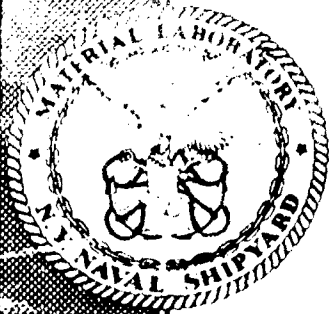


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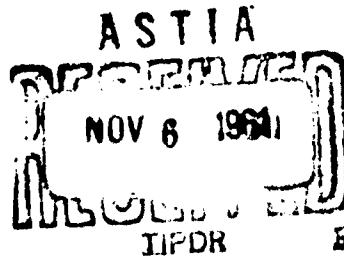
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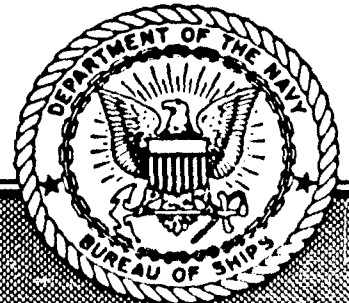
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U N C L A S S I F I E D

RESEARCH REPORT
on
THE SPECTRAL REFLECTANCE AND TRANSMITTANCE
OF STANDARD FABRICS FOR
THERMAL RADIATION EFFECTS STUDIES

Lab. Project 5046-3, Part 71, Final Report
NF 061-001
Technical Objective A-7, AFSPF 957

28 Aug 1956

G. P. de Ihery
W. Darksen
T. I. Monahan

Optics and Nucleonics Branch
J. M. McGreevy, Head

Superintending Engineer
GEO. J. DASHEFSKY

The Director
CAPTAIN A. B. JONES, Jr., USN

NAVAL MATERIAL LABORATORY
New York Naval Shipyard
Brooklyn 1, N. Y.

U N C L A S S I F I E D

SUMMARY

The spectral reflectance and transmittance of standard fabrics for thermal radiation research, varying in color from undyed to deep black, were measured for radiation of wave lengths from 0.40 to 2.7 microns. The spectral characteristics of white sheeting, olive green 107 cotton sateen, and wind resistant poplin, shade 116, were also measured. These standard cloths are being employed in the thermal radiation studies at NML and other laboratories. The reflectance for carbon-arc radiation of the standard fabrics ranged from 0.63 for the undyed sateens to 0.09 for the deep black. The carbon-arc radiant transmittances ranged from 0.12 for the undyed sateens to 0.00 for the dark gray, black and deep black. The radiant absorptances ranged from 0.25 for the undyed sateens to 0.91 for deep black.

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ADMINISTRATIVE INFORMATION

1. This investigation has been conducted at the Naval Material Laboratory as part of the program originally proposed by Commander, New York Naval Shipyard, confidential letter S99/15, Ser 960-22, of 15 March 1950 and approved by Bureau of Ships speedletter S99-(0)(340), Ser 340-75, of 6 April 1950. The Thermal Radiation studies at the Naval Material Laboratory are sponsored by the Armed Forces Special weapons Project. The reflectance and transmittance data of the standard fabrics were requested by Armed Forces Special Weapons Project letter, SWPEF-1 928 of 30 November, 1955 and the Quartermaster Research and Development Command letter, QMRDO-PRS of 30 November, 1955.

INTRODUCTION

2. A series of fabrics have been prepared by the Quartermaster Research and Development Command for use by the various agencies conducting thermal radiation effects studies under the sponsorship and coordination of the Armed Forces Special Weapons Project. These special fabrics consist of 9 oz./yd² cotton sateen dyed to various shades of gray with finely divided lampblack as a pigment and a methyl cellulose binder. Also included in the standard cloths were a light weight cotton sheeting and a poplin to be employed as component of the Hot-Wet uniform. The cloths were designated as follows:

- QM-1. cotton, sheeting, 4 oz., bleached.
- QM-2. cotton, sateen, 9 oz., prepared for dying.
- QM-3. cotton, sateen, 9 oz., O.G.107.
- QM-4. cotton, sateen, 9 oz., undyed, W/GMC.
- QM-5-65. cotton, sateen, 9 oz., GMC and carbon black, light gray.
- QM-6-40. cotton, sateen, 9 oz., GMC and carbon black, medium gray.
- QM-7-22. cotton, sateen, 9 oz., GMC and carbon black, dark gray.
- QM-8-12. cotton, sateen, 9 oz., GMC and carbon black, black.
- QM-9-7. cotton, sateen, 9 oz., GMC and carbon black, deep black.
- QA-RRS-1. cotton, W. R. Poplin, 5 oz., Type II, class A, shade 116.

3. For use in thermal radiation effect studies it is desirable to know the spectral reflectance and transmittance as well as the radiant absorptance, reflectance, and transmittance for the particular source employed. The Naval Material Laboratory has measured the spectral reflectance and transmittance for wave lengths from 0.40 to 2.7 microns and has computed the radiant absorptance, reflectance and transmittance for the carbon-arc and 3000 K black-body spectra.

EXPERIMENTAL PROCEDURE

4. The spectral reflectance and transmittance of special fabrics for thermal radiation studies were measured employing three spectrophotometers covering the wave length range from 0.40 to 2.7 microns. The data for the visible spectrum, from 0.40 to 0.70 micron, were obtained by the General Electric, dual beam, recording spectrophotometer. The near infra-red measurements, from 0.70 to 1.0 micron, were made with a similar spectrophotometer modified to measure longer wave lengths. The data for the infrared wave lengths from 1.0 to 2.7 microns, were measured employing a recording reflectometer, constructed at NML.¹

Bibliography.

5. The data on the infrared reflectometer were extended to 0.50 micron so that correlation between the three measuring devices could be obtained.
6. In the visible and near infrared regions a vitrolite reflectance standard, which had been calibrated against a smoked magnesium oxide surface by the National Bureau of Standards, was employed. The absolute reflectance of vitrolite was computed from data for magnesium oxide published by Middleton.²
7. In the infrared region above 1.0 micron, an aluminized glass mirror was employed as a reference reflectance standard. The reflectance of the aluminized mirror for wave lengths less than 1.0 micron was measured on the O. E. Spectrophotometers, and values for the longer infrared wave lengths were extrapolated employing the data for aluminized films as published by Hass.³
8. When measuring transmittances for diffuse substances, in the visible and near infrared, a light baffle was employed inside the collecting sphere of the General Electric Spectrophotometer to block transmitted light that would be directly deflected to the receiving cell before reflection from the sphere wall. The fabric samples were placed against the port in the sphere wall rather than in the normal position for specular samples. The diffusely transmitted energy which failed to enter the sphere in the specular position could be as much as 50 per cent.

RESULTS

9. The spectral reflectance and transmittance for the standard fabrics are given in Tables 1 and 2. For ease of inspection the spectral transmittance is plotted, in Figure 1 for the grays and in Figure 2 for the uniform fabrics. The spectral reflectance is similarly plotted in Figures 3 and 4, and the absorptance in Figures 5 and 6.
10. As an indication of the reproducibility of the reflectances obtained with the instruments used at NML, it was determined that the reflectance of the olive green cotton sateen deviated no more than ± 0.02 from the samples of the 9 oz/yd² OG 107 cotton sateen investigated periodically during the past four years.
11. The transmittance of the three darkest grays, the deep black, the black and dark gray was found to be less than 0.005 for all wave lengths. The two outer uniform fabrics, the OG sateen and poplin, likewise did not transmit radiation in the visible and near infrared but for wave lengths longer than 1.0 micron the transmittance was as high as 0.11 for the sateen and as high as 0.23 for the lighter poplin. The light sheeting, intended for an underwear fabric, transmitted 0.36 non-selectively in the visible and near infrared regions; for wave lengths longer than 1.4 microns, however, the transmittance decreased irregularly to a minimum of 0.15 at 2.5 microns. The transmittance of the medium gray, light gray and undyed fabrics was about 0.01 at 0.4 micron and at 2.7 microns, with a maximum value in the region of 1.0 micron, dependent on the amount of dye added. The fabrics which transmit, do so selectively with wave length.

12. The reflectance of the darker gray fabrics gradually increases from its lowest value at 0.4 microns to a maximum about twice this value at approximately 2 microns, resulting in a selectivity to this extent. The lighter grays and undyed sateens show the typical irregular spectral reflectance of cotton fabrics in general, with a maximum value in the red and near infrared regions. The reflectance is influenced only for the visible radiation by the finely divided lampblack pigment. The uniform fabrics which were dyed olive green have a low reflectance in the visible region, the irregular reflectance varying from a low of 0.05 at 0.4 microns to a maximum of about 0.1 at 0.55 microns and decreasing again for the red wave lengths. The reflectance for the uniform fabric increases rapidly in the near infrared to values of 0.60 to 0.65 at about 1.3 microns and follows the reflectance characteristic of the undyed fabrics for the longer infrared wave lengths. The reflectance characteristic of having twice the reflectance for the green radiant energy than for the other colors imparts the green color to the fabric; the low reflectance results in the dark or olive green shade.

13. The spectral absorptance for the three darkest gray sateens is high and only slightly selective. The other fabrics have a wave length selectivity to thermal radiation which is important in most studies.

14. The radiant reflectance, transmittance and absorptance were computed for the carbon-arc and the tungsten spectra and are listed in Table 3. Also included in the table are the values for the fabrics with special absorption characteristics prepared similarly as the present standard thermal radiation fabrics. The absorptance of the standard fabrics range from 91 per cent for the deep black to 25 per cent for the undyed sateen. Table 3 illustrates that the effect of the spectral selectivity of the standard fabrics is small for the range of sources normally employed in laboratory studies of intense thermal radiation effects. The carbon-arc and 3000 K black body radiant absorptance reflectance and transmittance for the three uniform fabrics, the O.G. cotton sateen, the poplin and the bleached sheeting however are appreciably selective.

15. The three darkest grays have no net thermal radiation energy transmittance as determined from the spectrophotometric data; the other fabrics, however, all have some transmittance even though only the 4 oz/yd² sheeting has visible transmittance. The difference in radiant absorptance between the poplin and sateen uniform fabrics is due only to the difference in the amount of infrared energy transmitted.

16. Visual examination of the gray fabrics of recent fabrication compared to those made several years ago indicates that the color designations will cause confusion. This is borne out by the reflectance and absorptance of the "deep black" fabric which has less absorption than one previously called "dark gray". Considerable burn and other thermal effect data have been obtained with the earlier gray sateens which will be of value in studies with these fabrics if proper corrections are made. For precise reference to a fabric the actual absorptance would provide definite designation of the particular fabric.

Approved:


A. D. JONES, JR., CAPTAIN, USN
The Director

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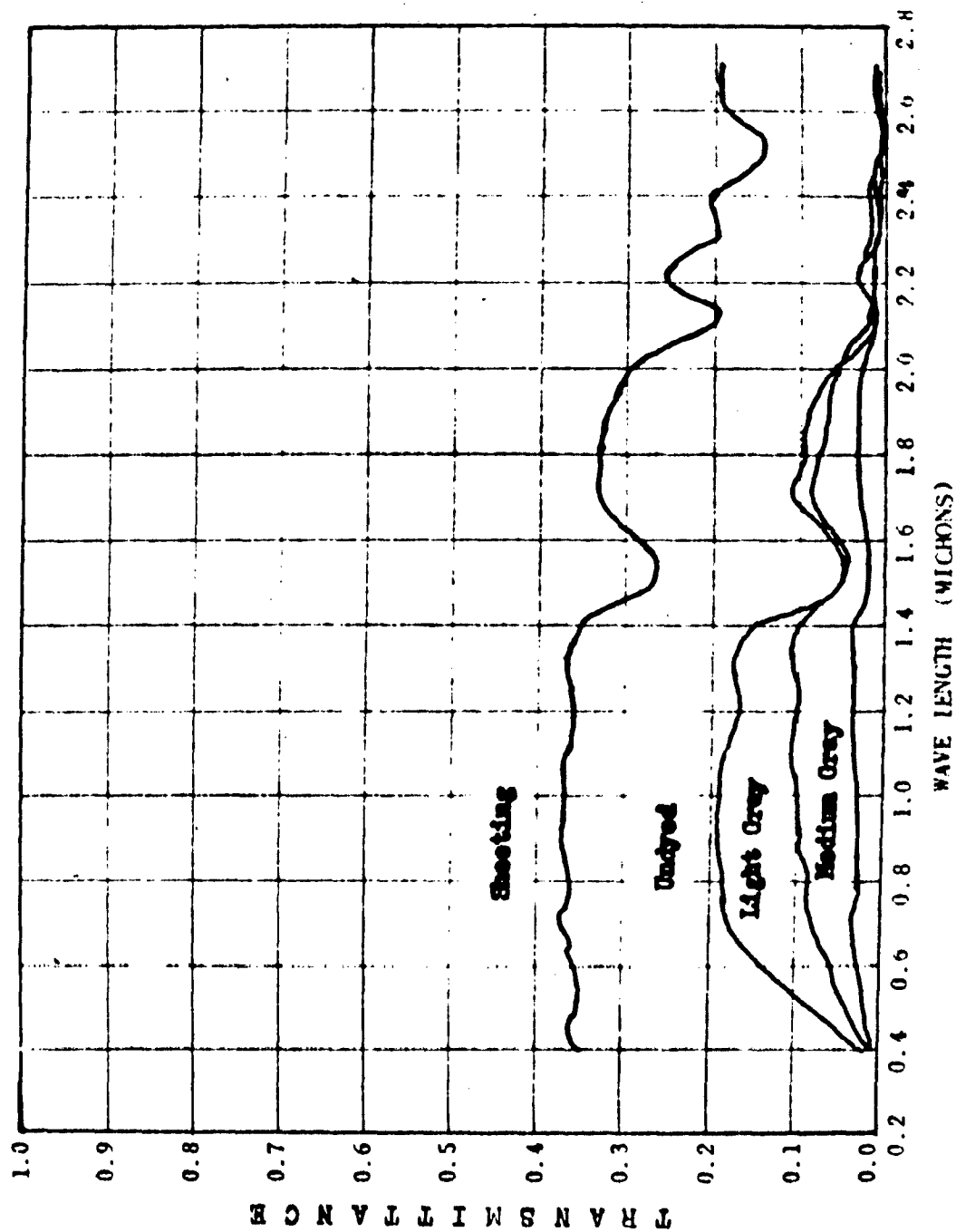


FIGURE 1. THE SPECTRAL TRANSMITTANCE OF THE STANDARD FABRICS FOR THERMAL RADIATION EFFECTS STUDIES

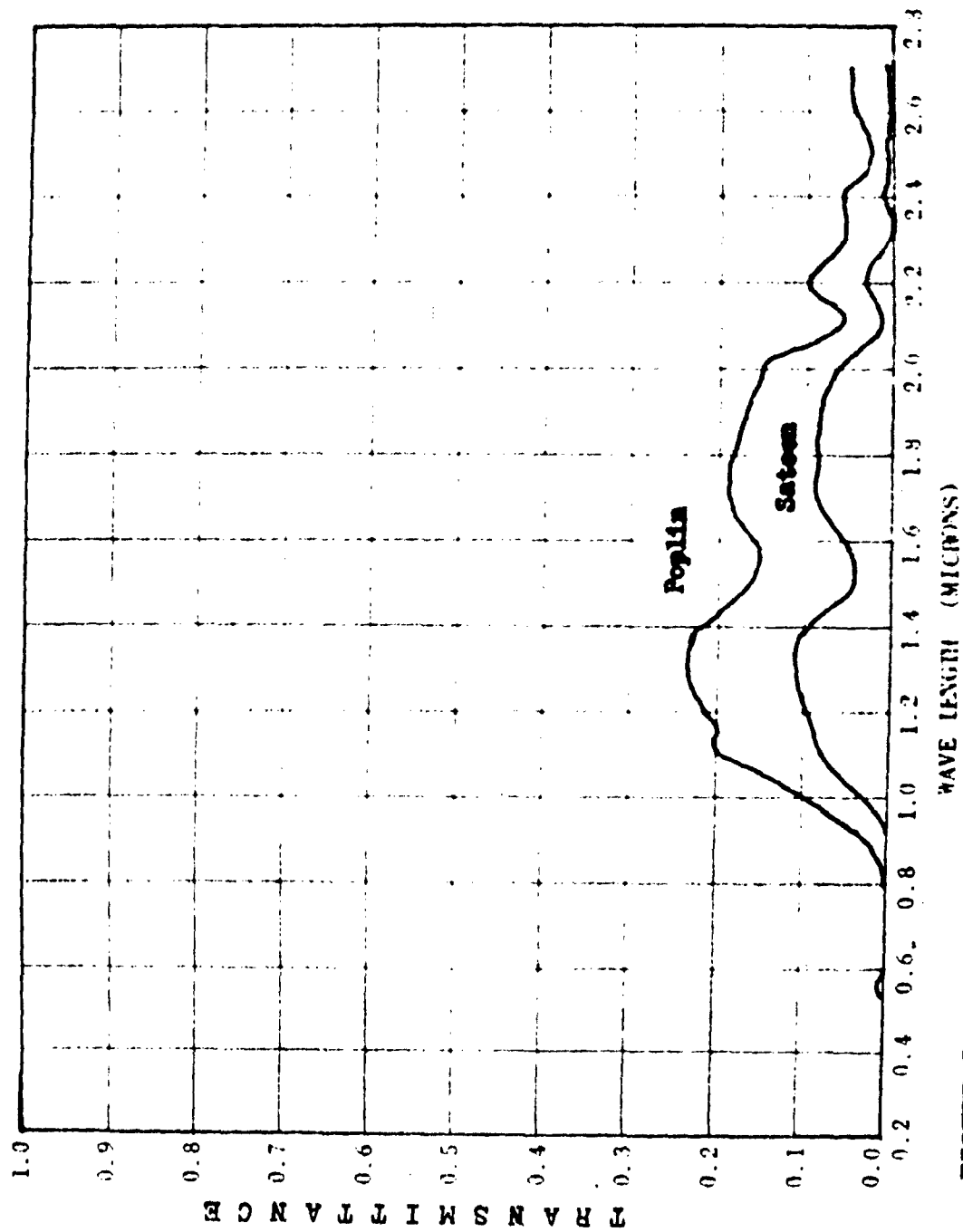


FIGURE 2. THE SPECTRAL TRANSMITTANCE OF THE UNIFORM FABRICS

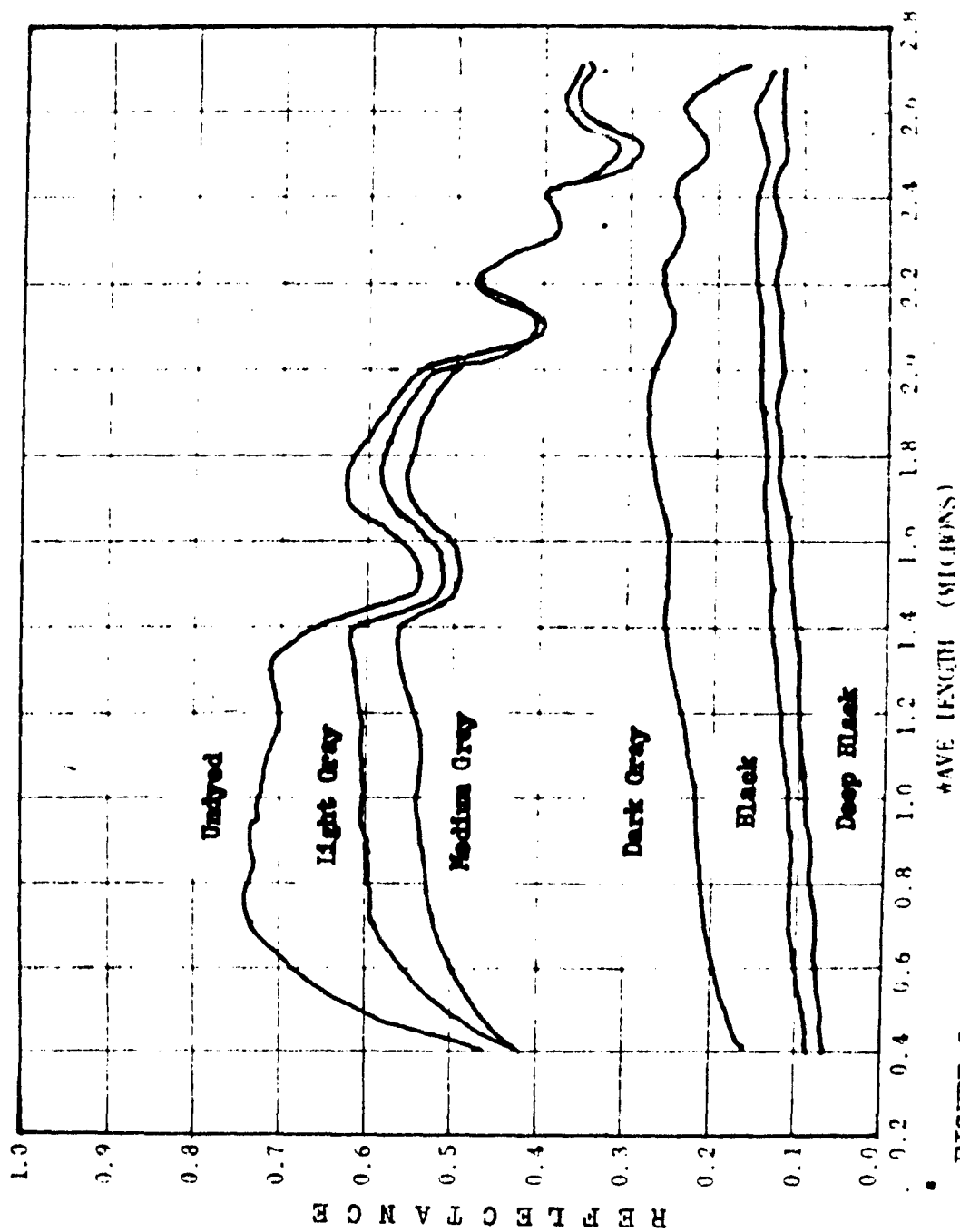


FIGURE 3. THE SPECTRAL REFLECTANCE OF THE STANDARD FABRICS
FOR THERMAL RADIATION EFFECTS STUDIES

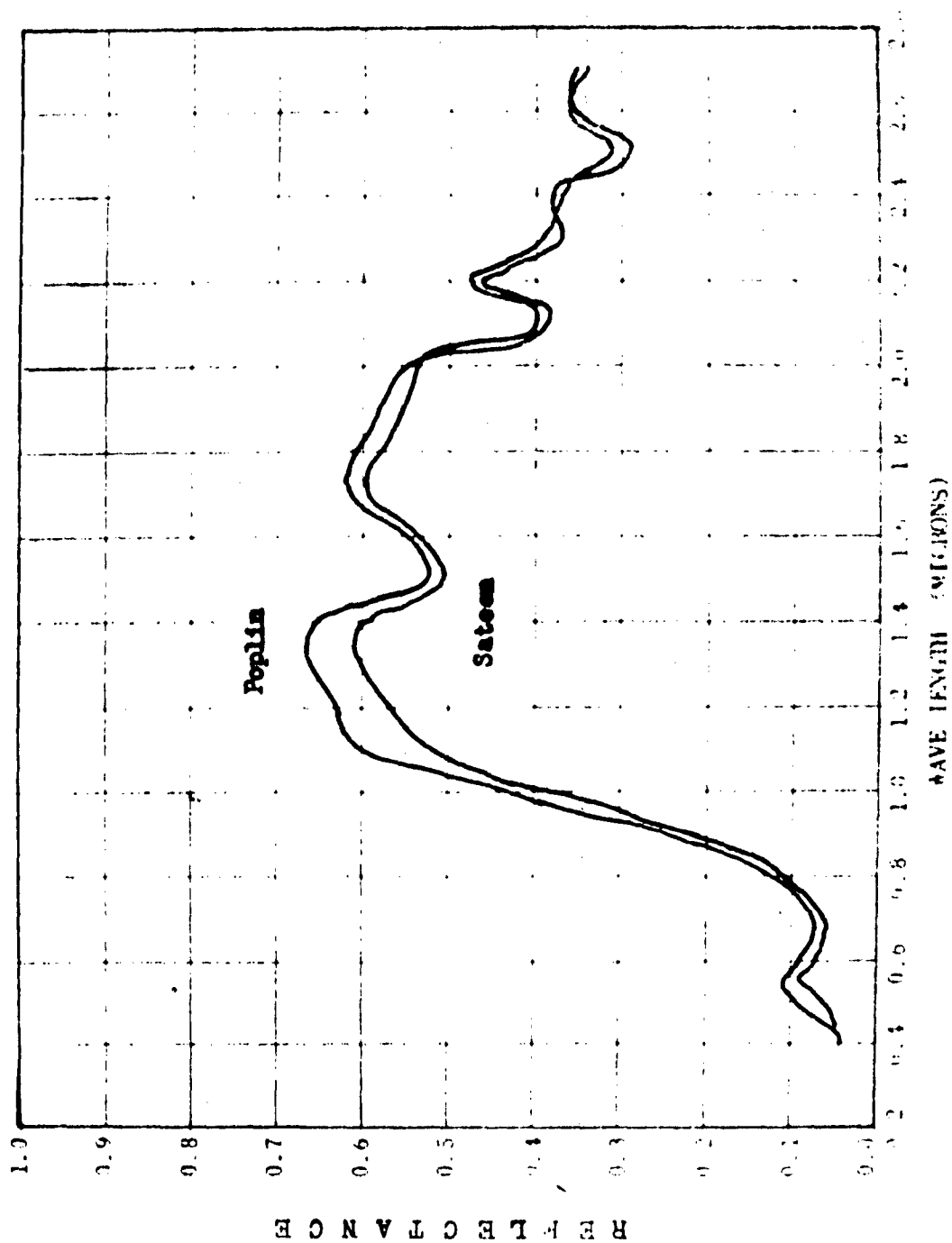


FIGURE 4. THE SPECTRAL REFLECTANCE OF
THE UNIFORM FABRICS

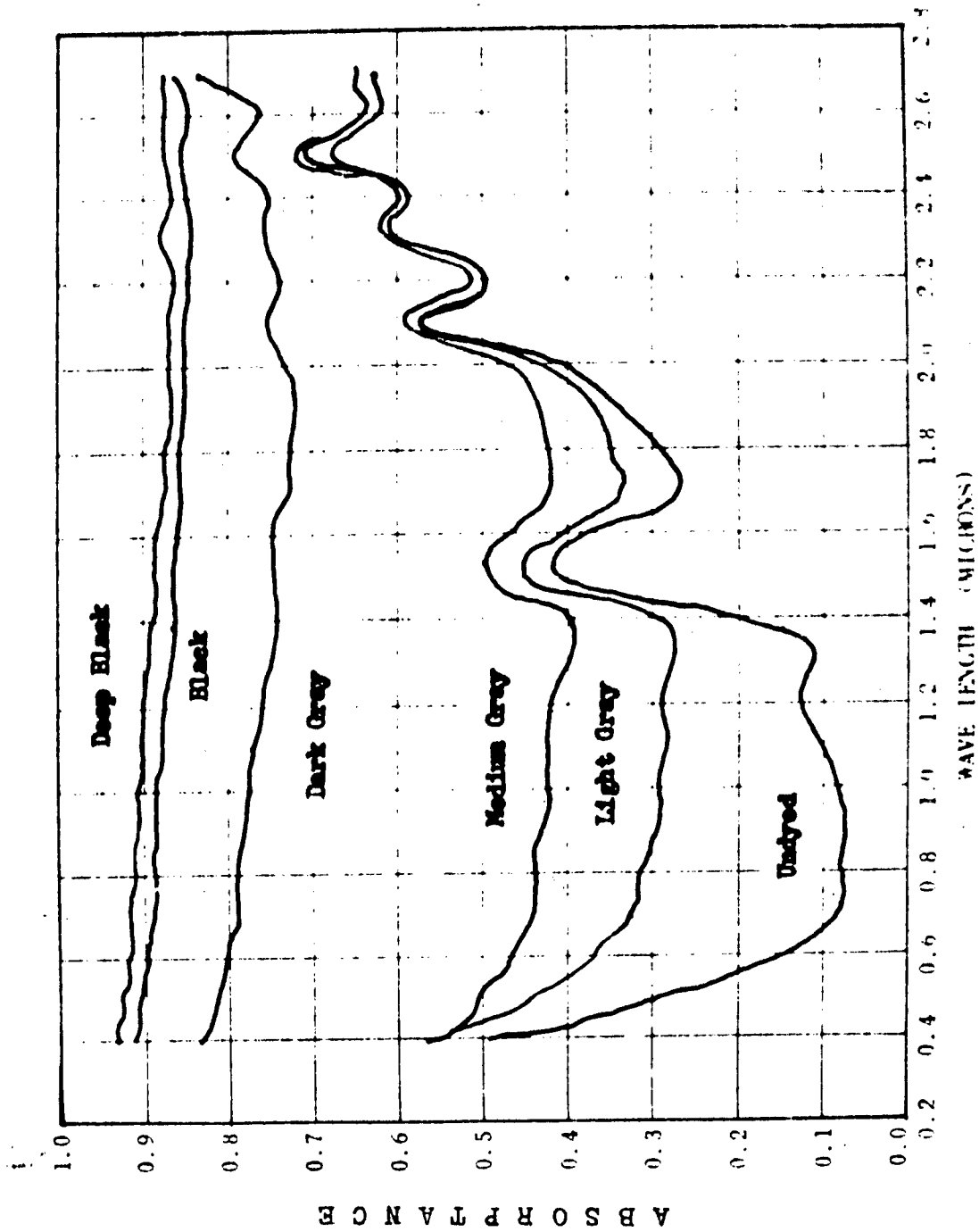


FIGURE 5. THE SPECTRAL ABSORPTANCE OF THE STANDARD FABRICS FOR THERMAL RADIATION EFFECTS STUDIES

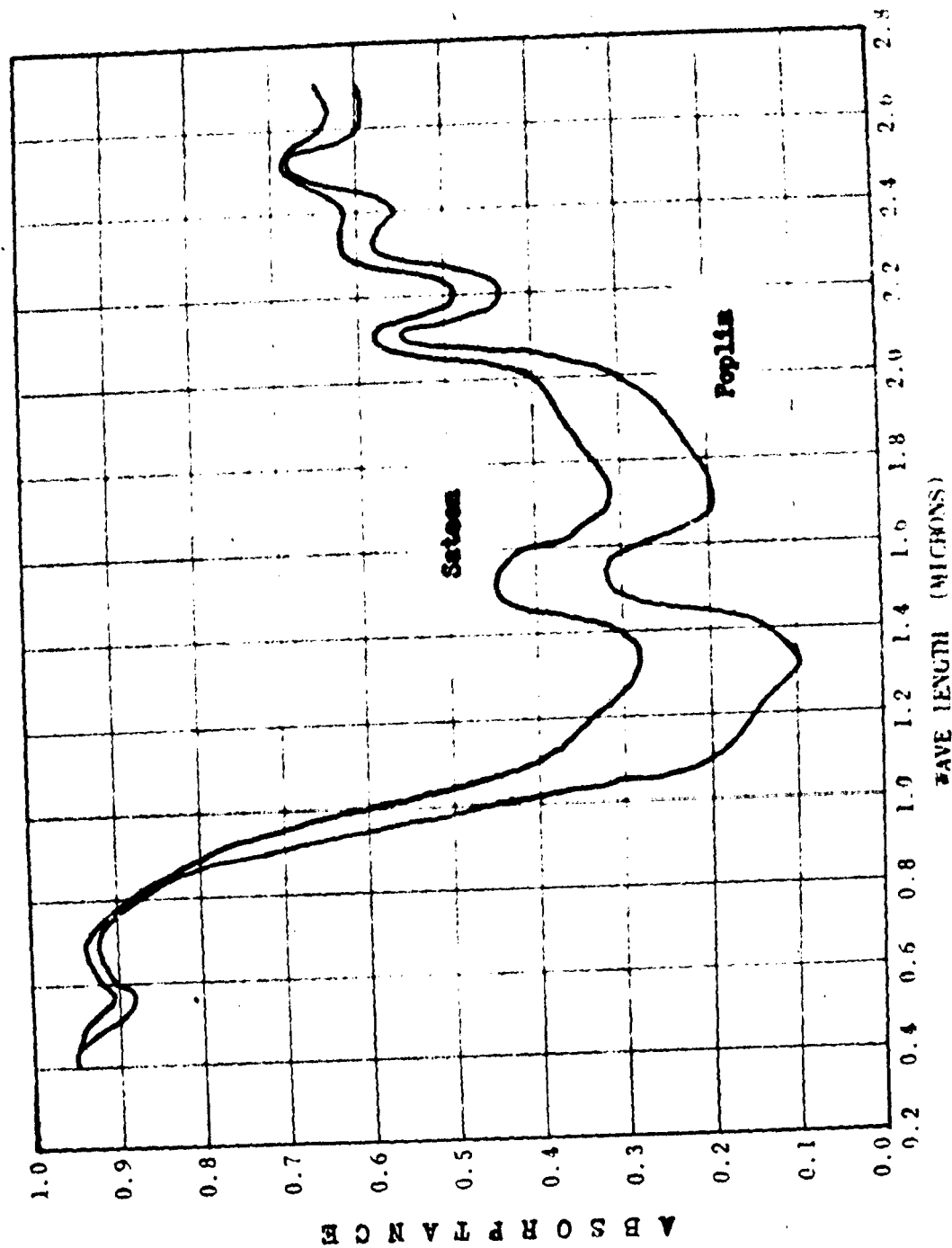


FIGURE 6. THE SPECTRAL ABSORPTANCE OF THE UNIFORM FABRICS

TABLE 1
The Spectral Transmittance and Reflectance of the
Standard Fabrics for Thermal Radiation Effect Studies

Wave Length (microns)	Cotton Sateen Prepared for Dyeing (2)		Undyed Cotton Sateen (4)		Light Gray Cotton Sateen (5-65)		Medium Gray Cotton Sateen (6-10)		Dark Gray Cotton Sateen (7-22)		Black Cotton Sateen (8-12)		Deep Black Cotton Sateen (9-7)	
	R	T	R	T	R	T	R	T	R	T	R	T	R	T
0.40	0.42	0.02	0.47	0.02	0.42	0.02	0.42	0.01	0.16	0.00	0.09	0.00	0.07	0.00
0.42	0.46	0.03	0.50	0.04	0.44	0.02	0.44	0.02	0.17	0.00	0.09	0.00	0.07	0.00
0.44	0.49	0.04	0.53	0.05	0.46	0.03	0.45	0.02	0.17	0.00	0.09	0.00	0.07	0.00
0.46	0.52	0.05	0.56	0.06	0.48	0.03	0.46	0.02	0.18	0.00	0.09	0.00	0.07	0.00
0.48	0.55	0.07	0.59	0.07	0.50	0.04	0.47	0.02	0.18	0.00	0.09	0.00	0.07	0.00
0.50	0.58	0.08	0.61	0.09	0.51	0.04	0.47	0.02	0.18	0.00	0.10	0.00	0.07	0.00
0.52	0.60	0.09	0.63	0.10	0.52	0.05	0.48	0.02	0.19	0.00	0.10	0.00	0.07	0.00
0.54	0.63	0.11	0.65	0.11	0.54	0.05	0.49	0.03	0.19	0.00	0.10	0.00	0.08	0.00
0.56	0.65	0.12	0.67	0.12	0.55	0.06	0.49	0.03	0.19	0.00	0.10	0.00	0.08	0.00
0.58	0.67	0.13	0.68	0.13	0.55	0.06	0.50	0.03	0.19	0.00	0.10	0.00	0.08	0.00
0.60	0.68	0.14	0.70	0.14	0.56	0.06	0.50	0.03	0.20	0.00	0.10	0.00	0.08	0.00
0.62	0.70	0.15	0.71	0.15	0.57	0.07	0.51	0.03	0.20	0.00	0.10	0.00	0.08	0.00
0.64	0.71	0.16	0.71	0.16	0.57	0.07	0.51	0.03	0.20	0.00	0.10	0.00	0.08	0.00
0.66	0.72	0.17	0.72	0.17	0.58	0.08	0.51	0.04	0.20	0.00	0.11	0.00	0.08	0.00
0.68	0.73	0.18	0.73	0.18	0.59	0.08	0.52	0.04	0.21	0.00	0.11	0.00	0.08	0.00
0.70	0.73	0.19	0.74	0.18	0.57	0.08	0.50	0.04	0.21	0.00	0.11	0.00	0.08	0.00
0.75	0.72	0.19	0.72	0.19	0.58	0.09	0.51	0.03	0.20	0.00	0.10	0.00	0.08	0.00
0.80	0.74	0.19	0.74	0.19	0.60	0.09	0.53	0.03	0.21	0.00	0.11	0.00	0.09	0.00
0.85	0.74	0.20	0.73	0.19	0.60	0.10	0.53	0.03	0.21	0.00	0.11	0.00	0.09	0.00
0.90	0.74	0.20	0.74	0.19	0.60	0.10	0.54	0.03	0.22	0.00	0.11	0.00	0.09	0.00
0.95	0.74	0.19	0.73	0.19	0.61	0.10	0.54	0.03	0.22	0.00	0.11	0.00	0.09	0.00
1.00	0.74	0.20	0.73	0.19	0.60	0.10	0.54	0.03	0.22	0.00	0.11	0.00	0.09	0.00
1.10	0.72	0.19	0.71	0.19	0.61	0.11	0.54	0.04	0.23	0.00	0.12	0.00	0.10	0.00
1.20	0.71	0.17	0.70	0.17	0.61	0.10	0.54	0.04	0.24	0.00	0.12	0.00	0.10	0.00
1.30	0.71	0.18	0.71	0.18	0.62	0.11	0.56	0.04	0.25	0.00	0.13	0.00	0.10	0.00
1.40	0.68	0.15	0.66	0.15	0.62	0.10	0.56	0.04	0.26	0.00	0.14	0.00	0.11	0.00
1.50	0.54	0.06	0.54	0.05	0.51	0.05	0.50	0.02	0.25	0.00	0.13	0.00	0.11	0.00
1.60	0.56	0.07	0.56	0.06	0.53	0.06	0.50	0.02	0.25	0.00	0.14	0.00	0.11	0.00
1.70	0.63	0.11	0.63	0.11	0.58	0.08	0.55	0.03	0.27	0.00	0.14	0.00	0.12	0.00
1.80	0.61	0.10	0.61	0.10	0.58	0.07	0.55	0.03	0.27	0.00	0.14	0.00	0.12	0.00
1.90	0.58	0.09	0.58	0.09	0.57	0.07	0.54	0.03	0.28	0.00	0.15	0.00	0.13	0.00
2.00	0.55	0.07	0.54	0.06	0.52	0.06	0.51	0.03	0.27	0.00	0.15	0.00	0.13	0.00
2.10	0.41	0.02	0.40	0.01	0.41	0.02	0.41	0.01	0.25	0.00	0.15	0.00	0.13	0.00
2.20	0.48	0.04	0.48	0.03	0.47	0.03	0.47	0.02	0.26	0.00	0.15	0.00	0.13	0.00
2.30	0.42	0.02	0.39	0.01	0.39	0.02	0.39	0.01	0.24	0.00	0.15	0.00	0.12	0.00
2.40	0.39	0.02	0.40	0.01	0.40	0.02	0.39	0.01	0.25	0.00	0.15	0.00	0.13	0.00
2.50	0.30	0.01	0.29	0.00	0.29	0.01	0.32	0.01	0.21	0.00	0.14	0.00	0.12	0.00
2.60	0.36	0.01	0.36	0.01	0.36	0.01	0.37	0.01	0.24	0.00	0.15	0.00	0.12	0.00
2.70	0.34	0.01	0.35	0.01	0.34	0.01	0.36	0.01	0.16	0.00	0.13	0.00	0.12	0.00

R - reflectance
T - transmittance

TABLE 2
The Spectral Transmittance and Reflectance of
the Uniform Fabrics

Wave Length (microns)	Bleached Cotton Sheeting (1)		Cotton Sateen O.G.107 (3)		Cotton Poplin Shade 116 (21S-1)	
	R	T	R	T	R	T
0.40	0.61	0.35	0.05	0.00	0.05	0.00
0.42	0.61	0.36	0.05	0.00	0.05	0.00
0.44	0.61	0.37	0.05	0.00	0.05	0.00
0.46	0.61	0.37	0.05	0.00	0.06	0.00
0.48	0.61	0.36	0.06	0.00	0.08	0.00
0.50	0.61	0.36	0.06	0.00	0.09	0.00
0.52	0.61	0.36	0.07	0.00	0.10	0.00
0.54	0.60	0.36	0.09	0.00	0.11	0.01
0.56	0.60	0.36	0.10	0.00	0.11	0.01
0.58	0.60	0.36	0.09	0.00	0.11	0.01
0.60	0.59	0.36	0.09	0.00	0.10	0.00
0.62	0.59	0.37	0.08	0.00	0.09	0.00
0.64	0.59	0.37	0.07	0.00	0.08	0.00
0.66	0.59	0.37	0.07	0.00	0.08	0.00
0.68	0.59	0.37	0.06	0.00	0.08	0.00
0.70	0.59	0.38	0.07	0.00	0.08	0.00
0.75	0.58	0.37	0.08	0.00	0.09	0.00
0.80	0.59	0.37	0.11	0.00	0.12	0.01
0.85	0.59	0.37	0.15	0.00	0.17	0.01
0.90	0.59	0.38	0.22	0.00	0.25	0.03
0.95	0.60	0.38	0.30	0.01	0.35	0.06
1.00	0.59	0.37	0.37	0.03	0.43	0.10
1.10	0.58	0.37	0.52	0.08	0.60	0.20
1.20	0.58	0.36	0.57	0.10	0.64	0.22
1.30	0.57	0.37	0.61	0.11	0.67	0.24
1.40	0.58	0.36	0.60	0.10	0.66	0.22
1.50	0.50	0.27	0.51	0.05	0.53	0.16
1.60	0.51	0.29	0.53	0.06	0.54	0.16
1.70	0.55	0.34	0.60	0.09	0.62	0.19
1.80	0.55	0.33	0.59	0.09	0.61	0.18
1.90	0.53	0.32	0.56	0.08	0.59	0.17
2.00	0.51	0.30	0.54	0.07	0.55	0.15
2.10	0.39	0.20	0.10	0.02	0.39	0.06
2.20	0.46	0.26	0.48	0.04	0.47	0.10
2.30	0.38	0.20	0.39	0.01	0.38	0.06
2.40	0.32	0.20	0.37	0.02	0.38	0.06
2.50	0.31	0.14	0.31	0.01	0.29	0.03
2.60	0.37	0.19	0.36	0.01	0.36	0.05
2.70	0.36	0.19	0.34	0.01	0.35	0.05

TABLE 3
The Carbon-arc and 3000°K Black-body
Radiant Absorptance, Reflectance and Transmittance
of the Standard Fabrics for Thermal Radiation Effects Studies

QMRDL No.	QMRDL Color	Cloth	Carbon-arc Spectrum			3000°K Black-body		
			R	T	A	R	T	A
9-7	Deep Black	Cotton Sateen	0.09	0.00	0.91	0.10	0.00	0.90
8-12	Black	Cotton Sateen	0.11	0.00	0.89	0.12	0.00	0.88
7-22	Dark Gray	Cotton Sateen	0.21	0.00	0.79	0.23	0.00	0.77
6-40	Medium Gray	Cotton Sateen	0.50	0.02	0.47	0.51	0.03	0.46
5-65	Light Gray	Cotton Sateen	0.54	0.07	0.39	0.56	0.07	0.37
4	Undyed	Cotton Sateen	0.63	0.12	0.25	0.63	0.13	0.24
3	O.G. 107	Cotton Sateen	0.28	0.03	0.69	0.40	0.05	0.55
2	Prepared for Dying	Cotton Sateen	0.63	0.12	0.25	0.64	0.13	0.23
1	Bleached	Cotton Sheeting	0.58	0.34	0.08	0.54	0.33	0.13
RRS-I	Shade 116	Cotton Poplin	0.30	0.07	0.63	0.57	0.12	0.31
	Black	Cotton Sateen	0.04	0.00	0.96	0.05	0.00	0.95
	Dark Gray	Cotton Sateen	0.07	0.00	0.93	0.07	0.00	0.93
	Medium Gray	Cotton Sateen	0.31	0.00	0.69	0.33	0.00	0.67
	Light Gray	Cotton Sateen	0.50	0.06	0.44	0.52	0.06	0.42
	White	Cotton Sateen	0.71	0.15	0.14	0.73	0.12	0.15

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