AD894539

TECHNICAL REPORT
72-30-CE

REFLECTANCE PROPERTIES OF FABRICS IN RELATION TO DETECTION BY A NIGHT VISION DEVICE

by

Lyman Fourt
and
Norman R. S. Hollies

Harris Research Laboratories
The Gillette Company
Rockville, Maryland

Contract No. DAAG17-70-C-0201

October 1971

~~Distribution limited to U. S. Government agencies only; proprietary information; 1 March 1971. Other requests for this document must be referred to the U. S. Army Natick Laboratories, Natick, Mass. 01760~~

UNITED STATES ARMY
NATICK LABORATORIES
Natick, Massachusetts 01760

U.S. ARMY MATERIEL COMMAND

Clothing and Personal Life Support Equipment Laboratory

TS-180

[redacted]

Distribution limited to US
Government agencies only;
proprietary information;
1 March 1971. Other requests
for this document must be referred
to the US Army Natick Laboratories,
Natick, MA 01760

AD______________

Technical Report
72-30-CE

REFLECTANCE PROPERTIES OF FABRICS IN RELATION TO DETECTION BY A NIGHT VISION DEVICE

by

Lyman Fourt
and
Norman R. S. Hollies

Harris Research Laboratories Department
The Gillette Company Research Institute
Rockville, Maryland 20850

Contract No. DAAG-17-70-C-0201

Project Reference:
1J662708D504

Series: TS-180

October 1971

Clothing and Personal Life Support Equipment Laboratory
US Army Natick Laboratories
Natick, Massachusetts 01760

FOREWORD

To achieve good camouflage in any given situation requires consideration of many factors related to the characteristics of the background, the properties of the 'target', the nature of the sensor and the time and circumstance of the observation. The relative contributions of these parameters to the lowering of the probability of detection in a countersurveillance scheme can vary considerably depending upon the specific surveillance/countersurveillance measures being deployed and the circumstances existing at a given point in time.

In this study, emphasis has been given to one specific property of the surface of materials, namely, the gloss, sheen or retroreflectivity factor as it affects nighttime observation through a passive detecting device. Because of the wide variation in background properties, one can only expect to achieve guidance with respect to those combined attributes that provide a means of effecting a significant lowering of the detectability index in the average situation. This, the work being reported has done.

The effort represents a good illustration of a combined field study and laboratory evaluation to achieve a definition of a practical solution to a given problem. The field study required operation at unusual times and under variant conditions of illumination.

The authors personally participated in all aspects of the field trials. Acknowledgement is made of the aid given to the authors by Mr. John Krasny, Mr. Berry Davis and Mr. Lee Snyder of the Gillette Company Research Institute in taking the night photographs and of Mrs. Margaret Whiting and Mrs Margaret Whitcraft in performing the densitometric and directional reflectance measurements. The work was carried out under Project 1J662708D504 and was under the technical supervision of Mr. Frank J. Rizzo as Project Officer with Mr. Alvin O. Ramsley assisting.

TABLE OF CONTENTS

TABLE OF CONTENTS (cont'd)

LIST OF TABLES

LIST OF TABLES (cont'd)

LIST OF FIGURES

LIST OF FIGURES (cont'd)

LIST OF FIGURES (cont'd)

CONTENTS OF APPENDIX

CONTENTS OF APPENDIX (cont'd)

ABSTRACT

The directional reflectance properties and infrared reflectance properties of 25 fabrics of varied structural characteristics have been compared using the principal fabric orientations and directions of illumination and view. Detection by a night vision device, an image intensifier Model 9927A on seven natural backgrounds in four fabric orientations has been estimated visually and measured by densitometry of photographic negatives of the fluorescent screen of the device. The chief correlations found are with the increased reflectance, gloss or sheen at high angles of reflectance, (gloss or sheen from increased reflectance according to Fresnels' Law) and with general level of lightness or darkness of the fabrics in the visible and near infrared ranges. No single reflectance level can match a wide variety of background but this match can be extended by variation of pattern of reflectance level and pattern on the fabrics.

REFLECTANCE PROPERTIES OF FABRICS IN RELATION TO DETECTION BY A NIGHT VISION DEVICE

I. INTRODUCTION

The purpose of this work has been to investigate the gloss, sheen or directional reflectance characteristics of a variety of fabrics in relation to their detection against a variety of backgrounds by means of a night vision device (1,2). The fabrics, selected by the U. S. Army Natick Laboratories, represent a diversity of structures and surface reflectance characteristics from a satin with a very high directional characteristic to a short pile velveteen with very little difference in any direction. Included are army sateen and uniform twill with moderate directional effect and a variety of pile and special surface structure fabrics. Each fabric is uniform in color, without pattern, except as produced by the weave. Seven backgrounds were chosen including silhouette against the sky, rubble, in dark woods and against green leafy vegetation. All of the examinations for detectability against backgrounds were done after the moon had set or before it had risen with only the illumination of the night sky, by means of a night vision sight, model 9927A, which is an image intensifier that displays the scene on a small fluorescent screen. This screen was photographed and densitometer measurements were made upon the negatives thus obtained. Both visual inspection of the negatives and the densitometer measurements have been used in estimating the degree of visibility or the contrast between the fabric area and the background.

The directional reflectance characteristics of the fabrics have been measured with a goniophotometer using a range of angles of viewing or illumination, in order to obtain measurements characteristic of the general diffuse reflectance of the fabric and measurements of the increased reflectance at mirror angles or more glancing angles. The various possible orientations of the fabric have been used in the measurements both in the night photographs and in the directional reflectance work. Correlations of the night vision results with structural features of the fabric and the directional reflectance characteristics have been made.

The chief findings are: Most natural backgrounds are themselves varied and have a greater range of variation than these solid color fabrics, so there is usually some clue to the presence of the fabric. The density of the fabric image depends on the general diffuse reflection characteristics of the fabric and also on its change with direction. The general illumination of the night sky gives a glancing angle reflection off of the sides of a cylinder which gives a highlight at the sides in comparison with the center of the cylinder. Nevertheless, for most of this group of fabrics the general diffuse reflection is the dominant characteristic of the fabric and determines density in the photographic negative. The densities of the different fabrics tend to line up in the same order against different backgrounds. Hence, to match the variation in given backgrounds and to cover a wider range of backgrounds, a variegated pattern of reflectance on the fabric would be superior to any one uniform level of reflectance.

The night vision device utilizes infrared radiation as well as the visible radiation from night sky (2). This leads to higher density values for fabrics which are higher in their infrared reflectance although matched to the eye.

II. MATERIALS AND BACKGROUNDS

The 25 fabrics selected by the Clothing and Personal Life Support Equipment Laboratory of the U. S. Army Natick Laboratories are listed in Table I. Color or the Army shade and the general diffuse reflectance, the 45^{o}, 0^{o} reflectance as measured in the goniophotometer have been included in this table. Two pairs of fabrics, 4 and 5, terry cloth, and 7 and 8, Simplex knit are similar in shade to the direct vision and are close to each other in reflectance measurement but differ in infrared reflectance. Weight, thread count, thickness and weave pattern have been supplied by the Natick Laboratories and are listed in Appendix Table A XVII.

Seven backgrounds were used representing different types of terrain. All were distant from town lights which might reflect from cloudy skies. Data on the photographic conditions are given in Table II. Daylight photographs of the sites are presented in the appendix, Figures A-1 through A-7, with some descriptive notes.

III. METHODS

A. Night Photography

The guiding consideration in selecting a photographic method was to obtain a negative of sufficient size to permit distinguishing variation in the background and variation or highlights in fabric by means of the densitometer. The method chosen worked out so that approximately 1 mm on the negative corresponds to 25 mm, 1 inch, at the site being photographed. Since the slit of the densitometer is 0.1 mm wide, and 1.0 mm long, this permits relatively fine measurement with respect to the objects themselves. The fabrics were mounted on half cylinders 10 inches in diameter and the area of a significant variation in the background may be only a few inches. The distance from night viewing device to object was the minimum at which focus was possible, 50 meters, and a view camera suitable for 4" by 5" negatives was used to photograph the fluorescent screen. The arrangement of the night viewing device and the camera is shown in Figure 1, which shows how the camera, on a separate tripod, is placed immediately behind the ocular of the viewing device, with the rubber eye-guard removed. The camera has a f/6.3 lens, 215 mm focal length, and a long bellows.

Preliminary focusing was done by eye using the ground glass back of the camera, after the night vision device had been separately focused. This camera focusing was checked and the exposure time determined by use of Polaroid* type 52 film, 4" by 5". This gave an immediate check on the line-up of the two devices and the centering of the desired material in the field.

The photographs for densitometry were taken on Tri-X* roll film type 220 which gives 20 exposures per roll. The roll film holder was inserted in the back of the view camera. The lesser width of the Tri-X film, 2.37 in. requires that the material be centered. Checks with Polaroid were taken after completing rolls of Tri-X.

*Mention of this specific item does not imply endorsement over other equivalent products.

The exposure time was determined by the considerations that the ASA speed of the Polaroid type 52 is 400 and that of the Tri-X, developed with Accufine* developer is 1200, so that one third of the exposure time required for the Polaroid was used for the Tri-X. The largest opening of the lens, f/6.3 was used, except f/11 for the horizon series.

Certain conventions were followed in all the photography. Two hemicylinders were used to mount the fabrics. Each hemicylinder was 10 in. in diameter, and 24 in. high. Two specimens of each fabric were photographed together, one with the warp or principle direction running in the long direction of the cylinder ("along the cylinder") the other with the warp direction running around the cylinder and the filling along the cylinder, as shown in Figure 2. With the cylinders standing vertical the warp on one cylinder was running vertical as in most clothing. With the cylinders lying on their flat sides, the warp was running at right angles to the line of sight in the cylinder in which it ran in the long direction of the cylinder while it ran with the line of sight in the other cylinder. Two reflectance standards were photographed in every negative, one white card, reflectance 90%, the other grey card, reflectance 19%. The two reflectance standard cards were exposed at the base of the cylinders when they were standing vertically and at one end of the cylinders when they were lying horizontally. In all cases, the white card, which makes the darker or more dense portion on the negative, was with the half cylinder in which the warp direction ran with the length of the cylinder. The gray card which made the light or lower density area in the negative was with the other direction, as shown in Figure 2. Thus, the fabric orientation can be recognized at once in the negatives.

The photographs offer some advantages over the direct view of the fluorescent screen, since this has a rather twinkling or scintillating appearance. The instant to instant variation on the fluorescent screen averaged out in the time of an exposure and of course, longer exposure develops more density in the negative so that scenes that were rather dim on the screen when the illumination was very low could be satisfactorily photographed.

*Mention of this specific item does not imply endorsement over other equivalent products.

The conditions of the illumination varied from night to night and in the course of a given night. Hence, the exposure times as determined by use of the Polaroid also varied. All photographs were taken after the moon had set or before it had risen and in general from 10 p.m. or later on through the night. We observed that most nights appeared to become darker after 11 or 12 p.m. Therefore, in some cases the exposure time was lengthened as from 3 to 5 seconds as the night went on. In one series, taken in the woods, rain came up and clouds darkened the sky in the last five or six pictures so that the time was lengthened from the already long period of 30 seconds to 45 or 60 seconds. Table II shows the exposure times and other conditions used; it also shows the average density of the white and grey card portions of the negatives taken under these conditions. This table also includes an estimate of the radiant energy of the night sky in the visible and near infrared, extending out to 0.95 microns. These measurements were obtained with a gallium arsenide photomultiplier radiometer, Cintra probe model #1534* and readout system #101*.

The density on the dark or high density image (white card) and the light or low density image (gray card) in a series of negatives taken in one night is shown in Figure 3. The two levels of density run a generally parallel course.

The average density of the background in the negative also goes up and down with the white card or gray card density. Hence, to the extent that light reflectance from the fabric varies from fabric to fabric, it can be followed by either the density difference (white card)-(fabric) or background)-(fabric). The latter has been used because it is the contrast between fabric and background.

B. <u>Handling Fabrics in the Field</u>

Figure 4 shows the dimensions of the fabric specimens and the way they were marked. Two specimens were cut of each fabric, except fabric 16 for which material was available for only one. The dimensions were 22 x 30 in. In one case the

*Mention of this specific item does not imply endorsement over other equivalent products.

30 in. ran with the warp direction, in the other with the filling. A 1 x 5 in. strip of white heat sealing tape was bonded to one corner of the reverse side of each specimen, with the 5 in. direction running with the warp. This permitted easier identification in the dark or poor light in the field. The fabric numbers were put on these tapes and had also been marked on the fabrics themselves.

Figure 5 shows the means of holding the fabrics on the half cylinders. The flat side of each hemicylinder measured 10 by 24 in. plus 0.5 in. at the lower end where a half cylinder sector of 0.5 in. aluminum plate was attached. This plate gives the cylinder increased stability when standing vertically. Two brass plates were attached to the flat side of each half cylinder. These brass plates were made from strips 1/32 in. thick, 9 by 3 in. Each strip was turned up 1 in. at right angles at each end so that the final flat portion was 7 by 3 in. This flat portion was cemented with epoxy cement to the flat side of the cylinder with its outer 7 in. edge 3 in. from the end of the cylinder and with the turned up ends of the strip each 1.5 in. inward from the long edge of the flat side as shown in Figure 5. Thus, when the cylinder was laid with its curved side in the center of the specimen (11 in. from each edge) the ends of the fabric could be brought up along each curved side and fastened to the upturned ends of the brass strips by means of spring action clothes pins. This proved to be suitable for work in the dark or in the relatively poor light of flashlights lying on the ground and permitted a relatively smooth fabric surface on the curved surface of the cylinders. The half cylinders were each made from three sections of 6 in. thick polystyrene foam cemented together and cemented to the aluminum base plate. The curved surfaces of the cylinders were painted black with low reflectance paint less than 0.5% reflectance. The paint used did not cause dimensional change in the polystryene foam; Spray paint should be avoided or tested carefully on scrap pieces before being used on polystyrene because many propellants or solvents cause shrinkage and deformation. A wooden board 6 in. x 24 in. with holes placed along its center 15 in. apart was used for locating the cylinders in the field. A spike was prepared which could be threaded into the aluminum baseplate of the cylinders so that it could go through the hole in the board and stabilize the cylinders against wind. In most cases, the cylinders were also stabilized and location established for each photograph by means of a quarter inch stainless steel rod with a handle at its top end which could be inserted in the ground at the back of the board in such position as to stabilize the vertical cylinder. The stakes can be seen in some of the horizontal cylinder photographs.

C. Optical Density Measurements

Optical density was measured in transmission on the negatives. It is the logarithm (base 10) of the reciprocal of the fraction of light transmitted. The light transmitted through unexposed portions of the negative, such as the space between successive negatives, was taken as unity. Thus, the lightly exposed portions of the negative have low densities while the highly exposed portions have high densities. The numerical value of the density increases with the amount of light reflected from an object in the field so that the white reference standard card has a higher density in every negative than the gray standard. Likewise, in a series of negatives a dark colored fabric will have a lower density than a light colored fabric.

An instrument designed for measurement of chromatographic plates was used with a reduced size of slit. The measuring slit is placed close above the negative so that the reading corresponds chiefly to the light coming through the small portion of the negative which can transmit light through the slit. The slit width was 0.1 mm, the length 1.0 mm. Movement of the negative under the slit was always in the direction of the narrow dimension of the slit, so that distinctly different measurements could be obtained for a motion as small as 0.5 mm on the negative. The optical density of the background and the fabrics can be sampled in a number of ways. As illustrated in Figure 12 three methods have been examined: A. to sample separately the fabric and in the background above the fabrics at intervals of 1 mm., B. to sample continuously across the boundary between background and fabric at intervals of 0.5 mm., C. to sample along lines parallel to the edge, one in the background the other on the fabric at intervals of 1 mm. The results of these methods are compared in the section entitled "Choices in Measurements" in the presentation of the results.

D. Directional Reflectance Measurements

1. Angle Relations

The objective of the goniophotometric measurements has been to obtain indications of the gloss or sheen characteristics of the fabrics in their principal orientations for correlation with the optical contrast or ease of detection shown in the photographs taken with the night vision device. Certain conventions are used in discussing the directional reflectance measurements. All of these measurements are taken along a definite narrow band of view and a definite narrow band of illumination. The central ray of one of these bands is the angle of view, the central ray of the other angle of illumination, each taken with respect to the normal (perpendicular) to the fabric surface. Unless otherwise specified, the fabric plane is perpendicular to the plane defined by the line of view and the line of illumination. In the special series in which the fabric was tipped out of its original plane, the same reference is maintained, with the angle of view at 45° to the original plane and the angle of illumination kept along the original normal. Every directional reflectance measurement is specified by two angles, the first being the angle of view, the second the angle of illumination. Thus, for 45° angle of view and 0° angle of illumination, that is illumination along the normal or line perpendicular to the fabric, we write 45°, 0° reflectance. For the mirror angle in which the angle of view is equal to the angle of incidence, we write 45°, 45° reflectance.

The goniophotometer mounts the fabric specimen along a diameter centered on the axis of rotation. The illumination is carried on a swinging arm which can move from 22.5° separation from the angle of view to 180°. This complete arc is not required in every series. Angles of view of 30°, 45°, and 60° were used with measurements of reflectance from angles of illumination on the same side of the normal as the view through the mirror angle to angles as high as 75° beyond the normal. Because of limitations of the photometric system, and the increased reflection at more grazing angles, the measurements were terminated when the reflectance reached 1040 on the scale $MgO = 1000$. This was usually at a point above 60°.

Figure 6 shows the relation of the three angles of view, 30°, 45°, and 60°, to the normal to the specimen and to the arc of angles of illumination used. For the 30° angle of view, only 5° was available on the same side of the normal as the angle of view, but the others were extended to 15° below the normal.

2. Photometry

Measurements of amounts of directional reflectance have all been made in terms of a uniform diffusing surface of which magnesium oxide surfaces are the physical representation. Such a surface would show uniform directional reflectance for a particular angle of view and a wide ideally complete range of angles of illumination. In practice, we standardized the reflectance measurements by means of a series of enamel on metal standards of known 45°, 0° reflectance ranging from very low reflectance, (a value of 24) to very high reflectance on the scale (a value of 838); magnesium oxide equals 1000. All directional reflectance measurements reported here are referred to this scale.

The instrumentation involved a photomultiplier tube and potentiometric circuits by which the current produced by the light falling on the photomultiplier tube could be balanced. One portion of the balancing potentiometric circuits was scaled from 0 to 1000. This measuring scale can be set to the calibration value of the reflectance standard, for example 838 and the circuit balanced by other potentiometers. Then changes in the light received at the tube can be measured on the measuring scale. This procedure is satisfactory for amounts of light near to that of the calibration standard but becomes increasingly inaccurate as the amount of light differs more and more from the calibration level. This is because there is a substantial dark current from the photocell. However, if a series of reflectance standards are measured in terms of the original calibration standard, the measured values fall in a straight line which extrapolates at 0 reflectance to the dark current. This is shown in Figure 7. Hence, measurements over the whole range of reflectance values can be established by a correction proportional to the departure from the calibration value. A computer program for making this correction was developed, and all reflectance values in this report have been corrected by this means.

IV. RESULTS

The basic measurements of this work are presented in the Appendix, in tabular form listing the data for each fabric by its arbitrary fabric number from one to twenty-five. These tables can be referred to for the data on any particular fabric. In the discussion section the results are taken up by topics, with graphs presenting data for selected fabrics or fabric comparisons, and with ranking tables or other rearrangements of portions of the basic data. Table III is an index table indicating the text figures in which results on individual fabrics are presented. Thus, fabric 6, the dark rayon satin, is discussed as the extreme representative in this series of highly directional reflectance, and the black rayon velveteen number 18 is also frequently discussed because it has the lowest directionality.

The main questions to which this work is addressed are:

(1) How do the fabrics rank and scale with regard to contrast to a variety of backgrounds?

(2) How do fabric properties such as general lightness, directional reflectance, (and its difference with fabric orientation), and infrared reflectance affect the contrast or ease of recognition against different backgrounds?

(3) How do various fabric structures interact with the directional reflectance with particular reference to recognition or detection in the night vision device? This, of course, is really a rephrased form of question 2 with more emphasis on fabric structure.

The field observations of density in the photonegatives taken with the night vision device are presented in Tables A-1 through A-XIII in the Appendix. The directional reflectance measurements for all fabrics for 45° angle of view are presented in Table A-XIV and for 15 fabrics at 30° and at 60° angle of view in Tables A-XV and A-XVI, respectively. These 15 fabrics were chosen to represent all the principle variations shown among the whole group of 25.

The discussion of the results follows the order of the questions presented above.

V. DISCUSSION

A. Optical Density and Contrast Between Fabrics and Background

1. General

The discussion of the field results is organized in four stages: the first being the choice of measurements in the photo-negatives; the second an analysis of contrast between fabrics and backgrounds; the third a search for the fabric properties on which the contrast between background and fabric depend; and fourth a special consideration of infrared reflectance as illustrated by two pairs of fabrics which are matched in their visual characteristics but differ in their infrared reflectance. The discussion of fabric properties will have to anticipate some of the results of the next general section, Section VB, page 19, the direction reflectance measurements, where the fabric properties will be taken up in greater detail.

The general nature of the field photographs are indicated in Figures 8 to 11 which are positive prints made from the negatives. The negatives were used throughout in the evaluation of fabric to background differences. Figure 8, for example, taken of a wool blanket (Fabric 3) wrapped on the cylinders supported against a horizon background shows the relative positions of the cylinders and reflectance cards used throughout this work. In every case two photos of the same fabric covered cylinders were taken in sequence, first with the cylinders upright, then lying on the ground. The high reflectance card on the left cylinder was associated with the warp of the fabric being aligned with the long direction of the cylinder in every case. The low reflectance card on the right cylinder and the supporting rods for the cylinders are also visible in both photographs.

A corresponding view of Fabric 8, the cotton knit, taken at very low light levels against an open field background is shown in Figure 9. Clearly in this case light reflection from the background was greater than from the fabric sample in either orientation giving rise to a contrast in viewing in which the outline of the cylinders was clearly visible.

Figure 10 includes the photos of a cotton uniform twill (Fabric 19) against a rubble background. Not only are the fabric-covered cylinders and reflectance cards clearly visible but also the individual rocks in the rubble background which reflected light extremely well. The blurred object in the right foreground of the photos was a fence post closer to the camera and therefore somewhat out of focus.

Fabric 2, napped wool frieze was photographed against a green grass and foliage background as shown in Figure 11. Although the actual light level in these photos through the night viewing device was extremely low, the fabrics mounted on the cylinders were plainly visible. This was true in spite of the fact that the actual reflectance levels of fabric and background were similar. In this photo pair as with the other fabrics and backgrounds (Figures 8 to 10), the position of the cylinders could be readily detected by observing two characteristics of the fabric and background portions of the photo: (1) the reflectance from the fabric was fairly uniform over the total fabric area while that from the background was not uniform, (2) the intensity of reflection from the cylinder edge not only followed a straight line, but also was more easily detected due to modest highlights at the edge-background boundary. The characteristics of reflection patterns were of course apparent in the photonegative used for fabric analysis, high reflectance giving rise to high density values in the negatives. Indeed, as will be apparent in the analyses which follow, optical densities in the photonegatives were compared directly.

2. Choices in Measurement

Certain choices are required in obtaining optical density data by which to measure the contrasts between fabric and background. The three alternatives which we have examined are depicted in Figure 12. Method A makes separate measurements on the fabric and on the background. Method B measures continuously across the boundary between background and fabric. Method C measures in the background and in the fabric along lines close to and parallel to the boundary. One question concerns the feasibility of making measurements right across the boundary between fabric and background, as in Method B. This might be expected to show a large change of density on crossing the boundary. However this depends on how sharp the boundary is in the photograph, and how well the densitometer can accomplish measurements strictly related to one small area. We have found that with the equipment used there are difficulties in precisely defining the boundary in comparison with visual impression. While a change might be expected on the fabric side of the boundary, arising from differences of angle relations, we also found a change continuing on what could be visually recognized as the background side of the boundary. As shown in Figure 13 data for terry cloth Fabric 4, at a distance of 1 mm or more from the boundary, however, the density measurements on the cylinder itself became relatively uniform, and correspondingly the measurements in the background away from the cylinder, although more variable than those on the cylinder, center around a characteristic value.

A better choice, therefore, and the one used in the major part of this work, as tabulated in Tables A-1 through A-XII (Appendix), has been to measure on the cylinder in a horizontal direction from the near the edge to past the center, and to measure in the background in a horizontal direction, but at a distance from, and usually above the cylinder on the negative. These measurements were spaced 1 mm apart on the vertical cylinders bearing fabric, and 4 mm apart in the background. The average of six measurements and the range is reported in the Appendix tables.

A third choice, carried out with the green foliage background negatives of Table A-XIII in the Appendix is to make measurements parallel to the edge but more than 1 mm away from the edge in the background, and on a cylinder. The parallel-to-edge measurements have the advantage of sampling the background in close proximity to the cylinder.

Table IV shows a comparison of density results for five fabrics obtained by each of the methods of sampling the background - fabric relation. The table shows the averages of the fabric densities, and the averages of the difference between background density minus fabric density for each fabric by each method. In the first three data columns we see a very clear similarity between the results of all the methods consistent with the view that reflectance from each fabric was fairly uniform. Again, in the three columns of optical density difference we see for each fabric a clearly similar result by each method, the variations being due to the portion of the background sampled in the respective methods. It is clear, therefore, that the difference in optical density between background and fabric by any of the sampling techniques provides an adequate means for characterizing the specific contrast between fabric and background and in addition has the advantage of normalizing the fabric density data to a common light level (cf Figure 3). The agreement shown in Table IV has been taken as justification for the use of Method A for six of the backgrounds along with Method C for the seventh.

3. Density Difference or Contrast, Background Minus Fabric

Table V shows the optical density averages of the white reflectance card and the background for the photonegatives on all fabrics and all backgrounds arranged in decreasing order of white card density. Table V also shows the averages for measurements of fabrics on the different cylinders, horizontal and vertical and indicates the average for each of the fabric orientations, that is where the data is available. The fabric averages indicate that the effect of fabric and cylinder orientation is relatively small, while the differences between backgrounds vary over a wide range. Hence, any material which comes close to matching one background could be relatively far removed from another background. It is clear also from Table V that the density levels for a fixed fabric orientation in each background tend to follow the density levels for white card or background presumably due to differences in the light levels and exposure combinations used at each viewing sight. Hence, the background minus fabric density is approximately normalized for differences in light level and photographic exposure.

The analysis to be discussed is based primarily on the results with the cylinders in the vertical orientation since this set of negatives lends itself better to the density measurements and is more complete than the series with cylinders horizontal. The results on directional reflectance, to be discussed in Section V-B, along with those of Table V indicate that for most of the fabrics there is relatively little difference with orientation. The vertical cylinder negatives indeed contain two orientations of the fabric, one with the warp vertical running along the cylinder, the other with warp horizontal or running around the cylinder. Both sets of results for one background are shown in Table VI, in which the fabrics are arranged in the order of the sums of the differences between background and fabric for the two orientations. This includes the fabrics in which the difference background-minus-fabric, was negative through zero to those where it was most positive, that is, where the background was of greater density than the fabric. One can see that roughly both orientations follow the same trend.

This table also tests the assumption that the difference in density will correspond to the difference in recognizability. Two observers independently rated the negatives for degree of contrast of the fabric covered cylinder with the background and for sharpness of the cylinder edge. They used a rating scale of 1 for low, 2 for medium and 3 for high contrast or sharpness. Employing both rating scales, the minimum score would be 2 and the maximum score for greatest contrast and sharpest outline would be 6. In a corresponding manner, for the two observers together the minimum would be 4 and the maximum 12. Table VI shows that indeed the minimum contrast range in visual observation corresponds to the minimum difference range for density and that densities of background which are markedly above or below that of the fabric result in increased visibility, thus validating the hypothesis on which the density differences are used to evaluate the visibility of the fabric against any given background.

Table VI also suggests that there is considerable fluctuation in the values of the density difference so that the values as shown in this table to 3 decimals or even rounded to 2 figures would be a rather too fine grained criterion for judgement of relative rank. For this reason, we have adopted a grouping system for each of the series of observations, as illustrated in Table VII for one background. Here the fabrics are divided into seven groups from those which are most negative in optical density difference, group 1, to those which are most positive in optical density difference, group 7. The results for the other backgrounds were also ranked and divided into groups in order of optical density. Table VIII shows a general summary and comparison of these rankings. The general trend was for all of the rankings to agree, that is for a given fabric to be in the same ranking group or a neighboring ranking group in most of the sets. A general ranking was set up based on the average of the seven separate groupings and each of the seven groupings was compared with this general grouping in the manner shown in Table VIII.

A plus indicates that the group assigned to this fabric was within one step of the general average while a minus indicates that the match missed by more than one step. The last column gives the percentage of the backgrounds within which the match was within one step. Only four fabrics show percentages that match less than 50%, out of the 25. Hence it is clear that there is a dominantly similar trend for all the fabrics against each of the backgrounds even though it is considerably influenced by variations in the individual backgrounds (or photographs).

An appreciation of the specific effects of fabric choice or ease of viewing by the night-vision device is considered next.

4. Fabric Properties

Referring again to Table V in which the optical density differences (background-fabric) for all of the fabrics held with warp vertical and horizontal against a green foliage background were observed, two kinds of behavior were noted. For several of the fabrics at the top of the table, the optical density differences were larger for the fabrics held with the warp horizontal, than held vertical. In particular the wool frieze (Fabric 2), widewale corduroy (Fabric 24), and the terry cloth, high IR (Fabric 5) exhibited density differences > 0.05 when the warp of each fabric was in the direction around the cylinder (warp horizontal) and < 0.01 when the warp was along the length of the cylinder (warp vertical). The reverse was true of the cotton birdseye sample (Fabric 3) with a warp vertical value > 0.1 and a warp horizontal value < 0.02. Nevertheless, the subjective contrast ratings were high whether warp or filling or both optical density differences were high revealing that a warp horizontal to warp vertical difference in appearance was generally a strong contributing factor in distinguishing the cloth covered cylinders from background. This effect is borne out quite convincingly by the data for the black satin rayon fabric (Fabric 6) in Table V which had the largest vertical to horizontal optical density difference of any fabric studied. A quick look at the actual optical density values for fabric and background as shown in Figure 14 revealed the size of this contribution.

In the left hand side of the figure are the results of the warp vertical orientation with the warp running along the vertical cylinder, while on the right hand side we have the opposite orientation of the warp, around the cylinder or parallel to the ground. The background data in this case comes from separate traces, one on the left of the paired cylinders, the other on the right, but are relatively similar, and each shows greater variability than the data on the fabric. The fabric reflectances, however, lie at distinctly different levels and show less reflectance to the night viewing device and therefore lower density for the warp vertical orientation. The effects of fabric orientation will be discussed in more detail in connection with the directional reflectance data presented in part VB, but we can note here that the difference of reflection for the two orientations is larger for this fabric than for most others in that it stands at the top of the list in several indications of directional difference, gloss, sheen, or luster.

Figure 15 shows the optical density results for the two knit fabrics, numbers 7 and 8, which differ chiefly in reflectance in the infrared range. In these two negatives, the backgrounds are relatively close to each other, and the exposures were closely similar as shown in white card values of 0.87 and 0.86, respectively. The marked difference in infrared reflectance shows in the higher value for the high infrared fabric number 7. While there is irregularity from point to point along each track, it can be appreciated that the variation is somewhat greater in the background than in the fabric. The findings regarding infrared reflectance from photographs taken against other backgrounds and for the other fabric pair numbers 4 and 5 will be taken up later in section VA5.

Specific fabric properties will be considered further in presentation of the directional reflectance data and the correlation of these data with the field data.

5. Correlation with Infrared Reflectance

Two pairs of fabrics, the terry cloth numbers 4 and 5 and the simplex knit numbers 7 and 8, are similar in visual appearance but differ in infrared reflectance. Table IX shows spectrophotometric data supplied by the U. S. Army Natick

Laboratories at a number of wavelengths in the visible and in the infrared range. The percent reflectances are very similar in the visible range, but differ widely in the infrared. Although this anticipates the general discussion on reflectance behavior of fabrics, Figures 16 and 17 show the directional reflectance curves for the parallel to warp direction for the two pairs of fabric and indicate their general similarity over the whole range of angles for visible light.

Since the night vision device utilizes the infrared radiation from the night sky as well as the visible, we would expect that the fabrics higher in infrared reflectance would show greater density on the photographic negatives. The seven backgrounds were photographed on six different nights in different seasons of the year, late fall, winter and spring. Some nights were cloudy, others clear so that it can be expected that there will be night to night variation in the amount of infrared radiation compared to the energy in the visible. Each pair of negatives with cylinders vertical permits two comparisons, one with warp along the cylinder the other will filling along the cylinder direction, and correspondingly each pair of photographs with cylinders horizontal permits two comparisons. Thus, a maximum of 14 comparisons for each orientation of the cylinders is available for each pair.

The data from the tables in the Appendix have been analyzed, with a summary of the results shown in Table X. Because of the defects in the negatives, or interference by detail in the foreground, not every pair is available for analysis, but at least eleven of the possible fourteen pairs are available in every series. An adjustment to the density data is needed, however, because as was shown and discussed earlier in Figure 3, the general level of density goes up or down from one negative to another in response to variations in the illumination and in the time of exposure. An adjustment for this general level variation can be made on the basis of the density measured on the white reference card. By adding the difference between the two white reference cards to the fabric or cylinder measurement for that member of the pair which has the lower white card density, the two fabric densities can be adjusted for the variation in general level. When this is done, the results shown in Table X are obtained. The higher infrared reflectance fabrics give higher densities in the majority of cases. An example of effective high infrared reflectance was shown in Figure 15. The variations from case to case may be due in part to variation in the level of infrared radiation compared with visible radiation in the illumination of the night sky from night to night (3,4,5). There was no particular difference between the two fabric orientations in this regard. It is not clear why there should be a variation between the cylinder orientations seen in Table X and indeed this variation may not really be significant from a statistical point of view.

B. Directional Reflectance

1. General

The directional reflectance characteristics of the group of fabrics have been studied in two principle ways, which are shown schematically in Figure 18. First, the most extensively used method is with the normal to the fabric in the plane of the path of the light. That is with the specimen plane perpendicular to the plane which is defined by the line of viewing and the line of illumination; and second, with the specimen plane departing from this vertical plane. The second condition with the plane of the fabric tipped, corresponds to viewing from an elevation rather than at the level of the specimen. Three principle kinds of information are sought in this work: 1) on the general lightness or brightness of the fabrics, that is, the general reflectance level; 2) the sheen, gloss or luster characteristics of the fabric; and 3) the effect of particular surface structure characteristics in the fabric on its directional reflectance properties. This includes the comparison of smooth surface fabrics with those which have built in hills and valleys and the effect of pile fabric surfaces in comparison with surfaces which are essentially yarns which are in the plane of the fabric except for weaving crimp.

2. General Brightness or Lightness

The general brightness characteristic of the fabrics as measured by the 45°, 0° reflectance and the color of each fabric have been tabulated in Table I for two fabric orientations.

Figure 19 diagrams the two principal orientations used. In one, the warp yarns (or the machine or wales direction of a knit fabric) run parallel to the plane of the path of the light, which contains the lines of illumination and viewing. In the other, the warp or machine direction runs perpendicular to that plane. The reflectance figure for the warp running parallel to the plane of the light beams is referred to as the warp parallel orientation. The warp perpendicular orientation has also been measured. In general, the fabric orientation effect on the 45°, 0° reflectance is among the smallest of the fabric orientation effects and so the 45° warp parallel data are conventionally taken to represent the brightness or lightness of fabrics as determined from directional reflectance measurements. It may be noted that other instruments integrate the 45°, 0° reflectance from all fabric orientations by rotating the specimen or by using an integrating sphere, but it has been shown (6) that the 45°, 0° reflectance is very close to that obtained with uniform illumination from all directions. Table XI arranges the 25 fabrics in the order of their 45°, 0° warp parallel reflectances and their 45°, 0° warp perpendicular reflectances. It can be seen that the rank order in these two series is highly correlated.

3. Luster, Gloss, Sheen

The principal information which is sought from directional reflectance is on the luster, gloss or sheen of fabrics. The concepts of gloss, sheen or luster vary in different applications but in general the ideas share the point of a considerably higher reflectance at certain angles, particularly the mirror angle or higher angles. With an ideal mirror the directional reflectance is concentrated at the mirror angle and is very low or zero at angles away from this. Very few of the fabrics in the present series show any concentration of light reflection at the mirror angle, but all show increasing reflection as the angle of illumination goes above the mirror angle and towards angles which are more grazing to the fabric surface. There is always an increase of reflection at more grazing angles because of the increased efficiency of reflection according to Fresnel's law (7,8,9), which describes the increase in fraction of incident light reflected as the angle from the normal increases until for light parallel to the fabric surface, there is no loss of light because of the surface. Figure 20 shows the directional reflection for fabric 6, the black rayon satin which is the only fabric of this group which shows a peak of reflection near the mirror angle. Figure 21 shows the warp parallel direction at three angles of view and indicates that the peak is clearly seen for 30° angle of view. Figure 22 shows the 30° angle of view reflection curves for warp parallel, and warp perpendicular in this fabric, the black satin. Only the curve for warp parallel shows the peak. In the warp parallel direction the long floats of the satin weave act as relatively good mirrors while in the warp perpendicular orientation the light is being reflected from the rounded edges of cylinders and the reflection changes relatively little until high angles are reached where the Fresnel effect begins to dominate. Figure 23 and 24 show the directional reflectance 45° angle of view for wool frieze, in the one case with Figure 23 with the pebbled surface of the wool yarns, in the other Figure 24 with the smoother surface produced by napping. In each case, however, there is no peak near the mirror angle and the two fabric orientations are very similar. The chief difference between Figure 23 and Figure 24 is due to the lightness or difference in color of the fabrics, the napped frieze is of a considerably lighter shade as indicated by the difference in level at 45°.

Figure 25 shows directional reflectance at 45° angle of view for the lightest colored fabric in this series, the uniform twill fabric 19. This is usually regarded as a lustrous fabric but does not show any peak at the 45° angle of illumination, the mirror angle. All values lie at a higher level than for the other fabrics but the two directions are very close to each other in spite of the fact that the twill weave has a 3/1 float in the warp direction so that the same sort of difference observed with the satin might be expected although to a lesser degree. Figure 26 shows the opposite extreme in two respects. This is for the black rayon velveteen with a very short pile, the darkest fabric in the series. The short pile on the velveteen acts as a light trap to increase the absorption of light and decrease the reflectance at all angles. Note that the reflectance rises only at very high angles where the Fresnel effect begins to be most important.

Another fabric which might be expected to have relatively high luster because of its structure is number 13, the cotton/nylon sateen shown in Figure 27. In this fabric, the floats run in the filling direction but as Figure 27 shows, there is very little difference between either direction in the fabric.

Several indexes can be used to indicate the relative gloss, sheen or luster of fabrics. The ideas involved are complex and the components of the ideas vary in different applications so there is no one criterion for luster. Two which are useful in the present undertaking are 1) the luster ratio, the ratio reflectance at 45°, 45° divided by reflectance at 45°, 0°; 2) the reflectance difference between 45°, 45° and 45°, 0°. Table XII shows the fabrics in rank order of luster ratio for 45° angle of view for both warp parallel and warp perpendicular orientations. The effect of long float yarns parallel to the plane of the path of the light is shown dramatically by fabric 6, the rayon satin which has a ratio of 16 with the warp parallel, that is in the plane of the light and stands at the top of the rank while it has a ratio of 1.56 with warp yarns perpendicular and stands near the bottom of the rank. In general, high luster ratios are observed for the satin parallel to the floats of its yarns, and for certain pile fabrics, an acrylic pile number 15, and alpaca pile number 16. The alpaca pile shows more luster in the warp perpendicular orientation. The napped wool frieze number 2, also shows relatively high luster ratio in each direction. At the low end, the waffle weave shows up in each column as might be expected from its relatively uniform hill and valley structure in each direction and two of the corduroys, wide wale, number 24 and pin wale, number 23, are toward the bottom. However, number 17, corduroy subdued wale is well up in the warp parallel series and in the middle in the warp perpendicular series. The Raschel knit, number 22, is low in both series. The acrylic pile, number 15, was the only pile fabric with a prominently mobile pile. It could be smoothed by brushing with the hand as indicated by the term brushed or it could be exposed simply in a smooth condition, the normal unmodified condition which corresponded to the exposure in the field for night photography. Evidently, the additional brushing aligned surface fibers more perfectly so that a higher luster ratio is obtained. The other fabrics shown vary in degree of correlation in the middle area of the ranking, and do not require individual comment.

Table XIII shows ranking in order of difference in reflectance between 45°, 45° and 45°, 0°. This table also has two columns one for the warp parallel orientation in which the warp is parallel to the plane of the path of the light, the other for the warp perpendicular. Again, the difference between long yarn floats in the satin number 6 in the two orientations is conspicuous. Again, the acrylic pile shows high luster as so the alpaca, number 16, and the napped wool frieze, number 2. However, the wool blanket, number 3, is in the middle instead of near the top and the wide wale and pin wale corduroys, 24 and 23, are also in the middle instead of near the bottom. At the bottom of the ranking by the difference criterion, are the Raschel knit, number 22, and the rayon velveteen, number 18. Also near the bottom are burlap, number 9, and wool frieze, number 1, each of which has a coarsely pebbled surface and the double knit polyester, number 21. The nylon tri-acetate which has a short surface pile, number 14, is also near the bottom in each column. Other fabrics stand at various heights in the two columns and do not require separate comment. The corduroys do not show a consistent pattern in this analysis.

We can note that the higher density values correspond to more light received and therefore, will be influenced by the general level of reflectance of the fabrics and by the highlight or peak of reflectance from folds or curves. For this reason, it seems best to note that any fabric which ranks high by either of the criteria, luster ratio or difference with angle, shows a luster characteristic regardless of its general reflectance level and therefore may be expected to show a highlight effect in the photographs. It seems better to leave the four separate rankings to stand individually rather than to attempt any composite ranking.

The directional reflectance results obtained with the other angles of view, 30° and 60°, in general parallel those obtained at 45°. The chief difference is that the 30° angle of view reveals more of the mirror angle concentration characteristic of the fabrics than do the other angles. This can be understood by reference to Figure 6 in the Methods section which shows the three angles of view in diagram. As the angle of view departs from the normal, so also does the mirror angle for illumination so that at 60° the relatively grazing angles and the increased Fresnel reflection efficiency completely obscures any tendency for falling off after a peak of reflection at the mirror angle. The condition is much the same at 45°, but at 30° the mirror angle is well below the major Fresnel effect. Figure 28 shows how the Fresnel effect increases with increasing angle of illumination for 45° angle of view (8,9). The shape of this curve indicates why the reflectance values are so high at the high angles of illumination.

4. <u>Tipping the Fabric Out of the Plane Perpendicular to the Path of Light</u>

The special question of viewing a fabric from an elevation or what amounts to the same thing changing the plane of the fabric specimen so that the normal to the fabric is tipped out of the plane of the path of the light has been investigated experimentally using the goniophotometer. Table XIV shows the results for the 15 fabrics examined. The angle of tipping of the normal out of the optical plane or the fabric out of the vertical plane is indicated at the head of the columns. Zero degrees change indicates the usual 45°, 0° reflectance. Since this is an independent measurement, it will agree generally with but not be exactly the same as the 45°, 0° reflectances of Tables I or A-XVI. The successive degrees of tilt show in every case a decrease of the reflectance from the value at 45°, 0° fabric perpendicular. The largest change is in the first step from 0° to 9.2°, so this has been used as the basis of analysis. If the specimen surface were a perfect mirror, a small change of angle away from the perpendicular to the optical plane would completely remove the reflected ray from the optical plane and the reflectance reading would drop to zero. The more nearly perfect diffuse reflector the fabric is, the less difference the initial change or further changes will make. Hence, the extent of change is a measure of either the directional reflectance or the scattering power of the fabric surface.

Table XV shows the fabrics ranked in the order of the magnitude of this initial change, for warp parallel and warp perpendicular (original directions), respectively. The relations can be understood by examining the results obtained with the black satin which is the most strongly directional of all the fabrics. The long rayon floats act as cylinders which in the warp parallel orientation of the fabric lie parallel to the plane of the light. As the fabric is tipped out of its original vertical plane the cylinders are still parallel to their original direction and are not shadowed by each other to any great degree. Hence, the change for the first step for the black rayon satin, with warp parallel is zero. Likewise, the black rayon velveteen, fabric 18, is the least directional of all the fabrics and shows the next to smallest change for the warp parallel original orientation. In the warp originally perpendicular orientation, however, the velveteen also shows very little change while the satin shows a large change, being fourth from the highest. This is because, while the velveteen is truly nearly non-directional the satin, as an assembly of cylinders, is nearly non-directional for tipping when the cylinders remain parallel to the path of the light but is highly directional for tipping when the cylinders start from right angles to the path of the light. In this case, the reflection is tipped away from the receiving photocell much as if a good mirror were being tipped. This analysis indicates that the column for warp originally perpendicular will reveal the most regarding the luster or mirror-like characteristics. One notes that the uniform twill fabric 19, the pin wale corduroy fabric 23 and the alpaca pile fabric 16, all of which have shown themselves as high in one or another of the rankings of the usual directional reflectance analysis, are highest in change in the warp perpendicular orientation here. Similarly, the waffle weave number 25, the unnapped wool frieze, number 1, and the Raschel knit number 22, each of which has a pebbly surface of rather large scale, are low in ranking in this table for the warp originally perpendicular orientation.

This method of examination supplements the others, and suggests that low directional effect would be desirable for minimizing observability with change of elevation, if the illumination were in the same plane as the object. A more thorough analysis of observation with change of plane and with rather general illumination shows that both rotation and inclination of the fabric are involved. The present experimental examination involves only inclination of the fabric, but it can be seen from the directional reflectance results with warp perpendicular and warp parallel that there is not much range for the effects of fabric rotation since the directional reflectance curves for the two extremes of orientation in practically all cases that would be used in army field uniforms follow each other very closely. The rayon satin in fact is the only fabric in this series in which there is a large difference between the two orientations. Hence, for all the relatively non-directional fabrics which would be used for Army field uniforms, the effects of change of orientation from parallel to warp to parallel to filling or from vertical to inclined are relatively small. Results from the photonegatives agree in showing relatively little difference for warp along cylinder or filling along cylinder or for cylinders vertical or cylinders horizontal. The chief correlation is with general reflectance level or lightness as measured at 45°, 0° rather than with directional characteristics or luster.

VI. CORRELATION OF FIELD DATA WITH REFLECTANCE PROPERTIES AND FABRIC STRUCTURE

A. Correlation with Reflectance

1. Highlights from Grazing Angles

All of the directional reflectance data show a marked increase of reflectance as the angle of illumination goes further beyond the normal and approaches grazing angles at angles from the normal above 60 degrees. Even the black rayon velveteen, number 18 which is lowest of all the fabrics in directionality shows this increase at high angles and in all the other fabrics the increase is very large. In the photonegatives there is usually a narrow region of higher density at the margins of the cylinders, especially of the vertical cylinders, where apparently the light which reaches the night viewing device has come from the background at a grazing angle to a fabric surface. This was seen in Figure 13 which shows the transition of densities across the cylinder edge. The densitometer measurements by Method A were taken in order from the edge of the cylinder toward the center and on toward the other edge, and show that in more than half the sets, the first measurement is higher than the average. This indicates that while the edge highlight is a general trend, other influences intervene and it is not universal. However, a particularly good example is shown in Figure 29 which shows measurements extending all the way across a cylinder covered with fabric 8, low IR Simplex knit, with warp vertical, against the horizon background. The illumination at night is practically omni-directional from the whole bowl of the sky and from the surroundings. In such backgrounds as the horizon, open field, and brushy field, where no object was close behind the cylinders, this omni-directional effect would be particularly strong. In others, such as the green foliage background or in the woods, a background object was close to the cylinders so that the omni-directional illumination might be shut off from that side or modified. Even these modified conditions seem to give a highlight at the edges of the vertical cylinders. In general, the center of the cylinder showed little or no highlight effect. The cylinders were remarkably uniform from near one edge to near the other. We have seen some highlights in some photographs due to folds but not due to the curvature of the cylinder when the fabric was mounted close and flat to the cylinder surface, as was the usual case.

2. General Correlation with Fabric Lightness

A general correlation of reflectance property with the optical density is to be expected for general lightness or darkness of the fabrics. The chief question in demonstrating such a correlation from the present data is the influence of other circumstances, and the choice of a representative reflectance for the general lightness/darkness characteristic. The conventional choice for the lightness characteristic is the 45°, 0° reflectance. Table V showed the high, average and low densities for each orientation of the cylinders and each orientation of the fabrics for each background. Since some of the fabrics do not differ very much and interchange in rank order and since some fabrics were not represented on every background, we have chosen to compare the three fabrics of highest density in each orientation and background with the three fabrics of lowest density in each. In addition, the data has been normalized for variation in illumination condition and exposure time by taking the optical density difference, background density minus fabric density, rather than the density directly. This removes at least part of the variation from negative to negative. If the same fabric were available in each series, and if the same fabric came out highest and correspondingly another fabric came out lowest in each series, there would be 25 possibilities that a particular fabric might show in either the high or low category. Table XVI shows that the maximum tally for any one fabric was ten and indeed most fabrics showed in both categories, possibly due to orientation effects, but usually predominantly in one category rather than the other. Table XVII shows those fabrics which occurred more than four times in one category or the other. The table also shows that the 45°, 0° reflectance for the high density group is indeed higher than that for the low density group indicating a degree of correlation between general brightness and optical density, as would be expected, other influences being equal.

3. Correlation on Particular Backgrounds

We have examined the possibility of demonstrating a close relationship at particular background sites. In general, this type of correlation by plotting optical density on one axis against reflectance on the other axis does not show any well defined regression line for the group of 25 fabrics, so the main evidence must be from extreme values as set forth in Table XVII. The main group of these 25 fabrics are all relatively close in reflectance characteristics as might be expected from the fact that one or two Army shades comprise the bulk of the group. The correlation diagram showing the greatest degree of trend, is shown in Figure 30. This data is from the rubble site. In this figure, the fabrics which were picked out from the whole mass of the data, and tabulated in Table XVII, are indicated by solid circles for the high densities, and by open circles for low densities, so it can be seen that there is some trend between the extremes.

Table XVII lists the colors of the fabrics in the two groups. It can be seen that some of the colors for the high density group tend to be lighter, notably wool frieze number 2, uniform twill number 19 and corduroy number 24, but in general it is the combined effect of directional reflectance curves and color which dominate here; thus number 25, waffle weave which is lighter in color is in the low group. The color effect is also shown by the presence of the black velveteen number 18 in the low density group and by the fact that number 7 the high IR simplex knit is in the high density group while number 8, the corresponding low IR knit, is in the low density group. The table also shows the sum of all the directional reflectance measurements up to 60° and this sum is larger for the high density group than for the low, just as the 45°, 0° reflectances were larger.

B. Analysis by Fabric Structure Types

Table XVIII classifies the 25 fabrics examined into several types on the basis of their structural characteristics. The first main type is the group of woven or knit fabrics whose structure arises from the yarn itself in a uniform pattern of inter-lacing. This includes plain weaves, float weaves, (twill, satins and other patterns) and smooth knits. The second group is characterized by hill and valley effects which arise from variations in the weaving pattern or knitting pattern larger than the yarn to yarn or course to course or wale to wale variation and might be defined without regard to method of construction as hill and valley effects. Very coarse knits or very coarse woven structures might physically fall into this group. The representatives among the 25 fabrics are the Raschel knit and the waffle weave patterns. If puckered fabrics such as seersucker has been included, they would belong in this group because of their physical hill and valley effect. The third major group contains the fabrics with a fiber or pile surface. Fiber surfaces can be produced by brushing or napping or pile can be woven in as in the terry cloth and the unnapped frieze. Pile fibers can also be inserted by knitting processes but the important distinction here is that one sees a more mobile surface in which the basic weave is covered by additional fiber or pile structures. In a sense, all staple fiber fabrics have a degree of the fibrous surface characteristic in comparison with filament yarn fabrics, but with few exceptions the fabrics here are staple fiber fabrics so the relatively clear staple fabrics have been put in the first group. Some short naps on fabrics have classified them in the third group: the rayon velveteen and the brushed triacetate/nylon. The corduroy fabrics have also been classified in this group although they have a linear hill and valley effect arising from the wale pattern. Each of the 25 fabrics have been classified into one subdivision of these three main groups in Table XVIII.

It is easier to find correlations between structure and the directional reflectance curves (and indeed this has been pointed out in the course of the discussion of these curves) than to find correlations between structure and the overall effect on contrasts as seen in the night vision device. Table XVIII also indicates the fabrics which showed four times or more as high density fabrics and which fabrics showed as low density fabrics in the photographic negatives, but does not indicate any systematic correlation between density in the negatives and structure. The general conclusion to be drawn from this appears to be that within the group of fabrics studies here variation in structure is of less significance than the combined effect of other factors, especially general lightness or color. Our judgement is that the structure variations within this group are all on a scale smaller than that which is required to accomplish a match with the variation of the background. It may be that high sheen fabrics such as the pile fabrics have at least that factor working towards increase of reflection from the fabrics along certain directions, but unless color (or lightness) also works in the same direction, no exceptional result is obtained. As a general safe measure, the fabrics with yarn surfaces or with pebbly surfaces and the fabrics with a small degree of brushed nap or at least, staple fiber in preference to filament yarn, can be expected to produce less directional effect and thus lower densities.

A suggestion made by Natick personnel (10) in discussion of this project bears on this point: improved camoflage can be obtained by linear patterns parallel to the edge so that the contrast at the edge is less marked. None of the linear patterns, such as those of the corduroy, in this series are sufficiently marked or sufficiently broad to accomplish this but it is conceivable that fabric could be economically woven with alternating warp yarns of different dyeing capacities so that a linear pattern parallel to the warp and thus to most long garment edges could be accomplished. It is probable that the width of the pattern should be on the order of 1 cm or 0.5-inch or greater and of varied widths. The herringbone twill is a step in this direction which could be extended by using yarns of different dye uptake characteristics as well as variation of the twill line which in itself would probably accomplish very little in obscuring the edge contrast.

C. Best Matches of Fabrics with Background

Since the backgrounds differ in their general levels of brightness as shown in Table V, and since the fabrics tend to line up on all backgrounds in the same order of brightness, it is not surprising that somewhat different fabrics provide better matches against one background than another. The horizon background can be excluded from this comparison because the sky, which was the background here, is much brighter than any of the fabrics and in all cases there was a clear silhouette line. Table XIX shows for the other backgrounds which fabrics provided density differences, background minus fabric, within 0.2 density units above or below the background. It can be seen that quite different fabrics provided this match against the different backgrounds. This emphasizes the point discussed at other places in this report, that no single fabric with a single color and only a small scale pattern can match very many different backgrounds. A variegated pattern on the fabric with at least two levels of brightness would provide a match against a wider variety of backgrounds.

VII. SUMMARY OF FINDINGS

(1) Fabrics differ from background in:

a. Greater uniformity

b. Linear edges

c General difference of light level

(2) Directional reflectance features of most of the fabrics, including the knits, uniform twill, and sateen, show up in the field as a highlight near the edge, accentuating the edge effect. Only the most highly directional pile fabrics and the black satin show marked differences with orientation in the field photographs. Fabric structure such as float weaves or long and oriented pile contribute to high directional effect.

(3) All the fabrics show a gloss or sheen effect: the reflectance rises sharply at grazing angles of illumination (or view). This increase arises from increased efficiency of reflection according to Fresnel's Law, rather than as mirror-like reflection, which is a minor factor for all of the fabrics of this group except the satin. Scattering by fibers and by cross yarns (or curved yarns, in knits) and by the changes of yarn direction involved in weaving crimp, knit loop interlacing, and special hill and valley effects overwhelms the mirror-like features of reflectance so that the gloss or sheen effects (Fresnel effects) are dominant.

(4) Match of single color fabric with a background depends chiefly on general brightness level of each.

(5) Fabrics with good visual match but with high or low reflectance in the near infrared show a tendency for the high IR fabrics to show a higher optical density, that is, to appear lighter in the night vision device. This varies however, from night to night, perhaps because of variation in the amount of IR radiation. Match will depend on the IR reflectance of the background as well as on the level of IR radiation.

(6) Structural patterns arising from weaving in the range represented in this series are too fine in scale to give patterns comparable to the patterns of the backgrounds, or to confuse the linear edge of garments, wider strips might aid in obscuring the edges. Short fiber pile and more than one yarn direction in the fabric surface as with plain weave and knits reduces directionality and increases scatter in all directions. The scattering effect of different yarn directions in knits and even in float weaves up to at least 3/1 floats reduces the directional effect, especially for staple fiber yarns.

VIII. RECOMMENDATIONS

Recommendations for choice of fabrics to minimize detection by night vision devices:

(1) Avoid very light and very dark colors. Use a middle range.

(2) Avoid fabrics with pile which can be changed in orientation by brushing.

(3) Use plain weave or short float fabrics (up to 3/1), or knits.

(4) Use staple fiber yarns instead of filament.

(5) Creation of a very short pile by brushing or the fuzz which arises from use and washing is helpful in reducing the directional effect and thus reducing edge contrast.

(6) This work implies the value of blotch or linear patterns of two or more shades. The blotches will help match background variation. The linear pattern could help obscure or confuse edge effects. The patterns need to be larger than the hill and valley effects which can be produced by weaving or knitting. Blotch effects should be on the order of one to several inches; linear effects on the order of half inches, and perhaps mixed in width and spacing.

(7) A special study of linear pattern with respect to its effect on detection, including comparison with similar fabrics in single colors would be informative and could furnish a rational basis for pattern selection.

IX. REFERENCES

1. Department of the Army Technical Manual, TM 11-5855-202-13. Night Vision Sight: Crew Served Weapons Models 9927 and 9927A and Changes C1 and C2. AN/TVS-2 and AN/TVS-2A. 19f7, 1969.

2. Ramsley, A. O., Camouflage of the Individual Soldier at Night, United States Army Natick Laboratories, Technical Report 68-37-CM, Natick, Massachusetts, March 1968.

3. Stark, A. M. and B. W. Manley, Feasibility Study of Emissive-Conductive Photocathodes, Mullard Research Laboratories, C.V.D. Terminal Report, Research Project RP8-31, February 1964. AD 441168.

4. Chamberlain, J. W., Physics of Aurora and Airglow, International Geophysical Series, Chap. 9.

5. Weinberg, J. L., A Photoelectric Study of the Nightglow, University of Hawaii, Nov. 1968, N70-18676.

6. McNicholas, H. J., B.S.J. Research 1, 29 (1928); RP3.

7. Moon, P., J. Math. Phys. 19, 1-33 (1940).

8. Fourt, Lyman, Improvement of Luster of Cotton, Textile Res. J., 24, 163-172, February 1954.

9. Fourt, Lyman, Improvement of Luster of Wool Fabrics, Textile Res. J. 36, 915-924, 1966.

10. Rizzo, F. J., Personal Communications.

TABLE I

FABRIC LIST

NAMES, COLOR, 45°, 0° REFLECTANCES FOR VISIBLE RANGE IN TWO ORIENTATIONS: WH INDICATES WARP HORIZONTAL, PARALLEL TO THE PLANE OF THE PATH OF THE LIGHT. WV INDICATES WARP VERTICAL

No.	Fabric	Color	Reflectance at 45°, 0° $MgO = 1000$	
			WH	WV
1	Cloth, Wool, Frieze	OG118	50	43
2	Cloth, Wool, Frieze, Napped	OG108	125	119
3	Blanket, Bed, Wool	OG118	65	62
4	Cloth, Cotton, Terry, Low IR	OG107	90	94
5	Cloth, Cotton, Terry, High IR	OG107	97	94
6	Cloth, Rayon Satin, Wool napped Back	Blue 65012[a]	25	68
7	Cloth, Cotton, Simplex Knit, High IR	OG107	92	100
8	Cloth, Cotton, Simplex Knit, Low IR	OG107	82	72
9	Burlap, Low IR	OG107	47	40
10	Cloth, Cotton, (Diaper) Birdseye	OG107	77	75
11	Cloth, Double Knit, Acrylic (Pique)	Green 329	56	56
12	Cloth, Cotton, Osnaburg	OG107	62	62
13	Cloth, W.R. Sateen Cotton/Nylon, Low IR	OG107	87	81
14	Cloth, Nylon/Triacetate, Tricot, Napped	OG106	56	47
15	Cloth, Acrylic Pile	Medium Blue	27	43
16	Cloth, Alpaca, Pile (3/8")	Natural	171	170
17	Cloth, Cotton, Corduroy (Subdued wale)	Yellow Brown	40	56
18	Cloth, Rayon Velveteen	Black	22	18
19	Cloth, Cotton, Uniform Twill, 8.2 oz.	Khaki	257	225
20	Cloth, Cotton, Sheeting	OG107	80	94
21	Cloth, Double Knit Polyester	Blue	52	43
22	Cloth, Nylon, Raschel Knit	OG106	66	58
23	Cloth, Corduroy, Pin Wale	Gray	257	245
24	Cloth, Corduroy, Wide Wale	Light Brown	228	160
25	Cloth, Waffle Weave	Light Brown	97	100

a. Fabric 6 appears black in daylight to all observers rather than blue

TABLE II

EXPOSURE CONDITIONS FOR FIELD PHOTOGRAPHS

Background and Location	Average Density of White Cards	Camera Stop f/	Area Ratio	Time sec.	Relative Photographic Illumination (Note 5)	Measured Radiation Watts/cm^2 (Note 6)	Date
Open Field, (1a)	1.11	6.3	1	20	2.8		12/3/70
Brushy Field, (1b)	0.96	6.3	1	10	3.9		12/2/70
Edge of Woods, (1c)	0.92	6.3	1	30	1.2		12/1/70
In the Woods, (1d), first 20 only (7)	0.82	6.3	1	30	1		12/3/70
Green Foliage, (2a), early to late	0.69 1.07 .32	6.3	1	22(8) 20 24	1.0 2.9 .4		6/29/71
Rubble (3)	0.63	6.3		3 to 5 (8)	6.7 6.0	$6-7x10^{-10}$	12/1/70
Horizon (4)	0.59	11	0.5	5	6.0	$1.0x10^{-10}$	12/28/70
Calibration (2b)							
low	0.75	6.3	1	30		$2.5x10^{-11}$	2/24/71
high	1.81	6.3	1	240			

(See NOTES - Page 38 for details)

NOTES*

1 through 4. All locations were more than 20 miles from town lights which might reflect from clouds.

1a. Meadow near Micheaux National Forest, Pennsylvania (between Chambersburg and Carlyle).

1b. Lane at same field as 1a.

1c. Along the Appalachian Trial, Micheaux National Forest, Pennsylvania.

1d. Lane in woods, Micheaux National Forest, Pennsylvania.

2a. Violet's Locks, Chesapeake and Ohio Canal, Maryland.

2b. Same location, clear night, very humid, overcase sky.

3. Gatchland State Park, Maryland

4. Neely Farm near Lovettsville, Virginia.

5. Relative photographic illumination measures the effect on the fluorescent screen from the white card portion of the negatives. It measures variation in total light (visible and IR) coming from the white card, according to the relation:

$$D_1 - D_2 = K \log \frac{A_1 T_1 L_1}{A_2 T_2 L_2}$$

when D=optical density, K=constant determined from the calibration data, A=aperture area dependent on the f/ stop used, T=time of exposure, L=light on fluorescent screen, which depends on the amounts of both visible and infrared radiation available to the night vision device.

In the table, one of the dark (low light level) conditions, in the woods, was taken as unity.

6. Radiation measurements with Ga As photomultiplier sensitive to 0.95 microns. Data taken at earlier sites lacked proper calibration.

7. The last five were at a much lower light level, when light rain fell.

8. Exposure time was increased as the night darkened (after 11-12 P.M.). In general, we did not increase the time enough to completely compensate. The progressively lower light level was especially marked for the green foliage series.

(*See Table II)

TABLE III

FABRIC INDEX FOR FIGURES

Fabric No.	WH[a] 30°, 45°, 60°	WH, WV[b] 45°	WH, WV[c] 30°	Prints from field negatives	Two Fabrics Directional Reflectance	Densitometer Data
1	--	23	--	--	--	--
2	--	24	--	11	--	--
3	--	--	--	8	--	--
4	--	--	--	--	16	13
5	--	--	--	--	16	--
6	21	20	22	--	--	14
7	--	--	--	--	17	15
8	--	--	--	9	17	15, 29
13	--	27	--	--	--	--
18	--	26	--	--	--	--
19	--	25	--	10	--	--

a. Directional reflectance, 3 angles of view, warp parallel to plane of light (WH).

b. Directional reflectance, warp parallel to plane of light (WH) and warp perpendicular (WV), for 45° angle of view.

c. Directional reflectance, warp parallel to plane of light (WH) and warp perpendicular (WV), for 30° angle of view.

TABLE XV

COMPARISON OF OPTICAL DENSITY SAMPLING TECHNIQUES ON PHOTONEGATIVES. FABRICS ON VERTICAL CYCLINDERS, WARP HORIZONTAL, GREEN FOLIAGE BACKGROUND

No.	Fabric Description	Optical Density Averages			Averages of Optical Density Differences		
		Method A	Method B	Method C	Method A	Method B	Method C
4	Terry Cloth, Low IR	0.51	0.50	0.50	0.01	0.04	0.06
5	Terry Cloth, High IR	0.62	0.63	0.60	-0.14	-0.12	-0.06
6	Black Rayon Satin	0.54	0.52	0.52	-0.04	-0.03	-0.03
7	Cotton Knit, High IR	0.61	0.62	0.60	-0.11	-0.08	-0.05
8	Cotton Knit, Low IR	0.45	0.45	0.40	0.04	0.07	0.07

Method A: Background densities measured horizontally above cylinders and on fabrics across cylinders.

B: Background and fabric densities measured horizontally across cylinders through cylinder background boundary.

C: Background and fabric densities measured vertically along cylinder edge but 1mm from boundary.

TABLE V

A COMPARISON OF THE OPTICAL DENSITY VALUES IN PHOTONEGATIVES OF WHITE REFLECTANCE CARDS, FABRICS AND BACKGROUNDS FOR ALL BACKGROUNDS AND FABRICS.

				Fabric Values			
Background	White Card	Back-ground	No. of Fabrics	Most Dense	Average	Least Dense	Orientation of Fabric*
Open Field	1.07	0.89	15	1.5	0.87	0.72	CV, WA
			14	1.07	0.83	0.68	CV, FA
	1.15	0.87	15	1.16	0.91	0.58	CH, WA
			15	1.16	0.86	0.57	CH, FA
Brushy Field	0.96	0.84	20	0.83	0.69	0.51	CV, WA
			20	0.85	0.68	0.54	CV, FA
	0.96	0.86	19	0.86	0.72	0.60	CH, WA
			20	0.89	0.71	0.57	CH, FA
Edge of Woods	0.92	0.64	22	0.74	0.56	0.31	CV, WA
			22	0.74	0.56	0.39	CV, FA
	0.91	0.67	22	0.83	0.65	0.47	CH, WA
			20	0.82	0.65	0.48	CH, FA
In the Woods	0.83	0.34	20	0.57	0.41	0.24	CV, WA
			19	0.53	0.38	0.22	CV, FA
	0.81	0.32	19	0.59	0.50	0.26	CH, WA
Green Foliage	0.69	0.38	25	0.75	0.35	0.10	CV, WA
			24	0.77	0.37	0.11	CV, FA
Rubble	0.67	0.58	25	0.54	0.36	0.21	CV, WA
			24	0.67	0.37	0.20	CV, FA
	0.58	0.55	24	0.68	0.39	0.20	CH, WA
			24	0.79	0.38	0.18	CH, FA
Horizon	0.58	0.77	25	0.64	0.42	0.30	CV, WA
			24	0.60	0.42	0.33	CV, FA
	0.60	0.77	25	0.62	0.43	0.29	CH, WA
			24	0.59	0.43	0.33	CH, FA

* C - cylinder, V - vertical, H - horizontal
W - warp, F - filling, A - along the cylinder

TABLE VI

CONTRAST OF FABRICS ON VERTICAL CYLINDERS WITH GREEN FOLIAGE BACKGROUND BY OPTICAL DENSITY AND SUBJECTIVE RATINGS ON PHOTONEGATIVES

		Optical Density Difference			Subjective Contrast Rating		
	Fabric	Warp	Warp		Observer		
No.	Description	Vertical	Horizontal	Total	#1	#2	Total
2	Wool Frieze, Napped	-.006	-.080	-.086	4	4	8
24	Corduroy, Widewale	-.009	-.053	-.062	3	4	7
5	Terry Cloth, High IR	.003	-.055	-.052	4	4	8
19	Cotton Uniform Twill	-.008	-.033	-.041	3	3	6
7	Cotton Knit, High IR	-.001	-.031	-.032	4	4	8
23	Corduroy, Pinwale	.001	-.031	[illegible]	3	3	6
3	Wool Blanket	.029	-.058	-.029	2	2	4
22	Raschel Knit	.001	-.020	-.019	2	2	4
1	Wool Frieze	-.001	-.003	-.004	2	2	4
15	Acrylic Pile	.007	-.009	-.002	2	2	4
25	Waffle Weave	.003	.002	.005	2	2	4
6	Black Rayon Satin	.046	-.038	.008	3	3	6
11	Acrylic Double Knit	.003	.013	.016	3	2	5
21	Polyester Double Knit	.027	-.009	.018	2	2	4
16	Alpaca Pile	.039	-.005*	.032	2	2	4
14	Nylon/Triacetate Knit	.041	-.004	.037	3	3	6
17	Corduroy, Subdued Wale	.043	-.001	.042	5	4	9
20	Cotton Sheeting	.040	.018	.058	3	3	6
18	Black Rayon Velveteen	.042	.016	.058	4	5	9
12	Cotton Osnaburg	.062	.060	.122	6	6	12
10	Cotton Birdseye	.106	.019	.125	6	5	11
13	Cotton/Nylon Sateen	.069	.058	.127	6	5	11
4	Terry Cloth, Low IR	.074	.061	.135	6	6	12
9	Burlap	.085	.082	.167	6	6	12
8	Cotton Knit, Low IR	.110	.073	.183	6	6	12

* Estimated from reflectance data.

TABLE VII

GROUPING OF FABRICS BY OPTICAL
DENSITY DIFFERENCE IN PHOTONEGATIVES
AGAINST AN "IN THE WOODS" BACKGROUND

Fabric No.	Fabric Description	Optical Density Difference	Group Assignment
2	Wool Frieze, Napped	-.182	1
19	Cotton Uniform Twill	-.176	1
11	Acrylic Double Knit	-.152	2
5	Terry Cloth, High IR	-.150	2
16	Alpaca Pile	-.140	2
7	Cotton Knit, High IR	-.120	2
14	Nylon/Triacetate Knit	-.120	2
3	Wool Blanket	-.098	3
17	Corduroy, Subdued Wale	-.090	3
15	Acrylic Pile	-.084	3
13	Cotton/Nylon Sateen	-.080	3
24	Corduroy, Widewale	-.072	4
1	Wool Frieze	-.062	4
25	Waffle Weave	-.048	4
6	Black Rayon Satin	-.034	5
12	Cotton Osnaburg	-.020	5
20	Cotton Sheeting	-.004	6
18	Black Rayon Velveteen	-.002	6
22	Raschel Knit	.002	6
4	Terry Cloth, Low IR	.008	6
21	Polyester Double Knit	.028	7
10	Cotton Birdseye	.030	7
8	Cotton Knit, Low IR	.032	7
9	Burlap	.048	7

TABLE VIII

PRIMARY GROUP MATCHING BY FABRIC AND BACKGROUND USING OPTICAL DENSITY DIFFERENCE ON PHOTONEGATIVES

Match Code: 1 (+), Missing (0), 1 (-)

		Background							
No.	Fabric Description	Horizon	Edge of Woods	In the Woods	Rubble	Green Foliage	Open Field	Brushy Field	Degree of Match (%)
1	Wool Frieze	-	-	+	-	+	+	-	43
2	Wool Frieze, Napped	-	+	+	+	+	+	+	86
3	Wool Blanket	+	+	-	+	+	+	+	86
4	Terry Cloth, Low IR	+	+	+	-	+	-	+	71
5	Terry Cloth, High IR	+	+	-	+	+	+	+	86
6	Black Rayon Satin	+	-	+	+	+	+	+	86
7	Cotton Knit, High IR	-	+	+	-	+	+	+	71
8	Cotton Knit, Low IR	+	+	-	-	-	+	+	57
9	Burlap	-	-	+	+	+	+	0	57
10	Cotton Birdseye	+	+	-	+	-	0	-	50
11	Acrylic Double Knit	+	+	+	+	+	0	+	100
12	Cotton Osnaburg	+	+	+	-	+	0	0	80
13	Cotton/Nylon Sateen	+	-	+	-	-	0	0	40
14	Nylon/Triacetate Knit	-	0	-	+	+	+	0	60
15	Acrylic Pile	-	0	+	-	+	-	0	40
16	Alpaca Pile	+	+	+	+	+	+	0	100
17	Corduroy Subdued Wale	+	+	-	+	+	-	+	71
18	Black Rayon Velveteen	+	-	+	-	+	0	+	67
19	Cotton Uniform Twill	+	+	+	-	+	0	-	67
20	Cotton Sheeting	-	+	-	0	-	0	+	40
21	Polyester Double Knit	+	-	+	0	+	0	+	80
22	Raschel Knit	+	+	-	0	+	0	-	60
23	Corduroy Pinwale	+	+	0	0	+	0	+	100
24	Corduroy Widewale	+	+	-	0	+	+	+	83
25	Waffle Weave	-	+	+	0	+	+	+	83

TABLE IX

SPECTROPHOTOMETRIC DATA (FROM U. S. ARMY NATICK LABORATORIES) ON PAIRS OF FABRICS DIFFERING IN INFRARED REFLECTANCE BUT SIMILAR WITHIN 1.5% UP TO 600 NANOMETERS

Fabric	Percent Reflectance at Indicated Wave Lengths (nanometers)							
	Visible					Infrared		
	400 %	500 %	570 %	600 %	700 %	800 %	900 %	1000 %
#4, Terry Cloth, Low IR, OG107	4	5.5	10	8.5	4	4	6.5	16
#5, Terry Cloth, High IR, OG107	6.5	6.5	9	8	19	69	80	82.5
#7, Simplex Knit, High IR, OG107	5	5.5	8	7.5	33	70	83	83
#8, Simplex Knit, Low IR, OG107	4	5.5	9.5	8.5	4	4.5	7	16

TABLE X

INFLUENCE OF INFRARED REFLECTANCE ON DENSITY IN NEGATIVES FROM SEVEN BACKGROUNDS, TAKEN ON SIX NIGHTS

Orientation of Cylinders	Vertical		Horizontal	
Fabric Pairs	4,5	7,8	4,5	7,8
Number of Pairings	14	13	11	11
Pairings in which higher IR is more dense, after adjustment for white card density.	12	8	8	8

TABLE XI

RANKING OF 45^{o}, 0^{o} REFLECTANCES IN ORDER FROM HIGHEST TO LOWEST GENERAL LIGHTNESS LEVEL

Warp Parallel			Warp Perpendicular		
19	Uniform Twill	257	23	Corduroy Pinwale	245
23	Corduroy, Pinwale	257	19	Uniform Twill	225
24	Corduroy, Widewale	228	16	Alpaca Pile	170
16	Alpaca Pile	171	24	Corduroy, Widewale	160
2	Wool Frieze, napped	125	2	Wool Frieze, napped	119
5	Terry Cloth, High IR	97	7	Cotton Simplex Knit, High IR	100
25	Waffle Weave	97	25	Waffle Weave	100
7	Cotton Simplex Knit, High IR	92	4	Terry Cloth, Low IR	94
4	Terry Cloth, Low IR	90	5	Terry Cloth, High IR	94
13	Sateen, Cotton/Nylon	87	20	Cotton Sheeting	94
8	Cotton Simplex Knit, Low IR	82	13	Sateen Cotton/Nylon	81
20	Cotton Sheeting	80	10	Cotton Birdseye	75
10	Cotton Birdseye	77	8	Cotton Simplex Knit, Low IR	72
15	Acrylic Pile - brushed	68	6	Black Rayon Satin	68
22	Raschel Knit	66	3	Wool Bed Blanket	62
3	Wool Bed Blanket	65	12	Cotton Osnaburg	62
12	Cotton Osnaburg	62	11	Double Knit, Acrylic	56
11	Double Knit Acrylic	56	15	Acrylic Pile-brushed	56
14	Knit Triacetate	56	17	Corduroy Subdued wale	56
21	Double Knit Polyester	52	22	Raschel Knit	58
1	Wool Frieze	50	14	Knit Triacetate	47
9	Burlap	47	1	Wool Frieze	43
17	Corduroy Subdued wale	40	15	Acrylic Pile - smooth	43
15	Acrylic Pile - smooth	27	21	Double Knit Polyester	43
6	Black Rayon Satin	25	9	Burlap	40
18	Black Rayon Velveteen	22	18	Black Rayon Velveteen	18

TABLE XII

RANKING OF RATIO OF 45°, 45° TO 45°, 0° REFLECTANCES.
THIS LUSTER RATIO IS AN INDEX OF MIRROR-LIKE DIRECTIONALITY

Warp Parallel			Warp Perpendicular		
6	Black Satin	16.28	15	Acrylic Pile, brushed	5.04
15	Acrylic Pile, brushed	5.06	15	Acrylic Pile, normal	3.67
15	Acrylic Pile, normal	4.41	16	Alpaca Pile	3.06
2	Wool Frieze, napped	2.90	2	Wool Frieze, napped	2.84
17	Corduroy, Subdued wale	2.75	5	Terry Cloth, High IR	2.60
4	Terry Cloth, Low IR	2.58	13	Sateen, Cotton/Nylon	2.23
10	Cotton Birdseye	2.27	3	Wool Bed Blanket	2.18
20	Cotton Sheeting	2.26	19	Uniform Twill	1.98
11	Double Knit Pique	2.23	18	Rayon Velveteen	1.94
9	Burlap	2.13	12	Cotton Osnaburg	1.92
5	Terry Cloth, High IR	2.12	17	Corduroy Subdued wale	1.89
13	Sateen, Cotton/Nylon	2.05	1	Wool Frieze	1.88
3	Wool Bed Blanket	2.02	9	Burlap	1.88
8	Simplex Knit, Low IR	1.99	14	Tricot Nylon/Triacetate	1.85
12	Cotton Osnaburg	1.92	10	Cotton Birdseye	1.83
16	Alpaca Pile	1.76	4	Terry Cloth, Low IR	1.80
14	Tricot Nylon/Triacetate	1.73	11	Double Knit Pique	1.79
19	Uniform Twill	1.70	25	Waffle Weave	1.70
18	Rayon Velveteen	1.68	8	Simplex Knit, Low IR	1.69
7	Simplex Knit, High IR	1.66	7	Simplex Knit, High IR	1.65
21	Double Knit Polyester	1.63	21	Double Knit Polyester	1.58
1	Wool Frieze	1.62	22	Raschel Knit	1.57
25	Waffle Weave	1.61	6	Black Satin	1.56
23	Corduroy Pinwale	1.52	24	Corduroy Widewale	1.47
22	Raschel Knit	1.47	23	Corduroy Pinwale	1.38
24	Corduroy Widewale	1.15	20	Cotton Sheeting	1.16

TABLE XIII

RANKING OF DIFFERENCES OF 45°, 45° AND 45°, 0° REFLECTANCE, AN INDICATOR OF DIRECTIONALITY

Warp Parallel			Warp Perpendicular		
6	Black Rayon Satin	382	16	Alpaca Pile	350
15	Acrylic Pile, brushed	276	15	Acrylic Pile, brushed	226
2	Wool Frieze, napped	183	19	Uniform Twill	220
19	Uniform Twill	179	2	Wool Frieze, napped	219
4	Terry Cloth, Low IR	142	5	Terry Cloth, High IR	150
23	Corduroy Pinwale	134	15	Acrylic Pile, normal	115
16	Alpaca Pile	130	13	Sateen, Cotton/Nylon	100
5	Terry Cloth, High IR	109	20	Cotton Sheeting	96
20	Cotton Sheeting	101	23	Corduroy Pinwale	93
10	Cotton Birdseye	98	24	Corduroy Widewale	75
15	Acrylic Pile, normal	92	4	Terry Cloth, Low IR	75
13	Sateen, Cotton/Nylon	91	3	Wool Bed Blanket	73
8	Simplex Knit, Low IR	81	25	Waffle Weave	70
17	Corduroy Subdued wale	70	7	Simplex Knit, High IR	65
11	Double Knit Pique	69	10	Cotton Birdseye	62
3	Wool Bed Blanket	66	12	Cotton Osnaburg	57
7	Simplex Knit, High IR	61	8	Simplex Knit, Low IR	50
25	Waffle Weave	59	17	Corduroy, Subdued wale	50
12	Cotton Osnaburg	57	11	Double Knit Pique	44
9	Burlap	53	14	Knit,Nylon/Triacetate	40
14	Knit, Nylon/Triacetate	41	1	Wool Frieze	38
24	Corduroy Widewale	35	6	Black Satin	38
21	Double Knit Polyester	33	9	Burlap	35
1	Wool Frieze	31	22	Raschel Knit	33
22	Raschel Knit	31	21	Double Knit	25
18	Rayon Velveteen	15	18	Rayon Velveteen	17

TABLE XIV

CHANGE OF REFLECTANCE ON TIPPING FABRIC
AWAY FROM ORIGINAL PLANE

Original plane of fabric was perpendicular to the plane of the path of the light (0^o column).

No.	Fabric	Orientation	Reflectance At Indicated Angle From Vertical			
			0^o	9.2^o	18.0^o	25.9^o
1	Wool Frieze	Par.	43	30	21	10
		Perp.	42	21	10	10
2	Wool Frieze, napped	Par.	182	66	44	27
		Perp.	113	56	35	19
6	Black Satin	Par.	8	8	10	7
		Perp.	88	20	5	3
7	Cotton Simplex Knit, High IR	Par.	54	25	15	5
		Perp.	64	34	20	3
8	Cotton Simplex Knit, Low IR	Par.	49	22	12	3
		Perp.	57	27	13	5
13	Cotton Nylon Sateen	Par.	53	18	12	0
		Perp.	50	22	12	2
15	Acrylic Pile, normal	Par.	18	5	2	0
		Perp.	41	13	12	8
15	Acrylic Pile, brushed	Par.	75	10	3	0
		Perp.	52	8	3	0
16	Alpaca Pile	Par.	197	76	54	29
		Perp.	152	59	30	7
18	Rayon Velveteen	Par.	2	0	0	2
		Perp.	5	5	5	5
19	Uniform Twill	Par.	170	76	44	17
		Perp.	240	118	49	13
21	Double Knit Polyester	Par.	19	10	5	0
		Perp.	15	10	5	0
22	Raschel Knit	Par.	34	19	10	0
		Perp.	22	12	5	2
23	Corduroy Pinwale	Par.	210	114	77	22
		Perp.	194	92	55	22
24	Corduroy Widewale	Par.	74	37	19	8
		Perp.	105	47	20	0
25	Waffle Weave	Par.	78	47	29	13
		Perp.	73	44	32	17

TABLE XV

EFFECT OF TIPPING FABRIC PLANE: RANKING

Ranking of fabrics in degree of change of reflectance in the original plane of the light when fabric plane is tipped 9.2° away from its original plane, originally perpendicular to the plane of the light.

No.	Fabric	Warp Parallel	No.	Fabric	Warp Perpen-dicular
16	Alpaca Pile	121	19	Uniform Twill	122
2	Wool Frieze,	116	23	Corduroy Pinwale	102
	napped		16	Alpaca Pile	93
23	Corduroy Pinwale	96	6	Black Satin	68
19	Uniform Twill	94	24	Corduroy Widewale	58
15	Acrylic Pile,	65	2	Wool Frieze,	57
	brushed			napped	
24	Corduroy Widewale	37	15	Acrylic Pile,	44
13	Cotton/Nylon	35		brushed	
	Sateen		7	Simplex Knit,	30
25	Waffle Weave	31		High IR	
7	Cotton Simplex	29	8	Simplex Knit,	30
	Knit, High IR			Low IR	
8	Cotton Simplex	27	25	Waffle Weave	29
	Knit, Low IR		15	Acrylic Pile,	28
22	Raschel Knit	15		normal	
15	Acrylic Pile,	13	13	Cotton/Nylon	28
	normal			Sateen	
1	Wool Frieze	13	1	Wool Frieze	21
21	Double Knit	9	22	Raschel Knit	10
	Polyester		21	Double Knit,	5
18	Rayon Velveteen	2		Polyester	
6	Black Satin	0	18	Rayon Velveteen	0

TABLE XVI

NUMBER OF TIMES EACH FABRIC IS FOUND AMONG THE THREE WITH HIGHEST OR LOWEST OPTICAL DENSITY.

Orientations:

CV, Cylinders vertical
CH, Cylinders horizontal
WA, Warp along cylinder long axis
FA, Filling along cylinder long axis

Fabric No.	Description	Most Dense CV WA	Most Dense CV FA	Most Dense CH WA	Most Dense CH FA	Lease Dense CV WA	Lease Dense CV FA	Lease Dense CH WA	Lease Dense CH FA	Total for Most Dense WA	Total for Most Dense FA	Total for Most Dense Both	Total for Lease Dense WA	Total for Lease Dense FA	Total for Lease Dense Both
1	Wool Frieze	1	1	2	2	1		2	2	3	3	6	3	2	5
2	Wool Frieze, napped	1		1		3	3	2	2	2		2	5	5	10
3	Wool Blanket	1	1	2	1		1			3	2	5		1	1
4	Terry Cloth, Low IR	2	3	1	3			1		3	6	9	1		1
5	Terry Cloth, High IR	1	1			1	2			1	1	2	1	2	3
6	Black Satin							2	2				2	2	4
7	Simplex Knit, High IR							4	1				4	1	5
8	Simplex Knit, Low IR	2	2					1		2	2	2	1		1
9	Burlap	3	3	1	2	1	1	1	1	4	5	9	2	2	4
10	Cotton Birdseye	2	1	1	1		1	1		3	2	5	1	1	2
11	Double Knit Pique					2	2						2	2	4
12	Cotton Osnaburg	1	1	2	1				2	3	2	5		2	2
13	Sateen	1			1	1	2			1	1	2	1	2	3
14	Knit Triacetate			1			1	1		1		1	1	1	2
15	Acrylic Pile					1	1	1					2	1	3

TABLE XVI (Concluded)

Fabric No.	Description	Most Dense CV WA	Most Dense CV FA	Most Dense CH WA	Most Dense CH FA	Least Dense CV WA	Least Dense CV FA	Least Dense CH WA	Least Dense CH FA	Total for Most Dense WA	Total for Most Dense FA	Total for Most Dense Both	Total for Least Dense WA	Total for Least Dense FA	Total for Least Dense Both
16	Alpaca Pile	1	1			2			1	1	1	2	2	1	3
17	Corduroy, Subdued Wale	1	2							1	2	3			
18	Black Velveteen	2	3	2	1	1	1		1	4	4	8	1	2	3
19	Uniform Twill					3	2	1	1				4	3	7
20	Cotton Sheeting				1	1	1	1	1		1	1	2	2	4
21	Double Knit Polyester	1	1		1					1	2	3			
22	Raschel Knit			1						1		1			
23	Pinwale Corduroy			1		1				1		1	1		1
24	Wide wale Corduroy			1		3	2		1	1		1	3	3	6
25	Waffle Weave	1	1	2	1		1			3	2	5		1	1

TABLE XVII

REFLECTANCE COMPARISONS FOR FABRICS WHICH ARE IN THE HIGHEST OR LOWEST THREE IN OPTICAL DENSITY FOUR OR MORE TIMES.

No.	Description	Times in Group	Reflectances 45°, 0°		Reflectances 45°, 0°		Reflectances -15° to 40°		Sum 45° to 60°	
			WH	WV	WH	WV	WH	WV	WH	WV
A.	High Optical Density									
2	Wool Frieze, napped	10	125	119	363	338	806	792	1912	1835
19	Uniform Twill	7	257	225	436	445	1485	1430	2035	1598
24	Pinwale Corduroy	6	228	160	263	235	1174	904	908	905
1	Wool Frieze	5	50	43	81	81	287	257	336	394
7	Simplex Knit, High IR	5	92	100	153	165	541	552	506	568
6	Black Rayon Satin	4	25	68	407	106	370	379	1799	412
9	Burlap	4	47	40	100	75	295	245	463	350
11	Double Knit Pique	4	56	56	125	100	360	330	456	438
20	Cotton Sheeting	4	80	94	18	190	538	599	694	710
TOTAL							5856	5488	9109	7210
AVERAGE							651	610	1012	801
Combined Total			2865		3681		11344		16319	
Combined Average			159		205		630		907	
B.	Low Optical Density									
9	Burlap	9	47	40	100	75	295	245	463	350
4	Terry Cloth	9	90	94	232	169	562	536	1172	883
18	Velveteen	8	22	18	37	35	123	124	119	114
1	Wool Frieze	6	50	43	81	81	287	257	336	394

TABLE XVII (Continued)

No.	Description	Times in Group	Reflectances 45°, 0° WH	Reflectances 45°, 0° WV	Reflectances 45°, 45° WH	Reflectances 45°, 45° WV	Reflectances -15° to 40° WH	Reflectances -15° to 40° WV	Sum, 45° to 60° WH	Sum, 45° to 60° WV
B.	Low Optical Density (Concluded)									
3	Wool Blanket	5	65	62	131	135	390	397	578	516
10	Cotton Birdseye	5	77	75	175	137	508	446	613	525
12	Cotton Osnaburg	5	62	62	119	119	387	377	413	407
25	Waffle Weave	5	97	100	156	170	575	599	610	608
8	Simplex Knit low IR	4	82	72	163	122	503	408	568	384
TOTAL							3630	3389	4872	4181
AVERAGE							403	377	541	465
Combined Total			1158		2237		7019		9053	
Combined Average			64		124		390		503	

C. Fabrics Found Less than 4 Times in High or Low Density Groups

HIGH DENSITY No.	HIGH DENSITY	Times in Group	LOW DENSITY No.	LOW DENSITY	Times in Group
5	Terry Cloth, High IR	3	17	Corduroy Subdued Wale	3
13	Sateen	3	21	Double Knit Polyester	3
15	Acrylic Pile	3	2	Wool Frieze, napped	2
16	Alpaca Pile	3	5	Terry Cloth, High IR	2
18	Rayon Velveteen	3	13	Sateen	2
12	Cotton Osnaburg	2	16	Alpaca Pile	2
10	Cotton Birdseye	2	14	Knit Triacetate	1
14	Knit Triacetate	2	20	Cotton Sheeting	1
3	Wool Blanket	1	22	Raschel Knit	1

TABLE XVII (Continued)

C. Fabrics Found Less than 4 Times in High or Low Density Groups (Concluded)

HIGH DENSITY			LOW DENSITY		
No.	Description	Times in Group	No.	Description	Times in Group
4	Terry Cloth, Low IR	1	23	Corduroy Pinwale	1
8	Simplex Knit, Low IR	1	24	Corduroy Widewale	1
23	Corduroy Pinwale	1			
25	Waffle Weave	1			

TABLE XVIII

FABRICS CLASSIFIED BY STRUCTURE

No.	Type	Fabric No.	Description	Fiber	Notes	Density[a] High	Density[a] Low
1.	Surface varied only by yarn interlacing, no thicker than two yarn diameters.						
1.1	Plain weaves	20	Sheeting	Cotton		4	
		12	Osnaburg	Cotton	Coarse.		
		9	Burlap	Jute	Long smooth fibers, coarse large hill and valley effect from yarns.		5
1.2	Float weaves	6	Black Satin	Rayon	Filament, 6/1 floats.	4	
		13	Sateen	Cotton/ Nylon	3/1 filling floats, WR finish.		
		19	Uniform Twill	Cotton	3/1 Warp twill.	7	
1.3	Other flat weaves	10	Birdseye diaper	Cotton	Small diamond pattern floats.		5
1.4	Smooth knits	7	Simplex	Cotton	High IR.	5	
		8	Simplex	Cotton	Low IR.		4
		11	Double knit pique	Acrylic	Small wales.	4	
		21	Double knit	Polyester			

a. Number of times this fabric is found in highest 3 or lowest 3 in optical density.

(Continued)

TABLE XVIII (Concluded)

No.	Type	Fabric No.	Description	Fiber	Notes	Density[a] High	Density[a] Low
2.	Hill and valley effects larger than two yarn thicknesses.	22	Raschel knit netting	Nylon filament	Mesh, relaxed 5.7 x 6.3 per inch.		
		25	Waffle weave	Cotton	Ridges 3.7 x 5.7 per inch.		5
3.	Pile or Fiber Surfaces						
3.1	Short Fiber Nap	14	Tricot	Nylon/ Triacetate	Brushed		
		18	Velveteen	Rayon	Black very good light trap.		8
3.2	Corduroy	17	Subdued wale	Cotton			
		23	Pinwale	Cotton			
		24	Wide wale	Cotton		6	
3.3	Longer Fiber Pile	2	Frieze, napped	Wool		10	
		3	Bed Blanket	Wool			5
		15	Pile	Acrylic			
		16	Pile	Alpaca	3/8 inch.		
3.4	Yarn Pile	1	Frieze	Wool		5	
		4	Terry Cloth	Cotton	Low IR.		5
		5	Terry Cloth	Cotton	High IR.		[illegible]

a. Number of times this fabric is found in highest 3 or lowest 3 in optical density.

TABLE XIX

MATCHING OF OPTICAL DENSITY OF FABRIC WITH THAT OF BACKGROUNDS

All matches within 0.02 density units are shown.

Fabric No.	Description	Open Field	Brushy Field	Edge of Woods	In the Woods	Green Foliage	Rubble	Total Match
1	Wool Frieze	1				2		3
2	Wool Frieze, napped	2				1		3
3	Wool Blanket	1						1
4	Terry Cloth, Low IR	2			1			3
5	Terry Cloth, High IR	1		1		1		3
6	Black Satin			2				2
7	Simplex Knit, High IR	1				1		2
8	Simplex Knit, Low IR	2		1				3
9	Burlap		1	2				3
10	Cotton Birdseye			1		1		2
11	Double Knit Pique					2		2
12	Cotton Osnaburg	2			1			3
13	Sateen			2				2
14	Knit Triacetate	2				1	1	4
15	Acrylic Pile	1				2		3
16	Alpaca Pile			1				1
17	Corduroy Subdued Wale	2				1		3
18	Rayon Velveteen			4	2	1		7
19	Uniform Twill			3		1		4
20	Cotton Sheeting		3		2	1		6

(Continued)

TABLE XIX (Concluded)

Fabric No.	Description	Open Field	Brushy Field	Edge of Woods	In the Woods	Green Foliage	Rubble	Total Match
21	Double Knit Polyester			1	1	1		3
22	Raschel Knit				2	2		4
23	Pinwale Corduroy			4		1		5
24	Widewale Corduroy	1	1			1		3
25	Waffle Weave	2				2		4
	Chances For Match	4	4	4	3	2	4	21

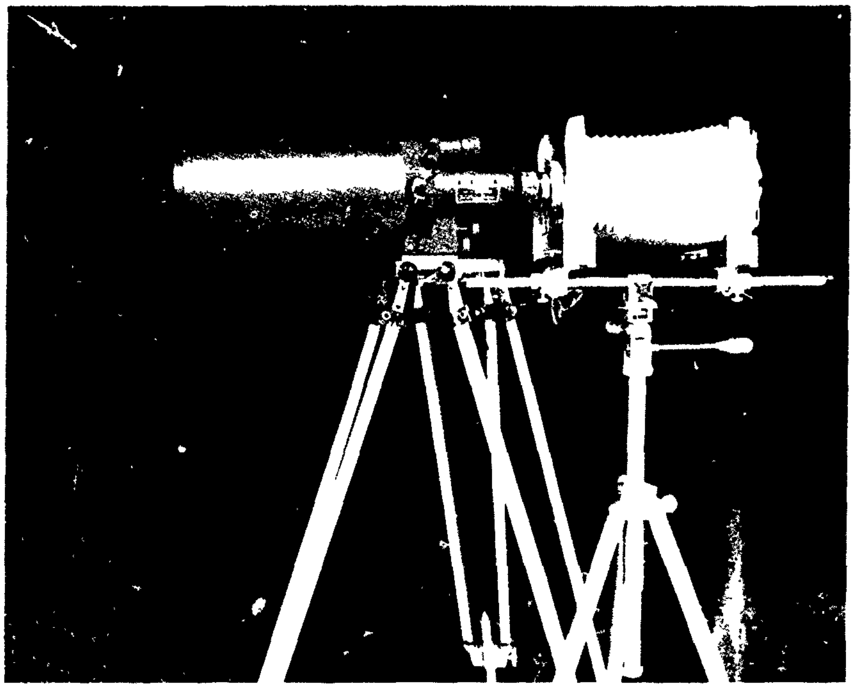


Figure 1. Arrangement of night viewing device (Model 9927 A) and view camera on separate tripods to photograph fluorescent screen of the viewing device. Rubber eye guard of viewing device mu't be removed to bring camera lens close to eye piece.

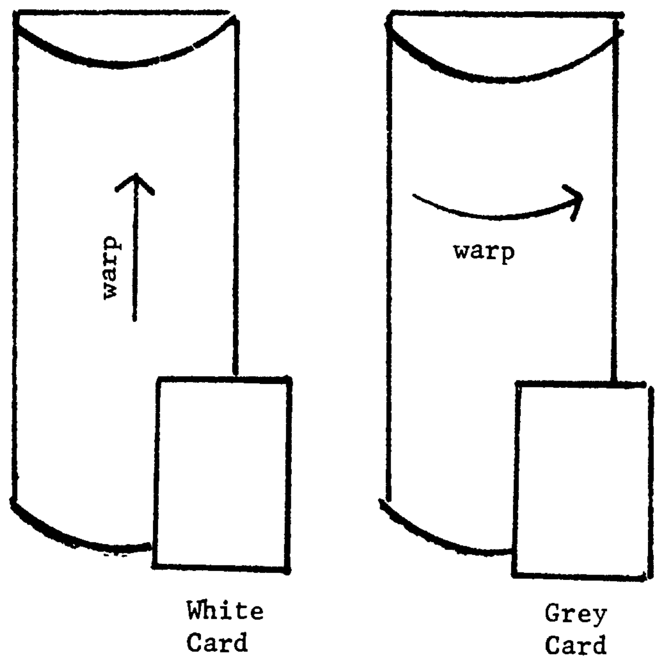


Figure 2. Orientation of fabrics on the cylinders, and association with reflectance standard cards. Arrows on cylinders run with the warp of the fabric.

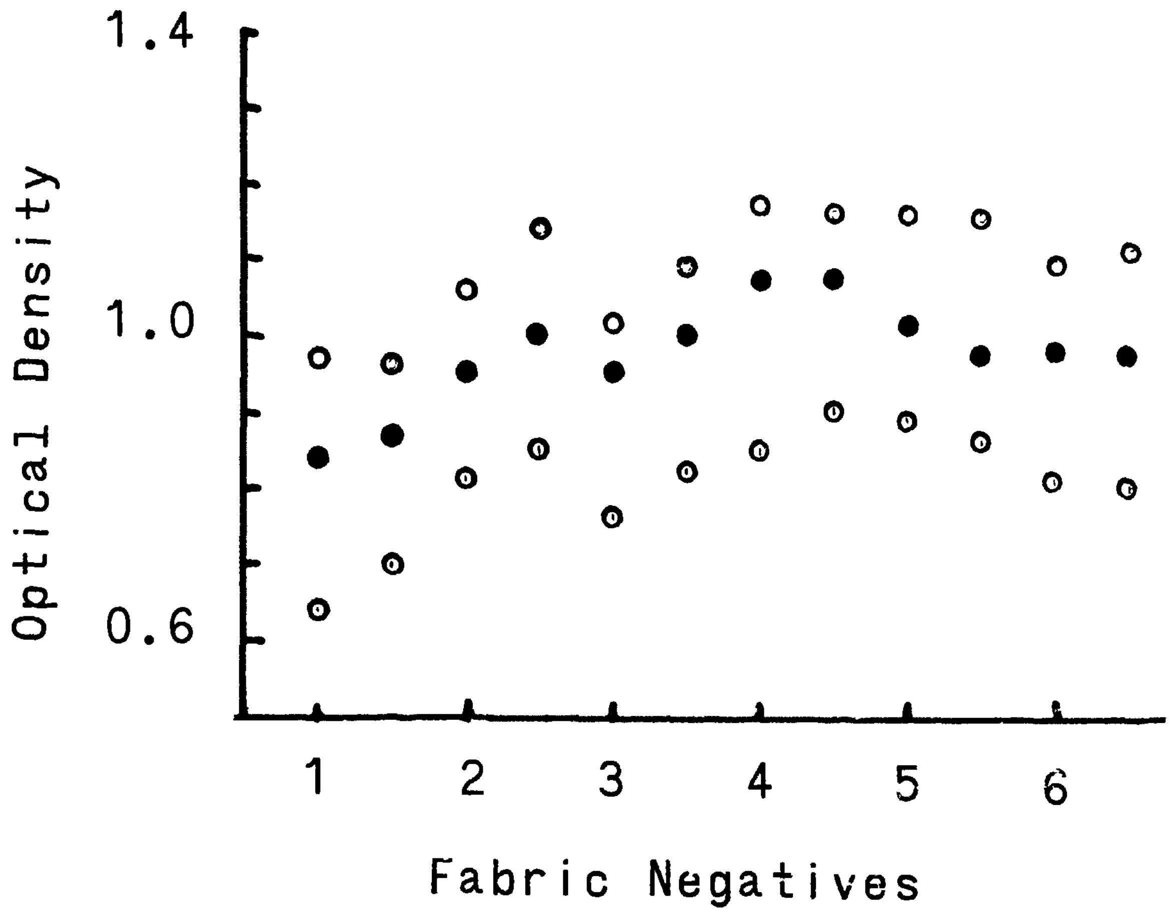


Figure 3. Similarity of trend of density for white card (upper) background (middle) and grey card (lower) in negatives taken in succession. (Data from Brushy Field, Tables A-III and A-IV). The order is cylinders vertical, then horizontal, for each fabric.

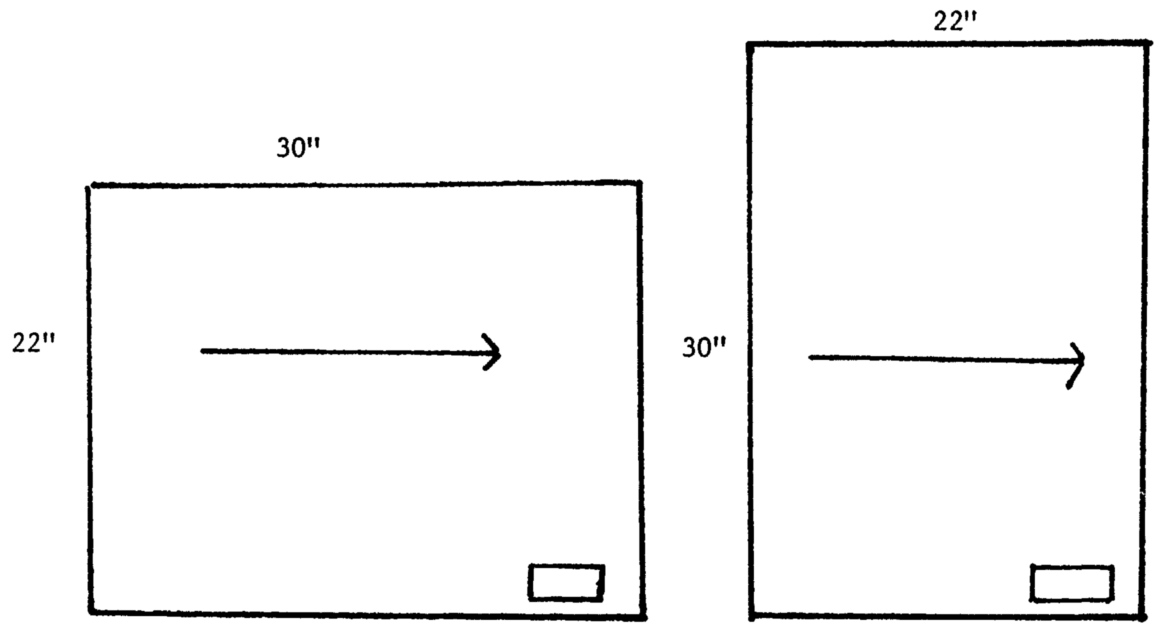


Figure 4. Orientation and marking of specimens. The arrows indicate the warp direction. The long axis of the tape (rectangle in corner of specimen) runs with the warp, on the reverse side of each specimen.

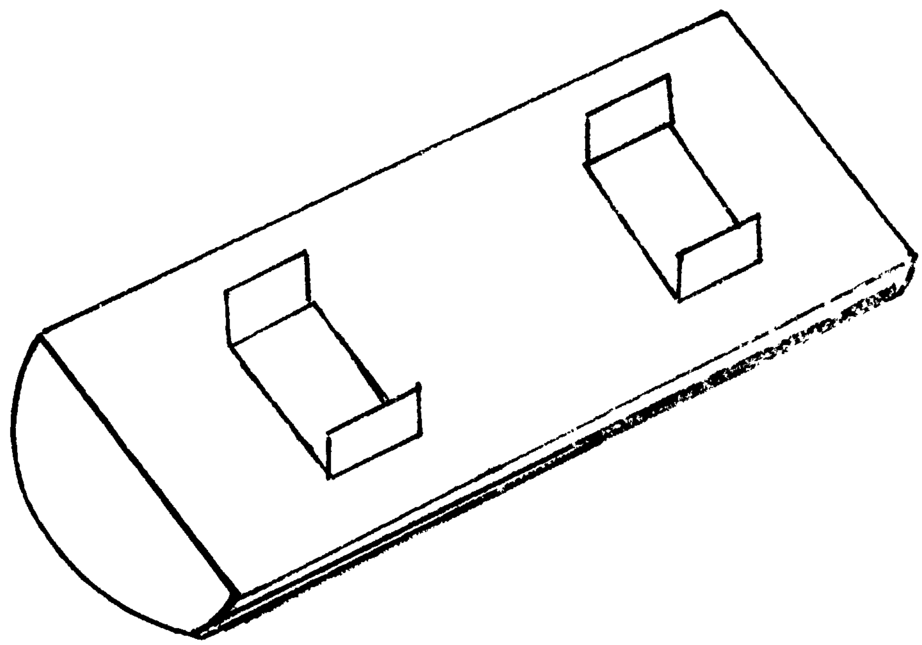


Figure 5. Arrangement of brass plates on flat side of the half cylinder, for attachment of fabrics. The 22 inch direction of each specimen just reaches around from one turned up end to the other, permitting attachment by spring clothes pins.

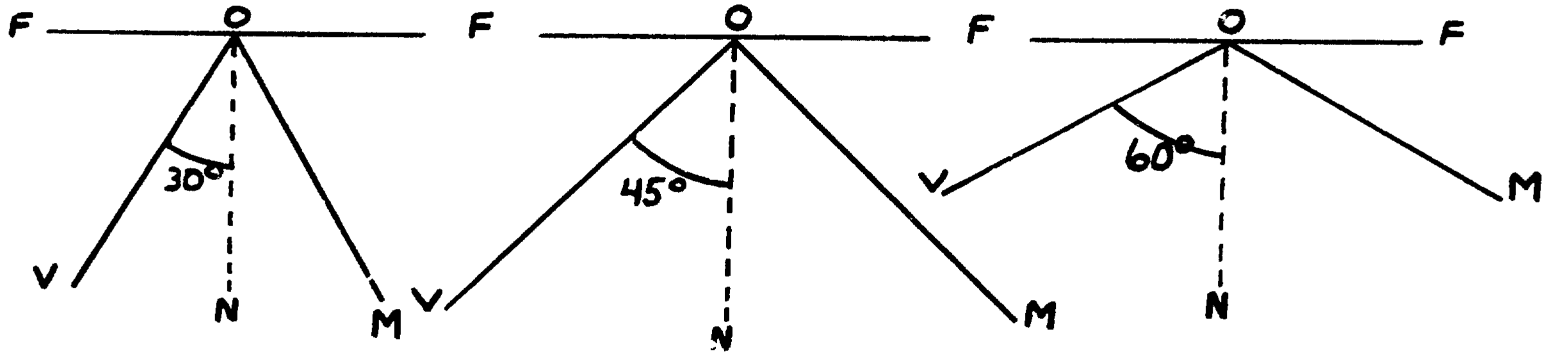


Figure 6. Relations in the goniophotometer for the three angles of viewing used. F-F is the Fabric plane intersecting the plane of the path of the light, VO the line of view and MO, the line of illumination for the mirror angle. NO is the normal to the fabric from which the angle of view, VON, and the angle of illumination such as NOM are measured.

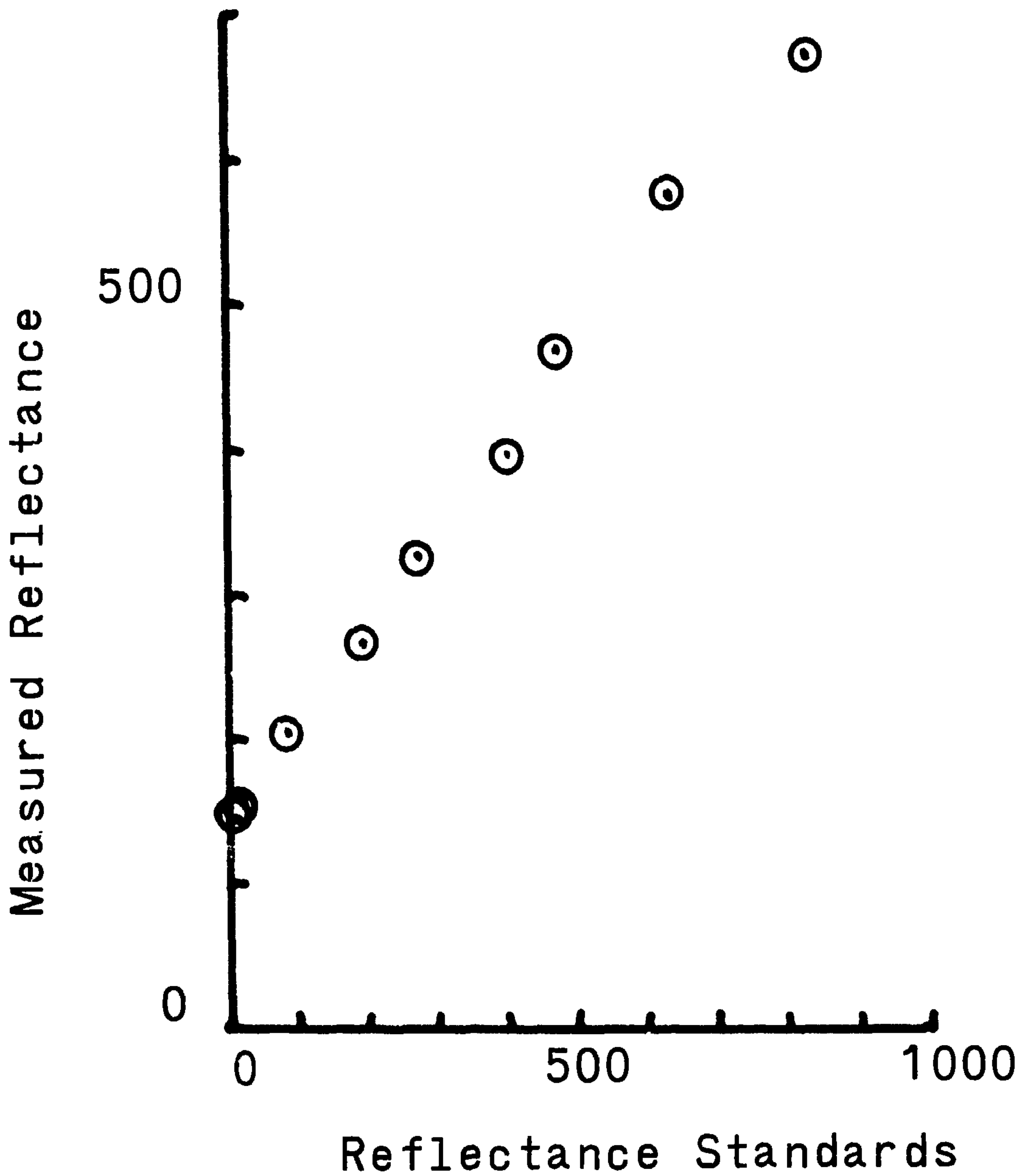


Figure 7. Comparison of measured arbitrary scale values (vertical) with calibration values of a series of standard plates. The measured values extrapolate to the dark current measured with no light admitted to the photomultiplier tube.

Fabrics Draped on Cylinders as Photographed Through Night Vision Device

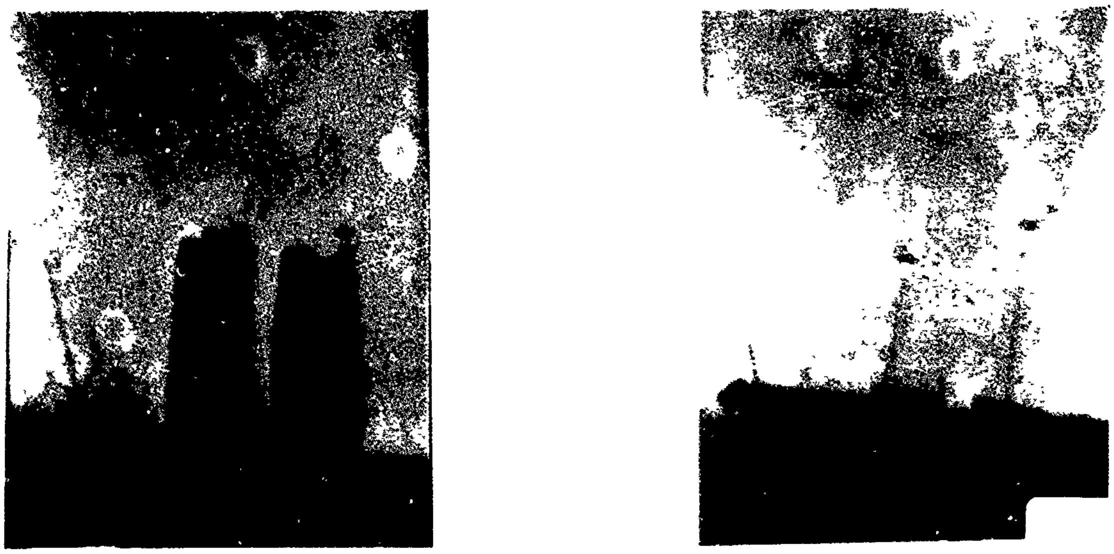


Figure 8. Horizon Background
Fabric 3, Wool Blanket

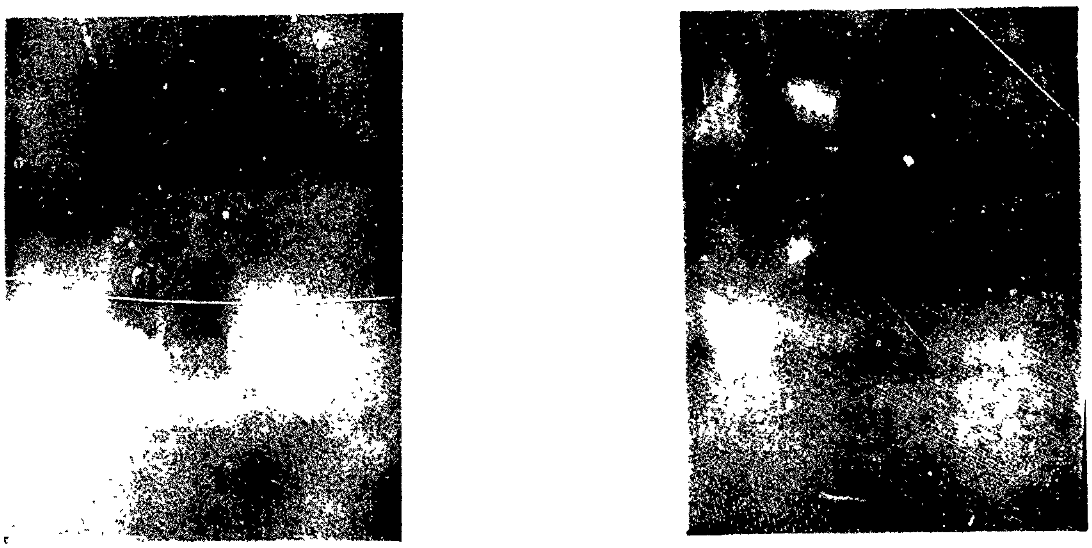


Figure 9. Open Field Background
Fabric 8, Cotton Knit, Low IR

Fabrics Draped on Cylinders as Photographed Through Night Vision Device

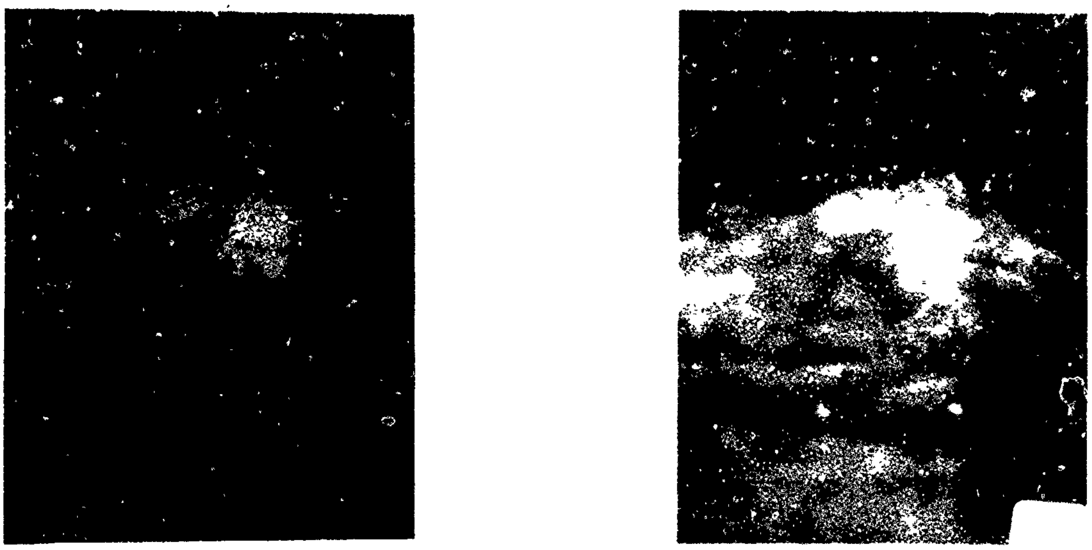


Figure 10. Rubble Background
Fabric 19, Cotton Uniform Twill

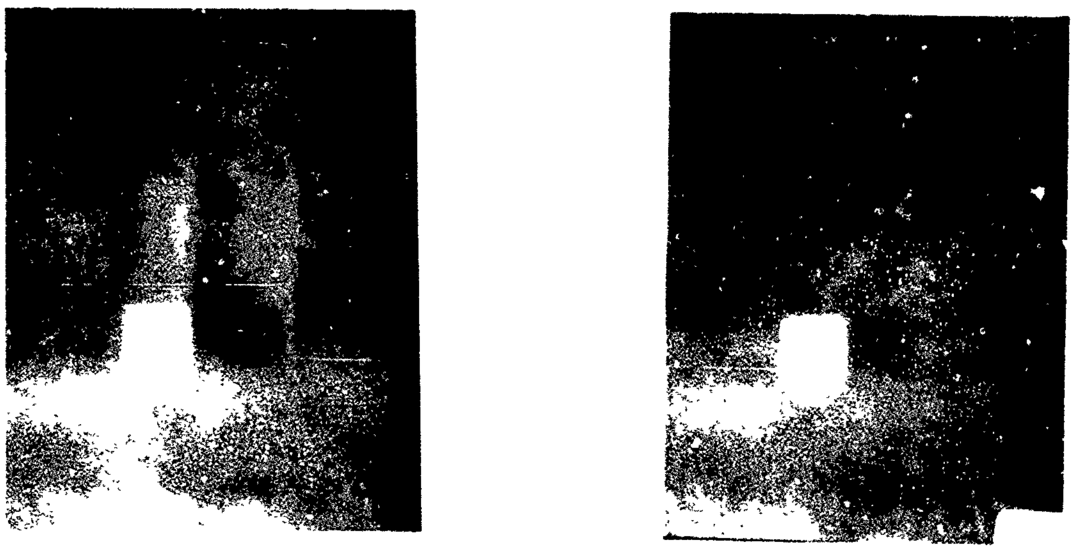
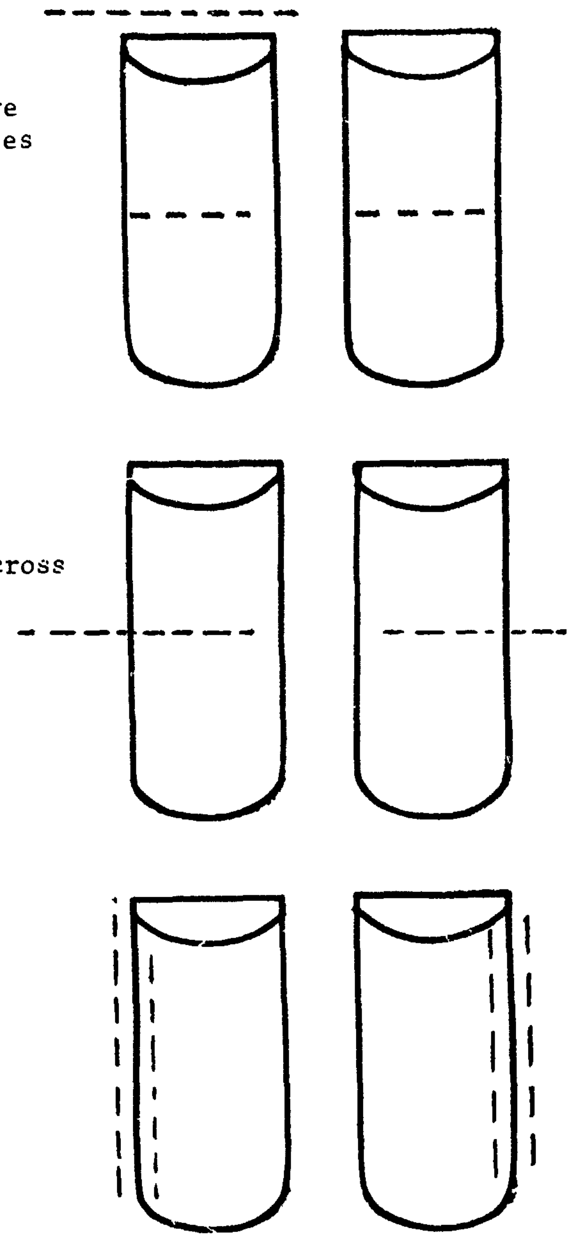


Figure 11. Green Foliage Background
Fabric 2, Wool Frieze, Napped

Figure 12

METHODS FOR SAMPLING DENSITY



A. Background sampled above cylinders, fabric samples across central part of cylinders.

B. Background and fabric measured in one line across boundary.

C. Background and fabric sampled parallel to boundary.

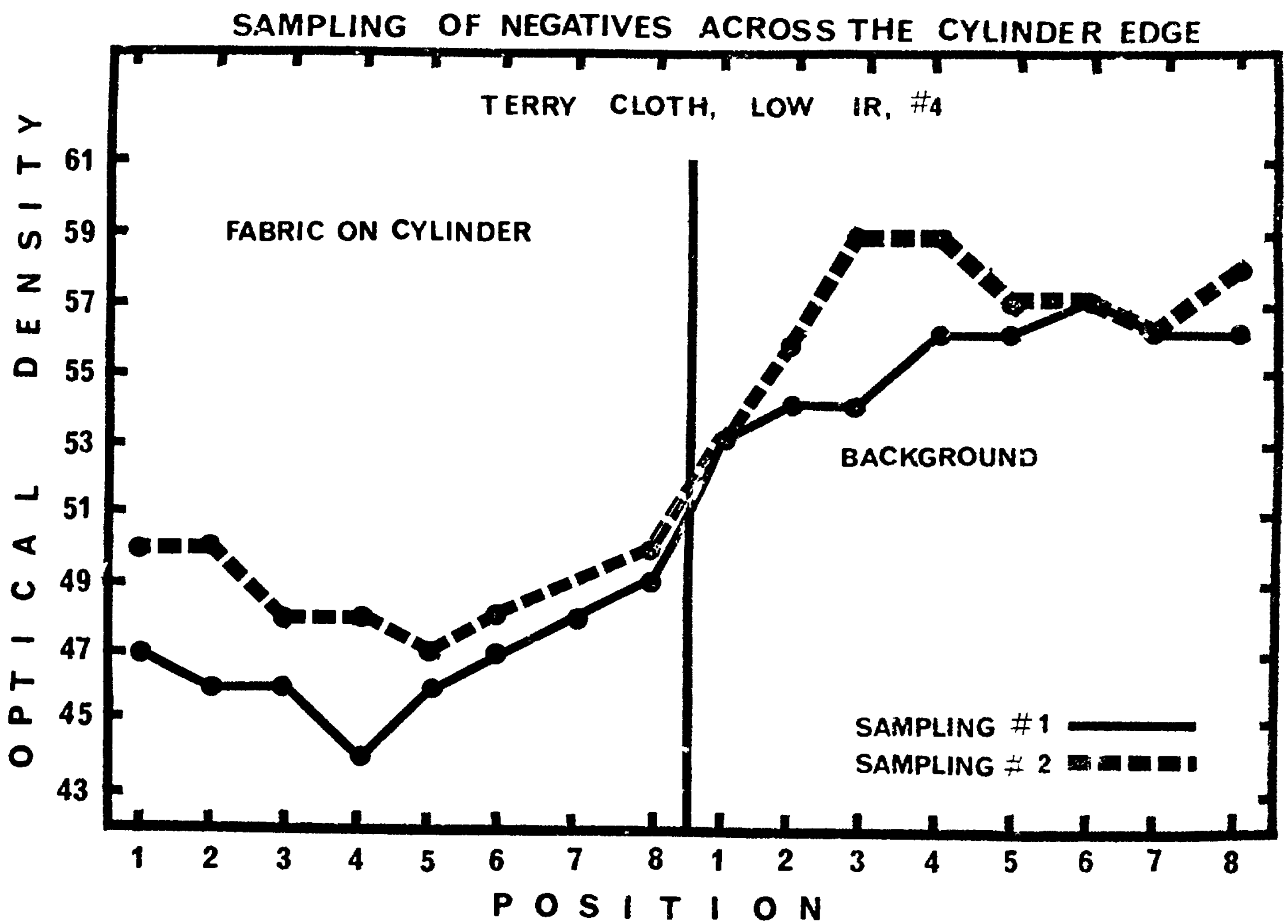


Figure 13. Optical Density measured at 0.5 mm intervals by Method B. Optical density is X100.

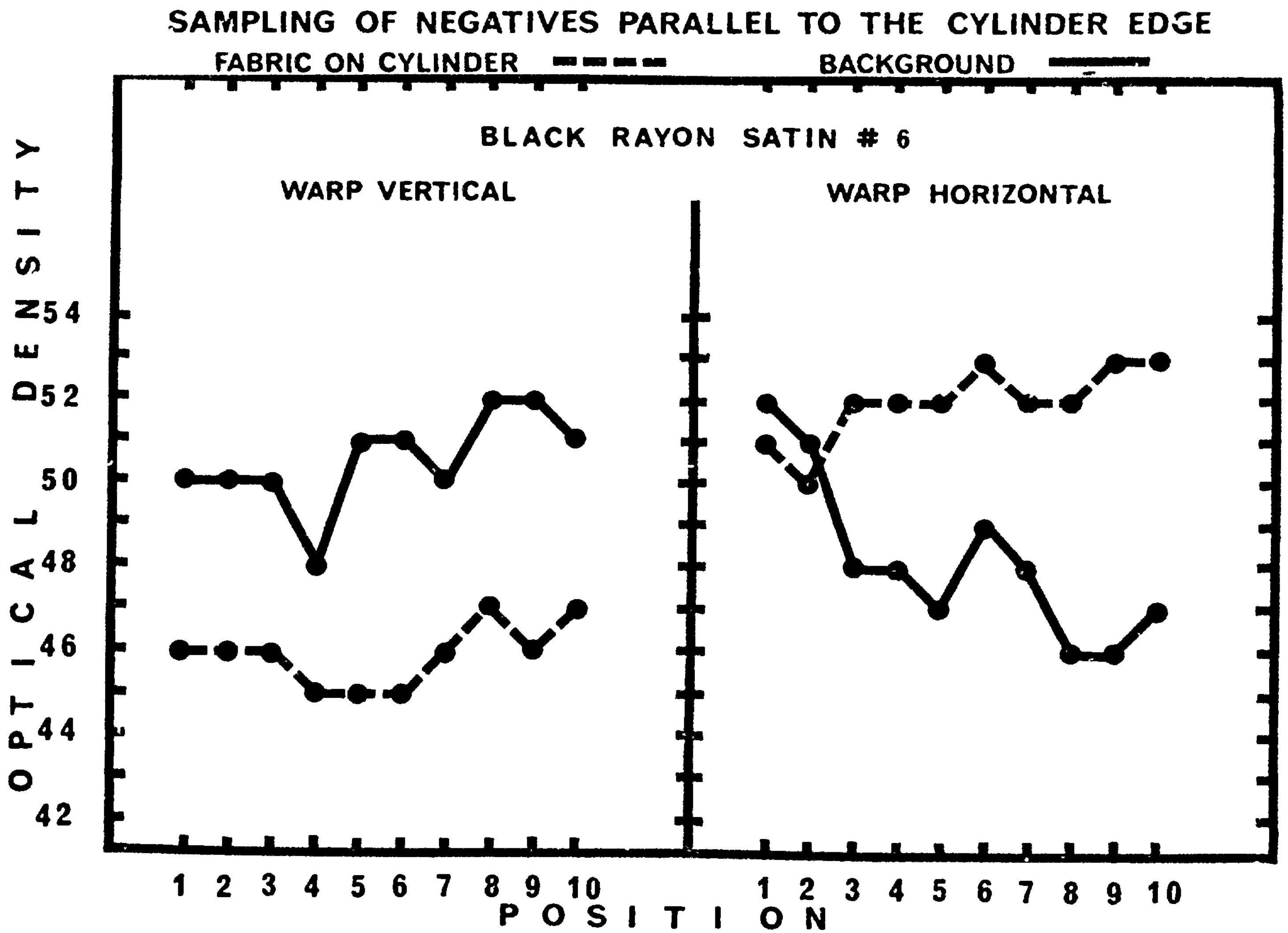


Figure 14. Optical Density by Method C, parallel to edge, for highly directional fabric on vertical cylinders. Optical density is X100.

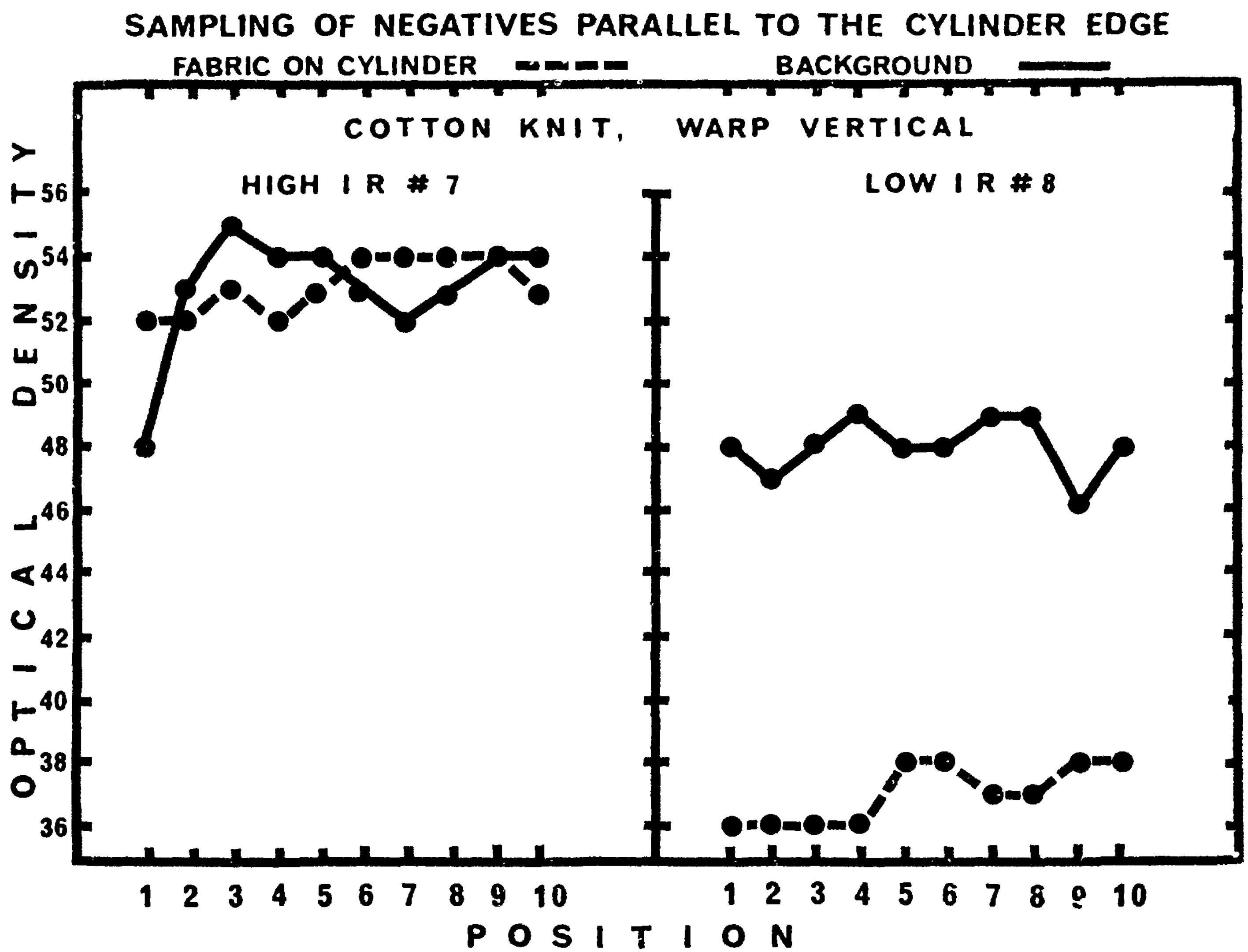


Figure 15. Comparison of fabrics differing in IR reflectance, against green foliage background. Optical density is X100.

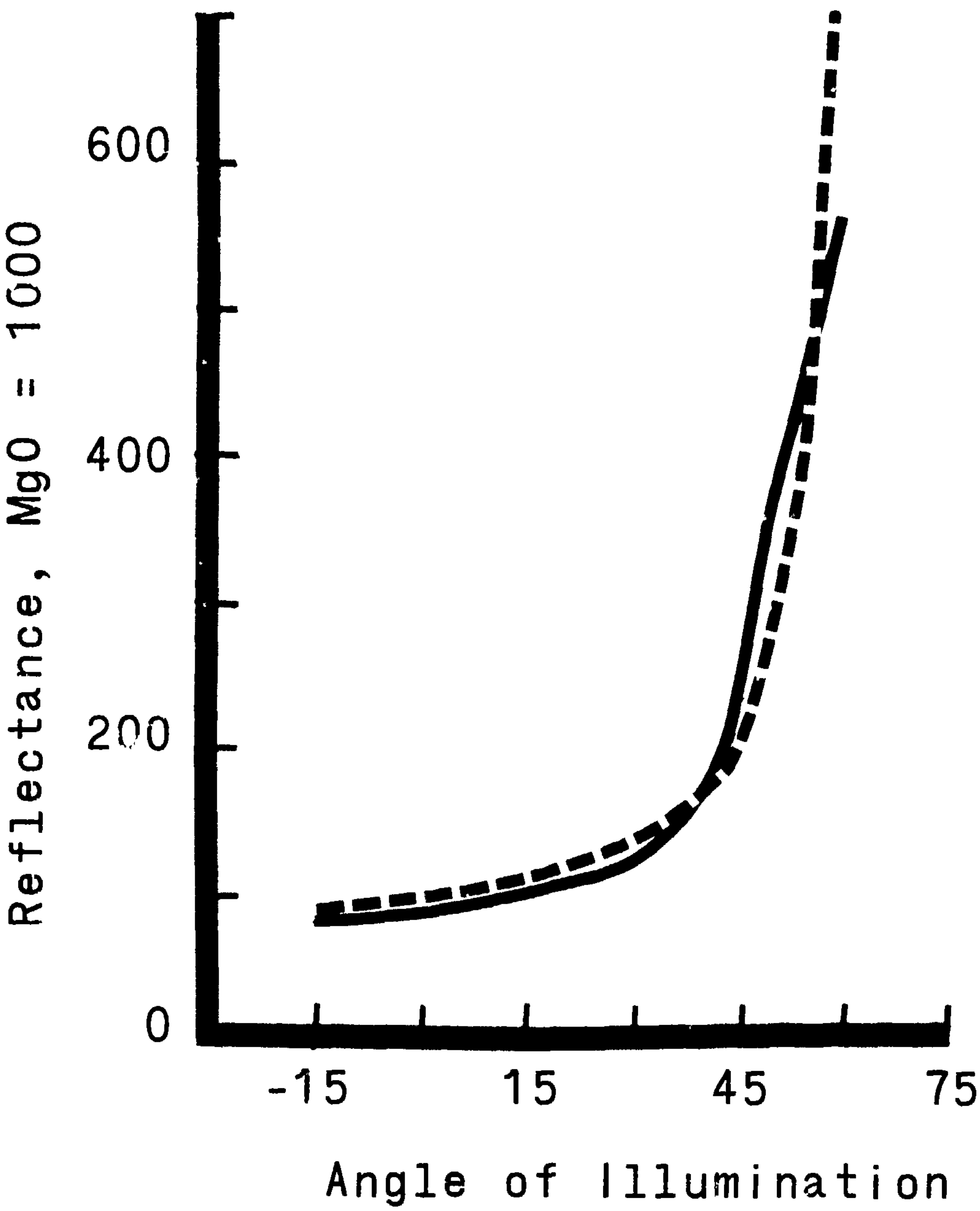


Figure 16. Fabrics No. 4, Low IR, and No. 5, High IR reflectance, Terry cloth. Directional reflectance, visible range for 45° angle of view, warp parallel to path of light.

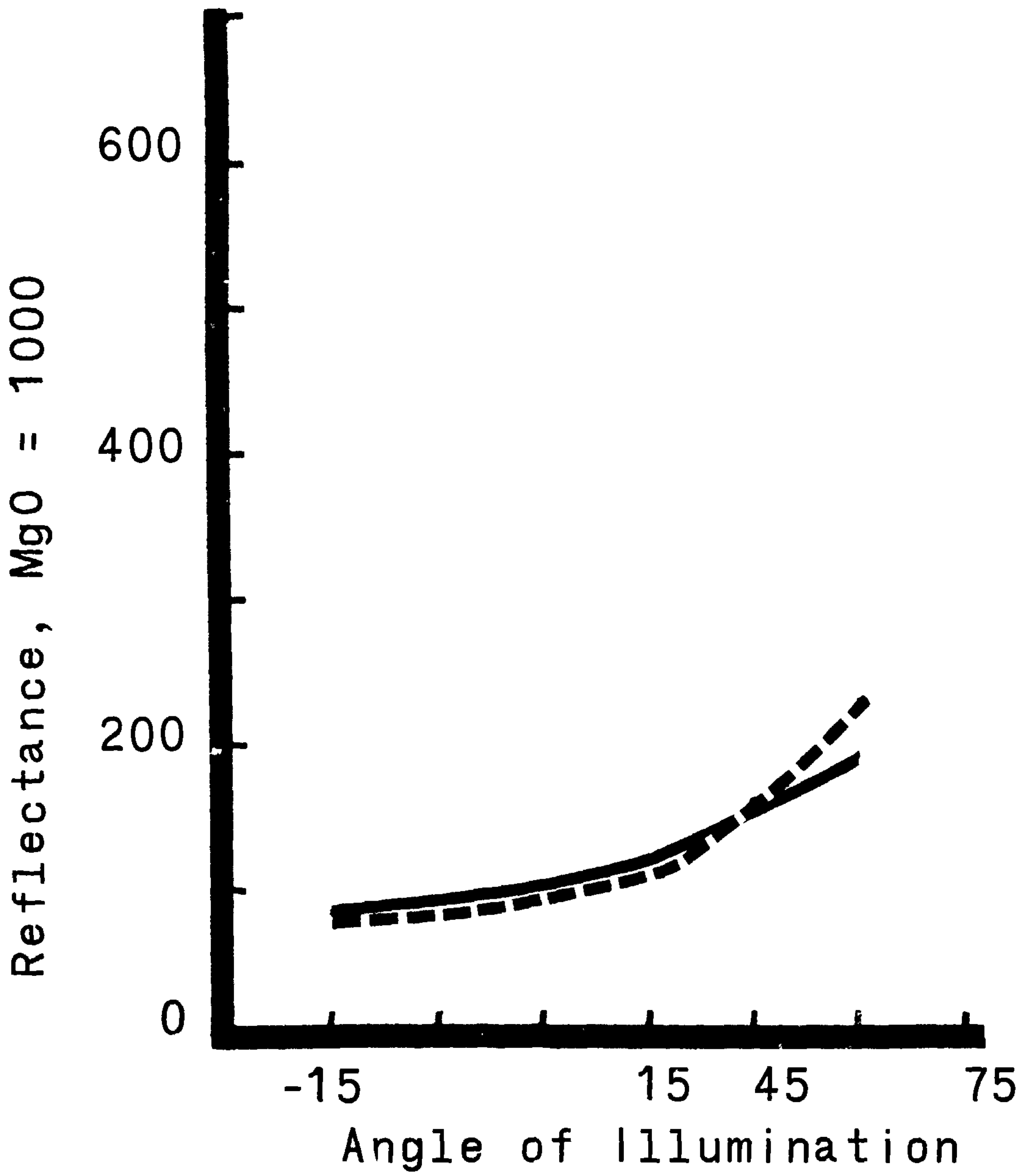


Figure 17. Fabrics 7, High IR and 8, Low IR reflectance. Directional reflectance, visible range, for 45° angle of view.

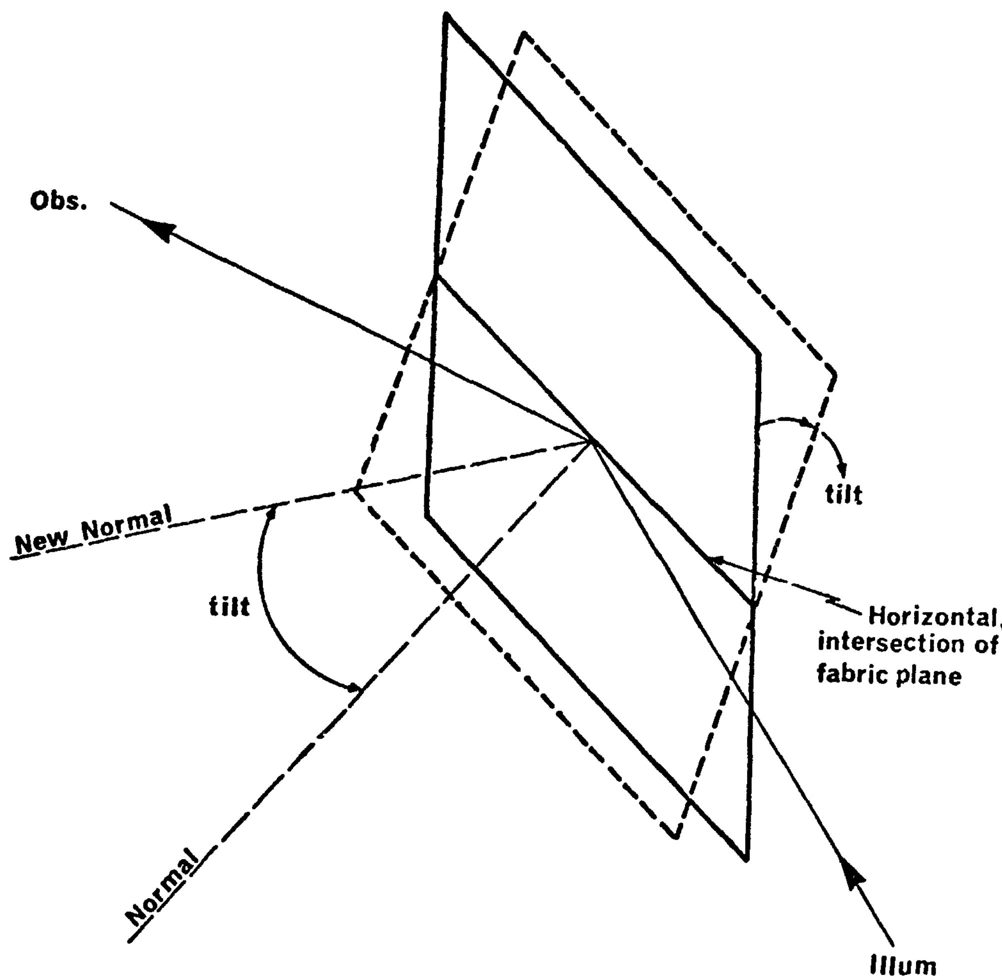


Figure 18. Relation between the usual method of observation, with fabric plane perpendicular to plane of observation (viewing) and illumination, and observation with fabric plane tipped or tilted away from perpendicular.

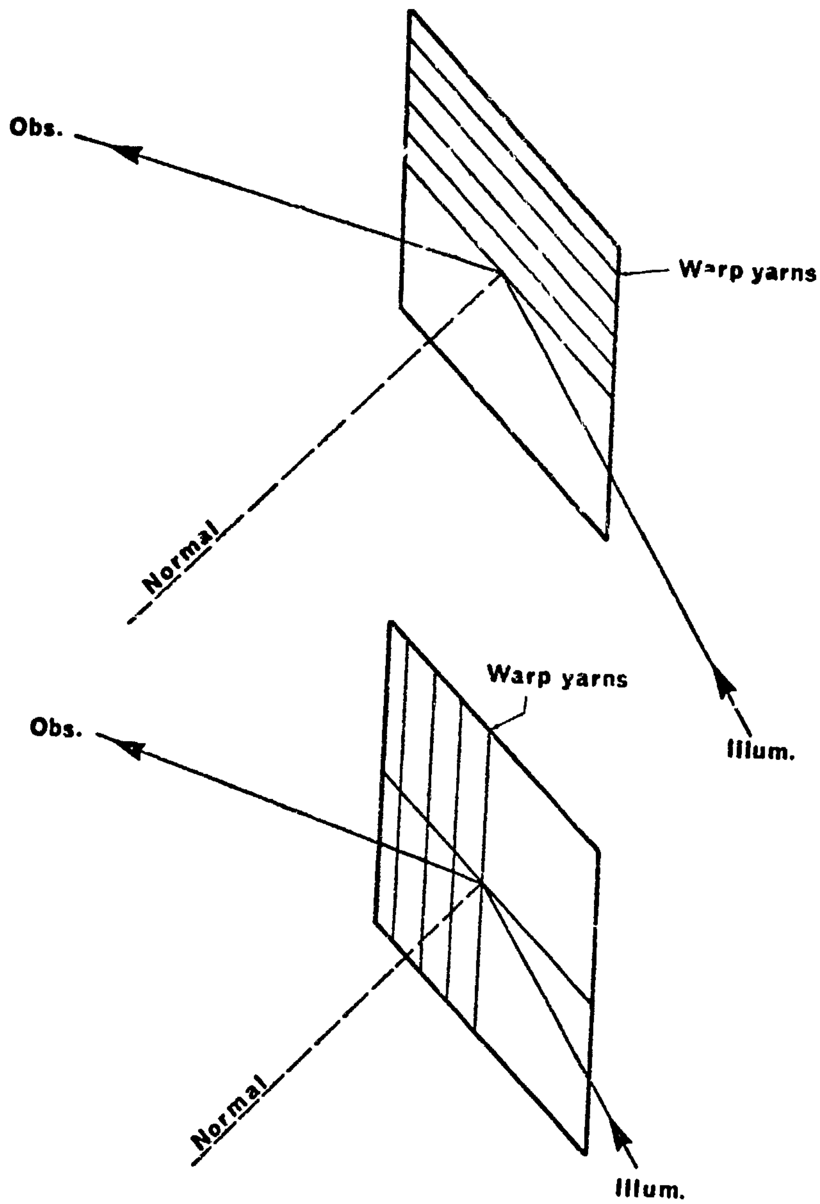


Figure 19, Relation of warp direction in fabric plane to plane of path of light, which is defined by the lines of illumination and view (observation, obs.). With fabric plane at right angles to the plane of the light, the normal to the fabric lies in the light plane, and the warp may be either parallel (top) or perpendicular (bottom) to the plane of the light.

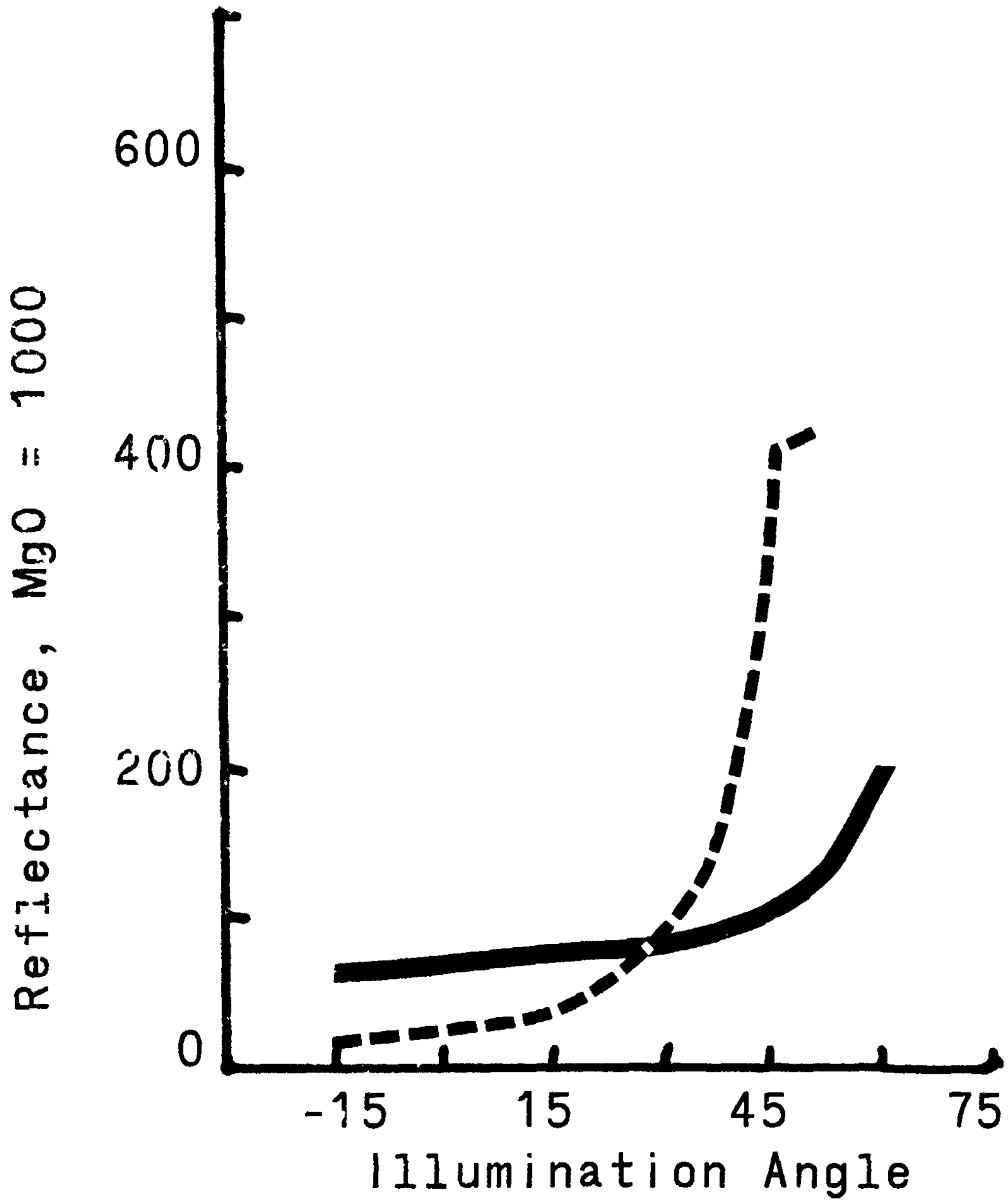


Figure 20. Fabric No. 6, Black Rayon Satin. Directional reflectance, 45° angle of view. Solid line, warp perpendicular to plane of light, broken line, warp parallel.

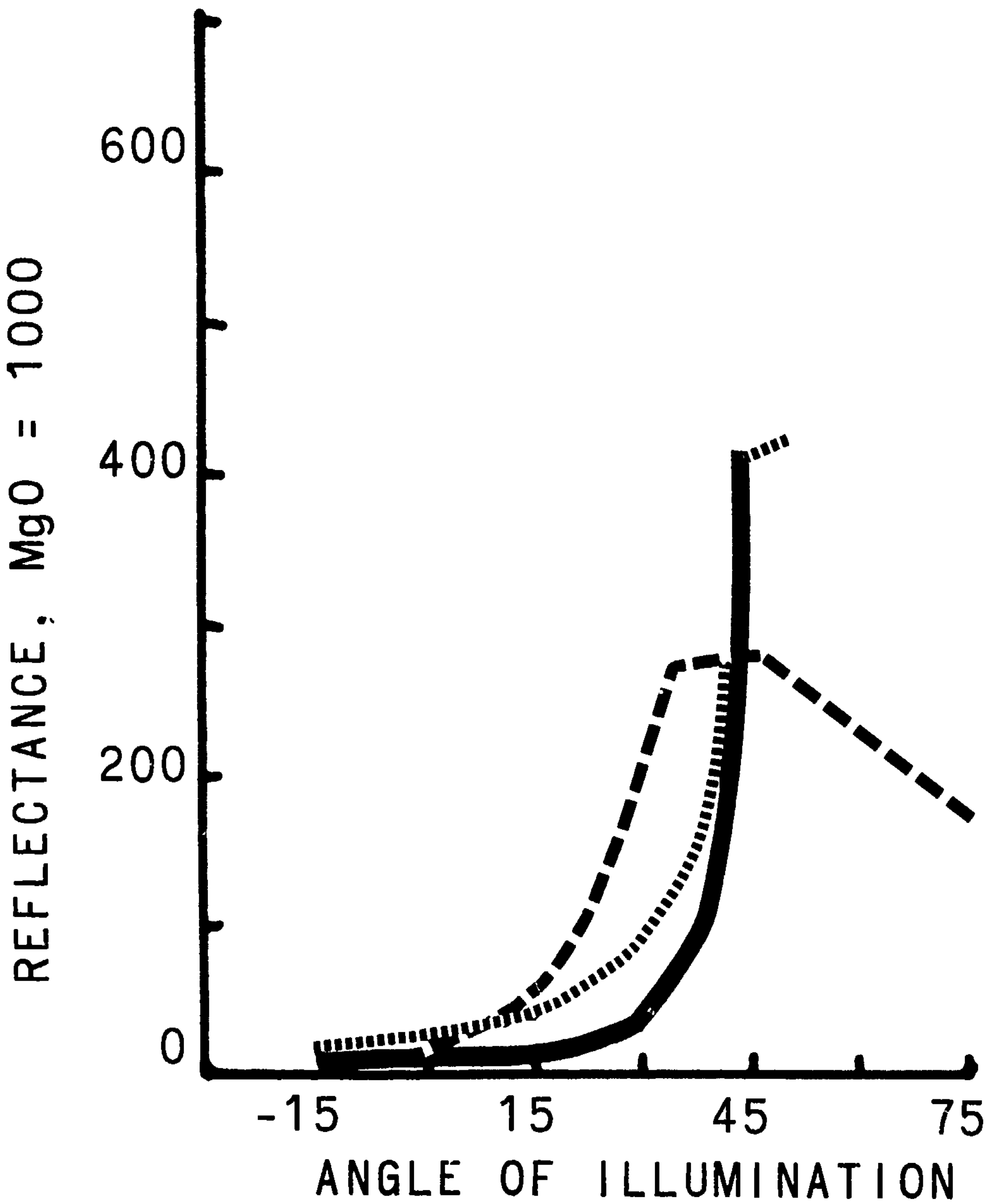


Figure 21. Fabric No. 6, Black Rayon Satin. Directional reflectance for warp parallel to path of the light for 3 angles of view: dash line, 30°; dot line, 45°; solid line 60°. Note peaks near 30° and 45° illumination.

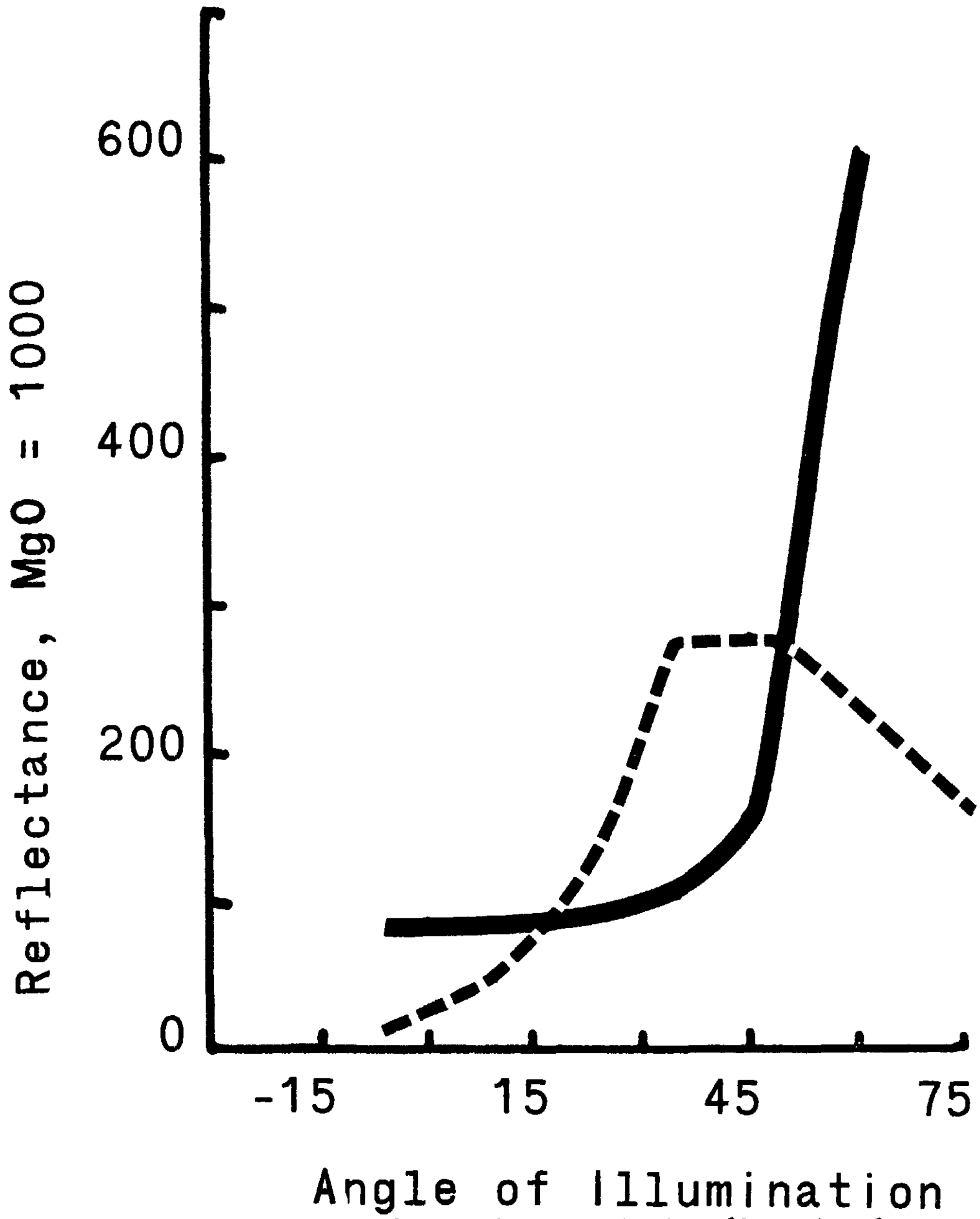


Figure 22. Fabric No. 6, Black Rayon Satin, directional reflectance for 30° angle of view. Solid line, warp perpendicular; dash line, warp parallel to plane of path of light. Note peak with warp parallel.

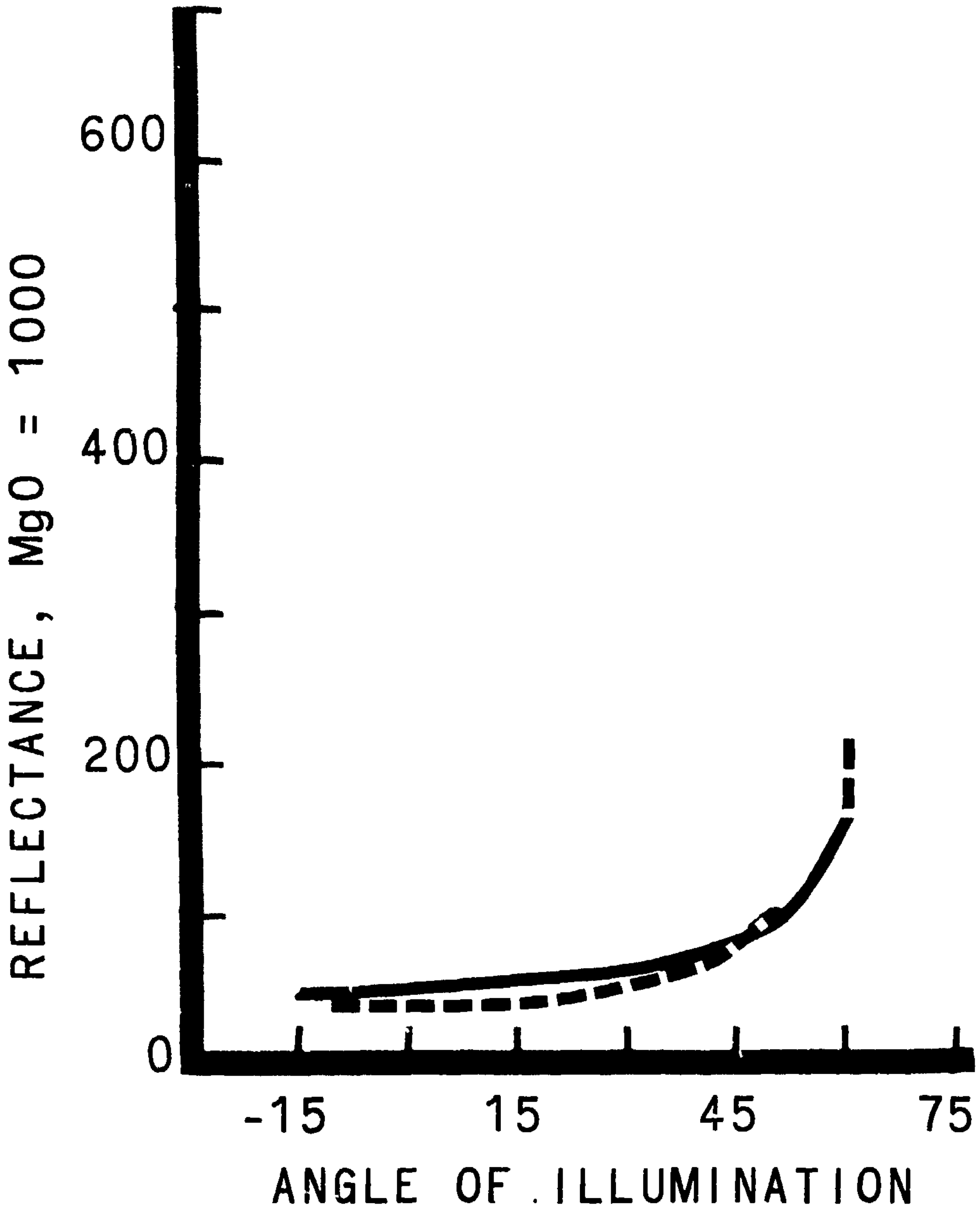


Figure 23. Fabric No. 1, Wool Frieze, Directional reflectance, 45° angle of view, warp parallel to path of light (horizontal) broken line; filling, solid.

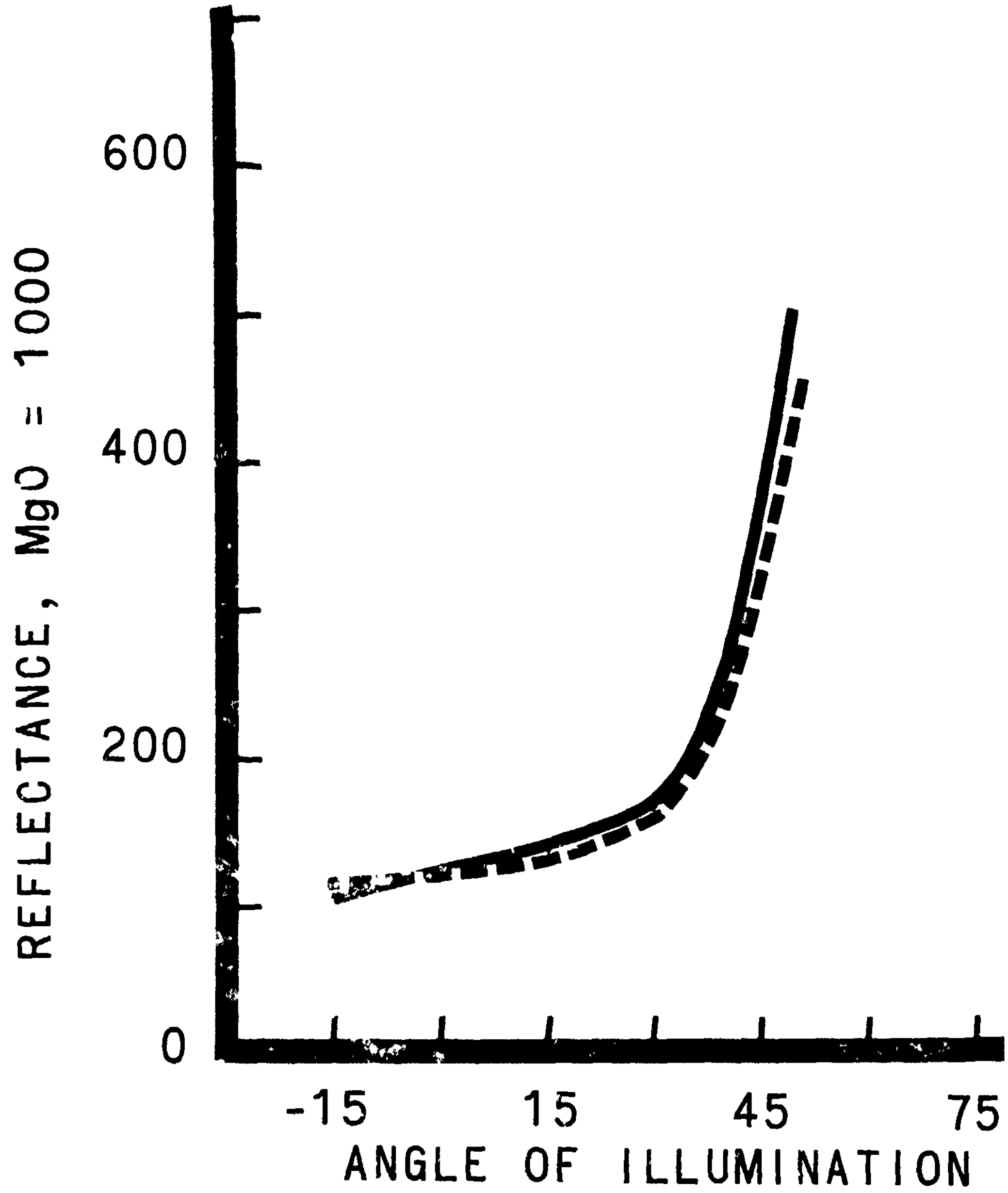


Figure 24. Fabric No. 2, Wool Frieze, napped, directional reflectance, 45° angle of view. Broken line, warp parallel to plane of path of light (horizontal); solid line, filling.

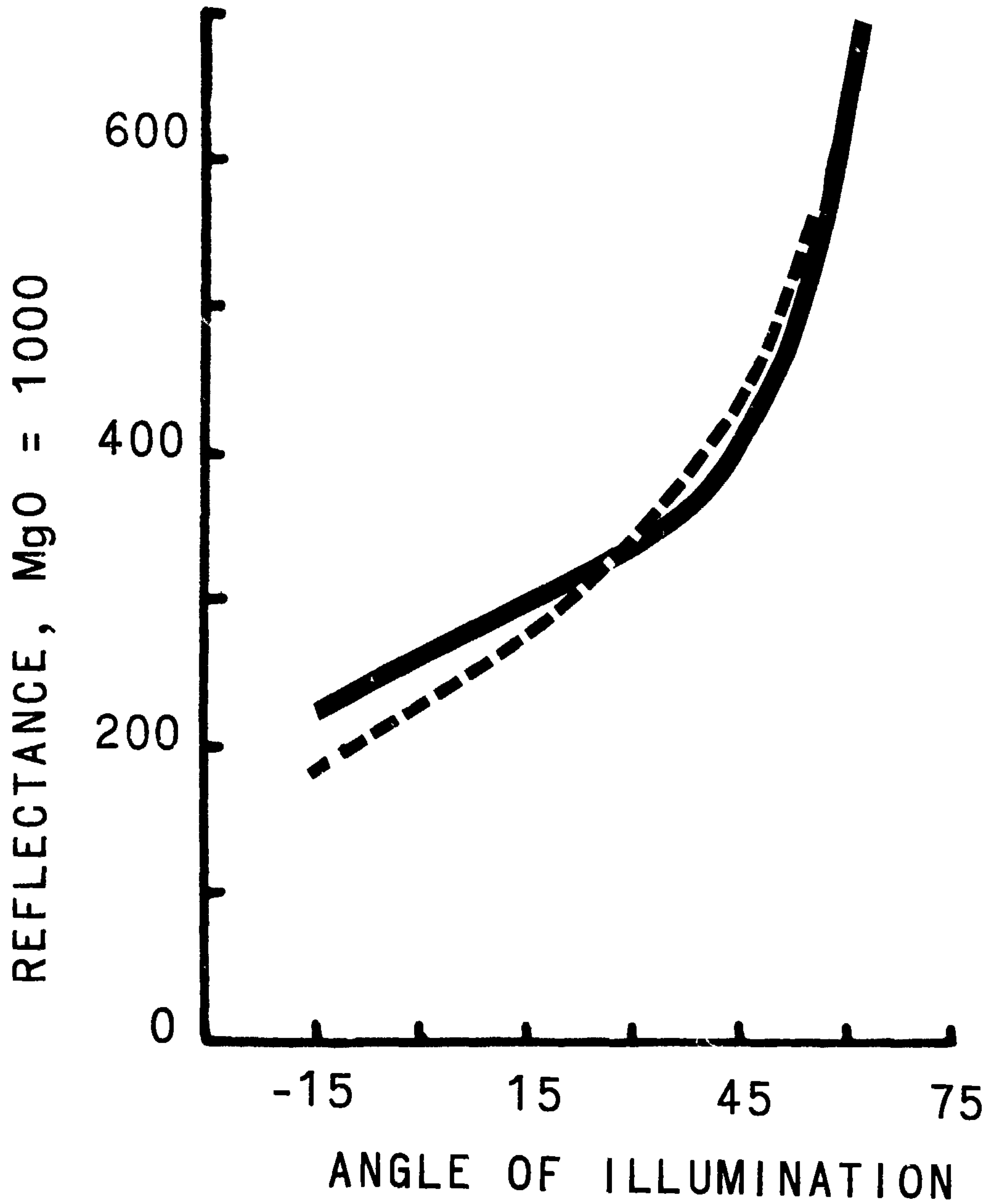


Figure 25. Fabric No. 19, Uniform Twill, Directional reflectance, 45° angle of view, Broken line, warp parallel to plane of path of light (horizontal); solid line, filling.

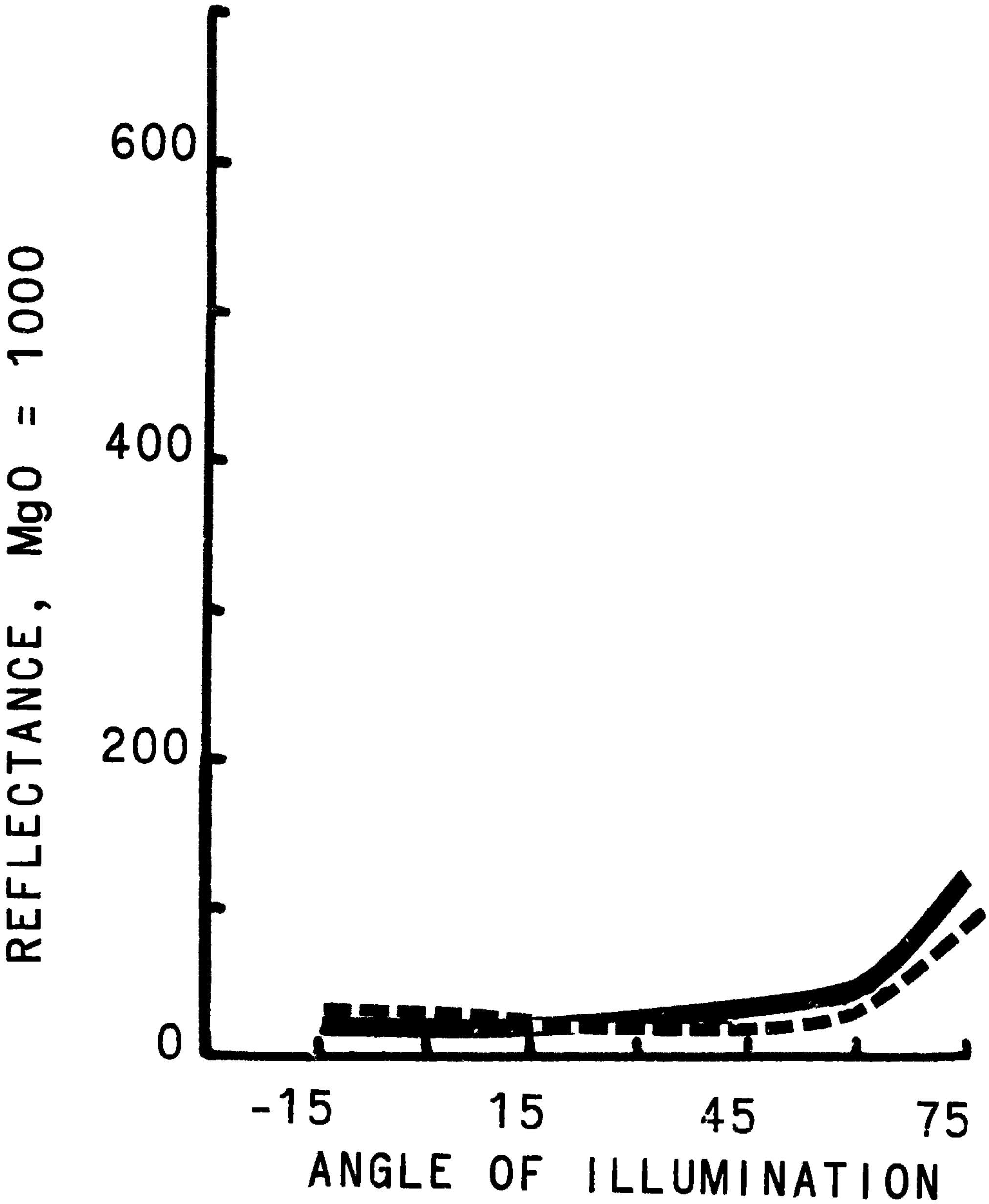


Figure 26. Fabric No. 18, Black Rayon velveteen. Directional reflectance, 45° angle of view. Broken line, warp parallel to plane of path of light (horizontal); solid line, filling.

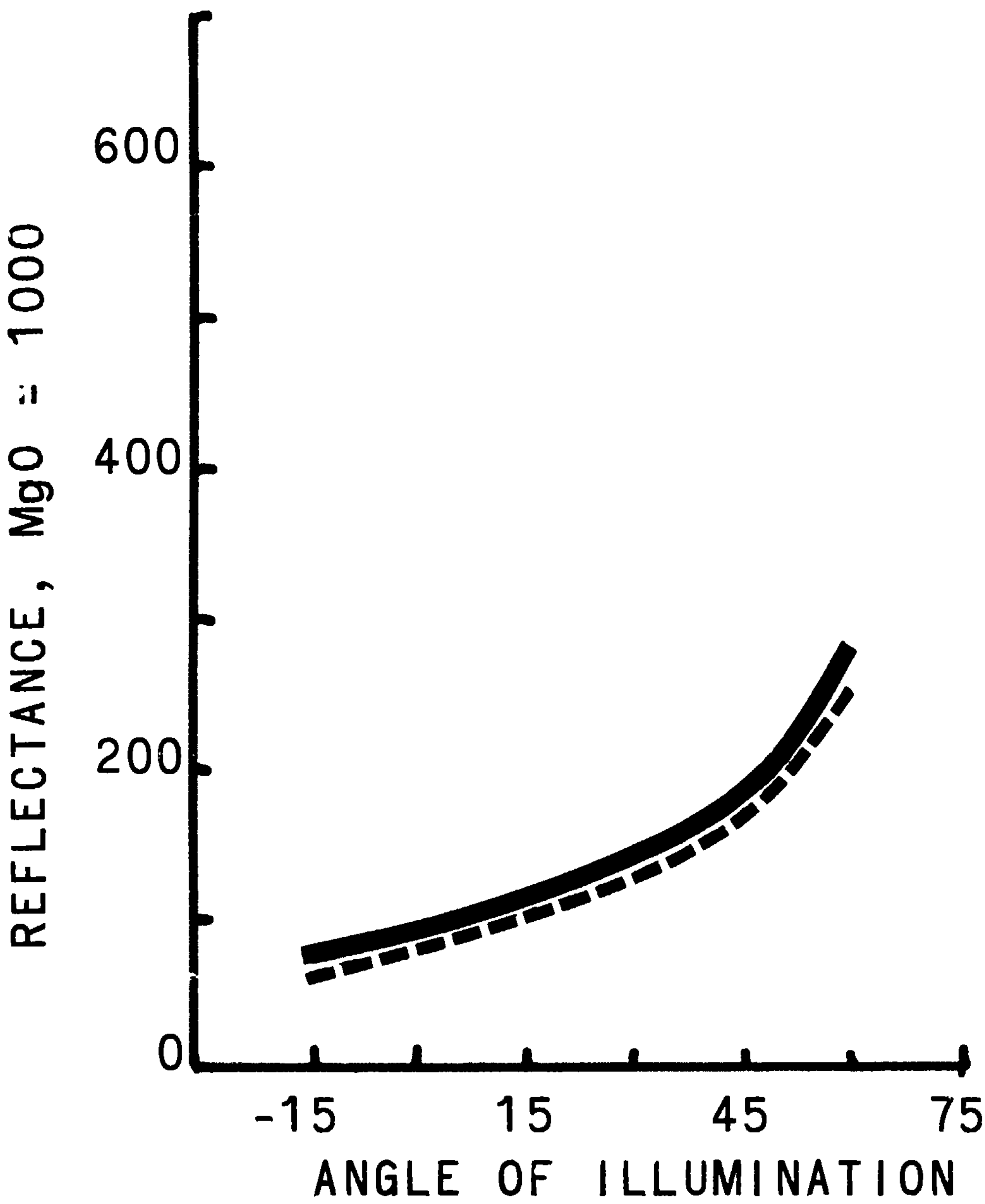


Figure 27. Fabric No. 13, Sateen. Directional reflectance, 45° angle of view. Broken line, warp parallel to plane of path of light (horizontal); solid line, filling.

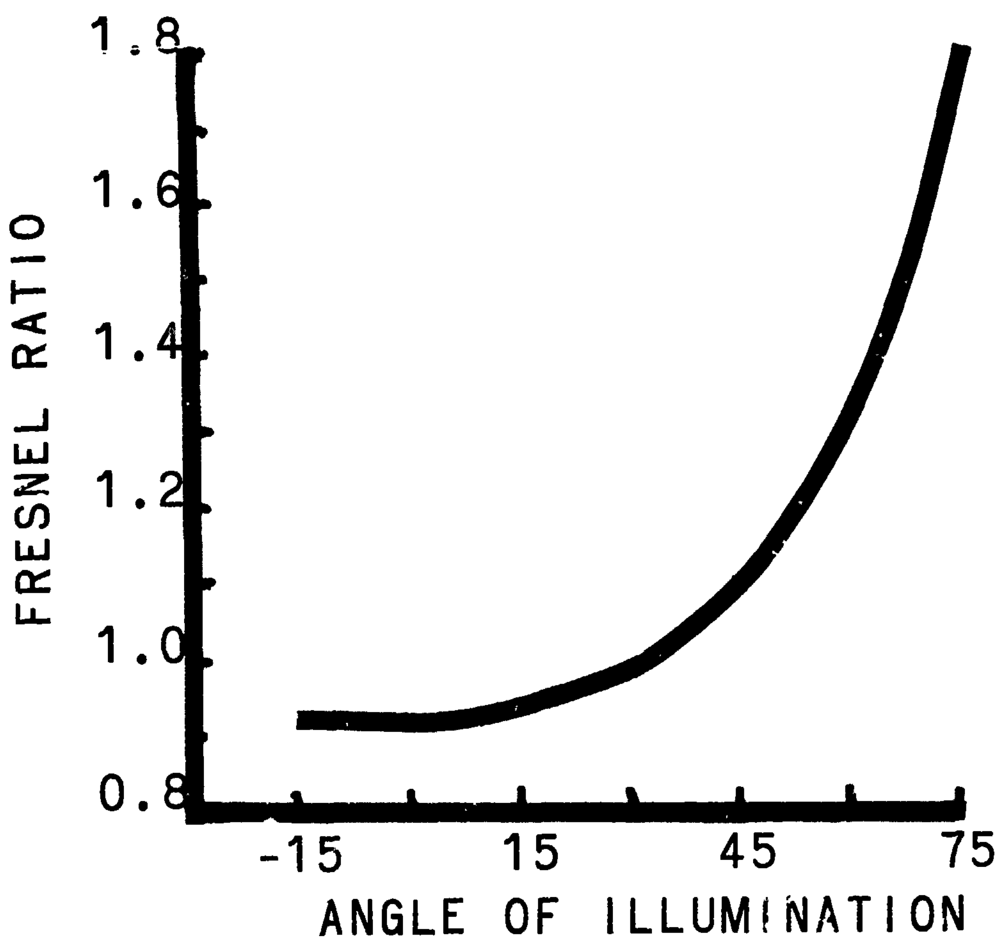


Figure 28. Fresnel ratio for 45° angle of view. This is the reflectance at the indicated angle of illumination, divided by the reflectance at 45°, 45°. It increases with increasing efficiency of reflection at more grazing angles.

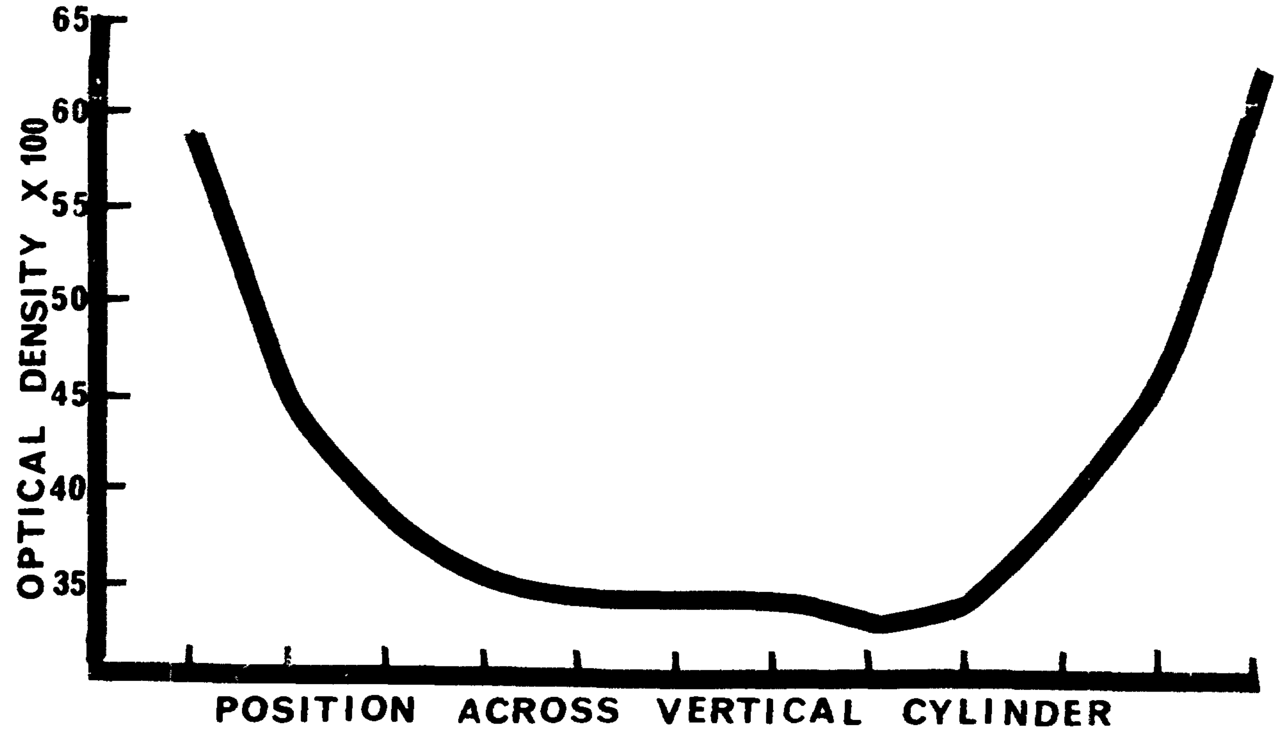


Figure 29. Example of highlight at edge: optical density, vertical cylinder, warp vertical, horizon background. Measurements at 1 mm interval.

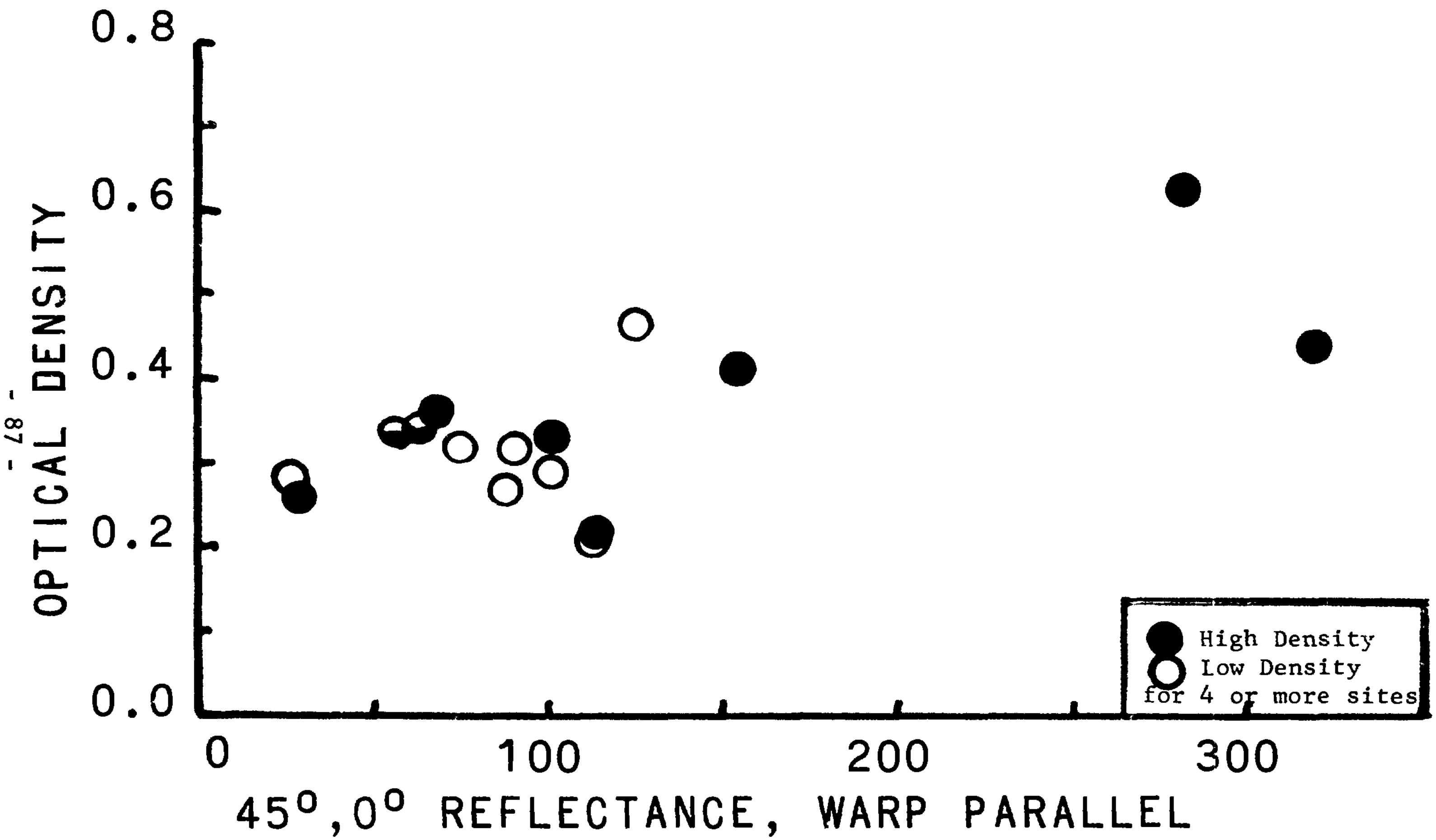


Figure 30. Correlation between optical density in negatives taken on rubble background, and general light reflectance level (45°,0°, warp parallel to plane of path of light).

APPENDIX

Several listings of basic data are covered in the appendix.

1. Tables A-I through A-XIII give the optical density values from the densitometer measurements on all the photonegatives taken using the view camera to photograph the screen of the night vision device. Density values were taken of the white reference card, the fabrics on the cylinders and the grey reference card. All 25 fabrics with warp along the cylinder and filling along the cylinder, cylinders standing vertical and lying down (horizontal) are included.

2. Tables A-XIV through A-XVI give directional reflectance values measured with the goniophotometer for all 25 fabrics using 45°, 30°, and 60° angles of view for the warp horizontal (parallel to the plane of light) and warp vertical (perpendicular to the plane of light).

3. Table A-XVII summarizes certain characteristics of the fabrics, related to surface appearance namely: weight, weave density (threads per inch), thickness (which combined with weight reflects differences in drape), air permeability, and weave pattern. Diagrams for the frieze, birdseye, and waffle weaves are appended to the table.

4. Figures A-1 through A-7 are daylight photos of the backgrounds used in the night photography work. An arrow in each photo shows approximately the positions of the cylinders in night photos. More detailed descriptions of the location of these viewing spots are given in the "Notes" following Table II in the body of the report.

TABLE A-I

DENSITY DATA, OPEN FIELD NEGATIVES, CYLINDERS HORIZONTAL

Fabric	White	Warp along Cylinder		Gray	Fill along Cylinder		Background	
No.	Card	Average	Range	Card	Average	Range	Average	Range
1	----	0.786	0.75-0.85	0.78	0.718	0.70-0.74	0.754	0.72-0.78
2	1.04	0.840	0.81-0.88	0.81	0.778	0.75-0.81	0.814	0.81-0.82
3	1.00	0.783	0.72-0.86	0.77	0.751	0.73-0.78	0.810	0.79-0.83
4	0.89	0.730	0.71-0.76	0.74	0.702	0.68-0.73	0.750	0.72-0.78
5	1.00	0.864	0.85-0.90	0.86	0.847	0.84-0.86	0.932	0.90-0.97
6	----	0.842	0.80-0.91	----	0.800	0.78-0.81	0.872	0.82-0.89
7	----	0.873	0.83-0.92	0.85	-----	-----	0.845	0.83-0.86
8	1.17	0.831	0.81-0.86	0.88	0.801	0.77-0.82	0.876	0.84-0.90
9	0.94	0.722	0.69-0.80	0.78	0.679	0.66-0.74	0.876	0.85-0.90
10	---	---	---	negative	missing	---	---	---
11	---	---	---	negative	damaged	---	---	---
12	---	---	---	negative	damaged	---	---	---
13	---	---	---	negative	damaged	---	---	---
14	1.41	1.050	1.02-1.10	1.10	1.025	0.98-1.08	1.09	1.07-1.12
15	----	1.150	1.11-1.22	----	1.074	1.06-1.10	1.088	1.06-1.12
16	1.28	0.976	0.97-0.98	1.06	0.960	0.93-1.02	1.050	1.04-1.06
17	1.10	0.851	0.84-0.88	----	0.842	0.82-0.88	0.967	0.95-0.98
18	---	---	---	negative	missing	---	---	---
19	---	---	---	negative	damaged	---	---	---
20	---	---	---	negative	damaged	---	---	---
21	---	---	---	negative	damaged	---	---	---
22	---	---	---	negative	damaged	---	---	---
23	---	---	---	negative	damaged	---	---	---
24	1.06	0.924	0.90-0.98	0.80	0.881	0.83-0.95	0.830	0.82-0.84
25	0.95	0.846	0.81-0.90	0.85	0.810	0.79-0.83	0.840	0.80-0.86

TABLE A-II

DENSITY DATA, OPEN FIELD NEGATIVES, CYLINDERS HORIZONTAL

Fabric No.	White Card	Warp along Cylinder Average	Warp along Cylinder Range	Gray Card	Fill along Cylinder Average	Fill along Cylinder Range	Background Average	Background Range
1	1.13	0.855	0.85-0.86	0.76	0.765	0.76-0.77	0.756	0.72-0.82
2	1.03	0.760	0.76	0.80	0.746	0.74-0.75	0.758	0.74-0.78
3	1.16	0.890	0.89	0.88	0.843	0.84-0.85	0.843	0.79-0.86
4	1.02	0.796	0.79-0.80	0.78	0.820	0.82	0.837	0.82-0.86
5	1.02	0.860	0.86-0.88	0.82	0.835	0.83-0.84	0.834	0.81-0.90
6	1.17	0.872	0.86-0.88	0.78	0.832	0.83-0.84	0.797	0.76-0.86
7	1.04	0.843	0.84-0.85	0.81	0.795	0.78-0.81	0.780	0.76-0.80
8	1.16	0.886	0.88-0.90	0.82	0.860	0.86	0.868	0.86-0.88
9	----	0.843	0.83-0.86	0.77	0.766	0.76-0.78	0.801	0.78-0.82
10	----	----	----	negative	missing	----	----	----
11	----	----	----	negative	damaged	----	----	----
12	1.63	1.143	1.14-1.15	1.14	1.160	1.16	1.140	1.12-1.17
13	----	----	----	negative	damaged	----	----	----
14	1.14	1.116	1.11-1.12	1.10	1.110	1.10-1.12	1.111	1.10-1.14
15	1.36	1.100	1.10-1.12	1.08	-----	---------	1.070	1.04-1.09
16	1.46	1.160	1.14-1.18	1.14	1.150	1.14-1.16	1.101	1.09-1.12
17	0.83	0.580	0.57-0.60	0.56	0.570	0.56-0.58	0.575	0.52-0.62
18	----	----	----	negative	missing	----	----	----
19	----	----	----	negative	damaged	----	----	----
20	----	----	----	negative	damaged	----	----	----
21	----	----	----	negative	damaged	----	----	----
22	----	----	----	negative	damaged	----	----	----
23	----	----	----	negative	damaged	----	----	----
24	1.03	-----	---------	0.81	0.810	0.80-0.82	0.812	0.80-0.82
25	1.04	0.926	0.92-0.94	0.85	0.870	0.86-0.88	0.890	0.87-0.90

TABLE A-III

DENSITY DATA, BRUSHY FIELD NEGATIVES, CYLINDERS VERTICAL

Fabric No.	White Card	Warp along Cylinder Average	Warp along Cylinder Range	Gray Card	Fill along Cylinder Average	Fill along Cylinder Range	Background Average	Background Range
1	0.87	0.546	0.53-0.56	0.54	0.558	0.55-0.57	0.742	0.72-0.76
2	0.96	0.704	0.69-0.72	0.71	0.706	0.69-0.71	0.856	0.85-0.87
3	0.91	0.704	0.68-0.72	0.66	0.670	0.67	0.848	0.83-0.87
4	1.07	0.698	0.69-0.71	0.75	0.698	0.69-0.70	0.974	0.93-1.01
5	1.06	0.756	0.75-0.77	0.79	0.772	0.77-0.78	0.908	0.88-0.94
6	0.99	0.696	0.69-0.70	0.71	0.720	0.71-0.73	0.884	0.83-0.93
7	1.28	0.824	0.81-0.84	0.85	0.834	0.83-0.84	0.958	0.93-0.98
8	1.03	0.788	0.78-0.79	0.75	0.736	0.72-0.76	0.910	0.90-0.93
9	1.01	0.794	0.74-0.85	0.77	0.656	0.64-0.67	0.816	0.80-0.83
10	0.71	0.508	0.49-0.53	0.53	0.538	0.53-0.55	0.632	0.63-0.64
11	0.82	0.620	0.60-0.64	0.59	0.602	0.58-0.62	0.768	0.70-0.82
12	-------	-------	-------	negative	damaged	-------	-------	-------
13	-------	-------	-------	negative	damaged	-------	-------	-------
14	-------	-------	-------	negative	damaged	-------	-------	-------
15	-------	-------	-------	negative	damaged	-------	-------	-------
16	-------	-------	-------	negative	damaged	-------	-------	-------
17	0.85	0.594	0.58-0.62	0.63	0.578	0.57-0.59	0.734	0.72-0.76
18	0.79	0.558	0.55-0.56	0.60	0.548	0.54-0.56	0.776	0.75-0.81
19	0.91	0.674	0.66-0.69	0.71	0.670	0.66-0.69	0.864	0.85-0.89
20	0.76	0.652	0.64-0.66	0.60	0.650	0.65-0.66	0.710	0.69-0.74
21	0.92	0.715	0.69-0.74	0.67	0.700	0.68-0.73	0.826	0.82-0.84
22	0.87	0.686	0.68-0.69	0.71	0.704	0.70-0.71	0.854	0.85-0.86
23	1.10	0.781	0.76-0.89	0.82	0.791	0.79-0.80	0.894	0.89-0.90
24	0.95	0.828	0.81-0.85	0.72	0.802	0.75-0.84	0.862	0.85-0.88
25	0.87	0.672	0.66-0.69	0.66	0.669	0.66-0.68	0.814	0.81-0.82

TABLE A-IV

DENSITY DATA, BRUSHY FIELD NEGATIVES, CYLINDERS HORIZONTAL

Fabric No.	White Card	Warp along Cylinder		Gray Card	Fill along Cylinder		Background	
		Average	Range		Average	Range	Average	Range
1	0.86	0.600	0.59-0.61	0.60	0.568	0.55-0.59	0.776	0.74-0.83
2	1.04	0.766	0.76-0.77	0.75	0.732	0.72-0.75	0.896	0.88-0.94
3	0.99	0.730	0.71-0.75	0.72	0.700	0.67-0.73	0.902	0.85-0.96
4	1.06	0.784	0.77-0.80	0.80	0.748	0.73-0.76	0.876	0.86-0.89
5	1.06	0.754	0.73-0.77	0.76	0.724	0.71-0.73	0.872	0.86-0.88
6	1.01	0.728	0.72-0.74	0.70	0.710	0.69-0.73	0.872	0.86-0.89
7	0.99	0.768	0.75-0.78	0.74	0.738	0.72-0.77	0.807	0.77-0.86
8	1.07	0.788	0.77-0.81	0.74	0.696	0.67-0.71	0.884	0.86-0.93
9	1.08	0.858	0.83-0.90	0.83	0.806	0.79-0.82	0.986	0.96-1.00
10	0.87	0.612	0.60-0.63	0.55	0.542	0.53-0.55	0.690	0.67-0.71
11	----	----	----	negative	damaged	----	----	----
12	----	----	----	negative	damaged	----	----	----
13	----	----	----	negative	damaged	----	----	----
14	----	----	----	negative	damaged	----	----	----
15	----	----	----	negative	damaged	----	----	----
16	0.85	0.632	0.62-0.65	0.67	0.668	0.65-0.70	0.766	0.74-0.79
17	0.81	0.644	0.63-0.67	0.67	0.630	0.62-0.65	0.782	0.76-0.81
18	1.22	-----	---------	----	0.788	0.69-0.91	0.758	0.73-0.77
19	0.90	0.670	0.66-0.68	0.68	0.648	0.63-0.67	0.820	0.79-0.87
20	0.87	0.716	0.71-0.74	0.68	0.714	0.69-0.75	0.738	0.73-0.75
21	0.93	0.792	0.75-0.83	0.71	0.698	0.69-0.70	0.948	0.91-0.97
22	0.85	0.668	0.66-0.68	0.70	0.678	0.67-0.69	0.800	0.79-0.82
23	0.97	0.778	0.77-0.78	0.78	0.757	0.73-0.77	0.910	0.87-0.98
24	0.90	0.710	0.69-0.75	0.73	0.894	0.68-0.81	0.866	0.82-0.95
25	0.90	0.640	0.62-0.66	0.67	0.658	0.64-0.68	0.826	0.82-0.84

TABLE A-V

DENSITY DATA, EDGE OF WOODS NEGATIVES, CYLINDERS VERTICAL

Fabric No.	White Card	Warp along Cylinder Average	Warp along Cylinder Range	Gray Card	Fill along Cylinder Average	Fill along Cylinder Range	Background Average	Background Range
1	1.02	-----	---------	0.54	0.462	0.43-0.50	0.623	0.58-0.66
2	0.83	0.657	0.62-0.69	0.67	0.638	0.60-0.68	0.742	0.72-0.76
3	0.92	0.562	0.55-0.58	0.66	0.556	0.55-0.57	0.731	0.70-0.77
4	0.85	0.502	0.49-0.54	0.52	0.497	0.48-0.53	0.680	0.66-0.71
5	0.96	0.578	0.57-0.59	0.67	0.585	0.58-0.60	0.765	0.73-0.78
6	0.99	0.595	0.57-0.62	0.68	0.595	0.62-0.64	0.630	0.60-0.66
7	1.03	0.740	0.71-0.76	0.71	0.740	0.69-0.77	0.808	0.78-0.83
8	0.99	0.644	0.62-0.68	0.63	0.680	0.64-0.70	0.738	0.71-0.76
9	1.02	0.635	0.62-0.65	----	0.668	0.64-0.68	0.732	0.69-0.76
10	0.81	0.407	0.40-0.42	0.53	0.427	0.42-0.44	0.556	0.54-0.58
11	----	0.474	0.46-0.51	----	0.442	0.43-0.46	0.540	0.54
12	0.74	0.338	0.31-0.41	0.45	0.385	0.37-0.41	0.486	0.46-0.53
13	0.77	0.306	0.30-0.34	0.52	0.390	0.37-0.42	0.300	0.28-0.32
14	----	----	----	negative	damaged	----	----	----
15	----	----	----	negative	damaged	----	----	----
16	0.96	0.610	0.58-0.65	0.58	-----	---------	0.616	0.60-0.64
17	0.82	0.366	0.36-0.38	0.50	0.380	0.36-0.41	0.516	0.49-0.54
18	0.92	0.651	0.64-0.66	0.66	0.651	0.64-0.66	0.653	0.64-0.70
19	0.99	0.624	0.61-0.64	----	0.643	0.64-0.66	0.646	0.63-0.67
20	0.87	0.553	0.54-0.58	0.62	0.553	0.53-0.58	0.580	0.57-0.60
21	1.00	0.690	0.67-0.70	0.70	0.678	0.65-0.70	0.748	0.63-0.80
22	0.96	0.649	0.64-0.68	0.71	0.628	0.61-0.65	0.750	0.72-0.78
23	0.94	0.640	0.63-0.65	----	0.628	0.62-0.64	0.650	0.63-0.67
24	0.92	0.555	0.54-0.58	0.62	0.551	0.54-0.58	0.605	0.55-0.62
25	0.88	0.518	0.50-0.58	0.57	0.507	0.48-0.58	0.636	0.60-0.66

TABLE A-VI

DENSITY DATA, EDGE OF WOODS NEGATIVES, CYLINDERS HORIZONTAL

Fabric No.	White Card	Warp along Cylinder Average	Warp along Cylinder Range	Gray Card	Fill along Cylinder Average	Fill along Cylinder Range	Background Average	Background Range
1	0.92	0.523	0.52-0.53	0.64	0.527	0.52-0.54	0.652	0.64-0.69
2	0.94	0.748	0.70-0.79	0.68	0.728	0.69-0.78	0.692	0.68-0.71
3	----	-----	---------	negative	damaged	---------	-----	---------
4	1.00	0.720	0.69-0.75	0.72	0.672	0.64-0.72	0.767	0.75-0.80
5	0.99	0.660	0.64-0.70	0.74	0.706	0.64-0.76	0.724	0.70-0.75
6	0.99	0.716	0.70-0.73	0.72	0.696	0.68-0.70	0.715	0.70-0.74
7	0.99	0.790	0.77-0.81	0.68	0.737	0.69-0.78	0.693	0.66-0.73
8	0.96	0.806	0.78-0.83	0.62	0.760	0.74-0.78	0.746	0.72-0.78
9	1.10	0.833	0.82-0.85	0.82	0.816	0.81-0.82	0.822	0.80-0.86
10	----	0.602	0.59-0.62	0.62	0.564	0.54-0.60	0.605	0.60-0.62
11	0.76	0.466	0.46-0.48	0.50	0.482	0.47-0.50	0.530	0.50-0.55
12	0.82	0.507	0.48-0.53	0.55	0.628	0.59-0.67	0.555	0.55-0.56
13	0.82	0.630	0.62-0.64	----	-----	---------	0.610	0.59-0.63
14	--------	--------	--------	negative	damaged	--------	--------	--------
15	--------	--------	--------	negative	damaged	--------	--------	--------
16	0.76	0.540	0.54	0.55	-----	---------	0.505	0.46-0.55
17	0.78	0.514	0.48-0.54	0.54	0.508	0.47-0.54	0.567	0.55-0.58
18	0.92	0.653	0.64-0.67	0.64	0.626	0.62-0.63	0.646	0.62-0.69
19	0.80	0.586	0.58-0.60	0.56	0.573	0.56-0.60	0.600	0.57-0.65
20	0.88	0.594	0.56-0.63	0.60	0.557	0.54-0.58	0.657	0.62-0.70
21	1.02	0.733	0.72-0.75	0.71	0.686	0.67-0.70	0.733	0.71-0.77
22	0.83	0.700	0.68-0.73	0.69	0.690	0.67-0.70	0.760	0.74-0.79
23	----	0.695	0.67-0.73	0.68	0.712	0.70-0.74	0.716	0.68-0.75
24	0.97	0.642	0.61-0.70	0.66	0.650	0.63-0.68	0.708	0.64-0.76
25	0.92	0.590	0.56-0.64	0.64	0.638	0.61-0.68	0.676	0.66-0.70

TABLE A-VII

DENSITY DATA, IN THE WOODS NEGATIVES, CYLINDERS VERTICAL

Fabric No.	White Card	Warp along Cylinder		Gray Card	Fill along Cylinder		Background	
		Average	Range		Average	Range	Average	Range
1	0.63	0.362	0.35-0.37	0.42	0.370	0.37	0.300	0.28-0.32
2	0.88	0.516	0.51-0.53	0.48	0.476	0.47-0.49	0.334	0.31-0.35
3	0.75	0.450	0.42-0.49	0.49	0.436	0.42-0.45	0.352	0.33-0.38
4	0.87	0.390	0.37-0.42	----	0.428	0.41-0.45	0.398	0.37-0.42
5	0.74	0.438	0.41-0.46	0.40	0.370	0.37	0.288	0.27-0.31
6	0.80	0.358	0.35-0.38	0.44	0.372	0.34-0.42	0.324	0.31-0.36
7	0.81	0.434	0.42-0.45	----	0.360	0.33-0.40	0.314	0.28-0.35
8	0.74	0.308	0.30-0.31	0.42	0.298	0.29-0.30	0.340	0.30-0.38
9	0.76	0.302	0.29-0.32	0.45	0.284	0.27-0.30	0.350	0.33-0.38
10	0.87	0.328	0.31-0.35	0.46	0.312	0.30-0.33	0.358	0.32-0.38
11	0.93	0.568	0.55-0.59	0.61	0.534	0.52-0.55	0.416	0.41-0.44
12	0.86	0.370	0.36-0.38	0.42	0.406	0.38-0.49	0.350	0.33-0.37
13	0.92	0.506	0.48-0.53	0.55	0.386	0.37-0.40	0.426	0.39-0.46
14	0.76	0.462	0.45-0.48	0.55	0.444	0.42-0.48	0.342	0.33-0.37
15	0.85	0.456	0.45-0.47	0.51	0.430	0.43	0.372	0.35-0.39
16	0.96	0.568	0.56-0.57	----	-----	---------	0.428	0.39-0.48
17	0.98	0.482	0.47-0.49	0.54	0.426	0.41-0.45	0.392	0.38-0.41
18	0.85	0.242	0.23-0.25	0.40	0.216	0.21-0.23	0.240	0.22-0.26
19	0.78	0.406	0.39-0.41	----	0.362	0.35-0.37	0.230	0.20-0.27
20	0.78	0.240	0.21-0.30	0.31	0.248	0.24-0.26	0.236	0.20-0.27
21	0.47	0.112	0.10-0.13	0.20	0.134	0.11-0.16	0.140	0.14
22	0.27	0.046	0.04-0.05	0.07	0.066	0.05-0.08	0.048	0.04-0.06
23	0.10	-----	---------	----	-----	---------	0.038	0.03-0.04
24	0.39	0.166	0.16-0.17	0.15	0.130	0.13	0.094	0.09-0.10
25	0.63	0.278	0.27-0.29	0.30	0.274	0.24-0.30	0.230	0.21-0.24

TABLE A-VIII

DENSITY DATA, IN THE WOODS NEGATIVES, CYLINDERS HORIZONTAL

Fabric No.	White Card	Warp along Cylinder Average	Warp along Cylinder Range	Gray Card	Fill along Cylinder Average	Fill along Cylinder Range	Background Average	Background Range
1	0.77	0.474	0.44-0.52	----	-----	---------	0.334	0.31-0.36
2	0.56	0.548	0.53-0.56	----	-----	---------	0.306	0.29-0.32
3	0.74	0.492	0.47-0.52	----	-----	---------	0.288	0.28-0.30
4	0.90	0.548	0.48-0.53	----	-----	---------	0.272	0.25-0.28
5	0.67	0.442	0.41-0.47	----	-----	---------	0.254	0.24-0.27
6	0.81	0.472	0.44-0.51	----	-----	---------	0.300	0.28-0.31
7	0.81	0.480	0.46-0.52	----	-----	---------	0.294	0.28-0.31
8	0.81	0.452	0.43-0.47	----	-----	---------	0.308	0.29-0.33
9	0.86	0.478	0.45-0.51	----	-----	---------	0.332	0.32-0.35
10	------	------	------	negative	damaged	------	------	------
11	0.87	0.644	0.63-0.68	----	-----	---------	0.486	0.47-0.51
12	0.93	0.538	0.50-0.57	----	-----	---------	0.418	0.40-0.43
13	0.95	0.556	0.53-0.59	----	-----	---------	0.342	0.32-0.37
14	0.81	0.506	0.47-0.53	----	-----	---------	0.352	0.33-0.38
15	0.97	0.586	0.55-0.67	----	-----	---------	0.364	0.33-0.39
16	0.96	0.626	0.59-0.67	----	-----	---------	0.438	0.42-0.45
17	0.85	0.474	0.42-0.53	----	-----	---------	0.268	0.25-0.29
18	0.77	0.264	0.25-0.29	----	-----	---------	0.196	0.17-0.23
19	0.66	0.458	0.40-0.52	0.39	0.374	0.34-0.42	0.240	0.23-0.27
20	0.77	0.368	0.33-0.40	----	0.362	0.35-0.37	0.230	0.20-0.27
21	0.49	0.134	0.12-0.15	----	-----	---------	0.130	0.11-0.14
22	0.27	0.090	0.08-0.10	----	-----	---------	0.040	0.04
23	0.14	0.078	0.07-0.09	----	-----	---------	0.034	0.03-0.04
24	0.55	0.274	0.23-0.31	0.20	0.202	0.18-0.23	0.116	0.11-0.13
25	0.67	0.382	0.36-0.41	0.32	0.292	0.29-0.30	0.204	0.19-0.21

TABLE A-IX

DENSITY DATA, RUBBLE NEGATIVES, CYLINDERS VERTICAL

Fabric No.	White Card	Warp along Cylinder Average	Warp along Cylinder Range	Gray Card	Fill along Cylinder Average	Fill along Cylinder Range	Background Average	Background Range
1	0.64	0.338	0.31-0.38	0.38	0.329	0.30-0.39	0.634	0.62-0.66
2	0.71	0.411	0.38-0.47	0.38	0.426	0.39-0.51	0.584	0.52-0.65
3	----	0.277	0.21-0.42	0.33	0.203	0.16-0.24	0.472	0.43-0.52
4	0.52	0.251	0.22-0.35	0.23	0.229	0.21-0.28	0.528	0.39-0.59
5	0.50	0.208	0.20-0.23	0.24	0.310	0.31	0.356	0.34-0.37
6	0.41	0.260	0.23-0.32	0.25	0.266	0.24-0.30	0.440	0.41-0.47
7	0.48	0.209	0.19-0.24	0.23	0.237	0.21-0.30	0.410	0.37-0.45
8	0.59	0.291	0.24-0.43	0.34	0.311	0.30-0.33	0.506	0.47-0.53
9	0.71	0.345	0.30-0.41	0.42	0.340	0.32-0.37	0.628	0.59-0.67
10	0.61	0.313	0.28-0.43	0.34	0.319	0.28-0.41	0.524	0.46-0.56
11	0.67	0.357	0.33-0.43	0.37	0.376	0.35-0.41	0.514	0.45-0.55
12	0.69	0.316	0.30-0.35	0.45	0.306	0.30-0.32	0.624	0.61-0.65
13	0.66	0.294	0.27-0.33	0.36	0.309	0.29-0.34	0.600	0.59-0.62
14	0.67	0.352	0.30-0.47	0.41	0.366	0.35-0.41	0.576	0.57-0.58
15	0.66	0.390	0.35-0.47	0.38	0.383	0.36-0.42	0.642	0.63-0.66
16	0.66	0.426	0.39-0.45	0.43	-----	---------	0.626	0.58-0.65
17	0.70	0.326	0.31-0.37	0.40	0.311	0.29-0.35	0.518	0.46-0.57
18	0.66	0.281	0.26-0.32	0.34	0.278	0.24-0.32	0.582	0.52-0.62
19	0.72	0.428	0.41-0.46	0.38	0.496	0.47-0.53	0.682	0.66-0.71
20	0.69	0.330	0.31-0.36	0.43	0.350	0.34-0.36	0.490	0.46-0.54
21	0.85	0.428	0.41-0.46	0.48	0.445	0.42-0.47	0.696	0.62-0.78
22	0.85	0.472	0.46-0.50	0.46	0.504	0.49-0.52	0.734	0.66-0.81
23	0.83	0.542	0.54-0.55	0.50	0.625	0.61-0.64	0.728	0.64-0.80
24	0.87	0.618	0.60-0.64	0.52	0.674	0.65-0.70	0.781	0.66-0.87
25	0.77	0.462	0.41-0.52	----	0.488	0.47-0.52	0.678	0.54-0.82

TABLE A-Y

DENSITY DATA, RUBBLE NEGATIVES, CYLINDERS HORIZONTAL

Fabric No.	White Card	Warp along Cylinder Average	Warp along Cylinder Range	Gray Card	Fill along Cylinder Average	Fill along Cylinder Range	Background Average	Background Range
1	----	-----	--------	0.43	0.299	0.20-0.43	0.472	0.44-0.54
2	0.55	0.334	0.27-0.46	0.34	0.386	0.25-0.51	0.476	0.43-0.51
3	0.51	0.332	0.29-0.37	0.38	0.342	0.25-0.43	0.518	0.49-0.55
4	----	0.277	0.21-0.42	0.33	0.203	0.16-0.24	0.472	0.43-0.52
5	----	0.270	0.23-0.33	0.28	0.180	0.15-0.25	0.374	0.35-0.40
6	----	0.358	0.28-0.47	0.34	0.247	0.21-0.30	0.306	0.28-0.35
7	----	0.267	0.22-0.34	0.31	0.243	0.21-0.30	0.410	0.38-0.43
8	0.51	0.204	0.17-0.21	0.33	0.185	0.17--.21	0.386	0.32-0.41
9	0.42	0.286	0.27-0.31	0.38	0.236	0.22-0.25	0.510	0.49-0.55
10	----	0.361	0.31-0.46	0.43	0.373	0.30-0.48	0.588	0.55-0.62
11	----	0.442	0.37-0.50	0.37	0.388	0.35-0.45	0.614	0.61-0.62
12	0.57	0.376	0.34-0.45	0.54	0.320	0.29-0.36	0.606	0.58-0.64
13	----	0.332	0.29-0.40	0.45	0.393	0.32-0.47	0.548	0.50-0.57
14	----	0.404	0.32-0.54	0.42	0.340	0.30-0.40	0.412	0.34-0.49
15	----	0.399	0.35-0.45	0.47	0.356	0.31-0.41	0.568	0.49-0.62
16	----	0.364	0.29-0.44	0.42	-----	---------	0.558	0.54-0.57
17	----	0.323	0.25-0.45	0.42	0.310	0.25-0.41	0.480	0.44-0.50
18	----	0.310	0.26-0.41	0.38	0.254	0.24-0.28	0.501	0.40-0.58
19	----	0.676	0.59-0.75	0.62	0.677	0.63-0.75	0.734	0.71-0.77
20	0.70	0.385	0.36-0.42	0.62	0.490	0.42-0.54	0.561	0.42-0.68

(Continued)

TABLE A-X (Concluded)

DENSITY DATA, RUBBLE NEGATIVES, CYLINDERS HORIZONTAL

Fabric No.	White Card	Warp along Cylinder		Gray Card	Fill along Cylinder		Background	
		Average	Range		Average	Range	Average	Range
21	----	0.472	0.44-0.50	0.57	0.467	0.45-0.48	0.708	0.62-0.80
22	----	0.500	0.49-0.52	0.53	0.482	0.44-0.52	0.712	0.64-0.78
23	----	0.772	0.72-0.80	0.56	0.788	0.74-0.82	0.730	0.64-0.80
24	0.82	0.654	0.64-0.67	0.65	0.766	0.72-0.80	0.748	0.66-0.86
25	0.58	0.350	0.34-0.36	0.48	0.416	0.40-0.43	0.[illegible]5	0.53-0.70

TABLE A-XI

DENSITY DATA, HORIZON NEGATIVES, CYLINDERS VERTICAL

Fabric No.	White Card	Warp along Cylinder		Gray Card	Fill along Cylinder		Background	
		Average	Range		Average	Range	Average	Range
1	0.54	0.370	0.36-0.40	----	0.396	0.38-0.41	0.781	0.75-0.82
2	0.54	0.417	0.40-0.46	0.38	0.441	0.42-0.50	0.815	0.79-0.86
3	0.52	0.346	0.33-0.42	0.30	0.332	0.30-0.41	0.725	0.70-0.78
4	0.52	0.295	0.26-0.42	0.33	0.353	0.32-0.42	0.684	0.67-0.70
5	0.51	0.335	0.31-0.44	0.28	0.347	0.30-0.45	0.702	0.68-0.73
6	0.56	0.364	0.32-0.50	0.37	0.394	0.36-0.45	0.725	0.71-0.74
7	0.68	0.440	0.42-0.46	0.38	0.465	0.43-0.54	0.826	0.82-0.84
8	0.52	0.410	0.33-0.62	0.34	0.407	0.35-0.55	0.745	0.70-0.78
9	0.56	0.349	0.30-0.51	0.33	0.353	0.29-0.59	0.646	0.63-0.66
10	0.42	0.306	0.26-0.42	----	0.350	0.28-0.51	0.668	0.63-0.74
11	0.50	0.327	0.28-0.52	0.31	0.332	0.28-0.46	0.647	0.62-0.72
12	0.56	0.395	0.35-0.52	0.39	0.395	0.36-0.49	0.754	0.74-0.77
13	0.55	0.352	0.30-0.52	0.36	0.396	0.35-0.53	0.696	0.66-0.75
14	0.55	0.394	0.34-0.52	0.34	0.387	0.34-0.55	0.689	0.66-0.72
15	0.55	0.406	0.35-0.56	0.34	0.396	0.35-0.51	0.788	0.76-0.84
16	0.79	0.564	0.50-0.64	0.50	-----	---------	0.825	0.80-0.86
17	0.40	0.419	0.38-0.54	0.37	0.381	0.34-0.50	0.790	0.77-0.82
18	0.60	0.421	0.35-0.62	0.47	0.372	0.35-0.46	0.804	0.76-0.82
19	0.55	0.454	0.42-0.54	0.36	0.434	0.36-0.63	0.747	0.72-0.78
20	0.64	0.441	0.40-0.58	0.38	0.416	0.37-0.55	0.788	0.74-0.86
21	0.70	0.446	0.40-0.60	0.42	0.442	0.38-0.60	0.816	0.79-0.86
22	0.61	0.508	0.43-0.75	0.43	0.449	0.38-0.65	0.833	0.82-0.86
23	0.66	0.551	0.51-0.70	0.45	0.536	0.49-0.72	0.842	0.80-0.90
24	0.73	0.615	0.57-0.77	0.54	0.601	0.54-0.76	0.920	0.88-0.97
25	0.79	0.645	0.60-0.76	0.57	0.597	0.56-0.68	1.10	1.08-1.12

TABLE A-XII

DENSITY DATA, HORIZON NEGATIVES, CYLINDERS HORIZONTAL

Fabric No.	White Card	Warp along Cylinder		Gray Card	Fill along Cylinder		Background	
		Average	Range		Average	Range	Average	Range
1	0.51	0.416	0.39-0.45	0.34	0.471	0.42-0.54	0.680	0.64-0.72
2	0.60	0.461	0.44-0.52	0.40	0.495	0.44-0.55	0.758	0.74-0.77
3	0.60	0.374	0.34-0.44	0.47	0.428	0.38-0.48	0.804	0.79-0.82
4	0.52	0.287	0.28-0.30	0.34	0.372	0.33-0.46	0.651	0.64-0.68
5	0.51	0.374	0.34-0.42	0.32	0.418	0.38-0.52	0.738	0.70-0.78
6	0.54	0.402	0.39-0.42	0.34	0.363	0.33-0.39	0.705	0.68-0.78
7	0.61	0.482	0.46-0.54	0.40	0.430	0.40-0.48	0.741	0.72-0.77
8	0.60	0.396	0.34-0.56	0.47	0.430	0.40-0.52	0.696	0.68-0.73
9	0.46	0.303	0.24-0.51	0.26	0.328	0.28-0.51	0.588	0.57-0.61
10	0.55	0.435	0.37-0.62	0.38	0.396	0.35-0.54	0.795	0.78-0.82
11	0.52	0.348	0.31-0.40	0.32	0.350	0.34-0.37	0.705	0.66-0.78
12	0.48	0.295	0.26-0.35	0.33	0.336	0.30-0.43	0.641	0.63-0.66
13	0.58	0.390	0.35-0.48	0.38	0.392	0.36-0.42	0.801	0.68-0.71
14	0.63	0.384	0.34-0.46	0.46	0.431	0.40-0.50	0.799	0.77-0.85
15	0.53	0.390	0.34-0.56	0.38	0.388	0.33-0.51	0.720	0.69-0.82
16	0.65	0.513	0.49-0.55	0.52	0.528	0.49-0.60	0.826	0.80-0.87
17	0.63	0.492	0.47-0.52	0.60	-----	---------	0.833	0.80-0.90
18	0.64	0.426	0.41-0.45	0.42	0.400	0.35-0.57	0.847	0.80-0.90
19	0.64	0.531	0.48-0.60	0.46	0.484	0.46-0.53	0.833	0.80-0.88
20	0.65	0.456	0.42-0.54	0.44	0.418	0.40-0.50	0.802	0.77-0.84
21	0.70	0.432	0.42-0.46	0.36	0.388	0.33-0.54	0.756	0.72-0.78
22	0.62	0.468	0.45-0.52	0.42	0.442	0.39-0.66	0.806	0.78-0.84
23	0.62	0.520	0.50-0.58	0.51	0.548	0.50-0.63	0.890	0.86-0.92
24	0.74	0.601	0.56-0.65	0.52	0.576	0.53-0.68	0.927	0.90-0.96
25	0.82	0.616	0.60-0.65	0.72	0.585	0.55-0.62	0.974	0.94-1.00

TABLE A-XIII

DENSITY DATA, GREEN LEAF NEGATIVES, CYLINDERS VERTICAL.
MEASUREMENTS ARE PARALLEL TO EDGE OF CYLINDER AND
BACKGROUND IS MEASURED ON EACH SIDE OF THE PAIR OF CYLINDERS

Fabric	White	Warp along Cylinder		Background		Gray	Fill along Cylinder		Background	
No.	Card	Average	Range	Average	Range	Card	Average	Range	Average	Range
1	1.07	0.750	0.71-0.76	0.749	0.73-0.76	0.72	0.765	0.75-0.79	0.762	0.76-0.78
2	1.06	0.665	0.66-0.68	0.659	0.63-0.68	0.63	0.732	0.72-0.74	0.652	0.62-0.67
3	0.92	0.556	0.54-0.58	0.585	0.54-0.60	0.56	0.633	0.63-0.64	0.575	0.54-0.61
4	0.88	0.466	0.46-0.49	0.540	0.51-0.56	0.52	0.497	0.49-0.51	0.558	0.54-0.59
5	0.86	0.522	0.50-0.55	0.525	0.50-0.54	0.54	0.599	0.58-0.60	0.539	0.52-0.57
6	0.94	0.459	0.45-0.47	0.505	0.48-0.52	0.52	0.520	0.50-0.53	0.482	0.46-0.52
7	0.87	0.531	0.52-0.54	0.530	0.48-0.55	0.50	0.602	0.58-0.62	0.571	0.49-0.55
8	0.86	0.370	0.36-0.38	0.480	0.46-0.49	0.44	0.398	0.39-0.40	0.471	0.44-0.50
9	0.78	0.341	0.33-0.35	0.426	0.41-0.44	0.42	0.331	0.32-0.34	0.413	0.39-0.45
10	0.87	0.441	0.42-0.46	0.547	0.54-0.55	0.53	0.483	0.46-0.50	0.502	0.48-0.53
11	0.76	0.452	0.43 0.46	0.455	0.40-0.49	0.43	0.460	0.44-0.48	0.473	0.45-0.50
12	0.70	0.308	0.30-0.32	0.370	0.36-0.38	0.37	0.314	0.30-0.32	0.374	0.35-0.39
13	0.77	0.326	0.32-0.34	0.395	0.39-0.40	0.36	0.338	0.33-0.34	0.396	0.37-0.41
14	0.72	0.314	0.30-0.32	0.355	0.34-0.37	0.34	0.331	0.31-0.34	0.327	0.30-0.35
15	0.60	0.296	0.29-0.30	0.303	0.26-0.32	0.26	0.309	0.30-0.32	0.289	0.25-0.31
16	0.73	0.386	0.36-0.40	0.425	0.41-0.44	----	-----	---------	-----	---------
17	0.58	0.222	0.20-0.24	0.265	0.26-0.28	0.27	0.244	0.24-0.26	0.245	0.22-0.27
18	0.47	0.176	0.17-0.19	0.218	0.20-0.22	0.22	0.202	0.20-0.21	0.218	0.20-0.23
19	0.46	0.174	0.16-0.18	0.166	0.16-0.18	0.17	0.186	0.18-0.20	0.153	0.14-0.17

(Continued)

TABLE A-XIII (Concluded)

Fabric No.	White Card	Warp along Cylinder Average	Warp along Cylinder Range	Background Average	Background Range	Gray Card	Fill along Cylinder Average	Fill along Cylinder Range	Background Average	Background Range
21	0.41	0.124	0.12-0.14	0.151	0.14-0.16	0.16	0.142	0.14-0.15	0.133	0.13-0.16
22	0.36	0.141	0.14-0.15	0.142	0.13-0.15	0.12	0.153	0.14-0.17	0.133	0.12-0.14
23	0.36	0.145	0.14-0.16	0.145	0.13-0.16	0.12	0.178	0.17-0.19	0.147	0.14-0.16
24	0.42	0.197	0.18-0.20	0.188	0.17-0.20	0.16	0.217	0.20-0.23	0.164	0.15-0.18
25	0.32	0.156	0.13-0.16	0.159	0.15-0.17	0.15	0.163	0.15-0.18	0.165	0.16-0.18

TABLE A-XIV

DIRECTIONAL REFLECTANCE DATA FOR 45° ANGLE OF VIEW. FOR EACH FABRIC DATA FOR WARP HORIZONTAL (H), WITH WARP PARALLEL TO THE PLANE OF THE LIGHT, ARE GIVEN FIRST, THEN WARP VERTICAL (V). FOR FABRIC 15, B INDICATES BRUSHED.

Fabric and Orientation	Reflectance (MgO = 1000) for indicated illumination angle								
	-15	0	15	30	40	45	50	60	75
1H	47	50	56	62	72	81	92	163	1041
1V	40	43	50	56	68	81	100	213	1041
2H	106	125	137	165	273	363	508	1041	----
2V	110	119	137	169	257	338	456	1041	----
3H	57	65	75	87	106	131	153	294	1041
3V	52	62	70	94	119	135	148	233	1041
4H	81	90	100	122	169	232	376	564	1041
4V	87	94	100	115	140	169	219	495	1041
5H	85	97	102	131	169	206	307	821	1041
5V	87	94	106	125	175	244	373	840	1041
6H	15	25	40	90	200	407	420	972	1041
6V	65	68	72	77	97	106	112	194	1041
7H	87	92	102	117	143	153	163	190	1041
7V	75	100	111	122	144	165	180	223	1041
8H	75	82	97	112	137	163	173	232	1041
8V	62	72	77	90	107	122	125	137	263
9H	37	47	56	68	87	100	119	244	1041
9V	25	40	50	62	68	75	100	175	1041
10H	62	77	100	119	150	175	188	250	1041
10V	71	75	81	100	119	137	163	225	1041

(Continued)

TABLE A-XIV (Continued)

Fabric and Orientation	Reflectance (MgO = 1000) for indicated illumination angle								
	-15	0	15	30	40	45	50	60	75
11H	43	56	68	87	106	125	137	194	1041
11V	50	56	62	75	87	100	106	232	1041
12H	50	62	75	94	106	119	131	163	1041
12V	56	62	72	87	100	119	125	163	1041
13H	75	87	106	131	163	178	200	288	1041
13V	62	81	100	131	156	181	206	275	1041
14H	50	56	62	72	87	97	112	213	1041
14V	53	47	56	62	81	87	94	106	451
15H	25	27	37	55	87	119	188	558	1041
15V	37	43	52	72	110	158	248	725	1041
15HB	45	68	117	198	278	344	401	533	671
15VB	43	56	92	165	232	282	326	514	865
16H	155	171	193	223	263	301	376	1003	1041
16V	144	170	215	282	401	520	752	1041	----
17H	32	40	55	72	95	110	125	188	1041
17V	50	56	70	81	94	106	119	173	1041
18H	18	22	25	27	31	37	42	40	125
18V	25	18	22	27	32	35	37	42	110
19H	228	257	288	336	376	436	482	679	1041
19V	188	225	278	344	395	445	489	664	1041
20H	68	80	100	130	160	181	206	307	1041
20V	81	94	115	140	169	190	213	307	1041
21H	37	52	60	68	77	85	92	117	771
21V	40	43	47	52	62	68	77	100	809

TABLE A-XIV (Concluded)

Fabric and Orientation	Reflectance (MgO = 1000) for indicated illumination angle								
	-15	0	15	30	40	45	50	60	75
22H	62	66	71	75	87	97	105	137	1041
22V	56	58	62	72	81	91	102	122	922
23H	238	257	286	326	363	391	401	514	1041
23V	232	245	391	288	313	338	356	560	1041
24H	203	228	238	248	257	263	269	376	1041
24V	153	160	173	200	218	235	257	413	1041
25H	94	97	112	127	145	156	171	283	1041
25V	87	100	119	137	156	170	185	253	1041

TABLE A-XV

DIRECTIONAL REFLECTANCE DATA FOR 30° ANGLE OF VIEW. DATA FOR WARP HORIZONTAL (H) PARALLEL TO PLANE OF LIGHT ARE GIVEN FIRST. THEN DATA FOR WARP VERTICAL (V). FOR FABRIC 15, B INDICATES BRUSHED.

Fabric and Orientation	Reflectance (MgO = 1000) at indicated illumination angles								
	- 5	0	15	25	30	35	45	60	75
1H	61	61	73	102	124	148	221	514	866
1V	53	52	53	61	73	89	144	366	770
2H	119	119	136	184	229	295	489	1035	----
2V	135	138	179	259	320	396	648	1035	----
6H	19	23	57	148	209	271	280	227	168
6V	83	83	85	90	95	102	166	604	1035
7H	78	81	91	103	111	115	138	385	1035
7V	94	93	100	114	124	140	240	834	1035
8H	73	74	83	95	100	107	136	435	1035
8V	77	77	83	90	98	103	136	431	1035
13H	2	3	14	26	33	38	62	331	1035
13V	10	11	22	37	45	50	75	356	1035
15H	26	28	43	77	108	143	277	626	941
15H	39	44	80	139	179	224	354	660	747
15HB	40	48	76	99	116	130	170	263	303
15VB	35	39	63	91	110	127	175	279	317
16H	142	148	172	208	243	298	504	1035	----
16V	162	168	203	261	322	410	721	1035	----
18H	7	7	10	13	15	15	17	35	106
18V	10	10	13	17	22	22	33	73	155
19H	217	235	309	361	385	417	604	1035	----
19V	251	251	261	272	287	285	312	769	1035
21H	41	41	49	65	83	106	188	248	591
21V	34	34	34	37	38	38	41	71	350

(Continued)

TABLE A-XV (Concluded)

Fabric and Orientation	Reflectance (MgO = 1000) at indicated illumination angles								
	- 5	0	15	25	30	35	45	60	75
22H	22	18	17	19	23	26	45	220	738
22V	19	17	15	19	22	25	41	235	769
23H	243	251	280	310	330	356	524	1035	----
23V	241	245	256	263	268	272	296	729	1035
24H	233	233	211	203	204	211	281	794	1035
24V	132	132	132	138	144	150	191	619	1035
25H	84	84	89	95	102	105	126	332	1033
25V	86	87	94	103	108	114	131	298	1033

TABLE A-XVI

DIRECTIONAL REFLECTANCE DATA FOR 60° ANGLE OF VIEW. DATA FOR WARP HORIZONTAL (H) PARALLEL TO THE PLANE OF THE LIGHT ARE GIVEN FIRST, THEN DATA FOR WARP VERTICAL (V). FOR FABRIC 15, B INDICATES BRUSHED.

Fabric and Orientation	Reflectance (MgO = 1000) for indicates illumination angles								
	-5	0	15	30	45	55	60	65	75
1H	57	57	61	86	131	295	525	927	1092
1V	59	53	54	75	124	316	539	966	1092
2H	125	143	191	330	795	1108	---	----	----
2V	112	120	149	231	557	1108	---	----	----
6H	7	8	12	31	109	409	1073	1108	----
6V	71	71	79	96	130	192	320	674	1108
7H	56	64	80	103	143	186	230	294	1108
7V	80	84	93	113	145	192	240	313	1108
8H	50	58	71	92	125	161	195	230	1026
8V	66	70	79	94	125	165	204	245	1108
13H	67	75	92	126	181	246	308	402	1105
13V	57	77	88	122	188	269	359	562	1105
15H	52	59	72	102	185	391	688	1092	----
15V	69	72	83	119	236	547	896	1092	----
15HB	80	93	118	172	288	463	602	787	1008
15VB	126	170	197	226	318	484	650	813	1092
16H	150	158	172	211	355	953	1108	----	----
16V	143	166	199	258	391	685	1077	1108	----
18H	12	14	15	21	28	41	56	57	119
18V	17	18	20	24	30	43	58	58	117
19H	207	238	283	340	414	485	555	670	1108
19V	168	198	231	297	385	523	524	596	1108
21H	44	54	67	94	191	418	671	1035	1108
21V	44	47	50	60	74	97	120	140	583

(Continued)

TABLE A-XVI (Concluded)

Fabric and Orientation	Reflectance (MgO = 1000) for indicated illumination angles								
	- 5	0	15	30	45	55	60	65	75
22H	55	57	64	78	122	241	435	797	1105
22V	51	52	57	69	92	125	161	224	1105
23H	225	248	289	360	534	1108	---	----	----
23V	224	234	250	276	316	356	402	506	1108
24H	199	248	301	340	358	386	510	852	1108
24V	138	139	149	165	198	222	257	310	1108
25H	111	113	124	148	171	208	237	301	1092
25V	112	123	138	166	208	255	322	473	1092

TABLE A-XVII

MATERIAL CHARACTERISTICS OF FABRICS
Methods of Federal Specification CCC-T-191b
Data from U. S. Army Natick Laboratories

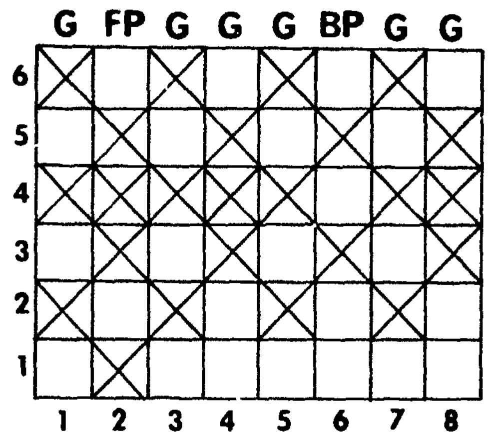
Sample No. - Cloth	Weight Method 5047 oz/yd^2	Threads/Inch Method 5050 W X F / W X C	Thickness Method 5030 in at 0.6 psi	Air Permeability Method 5450 ft^3/ft^2 min. at 0.5" w.g.	Weave Method Visual
1. Wool Frieze	15.5	See Diagrams	0.125	46.7	See Diagrams
2. Wool Frieze, Napped	13.8	See Diagrams	0.170	98.1	See Diagrams
3. Blanket, Wool	15.3	See Diagrams	0.098	64.7	Plain
4. Terry, Cotton, Low IR	8.9	62 x 32	0.077	163.0	Terry
5. Terry, Cotton, High IR	8.9	62 x 32	0.081	168.0	Terry
6. Satin, Rayon	9.9	-- --	0.045	52.9	Satin
7. Simplex Knit, Cotton, High IR	9.3	72 x 56	0.034	31.7	Simplex
8. Simplex Knit, Cotton, Low IR	9.2	72 x 56	0.034	31.4	Simplex
9. Burlap, Low IR	5.6	10 x 9	0.060	Too open	Plain
10. Birdseye, Cotton	3.9	62 x 47	0.015	228.0	See Diagrams
11. Pique Knit, Acrylic	6.6	22 x 22	0.035	354.0	Knit
12. Osnaburg, Cotton	5.8	42 x 23	0.020	226.0	Plain
13. Sateen, Nylon/Cotton	9.0	124 x 74	0.020	4.7	5 Harness Sateen
14. Knit, Nylon/Triacetate	5.3	41 x 57	0.040	191.0	Knit
15. Pile, Acrylic Fiber	9.3	21 x 19	0.072	315.0	Knit

(Continued)

TABLE A-XVII (Concluded)

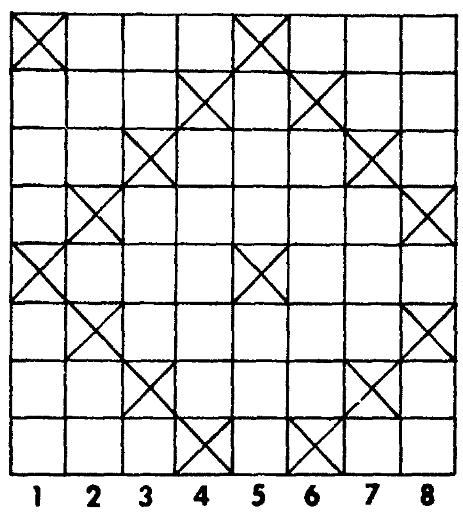
Sample No. - Cloth	Weight Method 5047 oz/yd²	Threads/Inch Method 5050 W X F W X C	Thickness Method 5030 in at 0.6 psi	Air Permeability Method 5450 ft³/ft² min. at 0.5" w.g.	Weave Method Visual
16. Pile, Alpaca	10.3	-- --	0.080	85.2	Plain/2 ends Heddled in Alternate Order
17. Corduroy, Cotton	6.5	90 x 42	0.029	28.7	15 Ribbs/Inch
18. Velveteen, Rayon	6.2	76 x 72	0.032	18.7	Velveteen
19. Uniform Twill, Cotton	7.9	116 x 55	0.018	11.5	3/1 RT
20. Sheeting, Cotton	4.3	72 x 66	0.011	49.7	Plain
21. Double Knit Polyester	7.2	26 x 46	0.044	378.0	Double Knit
22. Raschel Knit, Nylon	12.3	65 ends/inch 6 mesh/inch	0.043	Very open	Raschel Mesh
23. Corduroy, Pinwale, Cotton	6.0	92 x 38	0.024	24.4	15.5 Wales/Inch
24. Corduroy, Wide Wale	7.9	70 x 47	0.033	39.1	6 Wales/Inch
25. Waffle, Weave, Cotton	6.6	102 x 6	0.036	39.7	Waffle, repeats/ in. 3.7 x 5.7

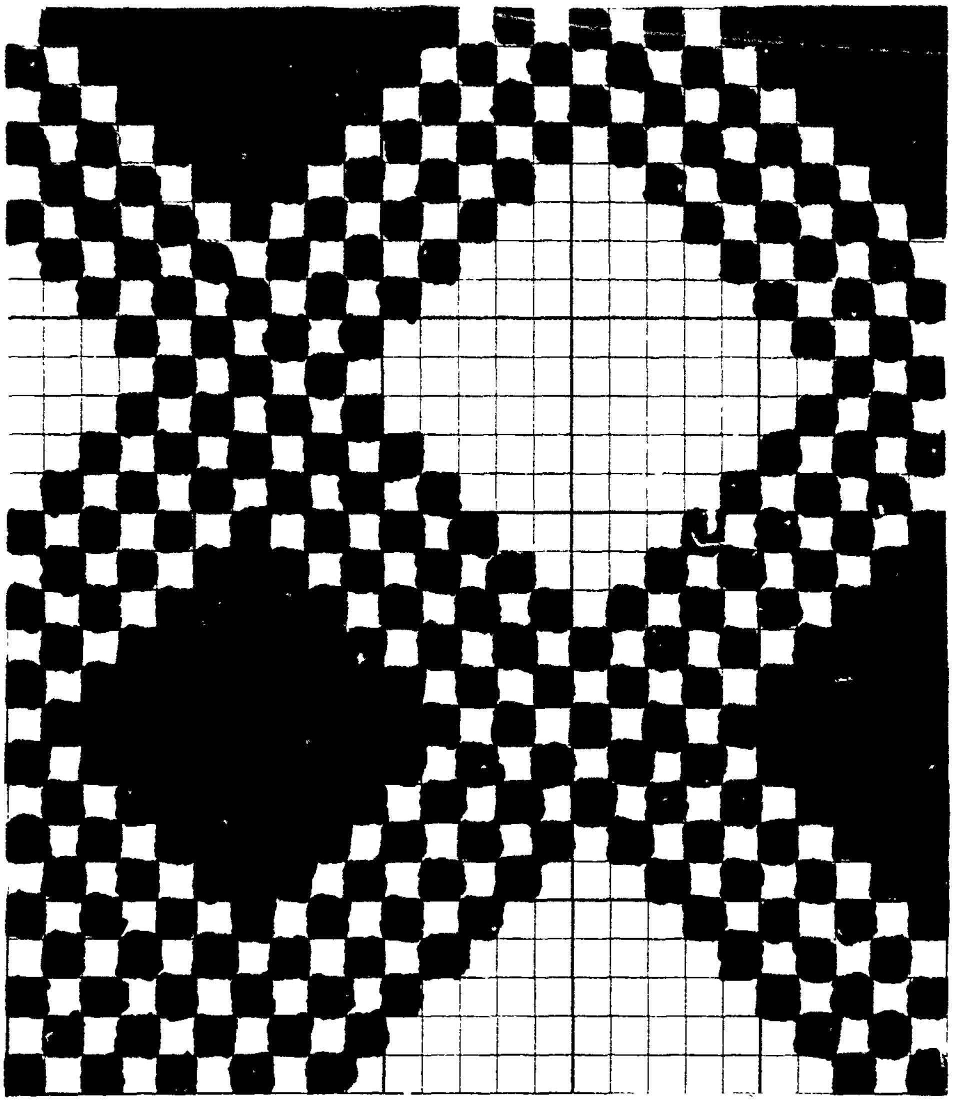
Wool Frieze, Fabrics 1 and 2



Threads/in (minimum)	
Ground warp	36
Pile warp (face)	9
Pile warp (back)	9
Filling	60

Birdseye, Fabric 10





Waffle Weave, Fabric 25

Repeats on 18 x 18
Longest warp float, 11
Longest filling float, 13

Figure A-1. Open Field

Figure A-2. Brushy Field

Figure A-3. Edge of Woods

Figure A-4. In the Woods

Figure A-5. Green Foliage

Figure A-6. Rubble

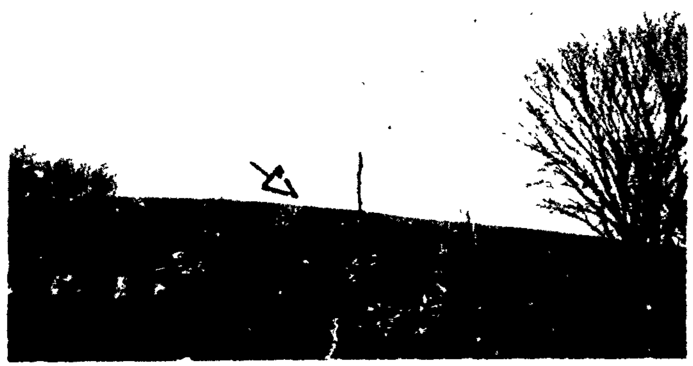


Figure A-7. Horizon

DISTRIBUTION

Copies	
1	Commandant US Army Armor School ATTN: Chief, Pol & Tng Lit Div Fort Knox, Kentucky 40121
1	Commanding Officer US Army Arctic Test Center APO Seattle, Washington 98733
1	President HQ US Army Artillery Board Fort Sill, Oklahoma 73504
2	US Army Aviation School Library Building 5313 Fort Rucker, Alabama 36362
1	Office of The Surgeon General Department of the Army Washington, DC 20314
1	President US Army Aviation Test Board Fort Rucker, Alabama 36362
1	Commanding General US Army Materiel Command ATTN: AMCRD-TC Washington, DC 20315
1	Commanding Officer US Army Coating and Chem Labs Aberdeen Proving Ground, MD 21005
1	Commanding General US Army Electronics Research & Development Laboratories ATTN: Technical Information Division Fort Monmouth, NJ 07003

DISTRIBUTION (cont'd)

Copies

Copies	
1	Director US Army Mechanics & Materials Research Center ATTN: Technical Library Watertown, Mass. 02172
1	US Army Materiel Command Research Division AMCRD-RL R&D Directorate Building T-7 Washington, D. C. 20315
1	Director of Research Labs US Army Personnel Research Office ATTN: Technical Library 2nd and T Streets, S.W. Washington, D. C. 20315
2	Commandant US Army Quartermaster School ATTN: Quartermaster Library Fort Lee, Virginia 23801
1	Commanding Officer US Army Research Office Durham ATTN: CRD-AA-IP Box CM, Lake Station Durham, N. C. 27706
1	US Army Special Warfare School ATTN: Assistant Secretary Director of Instruction Fort Bragg, N.C. 28307
1	Mr. Jack R. Ross Fibrous Materials Branch AFML-LNF Wright Patterson AFB, Ohio 45433

(Continued)

DISTRIBUTION (cont'd)

<u>Copies</u>

Copies	
1	Director Army Technical Information US Army Research Office OCRD, Room 209A Arlington, Va. 22200
2	Commanding Officer US Army Aviation Materiel Command ATTN: Technical Library P. O. Box 209 St. Louis, Mo. 63166
1	Commanding General US Army Combat Development Command ATTN: CDCMR-O Ft. Belvoir, Va. 22060
1	Commanding Officer US Army Combat Development Command ATTN: CDCQMA-F Fort Lee, Va. 23801
1	US Army Command & General Staff College Library Division Fort Leavenworth, Kansas 66027
1	Commanding General US Continental Army Command ATTN: DCSLOG, Maintenance Division Fort Monroe, Va. 23351
6	Director MERDC ATTN: Technical Document Center Ft. Belvoir, Va. 22060
2	Commanding Officer US Army Human Engineering Labs ATTN: Technical Library Aberdeen Proving Ground, Md. 21005

(Continued)

DISTRIBUTION (cont'd)

Copies

1 President
US Army Infantry Board
Fort Benning, Ga. 31905

1 The Army Library
ATTN: Procurement Section
Room 1A522, The Pentagon
Washington, D. C. 20301

1 Director
US Army Limited Warfare Laboratory
ATTN: Technical Library
Aberdeen Proving Ground, Md. 21005

1 Commanding General
US Army Test & Evaluation Command
ATTN: AMSTE-TAA
Aberdeen Proving Ground, Md. 21005

1 Director, Library
US Army War College
Carlisle Barracks
Pennsylvania 17013

1 Director
US Army Advanced Materiel Concepts Agency
Washington, D. C. 20315

1 Commanding General
US Army Materiel Command
Research, Development and Engineering Directorate
Individual Soldier Division
ATTN: AMCRD-JI
Washington, D. C. 20315

1 Commanding General
US Army Materiel Command
Director of Materiel Requirements
ATTN: AMCMR-T
Washington, D. C. 20315

(Continued)

DISTRIBUTION (cont'd)

Copies

1 Commanding General
US Army Materiel Command
Director of Materiel Requirements
ATTN: AMCMR-TA
Washington, D. C. 20315

1 Commanding General
US Army Materiel Command
Science & Technology Division
ATTN: AMCRD-TC
Washington, D. C. 20315

1 Commander
Defense Personnel Support Center
ATTN: NLABS Representative
2800 South 20th Street
Philadelphia, Pa. 19101

1 Commanding General
US Army Materiel Command
ATTN: Infantry R&D Liaison Office
Washington, D. C. 20315

1 Mr. W. Ferguson
Naval Research Laboratory
Technical Information Division
(for Code 6214)
Washington, D. C. 20370

1 Commander
Air Force Materials Laboratory (MAAE)
Wright Patterson AFB, Ohio 45433

1 Commandant of the Marine Corps
Code: A04G
Headquarters, US Marine Corps
Washington, D. C. 20380

(Continued)

DISTRIBUTION (cont'd)

Copies

1 Director
Development Center
Marine Corps Development & Ed. Command
Quantico, Va. 22134

1 Commandant of the Marine Corps
Code: AX
Headquarters, US Marine Corps
Washington, D. C. 20380

1 NASA Scientific and Technical Information Facility
ATTN: Acquisitions Branch (S-AK/DL)
P. O. Box 33
College Park, Md. 20740

1 Library of Congress
Science and Tech. Division
Washington, D. C. 20540

1 Library
Southern Marketing and Nutrition Research Division
Agricultural Research Service
US Department of Agriculture
P. O. Box 19687
New Orleans, La. 70179

1 Library
School of Textiles
North Carolina State University
P. O. Box 5006
Raleigh, N. C. 27607

2 Technical Library

3 Marine Corps Liaison Officer, NLABS

1 USA NLABS Liaison Office
ASDL-8 (Mr. Hogan)
Wright Patterson AFB, Ohio 45433

(Continued)

DISTRIBUTION (cont'd)

Copies	
1	Airdrop Engineering Laboratory, NLABS
6	Technical Editor, C&PLSEL
12	Defense Documentation Center Cameron Station Alexandria, VA 22134
1	General Equipment & Packaging Laboratory, NLABS
2	Pioneering Research Laboratory, NLABS
1	Officer in Charge Navy Clothing & Textile Research Unit US Army Natick Laboratories
1	Commanding Officer US Army Combat Development Command Combat Service Support Group Fort Lee, VA 23801

UNCLASSIFIED
Security Classification

DOCUMENT CONTROL DATA - R & D

(Security classification of title, body of abstract and indexing annotation must be entered when the overall report is classified)

1. ORIGINATING ACTIVITY *(Corporate author)* Harris Research Laboratories The Gillette Company Research Institute Rockville, MD 20850	2a. REPORT SECURITY CLASSIFICATION UNCLASSIFIED 2b. GROUP

3. REPORT TITLE
Reflectance Properties of Fabrics in Relation to Detection by a Night Vision Device

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

5. AUTHOR(S) *(First name, middle initial, last name)*
Lyman Fourt and Norman R. S. Hollies

6. REPORT DATE	7a. TOTAL NO. OF PAGES	7b. NO. OF REFS
October 1971	116	10

8a. CONTRACT OR GRANT NO. DAAG17-70-C-0201 b. PROJECT NO. 1J662708D504 c. d.	9a. ORIGINATOR'S REPORT NUMBER(S) 72-30-CE (TS-180) 9b. OTHER REPORT NO(S) *(Any other numbers that may be assigned this report)*

10. DISTRIBUTION STATEMENT
Distribution limited to US Government agencies only; proprietary information; 1 March 1971. Other requests for this document must be referred to the US Army Natick Laboratories.

11. SUPPLEMENTARY NOTES	12. SPONSORING MILITARY ACTIVITY
	US Army Natick Laboratories Natick, MA 01760

13. ABSTRACT

The directional reflectance properties and infrared reflectance properties of 25 fabrics of varied structural characteristics have been compared using the principal fabric orientations and directions of illumination and view. Detection by a night vision device, an image intensifier Model 9927 A on seven natural backgrounds in four fabric orientations has been estimated visually and measured by densitometry of photographic negatives of the fluorescent screen of the device. The chief correlations found are with the increase reflectance, gloss or sheen at high angles of reflectance (gloss or sheen from increased reflectance according to Fresnels' Law) and with general level of lightness or darkness of the fabrics in the visible and near infrared ranges. No single reflectance level can match a wide variety of backgrounds but this match can be extended by variation of pattern of reflectance level and pattern on the fabrics.

DD FORM 1 NOV 65 1473 REPLACES DD FORM 1473, 1 JAN 64, WHICH IS OBSOLETE FOR ARMY USE.

UNCLASSIFIED
Security Classification

UNCLASSIFIED
Security Classification

14 KEY WORDS	LINK A		LINK B		LINK C	
	ROLE	WT	ROLE	WT	ROLE	WT
Infrared	0					
Reflectance	8					
Detection	7		8			
Fabrics	9		9			
Visual Acuity	6					
Visual Perception	6					
Image Intensifier			10			
Densitometry			10			
Camouflage	4		4			

UNCLASSIFIED
Security Classification