6-1-1975

The effect of blue base tint on the sensitivity and acutance of X-Ray films

Michael Klein

THE EFFECT OF BLUE BASE TINT ON THE SENSITIVITY AND ACUTANCE OF X-RAY FILMS

by

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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

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ACKNOWLEDGEMENTS

The author would like to express his appreciation for the valuable contributions and assistance from the following persons:

Dr. G.H. Schumann	R.I.T.
Mr. R. Norman	R.I.T.
Mr. R.E. Swing	National Bureau of Standards
Mr. J.T. Mathes	3M Company

and the Central Intelligence Agency for a research grant.

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ABSTRACT

An experiment was devised to quantitatively measure the effect of blue base tint (inherent in most medical x ray films) on the sensitivity and acutance of an x ray film. Results showed no significant difference due to the blue base tint for sensitivity. However, a significant difference was found for the base tint's effect on acutance of an x ray film. It was determined that the difference in acutance was due to an "anti-halation effect" of the blue base dye.

INTRODUCTION

Many changes in the x-ray film product have occurred during this century. Glass was replaced by cellulose nitrate, cellulose nitrate by cellulose diacetate, and cellulose diacetate by the modern Cronars, Estars, and Gafstar bases. In the 1950's Du Pont introduced a blue base tint to their x-ray products as a marketing and sales idea. To this day, there has been no quantitative explanation for the presence of this blue tint.

It has been written in the literature that the blue tint is commonly incorporated to give the radiograph a pleasing appearance[1] and when viewing the radiograph to apparently emphasize the subjective contrast.[2]

Studies involving the optimization of the viewing conditions for viewing radiographs have been made.[3,4,5] Recent investigations have looked into the effect of color on the observer's visual performance.[6,7]

A recent study by Schneider[8] found significance in the background color used to view radiographs. This study found an improvement in detection of x-ray images.

Many methods have been proposed and used for the objective evaluation of radiographic images.[9,10,11,12,13]

Image sharpness has been evaluated by many of these methods. Most evaluations have involved the MTF - the Fourier transform of the line spread function. Rossman[14] and Morgan[15] have applied this technique to x-ray film systems. This requires the use of the line spread function to obtain the MTF. Schwenker [16], on the other hand has used the edge trace to obtain similar results. This technique involves the imaging of an edge. The differential of the edge gives rise to the line spread function, which is then Fourier transformed to get the MTF.

The edge analysis technique is quite useful because it can also be used to calculate the acutance of a film system. The sharpness of a system is one criterion that is usually desired, and acutance-- is the objective correlate of sharpness.

Acutance may be calculated by the following formulas:

$$\langle G\,x^2 \rangle_{AVE} = \frac{\Sigma\,(\Delta D/\Delta X)^2}{N} \qquad (1)$$

where: ΔD = change in density
ΔX = change in distance in microns

when $\dfrac{\Delta D}{\Delta X} = 0.005$

$$\text{Acutance} = \frac{\langle G\, x^2 \rangle_{Ave}}{DS} \qquad (2)$$

where DS = Density range of the two points where $\frac{\Delta D}{\Delta X}$ is 0.005

Sharpness and unsharpness have long been terms familiar to the x-ray field. Although the method of acutance has been used to evaluate the sharpness of other systems, it has not been used to evaluate x-ray systems.

It has been well established[17] that the loss of image sharpness can be ascribed to the image spread caused by the reflection and scattering of the light emitted by the crystals of the fluorescent screen materials when exposed to x radiation. This scattering of light not only causes deterioration of the adjacent image but even deteriorates the areas remote from the screen.

The light which passes through the emulsion and enters the base may either be reflected back into the foward emulsion or pass into the backside emulsion. The degree of degradation depends on the angle at which the light meets the air-base interface. A diagram of this property is shown in figure 1.

HYPOTHESIS

It is my hypothesis that the blue base inherent to most x-ray films acts like an anti-halation backing, and thus by doing so creates what

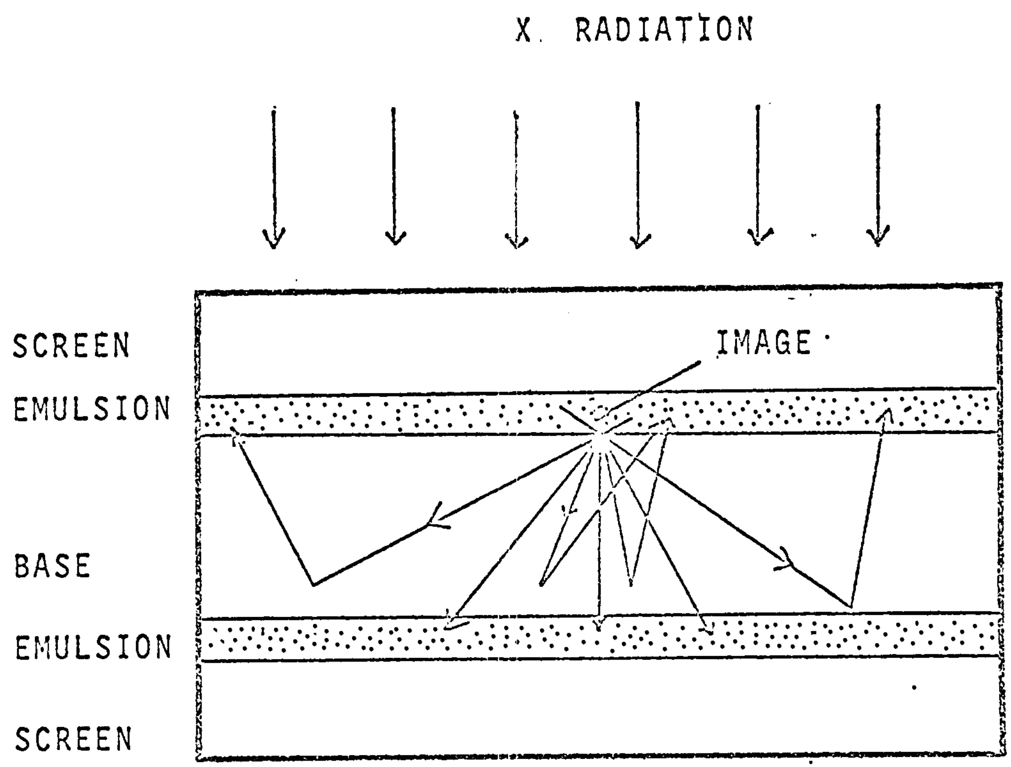


Figure 1 DIVERGENCE OF FLUORESCENT LIGHT

appears to be and is a sharper photographic image. If we follow the path of light through a single side of the film, we may understand the image forming process and describe the action of the blue tint. I shall describe the case of a singly coated emulsion.

First, assume that the emulsion will absorb 10% of the incident light. If 100 units of light are incident, 10% of these units or 10 will be absorbed and 90 units transmitted into the base. These 90 units are reflected (if we assume no absorption in the base) from that base back into the emulsion where 10% of the 90 units is absorbed. Thus, 81 units are now present at the screen-film interface.

In the case of the blue base, the same situation occurs with one slight change. The density of the blue base will stop a certain per centage of light units from being transmitted.

Let us assume a 0.1 density (79% transmission) for the dye of the blue base. Initially there are 100 units of light. The first exposure 90 are transmitted and 10 are absorbed. Upon scattering in the base and returning into the emulsion, only 79% of the 90 units or 71.1 remain after a secondary exposure.

In examining Table 1, we find that after several passes this "neutral density effect" becomes considerable and by the end of the 6th pass there is approximately one half the incident light for the blue base material than the clear base.

If we consider that the secondary, tertiary, and following exposures

Table 1 NEUTRAL DENSITY EFFECT OF BASE TINT

	CLEAR			BLUE		
	START	ABSOR.	TRANS.	START	ABSOR.	TRANS.
EXPOSURE						
1	100	10	90	100	10	90
2	90	9	81	* 71.1	7.1	64
3	81	8.9	72.9	64	6.4	57.6
4	72.9	7.3	65.6	* 45.5	4.6	41
5	65.6	6.6	59	41	4.1	36.9
6	59	5.9	53.1	* 29.1	2.9	26.6

* INDICATES NEUTRAL DENSITY EFFECT

are causing images, then the reduction of these "after images" would lead to sharper and more distinct images. By adding another emulsion to the other side of the base, the effct does not change considerably, except that this process proceeds in both directions and part of the non-absorbed radiation pass through into the opposite emulsion.

It is my opinion that the claims by others of the "sharper" images seen with the blue based film may be partly due to the halation property of the blue base during exposure.

The blue base is in effect filtering out and absorbing scattered radiation-- radiation that would have caused a certain amount of blur on the film emulsion.

EXPERIMENTAL PROCEDURE

The principal photographic material used in this investigation was 3M Type R emulsion. Type R is an ammoniacal iodo-bromide emulsion designed for use with intensifying screens. The same emulsion was coated on clear base and a standard blue base (referred to hereafter as the clear and the blue), each a Polyester base 0.007 inches thick. The coating weight of the samples contained between 9.3 and 9.5 grams of silver/square meter.[18]

A platinum edge and wire were used to generate an edge image and wire image on the film samples. The edge was a piece of platinum 58.4 microns thick with a highly polished edge. A platinum wire

378.5 microns thick, used for testing the halation properties of the film, was placed 1.2 centimeters from the polished edge for exposures. A diagram of the platinum pattern used to generate the sample images is shown in figure 2.

Exposures were generated with 40 kilovolt, 0.5 mm aluminum equivalent filtered radiation at 5 milliamperes. The x-ray source was one meter from the film sampb and contained a one millimeter focal spot. Radiographs were made of the platinum targets with a screen-film system consisting of two Du Pont medium speed calcium tungstate Cronar screens and the blue and clear base films.

The targets screens and film were placed in a vacumm cassette to insure the best film-screen-target contact. The cassette system is shown in figure 3.

Time-scale exposures were used to obtain a series of exposures such that a calibration curve and an appropriate edge image could be found.

A lead mask, consisting of a center slit 1.4 x 8 mm, was used as an aperture during exposure. The mask was placed on top of the cassette, between the cassette and exposing source. A diagram of this is expressed in figure 4.

An exposure of 40 kilovolts, 5 milliamperes was maintained as the cassette was moved across varying the exposure time from 1/8 to 14 seconds.

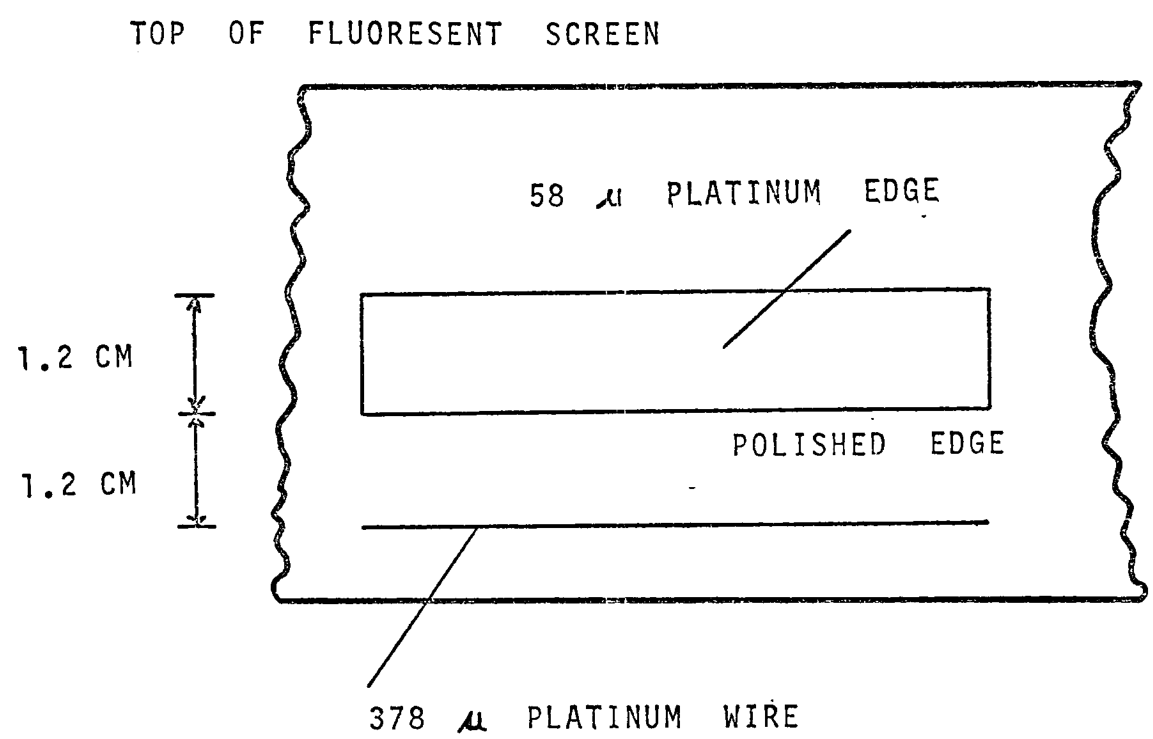
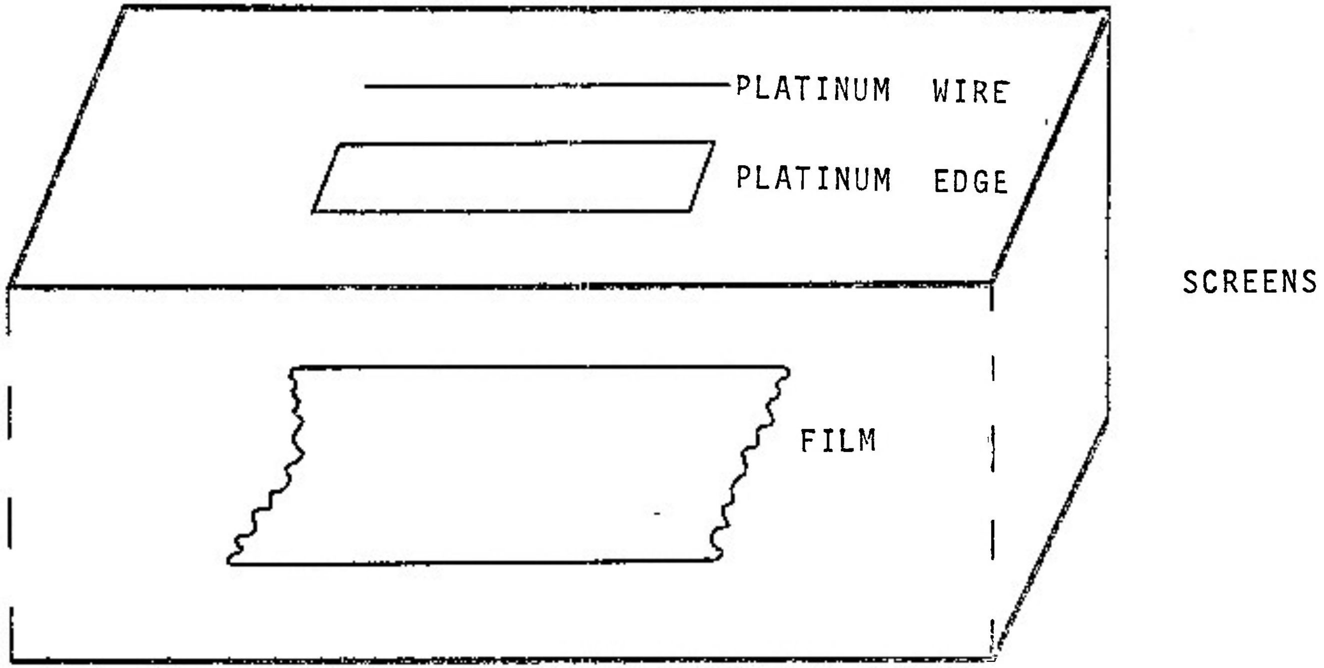


Figure 2 PLATINUM AND WIRE EDGE



<u>Figure 3</u> EDGE - FILM - SCREEN SYSTEM

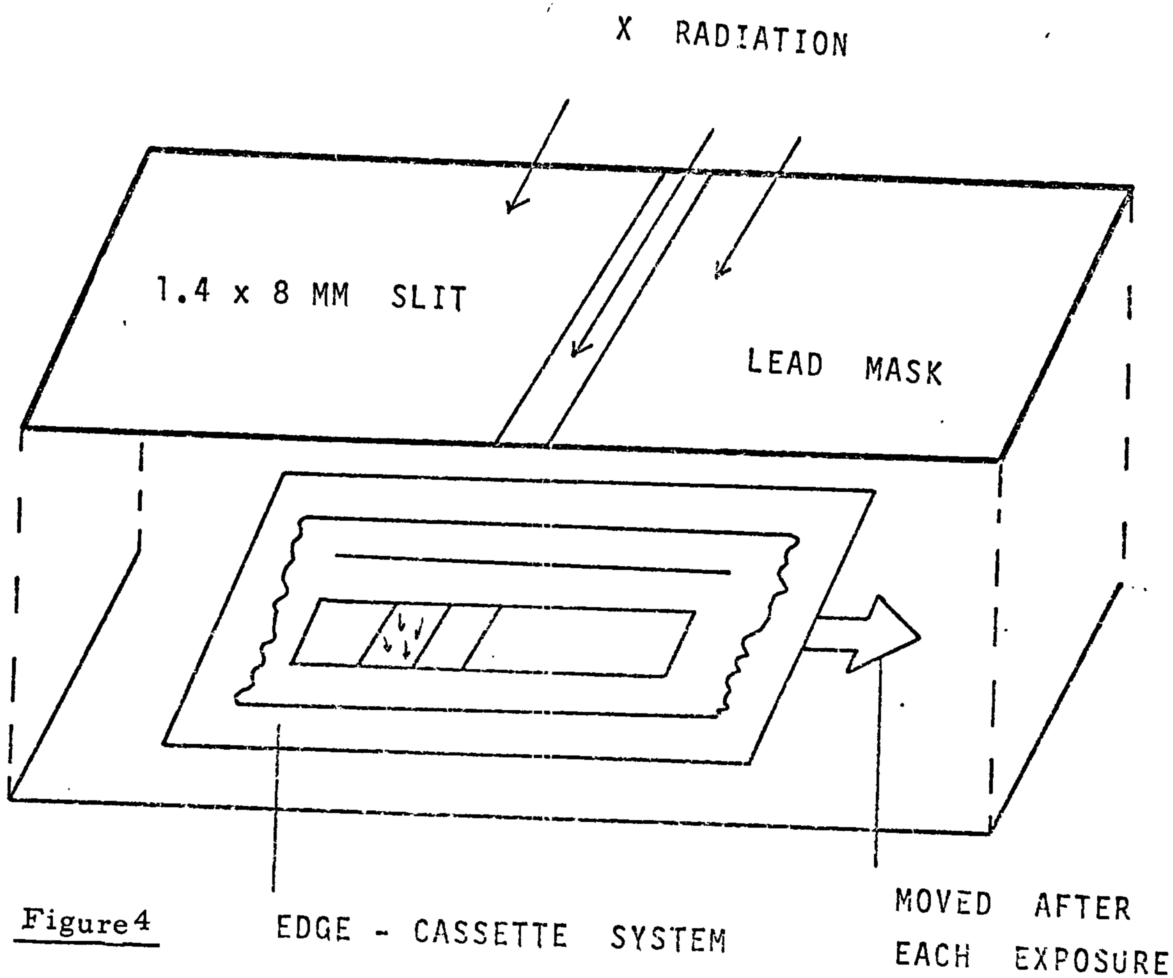


Figure 4 METHOD OF EXPOSURE

An exposure of 40 kilovolts, 5 milliamperes, and 3 seconds was found to be the optimum exposure producing an edge having a diffuse density of 2.0.

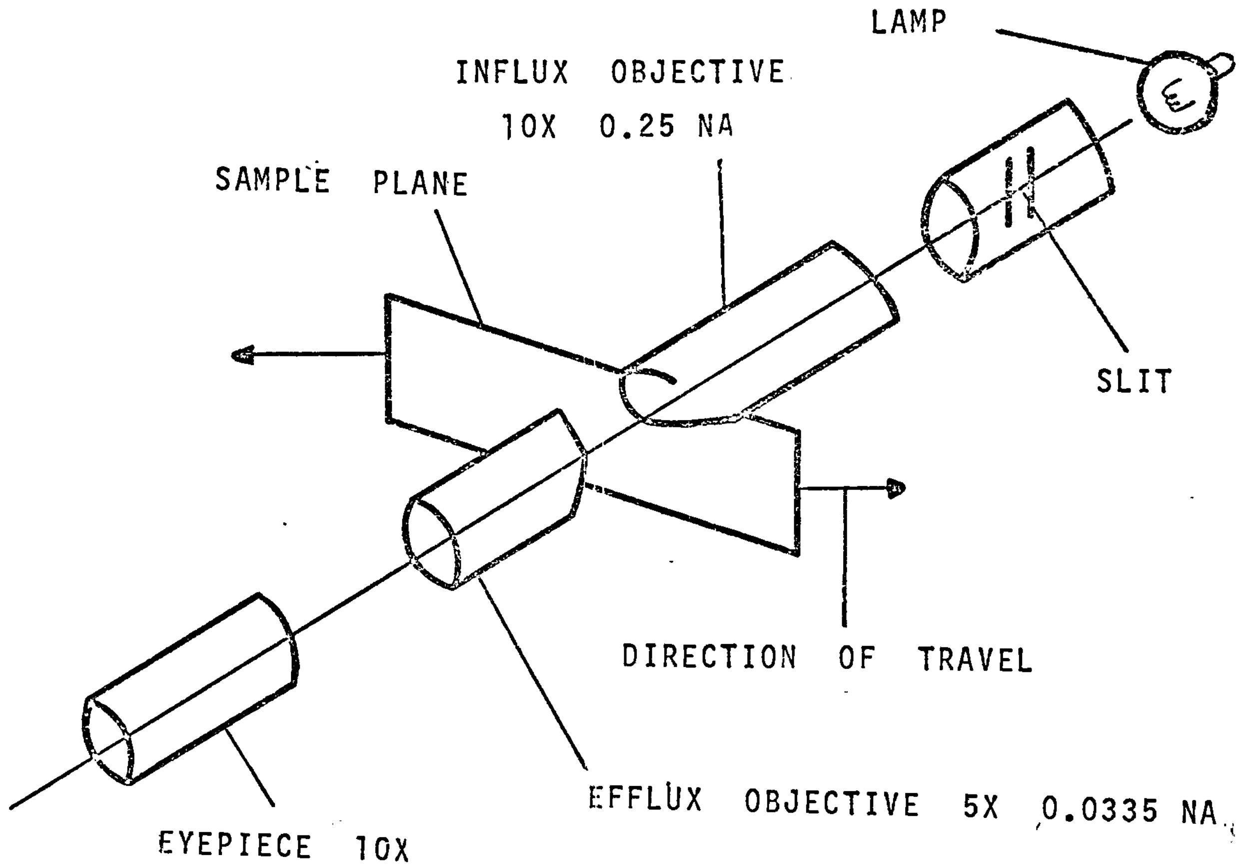
Samples were evaluated using an Ansco Model 4 Microdensitometer The optical configuration, as shown in figure 5, was :

Influx Objective:	Bausch & Lomb 10X- 0.25 NA
Efflux Objective:	Bausch & Lomb 5X - 0.0335 NA*
Influx Slit:	40 μ
Effective Slit:	10 μ x 300 μ
Scanning Speed:	1 mm/minute

The choice of such optics was dictated by the inherent properties of the photographic samples and optical considerations necessary for the evaluation of microdensitometer images.[19] X ray films are typically 200-225 microns thick (see figure 6)[20,21] and involved in a screen-film system will not be capable of resolving beyond 20 cycles/mm.[22,23]

The clear and blue based samples were processed in a Kodak X-Omat 90 second processor. Kodak MX8-10 developer, an acetic acid stop bath, and 3M LFC-5 fixer were used for the development stop, and fix cycles.

* This objective was a modified 5X objective, with a field stop placed behind the rear element.



<u>Figure 5</u> OPTICS USED FOR IMAGE EVALUATION

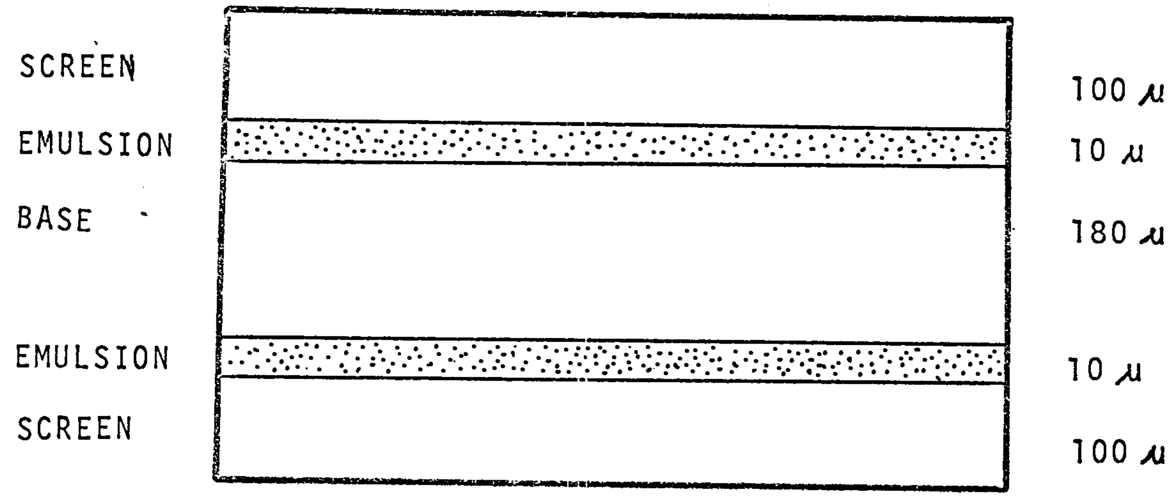


Figure 6 PHYSICAL DIMENTIONS OF A TYPICAL SCREEN - FILM SYSTEM

DATA ANALYSIS

The diffuse densities for each of the processed blue and clear samples were foundand a characteristic curve— consisting of density as a function of Log milliamp-seconds – was generated. Sensitivity, which I defined as: The reciprocal of the exposure necessary to produce a density of 1.0 above base plus fog, was determined for each of the clear and blue based samples.

Edge trace samples were evaluated by use of a computer and the computer program ACUMTF,* written by Richard E. Swing, National Bureau of Standards. ACUMTF requires the user to first visually smooth the edge trace from the microdensitometer. Data points are then taken from the smoothed curve from where the trace slopes are zero. The program then computes the the acutance of the samples by equations (1) and (2) using the criterion mentioned earlier.

Edge width and gradient were also calculated for the clear and blue based samples. Each sample was examined to determine the density range, DR, of the trace, as is shown in figure 7. The arbitrary value of 5% DR was chosen to determine endpoints to measure image width and gradient. The points D_A and D_B were calculated corresponding to Dmin - 0.05 DR and Dmax - 0.05 DR respectively.

The corresponding distance coordinates were found for D_A (X_A)

* See appendix

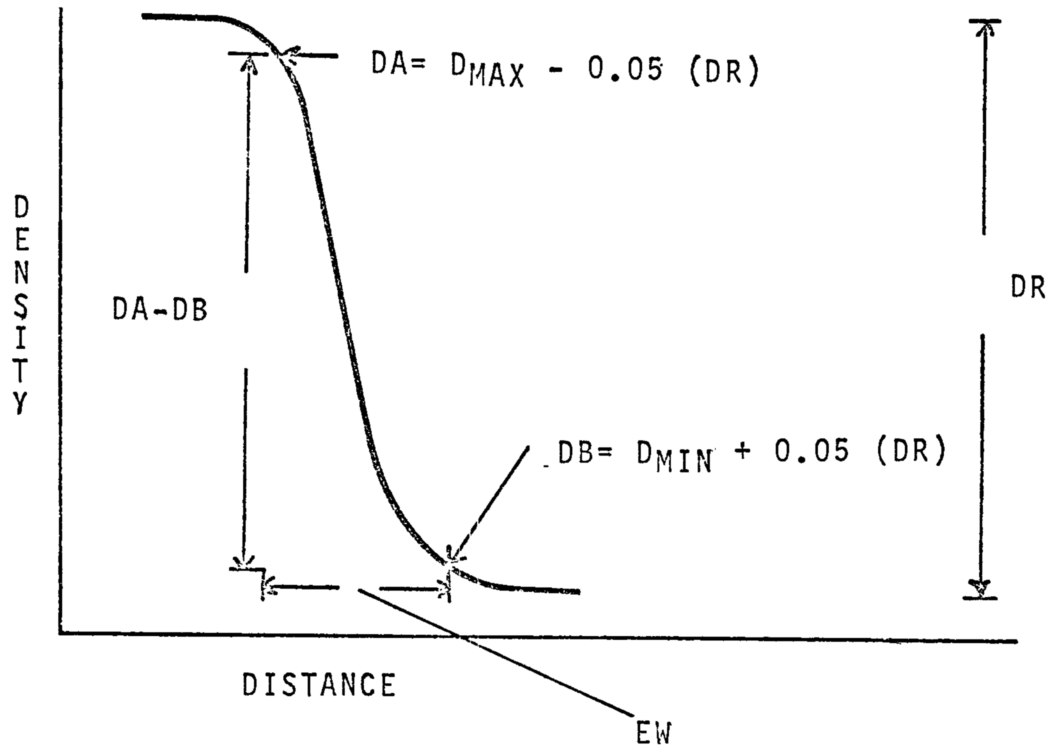


Figure 7 DETERMINATION OF EDGE WIDTH FROM MICRODENSITOMETER TRACE

and D_B (X_B). The difference of these points X_A and X_B was defined as the Edge Width , E_W . The gradient was defined as E_W / (D_A-D_B) or $(X_A - X_B)/(D_A - D_B)$, where the distance was measured in millimeters and the density measured as specular density.

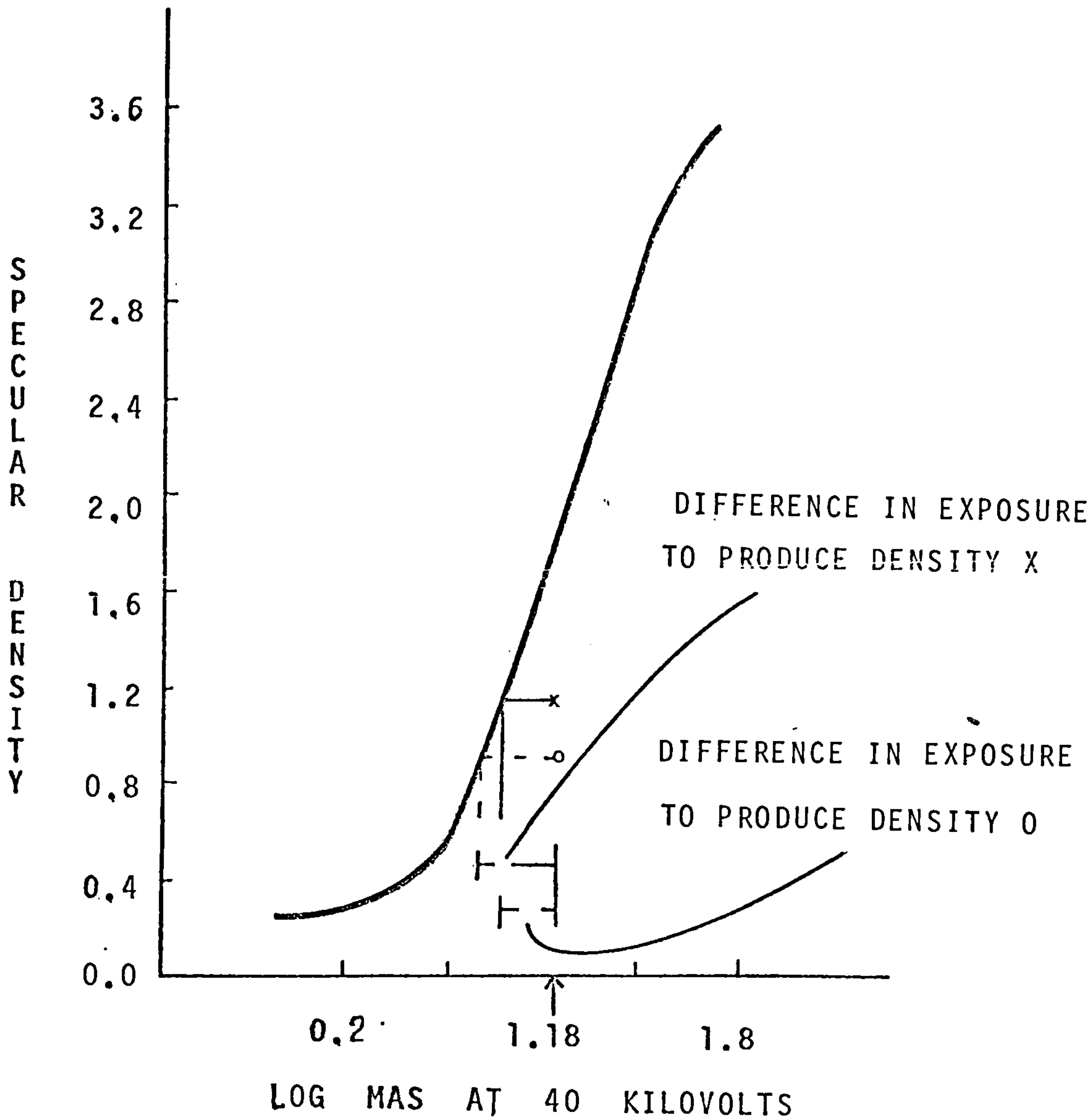
The determination of a comparison of the halation properties of each film base was carried out. This method[24, 25] involved the use of a stretched wire and a neutral wedge. A stepped exposure was generated on the film by placing the wire in front of the forward screen (one closest to exposing source) as close to the screen as possible. A density - log milliamp-second curve was determined from the density areas outside the wire's image.

An exposure level was chosen, in this case log mas equal to 1.18. Density values at the center of the wires for this exposure were plotted on the same axis as the characteristic curves. The center of the wire densities were converted to exposure using the characteristic curves. The relative differences in exposure were found for the clear and blue base film samples. These differences represented the exposure difference necessary to produce the same density with a filter (wire) in the x ray path, as displayed in figure 8.

RESULTS

The results of the sensitivity measurements statistically showed

Figure 8



DETERMINATION OF HALATION PROPERTIES

no significant difference in the sensitivity between the clear and blue based films. The clear based samples were found to have a mean sensitivity value of 0.149 with a σ of 0.010 and the corresponding blue samples values were 0.147 and 0.009 for the mean and standard deviation respectively. The respective characteristic curves are expressed in figure 9.

The determination of acutance and image width showed significance at the 90% confidence level. Clear based films were found to have an acutance mean value of 4.43 and image width of 523 μ at the specific interval used. Blue based samples had a corresponding acutance value of 6.17 and edge width of 495 μ.

No significant difference was found for the difference in gradients of the two film samples.

The test for halation was found to be significant at the 95% confidence level. Both density produced at a fixed exposure, and exposure difference necessary to produce a given density were found to be different for the two different bases.

A summary of the results appears in table 2.

CONCLUSIONS

The effect of base tint on the sensitivity of the emulsion has been found of no significance.

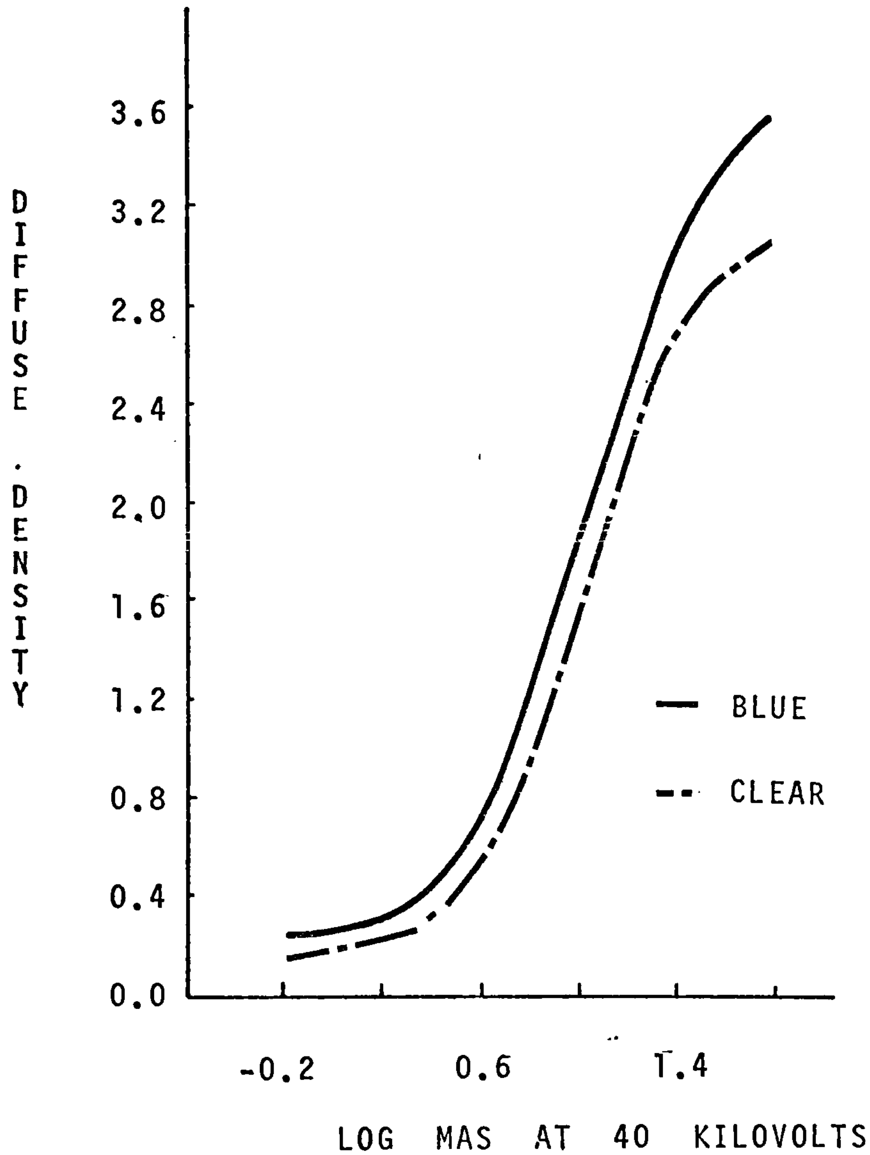


Figure 9 CHARACTERTICS CURVES

Table 2

RESULTS

SENSITIVITY				
Blue Base	$\bar{X}$ = 0.147		Clear Base	$\bar{X}$ = 0.149
	S = 0.009			S = 0.010
ACUTANCE **				
Blue Base	$\bar{X}$ = 6.17		Clear Base	$\bar{X}$ = 4.43
	S = 1.10			S = 0.72
EDGE WIDTH* (in microns)				
Blue Base	$\bar{X}$ = 495		Clear Base	$\bar{X}$ = 523
	S = 55.8			S = 61.3
EDGE GRADIENT				
Blue Base	$\bar{X}$ = 0.21		Clear Base	$\bar{X}$ = 0.22
	S = 0.03			S = 0.23
HALATION TEST** (density at wire's center)				
Blue Base	$\bar{X}$ = 0.93		Clear Base	$\bar{X}$ = 1.14
	S = 0.07			S = 0.10

* Indicates significance at 90% confidence level

** Indicates significance at 95% confidence level

The acutance values for a blue base film are statistically different from ~~than~~ those of the clear based film, and in fact are much greater.

Edge width has been found to be less for a blue based film than for the same emulsion coated on a clear based film.

The effect of the base tint on the halation properties of the film can be seen in the difference in density produced in the wire test. Since it was established that there was no difference in the sensitivity of the two films, then the difference in the density at the wire's center can not be attributed to the difference in sensitivity difference of the films.

Therefore, it is the opinion of this author that the greater density found at the center of the wires was due to halation— and thus the lower density was due to the "anti-halation" properties of the blue base.

Thus, the claims of "sharper" images with blue based films in subjective tests may be attributed to the halation properties of the film base.

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Appendix

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1 REM RICHARD L. SWING-MODIFIED BY MIKE KLEIN '75  4-26-75
2 REM THIS PROGRAM CALCULATES ACUTANCE FROM THE TRACE OF AN
3 REM EDGE BY A MICRODENSITOMETER. IT SHOULD BE USED FOR
4 REM EDGES WHICH HAVE ACUTANCES LESS THAN 1000.
15 DIM X(40),Y(40),D(40),P(40),E(40),C(4,40),A(40,4)
16 DIM B(40),Z(40),K(40),F(40),T(40),V(40)
17 DIM G(350),H(350),L(350),R(350)
20 C1=1
21 FOR J= 1 TO 5
22 PRINT
23 NEXT J
24 READ N
25 GO TO 270
26 FOR I = 1 TO N          'INPUT DENSITY CALIBRATION DATA'
27 READ X(I),Y(I)
28:                                   ##.#          ##.##
30 PRINTUSING 28,X(I),Y(I)
31 NEXT I
32 N1 = N-1                 'CALCULATE FIT COEFFICIENTS'
34 FOR K= 1 TO N1
36 D(K)= X(K+1)-X(K)
38 P(K) = D(K)/6
40 E(K) = (Y(K+1)-Y(K))/D(K)
42 NEXT K
44 FOR K= 2 TO N1
46 B(K) = E(K)-E(K-1)
48 NEXT K
50 A(1,2)= -1.0 - D(1)/D(2)
52 A(1,3)= D(1)/D(2)
54 A(2,3)= P(2)-P(1)*A(1,3)
56 A(2,2)= 2.0*(P(1)+P(2))-P(1)*A(1,2)
58 A(2,3)= A(2,3)/A(2,2)
60 B(2) = B(2)/A(2,2)
62 FOR K= 3 TO N1
64 A(K,2)= 2*(P(K-1)+P(K))-P(K-1)*A(K-1,3)
66 B(K)= B(K)-P(K-1)*B(K-1)
68 A(K,3)= P(K)/A(K,2)
70 B(K)= B(K)/A(K,2)
72 NEXT K
74 Q = D(N-2)/D(N-1)
76 A(N,1)= 1 + Q + A(N-2,3)
78 A(N,2) = -Q-A(N,1)*A(N-1,3)
80 B(N) = B(N-2)-A(N,1)*B(N-1)
82 Z(N)= B(N)/A(N,2)
84 N2 = N-2
86 FOR I= 1 TO N2
88 K= N-I
90 Z(K)= B(K)-A(K,3)*Z(K+1)
92 NEXT I
94 Z(1)= -A(1,2)*Z(2) - A(1,3)*Z(3)
96 FOR K = 1 TO N1
98 Q= 1/(6*D(K))
100 C(1,K)= Z(K)*Q
102 C(2,K)= Z(K+1)*Q
104 C(3,K)= (Y(K)/D(K))-(Z(K)*P(K))
>
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```
106 C(4,K)= (Y(K+1)/D(K))-(Z(K+1)*P(K))
108 NEXT K
109 IF Q1=2 GO TO 225
110 B= X(N)/(0.50)        'GENERATE INDEPENDENT VARIABLE VALUES'
114 FOR J = 1 TO B
115 IF Q1= 2 GO TO 118
116 G(J) = X(1) + (J-1)*(0.50)
117 GO TO 122
118 G(J)=(J-1)*(1/N7)
122 IF (G(J)-X(1))<0 GO TO 146      'GENERATE DEPENDENT VARIABLE'
123 IF (G(J)-X(1))=0 GO TO 125
124 IF (G(J)-X(1))>0 GO TO 128
125 H(J)= Y(1)
126 GO TO 147
128 K = 1
129 IF (G(J)-X(K+1))<0 GO TO 140
130 IF (G(J)-X(K+1))= 0 GO TO 132
131 IF (G(J)-X(K+1))>0 GO TO 136
132 H(J)= Y(K+1)
134 GO TO 147
136 K = K+1
137 IF (G(J)-X(N))<0 GO TO 129
138 IF (G(J)-X(N))= 0 GO TO 146
139 IF (G(J)-X(N))>0 GO TO 146
140 H(J)= (X(K+1)-G(J))*(C(1,K)*((X(K+1)-G(J))**2)+C(3,K))
142 H(J)= H(J)+(G(J)-X(K))*(C(2,K)*((G(J)-X(K))**2)+C(4,K))
143 GO TO 147
146 H(J)= Y(N)
147 NEXT J
148 IF Q1=2 GO TO 230
149 GO TO 290
150 PRINT
151 READ N2,N,Q4
152 P7= N/Q4
153 PRINT"                                              RELATIVE"
154 PRINT"       CHART          DIFFUSE          SAMPLE"
155 PRINT"      READING         DENSITY          DISTANCE"
161 PRINT
163 N1= N2
166 FOR J= 1 TO N2
168 READ X(J),R(J)                   'INPUT EDGE-TRACE DATA'
169 IF (R(J)-G(1))<0 GO TO 172        'CONVERT TO DENSITY'
170 IF (R(J)-G(1))=0 GO TO 172
171 IF (R(J)-G(1))>0 GO TO 176
172 L(J)=H(1)
174 GO TO 188
176 K=1
178 IF(R(J)-G(K+1))<0 GO TO 181
179 IF(R(J)-G(K+1))=0 GO TO 181
180 IF(R(J)-G(K+1))>0 GO TO 184
181 L(J)= H(K+1)
182 GO TO 188
184 IF (R(J)-G(K+1)) < 0.00001 THEN 181
185 K= K+1
186 GO TO 178
188 NEXT J
>
```

```
189 FOR J= 1 TO M2
193:           ##.#            #.##          ####.###
194 PRINTUSING 193,K(J),L(J),M*F(J)
202 NEXT J
210 Q1=2
214 FOR J=1 TO M2
216 X(J)= M*(F(J)-F(1))
218 Y(J)= L(J)
220 NEXT J
222 N=M2
224 GO TO 632
225 M6=INT(1 + X(N))
226 M7= INT(350/M6)
227 D= M6*M7
228 GO TO 114
230 FOR K= 1 TO (D-1)
232 R(K)= (M7)*(H(K+1)-H(K))   'COMPUTE  (DELTA-D)/(DELTA-X)'
234 NEXT K
236 K=1
237 IF (R((D/4)-K)-0.005)  <0 GO TO 240
238 IF (R((D/4)-K)-0.005)  =0 GO TO 242
239 IF (R((D/4)-K)-0.005)  >0 GO TO 244
240 M4= (D/4)-K
241 GO TO 248
242 M4= (D/4)-K-1
243 GO TO 248
244 K= K+1
246 GO TO 237
248 K=1
249 IF (R(D-(D/4)+K)-0.005)  <0 GO TO 252
250 IF (R(D-(D/4)+K)-0.005)  =0 GO TO 254
251 IF (R(D-(D/4)+K)-0.005)  >0 GO TO 256
252 M5= (D/4)-K+1
253 GO TO 260
254 M5= (D/4)-K
255 GO TO 260
256 K = K+1
258 GO TO 249
260 P9= H(D-M5)-H(M4)
266 S = 0
268 GO TO 296
270 PRINT"                          BASIC CALIBRATION DATA"
272 PRINT
274 PRINT"                            CHART          DIFFUSE"
276 PRINT"                           READING         DENSITY"
286 PRINT
288 GO TO 526
289 PRINT
290 PRINT
291 PRINT
292 PRINT"                              BASIC EDGE-TRACE DATA"
294 GO TO 150
296 FOR J= M4 TO (D-M5)
298 S = S + (R(J))^2         'SUM OF SQUARED-SLOPE VALUES'
299: ACUTANCE= #####.##        C1= ##       C2= #####.###
300 NEXT J
>
```

```
301 G2= (10^6)*S/(B-M5-M4)
302 A= (G2/P9)*(P7**2)
303 GO TO 310
304: D-MAX = #.##     HIGH-END SLOPE=     .####               .####
305 PRINTUSING 299,A,N,Q4
306 FOR J= 1 TO 15
307 PRINT
308 NEXT J
309 GO TO 999
310 PRINT
313 PRINTUSING 304,H(B-M5),R(B-M5)/N,R(B-M5+1)/N
316: D-MIN = #.##     LOW-END SLOPE =     .####               .####
317 PRINTUSING 316,H(M4),R(M4)/N,R(M4-1)/N
320 PRINT
348 PRINT
370 IF A => 1000 GO TO 378
371 IF A=> 100 GO TO 382
372 IF A=> 10 GO TO 386
374 A = INT((A + 0.005)*100)/100
376 GO TO 388
378 A = INT (( A + 5.0)/10)*10
380 GO TO 388
382 A = INT( A + 0.5)
384 GO TO 388
386 A = INT(( A + 0.05)*10)/10
388 GO TO 305
900 DATA 8
901 DATA 0,0,9.8,.25,18.8,.5,34.3,.89,46.5,1.24
902 DATA 55.5,1.75,77.3,2.1,96.5,2.79
930 DATA 21,2,500
931 DATA 6,.2,6,.3,6.5,.5,7,.6,7.5,.7,9,.8,10,.9
932 DATA 12,1.0,14,1.1,22.5,1.2,38,1.3,51,1.4,60.5,1.5
933 DATA 64.5,1.6,66.5,1.7,69,1.9,70,2.1,71.5.2.3
934 DATA 72.5,2.55,73,2.85,73,2.95
999 END
>
```

BASIC CALIBRATION DATA

CHART READING	DIFFUSE DENSITY
0.0	0.08
12.3	0.35
24.8	0.60
32.3	0.95
48.8	1.34
68.8	1.88
79.3	2.28
97.0	2.84

BASIC EDGE-TRACE DATA

CHART READING	DIFFUSE DENSITY	RELATIVE SAMPLE DISTANCE
6.0	0.24	0.600
6.0	0.24	0.800
9.5	0.31	1.400
10.0	0.32	1.600
11.0	0.33	1.800
13.0	0.36	2.000
16.5	0.46	2.200
29.0	0.79	2.400
47.5	1.32	2.600
56.0	1.54	2.800
62.0	1.66	3.000
66.5	1.87	3.200
71.0	1.96	3.400
74.0	2.07	3.800
75.0	2.11	4.200
75.5	2.13	4.600
76.0	2.15	5.000
76.0	2.15	5.200

D-MAX = 2.15   HIGH-END SLOPE=   .0033   .0015
D-MIN = 0.23   LOW-END SLOPE =   -****   -****

ACUTANCE=   5.54   C1= 2   C2=   500.000