RAI RESEARCH
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RAI 370

DEVELOPMENT OF A PROTOTYPE PLASTIC SPACE ERECTABLE SATELLITE

Contract No. NAS5-3923

with the

National Aeronautics and Space Administration
Goddard Space Flight Center
Greenbelt, Maryland

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TABLE OF CONTENTS

LIST OF TABLES

LIST OF ILLUSTRATIONS

LIST OF ILLUSTRATIONS (Continued)

1.0 INTRODUCTION

During the current reporting period ten rolls of the higher density 1-mil polyethylene film* was received from Sea Space Systems Incorporated. Initial tests have been performed on the film and it appears to be satisfactory. The testing program was started upon receipt of the film.

To achieve a lower thickness material for the satellite design, samples of polyethylene film of varying thickness were electrolessly plated with copper to 5×10^{-6} inch and 10×10^{-6} inch on both sides. Flexural rigidities of the plated films were then determined. The experimental flexural rigidities were then used in revised buckling pressure calculations to find the minimum film thickness which will withstand an initial buckling pressure of five times solar pressure. The minimum thickness found from the buckling pressure equations and flexural rigidity data is 1.50 mil with 10×10^{-6} inch of copper plated on both sides. This thickness of 1.50 mil with copper gives a nonperforated sphere weight of 4295 lbs.

To achieve a lower satellite weight a flexural rigidity-thickness curve for PE12 plated on both sides to 15×10^{-6} inch was determined. The new flexural rigidity curve was then used in a calculation to determine the film thickness required to withstand the critical buckling pressure. The minimum thickness found was 0.27 mil. This thickness of 0.27 mil with 15×10^{-6} in. of copper plated on both sides results in a nonperforated sphere weight of 1413 lbs.

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* To be referred to as PE12 from here on

In conjunction with the deliverable items, an ultrasonic bonder has been rented from Ultra Sonic Seal, Inc., Ardmore, Pa., to be received September 15. Samples of standard density polyethylene film** (irradiated and unirradiated) and PE12 were sent to Standard Packaging Company for vacuum deposition to determine if our film can be satisfactorily plated by their process. To date, the film has been irradiated by Electronized Chemical and is currently being heat treated at Sea Space Systems, Inc. Upon completion of the heat treatment, the film will be sent to Standard Packaging Co. to be metallized.

In anticipation of the perforation study, perforation dies have been designed and are being constructed at GSFC. Initial perforation tests have been conducted using hand punched, metallized samples. The tests performed were to determine the effect of open area (F_v) on electrical resistance and flexural rigidity. Initial results indicate that the resistance increases sharply and flexural rigidity decreases sharply at an F_v of 30%. Density gradient columns were completed and density measurements were made on the extracted PE12 film. The change in density for the extracted material was found to be greater than for the unextracted, crosslinked film. The adverse results of the extraction tests are at present unimportant, since the weight specifications have already been met without extraction.

Finally, calculations have been carried out to determine the amount of film necessary to build the deliverable items. It was found that 2 rolls of film (2400 ft.) are not quite enough to complete the deliverable items. It is, therefore, recommended that the size of a number of the cap sections be reduced to 24 ft.

**To be referred to as PE11 from here on

2.0 SEA SPACE INTERMEDIATE DENSITY, 1 MIL, BIAXIALLY ORIENTED POLYETHYLENE FILM (PE12)

2.1 Initial Properties - Summary

Ten (10) rolls of PE 12 have been received from Sea Space Systems, Inc. The initial properties of the film, listed in Table 1, have been examined and they have been found to be acceptable.

Table 1

Physical Properties of Sea Space Intermediate Density, 1 Mil, Biaxially Oriented Polyethylene Film (PE12)

Direction	σ_y (psi x 10^3)	σ_u (psi x 10^3)	E (psi x 10^3)	T_m (°C.)	ρ (gms./cc.)
0°	0.94±0.03*	2.35±0.13	29.2±2.2		
45°	0.87±0.04	2.00±0.11	26.2±1.5	116.5**	0.931
90°	0.94±0.04	1.65±0.07	33.2±3.2		

σ_y = Yield Stress
σ_u = Ultimate Stress
E = Modulus of Elasticity
T_m = Crystalline Melting Point
ρ = density

* All tensile tests performed on a Table Model Instron with a strain rate of 2 in./min.,5 lbs. full scale load.

**The average result of four crystalline melting tests presented in Section 2.2 to follow.

2.2 Crystalline Melting Point (T_m) of PE12

The crystalline melting point (T_m) of the Sea Space film was determined in the following four ways:

1. Immersion heating
2. Heating while restrained
3. Stress relaxation upon increased temperature
4. Modulus of elasticity changes with temperatures.

2.2.1 Immersion Heating

A small sample of film was immersed in silicone oil at room temperature and heated slowly. At 103°C. the sample lost some opacity and at 109°C. became completely transparent. In addition, at 109°C. the sample exhibited some fluid properties, i.e., flowing and fusion. This property change with temperature indicated that 109°C. was the crystalline melting point of the polyethylene film as determined by this method.

2.2.2 Heating While Restrained

This experiment consisted of restraining 1 mil film, with seven 1.8 cm. diameter circles punched in a face-centered hexagonal array,[1] in a steel ring.[2] The restrained sample was then heated slowly from room temperature. As the temperature increased, the circles became elliptical in shape. At 116°C. the elliptical holes became more elongated and began to tear. This temperature, where large deformations begin to occur, is indicative of the T_m (crystalline melting point).

2.2.3 Thermal Stress Relaxation

One inch wide samples of Sea Space film were elongated at 75°C. to their yield points on an Instron tensile tester operating at a strain rate of 2 inch/min. The straining was then stopped and heating was begun. The force to keep the film at its constant elongation was then measured as temperature increased. The resulting data points are shown plotted in Figure 1. It can be seen that the force begins to drop to zero at 115°C. This temperature (115°C.) is indicative of the crystalline melting point temperature.

2.2.4 Modulus of Elasticity Changes with Temperature

The modulus of elasticity, E, of the film was determined from standard tensile tests at temperatures from 28°C. to 116°C. The results are plotted in Figure 2. The temperature where E approaches zero is considered the crystalline melting point, since this is the temperature where the material looses its solid properties and begins to behave as a fluid.

2.3 Density of PE12

The density of PE12 was determined using a density gradient column consisting of isopropanol and water operating at 23.3°C. The column, whose dimensions are given in Figure 3, is recommended in an article by G. Oster and M. Yamamoto.[3] Further procedures for constructing, maintaining and operating the density gradient column have been drawn from the ASTM-Standards, "Density of Plastics by the Density Gradient Technique,"[4] and the article "Setting Up a Density Gradient Laboratory."[5] The density gradient prepared is shown in Figure 4. It is capable of measuring densities between 0.7900 gms./cc. and 1.000 gms./cc. at 23.3°C. The sample of PE12 tested in the gradient column came to equilibrium at 11.8 cm. corresponding to a density of 0.932 gms./cc.

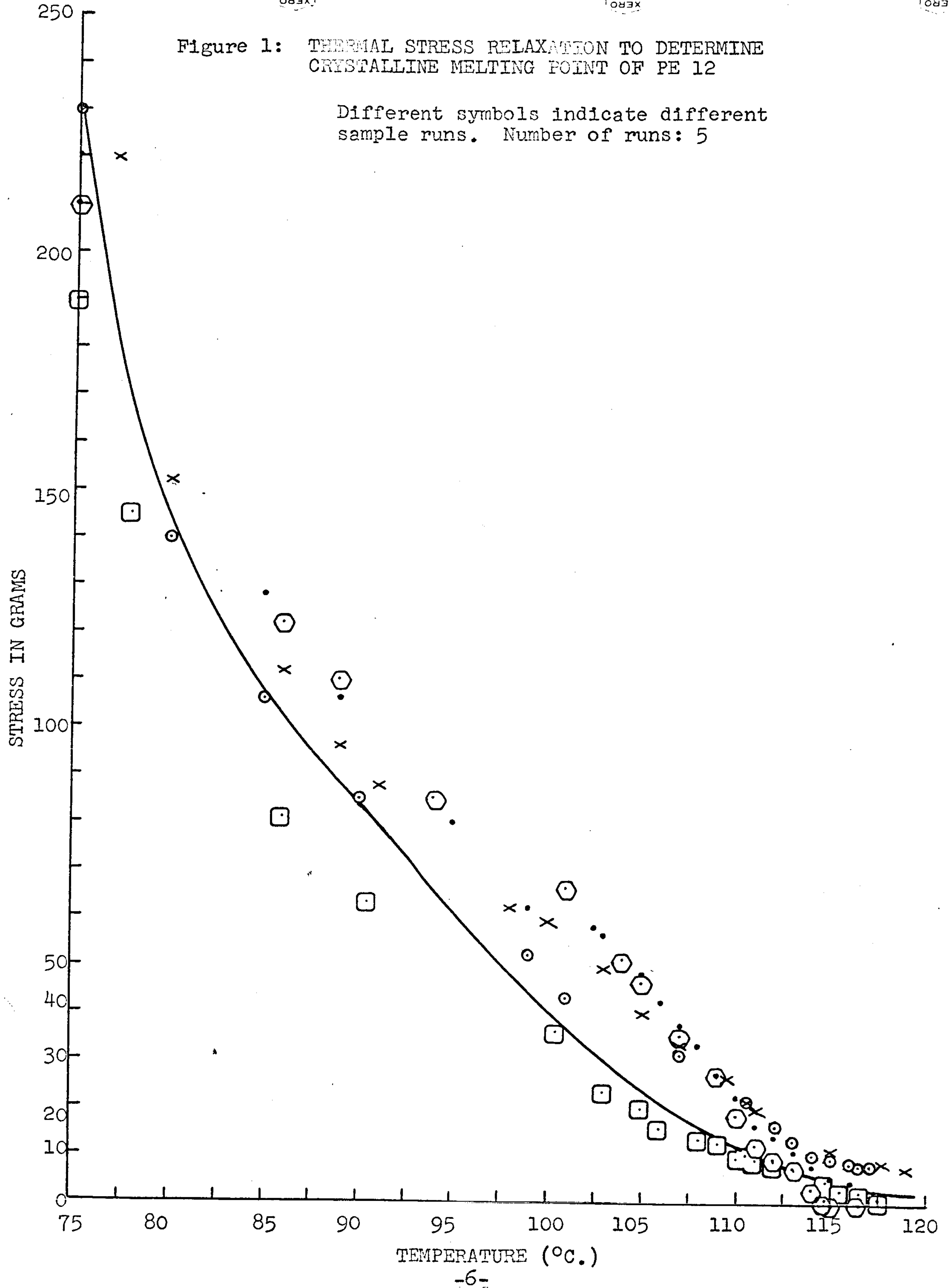


Figure 1: THERMAL STRESS RELAXATION TO DETERMINE CRYSTALLINE MELTING POINT OF PE 12

Different symbols indicate different sample runs. Number of runs: 5

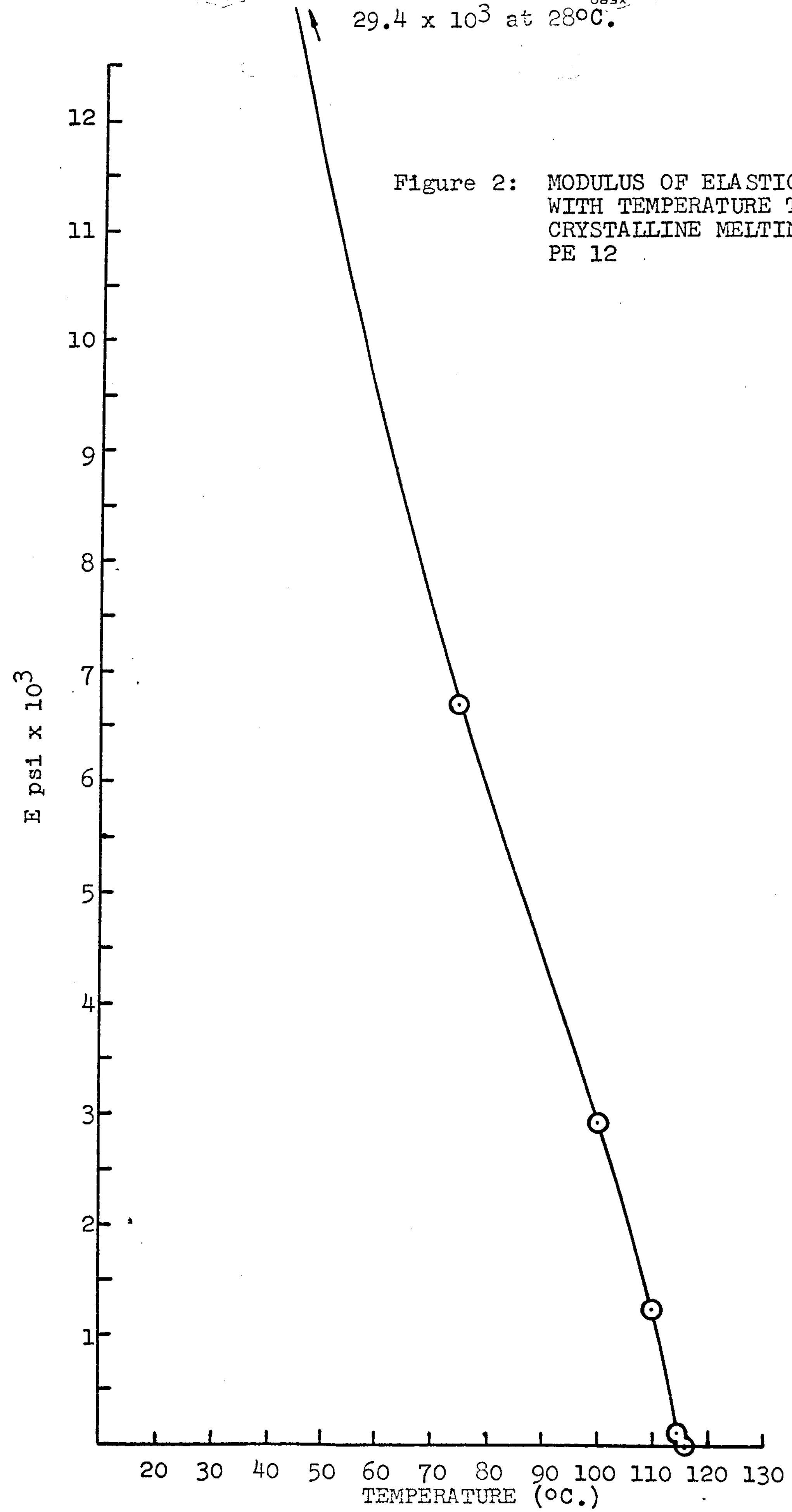
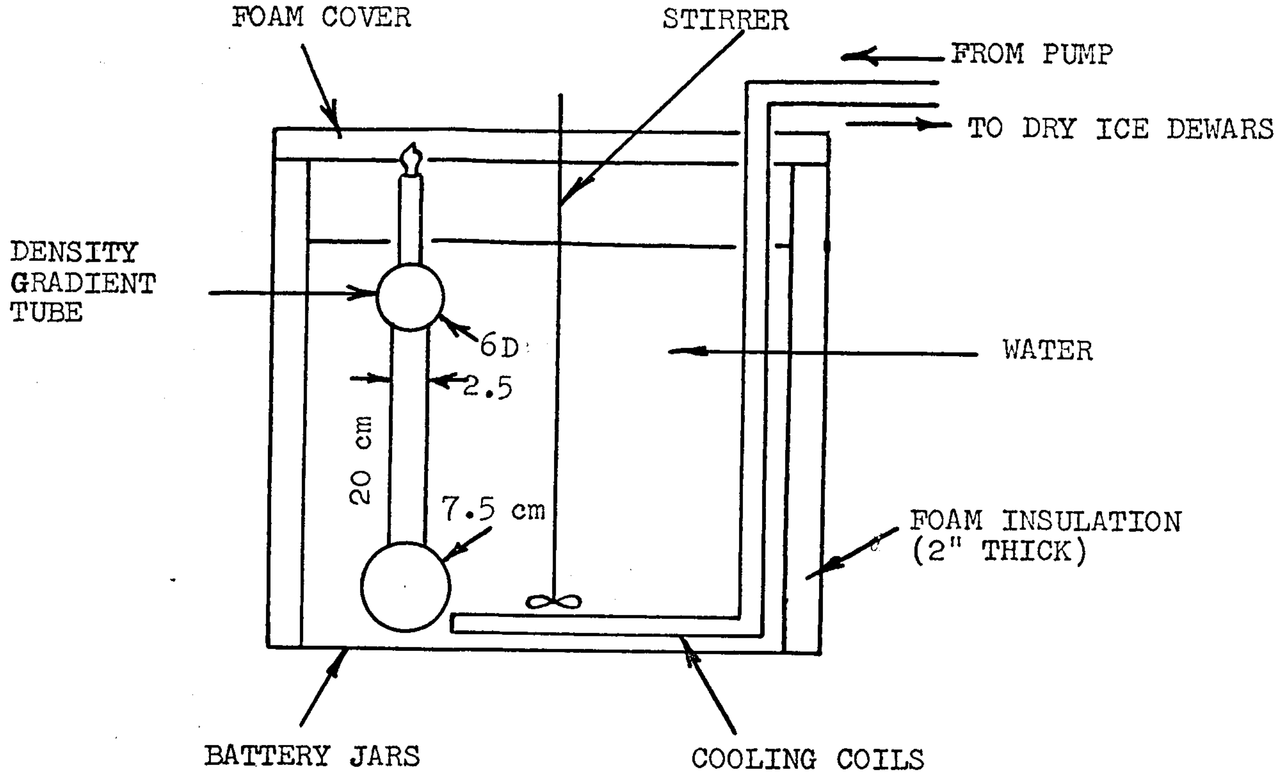


Figure 2: MODULUS OF ELASTICITY CHANGES WITH TEMPERATURE TO DETERMINE CRYSTALLINE MELTING POINT OF PE 12

Figure 3: DENSITY GRADIENT APPARATUS



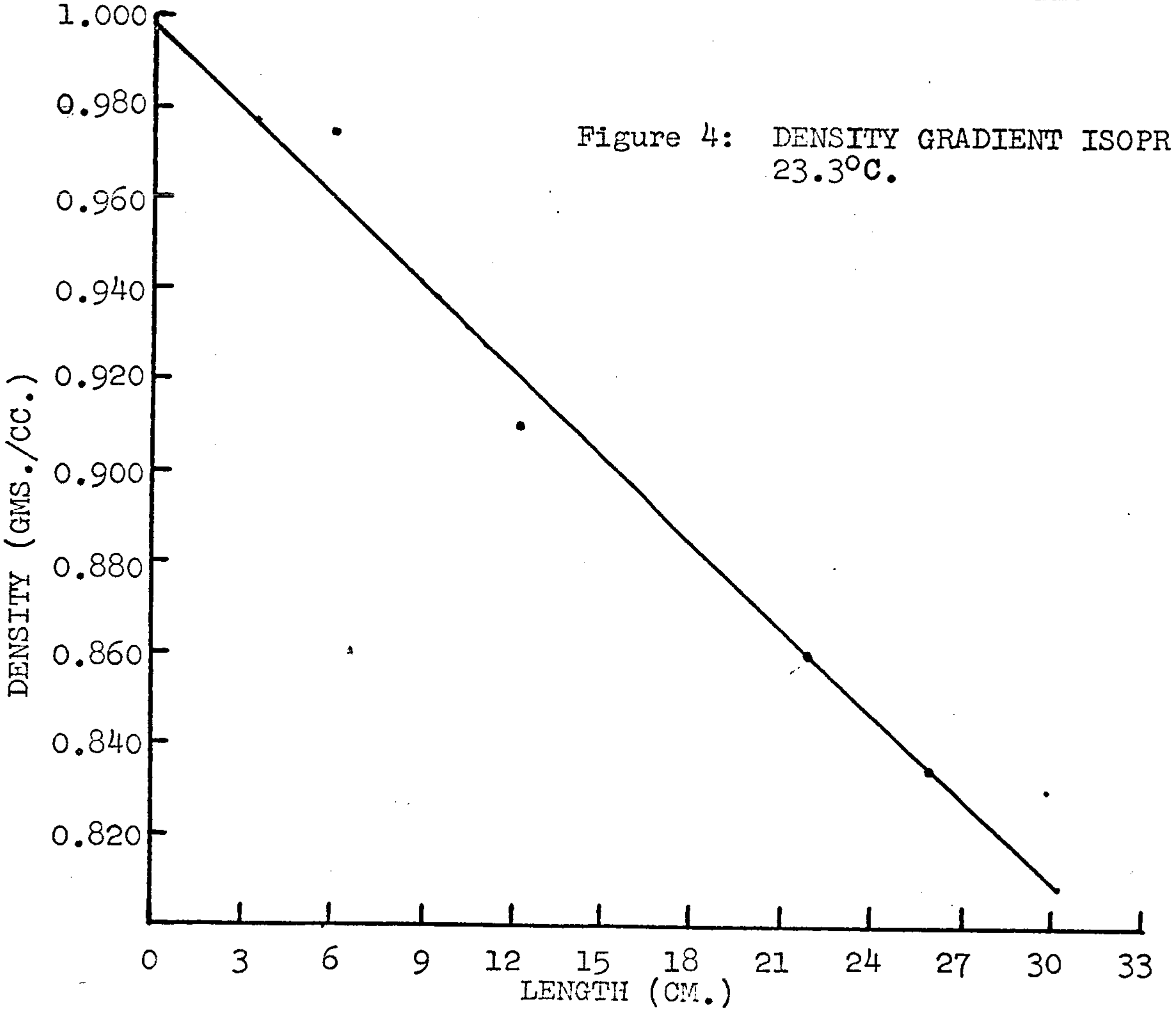


Figure 4: DENSITY GRADIENT ISOPROPANOL-WATER, 23.3°C.

3.0 FLEXURAL RIGIDITIES OF METALLIZED POLYETHYLENE FILM

In an effort to lower the required thickness of the polyethylene-metal laminate, experiments were run where both sides of thin polyethylene film were plated. Polyethylene films of various densities and thicknesses were electrolessly plated with copper in thicknesses from 5×10^{-6} to 15×10^{-6} inches.

The length of overhang of the plated films was determined using the Standard ASTM D138855T Beam Cantilever Test for flexural rigidities.

Flexural Rigidities, $G^F(t)$ were calculated as follows:

$$G^F(t) = W_A\left(\frac{l_F}{2}\right)^3 \qquad (1)$$

where l_F = length of overhang of plated film

W_A = Area weight of plated film

= area weight of film + area weight of deposited copper film

= (density of the film)(thickness of film) + (density of copper)(thickness of copper film)

$= \rho_F t + \rho_{cu} t_{cu}$

where

ρ_{cu} = 8.9 gm./cc.

ρ_F = 0.920 gm./cc., 0.931 gm./cc.

3.1 Flexural Rigidities of PE11 (Plated) Type Films

Low density (0.920) polyethylene films, ranging in thickness from 0.15 mil to 4 mils, were electrolessly copper plated to a depth of either 5×10^{-6} or 10×10^{-6} inches on each of both sides. Lengths of overhang were determined and the flexural rigidities were calculated.

The results are given in Table 2 below and are plotted in Figure 5, curves A and B.

3.2 Flexural Rigidities of PE12 (plated) Films

Samples of PE12 film (0.931) plated with 5×10^{-6} inches or 10×10^{-6} inches of copper were tested for flexural rigidity. It was found that the higher density plated film gives a considerably higher flexural rigidity as compared to the plated low density film. In addition to the higher density material, having a higher modulus of elasticity, it also gives a surface that is more receptive to the metallization process. This is evident from Figure 5 where the flexural rigidities of the plated PE12 are compared with the flexural rigidities of the plated 1-mil PE11.

3.3 Flexural Rigidities of Plated PE12 Film over the Complete Range of Film Thicknesses

The necessity of a stiff film at low area weight prompted the use of PE12 as the base material. It was plated to a depth of 15×10^{-6} in. on each side. Use was made of the flexural rigidities of plated 1 mil PE12 to give the displacement above the low density curves and its contour in an effort to determine a valid flexural rigidity vs. thickness curve. The "limiting" points for the flexural rigidities were experimentally determined. For the upper point a 2-mil laminate of PE12 plated to a 15×10^{-6} in. depth on each side was used while the lower point was determined using an 0.15 mil PE11 film plated to 15×10^{-6} in. thickness on each side. PE11 film could be used for the lower point because the type of polyethylene film becomes unimportant as the polyethylene film thickness becomes very small, since

Table 2

Flexural Rigidity as a Function of Film Thickness with Electroless Plating Time as a Parameter

t (mil)	5 Minute Plate			10 Minute Plate		
	G_0 lb.in.x10^{-6*}	G_{90} lb.in.x10^{-6*}	$\hat{G}$ lb.in.x10^{-6*}	G_0 lb.in.x10^{-6*}	G_{90} lb.in.x10^{-6*}	$\hat{G}$ lb.in.x10^{-6*}
0.15	1.293	1.635	1.45	1.341	1.010	1.16
0.21	1.443	0.967	1.18	1.460	1.007	1.21
0.30	2.566	1.837	2.17	2.385	2.464	2.42
0.55	3.911	3.174	3.52	3.819	8.572	5.72
1.00	18.686	24.937	21.58	37.89	18.26	26.30
2.85	146.8	168.7	157.5	247.9	339.2	299.0
4.00	678.4	702	689.9	929.6	743.7	831.0

*lb.in. = lb.in.^{2}/in. since samples are 1 inch wide it does not contribute to the flexural rigidity of the laminate in any substantial way. This is shown in curve D of Figure 5, where the flexural rigidity of unplated, low density film is plotted vs. thickness using the beam cantilever test data (listed in Table 3). The final flexural rigidity-thickness curve constructed from the three data points and the contour of the 5×10^{-6} and 10×10^{-6} in. thickness curve is given in Figure 5, curve C. The extrapolated flexural rigidities given by curve C will be used to determine the polyethylene thickness needed to withstand five-times solar pressure, and to determine the satellite weight. The calculation is carried out in Section 4.0.

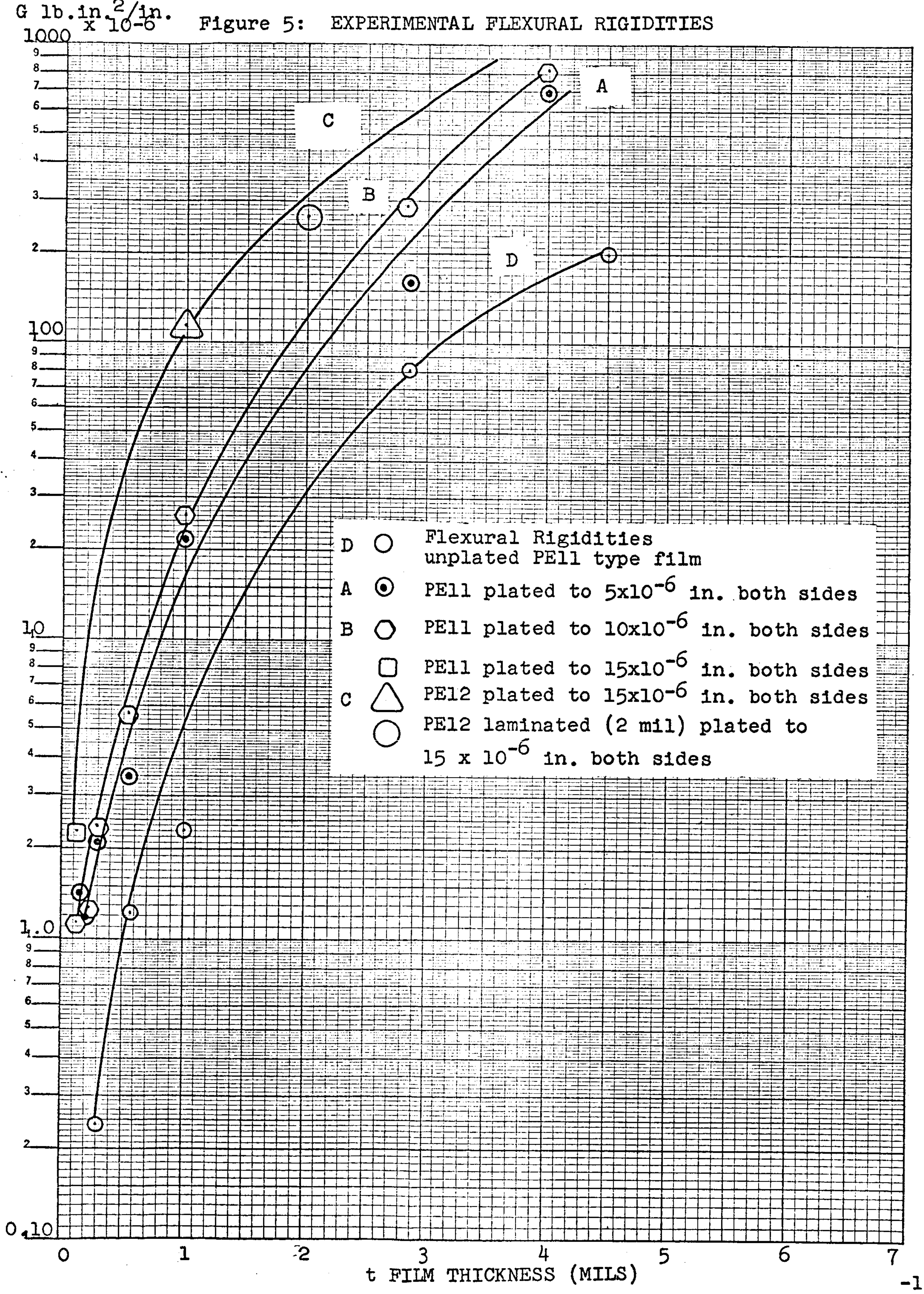
Table 3

Flexural Rigidity of Unplated PE11 vs. Thickness

t (mil)	G* ($\text{lb.in.}^2/\text{in.} \times 10^{-6}$)
0.15	No reading obtainable
0.21	0.0567
0.30	0.2431
0.55	1.226
1.0	2.30
2.85	81.714
4.5	196.155

*Arithmetic mean reported

Figure 5: EXPERIMENTAL FLEXURAL RIGIDITIES



4.0 BUCKLING PRESSURE - THICKNESS CALCULATION

An approach we believe to be realistic, has been used to determine the composite film thickness that will withstand the specified buckling pressure of five-times solar pressure. The approach consists of modifying the basic buckling equation

$$P_{cr} = \frac{2E}{\pi R^2 k^{\frac{1}{2}}} \left(\frac{10^{-2} k \rho}{4} + \frac{1}{\rho} \right) t^2 \qquad (2)$$

(derived with variables defined in quarterly report, RAI 368, March-May 1966, pp. 14-17) for the effect of small film thickness and the effect of metallic laminates. The method used corrects equation (2) for actual film-metal laminate flexural rigidity by the application of the following factor

$$\frac{G^F(t)}{G^P(t)} = \frac{G^F(t)}{\frac{1}{12} E t^3}$$

where $G^F(t)$ is the measured flexural rigidity of the metal-plastic film laminates and $G^P(t)$ is the flexural rigidity of the polyethylene alone. If the flexural rigidity correction factor is applied to equation (2) the following equation is obtained:

$$P_{cr} = \frac{G^F(t)}{t} \frac{24}{\pi R^2 k^{\frac{1}{2}}} \left(\frac{10^{-2} k \rho}{4} + \frac{1}{\rho} \right) \qquad (3)$$

If equation (3) is rearranged as follows:

$$\frac{t}{G^F(t)} = \frac{24}{\pi R^2 k^{\frac{1}{2}} P_{cr}} \left(\frac{10^{-2} k \rho}{4} + \frac{1}{\rho} \right)$$

and the following functions defined

$$H(t) = \frac{t}{G^F(t)}$$

$$F^c(\rho) = \frac{24}{\pi R^2 k^{\frac{1}{2}} P_{cr}} \left(\frac{10^{-2} k \rho}{4} + \frac{1}{\rho} \right)$$

equation (3) many then be stated as

$$H(t) = F^c(\rho) \tag{4}$$

With the experimental values of $G^F(t)$ given in Figure 5, curve C, $H(t)$ has been plotted in Figure 6. With the function $F^c(\rho)$ plotted in Figure 7, equation (4) has been solved graphically for film thickness for various values of ρ. The results are summarized in Table 4.

Table 4

Polyethylene Thicknesses of Composite Film - Solutions to Equation (4) (30 x 10^{-6} inches of Copper Plate)

ρ	$F^c(\rho) = H(t)$	$t \times 10^3$
4	45	0.18
10	21	0.22
22	17.5	0.27
30	18	0.25
100	32.5	0.19
210	63.0	0.15
>210	>63.0	No solution

Figure 6: THE FUNCTION $H(t) = \frac{t}{G^F(t)}$ WHERE $G^F(t)$ IS THE FUNCTION GIVEN BY CURVE C, FIGURE 5

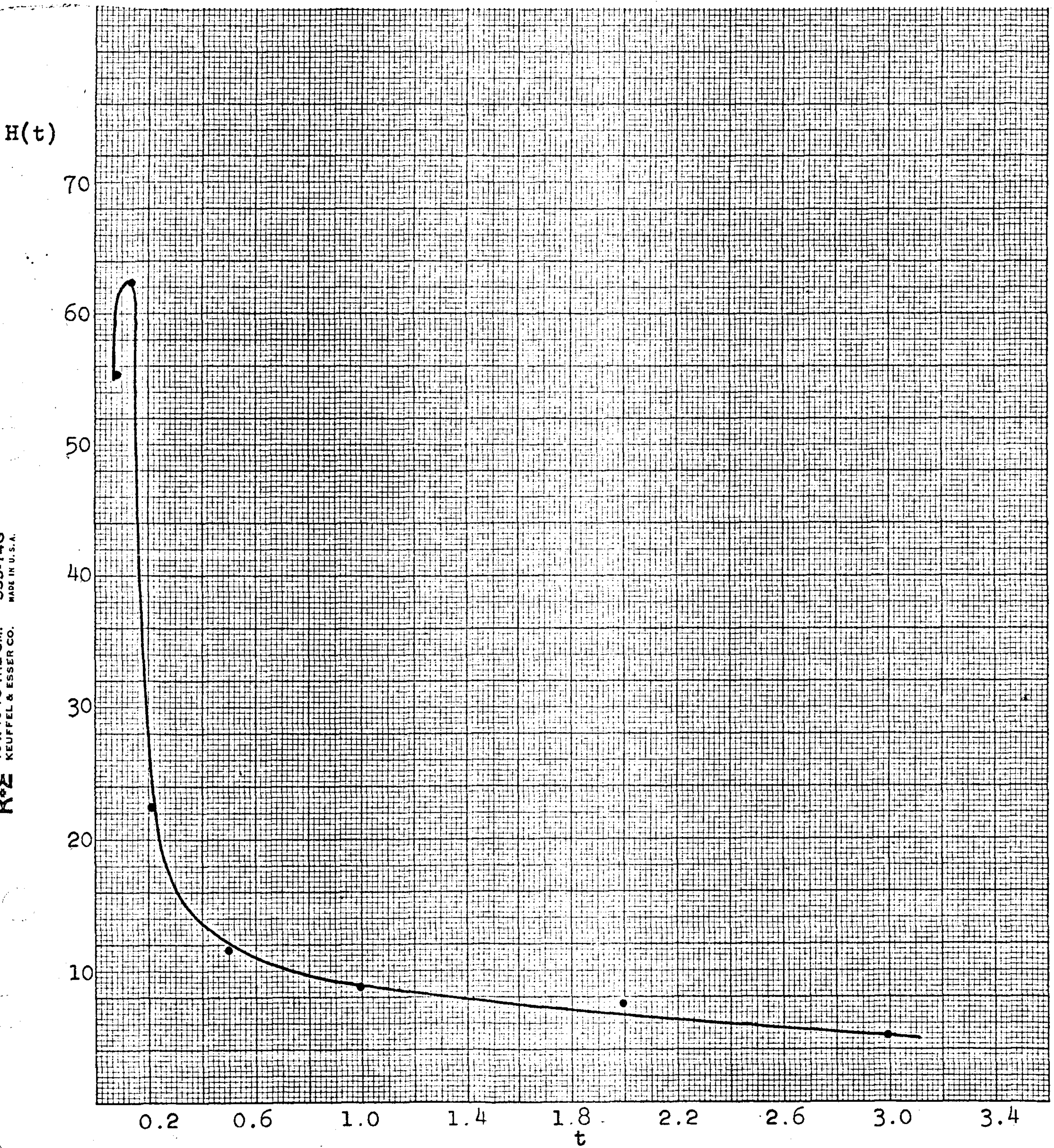
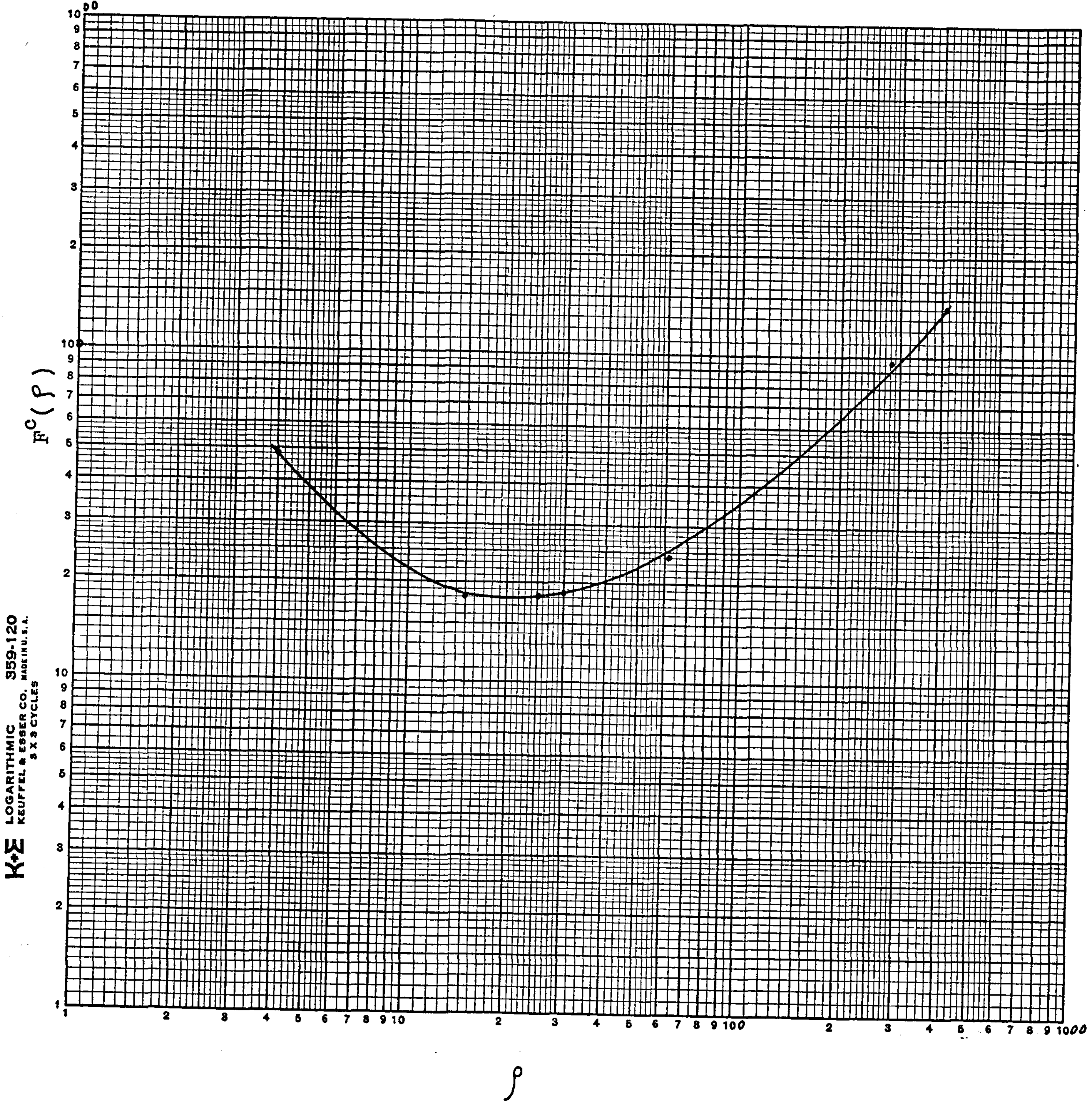


Figure 7: THE FUNCTION $F^{c}(\rho) = \frac{24}{\pi R^2 k^{\frac{1}{2}} P_{cr}} \left(\frac{10^{-2} k}{4}\rho + \frac{1}{\rho} \right)$



5.0 SATELLITE WEIGHT

With the maximum film thickness of 0.27 mil calculated from Section 4.0 above, the satellite weight is calculated as follows.

5.1 Polyethylene Film Area Weight

For polyethylene film having the following properties

density: 58.09 lb./ft.^3

thickness: 0.27 mil

the resultant area weight is calculated to be

$$W_p = 1.3069 \times 10^{-3} \text{ lb./ft.}^2$$

5.2 Electroless Copper Plate Area Weight

For an electroless plated copper coating on both sides of the polyethylene film and having the following properties

density of electroless Cu: 473.7 lb./ft.^3

thickness: 15×10^{-6} in.

the resultant area weight contribution of the metal coating is

$$W_M = 1.184 \times 10^{-3} \text{ lb./ft.}^2$$

5.3 Composite Film Area Weight

The composite film area weight is obtained by summing the contributions from both the plastic and metal layers

$$\begin{aligned} W_T &= 1.3069 \times 10^{-3} \text{ lb./ft.}^2 + 1.184 \times 10^{-3} \text{ lb./ft.}^2 \\ &= 2.4909 \times 10^{-3} \text{ lb./ft.}^2 \end{aligned}$$

5.4 Satellite Weight - Nonperforated

With a diameter of 425 ft., the surface area of the sphere is 567,344 $ft.^2$ With the composite area weight of 2.4909 $lb./ft.^2$ the total weight of the nonperforated sphere is 1413.197 lbs.

5.5 Satellite Weight - Perforated

With a 25 to 30% or above open area obtainable from perforating, the satellite weight can be reduced according to the following table.

Table 5

Satellite Weights - Perforated

Film Thickness: 0.27 mil
Metal Thickness: 15×10^{-6} in. (both sides)

Percent Open Area	Total Weight (lbs.)
85	211.979
80	282.639
75	353.299
60	565.279
50	706.599
40	847.918
30	989.238
20	1130.558
10	1271.877

It can be seen from the above table that the specified total weight of 1000 lbs. can be obtained with a percent open area in the range of 25 to 30%.

6.0 DELIVERABLE ITEMS

6.1 Irradiation

With the procurement of the PE12 film from Sea Space Inc., arrangements have been made to irradiate both lots of film to 15 Mrads at a cost of $1700.

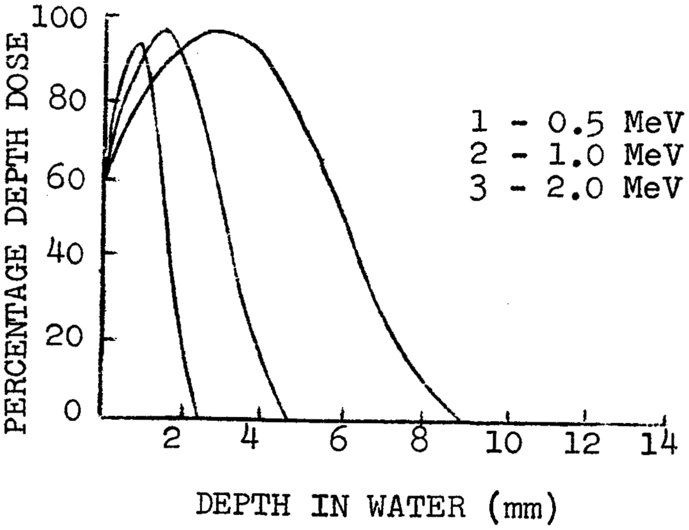
The cause of the problem which made the first run or irradiated film fuse, has been determined. The eight (8) thicknesses of film used in the first run were rolled upon a take-up roll immediately after passing the electron beam, consequently, the film did not have an opportunity to cool and therefore stuck together. The irradiation of the film in a single thickness as well as the use of cooling fans on the film after it passes the beam was used to prevent sticking during the subsequent irradiation.

Due to maintenance shutdown and a mechanical breakdown in the vacuum system of Electronized Chemical's accelerating equipment, an additional delay was encountered in the irradiation of the film for the deliverable items. Electronized Chemical's accelerator was finally back in operation on Thursday, August 4 The irradiation of the film was started on Friday, August 5 and it was found that due to a heat-buildup caused by the electron beam on the conveyor, which carries the film, a sticking problem developed. Before any significant amount of the film was damaged, irradiation was stopped and the film was lined with paper to prevent further sticking. The irradiation of the film was successfully completed with the above precautions, by mid-August.

6.1.1 Scatter in the Irradiation Atmosphere Tests

The scatter observed in many of the irradiation strength-time tests is in all probability due to the effects of the effectiveness of dose variation with sample thickness. For a given sample (or bundle of samples) of a material the dose at the surface of the sample and to about 2 mm. inward is not 100% effective since the high speed of the electrons do not have sufficient time to interact with the molecules. Data showing how interaction efficiency varies with depth from the surface is given in Figure 8, which was taken from "Radiation Chemistry of Polymeric Systems."[6]

Figure 8: PERCENTAGE DEPTH DOSE IN WATER FOR HIGH ENERGY ELECTRONS



It can be seen that for a 1.0 Mev accelerator the effective dose may vary between 60 and 100% for samples 2 mm. thick or less. It is believed that since many of our samples were within this depth range, they received non-uniform doses as given by the above curve. This situation has been corrected for the irradiation of the deliverable items. The applied dose will be increased to account for the lower efficiency at and near the surface. The total dose the film will receive on its surface and throughout will be a constant 15 Mrads, since there will be very little variation in dose with depth.

6.2 Heat Treatment

The heat treatment of the film for the deliverable items has been started at Sea Space Systems, Inc. The film will be heated to 93°C. for 1/2 hour contact time in an oven. The film will be passed through the oven in single thickness by the use of take-up rolls. Precautions have been taken to heat-treat the film so it will remain in a smooth and flat condition. Additionally, precautions have been taken to allow the film to shrink, without inducing thermal stresses by keeping the tension on the take-up rolls at a minimum. It is expected that the heat treatment will be completed in early September.

6.3 Metallization

Irradiated and unirradiated samples of PE11 as well as an unirradiated sample of PE12 were sent to the National Metallizing Division of Standard Packaging Co. Standard Packaging will vacuum deposit 1500-2500 Å of aluminum on the film samples. The purpose of this initial test is to determine if the 15 Mrad irradiation is sufficient surface treatment for the vacuum deposition of the polyethylene film.

At present we are still awaiting the return of the samples. Additionally, with the facts that ca. 1/2-1 Ω/sq. resistance results from 1500 Å of aluminum and ca. 30% perforation open area doubles the resistance of the laminate, it will be recommended that a high vacuum deposit (ca. 2000 Å) be applied to the film to insure meeting the specification of 2 Ω/sq.

6.4 Perforations

In recent correspondence with Arthur A. Struble, General Manager of Sea Space Systems, Inc., Torrance, Calif., it was determined that it would be impossible to perforate the film on a continuous basis at the level of funding allotted. It is possible to achieve various fractions of perforated open area by continuous perforation techniques but not within our budget requirements.

Mr. Struble believes that a cost exceeding $4500 would be necessary to achieve perforations on a continuous basis for the thin film. In light of this information it is believed most practical at this point to have the film perforated to ca. 30% open area, in 100 ft. lengths, which would be within the funds of the contract.

In light of the cost considerations and the fact that both conductance and flexural rigidity sharply decrease at ca. 30% open area, it is advisable to have the film for the deliverable items perforated to 30% open area.

It should also be noted that Sea Space is capable of perforating film to 60% open area on a continuous basis and even to higher fraction open areas on a non-continuous basis. The only problem with achieving this higher open area at present is that the cost for perforating is excessive.

6.4.1 Perforation Pattern

The perforation pattern to be used are staggered circles. Originally a staggered hexagonal pattern was suggested because it gives more rigidity than circles[7] but in order to lower costs, the lower priced pattern had to be accepted. The reason a staggered pattern has been chosen is because a staggered arrangement has been found to possess more rigidity than a pattern of uniform rows.[8]

6.5 Ultrasonic Bonder

An ultrasonic bonder has been ordered from Ultrasonic Seal, a Division of Kleer-Vu Industries, New York, N.Y. The bonder has been ordered on a rental basis for $1,335. Delivery is scheduled for Sept. 15 and the unit will be available for 3 months. Along with the transducer and power supply, 2 ultrasonic welding heads have also been ordered. One welding head to be used for continuous welding and one for non-continuous welding. A selection will be made after evaluation of both heads as to which unit is best suited for fabrication of the deliverable items.

6.6 Supply of Film Necessary to Build Deliverable Items

The amount of film necessary to complete the remaining number of deliverable items is 2464 ft. Since there are 1200 ft. of film per roll, 2 rolls of film will be just short of enough to complete the fabrication of the remaining deliverable items. Calculations for determining the amount of film required have been based on a 26 ft. diameter cap section and an 18-inch wide film. It is recommended at this point, so as to complete all of the deliverable items, to use 2 rolls of film to complete the construction of the cap sections. Processing a third roll of film would increase cost beyond available funds.

7.0 TESTING PROGRAM

The testing program has been started in two areas, the tensile test and the flexural rigidity test.

7.1 Test Specifications

7.1.1 Tensile Test

Tensile tests are under way to determine the Modulus of Elasticity, E, and the Yield Force, F_y. Strengths will be reported in terms of force rather than stress because the film will be perforated. The perforations lead to ambiguity as to what area is operated on when the sample is stretched.

The test conditions are as follows:

a. Full scale load: 5 pounds
b. Crosshead speed: 0.2 inches per minute
c. Cell: CT
d. Sample Dimensions: 1 in. x 1 in.
e. Temperature: ambient

The results are summarized in Table 6.

7.1.2 Flexural Rigidity Test

This test is performed according to ASTM D1388-55T specifications. The results are summarized in Table 6.

Table 6

Results of Mechanical Tests

Direction (Degrees)	G (lb.ft. x 10^{-6})	F_y (lbs.)	E (psi x 10^3)
Unirradiated PE12			
0	4.282 ± 0.495	0.699 ± 0.056	31.04 ± 3.9
45	5.771 ± 2.552	0.578 ± 0.030	28.73 ± 3.2
90	5.547 ± 1.718	0.643 ± 0.029	37.49 ± 4.3
Irradiated PE12			
0	4.917 ± 1.443	0.693 ± 0.086	29.10 ± 1.74
45	5.523 ± 1.346	0.522 ± 0.022	29.54 ± 1.6
90	7.603 ± 2.830	0.634 ± 0.089	37.36 ± 3.8

8.0 PERFORATION STUDY

An initial perforation test has been started to determine the effects of void fraction on flexural rigidity and resistance. In preparation for the final Perforation Study dies have been designed to give void fractions from 10 to 65%.

8.1 Effect of Perforation on Resistance and Flexural Rigidity

Experiments were designed with the purpose of optimizing the resistance, flexural rigidity, and weight of the deliverable items. The data gives an insight into future work for the final satellite design.

Perforation was accomplished by hand punching holes with the estimation of spacing between holes accomplished visually. The number of holes were counted, the total area was measured, the displaced area was calculated and the resulting open area was calculated.

8.1.1 Resistance (R) vs. Percent Open Area (F_v)

The resistance (in Ω/sq.) was measured in two directions. This was done because the copper plate is subject to mechanical stress in the process.

The data, Table 7 [plotted, in Figure 9, as Resistance (ohms/sq.) vs. Percent Open Area (F_v)] shows that the percent open area must be kept below ca. 30%. Since this data applies to copper, corrections must be taken into account because aluminum will be used for the deliverable items. Since aluminum has about twice the resistivity, even less of an open area should be tolerated to meet the resistance specification of 2 Ω/sq., when samples of aluminized films and more accurate punches arrive, the data will be subject to greater refinement.

8.1.2 Flexural Rigidity (G) vs. Percent Open Area (F_v)

As seen from Figure 10 (Table 7) where flexural rigidity is plotted vs. percent open area, it can be seen that the flexural rigidity falls off as the percent open area increases. The critical value is approximately 30% open area. This value also will be subject to refinment when aluminized film is used.

8.2 Perforation Test

In preparation for the perforation study, dies have been designed so that sample amounts of thin film may be perforated from 10 to 65% open area with staggered circular patterns. In this way, flexural rigidity tests, such as the "beam cantilever test" (ASTM D1388 55T) or membrane tests, can be used on the perforated film to find their flexural rigidities.

The prints of dies designed are given in Figures 11 and 12 along with a table of dimensions given in Table 8. Only the patterns giving 10, 20, 40, 50 and 65% open area will be constructed.

Table 7

The Effect of Percent Open Area on the Resistance and Flexural Rigidity of Plated Polyethylene Film*

		Non-Perforated		Non-Perforated	Perforated		Perforated		
F_v (%)	Sample Dimensions (in. x in.)	R_0 Ω/sq.	R_{90} Ω/sq.	average R Ω/sq.	R_0 Ω/sq.	R_{90} Ω/sq.	average R Ω/sq.	1^3 (in.^{3})	G (lb.in.^{2}/in.)
9.8	3 x 3	2.2	2.1	2.15	2.7	2.4	2.55	3.112	12.322 x 10^{-6}
24.5	3 x 3	2.1	1.9	2.0	2.8	2.5	2.65	3.705	12.278 x 10^{-6}
34.2	3 x 3	1.95	2.0	2.0	3.4	3.6	3.5	3.778	10.911 x 10^{-6}
42.5	4 x 2	2.25	4.6	3.4	8	24	16	1.159	2.925 x 10^{-6}
54.1	4 x 2	2.25	4.8	3.5	10	28	19	0.7795	1.571 x 10^{-6}

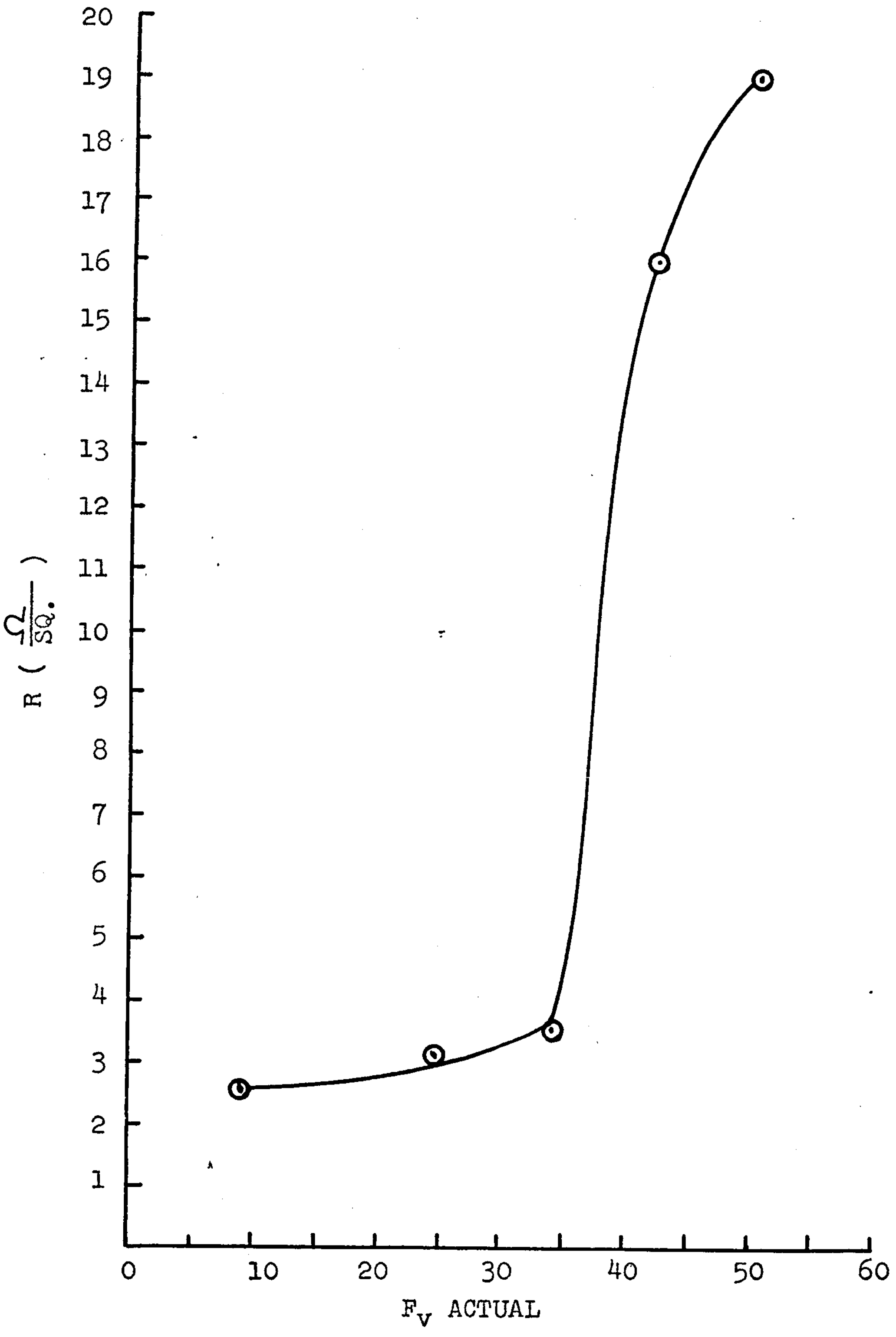
* All Values for PE12 plated 5 minutes one side

Table 8

Peforator Dimensions

F_V	l	x	y	z	n_R	a
0.10	0.2012	0.2608	0.1506	0.1304	6	0.2470
0.20	0.1129	0.1844	0.1066	0.0922	7	0.3613
0.30	0.0739	0.1506	0.0870	0.0753	9	0.3044
0.40	0.0506	0.1304	0.0753	0.0652	10	0.3223
0.50	0.0347	0.1167	0.0674	0.0584	11	0.3264
0.60	0.0229	0.1064	0.0615	0.0532	12	0.3241
0.65	0.0181	0.1023	0.0591	0.0512	13	0.2914

Figure 9: RESISTANCE (Ω/SQ.) OF PERFORATED PE12 (PLATED TO 5 x 10^{-6} IN.CU. ON ONE SIDE) VS. PERCENT OPEN AREA



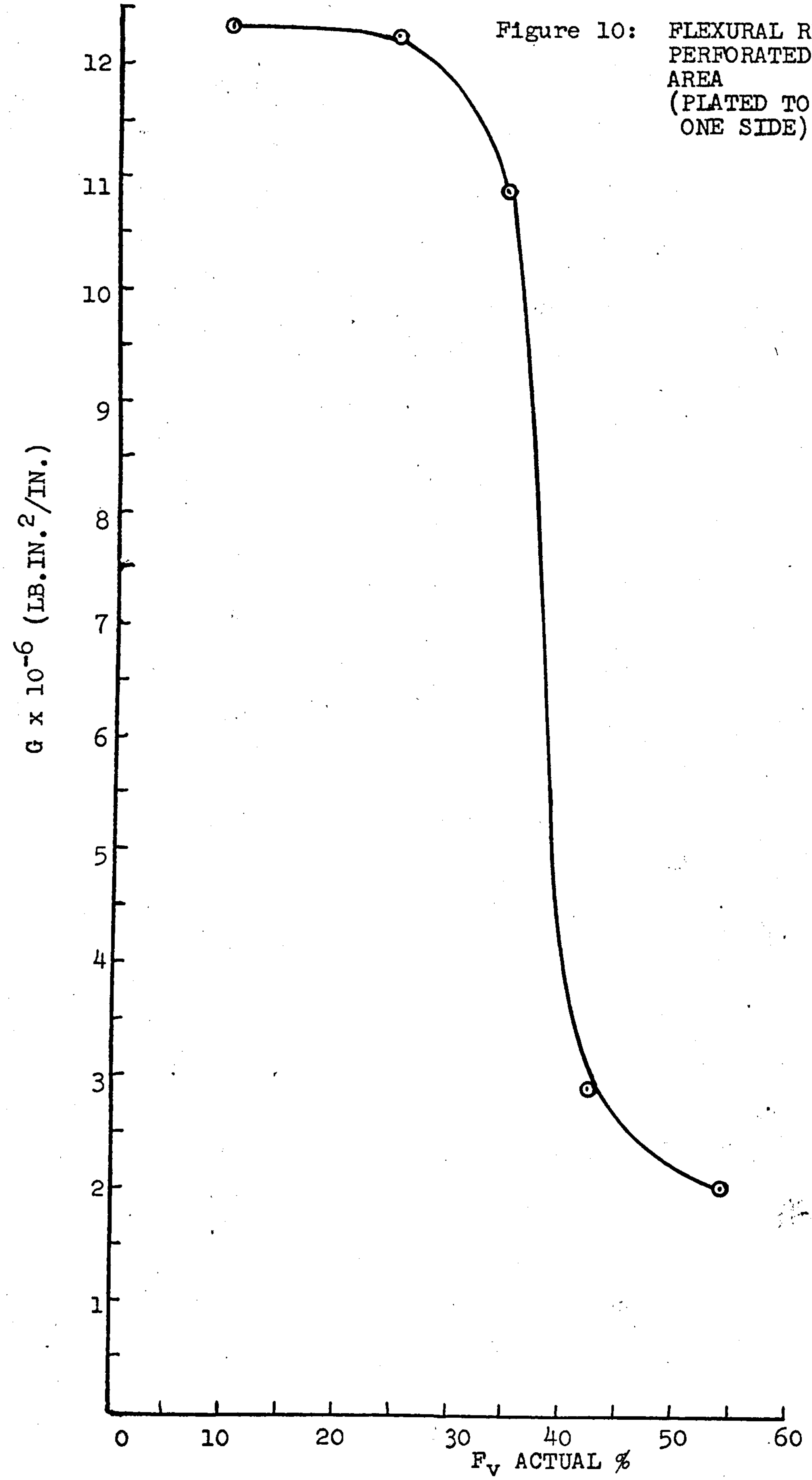
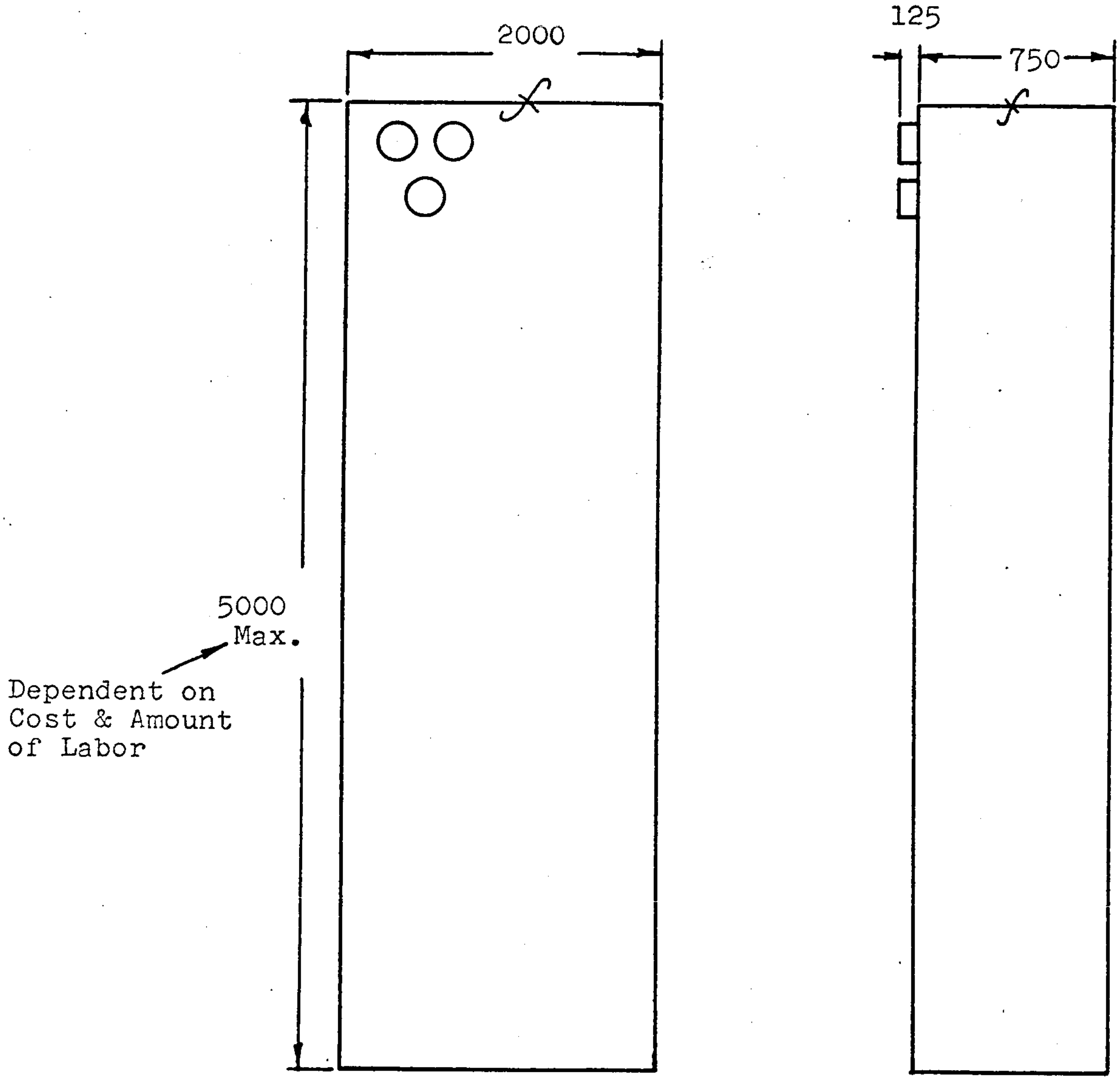


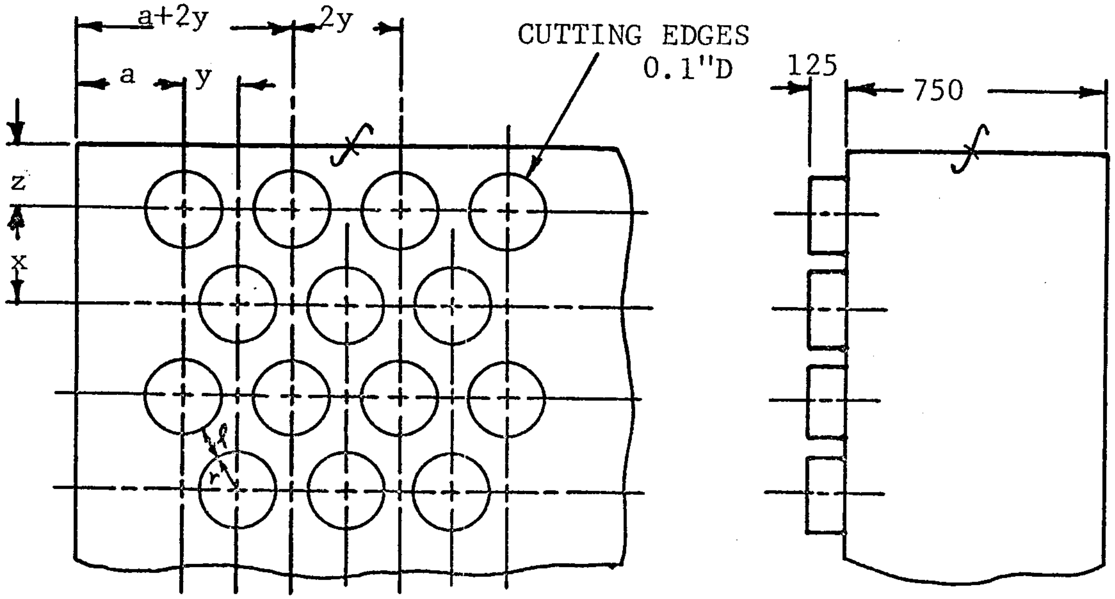
Figure 10: FLEXURAL RIGIDITY OF PERFORATED PE12 PERCENT OPEN AREA (PLATED TO 5×10^{-6} IN.CU. ON ONE SIDE)

Figure 11



DIMENSIONS IN THOUSANDTHS

J.A. RAFFO	PERFORATOR	7-21-66
	RAI RESEARCH CORPORATION 36-40 37th STREET LONG ISLAND CITY, NEW YORK 11101	



$2r = 0.1$

$x = 0.866(\ell + 0.1)$

$y = \dfrac{(\ell + 0.1)}{2}$

$z = \dfrac{x}{2}$

DIMENSIONS IN THOUSANDTHS

Figure 12: PERFORATOR-DETAIL FOR VARIOUS VALUES OF F_V (10-65)

9.0 DENSITIES OF PE11

The densities of crosslinked-extracted PE11 were determined using the density gradient apparatus described in Section 2.3. The film samples were given doses of irradiation from 5 to 75 Mrads and were extracted in xylene at 100°C. The values of the new densities are given in Table 9 below.

Table 9

Densities of Extracted-Crosslinked PE11

Dose (Mrads)	ρ (gm./cc.)
0 (Unextracted)	0.920
10	0.941
15	0.943
50	0.932
60	0.932
70	0.932
75	0.932

It can be seen from the results of this experiment that an extraction technique does not lower the density of the polymer and in fact increases it somewhat. The increase is probably due to further alignment and collapsing of the molecular chains. It is believed, from the results of these tests, that extraction will not lower the density of irradiated polyethylene film.

10.0 FUTURE WORK

During the next reporting period work will be continued on the deliverable items. In conjunction with the deliverable items, the testing program will be continued. Finally, upon receipt of the perforation dies the perforation study will be continued.

11.0 REFERENCES

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