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This report also describes the means of applying color values to an ink formulation and specification system for the manufacture/blending of color matched lithographic inks. The ink formulation is based on using eight basic colors plus black and white. Blending these in specified parts can produce virtually all ink colors.

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STANDARD PRINTING COLOR IDENTIFICATION SYSTEM

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Printing and Distribution Division

February 1972

PREFACE

GENERAL: This technical report describes the Department of Defense (DOD) Standard Printing Color (SPC) Identification System as used by the Mapping, Charting, and Geodesy agencies of the United States Army, United States Navy, and United States Air Force.

PURPOSE: This report gives technical information on a method of identifying and cataloging printing colors.

SCOPE: This report defines the DOD Standard Printing Color Identification System in which all participants use a common method of identifying color. The system allows easy color communication between agencies and the use of identical colors on common agency produced products.

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ABSTRACT

The Department of Defense - Mapping, Charting, and Geodesy (DOD-MC&G) Color Identification System for Lithographic Printing is broad enough in scope to include and catalog all colors in a logical, orderly arrangement. Under this system, lithographic colors are assigned numbers which are descriptive of the color values. The system is based on international values as seen by an international standard observer and illuminant. The CIE description of color is applied as the basis for color identification.

This report also describes the means of applying color values to an ink formulation and specification system for the manufacture/blending of color matched lithographic inks. The ink formulation is based on using eight basic colors plus black and white. Blending these in specified parts can produce virtually all ink colors.

DEFINITIONS

Basic Colors - Eight commercially available specific colors plus black and white from which infinite colors may be blended. Physical samples and specifications of these basic colors are shown in the Standard Printing Color Catalog.

CIE - International color system which resulted from the 1931 convention in London of the Commission Internationale de l'Eclairage.

CIE Values - Tri-stimulas values in terms of X, Y and Z representing the measurement of color as achieved on a full color spectrophotometer.

Color Values - CIE color system data translated into dominant wavelength, purity and reflectance.

Dominant (or Complementary) Wavelength - A precise correlation of hue, expressed in Nanometers (nm).

Hue - A particular variety of color; shade; color family; i.e., red, yellow, blue, etc.

Nanometer (nm) - (formerly millimicron) 1/billionth of a meter.

Purity - A precise measurement expressed in percentage of the lack of grayness of a color. The total absence of color (as in black, gray, and white) corresponds to 0% purity. The total presence of pure color (absence of gray content) corresponds to 100% purity.

Reflectance - A precise correlation of the lightness of a color expressed in percentage. Darkest colors approach 0% reflectance while the lightest (most pastel colors) approach 100% reflectance.

SPC - Standard Printing Color.

INTRODUCTION

The Standard Printing Color Identification System provides a standard method of identifying colors for the Department of Defense Mapping, Charting, and Geodesy Agencies. With geographically dispersed printing facilities of two or more independent producing organizations, the color matching of printed charts can only be accomplished by using a common color system. The system must have a common language by which, in the communication of colors, the language communicates the total requirement for all parties to understand. The communication of colors includes three basic requirements:

a. Visual Color sample/standard for visual communication

b. Specification and tolerance (numerical) for technical communication

c. Identification (name/number) for verbal communication

The Standard Printing Color Identification System for lithographic colors is broad enough in scope to include any conceivable color, and catalog all colors in a logical, orderly arrangement. This method of identifying colors may also be applied to other color systems used in producing maps, charts, and publications.

SELECTION A COLOR IDENTIFICATION SYSTEM

The specification and description of color is not a new problem nor is it unique to the DOD Mapping, Charting and Geodesy (MC&G) community. The scientific and industrial community has been working on the problem since Newton's time in the 17th century. The talents of such people as Newton, Judd, Maxwell, Munsell, Ostwald, and many others have been devoted to developing solutions and techniques for helping to resolve some of the problems involved.

A review of the various color identification systems in use today disclosed that no one system satisfied all the following criteria:

a. Provide an identification number that actually describes the color in nationally and internationally understood terms.

b. Have a space for every conceivable color and impose no limitation on creation of additional colors; i.e., any newly devised color would already have a numbered space waiting that would put the color into an orderly arrangement relative to the existing colors.

c. Function with and be representative of the lithographic printing process.

d. Have a color standard that is durable, not subject to variations due to age and use.

e. Provide an immediate and automatic alert of the similarity of a new color to existing colors by use of identification numbers.

Limitations of existing color systems fall in categories as follows:

a. <u>Arbitrary Identification</u> - The identification bears no relation to the description of the color or to other colors, therefore, the identification does not properly lend itself to cataloging.

b. <u>Limited Selection</u> - Does not contain within the scope of the system unlimited establishment of additional colors without disturbing the system.

c. <u>Durability</u> - Reliance on physical samples presenting problems caused by color fade, aging and use in addition to problem of color matching over periods of time. Instrumentation and numerical values represent the only durable color standard.

d. <u>Opaque Colors</u> - Designed for paints and other such opaque substances rather than for the relatively transparent lithographic inks.

e. Surface Characteristics - Physical samples prepared on materials which give a different visual appearance than is obtained by the lithographic ink on basic paper base.

f. International Recognition - Lack of relationship of basic color values to international standards.

The color identification numbers in the DOD SPC system are based upon the most significant digits of the full color values derived from the evaluation of the CIE values of a particular color. The CIE system is by far the best known system using instrumentation to evaluate a color. The CIE system is used as a basis for national standards by the National Bureau of Standards, and is used by major industries involved in producing closely matched colored products over periods of time, or in plants that are geographically separated. The CIE system is kept current by national and international meetings, and its values integrate the spectral curve of any color into a set of values as seen by an international standard observer and illuminant. Using the standard observer and illuminant, any two colors with equal values will look alike. Any two colors with different values will appear visually different.

APPLYING THE CIE SYSTEM

The CIE system denotes a color in terms of values of X, Y and Z and also in terms of chromaticity coordinates of x and y. This information is important to the technical evaluation of a color, as it translates to dominant wavelength, purity, and reflectance.

In the DOD-SPC identification system, CIE values are obtained by measuring on a spectrophotometer, a controlled sample litho print which truly represents the color and strength a particular ink will produce in normal lithographic production. To avoid possible color contamination or loss of ink film thickness control on lithographic equipment, all variables, including paper, must be controlled to guarantee true representation of normal ink color. These variables are:

a. Cleanness of all press components

b. Ink/water balance

c. Ink film thickness

d. Paper whiteness/brightness

Although densitometers or tri-stimulus colorimeters can provide spectral readings, the full color spectrophotometer best assures the precision and calibration necessary for national or international standards.

Regardless of the equipment used, the sheet on which the color is printed is used as a reference, a zero point, or a standard. This makes paper brightness significantly important. Paper used in the printing of the litho prints/standards, must be of a common whiteness established to some standard. JCP E-20 paper, procured single sheeted, and having a paper brightness factor of 77% is being used for the litho prints. The absolute color value of the paper standard desired for the litho prints, as compared to Barium Sulfate ($BaSO_4$), is as follows:

$$x = .3136$$

$$y = .3214$$

$$Y = 76.48\%$$

Readings of color prints/standards must be converted into CIE values using a method designed around the equipment being used. Full color spectrophotometer equipment can be installed with recorders and the data translated into computer language for evaluation.

DERIVING CIE VALUES AND COLOR VALUES

To explain the derivation of CIE values, extracts from the Chromaticity Table (Figure 1) were devised as a weighted ordinate method which could be used to translate eleven ordinate readings into CIE X, Y, Z values. The table was devised by modifying Table XV from page 45 of the Handbook of Colorimetry, by A. C. Hardy. (Only 11 ordinates were used to simplify the example given. At least 31 ordinates are required to obtain the required accuracy of CIE X, Y, and Z values.)

Based on the Chromaticity Table, Figure 1, and using a green color for an example, the following values were derived.

WAVELENGTH	% REFLECTANCE	ECX	ECY	ECZ
420	17	.48	.01	2.32
445	20	1.85	16	9.46
465	26	1.73	.51	10.51
485	30	.46	1.34	4.88
505	33	02	3.09	1.48
525	35	.80	5.78	.42
545	32	2.58	7.00	.09
507	26	4.36	5.44	.01
595	19	3.93	2.59	------
615	15	2.67	1.26	------
650	14	.75	.28	------
		X = 19.63	Y = 27.46	Z = 29.17

X + Y + Z = Grand Total = 76.26

The X, Y, and Z values are inserted into the following equations to obtain chromaticity coordinates in terms of x and y.

$$x = \frac{X}{X + Y + Z} \qquad y = \frac{Y}{X + Y + Z}$$

$$x = \frac{19.63}{76.26} = .2574 \qquad y = \frac{27.46}{76.26} = .3601$$

Using these values of x and y, refer to the Chromaticity Key Chart (Figure 2) and note that x, y chromaticity coordinates are to be found on Chromaticity Chart #8 (Figure 3). Relocate x, y intersection on chart 8 and assign dominant wavelength and purity from the values on this chart. Add to this the value Y which denotes the reflectance value, and we then have three values which describe the color. These values are known as color values.

Dominant wavelength	501.5	nm
Purity	17.2	%
Reflectance	27.26	% (Y value from above)

<u>NOTE</u>: Although this exercise appears complex and cumbersome, it can readily be computerized. Commercial testing laboratories are equipped to furnish CIE values X, Y, Z and x, y along with the plotted spectral curve for each color.

CHROMATICITY TABLE

READING % REFLECTANCE	X	Y	Z
420 Mu			
15	.43	.01	2.04
16	.45	.01	2.18
17	.48	.01	2.32
18	.51	.02	2.45
19	.54	.02	2.59
445 Mu			
18	1.66	.14	8.52
19	1.76	.15	8.99
20	1.85	.16	9.46
21	1.94	.17	9.94
22	2.03	.17	10.41
465 Mu			
24	1.60	.47	9.71
25	1.66	.49	10.11
26	1.73	.51	10.51
27	1.80	.53	10.92
28	1.86	.53	11.32
485 Mu			
28	.43	1.25	4.56
29	.44	1.30	4.72
30	.46	1.34	4.88
31	.47	1.39	5.05
32	.49	1.43	5.21
505 Mu			
31	.02	2.90	1.39
32	.02	3.00	1.43
33	.02	3.09	1.48
34	.02	3.18	1.52
35	.02	3.28	1.57
525 Mu			
33	.75	5.45	.39
34	.78	5.61	.41
35	.80	5.78	.42
36	.82	5.94	.43
37	.84	6.11	.44

READING % REFLECTANCE	X	Y	Z
545 Mu			
30	2.41	6.57	.09
31	2.49	6.78	.09
32	2.58	7.00	[illegible]
33	2.66	[illegible]	.10
34	2.74	7.44	.10
570 Mu			
24	4.02	5.02	.01
25	4.19	5.23	.01
26	4.36	5.44	.01
27	4.52	5.65	.01
28	4.69	5.86	.01
595 Mu			
17	3.52	2.32	0
18	3.73	2.46	0
19	3.93	2.59	0
20	4.14	2.73	0
21	4.35	2.87	0
615 Mu			
13	2.31	1.09	
14	2.49	1.17	
15	2.67	1.26	
16	2.85	1.34	
17	3.03	1.43	
650 Mu			
12	.65	.24	
13	.70	.26	
14	.75	.28	
15	.81	.30	
16	.86	.32	

Figure 1-Chromaticity Table

Key Chart

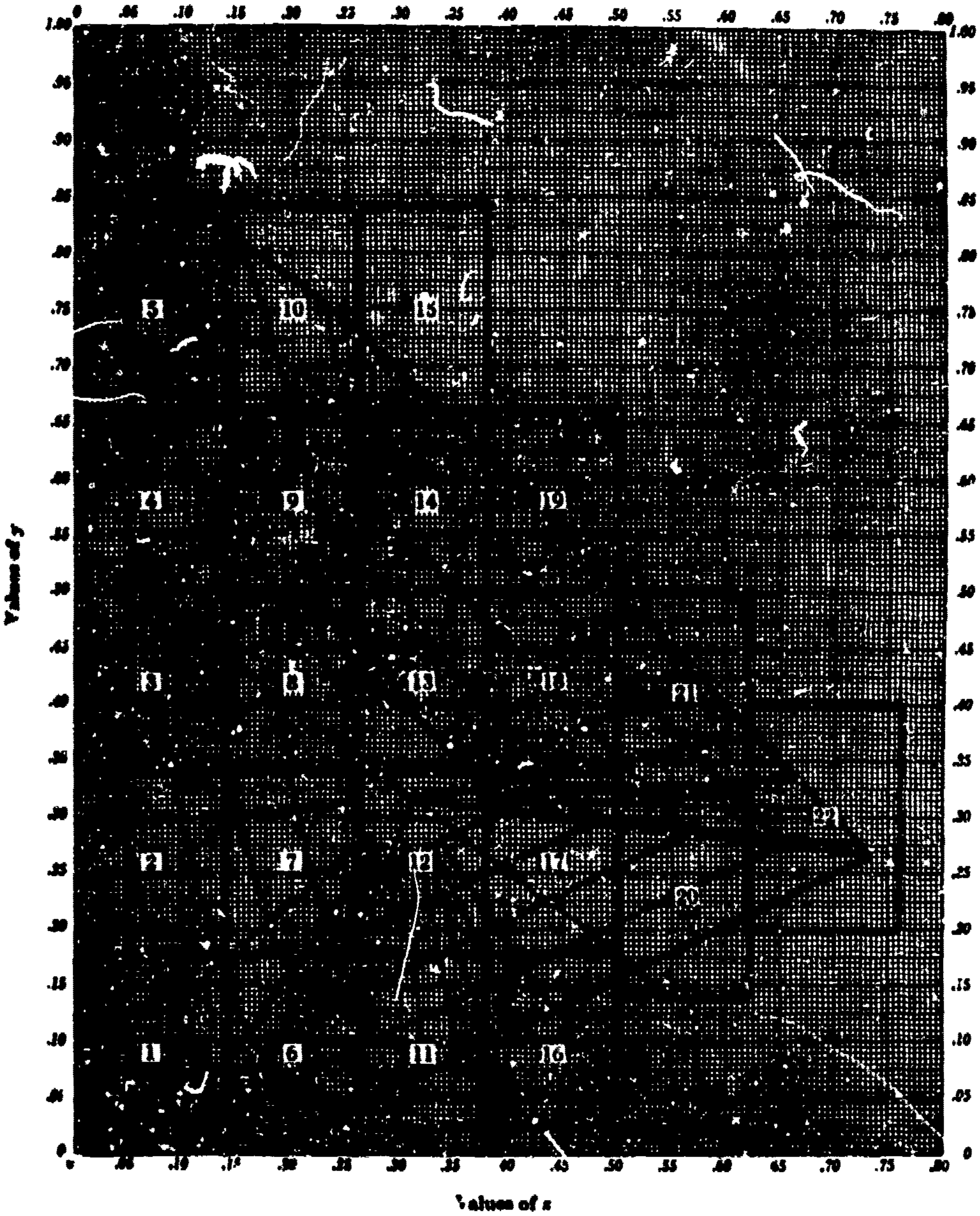

Figure 2 - Key Chart

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Chart No. 8

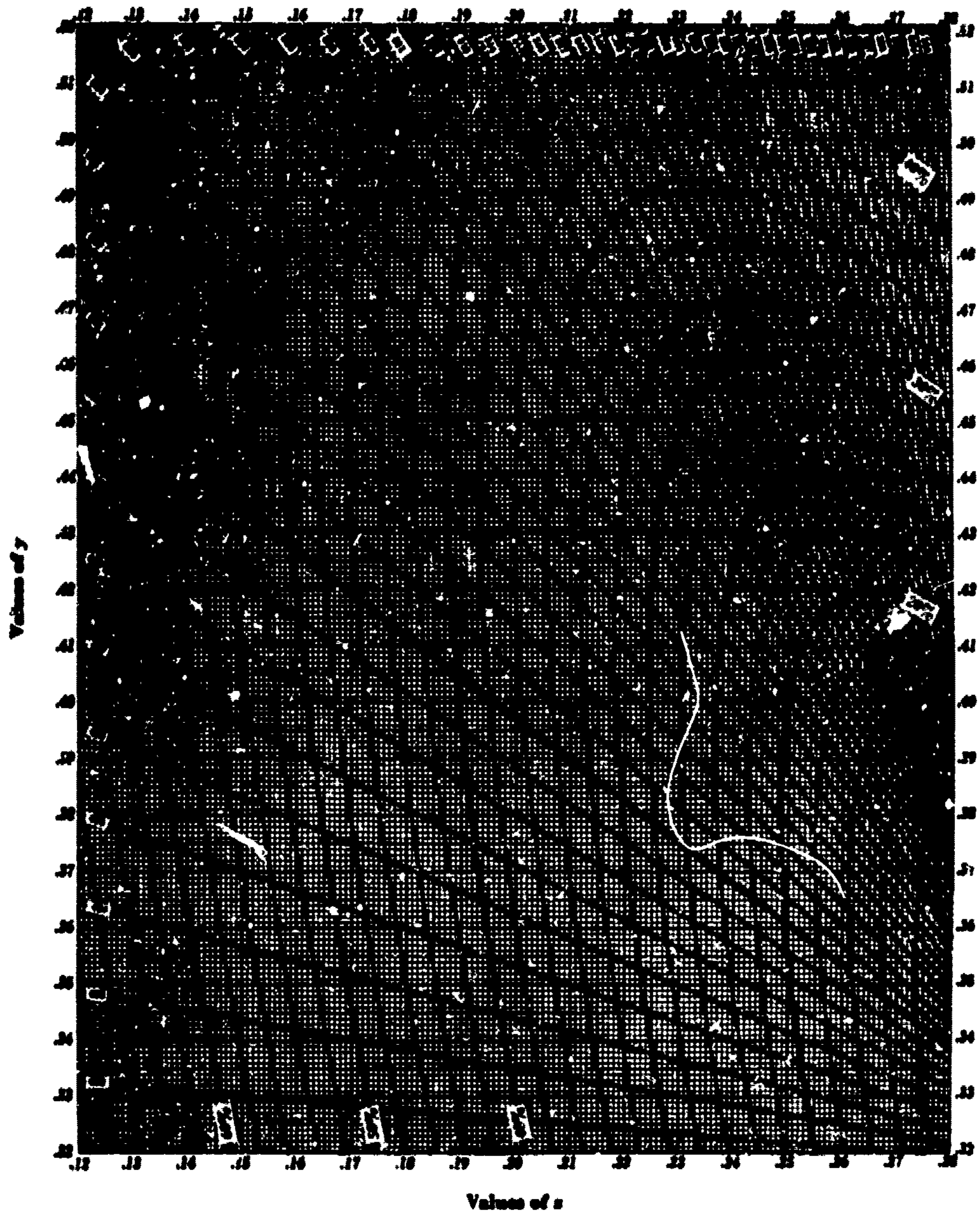

Figure 3- Chromaticity Chart 8

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UNDERSTANDING COLOR VALUES

Dominant Wavelength - A precise measurement in Nanometers (nm), which directly relates the color to its position in the spectrum. Roughly, the visible spectrum ranges from 400 nm to 700 nm. The dominant wavelengths can be identified as follows:

400 nm to 450 nm	------ Violets
450 nm to 500 nm	------ Blues
500 nm to 570 nm	------ Greens
570 nm to 590 nm	------ Yellows
590 nm to 610 nm	------ Oranges
610 nm to 700 nm	------ Reds
*c 493 nm to *c 530 nm	------ Reddish Purples
*c 530 nm to *c 566 nm	------ Purples

Purity - A precise measurement which expresses the percentage of grayness of a color. The absence of color (as in black, gray and white) corresponds to 0% purity. The presence of pure color (total absence of gray content) corresponds to 100% purity.

Reflectance - A precise measurement of the lightness of a color expressed in percentage. Darkest colors approach 0% reflectance while the lightest colors approach 100% reflectance.

The three-dimensional model of color -- dominant wavelength, purity, and reflectance -- is diagrammed in figure 4. The flat plane of the diagram is called the chromaticity diagram. The pure spectral colors ranging from 400 to 700 nm are located around its perimeter, the point C locates the standard illuminant, while the straight line from 400 to 700 nm portrays the pure non-spectral colors of reddish purple and purple. As a color's location moves from the perimeter toward point C, the color loses purity and becomes grayer. When the color's location moves upward from the base plane, the color becomes progressively lighter until at the peak it reaches white.

* "c" colors are not found in the spectrum and are therefore identified by complementary wavelength.

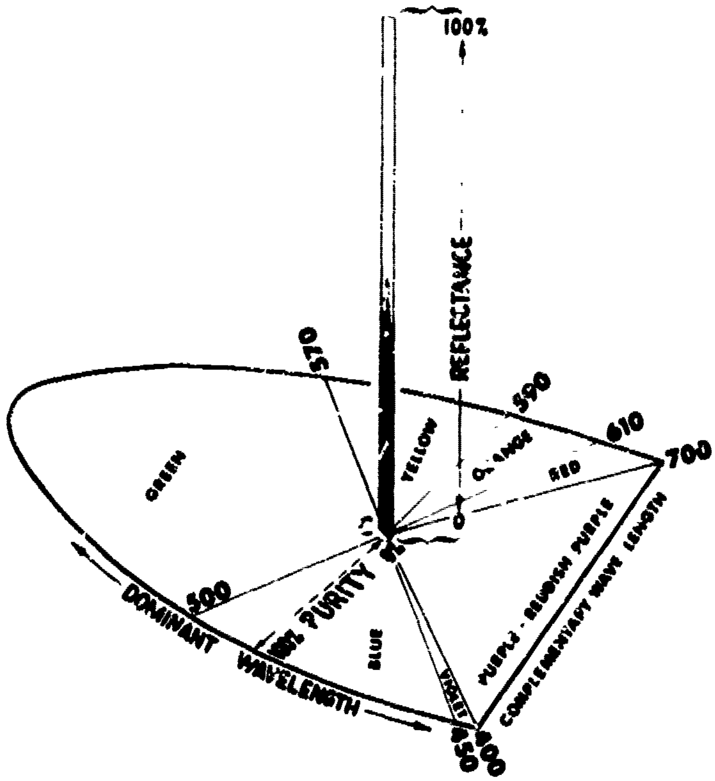

Figure 4-Color Space Diagram

ASSIGNING SPC NUMBERS

The discussion to this point explained the basic values needed to understand how color numbers are assigned under the SPC system and what these numbers mean. The color values (dominant wavelength, purity, and reflectance) measure the three variables which the human eye perceives. These variables may be presented as a mathematical model in three dimensions. The full CIE values, when expressed to the first decimal point, require ten numbers and represent a relatively small point of color space.

The SPC number system simply identified a quadrate in color space one nm wide (color-hue), 10% long (purity) and one increment deep, (reflectance). (See Figure 5). This reduces the number of color space identifications from millions to color quadrates in thousands and permits use of a representative color number of five digits, a more manageab'e identification. The full color specification would continue to use the full CIE values. The five digits are merely for identification.

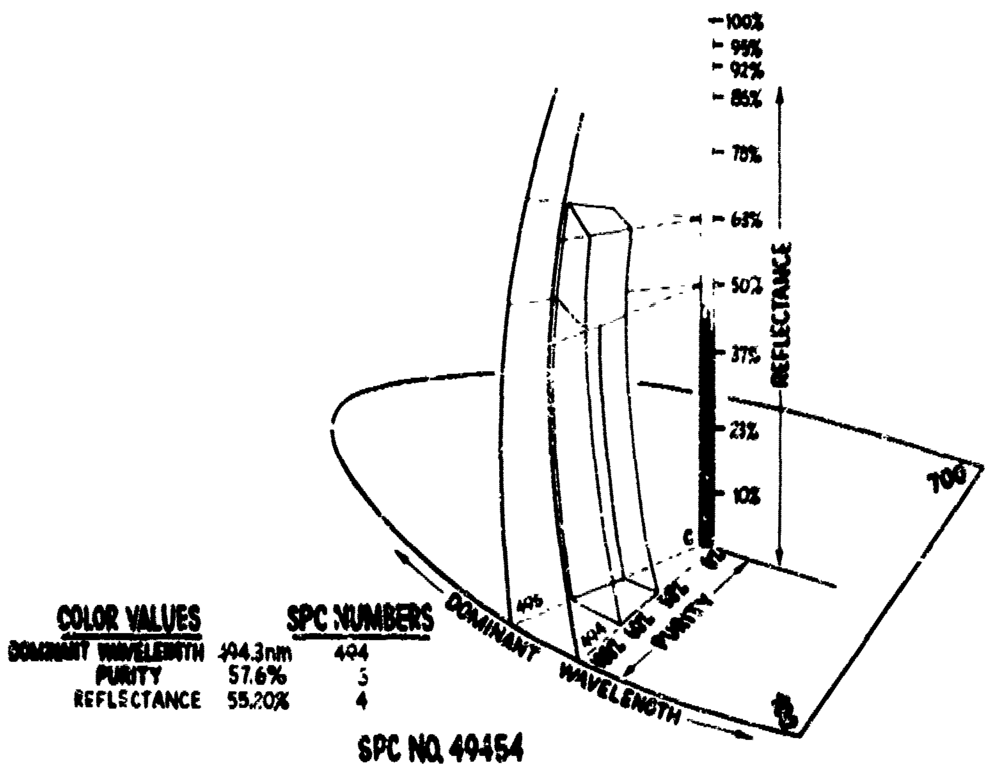

Figure 5-Quadrate in Color Space For SPC Identification

Dominant Wavelength (nm)

The first three digits of the five digit SPC number represent dominant wavelength (nm) and are the full nm value rounded off to the first three digits, with half or more of the decimal carried to the next full number; e.g.:

Dominant Wavelength Values	SPC Digits
494.3 nm	494
495.6 nm	496

The spectrum produced by passing white light through a prism includes only natural or pure spectral colors. These colors start with the shortest wavelengths, which are blue, and progress through the longer wavelengths which are commonly called blue green, green, yellow green, yellow, yellow orange, orange, orangish red, and finally red. Shorter wavelengths are invisible ultraviolet, and longer wavelengths are invisible infrared. The spectrum does not include those man-made colors which combine red and blue. These colors are commonly known as maroon, magenta, reddish purple, purple, etc.

These non-spectral colors are located in the Color Space Diagram (Figure 4) inside the triangle formed by C, 400, 700 nm, and are identified as complements of natural spectral colors; e.g., 500C. The triangle-C, 400, 700 nm will identify complements (C) from 493C to 566C. To preclude the need to apply a C after the SPC number, the SPC system simply identifies these colors as 80000 and 90000 series by adding 400 to the complementary wavelength; for example:

Complementary Wavelength Values		SPC Digits
493.5C + 400	=	894
495.0C + 400	=	895
566.0C + 400	=	966

As the need for a new color arises and the color is analyzed to determine the CIE values and SPC numbers, the color is automatically being cataloged and arranged in its proper position relative to existing colors. If two colors are very similar, they may fall into the same SPC color quadrate and therefore alert users of their similarity. If after existing colors in that quadrate are reviewed and the new color is still justified, it will be identified with the same quadrate number, however, an alpha suffix will be assigned to indicate that it differs from the first SPC color identified in that quadrate. For instance, there may well be an SPC 54365, 54365A, 54365B, etc.

Purity

The fourth digit of the five digit SPC number represents purity. The purity values range in percent from 0 to 100. The number assigned to the SPC identification is 0 for values less than 10% and the first digit of values 10 to 99.9% (includes 100%) as follows:

PURITY INCREMENT TABLE

Purity Values	SPC Digits
0 - 9.9%	0
10% - 19.9%	1
20% - 29.9%	2
thru	
90 - 100%	9

Reflectance

The fifth and last digit of the SPC number represents reflectance. A "Standard Observer" concept was employed whereby the visual observations of approximately 165 persons were used to arrive at the following table of equaldistant reflectance values. The reflectance SPC digit is taken from this table.

REFLECTANCE INCREMENT CONVERSION TABLE

CIE Value Y

CIE REFLECTANCE VALUE	SPC DIGIT
0% - 10.49%	0
10.50% - 23.40%	1
23.41% - 37.05%	2
37.06% - 50.77%	3
50.78% - 63.85%	4
63.86% - 75.59%	5
75.60% - 85.33%	6
85.34% - 92.31%	7
92.32% - 95.89%	8
95.90% - 100.00%	9

As illustrated in Figure 5, the Color values are converted to SPC identification numbers as follows:

Color Values		SPC Digits	SPC Number
Dominant Wavelength (nm)	494.3	494	
Purity	57.6	5	SPC 49454
Reflectance	55.20	4	

Figure 6 illustrates the orderly arrangement of chromatic colors achieved by using the color values and/or the SPC identification system. Chromatic colors are all visible colors except gray and black. The color file may be visualized as a cabinet ten drawers high and an appropriate number of drawers wide, depending on the groupings of dominant wavelength values which are the first three digits of the SPC identification. (To illustrate, the SPC nm values were assigned one to a drawer. In practice, groupings into six drawers would be more logical.) The width of the file represents dominant wavelength, the first three digits of the SPC identification; the height represents reflectance; and the depth represents purity. Thus, in a six-drawer wide file, the first vertical row represents colors described as violets. The dark colors, those having smallest values of reflectance, would be in the bottom drawer, while those having the highest value of reflectance would be in the top drawer. Moving to the right, the same is repeated for hues of blue, green, yellow, orange, and red. In any given drawer the colors would be arranged according to purity, with grayish colors at the front, pure colors at the back.

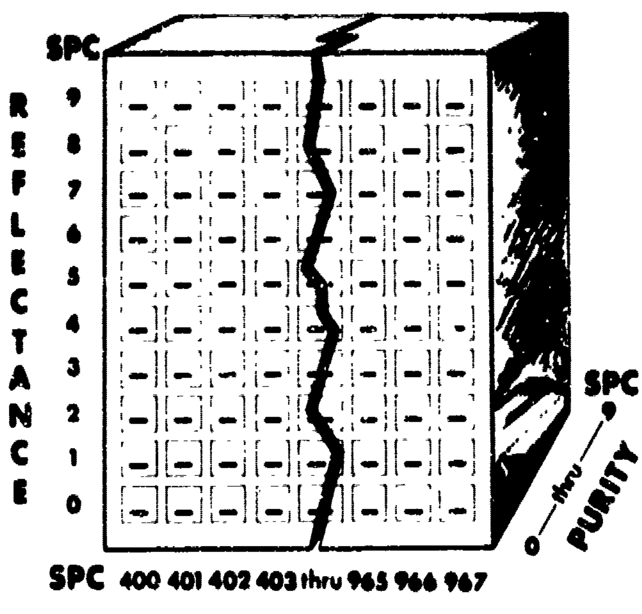

Figure 6-Cataloging Colors in an Orderly Arrangement. *

Grays and blacks are called achromatic colors and will follow the same orderly arrangement but may be placed separately in the system. Grays and blacks

* Adapted from "Measurement and Specification of Color and Small Color Differences" by W. J. Goodwin, June 1955.

will fall on or near the achromatic pole (Perpendicular pole on Figure 4 - Color Space Diagram) however, each will have a dominant wavelength the same as chromatic colors. To separate the chromatic from the achromatic colors, the latter may be recognized by the fourth digit being 0 for grays; and the fourth and fifth digits (purity and reflectance) being 0 for blacks. Grays and blacks may then be placed in their own family in orderly arrangement. There is one exception to this general rule in that very pastel chromatic colors will have a fourth digit (purity)of 0. In these cases human judgement must prevail.

COLOR DIFFERENCE UNITS

Previous discussions were directed toward identifying a given color in precise international values. Once this has been accomplished, the ink manufacturer or color matcher may properly question the tolerance allowed in meeting the color required. As previously indicated, any two colors which appear visually different will have different values; therefore, unless a tolerance is established, only an absolute color match will fulfill the stated values. Such a requirement is usually impractical, therefore, a color tolerance is necessary. Since each application of a given color has its own tolerance standard, only a means of specifying such a tolerance is required of the SPC identification system. The exact number of color difference units may be expressed as this tolerance.

An acceptable tolerance, in terms of color difference units, must be based upon what is visually acceptable as a tolerable color match. Many systems have been designed to do this and they differ only in their method of weighing the differences in hue, purity, and reflectance.

Color difference unit systems by Adams; Hunter; NBS; MacAdam; MacAdam, Friele, and Chickering; MacAdam, Simon, Goodwin, and Wyszecki were reviewed for the following criteria:

a. A system that reasonably represents, numerically, the amount of color differences as visually observed.

b. A system that is nationally and internationally recognized.

c. A system that is easily converted mathematically from CIE values to color difference units.

In evaluating the various color difference systems, two basic problems were noted. The mathematical computations for converting from CIE values to color difference units were too long, and/or the numeric color difference units did not appear to correlate to the visual color differences. The most applicable system was judged to be the Hunter (1948-1958) L, a, b System. This system meets the prescribed criteria, can be easily converted mathematically from CIE values or measured directly from moderately priced color and color difference meters, furnishes easily understood color difference data, and reasonably equates numerical color difference units to visual observations of differences in like color prints. As an example, two like prints with a just barely noticeable color difference have numerical color difference values of +0.41L (Lighter), +1.62a (Redder), and +2.09b (Yellower); while two different like color prints with a very noticeable visual difference, have numerical color difference values of +3.75L (Lighter), +6.74a (Redder), and +3.82b (Yellower). The Hunter system has an orderly progression of values as a greater noticeable visual difference in color occurs.

There is no attempt made here to establish a tolerance limit scale. This can only be determined by converting CIE values to color difference units, comparing the numeric results with the visual color samples, and then determining what are acceptable limits for that color. As colors are created or matched to existing standards, the tolerance limit scales will automatically develop.

For further information in determining how to calculate color difference units, refer to the SPC Operator's Manual.

INK FORMULATION

The SPC identification system is based upon absolute CIE values and will remain the same throughout the years. It will provide the same identification number regardless of the ink formulation used, so long as the color remains the same. Since the SPC identification system can be understood internationally, it is considered to be an acceptable ink color matching system for the modern printing industry.

The SPC system is based upon using eight basic colors plus black and white. (Color samples of the basic colors are found in the DOD Standard Printing Color Catalog). Virtually all DOD MC&G colors can be matched by blending from these basic colors. Ink inventories can be reduced from hundreds of separate colors to the eight basics plus black and white. A breakeven point can be established so that it can be determined where it is more economical to purchase large quantities of popular ink colors blended by the ink manufacturer, and where it is more economical to blend small quantities of less popular ink colors in-house.

Each SPC color, including the eight basic colors, will be identified by an SPC number. The use of color names will be avoided, except for the basic and process colors.

The SPC Ink Color Specifications for the eight basic colors plus black and white will show the CIE values of x, y, Y, the SPC color, and the SPC number. Blended color specifications will also include a suggested formula with the added provision that CIE values override formula which would be included for the manufacturer's convenience. The formula is only suggested as it represents an approximate rather than a precise color match. The CIE values override the formula because it is a precise specification of the color. The tolerance allowed in any color matching actually determines the real color quality.

Ink formulas recommended for the blending of inks are given in terms of the percent of each basic color needed, rather than number of parts of each basic color. This allows for more efficient calculation of the amount of each basic color required for the blend, based upon the total quantity ordered.

Color consistency between batches of blended colors depends upon a number of variables, one of which is changes in the specific gravity of the basic colors. For purposes of standardization, all SPC formulas shown in the DOD SPC Color Catalog are adjusted to a specific gravity of 1.12, which is considered to be a reasonable average. As subsequent batches of SPC colors are being blended, differences in the specific gravity of the basic colors being used should be recognized and adjusted. If the specific gravity of all the basic colors is not 1.12, the percentage of each ingredient should be adjusted as shown in the SPC Operator's Manual. The use of the specific gravity table for blending colors with the recommended formula represents the best approximate rather than a precise color match. Final color match quality is a matter of blending adjustments to satisfy the specific color quality requirements. The tolerance allowed will actually determine the color quality. Any real implementation of this system requires a separately stated quality tolerance and control system or real color quality cannot be maintained.

OTHER APPLICATIONS OF THE SPC SYSTEM

This color identification system is designed to include all conceivable colors and can be applied to other media such as:

a. Fluids

b. Transparent, translucent and opaque sheetings

c. Papers

d. Films

e. Dyes

f. Pigments

etc.

When the basic concepts of the Standard Printing Color (SPC) Identification System are applied to media other than printing colors, the name of the color identification system should then be known as the Standard Production Color (SPC) Identification System.

DOD MC&G STANDARD PRINTING COLOR CATALOG

A standard printing color catalog is published to provide a visual sample for each interagency color standard. It includes, in addition to the visual color sample, ink specification and blending formulation, SPC numbers, CIE values, and standard dot screens.

DOD MC&G STANDARD PRINTING COLOR OPERATOR'S MANUAL

An operator's manual is published to provide the necessary instructions on how to obtain CIE values, establish SPC numbers, and determine color difference units. This manual is complete with a full set of chromaticity diagrams.