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Optimizing the Photographic Variables of Spark Chamber Film for Automatic Measurement

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Science Research Council

Computer Applications Group
Rutherford High Energy Laboratory
Chilton Didcot Berkshire
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OPTIMIZING THE PHOTOGRAPHIC VARIABLES OF SPARK CHAMBER FILM FOR AUTOMATIC MEASUREMENT

R A Lawes

ABSTRACT

Exposure and development of film for measurement on Flying Spot Digitizers has not previously taken into full account the problems peculiar to such devices.

This paper discusses the relationship between photographic density and the film transmission changes seen by the Hough Powell Device. A case study for a spark chamber experiment is presented and the use of an optimization technique demonstrated.

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March 1972

CONTENTS

Section		Page
1.	Introduction	1
2.	Derivation of Optimum Film Development Criteria	1
2.1	Relationship between Density, Transmission and Exposure	2
2.2	Development for Maximum Signal	2
2.3	Development for Optimum Signal/Noise Ratio	4
3.	A Guide to Optimum Conditions	6
4.	An Application of the Technique	7
5.	Conclusions	9
6.	Acknowledgements	9
7.	References	10

Figures

Figure 1	Density v Log Exposure for Reverse Developed Aerial A	11
Figure 2	Transmission v Log Exposure for Reverse Developed Aerial	12
Figure 3	Definitions of HPD Track Signal and Background	13
Figure 4	Change in Transmission v Background Development for Constant Subject Exposure	14
Figure 5	Max ΔT v Log. Exposure	15
Figure 6	Background Development v Exposure for maximum ΔT	15
Figure 7	Signal/Film Noise Ratio v Background Transmission	16
Figure 8	Background Transmission v Developer Temperature	17
Figure 9	Typical Frame from RHEL-Rome S104 Experiment	18
Figure 10	Improvement of RHEL-Rome S104 Film Exposure/Development	19
Table 1	Relationship of Photographic Density to Transmission	20

1. INTRODUCTION

When a photographic emulsion has been exposed to light and immersed in a developing solution, grains of silver halide which have received sufficient illumination are reduced to silver. This is the basic photographic effect and the resultant 'negative' (black subjects on a clear background) may be presented as input information to a Flying Spot Digitizer (F.S.D.) for automatic digitizing and analysis.

A refinement in preparing film for such machines utilizes the so-called 'reverse development' process. This process starts by exposing and developing the film in the usual way and at this stage the background density may be controlled by the use of a silver halide solvent. The developed silver is then bleached and the whole film uniformly exposed to light. After a further development procedure the 'positive' image (clear subjects on a dark background) is produced and the resultant film may also be used as input for an F.S.D.

Reverse developed film offers some advantages to an F.S.D.[1] as scratches and dust particles introduced during mechanical handling contribute fewer 'noise' digitizings than negative film. Also, many F.S.D.s have basic Signal/Noise ratios dominated by photon (Shot) noise and as photon noise is proportional to the square root of transmission, higher ratios may therefore be obtained for reversal film.

The work to be described in this paper is based upon results recently obtained by using the HPD2 digitizer at the Rutherford Laboratory with spark chamber film. This F.S.D. has a powerful laser generated measuring spot (2×10^{12} photons/sec at 488nm) and performance is not dominated by photon noise[2]. However, reverse development is well established for spark chamber film and is therefore assumed throughout the analysis.

2. DERIVATION OF OPTIMUM FILM DEVELOPMENT CRITERIA

The measured relationships between the film density, transmission and subject exposure may be used to predict the signals produced by an HPD. A study of these signals as a function of subject exposure and film development will lead to an optimization criterion for spark chamber film. Film noise due to the granular structure of the emulsion may also be used to produce an alternative

criterion based upon the theoretical signal/noise ratio.

2.1 The Relationship between Density, Transmission and Exposure[3]

The transmission (T) of a film is equal to the ratio of the transmitted to the incident light. It is a well-established relationship that $\text{Log}_{10}(\frac{1}{T})$ is proportional to the amount of silver present and is defined by:-

$$\text{Photographic Density } D = \text{Log}_{10}(\frac{1}{T}) \quad \ldots\ldots \quad (1)$$

The quantity D is widely used in photographic work and the simple numerical relationship between Density (D), Opacity $(\frac{1}{T})$ and transmission (T) is given in Table 1.

The density of the subject will depend upon the exposure (E) and the development conditions chosen. The shape and scale of the Density v Exposure graphs are shown for reverse developed Ilford 'Aerial A' film in Figure 1 (where E is represented logarithmically). This is the reverse of the more usual negative form but the essential features are the same. These are a 'shoulder' region at high densities, an approximately linear region and a 'toe' region at low densities.

'Aerial A' is a fast, medium grain film in established use at the Rutherford Laboratory for spark chamber experiments. Figure 1 represents the calibration data which is used throughout the following analysis.

The HPD itself measures transmission so that the characteristics of the film must be converted from D v E to T v E by using Figure 1 and Table 1. The results of this operation are shown in Figure 2.

2.2 Development for Maximum Signal

A typical output signal from the measuring spot channel of the HPD 2 is shown in Figure 3. The essential features are:

(i) An average background signal $T_B(D_B)$

(ii) Film Noise $\delta_T(\delta_D)$ due to the granular structure of the developed film.

(iii) A track signal ΔT relative to T_B.

The method used by HPD 2 to produce a track pulse is based upon signal amplitude. Thus, unless there is a disproportional increase in film noise,

exposure and development of the film should attempt to maximize ΔT.

Now from Figure 2 it is possible to calculate the relationship ΔT v T_B for an exposure E_s, remembering that the background exposure in a spark chamber is virtually zero. The relationship is shown in Figure 4 and it is of immediate interest that there is an optimum development (background transmission $T_{B_{max}}$) for a given subject exposure. (E_s). Further, failure to achieve optimum development potentially makes significant reductions to signal amplitude.

The maximum ΔT available from the film will decrease linearly as the background T_B becomes higher and this is also shown in Figure 4. This maximum can be achieved at low background transmissions only by relatively bright subjects. As subject exposure decreases the film is able to produce a lesser proportion of the maximum nominally available.

The combination of camera variables (aperture and shutter speed) and subject illumination will determine the relative exposure of the subject. Clearly, the objective with a spark chamber is to get the maximum exposure consistent with accurate (spatial) reproduction of the subjects. This is not always possible and it is therefore important to be able to predict the signal and to ensure that it is near optimum for the HPD.

The maximum signal (ΔT_{max}) available from the film may be derived from Figure 4 and shown to follow a simple linear relationship up to saturation:

$$\Delta T_{max} = 42\ E - 13 \quad (\%) \qquad \ldots\ldots \qquad (2)$$

Where $E = \log_{10}$(Relative Exposure) and the relationship is plotted in Figure 5.

Thus, if $E = 1.0$ then $\Delta T_{max} = 29\%$
$E = 1.6$ then $\Delta T_{max} = 54\%$ } i.e. two camera stops gives twice the signal

However, from Figure 4 it can be seen that these maximum transmission changes are obtained at different backgrounds T_B. The relationship between the background $T_{B_{max}}$ to give the maximum signal and the subject exposure may also be derived from Figure 4 and is shown in Figure 6.

Again a simple linear relationship exists:

$$T_{B_{max}} = -20E + 56 \quad (\%) \qquad \ldots\ldots \qquad (3)$$

Thus for the previous example:

$$\Delta T_{max} = 29\% \text{ at } T_B = 36\% \ (D_B = 0.4) \text{ for } E = 1.0$$
$$\Delta T_{max} = 54\% \text{ at } T_B = 24\% \ (D_B = 0.65) \text{ for } E = 1.6$$

It is interesting to note that traditionally spark chamber film has been developed to much darker backgrounds (e.g. $T_B \simeq 3\%$, $D_B = 1.5$) than optimum, mainly because it seems more pleasing to the eye. It can now be seen that this is only satisfactory if the subject exposure is relatively strong. From Figure 4:

$$\Delta T_{max} = 70\% \text{ at } T_{B_{max}} = 15\% \ (D_B = 0.8) \text{ for } E = 2.0$$
$$\Delta T = 60\% \text{ at } T_B = 3\% \ (D_B = 1.5) \text{ for } E = 2.0$$

$$\text{i.e. } \frac{\Delta T}{\Delta T_{max}} = 0.85$$

However, for a weak subject, such development would have a deleterious effect on the signal:

$$\text{e.g. } \Delta T_{max} = 20\% \text{ at } T_{B_{max}} = 40\% \text{ for } E = 0.8$$
$$\text{but } \Delta T = 3\% \text{ at } T_B = 3\% \text{ for } E = 0.8$$

Not only is $\frac{\Delta T}{\Delta T_{max}} = 0.15$, representing a considerable loss of signal amplitude but the Signal/Noise ratio approaches one. (See Figure 7).

Thus, if a photograph has a wide range of subject exposure, then development to maximum ΔT for the weakest subject is advisable. There should be no significant effect on the stronger subjects.

2.3 Development for Optimum Signal/Noise Ratio

The analysis presented above deals in the signal change ΔT, whereas fundamentally one is interested in the Signal/Noise ratio. In the case of the HPD 2, the laser illumination system ensures that photon noise is negligible compared to film noise.

Theoretical considerations of film noise are based upon granularity, an effect due to the random distribution of developed grains of varying density. A Gaussian distribution is in good agreement with practical

measurements so that the Granularity may be expressed as the Standard Deviation δ of the distribution (δ_D density or δ_T transmission units).

$\delta = f(D_B, \phi)$ where D_B = Background Density

ϕ = Measuring Spot Diameter (10 microns for HPD2)

It is generally accepted that $\delta \propto \sqrt{D}$ so that

$$\delta_D = \sqrt{D}\,\delta_{DO} \qquad \ldots\ldots \qquad (4)$$

where

δ_{DO} = Granularity under reference conditions i.e. D = 1.0 an HPD2 scanning aperture of 10 μm and a bandwidth of Δf = 2.5 MHz.

Now from differentiation of Equation (1)

$$\delta_D = 0.434\,\frac{\delta T}{T} \qquad \ldots\ldots \qquad (5)$$

so that

$$\delta_T = 2.3\,T_B\sqrt{D}\;\delta_{DO} \qquad \ldots\ldots \qquad (6)$$

Thus, δ_T has a maximum at T = 60% and zero values at T_B = 0 (clear film) and T_B = 100% (black film).

It is difficult to get reliable figures for δ_D that are applicable to the scan of the HPD. However, δ_T as a function of T_B was measured directly from the HPD signals and the results are shown in Figure 7. Despite difficulties in correctly identifying film noise, the relationship is clearly shown to follow Equation (6) and the absolute values are sufficiently accurate for this analysis.

From Figure 3 it is clear that the noise seen by the HPD signal processing electronics must be taken as the peak value rather than the standard deviation. For a Gaussian distribution, we may assume that the 'Effective Film Noise' $\delta_T = 2\delta_T$. The Signal/Noise ratio is given by:

$$S/N = \frac{\Delta T}{2\delta_T} \qquad \ldots\ldots \qquad (7)$$

S/N as a function of T_B for different subject exposures is also plotted in Figure 7.

3. A GUIDE TO OPTIMUM CONDITIONS

If these relationships are now used to optimize the film development, results slightly different from those obtained by optimizimg ΔT alone (shown in brackets) will be obtained.

For $E = 0.5$ $S/_N = 2.1$ at $T_{B\,max} = 40\%$ (ΔT_{max} at 45%)

$E = 1.0$ $S/_N = 7.5$ at $T_{B_{max}} = 26\%$ (ΔT_{max} at 35%)

$E = 1.2$ $S/_N = 10$ at $T_{B_{max}} = 25\%$ (ΔT_{max} at 30%)

Theoretically the $S/_N$ ratio rises (to ∞) at low transmissions. Under such conditions the contributions of film blemishes, optical imperfections and electronic noise become significant and the simple analysis is no longer valid. Thus $S/_N$ ratios at very low T_B are not considered in the figures above.

It would appear that for weak/medium subjects ($E < 1.5$) there is little practical difference between optimizing for signal ΔT or signal/noise ratio $S/_N$. For strong subjects the arguments become academic and the main problem is that the subjects may become over-exposed to the extent of producing distorted images.

<u>It is therefore proposed to use the ΔT criterion exemplified by Figures 4, 5 and 6 as a means of determining film development.</u>

Figure 8 shows T_B as a function of developer temperature and it is clear that for $T_B > 5\%$ ($D_B < 1.1$) temperature control of the film processing plant becomes critical. Subject to improvements in development techniques, reliable control of such background transmissions is unlikely and the optimum value of T_B will be difficult to achieve and maintain, e.g. a temperature of $28.5^{\circ} \pm 1^{\circ}$ will yield $T_B = 18\% \pm 9\%$.

As one lowers the discrimination level below which the HPD rejects signals, a point is reached where control of the noise digitizings becomes operationally more difficult. At the present state of development of the HPD 2, $\Delta T = 5\%$ is about the minimum signal detectable and $\Delta T \simeq 10\%$ is a good operational figure. This suggests from Figure 5, that an exposure $E \nless 0.6$ is required and from Figures 6 and 8 this would require $T_B = 50\%$ at a temperature of $> 30^{\circ}C$.

If one now considers practical values of developer temperature, a minimum ΔT = 10% and consults Figure 4 then a recommended (but not theoretically optimum) exposure and development becomes apparent.

It is therefore recommended that:

Log_{10} (Relative Subject Exposure)	$E \nless 1.0$
Background Transmission	$T_B \simeq 10 - 16\%$
	$D_B \simeq 1.0 - 0.8$

4. AN APPLICATION OF THE TECHNIQUE

The methods described have been used recently to initially measure and then to optimize the subject exposures for two spark chamber experiments. One of these was the RHEL-Rome S104 experiment using wide-gap chambers. The characteristics of the experiment and its apparatus presented a wide range of subject illumination and was therefore an excellent illustration of the technique. A typical frame is shown in Figure 9.

The procedure was initialized by taking a few test exposures under normal experimental conditions and developing the resultant film to a background transmission used for previous experiments, i.e. T_B = 2% (D_B = 1.7). The film was then digitized by HPD2 and with the aid of a computer display the various subjects were identified in the track signals. The subject transmissions were then computed from these signals and from the T_B = 2% curve of Figure 2 the subject exposures were estimated. The average range of subjects, as indicated in Figure 9, is listed below:

Subject		T%	ΔT%	E	Expected E
Brenner Mark	(BM)	20	18	1.55	(2.15)
Binary Numbers	(BN)	57	55	2.0	(2.3)
HPD Fiducials	(HFID)	30	28	1.7	(2.0)
Chamber Fiducials	(CFID)	6	4	1.15	(1.45)
Tracks - Strong	(TS)	20	18	1.55	(1.85)
Tracks - Weak	(TW)	See Text			

From Figure 4 it was clear that, under these conditions, only the binary number had near maximum exposure and that all other subjects required an

exposure increase of at least a factor of two (ΔE = Log Exposure = 0.3). Thus, an increase in camera aperture from f/11 to f/8 was recommended and in order to facilitate detection, the brenner mark exposure was increased in brightness to give a further factor of two. The expected subject exposures (in brackets) are indicated above.

The weak sparks were, in some instances, hardly discernible by eye. It was clear from Figure 4 (e g for Es < 1.0) that the maximum practical improvement in exposure and development was necessary if significant spark information was not to be lost.

A second series of exposures were taken and an attempt made to develop the film for $T_B \simeq 10 - 16\%$. T_B turned out to be 9% (D = 1.04) which demonstrates the difficulties suggested by Figure 8.

The samples yielded the following results:

Subject	T%	ΔT%	E
Brenner Mark	83	74	2.2
Binary Numbers	82	73	2.2
HPD Fiducials	73	64	2.0
Chamber Fiducials	42	33	1.55
Tracks (Strong)	61	52	1.8
Tracks (Weak)	See Text		-

Considering the uncertainty in interpreting exactly Figures 1 and 2 and in measuring transmissions on the HPD,these figures are in good agreement with predictions. The effect of improving subject exposure and the film development for the S104 experiment is summarized in Figure 10.

It has been possible to increase the exposure of relatively bright subjects close to the maximum available without over-exposure e.g. the brenner mark has gone from ΔT = 18% to ΔT = 74% (which makes the problem of reliable detection much easier).

For relatively weak subjects, the improvements are impressive. For example, the chamber fiducials taken at f/8 and developed at T_B = 2% would have given ΔT = 17% only marginally above the recommended limit for HPD. Developing to a background of T_B = 9% has improved this signal to ΔT = 33% which is excellent for the HPD.

Similarly, the range of sparks seen by the HPD2 has been extended. In

the first film series the minimum spark detected (SPARK MIN(1)) for ΔT = 5% had an exposure of E = 1.25. Sparks with 50% of this intensity would have been detectable if only the camera aperture had been changed. By also changing the development, sparks with an intensity of 30% x SPARK MIN(1) were detectable in the second film series. Alternatively, the improvement may be seen as giving SPARK MIN(1) in the first series, a signal of ΔT = 32% in the second film series. This is also shown in Figure 10.

The range of subject exposures is limited by the minimum ΔT detectable by the HPD and the maximum intensity acceptable before over-exposure. The range accommodated for the S104 experiment was about 20:1 but it is likely that a range of more than 100:1 would be possible for this film and development.

5. CONCLUSIONS

The analysis presented in this paper provides a simple, quantitative method of determining the exposure and development of spark chamber film for automatic measuring machines.

It is important to recognise that choosing a nominally dark background, which may be acceptable to the eye, can have a deleterious effect on measuring performance. This is particularly true for relatively weak subjects and in such cases, apparently marginal changes in exposure and/or background transmission, become significant.

6. ACKNOWLEDGEMENTS

All film samples, including the calibration data for Figure 1, were prepared by H Edwards of the Photographic Section.

Dr G Conforto of the High Energy Physics Division cheerfully allowed his apparatus and film to be exploited for the above analysis.

7. REFERENCES

(1) D Eastwood. An Evaluation of Reverse Developed film measured on HPD. International Conference on Data Handling Systems in High Energy Physics 1970. CERN 70-21.

(2) R A Lawes, W T Welford. A Laser Illumination System for an HPD. RHEL/R 212.

(3) C E Mees, T H James. Theory of the Photographic Process. Third Edition. Macmillan Co.

FIG. 1 DENSITY v. LOG EXPOSURE for REVERSE DEVELOPED AERIAL 'A'

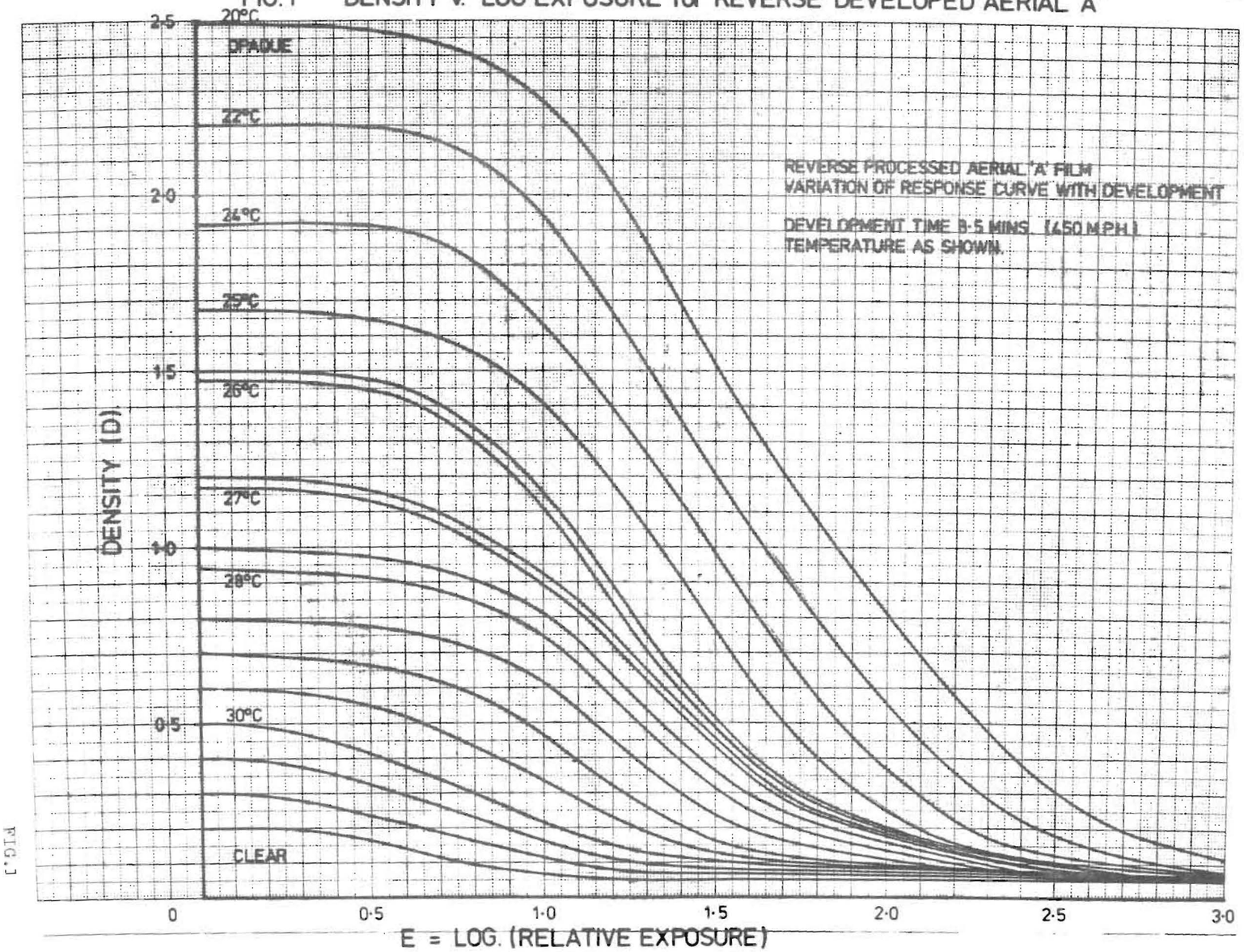


FIG. 1

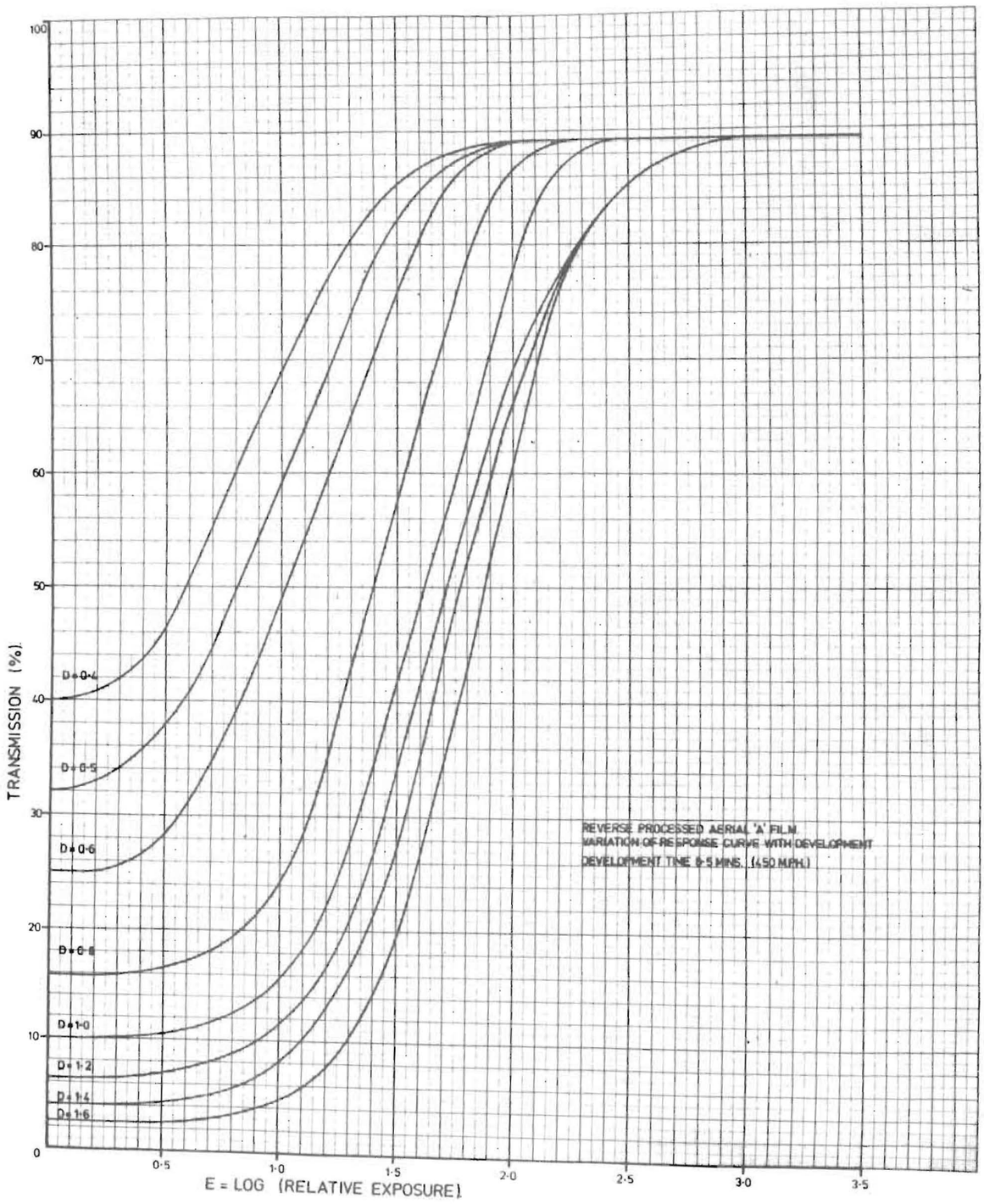


FIG.2. TRANSMISSION v LOG EXPOSURE for REVERSE DEVELOPED AERIAL 'A'.

FIG.2

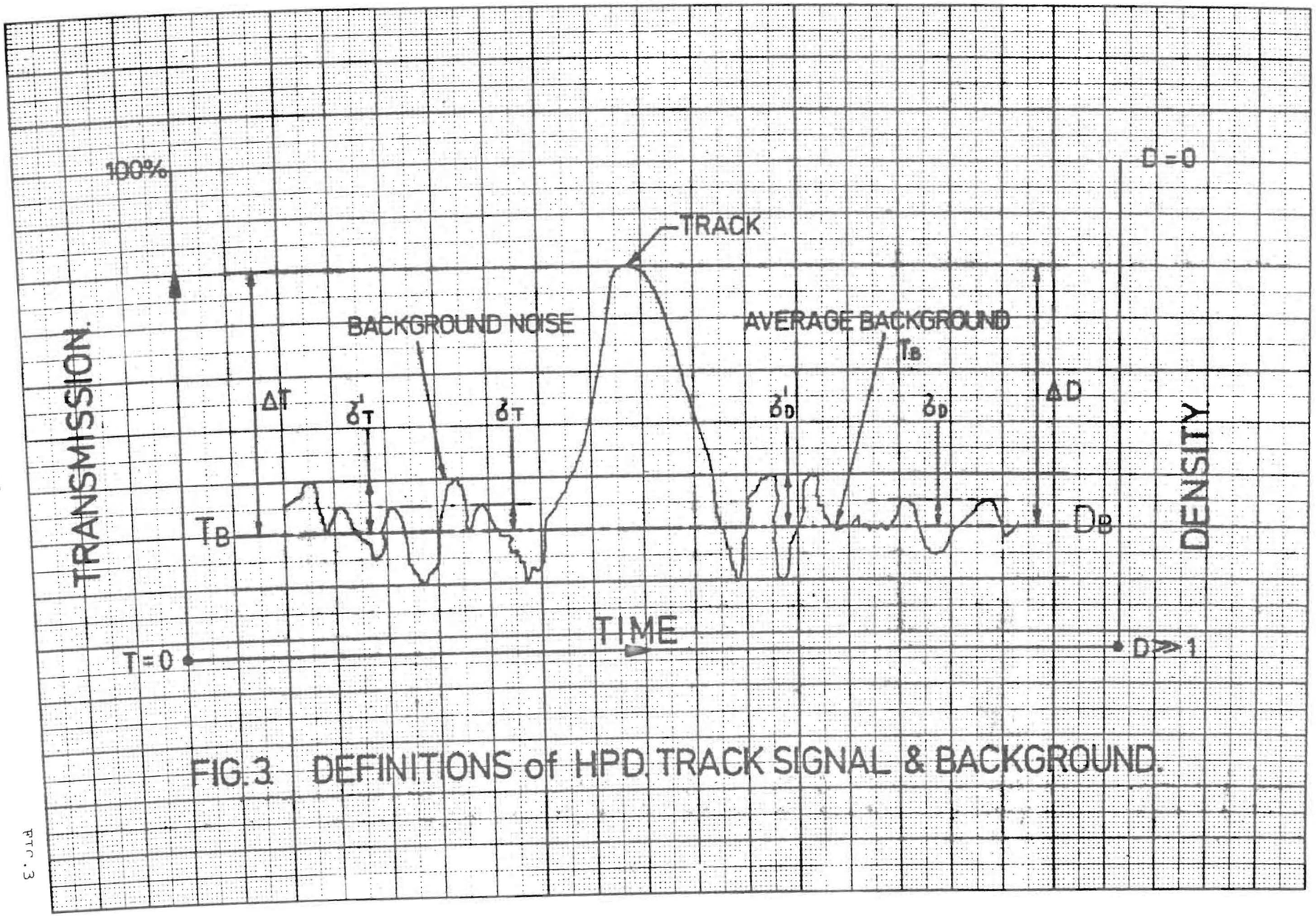


FIG.3 DEFINITIONS of HPD TRACK SIGNAL & BACKGROUND.

FIG. 3

FIG. 4. CHANGE IN TRANSMISSION v. BACKGROUND DEVELOPMENT for CONSTANT SUBJECT EXPOSURE

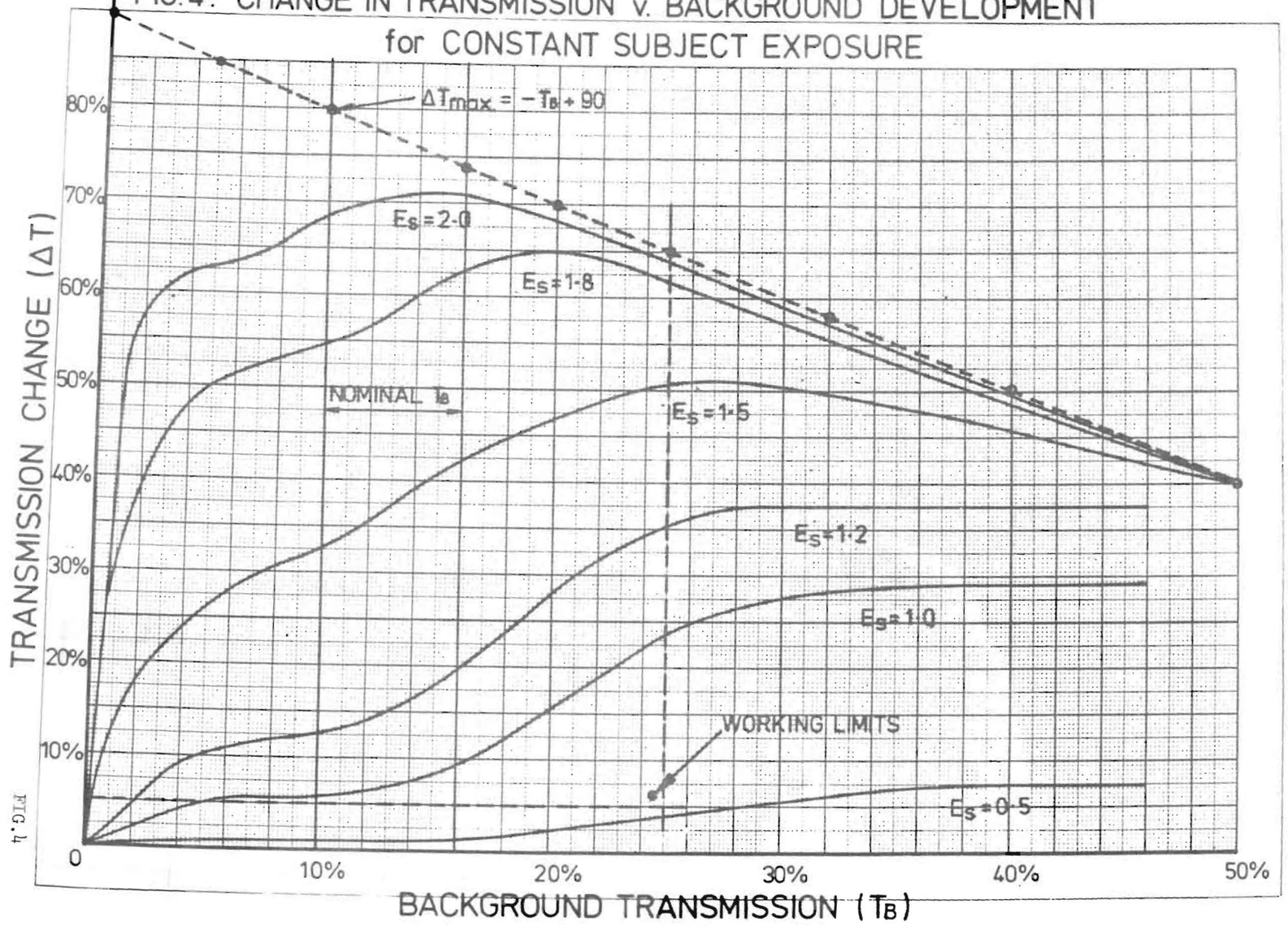


FIG. 4

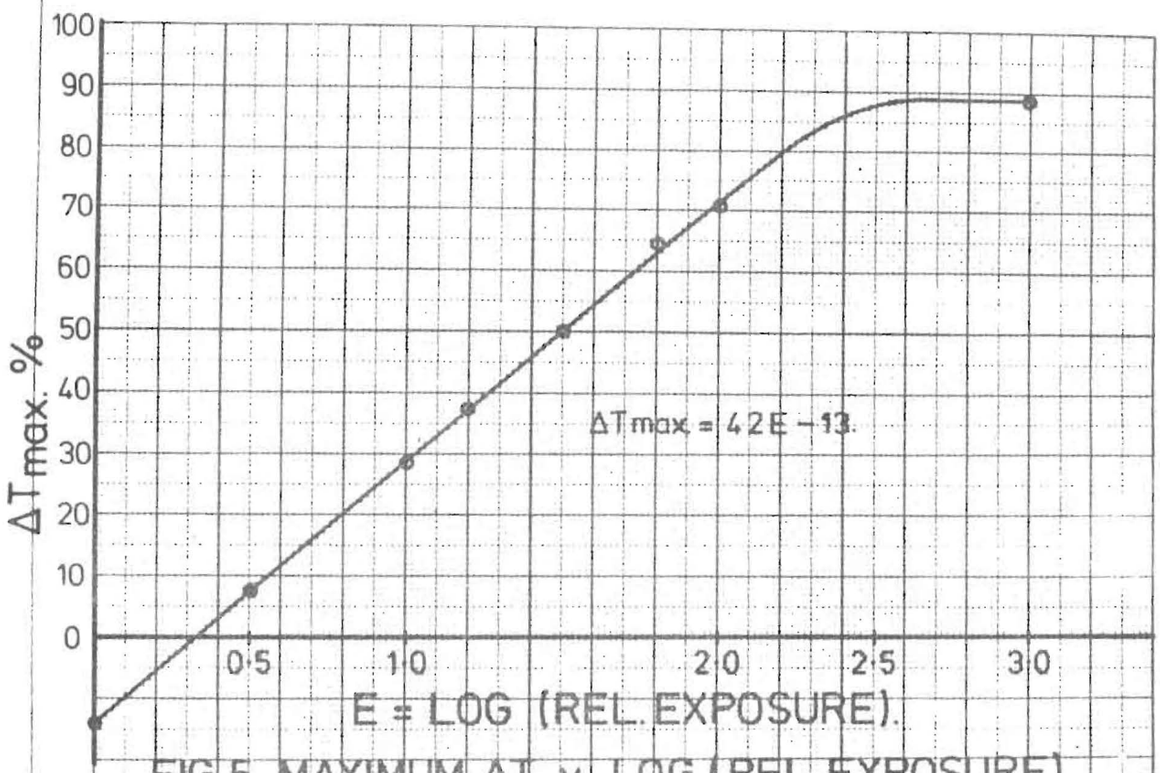


FIG. 5. MAXIMUM ΔT v. LOG. (REL EXPOSURE).

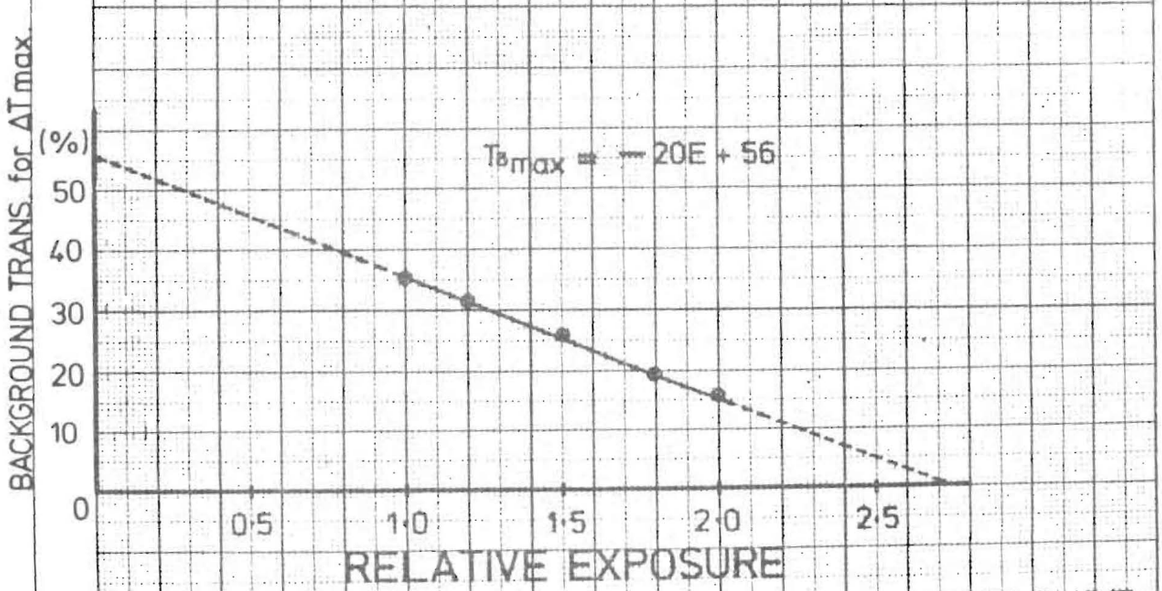


FIG. 6. BACKGROUND DEV. T_B v. REL SUBJECT EXPOSURE. for MAXIMUM ΔT.

FIGS. 5&6

FIG.7. SIGNAL / NOISE RATIO v. TRANSMISSION. T_B

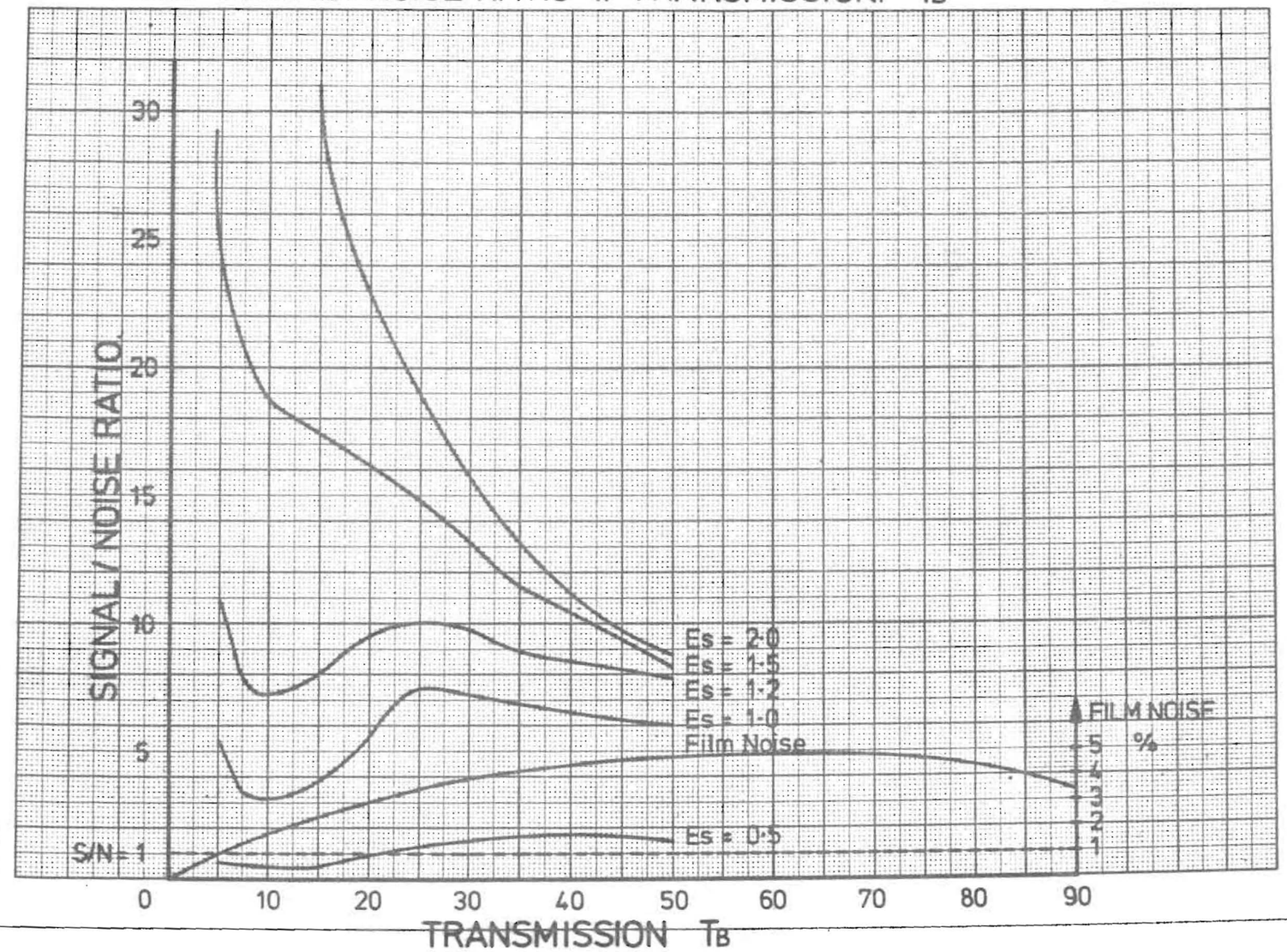
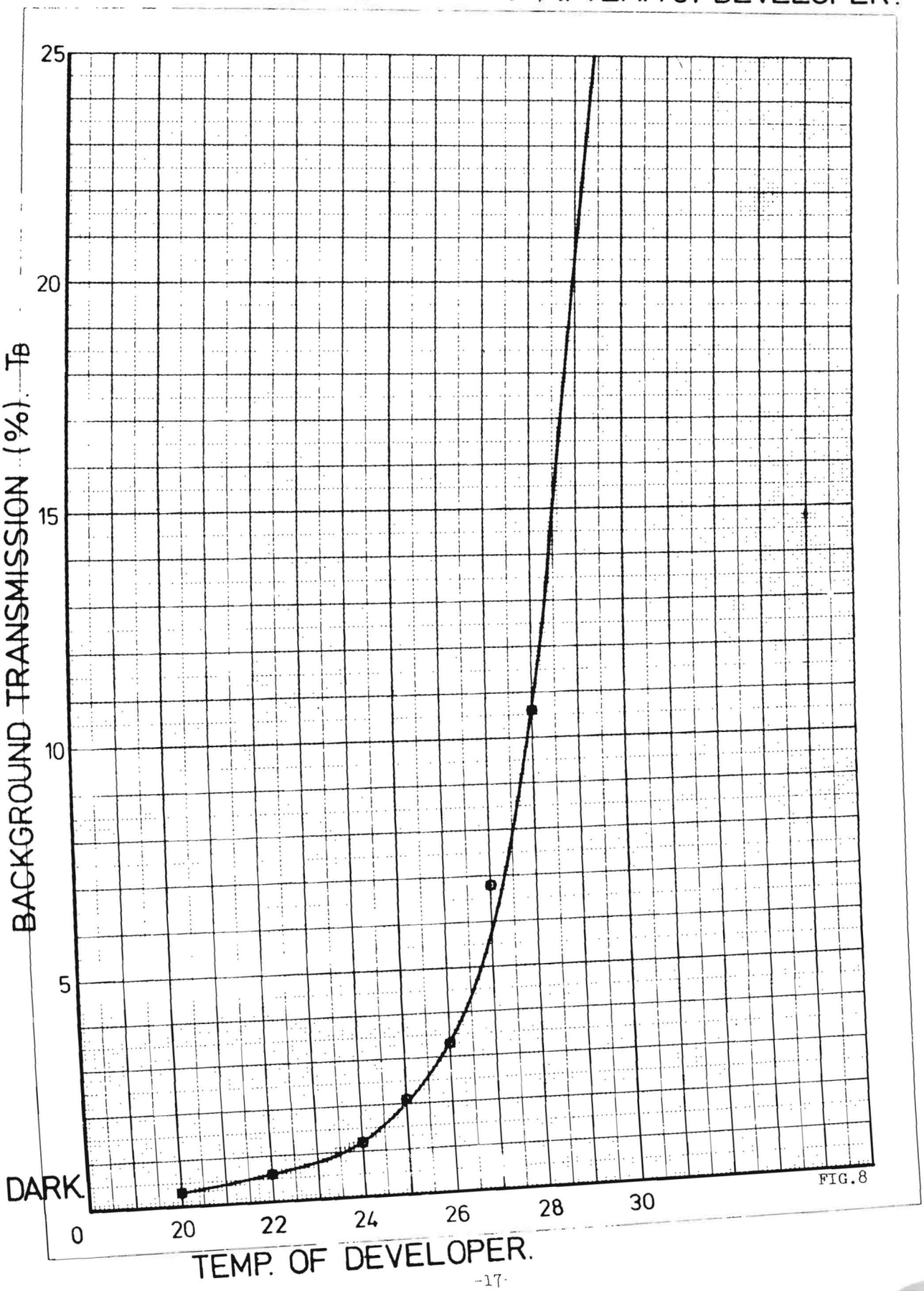


FIG.7

FIG.8. BACKGROUND TRANSMISSION v. TEMP. of DEVELOPER.



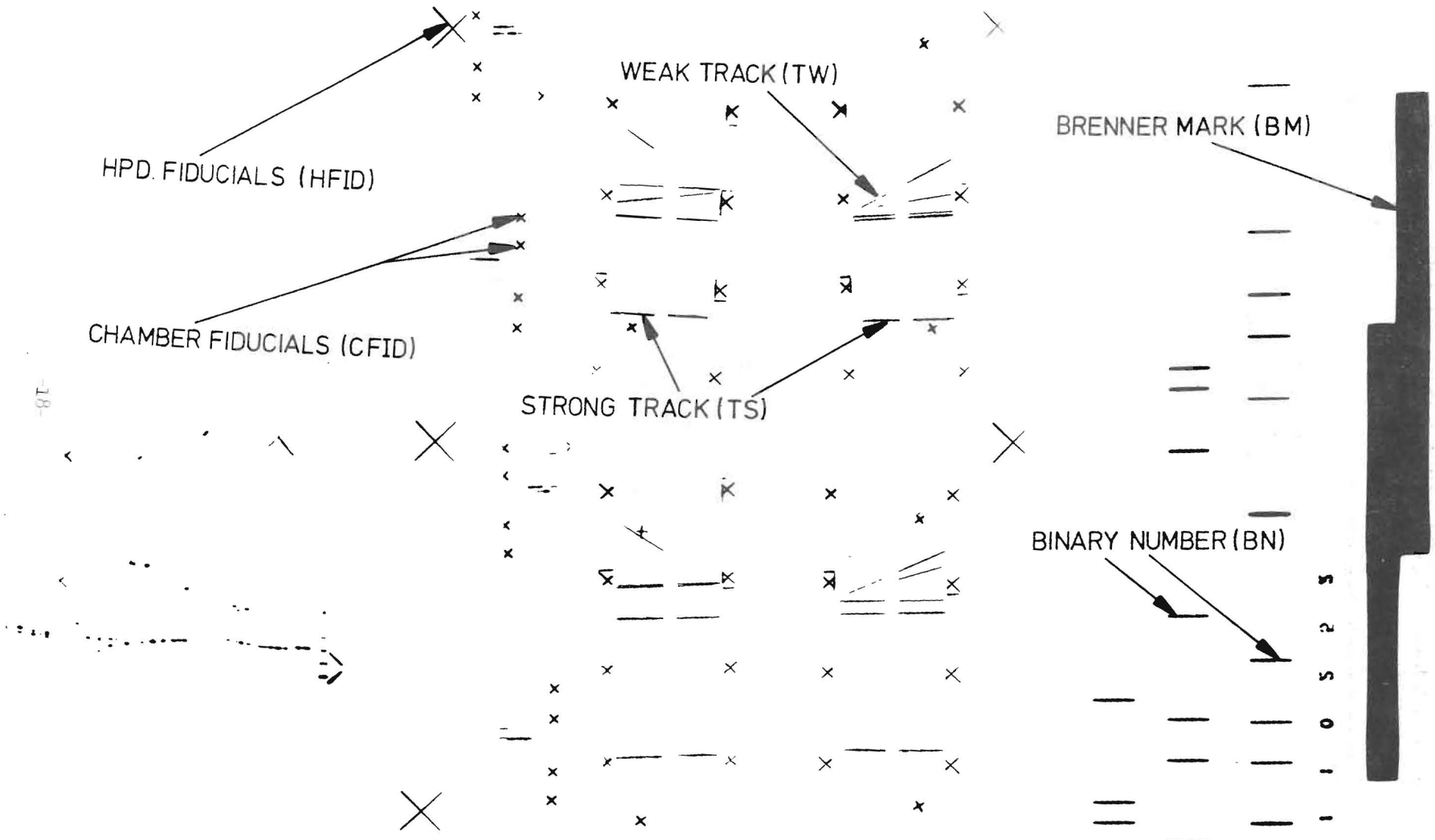


FIG. 9. TYPICAL FRAME FROM A RHEL–ROME S104 EXPERIMENT.

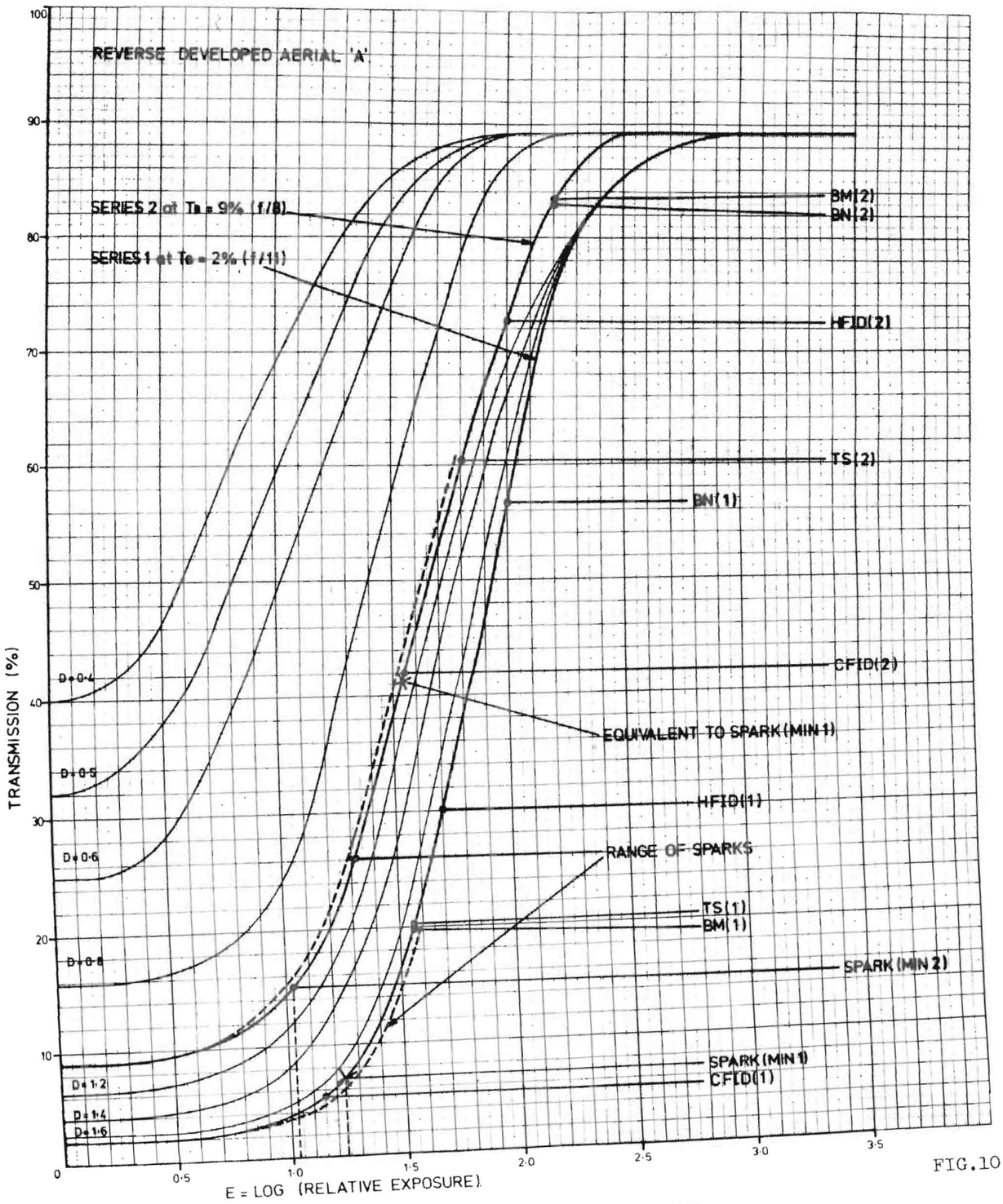


FIG.10

FIG.10 IMPROVEMENT of RHEL – ROME S104 EXPOSURE / DEVELOPMENT.

PHOTOGRAPHIC DENSITY = Log_{10} OPACITY = $\text{Log}_{10}[(\text{TRANSMISSION})^{-1}]$.

DENSITY	OPACITY	TRANSMISSION %
0·0	1·0	100
0·1	1·3	79
0·2	1·6	63
0·3	2·0	50
0·4	2·5	40
0·5	3·2	32
0·6	4·0	25
0·7	5·0	20
0·8	6·3	16
0·9	8·0	12·5
1·0	10	10
1·1	13	7·9
1·2	16	6·3
1·3	20	5·0
1·4	25	4·0
1·5	32	3·2
1·6	40	2·5
1·7	50	2·0
1·8	63	1·6
1·9	79	1·25
2·0	100	1·0
2·1	126	0·8
2·2	158	0·6
2·3	200	0·5
2·4	251	0·4
2·5	316	0·3

Table 1. Relationship of Photographic Density to Transmission.