Final Report | *June 1964 to August 1967*

POLYMERS FOR SPACECRAFT APPLICATIONS

Prepared for:

JET PROPULSION LABORATORY
CALIFORNIA INSTITUTE OF TECHNOLOGY
PASADENA, CALIFORNIA

JPL CONTRACT NO. 950745
UNDER NAS7-100

STANFORD RESEARCH INSTITUTE

MENLO PARK, CALIFORNIA

SRI

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September 15, 1967

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JPL Technical Representative: E. L. CLELAND

By R. F. MURACA AND J. S. WHITTICK

SRI Project ASD-5046

Approved: R. F. MURACA, DIRECTOR
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FOREWORD

This Final Report summarizes work which has already been performed by Stanford Research Institute under Contract No. 950745 with the Jet Propulsion Laboratory of the California Institute of Technology during the period June 1964 to August 1966, and includes in detail the work completed during the period August 1966 to August 1967.

Technical Representative of the Jet Propulsion Laboratory's Materials and Methods Group for the final period of this contract was Mr. E. L. Cleland.

The technical effort at Stanford Research Institute was under the supervision of Dr. R. F. Muraca, Director, Analyses and Instrumentation.

The work was performed largely within the Department of Analyses and Instrumentation under direction of J. S. Whittick, Chemist-Program Coordinator and A. A. Koch, Chemist. Department Chemists contributing to this work were: F. M. Church, J. A. Havir, and W. Kaczkowski.

Acknowledgment is made of the dedicated work of R. McNeely and L. Salas, Chemical Technicians.

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ABSTRACT

Stanford Research Institute, Menlo Park, California
POLYMERS FOR SPACECRAFT APPLICATIONS
Final Report, June 1964 to August 1967
R. F. Muraca and J. S. Whittick, September 15, 1967
NASA Contract No. NAS7-100; JPL Contract No. 950745; SRI Project ASD-5046.

The objective of this program was to assist JPL in the selection of polymeric materials to be used in connection with spacecrafts, with special attention to determination of the effects of a simulated spacecraft environment on selected commercial products. The spacecraft environment was considered to be a shielded thermal-vacuum environment of about 125°C and 10^{-6} torr. During the three-year period of this contract, test equipment was designed and procedures and techniques were developed to permit qualification of polymeric products for use in spacecrafts.

The theory of the release and condensation of substances from polymers exposed to the thermal-vacuum environment is discussed in detail, and the equipment and procedures for identifying and measuring the release of volatile condensable material (VCM) are described. The apparatus and techniques for evaluating the effect of pre-flight decontamination cycles and thermal-vacuum exposure on the mechanical and electrical properties of polymeric products are described, and the applicability of short-term tests (24-500 hours) in predicting long-term performance is reviewed.

About 350 polymeric products were screened for outgassing characteristics, of which about 100 qualify within the limits of <1% wt-loss and <0.1% VCM content. About 20 products were examined in greater detail and found to be satisfactory for spacecraft construction because they maintain their mechanical and electrical properties through decontamination cycles and thermal-vacuum exposures. A thorough test and evaluation program to qualify polymeric products through any pre-flight or space environment is described.

Five disclosures of New Technology are summarized and the transfer of one of these is noted.

Appendices include a catalog of the infrared absorbance spectra of the VCM from 96 polymeric products and an interim list of recommended products. An alphabetical Index lists all of the products which have been examined and the tests which have been performed; on the basis of test results, each product is assigned an acceptance rating.

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I. INTRODUCTION

This Final Report describes in detail the work performed by Stanford Research Institute for the Jet Propulsion Laboratory of the California Institute of Technology under Contract No. 950745 during the period August 1966 to August 1967. Exploratory and development work during the period June 1964 to November 1966 is summarized in three Interim Reports: No. 1, August 1965; No. 2, March 1966; and No. 3, December 1966. This report incorporates the most significant data from the interim publications and summarizes the theories and techniques which have led to recognition in the evaluation of polymeric materials for spacecraft use.

The primary objective of this program was to assist the Jet Propulsion Laboratory in the selection of polymeric materials to be used in the construction of spacecrafts. The program plan was predicated on the determination of the effects of simulated spacecraft environment on commercial polymeric products. The materials and products examined were largely provided by the JPL Technical Representative; a few special products were purchased by SRI.

For the purpose of this program, a spacecraft environment is defined as the thermal-vacuum conditions existing within a scientific satellite or probe, or the unpressurized portions of a manned spacecraft. Since electronic assemblies, associated components, and various structures are protected from as many hazards as possible in space flights, the environment under consideration is obviously one shielded from the extremes of temperature, electromagnetic and particle radiation, and meteoroids. The thermal-vacuum conditions employed during this program of work were established as consisting of pressures less than 10^{-5} torr (readily-attainable in batch-testing equipment) and temperatures of the order of 125°C (the maximum temperature anticipated in locations where polymeric materials might be used).

The simulation of the vacuum of space for evaluation of materials does not require that expensive and intricate equipment be used to provide pressures such as may be encountered in interplanetary flight (e.g., 10^{-13} torr). It is sufficient that a test facility maintain a pressure low enough so that the mean free path of residual gas molecules is long in comparison with chamber dimensions. For residual gas molecules at ambient temperature (O_2, N_2, H_2O), the mean free path at 1×10^{-5} torr is of the order of several meters and thus, by maintaining a vacuum of at least this order of magnitude, the rate at which organic molecules leave the surface of a polymeric sample is not governed by collisions with residual gas molecules. For testing materials such as polymers, refrigerated baffles and/or traps will ensure that organic molecules leaving the sample cannot return to the sample and thus establish an equilibrium vapor pressure. Additionally, large cross-sectional areas of pumping ducts increase the probability that molecules leaving the sample will not return. The vacuum systems employed for this work have been designed to provide pressures less than 10^{-5} torr by means of "large-" diameter ducts; they are equipped with cold traps and have baffles to prevent cross-contamination of samples.

The selection of materials for use in a spacecraft is based on a study of their behavior in a thermal-vacuum environment and a knowledge of the nature of the substances they release Thus, results of determinations of the loss of weight, of the amount of released material which may condense on cool surfaces adjacent to the warmed polymer, and the identification of the released substances in the thermal-vacuum environment conditions of interest must be combined with measurements of physical and mechanical property changes which may occur over a period of time in the environment in order to confirm the suitability of polymers for spacecraft construction. Added to the above criteria, because of the quest for life on distant planets, is the capability of polymers to undergo decontamination and sterilization procedures without loss of mechanical properties when subsequently exposed to a thermal-vacuum environment.

A discussion is given in Section II of the significance of the loss in weight incurred by polymeric materials which are exposed to a thermal-vacuum environment, the nature of the substances which are released, and the theory of the release, condensation, and re-evaporation of volatile condensable materials (VCM).

In Section III, the equipment and procedures developed for various analyses of VCM are discussed in some detail. These include the micro-VCM technique for rapid screening (24-hour exposure in the thermal-vacuum environment) of 24 polymeric materials simultaneously for determination of loss in weight and maximum VCM content, the modification of the micro-VCM technique to produce infrared spectra of the VCM, the macro-VCM determinations which provide quantitative values for the loss in weight and for the deposition and re-evaporation of VCM with time over a period of 330 hours, and the mass spectrometric technique for the identification _in situ_ of the substances which are released by polymeric materials in the thermal-vacuum environment.

Section IV describes the equipment and procedures for determining mechanical and electrical properties of 30 polymeric materials simultaneously which have been exposed to three environments (called the "comprehensive polymer test program"):

(1) Six decontaminating cycles of an humidified ethylene oxide-Freon atmosphere at 50°C for 30 hours each;

(2) Exposure for 500 hours to a thermal-vacuum environment of 135°C and 10^{-6} torr;

(3) Decontamination cycles followed by thermal-vacuum exposure.

Section IV Supplement provides design drawings for the adhesive creep testers used in this work. (Detailed design drawings of all test equipment, except the few in this report, were given in Interim Report No. 3, Part II, December 1966.)

In Sections V to XXII, the results obtained from all of the foregoing procedures are presented in detail, and an interpretation of the results is given. The Sections are arranged alphabetically according to spacecraft applications.

All of the polymers which are discussed have been screened by the micro-VCM technique, and a complete summary is given of the data obtained on more than 340 polymeric products (500 determinations). Less than one-third of the products are suitable candidates for further evaluation and for inclusion in an interim list of recommended materials.

> The micro-VCM data in this report are complete to date and supercede all values previously reported.

The results of macro-VCM determinations are reported for about 20 polymeric products, selected because of acceptance by micro-VCM screening standards or because of interest in the performance of marginal materials. The equipment has also been used for completing the experimental work on the theories of VCM deposition and evaporation described in Section II. In general, the macro-VCM determinations have confirmed the qualification of products by the micro-VCM technique.

Mass spectrometric analyses of the materials released by about 20 polymeric products have been performed; the products were selected to furnish information on the character of the materials which contribute to loss of weight and VCM and to provide correlation with macro-VCM determinations. The results of the analyses reveal that most of the volatile substances are compounds of low molecular weights, such as water and solvents; high-molecular-weight components deliberately added in the compounding of the polymeric formulations and low-molecular-weight polymeric structures were easily identified.

About 70 polymers have been examined for changes in mechanical properties during the comprehensive polymer test program. These materials were selected in an effort to provide data for as many different types of end-use applications as possible, but the selection was dictated largely by the availability of sufficient material for complete testing. It was found that the electrical properties of most polymers were not changed significantly by decontamination or thermal-vacuum exposures. The decontamination cycles had little effect on the majority of materials examined except for slight gains in weight. The sequence of decontamination plus thermal-vacuum exposure affects only a few materials. The following correlations are interesting: In general, a rating of acceptable or "good" by micro-VCM techniques is reflected in a "good" rating for the mechanical properties tested. With a few exceptions, a rating of not-acceptable ("X") is reflected by an "X" rating for mechanical properties, and a marginal rating from micro-VCM values will indicate over a range of good to not-acceptable mechanical performance. (See Appendix E.)

The results of long-term (7-9 months) storage of selected polymers in the thermal-vacuum environment are given in Section XXIII. It appears that 1000-hour tests are required for estimating long-term maintenance of mechanical properties of polymers and that micro-VCM data can be correlated to mechanical property performance. Long-term tests currently in progress also are discussed. Section XXIII Supplement provides detailed design drawings for the adhesive creep testers employed in the long-term storage tests.

Conclusions from the data presented in this report are given in Section XXIV, and recommendations are made for a comprehensive test and evaluation program for pre-flight and flight environments. In Section XXV, an announcement of New Technology since November 1966 is made, and new technologies announced during this contract are re-capitulated.

In Appendix A, the basic structures of the polymers considered for spacecraft use are outlined and Appendix B provides a code-listing of manufacturers of the products which have been examined.

Appendix C consists of a catalog of infrared spectra of the VCM from 96 polymers. A numerical listing is given for the products in the order of polymer classes and an alphabetical listing of products is also provided.

In Appendix D, an interim list of recommended products is given. (Final recommendations can be made only after more comprehensive testing of materials for the effects of decontamination, sterilization, and thermal-vacuum exposures.)

Appendix E provides an alphabetical Index of all the polymers which have been screened and lists their ratings as indicated by the results obtained from the various determinations for volatile materials, mechanical properties, and electrical properties. References are given to appropriate sections of the report and to the infrared catalog of VCM from polymeric products.

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II. MATERIALS RELEASED BY POLYMERS IN A THERMAL-VACUUM ENVIRONMENT

The loss of matter by outgassing and by evaporation or sublimation is one of the most obvious effects of a thermal-vacuum environment on polymers. Because gross loss of material generally implies that the physical properties of polymers are altered or that test chambers and spacecraft components will be contaminated by the vaporized substances, the polymers which are considered suitable for use in spacecrafts are those which in laboratory tests (1) exhibit a minimum loss of weight when exposed to the simulated conditions of the vacuum and thermal environment of space, and (2) are found to contain a minimum of materials that vaporize at an elevated temperature in a vacuum and deposit on adjacent, cooler surfaces.

The simplest quantitative value which can be obtained for the behavior of a polymer in a thermal-vacuum environment is the loss of weight. This value does not reveal the nature of the components released by the polymer but, nevertheless, is useful for selecting polymers for spacecrafts because, in the majority of instances, it has been shown that mechanical and other useful properties of the polymers are degraded when substantial amounts of materials are removed by vacuum. It is customary to assume that polymeric substances which lose less than 1% of their weight in a thermal-vacuum environment are suitable for spacecraft application, for it has been shown that small losses are due to adsorbed gases, moisture, and extraneous solvents. However, losses up to 5% in weight generally do affect mechanical properties of materials. It is important to recognize that it is the nature of the materials lost in a vacuum which determine the change of physical properties and not the amount that is lost. For example, it has been found that as much as 3% loss in weight does not significantly affect the mechanical properties of various silicone sealant materials for, in these instances, the loss in weight is due not only to extraneous solvents and adsorbed gases, but also to low-molecular-weight silicone substances which do not significantly affect physical properties. On the other hand, the loss of 1% of a plasticizing or softening oil in certain elastomers (e.g., butyl rubbers) is usually detrimental to mechanical properties. These differences are not difficult to understand when one realizes that the volatile low-molecular-weight silicones only dilute the intrinsic mechanical properties of the sealants whereas the plasticizing oils are primary contributors to the very properties which make the materials attractive for use in spacecrafts.

The term "outgassing" is often used to describe loosely the observation that the substances given off by a material in a vacuum are in the form of a gas regardless of whether the substances themselves are true gases, liquids, or solids. For many years, especially during the time when a vacuum of 10^{-4} torr was considered an achievement, it was quite common to describe this release of matter from polymers in terms of an "outgassing rate." The measurement of "outgassing rate" was generally performed over a short interval of time and no attempt was made to identify the materials released in a vacuum; in fact, the various outgassing rates were used as criteria for selecting appropriate materials for constructing vacuum systems, and it became readily apparent that polymers, waxes, greases, and other organic matter were best left out of vacuum systems. The term also left the impression that the outgassing rate would be constant until the organic matter disappeared or until the experimenter would depart to a sweeter world. A few diligent workers, however, measured "outgassing rates" over long intervals of time and found that they became progressively less, and that some organic substances could be substantially "degassed" by the combination of vacuum and elevated temperatures to the point where their use in vacuum systems became possible. Then, "high vacuum" greases, cements, waxes, etc. began to be commonplace.

About the time the first space probes were to be launched, it became necessary to seek information about the applicability of polymers as materials of construction. There was, of course, very little information about the behavior in vacuum of the ever-increasing number of newer polymers; measurements of the outgassing rates of the older polymers were combined with their measured weight losses (short-term tests) and from these data it was extrapolated that few polymers could remain in space without evaporating completely (or in part) and render the spacecraft useless. Most damaging, however, was the propagation of the erroneous conclusion that all polymers would evaporate in space, in spite of evidence to the contrary [the increasing number of successful space probes that were laden with a variety of polymeric materials]. In a short time, however, the pendulum swung the other way, and it was assumed that the polymeric materials used in the probes and spacecrafts launched in the early phases of the National space program were completely satisfactory and, thus, they were used indiscriminately in the construction of newer, more complex crafts. It was inevitable that some faulty operations in ground tests would be encountered and that the failures could be shown to be due to the polymers, but this did not reduce the tendency to continue to use the polymeric substances which "flew successfully."

The following statements are offered as summaries of the behavior of polymeric materials in a thermal-vacuum environment:

(1) Polymers which are highly crosslinked have such high molecular weights that they cannot be considered vaporizable at temperatures less than about 125^{0}C, provided pyrolysis or degradation does not take place. The mass spectrometer can easily detect degradation.

(2) All polymers consist of distributions of various molecular weights; if the polymerization has not been carried out correctly, the lower-molecular-weight polymers will have sufficient vapor pressure to allow their rapid removal in a vacuum-thermal environment. As a result, all polymers tend to lose some of the lower-molecular-weight species in a thermal-vacuum environment. The loss is exceptionally small for polymers like Teflon because the method of polymerization yields material consisting of very high-molecular-weight _n_-mers. A large number of commercial polymers also have in them small amounts of their monomers or starting materials.

(3) Linear polymers also consist of mixtures, and the lower-molecular-weight species may be removed in a thermal-vacuum environment. It is considered that the distribution of molecular weights tends to remain constant; as the lower-weight species are removed, the heavier degrade and maintain the equilibrium distribution especially in the presence of the catalysts which were added to initiate

polymerization. Thus, at elevated temperatures polymethylmethacrylate and Teflon can be distilled off as their monomers, dimers, trimers, etc. At lower temperatures, the redistribution reaction may be so slow that lower-molecular-weight fragments may be removed from a polymer mass and not be replaced. The relative ease with which these fragments are removed in a vacuum makes it easy to distinguish between low-molecular-weight polymers present at the start of a test from those that are formed by redistribution or equilibrium reactions. For example, Teflon at 275°C has been maintained in the vacuum of a mass spectrometer for seven years without detectable evolution of its monomer or lower-molecular-weight degradation products. In contrast, the presence of monomer in polystyrene is easily detectable. Other linear polymers are not as stable as Teflon; it is necessary to test each candidate before use in spacecrafts, especially since the materials evolved can deposit on cooler surfaces, polymerize, and never re-evaporate.

(4) A great number of commercial polymers are mixtures of basic polymeric materials and various additives (to impart desirable properties), for example, organic matter such as plasticizers, solvents, catalysts, crosslinking agents, antioxidants, etc. These organic materials usually distill out of the polymer mixtures to form a significant if not the entire part of the "weight loss," and the remaining polymer matrix will have significantly different physical properties than the starting material because of their removal. Additives are used in rather large quantities; since they are readily vaporizable, they overload the vacuum pumping systems of test chambers ("lugging").

(5) The rate of evaporation of a pure substance in a vacuum is a function of the temperature, its molecular weight, and its vapor pressure. However, its rate of removal from a polymer is nearly entirely controlled by the rate at which the molecules can diffuse through the polymer matrix and come to the surface. Clearly, removal of a volatile material from a polymer can be effected more rapidly from thin sections than from thick sections, and at higher temperatures than at lower temperatures. Thick sections can be considered to furnish a reservoir of vaporizable material which is fed at an almost continuous rate to the surface that is exposed to vacuum; hence, the "outgassing rate" so popular some time ago, is controlled by the rate of arrival of material to the exposed surface from the large supply within the section. The "outgassing rate" of a thick section will remain quite constant when diffusion is at equilibrium, and the constant rate can very easily be misinterpreted as a constant evaporation of the polymer itself.

> It is obvious that if the evaporation of substances unrelated to the basic polymer structure is to be differentiated from vaporization of the polymer or its degradation products, the vapors released from the polymer must be analyzed and identified; if thin sections are used, the release of vaporizable substances will be rapid and essentially complete within 24 to 48 hours (the micro-VCM test described in Section III). In a mass spectrometer, the sample size is of the order of 1 milligram and thicknesses seldom exceed 0.010 inch; as a result, the release of vaporizable substances is complete within several hours and it is also possible to detect polymer degradation or vaporization.

Volatile condensable material (VCM) is defined as the weight of condensate obtainable at 25°C in a given interval of time from a given weight of material (<1/8" thick) maintained at 125°C in a vacuum of at least 5×10^{-6} torr. The temperature of 125°C was selected in 1962 by JPL and SRI as the upper limit which might be encountered in spacecraft operations (in space). Space probes and satellites are generally designed to maintain internal temperatures of the order of 25°C, but much higher temperatures may occur in the vicinity of power-dissipating components; for example, thermal data from SURVEYOR I (lunar-soft-lander) reveal temperatures of the order of 60°C in various compartments of the spacecraft while camera temperatures were of the order of -80°C; thus, the migration of volatilized substances between spacecraft components which are at different temperatures is always possible, and it becomes necessary to test every polymer which is to be used in a spacecraft to determine whether it releases materials which can condense and invalidate certain of the craft's functions.

The effect on electrical contacts of extremely thin films of oils, "varnishes," or polymers is well-known to electronic engineers whether they be affiliated with the Department of Defense, with public utilities, or the space effort. Equally important to producers of vacuum spectrophotometric equipment or space-experiment designers is the effect of films on optical components such as lenses and mirrors. A dramatic illustration of this is given in Figure 1 a which demonstrates the scattering of light in the infrared region of 2-6 microns due to the deposition of a VCM film of less than 2-mil thickness on an optical flat of sodium chloride. This type of interference could lead to erroneous evaluation of the electromagnetic spectrum from a planet and could also result in an inaccurate photographic or televised view of a planet's surface. Condensates which have aromatic structures fluoresce when illuminated with ultraviolet light or absorb it strongly; very thin films of such materials deposited on astronomical mirrors or optical surfaces can completely invalidate observations in the ultraviolet.

A pound of polymeric material which releases 0.1% of VCM at 125°C will deposit on a square foot of surface at 25°C a film of about 0.00015 inch in thickness (0.15 mil); films of this thickness are more than enough to foul lenses or electrical contact points. Ideally, the VCM content of a polymer should be zero, or of a kind which will subsequently evaporate from the cooler surface. (It should be recognized that most condensed films eventually evaporate, but some may remain in place because of reaction with the surface or because of polymerization in place.)

In view of the above discussions, it has been proposed that the maximum-VCM content of candidate spacecraft materials must be 0.1% or less, and that weight-loss values must be 1% or less. Although it is possible that weight-loss values greater than 1% may not affect mechanical properties, it is also to be understood that the volume change accompanying a weight-loss of greater than 1% usually cannot be tolerated.

> Thus, a polymeric material should not be considered suitable for use in spacecrafts or be subjected to further evaluation unless it exhibits 1% or less weight-loss and 0.1% or less maximum-VCM content on exposure to the thermal-vacuum environment of 125°C and 10^{-6} torr.

Techniques developed in the course of this contract have provided not only quantitative measurement of loss in weight but also quantitative measurement of the maximum amount of volatile condensable material in a particular polymeric product. Concurrently, techniques have been developed for measuring the evaporation of condensates with time in vacuum and for the identification of volatile substances. The equipment and procedures used in these determinations are described in Section III.

It has been noted above that most volatile condensable substances are subsequently evaporated from the surface on which they have condensed. The theories and illustrations for the deposition and removal of VCM with time are given in the following paragraphs.

The determination of VCM depends upon differences in the rates of evaporation of material. The Langmuir equation permits estimation of the rate of evaporation of a pure compound:

$$W = \frac{P}{17.14}\sqrt{\frac{M}{T}}$$

where

W = rate of evaporation in $g/cm^2/sec$
M = molecular weight
T = absolute temperature
P = vapor pressure in mm.

The vapor pressure of pure compounds may be expressed by the equation:

$$\text{Log } P_{mm} = A - \frac{B}{T}$$

and this is easily transformed to

$$P_{mm} = 10^{A-B/T}$$

Now, if it is desired to compare the rate of evaporation of a pure compound at two temperatures, it is obvious that the Langmuir equation can be combined with the exponential form of the vapor pressure expression to yield:

$$\frac{W_1}{W_2} = \frac{10^{A-B/T_1}}{10^{A-B/T_2}}\sqrt{\frac{T_2}{T_1}}$$

where the subscript 2 refers to the higher temperature.

Thus, in the instances of the VCM determination, where the higher temperature is 125°C (398°K), the rates of evaporation at the two temperatures are related by the equation:

$$\frac{W_{398}}{W_{298}} = 0.8653 \; \frac{10^{A-B/398}}{10^{A-B/298}}$$

Some of the initial work done on VCM determinations was with silicone polymers. Since it is instructive to consider the vapor pressures expected from silicone polymers, the work of Wilcox* is used. Data given in this reference include the vapor pressure equations for compounds of the general form:

$$(CH_3)_3SiO_{1/2}[(CH_3)_2SiO]_n(CH_3)_3SiO_{1/2} \quad .$$

The coefficient A and B of the vapor pressure equations given in the reference were plotted and extrapolated to lower molecular weight values purely for sake of example. Using these data, the evaporation rates for various molecular weight compounds were computed; Figure 2 is a Cox-chart plot of the evaporation rates, and some of these rates are included in the table below:

RATIO OF EVAPORATION RATES AT 398°K AND 298°K

No. of Si Atoms	M.W.	W_{298}	Ratio $\frac{398^\circ K}{298^\circ K}$	Ratio $\frac{373^\circ K}{298^\circ K}$
18	1346	1.5×10^{-9}	2,000,000	130,000
12	904	6.5×10^{-5}	150,000	3,000
6	458	1.9	450	150

The ratios obviously indicate that in comparison to the rate at 298°K the silicone materials evaporate much faster at 398°K than at 373°K. More importantly, however, the high molecular weight material is evaporated much faster at higher temperatures than at lower temperatures;

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* Wilcox, D. F., J. Am. Chem. Soc., 68, 691 (1946).

however, the rate of evaporation of the lower molecular weight material is not influenced very much by an increase in temperature, but the lower molecular weight material evaporates millions of times faster than high molecular weight material at temperatures between 298°K and 398°K. The same conclusions can be made by reference to Figure 2; this figure clearly shows that the rate of evaporation of high-molecular-weight substances is affected by temperature more than the rate for low-molecular-weight materials (flattening of the lines as the molecular weight increases).

For a polymeric material consisting of a distribution of various molecular weights, it is difficult to make quantitative predictions of evaporation rates at various temperatures; the rates are nearly impossible to compute when various effects such as diffusion of species through a molecular matrix, nonideal vapor pressures, and impermeable surface layers are involved. Nevertheless, when work on this program was begun, some qualitative generalizations were made about the kind of results expected to be obtained from a VCM determination, provided impermeable membranes are not formed and the resin sample is thin enough (or porous) so that diffusion effects are negligible. Referring to Figure 3, the upper (solid-line) curve in the upper graph indicates the cumulative loss of weight in a vacuum expected from a resin (say at 398°K) which has volatile matter consisting of a more or less uniform distribution of molecular weight species. The solid-line curve in the lower graph represents the cumulative loss from a resin which has a preponderance of low molecular weight species in the volatile matter. The dotted-line curve in each graph represents, qualitatively, the predicted cumulative weight on a cold (298°K) collector which receives (straight-line) the material released by the warm resin in a VCM apparatus; an attempt is made, in these graphs, to show that the material collected on the cold collector evaporates slowly and that the weight of material on the cold collector is never stable.

The interesting point brought out by the graphs in Figure 3 is that the weight of material on the collector plate after a very long time should continue to rise slowly if the resin gives off high molecular weight substances, and that the weight on the plate will eventually be zero if the resin ceases to give off material early in the test. The graphs do not give any idea of the times involved, but it is important to realize that the relative evaporation rate data tabulated above indicates that considerable time at 298°K will be required to remove thin films of high molecular weight material; for example, for an 18-atom silicone, the weight of material evaporated in one hour at the higher temperature (398°K) will require 2,000,000 hours for evaporation at 298°K! Moreover, since the evaporation rates of high molecular weight materials are small, an exceptionally long time is required to remove volatile material of this type from resins, and, as implied by the curves in Figure 3, a very long time must be utilized in the determination of VCM to obtain weights of material on the cold collector plates which have "leveled off." Thus, according to these predictions, if a VCM determination is performed appropriately, it should be possible to detect a low steady rate of vaporization of matter; this should be very important in the selection of polymers for use in a spacecraft.

In an experiment to check the predictions of the rates of release of easily-volatile and difficultly-volatile substances in polymers, segments of good quality vacuum tubing were impregnated, with common plasticizers: dibutyl phthalate (easily volatile, m.w. 278) and dioctylphthalate (difficultly-volatile, m.w. 390); then, weight-loss and VCM were measured after periods of 24, 48, 96, and 330 hours in the thermal-vacuum environment of 125°C and $<10^{-6}$ torr. The resulting data are plotted in Figure 4, and it is evident that the anticipated curves in Figure 3 were nearly exactly reproduced in the experimentally-determined curves.

REDUCTION OF WEIGHT LOSS AND VCM

Because volatile materials are released in a thermal-vacuum environment, it is natural to conjecture that a polymer's weight-loss and VCM values may be eliminated by "postcuring" thick sections in vacuum at an elevated temperature; of course, this thought pattern ignores the fact that the determination of VCM is based on the use of thin sections of materials (<1/8" thick) and thus is not limited by the rate of diffusion of matter through thick sections. High-molecular-weight species have such low diffusive rates in polymers that thick sections cannot easily be stripped of these substances. On the other hand, there are instances where an extension of curing time or an elevation of curing temperature has reduced subsequent loss in weight or VCM content of thick sections of finished polymer, but the reduction came about because of removal of readily volatile and diffusive matter, or because the elevated temperature forced completion of polymerization. Perhaps storage of polymers for extended periods of time at an elevated temperature in vacuum may serve as a general procedure to reduce the amount of volatile matter, but the time required may be completely out of the realms of practicality, especially when thick sections of materials are to be treated. For example, a series of one-inch thick, RTV-type silicone sealants, notorious for VCM content, were "postcured" at JPL in vacuum at 150° and 232°C and were submitted for test. In order to determine the weight loss and VCM values of these materials, two samples for the micro-VCM determinations (Section III) were taken from each submitted specimen: (1) from an outer corner of the specimen and (2) from the center core of the specimen. The data are recorded in Table 1. For a thick material prepared in the normal fashion with no "postcure," little difference if any can be noted in either the weight-loss or VCM between a surface specimen or a specimen from the deep interior. During a thermal-vacuum postcure, the surface areas are more quickly depleted of low-molecular-weight material than the central area; naturally, relatively higher weight-loss and VCM values will be obtained for the center portion. More importantly, however, the center sections are not stripped of low-molecular weight polymers, as is borne out by the relative constancy of the VCM values.

The weight-loss and VCM values are improved in the thick pieces after the higher-temperature treatment, but still are not low enough to qualify the usual types of RTV silicones for spacecraft candidacy. The infrared spectra of the VCM from these silicones [Figure 1(b) and 1(c)] show that there is no difference in the VCM released from either the edges or the interior of the specimens and also that the characteristics are the same after thermal-vacuum postcuring. Thus, it can be stated again that it is primarily low-molecular-weight silicone polymers which contribute to this VCM and not solvents, additives, catalysts, etc. The characteristic structures of materials released by silicones were identified by the authors in the Final Report for JPL Contract 950324 (Oct. 1962 to Dec. 1963) and were considered to be indigenous and not deliberate additives (cf. pp. 55 and ii of Interim Report No. 1, JPL Contract 950745, June 1964 to August 1965).

On the other hand, a specially-processed version of Sylgard-184 (E-691-22E) was included in the experiment; this material is the first RTV-type material which has been screened that can qualify as a candidate for spacecraft use as-prepared. Interestingly, there are no differences in weight-loss or VCM values (Table 1) between the normally-cured material and the material which was subjected to thermal-vacuum treatment. It appears that the low-molecular-weight silicone fraction, which has been identified many times at SRI by mass spectroscopy (e.g., Figure 5) and infrared techniques (e.g., Figure 1) was "cleaned-out."

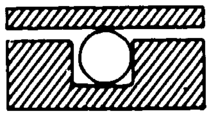
The postcuring of polymers at an elevated temperature in air is limited by the deleterious effects of heat. It was observed that the weight-loss and VCM of RTV-41/T-12 (GE) could be improved to acceptable values by a postcure of 24 hours at 250°C such as is practical for silicone elastomers (see Table 2), but it appeared that its physical properties were degraded. In order to check these observations, freshly-prepared materials were cured for 24 hours at 25°C, for 24 hours at 150°C, and for 24 hours at 250°C, and then were subjected to several mechanical-properties tests. As shown in Table 3, the ultimate tensile strength drops sharply after the 150°C cure, and remains about the same after a 250°C cure; elongation does not vary very much after the 150°C cure, but increases significantly after the 250°C cure. Shore hardness drops drastically after the 150°C cure, with the same value after the 250°C cure.

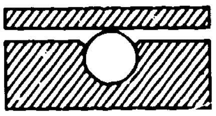
> The results in Tables 1, 2, and 3 clearly demonstrate that it is better to spend time and effort to produce a "clean" polymer than to attempt to rectify inferior material. Stated in another way, the space program should not be involved with remedial measures when appropriate material is available.

RESTRICTION OF WEIGHT LOSS AND VCM

Various schemes have been described for mechanically impeding the evolution of material from polymers in a thermal-vacuum environment. Obviously, if a polymer is hermetically sealed in a suitable container so that it is not exposed to vacuum, there can be no loss of material. If apertures are present, then the vaporization will be controlled by the mobility of the vapors in the ullage space and, to a large measure, by the rate of migration of the materials through the polymer matrix. If the apertures are very small, then a Knudsen effusion cell is at hand and the loss of material will be controlled by the pressure in the cell. Gasket materials in their seats pose different problems and may behave as follows: (1) There may be virtually no loss of matter because of tightness of seal or size of opening; (2) The loss of matter will be the same as from an open gasket except that a much longer period of exposure will be required; and (3) The release of matter will take place at nearly the same rate as from an open gasket. Recent experiments with a variety of gasket materials, of low to extremely high VCM contents, have shown that as much as 16 mg of VCM can be released in 96 hours from a 4-gram sample through an exposed area as small as 0.03 in^2.

Flange test-fixtures were designed according to the Parker Seal Company recommendations (Figure 6) which permitted an exposed depth of only 5 mils around the periphery of 2-inch O-rings, but provided an additional free surface area because of the square point-contact construction of the O-ring grooves. Also shown in Figure 6 is the design of a rounded, maximum-contact O-ring groove which provides for a free surface area of only about 0.03 in^2. The differences in these constructions and the contact of inserted O-rings is easily illustrated:


CONTACT-POINT
COMPRESSION


MAXIMUM CONTACT
COMPRESSION

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Specially-compounded O-rings of silicone, ethylene-propylene, neoprene, and Viton elastomers were sealed (duplicates) within both types of fixtures and then were exposed to the thermal-vacuum environment of 125°C and 10^{-6} torr for 96 hours in the macro-VCM apparatus (Section III). Concurrently, completely-exposed O-rings under no restriction were run. As shown by the data in Table 4, it is difficult to distinguish differences in weight-loss or VCM incurred by either sealed-in or totally-exposed O-rings with a maximum-VCM content of less than 0.5%. Thus, the fact that the exposed surface areas were quite different (that is, from 3.5 in^2 of totally-exposed surface down to about 0.03 in^2 for the O-rings under maximum compression) had little effect on the release of volatile materials from the Viton, silicone, and ethylene-propylene polymers.

However, the reduction of surface area clearly affects the diffusion rate of the VCM from the neoprene which has a gross maximum-VCM content (1.5%); it is intuitively obvious that this VCM will be released entirely with time and that sufficient VCM to cause concern is released within the first few hours of exposure in a thermal-vacuum environment.

That VCM did not migrate between the collector plates, possibly leading to averaging-out of condensate weights, was clearly shown by the cleanliness of the collector plates for the silicone elastomers and the absence of condensate on the collector plates for the Viton materials. At the same time, the collector plates for the neoprene and ethylene-propylene materials were covered with "oil" and dripping so that some VCM remained on the cooling block when the plates were removed for weighing. It is not surprising that these VCM values are a little lower than those reported in the micro-VCM determination; however, there is excellent agreement in weight-loss values.

Also shown in Table 4 are the effects of the thermal-vacuum environment on mechanical properties of the gasket materials. After this short period of exposure (96 hours) little effect can be discerned on the Viton, silicone, and ethylene-propylene materials which cannot be attributed to the statistics of comparing quadruplicate controls with duplicate test specimens. However, there is no doubt about the gross loss in properties of the neoprene material, undoubtedly due to the loss of plasticizing oils.

> Thus, it can be stated again that a polymer with unacceptable weight-loss value and particularly with unacceptable maximum-VCM value should not be considered for use in spacecrafts where it will be at temperatures higher than the surfaces of critical components. It is possible, of course, that materials such as potting compounds can be confined in hermetically-sealed cans, but it is unnecessary to use poor materials and to fabricate special containers when suitable polymers are readily available.

Acceptable products have not yet been identified for several specific applications, e.g., temperature control coatings; in these instances, the products can be cleaned up by a thermal-vacuum treatment since they are usually used as thin films and their volatile contents can be readily removed.

Table 1

MICRO-VCM DETERMINATIONS:
EFFECT OF THERMAL-VACUUM TREATMENT (AT JPL)
ON DOW-CORNING SILICONE ABLATIVE MATERIALS (1" THICK)

(24 hr at 125°C and 10^{-6} torr)
(VCM collectors at 25°C)

MATERIAL	TREATMENT	SAMPLE AREA	TOTAL WT. LOSS, %	VCM, WT-%
Sylgard-184 (no phenyl)	as received	surface	1.30	0.65
		center core	1.36	0.68
	24 hr 150°C 10^{-6} torr	surface	0.85	0.39
		center core	1.09	0.55
	24 hr 232°C 10^{-6} torr	surface	0.43	0.24
		center core	0.93	0.53
XR-63492 (low phenyl)	as received	surface	1.86	0.61
		center core	1.95	0.62
	24 hr 150°C 10^{-6} torr	surface	0.99	0.40
		center core	1.47	0.28
	24 hr 232°C 10^{-6} torr	surface	0.47	0.12
		center core	0.51	0.50
93-002 (high phenyl)	as received	surface	2.96	0.52
		center core	2.98	0.44
	24 hr 150°C 10^{-6} torr	surface	0.95	0.14
		center core	1.55	0.41
	24 hr 232°C 10^{-6} torr	surface	0.42	0.06
		center core	1.15	0.32
E691-22E (exptl resin, specially processed Sylgard-184)	as received	surface	0.19	0.06
		center core	0.18	0.03
	24 hr 150°C 10^{-6} torr	surface	0.19	0.06
		center core	0.19	0.06
	24 hr, 232°C 10^{-6}	surface	0.11	0.03
		center core	0.17	0.06

Table 2

MICRO-VCM DETERMINATIONS: EFFECT OF ELEVATED-TEMPERATURE CURING ON RTV-41 T-12 SILICONE (GENERAL ELECTRIC)

MATERIAL	CURE	TOTAL WT. LOSS, %	VCM, WT-%
RTV-41,T-12	8 hr 25°C + 4 hr 50°C	2.06	0.45
RTV-41 T-12	Postcured 24 hr 150°C	1.09	0.60
RTV-41 T-12	Postcured 24 hr 250°C	0.47	0.12

Table 3

EFFECT OF CURING CYCLES OF MECHANICAL PROPERTIES OF RTV-41 T-12 (GENERAL ELECTRIC)

CURE SAMPLE	ULTIMATE TENSILE STRENGTH		ELONGATION,	SHORE HARDNESS, TYPE A
	lb	lb/in²		
24 hr 25°C				
A	6.8	340	120	
B	6.5	325	150	
C	6.3	315	150	
D	8.1	405	175	
E	9.2	460	200	
Average		369	160	57
24 hr 150°C				
A	5.0	236	110	
B	4.6	217	140	
C	6.0	283	160	
D	6.9	325	175	
E	5.0	236	130	
Average		259	149	48
24 hr 250°C				
A	5.7	285	200	
B	3.9	195	170	
C	6.2	310	225	
D	6.1	305	210	
E	5.2	260	200	
Average		290	201	47

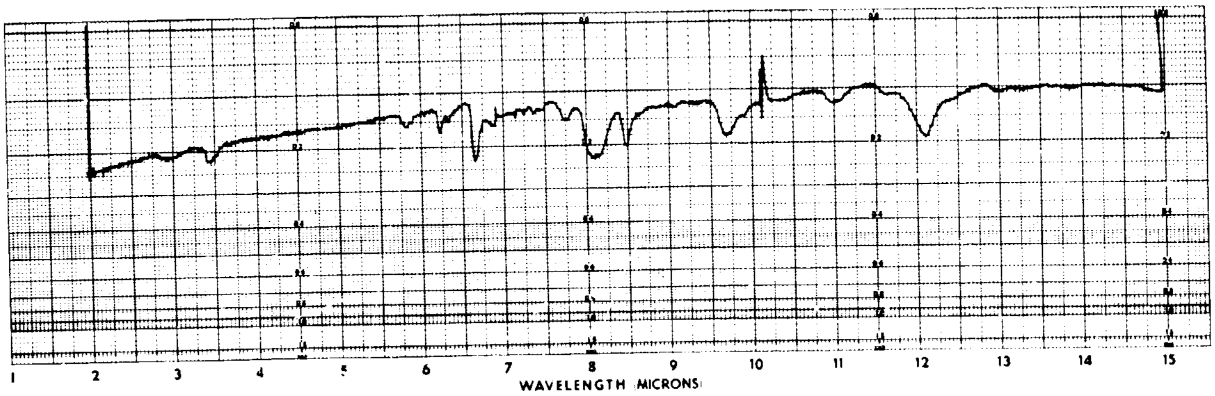
Table 4

MACRO-VCM DETERMINATIONS:
COMPARISON OF OUTGASSING CHARACTERISTICS AND MECHANICAL PROPERTIES
OF TOTALLY-EXPOSED O-RINGS WITH SEALED-IN O-RINGS
AFTER 96 HOURS AT 125°C AND 10^{-6} TORR

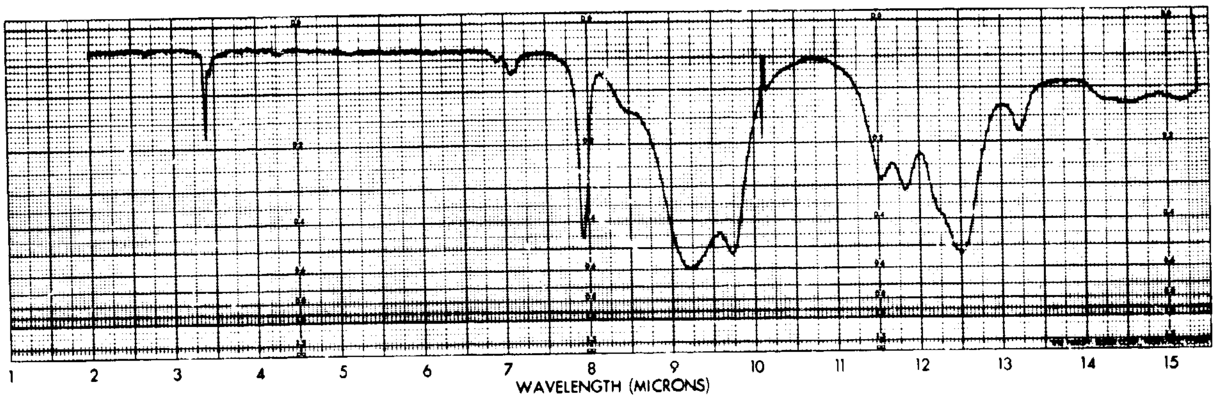
MATERIAL / CONDITION	TOTAL WT. LOSS, %	VCM, wt-%	SHORE HARDNESS	TENSILE, psi	ELONGATION AT BREAK, %
Viton 377-9					
As received	n.a.	n.a.	96.7	1521	82
Totally exposed	0.35	0.01	94.9	1516	71
Point-contact compression	0.35	0.00	96.8	1743	85
Maximum-contact compression	0.30	0.01	--	1632	78
Silicone 5604-7					
As received	n.a.	n.a.	71.5	710	126
Totally exposed	0.20	0.05	76.3	715	117
Point-contact compression	0.26	0.03	75.4	851	124
Maximum-contact compression	0.45	0.12	--	363	44
Ethylene-propylene E515-8					
As received	n.a.	n.a.	82.7	1283	132
Totally exposed	1.90	0.47	88.0	1392	166
Point-contact compression	1.82	0.53	84.3	1612	185
Maximum-contact compression	1.88	0.43	--	1155	137
Neoprene C526-7					
As received	n.a.	n.a.	71.3	1550	218
Totally exposed	3.28	1.54	74.1	698	114
Point-contact compression	2.43	0.92	74.2	759	124
Maximum-contact compression	1.10	0.37	--	950	160

NOTES:

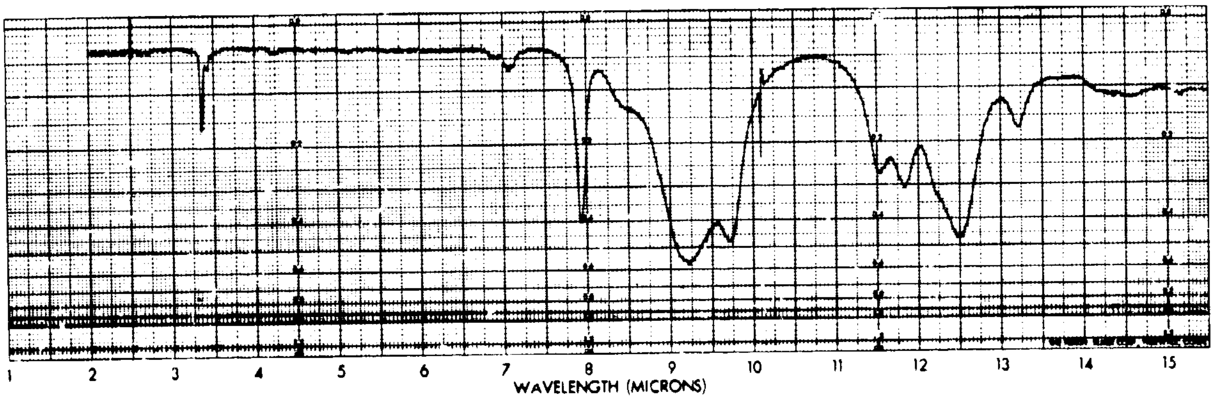
1. All samples were 2" O-rings with 3/16" walls, and were specially compounded by the Parker Seal Company.
2. As-received O-rings were tested in quadruplicate for mechanical properties; exposed O-rings were tested in duplicate.



(a) Epoxylite 295-1 A/B (batch 2649). Manufacturer's sample; mixed 1:1 and cured 8 hr/113°C



(b) Sylgard-184; outer corner of 1"-thick slab cured at ambient temperature



(c) Sylgard-184; center core of 1"-thick slab after treatment for 24 hr at 232°C and 10^{-6} torr

FIG. 1 INFRARED ABSORBANCE CURVES OF VCM (at 125 25°C) FROM POLYMERIC MATERIALS EXAMINED FOR SPACECRAFT USE

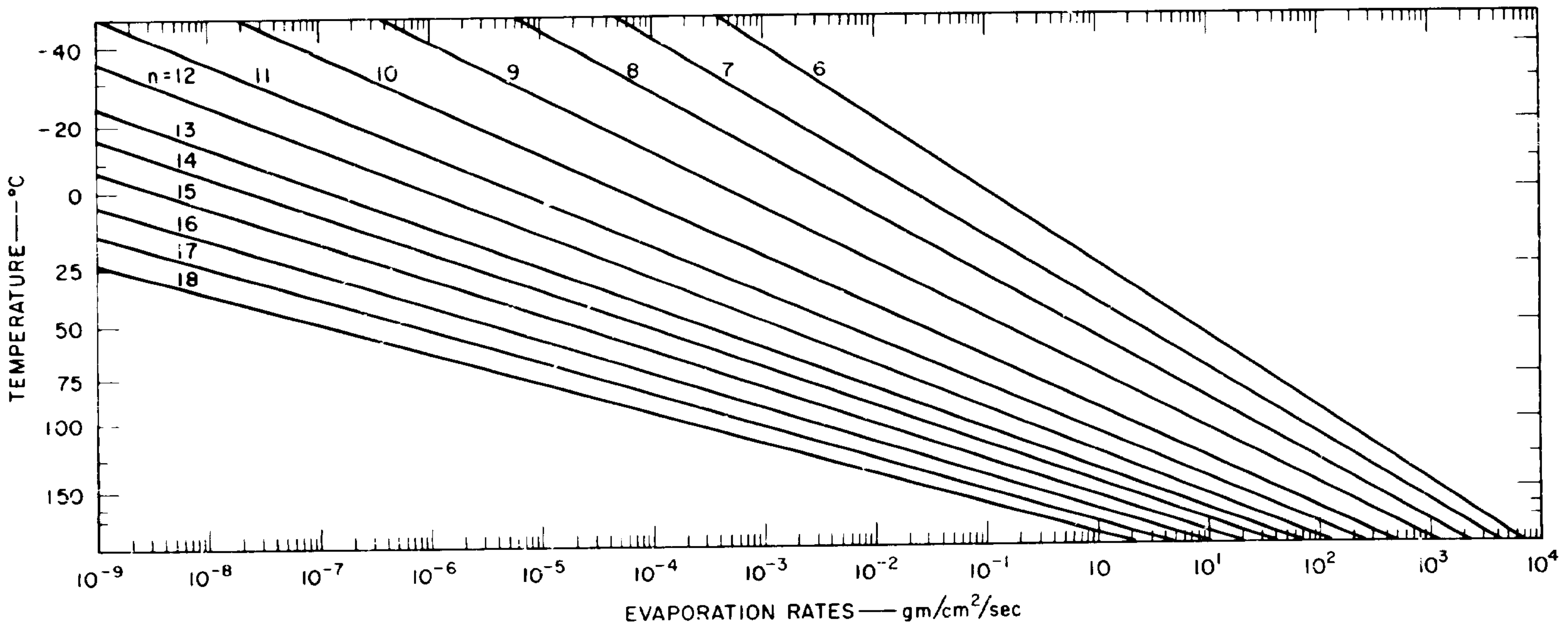


FIG. 2 EVAPORATION RATES OF SILICONES OF THE GENERAL FORMULA $(CH_3)_3SiO_{1/2}[(CH_3)_2SiO]_n(CH_3)_3SiO_{1/2}$

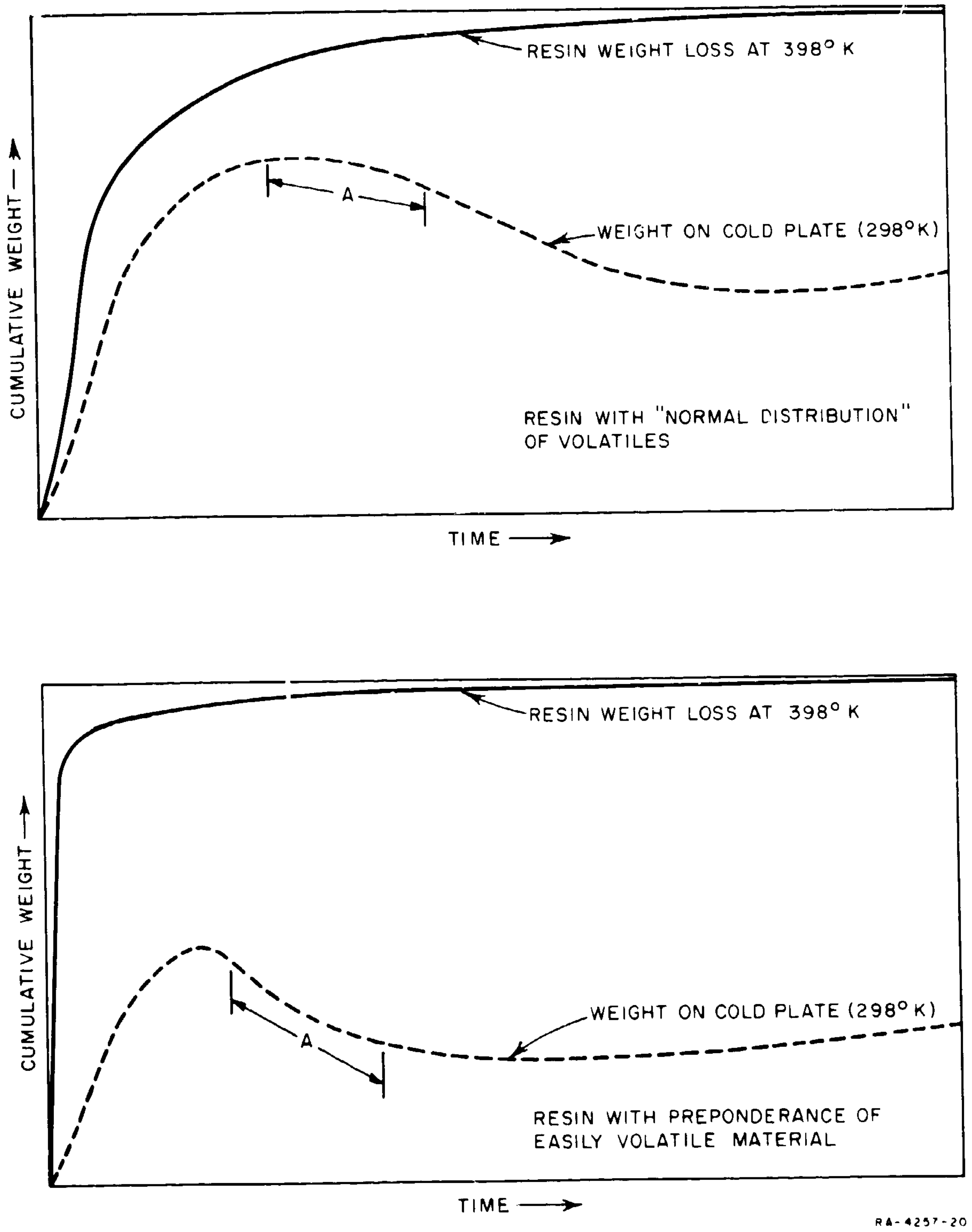


FIG. 3 DIAGRAMMATIC REPRESENTATION OF THE QUALITATIVE RELATION OF LOSS OF WEIGHT OF RESINS AT 398°K TO VCM RESULTS

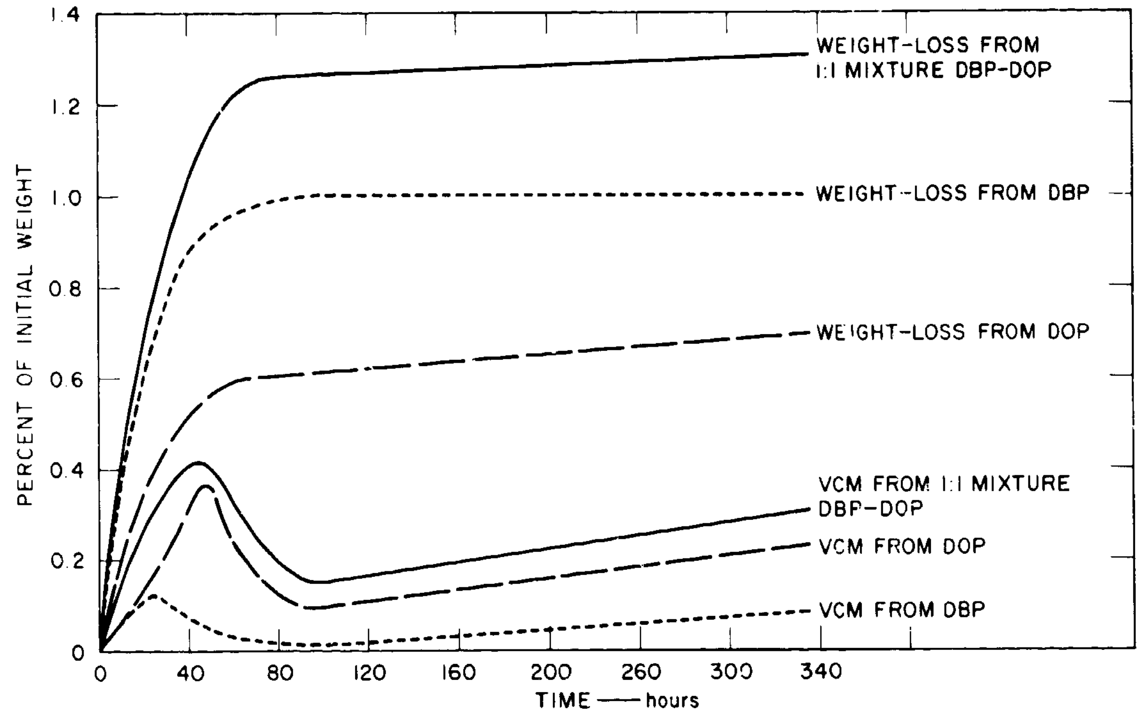


FIG. 4 WEIGHT LOSS AND VCM DATA FROM EXPERIMENTAL RUNS WITH RUBBER TUBING SATURATED WITH DIBUTYLPHTHALATE (m.w. 278) AND DIOCTYLPHTHALATE (m.w. 390)

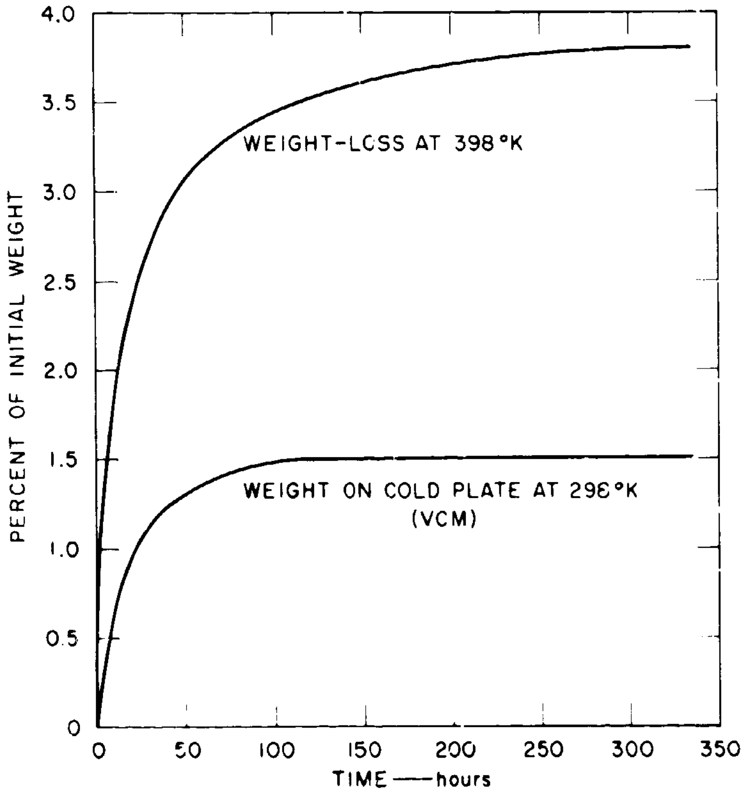


FIG. 5 WEIGHT LOSS AND VCM DATA FROM RUBBER TUBING ITSELF

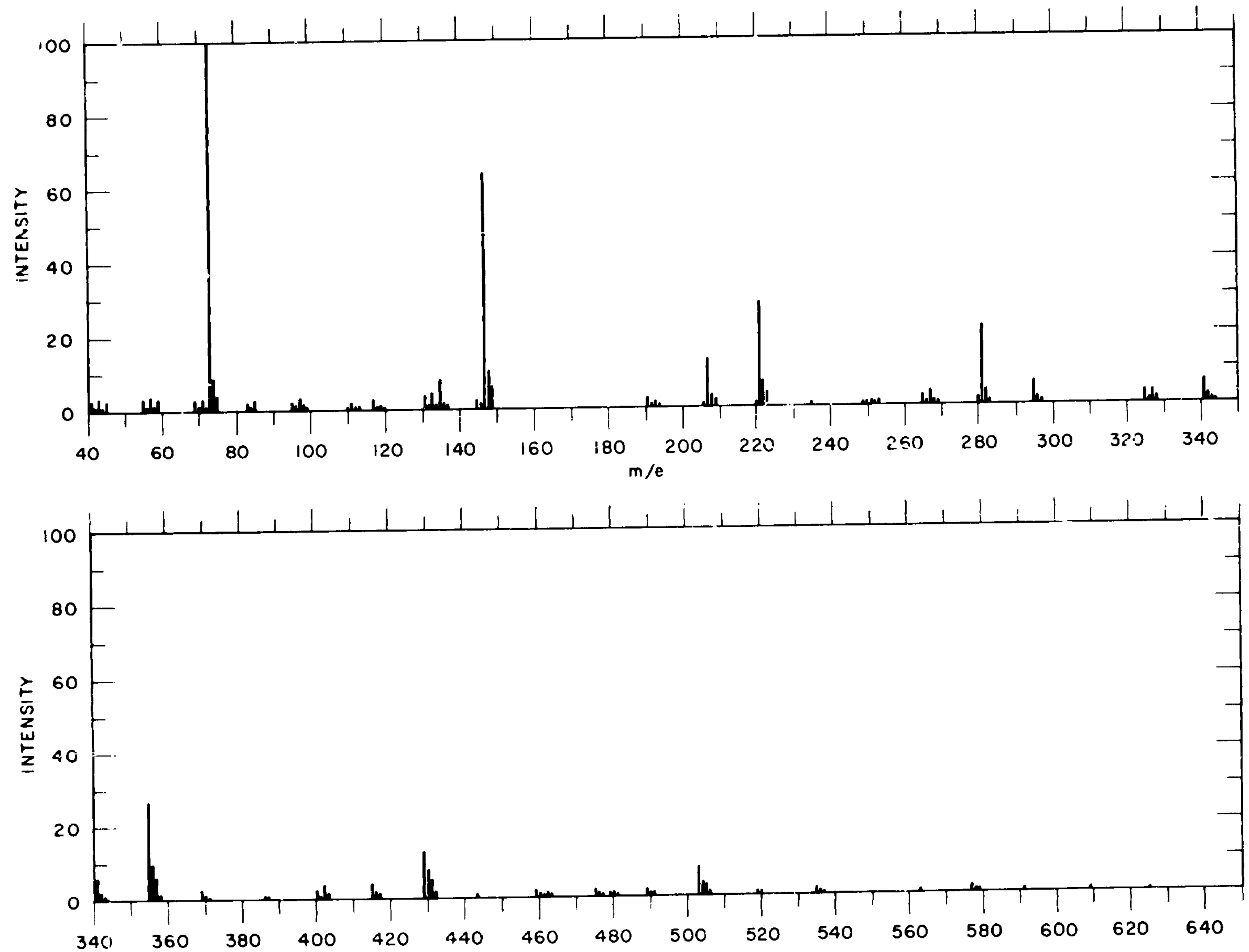


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FIG. 6 MASS SPECTRUM OF LINEAR AND CYCLIC SILICONES RELEASED FROM RTV-60 (GE) AT 125°C AND 10^{-6} TORR

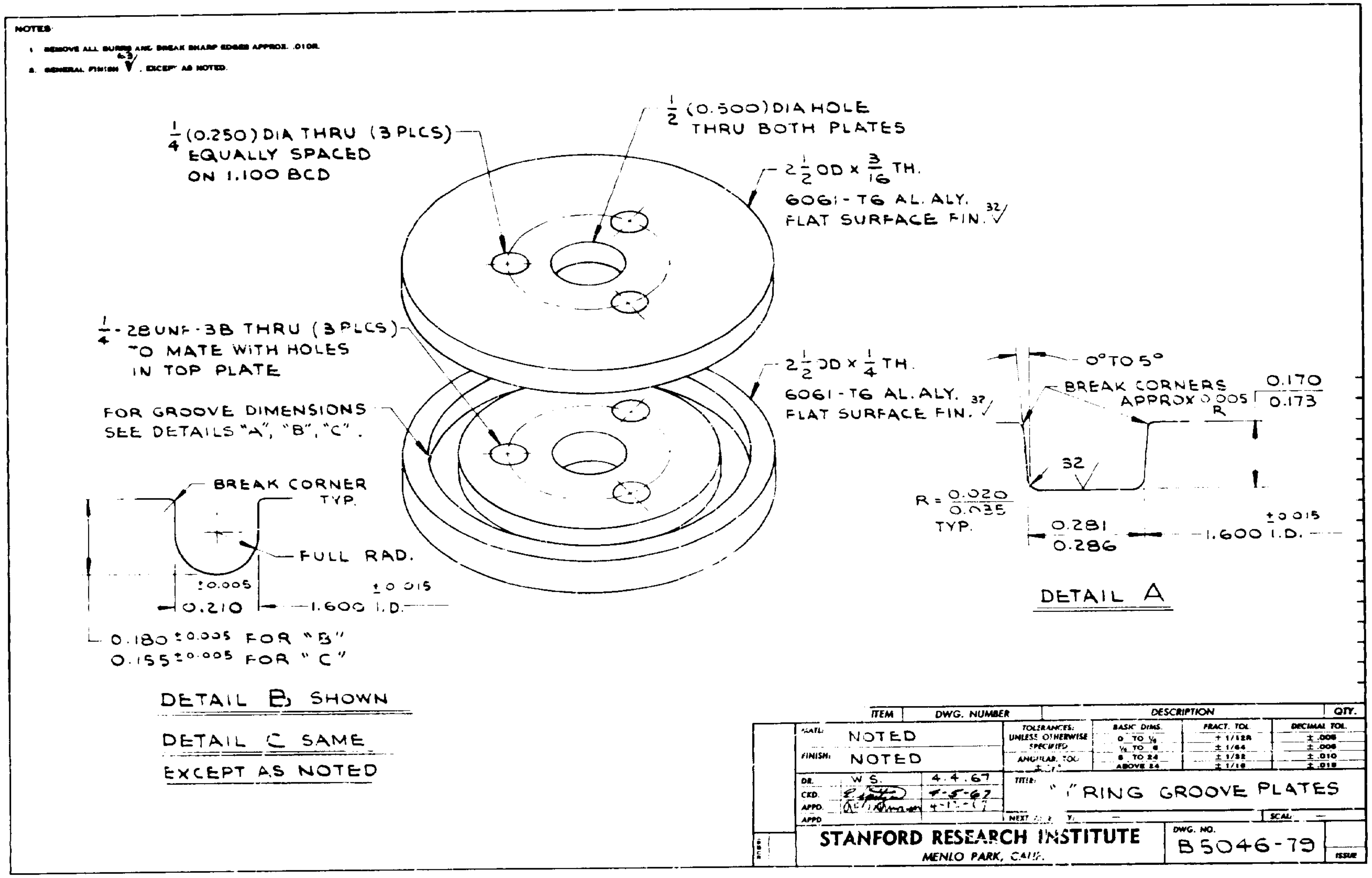


FIG. 7 FLANGE TEST FIXTURES FOR DETERMINING VCM RELEASED BY SEALED-IN O-RINGS IN THE THERMAL-VACUUM ENVIRONMENT

III. EQUIPMENT AND PROCEDURES FOR DETERMINING THE AMOUNT, BEHAVIOR, AND IDENTITY OF VOLATILE MATERIALS

Thermal-vacuum analytical procedures are used for determinations of loss in weight, maximum-VCM content, and the character of the VCM released by polymeric products. "Fingerprints" of VCM are obtained by infrared spectrophotometry; and noncondensable substances are identified by mass spectrometry.

MICRO-VCM DETERMINATIONS

The technique developed at SRI for the rapid screening of candidate polymeric materials for spacecraft use has been called the "micro-VCM" determination because the quantity of sample used is of the order of milligrams and the amount of volatile condensable material collected is generally of the order of micrograms. The maximum-VCM content and the total weight loss of as many as 24 samples can be determined by this procedure after only 24 hours of exposure to a thermal-vacuum environment of 125°C and 10^{-6} torr. That the VCM value obtained in this way is very close to maximum has been proven many times (vide infra).

The basic unit for the micro-VCM determination is shown mounted on a 6-inch vacuum console in Figure 8. The micro-VCM apparatus is attached via a 6-inch elbow to the high-speed vacuum system, equipped with a Welch 1397B forepump and a CVC MCF-700 diffusion pump; a liquid nitrogen trap is included in the system. The elbow is fitted with vacuum gages and utility plugs which carry the lines for power, water cooling, and thermocouples; a pressure of at least 10^{-6} torr is easily maintained.

The micro-VCM apparatus consists of two copper-block heater units, each of which accommodates 12 samples, and a common cooling unit for the VCM collector plates. Samples are contained in individual bored-out compartments in the solid copper blocks; the compartments are covered by copper discs sealed with Teflon O-rings. The heating elements for the blocks are made of XacTglo wire which has been silver-soldered in place at sufficient intervals to maintain a block temperature of 125°C.

(The two copper-block heaters are independent; this makes it possible to make runs where one set of samples is held at 70°C and a second set is held at 125°C, for example.)

The path from any sample compartment to its VCM-collector plate is defined by a large hole (in comparison with the compartment size); cross-contamination between compartments is abated by insertion of an egg-crate baffle. The efficiency of this system in preventing cross-contamination has been demonstrated statistically by running numerous blanks at the same time with samples containing large amounts of VCM; the efficiency of the baffle system was also confirmed when samples with exceptionally-high VCM contents were run at the same time as samples with acceptably-low VCM contents.

(Complete design drawings for the apparatus were published in Interim Report No. 3, Part II, under this contract.)

Procedure. - Finished polymeric products (e.g., elastomers, hardware and structural) are cut into small pieces of about 1/16" x 1/16" and post-cured as required. Products which require compounding are mixed in at least 100-gram batches in order to ensure representative samples, cured as slabs of no more than 1/8" thick, and then cut into small pieces. Polymers to be used as coating materials are applied to stainless-steel screens; the thin coatings are then cured. Oils or viscous liquids are taken up in ignited asbestos.

Samples of 100-200 milligrams are placed in previously-weighed micro aluminum boats and stored in an atmosphere of 50% humidity for at least 24 hours. Then the samples are weighed on a microbalance and placed in the compartments in the copper blocks; the compartment covers, sealed with Teflon gaskets, are secured by screws. The polished and cleaned copper collector plates are weighed on a microbalance and fastened firmly to the copper cooling block by screws. When the bell-jar (shown in Figure 8) has been set over the apparatus, and the system has been evacuated to a pressure less than 10^{-5} torr, the copper blocks are brought to 125°C. The temperature is maintained for 24 hours; then the blocks are allowed to cool under vacuum to at least 50°C, whereupon the bell-jar containing the apparatus is vented with dry nitrogen or helium. The samples and collector plates are removed, placed in desiccators, and weighed in order of their removal from the apparatus.

The results of the micro-VCM determinations which are summarized throughout this report are based on a minimum of 2 determinations per sample. Preliminary work and subsequent observations have shown the average reproducibility of determinations to be as follows:

Av. wt-% of VCM	Av. reproducibility (abs.)
<1%	±0.05%
1-5	±0.20
5-10	±0.50
10-20	±1.0

In the initial work on this program, blank runs were made at random and the VCM collectors were always found to be free of condensed material; since March 1966 blanks have not run routinely since it was established that no cross-contamination was occurring between sample compartments and that the change in weight of blank VCM collector plates did not vary more than ±10 micrograms.

MICRO-VCM BY IR

The micro-VCM determination has been extended to include the recording of infrared spectrophotometric "fingerprints" of the VCM released by polymeric products. For this purpose, the copper collector plates have been replaced with optical salt flats. The design of retaining rings and pertinent dimensions of the salt flats are given in Figure 9. The amount of VCM collected on the plates can be obtained with a microbalance or the amount of VCM can be obtained from calibration curves by measuring the infrared absorbance. At present, both weights and infrared absorbances are being recorded. The correlation of VCM weights collected on copper plates and on salt flats is shown in Table 5; apparently, both methods of collecting material are equally efficient.

By itself, the infrared (IR) technique provides an excellent method for quality control since the volatile materials from different classes of polymers show different absorptions in the IR, and the volatile materials from the same basic polymers may have different characteristics because of sbustituents on the basic polymer linkage or differences in compounding formulations. An example of the efficacy of infrared "fingerprints" of VCM as a measure of quality control is illustrated in Figure 10; curves (b) and (c) vary distinctly from curve (a) for the VCM from epoxy-glass fiber circuit-board materials, ostensibly of similar nature (Micaply EG series, the Mica Corporation). The strong double peaks in curves (b) and (c) were identified as -CN-bearing functions, and the material was subsequently identified as a polyamide.

A catalog of the infrared spectra of the VCM from polymeric products is given in Appendix C. It is anticipated that this catalog will serve a two-fold purpose: (1) For the laboratories which are equipped to collect VCM by the micro-VCM IR procedure or by macro-VCM procedures which will provide a sufficient amount of material to be transferred to an optical salt flat, the spectra become a reference file for checking conformity of new batches of the same products or of materials claimed to be equivalent. (2) Alternatively, the spectra become a first reference for isolating the source of contamination of space-simulation chambers or spacecrafts undergoing tests in a simulated space environment; this is particularly advantageous at facilities where analytical equipment and personnel are limited since the spectra need not be interpreted but only matched against "fingerprints."

Exploratory experiments have shown that the infrared absorbance of the VCM can be measured and calibrated vs actual weight of VCM so that VCM can be determined quantitatively by IR without recourse to precise weighings on microanalytical balances. An example of the relationship of IR absorbance to weight of VCM is given in Figure 11; also shown is the fact that different types of silicones will have different degrees of absorbance at the same wavelength. (The actual data are summarized in Table [illegible].)

MACRO-VCM DETERMINATIONS

The macro-VCM determinations, utilizing 4- to 10-gram samples, provide information on the rate at which offending VCM is re-evaporated (see Section I.). The results of these determinations also provide insight into whether a modified cure or a modified blend of components will yield a polymeric product suitable for spacecraft use.

A photograph of the assembly of 12 macro-VCM sample cells within the vacuum chamber is given in Figure 12, and Figure 13 illustrates the entire vacuum system used for obtaining macro-VCM data. (Complete design drawings for the macro-VCM sample cells, fixtures, and assembly are given in Interim Report No. 3, Part II.) The vacuum chamber is a 24-inch diameter, 35-inch long cast-steel bell jar. The essential components of the vacuum system are a Cenco Hypervac-100 roughing pump, a Welch Model 1400 holding pump, a Temescal F-2530 vacuum valve, a CVC PMCU-10B diffusion pump, and a cooled baffle employing Freon-502 refrigeration.

The supporting rack for the VCM apparatuses is fastened to the faceplate of the vacuum chamber, and the bell jar is moved into place on a track. The nozzle of each sample cell is positioned so that substances volatilized at 125°C will pass through an opening in an aluminum baffle to a polished aluminum VCM-collector plate maintained at about 25°C by water-cooled lines soldered to the collector-plate support.

The heated sample chambers consist of two spun-copper halves (Figure 12), each wound with an NacTglo heating element silver-soldered in place. The halves are joined and sealed with Teflon gaskets. Individual thermal control and thermocouple systems are provided for each half of each sample cell (control panels, Figure 13).

During a run, the sample cells are maintained at 125°C; operation records indicate that the chamber pressure ranges from about 10^{-6} torr in the 24- and 48-hr runs to about 10^{-7} torr in the 96- and 336-hr runs. Since preliminary work indicated that "blank" collector plates adjacent to plates on which material is deposited suffer no increase in weight, a full complement of 6 samples (in duplicate) has been used for making most of the macro-VCM determinations reported at this time. Recent work with gasket materials (Section II) has confirmed the lack of cross-contamination.

Procedure.- Sufficient sample material is collected or prepared prior to a run to provide for 4 determinations in duplicate; this is done to ensure the uniformity of the sample used in establishing the VCM curve. Samples are mixed and cured as described for the micro-VCM determinations, but they are cut into pieces such that no thickness will be greater than 1/8" in order to minimize diffusion-rate effects. Configurations such as sections of sleevings, honeycombs, electronics modules, etc. can be accommodated easily in the macro-VCM sample cells since they have a volume of about 12 in^3. The samples are weighed without prior exposure to a constant-humidity atmosphere. They are placed either directly on perforated shelves in the sample cells or contained in aluminum dishes which are then placed on the shelves.

A macro-VCM determination consists of measuring the amount of VCM collected (and weight-loss incurred) from polymeric products at intervals of 24, 48, 96, and 336 hours in an environment of 125°C and 10^{-6} torr.

> It is to be emphasized that samples are not taken out and re-inserted for additional periods of time; each run in the series is made up of fresh samples. In fact, the 336-hr run is often performed before the 24-hr run for maximum utilization of hours over weekends and Holidays.

The results obtained with the macro-VCM apparatus are definitive and provide the final data by which polymer candidacy for spacecraft use is determined (see Section II); in contrast, micro-VCM results are used only for eliminating grossly inadequate polymers. Eventually, data obtained from the macro-VCM determinations may be used for definitive studies of the diffusion rates of the volatile substances relative to thickness of materials or surface-to-volume ratios; an indication of this relationship has been shown in Section II (VCM from gasket materials).

IDENTIFICATION OF VOLATILE MATERIAL

Confirmation of the effectiveness of the micro-VCM determination as a screening technique for the selection of candidate spacecraft materials is afforded by the results of the macro-VCM determination. Results of many determinations with the macro-VCM apparatus indicate that the maximum weight of condensable material is collected in about 24 hours and that a 24-hour exposure of finely-divided material in the micro-VCM apparatus gives essentially the same value. Since the nature of the materials evolved is of interest, mass spectrometric examination of the volatile substances has been undertaken (1) to identify readily-volatile substances which cause the observed weight-loss in a thermal-vacuum environment, and (2) to identify substances which may be responsible for the observed VCM.

One of the mass spectrometers used at SRI for the identification of substances released from polymers is a CEC Model 21-103C which has been modified to include an ion-pump exhaust system (which ensures that any detected hydrocarbons or silicones emanate only from the material under examination) and a versatile sample-inlet system which permits operation of the spectrometer with or without the restricting molecular leak as well as a direct line-of-sight path for vaporized molecules into the ionizing region. Another CEC Model 21-103C mass spectrometer has been converted to a medium-resolution instrument by the addition of a Wien filter and electron multiplier; a direct-probe system is used for the introduction of polymeric samples. This spectrometer is used for identification of high-molecular-weight species.

The mass spectrometric analysis procedure involves pumping the sample at room temperature until a pressure of at least 10^{-6} torr is reached in order to remove surface moisture and gases; then the sample is heated quickly to 125^{0}C and the spectrum of the volatilized substances is recorded within a few minutes. Sample sizes range from 1 milligram to 10 micrograms depending on the sensitivity of the instrument used. The mass spectrometer runs also confirm that small pieces of polymeric material are completely stripped of volatile substances within 24 hours at 125°C (in vacuum). Hence, when small pieces of polymers are subjected to micro-VCM conditions, the material collected on the cold plate will be nearly the maximum amount given off.

Table 7

COMPARISON OF VCM PICK UP ON
OPTICAL SALT FLATS VS COPPER COLLECTORS

(24 hr at 125°C and $10^{-?}$ torr)
(VCM collectors at 25°C)

SAMPLE	WT % VCM, COPPER COLLECTORS	WT % VCM, SALT FLATS
Eccocoat PH-7	2.08	[illegible]
SR-220	2.71	2.44
RTV-60 (24 hr 150°C)	0.74	0.54
SE-555 (Red)	0.53	0.55
Ben-Har 1151 HA-1	0.37	[illegible]
Ben-Har 263 FC-3	0.32	0.58
Eccocoat IC-2	0.29	0.32
Ben-Har 1062 HA-1	0.23	0.13
Stycast 1217-9	0.14	0.12
Teflon FEP 100A	0.08	0.04
Ben-Har Acryl A FA-1	0.05	[illegible]

Table 8

INFRARED ABSORBANCE VS WEIGHT OF VCM
FROM TWO DIFFERENT TYPES OF SILICONE EFFLUENTS
(Preliminary Data)

MATERIAL	WT. VCM, MICROGRAMS	IR ABSORBANCE AT 7.[illegible] MICRONS
Silicone "A"		
Ben-Har 1062 HA-1	140	[illegible]
	126	0.122
Ben-Har 1151 HA-1	[illegible]	0.187
	291	0.187
Silicone "B"		
SE-555 (Red)	[illegible]	[illegible]
	[illegible]	[illegible]
SR-220	[illegible]	[illegible]

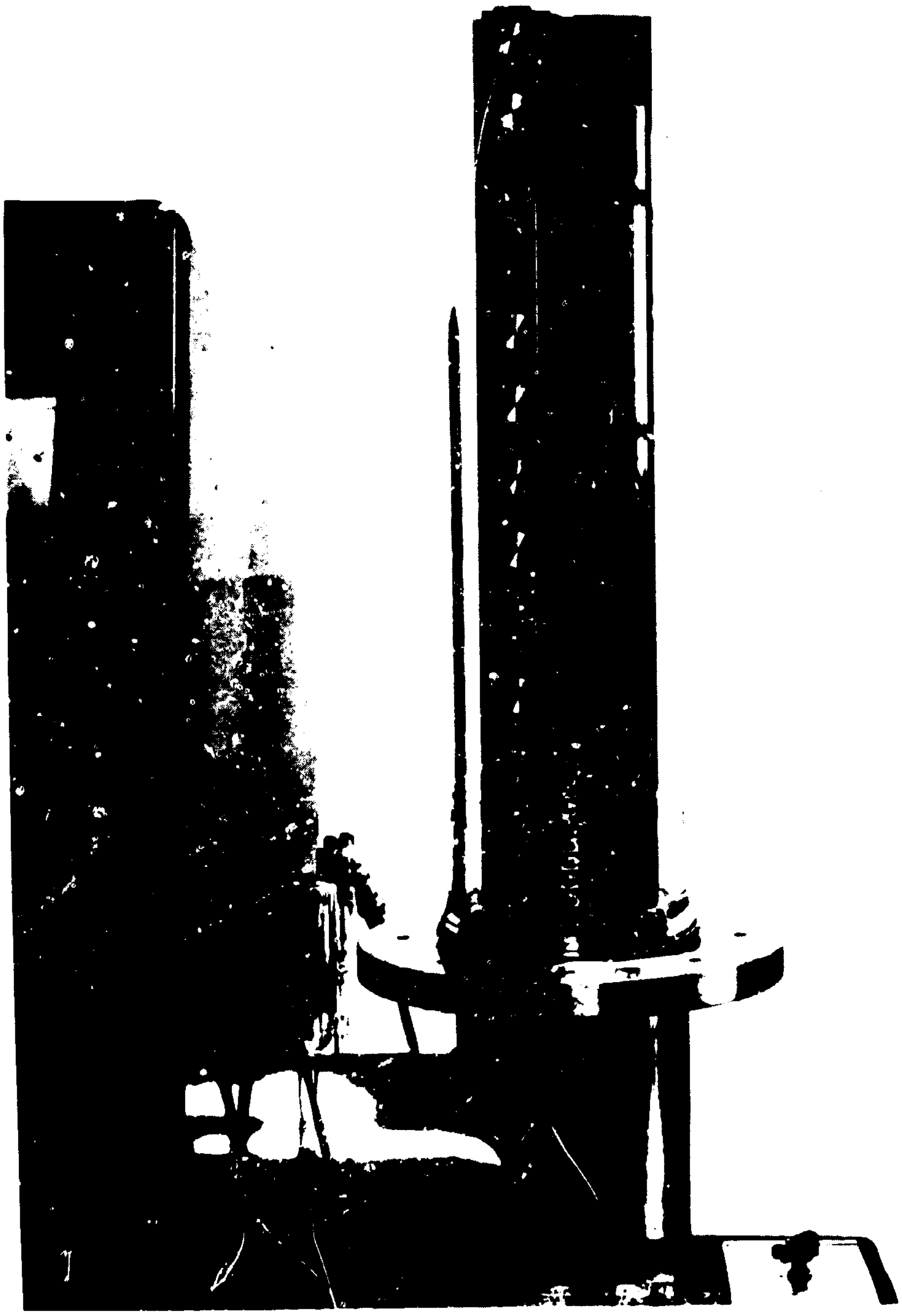


FIG. 8 MICRO-VCM APPAPATUS MOUNTED ON 6-INCH VACUUM CONSOLE

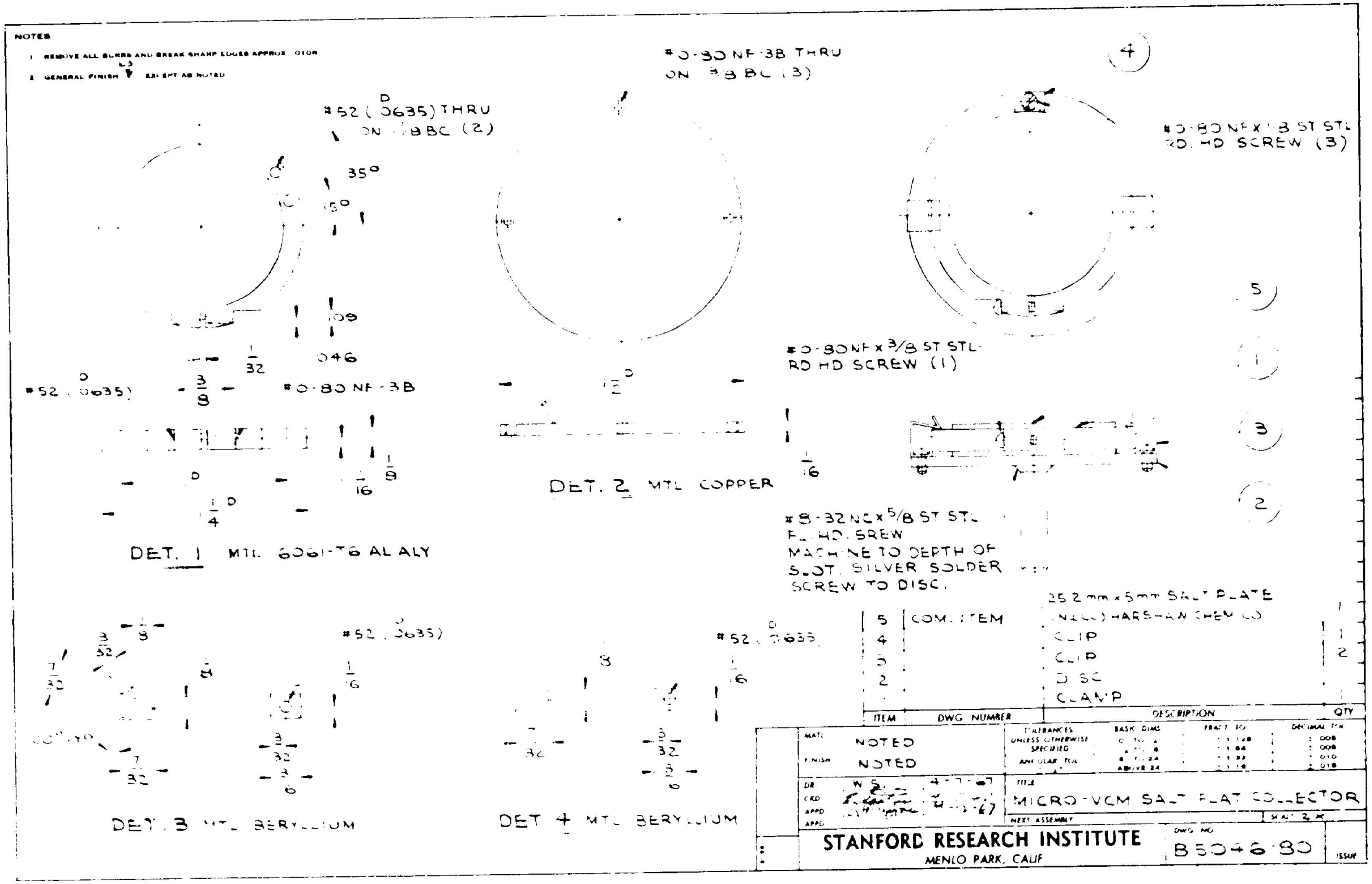
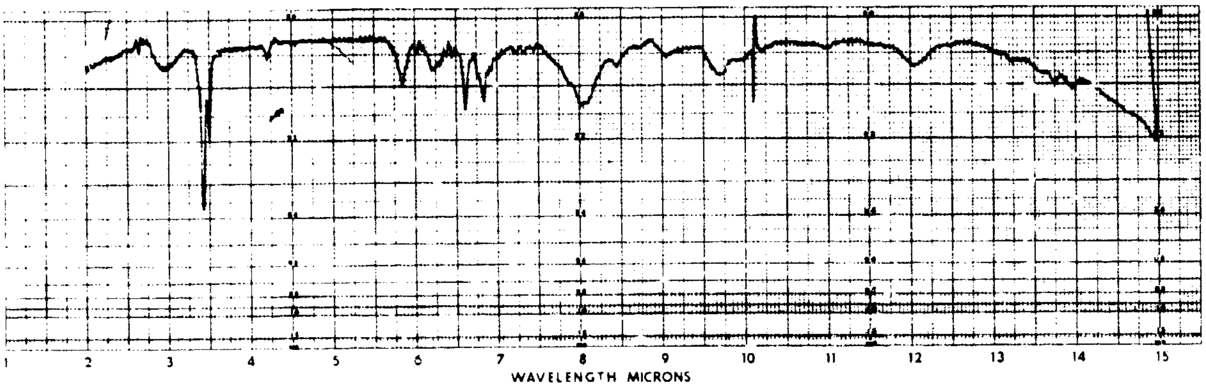
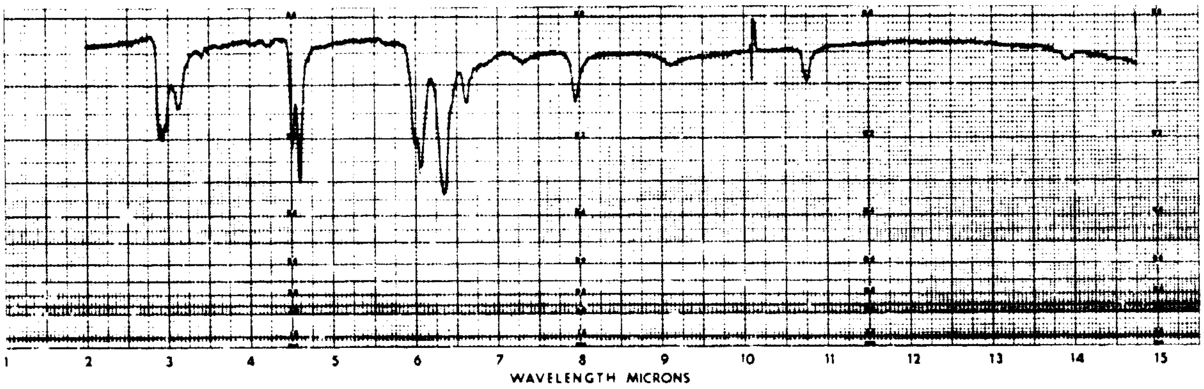


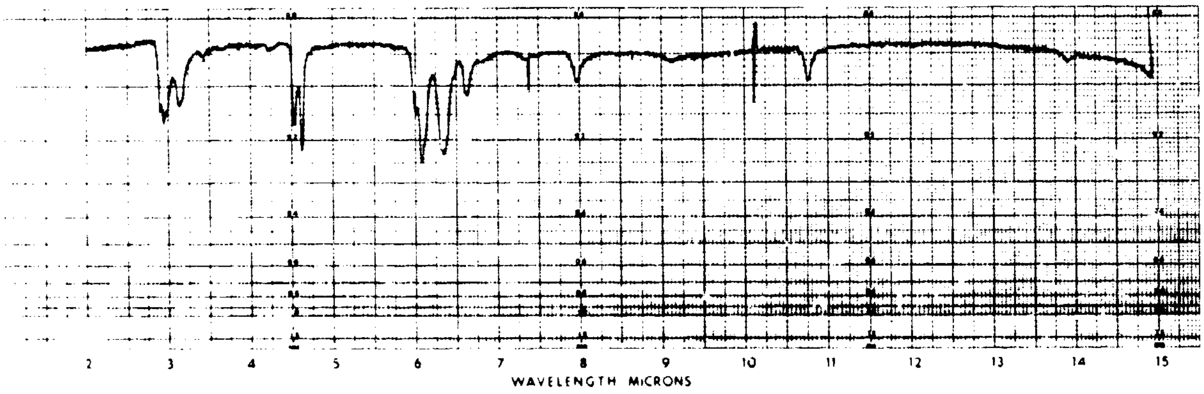
FIG. 9 DESIGN DRAWINGS OF RETAINER RINGS AND OPTICAL SALT FLATS FOR MICRO-VCM DETERMINATIONS BY IR



(a) MICAPLY EG-284T, TYPE GH. As received, stripped of copper. (Scale expansion 5X)



(b) MICAPLY EG-758T, TYPE GE. As received, stripped of copper.



(c) MICAPLY EG-899T, TYPE GF. As received, stripped of copper.

FIG. 10 INFRARED ABSORBANCE SPECTRA OF VCM AT 125/25°C FROM EPOXY-GLASS FIBER CIRCUIT BOARDS

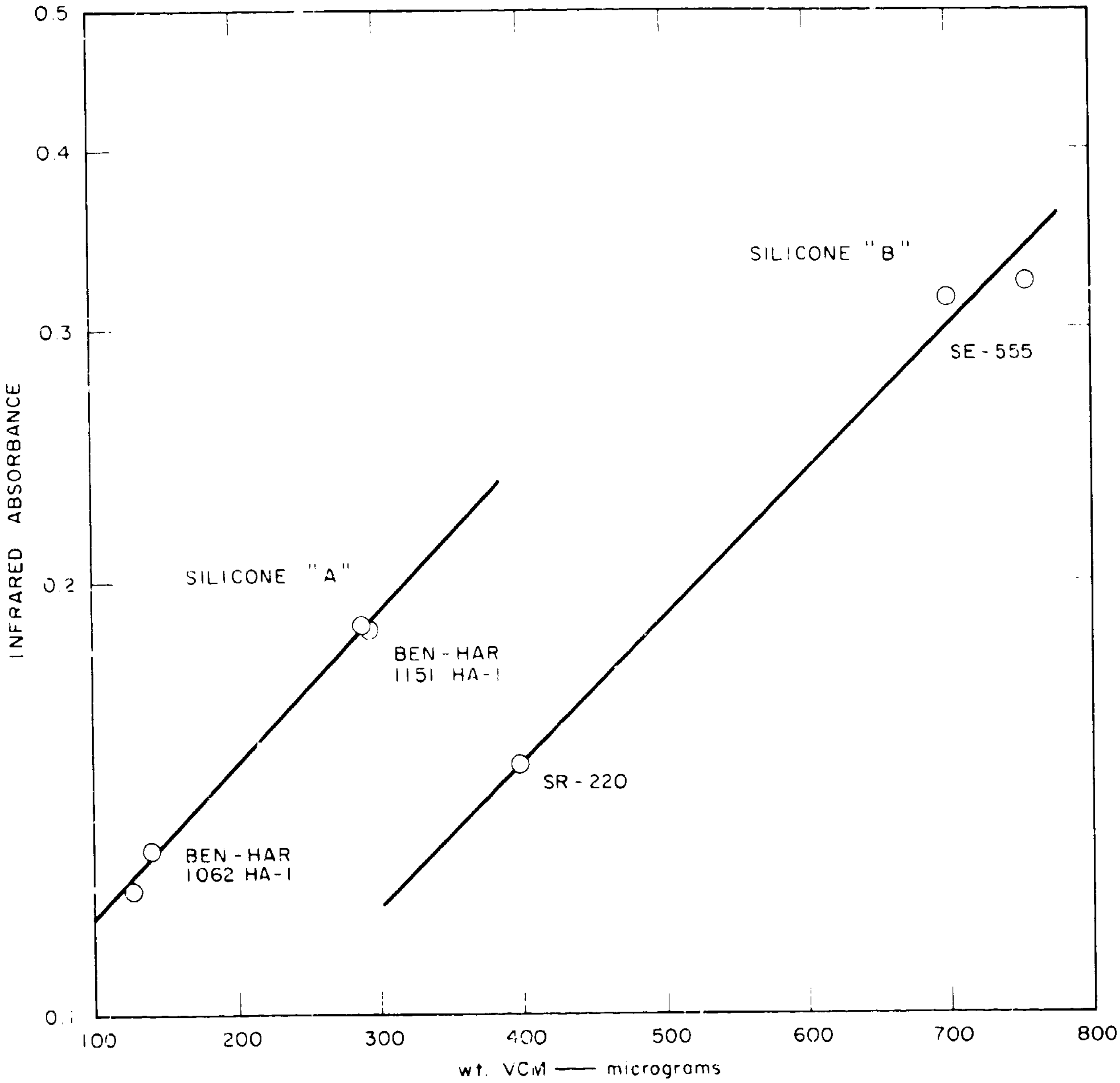


FIG. 11 INFRARED ABSORBANCE AT 7.95 μ vs WEIGHT OF VCM FROM TWO DIFFERENT TYPES OF SILICONE EFFLUENTS (Preliminary Data)

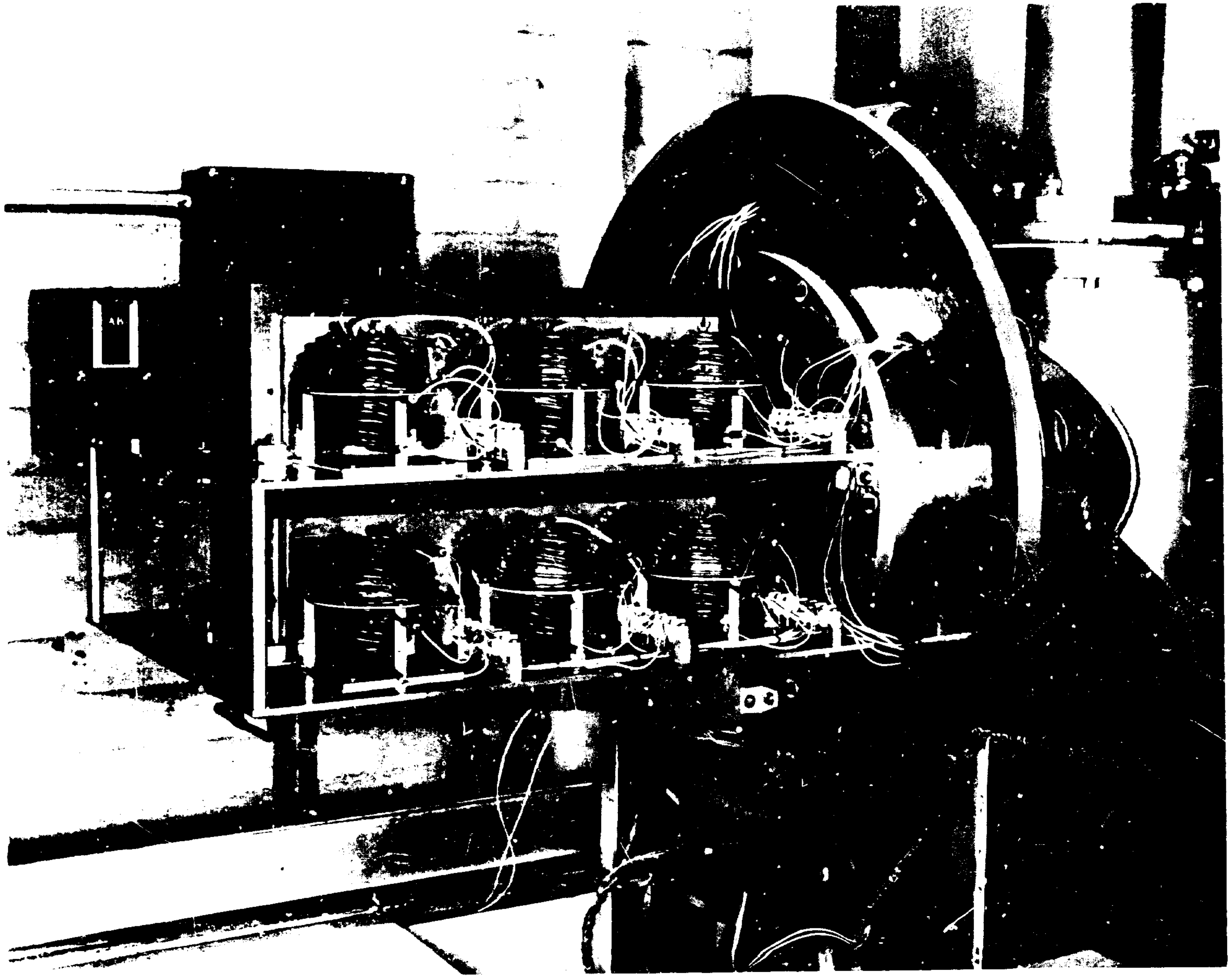


FIG. 12 ASSEMBLY OF MACRO-VCM SAMPLE CELLS WITHIN THE VACUUM CHAMBER

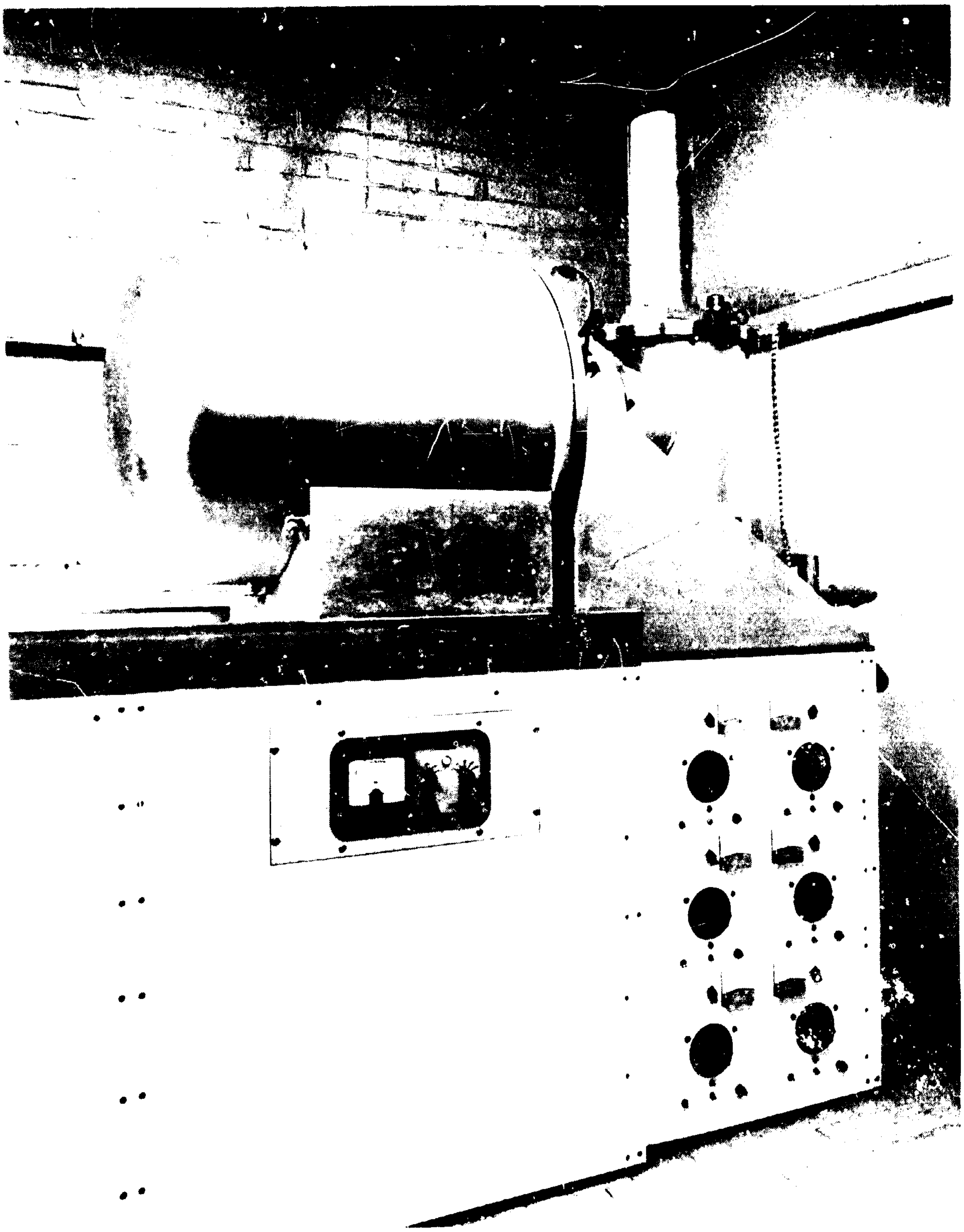


FIG. 13 PHOTOGRAPH OF THE TOTAL VACUUM ASSEMBLY FOR MAKING MACRO-VCM DETERMINATIONS

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IV. EQUIPMENT AND PROCEDURES FOR COMPREHENSIVE TESTS (PHYSICAL, MECHANICAL, ELECTRICAL PROPERTIES)

The importance of screening polymeric products for volatile and volatile condensable materials has been emphasized in the first few sections of this report and suggestions have been made that there is a relationship between the loss of volatile material and the ultimate mechanical properties a polymer will have after prolonged exposure to a thermal-vacuum environment. Thus, it was necessary in this program to measure the changes in mechanical and electrical properties which occur when polymeric products are exposed to a thermal-vacuum environment because spacecrafts must perform reliably for periods of months, and eventually for periods of years. (Long-term storage tests in the thermal-vacuum environment will be discussed later in this report.) More importantly, however, since the polymeric materials examined under this contract are intended for use in the sterile unmanned spacecrafts which may be used for landing on distant planets to search for life forms, the effects of decontaminating and sterilizing treatments on polymers also had to be measured. It is obvious then, that polymers which qualify for use in unmanned spacecraft must be able to retain their properties through decontamination and sterilization cycles and continue to maintain these properties when subsequently exposed to the thermal-vacuum environment of space flight.

Several studies have been made (not at SRI) of the effects on polymeric products of (1) decontamination cycles only (humidified ethylene oxide-Freon at 50°C); (2) sterilization cycles only (nitrogen atmosphere at 135°C); or (3) decontamination cycles followed by sterilization cycles. The results of these studies unfortunately can not be combined to determine whether a polymeric material can successfully withstand sterilization and then resist a thermal-vacuum environment. A comprehensive program was initiated at SRI to provide data on (1) the effects of decontamination cycles, (2) the effects of a thermal-vacuum environment, and (3) the effects of successive exposures to decontamination cycles and a thermal-vacuum environment:

(1) Decontamination. Six 30-hr cycles of humidified ethylene oxide-Freon-12 at 50°C;

(2) Thermal-vacuum environment only. Three weeks (500 hr) of exposure at 135°C and 10^{-6} torr;

(3) Decontamination cycles plus thermal-vacuum exposure.

Equipment

A multiple-cell test unit was designed to accommodate 30 sample cells, each of which could contain several configurations of a single polymeric material according to the subsequent physical/mechanical property tests to be performed (see Figure 14), and each of which was isolated from its neighbor so that all possibilities of cross-contamination are eliminated. The system was so designed that the materials could be exposed at atmospheric pressure to decontamination cycles and subsequently exposed, in the same sample cells, to a thermal-vacuum environment.

The primary manifold (responsive to the 30 cell-units) leads via a 6-inch duct to the vacuum system which includes a fore-pump, a 6-inch diffusion pump, water-cooled chevron baffle, and a gate valve. The valve is used to isolate the vacuum system when the upper assembly is being used for pressurized exposures. The test unit includes two electrically-heated ovens; circulation is prompted by a blower-duct system.

Complete design drawings for this unit are given in Interim Report No. 3, Part II, December 1966, under this contract.

Operation Procedure

(1) Each sample material is prepared in suitable sizes and shapes according to the tests to be performed. Where possible, a single specimen is used for more than one test (e.g., weight-loss and dimensional change). The test specimens are either suspended in the sample cell (see Figure 14) or laid flat on a wide-mesh screen. It is to be noted that only one polymeric product is contained in each cell.

(2) The sample cells are sealed in place in the oven chamber which is brought to 50°C within one hour. The cells are then evacuated

to about 10^{-3} torr and water vapor at 50°C is introduced through heated valving systems to provide a relative humidity of about 50%. The decontaminating agent (12:88 ethylene oxide:Freon-12, Matheson Company) is passed through a heat exchanger which brings it to 50°C and into the sample cells to provide an atmosphere of 455 mg/liter ETO.

After a 28-hr period of 50°C in the humidified ETO atmosphere, the system is cooled to room temperature within one hour. During this period, the cells are evacuated for 10 minutes and vented to the atmosphere; evacuation and venting is repeated twice more to ensure complete flushing.

Six 30-hr cycles, as described above, complete the decontamination treatment.

(3) Samples to be tested only for the effects of the decontamination treatment are withdrawn, and fresh samples are put in their place for tests of the effects of the thermal-vacuum exposure only. Other samples are left in place for final tests of the effects of the decontamination treatment followed by a thermal-vacuum treatment.

(4) The cells are then evacuated to 10^{-6} torr while the oven temperatures are raised to 135°C. The samples are maintained in this thermal-vacuum environment for 500 hours. At the end of this period, the ovens are cooled to room temperature and the cells are vented to the atmosphere. The samples are all removed for final testing.

Test Procedures

Note: Duplicate samples of 1" x 6" were used for dimensional change, change in weight, and change in hardness.

(1) Dimensional change

The distance between bench marks on samples was measured to within ±0.001 inch with vernier calipers with an accuracy considered to be ±0.001 inch. The bench marks were located from 5.0-5.5 inches apart. The change in length is expressed as per cent of initial length.

(2) Change in weight

Samples were weighed either on an analytical balance or a micro-balance as required by the initial weight of the sample. The change in weight is expressed as percent of initial weight.

(3) Hardness

The hardness of structural materials was measured with a Wilson "Rockwell" Hardness Tester according to ASTM D785-62, using a 0.500-in. ball with a 60-kg load.

The hardness of seal and gasket materials was measured with a Shore Durometer Type A-2 according to ASTM D2240-64T, using a 1-kg weight; readings were made within one second after application of the load.

An average of 5 determinations was made for each sample. Results are reported as Rockwell or Shore numbers.

(4) Tensile and Elongation

The tensile and elongation measurements were made at about 70°F using an Instron Model TTCLM-6.

Duplicate test specimens of film and sheet materials were cut with an ASTM die D: the speed of testing was 1.00 in/min.

Test specimens of structural materials were prepared and tested according to ASTM D638-64T. Duplicate type III test specimens were machined for each sample; the speed of testing was 0.05 in/min.

Tensile specimens of seal and gasket material were cut from 6" x 6" x 1/16" cured stock by an ASTM die C.

A modified method, employing a scaled-down die, was used for testing many of the seal and gasket materials in order to ensure sufficiency of specimens for the entire test program. The test specimens had a gage length of 1.000 inch and a width of 0.125 inch. Triplicate determinations were made on each sample at a testing speed of 1.00 in/min.

Duplicate specimens of tie cord (lacing tape) materials were tested according to ASTM D638-64T at a testing speed of 1.00 in/min. They were cut 8" long from the spools and used as received.

(5) Dielectric Constant and Dissipation Factor

Dielectric constant and dissipation factor measurements were made according to ASTM D150-64T. The test equipment consisted of a General Radio R-F bridge Type 916A, a Hewlett-Packard signal generator Model 606A, and a Hallicrafter SX71 radio-receiver in conjunction with a General Radio tuned amplifier and null detector Type 1232A.

Dielectric specimens 1.000 inch in diameter were machined from the structural materials. The measurements performed on these samples were made using a micrometer electrode system (General Radio "Dielectric Sample Holder," Type 1690A).

Specimens of protective coating material were first cured in flat sheet 1/16" thick and then die-cut to 2.000" diameter. Specimens of sealant material were cast in aluminum molds 2.000" in diameter and 1/8" thick.

The dielectric specimens of film and sheet materials were die-cut at 1.000 inch in diameter. The electrodes were made from aluminum foil 0.7 mil thick by 0.950 inch in diameter. Silicone oil was used to increase the contact between the foil and the test specimen. The specimen and electrodes were then placed between a stiff wire connector for two-terminal measurement as shown in Figure 15.

It is to be noted that the majority of the samples tested were of a thickness of 2 mils or less; since the silicone oil was in series with the test specimen, it could cause the measured dielectric constant to be too low and the dissipation factor to be too high, which seems apparent. With this in mind, the data for film and sheet materials should be examined only from the point of view of comparison between control and test specimens and not as an absolute measurement of either dielectric constant or dissipation factor.

(6) Compression Set

Compression set measurements were made in accordance with ASTM D-395, Method B (constant deflection).

Aluminum molds were fabricated for casting and curing samples for compression-set measurements. The compression-set test-blocks were designed and fabricated to fit the sample cells; the flat plates of the test-blocks were made from stainless steel and the bolts and spacers from Invar. Taking into account the relative thermal expansion coefficients between Invar and stainless steel 304 (0.8×10^{-6} vs 9.6×10^{-6}), there should be little if any detectable change of the initial compressive pressure. Compression of 25% was applied to samples of 1/2" thickness.

(7) Compressive Strength

Compressive strength measurements were made according to ASTM D-1621; the rate of compression was 0.1 in/min.

Test specimens of foam material were cut with a rotating die which had a diameter of 2.250". Sealant material was cast in 2.250"-diameter molds at a thickness of 1.000 in.

(8) Adhesion Shear

Aluminum strips 1" x 4" x 1/16" with a hole drilled 1/4" from one end were prepared from grade 2024-T3 (unclad) aluminum. The strips were cleaned by sandblasting, de-greased with acetone, and then immersed in an aqueous solution of Altrex (6-8 oz/gal) at about 80°C for 8-12 minutes. They were then rinsed with de-ionized water and oven-dried at 70°C. All applications of adhesive or protective coatings to the test strips were made within 8 hours of the cleaning process.

The adhesives and protective coatings to be tested were applied to a ruled area measuring 1.0" x 0.5" at the end of each aluminum strip, opposite the hole used for suspending test specimens in the various environments. The strips were then mated and a load of 25 psi was applied, in most instances, and the samples were cured as indicated in the appropriate tables.

Control and exposed specimens were pulled with a crosshead speed of 0.05"/min, using an Instron Model TTCLM-6. The temperature of the test specimens was 70°F during all testing.

(9) T-Peel Test

T-peel test specimens were prepared from 23"-lengths of tape and thermal insulation material. They were folded in such a manner as to bring the adhesive-coated sides of the tape in contact with each other and give 6" of test area in which to measure the peel resistance (see Figure 16). After folding the specimens, they were rolled with a 1/2-in diameter roller.

The tab ends (Figure 16) of the test specimens were clamped in the grips of the tension testing machine and pulled with a crosshead speed of 1.00 in/min.

Note: This crosshead speed will cause separation of the bond area at a rate of 0.50 in/min.

From the load curves, recorded on the Instron, the average peeling load for the first 5 inches of peeling after the initial peak was determined and reported in lb/in width. All measurements were made at 70°F.

(10) Adhesive Creep

The adhesives were tested <u>in situ</u> for creep under a load of 1000 psi. Aluminum and stainless steel fixtures, fitted with compression springs rated at 650 pounds were designed to hold the test specimens in shear throughout the exposure periods. Design drawings for these fixtures are given in the supplement to this section.

Over-sized shear plates were cut from 2024-T3 (unclad) aluminum (0.063-in thick). After being sandblasted on each side, the edges of the plates were machined to 1.000 ± 0.001 × 1.750 ± 0.001 inches and cleaned as described in Adhesion Shear (8) All applications of adhesives to shear plates were made within 8 hours of the cleaning process. Each of the [illegible] was applied to the lower half-inch of one shear plate and the other plate was put in place, taking care not to entrap air in the bond area. After the specimens were cured, one edge of the bonded plates was polished with 600 wet-or-dry paper, and a line was scribed perpendicular to the glue-line with a razor blade.

The test specimens were then placed in the creep fixtures and the springs compressed, using an Instron Model TTCIM-G. The loads were measured and each spring was set to give a load of 500 ± 5 pounds. Since each test specimen had a bond area of 0.5 in^2, the resulting shear load was 1000 psi.

Creep measurements were made to ±0.005 mm during the exposure of the specimens in the various environments, using a Gaertner cathetometer to view the scribed lines on the test specimens.

(11) Breaking Strength

The breaking strength of coated fabrics was determined using ASTM D751-64T, Method B, with specimens of 2" × 6". The values reported represent the average for specimens pulled in both warp and weft directions of the materials; these directions of weave were not identified easily, and insufficient sample was available for adequate testing in both directions.

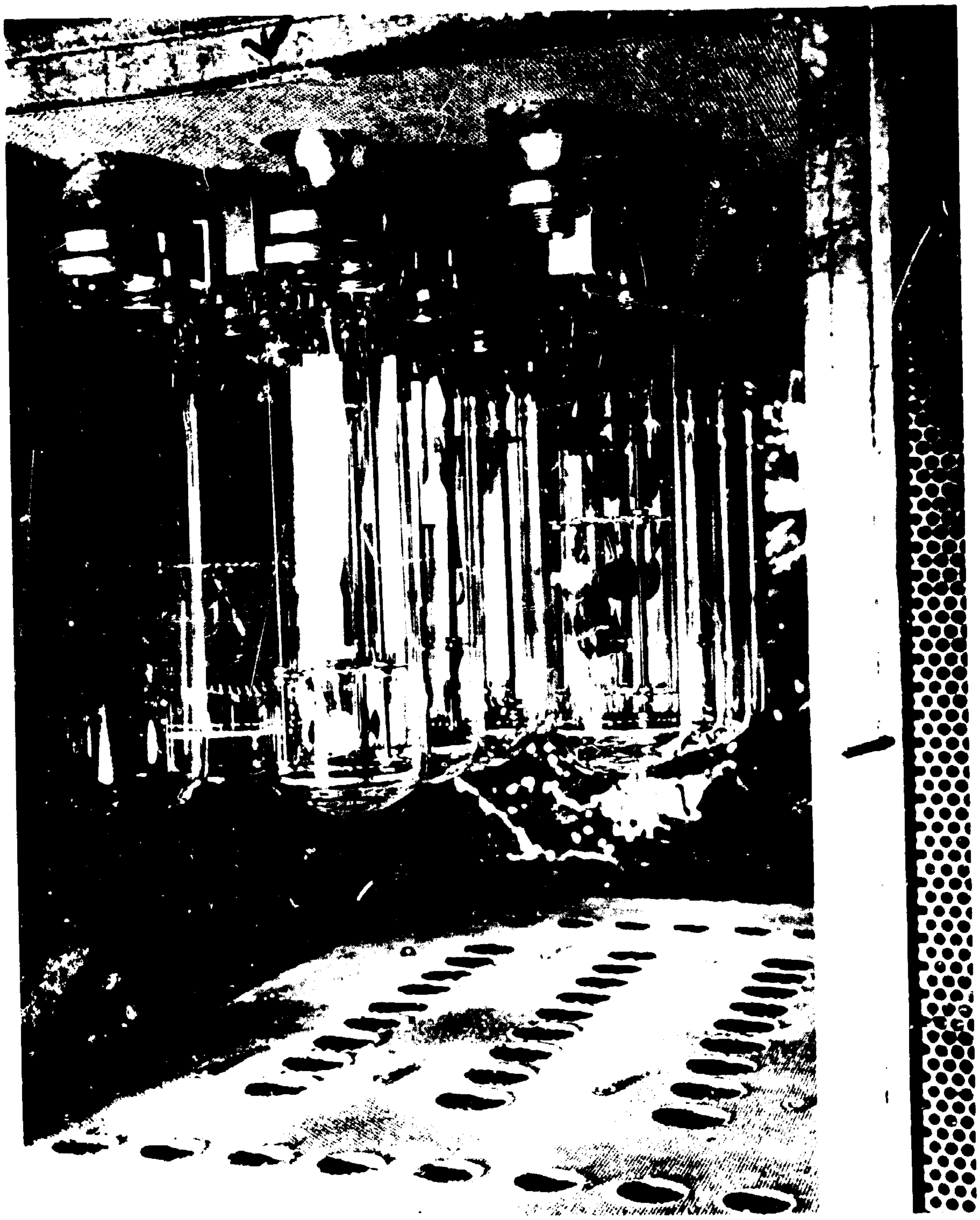

FIG. 14 VIEW OF MULTIPLE-CELL TEST UNIT SHOWING THE LOCATION OF SAMPLES IN THE TEST CELLS

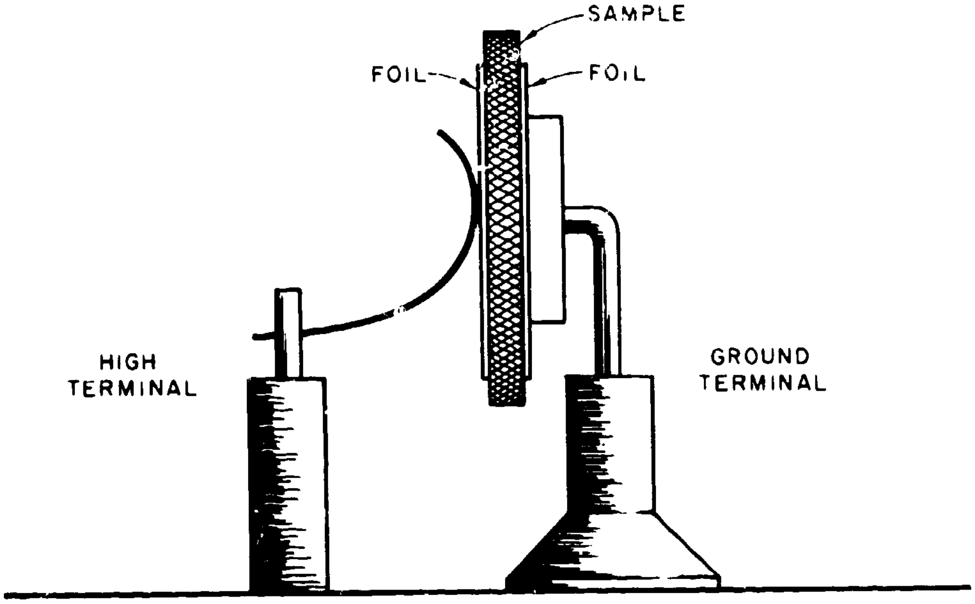

FIG. 15 STIFF WIRE CONNECTOR FOR TWO-TERMINAL MEASUREMENTS OF DIELECTRIC CONSTANT

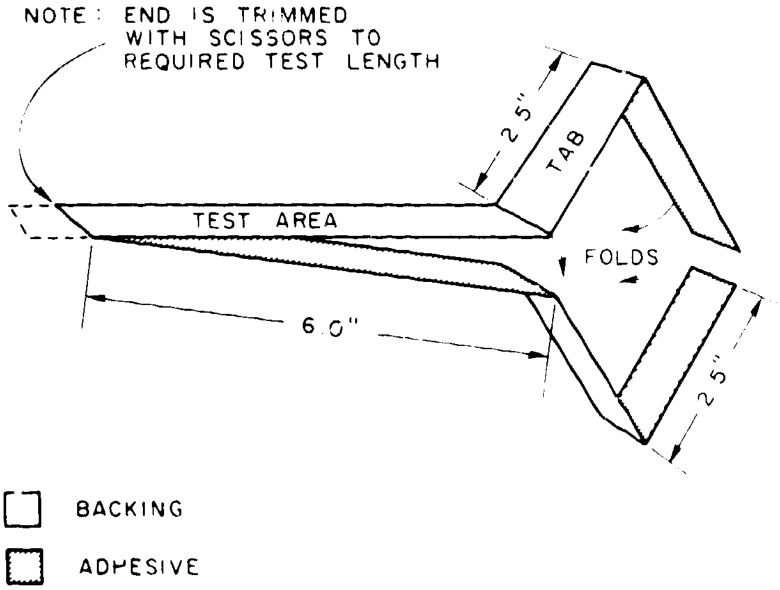

FIG. 16 METHOD OF FOLDING TAPE AND INSULATION MATERIAL FOR T-PEEL TESTING

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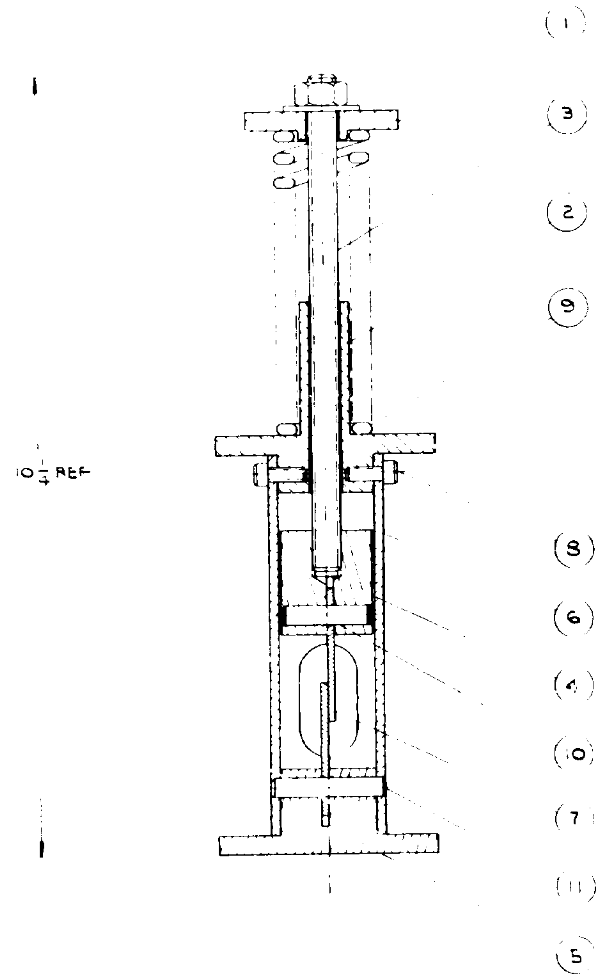
IV. SUPPLEMENT

DESIGN DRAWINGS FOR ADHESIVE CREEP TESTER

C5046-82	CREEP TESTING TUBE (SAMPLE TEST FIXTURE)	
	A5046-83	Spring Retainer - upper
	A5046-84	Spring Retainer - lower
	A5046-85	Stud
	A5046-86	Blade Retainer - upper
	A5046-87	Blade Retainer - lower
	A5046-88	Tube
	A5046-89	Blade

NOTES

1. REMOVE ALL BURRS AND BREAK SHARP EDGES APPROX .010R
2. GENERAL FINISH ▽ EXCEPT AS NOTED
3. DECO MH-41 (M R SUPPLY CO
107 McCLURE AVE SAN CARLOS, CALIF.
1/4 OD x 5/8 ID FREE LENGTH 4 in.
600 LB @ 37% COMP.



ITEM	DWG NUMBER	DESCRIPTION	QTY
11	COM. ITEM	DOWEL PIN 1/4 DIA X 1 1/2 LG	1
10	" "	DOWEL PIN 1/4 DIA X 1 3/16 LG	1
9	" "	COMP. SPRING (3)	1
8	" "	SOCKET HD SCR #10-32 X 1/2 LG	2
7	A5046-89	BLADE	2
6	A5046-88	TUBE	1
5	A5046-87	BLADE RETAINER - LOWER	1
4	A5046-86	BLADE RETAINER - UPPER	1
3	A5046-85	STUD	1
2	A5046-84	SPRING RETAINER - LOWER	1
1	A5046-83	SPRING RETAINER - UPPER	1

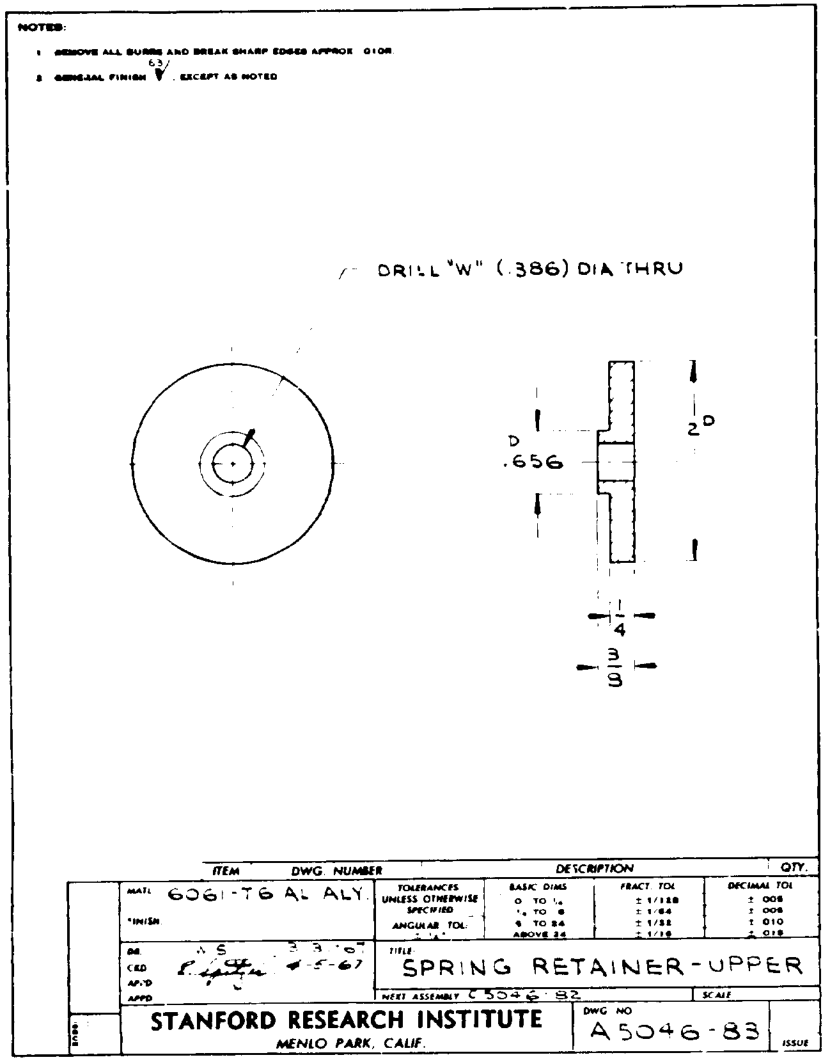
TOLERANCES UNLESS OTHERWISE SPECIFIED	BASIC DIMS	FRACT TOL	DECIMAL TOL
ANGULAR TOL	0 TO 1/4	± 1/128	± .003
	1/4 TO 6	± 1/64	± .005
	6 TO 24	± 1/32	± .010
	ABOVE 24	± 1/16	± .015

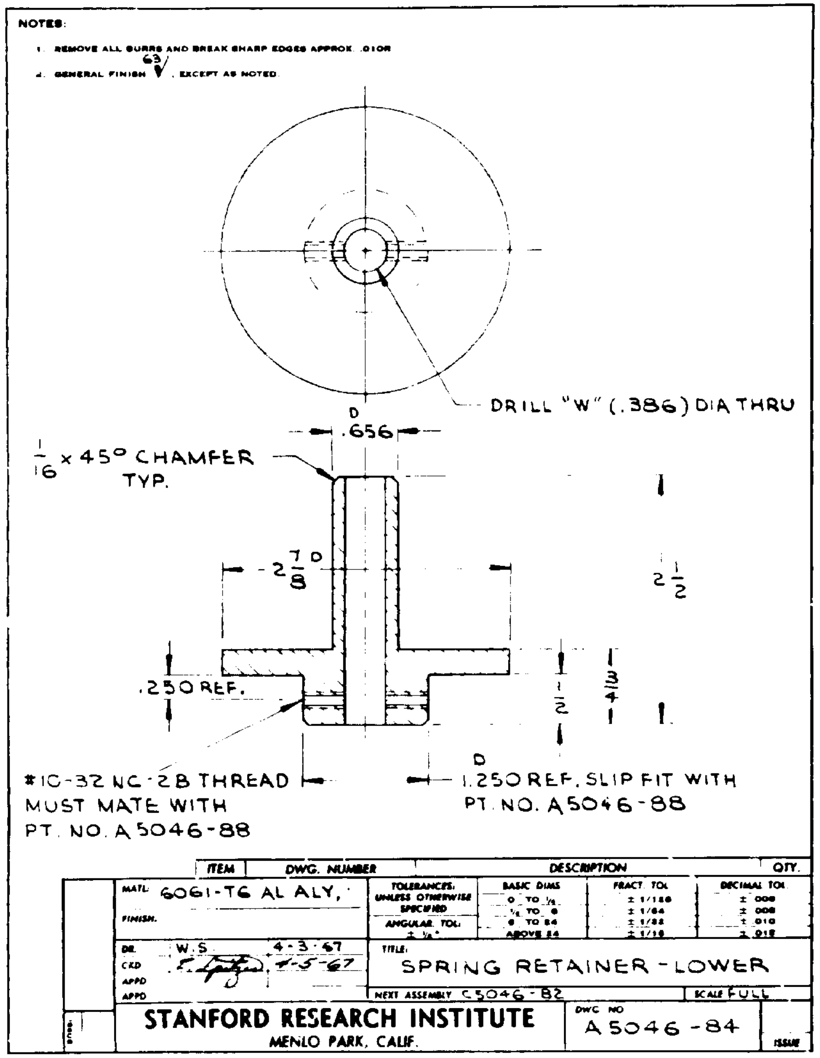
MATL —
FINISH
DR W S 3-5-67
CKD 3-3-67
APPD
APPD

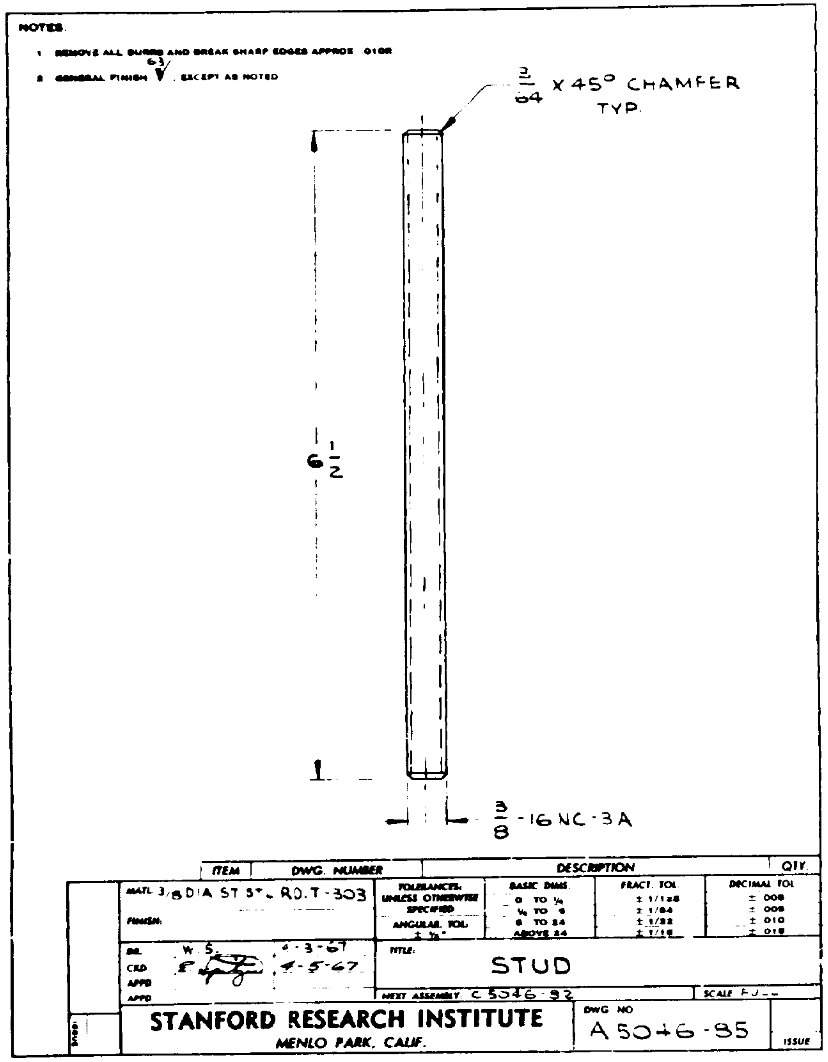
TITLE CREEP TESTING TUBE
NEXT ASSEMBLY
SCALE FULL

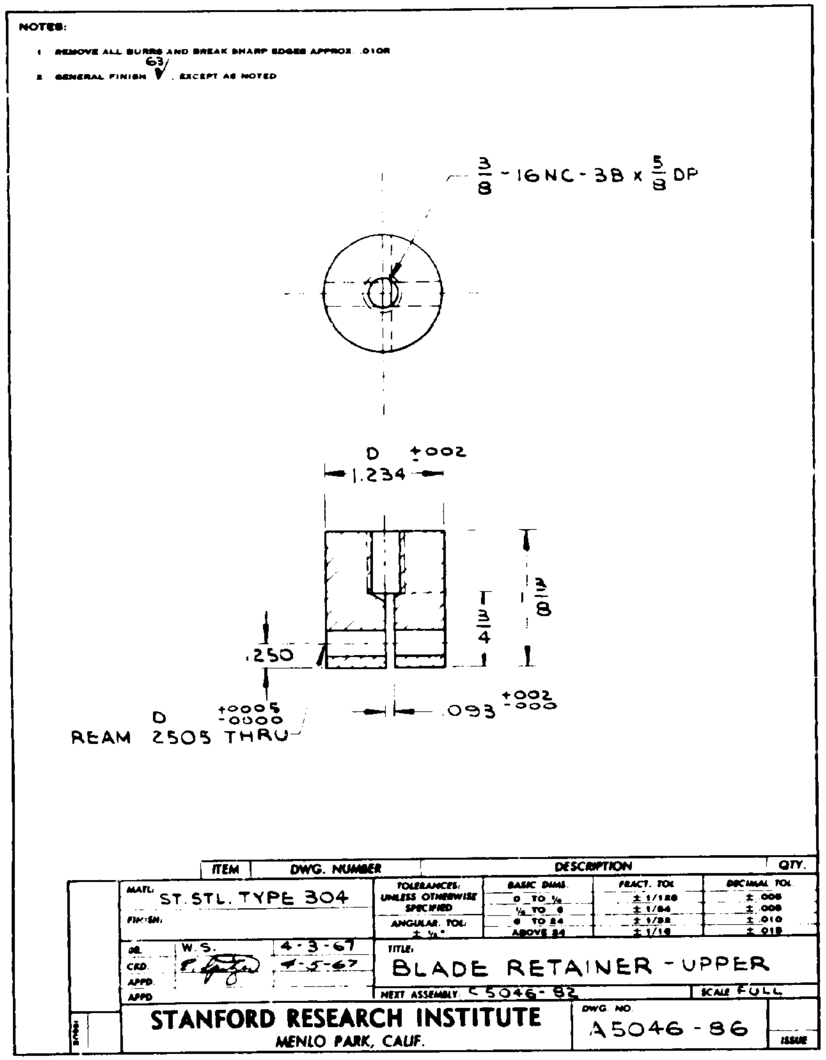
STANFORD RESEARCH INSTITUTE
MENLO PARK, CALIF

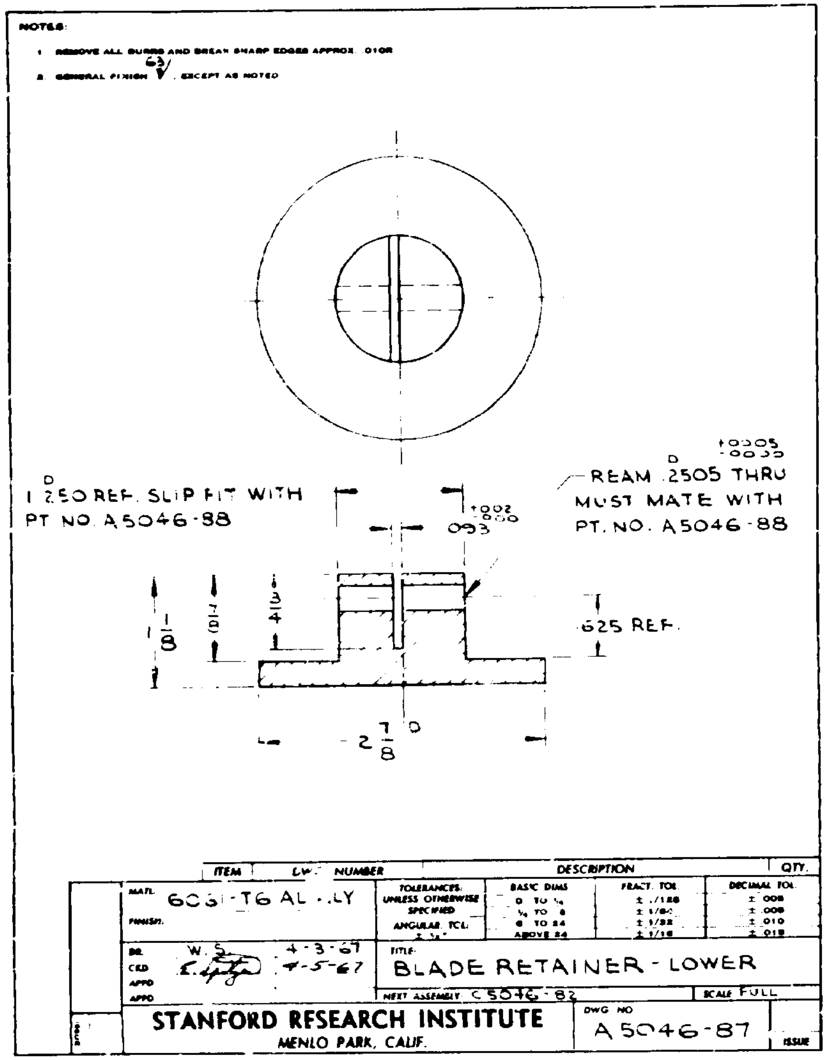
DWG NO C5046-82
ISSUE

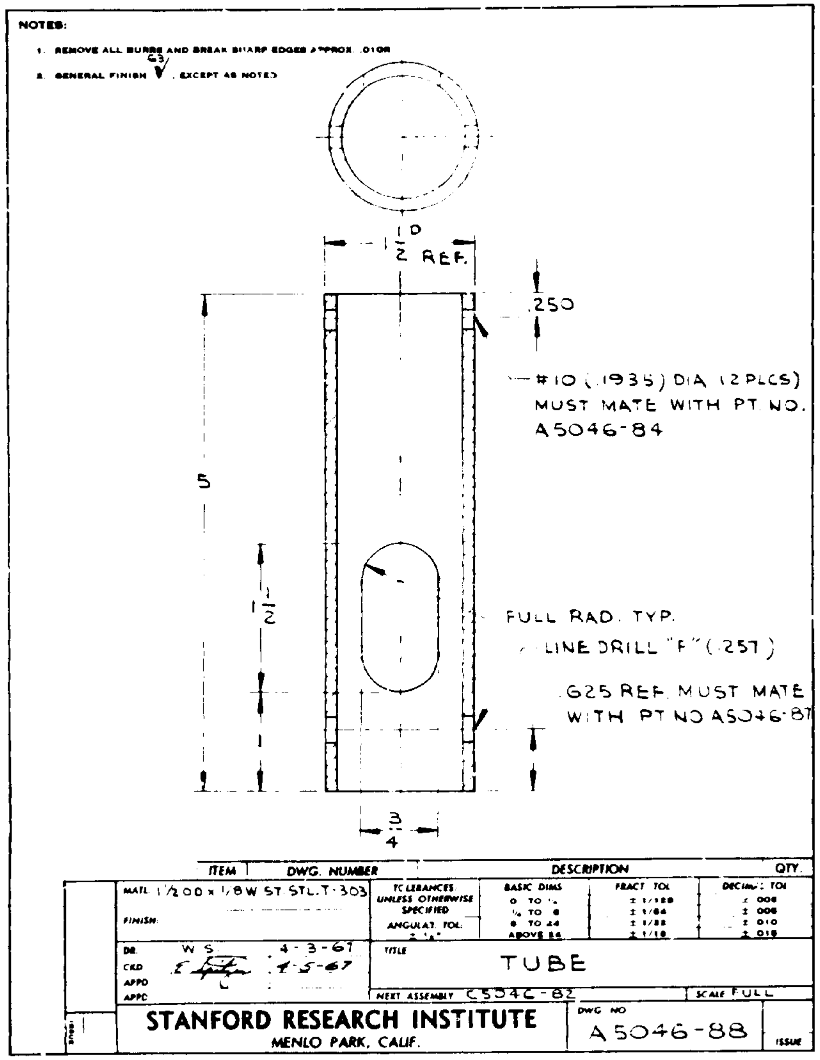

NOTES:
1. REMOVE ALL BURRS AND BREAK SHARP EDGES APPROX .010R
2. GENERAL FINISH 63∨, EXCEPT AS NOTED
DRILL "W" (.386) DIA THRU
D .656
2 D
1/4
3/8
ITEM
DWG NUMBER
DESCRIPTION
QTY.
MAT'L 6061-T6 AL ALY
FINISH
TOLERANCES UNLESS OTHERWISE SPECIFIED
ANGULAR TOL
BASIC DIMS
0 TO 1/4
1/4 TO 6
6 TO 24
ABOVE 24
FRACT TOL
± 1/128
± 1/64
± 1/32
± 1/16
DECIMAL TOL
± .005
± .008
± .010
± .015
DR. W.S 3-3-67
CKD 4-5-67
APPD
APPD
TITLE SPRING RETAINER-UPPER
NEXT ASSEMBLY C5046-82
SCALE
STANFORD RESEARCH INSTITUTE
MENLO PARK, CALIF.
DWG NO A5046-83
ISSUE

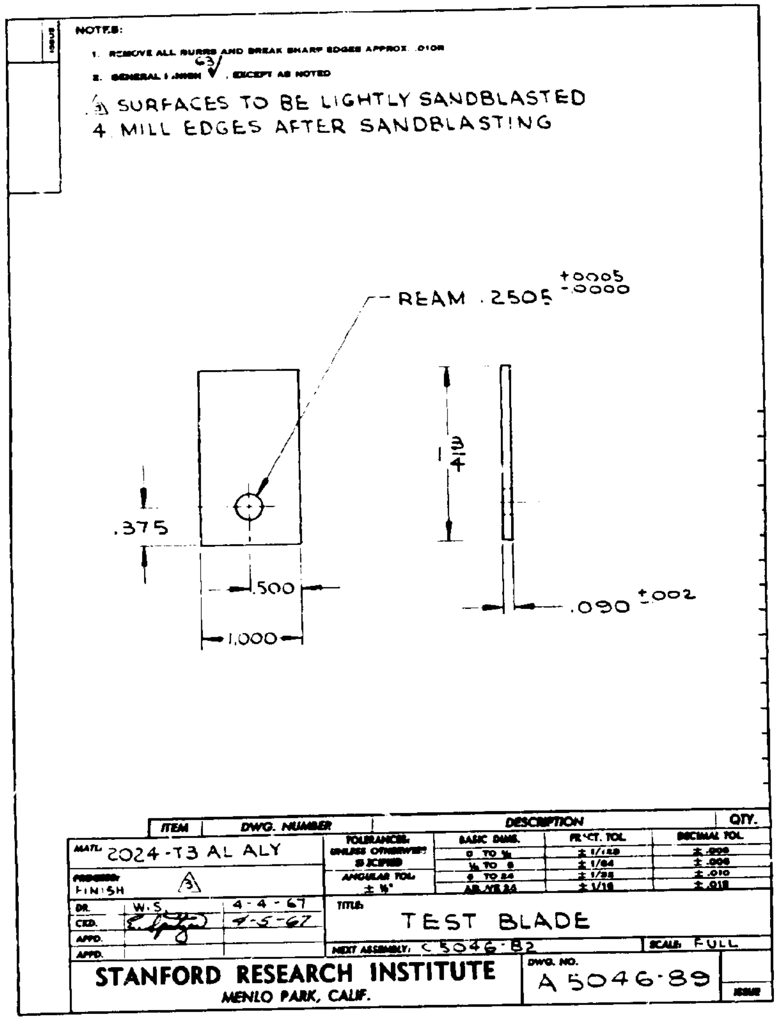

NOTES:
1. REMOVE ALL BURRS AND BREAK SHARP EDGES APPROX .010R
2. GENERAL FINISH 63∨, EXCEPT AS NOTED
DRILL "W" (.386) DIA THRU
D .656
1/16 x 45° CHAMFER TYP.
2 7/8 D
2 1/2
.250 REF.
1/2
3/4
#10-32 NC-2B THREAD MUST MATE WITH PT. NO. A5046-88
D 1.250 REF. SLIP FIT WITH PT. NO. A5046-88
ITEM
DWG. NUMBER
DESCRIPTION
QTY.
MAT'L 6061-T6 AL ALY.
FINISH.
TOLERANCES, UNLESS OTHERWISE SPECIFIED
ANGULAR TOL. ± 1/2°
BASIC DIMS
0 TO 1/4
1/4 TO 6
6 TO 24
ABOVE 24
FRACT TOL
± 1/128
± 1/64
± 1/32
± 1/16
DECIMAL TOL
± .005
± .008
± .010
± .015
DR. W.S 4-3-67
CKD 4-5-67
APPD
APPD
TITLE: SPRING RETAINER-LOWER
NEXT ASSEMBLY C5046-82
SCALE FULL
STANFORD RESEARCH INSTITUTE
MENLO PARK, CALIF.
DWG NO A5046-84
ISSUE


NOTES.
1 REMOVE ALL BURRS AND BREAK SHARP EDGES APPROX .010R.
2 GENERAL FINISH 63√, EXCEPT AS NOTED
3/64 X 45° CHAMFER TYP.
6 1/2
3/8-16NC-3A
ITEM
DWG. NUMBER
DESCRIPTION
QTY.
MATL 3/8 DIA ST ST'L RD. T-303
FINISH
TOLERANCES: UNLESS OTHERWISE SPECIFIED
ANGULAR TOL ± ½°
BASIC DIMS: 0 TO ½, ½ TO 6, 6 TO 24, ABOVE 24
FRACT. TOL: ± 1/128, ± 1/64, ± 1/32, ± 1/16
DECIMAL TOL: ± .005, ± .005, ± .010, ± .015
DR. W.S. 4-3-67
CKD 4-5-67
APPD
APPD
TITLE: STUD
NEXT ASSEMBLY C 5046-82
SCALE FULL
STANFORD RESEARCH INSTITUTE
MENLO PARK, CALIF.
DWG NO A 5046-85
ISSUE


NOTES:
1 REMOVE ALL BURRS AND BREAK SHARP EDGES APPROX .010R.
2 GENERAL FINISH 63√, EXCEPT AS NOTED
3/8-16NC-3B x 5/8 DP
D 1.234 ±.002
1 3/8
3/4
.250
D REAM .2505 +.0005 -.0000 THRU
.093 +.002 -.000
ITEM
DWG. NUMBER
DESCRIPTION
QTY.
MATL. ST. STL. TYPE 304
FINISH
TOLERANCES: UNLESS OTHERWISE SPECIFIED
ANGULAR TOL ± ½°
BASIC DIMS: 0 TO ½, ½ TO 6, 6 TO 24, ABOVE 24
FRACT. TOL: ± 1/128, ± 1/64, ± 1/32, ± 1/16
DECIMAL TOL: ± .005, ± .005, ± .010, ± .015
DR. W.S. 4-3-67
CKD 4-5-67
APPD
APPD
TITLE: BLADE RETAINER - UPPER
NEXT ASSEMBLY C 5046-82
SCALE FULL
STANFORD RESEARCH INSTITUTE
MENLO PARK, CALIF.
DWG NO A5046-86
ISSUE


NOTES:
1. REMOVE ALL BURRS AND BREAK SHARP EDGES APPROX .010R
2. GENERAL FINISH 63 √, EXCEPT AS NOTED
1.250 REF. SLIP FIT WITH PT NO. A5046-88
REAM .2505 +.0005 -.0000 THRU MUST MATE WITH PT. NO. A5046-88
.093 +.002 -.000
3/4
7/16
1 1/8
.625 REF.
2 7/8 D
ITEM
DWG. NUMBER
DESCRIPTION
QTY.
MATL 6061-T6 AL ALLY
FINISH
TOLERANCES UNLESS OTHERWISE SPECIFIED
ANGULAR TOL. ± 1/2°
BASIC DIMS 0 TO 1/4, 1/4 TO 6, 6 TO 24, ABOVE 24
FRACT. TOL ±1/128, ±1/64, ±1/32, ±1/16
DECIMAL TOL ±.005, ±.008, ±.010, ±.015
DR. W.S. 4-3-67
CKD 4-5-67
APPD
APPD
TITLE BLADE RETAINER - LOWER
NEXT ASSEMBLY C5046-82
SCALE FULL
STANFORD RESEARCH INSTITUTE
MENLO PARK, CALIF.
DWG NO A5046-87
ISSUE


NOTES:
1. REMOVE ALL BURRS AND BREAK SHARP EDGES APPROX .010R
2. GENERAL FINISH 63 √, EXCEPT AS NOTED
1 1/2 D REF.
.250
#10 (.1935) DIA (2 PLCS) MUST MATE WITH PT. NO. A5046-84
5
1 1/2
FULL RAD. TYP.
LINE DRILL "F" (.257)
.625 REF. MUST MATE WITH PT NO A5046-87
3/4
ITEM
DWG. NUMBER
DESCRIPTION
QTY.
MATL 1 1/2 OD x 1/8 W ST. STL. T-303
FINISH
TOLERANCES UNLESS OTHERWISE SPECIFIED
ANGULAR TOL. ± 1/2°
BASIC DIMS 0 TO 1/4, 1/4 TO 6, 6 TO 24, ABOVE 24
FRACT. TOL ±1/128, ±1/64, ±1/32, ±1/16
DECIMAL TOL ±.005, ±.008, ±.010, ±.015
DR. W.S. 4-3-67
CKD 4-5-67
APPD
APPD
TITLE TUBE
NEXT ASSEMBLY C5046-82
SCALE FULL
STANFORD RESEARCH INSTITUTE
MENLO PARK, CALIF.
DWG NO A5046-88
ISSUE


NOTES:
1. REMOVE ALL BURRS AND BREAK SHARP EDGES APPROX. .010R
2. GENERAL FINISH 63√, EXCEPT AS NOTED
3 SURFACES TO BE LIGHTLY SANDBLASTED
4 MILL EDGES AFTER SANDBLASTING
REAM .2505 +.0005 -.0000
.375
.500
1.000
1 3/4
.090 ±.002
ITEM
DWG. NUMBER
DESCRIPTION
QTY.
MATL. 2024-T3 AL ALY
FINISH 3
TOLERANCES: UNLESS OTHERWISE SPECIFIED
ANGULAR TOL. ± 1/2°
BASIC DIMS.
FRACT. TOL.
DECIMAL TOL.
0 TO 1/2 ± 1/128 ±.005
1/2 TO 6 ± 1/64 ±.005
6 TO 24 ± 1/32 ±.010
ABOVE 24 ± 1/16 ±.015
DR. W.S. 4-4-67
CKD. 4-5-67
APPD.
APPD.
TITLE: TEST BLADE
NEXT ASSEMBLY: C 5046-82
SCALE: FULL
STANFORD RESEARCH INSTITUTE
MENLO PARK, CALIF.
DWG. NO. A 5046-89
ISSUE

V. ADHESIVES (AD)

More than 40 adhesives have been screened by the micro-VCM technique for total weight loss and maximum VCM content. As shown by the data given in Table 7, about 15 of these are suitable candidates for further evaluation--all of them epoxy-based; the polyesters and silicones are not acceptable. Whether the VCM results from the cleavage of polymeric structures or is due simply to incompletely polymerized fractions of the products cannot be ascertained from the VCM data. On the other hand, the infrared spectra of the VCM of a number of the adhesives are given in Appendix C and indicate that low-molecular-weight epoxies (e.g., Eccobond 45/15, EC-2216) or polyamides (e.g., Epibond-115, Scotchcast AF-126) are released in the thermal-vacuum environment and condense to furnish the offending VCM. The mass spectrum of the substances volatilizing in vacuum at 125°C from FM-1000 was intense, indicating generous release of low-molecular-weight epoxies, and confirmation of micro-VCM disqualification. Since so many adhesives immediately pass micro-VCM screening, it is not necessary to give further consideration to marginal or inferior materials.

A number of the adhesives were examined for changes in mechanical properties after exposures to decontamination cycles and the thermal-vacuum environment. As shown in Tables 10, 11, and 12, Adhesive 46951 lost half its shear strength after ETO exposure and failed completely in the thermal-vacuum environment. Little difference is noted after any exposure for Adhesive 4684, but weight loss is excessive. Of the epoxy paste adhesives tested only for shear strength, all show satisfactory performance with apparent increased strength after exposure to the thermal-vacuum environment; these can be suggested for use under no-load conditions. The paste adhesives which failed the tests for creep under load were those which had excessive VCM contents, except for the Epon 901/B-3 which perhaps is not compounded for use under load.

The only film adhesive which failed under load was FM-61, which had an excessive VCM content (probably low-mol-wt nylons). The excellent thermal-vacuum performance of the other film adhesives was indicated by the good VCM data; not predictable, of course, was the deleterious effect of the ETO cycles and subsequent TVE exposure on Metlbond-329.

Table 7

MICRO-VCM DETERMINATIONS: ADHESIVES

(24 hours at 125°C and 10^{-6} torr)
(VCM collectors at 25°C)

MATERIAL[1]	MFR.[2]	TREATMENT	TOTAL WT. LOSS, %	VCM, WT-%
Epoxy				
Armstrong A-2 A	APC	100pA-2 4pA; 45 min 74°C + 45 min 93°C	0.17	0.03
Armstrong A-2 E	APC	100pA-2 6pE; 45 min 93°C	0.26	0.03
Armstrong A-12 A	APC	JPL sample; cured 2 hr 85°C	0.85	0.03
Armstrong A-12 A	APC	JPL sample; cured 2 hr 85° + 48 hr 125°C and 10^{-5} torr	0.62	0.02
Armstrong A-32 A B	APC	100pA 60pB; 24 hr 25°C	3.14	0.24
EC-1614 A B	MMA	100pA 100pB; 1-1 2 hr 65°C	2.03	0.66
EC-2216 A B	MMA	140pA 100pB; 2 hr 65°C	0.82	0.06
EC-2216 A B	MMA	150pA 100pB; 8 hr 25°C + 1 2 hr 125°C	0.60	0.24
Eccobond 45 15 (black)	EMC	100p45 100p15; 16 hr 52°C	6.06	0.63
Eccobond 45 15 (black)	EMC	Contractor's sample, as above; 2 hr 85°C + 23 hr 100°C 10^{-6} torr + 1 hr 100°C 10^{-7} torr	6.02	0.28
Eccobond 45 15 (black)	EMC	Contractor's sample, as above; 2 hr 85°C + 23 hr 150°C 10^{-6} torr + 1 hr 150°C 10^{-7} torr	5.82	0.35
Eccobond 55 9	EMC	100p55 12p*9; 24 hr 25°C	0.40	0.06
Eccobond 55 9	EMC	100p55 12p*9; 16 hr 65°C	0.17	0.07
Eccobond 55 9	EMC	100p55 12p*9; 24 hr 150°C	0.15	0.10
Eccobond 55 11	EMC	100p55 17p*11; 1 2 hr 150°	3.76	3.40
Eccobond 55 11	EMC	100p55 17p*11; 24 hr 150°C	0.43	0.43
Eccobond 104 A B	EMC	100p A 64pB; 3 hr 150°C	0.30	0.24
Eccobond 104 A B	EMC	100pA 64B; 8 hr 150°C	0.35	0.03
Eccobond Solder 56C 9	EMC	100p56C 5p*9; 16 hr 50°C	0.30	0.03
Eccobond Solder 56C 9	EMC	100p56C 5p*9; 16 hr 65°C	0.42	0.03
Eccobond Solder 57C A B	EMC	100pA 100pB; 16 hr 52°C	0.67	0.06
Epibond 115	FPI	As received; 16 hr 25°C + 16 hr 125°C	11.63	0.49
Epiphen ER825A	BCM	100p825A 12pMod-T 40pFiller 16p-825A-converter; 48 hr 25°C	1.07	0.01
Epiphen ER825A	BCM	100p825A 12pMod-T 40pFiller 16p-825A-converter; 48 hr 75°C	0.84	0.01

Table 7 (Continued)

MATERIAL[1]	MFR.[2]	TREATMENT	TOTAL WT. LOSS, %	VCM, WT-
Epoxy (Concluded)				
Epon 828 A	SCA	100p828 8pA; 3 hr 95°C	0.70	0.66
Epon 828 Z	SCA	100p828 20pZ; 2 hr 75°C + 2 hr 135°C	0.42	0.03
Epon 828 Versamid-125	SCA	100p828 50p125; 1 hr 65°C + 1 hr 95°C + 1 hr 150°C	1.65	0.77
Epon 828 Versamid-125	SCA	100p828 50p125; 1 hr 65°C + 1 hr 95°C + 24 hr 150°C	0.51	0.12
Epon 901 B-1	SCA	100p901 23pB-1; 1 hr 93°C	0.34	0.14
Epon 901 B-1	SCA	100p901 23pB-1; 16 hr 52°C	1.28	0.04
Epon 901 B-3	SCA	100p901 23pB-3; 1-1 2 hr 115°C + 1-1 2 hr 175°C	0.19	0.01
Epon 903	SCA	As received; 1 hr 175°C	0.36	0.21
Epon 914	SCA	As received; 1 hr 175°C	0.24	0.15
Epon 917	SCA	As received; 15 min 175°C	0.17	0.03
Epon 919 A B	SCA	100pA 16pB; 3 hr 82°C	1.45	0.23
Epon 919 A B	SCA	100pA 33pB; 3 hr 93°C	4.71	0.33
Epon 931 A B	SCA	100pA 1pB; 1 hr 125°C	0.13	0.01
Epon 934 A B	SCA	100pA 33pB; [illegible] hr 82°C	0.10	0.08
Epoxi-Patch A B	HYS	Equal lengths A-B; 2 hr 60°C	1.18	0.01
FM-1000	ACB	As received 1 hr 150°C	8.31	4.64
FM-1000	ACB	As received; 2 hr 150°C	6.22	5.08
FM-1000	ACB	As received; 2 hr 170°C	5.39	4.35
FM-1000	ACB	As received; 2 hr 200°C	5.55	4.71
FM-1044	ACB	As received; 1 hr 150°C	7.95	3.76
FM-1044	ACB	As received; 24 hr 150°C	5.84	2.99
Scotchweld AF-126 (BMS-551)	MMA	As received (no primer); 1 hr 125°C	1.97	0.85
Epoxy, modified				
FM-96U	ACB	As received; 1 hr 175°C	0.15	0.01
Metlbond-328	WCN	As received; 90 min 165°C	0.12	0.10
Metlbond-329	WCN	As received; 90 min 165°C	0.26	0.08
Epoxy-nitrile-nylon				
FM-61	ACB	As received; 1 hr 175°C	0.68	0.21
Epoxy-phenolic Al-glass				
HT-424	ACB	As received; 30 min 65°C	0.63	0.17
HT-424	ACB	As received; 2 hr 165°C	0.65	0.16

Table 7 (Concluded)

MATERIAL[1]	MFR.[2]	TREATMENT	TOTAL WT. LOSS, %	VCM, WT-%
Fluorocarbon				
Fairprene 5159 Activator (Viton-A cement)	DUF	100p5159 1pActivator; 48 hr 25°C + 8 hr 104°C	2.08	0.16
Polyester				
Adhesive 46950	DUP	As received; 3 min 150°C	1.54	0.59
Adhesive 46951	DUP	As received; 16 hr 25°C + 4 hr 150°C	0.60	0.24
Cement 4684	DUP	As received; 16 hr 25°C + 4 hr 150°C	7.26	5.62
Silicone				
Chemlok 607	DCC	As received; 24 hr 25°C	12.62	1.02
Chemlok 607	DCC	As received; 24 hr 150°C	2.95	0.56
Silicone Primers				
Eccosil Primer-33	EMC	As received; 1 hr 25°C	12.5	7.6
SS-4004	GES	As received; 24 hr 25°C	22.67	7.87
SS-4004	GES	As received; 24 hr 150°C	0.40	0.20
SS-4044	GES	As received; 24 hr 25°C	19.67	8.02
SS-4044	GES	As received; 24 hr 150°C	1.05	0.35
SS-4101	GES	As received; 24 hr 25°C	23.76	7.35
SS-4101	GES	As received; 24 hr 150°C	6.72	4.16
SS-4120	GES	As received; 24 hr 25°C	24.98	14.60
SS-4120	GES	As received; 24 hr 150°C	2.00	0.00

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[1] See Appendix A.

[2] See Appendix B.

Table 8

MACRO-VCM DETERMINATIONS: ADHESIVES

MATERIAL*	PROPERTY	HOURS OF EXPOSURE AT 125°C AND 10^{-6} TORR			
		24	48	96	336
Epoxi-Patch A/B	Wt-loss, % VCM, wt-%	0.70 0.01	0.96 0.01	1.16 0.01	1.62 0.01

* Mixed equal lengths of A and B; cured 2 hr 60°C.

Table 9

MASS SPECTROMETRIC ANALYSIS IN SITU OF MATERIALS VOLATILIZED AT 125°C AND 10^{-6} TORR: ADHESIVES

MATERIAL	IDENTIFIED COMPONENTS	
	Major	Minor
Epoxi-Patch A/B	butyl acetate	-
FM-1000	low-m.w. (to 600) epoxy resins	--

Table 10

EFFECTS OF DECONTAMINATION CYCLES ON ADHESIVES

(Six cycles of humidified ETO-Freon for 30 hr at 50°C)

MATERIAL[1]	WEIGHT CHANGE, %	ADHESION SHEAR, psi		CREEP	
		Control	Test	Control	Test
Paste Adhesives					
Adhesive 4684/BC-805	+1.98	1627	1066	--	--
Adhesive 46951	+0.66	962	532	--	--
Armstrong A-2/E	+1.13	2640	2193	none	none[2]
Eccobond 45/15	+9.84	1237	1274	failed	failed
Eccobond 55/9	+0.23	4450	4120	--	--
Eccobond Solder 57C A/B	+1.07	900	912	--	--
Eccobond 104 A/B	+0.29	1462	1315	--	--
Epon 828/Versamid 125	+3.15	2482	2242	--	--
Epon 901/B-3	-0.18	2733	2653	none	none[3]
Epon 919 A/B	+1.77	2540	2833	none	failed[3]
Film Adhesives					
FM-61	+1.27	2433	2283	none	none[3]
FM-961	+0.04	3367	3097	none	none[3]
HT-424	+0.52	2193	2128	none	none[3]
Metlbond-328	+0.45	3380	3013	none	none[3]
Metlbond-329	+0.36	2177	1566	none	none[3]

[1] All samples mixed and cured under load according to mfr's instructions.

[2] Control and test samples under 500-psi load; control samples [illegible] in air [illegible] at [illegible]°C.

[3] Control and test samples under 1000-psi load; control samples maintained in air [illegible] at 25°C.

Table 11

EFFECTS OF THERMAL VACUUM ENVIRONMENT ON ADHESIVES

(500 hours at 135°C and 10^{-6} torr)

MATERIAL[1]	WEIGHT CHANGE, %	ADHESION SHEAR, psi		CREEP	
		Control	Test	Control	Test
Paste Adhesives					
Adhesive 4684 RC-805	2.90	1627	1509	--	--
Adhesive 46951	--temperature service limit exceeded--				
Armstrong A-2/E	0.80	2040	2793	none	none[2]
Eccobond 45/15	5.02	1257	2651	failed	failed[3]
Eccobond 55/9	-0.14	4450	4400	--	--
Eccobond Solder 57C A/B	-0.86	909	1156	--	--
Eccobond 104 A/B	0.47	1462	1770	--	--
Epon 828/Versamid 125	-0.36	2482	3180	--	--
Epon 901/B-3	-0.33	2733	3440	none	failed[3]
Epon 919 A/B	-0.64	2540	3467	--	--
Film Adhesives					
FM-61	-0.90	2433	2180	none	failed[3]
FM-96l	0.57	3367	3584	none	none[2]
HT-424	-0.29	2193	2424	none	none[2]
Metlbond 328	-0.34	3380	3273	none	none[3]
Metlbond-329	-0.65	2177	2273	none	none[3]

[1] All test samples mixed and cured under load according to mfr's instructions.

[2] Control and test samples under 500-psi load; control samples maintained in air for 680 hours at 25°C.

[3] Control and test samples under 1000-psi load; control samples maintained in air for 680 hours at 25°C.

Table 12

EFFECTS OF DECONTAMINATION CYCLES PLUS THERMAL-VACUUM ENVIRONMENT ON ADHESIVES

MATERIAL[1]	WEIGHT CHANGE, %	ADHESION SHEAR, psi		CREEP	
		Control	Test	Control	Test
Paste Adhesives					
Adhesive 4684 RC-805	-3.15	1627	1594	--	--
Adhesive 46951	--temperature service limit exceeded--				
Armstrong A-2/E	-0.56	2040	2859	none	none[2]
Eccobond 45/15	+0.40	1257	2499	failed	failed[2]
Eccobond 55/9	-0.07	4450	4040	--	--
Eccobond Solder 57C A/B	-0.53	909	1267	--	--
Eccobond 104 A/B	+0.02	1462	1670	--	--
Epon 828/Versamid 125	+0.67	2482	3090	--	--
Epon 901/B-3	-0.40	2733	2933	none	failed[3]
Epon 919 A/B	-1.00	2540	3667	--	--
Film Adhesives					
FM-61	-0.36	2433	2640	none	failed[3]
FM-96l	-0.96	3367	3175	none	none[2]
HT-424	-0.04	2193	2544	none	none[2]
Metlbond-328	+0.23	3380	3726	none	none[3]
Metlbond-329	-0.25	2177	1667	none	none[3]

[1] All test samples mixed and cured under load according to mfr's instructions.

[2] Control and test samples under 500-psi load; control samples maintained in air for 680 hours at 25°C.

[3] Control and test samples under 1000-psi load; control samples maintained in air for 680 hours at 25°C.

VI. CIRCUIT BOARDS (CB)

The circuit board materials discussed in this section are those designed specifically for etched circuits, that is, copper-clad laminates. Data for materials which may be used as circuit boards but also have other structural applications (e.g., epoxy-glass fiber laminates) are summarized with hardware and structural materials in Section X.

As shown by the micro-VCM data in Table 13, the circuit board materials which have been tested are excellent candidates for use in spacecrafts. The candidacy of Micarta 65M25 is further supported by the macro-VCM determination (Table 14) which indicates the small amount of VCM is disappearing with time; the probable contributor to VCM has been identified as styrene (Table 15) which may re-polymerize. VCM-contributor from Micaplys EG-899T and EG-758T was identified from its infrared absorbance (see Section III) as a polyamide; this may re-evaporate with time.

Table 13

MICRO-VCM DETERMINATIONS: CIRCUIT BOARD
(24 hours at 125°C and 10^{-7} torr)
(VCM collector at 25°C)

MATERIAL[1]	MFR.[2]	TREATMENT	TOTAL WT. LOSS,	VCM, WT-%
Epoxy-glass, copper-clad				
Micarta 65M25	WEM	As received	0.43	0.00
Micaplys EG-899T	TMC	As received, stripped of copper	0.29	0.03
Micaplys EG-758T	TMC	As received, stripped of copper	0.46	0.07
Micaplys EG-824T	TMC	As received, stripped of copper	0.40	0.05
EG--2028FR, Type FL-GF	FLC	As received, stripped of copper	0.44	0.01
EG-2028, Type FL-GE	FLC	As received, stripped of copper	[illegible]	0.01

Table 14

MACRO VCM DETERMINATIONS: CIRCUIT BOARD

MATERIAL	PROPERTY	HOURS OF EXPOSURE AT 125°C AND 10^{-6} TORR			
		24	48	96	336
Micarta 65M25	Wt-loss, % VCM, wt-%	0.36 0.01	0.36 0.02	0.44 0.04	0.35 0.04

* As received, dimensions: 2" × 2" × 0.075"

Table 15

MASS SPECTROMETRIC ANALYSIS IN SITU OF MATERIALS VOLATILIZED AT 125°C AND 10^{-6} TORR. CIRCUIT BOARD

MATERIAL	IDENTIFIED COMPONENTS	
	Major	Minor
Micarta 65M25	methyl cellosolve	styrene

VII. COATED FABRICS (CF)

Practically all of the fluorocarbon-coated materials listed in Table 16 are excellent candidates for spacecraft use on the basis of micro-VCM data. The polyimide- and phenolic-coated glass fabrics also can be included in a list of qualified materials.

Representative fabrics from the various polymer classes were selected for further testing in order to ascertain the changes in mechanical and electrical properties after their exposure to decontamination cycles and the thermal-vacuum environment. The results of these tests are given in Tables 17 to 19. As shown by the test data, the polyimide- and phenolic-coated glass fabrics display the greatest breaking strength and incur virtually no change in mechanical and electrical properties after any of the exposures.

The silicone-coated fabrics do not suffer much change in mechanical or electrical properties after the various exposures, but cannot be recommended because of their excessive VCM contents.

The fluorocarbon-coated Armalon 98-101 incurs a 5-fold increase in elongation after all exposures which may disqualify it for considered use. On the other hand, Fairprene 84-001 not only shows the same tendency to increased elongation, but also has a disqualifying high VCM content; this is unfortunate for it has the highest dielectric constant of the materials tested.

Table 16

MICRO-VCM DETERMINATIONS: COATED FABRICS
(24 hr at 125°C and 10^{-6} torr)
(VCM collectors at 25°C)

MATERIAL[1]	MFR.[2]	TREATMENT	TOTAL WT. LOSS, %	VCM, WT-%
Fluorocarbon-coated polyamide				
Armalon 98-101	DUF	As received	0.46	0.02
Fluorocarbon-coated polyester				
Fairprene 84-001	DUF	As received	1.33	0.21
Fairprene 80-060	DUF	As received	0.34	0.01
Fairprene 80-070	DUF	As received	0.30	0.01
Fairprene 80-080	DUF	As received	0.30	0.01
Fluorocarbon-coated glass				
TB5-PTFE	MMI	As received	0.05	0.05
Phenolic				
Phenolic-glass fiber	GEC	As received	0.53	0.01
Polyimide-coated glass				
PYRE-M.L. Type 1	DUF	As received	0.50	0.01
Silicone-coated polyester				
SRD-5905	MMI	As received	0.89	0.43
Silicone-coated glass				
SRG-1810	MMI	As eceived	0.70	0.39
Silicone-coated aluminized glass				
SRGA-0214	MMI	As received	0.62	0.34

[1] See Appendix A.
[2] See Appendix B.

Table 17

EFFECTS OF DECONTAMINATION CYCLES ON COATED FABRICS

(Six cycles of humidified ETO-Freon for 30 hours at 50°C)

MATERIAL[1]	MECHANICAL PROPERTIES						ELECTRICAL PROPERTIES				
	Dimensional Change, %	Weight Change, %	Breaking Strength, psi		Elongation, %		Freq., MHz	Dielectric Constant		Dissipation Factor	
			Control	Test	Control	Test		Control	Test	Control	Test
Amalon 98-101	L, −0.07	+0.37	11,875	13,150	5	24	1	2.35	2.56	0.002	0.006
	W, +0.50						15	2.36	2.42	0.016	0.014
							25	2.35	2.40	0.022	0.023
							35	2.41	2.54	0.031	0.027
							50	2.28	2.32	0.062	0.068
Fairprene 84-001	L, +0.17	+1.05	8,819	8,562	77	74	1	6.60	5.48	0.108	0.090
	W, +0.23						15	5.48	4.38	0.126	0.065
							25	5.72	4.12	0.300	0.106
							35	4.69	4.38	0.126	0.146
							50	4.64	3.29	0.187	0.056
PYRE-M.L., Type 1	L, n.c.	+1.26	28,917	27,117	5	5	1	2.43	2.03	0.006	0.001
	W, n.c.						15	2.61	2.61	0.034	0.034
							25	2.89	2.38	0.062	0.058
							35	2.63	2.63	0.078	0.111
							50	2.17	2.61	0.093	0.162
SRG-1810	L, +0.12	+0.09	5,229	7,157	4	6	1	2.46	2.74	0.003	0.006
	W, +0.28						15	2.40	2.61	0.007	0.006
							25	2.34	2.56	0.007	0.009
							35	2.29	2.46	0.010	0.012
							50	2.23	2.46	0.001	0.028
SRG-0211	L, +0.25	+0.59	11,612	10,729	7	9	1	2.78	2.47	0.004	0.011
	W, −0.05						15	2.65	2.25	0.009	0.012
							25	2.45	2.18	0.008	0.006
							35	2.46	1.91	0.012	0.001
							50	2.19	2.45	0.001	0.001
Phenolic-Coated Glass	L, +0.06	+0.02	27,256	26,131	7	8	1	3.61	3.82	0.001	0.001
	W, n.c.						15	3.43	3.50	0.001	0.001
							25	3.50	3.10	0.001	0.001
							35	3.24	3.58	0.001	0.001
							50	3.42	3.82	0.001	0.001

[1] All materials used as received.

Table 18

EFFECTS OF THERMAL-VACUUM ENVIRONMENT ON COATED FABRICS
(500 hours at 135°C and 10^{-6} torr)

MATERIAL[1]	MECHANICAL PROPERTIES						ELECTRICAL PROPERTIES				
	Dimensional Change, %	Weight Change, %	Breaking Strength, psi		Elongation, %		Freq., MHz	Dielectric Constant		Dissipation Factor	
			Control	Test	Control	Test		Control	Test	Control	Test
Armalon 98-101	L, +0.04 W, -0.51	-0.25	11,875	12,996	5	25	1	2.35	2.63	0.002	0.006
							15	2.36	2.46	0.016	<0.001
							25	2.35	2.48	0.022	<0.001
							35	2.41	2.48	0.031	0.009
							50	2.28	2.35	0.062	<0.001
Fairprene 84-001	L, -0.64 W, -0.35	-1.34	8,819	8,620	77	101	1	6.60	5.42	0.103	0.089
							15	5.48	4.06	0.126	0.099
							25	5.72	4.64	0.300	0.150
							35	4.69	4.07	0.126	0.070
							50	4.64	2.83	0.187	0.087
PYRE-M.L., Type I	L, -0.06 W, -0.10	-0.27	28,917	26,018	5	5	1	2.43	2.26	0.006	0.003
							15	2.61	2.17	0.036	0.018
							25	2.89	2.60	0.062	0.010
							35	2.63	2.36	0.078	0.028
							50	2.17	2.89	0.093	<0.001
SRG-1810	L, +0.03 W, -0.22	-0.58	5,229	8,095	4	8	1	2.46	2.77	0.003	0.003
							15	2.40	2.56	0.007	<0.001
							25	2.34	2.63	0.007	0.001
							35	2.29	2.62	0.010	0.018
							50	2.23	2.38	<0.001	<0.001
SRGA-0213	L, +0.00 W, +0.31	0.27	11,612	11,605	7	6	1	2.78	2.77	0.004	0.010
							15	2.65	2.70	0.009	0.010
							25	2.15	2.40	0.008	0.007
							35	2.41	2.20	0.012	<0.001
							50	2.19	2.29	<0.001	<0.001
Phenolic-Coated Glass	L, +0.00 W, +0.06	-0.18	27,256	26,120	7	5	1	3.61	3.38	<0.001	<0.001
							15	3.43	3.21	<0.001	<0.001
							25	3.50	4.06	<0.001	<0.001
							35	3.24	3.38	<0.061	<0.001
							50	3.42	3.38	<0.001	<0.001

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[1] All materials used as received.

Table 19

EFFECTS OF DECONTAMINATION CYCLES PLUS THERMAL-VACUUM ENVIRONMENT ON COATED FABRICS

MATERIAL[1]	MECHANICAL PROPERTIES						ELECTRICAL PROPERTIES				
	Dimensional Change, %	Weight Change, %	Breaking Strength, psi		Elongation, %		Freq., MHz	Dielectric Constant		Dissipation Factor	
			Control	Test	Control	Test		Control	Test	Control	Test
Armalon 98-101	L, -0.19 W, -0.35	-0.03	11,875	13,496	5	34	1	2.35	2.63	0.002	0.004
							15	2.36	2.63	0.016	0.010
							25	2.35	2.48	0.022	0.003
							35	2.41	2.48	0.031	0.012
							50	2.28	2.48	0.062	<0.001
Fairprene 84-001	L, -0.44 W, -0.22	-1.14	8,819	8,620	76	105	1	6.60	6.50	0.103	0.117
							15	5.48	6.00	0.126	0.079
							25	5.72	4.33	0.300	0.087
							35	4.69	4.64	0.126	0.105
							50	4.64	4.06	0.187	<0.001
PYRE-M.L., Type 1	L, 0.08 W, -0.20	+0.09	28,917	24,723	5	5	1	2.43	2.03	0.006	0.002
							15	2.61	2.03	0.034	<0.001
							25	2.89	2.32	0.062	0.001
							35	2.63	2.03	0.078	<0.001
							50	2.17	1.95	0.093	<0.001
SRG-1810	L, 0.16 W, 0.08	-0.49	5,229	6,810	4	5	1	2.46	2.77	0.003	0.004
							15	2.40	2.77	0.007	0.009
							25	2.34	2.85	0.007	0.004
							35	2.29	2.62	0.010	<0.001
							50	2.23	2.50	<0.001	<0.001
SRGA-0214	L, +0.02 W, +0.27	0.16	11,612	12,556	7	6	1	2.78	2.93	0.002	0.011
							15	2.65	2.93	0.009	0.004
							25	2.45	2.51	0.008	0.008
							35	2.41	2.51	0.013	<0.001
							50	2.19	2.77	<0.001	<0.001
Phenolic-Coated Glass	L, 0.09 W n.c.	+0.20	27,256	22,102	7	5	1	3.61	3.38	<0.001	<0.001
							15	3.43	3.38	<0.001	<0.001
							25	3.50	3.38	<0.001	<0.001
							35	3.24	3.38	<0.001	<0.001
							50	3.42	3.38	<0.001	<0.001

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[1] All materials used as received.

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VIII. FILMS AND SHEETS (FS)

All of the film and sheet materials which have been screened with the micro-VCM procedure appear to be suitable candidates for spacecraft use except for a polyvinylidene fluoride (Kynar-200) and the polyamides (nylons); a marginal suitability may be conceded to Mylars Type T and S. These data are summarized in Table 20. As shown in Table 21, the macro-VCM determinations verify the qualification for PPO 681-111 and Teflon FEP 500A. The apparent increase in weight-loss value for the PPO film indicated by the macro-VCM determination (compared with micro VCM data) is due only to the fact that the film was used as received, whereas it was annealed at 180°C prior to the micro-VCM determination. This is further confirmed by the identification of solvents as constituting the greater part of volatile materials (Table 22); these were undoubtedly released at the high temperature of annealing. Mechanical property data for the PPO film obtained after long-term storage tests (Section XXIII) also confirm the suitability of this film for spacecraft use.

The excellent values for Teflon FEP 500A from the micro- and macro-VCM determinations are verified by the data for its mechanical and electrical properties after exposure to decontamination and thermal-vacuum environments as shown in Tables 23 to 25.

The electrical and tensile properties of Mylar Type T suffers little by exposure to the decontamination and thermal-vacuum environments; however, the dimensional change of about 10% in the thermal-vacuum environment is excessive and the micro-VCM rating is marginal. On the other hand, Mylar Type A easily passes micro-VCM screening and incurs no changes in mechanical and electrical properties after decontamination and thermal-vacuum exposures.

The polysulfone P-2300 reflects in the thermal-vacuum environment the same good rating as given by micro-VCM screening. However, there is a distinct reduction of elongation values after exposure to ETO and subsequently ETO/TVE environments. The polyimide film 200XH667 (formerly called H-film) is one of the strongest films suitable for spacecraft use and displays excellent retention of physical properties throughout all decontamination and thermal-vacuum exposures. Because of the indicated data, this film is undergoing an 8-month storage test (Section XXIII) in the thermal-vacuum environment for plastic creep under load.

The two Tedlar films, transparent and filled, easily pass micro-VCM screening and incur little change in tensile and electrical properties; however, both of these films tend to stretch during exposure to the thermal-vacuum environment, and this must be taken into consideration before recommendation for use.

Table 20

MICRO-VCM DETERMINATIONS: FILMS AND SHEETS

(24 hr at 125°C and 10^{-6} torr)
(VCM collectors at 25°C)

MATERIAL[1]	MFR.[2]	TREATMENT	TOTAL WT. LOSS, %	VCM, WT-%
Polyamide				
Nomex, 5-mil	DUP	As received	3.25	0.02
6-Nylon	DUP	As received	3.40	0.17
Polyfluoroethylene-propylene				
Teflon FEP 500C	DUP	As received	0.02	0.01
Teflon FEP 100A	DUP	As received	0.16	0.06
Teflon FEP 500A	DUP	As received	0.05	0.05
Polyimide				
Kapton 200XH667	DUP	As received	0.14	0.09
Polyimide, fluorocarbon-coated				
Kapton 200XHF929A	DUP	As received	0.54	0.05
Polyphenylene oxide				
PPO 681-111 (clear)	GEC	Annealed 1/2 hr 180°C	0.07	0.05
PPO 531-081 (opaque)	GEC	As received	0.09	0.02
Polysulfone				
P-2300	UCP	Annealed 1/2 hr 125°C	0.03	0.01
P-73905-121-2	UCP	As received	0.09	0.02
Polyterephthalate				
Mylar Type 500A	DUP	As received	0.21	0.06
Mylar Type 100S	DUP	As received	0.22	0.12
Mylar Type 100T	DUP	As received	0.20	0.12
Polyvinyl fluoride				
Tedlar A130WH	DUP	As received	0.47	0.06
Tedlar 100BG30TR	DUP	As received	0.23	0.10
Tedlar 100BG30TL	DUP	As received	0.09	0.09
Polyvinylidene fluoride				
Kynar 200	PCC	As received	0.21	0.15
Poly-p-xylylene				
Parylene C	UCP	As received	0.12	[illegible]
Parylene N	UCP	As received	[illegible]	[illegible]

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[1] See Appendix A.

[2] See Appendix B.

Table 21

MACRO VCM DETERMINATIONS: FILMS AND SHEETS

MATERIAL*	PROPERTY	HOURS OF EXPOSURE AT 125°C AND 10^{-6} TORR			
		24	48	96	336
PPO 681-111 (clear)	Wt loss, %	0.57	0.67	0.74	0.72
	VCM, wt %	0.07	0.00	0.01	0.01
Teflon-FEP 500A	Wt loss, %	0.01	0.01	0.01	0.01
		0.01	0.01	0.01	0.01

* PPO 681-111, as received; 30" × 2" × 0.001".
Teflon FEP 500A, as received, 6" × 1" × 0.05".

Table 22

MASS SPECTROMETRIC ANALYSIS *IN SITU* OF MATERIALS VOLATILIZED AT 125°C AND 10^{-6} TORR: FILMS AND SHEETS

MATERIAL	IDENTIFIED COMPONENTS	
	Major	Minor
Mylar Type 500A	—glycols to m.w. 500	dioctylphthalate
PPO 681-111	aromatic solvents	squalene
Teflon-FEP 500A	dioctylphthalate, squalene	carbon dioxide

Table 23

EFFECTS OF DECONTAMINATION CYCLES ON FILMS AND SHEETS

(Six cycles of ETO-Freon for 30 hours at 50°C)

MATERIAL*	MECHANICAL PROPERTIES						ELECTRICAL PROPERTIES				
	Dimensional Change, %	Weight Change, %	Tensile, psi		Elongation at Break, %		Frequency, MHz	Dielectric constant		Dissipation Factor	
			Control	Test	Control	Test		Control	Test	Control	Test
Kapton 200XB567	+0.24	+3.06	24,505	24,076	39	36	1	2.92	2.90	<0.001	0.001
							15	2.90	2.84	<0.001	<0.001
							25	2.86	2.75	0.011	0.016
							35	2.79	2.75	0.112	0.023
							50	2.33	2.30	0.031	0.066
Mylar Type 150T	n.c.	+0.59	38,680	37,730	22	17	1	2.74	2.89	0.018	0.020
							15	2.64	2.79	0.015	0.016
							25	2.60	2.79	0.013	0.018
							35	2.55	2.70	0.013	0.010
							50	2.05	2.30	0.016	0.018
Mylar Type 100A	-0.38	+1.31	19,845	17,840	120	98	1	2.80	2.65	0.016	0.016
							15	2.71	2.58	0.014	0.014
							25	2.71	2.58	0.013	0.014
							35	2.65	2.58	0.012	0.012
							50	2.41	2.35	0.013	0.018
P-2300	n.c.	+1.13	9,310	9,540	93	63	1	2.99	3.05	0.004	0.005
							15	3.30	3.28	0.007	0.007
							25	3.30	3.36	0.005	0.014
							35	2.98	2.93	0.010	0.013
							50	2.82	2.77	0.018	0.001
Teflon FEP-500A	+0.22	+4.98	2,869	2,720	311	338	1	2.02	2.09	0.0001	0.0001
							15	1.78	1.83	0.0001	<0.0001
							25	1.91	1.91	<0.0001	0.0001
							35	1.75	1.60	0.0001	0.0001
							50	1.12	1.17	0.0001	0.0001
Tedlar 100BG30TR	+2.15	+6.04	10,909	10,364	153	134	1	4.02	4.02	0.081	0.081
							15	3.34	3.13	0.096	0.099
							25	3.15	3.36	0.080	0.086
							35	2.52	2.52	0.075	0.075
							50	2.52	2.52	0.086	0.086
Tedlar 200BG30WH	n.c.	+0.33	11,660	11,880	110	100	1	5.51	6.53	0.085	0.080
							15	4.66	5.37	0.086	0.086
							25	4.48	5.22	0.084	0.084
							35	4.36	5.08	0.082	0.083
							50	3.64	4.24	0.096	0.089

*All materials used as received

Table 24

EFFECTS OF THERMAL-VACUUM ENVIRONMENT ON FILMS AND SHEETS

(500 hours at 135°C and 10^{-6} torr)

MATERIAL*	MECHANICAL PROPERTIES						ELECTRICAL PROPERTIES				
	Dimensional Change,	Weight Change,	Tensile, psi		Elongation at Break,		Frequency, MHz	Dielectric Constant		Dissipation Factor	
			Control	Test	Control	Test		Control	Test	Control	Test
Kapton 200XH667	0.60	0.11	24,605	23,082	39	48	1	2.92	2.84	<0.001	<0.001
							15	2.90	2.82	<0.001	0.006
							25	2.86	2.80	0.014	0.005
							35				
							50				
Mylar Type 150T	0.94	0.31	38,680	32,660	22	25	1	2.71	2.47	0.018	0.015
							15	2.64	2.44	0.015	0.013
							25	2.60	2.39	0.013	0.012
							35	2.55	2.22	0.013	0.012
							50	2.05	2.22	0.016	0.016
Mylar Type 100A	1.33	0.09	19,845	21,692	120	133	1	2.80	2.53	0.016	0.014
							15	2.17	2.37	0.017	0.011
							25	2.71	2.38	0.013	0.011
							35	2.65	2.38	0.012	0.012
							50	2.44	2.18	0.013	0.008
P 2300	n.c.	0.12	9,310	8,880	43	90	1	2.99	3.04	0.004	0.004
							15	3.30	2.89	0.007	0.003
							25	3.30	2.91	0.005	0.003
							35	2.90	2.84	0.010	0.001
							50	2.82	2.77	0.018	0.003
Teflon FEP-500A	+0.04	0.12	2,869	3,324	338	313	1	2.02	1.97	<0.0001	<0.0001
							15	1.78	1.96	0.0001	<0.0001
							25	1.91	1.90	<0.0001	<0.0001
							35	1.75	1.56	0.0001	<0.0001
							50	1.12	1.23	0.0001	<0.0001
Tedlar 100BG30TB	+4.98	0.34	10,909	10,158	173	11	1	3.02	2.92	0.081	0.063
							15	3.37	2.77	0.096	0.073
							25	3.17	2.69	0.080	0.072
							35	2.72	2.64	0.077	0.070
							50	2.52	2.33	0.086	0.073
Tedlar 200BG30TB	+2.74	0.19	11,660	11,050	110	98	1	3.51	3.31	0.085	0.075
							15	3.66	3.06	0.086	0.080
							25	3.48	3.92	0.084	0.082
							35	3.36	3.89	0.082	0.076
							50	3.64	3.34	0.090	0.096

* All materials used as received

Table 25

EFFECTS OF DECONTAMINATION CYCLES PLUS THERMAL-VACUUM EXPOSURE ON FILMS AND SHEETS

MATERIAL*	MECHANICAL PROPERTIES						ELECTRICAL PROPERTIES				
	Dimensional Change, %	Weight Change, %	Tensile, psi		Elongation at Break, %		Frequency MHz	Dielectric Constant		Dissipation Factor	
			Control	Test	Control	Test		Control	Test	Control	Test
Kapton 200XH667	-0.02	+0.20	24,605	25,296	39	42	1	2.92	2.80	0.001	0.007
							15	2.90	2.80	<0.001	0.007
							25	2.86	2.75	0.044	0.006
							35	2.79	2.71	0.112	0.006
							50	2.33	2.35	0.031	0.008
Mylar Type 156T	-9.73	-0.36	38,680	32,500	22	33	1	2.74	2.29	0.018	0.013
							15	2.64	2.28	0.015	0.012
							25	2.60	2.29	0.013	0.011
							35	2.55	2.26	0.013	0.012
							50	2.05	2.02	0.016	0.014
Mylar Type 100A	-1.27	-0.13	19,845	18,769	120	125	1	2.80	2.51	0.016	0.014
							15	2.71	2.53	0.015	0.012
							25	2.71	2.57	0.013	0.011
							35	2.65	2.46	0.012	0.011
							50	2.41	2.31	0.013	0.006
P-2300	n.c.	-0.15	9,310	11,300	93	66	1	2.99	3.18	0.004	0.004
							15	3.30	3.04	0.007	0.003
							25	3.30	3.04	0.005	0.003
							35	2.90	2.98	0.010	0.004
							50	2.82	--	0.018	0.004
Teflon FEP 500A	+0.10	-0.03	2,869	3,074	311	318	1	2.02	2.00	<0.0001	<0.0001
							15	1.98	1.96	<0.0001	0.0001
							25	1.91	1.87	<0.0001	0.0001
							35	1.55	1.75	0.0001	0.0001
							50	1.12	1.22	0.0001	0.0001
Tedlar 100BG30TR	+4.51	-0.08	10,909	10,744	153	116	1	4.02	3.74	0.081	0.064
							15	3.34	3.58	0.096	0.081
							25	3.15	3.31	0.080	0.078
							35	2.52	3.70	0.075	0.070
							50	2.52	2.68	0.086	0.079
Tedlar	+2.82	-0.14	11,660	11,150	110	100	1	5.51	4.31	0.085	0.079
							15	4.66	4.16	0.086	0.082
							25	4.48	4.00	0.084	0.080
							35	4.36	3.95	0.082	0.085
							50	3.64	3.34	0.090	0.097

* All materials used as received

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IX. FOAM MATERIALS (FO)

The screening data summarized in Table 26 for foam materials indicate that two epoxy and two polyurethane materials appear to be good candidates for further evaluation. However, it is to be noted that the epoxy materials (Stycasts 1090/11 and 1095/11) are rigid foamed-in-place materials, and the polyurethanes (Eccofoams S and SH) are pre-foamed rigid materials. Careful examination of the data in Table 26 also reveals that the nature of foam materials makes difficult the comparison of the effect of alternative curing cycles on a micro-scale but, in general, excessive observed test values remain excessive after different treatments; i.e., variation of cure has little effect.

Confirmation of the good outgassing properties of the Stycasts is given in Table 27 where macro-VCM determinations indicate negligible VCM and weight-loss values. Mass spectrometric analysis of the substances evolved at 125°C *in vacuo* (Table 28) reveals the presence of a piperidine and/or polyamide material, often used as cross-linking agents for epoxies; these substances should evaporate without causing deterioration of the properties of the polymer, but this must be checked by further evaluation.

Macro-VCM data for the Eccofoams (Table 27) show negligible values, but there may be a continuing increase in weight-loss with time. In the case of Eccofoam SH, the primary constituent of evolved substances has been shown to be nitrogen (Table 28); the gradual increase of weight-loss, not accompanied by a similar increase in VCM value apparently confirms this finding. Further evaluation of Eccofoam SH (Tables 29-31) for mechanical property changes shows that the material is subject to compression set but does not lose its compressive strength after exposures to decontamination and thermal-vacuum cycles. In comparison, Eccofoam S not only suffers compression set but also a loss in compressive strength after exposure to the decontamination and thermal-vacuum cycles (Tables 29-31).

The one flexible polyurethane, Eccofoam FS, unfortunately does not qualify for further evaluation at all (Table 26). Scotchcast XR-5068, epoxy-coated micro glass cells, has a gross VCM value which has not been changed by extension of curing time. As shown by mass spectrometric identification in Table 28 (and confirmed by the infrared spectrum of the VCM shown in Appendix C), the VCM is apparently composed of polyamides or amines. Most importantly, however, the macro-VCM data in Table 27 indicate that the substances which are released at 125°C do not evaporate with time from a 25°C condensing surface.

Table 26

MICRO-VCM DETERMINATIONS: FOAM MATERIALS

(24 hr at 125°C and 10^{-6} torr)

(VCM collectors at 25°C)

MATERIAL[1]	MFR.[2]	TREATMENT	TOTAL WT. LOSS, %	VCM, WT-%
Epoxy				
Scotchcast #3 A/B	MME	200pA/300pB: 4 hr 121°C	4.62	0.24
Scotchcast XR-5068	MME	As received: 4 hr 121°C	0.57	0.34
Scotchcast XR-5068	MME	As received: 20 hr 9[illegible]°C	0.78	0.38
Scotchcast XR-5068	MME	As received: 24 hr 125°C	0.60	0.35
Scotchcast XR-5068/#3	MME	100p5068/100p#3: 4 hr 121°C	1.30	0.20
Stycast 1090/9	EMC	100p1090/9p#9: 24 hr 25°C	0.57	0.50
Stycast 1090/9	EMC	100p1090/9p#9: 16 hr 50°C	0.31	0.07
Stycast 1090/9	EMC	100p1090/9p#9: 16 hr 52°C	0.56	0.29
Stycast 1090/11	EMC	100p1090/12p#11: 12 hr 60°C + 3 hr 82°C	0.63	0.11
Stycast 1090/11	EMC	100p1090/12p#11: 24 hr 100°C	[illegible].13	0.13
Stycast 1090/11	EMC	100p1090/12p#11: 24 hr 125°C	0.[illegible]4	0.04
Stycast 1090/S-1/24LV	EMC	100p1090/23p24LV: 24 hr 25°C	4.02	0.09
Stycast 1090/S-1/24LV	EMC	100p1090/23p24LV: 24 hr 25°C + 16 hr 52°C	3.61	0.05
Stycast 1095/11	EMC	100p1095/12p#11: 3 hr 95°C + 3 hr 150°C	0.92	0.11
Stycast 1095/11	EMC	100p1095/12p#11: 2 hr 100°C	1.30	0.08
Stycast 1095/11	EMC	100p1095/12p#11: 24 hr 125°C	0.50	0.11
Polyurethane				
Eccofoam FPH/12oH	EMC	100pFPH/75p12oH: 24 hr 25°C + 3 hr 150°C	2.25	0.15
Eccofoam FPH/12oH	EMC	100pFPH/75p12oH: 24 hr 25°C + 24 hr 150°C	1.39	0.20
Eccofoam FPH/12oH	EMC	100pFPH/75p12oH: 24 hr 25°C + 16 hr 125°C	1.67	0.27
Eccofoam FPH/12oH	EMC	100pFPH/75p12oH: 24 hr 25°C + 16 hr 125°C + 24 hr 150°C	1.43	0.24
Eccofoam FS	EMC	As received	4.60	1.03
Eccofoam FS	EMC	As received: 24 hr 125°C	1.25	0.63
Eccofoam S (4.5 lb/ft^3)	EMC	As received	2.01	0.07
Eccofoam SH (7.24 lb/ft^3)	EMC	As received	1.03	0.01

[1] See Appendix A.

[2] See Appendix B.

Table 27

MACRO-VCM DETERMINATIONS: FOAM MATERIALS

MATERIAL*	PROPERTY	HOURS OF EXPOSURE AT 125°C AND 10^{-6} TORR			
		24	48	96	336
Eccofoam S	Wt-loss, %	0.21	0.31	0.48	0.50
	VCM, wt-%	0.01	<0.01	0.01	<0.01
Eccofoam SH	Wt-loss, %	0.35	0.70	0.87	(0.49)
	VCM, wt-%	<0.01	<0.01	<0.01	0.01
Stycast 1090/11	Wt-loss, %	0.20	0.18	0.28	0.31
	VCM, wt-%	0.01	0.01	0.01	<0.01
Stycast 1095/11	Wt-loss, %	0.01	0.02	0.02	0.02
	VCM, wt-%	<0.01	0.01	0.01	0.01
Scotchcast XR-5068	Wt-loss, %	--	0.51	0.55	0.54
	VCM, wt-%	--	0.35	0.35	0.37

* Eccofoam S: - As received; cut into strips of ~1/8" thick.
Eccofoam SH: - As received, cut into strips of ~1/8" thick.
Stycast 1090/11: - Mixed 100p1090/12p#11; cured 2 hr 100°C.
Stycast 1095/11: - Mixed 100p1095/12p#11; cured 2 hr 100°C.
Scotchcast XR-5068: - As received; cured 24 hr 125°C.

Table 28

MASS SPECTROMETRIC ANALYSIS IN SITU OF MATERIALS VOLATILIZED AT 125°C AND 10^{-6} TORR: FOAM MATERIALS

MATERIAL	IDENTIFIED COMPONENTS	
	Major	Minor
Eccofoam SH	nitrogen	N-methyl morpholine; carbon dioxide; toluene; styrene
Scotchcast XR-5068	polyamide	dioctylphthalate
Stycast 1090/11	piperidine and/or polyamide	carbon dioxide
Stycast 1095/11	piperidine and/or polyamide	carbon dioxide

Table 29

EFFECTS OF DECONTAMINATION CYCLES ON FOAM MATERIALS

(Six cycles of humidified ETO-Freon for 30 hours at 50°C)

MATERIAL[1]	DIMENSIONAL CHANGE, %	WEIGHT CHANGE, %	COMPRESSION[2] SET, %	COMPRESSIVE STRENGTH, PSI AT 5%	
				Control	Test
Eccofoam S	Dia, n.c. L, -0.69	+0.01	97.2	720	674
Eccofoam SH	Dia, n.c. L, -0.30	+0.78	96.8	211	244

[1] As received.

[2] 25% compression.

Table 30

EFFECTS OF THERMAL-VACUUM ENVIRONMENT ON FOAM MATERIALS

(500 hours at 135°C and 10^{-6} torr)

MATERIAL[1]	DIMENSIONAL CHANGE, %	WEIGHT CHANGE, %	COMPRESSION[2] SET, %	COMPRESSIVE STRENGTH, PSI AT 5%	
				Control	Test
Eccofoam S	Dia, -0.18 L, -0.68	-1.35	116.6	720	580
Eccofoam SH	Dia, n.c. L, +0.20	-1.09	101.6	211	206

[1] As received.

[2] 25% compression.

Table 31

EFFECTS OF DECONTAMINATION CYCLES PLUS THERMAL VACUUM ENVIRONMENT ON FOAM MATERIALS

MATERIAL[1]	DIMENSIONAL CHANGE, %	WEIGHT CHANGE, %	COMPRESSION[2] SET, %	COMPRESSIVE STRENGTH, PSI AT 5%	
				Control	Test
Eccofoam S	Dia, -0.11 L, -0.76	-2.00	100.5	720	617
Eccofoam SH	Dia, n.c. L, +1.00	-0.93	101.9	211	206

[1] As received.

[2] 25% compression.

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X. HARDWARE AND STRUCTURAL (HS)

Except for the nylon-type plastics and one epoxy-glass laminate, all hardware and structural materials which have been examined appear to be suitable candidates for further evaluation on the basis of maximum-VCM content; as shown in Table 32, however, several materials are subsequently disqualified by excessive (>1%) weight-loss values.

Macro-VCM determinations for a number of these materials (Table 33) indicate that the acetal and polycarbonate plastics are most acceptable, and that the polyvinyl carbazole and nylon-types appear to release substances in the thermal-vacuum environment which apparently not only condense but re-polymerize so that VCM values tend to increase with time. Mass spectrometric identification of released substances, shown in Table 34, confirms these observations. In another instance, the apparent increase for VCM and weight loss was unexplained by the mass spectrometric identification of gross materials; however, the infrared spectrum of the VCM from Zytel-101 (see Appendix C) indicates that the VCM is due to low-molecular-weight fractions of nylon-11. This confirms observations from earlier work (with nylon-6) that the nylons are not suitable spacecraft materials since they do de-polymerize at relatively low temperatures in vacuum.

As shown in Tables 35 to 37, tests for mechanical and electrical properties of an acetal, Delrin 100NC10, indicate that no significant changes are incurred after exposures to decontamination and thermal-vacuum environments. Little changes are incurred also by Doryl H-17511 (a diphenyl oxide-glass fiber structure) after any exposure except for some increase in dielectric constant and a slight reduction in tensile strength. The phenolic-glass laminate Micarta H-5834 incurs less than 10% change in any mechanical or electrical properties. The silicone-glass laminate Micarta 20201-2 suffers a significant loss of tensile strength after thermal-vacuum exposures and softening after ETO and ETO/TVE exposures, but electrical properties are unaffected.

Table 32

MICRO-VCM DETERMINATIONS: HARDWARE AND STRUCTURAL

(24 hr at 125°C and 10^{-6} torr)

(VCM collectors at 25°C)

MATERIAL[1]	MFR.[2]	TREATMENT	TOTAL WT. LOSS, %	VCM, WT-%
Acetal plastics				
Delrin 100NCL0	DUP	As received	0.58	0.06
Delrin 150NCL0	DUP	As received	0.56	0.06
Delrin 00NCL0	DUP	As received	0.48	0.07
Delrin 500NCL0	DUP	As received (boot)	0.33	0.01
Delrin 507NCL9	DUP	As received	3.12	0.11
Delrin 900NCL0	DUP	As received	0.56	0.08
Chlorofluorocarbon				
Kel-F 81	MMA	As received	0.03	0.01
Diallylphthalate plastics				
Diall FS-4	ACM	Postcured 24 hr 150°C	0.58	0.02
Diall FS-10	ACM	Postcured 24 hr 150°C	0.70	0.03
Diall FS-40	ACM	Postcured 24 hr 150°C	1.00	0.02
Diall 52-40-40	ACM	As received	0.70	0.06
Diall 52-40-40	ACM	Postcured 24 hr 150°C	0.30	0.00
Diphenyl oxide-glass				
Doryl H-17479	WEM	Postcured 24 hr 150°C	0.34	0.13
Doryl H-17511	WEM	As received	0.44	0.04
Epoxy				
Furane Type 403	FPI	As received	0.43	0.01
Epoxy-glass laminate				
Micaply EG-725	TMC	As received	1.13	0.57
Micaply G-284	TMC	As received	0.49	0.06
Micarta H-2497	WEM	As received	0.18	0.00
Micarta H-8457	WEM	As received	0.80	0.12
Micarta H-17690	WEM	As received	0.48	0.07
Epoxy-glass molding				
Epiall 1906L	ACM	As received	0.39	0.06
Epiall 1906L	ACM	Postcured 24 hr 150°C	0.16	0.03
Epiall 1914	ACM	Postcured 24 hr 150°C	0.55	0.03
Phenolic-glass laminate				
Micarta H-5834	WEM	As received	0.70	0.03
91-LD-1581	ARP	As received	2.51	0.08

Table 32 (Concluded)

MATERIAL[1]	MFR.[2]	TREATMENT	TOTAL WT. LOSS, %	VCM, WT-%
Phenolic-glass molding				
Phenall 8010	ACM	Postcured 24 hr 150°C	1.25	0.02
Phenall 8060	ACM	Postcured 24 hr 150°C	1.56	0.02
Phenall 8700	ACM	Postcured 24 hr 150°C	1.25	0.01
Polyamide plastics				
Zytel-101 (boot)	DUP	As received	2.26	0.02
Zytel-31	DUP	As received	1.85	0.42
Zytel-42	DUP	As received	2.57	0.26
Zytel 101NC10	DUP	As received	3.58	0.21
Polycarbonate plastics				
Lexan 100-111	GEC	As received	0.06	0.02
Lexan 101-111	GEC	As received	0.08	0.01
Lexan 101-112	GEC	As received	0.09	0.04
Lexan 103-112	GEC	As received	0.17	0.01
Lexan 130-111	GEC	As received	0.17	0.01
Lexan 131-111	GEC	As received	0.18	0.01
Lexan 131-112	GEC	As received	0.17	0.01
Lexan 133-112	GEC	As received	0.20	0.01
Lexan 140-111	GEC	As received	0.17	0.03
Lexan 141-111	GEC	As received	0.17	0.04
Lexan 141-112	GEC	As received	0.17	0.02
Lexan 243-112	GEC	As received	0.16	0.01
Polyethylene plastic				
Beckman #101577	DCC	As received	0.62	0.35
Polyimide plastic				
Vespel SP-1	DUP	As received	1.24	0.01
Polyvinylcarbazole				
Luvican M170	BCC	As received	0.31	0.06
Luvican M170	BCC	Postcured 24 hr 150°C	0.11	0.09
Silicon-base				
High K707 (K = 15)	GES	As received	0.79	0.08
High K707 (K = 12)	GES	As received	0.41	0.01
Silicone-glass laminate				
Micarta 20201-2	WEM	As received	0.16	0.04

[1] See Appendix A.

[2] See Appendix B.

Table 33

MACRO-VCM DETERMINATIONS: HARDWARE AND STRUCTURAL

MATERIAL*	PROPERTY	HOURS OF EXPOSURE AT 125°C AND 10^{-6} TORR			
		24	48	96	336
Delrin 150NC10	Wt-loss, %	0.20	0.26	0.37	0.35
	VCM, wt-%	0.01	0.02	0.02	0.01
Delrin 500NC10 (boot)	Wt-loss %	0.32	0.23	0.26	0.38
	VCM, wt-%	0.03	0.05	0.04	0.04
Lexan 141-112	Wt-loss, %	--	0.15	0.15	0.17
	VCM, wt-%	--	0.01	0.01	0.01
Luvican M170	Wt-loss, %	0.05	0.06	0.09	0.09
	VCM, wt-%	0.01	0.01	0.01	0.03
Zytel-101 (boot)	Wt-loss, %	2.30	1.85	1.86	2.09
	VCM, wt-%	0.03	0.02	0.02	0.05

* Delrin 150NC10:	As received, cut in small pieces.
Delrin 500NC10:	As received, whole boot.
Lexan 141-112:	As received, whole chip.
Luvican M170:	As received, cut in small pieces.
Zytel-101:	As received, whole boot.

Table 34

MASS SPECTROMETRIC ANALYSIS IN SITU OF MATERIALS VOLATILIZED AT 125°C AND 10^{-6} TORR: HARDWARE AND STRUCTURAL

MATERIAL	IDENTIFIED COMPONENTS	
	Major	Minor
Delrin 150NC10	water	ester of phthalic acid; —cresol
Lexan 142-112	water; mixed hexanes	carbon dioxide; phenols; propylamine; squalene; hydrochloric acid
Luvican M170	vinyl carbazole	-
Zytel-101	water	dioctylphthalate

Table 35

EFFECTS OF DECONTAMINATION CYCLES ON HARDWARE AND STRUCTURAL MATERIALS

(Six cycles of humidified ETO—Freon for 30 hours at 50°C)

MATERIAL	PHYSICAL AND MECHANICAL PROPERTIES								ELECTRIC PROPERTIES				
	Dimensional Change, %	Weight Change, %	Rockwell Hardness		Tensile, psi		Elongation at Break, %		Frequency, MHz	Dielectric Constant		Dissipation Factor	
			Control	Test	Control	Test	Control	Test		Control	Test	Control	Test
Delrin 100NC10	-0.13	+0.16	18.9	19.0	10,646	10,021	13	20	1	3.47	3.67	<0.0001	<0.0001
									15	3.64	3.56	0.0001	<0.0001
									25	3.37	3.58	0.0002	<0.0001
									35	3.33	3.36	<0.0001	<0.0001
									50	3.48	3.36	0.0007	<0.0001
Doryl H-17511	0.05	+0.21	26.1	25.5	47,097	41,955	0	0	1	5.12	5.46	0.0015	0.0013
									15	4.94	5.38	0.0025	0.0020
									25	4.94	5.36	0.0026	0.0017
									35	4.83	5.38	0.0022	0.0008
									50	4.83	5.36	0.0031	0.0026
Micarta H-5834	0.52	+0.09	23.3	23.4	50,472	49,328	0	0	1	5.57	5.51	0.0018	0.0012
									15	5.46	5.46	0.0020	0.0023
									25	5.43	5.40	0.0010	0.0023
									35	5.35	5.40	0.0029	0.0012
									50	5.20	5.46	0.0023	<0.0001
Micarta 20201-2	-0.70	+0.15	19.3	18.7	39,106	32,185	0	0	1	4.94	4.89	0.0006	0.0004
									15	4.69	4.89	0.0007	0.0003
									25	4.94	4.89	0.0010	0.0005
									35	4.96	4.89	0.0011	0.0004
									50	4.96	4.89	0.0011	0.0002

Table 36

EFFECTS OF THERMAL-VACUUM ENVIRONMENT ON HARDWARE AND STRUCTURAL MATERIALS

(500 hours at 135° and 10^{-6} torr)

MATERIAL	PHYSICAL AND MECHANICAL PROPERTIES								ELECTRICAL PROPERTIES				
	Dimensional Change, %	Weight Change, %	Rockwell Hardness		Tensile, psi		Elongation at Break, %		Frequency, MHz	Dielectric Constant		Dissipation Factor	
			Control	Test	Control	Test	Control	Test		Control	Test	Control	Test
Delrin 100NC10	-0.61	-0.56	18.9	19.3	10,646	9,921	13	7	1	3.47	3.63	<0.0001	<0.0001
									15	3.64	3.46	0.0001	0.0001
									25	3.37	3.44	0.0002	0.0001
									35	3.33	3.43	<0.0001	0.0002
									50	3.48	3.46	0.0007	0.0003
Doryl B-17511	n.c.	-1.70	26.1	26.6	47,097	45,175	0	0	1	5.12	5.12	0.0015	0.0012
									15	4.94	5.05	0.0025	0.0014
									25	4.94	5.03	0.0026	0.0016
									35	4.83	5.03	0.0022	0.0012
									50	4.83	5.03	0.0031	0.0017
Micarta H-5834	n.c.	-0.46	23.3	23.9	50,472	49,194	0	0	1	5.57	5.23	0.0018	0.0014
									15	5.46	5.23	0.0020	0.0017
									25	5.43	5.23	0.0010	0.0026
									35	5.35	5.20	0.0020	0.0020
									50	5.20	5.23	0.0023	0.0024
Micarta 20201-2	n.c.	-0.01	19.2	19.0	39,106	28,300	0	0	1	4.94	4.96	0.0006	0.0002
									15	4.69	4.91	0.0007	0.0003
									25	4.94	4.91	0.0010	0.0004
									35	4.96	4.91	0.0011	0.0005
									50	4.96	4.89	0.0011	0.0008

Table 37

EFFECTS OF DECONTAMINATION CYCLES PLUS THERMAL-VACUUM EXPOSURE ON HARDWARE AND STRUCTURAL MATERIALS

MATERIAL	PHYSICAL AND MECHANICAL PROPERTIES								ELECTRICAL PROPERTIES				
	Dimensional Change, %	Weight Change, %	Rockwell Hardness		Tensile, psi		Elongation at Break, %		Frequency, MHz	Dielectric Constant		Dissipation Factor	
			Control	Test	Control	Test	Control	Test		Control	Test	Control	Test
Delrin 100NC10	-1.03	-1.27	18.9	19.5	10,646	10,138	13	9	1	3.47	3.41	<0.0001	<0.0001
									15	3.64	3.44	0.0001	0.0001
									25	3.37	3.57	0.0002	0.0002
									35	3.33	3.38	<0.0001	0.0002
									50	3.48	3.42	0.0007	0.0003
Doryl H-17511	n.c.	-1.64	26.1	25.1	47,097	42,294	0	0	1	5.12	5.13	0.0015	0.0012
									15	4.94	5.02	0.0025	0.0013
									25	4.94	5.04	0.0026	0.0015
									35	4.83	5.02	0.0022	0.0014
									50	4.83	5.02	0.0031	0.0013
Micarta H-5834	n.c.	-0.36	23.3	23.4	50,472	46,470	0	0	1	5.57	5.20	0.0018	0.0013
									15	5.46	5.12	0.0020	0.0016
									25	5.43	5.12	0.0010	0.0016
									35	5.35	5.12	0.0020	0.0016
									50	5.20	5.15	0.0023	0.0015
Micarta 20201-2	n.c.	0.03	19.2	18.7	39,106	36,993	0	0	1	4.94	4.90	0.0006	0.0002
									15	4.69	4.85	0.0007	0.0004
									25	4.94	4.85	0.0010	0.0004
									35	4.96	4.83	0.0011	0.0005
									50	4.96	4.80	0.0011	0.0008

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XI. HONEYCOMB CORE STRUCTURES (HC)

None of the honeycomb core materials listed in Table 38 approaches candidacy for spacecraft use on the basis of VCM and weight-loss values. On the other hand, the macro-VCM determinations made for the polyester HMH indicate (Table 39) that the VCM is re-evaporating with time. Unfortunately, it was found that the HMH samples (2" × 2" × 1") collapsed in the thermal-vacuum environment, that is, they lost all semblance of a honeycomb structure. It is emphasized that the core structures were examined per se; they were not fitted with facings. It is possible that the integrity of the structure may have been maintained had it been fastened suitably to a facing material, but, it is also equally possible that the thermal-vacuum exposure would cause severe warping of the structure even though the edges maintained their spacings by firm attachment to a facing.

The data for the composite structure listed in Table 38 is given here simply because the material tested is part of such a structure. For the small sample submitted, data was requested only for the facing. Thus, no recommendations can be made for the composite itself.

In view of the importance of honeycomb core structures as structural members of spacecrafts, it is suggested that sufficient material of strucutres in the form in which they are to be used be furnished for complete macro-VCM determinations and mechanical-property determinations.

Table 38

MICRO-VCM DETERMINATIONS: HONEYCOMB CORE STRUCTURES
(24 hr at 125°C and 10^{-6} torr)
(VCM collectors at 25°C)

MATERIAL[1]	MFR.[2]	TREATMENT	TOTAL WT. LOSS, %	VCM, WT-%
Phenolic				
HRP	HEX	As received	1.30	0.20
Polyester				
HMH	HEX	As received	0.18	0.17
Silicone				
HRS-asbestos	HEX	As received	0.37	0.37
HRS-glass fiber	HEX	As received	0.50	0.40
Composite				
HRP Adlock 851 FM-96U 6 ply	--	As received, facing only	0.81	<0.01
HRP Adlock 851 FM-96U 12 ply	--	As received, facing only	0.65	<0.01

[1] See Appendix A.
[2] See Appendix B.

Table 39

MACRO-VCM DETERMINATIONS: HONEYCOMB CORE STRUCTURES

MATERIAL*	PROPERTY	HOURS OF EXPOSURE AT 125°C AND 10^{-6} TORR			
		24	48	96	336
HMH	Wt-loss, %	--	0.15	0.15	0.20
	VCM wt-%	--	0.13	0.02	0.02

* As received; 2" × 2" × 1" section; the sample sections collapsed during all exposures.

XII. LUBRICANTS (LU)

As shown by the data in Table 40, the lubricants which are commonly used as diffusion pump oils and vacuum gasket lubes distill readily at 125°C in vacuum and easily condense at 25°C. However, a silicone vacuum grease recently marketed by the General Electric Company, G-683, has passed the screening tests with excellent weight-loss and VCM values. A cross-check in the macro-VCM apparatus, employing 10-gram samples, has confirmed the micro-VCM results as shown in Table 41. G-683 is recommended for void filling and for sealing and protecting electrical components. Used between structural members, it provides a "thermal joint" and improves the rate of heat dissipation of electrical components to their heat sinks. The use of this compound for lubrication of moving parts should be investigated.

A solid-film lubricant for moving parts, Electrofilm 4306, also can be recommended. The low weight-loss and VCM values shown in Table 40 are confirmed by the macro-VCM data in Table 41. The primary volatile component is simply a solvent (Table 42) which evaporates largely during spray application and is further removed in the curing cycle. This product must be thoroughly mixed prior to use. The companion Electrofilm, 2396, yields even better macro-VCM values, but these do not correlate as expected with the micro-VCM data, it may be that the thin film used for the macro determination was more completely cured than the 1/8" deep sample prepared for the micro determination. However, the identification of silicones and sulfur dioxide (Table 42) in the substances released at 125°C in vacuum precludes recommendation of this product.

A fluid lubricant has been identified as a candidate for spacecraft use; this is Union Carbide Chemicals' Ucon 50HB5100. It is a water-soluble polyalkylene glycol with a viscosity of 71,000 centistokes at 0°F and 168 at 210°F. The weight-loss shown by the micro-VCM determinations (Table 40) is marginal (probably water), but the VCM is well within the limit of 0.1%. A 48-hour run on large samples in the macro-VCM apparatus indicates a similar weight-loss value and a marginal VCM value (Table 41). A thousand-hour run with large samples (macro-VCM) is required before this lubricant can be fully qualified. However, it remains the most potential candidate compared with the other fluid lubricants which have been tested.

Table 40

MICRO-VCM DETERMINATIONS: LUBRICANTS

(24 hr at 125°C and 10^{-6} torr)

(VCM collectors at 25°C)

MATERIAL[1]	MFR.[2]	TREATMENT	TOTAL WT. LOSS, %	VCM, WT-%
Fluorocarbon				
PR-240-AC	DuP	As received	20.02	7.42
Phenolic-MoS_2				
Electrofilm 4306	EFI	As received; 1-1/2 hr 190°C	0.72	0.20
Electrofilm 4306	EFI	As received; 16 hr 190°C	0.67	0.09
Polyalkylene glycol				
Ucon 50HB55	UCC	As received	96.0	24.0
Ucon 50HB170	UCC	As received	24.5	16.0
Ucon 50HB660	UCC	As received	5.47	1.30
Ucon 50HB5100	UCC	As received	1.69	0.04
Polyphenyl ether				
Convalex-10 (0-061)	CVC	As received	46.4	40.0
Silicate-MoS_2-resin				
Electrofilm 2396	EFI	As received; 2 hr 80°C + 2 hr 205°C	0.32	0.20
Electrofilm 2396	EFI	As received; 2 hr 80°C + 16 hr 205°C	0.21	0.16
Silicone				
DC-11	DCC	As received	3.40	1.30
DC-705	DCC	As received	97.2	81.0
G-683	GES	As received	0.62	0.07
Versilube F-50	GES	As received	6.96	5.51
Versilube G-300	GES	As received	5.70	3.63

[1] See Appendix A.

[2] See Appendix B.

Table 41

MACRO-VCM DETERMINATIONS: LUBRICANTS

MATERIAL*	PROPERTY	HOURS OF EXPOSURE AT 125°C AND 10^{-6} TORR			
		24	48	96	336
Electrofilm 2396	Wt-loss, %	0.05	0.03	--	0.02
	VCM, wt-%	<0.01	<0.01	<0.01	<0.01
Electrofilm 4306	Wt-loss, %	0.05	0.13	0.30	0.22
	VCM, wt-%	<0.01	0.02	0.01	0.01
G-683	Wt-loss, %	0.51	0.64	0.62	0.64
	VCM, wt-%	0.01	0.02	0.02	0.03
Ucon 50HB5100	Wt-loss, %	--	1.50	--	--
	VCM, wt-%	--	0.13	--	--

* Electrofilms were prepared as thin films:

Electrofilm 2396, cured 2 hr 80°C + 2 hr 205°C.

Electrofilm 4306, cured 1-1/2 hr 190°C.

G-683, used as received.

Ucon 50HB5100, used as received.

Table 42

MASS SPECTROMETRIC ANALYSIS *IN SITU* OF MATERIALS VOLATILIZED AT 125°C AND 10^{-6} TORR: LUBRICANTS

MATERIAL	IDENTIFIED COMPONENTS	
	Major	Minor
Electrofilm 2396	mixed silicones	sulfur dioxide
Electrofilm 4306	Freon solvent	--

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XIII. MARKING MATERIALS (MM)

Because many components, sub-assemblies, etc. for spacecrafts are marked for identification and location, the amount of VCM which might occur from various marking materials (inks) is of interest. Thus, a set of determinations was made for the kinds of materials most likely to be used. In order to simulate actual use, that is, as a thin film of print, stamp-pad and marking inks were applied to small stainless steel screens by dipping the screens into the inks, draining, and drying for at least one hour. Felt-pen inks were applied to 1/2 X 12" aluminum foil strips by brushing with the felt tips; the strips were dried for one hour and rolled to fit into the sample compartments of the micro-VCM apparatus. Type-ribbon inks were applied also to aluminum foil strips by pressing the ink onto the strips with a blunt instrument.

As shown in Table 43, a gross weight loss is incurred by all of the materials, which is to be expected since the pigments are dispersed in a solvent mixture. The VCM values are also quite large, and probably due to viscosity-control agents such as glycols and binding agents such as resins.

However, the weight of ink actually used in a spacecraft assembly is not apt to be very great; it was determined that the weight of printed matter per area is about 0.13 mg/in^2 or 18.7 mg/ft^2. Thus, a little more than five square feet would have to be covered with stamped numerals or letters to provide 1 gram of ink weight. The determination was made by covering weighed 2" X 5" pieces of aluminum foil with numbers and letters applied by using stamp pads and a date stamp, by hand-lettering with the fine tip of the felt pens, and by typing with the ribbons. The printed matter was allowed to dry for one hour before reweighing.

Table 43

MICRO-VCM DETERMINATIONS: MARKING MATERIALS
(24 hours at 125°C and 10^{-6} torr)
(VCM collectors at 25°C)

MATERIAL	MFR.[1]	TREATMENT	TOTAL WT. LOSS, %	VCM, WT-%
Stamp-Pad Inks				
Sanford 580 (black)	SAN	Cured 1 hr 25°C	88.4	0.2
Carter's 411 (red)	CAR	Cured 1 hr 25°C	88.6	0.3
Marking Inks				
73X (black)	IND	Cured 1 hr 25°C	62.2	0.9
73X (white)	IND	Cured 1 hr 25°C	12.4	1.2
Felt Marking Pens				
Rembrandts' (black)	REM	Cured 1 hr 25°C	28.5	5.4
Rembrandts' (red)	REM	Cured 1 hr 25°C	33.2	5.4
Type Ribbon Inks				
Nylon ribbon	IBM	Cured 1 hr 25°C	54.0	20.0
Cotton ribbon	PKA	Cured 1 hr 25°C	48.6	15.9

[1] See Appendix B.

XIV. PROTECTIVE COATINGS (PC)

Of the twenty-eight protective coating materials listed in Table 44, only three can qualify within the limits of less than 1% weight loss and less than 0.1% VCM; these are Eccocoat PCA/16 (postcured) and JPL-1001 and -1002. Identification of the substances given off by JPL-1002 (Table 45) indicates that only excess solvents and reagent are evolved and are of a kind that can be removed in the vacuum of space with no effect on mechanical properties (especially in view of the small weight-loss values). The only difference between JPL-1001 and -1002 is the addition of a trace of fluorescent dye to JPL-1001.

Marginal candidates such as Doryl B109-4 (or B109-5) may qualify by more extended curing, but the high temperature of cure is forbidding; the first attempts to cure these materials at a lower temperature for a longer time, 24 hours at 150°C, resulted in weight-losses and VCM values of about 3% and 1%, respectively. On the other hand, a marginal rating for the polyurethane Laminar X-500 (clear) is given because of an excessive weight-loss value since the VCM value is within limits. It is possible that alternative curing cycles, particularly extension of time or vacuum-curing, will remove the apparently excessive solvent component.

Changes in mechanical properties of two other protective coatings during decontamination and thermal-vacuum cycles are summarized in Tables 46 to 48 and show that the adhesion shear of Eccocoat EP-3 is affected by the decontamination cycles, but remains well above that of the control; shrinkage values may have to be considered, however, for end use. The Eccogel 1265 is less subject to change, but the excessive weight-loss and VCM values (Table 44) must be considered. The electrical properties of either material are affected less than 10% during any exposure.

Table 44

MICRO-VCM DETERMINATIONS: PROTECTIVE COATINGS

(24 hr at 125°C and 10^{-6} torr)
(VCM collectors at 25°C)

MATERIAL[1]	MFR.[2]	TREATMENT	TOTAL WT. LOSS, %	VCM, WT-%
Alkyd				
B224-2	WEI	As received, 3 hr 95°C + 1 hr 150°C	8.99	3.86
Glyptal 1201	GEI	As received; 4 hr 125°C	6.10	2.55
Glyptal 1201	GEI	As received; 24 hr 150°C	3.70	1.60
Glyptal 1202	GEI	As received; 4 hr 125°C	5.55	2.46
Glyptal 1202	GEI	As received; 24 hr 150°C	5.20	2.78
Diphenyl oxide				
Doryl B109-4	WEI	As received; 2 hr 250°C	0.30	0.15
Doryl B109-5	WEI	As received; 2 hr 250°C	0.18	0.14
Epoxy				
B-276	WEI	As received; 3 hr 95°C + 1 hr 150°C	3.52	1.15
Cat-a-Lac Clear 473-1	FPC	As received; 24 hr 25°C	25.48	3.30
Cat-a-Lac Clear 473-1	FPC	As received; 24 hr 150°C	1.09	0.82
Eccocoat C-26 A B	EMC	100pA 60pB; 2 hr 93°C + 2 hr 175°C	0.91	0.35
Eccocoat EC-200 A B	EMC	100pA 10pB, 8 hr 121°C	1.74	0.48
Eccocoat PCA 16	EMC	100pA 2p16, 8 hr 121°C	0.85	0.14
Eccocoat PCA 16	EMC	100pA 2p16; 1 hr 25°C + 2 hr 95°C + 24 hr 150°C	0.18	0.02
Eccocoat VE A B	EMC	100pA 100pB, 8 hr 121°C	2.42	0.92
Eccocoat VE A B	EMC	100pA 100pB, 6 hr 125°C + 24 hr 150°C	1.51	0.52
Eccocoat 210 A B	EMC	100pA 35pB; 24 hr 25°C + 1 hr 75°C	2.86	0.36
Eccocoat 210 A B	EMC	100pA 35pB, 24 hr 25°C + 1 hr 75°C + 24 hr 150°C	0.78	0.36
Eccogel 1265 A B	EMC	100pA 100pB, 16 hr 65°C	5.10	3.75
Eccogel 1265 A B	EMC	100pA 100pB; 16 hr 65°C + 24 hr 150°C	1.66	0.87
PT-401 H-11	PTI	100p401 6pH-11, 20 min 93°C	18.29	0.65
PT-401 H-11	PTI	100p401 6pH-11, 16 hr 65°C	14.20	0.10
Stycast 1217 9	EMC	100p1217 13p9, 16 hr 52°C	1.74	0.14
Stycast 1217 9	EMC	100p1217 13p9, 16 hr 52°C + 24 hr 150°C	0.57	0.12
Polyester-phenolic				
Eccocoat PH7	EMC	As received, 2 hr 150°C	5.22	1.92
Eccocoat PH7	EMC	As received, 24 hr 150°C	1.55	0.84

Table 44 (Concluded)

MATERIAL[1]	MFR.[2]	TREATMENT	TOTAL WT. LOSS, %	VCM, WT-%
Polyimide				
PYRE-M.L. BK-692	DUF	As received; 1 hr 95°C + 1 hr 150°C + 1 hr 205°C	1.34	0.35
PYRE-M.L. BK-692	DUF	As received; 24 hr 150°C	3.00	0.48
Polyurethane				
Eccocoat EP-3 A B	EMC	100pA 50pB; 48 hr 25°C	3.71	0.28
Eccocoat EP-3 A B	EMC	100pA 50pB; 48 hr 25°C + 16 hr 50°C	3.05	0.18
Eccocoat IC2 A B	EMC	100pA 50pB; 1 hr 25°C + 2 hr 95°C + 24 hr 150°C	6.99	1.48
JPL-1001	AAC	As received; 4 hr 75°C	0.20	0.10
JPL-1002	AAC	As received; 4 hr 75°C	0.19	0.02
Laminar X-500 (4C-8 clear) 10C-45	MCC	100p4C-8 100p10C-45; 72 hr 25°C	20.44	0.10
Laminar X-500 (4C-8 clear) 10C-45	MCC	100p4C-8 100p10C-45; 72 hr 25°C + 24 hr 125°C	4.65	0.08
Silicone				
A-2841-L-618 (gray)	BIW	As received; coating stripped from wire	1.08	0.73
A-2841-L-618 (gray)	BIW	As received; coating stripped from wire; 24 hr 150°C	0.70	0.41
A-2841-L-618 (yellow)	BIW	As received, coating stripped from wire	1.27	0.55
A-2841-L-618 (yellow)	BIW	As received, coating stripped from wire 24 hr 150°C	0.84	0.45
SR-17	GES	As received, 24 hr 150°C	1.22	0.80
SR-98	GES	As received, 24 hr 150°C	2.48	1.61
SR-220	GES	As received, 5 hr 150°C	3.76	2.71
SR-220	GES	As received; 24 hr 150°C	3.52	2.86
SR-290	GES	1pSR-98 1pSR-220; 1 hr 125°C	4.87	1.42

[1] See Appendix A.

[2] See Appendix B.

Table 45

MASS SPECTROMETRIC ANALYSIS *IN SITU* OF MATERIALS VOLATILIZED AT 125°C AND 10^{-6} TORR: PROTECTIVE COATING

MATERIAL	IDENTIFIED COMPONENTS	
	Major	Minor
JPL-1002	aromatic solvent	toluene diisocyanate; cellosolve acetate

Table 46

EFFECTS OF DECONTAMINATION CYCLES ON PROTECTIVE COATINGS

(Six cycles of Humidified ETO-Freon for 30 Hr at 50°C)

MATERIAL*	MECHANICAL PROPERTIES				ELECTRICAL PROPERTIES				
	Dimensional Change, %	Weight Change, %	Adhesion Shear, psi		Frequency, MHz	Dielectric Constant		Dissipation Factor	
			Control	Test		Control	Test	Control	Test
Eccocoat EP-3 A B	Dia., n.c. L., n.c.	+1.87	251	154	1	3.45	3.84	0.008	0.014
					15	3.41	3.66	0.006	0.013
					25	3.25	3.59	0.009	0.012
					35	3.30	3.53	0.008	0.020
					50	3.20	3.50	0.007	0.009
Eccogel 1265 A B	Dia., +0.25 L., n.c.	+0.96	190	206	1	4.85	4.93	0.055	0.001
					15	4.10	4.15	0.042	0.043
					25	4.01	4.02	0.038	0.040
					35	3.92	3.94	0.034	0.035
					50	3.81	3.86	0.021	0.044

* See footnote, Table 48.

Table 47

EFFECTS OF THERMAL-VACUUM ENVIRONMENT ON PROTECTIVE COATINGS
(500 Hr at 135°C and 10^{-6} Torr)

MATERIAL*	MECHANICAL PROPERTIES				ELECTRICAL PROPERTIES				
	Dimensional Change, %	Weight Change, %	Adhesion Shear, psi		Fre-quency, MHz	Dielectric Constant		Dissipation Factor	
			Control	Test		Control	Test	Control	Test
Eccocoat EP-3 A B	Dia., -1.15 L., -1.01	-4.52	251	509	1	3.45	3.49	0.008	0.008
					15	3.41	3.44	0.006	0.009
					25	3.25	3.35	0.009	0.009
					35	3.30	3.30	0.008	0.008
					50	3.20	3.30	0.007	0.005
Eccogel 1265 A B	Dia., -0.30 L., n.c.	-1.06	190	382	1	4.85	4.73	0.055	0.051
					15	4.10	3.96	0.042	0.040
					25	4.01	3.94	0.038	0.035
					35	3.92	3.81	0.034	0.016
					50	3.31	3.76	0.021	0.028

* See footnote, Table 48.

Table 48

EFFECTS OF DECONTAMINATION CYCLES PLUS THERMAL VACUUM ENVIRONMENT ON PROTECTIVE COATINGS

MATERIAL*	MECHANICAL PROPERTIES				ELECTRICAL PROPERTIES				
	Dimensional Change, %	Weight Change, %	Adhesion Shear, psi		Fre-quency, MHz	Dielectric Constant		Dissipation Factor	
			Control	Test		Control	Test	Control	Test
Eccocoat EP-3 A B	Dia., -1.77 L., -1.98	-4.49	251	450	1	3.45	3.57	0.008	0.006
					15	3.41	3.34	0.006	0.007
					25	3.25	3.31	0.009	0.009
					35	3.30	3.31	0.008	0.009
					50	3.20	3.33	0.007	0.002
Eccogel 1265 A B	Dia., -0.36 L., n.c.	-2.46	190	606	1	4.85	4.66	0.055	0.047
					15	4.10	4.02	0.042	0.042
					25	4.01	3.94	0.038	0.034
					35	3.92	3.78	0.034	0.030
					50	3.81	3.70	0.021	0.027

* Samples for all exposures were prepared as follows:

Eccocoat EP-3 A B. - Mixed 100 parts A with 50 parts B; cured after application to test strips for 48 hours at 25°C.

Eccogel 1265 A B. - Mixed 100 parts A with 100 parts B; cured after application to test strips for 16 hours at 65°C.

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XV. SEALANTS (SE)

On the basis of the micro-VCM data given in Table 49, there are nine rigid epoxy encapsulants which qualify as spacecraft candidates; five of these can be cured satisfactorily at temperatures less than 85°C, but mechanical property data must be obtained before these products can be fully recommended. For the rigid encapsulants particularly, data should be acquired on the level of internal stresses set up within them since delicate electronic components may be damaged when a potted module is exposed to the thermal-vacuum environment.

Of twenty-five flexible silicone encapsulants which have been examined, only one has passed the screening tests--and that with superior performance. The encapsulant is an experimental silicone resin, E691-22E, prepared by the Dow-Corning Company; it is a specially-processed version of Sylgard-184. The only information provided on this sample is that the low-molecular-weight silicone fraction was "cleaned-out" prior to delivery.

Another flexible encapsulant, polyurethane Stycast CPC-41, meets candidacy requirements after a postcure of 24 hours at 150°C. However, the small difference in values from the material cured 48 hours at 65°C implies that a longer cure at 65°C not only may provide the same results but may even reduce the weight-loss and VCM values even further.

Data for mechanical and electrical properties after decontamination (ETO) and thermal-vacuum treatments (TVE) are given for several RTV silicones in Tables 50 to 52. None of these products exhibits any significant changes in electrical properties after any of the cycles. RTV-40 and RTV-511 are subject to shrinkage and compression set after all exposures; little change in hardness or compressive strength is noted. RTV-615 incurs the least compression set, an increase in compressive strength after TVE and ETO/TVE exposures, and little change in hardness.

The most noticeable changes in mechanical properties following ETO treatment are incurred by RTV-602. It shows a pronounced loss of hardness after ETO/TVE treatment; compressive strength is lost after ETO and TVE treatment and can not be measured after ETO/TVE exposures. The material is subject to gross compression set, particularly after the combined ETO/TVE exposures.

It was observed that RTV-602 samples which had been exposed to the ETO cycles apparently released gases during the subsequent exposures to the thermal-vacuum environment (see Figure 17), as indicated by "holes" or "gas pockets" in the samples. Thus, these samples were examined by infrared spectrophotometry and mass spectroscopy in an effort to detect any differences in structure or volatilized material.

The infrared spectra for the control sample and the three exposed samples revealed no differences in characteristic features nor any additional features.

Pieces of the samples were cut away from the surface (about 1/4" x 1/4" x 1/2") for mass spectrometric examination. They were placed in a sample holder which was fastened directly to the 3-liter reservoir of a standard inlet system. The sample holder was evacuated at room temperature and immediately brought to 125°C; the vapors were collected in the 3-liter reservoir until sufficient sample pressure was available for scanning.

> It is interesting to note that even after 500 hours of exposure to an environment of 135°C and 10^{-6} torr, the TVE sample was still releasing sufficient substances (VCM) at 125°C in vacuo for mass spectrometric study. Since the original sample was about 1" thick and 2" in diameter, it appears that thermal-vacuum clean-up cannot be recommended for thick materials.

Previous examination of silicone polymers (SE-555 white, red, and gray, and RTV-60) has revealed the presence of low-molecular-weight silicones in the vapors released at 125°C in vacuum. These silicones were found in the vapors released by RTV-602. However, an additional component, trimethyl silanol, was also identified in the control sample and the samples which had been exposed to the ETO, TVE, and ETO/TVE cycles; it is used generally as a cross-linker for silicone resins. At this time, it is not certain whether the initial presence of this material contributes to the loss in properties after the various exposures, or whether cross-linkages have been broken or hydrolyzed during the various exposures. No ethylene oxide, Freon, or ethylene glycol was present in the samples used for the analyses. An extensive study of the samples to ascertain the reaction which might have taken place to cause the reduction of mechanical properties and the formation of the gas pockets was not undertaken. (The specimens photographed in Figure 17 were used for compressive strength tests; duplicate, thinner specimens used for compression set after ETO/TVE did not show the internal holes, but the surfaces were covered with features suggesting the breaking of gas bubbles.)

Table 49

MICRO-VCM DETERMINATIONS: SEALANTS

(24 hr at 125°C and 10^{-6} torr)
(VCM Collectors at 25°C)

MATERIAL[1]	MFR.[2]	TREATMENT	TOTAL WT. LOSS, %	VCM, WT-%
Epoxy				
BR-617 A/B	ACB	100pA/25pB; 48 hr 25°C	31.02	0.91
BR-617 A/B	ACB	100pA/25pB; 48 hr 25°C + 16 hr 52°C	30.82	0.89
Corfil 615/Z	ACB	100p615/14.5pZ; 16 hr 50°C + 1 hr 150°C	2.00	0.07
Epocast 168/995	FPI	90p168/10p995; 16 hr 50°C + 1 hr 150°C	1.53	0.06
Epoxylite 295-1 A/B (batch 2469)	EPC	Mfrs' sample, as received (1:1; 8 hr 113°C)	1.27	0.17
Epoxylite 295-1 A/B (batch 4024-1)	EPC	Contractor's sample, as received (1:1; 24 hr/85°C + 4 hr 115°C)	1.67	0.09
Epoxylite 295-1 A/B (batch 4024-2)	EPC	Contractor's sample, as received (1:1; 24 hr/85°C + 4 hr 115°C)	1.00	0.35
Hysol 5150/3690	HYS	100p5150/100p3690; 24 hr 25°C	1.82	0.17
Hysol C7/4248	HYS	100pC7/100p4248; 2 hr 25°C + 16 hr 175°C	0.66	0.23
Maraset 655/553	MRC	100p655/20p553; 16 hr 82°C	0.59	0.00
Maraset 655/553	MRC	100p655/20p553; 16 hr 82°C + 24 hr 150°C	0.32	0.00
Maraset 655/555	MRC	100p655/7p555; 16 hr 82°C	0.41	0.00
Maraset 655/555	MRC	100p655/7p555; 16 hr 82°C + 24 hr 150°C	0.25	0.00
Scotchcast 235 A/B (brown)	MME	50pA/100pB; 6 hr 93°C	6.20	0.31
Scotchcast 235 A/B (brown)	MME	50pA/100pB; 16 hr 93°C	2.78	0.02
Scotchcast 241 A/B	MME	50pA/100pB; 6 hr 95°C	2.97	0.04
Scotchcast 241 A/B	MME	50pA/100pB; 3 hr 121°C	1.93	0.05
Scotchcast 260	MME	As received; 30 min 150°	0.52	0.03
Scotchcast 281 A/B	MME	100pA/150pB; 20 hr 75°C	0.36	0.05
Stycast 1210 A/B	EMC	100pA/50pB; 24 hr 150°C	1.67	0.05
Stycast 1263/31	EMC	100p1263/3p31; 16 hr 107°C + 24 hr 150°C	0.12	0.01
Stycast 1264 A/B	EMC	100pA/45pB; 48 hr 25°C	2.80	0.14
Stycast 1269 A/B	EMC	100pA/55pB; 16 hr 75°C + 4 hr 100°C + 4 hr 120°C	2.02	1.10
Stycast 1269 A/B	EMC	100pA/100pB; 16 hr 100°C + 24 hr 150°C	0.18	0.05
Stycast 2741/15	EMC	100p2741/150p15; 8 hr 25°C	10.63	2.00
Stycast 2741/15	EMC	100p2741/150p15; 8 hr 25°C + 24 hr 150°C	1.65	0.10
Stycast 2850 FT/9	EMC	100p2850/3.5p9; 16 hr 25°C	0.34	0.04
Stycast 2862 A/B	EMC	100pA/100pB; 16 hr 120°C	0.32	0.04

Table 49 (Continued)

MATERIAL[1]	MFR.[2]	TREATMENT	TOTAL WT. LOSS, %	VCM, WT-%
Stycast 2862 A B	EMC	100pA 100pB; 16 hr 120°C + 24 hr 150°C	0.00	0.00
Stycast 3050/11	EMC	100p3050/9.5p11; 16 hr 77°C	0.68	0.06
Polyester				
Stycast 40 7	EMC	100p40 2p7; 16 hr 25°C + 2 hr 85°C + 24 hr 150°C	2.26	0.35
Polyethylene				
TPM-2/10	EMC	100pTPM-2 1p10; 12 hr 50°C + 4 hr 80°C	6.41	0.42
TPM-3/10	EMC	100pTPM-3 1p10; 12 hr 50°C + 4 hr 80°C	3.33	0.90
TPM-6 A B	EMC	100pA 4pB; 16 hr 105°C + 4 hr 145°C + 4 hr 175°C	2.29	0.47
Polyurethane				
Ecco CP6 R6	EMC	100pCP6 17pR6; 3 hr 105°C	5.78	2.01
PR-1527 A B	PRC	26pA 100pB; 6 hr 82°C	1.65	0.44
PR-1527 A B	PRC	33pA/100pB; 7 das 25°C	1.14	0.23
PR-1538 A B	PRC	32pA 100pB; 6 hr 82°C	2.07	0.56
PR-1538 A B	PRC	33pA 100pB; 3 hr 25°C + 3 hr 82°C	1.15	0.16
Stycast CPC-21 A B	EMC	100pA 60pB; 6 hr 95°C	17.33	4.18
Stycast CPC-21 A B	EMC	100pA 60pB; 6 hr 95°C + 24 hr 150°C	15.32	4.03
Stycast CPC-22 A B	EMC	100pA 60pB; 40 hr 65°C	29.86	5.48
Stycast CPC-22 A B	EMC	100pA 60pB; 40 hr 65°C + 24 hr 150°C	28.25	5.12
Stycast CPC-41 A B	EMC	100pA 120pB; 48 hr 65°C	0.66	0.14
Stycast CPC-41 A B	EMC	100pA 120pB; 48 hr 65°C + 24 hr 150°C	0.58	0.10
Silicone				
E691-22E (exptl resin, specially-processed Sylgard-184)	DCC	Mfr's sample; used as received	0.19	0.04
RTV-11	GES	Mfr's sample; postcured 24 hr/150°C	0.91	0.55
RTV-30 T-12	GES	100p30 0.1pT-12; 24 hr 25°C + 24 hr 135°C	0.74	0.34
RTV-40 T-12	GES	100p40 0.1pT-12; 24 hr 25°C	1.49	0.43
RTV-40 T-12	GES	100p40 0.1pT-12; 24 hr 25°C + 24 hr 150°C	1.07	0.56
RTV-40 T-12	GES	100p40 0.1pT-12; 7 das 25°C	1.07	0.33
RTV-41 T-12	GES	100p41 0.1pT-12; 8 hr 25°C + 4 hr 50°C	2.06	0.45
RTV-41 T-12	GES	100p41 0.1pT-12; 8 hr 25°C + 24 hr 150°C	1.09	0.60
RTV-41 T-12	GES	100p41 0.1pT-12; 8 hr 25°C + 24 hr 250°C	0.17	0.12
RTV-60	GES	Mfr's sample; postcured 24 hr 150°C	0.69	0.54
RTV-77 T-12	GFS	100p77 0.1pT-12; 8 hr 25°C + 24 hr 150°C	1.69	1.02

Table 49 (Concluded)

MATERIAL[1]	MFR.[2]	TREATMENT	TOTAL WT. LOSS, %	VCM, WT-%
RTV-88/T-12	GES	100p88/0.1pT-12; 24 hr 25°C + 24 hr 135°C	0.66	0.36
RTV-90	GES	Mfr's sample; postcured 24 hr 150°C	0.62	0.49
RTV-102 (white)	GES	As received; 24 hr 25°C	5.45	1.63
RTV-102 (white)	GES	As received; 24 hr 25°C + 24 hr 125°C	2.97	1.55
RTV-103 (black)	GES	As received; 24 hr 25°C	5.35	1.72
RTV-103 (black)	GES	As received; 24 hr 25°C + 24 hr 150°C	2.92	1.65
RTV-108 (clear)	GES	As received; 24 hr 25°C	5.52	1.60
RTV-108 (clear)	GES	As received; 24 hr 25°C + 24 hr 150°C	3.11	1.60
RTV-560	GES	Mfr's sample; postcured 24 hr 150°C	1.03	0.68
RTV-580/T-12	GES	100p580/0.1pT-12; 24 hr 25°C + 24 hr 150°C	1.81	0.81
RTV-602/SRC-05	GES	100p602/0.25pSRC-05; 24 hr 25°C	3.10	0.96
RTV-602/SRC-05	GES	100p602/0.25pSRC-05; 24 hr 25°C + 24 hr 150°C	2.07	1.04
RTV-615	GES	Mfr's sample; postcured 24 hr 150°C	1.01	0.77
RTV-630 A/B	GES	100pA/10pB; 48 hr 25°C + 24 hr 150°C	1.30	0.81
RTV-632 A/B	GES	100pA/10pB; 48 hr 25°C + 24 hr 150°C	1.25	0.74
RTV-655	GES	Mfr's sample; postcured 24 hr 150°C	2.72	1.27
Silastic-501/T-12	DCC	100p501/4pT-12; 7 das 25°C	5.32	3.62
Silastic-501/T-12	DCC	100p501/4pT-12; 7 das 25°C + 24 hr 125°C	4.12	3.01
Silastic-732 (clear)	DCC	As received; 24 hr 25°C	2.39	0.75
Silastic-732 (clear)	DCC	As received; 24 hr 25°C + 24 hr 150°C	1.59	0.80
Silastic-732 (black)	DCC	As received; 24 hr 25°C	2.50	0.84
Silastic-732 (black)	DCC	As received; 24 hr 25°C + 24 hr 150°C	1.76	0.85
Silastic-732 (white)	DCC	As received; 24 hr 25°C	2.96	0.96
Silastic-732 (white)	DCC	As received; 24 hr 25°C + 24 hr 150°C	1.73	0.93
Silastic-881/Cat	DCC	100p881/4.6pCat; 24 hr 25°C	2.95	0.78
Silastic-881/Cat	DCC	100p881/4.6pCat; 24 hr 25°C + 24 hr 125°C	1.43	0.80
Silastic-881/Cat	DCC	100p881/4.6pCat/0.32pT-12; 24 hr 25°C	3.15	1.07
Silastic-881/Cat	DCC	100p881/4.6pCat/0.32pT-12; 24 hr 25°C + 24 hr 125°C	1.66	0.88
Silastic-3116/T-12	DCC	100p3116/4.0pT-12; 7 das 25°C	1.84	0.61
Silastic-3116/T-12	DCC	100p3116/4.0pT-12; 7 das 25°C + 24 hr 125°C	1.05	0.63
Silastic-3116/T-12	DCC	100p3116/4.24pT-12; 7 das 25°C	1.77	0.[illegible]
Sylgard-184/Cat	DCC	90p184/10pCat; 4 hr 65°C	1.77	0.89
Sylgard-184/Cat	DCC	90p184/10pCat; 4 hr 65°C + 24 hr 150°C	0.94	0.62

[1] See Appendix A.

[2] See Appendix B.

Table 50

EFFECTS OF DECONTAMINATION CYCLES ON SEALANTS
(Six cycles of humidified ETO-Freon for 30 hr at 50°C)

MATERIAL[1]	MECHANICAL PROPERTIES							ELECTRICAL PROPERTIES				
	Dimensional Change, %	Weight Change, %	Shore Hardness		Compressive Strength, psi at 10%		Compression Set, %[2]	Frequency, MHz	Dielectric Constant		Dissipation Factor	
			Control	Test	Control	Test			Control	Test	Control	Test
RTV-40 T-12	L, n.c.; W, n.c.	-0.21	58.0	60.3	47.4	48.9	95.69	1	3.19	3.40	0.0026	0.0009
								15	3.19	3.39	0.0012	0.0009
								25	3.19	3.38	0.0009	0.0011
								35	3.19	3.37	<0.0001	0.0010
								50	3.19	3.19	<0.0001	0.0008
RTV-511 T-12	L, n.c.; W, 0.49	-1.00	50.2	50.5	31.7	29.8	74.42	1	3.62	3.59	0.0023	0.0009
								15	3.64	3.59	0.0015	0.0005
								25	3.63	3.57	0.0015	0.0002
								35	3.62	3.57	0.0043	0.0009
								50	3.52	3.70	<0.0001	0.0012
RTV-602 13	L, n.c., W, -0.09	-0.44	30.8	28.5	17.4	13.0	108.83	1	2.92	2.91	0.0010	0.0009
								15	2.88	2.92	0.0010	<0.0001
								25	2.88	2.92	<0.0001	<0.0001
								35	2.88	2.92	<0.0001	<0.0001
								50	2.88	2.92	<0.0001	<0.0001
RTV-615 A B	L, -0.20, W, n.c.	+0.05	60.8	58.8	33.5	29.5	15.25	1	2.89	2.98	0.0003	<0.0001
								15	2.86	2.96	<0.0001	<0.0001
								25	2.88	2.97	<0.0001	<0.0001
								35	2.88	2.97	<0.0001	<0.0001
								50	2.88	2.97	<0.0001	<0.0001

[1] Mixed according to mfr. instructions, cured 1 hr 65°C + 1 hr 95°C.

[2] 25% compression.

Table 51

EFFECTS OF THERMAL-VACUUM ENVIRONMENT ON SEALANTS

(500 hr at 135°C and 10^{-6} torr)

MATERIAL[1]	MECHANICAL PROPERTIES							ELECTRICAL PROPERTIES				
	Dimensional Change, %	Weight Change, %	Shore Hardness		Compressive Strength psi at 10%		Compression Set, %[2]	Frequency, MHz	Dielectric Constant		Dissipation Factor	
			Control	Test	Control	Test			Control	Test	Control	Test
RTV-40 T-12	L, -1.20; W, -0.50	-1.71	58.0	59.2	47.4	52.8	102.63	1	3.19	3.41	0.0026	0.0011
								15	3.19	3.41	0.0012	0.0007
								25	3.19	3.39	0.0009	0.0006
								35	3.19	3.40	<0.0001	0.0017
								50	3.19	3.39	<0.0001	0.0904
RTV-511 T-12	L, -2.21; W, -1.75	-4.96	50.2	51.3	31.7	37.2	101.72	1	3.62	3.51	0.0033	0.0028
								15	3.64	3.54	0.0015	0.0014
								25	3.63	3.51	0.0015	0.0031
								35	3.62	3.51	0.0043	<0.0001
								50	3.52	3.51	<0.0001	<0.0001
RTV-602 13	L, -0.40; W, -0.86	-2.31	30.8	29.0	17.4	13.3	87.27	1	2.92	3.03	0.0010	0.0007
								15	2.88	3.10	0.0010	<0.0001
								25	2.88	3.04	<0.0001	<0.0001
								35	2.88	3.06	<0.0001	<0.0001
								50	2.88	3.06	<0.0001	<0.0001
RTV-615 A B	L, -1.18; W, -0.65	-1.72	60.8	60.9	33.5	41.8	75.42	1	2.89	2.95	0.0003	0.0002
								15	2.88	2.97	<0.0001	0.0606
								25	2.88	2.95	<0.0001	0.0003
								35	2.88	2.94	<0.0001	<0.0001
								50	2.88	2.95	<0.0001	<0.0001

[1] Mixed according to mfr. instructions; cured 1 hr/65°C + 1 hr/95°C.

[2] 25% compression.

Table 52

EFFECTS OF DECONTAMINATION CYCLES PLUS THERMAL-VACUUM ENVIRONMENT ON SEALANTS

MATERIAL[1]	MECHANICAL PROPERTIES							ELECTRICAL PROPERTIES				
	Dimensional Change, %	Weight Change, %	Shore Hardness		Compressive Strength, psi at 10%		Compression Set, %[2]	Frequency, MHz	Dielectric Constant		Dissipation Factor	
			Control	Test	Control	Test			Control	Test	Control	Test
RTV-40 T-12	L, -1.02; W, 0.00	-1.84	58.0	60.7	47.4	51.8	107.76	1	3.19	3.43	0.0026	0.0013
								15	3.19	3.42	0.0012	0.0009
								25	3.19	3.38	0.0009	0.0008
								35	3.19	3.38	<0.0001	0.0008
								50	3.19	3.38	<0.0001	0.0005
RTV-511 T-12	L, -2.10; W, -2.25	-5.37	50.2	51.2	31.7	34.6	113.56	1	3.62	3.61	0.0023	0.0002
								15	3.64	3.63	0.0015	<0.0001
								25	3.63	3.61	0.0015	0.0010
								35	3.62	3.61	0.0043	0.0020
								50	3.52	3.61	<0.0001	<0.0001
RTV-602 13	L, -2.19; W, -1.04	-4.97	30.8	16.8	17.4	--	142.73	1	2.92	3.08	0.0010	0.0004
								15	2.88	3.19	0.0010	0.0002
								25	2.88	3.11	<0.0001	0.0003
								35	2.88	3.13	<0.0001	<0.0001
								50	2.88	3.10	<0.0001	<0.0001
RTV 615 A B	L, -0.40; W, -9.50	-1.56	60.8	61.4	33.5	51.8	76.92	1	2.89	2.97	0.0003	<0.0001
								15	2.88	2.97	<0.0001	0.0003
								25	2.88	2.97	<0.0001	<0.0001
								35	2.88	2.98	<0.0001	<0.0001
								50	2.88	2.98	<0.0001	<0.0001

[1] Mixed according to mfr. instructions; cured 1 hr 65°C + 1 hr 95°C.

[2] 25% compression.

(1) CONTROL SAMPLE

(2) AFTER EXPOSURE TO HUMIDIFIED ETO-FREON ATMOSPHERE

(3) AFTER EXPOSURE TO ETO-FREON ATMOSPHERE PLUS EXPOSURE TO THERMAL-VACUUM ENVIRONMENT

(4) AFTER EXPOSURE TO THERMAL-VACUUM ENVIRONMENT ONLY

FIG. 17 APPEARANCE OF RTV-602/13 SAMPLES AFTER EXPOSURE TO DIFFERENT ENVIRONMENTS

XVI. SEALS AND GASKETS (SG)

According to the micro-VCM data given in Table 53, the most suitable seal and gasket materials for spacecrafts might be any of the fluorocarbons, a number of the silicones (with appropriate postcures), and the flurosilicones. The macro-VCM data in Table 54 and the mass spectrometric analyses in Table 55 offer additional confirmation. For example, macro-VCM data for Viton A4411A-990 indicate that this material is superior to Hycar-1 or an SE-3604 which was inadequately postcured (according to preliminary instructions). Mass spectrometric data show that some silicones are prone to release low-molecular-weight silicones which do not re-evaporate from cooler surfaces, and a typical rubber for terrestrial use, Hycar-1, releases excessive plasticizing oils in the thermal-vacuum environment; this could lead to drastic changes in mechanical properties.

The effect of loss of plasticizing oil on mechanical properties after exposure to the thermal-vacuum environment are shown by the data for Hycar elastomers in Tables 56 to 58. Although the properties of the elastomers are only slightly influenced by the decontamination cycles, subsequent thermal-vacuum exposure or TVE causes unacceptable increases in hardness and reductions of elongation. Similar changes in properties were noted for Hycar-1 after a 9-month storage test (Section XXIII).

The butyl elastomers are not much affected by the decontamination cycles, but unacceptable changes are noted in either tensile strength or elongation, particularly the latter, after exposure to the thermal-vacuum environment.

The ethylene-propylene elastomer remains relatively unchanged after any of the exposures; however, micro-VCM data indicate disqualification of the material tested in the as-received state. A postcure results in improved micro-VCM values (but still excessive) and causes drastic reduction in mechanical properties as shown in Tables 56 to 58. This behavior indicates that although a postcure may be used to improve outgassing properties, the thermal-vacuum properties may suffer. It is predicted that the ethylene-propylene elastomer in the as-received state would gradually lose mechanical properties upon prolonged exposure to the thermal-vacuum environment (because of excessive loss of material).

The fluorocarbon elastomer, Viton A4411A-990, shows good retention of mechanical properties after all exposures. This is confirmed by the good results obtained for the elastomer after 9 months of storage in the thermal-vacuum environment (Section XXIII).

Micro-VCM data for the silicone elastomers indicate that some of these may be the best materials available for seals and gaskets while others are mediocre. All the silicones tend to harden in the thermal-vacuum environment, but other mechanical property changes are of the order of less than 25%. The SE-3604 was found to have acceptable properties after 9 months of storage in the thermal-vacuum environment (Section XXIII); long-term storage tests at constant strain are in progress on SE-4511.

Table 53

MICRO-VCM DETERMINATIONS: SEALS AND GASKETS

(24 hr at 125°C and 10^{-6} torr)

(VCM collectors at 25°C)

MATERIAL[1]	MFR.[2]	TREATMENT	TOTAL WT. LOSS, %	VCM, WT-%
Acrylic				
Hycar 520-67-108-1	BFG	As received	1.90	0.17
Hycar 520-67-108-2	BFG	As received	1.22	0.13
Hycar 520-67-108-3	BFG	As received	1.31	0.08
Hycar 520-67-108-4	BFG	As received	1.70	0.04
Hycar 520-67-108-5	BFG	As received	0.95	0.03
Hycar 520-67-108-6	BFG	As received	1.03	0.03
Butyl				
EX-1090	ENJ	Postcured 4 hr 150°C	0.80	0.24
EX-1091	ENJ	Postcured 4 hr 150°C	0.70	0.20
EX-1092	ENJ	Postcured 4 hr 150°C	0.86	0.10
FR-60-26	[illegible]	As received	4.06	0.10
SR-613-75	SIS	As received	2.39	0.39
SR-634-70	SIS	As received	1.40	0.18
805-70	PRP	As received	1.30	0.48
Ethylene-Propylene				
E515-8	PSC	As received	1.95	0.69
SR-722-70	SIS	As received	2.00	0.85
SR-722-70	SIS	Postcured 24 hr 150°C	0.98	0.60
Fluorosilicone				
1050-70	PRP	As received	0.59	0.03
L-449-6	PSC	As received	0.53	0.07
Neoprene				
C526-7	PSC	As received	3.01	1.72
Silicone				
Hadbar 28-80	PPH	As received	0.86	0.21
Hadbar 4000-80	PPH	As received	0.54	0.14
SE-555 (white)	GES	As received	0.55	0.33

Table 53 (Concluded)

MATERIAL[1]	MFR.[2]	TREATMENT	TOTAL WT. LOSS, %	VCM, WT-%
SE-555 (gray)	GES	As received	0.53	0.30
SE-555 (red)	GES	As received	0.76	0.53
SE-556	GES	Postcured 24 hr 250°C	0.10	0.01
SE-3604 (24/480)	GES	As received	0.51	0.12
SE-3604	SIS	As received	1.71	0.73
SE-3604	SIS	Postcured 3 hr/200°C	1.40	0.80
SE-3604	SIS	Postcured 24 hr/250°C	0.03	0.03
SE-3704	SIS	As received	1.37	0.60
SE-3704	SIS	Postcured 3 hr/200°C	1.12	0.67
SE-3804	SIS	As received	1.70	0.62
SE-3804	SIS	Postcured 3 hr/200°C	0.81	0.49
SE-3613	GES	As received	1.05	0.55
SE-3613 (24/480)	GES	As received	0.09	0.06
SE-3713	GES	As received	0.82	0.61
SE-3713 (24/480)	[illegible]	As received	0.20	0.09
SE-3813	GES	As received	[illegible]	0.61
SE-3813 (24/480)	GES	As received	0.27	0.04
SE-4511 (24/480)	GES	As received	[illegible]	0.10
SE-4503 (24/480)	GES	As received	0.07	0.03
SE-5604-7	PSC	As received	0.37	0.15
Silastic S-9711	DCC	As received	0.27	0.10
Silastic S-9711	DCC	Postcured 24 hr 125°C	0.19	0.05
Vinylidene fluoride-hexafluoropropylene				
Viton A4411A-776	DUE	As received	0.29	0.05
Viton A4411A-776	DUE	Postcured 24 hr 200°C	0.03	0.01
Viton A4411A-777	DUE	As received	0.27	0.03
Viton A4411A-777	DUE	Postcured 24 hr 200°C	0.01	0.01
Viton A4411A-778	DUE	As received	0.35	0.01
Viton A4411A-778	DUE	Postcured 24 hr 200°C	0.03	0.00
Viton A4411A-990	DUE	As received	0.54	0.03
V377-9	PSC	As received	0.33	0.01

[1] See Appendix A.

[2] See Appendix B.

Table 54

MACRO-VCM DETERMINATIONS: SEALS AND GASKETS

MATERIAL*	PROPERTY	HOURS OF EXPOSURE AT 125°C AND 10^{-6} TORR			
		24	48	96	336
Hycar 520-67-108-1	Wt-loss, %	1.19	1.29	1.24	1.48
	VCM, wt-%	0.10	0.05	0.12	0.15
SE-3604 (SIS)	Wt-loss, %	0.28	0.24	0.50	0.57
	VCM, wt-%	0.12	0.14	0.18	0.29
Viton A4411A-990	Wt-loss, %	0.44	0.46	0.53	0.61
	VCM, wt-%	0.02	0.02	0.01	0.01

*Hycar-1, as received; 6" x 1" x 0.08" .
SE-3604, postcured 4 hr 205°C; 2" x 1.5" x 0.08" .
Viton A4411A-990, as received; 6" x 1" x 0.08" .

Table 55

MASS SPECTROMETRIC ANALYSIS *IN SITU* OF MATERIALS VOLATILIZED AT 125°C AND 10^{-6} TORR: SEALS AND GASKETS

MATERIAL	IDENTIFIED COMPONENTS	
	Major	Minor
SE-555 (gray, red, and white)	mixed silicones	--
Hycar 520-67-108-1	hydrocarbon oils to m.w. ~400	--
Viton A4411A-990	benzyl ether	carbon dioxide; $(CF_2)_n$ and $C_nH_nF_n$; dioctylphthalate

Table 56

EFFECTS OF DECONTAMINATION CYCLES ON SEAL AND GASKET MATERIALS

(Six cycles of humidified ETO-Freon for 30 hours at 50°C)

MATERIAL*	DIMENSIONAL CHANGE, %	WEIGHT CHANGE, %	SHORE HARDNESS		TENSILE, psi		ELONGATION AT BREAK, %	
			Control	Test	Control	Test	Control	Test
Acrylic								
Hycar 502-67-108-1	L, n.c.	+0.64	86.3	85.4	1860	1910	128	128
Butyl								
805-70	L, +0.41	+1.22	77.2	76.9	1120	1350	295	325
EX-1090	L, +0.15	+0.72	70.7	72.2	2240	2180	550	500
EX-1091	L, +0.32	+1.14	71.0	71.7	1800	1610	380	325
EX-1092	L, +0.17	+0.76	76.2	76.4	1880	1630	210	182
FR 60-26	L, +0.30	+1.07	62.5	62.6	2292	1968	554	580
SR 613-75	L, +1.07	+3.32	82.1	77.1	1394	1191	150	159
SR 634-70	L, +0.10	+0.91	71.1	74.0	2058	1865	400	300
Ethylene-Propylene								
SR 722-70 (A)	L, -0.05	+0.38	77.0	76.5	2488	2352	268	250
SR 722-70 (B)	L, +0.06	+0.49	77.5	77.8	1571	1766	195	212
Fluorocarbon								
Viton A4411A-990	L, +0.47	+1.47	85.4	84.6	2030	2080	358	417
Silicone								
Hadbar 28-80	L, -0.12	+0.24	77.0	79.8	1108	1057	331	340
Hadbar 4000-80	L, +0.02	+0.06	85.6	87.2	971	918	116	119
SE-555 (red)	L, +0.04	+0.12	70.6	69.8	1080	1160	500	488
SE-555 (gray)	L, +0.02	+0.23	60.1	57.9	1115	1371	442	447
SE-555 (white)	L, +0.09	+0.20	60.8	59.4	1640	1443	480	497
SE-556	L, +0.21	+0.14	54.6	58.6	1390	1423	515	483
SE-3604 (24 480)	L, n.c.	+0.03	77.4	77.4	849	804	142	127
SE-3613 (24 480)	L, n.c.	+0.14	70.6	70.5	1020	891	212	150
SE-3713 (24 430)	L, n.c.	+0.17	77.9	81.4	1090	1128	126	131
SE-3813 (24 480)	L, n.c.	+0.50	87.4	87.6	1074	1123	79	92
SE-4511 (24 480)	L, +0.11	+0.11	52.1	50.9	733	672	311	267

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[*] All samples were used in the as-received state, except for SR 722-70 (B) which was postcured 24 hr 150°C.

Table 57

EFFECTS OF THERMAL-VACUUM ENVIRONMENT ON SEAL AND GASKET MATERIALS

(500 hours at 135°C and 10^{-6} torr)

MATERIAL*	DIMENSIONAL CHANGE, %	WEIGHT CHANGE, %	SHORE HARDNESS		TENSILE, psi		ELONGATION AT BREAK, %	
			Control	Test	Control	Test	Control	Test
Acrylic								
Hycar 520-67-108-1	L, n.c.	-1.06	86.3	89.1	1860	2140	128	88
Butyl								
805-70	L, -1.00	-2.42	77.2	79.9	1120	1100	295	208
EX-1090	L, -0.39	-1.57	70.7	86.6	2240	1710	550	129
EX-1091	L, -0.50	-1.49	71.0	79.8	1800	1840	380	200
EX-1092	L, -0.96	-2.11	76.2	85.7	1880	1380	210	78
FR 60-26	L, -1.60	-4.30	62.5	78.8	2292	1520	554	228
SR 613-75	L, -0.81	-2.15	82.1	81.6	1108	1011	150	216
SR 624-70	L, n.c.	-1.78	71.1	93.1	2058	996	400	97
Ethylene-Propylene								
SR 722-70 (A)	L, -0.95	-1.68	77.0	80.5	2488	2294	269	245
SR 722-70 (B)	L, -0.76	-1.44	77.5	82.5	1571	1990	195	182
Fluorocarbon								
Viton A4411A-990	L, n.c.	-0.54	85.4	86.7	2030	2220	358	273
Silicone								
Hadbar 28-80	L, -0.43	-0.67	85.6	88.6	971	866	116	100
Hadbar 4000-80	L, -0.26	-0.56	77.0	80.8	1108	910	331	282
SE-555 (red)	L, -0.08	-0.75	70.6	69.6	1080	1440	500	512
SE-555 (gray)	L, -0.26	-0.95	60.1	66.8	1115	1380	442	347
SE-555 (white)	L, +0.21	-0.85	60.8	69.0	1640	1461	480	425
SE-556	L, -0.31	-1.04	54.6	65.3	1390	1390	515	458
SE-3604 (24 480)	L, n.c.	-0.18	77.4	78.4	849	917	142	105
SE-3613 (24 480)	L, n.c.	-0.13	70.6	70.7	1020	977	212	122
SE-3713 (24 480)	L, n.c.	-0.25	77.9	77.9	1090	1176	126	117
SE-3813 (24 480)	L, n.c.	-0.33	87.4	88.2	1074	1230	79	80
SE-4511 (24 480)	L, -0.03	-0.21	52.1	57.4	733	753	312	253

* All samples were used in the as-received state, except for SR 722-70 (B) which was postcured 24 hr 150°C.

Table 58

EFFECTS OF DECONTAMINATION CYCLES PLUS THERMAL-VACUUM ENVIRONMENT ON SEALS AND GASKETS

MATERIAL*	DIMENSIONAL CHANGE, %	WEIGHT CHANGE, %	SHORE HARDNESS		TENSILE, psi		ELONGATION AT BREAK, %	
			Control	Test	Control	Test	Control	Test
Acrylic								
Hycar 520-67-108-1	L, n.c.	-1.44	86.3	90.8	1860	2120	128	85
Butyl								
805-70	L, -1.44	-2.22	77.2	80.1	1120	1350	295	238
EX-1090	L, -0.63	-2.20	70.7	84.6	2240	1970	550	170
EX-1091	L, -0.74	-1.63	71.0	79.8	1800	1840	380	200
EX-1092	L, +0.86	-2.93	76.2	84.5	1880	1510	210	91
FR 60-26	L, -1.80	-4.73	62.5	76.5	2292	1559	554	259
SR 613-75	L, -0.65	-2.22	82.1	82.7	1394	1098	150	190
SR 634-70	L, -0.57	-2.03	71.1	84.0	2058	1023	400	165
Ethylene-Propylene								
SR 722-70 (A)	L, -0.68	-2.24	77.0	80.6	2488	2341	269	245
SR 722-70 (B)	L, -0.72	-1.51	77.5	82.6	1571	2000	195	189
Fluorocarbon								
Viton A4411A-990	L, n.c.	+0.14	85.4	87.6	2030	2420	358	347
Silicone								
Hadbar 28-80	L, -0.67	-0.64	85.6	89.5	971	850	116	100
Hadbar 4000-80	L, -0.26	-0.39	77.0	81.9	1108	894	331	269
SE-555 (red)	L, n.c.	-0.75	70.6	70.0	1086	1630	500	475
SE-555 (gray)	L, -0.36	-0.91	60.1	66.7	1115	1453	442	377
SE-555 (white)	L, -0.38	-0.79	60.8	69.7	1640	1268	480	400
SE-556	L, -0.40	-0.92	54.6	66.0	1390	1476	515	438
SE-3604 (24/480)	L, n.c.	-0.22	77.4	77.6	849	1070	142	125
SE-3613 (24/480)	L, n.c.	-0.04	70.6	70.1	1029	930	212	110
SE-3713 (24/480)	L, n.c.	-0.20	77.9	79.4	1090	1103	126	112
SE-3813 (24/480)	L, n.c.	-0.21	87.4	89.0	1074	1220	79	78
SE-4511 (24/480)	L, -0.07	-0.18	52.1	58.0	733	701	312	258

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* All samples were used in the as-received state, except for SR 722-70 (B) which was postcured 24 hr 150°C.

XVII. SHRINKABLE MATERIALS (SM)

Micro-VCM data for shrinkable materials are given in Table 59. The fluorocarbon and polyester materials easily qualify as space-grade candidates. Since two of the polyolefins had acceptable weight-loss values, a further evaluation was made of Thermofit RNF-100 in order to determine whether the VCM was of a kind that would evaporate with time. As shown by the data in Table 60, the VCM increases with time and thus the initial disqualification by micro-VCM screening was confirmed.

Table 59

MICRO-VCM DETERMINATIONS: SHRINKABLE TUBING

(24 hours at 125°C and 10^{-6} torr)
(VCM collector plates at 25°C)

MATERIAL[1]	MFR.[2]	TREATMENT	TOTAL WT. LOSS, %	VCM, WT-%
Fluorocarbon				
Thermofit TFE (7-30-09)	RAY	Postcured 1 hr 150°C	0.01	0.00
Thermofit TFE (7-32-16)	RAY	Postcured 1 hr 150°C	0.00	0.00
Thermofit TFE-R	RAY	Postcured 1 hr 150°C	0.01	0.00
Penntube II-SMT	RAY	Postcured 1 hr 150°C	0.00	0.00
Fluorocarbon, irradiated				
Thermofit Kynar	RAY	Postcured 1 hr 150°C	0.27	0.09
Polyester				
Mylar, 0.004" wall	STP	Postcured 10 min 110°C	0.62	0.03
Mylar, 0.012" wall	STP	Postcured 10 min 110°C	0.68	0.05
Polyolefin, irradiated				
Thermofit RNF-100	RAY	Postcured 1 hr 150°C	0.78	0.20
Thermofit CRN (clear)	RAY	Postcured 1 hr 150°C	0.52	0.28
Thermofit CRN (white)	RAY	Postcured 1 hr 150°C	2.01	0.60
Thermofit CRN (black)	RAY	Postcured 1 hr 150°C	2.09	0.39

[1] See Appendix A.
[2] See Appendix B.

Table 60

MACRO-VCM DETERMINATIONS: SHRINKABLE TUBING

MATERIAL	PROPERTY	HOURS OF EXPOSURE AT 125°C AND 10^{-6} TORR			
		24	48	96	336
Thermofit RNF-100*	Wt. loss, % VCM, wt-%	-- --	0.59 0.26	0.62 0.24	0.62 0.27

* Postcured 1 hr 150°C; dimensions, 6" x 5/16" O.D.

XVIII. SLEEVING (SL)

Weight-loss and VCM data for sleeving materials are given in Table 61. None of the materials which have been screened were available in sufficient supply for mechanical-property tests.

On the basis of micro-VCM data the best sleeving materials which were tested appear to be formulated from acrylic-glass fiber combinations; however, macro-VCM determinations (Table 62) for Ben Har Acryl A indicate increasing VCM with time. No fluorocarbon materials in the form of sleevings have been evaluated.

Table 61

MICRO-VCM DETERMINATIONS: SLEEVING

(24 hours at 125°C and 10^{-6} torr)

(VCM collectors at 25°C)

MATERIAL[1]	MFR.[2]	TREATMENT	TOTAL WT. LOSS, %	VCM, WT-%
Glass fiber (coated)				
Ben-Har Ex-Flex 1500	BHM	Postcured 24 hr/150°C	0.18	0.14
Ben-Har Pyro-Sleeve ST	BHM	As received	0.20	0.23
Ben-Har Pyro-Sleeve ST	BHM	Postcured 24 hr/150°C	0.13	0.11
Acrylic-glass fiber				
Ben-Har 1258-1, B	BHM	Postcured 24 hr/150°C	0.56	0.35
Ben-Har 263 FC-3	BHM	As received	0.54	0.32
Ben-Har 263 G-3	BHM	Postcured 24 hr/150°C	1.40	0.27
Ben-Har Lecton B	BHM	Postcured 24 hr/150°C	0.09	0.09
Ben-Har Acryl A FAl	BHM	As received	0.49	0.05
Ben-Har Acryl A FAl	BHM	Postcured 24 hr/150°C	0.22	0.05
Ben-Har Acryl C-2	BHM	As received	0.33	0.01
Silicone-glass fiber				
Ben-Har 1062 HA-1	BHM	As received	0.31	0.23
Ben-Har 1062 HA-1	BHM	Postcured 24 hr/150°C	0.29	0.13
Ben-Har 1151 HA-1	BHM	As received	0.37	0.35
Ben-Har 1151 HA-1	BHM	Postcured 24 hr/150°C	0.42	0.24
Ben-Har 1151, Armasil-2	BHM	Postcured 24 hr/150°C	0.54	0.42
Ben-Har 1151, UL	BHM	Postcured 24 hr/150°C	0.66	0.43
Ben-Har 1151, Superwall	BHM	Postcured 24 hr/150°C	0.31	0.31

[1] See Appendix A.

[2] See Appendix B.

Table 62

MACRO-VCM DETERMINATIONS: SLEEVING

MATERIAL	PROPERTY	HOURS OF EXPOSURE AT 125°C AND 10^{-6} TORR			
		24	48	96	336
Ben-Har Acryl A*	Wt. loss, %	0.09	0.10	0.33	0.26
	VCM, wt-%	0.03	0.05	0.05	0.06

* Postcured 24 hr/150°C; Dimensions: 1-1/2" × 5/8" O.D.

XIX. TAPES (TP)

Micro-VCM data are given in Table 63 for a number of pressure-sensitive tapes. One of these tapes (Mystik 7452) was evaluated further by a macro-VCM determination (Table 64) and the volatile materials were identified (Table 65). The results of comprehensive testing for a number of the tapes are summarized in Tables 66 to 68.

As shown in Table 63, only two tapes (Mystik 7452 and Fibremat Type 2539) have passable weight-loss and VCM values. Macro-VCM determinations for the Mystik tape revealed that the small amount of VCM apparently will re-evaporate in time from a condensing surface; the VCM is probably a glycol-benzoate and a phthalate ester as indicated by mass spectroscopic analysis.

In Tables 66 to 68, it is shown that Mystik 7452 not only maintains the best mechanical properties throughout all ETO and TVE testing, but also appears to become stronger in the various environments.

Of the Mystik tapes tested for mechanical properties, the best performers appear to be those with the rubber-resin bases (7452, 7020, and 7455), although the high-VCM values for 7020 and 7455 and the shrinkage of 7455 must be considered in the light of their end-use.

The Mystik tapes which are not satisfactory either for VCM content or mechanical properties are those based on combinations of polyesters or silicones with other materials (7300, 7352, and 7503). However, the polyester-base Fibremat (Type 2539) has excellent micro-VCM values; unfortunately, it is a recent acquisition and has not been checked for mechanical properties.

Scotch Tape #27 is the familiar electrical "glass-tape" found in any laboratory or home shop and was checked in the micro-VCM determination because of its ready availability; the data show it is to be avoided for spacecraft use.

Table 63

MICRO-VCM DETERMINATIONS: TAPES
(24 hr at 125°C and 10^{-6} torr,
(VCM collector plates at 25°C)

MATERIAL[1]	MFR.[2]	TREATMENT	TOTAL WT. LOSS, %	VCM, WT-%
Epoxy				
Scotch Electric Tape #62	MME	As received	1.11	0.97
Scotch Electric Tape #62	MME	Cured 24 hr at 150°C	0.86	0.70
Fluorocarbon-silicone				
Mystik 7503	BCM	As received	1.17	0.73
Mystik 7503	BCM	Cured 24 hr at 150°C	1.02	0.81
Polyester				
Mystik 7352	BCM	As received	4.34	1.58
Mystik 7352	BCM	Cured 24 hr at 150°C	1.60	0.72
Fibremat-1 (Type 2539)	MME	As received	0.19	0.02
Polyester-aluminum				
Scotch Tape #852	MME	As received	1.69	0.70
Scotch Tape #852	MME	Cured 24 hr at 150°C	0.57	0.40
Polyester-glass				
Scotch Tape #27	MME	As received	6.08	2.27
Scotch Tape #27	MME	Cured 24 hr at 150°C	4.37	2.29
Polyester-silicone				
Mystik 7300	BCM	As received	1.90	1.28
Mystik 7300	BCM	Cured 24 hr at 150°C	1.44	1.03
Rubber resin-aluminum				
Mystik 7452	BCM	As received	0.37	0.04
Rubber resin-glass-Al				
Mystik 7455	BCM	As received	3.82	2.62
Mystik 7455	BCM	Cured 24 hr at 150°C	1.71	1.34
Rubber resin-glass				
Mystik 7020	BCM	As received	2.63	0.62
Mystik 7020	BCM	Cured 24 hr at 150°C	1.44	0.56

[1] See Appendix A.
[2] See Appendix B.

Table 64

MACRO-VCM DETERMINATIONS: TAPE

MATERIAL	PROPERTY	HOURS OF EXPOSURE at 125°C and 10^{-6} torr			
		24	48	96	336
Mystik 7452*	Wt. Loss, %	0.15	0.18	0.18	0.19
	VCM, wt-%	0.06	0.03	0.05	0.03

* As received; dimensions: 0.5" x 48" x 0.004"

Table 65

MASS SPECTROMETRIC ANALYSIS *IN SITU* OF MATERIALS VOLATILIZED AT 125°C AND 10^{-6} TORR: TAPE

MATERIAL	IDENTIFIED COMPONENTS	
	Major	Minor
Mystik 7452	glycol-benzoate; mono-ester of phthalic acid	toluene; water; dioctylphthalate

Table 66

EFFECTS OF DECONTAMINATION CYCLES ON TAPES
(Six cycles of humidified ETO-Freon for 30 hr at 50°C)

MATERIAL*	DIMENSIONAL CHANGE, %	WEIGHT CHANGE, %	T-PEEL TEST, lb/in-WIDTH	
			Control	Test
Mystik 7020	n.c.	+2.64	5.61	6.10
Mystik 7300	-0.37	+1.24	3.18	3.64
Mystik 7352	-0.11	+0.58	2.10	1.68
Mystik 7452	n.c.	+0.33	2.10	4.86
Mystik 7455	-0.10	+0.04	3.74	3.72
Mystik 7503	-0.17	+0.02	2.70	2.98

* As received.

Table 67

EFFECTS OF THERMAL VACUUM ENVIRONMENT ON TAPES
(500 hr at 135°C and 10^{-6} torr)

MATERIAL*	DIMENSIONAL CHANGE, %	WEIGHT CHANGE, %	T-PEEL TEST, lb in-WIDTH	
			Control	Test
Mystik 7020	n.c.	-2.32	5.61	8.16
Mystik 7300	-2.44	-1.44	3.18	2.98
Mystik 7352	-1.21	-3.08	2.10	1.42
Mystik 7452	n.c.	-0.31	2.10	11.07
Mystik 7455	-0.71	-2.56	3.74	3.75
Mystik 7503	-0.71	-1.20	2.70	2.12

* As received.

Table 68

EFFECTS OF DECONTAMINATION CYCLES PLUS THERMAL-VACUUM ENVIRONMENT ON TAPES

MATERIAL*	DIMENSIONAL CHANGE, %	WEIGHT CHANGE, %	T-PEEL TEST lb in-WIDTH	
			Control	Test
Mystik 7020	n.c.	-2.64	5.61	5.59
Mystik 7300	-2.36	-1.94	3.18	1.86
Mystik 7352	-1.19	-2.72	2.10	1.90
Mystik 7452	n.c.	-0.34	2.10	9.01
Mystik 7455	n.c.	-2.57	3.74	3.55
Mystik 7503	-1.04	-0.92	2.70	2.38

* As received.

XX. TEMPERATURE CONTROL COATINGS (TM)

The screening data given for temperature control coatings in Table 69 indicate that some of the products may be useful for spacecraft use when the optimum conditions of curing are determined. For example, the observed VCM value for an epoxy coating, Velvet Black 401-C10, is satisfactory, but the weight-loss value is entirely too large after mild curing. As shown in Table 71, the weight loss is due essentially to high-boiling solvents (130-150°C). Thus, the coating must be cured for long times at mild temperatures such as 110°C if assembled optical components cannot withstand higher temperatures; alternatively, the coating might be cured at lower temperatures in vacuum. The effect of elevated temperature and vacuum on the integrity of this material will be determined when the 8-month storage tests (see Section XXIII) are terminated. As mentioned in that section, Velvet Black 401-C10 is being used as a heat transfer medium in the long-term storage apparatus.

The same attention to curing temperature and time may be required to provide suitable polyurethane coatings (white and black Laminar X-500). The nature of the volatile components has not been examined, but the large differences between weight-loss and VCM values again indicates the presence of solvents.

Improvement of the other coatings listed in Table 69 by alternative curing cycles is doubtful since many of these still are not satisfactory after such attempts. Further examination of one of these, Velvet Black 101-C10, indicates high-molecular-weight plasticizers are released (Table 71) and that these evaporate slowly from cold surfaces (Table 70).

In view of our experiences with these coatings, the importance of absolutely thorough mixing of components before and after blending cannot be emphasized strongly enough.

Table 69

MICRO-VCM DETERMINATIONS: TEMPERATURE CONTROL COATINGS
(24 hr at 125°C and 10^{-6} torr)
(VCM collectors at 25°C)

MATERIAL[1]	MFR.[2]	TREATMENT	TOTAL WT. LOSS, %	VCM, WT-%
Alkyd, modified				
Velvet Black 101-C10	MMA	As received; 24 hr/25°C	5.56	1.12
Velvet Black 101-C10	MMA	As received; 160 hr/25°C	4.30	0.83
Velvet Black 101-C10	MMA	As received; 24 hr/110°C	0.95	0.24
Velvet Black 101-C10	MMA	As received; 96 hr/110°C	0.68	0.17
Velvet Black 101-C10	MMA	As received; 168 hr/110°C	0.33	0.17
Velvet Black 101-C10	MMA	As received; 24 hr/150°C	0.57	0.25
Epoxy				
Cat-a-lac Flat Black (463-1-8)	FPC	As received; 24 hr/25°C	13.00	1.52
Cat-a-lac Flat Black (463-1-8)	FPC	As received; 24 hr/150°C	0.38	0.23
Cat-a-lac White Gloss (443-1-500)	FPC	As received; 24 hr/25°C	15.79	0.95
Cat-a-lac White Gloss (443-1-500)	FPC	As received; 24 hr/150°C	0.86	0.52
Corlar-585 (Black)	DUP	As received; 72 hr/25°C	8.58	1.28
Corlar-585 (Black)	DUP	As received; 24 hr/150°C	2.38	1.28
Velvet Black 401-C10 A/B	MMA	3pA/1pB; 7 das/25°C	5.30	0.03
Velvet Black 401-C10 A/B	MMA	3pA/1pB; 2 hr/25°C + 1 hr/65°C	5.32	0.03
Velvet Black 401-C10 A/B	MMA	3pA/1pB; 2 hr/25°C + 16 hr/65°C	4.72	0.03
Velvet Black 401-C10 A/B	MMA	3pA/1pB; 2 hr/25°C + 7 das/110°C	3.60	0.04
Polyurethane				
Laminar X-500 (4B-1 black)/10C-45	MMC	100p4B-1/100p10C-45; 72 hr/25°C	18.45	0.05
Laminar X-500 (4B-1 black)/10C-45	MMC	100p4B-1/100p10C-45; 72 hr/25°C + 24 hr/125°C	1.23	0.05
Laminar X-500 (4B-3 flat black)/10C-45	MMC	100p4B-3/100p10C-45; 72 hr/25°C	11.90	0.01
Laminar X-500 (4B-3 flat black)/10C-45	MCC	100p4B-3/100p10C-45; 72 hr/25°C + 24 hr/125°C	2.10	0.01
Laminar X-500 (8W-24 white with Teflon filler)	MCC	4p8W-24/1pHardener/1pReducer; two coats, each cured 2 hr/55°C	8.63	0.09
Laminar X-500 (8W-24 white with Teflon filler)	MCC	4p8W-24/1pHardener/1pReducer; two coats, each cured 2 hr/55°C, post-cured 1 hr/95°C/10^{-6} torr	1.62	0.02
Silicone-alkyd				
PV-100 (White)	VVP	As received; 16 hr/25°C	2.48	0.30
PV-100 (White)	VVP	As received; 24 hr/150°C	1.51	0.15

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[1] See Appendix A.

[2] See Appendix B.

Table 70

MACRO-VCM DETERMINATIONS: TEMPERATURE CONTROL COATING

MATERIAL	PROPERTY	HOURS OF EXPOSURE AT 125°C AND 10^{-6} TORR			
		24	48	96	336
Velvet Black 101-C10*	Wt-loss, %	0.84	0.70	1.01	1.38
	VCM, wt-%	0.10	0.09	0.14	0.13

* Applied to 3-ft lengths of 18-ga copper wire and cured 168 hr 110°C

Table 71

MASS SPECTROMETRIC ANALYSIS *IN SITU* OF MATERIALS VOLATILIZED AT 125°C AND 10^{-6} TORR: TEMPERATURE CONTROL COATINGS

MATERIAL	IDENTIFIED COMPONENTS	
	Major	Minor
Velvet Black 101-C10	dioctylphthalate	--sebacate
Velvet Black 401-C10	cellosolve acetate	xylenes

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XXI. TIE CORD/LACING TAPE (TC)

Micro-VCM data for tie cord/lacing tape materials are given in Table 72 and mechanical-property data are given in Tables 73 to 75. As indicated by the micro-VCM data, the Dacron-synthetic rubber materials incurred excessive weight losses in the as-received state; further examination revealed a loss of mechanical properties of one of these (18-D96) in the TVE and ETO-TVE testing, although no change was affected by ETO only. The other (18DH) appears to maintain tensile properties in the TVE and ETO-TVE testing, but is subject to shrinking. The Nomex-silicone has poor VCM values as-received and is subject to stretching after ETO and ETO-TVE testing. Fluorocarbon lacing tape (Temp-Lace 256H) maintained its properties throughout all our tests.

Table 72

MICRO-VCM DETERMINATIONS: TIE CORD LACING TAPE
(24 hr at 125°C and 10^{-6} torr)
(VCM collector plates at 25°C)

MATERIAL[1]	MFR.[2]	TREATMENT	TOTAL WT. LOSS,	VCM WT-
Nomex-silicone				
Gudebrod 721H	GBE	As received	3.07	0.25
Gudebrod 721H	GBE	Postcured 24 hr at 150°C	2.58	0.10
Gudebrod 722S	GBE	As received	4.92	1.80
Gudebrod 722S	GBE	Postcured 24 hr at 150°C	2.44	0.62
Dacron-synthetic rubber				
Gude-Space 18D96	GBE	As received	1.87	0.09
Gude-Space 18D96	GBE	Postcured 24 hr at 150°C	0.42	0.10
Stur-D-Lace 18DH	GBE	As received	1.26	0.20
Stur-D-Lace 18DH	GBE	Postcured 24 hr at 150°C	0.34	0.06
Impregnated fluorocarbon fibre				
Temp-Lace H256H	GBE	As received	0.66	0.05

[1] See Appendix A.

[2] See Appendix B.

Table 73

EFFECTS OF DECONTAMINATION CYCLES ON TIE CORD LACING TAPES

(Six Cycles of Humidified ETO-Freon for 30 Hours at 50°C)

MATERIAL*	DIMENSIONAL CHANGE, %	WEIGHT CHANGE, %	TENSILE, psi		ELONGATION AT BREAK, %	
			Control	Test	Control	Test
Gude-Space 18D96	L, n.c.	+1.08	42,000	42,900	27	32
Gudebrod 722S	L, +3.50	+2.50	36,000	32,800	< 1	< 1
Stur-D-Lace 18DH	L, +2.40	+1.35	32,000	39,000	< 1	< 1
Temp-Lace 256H	L, n.c.	+0.52	14,900	15,100	32	40

* As received.

Table 74

EFFECTS OF THERMAL-VACUUM ENVIRONMENT ON TIE CORD LACING TAPES

(500 Hr at $135°C$ and 10^{-6} Torr)

MATERIAL*	DIMENSIONAL CHANGE, %	WEIGHT CHANGE, %	TENSILE, psi		ELONGATION AT BREAK, %	
			Control	Test	Control	Test
Gude-Space 18D96	L., -0.23	-0.45	42,000	30,500	29	19
Gudebrod 722S	L., -0.21	-4.28	36,100	32,600	< 1	< 1
Stur-D-Lace 18DH	L., -11.04	-1.45	32,000	34,100	< 1	< 1
Temp-Lace 256H	L., -0.61	-0.49	14,900	14,050	32	28

* As received.

Table 75

EFFECTS OF DECONTAMINATION CYCLES PLUS THERMAL-VACUUM ENVIRONMENT ON TIE CORD LACING TAPES

MATERIAL*	DIMENSIONAL CHANGE, %	WEIGHT CHANGE, %	TENSILE, psi		ELONGATION AT BREAK, %	
			Control	Test	Control	Test
Gude-Space 18D96	L., -0.22	-0.43	42,000	29,400	29	20
Gudebrod 722S	L., +3.29	-3.25	36,100	35,900	< 1	< 1
Stur-D-Lace 18DH	L., -7.17	-1.39	32,000	38,600	< 1	< 1
Temp-Lace 256H	L., -1.35	-0.54	14,900	14,300	32	30

* As received.

XXII. WIRE ENAMELS (WE)

The results of micro-VCM screening of several wire enamels are given in Table 76. Any of the three materials tested appear to be suitable candidates based on these data; no other tests were performed. No additional work was performed with the polyimide enamel.

Table 76

MICRO-VCM DETERMINATIONS: WIRE ENAMELS

(24 hr at 125°C and 10^{-6} torr)

(VCM collector plates at 25°C)

MATERIAL[1]	MFR.[2]	TREATMENT	TOTAL WT. LOSS, %	VCM, WT-%
Acetal (Formex)				
Magnet wire (AWG-35)	GEW	As received	0.06	0.03
Polyimide				
PYRE-M.L. R.C.-5057	GEI	Cured 24 hr at 150°C	1.12	0.00
Polyurethane				
Magnet wire (AWG-22)	GEW	As received	0.22	0.09

[1] See Appendix A.

[2] See Appendix B.

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XXIII. LONG-TERM STORAGE TESTS

The recommendations made in prior sections of this report are based on the results of short-term tests, that is, from measurements of the effects of thermal-vacuum exposures of 24 to 500 hours on various physical properties of polymers. There was ever present the question of whether short-term tests could adequately describe the behavior of polymers when exposed for a long time to a thermal-vacuum environment. Thus, it was of interest to develop equipment which could provide over extended periods of time measurements of significant mechanical properties. A storage time of about 8 months was selected because it represented about the longest time a spacecraft would be called upon to perform in the near future and because it would permit set-up, observation, and terminal evaluation during a 12-month contract period. Thus, the primary objectives of the long-term exposures of polymeric materials to the thermal-vacuum environment of 125°C and $<10^{-6}$ torr are:

(1) To test the reliability of performance of polymeric materials in an environment which simulates a long-term space flight, e.g., 8000 hours to Mars;

(2) To determine the effectiveness of short-term tests in the evaluation of polymers for long-term use.

The long-term storage apparatus at SRI (see Figure 18) consists of four vacuum units, each operating as an independent system. Since there must be no question of cross-contamination in tests of such long duration, only one polymeric product is used in each unit. In the first series of long-term tests (terminated during this contract), the best elastomer was selected for storage under constant strain from each of the three polymeric classes previously tested on the basis of mechanical performance within each class during and after 1000-hour exposures to the thermal-vacuum environment. The plastic material stored for creep under constant load was selected in the light of current interest in a relatively new material.

For the second series of long-term tests (in progress), products were selected on the basis of micro-VCM determinations, and include an elastomer for constant strain, a plastic film for creep under load, and an adhesive film for creep under load.

APPARATUS

The photograph in Figure 18 shows each individual vacuum chamber covered with a protective aluminum shield. The shields serve a dual purpose, i.e., maintenance of thermal equilibrium and protection from radiation (daylight and fluorescent fixtures). Each unit has a separate heating control, three-position thermocouple read-out, and vacuum system. As each vacuum chamber is loaded with its samples, the chamber is evacuated to less than 10^{-3} torr with a mechanical pump; then its ion pump (Varian, 15-liter) is activated. When chamber pressure is less than 10^{-5} torr, the unit is sealed-off for the duration of the test by crimping the fore-pump line. The temperature of the chamber is then raised gradually over a period of about 48 hours to 125°C.

Figure 19 illustrates the apparatus for storing plastic films under constant load. The cylinders are made of brass and are filled with lead shot to provide the desired loads. They are suspended from clamps affixed to the ends of the samples and are provided with a stationary central rod to guide the weight in the event of sample rupture; this position is shown in the photograph, taken at the end of a storage period. Figure 20 shows the apparatus within the bell-jar, ready for evacuation. Also shown in Figure 20, within the bell-jar and surrounding the test apparatus, is the cylindrical glass heater. The glass has been coated at SRI with a bismuth oxide/gold/bismuth laminate; the gold layer is of the order of 90-100 Å in thickness. At intervals, current-carrying copper wire is affixed to conducting silver paint or epoxy-silver solder. The assembly was annealed at 400°C. As can be seen in the photograph, objects are clearly visible through the heater.

The apparatus for storing elastomeric materials under constant strain is shown in Figure 21. The support pins are positioned so that rings of elastomers can be stretched over them at several different values of strain.

Complete design drawings for the constant-load and constant strain apparatuses, glass heater, and general assemblies are given in Interim Report No. 3, Part II, December 1966, under this contract.

A close-up view of the creep testers for adhesives is given in Figure 22. The outer body of the tester is made of stainless steel; the compression springs are set with an Instron testing machine to provide specified loads on the sample specimens. The creep testers are designed to contain the shock in the case of a rupture so that no part of the total assembly will be damaged. In order to promote uniform heat transfer throughout the heavy metal fixtures, the supporting aluminum plates have been painted with 3M's Velvet Black 401-C10, which was baked on for 24 hours at 150°C prior to installation. In this way, a secondary long-term storage test is being conducted, that is, the maintenance of integrity of a candidate temperature control coating. The total assembly of creep testers within the glass heater and bell jar is shown in Figure 23 and complete design drawings for the creep testers and the supporting fixture are given in the supplement to this section.

LONG-TERM STORAGE TESTS (COMPLETED)

Three elastomeric materials for constant strain and one plastic material for creep under constant load were stored in the thermal-vacuum environment of 125°C and $<10^{-6}$ torr for periods of 6550 and 5060 hours, respectively; these were:

SE-3604
Viton A4411A-990
Hycar 520-67-108-1
} elastomers, used as received.

and PPO 681-111 (clear), plastic film, annealed 1/2 hr/180°C.

Elastomers

The elastomers were cut into rings and stretched at room temperature over the supporting pins on the constant-strain apparatus. Two to four specimens were subjected to each strain, and at least four rings were stored in the apparatus at zero strain. Rings from each elastomer ruptured at maximum strain during the first 2 weeks of exposure to vacuum and temperature; subsequently, only one rupture occurred during the rest of the 6550-hour storage period, Hycar-1, and that was attributed to a faulty specimen rather than thermal-vacuum effects in view of the total data. At the end of the test, all of the rings remained fixed in the set they assumed in the stretched positions when they were removed from the supporting pins. They were then tested for tensile strength and elongation; a summary of the results appears in Table 77.

With the exception of the rings stored at maximum strain, which approximated as-received control sample elongation values, terminal tests for tensile strength indicated that these values for all the strained specimens did not vary more than 20-30% from those which were stored at zero strain nor from the unexposed control samples. Similarly, terminal elongation values did not vary more than 30% from samples stored under strain from those under no strain, but per cent change over control was excessive for the Viton and grossly excessive for the Hycar.

A comparison of changes in mechanical properties over control sample properties after different lengths of time of storage in a thermal-vacuum environment is given in Table 78. Although the samples used for the 500-hour tests were from different batches of materials, the results are comparable to those obtained after the 1000-hour tests. Compared with 500- and 1000-hour storage, the changes in properties after 6550 hours are not significant for the SE-3604 and are probably within the limits of testing accuracy for the Viton. The tensile strength of Hycar is little different after 6550 hours but the elongation is severely reduced. Assuming (from general opinion) that 20-25% change over control is acceptable, Hycar would immediately be disqualified after the 500-hour storage, verified by the 6550-hour storage results; the material is also disqualified by micro-VCM data. The SE-3604 is considered acceptable by micro-VCM data and 500-hour storage tests, verified by the results of 6550-hour storage. The Viton also is considered acceptable by micro-VCM data and 500-hour storage, but marginal after the 1000- and 6550-hour storage periods; however, it maintains the best over-all properties. In general (again remembering that different batches of materials are being discussed), it would appear that 1000-hour storage periods will provide for more accurate evaluation of long-term use than periods of 500 hours or less, but disqualification at the 500-hour level is final.

Plastic Film

The PPO 681-111 film was cut as dog-bone shaped micro tensile specimens. Duplicates were run at loads of 1500 and 1750 psi and four specimens were run at 2000 psi; several specimens were placed in the apparatus under zero load. No specimens at 1500 psi ruptured during the 5060-hour storage period, one specimen at 1750 psi ruptured at about 1540 hours, and one specimen at 2000 psi ruptured at about 4000 hours. Observed deformation for all specimens was less than 1%. The specimens under zero load and under 2000-psi load were tested for tensile properties when they were removed from storage after 5060 hours; test data are summarized in Table 79. The per cent changes in mechanical properties over control sample properties are summarized in Table 80 and compared with data obtained after 1000-hour storage periods. The results of tests after both storage periods indicate that the 1000-hour tests were sufficient for evaluation.

LONG-TERM STORAGE TESTS (IN PROGRESS)

Currently, four different polymeric products are being stored in the thermal-vacuum environment of 125°C and $<10^{-6}$ torr for different properties; these are:

Metlbond-328, adhesive, for adhesive creep;
Kapton 200XH667, plastic film, for creep under constant load;
SE-4511, elastomer, for stress under constant strain;
Velvet Black 401-C10, temperature control coating, for adhesion.

A summary of test data to July 26, 1967 is given in Table 81.

Temperature Control Coating

Velvet Black 401-C10 was mixed according to manufacturer's instructions, applied with a camel's hair brush to the aluminum supporting plates of the adhesive creep testers, and baked for 24 hours at 150°C.

The coating will be examined for evidences of crazing and firmness of bonding at the end of the storage period which commenced April 26, 1967.

Plastic Film

Kapton 200XH667 was prepared as micro tensile specimens which are stored as duplicate samples in the constant load apparatus at loads of 2500, 5000, 7500, and 10,000 psi; the test sections of the specimens are 0.125-in wide and 0.8-in long. Observation of creep during storage are made by sighting with a cathetometer over the top of each cylindrical weight (Figure 20) to a precision scale graduated in 0.01-in markings. At the termination of the storage period, initiated May 19, 1967, the surviving specimens will be tested for tensile strength and elongation. Only negligible creep has been observed to July 19.

Elastomer

Elastomer SE-4511 was cut into rings and stretched at room temperature over the supporting pins in the constant strain apparatus at the strains indicated in Table 81. Environmental storage began on May 15, 1967 and the 4 rings at maximum strain ruptured during the first week of vacuum exposure. No others have ruptured to July 26.

Adhesive

Samples of Metlbond-328 were bonded to lapped aluminum plates (1.50" X 0.50" X 0.09") using the cleaning and specimen-preparation procedures described in Section III for adhesive creep testing; the adhesives were bonded under 18 psi for 1-1/2 hours at 165°C. Specimens in triplicate were stored on April 26, 1967 at loads of 250,500, 750, and 1000 psi and at zero load. Observations of creep are made by sighting the bench-marks (shown in Figure 22) on the test specimens with a cathetometer. As of July 26, no creep has been observed for any of the specimens. At the termination of the storage period, surviving specimens will be tested for adhesion shear.

Table 77

SUMMARY OF DATA FOR LONG-TERM STORAGE TESTS OF ELASTOMERS
(6550 hr at 125°C and $<10^{-6}$ torr)

ELASTOMER	APPROX. STRAIN, in/in	NO. OF RINGS	APPROX. RUPTURE TIME, HR AT 125°C	TENSILE STRENGTH, psi	ELONGATION AT BREAK, %
SE-3604	Control	2		637	104
	0	5		740	99
	0.25	4		609	100
	0.35	4		572	99
	0.50	4		584	100
	0.75	4		575	102
	1.00	4		562	100
	1.50	4	1 at -160 1 at -7 1 at 0	500	106
Viton A4411A-990	Control	2		1495	465
	0	8		1885	260
	0.25	4		1940	303
	0.35	4		1610	284
	0.50	4		1720	325
	0.75	4		1600	288
	1.00	4		1440	308
	1.50	4		1360	269
	2.50	4		1625	319
	3.50	4	2 at -3	1030	325
Hycar 520-67-108-1	Control	2		1180	187
	0	4		923	72
	0.25	2		1150	84
	0.35	2		1170	93
	0.50	2	1 at 4900	1110	95
	0.75	4		840	94
	1.00	4		625	82
	1.50	4	2 at 130 1 at 175	738	87

Table 78

SUMMARY OF CHANGES IN MECHANICAL PROPERTIES OF ELASTOMERS STORED FOR DIFFERENT LENGTHS OF TIME IN A THERMAL-VACUUM ENVIRONMENT

ELASTOMER	PER CENT CHANGE OVER CONTROL					
	Tensile Strength			Elongation at Break		
	500 hr[1]	1000 hr[2]	6550 hr[3]	500 hr[1]	1000 hr[2]	6550 hr[3]
SE-3604	+8	+4	+16	-26	0	-7
Viton A4411A-990	+9	+30	+26	-24	+4	-44
Hycar 520-67-108-1	+15	-16	-22	-31	-46	-62

[1] Comprehensive test program data, T = 135°C.

[2] Prior work under Contract 950324 and earlier work under this contract, T = 125°C.

[3] Long-term storage tests, T = 125°C.

Table 79

SUMMARY OF DATA FOR LONG-TERM STORAGE TEST OF PLASTIC FILM (5060 hr at 125°C and 10^{-6} torr)

FILM	LOAD, psi	NO. OF SPECIMENS	APPROX. RUPTURE TIME, HR AT 125°C	DEFORMATION	TENSILE STRENGTH, psi	ELONGATION AT BREAK, %
PPO 681-111 (clear)	Control	4		-	6,560	75
	0	4		-	7,040	77
	1500	2		<1%	--	--
	1750	2	1 at 1540	<1%	--	--
	2000	4	1 at 4000	<1%	5,200	38

Table 80

SUMMARY OF CHANGES IN MECHANICAL PROPERTIES OF PLASTIC FILM STORED FOR DIFFERENT LENGTHS OF TIME IN A THERMAL-VACUUM ENVIRONMENT

FILM	LOAD, psi	PER CENT CHANGE OVER CONTROL			
		Tensile		Elongation	
		1000 hr	5060 hr	1000 hr	5060 hr
PPO 681-111 (clear)	0	-23	+7	-16	+3
	2000	-14	-21	-45	-49

Table 81

PRELIMINARY DATA FOR LONG-TERM STORAGE TESTS IN PROGRESS*

($125°C$ and $< 10^{-6}$ torr)

TEST	MATERIAL	NO. OF SPECIMENS	LOAD OR STRAIN	TIME IN STORAGE	REMARKS
Constant load; adhesive creep	Metlbond-328	3	0	3 mos.	-
		3	250 psi		no apparent creep observed for all specimens
		3	500 psi		
		3	750 psi		
		3	1,000 psi		
Coating integrity	Velvet Black 401-C10 I/II	3	-	3 mos.	uniform appearance
Constant strain	SE-4511	8	-	2 mos.	-
		4	0.18 in/in		-
		4	0.28 in/in		-
		4	0.38 in/in		-
		4	0.58 in/in		-
		4	0.83 in/in		-
		4	1.08 in/in		-
		4	2.17 in/in		4 ruptured within 168 hours of test
Constant load; plastic creep	Kapton 200XH667	8	0	2 mos.	-
		2	2,500 psi		negligible creep observed for all specimens
		2	5,000 psi		
		2	7,500 psi		
		2	10,000 psi		

* See report sections on adhesives, films and sheets, seals and gaskets, and temperature control coatings for outgassing data and for mechanical property tests after 500 hours of storage at 135°C and 10^{-6} torr.

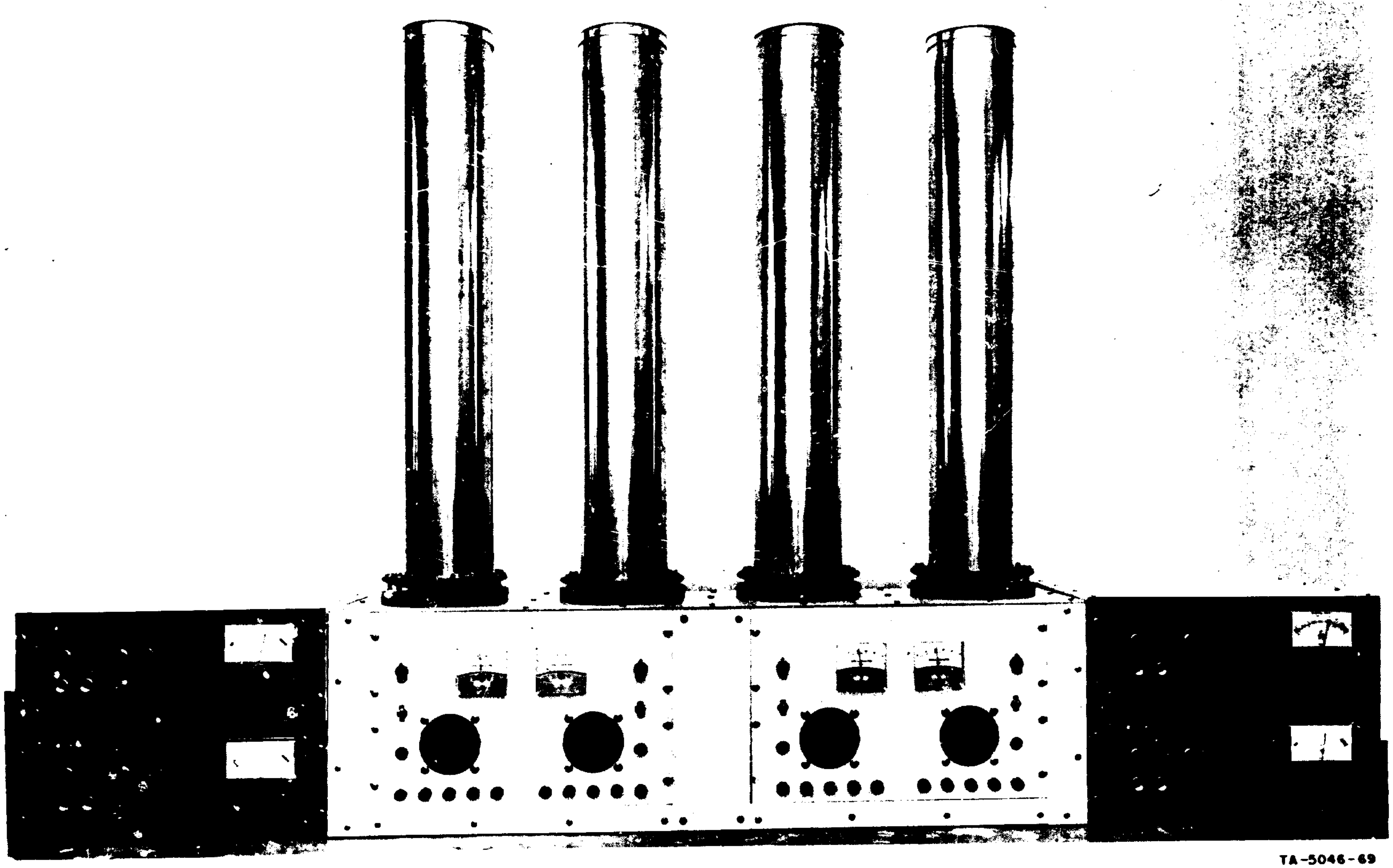

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FIG. 18 PHOTOGRAPH OF TOTAL ASSEMBLY FOR LONG-TERM THERMAL-VACUUM TESTS OF SELECTED POLYMERIC MATERIALS

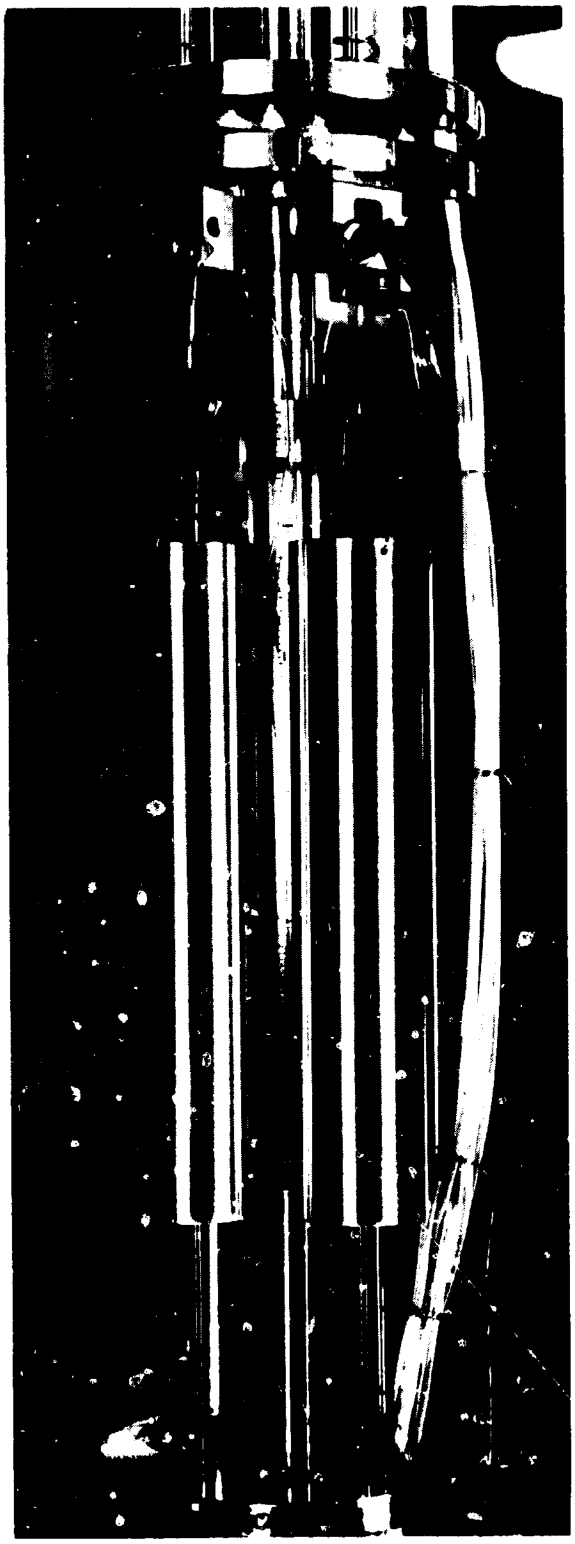


FIG. 19 LONG-TERM STORAGE CONSTANT LOAD APPARATUS SHOWING CYLINDRICAL WEIGHTS

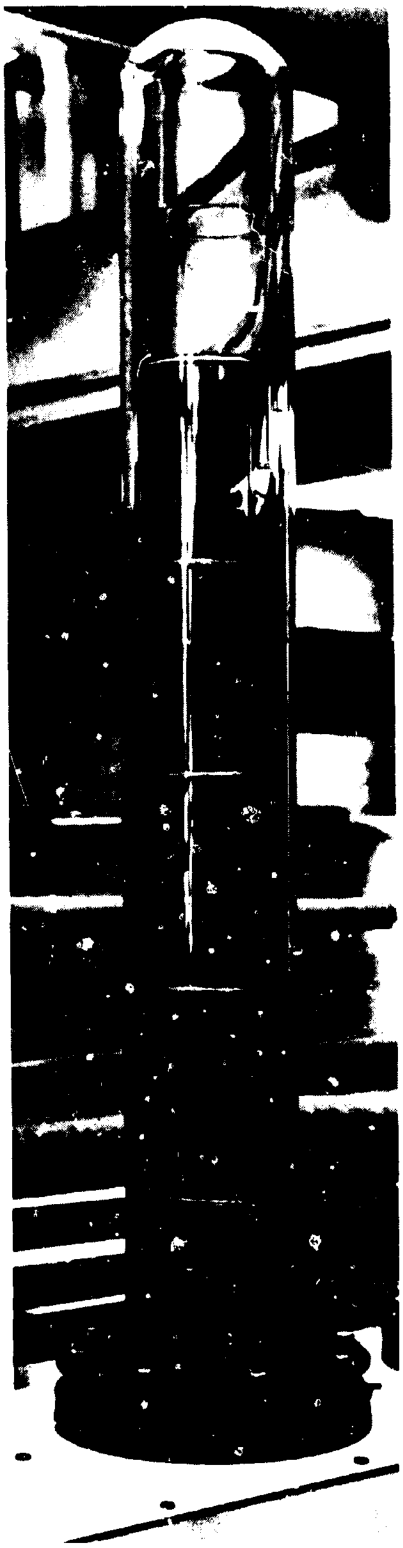
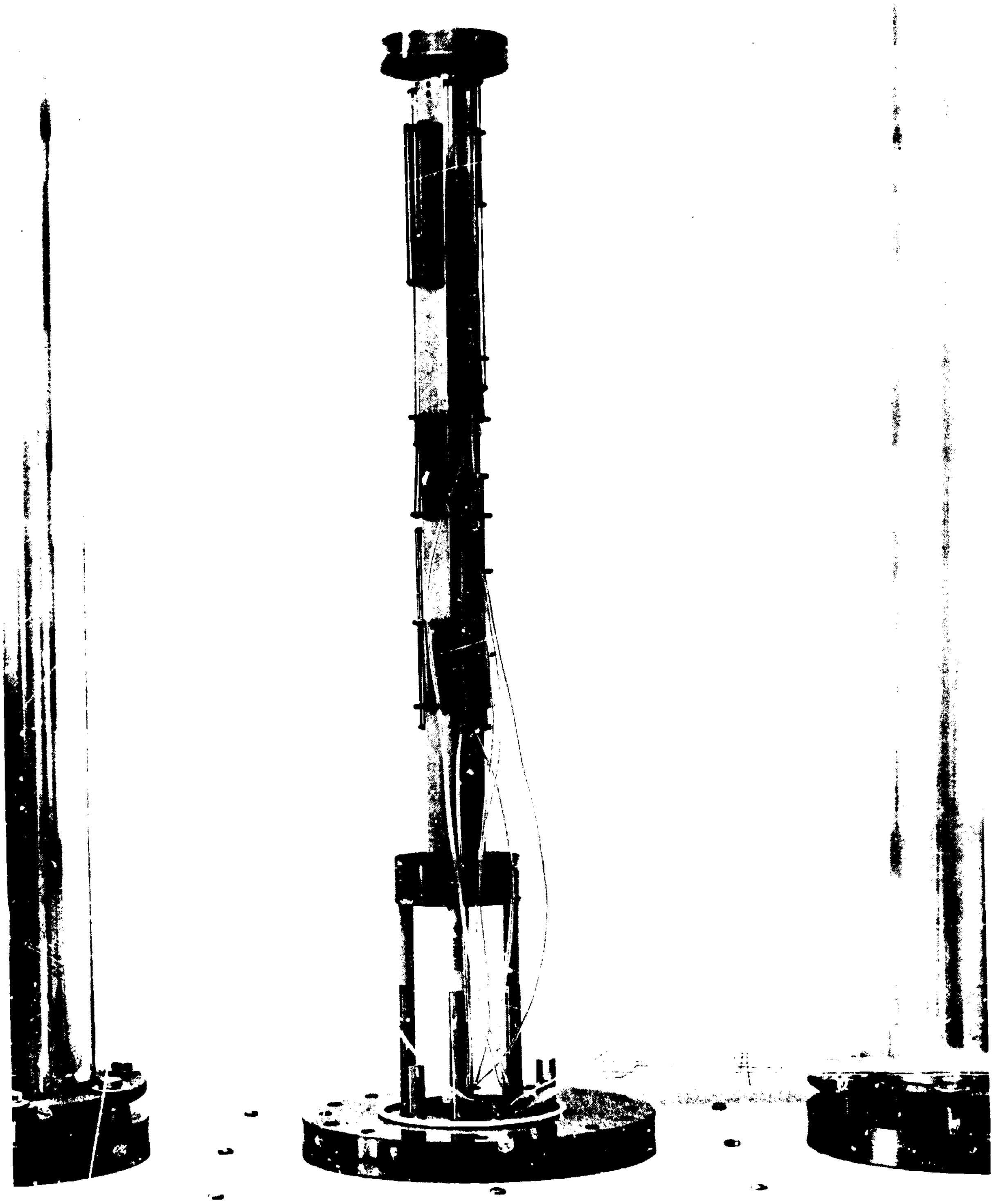
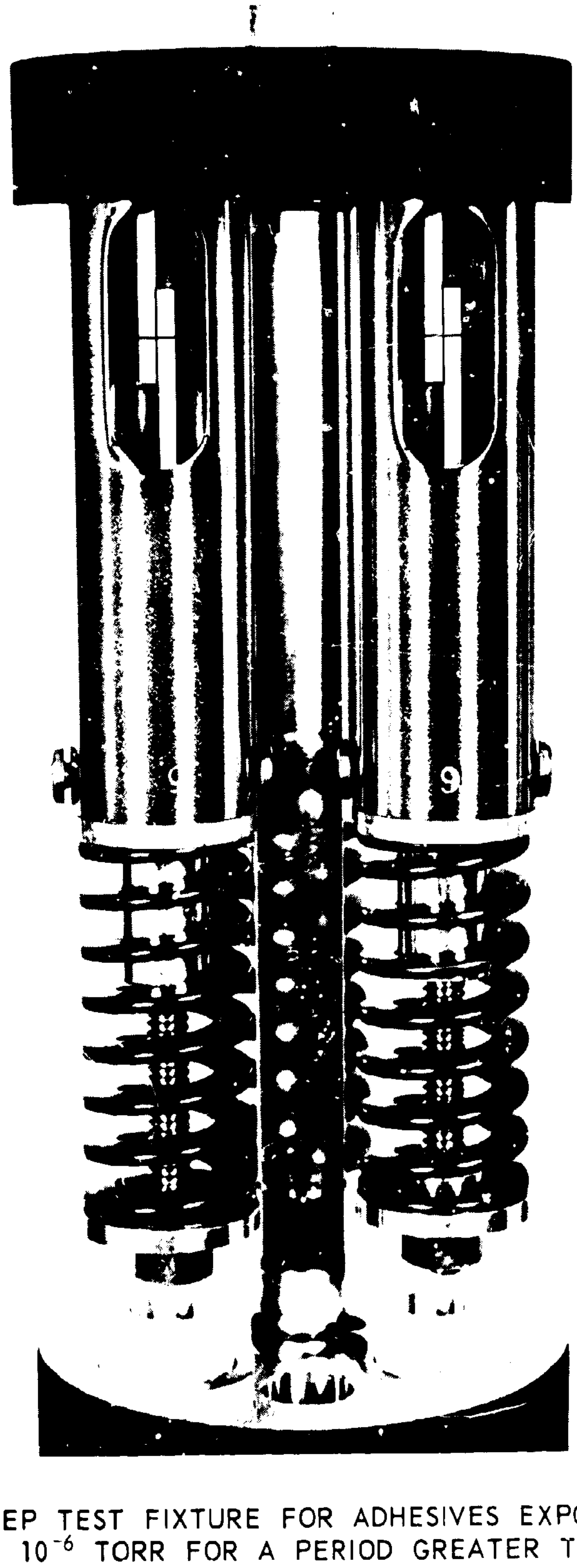


FIG. 20 LONG-TERM CONSTANT LOAD APPARATUS WITHIN BELL-TUBE



TA-5046-66

FIG. 21 BASIC STRUCTURE FOR SUBJECTING SELECTED ELASCOMERS TO SPECIFIC INITIAL STRAINS



TA-5046-61

FIG. 22 CREEP TEST FIXTURE FOR ADHESIVES EXPOSED TO 125°C AND 10^{-6} TORR FOR A PERIOD GREATER THAN EIGHT MONTHS, SHOWING THE LOCATION OF SPECIMENS WITHIN THE CREEP TESTER AND THE SCRIBED BENCH MARKS

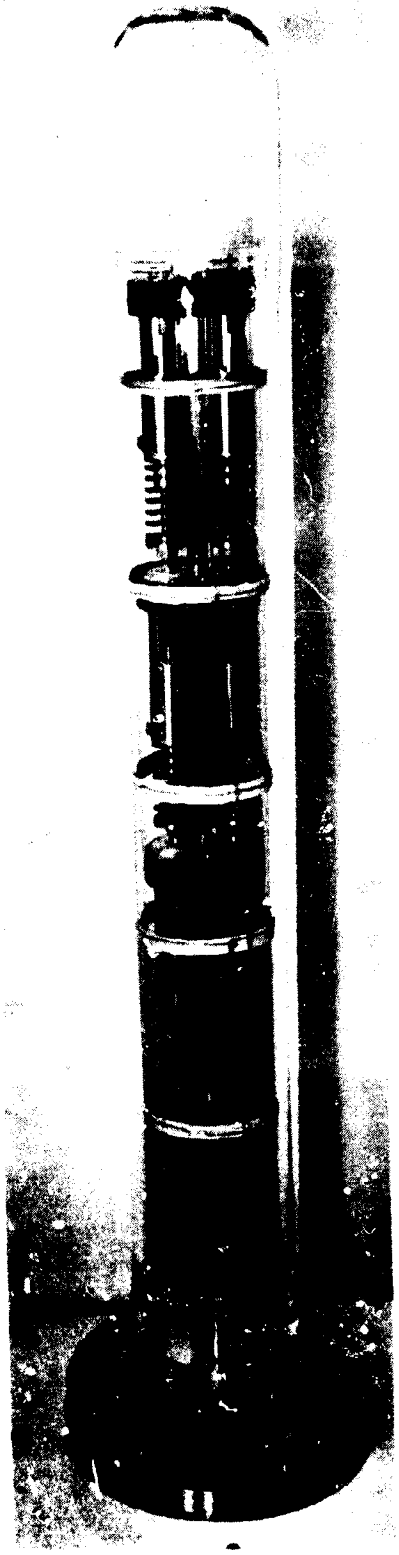


FIG. 23 PHOTOGRAPH OF THE TOTAL ASSEMBLY OF ADHESIVE CREEP TEST FIXTURES FOR LONG-TERM STORAGE TESTS

XXIII. SUPPLEMENT

DESIGN DRAWINGS FOR ADHESIVE CREEP TESTER AND ASSEMBLY FOR LONG-TERM STORAGE TESTS

B5046-63 CREEP TESTING TUBE (SAMPLE TEST FIXTURE)

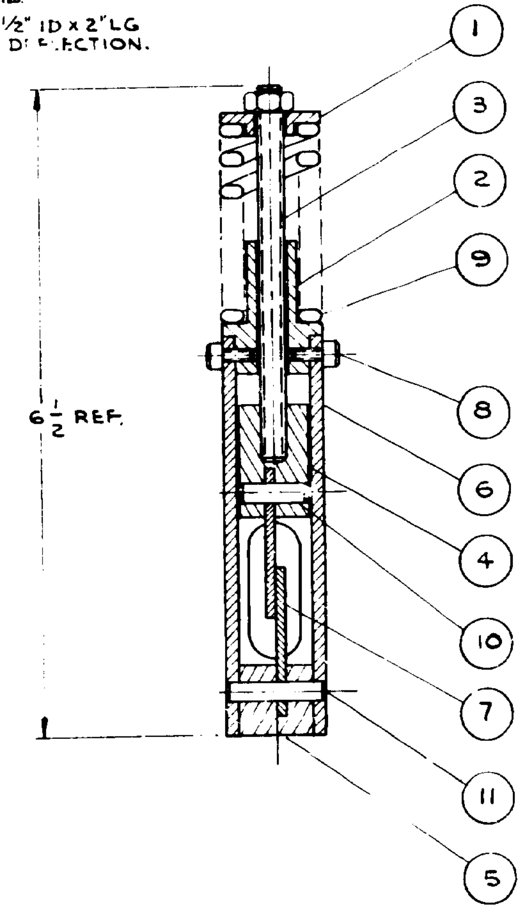
A5046-64	Spring Retainer - Upper
A5046-65	Spring Retainer - Lower
A5046-66	Stud
A5046-67	Blade Retainer - Upper
A5046-68	Blade Retainer - Lower
A5046-69	Tube
A5046-70	Blade

D5046-71 CREEP TESTER TREE (TESTER SUPPORT ASSEMBLY)

A5046-72	Test Tube Holder
A5046-73	Test Tube Holder
A5046-74	Plate - Lower
A5046-75	Plate - Lower
A5046-76	Plate - Upper
B5046-77	Rod (Supporting Center)
A5046-78	Stud

NOTES:

1. REMOVE ALL BURRS AND BREAK SHARP EDGES APPROX. .010R.
2. GENERAL FINISH 125 √, EXCEPT AS NOTED.
3. "DIECO" 1.0" OD x 1/2" ID x 2" LG [illegible] LB AT 50% DEFLECTION.



11	COM. ITEM	DOWEL PIN 3/16 DIA x 1.0 LG	1
10	" "	DOWEL PIN 3/16 DIA x 11/16 LG	1
9	" "	COMP. SPRING ⚠3	1
8	" "	SOCKET HD. SCREW #8-32 x 5/16	2
7	A5046-70	BLADE	2
6	A5046-69	TUBE	1
5	A5046-68	BLADE RETAINER - LOWER	1
4	A5046-67	BLADE RETAINER - UPPER	1
3	A5046-66	STUD	1
2	A5046-65	SPRING RETAINER - LOWER	1
1	A5046-64	SPRING RETAINER - UPPER	1
ITEM	DWG. NUMBER	DESCRIPTION	QTY.

TOLERANCES: UNLESS OTHERWISE SPECIFIED	BASIC DIMS.	FRACT. TOL.	DECIMAL TOL.
	0 TO ½	± 1/128	± .005
	½ TO 6	± 1/64	± .005
ANGULAR TOL. ± ½°	6 TO 24	± 1/32	± .010
	ABOVE 24	± 1/16	± .015

MATL.	—	
FINISH	—	
DR.	W. S.	3-16-67
CKD.	E. [illegible]	3-21-67
APPD.	J. Kok H	3-21-67
APPD.		

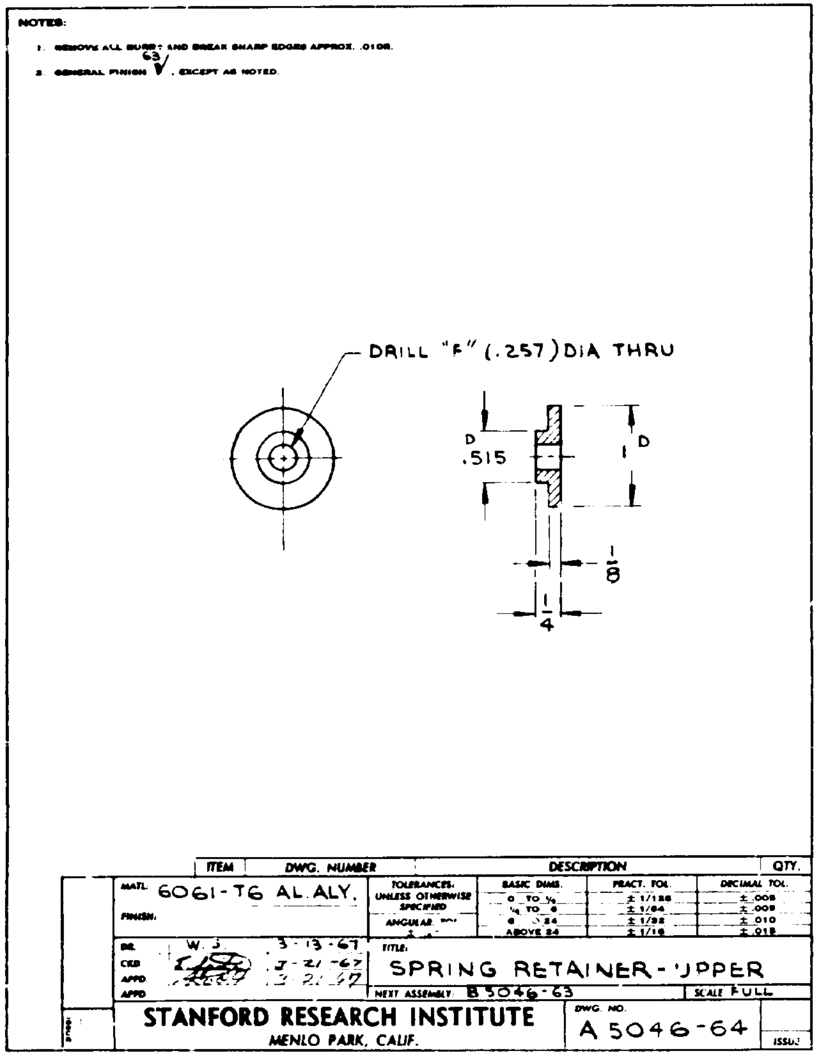
TITLE: CREEP TESTING TUBE

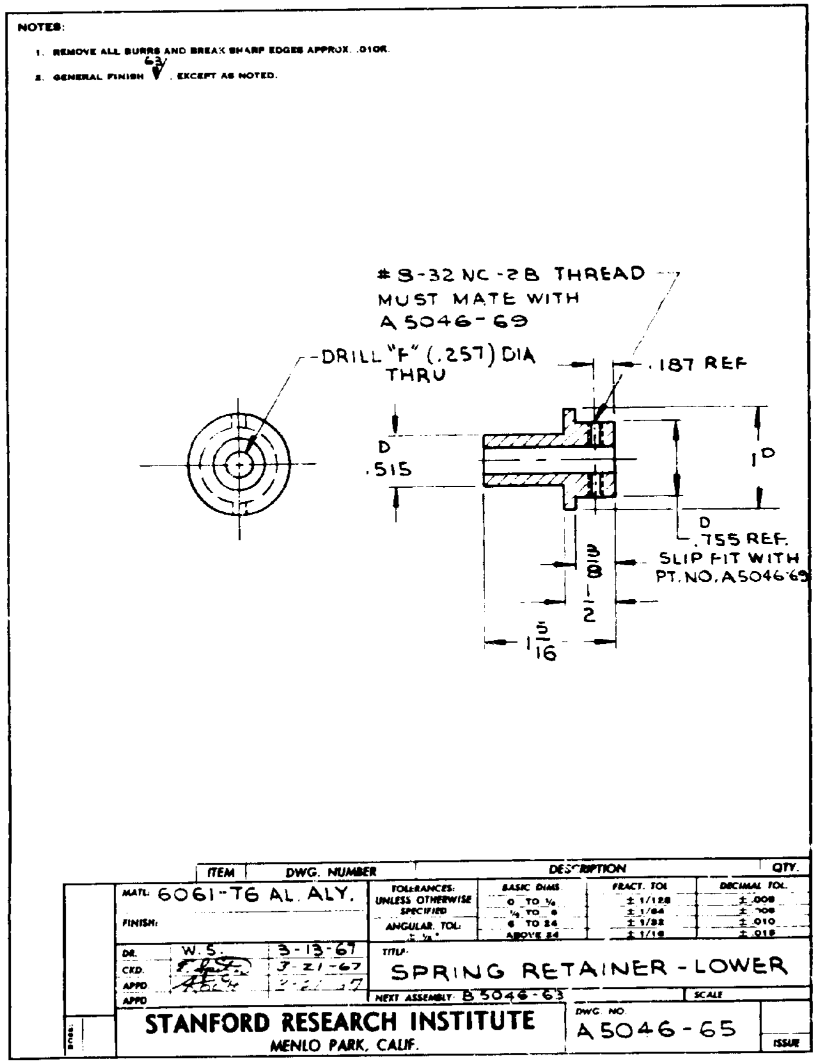
NEXT ASSEMBLY: D 5046-71

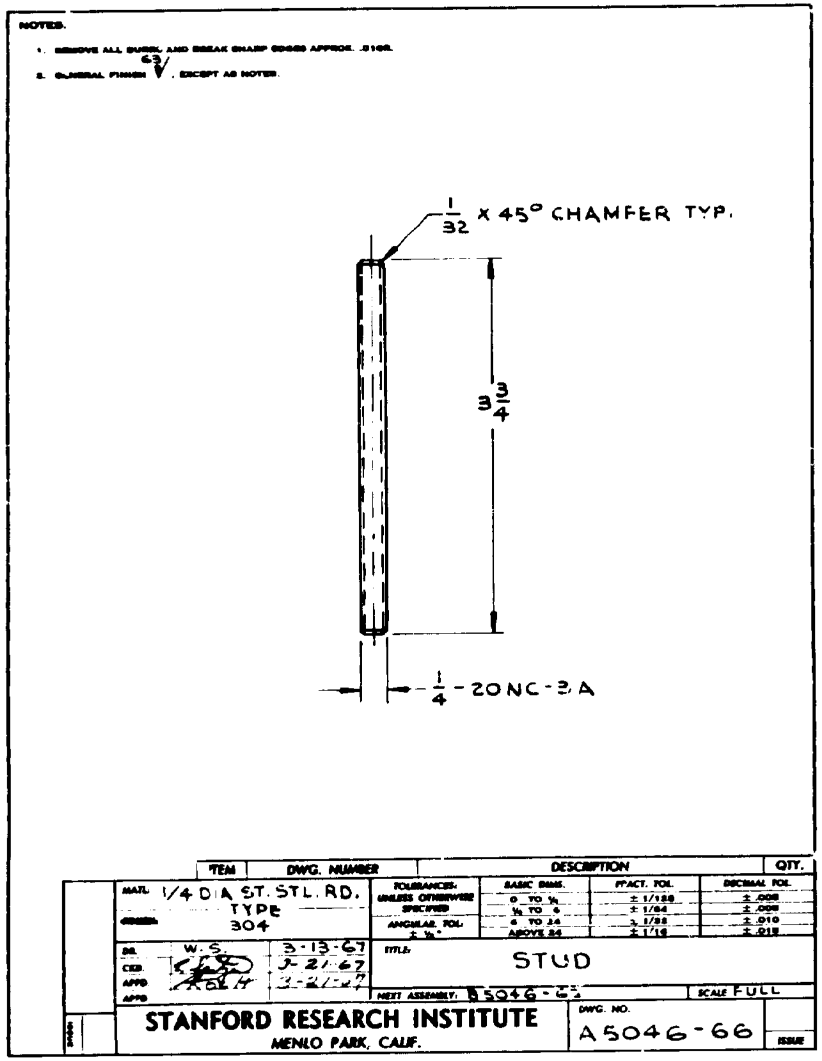
SCALE FULL

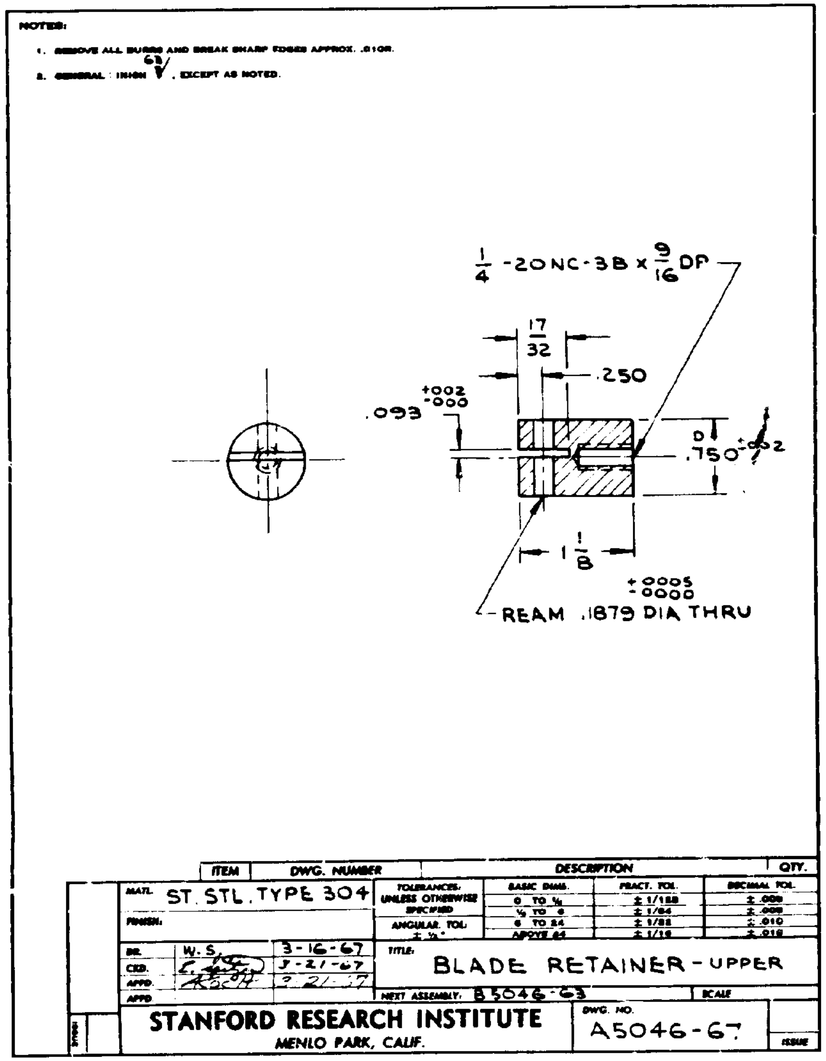
STANFORD RESEARCH INSTITUTE
MENLO PARK, CALIF.

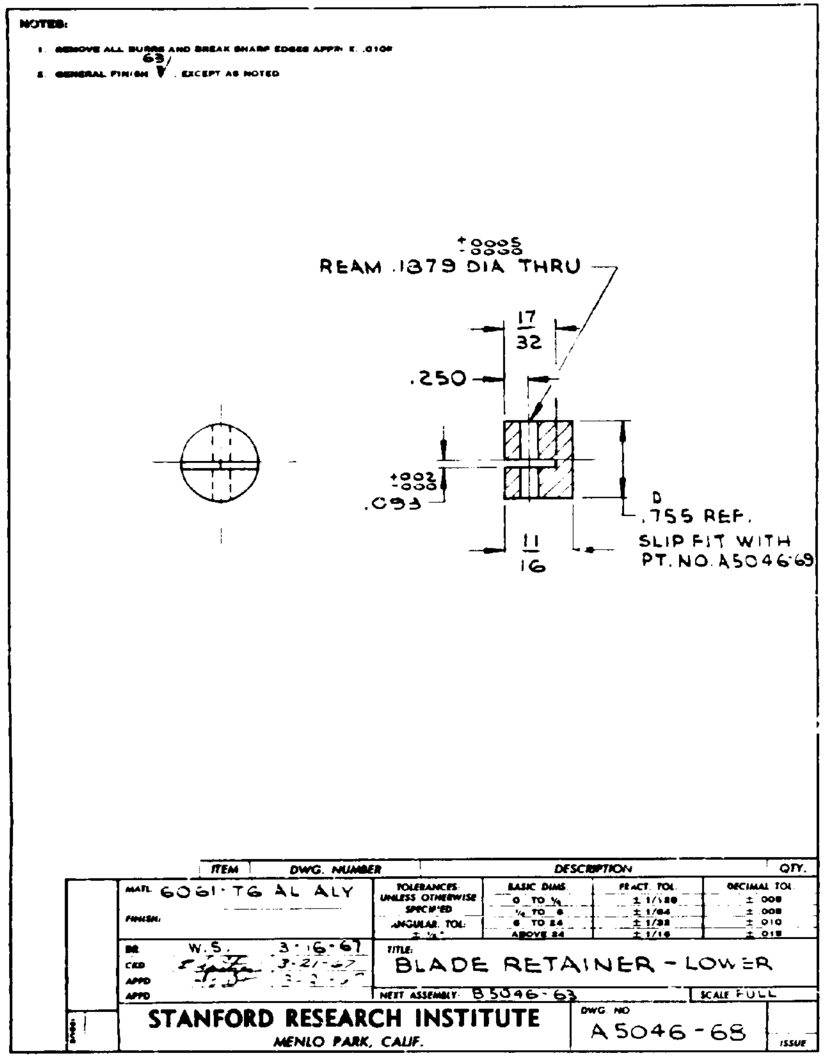
DWG. NO. B 5046-63

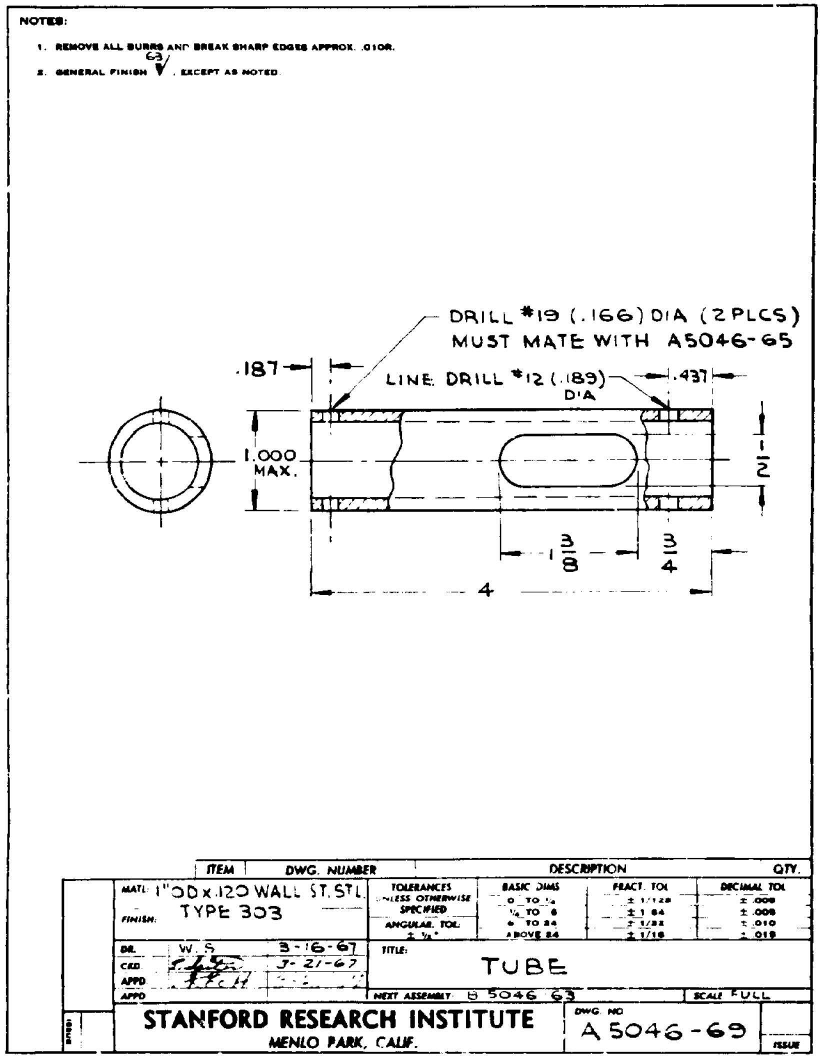

NOTES:
1. REMOVE ALL BURRS AND BREAK SHARP EDGES APPROX. .010R.
2. GENERAL FINISH 63 √. EXCEPT AS NOTED.
DRILL "F" (.257) DIA THRU
D .515
1 D
1/8
1/4
ITEM
DWG. NUMBER
DESCRIPTION
QTY.
MATL. 6061-T6 AL. ALY.
FINISH:
TOLERANCES: UNLESS OTHERWISE SPECIFIED
ANGULAR TOL.
BASIC DIMS.
0 TO ¼
¼ TO 6
6 TO 24
ABOVE 24
FRACT. TOL.
± 1/128
± 1/64
± 1/32
± 1/16
DECIMAL TOL.
± .005
± .008
± .010
± .015
DR. W. S. 3-13-67
CKD. 3-21-67
APPD. 3-21-67
APPD
TITLE: SPRING RETAINER - UPPER
NEXT ASSEMBLY B 5046-63
SCALE FULL
STANFORD RESEARCH INSTITUTE
MENLO PARK, CALIF.
DWG. NO. A 5046-64
ISSUE


NOTES:
1. REMOVE ALL BURRS AND BREAK SHARP EDGES APPROX. .010R.
2. GENERAL FINISH 63 √. EXCEPT AS NOTED.
#8-32 NC-2B THREAD MUST MATE WITH A 5046-69
DRILL "F" (.257) DIA THRU
.187 REF
D .515
1 D
D .755 REF. SLIP FIT WITH PT. NO. A5046-69
3/8
1/2
1 5/16
ITEM
DWG. NUMBER
DESCRIPTION
QTY.
MATL. 6061-T6 AL. ALY.
FINISH:
TOLERANCES: UNLESS OTHERWISE SPECIFIED
ANGULAR TOL. ± ½°
BASIC DIMS.
0 TO ¼
¼ TO 6
6 TO 24
ABOVE 24
FRACT. TOL.
± 1/128
± 1/64
± 1/32
± 1/16
DECIMAL TOL.
± .005
± .008
± .010
± .015
DR. W. S. 3-13-67
CKD. 3-21-67
APPD
APPD
TITLE: SPRING RETAINER - LOWER
NEXT ASSEMBLY B 5046-63
SCALE
STANFORD RESEARCH INSTITUTE
MENLO PARK, CALIF.
DWG. NO. A 5046-65
ISSUE


NOTES:
1. REMOVE ALL BURRS AND BREAK SHARP EDGES APPROX. .010R.
2. GENERAL FINISH 63√, EXCEPT AS NOTED.
1/32 X 45° CHAMFER TYP.
3 3/4
1/4 - 20NC-3A
ITEM
DWG. NUMBER
DESCRIPTION
QTY.
MATL. 1/4 DIA ST. STL. RD. TYPE 304
FINISH
TOLERANCES: UNLESS OTHERWISE SPECIFIED
ANGULAR TOL. ± ½°
BASIC DIMS.
0 TO ½
½ TO 6
6 TO 24
ABOVE 24
FRACT. TOL.
± 1/128
± 1/64
± 1/32
± 1/16
DECIMAL TOL.
± .005
± .005
± .010
± .015
DR. W. S. 3-13-67
CKD. 3-21-67
APPD. 3-21-67
APPD.
TITLE: STUD
NEXT ASSEMBLY: B5046-63
SCALE FULL
STANFORD RESEARCH INSTITUTE
MENLO PARK, CALIF.
DWG. NO. A5046-66
ISSUE

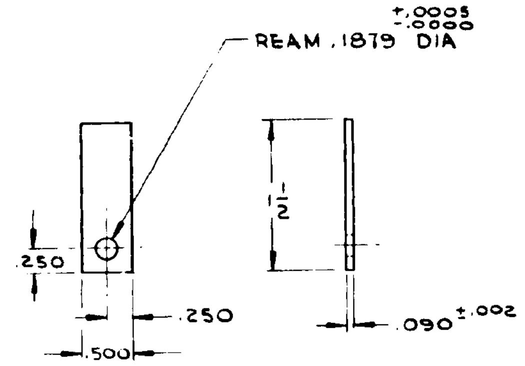

NOTES:
1. REMOVE ALL BURRS AND BREAK SHARP EDGES APPROX. .010R.
2. GENERAL FINISH 63√, EXCEPT AS NOTED.
1/4 - 20NC-3B x 9/16 DP
17/32
.250
.093 +.002 -.000
D
.750 +.002
1 1/8
REAM .1879 +.0005 -.0000 DIA THRU
ITEM
DWG. NUMBER
DESCRIPTION
QTY.
MATL. ST. STL. TYPE 304
FINISH
TOLERANCES: UNLESS OTHERWISE SPECIFIED
ANGULAR TOL. ± ½°
BASIC DIMS.
0 TO ½
½ TO 6
6 TO 24
ABOVE 24
FRACT. TOL.
± 1/128
± 1/64
± 1/32
± 1/16
DECIMAL TOL.
± .005
± .005
± .010
± .015
DR. W. S. 3-16-67
CKD. 3-21-67
APPD. 3-21-67
APPD.
TITLE: BLADE RETAINER - UPPER
NEXT ASSEMBLY: B5046-63
SCALE
STANFORD RESEARCH INSTITUTE
MENLO PARK, CALIF.
DWG. NO. A5046-67
ISSUE


NOTES:
1. REMOVE ALL BURRS AND BREAK SHARP EDGES APPROX. .010R.
2. GENERAL FINISH 63/√, EXCEPT AS NOTED
REAM .1879 +.0005 -.0000 DIA THRU
17/32
.250
+.002 -.000
.093
11/16
D
.755 REF.
SLIP FIT WITH PT. NO. A5046-69
ITEM
DWG. NUMBER
DESCRIPTION
QTY.
MAT'L 6061-T6 AL ALY
FINISH:
TOLERANCES UNLESS OTHERWISE SPECIFIED
ANGULAR TOL ± ½°
BASIC DIMS
0 TO ¼
¼ TO 6
6 TO 24
ABOVE 24
FRACT. TOL
± 1/128
± 1/64
± 1/32
± 1/16
DECIMAL TOL
± .005
± .008
± .010
± .015
DR. W.S. 3-16-67
CKD 3-21-67
APPD
APPD
TITLE: BLADE RETAINER - LOWER
NEXT ASSEMBLY B5046-63
SCALE FULL
STANFORD RESEARCH INSTITUTE
MENLO PARK, CALIF.
DWG NO A5046-68
ISSUE


NOTES:
1. REMOVE ALL BURRS AND BREAK SHARP EDGES APPROX. .010R.
2. GENERAL FINISH 63/√, EXCEPT AS NOTED
DRILL #19 (.166) DIA (2 PLCS)
MUST MATE WITH A5046-65
.187
LINE DRILL #12 (.189) DIA
.437
1.000 MAX.
1/2
1 3/8
3/4
4
ITEM
DWG. NUMBER
DESCRIPTION
QTY.
MAT'L 1" OD x .120 WALL ST. STL.
TYPE 303
FINISH:
TOLERANCES UNLESS OTHERWISE SPECIFIED
ANGULAR TOL ± ½°
BASIC DIMS
0 TO ¼
¼ TO 6
6 TO 24
ABOVE 24
FRACT. TOL
± 1/128
± 1/64
± 1/32
± 1/16
DECIMAL TOL
± .005
± .008
± .010
± .015
DR. W.S. 3-16-67
CKD 3-21-67
APPD
APPD
TITLE: TUBE
NEXT ASSEMBLY B5046-63
SCALE FULL
STANFORD RESEARCH INSTITUTE
MENLO PARK, CALIF.
DWG NO A5046-69
ISSUE

NOTES:

1. REMOVE ALL BURRS AND BREAK SHARP EDGES APPROX. .010R.
2. GENERAL FINISH 63 ✓, EXCEPT AS NOTED.
3. SURFACES TO BE LIGHTLY SANDBLASTED
4. MILL EDGES AFTER SANDBLASTING



ITEM	DWG. NUMBER	DESCRIPTION	QTY.

MATL. 2024-T3 AL. ALY.
FINISH: 3

TOLERANCES: UNLESS OTHERWISE SPECIFIED	BASIC DIMS.	FRACT. TOL.	DECIMAL TOL.
	0 TO ¼	± 1/128	± .005
	¼ TO 6	± 1/64	± .005
ANGULAR. TOL. ± ½°	6 TO 24	± 1/32	± .010
	ABOVE 24	± 1/16	± .015

DR. W.S. 3-5-67
CKD. 3-21-67
APPD. 3-21-67
APPD.

TITLE: TEST BLADE

NEXT ASSEMBLY: B5046-65
SCALE FULL

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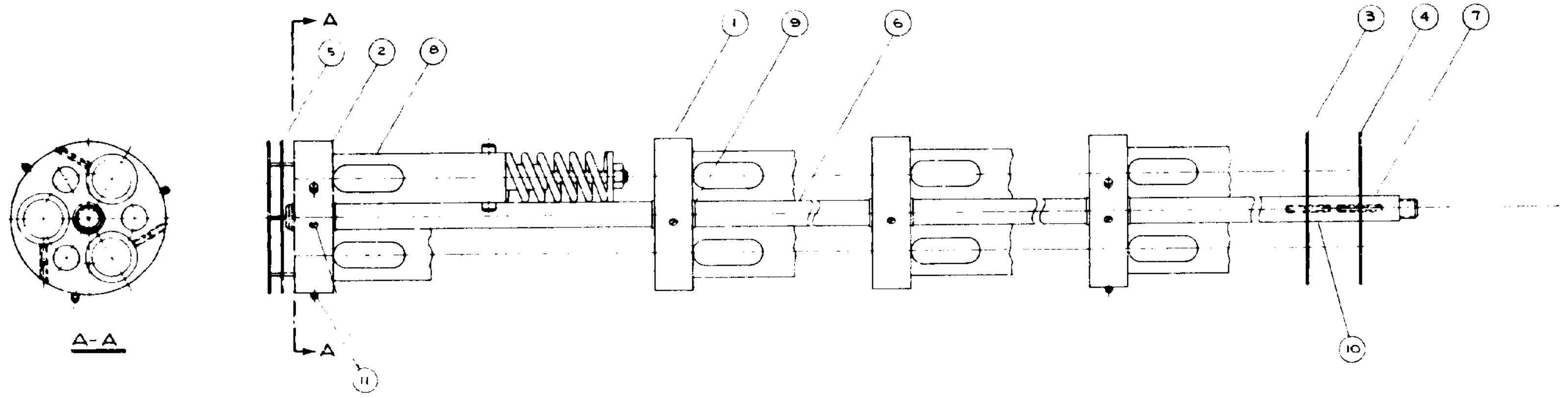
MENLO PARK, CALIF.

DWG. NO. A 5046-70
ISSUE
ISSUE

[illegible]



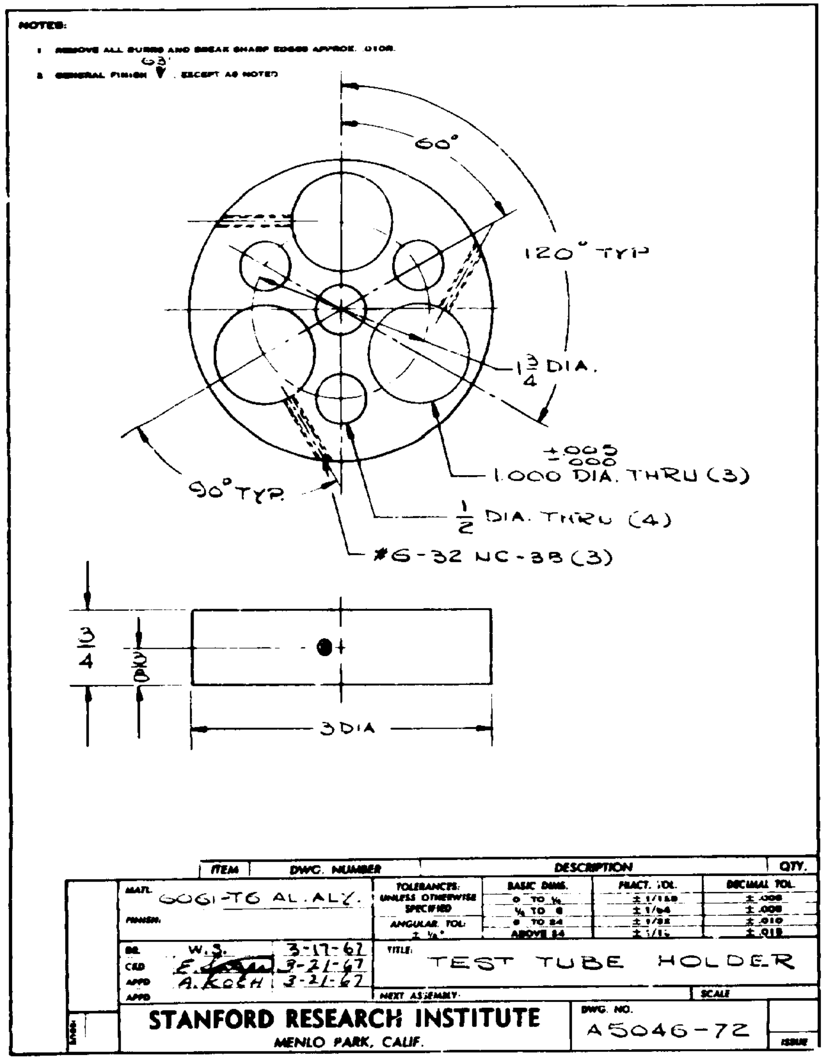
ITEM	DWG NUMBER	DESCRIPTION	QTY
11	COM ITEM	#6-32NC x 3/8 SET SCREW	16
10	COM ITEM	CERAMIC STAND-OFF △	1
9	COM ITEM	TRUARC 5100-50 RING	8
8	B5046-63	CREEP TESTING TUBE	12
7	A5046-78	STUD	1
6	B5046-77	ROD	1
5	A5046-76	PLATE - UPPER	2
4	A5046-75	PLATE - LOWER	1
3	A5046-74	PLATE - LOWER	1
2	A5046-73	TEST TUBE HOLDER	2
1	A5046-72	TEST TUBE HOLDER	2

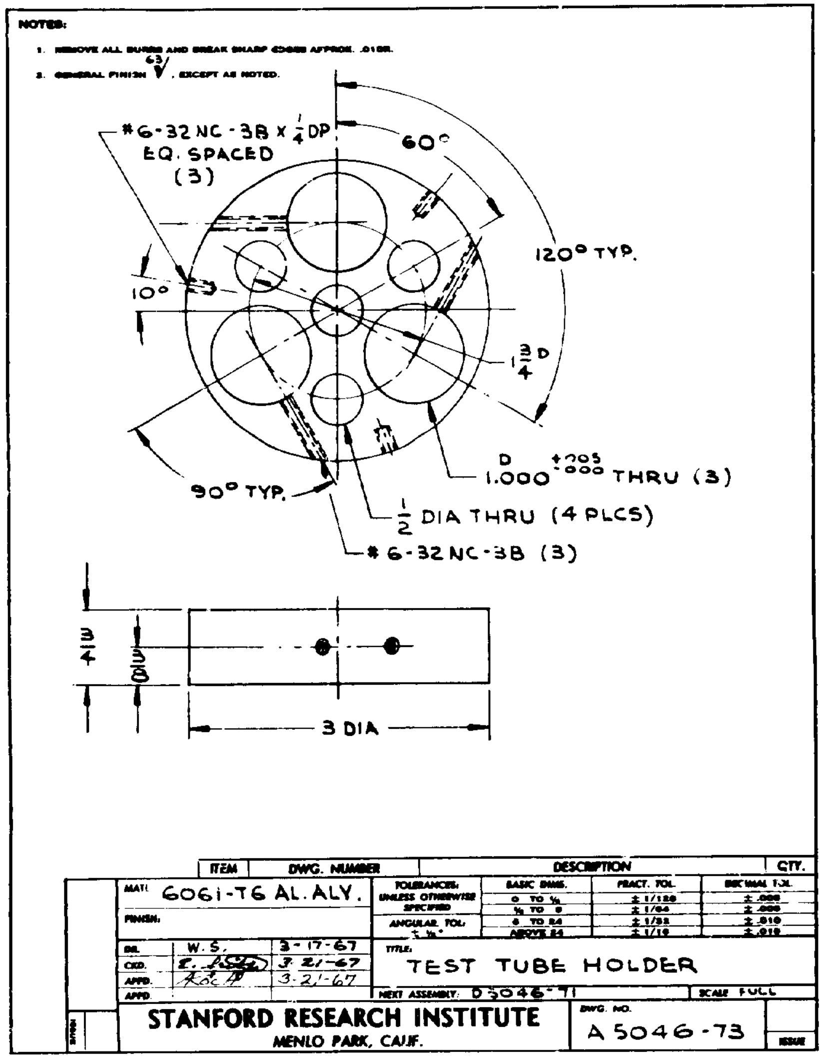
3-29-67
7-2-67

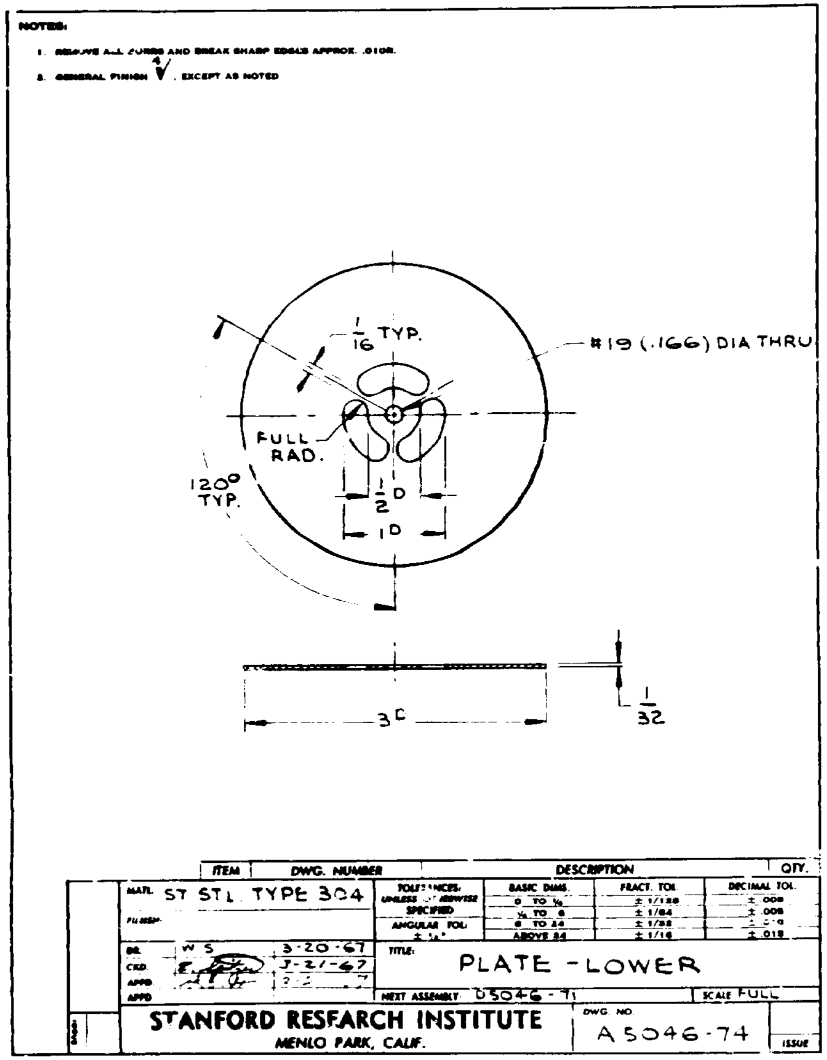
CREEP TESTER TREE

STANFORD RESEARCH INSTITUTE
MENLO PARK, CALIF

D5046-71

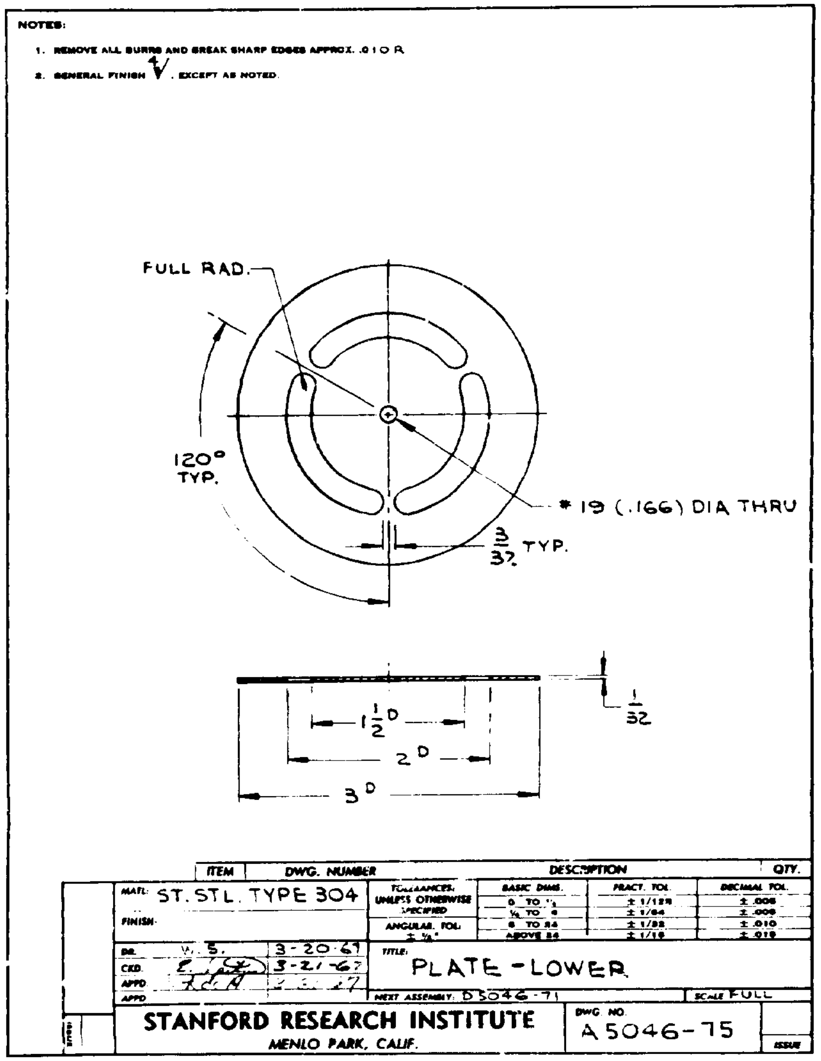

NOTES:
1. REMOVE ALL BURRS AND BREAK SHARP EDGES APPROX. .010R.
2. GENERAL FINISH 63 ∨, EXCEPT AS NOTED
60°
120° TYP
$1\frac{3}{4}$ DIA.
$1.000^{+.005}_{-.000}$ DIA. THRU (3)
$\frac{1}{2}$ DIA. THRU (4)
#6-32 NC-3B (3)
90° TYP.
$\frac{3}{4}$
$\frac{3}{8}$
3 DIA
ITEM
DWG. NUMBER
DESCRIPTION
QTY.
MAT'L 6061-T6 AL. ALY.
FINISH
TOLERANCES: UNLESS OTHERWISE SPECIFIED
ANGULAR TOL. ± ½°
BASIC DIMS.
FRACT. TOL.
DECIMAL TOL.
DR. W.S. 3-17-67
CKD E. [illegible] 3-21-67
APPD A. KOCH 3-21-67
APPD
TITLE: TEST TUBE HOLDER
NEXT ASSEMBLY
SCALE
STANFORD RESEARCH INSTITUTE
MENLO PARK, CALIF.
DWG. NO. A5046-72
ISSUE


NOTES:
1. REMOVE ALL BURRS AND BREAK SHARP EDGES APPROX. .010R.
2. GENERAL FINISH 63 ∨, EXCEPT AS NOTED.
#6-32 NC-3B × $\frac{1}{4}$ DP EQ. SPACED (3)
60°
120° TYP.
10°
$1\frac{3}{4}$ D
D $1.000^{+.005}_{-.000}$ THRU (3)
$\frac{1}{2}$ DIA THRU (4 PLCS)
#6-32 NC-3B (3)
90° TYP.
$\frac{3}{4}$
$\frac{3}{8}$
3 DIA
ITEM
DWG. NUMBER
DESCRIPTION
QTY.
MAT'L 6061-T6 AL. ALY.
FINISH
TOLERANCES: UNLESS OTHERWISE SPECIFIED
ANGULAR TOL. ± ½°
BASIC DIMS.
FRACT. TOL.
DECIMAL TOL.
DR. W.S. 3-17-67
CKD. E. [illegible] 3-21-67
APPD. Koch 3-21-67
APPD
TITLE: TEST TUBE HOLDER
NEXT ASSEMBLY D5046-71
SCALE FULL
STANFORD RESEARCH INSTITUTE
MENLO PARK, CALIF.
DWG. NO. A5046-73
ISSUE



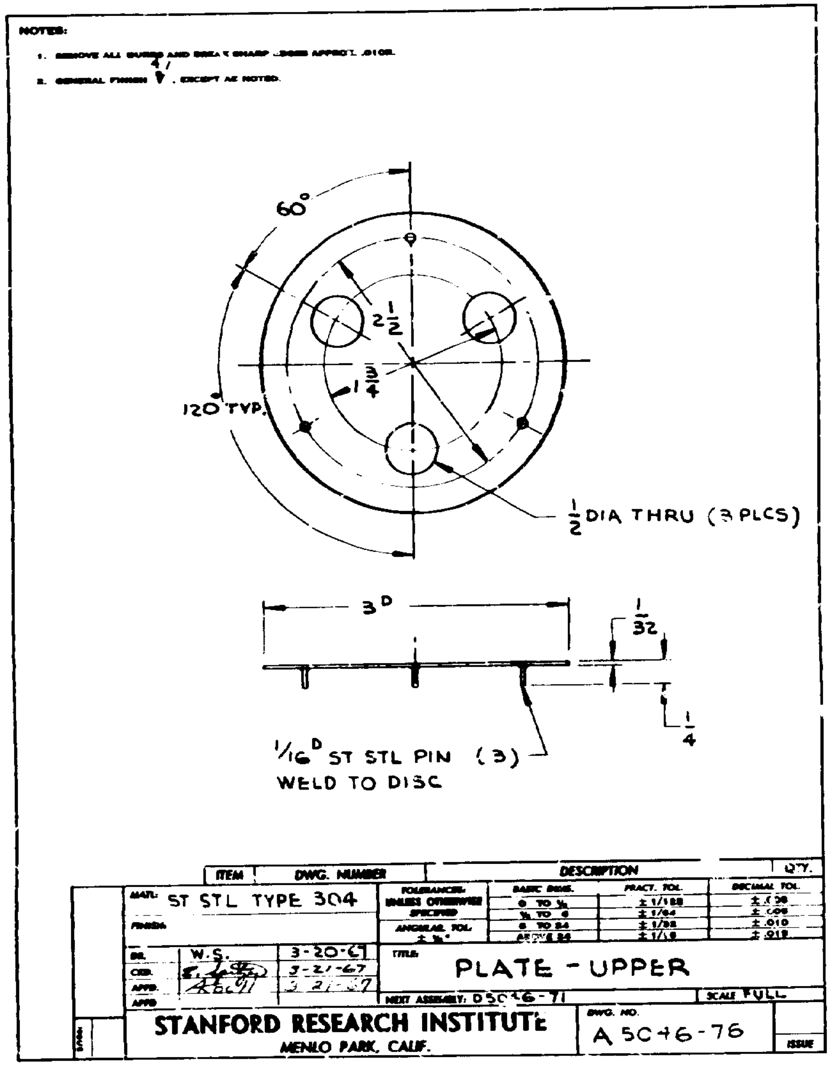
NOTES:
1. REMOVE ALL BURRS AND BREAK SHARP EDGES APPROX. .010R.
2. GENERAL FINISH $\overset{4}{\vee}$, EXCEPT AS NOTED

MAT'L: ST. STL. TYPE 304
FINISH:
DR. W. S. 3-20-67
CKD. 3-21-67
TITLE: PLATE - LOWER
NEXT ASSEMBLY D5046-71
SCALE FULL
STANFORD RESEARCH INSTITUTE
MENLO PARK, CALIF.
DWG NO. A5046-74



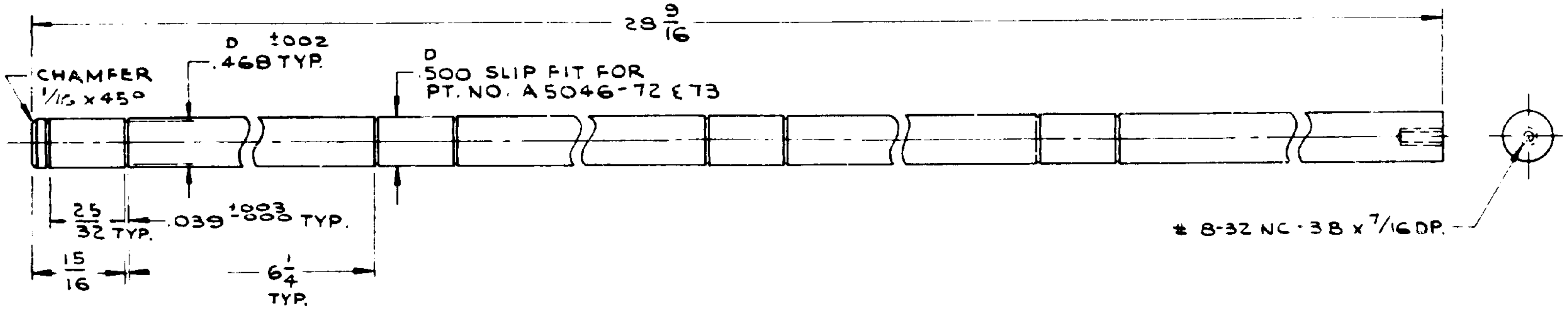
NOTES:
1. REMOVE ALL BURRS AND BREAK SHARP EDGES APPROX. .010 R.
2. GENERAL FINISH $\overset{4}{\vee}$, EXCEPT AS NOTED.

MAT'L: ST. STL. TYPE 304
FINISH:
DR. W. S. 3-20-67
CKD. 3-21-67
TITLE: PLATE - LOWER
NEXT ASSEMBLY D5046-71
SCALE FULL
STANFORD RESEARCH INSTITUTE
MENLO PARK, CALIF.
DWG NO. A5046-75


NOTES:
1. REMOVE ALL BURRS AND BREAK SHARP EDGES APPROX. .010R.
2. GENERAL FINISH 4√, EXCEPT AS NOTED.
60°
$2\frac{1}{2}$
$1\frac{3}{4}$
120° TYP.
$\frac{1}{2}$ DIA THRU (3 PLCS)
3^D
$\frac{1}{32}$
$\frac{1}{4}$
$1/16^D$ ST STL PIN (3)
WELD TO DISC
ITEM
DWG. NUMBER
DESCRIPTION
QTY.
MATL. ST STL TYPE 304
FINISH
TOLERANCES UNLESS OTHERWISE SPECIFIED
ANGULAR TOL. ± ½°
BASIC DIMS.
0 TO ½
½ TO 6
6 TO 24
ABOVE 24
FRACT. TOL.
± 1/128
± 1/64
± 1/32
± 1/16
DECIMAL TOL.
± .003
± .005
± .010
± .015
DR. W.S. 3-20-67
CHK. 3-21-67
APPD. 3-21-67
APPD.
TITLE: PLATE - UPPER
NEXT ASSEMBLY: D5C46-71
SCALE FULL
STANFORD RESEARCH INSTITUTE
MENLO PARK, CALIF.
DWG. NO. A 5C46-76
ISSUE

NOTES:

1. REMOVE ALL BURRS AND BREAK SHARP EDGES APPROX. .010R.
2. GENERAL FINISH $\overset{63}{\checkmark}$, EXCEPT AS NOTED.



ITEM	DWG. NUMBER	DESCRIPTION	QTY.

MAT'L: ST STL TYPE 304	TOLERANCES: UNLESS OTHERWISE SPECIFIED	BASIC DIMS.	FRACT. TOL.	DECIMAL TOL.
		0 TO 1/4	± 1/128	± .005
FINISH:		1/4 TO 6	± 1/64	± .008
	ANGULAR TOL: ± 1/2°	6 TO 24	± 1/32	± .010
		ABOVE 24	± 1/16	± .015

DR.	W. S.	3-20-67
CKD.		3-23-67
APPD.		
APPD.		

TITLE: ROD

NEXT ASSEMBLY: D 5046-71

SCALE

STANFORD RESEARCH INSTITUTE
MENLO PARK, CALIF.

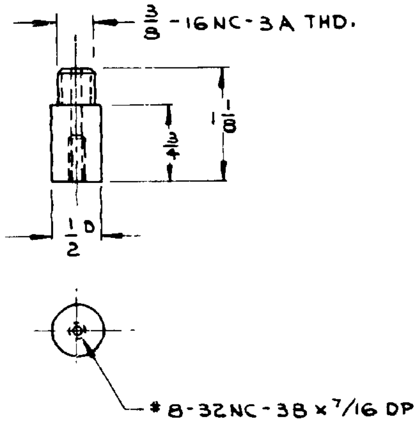
DWG. NO. B 5046-77

ISSUE

ISSUE

NOTES:

1. REMOVE ALL BURRS AND BREAK SHARP EDGES APPROX. .010R.
2. GENERAL FINISH $\overset{63}{\surd}$, EXCEPT AS NOTED.



ITEM	DWG. NUMBER	DESCRIPTION	QTY.

MAT'L ST STL TYPE 304	TOLERANCES: UNLESS OTHERWISE SPECIFIED	BASIC DIMS.	FRACT. TOL.	DECIMAL TOL.
FINISH:		0 TO 1/16	± 1/128	± .005
		1/16 TO 6	± 1/64	± .005
	ANGULAR TOL: ± 1/2°	6 TO 24	± 1/32	± .010
		ABOVE 24	± 1/16	± .015

DR.	W. S.	3-20-67
CKD.		3-21-67
APVD.		3-21-67
APVD.		

TITLE: STUD

NEXT ASSEMBLY: D5046-71

SCALE FULL

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MENLO PARK, CALIF.

DWG. NO. A5046-78

ISSUE

XXIV. SUMMARY AND RECOMMENDATIONS

Recommendations of polymeric products for spacecraft applications must be based on the results of comprehensive test and evaluation programs which provide for the examination of properties which are significant in estimating the performance of such materials for long-term use in the space environment and their resistance to pre-flight environments. The work performed under this contract has been directed toward the development of test equipment and techniques which will provide useful data for the evaluation of polymeric materials, the selection of properties to be determined, the establishment of correlations between outgassing properties and mechanical properties, and the identification of candidate materials. Out of this exploratory and development work has crystallized a test scheme which ensures that a qualified material can withstand any combination of pre-flight and space environments.

At the outset of this program, the work was involved largely with the behavior of polymeric materials in a thermal-vacuum environment and it was shown that the values for loss in weight and VCM content could provide insight into the mechanical performance of polymers and afford a measure as to the extent of damage that might be caused by deposition of volatile matter on a spacecraft. Since deposition of volatile matter has been shown to be particularly undesirable, micro-VCM determinations have become the primary screening test for polymeric products. The infrared absorbance of the released VCM provides an additional qualification parameter.

Preliminary work with determining mechanical properties <u>in situ</u> provided only a few data on the stress and strain properties of elastomers and plastic films with some auxiliary data on tensile properties of these two kinds of materials after thermal-vacuum storage. In order to examine greater numbers and varieties of materials for additional properties, the multiple-cell unit was designed for exposing 30 samples simultaneously, each in a separate container. Thus, 30 products for applications as adhesives, foams, coated fabrics, tapes, etc., etc. could be processed over a 2-month period rather than the 6 or 8 elastomers and films handled previously in the same length of time. In view of the increasing interest in sterilizable polymers, it was appropriate to include also a decontamination exposure in these test runs.

Examination of property data from the comprehensive test runs (decontamination plus vacuum-thermal environment) and comparison with available data on similar materials from 1000-hour and 5000-hour exposures revealed that good polymers changed little after the 500-hour thermal-vacuum storage period, that 1000 hours was more appropriate for marginal materials (although negative 500-hr data were final), and that there was little difference in 1000-hour or 5000-hour storage test data.

The developments and findings described briefly above, coupled with the interest in ensuring that a qualified polymer will maintain its properties in any environment, suggest that a comprehensive test and evaluation program shall include any combination of three exposures: decontamination, thermal-sterilization, and thermal-vacuum environment, all for optimum times and temperatures. Additionally, by testing for all properties after each exposure or sequence of exposures, appropriate data will be available for any treatment considered prior to spaceflight. Such a program will be complex and time consuming; therefore, it is recommended that only products which pass the micro-VCM criteria be considered for final qualification testing and that those with a good history in decontamination/thermal-vacuum testing be given top priority. Examples of suitable candidates are given in Appendix D, and a block diagram of a proposed program is given in Figure 24.

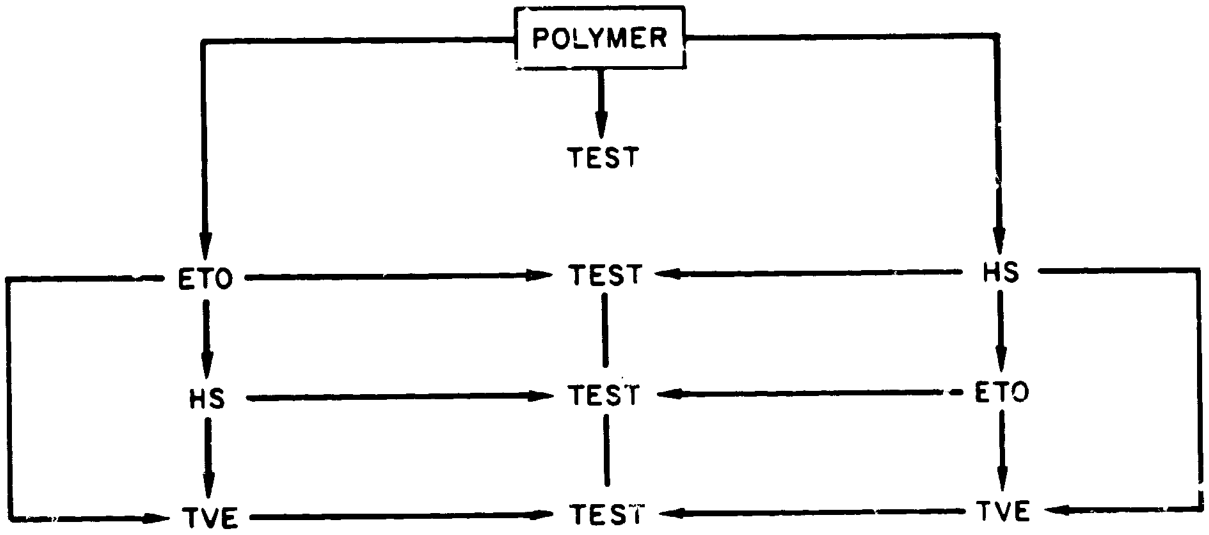

FIG. 24 BLOCK DIAGRAM OF PROPOSED COMPREHENSIVE TEST AND EVALUATION PROGRAM FOR STERILIZABLE POLYMERS

(ETO = ethylene oxide decontamination
HS = heat sterilization in nitrogen atmosphere
TVE = thermal-vacuum environment
TEST = micro-VCM; mechanical properties; electrical properties, etc.)

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XXV. NEW TECHNOLOGY

In accordance with the New Technology Clause of Contract No. 950745 under NAS7-100, formal announcement is made of the various technologies which have been developed or advanced at Stanford Research Institute under JPL/NASA sponsorship during the period of the contract.

New Announcement

INFRARED SPECTROPHOTOMETRIC DETERMINATION OF VOLATILE CONDENSABLE MATERIAL (VCM)

Innovator:	R. F. Muraca
First Used:	January 1967
Reports:	Monthly Report No. 32, February 1967, and following
Announced:	Final Report, September 15, 1967

Volatile condensable material (VCM) is defined as the weight of condensate obtainable at 25°C in a given interval of time from a unit weight of a thin or comminuted sample of material maintained at 125°C in a vacuum of at least 5×10^{-6} torr. An infrared spectrophotometric method has been designed not only to provide an alternate means of "weighing" the condensate but also to characterize the nature of the condensate as a quality-control measure.

Samples for the determination of weight-loss and VCM are prepared in the same manner and emplaced in the same micro-VCM apparatus as described in Interim Report No. 3 (December 9, 1966). (Announcement of the micro-VCM apparatus is given below.) In this instance, however, the VCM is collected on optical salt flats, 1/4" thick and 1" in diameter. (Design drawings for the salt flats and holders are given in Section III of this report.) At the termination of a run, the infrared spectrum of the VCM on the salt flat is recorded and the absorbance of significant peaks can be measured. The salt flat in its holder can be weighed.

For calibration runs, the weight of sample is plotted against absorbance of a significant peak. For quality control, the absorbance of the peak divided by the sample weight must not exceed a given maximum.

A catalog of infrared absorbance spectra of VCM from 96 polymeric products is given in Appendix C of this report.

Prior Announcements

MICRO-VCM APPARATUS FOR POLYMERIC MATERIALS

Innovator: R. F. Muraca
First Used: January 1966
Reports: Monthly Reports 17, November 1965, and following
Announced: Interim Report No. 2, March 1966

The micro-VCM apparatus is a multiple unit (24 samples) designed for screening all kinds of polymeric materials in a simulated spacecraft environment. Vacuum-weight-loss and VCM (volatile condensable material) are determined concurrently. Complete design drawings and details of the procedure for micro-VCM determinations are given in Interim Report No. 3, December 1966.

MACRO-VCM APPARATUS FOR POLYMERS

Innovator: R. F. Muraca
First Used: June 1966
Reports: Interim Report No. 2, March 1966
Announced: Interim Report No. 3, December 1966

The macro-VCM apparatus and accompanying vacuum system are designed to provide information on the deposition and subsequent removal of volatile condensable material released by all kinds of polymers exposed to a simulated spacecraft environment. Complete design drawings and details of the procedure are given in Interim Report No. 3.

MULTIPLE-CELL TEST UNIT FOR POLYMERS

Innovator:	R. F. Muraca
First Used:	August 1966
Reports:	Monthly Report No. 22, April 1966, and following
Announced:	Interim Report No. 3, December 1966

The multiple-cell unit is designed to accommodate 30 sample cells, each of which may contain several configurations of a single polymeric product according to the subsequent physical/mechanical property tests to be performed. The system is so designed that the materials may be exposed at atmospheric pressure to decontamination cycles and subsequently exposed, in the same sample cells, to a thermal-vacuum environment. Complete design drawings and procedures are given in Interim Report No. 3.

LONG-TERM STORAGE APPARATUS FOR POLYMERS

Innovator:	R. F. Muraca
First Used:	December 1965
Reports:	Monthly Report No. 16, October 1965, and following
Announced:	Interim Report No. 2, March 1966

The long-term storage apparatus consists of 4 units which are independently-pumped (ion pumps) glass-walled vacuum chambers with internal cylindrical glass heaters. Polymeric materials, one product in each unit, are stored under various conditions of load, strain, etc. for periods of more than 6 months.

Contributors to the various fixture designs used in the units are:

N. Fishman -Elastomers, constant strain
N. Fishman -Plastic films, constant load
A. A. Koch -Adhesives, creep under load.

Complete design drawings for constant load and strain are given in Interim Report No. 3, December 1966, and for adhesive creep in this Final Report.

Technology Transfer

It is a pleasure to announce the transfer of one of these technologies, MICRO-VCM APPARATUS FOR POLYMERS, to NASA centers and contractors who are concerned with the screening and quality-control of polymeric products.

A duplicate unit is in operation at the Goddard Space Flight Center, and one is near completion at the Jet Propulsion Laboratory. Drawings have also been delivered to McDonnell Aircraft and fabrication is under consideration.

The unit is described also in the forthcoming NASA Technology Utilization Survey, "Contributions of the NASA to Analytical Chemistry Instrumentation," by J. S. Whittick, R. F. Muraca, and L. Cavanagh. It is anticipated that this document will receive wide dissemination.

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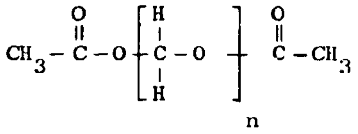
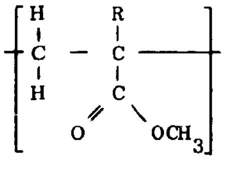
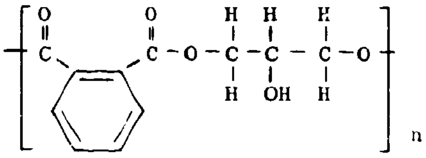
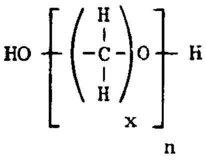
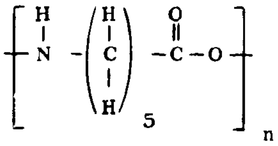
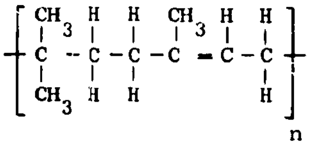
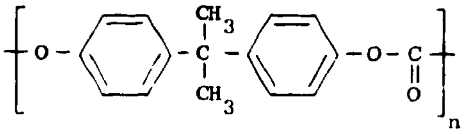
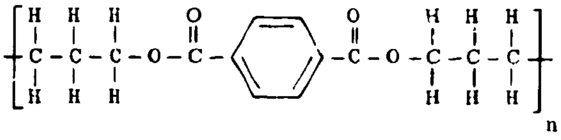
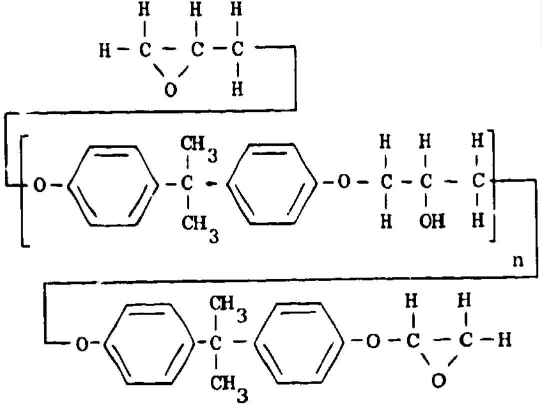
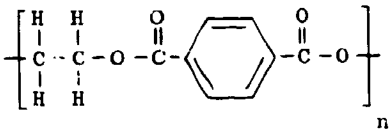
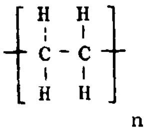
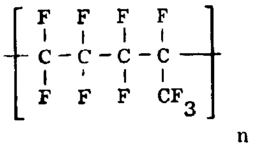
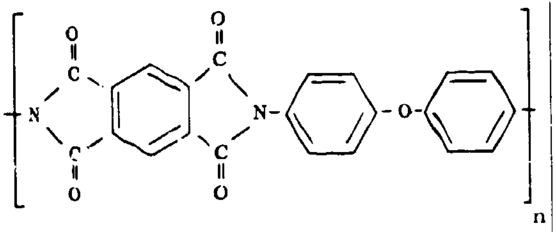
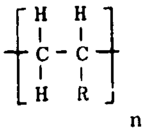
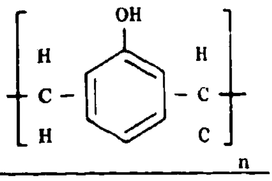
APPENDIXES

Appendix A

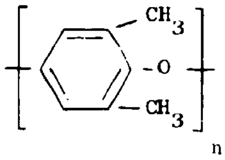
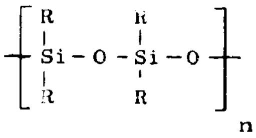
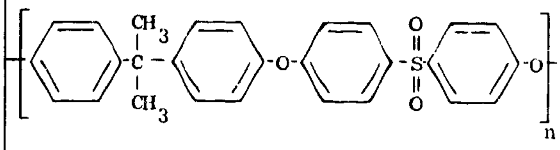
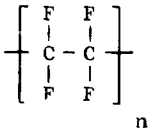
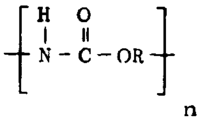
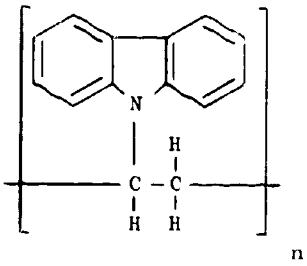
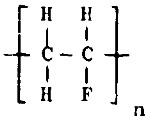
CANDIDATE POLYMERIC MATERIALS FOR SPACECRAFT APPLICATIONS

Name	Typical Structure	Spacecraft Applications
Acetal	 $CH_3-\overset{O}{\overset{\parallel}{C}}-O\left[\overset{H}{\underset{H}{C}}-O\right]_n\overset{O}{\overset{\parallel}{C}}-CH_3$	Hardware and Structural Wire enamels
Acrylic	 $\left[\overset{H}{\underset{H}{C}}-\overset{R}{\underset{C(=O)OCH_3}{C}}\right]_n$	Seals and gaskets Sleeving
Alkyd		Protective coatings Thermal coatings
Alkylene glycol	 $HO\left[\left(\overset{H}{\underset{H}{C}}\right)_x O\right]_n H$	Lubricants
Amide	 $\left[\overset{H}{N}-\left(\overset{H}{\underset{H}{C}}\right)_5-\overset{O}{\overset{\parallel}{C}}-O\right]_n$	Coated fabrics Films and sheets Hardware and structural Tie cord/lacing tape
Butyl	 $\left[\overset{CH_3}{\underset{CH_3}{C}}-\overset{H}{\underset{H}{C}}-\overset{H}{\underset{H}{C}}-\overset{CH_3}{C}=\overset{H}{C}-\overset{H}{\underset{H}{C}}\right]_n$	Seals and gaskets
Carbonate		Hardware and structural
Diallylphthalate		Hardware and structural

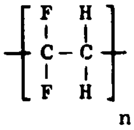
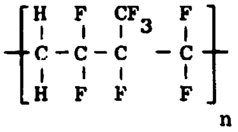
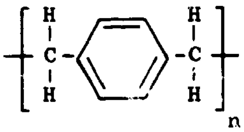
Appendix A (Continued)

Name	Typical Structure	Spacecraft Applications
Epoxy		Adhesives Circuit boards Foams Hardware and structural Protective coatings Sealants Tapes
Ester		Adhesives Coated fabrics Films and sheets Honeycomb structures Protective coatings Tapes Tie cords/lacing tape
Ethylene	 $\left[-\mathrm{CH_2}-\mathrm{CH_2}-\right]_n$	Hardware and structural Sealants
Fluroethylene-propylene co-polymer	 $\left[-\mathrm{CF_2}-\mathrm{CF_2}-\mathrm{CF_2}-\mathrm{CF(CF_3)}-\right]_n$	Seals and gaskets
Imide		Films and sheets Hardware and structural Protective coatings Wire enamels
Olefin	 $\left[-\mathrm{CH_2}-\mathrm{CHR}-\right]_n$	Shrinkable materials
Phenolic		Hardware and structural Honeycomb structures Lubricant binders

Appendix A (Continued)

Name	Typical Structure	Spacecraft Applications
Phenylene oxide		Hardware and structural
Silicone	 $\left[-\mathrm{Si}(R)_2-O-\mathrm{Si}(R)_2-O- \right]_n$	Adhesives Coated fabrics Foams Hardware and structural Honeycomb structures Lubricants Protective coatings Sealants Seals and gaskets Sleeving Tapes Tie Cord/lacing tape
Sulfone		Hardware and structural
Tetrafluoroethylene	 $\left[-CF_2-CF_2- \right]_n$	Coated fabrics Hardware and structural Seals and gaskets Shrinkable materials
Urethane	 $\left[-N(H)-C(=O)-OR- \right]_n$	Foams Protective coatings Sealants Thermal coatings
Vinyl carbazole		Hardware and structural Circuit board
Vinyl fluoride	 $\left[-CH_2-CHF- \right]_n$	Films and sheets

Appendix A (Concluded)

Name	Typical Structure	Spacecraft Applications
Vinylidene fluoride	 $\left[\mathrm{-CF_2-CH_2-}\right]_n$	Films and sheets
Vinylidene fluoride-hexafluoropropylene co-polymer	 $\left[\mathrm{-CH_2-CF_2-CF(CF_3)\ -CF_2-}\right]_n$	Seals and gaskets
p-Xylylene		Films and sheets

Appendix B

CODE LISTING OF MANUFACTURERS

AAC	Ablestik Adhesive Company
ACB	American Cyanamid Company, Bloomingdale Department
ACM	Allied Chemical Corporation, Mesa Products, Plastics Division
APC	Armstrong Products Company
ARP	American Reinforced Plastics Company
BCC	BASF Colors and Chemicals, Inc.
BCM	The Borden Company, Mystik Tape, Inc.
BFG	B. F. Goodrich Chemical Company
BIW	Boston Insulated Wire
CAR	Carter's Ink Company
CVC	Consolidated Vacuum Corporation
DCC	Dow-Corning Company
DUE	E. I. Du Pont de Nemours and Company, Inc., Elastomer Chemicals Department
DUF	E. I. Du Pont de Nemours and Company, Fabrics and Finishes Department
DUM	E. I. Du Pont de Nemours and Company, Film Department
DUP	E. I. Du Pont de Nemours and Company, Plastics Department
EFI	Electrofilm, Inc.
EMC	Emerson and Cuming, Inc.
ENJ	Enjay Chemical Company
EPC	Epoxylite Corporation
FLC	Fortin Laminating Corporation

Appendix B (Continued)

FPC	Finch Paint and Chemical Company
FPI	Furane Plastics, Inc.
FRC	Fargo Rubber Corporation
GBE	Gudebrod Brothers Silk Company, Inc., Electronics Division
GEC	General Electric Company, Chemical Materials Department
GES	General Electric Company, Silicone Products Department
GEW	General Electric Company, Wire and Cable Department
HCC	Hughson Chemical Company
HEX	Hexcel Products, Inc.
HYS	Hysol Corporation
IBM	IBM Corporation
IND	Independent Ink Company
MCC	Magna Coatings and Chemical Corporation
MMA	3M Company, Adhesives, Coatings, and Sealers Division
MMC	3M Company, Chemical Division
MME	3M Company, Electrical Products Division
MMI	3M Company, Irvington Division
MRC	The Marblett Corporation
PER	Permacel
PFC	Pennsylvania Fluorocarbon Company
PKA	Park Avenue
PPH	Purolator Products, Inc., Hadbar Division
PRC	Products Research and Chemical Corporation
PRP	Plastic and Rubber Products Company
PSC	Parker Seal Company

Appendix B (Concluded)

PTI	Product Techniques, Inc.
RAY	Rayclad Tubes, Inc.
REM	Rembrandt
SAN	Sanford's Ink Company
SCA	Shell Chemical Company, Adhesives Department
SIS	Sargent Industries, Stillman Rubber Division
SPT	Stone Paper Tube Company
TMC	The Mica Corporation
UCC	Union Carbide Chemicals Company
UCP	Union Carbide Corporation, Plastics Division
VVP	Vita Var Paint Company
WCN	Whittaker Corporation, Narmco Division
WEI	Westinghouse Electric Corporation, Insulating Materials Division
WEM	Westinghouse Electric Corporation, Micarta Division

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Appendix C

CATALOG OF INFRARED ABSORBANCE SPECTRA OF VCM FROM POLYMERIC PRODUCTS

The 96 spectra in this catalog were obtained by the micro-VCM technique described in Section III and provide a fair representation of the VCM which might be expected from the 340 polymeric products which were screened during the course of this contract.

Examination of the spectra revealed that distinctive features could be related directly to specific polymer classes; thus, the spectra are arranged according to these classes, and within each class the spectra have been grouped according to readily-visible characteristics. The following information is given for each spectrum: sample preparation, sample weight, and weight of VCM collected on the 1"-diameter salt flats.

Polymers which have VCM values less than 0.1% yield spectra which show hardly any significant features; however, the spectra of these polymers are included to illustrate that an acceptable polymer should have insufficient VCM to provide a spect[illegible] and that cross-contamination does not occur in the micro-VCM apparatus. In a number of instances, the "baseline" spectrum of the polished blank salt flat before exposure is shown above the spectrum of the sample; this illustrates that absorption is due to the sample and not to imperfections or contaminations of the salt flat prior to use.

On the following pages are given a numerical listing of the subsequent spectra according to polymer classes and an alphabetical listing according to polymeric products.

NUMERICAL LISTING OF SPECTRA

ACETAL-BASE

(1) Delrin 500NC10

ALKYD-BASE

(2) Velvet Black 101C10

EPOXY-BASE

(3) Epon 828/A
(4) FM-96U
(5) Epoxi-Patch A/B
(6) Scotchcast 235 A/B (brown)
(7) Epiphen ER825A
(8) Epon 828/Z
(9) Fibremat-1, Type 2539
(10) Velvet Black 401C10 I/II
(11) Armstrong A-12/A
(12) Epocast 168/995
(13) Eccobond 45/15 (black)
(14) Eccobond Solder 57C A/B
(15) PT 401/H-11
(16) Scotchcast 281 A/B
(17) Corfil 615/Z
(18) EC-2216 A/B
(19) Stycast 1090 S-1/24LV
(20) Eccogel 1265 A/B
(21) BR-617 A/B
(22) Epoxylite 295-1 A/B (Batch 2469)
(23) Epoxylite 295-1 A/B (Batch 4204-1)
(24) Epoxylite 295-1 A/B (Batch 4204-2)

EPOXY-BASE (continued)

(25) Micaply EG-284T, Type GH
(26) Micaply EG-758T, Type GE
(27) Micaply EG-899T, Type GF
(28) EG-2028, Type FL-GE
(29) EG-2028FR, Type FL-GF
(30) Epibond 115
(31) Scotchcast 260
(32) Scotchweld AF-126
(33) Scotchcast XR-5068
(34) Scotchcast XR-5068/#3
(35) Scotchcast #3 A/B

CHLOROFLUOROCARBON-BASE

(36) Kel-F 81

FLUOROCARBON-BASE

(37) V377-9
(38) Fairprene 5159/Activator

HYDROCARBON-BASE

(39) Ben-Har Acryl C-2
(40) E515-8
(41) FR-60-26
(42) C526-7
(43) Parylene-C
(44) Parylene-N
(45) SR-613-75
(46) SR-634-70

NUMERICAL LISTING OF SPECTRA (Concluded)

PHENOLIC-BASE

(47) HRP/Adlock 851/FM96U/12 ply
(48) HRP/Adlock 851/FM96U/6 ply

POLYALKYLENE GLYCOL-BASE

(49) Ucon 50HB55
(50) Ucon 50HB170
(51) Ucon 50HB660

POLYAMIDE-BASE

(52) Zytel
(53) Nomex, 5-mil

POLYESTER-BASE

(54) Adhesive 46950
(55) Mylar, 0.004" wall
(56) Mylar, 0.012" wall

POLYIMIDE-BASE

(57) PYRE-M.L., Type 1

POLYPHENYL ETHER-BASE

(58) Convalex-10 (0-061)

POLYURETHANE-BASE

(59) Stycast CPC-41 A/B
(60) Laminar X-500 (4C-8 clear)
(61) Stycast CPC-21 A/B
(62) Laminar X-500 (4B-1 black)
(63) Ecco CP6/R6
(64) Stycast CPC-22 A/B
(65) Eccofoam FPH/126H
(66) Laminar X-500 (4B-3 black)
(67) Laminar X-500 (8W-24 white)

SILICONE-BASE

(68) A2841-L-618 (gray)
(69) A2841-L-618 (yellow)
(70) DC-11
(71) G-683
(72) Hadbar 28-80
(73) RTV-30/T12
(74) RTV-40/T12
(75) RTV-88/T-12
(76) Silastic 881/Cat
(77) Silastic 3116/T-12
(78) Silastic-732 (clear)
(79) Silastic-732 (white)
(80) Silastic-S9711
(81) E-691-22E
(82) Hadbar 4000-80
(83) RTV-102 (white)
(84) RTV-103 (black)
(85) RTV-108 (clear)
(86) Sylgard-184
(87) XR-63492
(88) 93-002
(89) SE-5604-7
(90) Silastic-732 (black)
(91) SR-290
(92) DC-705
(93) Silastic-501/T-12
(94) Versilube G-300

FLUOROSILICONE-BASE

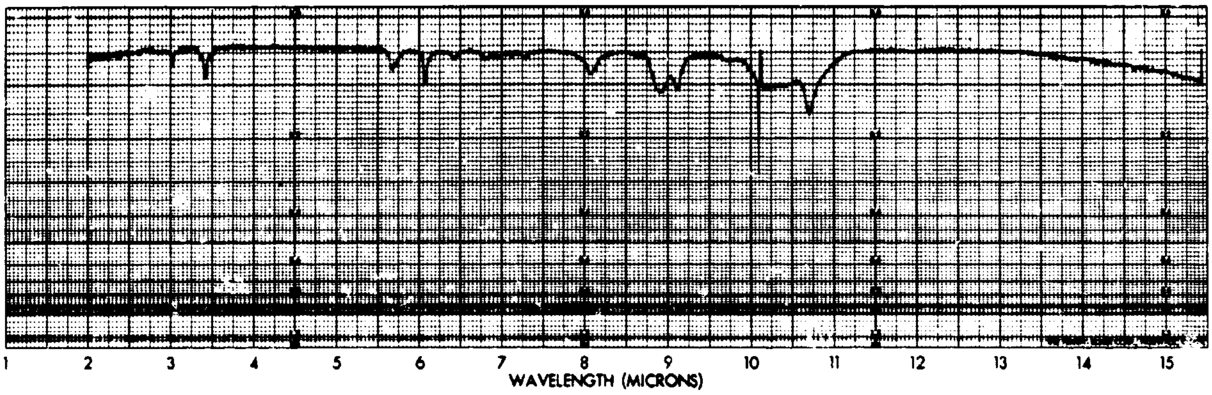
(95) 1050-70
(96) L-449-6

ALPHABETICAL LISTING OF SPECTRA

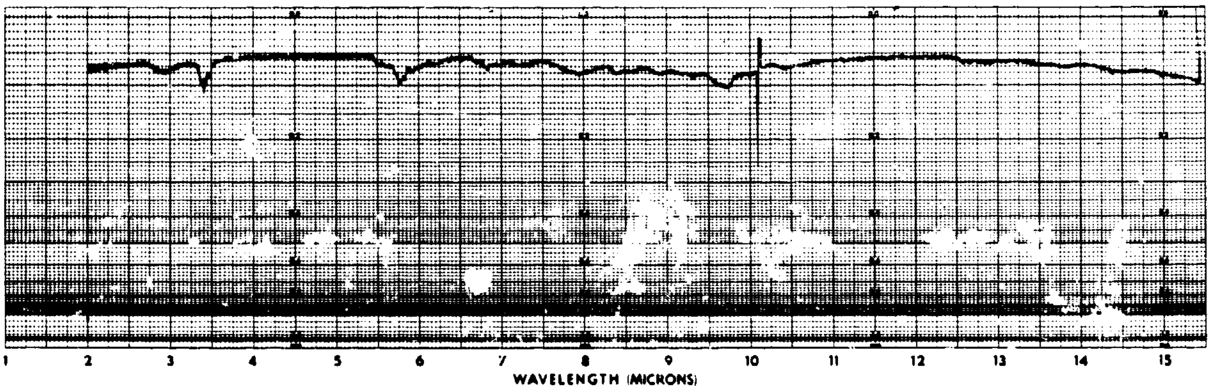
Polymeric Product	No.	Polymeric Product	No.
A2841-L-618 (Gray)	(68)	Fairprene 5159/Activator	(38)
A2841-L-618 (Yellow)	(69)	Fibremat-1, Type 2539	(9)
Adhesive 46950	(54)	FM-96U	(4)
Armstrong A-12/B	(11)	FR-60-26	(41)
Ben-Har Acryl C-2	(39)	G-683	(71)
BR-617 A/B	(21)	Hadbar 28-80	(72)
C526-7	(42)	Hadbar 400-80	(82)
Convalex-10 (0-061)	(58)	HRP Composite	(47)
Corfil 615/Z	(17)	Kel-F 81	(36)
DC-11	(70)	L-449-6	(96)
DC-705	(92)	Laminar X-500 (4B-1 Black)	(62)
Delrin 500NC10	(1)	Laminar X-500 (4B-3 Black)	(66)
E515-8	(40)	Laminar X-500 (4C-8 Clear)	(60)
E691-22E	(81)	Laminar X-500 (8W-24 White)	(67)
EC-2216 A/B	(18)	Micaply EG-284T	(25)
Ecco CP6/R6	(63)	Micaply EG-758T	(26)
Eccobond 45/15 (Black)	(13)	Micaply EG-899T	(27)
Eccobond Solder 57C A/B	(14)	Mylar, 0.004" Wall	(55)
Eccofoam FPH/126H	(65)	Mylar, 0.012" Wall	(56)
Eccogel 1265 A/B	(20)	Nomex, 5-Mil	(53)
EG-2028, Type FL-GE	(28)	Parylene-C	(43)
EG-2028FR, Type FL-GF	(29)	Parylene-N	(44)
Epibond 115	(30)	PT-401/H-11	(15)
Epiphen ER-825A	(7)	PYRE-M.L. Type 1	(57)
Epocast 168/995	(12)	RTV-30/T-12	(73)
Epon 828/A	(3)	RTV-40/T-12	(74)
Epon 828/Z	(8)	RTV-88/T-12	(75)
Epoxylite 295-1 A/B	(22)	RTV-102 (White)	(83)
Epoxi-Patch A/B	(5)	RTV-108 (Clear)	(85)

ALPHABETICAL LISTING OF SPECTRA (Concluded)

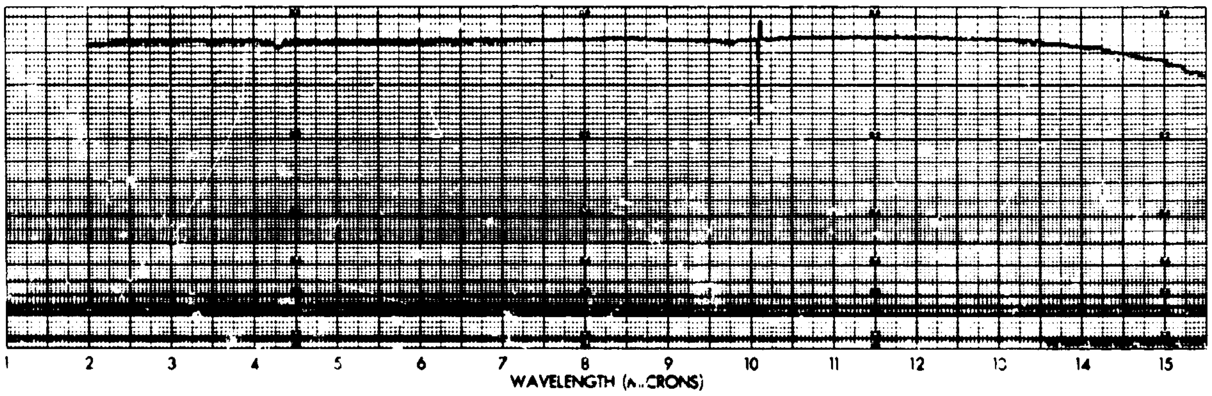
Polymeric Product	No.
RTV-103 (Black)	(84)
Scotchcast #3 A/B	(35)
Scotchcast #3/XR-5068	(34)
Scotchcast 235 A/B	(6)
Scotchcast 260	(31)
Scotchcast 281 A/B	(16)
Scotchcast XR-5068	(33)
Scotchweld AF-126	(32)
SE-5604-7	(89)
Silastic-501/T-12	(93)
Silastic-732 (Black)	(90)
Silastic-732 (Clear)	(78)
Silastic-732 (White)	(79)
Silastic-881/Cat	(76)
Silastic-3116/T-12	(77)
Silastic-S9711	(80)
SR-290	(91)
SR-613-75	(45)
SR-634-70	(46)
Stycast 1090-S1/24LV	(19)
Stycast CPC-21 A/B	(61)
Stycast CPC-22 A/B	(64)
Stycast CPC-41 A/B	(59)
Sylgard-184	(86)
Ucon 50ZHB55	(49)
Ucon 50HB170	(50)
Ucon 50HB660	(51)
V377-9	(37)
Velvet Black 101-C10	(2)
Velvet Black 401-C10	(10)
Versilube G-300	(94)
XR-63492	(87)
Zytel	(52)
93-002	(88)
1050-70	(95)



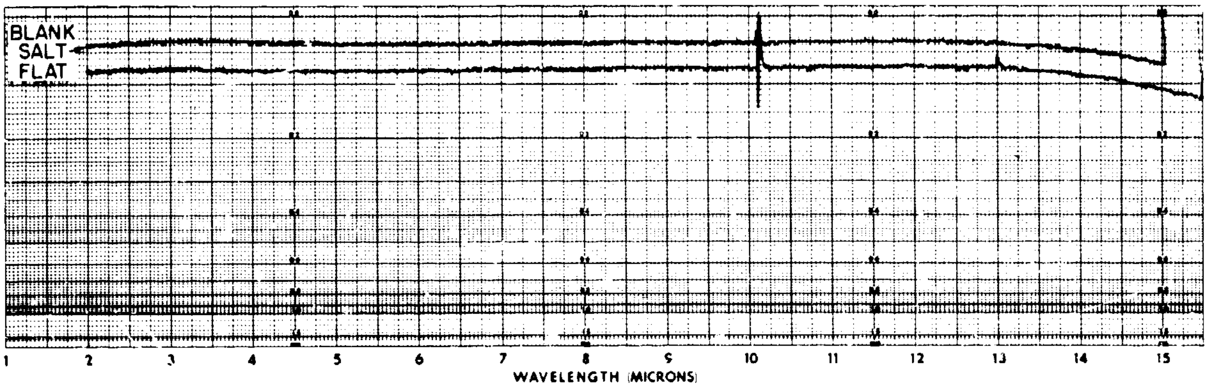
(1) DELRIN 500NC10. As received. (s. wt., 239.37mg; VCM, 0.003 mg)



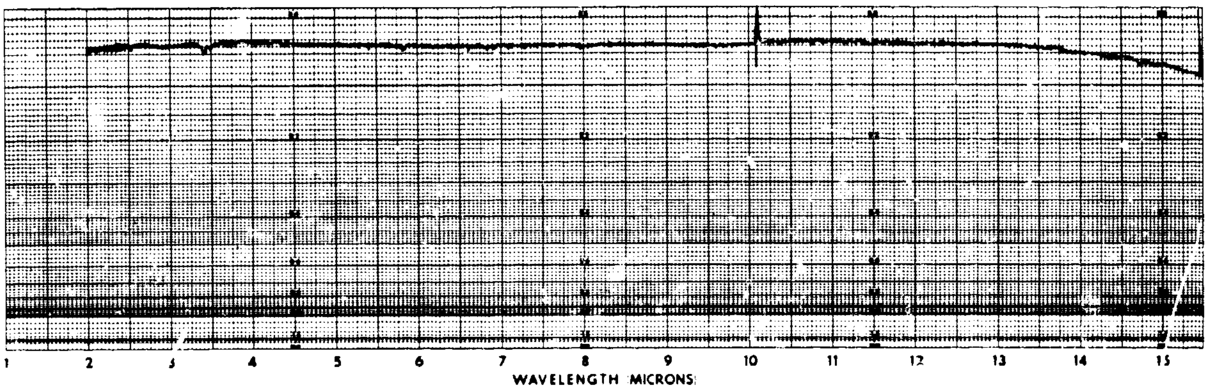
(2) VELVET BLACK 101-C10. As received; 24 hr 125° C. (s. wt., 76.38 mg; VCM, 0.115 mg)



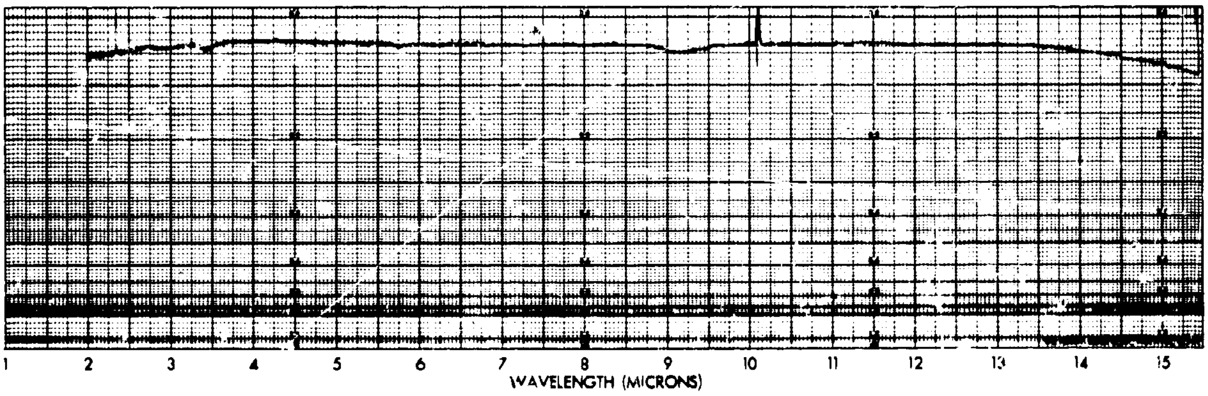
(3) EPON 828 A. Mixed 100p828 8pA; 3 hr 95° C. (s. wt., 165.49 mg; VCM, 0.094 mg)



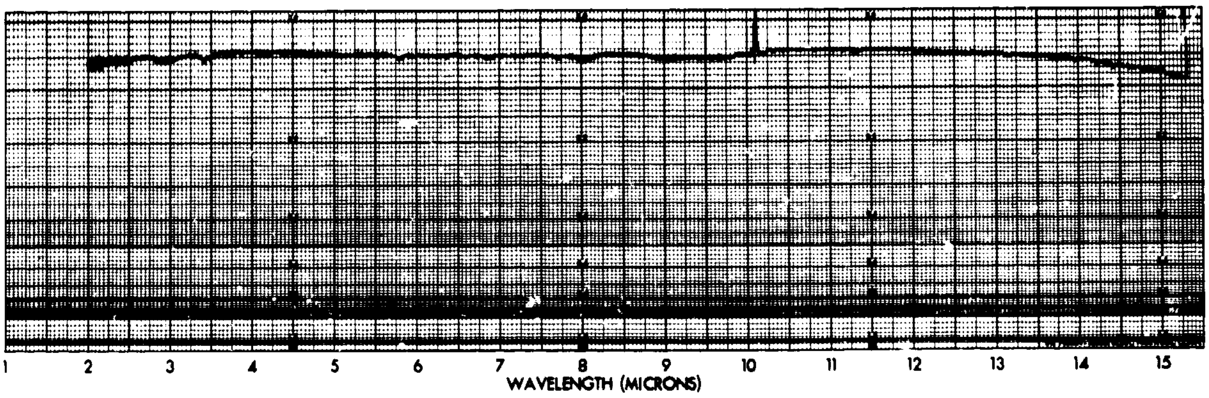
(4) FM 96U. As received; 1 hr 175° C. (s. wt., 173.55 mg; VCM, 0.004 mg)



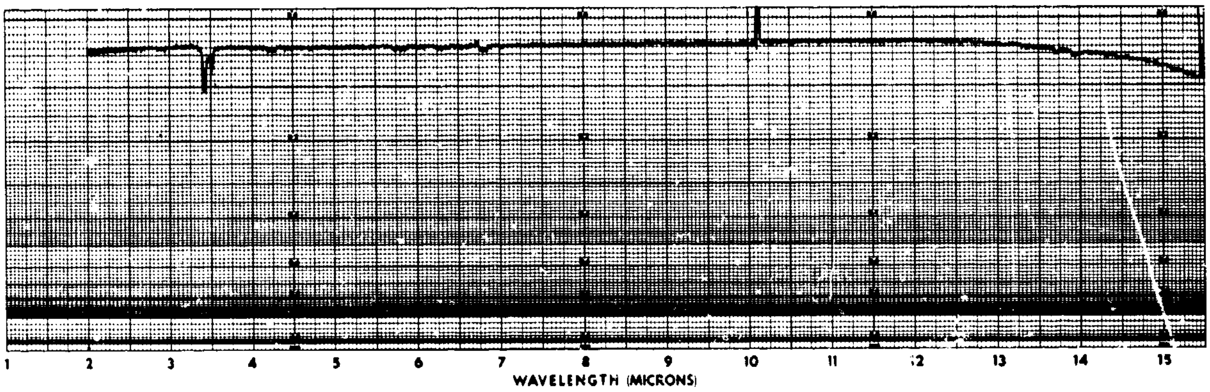
(5) EPOXI-PATCH A B. Mixed equal lengths; 2 hr 60° C. (s. wt., 232.52 mg; VCM, 0.005 mg)



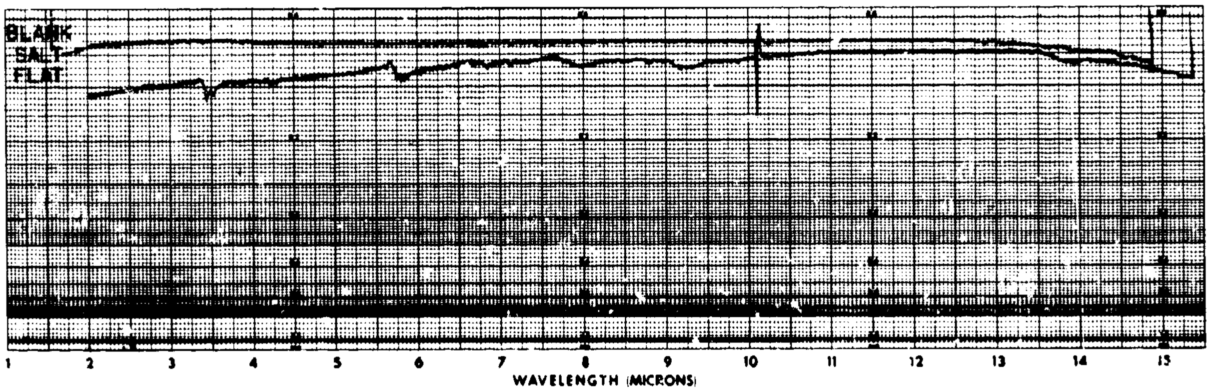
(6) SCOTCHCAST 235 A B (BROWN). Mixed 50pA 100pB; 16 hr 93° C. (s. wt., 197.30 mg; VCM, 0.024 mg)



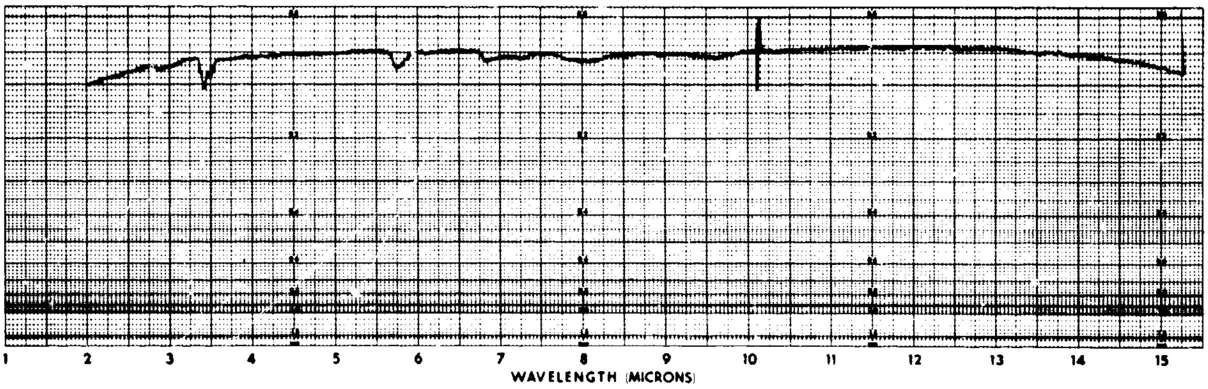
(7) EPIPHEN ER825A. Mixed 100p825A/12pMod-T/40pFiller/16pConverter; 48 hr 25° C. (s. wt., 268.90 mg; VCM, 0.030 mg)



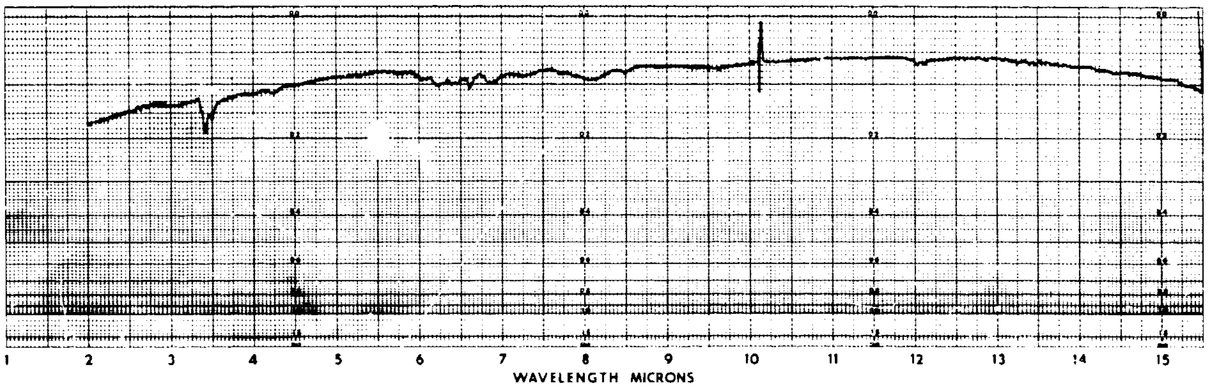
(8) EPON 828/Z. Mixed 100p828/20pZ; 2 hr/75° C + 2 hr 135° C. (s. wt., 235.30 mg; VCM, 0.059 mg)



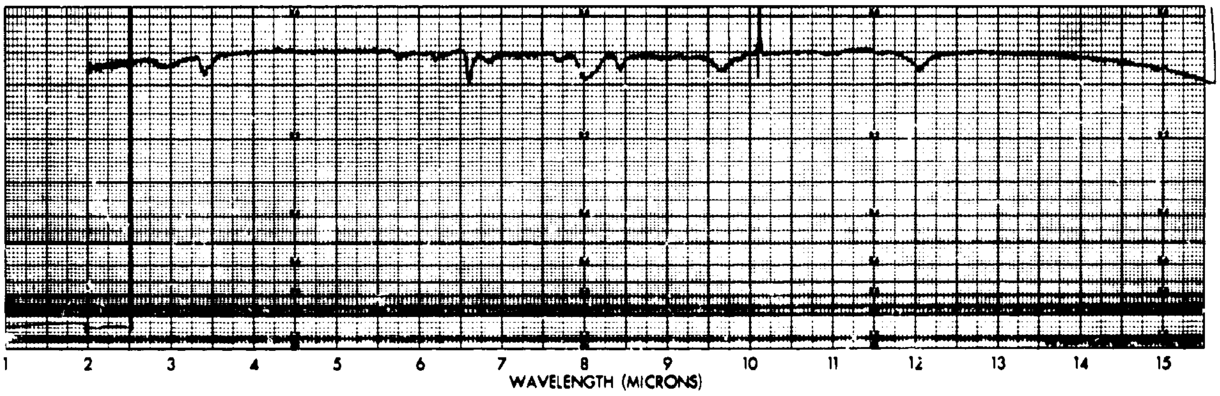
(9) FIBREMAT-1, TYPE 2539. As received. (s. wt., 126.33 mg; VCM, 0.020 mg)



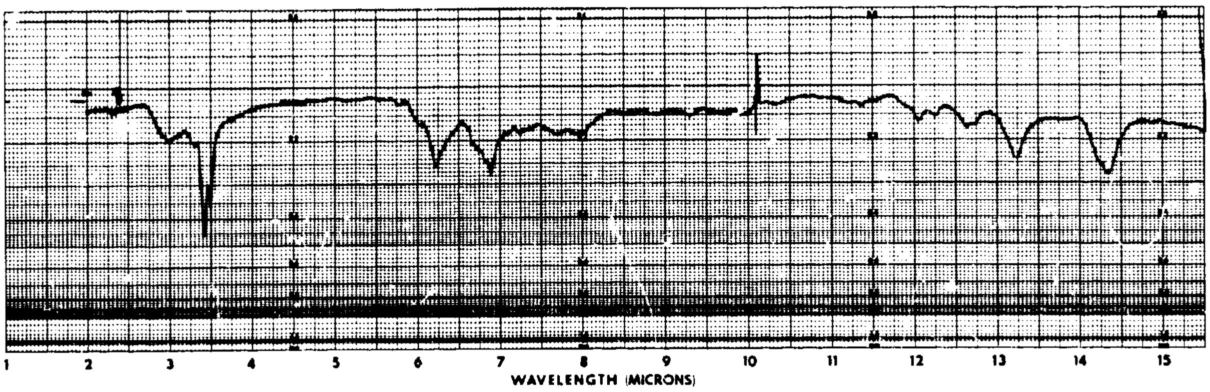
(10) VELVET BLACK 401-C10 I/II. Mixed 90pI 30pII; 7 das 25° C. (s. wt., 131.15 mg; VCM, 0.046 mg)



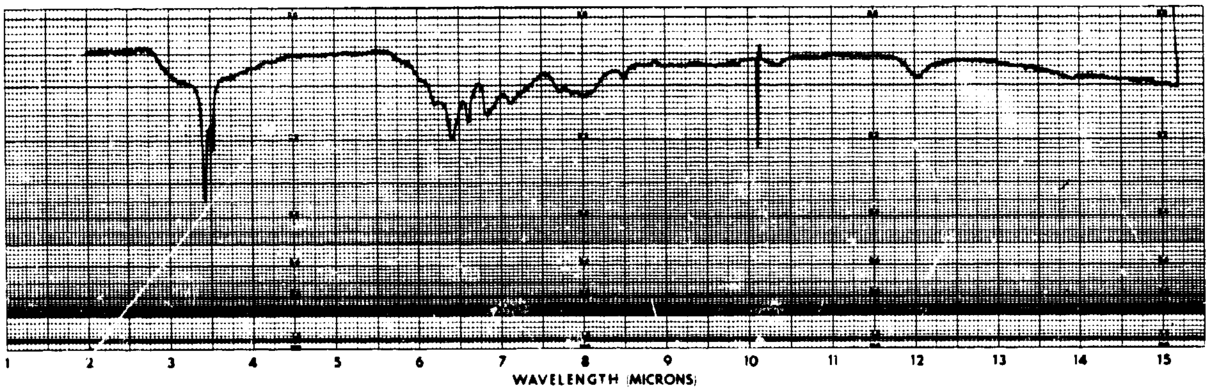
(11) ARMSTRONG A-12 A. JPL sample; cured 2 hr, 85° C. (s. wt., 272.41 mg; VCM, 0.072 mg)



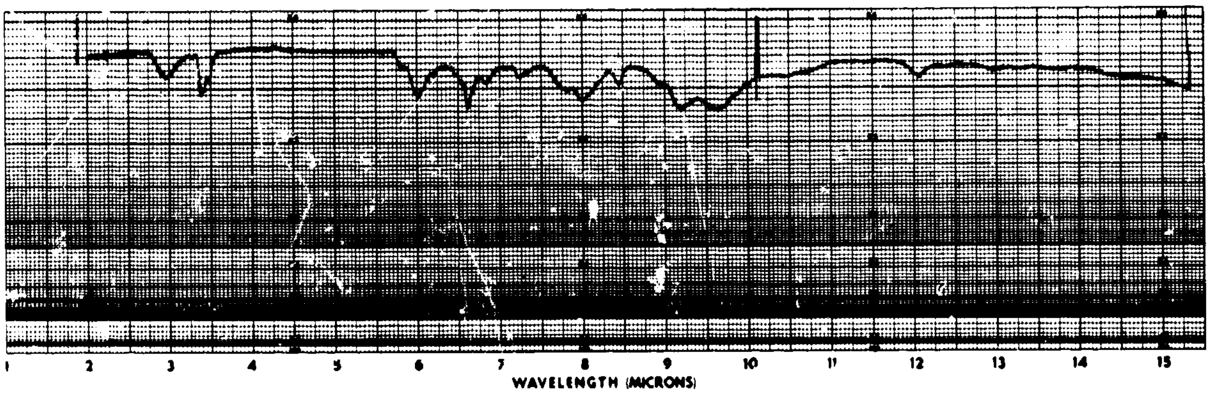
(12) EPOCAST 168/995. Mixed 90p168 10p995; 16 hr. 50° C + 1 hr 150° C. (s. wt., 203.92 mg; VCM, 0.091 mg)



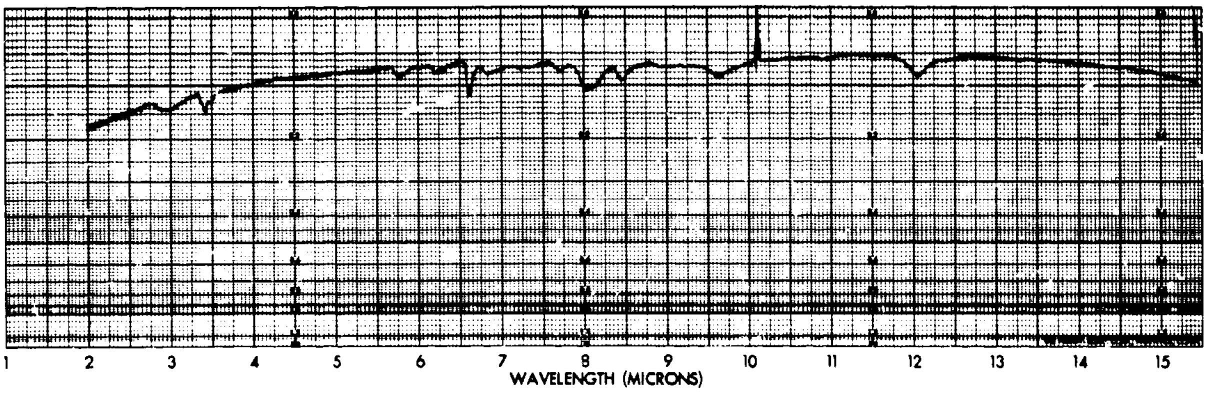
(13) ECCOBOND 45/15 (BLACK). Contractor's sample; cured 2 hr/85° C + 23 hr/150° C/10^{-6} torr + 1 hr/150° C/10^{-7} torr. (s. wt., 234.76 mg; VCM, 0.854 mg)



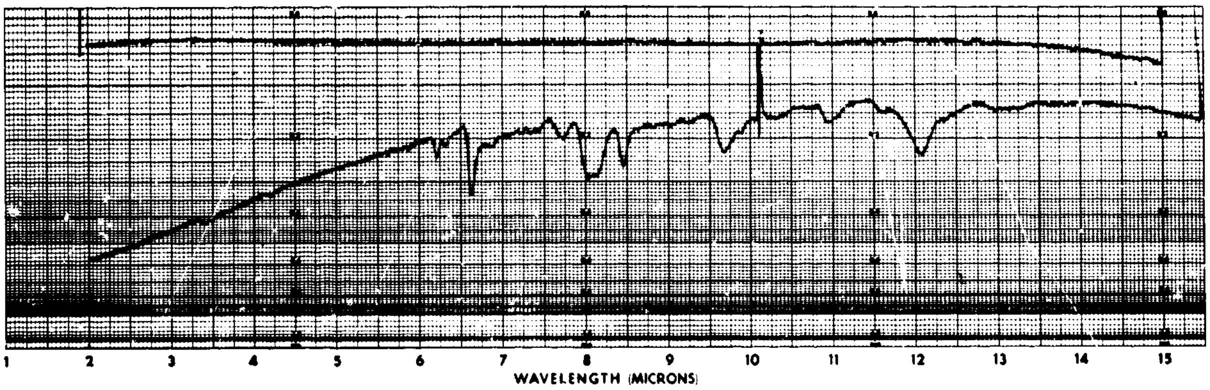
(14) ECCOBOND SOLDER 57C A/B. Mixed 100pA/100pB; 16 hr/52° C. (s. wt., 316.93 mg; VCM, 0.230 mg)



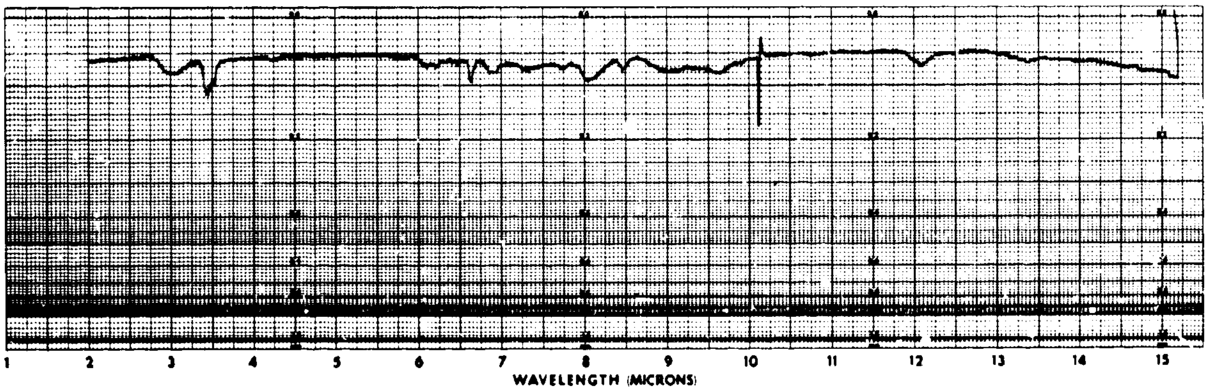
(15) PT 401 H-11. Mixed 100p401/6pH-11; 16 hr/65° C. (s. wt., 73.86 mg; VCM, 0.139 mg)



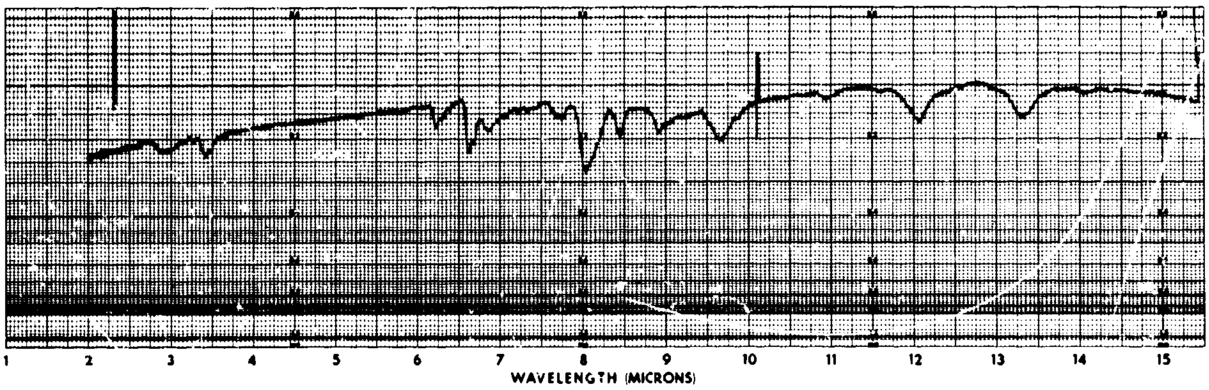
(16) SCOTCHCAST 281 A/B. Mixed 100pA/150pB; 20 hr/75° C. (s. wt., 225.25 mg; VCM, 0.068 mg)



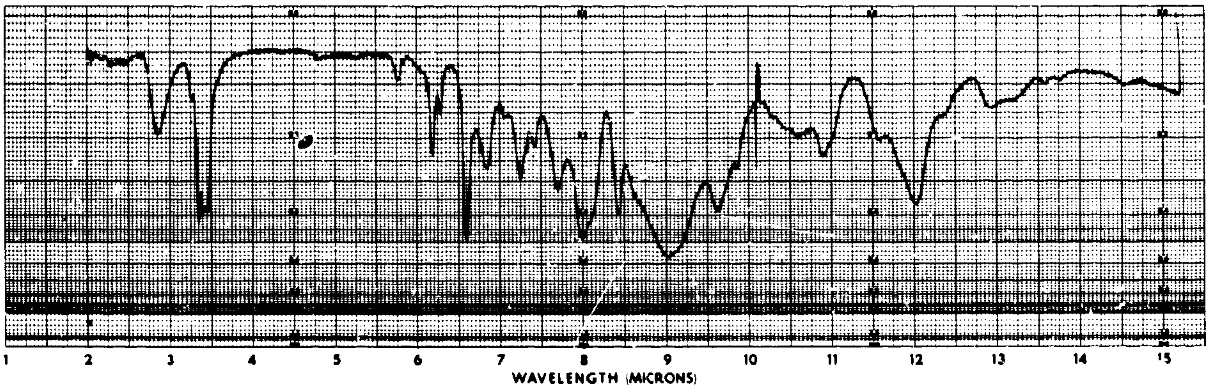
(17) CORFIL 615 Z. Mixed 100p615/14.5pZ; 16 hr 50° C + 1 hr 150° C. (s. wt., 116.73 mg; VCM, 0.103 mg)



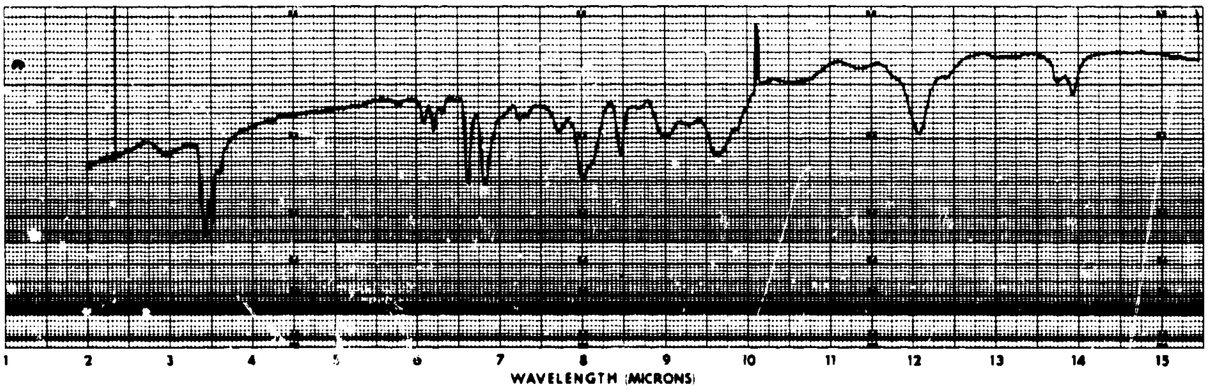
(18) EC-2216 A/B. Mixed 140pA/100pB; 2 hr/65° C. (s. wt., 176.43 mg; VCM, 0.107 mg)



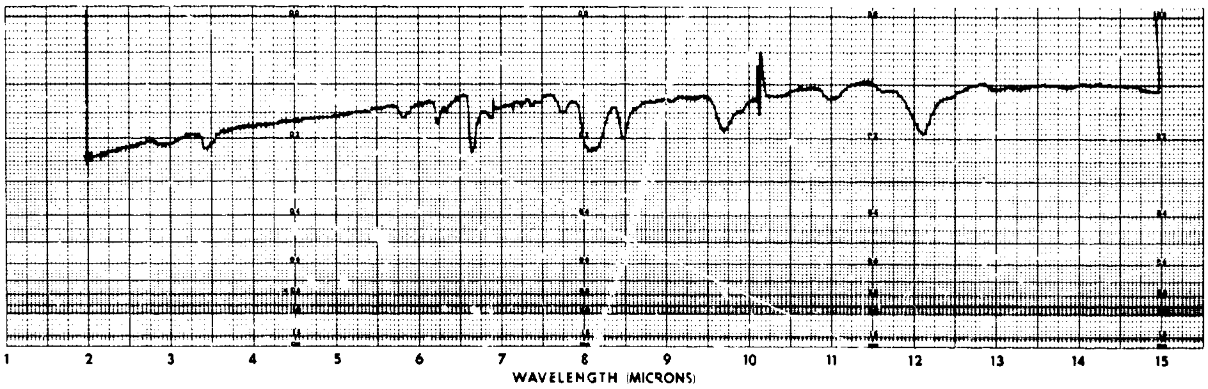
(19) STYCAST 1090 S-1/24LV. Mixed 100p1090/23p24LV; 24 hr/25° C. (s. wt., 205.44 mg; VCM, 0.164 mg)



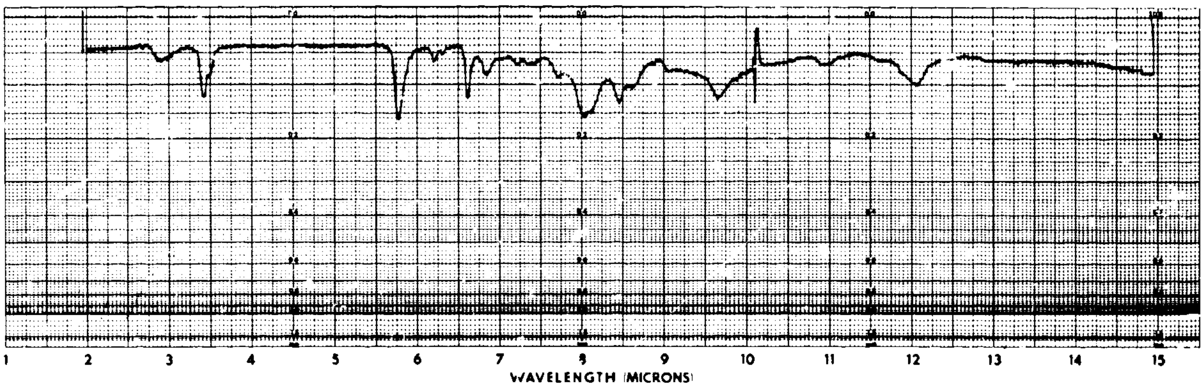
(20) ECCOGEL 1265 A/B. Mixed 100pA/100pB; 16 hr/65° C. (s. wt., 209.80 mg; VCM, 7.855 mg)



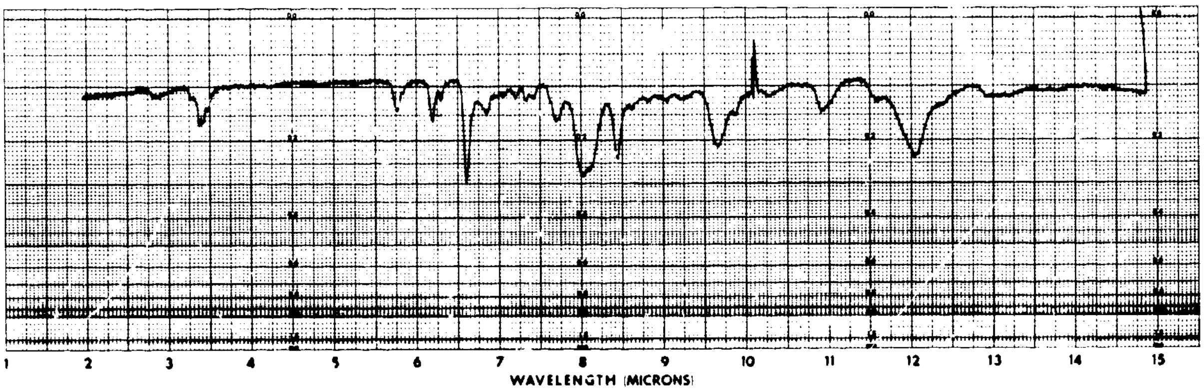
(21) BR-617 A B. Mixed 100pA/25pB, 48 hr/25° C. (s. wt., 243.04 mg; VCM, 2.305 mg)



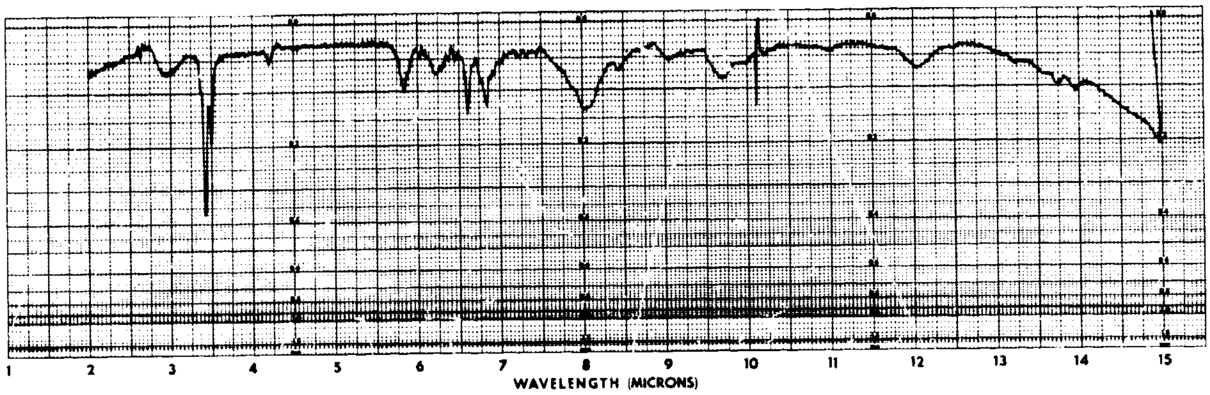
(22) EPOXYLITE 295-1 A/B (BATCH 2469). Mfr's sample; mixed 100pA/100pB; 8 hr/113° C. (s. wt., 144.71 mg; VCM, 0.245 mg)



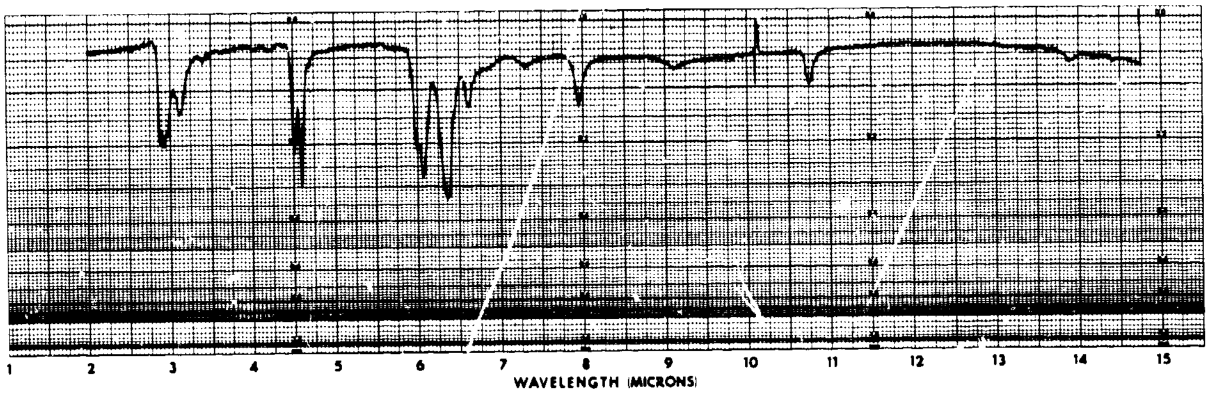
(23) EPOXYLITE 295-1 A/B (BATCH 4204-1). Contractor's sample; mixed 100pA/100pB; 24 hr/85° C + 4 hr/115° C. (s. wt., 163.18 mg; VCM, 0.114 mg)



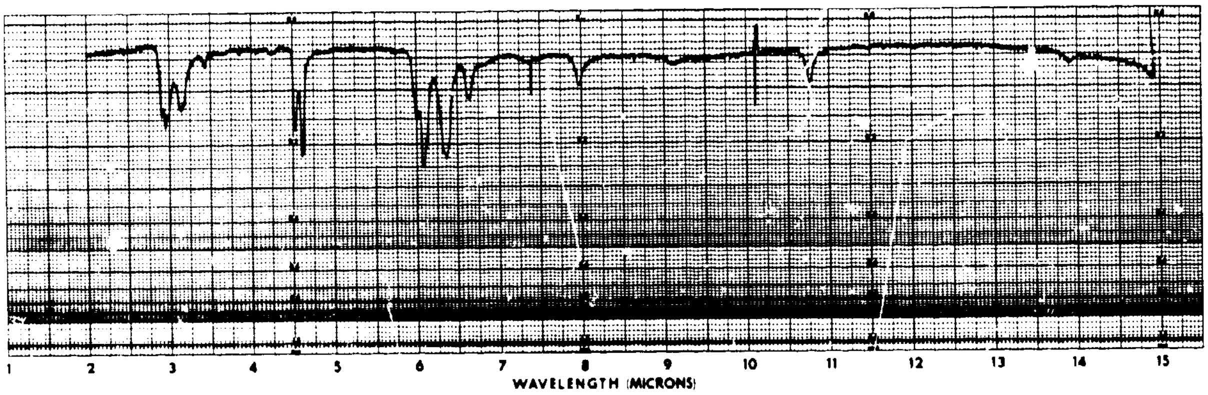
(24) EPOXYLITE 295-1 A/B (BATCH 4204-2). Contractor's sample; mixed 100pA/100pB; 24 hr/85° C + 4 hr/115° C. (s. wt., 199.23 mg; VCM, 0.751 mg)



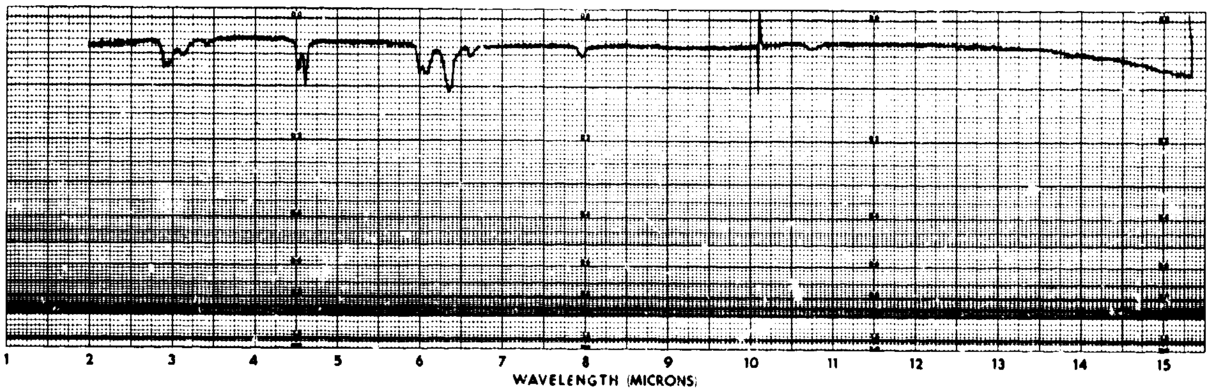
(25) MICAPLY EG-284T, TYPE GH. As received, stripped of copper. (s. wt., 174.88 mg; VCM, 0.076 mg)



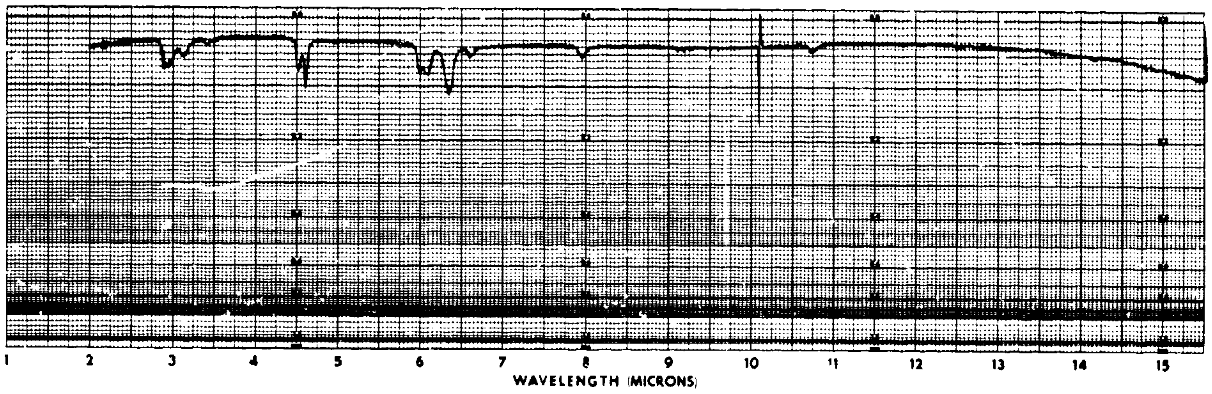
(26) MICAPLY EG-758T, TYPE GE. As received, stripped of copper. (s. wt., 186.67 mg; VCM, 0.168 mg)



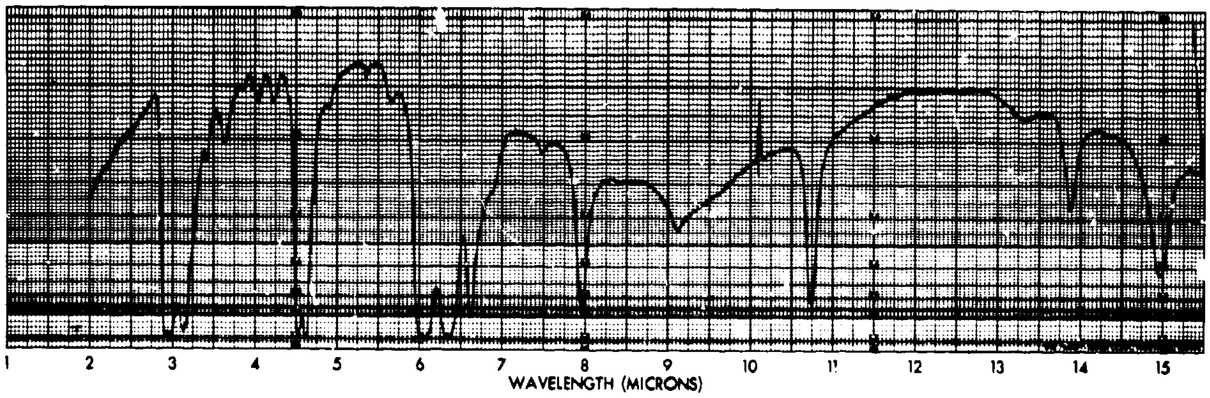
(27) MICAPLY EG-899T, TYPE GF. As received, stripped of copper. (s. wt., 239.17 mg; VCM, 0.077 mg)



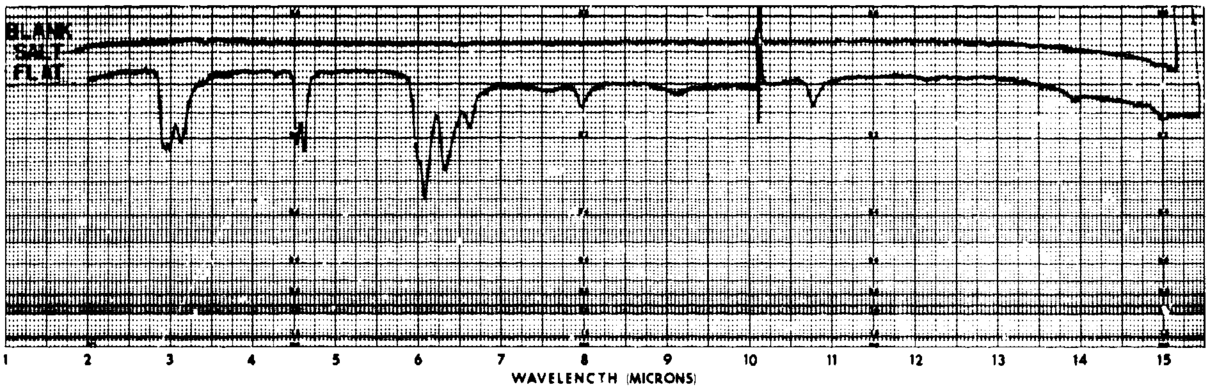
(28) EG-2028, TYPE FL-GE. As received, stripped of copper. (s. wt., 185.80 mg; VCM, 0.010 mg)



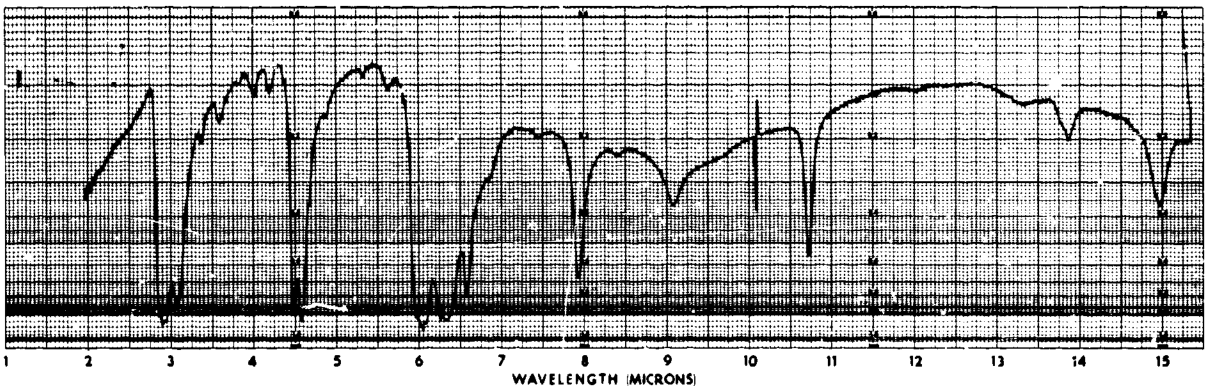
(29) EG-2028, TYPE FL-GF. As received; stripped of copper. (s. wt., 206.63 mg; VCM, 0.010 mg)



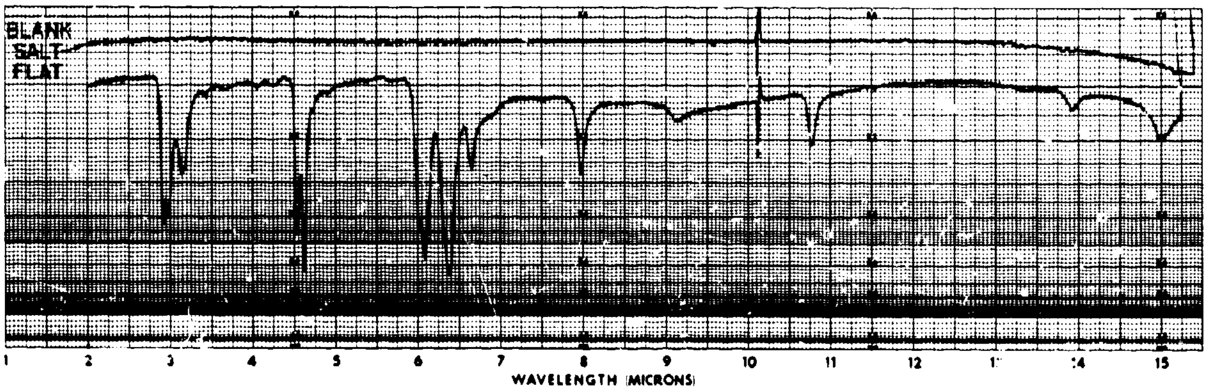
(30) EPIBOND 115. As received; 16 hr 25° C + 24 hr 125° C. (s. wt., 277.05 mg; VCM, 1.454 mg)



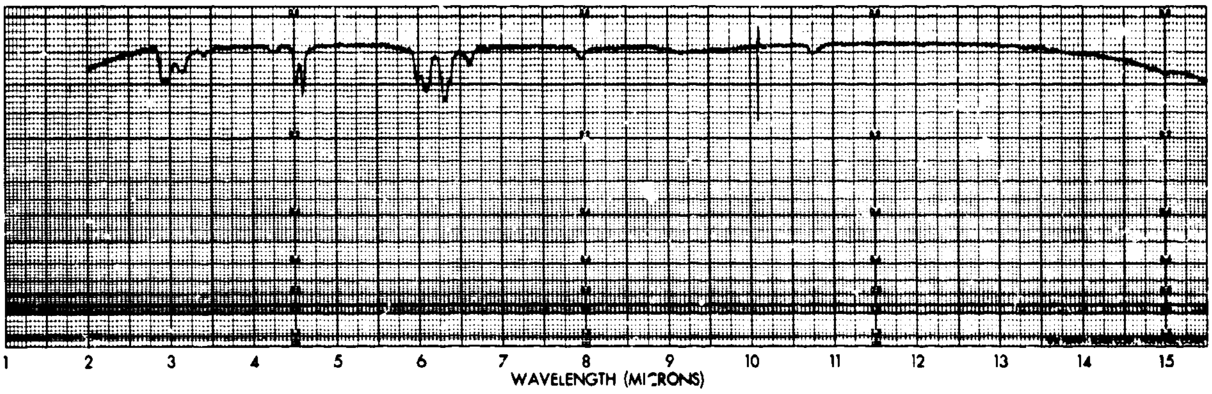
(31) SCOTCHCAST 260. As received; 30 min/150° C. (s. wt., 258.37 mg; VCM, 0.061 mg)



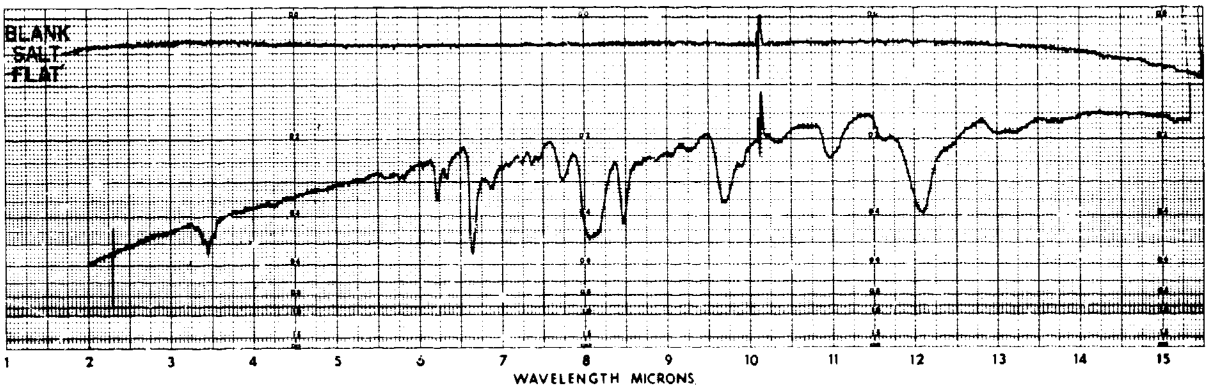
(32) SCOTCHWELD AF-126. As received; 1 hr/125° C. (s. wt., 86.330 mg; VCM, 0.738 mg)



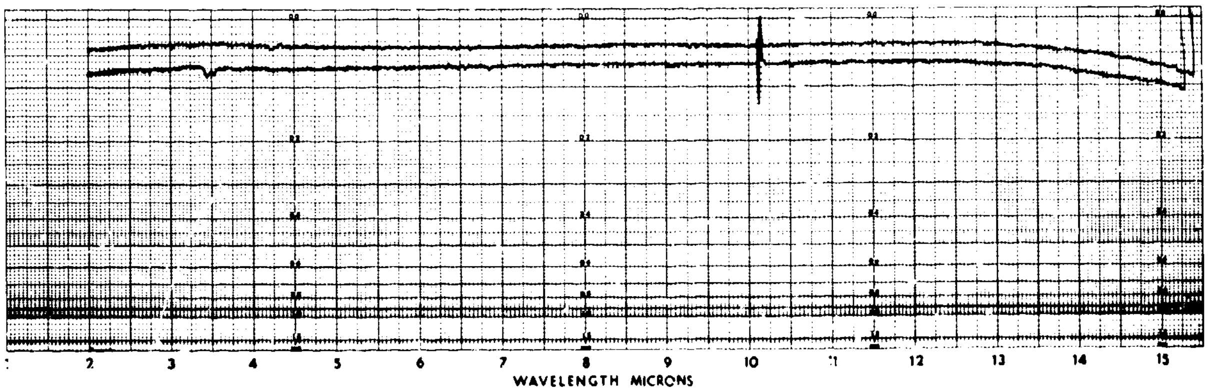
(33) SCOTCHCAST XR-5068. As received; 4 hr/121° C. (s. wt., 39.230 mg; VCM, 0.142 mg)



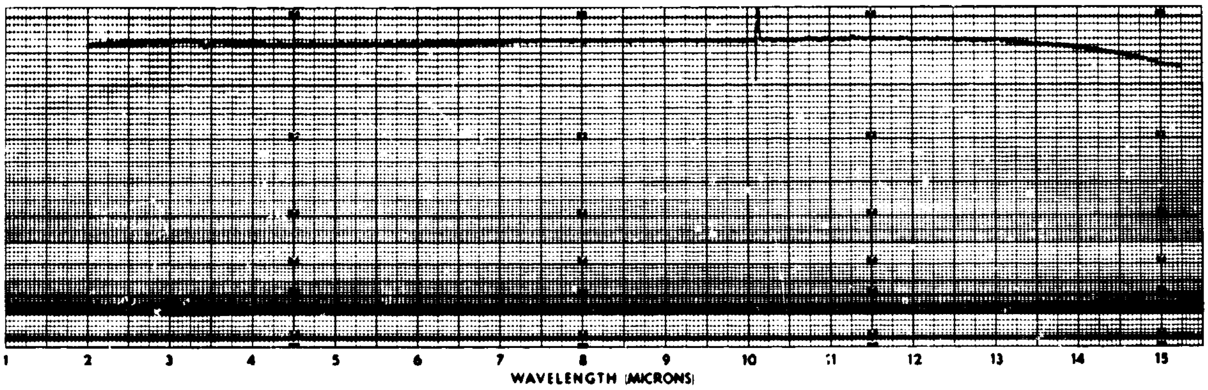
(34) SCOTCHCAST XR-5068/#3. Mixed 100p5068/100p#3; 4 hr/121° C. (s. wt. 93.057 mg; VCM, 0.188 mg)



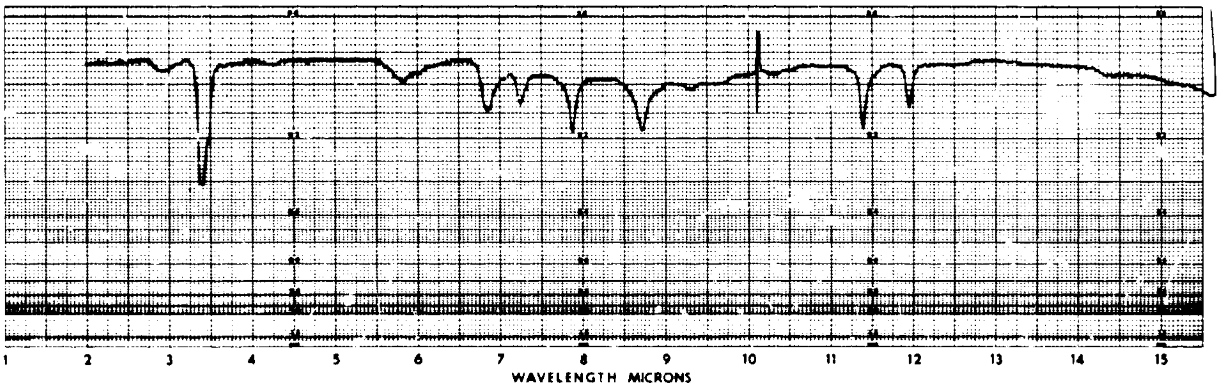
(35) SCOTCHCAST #3 A/B. Mixed 100pA/150pB; 4 hr/121° C. (s. wt., 174.72 mg; VCM, 0.410 mg)



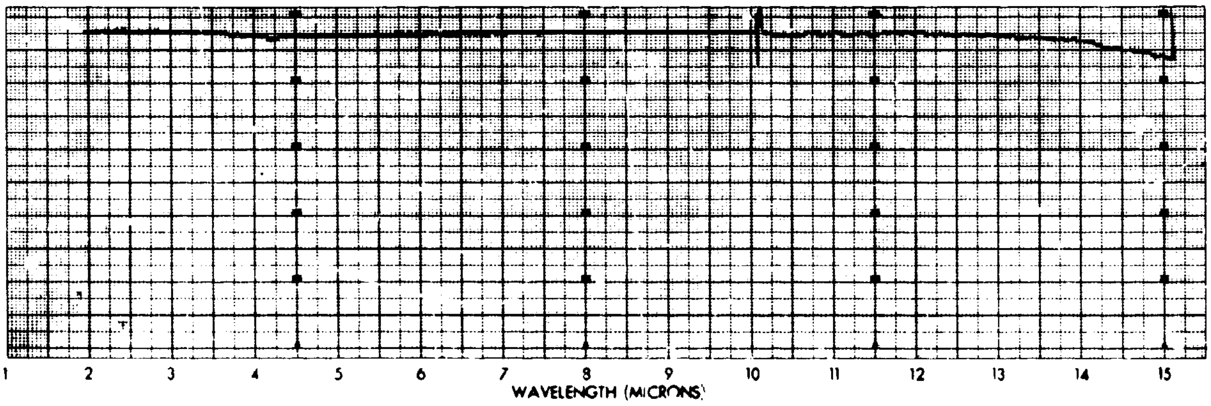
(36) KEL-F 81. As received. (s. wt., 118.44 mg; VCM, 0.012 mg)



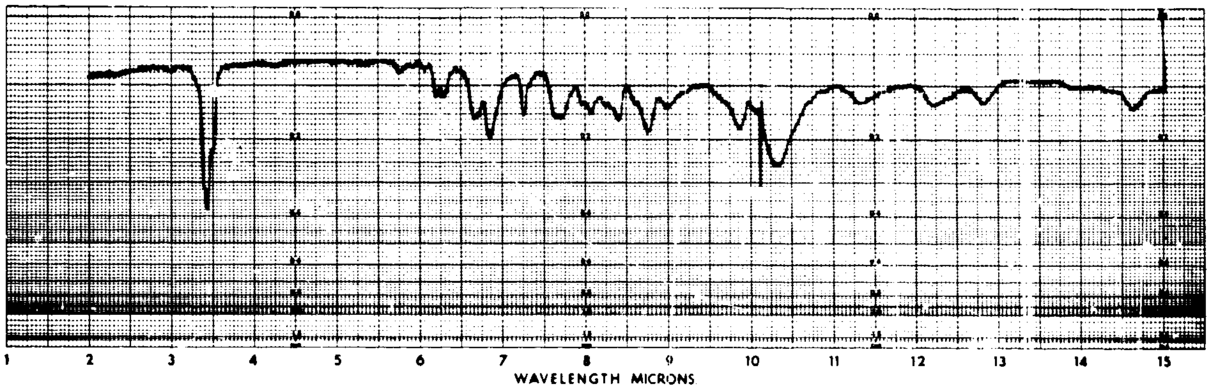
(37) V377-9. As received. (s. wt., 317.08 mg; VCM, 0.006 mg)



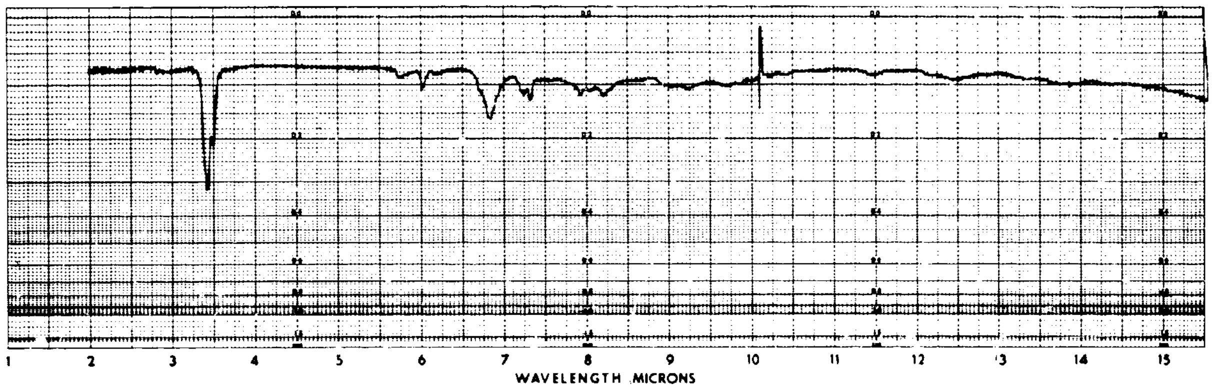
(38) FAIRPRENE 5159 ACTIVATOR. Mixed 100p5159 1pActivator; 48 hr 25°C + 8 hr 104°C (s. wt., 290.14 mg; VCM, 0.058 mg)



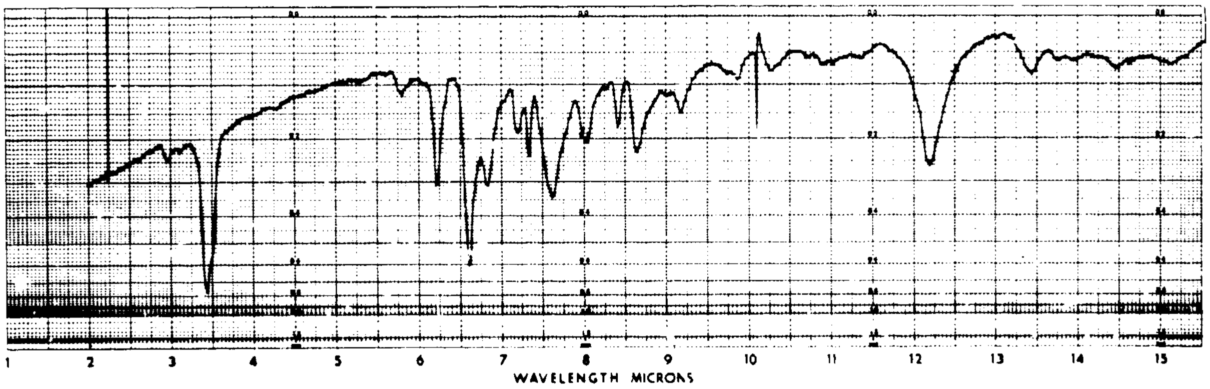
(39) BEN-HAR ACRYL C-2. As received. (s. wt., 293.12 mg; VCM, 0.063 mg)



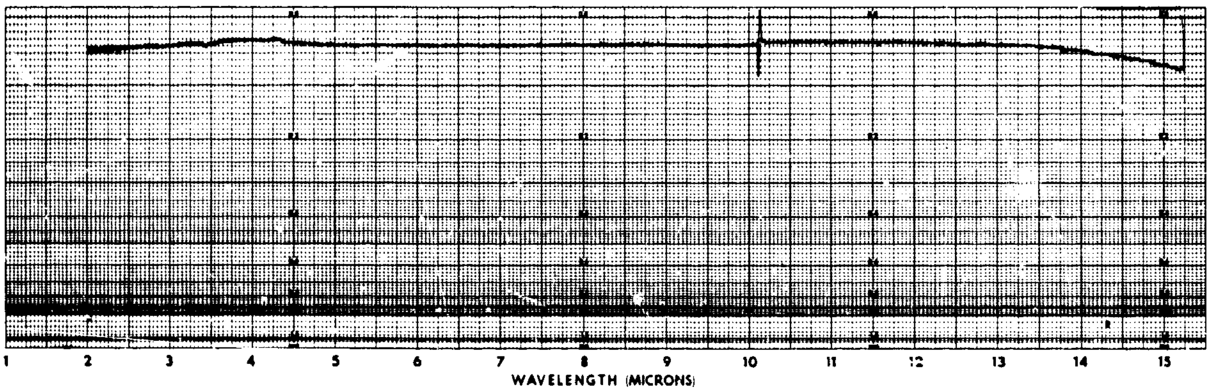
(40) E515-8. As received. (s. wt., 264.4 mg; VCM, 1.815 mg)



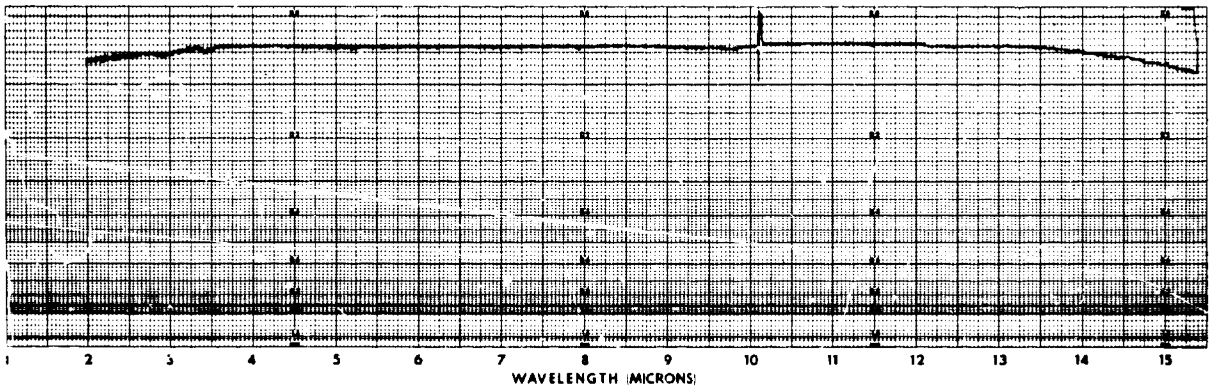
(41) FR-60-26. As received. (s. wt., 276.87 mg; VCM, 0.288 mg)



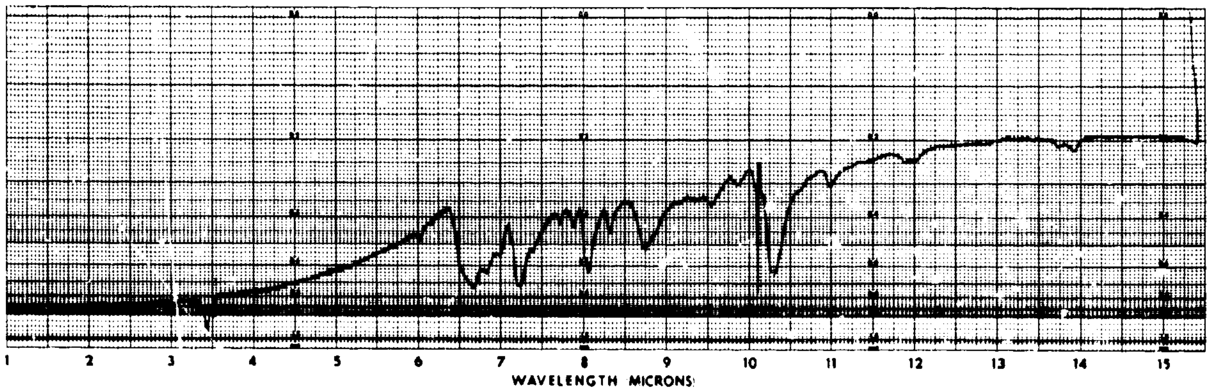
(42) C526-7. As received. (s. wt., 254.5 mg; VCM, 0.287 mg)



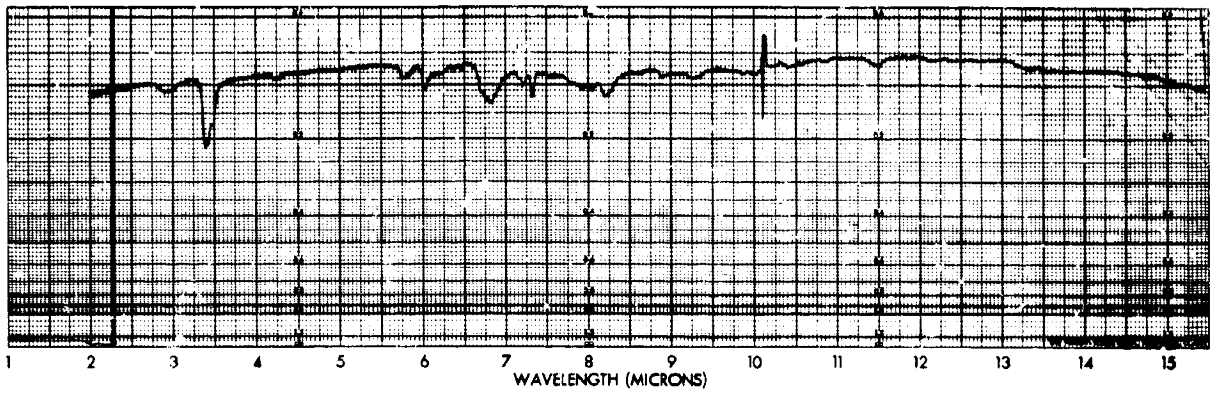
(43) PARYLENE-C. As received. (s. wt., 101.03 mg; VCM, 0.010 mg)



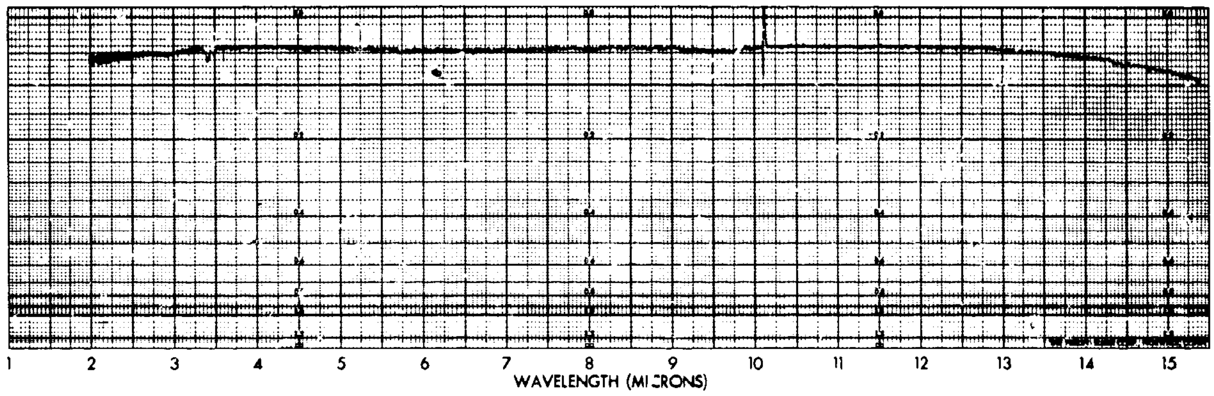
(44) PARYLENE-N. As received. (s. wt., 188.0 mg; VCM, 0.027 mg)



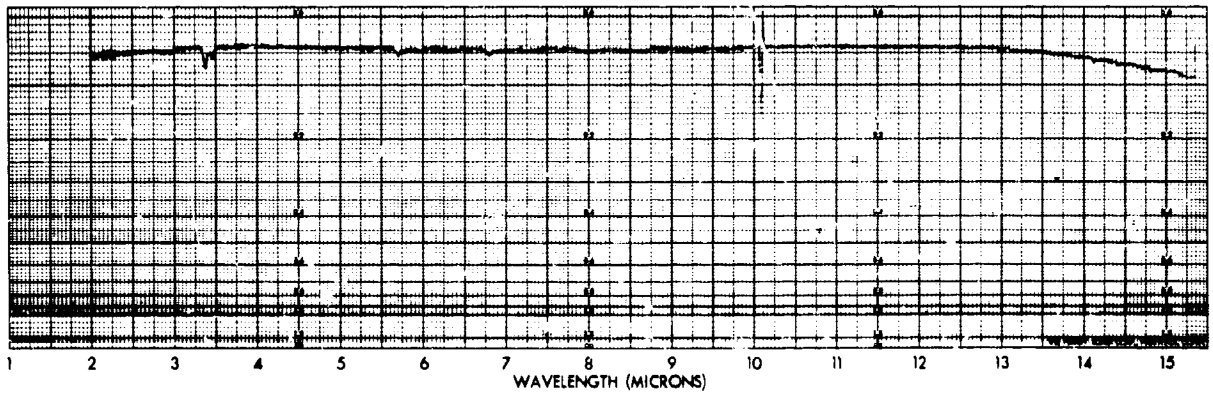
(45) SR-613-75. As received. (s. wt., 247.8 mg; VCM, 1.081 mg)



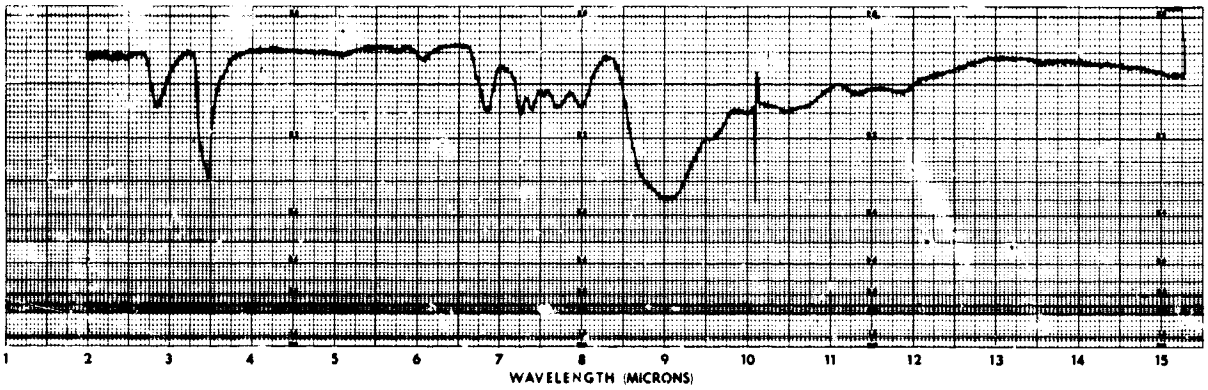
(46) SR-634-70. As received. (s. wt., 233.9 mg; VCM, 0.39[illegible] mg)



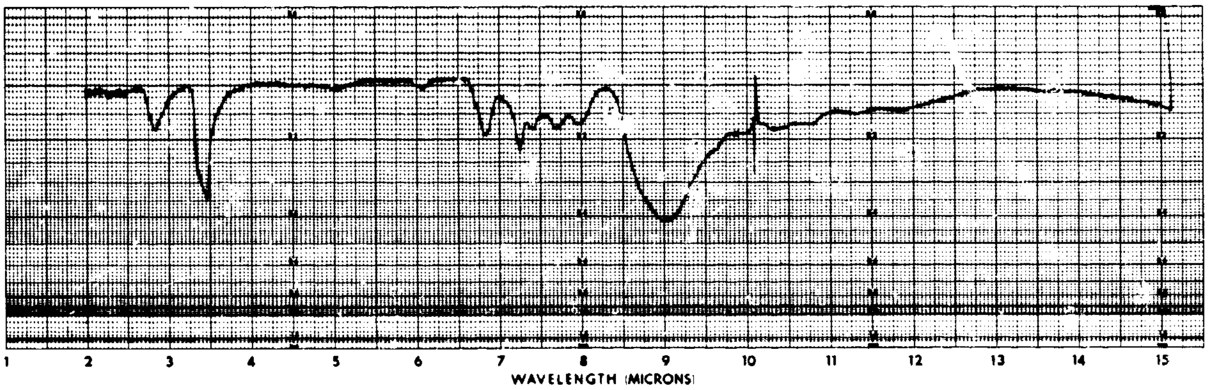
(47) HRP/ADLOCK 851/FM 96U/12 PLY. As received, facing only. (s. wt., 286.91 mg; VCM, 0.027 mg)



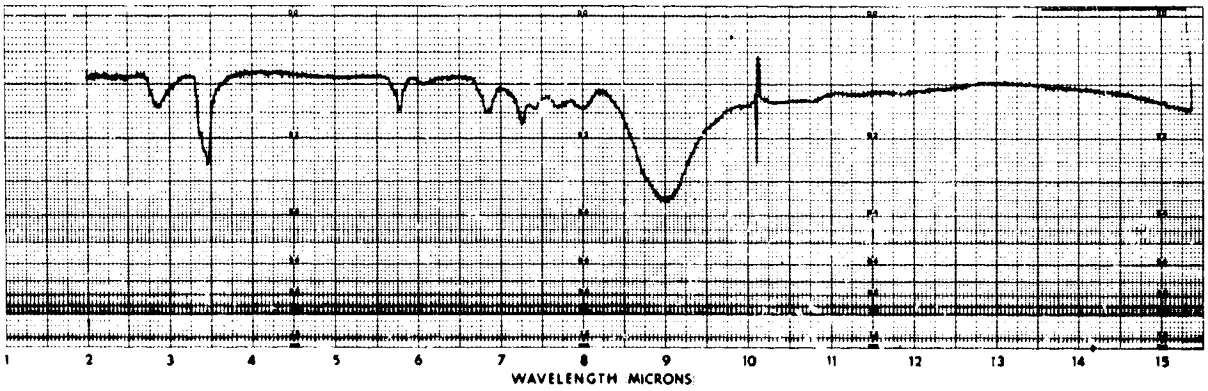
(48) HRP/ADLOCK 851/FM 96U/6 PLY. As received, facing only. (s. wt., 283.45 mg; VCM, 0.026 mg)



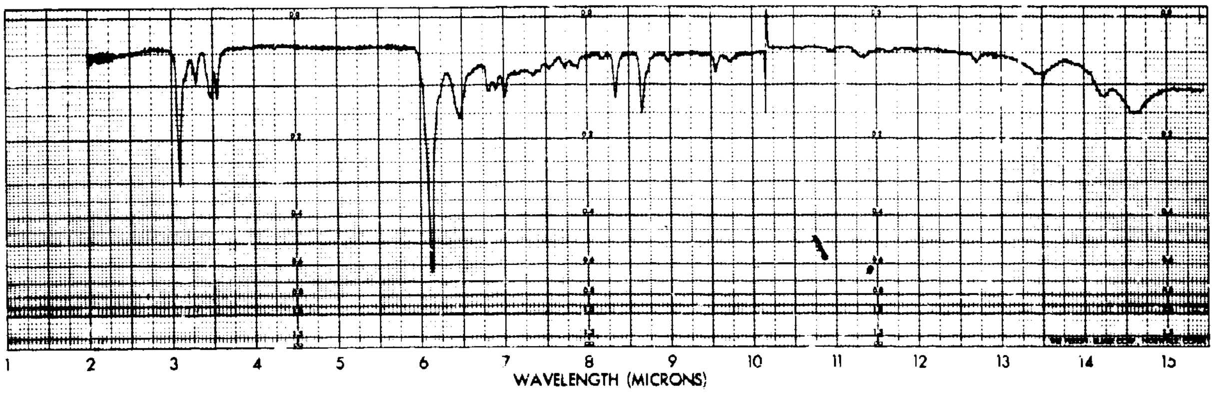
(49) UCON 50HB55. As received. (s. wt., 25.37 mg; VCM, 6.152 mg)



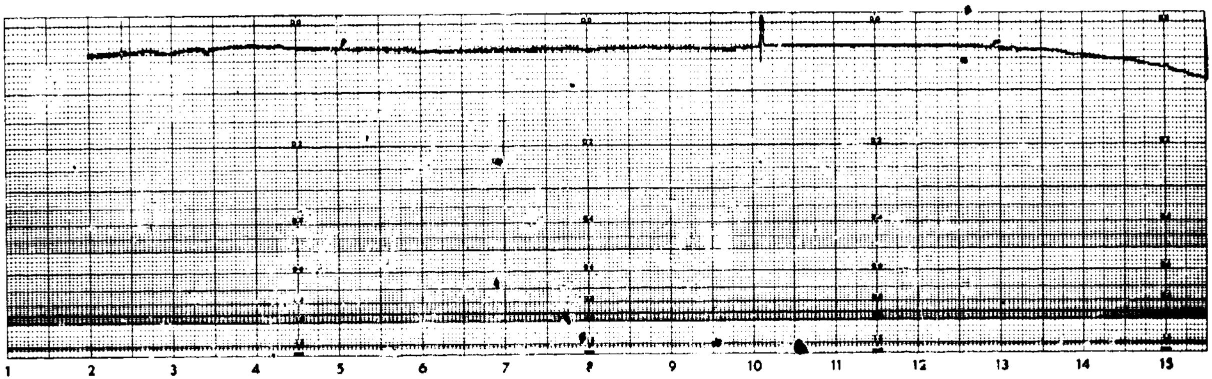
(50) UCON 50HB170. As received. (s. wt., 48.99 mg; VCM, 7.503 mg)



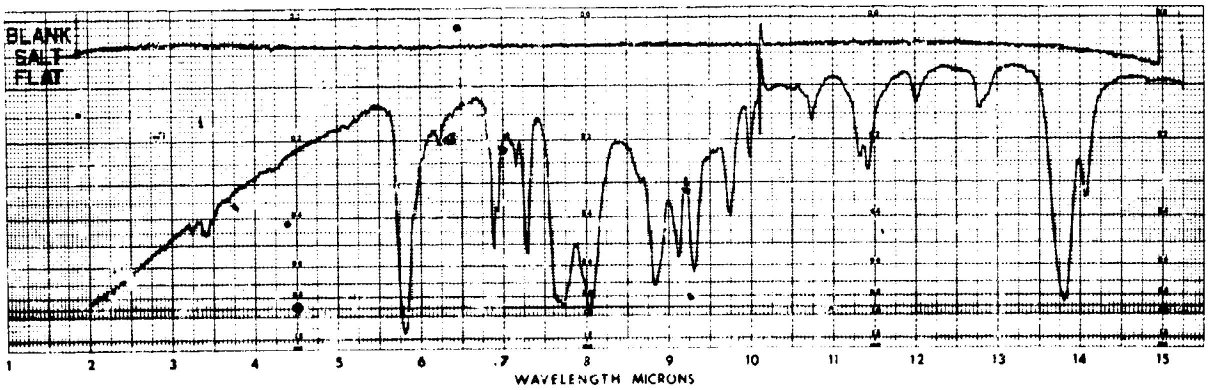
(51) UCON 50HB660. As received. (s. wt., 66.96 mg; VCM, 0.899 mg)



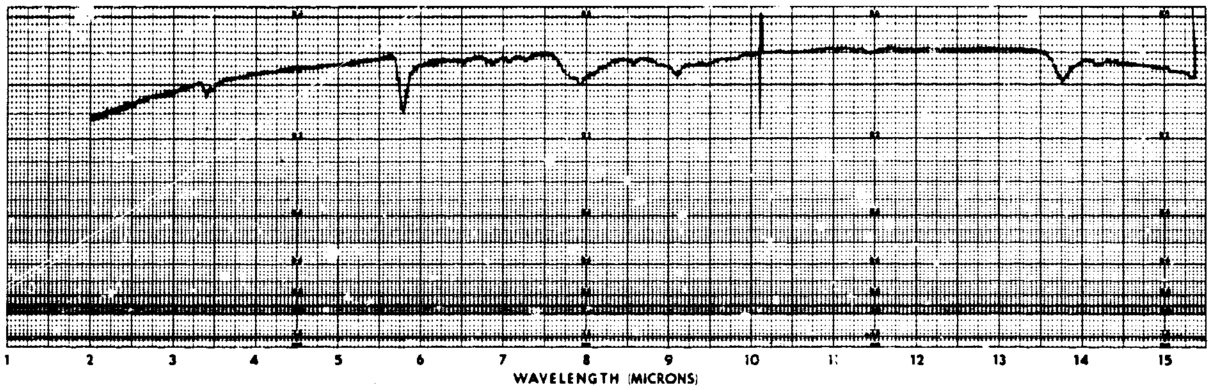
(52) ZYTEL-101. As received. (s. wt., 248.22 mg; VCM, 0.065 mg)



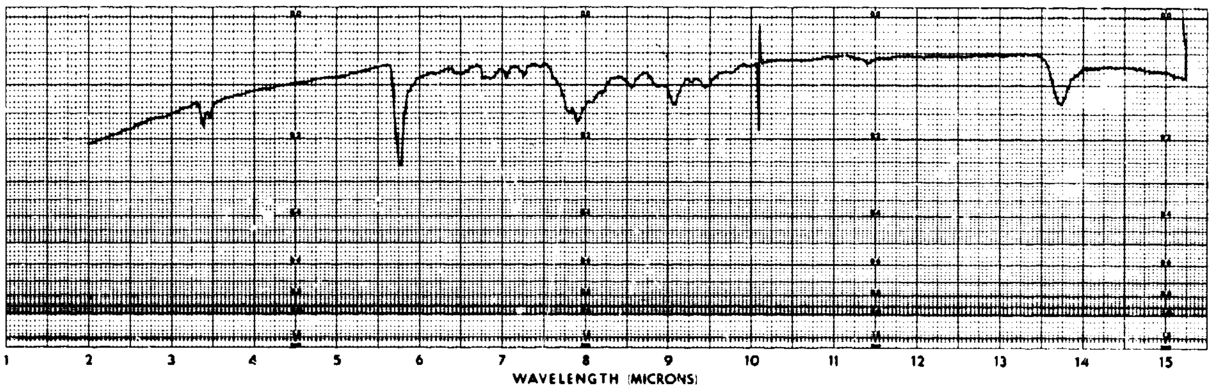
(53) NOMEX, 5-MIL. As received. (s. wt., 191.34 mg; VCM, 0.009 mg)



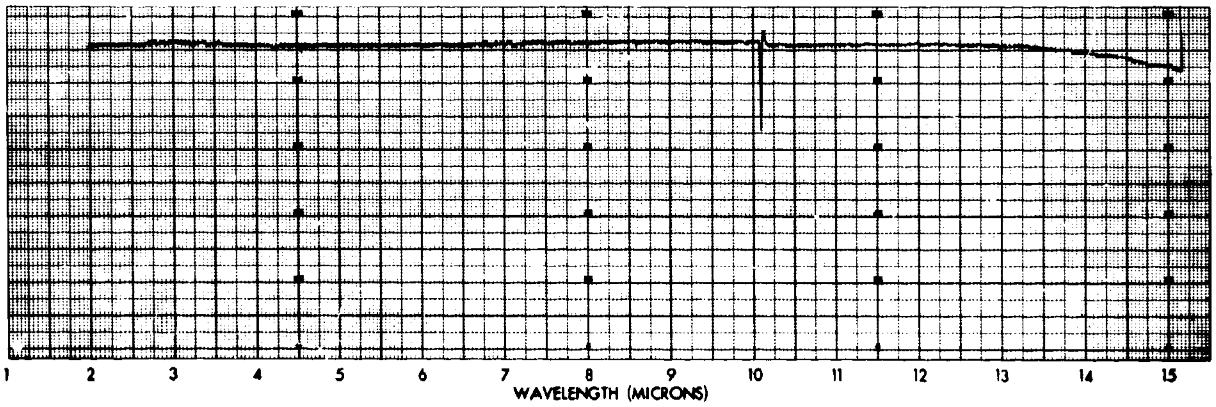
(54) ADHESIVE 46950. As received; 3 min 150° C. (s. wt., 143.79 mg; VCM, 0.593 mg)



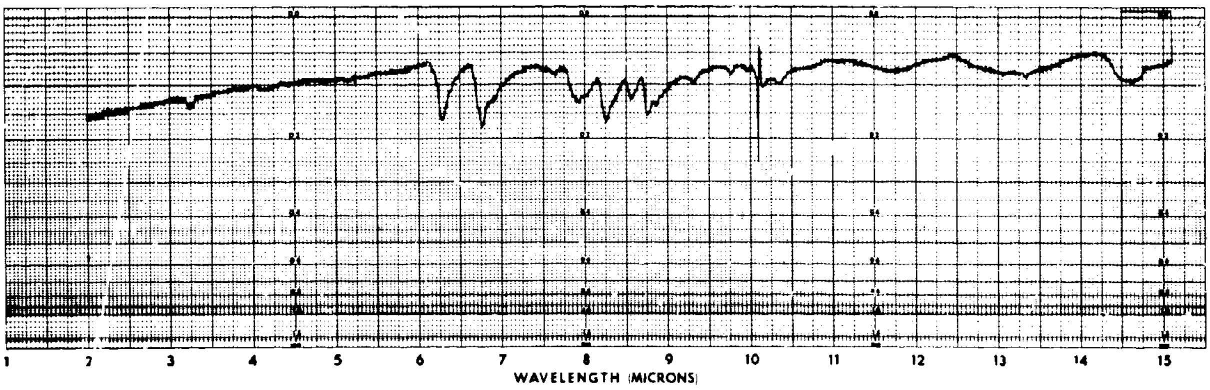
(55) MYLAR, 0.004" WALL. As received; 10 min/110° C. (s. wt., 74.97 mg; VCM, 0.018 mg)



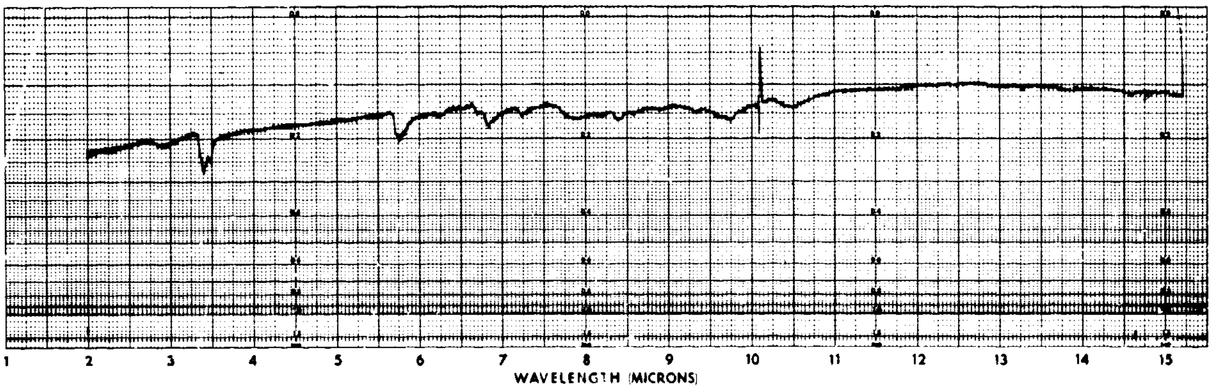
(56) MYLAR, 0.012" WALL. As received; 10 min/110° C. (s. wt., 130.10 mg; VCM, 0.070 mg)



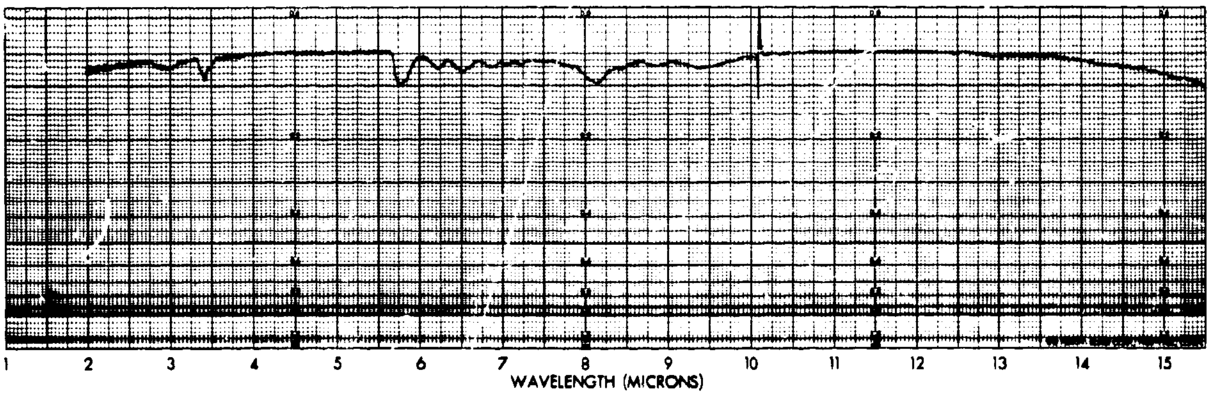
(57) PYRE-M.L., TYPE 1, F2429. As received. (s. wt., 206.43 mg; VCM, 0.045 mg)



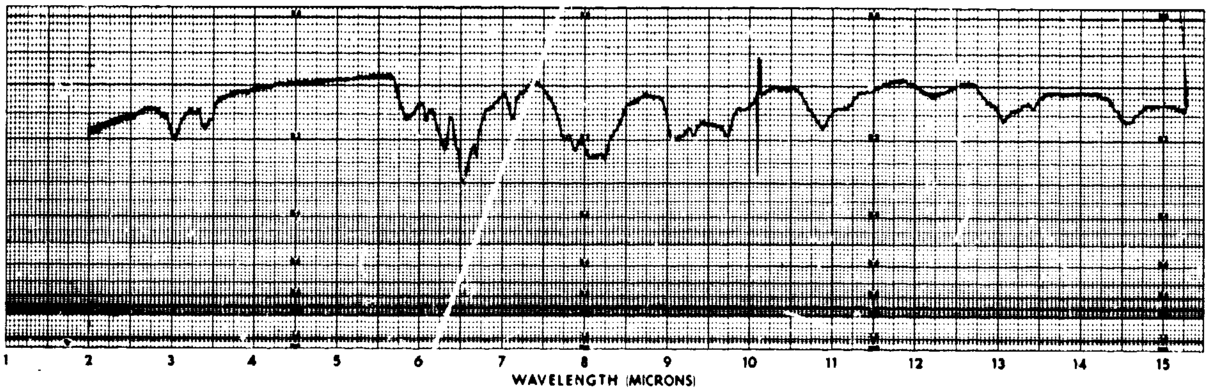
(58) CONVALEX-10 (0-061). As received. (s. wt., 41.36 mg; VCM, 17.96 mg)



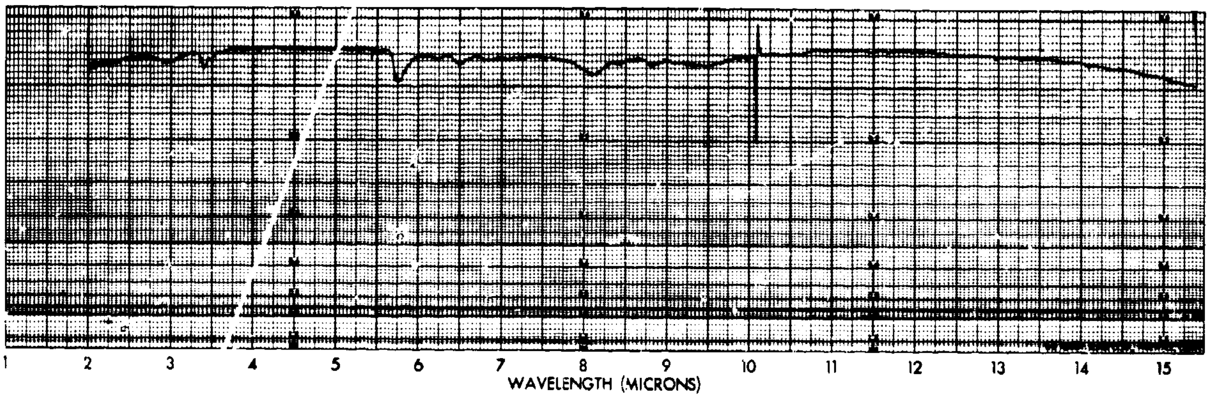
(59) STYCAST CPC-41 A/B. Mixed 100pA/120pB; 48 hr/65° C. (s. wt., 161.15 mg; VCM, 0.233 mg)



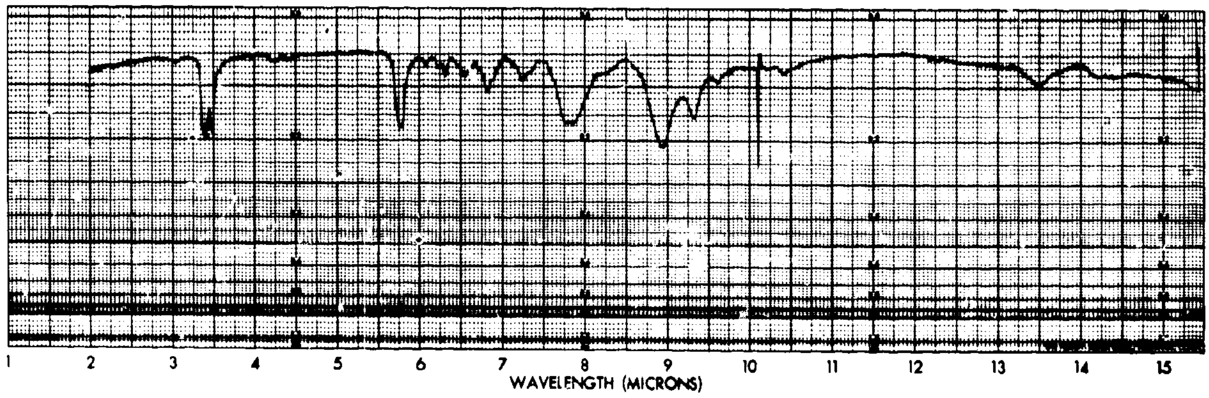
(60) LAMINAR X-500 (4C-8 CLEAR) 10C-45. Mixed 100p4C-8/100p10C-45; 72 hr/25° C. (s. wt., 74.10 mg; VCM, 0.065 mg)



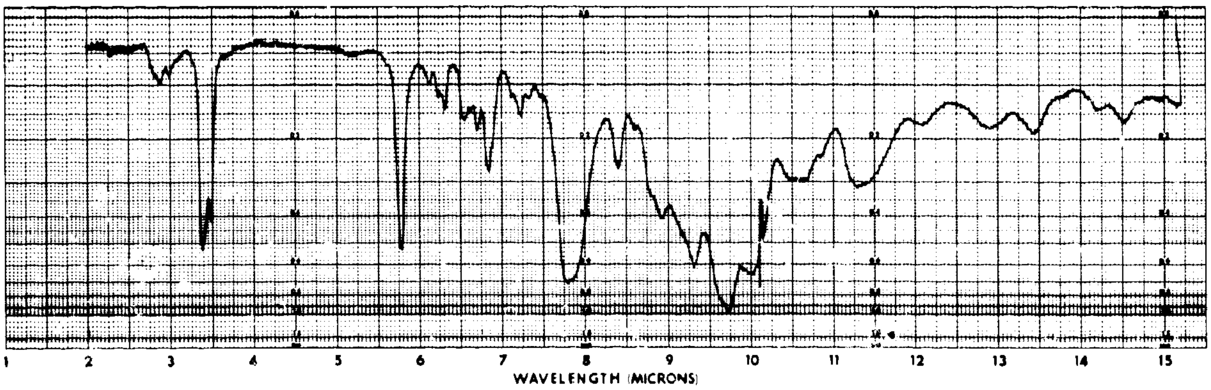
(61) STYCAST CPC-21 A/B. Mixed 100pA/60pB; 6 hr/95° C + 24 hr/125° C.
(s. wt., 211.93 mg; VCM, 0.405 mg)



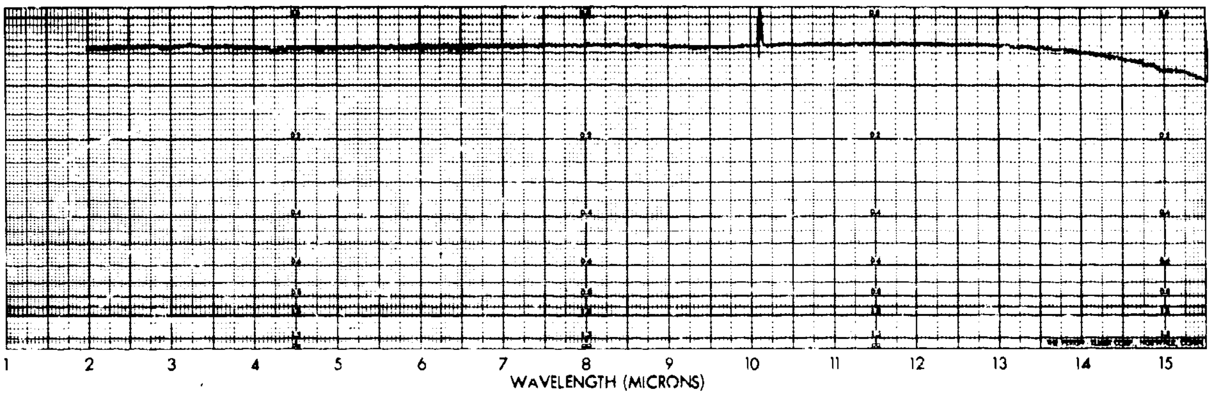
(62) LAMINAR X-500 (4B-1 BLACK)/10C-45. Mixed 100pA/100pB; 48 hr/25° C.
(s. wt., 89.25 mg; VCM, 0.026 mg)



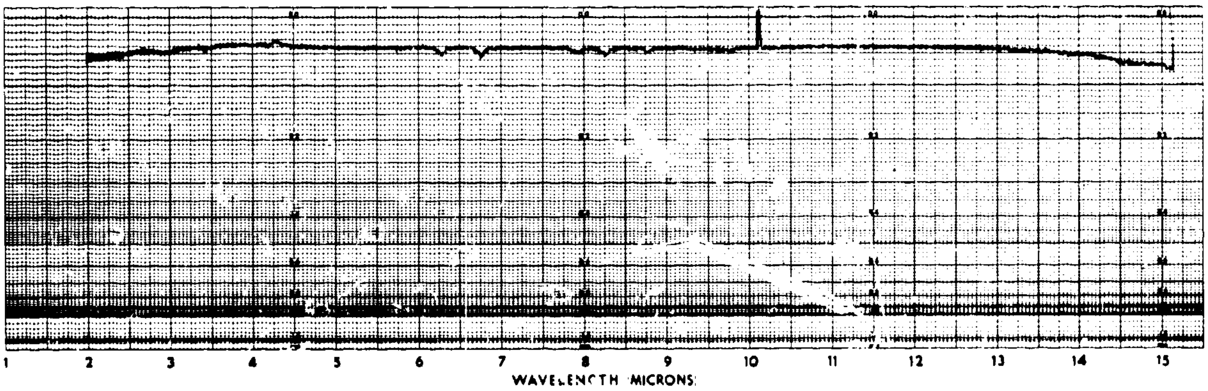
(63) ECCO CP6/R6. Mixed 100pCP6/17pR6; 3 hr/105° C. (s. wt., 204.67 mg; VCM, 4.188 mg)



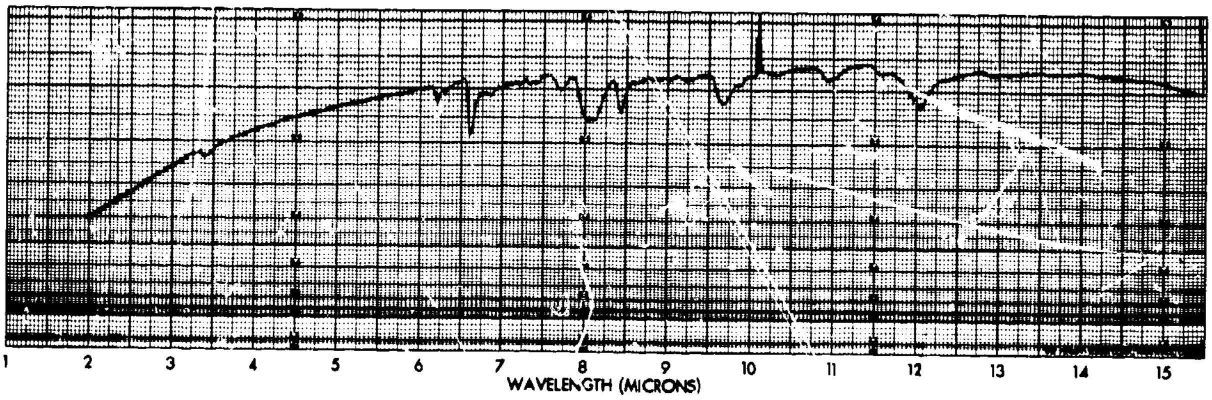
(64) STYCAST CPC-22 A/B. Mixed 100pA/60pB; 40 hr/65° C. (s. wt., 190.90 mg; VCM, 45.785 mg)



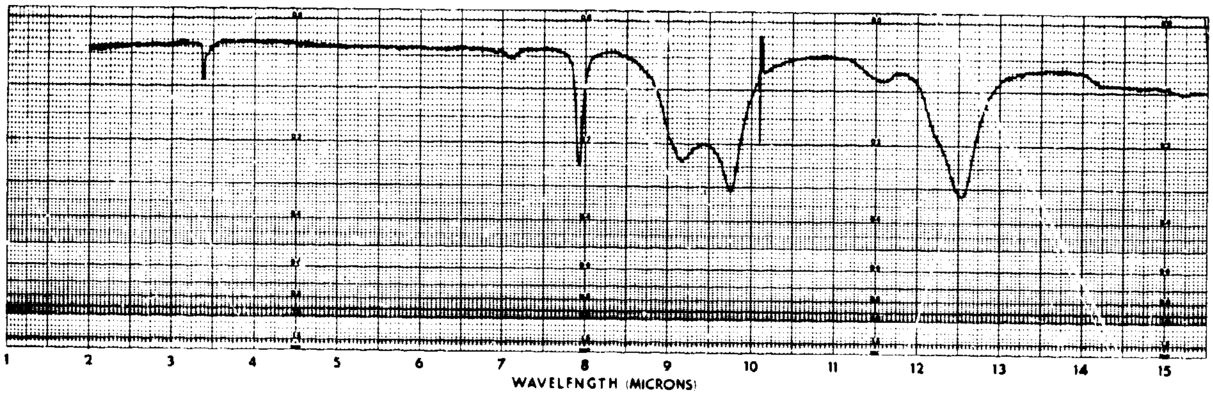
(65) ECCOFOAM FPH/126H. Mixed 100pFPH/75p126H; 16 hr/52° C. (s. wt., 45.64 mg; VCM, 0.100 mg)



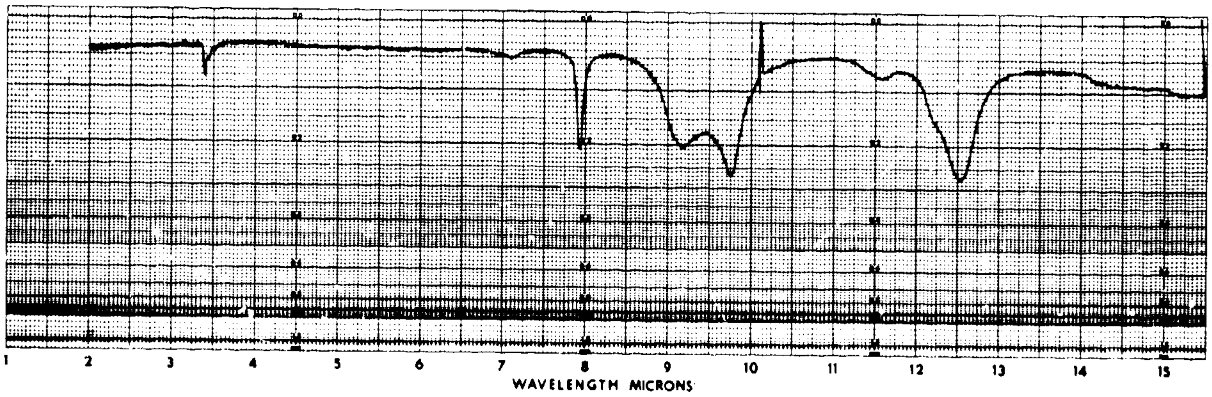
(66) LAMINAR X-500 (4B-3 FLAT BLACK)/10C-45. Mixed 100p4B-3/100p10C-45; 24 hr/25° C. (s. wt., 93.03 mg; VCM, 0.009 mg)



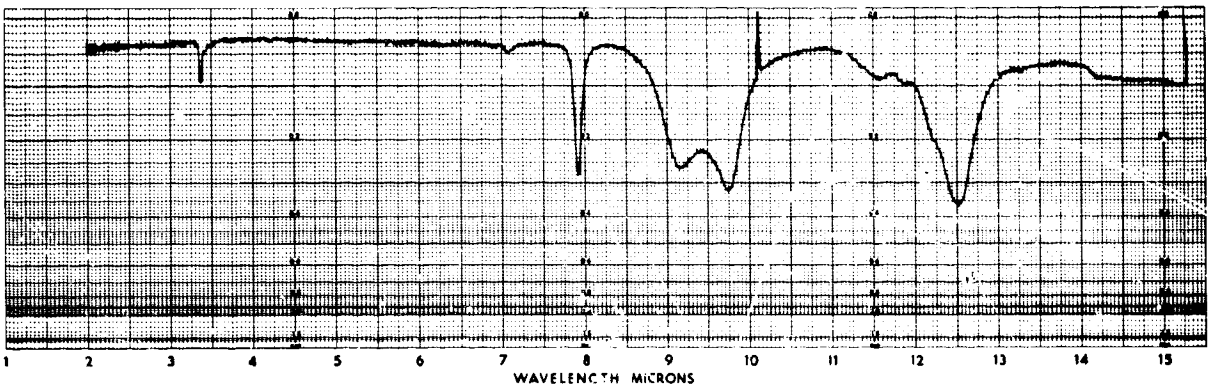
(67) LAMINAR X-500 (8W-24 WHITE). Mixed 100p8W-24/25pHardener/25pReducer; 2 hr/55° C. (s. wt., 95.31 mg; VCM, 0.111 mg)



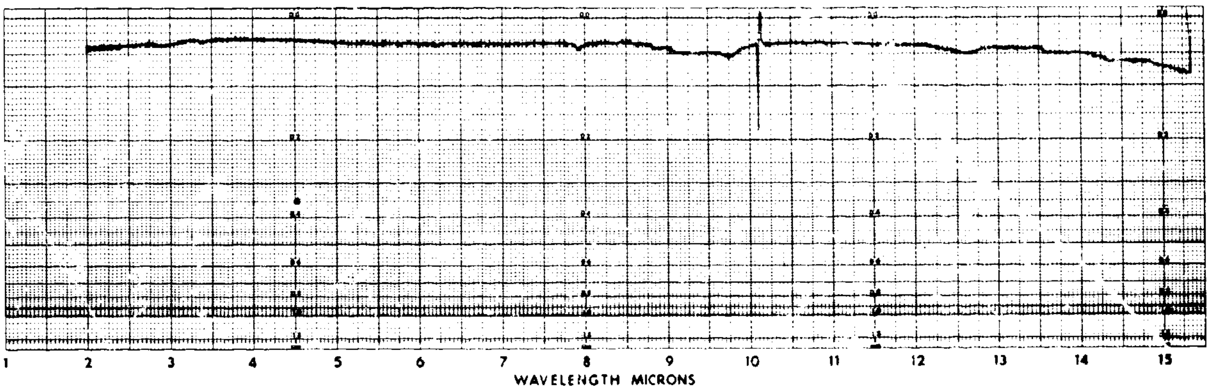
(68) A2841-L-618 (GRAY). As received, stripped from wire. (s. wt., 262.1 mg; VCM, 1.127 mg)



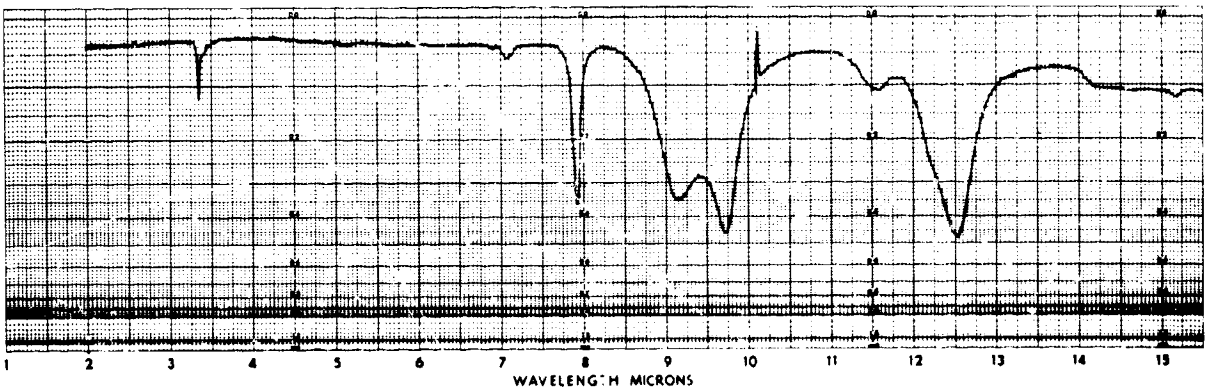
(69) A2841-L-618 (YELLOW) As received, stripped from wire. (s. wt., 266.13 mg; VCM, 1.424 mg)



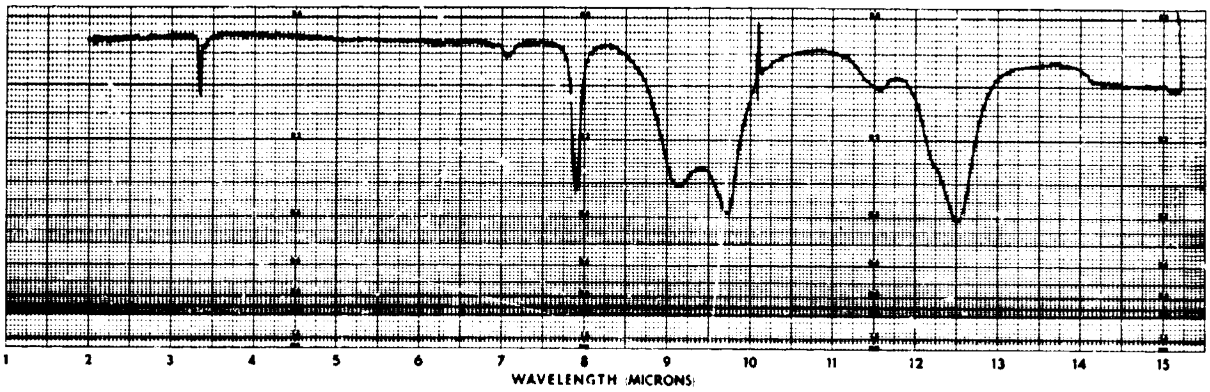
(70) DC-11. As received. (s. wt., 24.78 mg; VCM, 0.078 mg)



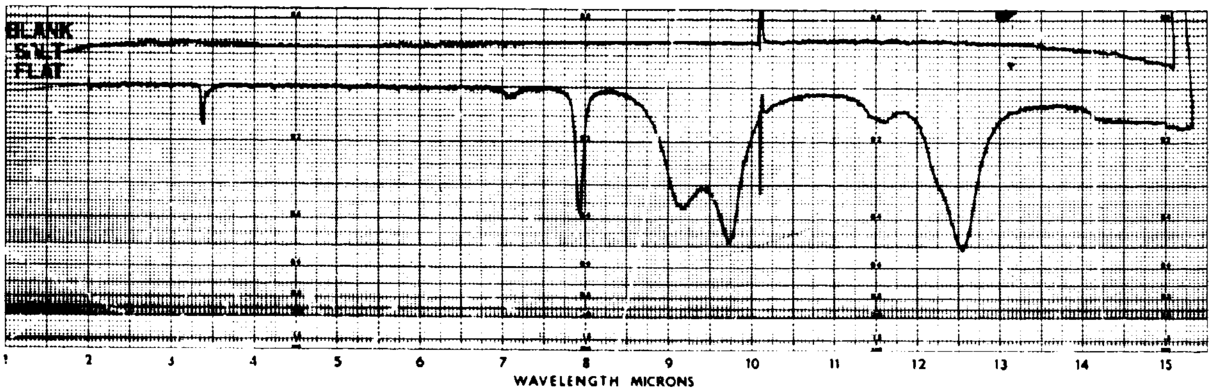
(71) G-683. As received. (s. wt., 25.05 mg; VCM, 0.015 mg)



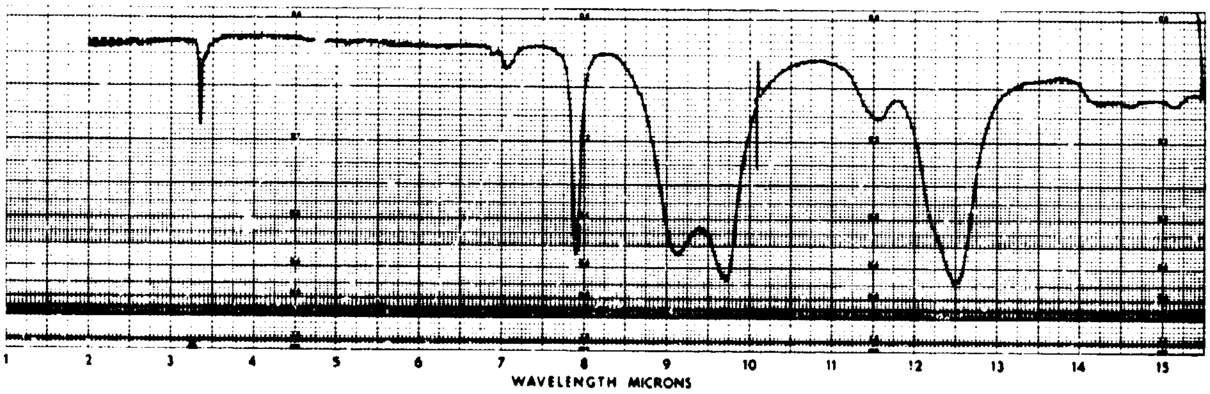
(72) HADBAR 28-80. As received. (s. wt., 276.99 mg, VCM, 0.671 mg)



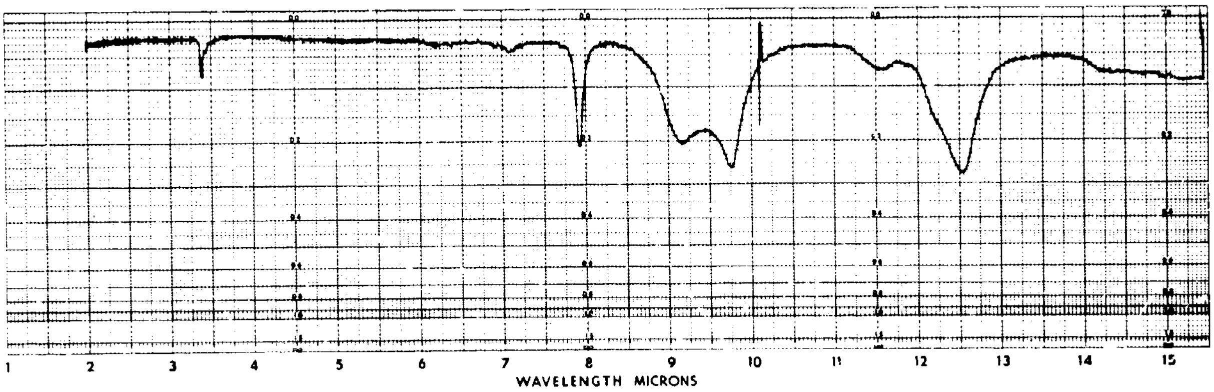
(73) RTV-30 T-12. Mixed 100p30 0.1pT-12; 24 hr 25°C + 24 hr 135°C. (s. wt., 217.57 mg; VCM, 0.771 mg)



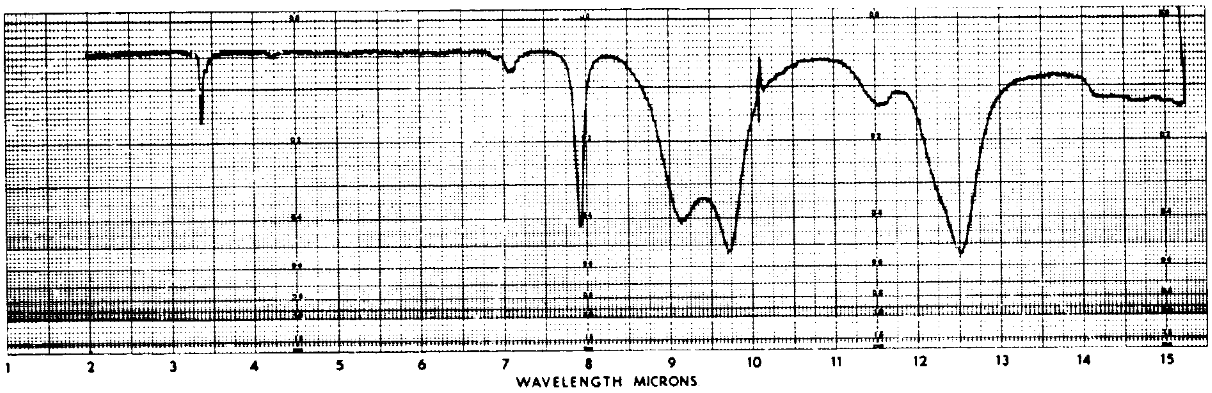
(74) RTV-40 T-12. Mixed 100p40 0.1pT-12; 7 das 25°C. (s. wt., 292.12 mg; VCM, 1.177 mg)



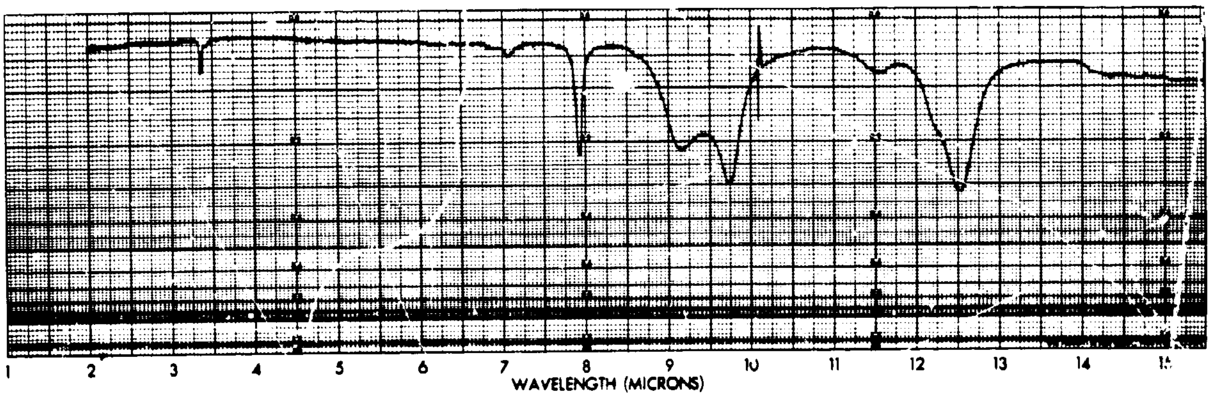
(75) RTV-88 T-12. Mixed 100p88 0.1pT-12; 24 hr 25°C + 24 hr 135°C. (s. wt., 242.74 mg; VCM, 0.910 mg)



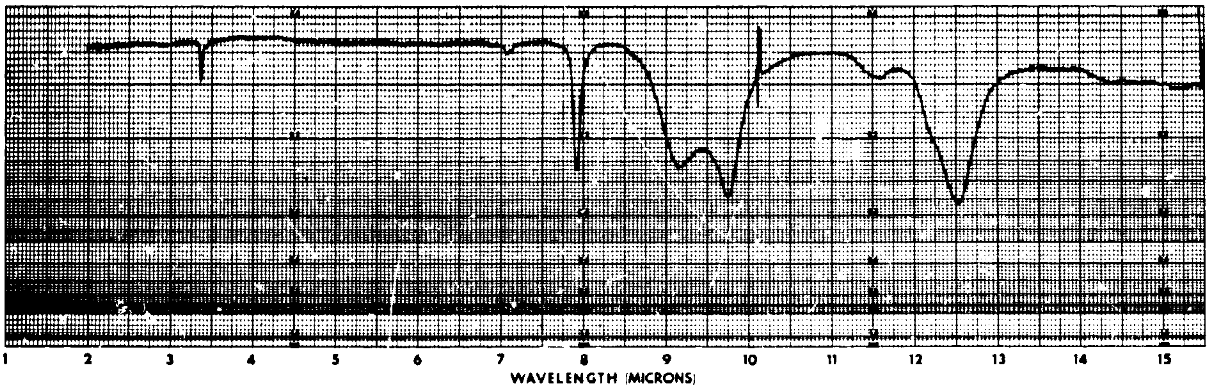
(76) SILASTIC-881/CAT. Mixed 100p881/4.6pCat; 24 hr/125°C. (s. wt., 209.36 mg; VCM, 1.623 mg)



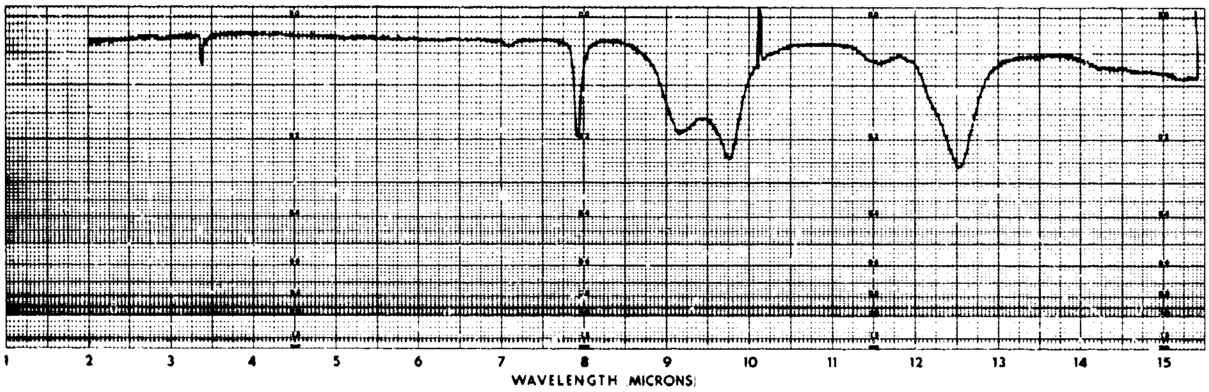
(77) SILASTIC-3116/T-12; 7 das/25°C. (s. wt., 281.78 mg; VCM, 1.741 mg)



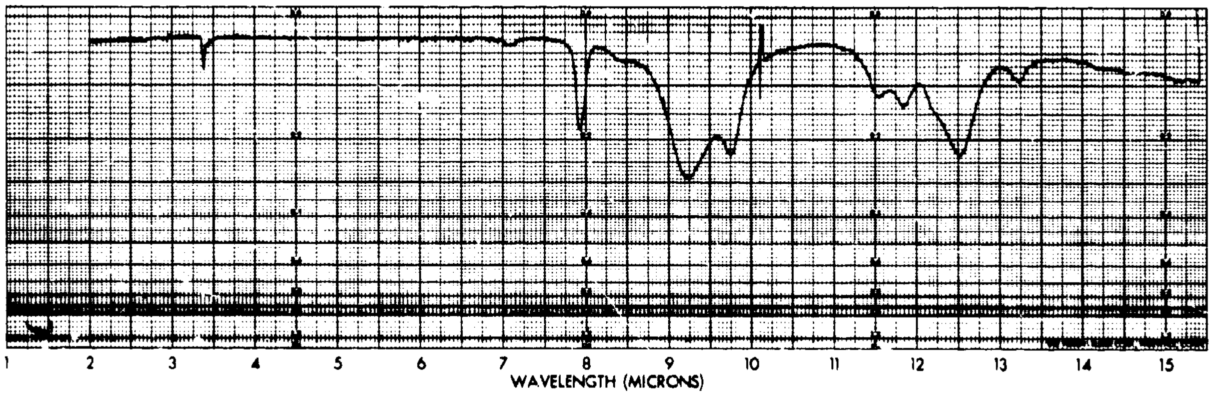
(78) SILASTIC-732 (CLEAR). As received; 24 hr 25°C. (s. wt., 186.79 mg; VCM, 1.545 ng)



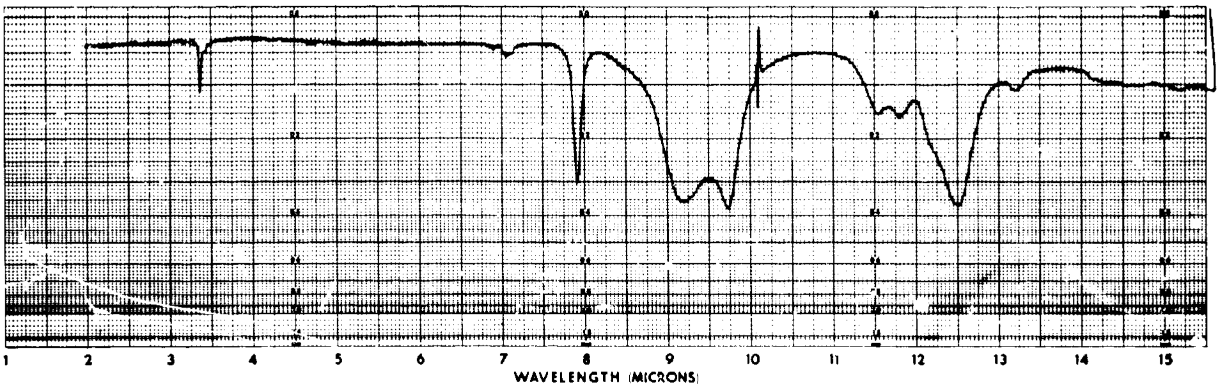
(79) SILASTIC-732 (WHITE). As received; 24 hr/25° C. (s. wt., 192.68 mg; VCM, 1.746 mg)



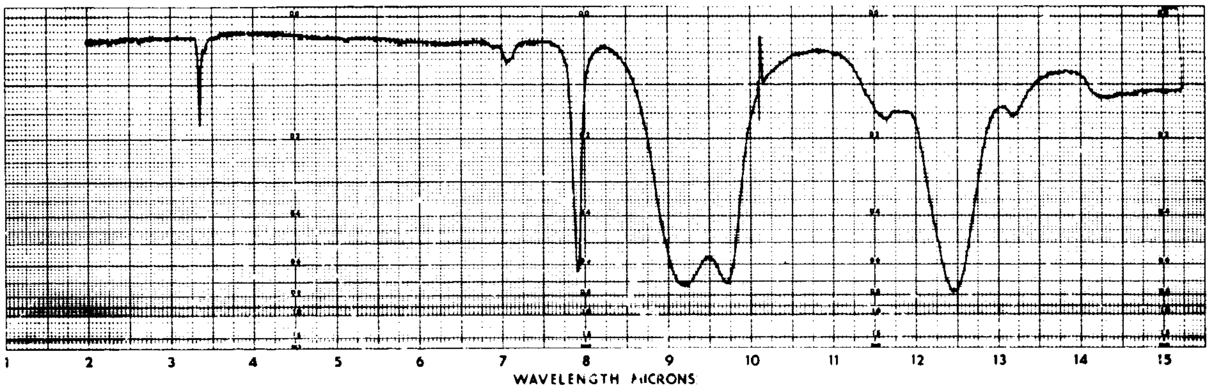
(80) SILASTIC-S9711. As received. (s. wt., 211.89 mg; VCM, 0.172 mg)



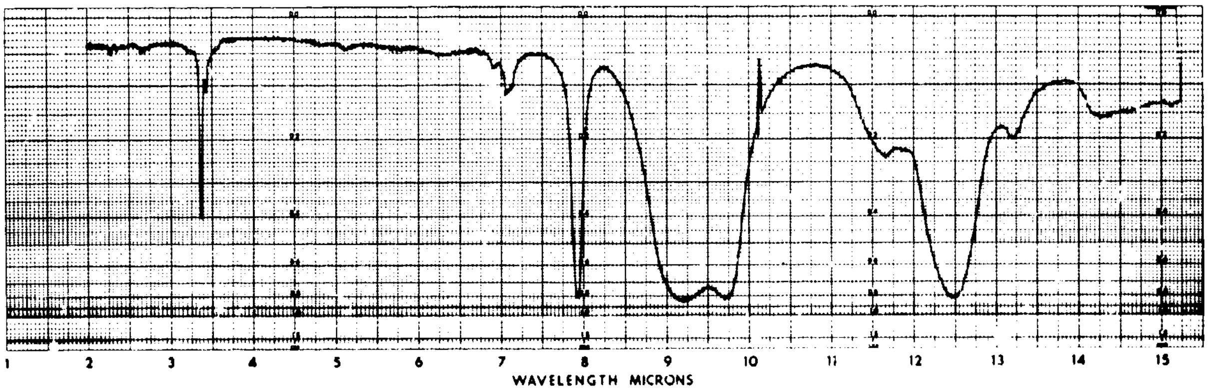
(81) E691-22E. Mfr's sample. (s. wt., 176.08 mg; VCM, 0.106 mg)



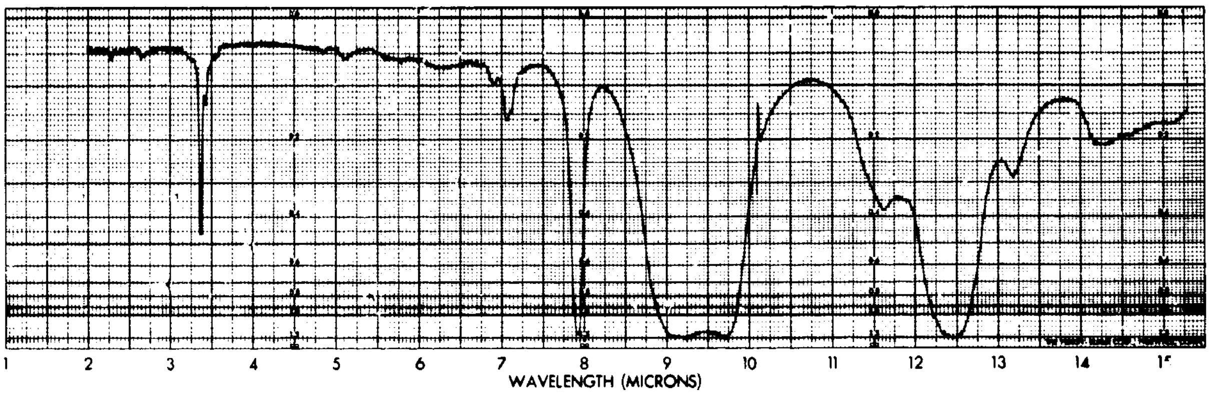
(82) HADBAR 4000-80. As received. (s. wt., 287.96 mg; VCM, 0.406 mg)



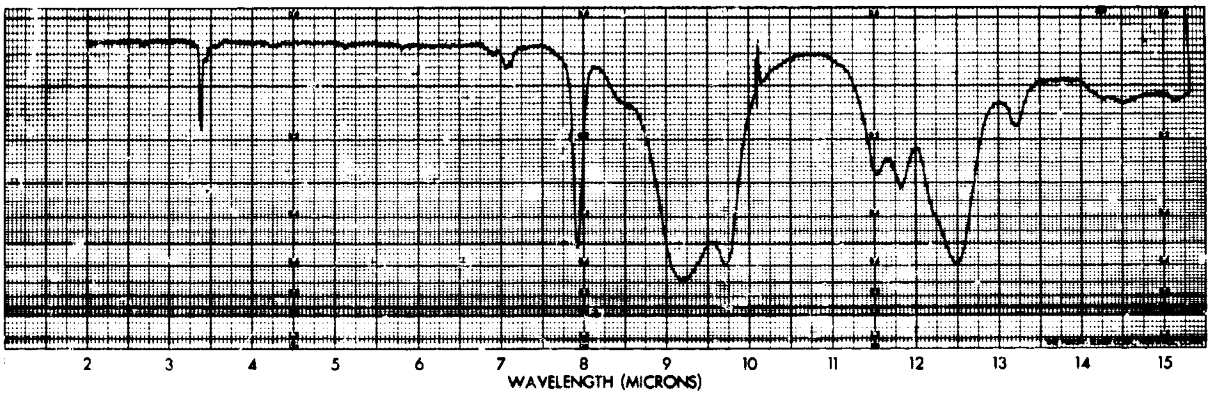
(83) RTV-102 (WHITE). As received; 24 hr/25°C. (s. wt., 197.39 mg; VCM, 2.952 mg)



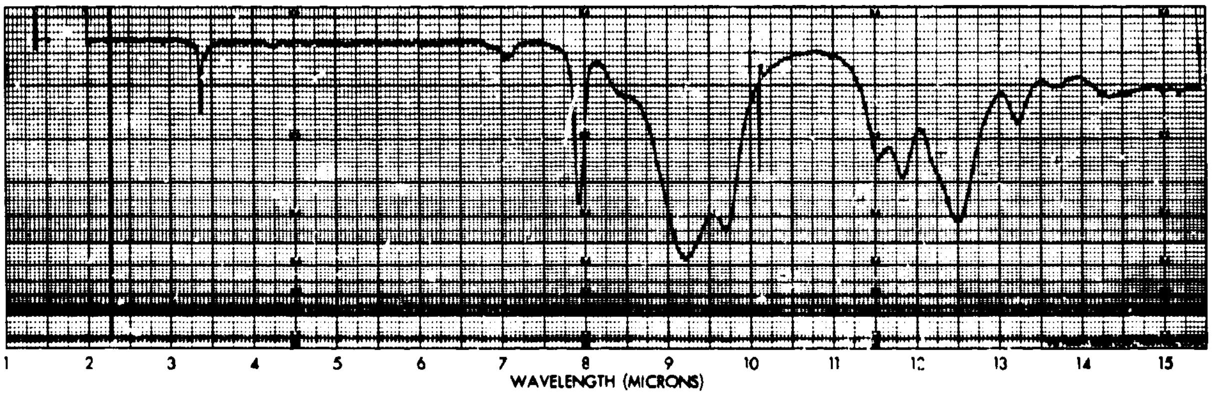
(84) RTV-103 (BLACK). As received; 24 hr 25°C. (s. wt., 202.97 mg; VCM, 3.640 mg)



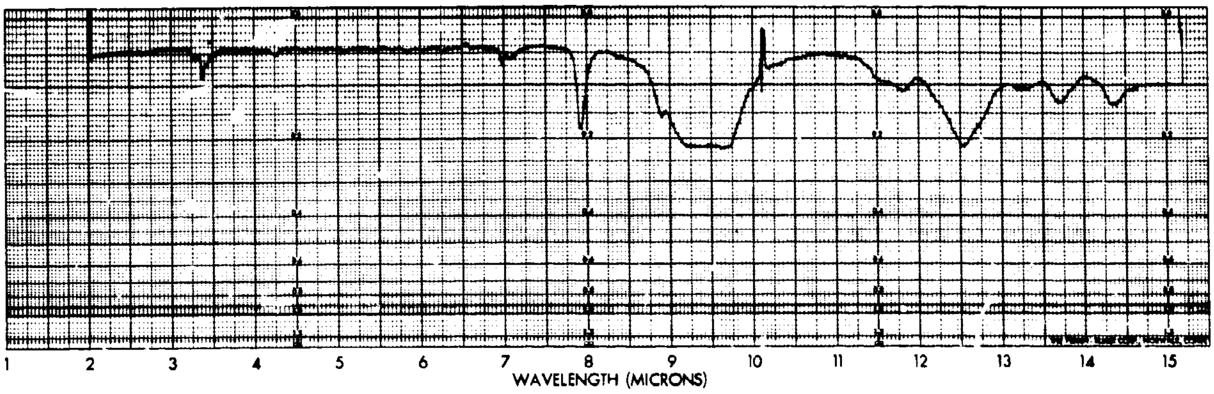
(85) RTV-108 (CLEAR). As received; 24 hr/25°C. (s. wt., 191.22 mg; VCM, 2.984 mg)



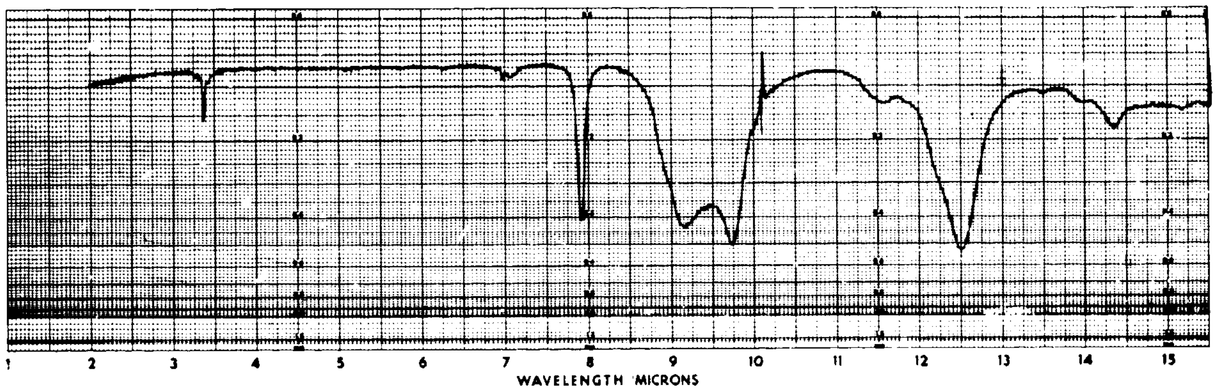
(86) SYLGARD-184. Mfr's sample. (s. wt., 174.57 mg; VCM, 1.200 mg)



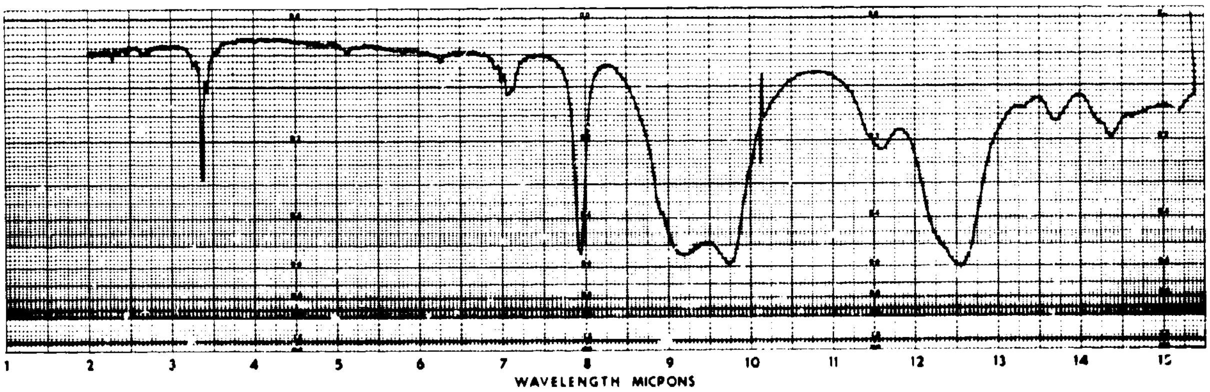
(87) XR-63492. Mfr's sample. (s. wt., 177.05 mg; VCM, 1.079 mg)



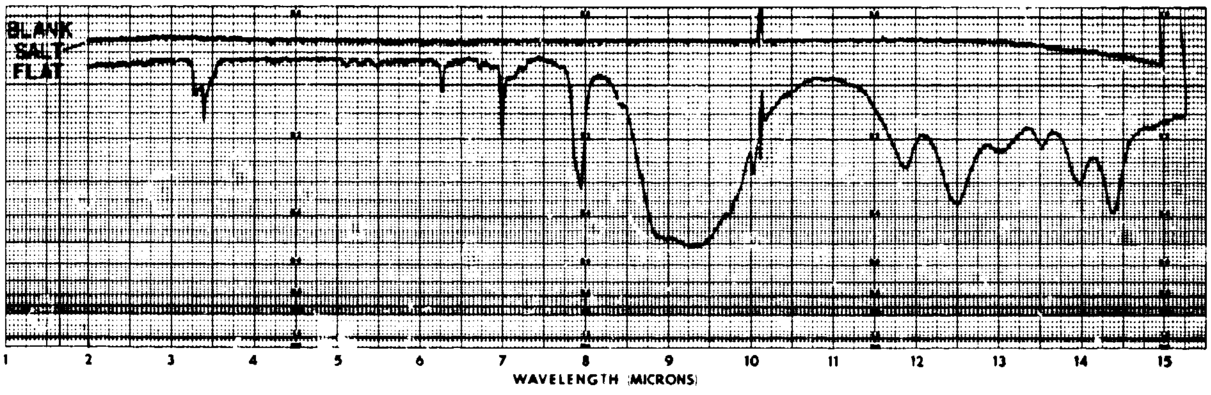
(88) 93-002. Mfr's sample. (s. wt., 233.31 mg; VCM, 1.217 mg)



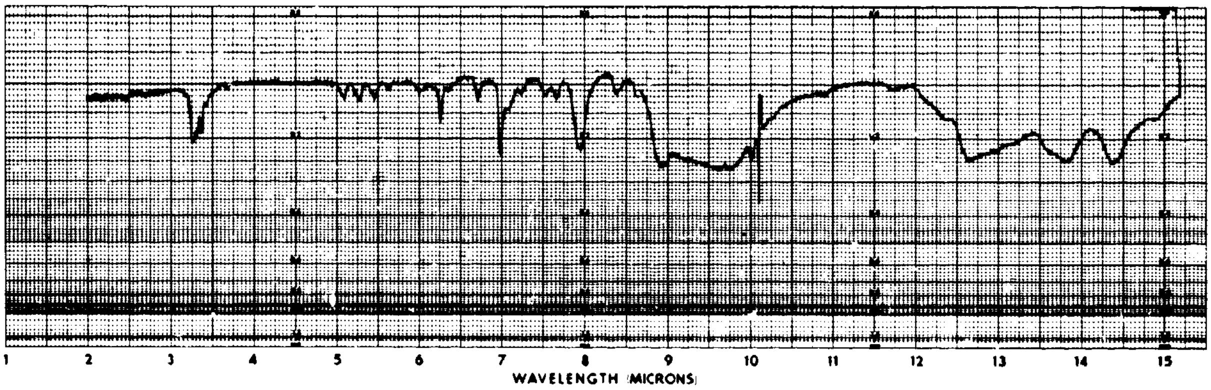
(89) SE-5604-7. As received. (s. wt., 258.36 mg; VCM, 0.391 mg)



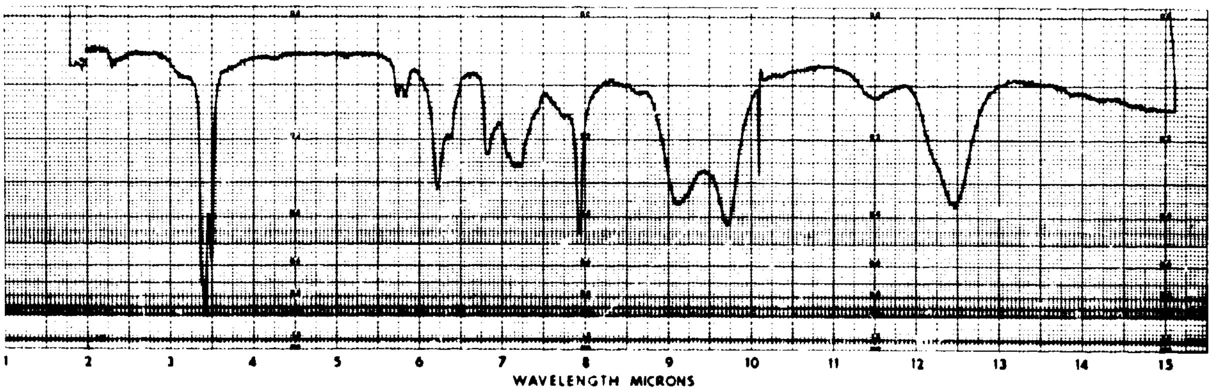
(90) SILASTIC-732 (BLACK) As received; 24 hr 25 °C. (s. wt., 171.68 mg; VCM, 1.581 mg)



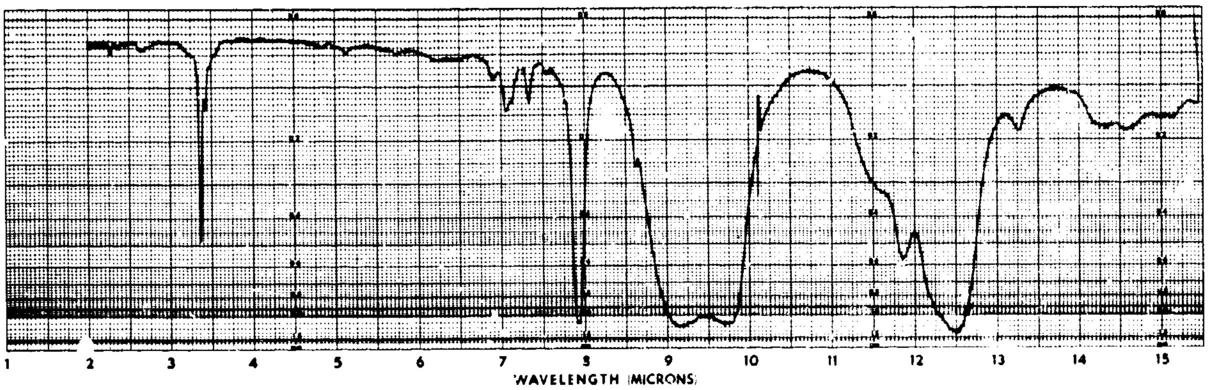
(91) SR-290. Mixed 100pSR-98/100pSR-220; 1 hr/135°C. (s. wt., 80.23 mg;VCM, 1.353 mg)



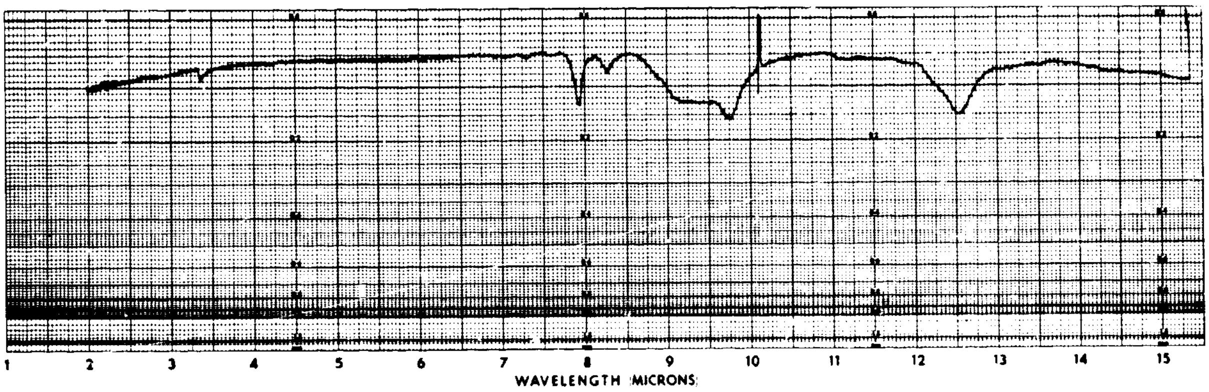
(92) DC-705. As received. (s. wt., 68.06 mg; VCM, 55.110 mg)



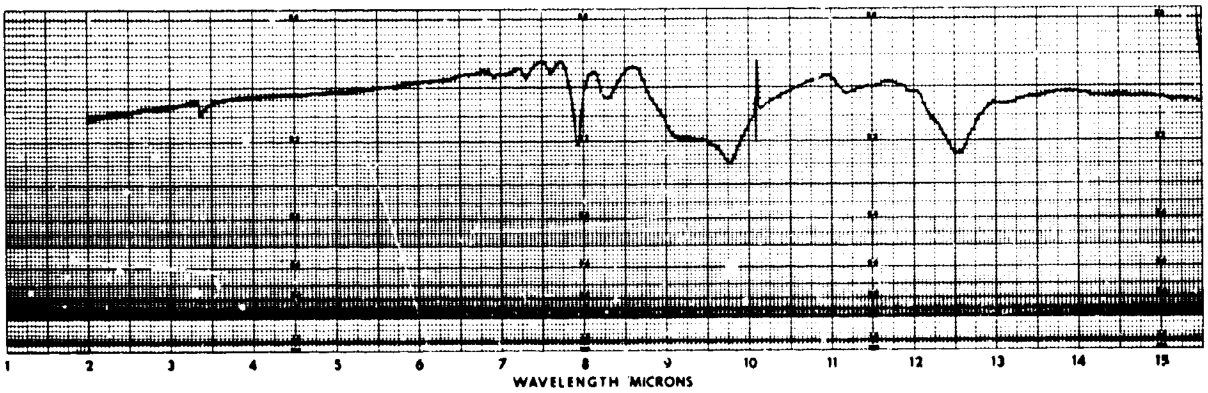
(93) SILASTIC-501/T-12. Mixed 100p501/4p T-12; 7 das/25°C. (s. wt., 268.41 mg; VCM, 9.920 mg)



(94) VERSILUBE G-300. As received. (s. wt., 39.14 mg; VCM, 1.436 mg)



(95) 1050-70. As received. (s. wt., 189.11 mg; VCM, 0.047 mg)



(96) L-449-6. As received. (s. wt., 189.16 mg; VCM, 0.173 mg)

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Appendix D

INTERIM LIST OF RECOMMENDED POLYMERIC PRODUCTS

An interim list has been compiled of the best available polymeric products for spacecraft use. Each product on this list is considered acceptable because it showed less than 1% weight loss and less than 0.1% VCM content in the micro-VCM test. Of the 90-100 products listed, about 20 have been shown to be able to withstand a total of 168 hours in a decontaminating atmosphere (humidified ETO/Freon at 50°C), or a total of 500 hours in the thermal-vacuum environment (135°C and 10^{-6} torr), or a combination of the above; these products are identified by asterisks.

The polymeric products on this list have good potential for spacecraft applications, especially those which have undergone successfully the decontamination and thermal-vacuum exposures. However, it is emphasized that a final list of recommendations cannot be made until the products have passed successfully the various sequences of decontamination and heat-sterilization which are being considered for spacecrafts and then still maintain good properties in the thermal-vacuum environment.

As a rule, very low values for loss weight and VCM content indicate that mechanical properties will be maintained in a thermal-vacuum environment; however, the effect of ETO/Freon decontamination cannot be predicted; for example, both Metlbond-328 and Metlbond-329 had good outgassing properties and maintained good mechanical properties throughout the 500-hour thermal-vacuum exposure, but after ETO treatment and ETO/TVE treatment the Metlbond-329 suffered a significant loss of shear strength while the Metlbond-328 suffered no loss in properties. (See Section V, Adhesives.)

Appendix D

INTERIM LIST[1] OF RECOMMENDED POLYMERIC PRODUCTS

APPLICATION / PRODUCT	MFR.[2]	TREATMENT
Adhesives		
Armstrong A-2/A	APC	100pA-2 4pA; 45 min 74°C + 45 min 93°C
Armstrong A-2 E*	APC	100pA-2 6pE; 45 min 93°C
EC-2216 A B	MMA	140pA 100pB; 2 hr/65°C
Eccobond 55 9*	EMC	100p55 12p*9; 24 hr 25°C
Eccobond Solder 56C 9	EMC	100p56C 5p*9; 16 hr 50°C
Eccobond Solder 57C A B*	EMC	100pA 100pB; 16 hr 52°C
Eccobond 104 A B*	EMC	100pA 64pB; 8 hr/150°C
Epiphen ER-825A	BCM	25p825A 3p"T" modifier 10pFiller 4p825A-conv; 48 hr 75°C
Epon 828 A	SCA	100p828 8pA; 3 hr 95°C
Epon 828 Z	SCA	100p828 20pZ; 2 hr/75°C + 2 hr 135°C
Epon 901 B-3*	SCA	100p901 23pB-3; 1-1 2 hr 115°C + 1-1 2 hr 175°C
Epon 917	SCA	As received; 15 min 175°C
Epon 931 A B	SCA	100pA 1pB; 1 hr 125°C
Epon 934 A B	SCA	100pA 33pB; 1 hr 82°C
FM-961*	ACB	As received; 1 hr 177°C
Metlbond-328*	WCN	As received; 90 min 165°C
Circuit Boards		
EG-2028, Type FL-GE	FLC	As received
EG-2028FR, Type FL-GF	FLC	As received
Micaply EG-284T	TMC	As received
Micaply EG-758T	TMC	As received
Micaply EG-890T	TMC	As received
Micarta 65M25	WFM	As received
Coated Fabrics		
Fairprene 80-0xx	DUF	As received
Phenolic-glass fiber*	GEC	As received
Pyre-M.L., Type 1*	DUF	As received
TB5-PTFE	MMI	As received
Films and Sheets		
Kapton xxxXH667*	DUM	As received
Kapton xxxXHF929A	DUM	As received
Mylar Type xxxA*	DUM	As received
P-7395-121-2	UCP	As received
Parylene C or N	UCP	As received
PPO 531-081 (opaque)	GEC	As received
PPO 681-111 (clear)	GEC	As received
Tedlar A130WH	DUM	As received
Tedlar xxxBG30TL	DUM	As received
Teflon FEP xxxA*	DUP	As received
Teflon FEP xxxC	DUP	As received
Foams		
Stycast 1090 11	ECM	100p1090 12p11; 2 hr/100°C
Stycast 1095/11	ECM	100p1095 12p11; 2 hr/100°C
Hardware and Structural		
Delrin xxxNC10*	DUP	As received
Kel-F 81	MMA	As received
Diall FS-xx	ACM	Postcured 24 hr 150°C
Diall 52-40-40	ACM	As received
Doryl H-17511*	WEM	As received
Furane Type 403	FPI	As received

Appendix D (Continued)

APPLICATION PRODUCT	MFR.^{2}	TREATMENT	APPLICATION PRODUCT	MFR.^{2}	TREATMENT
Hardware and Structural			Sealants		
Micaply G-284	TMC	As received	Scotchcast 260	MME	As received; 30 min 150°C
Micarta H-2497	WEM	As received	Scotchcast 281 A/B	MME	100pA/150pB; 20 hr 75°C
Micarta H-17690	WEM	As received	Stycast 1263/31	EMC	100p1263/3p1; 16 hr 107°C
Epiall 19xx	ACM	As received	Stycast 1269 A/B	EMC	100pA/100pB; 16 hr 100°C + 24 hr 150°C
Micarta H-5834*	WEM	As received			
Lexan 1xx-11x	GEC	As received	Stycast 2850 FT/9	EMC	100p2850/3.5p9; 16 hr 25°C
High K707	GES	As received	Stycast 2862 A/B	EMC	100pA/100pB; 16 hr 120°C
			Stycast 3050/11	EMC	100p3050/9.5p11; 16 hr 77°C
Honeycomb Core			E691-22E	DCC	Mfr's instructions
--No recommendations			Seals and Gaskets		
Lubricants			1050-70	PRP	As received
Electrofilm 4306	EFI	As received; 16 hr 190°C	L-449-6	PSC	As received
G-683	GES	As received	SE-556	GES	Postcured 24 hr 150°C
Icon 50HB5100	UCC	As received	SE-3xxx (24/480)*	GES	As received
			SE-45xx (24/480)*	GES	As received
Marking Materials			Silastic S-9711	DCC	As received
			Viton B (any)*	DUE	As received
Sanford 580	SAN	As received; 24 hr 25°C			
Carter's 441	CAR	As received; 24 hr 25°C	Shrinkable Materials		
Protective Coatings			Thermofit TFE	RAY	Postcured 1 hr 150°C
			Penntube II-SMT	PFC	Postcured 1 hr 150°C
Ecocoat PCA 16	EMC	100pA/2p#16; 1 hr 25°C + 2 hr 95°C + 24 hr 150°C	Thermofit Kynar	RAY	Postcured 1 hr 150°C
			Mylar	[illegible]TP	Postcured 10 min 110°C
JPL-1001	AAC	As received; 4 hr 75°C			
JPL-1002	AAC	As received; 4 hr 75°C	Sleeving		
Sealants			Ben-Har Lecton B	BHM	Postcured 24 hr 150°C
			Ben-Har Acryl A FAI	BHM	As received
Maraset 655/553	MRC	100p655/20p553; 16 hr 82°C	Ben-Har Acryl C-2	BHM	As received
Maraset 655/555	MRC	100p655/7p555; 16 hr 82°C			

Appendix D (Concluded)

APPLICATION / PRODUCT	MFR.[2]	TREATMENT	APPLICATION / PRODUCT	MFR.[2]	TREATMENT
Tapes			Tie Cord Lacing Tape		
Mystik 7452*	BCM	As received	Temp-Lace H256H*	GBE	As received
Fibremat-I (Type 2539)	MME	As received	Wire Enamels		
Temperature Control			Magnet wire (Formex)	GEW	As received
--No recommendations--			Magnet wire (Urethane)	GEW	As received
(see Section XX)					

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* The asterisk next to a product name indicates that the product also has passed the decontamination and thermal-vacuum exposures without a loss in mechanical and electrical properties.

[1] This "interim list" of recommended polymeric products is based primarily on the micro-VCM data for all the polymers which have been screened.

[2] See Appendix B for code listing of manufacturers.

Appendix E

INDEX OF POLYMERIC PRODUCTS AND RESULTS OF TESTS PERFORMED; PRODUCT RATINGS

An alphabetical index is given of the polymeric products which have been examined under this contract; all available information on each product is given in the section of this report which is cited. Also cited is the catalog number of the infrared spectrum of the VCM from the various products which are published in Appendix C.

The index also provides a summary of the work which has been performed with each product and ratings of acceptability for spacecraft use or additional evaluation, based on the results of the tests performed. An explanation of the ratings of "G" (Good), "M" (Marginal), and "X" (Not Recommended) is given as follows:

<u>Micro-VCM</u>	G = <1% wt-loss and <0.1% VCM; M = up to 1.5% wt-loss or up to 0.15% VCM; X = >1.5% wt-loss or >0.15% VCM.
<u>Macro-VCM</u>	Same as above, tempered by whether VCM is increasing or decreasing with time.
<u>Mass Spec</u>	G = solvents or gases only identified; M = low-molecular-weight additives; X = low-molecular-weight polymers.
<u>Mechanical Properties</u>	G = no change or improved values; M = borderline losses in properties or significant loss in perhaps only one property whereas others are unchanged or improved; X = significant losses in properties.
<u>Electrical Properties</u>	Same as above.

Appendix E

INDEX OF POLYMERIC PRODUCTS AND RESULTS OF TESTS PERFORMED

(G - Good, M - Marginal, X - Not Recommended)

POLYMERIC PRODUCT	MFR.[1]	USE[2]	VOLATILE MATERIALS			MECHANICAL PROPERTIES		ELECTRICAL PROPERTIES		REPORT SECTION NO.	INFRARED[3] CATALOG NO.
			Micro-VCM	Macro-VCM	Mass Spec	after TVE Only	after ETO/TVE	after TVE Only	after ETO/TVE		
73X (black)	IND	MM	X	-	-		-	-	-	XIII	-
73X (white)	IND	MM	X	-	-	-	-	-	-	XIII	-
91-LD-1581	ARP	HS	M	-	-	-	-	-	-	X	-
805-70	PRP	SG	X	-	-	M	X	-	-	XVI	-
93-002	DCC	SE	X	-	-	-	-	-	-	II	88
1050-70*	PRP	SG	G	-	-	-	-	-	-	XVI	95
A-2841-L-618 (gray)	BIW	PC	X	-	-	-	-	-	-	XIV	68
A-2841-L-618 (yellow)	BIW	PC	X	-	-	-	-	-	-	XIV	69
Adhesive 4684/RC-805	DUP	AD	X	-	-	M	M	-	-	V	-
Adhesive 46950	DUP	AD	X	-	-	-	-	-	-	V	54
Adhesive 46951	DUP	AD	X	-	-	X	X	-	-	V	-
Armalon 98-101	DUF	CF	G	-	-	X	X	G	G	VII	-
Armstrong A-2/A*	APC	AD	G	-	-	-	-	-	-	V	-
Armstrong A-2/E*	APC	AD	G	-	-	G	G	-	-	V	-
Armstrong A-12/A*	APC	AD	G	-	-	-	-	-	-	V	11
Armstrong A-32/A-C	APC	AD	X	-	-	-	-	-	-	V	-
B224-2	WEI	PC	X	-	-	-	-	-	-	XIV	-
B276	WEI	PC	X	-	-	-	-	-	-	XIV	-
Beckman *101577	DCC	HS	X	-	X	-	-	-	-	X	-
Ben-Har 263 FC-3	BHM	SL	X		-	-	-	-	-	XVII	-
Ben-Har 263 G-3	BHM	SL	X	-	-	-	-	-	-	XVII	-
Ben-Har 1062 HAI	BHM	SL	X	-	-	-	-	-	-	XVII	-
Ben-Har 1151, Armasil-2	BHM	SL	X	-	-	-	-	-	-	XVII	-
Ben-Har 1151, HAI	BHM	SL	X	-	-	-	-	-	-	XVII	-
Ben-Har 1151, Superwall	BHM	SL	X	-	-	-	-	-	-	XVII	-
Ben-Har 1151, UL	BHM	SL	X	-	-	-	-	-	-	XVII	-
Ben-Har 1258-1 B	BHM	SL	X	-	-	-	-	-	-	XVII	-
Ben-Har Acryl A FAI*	BHM	SL	G	-	-	-	-	-	-	XVII	-
Ben-Har Acryl C-2*	BHM	SL	G	-	-	-	-	-	-	XVII	-
Ben-Har Ex-Flex 1500	BHM	SL	M	-	-	-	-	-	-	XVII	-

Appendix E (Continued)

POLYMERIC PRODUCT	MFR.[1]	USE[2]	VOLATILE MATERIALS			MECHANICAL PROPERTIES		ELECTRICAL PROPERTIES		REPORT SECTION NO.	INFRARED[3] CATALOG NO.
			Micro-VCM	Macro-VCM	Mass Spec	after TVE Only	after ETO TVE	after TVE Only	after ETO/TVE		
Ben-Har Lecton B*	BHM	SL	G	-	-	-	-	-	-	XVII	-
Ben-Har Pyrosleeve ST	BHM	SL	M	-	-	-	-	-	-	XVII	-
BMS-551 (see Scotchcast AF-426)											
BR-617 A B	ACB	SE	X	-	-	-	-	-	-	XV	21
C526-7	PSC	SG	X	X	-	-	-	-	-	II, XVI	42
Carter's 411	CAR	MM	X	-	-	-	-	-	-	XIII	-
Cat-a-Lac Clear (473-1)	FPC	PC	X	-	-	-	-	-	-	XIV	-
Cat-a-Lac Flat Black (473-1)	FPC	TM	X	-	-	-	-	-	-	XX	-
Cat-a-Lac White Gloss (473-1)	FPC	PC	X	-	-	-	-	-	-	XX	-
Chemlok 607	HCC	AD	X	-	-	-	-	-	-	V	-
Convalex-10 (*0-061)	CVC	LU	X	-	-	-	-	-	-	XII	58
Corfil 615 Z	ACB	SE	M	-	-	-	-	-	-	XV	17
Corlar 585 (black)	DUP	TM	X	-	-	-	-	-	-	XX	-
DC-11	DCC	LU	X	-	-	-	-	-	-	XII	70
DC-705	DCC	LU	X	-	-	-	-	-	-	XII	92
Delrin 100NC10*	DUP	HS	G	-	-	G	G	G	G	X	-
Delrin 150NC10*	DUP	HS	G	G	G	-	-	-	-	X	-
Delrin 505NC10	DUP	HS	G	G	-	-	-	-	-	X	1
Delrin 507NC10	DUP	HS	M	-	-	-	-	-	-	X	-
Delrin 900NC10*	DUP	HS	G	-	-	-	-	-	-	X	-
Diall FS-4*	ACM	HS	G	-	-	-	-	-	-	X	-
Diall FS-10*	ACM	HS	G	-	-	-	-	-	-	X	-
Diall FS-49*	ACM	HS	G	-	-	-	-	-	-	X	-
Diall 52-40-40*	ACM	HS	G	-	-	-	-	-	-	X	-
Doryl B109-4	WEI	PC	M	-	-	-	-	-	-	XIV	-
Doryl B109-5	WEI	PC	M	-	-	-	-	-	-	XIV	-
Doryl H-17479	WEI	HS	M	-	-	-	-	-	-	X	-

Appendix E (Continued)

POLYMERIC PRODUCT	MFR.[1]	USE[2]	VOLATILE MATERIALS			MECHANICAL PROPERTIES		ELECTRICAL PROPERTIES		REPORT SECTION NO.	INFRARED[3] CATALOG NO.
			Micro-VCM	Macro-VCM	Mass Spec	after TVE Only	after ETO/TVE	after TVE Only	after ETO/TVE		
Doryl H-17511*	WEI	HS	G	-	-	G	G	G	G	X	-
E515-8	PSC	SG	X	X	-	-	-	-	-	II, XVI	40
E691-22E*	DCC	SE	G	G	-	-	-	-	-	II, XVI	81
EC-1614 A/B	MMA	AD	X	-	-	-	-	-	-	V	-
EC-2216 A/B*	MMA	AD	G	-	-	-	-	-	-	V	18
Ecco CF6 R6	EMC	SE	X	-	-	-	-	-	-	XVI	63
Eccobond 45/15 (black)	EMC	AD	X	-	-	X	X	-	-	V	13
Eccobond 55/9*	EMC	AD	G	-	-	G	G	-	-	V	-
Eccobond 55/11	EMC	AD	X	-	-	-	-	-	-	V	-
Eccobond Solder 56C/9*	EMC	AD	G	-	-	-	-	-	-	V	-
Eccobond Solder 57C/9*	EMC	AD	G	-	-	G	G	-	-	V	14
Eccobond 104 A/B	EMC	AD	G	-	-	G	G	-	-	V	-
Eccocoat C-26 A/B	EMC	PC	X	-	-	-	-	-	-	XIV	-
Eccocoat EC 200 A/B	EMC	PC	X	-	-	-	-	-	-	XIV	-
Eccocoat 210 A/B	EMC	PC	X	-	-	-	-	-	-	XIV	-
Eccocoat EP-3	EMC	PC	X	-	-	M	M	G	G	XIV	-
Eccocoat IC-2	EMC	PC	X	-	-	-	-	-	-	XIV	-
Eccocoat PCA-16*	EMC	PC	G	-	-	-	-	-	-	XIV	-
Eccocoat PH-7	EMC	PC	X	-	-	-	-	-	-	XIV	-
Eccocoat VE A/B	EMC	PC	X	-	-	-	-	-	-	XIV	-
Eccofoam FPH 12/6H	EMC	FO	X	-	-	-	-	-	-	IX	65
Eccofoam FS	EMC	FO	X	-	-	-	-	-	-	IX	-
Eccofoam S	EMC	FO	M	G	-	X	X	-	-	IX	-
Eccofoam SH	EMC	FO	M	G	G	M	M	-	-	IX	-
Eccofoam SIL 25	EMC	FO	X	-	-	-	-	-	-	IX	-
Eccogel 1265 A/B	EMC	PC	X	-	-	G	M	G	G	XV	20
Eccosil 5000 A/B	EMC	FO	X	-	-	-	-	-	-	IX	-
Eccosil Primer-33	EMC	AD	X	-	-	-	-	-	-	V	-
EG-2028, Type FL-GF*	FLC	CB	G	-	-	-	-	-	-	VI	28
EG-2828FR, Type FL-GF*	FLC	CB	G	-	-	-	-	-	-	VI	29

Appendix E (Continued)

POLYMERIC PRODUCT	MFR.[1]	USE[2]	VOLATILE MATERIALS			MECHANICAL PROPERTIES		ELECTRICAL PROPERTIES		REPORT SECTION NO.	INFRARED[3] CATALOG NO.
			Micro-VCM	Macro-VCM	Mass Spec	after TVE Only	after ETO/TVE	after TVE Only	after ETO/TVE		
Electrofilm 2396	EFI	LI	M	G	N	-	-	-	-	XII	-
Electrofilm 4306*	EFI	LI	G	G	G	-	-	-	-	XII	-
Epiall 1906L*	ACM	HS	G	-	-	-	-	-	-	X	-
Epiall 1914*	ACM	HS	G	-	-	-	-	-	-	X	-
Epibond 115	FPI	AD	N	-	-	-	-	-		V	30
Epiphen ER-825A*	BCM	AD	G	-	-	-	-	-	-	V	7
Epocast 168 995	FPI	SE	M	-	-	-	-	-	-	XV	12
Epon 828 A*	SCA	AD	G	-	-	-	-	-	-	V	3
Epon 828 Z*	SCA	AD	G	-	-	-	-	-	-	V	8
Epon 828 Versamid 125	SCA	AD	M	-		G	G	-	-	V	-
Epon 901 B-1	SCA	AD	M	-	-	-	-	-	-	V	-
Epon 901 B-3*	SCA	AD	G	-	-	G	G	-	-	V	-
Epon 903	SCA	AD	N	-	-	-	-	-	-	V	-
Epon 913	SCA	AD	M	-	-	-	-	-	-	V	-
Epon 917*	SCA	AD	G	-	-	-	-	-	-	V	-
Epon 919 A B	SCA	AD	N	-	-	M	M	-	-	V	-
Epon 931 A B*	SCA	AD	G	-	-	-	-	-	-	V	-
Epon 934 A B*	SCA	AD	G	-	-	-	-	-	-	XV	-
Epoxylite 295-1 A B	FPC	SE	M	-	-	-	-	-	-	XV	22-4
Epoxi-Patch A B	HYS	AD	M	M	G	-	-	-	-	V	5
EX-1090	ENJ	SG	N	-	-	N	N	-	-	XVI	-
EX-1091	ENJ	SG	N	-	-	N	N	-	-	XVI	-
EX-1092	ENJ	SG	N	-	-	N	N	-	-	XVI	-
Fairprene 84-001	DUF	CF	N	-	-	N	N	M	M	VII	-
Fairprene 80-070*	DUF	CF	G	-		-	-	-	-	VII	-
Fairprene 80-080*	DUF	CF	G	-	-	-	-	-	-	VI	-
Fairprene 5159 Activator	DUF	AD	N	-	-	-	-	-	-	V	38
Fibremat 1 (Type 2539)*	MME	TP	G	-	-	-	-	-	-	X/V	9
FM-61	ACB	AD	N	-	-	N	N	-	-	V	-
FM 961*	ACB	AD	G	-	-	G	G	-		V	4

Appendix E (Continued)

POLYMERIC PRODUCT	MFR.[1]	USE[2]	VOLATILE MATERIALS			MECHANICAL PROPERTIES		ELECTRICAL PROPERTIES		REPORT SECTION NO.	INFRARED[3] CATALOC NO.
			Micro-VCM	Macro-VCM	Mass Spec	after TVE Only	after ETO/TVE	after TVE Only	after ETO/TVE		
FM-1000	ACB	AD	X	-	X	-	-	-	-	V	-
FM-1044	ACB	AD	X	-	-	-	-	-	-	V	-
FR 60-26	FRC	SG	X	-	-	-	-	-	-	XVI	41
Furane Type 403*	FPI	HS	G	-	-	-	-	-	-	X	-
G-683*	GES	LU	G	G	-	-	-	-	-	XII	71
Glyptal 1201	GEI	PC	X	-	-	-	-	-	-	XIV	-
Glyptal 1202	GEI	PC	X	-	-	-	-	-	-	XIV	-
Glyptal 9564	GEI	PC	X	-	-	-	-	-	-	XIV	-
Gudebrod 721H	GBE	TC	M	-	-	-	-	-	-	XXI	-
Gudebrod 722S	GBE	TC	X	-	-	M	M	-	-	XXI	-
Gude-Space 18D96	GBE	TC	M	-	-	X	X	-	-	XXI	-
Hadbar 28-80	PPH	SG	X	-	-	M	M	-	-	XVI	72
Hadbar 4000-80	PPH	SG	M	-	-	M	M	-	-	XVI	82
High K707 (K [illegible] 15)*	GES	HS	G	-	-	-	-	-	-	X	
High K707 (K [illegible] 12)*	GES	HS	G	-	-	-	-	-	-	X	-
HMH	HEX	HC	X	X	-	-	-	-	-	XI	-
HRP	HEX	HC	[illegible]	-	-	-	-	-	-	XI	-
HRP-Composite (facing)	VAR	HC	[illegible]	-	-	-	-	-	-	XI	-
HRS-asbestos	HEX	HC	[illegible]	-	-	-	-	-	-	XI	-
HRS-silicone	HEX	HC	[illegible]	-	-	-	-	-	-	XI	-
HT-424	ACB	AD	X	-	-	G	G	-	-	V	-
Hycar 520-67-108-1	BFG	SG	X	X	X	X	X	-	-	XVI	-
Hycar 520-67-108-2	BFG	SG	X	-	-	-	-	-	-	XVI	-
Hycar 520-67-108-3	BFG	SG	X	-	-	-	-	-	-	XVI	-
Hycar 520-67-108-4	BFG	SG	X	-	-	-	-	-	-	XVI	-
Hycar 520-67-108-5	BFG	SG	M	-	-	-	-	-	-	XVI	-
Hycar 520-67-108-6	BFG	SG	M	-	-	-	-	-	-	XVI	-
Hysol 5150/3690	HYS	SE	X	-	-	-	-	-	-	XV	-
Hysol C7/3690	HYS	SE	X	-	-	-	-	-	-	XV	-
IBM Ribbon	IPM	MM	X	-	-	-	-	-	-	XII	-

Appendix E (Continued)

POLYMERIC PRODUCT	MFR.[1]	USE[2]	VOLATILE MATERIALS			MECHANICAL PROPERTIES		ELECTRICAL PROPERTIES		REPORT SECTION NO.	INFRARED[3] CATALOG NO.
			Micro-VCM	Macro-VCM	Mass Spec	after TVE Only	after ETO/TVE	after TVE Only	after ETO/TVE		
JPL-1001*	AAC	PC	G	-	-	-	-	-	-	XII	-
JPL-1002*	AAC	PC	G	-	G	-	-	-	-	XII	-
Kapton 200XH667	DCM	FS	G	-	-	G	G	G	G	VII	-
Kapton 300XHF929A	DCM	FS	G	-	-	-	-	-	-	VII	-
Kel-F 81*	MMA	HS	G	-	-	-	-	-	-	X	36
Kynar-200	PCC	FS	M	-	-	-	-	-	-	VII	-
L-449-6	PSC	SG	G	-	-	-	-	-	-	XVI	96
Laminar X-500 (4B-1 black) 10-C-45	MCC	TM	M	-	-	-	-	-	-	XX	62
Laminar X-500 (4B-3 flat black) 10-C-45	MCC	TM	M	-	-	-	-	-	-	XX	66
Laminar X-500 (4C-8 clear) 10-C-45	MCC	PC	M	-	-	-	-	-	-	XIV	60
Laminar X-500 (8W-24 white, Teflon filled) 10C-45 and Reducer	MCC	TM	M	-	-	-	-	-	-	XX	67
Lexan 100-111*	GEC	HS	G	-	G	-	-	-	-	X	-
Lexan 101-111*	GEC	HS	G	-	G	-	-	-	-	X	-
Lexan 101-112*	GEC	HS	G	-	G	-	-	-	-	X	-
Lexan 103-112*	GEC	HS	G	-	G	-	-	-	-	X	-
Lexan 131-111*	GEC	HS	G	-	-	-	-	-	-	X	-
Lexan 131-112*	GEC	HS	G	-	-	-	-	-	-	X	-
Lexan 133-112*	GEC	HS	G	-	-	-	-	-	-	X	-
Lexan 140-111*	GEC	HS	G	-	-	-	-	-	-	X	-
Lexan 141-111*	GEC	HS	G	-	-	-	-	-	-	X	-
Lexan 141-112*	GEC	HS	G	G	-	-	-	-	-	X	-
Lexan 243-112*	GEC	HS	G	-	-	-	-	-	-	X	-
Luvican M170	BCC	HS	G	M	M	-	-	-	-	X	-
Magnet Wire (Formex)*	GEW	WE	G	-	-	-	-	-	-	XXII	-
Magnet Wire (Urethane)*	GEW	WE	G	-	-	-	-	-	-	XXII	-
Marasett 655 553*	MRC	SE	G	-	-	-	-	-	-	XV	-

Appendix E (Continued)

POLYMERIC PRODUCT	MFR.[1]	USE[2]	VOLATILE MATERIALS			MECHANICAL PROPERTIES		ELECTRICAL PROPERTIES		REPORT SECTION NO.	INFRARED[3] CATALOG NO.
			Micro-VCM	Macro-VCM	Mass Spec	after TVE Only	after ETO/TVE	after TVE Only	after ETO/TVE		
Marasett 655 555*	MRC	SE	G	-	-	-	-	-	-	XV	-
Metlbond-328*	WCN	AD	G	-	-	G	G	-	-	V	-
Metlbond-329	WCN	AD	G	-	-	G	X	-	-	V	-
Micarta 65M25*	WEM	CB	G	G	G	-	-	-	-	VI	-
Micarta 20291-2	WEM	HS	G	-	-	M	M	G	G	X	-
Micarta H-2497*	WEM	HS	G	-	-	-	-	-	-	X	-
Micarta H-5834*	WEM	HS	G	-	-	G	G	G	G	X	-
Micarta H-8457*	WEM	HS	C	-	-	-	-	-	-	X	-
Micarta H-17690*	WEM	HS	G	-	-	-	-	-	-	X	-
Micaply EG-284T*	TMC	CB	G	-	-	-	-	-	-	VI	25
Micaply EG-725	TMC	HS	X	-	-	-	-	-	-	X	-
Micaply EG-758T*	TMC	CB	C	-	-	-	-	-	-	VI	26
Micaply EG-899T*	TMC	CB	G	-	-	-	-	-	-	VI	27
Micaply G-284*	TMC	HS	G	-	-	-	-	-	-	X	-
Mylar, 0.004" wall*	STP	SM	G	-	-	-	-	-	-	XVII	55
Mylar, 0.012" wall*	STP	SM	G	-	-	-	-	-	-	XVII	56
Mylar Type 100S	DUM	FS	M	-	-	-	-	-	-	VIII	-
Mylar Type 150T	DUM	FS	M	-	-	M	M	G	G	VIII	-
Mylar Type 100A*	DUM	FS	-	-	-	G	G	G	G	VIII	-
Mylar Type 500A*	DUM	FS	G	-	G	-	-	-	-	VIII	-
Mystik 7020	BCM	TP	X	-	-	G	G	-	-	XIX	-
Mystik 7300	BCM	TP	X	-	-	M	G	-	-	XIX	-
Mystik 7352	BCM	TP	X	-	-	X	X	-	-	XIX	-
Mystik 7452*	BCM	TP	G	G	G	G	G	-	-	XIX	-
Mystik 7455	BCM	TP	X	-	-	G	G	-	-	XIX	-
Mystik 7503	BCM	TP	X	-	-	X	X	-	-	XIX	-
Nomex, 5-mil	DUF	FS	M	-	-	-	-	-	-	VIII	53
6-Nylon	DUM	FS	X	-	-	-	-	-	-	VIII	-
P-2300	UCP	FS	G	-	-	G	M	G	G	VIII	-
P-7395-121-2*	UCP	FS	G	-	-	-	-	-	-	VIII	-
Park Avenue Ribbon	PKA	MM	X	-	-	-	-	-	-	XIII	-

Appendix E (Continued)

POLYMERIC PRODUCT	MFR.[1]	USE[2]	VOLATILE MATERIALS			MECHANICAL PROPERTIES		ELECTRICAL PROPERTIES		REPORT SECTION NO.	INFRARED[3] CATALOG NO.
			Micro-VCM	Macro-VCM	Mass Spec	after TVE Only	after ETO/TVE	after TVE Only	after ETO/TVE		
Parylene C*	UCP	FS	G	-	-	-	-	-	-	VIII	43
Parylene N*	UCP	FS	G	-	-	-	-	-	-	VIII	44
Penntube II-SMT*	PFC	SM	G	-	-	-	-	-	-	XVII	-
Phenall 8010	ACM	HS	M	-	-	-	-	-	-	X	-
Phenall 8060	ACM	HS	M	-	-	-	-	-	-	X	-
Phenall 8700	ACM	HS	M	-	-	-	-	-	-	X	-
Phenolic-glass fiber*	GEC	CF	G	-	-	G	G	G	G	VII	-
PPO 531-081 (opaque)*	GEC	FS	G	-	-	-	-	-	-	VIII	-
PPO 681-111 (clear)*	GEC	FS	G	G	G	-	-	-	-	VIII	-
PR-240-AC	DUP	LF	X	-	-	-	-	-	-	XII	-
PR-1527 A B	PRC	SE	X	-	-	-	-	-	-	XV	-
PR-1538 A B	PRC	SE	X	-	-	-	-	-	-	XV	-
PT-401 H-11	PTI	PC	X	-	-	-	-	-	-	XIV	15
Pyre-M.L. RK-692	DUF	PC	X	-	-	-	-	-	-	XIV	-
Pyre-M.L., Type I*	DUF	CF	G	-	-	G	G	G	G	VII	57
PV-100	VVP		X	-	-	-	-	-	-	XIV	-
Rembrandt Markers	REM	MM	X	-	-	-	-	-	-	XIII	-
RTV-11	GES	SE	X	-	-	-	-	-	-	XV	-
RTV-30 T-12	GES	SE	X	-	-	-	-	-	-	XV	73
RTV-40 T-12	GES	SE	X	-	-	M	M	G	G	XV	74
RTV-41 T-12	GES	SE	X	-	-	-	-	-	-	XV	-
RTV-60	GES	SE	X	-	X	-	-	-	-	XV	
RTV-77 T-12	GES	SE	X	-	-	-	-	-	-	XV	-
RTV-88 T-12	GES	SE	X	-	-	-	-	-	-	XV	75
RTV-90	GES	SE	X	-	-	-	-	-	-	XV	-
RTV-102 (white)	GES	SE	X	-	-	-	-	-	-	XV	83
RTV-108 (clear)	GES	SE	X	-	-	-	-	-	-	XV	85
RTV-103 (black)	GES	SE	X	-	-	-	-	-	-	XV	84
RTV-511 T-12	GES	SE	X	-	-	M	M	G	G	XV	-
RTV-560	GES	SE	X	-	-	-	-	-	-	XV	-

Appendix E (Continued)

POLYMERIC PRODUCT	MFR.[1]	USE[2]	VOLATILE MATERIALS			MECHANICAL PROPERTIES		ELECTRICAL PROPERTIES		REPORT SECTION NO.	INFRARED[3] CATALOG NO.
			Micro-VCM	Macro-VCM	Mass Spec	after TVE Only	after ETO/TVE	after TVE Only	after ETO/TVE		
RTV-580 T-12	GES	SE	X	-	-	-	-	-	-	XV	-
RTV-602 13	GES	SE	-	-	X	M	X	G	G	XV	-
RTV-602 SRC-05	GES	SE	X	-	-	-	-	-	-	XV	-
RTV-615 A B	GES	SE	X	-	-	M	M	G	G	XV	-
RTV-630 A B	GES	SE	X	-	-	-	-	-	-	XV	-
RTV-632 A B	GES	SE	X	-	-	-	-	-	-	XV	-
RTV-655	GES	SE	X	-	-	-	-	-	-	XV	-
Sanford's Stamp Ink	SAN	MM	M	-	-	-	-	-	-	XIII	-
Scotchcast *3 A B	MME	FO	X	-	-	-	-	-	-	IX	35
Scotchcast *3 XR-5068	MME	FO	X	-	-	-	-	-	-	IX	34
Scotchcast-235 A B	MME	SE	X	-	-	-	-	-	-	XV	6
Scotchcast 241 A B	MME	SE	M	-	-	-	-	-	-	XV	-
Scotchcast-260*	MME	SE	G	-	-	-	-	-	-	XV	31
Scotchcast-281 A B*	MME	SE	G	-	-	-	-	-	-	XV	16
Scotchcast-XR-5068	MME	FO	X	X	M	-	-	-	-	IX	33
Scotch Electric Tape *62	MME	TP	X	-	-	-	-	-	-	XVIII	-
Scotch Tape *27	MME	TP	X	-	-	-	-	-	-	XVIII	-
Scotch Tape *852	MME	TP	X	-	-	-	-	-	-	XVIII	-
Scotchweld AF-126	MME	AD	X	-	-	-	-	-	-	V	32
SE-555 (gray)	GES	SG	X	-	X	M	M	-	-	XVI	-
SE-555 (red)	GES	SG	X	-	X	G	G	-	-	XVI	-
SE-555 (white)	GES	SG	X	X	-	M	M	-	-	XVI	-
SE 3604 (24 480)*	GES	SG	G	-	-	G	G	-	-	XVI	-
SE-3613 (24 480)	GES	SG	G	-	-	M	M	-	-	XVI	-
SE 3713 (24 480)*	GES	SG	G	-	-	G	G	-	-	XVI	-
SE-3813 (24 480)*	GES	SG	G	-	-	G	G	-	-	XVI	-
SE-4511 (24 480)*	GES	SG	G	-	-	G	G	-	-	XVI	-
SE-5604-7*	PSC	SG	G	-	-	-	-	-	-	II, XVI	89
Silastic-501/T-12	DCC	SE	X	-	-	-	-	-	-	XV	93
Silastic-732 (black)	DCC	SE	X	-	-	-	-	-	-	XV	90

Appendix E (Continued)

POLYMERIC PRODUCT	MFR.[1]	USE[2]	VOLATILE MATERIALS			MECHANICAL PROPERTIES		ELECTRICAL PROPERTIES		REPORT SECTION NO.	INFRARED[3] CATALOG NO.
			Micro-VCM	Macro-VCM	Mass Spec	After TVE Only	After ETO TVE	After TVE Only	After FTO TVE		
Silastic-732 (clear)	DCC	SE	X	-	-	-	-	-	-	XV	78
Silastic-732 (white)	DCC	SE	X	-	-	-	-	-	-	XV	79
Silastic-881 Cat	DCC	SE	X	-	-	-	-	-	-	XV	76
Silastic-3116 T-12	DCC	SE	X	-	-	-	-	-	-	XV	77
Silastic S-9711*	DCC	SG	G	-	-	-	-	-	-	XVI	80
SR-17	GES	PC	X	-	-	-	-	-	-	XIV	-
SR-98	GES	PC	X	-	-	-	-	-	-	XIV	-
SR-220	GES	PC	X	-	-	-	-	-	-	XIV	-
SR-290 (SR-98 + SR-220)	GES	PC	X	-	-	-	-	-	-	XIV	91
SR-613-75	SIS	SG	X	-	-	G	M	-	-	XVI	45
SR-624-70	SIS	SG	X	-	-	X	X	-	-	XVI	46
SR-722-70	SIS	SG	X	-	-	X	X	-	-	XVI	-
SRD-5905	MMI	CF	X	-	-	-	-	-	-	XVI	-
SRG-1810	MMI	CF	X	-	-	M	G	G	G	VII	-
SRGA-0214	MMI	CF	X	-	-	G	G	G	G	VII	-
SS-4004	GES	AD	X	-	-	-	-	-	-	V	-
SS-4044	GES	AD	X	-	-	-	-	-	-	V	-
SS-4101	GES	AD	X	-	-	-	-	-	-	V	-
SS-4120	GES	AD	X	-	-	-	-	-	-	V	-
Stur-D-Lace H18DB	GRE	TC	G	-	-	M	M	-	-	XXI	-
Stycast 40 7	EMC	SE	X	-	-	-	-	-	-	XV	-
Stycast 1090 9*	EMC	FO	G	-	-	-	-	-	-	XV	-
Stycast 1090 11*	EMC	FO	G	G	G	-	-	-	-	XV	-
Stycast 1090-SI 24LV	EMC	FO	M	-	-	-	-	-	-	XV	19
Stycast 1095 11*	EMC	FO	G	G	G		-	-	-	XV	-
Stycast 1210 A B	EMC	PC	M	-	-	-	-	-	-	XIV	-
Stycast 1217 9	EMC	SE	M	-	-	-	-	-	-	XV	-
Stycast 1263 A B*	EMC	SE	G	-	-	-	-	-	-	XV	-
Stycast 1264 A B	EMC	SE	X	-	-	-	-	-	-	XV	-
Stycast 1269 A B*	EMC	SE	G	-	-	-	-	-	-	XV	-

Appendix E (Continued)

POLYMERIC PRODUCT	MFR.[1]	USE[2]	VOLATILE MATERIALS			MECHANICAL PROPERTIES		ELECTRICAL PROPERTIES		REPORT SECTION NO.	INFRARED[3] CATALOG NO.
			Micro-VCM	Macro-VCM	Mass Spec	After TVE Only	After ETO TVE	After TVE Only	After ETO TVE		
Stycast 2[illegible]	EMC	SE	X	-	-	-	-	-	-	XV	-
Stycast [illegible]	EMC	SE	G	-	-	-	-	-	-	XV	-
Stycast 28[illegible]	EMC	SE	G	-	-	-	-	-	-	XV	-
Stycast 2050 [illegible]	EMC	SE	G	-	-	-	-	-	-	XV	-
Stycast [illegible]-21 A/B	EMC	SE	X	-	-	-	-	-	-	XV	61
Stycast CPC-2[illegible] A/B	EMC	SE	X	-	-	-	-	-	-	XV	64
Stycast CPC-41 A/B	EMC	SE	M	-	-	-	-	-	-	XV	59
Sylgard-184	DCC	SE	X	-	-	-	-	-	-	II, XV	60
Teflon FEP 100A*	DUF	FS	G	-	-	-	-	-	-	VIII	
Teflon FEP 500A*	DUF	FS	G	G	G	G	G	G	G	VIII	-
Teflon FEP 500C*	DUF	FS	-	-	-	-	-	-	-	VIII	-
TB5-PTFE*	DUF	CF	G	-	-	-	-	-	-	VII	-
Tedlar A130WH*	DUM	FS	G	-	-	-	-	-	-	VIII	-
Tedlar 100BG30TR	DUM	FS	G	-	-	M	M	G	G	VIII	-
Tedlar 200BG30WH	DUM	FS	-	-	-	M	M	G	G	VIII	-
Tedlar 100BG30TL*	DUM	FS	G	-	-	-	-	-	-	VIII	-
Temp-Lace H256H*	GRE	TC	G	-	-	G	G	-	-	XXI	-
Thermofit CRN (black)	RAY	SM	X	-	-	-	-	-	-	XVII	-
Thermofit CRN (white)	RAY	SM	X	-	-	-	-	-	-	XVII	-
Thermofit kynar*	RAY	SM	G	-	-	-	-	-	-	XVII	-
Thermofit RNF-100	RAY	SM	X	X	-	-	-	-	-	XVII	-
Thermofit TFE*	RAY	SM	G	-	-	-	-	-	-	XVII	-
Thermofit TFE-R*	RAY	SM	G	-	-	-	-	-	-	XVII	-
TPM 2/10	EMC	SE	X	-	-	-	-	-	-	XV	-
TPM 3/10	EMC	SE	X	-	-	-	-	-	-	XV	-
TPM-6 A/B	EMC	SE	X	-	-	-	-	-	-	XV	-
Ucon 50HB55	UCC	LI	X	-	-	-	-	-	-	XII	49
Ucon 50HB170	UCC	LI	X	-	-	-	-	-	-	XII	50
Ucon 50HB660	UCC	LI	X	-	-	-	-	-	-	XII	51
Ucon 50HB5100*	UCC	LI	M	-	-	-	-	-	-	XII	-

Appendix E (Concluded)

POLYMERIC PRODUCT	MFR.[1]	USE[2]	VOLATILE MATERIALS			MECHANICAL PROPERTIES		ELECTRICAL PROPERTIES		REPORT SECTION NO.	INFRARED[3] CATALOG NO.
			Micro-VCM	Macro-VCM	Mass Spec	After TVE Only	After ETO/TVE	After TVE Only	After ETO/TVE		
V377-9*	PSC	SG	G	G	-	-	-	-	-	XIV	2
Velvet Black 101C10	MMA	TM	M	M	M	-	-	-	-	XIV	2
Velvet Black 401C10	MMA	TM	M	-	G	-	-	-	-	XIV	10
Versilube F-50	GES	LU	X	-	-	-	-	-	-	XII	-
Versilube G-300	GES	LU	X	-	-	-	-	-	-	XII	94
Vespel SP-1*	DUP	HS	G	-	-	-	-	-	-	X	-
Viton A4411A-776*	DUE	SG	G	-	-	-	-	-	-	XVI	-
Viton A4411A-777*	DUE	SG	G	-	-	-	-	-	-	XVI	-
Viton A4411A-778*	DUE	SG	G	-	-	-	-	-	-	XVI	-
Viton A4411A-990*	DUE	SG	G	G	G	G	G	-	-	XVI	-
XR-63492	DCC	SE	X	-	-	-	-	-	-	XV	87
Zytel-31	DUP	HS	X	-	-	-	-	-	-	X	-
Zytel-42	DUP	HS	X	-	-	-	-	-	-	X	-
Zytel-101	DUP	HS	M	M	G	-	-	-	-	X	52
Zytel 101NC10	DUP	HS	X		-	-	-	-	-	X	-

* On interim list of recommended polymeric products, see Appendix D.

[1] See Appendix B for code listing of manufacturers.

[2]

AD	adhesives	HS	hardware and structural	SE	sealants	TM	temperature control coatings
CB	circuit boards	HC	honeycomb core structures	SG	seals and gaskets	TC	tie cord lacing tape
CF	coated fabrics	LU	lubricants	SM	shrinkable materials	WE	wire enamels
FS	films and sheets	MM	marking materials	SL	sleeving		
FO	foams	PC	protective coatings	TP	tapes		

[3] See Appendix C for catalog of infrared spectra of VCM.

END

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