A Comparison of High-Speed Photographic Films With Different Vigorous Development Conditions

PAPER B—5

By ZEV PRESSMAN

A series of exposure-development tests was conducted to determine the most effective combination of high-speed film and processing procedure to be used with ultra-high-speed framing and streak cameras for investigations of explosive and shock-wave phenomena. Data obtained from the varied experience of technical personnel and film manufacturers' recommendations influenced the design of a brief-exposure electronic-flash sensitometric device using a calibrated gray step-scale for a standard image.

Various "strong" developers were used including stock solutions of paper and x-ray as well as standard commercial film developers. Films were processed at 70 F for normal, normal +50% and twice normal time. Densities were measured on the Welch Densichron and curves plotted. The rating of films in reference to the minimum exposure necessary to raise film density to 0.1 above fog as well as 1.0 above fog was based on ASA and DIN criteria. Royal-X Pan (Kodak) proved to be fastest with Isopan Record (Agfa) next; although, it required ½-stop more exposure for equal useful density. Other films tested, such as Superior 4 (Du Pont) and special-purpose films such as Shellburst, Photoflure and ID2, showed useful characteristics worth considering in special applications.

THIS PROGRAM was undertaken to help provide criteria for the selection of photographic films. Because of the special nature of the intended applications of the films at the Test Site, the usual general recommendations for exposure and development are not adequate. To make use of the maximum potential of the films in recording information, the correct film has to be matched to the best developer. This, in turn, has to be suited to the subject type, lighting conditions, and the results desired.

A series of exposure/development tests under carefully controlled sensitometric conditions has produced a large number of negatives of a calibrated gray scale that show very clearly the relationship of the density produced on various films to development, exposure and film type.

The apparatus used for sensitometric control was quite simple. It consisted of an 11-step calibrated film gray scale used as a photographic subject. The increments were 0.3 log E steps. This transparent scale was translighted by a well-diffused xenon flashlight source. A Pentacon 35mm prism camera was set to photograph the scale through a 200mm focal length lens which, after preliminary test exposures, remained set at a particular aperture.

Because our usual subjects are photographed at high speeds with very short exposure time, a moderately high-speed electronic flash* was used (with slight color temperature modification) as the sensitometric light source. This light unit had a duration of approximately 0.0003 sec at ½ peak. Although shorter exposures would have matched our field practices more closely, the higher intensity units tested proved to be less uniform† in light output. A voltmeter was adapted to cover the working voltage range of the discharge condenser and it served as a constant check.

Failure of the reciprocity law is often mentioned as a factor to be considered in arranging exposure conditions for a particular film. In high-speed photography we are seldom concerned with dim light. Fortunately, for our purposes, within the range investigated there is only slight failure of the reciprocity law under bright light conditions, even though the exposure is very brief.‡

Selection of Films

A representative selection of films and developers was tested. In some instances the choice of films and developers was arbitrary because of the similarity of various manufacturers' products. It was not practical to duplicate this series of tests using every film manufacturer's super-speed film or special developer. Since we use Kodak Tri-X and Du Pont Superior 4 film for much of our work, they had to substitute for Ansco Super Hypan, a similar high-quality fast film. Agfa's Isopan Record was selected from among the better European films.

In addition to these three high-speed films we tested Royal-X Pan Recording film, a new improved Tri-X Pan, green-sensitive Photoflure film, ID-2 (a high-speed panchromatic spectroscopic recording film) and Linagraph Shellburst film. With the exception of Royal-X Pan and the new improved Tri-X, the latter are specialized films designed for particular applications such as photographing oscilloscope screens, spectrographic analysis, and phototheodolite tracking of missiles.

The response of each film to a given exposure range, using three different processing times in each of a number of representative developing solutions, was studied. The characteristic curves of density vs. log of exposure, were plotted on all the films tested. A Welch Densichron, calibrated to match National Bureau of Standards densities, was used in reading all films.

The films were rated with regard to the least exposure and to the most practical processing procedure that produced densities of 0.1 above fog level. This is con-

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*Ultrablitz Meteor II operated at 1/2 power.

†A series of exposures on high-contrast 35mm film showed density variations from frame to frame indicating exposure variation up to 15%.

‡For a further discussion of this subject see J. L. Tupper, "Practical aspects of the reciprocity law failure," *Jour. SMPTE, 60:* 20–29, Jan. 1953.

Table I. Development of 35mm Fast Films for Achieving Maximum Speed.*

Film	Developer	Time (min.)	Temp. (F)	Fog D	Gamma	Rel. exp. index	ASA equiv.
Royal-X	DK-50	10	70	0.41	1.00	100	3000
ID-2	Dektol	5	70	0.67	1.08	80	2400
Isopan-Record	X-500	12	75	0.59	1.16	74	2214
Tri-X (1959 type)	Dektol (stock sol.)	7.5	70	0.56	0.86	64	1920
Superior-4	Supermix (G.E. X-ray)	7	70	0.66	0.90	64	1920
Photoflure (green sensitive)	Liq. X-ray (Kodak)	7	70	0.36	1.66	40	1180
Tri-X (improved type)	UFG	10	70	0.41	1.02	35	1030
Shellburst	Dektol (stock. sol.)	7.5	70	0.375	1.80	26	775

*With least objectionable fog level.

sidered by both the ASA and DIN[§] as the minimum useful density in printing procedures and information recording. The differences in required exposure were considerably less for most of the films when they were compared at a density of 1.0, which is well up in the normal range of exposure, rather than at 0.1, which is in the weak range of underexposure frequently encountered in practice.

Selection of Developers

Extreme acutance and other benefits of the new thin-coated films were of secondary interest at the time of these tests, so no diluted developing solutions were used. Also, the obviously useful characteristics of monobath developing solutions were not compared because of the excessive softening of film emulsions in these solutions. With the advent of some recently announced hardening solutions, it is likely that monobath solutions will be more widely accepted.

Full-strength developers were used, with the exception of the x-ray developers which were diluted according to manufacturer's recommendations. The processing times were the normal full time, 50% over normal and 100% overtime. The following developers were used: Kodak D-8, DK-50, D-19 and Dektol; Plymouth Products Ethol 90 and Ethol UFG; FR X-500, Kodak Liquid X-ray and General Electric Supermix X-ray. All were used at 70 F, with the exception of X-500 which was used at 75 F in order to reduce the total time of processing. Fresh developer was used to process each strip of 10 exposures on a film and then discarded.

No doubt other developing solutions might have produced different, and in some respects, superior results; but the above were considered a representative selection for measurement and evaluation.

Results of Tests

High-speed and general purpose films show substantial gains in sensitivity when conventional developing times are increased more than 50%. With the exception of Royal-X Pan Recording film, even more gain in film speed will result by using high-energy developing solutions similar to those described in Table 1. The results of tests are shown in the accompanying graphs. Kodak Royal-X Pan Recording film is the fastest film tested and performs best using the manufacturer's recommended processing time of 10 min in DK-50; although, the author prefers working at 70 F rather than at 68 F. The exposure index ASA 2000 is conservative. The fog level (about a density of 0.4) is noticeable, but the great sensitivity of the film is undeniable. It is quite grainy under these processing conditions but will resolve about 40 lines/mm[#] on the film when high-contrast resolution test charts are photographed. Under extreme conditions its speed can be forced to nearly ASA 8000 by using DK-60a[‖] developer for 17 min. However, there is a considerable increase in granularity and fog level, with consequent loss of resolution.

Among the general purpose films, Agfa Isopan Record film proved to be the second fastest film tested. When processed for 7½ min at 75 F in FR X-500 developer, Isopan Record required approximately 40% more exposure to achieve the same minimum density as Royal-X Pan. Owing to the higher contrast of the Agfa film, it appeared more brilliant despite its higher fog level under this type of processing. The sharpness of the image was noticeably superior even though this film was not given the special development usually recommended for this characteristic.

Du Pont Superior 4 film, which responded best when processed at 70 F in General Electric Supermix X-ray developer for 7 min, needed nearly 20% more exposure than Isopan Record required, but appeared even more brilliant owing to its greater density range.

Kodak Tri-X[¶] Panchromatic negative film, 1959 type, when processed for 7½ min in full strength Dektol, was about as fast as Superior 4; however, its longer scale is frequently more useful for high-contrast subjects because this results in better tone separation in highlight or overexposed areas. Also, the fog level was lower. The fog level can be dropped still lower, with no loss of film speed, by developing in X-500 up to 15 min at 75 F. A useful compromise when processing Tri-X is to develop in Ethol UFG for 10 min at 70 F. This produces less fog and gives finer grain structure with only slight loss of speed. Ethol 90, used for 6 min at 70 F, produces noticeably higher contrast while still achieving the lower fog level of Ethol UFG, and the film speed will remain nearly as high as when processed in Dektol.

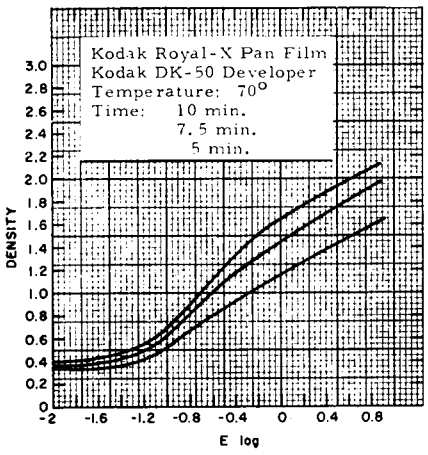
Tri-X Pan negative film, 1960 type, recently brought out by Kodak, proved to be more than 25% slower than the former Tri-X film. It produced its maximum sensitivity when processed in Ethol 90 for 6 min at 70 F.

§ American Standards Association and the German Standards Association (Deutsche Industrie Normen).

#If the resolving power is given as 40 lines, it means that 40 lines to the millimeter are distinguishable as separate and distinct on the film negative. This usually refers to white lines on a black background. The distance between the centers of adjacent white lines is 0.001 in. or 25 microns.

‖In this instance, DK-60a is substituted for DK-50 developer in order to save a few minutes processing.

¶Tri-X, indicated by the author as 1959 type, although superseded by a similarly named film having somewhat different characteristics, has been included because supplies of the former film will no doubt continue to be available for some time owing to its excellent keeping qualities under refrigeration, and to the substantial quantities on hand.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Kodak DK-50 Developer
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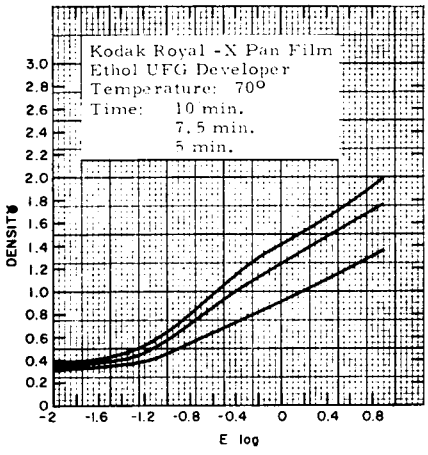
5 min.
DENSITY
E log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Ethol UFG Developer
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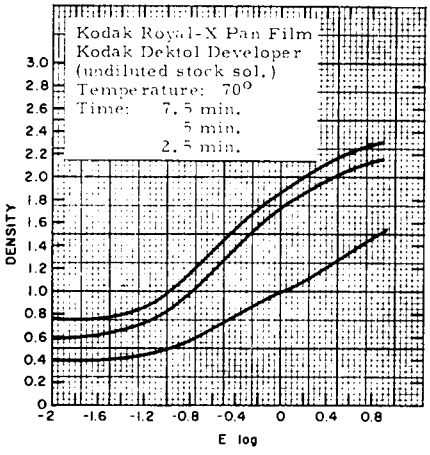
Time: 10 min.
7.5 min.
5 min.
DENSITY
E log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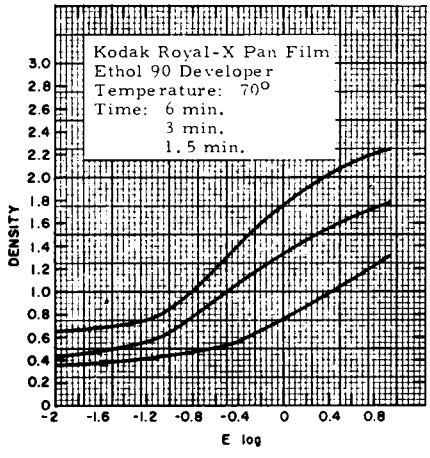
Temperature: 70°
Time: 7.5 min.
5 min.
2.5 min.
DENSITY
E log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3 min.
1.5 min.
DENSITY
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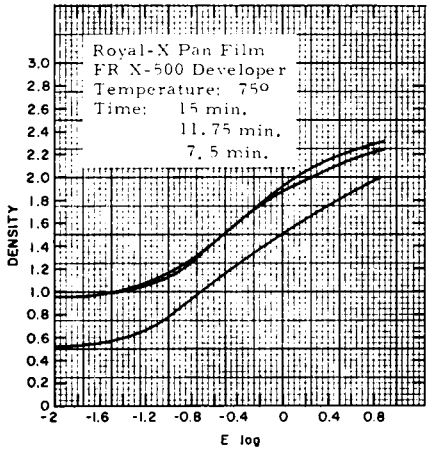
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FR X-500 Developer
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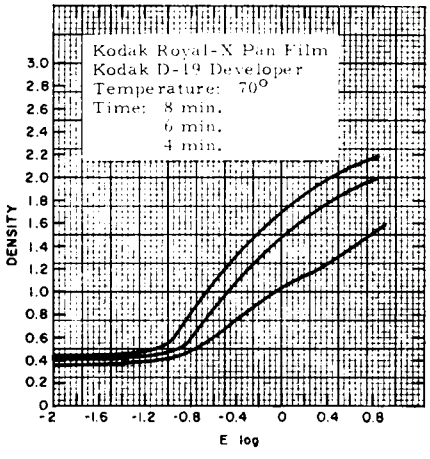
Time: 15 min.
11.75 min.
7.5 min.
DENSITY
E log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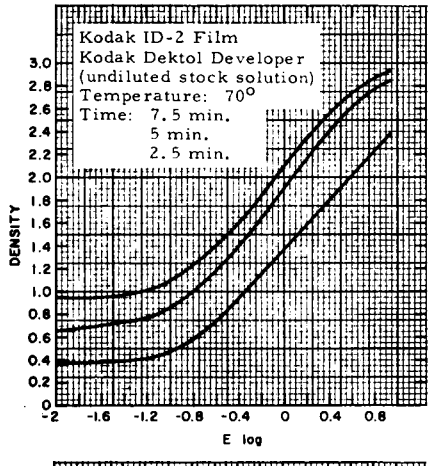
Temperature: 70°
Time: 8 min.
6 min.
4 min.
DENSITY
E log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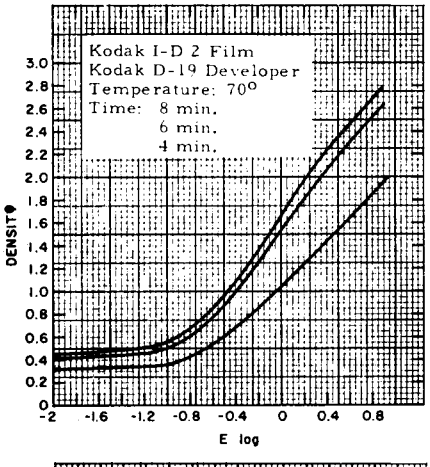
Time: 7.5 min.
5 min.
2.5 min.
DENSITY
E log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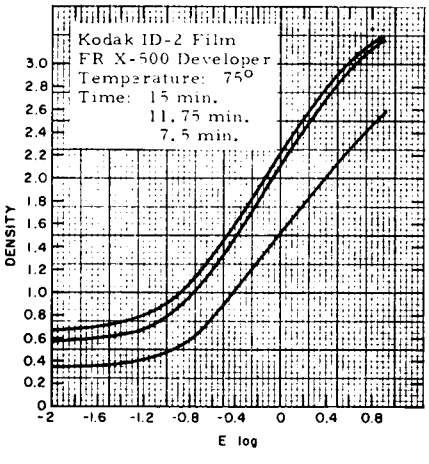
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11.75 min.
7.5 min.
DENSITY
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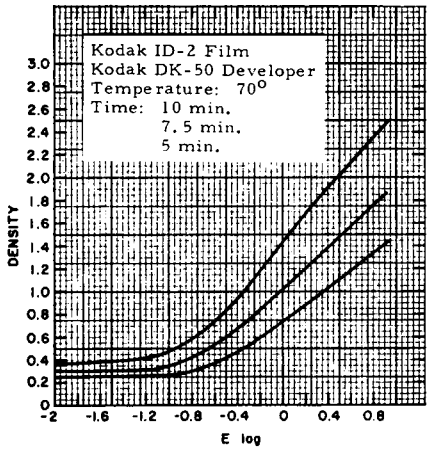
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Kodak DK-50 Developer
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7.5 min.
5 min.
DENSITY
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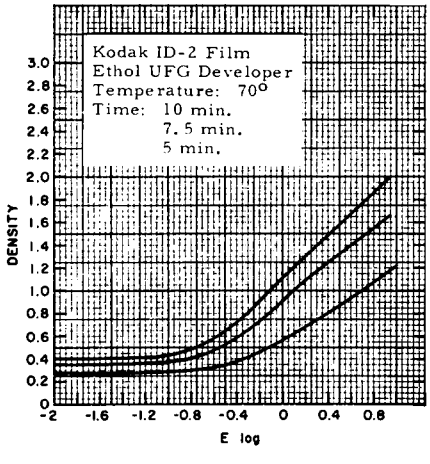
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5 min.
DENSITY
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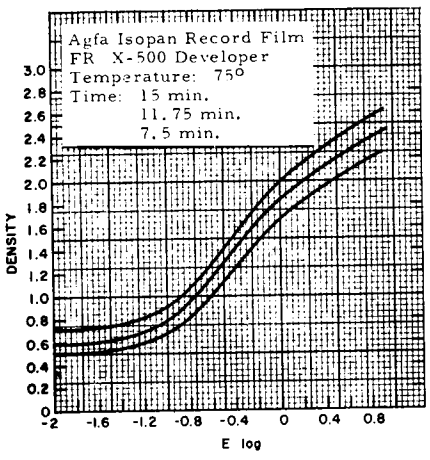
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FR X-500 Developer
Temperature: 75°
Time: 15 min.
11.75 min.
7.5 min.
DENSITY
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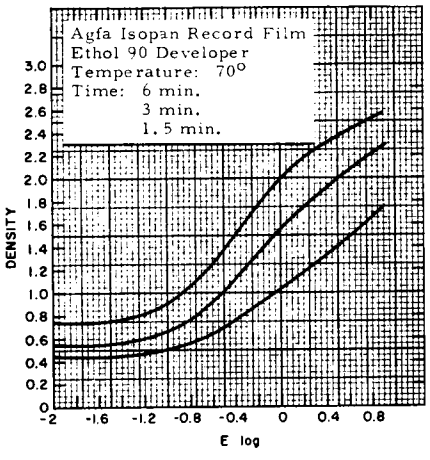
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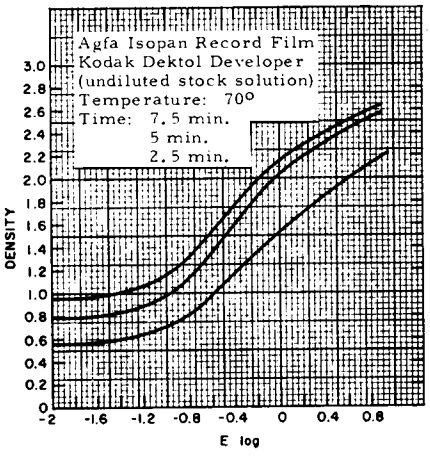
Ethol 90 Developer
Temperature: 70°
Time: 6 min.
3 min.
1.5 min.
DENSITY
E log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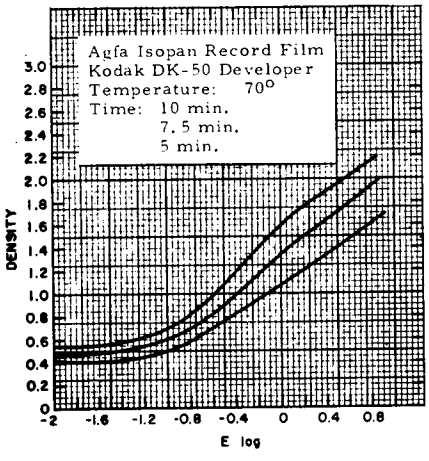
Kodak Dektol Developer
(undiluted stock solution)
Temperature: 70°
Time: 7.5 min.
5 min.
2.5 min.
DENSITY
E log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Kodak DK-50 Developer
Temperature: 70°
Time: 10 min.
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5 min.
DENSITY
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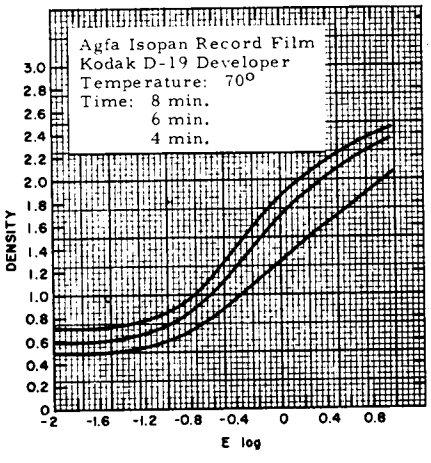
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Kodak D-19 Developer
Temperature: 70°
Time: 8 min.
6 min.
4 min.
DENSITY
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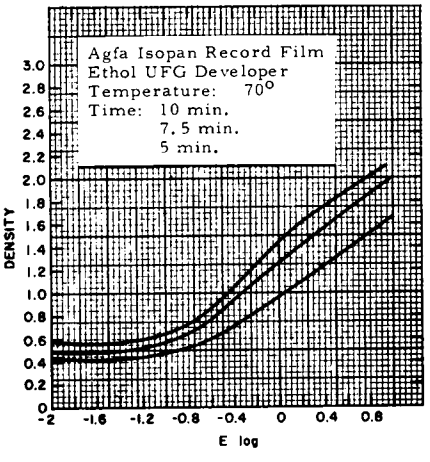
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5 min.
DENSITY
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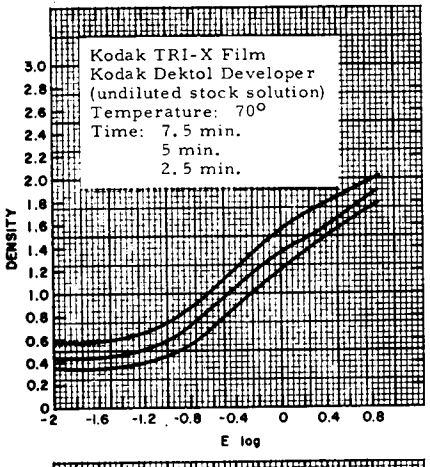
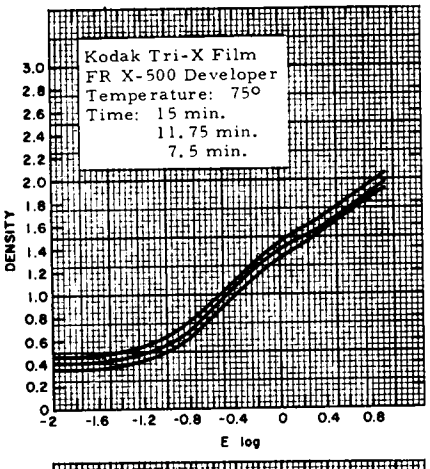

Kodak TRI-X Film
Kodak Dektol Developer
(undiluted stock solution)
Temperature: 70°
Time: 7.5 min.
5 min.
2.5 min.
DENSITY
E log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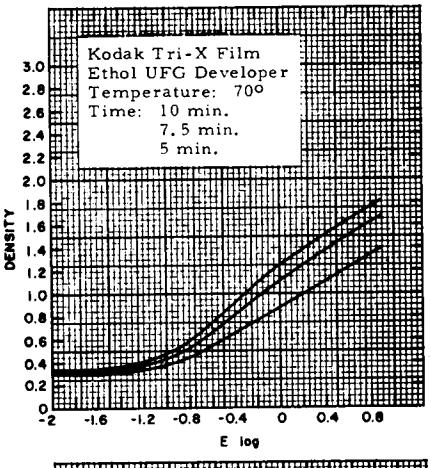
FR X-500 Developer
Temperature: 75°
Time: 15 min.
11.75 min.
7.5 min.
DENSITY
E log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Ethol UFG Developer
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Time: 10 min.
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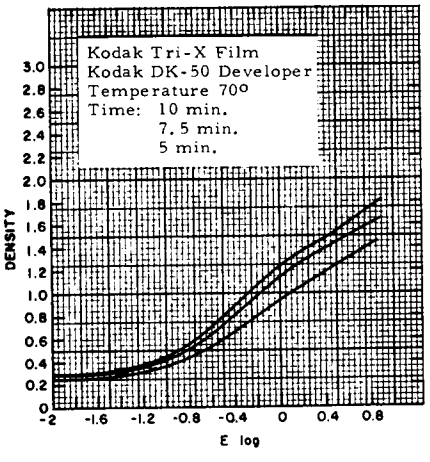
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Kodak DK-50 Developer
Temperature 70°
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DENSITY
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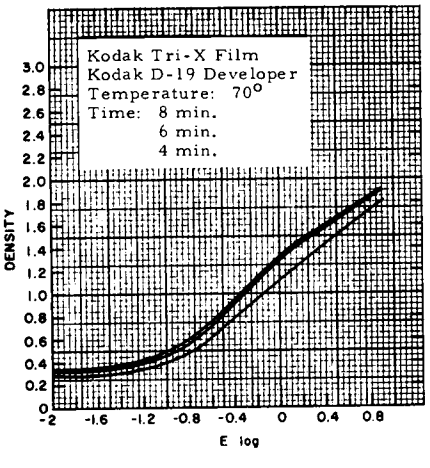
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Temperature: 70°
Time: 8 min.
6 min.
4 min.
DENSITY
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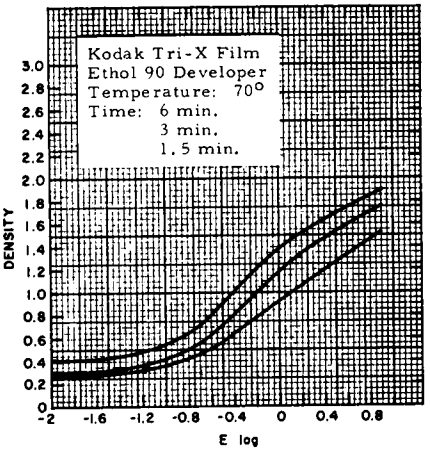
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Temperature: 70°
Time: 6 min.
3 min.
1.5 min.
DENSITY
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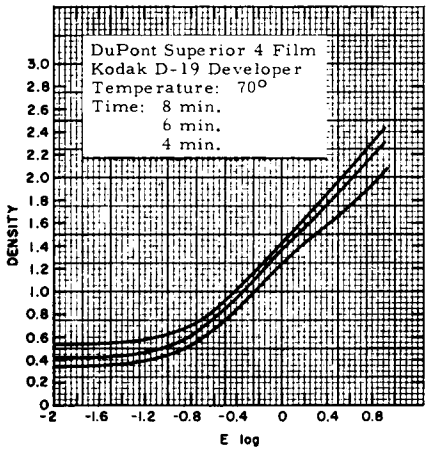
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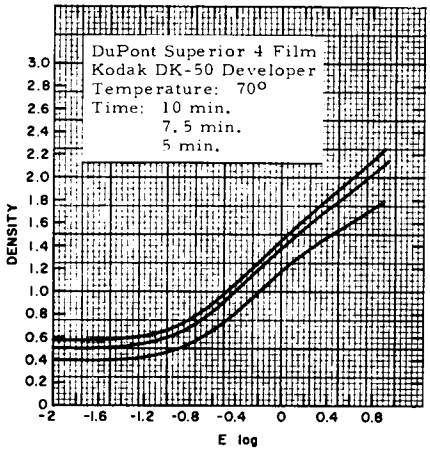
Kodak D-19 Developer
Temperature: 70°
Time: 8 min.
6 min.
4 min.
DENSITY
E log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Kodak DK-50 Developer
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DENSITY
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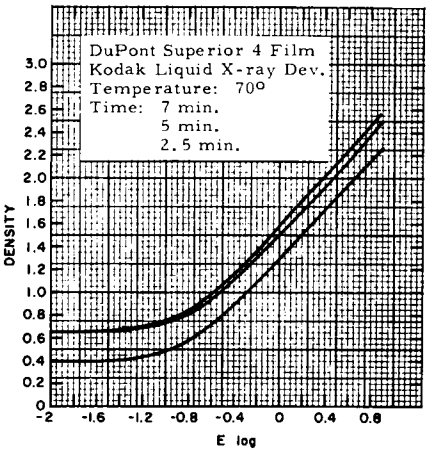
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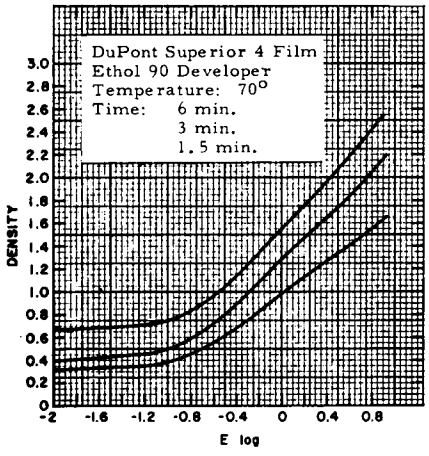
Kodak Liquid X-ray Dev.
Temperature: 70°
Time: 7 min.
5 min.
2.5 min.
DENSITY
E log


DuPont Superior 4 Film
Ethol 90 Developer
Temperature: 70°
Time: 6 min.
3 min.
1.5 min.
DENSITY
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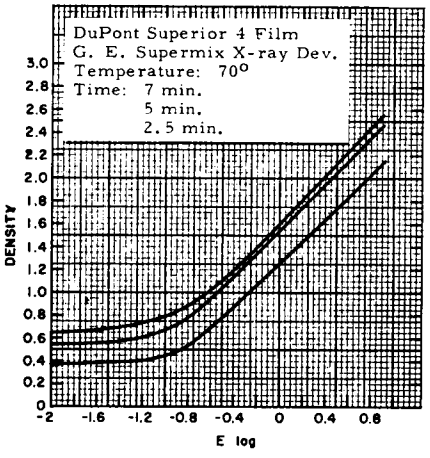
DuPont Superior 4 Film
G. E. Supermix X-ray Dev.
Temperature: 70°
Time: 7 min.
5 min.
2.5 min.
DENSITY
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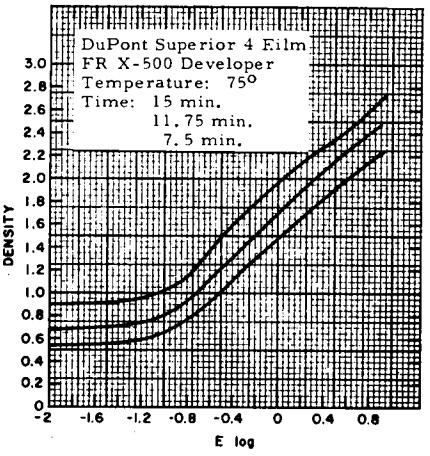
DuPont Superior 4 Film
FR X-500 Developer
Temperature: 75°
Time: 15 min.
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DENSITY
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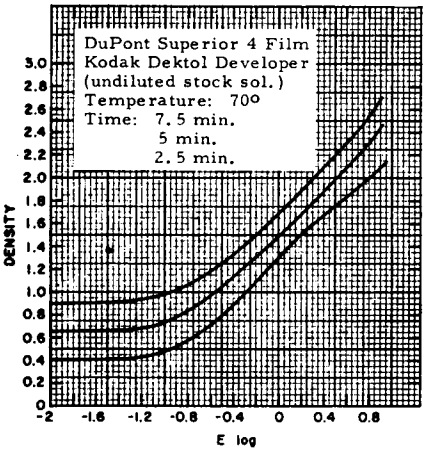
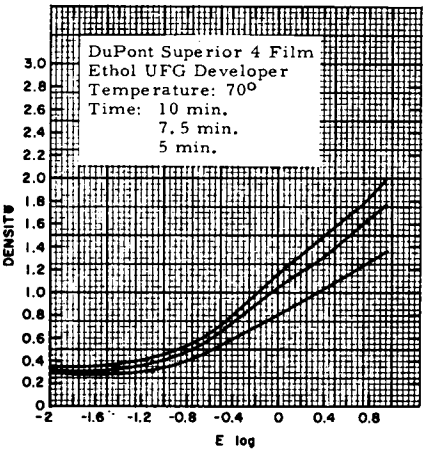
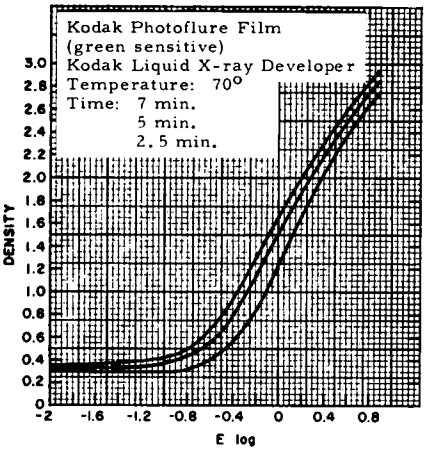
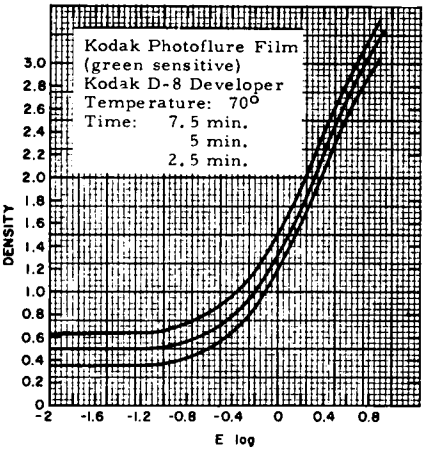
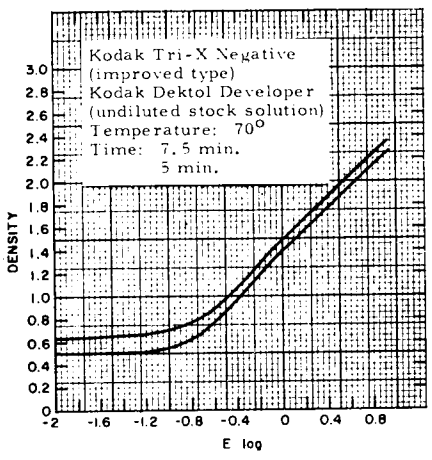
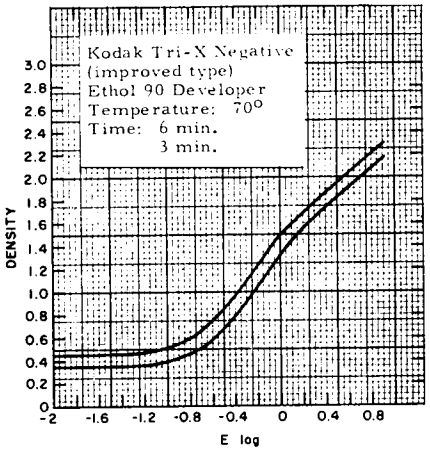

DuPont Superior 4 Film
Kodak Dektol Developer
(undiluted stock sol.)
Temperature: 70°
Time: 7.5 min.
5 min.
2.5 min.
DENSITY
E log

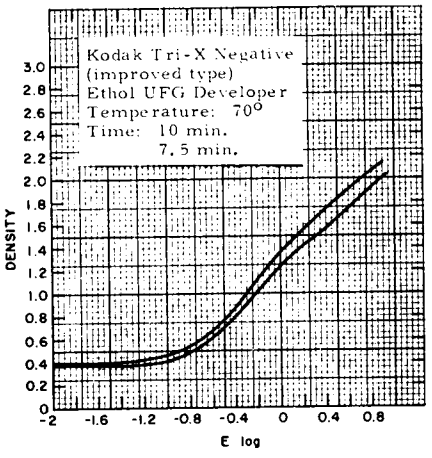

DuPont Superior 4 Film
Ethol UFG Developer
Temperature: 70°
Time: 10 min.
7.5 min.
5 min.
DENSITY
E log

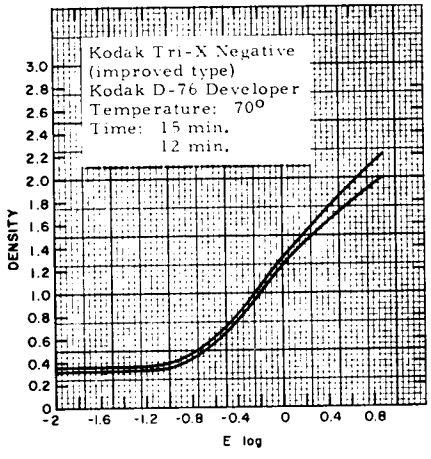

Kodak Photoflure Film
(green sensitive)
Kodak Liquid X-ray Developer
Temperature: 70°
Time: 7 min.
5 min.
2.5 min.
DENSITY
E log

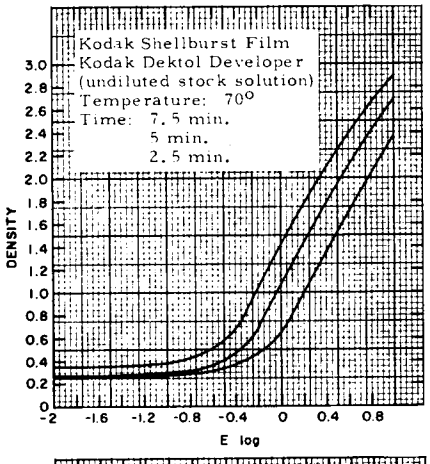

Kodak Photoflure Film
(green sensitive)
Kodak D-8 Developer
Temperature: 70°
Time: 7.5 min.
5 min.
2.5 min.
DENSITY
E log

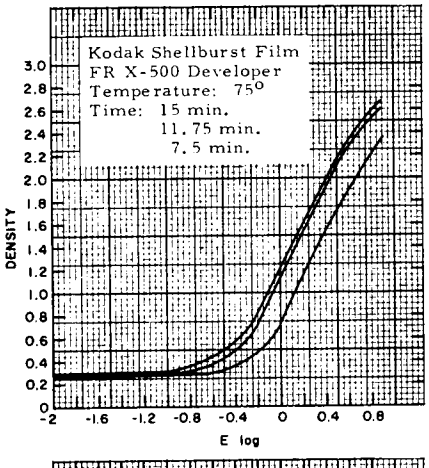

Kodak Tri-X Negative
(improved type)
Kodak Dektol Developer
(undiluted stock solution)
Temperature: 70°
Time: 7.5 min.
5 min.
DENSITY
E log

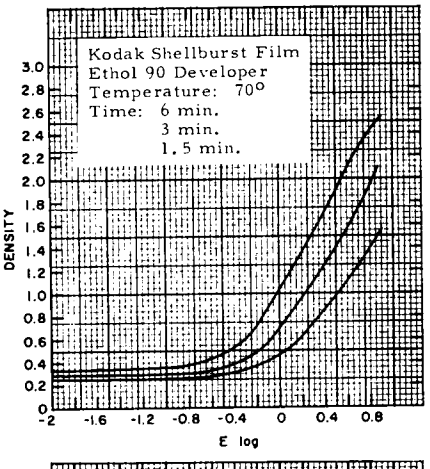

Kodak Tri-X Negative
(improved type)
Ethol 90 Developer
Temperature: 70°
Time: 6 min.
3 min.
DENSITY
E log

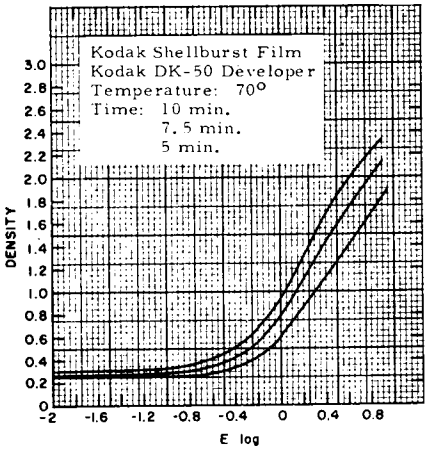

Kodak Tri-X Negative
(improved type)
Ethol UFG Developer
Temperature: 70°
Time: 10 min.
7.5 min.
DENSITY
E log

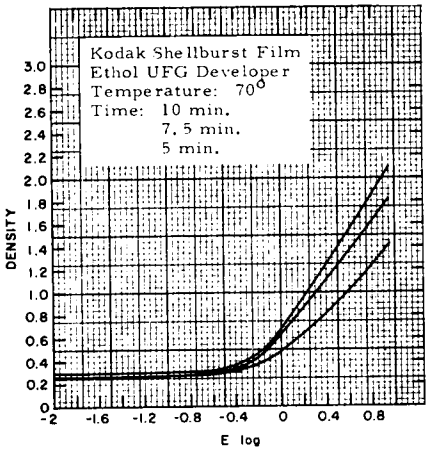

Kodak Tri-X Negative
(improved type)
Kodak D-76 Developer
Temperature: 70°
Time: 15 min.
12 min.
DENSITY
E log

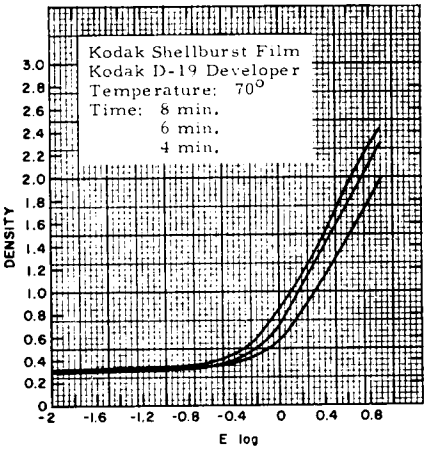

Kodak Shellburst Film
Kodak Dektol Developer
(undiluted stock solution)
Temperature: 70°
Time: 7.5 min.
5 min.
2.5 min.
DENSITY
E log


Kodak Shellburst Film
FR X-500 Developer
Temperature: 75°
Time: 15 min.
11.75 min.
7.5 min.
DENSITY
E log


Kodak Shellburst Film
Ethol 90 Developer
Temperature: 70°
Time: 6 min.
3 min.
1.5 min.
DENSITY
E log


Kodak Shellburst Film
Kodak DK-50 Developer
Temperature: 70°
Time: 10 min.
7.5 min.
5 min.
DENSITY
E log


Kodak Shellburst Film
Ethol UFG Developer
Temperature: 70°
Time: 10 min.
7.5 min.
5 min.
DENSITY
E log


Kodak Shellburst Film
Kodak D-19 Developer
Temperature: 70°
Time: 8 min.
6 min.
4 min.
DENSITY
E log

It has noticeably finer grain and higher acutance; and gains in contrast as the exposure level rises. This last quality, in particular, could be most useful when photographing subjects having low contrast and when ample illumination is available.

Special Purpose Films

The two higher-contrast films, Linagraph Shellburst and green-sensitive Photoflure, were both considerably slower than the regular high-speed films. Shellburst responded best to 7½-min development in Dektol and achieved the highest gamma (1.82) of all the high-speed films tested. Photoflure developed best in Kodak Liquid X-ray developer, for 7 min, but required nearly three times as much exposure to white light as Royal-X Pan. Shellburst required 50% more exposure than Photoflure.

A special film designed for spectroscopic purposes, Kodak ID-2, was slightly faster than either Tri-X or Superior 4. However, to achieve this speed it had to be developed in Dektol for 7½ min which produced an objectionably high fog. This fog could be reduced substantially, and the film increased in speed still more, by processing for 11 min in X-500 at 75 F; however, the danger of reticulation** and the pronounced frilling†† due to the softened film emulsion coating made this impractical.

Color Sensitivity

As mentioned previously, a xenon electronic flash unit was used as a light source in the sensitometric procedures. The color temperature was modified so that it was similar to that of noon sunlight by placing several layers of slightly off-white flashed opal glass between the light source and the test target.

Simultaneous with the exposure of the gray steps onto the films being tested, four small color-filter patches were photographed. These patches were the standard tri-color separation filters and a yellow filter. The densities produced by photographing each of the color patches were measured and the relative response to the color spectrum was determined.

Although unusual developing solutions and developing times affected densities, contrast, grain size and other film characteristics, the color sensitivity remained basically unchanged. This indicates that films having the general color qualities suitable for use in spectrographic applications could tolerate processing manipulation when greater speed or density range was required. This could be of value when working with a time-resolving spectrographic streak camera.

Kodak green-sensitive Photoflure film was the film most sensitive to green light generally similar in color to oscilloscope phosphor P-7 green. (Seven minutes development in Kodak Liquid X-ray developer produced maximum sensitivity without serious fog.) Royal-X Pan and Agfa Isopan Record were slightly less sensitive to green light. The tests confirmed that even under the operating conditions described in this paper, Superior 4 film behaves as a type C panchromatic film; that is, it has a high red-to-yellow sensitivity. Tri-X, including the newly improved Tri-X, is a type B film with slightly higher blue-to-green sensitivity; and at maximum development, it would produce greater density on the weaker oscilloscope traces than Superior 4 film.

**Wrinkling caused by expansion of film image layer without corresponding expansion of film base support.

††Irregular edge tearing which deposits film emulsion debris on image areas.