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Optimization of a Particular Aerial Photographic System by Simultaneous Intensification

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OPTIMIZATION OF A PARTICULAR
AERIAL PHOTOGRAPHIC SYSTEM BY
SIMULTANEOUS INTENSIFICATION

A Thesis

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by
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ABSTRACT

Under the conditions of a low-altitude, rapid access photographic system, a method of simultaneously intensifying image exposures is compared to low intensity latensification. The simultaneous intensification resulted in a speed increase of 2.4 times, while latensification produced a speed increase of 1.7 times. Latensification was more effective in most of the other responses that were analyzed: reduction of Contrast Index was less by 0.1; speed at the minimum gradient point defined by the untreated strips was increased by latensification by 1.29 times compared to 1.23 times by simultaneous intensification. The detective quantum efficiency of the latensified film was higher than that produced by simultaneous intensification except for the extreme toe region where simultaneous intensification did increase information content. The maximum DQE found for the untreated film was maintained by latensification; the simultaneously intensified film showed a reduction of maximum DQE by 0.66 . Because latensification permitted density increases with less loss of contrast, it was found to be the more effective treatment in terms of information, except in the extreme toe, leading to certain compromises. Simultaneous intensification may be suitable only for specialized applications in which use of an exposure in the extreme toe is required over optimum pictorial exposures.

INTRODUCTION

A specific case of aerial photography, to which this report is addressed, is one involving low-altitude, rapid access reconnaissance. The film is Kodak type Tri-X 5063, exposed at a shutter speed of from 1/1000 second to 1/3000 second and processed to a gamma of 0.75 to 0.80. The critical criteria here are the relatively short exposure times and the requirement to view information as soon as possible after initial exposure. The first presents a frequent condition of insufficient light for adequate film exposure; the second prohibits extensive post-exposure image intensification. Ideal optimization of exposures in this particular aerial photographic system must, then, utilize all possible developable grains in the exposed emulsion without appreciably lengthening film processing after exposure.

Two methods of latent image intensification known for many years are pre- or post-exposure applications of a diffuse exposure.[1] The pre-exposure of the emulsion to a diffuse light source is known as hypersentization; post-exposure is latensification. Both treatments are assumed to be, in essence, the addition of a uniform exposure to the main image exposure that results in a net increase of density and apparent film sensitivity (speed).[2] However, the conditions for their application, and the resultant effects, differ somewhat.[3,4]

Hypersensitization takes the form of a high-intensity, short-time, diffuse pre-exposure that forms latent image (or fog) sites uniformly throughout the emulsion (surface). These sites are relatively small, but their existence allows a subsequent longer-time exposure of relatively low intensity (the image exposure) to produce latent image that grows more readily. Such treatment may capture latent image that might otherwise be lost because of low intensity reciprocity failure (LIRF). Latensification, in the form of a long-time, low-intensity post-exposure, produces the conditions for growth of latent image (small sites) that has been produced from a relatively short, high-intensity image exposure. This treatment may capture latent image that might otherwise be lost because of high intensity reciprocity failure (HIRF). Short of retrieving image that could be lost through several inefficiencies of the photographic process, the application of a supplementary, diffuse exposure merely adds exposure to that available from the object to be imaged.

Latensification is generally considered as the more effective of the two treatments.[4] Its supplementary exposure is normally one that falls well within the limits of the emulsion's inherent LIRF. As a result, in those areas of original image exposure, substantial growth of latent image occurs. In areas of no original image exposure, the effects of LIRF limit additional creation of fog from the supplementary exposure. On the other hand, hypersensitization must produce stable latent image (sites) r. sub. throughout the emulsion (surface), thereby creating fog in areas of no image exposure.

Experience has shown that, although hypersensitization and latensification should be at least additive to image exposure, they seldom attain the limits of additivity of exposures in practice.[5] This occurs because of the various inefficiencies associated with latent image formation that also apply to these two processes. There is some inevitable latent image loss occurring between the pre-exposure and the main exposure, as well as some effect of HIRF and LIRF on both treatments.

A third method of secondary exposure, not yet thoroughly investigated, is the application of a uniform supplementary exposure simultaneously with the image exposure. This will be called "simo-fogging,"[6] or simultaneous intensification. Its advantages, assuming that it can produce comparable film speed increases, are readily apparent. It does not lengthen the time period between initial exposure and access to information. It is not as susceptable to latent image losses because it is applied simultaneously with initial film exposure. Simo-fogging does promise to attain the limits of additivity of exposures,[5] and hence should be the most effective treatment in terms of film speed.

Despite simo-fogging's apparent advantages, such a method of intensification may not be more effective than latensification. It is therefore very important to carefully compare the two treatments. Such a comparison must, to be complete, include image quality as well as film speed.

Any increases in film speed will, by definition, be dependent upon the extent to which density is increased. Here, the increase in the level of base and fog density is critical. Latensification has the advantage of operating within the limits of the emulsion's LIRF, while simo-fogging must operate at the same exposure time as the main image exposure. The comparison, then, involves the effects of latensification and simo-fogging when both treatments produce the same level of base and fog density.

The effect of the intensifying treatment on image contrast will in turn affect both film speed and image quality. It is known that latensification serves to increase film speed while lowering the maximum gradient of the characteristic curve; the net increase in density decreases ? with increasing density towards the shoulder of the curve. Figure 1 represents, in qualitative terms, the relative responses of intensification treatments based on current experience.[5]

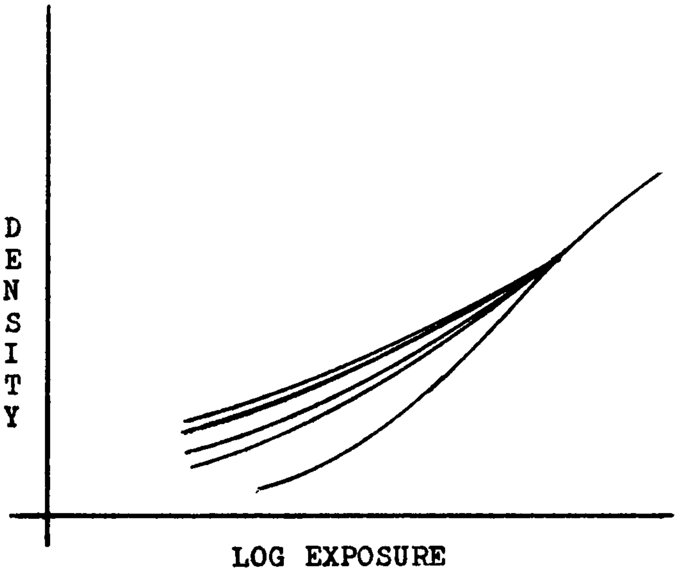


Figure 1: Qualitative (relative) comparison of image intensification by diffuse supplementary exposure. The curves illustrate, from top to bottom: additivity of exposures, simo-fogging, latensification, hypersensitization, and untreated.

One of the most comprehensive comparisons of simo-fogging and latensification is detective quantum efficiency (DQE). It is based on the ratio of output signal-to-noise to input signal-to-noise.[7] For photographic emulsions, this ratio considers film speed, granularity (noise) and contrast. Latensification has been included in a recipe for achieving maximum DQE, as was simultaneous intensification (without supporting data):[8]

I. fast informational exposure;
II. slow, uniform post-exposure;
III. "If I + II does not arrive at the density for optimum DQE, add a simultaneous wash exposure to I." [8]

It is therefore important to determine the extent to which simo-fogging and latensification affect the information capacity (image quality) of the emulsion under test by comparison of DQE.

Simultaneous intensification, at an exposure time of 1/1000 second, may be subject to effects of HIRF. The main image exposure together with simo-fogging could conceivably surpass the emulsion's capability to accept the overall exposure, characteristic of HIRF. Such a condition could be partially overcome by applying the supplementary exposure (at 1/1000 second) just before, or just after, the image exposure. This variation is essentially hypersensitization and high intensity latensification applied with very short (milliseconds) delays between first and second exposures, and is an essential test for adequate comparison of treatments.

Because of the complexities of latent image formation, and because of the variability among different emulsions, no attempt is made here to quantitatively predict the ultimate effect of simo-fogging for the emulsion under test. Much of the previous work with latensification has been done with emulsions that were experimental or are now out-of-date. The effectiveness of latensification has been supported by several computer models based on a decreased exposure threshold for developable grains.[8] Further, it has been informally reported that simo-fogging produced the greatest effect on Royal-X Pan,[6] but the conditions under which these effects were found (oscillography) and the film type make extrapolation of results impossible. This project, then, becomes one of much "trial and error," with potential for additional optimization upon suitable refinement of identified areas. The overall aim here is to identify areas for optimization of a particular photographic system, with applications and assistance in predicting effects for pictorial photography in general.

EXPERIMENTAL

The overall aim of this project was to attempt application of a system of simultaneous intensification to a particular aerial photographic situation. Modifying and using an aerial camera, one later to be used in practice, was first attempted. The camera, however, limited the repeatability of supplementary exposures just before and just after the image exposure because the camera shutter (continuous belt -- focal plane) required a manually induced trigger: the interval between the first and second exposures was thus difficult to control. This interval also depended upon the velocity of the shutter since the exposure slit was a part of the continuous belt. Generally then, it was found that use of the camera experimentally was impractical; it was designed for multiple single exposures that produced long strips of exposed film incompatible with single-shot requirements here and available processing apparatus. Modification of the camera to accept a means of simultaneous intensification was left to a later stage of design engineering, the adviseability of which would depend upon the results shown here.

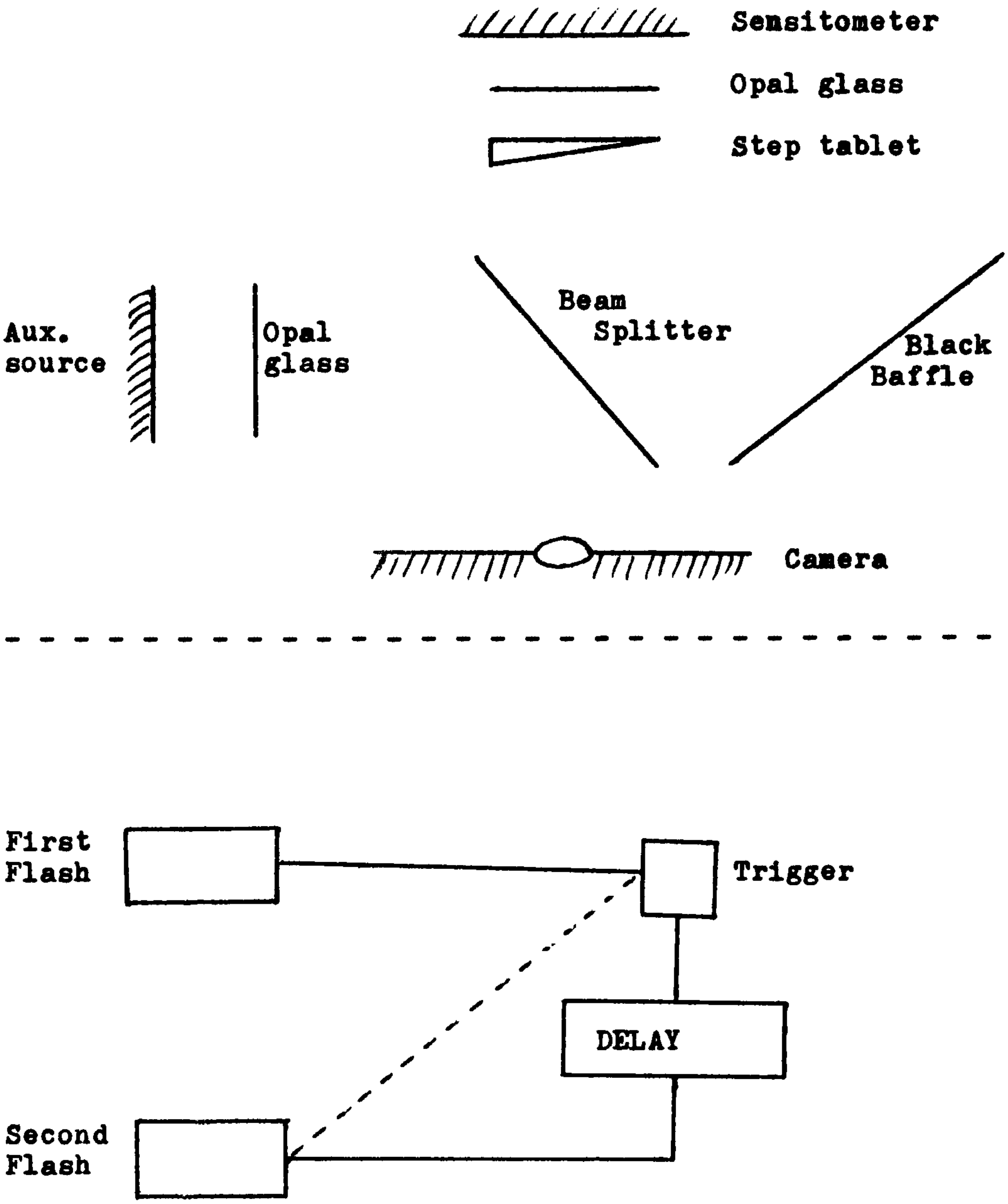
Apparatus, similar to that described by Tamura,[9] was ultimately chosen. The image exposure was made with an EG&G Sensitometer (Mark VI) set for an exposure time of 1/1000 second and equipped with a Kodak number 2 step tablet. The step tablet was imaged on individual film strips by a 4 X 5 view camera looking through an enclosed box with blackened sides. Neutral density filters were added behind the step tablet (toward the light source), and the lens aperture was adjusted to allow an exposure that produced a visible image of the third step when the film was processed to the required gamma. The auxiliary flash unit for the diffuse supplementary exposures was constructed with a circuit identical to the main sensitometer; this unit was plugged into the sensitometer for power. The flash tube, main discharge condenser, and trigger coil were of the same type and brand for both flash units (auxiliary and sensitometer). The auxiliary unit was adjusted with the aid of an oscilloscope to provide precisely the same flash duration as the original; this ensured that the two exposures would be simultaneous when so desired. For supplementary exposures, neutral density filters again provided the necessary attenuation.

A timer-delay circuit was constructed (see Appendix A) to allow adjustments of the time between flashes: simultaneous, 10^{-3} and 10^{-2} second. Actual delay times were found to be (by oscilloscope measurement) 1.3 milliseconds and 10.2 milliseconds respectively, with the shorter time permitting commencement of the second flash before the first had completely terminated.

The two flash units were placed in front of the camera lens as shown in Figure 2. Since a beam splitter of a high transmittance-to-reflectance ratio was required, a thin glass plate of the type used for high resolution emulsions was selected. The uniformity of the supplementary exposure, particularly in the area of the step tablet of most concern, was verified by exposing and processing strips of film to a density of approximately 0.5 and reading random areas of the strip. The maximum variation found was 0.03 density unit, representing six percent (6%). The variation was much less in the small area of the step tablet of most concern, that area which provided exposure in the toe region of the characteristic curve.

The control strips and the simultaneously intensified strips were dispersed randomly among the strips that were pre- and post-exposed (flashed) at the two short delay times. All were processed, again randomly, in DK-50 developer solution diluted 1 : 1 ; the control strips were used to determine the developing time for all, and were processed to an average gamma of 0.72. Gaseous burst agitation was selected as the most repeatable of the methods available, using one second bursts at 10 seconds intervals and a pressure of four pounds throughout. The variations in development times were as follows: control,

Figure 2: Experimental Apparatus.



flashed, and normally latensified strips were developed for seven minutes to attain the average gamma for control; development for the simo-fogged strips (simo + dev.) to regain the gamma of control (considered as an additional treatment) was for 8½ minutes; for comparison purposes, control, simo-fogged and latensified strips were processed for 20 minutes. The temperature of the processing solutions was maintained at 74 degrees Fahrenheit (room temperature).

Normal low intensity latensification of the film was accomplished with a Simmon Omega condenser enlarger that was equipped with a GE number 211 lamp. This source was attenuated to a level of illuminance that produced the same gross fog as did the auxiliary flash, while operating well within the region of the emulsion's LIRF. Diffuse exposure time was 20 seconds, occurring within two minutes of initial exposure with the apparatus (except for the auxiliary flash unit of course) illustrated in Figure 2. The images were latensified with and without filtration to the same approximate colour temperature of the Xenon flash tubes to avoid any effect from changes in colour temperature.

All diffuse densities were determined with a MacBeth TD-504 Densitometer (digital). Granularity data for DQE computation were generated by an Ansco Model IV Micro-densitometer at an effective scanning aperture diameter of 21.5 micrometers. It was assumed that Selwyn granularity varies as the square root of density[10] for film processed under constant conditions. The granularity measurements here were accordingly taken at one specific density level (on a control strip) and applied to the appropriate density levels for control, simo-fogged and latensified strips. It was considered that the additional development of some simo-fogged strips constituted a change in processing conditions; consequently granularity for the simo-fogged plus development strips was determined separately at one specific density level, and applied to the other density levels for ~~for~~ this treatment only. Data points for granularity numbered 260 and 250 respectively.

Film speed, as defined for this study, follows the definition used for this film type under the conditions of its use in the particular photographic system: reciprocal of the threshold exposure, where the threshold exposure is that which produces a density of 0.1 above base and fog density.

$$S = \frac{1}{H_s} \qquad (1)$$

Contrast Index was determined from the plots of the characteristic curves (from the raw data of each treatment) through the use of an Eastman Kodak Contrast Index Meter Model B.[11]

Minimum gradient[12] was calculated from the determination of average gradient of the characteristic curves of the control strips through the use of a fractional gradient meter. This minimum gradient was then applied to the results of simo-fogged, simo-fogged plus development, and low intensity latensified strips to determine the minimum density and exposure at which the minimum gradient occurred for all treatments. The minimum gradient speed was then defined as 0.8 of the reciprocal of this minimum exposure, thus:[13]

$$S_m = \frac{0.8}{H_{min}} \qquad (2)$$

where H_{min} occurs at $G_{min} = 0.3 \times \bar{G}_{control}$

A second order regression analysis[14] of density as a function of the logarithm of exposure was done for control, simo-fogged, simo-fogged plus development, and low intensity latensified data. A limited range of log exposure was chosen to retain maximum validity of the resultant second order equations (the range is that covered by Table 6). These equations (see RESULTS) permitted more accurate determination of minimum gradient speeds, and more accurate gradients for DQE calculations.

All applicable data were subjected to a statistical test of two populations[14] using Student's t critical values at a two-tailed alpha-risk of 0.05. Except as otherwise noted in tables of results, pooled values are reported (both for mean and standard deviation) in all cases of insignificant differences. All data are reported as mean value/standard deviation wherever applicable.

Formulae for detective quantum efficiency take several forms[5,7] although its principle has been well defined. It was decided to use a form that contained the most familiar terms:[8]

$$DQE = \frac{(0.434)^2 E}{H(A\sigma^2)} \left\{ \frac{dD}{d \log_{10} H} \right\}^2 \qquad (3)$$

where, E = photon energy
H = exposure energy
$A\sigma^2$ = square of Selwyn granularity
and the remaining term is the square of the gradient of the characteristic curve.

Taking E in this case to be an average photon energy (assuming that the Xenon flash reproduced the visible spectrum) at a wavelength (λ) of 490 nanometers, and using the equation:

$$E = \frac{hc}{\lambda} \qquad (4)$$

$h = 6.6238 \times 10^{-27}$ erg-sec.
$c = 2.9979 \times 10^{10}$ cm/sec.

then $E = 4.0525 \times 10^{-12}$ erg (constant)

The square of the gradient was found from the second order regression equations (differentiated).

RESULTS

NOTE: In the tables of most treatment results, the mean value/standard deviation is reported.

Under the established processing conditions, it was found that the film under test produced an inherent emulsion and processing fog level of 0.13 to 0.14 density units. This was calculated from a base density of 0.22 and from the relatively high base plus fog density (for the control strips) of 0.35 to 0.36. This condition may have had an effect on the intensity of the supplementary exposure that was chosen for simo-fogging: that producing a base and fog density that was 0.06 density unit higher than the control (see Table 1 below). The film speed for the three simo-fogging treatments attempted were within ± 7 of each other (see also Table 2).

Table 1: Selected optimum* for Simo-Fogging.

	Base and fog Density	Base and fog Increase	Maximum density Increase
Control	.36	----	----
Simo-1	.39	.03	.10
Simo-2	.42*	.06*	.18*
Simo-3	.59	.23	.29

Application of the supplementary exposure used for simo-fogging just before and just after the main exposure (noted as essentially hypersensitization and high intensity latensification at short delay times) produced exactly the same effects as did the simultaneous application. Hence, the results shown here are for simo-fogging, simo-fogging plus additional development to regain control gamma, and normal low intensity latensification, all compared to the control (untreated) strips. The usual sensitometric results are shown in Tables 2 and 3, including the treatments developed for 20 minutes.

Data for control and the three treatments, in terms of minimum gradient as previously defined, are shown in Tables 4 and 5.

The supplementary exposure was not considered as contributory to the exposure used in the calculation of any values; it was considered as a method of enhancement only. In fact, if the supplementary exposure was added to image exposure, the speed value was lowered. Relative log exposure values were used throughout.

The second order regression analysis produced the following equations, accompanied by the applicable coefficient of determination (R^2):

$$\text{Control: } D = .4264 - .3329(\log H) + .4335(\log H)^2$$
$$R^2 = .984$$

$$\text{Simo-fogged: } D = .4704 - .0341(\log H) + .2336(\log H)^2$$
$$R^2 = .942$$

$$\text{Simo + dev.: } D = .5768 - .0378(\log H) + .2532(\log H)^2$$
$$R^2 = .991$$

$$\text{Latensified: } D = .4674 - .1678(\log H) + .3883(\log H)^2$$
$$R^2 = .996$$

no significant difference Why?

Table 2: Treatment Results

	B + F D/σ	S X 10^{-3}	Gamma	Contrast Index
Control	.358/.008	136.2/7.5	.717/.011	.722/.004 ?
Simo-fogged	.417/.011	331.3/11.5	.661/.006	.538/.010
Simo + dev.	.518/.010	331.3/11.5	.717/.011	.573/.015
Latensified	.417/.011	226/12.1	.661/.006	.607/.006
20 min. dev.				
Control	Note 1	168/9.5	.988/.005	.903/.011
Simo-fogged	.670/.014	317/31.1	.884/.005	.70/.014
Latensified	.560/.014	206.5/3.5	.810/.014	.805/.007

Note 1: Two sets (sample size two each) of controls at 20 minutes development were run, one set each with simo-fogging and latensification at 20 minutes development. The level of base and fog density between the two sets was significantly different (.555/.007 and .475/.007). However, the other values were not significantly different between the two sets, and the values reported here represent pooled values.

Note 2: The difference in speed (S) shown between simo-fogging and simo-fogging with 20 minutes development is not statistically significant. Similarly, the difference between latensified and latensified with 20 minutes development Speeds is not statistically significant.

Table 3: Speed ~~difference Factors~~ RATIOS (highest divided by lowest)

	Control	Simo	Simo + dev.	Latensified
Control	-----	2.4 X	2.4 X	1.7 X
Simo-fogged	-------	------	--------	1.5 X
Simo + dev.	-------	------	--------	1.5 X
Latensified	-------	------	------------	-------
20 min. Control	1.2 X	2.0 X	2.0 X	1.3 X
20 min. Simo	2.4 X	------	--------	1.5 X
20 min. Latens.	1.7 X	1.6 X	1.6 X	-------

Table 4: Minimum Gradient Speeds Relative to Control

	$\bar{G}$ / σ	G_{min} / σ	D_{min} / σ	S_m X 10^{-3}
Control	.643/.010	.193/.003	.383/.005	212.3/15.3
Simo-fogged	control	control	.51	261.0/3.7
Simo+ dev.	control	control	.61	280.3/4.0
Latensified	control	control	.47	274.3/2.7

Note: Data for control were found from the graphs of individual sample characteristic curves. Data for the treatments were found through computation from the equations of density versus the logarithm of exposure by second order regression analysis.

Table 5: Speed (S_m) ~~Difference Factors~~ RATIOS (highest divided by lowest)

	Simo-fogged	Simo + dev.	Latensified
Control	1.23 X	1.32 X	1.29 X
Simo-fogged	------	1.07 X ← Simo + dev / simo	1.05 X ← Latens / simo
Simo + dev.	------	------	1.02 X ← Latens / simo + dev

Figures 3 and 4 illustrate the characteristic curves achieved from simo-fogging and low intensity latensification treatments, compared to control. The maximum density increase, occurring at one particular step, with simo-fogging was 0.18, achieved with a 0.06 increase in base and fog density; for latensification, the maximum increase was 0.14 with a 0.06 increase in base and fog density. All characteristic curves are plotted from raw data, not from the regression equations.

Visually, both the simo-fogged and the latensified strips produced images of three more 0.15 logarithmic exposure steps of the step tablet than were reproduced on the control strips.

The relative stability of the latent image for the emulsion under test was determined over a 24-hour period. Untreated film processed 24 hours after exposure showed a fade of a maximum of 0.07 density unit. It was concluded that processing within three minutes of exposure would be acceptable for the purposes of this project, particularly since the fade was much less than this maximum in the low-density area of the characteristic curve (of most concern here). The fade of simo-fogged material also verified that these processing conditions were adequate. Sample fade data are shown in Appendix B.

The results of simo-fogging were compared to strict additivity of exposures (Figure 5); the additivity curve was the same as that produced by simo-fogging. Normal low intensity latensification, then, with its generally lower densities when compared to simo-fogging, was somewhat less than additive since the illuminance used for these latensification treatments was adjusted to produce the same photographic effect (base plus fog density) as was produced by simo-fogging. Further, because of LIRF, the exposure used for low intensity latensification must have been somewhat greater than that for simo-fogging.

Figures 6 and 7 illustrate the results of processing nearing completion (20 minutes development). Here, the effect of extended development, after the various treatments shown, on the contrast in the toe and on film speed as tabulated in Table 2 were the significant results.

Exposure through the step tablet that was made on film placed directly on the sensitometer did not result in a difference in curve shape. There was not, then, detectable flare[15] introduced by the camera/box apparatus.

Table 6 contains the computations for DQE as defined for this study. The range of exposure over which the regression equations were calculated was sufficient to achieve the maximum DQE point for each treatment. These results are perhaps best shown by the curves of Figure 8.

As an easy means of summarizing all of the results for the various treatments, and of subsequently comparing them, Table 7 is presented. If it is assumed that the five criteria listed are of equal importance (DQE is more important than the others), the following ranking from best to worst treatment is found by totalling the ranking values of Table 7:

1. Latensified and simo + development;
2. Control;
3. Simo-fogged.

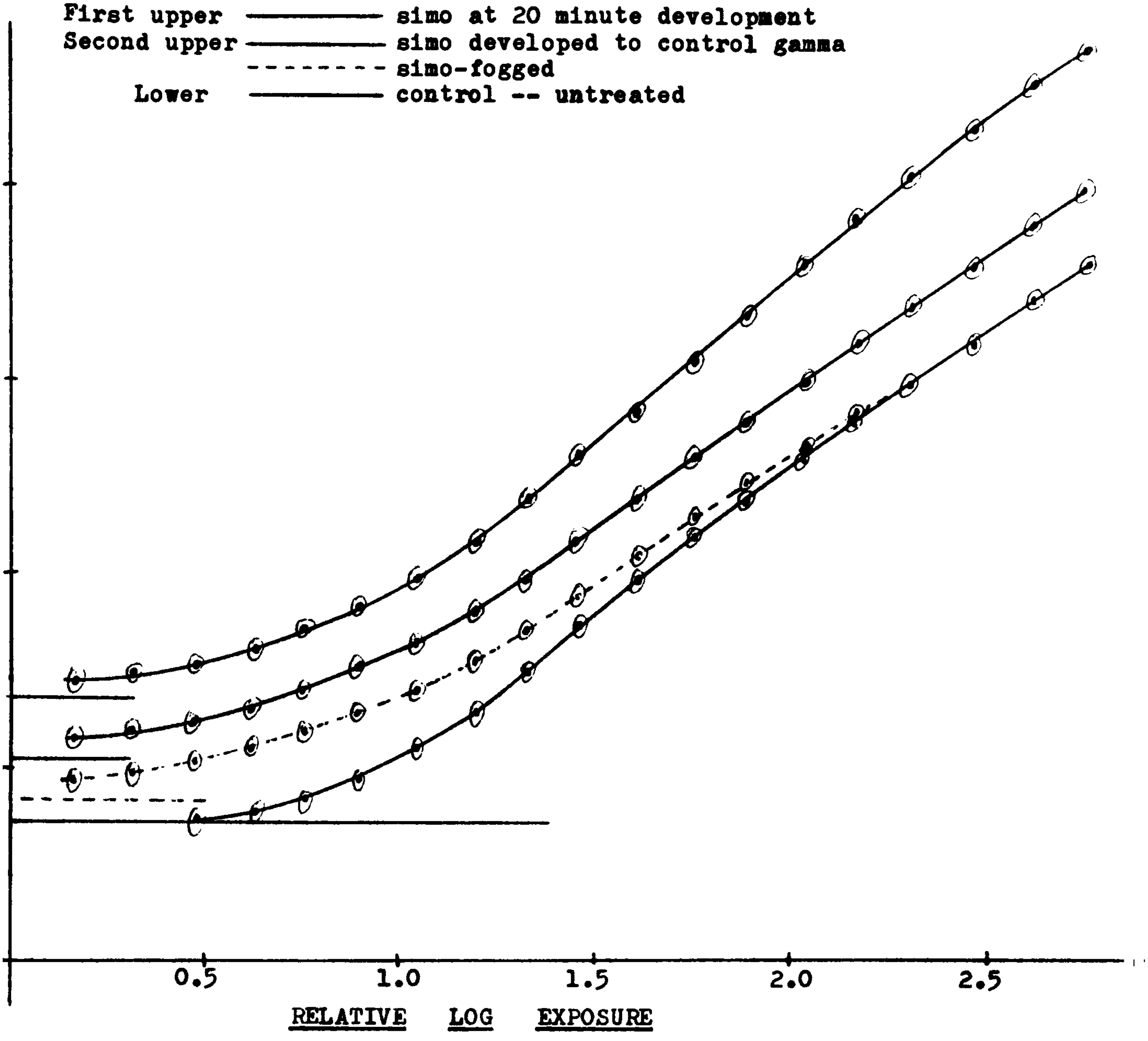


Figure 3: Characteristic curves (density versus log exposure) of the simultaneously intensified film compared to the untreated control. Curves are plotted from mean densities at relative log exposure steps. The horizontal lines indicate the level of base and fog density for the curve immediately above the respective line.

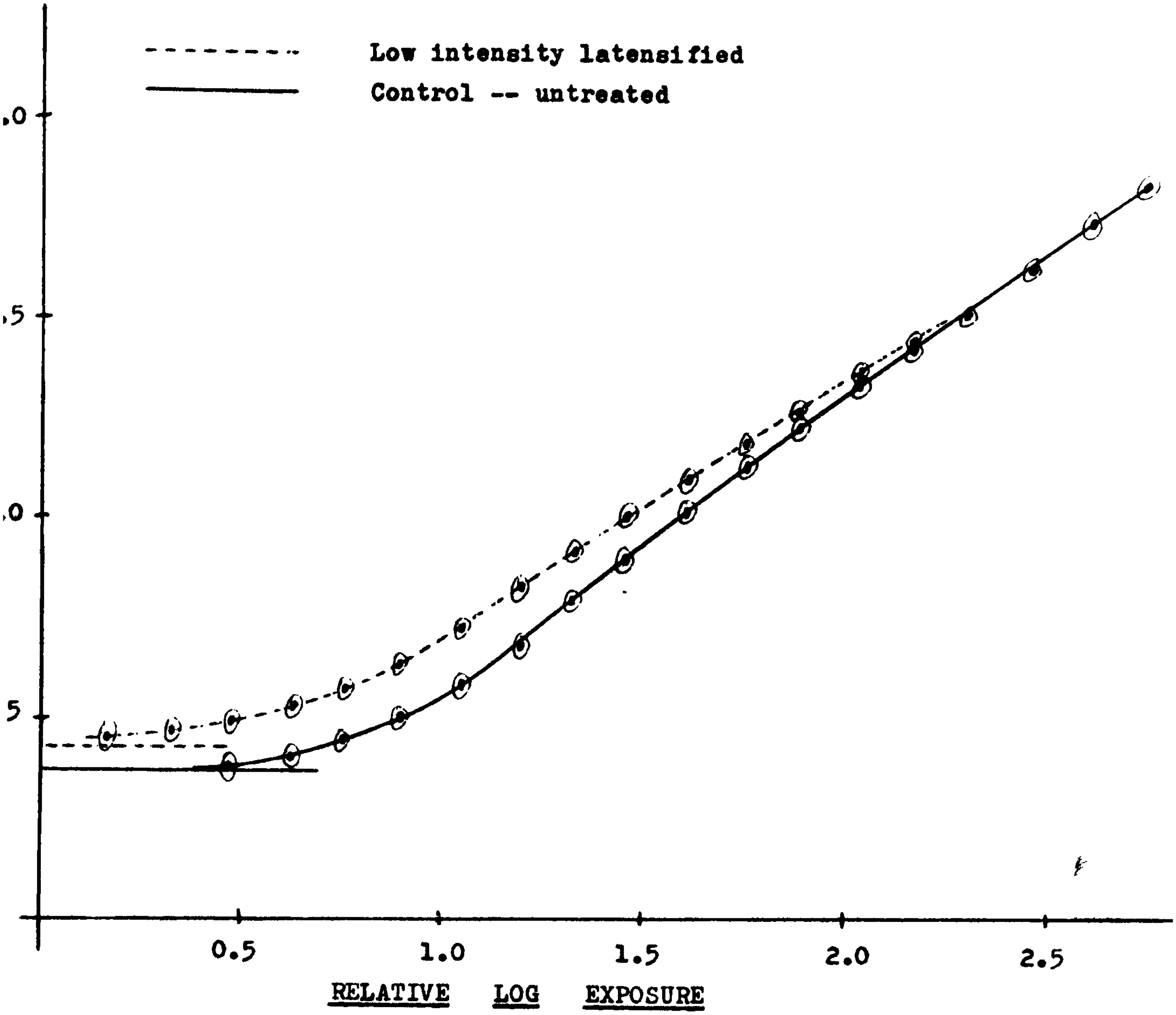


Figure 4: Characteristic curves of low intensity post-exposure latensification compared to its control. Curves are plotted from mean densities.

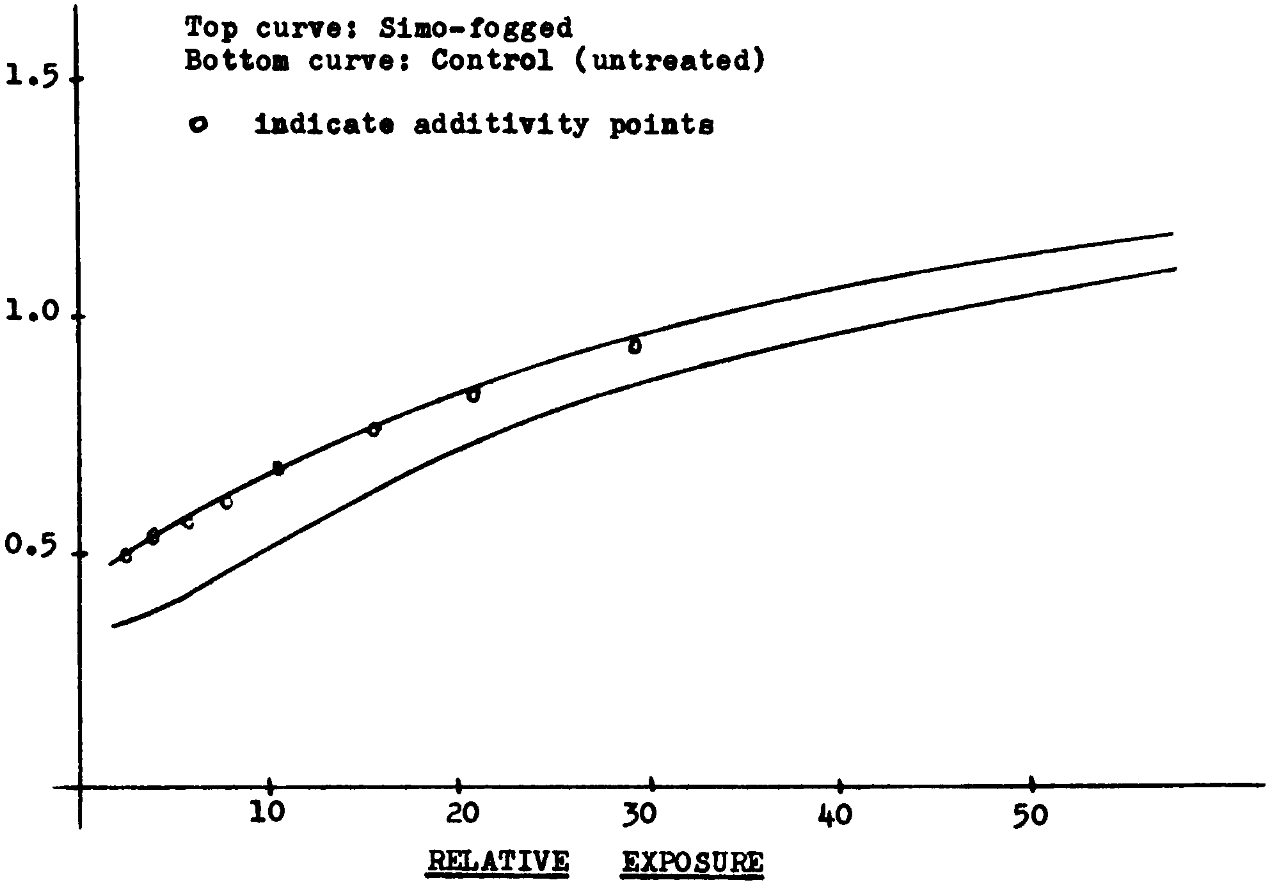


Figure 5: Characteristic curves, density versus exposure, of the control strips and the simo-fogged strips. Exposure additivity points are superimposed on the simo-fogged film curve, and were calculated from strict additivity of the simo-fogging exposure to that producing the control strips. The relative exposure used for simo-fogging was determined from the diffuse density of strips exposed to the supplementary flash only.

NOTE: Additivity of exposures is illustrated for eight exposure steps only, beyond which the uniformity of the auxiliary flash is not reliable.

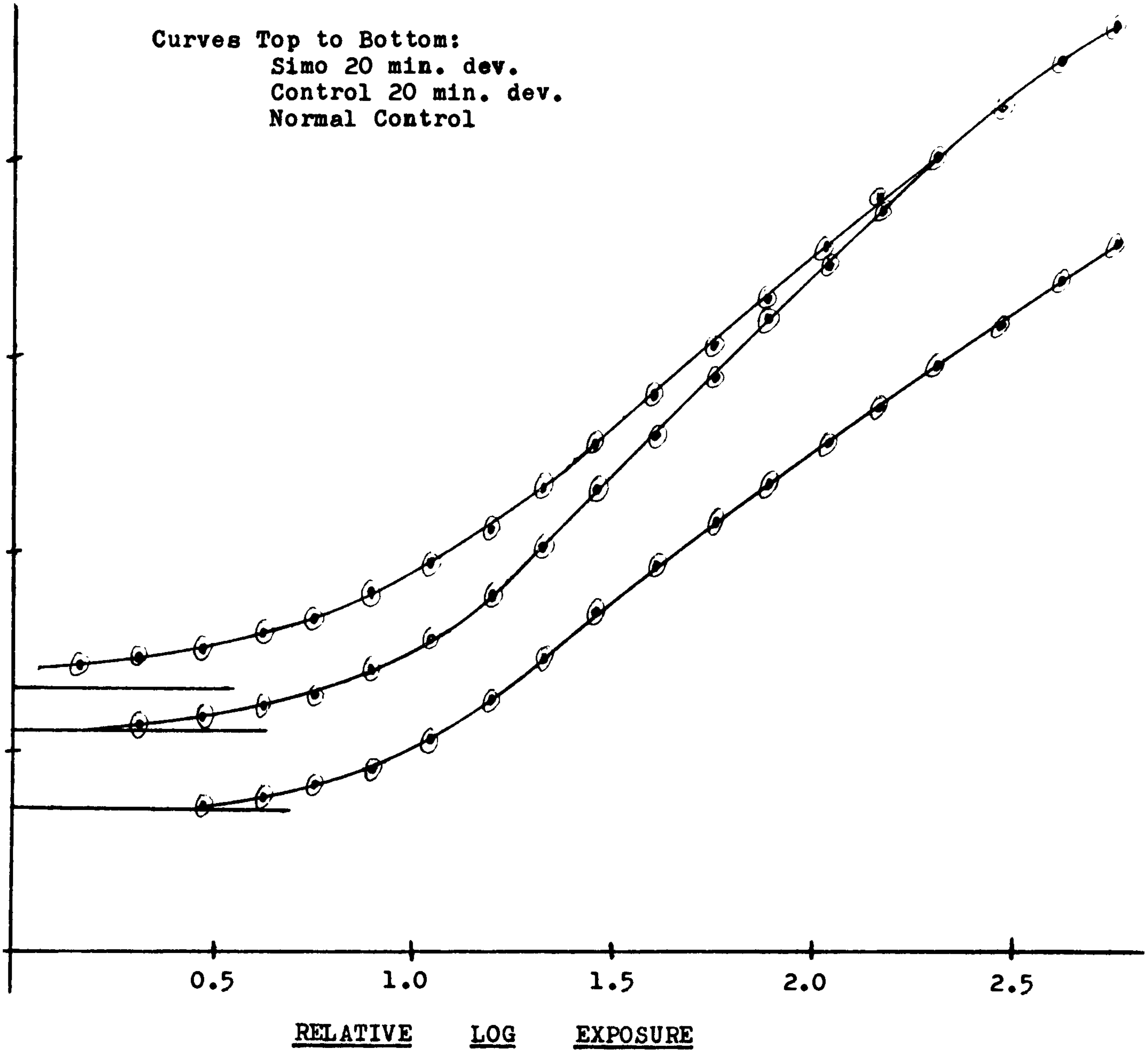


Figure 6: Characteristic curves of the control strips processed to the required gamma, compared to untreated (control) and simo-fogged processed for 20 minutes. Curves are plotted from mean densities.

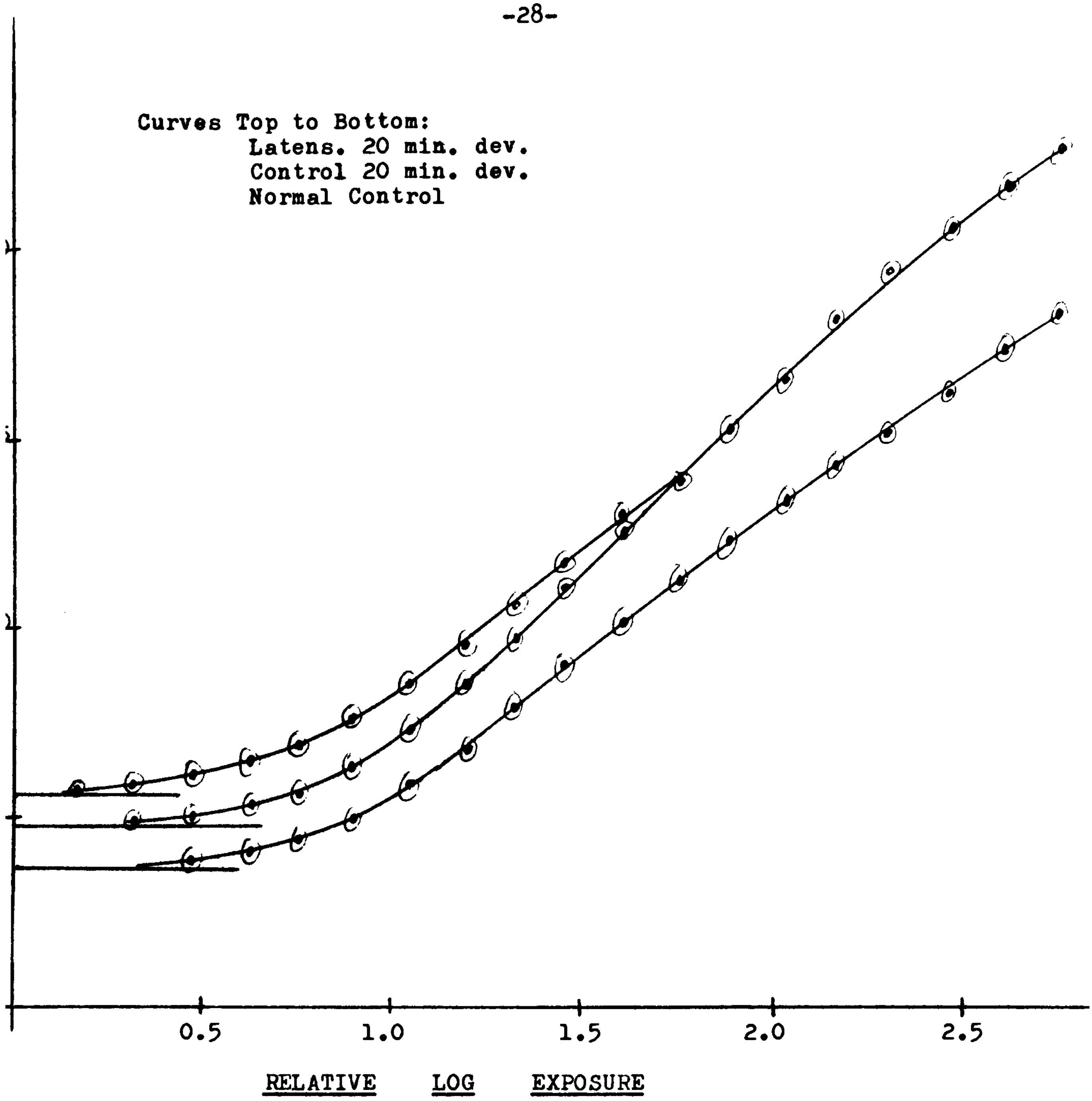


Figure 7: Characteristic curves of the control strips processed to the required gamma, compared to untreated (control) and latensified processed for 20 minutes. Curves are plotted from mean densities.

Table 6: DQE Computations.

	Log H	.17	.32	.48	.63	.76	.90	1.05	1.20	1.33
	H	1.479	2.089	3.020	4.266	5.754	7.943	11.22	15.85	21.38
CONTROL	Density	----	----	.366	.389	.424	.478	.555	.651	.750
	Gradient	0	0	.083	.213	.326	.447	.577	.708	.820
	$A\sigma^2$ X 10^{-6}	----	----	.0064	.0068	.0074	.0084	.0098	.0115	.0132
	DQE X 10^{-6}	0	0	.27	1.19	1.89	2.29	2.32	2.11	1.97
	Factor	----	----	----	----	----	----	----	----	----
SIMO-FOGGED	Density	.471	.483	.508	.542	.579	.629	.692	----	----
	Gradient	.045	.115	.190	.260	.321	.386	.456	----	----
	$A\sigma^2$ X 10^{-6}	.0083	.0085	.0089	.0095	.0102	.0111	.0122	----	----
	DQE X 10^{-6}	.128	.572	1.02	1.27	1.34	1.30	1.16	----	----
	Factor	----	----	3.78	1.07	.71	.57	.50	----	----
SIMO&DEV.	Density	.578	.591	.617	.653	.694	.748	.816	----	----
	Gradient	.048	.124	.205	.281	.347	.417	.494	----	----
	$A\sigma^2$ X 10^{-6}	.0088	.0090	.0094	.0099	.0105	.0113	.0124	----	----
	DQE X 10^{-6}	.137	.629	1.12	1.43	1.52	1.48	1.34	----	----
	Factor	----	----	4.15	1.20	.80	.65	.58	----	----
LATENSIFIED	Density	.450	.453	.476	.516	.564	.631	.719	----	----
	Gradient	0	.081	.205	.321	.422	.531	.648	----	----
	$A\sigma^2$ X 10^{-6}	----	.0080	.0084	.0091	.0099	.0111	.0126	----	----
	DQE X 10^{-6}	0	.298	1.27	2.04	2.39	2.44	2.26	----	----
	Factor	----	----	4.70	1.71	1.26	1.07	.97	----	----

Note 1: The logarithm of exposure range over which the DQE values are calculated is that range over which the second order regression equations are valid.

Note 2: The "Factor" is the ratio of Treatment DQE to Control DQE.

Note 3: Density and gradient values reported here were calculated from the second order regression equations, using the log H values at the top of each column.

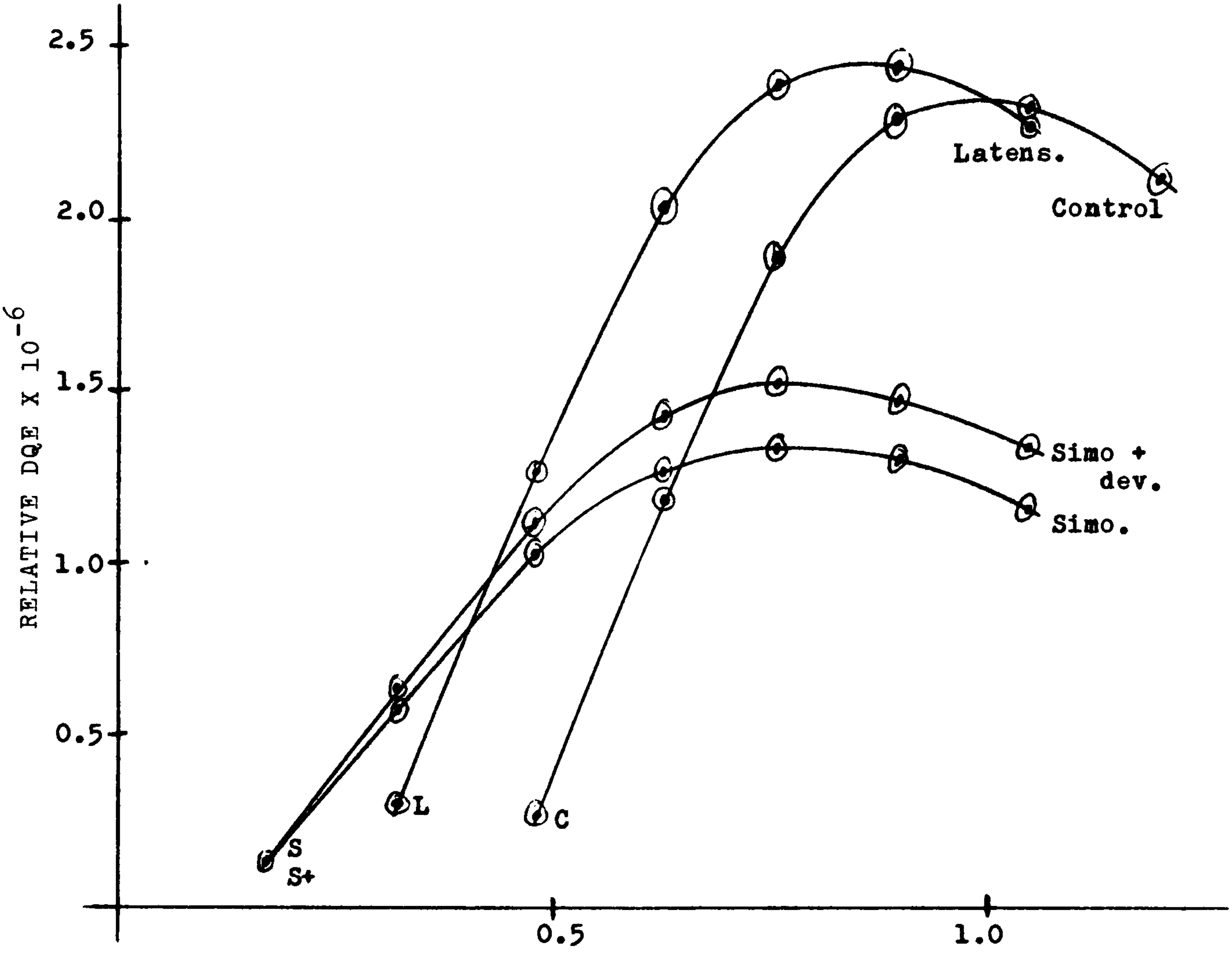


Figure 8: Plot of DQE as a function of log exposure from the values in Table 6.

Table 7: Summary of treatment results.

	Control	Simo	Simo + dev.	Latensified
Speed	3	1	1	2
Gamma	1	2	1	2
Contrast Index	1	4	3	2
Minimum gradient Speeds	4	3	1	2
DQE (Maximum)	2	4	3	1

NOTE: Treatments are ranked with 1 being the highest (best) value, and 4 being the lowest (worst) value.

DISCUSSION

Simultaneous intensification, at a diffuse exposure time of 1/1000 second, produced the same results as did the application of this diffuse exposure just before (10^{-2} and 10^{-3} second delay times) and just after (same delay times) the image exposure. However, the treatment of the film by low intensity latensification at a diffuse exposure time (20 seconds) well into the region of LIRF for this emulsion resulted in significantly different results. Although these secondary exposure treatments produced the same level of base and fog density, low intensity latensification (applied within two minutes of image exposure) resulted in densities that were on the order of four to 17 percent lower than simo-fogging. Although film speed was also lower for this latensification, all other performance criteria revealed its significantly greater effectiveness compared to simo-fogging. The effectiveness of latensification, then, is substantially dependent upon the level of the supplementary illuminance (effect may vary with emulsion characteristics); the diffuse exposure must utilize the emulsion's inherent LIRF to produce preferential density increases in areas that have been previously exposed.

The results from simo-fogging for data analysis were selected on the basis of differential density in Table 1. An exposure that produced a base and fog density of 0.06 density unit beyond that of the control (untreated) strips appeared to provide the highest net density, and gave an apparent film speed increase of two times. If other criteria were combined with speed for optimization, criteria such as toe contrast and fog level to be tolerated, somewhat different results might have evolved. This is suggested by the similar speeds for the separate simo-fogging tests of Table 1 that indicate only a small effect of increasing simo-fogging exposure intensity on speed. It is known that progressively longer times for low intensity latensification treatments, times of up to 30 minutes or more, often provide greater speed increases for a given fog generated because of the greater effect of LIRF in originally unexposed areas of the emulsion. Overall density may be lower with normal latensification, but fog may also be lower. Latensification for 30 minutes may not always be practical, however, and it obviously introduces at least 30 minutes additional delay in access to information. Under these circumstances, and since both treatments were pursued at an identical level of gross fog, simo-fogging was certainly as effective as low intensity latensification for this film type.

As shown in Figure 5, the curve produced from simo-fogging was essentially that predicted by additivity of exposures while low intensity latensification exposures were somewhat less than additive. Simo-fogging, then, was the more efficient in terms of additivity of exposures; it permitted the development of latent image that was not developed after latensified or untreated exposures under idential processing conditions. However, extended development (20 minutes) also permitted development of additional latent image; only the control (untreated) strips showed a real increase in speed. Simo-fogging did not produce latent image centres beyond those produced by image exposure: there was no evidence of superadditivity of exposures.

Despite the greater apparent film speed increases by simo-fogging, the effects on contrast may limit its practice for pictorial photography. Simo-fogging is supposedly more controlled than normal flare in camera systems, since it is physically and purposely introduced into the system, but its results are those exhibited by considerable flare. Gamma was lowered by a factor of 0.8, and the toe of the characteristic curve produced by simo-fogging was severely depressed to almost a straight line in the extreme. Simo-fogging also produced the lowest Contrast Index (25 percent lower than control). Thus, the film speed results previously discussed may be deceiving, as will be seen by examination of the DQE data.

The effect of intensification treatments on contrast is indicated to some extent by the minimum gradient speeds of Table 4. Here, it was assumed that, when the control strips were processed to the required gamma, the minimum gradient of the control strips occurred at an exposure point for all treatments that was a minimum for an acceptable print.[12] This assumption was made in lieu of inavailable data from practical experience with the film being tested. The higher contrast permitted by low intensity latensification produced a minimum gradient speed that was 1.29 times greater than control compared to simo-fogging's increase of 1.23 times.

The results to this point are inconsistent. The effect of intensification treatments on contrast has produced what appear to be conflicting results in terms of film speed and minimum gradient speeds. Hence, the combination of speed and contrast is mandatory, and is best achieved by analysis of DQE. The DQE results are perhaps the most important because they represent best the effects that the treatments had on image quality from the data available. They show that simo-fogging begins with the greatest increases of DQE in the extreme toe region of the characteristic curve, but quickly begins to degrade the information capacity, as measured by DQE, to a point at which its maximum DQE is 0.66 that of the control strips maximum. Low intensity latensification, on the other hand, does not degrade the information capacity of the control strips. The DQE responses are best shown by the curves of Figure 8 (these curves compare favourably with the DQE curves of other investigations of DQE in general[7,8]).

Comparison of the DQE values at the densities for minimum gradient speeds shows identical patterns between these two forms of data analysis. Control strips produced the lowest value, followed by (in ascending order) simo-fogging, low intensity latensification, and simo-fogging plus development to original gamma. Initially, this phenomenon shows a promising return for the minimum additional effort of slightly increased development (by 1½ minutes) of simo-fogged material to regain the original control gamma. However, simo-fogging depresses

good

contrast to a point that might be considered as beyond simple recovery methods, at least when granularity (noise) is included in the considerations. This is indicated by the marginally increased DQE of simo plus development over simo-fogging alone (see Figure 8). This increase does not approach the DQE produced by low intensity latensification, except in the extreme toe.

The DQE results in the extreme toe region do offer a limited choice with simo-fogging and latensification. Both treatments showed measureable information (DQE) for exposures and subsequent development that produced no information (DQE) on the control strips. Where the choice is between a low-quality image or no image at all, these treatments -- simo-fogging in particular -- offer the possibility of gaining some information at the sacrifice of image quality at optimum exposures. The sacrifice may be minimal under circumstances that require use of exposure in the extreme toe only.

Since the supplementary exposure of simo-fogging was merely additive to the image exposure, it is a relatively simple task to calculate the DQE results of simo-fogging. A given film will produce a characteristic curve that can be described by a second order equation (over a limited exposure range) of density (D_0) as a function of exposure (H_0), or logarithm of exposure.

Assuming additivity, the densities produced by simo-fogging can be calculated over the range of log exposure (log H_0) by substituting the addition of exposures (log $H = \log(H_0 + H_1)$ where H_1 = supplementary exposure). This new series of density points (D_1) can be described by another second order equation of density (D_1) as a function of original exposure (log H_0). The applicable gradients can then be found. All that remains is a suitable measure of granularity, and this aspect can be largely reduced by considering only one or two specific exposure points, thereby reducing much of the DQE formula to a constant. This method of calculation was tried with the data presented here; the densities for simo-fogging were calculated, and came within four percent of density found experimentally. Appendix C contains the results of such a calculation for a simo-fogging exposure supposedly producing a base and fog density 0.03 density unit above that of the control strips. There was not an appreciable alteration of results. A similar pattern is presented at Appendix D for Kodak film type Infrared Aerographic 2424, with computations from Kodak data (approximations). These calculations do not replace experimental evidence; they merely provide a rough estimation of effects to be anticipated without consideration for varying emulsion characteristics.

CONCLUSIONS

For the photographic system described, simo-fogging does not permit achievement of maximum DQE and does not produce enhanced image quality at practical, optimum levels of exposure. An increase in development to permit simo-fogged film to regain the original processing gamma does not appreciably enhance the results of simo-fogging.

Normal low intensity latensification is most effective because of increased density with less loss of contrast, permitted by its operation within the limits of the emulsion's LIRF. It is doubtful that low intensity latensification of film that had been simo-fogged would attain the results of latensification alone.

Application of simo-fogging, as described in this study, may be limited to specialized situations such as oscillography. It is not suitable for pictorial photography, or is less suitable than normal latensification, except for utilization of exposure in the extreme toe.

Further study in this area of latent image intensification might include:

(1) electronic or photographic methods of increasing the contrast of simo-fogged material;

(2) application of simo-fogging at lower levels of supplementary exposure (lower levels of base and fog density);

(3) simultaneous intensification of standard aerial films that have a higher inherent contrast;

(4) optimization of such treatments based on DQE.

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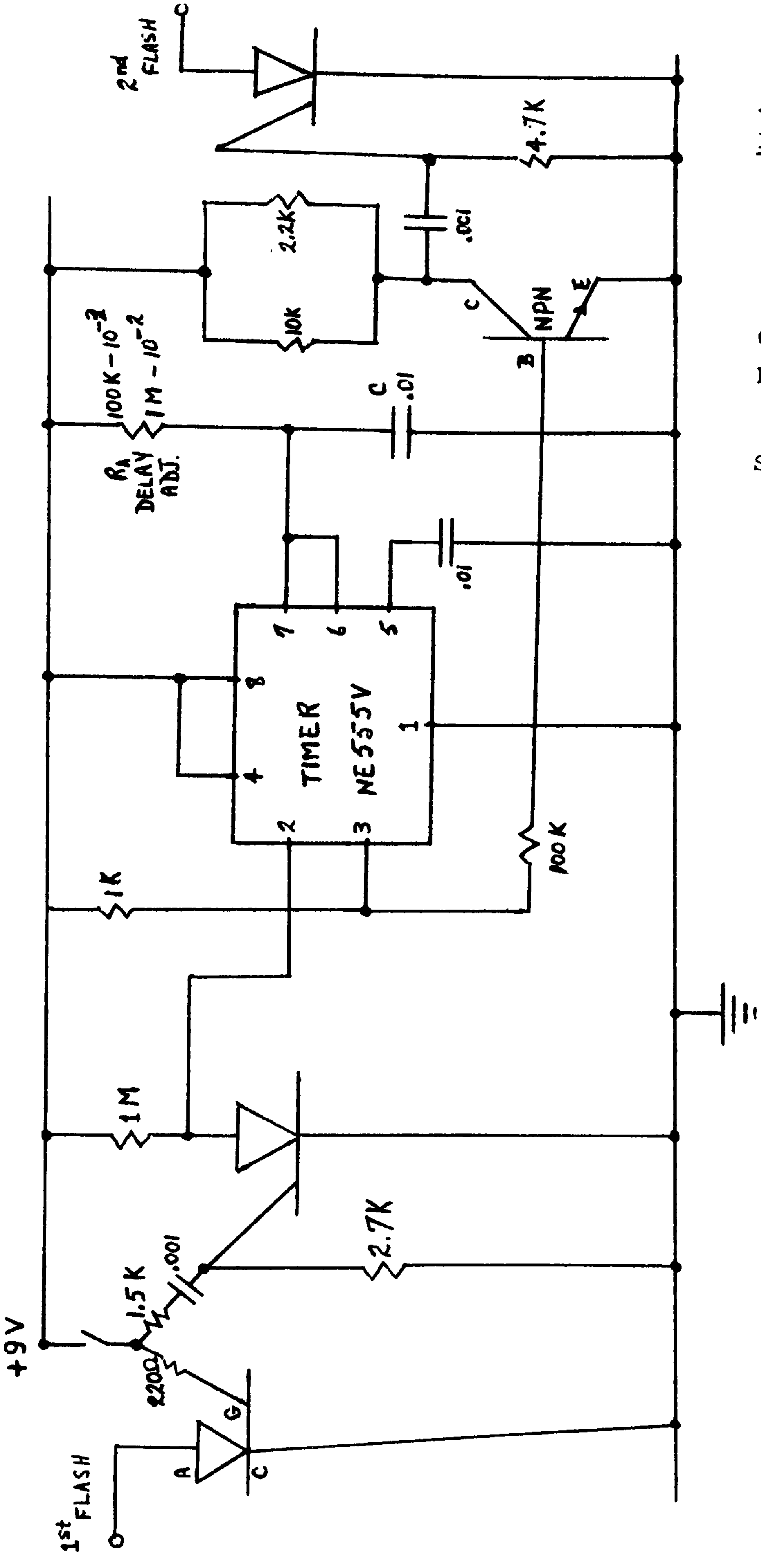
APPENDIX A

FLASH DELAY CIRCUIT



Capacitance is in μf

Resistors are ½ watt unless otherwise indicated.

SCR's that trigger the flash units rated for 200V DC at 3 amps peak.

APPENDIX B

SAMPLE DATA -- LATENT IMAGE FADE

NORMAL	24 HR.	NORMAL SIMO-FOGGED	24 HR. SIMO- FOGGED
1.70	1.68	1.91	1.87
1.61	1.58	1.81	1.77
1.50	1.45	1.71	1.65
1.39	1.35	1.61	1.56
1.30	1.26	1.51	1.46
1.20	1.16	1.42	1.37
1.11	1.05	1.33	1.27
1.01	0.94	1.24	1.18
0.90	0.83	1.15	1.07
0.79	0.72	1.05	0.97
0.69	0.62	0.96	0.87
0.60	0.55	0.87	0.78
0.53	0.49	0.79	0.71
0.47	0.46	0.73	0.64
0.44	0.44	0.67	0.59
0.43	0.43	0.63	0.56
		0.60	0.53
		0.57	0.51
		0.55	0.50

NOTE: The increased density (at a given step) of the simo-fogged material is purely coincidental. This data is to illustrate only the difference between the density of immediate processing compared to that produced 24 hours after exposure. Comparisons between the untreated strips and simo-fogged strips must therefore be made at the same density.

DQE PREDICTION* FOR KODAK TRI-X 5063

NOTE: This prediction is based on the continued assumption of additivity of exposures, and on a simo-fogging exposure that produces a base and fog density of 0.39* under the conditions described in this report. The values for control and simo-fogged DQE are those in Table 6.

Log H_o	.17	.32	.48	.63	.76	.90	1.05
H_o	1.479	2.089	3.020	4.266	5.754	7.943	11.22
Control DQE	----	----	0.27	1.19	1.89	2.29	2.32
Simo-fogged DQE	.128	.572	1.02	1.27	1.34	1.30	1.16
*Predicted DQE	.14	.60	1.08	1.35	1.41	1.37	1.22

The second order equation for the predicted curve, calculated from additivity of exposure data through the original control curve equation, is:

$$D = .4242 - .0351(\log H_o) + .2309(\log H_o)^2$$

APPENDIX D

DQE PREDICTION FOR KODAK INFRARED 2424

Rel. log H_o	.125	.25	.375	.50	.625	.75
D_o	.10	.14	.20	.30	.45	.59
$(G_o)^2$	.0328	.1822	.4524	.8433	1.3550	1.9874
$DQE_o \times 10^{-6}$	6.92	20.59	26.83	25.00	20.08	16.85
D_1	.288	.345	.418	.512	.628	.742
$(G_1)^2$	.1664	.2900	.4477	.6395	.8654	1.1254
$DQE_1 \times 10^{-6}$	12.18	13.30	11.55	11.11	9.12	7.58

NOTES: 1. Original density (D_o) and exposure (H_o) were found from Kodak published data (rough determination), ultimately producing an equation for D_o as a function of log H_o.

2. $(G)^2 = (\text{Gradient})^2$

3. Granularity data is from Kodak published data for this film, determined for the various density points chosen here on the assumption that granularity varies as the square root of density.

4. Predicted simo-fogged density (D_1) is determined from the original equation for D_o by substituting log $(H_o + H_1)$ for log H_o. This produced an equation of D_1 as a function of log H_o. The supplementary exposure was arbitrarily chosen: $H_1 = 1.70$.

5. Relative values only are shown above.