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Safety Factors in Camera Exposures

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Many photographers give less camera exposure for black-and-white films than is indicated by exposure meters used with the American Standard exposure index of the film. This practice is successful because the "standard exposure" contains a substantial safety factor and the reduced exposure gives negatives that are better for enlarging. The magnitude of the safety factor has for many years been assumed to be 2.5, but the validity of this assumption has been questioned. The present study of the magnitude of this factor was undertaken in connection with the proposed reduction in the safety factor by means of a revision of the American Standard for photographic speed and exposure index. This study, which included independent mathematical and experimental approaches, indicates that the safety factor is approximately 2.4 for sunlit scenes when accurate meters, shutters, and lens apertures are used. Data are also presented showing the speed, exposure index, and camera-exposure latitude relationships between color reversal films and black-and-white negative films. A proposed change in the sensitometric speed criterion for the black-and-white films is discussed.

During the past three or four years, much criticism has been aimed at the safety factor involved in the use of American Standard exposure indexes' with exposure meters calibrated in accordance with American Standard procedures.[2] A number of articles in photographic magazines have pointed out the penalties and disadvantages resulting from the use of too large a safety factor and have urged that a smaller safety factor be introduced by means of a revision in the American Standard for determining ASA exposure indexes for black-and-white negative films. The general spirit of these articles is illustrated by the following title of one of them: "ASA Exposure Index: Dangerously Safe."[3]

A safety factor exists in a camera exposure whenever that exposure is greater than the minimum camera exposure that will produce a negative from which a print of excellent quality can be made. The ratio of the actual camera exposure to this minimum camera exposure is, by definition, the safety factor.

If a large safety factor is used, the negatives obtained will, on the average, be much denser than is required for making a high-quality print. A small safety factor means thinner negatives. The main advantages of negatives resulting from the use of a small safety factor are:

1. Easier focusing of enlargers
2. Shorter printing times
3. Less graininess in enlargements
4. Sharper pictures
   a. Greater depth of field
   b. Reduced subject-motion blur
   c. Reduced camera-motion blur

Another advantage, found with the use of some films (especially if they have been overdeveloped), is that the shape of the part of the density-vs.-log exposure curve which is used for the thinner negatives is better than the shape of the part of the curve used for the heavily exposed negatives.

Because of these advantages, many photographers are convinced chat the best camera exposure is one which is only slightly greater than the minimum camera exposure required for a print of high quality.

The main disadvantage of a small safety factor is that occasionally an underexposed negative will be obtained as a result of an error in camera exposure. The original purpose of the safety factor was to absorb such errors. Present-day experience with color reversal films, for which a large safety factor cannot be used, shows, however, that the number of underexposed pictures resulting from the use of a small safety factor is remarkably small.

If a large safety factor is undesirable at the present time, why was it thought to be necessary when the American Standards for film ratings and exposure meters were first adopted in the 1940's? The first reason is that exposure meters, camera shutters, and lens apertures were not as accurate in the 1940's as they are in 1959. The second reason is that the camera-exposure latitude of black-and-white films was effectively greater in those earlier years, largely because the increase in print graininess with increase, in camera exposure was not as evident with

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1. *American Standard for Determining Photographic Speed and Exposure Index, PH2.*5-1954, American Standards Association,' 70 E. 45 St., New York 17, N.Y.
2. *American Standard for Photographic Exposure Meters, Photoelectric Type,* Pff2.12-1957, American Standards Association, 70 E. 45 St., New York 17, N.Y.
3. Lloyd E. Varden, *PMI (Photo Methods for Industry),* **1:** 39 (May 1958).

the large cameras, large negatives, and small degree of enlargement or contact printing then commonly used. The great increase in the number of small cameras in recent years and the increase in the degree of enlargement has made the graininess problem more acute.

Many photographers have adopted the practice of giving less exposure than is indicated by the use of ASA exposure indexes with exposure meters. The American Standard indexes for black-and-white films are used by them only as a starting point for deriving a new kind of exposure index which is obtained by the simple procedure of doubling the Standard exposure index. This practice, of course, has the effect of cutting the safety factor in half, giving the preferred thinner negatives.

In recognition of this practice, a new Subcommittee, PH2-18, of the American Standards Association was formed a little more than a year ago for the purpose of revising the *American Standard for Determining photographic speed and Exposure Index.* Under the chairmanship of J. L. Tupper, .his Subcommittee has prepared a draft of a new Standard which will very likely be officially approved soon by the ASA Sectional Committee PH2 on Photographic Sensitometry (M. G. Anderson, Chairman), the Photographic Standards Board, and the officials of the American Standards Association. In this proposed Standard, the level of the numbers used for rating black-and-white films is approximately doubled. Such a change would have the fleet of reducing the safety factor to one half its present value.

There are no plans for reducing the safety factor by means of a change in the calibration formula or exposure meters because there are too many meters in existence with the present calibration and because the meters are also used for color film for which no change in exposure level or film rating is required or desired.

The present magnitude of the safety factor is usually assumed to be somewhere between 2 and 4. The most common estimate is 2.5. A few writers five stated that it is 4. It is a remarkable fact that the exact size of the safety factor has not been definitely known. It is not mentioned in either the standard on exposure indexes or the Standard on calibration of exposure meters. The published papers[4,5] of Jones and Condit on the computation of camera exposures give considerable information on the problem of determining how large the safety factor should be to absorb errors in equipment, variations in camera flare, and variations in scene illuminance range, but they do not deal directly with the question of what the size of the safety factor actually is.

The purpose of the present paper is to present new evidence on the magnitude of the safety factor ' the photography of average sunlit scenes. Two independent approaches were used, one theoretical and the other experimental.

[4] • L. A. Jones and H. R. Condit, *J. Opt. Soc. Am.*, ***31:*** 651 (1941).
•• **rttd.,38:** 123(1948); **39:** 94(1949).

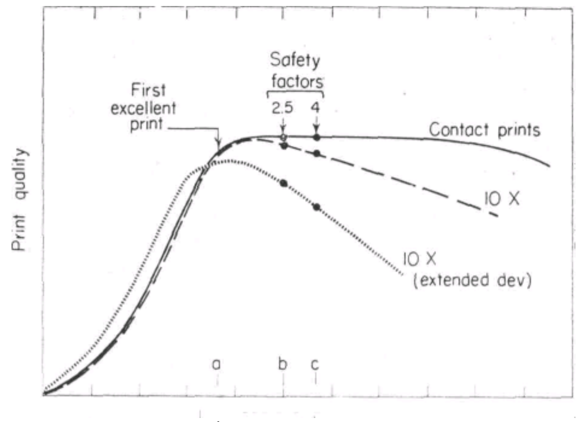


Fig. 1. Print quality vs. log camera exposure for a high-speed negative film. Solid line—contact prints; dashed line— 10-diameter enlargements; dotted line—10-diameter enlargements from negatives given extended development.

This study was undertaken by the writer as a member of the ASA Subcommittee on film speed and exposure index, and as a member of the ASA Subcommittee on exposure meters.

Effect of Graininess on the Optimum Safety Factor

A preliminary experiment was carried out, the results of which are worth reviewing at this point because they illustrate the effect which the change from contact printing to enlarging has in reducing the camera-exposure latitude of a typical high-speed negative black-and-white film. The results also illustrate the reduction in camera-exposure latitude caused by over-development of negatives.

The results are summarized in Fig. 1. The solid curve shows that the quality * of the contact prints increases rapidly at first as the camera exposure increases and then reaches a plateau, where it remains constant over a long range of camera exposures. Eventually, the quality decreases. The range of camera exposures over which the print quality remains nearly equal to the maximum quality is defined as the *camera-exposure latitude.* Each of the intervals marked along the camera-exposure axis is one camera stop. In the case of the solid curve, where the contact prints were made from 4- X 5-in. negatives of a studio portrait scene, using the optimum grade of paper for printing each negative, the camera-exposure latitude was 32 times, or five camera stops. The camera exposure marked *a* corresponds to a safety factor of 1. The camera exposures marked *b* and c correspond to safety factors of 2.5 and 4, respectively. There was, obviously, no loss in print quality at either of these

• The method of determining the quality of each print is described in paragraph 6 of the section of this paper on Experimental Determination of the Safety Factor (page 52).

two levels of exposure when the prints were made by contact.

In the next part of the test, represented by the dashed line in Fig. 1, the same film, subject, and lens were used as before but the size of the negatives was much smaller as a result of increasing the camera-to-subject distance until the size was typical of the negatives obtained in a 35mm camera. These negatives were enlarged 10 diameters, using the optimum grades of paper, and the enlargements were judged for quality. As shown by the dashed curve, the heavily exposed negatives gave enlargements of lower quality. This loss in quality was due to a very noticeable increase in graininess with increase in negative exposure. At the exposure corresponding to a safety factor of 2.5, the quality was slightly below the maximum quality. The camera-exposure latitude was about 3 times, or approximately one and two-thirds camera stops.

Although this test was not designed to provide an accurate evaluation of the safety factor, it is of interest that the exposure meter that was used indicated a camera exposure corresponding to a safety factor of 2.5.

The dotted curve of Fig. 1 shows what happens when the negatives are developed for twice the recommended development time and are enlarged 10 diameters. The quality of the prints obtained from the heavily exposed negatives was poor because the graininess was excessive and because the print contrast and tone-reproduction characteristics were inferior as a result of a change in the shape of the -D-log *E* curve of the negative material when the development was extended too far beyond the normal time. The camera-exposure latitude was about 2 times, and the print quality corresponding to the use of a safety factor of 2.5 was well below the maximum quality.

These results emphasize the importance of using a small safety factor when a high degree of enlargement is used, and especially when the negatives are given more than the recommended development time. A number of similar tests, made in these Laboratories over a period of years, confirm these conclusions. Some of these tests have been reported by Peed.'

Calculation of the Safety Factor

An estimate of the size of the safety factor can be obtained by means of calculations based on the following three formulas:

1. The camera image illumination formula,[5]

$$I = \frac{10.76\ B\ (u - F)^2\ THcos^4\theta}{4\ u^2 f^2} \qquad (1a)$$

where

F = focal length of lens
T = lens transmittance
u = distance from lens to object
H = vignetting factor for the lens barrel
θ = angle of image point off axis of lens
I = image illuminance on the film in meter candles
B = object luminance in candles per square foot
f = relative aperture or *f*-value of the lens

6. **Allie C. Peed,** Jr., *U.S. Camera,* **21:** 54 (Aug. 1958).

This equation may be simplified to

$$I = 6.5B/f^2 \qquad (1b)$$

if the assumptions are made that the distance from the lens to the object is forty times the focal length of the lens, the lens transmittance is 0.90, the vignetting factor is 1.0, and the object is 13 deg off the camera-lens axis ($\cos^4\theta = 0.90$). These assumptions are believed to be approximately correct for an average camera used under average conditions of photography.

2. The American Standard formula for calibration of exposure meters,[2]

$$t = Kf^2/BZ \qquad (2)$$

where
t = exposure time
f = relative aperture or *f*-value of the lens
B = object luminance in candles per square foot
Z = American Standard exposure index for the film
K = 1.17

3. The American Standard formula for the film exposure index,[1]

$$Z = k/E_s \qquad (3)$$

Where

Z = American Standard exposure index
k = 1/4
E_s = the exposure in meter-candle-seconds required to obtain a specified minimum response on the film as determined by the fractional-gradient speed criterion (American Standard Speed = 1 /E_s)

It is assumed, in the use of these formulas to compute the safety factor, that a photograph is to be taken of an average sunlit scene and that the camera settings of *f*-value and exposure time are to be determined by a calibrated exposure meter which is used to measure the "average luminance" of the scene. It is also assumed that a spectrally nonselective gray object is placed in the scene, having a reflectance and an orientation such that its luminance is equal to the "average luminance" of the scene. The exposure, E_a, on the film in the camera in the image of the gray object is the product of the illuminance, I_a, on the film and the exposure time. Thus,

$$E_a = I_a t \qquad (4)$$

The expression for I_a can be obtained from Formula (1b). Inserting this expression in Eq. (4) gives:

$$E_a = 6.5B_a t/f^2 \qquad (5)$$

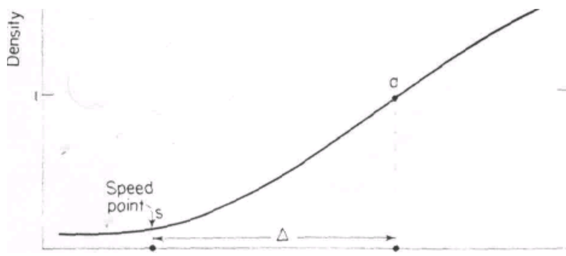


Fig.2. The D-log E curve for a negative film, showing the location of the exposure, E_a, for the gray object measured by the exposure meter.

The exposure time, *t,* in this equation is determined by the exposure meter and, therefore, the value of *t* from Formula (2) can be substituted for *t* in Eq. (5) to obtain E_a in terms of the exposure-meter constant, *K,* and the exposure index, *Z,* as follows:

$$E_a = 6.5\ K/Z. \qquad (6)$$

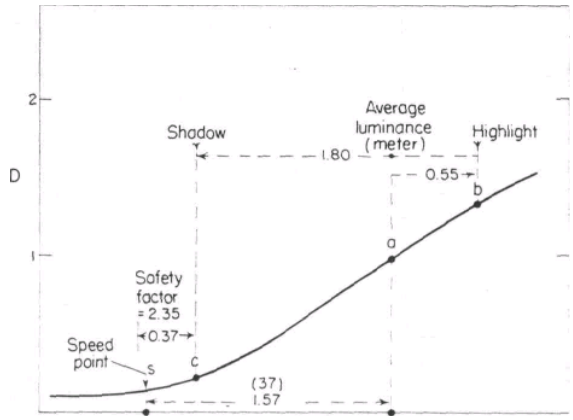
Fig. 3. The predicted location, on the D-log f curve, of an average

A correction of this equation is required because the spectral quality of the light on the film in the camera is not the same as that of the light on the film in the sensitometer used in deriving the film exposure index. In the photography of the assumed outdoor scene, in which the gray object is illuminated by sunlight and skylight, the proportionate amount of ultraviolet and blue radiation in the total radiation on the film in the camera is greater than that in the radiation on the film in the sensitometer. The latter provides "simulated sunlight" by means of a tungsten lamp and a blue filter. The sensitometric radiation is less actinic. Its relative photographic efficiency, as defined by Wolfe and Milligan,[7] is 1.0, compared with 1.3 for natural daylight. This means that, for daylight photography, E_a is 1.3 times greater than is indicated by Eq. (6). Two smaller corrections should also be made in Eq. (6). One of these is an increase in exposure of about 4%, due to the effect of camera flare light on the image of the gray object. The other is a decrease in exposure of about 10%, due to the high blue sensitivity of most exposure meters and the consequent difference in the response of the meter to daylight compared with its response to the 2700° K tungsten light source specified for use in calibrating the meter. The total correction factor to be applied to Eq. (6) is, therefore, 1.3(1.04)/1.1 or 1.23.

The corrected expression for E_a is then

$$E_a = 8\ K/Z. \qquad (7)$$

[7]- R. N. Wolfe and F. H. Milligan, *J. Opt. Soc. Am.,* **43:** 791 (1953).



camera image of an average exterior scene when the camera exposure is based on the ASA exposure index and the exposure-meter reading of the average luminance of the scene.

Inserting the American Standard formula (Formula (3)) for the exposure index in Eq. (7) gives

$$E_a = 8\ K(E_s k) \qquad (8)$$

or

$$E_a / E_s = 8\ K/k \qquad (9)$$

where *K* is the exposure-meter calibration constant and *k* is the constant in the formula for deriving the exposure index from the fractional-gradient speed of the film.

If the American Standard values of $K = 1.17$ and $k = 1/4$ are substituted in Eq. (9), the ratio of E_a to E_s becomes

$$E_a/E_s = 37 \qquad (10)$$

where E_s is the exposure on the film for the gray object representing the "average luminance" of the scene and E_s is the "minimum useful exposure" defined by the fractional-gradient speed criterion specified in American Standard PH2.5 —1954.

The ratio, E_a/E_s, is important because it is an indication of the level of the exposures obtained by the use of the American Standard exposure index with a calibrated exposure meter (for the photographic conditions assumed). The ratio, E_a/E_s, can be shown to be proportional to the safety factor.

As illustrated in Fig. 2, the exposure, E_a, associated with the "average luminance" of the scene lies at a certain interval, Δ, to the right of the speed point on the D-log *E* curve of the film. According to the preceding calculations, E_a is 37 times greater than E_s. This ratio corresponds to a logarithmic interval of 1.57, and therefore, Δ is 1.57.

The safety factor may now be derived by making use of this interval and the scene-luminance measurements published by Jones and Condit.[4,5] They found that, for 126 outdoor scenes, most of which were sunlit, the maximum luminance was, on the average, 3.6 times greater than the "average luminance." This result is used in Fig. 3 to locate the maximum luminance of "highlight" point, *b,* on the .D-log *E* curve of the film. Since the exposure at *b* is 3.6 times greater than the exposure at a, the highlight point, *b,* should be placed 0.55 logarithmic units to the right of *a.* Jones and Condit also found that, in an average outdoor scene, the maximum luminance was 160 times greater than the minimum luminance. In the corresponding camera image, however, the maximum image illuminance was only 64 times greater than the minimum image illuminance because of the compression of the range by camera-flare light. They introduced the concept of the "flare factor" to express the amount of compression of the image illumination range caused by flare light. The flare factor is defined as the ratio of the luminance range of the scene to the illuminance range of the camera image. The factor for present-day cameras used with an average scene is believed to be about 2.5. Earlier cameras with no antireflection coatings on the lenses were found to have, on the average, a flare factor of about 4. For the present calculations, a flare factor of 2.5 and a consequent image illuminance range of 64 are adopted, since they are considered to be typical of an average camera used with an average scene. The logarithm of 64 is 1.8 and, therefore, the shadow point, c, in Fig. 3 should be placed 1.8 to the left of the highlight point, *b.*

The shadow point is, by this method, found to be 0.32 in log *E* units to the right of the speed point, as illustrated in Fig. 3. This interval is nearly equal to the logarithm of the safety factor. For the production of a "first-excellent" print, the negative of an average scene should be exposed so that the deepest shadow in the camera image falls at a log *E* value lying near the speed point. As pointed out by Jones and Condit,' however, the shadow point should coincide with the speed point only when tlie flare factor is 4. When the flare factor is 2.5, the deepest shadow can be placed about 0.05 to the left of the speed point because a lower slope on the toe of the curve becomes usable when the shadow contrast in the camera image is increased by the reduction in camera flare.

Consequently, the "first-excellent" point in Fig. 3 is considered to lie 0.05 to the left of the speed point. The "first-excellent" point, therefore, lies 0.37 in log *E* units to the left of the shadow point, c, representing the exposure obtained from the use of the exposure meter and the ASA exposure index. This interval of 0.37 is the logarithm of the safety factor. These calculations, therefore, lead to the conclusion that the safety factor is 2.35.

Experimental Determination of the Safety Factor

In the experimental approach to the estimation of the safety factor, five outdoor sunlit scenes, each containing a person, were photographed on Kodak Panatomic-X Film with a series of six different camera exposures for each scene. The interval between successive exposures was a factor of 2. The

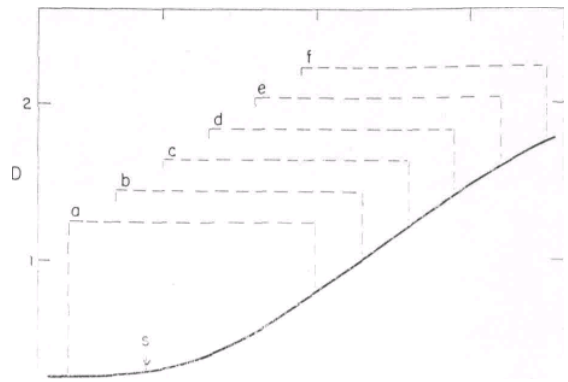


Fig. 4. The D-log E curve for the film used in the experimental study of the safety factor. Dashed lines show the log E positions of the six camera negatives for Scene 1.

camera settings were nominally 1/200 at *f/16,* 1/100 at *f*/16, 1/100 at *f*/11, 1/50 at / 11, 1/50 at *f/8,* 1/50 at *f*/5.6. A 35mm camera having an *f*/2.8 coated lens was used for the first three scenes, and a 2¼- by 2¼ in. camera having an *f/* 3.5 coated lens was used for the last two scenes. The actual shutter times were measured in a separate test and the corrected times were used in the analysis of the data.

Exposure-meter readings were made on each scene using the "reflected-light" ("average brightness") method. Three different exposure meters, each made by a different manufacturer, were employed. The calibration constant of each meter was measured in a preliminary test so that the meter readings made on the scenes (expressed in terms of *f* and *t)* could be adjusted to those that would have been obtained if the meter calibration constant had been exactly 1.17, as specified by the American Standard for exposure meters.

The negatives were developed for 8 min at 68 °F in Kodak D-76 Developer with intermittent agitation of the solution, and were fixed, washed, and dried. In the same process were included sensitometric samples of the same film exposed for 1/50 sec on an intensity-scale sensitometer. A tungsten lamp and a blue filter in the sensitometer provided the simulated sunlight specified by the American Standard on photographic speed and exposure index.

The maximum, minimum, and face densities were measured in each of the negatives with a diffuse densitometer having a measuring aperture 0.25 mm in diameter. Figure 4 shows the log exposure position of each negative on the density-vs.-log exposure curve of the negative material for one of the scenes.

The negatives were printed on Kodak Medalist F Paper using the best grade of paper and the best printing exposure for each negative. The printer was a semispecular projection printer and the degree of enlargement was 5 diameters.

The prints were judged by ten observers who expressed their estimation of the quality of each print by means of the terms: Excellent, Good, Fair, Poor, and Very Poor. The observers were provided with a chart on which to record their judgments. On the chart, the quality terms were shown equally spaced along a scale on which each observer placed a mark for each print. Thus he could rate the print at one of the five quality levels or at any intermediate level. These judgments took into account not only the tone-reproduction characteristics of the print but also the other factors that affect quality, such as graininess, sharpness, depth of field, and camera motion. The judgments of the observers were averaged to obtain the final ratings. The details of this method of judging have been described by Sorem.[6]

Figure 5 shows the print-quality ratings plotted against the camera exposures, these exposures being expressed on a logarithmic scale. As should be expected, the print quality rises at first, reaches a plateau, and eventually declines as the camera exposure is increased. The camera exposure required to obtain the "first-excellent print" was obtained by taking the first point on the curve at which the quality reached a value of 95 percent of the maximum quality. To the right of the "first-excellent" point is a point marked "meter" which shows the camera exposure prescribed by the exposure meter. The ratio of the camera exposure indicated by the meter to the camera exposure required for the first-excellent prints is the *safety factor.* For Scene 1, for example, this ratio is 2.10.

The results for all five scenes are:

Scene	Safety Factor
1	2.10
2	2.24
3	2.62
4	2.45
5	2.62

Average 2.41 (Standard deviation == 0.2)

This average safety factor of 2.4 is in close agreement with the value of 2.35 obtained by the calculations described earlier. It also agrees very well with the value of 2.5 which has generally been assumed to be the magnitude of the safety factor.

It should be remembered that these results apply when the camera settings of aperture and time are accurate and the exposure-meter calibration is precisely that specified in the American Standard for exposure meters. In practice, most between-the-lens shutters give exposure times that are greater than the marked values when small apertures are used. Camera shutters are generally calibrated at maximum lens aperture where the efficiency of the shutter is at its lowest value. When the lens

[8]. *A.l,.Sorem,Jour.SMPTE,62:* 24(1954).

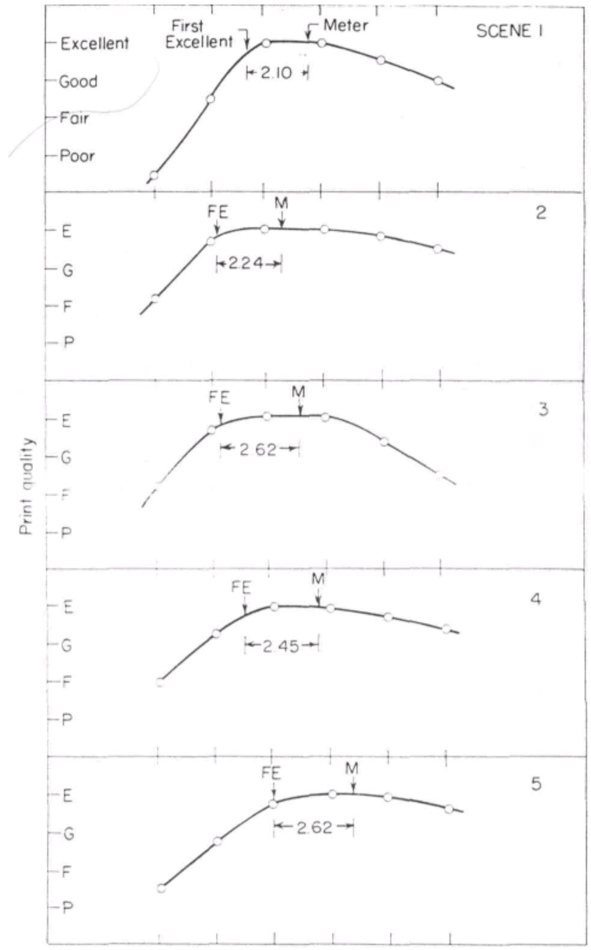


Fig. 5. The print-quality vs. log-camera-exposure curves obtained by the experimental method. The number shown under each curve is the safety factor.

opening is reduced, the efficiency of the shutter increases and the effective exposure time becomes longer. Furthermore, some exposure meters have calibration constants that lead to greater exposure. The net result is that the effective safety factor is in practice, often greater than 2.4.

Negative Exposure Levels and Negative Densities

Some additional information can be extracted from the experimental data that should be useful for reference. This information is given in Figs. 6-9.

Figure 6 shows the log *E* positions and densities of the five "first-excellent" negatives with respect to the *D-log E* curve of the negative material. These positions and densities were, of course, derived by interpolation between the actual negative

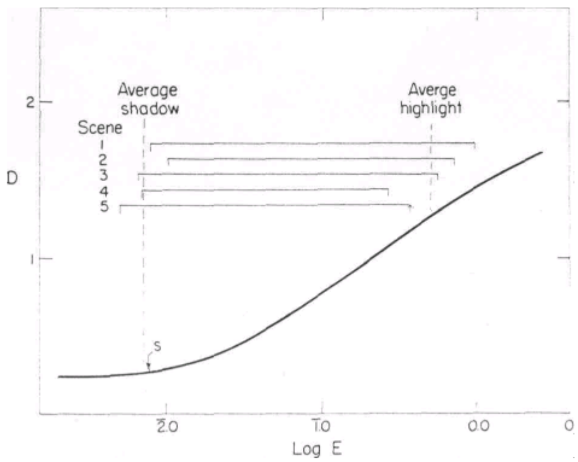


Fig. 6. The log E positions of the negatives that gave the "first-excellent" prints.

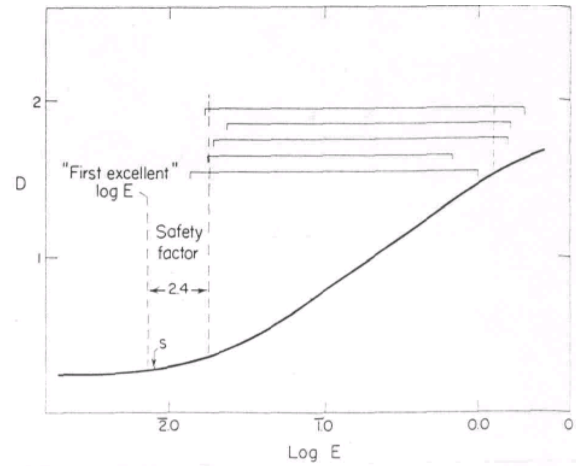


Fig. 7. The log *E* positions of the negatives exposed as prescribed by a calibrated exposure meter used with the ASA exposure index of the film.

obtained from the camera-exposure series and were based on the camera exposures required to produce the negatives which yielded the first-excellent prints. It is seen that the deepest shadow lies, on the average, about 0.04 below the fractional-gradient speed point. The log exposure interval between the maximum and minimum densities of the five negatives is, on the average, 1.85. This value should be compared with the "classical" value of 1.5 determined a number of years ago when lenses did not have an antireflection coating. The present results are believed to be typical of a camera with a coated lens and an average sunlit scene.

Figure 7 shows the log *E* positions and densities for the five negatives having the camera exposures prescribed by the exposure meter used with the ASA exposure index. The safety factor, as shown; is 2.4.

Figure 8 summarizes the results given in Fig. 7 and, in addition, shows the average log *E* positions for the "average luminances," the light tones of the faces, and the white objects. Again, these data apply to the camera exposures indicated by the calibrated exposure meters used with the ASA index. The face tones are seen to lie at an exposure which is 80 times greater than the exposure at the speed point. In terms of the logarithmic units shown near the bottom of the graph, the faces are recorded 1.9 units and the white objects 2.35 units to the right of the speed point. Thus both the faces and the white objects are recorded a remarkably great interval above the speed point. The resulting densities are higher than those desired for convenient printing of negatives.

Proposed Level of Exposure

The results of this study support the conclusion reached by many photographers, manufacturers of

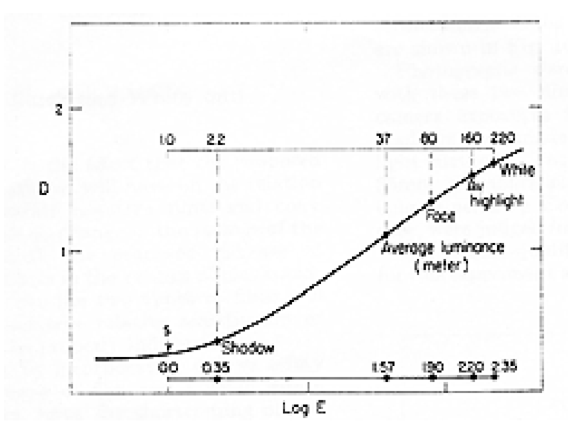
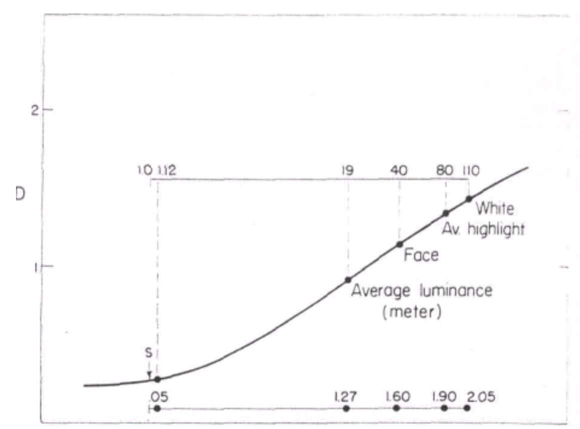


Fig. 8. The exposure levels, for various scene elements, associated with the safety factor of 2.4.



Log E

Fig. 9. The exposure levels, for various scene elements, associated with the proposed safety factor of 1.2.

photographic materials and equipment, and by the members of ASA committees concerned with this subject, that the safety factor should be reduced by a factor of about 2. The effect that this proposed change will have on the densities in the negatives is illustrated in Fig. 9. The faces will be recorded at an exposure which is about 40 times, or 1.6 in log *E* units, above the exposure at the speed point. If the negative material is developed to a gamma of 0.7 and its curve has an average shape, the density of the faces will be about 0.93 above fog density, and the density of the white objects will be about 1.25 above fog density. The shadows will fall slightly above the speed point. This level of exposure, corresponding to a safety factor of slightly more than 1.2, appears to be suitable for most practical work.

Although the conclusions given previously were drawn from data on the photography of typical sunlit scenes, a similar study made with portrait scenes seems to indicate that the proposed reduction in the safety factor will also be satisfactory for this type of photography. Certain types of scenes will undoubtedly be encountered in both interior and exterior photography in which the luminance distribution is such that under-exposure will occur if the meter reading of average luminance is used with the proposed higher film ratings. It is believed that these unusual scenes can be described and "classified" so that they will be recognized by the photographer, who can then make a correction in the camera exposure.

Relation between Black-and-White and Color Films

Of special interest is the effect that the proposed change in the safety factor will have on the relation between black-and-white negative films and color reversal films. Since no change in the ratings of the color films is planned, the proposed increase of approximately two times in the ratings of black-and-white films means that the two types of films will be rated so that their true relative sensitivities or basic "speeds" will be properly indicated.

Exposure indexes, by incorporating a large safety factor for the one type of film and a small safety factor for the other, have the shortcoming of not revealing the fact that a color reversal film having an exposure index of 32, for example, is *slower* (in terms of the minimum camera exposure that will give a picture of excellent quality) than a black-and-white film having the same exposure index of 32. Not all photographers have been aware that the black-and-white film rating can be increased to 80 without an appreciable loss in picture quality, While the color reversal film rating can be increased only to 40, when the normal rating is 32 for both films.

An experiment was carried out to demonstrate the actual speed relation between a black-and-white film and a color reversal film having the same expose index. Kodak Ektachrome Film, which has an

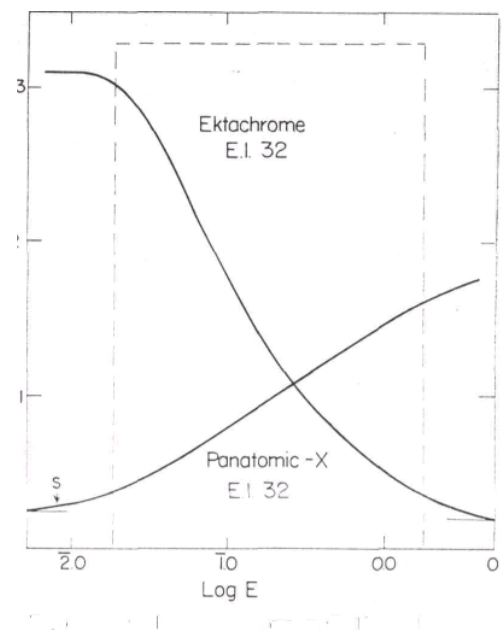


Fig. 10. The density vs. log-exposure curves for Kodak Panatomic-X and Kodak Ektachrome Films used in the present study.

exposure index of 32, was chosen for comparison with a sample of Kodak Panatomic-X Film which also had a measured exposure index of 32. The sensitometric *D-log E* curves for these two films are shown in Fig. 10.

Photographs were made of three sunlit scenes with these two films, using an identical series of camera exposures for each film. Exposure-meter readings were made of the scenes by the reflected-light method. The final photographs, which were 35mm transparencies in one case and 5- by 7-in. enlargements on Kodak Medalist Paper in the other case, were judged for quality.

The picture-quality vs. log-camera exposure curves for this experiment are shown in Fig. 11. The camera

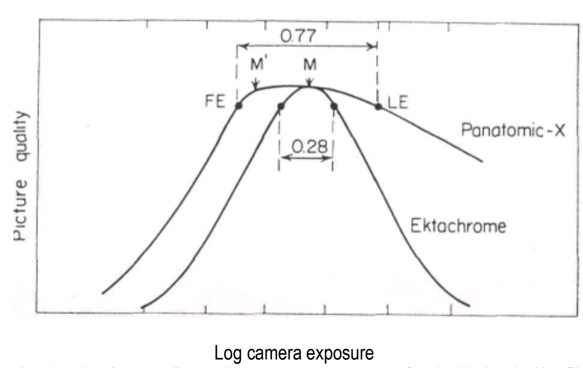


Fig. 11. The picture-quality vs. log-camera-exposure curve for the black-and-white film compared with the corresponding curve for the color reversal film having the same exposure index. FE represents "first excellent;" LE, "last excellent." M represents the present exposure level; M', the proposed exposure level for the black-and-white film.

exposure prescribed by the exposure meter is indicated on the graph by the letter *"M."* This "meter exposure" was found to lie at the peak of the quality curve for the color film, and near the center of the useful range of camera exposures for the black-and-white film. As the camera exposure was decreased from this point, the quality of the color pictures decreased rapidly, while the quality of the black-and-white pictures remained constant over a considerable exposure interval. The "first-excellent" black-and-white picture, marked *"FE"* on the graph, occurred at a camera exposure lying 0.41 log *E* units (or slightly more than one and one-third camera stops) to the left of the point "At." The "first-excellent" color picture, on the other hand, occurred at a camera exposure lying only 0.13 in log *E* units to the left of the point "Af." This result shows that the basic *speed* of this black-and-white film is approximately two times greater than the basic speed of the color film, whereas their exposure indexes are equal.

The proposed reduction in the safety factor for the black-and-white films will eliminate this discrepancy, and will lead to film ratings that indicate the true speed relationships between films.

Proposed Change in Speed Criterion

The reduction in the safety factor could be accomplished simply by changing the constant in the ASA formula for deriving the ASA exposure index from the ASA fractional-gradient speed of the film. The present formula, which gives a safety factor of about 2.4, is

$$\text{Exposure Index} = \frac{\text{Fractional-Gradient Speed}}{4E_s} \quad (11)$$

$$\text{or} \quad \text{Exposure Index} = 1/\,4E_s \quad (12)$$

where E_s is the exposure in meter-candle-seconds at the fractional-gradient speed point and $1/E_s$ is the ASA fractional-gradient speed. If the constant of ¼ were replaced by a constant of ½, a new type of "exposure index" would be obtained which would provide the proposed lower safety factor of about 1.2.

There are several reasons, however, for adopting not only a new constant but also a different speed criterion. The fractional-gradient criterion was originally chosen because it has the desirable feature of giving speeds that correlate closely with speeds obtained by practical picture tests.[9-11] It has the objectionable feature, however, of being somewhat inconvenient and difficult to use. Consequently, a simpler and more convenient criterion, such as that based on a fixed density above fog density, is often desired. Fortunately, as shown by the recent data of Nelson and Simonds,[12,13] a good correlation exists between fractional-gradient speed and speeds based on a density of 0.1 above fog, *provided the development condition's are controlled so that a fixed "average gradient" is obtained.* This average gradient is measured on the portion of the .D-log *E* curve of the film lying between two exposures, *E* and 20 *E,* where *E* is the exposure at a density of 0.1 above fog. The specification of a fixed average gradient in an American Standard would be justified by the fact that such a specification corresponds to the common photographic practice of developing negatives so that they print satisfactorily on a "normal" grade of photographic paper. Thus the adoption of the 0.1 fixed-density speed criterion in combination with a suitable development specification would offer the advantages of convenience and practical significance.

Another important advantage to be gained by adopting the fixed-density speed criterion as part of an American Standard is that this step would encourage eventual agreement on an international standard for photographic speed. The fixed-density criterion[14-21] has for many years been a preferred criterion in a number of countries. The use of this criterion in the DIN system," for example, is particularly well known.

The reported[9-11] lack of correlation between fractional-gradient speeds and fixed-density speeds is now known[12] to be due mainly to lack of agreement on a suitable development specification. It was originally thought that the variation in the length of the toes of the *D-log E* curves of the negative materials would always prevent the realization of a high correlation between the speeds obtained by the two criteria. The more recent study,[12,13] however, reveals that good correlation exists even for materials differing greatly in toe length if the development is controlled so that a constant average gradient is maintained. Gamma, the slope of the straight-line portion of the *D-log E* curve, is not as satisfactory as the average gradient for specifying the development because gamma does nut take into account the different toe lengths. The increasing use of a smaller safety factor in camera exposures means that the toe portion of the D-log *E* curve is being used more fully. The proposed average gradient, which involves part of the toe and part of the straight-line portion, is more significant than gamma as an indication of the "contrast" of the camera negatives.

Figures 12 and 13 show some of the data from the recent study[12] of the relation between fractional –gradient

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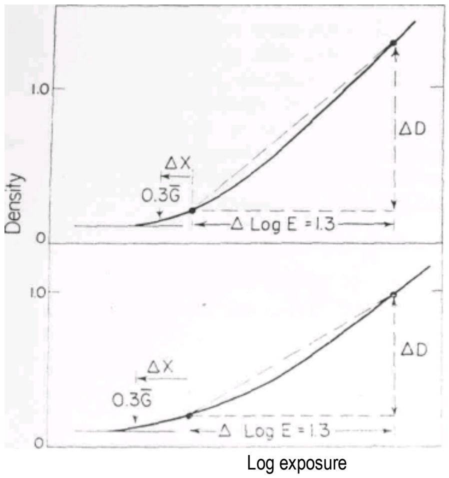

Fig. 12. D-log f curves showing the inverse relation between ΔD and ΔX. ΔX increases when ΔD decreases.

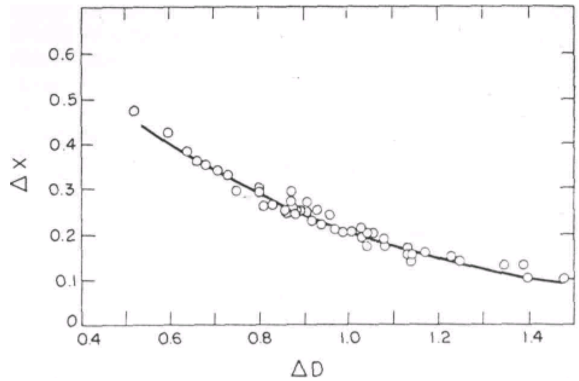

fig. 13. Data for a number of different films and various development conditions showing ΔX plotted against _a.o, where ΔX is the log f difference between the exposure at a density c' 0.1 above fog and the exposure at the fractional-gradient speed point.

gradient speeds and 0.1 fixed-density speeds. The interval, ΔX, *in* Fig. 12, is the log *E* interval between the fractional-gradient speed point and the fixed-density speed point on the D-log *E* curve of the film. If this interval were constant, the two types of speed would correlate perfectly. The value of ΔX is seen to be small when the average gradient is high and large when the average gradient is low. The density difference, ΔD, shown in Fig. 12 is simply another way of expressing this average gradient, since the log *E* interval is constant. The "inverse" relation between ΔX and average gradient (or ΔD), as illustrated in Fig. 12, suggests that ΔX should be plotted against average gradient or ΔD for a number of different films processed in different developers for several development times. This experiment was carried out with ten films of current manufacture, including films having different toe lengths (Fig. 13). It is seen that the logarithmic difference, ΔX, between the fractional-gradient speed and the fixed-density speed varies from 0.10 to 0.48 when Δ*D* is allowed to vary from 0.45 to 1.5. When A.D is held constant at any arbitrary value, however, ΔX becomes nearly constant. If ΔZ) is 0.80, for example, ΔX becomes approximately 0.29.

Thus when development is controlled so that Δ*D* remains constant, a good correlation exists between speeds based on a density of 0.1 above fog and fractional-gradient speeds.

A new formula for speed can be derived which will make use of the 0.1 fixed-density speed criterion and will also provide the desired safety factor of approximately 1.2. If a specification is adopted requiring development to a ΔD of 0.80 or an average gradient of 0.62, for example, the log *E* difference (ΔX) between the two types of speed becomes 0.29, and the exposure, E_d, at a density of 0.1 above fog becomes 1.9 times greater than the exposure, E_s, *at* the fractional-gradient speed point.

A revised form of Eq. (12), giving a new kind of film rating or speed that would provide a safety factor of 1.2, may be expressed as follows:

$$\text{Speed} = 1/2.E_s. \qquad (13)$$

Since $E_d = 1.9\,E_s$ for the assumed development condition, the equation may be rewritten as

$$\text{Speed} = 1.9/2E_d, \qquad (14)$$

or

$$\text{Speed} = 0.95\,/E_s. \qquad (15)$$

A change in the spectral quality of the light to be used in the sensitometer, from simulated sunlight to simulated daylight (sunlight plus skylight), is also contemplated which will have the effect of requiring a constant of slightly more than 0.8 in place of 0.95 in Eq. (15) in order to keep the safety factor at 1.2. If this change in light quality is adopted, the formula for the new photographic speed will be

$$\text{Speed} = 0.8/E_d \qquad (16)$$

where E_d is the exposure in meter-candle-seconds required to obtain a density of 0.1 above fog when the development is such that the average gradient is 0.62 and ΔD is 0.8. This formula will give speeds that, if used with accurate exposure meters and cameras, will provide a safety factor of slightly over 1.2, since the constant in Formula (16) was rounded off to 0.8.

The fractional-gradient speed criterion (and its approximate equivalent, the simpler ΔX speed criterion described in Ref. 12) will continue to be useful as a supplement to the fixed-density speed criterion when an evaluation is desired of the effective picture-taking speeds of films that have been developed to average gradients higher or lower than the proposed standard average gradient. The fixed-density criterion tends to underrate films that are developed to a lower average gradient and to overrate films that are developed to a higher average gradient. A new constant in the formula for fractional-gradient speed is desirable for this non-standard application in order to provide a safety factor of about 1.2 and thus make the speeds comparable with the proposed fixed-density speeds. The fractional-gradient speeds (as distinct from exposure indexes) have heretofore had the disadvantage of being expressed by numbers that do not fit exposure meters. Although the fractional-gradient speeds were originally based on the "minimum camera exposure that would yield a negative capable of giving an excellent print," they were arbitrarily expressed on a scale of numbers which, if used with a typical exposure meter, would have led to exposures that were consistently about two-thirds of a camera stop less than the minimum exposure required for an excellent print. To correct this situation, a change in the formula is suggested. The formula, $S = 0.5/E_s$, gives the desired adjustment of the speed scale when simulated sunlight is used in the sensitometer but, since the use of simulated daylight is proposed, the appropriate formula is:

$$\text{Fractional-Gradient Speed} = 0.4/\,E_s \qquad (17)$$

where E_a .is the exposure in meter-candle-seconds at the 0.3 *G* fractional-gradient point' on the D-log *E* curve of the negative material. This formula provides a safety factor of slightly over 1.2, as does Formula (16) for the proposed Standard speed based on a density of 0.1 above fog. :