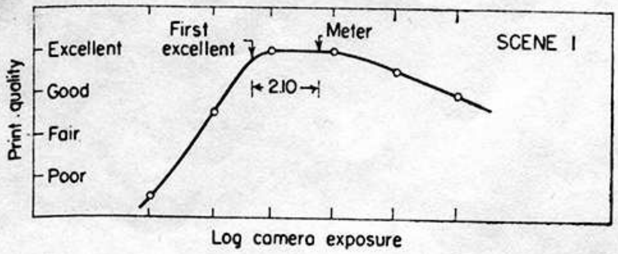

Fig. 5. Curve showing print quality vs. log camera exposure for Scene 1, obtained by the experimental method. The number under the curve is the safety factor.

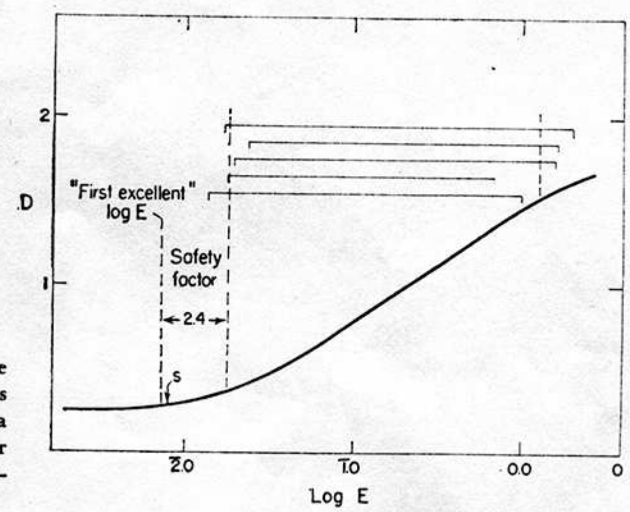

Fig. 7. Log E positions of the negatives of the five scenes exposed as prescribed by a calibrated exposure meter used with the ASA exposure index of the film.

because a lower slope on the curve is usable when the shadow contrast in the camera image is increased by the reduction in camera flare.

Consequently, the minimum negative exposure that will result in a print of high quality is considered to lie about 0.05 to the left of the fractional-gradient speed point. The total log E interval in Fig. 3 between the shadow point c and the minimum exposure that will give an excellent print is, therefore, 0.37. This interval is equal to the logarithm of the safety factor. These calculations, therefore, lead to the conclusion that the safety factor associated with the ASA exposure index 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, using an accurately calibrated camera. The interval between successive exposures was a factor of 2. Exposure-meter readings were made on each scene using the "reflected light" ("average luminance") method. Three different exposure meters, each made by a different manufacturer and each accurately calibrated, were employed.

The negatives were developed for 8 min at 68 F in Kodak Developer D-76. In the same process were included sensitometric samples of the same film exposed on an intensity-scale sensitometer. The negatives were projection-printed on Kodak Medalist Paper using the best grade of paper and the best printing exposure for each negative. 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. 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.

Figure 5 shows the print-quality ratings for Scene 1 plotted against the camera exposures. The exposures are expressed on a logarithmic scale, the interval between the small vertical marks being 0.3. 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% 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 print is the safety factor. 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 in the preceding section. It also agrees very well with the value of 2.5 which has generally been assumed.

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 opening is reduced, the efficiency of the shutter increases and the effective 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

Figure 7 shows the log E positions for the five negatives having the camera exposures indicated by the calibrated exposure meters used with the ASA exposure index of the film. The negatives were located with respect to the D-log E curve by means of measurements of the maximum and minimum densities in each negative. Interpolation between negatives in the exposure series was, of course, necessary. The negatives prescribed by the meter are seen to have greater density than is generally preferred. The diffuse white objects in the scene are recorded 2.35 logarithmic units and the face areas 1.9 units to the right of the fractional gradient speed point. The extreme-shadow areas lie 0.34 unit to the right of the speed point, and 0.38 unit to the right of the log E position of the shadow areas of the negatives that gave the first excellent prints. The safety factor, as shown, is 2.4 in arithmetic units.

Figure 9 shows the log E position for the negative of an average scene when the camera exposure is that indicated by a calibrated exposure meter used with the new ASA speed of the film. The safety factor is 1.2. The light tones of the face are recorded at an exposure which is about 40 times, or 1.6 in logarithmic units, greater than the exposure at the fractional gradient speed point, S. Diffuse white objects in the scene are recorded 2.05 logarithmic units to the right of the speed point. The shadows fall 0.05 to the right of the speed point, but are 0.09 to the right of the first excellent point (shown on the preceding graph). This level of exposure is preferred for most practical work.

Color Reversal Films

Color films do not fall within the scope of the new American Standard on speed, PH2.5-1960, or the former American Standard on exposure index. Exposure indexes for color films are ordinarily assigned by means of practical camera tests. An American Standard method for determining the speed of color reversal films is in preparation, however, and

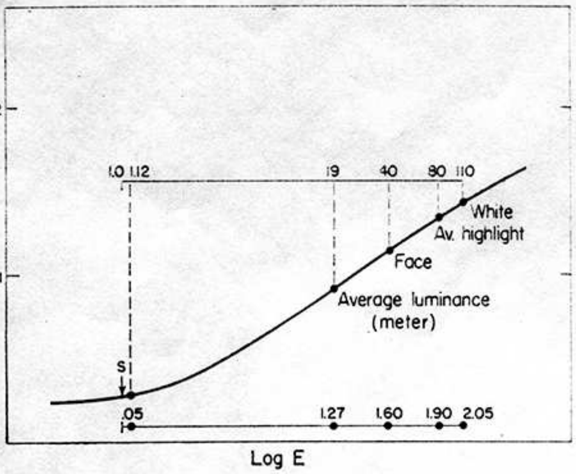

Fig. 9. Log E positions of the various scene elements recorded in a negative exposed as prescribed by a calibrated exposure meter used with the new ASA speed of the film.

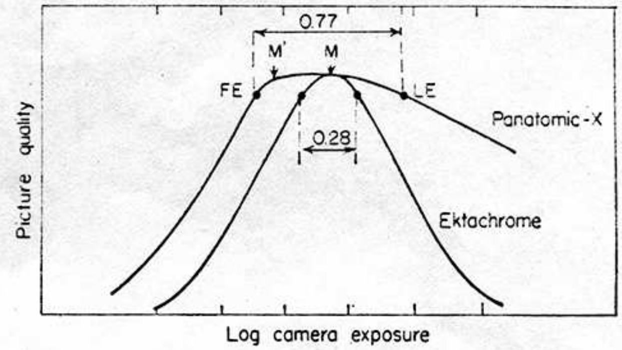

Fig. 11. Picture-quality vs. log-camera-exposure curve for a black-and-white film compared with the corresponding curve for a color reversal film having the same exposure index. FE represents "first excellent"; LE, "last excellent." M is the recommended exposure level for the color film. M′ is the new exposure level recommended for the black-and-white film.

may be released soon. The safety factor involved in the exposure index of a color reversal film is generally small because of the limited camera-exposure latitude of the film. The exposure indexes of this type of film are chosen so that when the numbers are used with exposure meters, the resulting transparencies will have a quality equal to the best that can be obtained by varying the camera exposure (Fig. 11). Decreasing or increasing the exposure by approximately one-third of a camera stop gives a slight but noticeable loss in quality. The slight loss is approximately equal to that used in defining the first excellent level of camera exposure for black-and-white negative films. Thus, on this comparable basis, the safety factor associated with the exposure indexes of color reversal films is approximately the same as that associated with the new ASA speeds of black-and-white negative films (slightly over 1.2).

Exposure indexes, by incorporating a relatively large safety factor (2.4) for black-and-white films and a small safety factor (1.2+) for color reversal films, did not reveal the fact that the basic speed of the black-and-white film was approximately twice that of a color reversal film assigned the same exposure index.

The latest film ratings eliminate this discrepancy and indicate the true speed relationship between these two types of film.

Change in the Speed Criterion

The reduction in the safety factor could have been 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. 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. 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 and base density, is often desired. Fortunately, as shown by the recent data of Nelson and Simonds,[6] a good correlation exists between fractional-gradient speeds and speeds based on a density of 0.1 above fog, *provided the development conditions 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 $20E$, where E is the exposure at a density of 0.1 above fog.

The new American Standard speed is defined as follows:

$$\text{Speed} = 0.8/E_m \qquad (5)$$

where E_m 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, as defined above, is 0.62.

The specification of a fixed average gradient 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 this development specification gives the advantages of practical significance and ease of measurement.

Another important advantage gained by adopting the fixed-density speed criterion as part of an American Standard is that this step is likely to encourage eventual agreement on an international standard for photographic speed. The fixed-density criterion 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 constant of 0.8 in the new formula for speed was chosen so that the desired safety factor of slightly more than 1.2 is obtained, on the average, when the speeds are used with accurate exposure meters and accurate cameras.

The Additive System of Photographic Exposure

A remarkably simple system of *additive* units[4,7] for film speed, scene light, lens aperture and shutter speed is offered by the revised American Standard on photographic speed and the forthcoming revised Standard on exposure meters. The scale used for each of these variables is a series of small numbers: 0, 1, 2, 3, 4, 5, 6, 7, 8, 9, 10, 11. Each step on this scale represents a factor-of-2 change in the variable.

The system is known as the *A*dditive System of *P*hotographic *EX*posure (APEX). The calculation of the camera settings required for any film-and-scene combination can be done by simple, mental arithmetic. The rule is as follows: The film "speed value" (S_v) is added to the "light value" (B_v) and the sum is noted. An "aperture value" (A_v) and a "shutter value" (T_v) are then chosen which have the same sum. This rule is expressed by the equation:

$$S_v + B_v = A_v + T_v$$

The APEX values are additive because the numbers are logarithms (base 2). The sum of A_v and T_v is the "exposure value" (E_v) which has appeared on a number of cameras and exposure meters in recent years.

The relation between the new and the old units is shown in Table I.

The new "speed value" is written with a degree sign, for example, ASA 5°, to distinguish it from the "speed" which, for example, is written, ASA 100 or ASA 5. Intermediate values, such as $5\frac{1}{2}$, $6\frac{1}{2}$ and $7\frac{1}{2}$, are used for any of the APEX variables when finer steps (square root of 2) are desired.

The ease with which the additive system can be used in practice is illustrated by the following example: The light value of an average sunlit scene is approximately 10. If the speed value of the film is 4°, the sum of the two numbers is 14. Aperture and shutter values are, therefore, chosen which have a sum equal to 14, with the restriction that if the camera is hand-held, the shutter value should be not less than 6 (equivalent to 1/60 sec) in order to "stop" camera motion and subject motion adequately. Thus, if a shutter value of 7 is selected, an aperture value of 7 must be chosen in order to balance the equation and obtain the proper exposure. The arithmetic of the operation is

$$10 + 4 = 7 + 7.$$

In the old system, the calculation of the *f*-number required for the proper exposure is based on the formula,

$$t/f^2 = 1.17/BS_x$$

where t is the exposure time, B is the average luminance of the scene in candles per square foot, and S_x is the ASA speed of the film. Solving the equation for f involves multiplying, dividing, and extracting a square root. Because of the inconvenience of this task, it is usually done by means of the computer on an exposure meter or exposure guide.

The advantage of the APEX system will be most apparent to beginners in photography, who often have difficulty understanding the intricacies of *f*-numbers. Experienced photographers will recognize that the new system makes use of one of their valuable aids: the rule that the *f*-number series, *f*/2.8 *f*/4, *f*/5.6, *f*/8, *f*/11 and *f*/16, represents factor-of-2- steps in exposure.

Table I. Relations Between the New and Old Units.

APEX value	Film speed	Reflected light*	Incident light†	Shutter time	*f*-No.
0	3	0.3	6	1	1
1	6	0.6	12	1/2	1.4
2	12	1.2	25	1/4	2
3	25	2.5	50	1/8	2.8
4	50	5	100	1/15	4
5	100	10	200	1/30	5.6
6	200	20	400	1/60	8
7	400	40	800	1/125	11
8	800	80	1600	1/250	16
9	1600	160	3200	1/500	22
10	3200	320	6400	1/1000	32
11	6400	640	12500	1/2000	45

* Candles per square foot.
† Foot-candles on a vertical plane facing the camera.

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An Image Intensifier With Transmitted Secondary Electron Multiplication*

REPRINT

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The use of transmitted secondary electron emission for electron multiplication has been proposed by Lubszynski,[1] McGee[2] and Sternglass,[3] and photoemissive image intensifiers incorporating thin films of potassium chloride as transmitted secondary emitters have been described by Wachtel, Doughty and Anderson.[4] We also have been experimenting with the construction of image intensifiers of this kind.

The form of the tubes we have made is shown in Fig. 1. They consist essentially of an antimony-caesium photocathode, an aluminium-backed zinc sulphide-silver phosphor, and between these a set of parallel electron-multiplying dynodes which are layers of aluminium and potassium chloride deposited on a supporting film of aluminium oxide. Electrons from the photocathode are accelerated and focused on the first dynode by means of coaxial electric and magnetic fields, and secondary electrons are produced which escape from the dynode on the side remote from the photocathode. These transmitted secondaries are similarly accelerated and focused on the second dynode, where further transmitted secondary electrons are produced; and this process is repeated down the tube. Finally, the electrons which emerge from the last dynode are accelerated and focused on the phosphor.

The electric field is provided by cylindrical electrodes on the inner wall of the tube, which are connected to an external potential divider. The magnetic field is provided by a long solenoid which surrounds the tube. In order to prepare the photocathode without admitting caesium to the working section of the tube we have made use of the arrangement described by McGee.[5] At a short distance from the front window of the tube there is an annular metal shelf which fits the inside of the tube closely enough to act as a barrier to caesium vapour, and a glass plate is held to this shelf by means of a spring catch which can be released by tapping the outside of the tube. The photocathode is formed on the surface of the plate which faces the front window of the tube. After the tube is sealed off from the pumps, the plate is released and turned over so that the photocathode faces the dynode system.

Reprinted by permission from *Nature*, vol. 185, No. 4710, pp. 370–371, Feb. 6, 1960. The authors are at the Department of Physics, Instrument Technology Section, Imperial College, London, S.W. 7, England.

* A more extensive account of this work is given in "Work at Imperial College on Image Intensifiers With Transmitted Secondary Electron Multiplication," W. L. Wilcock, D. L. Emberson and B. Weekley, *Trans. IRE* (*Nuclear Science*), to be published in the near future.