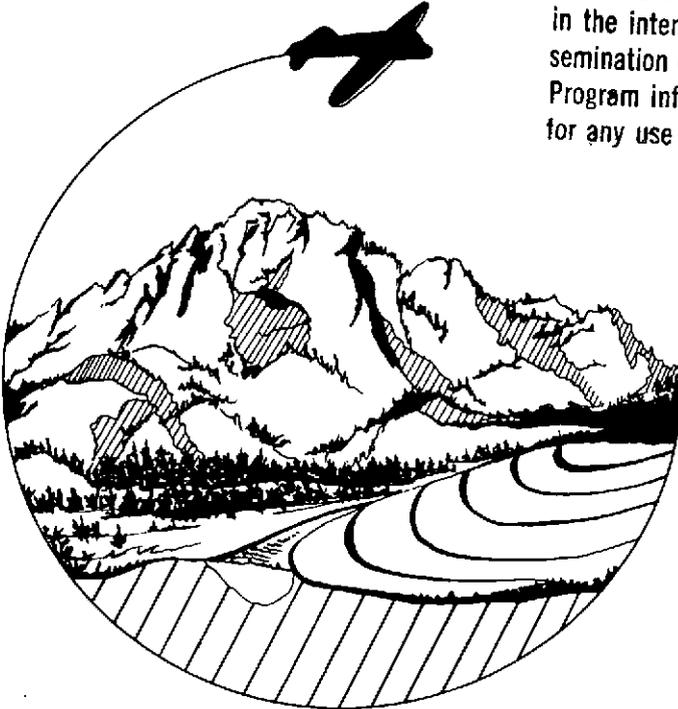


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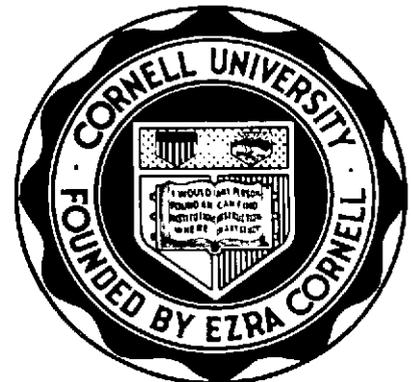
PHOTOGRAPHIC ENHANCEMENT OF ERTS IMAGERY

JANUARY, 1974

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**DEPARTMENT OF NATURAL RESOURCES
NEW YORK STATE COLLEGE OF
AGRICULTURE AND LIFE SCIENCES
AT CORNELL UNIVERSITY**



PHOTOGRAPHIC ENHANCEMENT OF ERTS IMAGERY

By

E. S. Phillips

Progress Report

January 15, 1974

Contract #NAS5-21886

Agency: New York State College of Agriculture and Life Sciences
Department of Natural Resources
Cornell University
Ithaca, New York 14850

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PREFACE

This report is one of a series of project reports prepared and supported under NASA Contract NAS 5-21886 "Evaluation of Satellite Sensed Information as a Source of Resource Inventory Information". The complete contents of this report also appear as part of the Final Report to be completed as of February 13, 1974.

INTRODUCTION

The methods outlined in this publication summarize the steps involved in the search for a method to convert ERTS imagery with the following objectives:

1. low cost
2. hard "in hand" copy that can be conveniently handled and stored for future reference.
3. approximation of "false color" similar to Kodak's Aerochrome Infrared Film 2443 or 3443.
4. maximum definition
5. ready interpretation and conversion to pre-determined scales

It was felt that if procedures to achieve these objectives could be attained, it would be possible in later experiments to assign specific color combinations to the various bands (positive or negative) to achieve clearer demarcation of specific objects of investigation.

Subsequent pages will, therefore, expand in detail on the essential steps involved. They are:

1. produce "corrected" negatives from the ERTS 70mm positives
2. produce enlarged positives from the above negatives
3. print the enlarged positives on transparent diazo material
4. superimpose in register the diazo material

The problems encountered will be explained and the solutions described. Future work may modify the solutions.

For further information, an Appendix is included which contains a set of characteristic exposure/density curves for several films and developers. A photographic enhancement kit is also included to demonstrate the stages of enhancement discussed in this report.

TRI-COLOR SUBTRACTIVE PREREQUISITES

If we turn briefly to the methods involved in the production of color in either the graphic arts or with older (pre-1930) color printing methods, the reasons for the subsequent steps and the principles will be clearer for those unfamiliar with color photography.

Early experiments showed that where a color object is photographed on film sensitive to the full visible spectrum through red, green, and blue filters respectively, three different negatives result. These negatives must result from meticulous exposures and careful development. Each negative must represent densities directly related to brightnesses reflected from the object. To assure accuracy, it is common practice to include a neutral grey scale in (but at the edge of) the object. Thus, it is possible by reference to the grey scale to compare directly the exposures and degree of development of each negative without being influenced by the colored objects in the picture. See Figure 1.

The objective is to expose and develop each negative until the grey scales appear identical. Then, visually or better yet with a densitometer, plot the exposures against the densities for each. When through proper adjustments three identical sensitometric curves result, a balanced color print is possible. See Figure 2.

Irrespective of the color printing process involved, the positive prints from the negatives are dyed the "light" complimentary color of the negatives. Thus, the positive from the blue negative is dyed yellow, green sensitive is dyed magenta, and red sensitive dyed cyan. Superimposed and in register each layer subtracts from white light that portion of the full spectrum in proportion to its density. In the case of a projected image, the color positive transparency reproduced the original scene as does the multi-layer emulsion of

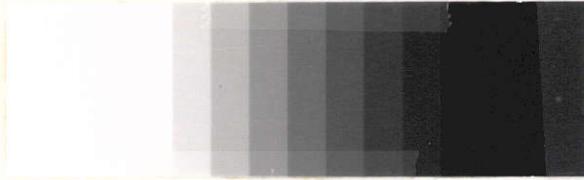


Figure 1. Photo Grey Scale. Every second step is equal to a double exposure.

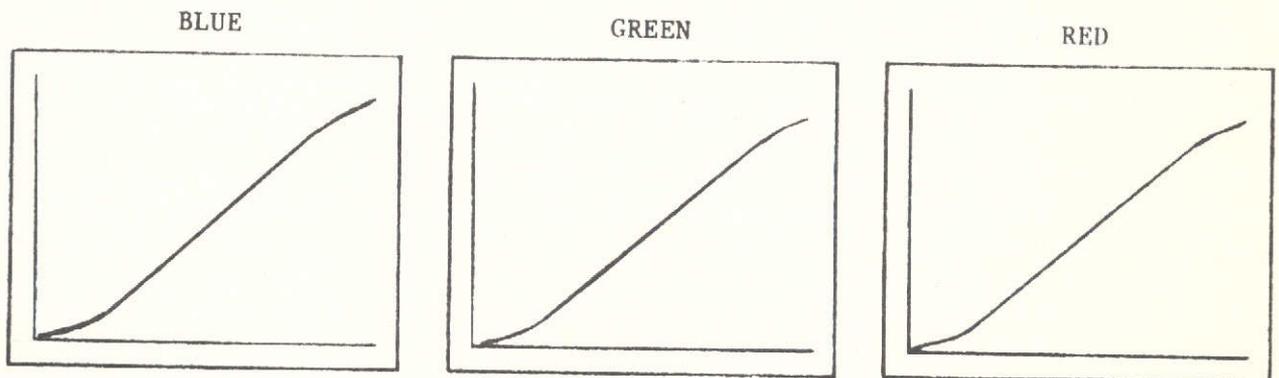


Figure 2. Sensitometric curves (exposure plotted against density) of three black and white negatives properly manipulated for color printing.

Kodachrome film that is sensitive to blue, green, and red light.

Current "false color" film operates on the same principle but differs from the usual layered color film by eliminating the blue sensitive layer and substituting an emulsion sensitive to infrared.

Figure 3.

	Layered color film	Positive dye	"False color"
emulsion layers	blue sensitive	yellow	green sensitive
	green sensitive	magenta	red sensitive
	red sensitive	cyan	IR sensitive

It is obvious from this comparison that ERTS imagery (green, red, and two IR bands) is ideally suited to "false color" reproduction.

GENERAL CONSIDERATIONS

Although ERTS imagery can be obtained in either the negative or positive form, it seemed desirable to begin with the positives for several reasons:

1. immediate tests of the images furnished could be run on diazo material
2. if alterations are needed to optimize the details of the received imagery, two steps of correction are possible

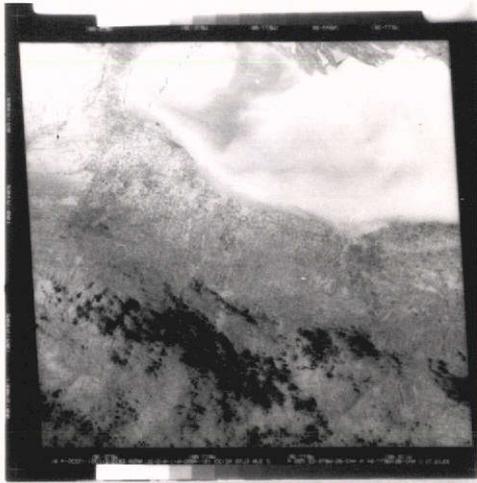
ERTS imagery does not contain a grey scale in the essential image and thus in a complex area such as is found generally throughout New York State, it is almost impossible to find some radiation that can be used as a constant to compare negatives. Water, chlorophyll, even clouds vary from one band to another, and thus induces a measure of subjective interpretation. Despite this, slight variations in treatment of the negatives or positives in the process, although deviating from perfection seem to cause little trouble in interpretation.

Cursory inspection of bands 4, 5, 6, and 7 makes it obvious that the four positives are not always equal. Due to a variety of reasons, the densities and contrasts vary from band to band. Atmospheric conditions may be the primary cause. The only two that most persons can objectively compare are bands 4 and 5. These are the only two in the visible spectrum. Band 4 almost invariably appears to lack contrast by comparison with the red recording band 5. In most cases, 5 appears fairly normal. Bands 6 and 7 appear out of balance by comparison with the visible bands. Overall contrast appears high when contrasting water and land areas. Cloud density appears different from band 5 but one must then realize that IR and visible transmission through clouds may vary.

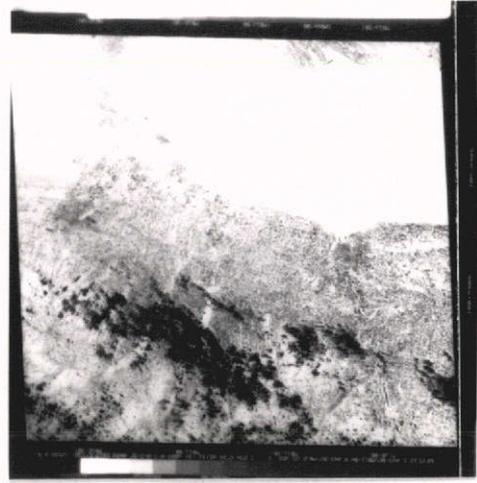
Thus, if imbalance of the four bands is assumed, the following procedure is helpful. We shall assume that the positive to be used in diazo printing will be approximately 8" X 10". We shall further assume that temporarily 1 to 1 negatives will be made from the ERTS positives. Enlarged negatives will be discussed later.

Step 1 - Negative Production

1. Place a 70mm positive in the negative carrier and adjust the enlarger so that the entire image plus the base sensitometric strip is included in the 8" X 10" area of the easel.
2. Remove the positive and throw the focusing adjustment slightly out of focus.
3. Mount all four positives on a flat scratch-free glass at least 5" X 7" in size. Good plate glass will suffice. Be sure that the emulsion surface is positioned away from the glass.
4. Place a piece of enlarging paper in the easel. (Kodak Polycontrast standard for our experiments unless otherwise noted).
5. Place the glass-positive sandwich on the paper with the emulsions in contact. Use "normal" contrast paper or filter.
6. Expose successive sheets of paper to the enlarger illumination until all of the bands' exposures range from "too light" to "too dark". Be sure to record each exposure on the paper before developing. See Figure 4.



Band 4



Band 5



Band 6



Band 7

Figure 4. One of a series of exposures. ERTS positives exposed 10 seconds simultaneously. Band 6 appears properly exposed.

The resulting prints give a series of exposures and densities that can be used for comparisons. The object is to find the series of exposures that yield approximately equal densities for the four bands. Corrections for contrast differences will be attempted in Step 2.

See Figure 5.

Exposures for Figure 5 are as follows:

band 4	14 seconds
5	24 seconds
6	10 seconds
7	8 seconds

Step 2 - Enlarged "Prints" from ERTS Positives

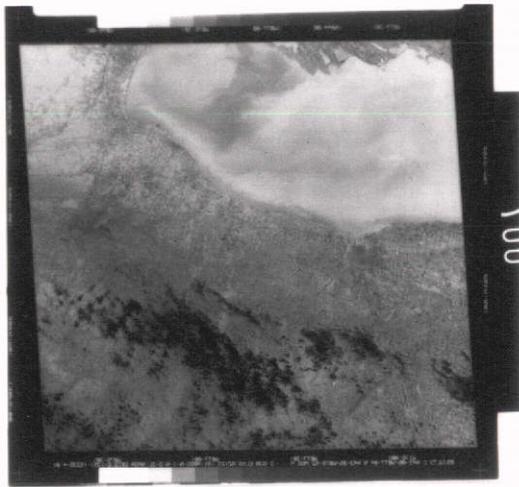
If false color is the objective, bands 4, 5, and 6 or 7 will be used. The illustrations used were all with band 7.

For each band expose (with the appropriate filter or paper grade) and develop to achieve a normal looking negative. Shadow detail must have a slight film of grey. These may often be the cloud areas. A full range of greys to black must be present. Begin with band 5 because it more nearly approximates a normal scene. Use "f" stop 11 or 16.

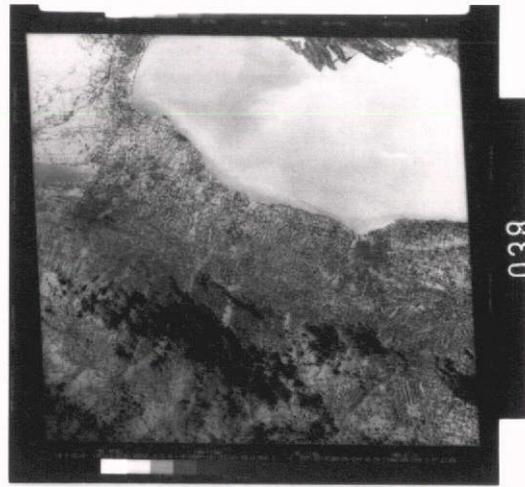
Results from the examples used:

Bands	Exposure	"f" stop	Filter for Polycontrast Paper or Alternate Paper
5	30 seconds	f 11	#1
4	14 seconds	f 11	Agfa Brovira BH
6	14 seconds	f 11	#3
7	11 seconds	f 11	#3

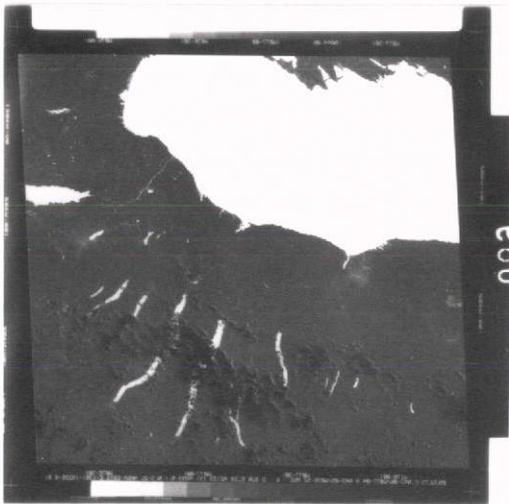
Bands 5, 6, and 7 could be printed on Kodak Polycontrast Paper with the filters indicated. However, band 4 yielded poor results even with the #4 filter. However, a print on Agfa Brovira BH grade 5 matched the other prints.



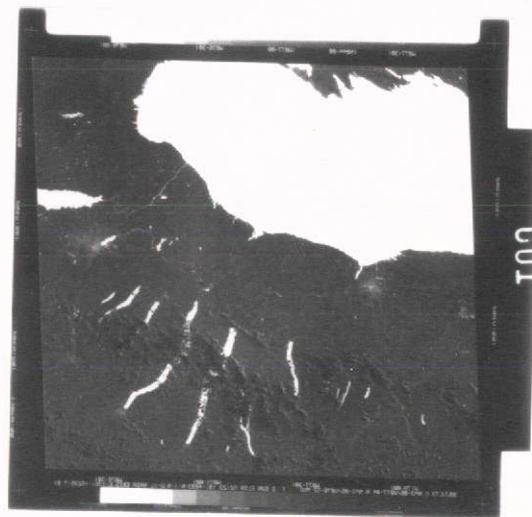
Band 4



Band 5



Band 6



Band 7

Figure 5. Differential exposures for each band.

Band 4	14 seconds
Band 5	24 seconds
Band 6	10 seconds
Band 7	8 seconds

The purpose in this step is to correlate the known density ranges of paper to the density ranges of the positives. Thus, one derives the approximate density range of the ERTS positives.

From tables such as on Page 76 of the data book "Aerial Photography" by Kodak, one derives the density range for each band.

(Kodak Polycontrast Rapid Paper)

Kodak Polycontrast Filter	Speed	Log Exposure Range
#1	320	1.25
1 1/2	320	1.15
2	320	1.05
2 1/2	320	.95
3	200	.85
3 1/2	160	.75
4	100	.70
No filter	500	1.05

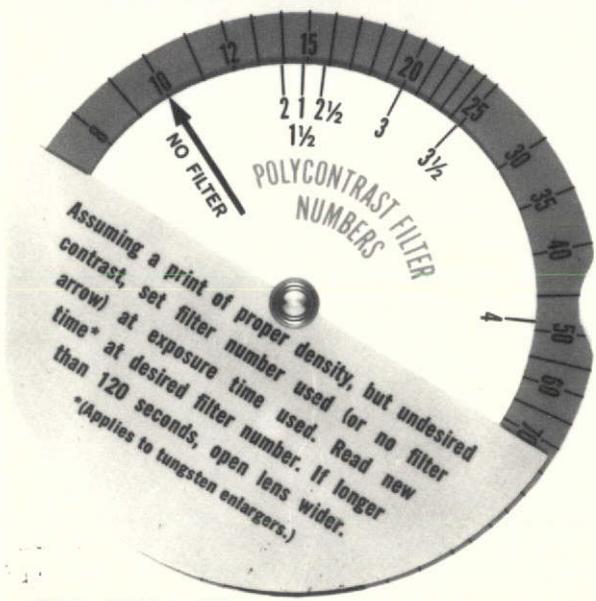
Agfa Brovira was judged to be in the range of .5 to .55.

Because these exposure ratios will be used to determine the exposure for the negative material, they must be recomputed for a "no filter" factor where polycontrast paper is employed. By using the exposure computer for polycontrast filters and placing the appropriate filter number opposite the exposure for the enlargement, one can derive the "no filter" exposure at the arrow that says "no filter". See Figure 6.

Thus, by now a table begins to form:

Band	Simultaneous Print Exposure	Enlarged Print Exposure	D-Range	Corrected Exposure
5	24 seconds	30 seconds #1	1.05 1.25	19 seconds
4	14 seconds	14 sec. Brovira	.55	(14 seconds)
6	10 seconds	14 seconds #3	.85	7 seconds
7	8 seconds	11 seconds #3	.85	6 seconds
Notes		(1)	(2)	(3)

EXPOSURE COMPUTER for KODAK POLYCONTRAST FILTERS



© Eastman Kodak Company, 1964

Figure 6. Polycontrast Exposure Computer used to determine the "no filter" exposure time. 20 seconds with the #3 filter is equivalent to 10 seconds with no filter.

- (1) Polycontrast Rapid except band 4 for which Agfa Brovira BH was used.
- (2) Table on Page 76, Filter, Speed, and Log Exposure Range*
- (3) Corrected using Kodak's Exposure computer for Polycontrast filters

This may seem like a lot of unnecessary work. However, care at this point makes all other operations strictly routine. Once undertaken, the sequence becomes habitual and easy.

Step 3 - Negatives from ERTS Positive

Because our objective is to work in areas of readily available equipment and supplies, we ruled out use of Kodak Aerial Plotting Plates. They exceed the size limitation we had placed on negative material (4" X 5"). Because of an assumed strong similarity to 3 1/4" X 4" lantern slide plates we chose to make our negatives on this material. A few trials, however, showed inconsistencies that needed explanation, and we decided to make sensitometric tests with both the contrast and medium plates in various developers. Kodak's step tablet #2 was used in conjunction with the enlarger and despite slight exposure variations pinpointed the problem. See Figure 7. The three medium plate charts show a good straight line relationship between exposure and density with the greatest contrast achieved with DK50. With Dektol as the developer, the fog component built so fast that it was eliminated from further consideration. The dotted line in all charts indicated 0.3 density.

The contrast plates are entirely different. The shorter the development, the shorter is the straight line portion with either developer tried. If one compares the contrast plate developed for two minutes in DK50 with the Medium Plate developed for six minutes in DK50, the gammas are about the same. However, the medium plate gives a fairly straight line to a density of 3.0. The contrast plate straight line goes to about 1.5 and then curves to a density

*"Kodak Data for Aerial Photography", M-29, Eastman Kodak Company, 1971, third edition.

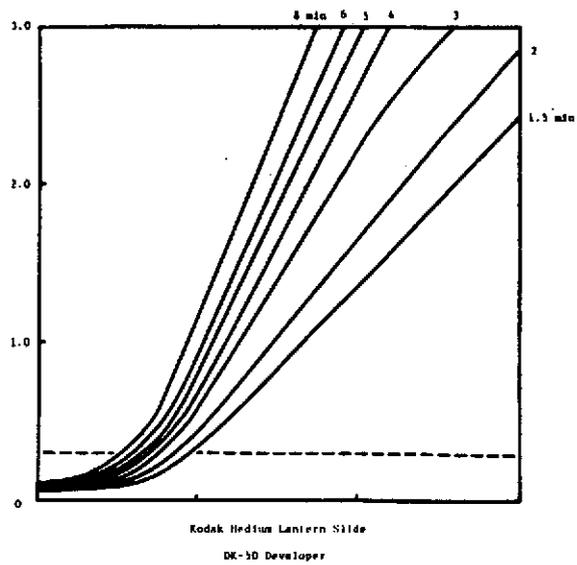
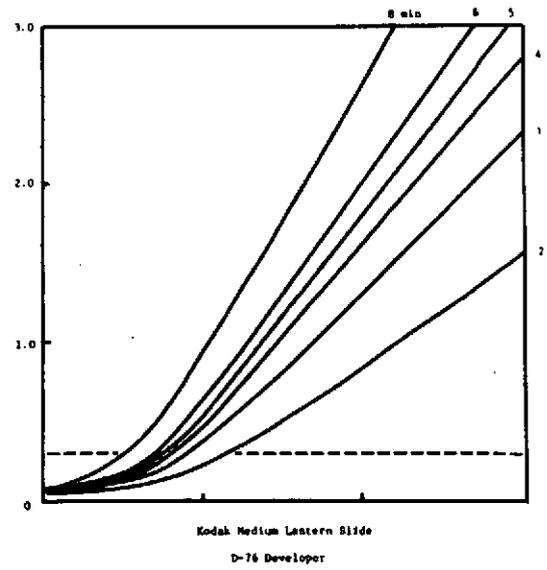
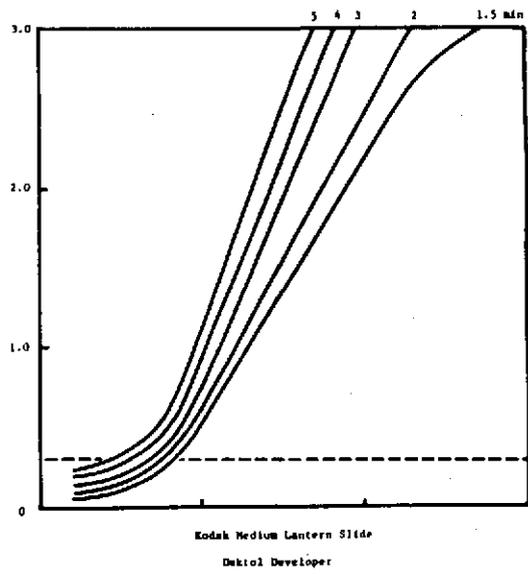
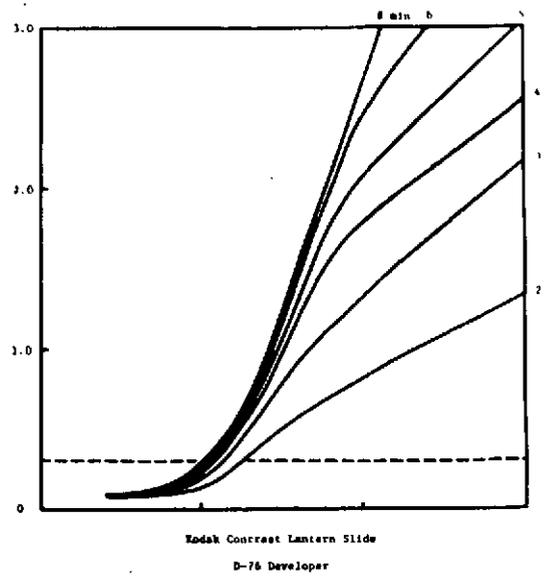
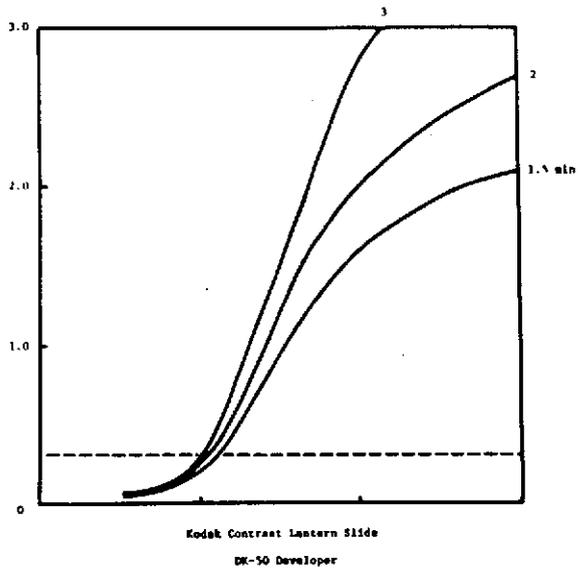


Figure 7.

of about 2.7. Interestingly, if the development of the contrast plate is carried an additional minute, the straight line portion becomes useful. All of this points to the extreme care that must be exercised if contrast lantern slide plates are used. An analysis of the sensitometric data available for Kodak Aerial Plotting Plates shows a similar response in DK50.

FURTHER CONSIDERATIONS

Lantern slide plates were an initial choice because:

1. of their flatness
2. they fit into 3 1/4" X 4 1/4" glassless holders for the enlarger
3. if mass-produced, they could be tank developed in 3 1/4" X 4 1/4" negative holders
4. fine grain
5. blue sensitive (for easy darkroom use)
6. dimensional stability

Initially, contact negatives were made by exposing the lantern slide to light from the enlarger (set as in previous work), that passed through flat glass, through the 70mm positive to the lantern slide. See Figure 8. Be sure the positive and lantern slide are oriented emulsion to emulsion.

Fresh developer at 68-70°F was always used with continuous agitation.

Factors were employed from the polycontrast paper to determine the exposure for the lantern slide. Roughly one finds this as half the "no filter" exposure for polycontrast paper. However, this will vary with the plate used, developers, and developing times, and can be offered only as a suggestion. Density of the negative in the shadow area is, however, critical. To minimize the effect of the toe portion of the emulsion, the shadow detail must have a density of about 0.3. If you do not have a densitometer 0.3 density is sufficient silver in the shadow area to be easily identifiable and on the verge

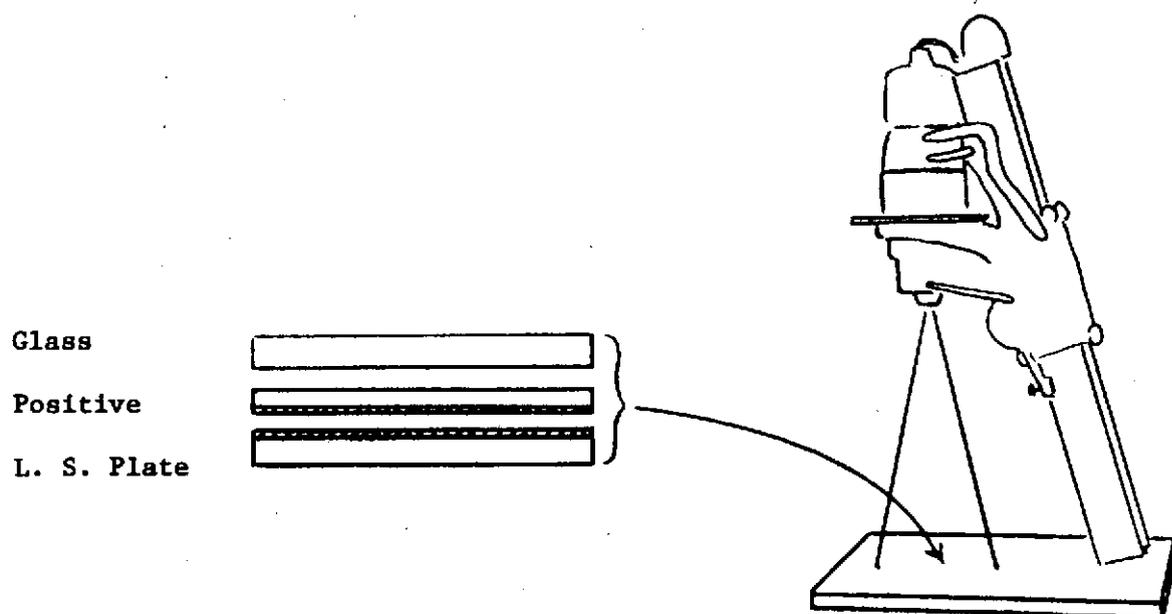


Figure 8. Contact printing a 70mm positive on a lantern slide plate.

of objectionable in a normal negative. Stated another way--a negative with good clean highlights would very likely cause false results in one or more bands when the final prints are made in color.

Ultimately, one must wrestle with the accumulated sensitometric and other data to produce three negatives that so closely match density ranges that color reproductions are possible. This may mean using different developers and plates from which equivalent negatives will result. To accomplish this, a simple calculator (jokingly called in our laboratory "Flip's Calculator") was devised from the graph paper used to assemble the sensitometric data of the various films and developers. It can be made easily by contact printing through the graph paper to produce a negative on Kodalith or equivalent film. In turn, the usable part is again printed on Kodalith through the negative (make two prints). By cutting both positives and attaching several strips of cardboard with Duco cement (or a similar product) a U-shaped calculator results as shown in Figure 9.

Figure 10 shows the calculator in use. Band 5 showed (in the enlarged prints) an assumed density range of 1.05. If we desire a negative with a density range nearer 1.2 we determine the developing time by placing the horizontal base line of the calculator on the dotted line. Adjust the position of the moveable right hand vertical axis at the point where "0" intersects 1.05 and move the entire calculator back and forth until the left hand "0" intersects a line that ultimately intersects the right hand axis at 1.2. The illustration shows the need for a medium plate developed in D76 for four minutes in 70°F.

Ultimately, sensitometric data coupled with other information offers the experimenter a variety of options. As an example, a band 4 positive with an assumed density range of 0.5 to 0.55 could be treated either of two ways:

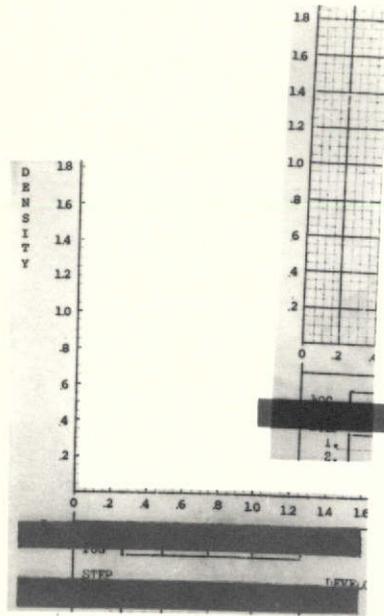


Figure 9. Graph calculator.

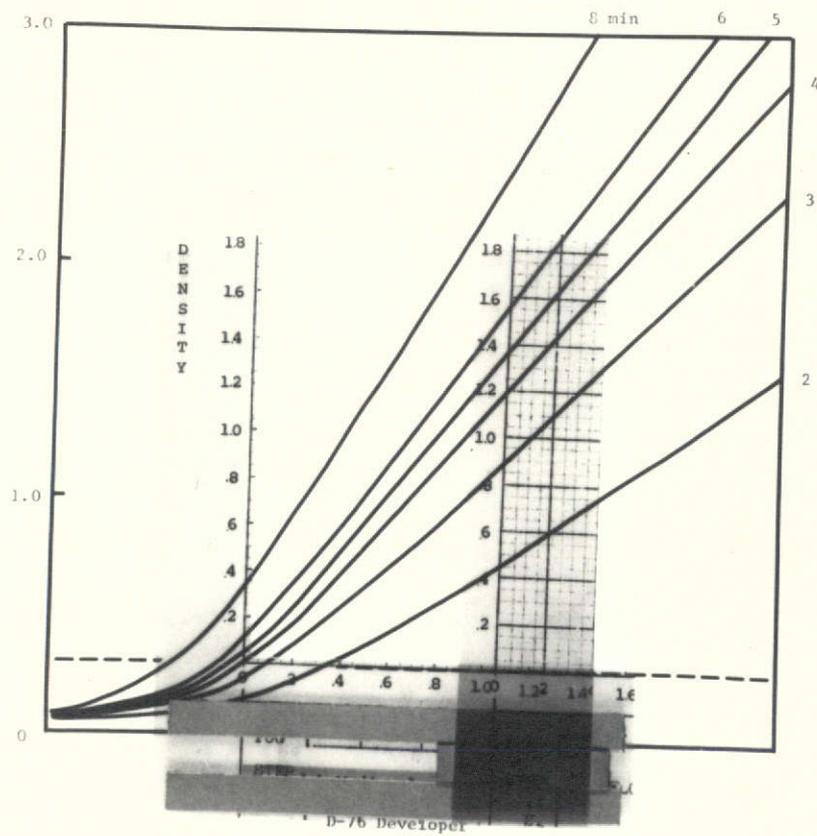


Figure 10. Graph calculator in use with D-76 developer curves to determine the correct development time.

	Plate	Exposure	Developer	Time
#1	medium	2 seconds	DK50	6-8 minutes
	or			
#2	contrast	3 seconds	D 76	5 minutes

Gammas would be very similar; grain would be different; but more important, because of the toe and long shoulder of the contrast plate, the exposure would be extremely critical. Any deviation from straight line reproduction would alter the color in either the highlight or shadow area. In general, this experimenter prefers to use the medium plate.

By following the same steps for the remaining bands, we can add the following data to our original table:

	Plate	Exposure	Developer	Development Time
Band 5	M	9 seconds	D 76	5 minutes
4	M	2 seconds	DK50	6-8 minutes
4	C	3 seconds	D 76	5 minutes
7	M	2 seconds	D 76	5-6 minutes

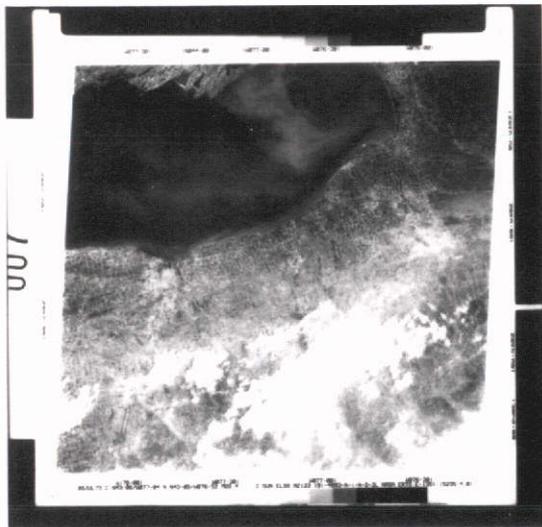
See Figure 11.

Step 4 - Paper Enlargements

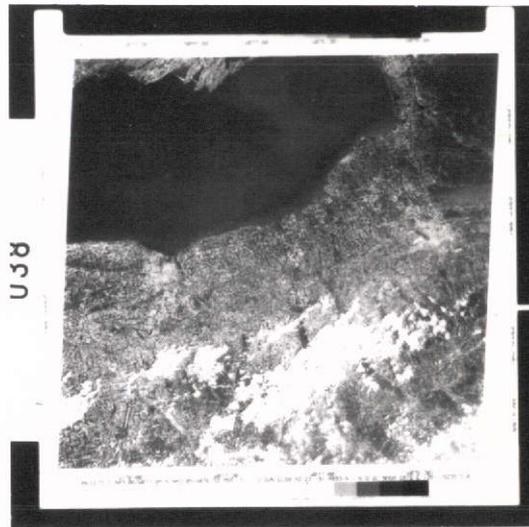
When the lantern slide plates are dry, make 8" X 10" matching prints. If the previous work was carefully done, there will likely be little change in the exposures for the prints. If there are differences, record the results. If the contrast of the paper has to be varied from "normal" to produce matching prints, this information must also be recorded.

Step 5 - Enlarged Positive Transparencies

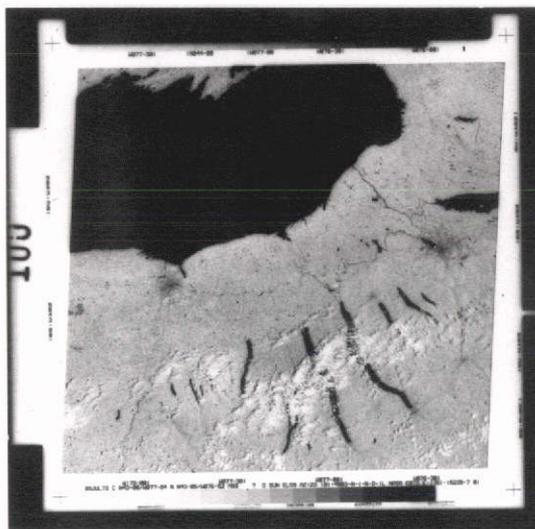
Three different materials and three developers have been used in this step.



Band 4



Band 5



Band 7

Figure 11. Simultaneous prints from lantern slide negatives that indicate a nearly balanced set from which 8" x 10" transparencies are made.

1. Kodak Commercial film #4127. The film is blue sensitive with moderate speed, contrast, and grain. Its long toe may cause some color imbalance. Tungsten ASA-8.
2. Kodak Blue Sensitive masking film 2136. This film is similar to commercial but has the advantage of finer grain and a less fragile emulsion surface. Tungsten ASA-25.
3. Kodak Aerographic Duplicating film 4427. This blue sensitive film is designed for duplicating negatives made on medium grain aerial films and may be used as either a negative or positive.
4. D-76 was tried on the Aerographic film along with DK50. Both D19 and DK50 were used with the commercial and masking film. In general, the developers are similar but D19 is a bit cleaner working and gives slightly higher contrasts.

Procedures:

If the 8" X 10" enlargements from the previous step are in balance, positive transparencies on commercial film can be made using 1/10 the polycontrast exposure. Development for 5 minutes in DK50 is considered normal.

If contrast adjustments are necessary in the previous step (Step 4), match the prints with the appropriate filter and when dry use the density table (Page 9) and the homemade calculator to adjust the development times for the positives.

Although commercial film is mentioned here, each of the others has advantages. Blue masking film has a shorter toe and slightly better straight line portion of the curve. Aerographic duplicating film gives higher contrasts with DK50 than the other films.

The density range of the transparencies to be printed on diazo material should be close to 1.3. IR bands will exceed this if waterbodies are included in the range.

Step 6 - Diazo Printing

For "false color" quick and relatively satisfactory color transparencies

are possible when band 4 is printed yellow, band 5 magenta, and band 6 or 7 cyan.

If the steps as outlined in this paper are followed and if the grey scale supplied with each ERTS image is included in the final color composite, it will be far from neutral. This is to be expected with the steps that have been taken to optimize the information contained in each band. In general, the low densities will be blue. The middle tones green, and the dim portions a near black.

The final report of the Cornell Project will include different color designations to be applied to specific bands that enhance color differences and thus optimize information readout (see Figures 12 and 13).

GENERAL OBSERVATIONS AND SUGGESTIONS

From the inception of research, it was recognized that although diazo printing could give quick color reproduction, it might not necessarily be perfect. After all, diazo use in the graphic arts depends on relative dot size in a screened reproduction. Our use would be with continuous tone material and final reproductions would depend on the accuracy of dye balance. Sensitometric and spectro photometric tests have shown imbalances that one wishes did not exist. Further tests are planned with slower photographic methods such as Kodak's Dye Transfer process in the search for more perfect reproduction.

Despite recognized imbalances the diazo-photo process as outlined here has the advantage of making available, quickly, hard copy that a trained interpreter can use.

If different researchers plan to interchange transparent color material, it will be essential that some standard be set for critical viewing. Currently,

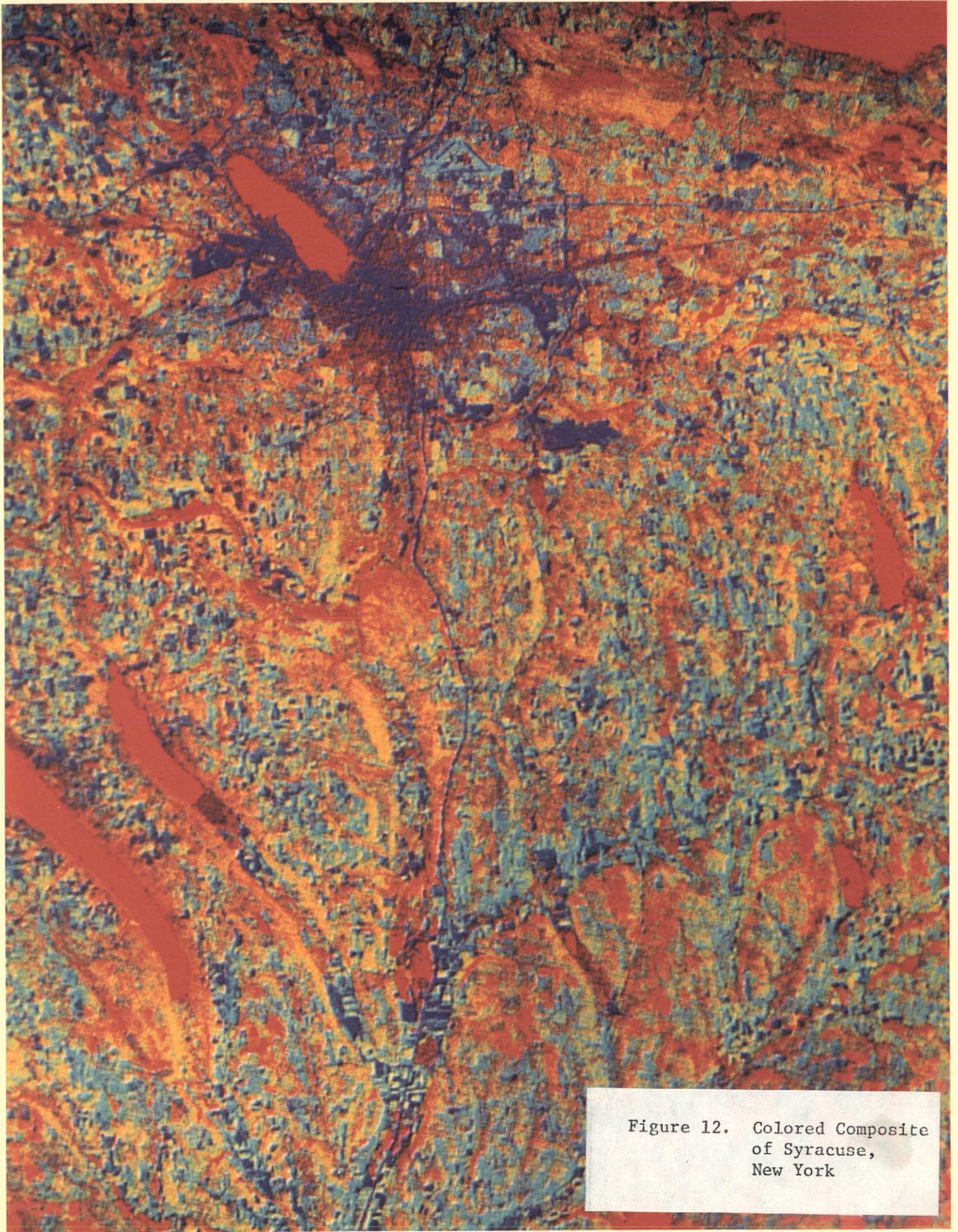


Figure 12. Colored Composite
of Syracuse,
New York



Figure 13. "False Color"
Infrared Composite
of Central New
York

most tungsten sources are too red; most fluorescent sources are short of red. The Macbeth viewer with 5000 Kelvin output appears to be satisfactory. However, to more perfectly fit the diazo process, it may be that a mild amber filter would help.

Most of the experimental work to determine the density range of the ERTS positives was performed on Kodak's Polycontrast Rapid paper. Other suppliers market products with an extended range that holds promise for future work.

Kodak's Polycontrast Rapid	0.7-1.25 log exposure range
GAF Cy Kora	0.7-1.45
Ilford Ilfobrom	0.6-1.6
Agfa Brovira	complete data not available at this writing.

Ilfobrom has an interesting characteristic. The first five contrast grades have the same emulsion speed and the remaining grade is half the speed of the others.

If original negatives from ERTS positives are enlarged (often from 3 to 5X) it is desirable to mark a paper template (the size and thickness of the negative material) with important and/or easily recognizable features. Furthermore, if these features can be located diagonally from one another, it will be possible to approximately register the images for all bands on the negative. Simple penciled arrows contiguous to the identified spot on the positive projection is adequate.

Because the edge data from NASA can no longer be used to identify the negatives from the different bands, some other system may be necessary.

Glass plates may be marked (on the emulsion surface) with an indelible black felt marker. Light will not penetrate the mark and thus clear film results after processing. Films may have small sections of the corners removed for identification, i. e., band 4 - no cut, band 5 - 1, band 6 - 2, band 7 - 3.

The same procedure applies to 8 X 10 positive transparencies for diazo printing.

Registration of the final composite should pose no problem. One to one negatives contain film register marks and can be used if the enlargement retains these marks. If not, the template method as described in the preceding paragraph will assure register within the thickness of a fine pencil line (for the negatives). The final dry photographic positives can be registered by superimposing one over the other (such as band 4 over band 5) and applying pressure-sensitive register marks on diagonal corners of the films. The bottom film should be treated first. Remaining bands (6 and/or 7) will then be registered--also with band 5. Be sure that the register marks will stand the heat of the diazo machine.

Some of the images supplied by NASA have a density differential between opposite edges of about 0.5. This leaves one side less saturated with color. The cure has been accomplished by producing a lantern slide plate that in its long dimension uniformly grades from 0 density to 0.7 density. This plate is mounted above the positive or negative, to neutralize the original density differential.

GENERAL PROCESSING SUGGESTIONS

All processing was done in a tray with fresh developer at 70°F.

All experimental development employed a hypo eliminator to shorten the "wet" processing time. In addition, all plates and film were partially dried with a viscous sponge and dipped in a mild Photo-Flo solution and squeezed dry before sponging the film or plates.

Where film or plates contained a non-exposed area, pertinent information about exposure and development was written on the gelatin with a permanent marking felt pen. In some cases (where confusion might result) the data was either written or keyed before exposure.

Most of the 1 to 1 contact negatives made on the lantern slide plates had sufficient room along one edge so that an exposure through Kodak's Photographic Step Tablet #1A could be included. This gave a constant check on the exposure and development accuracy.

Information for the sensitometric graphs included in this report were derived by the use of Kodak's Photographic Step Tablet #2.

EQUIPMENT

Enlarger - Omega D-3 auto focus with variable condensor

Lens - 80mm F5.6 Rodenstock
135mm F5.6 Rodenstock

HOLDERS - glass negative holder, 3 1/4" X 4 1/4" and 4" X 5"
glassless negative holder

A 3/8" steel tape was glued to the right hand rail with a pointer attached to the locking nut. This allowed duplicate enlargements of extreme accuracy.

Photo Timer

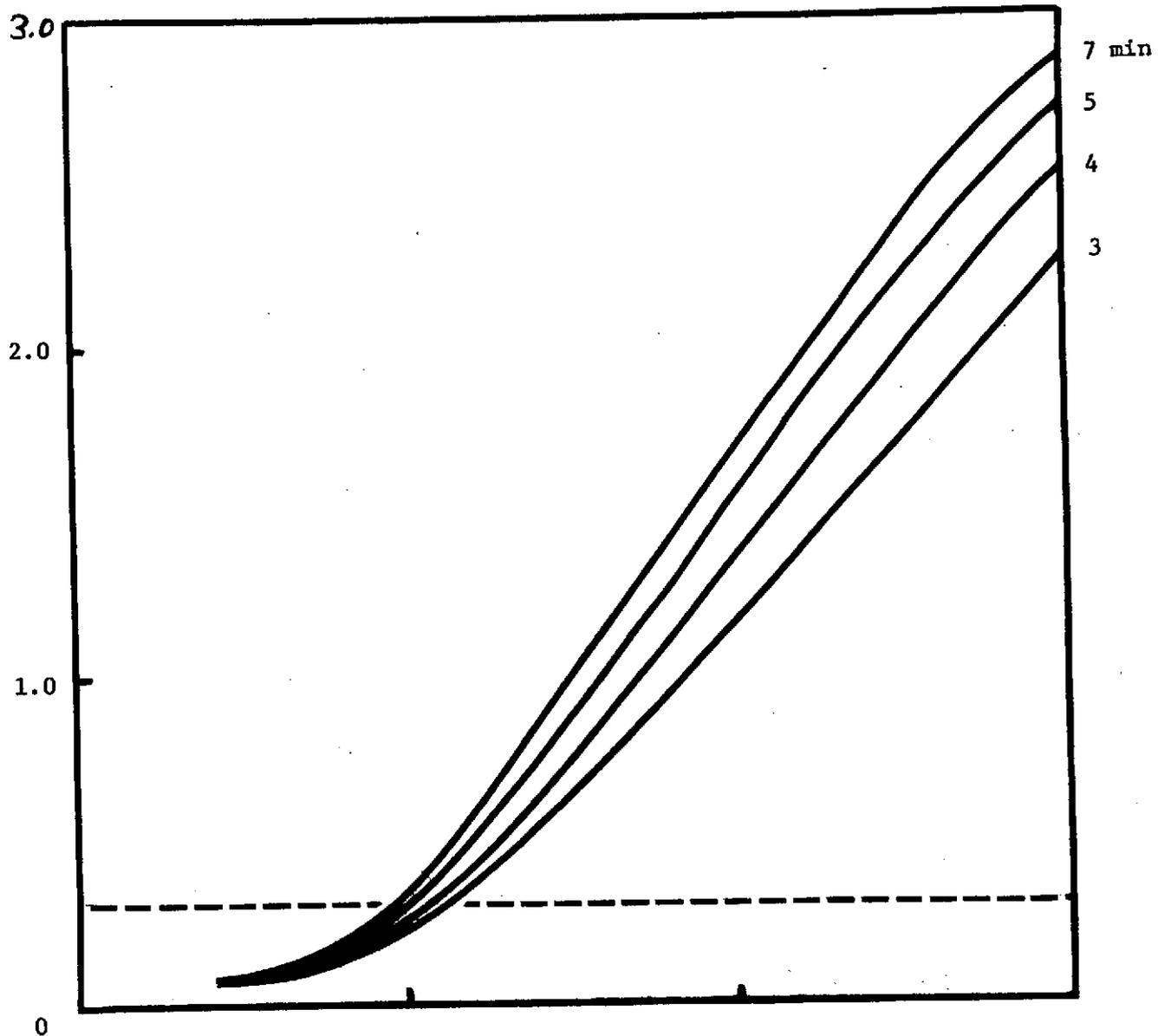
Heath Photo Timer - An accurate unit with 0-99 second capability with 10% separation between increments. In addition, a separate switch gives a 1 to 10 ratio that interestingly covered the time reduction from Polycontrast Paper to Commercial film.

Densitometer

Initial work was accomplished in a Kodak Color Densitometer RT that reads either transmitted or reflected densities. Although inordinately slow, the results are sufficiently accurate and compare favorably with the Macbeth Densitometer TD 518.

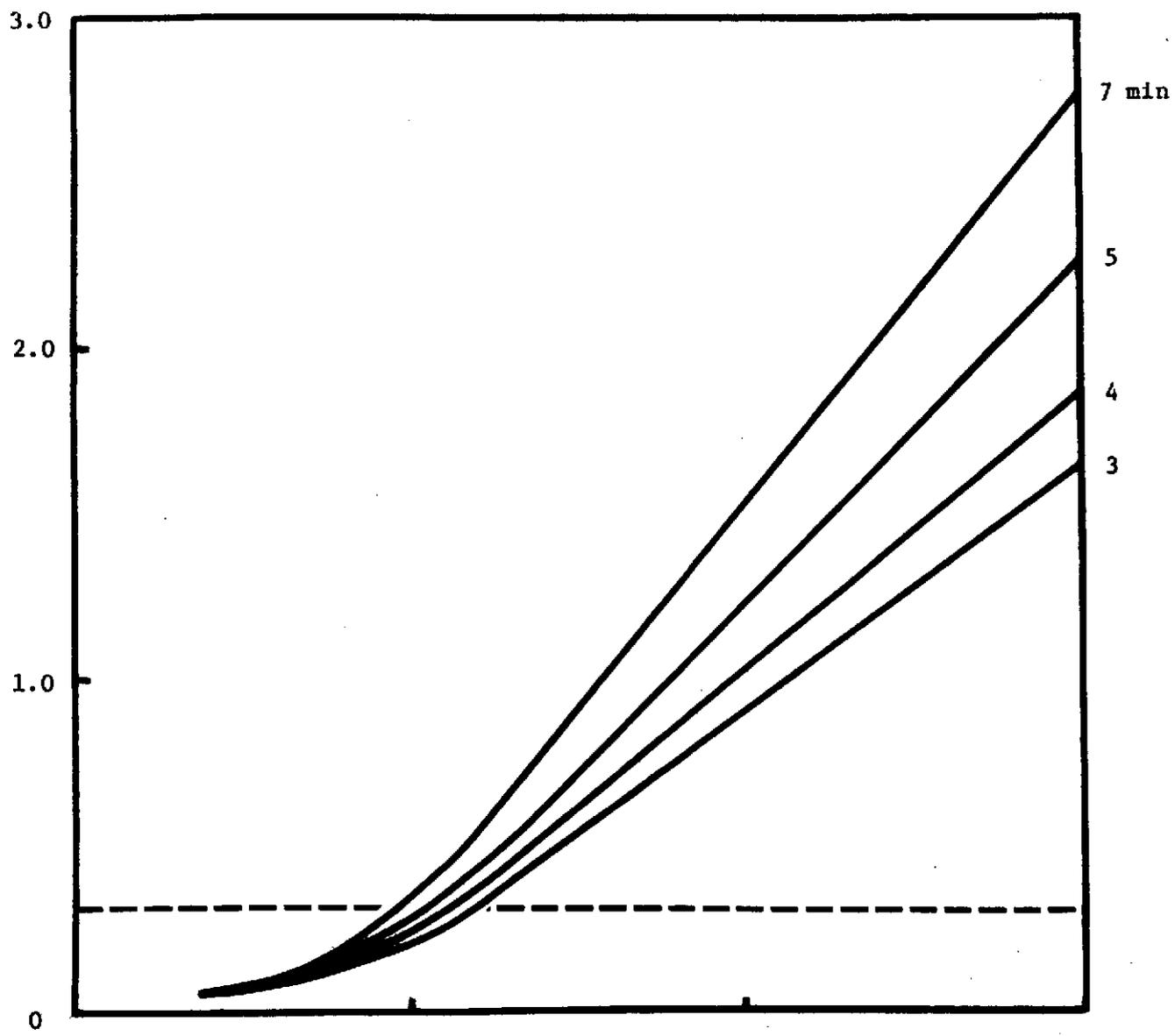
In addition, your author assembled a Heath-Mitchell Fotoval II photometer to read the occasional projected densities needed,

APPENDIX



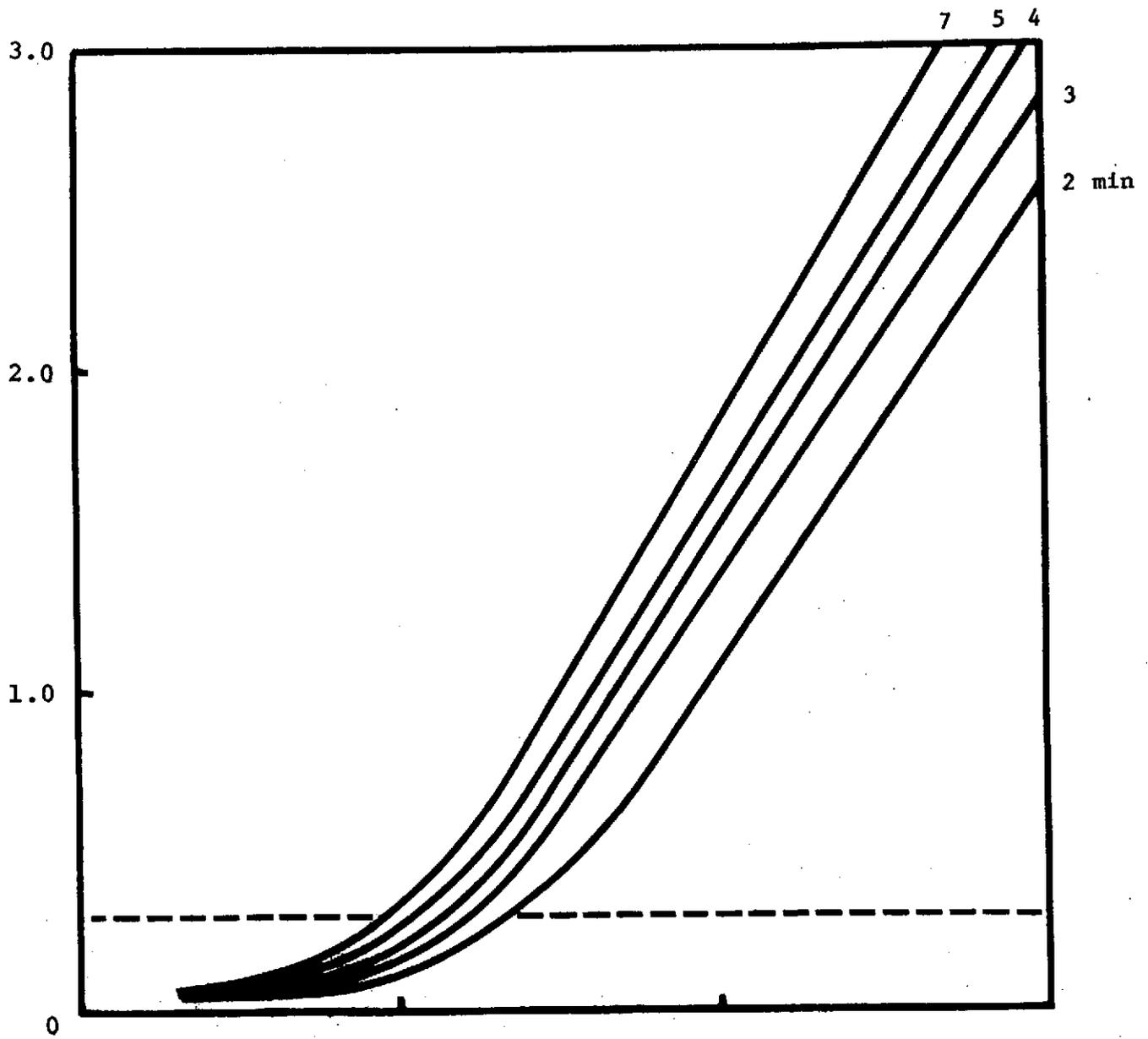
Kodak Blue Sensitive Masking Film 2136

D-19 Developer



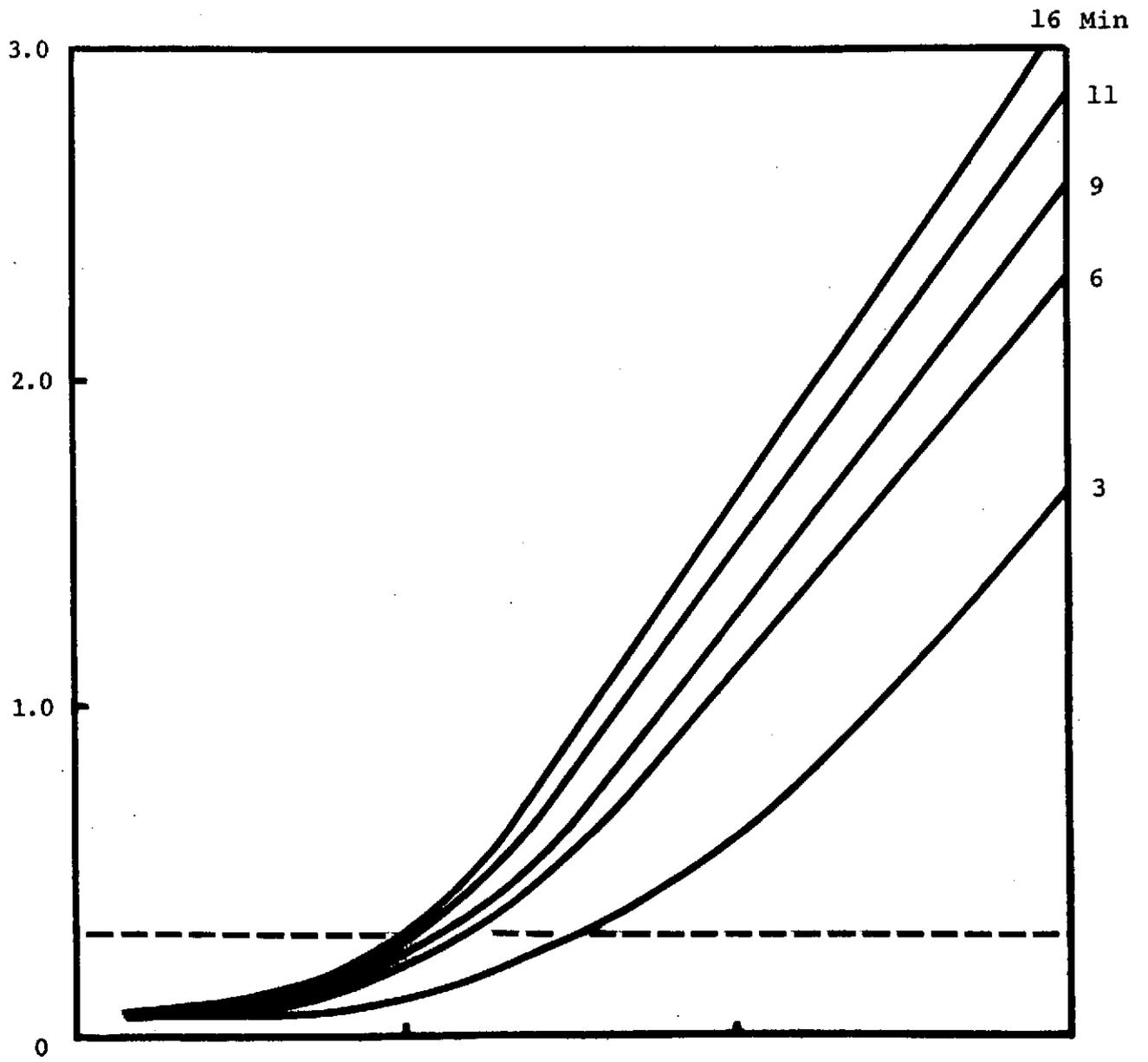
Kodak Blue Sensitive Masking Film 2136

DK-50 Developer



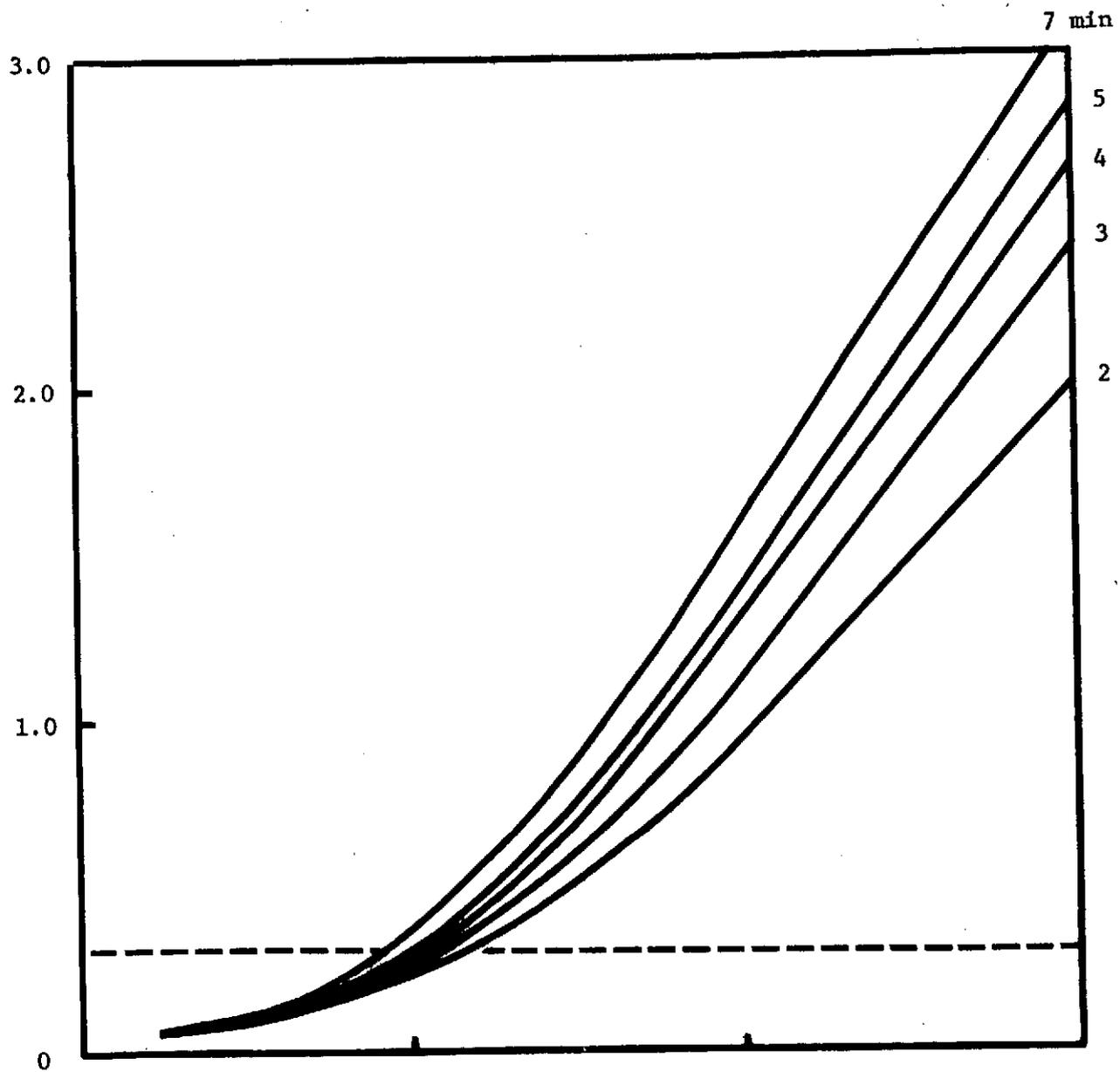
Kodak Aerographic Film

DK-50 Developer



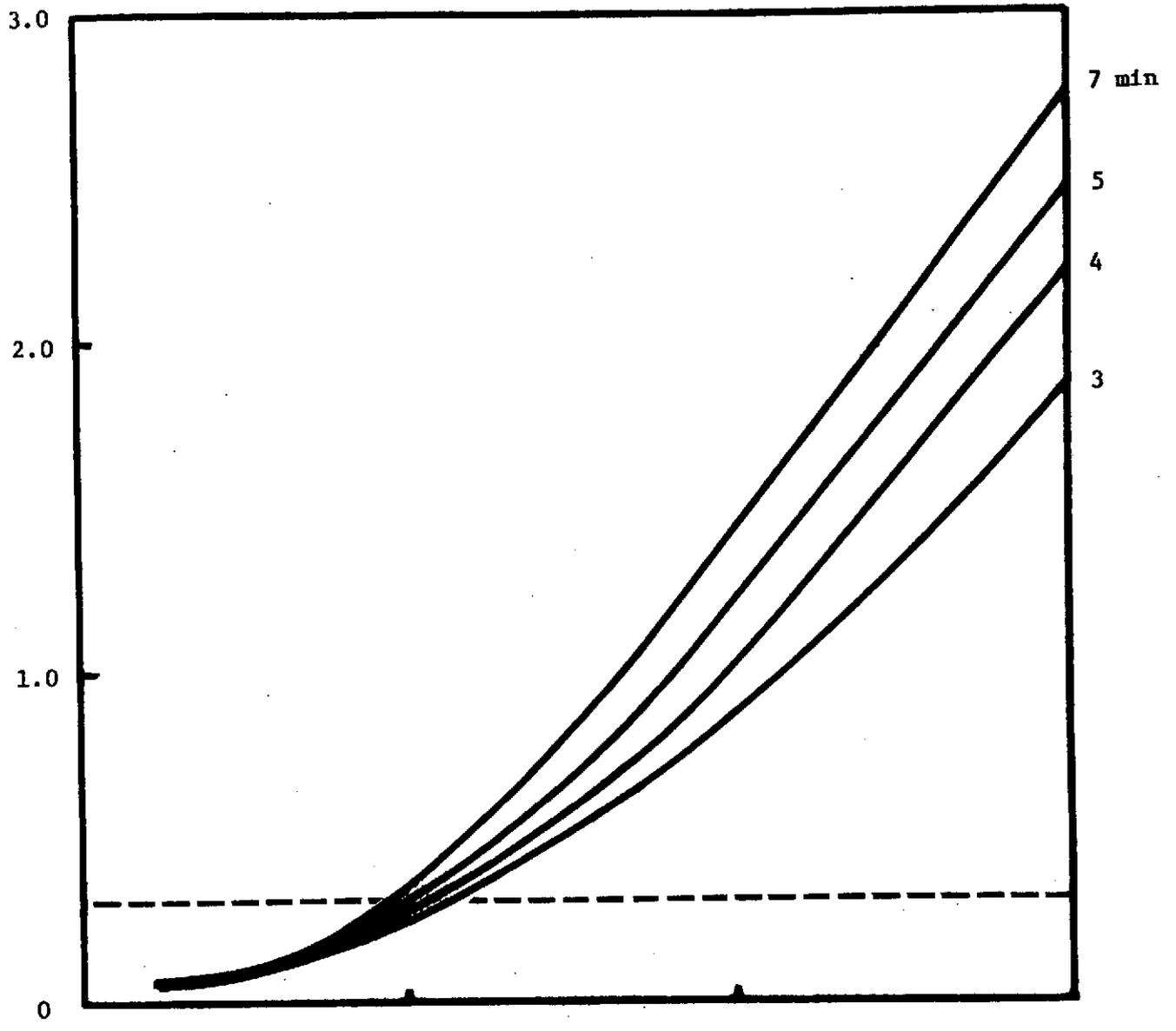
Kodak Aerographic Film

D-76 Developer



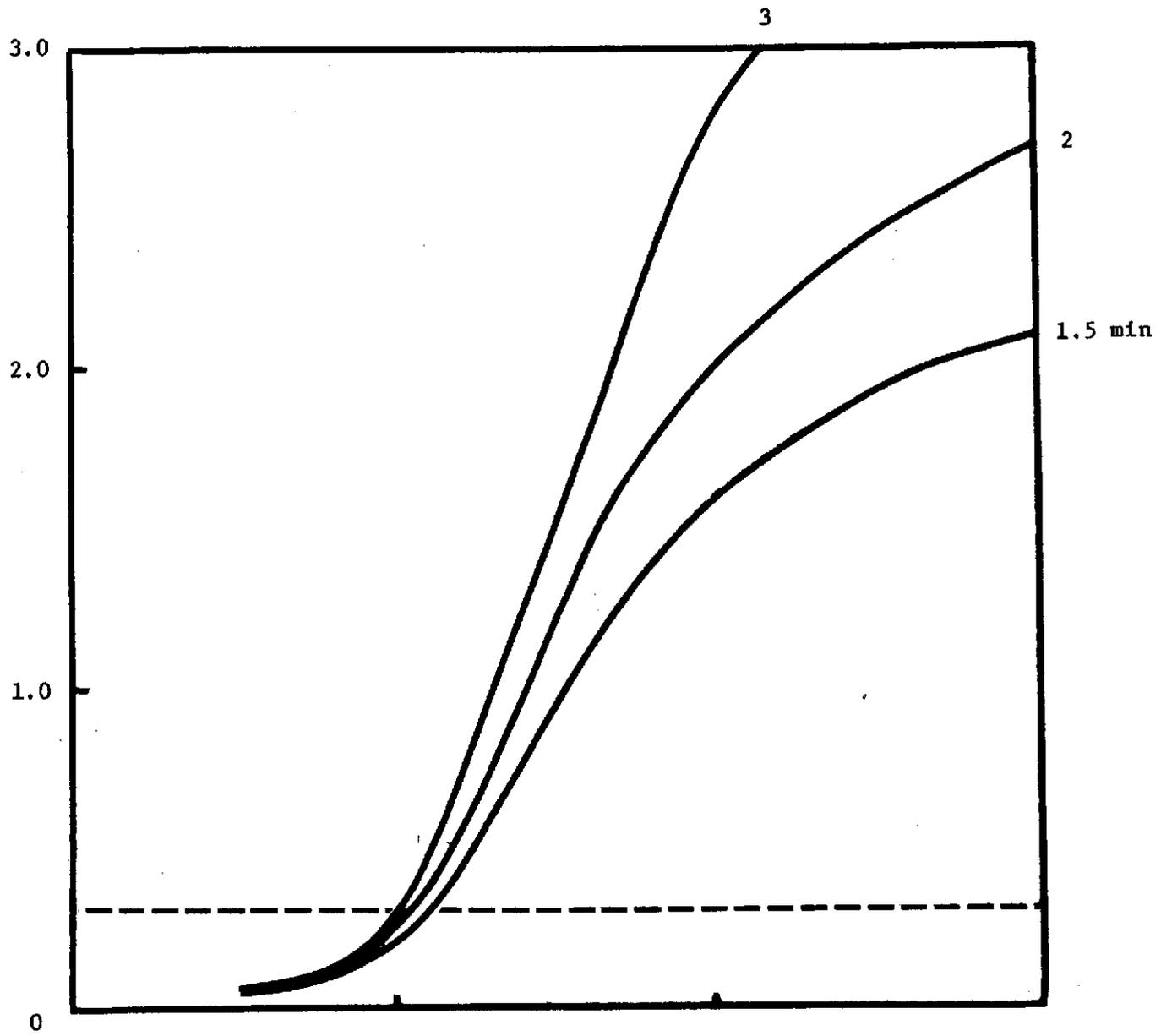
Kodak Commercial Film

D-19 Developer



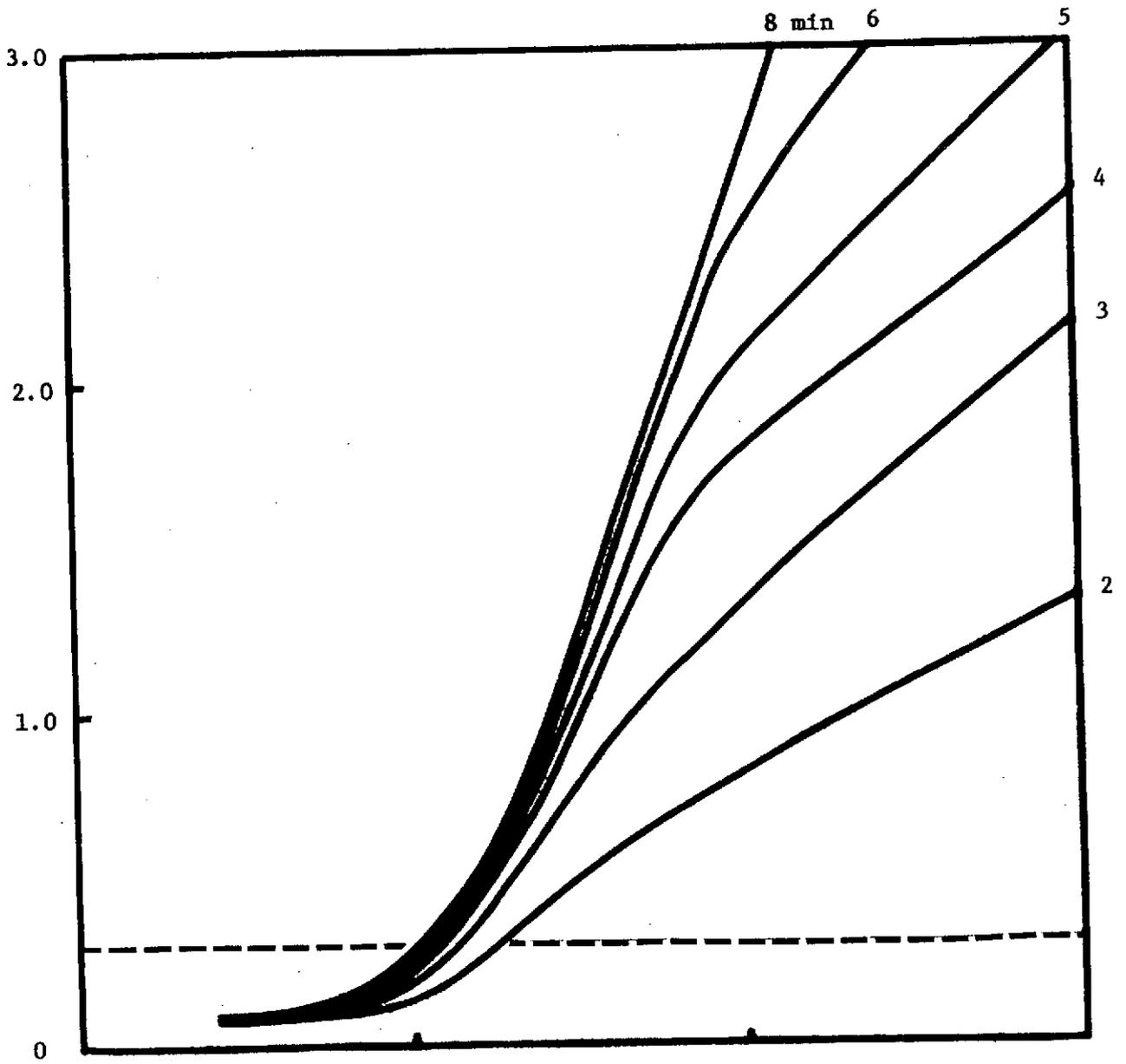
Kodak Commercial Film

DK-50 Developer



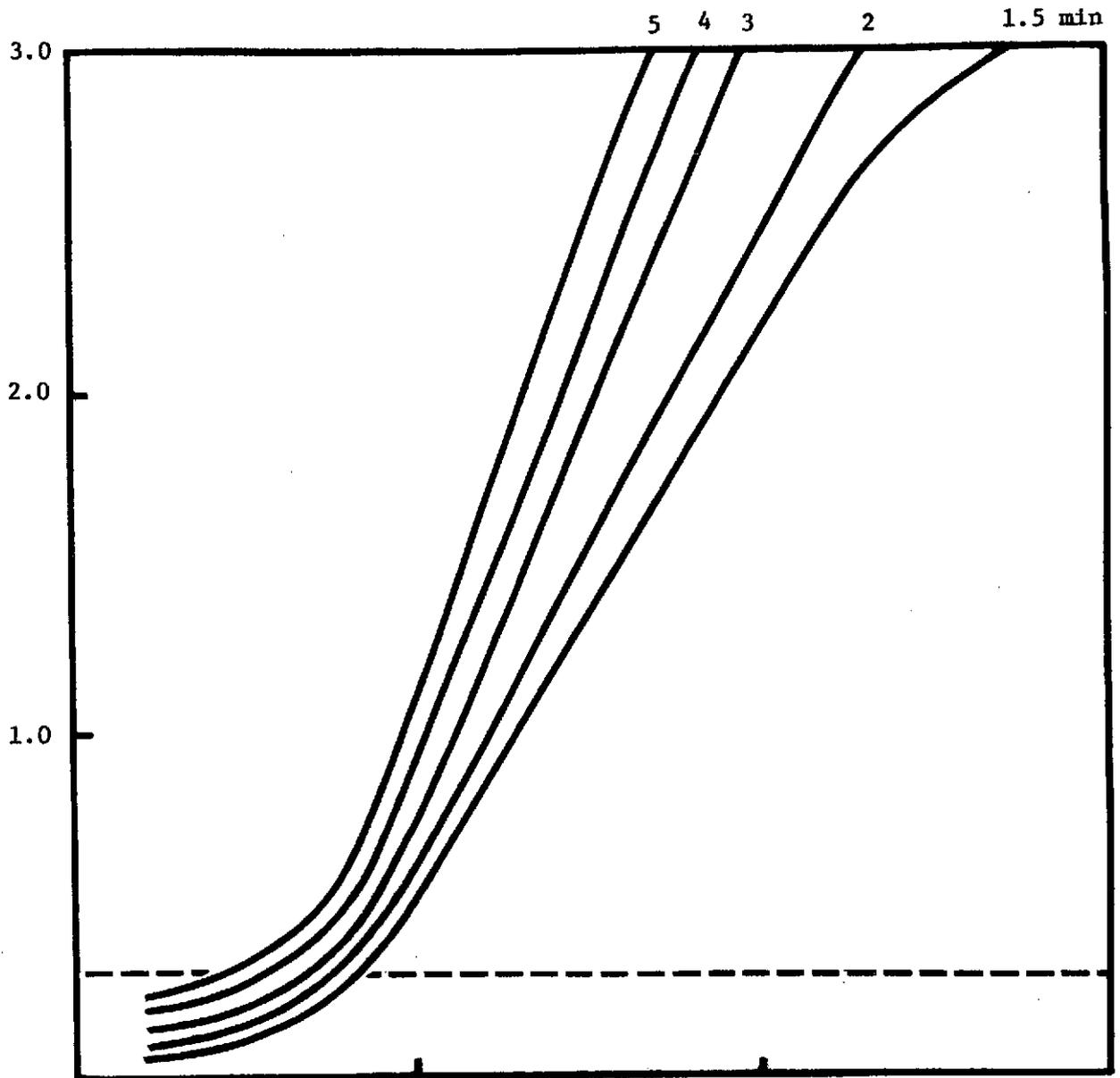
Kodak Contrast Lantern Slide

DK-50 Developer



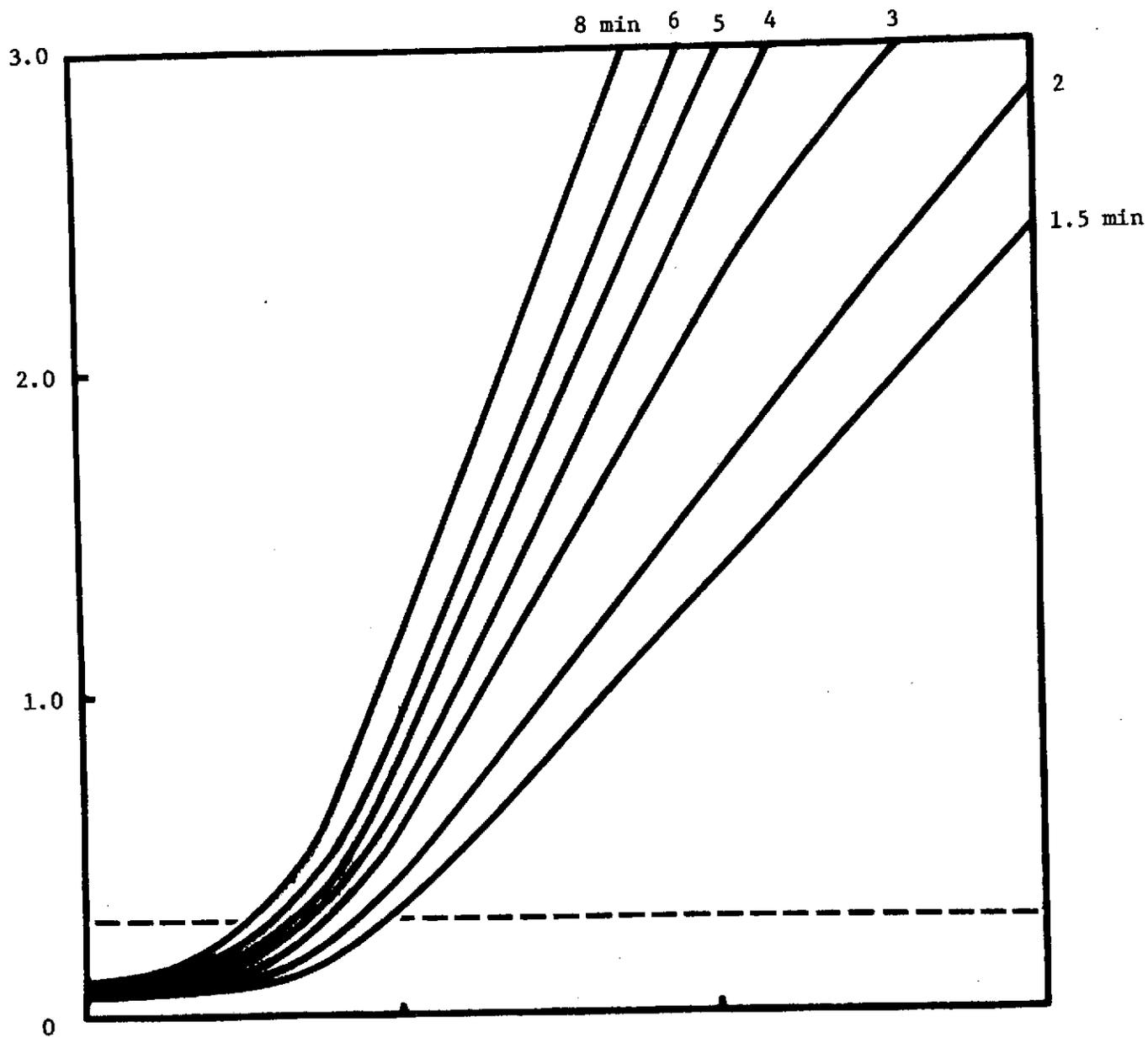
Kodak Contrast Lantern Slide

D-76 Developer



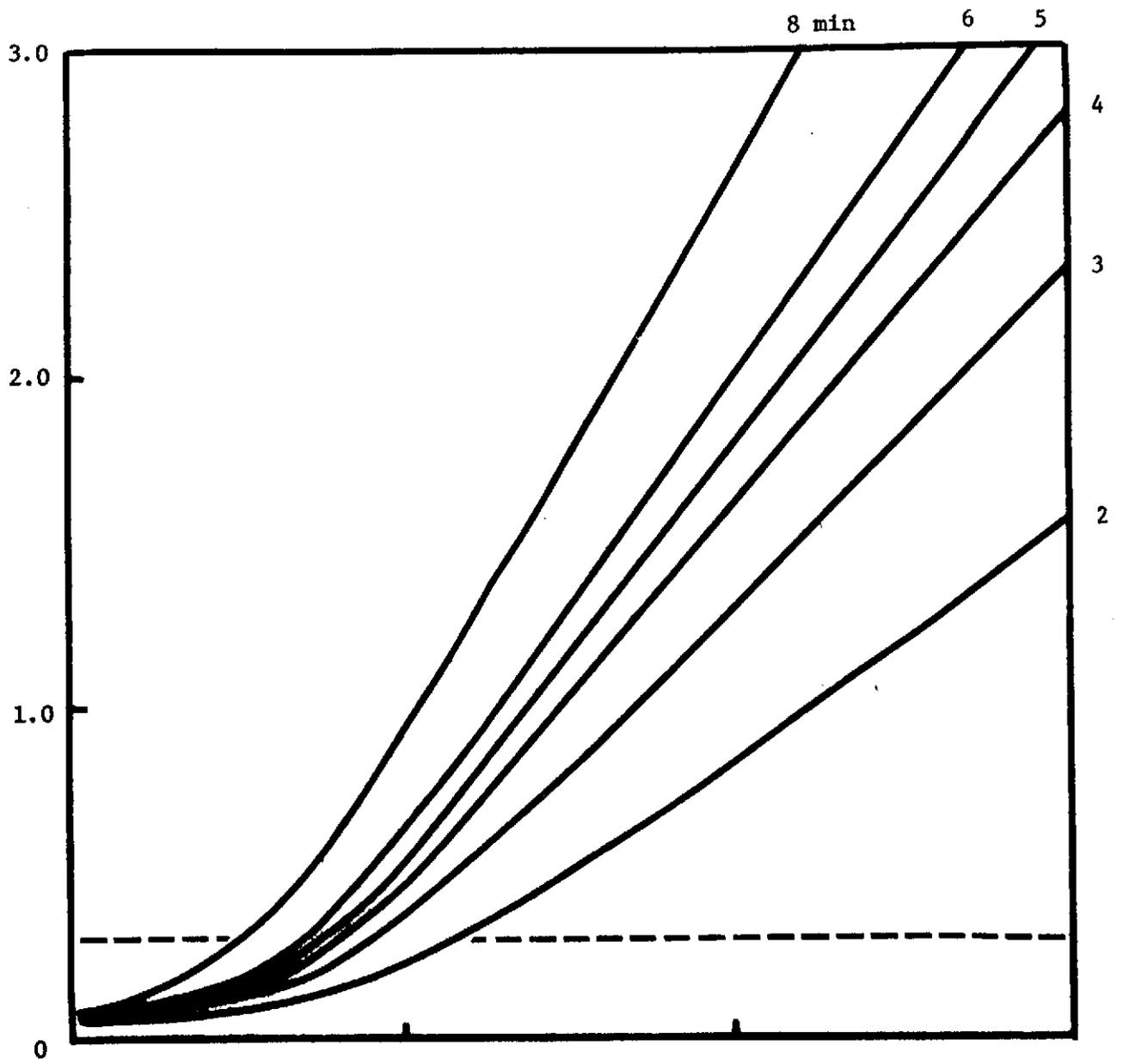
Kodak Medium Lantern Slide

Dektol Developer



Kodak Medium Lantern Slide

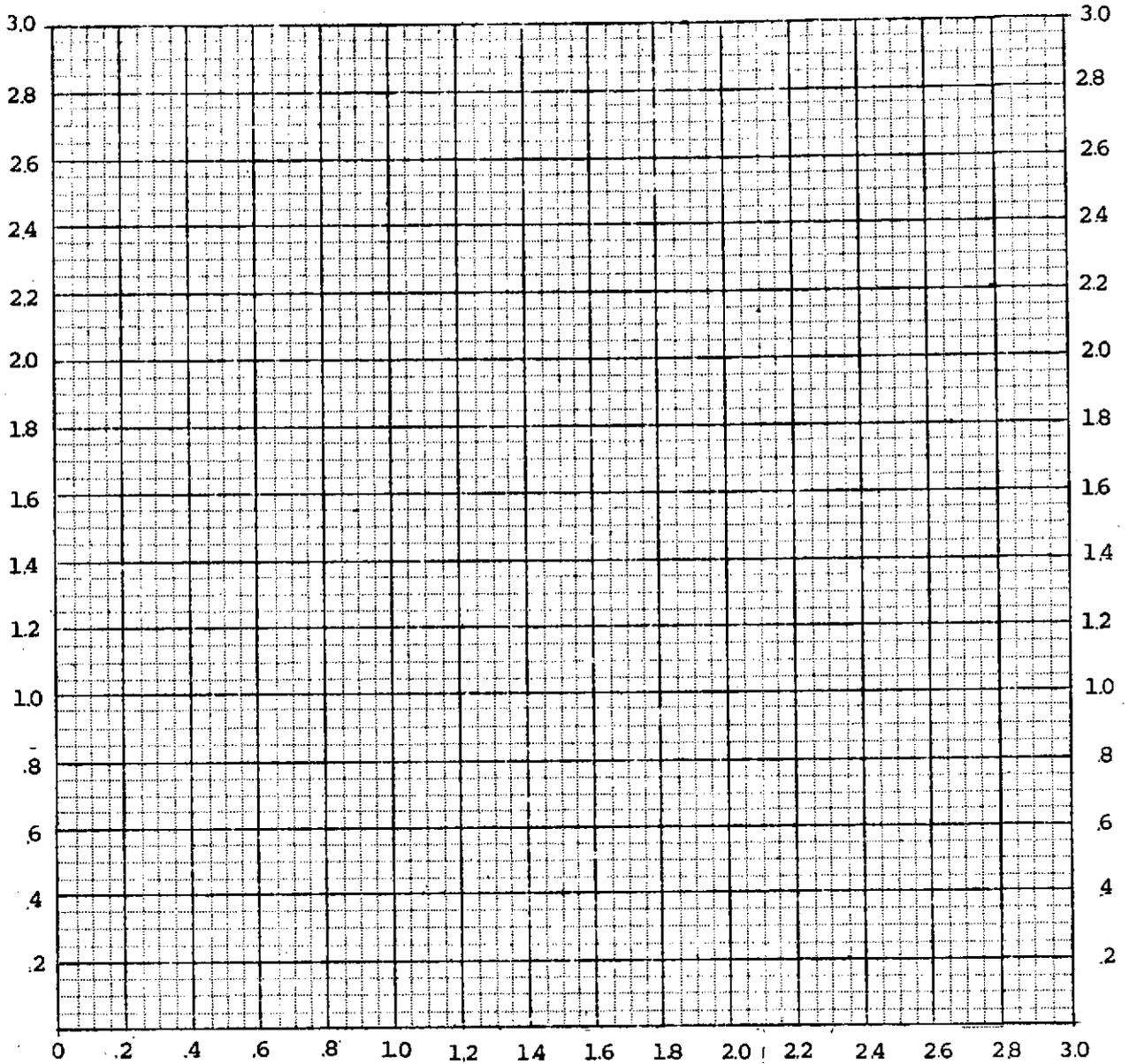
DK-50 Developer



Kodak Medium Lantern Slide

D-76 Developer

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PHOTOGRAPHIC ENHANCEMENT KIT

A working set of duplicate film products which were used to produce Figure 13 in this report and can be used as a photographic experiment package.

1. Duplicate film positives (70mm) as received from NASA
2. Duplicate film negatives (70mm) of bands 4, 5, and 7 after being balanced
3. Paper prints of balanced bands 4, 5, and 7 as a 3X enlargement
4. Film positives of balanced bands 4, 5, and 7 as a 3X enlargement
5. Contact printed diazo films with band 4+ yellow, band 5+ magenta, and band 7+ cyan.