1975

Evaluation and Testing of Color Strength Measuring Methods in the Graphic Arts

Barry Sullivan

Donald Wilkalis

EVALUATION AND TESTING OF COLOR STRENGTH MEASURING METHODS IN THE GRAPHIC ARTS

by

Barry Sullivan

Donald Wilkalis

A thesis submitted in partial fulfillment of the requirements for the degree of Bachelor of Science in the School of Photographic Arts and Sciences in the College of Graphic Arts and Photography of the Rochester Institute of Technology

June, 1975

Thesis Advisor: Mr. Chester Daniels

6923923

ACKNOWLEDGEMENTS

The following individuals and organizations contributed greatly to our project. Without their help this paper would not have been possible and we thank them immensely. Special note is given here to the Central Intelligence Agency from whom we were given a grant at the completion of this project.

Mohamed Abouelata

Robert Bayley

George Beard

Chester Daniels

Milton Pearson

Irving Pobboravsky

Gerhard Schumann

Kathryn Wilkalis

Ron Ink Company

Central Intelligence Agency

TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

ABSTRACT

The term color strength is defined as the hue, saturation, and brightness of an ink in the C.I.E. scheme of color specification. With this definition two color strength measuring methods are evaluated on a common basis. A colorimeter is used to read samples produced with varied ink-film thicknesses and varied ratios of white pigment to sample ink. Colorimetric properties are plotted on a U.C.S. diagram with coordinates modified to include the C.I.E. brightness factor W*. The ink-film thickness method is chosen as the preferred method for determining color strength.

INTRODUCTION

The printing industry today employs several methods for determining the color strength of an ink. Unfortunately, there are also many definitions for the term color strength. These definitions include the amount of colorant in an ink, its hue, saturation, and brightness, its ability to cover a number of sheets of substrate which is commonly referred to as mileage, and finally its relation to another ink when it is diluted with given amounts of white opaque ink. Other definitions may arise to suit the user. However, in this report we will define color strength to mean the hue, saturation, and brightness of an ink as it relates to the C.I.E. scheme of color specification. This definition has been chosen, as color strength is commonly used in conjunction with visual perception of an ink, that is, one ink looks stronger than another if it is more saturated.

Methods of determining color strength rely heavily on visual judgements and there is a definite lack of instrumentation. There is no simple quantitative measure that works well even though attempts have been made to use spectrophotometry and several different schemes of color specification. A visual comparison is made from drawing down two inks simultaneously or by diluting a known and unknown ink with equal volumes of white ink. Densitometry may be employed on ink samples to determine color strength but these readings are not valid unless the filters in the densitometer match the spectral response of the eye. Spectrophotometric methods also have their drawbacks as will be shown.

We have chosen to examine color strength and its methods of determination as there is a wide disparity in defining and effectively utilizing the property of color strength. A standard method would enable the printer to predict changes needed to match inks. This would reduce the number of trial runs needed to reproduce a color thus conserving paper, time, and energy.

Current practices which require visual judgement are a simple draw-down of two inks or a dilution of the two inks with a white pigment. In the first method two inks are placed side by side on a substrate and drawn down together with a draw-down knife. They are then compared with a visual judgement dependent on the observer. A more reliable visual judgement can be made by use of the second method which uses white ink dilution. The known ink and the unknown ink are mixed with equal volumes of a white opaque ink. The inks are then drawn down as previously described. Several ratios of white ink to sample ink are used until the perception of color strength becomes more apparent in one of the inks. This is commonly referred to as a burn test. Again this method relies on visual judgement, but as dilutions increase differences become more obvious.

Studies involving specrophotometry and color strength have shown that the exact color specification of an ink can be made in the C.I.E. system. Problems with this system have been noted by Yule[1] as follows:

> 1. The fact that one ink shows a higher purity than another (that is, its plotted point is closer to the spectrum locus) may be purley accidental, depending on how heavily it was printed. To overcome this difficulty, it is necessary to use several different ink-film thicknesses.
> 2. The distance between two points on the chart does not correspond to the visual difference between the colors, even when luminances are equal.
> 3. The chromaticity gives no information about the cleanness of color, which depends on the relation between the saturation and the luminance.
> 4. Inks which plot at the same point on the diagram may differ not only in luminance (which would be represented perpendicularly to the plane of the paper), but also in color saturation and, to a lesser extent, in hue, since these characteristics vary with luminance.

Problems with the visual and spectrophotometric methods have been considered. In order to alleviate the problem associated with point one, mentioned earlier, a method of

---

[1]Yule, J.A.C., Principles of Color Reproduction, Page 173.

establishing a curve with varying ink-films was considered. A similar curve with ratios of white ink to sample ink was also considered. Problems with unequal distances (point two) could be overcome with the use of the Uniform Chromaticity Scale (U.C.S.) system instead of normal C.I.E. coordinates. Finally, if coordinates found under the U.C.S. system were multiplied by the brightness of the sample a new scale would be formed that should eliminate problems associated with points three and four.

Measurements on the ink-film thickness method and the burn test method should be made with a colorimeter rather than a spectrophotometer. This would reduce calculation as reflection data obtained could be used directly in calculating C.I.E. values. A more involved calculation was needed with the spectrophotometer to obtain the same end result.

By establishing colorimetric curves of both the ink-film thickness variations and burn test ratio variations the two methods can be compared on a common basis. The comparison should enable both strengths and weaknesses of the methods to be shown. A choice to use one or both of the methods could then be made on the basis of this comparison.

An important consideration in this analysis was the choice of substrate. A paper base was deemed unsuitable as there was wide variability in paper surfaces. A paper base would also be prone to multiple internal reflections which gave rise to variations in reflection readings. The ideal surface would then be non-absorbing and high reflecting. To approximate this condition a DuPont Cronaflex film base was used as the substrate for all samples. The film is a high reflecting white and because it is an acetate film base it is stable and not prone to the variations found in fibrous paper material.

It therefore will be shown that it is possible to establish colorimetric curves for both ink-film thickness variations and burn test ratio variations; that these curves can then be expanded to include the brightness factor of the sample; and thus be utilized to predict properties of unknown inks from which colorimetric curves have been ascertained.

EXPERIMENTAL

Ink Selection

Six cyan, two magenta, and three yellow inks were obtained to represent a wide variety of printing inks. In addition, a two pound can of white ink for mixing was secured. Color ink samples were drawn from twenty-five pound containers of the ink and placed in small sample cans

Specific gravity of each ink was found by measuring out one cubic centimeter of the ink with an IGT ink pipette, RIT #83464. The sample was then weighed on a Mettler analytical balance, RIT #30027, to determine its specific gravity. Two replicates were made for each ink and the average was taken for the final result. (See Table One for ink data.)

IGT Printability Tester Method

The method of laying down an ink with the IGT Printability Tester was examined. The sample ink was first placed on an IGT Inking Apparatus, RIT #83458, to spread the ink evenly on a roller. The roller was then transferred to an IGT Printability Tester, RIT #70121. Standard procedures for each of these machines were followed. A 2.5 centimeter by 30.0 centimeter sample of Cronaflex substrate was cut and placed on the tester. It was then drawn over the roller by hand control of the pendulum drive mechanism. Samples using 0.5, 1.0, and 1.5 cubic centimeters of ink, as metered from the pipette, were produced in this manner.

<u>Hand Roller Method</u>

In order to facilitate hand rolling a five inch square vacuum frame was devised by Mr. Chester Daniels to hold a similar sized sample of substrate. A sample ink was metered out with the pipette onto a five inch square metal mixing slab. The ink was then transferred to a six inch hand brayer until it was evenly distributed on the roller. It was subsequently rolled onto the substrate until an even coat was built up. Samples using the three volumes of ink as in the previous test were produced in this manner.

Problems with hand rolling occured. A four inch soft rubber roller was used for initial testing. The roller decomposed after inking so a four inch synthetic rubber brayer was substituted. Another problem was that the substrate stuck to the inked roller after inking was started. This was solved by obtaining a roller slightly larger than the sample width and by using a diagonal motion across the sample.

Comparison of Inking Methods

The samples produced with the two methods were measured at random spots with a Macbeth reflection densitometer, RIT #58741, using the appropriate filtration for each sample. A pair comparison test was run between results obtained from the two methods. (See Table Two for a sample test result.) A decision to use the hand roller method was then made based on the results of the comparison test and the ease of application of the ink by hand rolling.

Ink-Film Thickness Sample Production

A 12.7 centimeter square template was cut from a metallic printing plate. This was used as a guide in cutting samples from the sheet of Cronaflex substrate. Samples were cut, numbered, and weighed on the Mettler analytical balance.

Varied ink films were produced by placing 0.10 cubic centimeters of ink on the mixing slab. The ink was distributed onto the synthetic rubber brayer and then transferred to the substrate. For the next sample the ink remaining on the slab and roller was used. The third and fourth samples were produced in a similar manner but an additional 0.15 cubic centimeters of ink were metered out on the mixing slab. Four ink films from each of the nine samples of ink were obtained in this fashion.

The substrate was weighed before and immediately after inking to determine the weight of the ink applied. After the ink had air dried overnight the area of the substrate was calculated by measuring it with a Craftsman vernier caliper #40257. From this data and previously gathered data on specific gravity, the ink-film thickness for each sample was calculated. (See Table Three, sample numbers 1-36.)

Colorimetric Data

Samples produced from the above method were then measured with a ColorMaster Differential Colorimeter, RIT #04818, to obtain percent reflection values through red, green, and blue filters. The colorimeter was zeroed on the Cronaflex substrate. Data obtained from these readings were plugged into a program designed for a Hewlett-Packard HP9100A calculator, RIT #59995. The program was obtained from Mr. Irving Pobboravsky at the Graphic Arts Research Center, and gave C.I.E. values of x, y, X, Y, Z. (See Table Four.) Formulas involved in obtaining these C.I.E.

values are:

$$X = 0.784R + 0.196B$$

$$Y = G$$

$$Z = 1.18B$$

$$x = X / (X + Y + Z)$$

$$y = Y / (X + Y + Z)$$

Standard Uniform Chromaticity Scale coordinates were then obtained from the C.I.E. data. Formulas involved in this calculation are:

$$u = 4x / (12y - 2x + 3)$$

$$v = 6y / (12y - 2x + 3)$$

In addition to normal C.I.E. and U.C.S. system coordinates a third system was created by including the brighness factor of the ink sample. The factor $W* = 25Y^{1/3} - 17$ is a standard C.I.E. consideration for brightness. The calculated value of W* was normalized by dividing by 8.0. U.C.S. coordinates were then altered by the following calculations:

$$uW* = (u - u_0)\ W* + u_0$$

$$vW* = (v - v_0)\ W* + v_0$$

Where: $u_0 = 0.2009$, $v_0 = 0.3073$.

The calculation includes the brightness factor and returns the coordinates to the U.C.S. system. (See Table Five.)

Burn Test Sample Production

The samples for the burn test were produced in a similar manner as for the ink-film thickness test. Sample inks were mixed in ratios of 9:1, 3:1, and 1:1 of white mixing ink to sample ink. For each ink sample 0.10 cubic centimeters were metered out on the mixing slab and consequently transferred to the Cronaflex substrate as previously described. Twenty-seven samples were produced in this manner. In addition to the ratio samples, a sample of just the white mixing ink was produced.

Ink-film thickness data and colorimetric data was obtained as previously described. (See Tables Three - Five, sample numbers 37-64 for data.)

Estimate of Error in Ink-Films

To establish an estimate of error in ink-films produced, all the samples produced with a volume of 0.10 cubic centimeters were used. The total number of these samples was thirty-seven. The standard deviation of these samples was then computed with a Hewlett-Packard HP-45 calculator, #1349A 18464.

DATA REDUCTION

The data from the colorimetric measures were plotted on standard C.I.E. and U.C.S. diagrams. Ink-film thickness and burn test curves for each ink were plotted together to show their relation to each other and to each type of diagram. With the modified U.C.S. system burn tests and ink-film tests for each color were plotted together. In addition, two graphs were made of the magenta inks with their respective burn test curves plotted together. In addition to the colorimetric plots, comparison diagrams were made to show the relation of visual color strength to specific gravity.

The modified U.C.S. plots were then used to analyze the data. An arbitrary line was established which ran through the two curves and extended from the point of Illuminant C out to the spectrum locus. Points of intersection were noted as color matches between the two curves. A visual matching of the ink samples was then made and compared with predicted results. Conclusions about the color strength measuring methods were then made.

Futher analysis of the curves involved an attempt to correlate the ink-film thickness curves to the burn test curves. This involved the use of the same arbitrary line from Illuminant C to the spectrum locus. The ratio of white ink to sample ink was read from the point of intersection on the burn test curve. Another ratio was then computed from the ink-film thickness found at the point of intersection on the ink-film curve to the constant ink-film thickness of the burn test samples. These ratios were then compared to correlate the methods.

CONCLUSIONS

Results

Hand rolling was chosen over the IGT Printability Tester method. No significant difference was found between samples produced by either method. With hand rolling sample areas could be varied, no complicated machinery was needed, and application time was found to be shorter.

Sample average and standard deviation for ink-films produced with a volume of 0.10 cubic centimeters of ink was: $\bar{x} = 1.79 \times 10^{-4}$ centimeters, $s = 0.44 \times 10^{-4}$ centimeters.

C.I.E. plots showed color coordinates as would normally be obtained from colorimetric calculation. (See Figures 1 - 6.) Standard U.C.S. plots showed expansions and compressions of scale as expected. (See Figures 7 - 12.) Transformations from the standard U.C.S. system to a brightness modified U.C.S. system showed further expansions and compressions of scale. (See Figures 17 - 22.)

A visual comparison of color strength using a simple draw-down test showed that weaker visual colors had higher specific gravities. (See Figure 13.) Exceptions noted were cyan ink numbers two and four.

The analysis of the modified U.C.S. diagrams with the method of drawing a line from Illuminant C to the spectrum locus showed that no relation between different inks could be made with the burn test. The burn test ratios only served to show that two inks were very similar or very dissimilar. Ratio curves that crossed indicated hue shifts that were readily detectable to the eye. Curves which ran parallel to each other corresponded to samples which showed visual hue shifts at 9:1 dilutions. Curves which were closely parallel to each other, however, corresponded to samples that were visually hard to differentiate from each other at any given dilution.

The above method, applied to the ink-film thickness curves, gave the following results of predicted matches to actual visual matches between the two inks:

	Predicted Match	Visual Match
Cyan	22 - 25	22 - 25
	24 - 28	24 - 28
	23 - 22 - 21*	23 - 22 - 21*
Magenta	3 - 6	3 - 6
	4 - 5	4 - 5
	2 - 8	2 - 8
Yellow	11 - 14	11 - 14 - 10
	12 - 13	12 - 13
	15 - 16*	15 - 16*

*These matches indicate the same ink but the close proximity of coordinates of these sample numbers indicated they may be visually matched.

Correlation analysis between the ink-film thickness test and burn test curves was accomplished in the U.C.S. system. The range of burn test curves was found to extend from a point on the ink-film thickness curve, which is equal to the thickness of the burn test samples, to a point where a pure white sample of the given thickness would plot.

Ratios found in correlation analysis, as previously described, were found to be approximately equal. The ratio relation is as follows:

$$\frac{\text{IFT (IFT curve)}}{\text{IFT of Burn Test}} \approx \frac{\text{Sample Ink Concentration}}{\text{Total Ink Concentration}}$$

Discussion

The decision to use the hand roller was based on several factors. Since no significant difference between the two methods was found, other factors were considered. One of the research objectives was to find a simple but reliable method for ink application. By using the IGT inking devices, two expensive pieces of machinery were involved. Hand rolling equipment consisted of an inexpensive hand brayer, an inexpensive mixing slab, an inexpensive home-made vacuum frame, and a vacuum pump.

With time as a consideration the hand roller method provided for quicker application. Long ink distribution times with the inking apparatus were eliminated and clean-up time of rollers and surfaces was reduced with hand equipment.

Sample size was another consideration. With the IGT devices sample size was limited to 2.5 by 30.0 centimeters. With the hand method, size could be altered to suit any requirements. The colorimeter required a minimum 2.2 by 3.2 centimeter reading area. To insure this would occur, a larger sample than could be produced with the IGT apparatus was needed. For this reason a 12.7 square centimeter sample was produced with the hand rolling method.

In the method of determining ink-film thicknesses it was necessary to have the ink run out to the edges of the substrate. This was possible with the hand method as the vacuum frame held the substrate down. The IGT Printability Tester required a small amount of the sample to hold the substrate. This was not inked and would be impossible to consider in determining the weight of the ink applied.

An average of all samples produced with a volume of 0.10 cubic centimeters of ink was found as well as the standard deviation for these samples. The average was 1.79×10^{-4} centimeters with a standard deviation of 0.44×10^{-4} centimeters. Calculations took into account all factors of error. These include substrate area, ink tack, variations in roller pressure, error in metering ink from the pipette, weighing, and measuring errors. A few points were noted as extraordinarily large. Replication of these points may have been in order but was not deemed essential. Procedures were employed to keep variations at a minimum. A template was used to cut the samples in order to reduce variations in sample area. Samples were weighed immediately after inking to eliminate variations caused by air drying.

Ranges of ink-films varied greatly in the production of samples for the ink-film thickness test. These variations resulted from the method of production. Better technique for sample production would be to clean the brayer and mixing slab in between each sample. In this way a specific volume of ink could be applied to the mixing slab each time. The volume of ink needed to produce a given ink-film thickness could then be established for future reference and use with this method.

A simple draw-down test was made to establish a general visual standing of the inks. After the inks were ranked a plot was made of specific gravity versus relative visual color strength. (See Figure 13.) The general trend of the curves showed that as color strength decreased, specific gravity increased. Two exceptions were noted but this may have been an error in visual judgement. One of the definitions encountered for color strength was the amount of colorant in an ink. The graphical evidence bears out the relation between visual rank and color strength. As the research was not directed in this line of investigation, the matter was noted as having a possible bearing on analysis and for possible further investigation.

The effectiveness of the burn test was evaluated by use of a line from Illuminant C, passing through the curves, to points on the spectrum locus. In theory, equivalant hues should be found along this line. Points on curves intersecting this line should therefore be of the same dominant wavelength. The only difference between these points is the excitation purity and luminance of the sample. Keeping this in mind, burn test plots for each ink color were evaluated. Three main trends were noted. The burn test curves crossed, or were either parallel or closely parallel. Curves that crossed could not be matched by drawing the line from Illuminant C to the spectrum locus. This condition indicated that the colors were of different dominant wavelength and indeed, visually, they were different for any given ratio of white to sample ink. Information gained from dilutions would only reinforce the fact that the dominant wavelength of the colors was different.

In the case of burn test curves that ran approximately parallel to each other no matches could be made by the dominant wavelength line method. A difference of hue was therefore indicated but visually this was not detected until ratios were increased.

Similar ratios were visually matched as they were in close proximity to each other on the diagram. Larger dilutions enabled the shift in dominant wavelength to be discerned more readily. Luminosity increased with an increase of white ink while purity of the sample ink decreased. As a result, perception of color strength became better since the perceived quality of color strength is based on the qualitative value of darkness. When the luminosity increased the darkness created by the sample ink could be detected.

A problem arose in matching the yellow inks because the curves were parallel and the yellow inks were already bright to the eye. Cyan and magenta inks were readily distinguishable.

In the case of the magenta inks the curves were closely parallel to each other and it was impossible to tell the two inks apart with visual comparison. Similar ratios could be matched but patches of one ink could be mistaken for the other ink. Information gained from the burn test, in this case, was that the two inks were the same. By examining the graphs of the two inks a difference could be noted. However, because of their close proximity on the modified U.C.S. diagram, a prediction could be made that there would be no visual difference. It is concluded that at some distance of separation on the modified U.C.S. diagram, colors are perceived as the same. It would be extremely useful to find the point of separation at which the eye can detect a shift in dominant wavelength but this was beyond the scope of the research.

Ink-film thickness curves were evaluated by using the dominant wavelength line as previously described. Curves produced showed three general tendancies. They either crossed, were widely separated, or were in close proximity to each other. In each case it was shown that color matches could be accurately predicted by comparing the inks with the dominant wavelength line.

The yellow inks examined exhibited a tendancy to cross each other. Two matches were predicted by examination of the curves. One match was at the point of intersection where the yellow inks would cross each other and the other match was along the dominant wavelength line. These predicted matches were then confirmed by visual evaluation.

Magenta ink curves were closely overlapping. Predictions of color matches by the dominant wavelength line were again confirmed by visual matching. Visual matches, however, included other samples that were in relatively close positions.

Cyan ink curves were widely separated. The dominant wavelength line could not be drawn through the two curves so no color match was indicated. Indeed, no color match could be made by visual comparison. Samples of another cyan ink, which were not plotted, were matched with the original two cyan inks. Visual matches were noted. The third ink was then plotted and visual matches were compared with graphical matches. By visual matching it was predicted that the inks would have similar curves. The plots showed that this was true. (See Figure 14.)

As found in the burn test analysis, samples which were in close proximity to each other were considered to be matches. Samples of different ink-film thicknesses of one ink were also matched if they were close to each other on the diagram. Judgement errors could readily occur if no method of determining the exact colorimetric properties was used.

The analysis of the U.C.S. plots for curves of a given ink was based on the theoretical level for which the range of the curves would extend. Since the colorimeter was zeroed on the white base to produce readings only affected by the ink, the range of the ink-film thickness curves extended from Illuminant C out to a point near the spectrum locus where the ink-film thickness approaches infinity.

The range fo, the burn test curves will extend from a point near Illuminant C, where the white pigment plots, to a point on the ink-film thickness curve which matches the constant thickness of the burn test curve. In terms of ratios, the curve will extend from a ratio of one to zero to a ratio of zero to one of white pigment to sample ink. If the reflectance factor of the white pigment was equal to the reflectance factor of the white base the two curves would coincide. Therefore, the difference between the curves is a factor of reflection differences between particle and surface reflection and the saturation difference of the white mixing ink. Again, constructing a ray from Illuminant C to the spectrum locus the curves are intersected at two points. Point one is on the ink-film thickness curve and point two is on the burn test curve. Considering the spectral density of both points:

$$\rho_1(\lambda) \propto c_1 x_1 \quad \text{and} \quad \rho_2(\lambda) \propto c_2 x_2$$

Where: c = sample ink concentration

x = ink film thickness

Using k for a proportionality constant:

$$\rho_1(\lambda) = k_1 c_1 x_1 \quad \text{and} \quad \rho_2(\lambda) = k_2 c_2 x_2$$

If $\rho_1(\lambda) = \rho_2(\lambda)$ and if it is assumed that $k_1 = k_2$, then:

$$k_1 c_1 x_1 = k_2 c_2 x_2$$

$$c_2/c_1 = K(x_2/x_1)$$

Where: $K = (k_1/k_2) = 1$

$$c_1 = 1$$

$$c_2 = \frac{\text{volume of sample ink}}{\text{total volume of ink}}$$

From the U.C.S. plots for ink number seven we can test the above formula. A line drawn from Illuminant C crosses the ink-film thickness curve at a thickness of 1.17, which is x_1 in the formula. The average thickness ($\bar{x}$) of the burn test curve is 1.79. At a point A, which is the crossing point of the line and the burn test curve, the coordinates were found to be (0.3710, 0.2870). (See Figure 15.) This point is between the 1:1 ratio point and the 0:1 ratio point of the burn test curve. The ratio of white pigment to sample ink was found to be 0.50:1 by interpolating the distance between the two points. Interpolation is possilbe as the plots are in the U.C.S. system.

The value of c_2 was then found to be 0.66 and the ratio of x_1 to x_2 was found to be 0.65. This represents a difference of 0.01. The same procedure was applied to ink number eight. (See Figure 16.) From these plots c_2 was found to be 0.50 and the ratio of x_1 to x_2 was found to be 0.56, a difference of 0.06.

Considering the difference between the curves to be k_0, and k_1 not equal to k_2 as was previously assumed:

$$c_1x_1k_1 = c_2x_2k_2 + k_0$$

$$x_1 = c_2x_2k_2 \;/\; c_1k_1 \;+\; k_0 \;/\; c_1k_1$$

$$x_1/x_2 = c_2k_2 \;/\; c_1k_1 \;+\; k_0 \;/\; c_1k_1x_2$$

Since: $c_1 = 1$

x_2 = constant thickness for burn test samples

Then: $c_2 = (x_2/x_1)K + K_0$

With this relation values for K and K_0 can be determined. These values will be dependant on saturation of white pigment, and the ink-film thickness at which the burn test samples are made. By knowing the burn test curve of a given ink, and the properties of the white ink used, a prediction can be made as to what color will be produced at a given ink-film thickness. The analysis is by no means complete as insuficient data was gathered. The method, previously described, becomes inefficient when ink-film thicknesses become very small and burn test ratios become very large.

In conclusion, the ink-film thickness test has been chosen as the preferred method of evaluating color strength. Both methods have their merits but practical considerations rule out the burn test. The burn test is good in a yes-no situation and would be a quick way to determine the stronger of two inks. The printer is concerned with the ink-film needed to produce a color. The burn test does not directly give this information. The burn test only serves to show that inks are either similar or dissimilar. As preveiously described, burn test curves graphically showed hue shifts and changes of dominant wavelength. Since the burn test is only useful in the determination of color strength, its use is limited.

The ink-film thickness test, on the other hand, is more useful. By examining the plots on the modified U.C.S. diagram a stronger color can be picked out by noting the change in purity along a given line of dominant wavelength. The stronger color will be the one whose coordinates plot closer to the spectrum locus. The ink-film thickness test is also useful for determining the ink-film required to match one ink with another. Points can be read from the curves to show at what ink-films color matches will occur. For example, if it is known that a desired color has been laid down at an ink-film thickness of two microns, a line can be drawn from Illuminant C through the two micron point and a curve of another ink. If this line crosses the second curve at a thickness of one micron, one will know that the second ink can be laid down at half the thickness to produce the same visual color. It must be kept in mind there may be a shift in purity. By knowing what ink-film thickness is needed, trial runs may be reduced and paper, time, and energy conserved. A final visual match is still needed but the method may eliminate alot of the guess work now used.

Recommendations For Future Work

Work is needed to further this research. The method was tried only with a non-paper substrate and now needs to be tried in an actual printing application. In producing samples, tighter control of the substrate size is needed. Hand cutting was used which lead to some unwanted variations. Using a substrate which was machine cut may have helped reduce these variations. In producing ink-films a fresh supply of ink should be metered out on the mixing slab for each sample. This would allow a relation between ink volume and ink-film thickness to be established.

As a separate topic for research one might examine the relation between specific gravity and color strength. One might also examine the spectral density method of analysis that was used with comparing ink-film thickness curves with burn test curves. Finally, an important area of research would be in determining the minimum separation distance of points on the modified U.C.S. diagram needed to perceive a change in dominant wavelength or purity.

REFERENCES

Apps, E.A., Ink Technology for Printers and Students, Leonard Hill, London, 1963.

Evans, Hanson, Brewer, Principles of Color Photography, John Wiley and Sons, New York 1953.

Larsen, L.M., Industrial Printing Inks, Reinhold Publishing Company, New York, 1962.

Reed, R.F., Instruments For Quality Control in Lithography, Lithographic Technical Foundation, Inc., New York, 1963.

S.P.S.E., SPSE Handbook of Photographic Science and Engineering, John Wiley and Sons, New York, 1973.

What the Lithographer Should Know About Ink, Lithographic Technical Foundation, Inc., New York 1960.

Yule, J.A.C., Principles of Color Reproduction, John Wiley and Sons, New York, 1967.

Journal of the Optical Society of America
- Glasser, L.G. and Troy, D.J., "A New High Sensitivity Differential Colorineter." Volume 42, No. 9, September, 1952.
- Nimeroff, Isadore, "Spectral Tristimulus Values For the C.I.E. (u,v,w) Uniform Spacing System." Volume 54, No. 11, November, 1964.

Technical Association of the Graphic Arts (Annual Proceedings)
- "Characteristics of Printing Ink Films", 1960, p.55.
- "An Experimental Study of Ink-Film Thickness", 1954, p.194.
- "Surface Properties of Thin Printing Inks", 1967, p.44.
- Tutorial IV - Printing Inks", 1968, p.209.

Periodicals:
- "Introduce Automatic Ink Color Matching System", American Ink Maker, Volume 49, No. 10, October 1971, p.98.
- "Techniques For Measuring Ink-Film Thickness" Lithoprinter, Volume 11, No. 6, June 1968, p.23.

TABLE ONE: EXPERIMENTAL INK SAMPLES

Sample Number	Description	Specific Gravity
1	Blue Web OS HS Process #GA74-1313 C27122 3-19 GPI Company	0.9819
2	Cyan 1d Web HS Process 20-44962 OB-1 6/21/74 Braden Utphin	1.0028
3	Blue Low Emission Offset HS 1d LH-22751 C4G875 Kohl and Madden	0.9757
4	Blue Offset HI Gloss Clean Air Process CH-71-12988 Kohl and Madden	1.0062
5	Blue WKN101 BA #706249 IPI Company	1.0930
6	Satted Blue OB-3535 #46300 10/3/74 Braden-Utphin	0.8632
7	Magenta 4th Dwn Web HS PI OR3500 6/21/74 Braden-Utphin	1.0179
8	Red Web Offset H/S Low Emission 2/0 NJ-74-898 7/10/74 Ba C-3552 Kohl and Madden	1.0010
9	Yellow Web Offset HS Low Emission 3/D NJ-74-899 7-10-74 Ba C-3551 Kohl and Madden	0.9969
10	Web HSPF 2/D Yellow OY-1206 20-44962 6/21/74 Braden-Utphin	0.8933
11	Yellow Offset HS 1/D BU-73-157 BV 488 Kohl and Madden	0.9710
Mixing	Offset Opaque White for CC 6/21/73 Lot 99 #90294 Capitol Printing Ink Company	1.6577

TABLE TWO: PAIR COMPARISON TEST

Reflection density readings taken from random positions on the two samples.

	Machine Method	Hand Method
	1.44	1.47
	1.43	1.47
	1.39	1.47
	1.43	1.49
	1.44	1.45
	1.45	1.49
	1.42	1.45
	1.43	1.49
	1.42	1.49
	1.45	1.45
	1.46	1.50
$\bar{x}$	1.43	1.48
s	0.02	0.02

There is no significant difference in standard deviation of the two methods.

TABLE THREE: INK-FILM THICKNESS

Sample Number		Specific Gravity g/cm	Ink Weight grams	Sample Area cm^2	Ink-Film Microns 10^{-4}cm
1	Ink 7	1.0179	0.0300	161.9254	1.82
2			0.0545	161.4154	3.32
3			0.0192	161.6708	1.17
4			0.0326	161.0982	1.99
5	Ink 8	1.0010	0.0266	161.4804	1.65
6			0.0162	161.7980	1.00
7			0.0528	161.4798	3.27
8			0.0469	161.0672	2.90
9	Ink 9	0.9969	0.0237	161.9254	1.47
10			0.0133	161.7341	0.83
11			0.0450	161.6712	2.79
12			0.0660	161.6074	4.10
13	Ink 10	0.8933	0.0251	161.4804	1.74
14			0.0163	161.7987	1.13
15			0.0568	161.6072	3.93
16			0.0634	161.2894	4.40
17	Ink 11	0.9710	0.0263	161.4798	1.68
18			0.0435	161.2891	2.78
19			0.0342	161.2896	4.58
20			0.0746	161.4169	4.76
21	Ink 1	0.9819	0.0434	161.4161	2.74
22			0.0336	161.4788	2.12
23			0.0398	161.3517	2.51
24			0.0628	161.0352	3.97
25	Ink 3	0.9757	0.0289	161.4158	1.83
26			0.0242	161.7980	1.53
27			0.0449	161.9892	2.84
28			0.0592	161.7980	3.75
29	Ink 6	0.8632	0.0235	161.4158	1.69
30			0.0195	161.6072	1.40
31			0.0407	161.1610	2.93
32			0.0309	161.0350	2.22
33	Ink 5	1.0930	0.0274	160.9080	1.56
34			0.0206	161.4795	1.17
35			0.0575	161.4795	3.26
36			0.0405	161.7890	2.30
37	Ink 9	1.5916	0.0446	161.9841	1.73
38		1.4925	0.0413	161.7347	1.71
39		1.3273	0.0254	161.8617	1.18

TABLE THREE: INK-FILM THICKNESS (continued)

Sample Number		Specific Gravity g/cm	Ink Weight grams	Sample Area cm^2	Ink-Film Microns 10^{-4}cm
40	Ink 10	1.5813	0.0421	161.8610	1.64
41		1.4666	0.0404	162.1163	1.70
42		1.2755	0.0359	162.2432	1.73
43	Ink 11	1.5890	0.0453	161.7334	1.76
44		1.4860	0.0426	161.7980	1.77
45		1.3144	0.0373	161.9250	1.75
46	Ink 6	1.5783	0.0416	161.3525	1.63
47		1.4591	0.0371	161.9885	1.57
48		1.2605	0.0338	161.8587	1.66
49	Ink 5	1.6012	0.0968	162.3074	3.72
50		1.5165	0.0400	161.7334	1.63
51		1.3754	0.0357	161.3530	1.61
52	Ink 3	1.5895	0.0430	161.7334	1.67
53		1.4872	0.0406	161.4798	1.69
54		1.3167	0.0331	161.9885	1.55
55	Ink 1	1.5901	0.0440	161.7338	1.71
56		1.4888	0.0711	161.5421	2.96
57		1.3198	0.0348	161.7334	1.63
58	Ink 8	1.5920	0.0446	161.7978	1.73
59		1.4935	0.0422	161.7343	1.75
60		1.3294	0.0378	162.0520	1.75
61	Ink 7	1.5937	0.0463	161.9254	1.79
62		1.4978	0.0423	162.4987	1.74
63		1.3378	0.0389	161.8613	1.80
64	White	1.6577	0.0405	161.6710	1.51

NOTE: Sample numbers 37-63 are in order of ratios 9:1, 3:1, and 1:1 respectively.

TABLE FOUR: COLORIMETRIC DATA

Sample Number		x	y	Y
1	Ink 7	0.4771	0.2419	0.1639
2		0.5608	0.2701	0.1196
3		0.4326	0.2462	0.2253
4		0.5050	0.2469	0.1482
5	Ink 8	0.4865	0.2481	0.1632
6		0.4276	0.2488	0.2305
7		0.5809	0.2774	0.1137
8		0.5604	0.2666	0.1210
9	Ink 9	0.4481	0.5003	0.8647
10		0.4226	0.4766	0.9028
11		0.4621	0.5086	0.8318
12		0.4701	0.5080	0.8104
13	Ink 10	0.4576	0.4908	0.8066
14		0.4387	0.4812	0.8508
15		0.4896	0.4873	0.7116
16		0.4927	0.4859	0.6934
17	Ink 11	0.4434	0.4931	0.8348
18		0.4594	0.5030	0.8166
19		0.4502	0.5025	0.8406
20		0.5374	0.4353	0.6178
21	Ink 1	0.1387	0.1408	0.1492
22		0.1452	0.1510	0.1725
23		0.1423	0.1479	0.1613
24		0.1348	0.1228	0.1060
25	Ink 3	0.1454	0.1550	0.1818
26		0.1489	0.1619	0.1991
27		0.1362	0.1330	0.1266
28		0.1343	0.1257	0.1072
29	Ink 6	0.1688	0.1247	0.1167
30		0.1746	0.1344	0.1428
31		0.1472	0.0817	0.0565
32		0.1540	0.1031	0.0862
33	Ink 5	0.1460	0.1585	0.1818
34		0.1553	0.1730	0.2248
35		0.1362	0.1291	0.1078
36		0.1437	0.1398	0.1351

TABLE FOUR: COLORIMETRIC DATA (continued)

Sample Number		x	y	Y
37	Ink 9	0.3791	0.4258	0.9004
38		0.4115	0.4672	0.8873
39		0.4246	0.4865	0.7715
40	Ink 10	0.3826	0.4247	0.9031
41		0.4153	0.4680	0.8726
42		0.4417	0.4926	0.8394
43	Ink 11	0.3763	0.4204	0.9155
44		0.4092	0.4622	0.7872
45		0.4327	0.4905	0.8668
46	Ink 6	0.2480	0.2547	0.5275
47		0.2117	0.2074	0.3358
48		0.1866	0.1606	0.1968
49	Ink 5	0.2157	0.2619	0.5301
50		0.1860	0.2284	0.3797
51		0.1625	0.1904	0.2608
52	Ink 3	0.2248	0.2700	0.5616
53		0.1876	0.2332	0.4043
54		0.1645	0.1981	0.2885
55	Ink 1	0.2244	0.2725	0.5799
56		0.1888	0.2328	0.4095
57		0.1662	0.1988	0.2944
58	Ink 8	0.3514	0.2476	0.4126
59		0.3952	0.2346	0.2686
60		0.4511	0.2353	0.1845
61	Ink 7	0.3444	0.2507	0.4438
62		0.3867	0.2346	0.2909
63		0.4359	0.2309	0.2021
64	White	0.3115	0.3180	0.9474

TABLE FIVE: UNIFORM CHROMATICITY SCALE DATA

Sample Number		u	v	uW*	vW*
1	Ink	0.3856	0.2933	0.1243	0.3131
2	7	0.4382	0.3165	0.0620	0.3019
3		0.3400	0.2903	0.1698	0.3111
4		0.4079	0.2991	0.1033	0.3112
5	Ink	0.3889	0.2975	0.1225	0.3114
6	8	0.3334	0.2910	0.1732	0.3107
7		0.4497	0.3221	0.0489	0.2983
8		0.4414	0.3150	0.0616	0.3028
9	Ink	0.2211	0.3703	0.2181	0.3610
10	9	0.2147	0.3632	0.2133	0.3573
11		0.2260	0.3731	0.2213	0.3609
12		0.2306	0.3737	0.2243	0.3597
13	Ink	0.2295	0.3693	0.2233	0.3559
14	10	0.2222	0.3656	0.2187	0.3560
15		0.2489	0.3716	0.2328	0.3501
16		0.2512	0.3716	0.2331	0.3485
21	Ink	0.1257	0.1915	0.2361	0.3614
22	1	0.1285	0.2004	0.2288	0.3485
23		0.1268	0.1976	0.2323	0.3538
24		0.1283	0.1753	0.2478	0.3926
29	Ink	0.1624	0.1799	0.2239	0.3835
30	6	0.1638	0.1891	0.2191	0.3654
31		0.1597	0.1330	0.2390	0.4687
32		0.1568	0.1574	0.2337	0.4189
37	Ink	0.2063	0.3475	0.2057	0.3432
38	9	0.2115	0.3602	0.2102	0.3537
39		0.2126	0.3654	0.2111	0.3581
40	Ink	0.2088	0.3476	0.2080	0.3434
41	10	0.2134	0.3607	0.2117	0.3533
42		0.2201	0.3682	0.2167	0.3574
46	Ink	0.1784	0.2748	0.1919	0.2943
47	6	0.1672	0.2457	0.1993	0.3048
48		0.1639	0.2116	0.2123	0.3367

TABLE FIVE: UNIFORM CHROMATICITY SCALE DATA (continued)

Sample Number		u	v	uW*	vW*
55	Ink	0.1542	0.2809	0.1784	0.2946
56	1	0.1394	0.2579	0.1889	0.2976
57		0.1316	0.2360	0.2041	0.3106
58	Ink	0.2668	0.2820	0.2142	0.3022
59	8	0.3146	0.2901	0.1885	0.3103
60		0.3666	0.2869	0.1436	0.3144
61	Ink	0.2590	0.2828	0.2159	0.3010
62	7	0.3068	0.2792	0.1951	0.3088
63		0.3559	0.2828	0.1558	0.3144
64	White	0.2012	0.3081	0.2012	0.3081

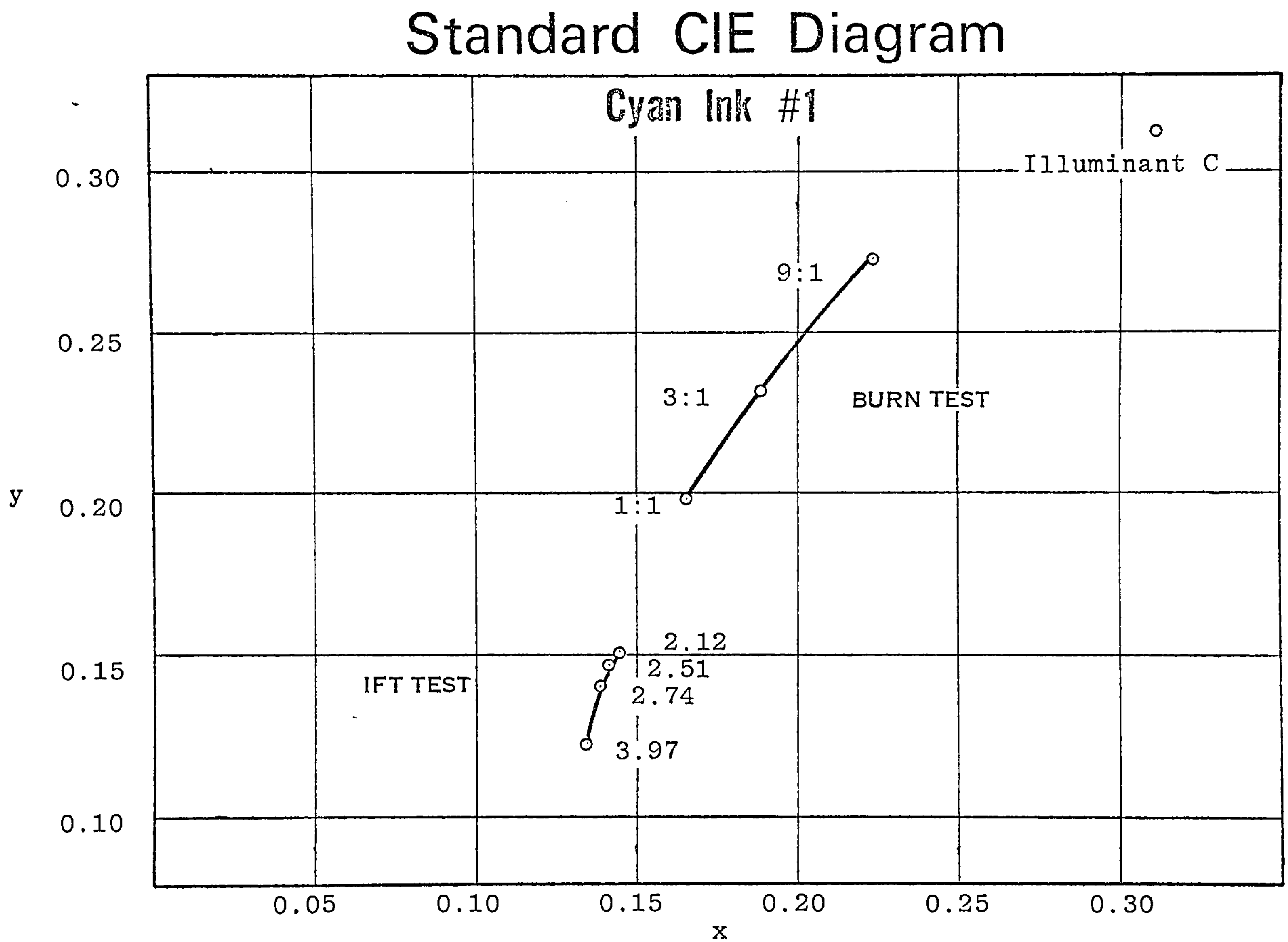

FIGURE 1 Ink-Film Thicknesses in microns. Burn Test in ratio of white to ink sample.

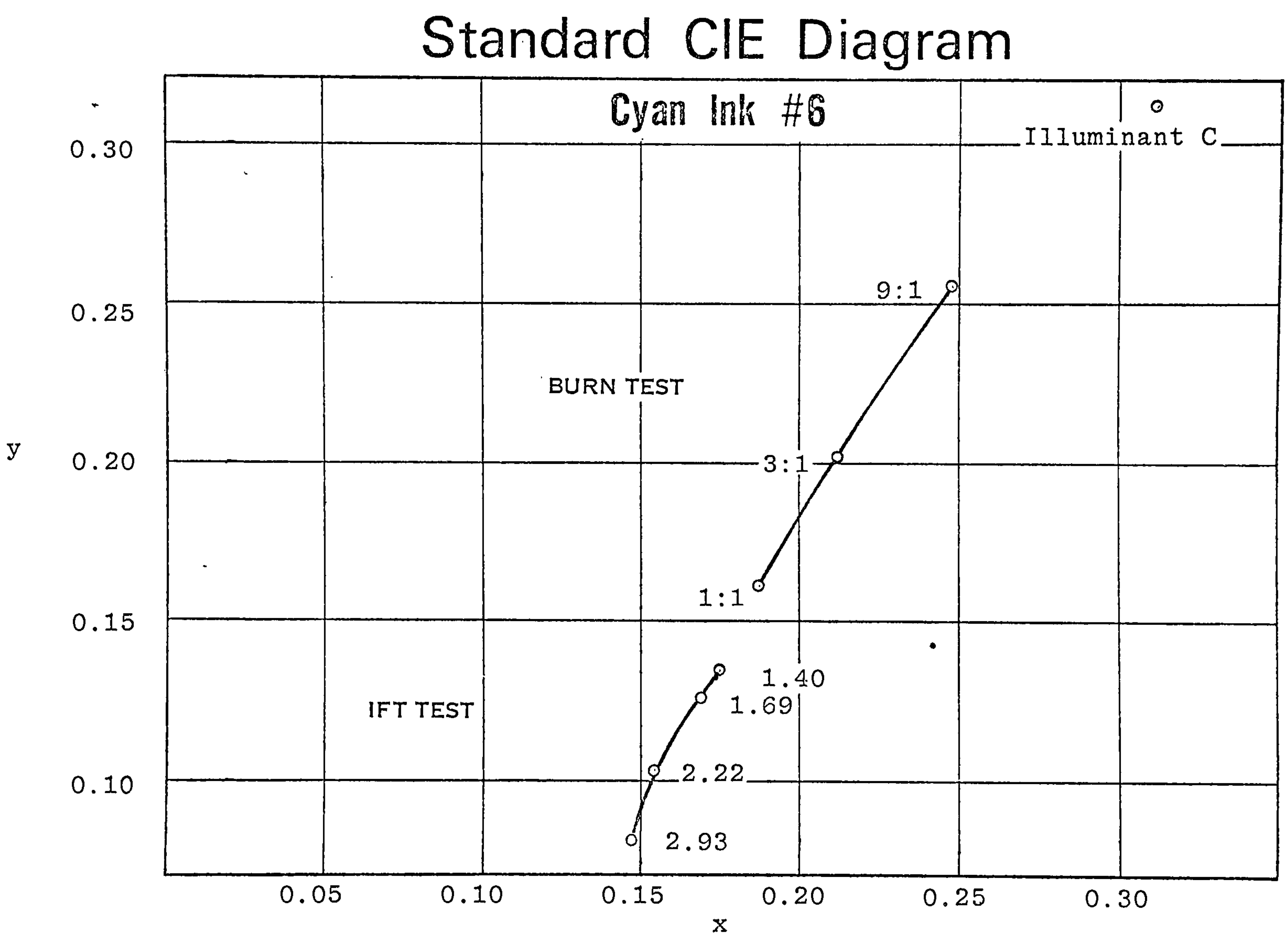

FIGURE 2 Ink-Film Thicknesses in microns. Burn Test in ratio of white to ink sample.

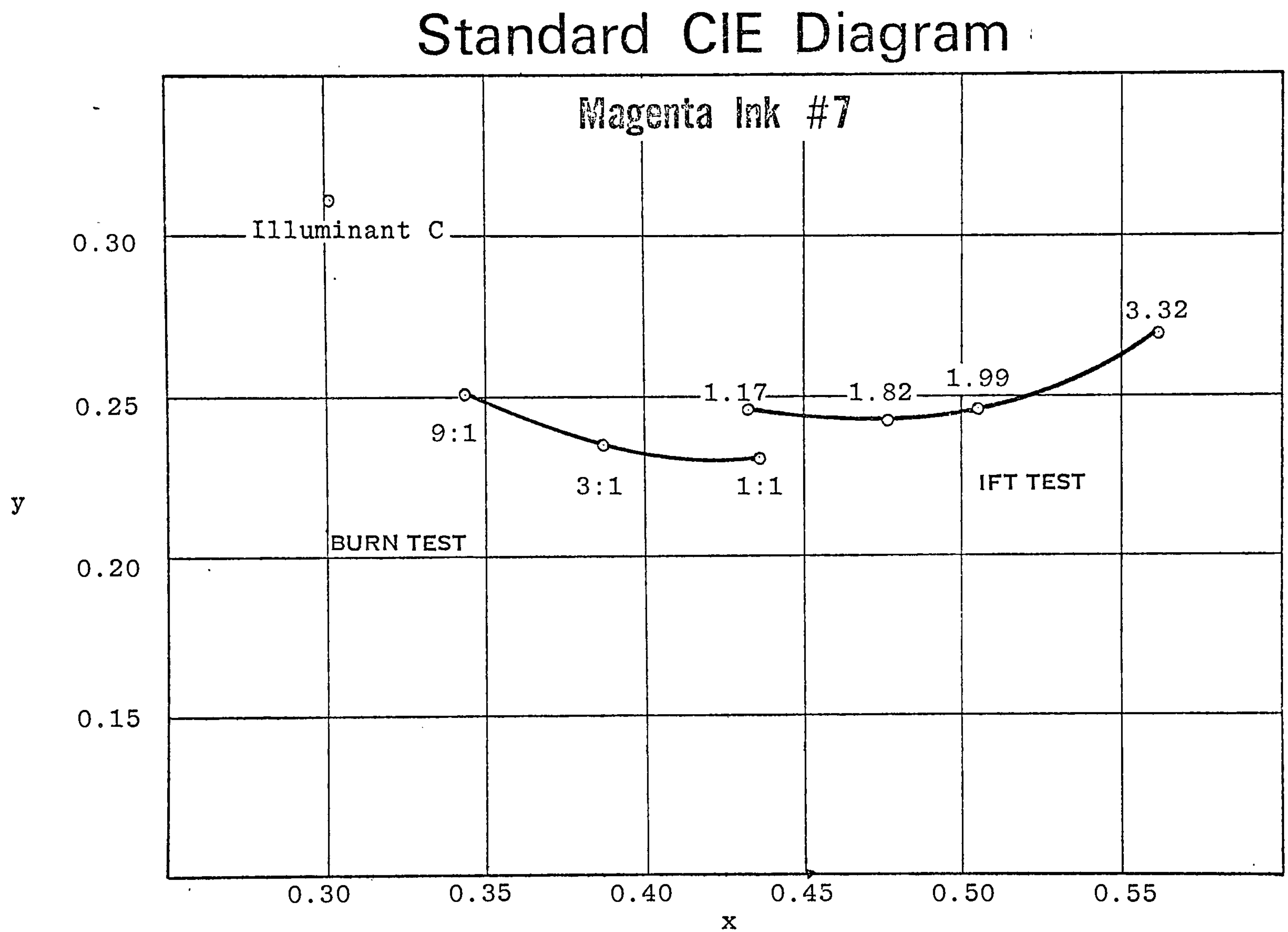

FIGURE 3 Ink-Film Thicknesses in microns. Burn Test in ratio of white ink to ink sample.

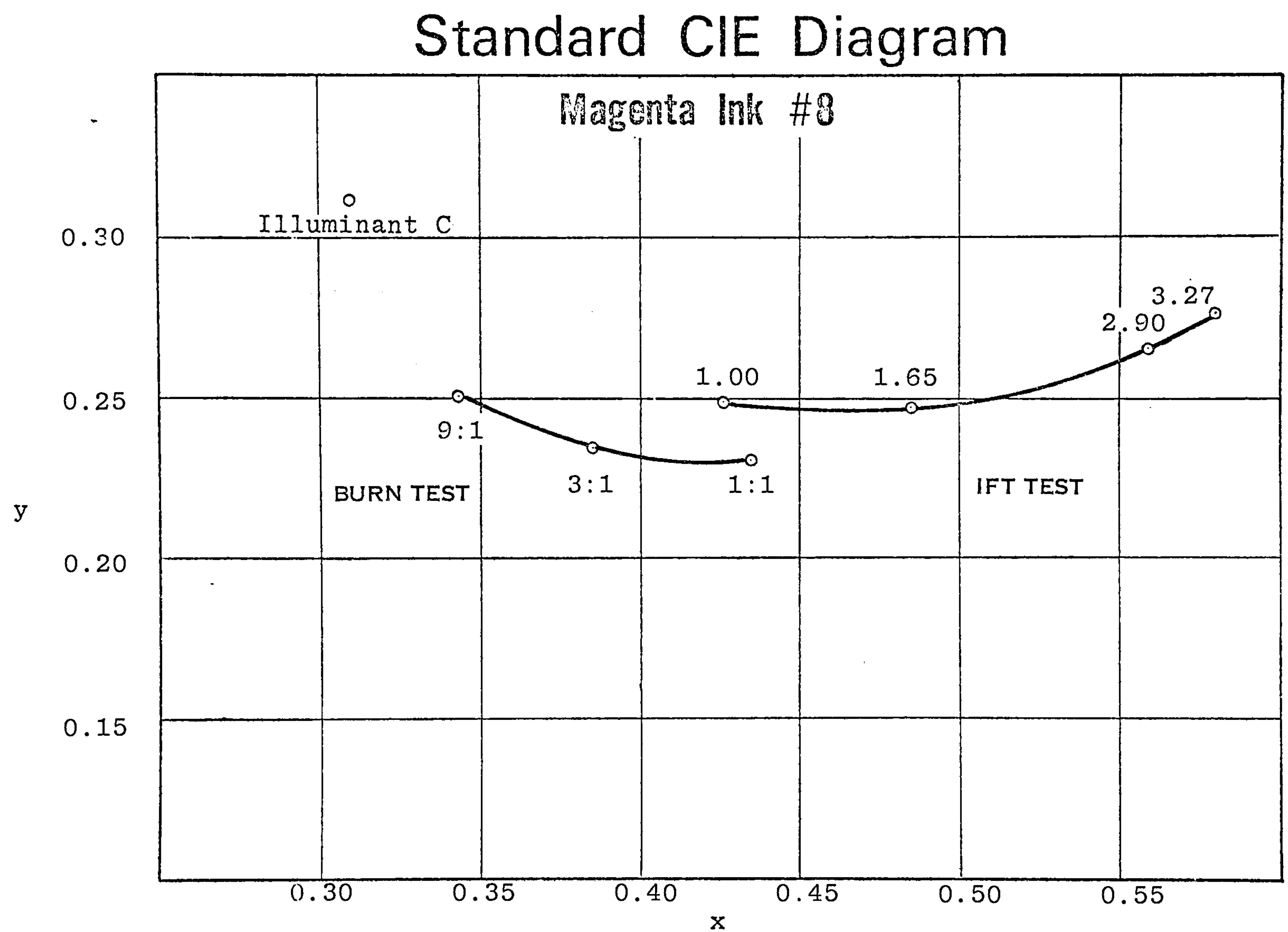

FIGURE 4 Ink-Film Thickness in microns. Burn Test in ratio of white ink to ink sample.

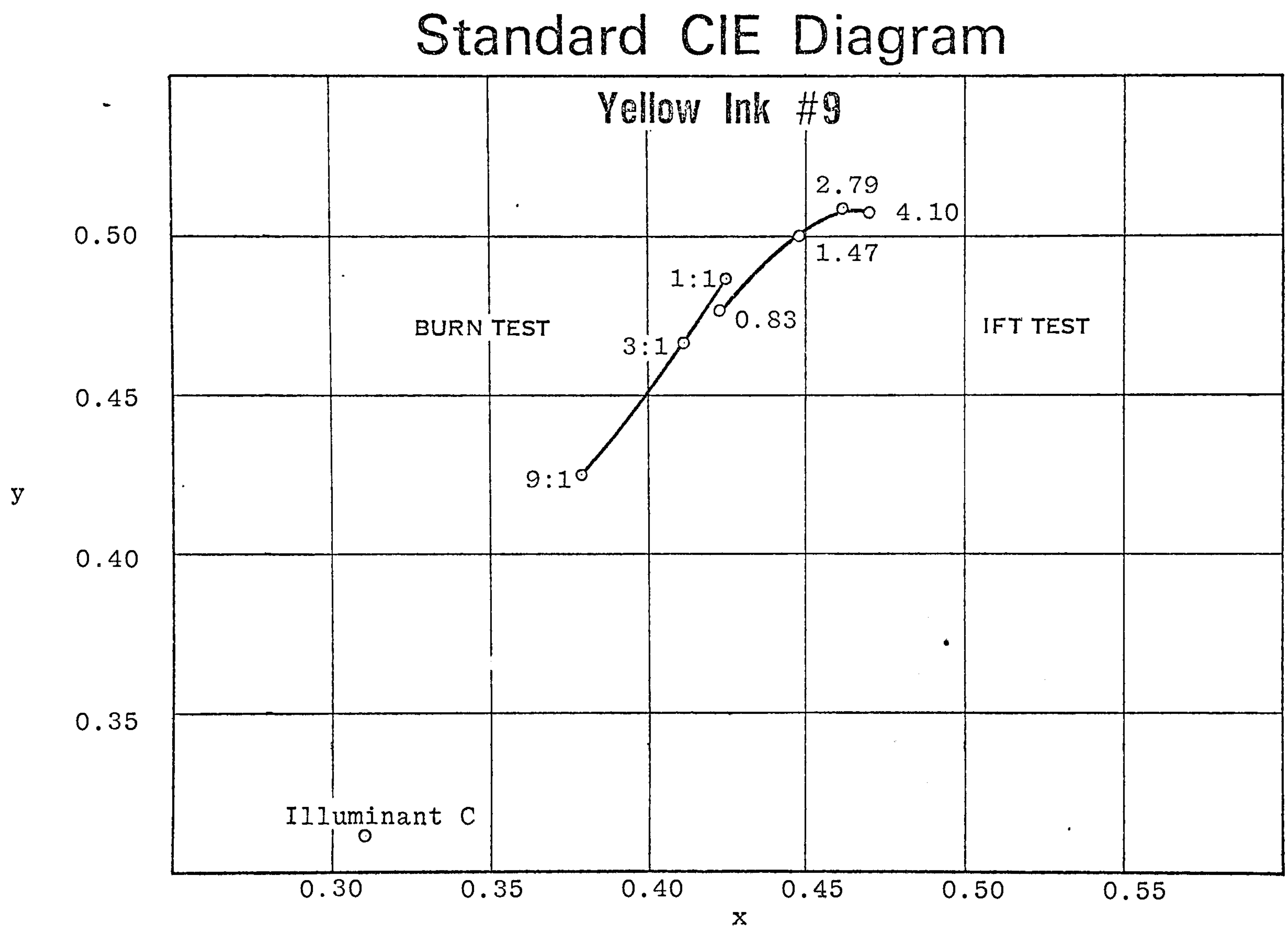

FIGURE 5 Ink-Film Thicknesses in microns. Burn Test in ratio of white ink to sample ink.

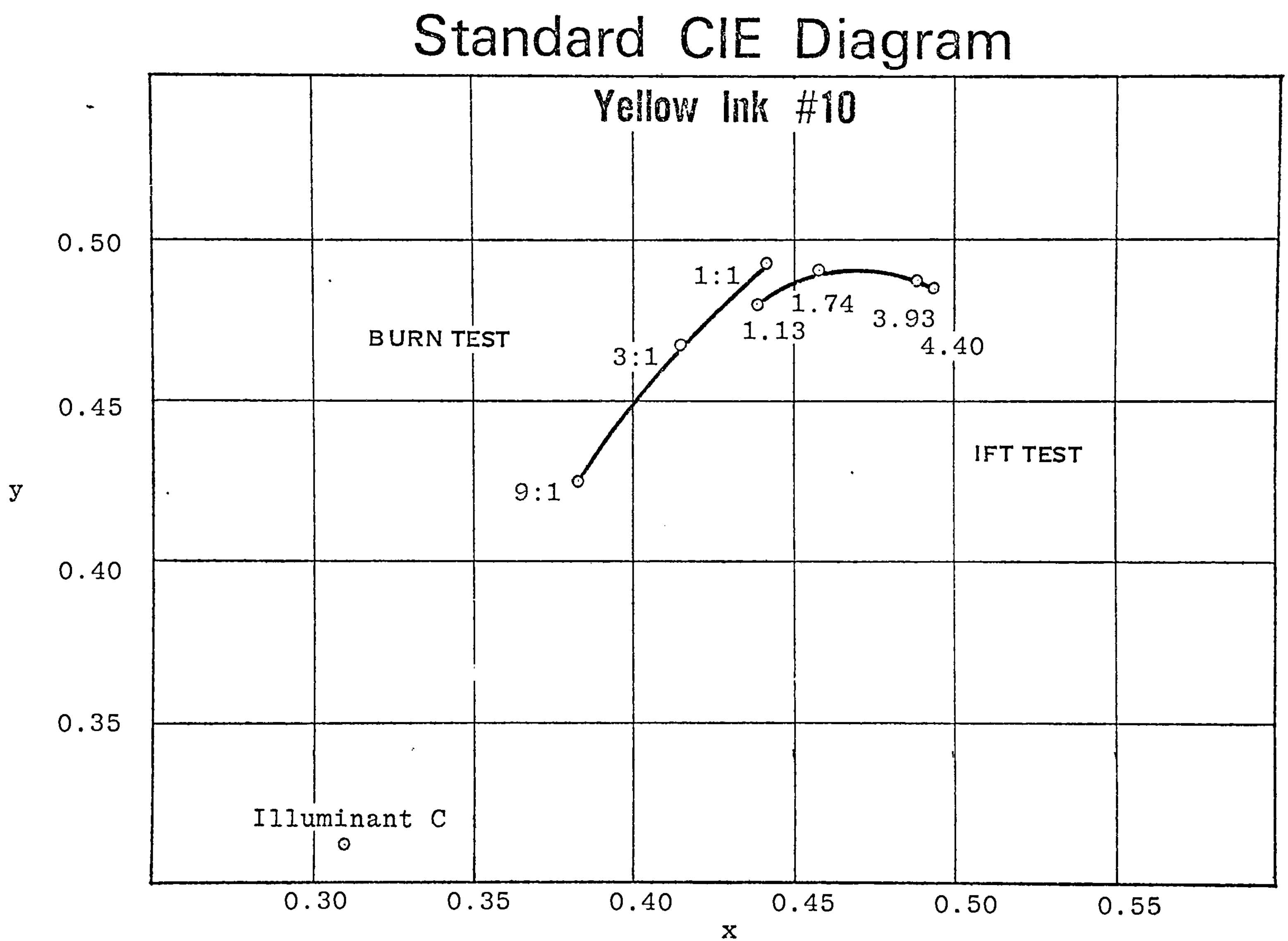

FIGURE 6 Ink-Film Thicknesses in microns. Burn Test in ratio of white ink to sample ink.

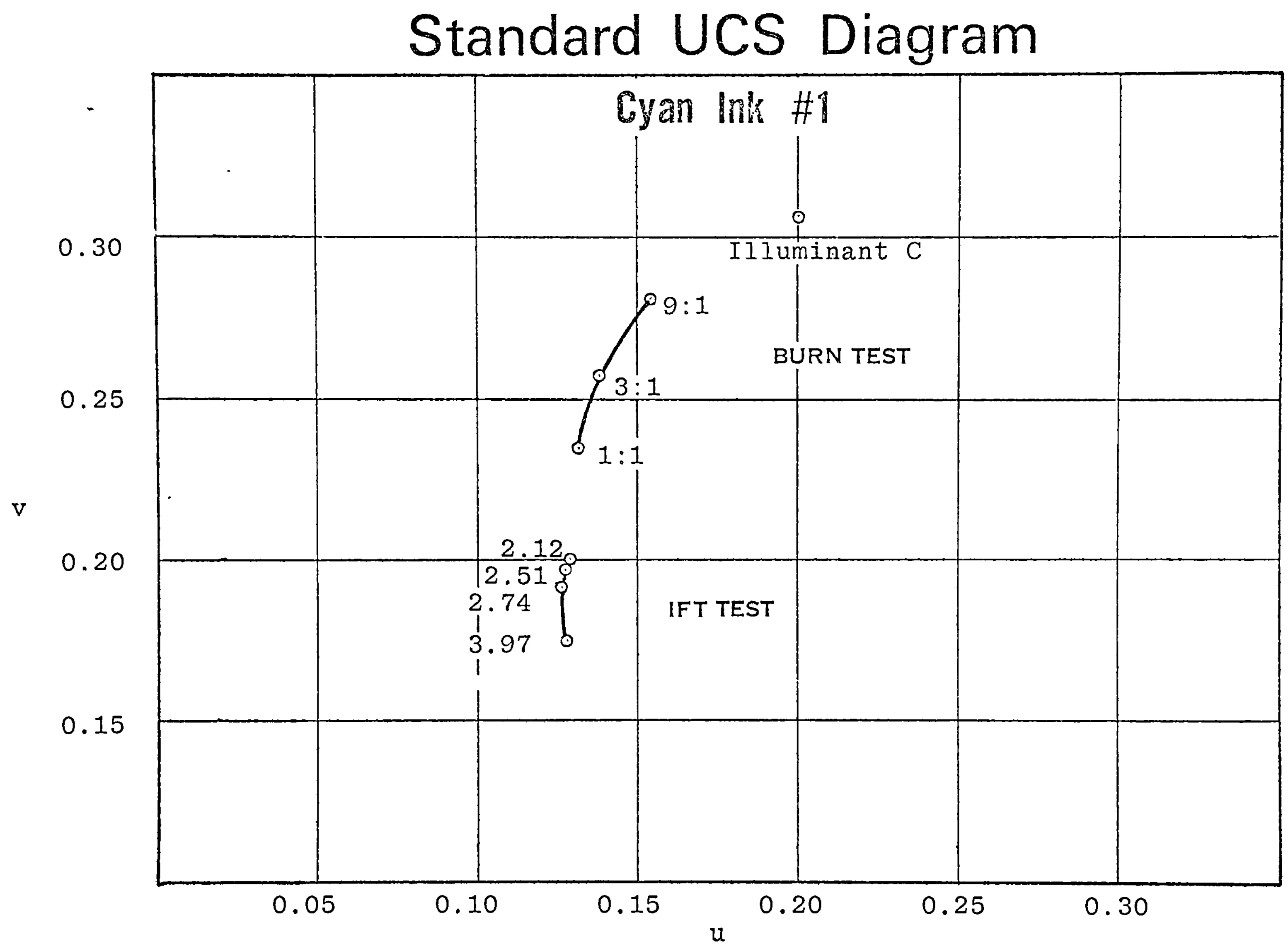

FIGURE 7 Ink-Film Thicknesses in microns. Burn Test in ratio of white ink to sample ink.

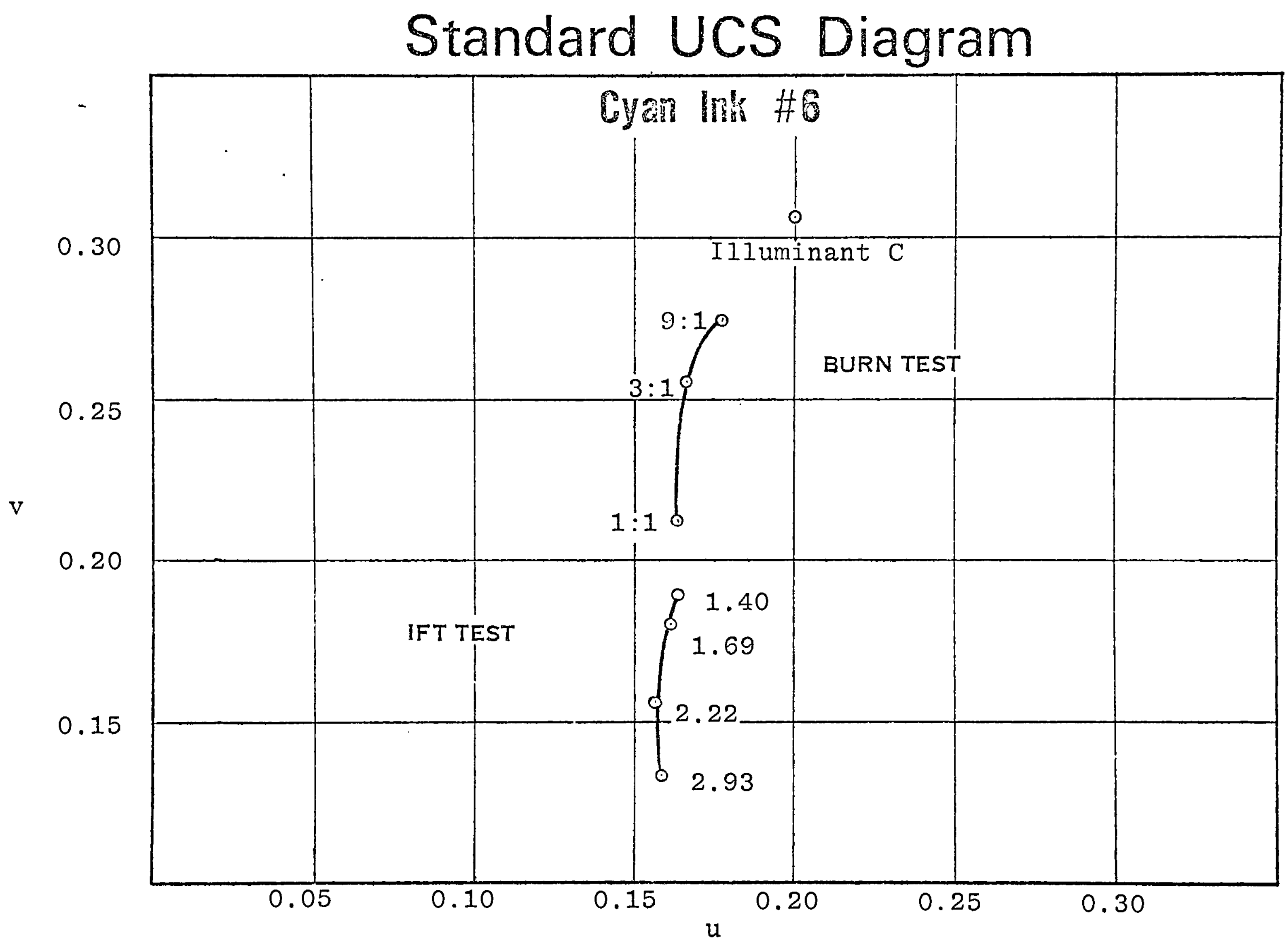

FIGURE 8 Ink-Film Thicknesses in microns. Burn Test in ratio of white ink to sample ink.

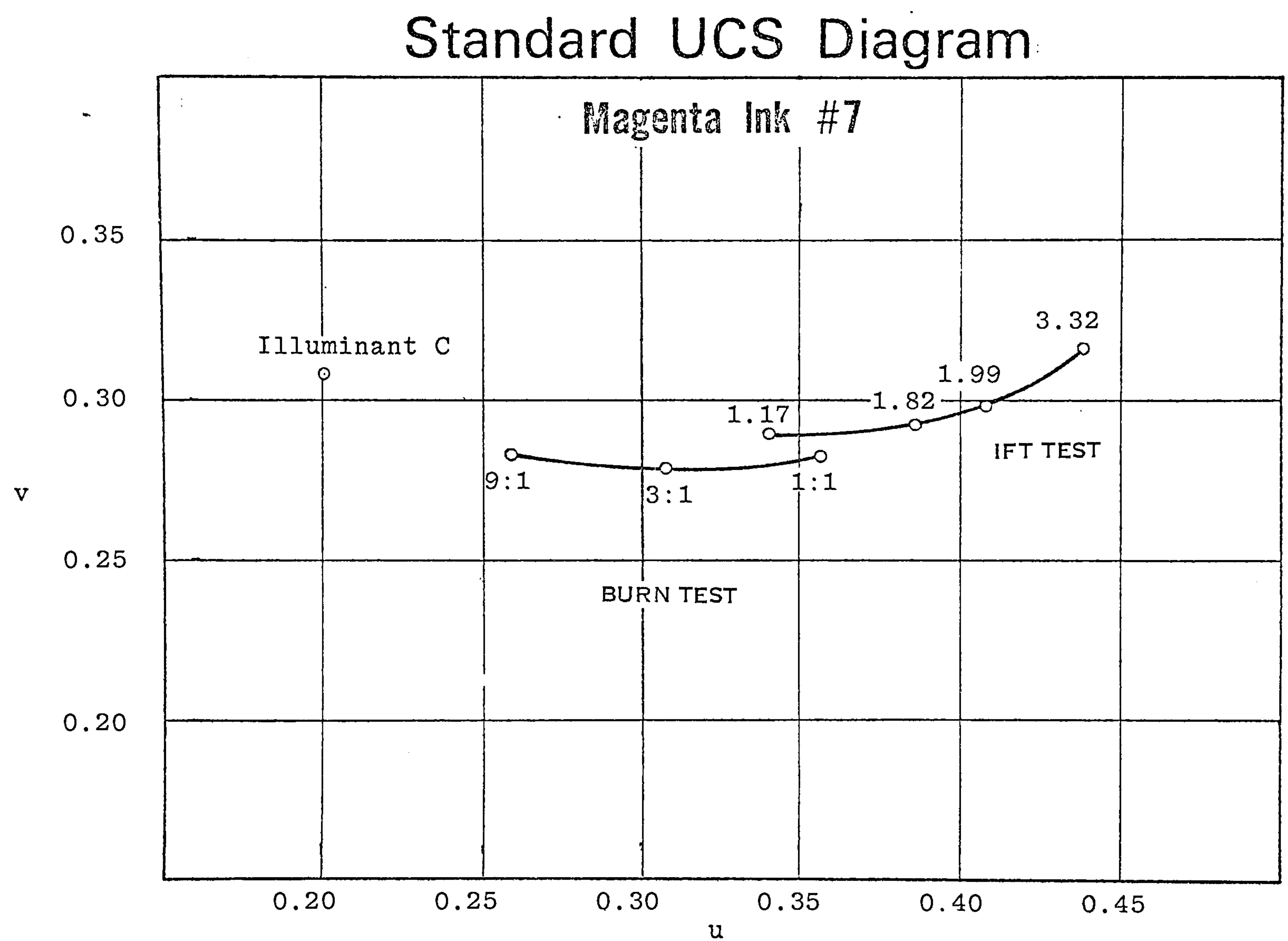

FIGURE 9 Ink-Film Thicknesses in microns. Burn Test in ratio of white ink to sample ink.

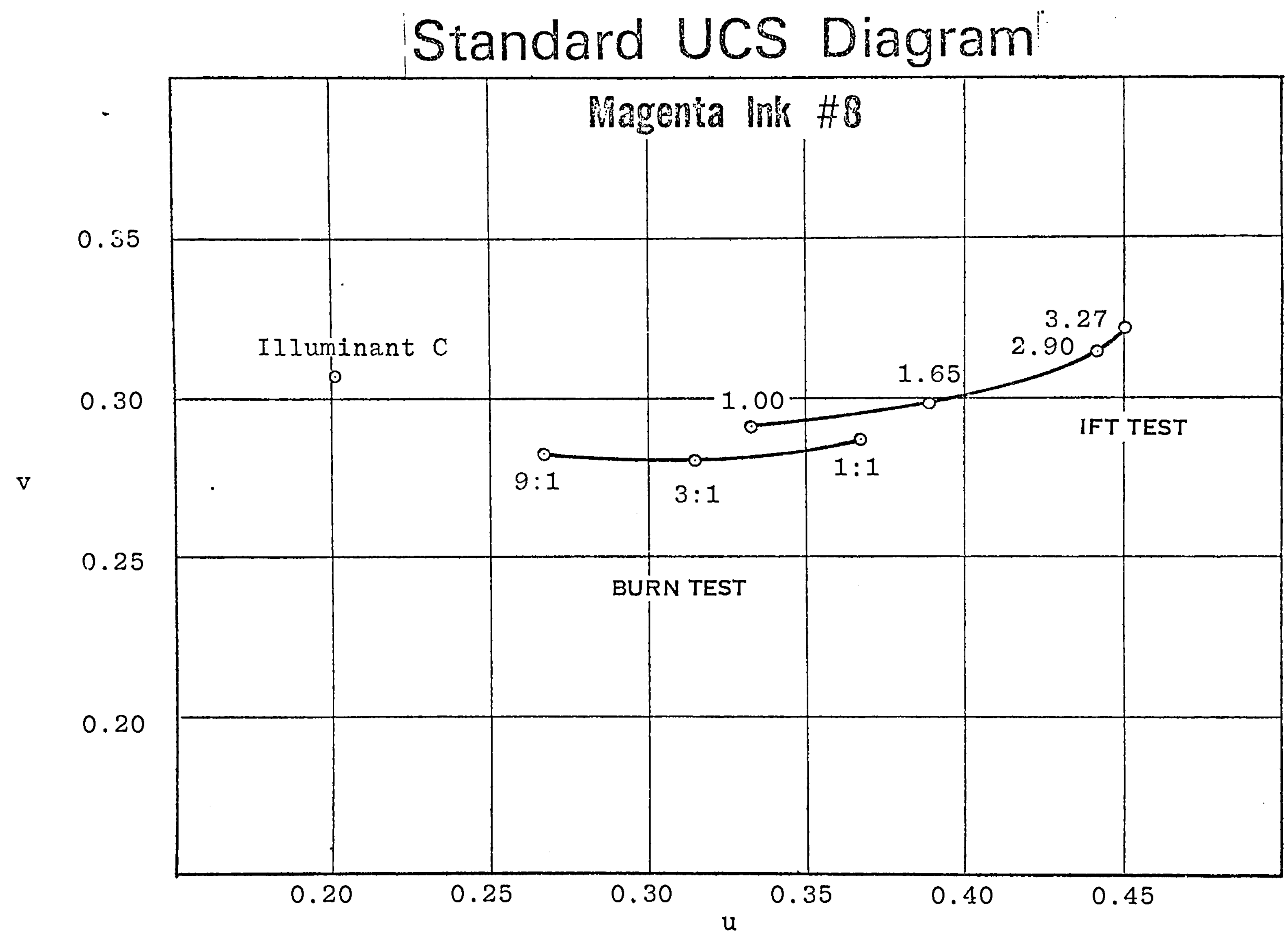

FIGURE 10 Ink-Film Thicknesses in microns. Burn Test in ratio of white ink to sample ink.

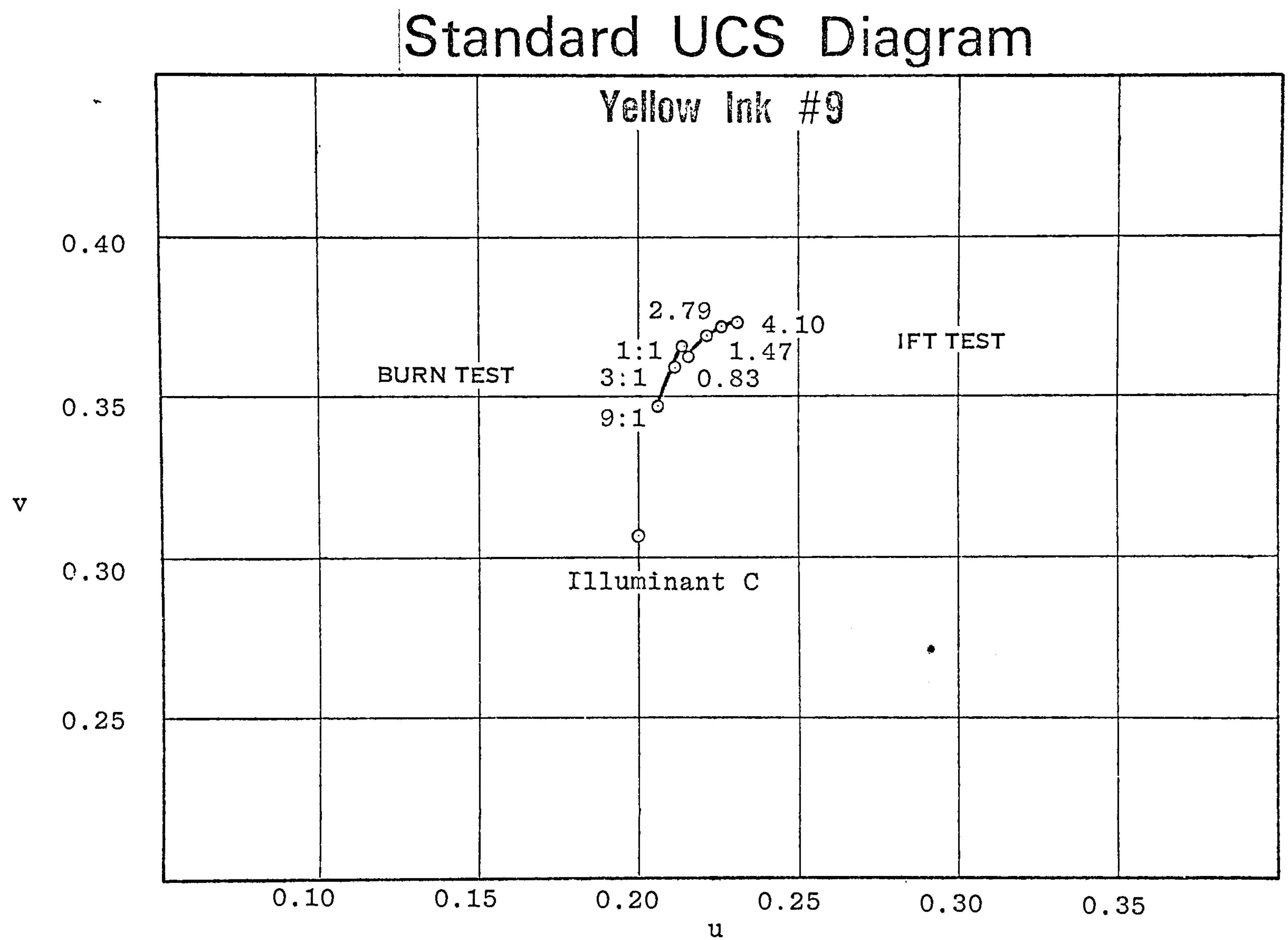

FIGURE 11 Ink-Film Thicknesses in microns. Burn Test in ratio of white ink to sample ink.

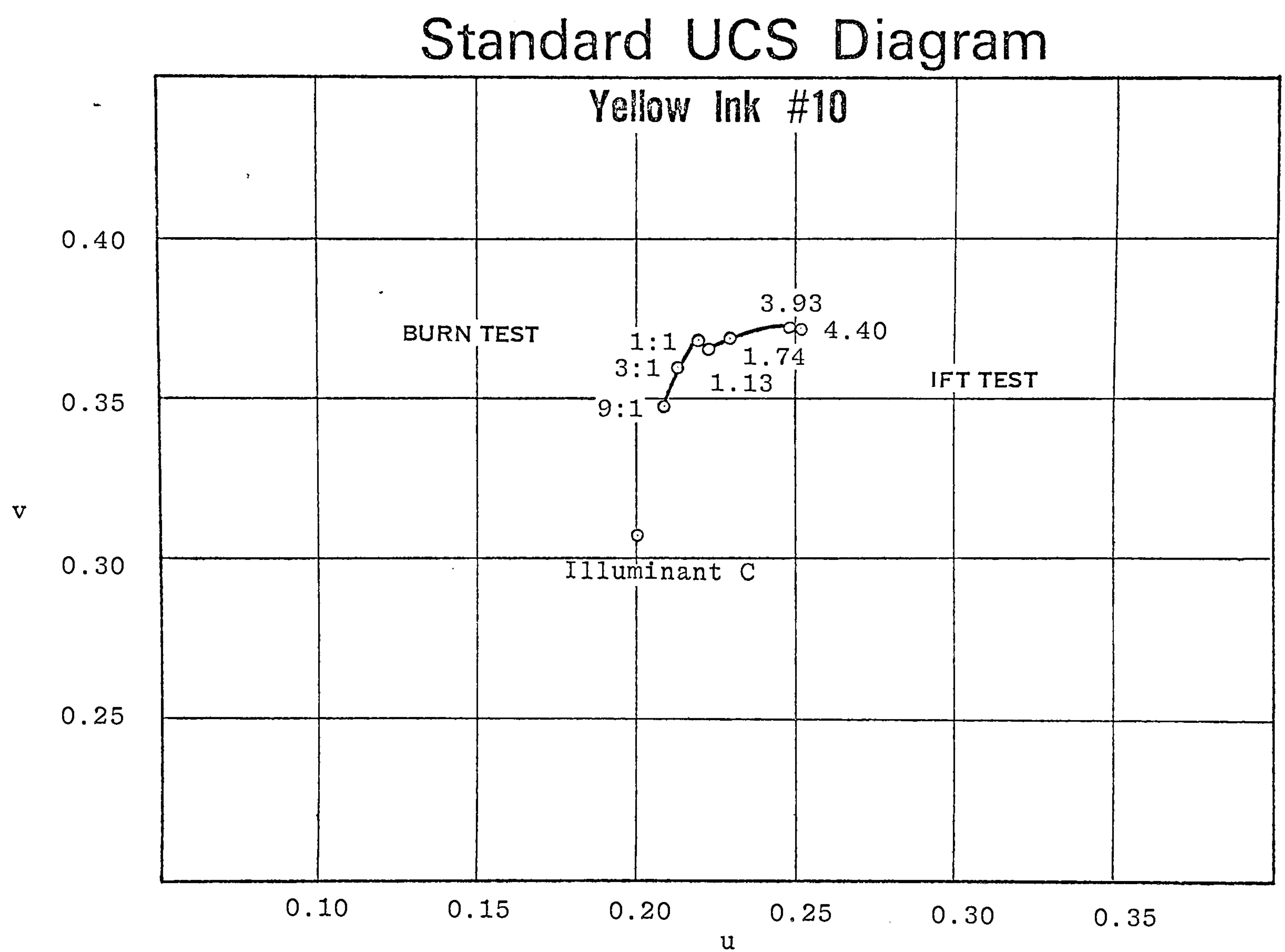

FIGURE 12 Ink-Film Thicknesses in microns. Burn Test in ratio of white ink to sample ink.

Visual Comparison

SPECIFIC GRAVITY VS. COLOR STRENGTH

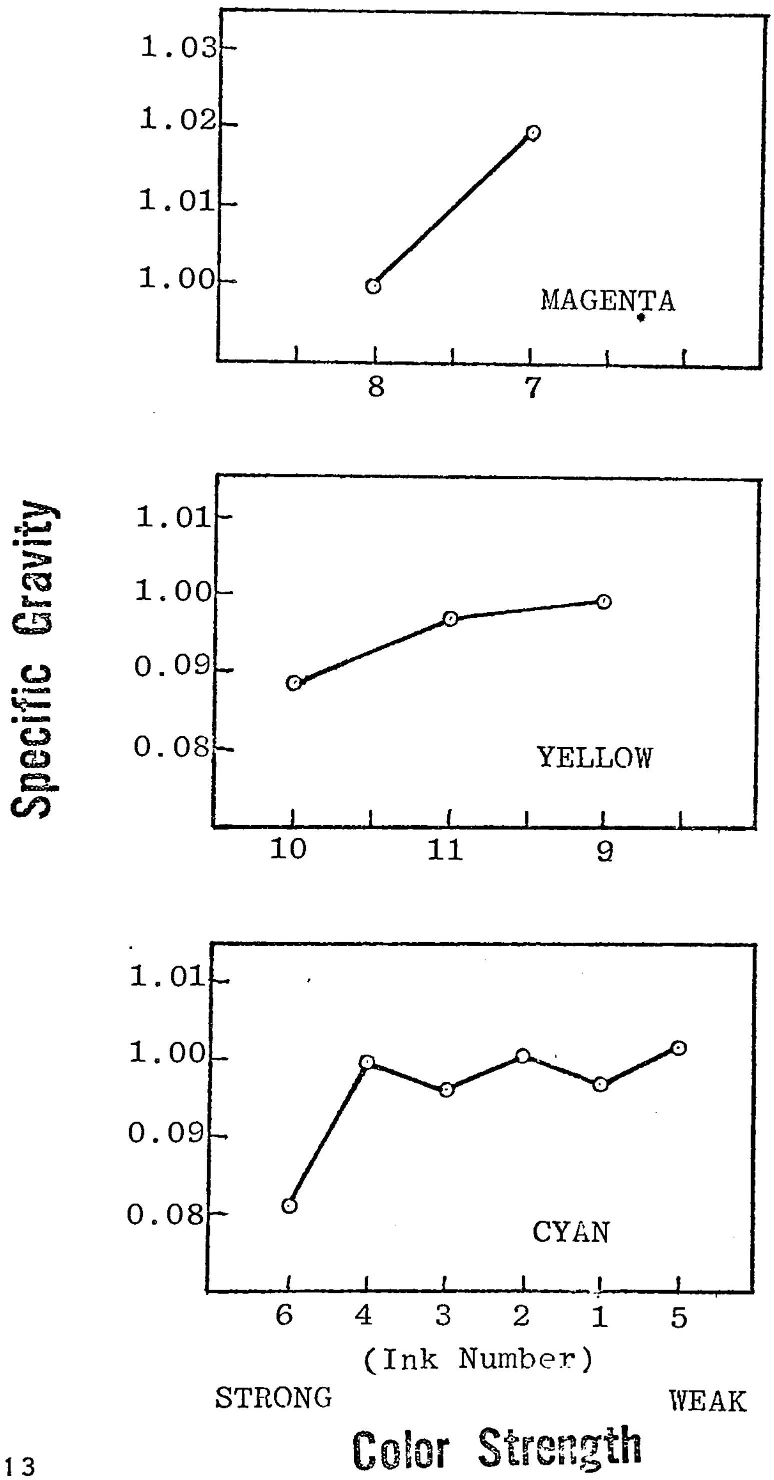

FIGURE 13

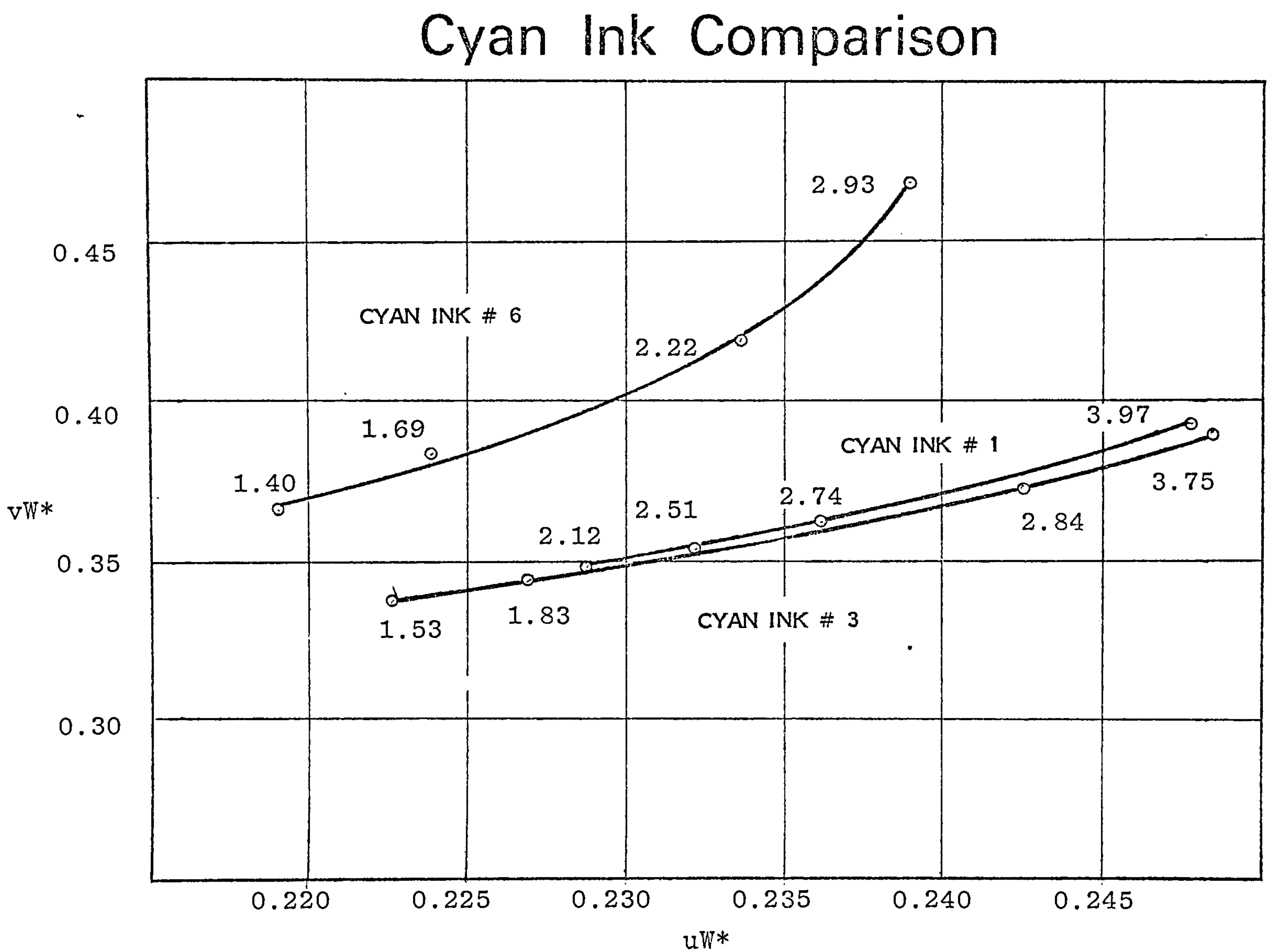

FIGURE 14 Ink-Film Thicknesses in microns.

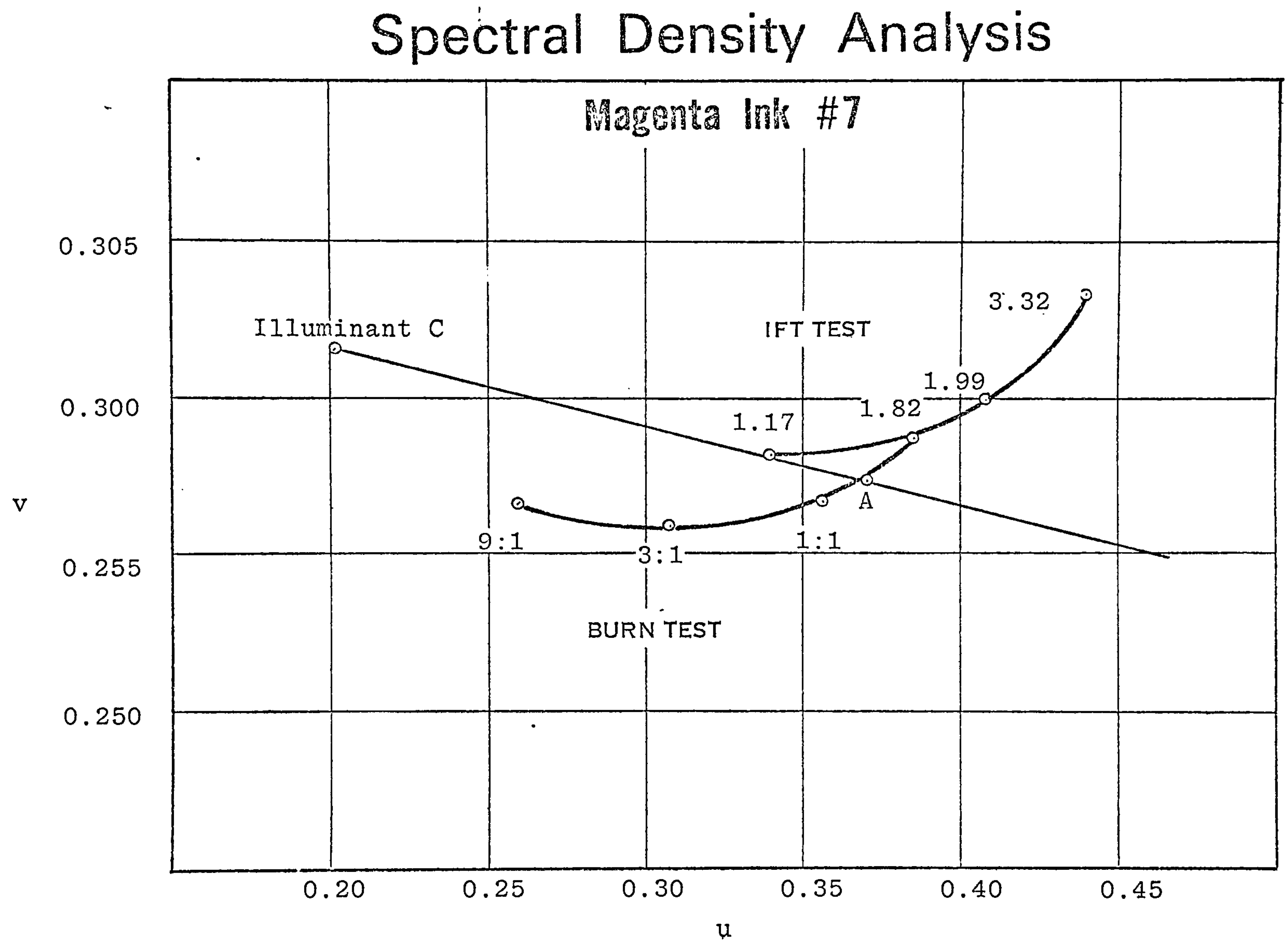

FIGURE 15 Standard U.C.S. Diagram. Ink-Film Thicknesses in microns.

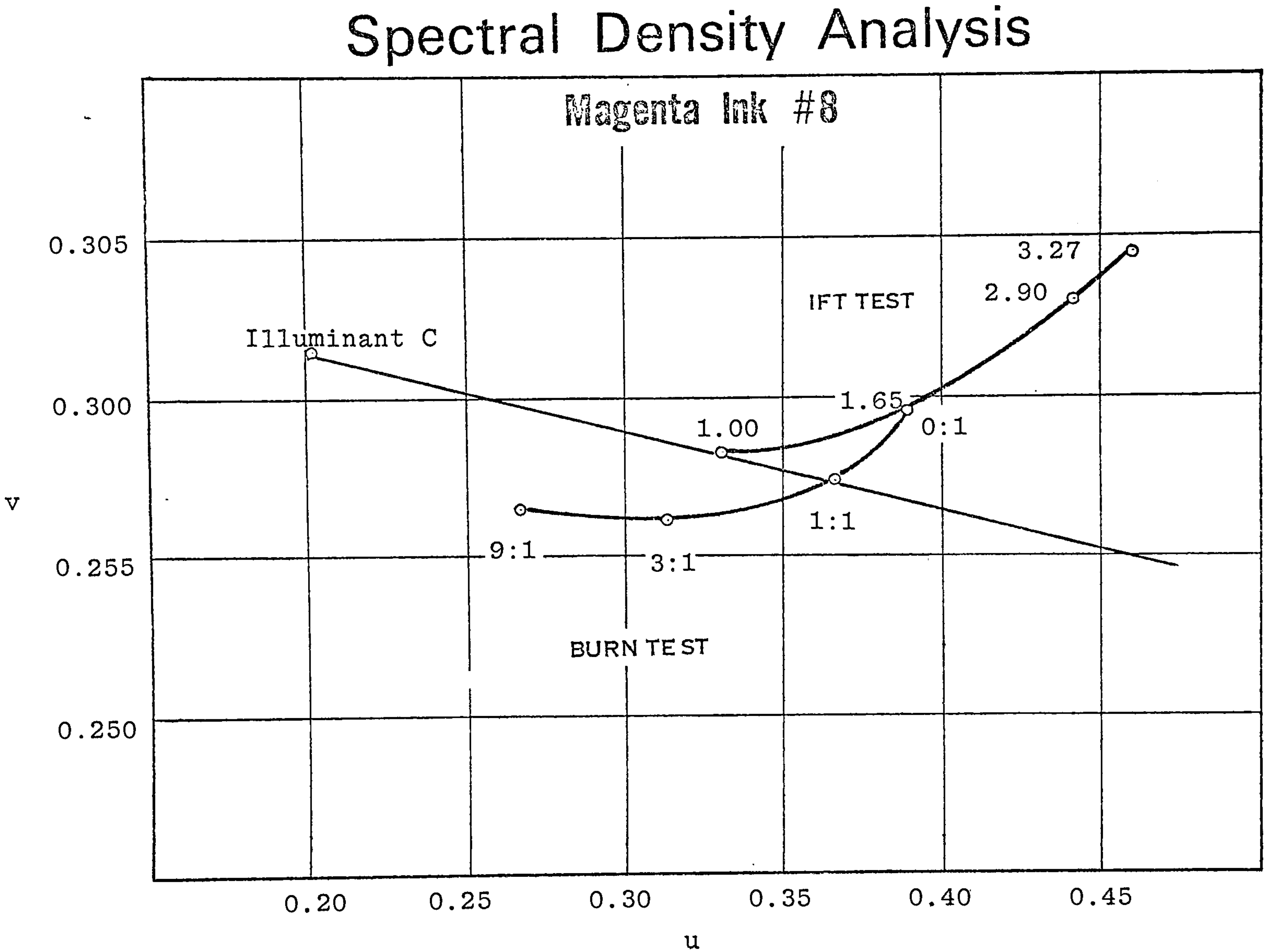

FIGURE 16 Standard U.C.S. Diagram. Ink-Film Thicknesses in microns.

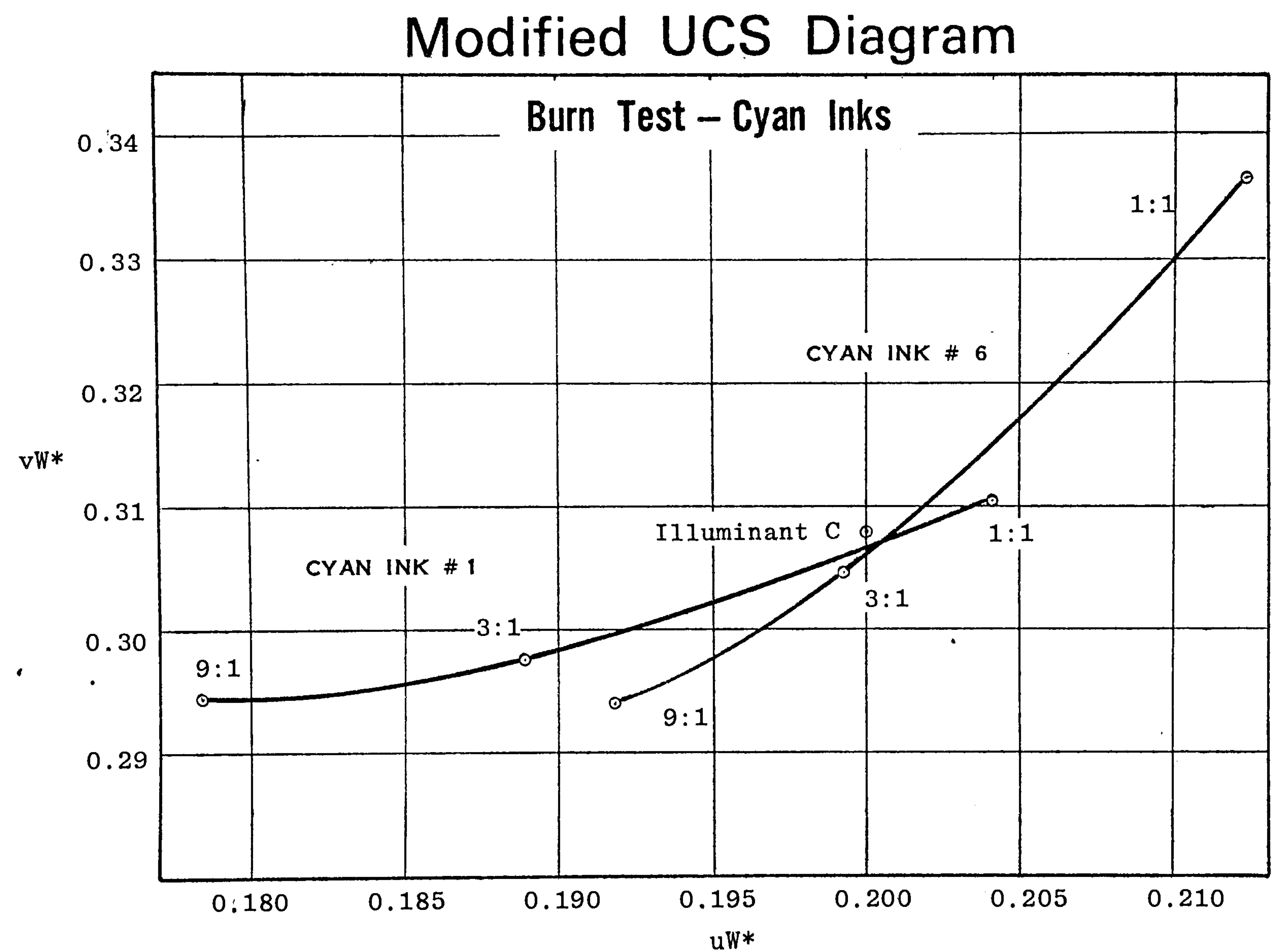

FIGURE 17 Burn Test in ratio of white pigment to sample ink.

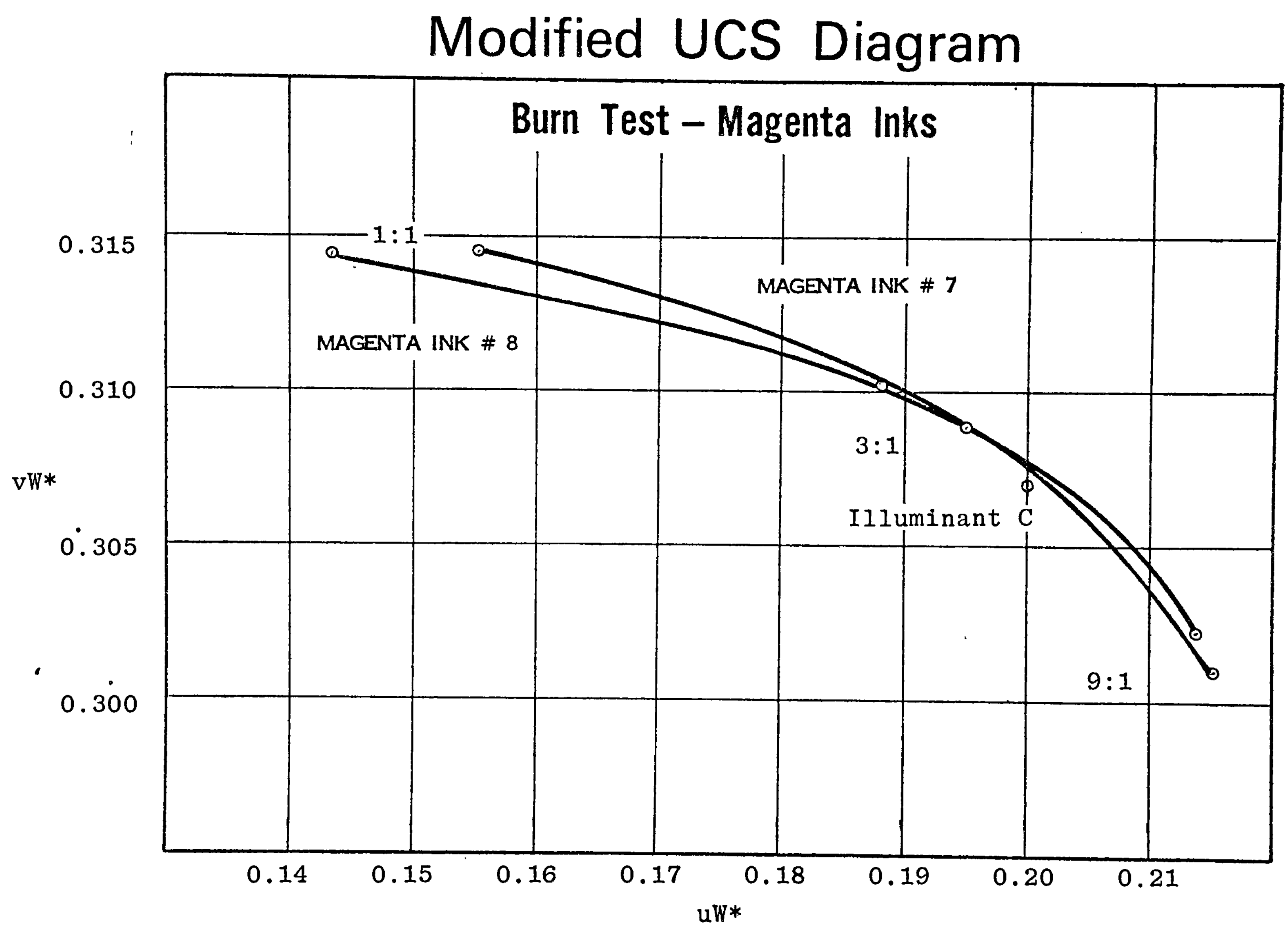

FIGURE 18 Burn Test in ratio of white pigment to sample ink.

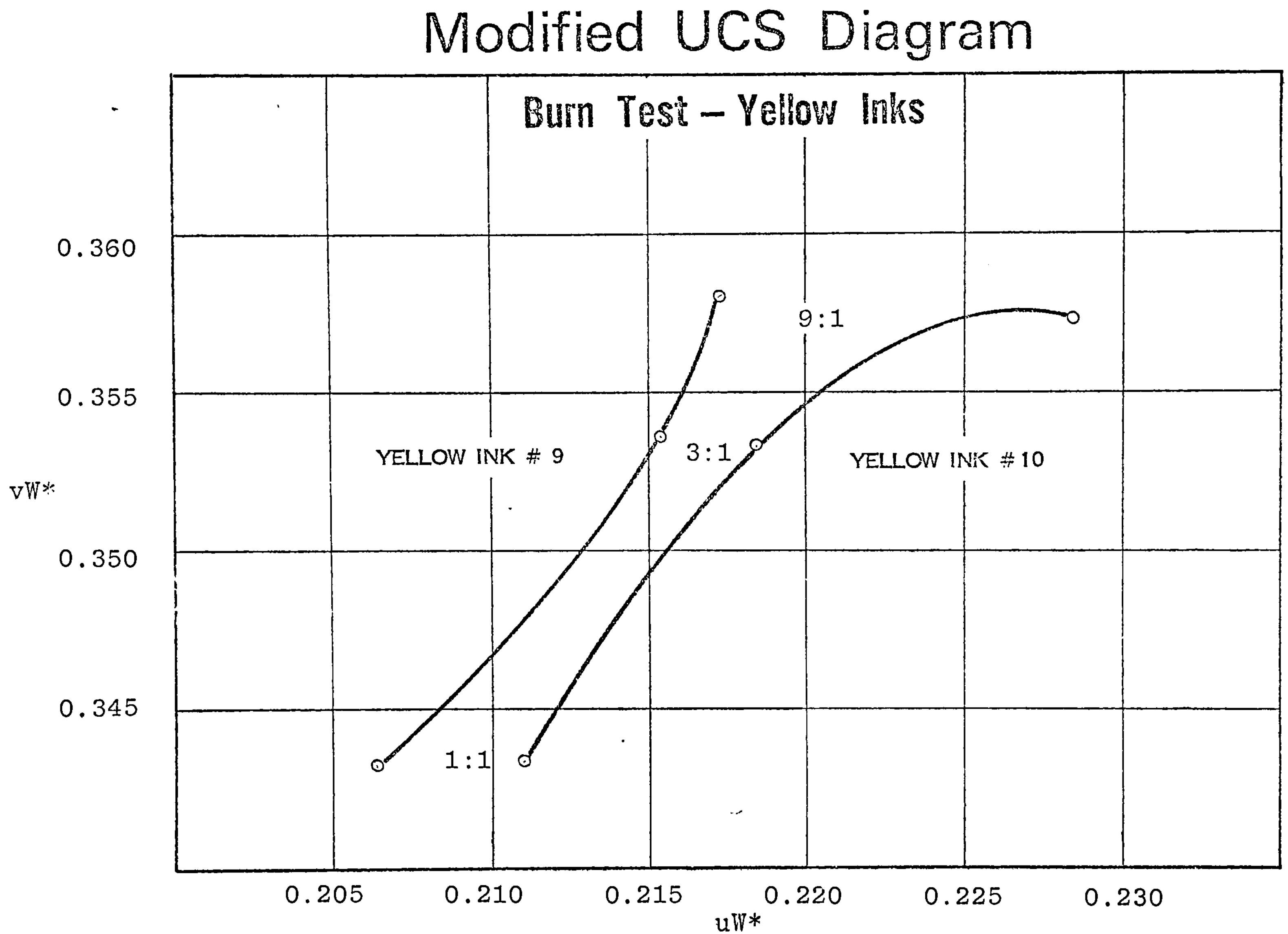

FIGURE 19 Burn Test in ratio of white pigment to sample ink.

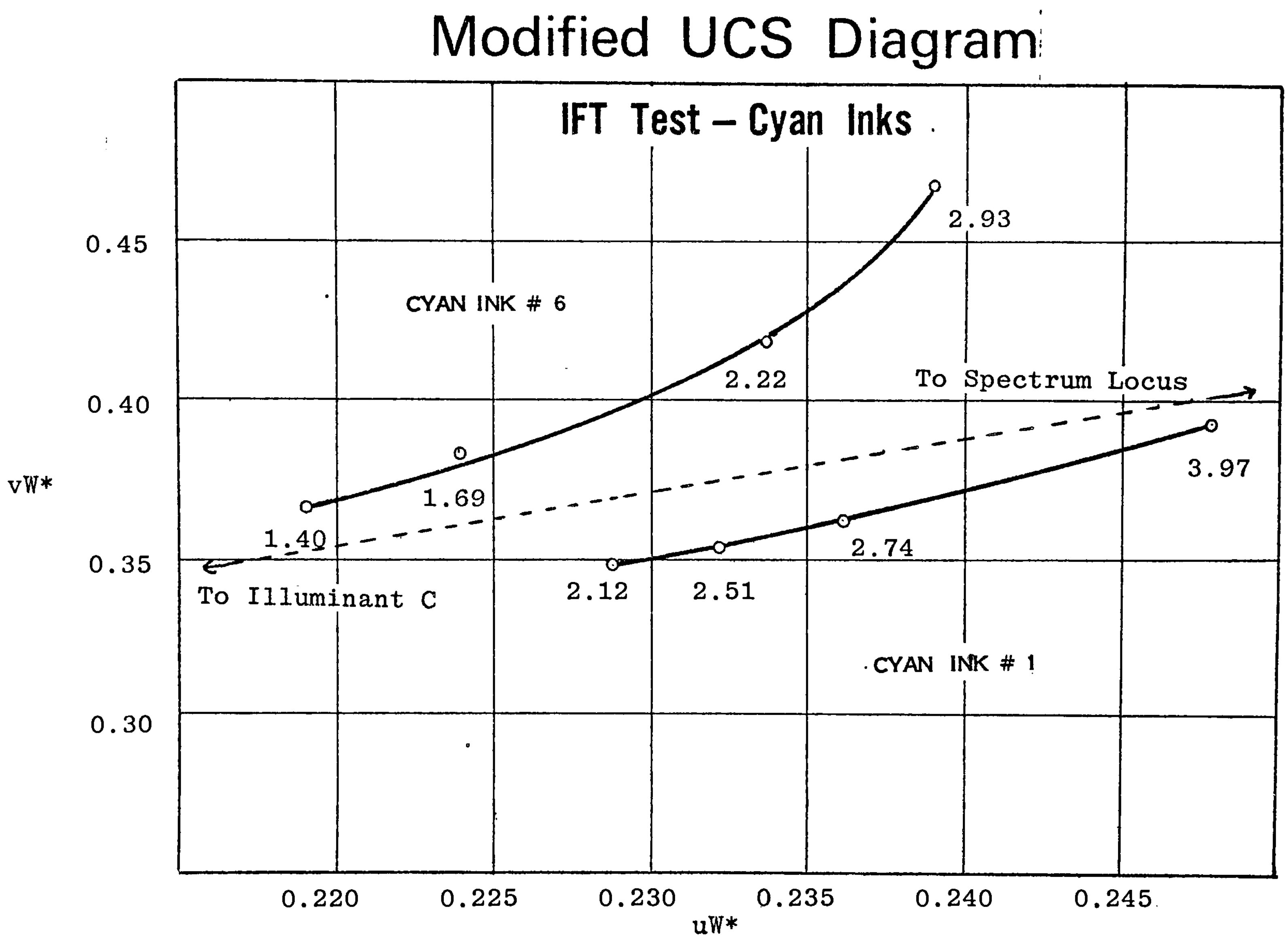

FIGURE 20 Ink-Film Thicknesses in microns.

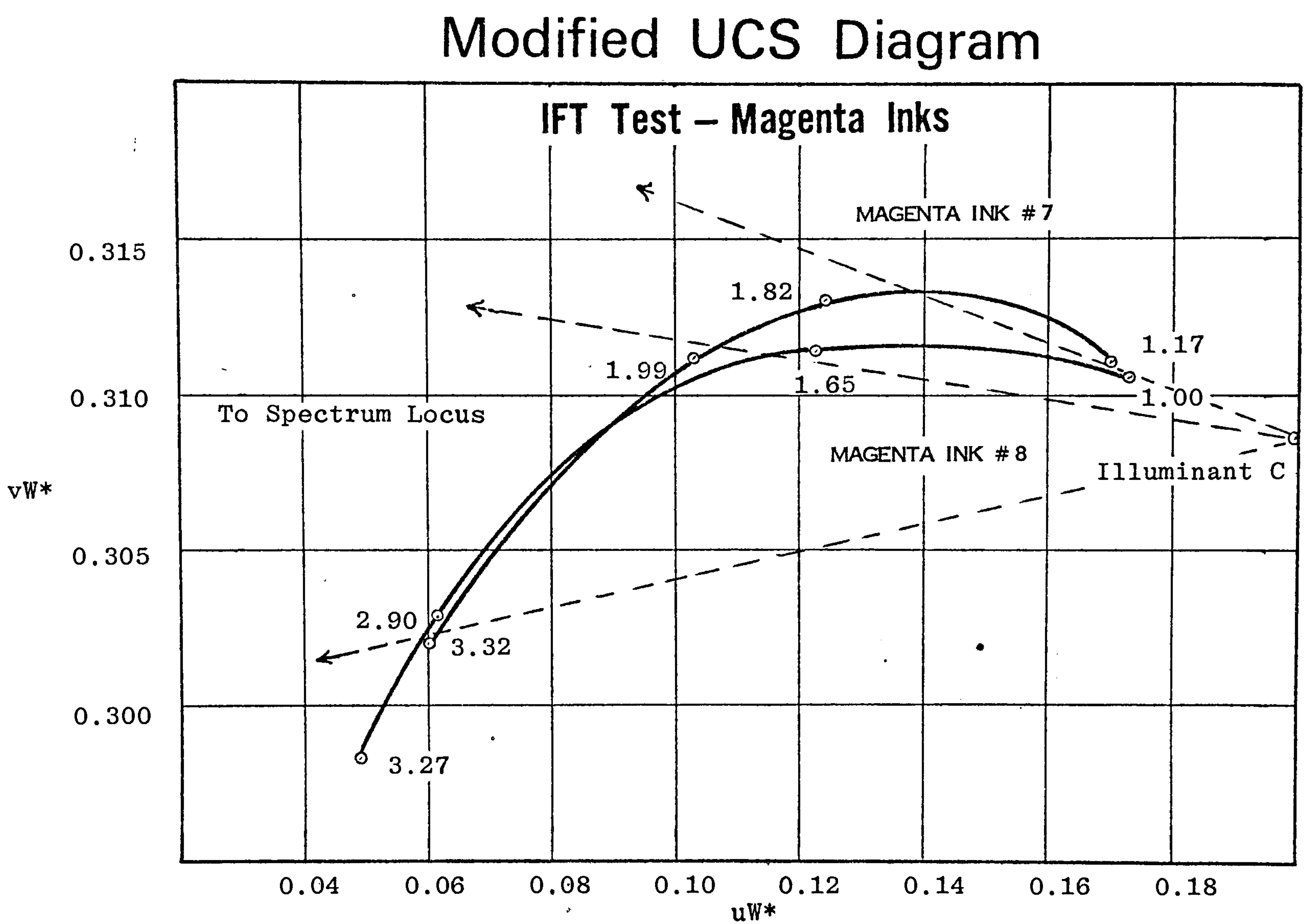

FIGURE 21 Ink-Film Thicknesses in microns.

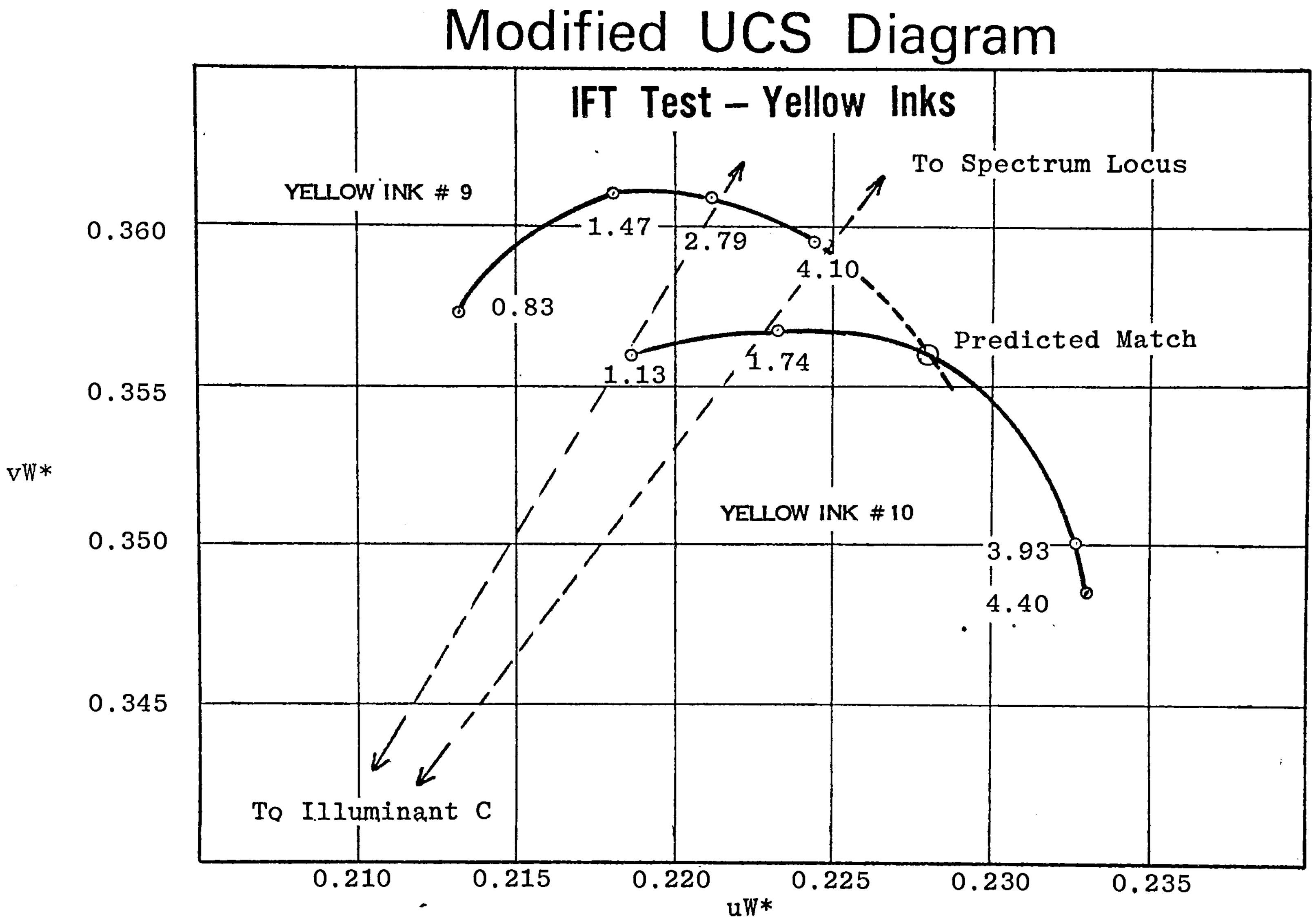

FIGURE 22 Ink-Film Thicknesses in microns.