NATIONAL AERONAUTICS AND SPACE ADMINISTRATION

Technical Report 32-1411

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Preface

The work described in this report was performed by the Engineering Mechanics Division of the Jet Propulsion Laboratory.

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Abstract

An investigation of 21 polymeric products was made to establish their suitability for use in spacecraft hardware. Each polymeric product, which included several material categories (e.g., films, adhesives, tapes, etc.), was given sequential exposure to the following three environments:

(1) Ethylene oxide–Freon 12 decontamination.

(2) Thermal sterilization.

(3) Long-term thermal-vacuum exposure.

The first two exposures were made in accordance with a JPL sterilization specification. The environmental conditions for the third exposure were 500 h at 135°C and 10^{-6} torr. The purpose of this work was to evaluate the total effect of all these exposures on the products tested. The effects of the individual exposures have been established by other investigators, and the results served as a bench mark for evaluating the results of this effort.

Compatibility ratings were assigned to each product tested. Of the products evaluated, 55% were rated as compatible, 30% marginal, and 15% noncompatible with the three exposures. The data obtained from this evaluation should have significant value to materials and design engineers in designing and fabricating future spacecraft.

Effects of Decontamination, Sterilization, and Thermal Vacuum on Spacecraft Polymeric Products

I. Introduction

In future planetary entry/lander missions, it is anticipated that biological sterilization will be a necessary step in spacecraft preflight preparation. One of the major objectives of planetary exploration, the detection of extraterrestrial life forms, would not be realized if viable earth-type organisms were carried aboard nonsterile spacecraft. Preflight sterilization at present consists of decontamination by treatment with a gaseous mixture of Freon and ethylene oxide (ETO), and subsequent dry-heat sterilization in an inert nitrogen atmosphere.

All material used in spacecraft fabrication must, therefore, be compatible with sterilization processes. The sterilization requirement was thought to be particularly severe for many organic polymeric products used in the spacecraft. A spacecraft polymeric product, as used here, is defined as a formulated (or compounded) organic polymer that is sold under a trade name. These include such materials as adhesives, sealants, encapsulants, etc., from which many spacecraft components and parts are prepared.

The capability of a particular product to withstand the rigorous sterilization processes is not only imperative for lander-type spacecraft, but it will also provide a high degree of reliability in nonlander spacecraft. This follows since less stable materials are screened out by the sterilization exposures.

In addition to the preflight sterilization, these same polymeric products must be capable of withstanding the anticipated space environment. This environment is defined as the thermal-vacuum conditions existing within a scientific satellite, or unmanned spacecraft, or within the unpressurized portions of a manned spacecraft. This environment is, therefore, one in which the polymeric materials have been essentially shielded from extremes of temperature and from electromagnetic and particle radiation. This environment has, therefore, generally been considered to comprise a pressure of 10^{-5} torr or less and a temperature maximum of 135°C. The duration of exposure to this environment will obviously depend on the particular planetary mission; however, exposures of the order of 500 h are considered minimal.

Compatibility of the polymeric products used in spacecraft fabrication is measured by the extent of degradation in the physical, electrical, or mechanical properties that occur as a result of preflight sterilization and in-flight thermal-vacuum exposure. The amount of degradation will, in general, be based on the intrinsic chemical

stability of the raw polymer that comprises the main portion of a polymer product. However, the minor constituents—such as processing and flexibilizing plasticizers, colorants, stabilizers, etc.—may exert an important influence on the overall stability of a particular polymeric product. The interaction of all the ingredients, or their selective removal by vaporization, could significantly alter the performance of a polymeric product.

A secondary (but important) compatibility criterion is the effect of outgassed products (both noncondensable and condensable) on the functions of spacecraft systems.

Several significant studies have been made of the compatibility of various polymeric products with the spacecraft sterilization procedures and to the spacecraft thermal-vacuum environment. The results of the studies are given in Refs. 1–5. The work described herein is an extension of those studies. Whereas the previous studies evaluated one or two of the exposures, none evaluated the total effect of all possible exposures, that is, ETO decontamination, thermal sterilization, and thermal vacuum. It was, therefore, the purpose of this program to evaluate the effects of all three exposures when performed in sequence. The determination of the total effect of these exposures was the sole objective; no attempt was made to isolate the effects of each exposure separately.

The polymeric products were selected from those that had shown acceptable performance in the preceding studies (see Refs. 1–5), and included such categories as adhesives, sealants, tapes, films, etc. The products tested, along with the procurement source for each, are listed in Table 1. Each product was subjected to the following sequence of exposures:

(1) Six decontamination cycles of a humidified ETO–Freon atmosphere at 50°C for 30 h each.

(2) Six thermal-sterilizing cycles of a dry nitrogen atmosphere at 135°C for 96 h each.

(3) One thermal-vacuum exposure for 500 h under conditions of 135°C temperature and 10^{-6} torr pressure.

By the performance of physical, mechanical, and electrical property tests on each product, both before and after the sequence of exposures, a measure of the stability or compatibility of the product with the exposures was obtained. Ratings were assigned to each product according to its ability to withstand the effects of the exposures. The rating criteria used had been previously established in similar studies (see Refs. 2 and 3).

Table 1. Product source list

Product number	Product (trade name)	Manufacturer
1	Epon 901/B-3	Shell Chemical Co.
2	Epon 828/Z	Shell Chemical Co.
3	HT 424	American Cyanamid Co.–Bloomingdale Dept.
4	Solithane 113/300	Thiokol Chemical Corp.
5	Stycast 1090/11	Emerson & Cumming Inc.
6	Stycast 1095/11	Emerson & Cumming Inc.
7	Scotchcast 281 A/B	3M Company–Electrical Products Div.
8	Mystik 7020	Borden Chemical Co.
9	Mystik 7503	Borden Chemical Co.
10	FEP 200A	E. I. Dupont de Nemours, Inc.
11	Tedlar 100 BG 30 WH	E. I. Dupont de Nemours, Inc.
12	Mylar 100A	E. I. Dupont de Nemours, Inc.
13	Kapton 200 X H667	E. I. Dupont de Nemours, Inc.–Dupont Film Div.
14	Micarta H 17511	Westinghouse Electric Corp.–Micarta Div.
15	Micarta 20201-2	Westinghouse Electric Corp.–Micarta Div.
16	Micarta 65M25	Westinghouse Electric Corp.–Micarta Div.
17	Viton B	E. I. Dupont de Nemours, Inc.
18	1050-70	Plastic & Rubber Products Co.
19	SRG 1810	3M Company–Irvington Div.
20	Armalon 98-101	E. I. Dupont de Nemours, Inc.–Industrial Coated Fabrics Div.
21	Pyre ML	E. I. Dupont de Nemours, Inc.

The data obtained in this program should complement those of the previous polymeric materials studies. It is anticipated that materials and design engineers will find these data helpful when designing future spacecraft for lander/probe-type missions.

II. Experimental Section

A. Sample Preparation and Testing

The polymeric products selected for evaluation in this program included the following material categories:

(1) Adhesives—structural.

(2) Coatings—conformal.

(3) Coated fabrics.

(4) Elastomers.

(5) Encapsulants.

(6) Films.

(7) Hardware and structural materials.

(8) Tapes.

The test sequence employed is outlined in Fig. 1. As indicated in this sequence, material properties were measured before exposure to all three environments (control specimens), and again after exposure to all the environments (exposed specimens). The physical, mechanical, and electrical property tests that were employed for each class of materials are indicated in the materials test matrix shown in Table 2. The test specimens of each material were prepared in accordance with the sizes and shapes specified in the particular standard American Society for Testing Materials (ASTM) test method used. In most cases, a minimum of six specimens (three control and three exposed specimens) were prepared from each polymeric product. Although most of the test data were obtained through standard ASTM test methods, it was not possible to use these methods in all instances. The nonstandard procedures used are outlined in the paragraphs that follow.

1. Dimensional change. Test specimens were either cut to the dimensions of 2 × 2 in. from the as-received materials or cast and cured to these dimensions, with thickness approximating 0.010 in. Bench marks just less than 2 in. apart were scribed on each specimen, and measured with vernier calipers having an accuracy of approximately ±0.002 in. Any change in distance between bench marks as a result of the exposures was expressed as a percent of the initial distance.

2. Weight change. Test specimens were prepared in a manner similar to that used for the dimensional change specimens. Samples (Fig. 2) were weighed to an accuracy of ±1 mg on an analytical balance. Any change in weight as a result of the exposures was expressed as a percent of the initial specimen weight.

3. Adhesive creep. The adhesives were tested *in situ* for creep under a load of 500 ±3 psi. In general, the test specimens were prepared according to an ASTM test procedure. Aluminum and stainless-steel test fixtures, fitted with compression springs rated at 650 lb, were used to hold the test specimens in shear throughout the exposure periods. Design drawings for these fixtures are given in Ref. 4. Creep measurements were made to ±0.005 mm using a Gaertner cathetometer to view the scribed lines on the test specimens.

B. Test Equipment and Exposure Procedures

The special exposure equipment used in this program included an ETO–Freon 12 decontamination chamber, a thermal sterilization chamber, and a thermal-vacuum exposure unit.

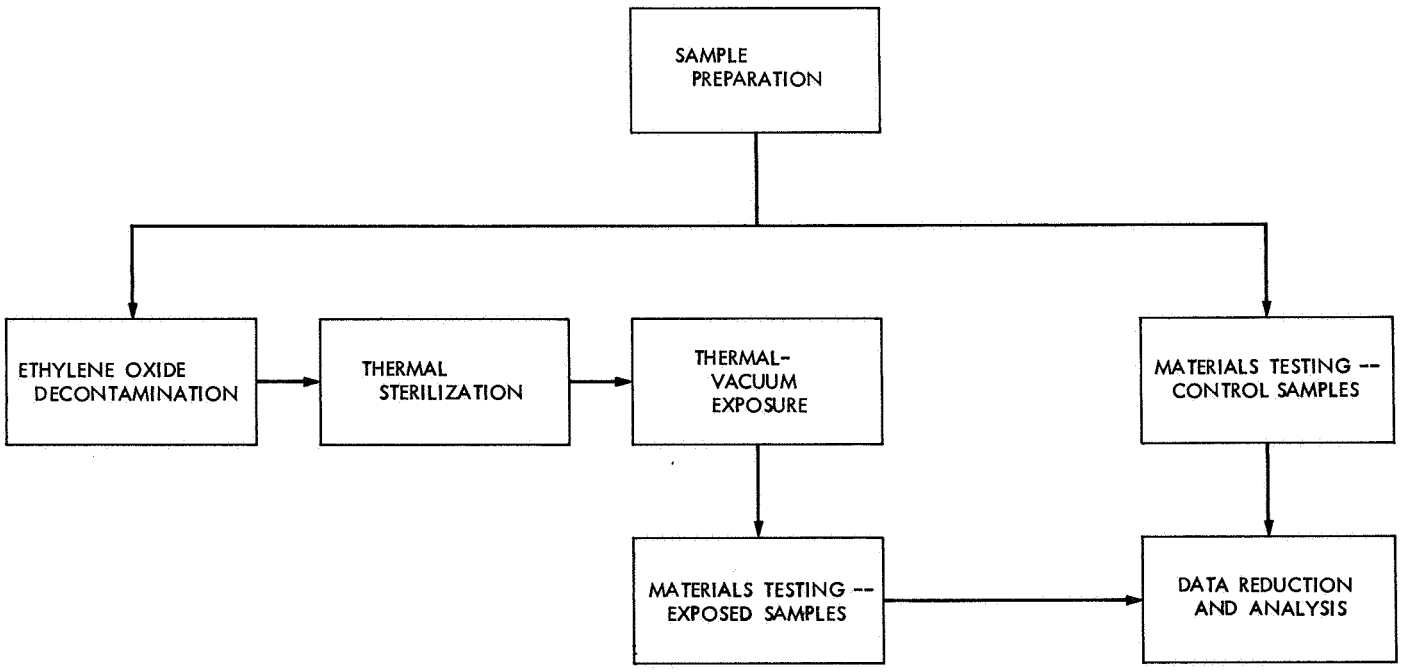

Fig. 1. Exposure and test sequence

Table 2. Material test matrix

Test	Adhesives	Coatings	Coated fabrics	Elastomers	Encapsulants	Films	Hardware and structural materials	Tapes	ASTM standard
Adhesive shear strength	X								D1002
Adhesion	X	X						X	D1000 D1876 D2197
Adhesive creep	X								D2294
Weight change	X	X	X	X	X	X	X	X	—
Volume resistivity		X			X	X	X		D257
Dielectric strength (short time)		X			X	X	X	X	D149 D1000
Breaking strength			X					X	D1000 D751
Dimensional change			X	X	X	X	X	X	—
Tensile strength				X	X	X	X		D882 D638 D412
Tear strength			X			X			D1004 D751
Hardness				X	X		X		D785 D2240
Compression set				X					D395

1. Ethylene oxide–Freon 12 decontamination. The automatic decontamination apparatus used in this program is described in detail in Refs. 3 and 6. This equipment, depicted in Fig. 3, is capable of performing the ETO–Freon decontamination procedure for piece parts and materials as specified in JPL sterilization specifications. The decontamination procedure performed by this equipment is described in the paragraph that follows.

Each complete decontamination exposure consisted of six identical cycles, with each cycle, in turn, composed of five phases. These phases are:

(1) Humidification of test specimens in clean air for 2¾ h.

(2) Application of a predecontamination vacuum at 60 torr for 18 min.

(3) ETO–Freon 12 decontamination for 30 h, at 600 ±50 mg/l ETO concentration, 50 ±2°C, and 50 ±5% relative humidity.

(4) Application of postdecontamination vacuum at 60 torr for 18 min.

(5) Application of an air wash for 2¾ h.

During each of these phases (except the vacuum phases), the temperature, pressure, and humidity levels were accurately controlled. The temperature was measured by means of four thermocouples and recorded by a strip chart recorder. After completion of cycle 6, the apparatus shut off automatically.

2. Thermal sterilization. The thermal-sterilization equipment shown in Fig. 4 consisted of a 25–343°C oven (Blue M Co., Model POM-16VB) fitted with a nitrogen manifold system that permitted a continuous nitrogen purge through the sterilization chamber during the specimen exposures. The oven chamber was fitted with two thermocouples that permitted continuous chamber temperature readout and recording by a strip chart recorder. The complete system was assembled to provide thermal sterilization as specified for piece parts and materials in a JPL sterilization specification. The sterilization apparatus was checked with regard to chamber temperature distribution, nitrogen flow, and nitrogen purity. The thermal-sterilization procedure for each lot of specimens was also performed in accordance with this JPL specification. The procedure included six separate 96-h cycles of sterilization at 135°C using a dry nitrogen

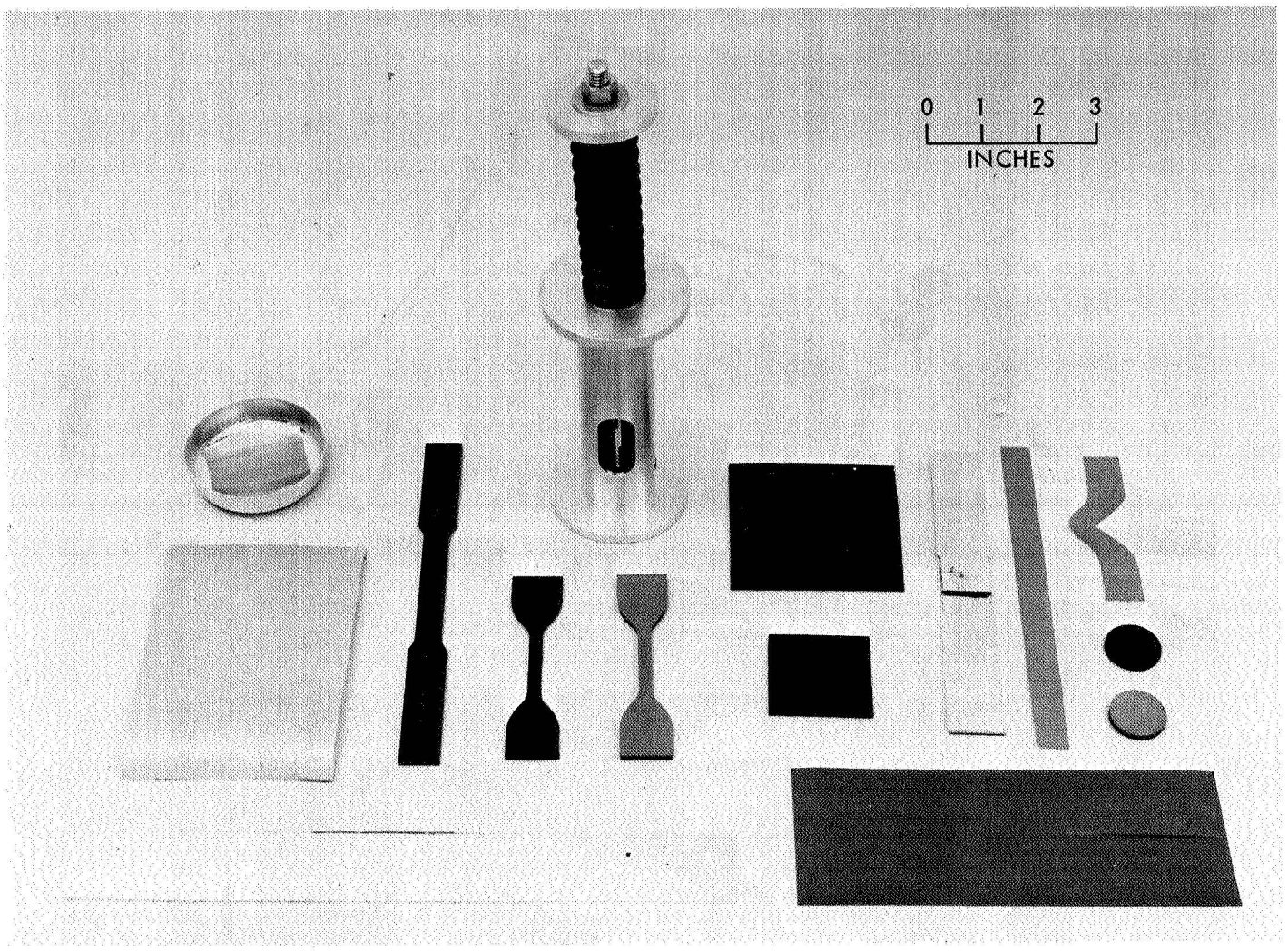

Fig. 2. Typical material test specimens

environment. A typical cycle is shown in Fig. 5. The following procedure was used:

(1) Specimens were placed in the sterilization chamber, which was stabilized within a temperature range of 20–25°C.

(2) Preheated dry nitrogen was continuously purged through the chamber at a rate of approximately 5 standard ft³/h and the chamber was heated at the approximate rate of 56°C/h until a temperature of 135 ±2°C (approximately 2 h) was attained.

(3) When the chamber temperature reached 135°C, the thermal sterilization cycle was started.

(4) After 2 h of sterilization, the nitrogen flow was reduced to approximately 2 standard ft³/h.

(5) After 92 h of sterilization, the chamber was allowed to cool to 20–25°C (approximately 2 h). During this time, the nitrogen flow was maintained.

(6) The sterilization cycle was repeated six times per load of specimens. Following cycle 6, the specimens were removed from the chamber.

3. Thermal-vacuum exposure. The thermal-vacuum exposure apparatus consisted of a multiple-cell test unit accommodating 30 sample cells. This unit is shown in Fig. 6. The test unit was so designed that each cell was isolated to eliminate all possibilities of cross-contamination. A primary manifold that was responsive to the 30 cell units led to the vacuum system via a 6-in. duct. The vacuum system included a fore-pump, a 6-in. diffusion pump, a water-cooled chevron baffle, and a

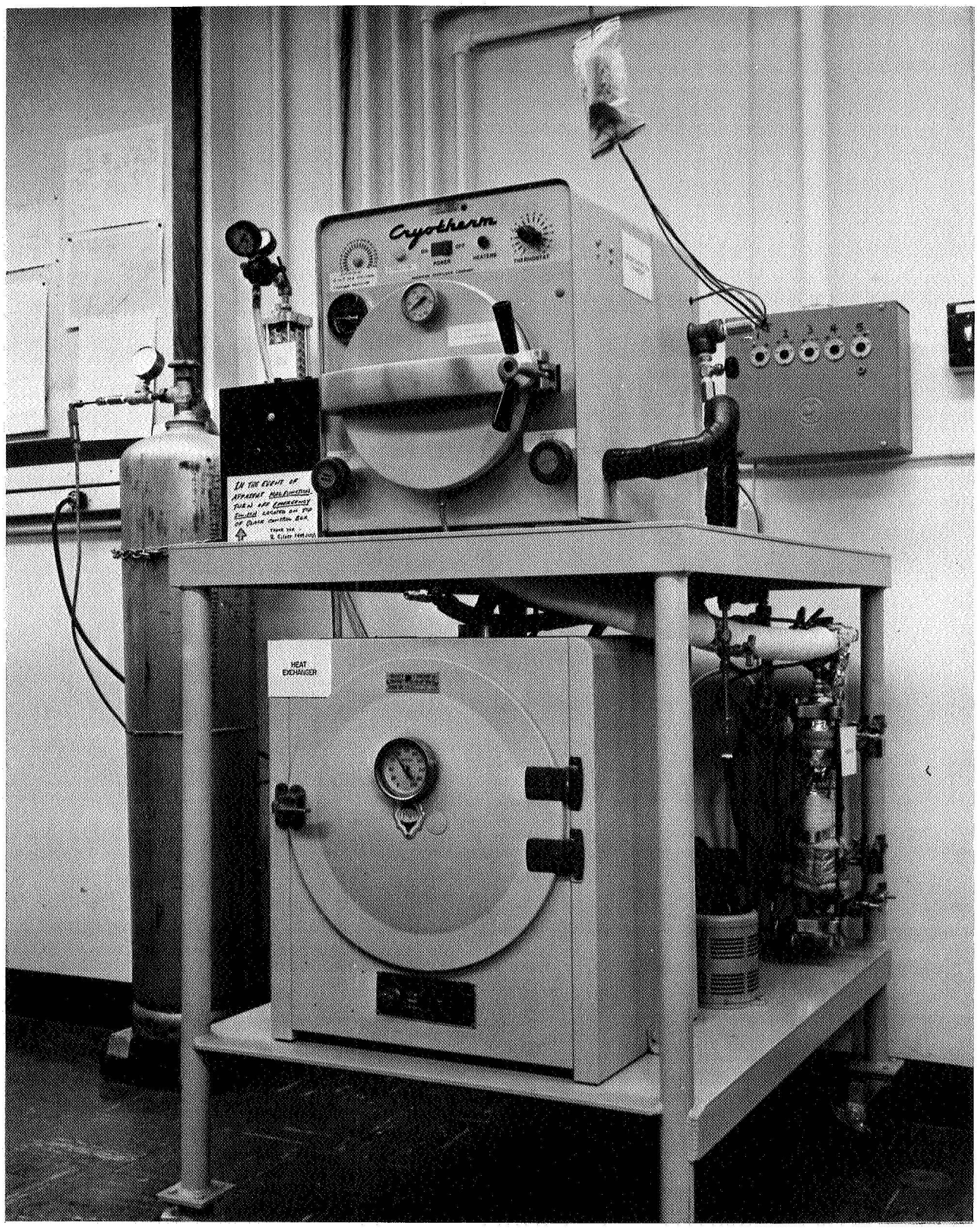

Fig. 3. Ethylene oxide decontamination apparatus

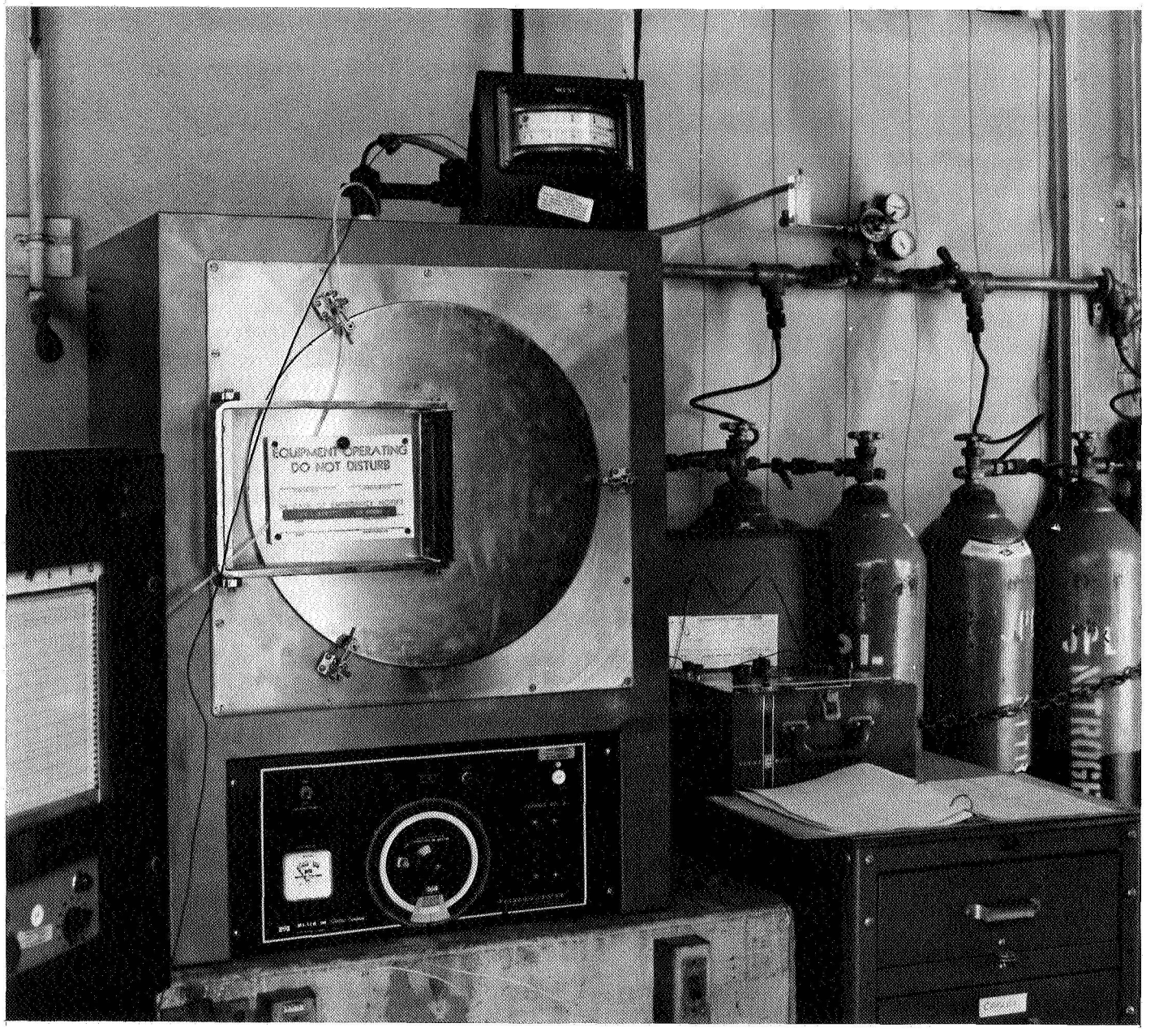

Fig. 4. Thermal-sterilization apparatus

gate valve. Heating of the cells was achieved by enclosure in two electrically heated ovens in which circulation was prompted by a blower system. The design details of this unit are described in Ref. 7.

The exposure procedure used with this apparatus comprised the following steps:

(1) Test specimens of the polymeric products were either suspended inside the test cells or they were laid across a wide-mesh screen. Only one polymeric product was placed in a cell. The sample loading was performed with the test unit at room temperature.

(2) The test cells were heated to 135 ± 2°C and simultaneously evacuated to a minimum pressure of 10^{-6} torr. Stabilization at these thermal-vacuum conditions was achieved approximately 24 h from start. The specimens remained in this environment for 500 h.

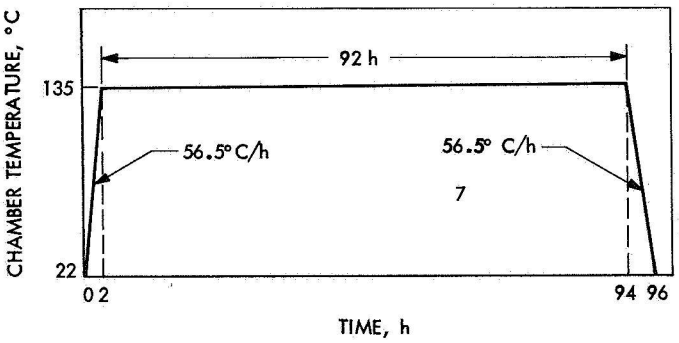

Fig. 5. Piece parts and materials heat sterilization cycle

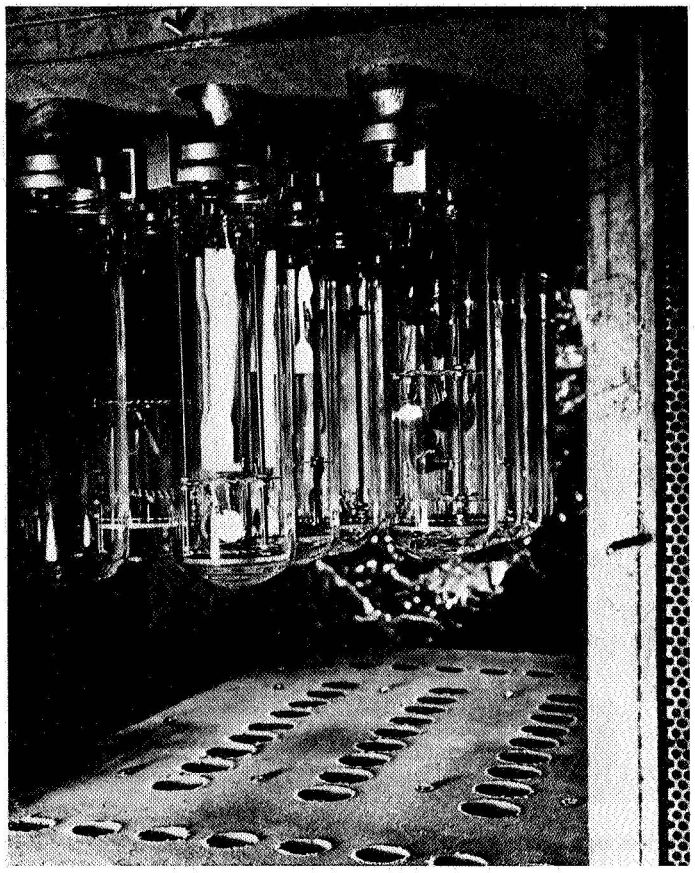

Fig. 6. Thermal-vacuum exposure apparatus

(3) At the end of the exposure period, the test cells were allowed to cool to room temperature before being vented to atmosphere.

C. General Criteria and Rating

To select the polymeric products most suitable for spacecraft use, a rating scheme was necessary. The scheme must evaluate the resultant effect of the various environmental exposures on each product. In this program, a criteria and rating scheme used previously (described in Refs. 2 and 3) was employed. In this scheme, the performance of each product is given a rating of compatible (C), marginal (M), or noncompatible (NC), according to the degree of retention of the key properties of the product after the various exposures. The key properties may be physical, mechanical, or electrical. The relative importance of key properties (for example, mechanical vs electrical) depended upon the particular material being evaluated. The criteria specific for each class of material are presented separately in the discussion of each material class. However, the general criteria for electrical and mechanical properties were as indicated in the paragraphs that follow.

1. Electrical properties. The general criteria for electrical properties were defined for each of the performance ratings as indicated in subsequent paragraphs.

a. Compatible. The product was compatible if the volume resistivity was greater than 10^7 Ω-cm and the decrease in volume resistivity was less than 10^3 Ω-cm. The product was also compatible if the dielectric strength was greater than 200 V/mil and the loss in dielectric strength was no more than 25% of the original value.

b. Marginal. Products with borderline values for volume resistivity, dielectric strength, and changes in these properties were rated as marginal.

c. Noncompatible. The product was rated noncompatible if volume resistivity was less than 10^7 Ω-cm and the decrease in volume resistivity was greater than 10^3 Ω-cm. The product was also rated noncompatible if dielectric strength was less than 200 V/mil and the loss in dielectric strength was more than 25% of the original value.

2. Mechanical properties and weight change. The criteria for mechanical properties and weight change were defined for each performance rating as indicated in subsequent paragraphs.

a. Compatible. The product was rated compatible if it retained 80% or more of its original key mechanical properties, and weight change was less than 1%.

b. Marginal. The product that retained 70–80% of its original key mechanical properties, with weight change between 1 and 4% was rated marginal.

c. Noncompatible. The product that retained less than 70% of its original key mechanical properties, whose weight change was more than 4%, was rated noncompatible.

III. Results and Discussions

The test results from this study are summarized in Tables 3–10. The discussion in the paragraphs that follow is made with reference to the tabulated data.

Table 3. Product compatibility summary

Material class	Product	Compatibility rating
Adhesives	Epon 901/B-3	C
	Epon 828/Z	NC
	HT 424	—
Coatings—encapsulants	Solithane 113/300	M
	Stycast 1090/11	C
	Stycast 1095/11	C
	Scotchcast 281 A/B	C
Tapes	Mystik 7020	M
	Mystic 7503	M
Films	FEP 200A	C
	Tedlar 100 BG 30 WH	M
	Mylar 100A	M
	Kapton 200 X H667	C
Hardware and structural materials	Micarta H 17511	C
	Micarta 20201-2	C
	Micarta 65M25	C
Elastomers	Viton B	M
	1050-70 (silicone)	NC
Coated fabrics	SRG 1810	C
	Armalon 98-101	C
	Pyre ML—Glass fabric	NC

A. Adhesives

The results of tests on the adhesives are shown in Table 4. Of the three adhesives examined, only one—Epon 901/B-3, which is an epoxy paste adhesive—was rated compatible. Although Epon 828/Z met most of the mechanical property criteria, it failed in creep. The creep specimens failed during heat sterilization, and this adhesive was therefore rated as noncompatible.

In all cases, the exposed specimens showed greater adhesion shear and peel strength than did the unexposed control specimens. This was undoubtedly due to the additional cure that resulted during the various exposures.

The film adhesive HT 424 (epoxy–phenolic adhesive) was not given a rating because it was suspected that this material may have been initially undercured. The adhesive creep specimens failed after assembly and just before the exposures. An undercure was indicated by the rather low adhesion shear strength of the control specimens (1100 psi) as compared with the manufacturer's reported value (3400–3600 psi). In addition, heat sterilization caused the HT 424 to soften and partially flow, resulting in damage and loss of the exposed adhesion shear specimens. This also indicated undercure of the material.

All adhesives showed little (if any) weight change as a result of the combined exposures. Weight changes of 0.025% or less were recorded as "None," since this was the limit of accuracy in the weight-change measurements.

B. Coatings and Encapsulants

The data obtained on this class of materials are given in Table 5. In addition to the previously outlined general criteria, the coating (Solithane 113/300) was also rated according to the following criteria:

(1) Compatible if
   (a) Scrape adhesion was more than 1.5 kg after the exposures.
   (b) There were no surface changes (blisters, pinholes, etc.).

(2) Marginal where either
   (a) Scrape adhesion was 0.5 to 1.5 kg after the exposures.
   (b) Electrical properties were borderline, based on the previously outlined criteria.

(3) Noncompatible where either
   (a) Scrape adhesion was less than 0.5 kg.
   (b) The material failed the surface condition requirements.
   (c) The material failed any one of the electrical criteria.

On the basis of these criteria, Solithane 113/300 was given a marginal rating. This was because of low adhesion (scrape) following the completion of the exposures. The decrease in adhesion of this material following the exposures was appreciable. The material also showed a slight yellowing in color following the exposure. The

Table 4. Summary of test results—adhesives

No.	Product	Material type (cure)[a]	Specimen type	Physical–mechanical properties				Compatibility rating
				Weight change, %	Adhesion shear strength, psi	Peel strength, lb/in. width	Creep, mils	
1	Epon 901/B-3	Epoxy (0.5/240 + 1.5/350)	Control Exposed	None 0.04	4050 4180	14.4 15.1	None None	C
2	Epon 828/Z	Epoxy (2/200 + 2/275)	Control Exposed	0.17 0.08	3370 3650	30.4 34.1	Failed Failed	NC
3	HT 424	Epoxy–phenolic (1/330)	Control Exposed	None None	1100 NT[b]	1.4 1.7	Failed Failed	—

[a]Where possible, material mix ratios and cures were in accordance with the applicable JPL material specification. Cure used as shown (h/°F).
[b]NT = not tested.

solid encapsulants—Stycast 1090/11, Stycast 1095/11, and Scotchcast 281 A/B—were rated by changes in weight, dimension, hardness, and electrical properties according to the following specific criteria:

(1) Compatible where
  (a) Weight change was less than 1%.
  (b) Dimensional change was less than 1%.
  (c) Drop in hardness was less than 10 units.
  (d) Electrical criteria were satisfied.

(2) Marginal where either
  (a) Weight change was 1–4%.
  (b) Dimensional change was 1–4%.
  (c) Drop in hardness was more than 10 but less than 15 units.
  (d) Electrical properties were borderline.

(3) Noncompatible where either
  (a) Weight change was more than 4%.
  (b) Dimensional change was greater than 4%.
  (c) Drop in hardness was more than 15 units.
  (d) Materials failed any of the electrical criteria.

On the basis of these criteria, all three encapsulants tested were rated as compatible with the exposures. The properties of these materials were primarily unaffected by the various exposures.

C. Tapes

The data obtained on the tapes tested are shown in Table 6. Criteria for rating of these materials were based on peel adhesion, breaking strength, weight change, and electrical properties. Tapes were rated as follows:

(1) Compatible where
  (a) Peel adhesion retained was 80% or more.
  (b) Breaking strength retained was 80% or more.
  (c) Weight change was less than 1%.

(2) Marginal where either
  (a) Peel adhesion retained was 70–80%.
  (b) Breaking strength retained was 70–80%.
  (c) Weight change was 1–4%.
  (d) Electrical properties were borderline.

(3) Noncompatible where either
  (a) Retained peel adhesion was below 70%.
  (b) Breaking strength retained was below 70%.
  (c) Weight change was more than 4%.
  (d) Tapes failed any of the electrical criteria.

On the basis of these criteria, both tapes tested were rated marginal because of their reduction in breaking strength following the several exposures. No values for peel adhesion were obtained because the tapes fractured during testing, and no tape-to-metal peel was obtained. This indicated that the tape adhesive strengths were in excess of the tensile strengths.

D. Films

The test results on the film materials tested are given in Table 7. Tensile strength, tear strength, weight and

Table 5. Summary of test results—coatings and encapsulants

No.	Product	Material type (cure)[a]	Specimen type	Physical–mechanical–electrical properties									Compatibility rating
				Weight change, %	Dimensional change, %	Hardness (Shore) D	Adhesion (scrape), kg	Tensile strength, psi	Elongation, %	Specimen thickness, in.	Volume resistivity, Ω-cm	Dielectric strength, V/mil	
4	Solithane 113/300	Polyurethane (2/75 + 5/130)	Control	−0.60	NT[b]	NT	2.66	NT[b]	NT	0.02	2.5×10^{15}	880	M
			Exposed	−0.81	NT	NT	0.55	NT	NT	0.02	0.6×10^{15}	1060	
5	Stycast 1090/11	Epoxy (12/140 + 3/180)	Control	0.17	None	78	NT[b]	4520	1.1	0.05	3.3×10^{16}	405	C
			Exposed	0.11	None	82	NT	4480	1.4	0.05	1.9×10^{16}	399	
6	Stycast 1095/11	Epoxy (1/160 + 3/212)	Control	None	None	81	NT	4060	1.2	0.04	1.2×10^{15}	352	C
			Exposed	None	None	81	NT	3950	1.2	0.04	1.6×10^{15}	484	
7	Scotchcast 281 A/B	Epoxy (24/150)	Control	0.05	None	78	NT	2000	13.2	0.08	1.3×10^{15}	> 569	C
			Exposed	0.16	None	83	NT	3100	4.9	0.08	3.6×10^{15}	> 573	

[a]Where possible, material mix ratios and cures were in accordance with the applicable JPL material specification. Cure used as shown (h/°F).

[b]NT = not tested.

Table 6. Summary of test results—tapes

No.	Product	Material type (cure[a])	Specimen type	Physical–mechanical–electrical properties							Compatibility rating
				Weight change, %	Dimensional change, %	Adhesion (to steel plate) oz/in. width	Breaking strength lb/in. width	Elongation, %	Specimen thickness, mils	Dielectric strength, V/mil	
8	Mystik 7020	Fiberglas-T/S adhesive (1/300)	Control	−0.05	None	TF[b]	200	6.4	7	470	M
			Exposed	−0.49	None	TF[b]	153	3.1	7	470	
9	Mystik 7503	Teflon-silicone (as received)	Control	None	−0.05	TF[b]	16.0	420	5	1570	M
			Exposed	−0.50	−0.07	TF[b]	11.3	230	5	1670	

[a]Where possible, material cure was in accordance with the applicable JPL material specification. Cure as shown (h/°F).
[b]Tape fractured (no tape to metal peel).

Table 7. Summary of test results—films

No.	Product	Material type	Specimen type	Physical–mechanical–electrical properties								Compatibility rating
				Weight change, %	Dimensional change, %	Tensile strength, psi	Elongation, %	Tear strength, lb/in. thickness	Specimen thickness, mils	Volume resistivity, Ω-cm	Dielectric strength, V/mil	
10	FEP 200A	Fluorocarbon	Control	None	None	4,220	410	610	2	3.6×10^{17}	3310	C
			Exposed	None	−0.74	3,860	380	580	2	10.9×10^{17}	3130	
11	Tedlar 100 BG 30 WH	Fluorocarbon	Control	None	None	15,200	117	1490	1	4.6×10^{15}	3450	M
			Exposed	None	−2.3	11,000	59	1690	1	4.5×10^{15}	3580	
12	Mylar 100A	Polyester	Control	None	None	28,200	89	2700	1	4.0×10^{16}	4800	M
			Exposed	−0.03	−1.8	26,900	96	2040	1	11.7×10^{16}	4490	
13	Kapton 200 X H667	Polyimide	Control	0.05	None	27,100	53	1630	2	10.0×10^{16}	4080	C
			Exposed	0.05	−0.28	26,500	53	2060	2	2.3×10^{16}	4000	

dimensional change, and electrical properties were used in the ratings of these materials. The criteria used were as follows:

(1) Compatible where
   (a) Tensile strength and tear strength retained were more than 80% of the original value.
   (b) Weight change and dimensional change were less than 1%.
   (c) Electrical criteria were met.

(2) Marginal where either
   (a) Mechanical properties retained were 70–80% of the original value.
   (b) Weight change and dimensional change were between 1 and 4%.
   (c) Electrical properties were borderline.

(3) Noncompatible where either
   (a) Mechanical properties retained were below 70% of the original values.
   (b) Weight change and dimensional change were more than 4%.
   (c) Film failed any of the electrical criteria.

On the basis of these criteria, two of the tested films (FEP 200A and Kapton 200 X H667) were rated compatible. The other two films (Tedlar 100 BG 30 WH and Mylar 100A) were rated marginal.

In the case of Tedlar, some embrittlement of the material was exhibited by the significant drop in elongation and reduction in ultimate tensile strength. The material also showed significant shrinkage. The Mylar 100A was rated marginal because of significant reduction in tear strength and apparent shrinkage.

E. Hardware and Structural Materials

The test data on these materials are given in Table 8. Rating of these materials was based on weight change, tensile strength, and electrical properties according to the general criteria previously outlined. On the basis of these criteria, all hardware and structural materials were rated as compatible.

F. Elastomers

The data obtained on these materials are given in Table 9. Rating of the elastomers was based on weight and dimensional change, tensile strength, elongation, hardness, and compression set. The elastomers were rated as follows:

(1) Compatible where

(a) They retained 80% of their original tensile strength.

(b) They retained 80% of their original elongation.

(c) Compression set change was less than 20%.

(d) Hardness change was less than 6 units.

(e) Weight change was less than 1%.

(f) Dimensional change was less than 1%.

(g) Electrical criteria were satisfied.

(2) Marginal where either

(a) Tensile strength retained was 70–80% of the original value.

(b) Elongation retained was 70–80% of the original value.

(c) Compression set change was between 20–30%.

(d) Hardness change was greater than 6 but less than 10 units.

(e) Weight change was 1–4%.

(f) Dimensional change was 1–4%.

(g) Electrical properties were borderline.

Table 8. Summary of test results—hardware and structural materials

No.	Product	Material type	Specimen type	Physical–mechanical–electrical properties								Compatibility rating
				Weight change, %	Dimensional change, %	Hardness (Rockwell), 15T	Tensile strength, psi	Elongation, %	Specimen thickness, in.	Volume resistivity, Ω-cm	Dielectric strength, V/mil	
14	Micarta H 17511	Glass-base diphenyl oxide	Control	−0.78	None	80	43,200	4.2	0.125	4.0×10^{14}	> 378	C
			Exposed	−0.30	None	82	47,500	4.2	0.125	6.3×10^{15}	> 339	
15	Micarta 20201-2	Glass-base silicone	Control	−0.10	None	41	24,800	2.6	0.07	4.6×10^{16}	505	C
			Exposed	−0.32	None	49	25,900	2.4	0.07	7.5×10^{15}	442	
16	Micarta 65M25	Glass-base epoxy	Control	None	None	73	33,000	2.6	0.06	5.6×10^{15}	577	C
			Exposed	−0.23	None	75	35,900	2.4	0.06	5.6×10^{15}	712	

Table 9. Summary of test results—elastomers

No.	Product	Material type	Specimen type	Physical–mechanical properties						Compatibility rating
				Weight change, %	Dimensional change, %	Hardness (Shore)	Compression[a] set, %	Tensile strength, psi	Elongation, %	
17	Viton B	Fluorocarbon	Control	0.05	None	80	36.1	2560	195	M
			Exposed	0.55	None	80	26.0	2150	140	
18	1050-70	Silicone	Control	None	None	70	23.9	300	103	NC
			Exposed	−0.70	None	73	24.2	256	47	

[a]Method B, 22 h at 70°C.

(3) Noncompatible where either
   (a) Tensile strength retained was below 70%.
   (b) Elongation retained was below 70%.
   (c) Compression set change was greater than 30%.
   (d) Hardness change was greater than 10 units.
   (e) Weight change was greater than 4%.
   (f) Dimensional change was greater than 4%.
   (g) Failed any of the electrical criteria.

Of the two elastomers evaluated, one was rated marginal (Viton B) and the other (1050-70, a silicone rubber) was rated noncompatible. The marginal rating was assigned to the Viton B as a result of change in compression set and reduction in elongation. These property changes indicate an embrittlement of the material as a result of the various exposures. The silicone rubber showed even more embrittlement, as evidenced by a large reduction in elongation. For this reason, the silicone material was rated noncompatible.

G. Coated Fabrics

Test data on these materials are shown in Table 10. Criteria for rating these materials were based on the general criteria outlined previously for mechanical properties and weight loss. The specific properties evaluated were weight change, breaking strength, elongation, and tear strength.

Both the SRG 1810 and the Armalon 98-101 were assigned a rating of compatible because the losses in mechanical properties were less than 20% and the weight changes were under 1%. Although weight change, breaking strength, and elongation changes for the Pyre ML coated fabric were within a rating of compatible, tear strength was significantly reduced (>50%) after the exposures. This material was, therefore, given a rating of noncompatible.

IV. Conclusions

As outlined previously, this program was the first attempt to evaluate the effects of all three anticipated exposures on spacecraft polymeric products; that is, ETO decontamination, heat sterilization, and a thermal-vacuum environment. Of the 21 products evaluated, 55% were rated compatible, 30% marginal, and 15% noncompatible with the three exposures. It should be noted that it was not the intent of this work to separately evaluate the effects of the individual exposures. The total effect of the exposures was the sole objective.

Because of the limited number of products tested, it is difficult to make broad generalizations with respect to the stability of particular polymer types. However, there are indications that the epoxy and fluorocarbon materials are the least affected by the exposures. Polyesters and polyurethanes are the most affected. The data also indicate that tape and elastomeric materials are the categories most affected. The degradation in properties of these products is undoubtedly due to the loss of the various compounding ingredients (plasticizers, antioxidants, tackifiers, etc.) that are added to the basic polymers during manufacture. Apparently it may be very difficult, if not impossible, to obtain completely satisfactory products within these latter two material categories.

Table 10. Summary of test results—coated fabrics

No.	Product	Material type	Specimen type	Physical–mechanical properties							Compatibility rating
				Weight change, %	Dimensional change, %	Breaking strength		Elongation		Tear strength, fill, lb	
						Warp, lb	Fill, lb	Warp, %	Fill, %		
19	SRG 1810	Glass-base silicone	Control	None	None	133	119	5.5	7.8	7.0	C
			Exposed	0.05	None	149	128	6.7	7.7	6.0	
20	Armalon 98-101	Polyamide-base fluorocarbon	Control	None	None	82	NT[a]	6.3	NT[a]	17.5	C
			Exposed	0.04	None	84	NT[a]	6.7	NT[a]	17.5	
21	Pyre ML	Glass-base polyimide	Control	None	None	204	113	3.9	7.2	1.3	NC
			Exposed	0.05	None	210	125	4.2	5.6	0.6	

[a]NT = not tested.

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