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THERMAL RADIATION PROPERTIES OF SOME POLYMER BALLOON FABRICS

Technical Report VI

report to

OFFICE OF NAVAL RESEARCH

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THERMAL RADIATION PROPERTIES OF SOME POLYMER BALLOON FABRICS

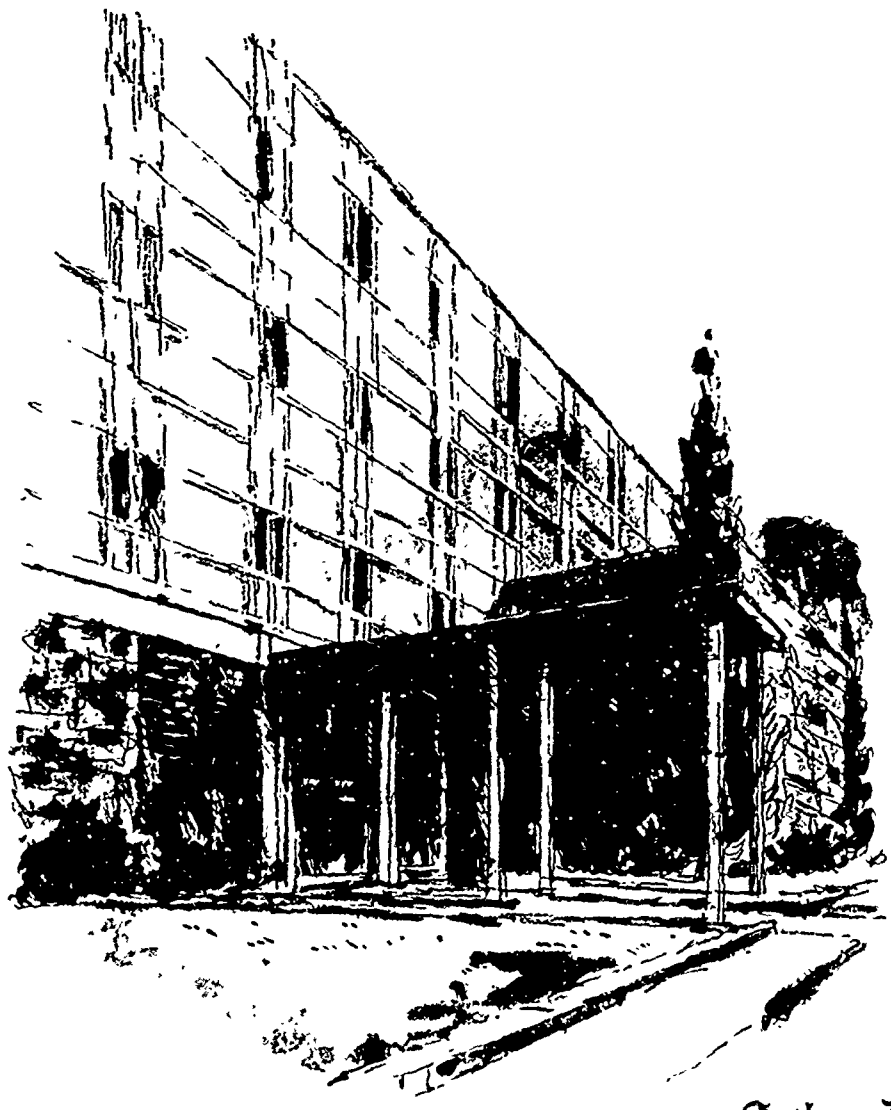
Technical Report VI

Report to

OFFICE OF NAVAL RESEARCH
PHYSICS BRANCH
CONTRACT NO. Nonr-3164(00)

By

I. W. Dingwell



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I. SUMMARY

This report is sixth in a series on the motion of high altitude balloons which have been prepared for the Office of Naval Research under contract Nonr-3164(00).

As the absorption of solar and earth atmosphere thermal radiation is an important factor in the vertical motion of high altitude balloons, the thermal radiation properties of the thin films that compose balloon fabrics must be determined. This report presents the results of property measurements made with spectrophotometer, emissometer, and thermal radiation measuring equipment. The films which were considered fall into three categories:

a. Polyethylenes

b. Mylar Composites

c. Other Fabrics

Polyethylenes are very transparent to thermal radiation. They have sharp, narrow bands at 3.5, 7 and 14 microns. Mylar composites tend to absorb more radiation as they have a broad band of absorption from 6 to 10 microns. The mylar composites tend to be affected by the reinforcing mesh (usually dacron) which raises the absorptivity.

II. INTRODUCTION

The performance of high altitude balloons is related, to a great extent, to the thermal radiation environment in which they operate. Thermal radiation to and from the balloon system is an important mode of heat transfer. Balloons absorb radiation from two primary sources; the sun (direct radiation and earth albedo) and, the earth and its atmosphere. Balloons also emit radiation as grey bodies in the range of temperatures of -60°C to +30°C. As the helium gas is virtually transparent to all thermal radiation, the absorbing and emitting surface is the thin polymer film which encloses the helium. In the case of a balloon floating at altitude, the rapid decrease in altitude following sunset is a dramatic example of the effect of thermal radiation on the balloon system.

Arthur D. Little has developed an analytical model which represents the vertical height time history of a high altitude balloon system[1,2]. In order to properly analyze this dynamic system, the thermal radiation properties of these thin polymer films must be known. Inspection of these properties, particularly the absorptivity, is of great use in predicting balloon performance. Thus, this data should be of importance to the balloon system designer.

III. MEASUREMENT OF PROPERTIES

A. TECHNIQUES

Since these thin (.001 inch) films are highly transparent, the absorptivity is difficult to measure. Several techniques may be used. The spectral transmissivity and reflectivity may be measured and the absorptivity deduced from these measurements. Or the back of the film can be coated with a film of highly reflective material (vapor deposited aluminum) and the absorptivity measured by comparing the reflected radiation to the incident radiation. Or the emissivity of the coated film may be measured directly with a emissometer. The last two techniques require highly sensitive instrumentation to detect small differences in radiation and that each sample be coated with vapor deposited aluminum.

Considering the available instrumentation and the number of samples to be processed, the measurement of film transmissivity was chosen as the most practical experimental technique.

The spectral absorptivity and emissivity of a film that both reflects and absorbs radiation are given by the following expressions:

$$\alpha(\lambda) = 1. - R(\lambda) - T(\lambda) \qquad (1)$$

and

$$\varepsilon(\lambda) = \frac{(1-R(\lambda))\cdot(1-\tau(\lambda))}{1-R(\lambda)\ \ T(\lambda)}$$

in which

λ = wavelength, microns

$\alpha(\lambda)$ = spectral absorptivity

$R(\lambda)$ = spectral reflectivity

$T(\lambda)$ = spectral transmissivity

$\varepsilon(\lambda)$ = spectral emissivity

B. EXPERIMENTAL EQUIPMENT

The spectral transmissivity $T(\lambda)$ and reflectivity $R(\lambda)$ can be measured by spectrophotometer equipment in the solar (.2 - 3. micron) and infrared (1. - 100. micron) spectral regions. In the solar spectrum, a Beckman DK Spectrophotometer was used.

The reflectance attachment to this spectrophotometer (an MgO coated integrating sphere) was used to make measurements of diffuse reflectivity of the front and back of the film. Because of the low reflectivity, accurate measurements of reflectivity were not possible and these measurements were not considered to be valid.

Initial spectral measurements indicated low values of transmissivity, especially at the short wavelength (.2 - .4 micron portion) of the spectrum. When the reflectance attachment was mounted behind the sample, the transmissivity measurement increased. We believe that without the use of the reflectance attachment as a collector, the back surface scattering from the original transmissivity measurements was not being detected. To a great extent, the integrating sphere collected this diffuse scattering and provided a more realistic measurement of transmissivity. A Vitrolite - MgO standard was used to provide absolute reference values of reflectivity.

In the infrared region, a Perkin-Elmer Infrared Spectrophotometer (Model 421) was used. This is a double-beam, optical-null instrument which requires no reference standard. The resultant measurements of transmissivity appeared to be satisfactory. We believe that back scattering is reduced at the longer, infrared wavelengths and can be considered to be unimportant.

C. CHECKING TECHNIQUES AND EQUIPMENT

The spectrophotometers were used to determine the spectral transmissivity of the films. This data must be numerically integrated over the solar spectrum to obtain the total transmissivity. Selective checks of the total transmissivity were made by measuring directly the amount of energy transmitted through the film. To do this, a bismuth-silver circular thermopile made by the Eppley Laboratory was exposed to sunlight on a clear day with and without film samples covering the 3/8 inch diameter sensor. The quartz window covering the sensor is transparent to solar radiation in the bandwidth from .3 to 3. microns.

As another check, the room temperature emissivity of three balloon film samples were measured after a coating of aluminum was vacuum deposited on the back side of the film. An emissometer was used which was developed by Arthur D. Little, Inc., for the measurement of the emissivity of high reflective insulating films.

IV. CALCULATION OF PROPERTIES

A. REFLECTIVITY

As mentioned, the small amount of energy which is reflected from the surfaces of the film is difficult to measure directly with sufficient accuracy. Early attempts to do this indicated that the reflectivity was less than .10. However, interference fringes were noted which resulted from internal reflections in the film. The reflectivity can be calculated from the refractive index determined by means of the interference fringes. Let a fringe maximum at wavelength λ, be numbered n. The refractive index, I_r, may be computed from two values n_1, n_2, observed at the corresponding wavelengths λ_1, λ_2 noted on the spectrometer record:

$$I_r = \frac{1.}{2d} (n_1 - n_2) \frac{\lambda_1 \lambda_2}{(\lambda_1 - \lambda_2)} \tag{2}$$

where d is the thickness of the film. From this, the reflectivity R may be computed according to the Fresnel formula (for normal incidence):

$$R = \frac{(I_r - 1.)^2}{(I_r + 1.)} \tag{3}$$

We have found that the reflectivity calculated in this manner was in the range of .04 to .06 for most balloon films. We have selected the value of .05 as a standard value for all balloon films.

B. ABSORPTIVITY - SINGLE PASS

At wavelength, λ, the radiation incident on the film is $I(\lambda)$. If the spectral transmissivity, $T(\lambda)$ and spectral reflectivity, $R(\lambda)$ are known, then the energy absorbed by the film is

$$I(\lambda)\ \alpha(\lambda) = I(\lambda)\ (1 - R(\lambda) - T(\lambda)) \tag{4}$$

Integrating this expression over the solar energy spectrum and the infrared spectrum gives the integrated absorptivity of the balloon fabric.

$$\alpha = \frac{\int_{\lambda_1}^{\lambda_2} \alpha(\lambda)\ I(\lambda)\ d\lambda}{\int_{\lambda_1}^{\lambda_2} I(\lambda)\ d\lambda} \tag{5}$$

C. ABSORPTIVITY - MULTIPLE PASS

Thin films of high transmissivity in a spherical shape absorb more energy due to multiple passes and internal reflections. Reference 2 shows that the effective absorption of energy of spherical shapes is:

$$\alpha_{eff} = \alpha \left[1 + \frac{T}{1-R}\right] \qquad (6)$$

If the integrated transmissivity, T, is high (.80) and the reflectance, R, low (.05), then the effective absorptance of incident radiation is nearly twice that of a single pass.

D. CALCULATION PROCEDURE

The integration of Equation 5 was carried out by digital computer. The solar energy spectrum was used without atmospheric absorption of energy. The water vapor and carbon dioxide absorbing bands may be included in the calculations, but as balloons normally operate above these layers, this attenuation of solar energy was omitted. For infrared spectrum, the radiation energy spectrum was calculated from Planck's law. A FORTRAN listing of the computer program is included in the Appendix.

V. THERMAL RADIATION PROPERTIES OF SOME POLYMER FILMS

A. POLYETHYLENE FILMS

Twenty-three samples which were identified as polyethylene were analyzed. This material is one of the most transparent to solar and infrared radiation. Sharp absorption bands occur at 3.5, 7 and 14 microns in the infrared. There are no noticeable absorption bands in the solar spectrum. The integrated transmissivity, τ, integrated absorptivity, α, and the effective absorptivity, α_{eff}, for these samples are listed on Tables I and II. The transmissivity of the films was measured from .22 to 20 microns. For room temperature and 225°K radiant sources, the proportion of total emitted energy is 72% and 58%, respectively, in this bandwidth. Therefore, an estimate of the transmissivity has been made from 20 to 100 microns using the measured value of τ at 20 microns. The estimated effective absorption, α_{est}, for the spectrum of 3 to 100 microns, has also been computed and is listed in Table I.

The integrated transmissivity of these films has been plotted on Figure 1 for the range of thicknesses which were tested. As films tend to have exponential transmission characteristics, the following relationship is also plotted.

$$\tau = (1 - R)e^{-\gamma t} \qquad (7)$$

τ = integrated transmissivity

R = integrated reflectivity (Equation 3)

γ = absorptivity coefficient

t = film thickness (mils)

A value of γ of .045 is used on the curve as reasonable correlation.

The spectral transmissivity of these films has been plotted on Figures 2 to 6 for the bandwidth .22 to 3 microns and on Figures 20 to 26 for the bandwidth 3 to 20 microns.

The checks of the solar transmissivity and infrared emissivity which were made tend to validate the computed absorptivity. In most cases, the variation was less than 5%.

The emissivity of the 1 mil polyethylene film was found to be .215. This included radiation emitted from the vapor deposited aluminum coating on the backside of the film. If the emissivity of the aluminum is taken to be .05, then the emissivity of the polyethylene film is .165. From this, the absorptivity can be computed to be .835 which is slightly lower than most values obtained from spectrophotometer measurements.

B. MYLAR COMPOSITES

Mylar films exhibit strong absorption bands from 6 to 10 microns. For a room temperature source of radiation, the peak intensity is at 10 microns and 23% of the radiant energy is centered in the 6-10 micron bandwidth. Mylar, therefore, tends to have much lower values of transmissivity than polyethylene for comparative thicknesses. The addition of a reinforcing mesh (usually dacron filaments) can only decrease the transmissivity.

In making measurements of spectral transmissivity, the reinforced films were oriented for maximum and minimum transmissivity. These values were used to obtain the integrated transmissivity.

The results from the Eppley thermopile experiments tend to indicate that the lower value of transmissivity be used for the transmission of solar energy. The measurements of room temperature emissivity also indicate that the lower or minimum value of transmissivity is the best value for composite films. We suggest that the minimum value be used as a representative value of composite film transmissivity.

The properties of G. T. Schjeldahl S-11, GT-111, and GT-66 fabrics are listed in Tables I and II and on Figures 7-12 and 27-29.

C. OTHER MATERIALS

As a service to manufacturers of balloon fabrics, Arthur D. Little, Inc. has performed tests to determine the thermal radiation properties of various reinforced and plain films. These properties are listed on Tables I and II and on Figures 13-19 and 30-45.

As urethane rubbers have been considered for superpressure balloons, the transmissivity of two samples (.3 and 1 mil) was measured in an unstretched and stretched condition. In the solar spectrum, the transmissivity was unaltered. However, the transmission of infrared was greatly increased (1.2 to 3.5 times the unstretched case).

VI. NOTES TO THE BALLOON DESIGNER

A. THERMAL RADIATION

The sun and the earth and its atmosphere can be considered to be black body radiators at 6,000°K and 300°K, respectively. A representative value of the radiant energy radiation which is incident on the surface of the balloon is 7.38 Btu ft^{-2} min^{-1} (2.002 cal $cm^{-2}min^{-1}$) from the sun and 2.45 Btu ft^{-2} min^{-1} from the earth and its atmosphere. For a one million cubic foot balloon (modeled by a 124 foot sphere), the solar radiation is assumed to contact an area equal to the projected area of 24,075 ft^2. The earth radiation is incident on the total surface area of the balloon which is 48,308 ft^2. The total incident radiation is 89,122 and 118,347 Btu/min from solar and earth radiant sources.

B. RADIATION ABSORPTION

Referring to Figures 1 and 2, a 1.5 mil polyethylene has an effective absorptivity, α_{eff}, of .12 and .21 for solar and earth radiation bandwidths, respectively. This value of absorptivity is the ratio of energy absorbed by the balloon to the energy incident on its surface. Therefore, the radiation absorbed by the balloon fabric is 10,694 Btu/min and 24,852 Btu/min for solar and earth sources. For a mylar scrim, GT-111, (α_{eff} = .17 and .63), the absorbed energy is 15,150 and 74,558 Btu/min, respectively.

C. RADIATION EMISSION

Balloons radiate thermal energy at rates proportional to the fourth power of the absolute temperature of the fabric. The emissivity of the balloon is equal to its absorptivity if the temperature of the fabric is equal to the radiation equilibrium temperature of the earth and its atmosphere. Thus, a fabric with high emissivity (mylar) floating in sunlight is less affected by solar radiation than a polyethylene balloon because the proportion of total radiant energy which comes from the sun is less (16% for mylar, 29% for polyethylene). This equilibrium temperature then, of a mylar balloon, tends to be less in sunlight than a polyethylene balloon. The ratio of absorptivity of sunlight and emissivity of energy is .57 for polyethylene and .25 for mylar. This ratio is useful for predicting radiation equilibrium temperatures. Because of the high value of emissivity, a reduction in the environmental equilibrium temperature will reduce the gas temperature of a mylar balloon more than that of a polyethylene balloon. This reduction in gas temperature will cause a mylar balloon to have less altitude stability at sunset or over clouds or flying from land to water.

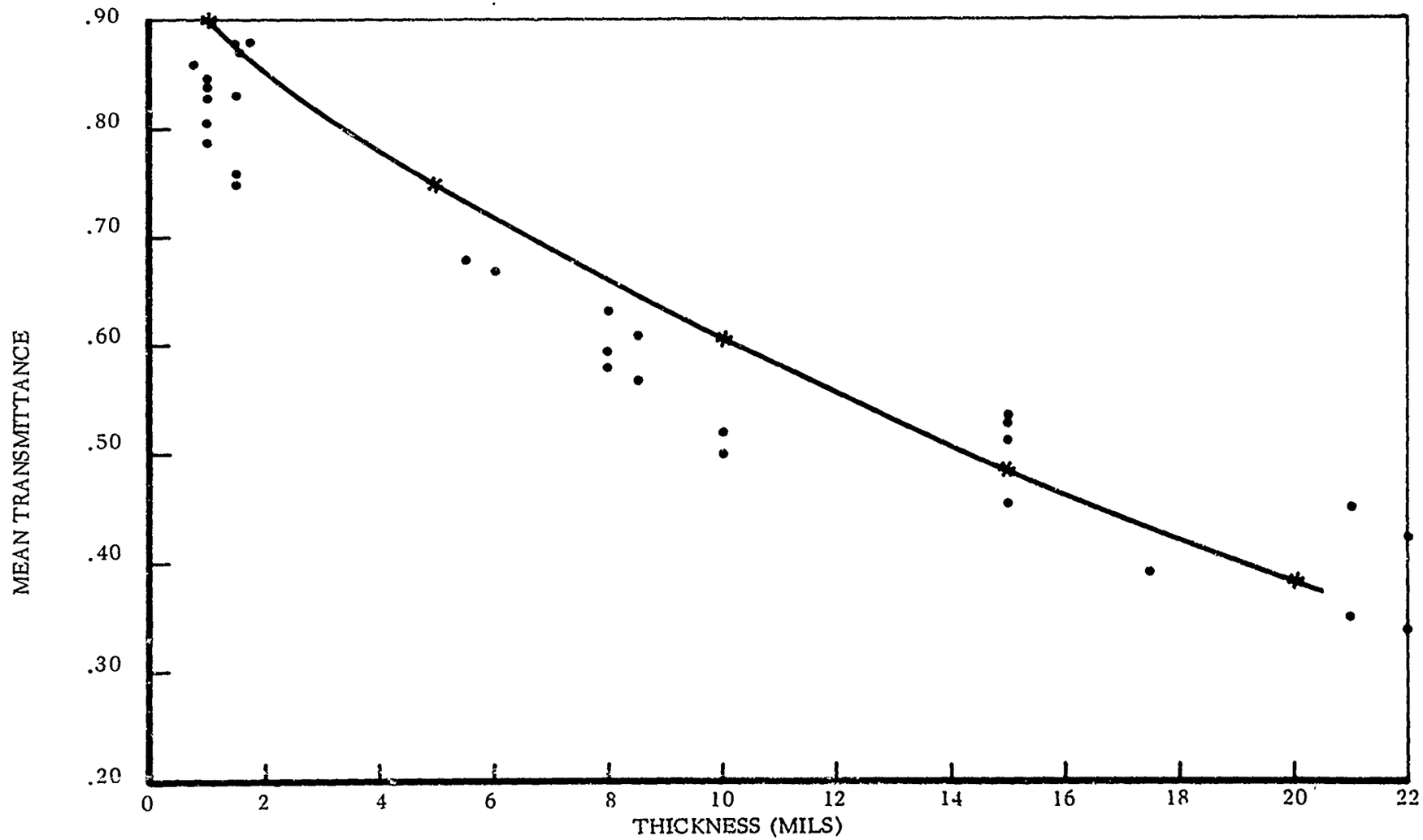


FIGURE 1 INTEGRATED TRANSMISSIVITY OF POLYETHYLENE FILMS OF VARYING THICKNESS --
Sample at Room Temperature
Spectrum: 3. to 20. Microns

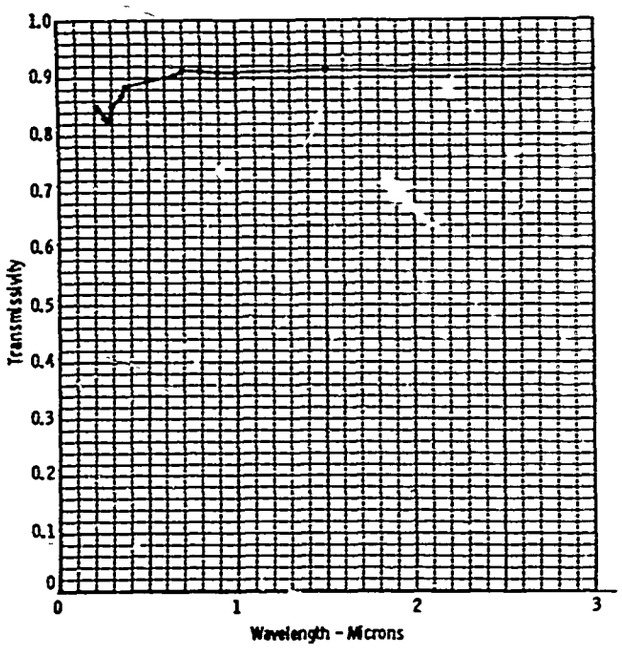


FIGURE 2 1 POLYETHYLENE .75 MIL

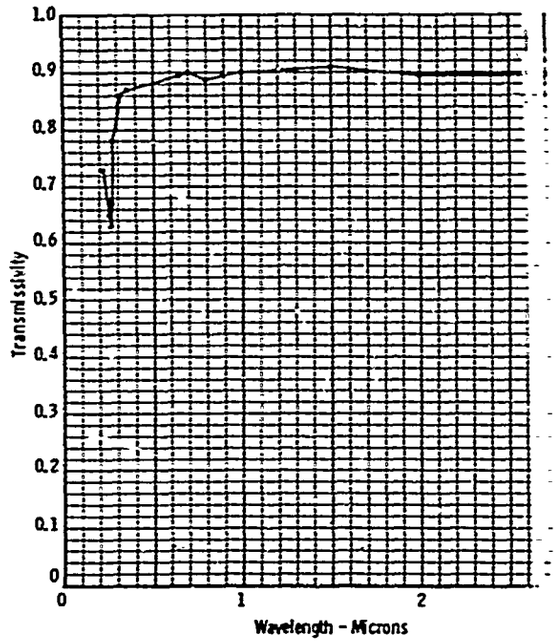


FIGURE 3 5 RAVEN/VISQUEEN 1.5 MIL

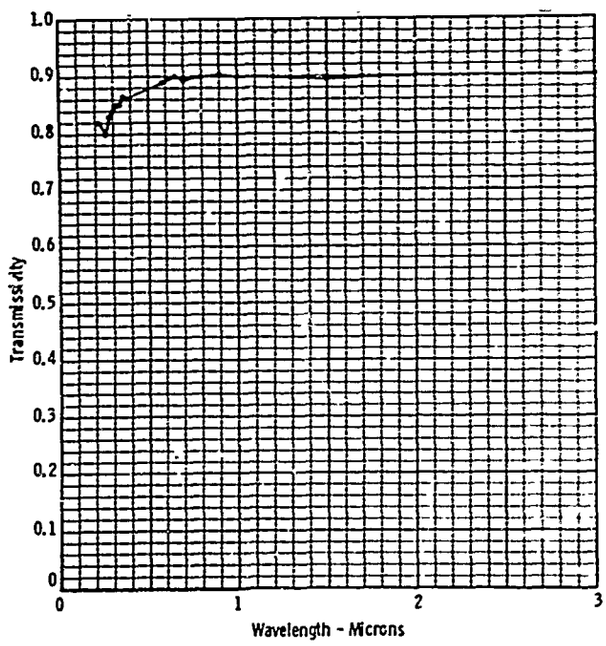


FIGURE 5 8 RAVEN/VISQUEEN 1.5 MIL ROLL 9996

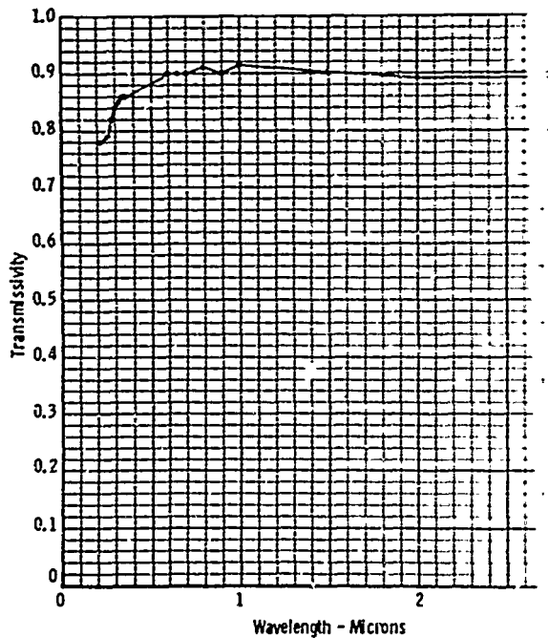
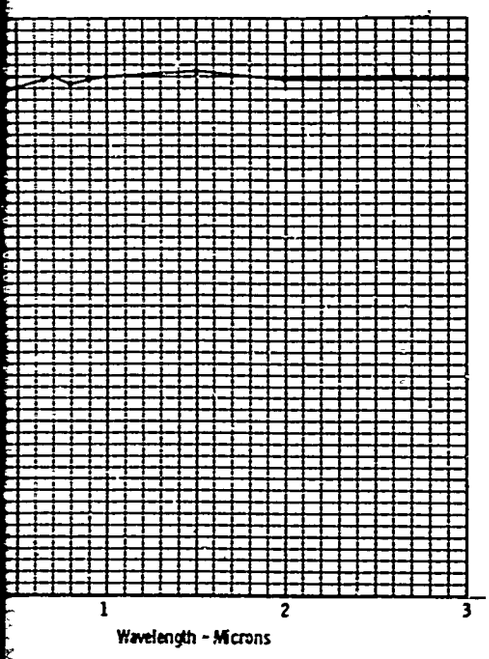


FIGURE 6 10 RAVEN/VISQUEEN 1.5 MIL



5 RAVEN/VISQUEEN 1.5 MIL ROLL 2580

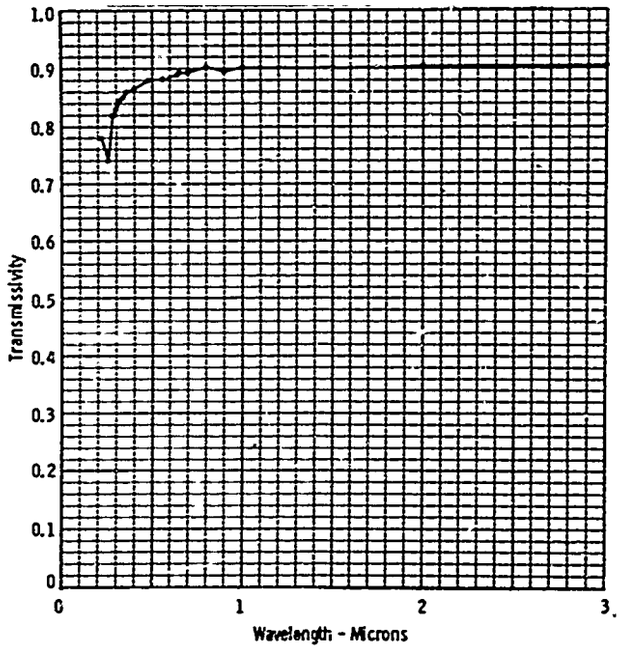
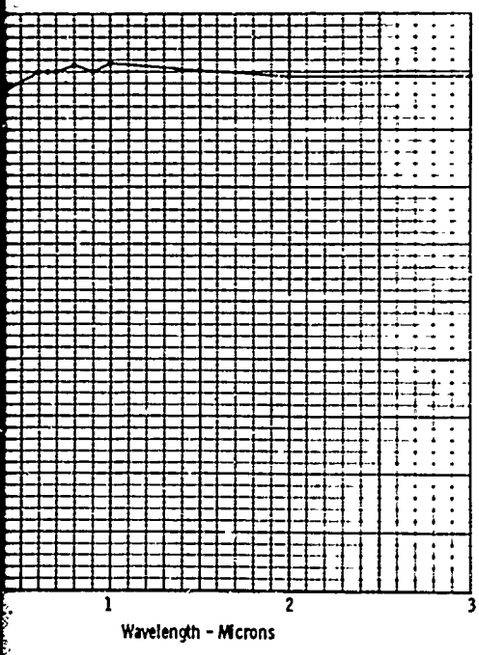


FIGURE 4 6 RAVEN/VISQUEEN 1.5 MIL ROLL 9988



10 RAVEN/VISQUEEN 1.5 MIL ROLL 10004

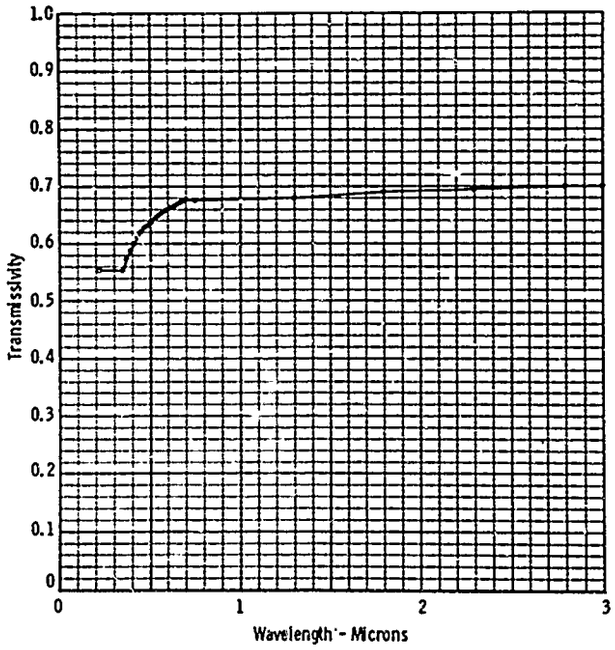


FIGURE 7 23 SCHJELDAHL/GT 66 .25 MIL SCRIM, MIN

B

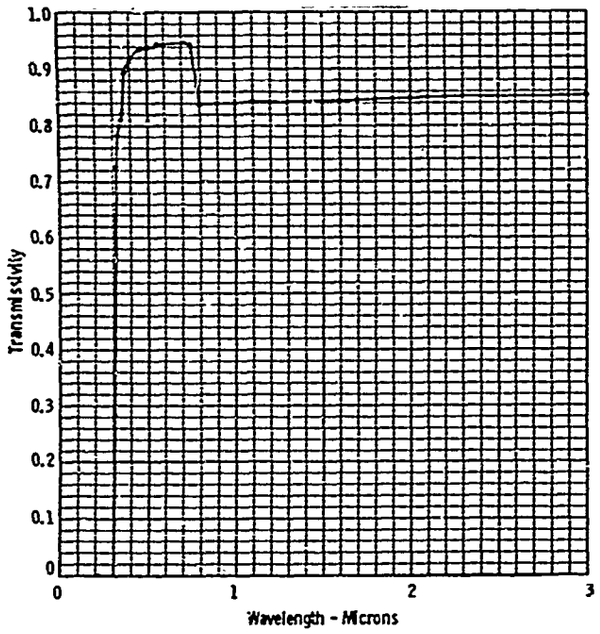


FIGURE 8 23 SCHJELDAHL/GT 66 · .25 MIL SCRIM, MAX

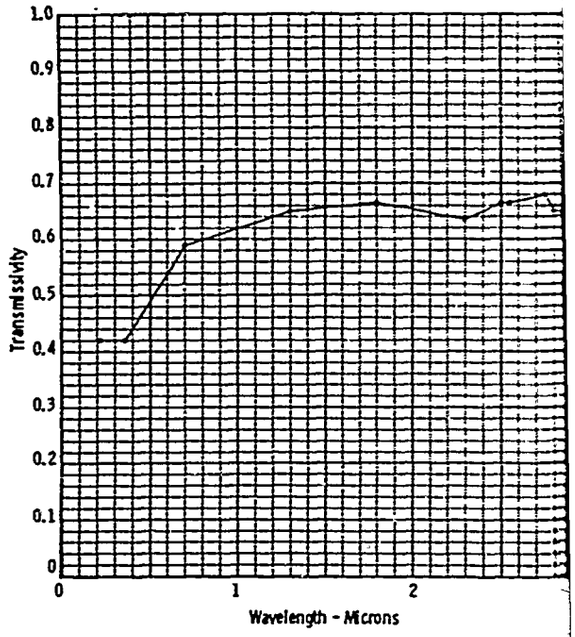


FIGURE 9 24 SCHJELDAHL/S-11 .35 MIL SC

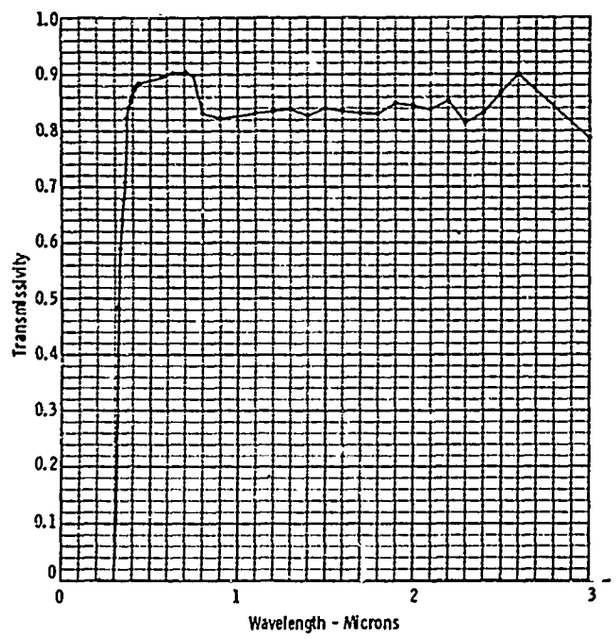


FIGURE 11 24 SCHJELDAHL/S-11 .35 MIL SCRIM, MAX

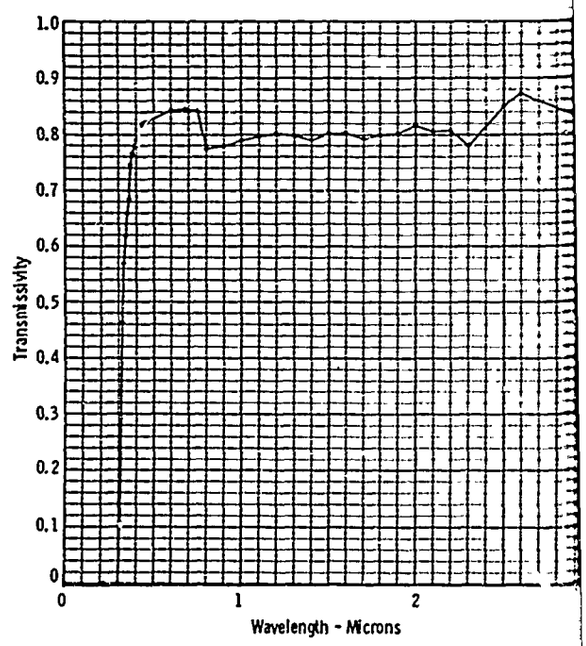
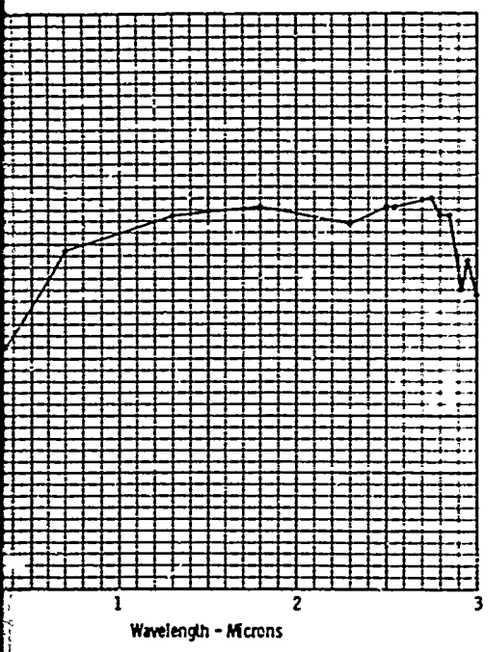


FIGURE 12 24 SCHJELDAHL/S-11 .35 MIL SC

A



24 SCHJELDAHL/S-11 .35 MIL SCRIM, MIN

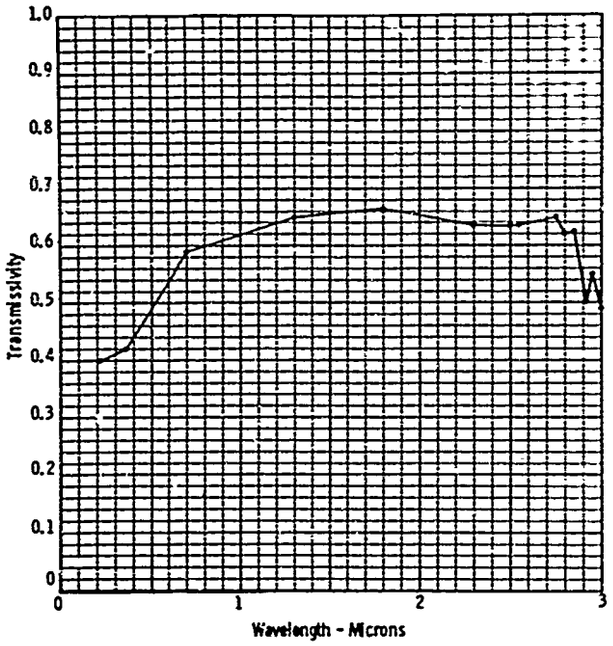
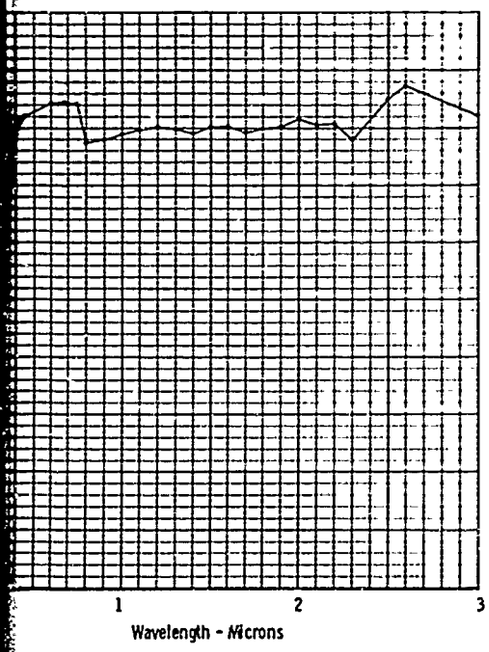


FIGURE 10 24 SCHJELDAHL/S-11 .35 MIL SCRIM, MIN



24 SCHJELDAHL/S-11 .35 MIL SCRIM, MAX

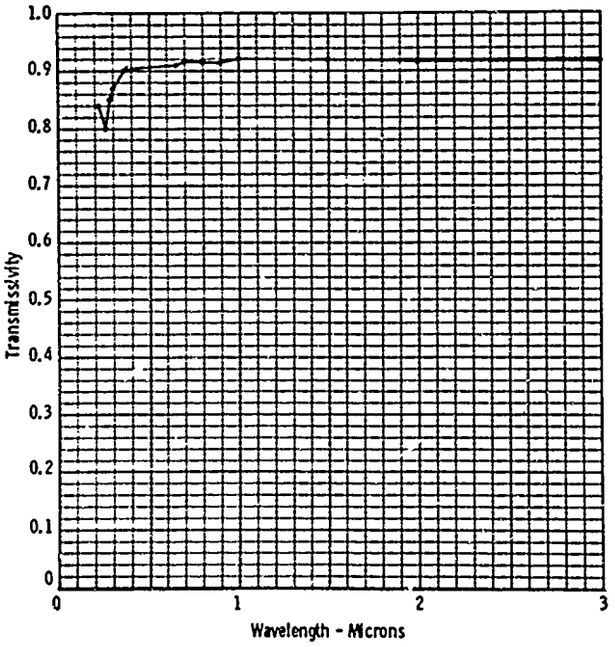


FIGURE 13 26 SEA SPACE/MERFILM .17 MIL

B

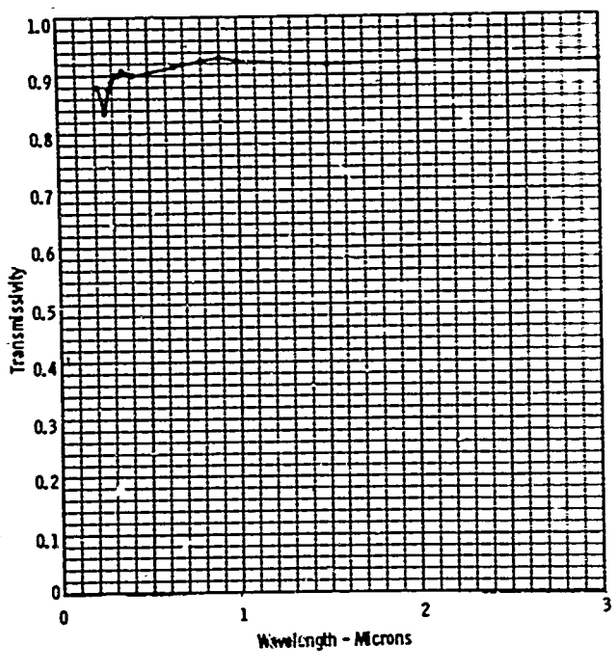


FIGURE 14 27 SEA SPACE/MERFILM .28 MIL

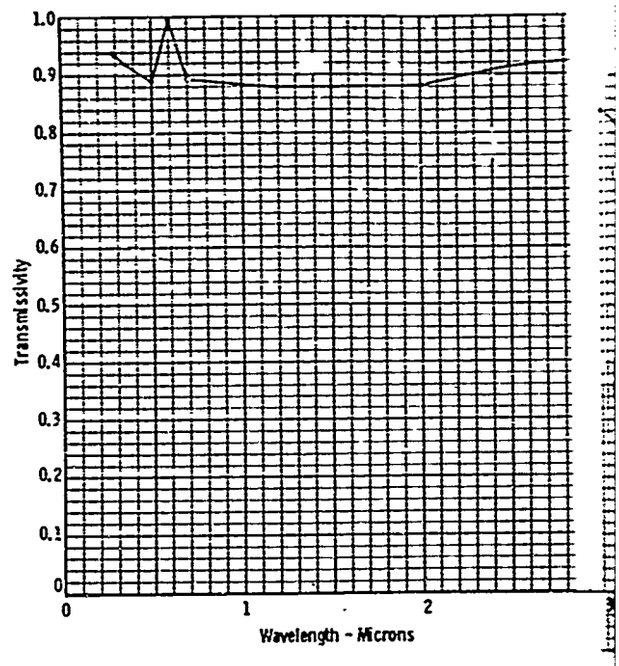


FIGURE 15 35 POLYPROPYLENE .5 M L

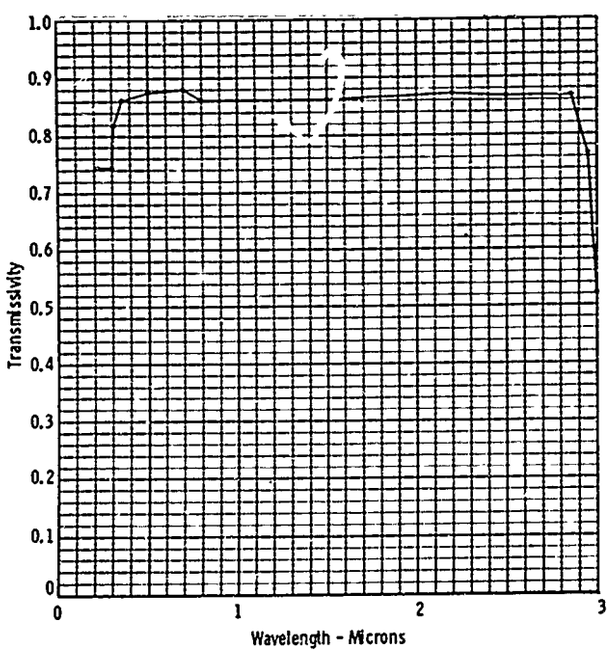


FIGURE 17 33 WINZEN/POLYURETHANE .3 MIL 50% ELONG

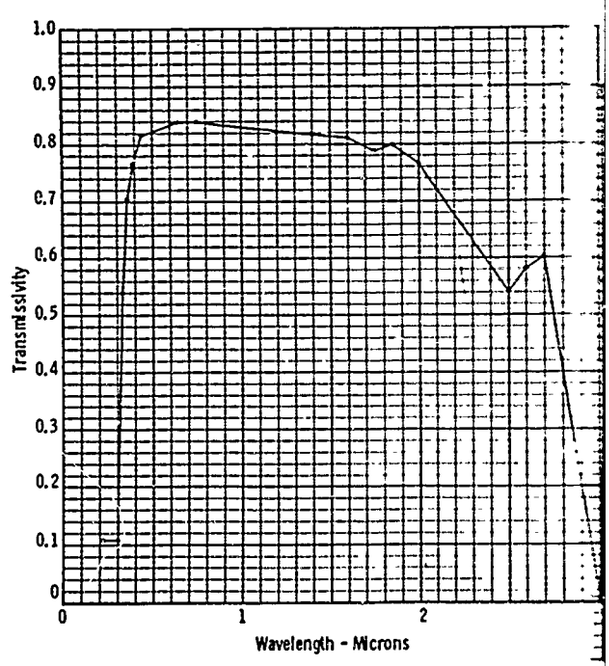
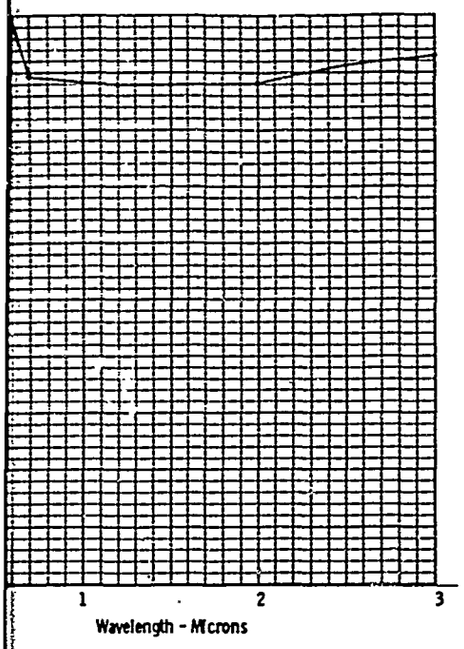


FIGURE 18 34 SEA SPACE/POLYURETHANE 1%

A



15 35 POLYPROPYLENE .5 MIL

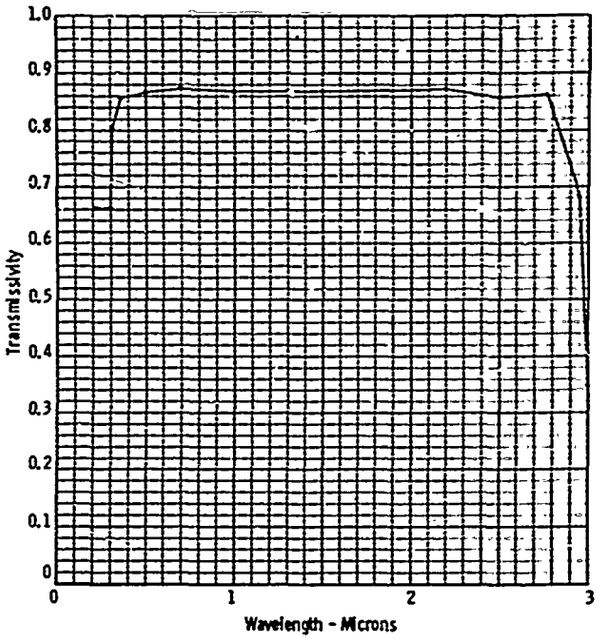
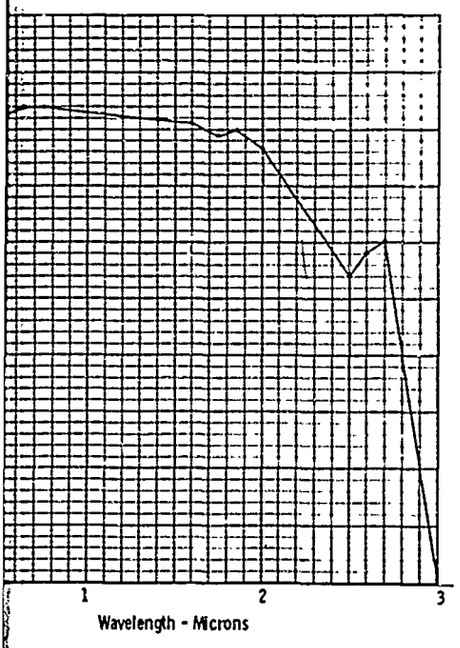


FIGURE 16 33 WINZEN/POLYURETHANE .3 MIL 0% ELONG



34 SEA SPACE/POLYURETHANE 0% ELONG

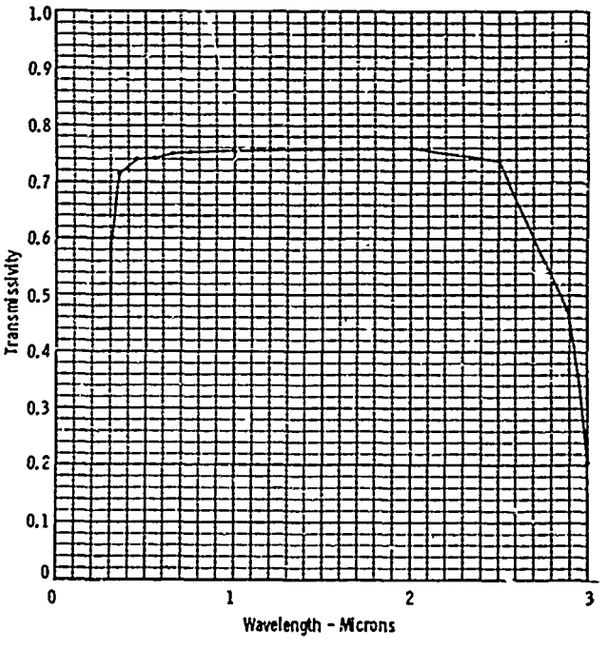


FIGURE 19 34 SEA SPACE/POLYURETHANE 1. MIL 100% ELONG

B

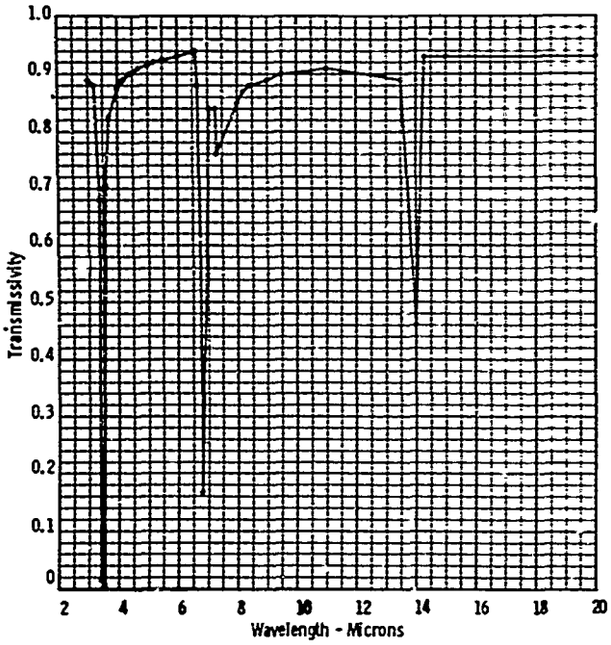


FIGURE 20 1 POLYETHYLENE .75 MIL

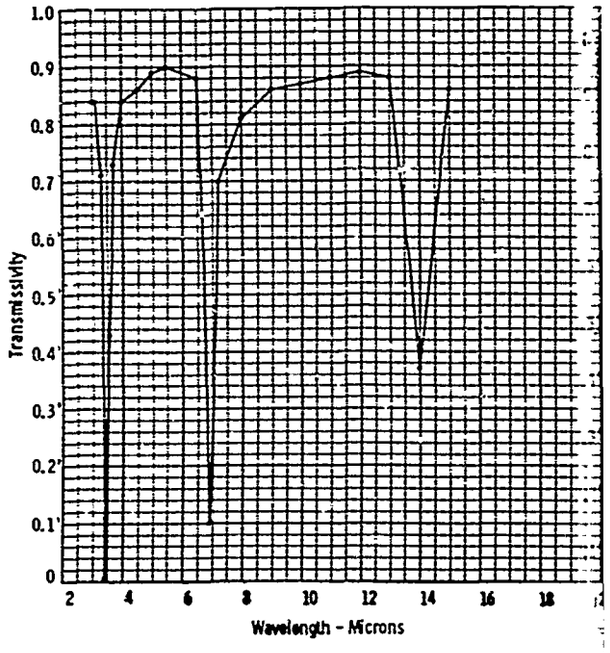


FIGURE 21 2 VIRON/POLYETHYLENE 1

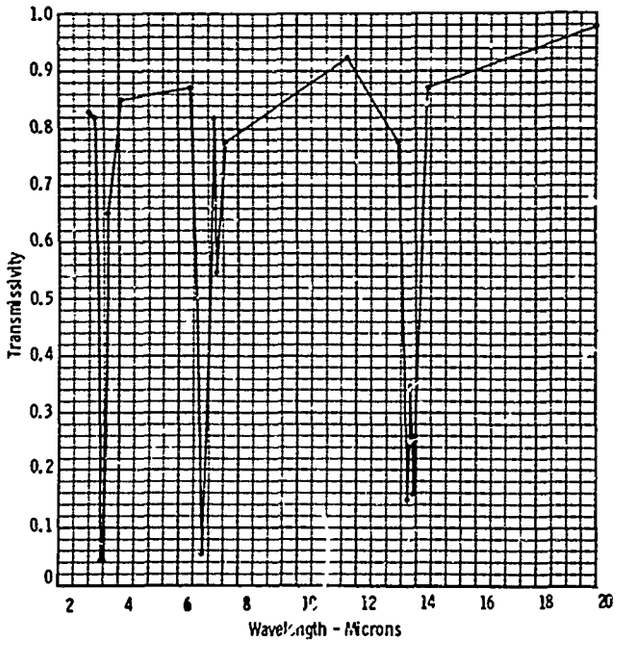


FIGURE 23 5 RAVEN/VISQUEEN 1.5 MIL ROLL 2580

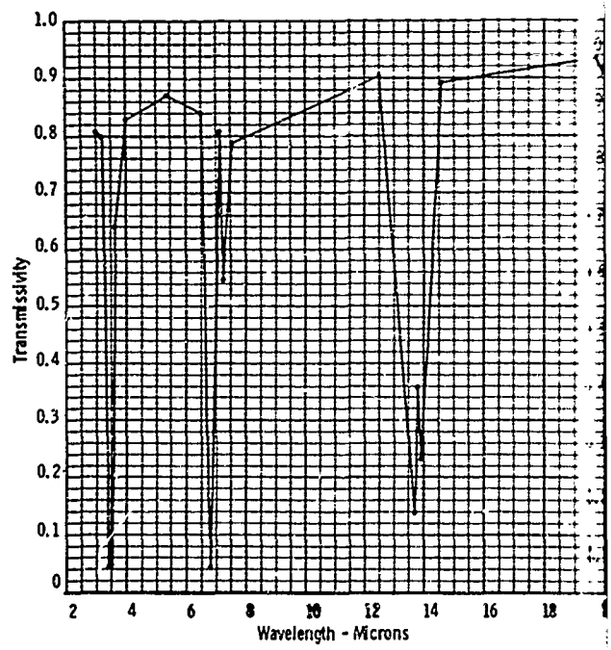
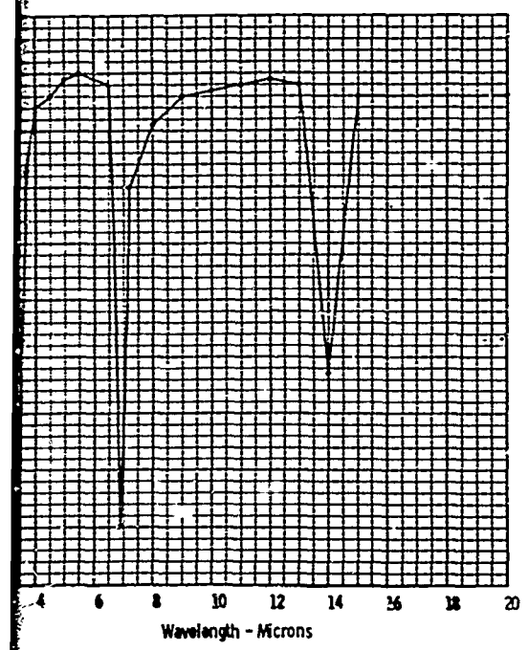


FIGURE 24 6 RAVEN/VISQUEEN 1.5 MIL ROL

A



E 21 2 VIRON/POLYETHYLENE 1 MIL

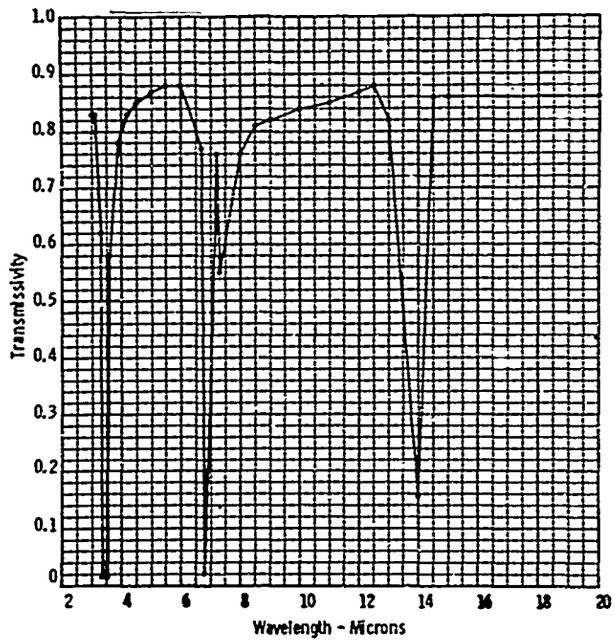
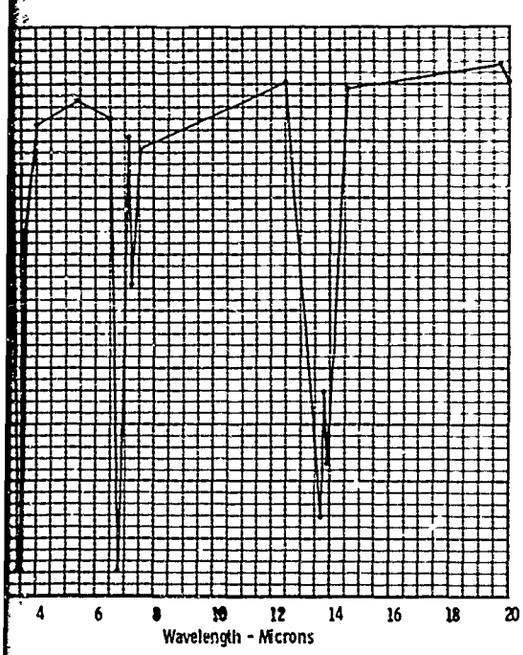


FIGURE 22 4 WINZEN/POLYETHYLENE 1.5 MIL



6 RAVEN/VISQUEEN 1.5 MIL ROLL 9938

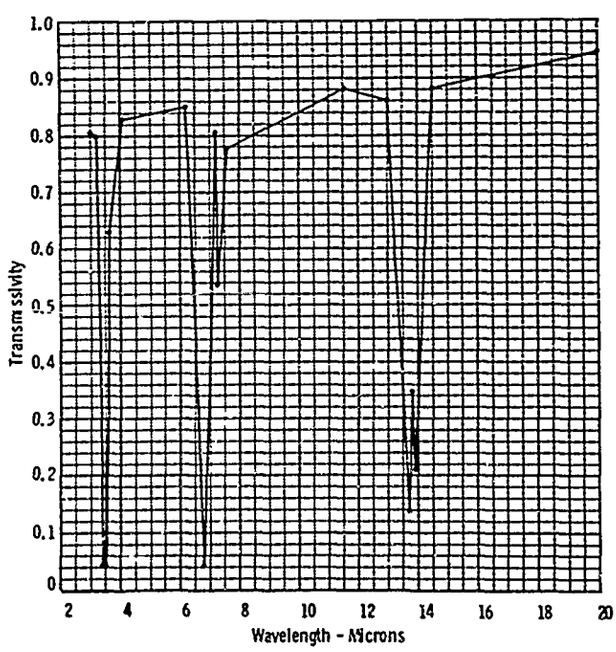


FIGURE 25 8 RAVEN/VISOUEEN 1.5 MIL ROLL 9996

B

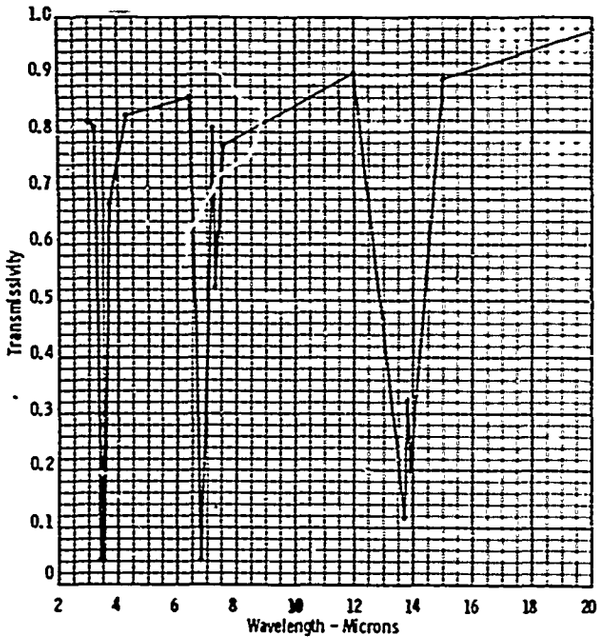


FIGURE 26 10 RAVEN/VISQUEEN 1.5 MIL ROLL 10004

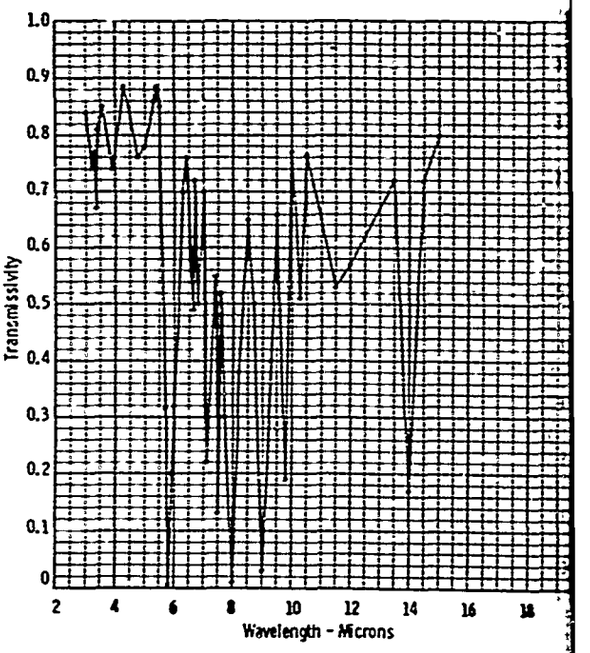


FIGURE 27 23 SCHJELDAHL/GT 66 .25 MIL S

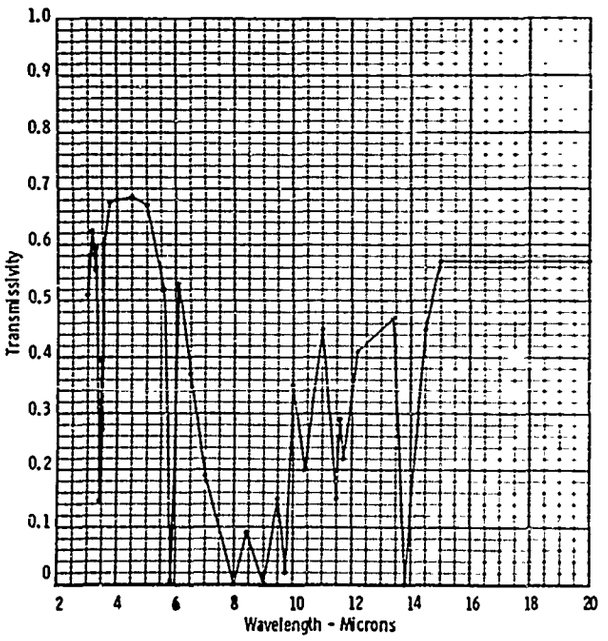


FIGURE 29 24 SCHJELDAHL/S-11 .35 MIL SCRIM, MIN

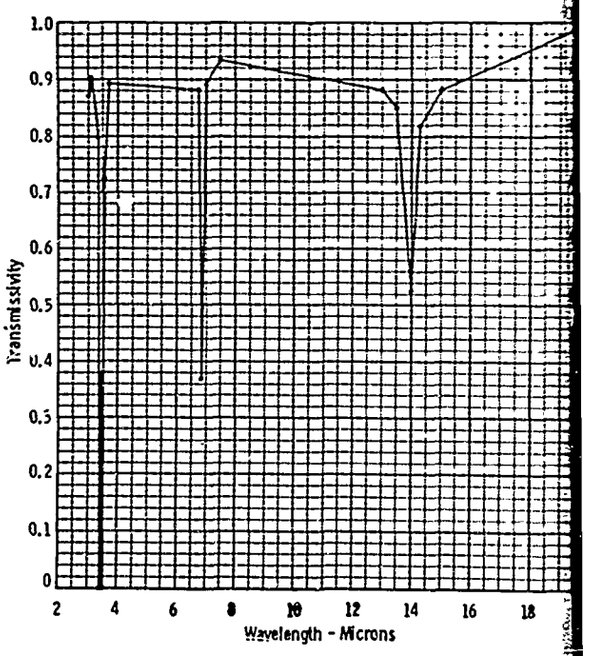
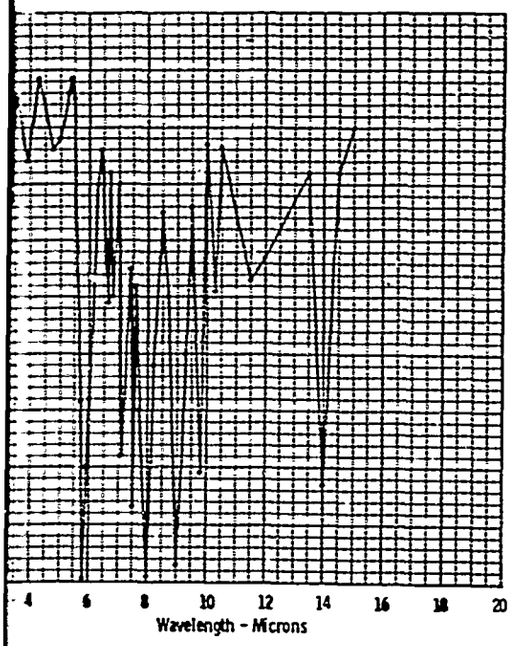


FIGURE 30 26 SEA SPACE/MERFILM .17



23 SCHJELDAHL/GT 66 .25 MIL SCRIM, MAX

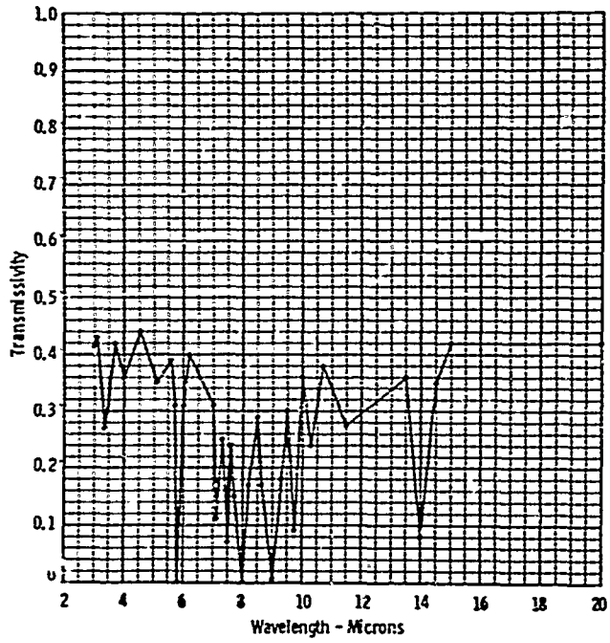
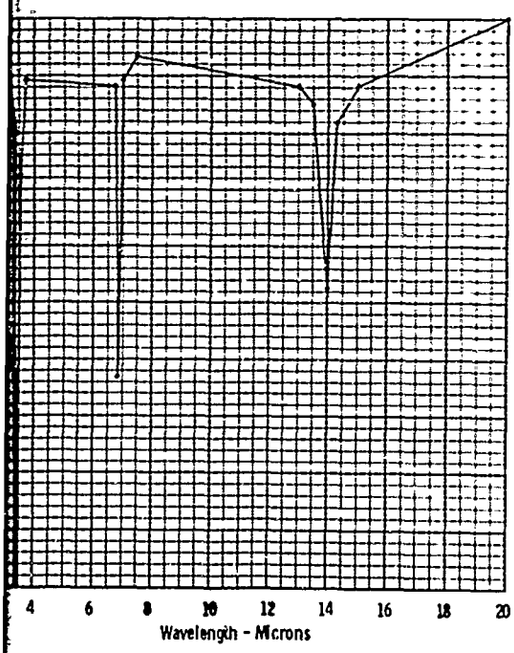


FIGURE 28 23 SCHJELDAHL/GT 66 .25 MIL SCRIM, MIN



E 30 26 SEA SPACE/MERFILM .17 MIL

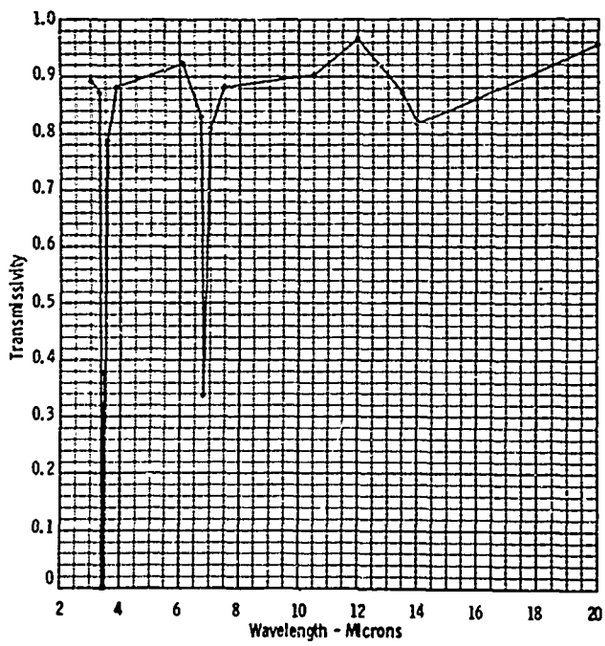


FIGURE 31 27 SEA SPACE/MERFILM .28 MIL

B

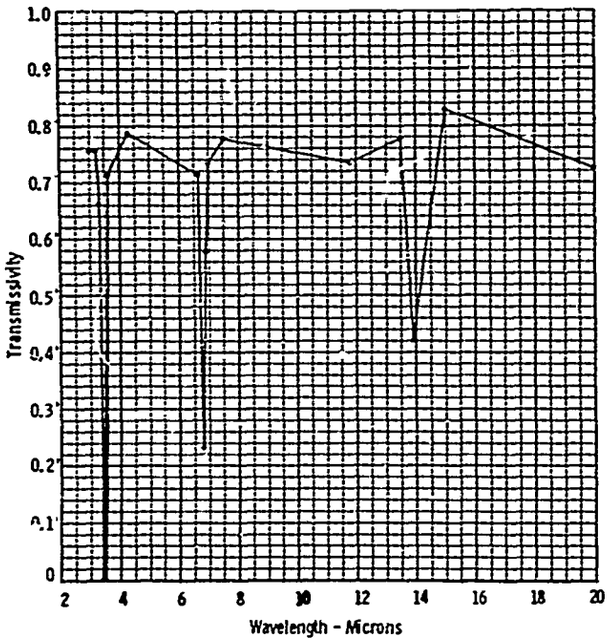


FIGURE 32 28 SEA SPACE/MERFAB SINGLE SCRIM, MIN

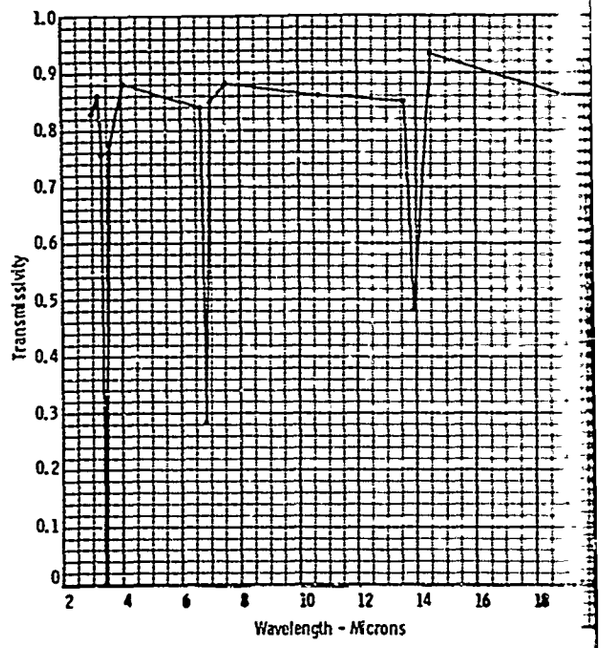


FIGURE 33 28 SEA SPACE/MERFAB SINGLE S

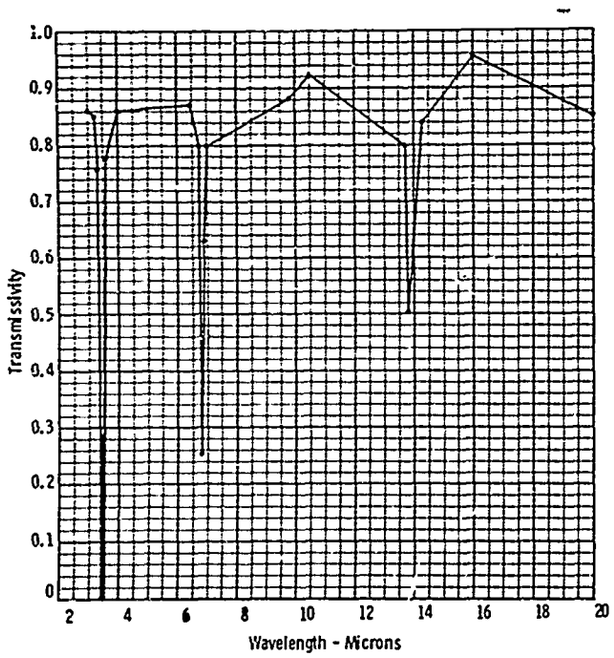


FIGURE 35 29 SEA SPACE/MERFAB SCRIM, MAX

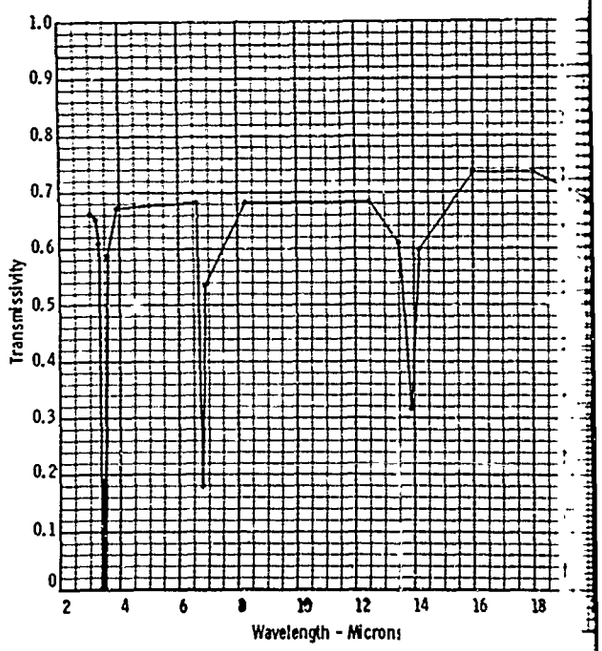
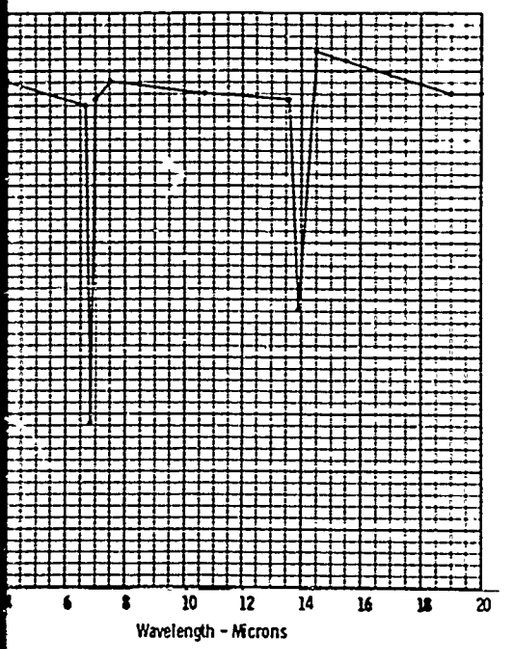


FIGURE 36 30 SEA SPACE/MERFAB LOAD WEB

A



28 SEA SPACE/MERFAB SINGLE SCRIM, MAX

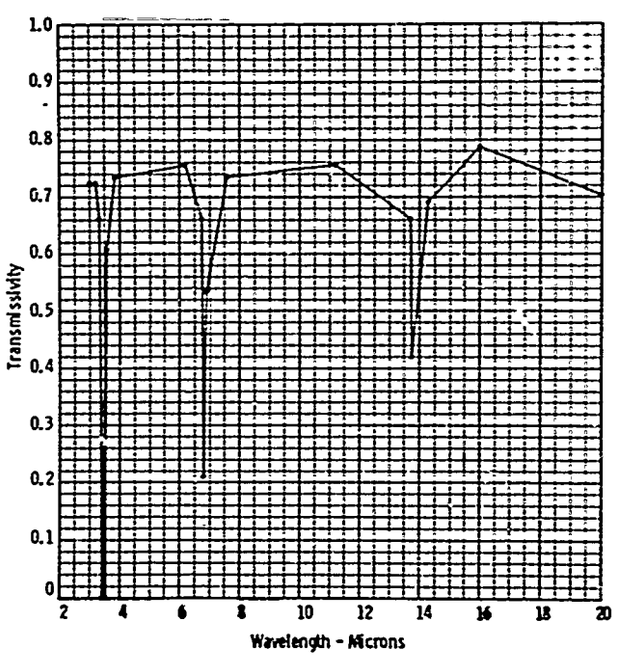
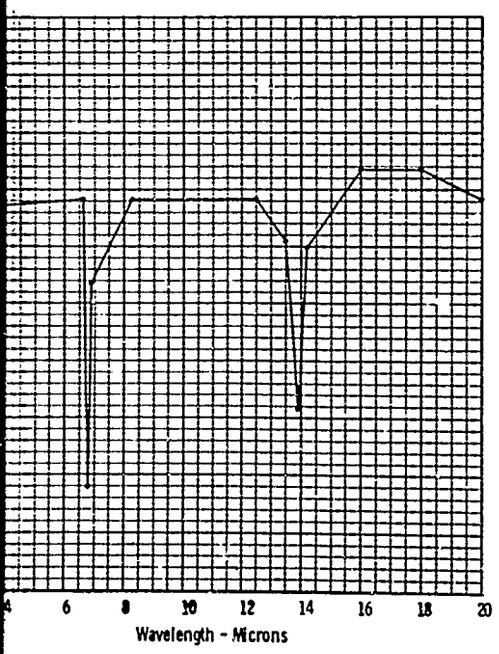


FIGURE 34 29 SEA SPACE/MERFAB SCRIM, MIN



30 SEA SPACE/MERFAB LOAD WEB SCRIM, MIN

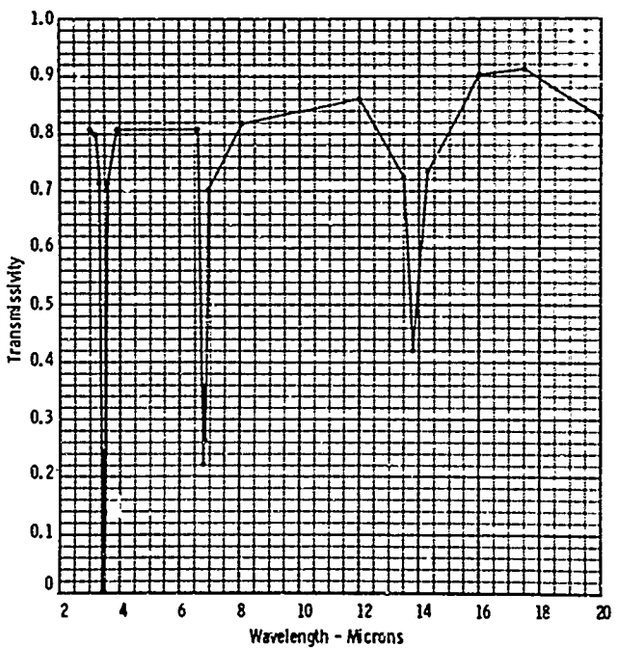


FIGURE 37 30 SEA SPACE/MERFAB LOAD WEB SCRIM, MAX

B

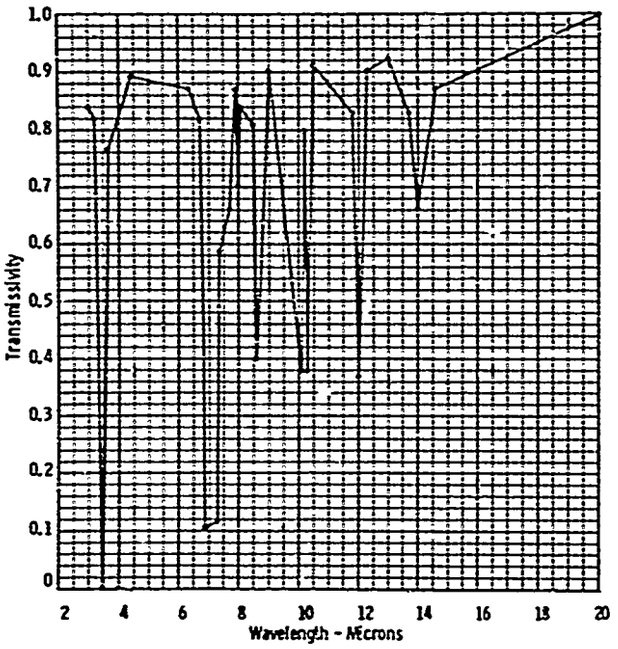


FIGURE 38 31 SEA SPACE/S-FAB

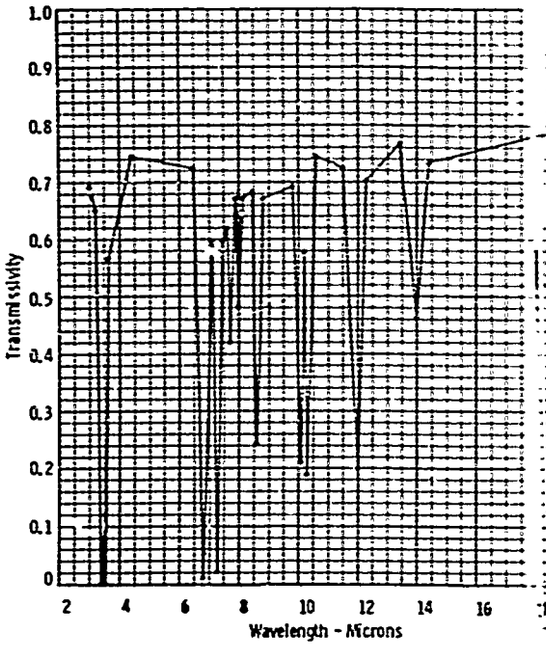


FIGURE 39 32 SEA SPACE/S-FAB SEAMED W

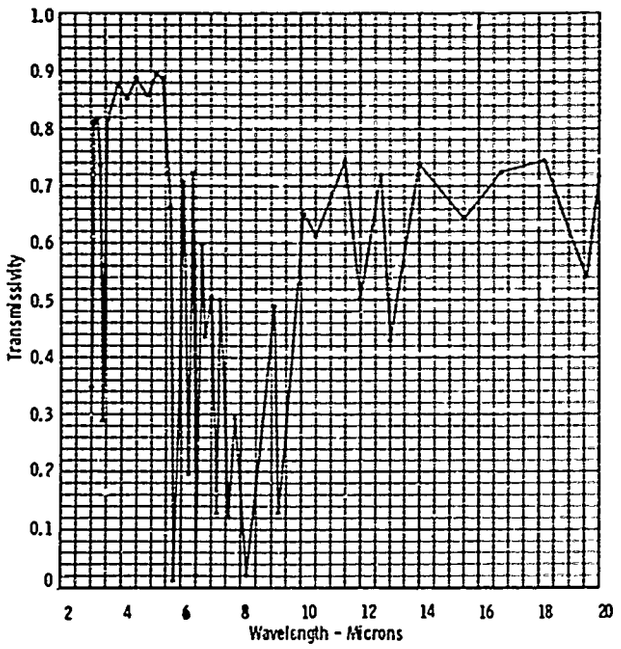


FIGURE 41 33 WINZEN/POLYURETHANE .3 MIL 0% ELONG

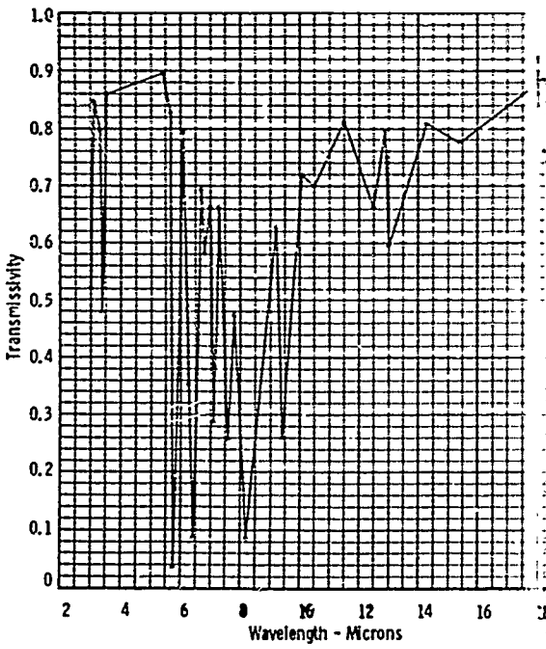
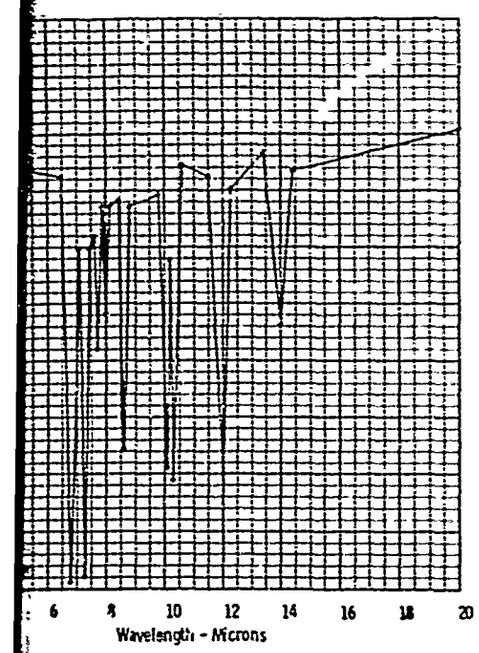


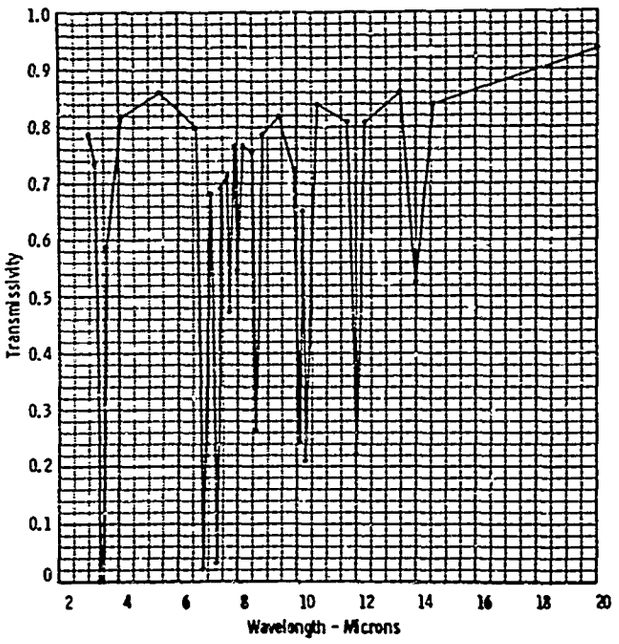
FIGURE 42 33 WINZEN/POLYURETHANE .3

A

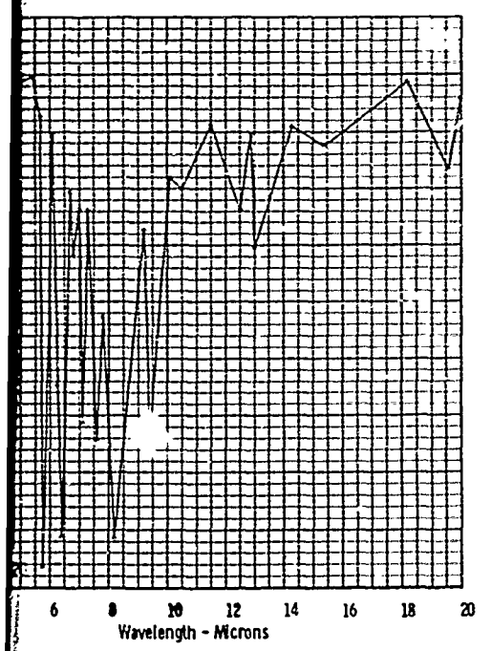


SEA SPACE/S-FAB SEAMED WITH SCRIM, MIN

FIGURE 40

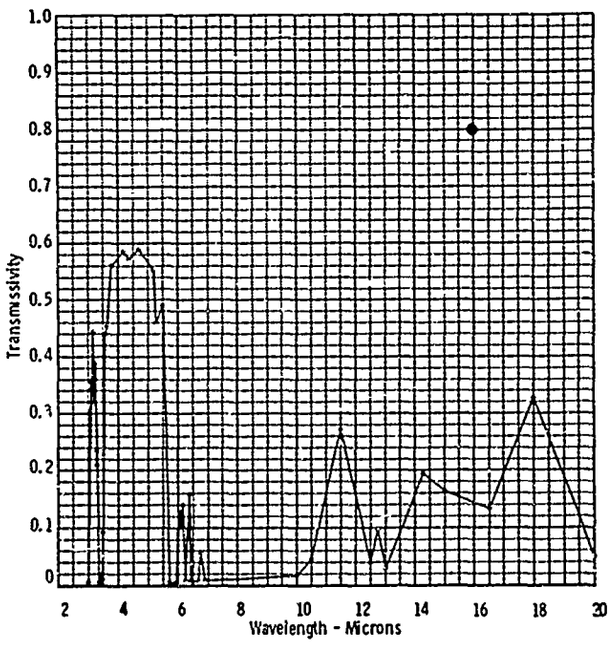


32 SEA SPACE/S-FAB SEAMED WITH SCRIM, MAX



WINZEN/POLYURETHANE .3 MIL 50% ELONG

FIGURE 43



34 SEA SPACE/POLYURETHANE 1. MIL 0% ELONG

B

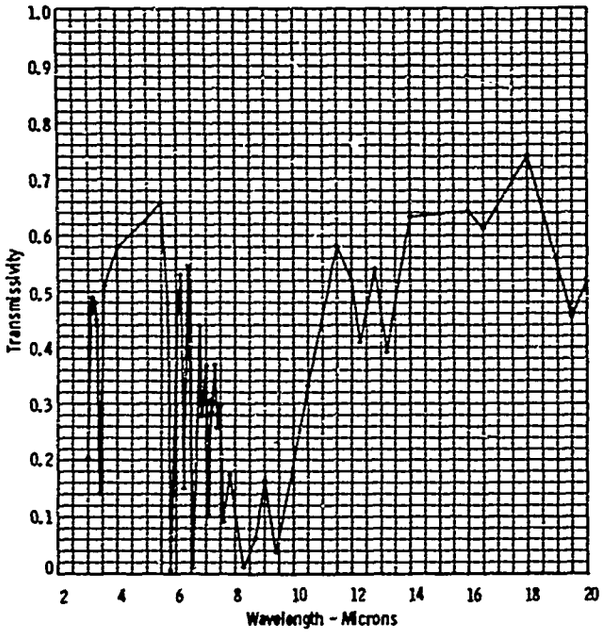


FIGURE 44 34 SEA SPACE/POLYURETHANE 1. MIL 100% ELONG

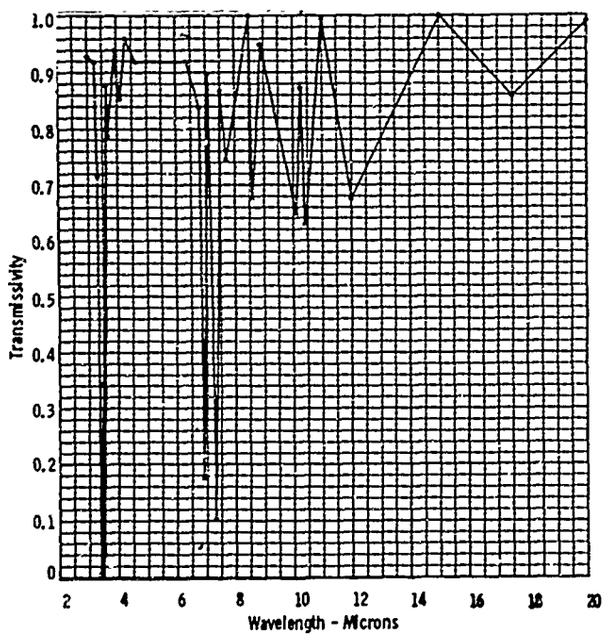


FIGURE 45 35 POLYPROPYLENE .5 MIL

TABLE I

THERMAL RADIATION PROPERTIES - SOLAR SPECTRUM
(.22 - 3. λ)

POLYETHYLENE		MANUFACTURER/TYPE		τ	α	α_{eff}
1	.75 mil	Unknown/Unknown		.8801	.0699	.1347
			Eppley Thermopile	.875		
2	1.0 mil	Viron		.8103	.1397	.2588
			Eppley Thermopile	.838		
4	1.5 mil	Winzen		.7854	.1646	.3007
			Eppley Thermopile	.863		
5	1.5 mil	Raven/Roll 2580		.8893	.0607	.1176
				.8748	.0752	.1445
			Average	.8820	.0679	.1310
			Eppley Thermopile	.888		
6	1.5 mil	Raven/Visqueen Roll 9988		.8881	.0619	.1197
7	1.5 mil	Stratofilm		.8912	.0587	.1138
				.8929	.0570	.1106
			Average	.8920	.0578	.1122
8	1.5 mil	Visqueen		.8885	.0615	.1187
				.8731	.0769	.1476
			Average	.8808	.0692	.1331
			Eppley Thermopile	.888		

TABLE I (Continued)

		MANUFACTURER/TYPE		τ	α	α_{eff}
POLYETHYLENE (continued)						
9	1.7 mil	Stratofilm		.8903	.0596	.1156
				.8896	.0603	.1168
			Average	.8899	.0599	.1162
10	2. mil	Raven		.8935	.0565	.1097
MYLAR COMPOSITES						
23	.25 mil scrim	GTS/GT-66		.8738	.0762	.1462
			Eppley Thermopile	.775		
24	.35 mil scrim	GTS/S-11		.8375	.1125	.2117
				.7889	.1611	.2949
			Average	.8132	.1368	.2533
			Eppley Thermopile	.700		
25	.25 mil scrim	GTS/GT-111		.8619	.0804	.1679
				.8579	.0920	.1752
			Average	.8599	.0862	.1716
OTHER MATERIALS						
26	.17 mil	Sea Space/ Merfilm		.9112	.0388	.076

TABLE I (Continued)

OTHER MATERIALS (continued)		MANUFACTURER/TYPE		τ	α	α_{eff}
			Eppley Thermopile	.875		
27	.28 mil	Sea Space/ Merfilm		.9146	.0354	.0694
			Eppley Thermopile	.884		
28	One way scrim	Sea Space/ Merfab				
			Eppley Thermopile	.838	.112	.210
29	Scrim	Sea Space/ Merfab				
			Eppley Thermopile	.850	.100	.189
30	Scrim	Sea Space/ Merfab-Loadweb				
			Eppley Thermopile	.800	.150	.376
31	Plain	Sea Space/ S-Fab				
			Eppley Thermopile	.888	.062	.119
32	Scrim	Sea Space/ S-Fab				
			Eppley Thermopile	.806	.144	.266
33	.3 mil	Winzen/ Polyurethane	0 percent elong	.8633	.0867	.1656
			50 percent elong	.8658	.0842	.1610

TABLE I (Continued)

				τ	α	α_{eff}
OTHER MATERIALS (continued)		MANUFACTURER/TYPE				
34	1. mil	Sea Space/ Polyurethane	0 percent elong	.7903	.1597	.2926
			100 percent elong	.7383	.2117	.3762
35	.5 mil	Polypropylene		.9060	.0440	.0860
36		Smoky Polyethy-lene		.7893	.1606	.2916
RECENT TESTS						
37	.55 mil	Visqueen X-124		.9142	.0357	.0702
				.9144	.0355	.0697
			A erage	.9143	.0356	.0699
38	.75 mil	Visqueen X-124		.9131	.0338	.0664
				.9151	.0318	.0626
			Average	.9141	.0328	.0645
39	1.0 mil	Visqueen X-124		.9129	.0460	.0898
				.9128	.0461	.0900
			Average	.9128	.0460	.0899
40	1.5 mil	Visqueen X-124		.9051	.0448	.0875
				.9102	.0397	.0779
			Average	.9076	.0422	.0827

TABLE 1 (Continued)

RECENT TESTS (continued)		MANUFACTURER/TYPE		τ	α	α_{eff}
41	.95 mil	India C		.8952	.0697	.1345
				.8875	.0774	.1486
			Average	.8914	.0736	.1416
42	1.03 mil	India A		.8906	.0553	.1070
				.8904	.0555	.1075
			Average	.8905	.0554	.1072
43	1.39 mil	India B		.8869	.0770	.1480
				.8832	.0807	.1546
			Average	.8851	.0789	.1513

TABLE II

THERMAL RADIATION PROPERTIES - INFRARED (3. - 20. λ)

POLYETHYLENE		MANUFACTURER/TYPE		Blackbody Temp. °C	τ	α	α_{eff}	α_{est}
1	.75 mil	Unknown/Unknown		289.6	.8647	.0853	.1630	.1072
2	1.0 mil	Viron/Unknown		289.6	.7894	.1606	.2941	.2390
		Measured Emissivity				.16		
3	1.0 mil	Ethyl/Visqueen	TNT	225.	.8387	.1117	.2103	.1235
				225.	.8458	.1037	.1961	.1062
			Average	225.	.8422	.1077	.2032	.1148
	1.0 mil	Ethyl/Visqueen	TNT	289.	.8347	.1157	.2174	.1602
				289.	.8386	.1109	.2088	.1487
			Average	289.	.8366	.1133	.2131	.1547
4	1.5 mil	Winzen/Unknown		225.				.2405
				289.6	.7572	.1928	.3465	.2684
5	1.5 mil	Raven/Roll 2580		225.	.7572	.1928	.3465	.2685
	(NCAR Photograph of Failure)			289.	.7497	.2003	.3584	.1682
6	1.5 mil	Raven/Visqueen Roll 9988		289.				.2377
7	1.5 mil	Stratofilm		225.	.8897	.0603	.1167	.0340
				225.	.8896	.0603	.1168	.0723
			Average	225.	.8897	.0603	.1167	.07145

TABLE II (Continued)

POLYETHYLENE (continued)		MANUFACTURER/TYPE		Blackbody Temp. °C	τ	α	α_{eff}	α_{est}
	1.5 mil	Stratofilm		289.	.8850	.0649	.1254	.0706
				289.	.8862	.0637	.1232	.0934
			Average	289.	.8856	.0643	.1243	.0825
8	1.5 mil	Raven/Visqueen Roll 9996						
		(ADL Flight)		225.	.8964	.1036	.1959	.1558
				289.	.8348	.1152	.2165	.1856
				289.				.2166
9	1.7 mil	Stratofilm		225.	.8873	.0626	.1211	.1198
				225.	.8821	.0678	.1308	.1412
			Average	225.	.8847	.0652	.1259	.1305
				289.	.8869	.0630	.1219	.1209
				289.	.8783	.0716	.1379	.1427
			Average	289.	.8826	.0673	.1299	.1318
10	1.5 mil	Raven/Visqueen Roll 10004		289.	.8231	.1269		.2368
11	5.5 mil	Ethyl/Visqueen	TNT	225.	.7043	.2556	.4432	.3675
				225.	.7003	.2597	.4491	.3711
			Average	225.	.7023	.2576	.4461	.3693
				289.	.6833	.2766	.4736	.4182
				289.	.6744	.2855	.4861	.4277
			Average	289.	.6788	.2810	.4798	.4229

TABLE II (Continued)

POLYETHYLENE (continued)		MANUFACTURER/TYPE	Blackbody	Temp. °C	τ	α	α_{eff}	α_{est}
12	6.0 mil	Ethyl/Visqueen	TNT	225.	.7057	.2564	.4445	.3698
				225.	.6992	.2629	.4540	.3689
			Average	225.	.7024	.2596	.4492	.3693
				289.	.6787	.2834	.4833	.4265
				289.	.6726	.2895	.4920	.4292
			Average	289.	.6756	.2864	.4876	.4278
13	1.0 mil	Ethyl/Visqueen	0-102	225.	.8274	.1222	.2287	.1521
				225.	.8445	.1059	.2000	.1092
			Average	225.	.8359	.1140	.2143	.1306
				289.	.8244	.1252	.2339	.1837
				289.	.8371	.1133	.2131	.1521
			Average	289.	.8307	.1197	.2235	.1179
14	8.0 mil	Ethyl/Visqueen	0-102	225.	.6561	.3056	.5142	.4062
				225.	.6616	.3001	.5065	.4050
			Average	225.	.6588	.3028	.5103	.4056
				289.	.6250	.3367	.5125	.4784
				289.	.6297	.3320	.5494	.4759
			Average	289.	.6273	.3343	.5309	.4771
15	8.5 mil	Ethyl/Visqueen	0-102	225.	.6518	.3251	.5421	.4339
				225.	.6086	.3683	.5978	.4785
			Average	225.	.6302	.3467	.5699	.4572

TABLE II (Continued)

POLYETHYLENE (continued)		MANUFACTURER/TYPE		Blackbody Temp. °C	τ	α	α_{eff}	α_{est}
				289.	.6160	.3609	.5885	.5102
				289.	.5777	.3992	.6353	.5508
			Average	289.	.5968	.3801	.6219	.5305
16	1.0 mil	Ethyl/Visqueen	MP	225.	.8098	.1206	.2255	.1987
				225.	.8571	.0733	.1408	.0862
			Average	225.	.8334	.0969	.1831	.1424
				289.	.8063	.1241	.2317	.2126
				289.	.8426	.0878	.1673	.1257
			Average	289.	.8244	.1059	.1995	.1691
17	8.0 mil	Ethyl/Visqueen	MP	225.	.6180	.3361	.5538	.5008
				225.	.6253	.3288	.5443	.5098
			Average	225.	.6216	.3324	.5490	.5052
				289.	.5815	.3726	.5997	.5549
				289.	.5908	.3633	.5882	.5553
			Average	289.	.5861	.3679	.5939	.5551
18	10. mil	Ethyl/Visqueen	MP	225.	.5761	.3844	.6150	.6026
				225.	.5453	.4153	.6510	.6338
			Average	225.	.5602	.3998	.6330	.6232
				289.	.5295	.4310	.6686	.6468
				289.	.5055	.4550	.6944	.6725

TABLE II (Continued)

POLYETHYLENE (continued)		MANUFACTURER/TYPE		Blackbody Temp. °C	τ	α	α_{eff}	α_{est}
			Average	289.	.5175	.4430	.6815	.6596
		Combined	Average		.5388	.4214	.6572	.6414
19	15. mil	Ethyl/Visqueen	MP	225.	.5025	.4586	.6984	.6715
				225.	.5090	.4521	.6916	.6652
			Average	225.	.5057	.4553	.6900	.6683
				289.	.4565	.5046	.7443	.7160
				289.	.5190	.4421	.6808	.7110
			Average	289.	.4887	.4733	.7125	.7135
		Combined	Average	225-289	.4972	.4643	.7012	.6909
20	17.5 mil	Ethyl/Visqueen	MP	225.	.4398	.5104	.7467	.7503
				225.	.4493	.5010	.7379	.7251
			Average	225.	.4945	.5057	.7423	.7377
				289.	.3904	.5598	.7899	.7806
				289.	.3996	.5507	.7823	.7632
			Average	289.	.3950	.5552	.7861	.7719
		Combined	Average	225-289	.4447	.5304	.7642	.7548
21	21. mil	Ethyl/Visqueen	MP	225.	.4080	.5426	.7755	.7493
				225.	.4101	.5405	.7737	.7466
			Average	225.	.4090	.5415	.7746	.7479
				289.	.4565	.5941	.8169	.7907
				289.	.3598	.5908	.8144	.7881

TABLE II (Continued)

		MANUFACTURER/TYPE		Blackbody Temp. °C	τ	α	α_{eff}	α_{est}
POLYETHYLENE (continued)								
			Average	289.	.4081	.5924	.8156	.7894
		Combined	Average	225-289	.4085	.5669	.7951	.7686
22	22. mil	Ethyl/Visqueen	MP	225.	.3893	.5740	.8060	.7788
				225.	.3947	.5687	.8017	.7776
			Average	225.	.3920	.5713	.8038	.7782
				289.	.3416	.6217	.8422	.8168
				289.	.3464	.6170	.8388	.8150
			Average	289.	.3440	.6193	.8405	.8159
		Combined	Average	225-289	.3680	.6453	.8221	.7970
MYLAR COMPOSITES								
23	.25 mil scrim	G.T. Scjheldahl/ GT-66		225.				.4222
				225.				.8093
			Average	225.				.6157
				289.	.5284	.4216	.6561	.4994
				289.	.2613	.6887	.8781	.8321
			Average	289.	.3948	.5551	.7671	.6657
		Combined	Average	225-289				.6407
			Emissivity			.42		

TABLE II (Continued)

				Blackbody Temp. °C	τ	α	α_{eff}	α_{est}
MYLAR COMPOSITES (continued)		MANUFACTURER/TYPE						
24	.35 mil scrim	G.T. Scjheldahl/ S-11		225.				.8149
				225.				.7239
			Average	225.				.7694
				289.	.2505	.6995	.8839	.8379
				289.	.2618	.6882	.8778	.7782
			Average	289.	.2561	.6938	.8808	.8030
		Combined	Average	225-289				.7062
		Measured Emissivity				.62		
25	.25 mil scrim	G.T. Scjheldahl/ GT-111		225.	.6203	.3296	.5449	.5540
				225.	.5223	.4276	.6628	.6634
			Average	225.	.5713	.3786	.6038	.6087
				289.	.5905	.3794	.6073	.5957
				289.	.4799	.4700	.7075	.6960
			Average	289.	.4952	.4247	.6574	.6458
		Combined	Average	225-289	.5332	.4016	.6306	.6272
OTHER MATERIALS								
26	.17 mil	Sea Space/Merfilm		289.	.9214	.0286		.0564
27	.28 mil	Sea Space/Merfilm		289.	.9067	.0433		.0846

TABLE II (Continued)

OTHER MATERIALS (continued)		MANUFACTURER/TYPE		Blackbody Temp. °C	τ	α	α_{eff}	α_{est}
28	One way scrim	Sea Space/Merfab		289.	.8565	.0935		.1778
				289.	.7360	.2140		.3798
			Average	289.	.7962	.2537		.2788
29	Scrim	Sea Space/Merfab		289.	.8567	.0933		.1775
				289.	.7156	.2344		.4110
			Average	289.	.7861	.2638		.2942
30	Scrim	Sea Space/ Merfab	Loadweb	289.	.8148	.1352		.2427
				289.	.6677	.2823		.4806
			Average	289.	.7412	.2087		.3616
31	Plain	Sea Space/S-Fab		289.	.8493	.1007		.1907
32	Scrim	Sea Space/S-Fab		289.	.7963	.1537		.2826
				289.	.6911	.2589		.4472
			Average	289.	.7437	.2063		.3649
33	.3 mil	Winzen/Polyurethane	0% elong	225.	.5929	.3771	.5800	.5114
			50% elong	225.	.7058	.2442	.4257	.3240
			0% elong	289.	.5516	.3984	.6298	.5144
			50% elong	289.	.6583	.2917	.4939	.4132
34	1.0 mil	Sea Space/Polyurethane	0% elong	225.	.1308	.8192	.9320	.9403
			100% elong	225.	.4781	.4719	.7090	.6904

TABLE II (Continued)

OTHER MATERIALS (continued)		MANUFACTURER/TYPE		Blackbody Temp. °C	τ	α	α_{eff}	α_{est}
			0% elong	289.	.1187	.8313	.9352	.9395
			100% elong	289.	.4231	.5269	.7616	.7362
35	.5 mil	Unknown/Polypro-pylene		225.	.8573	.0927	.1763	.0703
				289.	.8910	.1090	.2056	.1308
36		Smoky Polyethylene		225.	.8354	.1145	.2152	.1980
				289.	.8192	.1307	.2434	.2248
37	.55 mil	Visqueen X-124		289.	.8837	.0662	.1279	
				289.	.8661	.0838	.1491	
			Average		.8749	.0750	.1385	
38	.75 mil	Visqueen X-124		289.	.8672	.0797	.1528	
				289.	.8568	.0901	.1561	
			Average		.8620	.0849	.1544	
39	1.0 mil	Visqueen X-124		289.	.8390	.1199	.2248	
				289.	.8499	.1090	.2056	
			Average		.8444	.1144	.2152	
40	1.5 mil	Visqueen X-124		289.	.8238	.1261	.2356	
				289.	.8226	.1273	.2376	
			Average		.8232	.1267	.2366	

TABLE II (Continued)

OTHER MATERIALS (continued)		MANUFACTURER/TYPE		Blackbody Temp. °C	τ	α	α_{eff}	α_{est}
41	.95 mil	India C		289.	.8606	.1043	.1974	
				289.	.8482	.1167	.2193	
			Average		.8544	.1105	.2084	
42	1.03 mil	India A		289.	.8397	.1062	.2006	
				289.	.8486	.0973	.1660	
			Average		.8442	.1000	.1833	
43	1.39 mil	India B		289.	.8298	.1341	.2497	
				289.	.8190	.1449	.2680	
			Average		.8244	.1395	.2588	

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1. I. W. Dingwell, W. K. Sepetoski and R. M. Lucas, "Vertical Motion of High Altitude Balloons", Technical Report II, Arthur D. Little, Inc., for the Office of Naval Research, December 1963.

2. A. E. Germeles, "Vertical Motion of High Altitude Balloons", Technical Report IV, Arthur D. Little, Inc., for the Office of Naval Research, July 1966.

APPENDIX

FORTRAN LISTING OF COMPUTER PROGRAM USED TO CALCULATE INTEGRATED ABSORPTIVITY

```
// FOR
*LIST ALL
*IOCS(CARD,TYPEWRITER,KEYBOARD,1132 PRINTER,DISK)
C       APPARENT HEAT TRANSFER COEFFICIENTS IN A TRANSPARENT SPHERE
C       REFLECTANCE VALUES MUST BE SMALL IF WAVELENGTH DEPENDENT
        DIMENSION WL1(150),S(150),TITLE(20)
        C1=37413.0
        C2=14388.0
        SIGMA=5.6688E-12
        READ(2,15)WLMIN,WLMAX,T
   15   FORMAT(3F10.4)
        DO 16 I=1,117
   16   READ(2,15)WL1(I),S(I)
   11   READ(2,110)(TITLE(I),I=1,18)
  110   FORMAT(18A4)
        READ(2,515)WL,R,N
  515   FORMAT(2F10.4,I5)
        IF(WL)1000,1000,120
  120   IF(WL-.25)80,80,90
   80   ZIOT=.139641
        NWL=117
        ZIO=0.0
        DO 6 I=2,NWL
    6   ZIO=ZIO+.5*(S(I)+S(I-1))*(WL1(I)-WL1(I-1))
        ZIOV=ZIO
        IPRIN=1
        GO TO 100
   90   T=WL
        READ(2,15)WLMIN,WLMAX
        DW=(WLMAX-WLMIN)*.01
        WO=WLMIN-DW
        NWL=101
        Z=0.0
        DO 104 I=1,NWL
        WO=WO+DW
        WL1(I)=WO
        S(I)=C1/((WO**5)*(EXP(C2/(WO*T))-1.0))
  104   Z=Z+S(I)
        ZIO=DW*(Z-.5*(S(1)+S(NWL)))
        ZIOT=SIGMA*(T**4)
        ZIOV=0.0
        READ(2,15)WLL,RL
        READ(2,15)WLU,RU
        I=1
   21   R1=RL+((WL1(I)-WLL)*(RU-RL)/(WLU-WLL))
        S1=S(I)
        S(I)=S1*R1
        IF(I-1)17,17,107
  107   ZIOV=ZIOV+.5*(S(I)+S(I-1))*(WL1(I)-WL1(I-1))
   17   I=I+1
        IF(I-NWL)19,19,200
   19   IF(WL1(I)-(WLU+.0001))21,21,22
   22   WLL=WLU
        RL=RU
        READ(2,15)WLU,RU
```

```
      GO TO 19
  200 IPRIN=2
  100 WRITE(3,211)(TITLE(I),I=1,18)
  211 FORMAT(1H1,18A4)
      WRITE(3,105)WLMIN,WLMAX,T
  105 FORMAT(/////2X,'WAVELENGTH RANGE IS',F5.1,' TO',F5.1,' MICRONS
     1T=',F5.1,' DEGREES KELVIN')
      WRITE(3,106)ZIO
  106 FORMAT(2X,'SPECTRAL INTENSITY OVER THIS RANGE IS ',F12.8,' WATTS
     1PER SQ CM,')
      WRITE(3,1106)ZIOT
 1106 FORMAT(2X,'FROM A TOTAL OF ',F12.8,' WATTS PER SQ CM')
      GO TO(30,40),IPRIN
   40 WRITE(3,109)ZIOV
  109 FORMAT(//2X,'INTENSITY AFTER ABSORPTION',F12.8)
   44 READ(2,515)WL,R,N
   30 WRITE(3,18)WL,R,N
   18 FORMAT(14X,2F10.4,I5,32X,'.')
      WLO=WL
      RO= R
      NO=N
      YL=R*S(1)
      Z=0.0
      WLL=WL
      GO TO(303,302),NO
  303 RR1=1.-AR-R*R/(1.-AR)
      YL1=RR1*S(1)
      ZZ1=0.0
  302 I=2
  330 READ(2,515)WL,R,N
      WRITE(3,18)WL,R,N
      IF(N-NO)31,35,31
   31 WRITE(3,9)
    9 FORMAT(14X,'CARDS OUT OF ORDER')
      STOP
   35 NA1=1
      NA2=1
      IF(WL1(I)-WL+.001)36,37,38
   36 WLU=WL1(I)
      NA2=0
      R1=RO+((WLU-WLO)*(R-RO)/(WL-WLO))
      S1=S(I)
      GO TO 39
   37 WLU=WL
      S1=S(I)
      R1=R
      GO TO 39
   38 WLU=WL
      NA1=0
      R1=R
      S1=S(I-1)+((WLU-WL1(I-1))*(S(I)-S(I-1))/(WL1(I)-WL1(I-1)))
   39 YU=S1*R1
      DL=WLU-WLL
```

```
      Z=Z+.5*DL*(YU+YL)
      GO TO(311,310),NO
  311 RR1=1.-AR-R1*R1/(1.-AR)
      YU1=RR1*S1
      ZZ1=ZZ1+.5*DL*(YU1+YL1)
      YL1=YU1
  310 YL=YU
      WLL=WLU
      I=I+NA1
      IF(NA2)42,35,42
   42 WLO=WL
      RO= R
      IF(WL-WLMAX+.0001)330,3,3
    3 GO TO(112,111),NO
  111 ZIR=Z
      AR=ZIR/ZIOV
      GO TO 44
  112 ZIT=Z
      AT=ZIT/ZIOV
      AA=1.-AT-AR
      A2=ZZ1/ZIOV
      AAA=AA*(1.+AT/(1.-AR))
      WRITE(3,152)AR
      WRITE(3,151)AT
      WRITE(3,153)AA
      WRITE(3,154)A2
      WRITE(3,155)AAA
  152 FORMAT(///12X,'MEAN REFLECTANCE=        ',F10.4)
  151 FORMAT(12X,'MEAN TRANSMITTANCE=      ',F10.4)
  153 FORMAT(12X,'MEAN ABSORBTANCE=        ',F10.4)
  154 FORMAT(12X,'EFFECTIVE ALPHA,EPSILON=',F10.4)
  155 FORMAT(12X,'MEAN EFF. ALPHA,EPSILON=',F10.4)
      GO TO 11
 1000 CALL EXIT
      END
```

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4. DESCRIPTIVE NOTES *(Type of report and inclusive dates)*

Technical Report - 1967

5. AUTHOR(S) *(Last name, first name, initial)*

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6. REPORT DATE June 1967	7a. TOTAL NO. OF PAGES 43	7b. NO. OF REFS Two (2)
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As the absorption of solar and earth atmosphere thermal radiation is an important factor in the vertical motion of high altitude balloons, the thermal radiation properties of the thin films that compose balloon fabrics must be determined. This report presents the results of property measurements made with spectrophotometer, emissometer, and thermal radiation measuring equipment. The films ~~which~~ were considered ~~fall into~~ three categories:

a. Polyethylenes,

b. Mylar Composites

c. Other Fabrics.

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14. KEY WORDS	LINK A ROLE	LINK A WT	LINK B ROLE	LINK B WT	LINK C ROLE	LINK C WT
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Spectral Radiation Properties						
Absorptivity						
Reflectivity						
Emissivity						
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