COMPARISON OF GRANULARITY AND SPEEDS OF DIFFERENT TYPES OF PHOTOGRAPHIC FILMS

by

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I. INTRODUCTION

The amateur and professional photographers of today have at their disposal numerous types of photographic films of widely different characteristics. The serious workers may obtain information concerning the more important characteristics of these films from their manufacturers, but often the data supplied are insufficient and in some cases inaccurate.

The principal photographic properties of any emulsion may be listed as follows:

1. Speed or sensitivity
2. Grain size and granularity
3. Color sensitivity
4. Contrast
5. Latitude

These properties vary tremendously for different films, and all except the color sensitivity vary considerably for a given film in different developers and under different conditions of processing.

Innumerable developers are available for photographic use, the manufacturers claiming phenomenal properties for their products. These manufacturers, however, provide little or no specific data on the behavior of typical films in their developers, and if data are supplied they are often partial or incorrect.

The investigation under consideration was undertaken to provide for the serious photographer impartial comparative data on the granularity and speed of the more popular commercial films developed in typical developers under uniform processing conditions.

II. REVIEW OF LITERATURE

A. Granularity

1. Grain size and granularity

The individual silver grains of a photographic deposit vary in size for different emulsions, their average areas varying from approximately 0.1×10^{-8} cm.^{2} for slow positive emulsions to 1×10^{-8} cm.^{2} for fast negative emulsions. Consequently, individual silver grains are observable only in very large magnifications. However, even at relatively small magnifications, enlarged positive prints exhibit a definite nonhomogeneity due to the grouping of several grains into clumps or to the superposition of several grains in different layers of the emulsion. This nonhomogeneity is commonly referred to as graininess or granularity to distinguish it from the effect produced by the resolution of individual grains.

A. and L. Lumière and A. Seyewetz (28, 29) are often called the pioneers of fine-grain photography because of their important investigations made in 1904. They concluded that the size of the grains of reduced silver is practically independent of the developing agents used and of the development process, but later they reported that paraphenylenediamine and ammonium chloride are superior to other fine-grain developing agents because of their ability to "dissolve appreciable quantities of silver bromide".

On the other hand, R. J. Wallace (43) reported in the same year that the size of the silver grain is dependent upon the developer used. Even more significant were his observations, made while studying the development process through a microscope, on the coalescence of individual silver grains into clusters.

After thoroughly investigating the relationship between grain size and the development process, S. E. Sheppard and C. E. K. Mees (38) agreed with Lumière and Seyewetz that normally the developer does not affect the grain size.

Many lively and conflicting investigations on grain size and the development process followed this pioneer work, but it was not until 1917 that M. B. Hodgson (18) definitely differentiated between grain size and graininess in the photographic image. Since the photographer is more concerned with the granularity of the silver deposit than with the size of the individual grain, this differentiation aroused a new interest in fine-grain photography, resulting in many investigations of theoretical and practical value. These investigations have shown that the granularity of the photographic image is a function of the size and the distribution of individual silver grains, and E. W. H. Selwyn (37) has even published a mathematical theory of graininess in which the direct relationship between graininess and grain size is given. Other mathematical theories based upon the average transparency fluctuation of a uniformly exposed area have been developed, the one proposed by A. Dember, A. Goetz, and W. O. Gould (8) arousing particular interest.

2. The measurement of granularity

Many investigators have obtained important qualitative information on the granularity of certain photographic materials by visually comparing enlargements made from these materials and magnified to the same degree. Such a method offers no quantitative information and could never be reliable.

An apparent procedure for measuring granularity quantitatively is to make a series of carefully prepared enlargements from a given material and to use as an index of measurement the magnification at which the nonhomogeneity of the material first becomes apparent. This method would be costly since it requires a series of enlargements for each material and unreliable since the index depends upon viewing conditions which might differ during observations.

An equivalent method that removes these difficulties was developed by L. A. Jones and N. Deisch (22) in 1920. They devised an apparatus for viewing a magnified image at different distances and assumed that the graininess of the given material is proportional to the distance at which the appearance of nonhomogeneity is just perceptible under definite viewing conditions. Two years later A. C. Hardy and L. A. Jones (14) suggested an improved technique capable of remarkable precision in graininess measurements, and in 1936 E. M. Lowry (27) described another apparatus which permitted varying magnifications at a constant viewing distance. A related method utilizing a comparison microscope for balancing the apparent granularity of a sample material against that of an arbitrary standard under constant viewing conditions has been discussed by O. E. Conklin (4). The relative magnification of the two images was used as a measure of graininess.

The values for graininess obtained by these methods depend upon the visual acuity of the observer, which varies for different individuals and from time to time for a given individual. To eliminate discrepancies caused by changes in visual acuity, Jones and Deisch required that the blending distance for the material under consideration be compared with that of an arbitrary graininess standard such as a printer's half-tone screen.

Objective and absolute methods for measuring granularity have been developed by S. D. Threadgold (39), A. van Kreveld (24), V. Ronchi (35), Goetz and Gould (11), and others; but, since graininess is a subjective impression on the retina of the eye, these methods have failed to supplant the subjective methods listed above.

3. Factors affecting granularity

Shortly after the development of the devices permitting accurate quantitative measurements on granularity a tremendous amount of research on the control of graininess was excited by the lively interest of workers in the motion picture industry.

Hardy and Jones (14) found that the graininess of a photographic deposit depends upon the density of that deposit, maximum granularity occurring at densities of approximately 0.4. A consideration of the size and distribution of opaque clumps of silver grains shows that this result is reasonable. At optical densities of approximately zero, where the spaces between clumps are very large compared with the size of the clumps, and at high optical densities, where the size of the clumps are very large compared with the regions between clumps, the granularity must necessarily approach zero. It is to be expected that for completely opaque grains maximum granularity occurs at a transmission of 0.5 or an optical density of 0.3, the density at which the total area occupied by the grains is just equal to the total area of the spaces between grains. Van Kreveld and Scheffer (25), using their objective method of graininess measurement, reported that the maximum granularity of certain materials occurs at a density of approximately 1.00. George C. Higgins (17), on the other hand, found that maximum granularity is associated with deposits with a density close to 0.5. These values are higher than the theoretical value of 0.3 suggested above, but it must be remembered that that value applies only for completely opaque silver grains.

Van Kreveld and Scheffer (25), F. L. English (10), Higgins (17), and other investigators have shown that graininess increases with the degree of development or gamma. This important factor was neglected in early and in many recent investigations on graininess control, rendering the results worthless.

The influence of processing conditions -- such as temperature variation between solutions, temperature of washing, and drying conditions -- upon granularity have been considered, but little conclusive data have been obtained. A. Marriage (31) reported that sudden changes in temperature and widely varying drying conditions have no observable effect, and J. I. Crabtree (5) has suggested that an incipient reticulation often observed in enlargements may be mistaken for graininess. The manufacturers and users of photographic materials, however, hesitate to accept these results as conclusive.

4. Fine-grain development

The increasing popularity of the miniature camera has resulted in the preparation of numerous so-called fine-grain developers involving every imaginable type of developing agent.

Lumière and Seyewetz (28, 29), as early as 1904, reported that paraphenylenediamine and ammonium chloride were effective in reducing the granularity of a developed photographic deposit at the expense of emulsion speed. P. W. Vittum and J. I. Crabtree (42) and Crabtree and R. W. Henn (6) have listed other developing agents with the same properties. Van Kreveld and Scheffer (25) report that certain fine-grain developers are effective in reducing the granularity of fast, coarse grain emulsions but are practically ineffective for slow, fine grain emulsions. G. Schwarz (36), on the other hand, found that fine-grain developers reduce the granularity of slow, fine grain emulsions to a certain extent, but in most cases the differences in graininess produced by standard and fine-grain developers are negligible. In a thorough investigation of many developers Higgins (17) reported that certain developers are effective in reducing the granularity of fast, coarse grain emulsions and are slightly effective for slow, fine grain emulsions, but only at the expense of effective emulsion speed. He concluded that manufacture is more important in the control of granularity than the method of development employed.

B. Speed

Many methods of specifying the speed or sensitivity of a photographic emulsion have been devised, and the details of the more important methods, their advantages and disadvantages, have been described by L. A. Jones (21), C. B. Neblette (32), J. E. Mack and M. J. Martin (30), and other writers. Photographers have recently become enthusiastic over the minimum useful gradient method, since the quality of a reproduction depends upon the gradient characteristics of the photographic material rather than upon the density and since this method considers the useful region of underexposure as well as the linear portion of the characteristic curve in expressing speed. The minimum useful exposure, that at which the gradient of the characteristic curve is a certain fraction of the maximum gradient, is selected as the index for speed measurement.

L. A. Jones and M. E. Russell (23) and Clifton Tuttle (41) have listed the advantages of the method and have designed devices for measuring emulsion speeds from prepared sensitometric strips.

In spite of the advantages of the method and the enthusiasm of the photographers, very little practical data on the sensitivity of photographic emulsions as determined by the minimum useful gradient method have appeared in the literature. At the present time, however, it is generally believed that this method will ultimately supplant those now existing for speed specification.

C. Summary

A review of the literature on granularity and speed of photographic emulsions indicates that:

1. Many investigators have failed to distinguish between grain size and granularity.

2. The results of many investigations on granularity have been only qualitative, and the quantitative results show little uniformity in methods of measurement.

3. The graininess of a developed photographic deposit is a function of the density and the degree of development.

4. Investigations on granularity have been published in which the density and gamma were insufficiently controlled or completely ignored.

5. There are conflicting opinions on the effect of processing on granularity.

6. There are conflicting opinions between the manufacturers of certain fine-grain developers and the users of their products.

7. There are conflicting opinions in regard to the relative effect of fine-grain developers on fast, coarse grain emulsions and slow, fine grain emulsions.

8. There are conflicting opinions in regard to the effect of developers on emulsion speed.

9. It is generally believed that the minimum useful gradient method of specifying emulsion speeds is superior to

other methods and is likely to supplant these methods.

10. There are little data available on the sensitivity of photographic emulsions as determined by the minimum useful gradient method.

III. EXPERIMENTAL

A. Statement of Problem

In this investigation the relative granularity and speed of eleven of the more popular commercial 35 millimeter films developed in four typical fine-grain developers were determined. The films selected were Finopan, Plenachrome, Superpan Supreme, and Ultra Speed Panchromatic, manufactured by the Agfa Ansco Corporation; Micropan, Parpan, and Superior Panchromatic, manufactured by the Dupont Film Manufacturing Corporation; and Microfile, Panatomic X, Plus X, and Super XX Panchromatic, manufactured by the Eastman Kodak Company. Eastman D-76, Eastman DK-20, Champlin 16, and Harvey 777 Panthermic, widely used developers of different characteristics, were chosen as typical reducing solutions. All data listed were obtained from carefully prepared sensitometric strips developed to a gamma of 0.6 at the temperature recommended by the manufacturer of the developer and under uniform conditions of processing. The relative granularity of the films in the different developers was determined by a variation of the method described by Jones and Deisch and the relative speed by the minimum useful gradient method of speed specification.

B. Procedure

A particular film to be studied was placed in a specially designed "camera", given a series of graded exposures, and processed under constant conditions of temperature and agitation.

The "camera" was a light-tight metal box designed to expose four square centimeters of the film directly to the source of illumination at each exposure. The light source consisted of a 40 watt, 115 volt Mazda lamp enclosed in a compact housing with a four centimeter square opening. The lamp was mounted in such a manner that only diffuse light reflected from the white inner walls of the housing could reach the "camera" from the lamp. In order to furnish a source of artificial daylight for the exposures, the voltage of the lamp was maintained at 110 volts by means of a variable resistance in series with a 120 volt storage battery and a two inch square number 78 (daylight) Wratten filter was placed over the aperture in the housing. In exposing the film the intensity of illumination was held constant and the time of exposure increased geometrically by a factor of two. The exposure time was controlled by means of a rotating sector disc driven by a Telechron synchronous motor at the rate of one revolution per second. A 36° opening in the disc allowed light to pass through the aperture in the housing for one-tenth of each revolution, giving accurate exposures of one-tenth second each second. The complete apparatus for exposing the film is shown in Figure 1, while the details of construction of the "camera" and the light housing are pictured in Figures 2 and 3. Because of the widely varying sensitivity of the films used, the intensity was increased or decreased for different films by changing the distance from the source to the camera, but for any given film the intensity was maintained constant.

The exposed film was placed in a standard Leitz Correx developing tank and developed in a given solution for the time required to produce a gamma of 0.6 at the temperature recommended by the manufacturer of the developer. During development the film was agitated continuously by means of an electrically driven agitator which caused the developing reel to make twelve oscillations per minute. After development the film was rinsed in water or in a chrome alum stop bath if recommended by the manufacturer, fixed in an acid hardening fixing bath (Eastman F-5), washed thoroughly in running water, and dried. Throughout development and auxiliary processes the temperature of the solutions was held constant to within $\pm 0.5^{\circ}$ C. by means of controlled water baths. Especial care was taken to adhere strictly to the instructions of the manufacturer of film and developer during all processes.

The opacity of each step on the sensitometric strip was then determined by means of the photronic cell densitometer

Figure 1. Exposure Apparatus

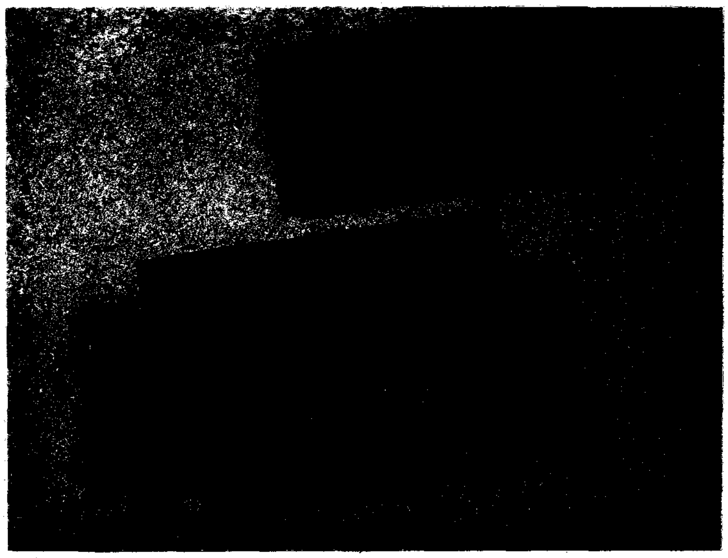


Figure 2. The "Camera"

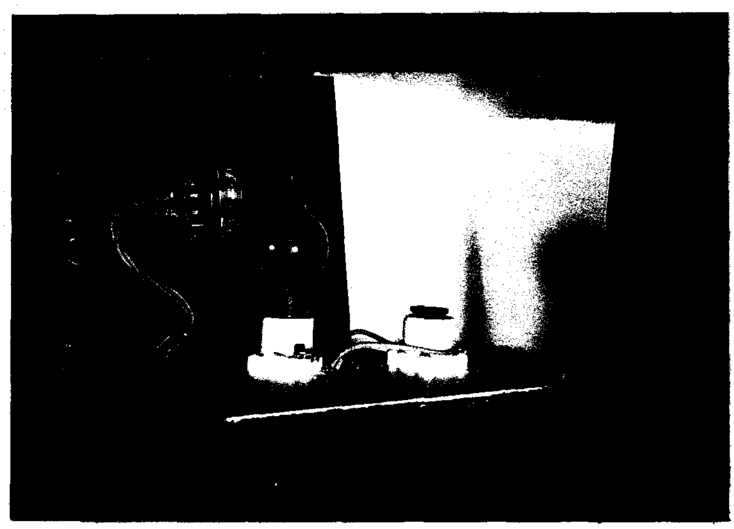


Figure 3. Light Housing

pictured in Figure 4. A specially prepared Weston photronic cell, which permitted the film to be placed in contact with the ground glass surface of the cell, served as a current source for a low resistance, sensitive Leeds and Northrup galvanometer when the cell was illuminated. To assure direct contact between film and cell and to insure the use of the same part of the cell for all readings, a bakelite plate with a five by ten millimeter rectangular aperture was pressed against the face of the cell by a set of springs. The source of illumination was a 6 volt Mazda bulb operated at 5.75 volts by means of a variable resistance in series with a 120 volt storage battery. Details of photronic cell construction are shown in Figure 5.

The optical density of each step on the sensitometric strip was obtained by observing the galvanometer deflections when light passed through the clear film and when light passed through the silver deposit and employing the definition for density,

$$\text{Density} = \log_{10} \frac{\text{incident light}}{\text{transmitted light}}.$$

Since the illumination falling on the film was constant, the characteristic curve was drawn by plotting density against the logarithm of exposure time, and the contrast factor (gamma) for the strip was then determined by measuring the slope of the linear portion of the curve.

Figure 4. Densitometer

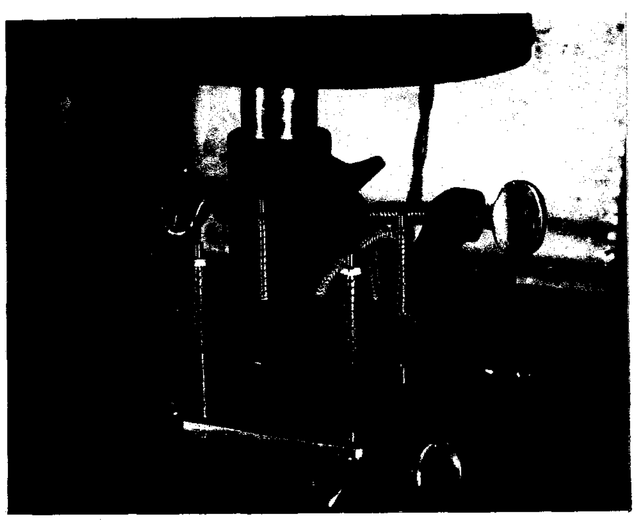


Figure 5. Photronic Cell Construction

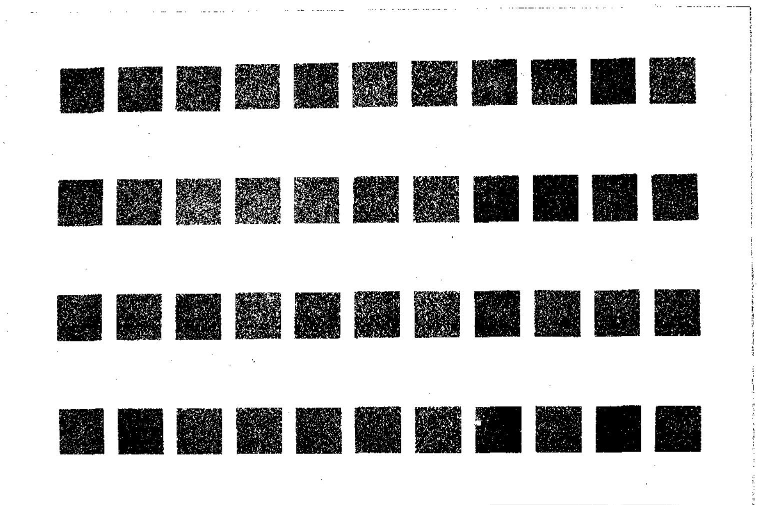
Since the chemical fog varied considerably for the different films, the density of the fog deposited on each strip was computed by taking the common logarithm of the ratio of the light transmitted through an undeveloped, fixed, and washed strip to the light transmitted through an unexposed portion of the given strip.

In the determination of the relative emulsion speeds of the films in different developers, the exposure at which the gradient of the characteristic curve was 0.3 was taken as an index of measurement and the speed of Eastman Super XX developed in Eastman D-76 was arbitrarily chosen as unity. All other emulsion speeds were compared with this value as a standard by dividing the exposure corresponding to a gradient of 0.3 on the curve of the standard by the exposure corresponding to the same gradient on the curve of the film under consideration.

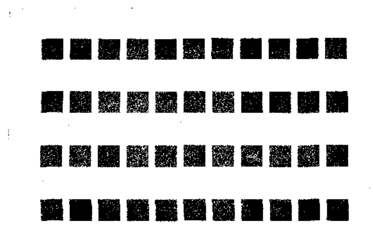
The granularity of the films was determined by a variation of the method described by Jones and Deisch. A set of photomicrographs with a magnification of 300 diameters was prepared from a representative portion of the deposit on each sensitometric strip with a density of approximately 0.4, and these were carefully printed on Azo number 4 glossy paper. The prints were exposed so that all appeared to have the same density when viewed from beyond their merging distances and were developed to the same contrast under uniform conditions of processing. The matched, $2\frac{1}{4}$ inch square positives, mounted upon a white board and uniformly illuminated for viewing, are pictured in Figure 6, which shows the prints photographed at different distances to indicate the blending effect. The distance at which each photomicrograph blended into a homogeneous area was determined by twenty randomly selected observers. To eliminate differences in the visual acuity of the observers the graininess of Eastman Super XX developed in Eastman D-76 was arbitrarily chosen as unity, and the graininess of each deposit was compared with this value as a standard by dividing the blending distance of the photomicrograph of that deposit by the blending distance of the standard.

C. Results

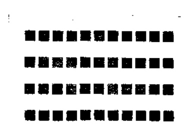
The exposure time - density data for the films tested are given in Table II in the Appendix, and the characteristic curves plotted from these data are shown in Figures 9 - 19. Curves A, B, C, and D in each figure represent the variation of density with exposure for a given film developed in Eastman D-76, Eastman DK-20, Champlin 16, and Harvey 777 Panthermic, respectively. To prevent the overlapping of the curves the density ordinates have been displaced by a convenient amount. The curves are consistently accurate in the regions of low and medium density, but in some cases there are slight discrepancies in the region of overexposure due to



(a) Photographed at four feet



(b) Photographed at eight feet



(c) Photographed at sixteen feet

Figure 6. Mounted Photomicrographs

the increased error arising from the small quantity of light transmitted at these higher densities and to layer peculiarities of certain emulsions.

The results of the study of the fogging effect of the developers and the relative emulsion speeds and granularity of the various films developed in D-76, DK-20, Champlin 16, and Harvey 777 are listed in Tables I-A, I-B, I-C, and I-D, respectively. The relative speeds were obtained directly from the characteristic curves, while the values for the relative granularity are the average of the results of the twenty observers shown in Table III. For convenience of study the same data on speed and graininess are represented graphically in Figures 7 and 8.

Table I

Speed - Graininess Data

A. Films developed in Eastman D-76 at 18° C.

Film	Development Time	Gamma	Density	Fog	Speed	Graininess
Agfa Finopan	7.0 min.	0.60	0.375	0.00	0.29	0.84
Agfa Plenachrome	6.5 min.	0.58	0.423	0.01	0.21	0.87
Agfa Superpan Supreme	7.5 min.	0.59	0.304	0.03	0.84	0.94
Agfa Ultra Speed	14.0 min.	0.59	0.347	0.03	1.67	1.06
Dupont Micropan	5.0 min.	0.61	0.398	0.07	0.15	0.76
Dupont Parpan	9.0 min.	0.60	0.390	0.04	0.17	0.96
Dupont Superior	13.0 min.	0.60	0.394	0.10	0.84	1.14
Eastman Microfile	2.0 min.	0.60	0.470	0.01	0.01	0.58
Eastman Panatomic X	10.0 min.	0.60	0.432	0.02	0.35	0.87
Eastman Plus X	12.0 min.	0.60	0.465	0.05	0.78	0.88
Eastman Super XX	13.5 min.	0.60	0.313	0.05	1.00	1.00

Table I (Continued)

B. Films developed in Eastman DK-20 at 18° C.

Film	Development Time	Gamma	Density	Fog	Speed	Graininess
Agfa Finopan	7.0 min.	0.60	0.412	0.01	0.15	0.83
Agfa Plenachrome	7.5 min.	0.58	0.459	0.04	0.25	0.92
Agfa Superpan Supreme	11.0 min.	0.60	0.413	0.05	0.66	0.86
Agfa Ultra Speed	18.0 min.	0.60	0.350	0.12	1.18	1.01
Dupont Micropan	4.5 min.	0.61	0.463	0.14	0.05	0.78
Dupont Parpan	7.5 min.	0.61	0.416	0.09	0.10	0.93
Dupont Superior	17.5 min.	0.58	0.353	0.13	0.38	1.08
Eastman Microfile	2.3 min.	0.61	0.380	0.02	0.01	0.60
Eastman Panatomic X	11.0 min.	0.59	0.382	0.08	0.20	0.81
Eastman Plus X	11.5 min.	0.61	0.407	0.06	0.45	0.80
Eastman Super XX	17.0 min.	0.60	0.343	0.11	0.71	0.87

Table I (Continued)

C. Films developed in Champlin 16 at 22.8° C.

Film	Development Time	Gamma	Density	Fog	Speed	Graininess
Agfa Finopan	7.5 min.	0.60	0.317	0.02	0.11	0.80
Agfa Plenachrome	8.0 min.	0.61	0.326	0.02	0.21	0.89
Agfa Superpan Supreme	11.5 min.	0.61	0.406	0.04	0.60	0.87
Agfa Ultra Speed	15.5 min.	0.61	0.315	0.11	1.92	1.11
Dupont Micropan	7.2 min.	0.61	0.481	0.15	0.12	0.86
Dupont Parpan	9.0 min.	0.58	0.328	0.08	0.11	0.89
Dupont Superior	15.5 min.	0.59	0.366	0.21	0.66	1.13
Eastman Microfile	2.5 min.	0.59	0.472	0.02	0.01	0.56
Eastman Panatomic X	9.5 min.	0.61	0.420	0.04	0.30	0.94
Eastman Plus X	12.0 min.	0.60	0.485	0.07	1.00	0.93
Eastman Super XX	15.5 min.	0.60	0.313	0.12	1.19	1.04

Table I (Continued)

D. Films developed in Harvey 777 Panthermic at 23° C.

Film	Development Time	Gamma	Density	Fog	Speed	Graininess
Agfa Finopan	5.8 min.	0.60	0.488	0.01	0.10	0.83
Agfa Plenachrome	8.2 min.	0.61	0.384	0.03	0.29	0.84
Agfa Superpan Supreme	9.5 min.	0.60	0.309	0.05	0.40	0.89
Agfa Ultra Speed	12.5 min.	0.60	0.371	0.08	1.08	1.04
Dupont Micropan	3.8 min.	0.60	0.369	0.15	0.09	0.78
Dupont Parpan	5.8 min.	0.60	0.400	0.12	0.07	0.87
Dupont Superior	12.5 min.	0.58	0.470	0.23	0.55	1.13
Eastman Microfile	2.0 min.	0.60	0.408	0.02	0.01	0.57
Eastman Panatomic X	12.0 min.	0.61	0.385	0.08	0.30	0.87
Eastman Plus X	9.2 min.	0.59	0.385	0.06	0.40	0.80
Eastman Super XX	10.0 min.	0.60	0.314	0.07	0.51	0.95

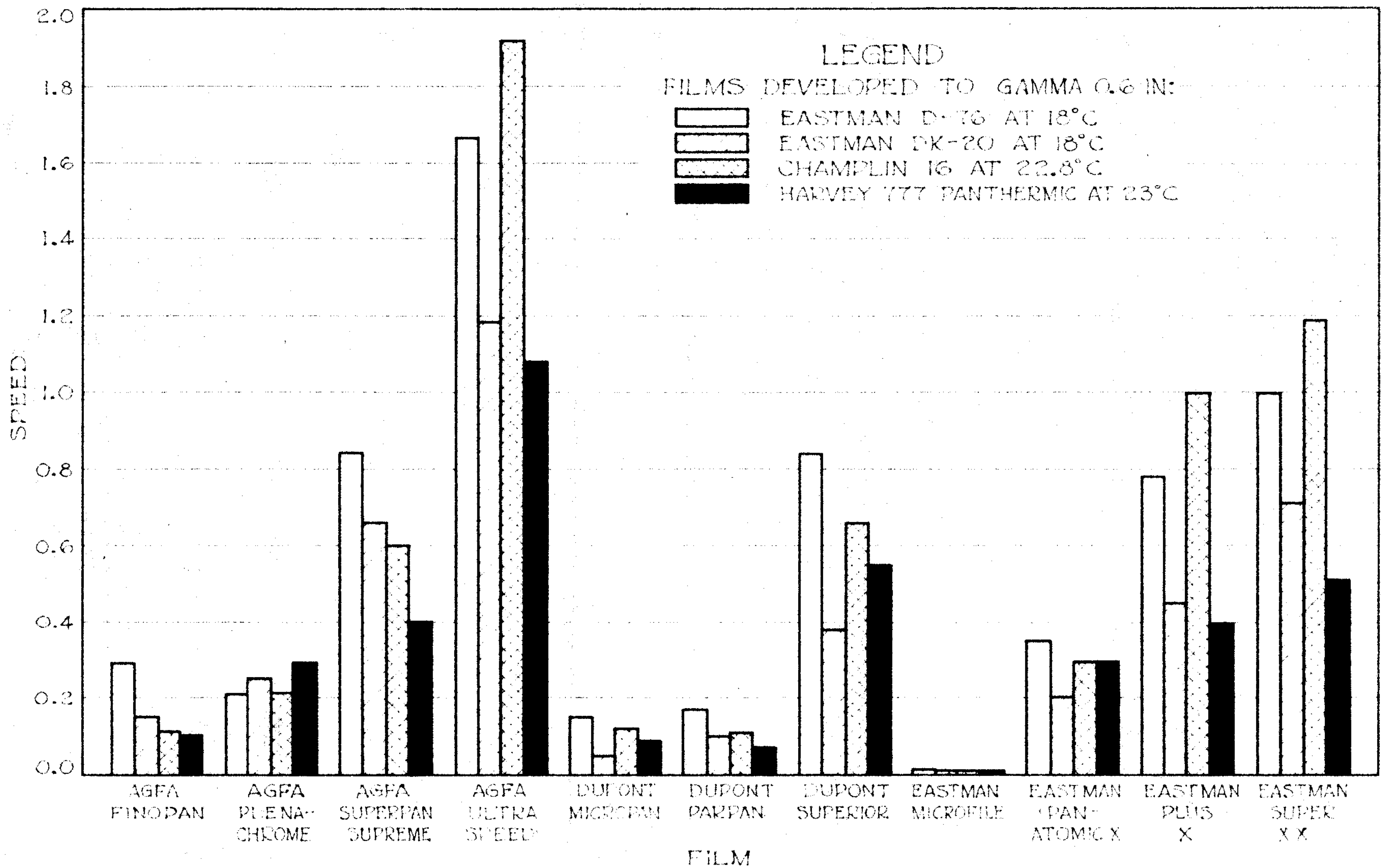


Figure 7. Speed Data

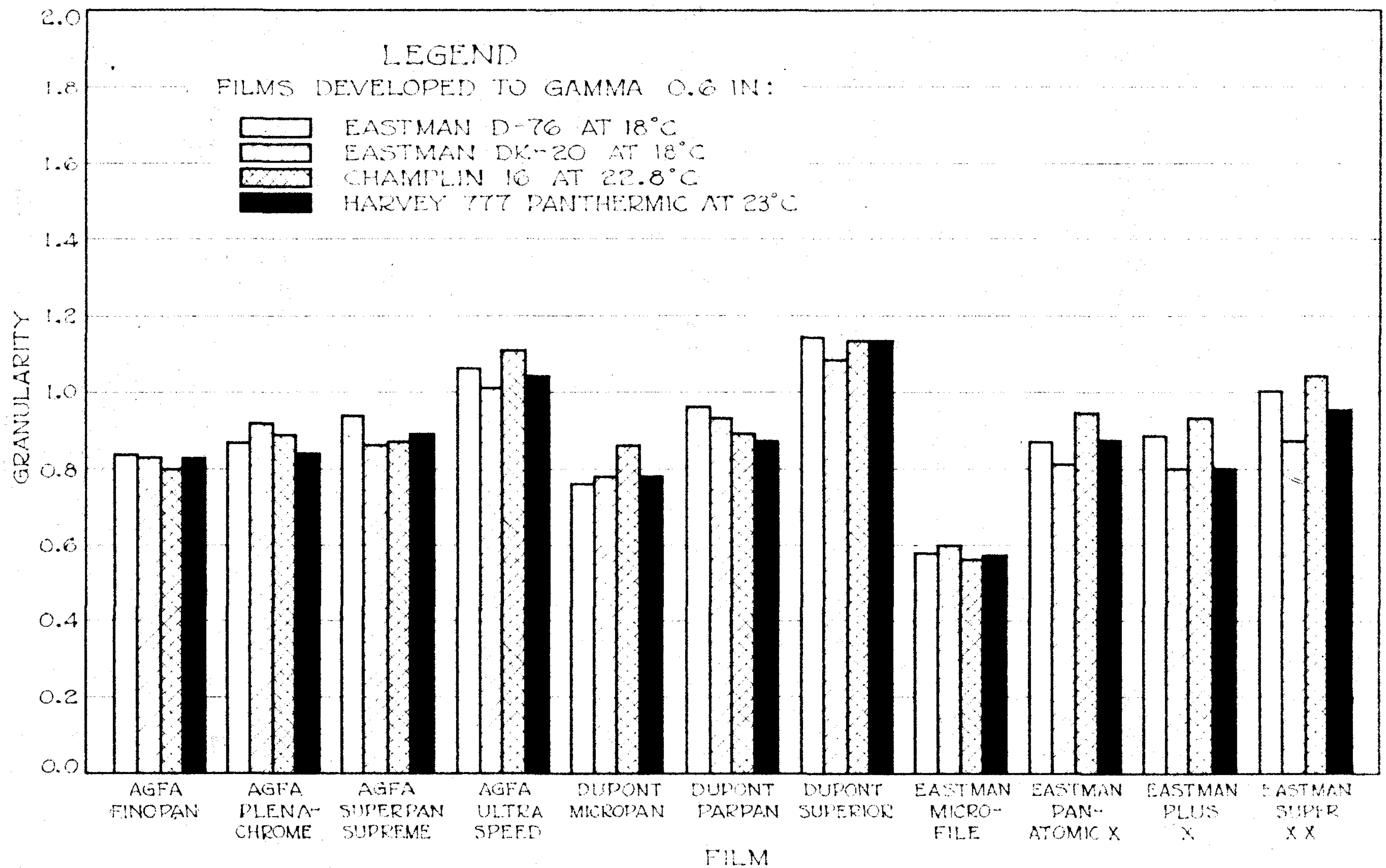


Figure 8. Graininess Data

IV. DISCUSSION

For convenience in the discussion the films tested may be divided into three general groups, namely, (1) fast films with relative speeds greater than 0.4, (2) moderately fast films with speeds between 0.2 and 0.4, and (3) slow films with speeds less than 0.2. A study of Figure 7 indicates that Superpan Supreme, Ultra Speed, Superior, Plus X, and Super XX fall into group 1; Finopan, Plenachrome, and Panatomic X into group 2; and Micropan, Parpan, and Microfile into group 3. A similar study of Figure 8 shows that, in general, the emulsions included in group 1 have the coarsest grain structure, those in group 2 slightly less graininess, and the slow emulsions of group 3 decidedly finer grain structure. Of course, the divisions between the groups are not sharp, and there are exceptions to this generality. For instance, Plus X has a granularity comparable to the films of group 2 and Parpan, an exceedingly slow emulsion, has a coarse grain structure.

The differences in granularity produced by the four developers in a given film are only slight in comparison with the inherent differences among the various films. The relative graininess obtained with DK-20 and Harvey 777 is definitely less than that produced by D-76 for all the films of group 1, but these developers are decidedly less effective for the films of groups 2 and 3. For these emulsions slight differences in density and contrast may completely obscure the effects of the developers. In all cases decreased graininess is obtained only at the sacrifice of effective emulsion speed. These results are in agreement with the work of van Kreveld and Scheffer (25) and Higgins (17), who definitely concluded that fine-grain developers were more effective in reducing the granularity in fast, coarse grain emulsions than in slow, fine grain emulsions.

When the films are developed to a gamma of 0.6, Champlin 16 is ineffective in reducing granularity. In several cases the granularity is actually greater than that produced by D-76, particularly with the fast coarse grain emulsions; in these cases, however, there are corresponding increases in effective emulsion speed. The development times recommended by Champlin (1) are insufficient to produce a practical contrast at the temperatures suggested, and under these conditions a fine grain structure is obtained at the expense of contrast and tonal quality.

The fogging effect of the different developers varies considerably, the fog produced by DK-20, Champlin 16, and Harvey 777 being consistently denser than that produced by D-76.

V. CONCLUSIONS

The results of this investigation on the granularity and speed of various types of photographic films indicate that:

1. The differences in granularity produced by fine-grain developers are only slight in comparison with the inherent differences among the various films.

2. Fine-grain developers are effective in reducing the granularity of fast, coarse grain emulsions.

3. Fine-grain developers are only slightly effective in reducing the granularity of slow, fine grain emulsions, and slight differences in density or contrast may completely obscure the effects of the developers.

4. Reduced granularity can be obtained only at the sacrifice of effective emulsion speed.

5. Reduced granularity may be obtained at the expense of contrast and tonal quality.

6. The fogging effect of fine-grain developers is greater than the fogging effect of a typical elon-hydroquinone developer.

VI. SUMMARY

In this investigation the granularity and speed of the more popular commercial films developed in typical developers were determined quantitatively. It was found that the differences in granularity produced by the developers were small in comparison with the inherent differences among the various films. Certain fine-grain developers were effective in reducing the granularity of fast, coarse grain emulsions, but only at the sacrifice of effective emulsion speed. These developers, however, were only slightly effective in reducing the granularity of slow, fine grain emulsions, small differences in density or contrast completely obscuring the effects of the developers.

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VIII. ACKNOWLEDGMENTS

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IX. APPENDIX

Table II

Exposure Time - Density Data

A. Films developed in Eastman D-76 at 18° C.

Film	Development Time	Gamma	Exposure Time (0.1 Sec.)	Density
Agfa Finopan	7.0 min.	0.60	1	0.018
			2	0.090
			4	0.200
			8	0.375
			16	0.542
			32	0.716
			64	1.012
			128	1.075
			256	1.161
Agfa Fine Grain Plenachrome	6.5 min.	0.58	1	0.013
			2	0.065
			4	0.162
			8	0.270
			16	0.423
			32	0.606
			64	0.782
			128	0.872
			256	0.994
Agfa Superpan Supreme	7.5 min.	0.59	1	0.017
			2	0.067
			4	0.160
			8	0.304
			16	0.499
			32	0.652
			64	0.715
			128	0.822
			256	0.971

Table II (Continued)

Film	Development Time	Gamma	Exposure Time (0.1 Sec.)	Density
Agfa Ultra Speed Panchromatic	14.0 min.	0.59	1	0.061
			2	0.157
			4	0.347
			8	0.542
			16	0.695
			32	0.867
			64	1.007
			128	1.154
			256	1.182
Dupont Micropan	5.0 min.	0.61	2	0.028
			4	0.098
			8	0.226
			16	0.398
			32	0.580
			64	0.771
			128	0.945
			256	1.130
			512	1.242
Dupont Fine Grain Parpan	9.0 min.	0.60	1	0.007
			2	0.033
			4	0.096
			8	0.222
			16	0.390
			32	0.554
			64	0.757
			128	0.930
			256	1.116
Dupont Superior	13.0 min.	0.60	2	0.058
			4	0.155
			8	0.297
			16	0.456
			32	0.640
			64	0.824
			128	0.975
			256	1.028
			512	1.125

Table II (Continued)

Film	Development Time	Gamma	Exposure Time (0.1 Sec.)	Density
Eastman Microfile	2.0 min.	0.60	1	0.009
			2	0.035
			4	0.125
			8	0.277
			16	0.470
			32	0.646
			64	0.827
			128	0.961
			256	1.023
Eastman Panatomic X	10.0 min.	0.60	2	0.017
			4	0.051
			8	0.127
			16	0.251
			32	0.432
			64	0.588
			128	0.788
			256	0.889
			512	1.008
Eastman Plus X	12.0 min.	0.60	1	0.006
			2	0.063
			4	0.147
			8	0.290
			16	0.465
			32	0.662
			64	0.816
			128	0.922
			256	1.093
Eastman Super XX	13.5 min.	0.60	1	0.045
			2	0.111
			4	0.196
			8	0.313
			16	0.497
			32	0.678
			64	0.837
			128	1.001
			256	1.122

Table II (Continued)

Exposure Time - Density Data

B. Films developed in Eastman DK-20 at 18° C.

Film	Development Time	Gamma	Exposure Time (0.1 Sec.)	Density
Agfa Finopan	7.0 min.	0.60	1	0.004
			2	0.022
			4	0.081
			8	0.223
			16	0.412
			32	0.598
			64	0.860
			128	0.951
			256	1.064
Agfa Fine Grain Plenachrome	7.5 min.	0.58	1	0.001
			2	0.033
			4	0.135
			8	0.281
			16	0.459
			32	0.622
			64	0.768
			128	0.874
			256	0.986
Agfa Superpan Supreme	11.0 min.	0.60	1	0.003
			2	0.017
			4	0.082
			8	0.227
			16	0.413
			32	0.580
			64	0.709
			128	0.846
			256	1.058

Table II (Continued)

Film	Development Time	Gamma	Exposure Time (0.1 Sec.)	Density
Agfa Ultra Speed Panchromatic	18.0 min.	0.60	1	0.006
			2	0.060
			4	0.171
			8	0.350
			16	0.539
			32	0.716
			64	0.899
			128	1.017
			256	1.090
Dupont Micropan	4.5 min.	0.61	2	0.001
			4	0.016
			8	0.063
			16	0.146
			32	0.289
			64	0.463
			128	0.653
			256	0.842
			512	1.018
Dupont Fine Grain Parpan	7.5 min.	0.61	1	0.006
			2	0.015
			4	0.040
			8	0.115
			16	0.227
			32	0.416
			64	0.607
			128	0.782
			256	0.962
Dupont Superior	17.5 min.	0.58	2	0.003
			4	0.037
			8	0.110
			16	0.210
			32	0.353
			64	0.529
			128	0.703
			256	0.821
			512	0.946

Table II (Continued)

Film	Development Time	Gamma	Exposure Time (0.1 Sec.)	Density
Eastman Microfile	2.25 min.	0.61	1	0.008
			2	0.027
			4	0.088
			8	0.227
			16	0.380
			32	0.572
			64	0.769
			128	0.948
			256	1.128
Eastman Panatomic X	11.0 min.	0.59	2	0.003
			4	0.014
			8	0.050
			16	0.133
			32	0.234
			64	0.382
			128	0.536
			256	0.727
			512	0.891
Eastman Plus X	11.5 min.	0.61	1	0.000
			2	0.022
			4	0.053
			8	0.171
			16	0.279
			32	0.407
			64	0.589
			128	0.776
			256	0.965
Eastman Super XX	17.0 min.	0.60	1	0.005
			2	0.044
			4	0.125
			8	0.233
			16	0.343
			32	0.501
			64	0.677
			128	0.876
			256	1.052

Table II (Continued)

Exposure Time - Density Data

C. Films developed in Champlin 16 at 22.8° C.

Film	Development Time	Gamma	Exposure Time (0.1 Sec.)	Density
Agfa Finopan	7.5 min.	0.60	1	0.000
			2	0.000
			4	0.033
			8	0.132
			16	0.317
			32	0.509
			64	0.762
			128	0.860
			256	0.901
Agfa Fine Grain Plenachrome	8.0 min.	0.60	1	0.004
			2	0.039
			4	0.139
			8	0.326
			16	0.511
			32	0.674
			64	0.770
			128	0.851
			256	0.944
Agfa Superpan Supreme	11.5 min.	0.61	1	0.000
			2	0.014
			4	0.069
			8	0.215
			16	0.406
			32	0.594
			64	0.773
			128	0.903
			256	1.008

Table II (Continued)

Film	Development Time	Gamma	Exposure Time (0.1 Sec.)	Density
Agfa Ultra Speed Panchromatic	15.5 min.	0.61	1	0.038
			2	0.134
			4	0.315
			8	0.527
			16	0.722
			32	0.879
			64	1.062
			128	1.180
			256	1.271
Dupont Micropan	7.2 min.	0.61	2	0.009
			4	0.043
			8	0.148
			16	0.303
			32	0.481
			64	0.671
			128	0.851
			256	1.023
			512	1.159
Dupont Fine Grain Parpan	9.0 min.	0.58	1	0.002
			2	0.018
			4	0.068
			8	0.161
			16	0.328
			32	0.497
			64	0.676
			128	0.838
			256	0.968
Dupont Superior	15.5 min.	0.59	2	0.018
			4	0.099
			8	0.226
			16	0.366
			32	0.536
			64	0.712
			128	0.884
			256	0.986
			512	1.120

Table II (Continued)

Film	Development Time	Gamma	Exposure Time (0.1 Sec.)	Density
Eastman Microfile	2.5 min.	0.59	1	0.012
			2	0.021
			4	0.050
			8	0.142
			16	0.295
			32	0.472
			64	0.650
			128	0.791
			256	0.917
Eastman Panatomic X	9.5 min.	0.61	2	0.009
			4	0.037
			8	0.102
			16	0.239
			32	0.420
			64	0.614
			128	0.804
			256	0.923
			512	0.956
Eastman Plus X	12.0 min.	0.60	1	0.008
			2	0.042
			4	0.150
			8	0.311
			16	0.485
			32	0.677
			64	0.850
			128	1.013
			256	1.144
Eastman Super XX	15.5 min.	0.60	1	0.006
			2	0.058
			4	0.161
			8	0.313
			16	0.491
			32	0.675
			64	0.851
			128	0.944
			256	1.072

Table II (Continued)

Exposure Time - Density Data

D. Films developed in Harvey 777 Panthermic at 23° C.

Film	Development Time	Gamma	Exposure Time (0.1 Sec.)	Density
Agfa Finopan	5.8 min.	0.60	1	0.000
			2	0.003
			4	0.041
			8	0.152
			16	0.301
			32	0.488
			64	0.656
			128	0.842
			256	1.018
Agfa Fine Grain Plenachrome	8.2 min.	0.61	1	0.005
			2	0.067
			4	0.198
			8	0.384
			16	0.579
			32	0.812
			64	0.952
			128	1.049
			256	1.174
Agfa Superpan Supreme	9.5 min.	0.60	1	0.000
			2	0.001
			4	0.042
			8	0.131
			16	0.309
			32	0.493
			64	0.660
			128	0.782
			256	0.919

Table II (Continued)

Film	Development Time	Gamma	Exposure Time (0.1 Sec.)	Density
Agfa Ultra Speed Panchromatic	12.5 min.	0.60	1	0.000
			2	0.054
			4	0.184
			8	0.371
			16	0.557
			32	0.719
			64	0.888
			128	1.044
			256	1.182
Dupont Micropan	3.8 min.	0.60	2	0.020
			4	0.037
			8	0.113
			16	0.221
			32	0.369
			64	0.543
			128	0.732
			256	0.917
			512	1.062
Dupont Fine Grain Parpan	5.8 min.	0.60	1	0.013
			2	0.023
			4	0.068
			8	0.147
			16	0.263
			32	0.400
			64	0.584
			128	0.763
			256	0.942
Dupont Superior	12.5 min.	0.58	2	0.000
			4	0.034
			8	0.144
			16	0.304
			32	0.470
			64	0.628
			128	0.824
			256	0.997
			512	1.164

Table II (Continued)

Film	Development Time	Gamma	Exposure Time (0.1 Sec.)	Density
Eastman Microfile	2.0 min.	0.60	1	0.005
			2	0.020
			4	0.084
			8	0.227
			16	0.408
			32	0.601
			64	0.777
			128	0.945
			256	1.033
Eastman Panatomic X	12.0 min.	0.61	2	0.000
			4	0.021
			8	0.086
			16	0.215
			32	0.385
			64	0.585
			128	0.763
			256	0.929
			512	1.070
Eastman Plus X	9.2 min.	0.59	1	0.000
			2	0.006
			4	0.031
			8	0.103
			16	0.212
			32	0.385
			64	0.566
			128	0.691
			256	0.811
Eastman Super XX	10.0 min.	0.60	1	0.012
			2	0.022
			4	0.053
			8	0.150
			16	0.314
			32	0.501
			64	0.628
			128	0.728
			256	0.802

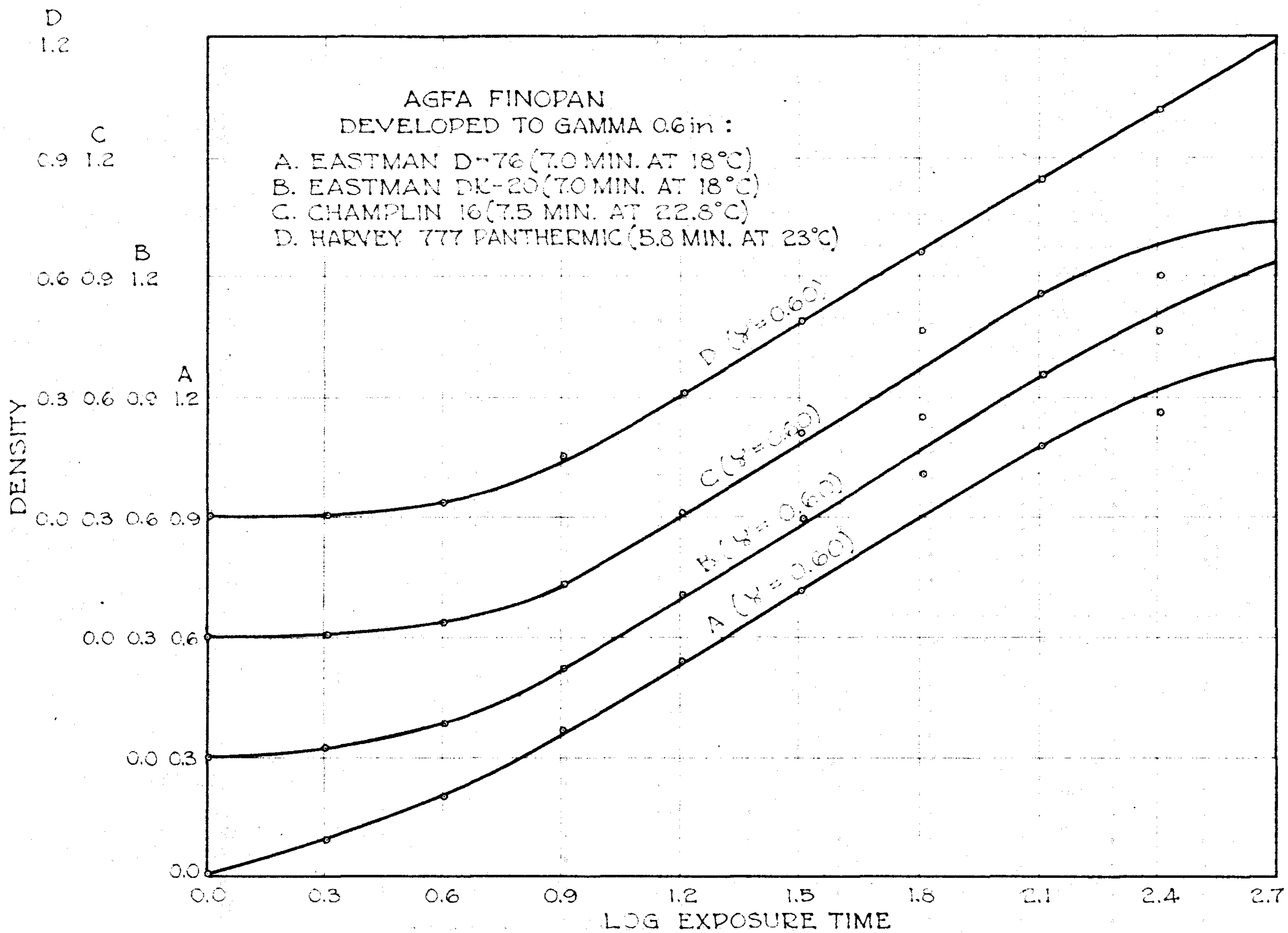

Figure 9. Characteristic Curves for Agfa Finopan

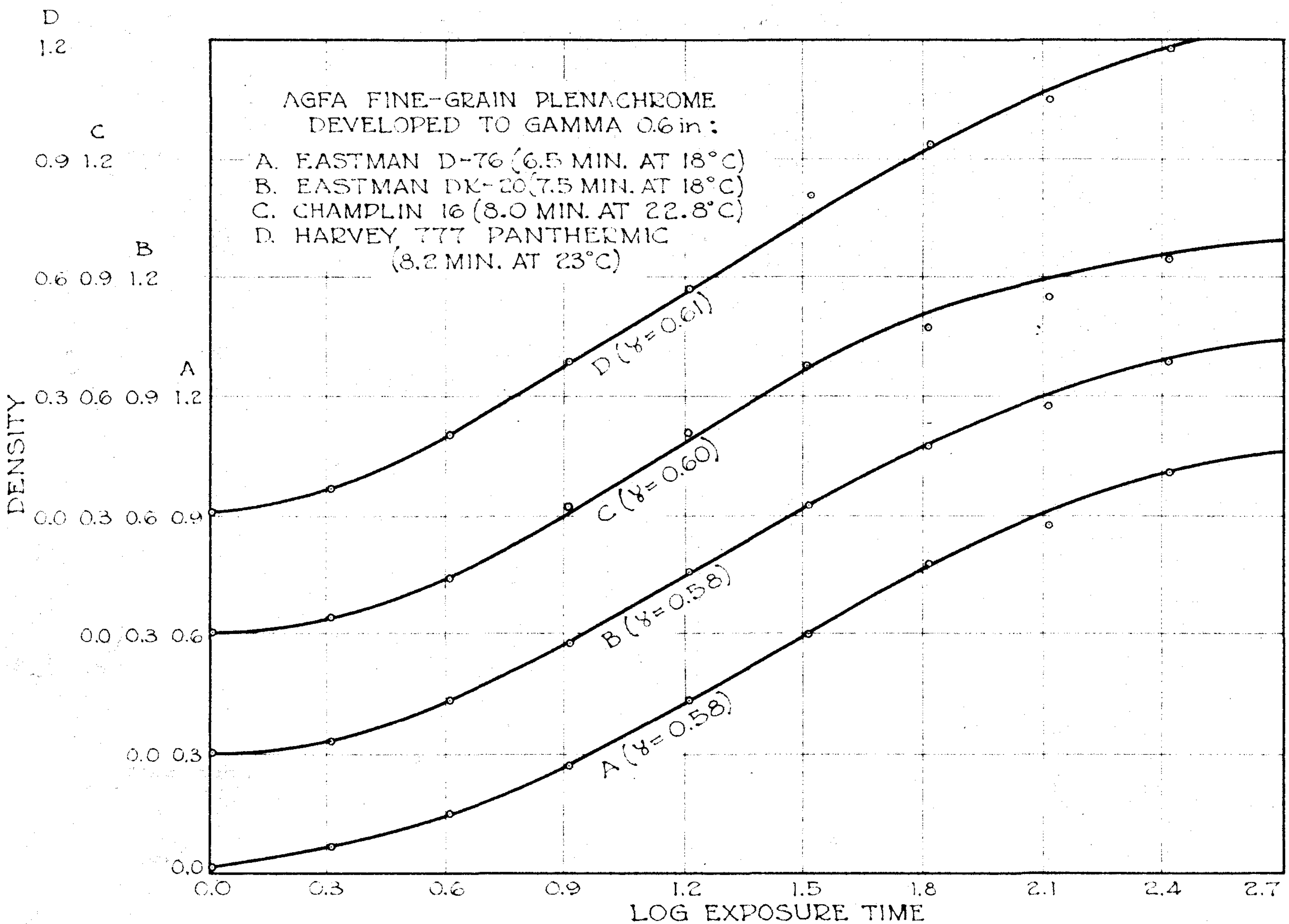

Figure 10. Characteristic Curves for Agfa Fine-Grain Plenachrome

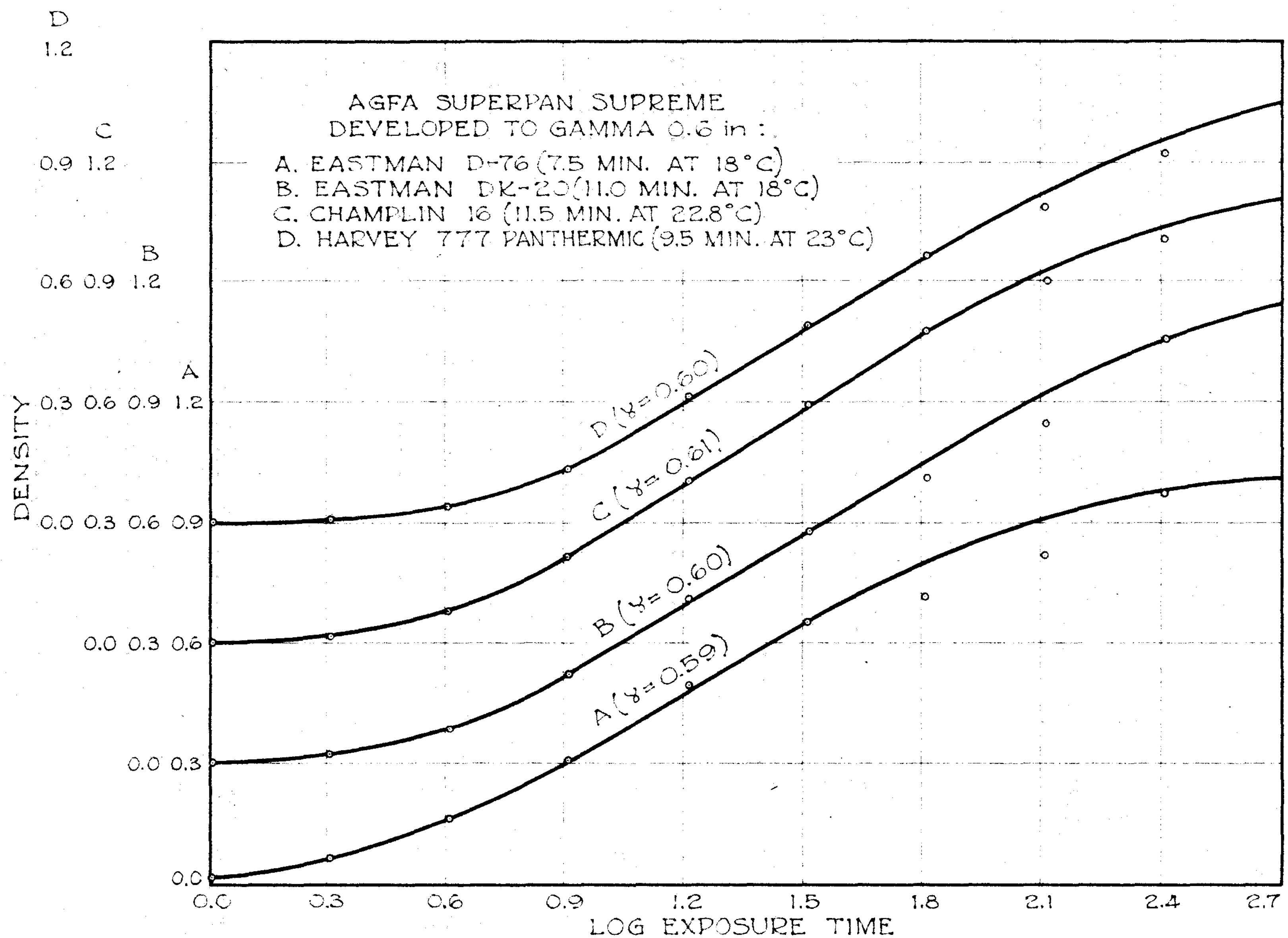

Figure 11. Characteristic Curves for Agfa Superpan Supreme

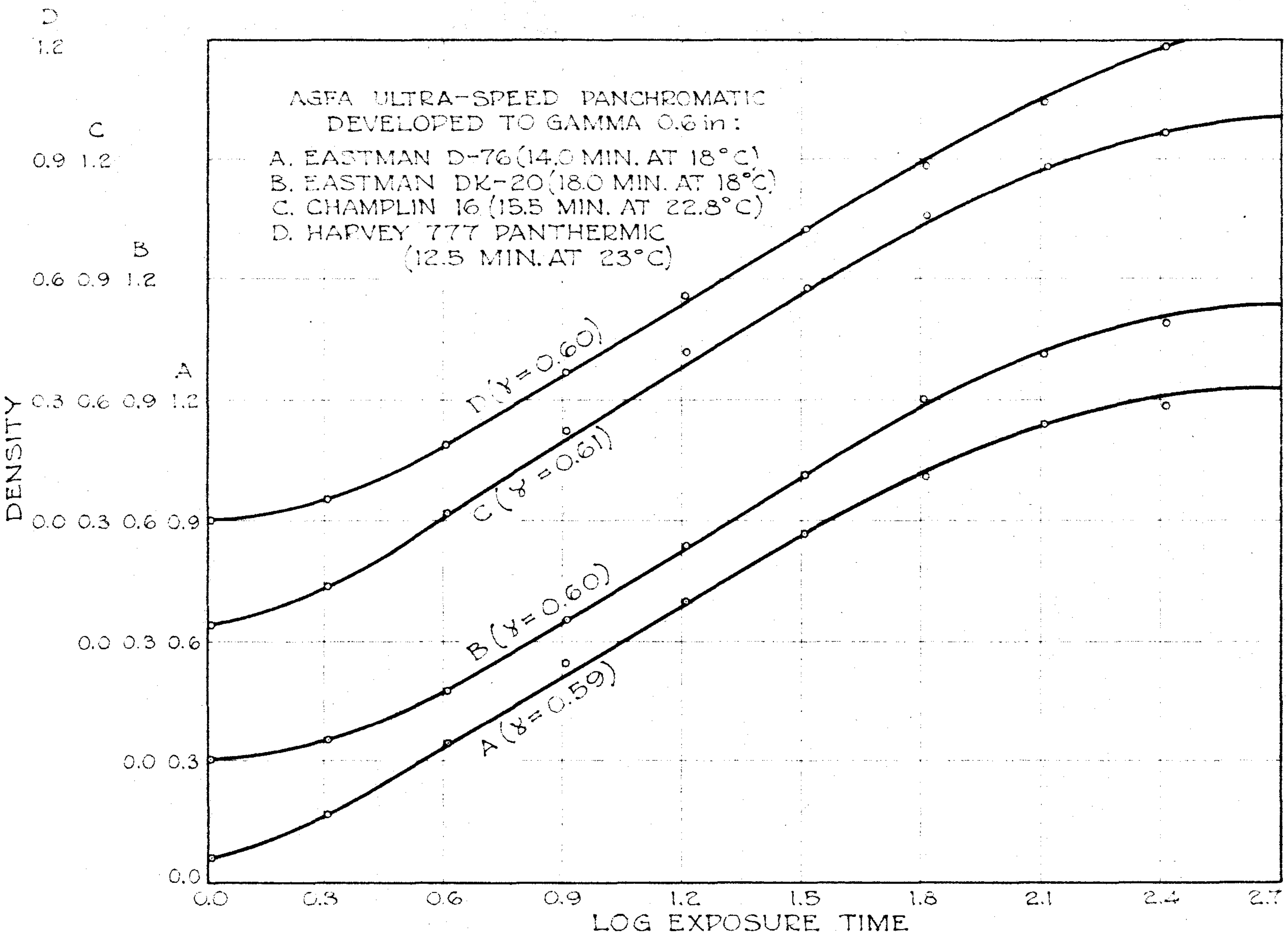

Figure 12. Characteristic Curves for Agfa Ultra-Speed Panchromatic

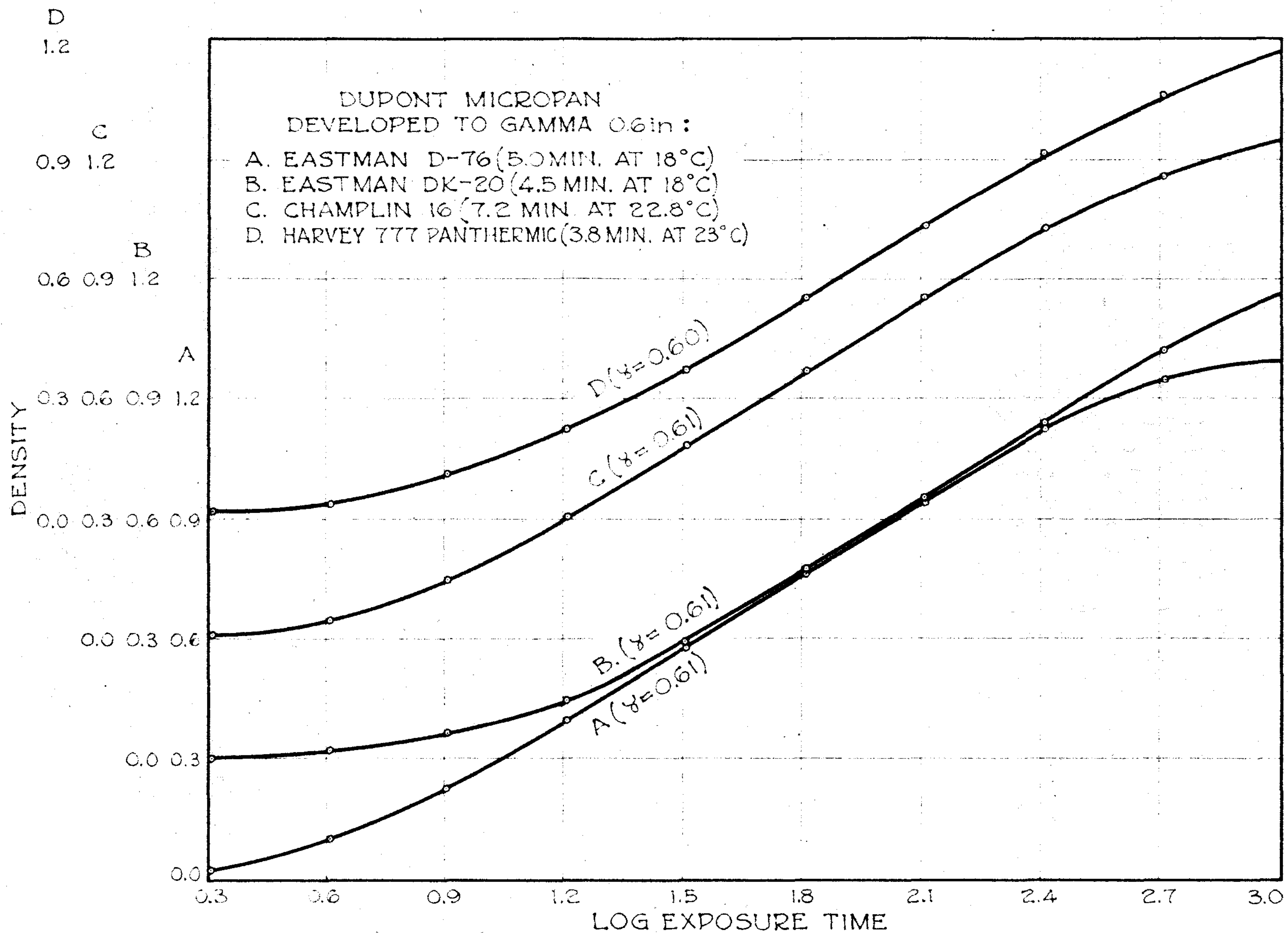

Figure 13. Characteristic Curves for Dupont Micropan

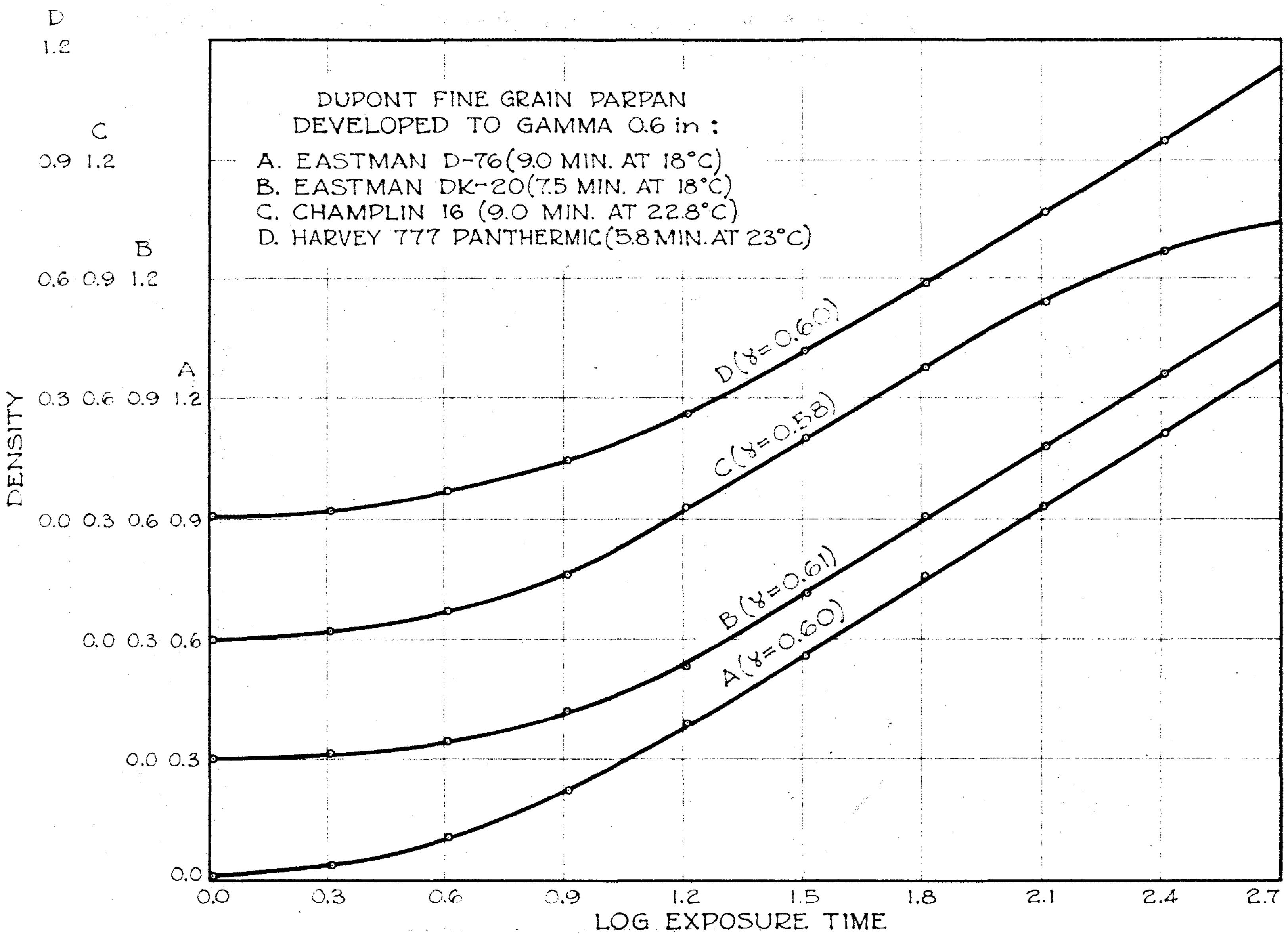

Figure 14. Characteristic Curves for Dupont Fine Grain Parpan

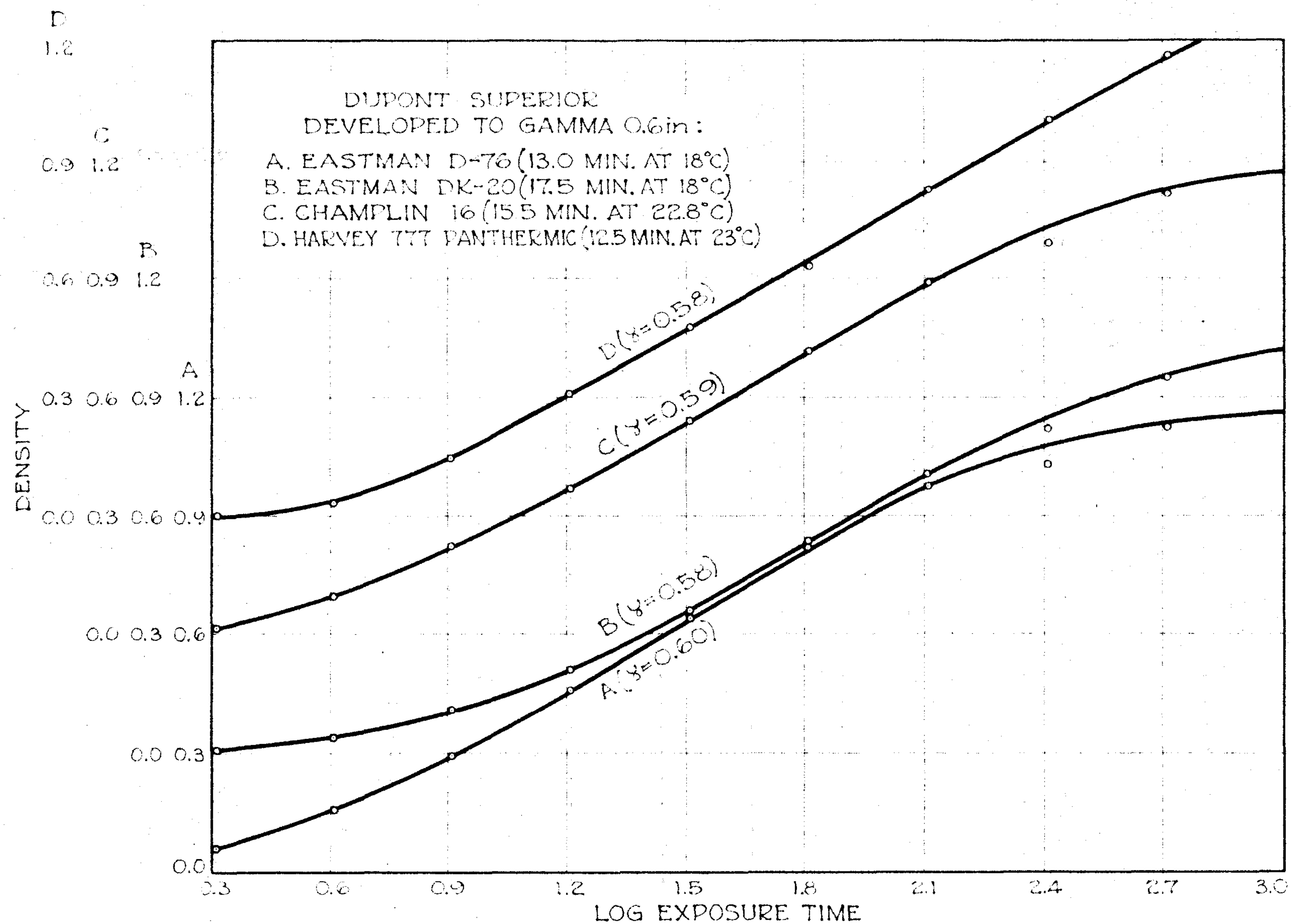

Figure 15. Characteristic Curves for Dupont Superior

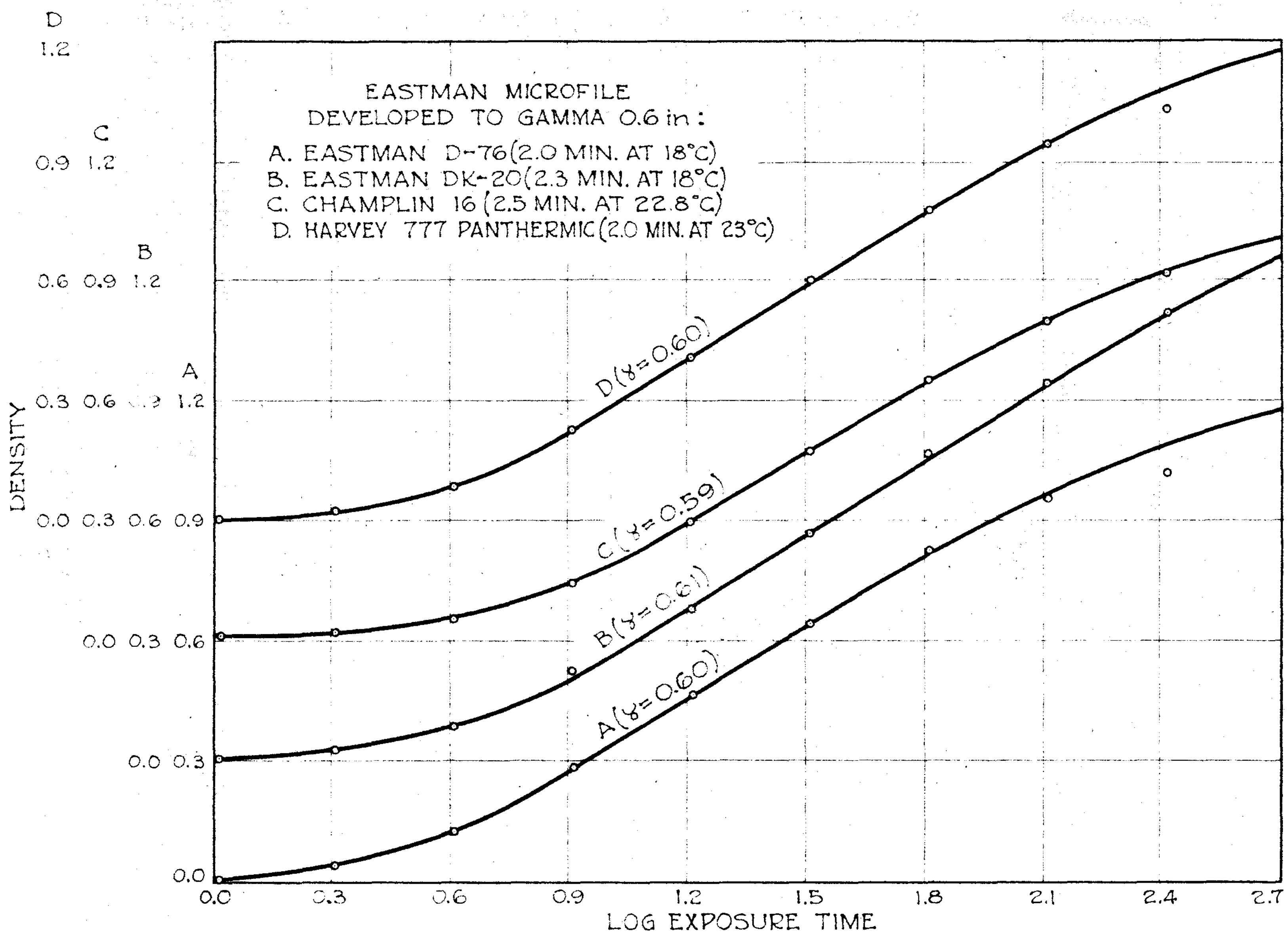

Figure 16. Characteristic Curves for Eastman Microfile

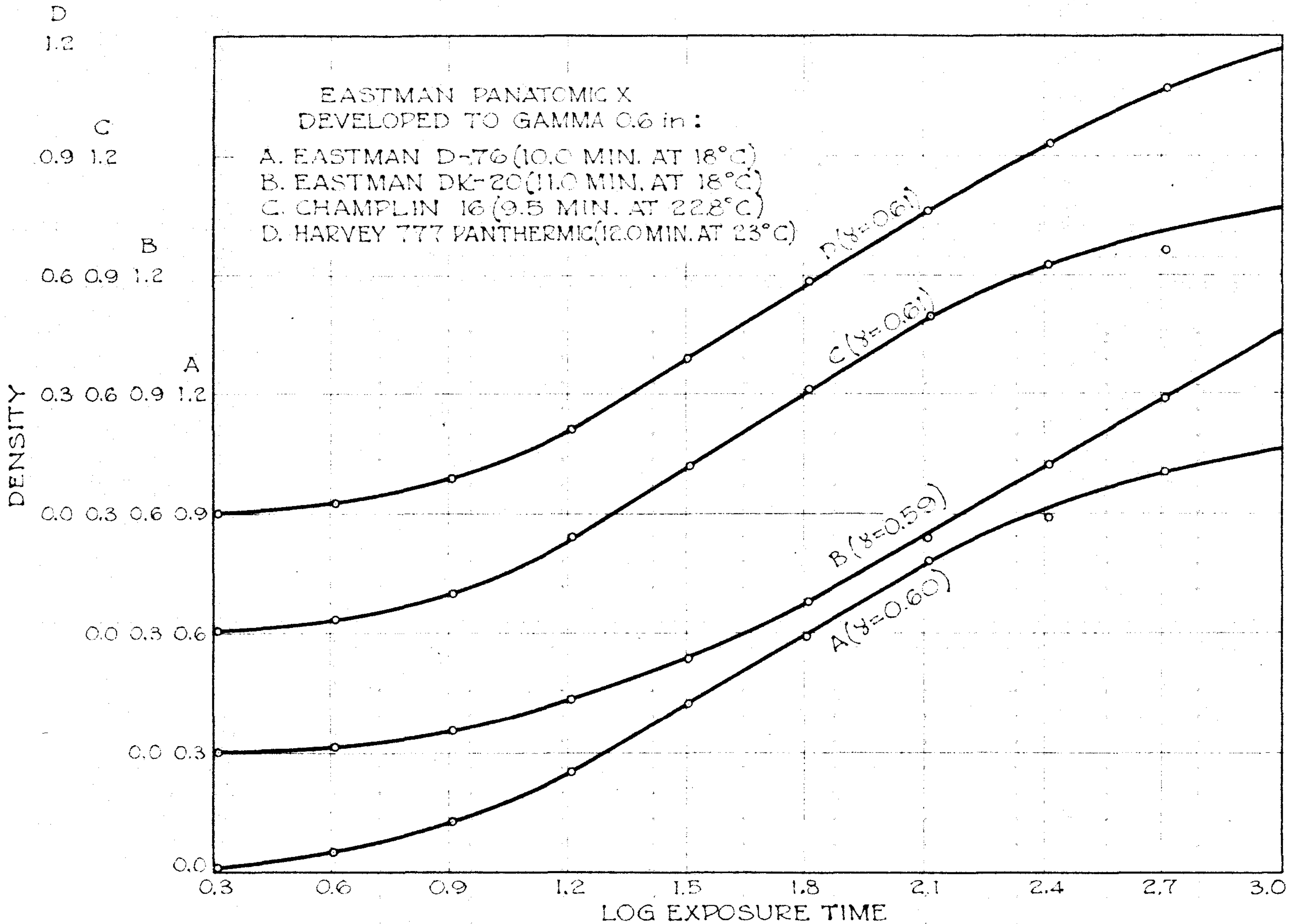

Figure 17. Characteristic Curves for Eastman Panatomic X

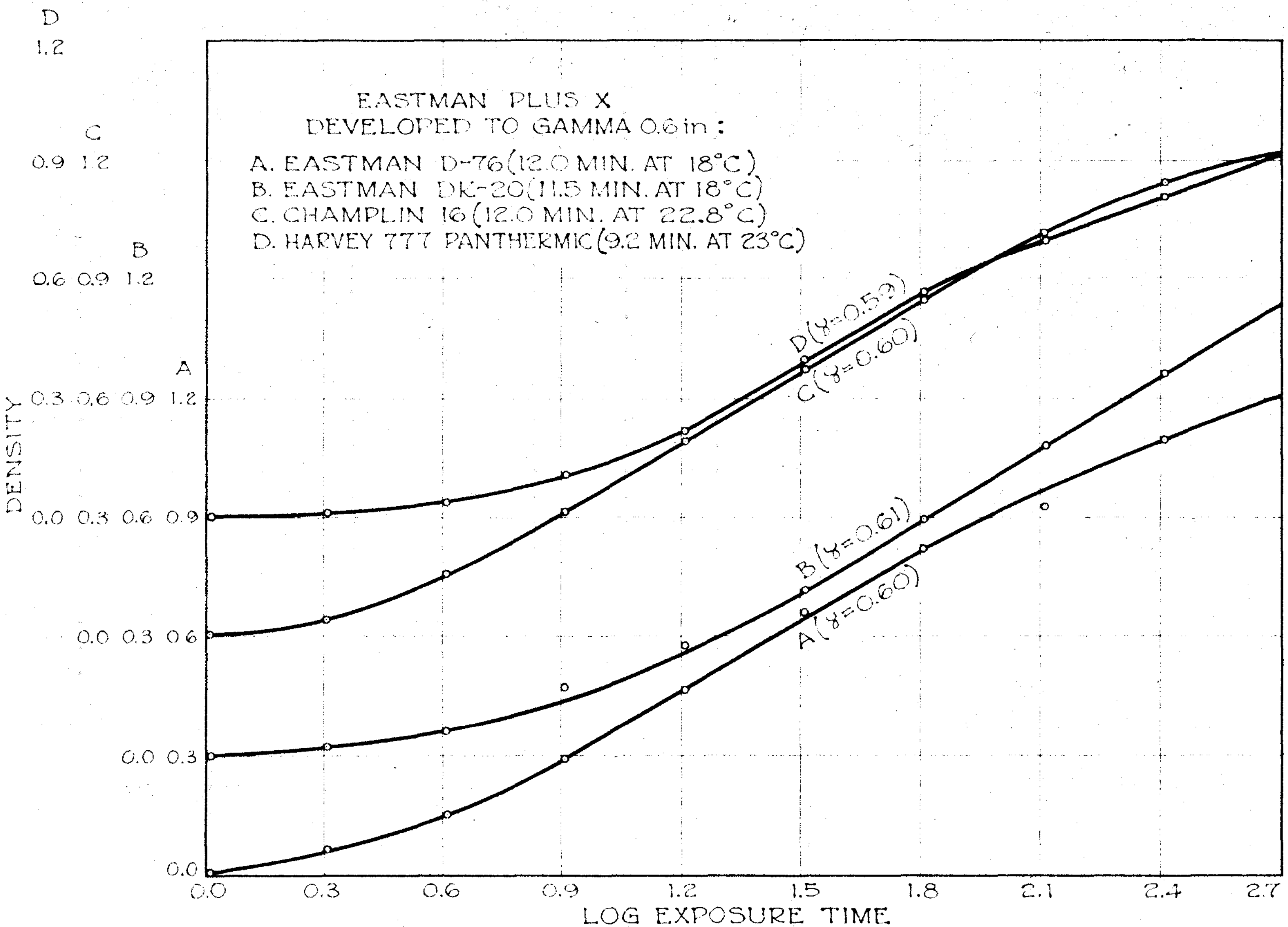

Figure 18. Characteristic Curves for Eastman Plus X

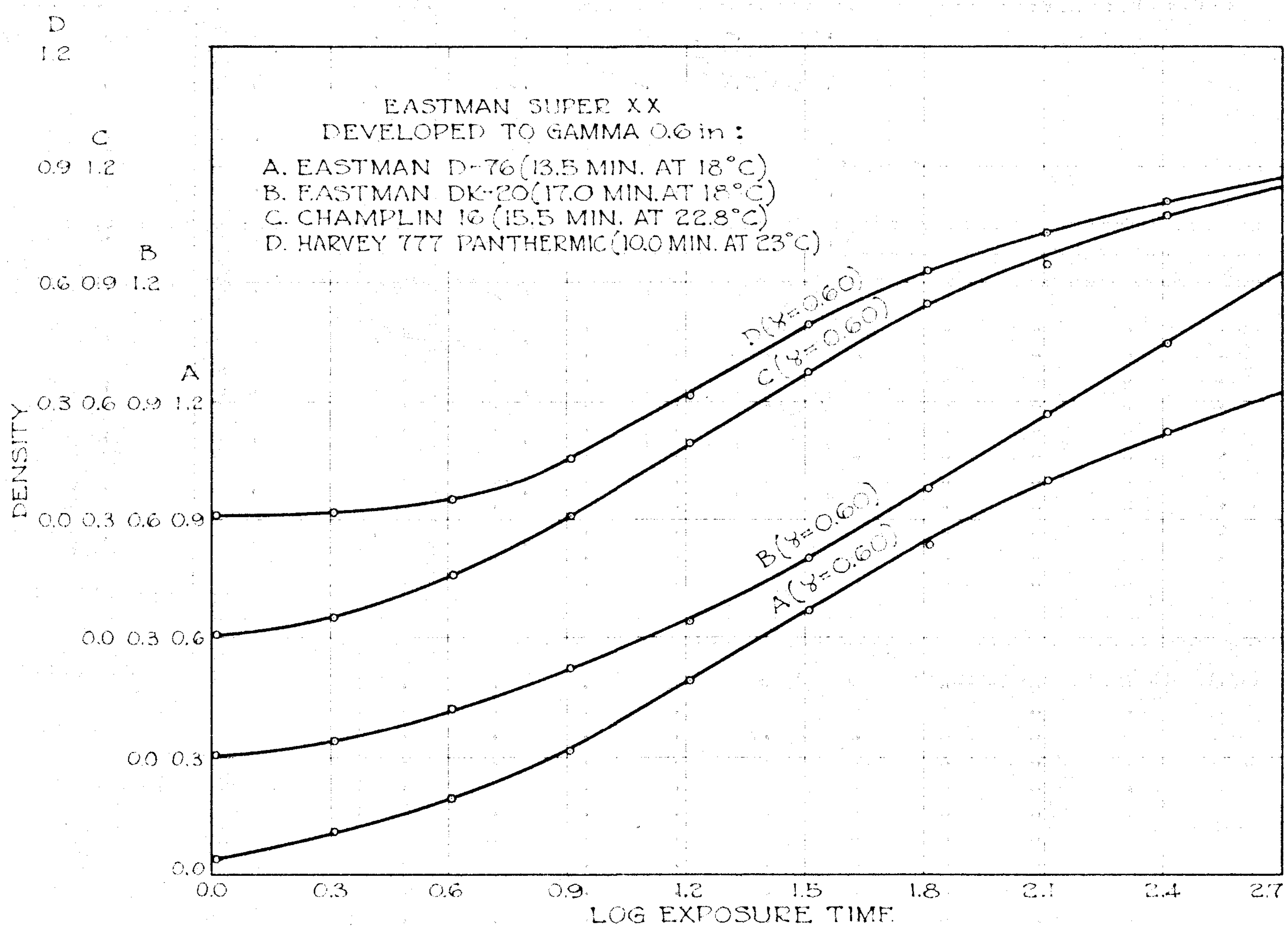

Figure 19. Characteristic Curves for Eastman Super XX

Table III

Graininess Data

A. Films developed to gamma 0.6 in D-76 at 18° C.

Film	Observer									
	1	2	3	4	5	6	7	8	9	10
Agfa Finopan	0.81	0.96	0.78	0.97	0.64	0.80	0.86	0.93	0.85	0.96
Agfa Plenachrome	0.88	0.87	0.89	0.89	0.72	0.96	0.77	0.97	0.93	0.98
Agfa Superpan Supreme	0.94	1.00	0.91	0.99	0.83	1.05	0.83	1.02	0.88	0.96
Agfa Ultra Speed	1.01	1.09	1.05	0.97	0.97	1.41	1.09	1.22	1.14	0.98
Dupont Micropan	0.75	0.59	0.69	0.78	0.72	0.75	0.77	0.87	0.88	0.83
Dupont Parpan	0.92	0.91	0.91	0.88	0.89	0.91	0.91	0.93	0.99	0.94
Dupont Superior	1.14	1.19	1.09	1.09	1.00	1.14	1.23	1.30	1.17	1.10
Eastman Microfile	0.57	0.43	0.55	0.58	0.53	0.41	0.63	0.60	0.63	0.60
Eastman Panatomic X	0.91	0.83	0.87	0.81	0.89	0.82	0.83	0.83	0.85	0.81
Eastman Plus X	0.88	0.83	0.87	0.75	0.86	0.80	0.83	0.90	0.83	0.94
Eastman Super XX	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
	11	12	13	14	15	16	17	18	19	20
Agfa Finopan	0.92	0.85	0.72	0.98	0.73	0.87	0.82	0.85	0.69	0.79
Agfa Plenachrome	0.87	0.85	0.86	0.93	0.65	0.97	0.98	0.92	0.74	0.87
Agfa Superpan Supreme	1.03	1.02	0.97	0.85	0.84	1.01	1.09	0.88	0.74	0.90
Agfa Ultra Speed	1.16	1.13	1.03	1.07	0.93	1.08	1.13	1.07	0.74	0.99
Dupont Micropan	0.95	0.96	0.70	0.76	0.62	0.82	0.87	0.78	0.56	0.63
Dupont Parpan	1.16	0.97	1.06	1.10	0.87	1.05	1.02	0.99	0.79	0.94
Dupont Superior	1.18	1.17	1.08	1.34	1.08	1.21	1.10	1.09	1.05	1.05
Eastman Microfile	0.62	0.63	0.64	0.67	0.54	0.63	0.74	0.58	0.36	0.56
Eastman Panatomic X	0.90	0.88	0.95	1.00	0.81	0.84	0.90	0.89	0.79	0.90
Eastman Plus X	0.90	0.92	0.93	1.00	0.87	0.90	0.98	1.01	0.62	0.91
Eastman Super XX	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00

Table III (Continued)

B. Films developed to gamma 0.6 in DK-20 at 18° C.

Film	Observer 1	2	3	4	5	6	7	8	9	10
Agfa Finopan	0.91	0.89	0.85	0.84	0.72	0.77	0.86	0.97	0.82	0.94
Agfa Plenachrome	1.02	1.04	0.95	0.84	0.86	1.05	0.77	0.97	0.89	0.96
Agfa Superpan Supreme	0.99	0.78	0.85	0.78	0.72	1.00	0.83	0.90	0.82	0.83
Agfa Ultra Speed	1.09	1.02	0.96	0.92	0.89	1.29	1.09	1.10	1.05	0.96
Dupont Micropan	0.83	0.56	0.75	0.73	0.75	0.70	0.80	0.87	0.82	0.83
Dupont Parpan	0.92	0.70	0.87	1.03	0.92	0.82	0.91	1.03	0.92	0.96
Dupont Superior	1.12	1.04	1.11	1.06	1.00	1.03	1.20	1.30	1.08	1.06
Eastman Microfile	0.60	0.56	0.60	0.62	0.58	0.45	0.63	0.63	0.66	0.60
Eastman Panatomic X	0.81	0.70	0.84	0.73	0.86	0.73	0.77	0.83	0.93	0.85
Eastman Plus X	0.82	0.76	0.82	0.81	0.86	0.82	0.84	0.83	0.70	0.83
Eastman Super XX	0.88	0.65	0.87	0.86	1.00	0.89	1.00	1.03	0.79	0.81

Film	11	12	13	14	15	16	17	18	19	20
Agfa Finopan	0.87	0.86	0.77	0.88	0.76	0.87	0.90	0.75	0.69	0.83
Agfa Plenachrome	1.00	1.02	0.97	1.00	0.92	0.95	0.92	0.79	0.74	0.90
Agfa Superpan Supreme	1.03	0.98	0.89	0.88	0.87	0.90	0.85	0.74	0.74	0.85
Agfa Ultra Speed	1.13	1.09	0.97	0.95	0.97	1.03	0.91	0.92	0.92	0.95
Dupont Micropan	1.00	1.00	0.72	0.82	0.78	0.82	0.85	0.77	0.56	0.69
Dupont Parpan	1.10	1.00	0.97	1.06	0.92	0.95	0.87	0.85	0.87	0.89
Dupont Superior	1.10	1.15	1.06	1.29	1.05	1.03	1.00	0.95	1.00	1.04
Eastman Microfile	0.66	0.64	0.64	0.68	0.54	0.66	0.77	0.58	0.38	0.55
Eastman Panatomic X	0.84	0.81	0.81	1.04	0.81	0.87	0.92	0.63	0.79	0.69
Eastman Plus X	0.79	0.77	0.97	0.85	0.81	0.90	0.87	0.69	0.62	0.74
Eastman Super XX	0.97	0.85	0.97	0.90	0.92	0.95	0.87	0.74	0.62	0.88

Table III (Continued)

C. Films developed to gamma 0.6 in Champlin 16 at 22.8° C.

	Observer									
	1	2	3	4	5	6	7	8	9	10
Agfa Finopan	0.81	0.85	0.76	0.69	0.64	0.73	0.74	0.87	0.86	0.96
Agfa Plenachrome	0.94	1.00	0.87	0.77	0.75	1.03	0.80	0.93	0.89	0.94
Agfa Superpan Supreme	0.91	0.65	0.89	0.75	0.72	0.95	0.77	1.03	0.92	0.90
Agfa Ultra Speed	1.04	1.24	1.02	1.06	1.05	1.14	1.09	1.17	1.21	1.10
Dupont Micropan	0.88	0.70	0.80	0.93	0.79	0.73	0.83	0.97	0.92	0.88
Dupont Parpan	0.88	0.61	0.87	1.00	0.86	0.77	0.91	1.03	0.82	0.92
Dupont Superior	1.14	1.17	1.13	1.16	1.00	1.23	1.23	1.33	1.04	1.13
Eastman Microfile	0.52	0.43	0.56	0.62	0.53	0.45	0.66	0.60	0.60	0.54
Eastman Panatomic X	0.91	0.91	0.91	1.02	0.97	0.89	0.86	0.97	1.02	0.98
Eastman Plus X	0.94	0.96	0.94	1.00	0.92	0.93	0.94	0.93	0.90	0.90
Eastman Super XX	1.01	0.91	1.02	1.12	1.14	0.93	1.11	1.17	0.96	1.06
	11	12	13	14	15	16	17	18	19	20
Agfa Finopan	0.90	0.85	0.86	0.85	0.84	0.90	0.92	0.70	0.69	0.72
Agfa Plenachrome	1.00	1.00	0.95	0.95	0.97	0.92	0.89	0.79	0.74	0.82
Agfa Superpan Supreme	0.95	0.96	0.86	0.91	0.81	0.96	0.92	0.90	0.79	0.80
Agfa Ultra Speed	1.24	1.06	1.11	1.17	1.08	1.10	1.14	1.05	1.00	1.04
Dupont Micropan	1.05	0.97	0.92	0.88	0.82	0.92	0.80	0.86	0.79	0.80
Dupont Parpan	1.05	0.99	0.95	0.99	0.89	0.95	0.92	0.78	0.87	0.85
Dupont Superior	1.16	1.14	1.14	1.22	1.05	1.00	1.02	1.14	1.05	1.11
Eastman Microfile	0.63	0.62	0.56	0.59	0.54	0.63	0.64	0.66	0.36	0.55
Eastman Panatomic X	0.95	1.04	1.00	1.18	0.87	0.90	0.98	0.81	0.79	0.85
Eastman Plus X	1.00	1.02	0.86	0.90	0.96	0.95	0.95	0.92	0.79	0.96
Eastman Super XX	1.18	1.13	1.00	0.96	1.00	1.05	1.02	0.96	0.92	1.01

Table III (Continued)

D. Films developed to gamma 0.6 in Harvey 777 Panthermic at 23° C.

	Observer									
	1	2	3	4	5	6	7	8	9	10
Agfa Finopan	0.94	1.00	0.84	0.84	0.64	0.75	0.77	0.87	0.85	0.88
Agfa Plenachrome	0.87	0.74	0.82	0.88	0.75	0.95	0.77	0.90	0.81	0.85
Agfa Superpan Supreme	0.92	0.94	0.93	0.94	0.75	0.86	0.83	0.97	0.86	0.94
Agfa Ultra Speed	0.99	1.15	0.98	1.12	0.92	1.09	1.09	1.10	1.05	1.06
Dupont Micropan	0.70	0.54	0.76	0.81	0.79	0.68	0.80	0.80	0.70	0.81
Dupont Parpan	0.80	0.59	0.87	0.88	0.81	0.75	0.91	0.93	0.86	0.88
Dupont Superior	1.14	1.22	1.11	1.19	1.00	1.09	1.23	1.37	1.02	1.17
Eastman Microfile	0.57	0.48	0.58	0.53	0.58	0.43	0.63	0.57	0.65	0.52
Eastman Panatomic X	0.83	0.74	0.86	0.88	0.89	0.82	0.86	0.83	0.76	0.90
Eastman Plus X	0.78	0.61	0.84	0.87	0.78	0.77	0.86	0.87	0.79	0.79
Eastman Super XX	0.94	0.78	0.95	1.09	1.08	0.86	1.03	1.07	0.86	0.90

	11	12	13	14	15	16	17	18	19	20
Agfa Finopan	0.92	0.80	0.81	0.87	0.81	0.84	0.80	0.77	0.74	0.85
Agfa Plenachrome	0.79	0.91	0.86	0.93	0.82	0.91	0.92	0.77	0.74	0.86
Agfa Superpan Supreme	0.98	0.87	0.83	0.85	0.96	1.00	0.87	0.84	0.79	0.96
Agfa Ultra Speed	1.21	1.11	1.08	1.12	1.01	1.03	1.00	0.88	0.79	1.04
Dupont Micropan	1.03	0.99	0.83	0.78	0.85	0.90	0.82	0.67	0.56	0.80
Dupont Parpan	1.03	1.00	0.89	0.95	0.91	0.97	0.92	0.82	0.79	0.90
Dupont Superior	1.21	1.08	1.07	1.27	1.09	1.18	1.08	1.03	1.05	1.11
Eastman Microfile	0.63	0.63	0.67	0.55	0.57	0.61	0.72	0.60	0.38	0.53
Eastman Panatomic X	0.90	1.04	0.95	1.01	0.84	0.95	0.90	0.77	0.74	0.94
Eastman Plus X	0.87	0.82	0.81	0.81	0.76	0.90	0.77	0.73	0.62	0.91
Eastman Super XX	1.13	0.99	0.83	0.87	0.89	1.00	0.95	0.93	0.74	1.00