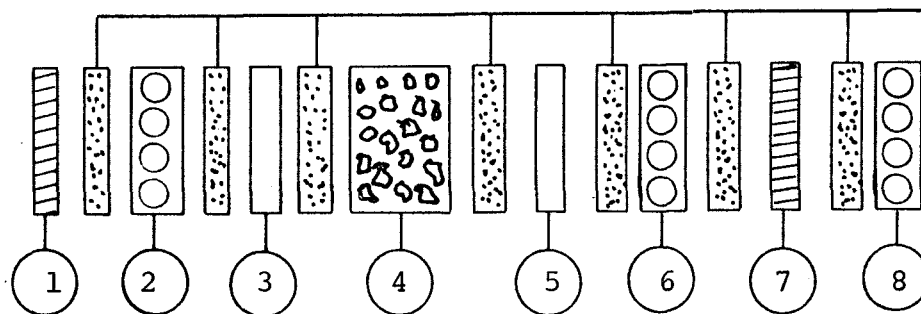
EXPERIMENTAL SAMPLE NO. XPB - 6



ADHESIVE	
TYPE	<u>Viton</u>
	<u>238-86-1</u>
LOT NO.	<u> </u>
	<u> </u>

LAYER NO.	DESCRIPTION	MATERIAL TYPE	THICKNESS, MILS	PRE-TREATMENT	SPECIAL INSTRUCTIONS
1	Foil	Aluminum 1100-0	1	Scour	Use vacuum bag method of assembly Cure 16 hr at 240°F
2	Fabric	116 Fiberglass Volan A Finish	1 Ply	Heat treat at 400°F for 24 hr	
3	Plastic Film	Aclar 33c	1	Scour	
4	Foam	Mosites 1062C	50	Heat treat at 400°F for 24 hr.	
5	Plastic Film	Aclar 33c	1	Scour	
6	Fabric	116 Fiberglass Volan A Finish	1 Ply	Heat treat at 400°F for 24 hr.	
7	Foil	Aluminum 1100-0	1 Mil	Scour	

EXPERIMENTAL SAMPLE NO. XPB - 7



ADHESIVE

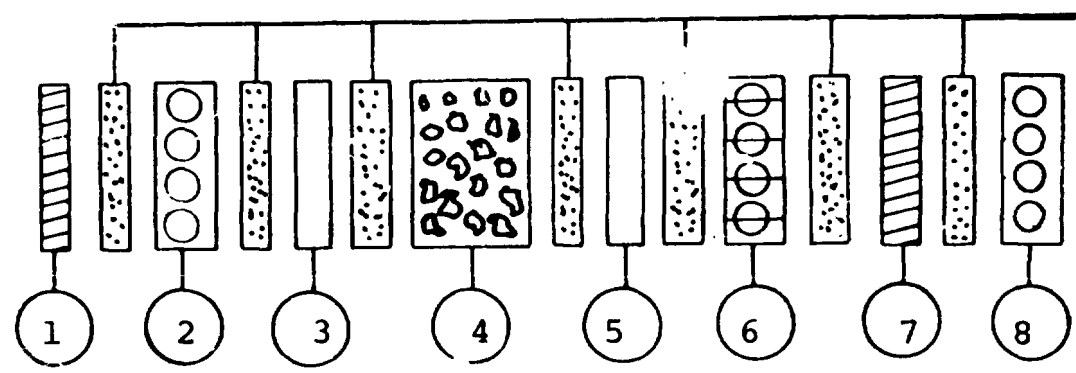
TYPE Fluorel

Mosites #1066

LOT NO. _____

LAYER NO.	DESCRIPTION	MATERIAL TYPE	THICKNESS, MILS	PRE-TREATMENT	SPECIAL INSTRUCTIONS
1	Foil	Aluminum 1100-0	1	Scour	Use vacuum bag method of assembly Cure 16 hours at 240°F
2	Fabric	81677 Beth Glass	1 Ply	Heat treat at 400°F for 24 hr.	
3	Plastic Film	Aclar 33c	1 Mil	Scour	
4	Foam	Mosites 1062C	50 Mil	Heat treat at 400°F for 24 hr.	
5	Plastic film	Aclar 33c	1 Mil	Scour	
6	Fabric	81677 Beta Glass	1 Ply	Heat treat at 400°F for 24 hr.	
7	Foil	Aluminum 1100-0	1	Scour	
8	Metal Fabric	Rene' 41	1 Ply	Heat treat at 400°F for 24 hr.	

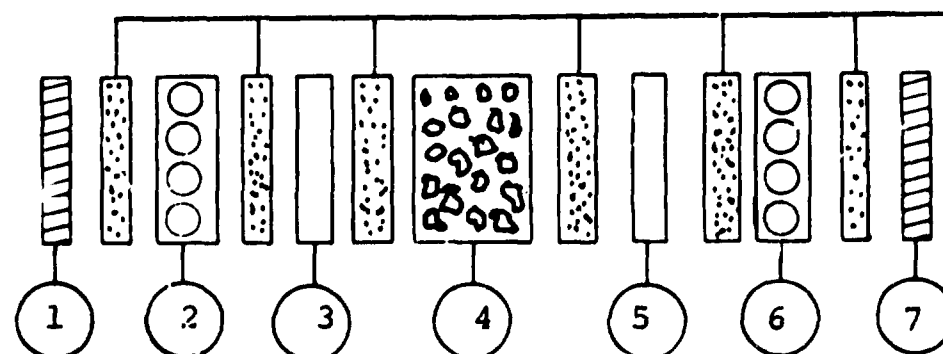
EXPERIMENTAL SAMPLE NO. XPB - 3



ADHESIVE
TYPE <u>Fluorel</u>
Mosites, #1066
LOT NO. _____

LAYER NO.	DESCRIPTION	MATERIAL TYPE	THICKNESS, MILS	PRE-TREATMENT	SPECIAL INSTRUCTIONS
1	Foil	Aluminum 1100-0	0.5	Same as XPB-7	Same as XPB-7
2	Fabric	81677 Beta Glass			
3	Plastic Film	Aclar 33c	1.0		
4	Sponge	Mosites 1062C Fluorel	50.0		
5	Plastic Film	Aclar 33c	1.0		
6	Fabric	81677 Beta Glass			
7	Foil	Aluminum 1100-0	0.5		
8	Fabric	Rene' 41	.16		

EXPERIMENTAL SAMPLE NO. XPB - 9

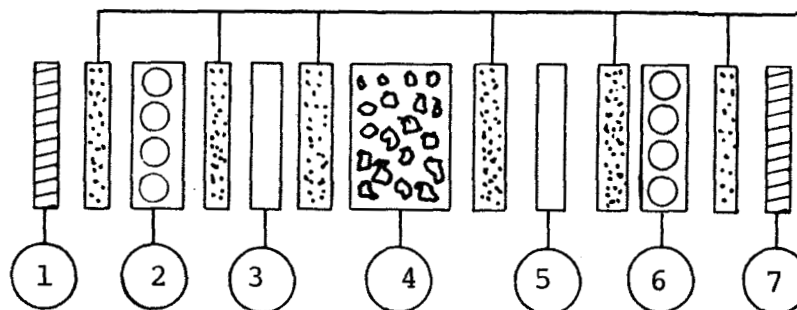


ADHESIVE

TYPE Raybestos
ManhattanLOT NO. RL 3788

LAYER NO.	DESCRIPTION	MATERIAL TYPE	THICKNESS, MILS	PRE-TREATMENT	SPECIAL INSTRUCTIONS
1	Foil	Aluminum 1100-0	1.0		Vacuum Bag Cure 60' @ 280°F
2	Fabric	81677 Beta glass			
3	Plastic Film	Aclar 33c	1.0		
4	Sponge	Mosites1062-C Fluorel	50.0	Same as XPB-4	
5	Plastic Film	Aclar 33c	1.0		
6	Fabric	81677 Beta glass			
7	Foil	Aluminum 1100-0	1.0		

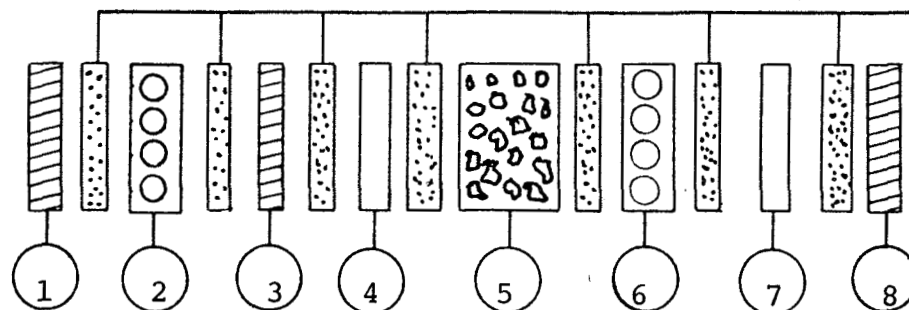
EXPERIMENTAL SAMPLE NO. XPB - 10



ADHESIVE
TYPE <u>Fluorel</u>
Mosites # <u>1066</u>
LOT NO. _____

LAYER NO.	DESCRIPTION	MATERIAL TYPE	THICKNESS, MILS	PRE-TREATMENT	SPECIAL INSTRUCTIONS
1	Foil	Aluminum - 1100-0	1	Scour	Use vacuum bag method of assembly Cure 16 hrs @ 240°F
2	Fabric	81677 Beta Glass	1 Ply	Heat treat at 400°F for 24 hr.	
3	Plastic Film	Aclar 33c	1	Scour	
4	Foam	Mosites 1062C	50	Heat treat at 400°F for 24 hr.	
5	Plastic Film	Aclar 33c	1	Scour	
6	Fabric	81677 Beta Glass	1 Ply	Heat treat at 400°F for 24 hr.	
7	Foil	Aluminum - 1100-0	1	Scour	

EXPERIMENTAL SAMPLE NO. XPB - 11



ADHESIVE

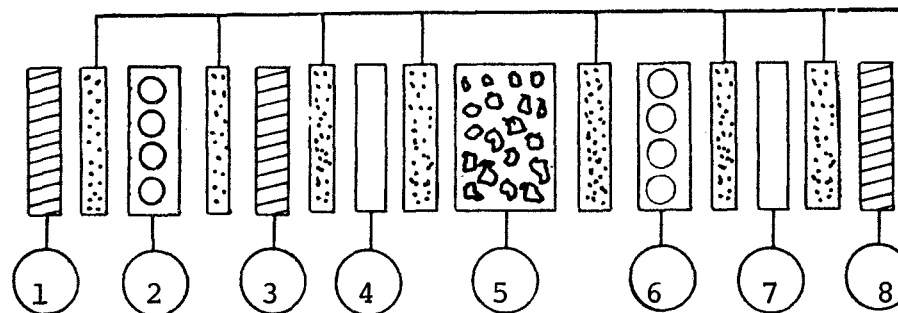
TYPE Fluorel

Mosites #1066

LOT NO. _____

LAYER NO.	DESCRIPTION	MATERIAL TYPE	THICKNESS, MILS	PRE-TREATMENT	SPECIAL INSTRUCTIONS
1	Foil	Aluminum - 1100-0	1/2	Scour	Use vacuum bag method of assembly Cure 16 hours at 240°F
2	Fabric (Asbestos)	Uniroyal 1700	(.0248")	Heat treat at 400°F for 24 hr.	
3	Foil	Aluminum - 1100-0	1	Scour	
4	Film	Aclar 33c	1	Scour	
5	Foam	Mosites 1062C	50	Heat treat at 400°F for 24 hr.	
6	Fabric	Beta 81677	1 Ply	Heat treat at 400°F for 24 hr.	
7	Film	Aclar 33c	1	Scour	
8	Foil	Aluminum	1	Scour	

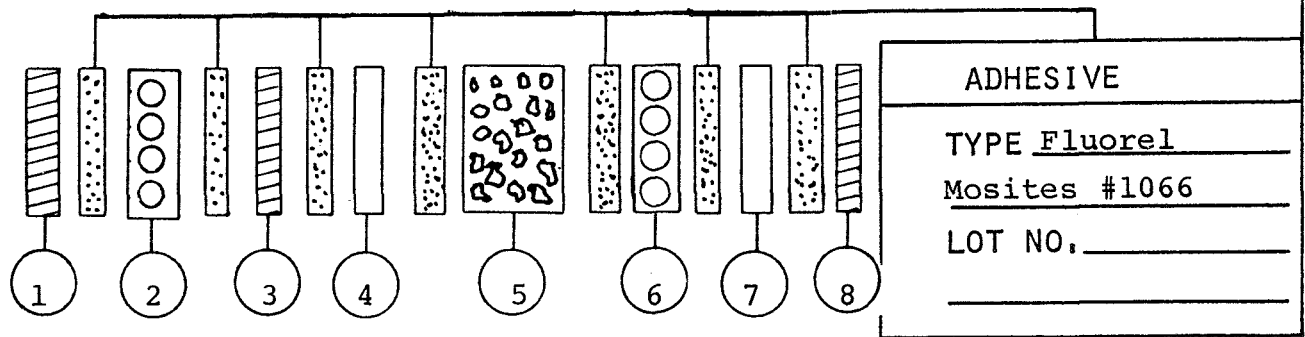
EXPERIMENTAL SAMPLE NO. XPB - 12



ADHESIVE
TYPE <u>Fluorel</u>
Mosites #1066
LOT NO. _____

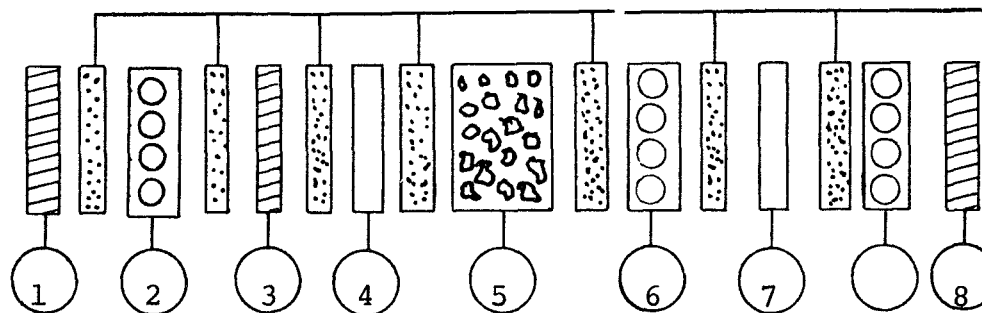
LAYER NO.	DESCRIPTION	MATERIAL TYPE	THICKNESS, MILS	PRE-TREATMENT	SPECIAL INSTRUCTIONS
1	Foil	Aluminum 1100-0	1/2	Scour	Use vacuum bag method of assembly Cure 16 hour at 240°F
2	Fabric	Hitco C100-28	(.014")	Heat treat at 400°F for 24 hr.	
3	Foil	Aluminum 1100-0	1	Scour	
4	Film	Aclar 33c	1	Scour	
5	Foam	Mosites 1062C	50	Heat treat at 400°F for 24 hrs.	
6	Fabric	Beta 81677	1 Ply	Heat treat at 400°F for 24 hr.	
7	Film	Aclar 33c	1	Scour	
8	Foil	Aluminum 1100-0	1	Scour	

EXPERIMENTAL SAMPLE NO. XPB - 13



LAYER NO.	DESCRIPTION	MATERIAL TYPE	THICKNESS, MILS	PRE-TREATMENT	SPECIAL INSTRUCTIONS
1	Foil	Aluminum 1100-0	1/2	Scour	Use vacuum bag method of assembly Cure 16 hours at 280°F
2	Fabric asbestos	Novatex	-	Heat treat at 400°F for 24 hrs.	
3	Foil	Aluminum 1100-0	1	Scour	
4	Film	Aclar 33c	1	Scour	
5	Foam	Mosites 1062C	50	Heat treat at 400°F for 24 hr.	
6	Fabric	Beta 81677	1 Ply	Heat treat at 400°F for 24 hr.	
7	Film	Aclar 33c	1	Scour	
8	Foil	Aluminum 1100-0	1	Scour	

EXPERIMENTAL SAMPLE NO. XPB - 14



ADHESIVE

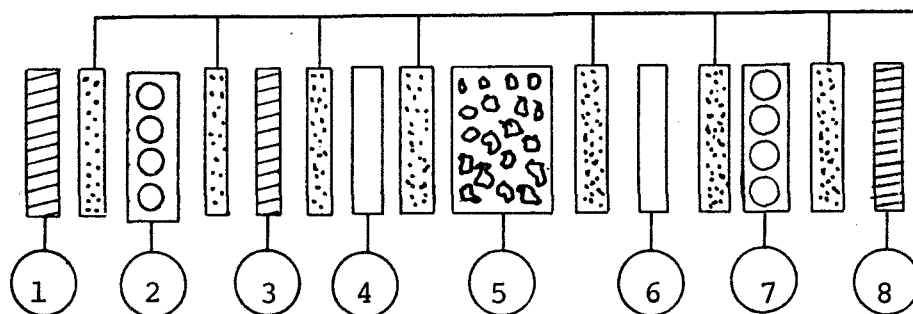
TYPE Fluorel

Mosites #1066

LOT NO. _____

LAYER NO.	DESCRIPTION	MATERIAL TYPE	THICKNESS, MILS	PRE-TREATMENT	SPECIAL INSTRUCTIONS
1	Foil	Aluminum 1100-0	0.5		Flash off solvents Vacuum bag and cure 16 hrs @ 280°F Spray coat adhesive
2	Fabric	Hitco C-100-28			
3	Foil	Refrasil			
4	Plastic Film	Aluminum 1100-0	1.0		
5	Sponge	Kapton	1.0		
6	Fabric	Mosites 1062C	50		
7	Plastic Film	Fluorel			
8	Foil	81677 Beta Glass			
		Aclar 33c	1.0		
		Aluminum 1100-0	1.0		

EXPERIMENTAL SAMPLE NO. XPB - 14A



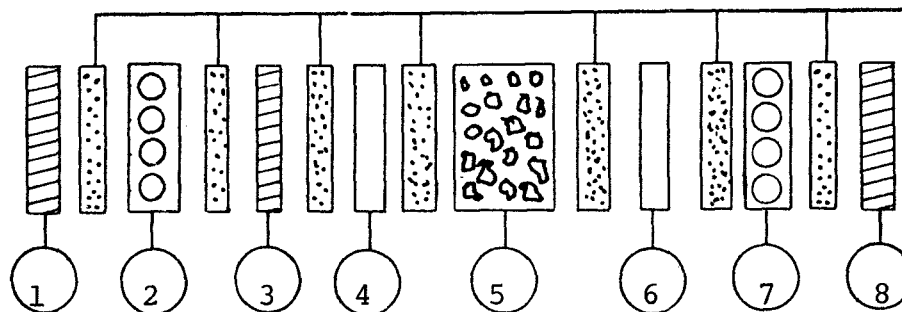
ADHESIVE

TYPE FluorelMosites #1066

LOT NO. _____

LAYER NO.	DESCRIPTION	MATERIAL TYPE	THICKNESS, MILS	PRE-TREATMENT	SPECIAL INSTRUCTIONS
1	Foil	Aluminum 1100-0	1/2	Scour	Use vacuum bag method of assembly Cure 16 hours at 280°F
2	Fabric	Refrasil C-100-28	14	Heat treat at 400°F for 24 hr.	
3	Foil	Aluminum 1100-0	1	Scour	
4	Film	Kapton	1	Scour	
5	Foam	Mosites 1062C	50	Heat treat at 400°F for 24 hrs.	
6	Film	Aclar 33c	1	Scour	
7	Fabric	Beta Glass 81677	4.8	Heat treat at 400°F for 24 hrs.	
8	Foil	Aluminum 1100-0	1	Scour	

EXPERIMENTAL SAMPLE NO. XPB - 14A -1



ADHESIVE

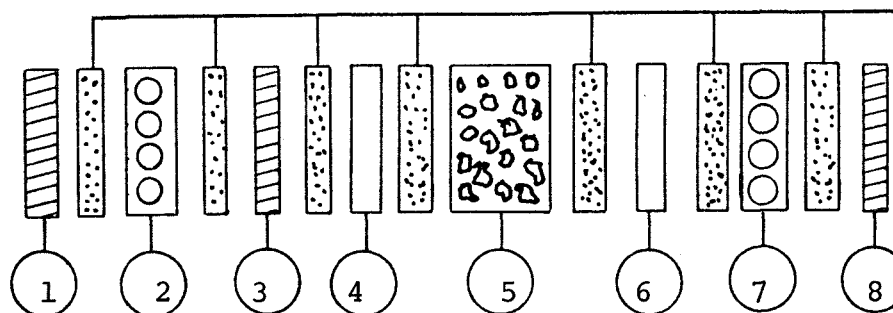
TYPE Fluorel

Mosites #1066

LOT NO. _____

LAYER NO.	DESCRIPTION	MATERIAL TYPE	THICKNESS, MILS	PRE-TREATMENT	SPECIAL INSTRUCTIONS
1	Foil	Aluminum 1100-0	1/2	Scour	1. Do not apply adhesive to layer No. 5 (sponge). 2. Use vacuum bag method of assembly. 3. Cure 16 hours @ 280°F
2	Fabric	Refrasil C-100-28	14	Heat treat at 400°F for 24 hr.	
3	Foil	Aluminum 1100-0	1	Scour	
4	Film	Kapton	1	Scour	
5	Foam	Mosites 1062C	50	Heat treat at 400°F for 24 hrs.	
6	Film	Aclar 33c	1	Scour	
7	Fabric	Beta Glass 81677	4.8	Heat treat at 400°F for 24 hrs.	
8	Foil	Aluminum 1100-0	1	Scour	

EXPERIMENTAL SAMPLE NO, XPB - 14A -2



ADHESIVE

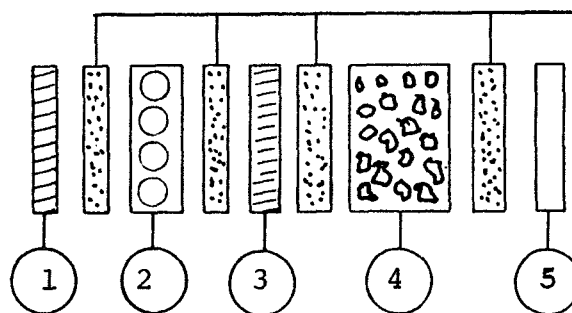
TYPE Fluorel

Mosites #1066

LOT NO. _____

LAYER NO.	DESCRIPTION	MATERIAL TYPE	THICKNESS, MILS	PRE-TREATMENT	SPECIAL INSTRUCTIONS
1	Foil	Aluminum 1100-0	1/2	Scour	1. Heat layers to 150°F for 1 hr after application of adhesive. 2. Use vacuum bag method of assy. 3. Cure 16 hours at 280°F.
2	Fabric	Refrasil C-100-28	14	Heat treat at 400°F for 24 hr.	
3	Foil	Aluminum 1100-0	1	Scour	
4	Film	Kapton	1	Scour	
5	Foam	Mosites 1062C	50	Heat treat at 400°F for 24 hrs.	
6	Film	Aclar 33c	1	Scour	
7	Fabric	Beta Glass 81677	4.8	Heat treat at 400°F for 24 hrs.	
8	Foil	Aluminum 1100-0	1	Scour	

EXPERIMENTAL SAMPLE NO. XPB - 16



ADHESIVE	
TYPE	<u>Fluorel</u>
RL-3788	_____
LOT NO.	_____

LAYER NO.	DESCRIPTION	MATERIAL TYPE	THICKNESS, MILS	PRE-TREATMENT	SPECIAL INSTRUCTIONS
1	Foil	Aluminum 1100-0	0.5		Flash Off Solvents. Vacuum Bag & Cure 16 hrs @ 280°F
2	Fabric	Hitco C-100-28 Refrasil			
3	Foil	Aluminum 1100-0	1.0		
4	Elastomer	Raybestos Manhattan L-3203-6	Approx. 15		
5	Foil	Aluminum 1100-0	1.0		
					Spray Coat Adhesive

PROCESS INSTRUCTION

Date 12-8-69

(Mosites/Chromel Panel)

<u>MATERIAL</u>	<u>SPOOL NO.</u>	<u>WEIGHT (GRAMS)</u>		<u>USED</u>
		<u>BEFORE</u>	<u>AFTER</u>	
A. Chromel Wire	C-1	1583	1370	213
	C-2	1562	1351	211
	C-3	1581	1370	211
B. Taslan	#4	495	463	32
	#5	493	460	33
	#6	421	391.5	29.5
C. Mosites Resin Mix - 200 grams Mosites 1066 120 grams Toluene 80 grams M.E.K.				
D. Vacuum Bag Cure - 16 hours at 300°F				
E. Size 29" x 58"				
F. Final Weight - 940 grams				

APPENDIX F

NASA-MSC MICROMETEOROID TEST RESULTS



NATIONAL AERONAUTICS AND SPACE ADMINISTRATION
MANNED SPACECRAFT CENTER
HOUSTON, TEXAS 77058

REPLY TO
ATTN OF: TG2

352 7 1970

Mr. K. L. Cordier
Department 457G
Goodyear Aerospace Corp.
Akron, Ohio 44315

Dear Mr. Cordier:

The data from the Lunar Shelter Materials Tests are attached to this letter. The table entitled, "High Velocity Tests," contains the usable data accumulated during the Hypervelocity Ballistic-Limit Tests. The first portion of this table contains the data of target type XTC-4 and the second, XTC-6. Included in the table are our shot numbers, the sequence of testing (used in the data plot), your panel number, the target and projectile data, and the results. The second table entitled, "Low Velocity Tests," contains data taken at velocities of approximately 1Kps. This table contains data in similar order to that enumerated for the High Velocity Tests, except that the sequence numbers are at the right-hand side of the table.

The data are plotted on the last sheet to show the order of testing and the results. Our estimate of the ballistic limit is found as a dashed line on each graph. The variations in the high velocity results are felt to be due primarily to the non-homogeneity of the target material (holes completely through the front layers of material were noted). Velocity variations would have a small influence on these variations.

Only a few of the targets were used for the Low-Velocity Tests; therefore, it was not possible to accurately determine the ballistic limit. It can be seen that the ballistic limit determined with these tests is approximate only.

Burton Cour-Palais
Burton Cour-Palais

Enclosure

HIGH VELOCITY TESTS

Glass Projectiles

DATA SHEET

Target Type - XTC-4

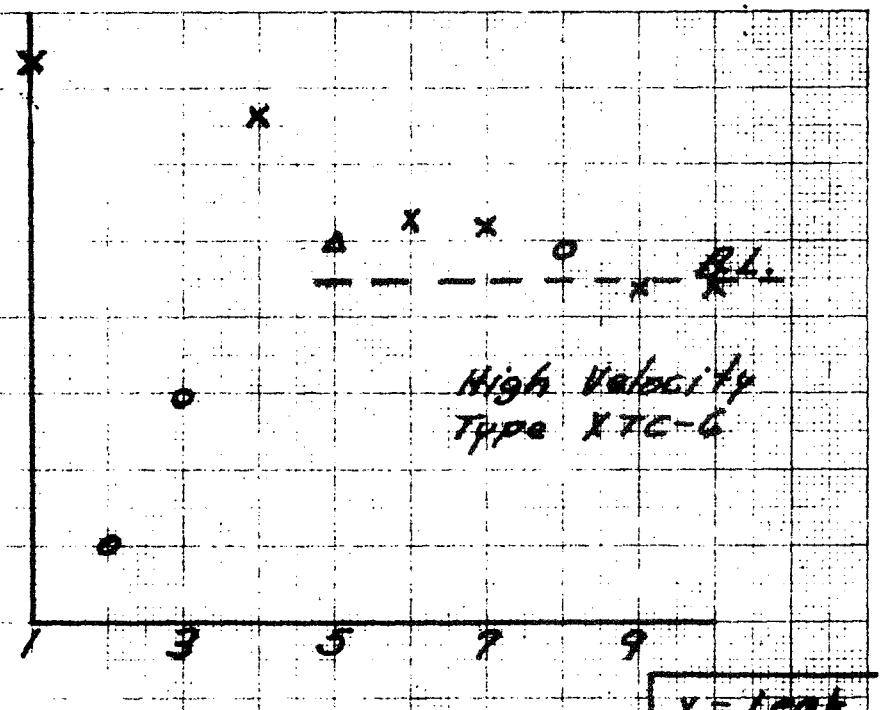
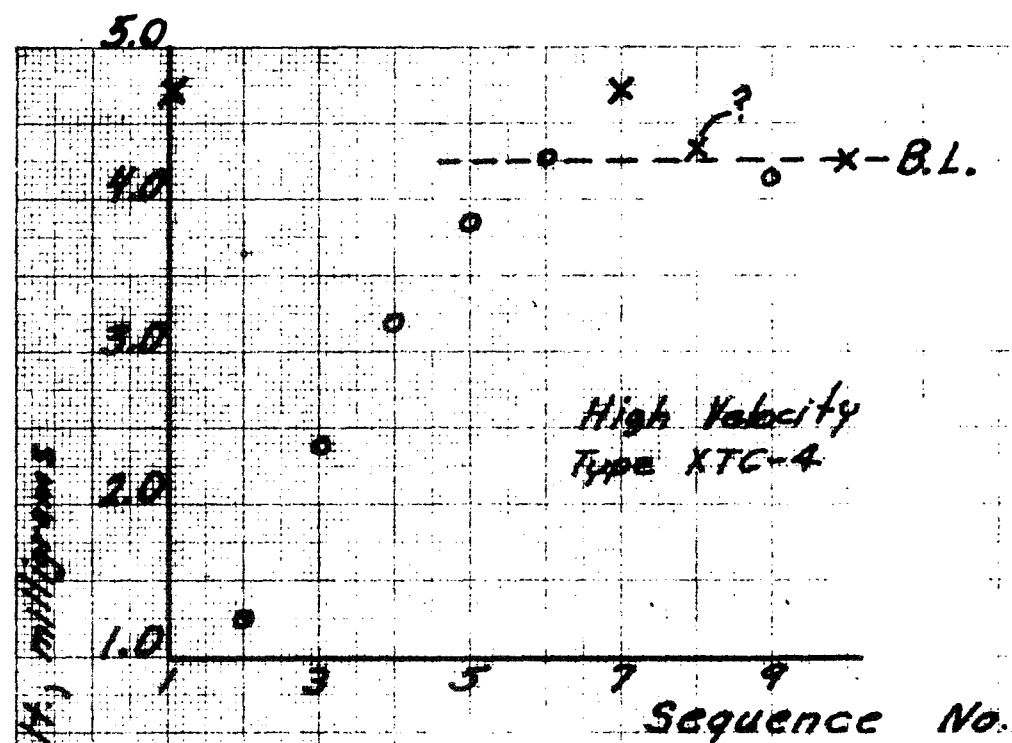
Shot No.	Sequence No.	Target No.	Target Wt., gms.	Projectile Veloc., KPS	Proj. Dia, inches	Proj. Wt., milligrams	Leakage	Notes:
5808	1	Pinel 5-#5	58.00	7.62	.0625	-(4.71)	Yes	Target badly damaged
5809	2	P2-#13	58.01	-	.0397	-(1.21)	None	
5810	3	P5-#1	56.8	7.53	.048	2.38	None	
5811	4	P5-#4	57.3	7.37	.052	3.20	None	
5812	5	P5-#7	57.40	-	.055	3.84	None	
5841	6	P5-#2	57.15	7.19	.059	4.28	None	
5859	7	P2-#15	57.3	-	.0625	-(4.71)	yes	
5896	8	P2-#18	57.60	7.65	.059	4.32	yes	Trash down + ball
5897	9	P5-#6	58.5	7.47	.058	4.15	None	
5898	10	P5-#3	57.30	-	.059	4.25	yes	
								Target type XTC-6
5899	1	#2		7.25	.0624	4.67	yes	
5900	2	#9		7.60	.0397	1.51	None	
5901	3	#1		7.47	.046	2.47	None	
5902	4	#20		7.47	.0595	4.31	yes	
5903	5	#19		7.56	.056	3.48	yes - slight but too much to measure	
5904	6	#17		7.56	.056	3.64	yes	
5905	7	#16		7.37	.056	3.59	yes	
5907	8	#15		7.38	.056	3.45	Slight	Too small to measure
5908	9	#14		7.50	.054	3.17	yes	
5909	10	#13		7.47	.054	3.18	yes	

DATA SHEET

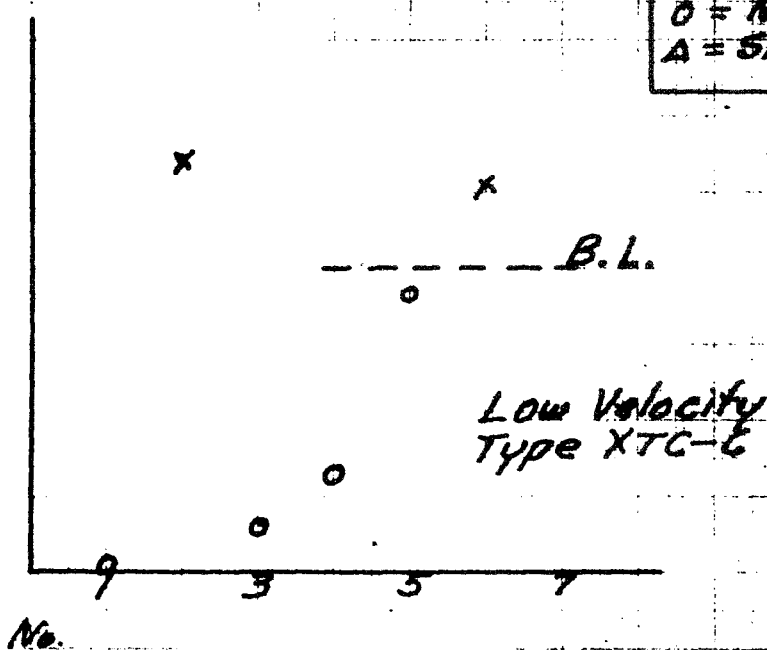
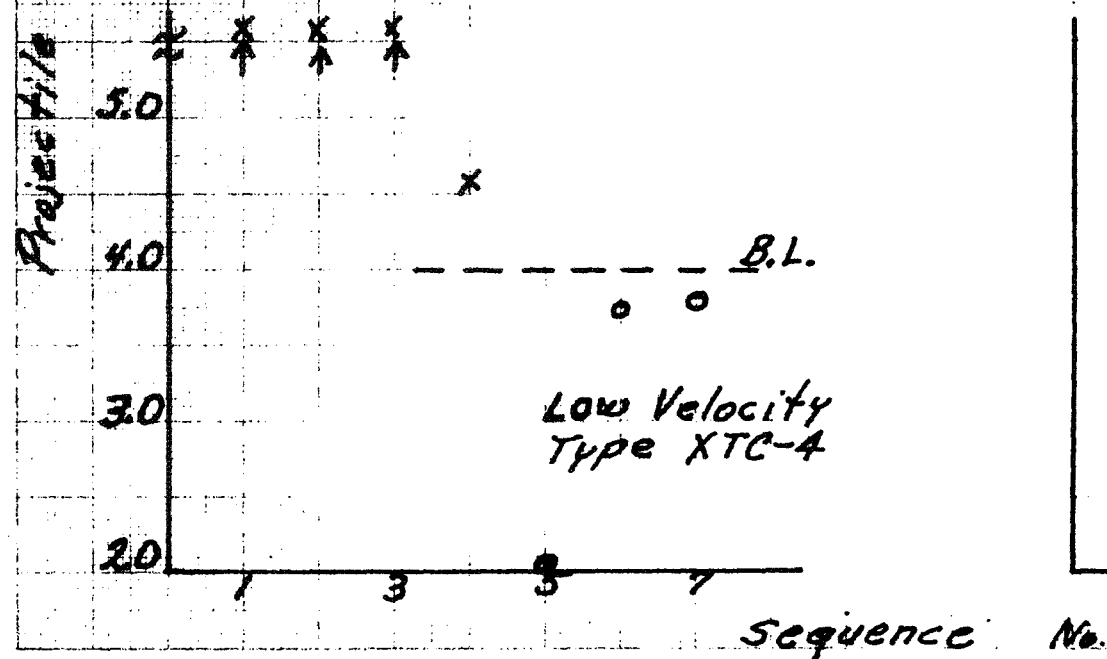
Target Type - XTC-4

[illegible]

Wts in () are calculated



x = Leak
o = No Leak
A = Slight "



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D. D. Davis, Jr., M/S 213	1
D. W. Conner, M/S 244	1
R. R. Heldenfels, M/S 188	1
J. R. Dawson, M/S 188-B	1
E. T. Kruszewski, M/S 188-B	1
J. F. McNulty, M/S 334	1
C. B. King, M/S 205	1
C. C. Kiser, M/S 334	1
D. H. Humes, M/S 498-B	1
Technology Utilization Office, M/S 103	1
Dr. L. R. Greenwood, M/S 187	1
E. S. Love, M/S 412	1
W. C. Hayes, Jr., M/S 156	1
R. L. Goble, M/S 411	1
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