WADC TECHNICAL REPORT 54-612
ASTIA DOCUMENT No. AD 110419

DEVELOPMENT OF DYEING FORMULATIONS FOR WOOL/SYNTHETIC BLENDS FOR USAF SHADE BLUE 84

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OCTOBER 1956

MATERIALS LABORATORY
CONTRACT No. AF 33(600)-16396
PROJECT No. 7320

WRIGHT AIR DEVELOPMENT CENTER
AIR RESEARCH AND DEVELOPMENT COMMAND
UNITED STATES AIR FORCE
WRIGHT-PATTERSON AIR FORCE BASE, OHIO

Carpenter Litho & Prtg. Co., Springfield, O.
500 - November 1956

FOREWORD

This report was prepared by the Lowell Technological Institute Research Foundation under U. S. Air Force Contract No. AF 33(600)-16396. The contract was initiated under Project No. 7320, "Air Force Textile Materials", Task No. 73202, "Air Force Clothing Textile Materials" (formerly, E. O. No. R602-198, "Textile Materials for Air Force Clothing"), and was administered under the direction of the Materials Laboratory, Directorate of Research, Wright Air Development Center, with Capt. R. D. Haire acting as project engineer.

The Barre Wool Combing Company dyed and blended fibers for all fabrics in accordance with specifications established by the Lowell Technological Institute Research Foundation. All the yarns and fabrics were manufactured by the Bachmann Uxbridge Worsted Company. The testing of the colorfastness and physical properties of the fabrics was performed by the Textile Testing Section of the Lowell Technological Institute Research Foundation. Mr. Roland Derby, Jr., supervised the spectrophotometric measurement of fabric color and fading.

We would like to acknowledge the cooperation and assistance offered by the following individuals and concerns in the dyestuff evaluation phase of this program: Mr. Elmer Nelson, Bachmann Uxbridge Worsted Corporation; Mr. Cyril J. Byron and Mr. John Gould, Barre Wool Combing Company; General Dyestuff Corporation; E. I. du Pont de Nemours & Company, Incorporated; National Aniline Division of Allied Chemical and Dye Corporation; Ciba Company, Sandoz Chemical Works; Textile Aniline and Chemical Company, Incorporated; and Union Carbide and Carbon Corporation.

Work under this contract was conducted during the period April 1952 to December 1954.

ABSTRACT

Dyeing formulae were developed for viscose, nylon, Dacron, Dynel, Acrilan and Orlon fibers to obtain suitable Blue Shade #84 wool/synthetic fabrics for U. S. Air Force uniforms. At the time that the development phase was terminated, no formulae were found which would give the desired colorfastness properties for Dynel and Acrilan. Consequently, these fibers were eliminated from the production phase of the project. (Subsequent developments have demonstrated that new techniques will afford adequate fastness on these fibers. However, the project had progressed to a point which precluded reconsideration of these fibers.)

A 100% wool control fabric and a series of wool/synthetic fabrics containing 10, 20, and 30% synthetic fiber were manufactured for subsequent evaluation of their physical and colorfastness properties. These fabrics were made to conform to the specifications set forth in MIL-C-849, Cloth, Wool, Serge, Blue Shade 84.

A comprehensive study of the properties of the wool and the wool/synthetic fabrics reveals that they meet the physical requirements desired and have adequate colorfastness as well as high resistance to fading.

The scope of this study was too broad to permit examination of all of the dyestuffs produced domestically or of all of the possible dyestuff combinations which conceivably would meet target properties; however, as many dyes and formulae were included as possible. Due to the rigid requirements of this investigation, many dyes and formulae were evaluated in conditions for which they were not intended. Hence, it must not be assumed that the results tabulated herein are equally valid for other test conditions or applications, nor is it to be construed that a dye or formula is not entirely satisfactory for the manufacturers intended use or advertised claims. Further, it is not to be construed that formulae other than those covered in this report cannot perform equally satisfactorily. The disclosure of dye formulae, dyeing procedures, and methods of colorimetry described herein does not constitute license for practice. The selection of a particular dye formula for producing fabric required in this project does not imply approval of the U. S. Air Force for the specific dye or formula for producing Blue Shade 84.

PUBLICATION REVIEW

This report has been reviewed and is approved.

FOR THE COMMANDER:

M. R. WHITMORE
Technical Director
Materials Laboratory
Directorate of Research

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I INTRODUCTION

The strenuous use and the interchanging of parts of military uniforms make it essential that uniform fabrics show little change in physical or color appearance after long periods of wear. In addition to its aesthetic value, color is an important functional property of a uniform fabric. The usefulness of fabrics made of blends of wool and the newer synthetic fibers would be evaluated in part by the ability of these synthetic fibers to be dyed to the same colors as the wool fibers, and have the same or a greater degree of colorfastness.

For this program, studies were made of dyeing formulae for viscose, nylon, Dacron, Orlon, Dynel, and Acrilan fibers which would permit the manufacture of a U. S. Air Force Serge Fabric, Blue Shade 84 from blends of these synthetic fibers and wool. The study established the fact that viscose, nylon, Dacron, and Orlon could be dyed with colorfastness equal to that of the wool fibers used in Blue Shade 84. When 90% wool/10% synthetic, 80% wool/20% synthetic, and 70% wool/30% synthetic fiber fabric blends were produced, their colorfastness properties were found to be equal to a 100% wool control fabric.

Before studying dyeing formulations, it was necessary first to determine the dyeing formulae to be employed for a 100% wool control fabric, since these formulae regulate the colors to which the synthetic fibers would be dyed. A primary objective of this program was to obtain dyeing formulae for the synthetic fibers so that their colorfastness properties would be equal to, or better than, the optimum colorfastness of wool.

The Lowell Technological Institute Research Foundation, under Contract No. AF 18(600)-182, had to develop a 100% wool fabric of the same type as specified for this project. This fabric was to meet the optimum colorfastness requirements of the Air Force and have a colorfastness to light of eighty or more Fadeometer hours without color change and not more than a small color change after 140 hours. Since this fabric was to be manufactured for possible use as a standard for Blue Shade 84, it was used as a reference for the comparison of the lightfastness and colorfastness of the wool/synthetic fabrics developed under this program.

Laboratory development of the depth of shade of each of the wool components was sufficient to predict approximate shades for the synthetic fiber components. Since two of the wool components were dark blue, it was believed that a single blue component -- the resultant color of the mixture of the two blue wool fibers -- would be adequate for the blue component of the synthetic fiber. This would considerably simplify blending, shade matching, and manufacturing problems by reducing the number of components in each wool/synthetic fabric from six to five. A change in the wool to synthetic fiber ratio, due to a greater loss of wool fiber by fabric wear, would not change the fabric color, because the color of the mixture of synthetic fibers would remain the same as the color of the mixture of wool fibers. The Air Force subsequently approved this procedure, to use only two synthetic fiber components, one grey equivalent to the wool grey, and one blue equaling the color of the mixture of the two blue wool fibers.

Note: "Manuscript released by authors April 1956 for publication as a WADC Technical Report.

Dyeing formulations were developed for the synthetic fibers to match the approximate colors determined from laboratory work on the wool fibers. These formulations were extensively evaluated for colorfastness. During this phase recommendations of the dyestuff manufacturers were obtained through frequent consultations.

While development of the dyeing formulations was underway, progress was made in the manufacturing of the 100% wool control fabric. However, most of the dyestuff development for the synthetic fibers was completed about six months before the final 100% wool control was accepted by the Air Force. None of the wool/synthetic fabrics could be manufactured before this control fabric was completed because all the wool and synthetic fibers in the wool/synthetic fabrics had to be dyed to the same shade as the fibers in the standard 100% wool fabric. Considerable time was required to produce the 100% wool control fabric because of the required accuracy of the color match to the available Air Force Standard fabric.

As soon as the control fabric was available, the colors of the synthetic fibers were adjusted to match the wool fibers and the manufacture of the wool/synthetic fiber blends was begun. Sufficient wool was dyed for the manufacture of all fabrics so that colorfastness of the wool portion for all fabrics would be held constant.

The concentration of effort on the color matching of the blended fabrics could not be as great as that devoted to the wool control. The color tolerance in shade matching in this case was considered to be that allowable for normal commercial delivers of fabrics to the Air Force. In producing the wool/synthetic fabrics a test fabric was first made to determine the color yield from one specific blend and the effect of finishing operations. The final fabric was manufactured after adjustments had been made to the blend which would compensate for the difference in color between the test fabric and the control fabric.

The colorfastness properties of the wool control fabric and all wool/synthetic fiber blends were extensively tested. Physical properties of the fabrics were evaluated by standard test procedures to determine conformance with specifications of the wool fabric and to evaluate the fabric properties which were markedly affected by the addition of the synthetic fiber.

Wool Fibers

The Lowell Technological Institute Research Foundation had been employed by the United States Air Force under another contract, No. AF 18(600)-182, to develop dyestuff formulations for Wool Serge Blue Shade 84. Formulae were developed under the above contract which would withstand eighty hours Fadeometer exposure without a perceptible break and 140 hours with only a moderate break in color.

These wool formulae were selected for use in the subject contract because they met optimum requirements of the Air Force.

Synthetic Fibers

Loose staple fiber was employed for all dyeing and testing during the development of dyestuff formulations, and a large sample for each fiber (except Acrilan) was obtained from one production lot. A sufficiently large sample of Acrilan could not be obtained from the manufacturer because the fiber composition was being changed continually. This limited the work on Acrilan, which was finally eliminated from the project, since a stable production fiber had not yet been developed.

The specifications for each of the fibers employed in the evaluation of the dyeing formulae are given in Table 1.

All dyeing methods which had been reported to be successful with the synthetic fibers were considered. Consultations with major dyestuff manufacturers resulted in recommendations for dyestuffs expected to yield the best colorfastness. After evaluating these recommendations the manufacturers were consulted again for suggestions to improve the results first obtained. Every possible effort was made to secure the maximum information from dyeing experts currently working in this field.

Dyestuff formulations were evaluated until the formulae of satisfactory light and wetfastness properties were discovered or until it was determined, as in the case of Dynel and Acrilan, that adequate fastness could not be obtained.

Fastness to light exposure, alkaline and acid perspiration, scouring, wet crocking, fulling, and wet dry cleaning were considered as the essential properties to be used as criteria for the selection of satisfactory formulae. When a dye or a formula gave markedly inferior results in one of these tests, it was eliminated from further consideration. Light and perspiration tests were performed first because they are the most rigorous and yield significant data most quickly. All samples having good fastness to eighty hours of Fadeometer exposure were subjected to perspiration tests, but only those showing good results after 160 hours of fading as well as good perspiration fastness were subjected to the remaining tests.

The efficiencies of the dyeing formulae were determined by visual examination and evaluation of the color changes produced by each test condition. Formulae showing good light and wetfastness properties were carefully evaluated and those formulae which met the requirements of the projects were established. Where more than one formula gave adequate results, ease of application and dyeing costs were considered in selecting the one formula to be employed in dyeing the fibers for each fabric to be manufactured.

III FIBER COLORFASTNESS TEST PROCEDURES

Lightfastness Test

The Atlas Fadeometer (3) was used to produce fading of dyestuffs. The main advantage of the Fadeometer is that twenty hours of exposure can be obtained each day while the maximum sunlight exposure is six hours. This rapidity of testing has made it the standard commercial method of testing and the only feasible technique in this project.

The operation control, and the variables of the Fadeometer are discussed in the literature (9). Such factors as the distance of the sample from the light source, the temperature of the sample and the degree of air circulation around the sample affect the rate of fading. If samples were to be tested in the tangled and lumpy form from dyeing, the variables listed above would greatly affect the fading results. It was, therefore, necessary to prepare a uniform specimen for each test in order to obtain accurate and reproducible results.

Carding the dyed fibers into a mat and mounting this mat on a test card was not satisfactory because the mat distorted when handled. Mounting a staple array of fibers was too time consuming.

The Abbott Pad Machine, which makes firmly felted pads of wool (10), was also employed in an attempt to prepare identical samples of the synthetics. Since the synthetics have poor felting properties only a soft pad of entwined fibers resulted when a dry sample was agitated under light pressure. These pads were unsatisfactory because they expanded after being placed in the Fadeometer holder and projected unevenly toward the light source. After fading, these samples could not be preserved for reference as distortion occurred in handling and the fade line disappeared.

The testing of a few specimens of hand spun yarn revealed that reproducible fading resulted when the yarns were fairly uniform in size and evenly mounted. These specimens are prepared by hand carding the dyed fibers into a thin web and hand spinning this web into a reasonably uniform yarn about one eight of an inch in diameter. Ten yarns are then mounted side by side on an open-back type of Fadeometer test card, placed in the metal Fadeometer holder, and exposed at 105°F to the light of the Fadeometer for the desired length of time. The open type holder for the specimen was used so that the temperature of the specimen remained as low as possible and so that an adequate flow of air around the specimens would be maintained.

During the first eighty hours of exposure the specimens were examined after each twenty hour period. If a large color change occurred in less than eighty hours, the color difference was evaluated at that particular time and the specimen was then eliminated from further tests. After eighty hours of exposure the color difference was measured before returning the samples for an additional eighty hours of exposure. The color difference was measured after 160 hours of

exposure and the test then discontinued. One hundred and sixty hours of Fadeometer exposure were considered sufficient for any significant change to occur.

The fastness of dyed fibers is governed by the length of time these fibers can be exposed without a color change occurring, the amount of color difference produced, and the type of color difference (that is, on-tone or off-tone fading). In this study the determination of lightfastness was based on the measurement of the color differences produced, as well as the type of color change which occurred.

Determination of the exposure time necessary to produce a change is quite difficult, and the reproducibility of the test is limited. Slight changes in the mechanical structure of the specimens caused by the pressure of the holder and the uneven distribution of twist in the yarns create visual differences which can be erroneously attributed to color changes of the dye. Furthermore, the degree of color difference necessary to be called a "break" is not a standardized value. Since the human factor is so large and the mechanical structure so critical, exposure time to a break was not considered an accurately measurable quantity. The exposure time when the first change seemed to occur was recorded as general data but was not considered a measurement of efficiency.

The Geometric Grey Scale of the Society of Dyers and Colourists was used to measure the color differences produced by light. Three independent measurements of each fading change were made and the results averaged. This average was recorded as the Color Difference Value. K. M. McLaren recently showed that this grey scale can be used for accurately assessing the changes in depth, hue, and brightness of color (7). The use and values of this scale were also discussed by this same author (8). The following table summarizes the scale values and the method of rating.

Geometric Grey Scale Values

VALUE	NUMBER OF PERCEPTIBLE COLOR STEPS	DEPTH Weak or Strong Noted After Value	HUE Hue Change Noted After Value	BRIGHTNESS Bright or Dull Noted After Value
5	0			
4	1.5			
3	3			
2	6			
1	12			
5-4	Between 0 and 1.5 (similarly for other intermediate values)			

Combined changes in hue, depth and brightness are noted in sequence after the Value.

Colorfastness Tests

Acid and alkaline perspiration fastness of dyed fibers was determined. The test cloth used was a cotton warp worsted filling fabric having floating yarns of cotton, wool, silk, acetate, viscose, staple nylon, and continuous filament nylon. Assessment of the fastness was made by measuring the color difference of treated and untreated specimens and by measuring the color transferred to the multi-fiber test cloth.

Colorfastness to fulling was determined by Test No. 2-52 of the A. A. T. C. C. employing a three hour fulling period in the Launderometer (1). Test specimens required special preparation to insure continuous contact of the dyed fibers with the multifiber test cloth. This was accomplished by sewing a quarter-section of a fiber pad prepared in the Abbott Pad Machine between two pieces of multifiber test cloth. The fastness was assessed by measurement of color transfer and color difference.

Colorfastness test Method 36-52 Test No. 3 was used to determine the fastness to laundering (2). In Test No. 3 the material is treated with a soap and soda ash solution at 160°F in a Launderometer for one hour. These conditions are more severe than those to which fabrics are subjected in commercial piece goods scouring. Piece goods are scoured with roughly the same concentration of chemicals but at a maximum temperature of 140°F. Thus, colors showing no deficiency in this test would have adequate scouring fastness. The conditions of Test No. 3 are also equal to that of commercial laundering and are more rigorous than the handwashing conditions of wool fabrics.

The test for wet dry cleaning was performed according to Government Specification CCC-T-191b. Determination of fastness was based on color loss and color transfer to the test cloth.

The specimens used in each of the above tests were prepared in the manner described for the fulling test specimens. Determination of the laundering fastness was based on the color difference of the treated sample and measurement of the color transferred to the multifiber test cloth.

The standard Crockmeter Test of the A. A. T. C. C. could not be used for the wet crocking of dyed fibers since the loose fibers could not be fixed in a rigid position for the test. Crocking was performed by hand rubbing of the wet fibers on the white test cloth of the A. A. T. C. C. (4); each sample tested was given twenty strokes. The fastness was determined by measuring the color transferred to the test cloth.

The A. A. T. C. C. Color Transference Chart was employed for measuring the color staining of the multifiber test cloth. This chart was easier to use because the standard for the chart and the test cloth is white. The resulting values can be determined rapidly and are generally reproducible.

The Society of Dyers and Colourists Geometric Grey Scale method is more difficult to employ because the basic standard of that system is a dark grey rather than white. The fact that the Munsell value increments are not defined color difference units is not a detriment to the use of this system since only the smallest degree of staining is permissible in fast colors and since it is

not required to relate color transfer to specific color difference units. When the value for the stain was found to lie between the two Munsell color chips, the results were recorded in a similar manner as the system used with the grey scale; that is, the numerical values of the two adjacent values are indicated as the range of the unknown value.

Judgment of the color change in a fabric after a wet treatment is directly related to visual color differences produced and is very critical. Since this is similar to the case of fading, the color change from wetfastness tests is measured by the Society of Dyers and Colourists Geometric Grey Scale in the manner described under lightfastness measurements. When a color change occurred on a wetfastness test, the grey scale value for the change was recorded with the staining value. The grey scale value for the change is placed below the staining results and is differentiated by the work "change".

Reproducibility of Fiber Fastness Tests

The fiber colorfastness and lightfastness test procedures must yield reproducible results since only a single test specimen was to be used as a basis for judging the properties. Reproducible results are obtained from colorfastness tests of dyed fibers only when test conditions are standardized and are duplicated for each test. Initially in this investigation, variations in results were assumed to be possible for two reasons: First, variations might result from the use of special yarn or pad test specimens devised for this investigation. This deviation from the standard colorfastness tests was necessary because the standard procedures do not provide for a satisfactory specimen of loose staple fiber. Second, the amount of variation of results caused by the slight differences in test conditions of successive tests was unknown. Tests could not all be run at the same time because of the large number of dyeings studied.

The effect of these variations on the final results was determined from the analysis of a series of repeated tests. A number of dyeing formulae having varying degrees of fastness for different fibers were subjected to duplicate wetfastness and lightfastness tests. Each repeat test was performed at a different time independent of the first test. Reproducible results would not be produced if the test conditions were not sufficiently constant.

Table 19 summarized the results obtained. Formulae specified in the table gave the same results on repeated light and wetfastness tests. These results establish the following facts:

1. Fading test results after 80 and 160 hour exposures on materials of different levels of fade resistance were reproducible even though the specimens were not tested concurrently.

2. Color transfer values for perspiration, fulling, laundering, and crocking tests of viscose, nylon, Dacron, and Orlon were identical although the specimens were not tested concurrently.

3. The level of resistance to wetfastness tests did not affect the results.

4. The depth of shade did not influence the results, since tests on the blue shades were as reproducible as those on grey shades.

Therefore, accurate judgment of the fastness properties of the fibers could be based on the results obtained by testing a single specimen of each dyeing.

Materials

Specifications for the fibers used in the fabrics are given in Table 1.

Twelve thirty-yard lengths of wool/synthetic fabrics were produced. A short test fabric of each blend was produced for color matching purposes prior to the manufacture of the specified yardages.

One twenty-yard length of 100% wool fabric was first manufactured from the wool components which were to be blended with the synthetic fibers. This fabric served as a control standard for evaluating the properties of all other fabrics, and was designated as the L. T. I. R. F. Control Fabric.

Procedure

The fibers for all fabrics were top dyed and blended in silver form. The dye formulae employed are listed in Table 2. Modifications of the laboratory percentages for the formulae were necessary in order to obtain a good match of each color component of the blend. The color of a fabric was predicted by comparing the color of pads of the wool/synthetic fiber blend to the color of a pad of the wool fibers used to manufacture the wool control fabric. The composition of the blend was always adjusted so that the proper percentage of synthetic fiber was employed and the ratio of blue to grey synthetic was equal (to the nearest one-half per cent) to the ratio of blue and grey wool fibers.

When a pad match was obtained, twenty pounds of material were blended and a test fabric was manufactured. The color of this fabric was evaluated and adjustments were made in the composition of the fiber blends to obtain a closer match of the wool control. The final thirty yards of fabric were manufactured from the corrected blend.

V FABRIC EVALUATION PROCEDURES

Fiber Composition

After manufacture each fabric was analyzed by chemical techniques to determine the percentage composition of the fibers present in the fabric. At least two determinations were made on each fabric. The specific methods used for analysis of the different fiber blends are described in Table 4.

Color

The color of each fabric manufactured was measured by a General Electric Recording Spectrophotometer. The measurements were made using MgO as a reference standard for whiteness. Four color measurements were made on each fabric, and the values reported were the mean value of these four measurements. The color of each fabric blend was measured immediately after the colors of the U. S. Air Force Standard Fabric and the L. T. I. R. F. Control Fabric were measured.

The trichromatic coefficients (Color Coordinates) were calculated from the spectrophotometric reflectance data. The colors of the various fabrics and the degree and direction of variation from both the U. S. Air Force Standard and the L. T. I. R. F. Control Fabric are shown by plotting the Trichromatic Coefficients in Chromaticity Diagrams. Color differences of 2.5 MacAdams ellipses (6) are plotted for the U. S. Air Force Standard and the L. T. I. R. F. Control Fabric.

Colorfastness

Colorfastness properties of all fabrics were evaluated using standard testing procedures. The test methods employed are described in Table 8.

Although the lightfastness test was performed in accordance with standard procedures, additional fading data were obtained with the General Electric Recording Spectrophotometer. The color reflectance of faded and unfaded samples was measured and the color difference was then calculated by the Adam's Color Difference formula (5). The spectrophotometric measurements were then used to show graphically fading by plotting color coordinates of exposed and unexposed samples. Through this means the amount of fade and the degree of variation from an on-tone fade can be seen.

A discussion of the theory and interpretation of the spectrophotometric measurements of color differences produced by fading is presented in the appendix of this report.

Physical Properties

The physical properties of the fabrics were tested in accordance with standard procedures with specific procedures described in Table 9. Tests of the fabrics outlined in Military Specification MIL-C-849 were performed in accordance with Specification CCC-T-191.

VI RESULTS AND DISCUSSION

Selection of Dye Formulations

Wool

Dyeing formulations for the wool fibers were developed under Contract No. AF 18(600)-182. The three dyeing formulae, two blue shades and one grey shade, are given in Table No. 2.

The fastness properties of each of the components are presented in Table 20. These results reveal that the components show little color change after 160 hours of exposure to light in the Fadeometer and that the fastness to all wet test procedure was excellent.

Amounts of wool fibers sufficient for the manufacture of all fabrics were dyed in top form with the formulae listed in Table 2. The manufacturer experienced no difficulty when applying these dyes in production equipment.

Viscose

Tables 21 and 22 show that fastness properties of a number of Vat dyeing formulae were excellent. All the viscose dyestuff formulae studied are tabulated in Table 33. Formulae Nos. 1-9 meet the established requirement for both light and wetfastness. Tests of formulae for both the blue and grey shades revealed only slight color changes after 160 hours of Fadeometer exposure and indicated complete resistance to the wetfastness treatments.

Formulae 1-4 are all suitable for dyeing the blue shade of viscose. No. 1 was finally selected because it appeared to be slightly less expensive than 2 or 3 and appreciably less than 4.

Formulae 5, 6, 7, and 9 for the grey shade were all suitable and comparable in price but 5 and 6 are somewhat more level dyeing and easier to use in top dyeing viscose. Nos. 5 and 6 are reported as being equal. No. 8 is very easy to dye but it is considerably more expensive than the others.

Several aftertreated direct dye formulae were tried (Nos. 10-14) in attempts to find less expensive dyeing processes. However, none of these was found to be successful. The grey shades did not possess sufficient fastness to light to meet requirements. Although Formula 14 for the blue shade shows just sufficient fastness, difficulty was encountered in removing surface deposits of dye from the fibers when dyed under production conditions. This could produce serious lowering of the fastness to crocking of the final fabric.

Dyeing was performed in a top dyeing machine. No difficulty was experienced during the production dyeings with these formulae. Adjustments had to be made to the laboratory percentages of dyes in order to produce the correct shade because machine dyeing conditions do not duplicate laboratory

conditions. Differences in volume ratios, circulation, and temperatures always produce some difference in color yields. When the fibers and dyes have very high affinity for one another these differences are quite small; when the affinity is low large differences result. In this case, the affinity was moderate, so appreciable, but not excessive, adjustment was necessary.

Nylon

The neutral dyeing type of premetallized dyes was selected for dyeing both the blue and grey shades of nylon fibers for the following reasons:

1. Ability to meet the fastness requirements - they are equal or better than any other dyes for these shades.

2. Ease of application and level dyeing qualities.

3. The adequate number of dyes in this class and their rapid acceptance by the dyers.

The above facts were considered to be more important than the moderately greater costs of these dyes.

Dyestuff formulae for nylon are given in Table 34. Formula No. 26 was selected for dyeing nylon to the blue shade, since the fastness properties reported in Tables 23 and 24 show it meets both light and wetfastness requirements. Formulae No. 21 and 24 could be considered as alternates. No. 21, a chrome formula, is somewhat difficult to chrome and harshens the fiber slightly. No. 24, an acid formula, has good fastness but may not be sufficiently fast to scouring and, therefore, could cause staining of the wool fibers when finishing the fabric.

Formulae 35, 36, 37, and 39 have equal colorfastness and are all suitable for the grey shade of nylon. They all show a distinct color change after 160 hours but the change is on-tone and is not any greater than the change encountered in the grey wool component. The colorfastness test results are presented in Tables 23 and 24.

Formula No. 38 was superior in fastness but had to be eliminated because of a very great change in shade when viewed in artifical light.

Nylon was dyed in top form employing No. 39 and no difficulty was experienced by the mill. Since the affinity of the dyes for nylon is very high, adjustments of the laboratory percentages of dyes were small.

Dacron

It was found necessary to use pressure dyeing to attain both adequate wetfastness and lightfastness on Dacron. This technique is a commercially acceptable one since many manufacturers have pressure dyeing machines.

Only one blue dyestuff, Eastman Fast Blue GLF, was found to yield adequate fastness in dyeing Dacron. Thus, both the blue and grey shades of Dacron had to be based on this dyestuff. The resultant properties of the dyed Dacron, however, are remarkably good. Both the blue shade and the grey shade show only a very slight color change after 160 hours of light exposure, and they have complete resistance to wetfastness test conditions.

Formulae for dyeing Dacron are given in Table 35. Tables 25 and 26 give the fastness results obtained. Formulae No. 51, 58, 59, 75, and 76 gave the high degrees of fastness. These results show that only one blue dyestuff was found to possess adequate fastness but that several red and yellow dyes were found to have satisfactory fastness. Therefore, the blue shade of Dacron can be obtained by any combination of the red, yellow, and blue components listed below:

Blue Dye	Red Dyes	Yellow Dyes
Eastman Fast Blue GLF	Cibacete Red 3B	Cibacete Yellow GLN
	Celanthrene Cerise B	Celanthrene Fast Yellow GL conc 300%
	Eastman Fast Red GLF	
		Latyl Orange R

Formula No. 67 for the grey shade has very high fastness and was selected for use. This formula gives only a slight fade after 160 hours light exposure and has excellent wetfastness properties.

The only difficulty encountered in the mill dyeings was the adjustment of the percentages of dyes required to secure the correct shade. Although the adjustments for the blue shade are large, they are not inherent faults or disadvantages of the dyes themselves. As explained for the viscose formulae, when the dye affinity of a fiber such as Dacron is low, large dye percentage differences are necessary to compensate for differences between laboratory and machine dyeing. Here the differences in color yields are also increased because the differences in volume ratios and liquor circulation of laboratory and machine pressure dyeing equipment are greater than in the case of non-pressure dyeing equipment.

Orlon

Work was carried out with two types of Orlon, Type 41 and Type 42. This was due to the marketing of Type 42 as a replacement for 41 before the Orlon fabrics of this project had been manufactured. The substitution of the new type of Orlon occurred after considerable dyeing experimentation had been performed on Type 41. A second dyeing investigation was carried out using Type 42 since this fiber was the logical one to employ in the manufacture of the fabrics.

Dyeing formulae investigated for Type 41 Orlon are listed in Table 36. The fastness properties of the dyeings are presented in Tables 27 and 28. It was found that selected formulae dyed by Cuprous Ion method at high temperatures gave excellent fastness results.

Dyeing development of Orlon 42 was carried out immediately after the fiber was marketed and, therefore, there was little available knowledge of its dyeing characteristics. The most important fact available, however, was that wetfastness properties (particularly perspiration) of dyed fiber were not better than those of the Type 41 fiber. This indicated the Cuprous Ion technique at high temperature would be necessary since it was previously found that very high degrees of lightfastness and adequate wetfastness could be obtained by this technique. The formulae tested are listed in Table No. 39. Formulae No. 151, 153, and 162 for the blue shade and 170, 171, 174 for the grey shade showed little or no color change after 80 hours Fadeometer exposure and only a small change after 160 hours. Formulae No. 150, 154, and 160 were also very fast but they did show a perceptible break in color after 80 hours Fadeometer exposure. Only a little increase in color change developed on exposure to 160 hours. Formula 162 for blue and formula 174 for grey were finally adopted for the production.

In dyeing the fibers for the final fabric, adjustments were made in the laboratory percentage of dyes to compensate for differences between laboratory and machine dyeing conditions for the reasons previously described for Dacron. Formula No. 153 which contains Pontocyl Navy Blue M4B was attempted in the first machine dyeings. This formula proved unsatisfactory and was discarded because it was found that the blue dye decomposed during the dyeing.

Dynel

It was not possible to dye Dynel to the desired degree of fastness because the necessary degree of wetfastness combined with good lightfastness could not be obtained by any formula for the blue shade. The formulae tested are listed in Table 37, and the properties of these dye formulae are given in Tables 29 and 30. The formulae tested are all that offered any chance of success. No further recommendations or dyes likely to give better results could be obtained from the dyestuff manufacturers.

The Air Force was informed of this condition, and Dynel was subsequently eliminated from all further consideration in the project.

After Dynel had been eliminated from the contract, Union Carbide and Carbon produced dope dyed fibers (colorspun) matching the grey and blue components used in this project. These fibers possessed the fastness required by the project, and their availability was brought to the attention of the Air Force. However, time did not permit reconsideration of dope dyed Dynel in this program.

Acrilan

Acrilan was also eliminated from this project during the dye evaluation phase of the program. Two facts were responsible for this decision. First, no production sample of Acrilan could be obtained from the producer because the company was constantly changing the fiber polymer. The company stated

that they did not wish to submit a sample knowing that a different fiber was being planned for the next batch to be manufactured. Second, the experimental dyeing using small lots of experimental Acrilan indicated that the wetfastness properties of the blue shade of the experimental fiber were inadequate.

The formulae tested for the experimental Acrilan (a type now obsolete) are given in Table 38, and their fastness properties are presented in Tables 31 and 32.

Fabric Properties

Fiber Composition

The composition of the fabrics was regulated by carefully controlling the fiber composition of the blend. Every effort was made to maintain fiber percentages within one per cent of the specified quantity. Since processing of the blends into fabric changes the fiber composition, it was not possible to control the percentage composition by means of chemical analysis unless a correction factor could be obtained from the manufacture of successive test lengths of each fabric blend. This would be an expensive and time consuming procedure.

To establish the exact fiber composition each final fabric was analyzed for fiber composition by standard chemical techniques. The methods used are described in Table 4. At least two specimens were analyzed for each fabric and the mean value reported. The results obtained in the analysis are presented in Table 5. These results show that with the exception of two fabrics the compositions were controlled to within 0.4 per cent of amounts specified. The 30% Orlon fabric was 0.8% less and the 20% nylon was 1.2% less than the amount specified for the synthetic. Only one fabric exceeded the desired 1% limit. The individual measurements show only small variations from the mean values.

Fabric Color

Control of manufacture of the various fabrics to achieve a good color match of the wool control was of primary importance in this program. It was without doubt the most difficult phase. Actually the production of an exact match is probably impossible because the exact surface structure of the 100% wool fabric cannot be reproduced in the wool/synthetic blends. In addition, the difference in the light absorbing and reflecting qualities of the synthetic fibers from those of wool (such as luster and opaqueness) creates visual color differences in the fabrics which probably cannot be completely eliminated.

Therefore, the problem of producing fabric blends of wool and synthetic fibers to closely match wool standards is very difficult. The control of the color is more difficult than in the 100% wool fabric because each of the blends reacts differently to such finishing processes as fulling, crabbing, and decating. It was not possible to manufacture a series of blanket fabrics as was done with wool before producing the final fabric because of the large number of fabrics involved in the process. Since the wool/synthetic fabrics are essentially experimental, a greater degree of color difference from the standard could be tolerated than with the 100% wool fabric. Under the conditions of the project it was only possible to manufacture one test blanket for

each blend, evaluate its color and adjust the blending percentage to give a better match of the standards. This procedure was subject to the possibility that the adjustments would prove too great, and would mean that the colors of the final fabric and the blanket could vary in different directions from the standard. Since a second blanket could not be made, and no bracketing of the adjustments could be obtained, the problem was therefore to make corrections without overcorrecting. In order to accomplish this, both the U. S. Air Force Wool Standard and the L. T. I. Wool Control were used as color references and considerable effort was expended to make the hue and depth of the blends lie between these wool standards. If both hue and depth were satisfactory, an excellent color match would be obtained. If one of these factors varied only slightly from the desired limits, a good match would still be obtained. Two criteria were used in this project for color acceptability. First, any material whose color fell within or close to a 2.5 MacAdams color elipse of the standards was considered good. Second, materials which by visual examination were judged to be within acceptable tolerances for production lots of Blue 84 were considered to be good matches.

Because exact color tolerance limits for acceptability are not known for either spectrophotometric measurements or for visual judgements, reporting of the color evaluation for the fabric blends cannot be specific. Quantitative color data for each of the fabrics were obtained from spectrophotometric measurements. The resulting Trichomatic Coefficients are presented in Table 3 and shown graphically in Figures 2 through 5. These results, however, cannot be used to state whether or not any of the fabrics would fall beyond production color tolerances. Such a conclusion must be made by visual examination of the materials by an Air Force official normally making such judgments.

However, limited judgments have been made to classify the color properties of as many of the blends as possible. The following fabrics, on the basis of spectrophotometric measurements and visual examinations, appear to be good color matches and to lie well within production color tolerances: 10% Viscose, 20% Viscose, 30% Viscose, 10% Nylon, 30% Nylon, 10% Dacron, 20% Dacron, and 10% Orlon fabrics. The 30% Dacron and the 20% Orlon fabrics were visually judged to be acceptable matches. On the basis of visual observation, the 20% nylon and the 30% Orlon fabrics were most different in color from the standard. These were not considered to be very good matches and were judged as probably lying just within acceptability limits. Spectrophotometric measurements did not help to resolve the question because, although the 20% nylon fabric is a little further from the wool control fabric, its visual appearance is better than that of the 30% Orlon fabric.

Lightfastness

The 100% wool control and the wool/synthetic fabrics resistance to fading by light were tested by 80 and 140 hours exposures in an Atlas Fadeometer. Fastness to light was evaluated by visual estimation of the exposure time required to produce a perceptible break in color and by computing the color differences between exposed and unexposed fabrics from the spectrophotometric measurements of fabric colors. Description of the test methods and the evaluation are given in Table 8.

The results of the fading tests are presented in Table 10. They establish the fact that the wool fabric and all synthetic fiber blends have very great resistance to fading. The data show that all fabrics can be exposed to 140 hours of Fadeometer light before a clearly distinguishable break in color is reached. This is based on the fact that the observer making the visual examination did not find a perceptible color break below 140 hours and that the largest color difference value obtained was 1.1. Color difference below 1.0 could not be seen and even those between 1.0 and 1.5 cannot be judged very reliably.

The fabrics developed under this project were found to be markedly superior to the Air Force wool standard for Shade Blue 84 because this standard when tested at the same time as the LTIRF fabrics had a perceptible color break at 60 hours and color difference values of 1.7 at 80 hours and 2.5 at 140 hours, indicating that the standard faded considerably more after 80 hours Fadeometer exposure than the LTIRF fabrics faded after 140 hours.

The fading of color of the fabrics is shown graphically by plotting the Trichromatic Coefficients of faded and unfaded samples in Figures 6 through 11. These results show the direction of fade as well as the amount of fading. The marked difference between the fading of the U.S.A.F. Standard and the LTIRF fabrics can be seen in these figures. Some fabrics appear to fade off-tone (not a perceptible amount) but this is believed to be due to contamination of the sample by handling rather than a true off-tone fade. There are two reasons for this opinion. First, fading for long exposure (140 hours) produces much less off-tone fading than short exposures. The color differences at 80 hours are so small that small amounts of contamination would show up more markedly than after 140 hours exposure where the color difference is a little larger. Second, nylon fabrics exhibited a tendency to fade off-tone but when exposed for periods exceeding 160 calibrated hours the fade was on-tone. This is shown in Figure 11, which is a plot of nylon samples run 160 hours when the Fadeometer was not calibrated. This 160 hours is appreciably greater than 160 calibrated hours.

Therefore, it may be concluded that all LTIRF fabrics produce a perceptible color change only after 140 hours of Fadeometer exposure and that they either fade on-tone or that the fade is too small to be judged for hue changes.

Colorfastness

Descriptions of the colorfastness tests to evaluate the fabric properties are presented in Table 8. The colorfastness tests for dry cleaning, crocking, and perspiration which are specified in Military Specification MIL-C-849, USAF Wool Serge Shade Blue 84, were performed in accordance with Specification CCC-T-191. However, additional tests were performed to provide more comprehensive information about the final colorfastness properties.

The results of all colorfastness tests are presented in Tables 11 through 14. They show that all fabrics have excellent wetfastness properties and that the fabrics would satisfy the military requirements established for wool type military uniform fabrics.

The only test results which were not of the highest ratings were the crocking tests for the wool, the 10% nylon, the 20% Viscose and the 30% Viscose fabrics, and the 120°F laundering tests for the 20% and 30% nylon fabrics. The fair rating of the crocking test, which indicates a very small amount of staining of the test cloth, can be attributed to the presence of fabric scouring. Since this pigment was removed from most of the fabrics, the crocking test results indicate small differences which may occur in scouring efficiency. The amount of pigment present is small because the dry cleaning and laundering tests indicate no loss of color or staining of the test fabrics. The amount of staining in the crocking test is not sufficient to lower the fabric quality.

Slight and moderate staining in the 120°F wash test for the 20% and 30% nylon fabrics, respectively, does not detract from the fabric quality as these test conditions are more rigorous than any which the fabric would be exposed to in use. Even if the fabrics were washed instead of dry cleaned, the washing temperature would not exceed 100°F. Since only nylon fibers were stained, however, these fabrics could be washed even at 120°F without serious difficulty.

In view of some existing opinions concerning poor colorfastness of synthetic fibers in steam pressing, a very strenuous steam pressing test was employed. Although a sixty pound steam pressure was employed to simulate commercial dry-cleaning practices, all fabrics gave the highest rating of fastness to this test.

Attempts made to evaluate color changes due to abrasion were unsuccessful and had to be eliminated from the evaluation of colorfastness properties. The difficulty in this evaluation was due to the fact that abrasion tests produced a modification of the physical structure of the fabric (Cutting marks by abrasives) which were far more prominent than color changes. This condition was similar to one where an observer tries to judge colors of two entirely different styles of fabric. Under these conditions, color change evaluations would be entirely unreliable, and would reflect the extent of physical damage to the fabric due to abrasion rather than the color changes due to the loss of fiber from abrasion. From the results of visual observations it can be stated that the color changes were believed to be relatively small and that they were much less than the change in appearance due to change in the physical structure of the fabric.

Physical Properties

The test results obtained in the evaluation of the physical properties of all fabrics produced under this contract are presented in Tables 15 through 18. The test methods employed to evaluate the physical properties are described in Table 9. The following properties for Wool Serge Shade Blue 84 specified in Military Specification MIL-C-849 were performed in accordance with Specification CCC-T-191: ends and picks, weight, breaking strength, shrinkage in sponging, and pH of water extract of fabric.

The results of the above tests conform, with but two exceptions, to the limits or minimum requirements specified by MIL-C-849. Although the wool fabric has a warp shrinkage 0.62% greater than the specification value, this

is considered to be insignificant. The wool fabric also has three picks per inch less than is specified. Small variations in ends and picks also exist in some of the wool/synthetic fabrics. The length of fulling time for these materials was based upon the resultant hand of the fabric rather than the number of ends and picks since excessive fulling would produce a harsh stiff fabric.

Only a general comparison of the physical properties of the synthetic fiber blend fabrics to those of the 100% wool fabric can be made. The different blends process differently and result in fabrics of somewhat different physical structures. Therefore, test results which are only slightly different cannot be considered significant. However, the results described below are considered to indicate significant differences in the performance of the blended fabrics as compared to the wool fabric.

Breaking Strength and Tear Strength - Nylon and Dacron fabrics had considerably greater breaking strength and tear strengths than the wool control. Viscose and Orlon fabrics appear to be slightly weaker in breaking strength tests but about the same as wool in the tear strength tests.

Shrinkage in Sponging - All of the synthetic fiber fabrics gave less shrinkage in the sponging tests than the wool. The Orlon fabrics results, however, were only slightly less than the wool.

Crease Recovery - No marked difference in crease recovery was shown by any of the fabrics.

Abrasion Resistance - The nylon and the Dacron fabrics showed greater resistance to both flex and surface abrasion than the wool fabric. The Viscose and Orlon fabrics resistance to abrasion cannot be considered to be significantly different from that of the wool fabric. Viscose gave small increases in the flex abrasion test but gave slightly decreasing values on the surface abrasion test. Results for Orlon were the reverse of the Viscose. Since the changes are relatively small and not in the same direction for the two tests, the Orlon and Viscose fabric results are not considered significantly different from those of the wool fabric.

Pilling Properties - Although the pilling test period was five times as great as that outlined in Specification CCC-T-191b, there was no evidence of pilling on any of the wool/synthetic fabrics.

TABLE 1

FIBER SPECIFICATIONS

Fibers Used for Evaluation of Dyeing Formulae

Wool	-	64's Grade
Viscose	-	5-1/2 Denier, 3-1/2 Inch Staple, Dull Crimped Staple
Nylon	-	3 Denier, 2-1/2 Inch Staple, Semi-Dull, Type 200
Dacron	-	3 Denier, 2-1/2 Inch Staple, Semi-Dull, Type 5400
Orlon	-	Type 41, 3 Denier, 2-1/2 Inch Staple, Semi-Dull
	-	Type 42, 3 Denier, 2-1/2 Inch Staple, Semi-Dull
Dynel	-	3 Denier, 4 Inch Staple
Acrilan	-	Two lots of Staple Fiber were employed, both are now obsolete.

Fibers Used in the Manufacture of Final Production Fabrics

Wool	-	64's Grade
Viscose	-	5-1/2 Denier, 3-1/2 to 5 Inch Staple, Semi-Dull
Nylon	-	3 Denier, 4-1/2 Inch Staple, Semi-Dull, Type 200
Dacron	-	3 Denier, 3 to 4-1/2 Inch Staple, Semi-Dull, Type 5400
Orlon	-	3 Denier, 4-1/2 Inch Staple, Semi-Dull, Type 42

TABLE 2

DYE FORMULATIONS FOR FINAL FABRICS

Wool

Shade	Laboratory Formula %	Production Formula %	Dyestuff
Primary No. 1 Blue	2.5	5.0	Helindon Blue B (C.I. 1177) or Algosol Blue O (C.I. 1178)
Primary No. 2 Blue	2.1	2.2	Acid Chrome Blue RRA (Pr. 7)
Primary No. 3 Grey	0.315	0.320	Alizarine Light Grey BBLW (Pr. 206)
	0.080	0.067	Anthraquinone Violet 3RA (C.I. 1080)
		Nylon	
Grey	0.70	0.80	Cibalan Grey BL
Blue	3.00	3.0	Capracyl Blue G
	0.03	0.05	Capracyl Orange R
		Viscose	
Grey	0.25	0.35	Carbanthrene Violet BNX Paste C.I. 1163
	0.75	0.50	Carbanthrene Blue BCF Dbl. Flakes C.I. 1113
	1.00	0.76	Ponsol Olive ARD Dbl. Paste C.I. 1150
Blue	3.00	1.6	Indanthrene Direct Black RBA Paste Pr. 289
	1.5	1.5	Indanthrene Navy Blue BRP Paste C.I. 1100
	2.5	0.8	Indanthrene Blue BFP Dbl. Paste C.I. 1113

TABLE 2 (continued)

DYE FORMULATIONS FOR FINAL FABRICS

Dacron

Shade	Laboratory Formula %	Production Formula %	Dyestuff
Grey	0.72	0.64	Eastman Fast Blue GLF
	0.18	0.17	Latyl Red B
	0.13	0.10	Celanthrene Fast Yellow GL Conc., 300% (Pr. 534)
	-	0.10	Latyl Violet BN
Blue	6.5	5.76	Eastman Fast Blue GLF
	-	2.12	Celanthrene Cerise B
			or
	1.4	-	Cibacete Red 3B Pr. 234
	3.0	-	Cibacete Yellow GLN (Pr. 537)
			or
	-	0.44	Celanthrene Fast Yellow GL Conc., 300% (Pr. 534)
	-	0.08	Latyl Orange R

Orlon

Grey	0.60	0.54	Alizarine Fast Grey BLN New CF (Pr. 206)
	0.12	0.11	Anthraquinone Violet 3RA (C.I. 1030)
Blue	1.2	0.26	Anthraquinone Blue B (C.I. 1054)
	1.3	0.009	Anthraquinone Violet 3RA (C.I. 1080)
	0.75	0.19	Fast Sulphon Black NB Conc., (C.I. 304)

TABLE 3

SPECTROPHOTOMETRIC MEASUREMENTS OF WOOL/SYNTHETIC FABRICS

Fabric	Trichromatic Coefficients Color Coordinates x	y	Y
U. S. A. F. Standard Fabric	.2623	.2540	.0469
LTIRF 100% Wool Fabric	.2619	.2525	.0464
Wool/Viscose Blends			
10% Viscose	.2620	.2525	.0445
20% Viscose	.2625	.2525	.0426
30% Viscose	.2614	.2504	.0428
Wool/Nylon Blends			
10% Nylon	.2616	.2526	.0439
20% Nylon	.2581	.2478	.0430
30% Nylon	.2596	.2505	.0463
Wool/Dacron Blends			
10% Dacron	.2641	.2544	.0450
20% Dacron	.2645	.2547	.0448
30% Dacron	.2648	.2576	.0466
Wool/Orlon Blends			
10% Orlon	.2645	.2558	.0466
20% Orlon	.2640	.2565	.0464
30% Orlon	.2645	.2564	.0466

TABLE 4

TEST METHODS FOR QUANTITATIVE ANALYSIS OF FIBER CONTENT

Standard test methods of the American Association of Textile Chemists and Colorists were employed to determine the percentage fiber composition of each blend. The analyses were performed in accordance with Test Method 20-53, described in the 1953 Technical Manual and Yearbook of the American Association of Textile Chemists and Colorists. The results reported are the mean of two determinations.

1. Wool/Viscose Fabrics - 5% NaClO Test Method
2. Wool/Nylon Fabrics - 5% NaOH Test Method
3. Wool/Dacron Fabrics - 5% NaClO Test Method
4. Wool/Orlon Fabrics - 5% NaClO Test Method

TABLE 5

FIBER CONTENT ANALYSIS OF WOOL/SYNTHETIC FABRIC

Fabric	Standard Regain Basis		Bone Dry Basis	
	% Synthetic	% Wool	% Synthetic	% Wool
Wool/Viscose Blends				
10% Viscose	10.3	89.7	10.7	89.3
20% Viscose	20.1	79.9	20.4	79.6
30% Viscose	29.9	70.1	30.4	69.7
Wool/Nylon Blends				
10% Nylon	10.2	89.8	11.0	89.0
20% Nylon	18.8	81.2	22.0	78.0
30% Nylon	29.8	70.2	31.5	68.5
Wool/Dacron Blends				
10% Dacron	10.0	90.0	11.0	89.0
20% Dacron	19.8	88.02	21.7	78.3
30% Dacron	29.6	70.4	32.0	68.0
Wool/Orlon Blends				
10% Orlon	10.3	89.7	11.4	88.6
20% Orlon	20.3	79.7	22.1	77.9
30% Orlon	29.2	70.8	31.8	68.2

TABLE 6

DYED FIBER COMPONENTS IN FINAL LTIRF FABRICS

Fabrics	Percentage Compositions: Wool Primary No. 1 Indigo	Wool Primary No. 2 Blue RRA	Wool Primary No. 3 Grey	Grey Synthetic	Blue Synthetic
100% Wool Control	33	35	32	-	-
Wool/Viscose Blends					
10% Viscose	30	27-1/2	32-1/2	3	7
20% Viscose	26-1/2	25	28-1/2	6	14
30% Viscose	24-1/2	20	25-1/2	9	21
Wool/Nylon Blends					
10% Nylon	30	28	32	3	7
20% Nylon	29	22	29	6	14
30% Nylon	24	16	30	9	21
Wool/Dacron Blends					
10% Dacron	21-1/2	35	33-1/2	4	6
20% Dacron	16-1/2	31-1/2	32	8	12
30% Dacron	11-1/2	27-1/2	31	12	18
Wool/Orlon Blends					
10% Orlon	23	34	33	3	7
20% Orlon	19-1/2	31	29-1/2	6	14
30% Orlon	17	27	26	9	21

TABLE 7

DYED FIBER COMPONENTS IN EXPERIMENTAL BLANKET FABRICS

Fabrics	Percentage Composition: Wool Primary No. 1 Indigo	Wool Primary No. 2 Blue RRA	Wool Primary No. 3 Grey	Grey Synthetic	Blue Synthetic
100% Wool Control	33	35	32	-	-
Wool/Viscose Blends					
10% Viscose	33	28	29	3	7
20% Viscose	30	25	25	6	14
30% Viscose	26	22	22	9	21
Wool/Nylon Blends					
10% Nylon	26	28	36	4	6
20% Nylon	23	25	32	8	12
30% Nylon	20	22	28	12	18
Wool/Dacron Blends					
10% Dacron	23	33	34	3	7
20% Dacron	20	31	29	6	14
30% Dacron	15	28	27	9	21
Wool/Orlon Blends					
10% Orlon	23	34	33	4	6
20% Orlon	20-1/2	31	28	9	11
30% Orlon	18	28-1/2	24	11	19

TABLE 8

COLORFASTNESS TEST PROCEDURES

Colorfastness to Light - Colorfastness to light was performed in accordance with Specification CCC-T-191.

Specimens, mounted in an open back type of holder, were exposed in an Atlas FDR-A Fadeometer for 80 and 140 hour periods. Temperature was regulated to 110°F. Standard fading paper supplied by the Bureau of Standards was used to calibrate exposure hours.

Visual examination and Spectrophotometric measurements of color changes were used to evaluate the results of fading. Specimens were examined after each 20 hours of exposure. The exposure time required to produce a perceptible break was judged by an operator who regularly performs this work for industrial projects of the Testing Division of the L.T.I Research Foundation.

Colorfastness to Laundering - The fabric was subjected to the following two tests:

a. Specification CCC-T-191b, Method 5614 (100°F).

b. AATCC Standard Test Method 36-52, Test 2; Temperature 120°F.

Colorfastness to Crocking - Wet and Dry Tests were performed in accordance with Specification CCC-T-191b, Method 5650. The results are:

Good - No appreciable staining of the wet white multifiber test cloth.

Fair - Appreciable staining of wet white multifiber test cloth but no appreciable staining of dry white multifiber test cloth.

Colorfastness to Perspiration - Acid and Alkali Perspiration Tests were made in accordance with Specification CCC-T-191b, Test Method 5682. A rating of "good" indicates no change in shade of the test specimen, no migration of color, and no staining of white multifiber test cloth.

Colorfastness to Dry Cleaning -

a. Dry cleaning tests were made in accordance with Specification CCC-T-191a, Method 5620. A rating of "good" indicates no change in shade, migration of color, and no staining of multifiber test cloth.

b. Dry and Wet Dry Cleaning Tests were made in accordance with Commercial Standard CS59-44. Class 4 shows no appreciable staining of the composite test fabric.

TABLE 8 (Continued)

COLORFASTNESS TEST METHOD

Colorfastness to Hot Pressing - Colorfastness to hot pressing was made in accordance with Specification CCC-T-191b, Test Method 5640, except that pressing was performed with a steam press at 60 pounds pressure. Both Wet and Dry Tests were performed. A Class 4 rating shows no appreciable change in color and no staining of composite test fabric.

TABLE 9

PHYSICAL TEST PROCEDURES

Ends and Picks per Inch - These were determined in accordance with Specification CCC-T-191b, Method 5050. The results are the means of two count determinations.

Weight Determination - 72 square inches of material was weighed on analytical balance. Fabric weight in oz/yd^2 was calculated from this determination.

Air Permeability - Air permeability tests were made in accordance with Specification CCC-T-191b, Test Method 5450.

Breaking Strength - Tests were performed in accordance with Specification CCC-T-191b, Test Method 5100, Grab Method. The results reported are the mean values for five warp and five filling tests.

Tear Strength - Tear strength measurements were made in accordance with Specification CCC-T-191b, Test Method 5134, Tongue Method. The results reported are the mean values for five warp and five filling tests.

Shrinkage in Dry Cleaning - Tests were performed in accordance with Commercial Standard CS 59-44, Shrinkage in Dry Cleaning, Dry and Wet Tests.

Crease Resistance - Tests were made in accordance with Specification CCC-T-191b, Method 5212. Three tests were made in both the warp and in the filling directions. Only the mean values are reported.

Stoll Q. M. Flex Abrasion - Tests were made in accordance with Specification CCC-T-191b, Method 5300. Five tests were made in the warp and the filling directions. The results reported are the means of these five tests.

Stoll Q. M. Inflated Diaphragm Abrasion - Tests were made in accordance with Specification CCC-T-191b, Method 5302. Five tests were made on each fabric, and the results reported are the minimum, maximum, and mean of these five tests.

pH of Water Extract - Acidity (pH) of fabrics, potentiometric method, tests were made in accordance with Specification CCC-T-191b, Method 2811, modified as follows: Measurements of pH were made directly in 250 ml glass stoppered Erlenmeyer flask instead of the 100 ml breakers specified in the test procedure. This modification became necessary when it was found that absorption of CO_2 from the air lowered the pH of the water solutions in a beaker from 0.6 to 1.0 pH units.

The distilled water used for these tests had a pH of 6.4.

TABLE 9 (Continued)

PHYSICAL TEST PROCEDURES

Pilling - The test procedure followed was that outlined in CCC-T-191b, Method 5310T, Appearance-Retention of Cloth, Pilling and Surface Wear (Press). Recommended conditions for the type of fabric involved were three minutes under a head load of 1.6 psi. Actually, a series of tests were run on the 30% Dacron blend (judged to be the one most likely to pill) varying the time from 5 to 30 minutes and the pressure from 0.45 psi to 1.6 psi. No pills were produced. Accordingly, each fabric was then tested using a 15 minute run under a pressure of 1.6 psi.

TABLE 10

FADING TEST RESULTS

Fabric	Spectrophotometric Measurements of Color Difference (Adams Units) 80 Hour Exposure	140 Hour Exposure	Visual Examination for Exposure Time to Perceptible Break Hours
U. S. A. F. Standard Fabric	1.700	2.540	60-80
LTIRF 100% Wool Control Fabric	0.860	1.080	140
Wool/Viscose Blends			
10% Viscose	1.04	0.836	No Break at 140 Hours
20% Viscose	0.628	0.880	No Break at 140 Hours
30% Viscose	1.05	1.05	No Break at 140 Hours *
Wool/Nylon Blends			
10% Nylon	0.620	0.712	No Break at 140 Hours
20% Nylon	0.668	0.936	No Break at 140 Hours
30% Nylon	0.748	1.124	No Break at 140 Hours
Wool/Dacron Blends			
10% Dacron	0.856	0.908	No Break at 140 Hours
20% Dacron	0.712	1.02	No Break at 140 Hours
30% Dacron	0.656	0.648	No Break at 140 Hours
Wool/Orlon Blends			
10% Orlon	0.560	1.02	No Break at 140 Hours
20% Orlon	0.544	1.10	No Break at 140 Hours
30% Orlon	0.692	1.04	No Break at 140 Hours

* Observer judged this as a possible break.

TABLE 11

COLORFASTNESS TEST RESULTS
WOOL/VISCOSE FABRICS

	LTIRF 100% Wool Control Fabric	10% Viscose Fabric	20% Viscose Fabric	30% Viscose Fabric
LAUNDERING				
CCC-T-191a (100°F Test)	No stain of composite test fabric. No color loss. No shade alteration.	No stain of composite test fabric. No color loss. No shade alteration.	No stain of composite test fabric. No color loss. No shade alteration.	No stain of composite test fabric. No color loss. No shade alteration.
AATCC (120°F Test)	No stain of composite test fabric. No color loss. No shade alteration.	No stain of composite test fabric. No color loss. No shade alteration.	No stain of composite test fabric. No color loss. No shade alteration.	No stain of composite test fabric. No color loss. No shade alteration.
DRY CLEANING				
CCC-T-191a Test	Good	Good	Good	Good
CS 59-44				
Wet Test	Class 4	Class 4	Class 4	Class 4
Dry Test	Class 4	Class 4	Class 4	Class 4
CROCKING				
Wet Test	Fair	Good	Good	Good
Dry Test	Good	Good	Fair	Fair
PERSPIRATION				
Acid Test	Good	Good	Good	Good
Alkaline Test	Good	Good	Good	Good
STEAM PRESSING				
Dry Test	Class 4	Class 4	Class 4	Class 4
Wet Test	Class 4	Class 4	Class 4	Class 4

TABLE 12

COLORFASTNESS TEST RESULTS
WOOL/NYLON FABRICS

	LTIRF 100% Wool Control Fabric	10% Nylon Fabric	20% Nylon Fabric	30% Nylon Fabric
LAUNDERING				
CCC-T-191a (100°F Test)	No stain of composite test fabric. No color lost. No shade alteration.	No noticeable staining. No color loss. No shade alteration.	No noticeable staining. No color loss. No shade alteration.	No noticeable staining. No color loss. No shade alteration.
AATCC (120°F Test)	No stain of composite test fabric. No color loss. No shade alteration.	slight stain of spun nylon. No color loss. No shade alteration.	Moderate staining of spun nylon. No color loss. No shade alteration.	Moderate staining of spun nylon. No color loss. No shade alteration.
DRY CLEANING				
CCC-T-191a Test	Good	Good	Good	Good
CS 59-44				
Wet Test	Class 4	Class 4	Class 4	Class 4
Dry Test	Class 4	Class 4	Class 4	Class 4
CROCKING				
Wet Test	Fair	Fair	Good	Good
Dry Test	Good	Good	Good	Good
PERSPIRATION				
Acid Test	Good	Good	Good	Good
Alkaline Test	Good	Good	Good	Good
STEAM PRESSING				
Wet Test	Class 4	Class 4	Class 4	Class 4
Dry Test	Class 4	Class 4	Class 4	Class 4

TABLE 13

COLORFASTNESS TEST RESULTS
WOOL/DACRON FABRICS

	LTIRF 100% Wool Control Fabric	10% Dacron Fabric	20% Dacron Fabric	30% Dacron Fabric
LAUNDERING				
CCC-T-191a (100°F Test)	No staining of composite test fabric. No color loss. No shade alteration.	No staining of composite test fabric. No color loss. No shade alteration.	No staining of composite test fabric. No color loss. No shade alteration.	No staining of composite test fabric. No color loss. No shade alteration.
AATCC (120°F Test)	No staining of composite test fabric. No color loss. No shade alteration.	No staining of composite test fabric. No color loss. No shade alteration.	No staining of composite test fabric. No color loss. No shade alteration.	No staining of composite test fabric. No color loss. No shade alteration.
DRY CLEANING				
CCC-T-191a Test	Good	Good	Good	Good
CS 59-44				
Wet Test	Class 4	Class 4	Class 4	Class 4
Dry Test	Class 4	Class 4	Class 4	Class 4
CROCKING				
Wet Test	Fair	Good	Good	Good
Dry Test	Good	Good	Good	Good
PERSPIRATION				
Acid Test	Good	Good	Good	Good
Alkaline Test	Good	Good	Good	Good
STEAM PRESSING				
Wet Test	Class 4	Class 4	Class 4	Class 4
Dry Test	Class 4	Class 4	Class 4	Class 4

TABLE 14

COLORFASTNESS TEST RESULTS
WOOL/ORLON FABRICS

	LTIRF 100% Wool Control Fabric	10% Orlon Fabric	20% Orlon Fabric	30% Orlon Fabric
LAUNDERING				
CCC-T-191a (100°F Test)	No noticeable staining of test fabric. No color loss. No shade alteration.	No noticeable staining of test fabric. No color loss. No shade alteration.	No noticeable staining of test fabric. No color loss. No shade alteration.	No noticeable staining of test fabric. No color loss. No shade alteration.
AATCC (120°F Test)	No noticeable staining of test fabric. No color loss. No shade alteration.	No noticeable staining of test fabric. No color loss. No shade alteration.	No noticeable staining of test fabric. No color loss. No shade alteration.	No noticeable staining of test fabric. No color loss. No shade alteration.
DRY CLEANING				
CCC-T-191a Test	Good	Good	Good	Good
CS 59-44				
Wet Test	Class 4	Class 4	Class 4	Class 4
Dry Test	Class 4	Class 4	Class 4	Class 4
CROCKING				
Wet Test	Fair	Good	Good	Good
Dry Test	Good	Good	Good	Good
PERSPIRATION				
Acid Test	Good	Good	Good	Good
Alkaline Test	Good	Good	Good	Good
STEAM PRESSING				
Wet Test	Class 4	Class 4	Class 4	Class 4
Dry Test	Class 4	Class 4	Class 4	Class 4

TABLE 15

PHYSICAL TEST RESULTS
WOOL/VISCOSE FABRICS

Properties	LTIRF 100% Wool Control Fabric	10% Viscose Fabric	20% Viscose Fabric	30% Viscose Fabric
Ends per inch	70.0	72.5	71.5	72.0
Picks per inch	55.0	58.5	57.5	58.5
Weight (oz/yd^2)	9.35	9.55	9.64	9.75
Air Permeability ($ft^3/min/ft^2$)	15.46	18.10	19.04	18.80
Breaking Strength (lbs)				
Warp	122.6	107.0	104.8	107.8
Filling	95.6	88.0	84.6	89.4
Tearing Strength (lbs)				
Warp	6.0	6.1	5.5	6.0
Filling	5.3	6.0	5.5	5.8
Abrasion Resistance				
Stoll-Q.M. Flex (No. cycles to break)				
Warp	1039.8	1232.6	1173.0	1173.8
Filling	737.2	1068.2	888.2	920.6
Stoll-Q.M. Surface (No. cycles to failure)				
Minimum	633	648	667	611
Maximum	795	744	820	796
Mean	720.2	706.2	744.4	682.6
Shrinkage in Sponging (%)				
Warp	5.62	3.75	3.75	2.71
Filling	0.00	0.62 s	0.62 s	0.00
Shrinkage in Dry Cleaning (%)				
Dry Test				
Warp	3.96	0.62	0.00	0.62
Filling	0.835	0.00	0.00	0.00
Wet Test				
Warp	8.12	5.00	3.33	4.37
Filling	0.215	0.62	0.21	0.83
Crease Resistance (% Crease Recovery)				
Warp	82	82	83	79
Filling	86	89	87	82
Pilling	None	None	None	None
pH of H_2O Extract	3.9	7.0	7.0	7.0

s - Designates stretch instead of shrinkage

TABLE 16

PHYSICAL TEST RESULTS
WOOL/NYLON FABRICS

Properties	LTIRF 100% Wool Control Fabric	10% Nylon Fabric	20% Nylon Fabric	30% Nylon Fabric
Ends per inch	70.0	71.5	71.0	71.0
Picks per inch	55.0	59.0	57.0	57.0
Weight (oz/yd^2)	9.35	10.10	9.61	9.52
Air Permeability ($ft^3/min/ft^2$)	15.46	12.00	13.92	12.98
Breaking Strength (lbs)				
Warp	122.6	161.3	181.8	150.0
Filling	95.6	129.7	207.4	175.4
Tearing Strength (lbs)				
Warp	6.0	8.4	10.0	12.20
Filling	5.3	7.2	10.7	12.51
Abrasion Resistance				
Stoll-Q.M. Flex (No. cycles to break)				
Warp	1039.8	1996.2	3309.6	3999.0
Filling	737.2	1664.0	4043.6	3898.6
Stoll-Q.M. Surface (No. cycles to failure)				
Minimum	633	860	1425	1970
Maximum	795	1064	1799	2259
Mean	720.2	960.8	1578	2059
Shrinkage in Sponging (%)				
Warp	5.62	2.29	2.71	3.54
Filling	0.00	0.21 s	0.83	1.04
Shrinkage in Dry Cleaning (%)				
Dry Test				
Warp	3.96	1.87	0.83	1.25
Filling	0.835	1.62	0.00	0.00
Wet Test				
Warp	8.12	4.17	1.04	1.25
Filling	0.215	1.67	0.00	0.00
Crease Resistance (% Crease Recovery)				
Warp	82	83	88.3	87.3
Filling	86	85	88.3	89.0
Pilling	None	None	None	None
pH of H_2O Extract	3.9	6.6	8.1	8.1

s - Designates stretch instead of shrinkage

TABLE 17

PHYSICAL TEST RESULTS
WOOL/DACRON FABRICS

Properties	LTIRF 100% Wool Control Fabric	10% Dacron Fabric	20% Dacron Fabric	30% Dacron Fabric
Ends per inch	70.0	72.0	72.0	71.5
Picks per inch	55.0	58.5	57.5	58.5
Weight (oz/yd^2)	9.35	9.96	9.71	10.12
Air Permeability ($ft^3/min/ft^2$)	15.46	14.50	13.36	11.84
Breaking Strength (lbs)				
Warp	122.6	144.8	175.6	211.2
Filling	95.6	124.6	149.2	175.0
Tearing Strength (lbs)				
Warp	6.0	8.1	9.4	12.8
Filling	5.3	7.5	10.3	12.9
Abrasion Resistance				
Stoll-Q.M. Flex (No. cycles to break)				
Warp	1039.8	2303.2	3208.4	2626.6
Filling	737.2	1939.8	3196.4	2991.4
Stoll-Q.M. Surface No. cycles to failure)				
Minimum	633	883	1113	973.4
Maximum	795	1423	1793	1570.2
Mean	720.2	2062	2378	2271.0
Shrinkage in Sponging (%)				
Warp	5.62	0.00	1.25	1.25
Filling	0.00	1.67	0.00	0.00
Shrinkage in Dry Cleaning (%)				
Dry Test				
Warp	3.96	0.21	0.42	0.42
Filling	0.835	0.00	0.00	0.00
Wet Test				
Warp	8.12	2.50	2.08	1.46
Filling	0.215	0.21	0.21	0.21 s
Crease Resistance (% Crease Recovery)				
Warp	82	86	85	82
Filling	86	86	85	87
Pilling	None	None	None	None
pH of H_2O Extract	3.9	7.1	7.2	7.2

s - Designates stretch instead of shrinkage

TABLE 18

PHYSICAL TEST RESULTS
WOOL/ORLON FABRICS

Properties	LTIRF 100% Wool Control Fabric	10% Orlon Fabric	20% Orlon Fabric	30% Orlon Fabric
Ends per inch	70.0	69.0	69.0	69.5
Picks per inch	55.0	53.5	54.0	54.0
Weight (oz/yd^2)	9.35	8.67	9.08	9.19
Air Permeability ($ft^3/min/ft^2$)	15.46	22.68	19.02	14.26
Breaking Strength (lbs)				
Warp	122.6	100.8	107.6	124.2
Filling	95.6	76.8	78.6	98.8
Tearing Strength (lbs)				
Warp	6.0	6.20	6.30	7.82
Filling	5.3	5.50	5.98	7.90
Abrasion Resistance				
Stoll-Q.M. Flex (No. cycles to break)				
Warp	1039.8	992.6	1038.2	1003.2
Filling	737.2	758.2	826.4	817.0
Stoll-Q.M. Surface (No. cycles to failure)				
Minimum	633	726	996	1089
Maximum	795	921	1340	1212
Mean	720	827	1109	1140
Shrinkage in Sponging (%)				
Warp	5.62	4.37	3.75	2.92
Filling	0.00	0.00	0.62	0.00
Shrinkage in Dry Cleaning (%)				
Dry Test				
Warp	3.96	1.67	2.50	2.50
Filling	0.835	0.21	0.83	1.04
Wet Test				
Warp	8.12	5.42	3.12	4.58
Filling	0.215	1.25	0.62	1.67
Crease Resistance (% Crease Recovery)				
Warp	82	90	89	90
Filling	86	93	91	91
Pilling	None	None	None	None
pH of H_2O Extract	3.9	7.6	7.6	7.5

TABLE 19

REPRODUCIBILITY OF FIBER COLORFASTNESS TESTS

Test Sample	LIGHTFASTNESS GREY SCALE COLOR DIFFERENCE VALUE		WETFASTNESS AATCC COLOR TRANSFER VALUE					
	80 Hour Exposure	160 Hour Exposure	Perspiration Acid	Perspiration Alkaline	Fulling	Laundering	Wet Dry Cleaning	Wet Crocking
VISCOSE								
No. 1	5	5-4 blue	5	5		5		
No. 1a*	5	5-4 blue	5	5		5		
No. 1b**	5	5-4 blue						
No. 7	5	5-4 red						
No. 7a	5	5-4 red						
No. 7b	5	5-4 red						
DACRON								
No. 54			4-3	3				
No. 54b			4-3	3				
No. 61	5-4 weak	5-4 weak, sl. red	5	5	5	5	5	5
No. 61a	5-4 weak	5-4 weak, sl. red	5	5	5	5	5	5
No. 61b	5-4 weak	5-4 weak, sl. red	5	5	5	5	5	5
ORLON								
No. 81	5-4 blue	4 strong, sl. blue	5-4	5-4				
No. 81b	5-4 blue	4 strong, sl. blue	5-4	5-4				
NYLON								
No. 21	4 weak	4-3 weak						
No. 21a	4 weak	4-3 weak						
No. 23			5	2	5	4	5	4
No. 23b			5	2	5	4	5	4
No. 24	5	5-4 weak	5	5	5-4	3-4	5	5
No. 24a	5	5-4 weak	5	5	5-4	3-4	5	5
No. 24b	5	5-4 weak	5	5	5-4	3-4	5	5

*a Designates a second test specimen prepared from same dye lot.
**b Designates third test specimen prepared from second dye lot.

TABLE 20

LIGHTFASTNESS TEST RESULTS FOR WOOL FIBERS

Formula Number	Exposure Time to First Color Change	GREY SCALE COLOR DIFFERENCE VALUE		AATCC COLOR TRANSFERENCE VALUE					
		80 Hour Exposure	160 Hour Exposure	Perspiration Acid	Perspiration Alkaline	Fulling	Laundering	Wet Dry Cleaning	Wet Crocking
BLUE SHADES									
Primary #1 (Helindon Blue B)	80 Hours	5	4 light	5	5	5	5	5	5-4
Primary #2 (Acid Chrome Blue RRA)	80 Hours	5	5-4 light	5	5	5	5	5	5
GREY SHADE									
Primary #3 (Alizarine Fast Grey BRLW)	60 Hours	4	4-3 weak	5	5	5	5	5	5

TABLE 21

LIGHTFASTNESS RESULTS FOR VISCOSE RAYON DYE FORMULAE

Formula Number	COLOR DIFFERENCE - GREY SCALE VALUE 80 Hour Exposure	160 Hour Exposure	Exposure Time to First Change
BLUE SHADE			
1	5	5-4 sl. blue	80
2	5	4 strong, sl. blue	80
3	5	5-4 strong, dull	80
4	5	5-4 blue, sl. strong	80
GREY SHADE			
5	5	5-4 blue	80
6	5	4 yellow	80
7	5	5-4 red	80
8	5-4 blue	5-4 blue	80
9	5	5-4 dull, sl. red	80

TABLE 22

WETFASTNESS RESULTS FOR VISCOSE RAYON DYE FORMULAE

COLOR TRANSFERENCE - AATCC COLOR TRANSFERENCE VALUE

Formula Number	Acid Perspiration	Alkaline Perspiration	Fulling	Laundering	Wet Dry Cleaning	Wet Crocking
BLUE SHADE						
1	5	5	5	5	5	5
2	5	5	5	5	5	5
3	5	5	5	5	5	5
4	5	5	5	5	5	5
GREY SHADE						
5	5	5	5	5	5	5
6	5	5	5	5	5	5
7	5	5	5	5	5	5
8	5	5	5	5	5	5
9	5	5	5	5	5	5

TABLE 23

LIGHTFASTNESS RESULTS FOR NYLON DYD FORMULAE

COLOR DIFFERENCE - GREY SCALE VALUE

Formula Number	80 Hour Exposure	160 Hour Exposure	Exposure Time to First Change-Hours
BLUE SHADE			
21	4 weak	4-3 weak	60
22	5	5-4 weak, sl. blue	80
23	4 weak	4-3 weak, sl. red	60
24	5	5-4 weak	80
25	4 blue		40
26	5-4 weak	5-4 weak	80
27	5	5-4 weak	80
GREY SHADE			
28	3 weak	3-2 weak, sl. red	20
29	3 weak, sl. red	1-2 weak, very red	20
30	3-2 blue, weak	1-2 large blue, weak	20
31	4 weak	4-3 weak	60
32	3 red, sl. weak		
33	4 weak, sl. red	3 weak, mod. red	60
34	4 weak	4-3 weak	60
35	4 weak	4-3 weak	60
36	4 weak	4-3 weak	60
37	4 weak	4-3 weak	60
38	5-4 weak	5-4 weak	80

TABLE 24

WETFASTNESS RESULTS FOR NYLON DYE FORMULAE

COLOR TRANSFERENCE - AATCC COLOR TRANSFERENCE VALUE

Formula Number	Acid Perspiration	Alkaline Perspiration	Fulling	Laundering	Wet Dry Cleaning	Wet Crocking
BLUE SHADE						
21	5	5	5	5	5	5
22	5	5	5	5	5	5
23	5	2	5	4	5	4
24	5	5	5-4	4-3	5	5
25	4	3				
26	5	5	5	5	5	5
27	5	4	5	4-3	5	5
GREY SHADE						
28	5	5	5	5	5	5
29	5	5	5	5	5	5
30	5	4		5 shade change 3		
31	5	5	5	5	5	5
32	5	5				
33	5	5	5	5	5	5
34	5	5	5	5	5	5
35	5	5	5	5	5	5
36	5	5	5	5	5	5
37	5	5	5	5	5	5
38	5	5	5	5	5	5

TABLE 25

LIGHTFASTNESS RESULTS FOR DACRON DYE FORMULAE

Formula Number	COLOR DIFFERENCE - GREY SCALE VALUE 80 Hour Exposure	160 Hour Exposure	Exposure Time to First Change	SPECIAL EXPOSURES Exposure Time Hours	Color Difference
BLUE SHADE					
51	5-4 blue	5-4 blue, sl. dull	60		
52	4-3 blue, dull		40		
53			20	60	3 blue
54			20	20	3 very red, dull
55			20	60	3 red
56			20	60	3 very red, weak
57			20	60	3 very red, bright
58	5-4 weak, sl. blue	5-4 weak, sl. blue	60		
59	5-4 blue	5-4 blue, dull	60		
60			20	60	3 very red, bright
GREY SHADE					
61	5-4 weak	5-4 weak, sl. red	60		
62	4 blue, weak	3 blue, weak	40		
63	4 weak, red	3 red, weak	40		
64	3 very green, weak	1-2 very green, weak	20		
65			20	60	3-2 very red
66	4-3 weak, blue	3-2 very blue, weak	20		
67	5-4 weak	5-4 weak, sl. red	60		
68	4 weak, blue	3 blue, weak	40		
69	4 weak	4-3 weak, sl. blue	40		
70	5-4 weak, sl. blue				
71	4 weak	3 weak, red			
72	4 weak	3 weak, red	40		

TABLE 26

WETFASTNESS RESULTS FOR DACRON DYE FORMULAE

COLOR TRANSFERENCE - AATCC COLOR TRANSFERENCE VALUE

Formula Number	Acid Perspiration	Alkaline Perspiration	Fulling	Laundering	Wet Dry Cleaning	Wet Crocking
BLUE SHADE						
51	5	5-4	5	5	5	5
52	2	3	3-2	4	5-4	4
53						
54	4-3	3				
55						
56	5	5				
57	5	5				
58	5	5	5	5	5	5
59	5	5-4	5	5	5	5
60	5	5				
GREY SHADE						
61	5	5	5	5	5	5
62	5	5	5	5	5	5
63	4	5-4	5	5	5	5
64	4	5	5	5	5	5
65	5	5				
66	5	5	5	5		
67	5	5	5	5	5	5
68	5	5-4				
69	5	5	5	5	5	5
70			5	5	5	5
71	4	4-5				
72	4	4-5				

TABLE 27

LIGHTFASTNESS RESULTS FOR ORLON TYPE 41 DYE FORMULAE

COLOR DIFFERENCE-GREY SCALE VALUE

Formula Number	80 Hour Exposure	160 Hour Exposure	Exposure Time to First Change	SPECIAL EXPOSURES Exposure Time (Hours)	Color Difference
81	5-4 blue	4 strong, sl. blue	60		
82				40	4 blue
83				40	4 blue
84	5-4 blue	4 strong, sl. blue	40		
85	5-4 blue	4 weak, sl. blue	40		
86	5-4 blue	4 strong, sl. blue			
87	4 blue	4-3 blue, weak			
88	4 blue	4-3 blue, weak			
GREY SHADE					
91	3-2 weak, green	2 green, weak	40		
92			20	60	2 red
93			20	60	3-2 blue
94			20	60	2 yellow
95	4-3 weak, sl. red	3 large red, weak	40		
96			20	60	2-1 large blue, bright
97				20	3 weak
98			20	60	2 large, blue, bright
99				40	4-3 blue
100	5-4 weak, sl. red	4-3 red, weak	20 40		
101	4 weak, sl. blue	3 blue, weak		40	

TABLE 28

WETFASTNESS RESULTS FOR ORLON TYPE 41 DYE FORMULAE

COLOR TRANSFERENCE - AATCC COLOR TRANSFERENCE VALUE

Formula Number	Acid Perspiration	Alkaline Perspiration	Fulling	Laundering	Wet Dry Cleaning	Wet Crocking
BLUE SHADE						
81	5-4	5	5	5	5	5
82		1				
83	4-3	5				
84	5	5	5	5	5	5
85	5	5-4	5	5-4	5	5
86	5	5	5	5	5	
87	3	4-3	5	5	5	5
88	5-4	4	5	5	5	5
GREY SHADE						
91	5	5	5	5	5	5
92	5-4	5-4		5		
93	5	4				
94	5	5				
95	5	5	5	5	5	5
96	5-4	5-4				
97	3-2	2				
98	3	2				
99	4	3				
100	5	5	5	5	5	5
101	5	5	5	5	5	5

TABLE 29

TABLE 31

LIGHTFASTNESS RESULTS FOR ACRILAN DYE FORMULAE

Formula Number	COLOR DIFFERENCE - GREY SCALE VALUE 80 Hour Exposure	160 Hour Exposure	Exposure Time to First Change	SPECIAL EXPOSURES Exposure Time (Hours)	Color Difference
BLUE SHADE					
131			20	30	3 blue
132	3 weak dull	1 weak yellow	20	40	4 dull
133			20	40	4 blue
GREY SHADE					
134	4-3 weak	3 weak	40	60	weak
135	4 weak	4-3 weak, sl. yellow	40		
136	4 red	4-3 weak, red	40		
137	4 weak	3 weak	40		

TABLE 32

WETFASTNESS RESULTS FOR ACRILAN DYE FORMULAE

COLOR TRANSFERENCE - AATCC COLOR TRANSFERENCE VALUE

Formula Number	Acid Perspiration	Alkaline Perspiration	Fulling	Laundering	Wet Dry Cleaning	Wet Crocking
BLUE SHADE						
131						
132	5	5-4	4-3	4	5	5
133	4-3	2				
GREY SHADE						
134	5	5	5	5-4	5	5
135	5-4	4		4		
136	4	4-3	5	4 (green) shade change 3	5-4	4
137	5	5-4	5-4	5	5	5

TABLE 33

VISCOSE RAYON DYEING FORMULAE

BLUE SHADE

No. 1		
A)	3.0% Indanthrene Direct Black RBA Paste pr. 289	Vat
B)	2.5% Indanthrene Blue BFP Dbl. Paste - 1113	
C)	1.5% Indanthrene Navy Blue BRP Paste - 1100	
No. 2		
A)	5.0% Carbanthrene Dark Blue DR Paste - C.I. 1099	Vat
B)	3.0% Carbanthrene Blue BCF Dbl. Paste - 1113	
C)	1.0% Carbanthrene Yellow G Dbl. Paste - 1118	
No. 3		
A)	5.0% Ponsol Navy Blue RA Dbl. Paste - C.I. 1100	Vat
B)	4.0% Ponsol Direct Black 3G Dbl. Paste	
No. 4		
A)	10% Cibanone Navy Blue RA Dbl. Paste - 1100	Vat
B)	5.0% Cibanone Olive S Paste- Pr. 547	
C)	1.5% Cibanone Olive 2B Dbl. Paste - Pr. 293	
No. 12		
A)	5% Navy Blue BL	Direct
B)	1% Blue GLN	
C)	3% Cuprofix #47	
No. 13		
A)	2.5% Diazone Blue BR - Pr. 74	Direct
B)	1.0% Erie Fast Green 2BG CGB - C.I. 589	
C)	0.10% Solantine Orange 4G Conc. Pr. 578	
No. 14		
A)	4% Resofix Navy Blue BL	Direct
B)	1% Resofix Blue GLN	

TABLE 33 (continued)

VISCOSE RAYON DYEING FORMULAE

GREY SHADE

No. 5

A) 1.0% Carbanthrene Olive R Dbl. Paste - 1150	Vat
B) 0.75% Carbanthrene Blue BCF Dbl. Flakes - 1113	
C) 0.25% Carbanthrene Violet BNX Paste - 1163	

No. 6

A) 1.20% Indanthrene Olive TA Paste - Pr. 547	Vat
B) 0.75% Indanthrene Blue BFP Dbl. Paste - 1113	
C) 0.50% Indanthrene Violet FF BNA Paste - 1163	

No. 7

A) 1.25% Ponsol Black BA Dbl. Paste - 1102	Vat
B) 0.30% Ponsol Navy Blue RA Dbl. Paste - 1100	

No. 8

A) Ciba Grey BLN Micro Powder

No. 9

A) 1.45% Indanthrene Direct Black RBA Paste - Pr. 289	Vat
B) 0.20% Indanthrene Blue BFP Dbl. Paste - 1113	
C) 0.10% Indanthrene Brilliant Green BN Pure Dbl. Paste conc. - 1101	

No. 10

A) 0.50% Solantine Blue FF Pr. 71	Direct
B) 0.25% Solantine Orange R	
C) 0.05% Solantine Rubine LB Pr. 512	

No. 11

A) 0.60% Diazine Blue BR Pr. 74	Direct
B) 0.20% Diazine Orange WD	
C) 0.10% Solantine Yellow FF Conc. C.I. 814	

TABLE 34

NYLON DYEING FORMULAE

BLUE SHADE

No. 21		
	A) 3.0% Pontachrome Blue Black RM Conc. - C.I. 202	Chrome Type
No. 22		
	A) 6.0% Alizarine Blue GRL Conc. 125% C.I. 1088 B) 2.8% Superchrome Blue BC - 201 C) 0.2% Superchrome Red EBC - 652	Chrome Type
No. 23		
	A) 2.0% Alizarine Fast Grey BLN-New CF Pr. 206 B) 0.5% Sulphon Cyanine 5RA-CF - 289 C) 0.25% Anthraquinone Violet 3RA C.I. 1080	Acid Type
No. 24		
	A) 1.2% Fast Wool Cyanone R - 289 B) 1.2% Fast Wool Cyanone 3R - 289 C) 1.2% Durol Black 2B - 307	Acid Type
No. 25		
	A) 2.5% Palatine Fast Blue GGNA-Extra CF Pr. 144 B) 1.25% Palatine Fast Red GREW - Pr. 391	Metallized Acid Type
No. 26		
	A) 2.4% Capracyl Blue G B) 0.16% Capracyl Yellow NW	Neutral Metallized Type
No. 27		
	A) 4.0% Nylofast Violet BLL B) 4.0% Nylofast Green Bl C) 4.0% Lanasyn Blue GL	Neutral Metallized & Acid Types
No. 40		
	A) 3.0% Capracyl Blue G B) 0.05% Capracyl Orange R	Neutral Metallized Type Neutral Metallized Type

TABLE 34 (continued)

NYLON DYEING FORMULAE

GREY SHADE

No. 28		
	A) 0.23% Alizarine Fast Grey BLN-New CF - Pr. 206 B) 0.08% Acid Alizarine Brown RLL C) 0.01% Supranol Yellow RA-CF - Pr. 289	Acid Type
No. 29		
	A) 0.25% Alizarine Fast Grey BLN-New CP - Pr. 206 B) 0.04% Anthraquinone Violet 3RA - 1080 C) 0.04% Supranol Yellow RA-CF - Pr. 289	Acid Type
No. 30		
	A) 0.40% Alizarine Fast Blue RB - Pr. 12 B) 0.17% Fast Acid Brown RG - Pr. 562 C) 0.03% Metanil Yellow 1955 - 138	Acid Type
No. 31		
	A) 0.50% Chromalan Grey G B) 0.18% Alizarine Light Grey 2BLW - Pr. 206 C) 0.08% Alizarine Light Brown BL	Metallized Acid & Acid Type
No. 32		
	A) 2.0% Palatine Fast Blue GGNA-Extra CF - Pr. 144 B) 1.10% Palatine Fast Orange GENA-CF - Pr. 315 C) 0.20% Palatine Fast Red GREW - Pr. 391	Metallized Acid Type
No. 33		
	A) 0.95% Chromalan Grey G B) 0.05% Alizarol Orange 3R	Metallized Acid & Acid Types
No. 34		
	A) 0.60% Chromalan Grey G B) 0.18% Alizarine Light Grey 2BLW - Pr. 206	Metallized Acid & Acid Types
No. 35		
	A) 0.30% Chromalan Grey G	Metallized Acid Type

TABLE 34 (continued)

NYLON DYEING FORMULAE

GREY SHADE

No. 36		
	A) 0.70% Cibalan Grey BL	Neutral Metallized Type
	B) 0.05% Cibalan Yellow GRL	
No. 37		
	A) 0.90% Capracyl Grey GN	Neutral Metallized Type
	B) 0.03% Capracyl Yellow N	
No. 38		
	A) 0.80% Nylofast Grey BLL B) 0.15% Nylofast Blue GL C) 0.007% Nylofast Rubine 2 RL	Neutral Metallized Type
No. 39		
	A) 0.80% Cibalan Grey BL	Neutral Metallized Type

TABLE 35

DACRON DYEING FORMULAE

BLUE SHADE

No. 51

A)	4.0% Eastman Fast Blue GLF	Dyeing Assistant #52
B)	3.2% Cibacete Yellow GLN - Pr. 537	250°F
C)	1.75% Cibacete Red 3B - Pr. 234	

No. 52

A)	8.0% Artisil Direct Blue GFL	
B)	1.4% Artisil Direct Red 3BF Conc. - Pr. 234	250°F
C)	0.7% Artisil Direct Yellow RN Conc.	

No. 53

A)	5.5% Eastman Fast Blue GLF	Monochlor Benzene
B)	5.5% Nacelan Printing Blue	212°F
C)	2.0% Nacelan Violet 5RL	

No. 54

A)	3.0% Celliton Fast Navy Blue BRA - Pr. 233	Para Phenyl Phenol
B)	1.75% Celliton Fast Blue Ga-Extra CF	212°F
C)	0.75% Celliton Fast Pink RFG - CF - Pr. 370	

No. 55

A)	4.0% Celliton Fast Navy Blue BRA - Pr. 233	
B)	0.25% Celliton Fast Brown 3RA - Pr. 230	
C)	0.20% Celliton Fast Pink RFG - Pr. 370	250°F

No. 56

A)	4.00% Celliton Fast Navy Blue BRA - Pr. 233	
B)	1.75% Celliton Fast Blue GA-Extra CF	
C)	0.50% Celliton Fast Pink RFG - Pr. 370	250°F

No. 57

A)	7.2% Latyl Violet B	Benzoic Acid
B)	0.9% Artisil Direct Blue GFL	212°F
C)	0.4% Celanthrene Fast Yellow GL Conc. 300% - Pr. 534	

TABLE 35 (continued)

DACRON DYEING FORMULAE

BLUE SHADE

No. 58

A) 4.0% Eastman Fast Blue GLF
B) 3.0% Cibacete Yellow GLN
C) 1.75% Eastman Fast Red GLF — 250°F

No. 59

A) 5.0% Eastman Fast Blue GLF
B) 3.2% Cibacete Yellow GLN - Pr. 537
C) 1.75% Cibacete Red 3B - Pr. 234 — 250°F

No. 60

A) 7.2% Latyl Violet B — 258°F
B) 0.9% Artisil Direct Blue GFL
C) 0.4% Celanthrene Fast Yellow GL Conc. 300% - Pr. 534

No. 75

A) 5.0% Latyl Blue GE — 250°F
B) 1.2% Celanthrene Fast Yellow GL Conc. 300% - Pr. 534
C) 2.5% Cibacete Yellow GLN - Pr. 537

No. 76

A) 5.5% Eastman Fast Blue GLF — 250°F
B) 3.0% Cibacete Yellow GLN - Pr. 537
C) 1.8% Celanthrene Cerise B

No. 77

A) 5.5% Eastman Fast Blue GLF — 250°F
B) 1.0% Celanthrene Fast Yellow GL Conc. 300% - Pr. 534
C) 1.5% Celanthrene Cerise B

No. 78

A) 6.0% Eastman Fast Blue GLF — 250°F
B) 2.0% Cibacete Yellow GLN - Pr. 537
C) 1.2% Cibacete Red 3B - Pr. 234
D) 0.15% Latyl Orange R

TABLE 35 (continued)

DACRON DYEING FORMULAE

GREY SHADE

No. 61

A)	0.72% Eastman Fast Blue GLF	Benzoic Acid
B)	0.18% Latyl Red B	212°F
C)	0.11% Celanthrene Fast Yellow GL Conc. 300% - Pr. 534	

No. 62

A)	0.80% Eastman Fast Blue GLF	Dyeing Assistant #52
B)	0.41% Eastman Fast Red GLF	212°F
C)	0.14% Cibacete Yellow GLN - Pr. 537	

No. 63

A)	0.6% Artisil Direct Blue GFL	
B)	0.19% Artisil Direct Red 3BP Conc. - Pr. 234	
C)	0.13% Artisil Direct Yellow RN Conc.	250°F

No. 64

A)	0.75% Celliton Fast Blue DAL	Para Phenyl Phenol
B)	0.08% Celliton Fast Brown 3RA - Pr. 230	212°F
C)	0.06% Celliton Fast Pink RFG - Pr. 370	

No. 65

A)	0.44% Nacelan Blue GLF	Monochlor Benzene
B)	0.56% Nacelan Yellow 4RLL	212°F
C)	0.25% Nacelan Violet 5RL	

No. 66

A)	0.75% Celliton Fast Blue DAL	
B)	0.08% Celliton Fast Brown 3RA - Pr. 230	
C)	0.06% Celliton Fast Pink RFG - Pr. 370	250°F

No. 67

A)	0.72% Eastman Fast Blue GLF	
B)	0.18% Latyl Red B	
C)	0.11% Celanthrene Fast Yellow GL Conc. 300% - Pr. 534	250°F

TABLE 35 (continued)

DACRON DYEING FORMULAE

GREY SHADE

No. 68

A) 0.80% Eastman Fast Blue GLF
B) 0.41% Eastman Fast Red GLF
C) 0.14% Cibacete Yellow GLN - Pr. 537 — 250°F

No. 69

A) 0.75% Celliton Fast Blue DAL
B) 0.10% Celliton Fast Pink RFG - Pr. 370
C) 0.08% Celliton Fast Brown 3RA - Pr. 230 — 250°F

No. 70

A) 0.75% Celliton Fast Blue DAL
B) 0.41% Eastman Fast Red GLF
C) 0.08% Celliton Fast Pink RFG - Pr. 370 — 250°F

No. 71

A) 0.6% Artisil Direct Blue GFL
B) 0.13% Artisil Direct Yellow RN Conc.
C) 0.12% Artisil Direct Red 3 BP Conc. - Pr. 234 — 250°F

No. 72

A) 0.6% Eastman Fast Blue GLF
B) 0.13% Artisil Direct Yellow RN Conc.
C) 0.12% Artisil Direct Red 3BP Conc. - Pr. 234 — 250°F

No. 73

A) 0.80% Latyl Blue GE — 250°F
B) 0.10% Latyl Red B
C) 0.20% Latyl Violet BN

No. 74

A) 0.70% Eastman Fast Blue GLF — 250°F
B) 0.10% Latyl Red B
C) 0.20% Celanthrene Fast Yellow GL Conc. 300% - Pr. 534
D) 0.05% Latyl Violet BN

TABLE 36

ORLON TYPE 41 DYEING FORMULAE

BLUE SHADE

No. 81		
	A) 4.0% Alizarine Fast Blue CL - Pr. 12 B) 0.6% Acid Orange II YA Conc. - 151 C) 0.2% Rocceline - 176	Cuprous Ion 250°F
No. 82		
	A) 7.0% Alizarine Fast Blue RB - Pr. 12 B) 0.50% Fast Red AS Conc. - 176 C) 0.30% Chinoline Yellow Extra Conc. - Pr. 533 D) 0.15% Wool Orange A Conc. - 151	Cuprous Ion 212°F
No. 83		
	A) 3.0% Alizarine Supra Blue A-CF - Pr. 12 B) 2.0% Wool Fast Orange GA-CF - 274 C) 1.0% Alizarine Cyanine Green G-Extra-New CF D) 0.5% Fast Red ALS C.I. 176	Cuprous Ion 212°F
No. 84		
	A) 3.0% Alizarine Supra Blue A-CF - Pr. 12 B) 1.00% Anthraquinone Violet 3RA C.I. 1080 C) 0.65% Fast Sulphon Black NB Conc. C.I. 304	Cuprous Ion 250°F
No. 85		
	A) 6.5% Anthraquinone Blue SWF Conc. - Pr. 12 150% B) 0.60% Pontacyl Fast Red AS Extra Conc. - 176 C) 0.30% Quinoline Yellow PN Extra Conc. C.I. 802	Cuprous Ion 212°F
No. 86		
	A) 1.5% Anthraquinone Blue B - 1054 B) 1.0% Anthraquinone Violet R - 1080 C) 0.75% Pontacyl Navy Blue M4B Conc. 200% -304	Cuprous Ion 250°F
No. 87		
	A) 4.0% Alizarine Light Blue B C.I. 1054 B) 0.7% Omega Chrome Blue Black RZN C.I. 202 C) 0.5% Xylene Light Yellow R	Cuprous Ion 212°F
No. 88		
	A) 3.0% Xylene Milling Blue GL C.I. 833 B) 1.25% Xylene Milling Black 2B Conc. C.I. 304	Cuprous Ion 250°F

TABLE 36 (continued)

ORLON TYPE 41 DYEING FORMULAE

BLUE SHADE

No. 89

A)	20% Brilliant Indigo 4B Paste Fine C.I. 1184	Vat
B)	10% Indanthrene Printing Black BA Suprafix	
C)	3% Indanthrene Navy Blue BRP Paste C.I. 1100	

No. 90

A)	1.5% Anthraquinone Blue B C.I. 1054	Cuprous Ion 212°F
B)	0.50% Fast Sulphon Black NB Conc. C.I. 304	
C)	1.00% Anthraquinone Violet 3RA C.I. 1080	

No. 107

A)	1.75% Pontacyl Navy Blue M4B 200% C.I. 304	Cuprous Ion 250°F

GREY SHADE

No. 91

A)	0.3% Fast Sulphon Black NB Conc. C.I. 304	Cuprous Ion 212°F
B)	0.2% Alizarine Cyanine Green G-Extra New DF - 1078	
C)	0.15% Wool Fast Orange GA-CF C.I. 274	

No. 92

A)	0.50% Roracyl Violet 2R C.I. 176	Cuprous Ion 250°F
B)	0.36% Anthraquinone Green GN - 1078	
C)	0.05% Roracyl Orange R C.I. 176	

No. 93

A)	0.65% Anthraquinone Blue SWF - Pr. 12 Conc. 150%	Cuprous Ion 212°F
B)	0.175% Pontacyl Fast Red AS Conc. C.I. 176	
C)	0.10% Quinoline Yellow PN Extra Conc. C.I. 802	

No. 94

A)	0.77% Anthraquinone Green GN C.I. 1078	Cuprous Ion 212°F
B)	0.45% Roracyl Violet 2R C.I. 176	
C)	0.10% Roracyl Orange R C.I. 176	

TABLE 36 (continued)

ORLON TYPE 41 DYEING FORMULAE

GREY SHADE

No. 95		
A)	0.37% Alizarine Fast Grey BLN-New CF - Pr. 206	Cuprous Ion
B)	0.15% Anthraquinone Violet 3RA C.I. 1080	250°F
C)	0.05% Alizarine Supra Blue A-CF - Pr. 12	
No. 96		
A)	0.6% Alizarine Fast Blue CL - Pr. 12	Cuprous Ion
B)	0.15% Rocceline C.I. 176	212°F
C)	0.10% Chinoline Yellow Conc. C.I. 801	
No. 97		
A)	0.75% Colliton Fast Black BTNA	Acetate 212°F
No. 98		
A)	0.54% Alizarine Fast Blue RB - Pr. 12	
B)	0.38% Alizarine Violet NRR	Cuprous Ion
C)	0.21% Wool Orange A Conc.	212°F
D)	0.15% Chinoline Yellow Extra Conc.	
No. 99		
A)	0.62% Alizarine Fast Blue RB - Pr. 12	Cuprous Ion
B)	0.48% Fast Acid Brown RG - Pr. 562	212°F
No. 100		
A)	0.7% Alizarine Light Grey RLL	
B)	0.32% Lansyn Green BL	Cuprous Ion
C)	0.04% Xylene Light Yellow R	250°F
No. 101		
A)	0.35% Alizarine Light Blue B C.I. 1054	
B)	0.09% Brilliant Sulphon Red B	Cuprous Ion
C)	0.07% Xylene Light Yellow R	250°F
No. 102		
A)	2.0% Brilliant Indigo 4B Paste Fine C.I. 1184	Vat
B)	1.0% Indanthrene Printing Black BL Suprafix	
C)	0.5% Indanthrene Navy Blue BRP Paste C.I. 1100	

TABLE 36 (continued)

ORLON TYPE 41 DYEING FORMULAE

GREY SHADE

No. 103		
A)	2.0% Brilliant Indigo 4B Paste Fine C.I. 1184	Vat
B)	1.0% Indanthrene Direct Black RBA Paste - Pr. 289	
C)	0.5% Indanthrene Navy Blue BRP Paste C.I. 1100	
No. 104		
A)	0.75% Alizarine Fast Grey BLN New CF - Pr. 206	Cuprous Ion 250°F
No. 105		
A)	0.60% Alizarine Fast Grey BLN New CF - Pr. 206	Cuprous Ion
B)	0.20% Anthraquinone Violet 3RA C.I. 1080	250°F

TABLE 37

DYNEL DYEING FORMULAE

BLUE SHADE

No. 111

A)	6.2% Eastman Blue GLF	Acetate
B)	1.3% Cibacete Red 3B - Pr. 234	
C)	1.0% Cibacete Yellow GLN - Pr. 537	

No. 112

A)	5.5% Celliton Blue BGF Extra - Pr. 538	Acetate
B)	3.5% Celliton Fast Pink RFD - Pr. 370	
C)	0.4% Celliton Fast Yellow GA-CF - Pr. 242	

No. 113

A)	7.0% Milling Navy Blue 4B - 304	Cuprous Ion
B)	4.0% Wool Fast Blue BL C.I. 833	
C)	1.0% Milling Black B - 304	

No. 114

A)	6.0 Anthraquinone Blue SWF - Pr. 12 Conc. 150%	Acetate and Cuprous Ion
B)	1.05% Acetamine Scarlet B - Pr. 244	
C)	0.6% Acetamine Yellow N	

No. 115

A)	2.6% Xylene Milling Blue GL C.I. 833	
B)	1.1% Eastman Fast Yellow 4RLF	Acetate and
C)	0.9% Eastone Fast Red GLF	Cuprous Ion
D)	0.8% Eastman Fast Blue GLF	

No. 116

A)	5.0% Xylene Milling Blue GL C.I. 833	
B)	2.0% Eastman Fast Yellow 4RLF	Acetate and
C)	1.85% Eastone Fast Red GLF	Cuprous Ion

No. 117

A)	3.0% Eastman Fast Blue GLF	
B)	2.0% Alizarine Supra Blue A - Pr. 12	Acetate and
C)	0.75% Celliton Fast Yellow 3RLL	Cuprous Ion
D)	0.50% Fast Red ALS C.I. 176	

TABLE 37 (continued)

DYNEL DYEING FORMULAE

GREY SHADE

No. 118		
A) 0.87% Celliton Fast Blue BGF B) 0.55% Celliton Fast Pink RFD - Pr. 370 C) 0.187% Celliton Fast Yellow GA-CF - Pr. 242		Acetate
No. 119		
A) 0.85% Eastman Fast Blue GLF B) 0.27% Cibacete Yellow GLN - Pr. 537 C) 0.26% Eastone Fast Red GLF		Acetate
No. 120		
A) 0.65% Anthraquinone Blue SWF Conc. 150% - Pr. 12 B) 0.15% Acetamine Scarlet B - Pr. 244 C) 0.10% Acetamine Yellow N		Acetate and Cuprous Ion
No. 121		
A) 0.6% Capracyl Brown RD B) 0.15% Eastman Fast Blue GLF C) 0.10% Eastman Fast Yellow 4RLF D) 0.10% Vialon Fast Red B		Acetate and Metallized
No. 122		
A) 0.68% Capracyl Brown RD B) 0.62% Eastman Fast Blue GLF C) 0.12% Eastone Fast Red GLF		Acetate and Metallized
No. 123		
A) 3.0% Alizarine Light Grey 2BLW - Pr. 206 B) 0.1% Alizarine Violet R C.I. 1080 C) 0.06% Fast Acid Brown RG - Pr. 562		Cuprous Ion
No. 124		
A) 0.80% Eastman Fast Blue GLF B) 0.70% Nacelan Yellow 4RLL C) 0.36% Nacelan Violet 5RL		Acetate

TABLE 38

ACRILAN DYEING FORMULAE

BLUE SHADE

No. 131

A)	6.0% Alizarine Fast Blue RB - Pr. 12	Acid
B)	1.00% Alizarine Violet NRR	
C)	0.85% Fast Acid Brown RG - Pr. 562	

No. 132

A)	2.35% Sulphon Cyanine 5RA-CF-Pr. 289	Acid
B)	0.65% Alizarine Cyanine Green G - Extra New CF C.I. 1078	

No. 133

A)	3.5% Pontacyl Navy Blue M4B Conc. 200%	Acid
B)	1.0% Anthraquinone Blue SWF Conc. 150% - Pr. 12	

No. 141

A)	20% Brilliant Indigo 4B Paste Fine C.I. 1184	Vat
B)	10% Indanthrene Printing Black BL Suprafix	
C)	3% Indanthrene Navy Blue BRP Paste C.I. 1100	

GREY SHADE

No. 134

A)	2.0% Algosol Grey IBL - Pr. 295	Sol. Vat

No. 135

A)	2.0% Neutral Grey L - Pr. 206	
B)	0.03% Crocein Scarlet N - 252	Acid

No. 136

A)	1.13% Alizarine Light Grey 2BLW - Pr. 206	Acid
B)	0.26% Alizarine Violet NRR	
C)	0.125% Fast Acid Brown RG - Pr. 562	

No. 137

A)	0.90% Cibalan Grey BL	Neutral
B)	0.05% Cibalan Yellow GRL	Metallized

TABLE 38 (continued)

ACRILAN DYEING FORMULAE

GREY SHADE

No. 138

A)	2.5% Algosol Grey IHL - Pr. 295	Sol. Vat
B)	0.3% Algosol Grey IHL	

No. 139

A)	1.5% Indanthrene Direct Black RBA Paste - Pr. 289	Vat
B)	1.0% Brilliant Indigo 4B Paste Fine C.I. 1184	
C)	0.3% Indanthrene Navy Blue BRP Paste C.I. 1100	

TABLE 39

ORLON TYPE 42 DYEING FORMULAE
(Cuprous Ion Dyeing at 250°F)

BLUE SHADE

No. 150

A) 3.0% Xylene Milling Blue GL C.I. 833
B) 1.25% Xylene Milling Black 2B Conc. C.I. 304

No. 151

A) 1.5% Alizarine Supra Blue ACF - Pr. 12
B) 0.9% Fast Sulphon Black NB Conc. C.I. 304
C) 1.2% Anthraquinone Violet 3RA C.I. 1080

No. 152

A) 2.50% Anthraquinone Blue SKY C.I. 1088
B) 0.70% Pontacyl Fast Red AS Extra Conc. C.I. 176

No. 153

A) 1.0% Anthraquinone Violet 3RA C.I. 1080
B) 0.5% Anthraquinone Blue B C.I. 1054
C) 0.75% Pontacyl Navy Blue M4B C.I. 304

No. 154

A) 3.0% Alizarine Fast Blue CL - Pr. 12
B) 0.75% Acid Orange II YA Conc. C.I. 151
C) 0.40% Rocceline C.I. 176

No. 155

A) 0.65% Fast Sulphon Black NB Conc. C.I. 304
B) 1.00% Anthraquinone Blue SWF Conc. 150% - Pr. 12
C) 0.30% Quinoline Yellow PN Extra Conc. C.I. 802

No. 160

A) 0.30% Quinoline Yellow PN Extra Conc. C.I. 802
B) 0.60% Pontacyl Fast Red AS Extra Conc. C.I. 176
C) 3.00% Anthraquinone Blue SKY C.I. 1088

No. 161

A) 1.80% Pontacyl Navy Blue M4B C.I. 304

TABLE 39 (continued)

ORLON TYPE 42 DYEING FORMULAE
(Cuprous Ion Dyeing at 250°F)

BLUE SHADE

No. 162

A) 1.50% Anthraquinone Blue B C.I. 1054
B) 1.00% Anthraquinone Violet 3RA C.I. 1080
C) 0.50% Fast Sulphon Black NB Conc. C.I. 304

No. 163

A) 0.7% Omega Chrome Blue Black RZN C.I. 202
B) 0.5% Xylene Light Yellow R
C) 3.50% Alizarine Light Blue B C.I. 1054

No. 164

A) 4.00% Anthraquinone Blue SWF Conc. 150% - Pr. 12
B) 0.50% Pontacyl Fast Red AS Extra Conc. C.I. 176
C) 0.25% Quinoline Yellow PN Extra Conc. C.I. 802

No. 165

A) 3.00% Alizarine Light Blue B C.I. 1054
B) 0.50% Omega Chrome Blue Black RZN C.I. 202
C) 0.30% Xylene Light Yellow R

No. 166

A) 1.50% Pontacyl Navy Blue M4B C.I. 304
B) 0.75% Anthraquinone Blue B C.I. 1054

GREY SHADE

No. 170

A) 1.00% Alizarine Light Grey RLL
B) 0.16% Lansyn Green BL
C) 0.02% Xylene Light Yellow R

No. 171

A) 0.50% Alizarine Fast Grey BLN New CF - Pr. 206
B) 0.05% Anthraquinone Violet 3RA C.I. 1080
C) 0.07% Alizarine Supra Blue A-CF - Pr. 12

TABLE 39 (continued)

ORLON TYPE 42 DYEING FORMULAE
(Cuprous Ion Dyeing at 250°F)

GREY SHADE

No. 172

A) 0.45% Alizarine Light Blue B C.I. 1054
B) 0.09% Brilliant Sulphon Red B
C) 0.07% Xylene Light Yellow R

No. 173

A) 0.30% Fast Sulphon Black NB Conc. C.I. 304
B) 0.25% Alizarine Cyanine Green G Extra New C.F. C.I. 1078
C) 0.25% Wool Fast Orange GA-CF C.I. 274

No. 174

A) 0.65% Alizarine Fast Grey BLN New CF - Pr. 206
B) 0.18% Anthraquinone Violet 3RA C.I. 1080

No. 175

A) 0.85% Alizarine Fast Grey BLN New CF - Pr. 206

No. 176

A) 0.60% Alizarine Fast Blue RB - Pr. 12
B) 0.45% Fast Acid Brown RG - Pr. 562

No. 177

A) 0.60% Alizarine Fast Blue CL - Pr. 12
B) 0.15% Rocceline C.I. 176
C) 0.10% Chinoline Yellow Conc. C.I. 801

No. 178

A) 0.60% Anthraquinone Blue SKY C.I. 1088
B) 0.15% Pontacyl Fast Red AS Conc. C.I. 176
C) 0.10% Quinoline Yellow PN Extra Conc. C.I. 802

TABLE 40

EXPERIMENTAL DYEING PROCEDURES

Boil-Off Procedure for All Fibers

Before dyeing, the producer finish of the synthetic fibers was removed by the following treatment:

Bath ratio 40:1
0.1% solution of Triton X-100
0.1% solution of tetra sodium pyrophosphate

The fibers were entered into the cold solution, the temperature was raised to 180°F, and the boil-off was continued for 20 minutes at this temperature. The bath was then dropped and the fibers were rinsed with warm water until free of detergent.

Scouring of Dyed Fibers

All fibers were scoured after dyeing to remove all uncombined dye and all residual dyeing assistants.

Bath ratio 40:1
0.1% solution of Triton X-100
0.1% solution of sodium carbonate

The fibers were treated in this solution for 20 minutes at 180°F. The bath was then dropped and the fibers were rinsed with warm water until free of detergent.

Vat Dyeing of Viscose Rayon

The selected percentage of each dye was pasted with 5 ml of a 5 g/liter of Igepon T Gel and then diluted with water to a bath ratio of 30:1.

The scoured fibers were entered into this cold solution. The temperature of the solution was raised to 130°F and the pigment dispersion treatment was continued at this temperature for 20 minutes. At that time the fibers were lifted from the solution and the following amounts of caustic soda and sodium hydrosulfite were added.

1/2 to 1 oz/gal. sodium hydroxide
1/2 to 1 oz/gal sodium hydrosulfite

The fibers were re-entered into the solution and worked for 30 minutes at 130°F. At the end of this time the dyebath was drained, the fibers were rinsed with cold water and then oxidized with a 1% solution of sodium perborate for 15 minutes. Rinsing and scouring completed the dyeing procedure.

TABLE 40 (continued)

EXPERIMENTAL DYEING PROCEDURES

Dyeing Nylon with Chrome Dyes

Bath ratio 30:1
Selected % of Dye
2% NH_4Ac

The fibers were entered into the above solution cold, the temperature was slowly raised to the boil, and boiling was continued for 30 minutes. At that time 1% of acetic acid (56%) was added and dyeing carried out for an additional 30 minutes at the boil. The fibers were rinsed before chroming for 30 minutes at the boil in a fresh bath of 2% $Na_2Cr_2O_7$ and 2% formic acid. Rinsing and scouring completed the dyeing process.

Dyeing Nylon with Acid Dyes

Bath ratio 30:1
Selected % of Dye
1% NH_4Ac

Dyeing was started cold, then slowly raised to the boil and boiled for 1-1/2 hours. One per cent of acetic acid (56%) was added after 30 minutes of boiling and an additional 1 or 2% was added after 1 hour of boiling. The fibers were rinsed and scoured to complete the process.

Dyeing Nylon with Metallized Acid Dyes

Bath ratio 30:1
Selected % of Dye
2% Na_2HPO_4

The dyeing in the above solution was started cold, the temperature was slowly raised to the boil and boiling was continued for 1-1/2 hours. A one per cent addition of acetic acid (56%) was made after 20 minutes and a 2% addition was made after 40 minutes boiling. Dyeing was completed by a rinse and a scour.

Dyeing Nylon with Neutral Dyeing Metallized Dyes

Bath ratio 30:1
Selected % of Dye
2-3% NH_4Ac

The fibers were entered into the cold solution, the temperature was raised to a boil and boiling was continued for 1-1/2 hours. One per cent of acetic acid was added after 30 minutes of boiling and a second addition of 1% acetic acid was made after one hour of boiling. The dyeing process was completed with a rinse and a scour.

TABLE 40 (continued)

EXPERIMENTAL DYEING PROCEDURES

Carrier Dyeing of Dacron with Acetate Dyes

Bath ratio 30:1
Selected % of acetate dyes
Selected % of Swelling Agent

The fibers were treated cold with the swelling agent in a 20:1 ratio bath for 20 minutes. The dyes were pasted with 5 ml of a 5 g/liter solution of Igepon T Gel, then diluted with water to a bath of 10 to 1 ratio. This solution of dye was added to the bath of swelling agent and fibers. The temperature was raised to the boiling point and the dyeing was continued for 1-1/2 hours at the boil. After the above, the fibers were rinsed and scoured to remove swelling agent and unfixed dye.

Pressure Dyeing of Dacron with Acetate Dyes

Bath ratio 30:1
Selected % of acetate dyes

The dyes were pasted with 5 ml of a 5 g/liter solution of Triton X-100, then diluted with the required volume of water to a bath ratio of 30:1. The fibers were immersed in the cold dyebath, the bath was raised to the boil and boiling was continued for 15 minutes. At the end of this time, the dyeing vessel was placed on the raised platform inside a pressure cooker which contained a quantity of preheated water sufficient to reach the bottom of the dye vessel. Melting and tarring of the acetate dyes was prevented by this arrangement because the metallic bottom of the dye vessel could not become excessively heated. The pressure cooker was now closed and heated slowly so that a 250°F temperature was reached after 15 minutes. Dyeing was continued at 250°F for 45 minutes. After this time, the pressure was released slowly and the dyed fibers were removed. The process was completed by rinsing and scouring.

Carrier Dyeing of Dacron under Pressure

This method is a combination of the carrier and pressure dyeing techniques. The treatment was identical with the carrier technique, explained above, until the boiling point was reached. In this method dyeing at the boil was carried out for 30 minutes after which the dyeing was placed in a pressure cooker and treated as a pressure dyeing. The temperature, however, was maintained at 250°F for only twenty minutes.

Dyeing of Orlon by the Cuprous Ion Technique with Swelling Agents

Bath ratio 30:1
Selected percentage of acid dyes
5 to 10% of $CuSO_4$
2 to 4% of Hydroxyl ammonium sulfate
Selected % of Swelling Agent

TABLE 40 (continued)

EXPERIMENTAL DYEING PROCEDURES

The fibers were first treated cold with the swelling agent in 2/3 the final volume of solution. The fibers were removed, the copper sulfate and hydroxyl ammonium sulfate were added, the solution was brought to volume, the pH was adjusted to 3.0 with NaOH and the fibers were now re-entered into the dye-bath. The temperature was slowly raised to the boil and boiling continued for 1-1/2 hours. Dyeing was completed by rinsing and scouring the fibers.

Pressure Dyeing Orlon by the Cuprous Ion Technique

Bath ratio 30:1
Selected % of acid dyes
2 to 5% $CuSO_4$
1/2 to 1-1/2% $NaHSO_3$
0.5% $NaNO_2$

The fibers were entered into the cold solution, the temperature was raised to the boil. When the boiling point was reached, the dye vessel was immersed in the pressure cooker and the temperature was raised to 250°F over a 20 minute period. Dyeing was continued for 45 minutes at 250°F. The fibers were rinsed and scoured to complete the dyeing process.

Dyeing of Dynel with Acetate Dyes

Bath ratio 30:1
Selected % of acetate dyes

The dyes were pasted with 5 ml of a 5 g/liter solution of Igepon T Gel and diluted with water to the required volume. The fibers were immersed in the cold bath and the temperature was raised to the boil. After boiling 3/4 of an hour, 50% NaCl was added and boiling was continued for an additional 3/4 of an hour. The fibers were then rinsed and scoured. Relustering of the fibers was carried out by heating the dried fibers at 250°F for 15 minutes. When dyeing the blue shades, 1-1/2% of p-phenylphenol was added to the bath at the start of the dyeing.

Dyeing Dynel by the Cuprous Ion Technique

Bath ratio 30:1
Selected % of acid dyes
1-1/2% p-phenylphenol with blue shades
1 to 5% $CuSO_4$
1/2 to 2-1/2% hydroxylammonium sulfate

TABLE 40 (continued)

EXPERIMENTAL DYEING PROCEDURES

The fibers were first treated for 15 minutes with copper sulfate, hydroxylammonium sulfate, and p-phenylphenol (blue shades) dissolved in the required volume. The dyes were then added and the solution was raised to the boil. Dyeing at the boil was continued for 1-1/2 hours. The fibers were rinsed with water, scoured, dried, and relustered by heating in hot air at 250°F for 15 minutes.

Dyeing Dynel with Combination of Acetate and Cuprous Ion Dyes

Bath ratio 30:1
Selected % of acetate
Selected % of acid dyes
1 to 5% $CuSO_4$
1/4 to 1-1/2% sodium hydrosulfite
1-1/2% p-phenylphenol (with blue shades)

The fibers were immersed in a 2/3 volume solution of p-phenylphenol at 150°F for 15 minutes. The dyes were then added to this solution, the temperature was raised to the boil, and dyeing was continued for 30 minutes. Forty per cent Na_2SO_4 was added and dyeing was run 15 minutes. At this time the copper sulfate and sodium hydrosulfite, dissolved in the remaining 1/3 volume of water, were allowed to drip slowly into the dyebath over a thirty minute period. The bath was kept boiling during this time and during an additional half hour after the last of the reducing solution was added. The dyed fibers were then rinsed, scoured, and heat relustered.

Dyeing of Acrilan

Acrilan was dyed with acid and metallized dyes using between 5 and 10% H_2SO_4 at the boil to exhaust the dye.

Bath 30:1
Selected % of dyes
5 to 10% H_2SO_4

Fibers were immersed in the cold solution of the dyes. The temperature was raised until boiling occurred and boiling was continued for 1 hour. The fibers were then rinsed and scoured.

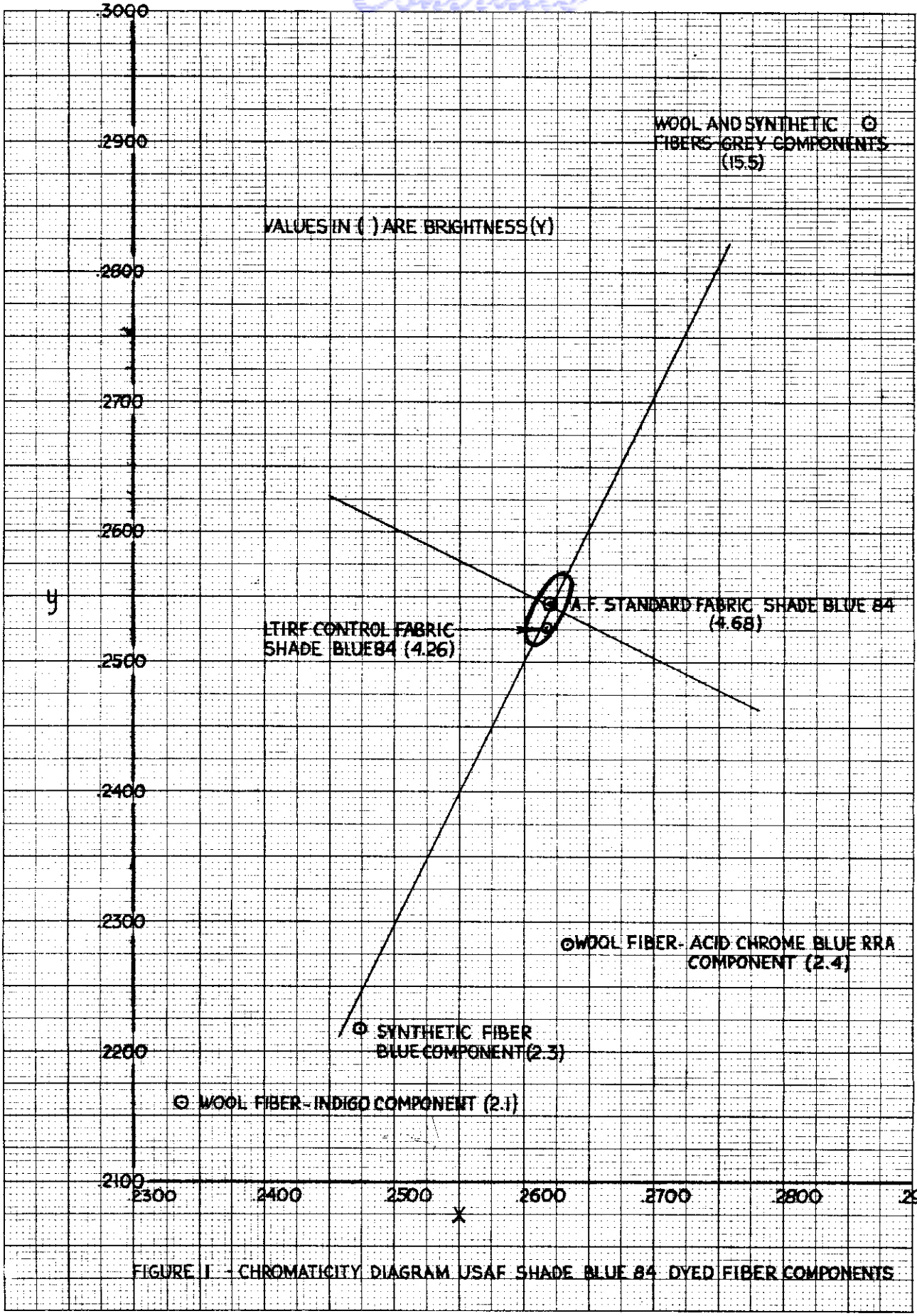

FIGURE I - CHROMATICITY DIAGRAM USAF SHADE BLUE 84 DYED FIBER COMPONENTS

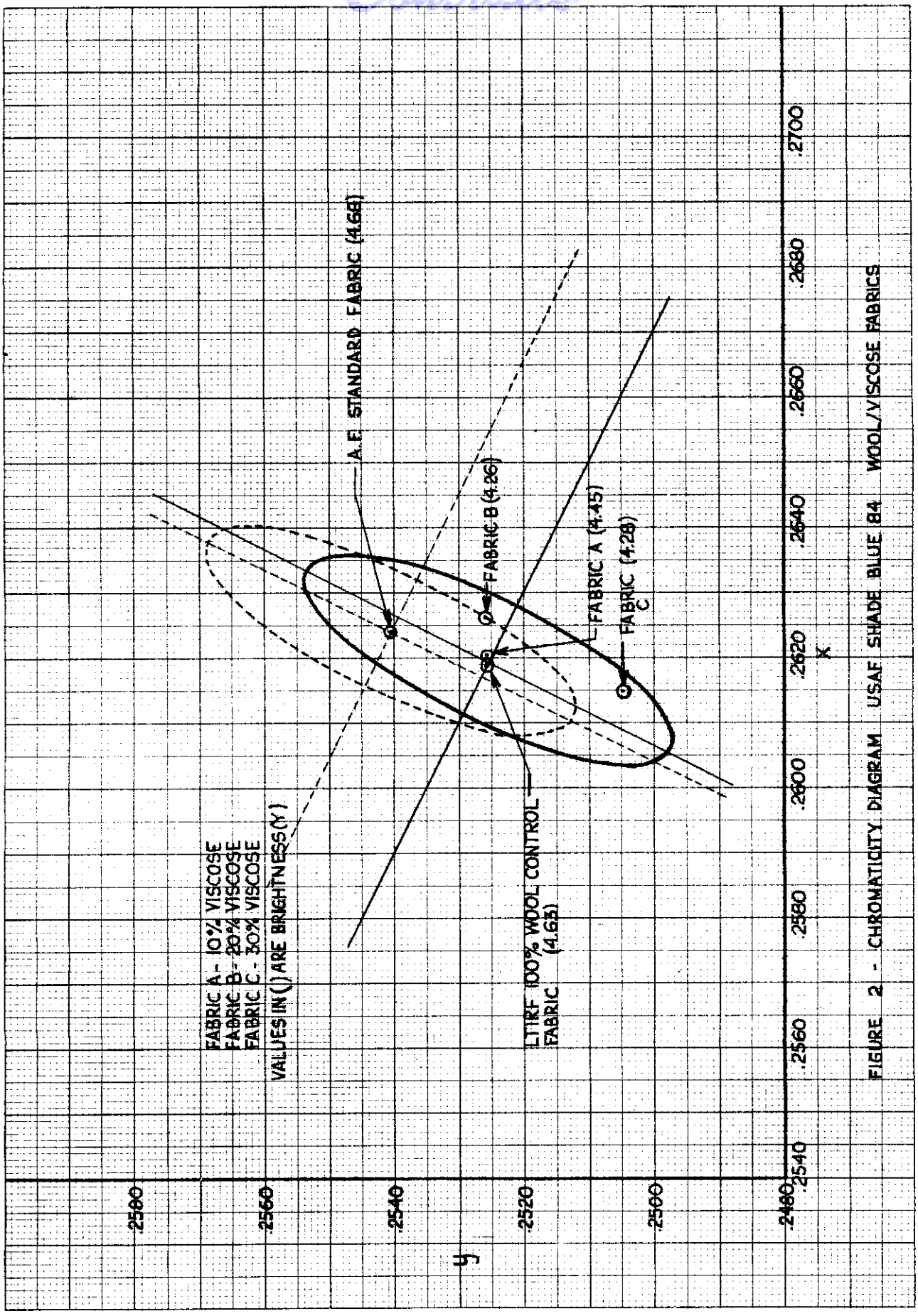

FIGURE 2 - CHROMATICITY DIAGRAM USAF SHADE BLUE 84 WOOL/VISCOSE FABRICS

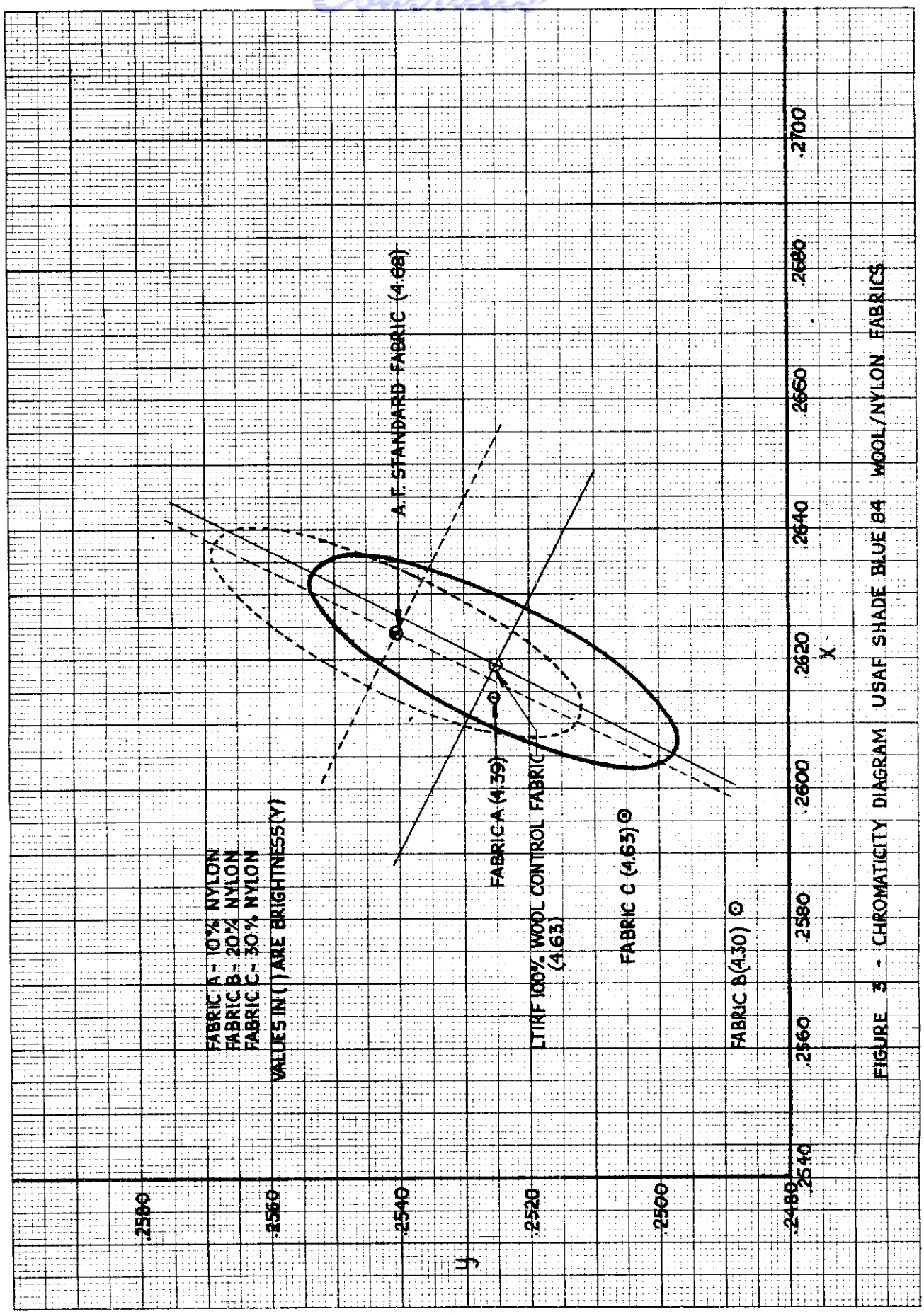

FIGURE 3 - CHROMATICITY DIAGRAM USAF SHADE BLUE 84 WOOL/NYLON FABRICS

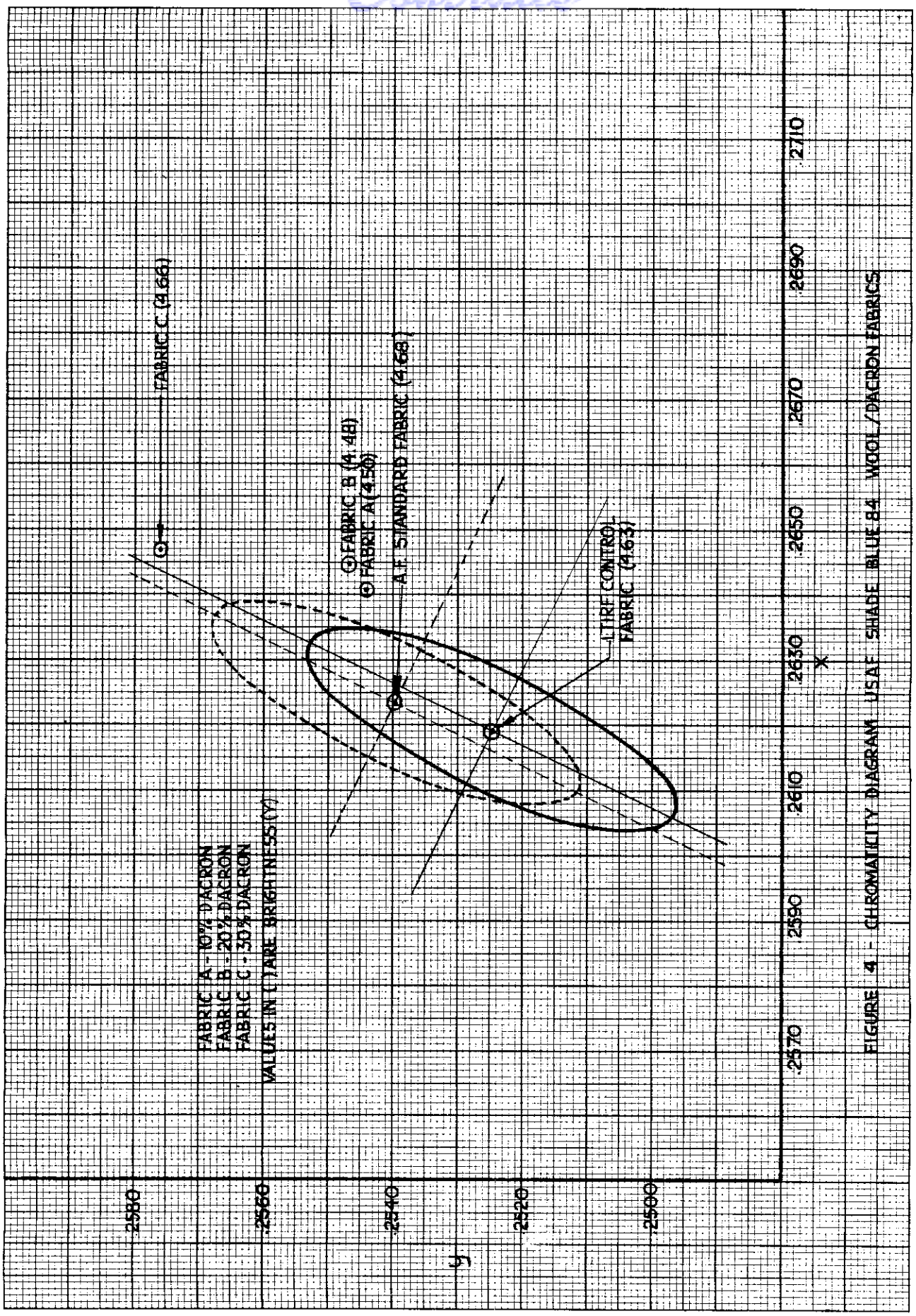

FIGURE 4 - CHROMATICITY DIAGRAM USAF SHADE BLUE 84 WOOL/DACRON FABRICS

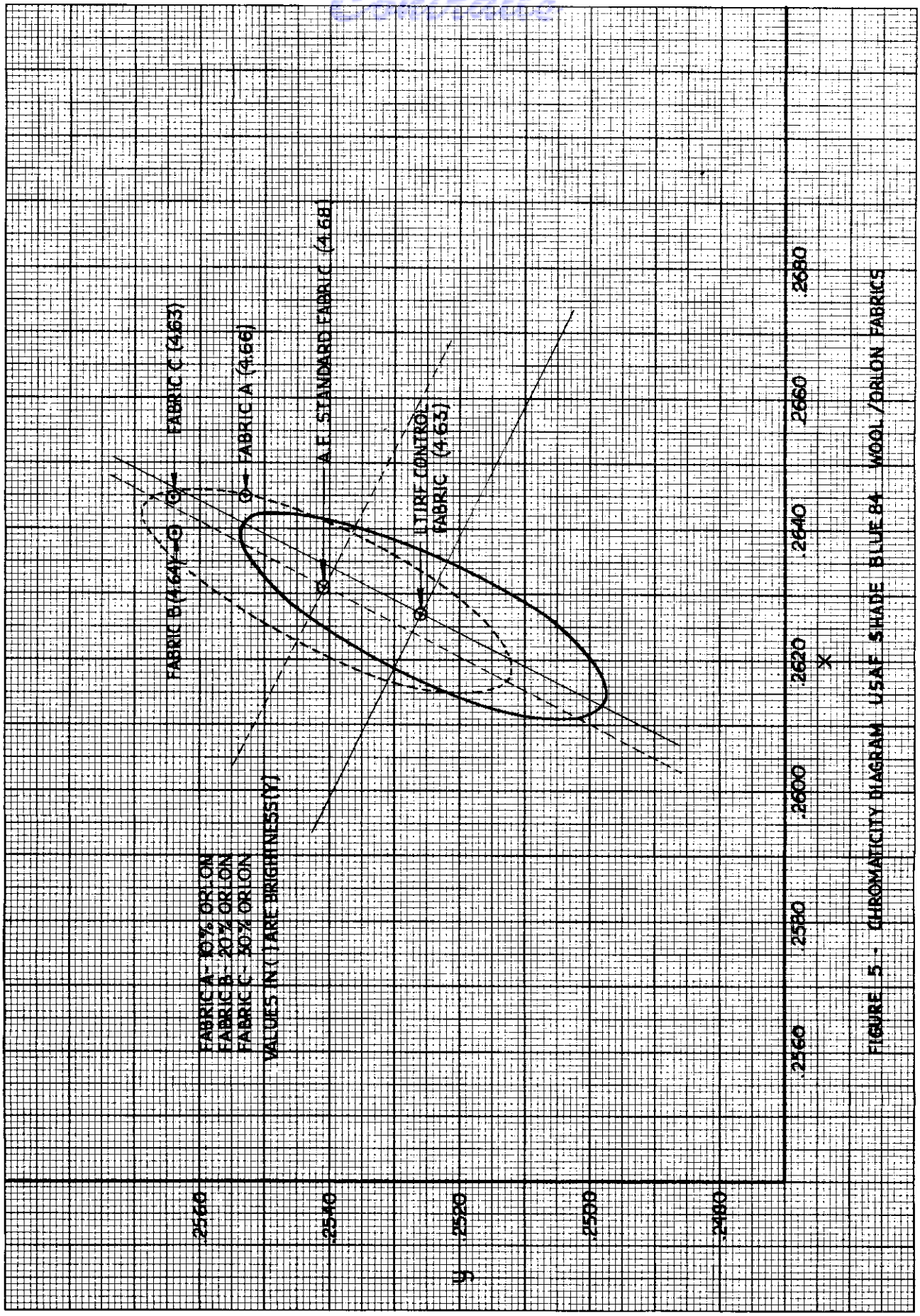

FIGURE 5 - CHROMATICITY DIAGRAM USAF SHADE BLUE 84 WOOL/ORLON FABRICS

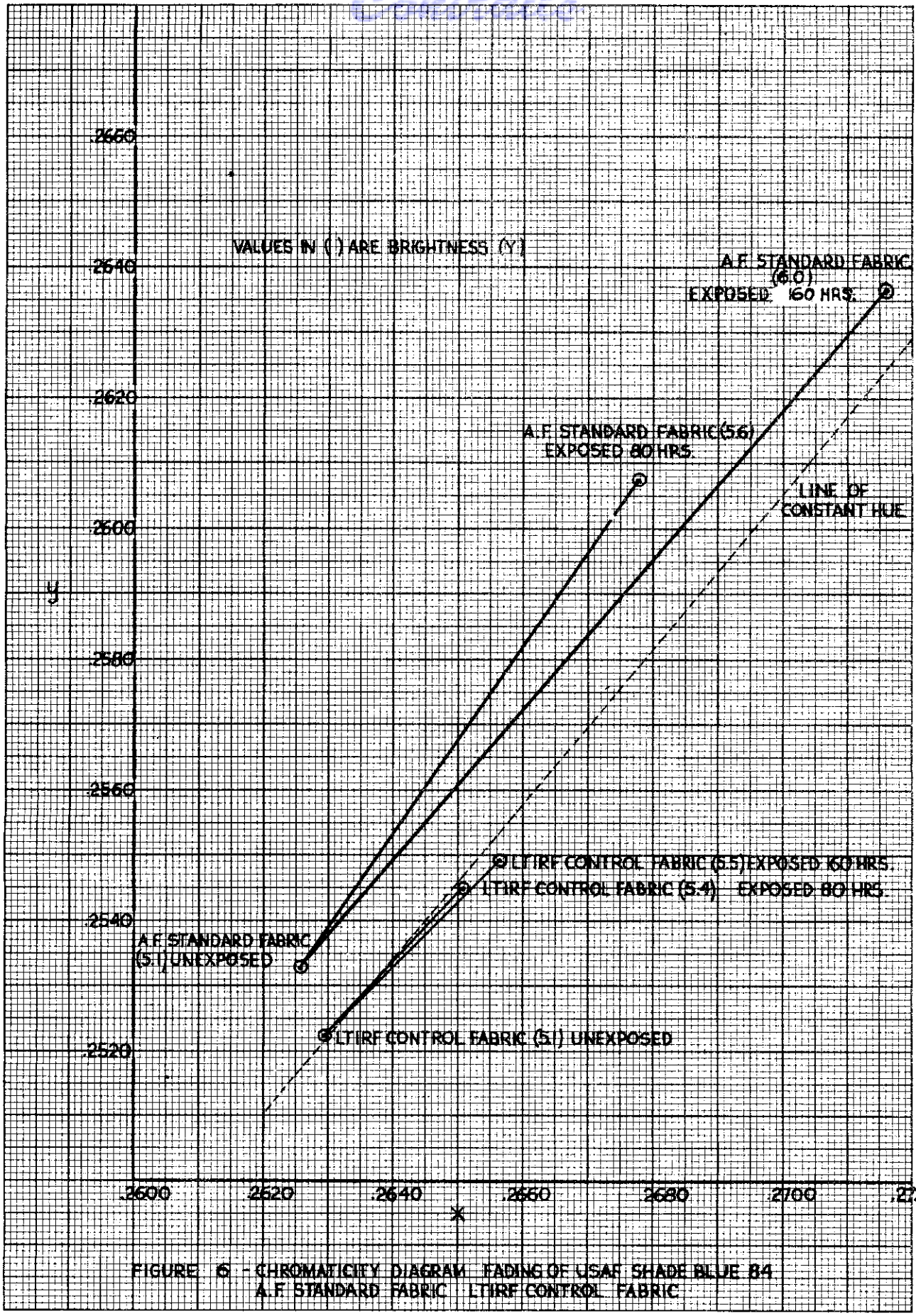

FIGURE 6 - CHROMATICITY DIAGRAM FADING OF USAF SHADE BLUE 84
A.F. STANDARD FABRIC LTIRF CONTROL FABRIC

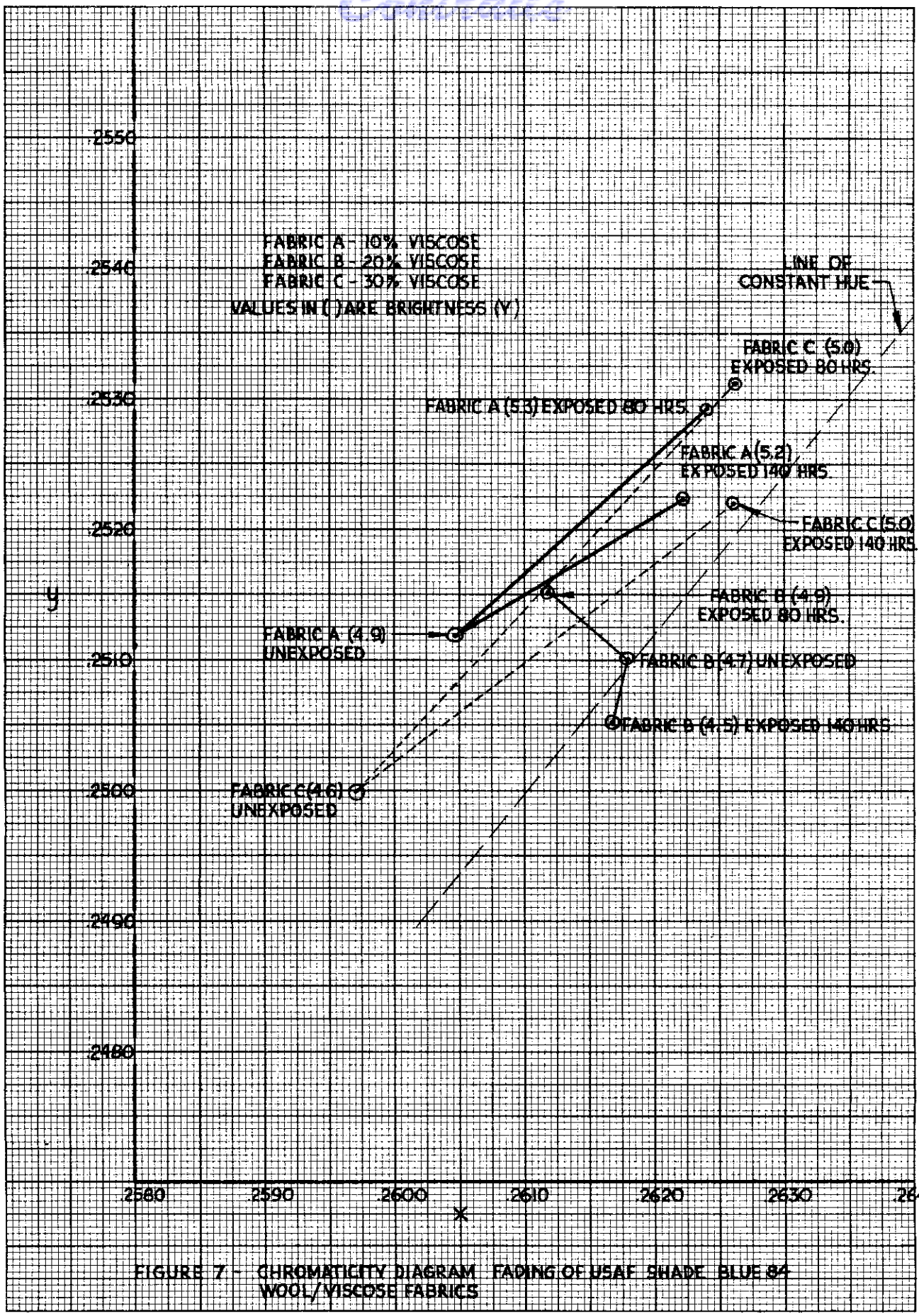

FIGURE 7 - CHROMATICITY DIAGRAM FADING OF USAF SHADE BLUE 84 WOOL/VISCOSE FABRICS

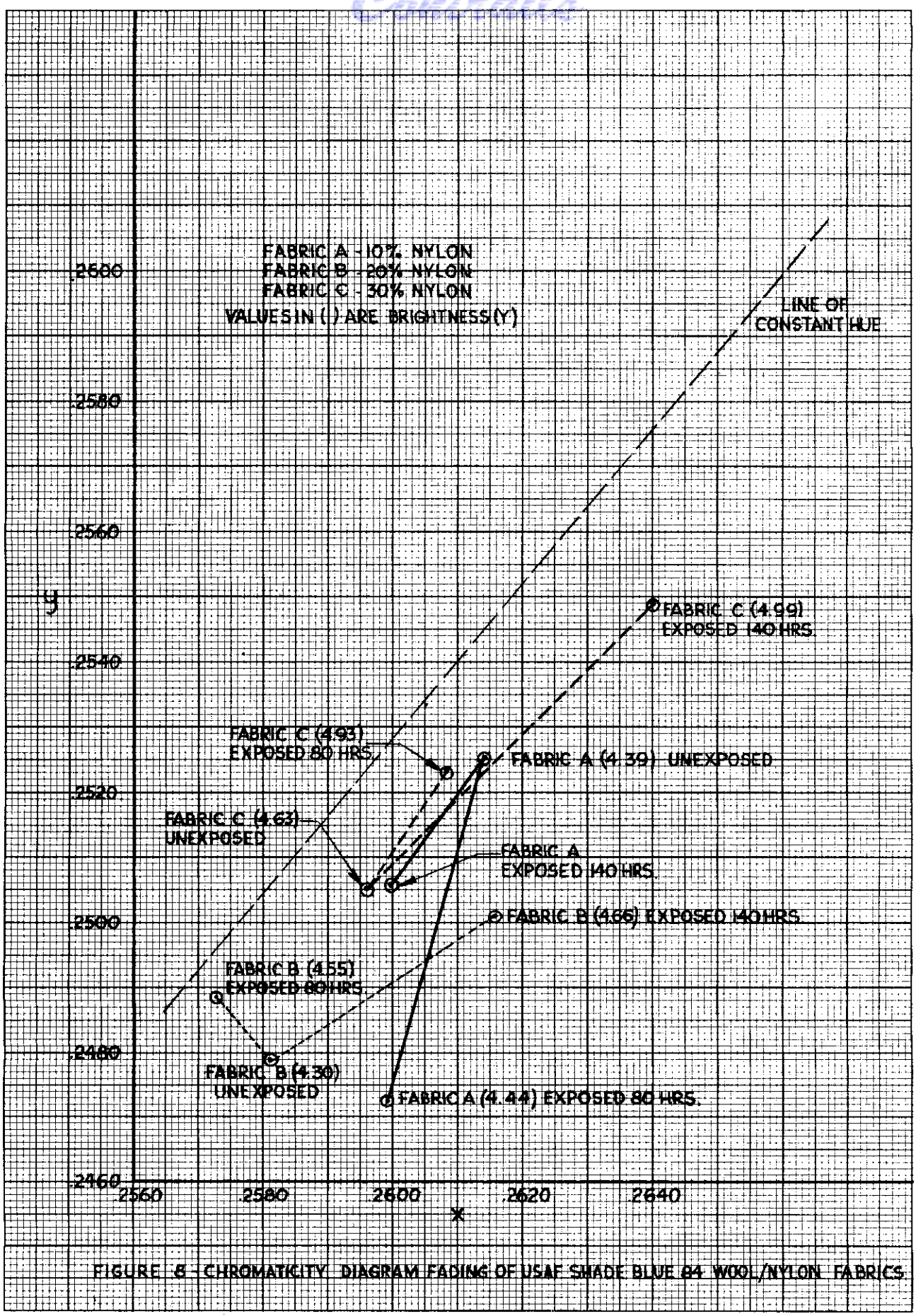

FIGURE 6 - CHROMATICITY DIAGRAM FADING OF USAF SHADE BLUE 84 WOOL/NYLON FABRICS

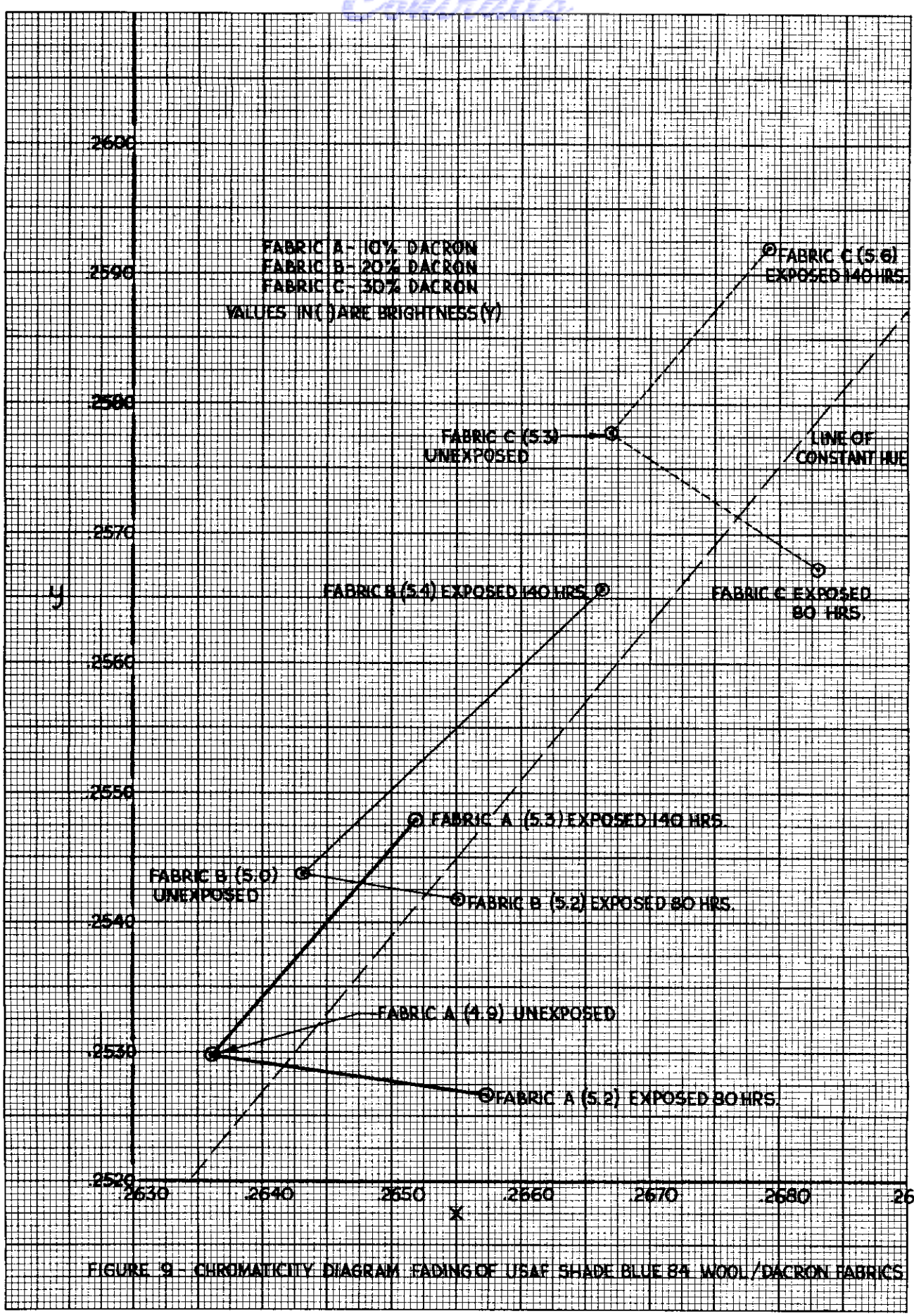

FIGURE 9 - CHROMATICITY DIAGRAM FADING OF USAF SHADE BLUE 84 WOOL/DACRON FABRICS

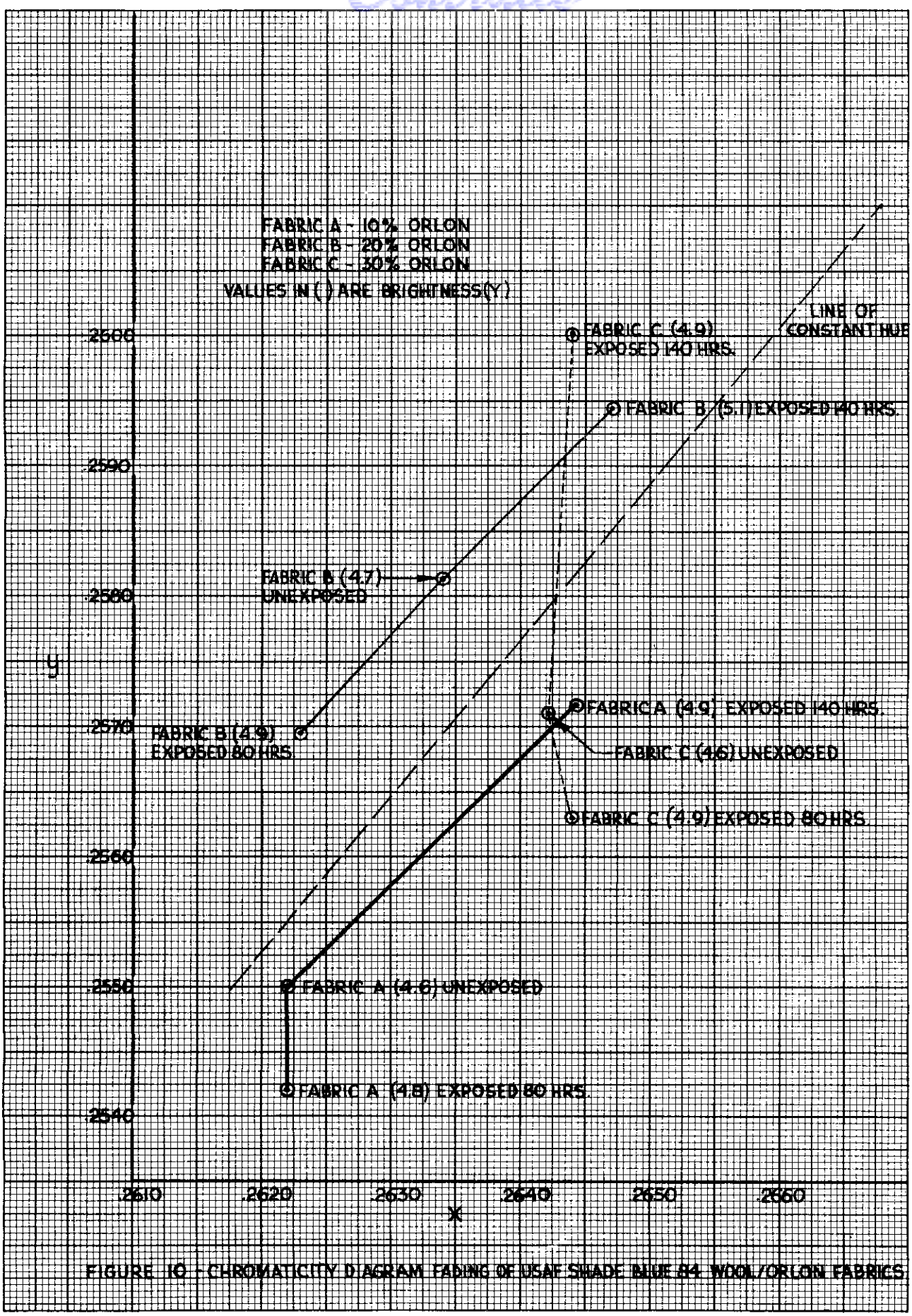

FIGURE 10 - CHROMATICITY DIAGRAM FADING OF USAF SHADE BLUE 84 WOOL/ORLON FABRICS

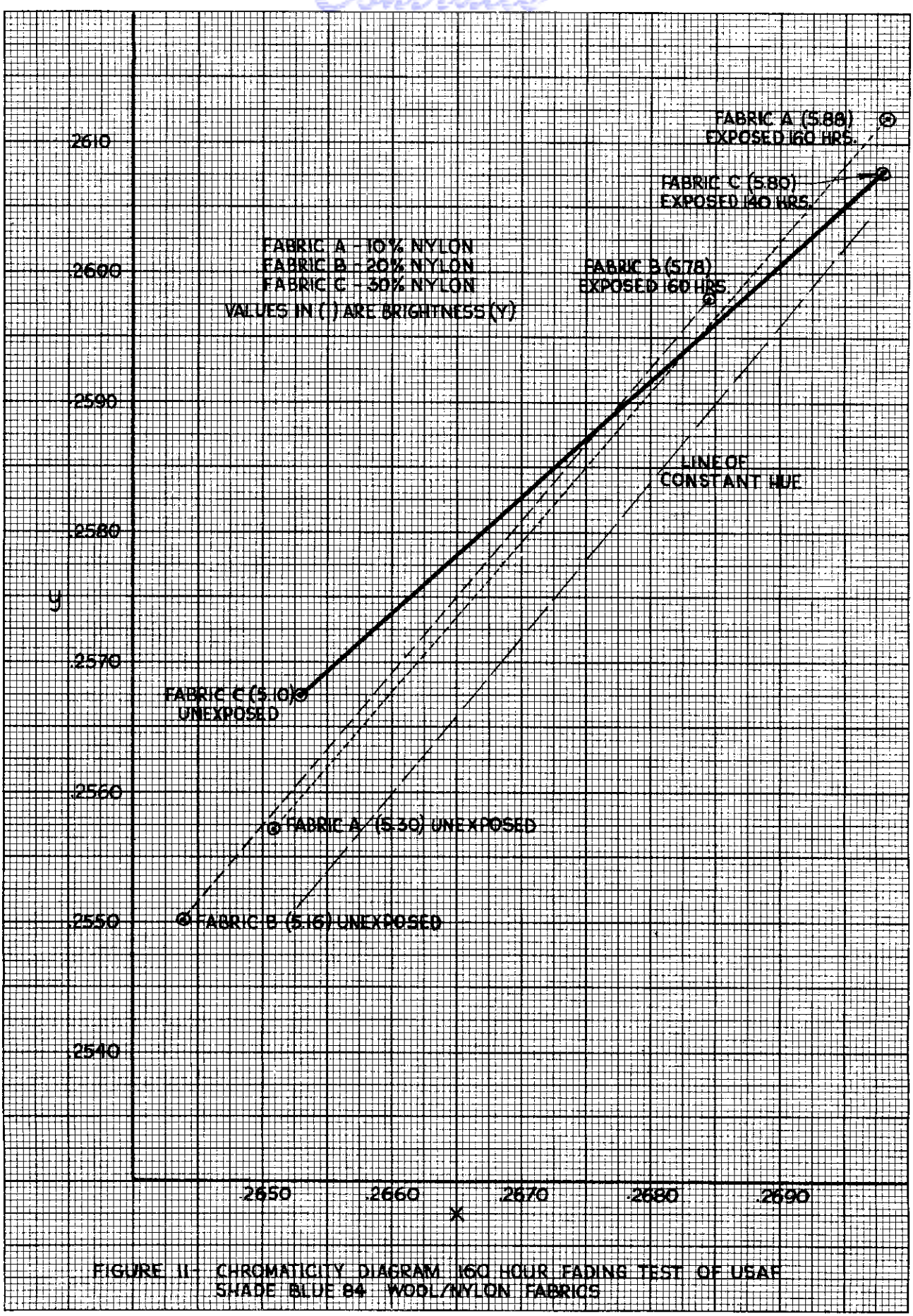

FIGURE 11- CHROMATICITY DIAGRAM 160 HOUR FADING TEST OF USAF SHADE BLUE 84 WOOL/NYLON FABRICS

APPENDIX

SPECTROPHOTOMETRY AND COLORIMETRY*

In the work associated with this report wide use has been made of spectrophotometry and colorimetry both in the development of dyestuff formulations and in the control of fabric manufacture. In this appendix, a brief discussion of the theoretical basis for that work is presented.

SPECTROPHOTOMETRY

In its simplest form a spectrophotometer is a device for analyzing the quantity of light a sample reflects or transmits as a function of wavelength relative to a standard (usually MgO). This is accomplished by splitting white light into a spectrum and then illuminating the sample and standard with successive narrow portions of this spectrum. Although the intensity difference which results due to the difference in absorbing power may be evaluated visually, this is quite tedious and subject to many errors. Today it is most frequently done by means of photoelectric cells and the result recorded automatically in a few minutes.

The result of such an operation is a plot of reflectance vs wavelength. By use of special cams it is also possible to plot a function of wavelength which will be proportional to the concentration of dye on the fiber. The most commonly used is the Kubelka-Munk function, i.e. $\frac{1-R^2}{2R}$. By plotting instead the logarithm of this function we obtain a graph in which the curve shape is independent of concentration (1).

In practice, plots such as those described above are used most frequently for shade matching, dye strength measurements, and trouble shooting. Since this report is concerned only with dyestuff formulation and shade matching, it will not be necessary to discuss other applications. In principle the technique is simple and proceeds as follows:

1. The standard to be matched is measured by means of a spectrophotometer with the special "R" cam attached.

2. A careful study of the resulting curve is made with the intention of selecting dyestuffs which will, in combination, closely approximate the standard curve.

* This discussion is based in part on a paper presented to the Textile Federation of Canada by Roland E. Derby, Jr.

3. A "match" is then constructed by combining graphical solutions of the appropriate equations with prepared curves of the selected dyes at known concentrations. If such curves are not available, they must be constructed from experimental dyeings. This "curve" or physical match is of utmost importance in assuring trouble-free matching problems which may occur at a later date.

4. If a combination can be found which possesses the desired properties plus matching the curve, the problem is solved.

In a case where one desired to optimize all properties of the formulation, compromises must be tolerated; however, a match under two or more illuminants is desirable. It should be emphasized that this is a compromise situation and at the earliest possible stage the old standard should be discarded and the new formulation established as the standard.

In the case of matches made by blending primaries of proper shade, a different procedure must be employed. The reason for this is that the laws governing blends are different from those affecting solid shades. Although certain semi-empirical additive relations are known which are of utility in such problems, their use is not as clear cut as the preceding solid shade problem.

The general procedure involved in initial formulation is as follows:

1. On the basis of colorimetry, one selects certain possible primaries.

2. A trial calculation is then made using these primaries by means of the Stearns-Noechel additive function (2).

3. The agreement with curve shape match is then examined and necessary changes in the dyestuff formulations of the primaries or the blend are undertaken.

4. In selecting the primaries it is desirable to employ the minimum number compatible with attaining the desired "heatheriness".

5. The primaries should be so located on a chromaticity diagram that the standard is quite centrally located with respect to the primaries. In other words, the standard blend should fall roughly at the geometric center of the figure formed by joining all the primaries by straight lines in such a manner that each primary is joined directly only to adjacent primaries.

In order to understand better the references to chromaticity, color coordinates, etc., made above, it is desirable to discuss briefly the physical concepts involved and at the same time to include a discussion of color tolerance specification.

COLORIMETRY

It has been demonstrated by thousands of experiments that it is possible to represent adequately the color of a textile material in a given illuminant by three numbers. These numbers are called tristimulus values and are designated X, Y, Z. For an authoritative account of the historical development one should consult "The Science of Color" by The Committee on Colorimetry of The Optical Society of America.

In order to determine the tristimulus values of a given object color, the following data are necessary:

1. The reflectance (or transmittance) of the material as a function of wavelength throughout the visible spectrum (400-700 millimicrons).

2. The energy distribution of the illuminant being considered (i.e., daylight, tungsten light, etc.) presented as a function of wavelength over the 400-700 millimicron range.

3. The basic color-matching characteristics of an average observer over the visible range of wavelengths.

The basic data for Item 1 may be readily obtained by means of a spectrophotometer. The necessary information regarding the energy distribution, Item 2, has been experimentally determined by spectroradiometry for average daylight (Illuminant C) and tungsten light (Illuminant A). These results have been made definitive by the C.I.E. (International Commission on Illumination).

Lastly, the ability of the average observer to discriminate between near color matches is represented by fundamental data determined by careful experiments. The results are represented by three curves called by tristimulus functions $\bar{x}$, $\bar{y}$, $\bar{z}$. The significance of these curves is perhaps best understood by noting that at any given wavelength the value of the function represents the amount of a given primary necessary to match a spectrum color of that wavelength. In other words, if one additively mixed the CIE primaries in the proportions indicated at a particular wavelength, the average observer would consider the mixture to be a match for the spectrum color. It should be noted that the selection of primaries is not unique, since the resulting specification based on one set can be transformed into that based on another mathematically, provided the relationship of one set of primaries

to the other is known. It is also important to realize that the data specify an average of several observers and thus can be considered more representative than a single observer.

In order to calculate the tristimulus values X, Y, Z, one must obtain the product of these functions over the visible region. Such a process may be performed by integration, where the tristimulus values are:

$$X = \int_{400}^{700} E(\lambda)R(\lambda)\bar{x}(\lambda)\,d\lambda$$

$$Y = \int_{400}^{700} E(\lambda)R(\lambda)\bar{y}(\lambda)\,d\lambda$$

$$Z = \int_{400}^{700} E(\lambda)R(\lambda)\bar{z}(\lambda)\,d\lambda$$

Since the products $(E \cdot \bar{x})$, $(E \cdot \bar{y})$, and $(E \cdot \bar{z})$ are constant, it is only necessary to evaluate R (the reflectance). As previously noted, this information is readily obtained by spectrophotometry. In this project all integrations were performed mechanically, the appropriate integrals being evaluated as rapidly as the General Electric Spectrophotometer determines the reflectance of the sample, i.e., approximately 2-1/2 minutes per sample.

In most cases it is more convenient to plot "color coordinates" obtained from the following relations:

$$x = - \frac{X}{X + Y + Z}$$

$$y = - \frac{Y}{X + Y + Z}$$

note: $z = 1 - (x + y)$

The primaries of the CIE system were originally chosen so that Y (in appropriate units) indicates the photometric reflectance (designated as the apparent luminous reflectance). Thus it is usually considered that x, y indicated chromaticity, namely hue and saturation of a given sample, while Y indicates its lightness. In conventional plotting techniques x, y, and Y are plotted in rectangular coordinates.

In this brief discussion it is impossible to justify the technique or the data. Perhaps the best justification is that in over twenty years, thousands of color calculations based on this system have revealed few significant deviations between visual experience and properly measured results.

GRAPHICAL REPRESENTATION OF COLOR

The conventional method of plotting color was outlined in the previous section, that is, in a rectangular coordinate system. Such a plot is called a "chromaticity diagram".

A most important development in the utility of the colorimetric method occurred when a plot was devised wherein the standard always appeared at the origin of the coordinate system regardless of the absolute position in color space. All samples are then plotted by their difference from the standard. This procedure was originally implied in a paper by MacAdam (3) and has been recently utilized extensively in publications by H. R. Davidson (4).

It has proven of value considerably beyond the original reasons for its development. Let us consider its role in the generalized problem of color control with reference to a specific standard color.

First, a suitable standard in the form of a swatch of material is agreed upon by those concerned. The colorimetric specification of the material is then determined with great care in the manner previously outlined. It is very important at this stage to assure adequate calibration of the spectrophotometer according to procedures recommended by the National Bureau of Standards. The automatic integrator should also be carefully calibrated at the same time. Several measurements (at least 2) should be made on the standard in order to specify the precision of measurement. If sufficient material is available, the standard is then divided in half, one half becoming a master standard and the other a working standard.

A chart is next prepared as shown in Figure 12. In this figure it will be noted that the standard (S) appears at the origin. Δ x and Δ y, the differences in color coordinates between the standard and any sample are plotted on the abscissa and ordinate respectively. This procedure tends to minimize the periodic or random instrumental variations (of a minor nature) which may enter into an exact specification of a given sample. The points P_1, P_2, P_3 and P refer to particular samples measured and plotted as described. The lightness difference Δ Y is shown in parenthesis beside the appropriate point.

In Figure12 an "acceptability" ellipse has been drawn about the standard. The ratio of the major and minor axis of this ellipse may be readily determined from data published by MacAdam (3). The dimensions of the ellipse in terms of the scale units being used are best determined experimentally; considerable variation being encountered depending on the type of material being

considered and the purpose for which it is intended. However, an ellipse which is 2.5 times the unit ellipse specified by the values given by MacAdam has been found to be satisfactory for this project. Lighter shades will require smaller multipliers and darker shades somewhat larger ones.

There are several ways of representing the Δ Y tolerance. For general control work a method of considerable utility is derived from the familiar contour terrain map. In this method a chart is prepared exactly as in Figure 12 with the exception that it is composed solely of a series of concentric ellipses inside the one shown. Each ellipse represents a line of constant Δ Y tolerance. This would be a maximum (corresponding to the top of the hill) when Δ x and Δ y = 0, and zero when the point falls on the edge of the ellipse (the one representing chromaticity tolerance). This is prepared on transparent paper, and it is merely necessary to place this over the chart shown in Figure 12 and note whether the point has too great a Δ Y for the particular chromaticity involved. For example, see point P_3 in the diagram where the value (+ 10) indicates it is too light. Point P_2, while adequate for depth, is "off shade", falling outside the ellipse. It should be pointed out that in certain cases the lightness tolerance on the heavy side will not be equal numerically to that on the light side (as indeed it should not be due to the Weber-Fechner relation, wherein Δ Y/Y = constant). This fact necessitates having two transparent charts, one for dark samples and another for light. It is also possible to present contours in different colors or even more simply a different color may be used in printing in the value assigned to the particular contour.

In Figure 12 it will be noted that designations such as redder, bluer, etc., have been shown by arrows. This is not a general scheme, for the particular designation depends on the shade being considered. However, such a chart can be easily prepared, for example, by reference to a book of Munsell colors and their basic colorimetric data (5).

A special plot devised by Davidson & Hanlon (6) is sometimes useful. In this case a new chart is prepared in which the x axis consists of units obtained by dividing the distance to any point (say P_2 in Figure 12) by the distance to the edge of the tolerance ellipse along the line joining the standard to the piece (i.e., P_2). On this scale (1) represents a tolerance when there is no lightness difference (Δ Y). The Y value for the sample is then plotted on the y axis. Under these conditions the Δ Y scale may be adjusted so that a circle results in which 1 unit (along the y axis) at zero chromaticity is equivalent to 1 unit (along the x axis) at zero lightness difference. Such a plot has the decided advantage that linear distances are directly equal to color differences. However, a somewhat empirical calibration must be made for each shade. This technique should prove most useful in cases where conditions are fixed and a large number of color differences are to be evaluated.

By plotting samples at various stages of production, it is possible to establish the "average" change which a piece undergoes in finishing. Thus, it is possible to predict where (on the chromaticity plot) future samples must fall in order that on the average a piece matching the standard will result.

FADING TEST EVALUATION

Since a considerable number of lightfastness test results have been published during the course of this project, a brief discussion of the procedure used would seem to be in order. The following outline indicates the procedure:

1. The unexposed area and exposed area are measured (two measurements on each area).

2. The color difference between areas is determined by a suitable formula. At present this is the Adams-Nickerson formula; complete details for its use being given in the Dyestuff Reporter (7).

3. The chromaticity and lightness of the two areas are plotted on a chart in the manner described earlier. These points are connected by a line.

4. A Munsell Constant Hue Line is drawn on the chart (5).

5. Steps 1 through 3 are carried out for the standard and all samples.

In order to clarify certain points regarding these charts, the following points should be noted:

1. In evaluating light tests a sharp line exists between faded and unfaded sections. It has been recognized for many years that this causes difficulty in attempting to employ color difference formulae which were developed for general conditions of sample comparison, i.e., two swatches. It is therefore important to consider carefully the data and the nature of the variations in using equations of the Adam's type.

2. Generally, if a sample fades parallel to a Munsell Constant-Hue Line over a short distance it will be more desirable than one which does not (if both show "equal" color differences). At any rate the degree of non-parallelism should not be greater than the standard.

3. If a change of formulation should be made, it is readily apparent by a drastic change of slope.

4. Due to the fact that there is a tolerance around the standard (i.e., the ellipse shown), it is frequently possible that a dyeing may exhibit inferior or better fastness than the standard, even though both are dyed with the same formulation. In other words, a piece may fall within the ellipse and be acceptable. However, on fading, this piece may fade off tone due to the slight unbalance of colors. That is, it may move more obliquely to the Munsell Constant-Hue Line or a greater distance. This is the danger of adding so-called "shading colors".

The method outlined is useful as a quality control procedure. For example, if it is specified that the sample must show less fading than a standard, then routine sampling of current production may be tested by the criteria of a smaller color difference and equal or better parallelism.

If standards and tolerances were set up on this basis, particularly in referee cases, most discussion and argument could be avoided. That this has been done only rarely is a matter of some concern.

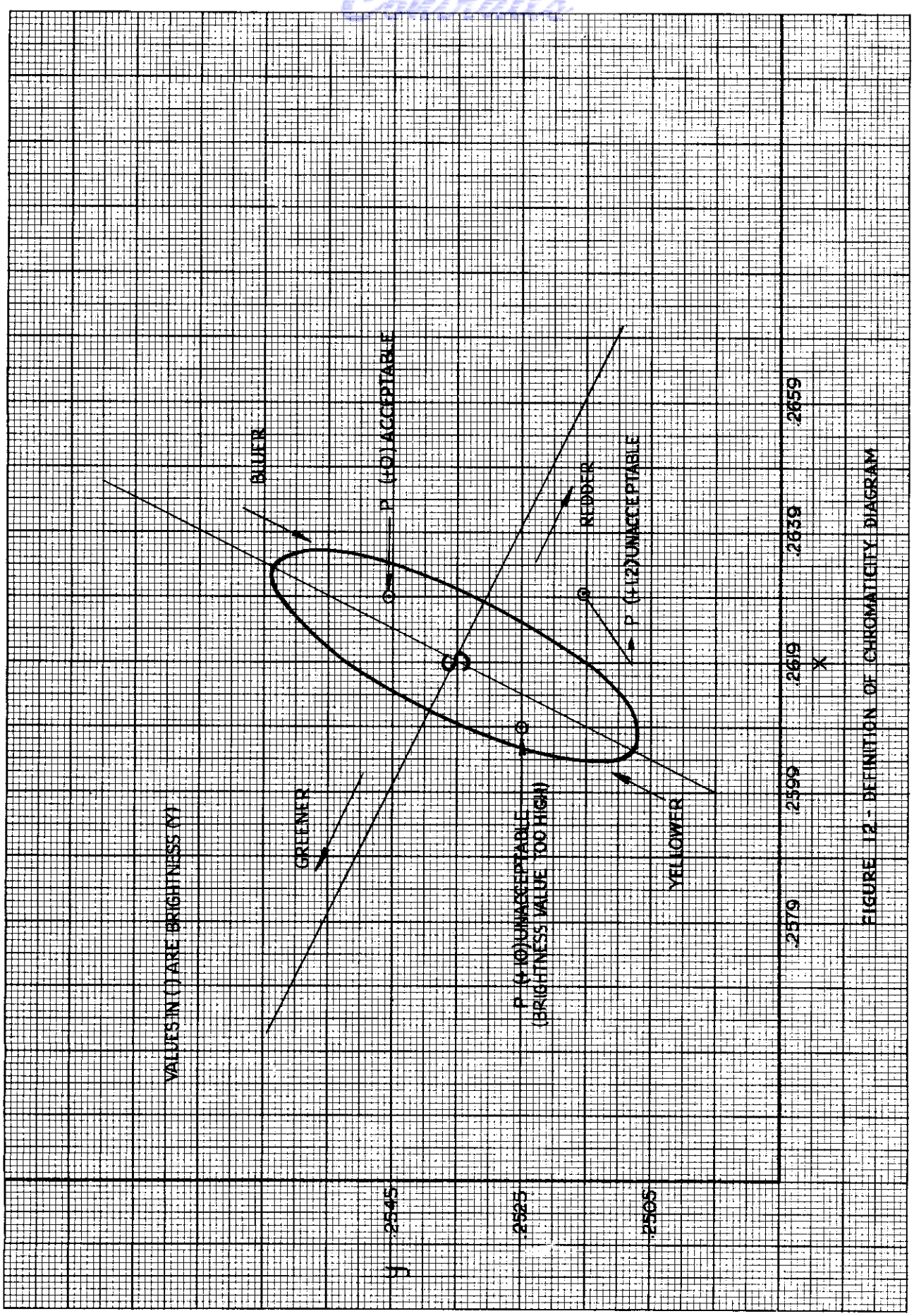

FIGURE 12 - DEFINITION OF CHROMATICITY DIAGRAM

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