Eastman Color High-Speed Negative Film 5293

By Glenn L. Kennel, Richard C. Sehlin, F. R. Reinking, S. W. Spakowsky, and G. L. Whittier

Eastman color high-speed negative film 5293/7293 has an exposure index of 250 and wide exposure latitude. This new film is designed to complement Eastman color negative film 5247, thus extending the creative freedom of the cinematographer in special applications where additional lighting is difficult, uneconomical, or undesirable. The sensitometric characteristics, image structure, color rendition, and performance of the new film are discussed.

The history of Eastman color negative films over the past 30 years traces the development of emulsion and chemical technology, which produced sequential improvements in speed and image structure. The evolution of Eastman color negative film from its introduction to the present is illustrated in Table 1. The original Eastman color negative film 5247[1] was introduced in 1950 — with an exposure index of 16 and balanced for daylight illumination. Eastman color negative film 5248,[2] with an exposure index of 25 and tungsten balance, was introduced in 1952. Since the blue-light component of tungsten illumination is much smaller than that of daylight illumination, the change to a tungsten-balanced film required a significant increase in blue speed.

In 1959, Eastman color negative film 5250,[3] with an exposure index of 50, was introduced. That was followed in 1962 by Eastman color negative film 5251,[4] which exhibited a significant improvement in grain at the same exposure index as 5250 film. The introduction of Eastman color negative film 5254 in 1968 provided a film with the image structure of 5251[5] at twice the film speed — an exposure index of 100. In 1972, Eastman color negative film 5247[6] with an exposure index of 100 was announced. This film featured significant improvements in image structure. In 1976, this product was modified to provide improved color reproduction for 35-mm film applications; and in recent years, it has been widely used for the production of high-quality film programs for theatrical, commercial, and television display.

Film Structure

The development of a high-speed motion-picture negative film required advances in emulsion technology to provide a significant increase in speed while maintaining the stringent requirements on image structure that are necessary for high-quality motion-picture display. A multilayer structure typical of color negative films is employed in 5293 film. As illustrated in Fig. 1, the film is topped with a protective gel overcoat containing matte particles and lubricants that aid film transport, handling, and printing properties. A barrier layer just below the gel overcoat prevents contamina-

Table 1 — History of Eastman Color Negative Film

Year	Type	EI	Characteristics
1950	5247	16 (D)	Original
1952	5248	25 (T)	More Blue Speed
1959	5250	50	Speed Doubled
1962	5251	50	Finer Grain
1968	5254	100	Speed Doubled
1972	5247	100	Finer Grain
1976	5247	100	Improved Color

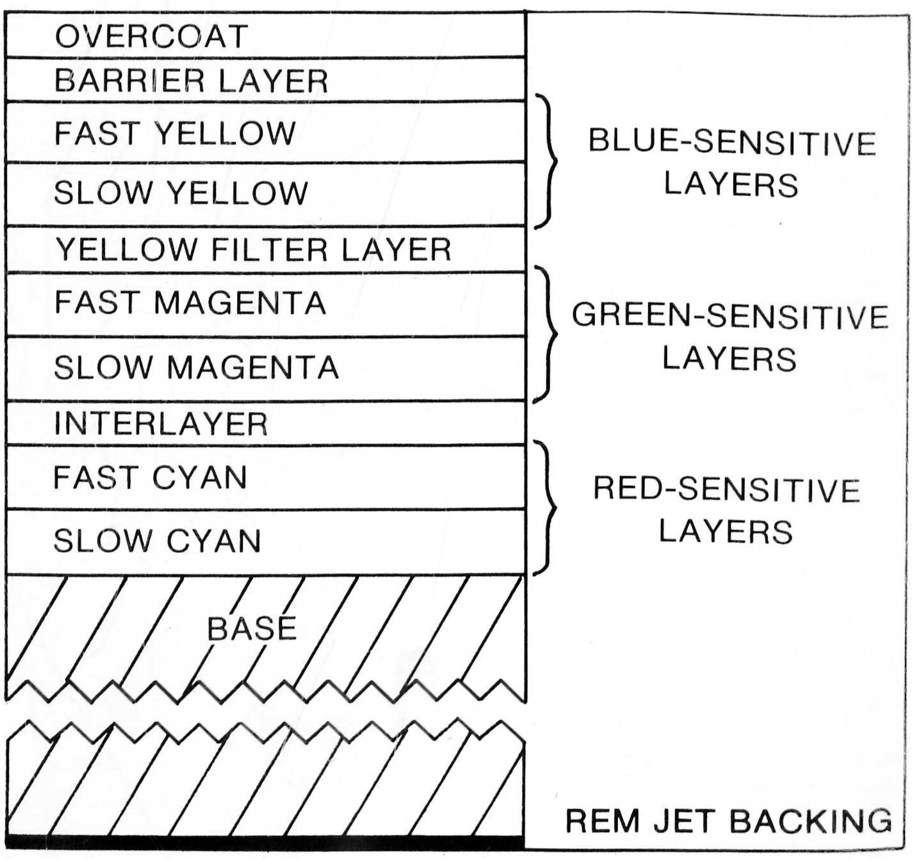

Figure 1. Layer structure of 5293 film.

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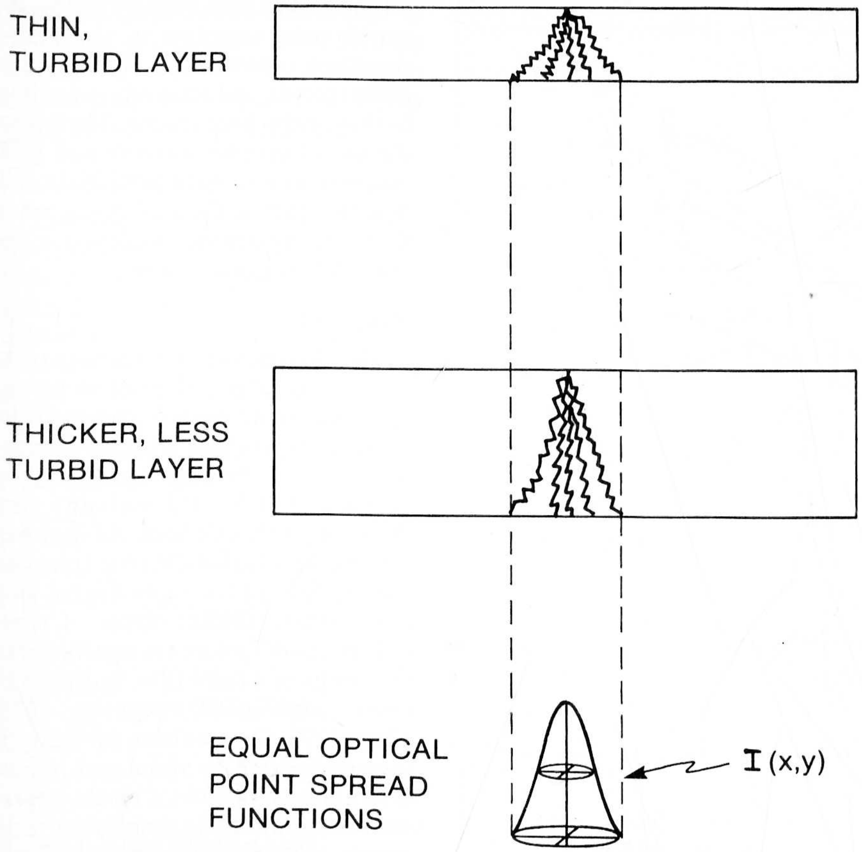


Figure 2. Light scattering is dependent on both the turbidity and thickness of the emulsion.

tion of the developer by trapping development by-products or fragments.

Each of the red-, green-, and blue-sensitive layers is composed of two separate coats, with the upper, or fast, layer of each pair containing the larger grain, faster silver-halide emulsions; the lower, or slow layer, containing the finer grained, lower-speed emulsions. The blue-sensitive layers contain conventional image couplers that form yellow dye. The green-sensitive layers contain magenta image coupler, development-inhibitor-releasing (DIR) coupler,[7] and a yellow-colored magenta-dye-forming colored coupler.[1,8] The red-sensitive layers contain image coupler, DIR coupler, and a magenta-colored cyan-dye-forming coupler. A yellow-filter layer located just above the green-sensitive layers is necessary to block blue light from the red- and green-sensitive layers, as these emulsions retain some of their intrinsic sensitivity to blue light.

Eastman color negative films are coated on a safety-film base of cellulose triacetate with a rem-jet backing. Rem-jet backing consists of a particulate carbon dispersion that is removed as the initial step in processing. The rem-jet backing minimizes halation during exposure of the negative and also acts as an antistatic and lubricating agent prior to processing.

Film Speed

The new Eastman color high-speed negative film is one-and-one-third stops (0.40 log E) faster than the current 5247 film. This increase in speed was obtained primarily through the use of larger grain silver-halide emulsions in the fast layers. Emulsion addenda and ripening procedures were optimized to obtain the maximum speed for the grain sizes employed.

Graininess

Maintaining a graininess level acceptable for a motion-picture film negative, while increasing the film speed, was achieved primarily by employing a technique called "coupler starving" and by using development-inhibitor-releasing (DIR)[9] couplers. Graininess in any color film is related to the size, morphology, and number of dye clouds formed. Generally, when larger grain-size emulsions are used to obtain higher speed, the dye clouds formed are larger and the granularity of the film increases. To minimize this increase in granularity, a two-layer structure is employed for each of the yellow, magenta, and cyan layers — a "fast" layer consisting of a large-grained fast emulsion and very little coupler (hence, coupler starving), and a "slow" layer consisting of fine-grained emulsion with enough coupler to provide the desired latitude. The fast layer thus yields the high-threshold speed with limited latitude. The slow layer provides the long latitude, fine-grain characteristics of the film. These two layers combine to form a high-speed, fine-grained film.

In addition, DIR couplers are used to modify the image in a number of ways. Their use produces edge enhancement and, consequently, improves image sharpness and resolution.[3,10] They are also employed to modify the development effect of one layer on another.[10] Finally, DIR couplers inhibit development and hence yield smaller dye clouds around a developing latent-image site, thereby reducing the granularity of the film.

Although each of the red, green, and blue records is important in repro-

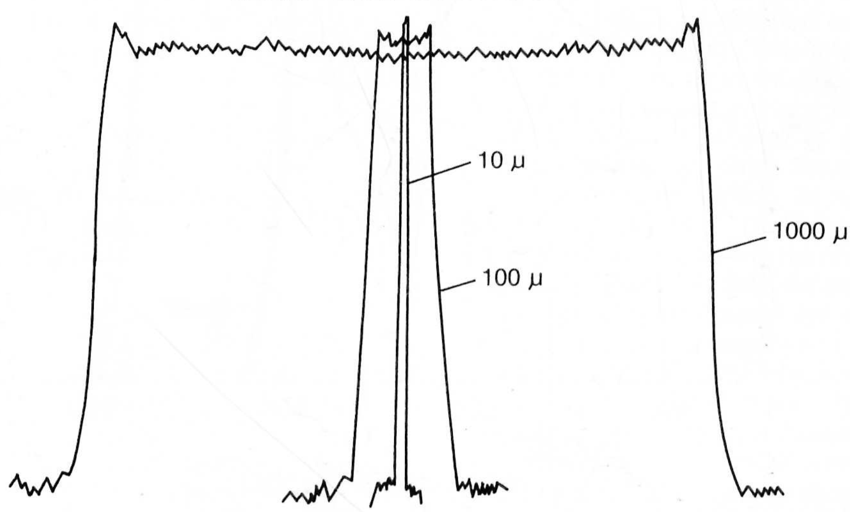


Figure 3. Light line exposures on 5293 film as scanned by a microdensitometer.

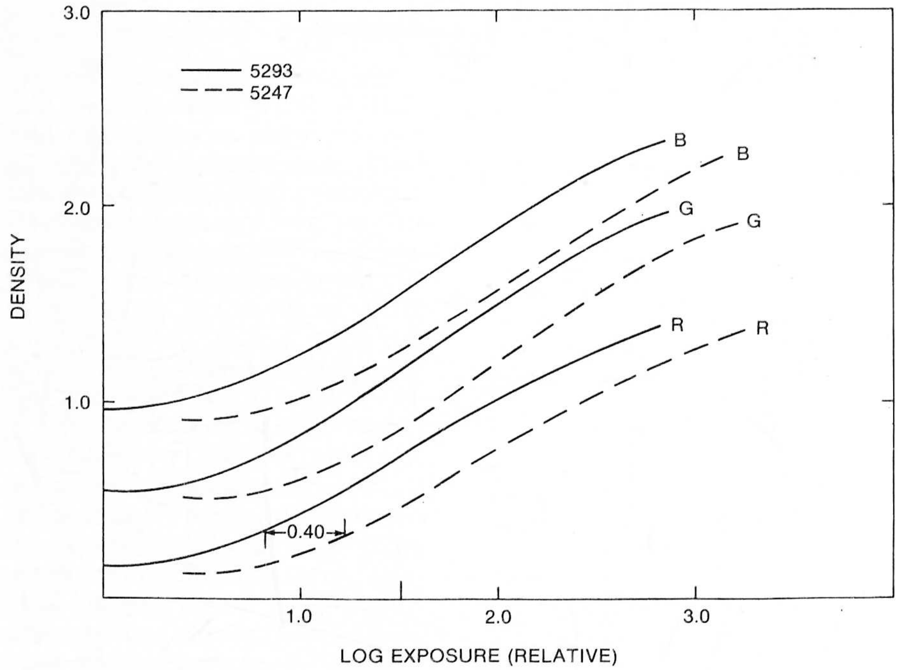


Figure 4. Sensitometric comparison of 5293 and 5247 films.

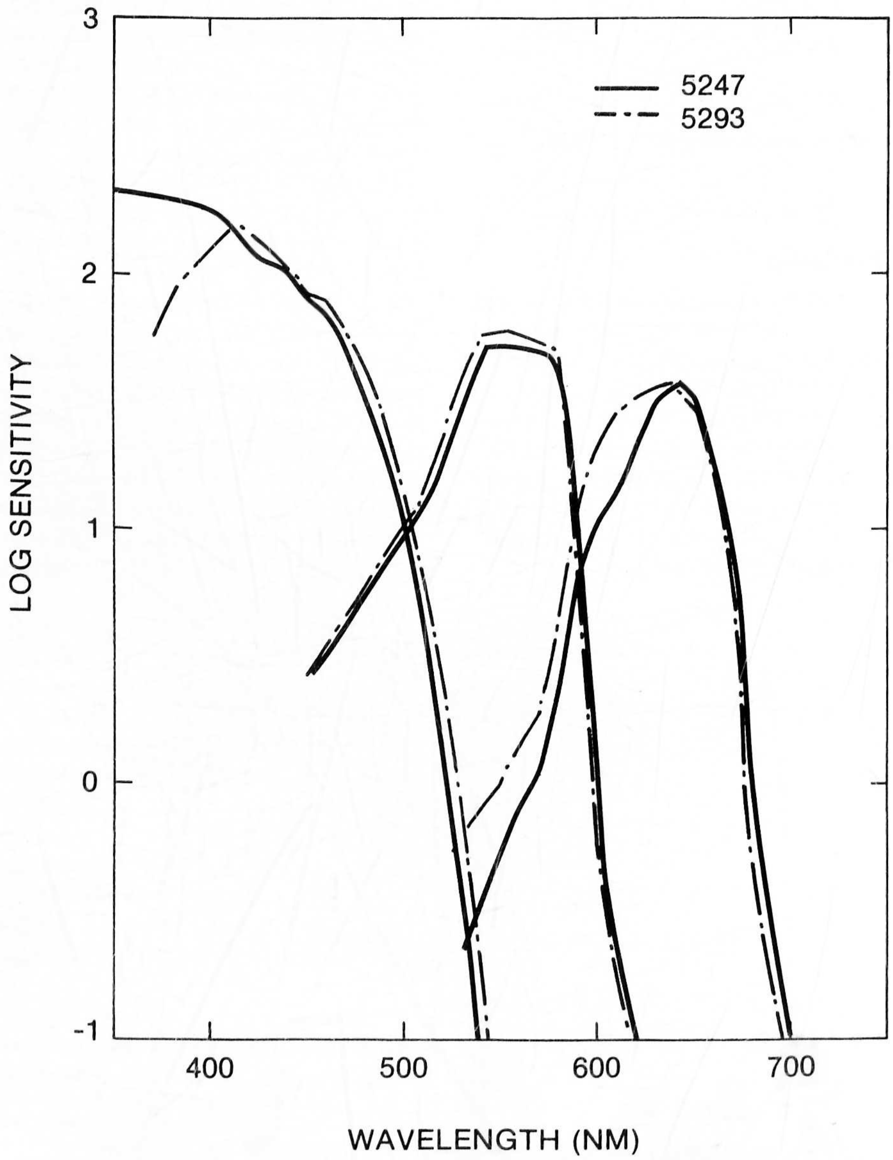


Figure 5. Comparison of the spectral sensitivity curves of 5247 and 5283 films.

ducing a color photographic image, the eye is most sensitive to the image structure recorded by the red and green records, and relatively insensitive to that of the blue record. Therefore, the use of coupler starving and DIR couplers to minimize graininess in a negative film is most effective when these techniques are employed in the cyan and magenta layers.

Sharpness

The sharpness of any photographic material is largely dependent on the light-scattering characteristics of the emulsion layers that make up the material.[11,12,13] The degree of scattering depends on both the turbidity and thickness of the emulsion. As shown in Fig. 2, a very turbid, thin top layer can scatter light to the same degree as a less turbid, thicker layer. Consequently, both factors are significant in the design of a color film. In Eastman color high-speed negative film 5293/7293, the emulsion turbidity is largely dictated by speed and granularity constraints. As a result, sharpness is optimized by employing techniques that minimize emulsion-layer thickness.

The sharpness in both 5247 film and 5293 film is also substantially improved by the use of DIR couplers. DIR couplers introduce Eberhardt or edge effects that enhance low-frequency edges and improve the resolution of narrow-line exposures. Figure 3 shows actual narrow-line exposures of 5293 film as scanned by a microdensitometer.

Color Reproduction

Eastman color high-speed negative film 5293/7293 is designed to provide the same excellent color-reproduction characteristics as Eastman color negative II film 5247/7247. Designing the new negative consequently involved adjusting the film parameters that influence color reproduction. These basic parameters are:

1. Neutral tone-scale sensitometry;
2. Spectral sensitivity;
3. Spectral dye density; and
4. Interlayer interimage effects (IIE).

Attaining other film characteristics such as speed and image structure also affects the color reproduction of the film, and these parameters must be balanced to produce the desired result.

Tone-Scale Sensitometry

The neutral-scale sensitometric response of 5293 film matches that of 5247 film, except that 5293 is 0.40 log E faster. As shown in Fig. 4, a neutral scale should be reproduced identically using either 5247 or 5293 film.

Spectral Sensitivity

The spectral sensitivities of 5293 film are compared with those of 5247 film in Fig. 5. Note that the two films differ somewhat in both blue and red sensitivities. The effect of these differences on the rendition of color may be estimated by calculating exposure densities of objects that occur in a typical scene. Exposure density[14,15,16] is defined as follows:

$$E_R = -\log T_R$$

$$E_G = -\log T_G$$

$$E_B = -\log T_B$$

where

$$T_R = \int_0^\infty R(\lambda)E(\lambda)S_R(\lambda)d\lambda \Big/ \int_0^\infty E(\lambda)S_R(\lambda)d\lambda$$

$$T_G = \int_0^\infty R(\lambda)E(\lambda)S_G(\lambda)d\lambda \Big/ \int_0^\infty E(\lambda)S_G(\lambda)d\lambda$$

$$T_B = \int_0^\infty R(\lambda)E(\lambda)S_B(\lambda)d\lambda \Big/ \int_0^\infty E(\lambda)S_B(\lambda)d\lambda$$

and

$R(\lambda)$ = spectral reflectance of a particular object.

$E(\lambda)$ = spectral energy distribution of the illuminant.

$S_R(\lambda)$, $S_G(\lambda)$, $S_B(\lambda)$ = spectral sensitivities of the red, green, and blue layers, respectively.

T_R, T_G, T_B = responses of the red, green, and blue layers, respectively, to a given object as a function of the spectral characteristics of the film, object, and illuminant.

The integration limits cover all wavelengths of light; however, the actual limits are restricted by the spectral sensitivity range of the film.

Trilinear plots comparing the exposure densities of 5293 and 5247 film for various "colors" are shown in Fig. 6. These plots represent the magnitude and hue of color-reproduction shifts caused by differences in spectral sensitivity. When the exposure densities representing light skin are balanced between the two films, the reds and neutrals of 5293 film appear slightly more yellow, while the blues appear slightly cyan. These shifts are primarily the result of the blue-sensitivity differences.

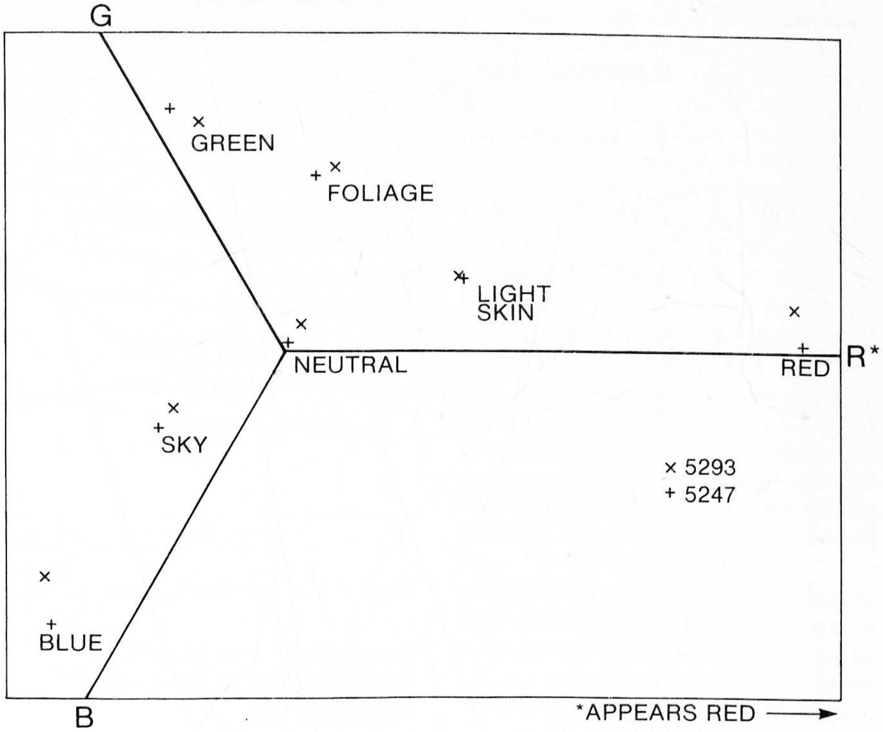


Figure 6. Trilinear plot of the calculated exposure densities for various colors on 5293 and 5247 films.

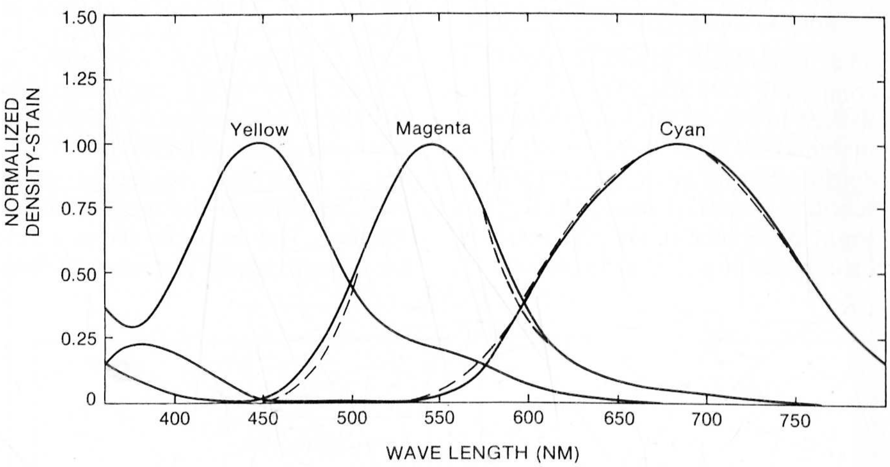


Figure 7. Comparison of the cyan, magenta, and yellow dyes of 5293 and 5247 films.

Spectral Dye Densities

The cyan, magenta, and yellow dyes of 5293 film are compared with those of 5247 film in Fig. 7. The curves are similar, except that the cyan dye of 5293 film has its peak spectral dye density at a slightly shorter wavelength. The effect of this difference may again be estimated by examining the exposure densities of 5293 and 5247 dyes printed onto Eastman color print film 5384. The dye amounts of 5293 film may be approximated by converting the original exposure densities (as calculated above) to dye amounts by reflecting them through the characteristic curves. In this manner, a "dye space" can be constructed that corresponds to the original exposure space.[17] To limit this study to the effects of the spectral dye differences between the negative films, the exposure densities and interimage effects are considered equal. Dye amounts are generated from the status M density and the analytical conversion equation. Then, exposure density onto 5384 film may be determined as follows.[18,19,20]

$$D_R^P = -\log\left\{\int_0^\infty T(\lambda)E(\lambda)S_R^P(\lambda)d\lambda \Big/ \int_0^\infty E(\lambda)S_R^P(\lambda)d\lambda\right\}$$

$$D_G^P = -\log\left\{\int_0^\infty T(\lambda)E(\lambda)S_G^P(\lambda)d\lambda \Big/ \int_0^\infty E(\lambda)S_G^P(\lambda)d\lambda\right\}$$

$$D_B^P = -\log\left\{\int_0^\infty T(\lambda)E(\lambda)S_B^P(\lambda)d\lambda \Big/ \int_0^\infty E(\lambda)S_B^P(\lambda)d\lambda\right\}$$

where

$D_{R,G,B}^P$ = exposure densities (R,G,B) of negative onto print film.

$T(\lambda)$ = spectral transmission of constructed dyes that correspond to a scene object.

$E(\lambda)$ = printer illuminant + UV filter (2B).

$S^P_{R,G,B}$ = spectral sensitivity (R,G,B) of Eastman color print film 5384.

The calculated exposure densities comparing 5293 and 5247 dye sets are plotted in Fig. 8. With print densities matched for light skin, the exposure densities for all other subjects are essentially equal. Consequently, the slight difference in the dye sets has little effect on color reproduction.

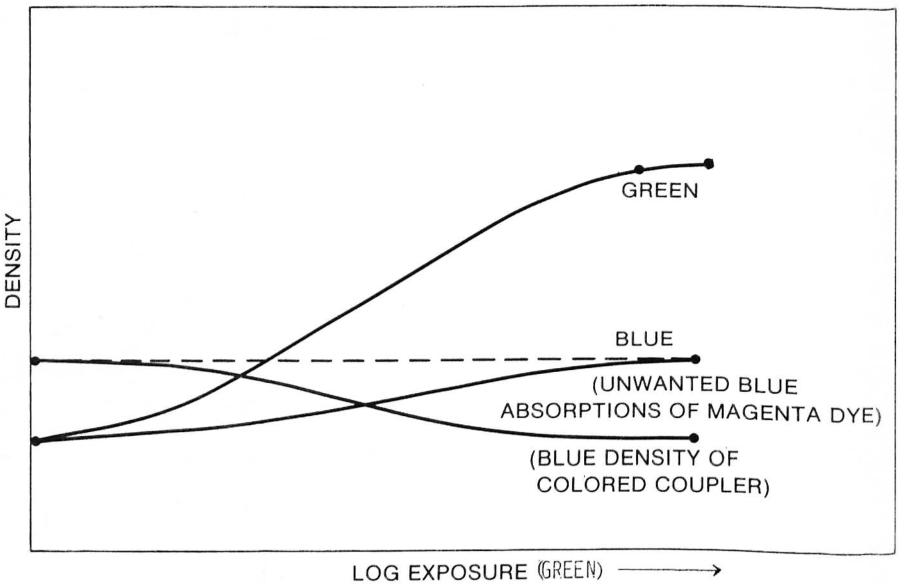


Figure 9. Corrective color masking by colored couplers.

Color Correction: Interlayer-Interimage Effects and Color Masking

Color correction in any film is an attempt to compensate for unwanted spectral dye absorptions, as well as spectral sensitivity deficiencies. In modern films, color correction is achieved by using color-masking techniques or by adjusting interlayer-interimage effects (IIE's).[21,22,23] Figure 9 illustrates corrective color masking through the use of colored couplers. This example shows a yellow-colored coupler that reacts to form magenta dye. As the colored coupler reacts to form magenta dye, the blue absorption of the magenta dye increases as the dye density increases. Ideally, the decrease in blue density resulting from the reactions of the colored coupler will exactly match the increasing unwanted blue absorption.

In addition to colored couplers, interimage effects are also used to achieve color correction. As one layer develops, the development in another layer is inhibited. Traditionally, "right-way" IIE's have been achieved by the release of a development inhibitor as a function of silver development or by the release of development inhibitors as a function of oxidized developer coupling to form dye. In either case, the result is an inhibition of development in another layer.

The inhibitor released from silver development is normally iodide, and that released from the coupling reaction is a fragment released by development-inhibitor releasing (DIR) couplers. The effect of the use of DIR couplers is shown in Fig. 10 where magenta dye development (green density) is shown to be a function of cyan dye development (red density). Note that interimage effects resulting from the use of DIR couplers exist only when there is density developed in the receiving layer. The 5293 film has been designed to match both the interimage effects and the colored-coupler correction levels of 5247 film. Hence, the color-correction effects of 5293 film will be similar to those of 5247 film.

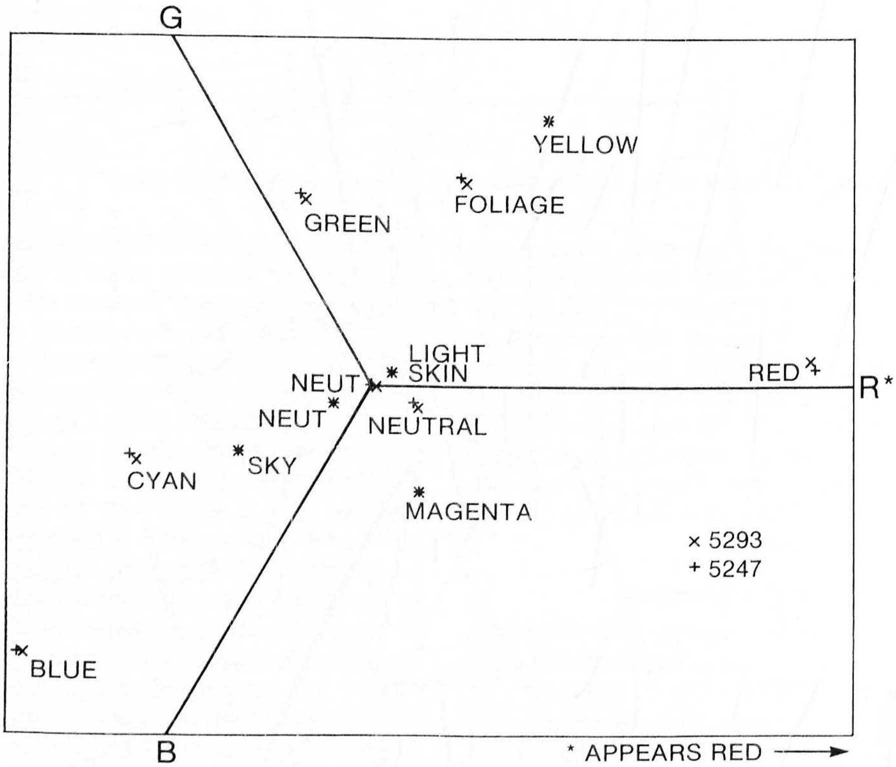
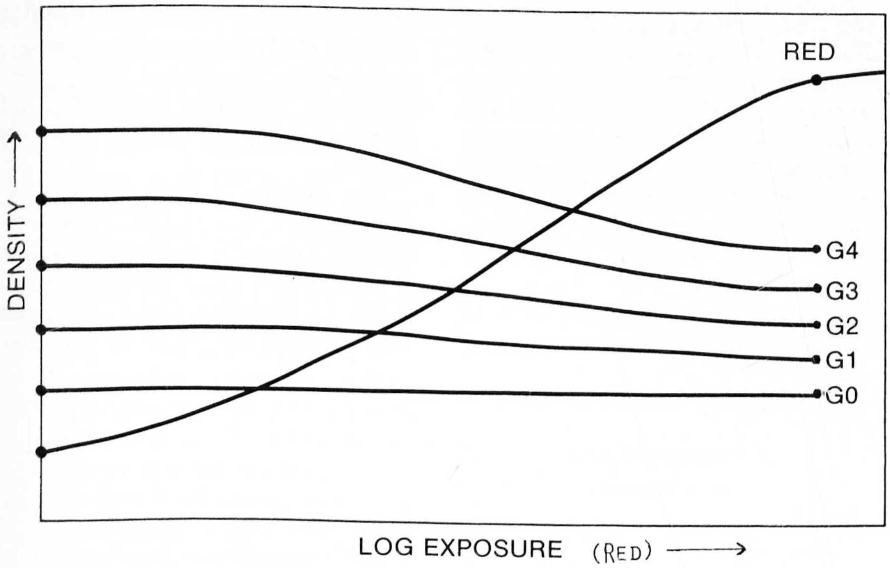


Figure 8. The exposure densities of several colors representing the printing of 5293 and 5247 negative films onto 5384 print film.

Color Specification

The color-reproduction character-



G0, G1, G2, G3, G4 REPRESENT SEQUENTIALLY HIGHER LEVELS OF UNIFORM GREEN-LIGHT EXPOSURE.

RED REPRESENTS STEP-SCALE EXPOSURE TO RED LIGHT.

Figure 10. DIR couplers coated in the red-sensitive layer inhibit development of magenta dye in the green-sensitive layer.

istics of a negative film may be specified by exposing the negative material (5247 or 5293 film) to various color scales that represent colors occurring in normal scenes. The negatives are then printed onto Eastman color print film 5384 using a commercial motion-picture printer. The status A densities of each color patch are then measured and converted to CIE-LAB color specifications.[24]

Figure 11 shows a plot of the CIE-LAB color specifications for prints of color patches from both 5293 and 5247 films. The sensitometric curves from 5293 and 5247 films are identical in this analysis, and the patch that represents light skin (average Caucasian flesh) on each is printed to the same density on 5384 film. With the two prints so matched, Fig. 11 shows only small differences in color reproduction between 5293 and 5247 films. All the color scales match quite closely. Only a small difference in the neutral scale and the rendition of blues is shown. In a comparison of prints matched for flesh, the print from the 5293 film has a tendency toward neutrals that appear more yellow and blues that appear more cyan than the print from 5247 film. The red-reproduction difference expected is too slight to appear as a deviation in the actual color specifications.

In summary, color reproduction of 5293 film will match that of 5247 film very closely. The only differences are slight tendencies for the neutral areas of prints from 5293 film to appear slightly warmer (yellow) and the blues to appear slightly cyan when flesh tones are matched.

Processing

Eastman color high-speed negative film 5293 is designed to be processed in Process ECN-2. This film is completely compatible with the other Eastman color films designed for Process ECN-2 films — 5247, 5243, and 5272. No changes in the replenishment rate or in the chemicals are necessary for any of the process solutions when processing 5293 film. There are no contamination or adverse seasoning effects, and the processing characteristics of 5293 film are nearly identical with those of 5247 film. The kinetics of bleaching and fixing are also similar to those for 5247 film. Eastman color high-speed negative film 5293, like the other Eastman color films designed for Process ECN-2, is compatible with both the ferricyanide and persulfate bleaches available for use with this process and can be push-processed in the same fashion as 5247 film.

Push processing of color negative film is a technique generally used to compensate for underexposure of the negative. Typically, the development time is extended so that an underexposed negative prints like a normally exposed negative. An increase of 40 seconds to 1 minute from the standard developer time corresponds to a Push-1 process, compensating for a one-step underexposure. This is usually accomplished by slowing down the film-transport speed for the entire process.

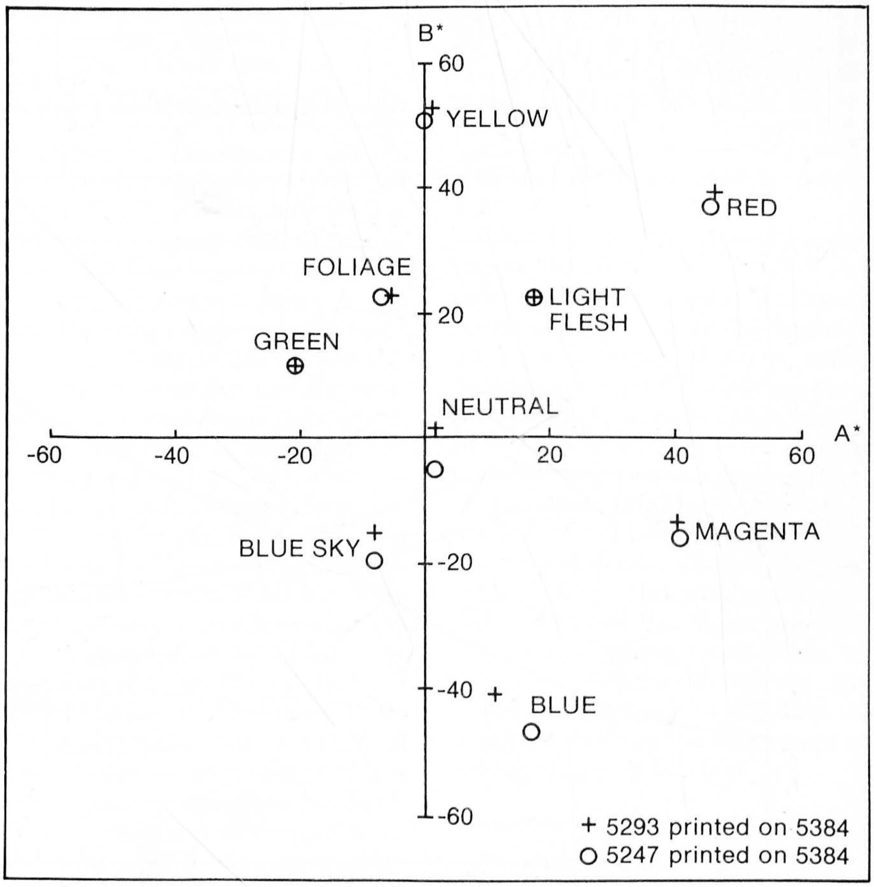


Figure 11. CIR-LAB color specifications for several color patches exposed on 5293 and 5247 films and printed onto 5384 print film.

Sensitometric curves for normal and push-processed 5293 negatives are illustrated in Fig. 12. The sensitometric effect of push processing is an increase in the overall density of the negative, resulting from a combination of increased speed, contrast, and fog. Push processing contributes, however, to a significant increase in the granularity of the negative, and the increased graininess of projected prints may be objectionable — particularly in the 16-mm format. In most cases, push processing improves the quality of prints made from an underexposed negative, although the quality obtained never matches that of a correctly exposed, normally processed negative.

Film Characteristics

The sensitometric characteristics of 5293 film are compared with those of 5247 film in Fig. 4. The 5293 film is 0.40 log E faster than 5247 film but has the same contrast and latitude as the other Eastman color negative films. The contrasts, as measured by status M densitometry, are designed so that the print-through contrasts made on Eastman color print film 5383 or 5384 produce matched neutral scales (END measurements).

The granularity of 5293 film is very similar to that of 5247 film. Visual RMS granularity values are plotted versus exposure in Fig. 13. In both films, granularity has its maximum in the toe region and decreases toward the mid- and upper-scale densities. Note that the granularity of 5293 film is higher in the toe region but is close to that of 5247 film in the mid and upper scales. In pictures, underexposures on 5293 film appear slightly more grainy than they do on 5247 film, but normal exposures and overexposures appear to have comparable graininess.

The sharpness characteristics of both 5293 and 5247 films, as measured in terms of their modulation transfer function (MTF) and resolving powers, are shown in Fig. 14 and Table 2, respectively. Note that the MTF's and resolving powers of the two films are similar.

Dye stability of 5293 film is comparable with that of 5247. A plot illustrating cyan dye fading versus time at various storage conditions is shown in Fig. 15. Stabilities of the yellow and magenta dyes in 5293 film are similar

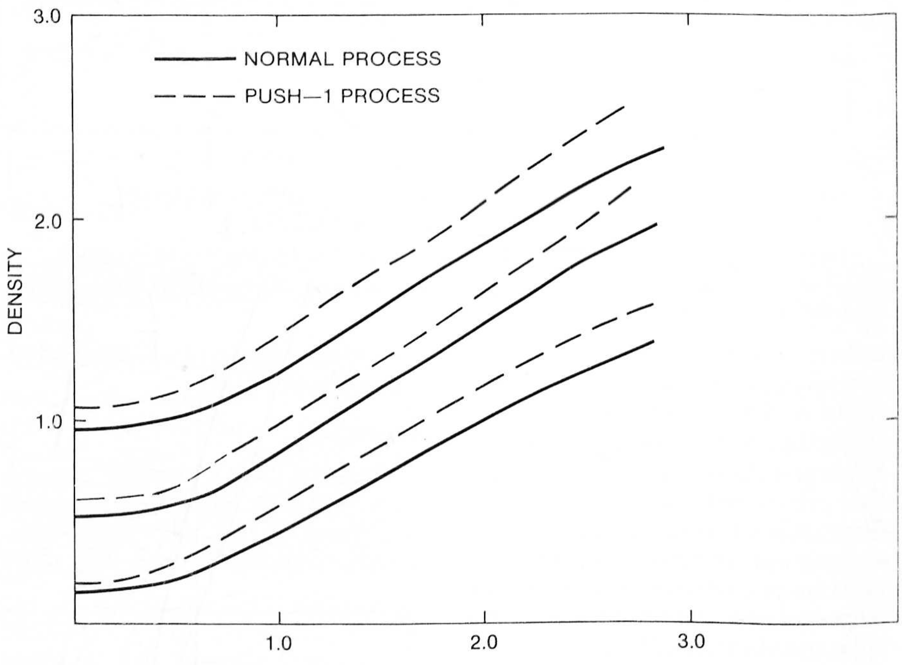


Figure 12. Comparison of normal process and push process sensitometry of 5293 film.

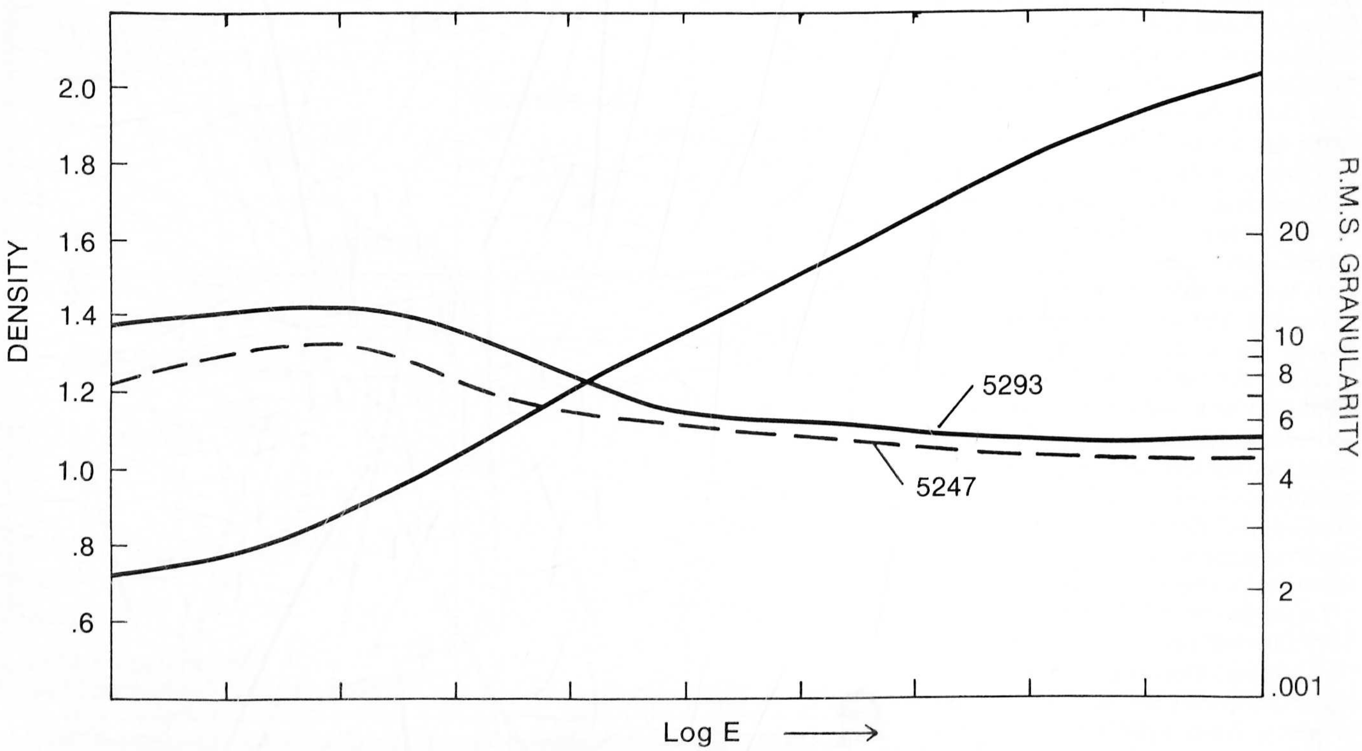


Figure 13. The visual RMS granularity curves of 5293 and 5247 films as a function of exposure.

to those in 5247 film.

Table 2 — Resolving Power of 5293 and 5247 Films

	Test Object Contrast	
	1.6:1	1000:1
5293	50 lines/mm	100 lines/mm
5247	50 lines/mm	100 lines/mm

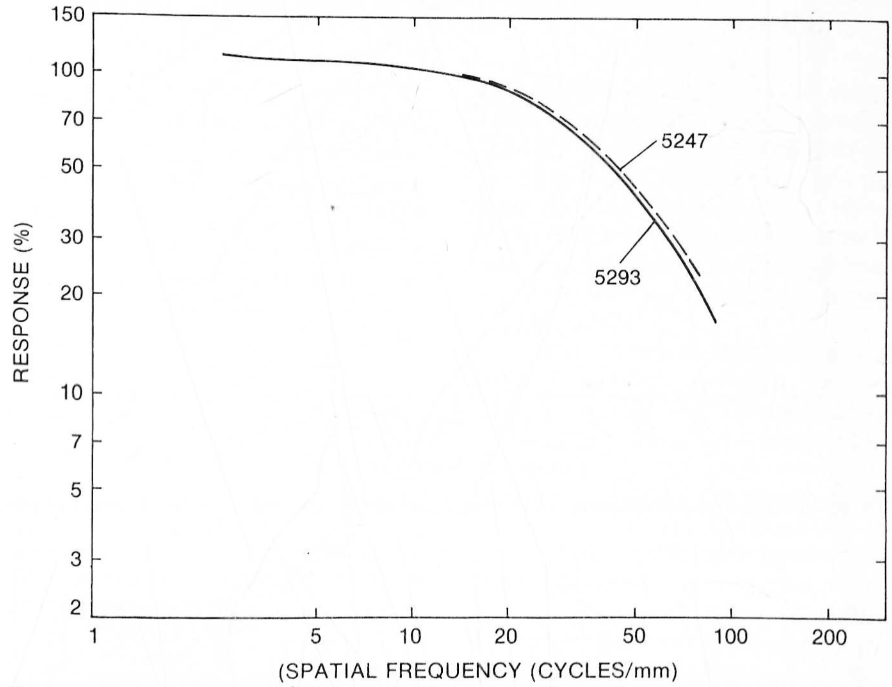


Figure 14. Modulation Transfer Function (MTF) curves representing the responses of 5293 and 5247 films.

Film Performance

Eastman color high-speed negative film 5293 yields excellent results under a wide range of applications. Some applications are completely new, while others improve the final image quality or simplify production procedures. Some of these applications and potential uses are summarized as follows:

1. Dimly lit, natural settings may be photographed without adding lights, allowing the cinematographer more creativity in reproducing the desired mood or effect.
2. Low-light-level situations may be photographed where it is either impossible or uneconomical to light the scene to a higher level.
3. Lighting reductions on a set minimize operating costs for both the lighting and the associated air-conditioning load necessary to keep a set comfortable.
4. Longer shooting days are possible with available daylight, minimizing the setup time required to finish filming an exterior scene.
5. Greater depth of field is possible at existing light levels.
6. High-speed action photography is possible at lower light levels or with a greater depth of field for ease of focusing.
7. Underwater photography is possible with much less supplemental lighting.

Both 5293 and 5247 films have excellent exposure latitude. Recent surveys indicate that less than 20 percent of the cinematographers using 35-mm 5247 film expose it at its rated exposure index (EI) of 100, whereas, more than 80% expose it at EI 125, 160, or even higher — sometimes with push processing. On the same speed scale that establishes 5247 film as having an exposure index of 100, the new 5293 film has an EI of 250.

As noted in the *Handbook of the American Society of Cinematographers*, "Exposure-index values are determined on the basis of practical picture tests. They should be considered . . . as a starting point for an exposure series from which the final values . . . may be adopted."

Where possible, a cinematographer may wish to evaluate the film with an exposure series on a particular scene in order to select the exposure best suited for the effect desired. Figure 16 represents data relating subjective screen quality — tone scale, color reproduction, graininess, shadow detail, etc. — to various exposure levels for 5247 and 5293 films. Picture tests were conducted exposing 5247 and 5293 films in 35-mm format at one-third-stop increments from an exposure index of 100 to an exposure index of 1000. The graph in Fig. 16 presents the subjective evaluations of the overall quality of prints made from negatives exposed at the various exposure conditions; the picture-quality judgments were made by a panel of experienced viewers. It is important to note that this is a summary of their evaluations and that any quality judgment is dependent on scene content, lighting, and the cinematographer's desired effect.

The pictorial qualities of 5293 film exposed at EI 250 are similar to those of 5247 film exposed at EI 100. Both films exhibit very little loss in quality when underexposed by as much as two-thirds of a stop (EI 160 for 5247 film and EI 400 for 5293 film). However, a noticeable loss in quality is readily observed when either film is underexposed by more than two-thirds of a stop. From picture evaluations, it is evident that a cinematographer shooting 5293 film at EI 500 might choose either a normal process or a Push-1 process — depending on scene content. At EI 1000 (two stops underexposed), the cinematographer would be more satisfied with a Push-1 process. A Push-2-process condition increases the graininess substantially without a significant improvement in tone scale.

The image quality obtained from an underexposed negative is highly dependent on scene content. Underexposing the negative normally results in a print with higher graininess, which becomes particularly objectionable if a uniformly lit scene is underexposed by more than one step. If the scene is dimly lit, however, or contains a large shadow area, an underexposed negative can be printed with a heavy balance to give the desired "low-light" or "night" effect. This printing compensation obscures the higher negative grain and produces a rich black, or D-max, in the print. In this way, excellent quality has been obtained on 5293 film with night scenes exposed at indices as high as EI 1000.

Conclusion

Eastman color high-speed negative film 5293/7293 has excellent exposure latitude and remarkably fine image-

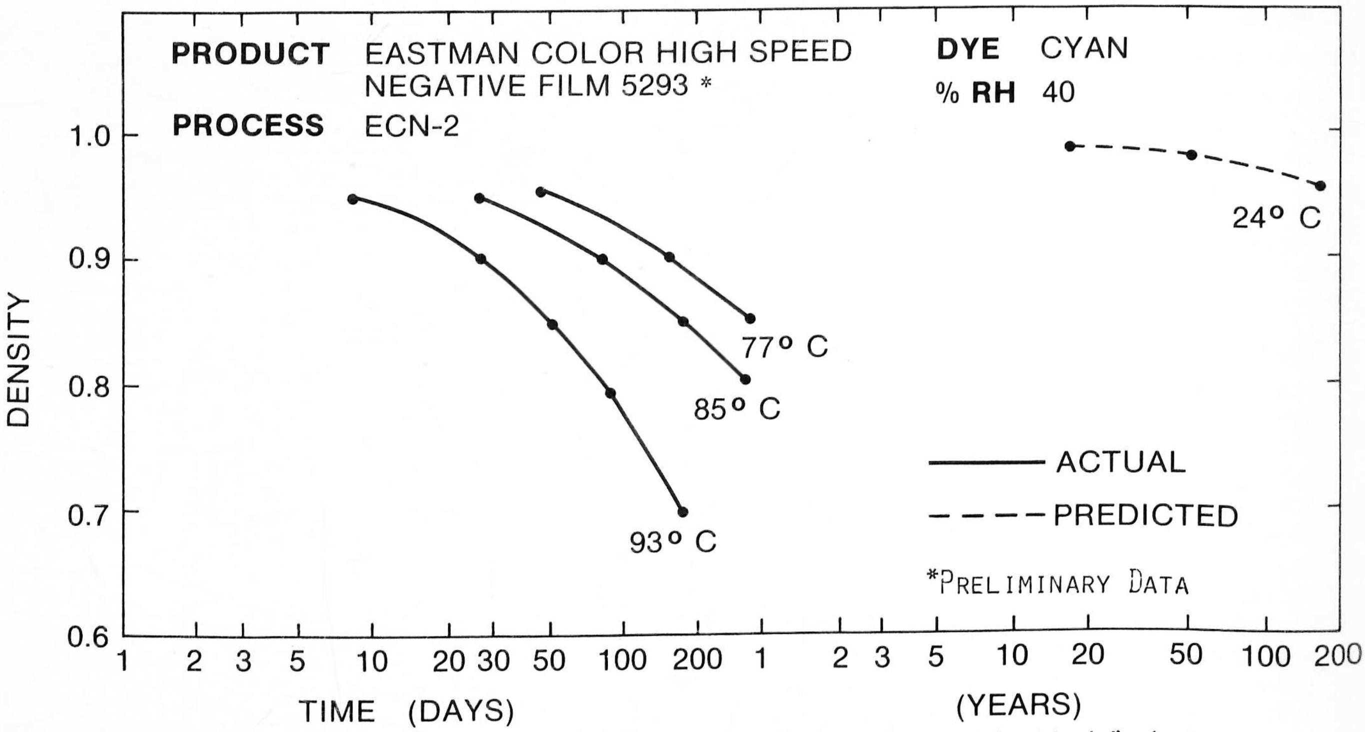


Figure 15. Plots of cyan dye fading versus time at various storage conditons. The dotted line represents predicted dye fading for storage.

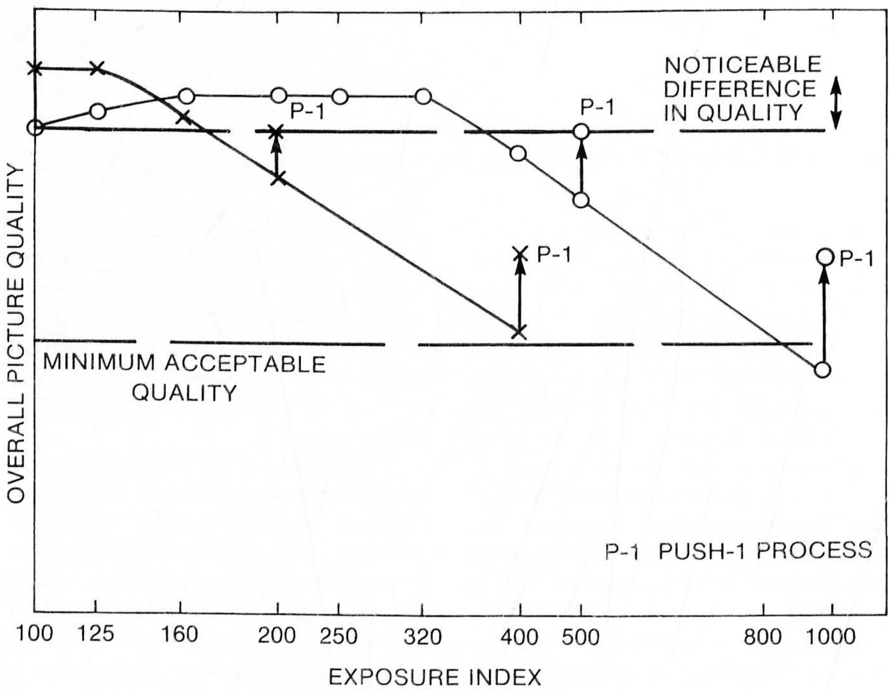


Figure 16. Overall picture quality of 5293 and 5247 films as a function of exposure index.

structure characteristics. It is designed to complement Eastman color negative film 5247/7247 in applications where a high-speed negative film is desired. The compatibility of 5293 with other Eastman color negatives is assured by maintaining essentially the same contrast and color-reproduction characteristics as those associated with 5247 film. In the continuing tradition of Eastman color negative films since the introduction of the product in the early 1950's, high speed negative film 5293/7293 joins ECN-II film 5247/7247 to provide more opportunities for creative cinematography in the production of high-quality motion pictures.

Acknowledgments

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