possibility involves an increase in the projection interruption rate (normally three times the projection pulldown rate). Although this possibility has been little explored, it may afford a more adequate solution.

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ABRIDGMENT

Safety Factors in Camera Exposures

By C. N. NELSON

A new American Standard for determining the speeds of black-and-white negative films for still cameras was issued in April 1960 by the American Standards Association. The new speeds are approximately twice the exposure indexes defined by the older version of the Standard. The level of the numbers was increased in order to reduce the "safety factor" in camera exposures indicated by exposure meters. The reduced exposures give negatives that are better from the standpoint of ease of printing, sharpness, and print graininess. The present paper is a report on a study, made in connection with this standardization project, to determine the absolute magnitude of the safety factor. Both the mathematical and experimental parts of this study indicate that the safety factor associated with the exposure index is approximately 2.4 for average sunlit scenes when accurate meters, shutters and lens apertures are used. The safety factor associated with the new ASA speed is slightly more than 1.2, the same as for color reversal films. The revised speed criterion and the new *additive* system of units for film speed, scene light, lens aperture and shutter speed are described.

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[1] 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 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. In the field of still photography, 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. subject-motion blur reduced,
   c. camera-motion blur reduced.

Another advantage, which occurs with some films (especially if they have been overdeveloped), is that the shape of the part of the density-vs.-log exposure curve 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 that 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, of course, 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 a substantial safety factor 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 1940 as they are in 1960. The second reason is that the camera-exposure latitude was effectively greater in those earlier years, largely because the increase in print graininess with increase in camera exposure was not so evident with the large cameras, large negatives, and the small degree of enlargement or contact printing then commonly used. The great increase in the number of small cameras in use in recent years and the increase in the degree of enlargement has made the graininess problem more significant.

Many photographers have adopted the practice of giving less exposure than is indicated by the use of ASA exposure in-

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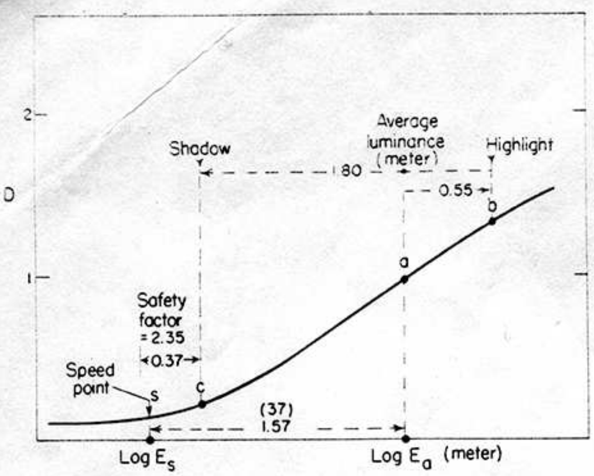

Fig. 3. Predicted location, on the D-log E curve, of the negative of an average sunlit scene exposed in accordance with the ASA exposure index used with a calibrated exposure meter.

dexes with exposure meters. They use the American Standard indexes 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, the American Standards Association formed a new subcommittee, under the chairmanship of J. L. Tupper, for the purpose of revising the American Standard on speed and exposure index. In April 1960, the revised Standard[4] was published, having been approved by the ASA Sectional Committee on Photographic Sensitometry (M. G. Anderson, Chairman), the Photographic Standards Board, and the officials of the ASA. Copies of the Standard can be purchased from the American Standards Association.

In the new Standard, the term "speed" replaces the term "exposure index." The new speeds are approximately twice the exposure indexes. This change reduces the safety factor to one-half its former value for the black-and-white materials covered by the Standard. Color films are not affected.

The magnitude of the safety factor associated with the exposure index of black-and-white films has usually been assumed to be somewhere between 2 and 4. The most common estimate has been 2.5. A few writers have contended 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 purpose of the present paper is to present new evidence on the magnitude of the safety factor in the photography of average sunlit scenes. Two independent approaches were used, one theoretical and the other experimental.

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

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]

$$I = CB/f^2 \qquad (1)$$

where
I = image illuminance on the film in meter-candles;
B = object luminance in candles per square foot;
f = f-number setting of the lens, and
C = a constant which is approximately equal to 7 if the assumptions are made that the lens transmittance is 0.95, the distance from the lens to the subject is forty times the focal length of the lens, and the subject is 12 degrees off the camera-lens axis ($\cos^4 \theta = 0.91$). These assumptions are believed to be appropriate for an average camera with a coated lens used under average conditions of photography.

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

$$t = 1.17f^2/BZ \qquad (2)$$

where
t = exposure time;
f = f-number of the lens;
B = object luminance in candles per square foot, and
Z = American Standard exposure index of the film.

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

$$Z = .4/E_s \qquad (3)$$

where
Z = American Standard exposure index, and
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.

In the use of these formulas to compute the safety factor, it is assumed that a photograph is to be taken of an average sunlit scene and that the camera settings of exposure time and f-number 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 equal to $I_a t$. Then, from Formula (1), $E_a = CB_a t/f^2$. Combining this expression with Formulas (2) and (3) and inserting certain corrections due to flare light and the ultraviolet content of the radiation used in determining the exposure index, as described in the original paper of which this is an abridgment, it is found that

$$E_a/E_s = 37 \qquad (4)$$

where E_a 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 the former American Standard, PH2.5-1954.

Figure 3* shows where E_a falls on the D-log E curve of the film. E_a, the exposure for the gray object read by the meter, lies a certain interval to the right of the speed point. According to the calculations, this interval is 37 times greater than E_s, or 1.57 in logarithmic units.

The safety factor can now be derived from this interval by making use of the scene luminance measurements published by Jones and Condit.[5] They found that for 126 outdoor scenes, the maximum luminance or "highlight" was on the average 0.55, in log unit, greater than the average luminance. This result is used in Fig. 3 to locate the highlight point, b, on the curve 0.55 unit to the right of point a. Jones and Condit also found that for average outdoor sunlit scenes and an average camera, the minimum luminance or deepest shadow in the scene is recorded 1.8 in log E units to the left of the highlight point, as shown in Fig. 3. It is seen that the shadow is recorded a certain log E interval to the right of the speed point. This interval would be equal to the logarithm of the safety factor if the flare light in the camera were equal to that which is typical of an average uncoated lens and an average scene. When camera flare is equal to that which is typical of an average coated lens and an average scene, the deepest shadow can be placed about 0.05 to the left of the speed point

* Figures 1, 2, 4, 6, 8, 10, 12 and 13 of the original article are omitted.